

# INDEX

1-D normal shock, 572-574  
 1-leucine, 195  
 1-tryptophan, 195  
 1,3-butadiene, 725  
 1,5-dihydroxynaphlene, 195  
 1.5 PVU line, 364, 441, 443  
 2  $\Delta x$  waves, 760-761  
 2 layer system of fluids, 657-661  
 3 second rule between lightning and thunder, 575  
 3DVar data assimilation, 273  
 4DVar data assimilation, 273  
 5-D nature of weather, 436  
 5th order rainbow, 840  
 9 degree  
   halo, 847, 854-855  
   Parry arc, 855  
 18 degree halo, 847, 855  
 20 degree halo, 847, 855  
 22 degree  
   angles, estimating, 847  
   halo, 842, 845-846, 854-855  
   Lowitz arc, 855  
   Parry arc (upper, lower, suncave, sunvex), 854-855  
 23 degree halo, 847, 855  
 24 degree halo, 847, 855  
 30-year average climate, 354, 355, 358, 816  
 30-30 rule for lightning safety, 570  
 35 degree halo, 847, 855  
 40-year natural hurricane cycle, 631  
 44 degree parhelia, 855  
 46 degree  
   halo, 842, 846, 854-855  
   Lowitz arc, 855  
   Parry arc (infralateral, supralateral), 854-855  
 53rd Reconnaissance Squadron (hurricane hunters), 637  
 100-50 kPa thickness charts, 345-349, 436, 439, 442  
 120° parhelia (or paranthelia), 854-855

## A

A Scientific Perspective (see summary in Appendix A), 877  
 Be Creative, 288, 293  
 Be Meticulous, 20  
 Be Safe, 485, 517, 567, 570, 583-584  
 Cargo Cult Science, 167  
 Check for Errors, 16  
 Citizen Scientist, 738  
 Consequences, 218  
 Creativity in Engineering, 288  
 Data Misinterpretation, 729  
 Descartes and the Scientific Method, 2, 343  
 Ethics and Data Abuse, 826  
 Expert vs. Novice, 72  
 Give Credit, 24  
 Great Scientists Make Big Mistakes, 863  
 Have Passion, 877



"Practical Meteorology:  
 An Algebra-based Survey  
 of Atmospheric Science"

by Roland Stull is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. View this license at <http://creativecommons.org/licenses/by-nc-sa/4.0/>. This work is available at [https://www.eoas.ubc.ca/books/Practical\\_Meteorology/](https://www.eoas.ubc.ca/books/Practical_Meteorology/)

Look for Patterns, 107-109  
 Mathematics & Math Clarity, 393, 762  
 Model Sensitivity, 350  
 Parameterization Rules, 715  
 Problem Solving, 869  
 Residuals, 340  
 Scientific Laws - The Myth, 38  
 Scientific Method, 2, 343  
 Scientific Revolutions, 773  
 Seek Solutions, 46  
 Simple is Best, 680  
 Toy Models, 330  
 Truth vs. Uncertainty, 470  
 U.S. Supreme Court Quotation, 470  
 A-grid, 753  
 abbreviations for  
   airmasses, 392  
   chemicals, 7  
   clouds, 168-170  
   METARs and SPECIs, 208, 270  
   states and provinces, 431  
   time zones, 5  
   weather-map symbols, 168-170, 208, 274-279, 614-615  
 ABI (advanced baseline imager) on satellite, 222-235  
 abrupt climate change processes, 810-812  
 abscissa - defined, 3  
 absolute  
   angular momentum for hurricanes, 617  
   circulation, 366  
   humidity, 91  
     definition, 14, 91  
     measurement, 97, 111  
     saturated, 91  
   phase speed, 658  
   stability, 140  
   temperature, 7  
   virtual temperature, 14-15  
   vorticity, 363, 448  
   advection of, 448  
   zero, 879  
 absolutely stable or unstable, 140  
 absorptance, 225  
 absorption  
   bands, 221  
   hygrometer, 111  
   lines, 221  
   of light, 833  
   of radiation, 41-43, 219-226  
   window, 43, 220, 796  
 absorptivity, 41  
   and Beer's Law, 43  
   and Kirchoff's Law, 41, 220  
   of atmosphere, 41-43  
 ac (altocumulus clouds), 168  
 ACARS (aircraft communication & reporting system), 272  
 accas (altocumulus castellanus clouds), 168  
 acceleration  
   definition, 292  
   gravitational, 15  
   in Newton's second law, 292, 301, 314, 746-749  
   vertical, 315, 554, 746  
 accessory clouds, 168-169  
 accretion (or riming), 205  
 accumulated heating or cooling, 394-395, 693-694  
   calculation of, 693-694  
   in fogs, 176-177  
   role in thunderstorm formation, 528  
 accumulation  
   mode for CCN, 188  
   storm-total rainfall, 257  
 accuracy  
   error definition, 875  
   of forecasts, 777  
 achieved heat transport globally, 339  
 acid rain, 567, 742  
 actinometers (radiometers), 45-47  
 action, take protective, 785  
 activated  
   droplets, 191-192  
   nuclei, 192-196  
 active  
   clouds, 162  
   remote sensors, 219  
   tracers, 731  
 adaptive, 771  
 adiabatic, 17  
   dry, 63, 119-158, 497  
   moist (saturated), and on thermo diagrams, 119-158  
 adiabatic  
   cooling, 60-64, 101-106  
     to create clouds, 159-161  
   effects in frontogenesis, 408-411  
   excess water variation, 187  
   lapse rate, 60-64, 101-106, 140, 880  
   dry (unsaturated), 60-64  
   moist (saturated), 101-106  
   process, 60, 121  
     on thermo diagrams, 121, 129  
   vertical movement, 60  
   warming, 60  
     in downslope winds, 676-677  
 adjacent faces of ice crystal, 842  
 adjustment  
   geostrophic, 343-349  
     part 1, 344  
     part 2, 349  
     part 3, 404-407  
   moist convective, 70  
 Admiral Beaufort, 635  
 Adriatic Sea, bora winds, 675  
 ADT, Atlantic daylight time, defined, 5  
 advanced baseline imager (ABI) on satellite, 222-235  
 advection, 65  
   adiabatic, 411  
   cold air, 349  
   differential, and castellanus clouds, 164  
   definition, 65-67  
   flux, 34-35, 65-67, 107  
   fog, 173-177  
   force, 294-295  
   heat, 65-67, 714  
   of TKE by mean wind, 708  
   mass, 317-318, 465  
   max, as found on weather maps, 458  
   moisture, 107  
   momentum, 294-295  
   numerical stability, 760-761  
   related to pressure tendency, 465  
   role in katabatic wind, 653  
   temperature, 65-67  
     self-development of cyclones, 468-469  
   turbulence, 708  
   turbulent heat, 714  
   term, 747  
   vorticity, 447-451  
     by thermal wind (cyclogenesis), 456-462  
   warm air, 349  
   water, 107  
 advective  
   clouds (stratiform), 94, 164  
   flux, 34-35, 65, 107, 294  
   force, 294  
 aeolian tones, 560  
 aerodynamic  
   drag on falling  
     cloud droplets, 202  
     hailstones, 204  
     ice crystals, 842  
     rain drops, 203  
   roughness length, 677-678, 700-703  
   typical values, 700  
 aerosol(s)  
   definition, 188  
   feedbacks for climate change, 811  
   haze, 193  
   scattering of radiation by, 221, 856-858  
   stratospheric, and climate change, 805, 856-858

- swelling, 193  
African easterly jet (AEJ) and waves, 611-612
- age  
  Calabrian, 799  
  ice, 795, 798-799  
  Ionian, 799  
  Tarantian, 799
- ageostrophic  
  definition, 304, 314, 343, 454  
  during approach to geostrophy, 304  
  flow, 343, 462, 454-462  
  dynamic frontogenesis, 412  
  right-hand rule, 455  
  wind, 304, 314, 454-462  
  direction of, 455  
  equations, 314, 454
- aggregation  
  in cold clouds, 205  
  in thunderstorms, 546  
  of ice crystals into snowflakes, 200, 202, 206-207  
  processes, 204-205
- Agung volcano eruption, 805
- air  
  characteristics, constants & parameters, 880  
  composition, 7  
  conditioning, 116  
  density, 10  
  forecast equation for, 746  
  standard (STP), 880  
  drag, 700-702  
  mass (see airmass), 389-399  
  conservation, 317-319, 660  
  mass of, 10  
  molecular weight, 7  
  molecule, scattering of light by, 220-222, 856-858  
  parcel, 57, 59, 687-688  
  adiabatic movement, 58-64  
  angular momentum of, 360-361  
  buoyancy, 135, 649, 687-688  
  definition, 11, 57  
  follows isentropes, 144  
  rise, 129-130, 648-649  
  temperature and humidity, 128  
  static stability method, 138-139, 687-689  
  vs. environment, 59, 134-141  
  water in, 99-106  
  pollution dispersion (see also pollution), 7, 723-744  
  brown cloud, 857-858  
  episodes, 741  
  events, 725, 741  
  exceedences, 725  
  thermo diagrams for, 151, 157-158  
  trapped in highs, 390  
  pressure, 7-10  
  quality standards, 7, 725  
  for individual gases, 7, 725  
  index, 743  
  USA, Canada, EU and UK, 7, 725  
  refractive index, 834-835  
  specific heats, 53-56, 880  
  stagnation (events), 559, 741
- aircraft  
  airspeed, using pitot-static system, 674  
  commercial, weather observations by, 272  
  communications & reporting sys. (ACARS), 272  
  glory, 860  
  hurricane hunter, 637  
  radars, 243  
  severe-weather hazards, 529, 556, 563  
  downbursts and gustfronts, 556, 563  
  sounding, 134, 496  
  turbulence experienced by  
  boundary layer, 649  
  clear-air, 141-142, 165  
  convective, 483, 498, 508  
  mountain wave, 667  
  wind shear; gust fronts at airports, 560-563  
  wings, flow over, 88
- AIREPS, 272
- airmass(es), 389-399  
  abbreviations for, 392  
  arctic vs. Antarctic, 392, 396  
  atmospheric boundary layers are, 691  
  blocking/damming by mountains, 397  
  boundary layers are, 393-397  
  boundaries = fronts, drylines, 397, 416  
  thunderstorm triggers, 525-526  
  channeling by mountains, 397  
  characteristics of, 391  
  classification, 391-392  
  codes for, 391-392  
  continental polar, 392  
  creation, 392-397  
  definition, 391  
  depth of cold air, 404-406  
  formation region map, 392  
  fronts at boundaries of, 397  
  genesis, 392-397  
  growth rate, 394-397  
  locations, 392  
  maritime tropical, 392  
  modification, 397-399  
  via flow over mountains, 398-399  
  via surface heat fluxes, 397-398  
  movement, 397  
  residence times, 392  
  temperature at distance from origin, 398  
  thickness, 394-397, 404-406  
  thunderstorms, 481-482, 486  
  energy released by, 499  
  triggering. Convective temperature, 526-527
- airplane  
  bumpy ride in, 649, 667  
  mass of air inside, 23  
  pitot-static system for airspeed, 674  
  shadow, white disk centered on (glory), 860  
  window, pressure against, 21
- airport  
  CYVR (Vancouver Internat. Airport in Canada), 647  
  KJFK (JFK Airport in New York), 563  
  routine meteorological report (METAR), 268-279  
  runway visual range (RVR), 270  
  runways vs. wind direction, 646-647  
  special meteorological report (SPECI), 268-279  
  wind-shear sensors, 563
- AIRS (atmospheric infrared sounding), 273  
  airspeed, using pitot-static system, 674  
  AKDT & AKST, Alaska daylight & standard times, 5
- Alaska, 431  
  current, 175  
  time zone, 5
- albedo, 42, 44, 793-794  
  average global, 42, 793-794  
  Bond, 831, 879  
  geometric, 831, 879  
  ice-albedo feedback, 808-812  
  in daisyworld, 813-815  
  Moon, 42  
  typical values, 42, 794
- Alembert, Jean le Rond d', 759
- Aleutian  
  low, 354-356  
  time zone, 5
- Alexander of Aphrodisias, 841  
  Alexander's dark band, 841  
  aligned coordinate, 727
- Al-Khalili, Jim, 754
- Allick, Susan Krueger, 639-640
- along  
  shore coastal low-level jet, 664-665  
  valley winds, 653-654
- alpha time zone (Europe), 5
- alphanumeric weather codes, 268-269
- alpine ski snow, 209
- alternative coordinates, horizontal & vertical, 746-747
- alternate faces of ice crystal, 842
- altitude  
  cooking time vs, 90  
  key, for thunderstorms, 496-499  
  pressure change with (see height), 3, 8-9, 12-13, 16-17
- alto prefix, 163  
  weather-map symbols for, 277
- altocumulus, 134, 162-163, 168  
  castellanus, 162, 164-165
- altostratus, 134, 162-164, 168
- AM  
  radio, static on, 568  
  satellite, 229
- ambient air-quality standards, 725
- Amdahl, Gene, 763
- Amdahl's Law, 763
- AMDAR (aircraft meteorological data relay) code, 269, 272
- American geography, 431
- amino acids as ice nuclei, 195
- ammonium sulfate, 190-192
- amount of  
  clouds, 170  
  substance, 870  
  flowing through area, 34-35
- units, 870
- ampere, 564, 870
- amplified response (positive feedback), 806-808
- amplitude of  
  Kelvin wave, 634  
  meridional displacement, 373-374  
  mountain lee waves, 666-668  
  oscillations, 818  
  Rossby waves in lee of mountains, 444
- AMSU (advanced microwave sounding unit), 273
- anabatic  
  cumulus clouds, 649-650  
  horizontal pressure gradient force, 650-652  
  wind, 649-652  
  high-pressure associated with, 391, 650-651
- anafront, 404
- analysis  
  data assimilation, 762, 765-767  
  definition, 267, 280-281, 762  
  in case study, 768-770  
  field, 763-765  
  initial conditions, 293, 762  
  objective methods, 280, 766-767  
  3DVar and 4DVar, 273, 767  
  optimum interpolation, 766  
  variational, 273, 767  
  verifying, 769  
  weather map, 274-281, 425-470  
  hand (subjective; manual), 279-281, 402  
  methods, 274-281, 402  
  numerical, 762  
  surface, 267, 402
- analytical solution, 749
- anemometers, 219, 321-322
- aneroid barometer, 19
- angle  
  azimuth, 4  
  solar, 33  
  between  
  Earth and perihelion (=true anomaly), 28-30, 802  
  Earth and vernal equinox (=true longitude), 801  
  perihelion and vernal equinox, 801  
  component, 836  
  conventions in math & meteorology, 2  
  critical, 837  
  elevation, 4-5  
  solar, 32  
  hour, 40-41, 801-802  
  incidence, 833  
  mean anomaly, 29  
  of turbine blades, 647-648  
  plane, definition of units, 870  
  refraction, 833-834  
  solar declination, 30-31  
  solar azimuth & elevation, 32-33  
  solid, definition of units, 870  
  true anomaly, 29  
  wedge, 843, 845-847, 855  
  zenith, 4-5
- ångström unit of distance, 870
- angular  
  frequency, 36  
  momentum, 360-361  
  conservation of, 360-361  
  equation, 360  
  of hurricane, 617  
  of tornado, 577  
  Rossby wave transport, 375  
  subtropical jet, effects on, 360-361  
  rotation rate of Earth, 297
- anisotropic, 708  
  turbulence, 708, 710, 727
- annual  
  mean global energy budget, 797  
  precipitation worldwide, 209
- anomalous propagation of radar beam, 244-245
- anomaly, 777  
  climate, 818, 821  
  correlation, 779-780  
  mean & true, for orbit of earth, 29  
  warm sea surface (for ENSO and PDO), 818-820  
  weather, 777
- Antarctic  
  airmass  
  code, 392  
  katabatic winds (downslope flow), 396, 652, 676  
  circle, 31  
  oscillation (AAO), 824
- antenna dish, radar, 240
- anthetic

- arc, 855  
point, 841
- antherion, 855
- anthropogenic, 723, 811  
climate change, 812  
clouds, 166  
greenhouse gases, 796, 811-812  
pollutants, 723
- anticyclones (see also highs, H), 389-391  
airmass creation within, 389-399  
aloft in hurricane core, 613  
atmospheric boundary layer within, 690-692  
convergence at top of, 391  
definition, 390  
divergence at bottom of, 390, 691  
dynamics, 391  
formation locations, 391  
isobars around, 390  
maximum height/pressure variation nearby, 306-307  
mesoscale, 391  
midlatitude, 331, 390-391  
polar, 391  
ridges, relationship to, 390  
structure, 390-391  
subsidence within, 390, 691  
subtropical, 391  
tilt with altitude, 390  
vertical structure, 391  
weather associated with, 390, 691  
winds around, 305-307, 390, 691
- anticyclonic  
radius of curvature, 304-306  
winds, 306-307, 311
- antimountain wind, 653
- antipodal point, 838
- antisolar  
arc, 855  
point, 837
- antitriptic wind, 312-313, 663
- antivalley wind, 654
- anvil  
cloud, 482-484  
conditions, 489  
debris stage of evolution, 485  
hurricane central dense overcast, 604, 614, 620, 624  
lightning from, 564  
thunderstorms, 481-602  
crawlers (lightning), 567  
lightning, 564, 567
- apex method (static stability), 139
- aphelion, Earth orbit, 28-30  
precession, 800-801
- apparent  
force, 299  
sunrise and sunset, 33-34, 861-862  
temperature, 76-78, 117  
heat index, 77-78, 117  
humidex, 77-78, 117  
wind chill, 76-77
- appearance of thunderstorms, 482
- applications of thermo diagrams, 127-133
- applied meteorology, 2
- approach to  
airports, 563  
geostrophy, 303-304
- approximate solution, 749
- approximations to spatial gradients, 754-755
- Aqua satellite, 273
- AR5 (report from Intergov. Panel on Climate Change), 39, 793-832
- Arakawa, Akio, 753  
NWP grids A - E, 753
- arbitrary vertical cross section (AVCS) radar display, 242
- arc  
catalog & diagram of most arcs, 854-855  
circumhorizon (optical phenomenon), 848-849, 855  
circumzenith (optical phenomenon), 848-849, 854-855  
(arcus) clouds, 169, 482, 562  
coloring, 848-849  
of maximum polarization, 856  
tangent, 851-853
- Archimedes, 135, 150
- Arctic  
aerosols and CCN at, 188  
airmass  
code for, 392  
formation, 396  
circle, 31  
dipole anomaly, 824  
oscillation (AO), 818-819, 824  
arcus, 482, 562  
area in a sounding, for CAPE & DCAPE, 503-508, 557-558  
ARFOR code, 269  
argon, Ar, 7  
Aristotle, 2, 26  
arrangement of clouds, 169  
as (altostratus clouds), 168  
ascending  
air parcels, 129-130  
motion in cyclones (lows), 356  
node, 228-229  
ASDAR (aircraft to satellite data relay), 272  
ash, volcanic, 170  
ASOS (Automated Surface Observing System), 271  
aspect ratio, 485  
of ice crystals, 200  
of thunderstorm cells, 485  
aspirated psychrometer, 94  
assimilation, data, 765-767  
AST, Atlantic standard time, defined, 5  
astronomical  
influences on climate variability, 797  
Milankovitch theory, 797  
twilight, 33-34  
unit (au or ua), 28, 870  
asynoptic observation data, 758
- Atlantic  
multi-decadal oscillation (AMO), 824  
North Atlantic oscillation (NAO), 818-819, 824  
South Atlantic Subtropical High, 354  
time zone, 5
- atlas of clouds, 168
- atm, atmospheres, a pressure unit, defined, 7
- atmosphere, 1-26  
one-layer, 795  
radiative models for climate, 795-797  
standard, 11-13, 688-690
- atmospheric  
attenuation factor in the radar eq., 245-246  
bending of light, 861-863  
composition, 7  
density, 10-12  
dynamics, 289-328  
heat transfer globally, 339  
gases, 7  
layers, defined, 13, 563, 565  
optics, 833-868  
physics, 872  
pressure head, 632  
radiation emissions, climate, 795-797  
radiative transfer, 220-226  
refraction of light, 861-863  
science, 205, 877  
sounding, pre thunderstorm, 496-499  
spectrum of transmittance, 222-223  
structure (in the vertical), 11-13  
window, 796, 811  
"closed", 796, 811
- atmospheric boundary layer (ABL), 13, 68, 687-722  
accumulated cooling or heating, 693-694  
aerosols within, 188  
African Sahara, 611  
airmasses are, 393-396, 691  
air parcels in, 687  
anticyclones, relationship to, 390, 690-692  
Ball ratio, 698  
buoyancy velocity, 704  
capping inversion, 496-499, 522-525, 687-692  
constant flux layer, 692  
convection: free vs. forced, 704  
convective  
boundary layer (CBL), 109, 649, 692  
velocity scales, 704  
cyclolysis, role in, 432  
daytime (convective), 692  
accumulated heating, 693-694  
Deardorff velocity, 69, 703-704  
defined, 13  
depth estimate from soundings, 143  
depth and strength over time, 110, 649  
during airmass genesis, 394-395  
depth within an anticyclone, 690-692  
depth within a cyclone, 319, 690-692  
dispersion of smoke within, 723-744  
neutral and stable ABLs, 732-734  
unstable ABLs, 735-737  
diurnal cycle, 687  
drag, 300-301, 699-702  
coefficients, 700-701  
in hurricane, 625  
encroachment method for ML growth, 697-698  
entrainment  
velocity, 697-698  
zone, 692  
fair weather, 69-70, 690-692  
flux-ratio method for entrainment, 698  
fogs within, 159, 173-177  
formation, 13, 689-692  
free atmosphere above top of ABL, 687-692  
free convection, 704  
friction velocity, 677-678, 700-713  
fuel tank for thunderstorms, 499-502, 547-548  
gradient (BLG) wind, 309-311  
heat flux profiles, 698  
highs, relationship to, 390  
hurricane, 618-620  
triggering by easterly wave, 611-612  
internal, thermal (TIBL), 654-657  
inversion at top of, 496-499, 522-525, 687-692  
jet, nocturnal (low-level), 699-700  
katabatic winds at night, 696  
kinematic heat flux, 698  
location, thickness, 13  
log profiles of wind, 702-703  
mixed layer (ML), 690, 692  
growth rate, 697-698  
kinematic heat flux profile, 698  
smoke dispersion within, 735-737  
modification near frontal zone, 70-71, 691-692  
neutral, statically, 300, 308, 319  
smoke dispersion within, 732-733  
smoke plume rise within, 732-733  
standard deviations for, 707  
winds, 702  
nighttime/nocturnal (stable), 692  
accumulated cooling, 693  
jet, 699-700  
Obukhov length, 703  
parameterizations, 714-716  
in NWP models, 751  
potential temperature vs. height, 690, 692  
standard deviations for, 707  
profiles of variables, 692, 702-705  
pumping, 319-320  
cyclolysis, role in, 432, 465  
in hurricanes, 628  
radiative forcings, 687  
radix layer, 700-705  
residual layer, 692-696  
response to heating and frictional drag, 687-705  
roughness length, 677-678, 700-703  
Davenport-Wieringa classification, 700  
rural, 677-679  
seasonal variations, 695-696  
slab model, 697-698  
stable boundary layer (SBL), 692, 696  
depth and e-folding height, 696  
smoke dispersion within, 732-734  
smoke plume rise within, 732-733  
standard deviations for, 707  
strength, 696  
winds, 702-703  
static stability, 687  
stormy, 691  
stress, 700-701, 712-715  
strength of stable boundary layer, 696  
structure and evolution, 692  
layers within, 692  
subgeostrophic winds, 699-700  
summer, 695-696  
supergeostrophic winds, 699-700  
surface layer, 692  
thickness, 700  
wind profiles, 700-703  
synoptic forcings, 690-692  
temperature, 13, 693-698  
cumulative heating or cooling, 693-694  
inversion, 690-695  
mixed-layer temperature, 697-698  
stable-boundary-layer temperature, 696  
temperature-profile evolution, 694-696  
temperature profiles, 688-698  
thermal-internal (TIBL), 654-657  
thermals, 648-649  
thermo diagrams for, 151, 157-158  
thermodynamic method for ML growth, 697-698  
thickness, 13, 300, 649  
top of, 496-499, 522-525, 689  
tropospheric constraints, 13, 689-692  
turbulence, 13, 687-690  
airmass, 393-396  
drag, 300-301  
free and forced convection, 704, 710

- isotropy, 707-708  
 mean and turbulent parts, 705-706  
 transport velocity, 300  
 turbulence kinetic energy (TKE), 708-709  
 turbulent fluxes and covariances, 711-713  
 variance and standard deviation, 706-708
- unstable (convective), 648-649, 704, 710  
 mixed layer, 692  
 smoke dispersion within, 735-737  
 smoke plume centerline, 736  
 standard deviations for, 707  
 static stability, 300, 308  
 winds in radix layer, 703-705
- urban, 678-679  
 vertical velocity at top of, 319-320
- wind, 307-309, 699-705  
 diurnal evolution, 699-700  
 log profile in the neutral surface layer, 700-702  
 log-linear profile in the stable surface layer, 700-703  
 low-level nocturnal jet, 699-700  
 profile evolution, 699-700  
 profile in convective radix layer, 699-705  
 shear, 300  
 subgeostrophic, 699  
 supergeostrophic, 699-700  
 wind profile evolution, 699-700  
 winter, 695-696
- atmospheres (a pressure unit), 7  
 atomic clock, 51  
 attenuation  
 coefficient in exponential wind profile, 678  
 factor in the radar equation, 245-246  
 radar energy, 241  
 rain gauges, 210  
 atto (10<sup>-18</sup>), 870  
 attractor, 790  
 fixed point, 790  
 strange, 773-776
- audibility distance of thunder, 575-576  
 aureole, 860  
 aurora, 11  
 Australian Bureau of Meteorology, 607  
 author, about the, XIV  
 automated weather  
 forecasts (NWP), 745-792  
 map analysis, 765-767  
 station METAR report, 270
- autumnal (Fall) equinox, 30-31, 800  
 availability of water for droplet formation, 186-187  
 available  
 energy, 503-508, 557-558  
 potential energy, 356  
 convective (CAPE), 503-508  
 downdraft (DCAPE), 557-558  
 supersaturation, 187
- average, 502, 705, 726  
 daily insolation, 40-41, 336, 799-802  
 energy budget, global, 797  
 ensemble, 776  
 jet stream speeds, winter, 357-361  
 meridional kinematic heat flux, 338-339, 375, 378  
 observations, 875  
 running, 599  
 total water mixing ratio, 98  
 wavelength of wind waves, 634  
 winds in global circulation, 330-331
- averaging, 502, 705, 726  
 distance, 706  
 time, 706
- aviation (also see aircraft and airplanes)  
 boundary layer turbulence, 649  
 runways vs. wind directions, 646-647  
 severe weather hazards, 529
- Avogadro constant, 879  
 AWIPS, 772  
 AWOS (Automated Weather Observing System), 271
- axes of graphs (defined, and switching of), 3  
 axial precession of Earth, 799-801  
 axis of  
 contraction, 320-321  
 dilation, 320-321, 410  
 tilt of earth, 30, 798-802  
 ridges and troughs, 281, 367, 399
- azimuth angle, 4-5  
 defined, 2, 4  
 Azores high, 354-356  
 role in steering hurricanes, 607-608
- B**
- B-grid, 753  
 background state, mean, 316  
 errors, 766  
 backing of wind, due to cold air advection, 349  
 backscatter cross-section, 245  
 backward scattering, 219, 857  
 backward trajectory, 724  
 in semi-Lagrangian NWP, 761  
 of pollutant emissions, 724  
 bacteria as ice nuclei, 195  
 bad-weather regions (extratropical cyclones), 425-480  
 local winds modified by terrain, 645
- balance of  
 forces to make winds, 302-314  
 heat, 64  
 globally, 338-339
- balanced mass and flow fields, 763-765
- balloons, weather, 134  
 pilot, 322  
 rawinsonde, 134, 322, 496
- ball  
 lightning, 567  
 ratio, 698
- bands  
 cumuliform cloud, 425-428  
 radar, 242-243  
 radiation absorption, 221  
 rain, 401, 604  
 spiral (in hurricanes), 604-605
- Bangladesh vs. hurricanes, 631  
 banks of clouds, 168  
 banner clouds, 165, 667  
 barbs for wind, on a weather map, 278  
 baroclinic, 343, 749  
 atmosphere, 343, 349, 359, 749  
 circulation in, 366  
 Bjerknes circulation theorem for, 366  
 instability, 371  
 in African easterly jet, causing waves, 611  
 vs. barotropic, 749  
 wave (Rossby), 371-374  
 idealized structure, 374  
 qualitative model, 371  
 quantitative approach, 372-374  
 zones and cyclone self-development, 469-471  
 strengthening, 469-470
- baroclinicity, 359  
 polar jet driven by, 359-360  
 role in tornado formation, 587
- barograph, 19, 278  
 barometer, 7, 19, 219  
 aneroid, contra, digital, electronic, mercury, 19  
 Torricelli (U-tube), 19
- barometric  
 pressure (see pressure), 7-19, 267, 270, 275  
 tendency, weather map symbols, 278
- barotropic, 749  
 atmosphere, 366, 749  
 circulation in, 366  
 Kelvin's circulation theorem for, 366  
 instability, 367-370  
 easterly waves in African jet caused by, 611  
 Rossby waves caused by, 367-370  
 vs. baroclinic, 749  
 wave, 367-370
- barren daisyworld, 815  
 barrier to ice formation, 194  
 bar(s), unit of pressure, 7, 870  
 barycenter, 27  
 basal face, 842
- base  
 cloud height, 93, 130, 162, 278  
 fog, 177  
 of natural logarithms, 879  
 rain-free, 483
- basic  
 dimensions, 870  
 thunderstorms, 486-487
- basis, scientific, for weather forecasting, 746-751  
 BATHY code, 269  
 battering of structures by waves, 634-635  
 be creative, 293  
 be safe, 485, 517, 567, 570, 583-584  
 beach erosion by ocean waves, 634-635  
 bead lightning, 567  
 beam, radar, 240  
 propagation  
 equation, 244  
 path, 243-245  
 width, 240
- bears's cage (region in supercell thunderstorm), 495, 583  
 beaver tail cloud, 483, 492, 494-495  
 Beaufort wind scale number, 635-636  
 related to tornado intensity, 599
- Beer's Law, 43, 856  
 bell curve, Gaussian, 729-730, 875  
 bending of light (refraction), 833-868  
 beneficial competition (cloud seeding), 553  
 bent-back front, 414-415  
 benzene, 725  
 Bergen School of Meteorology, 399  
 Bergeron, T., 201-202, 399  
 Bermuda high, 354-356  
 role in steering hurricanes, 607-608
- Bernoulli's  
 constant, 669-672  
 equation, 559, 669-674  
 applications, 672-675  
 derivation, 670  
 downbursts and gust fronts, 559  
 downslope winds - Bora and Föhn, 675-677  
 dynamic vs. static pressure, 672-674  
 for incompressible flow, 671-672  
 for incompressible flow, 669-671  
 hurricanes, 626  
 hydraulic jump, 670  
 limitations, 671  
 principles, 669-672  
 reduced gravity in, 670  
 requirements, 671  
 tornadoes, 578  
 venturi effect and gap winds, 674-675  
 function, 669-672
- Berra, Yogi, quotations, 5, 132, 228  
 beryllium-10, 803  
 beta  
 effect on  
 lee cyclogenesis, 444  
 tornadoes, 586  
 vorticity tendency, 447-451  
 plane, 369  
 term, 447-449, 586
- Betz  
 Albert, 647  
 law, 647-648  
 limit, 648
- bias (mean error; systematic error), 770, 778, 875  
 score, 781  
 Big Thompson Canyon flash flood, 487, 547-548  
 big whirls have little whirls (eddies), 708  
 billow clouds, 142, 165  
 bimetallic strip thermometer, 78  
 bin size, 646
- binary  
 bits, 759, 870  
 event verification, 780-782
- biogeochemical climate-change processes, 810  
 biological  
 climate change process, 810-812  
 homeostasis & daisyworld, 813-815
- bits, binary, 759, 870  
 Bjerknes  
 circulation theorem, 366  
 Jacob, 399, 450  
 Vilhelm, 399, 759
- bkn (broken) cloud cover, 170  
 blackbody, 36, 39, 794  
 radiance, 221, 224-225
- blades of wind turbines, 647  
 blank diagrams that you can copy  
 hodograph, 512  
 thermo diagrams, 151-158
- blanket-shaped clouds (see stratus), 162-163  
 blessing, 863  
 blizzard, 208-209  
 associated with extratropical cyclones, 425, 434-435
- blocking of airmass movement by mountains, 397, 667  
 blow up (of numerical weather forecast), 757, 760  
 blowing snow, weather-map symbol for, 275-276
- blue  
 color defined (also see optics chapter), 37, 834  
 haze, 858  
 jet, 563, 568  
 moon, 805, 858  
 sky, 857-858  
 Rayleigh vs. Newton theories, 863  
 sun, 858
- Bohr, Niels, 745  
 boiling, 90  
 bolometer, 46

- bolt  
 from the blue, 567  
 lightning (see return stroke), 556-567  
 Boltzmann constant, 37, 118, 189, 879
- bomb  
 cyclone, 426  
 nuclear, 499, 548
- Bond albedo, 831, 879
- bookend vortices, 490-491
- Bora winds vs. katabatic winds, 675-676
- bore: Morning Glory, 656
- Bosart, 765
- Bosnia, bora winds, 675
- boundary  
 airmass, 525-526  
 drylines, 416, 525  
 fronts, 399-415, 525  
 thunderstorm trigger, 525  
 conditions, 731, 756, 816  
 currents in oceans, 431
- boundary-layer (see atmospheric boundary layer, ABL), 13, 687-722  
 gradient wind, 309-311  
 in hurricanes, 609, 618-619  
 in tropical depression, 613  
 growth, 689  
 parameterizations in NWP models, 751  
 pre-storm, 496, 499-503  
 pumping, 319-320, 432  
 cyclolysis, role in, 432, 465  
 in hurricanes, 628  
 thermal internal (TIBL), 654-657  
 total water, 99  
 urban, 678-679  
 wind, 307-309  
 profilers, 259  
 tunnels, 689
- bounded weak echo region (BWER), 552-553
- bounds on climate change, 811
- Boussinesq approximation, 316
- bow echo, 490-491, 494, 516
- Bowen ratio, 74-76  
 measurement, 75  
 method of estimating surface fluxes, 75
- bows (rainbows, moon bows, supernumerary), 837-841, 860-861
- box  
 and whisker diagram (statistics), 539  
 counting (fractal dimension), 172
- Bradbury, Ray, 775
- branched star ice crystal shapes, 199
- breakdown  
 bubble in tornado, 592-593  
 of zonal flow, 367-376  
 potential for lightning, 566, 880
- breaking the cap of thunderstorm inhibition, 522-527
- breaking waves in the atmosphere (K-H waves), 142, 165  
 fluctus clouds, 169
- breath, condensation within, 160
- breeze, 635-636  
 lake, 654-657  
 sea, 654-657  
 inland, 654  
 urban, 679
- briefing, weather, 765
- Brier skill score, 782, 785
- bright band, 248
- brightness temperature, 211, 221-224
- British Commonwealth (thermo diagrams used by), 121
- broken (bkn) cloud cover, 170, 279
- brown cloud, 857-858
- Brunt-Väisälä frequency, 136-137, 658-659, 666-668  
 use in baroclinic wave equation, 372-373  
 use in group velocity for waves, 658-659  
 use in mountain lee waves, 666-668  
 use in Rossby radius of deformation, 344  
 use in smoke plume rise, 733-734
- bubble, updraft, 482
- budget  
 equation(s), 713, 746-747  
 energy, global annual mean, 797  
 heat, 57-76, 713, 746-747  
 mass, 746-747  
 momentum, 746-747  
 net heat, 72-73  
 radiation, 42, 44-45  
 global annual mean, 797  
 surface heat, 73-76  
 water, 99-111, 746-747
- BUFR = binary universal form for representation of data, 268
- bugs  
 computer coding, 759  
 radar observations of, 248-249
- building codes, 772
- bulb, wet or dry, 78, 94-96
- bulk  
 heat transfer coefficient, 68, 397-398  
 air mass modification, 397-398  
 moisture transfer coefficient, 109  
 Richardson number  
 dynamic stability, 141-142  
 shear, 522, 530-531  
 thunderstorm, 521-522, 530-531
- bullet shaped ice crystals, 199
- bumpy ride in aircraft, 649, 667
- Bunker's internal dynamics method, storm motion, 518-520
- BUOY code, 269, 271
- buoy, cycloidal paths of, 312
- buoyancy, 62, 135-136  
 definition, 135-136, 316-317  
 generated turbulence, 709  
 length scale, 733  
 negative (downward), 554-563  
 neutral, 135  
 on thermo diagram, 135  
 positive (upward; also see CAPE), 503-508  
 pressure-perturbation, 555  
 role in katabatic wind, 653  
 velocity, 68-69, 110, 300, 704  
 scale, 68-69, 110, 300, 394-395, 704  
 virtual potential temperature, 62  
 waves, 666-668, 710  
 thunderstorm triggering, 526
- buoyant  
 consumption of turbulence, 709  
 force, 135-136, 316-317, 554  
 along mountain slope, 650-651  
 in neutral and stable regions, 135-136  
 of rain laden air, 554-563  
 pressure-couplets caused by, 341  
 forcings, 135, 315-317, 341, 403, 496-499, 503-508, 554-559, 649-653  
 production of turbulence, 709  
 thermals, 648-649  
 turbulence, 704
- Burgers-Rott vortex, 599
- burning the air (by lightning), 567
- bursticane, 602
- bursts of rain, 547
- butterfly, Lorenz attractor, 774-775
- Byron, Lord, 805
- ## C
- C and C++ programming languages, trig conventions, 3
- C band radar, 242
- C, degrees Celsius or centigrade, 7
- C-grid, 753
- cadmium iodide, 195-196
- cal (calvus), 168
- Calabrian age, 799
- calculation of  
 weather (numerical), 745-792  
 secondary variables, 771-772
- calculus, 11, 16, 18, 293, 872
- calibrated probabilistic forecasts, 777
- calibration errors, 875
- California (advection) fog, 173-175
- calm winds, weather-map symbol for, 278
- calvus (cumulonimbus), 168, 482
- camera filters  
 haze, 858  
 polarizing, 857
- Canada/Canadian  
 air quality standards, 725  
 geography & province abbreviations, 431  
 Hurricane Centre, 617, 638  
 hurricanes, 617  
 lightning, 566  
 Vancouver, British Columbia, 32-33, 472, 646-647
- Cancer, Tropic of, 31
- candela, 870
- canopy flows, 677-679  
 forest or plant, 677-678  
 urban or city, 678-679  
 winds at canopy top, 678
- canyon, urban, 678
- cap  
 and nonlocal conditional instability, 503  
 breaking, 524-527  
 clouds, 165, 666-667  
 convective inhibition (CIN), 522-527  
 definition (inhibiting thunderstorms), 496-499, 522-524  
 strength reduction by jet streak, 526  
 traps humid-air fuel for thunderstorms, 503  
 vs. capping inversion, 497
- CAPE (convective available potential energy), 503-508, 530-531, 590  
 downdraft (DCAPE), 530-531, 557-559  
 vs. CAPE, 558  
 energy helicity index (EHI), 591-592  
 hail forecasting, 550-552  
 in hurricanes, 609
- Cape Verde Islands, 611
- capillatus/cap (cumulonimbus), 168, 482
- capped column ice-crystal shapes, 199
- CAPPI radar displays, 242
- capping temperature inversion, 496-499, 522-527, 687-698
- Capricorn, 31
- carbon  
 14 isotope, 803  
 cycle, global, 812  
 dioxide (also see CO<sub>2</sub>), 7, 805  
 effervescence from oceans, 812  
 greenhouse gas, 811-812  
 Keeling (hockey stick) curve, 812  
 film hygrometer, 111  
 monoxide, CO, 7, 725
- cardiopulmonary resuscitation (CPR), 567, 571
- cargo-cult science, 167
- Carnot cycle, 624-625
- Carnot, S., 89
- Cartesian coordinate system, 2, 293  
 framework, 293
- cartography, 4
- cas (castellanus), 168
- cascade of vertical vorticity, 586
- case study  
 cyclone, 433-443, 448-456, 459-463, 466, 745, 768-770, 776  
 forecast, 745, 768-770, 776  
 thermal wind, 348-349  
 thunderstorm, 500-501, 506-508, 522-525, 528-529, 532, 551-552, 558, 568, 590-591
- castellanus clouds, 162, 164, 168
- castle-like mirages: Fata Morgana, 862-863
- CAT = clear air turbulence, 142, 165  
 L band radar to view, 242
- categorical event verification, 780-782
- categories of  
 clouds, 168-169  
 hurricane intensities, 605-607  
 tornado intensities, 579-580
- cats and dogs, raining, 206
- cavity of reverse flow, 667
- cauliflower-shaped clouds (see cumulus), 161-162
- CB (cumulonimbus, thunderstorm), 481
- cc (cirrocumulus clouds), 168
- CCD, 46
- CCN (see cloud condensation nuclei), 188-189
- CDP (tropical Cyclone Damage Potential), 607
- CDT, Central daylight time (Americas), 5
- ceiling, 170  
 change criterion for SPECI, 270
- celestial sphere, 834, 854
- cell  
 closed-cell clouds, 167  
 direct and indirect circulation, 377  
 Ferrel, 332-333, 357, 377  
 grid, 750-758  
 Hadley, 329, 332-333, 350-351, 377-378  
 open-cell clouds, 167  
 polar, 329, 332-333, 352, 378  
 solar, 46  
 thunderstorm, 484-487, 492-495
- Celsius, degrees, unit of temperature, 7, 870
- center  
 of mass  
 hodograph, for normal storm motion, 516-517  
 pollutant, 729, 736  
 Storm Prediction Center (SPC), 532
- centered finite difference scheme, 755-757  
 spatial (2nd & 4th orders), 755  
 temporal (leapfrog), 757
- centerline height, 723, 729, 736
- centi (10<sup>-2</sup>), 870
- centigrade = celsius, 7
- central

- dense overcast (CDO), 614  
 limit theorem, 184  
 European time (CET), 5  
 time zone (Americas), 5
- centrifugal force, 296, 301  
 explanation of Coriolis force, 298-299  
 in hurricane, 617-618  
 sign coefficient, 296
- centripetal force, 296, 301  
 related to BLG wind, 309-311  
 related to cyclostrophic wind, 311-312  
 related to gradient wind, 304-307  
 related to hurricanes, 617-619  
 related to inertial wind, 312
- CET (Central European Time), 5  
 CFC-12 (freon; halocarbons), 796, 811-812  
 CFL criterion for numerical stability, 760-761
- channel(ed)  
 flow, open-hydraulics, 657-661  
 of lightning, 563  
 winds, 664
- channeling of airmasses by mountains, 397
- channels on satellites, 222-223, 230
- chaos, 1, 773  
 theory & nonlinear dynamics, 773-776
- characteristic soundings for clouds, 162, 496-499, 503-508
- charge, electric, 564  
 transfer to/from ice crystals, 565
- charge-coupled devices (CCDs), 46
- charging rate & zone of thunderstorm, 564-566
- Charney, Julie, 749, 759
- charts, weather  
 analysis methods, 274-281  
 case-study examples, 433-466  
 multi-field, utility of, 443
- chaser, storm, 583
- chasing storms, 484, 583  
 core punching, 583  
 safety, 485, 517, 567, 570, 583-584
- chemical energy, 54
- chemicals & chemical symbols, 7, 725  
 equilibria, 132  
 gases/pollutants in the atmosphere, 7, 725
- chill, wind, 76-77
- chilled mirror (dew-point) hygrometer, 97, 111
- Chinooks , 676-677
- Churchill, Winston, 530
- ci (cirrus clouds), 168
- CIN (convective inhibition, of thunderstorms), 522-525, 530-531, 590  
 cap on convection, 524  
 mean-layer, 524
- cinnamon roll shape of occluding cyclones, 472
- Circles  
 Arctic and Antarctic, 31  
 of light in the sky (see optics), 833-868
- circular  
 frequency, 36  
 orbits, 27  
 symmetry, 572
- circulation  
 absolute, 366  
 ageostrophic, 410, 455-456  
 along-valley, 653-654  
 atmospheric and oceanic, 339, 378  
 baroclinic & barotropic atmospheres, in, 366  
 Bjerknes theorem, 366  
 cells  
 direct vertical, 351  
 Ferrel, 333, 357  
 Hadley, 350-351  
 indirect vertical, 333, 357  
 polar, 352
- cross  
 frontal, 412  
 valley, 649-653
- defined, 365-366, 377
- direct, 351, 376-377, 456
- driven by pressure perturbations, 340-341
- general, 329-388
- global, 329-388  
 explaining, 350-356
- Hadley, 329, 332-333, 350-351
- horizontal, 365-366
- hurricane, 620-625
- indirect, 456
- Kelvin's theorem, 366
- lake breeze, 654-657
- monsoon, 333-334, 356
- mountain/valley, 649-654, 660-670, 675-677
- relative, 366
- Sawyer-Eliassen, 412
- sea-breeze, 654-657
- secondary, 412, 455-456
- thermal (hydrostatic), 341-342, 648-657
- thermally direct, 351, 412
- three-band general, 329, 376-378
- through hurricane, 620-625
- transverse frontal, 412
- urban, 679
- vertical, 332-333, 377-378
- vorticity, relationship to, 366  
 Walker, 820
- circumhorizon arc, 848-849, 855
- circumpolar trough, 432
- circumscribed halo, 851, 853-855
- circumzenith arc , 848-849, 854-855
- cirro prefix, 163
- cirrocumulus, 162-163, 168  
 satellite images of, 234
- cirroform clouds, weather-map symbol for, 276
- cirrostratus, 162-163, 168  
 satellite images of, 234
- cirrus, 162-163, 168  
 satellite images of, 234
- citing the work of others (giving credit where due), 24
- citizen scientist, 738
- city (urban) canopy, 678-679  
 temperature excess relative to rural, 679
- civil  
 defense sirens for storm warning, 529  
 twilight, 33-34
- Clapeyron, B.-P.-E., 89
- classes of stability, 138-141
- classic supercell, 482-483, 486, 492-494, 549  
 wind statistics for, 585
- classification of  
 clouds, 168-169  
 snow grains, 199  
 thunderstorm types, 486  
 winds, 302, 314
- Clausius, R., 89
- Clausius-Clapeyron equation, 88-92  
 as affects mixing and saturation, 160-161
- clay (kaolinite), 195
- Clean Air Act, 7
- clear  
 air scans; returns on radar, 249  
 air turbulence (CAT), 142, 165  
 L band radar to view, 242  
 sky, 170, 279
- CLIMAT codes (SHIP, TEMP, TEMP SHIP), 269
- climate, 793-832  
 30-year average, 354, 355, 358, 816
- abrupt-change causes, 810
- anomaly, 818-819, 821  
 warm (ENSO and PDO), 818-820
- anthropogenic vs. natural effects, 812
- Arctic Oscillation (AO), 818-819, 824
- astronomical influences, 797-803
- atmospheric window, 796, 811
- averaging time, 817
- change  
 abrupt, 810  
 bounds, 811  
 effects of pollutants on, 724  
 gradual, 810  
 natural vs. human-caused, 812
- classification (Köppen), 816-817
- clouds, and condensation, 810-811
- codes & criteria, 816-817
- daisyworld, 813-815
- definition, 816-817
- El Niño - Southern Oscillation (ENSO), 818-820
- feedbacks, 806-812
- global climate models (GCMs), 815-816
- gradual-change causes, 810
- greenhouse effect, 795-796
- ice-albedo feedback, 808-812
- IPCC (Intergovernmental Panel on Climate Change), 812
- Köppen classification, 816-817
- La Niña, 818-820
- Madden-Julian oscillation (MJO), 818-819, 824
- Milankovitch theory, 797-803
- natural processes, 793-832
- normal, 818
- North Atlantic oscillation (NAO), 818-819, 824
- of NWP model, 776
- orbital effects, 797-803
- oscillations, 818-824
- Pacific decadal oscillation (PDO), 818-820
- present, 816-817
- radiative equilibrium, 793-797
- astronomical influences, 797-803  
 reference state, 794
- sea-surface temperature variations, 818-820
- sensitivity, 810-812  
 definition, 810-812  
 factor & usage, 812  
 magnitudes & processes, 812
- southern oscillation, 818-820
- variability  
 astronomical influences, 797-803  
 continent movement, 804  
 tectonic influences, 804-805  
 volcanism, 804-805  
 water-vapor and cloud feedbacks, 810-811
- climatic precession, 799-802
- climatological average, 330  
 highs, 354-356  
 lows, 354-356  
 pressure patterns globally, 354-355  
 storm (extratropical cyclone) tracks, 430-431  
 vertical cross section of atmosphere, 359  
 winds near tropopause, 358
- climatology/climatologies of  
 hurricanes, typhoons, tropical cyclones, 630-631  
 lightning, 564  
 numerical weather forecasts, 772, 776  
 reference for verification, 780
- CLINP code, 269
- CLISA code, 269
- clock  
 24 hour, 6  
 mechanical & sundial, 34  
 time correction (eq. of time), 34
- clockwise, 2
- closed  
 cellular convection, 167  
 system of equations, 714
- closure, turbulence  
 K-theory & other local, 714-716  
 mathematical, 714  
 parameterization types, 714-716  
 problem, 713-714  
 transient theory & other nonlocal, 716
- cloud(s), 159-184  
 accessory, 168-169  
 active, 162  
 advective, 94, 164  
 airmass, 393-397  
 altocumulus, 134, 162-163, 168  
 castellanus, 164-165  
 altostratus, 134, 162-164, 168  
 anabatic cumulus, 162, 649-650  
 anthropogenic, 166  
 anvil (incus), 169, 482-484, 604, 614, 620, 624  
 debris, 485  
 arc/arcus or shelf, 169, 482, 562  
 arrangement, 169  
 aspect ratio of, 485  
 asperitas, 169  
 associated with thunderstorms, 482-484  
 atlas, 168  
 banks, 168  
 banner, 165, 667
- base  
 detrainment instability, 484  
 estimation of height, 93, 130, 162  
 for descending air, 130  
 on thermo diagram, 130, 134, 496-499  
 rain-free, 483  
 height, weather-map symbols for, 277-278  
 thunderstorm, 496-506
- beaver tail, 483
- billow, 142, 165
- broken, 170
- brown, 857-858
- buoyancy within, 159
- bursts, 547
- calvus, 168
- cap, 165
- capillatus, 168
- castellanus, 162, 164-165, 168
- categories, 168-169
- cauda, 169
- cavum, 169
- ceiling, 170  
 thunderstorm, 484-485  
 closed, 167  
 open, 167
- central dense overcast (CDO), 614  
 change criterion for SPECI, 270
- cirro prefix, 163
- cirrocumulus, 162-163, 168
- cirrostratus, 162-163, 168

- cirrus, 162-163, 168, 485
- classification, 168-169
- clear, 170
- climate feedbacks, 810-811
- cold
  - frontal cumuliform clouds, 162, 400, 404
  - process of precipitation formation, 201-202
- colors in, 856-861
- condensation nuclei (CCN), 185, 188-189
  - airmass characteristics of, 391
  - density equation, 189
  - giant, 206
  - Junge distribution of, 189
  - number density, 188-189
  - sources, 188
- congestus, 162, 168
- contrails, 160, 166
  - climate change effects, 812
- convective, 93, 161-162
- cooling in, 101-106
- coverage/cover fraction, 170
  - not measured, 170
  - parameterization in NWP models, 751
  - total, weather map symbol, 279
  - vs. PG turbulence type, 728
- creation processes, 159-161
- cumuliform, 93, 161-162, 170, 482-484
- cumulonimbus (cb), 161-162, 168, 481-602
- cumulus (cu), 161-162, 168
  - anabatic, 162
  - castellanus, 164-165
  - congestus (cu con), 161-162, 483
  - fair-weather (humilis), 161, 498
  - fractus (scud), 165-166, 483
  - humilis, 161, 498
  - mediocris (cu med), 161-162, 483
  - towering (tcu), 161-162, 483
- decks, 164
- destabilization and cloud formation, 162
- determination from soundings, 164
- development, 161-166
  - active-cumuliform, 161-162
  - passive-stratiform, 162-164
  - stratocumulus, 164
- dimensions, 168
- dome (overshooting thunderstorm top), 483
- droplets, 159, 185-218
  - fall velocities, 159, 202
  - distance between, 194
  - scattering of light by, 856-859
  - typical sizes, 185
- duplicatus, 169
- dust (haboob), 562
- electrification, 564-566
- eyewall, 604-605, 618-620, 624-629, 637
- feedbacks for climate, 810-811
- few, 170
- fibratus, 168
- filaments, 168
- flanking line, 483
- floccus, 168
- fluctus, 169
- flumen, 169
- foehn wall, 676-677
- fog, 159
- forecasts
- formation, 98, 159-161
  - in anabatic flows, 162
  - in cold air advection, 162
  - orographic, 168
  - via cooling, 159
  - via adding moisture, 160
  - via mixing, 160-161
- forms, 168
- fractus, 165-166, 168, 483
- free air around thunderstorms, 546
- frontal
  - cold front and cumuliform, 162, 400, 404
  - occluded fronts, 413
  - warm front and stratiform, 162-164, 401, 404
- fumulus, 166
- funnel (also see tornado), 169, 483
- genera, 168
- glaciated, 485
- haboob, 562
- hat, 165
- hole in a cloud layer (cavum), 169
- horizontal roll vortices, 167
- humilis, 161, 168
- hurricane, 603-644
- ice-crystal, in arctic airmasses, 393-397
- identification, 161-169
- incus, 169
- intortus, 169
- K-H wave, 142, 165
- lacunosus, 169
- Lagrangian heat budget within, 159
- lapse rate inside, 101-106
- layers, 168
  - as reported in METAR, 270
- lee-wave, 165, 666-668
- lenticular/lenticularis, 165, 168, 666-668, 684-685
  - optical phenomena, 859-860
- lines, 167
- mammatus/mamma, 169, 484
- man-made, 166
  - mesoscale cellular convection, 167
  - mesoscale convective complex, 486, 491
- mediocris, 161-162, 168
- mesocyclone, 483
- mesoscale cellular convection (MCC), 167
- METAR, 270
- meteors, 168-169
- microphysics, 185-218
  - parameterization in NWP models, 751
- (in) midlatitude cyclones, 425-428, 472
- morphology, 168
- mother, 168-169
  - of-pearl, 166
- mountain-related (orographic), 162, 165-168, 649-650, 676-677
- mountain-wave, 165
- movement, 483
- murus, 169
- nacreous, 166
- names, 161-169
- NAT, 166
- nebulosis, 168
- nimbostratus, 162-163, 168
- noctilucent, 166
- obscured, 170
- observation from satellite, 220
- occluded frontal clouds, 413
- opacus, 169
- organization, 167
  - orographic, 162, 165-168, 649-650, 676-677
- overcast, 170
- pannus, 169
- passive, 163
- perlucidus, 169
- photographic tips, 180, 484
- physics thunder parameter (CPTP), 530
- pileus, 165, 169, 483
- polar, 166
  - mesospheric (PMC), 166
  - stratospheric (PSC), 166
- praecipitatio, 169
- radiatus, 169
- rain, 482-483, 486
- rain-free base of, 483
- roll, 169
- rotor, 165, 667
- sand, 562
- satellite images of, 232-234
- saturation within, 159-161
- scarf, 165
- scattered, 170
- scattering of light from, 856-858
- scud (cumulus fractus), 483
- seeding, 195-196, 218, 553-554
  - creating a hole (cavum) in layer clouds, 169
- shapes, 171
- sheets, 168
- shelf, 482, 562
- shield
  - from hurricanes, 604
  - from thunderstorms, 488
  - warm-frontal, 425-428
- sizes, 170
- snow-banner, 165
- species, 168
- spissatus, 168
- standing lenticular, 165, 666-668, 684-685
  - optical phenomena, 859-860
- static stability within, 159
- stratiform/stratiformis, 94, 162-164, 168
- stratocumulus, 164, 168
- stratus, 162-163, 168
- streets, 167
- striations, 483
- structure, 168
- STS clouds, 166
- subcategories, 168-169
- supercell, 482-483
- supplementary features, 168-169
- surface-turbulence related, 165-166
- symbols on weather maps, 168
- tail, 483
- thermo diagram (detection using), 134
- thickness, 161-162
- thunderstorm, 481-602
  - to-air lightning (air discharge; CA), 563
  - to-cloud lightning (CC), 563
  - to-ground lightning (CG), 563
- top, 162
  - IR cooling at, 484, 488-489
- track winds, 321-322
- trade cumulus, 351
- translucidus, 169
- transparency, 169
- triggering mechanisms
  - cold fronts, 162
  - mountains, 162
- tuba, 169
- turbulence and mixing, 132, 165-166
- types, 168-169
- uncinus, 168
- undulatus, 169
- urban, 162
- varieties, 168-169
- veils, 168
- velum, 169
- vertebratus, 169
- virga, 169
- volutus, 168
- wall, 483, 581-583
- warm frontal, stratiform clouds, 162-164, 401, 404
- wave (see lenticular), 165, 168, 666-668, 684-685, 859
- weather map symbols for, 168, 277
- white color of, 857
- WMO cloud atlas, 168
- cloudiness
  - airmass characteristics of, 391
  - constant (isoneph), 18
  - feedback factor for climate change, 810
  - related to albedo, 44, 811
- cloud-radiation interaction, 131-132
- clusters of ice crystals, 199
- CO, carbon monoxide, 7, 725
- CO<sub>2</sub>, carbon dioxide, 7
  - biological climate feedback, 810-812
  - doubling, 812
  - fossil fuels vs. global cycle, 812
  - greenhouse gas, 811-812
  - Keeling (hockey stick) curve, 812
  - ocean, feedback for climate, 810-812
  - effervescence, 812
  - sequestered, 812
  - transpired and release during wild fires, 812
- coagulation, 188
- coalescence, 202-207
  - efficiency, 204-205
- coarse
  - mode CCN formation, 188
  - resolution NWP & GCMs, 752, 815
- coastal
  - breezes, 654-657
  - fogs (advection fog), 173-175
  - hazards of hurricanes, 634
  - jets, 664-665
  - waves and surf, 634-636
  - winds, 654-657, 661-665
- coastally trapped low-level barrier jets, 664-665
- cockroach, 151, 815
- CODAR code, 269
- CODATA, 876, 879
- codes for
  - airmasses, 391-392
  - building, 772
  - weather reports, 268-273
- coefficient
  - drag, 700-701
  - extinction, 43
- cold
  - air
    - advection and backing of wind, 349
    - advection and cloud formation, 162
    - aloft in pre-storm environment, 496, 503
    - pool from thunderstorms, 488-489
    - pool at night, 653
    - sector, 425-428
  - airmass, 392
    - depth, 404-406
    - genesis, 393-397
  - cloud
    - precipitation aggregation, 202, 205
    - process of precipitation formation, 201-202,

- 205-206, 546  
seeding, 196  
tops in thunderstorms, 206
- core systems, 426, 622  
vs. warm core, 622
- frontogenesis, 281, 399  
frontolysis, 281, 399  
front, 399-404  
aloft, map symbol for, 281, 399  
cumuliform clouds, 162, 400, 425-428  
definition, 404  
deformation behind, 470-471  
descent and diffluence behind, 433, 470-471  
depth, 405  
extratropical cyclone, attached to, 425-428  
horizontal structure, 400  
occlusion, 413  
propagation, found using Q-vectors, 470-471  
radar observations of, 248-249  
thunderstorms along, 400  
trigger for hurricanes, 612-613  
trigger for thunderstorms, 525  
weather map symbols for, 281
- high-pressure centers, 341-342  
katafront, 404  
mode rainfall estimates, 257  
sector of extratropical cyclones, 425-428  
vs. warm core cyclones, 622
- collection, 202-207  
and aggregation processes, 204-205  
efficiency, 205
- collision efficiency, 204  
collision and collection, 202-207  
of hydrometeors, 185, 202-207  
droplet size distributions, 207  
processes, 202-207  
terminal velocity of droplets, 202-204
- colors  
angles of 22 degree halo, 845  
defined, 37, 834-835, 862  
dispersion of, 834, 862  
Newton's work on, 862  
of halos and arcs, 845-851  
of rainbow, 838-840  
of sky, 857-858  
of sunset, 858  
scattered vs. particle diameter, 858  
wavelengths of, 37, 834-835, 862
- Columbus, Christopher, 607
- column  
ice crystals, 198-199, 842  
hollow, 198-199, 866  
optics caused by, 842-855  
of air in closed cylinder, 55, 463-465
- combined parameters and conversion factors, 880
- commercial aircraft, 563
- compass direction, 2, 646
- communicating NWP forecasts, 772
- complete thermo diagrams, 121, 151-158
- complexity of the atmosphere, 1
- component angles of refraction geometry, 833-836
- components of the atmosphere, 7
- composite parameter, for supercell, 591
- composition of atmosphere, 7
- compressible flow, 671-672  
adiabatic, 671-672  
isothermal, 671  
numerical weather prediction model for, 747
- compression, 8  
of NWP output into databases & climatologies, 772
- computational  
evolution, 680  
natural selection, 680
- computer  
Amdahl's Law, 763  
blowing up, 757, 760  
chips, 752  
crash, 757  
ENIAC, 749, 759  
Moore's Law, 752  
profilers, 763  
speed-up, 763  
vs. human contributions to forecasts, 772
- computerized (numerical) weather forecasts, 745-792
- concentration, 724-725  
of pollutant, 725  
crosswind-integrated, 735-737  
Gaussian distribution, 729-730, 734, 737  
of pollutant downwind, 724  
units for pollution, 724
- condensation, 56, 88  
amount in rising air parcels, 130  
convective condensation level (CCL), 526-527  
freezing, 195  
funnel of tornado, 581-583  
energy in hurricanes, 620  
latent heat of, 56  
lifting condensation level (LCL), 93-94, 496-506  
nuclei (see also CCN), 188  
on to snow, 110  
role in frontal strengthening, 411  
role in self development of cyclone, 465-471  
trail (contrail), 160, 166
- conditional instability, 140-141  
nonlocal, in hurricane environment, 609  
nonlocal, in thunderstorm environment, 140, 496-499, 503-508
- conditionally unstable, 140-141
- conditions favoring thunderstorms, 496-499
- conduction, 67-69  
contribution to airmass genesis, 393  
contribution to frontolysis, 411  
from cloud droplets, 185, 197  
(and) turbulence on windy days, 68
- conductive heat flux, 67-69  
at surface, 73-76
- conductivity, molecular, 67-68, 880
- cone shaped tornadoes, 577
- confidence in NWP forecasts, 776
- confluence, 409-410  
frontogenesis, 409-410
- conformal map projections, 748
- congestus/con, cumulus, 161-162, 168, 483  
pileus clouds created by, 165
- coning, pollutant plume, 710, 727
- consequences of doing science, 218
- conservation of  
angular momentum, 360-361  
breakdown of, 361  
energy along a streamline, 671-672  
heat, 1, 59, 64, 746-747  
isentropic potential vorticity, 364-365  
mass, 317-320, 660, 746-747  
momentum, 392-393, 746-747  
potential vorticity, 363-364, 445  
total water, 1, 107, 746-747
- conservative tracers, 731
- conserved variable, 61, 104
- constant  
altitude plan position indicator (radar), 242  
flux layer, 692  
gases in the atmosphere, 7  
height map (such as mean-sea level), 436  
case-study cyclone examples, 434, 438  
vs. isobaric map, 290-291, 436  
potential temperature map, 437  
potential vorticity map, 437  
pressure map, 436  
pressure difference (giving thickness charts), 436  
solar (total solar irradiance), 39  
von Kármán, 677, 701
- constants and conversion factors, 879-880  
Earth, 879  
math, 879  
universal, 879
- constantan, 78
- constituents (gases) in the atmosphere, 7
- constructive interference, 859-861
- contact freezing, 194-195
- continental  
airmass code, 392  
arctic airmasses, 396  
polar (cP) airmass, 392  
genesis, 393-397  
scale circulations (monsoons), 333-334
- continent(s)  
aerosols and CCN over, 188, 194  
movement, 804  
ocean circulations (monsoons), 333-334, 356  
super, 804
- contingency table, 780
- continuity, 317-318  
effects, 340-341  
downburst & gust fronts, 561-562  
driving vertical velocity, 452-456  
equation, 317-318  
flux form, 714  
sign convention, 320  
pressure perturbations related to, 340-341
- continuous variables, verification of, 777-780
- contours, 17, 121, 151
- contraction, axis of, 320-321
- contrails (condensation trails), 160, 166  
climate change effects, 812  
controlling the weather, 218
- convection  
deep (i.e., thunderstorms), 481-601  
parameterizations in NWP, 751  
definition, 66, 649  
forced vs. free, 704, 710, 727  
free, 704, 710  
smoke dispersion within, 735-737  
level of free (LFC), 496-506  
limit of (LOC), 498  
moist (i.e., thunderstorms), 496, 649  
organized, in tropical disturbance, 613  
parameterizations in NWP models, 751  
penetrative, 508
- convective  
adjustment, moist, 70  
available potential energy (CAPE), 503-508, 530-531  
boundary layer, 68, 109-110  
circulations, 134-139, 161-162, 332, 341-342, 350-351, 357, 376-378, 481-544, 648-657, 704  
clouds (including thunderstorms), 93, 138, 161-162, 481-601  
formation regions, 162  
condensation level (CCL), 526-527  
conditions for thunderstorm formation, 68, 496-499  
inhibition (CIN), 522-525, 530-531  
instability (nonlocal conditional), 498, 503-508  
mixed layer, 648-649, 692, 695, 697-698  
airmass, 393-396  
depth, 649, 695, 697-698  
humid. Role in thunderstorms., 497-501  
smoke dispersion within, 735-737  
winds in radix layer, 703-705  
mixing, 301  
outlooks, 528-530  
radix layer, 703-705  
temperature, 526-527  
towers, hot, 644  
transport coefficient, 68, 110  
for heat, 68, 110  
for moisture, 110  
turbulence, 508, 527-530, 704  
generation, 706  
velocity scales, 68-69, 704  
vortex, mesoscale, 492  
winds in boundary layer, 703-705
- conventions - mathematical and meteorological, 2
- convergence, 318-321  
evolution vs. cyclone evolution, 467  
line, 281, 399  
of air at bottom of cyclones (lows), 309, 331, 691  
of air at top of anticyclones (highs), 391  
of air in certain jet streak quadrants, 454-456  
of air in easterly waves, 612  
of mass, 318-321, 340-341  
of Q-vectors, 460-462, 469-471  
radar observations of, 252-253  
zone  
intertropical (ITCZ), 330-332  
Olympic Mtn. & Puget Sound, 472
- conversion  
constants and conversion factors, 879-880  
factors and combined parameters, 880  
of pollutant concentration units, 724  
of units, 871  
of wind components, 3  
conveyor belt of warm air, 433
- cooking  
boiling temperature vs altitude, 90, 115  
data, 826
- cooling  
accumulated in boundary layer, 693  
evaporative, in downbursts, 556  
process to make clouds, 159  
tower clouds, 166
- coordinate system, 2  
aligned with mean wind, 727  
alternative  
horizontal, 747  
vertical, 746  
Cartesian (rectangular), 2  
cylindrical, 2, 627  
eta, 746  
hybrid, 746  
map-projection, 747-748  
polar, 2  
stereographic, 747-748  
sigma, 746  
spherical, 747  
terrain-following, 746, 753



- Coordinated Universal Time (UTC), 5, 268  
 co-polar correlation coefficient, 256-257  
 copper-constantan thermocouple, 78  
 core  
   cold, 426, 622  
   of cyclone, 426, 622  
   of hurricane, 604, 614, 618-625  
   of jet stream, 357-361  
   of tornado, 577-578  
   pressure deficit in  
     hurricane, 621-624, 626, 633  
     tornado, 577-578  
   punching, 583  
   warm, 426, 614, 621-622  
     vs. cold, 622  
 Coriolis force, 297-299, 301  
   acting on  
     Antarctic winds, 652  
     katabatic winds, 652-653  
   as a component of centrifugal force, 298-299  
   derivation of equations for, 299  
   direction, 297  
   explanation of, 298-299, 301  
   factor, 879  
   in gap winds, 662-664  
   in hurricane, 609, 617-619  
   in 3D, 297  
   contributing to wind, 302  
     boundary layer, 307  
     boundary-layer gradient, 309  
     geostrophic, 302  
     gradient, 304  
     inertial, 312  
   magnitude, 297-299, 301  
   near equator, 297  
   on objects moving east/west, 298-299  
   on objects moving north/south, 299  
   role in cyclogenesis, 426, 443-450, 609  
   sign convention, 297  
   vertical component, 297  
 Coriolis, Gaspar Gustave, 298  
 Coriolis parameter, 297  
   rate of change (beta) with latitude, 297, 369, 879  
 corkscrew (helical) motion, 587-592  
 corollaries  
   numerical weather prediction, 756, 758  
   satellite sounding retrieval, 235-239  
 corona, 858-860  
   clouds that cause, 163, 667, 859  
   igneous meteors, 205  
   vs. halos, 860  
 correct negative or correct rejection, 780  
 correction of temperature for dynamic warming, 673  
 correlation coefficient, 711, 779  
   anomaly, 779-780  
 cosine law of radiation (see sine law), 40  
 cosmic rays, 565  
 cost, 780  
   function, 766-767  
   loss  
     decision model, 784-785  
     ratio, 785  
 Cotopaxi volcanic eruption, 805  
 cotton-ball shaped clouds (see cumulus), 161-162  
 coulombs, C, unit of electric charge, 7, 564, 870  
 counter-clockwise, 2  
 counter-rotating mesocyclones, 490-491, 587  
 coupled equations in math, 393, 747  
 coupled heat and moisture budgets, 108  
 couplet  
   wind, 253, 561  
   pressure, 340-341  
 Courant  
   condition, 760  
   number, 758  
   Friedrichs-Lewy (CFL) stability criterion, 760-761  
 courses on meteorology/atmospheric science, 863  
 covariance, 711-713, 821  
   matrix, 821-822  
 coverage of clouds, total, 279  
 Cp vs. Cv, 55  
 CPR (cardiopulmonary resuscitation), 567, 571, 638  
 crash  
   aircraft, due to bad weather, 563  
   computer, 757  
 CRC Handbook of Chemistry and Physics, 879  
 Creative Commons License, II  
 creativity in  
   engineering, 288  
   science, 293  
 crests of waves, 658, 668  
   tilt with altitude, 668  
 Cretaceous-  
   Paleogene extinction event, 805  
   Tertiary (KT) extinction event, 805  
 CREX = character form for the representation of data, 268  
 crimson sunset skies, 858  
 critical  
   angle, 837  
   evaluation exercises explained, 22  
   flows, 659  
   Froude number, 659  
   radius, 192  
     derivation, 193  
   Richardson number, 142, 880  
   success index, 781  
   supersaturation, 192  
   swirl ratio, 593  
 Croatia, bora winds, 675  
 crop  
   canopy flows/winds, 677-678  
   damage from hail, 549  
 cross  
   equatorial flow  
     in Hadley cell, 332-333  
     in monsoon circulations, 356  
   frontal circulation, 412  
   jet-stream flow, 415  
   isobaric flow, 307-311, 314, 318-320, 454, 691  
   product vector operator, 299  
   section in  
     baroclinic atmosphere, 373  
     extinction, 43  
     fronts, 403-416  
     global circulation cells, 332  
     hurricane, 605, 618-624, 629  
     jet streams, 357  
     valley circulation, 649-653  
   wind  
     direction definition (i.e., lateral), 727  
     integrated concentration, 735-737  
 crystal (see ice crystal)  
   liquid-crystal thermometer, 78  
 cs (cirrostratus clouds), 168  
 CST, Central standard time (Americas), 5  
 cu (cumulus clouds), 168  
   cubed sphere grid for NWP, 752  
   cubic ice (Ic), 198  
 cumulative  
   daytime heating, 693-694  
     seasonal differences, 695  
   nighttime cooling, 693  
     seasonal differences, 695  
   probabilities, 777  
 cumuliiform clouds  
   along cold fronts, 425-428  
   altitude of bases, 93  
   formed by adiabatic cooling in updrafts, 160  
   formed by turbulence near surface, 165-166  
   typical sizes, 170  
 cumulonimbus (see thunderstorm), 161-162, 168, 481-602  
   calvus, 482  
   capillatus, 482  
 cumulus, 161-162, 168  
   anabatic, 162, 649-650  
   castellanus, 164-165  
   congestus (cu con), 161-162, 483  
     triggering pileus clouds, 165  
   fair-weather, 161, 498  
   fractus, 165-166, 483  
   frontal, 400, 404, 413  
   humilis, 161, 498  
   mediocris (cu med), 161-162, 483  
   mixing caused by, 301  
   stage of thunderstorm evolution, 485  
   towering (tcu), 483  
   trade, 351  
   weather-map symbols for, 277  
 cup  
   anemometer, 321  
   shaped ice crystals, 199  
 cupric sulfide, 195-196  
 current  
   density, 565, 655-656  
   direct electric, 564  
     units, 564  
   gravity, 655-656  
   induced by lightning, 570  
   lightning, 564, 568-569  
   ocean, 339, 378, 431, 610, 701  
     Gulf Stream, 616  
     Labrador, 616  
 curvature, 375  
   Earth's, 244  
   effect, 189-192  
   jet stream, driving updrafts and cyclogenesis, 453  
   Laplacian, as a measure of, 450  
   of a line, 450  
   radius of light ray, 861  
   Rossby number, 306  
   Rossby wave, 375  
   terms in equations of motion, 747  
   vorticity, 362  
 cut  
   in wind speed for turbines, 648  
   out wind speed for turbines, 648  
 Cv or Cvd, 55, 880  
 cyan color defined (also see optics chapter), 37  
 cycle, global carbon, 812  
 cyclogenesis, 426-433  
   attributes, 446  
   characterized by, 426, 446  
     sea-level pressure decrease, 463-467  
     upward motion increase, 451-462  
     cyclonic vorticity increase, 446-450  
   evolution, 467  
   explosive, 426  
   favored regions, 426, 431-431, 450, 456  
   feedbacks, favoring self-development, 468-471  
   hurricane, 608-615  
   lee side, 430-431, 443-446  
     isentropic potential vorticity conservation, 364-365  
     potential vorticity conservation, 364-365, 445  
   omega equation, 456-462  
   Q-vectors, 460-462  
   rapid, 426  
   self-development, 468-471  
   Stutcliffe development theorem, 456  
   Trenberth omega equation, 458  
   tilt of trough with altitude, role of, 432  
 cycloidal paths of  
   damage from multi-vortex tornadoes, 593  
   drifting buoys, 312  
 cyclolysis, 426-433  
   evolution, 467  
 cyclone  
   atmospheric boundary layer within, 690-692  
   bomb, 426  
   Catarina, 631  
   case study, 433-443  
   characteristics, 426-433  
   cold vs. warm core, 622  
   convergence of horizontal winds, 691  
   damage potential, 607  
   deepening, 463  
   evolution, 427-429  
   filling, 463  
   glyphs (symbols) on weather maps, 426  
   graveyard, 431, 472  
   landfalling, at Pacific Northwest coast, 472  
   lifetime, 431  
   propagation and self-development, 469  
   self-development, 468-471  
   spin-up, 446-451  
   tracks and propagation, 425-426, 430, 469  
     Q-vectors, 469-471  
   warm vs. cold core, 622  
 cyclone types/names  
   comparison of, 425-426  
   cyclones (tropical or extratropical), 425-426  
   extratropical cyclones (lows), 425-480  
   hurricanes, 603-644  
   low-pressure centers (see extratrop. cyclones), 425-480  
   lows (see extratropical cyclones chapter), 331, 425-480  
   mesocyclones (see thunderstorm chapters), 481-602  
   midlatitude cyclones (see extratrop. cyclones), 425-480  
   polar cyclones (see extratrop. cyclones chap.), 425-480  
   storm systems (see extratrop. cyclones chap.), 425-480  
   tropical cyclones (see hurricane chapter), 603-644  
   typhoons (see hurricane chapter), 603-644  
 cyclonic  
   rotation direction of most tornadoes, 578, 586  
   vorticity, 446-450  
     spin-up, 446-450, 586-587  
 cyclonic winds, 306-307, 331

convergence in the boundary layer, 309, 691  
 definition, 425  
 cyclostrophic balance, 311-312, 578  
 cyclostrophic wind, 311-312  
   in hurricane, 609, 618  
   in tornadoes and waterspouts, 311, 578  
 cylindrical  
   coordinates - defined, 3  
   for hurricanes, 627  
   shaped tornadoes, 577  
 CYVR (Vancouver International Airport), 646-647

**D**

D-grid, 753  
 daily cycle (diurnal), 687  
   of thunderstorms, 528  
 daily solar effects, 32, 40, 687  
 daisyworld, 813-815  
 Dalton minimum in solar activity, 803  
 damage  
   paths  
     cycloidal vs. divergent, 593  
     parallel, 584  
   potential (CDP) for hurricanes, 607  
   scales  
     hurricane, 605-607  
     tornado, 579-580  
   wind, by hurricanes, 634-636  
 damming of cold air behind mountains, 661-665  
 damped  
   inertial oscillation, 311  
   response (negative feedback), 806  
 dark  
   band, Alexander's, 841  
   spot (waterspout evolution), 582  
 Darkness, by Lord Byron, 805  
 dart leader (lightning), 567  
 data  
   abuse, 826  
   analysis methods  
     on weather maps, 280, 765-768  
     (also see statistical methods)  
   assimilation and analysis, 765-768  
   element, 875  
   empirical orthogonal function (EOF), 820-823  
   ethics and abuse, 826  
   extrapolating, 826  
   fudging, 826  
   manufacturing, 826  
   massaging, 826  
   misinterpretation, 729  
   outliers, 502  
   principal component analysis (PCA), 820-823  
   reduction, 502, 823  
   reporting, 875  
   set, 875  
   slanting, 826  
   smoothing, 826  
   statistical (see statistical methods)  
   void, Pacific, 287-288, 765  
 databases, 772  
 date line, international, 5  
 daughter storm, 485  
 Davenport-Wieringa roughness-length classification, 700  
 day  
   duration, change of, 376  
   sidereal, 297  
   unit, 870  
   winds (anabatic; valley; sea-breeze), 649-657  
 daylight  
   duration of, 32-33, 40  
   time (DT) = daylight savings time, 5, 6  
 daytime (convective) boundary layer, 692  
 dazzled by bright sunlight sky, 842  
 dB (decibels), 246  
 dBZ (decibels of radar reflectivity factor), 246-247  
   hail, 247-248, 552  
 DCAPE (see downdraft CAPE), 557-558  
 Deardorff velocity, 69, 703-704, 736  
 deaths caused by  
   downbursts of air and aircraft crashes, 563  
   downpours of rains and flash floods, 548  
   hurricanes and storm surge, 606, 617, 631, 637  
   lightning, 564  
   tornado outbreaks, 583-584  
   winter storms, 434-435  
 debris cloud, tornado, 581-583  
 decade on logarithmic graph axis, 215  
 Deccan traps, 805

deci ( $10^{-1}$ ), 870  
 decibels, 246-247  
 decision model, cost/loss, 784-785  
 decks of clouds, 164  
 declination angle, solar, 30-31  
 decoding a METAR or SPECI, 270-279  
 decreasing, weather-map symbol for, 276  
 deductive reasoning, 107-109  
 deep convection (see thunderstorms), 481-601  
   parameterizations in NWP models, 751  
 deepening of lows (cyclones), 463  
 definition errors, 875  
 deformation, 320-321  
   internal Rossby radius of, 319-320, 344, 665  
   use in coastally trapped jets, 664-665  
   use in Rossby waves, 372-373  
   external Rossby radius of, 405-406, 665  
   frontal, 410, 433  
   shearing, 320-321  
   stretching, 320-321  
   total, 321  
 degrees  
   angle unit, 870  
   Celsius ( $^{\circ}\text{C}$ ), unit of temperature, 870  
   latitude & longitude, 4  
   temperature symbols ( $^{\circ}\text{C}$ ,  $^{\circ}\text{F}$ ,  $\text{K}$ ), 7  
 deka (10), 870  
 del operator, 458  
 deluge, 607  
 dendrite snowflake/ice-crystal, 198-199, 843  
   optics caused by, 842-843  
 dendrochronology (tree ring dating), 803  
 density  
   at sea level, 10  
   change with height, 10, 316  
   constant (isopycnic), 18  
   current, 655-656  
   definition, 10  
   forecast equation for, 746  
   hailstone, 549  
   ice, 209  
   interface, 657-661  
   of average tropospheric air, 72, 880  
   of droplet laden air, 14-15, 202  
   of liquid water vs. temperature, 835, 880  
   sea water, 880  
   mean background state, 316  
   partial, 91  
   scale height, 10  
   snow, 209  
   specific volume, 10  
   standard (STP), 880  
   units, 10  
 dependent variable, 3, 872  
 deposition  
   latent heat of, 56, 88  
   nucleation, 194-195  
 depression  
   tropical, 613-614  
   wet-bulb, 94-96  
 depth  
   Ekman layer in ocean, 378  
   evaporation rate, 108  
   liquid-water equivalent, 107, 208, 210  
   of atmospheric boundary layer, 144, 319, 687-705, 716  
   of the troposphere, 143, 163, 357-360, 414-415  
   optical, 43, 805, 856  
   parameter (Ekman) in ocean, 378  
   precipitable water, 98-99, 211, 501  
   precipitation rate, 108  
 derecho, 489, 491, 494  
 derivative  
   finite-difference approximation, 16, 872  
   total, 872  
 derived dimensions, 870  
 Des Moines, Iowa, 745, 776  
 Descartes, Rene, 2, 90, 680, 841  
 descending air (see subsidence)  
 descending node of satellite orbits, 228-229  
 description of global circulation, simplified, 330-334

descriptor on weather maps, 276  
 desert  
   Gobi, 397  
   oasis effect, 74  
   subtropical, 351  
   surface heat flux at, 74  
 design of an NWP system, 761  
 destabilization  
   of air to make cumulus clouds, 162  
   of well-mixed fog, 176-177  
   to maintain a circulation, 342

destructive interference, 859-861  
 detection networks, lightning, 568-569  
 deterministic forecasts, 777, 816, 818  
 detrainment of air, 57, 484  
   instability at cloud base, 484  
 development  
   clouds, 161-166  
   hurricanes, 617-618  
   theorem for cyclogenesis (Sutcliffe), 456  
   tornadoes, 583  
 dew, 93  
 dew-point  
   depression, 93  
   hygrometers, 111  
   temperature, 89, 92-93  
     constant (isodrosotherm), 18  
     definition, 92-93  
     in thunderstorm environment, 499-502  
     measurement, 111-112  
     plotted on weather maps, 275, 438, 500  
     reported in METAR, 270  
 diabatic  
   effects in frontogenesis, 411  
   excess water variation, 187  
   heating, 131  
     role in cyclone evolution, 465-466  
   numerical weather prediction model, 747  
   process, 61, 131  
   warming rate for frontogenesis, 411  
 diagnostic equations, 747  
 diagrams  
   Hovmöller, 824-825, 830  
   reliability, 782-783  
   ROC, 783-784  
   thermo, 63, 119-158  
 DIAL (differential absorption lidar), 112  
 diameter of rain drops, radar observed, 247-248  
 diamond dust (ice crystals), 276, 396, 842, 849  
 dice, 184  
 difference, finite, 872  
 differential  
   absorption lidar (DIAL), 112  
   advection (see also castellanus clouds), 164  
   equation, 16, 137, 872  
   heating, 329, 334-339  
     heat transport by global circulation, 338-339  
     meridional temperature gradient, 335-336  
     radiative forcings, 329, 334-339  
   reflectivity, 256-257  
 diffraction, 858-861  
   fringe, 858-860  
 diffuse arcs, 854-855  
 diffusion, 185, 196-197  
   definition, 196-197  
   equation, 196-197, 731  
   of water molecules, 185, 196-197  
 diffusive growth of  
   droplets, 196-197  
   ice crystals, 198-202  
 diffusive moisture flux, 196  
 diffusivity, 196-197  
   eddy (turbulent), 715  
   molecular, 196-200, 880  
 diffusometer, 46  
 diffuence, 410, 433  
   behind cold front, 433  
 dilation, axis of, 320-321, 410  
 dimensionless ratios  
   Froude number, 659, 667  
   Richardson number, 141-142, 521  
   Rossby number, 313  
     curvature, 306  
   scales for pollutant dispersion, 736  
 dimensions, 870  
   basic & derived, 870  
   fractal, 171  
   units, 870  
     conversions, 871  
 dimethyl sulfide, 188, 811  
 dinosaurs, 805  
 dipoles  
   Arctic, 824  
   Indian Ocean, 824  
   pressure couplets, 340  
 direct  
   cell, 377  
   circulations, 351, 376-377, 462  
     frontal, 412, 462  
   climatic response, 806-812  
   current (DC), 564  
   instruments (in situ), 219  
   sense, 332-333, 357, 377, 456  
   vertical circulation cells, 351, 376-377

- vs. indirect heating, 73
  - direction of
    - scattered light, 857
    - wind, 2, 3
      - frequency; wind rose, 646-647
      - isogon, 18
  - directional shear, 509-510
  - directions of up and down, 298
  - dirt, 188
    - dirty window, 220-223
  - disaster
    - plan, 638
    - relief, 631
    - supply kit, 638
  - discomfort indices (humidity), 117
  - discontinuity (tropical), 281, 399
  - Discours de la Méthod (book), 2
  - discretization, 750
    - equations of motion, 758-759
  - discriminate between event and non-event, 783
  - discriminator, statistical, for thunderstorm forecasts, 507
  - disdrometer, 210
  - dispersion, 723-744
    - color, 834-835, 862
    - equation, 731-732
    - Deardorff method for unstable ABLs, 735-737
    - factors of pollutants, 724-725
      - atmospheric turbulence, 724-728
      - plume rise, 724
      - wind speed and direction, 724-727
    - far from source, 732
    - fog, of, 175-177
    - in neutral and stable boundary layers, 708, 732-734
    - in unstable boundary layer, 708, 735-737
    - isotropy, 727
    - near pollution source, 732
    - of light into colors, 834-835, 862
      - Newton's work on, 862
    - of pollutants and smoke, 708, 723-744
    - Pasquill-Gifford turbulence type, 727-728
    - relation of waves, 369
      - baroclinic; planetary, 372
      - barotropic; Rossby, 369
    - statistics, 728-730
  - displacement
    - distance, 677
    - of fluid, causing buoyancy, 135
  - dissipation
    - length scale, 709
    - of fogs, 175-177
    - of turbulence, 315, 706, 709
    - rate, 709
    - stage of thunderstorm-cell evolution, 485
    - stage of tornadoes, 583
    - subrange, 315
  - dissipative turbulent behaviour, 706
  - distance
    - between cloud droplets, 194
    - between crest and trough (jet stream), 367-374, 453
    - between sun and earth, 30, 797-802
    - displacement, 677
  - distribution
    - Junge, 188-189
    - lognormal
      - cloud sizes, 170
      - drop sizes, 207
    - of pressure in hurricane, 618-633
    - of radiation, 39
    - of smoke concentrations, 734, 737
    - Weibull, for wind speed, 645
  - disturbance
    - tropical, 613
    - upper-level, 433
  - diurnal (daily) cycle, 27, 356, 687
  - heat, 73-76, 528, 687-698
  - of dry line, 416
  - of thunderstorms, 528
  - radiative fluxes, 27, 44, 687
  - winds, 699-704
- divergence, 318, 320-321
  - airmass formation, role of, 393-394
  - aloft in
    - low-pressure region, 432, 452-459, 463-467
    - tropical upper tropospheric trough, 612-613
  - at surface in a high-pressure region, 331, 390, 691
  - evolution vs. cyclone evolution, 467
  - in pressure systems, 340-341, 467
  - jet-stream winds, role in cyclogenesis, 427-428, 432, 452-459
  - of flux, 64, 109-110, 715
  - of mass, 318-321, 340
  - of Q-vectors, 460-462, 469-471
  - outflow straight-line thunderstorm winds, 252-253, 560-561
    - plotted on a weather map, 441, 449
    - pressure tendency at MSL, role in, 463-467
    - radar observations of, 252-253, 560-561
    - term in vertical vorticity eqn., 447-448
    - upward motion driven by, 452-459
  - DMSP (defense meteorological satellite program), 273
  - dogs, sun, 842, 850-851, 854-855
  - doing science, 877
  - doldrums, 331
  - domain of NWP, 750
  - dome (overshooting thunderstorm top), 483
  - dominant wavelength of lee Rossby waves, 444
  - Doppler
    - dilemma, 251
    - displays, 250-254
    - dual radars, 249, 253
    - maximum unambiguous velocity, 250-251
    - phase shift, 250
    - radar (see also radar), 241, 249-254, 552
      - downburst & gust-front detection, 556-560
      - locations worldwide, 272
      - radial wind speed (isodop), 18
      - thunderstorm diagram, 493
    - shift, 241, 249-250
  - Doswell III, Charles, 517, 567, 583-584
  - dot product, 239
  - doubling of carbon dioxide, 812
  - down, direction defined, 298
  - downbursts and gust fronts, 482-483, 554-563
    - bursticane, 602
    - causes, 555-556
      - evaporative cooling, 556
      - precipitation drag, 555
    - characteristics and definition, 554-555
    - downdraft CAPE (DCAPE), 557-559
    - pressure perturbation, 559-550
    - geographic locations, 556
    - intensity estimates from radar, 561
    - outflow straight-line winds, 560-563
    - radar observations of, 253, 560-561
    - triggering new thunderstorms, 525, 561
    - vertical velocities, 557-559
  - downdraft
    - CAPE (DCAPE), 530-531, 557-559
    - dangerously fast (downbursts), 554-563
    - equilibrium level (DEL), 557
    - forward-flank (FFD), 483
    - rear-flank (RFD), 482
    - speed, 554, 557-559
  - downshear propagation of derecho, 494
  - downslope winds, 652-653, 667, 675-677
    - Antarctic, 676
    - Bora, 675-676
    - Foehn, 676-677
    - katabatic, 652-653
    - mountain waves, 667
    - storms, 667, 675
  - downwelling radiation, 44-45
  - downwind mountain process, 443-446, 666-668
  - drag
    - atmospheric boundary layer, 699-702
    - coefficient, 300, 700-701
      - range, 300, 700-701
    - force, 300-301
      - related to antitriptic wind, 312-313
      - related to BL & BLG wind, 307-311
      - sign convention, 300
    - on air by falling rain, 202, 555
    - on falling
      - cloud droplets, 202
      - hailstones, 204
      - ice crystals, 842
      - rain drops, 203
    - on tornado rotation, 586
    - precipitation, 555
    - role in katabatic wind, 653
    - skin, 668
    - Stokes law, 202-203
    - wave, 668
      - parameterization in NWP, 751
  - drainage winds (see katabatic winds), 397
  - drawing weather maps by hand, 280-281
  - drifting snow, weather-map symbols for, 275-276
  - drizzle, 207-208
    - area coverage, 546
    - drops, 546
    - rate and symbols on weather maps, 208, 275-276
    - warm frontal, 401
  - drop (see also droplet)
    - deformed, 203, 255, 841, 860
    - diameter as affects radar returns, 247-248
    - flattening, 203, 255, 841, 860
    - number in cubic meter of air, 188, 194, 201, 207, 245-246
    - optics, 837-841, 856-861
    - radius, 185
    - shapes, 203, 255, 545-546, 841, 860
    - size distribution, 185, 545-546
    - terminal velocity, 203
    - typical sizes, 185
    - volumes, 185
  - droplet, 185-218
    - curvature and solute effects, 198-192
    - growth effects, 189
    - growth by diffusion, 196-197
      - growth rate, 196-197
      - max droplet radius via diffusion, 187
    - nucleation, 188-194
    - optics, 837-841, 856-861
    - radius, 185
      - equivalent, 203
      - increase with time, 197
      - maximum via diffusion, 187, 197
    - size distributions, 185, 207
      - lognormal, 207
      - Marshall-Palmer distribution, 207
    - terminal velocity, 202
    - typical sizes, 185
  - dropsonde sounding, 134, 322, 496
    - locations worldwide, 272
  - drowning due to
    - hurricane rain and storm surge, 632-637
    - thunderstorm flash floods, 547-548
  - dry (see also unsaturated), 57
    - absolutely unstable, 140
    - adiabatic lapse rate, 59-64, 880
      - to determine static stability, 139-141
    - adiabatic process
    - adiabats, 63
      - labeled by potential temp, 63
      - on thermo diagram, 119-158, 497
  - air
    - gas constant, 880
    - in highs, 390
    - in thunderstorm, 497
    - specific heat, 880
    - bulb temperature, 94, 111
    - lifting of air parcels, 129
    - lines, 416-417
      - airmass boundary, 416
      - distance moved over time, 416-417
      - radar observations of, 248-249
      - triggering thunderstorms, 525
      - weather-map symbols for, 281, 399
    - neutral stability, 140
    - tongue of air in cyclone, 429
  - drying in downslope winds, 676-677
  - dual Doppler radar, 249, 253
  - ducting of radar beam, 244-245
  - dummy index, 875
  - duplicatus, 169
  - duration of rain (IDF curves), 208
  - dust, 151, 170
    - airmass characteristics, 391
    - lithometeors, 205
    - storm (Habooob), 562
      - weather-map symbols for, 275-276
    - swirl, 583
  - dynamic
    - frontogenesis, 411-412
    - hail mitigation methods, 554
    - heating, 672-674
    - numerical stability, 759, 773-777
    - pressure, 559, 672-674
    - stability, 141
      - Richardson number, 141
      - turbulence determination, 142
    - temperature, 672-674
    - warming, 672-674
  - dynamical instability, 141-142
  - dynamics, 289-328
    - frontal strengthening, 411-412, 469-470
    - hurricane, 617
    - nonlinear, 773-776
    - numerical weather prediction, 749-750
    - topics, 1-2

## E

- e, base of natural logarithms, 9  
 E-grid, 753  
 early rainout, 553  
 Earth  
   albedo, 793-794  
   angular rotation rate, 297  
   average  
     global energy budget, annual, 797  
     surface temperature, 12, 793-797  
   axis, 34, 798-801  
   blackbody radiation emitted, 37, 39, 794  
   buldge of Earth at equator, 3-4  
   characteristics, 3-4, 879  
   climate  
     precession, 798-803  
     processes, natural, 793-832  
   constants, 879  
   daisyworld, 813-815  
   eccentricity, 28, 34, 797-802  
     variations and climate, 797-803  
   effective radiation emission temperature, 794, 879  
   emission of radiation, 37-39  
   energy budget, annual average, 797  
   frameworks, 3-4  
   gravity, 227  
   greenhouse effect, 795-797  
   mass, 28  
   moon barycenter, 27  
   obliquity (tilt of axis), 34, 797-802, 879  
     variations and climate, 797-803  
   orbital factors, 27-34, 797-802, 879  
   plastic, 298  
   precession (axial, aphelion, equinox, climate), 799-801  
   radiation balance, 793-797  
   radius, 3-4, 11, 879  
     average volume; at poles; at equator, 879  
   rotation rate, 34, 227, 297  
     change of, 376  
     controlling sub-tropical jet latitude, 350  
   satellite observations of, 228-234  
   shape, 3-4, 298, 879  
   snowball, 811  
   sun distance, 30, 802, 879  
     aphelion, average, perihelion, 879  
   surface  
     parameterizations, 751  
     temperature, 793-797  
   tectonic plates, movement of, 804  
   tilt of axis (obliquity), 30, 797-802, 879  
   viewed from space, 220, 228, 232-233  
   volcanism, 804-805  
 easterlies, easterly  
   African jet and wave, 611-612  
   polar, 352  
   tropical trade wind, 330-332, 351  
   wave and hurricane triggering, 611-612  
     low-altitude convergence, 612  
 Eastern  
   Hemisphere defined, 4  
   time zone, 5  
 eccentricity of Earth's orbit, 28, 797-803  
 echo  
   -free vault, 493, 552-553  
   hook, 494  
   intensity (=dBZ), 246  
   radar, 493  
   weak region, 493, 552-553  
 ecliptic, 30  
 ECMWF (Europ. Ctr. for Med.-range Weather Fcsts.), 271  
   locations of weather data worldwide, 271-273  
 economic value of forecasts, 784-785  
 EDT, Eastern daylight time, defined, 5  
 eddy, eddies, 706  
   -correlation fluxes, 713  
   -diffusion theory, 714-716  
   diffusivity (K), 715, 731  
   large, 716  
   microscale, 708  
   motions, 69, 705-706  
   planetary scale, heat transport by, 378  
   size in ABL, 706  
   turbulent, 138  
   viscosity, 715  
   whirls, 708  
 edge of smoke plume, 730  
 EF (enhanced Fujita) scale for tornadoes, 579-580  
 effective  
   bulk  
     shear, 522  
     wind difference, 522  
   gravity, 298  
   inflow  
     base, 590  
     layer into thunderstorms, 590  
   layer for thunderstorms, 522  
   radiation emission temperature, 794  
     variation with temperature, 794  
   storm relative helicity (eSRH), 590  
   surface heat flux, 68, 110  
   surface mixing ratio, 109  
   surface turbulent heat flux, 68  
   surface water vapor flux, 110  
   temperature, 117  
   thunderstorm depth, 522  
   vertical circulation, 377  
 effervescence, 812  
 efficiency of  
   droplet coalescence, collision, collection, 204-205  
   thunderstorms, 547  
   wind turbines, 647-648  
 e-folding  
   definition, 9, 879  
   distance, 9  
     Rossby radius of deformation, 344  
     sunlight through cloud top, 131-132  
   height, 8-9  
     of stable boundary layer, 696  
   ratio, 879  
   time, 9  
     airmass formation, 393-396  
 EHI (energy helicity index), 530-531, 591-592  
 eigenvalues and eigenvectors, 822  
 Einstein, Albert (quotations), 54, 99, 235  
 Ekman  
   layer depth, 378  
   pumping, 319  
   spiral in the ocean, 378  
   transport, 378, 610, 632-633  
 Ekman, V.W., 399  
 EL (equilibrium level), 483  
 El Chichon volcanic eruption, 805  
 El Niño, 818-820  
   cyclone track, influence on, 430  
   southern oscillation (ENSO), 818-820  
 electric  
   charge, 564, 870  
     origin in thunderstorms, 564-566  
   field, 255, 565  
     strength, 565  
 electrical  
   charge & units, 870  
   current, 564, 870  
     units, 870  
   energy, 564  
   potential, 564, 870  
     gradient, 565  
     units, 870  
   power, 564  
     generation by wind turbines, 647-648  
     surges in electric lines, 569-570  
   raindrop growth affected by lightning, 206  
   resistance, 564, 870  
     units, 870  
   voltage, 564  
 electricity  
   generation by wind turbines, 647-648  
   in a channel, 564  
   lightning, 564  
   in a volume, 565  
     electric field, 565  
     static, 564  
 electrification of clouds, 564-566  
 electromagnetic  
   radiation speed, 243-245, 834  
   spectrum, 220-223, 834-835  
   upwelling radiation, 220  
   waves, 219-226, 833, 837, 856-863  
 electrometeors, 205  
 electron  
   charge of, 565  
   movement in a lightning channel, 565  
 electrosphere, 565  
 elements  
   data, 875  
   of a good weather briefing, 765  
 elephant, 669  
 elevated thunderstorm inflow, 522  
 elevation angle, 4-5  
   defined, 4  
   of sun and radiative flux, 40  
     of sun vs. time, 32  
 elf, 563, 568  
 Eliassen, Arnt, 759  
 ellipsoid, Earth shape, 298  
 elliptical orbits, 27-28  
   eccentricity variations, 797-803  
 elves, 563, 568  
 emagram (a thermo diagram), 119-152  
   pre-storm soundings plotted on, 496-499  
   full, 152  
   simplified, 127  
 Emanuel, K. A., 625  
 embryo, hail, 549-553  
 emerald green sun during green flash, 862  
 emission(s)  
   limits for pollutants, 724  
   of radiation, 36-38, 41-42, 219  
     blackbody, 36-38  
     Earth temperature, 794  
   trading, 742  
 emissivity, 37, 41-42  
   and Kirchhoff's Law, 41, 220  
   infrared (table of typical values), 42  
   surface, 45  
   with water vapor feedback, 810  
 emittance, 36  
 empirical, 700, 715  
   orthogonal function (EOF) analysis methods, 820-823  
   wind profiles, 699-705  
 encroachment method of ABL growth, 394-395, 697-698  
 energy  
   balances, Earth climate, 795-797  
   budget  
     equation, 672  
     global annual mean, 797  
   chemical, 54  
   conservation along streamline, 671-672  
   convective available potential (CAPE), 503-508, 530-531  
   dimension of, 870  
   flow, 669-672  
   flux density, 221  
   heat, 53-86  
   helicity index (EHI), 530-531, 591-592  
   internal, 54, 672  
   kinetic, 150, 647, 669-672  
     dissipation in hurricanes, 625  
     turbulence, 708-709  
   latent, 54  
   lightning, 564  
   mechanical, 625, 670  
   nuclear, 54  
     bomb, 499, 548  
     -per-unit-mass diagram (emagram), 122  
   potential, 150, 503-508, 669-672  
   propagation via waves, 658  
   released in a  
     hurricane, 620, 625  
     thunderstorm, 499  
   sensible, 54  
   thermal, 672  
   thunderstorm, 499, 546-548  
   turbulence, 708-709  
   units, 870  
   wave, 658  
   wind, 647-648  
   work, 503  
     shaft, 672  
 engine, hurricane as, 620-625  
 engineering  
   boundary layers in wind tunnels, 689  
   creativity in, 288  
 enhanced Fujita (EF) scale for tornadoes, 579-580  
 ENIAC computer, 749, 759  
 enormous hail, 548  
 ensemble, 776  
   average, 776-777  
   calibrated probability forecasts from, 777  
   forecasts, 776-777  
   prediction system (EPS), 776  
   spread vs. skill, 777  
   uncertainty forecasts, 777  
 ENSO (El Niño Southern Oscillation), 818-820  
 enthalpy, 53, 58, 671  
 entrainment  
   at high-pressure regions, 390  
   flux-ratio method to estimate, 698  
   of dry air  
     into boundary layers and clouds, 57, 111, 649, 694  
     behind thunder shock front, 572

- velocity or rate into ABL top, 394-395, 697-698
- zone, 692
- entrance region of jet streaks, 454-456
- entropy
  - adiabat, 18
  - hurricane, 624-625
  - isentropic, 18
  - on thermo diagrams, to define tephigram, 122
  - thunder, 571
  - total, 624-625
- environment
  - Canada, 284
    - Hurricane Centre, 617, 638
    - Meteorological Service of Canada, 638
  - on a thermo diagram, 134
  - thunderstorm (pre-storm), 496-499
- environmental
  - lapse rate, 59, 134
    - in mixed layer, 692, 697-698
  - Protection Agency (EPA), air-quality standards, 7
  - sounding, 59, 134
    - pre-thunderstorm, 496-499
  - temperature profile, 59
  - wind (and thunderstorm motion), 516-520
- EOF (empirical orthogonal function) analysis methods, 820-823
- EPA, Environmental Protection Agency, air qual. Stds., 7
- episodes, air pollution, 741
- epitaxial substances, 195
- epoch
  - Holocene, 799
  - Pleistocene, 799
- equation(s)
  - Bernoulli's, 559
  - coupled, 747
  - diagnostic, 747
  - error propagation through, 876-877
  - forecast, 293
  - hypometric, 17
  - Navier-Stokes, 759
  - nonlinear, 747
  - of motion, 293, 301-302, 314-317, 713, 746-749
    - anabatic winds, 649-652
      - analytical solution, 749
    - boundary-layer winds, 307-308
      - discretized, 757-758
      - for slope flows, 652
      - horizontal, 301-302, 314, 652
      - katabatic winds, 652-653
      - typical magnitudes for terms, 301
    - vertical velocity, 315-317, 508, 554-558, 649
  - of state, ideal gas law, 14-15, 746
  - of time, 34
  - primitive, 747
  - prognostic, 747
  - scalar, 746
  - Young-Laplace, 215
- equator, 4, 330
  - to-pole temperature gradient, 335-336
- equatorial, 330
  - airmass code, 392
  - heating excess, 338-339
  - high-pressure belt aloft, 350-351
  - trough, 331, 350-351
  - winds, 343
- equatorward propagation of cyclones, 446
- equilibrium
  - geostrophic adjustment, 405
  - conditions in daisyworld: homeostasis, 813-815
  - earth's heating, 334-339, 793-797
  - height (or level), 483, 733
  - humidity, 87-96
  - level (EL), 483, 496-506
  - relative humidities, 190-193
  - saturation, 87
  - supersaturation, 88, 191
  - vapor pressure, 87-90
- equinox, Spring (vernal) and Fall (autumnal), 30-31, 800
  - precession, 800-801
- equipment factor in the radar equation, 245-246
- equitable threat score, 782
- equivalent potential temperature, 104-106
  - on weather maps, 500
- equivalent radius of drops, 203
- erosion (scour) of beaches by ocean waves, 634-635
- error(s), 875-877
  - accuracy, 875
  - anomaly correlation, 779
  - background, 766
  - bias, 770, 778, 875
  - calibration, 875
  - check for, 15
  - correlation coefficient, 779
  - definition, 875
  - experimental conditions, 875
  - first guess, 766
  - fluctuating conditions, 875
  - forecast, 777-785
  - imperfect technique, 875
  - instrument calibration, 875
  - judgement, 875
  - mean, 778, 875
    - absolute, 778
    - squared, 778
  - measurement, 875-877
  - numerical (round-off, truncation, etc.), 759-761
  - observation, 766
  - personal, 875
  - precision, 875
  - probabilistic forecast, 782-784
  - propagation, 876-877
  - random, 777, 875-877
  - repeatable, 875
  - root mean square (RMS), 778
  - small disturbances, 875
  - standard deviation, 875-877
  - systematic, 770, 777, 875
  - uncertainty, 875-877
  - verification, 778
- escape velocity, 6
- eSRH (effective storm-relative helicity), 590
- EST, Eastern standard time, defined, 5
- estimating 22 degree angles, 847
- eta coordinates for NWP, 746
- ethical issues, 218, 826
- EU air-quality standards, 725
- Euclidian geometry & dimensions, 171
- Euler, Leonhard, 759
- Euler method of finite differencing, 757
- Eulerian
  - definition, 53
  - equations of motion, 713, 746-749
  - framework, 34-35, 53
  - heat budget, 64-73, 746
    - advection, 65-67
      - conduction and surface fluxes, 67-69
      - cooling and heating of air parcels, 60-64, 159-160
    - equation, 64-65, 73
    - first law of thermodynamics, 64-65
    - latent heat, 72
    - net heat budget, 73
    - radiation, 71
    - turbulence, 69-71
    - unsaturated, 64-73
  - momentum budget, 293, 314-315, 746
  - streamlines, 668
  - water budget, 107-111, 746
    - horizontal advection, 107
    - precipitation, 107-108
    - surface moisture flux, 108-109
    - turbulent transport, 109-111
- EUMETSAT, 228
- Europe, airmasses in, 397
- European centre for medium-range weather forecasts, 271
  - (ECMWF), 271
- evacuation, 638-639
- evaporation, 88
  - of water from droplets, 189-193, 556
  - net, 92
  - rate from the surface, 108
  - rate of solutions, 190-193
  - zonally-averaged, vs. precipitation, 210
- evaporative
  - cooling of falling rain, 556
  - rain gauge, 210
- events
  - air pollution, 725, 741
  - binary/categorical, verification of, 780-782
- evolution
  - computational, 680
  - of
    - atmospheric boundary layer, 692-699
    - cyclones (extratropical lows), 427-429
    - fogs, 173-177
    - hurricanes, typhoons, tropical cyclones, 608-616
      - mixed layer, 692-698
      - thunderstorm cells, 484-485
      - tornadoes, 583
      - wind profile in boundary layer, 699-700
- exa ( $10^{18}$ ), 870
- exceedences of pollution concentration, 725
- excess water mixing ratio, 186-187
- exercises, explained
  - numerical problems, 21
  - synthesis questions, 25
  - tips for doing homework exercises, 20
  - understanding & critical evaluation, 23
  - web-enhanced questions, 24
- exhaust system of hurricane, 614, 618-621
- exit region of jet streaks, 454-456
- exitance, radiant, 36
- exobase, 13
- exosphere, 6, 13
- exothermal chemical reactions, 64
- experimental-condition errors, 875
- expert vs. novice scientists, 72
- explained variance (square of correl. coefficient), 779
- explosive
  - cyclogenesis, 426
  - growth of thunderstorms, 527
  - pressure increase, due to
    - air stagnation, 674
    - lightning, 571-574
- exponential
  - curve of the wind profile, 677-678
  - relationships and semi-log graphs, 873-874
- external
  - forcings (inputs) to feedback processes, 806
  - Rossby-radius of deformation, 405-406, 665
  - trigger mechanism for thunderstorms, 496-499, 525-526
- extinction (coefficients, cross-section), 43
- extrapolating data, 826
- extratropical cyclones, 330, 425-480
  - atmospheric boundary layer within, 690-692
  - baroclinic zone support, 427-429
  - birth and growth (cyclogenesis), 426-432
  - bomb, 426
  - case study, 433-443
    - 100-50 kPa thickness chart, 439
    - overview and storm track, 433-434
    - storm data, 434-435
    - surface weather, 438, 466
    - vertical cross section, 441
    - upper-level charts, 439-441, 443, 448-449, 451-452, 455-456, 459-463, 466
  - central-pressure evolution, 435
  - clouds, 400-401, 425-428, 691-692
  - convergence of horizontal winds, 691
  - death (cyclolysis), 426-432
  - deepening, 427, 463-467
  - definition, 425-426
  - descending air in cold sector, 433
  - development, rapid, 426
  - diffuence behind cold front, 433
  - direction of movement, 430-433
  - evolution, 427-429
  - explosive cyclogenesis, 426
  - graveyard, 431
  - lifetime, 431
  - marine, 414-415
  - meso (see mesocyclone), 492, 518, 586-592
  - midlatitude (lows), 331, 425-480
  - models (Norwegian; Shapiro-Keyser), 414-415
  - movement, 429-430
  - Norwegian model, 414-415
  - sea-level pressure tendency, 463-467
    - diabatic heating, 465
    - mass budget, 463
    - net pressure tendency, 466-467
  - Shapiro-Keyser cyclone model, 414-415
  - Southern Hemisphere, 426, 430-432
  - spin-up, 427, 446-450
    - application to typical weather patterns, 450
    - quasi-geostrophic approximation, 449
    - vorticity tendency, 447
  - tilt of trough axis, 622
  - transition of hurricanes into, 615
  - translation speed, 431
  - upward motion, 451-462, 691
    - continuity effects, 452-456
    - omega equation, 456-459
    - Q-vector estimates of, 460-462
- vigor, 446
- warm-air sector, 425-428
- winds around, 305-307, 690-692
- extreme
  - rainfall rates, 208
  - turbulence for aircraft in thunderstorms, 529
- eye of hurricane, 604-605, 618-619
- eyewall, 604-605, 618-619
- replacement cycle/double eyewall, 605

## F

- faces of ice crystals, 842
- factor (of)
- attenuation, in the radar eq., 245-246
  - beta, 368-369, 879
  - Coriolis, 297-299, 879
  - equipment, 245-246
  - feedback, 806-807
  - reflectivity, *Z*, 245-246
- faculae (surrounding sunspots), 803
- Fahrenheit, degrees, defined, 7
- fair weather (synoptic high pressure), 645
- cumulus (humilis), 161, 498
- turbulent heat flux, 69-70
- winds generated thermally, 645
- Fairy Morgan (Fata Morgana), 862-863
- faith, 680, 877
- Fall (autumnal) equinox, 30-31, 801
- fall
- line (downslope direction), 652
  - velocities of cloud droplets, 159
  - winds, 675
- falling pressure, 463
- symbol on weather map, 278
- false alarm, 780
- rate, 781, 783-784
  - ratio, 781
- family
- disaster plan, 638
  - of tornadoes, 584
- fan/fanning, pollutant plume, 708, 710, 727
- far
- field pollutant dispersion, 732
  - infrared and ultraviolet, 222-223
- Faraday cage, 570
- farads, *F*, 7
- fast-response weather instruments, 112
- Fata Morgana, 862-863
- fatalities (see deaths)
- favorable latitudes for hurricane formation, 609
- features of clouds, 168-169
- fecund daisyworld, 815
- Federal Meteorological Handbook No. 1, USA, 268
- Federation of Atomic Scientists/American Scientists, 218
- feedback, 793, 806-812
- aerosol, 811
  - amplification (positive feedback), 807-809
  - atmospheric processes, 1
  - biological
    - CO<sub>2</sub> feedback, 812
    - homeostasis, 813-815
  - climate change, 810-812
    - biological CO<sub>2</sub>, 812
    - cloud, 811
    - ice-albedo (surface), 808-812
    - infrared radiation, 810
    - lapse-rate, 810-811
    - ocean CO<sub>2</sub>, 812
    - water-vapor, 810
  - cloud, 811
  - concepts/basics, 806-807
  - daisyworld, 813-815
  - damping (negative feedback), 807-808
  - equation, 808-809
  - example, idealized, 807-810
    - blackbody radiative equilibrium, 807-808
    - ice-albedo feedback, 808-810
  - external inputs and forcings, 806
  - factor, 806-807
  - forces and winds, 302
  - gain, 806-810
    - different definitions, 807
  - ice-albedo, 808-810
  - infrared radiation, 810
  - internal, 806
  - lapse rate, 810-811
  - linear, 806
    - approximation to ice-albedo process, 808
    - approximation to nonlinear system, 806
  - multiple processes, 807
  - negative (damped), 793-794, 807
  - nonlinear, 806
  - ocean CO<sub>2</sub>, 812
  - positive (amplified), 807
  - reference state, 806-809
  - response, 806-810
    - ice-albedo, 808-810
    - negative (damped), 807
  - no-feedback, 807, 809
  - positive (amplified), 807, 809
  - runaway, 807
  - sensitivity, 810
  - turbulence, 704-705
  - water vapor, 810
- feeder
- cells for hail, 549
  - feeder flow in sea breeze, 655
- femto (10<sup>-15</sup>), 870
- Fengyun weather satellite, 228
- Fermi, Enrico, 669
- Ferrel Cell, 332-333, 357, 377
- fetch, 631, 634
- few clouds (coverage), 170, 279
- Feynman, Richard (quotations), 132, 167
- FFD (forward-flank downdraft), 483
- fibratus/fib, 168
- field, 280
- mill, 565
  - of height, mass, pressure, wind, 343, 359
  - of temperature, 280, 343, 359
- filling of lows, 429, 432-433, 463-467
- filter
- camera
    - haze, 857
    - polarizing, 856
  - Kalman, 770
- Findeisen, 201-202
- Finlayson, 817
- fine particulates (PM<sub>10</sub>) and aerosols, 188, 725
- fine-resolution grids, 752
- fine-scale turbulence, 315
- finite curve, 9
- finite-difference
- approximations, 872
    - spatial gradients, 754-755
    - temporal gradients, 757-758
  - equations, 754-759
  - numerical weather prediction (NWP), 745-792
- finite volume model - version 3 (FV3), 751
- fires (forest, wild, bush) caused by lightning, 564
- CO<sub>2</sub> release, 812
- firm snow, 209
- first
- guess, 766
    - NWP analyses, 765-767
    - satellite retrievals, 239
  - law of thermodynamics, 53, 58-59, 64-65
  - power, 873
- fitting an elephant, 669
- fixed point attractor, 790
- fjord winds (gap winds), 661-664
- flanking line, 482-483, 492, 494-495
- flash(es)
- floods, 487, 547-548
  - green, 862
  - lightning, 567-569
- flat surface of water, vapor pressure over, 87-90
- flattened rain drops, 203, 255, 841, 860
- flight operations near downbursts, 563
- floating, 135
- point operations per second (flops), 761
- floccus/flo, 168
- floods/flooding associated with
- coastal, 632-635
  - extratropical cyclones, 425, 434-435
  - hurricane caused storm surge, 632-635
  - inland, 637
  - return period (IDF curves), 208
  - thunderstorm caused flash floods, 487, 547-548
  - urban, 637
- flops (floating point operations per second), 761
- flow
- adiabatic compressible, 671-672
    - along a streamline, 669-672
    - around hills
    - balanced with mass fields, 763-765
    - canopy, 677-679
    - classification: subcritical, critical, supercritical, 659-661
    - compressible, 671-672
    - energy, 669-672
    - field in forecast models, 764
    - incompressible, 669-671
    - isothermal compressible, 671
    - laminar, 669
    - meridional, defined, 330
    - stability, 138-142
    - steady state, 669
    - through a constriction, 660
    - zonal, defined, 330
  - fluctuation-condition errors, 875
- fluid
- air, 1
  - mechanics, 1
  - object immersed in, 135
- flux
- advective, 35
  - conduction, 73-76
  - constant flux layer, 692
  - covariance vs., 710-713
  - defined, 34
  - density, 34
  - divergence, 64, 109-110, 715
  - dynamic, 35
  - eddy-correlation, 713
  - effective surface turbulent heat, 68
  - energy, 221
  - form of turbulent continuity eq., 714
  - gradients, 64
  - ground heat, 73-76
  - heat, 34-35, 711-712
  - kinematic, 35, 698, 711-713
  - latent heat at surface, 73-76
  - longwave radiative, net, 45
  - mass, 34-35
  - moisture, 108
  - momentum, 712-713
    - vs. Reynolds stress, 712-713
  - radiative, 35, 221
  - ratio method, 698
  - Richardson number, 709-710, 739
    - related to PG types, 710
  - sensible heat at surface, 73-76
  - sign of, 74
  - surface heat, 73-76
  - surface moisture, 108
  - turbulent, 35, 698, 711-713
- FNMO (Fleet Numerical Meteorology & Ocean. Ctr.), 608
- Foehn winds, 676-677
- wall (cloud), 676-677
- fog
- channel on satellites, 231
  - dissipation, 175-177
  - in satellite images, 234
  - nuclei, 177
  - processes, 173
  - types, 173
- fogs, 170, 173-177
- advection, 173-175
  - atmospheric boundary layer, 159, 173-177
  - dissipation of well-mixed fogs, 173-177
  - formation, 98, 173-177
  - frontal, 173
  - models, 173-177
  - radiation, 173-177
  - steam, 173
  - stratified, 175-177
  - upslope, 173
  - vs. clouds, 159, 173
  - weather-map symbols, 275-276
- fold(s) in tropopause, 364, 414-415
- isentropic potential vorticity, 364, 443
  - radionuclide injection at, 364
- footprint, 734
- forced convection, 710
- related to PG types, 710
- force(s), 295-302
- advection, 294-295, 301
  - apparent, 299
  - balance of, 302-314
  - buoyancy, 135-136, 316-317, 554
    - negative, 554-559
  - centrifugal, 296-297, 301
  - centripetal, 296-297, 301
  - convection (buoyant), 135-136, 317, 503-508, 648
  - Coriolis, 297-299, 301
  - dimension of, 870
  - driving horizontal winds, 289-328
  - driving vertical winds, 554-559
  - horizontal, 295-302, 301
  - imbalance of (causing centripetal force), 305-312
  - in Newton's 2nd law, 292, 294
  - net, 292, 294
  - pressure-gradient, 295-296, 301
  - summary table, 301
  - thunder, 571-574
  - turbulent drag, 300-301
  - units, 7, 292, 294, 870
  - vertical, 301, 554-555
- forcing (radiative) and responses (fluxes), 74
- forecast, weather
- accuracy, 777
  - blow up, 760

- case study, 433-443, 448-456, 459-463, 466, 745, 768-770, 776
- clouds, to aid in, 166
- confidence, 776
- cost/loss decisions, 784-785
- difficulties, 527
- equations
- Eulerian, 293
  - relative vorticity, 447
  - wind velocity, 293
- error, 777-785
- vs. time into future, 775, 780
- hurricane, 637-639
- lightning, 569
- max surface temperature, for thunderstorms, 506, 523
- models, 637, 751
- nowcasts, 552
- numerical, 745-792
- outlooks, 528-530
- persistence, 778-780
- post-processing, 770-772
- probabilistic, 777
- verification, 782-784
- probability of hurricanes, 638
- quality, 777-785
- ranges issued: outlook, watch, warning, 528-530
- nowcast, short, medium, long, seasonal, climate, 768
- refinement, 770-771
- Kalman filter, 770
  - model output statistics (MOS), 770
- schedule, 762
- scientific basis for, 746-751
- short-range (nowcasts), 552
- skill, 752, 777-784
- vs. time into future, 775, 780
- thunderstorm intensity, 501, 507, 516, 521-522, 524, 527-531
- tornadoes, 530-531, 588-592
- uncertainty, 776
- verification, 777-784
- watches & warnings, 528-530, 638
- forecasters (human), 772
- forest
- canopy, 677-678
  - death (waldsterben), 742
  - fire
    - clouds, 166
    - CO<sub>2</sub> release, 812
    - lightning causing, 564
    - nuclei from, 195
- forging data, 826
- formation and growth of
- airmasses, 389-399
  - atmospheric boundary layer, 689-692
  - fogs, 173-177
  - highs (anticyclones), 391
  - thunderstorms, 496-499
- forward
- flank downdraft (FFD), 483, 492-495
  - flank precipitation area, 483
  - problem, 235
  - scattering, 219, 857
  - trajectory, 724
- fossil fuels and climate, 812
- Fourier-transform spectrometers, 47
- fractals
- definition, dimensions and cloud shapes, 171
  - errors in measuring, 875
  - vs. Euclidean geometry, 171
- fraction of
- pollutants in air, 724
  - sky covered by clouds, 277-279
- fractus/fra, cumulus, 165-166, 168, 483
- scud, weather-map symbols for, 277
- frame of reference, 2-4
- on Earth, 3-4
- framework: source-receptor, 724
- free
- atmosphere, 687, 690-695
  - convection, 704, 710
    - level of (LFC), 497-506
    - related to PG types, 710, 727-730
    - smoke dispersion during, 735-737
  - sink level (LFS), 557
- freezing
- crops, 653
  - level altitude and hail formation, 551
  - nucleation, 194-195
  - precipitation change criterion for SPECI, 270
  - rain, 195
  - weather-map symbols, 276
- freon, 796, 811
- frequency
- angular, 36
  - beat, 828
  - Brunt-Väisälä, 136-137
  - circular, 36
  - dimension of, 870
  - of light, 36
  - of occurrence of wind
    - directions (plotted as wind rose), 646-647
    - speeds, 645-646
  - of oscillation, 136-137
  - of rain or floods (IDF curves), 208
  - of tornadoes in USA & Canada, 579
  - relative, 645
    - vs. probability, 645
  - shift (Doppler), 249
  - units, 870
- friction
- molecular, 301
  - velocity,  $u^*$ , 677, 700-713
    - typical values, 701
    - for air, 378, 700-713
    - for water, 378
- frictional drag
- in hurricane boundary layer, 625
  - on oscillating air parcel, 136-137
  - vs. stress, 700-702
- frigate sails, 635
- fringes, 858-861
- index, 859-860
- front(s), 280-281, 399-424, 389
- adiabatic processes, 408-410
  - aloft, 281, 413-414
  - ana-, 404
  - analyzing, 280-281, 402
  - attributes of, 399
  - bent-back, 414-415
  - between two boundary layers, 691
  - cold, 399-400, 525
    - aloft, 399
    - genesis, 399
    - triggering hurricanes, 612
  - depth, 403
  - drawing, rules, 280-281
  - drylines, 399, 525
  - dynamics, 411-412
  - formation, 408-413
  - geostrophic adjustment, 404-406, 412
  - glyphs (lines) on weather maps, 399
  - gust, 482, 525
  - horizontal structure, 400-402
  - kata-, 404
  - kinematics, 408-410
  - labeled by temperature, 281
  - lake-breeze, 525
  - layer stability affected by, 140
  - locating, 280-281
  - lows associated with, 389
  - occluded, 281, 399, 413-414
  - over-riding air, 407
  - polar, 352
  - rotation around lows, 389
  - sea-breeze, 525, 654-657
  - Shapiro-Keyser cyclone model, 414-415
  - squall line, 400
  - stationary, 281, 399, 404
  - sting jet, 414-415
  - strength, 408-412
    - structure, 400-417
      - horizontal, 400-402
      - vertical, 403-407
    - surface, 399-412
    - thermodynamics, 411
    - thunderstorm triggers, 525-526
    - upper-level (upper-tropospheric), 414-415
    - vertical structure, 403-404
    - warm, 399-401, 525
      - aloft, 399
      - genesis, 399
    - weather-map symbols for, 280-281, 399
    - winds above, 407
- frontal
- analysis, 280-281, 402
  - baroclinic zones, 427, 469-471
  - boundary on weather maps, 280-281
  - clouds
    - cumuliform at cold fronts, 162
    - stratiform at warm fronts, 162-164
  - fog, 173
  - forecasts, 427-429, 768
  - inversion, 403-404, 691
  - jets, 357-359, 407, 472
- lifting of air layers, 140
- line on weather maps, 280-281, 399
- pre-frontal waves, 400, 656
- propagation using Q-vectors, 470-471
- scale, 315
- shear, 407
- slope, 403-405
- strength, 408-412, 469-470
- symbols, 223, 281, 399
- thunderstorms, 400
- tilting, 412
- venting of boundary layer air, 691-692
- vorticity, 407
- wave (early cyclogenesis), 427-428
- winds aloft, 407
- zone(s)
- deformation at, 410
  - drawing on weather maps, 280-281
  - identification, 280-281, 403
  - relationship to frontal inversion, 403-407
  - strength, 408-412
  - strengthening, 469-471
- frontogenesis, 407-412
- definition, 407-408
  - dynamics, 411-412
  - kinematics, 408-410
  - Q-vectors, 469-471
  - quasi-stationary, 281, 399
  - thermodynamics, 411
  - vorticity and updrafts, 407
  - weather-map symbols for, 281, 399
- frontogenetic, 408
- frontolysis, 409
- weather-map symbols for, 281, 399
  - quasi-stationary, 281, 399
- frost as affects growing crops, 653
- frostbite, 77
- frost-point
- hygrometer, 111
  - temperature, 92
- Froude number, 659-661
1. For surface or interfacial waves, 659
  2. For internal waves, 659
  3. For flow over hills, 667-668
- fudging data, 826
- fuel
- for hurricanes, 620
  - for thunderstorms, 99, 499-502, 547-548
  - fossil: climate change issues, 812
- Fujita (F) scale for tornadoes, 579-580
- fulgurite, 570
- Fuller, R. Buckminster, 804
- funulus, 166
- functions, 872
- fundamentals of
- science, 869-878
  - weather radar, 240-245
- funnel cloud, 483, 581-583
- weather-map symbols for, 276
- fusion, latent heat of, 56
- FV3 (finite volume model-version 3), 751
- ## G
- gaia hypothesis, 813-815
- gain, feedback, 806-811
- different definitions of, 807
- gale, 635-636
- Galileo, 315
- gamma rays, 222
- gap winds/flows (for long and short gaps), 661-664
- gas
- anthropogenic greenhouse, 796, 811-812
  - constant
    - for dry air, 14, 572, 880
    - for water vapor, 14, 88, 880
    - ratio, epsilon, 91, 554, 880
  - ideal gas law, 14-15, 572
  - natural greenhouse, 805, 811-812
- gases
- atmospheric (constant and variable), 7
  - water vapor, 87-118
  - greenhouse, 811-812
  - on other planets in the solar system, 22
- gauges, rain and snow, 210-211
- Gaussian
- curve, 184, 729-730, 875
  - plume dispersion, 729-731
  - distribution of concentrations, 729, 737
  - parameters, 729-730
  - profile, 729

- GCMs (global climate models -or-, 815-816  
   general circulation models), 768  
 Geiger, Rudolf, 817  
 GEM (global environ. multiscale) model, 751  
 GEM-PAK, 772  
 gene expression programming, 680  
 genera (clouds), 168  
 general circulation (see global circulation), 329-388  
   models, 379, 768  
   three-band, 329, 376-378  
 generation of electricity by wind, 647-648  
 genesis of  
   airmasses, 392-397  
   anticyclones (highs), 390-391  
 genetic  
   bottleneck, 805  
   programming, 680  
 geographic information systems, 274  
 geography of  
   lightning, 564  
   North America, 431  
   Pacific Northwest (USA & Canada), 661  
 geomagnetic effects on Earth's rotation, 376  
 geometric  
   albedo, 831, 879  
   height, 11  
     measurement by GPS, 291  
   optics, 833  
   scattering, 857  
   sunrise and sunset, 33-34  
 geometry  
   of atmospheric optics, 833-868  
   of light rays, 833-868  
 geopotential, 11, 304  
   height, 11  
     errors, 766  
     global map example, 355  
     N. American map examples, 433-442  
     measurement errors, 766  
 geostationary satellites, 227-228  
 GOES, 228-229  
   international, 228  
   METEOSAT, 228-229  
   weather observation locations from, 272  
 geostrophic  
   adjustment, 343-344, 406, 412  
     part 1, 344  
     part 2, 349  
     part 3, 404-407  
   approach to geostrophy, 303-304  
   balance, 302-304  
   departure, 314  
   paradox, 459, 462  
   relative vorticity, 319  
   vorticity, 319  
     Laplacian form, 450  
   wind, 302-304, 343-349  
     at cold front, 405-407  
     at equator, 343  
     at mountains, 662-664  
     changes with altitude, 345-349  
     changes with latitude, 303  
     for atmospheric boundary layer, 699  
     gap, 663-664  
     related to thermal wind, 345-349  
     temperature advection, 458  
     vs. actual wind, 303  
   wind speed, 303  
     related to isobar packing, 303  
     related to tilt in isobaric surfaces, 359  
 geostrophy, approach to, 303-304  
 GFS (global forecast system) model, 751  
 ghost grid cells, 756  
 giant  
   CCN, 206  
   hail, 247, 548, 553  
 giants, on the shoulders of, 294  
 Gibbs free energy, 217  
 Gifford-Pasquill turbulence types, 727-728  
 giga (10<sup>9</sup>), 870  
 gigabit, 870  
 Gilbert's skill score, 782  
 GIS (geographic information systems), 274  
 giving a weather briefing, 765  
 glacial/interglacial (ice age) periods, 795, 799  
 glaciated clouds, 482, 485  
 glacier ice, 209  
 glaciogenic, 553  
 Gladwell, Malcolm, 924  
 glass windows, transparency of, 45  
 GLM (global lightning mapper, on satellite), 235  
 global  
   albedo, 793-794  
   carbon cycle, 812  
   climate models (GCMs), 379, 768, 815-816  
   circulation, 329-388  
     anticyclones (highs), formation locations, 391  
     explaining, for various latitudes, 350-356  
     heat transport by, 338-339  
     steering hurricanes, 607-608, 615  
     three-band, 329, 376-378  
   environmental multiscale (GEM) model  
   geopotential height patterns, 355  
   heat  
     budget, 166  
     transport, 338-339  
   insolation, 41, 336-337, 793  
   lightning mapper (GLM) on satellite, 235  
   nomenclature, 330  
   population vs. hurricane disasters, 631  
   positioning system (GPS), 112, 291  
   pressure patterns, 354-355  
   radiative forcings, 41, 793-794  
   telecommunication system (GTS), 268  
   temperatures, 335  
   warming, 150, 796  
     influence on hurricanes, 631  
   glory, 859-860  
     Morning, 656  
   glow, zero-order, 841  
   glyphs (symbols) plotted on weather maps, 275-279, 614-615  
   GMT (Greenwich Mean Time) defined, see UTC, 5  
   Gobi desert, 397  
   GOES satellite, 226-228  
     16 satellite, 222-235  
     ABI (advanced baseline imager), 222-235  
     channels for imager and sounder, 222-223  
     orbits, 227-228  
   Goethe, 249  
   GOMS satellite, 228  
   Gondwana; Gondwanaland, 804  
   governing equations, 746-750  
   GPS (Global Positioning System), 112, 291  
   GPU (graphics processing unit, on computers), 763  
   gradient  
     definition, 15, 295, 872  
     of flux, 64  
     of pressure, 295-296  
     of temperature, vertical, 872  
     of wind or momentum, 295  
     Richardson number, 710  
     supergradient wind, 643  
     transport theory, 714-716  
     wind, 304-307  
       imbalanced, 619  
       in anticyclones, 306-307, 391  
       in cyclones, 306-307, 432  
       in hurricanes, 609, 617-619  
       subgeostrophic, 304  
       supergeostrophic, 304  
       supergradient, 643  
   GrADS, 772  
   GRAF code, 269  
   graffito (the singular of graffiti) (see Science Graffiti)  
   grain size of snow, 199  
   granddaughter storm, 485  
   graphics processing unit (GPU), 762  
   graphing, 873-874  
     abscissa, 3  
     axes, 3, 873-874  
     linear, 9, 873  
     log-log, 215, 874  
     slope, 215  
     meteorological variables, 3, 9  
     ordinate (vertical) axis, 3  
     power, 874  
     pressure as height variable, 9-10,  
     relationships, 873-874  
     semi-log, 9, 873-874  
   graupel(n), 199, 205, 546-554  
     lightning, role in creating, 564-566  
     weather-map symbols for, 276  
   graveyard for extratropical cyclones, 430-432  
   gravitation law (Newton's), 11  
   gravitational  
     acceleration on Earth, 15, 879  
     variation with latitude & altitude, 879  
   constant, Newtonian, 6, 15, 879  
   force, 15, 301  
   gravity, 14-15  
     current, 355-656  
     Earth's, 227, 298  
     effective, 298  
   Eötvös effect, 317  
   force, 301  
   measurement, 317  
   Newton's discover of, 293  
   reduced, 135-136, 316, 658, 670  
   waves, 658-661, 666-668, 710  
     thunderstorm triggering, 526  
   great dying, 805  
   Greeks, 205, 444  
   green  
     color defined (also see optics chapter), 37, 834  
     flash, 862  
     sun, 862  
   greenhouse effect, 795-797  
   greenhouse gas(es), 724, 796, 805, 811-812  
     from volcanoes, 805  
   Greenland, 396  
     ice cores, 803  
   Greenwich Mean Time (GMT), 5  
   Greenwich Meridian, 4, 28  
   Gregorian calendar, 31  
   Grenfell, Sir Wilfred, 737  
   GRIB = gridded binary, 268  
   GRID code, 269  
   grid(s)  
     Arakawa A to E, 753  
     box, 750  
     cell, 750  
     ghost, 756  
     computation rules for NWP, 756  
     nested, one-way and two way, 752-753  
     points, 749-756  
     resolution, 750, 752, 761, 816  
     staggered, 753  
     variable, 752-753  
     volume, 750  
   grooming machines for snow trails, 209  
   ground  
     clutter in radar returns, 243-245, 254  
     subsurface heat and moisture parameterizations, 751  
   growing days for crops, 653  
   growth  
     rates for ice crystals, 200  
     rate of daisies (daisyworld), 814  
     rate of droplets, 196-197  
   GTS = global telecommunications system, 268  
   Gulf Stream current, 431, 616  
   gust  
     1 to 10 minute average, for hurricanes, 607  
     3-second, for tornado speeds, 579  
   gust fronts (related to downbursts), 482, 494, 554-563  
     arc & shelf clouds along, 532  
     depth of, 562  
     dust storm (haboob), 562  
     speed of, 562  
     radar observations of, 253, 556, 560  
     triggering new thunderstorms, 525  
   gustnado, 582  
**H**  
 habits, ice crystal, 198-200  
 haboob (sand storm), 562  
 Hadley cell, 329, 332-333, 350-351, 357, 377-378  
   influence on worldwide rain distribution, 209  
   heat transport in tropics, 339, 378  
   mixing caused by, 335-336  
 hail, 199, 205, 548-554  
   change criterion for SPECI, 270  
   damage from, 532, 549-554  
   embryo, 549-554  
   forecasting, 530-531, 550-552  
   formation, 549-550  
   giant, 548, 553  
   location climatology, 552-553  
   mitigation, 553-554  
   nucleus, 549  
   radar observations of, 247-248, 552-553  
   shaft, 552  
   significant hail parameter (SHIP), 530-531, 551-552  
   streak, 552  
   suppression, 553-554  
   swath on the ground, 163, 548, 552  
   weather map symbols for, 276  
 hailstones, 185, 548-554  
   fall speeds, 204, 549  
   layers, 550  
   size classification (TORRO scale), 548



- hair hygrometer, 111
- halo, 845-855  
 22 degree, 842, 845-846, 854-855  
 46 degree, 842, 846, 854-855  
 arctic airmass ice-cloud, 396  
 associated with pyramid crystals, 847  
 circumscribed, 851, 853-855  
 clouds that enable, 163  
 luminous meteors, 205  
 numerical computation, 756  
 others, 853-855  
 rare halos: 9, 18, 20, 23, 24, 35°, 847, 854-855  
 viewing angles, 846-847  
 vs. corona, 860
- halocarbons (e.g., freon; CFC-12 & others), 796, 811-812
- Halsey Jr., Admiral William F., 807
- hand analysis of weather maps, 279-281
- Handbook on Chemistry and Physics, 879
- Hansen and Kuiper's score, 781
- Hastings arcs, 854-855
- Hawaii time zone, 5
- Hawaiian high, 354-356
- hazards  
 coastal, 634-635  
 hurricane, 631-637  
 lightning, 569-571  
 thunderstorm, 545-602
- haze, 170, 191-193  
 filters for cameras, 857  
 lithometeors, 205  
 scattering of light in, 856-858  
 weather map symbols for, 276
- HDT, Hawaii daylight time, 5
- head, sea-breeze, 655
- headwinds, aircraft, 563
- heat, 53-86  
 adiabatic process, 60-64  
 balance, 64, 94  
 budget, 64  
 closure problem, 713-714  
 equation, 64, 73, 713, 746-747  
 Eulerian, 64-76, 713, 746-747  
 Lagrangian - saturated, 101-106  
 Lagrangian - unsaturated, 57-64  
 net, 73, 713  
 surface, 73-76
- capacity changes due to precipitation, 121
- conservation equation, 58, 64-76, 746
- engine, 624-625
- enthalpy, 58, 671
- flux, 34-35  
 airmass modification by, 397  
 at top of mixed layer, 698  
 bottom of ABL, 693-698  
 curvature, 375-377  
 effective surface turbulent, 68  
 kinematic, 34-35, 698  
 sinusoidal variation, 693  
 top of ABL, 698  
 turbulent, 711-715  
 vs. height, 698  
 vs. time, 693
- index, 77-78, 117
- internal sources, 64
- island, urban, 678-679
- latent, 53-56, 72, 101-106, 546, 880  
 condensation, vaporization, 56, 880  
 deposition, sublimation, 56, 880  
 fusion, melting, 56, 880
- lightning, 567  
 net budget, 72  
 released in thunderstorms, 546-548
- sensible, 53-56, 671
- specific, 53, 55
- stress, 77-78
- stroke, 78
- surface budget of, 73-76
- thermodynamics, 1, 53-86
- transfer coefficient, bulk, 68
- transferred, 58, 672
- transport  
 achieved, 338-339, 378  
 by jet stream (Rossby waves), 374-375, 378  
 global, 338-339, 378  
 needed, 338-339  
 to compensate radiative differences, 338-339  
 vs. latitude, 329, 335-336, 339, 378  
 urban heat island, 678-679
- heating  
 cumulative, 693-694  
 differential, 329, 334-339  
 dynamic, 672-674
- heavy rain, 207-208, 545-548, 637  
 weather map symbols for, 276
- hectare unit of area, 870
- hecto (10<sup>2</sup>), 870  
 Pascals, defined, 7, 8
- Heidke skill score, 781
- height  
 cloud-base, 130, 278  
 constant, map at, 436  
 contours on an isobaric map, 18, 121, 151, 290-291  
 errors, 766, 778  
 field, 343  
 geopotential, defined, 11  
 isohypse, 18  
 of smoke plume centerline, 723, 729, 733-734, 736  
 of temperature inversion, 144, 496-499  
 on weather maps, 436-437  
 on isobaric charts, 439-441  
 tendency (isallohypse), 18  
 tiling method for CAPE, 504-505  
 vs. pressure, 8, 9  
 relative maximum/minimum of height, 290  
 relative minimum/maximum of temperature, 138  
 scale heights for pressure and density, 8-10  
 tendency forecast equation, 463-467  
 variation of weather variables, 11-13  
 vs. pressure, 290-291
- heirarchy of operational forecast models, 768
- heliac arc, 854-855
- helicity, 587-592  
 energy helicity index (EHI), 530-531, 591-592  
 hodograph, determination using, 588-589  
 mesocyclone, 587-592  
 storm relative (SRH), 530-531, 588-592  
 effective, 590  
 tornado indices, 588-592  
 updraft (UH), 530
- helium, He, 7
- Helmholtz, Herman von, 759
- Helprin, Mark, quotations, 13, 171
- Hemispheres  
 Eastern & Western defined, 4  
 Northern & Southern defined, 4
- hemispheric weather maps, 441
- hertz (Hz), unit of frequency, 870
- heterogeneous nucleation  
 freezing, 194-196  
 liquid water, 188-194
- heuristic approach, 371
- heuristic (toy) models, 280, 330, 793
- hexagonal ice crystals, 198, 842-843  
 columns, 198-199, 842-843  
 dendrites, 198-199, 843  
 hollow columns and needles, 198-199  
 needles, 198-199  
 optics, 842-855  
 plates, 198-199, 842-843  
 pyramids, 198-199, 842  
 sheaths, 198-199
- Hg (see mercury), 7, 19
- high  
 altitude  
 clouds (stratospheric & mesospheric), 166  
 winds (upper-tropospheric), 331-332
- clouds, 162-163, 168  
 height variation with latitude, 163  
 weather-map symbols for, 168, 277
- Earth orbit satellites, 227-228
- humidity needed for formation of  
 hurricanes, 609-610  
 thunderstorms, 496, 499-502
- latitudes, defined, 330  
 global circulation, 352
- monsoon, 333-334, 354, 391, 615
- order truncation finite-difference scheme, 754-755
- plateaus, influence on drylines, 416-417
- precipitation supercell, 495  
 wind statistics for, 585
- pressure center (H, see also anticyclones), 389-391  
 airmass creation within, 389-399  
 aloft, in hurricane core, 613  
 boundary layer within, 390, 690-692  
 convergence at top of, 391  
 descending (subsiding) air in, 356, 390  
 divergence at bottom of, 390  
 formation locations, 391  
 isobars around, 390  
 meso-, 391, 488, 554, 559  
 mid-latitude, 331, 389-391
- monsoon-related, 333-334  
 named (Bermuda, Pacific, etc.), 354-356  
 polar, 331, 352, 391  
 ridges, relationship to, 390  
 Southern Hemisphere, named highs, 354  
 subtropical, 391  
 thermal (cold), 341-342  
 tilt with altitude, 390  
 vertical structure, 391  
 weather associated with, 390  
 winds around, 305-307, 390-391
- resolution, 752
- risk, high gain science, 863
- thunderstorm risk, 530
- Higher Math boxes, 11  
 Adiabatic Lapse Rate, 60  
 Advection Fog, 173  
 Apparent Forces, 299  
 Bernoulli [Equation] Derivation, 670  
 Beta Plane, The, 369  
 Betz' Law, 648  
 Brunt-Väisälä Frequency, 137  
 Calculus, 872  
 Clausius-Clapeyron Equation, 89  
 Critical Radius, 193  
 Cumulative Heating, 693  
 Diffusion Equation, 731  
 Error Propagation, 876  
 Explanation of purpose of these boxes, 11  
 Feedback Example, 809  
 Geopotential Height, 11  
 Geostrophic Adjustment, 406  
 Hypsometric Equation, 18  
 Incremental Changes, 38  
 Info Projection, 239  
 Laplacian, The, 450  
 No-feedback Response, 807  
 Non-equilibrium Winds [at hurricane top], 619  
 Omega Equation, The, 458  
 Physical Interpretation of Equations, 16  
 Pressure Reversal, 623  
 Q-vector Omega Equation, 462  
 Taylor Series, 755  
 Temperature Gradient, 336  
 Thermal Wind Effect, 346  
 Turbulence Terms, 714  
 Vorticity of a Wave, 368  
 Warm Core Winds, 623
- highs (see high pressure centers), 354, 390-391
- highways, as threat to safety, 517
- hills, flow over, 397-398, 472, 487, 526, 649-676
- Himalaya mountains, 397
- hindcast, 762
- history of  
 Beaufort wind scale, 635  
 numerical weather prediction, 759
- hit, 780  
 rate, 781, 783-784
- hockey-stick (Keeling) curve, 812
- hodograph, 510-522  
 basics, 510-513  
 blank, which you can copy, 512  
 using for thunderstorm prediction, 514-522  
 sea-breeze, 656-657  
 storm-relative  
 helicity, 588-589  
 winds, 585
- hollow ice crystals (needles, columns), 198-199, 866
- Holocene epoch, 799
- Holt, MO, 547
- homeostasis, 813-815
- homeothermic, 76
- homework exercises (at end of each chapter)  
 answers (see Solved Examples)  
 tips and explanations, 20-26
- homogeneous  
 freezing nucleation, 194  
 nucleation of liquid water droplets, 188-191
- homogenization, 109, 689
- Hong Kong Observatory (HKO), 607
- hook echo, 494
- horizontal  
 advection  
 of heat, 65-67  
 of momentum, 294-295  
 of total water, 107  
 of vorticity, 447-449
- circulation, 365-366  
 method for finding, 365-366
- convergence, 252-253, 318-321, 340-341
- coordinates, alternative, 747
- divergence, 318-321, 340-341  
 aloft, 449, 452-459

- equations of motion, 301-302, 314  
 forces, 294-302  
   advection, 294  
   centrifugal & centripetal, 296-297  
   Coriolis, 297-299  
   in slope flows, 650-651  
   pressure-gradient, 295-296, 619, 650-651  
   turbulent drag, 300  
 IR flux gradient, 71  
 local, 4  
 motions, scales of, 315  
 plates (ice crystal), 198-199, 842-855  
 roll vortices, 167  
 scales vs.  
   forecast skill, 768  
   time scales, 315  
 structure of fronts, 400-402  
 turbulent transport, 71-72  
 velocities, 314  
 vorticity (streamwise), 518, 586-587  
   advection of, 447-451  
   tilting of, 586-587  
 winds, 302-314  
 horse latitudes, 331  
 hot  
   convective towers, 644  
   film anemometer, 321  
   wire anemometer, 321  
 hour  
   angle, 41, 801-802  
   glass shaped tornadoes, 577  
   unit, 870  
 Hovmöller diagram, 824-825, 830  
 Howard, Luke, 168  
 howling sounds (aeolian tones), 560  
 HP (high-precipitation supercell), 495  
 hPa (hectoPascal) definition, 7-8  
 HST, Hawaii standard time, 5  
 hub height, 647  
 human  
   population & zoning for hurricanes, 631  
 humidex, 77-78, 117  
 humidity, 87-118  
   absolute, 14, 91  
   airmass, 391-392  
   comfort indices, 77-78  
   constant (isohume), 18  
   dew-point temperature, 92-93, 499-500  
   equivalent potential temperature, 500  
   errors, 766  
   gradient, 196-197  
   high (needed for thunderstorms), 499-502  
   hurricane cyclogenesis conditions, 609-610  
   indices of discomfort, 117  
   instruments, 97, 111-112  
   isohume, 18  
   lifting condensation level (LCL), 93-94, 501  
   mean-layer, 501  
   liquid water potential temperature, 500  
   mixing ratio, 91, 95, 500  
   precipitable water, 98, 501  
   relationships between moisture variables, 87-97  
   relative, 92, 95  
   satellite observations of, 226, 234, 273  
   saturation, 87-96  
   saturation level, 93-94  
   sensors, 97, 111-112  
   specific, 91  
   thunderstorm convective conditions, 496, 499-502  
   variables, 91-96  
   vs. dew point temperature, 95  
   weather maps of, 500-501  
   wet-bulb temperature, 94-95, 104, 500  
 humilis/hum (cumulus), 161, 168  
 humisery, 117  
 humiture, 117  
 hunter, hurricane, 637  
 hurricane(s), typhoons & tropical cyclones, 330, 603-644  
   along coastlines, 631-635  
   Andrew, 606, 643  
   bands, spiral rain, 604  
   boundary layer flow, 618-619  
   Canadian Hurricane Centre, 617, 638  
   Carnot cycle, 624-625  
   category, 605-606  
   Charley, 606  
   circulation of air through, 620-625  
   classification, 605-607  
   cloud shield, 604  
   cold water, movement over, 616  
   composite picture, 629  
   condensation energy, 620-621  
   core, 604, 615, 618-625  
   Coriolis force, 609  
   cyclone, 426  
   cyclogenesis (birth), 608-610  
   cyclolysis (death), 615-616  
   damage  
     potential, 607  
     scales, 605-607  
   dangerous portions, 627  
   disaster relief, 631  
   Dolly, 606  
   drag against the sea surface, 625  
   dynamics, 617-619  
     inflow and outflow, 618-619  
     initial spin-up, 617  
     subsequent development, 617-618  
   easterly jet and waves (from Africa), 611-612  
   Ekman transport, 610  
   El Niño/La Niña effects, 631  
   energy, 620, 625  
   entropy, 624-625  
   evacuation, 638-639  
   evolution, 608-616  
   exhaust system of, 614, 618-621  
   extratropical  
     cold fronts, triggering by, 613  
     systems, collision with, 616  
     transition, 615  
   eye, 604, 615, 621  
     downdrafts in, 605, 620, 628-629  
     photo inside, 637  
   eyewall, 604, 615  
     double, 605  
     replacement cycle, 605  
     second, 605  
   Floyd, 605, 608  
   force winds (Beaufort scale), 635-636  
   forecasting, 637-639  
   formation requirements, 608-606  
   Frances, 606  
   frequency, 630  
   fronts from midlatitude, interaction with, 612-613  
   fuel creation, 620  
   geographic distribution, 605-609, 615  
   global warming effects, 631  
   glyph (symbol) on weather maps, 426, 614-615  
   hazards, 631-637  
   Hazel, 617  
   heat engine, 624-625  
   hot convective towers, 644  
   Hugo, 639-670  
   human population and zoning, 631  
   humidity needed, 609-610  
   hunters, 637  
   idealized, 605  
   identification (ID) number, 613-614  
   incipient, 612-615  
   -induced ocean currents, 610  
   Inez, 621  
   inflow, 618-619  
   initial spin-up, 617  
   instability (nonlocal conditional) & CAPE, 609  
   insurance, 631  
   intake system of, 614, 618-620  
   intensity, 605-607  
   Isabel, 604, 616, 627  
   Isis, 614  
   ITCZ, 610-611  
   Ivan, 606, 614  
   Javier, 614  
   Juan, 617  
   Katrina, 603-604, 616, 620  
   kinetic energy dissipation, 625  
   latent heat release, 620-624  
   latitude of formation, 608-615  
   life-cycle, 613-615  
   moat, 605  
   model, 626-629  
     composite picture, 629  
     pressure distribution, 626  
     radial velocity, 624-628  
     tangential velocity, 626-627  
     temperature, 629  
     vertical velocity, 628-629  
   monsoon trough, 612  
   movement (translation), 607-608, 615  
   names for, 426, 614-615  
   retired, 615  
   National Hurricane Center (NHC), 638  
   natural 40-year cycle, 631  
   non-equilibrium winds, 619  
   -ocean interactions, 610  
   outflow, 618-619  
   over land, movement, 616  
   Pacific, 631  
   power, 620, 625  
   precipitation, 615  
   prediction, 637-638  
   pressure, 618-623, 626, 633  
     reversal with altitude, 621-623  
   probability of threat, 638  
   radar observations of, 254  
   radial winds, 627-628  
   rain bands, 604, 613-615  
   rainfall rate, 620  
   research aircraft, 637  
   right quadrant (most dangerous), 627  
   Rita, 605, 637  
   safety, 637-638  
   Saffir-Simpson hurricane wind scale, 605-606  
   satellite observations of, 603-605, 608, 614, 616, 620, 637  
   sea-surface temperature (SST), 608, 616  
   season, 630  
   social issues, 631  
   spiral bands, 604  
   stages in life cycle, 613-615  
   steered by global circulation & monsoons, 607-608, 615  
     Azores high, 607-608, 615  
     Bermuda high, 607-608, 615  
     Hawaiian high, 615  
     trade winds, 607-608, 615  
   storm surge, 632-634  
     atmospheric pressure head, 632  
     Ekman transport, 632-633  
     Kelvin wave, 633-634  
   structure, 604-605  
   surface wind-waves, 634-636  
   symbols on weather maps, 614-615  
   temperature (air), 621-622, 624, 629  
   thermodynamics, 620-625  
     Carnot cycle, 624-625  
     diagram, 624  
     warm core, 621-623  
   thunderstorms, 609  
   hazards, 637  
   tornadoes and tornado outbreaks in, 584, 627, 637  
   total entropy, 624-625  
   tracks (translation speeds & directions), 607-608, 615, 627  
   triggers, 610-613  
   tropical  
     cyclone, 426, 615  
     depression, 613-614  
     disturbance, 613  
     Prediction Center, 638  
     storm, 614  
   TUTT (tropical upper tropospheric trough), 613  
   typhoon, 426  
     intensity scales, 607  
   vertical  
     cross section, 605, 618, 620-622, 624, 629  
     velocity, 629  
   vorticity in environment, 610  
   warm core, 614-615, 618-625  
   warning, 631, 638  
   watch, 638  
   weak wind shear in environment needed, 610  
   winds  
     gust averaging time, 605  
     vs. geostrophic adjustment, 384  
     shear in hurricane environment, 610  
     tangential, 622-623  
     total (tangential + translational), 627  
     zoning and landuse, 631  
   Huxley, Aldous (quotations), 38, 236  
   Huygens, Christiaan, 837  
   Huygens' Principle, 837, 859  
   hybrid  
     coordinates in NWP model, 746  
     supercell thunderstorm, 492  
 HYDRA code, 269  
 hydrate, methane, 810  
 hydraulic(s)  
   jump, 656, 660-662  
   open-channel, 657-661  
 hydrogen, H<sub>2</sub>, 7  
 hydrogen peroxide, 190-192  
 hydrometeor(s), 185  
   definitions, 205  
   graupel, 205  
   hail, 205

- number, 187
  - radius, 187
  - size, 187
  - terminal velocities, 202-204
  - hydrometeorologists, 257
  - hydrometer(s), 111
  - hydrophilic, 188
  - hydrophobic, 218
  - hydrostatic
    - assumption/definition, 15-16
    - balance, 15-16, 316
    - equation, 15-16, 316
    - use of, for isobaric surfaces, 296
    - equilibrium, 15-16
    - thermal circulations, 341-342, 655
  - HYFOR code, 269
  - hygrometers, 75, 97, 111-112, 219
  - hygroscopic
    - cloud seeding, 553
    - pollutants, 191
  - hypothermia, 77
  - hypoxia, 874
  - hypsometric
    - constant, 17, 880
    - equation, 17-18
    - sea-level-pressure reduction, 267
    - use in explaining anabatic flow, 650-651
  - H<sub>2</sub>, hydrogen gas, 7
  - H<sub>2</sub>O, (see water), 7
- I**
- IAC code, 269
    - FLEET, 269
  - ICAO = international civil aviation organization, 149
    - weather station ID or code, 270
  - ice
    - ages, 795, 798-799
    - aggregation into snowflakes, 200, 202
    - albedo climate feedback, 808-810
    - cores, 803
    - crystal, 185,
      - clouds (cirrus clouds), 163
      - columns, 842, 866
      - electrification of clouds, role in, 564-566
      - faces, 842
      - fall speeds, 206
      - fogs in arctic airmasses, 393-397
      - geometry, 198-199, 842
      - habits, 198-199, 842-843
      - halos, 842-855
      - hollow columns, 198-199, 866
      - lattice, 194-195, 198
      - lightning creating, role in, 564-566
      - mass, 200
      - nucleation, 194-196
      - optics (also see Optics chapter), 163, 842-855
      - plates, 842
      - pyramids & pyramid optics, 842, 847
      - rotation angles, 843, 845-846
      - shapes, 198-199, 842-843
      - weather-map symbols for, 276
    - cubic (Ic), 198, 855
    - density, 209, 880
    - embryo, 194, 549-550, 553
    - fallout from arctic airmass, 396
    - formation on aircraft wings, 130
    - growth by diffusion, 198-202
      - growth rates, 200-202
      - ice crystal habits, 198
      - Wegener-Bergeron-Findeisen (WBF), 201-202
    - hail, 199
    - hexagonal (Ih), 198, 834-835
    - index of refraction, 834-835
    - loading, 14, 555
    - melting into rain, 206
    - mixing ratio, 97, 186
    - needles, 199, 276
    - nucleation, 194-196, 202
    - nuclei, 185, 194-195
    - particles, 185, 546
    - pellets (sleet), 199
      - weather-map symbols for, 276
    - phases, 198
    - refractive index, 834-835
    - saturation vapor pressure over, 88
    - snowflakes, 198-200
    - specific heat, 880
  - ICEAN code, 269
  - Icelandic low, 356
  - ideas, 99
  - ideal gas law, 14-15
    - gas constant, 14, 880
  - idealized
    - feedback example, 807-810
    - fog models, 173-177
    - hurricane model, 626-629
    - winds, 302
  - identification of
    - clouds, 161-169
    - hurricanes, using numbers and names, 613-615
    - lines (isopleths) on thermo diagrams, 126-127
    - different types of thermo diagrams, 126-127
  - identity matrix
  - IDF (intensity, duration, frequency) of rain, 208
  - IEEE standards board, 870
  - igneous meteors, 205
  - image(s)
    - interpretation of satellite photos, 231-233
    - radar reflectivity, 243, 246, 248, 254
  - imager, 230
    - channels on satellites, 222-223, 230
  - imbalanced
    - forces (causing a centripetal force), 305
    - initial conditions, 304
    - mass and flow fields, 763
    - systems, tendency to reach new balance, 329
  - immersion
    - buoyancy of objects, 135
    - freezing, 194-195
  - impact parameter, 839-841
  - imperfect-technique errors, 875
  - inaudible thunder, 575-576
  - incandescence, lightning, 564
  - inches of mercury (in. Hg), 7
  - incident
    - angle, 833
    - light, 833-863
    - radiation, 41-47, 334-339, 793-803, 833-863
  - INCLL code, 269
  - inclination of satellite orbits, 228
  - incoming solar radiation (insolation), 40-41, 334-337
  - incompressible
    - continuity equation, 318-319
    - flow, 669-671
  - increased water vapor, 810
  - increasing, weather-map symbol for, 276
  - incremental changes, Higher Math box, 38
  - incus, 169, 482
  - independent
    - observations, 236-239
    - variable, 3, 872
  - index
    - air quality, 743
    - discomfort, 117
    - dummy, 875
    - heat, 77-78, 117
    - humidity, 77-78
    - livestock weather safety, 117
    - of thermal stress, 77-78, 117
    - of refraction
      - light, 834-835, 880
      - radar, 243-244
      - sound, 575-576
    - summer-simmer, 117
    - temperature-humidity, 77-78, 117
    - thunderstorm-forecast, 530-531, 551-552
    - wind-chill, 76-77
  - India
    - monsoon, 356
    - Regional Specialized Meteorological Center, 607
  - Indian Ocean
    - dipole (IOD), 824
    - Southern Indian Ocean High, 354
  - indices for thunderstorm forecasting, 530-531
  - indigo color defined (also see optics chapter), 37
  - indirect
    - sense, 455-456
    - sunlight, 33-34, 46
    - vertical circulation cells, 377
  - induced electric currents, 570
  - inductive reasoning, 107-109
  - industrial centers, clouds forming over, 162
  - inefficient coalescence, 205
  - inertia, 292
  - inertial
    - forcing, 367-371
    - motion, 312
    - in downbursts, 559
    - oscillation, 304, 311-312, 700
    - damped, 311
  - infrared
    - subrange, 708
    - subrange turbulence scale, 315
    - transformation, 715
    - wind, 312
  - inferior mirages, 83, 861-862
  - infinite
    - loop, 759
    - number of equations, 714
  - inflection points, 730
  - inflow
    - layer (info box), 590
    - winds into thunderstorms, 483
    - elevated inflow base, 522
  - Info boxes
    - 30 - 30 Rule (for lightning safety), 570
    - A Holistic Approach to Stability, 139
    - Ageostrophic Right-hand Rule, 455
    - Albedo, 794
    - Alternative Horizontal Coordinates, 747
    - Alternative Vertical Coordinates, 746
    - Amdahl's Law, 763
    - Anabatic Slope Flow, 651
    - Approach to Geostrophy, 303-304
    - Astronomical Values for Time, 34
    - Barotropic vs. Baroclinic, 749
    - Beaufort Wind Scale History, 635
    - Bergen School of Meteorology, 399
    - Binary Multiples, 870
    - Boiling, 90
    - Cap vs. Capping Inversion, 497
    - CAPE vs. DCAPE, 558
    - Climate Sensitivity, 812
    - Coriolis Force in 3-D, 297
    - Cp vs. Cv, 55
    - Cubic Ice, 198
    - Cyclone Damage Potential, 607
    - Derecho, 494
    - Deriving the Radar Equation, 245
    - Downbursts and Flight Operations, 563
    - Droplet Growth, 191
    - E-folding Distance, 9
    - Early History of NWP, 759
    - Effective Inflow Layer, 590
    - Effervescence and CO<sub>2</sub>, 812
    - Electricity in a Channel, 564
    - Electricity in a Volume, 565
    - Engineering Boundary Layers, 689
    - Enthalpy vs. Heat, 58
    - Eötvös Effect, 317
    - Escape Velocity, 6
    - Estimating 22° Angles, 847
    - Force of Thunder, 571
    - Gain — Different Definitions, 807
    - Geostrophic Paradox, 459
    - Giving a Weather Briefing, 765
    - GOES 16 Global Lightning Mapper, 235
    - Greenhouse Gases, 811
    - Hail Suppression, 553
    - Hurricane Condensation Energy, 620
    - Hurricane-induced [Ocean] Currents, 610
    - Hurricane Juan Hits Canada, 617
    - In Newton's Own Words, 292
    - Internal Energy, 54
    - Isosurfaces & Their Utility, 436-437
    - Jet Stream Aspect Ratio, 357
    - Kalman Filter, 770
    - Landfalling Pacific Cyclones, 472
    - LeChatelier's Principle, 132
    - Lightning Burns the Air, 567
    - Lightning in Canada, 568
    - Linear Regression, 770
    - Lipschitz Continuity, 761
    - Mandatory and Significant Levels, 135
    - Map Projections, 748
    - Maximum Advection on Weather Maps, 458
    - Median, Quartiles, Percentiles, 502
    - Meteors and Meteorology, 205
    - Molecular vs. Turbulent Stress, 701
    - Moore's Law and Forecast Skill, 752
    - Multi-field Charts, 443
    - Newton and Colors, 862
    - North American Geography, 431
    - NWP, The Quiet Revolution, 772
    - On Naming Local Winds, 654
    - Pacific Data Void, 765
    - PCA and EOF, 821-823
    - Polar Front, 408
    - Pollution Concentration Units, 724
    - Power of Hurricanes, 625
    - Rainbows and the Renaissance, 841
    - Resolution and Grid Spacing, 761
    - Rosby Number, The, 306
    - Satellite Retrieval Difficulties, 239

- Scheiner's Halo, 855  
 Snow Grain Classification, 199  
 Solid-body Relative Vorticity, 363  
 Solution by Iteration, 310  
 Some Other Satellite Systems, 230  
 Southern Hemisphere Lows, 426  
 Special Crystal Orientations, 855  
 Specific Heat  $C_p$  for Air, 56  
 Speed of Sound, 674  
 Spreadsheet Thermodynamics, 63, 103  
 Stratospheric & Mesospheric Clouds, 166  
 Sun-Earth Distance, 802  
 Sutcliffe Development Theorem, 456  
 Time Differencing Methods, 757  
 Time of Max Airmass Thickness, 395  
 Tornado Watch, 529  
 Torques on the Earth, 376  
 Trade Inversion, 351  
 Warm Airmass Genesis, 394  
 Warm vs. Cold Core Cyclones, 622  
 What is an Oscillation, 818  
 What is Coriolis Force?, 298-299  
 Why Does  $Ro = (1-A)So/4$ , 795  
 Why So Many Moisture Variables?, 96-97  
 Why So Many Thermo Diagrams?, 121  
 Why Use Isobaric Maps?, 291
- info projection, 239  
 infralateral arc, 854-855  
 infrared (IR) radiation (see also longwave), 27, 37-39, 222-223, 793-794  
   cooling at cloud top, 484, 488-489  
   emissions from Earth system, 220, 334, 337, 794  
   emissivity (table of typical values), 42  
   feedback, for climate, 810  
   fog formation, role in, 173-177  
   hygrometer, 111  
   in troposphere, 71  
   rain drop growth affected by, 206  
   satellite images (photos), 230-233  
   satellite sensors, 46-47, 226, 230-232  
   scattering in atmosphere, 857  
   thermometer, 78
- inhibition, convective (CIN), 523-524, 530-531  
 initial  
   conditions, 731, 758, 762, 816  
   sensitivity, 773  
   spin-up of hurricane, 617  
   value problem, 293, 762
- initialization  
   objective optimum interpolation, 766  
   normal mode, 766  
   variational analysis, 767
- inland  
   flooding, 637  
   sea breeze, 654
- input, net solar, 795  
   external forcings to feedback processes, 806
- inquisition, 470  
 INSAT, 228  
 insects, 151  
 in situ (direct) sensors, 219  
 insolation (incoming solar radiation), 334-337  
   average annual, 336-337  
   average daily, 40-41, 336, 799-802  
   latitude variation of, 337  
   related to PG types, 727-728  
   variations vs. climate variability, 799-802
- instability  
   baroclinic, 353, 371-374  
   barotropic, 353, 367-370  
   CAPE & thunderstorm updrafts, 503-508  
   cloud-base detrainment instability, 484  
   dynamic  
     and chaos, 773-776  
     and the Richardson number, 141-142  
   line, 281, 399  
   nonlocal conditional (thunderstorm), 496, 503-508  
   nonlocal conditional (hurricane), 609  
   numerical, 759-761
- instantaneous  
   smoke plume, 728  
   wind part, 705-706
- instrument calibration error, 875  
 instrumented tower, 75  
 instruments (see weather instruments)  
 insurance, 772  
   hail/crop, 553  
   hurricane/disaster, 631  
 intake system of hurricanes, 608-620  
 integral/integration, approximation for, 872  
 integrated circuits (computer chips), 752  
 intensity  
   of rain, 207-208  
   of hurricanes, 605-607  
   of thunderstorms, 528-531  
   of tornadoes, 579-580  
   of turbulence, 503-508  
   of typhoons, 607  
   weather-map symbols for, 276
- intercept, 770  
 intercloud lightning, 563  
 interdecadal Pacific oscillation (IDPO), 824  
 interface, density, 657-661  
   light refraction across, 833  
 interfacial waves, 658-661  
 interference, 858-861  
   constructive and destructive, 859  
   fringes, 858-861  
 interferometers, interferometry, 46-47  
 interglacial/glacial (ice age) periods, 795, 799  
 Intergovernmental Panel on Climate Change (IPCC), 811
- intermittent  
   turbulence in entrainment zone, 692  
   weather-map symbol for, 276
- internal  
   boundary layer, thermal (TIBL), 654-657  
   dynamics (Bunker's) method for storm motion, 518-520  
   energy, 54, 672  
   feedback processes, 806  
   heat sources, 64, 72  
   Rossby radius of deformation, 319-320, 344, 665
- international  
   civil aviation organization (ICAO), 149  
   cloud atlas, 168  
   date line, 5  
   long scale number prefixes, 870  
   space station (obs. of hurricane & thunderstorms), 604  
   system of units (SI), 7, 870
- interpretation of  
   hodographs, 510-522  
   METARs and SPECIs, 270-279  
   satellite images, 231-233  
   weather maps, 436-472
- interquartile range (IQR), 502
- intertropical  
   convergence zone (ITCZ), 233, 330-332, 350-351  
   discontinuity, 281, 399
- intortus, 169  
 intracloud lightning, 563
- intrinsic  
   phase speed, 369, 658  
   unpredictability, 774
- inundation, 632-637  
 invariance, rotational, 320  
 inverse problem, 237-239  
 inverse square law of radiation, 39-40
- inversion  
   capping, 143-144, 496-499, 687-690  
     vs. thunderstorm cap, 497  
   frontal, 403-404, 691  
   lapse rate, 140  
   passat, 351  
   surfaces, 403, 687, 691, 695  
   temperature, 139, 687-691  
   trade, 351
- iodide (cadmium, lead, silver), 195  
 Ionian age, 799  
 ionized air, lightning, 565-566  
 ionosphere, 565  
 ions, 564  
 IPCC (Intergovernmental Panel on Climate Change), 39-45, 793-832
- IR (also infrared, terrestrial, or longwave radiation), 37-39  
   thermometer, 78
- iridescence, 165, 667, 685, 859-860  
 irradiance (see also radiation), 36  
 irregular ice crystal shapes, 199  
 irreversible processes, 121, 131, 765  
 irrotational winds, 385  
   in tornado, 577, 602
- isallobar, 17  
 isallohypse, 17  
 isallotherm, 17  
 isanabat, 17  
 isanomal, 17  
 isentrop, 17, 63, 103-105, 122-123, 143-144, 156, 365, 373, 403, 407-410, 414, 437, 624-625  
   on case-study weather maps, 438  
   on vertical cross section, 441
- isentropic  
   analysis, 144, 364, 437, 441, 443  
   chart, 437, 441  
   compressible flow, 671-672  
   potential vorticity (IPV), 364-365, 441-443  
   conservation, 364  
   lee cyclogenesis due to, 365  
   tropopause folds visible by, 364, 414-415  
   units (PVU), 364, 441  
   upper-level fronts, 414-415  
   processes in hurricanes, 625  
   surfaces, 437  
   in fronts, 403, 414-415  
   on weather maps, 437
- Islam, 754  
 island, urban heat, 678-679
- isobar, 17  
   for barotropic vs. baroclinic atmospheres, 749  
   frontal, 400-401  
   on thermo diagram, 63, 100, 119-158  
   packing vs. wind speed, 303, 307  
   rules for drawing on weather maps, 280-281  
   tornado, 581
- isobaric  
   charts, 290-291  
     for case-study cyclone, 433-466  
   definition, 17, 290, 436  
   maps/charts, 290-291, 436  
     reason for using, 291, 436-437, 442  
     20 kPa, 440-443, 452, 455-456  
     50 kPa, 433, 442, 448, 451  
     70 kPa, 439, 442  
     85 kPa, 439, 442, 449, 459-462  
     100 kPa, 438, 463  
   surfaces, 290-291, 345-349  
     mandatory, 772  
     on weather maps, 290-291, 436-442  
     vs. constant height maps, 290-291
- isobath, 17  
 isobathytherm, 17  
 isoceraunic, 17  
 isochrone, 17  
 isodop, 17, 250  
 isodrosotherm, 17  
   map of pre-thunderstorm environment, 500
- isoecho, 17  
 isogon, 17  
 isogram, 17  
 isohel, 17  
 isohume, 17, 100-101  
   on thermo diagram, 100-101, 119-158  
   pre-storm environment, 497-499  
   on weather maps  
     rules for drawing, 280-281  
     pre-storm environment, 499-501
- isohyet, 17  
 isohypse, 17  
 isoline, 17  
 isoneph, 17  
 isopleth, 17  
   hand analysis and drawing on maps, 280-281  
   of pollution concentration, 734, 737
- isopycnic, 17  
   for baroclinic vs. barotropic atmospheres, 749  
   process behind thunder shock front, 572
- isoshear, 17  
 isostere, 17  
 iso-surfaces, utility of, 436-437
- isotach, 17, 358-359  
   weather map of, 440, 443
- isotherm, 17  
   frontal, 400-401  
   on cross sections of atmosphere, 359  
   on thermo diagram, 63, 100, 119-158  
   on weather maps, 280, 400-402, 427, 439-440, 608, 768-769  
   rules of drawing, 280-281
- isothermal  
   compressible flow, 671  
   lapse rate, 140
- isotropic, 8, 221, 315  
   defined, 8, 707-708, 727  
   force, 8  
   motions and scales, 315, 707  
   radiation, 221  
   turbulence, 707-708, 727
- isotropy, 707-708, 727
- ITCZ (intertropical convergence zone), 233, 330-332, 350-351  
   hurricane trigger, 610-612  
   thunderstorms, 331-332
- iterative techniques, 103, 238, 308, 310, 394-395, 573-576

## J

- Japan Meteorological Agency (JMA), 607
- jet
- barrier, 664-665
  - blue, 563, 568
  - coastally trapped low-level barrier, 664-665
  - contrails, 160
    - climate change effects, 812
  - easterly, 611-612
  - low-level
    - coastal barrier, 664-665
    - nocturnal, 699-700
  - nocturnal, 699-700
  - prefrontal, 407, 433, 472
  - rear inflow (RIJ), 489
  - sting, 414-415
- jet-streak, 454
- driving updrafts and cyclogenesis, 454-456, 467
  - entrance and exit regions, 455-456
  - four quadrants, 455-456
  - of cyclone case study, 455-456
  - thunderstorm triggering, 526
- jet-stream(s), 357-361
- African easterly, 611-612
  - angular momentum, 360-361
  - aspect ratio, 357
  - axis, 362
  - baroclinicity, 359-360
  - core, 357-359, 414-415
  - circulation around the globe, 357-358
  - curvature, 453
    - driving updrafts and cyclogenesis, 453
  - cyclogenesis, role in, 427-429, 432
  - easterly, 611-612
  - equation, 359-361
  - exit region, 454-456
  - frontal zones, at, 407
  - maximum, 357-362, 454-456
  - meanders (Rossby waves), 329, 357, 367-376
  - polar, 233, 331-332, 352-353, 357-360
  - secondary circulations, 455-456
  - speed, 357-361
    - vs. season, 357-358
  - streaks of max winds, 454-456
  - subtropical, 233, 331-332, 350-351, 357-361
    - angular momentum effects, 360-361
- Joint Polar Satellite Systems, 229
- Joint Typhoon Warning Center (US), 607
- joule, unit of energy, 870
- JPSS, 229
- Juan
- de Fuca Strait, 661-663
  - Hurricane, 617
- judgement errors, 875
- Julian day, 29
- jump
- hydraulic, 660-661
  - potential temperature, 110, 690-698
- Junge distribution of cloud condensation nuclei, 189

## K

- K (degrees), 7
- K band radar (including Ka and Ku bands), 242
- K index (KI), 531
- K-Pg event (mass extinctions), 805
- K-T event (mass extinctions), 805
- K theory, 714-716
- Kalman filter & gain, 770
- kaolinite, 195
- Kármán, von, 677, 701
- katabatic wind
- equilibrium speed, 653
  - high pressure associated with, 391
  - in Antarctic air mass formation, 396, 676
  - in Antarctic cyclone formation, 432
  - in fog formation, 177
  - in forest trunk space, 678
  - in stable (nocturnal) boundary layer, 696
  - vs. Bora winds, 675-676
- katafront, 404
- Keeling curve (for CO<sub>2</sub>), 812
- Keith, David, 815
- Kelvin
- circulation theorem, 366
  - equation, 189-191
  - Helmholtz (K-H) waves, 142, 165, 169, 654-655, 710

- temperature units, defined, 7, 870
  - wave, 633-634
- Kepler, Johannes, 27
- Kepler's second law, 29
- Kern arc, 854-855
- key altitudes for thunderstorms, 496-499
- Keyser, (Shapiro-Keyser cyclone model), 414-415
- K-H waves, 142, 165, 654-655
- clouds (fluctus), 165, 169
- kilo (10<sup>3</sup>), 870
- kilobit, 870
- kilograms, 870
- force
  - mass, 870
- kiloPascals, defined, 7-8
- kinematic
- definition, 320-321
  - effective surface water-vapor flux, 110
  - flux of total water, 109-110
  - flux of water vapor, 108-110
  - frontogenesis, 408-410
  - heat flux profiles in ABL, 698
  - mass flux, 34-35
  - momentum flux, 704, 715
  - stress, 701
  - surface heat flux, 73-76
- kinematics, 320-321
- circulation, 365-366
  - convergence and divergence, 320-321
  - deformation, 320-321
  - vorticity, 320-321
- kinetic energy
- in Richardson number, 150
  - of flow, 669-672
  - of global circulation, 356
  - of molecules, 6
  - of wind, 150
  - turbulence, 708-709
- King Arthur legend, 863
- Kirchhoff's Law, 41, 220
- klystron vacuum tubes in radar, 240
- Knollenberg probe, 210
- knot unit of speed, 278, 291, 870
- knowledge, organizing, 72
- Köhler
- curves, 191
  - equation, 190
- Köppen climate classification, 816-817
- Köppen, Wladimir, 817
- kPa (kiloPascals) defined, 7-8
- Krakatau, 805
- krypton hygrometer, 111
- Kuiper's and Hansen's skill score, 781
- Kuroshio ocean current, 431

## L

- L band radar, 242
- Labrador current, 616
- lacunosus, 169
- Lagrangian
- definition, 53
  - heat budget-saturated, 101-106
    - liquid-water, wet-bulb, & equivalent potential temperatures, 104-106
    - saturated adiabatic lapse rate, 101
    - thermo diagrams, 102-103
  - heat budget-unsaturated, 57-64
    - adiabatic lapse rate, 60
    - first law of thermodynamics, 58-59, 64-65
    - potential temperature, 61-62
    - thermodynamic diagrams, 63
  - momentum budget, 292
    - Bernoulli's equation, 670
    - net source of water, 99
    - pollutant dispersion, 731
    - time scale, 732
    - trajectories, 669
    - water budget, 99-106
      - thermo diagrams, 100-101
      - water conservation, 99
- lake
- breeze, 654
  - fronts, 525, 655-657
  - high pressure, 391, 655
  - steam fog, 173
  - Toba, 805
- Lamb, Sir Horace, 705
- Lambert map projection, 748
- laminar air flow, 138, 140, 669-671, 688
- land
- breeze, 656
  - surface observation from satellite, 234
- landfalling Pacific cyclones, 472
- landscape vs. roughness length, 700
- landspout tornadoes, 582
- land-use observation from satellite, 220
- La Niña, 818-820
- cyclone track influence on, 430
- Laplacian, 450, 458
- form for geostrophic vorticity, 450
- lapse rate, 59-64, 139-140
- adiabatic, 139-140
  - environmental, 59, 134, 140-141
  - feedback in climate, 810-811
  - inversion, 140
  - isothermal, 140
  - moist vs dry, 104-106
  - names, 140
  - process, 59-64
  - saturated (moist), 101-106
  - standard atmosphere, 11-12, 70
  - subadiabatic, 139-140
  - superadiabatic, 139-140
  - thunderstorm environment, 496-499, 503-508
  - unsaturated (dry), 60-64
  - vs. static stability, 139
- large
- eddy simulation models, 786
  - scale (global) circulation, 329-388
- laser radar (lidar), 112, 322
- latent heat
- condensation, 56, 465-467
  - cyclogenesis, 465-471
  - deposition, 56, 88, 880
  - energy, 54
  - Eulerian heat budget, 72
  - evaporation, 54
  - factor, 56
  - flux at surface, 73-76
  - fusion, 56, 880
  - hurricanes, fuel for, 620
  - internal energy source, 64, 72
  - melting, 54, 56
  - on thermo diagrams, 130-131
  - precipitation, measure of net heating, 465-466
  - rate, 72, 465-466
  - release in
    - hurricanes, 613, 620
    - thunderstorms, 72, 465-466, 499-502, 546-548
  - self-development of cyclones, 468-471
  - sign convention, 56
  - sublimation, 56
  - thunderstorms, fuel for, 499-502
  - vaporization, 56, 88, 880
  - variation with temperature, 90, 880
  - water, 54
- lateral direction, defined, 727
- latitude(s)
- belts, 329-330, 350-355
    - radiative forcings, 338-339
  - change with distance north, 336
  - degrees of, 4, 330, 879
  - elevation angle of sun as function of, 32, 801-802
  - excluded, for hurricane formation, 609
  - high-, 330
  - horse, 331
  - hurricane, favored & excluded, 609
  - lines, 4
  - low-, 330
  - mid-, 330
  - of strongest jet-stream, 359-361
- Laurasia, 804
- Laws
- Amdahl's, 763
  - Beer's, 43, 856
  - first law of thermodynamics, 53, 58-59, 64-65
  - inverse square law of radiation, 39-40
  - Kirchhoff's, 41
  - gravitation (Newton's), 11
  - Moore's, 752
  - motion (Newton's), 292
  - myth of, 38
  - Newton's, 11, 292
  - sine law of radiation, 40
  - Snell's, 834-837
  - Stefan-Boltzmann, 37-38
  - Planck's, 36
  - Wien's, 37
- large hail, 548
- layer, 147
- atmospheric boundary, 687-722
  - clouds, 162-164, 168
  - method for static stability, 140-141

- triggering of thunderstorms, 526
  - radix, 703-705
  - stability classes, 140-141
- layers of the atmosphere, 12-13, 563, 565, 692, 700-705
- LCL (see lifting condensation level)
- LDN (lightning detection network), 568
- lead (Pb), the chemical, 725
  - iodide, 195-196
- lead time in forecasting, 762
- leaders
  - dart, 567
  - stepped, 566
- leap
  - day, 31
  - frog (time-differencing) scheme, 757
  - year, 31
- least squares, 770
- LeChatelier's Principle, 132, 141, 329, 344, 383, 429
- lee cyclogenesis, 430-431, 443-446
  - conservation of potential vorticity, 364-365, 445
  - isentropic, 364-365
  - equatorward propagation along the lee side, 446
  - stationary planetary waves, 443
- lee waves, 666-668
- left
  - moving supercells, 518-520
  - quadrants of jet streak, 454-456
- Leibniz, Gottfried Wilhelm, 759
- length, 870
  - buoyancy scale, 733
  - mixing (Prandtl), 715
  - momentum-scale, 733
  - Obukhov, 703
  - path (radiative), 43
  - roughness, 677, 700-703
  - scales, 315
    - buoyancy, 733
    - dissipation, 709
    - momentum, 733
  - units, 870
- lenticular/lenticularis/len clouds, 165, 168, 666-668, 684-685
  - optical phenomena caused by, 859-860
- LEO (low Earth orbiting) satellites, 227
- levels
  - mandatory, 134, 772
  - significant, 134, 147
  - radar echo intensity, 247
- level of
  - downdraft equilibrium (DEL), 557
  - equilibrium (EL), 483, 497-506
  - free convection (LFC), 497-506
  - free sink (LFS), 557
  - lifting condensation (LCL), 93-94, 496-499
- lidar (laser radar, including DIAL), 112, 219
  - anemometer, 322
  - image of thermals, 649
- life
  - controls on climate, 813
  - cycle of
    - hurricane, 613-615
    - thunderstorm, 484-485
    - tornado, 583
- lifted index (LI), 531
- lifting
  - condensation level (LCL), 93-96, 105-107, 130, 138, 162, 164, 483, 496-501, 530-531
  - cumuliform cloud base, 162
  - height change with precipitation, 130-131, 398, 676-677
  - mean-layer, 501, 530-531
  - of chinooks and foehns, 676-677
  - of lenticular clouds, 666-668
  - of upslope fog, 173
  - on thermo diagram, 129-130, 497-499
  - pre-thunderstorm, 497-501
  - pressure at, 93
  - stratiform cloud base (not related to), 164
  - temperature at, 96
  - tornado funnel cloud, 581
  - fog, 177
  - trigger for thunderstorms, 496, 522-526, 530-531
- light, 222
  - bending, 833
  - colors, 37, 834-835, 862
  - diffraction, 858-861
  - electromagnetic waves, 833
  - ice-crystal optics, 842-855
  - liquid drop optics, 837-841
  - mirages, 861-863
  - monochromatic, 833
  - optics in the atmosphere, 833-868
  - photon particles, 833
  - point, 834-835
  - polarization, 856-857
  - rainfall rate, 207-208
    - weather-map symbols for, 276
  - rays, 833-837
  - reflection, 833-844
  - refraction, 833-855
  - scattering, 856-857
  - spectrum, 37, 222, 834-835, 862
  - speed of, 36, 240, 243, 834-837, 879
  - transmission of, 73, 805, 856
  - ultraviolet, 222, 857
  - waves, 833
- lightning, 563-571
  - 30-30 safety rule, 570
  - air discharge (cloud-to-air, CA), 563
  - anvil, lightning from, 564
  - ball, 567
  - bead, 567
  - behavior and appearance, 566-568
  - blue jet, 563, 568
  - bolt (see return stroke), 566-567
    - from the blue, 567
  - breakdown potential, 566
  - burning the air, 567
  - Canadian, 566
  - channel, 563-567
  - climatology, 564
  - cloud-to-cloud (CC), 563
  - cloud-to-ground (CG), 563
  - CPTP, 569
  - creation by micropysical processes, 564-566
  - currents, peak, 568-569
  - deaths caused by, 564, 571
  - detection networks (LDN), 568-569
    - satellite low-light cameras, 569
    - satellite optical transient detectors, 569
  - duration, 569
  - electrometers, 205
  - elf / elves, 563, 568
  - fatalities from lightning strikes, 571
  - fires (forest, wild) caused by, 564
  - flashes, 567
  - flickering, 567
  - forecasting, 569
  - global lightning mapper (GLM), 235
  - hazards, 569-571, 607
  - heat, 567
  - hurricane, 637
  - igneous meteors, 205
  - incandescence, 564
  - intracloud, 563
  - intracloud (IC), 563
  - jet, 563, 568
  - median peak current, 564
  - MUCAPE, 569
  - negative (polarity), 563-564
  - odor, 567
  - plasma, 567
  - polarity, 563-564
  - positive (polarity), 563-564
  - power, peak, 569
  - pressure wave in thunder, 564, 571-574
  - red sprite, 563, 568
  - ribbon, 568
  - safety & warning signs, 567, 569-571
  - sferics, 568
  - sheet, 567
  - size, 563
  - spider, 567
  - sprite, 563, 568
  - staccato, 568
  - storm (see Thunderstorms), 481-602, 564
  - strike sequence, 566-568
  - temperature, 563
  - thunder, 571-576
  - types, 563
  - weather-map symbol for, 276
- likelihood of tornadoes, 591
- likely velocity
  - downburst in thunderstorm, 557-559
  - updraft in thunderstorm, 508
- limit of
  - convection, 498
  - predictability, 773-776
- line(s)
  - absorption, 221
  - clouds, 167
  - convergence, 281, 399
  - end vortices, 490
  - dry, 399
  - flanking, 482-483
  - instability, 281, 399
  - path, 668-669
  - shear, 281, 399
  - squall, 281, 399
  - streak, 668-669
  - stream, 611-612, 668-669
  - thunderstorms (squall line), 399, 490
- linear
  - depolarization ratio, 256-257
  - feedback processes, 806
    - approximation to nonlinear process, 806-809
  - graph, 873
  - regression, 770-771
  - relationship, 873
- Lipschitz condition/continuity/smoothness, 761
- liquid-crystal thermometers, 78
- liquid drop optics, 837-841
  - Alexander's dark band, 841
  - primary rainbow, 839-840
  - reflection from water, 838
  - secondary rainbow, 840-841
- liquid droplet nucleation, 188-194
- liquid-in-glass thermometers, 78
- liquid-water
  - content (LWC), 97
    - measurement, 210
  - density vs. temperature, 835, 880
  - equivalent, 107, 208
  - loading, 15, 555
  - mixing ratio, 97-98, 186
  - on thermo diagram, 130
  - potential temperature, 104-106
    - on thermo diagram, 103-106
    - on weather maps, 500
  - specific heat, 880
- liter (or litre) unit of volume, 870
- lithometeors, 205
- litre (or liter) unit of volume, 870
- livestock weather safety index, 117
- loading, liquid water or ice, 15, 555
- local
  - closure, 714-716
  - elevation angle of sun, 32
  - horizontal, 4, 5
  - shear across one layer, 514
  - winds, 645-686
    - naming, 654
- location parameter, Weibull distribution, 646
  - median as, 502
- locations of
  - hail, 552-553
  - strongest hurricanes, typhoons, trop. Cyclones, 631
    - weather observations worldwide, 271-273
- logarithmic
  - relationships and semi-log graphs, 873-874
  - wind profile, 677
- logarithms, base of natural, 879
- log-linear wind profile, 702-703
- log-log graph, 215, 874
  - slope, meaning of, 215
- lognormal distribution
  - clouds, 170
  - lightning surge probabilities, 569-570
  - rain-drop size, 207
- log wind profile, 677, 702-703
- London, Jack, 849
- long
  - gap winds, 662-664
  - range forecast models, 768
  - scale number prefixes (international), 870
  - waves
    - Rossby; planetary waves, 369
    - radiation, 37-39
- Longfellow, Henry Wadsworth, 847
- longitude, 4, 802
- longwave radiation (see infrared), 37-39, 220, 793-794
- loom, optically, 862
- looping of smoke plumes, 727-728, 735-737
- loops
  - radar, 241
  - satellite, 227
- Lord Byron, 805
- Lorenz strange attractor, 773-775
- Lorenz, Ed, 773, 775
- loss, 780
  - vs. cost, 785
- lottery, 711
- Lovelock, James, 813
- low
  - clouds (see also fog), 162, 168

- height variation with latitude, 163  
 scud, 483  
 weather-map symbols for, 168, 277  
 Earth orbit (LEO) satellites, 227  
 latitudes, defined, 330  
   global circulation, 350-351  
 level jet  
   coastal barrier, 664-665  
   nocturnal, 699-700  
 light level cameras for lightning detection, 569  
 order truncation finite difference schemes, 754-755  
 precipitation supercell (LP), 495  
   wind statistics for, 585  
 pressure  
   boundary-layer pumping, 319-320, 432  
   meso-lows, 489  
   mountain lee, 165  
   systems (see extratropical cyclones), 330, 425  
 pressure-centers (extratropical cyclones; lows; L), 425-480  
   fronts rotating around, 389, 425-426  
   glyph (symbol) on weather maps, 426  
   hurricane eye, 613-615  
   midlatitude, 331, 425-480  
   monsoon-related, 333-334  
   named (Aleutian, Icelandic, etc.), 354-356  
   rising air in, 356, 451-462  
   thermal, 341-342  
   tracks, 429-431  
   winds around, 305-307, 446-450  
 resolution NWP, 752  
 lower  
   quartile, 502  
   suncave Parry arc, 854-855  
   sunvex Parry arc, 854-855  
   tangent arc, 851-852, 854-855  
   Wegener arc, 854-855  
 Lowitz  
   arcs, 855  
   oriented crystal, 855  
 lows (see extratropical cyclone chapter), 425-480  
   midlatitude cyclones, 330-331, 425-480  
   models, 414-415  
   Southern Hemisphere, 426, 430-432  
   subpolar, 331  
 LP (low-precipitation supercell), 495  
 luminary, 858  
 luminous  
   intensity units, 870  
   meteors, 205  
 lumpy cloud shapes, 161-164  
 lunar tides, 376  
 Lyman-alpha hygrometer, 111
- M**  
 Mach number, 571-576, 579, 674  
   one, 579, 674  
 macroscale cloud electrification, 564-566  
 Madden-Julian oscillation (MJO), 818, 824  
 Maddox, Bruno, 54  
 MAFOR code, 269  
 magnetic  
   direction finders, 568  
   field, 255  
   variation, 647  
 magnetron vacuum tube in radar, 240  
 magnitude  
   component of scientific notation, 870  
   of total shear, 515-516  
 main updraft tower, 482-483  
 major Hadley cell, 332-333  
 mammatus/mamma clouds, 169, 484  
 mandatory levels for RAOBs & NWP output, 134-135, 772  
 Manhattan project, 218  
 man-made clouds, 166  
 manual (hand) analysis of weather maps, 279-281  
 Manual on Codes No. 306, WMO, 268  
 manufacturing data, 826  
 map, 274-281  
   factors, 747  
   polar stereographic, 747  
   NWP output, 772  
   projections, 747-748  
   conformal, 748  
   Lambert, 748  
   Mercator, 748  
   polar stereographic, 747-748  
   stereographic, 748
- weather  
   airmass locations, 392  
   analysis methods, 274-281, 402  
   CAPE, 506-508  
   surface, 267  
 marine air, 656  
 maritime  
   airmass code, 392  
   cloud condensation nuclei, 194  
   fogs, 173-174  
   tropical airmass, 392  
 Marshall-Palmer distribution, 207  
 mass, 870  
   air, in a column, or between pressure levels, 10, 464, 466  
   airmass, 389-399  
   budget, 317-318, 746-747  
   of air column (for MSL pressure), 463  
   center of, for  
   pollutants, 729  
   wind vector, 516-517  
   conservation, 317-318, 660, 746-747  
   boundary-layer pumping, 318-319  
   continuity equation, 317-318  
   incompressible continuity equation, 318  
   thunderstorm, 545-546  
   density, 10-13  
   Earth, 28, 879  
   extinction events, 805  
   field, 343  
   adjustment to wind field, 343-344  
   balanced with flow fields, 763-765  
   in forecast models, 764  
   flux (dynamic & kinematic), 34-35, 317-318  
   in Newton's second law, 292  
   inflow vs. outflow, 317-319  
   moon, 28  
   of air in column, 10  
   of air parcel mixture, 160  
   of solute in droplet, 190-193  
   of water vapor, 91  
   planets in the solar system, 22  
   units, 870  
 massaging data, 826  
 mathematical  
   closure, 714  
   constants, 879  
   framework, 2  
 mathematics, 315, 711, 762  
   clarity, 393  
 matrix, 822  
   covariance, 821-822  
   eigenvalues and eigenvectors of, 822  
   trace, 822  
 mature stage of  
   waterspout spray vortex, 582  
   thunderstorm cell evolution, 485  
   tornadoes, 583  
 Maunder minimum in sunspots, 39, 803  
 maximum  
   acceptable levels of air pollutants, 725  
   advection on weather maps, 458  
   likely  
   downdraft speed in thunderstorms, 557-559  
   updraft speed in thunderstorms, 508  
   precipitation for WBF process, 201-202  
   solar output, 803  
   surface temperature for thunderstorms, 506, 523  
   tangential winds around eye wall, 605, 622, 626-627  
   theoretical pressure ratio of hurricane, 625-626  
   unambiguous range, for radar, 240-241  
   unambiguous velocity, for Doppler radar, 250-251  
   updraft speed in thunderstorms, 508  
   vorticity advection, 458  
   wave-height, 634-636  
   winds through short mountain-gaps, 662  
 mb, millibar, definition, 7-8  
 MCC (mesoscale convective complex), 491  
 McMahon, 817  
 MCS (mesoscale convective system), 488-492  
   role of wind shear, 510  
 MCV (mesoscale convective vortex), 492  
 MDT, Mountain daylight time, defined, 5  
 mean, 502, 705, 726, 875  
   absolute error (MAE), 778  
   and turbulent parts of wind, 705-706, 726  
   anomaly, 29  
   background state, 316  
   bias, 778, 875  
   condition for air, 7  
   environmental wind (normal storm motion), 516-518  
   error, 778, 875  
   layer  
   CAPE, 506-507  
   CIN, 524  
   lifting condensation level (ML-LCL), 501, 530-531  
   persistence error, 778  
   running average, 599  
   sea level (MSL) pressure, 267, 275  
   forecast equation, 464-467  
   maps, 354  
   reduction from station pressure, 267  
   shear vector, 514-515  
   squared error (MSE), 778  
   skill score, 778  
   statistical definition (=average), 502, 705, 726  
   wind, 705, 726  
   radar observations of, 252-253  
   shear vector, 514-515  
   vector, 516-518  
 measurement of  
   fractal dimension, 172  
   humidity, 111-112  
   radiation, 45-47  
   rainfall, 210-211  
   soundings, 134-135  
   temperatures, 78-79  
   winds, 249-254, 321-322  
 mechanical  
   clocks & time, 34  
   energy, 625, 670  
   turbulent production, 704  
 Medawar, Sir Peter, 343  
 median, statistical definition, 502  
 medical symptoms for people struck by lightning, 571  
 medieval maximum in solar output, 803  
 mediocris/med, cumulus, 161-162, 168, 483  
 Mediterranean airmasses, 397  
 medium-range weather forecast models, 768  
 mega (10<sup>6</sup>), 870  
 megabit, 870  
 megaton bomb, energy of, 499, 548, 880  
 melting  
   ice crystals, as seen by radar, 248  
   latent heat of, 56  
 Mercator map projection, 748  
 mercury  
   barometer, 7, 19  
   inches of, 7  
   millimeters of, 7  
 meridians, 4, 330  
   defined, 4, 330  
   prime, 4, 28  
 meridional  
   displacement, 372  
   flow, defined, 330  
   gradient (MG) of zonal momentum, 376  
   kinematic heat flux, 374  
   overturning ocean circulation, 810  
   propagation of baroclinic waves, 372-374  
   temperature gradient, 335-336, 352  
   transport by Rossby waves, of, 374-376  
   heat, 374-375  
   momentum, 375-376  
   wave flux, 375  
 Merilees, Phil, 775  
 mesocyclone (see thunderstorm), 481, 483, 492-495, 586-592  
   counter-rotating, 490-491, 587  
   radar observations of, 253  
   wind shear, importance for, 510  
   as affects storm-center motion, 518-520  
   tornadoes, relationship to, 582, 586-592  
 meso-high, 488, 554, 559-563  
 meso-low (also see mesocyclone), 489  
 mesopause, 12-13  
 mesoscale, 315  
   cellular convection (MCC), 167  
   convective  
   complex (MCC), 140, 491  
   system (MCS), 488-492, 613  
   system, lightning from, 564  
   vortex (MCV), 492, 613  
   forces in gap winds, 662-664  
   gap geostrophic wind, 663  
   high pressure (see meso-high), 488, 554, 559-563  
 mesosphere, 12-13  
   polar clouds in, 166  
 MET (Middle European time), 5  
 metabolism, 76  
 metaldehyde, 195-196

- metamorphosis of snow crystals, 209  
 METAR = aviation routine weather report , 170, 268-271, 275-279  
   abbreviations for precipitation, 208  
 Météo-France, 607  
 meteogram, 117, 745, 772  
 meteoroids, 205  
 Meteorologica (book by Aristotle), 26  
 meteorological  
   aviation report (METAR), 270-279  
   conventions, 2  
 Meteorological Service of Canada (MSC), 243, 638  
 meteorology, 205  
   applied, 2  
   Bergen School of, 399  
   definition, 1, 205, 877  
   disciplines or components of, 1, 353  
   forecasting, 745-792  
   synoptic, 353  
   theoretical, 872  
 meteorite dust, seeding clouds, 166  
 meteoroids, 205  
 meteors, 11, 168-169, 205  
   hydrometeors, 205  
   other meteorological meteors, 205  
 meteosat, 228-229  
 meter, 870  
 methane, CH<sub>4</sub>, 7  
   greenhouse gas, 811  
   hydrates in ocean & permafrost, 810  
   sulfonic acid, 188  
 method of  
   moments, 730  
   problem solving, 869  
 meticulous, 19  
 metric  
   (SI) units, 7, 870  
   ton (or tonne), 870  
 Mexico time zone (MEX), 5  
 Michelson interferometer, 46  
 micro (10<sup>-6</sup>), 870  
 microbursts, 554  
 microphysics (of clouds and precipitation), 185-218, 546  
   parameterizations in NWP models, 751  
 microscale, 315, 708  
   processes creating cloud electrification, 564-566  
 microwave  
   bands, 223  
   energy from radars, 240  
   ovens, 243  
   radiation, 220  
   rain sensors, 211  
   refractometer, 111  
   satellite sensors, 211  
   wind profilers, 112  
 middle  
   clouds (prefix: alto), 162-163, 168  
   height variation with latitude, 163  
   satellite images of, 234  
   weather-map symbols for, 168, 277  
   European time (MET), 5  
 midlatitude, 330  
   anticyclones, 331, 390-391  
   cyclones, 331, 425-480  
     Southern Hemisphere, 426  
   highs, 331, 390-391  
   lows, 331, 425-480  
   system collision with hurricanes, 616  
   troughs and ridges, 367-376  
     baroclinic instability and planetary waves, 371-374  
     barotropic instability and Rossby waves, 367-370  
     heat transport , 374-375  
     momentum transport, 375-376  
     ridge axis, 367  
   weather  
     cloud heights, 163  
     tropopause heights, 163  
     variability, 353, 425-480  
 midlatitudes, defined, 330  
   global circulation, 352-355  
 mid-level vertical velocity, 452-462  
 mid-tropospheric fronts, 413-414  
 Mie scattering, 857-858  
   haze, 858  
 Mie, Gustav, 858  
 Milankovitch, Milutin, 797  
   theory, 797-803, 829  
 miles, nautical, 4  
 military , 218  
   polar orbiting weather satellite, 273  
   twilight, 33-34  
 milli (10<sup>-3</sup>), 870  
 millibars, defined, 7  
 minima in solar activity, 803  
 minimum  
   viewing angle, 846  
   visibility (in METAR), 270  
 minor Hadley cell, 332-333  
 minute unit, 870  
 mirages, 861-863  
   Fata Morgana, 862-863  
   green flash, 862  
   inferior, 83, 861-863  
   superior, 862  
 mirrors, ice crystals acting like, 843-844  
 misinterpretation of data, 729  
 miss, 780  
 missed approach to airports, 563  
 mist, 170  
   weather-map symbol for, 276  
 mitigated loss, 780  
 mixed-layer (see atmospheric boundary layer), 68, 692  
   airmass, 393-396  
   CAPE, 506-507  
   convective, 649, 692  
   Deardorff velocity for, 703-704  
   depth, 144, 649  
   determination of, 143-144  
   entrainment into, 649, 697-698  
   growth, 695  
   associated with airmasses, 393-395  
   associated with dry lines, 416  
   rate, 698  
   lifting condensation level (ML-LCL), 501  
   ocean, 610  
   scaling variables, 735-736  
   temperature profile, 692  
   thunderstorm environment, 496-497  
   top, 143-144, 497-499  
   transport coefficient, 68  
   unstable, 692  
   winds in radix layer, 703-705  
 mixing  
   length theory, Prandtl, 715  
   of air parcels to create clouds & contrails, 160-161  
   ratio, 91  
     average total water, 97-99  
     definition, 91  
     excess water, 186-187  
     gradient, 196  
     ice, 97, 186  
     liquid-water, 97-98, 186  
     pollutant, 724  
     saturated, 91  
     thermo diagram, 100  
     total water, average, 97-99  
     total-water, 97, 186  
     vs. RH and temp, 92  
     water vapor, 56, 89-98  
     weather maps of, 500  
     wet-bulb, 94-95  
     in middle of mixed layer, 109-110  
     turbulent, effects on frontolysis, 411  
 mixture of air parcels, 160-161  
 MJO (Madden-Julian oscillation), 818, 824  
 MKS units (see International System of Units), 7, 870  
 ML (see mixed layer)  
   CAPE, 506-507  
 moat, 605  
 mode of CCN growth, 188  
 Model Output Statistics (MOS), 770-771  
 modelers, 751  
 model(s), 751  
   climate, 792  
   fog, 173-177  
   GCM (Global Climate), 768  
   general circulation, 330-388  
   heuristic (also see toy models), 280, 330, 793  
   hurricane, 626-629, 637-638  
   numerical weather prediction, 751  
     current, 751  
     history of, 759  
   output statistics (MOS), 770-771  
     updateable, 771  
   pollution, 725  
   primitive equation, 747  
   sensitivity, 350  
   toy (simplified), 330  
 moderate  
   rainfall rate, 207-208  
   weather-map symbol for, 276  
   thunderstorm risk, 530  
 modern maximum in solar activity, 803  
 modification of airmass (see airmass), 397  
   via flow over mountains, 398-399  
   via surface fluxes, 397-398  
 Moilanen arc, 854-855  
 moist, 57  
   adiabatic lapse rate (saturated), 101-103  
     for determining static stability, 139  
 adiabats, 101-106, 497  
   on thermo diagrams, 102-106, 119-158  
   thunderstorms, 497-499  
   convection (thunderstorms), 496-499  
   convective adjustment, 70  
   process, 130  
 moisture, 87-118  
   budget at surface, 107-110  
   cyclogenesis, 426  
   flux, 108, 110  
     diffusive, 197  
   forecast equations for, 746  
   instruments, 111-112  
   transfer coefficient, bulk, 109  
   variables, 87-99  
 moisturizing process to form clouds, 159-160  
 mole, 870  
   molecular weights (g/mole), 7  
   ratio of pollutants, 724  
 molecular  
   compression, 7-10  
   conduction flux, 67-69, 73  
   conductivity, 67-68, 880  
   diffusivity (see also diffusivity), 196-200, 880  
   energy, 118  
   friction, 301  
   rotation lines in spectra, 221  
   scale, 315  
   scattering of radiation, 220-222  
   speed & temperature, 6-7  
   stress, 701  
   vibration lines in spectra, 221  
   viscosity, 709  
   weight, 7  
     of air, 7  
     of atmospheric gases, 7, 724  
     of solute in CCN, 190  
 moments, method of, 730  
 momentum, 292  
   advection, 294  
   angular, 360, 375  
     subtropical jet, 360-361  
   budget, 292-293  
     Eulerian, 293, 746-747  
     Lagrangian, 292  
   definition, 292  
   forecast equations for, 746  
   flux, 375-376  
     turbulent, 712-713  
     vs. stress, 712-713  
   gradient, 294  
   length scale, 733  
   reservoirs, 375  
   specific, 294  
   transport, 294  
     by Rossby waves, 375-376  
 Monin-Obukhov length, 703  
 monochromatic , 36  
   irradiance, 36  
   light ray, 833  
 monodisperse distribution, 197  
 monotonic, defined, 9, 290  
 monsoon  
   airmass code, 392  
   circulations, 333-334, 343, 356  
   highs associated with, 333-334, 354, 391, 615  
   steering hurricanes, 615  
   Indian, 356  
   trough hurricane trigger, 612  
 Moon, 27  
   albedo, 42  
   bows, 841  
   mass, 28  
   optical phenomena around, 163  
   orbital period & direction, 27-28, 879  
 Moore, Gordon E., 752  
 Moore's Law, 752  
 moral issues of doing science, 218  
 Morgana, Fata, 862-863  
 morning  
   Glory, 656  
   satellite, 229  
 morphology (shape) of



- clouds, 168
- ice crystals, 198-199
- MOS (model output statistics), 770-771
- most-unstable CAPE, 507
- mother
  - clouds, 168-169
  - Earth (gaia), 813
  - of-pearl clouds, 166
  - storm, 485
- motion
  - cyclone translation, 425, 429-431, 433-435
  - eddy, 35, 750, 704-716
  - equations of, 746-749
  - horizontal, 314
    - equations of, 301-302, 314, 746
    - scales of, 315
  - laws, 292
  - thunderstorm translation, 487, 492, 516-520
  - vertical, 315-320
    - boundary layer pumping, 319-320
    - equations of, 315-320, 746
    - in extratropical cyclones, 451-462
    - in hurricanes, 605, 612, 628-629
    - in thermals, 648-649, 694, 703-708, 711-716
    - in thunderstorms, 482, 485-498, 503-508
- mountain
  - anabatic (upslope) flow, 649-652
  - blocking of airmass & high pressure formation, 391
  - building (orogenesis), 804
  - clouds, 165, 649-650
  - convergence zones, 472
  - cyclogenesis (lee), 364-365, 443-446
  - downslope (katabatic) flow, 652-653
  - gap winds, 661-664
  - high pressure formation near, 391
  - katabatic (downslope) flow, 652-653
  - pass winds, 661-664
  - precipitation, 398-399, 472
  - ranges, 397, 661
  - slope
    - angle, 650-653
    - flows, 649-653
  - time zone, 5
  - related clouds, 165
  - triggering of
    - easterly waves, 611
    - Rosby waves, 364-367, 443-445
    - thunderstorms, 487, 526
  - upslope
    - flow (anabatic), 649-652
    - rain (orographic), 398-399, 472
  - wave(s)
    - behavior, 666-668
    - clouds, 165, 667
    - drag, 301, 668, 751
    - Froude number, 668-668
    - high-pressure regions in, 391
    - lenticular clouds, 165, 667
    - natural wavelength, 666
    - turbulence, 667
    - winds, 649-654, 660-670, 675-676
- movement of
  - airmasses, 397
  - lows (extratropical cyclones), 429-431
- MSL (see mean sea level)
  - pressure, case-study maps, 438
  - forecasts for cyclogenesis, 463-467
  - reduction to, 267
- MST, Mountain standard time, defined, 5
- Mt. Agung, 805
- Mt. Fuego, 805
- Mt. Pinatubo, 805
- MT-SAT, 228
- Mt. Tambora, 805
- Muana Loa, 805
- MU-CAPE, 507
- multicell thunderstorms, 486-487
- multi-field charts, utility of, 443
- multiple vortex tornadoes, 592-593
- mushroom cloud (thunderstorm appearance), 482, 532
- clouds, 161-169
- cyclones, 425-426
- hurricanes (tropical cyclones & typhoons), 614-615
  - retired, 615
  - local winds, 654
- nano ( $10^{-9}$ ), 870
- NAO (North Atlantic oscillation), 430, 818-819, 824
- NAT clouds, 166
- National
  - ambient air quality standards (NAAQS), 7, 725
  - ambient air quality objectives & guidelines, 725
  - Centers for Environmental Prediction (NCEP), 279, 283
  - Hurricane Center (NHC), 608, 638
  - Institute of Standards and Technology (NIST), 51, 879
  - Lightning Detection Network (NLDN), 569
  - Oceanic & Atmospheric Admin. (NOAA), 637
  - Weather Service (NWS), 532
  - radar used by, 243
- natural
  - climate processes, 793-832
  - cycles & changes in hurricane activity, 631
  - greenhouse gas, 811-812
  - logarithms, base of, 879
  - oscillations in climate, 818-824
  - selection, computational, 680
  - wavelength, 666
- nature of convection, 481, 704, 710, 716
- nautical miles, 4, 870
- Navier, Claude-Louis, 759
- Navier-Stokes equations, 293, 301-302, 314-317, 759
- NCAR-RIP, 772
- NDT, Newfoundland daylight time, 5
- nebulosis/neb, 168
- needed heat transport globally, 338-339
- needle ice crystals, 198-199
- neon, Ne, 7
- near
  - infrared and ultraviolet, 222-223
  - source pollutant dispersion, 732
  - surface (see also surface)
    - global circulation, 330-331
    - temperature, 330-331
    - winds, 330-331
- Nebeker, Frederik, 781
- negative
  - buoyancy, 556
  - feedbacks, 807
  - flux divergence (=convergence), 64
  - polarity lightning, 563-564
  - sign in scientific notation, 870
  - vorticity advection (NVA), 447-448
- nested grids (one-way and two-way), 752-753
- net
  - actinometer, 45-47
  - Ekman transport, 378, 610, 632-633
  - evaporation, 92
  - force, 292-294
  - heat budget (Eulerian), 72-73
  - heating, 72-73, 131-132, 336-339, 465, 546
  - longwave flux, 45, 337
  - meridional transport of zonal momentum, 375-376
  - pressure tendency, 466-467
  - pyranometer, 45-47
  - pyrgeometer, 45-47
  - pyrheliometer, 45-47
  - radiation, 27, 44-45
    - global distribution, 337-338
  - radiometer, 45-47
  - sea level pressure tendency equation, 466
  - sky transmissivity, 44
  - solar input, 795
  - spring force, 136
  - total water (Eulerian), 107
- neutral static stability, 139-140, 688-689
- neutral stability, 138, 140
  - air standard deviations of velocity, 707
  - boundary-layer wind, 308-310
  - boundary layers, 688-689
  - determination of, 139-140
  - dispersion within, 733-734
  - drag, turbulent, 701
  - dry, 140
  - plume rise within, 733
  - saturated, 140
  - surface-layer wind, 702
- neutrally buoyant, 135
- névé snow, 209
- Newfoundland time zone, 5
- Newton, Isaac, 292-294, 759, 841, 862-863
- great scientists and big mistakes, 863
- reflecting telescope, 862
- work on colors, 862-863
- newton (unit of force), 8, 870
- Newtonian
  - physics, 1
  - transformation, 715
- Newton's Law of Gravitation, 11
  - gravitational constant, 879
- Newton's Laws of Motion, 1, 292
  - second law, 1, 292, 301, 314-315, 554, 560-561, 670, 746-749
    - Eulerian momentum budget, 293
    - Lagrangian momentum budget, 292
  - in his own words, 292
- Newtons per square meter, 7, 8
- NEXRAD (weather surveillance radar WSR-88D), 243
  - locations, 272
- nighttime (nocturnal)
  - boundary layer (stable), 692
  - clouds visible during, 166
  - cooling, 690, 692-696
  - thunderstorms, 590
  - winds (katabatic; mountain; land-breeze), 649-657
- nimbo prefix, 163
- nimbostratus, 162-163
- nimbus suffix, 163
- Ninjo, 772
- NIST (National Institute of Standards and Technology), 51, 879
- nitric acid, 190-192, 858
  - trihydrate (NAT) clouds, 166
- nitrogen, 7
  - oxides (NOx), 7, 725, 796, 811-812
  - lightning produced, 567
  - nitrogen dioxide, NO<sub>2</sub>, 7, 725, 858
  - nitrous oxide, N<sub>2</sub>O, 7, 811
- NOAA (National Oceanographic and Atmos. Adm.), 637
  - satellites, 229, 273
  - weather radio, 529, 638
- noctilucent clouds, 166
- nocturnal
  - boundary layer (stable), 692
  - jet, 311, 699-700
- nodes of satellite orbits, 228-229
- nomenclature (global), 330
- nominal plume edge (depth), 730
- non-equilibrium wind (at hurricane top), 618-619
- nonhydrostatic, 316
  - global circulation components, 351
  - hurricane vertical motions, 622, 629
  - numerical weather prediction model, 747
- nonlinear
  - dynamics
    - and chaos, 773-776
    - causing T-storm forecast difficulties, 527
    - forecast equations, 747, 773-776
  - feedback processes, 806
  - linear approximation to, 806
- nonlocal
  - air-parcel movement, 497-499, 503-508, 557-558, 716
  - closure, 714, 716
  - conditional instability
    - for hurricanes, 609
    - for thunderstorms, 496-499, 503-508
  - flux, 716
  - stability, 138-139, 142-144
- non-parametric statistics, 502
- nonstationary flow, 669
- nonturbulent (see laminar), 138, 140, 669-671, 688
- nordic ski snow, 209
- normal
  - climate, 818
  - curve (Gaussian), 729-730
  - mode initialization, 766
  - shock (I-D) from thunder, 572-574
  - storm motion, 516-518
- normalized CAPE, 508
- Normand's Rule, 96, 105-106, 500
- North American geography, 431
- North Atlantic oscillation (NAO), 430, 818-819, 824
- north direction, 2-4, 30, 298-299, 330, 646-647, 797-802
- North Pole, 4, 30, 298-299, 330, 646-647, 797-802
- north-south (also see meridional), 4, 330
  - displacement of baroclinic wave, 371-376, 452-453
  - temperature gradient (see baroclinicity), 329, 334-336, 359, 749

## N

- n-CAPE, 508
- NAAQS (national ambient air quality standards), 7, 725
- NACLI code, 269
- nacreous clouds, 166
- names of

- Northern  
 annular mode (NAM), 824  
 Hemisphere, 4, 330  
   defined, 4  
   direction of geostrophic wind, 303, 314  
   sign of Coriolis force, 297-301  
   sign of centrifugal force, 296  
 not measured (cloud coverage symbol), 170, 279  
 Nova Scotia, 617  
 novice vs. expert, 72  
 nowcasting (short-range forecasting), 552, 768  
 ns (nimbostratus clouds), 168  
 NST, Newfoundland standard time, defined, 5  
 nuclear  
   bomb, 499, 548, 574, 880  
   energy, 54  
   winter, 151, 805  
 nucleation, 188  
   definition, 185  
   deposition, 194-195  
   freezing, 194-195  
   heterogeneous, 188-194  
   homogeneous, 188-194  
   ice crystals, 194-196  
   nuclei, 194-195  
   processes, 198-201  
   liquid droplets, 188-194  
   activated nuclei, 193  
   cloud condensation nuclei (CCN), 188  
   critical radius, 192  
   curvature and solute effects, 189-191  
   haze, 192  
 nuclei (see also cloud condensation nuclei, CCN), 188-195  
 number, 870  
   Ball ratio, 698  
   density of  
     CCN, 187  
     hydrometeors, 187  
     ice nuclei, 195-196  
   Froude number, 659, 667  
   hydrometers, 187  
   Mach, 571-576, 579, 674  
   prefixes, 870  
   Richardson, 141, 521, 709-710, 739  
   Rossby, 306, 313  
   scientific notation for, 870  
   swirl ratio, 592  
   value, 870  
 numerical  
   approximations to eqs. of motion, 749-750  
   instability, 759-761  
   model (see num. weather pred. model), 496, 751  
   parameterizations (numerics), 749-751  
   problems, explained, 21  
   solutions to atmospheric equations, 749  
   stability, 759-761  
   value, 870  
 numerical forecast models (see numerical weather prediction)  
 numerical weather prediction (NWP), 745-792  
   accuracy, 777  
   Amdahl's Law vs. NWP speed-up, 763  
   analysis/assimilation of data, 762, 765-767  
   verifying, 769  
   Arakawa grids A to E, 753  
   backward trajectory for semi-Lagrangian, 761  
   balanced mass and flow fields, 763-765  
   blowing up of solution, 757  
   boundary conditions, 756  
   ghost cell or halo grid points, 756  
   calculation of secondary variables, 771-772  
   calibrated probabilistic forecasts, 777  
   case study, 768-770  
   climate, 768, 815-816  
   climatology (as a skill reference), 780  
   computation rules, 756  
   confidence in the forecast, 776  
   coordinate systems, 746-748  
   cubed sphere, 752  
   eta, 746  
   hybrid, 746  
   polar stereographic, 747  
   sigma, 746  
   spherical, 747  
   terrain-following, 746, 753  
   corollaries, 756, 758  
   cost/loss decisions, 784-785  
   Courant number, 758  
   cubed sphere grid, 752  
   data assimilation and analysis, 765-767  
   design, 761  
   deterministic, 777  
   differencing schemes - spatial, 755  
     centered fourth order, 755  
     centered second order, 755  
     upwind first order, 755  
   differencing schemes - temporal, 757-758  
     Euler (first order), 757  
     leapfrog (second order), 757  
     Runge-Kutta (4th order), 757  
   discretization, 750  
     equations of motion, 758-759  
   domain, 750  
   dynamics, 749-750  
   economic value, 784-785  
   ensemble, 776  
     calibrated, 777  
     spread vs. skill, 777  
   equations of motion, 746-749  
     compressible, 747  
     diagnostic, 747  
     discretized, 758-759  
     non-hydrostatic, 747  
     primitive, 747  
     prognostic, 747  
   errors  
     bugs in the code, 759  
     dynamic instability, 759, 773-777  
     numerical, 759-761  
     numerical instability, 760-761  
     random, 777  
     round-off, 759  
     systematic, 770, 777  
     truncation, 754-755, 760  
     verification & error measures, 777-785  
     viruses, 759  
   file formats for output, 772  
   finite-difference equations, 754-759  
     applications to spatial gradients, 754-755  
     differencing schemes of various orders, 755  
     notation, 754  
     spatial differencing, 754-755  
     Taylor series, 754-755  
     time differencing, 757-758  
     truncation vs. order of terms, 754-755  
   finite-volume model, version 3 (FV3), 751  
   first guess, 765-767  
   flops (floating point operations per second), 761  
   forecast quality, 780  
     accuracy vs. skill, 777  
     verification scores, 777-785  
   forecast refinement, 770-771  
   forecast stage of NWP, 768  
   GCMS (global climate models - or -), 768, 815-816  
     (general circulation models), 768  
   governing equations (see eqs of motion), 746-750  
   GPUs, 763  
   graphical outputs, 772  
   grid  
     A - E, Arakawa, 753  
     cells, 750  
     computation rules, 756  
     cubed sphere, 752  
     nested, 752  
     notation, 754  
     points, 749, 752-753, 761  
     resolution, 752  
     spacing, 761  
     staggered, 753  
     variable, 752  
   heirarchy of operational forecast models, 768  
   hindcasts, 762  
   history, early, 759  
   human contributions to the forecast, 772  
   initial conditions, 758, 762  
     sensitive dependence, 773-776  
     synoptic vs. asynoptic data, 758  
   initial value problem, 762  
   initialization of NWP models, 763  
   instabilities  
     dynamic, 773-777  
     numerical, 759-761  
   lead time, 762  
   limit of predictability, 773-776  
   Lipschitz condition/continuity, 761  
   long-range forecasts, 768  
   Lorenz, 773-776  
   map  
     factors, 747  
     output graphics, 772  
     projections, 748  
   medium-range forecasts, 768  
   meteograms, 745, 772  
   models, 496, 751  
     GEM (global environ. multiscale), 751  
     GFS (global forecast system), 751  
     heirarchy, 768  
     WRF (weather research & forecasting), 751  
   moisture, 746  
   Moores' Law vs. NWP skill, 752  
   MOS (model output statistics), 770-771  
   nests, one-way and two-way, 752  
   non-linear dynamics and chaos, 773-777  
     ensemble & probability forecasts, 776-777  
     Lorenz strange attractor, 773-775  
     predictability, 773  
   notation for grid points, 754  
   nowcasts, 768  
   numerical stability, 759-761  
   numerics, 749-750  
   operational short-range vs. GCMs, 816  
   output graphics  
     compression and storage into databases, 772  
     graphics, 772  
   parameterizations (numerics), 749-751  
   perfect prog method (PPM), 770  
   persistence skill, 780  
   physics, 749-751  
     subgrid-scale, 750  
   post-processing, 762, 770-772  
   predictability limit, 773-776  
   probabilistic, 777  
     calibrated, 777  
     verification, 782-784  
   process, 762-772  
     balanced mass and flow fields, 763-764  
     case study, 768-769  
     data assimilation and analysis, 764-767  
     forecast refinement, 770-771  
     forecasts, 768  
     post-processing, 770-772  
   quality  
     control of input data, 765  
     of forecast, 777-785  
   quite revolution, 772  
   resolution, 750, 752, 761  
     vs. grid spacing, 761  
   scale vs. skill, 768  
   schedule, 762  
   scientific basis for, 746-751  
   seasonal forecasts, 768  
   semi-Lagrangian, 761  
   sensitive dependence to initial conditions, 773-776  
   short-range forecasts, 768  
   skill, 772, 777-784  
     vs. forecast time, 775, 780  
     vs. scale, 768  
   solutions to atmospheric equations, 749  
   spatial gradients, approximations, 754-755  
   spread (of ensembles) vs. skill, 777  
   staggered grids, 753  
   statistics, 777-785  
   stencil, 756  
   strange attractors, 773-776  
   temperature, 746  
   temporal gradients, approximations, 757-758  
   thunderstorm sounding forecasts, 496  
   time steps, 750, 761  
   uncertainty in the forecast, 776  
   valid time, 762  
   verification statistics, 777-785  
   visualization programs, 772  
   winds, 746  
 numerics, in numerical weather prediction models, 749-750  
 NVA (negative vorticity advection), 447-448  
 NWP (see numerical weather prediction), 745-792
- O**  
 O2, oxygen, 7  
 O3, ozone, 7  
 oasis effect, 74  
 object immersed in a fluid, 135  
 objective analysis method, 280, 766-767  
 objective optimum interpolation analysis, 766  
 oblate  
   rain drop shape, 255-257  
   spheroid of revolution (Earth is), 3  
 obliquity, Earth axis tilt, 30, 879  
   variations and climate, 798-803  
 obscuration, weather map symbols, 276  
 obscured sky, 170, 279  
 observations  
   errors, 766, 875-877

- locations worldwide, 271-273
  - reporting, 875
  - synoptic, 268
  - weather, 268-273
  - observers of atmospheric optics, 833-868
  - observing system simulation experiment (OSSE), 236
  - Obukhov length, L, 703
  - Occam, William of, 680
  - Occam's Razor, 680
  - occluded fronts, 413-414, 428-429
    - weather-map symbol for, 281, 399
    - trough of warm air aloft (TROWAL), 281, 399
  - occluding low, 428
  - at landfall in Pacific Northwest, 472
  - occlusion process, 428-429
  - ocean
    - aerosols and CCN over, 188
    - CO<sub>2</sub>
      - effervescence, 812
      - feedback process for climate, 810-812
    - continent circulations (monsoons), 333-334, 356
    - circulations, 804
      - meridional overturning, 810
      - thermohaline, 804
    - currents, 431, 610, 632-633, 701
      - Gulf Stream, 431
      - heat transport by, 339, 378
      - hurricane-induced, 610
      - Kuroshio, 431
      - wind-driven, 701
    - divergence of ocean water, 610
    - drag, 701
    - Ekman
      - spiral, 378
      - transport, 610
    - meridional overturning circulation, 810
    - methane hydrate release, 810
    - mixed layer, 610
    - storm surge, 632-635
    - surf, 635
    - thermocline, 610
    - thermohaline, 804
    - upwelling during hurricane, 610
    - waves during hurricane, 633-636
  - odor characteristics of airmasses, 391
  - ohm, unit of electrical resistance, 564-565, 870
  - oktas, 170, 279
  - Olympic Mountain convergence zone, 472
  - omega (vertical velocity in P coordinates), 451
    - equation, 456-459, 462
    - Q-vector, 462
    - Sutcliffe development theorem, 456
    - Trenberth, 456-458
    - shape of setting sun, 862
  - one-layer atmosphere, 795
  - one-way nesting of NWP grids, 752
  - Oort minimum in solar activity, 803
  - opacus, 169
  - opaque
    - atmosphere, 220
    - surface, 42
  - open
    - cellular convective clouds, 167
    - channel hydraulics, 657-661
  - operational numerical weather forecast models (OFMs), 751
    - heirarchy, 758
  - opposite faces of ice crystal, 842
  - optical
    - depth, 43, 856
      - due to volcanic eruptions, 805, 858
    - hygrometer, 111
    - thickness, 43, 856
    - transient (lightning) detectors, satellite borne, 569
  - optically thick fog, 176-177
  - optics, atmospheric, 833-868
    - arcs, 847-855
    - diffraction & interference, 858-860
    - halos, 842-855
    - ice crystal, 396, 842-855
    - liquid droplets, 837-841
    - mirages, 861-863
    - scattering, 856-858
  - optimistic probabilistic forecast scores, 785
  - optimum
    - interpolation analysis, 766
    - wind-speed decrease in wind turbine, 647-648
  - orange color defined (also see optics chapter), 37
  - orbit
    - geostationary satellite, 227
    - planetary, 28, 293
    - polar orbiting satellite, 227-228
    - satellite, 227-229
  - orbital factors of Earth, 27-34
    - climate variability, 797-803, 829
    - daily effects, 32
    - Milankovitch theory, 797-803, 829
    - orbit of earth, 27
    - period of satellites, 227-229
    - seasonal effects, 30
      - sunrise, sunset, and twilight, 33
  - orbital period of planets, 27-28, 872
  - orbital plane, 30-31, 799-802
  - ordinate (defined; and use of pressure as), 3
  - organization of
    - clouds, 167
    - thunderstorms, 486-495
  - organized convection in tropical disturbance, 613
  - organizing knowledge, 72
  - orientation of falling ice crystals, 842, 855
  - origin of tornadic rotation, 586-587
  - orogenesis (mountain building), 804
  - orographic (related to mountains)
    - cloud, 165, 168, 676-677
      - high-pressure formation near, 391
      - lee-side cyclogenesis, 443-446
      - lift and cloud formation, 162
      - precipitation modifying airmasses, 398-399
      - thunderstorms, 487, 526, 547-548
      - winds, 649-654, 660-670, 675-676
  - oscillation(s), 136-137
    - amplitude, 818
    - climate, natural, 818-824
      - damped, 666
      - inertial, 304, 311-312, 700
      - period, 137, 304, 818
      - phase shift, 818
    - TRUE, 818
    - waves
      - mountain lee, 666-668
      - Rosby, 367-376
      - what is an oscillation, 818
  - out of phase light waves, causing interference, 858-861
  - outbreaks of tornadoes, 583-584
  - outer space, 234
  - outflow winds from thunderstorm, 483, 554, 560-563
  - outgoing
    - radiation, 337
    - radiation from opaque atmosphere, 220
    - radiative flux, 337
    - terrestrial radiation, 337
    - transmitted radiative flux, 220-223
  - outlier data points, 502
  - outlook forecasts of severe weather, 528-530
  - overcast (ovc) cloud cover, 170, 279
  - over-pressure from thunder shock front, 571-574
  - over-riding air at fronts, 407
  - overshooting top (of thunderstorm), 483, 498, 508
  - oxides of nitrogen (also see nitrogen oxides), 193
  - oxygen, O<sub>2</sub>, 7, 723
  - ozone, O<sub>3</sub>, 7, 193
    - air-quality standards for, 725
    - greenhouse gas, 811-812
    - lightning produced, 567
    - odor, 567
    - tropopause folds, injection at, 364
- ## P
- P (Newfoundland time zone) defined, 5
  - Pacific, 431
    - airmass modification, 398-399
    - data void, 287-288, 765
    - decadal oscillation (PDO), 818-820
    - high, 356
    - landfalling cyclones, 472
    - North American pattern (PNA), 824
    - Northwest
      - geography & topography, 661
      - weather, 288, 397-399, 472, 765
    - oscillations in climate, 818-824
    - South Pacific subtropical high, 354
    - time zone, defined, 5
    - tropical cyclones, 631
  - packing of
    - height contours, 290-291
    - isentropes & relationship to stability, 143
    - isobars, 290-291, 307
  - PAH (polycyclic aromatic hydrocarbons), 725
  - paleotemperature estimates, 795, 803
  - Pangea, Pangaea, Pangaea, 388, 804
  - pannus, 169
  - Papa, Station, 288
  - paradigm shift, 773, 863
  - paradox, geostrophic, 459, 462
  - parallel damage paths, 584
  - parallels, defined, 4, 330
  - parameterization, 715
    - and models, 751, 816
    - physical and numerical, 750-751
    - rules, 715
    - turbulence closure, 714-716
  - parameters, 646, 669, 715, 750
    - combined, 880
    - physical, 879-880
  - paranethia, 854-855
  - parcel (see also air parcel), 57, 59
    - lapse rate (see also lapse rate), 59-64
    - method to determine stability, 138-139
    - vs. environment (on thermo diagram), 134
  - parhelia (sun dogs), 842, 850-851, 854-855
  - 120°, 854-855
  - sub, 842, 851, 854-855
  - parhellic circle, 842, 844, 854-855
  - Parry
    - arcs, 854-855
    - oriented ice-crystal columns, 855
  - partial
    - absorption, 220-223
    - density, 91
    - pressure, 14, 87, 115
    - weather-map symbol for, 276
  - particles in air, 188, 725
  - particulate matter (air pollution)
    - fine (PM10), 725
    - very fine (PM2.5), 725
    - volcanic eruptions, from, 804-805
  - parts of wind: mean, waves, turbulence, 705
  - parts per billion (ppb), 724
  - parts per million (ppm), 724
  - pascals (Pa), unit of pressure and stress, 7, 8, 870
  - Pasquill-Gifford (PG) turbulence types, 727-728
  - pass, winds through mountain gap, 661-664
  - passat (trade) inversion, 351
  - passion, scientists should have, 877
  - passive
    - clouds, 163
    - microwave sensors of rain, 211
    - sensors, 219
    - tracers, 731
  - past weather, as plotted on weather maps, 275
  - patchy, weather-map symbol for, 276
  - path length, Beer's Law, 43
  - path of
    - radar beam, 243-245
    - Rosby wave, 368-374
  - patterns, 107
    - dominant pattern finding via PCA, 821-823
  - Pauling, Linus, 99
  - PCA (principal component analysis) method, 820-823
  - PDO (Pacific Decadal Oscillation), 818-820
  - PDT, Pacific daylight time, defined, 5, 6
  - peak current in lightning, 568-569
  - Peel, 817
  - Peirce's skill score, 781
  - pellets, ice (sleet), 199, 276
  - snow (graupel), 199, 276, 546
  - pendulum day, 304, 312
  - penetrative convection, 483, 498, 508
  - pennant wind-speed symbol on weather maps, 278
  - percentiles, 502
  - perfect prog method (PPM), 770-771
  - perihelion, Earth orbit
    - angle relative to vernal equinox, 34, 801
    - climatic variation, 799-801
    - Earth orbit, 28-30
  - period
    - earth and moon rotation, 879
    - of oscillation, 137, 818
    - of satellite orbits, 227-229
    - Quaternary, 799
  - perlucidus, 169
  - permafrost, 810
  - Permian-Triassic boundary, 805
  - permittivity of free space, 569
  - persistence forecast, 778
    - error, 778
    - skill, 780
  - personal errors, 875
  - perspiration, 76
  - Persson, Anders, 298
  - perturbation pressure, 340-341, 554, 559-563

- pessimistic probability forecast scores, 785  
peta ( $10^{15}$ ), 870  
Watt, 339  
PG (Pasquill-Gifford) turbulence type, 728  
phase  
change, 56  
condensation, 56  
deposition, 56  
fusion, 56  
melting, 56  
sublimation, 56  
vaporization, 56  
water, 54  
diagram for  
attractors and strange attractors, 774, 790  
water, 198  
shift, 250-251  
in high-pressure regions, 390-391  
of deterministic oscillations, 818  
space, 774, 790  
specific differential, 256-257  
speed  
of Rossby wave, 369  
intrinsic, 369  
relative to ground, 369-372  
shallow-water, 633, 658  
space plot ("butterfly"), 774-775  
warm and cool (of ENSO and PDO), 818-820  
phased-array radar, 257-258  
phases of water, 198  
phenomena, optical, 833-868  
philosophers, 2  
philosophy of science, 877  
phloroglucinol, 195  
photo-detector in dew-point hygrometer, 111  
photoelectric effect, 46  
photographic tips, clouds, 180, 484  
photometer, 46  
photons, 833  
photoresistor, 46  
photovoltaic cells (solar cells), 46  
physical  
meteorology, 1  
parameterization (physics), 749-751  
physics  
atmospheric, 872  
parameterizations in NWP models, 749-751  
Newtonian, 1  
phytoplankton, 188, 811  
pi ( $\pi = 3.1415926535897932384626$ ), 879  
variant, 801  
pico ( $10^{-12}$ ), 870  
pileus clouds, 165-166, 169, 483  
pillar (sun, moon, Venus, street light), 843  
pillow, snow, 210  
PILOT code, 269, 272  
MOBIL, 269  
SHIP, 269  
pilot balloons (PIBALs), 272, 322  
pilots - weather issues, 165, 166  
altimeter setting, 275  
METAR weather reports, 268-279  
Pinatubo, Mt., volcanic eruption, 805  
pineapple express, 472, 824  
piste, 209  
pitfalls, scientific, 877  
pitot tube, 321, 674  
pitot-static pressure difference for air speed, 674  
plagiarism, 24  
Planck  
constant, 879  
curve, 36-39, 224  
function, linear approximations to, 239  
Planck's Law, 36-38, 221-224  
constants, 879  
plane angle, dimension and units, 870  
planetary  
boundary layer (see atmospheric boundary layer), 13  
data, 22, 47  
orbits, 27, 293, 874  
scale, 315  
general circulation, 329-388  
shear, 368  
vorticity, 363-364, 367-372, 447-449  
wavelength, 329, 367-376, 427, 468  
waves (also see Rossby waves), 367-376  
definition, 367  
highs associated with, 391  
horizontal, midlatitude, 367-376  
path taken, 372-374  
phase speed, 369, 372  
stationary (lee side), 443-444  
typical wavelength, 367  
planets in the solar system, data for, 22, 27, 874  
plan-position indicator (PPI), 242  
plant canopy, 677-678  
plasma, 565  
plateaus, 397  
plates, ice crystal, 198-199, 842  
optics caused by, 842-855  
Platzman, George, 759  
Pleistocene epoch, 799  
plotting  
by hand, 280-281  
station model, 274-279  
weather maps, 280-281  
winds, 210-513  
plume  
average, 728  
center of mass, 729  
centerline, 723, 729, 736  
centerline height, 723, 733-734, 736  
concentration, crosswind-integrated, 737  
coning, 727  
convective, 724  
definition, 724  
dispersion, 723-744  
edge, nominal, 730  
fanning, 727  
footprint, 734  
Gaussian concentration distribution, 729-730  
instantaneous (snapshot), 728  
looping, 727  
rise, 648-649, 723-724, 732-737  
smoke, 723-744  
spread, 723-744  
thermal, 648-649, 654, 704, 724  
urban, 679, 743  
PM (particulate matter) air pollutants, 725  
2.5 (very fine particulates, air pollution), 725  
10 (fine particulates, air pollution), 725  
PMC (polar mesospheric clouds), 166  
POES satellites, 229  
point source, 724  
polar, 330  
airmass code, 392  
cell, 329, 332-333, 352, 357, 378  
cloud heights, 163  
coordinate, 2, 646  
cyclones, 425  
easterlies, 352  
front, 352, 357, 367, 408  
graph used as a hodograph, 510-513  
heat deficit, 338-339  
highs (anticyclones), 331, 352, 391  
jet stream, 233, 331-332, 353, 357-360  
low, 332  
mesospheric clouds (PMC), 166  
orbiting satellites, 227-229  
regions, 330  
stereographic map projection, 748  
stratospheric clouds (PSC), 166  
tropopause height, 163  
upper-tropospheric low, 352  
vortex, 352, 397, 824  
polarity of lightning, 563-564  
polarimetric radar, 241, 255-257  
dual polarization, 255  
polarization diversity, 255  
polarization(s)  
circular, 255  
horizontal, 255-257  
vertical, 255-257  
polarized light, 856-857  
polarizing sunglasses, or filters for cameras, 856  
Poles (North & South), 4  
poleward transport of heat and momentum, 374-376  
police radar, 243  
pollen characteristics of airmasses, 391  
pollution/pollutants, 7, 725  
air quality standards, 7, 725  
airmass characteristics, 391  
brown cloud, 857-858  
concentration units, 724  
ppmm, 724  
ppmv, 724  
 $\mu\text{g}/\text{m}^3$ , 724  
conservative, 731  
conversion between units, 724  
crosswind-integrated concentration, 735-737  
dispersion, 723-744  
factors, 724-725  
forecast equations, 731-732  
dispersion in neutral & stable boundary-layers, 732  
Gaussian concentration distribution, 729-730  
plume rise, 732  
dispersion in unstable boundary layers, 735-737  
concentration, 737  
crosswind integrated concentration, 736  
plume centerline, 736  
relevant variables, 735-736  
dispersion statistics, 728-730  
center of mass, 729  
Gaussian curve, 729-730  
nominal plume edge, 730  
snapshot vs. average, 728  
standard deviation - sigma, 729-730  
episodes, events, exceedences, 725  
footprint, 733  
framework: source-receptor, 724  
Gaussian concentration distribution, 729-730  
in highs and airmasses, 390, 691  
in lows, 691  
mixing ratio, 724  
modeling, 725  
passive, 731  
point source, 724  
smoke stack, 724  
solution, 724  
source  
height, 723  
receptor framework, 724  
spread of pollutants, 729  
stack height, 723  
standards for air quality, 725  
Taylor's statistical theory, 731-732  
dispersion equation, 731-732  
dispersion near and far from source, 732  
passive conservative tracers, 731  
trapping, 390  
in valleys, 654  
turbulence statistics, 726-728  
Pasquill-Gifford (PG) turbulence types, 727-728  
pool of cold air, 653  
population vs.  
air pollution, 723  
hurricane disasters, 631  
urban heat-island temperature excess, 679  
portion  
correct, 781  
of forecasts correct, 781  
positive  
feedback, 807  
polarity lightning, 563-564  
vorticity advection (PVA), 447-448  
post-processing of numerical forecast, 762, 770-772  
postal abbreviations for US states & Canadian provinces, 431  
potential  
breakdown lightning, 566  
difference, electrical, 564  
energy, 150  
associated with horizontal temperature gradient, 406  
convective available (CAPE), 503-508, 530-531  
of flow, 669-672  
temperature, 61-64  
constant (see adiabatic or isentropic), 61-64  
definition, 61  
diurnal evolution, 690-698  
equivalent, 104-106, 500  
in atmospheric boundary layer, 689-698  
in buoyancy, 136  
in vertical cross section of front, 403, 405, 407-409, 414  
isentropic, 17-18, 63, 103-105, 122-123, 143-144, 156, 365, 373, 403, 407-410, 414, 437, 624-625  
liquid water, 103-106, 500  
maps of constant, 437, 443  
mixed layer, 689-698  
on weather maps, 437-438, 441  
profile in boundary layer, 110, 690, 692, 695-698  
substitute for advection, 67  
thermo diagram, 135-136  
vertical profile, 135-136, 689-698  
virtual, 61-62  
vs. height, 61-63, 104-106  
wet-bulb, 103-106, 500  
vorticity, 363-364  
conservation of, 363-365, 397, 445  
isentropic, 364-365

- units (PVU) definition and maps of, 364, 437, 441
- pounds-force per square inch, pressure units, 7
- powder snow, 209
- power
  - curve for wind turbines, 648
  - dimension of, 870
  - electrical by wind turbines, 647-648
  - electricity, 564
  - flashes, 584
  - lines, electrical surges caused by lightning, 569-570
  - of hurricanes, 620, 625
  - of lightning electricity, 569
  - output curve for wind turbines, 647-648
  - relationships on log-log graphs, 874
  - surge by lightning, 569-570
  - units, 870
- PPI radar scans, 242
- ppm (parts per million), 724
  - (perfect prog method), 770
- praecipitatio, 169
- Prandtl mixing length theory, 715
- precession of
  - Earth's orbit, 28, 798-803
    - aphelion, 800
    - axial, 800
    - climate, 801
    - equinox, 800-801
  - satellite orbits around Earth, 229
- precipitable water, 98-99, 501, 546
  - on weather maps, 501
- precipitating clouds, 163
- precipitation, 185-218
  - accumulation
    - isohyet, 18
    - weather-map symbols for, 278
  - amount, 18, 107-108
  - annual distribution worldwide, 209
  - characteristics, 207-210
  - cloudless ice
  - cold-cloud process, 201-202, 206
  - distribution worldwide, 209
  - drag, 555
  - efficiency of thunderstorms, 547
  - extreme, 207-208, 545-548
  - fog, 173
  - formation, 205-207
  - growth, 202-207
  - hail, 548-554
  - heavy rain, 207-208, 545-548
  - ice, from arctic airmasses, 396
  - in water budget, 107-108, 746
  - intensity, duration, frequency (IDF), 208
  - laden air, unsaturated, 555
  - likelihood or probability (POP), 782-784
  - loading of air, 555, 559
  - measurement, 210-211
  - METAR code, 208
  - midlatitude cyclones, associated with, 425-428, 435, 438, 466, 472
  - on thermo diagrams, 121, 130-131
  - orographic, 398-399, 676-677
  - parameterization in NWP models, 751
  - radar, 486
  - rate, 107-108, 207-208
    - as affects cyclone evolution, 465-467
    - and latent heating of an air column, 465-467
  - return period (IDF), 208
  - snow fall, 131
  - symbols on weather maps, 208, 275-276
  - terminal velocity, 202-204
  - thunderstorm, 206-207, 482, 486, 545-548
    - intensity forecasting using n-CAPE, 508
    - time for start or end, weather map symbols, 278
    - unknown type (weather-map symbol for), 276
    - visibility within, 208-209
    - vs. evaporation, 210
    - warm-cloud processes, 204-206
    - water equivalent, 208
    - WBF process, 201-202
    - weather-map symbols, 275-276
    - zonal average, 210
- precision and random errors, 875-877
- predictability
  - limit, 773
  - nonlinear dynamics & chaos, 773-776
- predicting (see forecasting; or numerical weather prediction), 745-792
- predictands, 770
- predictors, 770
- prefix component of scientific notation, 870
- prefrontal
  - jet, 407, 433, 472
    - pineapple express, 472
    - waves, 656
  - present
    - climate, 816-817
    - weather, as plotted on weather maps, 275-276
  - pressure, 8-10,
    - background state, 316
    - change with height, 8-9, 316
      - monotonic, 9
      - weather-map symbols for, 277-278
  - charts, 436-442
  - constant, 17, 55-56, 290, 439-441
  - cooker, 115
  - coordinates, 290-291, 451
  - couplets, non-hydrostatic, 340-341
  - deepening, 463
  - deficit in tornado, 577
  - definition, 7, 870
  - difference, as indicates mass of air, 10
  - dimension of, 870
  - distribution in hurricane, 626
  - driving the global circulation, 340-342
  - dynamic, 559, 672-674
  - errors, 766
  - evolution, for MSL, 467
  - falls, 463
  - field, 343, 359
  - filling, 463
  - free stream, 672-674
  - forecast equation for, at MSL, 463-467
  - global patterns, 331, 350-355
  - gradient, 295-296
    - horizontal, 295-296, 559-561
  - gradient force, 295-296, 301
    - cross-mountain, 662
    - horizontal, for anabatic flow, 650-652
    - near center of pressure region, 306-307
    - on isobaric surfaces, 296
    - related to packing of isobars, 303
    - sign convention, 295-296
    - winds driven by, 302
    - vertical, 15-16, 18, 315-317, 554
  - head, 632
  - height
    - as vertical axis on graphs, 9-10, increments, 103
    - tendency, 463
  - high (anticyclone), 354-355, 390-391
    - meso-, 554, 559-563
  - hurricane, 621-623, 626, 633
    - hydrostatic balance, 15-16, 316, 340, 622
    - hypsometric equation, 16-17
    - in eye of hurricane, 618-620, 622, 624, 626, 629, 632-633
  - instruments for measuring, 19
  - isallobar, 18
  - isobar, isobaric, 18
  - isotropic nature, 8
  - latent heating causing falls of, 466-467
  - lightning, 564
  - maps on surfaces of constant, 436-442
  - mass of air above, 10, 464-466
  - mean background state, 316
  - meso-high, 554, 559-563
  - mesoscale variations in thunderstorms, 488-489, 554-563
  - METAR, 270
  - non-hydrostatic couplets, 340-341, 622
  - observation errors, 267, 766
  - omega, 451
  - on weather maps, 275
  - partial, 87
  - perturbation
    - buoyancy force, 555
    - downburst and gustfront, 554, 559-563
  - profile in the vertical, 8-9, 340-342
  - reduction to sea level, 267
  - reversal in hurricane, 618-623
  - rises, 463
  - scale height, 8
  - sea level, 7
    - reduction method, 267
  - sensors, 19
  - shock front, 571-574
  - stagnation, 672-674
  - standard, 7
    - STP, 7, 107, 880
  - static, 7, 559, 672-674
  - tendency
    - cyclogenesis, 463-467
    - forecast equation for, 463-467
    - isallobar, 18
    - net, 466-467
    - rainfall-rate relationships for, 465-467
    - weather-map symbols for, 277-278
  - tendency equation, 463-467
  - thermo diagram, 63, 100, 103-106, 119-131, 151-158
  - thunder, 571-574
    - tiling method for CAPE, 505
  - tornado, core, 577-578
  - trough, 367-376, 399, 432-433, 443
  - units, 7, 870
  - vapor, 87
    - saturation, 87-90
  - vertical gradient, 8, 9
    - in hurricane, 622
  - pre-storm environments, 496-527
  - prevailing visibility (in METAR), 270
  - primary rainbow, 838-840
  - prime meridian, 4, 5, 28
  - primed variables, 368-376, 705-716, 726-729
  - primitive equations of motion (see also equations), 747
    - vs. quasi-geostrophic equations, 449
  - principal component
    - analysis (PCA) method, 820-823
    - of Pacific Decadal and Arctic Oscillations, 819-820, 824
  - Principle, Le Chatelier's, 132, 141, 329
  - principles of radiation, 36
  - prism
    - face, 842
    - shaped ice crystals, 199, 842
  - probabilistic forecasts, 777
    - calibrated, 777
    - cumulative, 777
    - scores, usage of, 785
    - verification, 782-784
  - probability
    - forecasts of hurricane threat, 638
    - of detection, 781
    - wind speed, 645-646
      - vs. relative frequency, 645
  - problem-solving methods, 72, 869
    - forward, 236
    - inverse, 236-239
  - process(es)
    - adiabatic, 17, 60
    - causing saturation, 159-161
    - cold cloud, 201, 205-206
    - cooling, 44-45, 59-76, 129-133, 393-397, 693, 793-797
    - diabatic, 61, 411, 465, 624, 648-657
    - isobaric, 17, 55
    - isohume, 100-101
    - isothermal, 100
    - lapse rate, 59
    - names, 17
    - nucleation of ice crystals, 194
    - saturation causing, 159-161
    - terminology, 17
    - thermo diagrams, 100-101
    - warm cloud, 204-205
    - WBF (Wegener-Bergeron-Findeisen), 201
  - profile, vertical
    - of pressure, 8, 9
  - profilers
    - computer code, 763
    - wind, 112
  - prognostic equations (also see numerical weather fcst), 747
  - projections
    - map, 748
    - vector or info, 239
  - propagation
    - anomalous, 244
    - equation for radar beam, 244
    - of cold fronts (using Q-vectors), 470-471
    - of errors through equations, 876-877
    - of radar beam path, 243-245
    - of radiaion, 36
    - of thunderstorms, 485, 561
  - propellor anemometer, 321
  - prop-vane anemometer (propellor), 321
  - provinces in Canada, 431
  - proximity symbols on weather maps, 276
  - proxy measures of climate information, 803
  - pseudoadiabatic diagrams, 121-123, 126-127, 153
  - PSI, pounds-force per square inch, pressure unit, 7
  - PST, Pacific standard time, defined, 5
  - psychrometer, 111
    - aspirated, 94, 111
    - sling, 94, 111
  - psychrometric

constant, 75, 108, 880  
 graphs, 95  
 tables, 95-96  
 publish or perish, 863  
 Puget Sound convergence zone, 472  
 pulse  
   duration & length, radar, 240  
   repetition frequency (PRF) of radar, 240  
   thunderstorm, 486  
 pumping, boundary layer, 319-320  
 PVA (positive vorticity advection), 447-448  
 PVU (potential vorticity units), 364  
   tropopause identification, 364  
   example on weather map, 364, 441  
 pyramid  
   face, 842  
   ice-crystal optics/halos, 847  
 pyranometer, 45-47, 219  
 pyrgeometer, 46-47  
 pyrheliometer, 46-47

## Q

Q time zone (Atlantic), defined, 5  
 Q-vectors, 460-462, 469-471  
   cold-front propagation, 470-471  
   convergence, 460-462, 469-471  
   cyclone propagation, 469-470  
   frontal intensification & propagation, 469-471  
   omega equation, 462  
   vertical velocity & cyclogenesis, 460-462  
   weather maps, case study cyclone, 461-462  
 quadrants of jet streak, 454-456  
 quality-control, 765  
 quality of  
   air, 725  
   forecasts, 777-786  
   life, 723  
 quantiles, 502  
 quartiles and interquartile range, 502  
 quasi-  
   biennial oscillation (QBO), 824  
   decadal oscillation (QDO), 824  
   stationary front (surface & aloft), 281, 399  
 quasi-geostrophic, 449  
   approximation, 449-451  
   vorticity, 449-451  
   equation for, 449  
   Laplacian form, 450  
 quaternary  
   period, 799  
   rainbow, 840

## R

r (correlation coefficient), 779  
 R time zone (Eastern), defined, 5  
 radar , 219, 240-260  
   antenna, 250  
   AVCS display, 242  
   bands (electromagnetic), 223, 242  
   beam, 240  
     propagation equation, 244  
     propagation paths, 243-245  
     width, 240  
   bounded weak echo region (BWER), 552-553  
   bow echo, 491  
   bright band, 248  
   C band, 242  
   CAPPI display, 242  
   defined, 219  
   difficulties, 254  
   Doppler, 241, 249-254, 493, 556, 560  
   downburst observations, 560  
   ducting and trapping, 244-245  
   echo intensity, 240  
     inside thunderstorms, 486, 560  
     isoecho, 18  
     weather maps, 438  
   echo-free vault, 552-553  
   energy  
     attenuation, 241  
     scattered (reflected) back, 240-241  
   equation, 245-246  
     derivation of, 245  
   false echo, 251  
   fundamentals, 240-244  
   gust front observations, 560  
   hail observations, 247-248, 552-553  
   hook echo, 494  
   humidity measurement using, 112  
   hurricane images, 604-605  
   image interpretation, 253-254, 491  
   insect returns, 248-249, 560  
   klystron tubes, 240  
   laser (lidar), 112  
   loop, 241  
   magnetron tubes, 240  
   max unambiguous range (MUR), 240-241, 251  
   max unambiguous velocity , 250-251  
   NEXRAD WSR-88D radar (in USA), 240-243  
   plan-position indicator (PPI), 242  
   phased array, 257  
   polarimetric, 241, 255-256  
   power, 240, 245  
   precipitation observation, 211  
   pulse  
     duration, 240  
     length, 240  
     repetition frequency (PRF), 240, 250  
   radome, 253  
   rainfall rate measurement, 211, 247, 257  
   range  
     height indicator (RHI), 242  
     measurement, 240-241  
   reflectivity (the name for scattered energy), 245-248  
     equation for, 245-246  
     factor, 245-246  
     isoecho, 18  
   returns, 240  
   S band, 242  
   sample volume, 240  
   scans, 241-242  
   shadows, 241  
   spectrum width, 254  
   standard refraction of beam, 244  
   thunderstorm images & diagrams, 482-483, 486-488, 490-493, 532, 560  
     right- and left-moving supercells, 519  
     tornado vortex signature (TVS), 251, 253  
   volume scans, 241, 249-254, 493  
   wind profilers, 257  
   WSR-88D weather surveillance radar, 240-243  
   Z-R relationships, 247  
 radial  
   component, 249  
   distance, 240-241, 296-301, 304-314, 319, 362-371, 453, 511-513, 560-562, 571-574, 577-578, 617-618, 622-623, 626-630, 837-855, 861  
   radar-, 242, 249  
   shear, 362-364  
   velocity, 249-254, 310, 318, 321, 560-562, 572-574, 627-628  
   wind in hurricane, 627-628  
   wind speed, 18  
     isodop, 18  
 radian, unit of plane angle, 870, 880  
 radiance  
   blackbody, 221-226  
   from atmospheric layers, 224-225  
   locations of satellite observations, 273  
 radiant energy (see also radiation)  
 radiant exitance (emittance), 36  
 radiation, radiative, 27-52  
   absorption in clouds, 131-132  
   airmass genesis, role in, 393-397  
   average annual, 336-337  
   average daily insolation, 40-41, 336  
   balance, 43  
   of the whole Earth, 793-797  
   blackbody, 36, 794  
   budget, 42  
   global, 793-797  
   surface, 44  
   climate-change issues, 806-815  
   cloud processes, 131-132  
   constants in Planck's law, 36, 221, 879  
   cooling / heating, 131  
   front strengthening, 411  
   of hurricane top, 624-625  
   of well-mixed fog, 175-177  
   daisyworld, 813-815  
   differential heating, 329, 334-339  
   distribution, 39  
   downwelling, 43-44  
   Earth-atmosphere system, 793-797  
   effect on circulation, 377  
   emission  
     emissivity, 36  
     temperature, effective, 794  
   equilibrium of whole Earth-atmosphere system,

793-797  
 exitance, 36  
 flux  
   gradient, 71  
   net at surface, 45, 74, 336-339, 528, 693-694, 793-797, 801-803, 807-815  
 fog, 173-177  
 forcings, 329, 334-339  
   by latitude belt, 338-339  
   climate-change, 793-815  
   incoming solar (insolation), 336-337  
   net, 337-338  
   outgoing terrestrial, 337  
   zonally integrated, 338-339  
 frontal effects, 411  
 global  
   albedo, 793  
   climate equilibrium, 794, 806-815  
   forcings, 329, 334-339, 793-797  
   heating, 70, 687  
   incoming, 793, 797  
   infrared (longwave), 27, 37  
   insolation, 40-41, 336-337, 797, 801-802  
   instruments for measuring, 45-47  
   inverse square law, 39-41, 245-246, 801  
   irradiance, 36  
   longwave (or terrestrial or IR), 37, 131, 793-794  
   net, at surface, 27, 797  
   outgoing, 794  
   parameterizations in NWP models, 751  
   principles, 36-45  
     absorption, reflection & transmission, 36  
     average daily insolation, 40  
     Beer's Law, 43  
     blackbody emission, 36-38  
     distribution, 39-40  
     emission definition, 36-37  
     emission temperature of Earth, 37  
     emissivity (IR) table, 42  
     propagation, 36  
     Stefan-Boltzmann Law, 37  
     transmittance windows, 43  
     Wien's Law, 37  
   rain drop growth affected by, 206  
   sensors, 45-47  
   solar (shortwave), 37, 793  
     constant (total solar irradiance), 793  
     up/downwelling, 44, 131-132  
   terrestrial (longwave or IR), 37  
   thermo diagram process, 131-132  
   warming of air, 71-73, 795-797  
   windows, 43, 220-223, 796, 811  
 radiative transfer equation, 224-225, 237-238  
   forward problem, 236  
   inverse problem, 236-239  
 radiatus, 169  
 radio  
   acoustic sounding system, 78, 266, 272  
   detection and ranging (radar), 219  
   NOAA weather, 529, 638  
   severe weather reporting, 529-532  
 radioactive decay, 364  
 radioactivity characteristics of airmasses, 391  
 radiometers, 45-47  
   satellite borne, 220  
 radionuclide injection at tropopause folds, 364  
 radiosondes (also see rawinsonde), 111, 134, 143, 291  
 radius  
   critical, 192  
   deformation, Rossby  
     external, 405-406  
     internal, 319-320, 344  
   droplet, 187, 202-204  
   Earth, 879  
   earth orbit, 879  
   equivalent, droplet, 203  
   hydrometeor, 187  
   of curvature, 445  
     of light rays in mirages, 861-863  
     in jet stream, 367-373  
     lee cyclogenesis, 445  
   of planets in the solar system, 22  
 radix layer, 700-705  
 radome, 253  
 RAOB code, 269  
 RADOF code, 269  
 RADREP code, 269  
 rain (also see precipitation), 185-218, 482-484  
   accumulation, storm total, 257  
   weather map symbols for, 278  
 acid, 742  
 bands

- at warm fronts, 401
- in tropical depressions & hurricanes, 604-605, 613-615
- clouds
  - cumuliform, 162-163
  - stratiform, 164
- drop
  - shape, 203, 545-546
  - size distribution, 207
  - velocity, 203
- evaporating (virga), 482-484
- gauges, 98, 210-211, 219
- heavy, 207-208, 545-548, 637
- hurricane, 604-605, 607, 637
- IDF (intensity, duration, frequency), 208
- in tropics, 209
- intensity, duration, frequency (IDF), 208
- leaving an air parcel, 130-131
- mid-latitude thunderstorm, 206
- orographic (upslope), 472
- scattered showers, 545-546
- shadow, 397, 472
- thunderstorm, 545-548
- weather map symbols, 275-276
- rainbow(s), 837-841
  - 5th order, 840
  - Alexander's dark band, 841
  - colors, 839-840
  - luminous meteors, 205
  - moon bows, 841
  - optics, 837-841
  - orientation, 837
  - primary, 839-840
  - quaternary, 840
  - red bows, 841
  - reflection, 841
  - renaissance, 841
  - sea-spray, 841
  - secondary, 840-841
  - supernumerary, 838, 860-861
  - tertiary, 840
  - thunderstorm conditions for, 545-546
  - twinned, 841
- raindrop (see also drop, or precipitation)
  - drizzle, 546
  - growth processes, 205-207
  - optics, 837-841, 856-861
  - shapes, 255, 545-546
  - terminal fall speeds, 203
  - typical sizes, 185, 545-546, 857-861
    - from stratiform clouds, 546
    - from thunderstorms, 545
- rainfall , 99
  - accumulations, storm total, 257
  - categories, 247
  - coverage, 545-546
  - distribution worldwide, 209
  - intensity, 207-208, 247
  - levels, 247
  - likelihood, 782-784
  - radar observations, 245-257
  - rate, 72, 108, 207-208, 545-548
    - and cyclogenesis, 465-467
    - and latent heating, 72, 465
    - definition, 208
    - IDF (intensity, duration, frequency), 208
    - polarimetric radar estimates of, 257
    - radar Z-R estimates of, 247
    - records, 208, 545-548
  - storm-total accumulations, 257
  - thunderstorm, 482
- raining cats and dogs, frogs, fish, nuts, animals, etc., 206
- rain-free cloud base, 483
- random
  - errors and precision, 777, 875-877
  - number generator, 184
- range
  - factor in the radar equation, 245-246
  - height indicator (RHI), 242
  - mountain, 397
  - radar, 240-241
- ranked data, 502
- Rankine combined vortex (RCV) for tornadoes, 577-578, 599
- RAOBs= Radiosonde Observations (see rawinsonde), 272
- rapid
  - changes in weather due to short waves, 370
  - cyclogenesis, 426
    - baroclinicity, 426
    - conditions needed, 426
    - static stability, 426
  - flow classification, 659
  - RASS (Radio acoustic sounding systems), 78, 266, 272
  - rate
    - of buoyant production/consumption of TKE, 709
    - of molecular diffusion, 196-202
    - of earth's rotation, 227, 297-299
    - of growth of mixed layer, 697-698
  - rated wind speed for turbines, 648
  - ratio
    - Bowen, 74-76
    - of gas constants, 91, 880
  - raw data, 765
  - rawinsonde (radiosonde) , 134, 272
    - balloon, 322, 496
    - code for reporting (TEMP), 269-271
    - data, 134
    - frontal structure using, 403
    - mandatory levels, 134, 772
    - significant levels, 134, 147
    - sites for launching, 271
  - ray
    - curved, in air, 575-576, 861
    - equations for air, ice, and water optics, 833-868
    - geometry, 833-837
      - critical angle, 837
      - for halos (ice crystals), 842-855
      - for rainbows (liquid water drops), 837-841
      - Huygens' Principle, 837, 859
      - reflection, 833-837
      - refraction, 833-837
      - Snell's law, 834-837
    - light, 833-868
    - path, 833-861
      - equation for sound refraction, 575-576
      - equation for light refraction, 861
    - sound, 575-576
  - Rayleigh scattering
    - haze, 856-858
    - of microwaves from radar, 245
    - of light, 857
      - blue sky and red sunsets, 857
  - Rayleigh, Lord, 863
  - read, how to
    - METARs and SPECIs weather reports, 270-279
    - weather maps, 274-279
  - rear-flank downdraft (RFD), 482-483, 492-495
  - rear inflow jet (RIJ), 488-491
  - derecho, 494
  - reasoning, inductive and deductive, 107-109
  - recency symbols on weather maps, 276
  - receptor, pollutant, 724
  - record rainfall rates, 208, 545-548, 637
  - rectangular (Cartesian) coordinate system, 2
  - recursive techniques, 103, 771
  - red
    - bows, 841
    - color defined (also see optics chapter), 37, 834
    - Deer, Alberta, 553
    - giant star, 803
    - glow sunsets, 805, 858
    - sky, 858
    - sprite, 563, 568
    - sun, 858
    - sunsets, 857-858
  - reduced gravity, 135-136, 316, 658
    - in Bernoulli's equation, 670
  - reduction
    - data (also see statistical methods), 823
    - method to sea-level pressure, 267
  - reference
    - height for surface wind measurement, 701
    - state, 316
      - Earth climate/radiative equilibrium, 794, 807-808
      - feedback-processes, 806-807
      - vapor pressure, 88, 880
  - reflected pollutants, 734
  - reflecting telescope, 293, 862
  - reflection
    - definition, 833
    - from ice crystals, 842-844
    - from water, 838-839
    - of radiation, 41, 219, 833-844
    - rainbows, 841
  - reflectivity, 41-42
    - albedo, 42, 793-794
    - differential, 256
    - equation for radar, 245-246
    - factor for radar, Z, 245-248
    - for water, 838
    - radar (the name for scattered energy), 240-241
  - table of,, 42
  - unit factor for radar, 245-246
  - refract
    - radar beam, 244-245
  - refraction, 833-855
    - atmospheric, 861-863
    - light, 33, 833
      - components in 3-D, 836
    - refractive index, 834-835
      - for radar, 243-244
    - Snell's Law, 575-576, 834-837
    - sound waves, 575-576
    - standard (for radar beams), 244
    - sub-, 244-245
    - sunrise & sunset effects, 33, 862
    - super-, 244-245
  - refractive index, 834-835, 861
    - light, through air, ice, and water, 834-835, 861, 880
    - magnitude of radar targets, 245-246
    - radar, 243-244
    - sound, 575-576
    - varying with air density, 243-244, 575-576, 861
  - refractivity, radar, 243-244
  - refractometer, microwave, 111
  - regression, linear, 770
  - relationships and graphs, 873
    - linear, 873
    - logarithmic, 873-874
    - power, 874
  - relative
    - circulation, 366
    - frequency of wind speeds, 645-646
    - helicity, 588-591
    - humidity, 92
      - definition, 92
      - equation, 92
      - in clouds, 189
      - measurement of, 76-79, 111
      - reduction of, in WBF, 201-202
      - saturation, 92
      - supersaturation, 186
      - thermo diagram, 133-134
      - maxima and minima, 138-139
      - operating characteristic (ROC) curve, 783-784
    - vorticity, 320-321, 362-363
      - geostrophic, 319
      - sign convention, 320, 362
      - south /north side changes, 446
      - tornadoic, 586-591
      - typical order of magnitude, 362
      - variation with distance in planetary wave, 368
      - winds, 584
  - reliable, 782
  - reliability, 782-783
    - diagram, 782-783
    - relative, 783
  - remote sensors, 134, 219-266
    - on ground, 240-260
    - radar (see radar), 240-260
    - satellites (see satellites), 219-239
  - renaissance and rainbows, 841
  - Rene Descartes, 2, 841
  - repeatable errors, 875
  - replacement cycle for hurricane eyewalls, 605
  - reporting observations, 875
  - reports, weather, 267-273
    - of storm damage, 532
  - research aircraft, 135
  - reservoirs of momentum, 375
  - residence times of air in airmasses, 392-397
  - residual layer (RL), 692-696
    - drylines, relationship to, 416-417
    - temperature, 416-417
  - residuals, finding unknowns as, 340
  - resistant statistics, 502
  - resistance, electrical, 564
  - resistivity, 565
  - resolution
    - coarse, 752, 815
    - fine, 752
    - frequency-distribution, 646
    - numerical weather prediction, 750, 752, 761, 816
    - subgrid scale (unresolved), 750, 816
    - vs. grid spacing, 761, 816
  - resolving the geostrophic paradox, 459, 462
  - resonating air in lee wave, 667
  - response, feedback, 806-810
    - ice-albedo, 808-810
    - negative (damped), 807
    - no-feedback, 807, 809
    - positive (amplified), 807-809

runaway, 807  
restoring force, 136-137, 367-374  
retired hurricane names, 615  
retrieval of soundings by satellite, 235-239  
  corollaries 1, 2, 3, 235, 236, 239  
return  
  flow  
    antimountain, 653  
    antivalley, 654  
    sea-breeze, 654-655  
    periods of disasters vs. intensity, 208, 547, 646  
    stroke(s) of lightning, 567, 569  
  returned energy from radar, 245-246  
  returning air mass code, 392  
  returns from radar, 240  
  reverse flow in cavity, 667  
  reversible process, 121  
  revolutions, scientific, 773  
  Reynolds stress, 701, 712-713  
    vs. turbulent momentum flux, 712-713  
  Reynolds, Osborne, 701  
  RFD (rear-flank downdraft), 482-483  
  RHI radar scan, 242  
  ribbon lightning, 568  
  Richardson number  
    bulk, 141, 710  
    dynamic stability, 141-142  
    shear, 522, 530-531  
    thunderstorm, 521, 530-531  
  critical, 142, 880  
  flux, 709-710  
  gradient, 710  
  Richardson, Lewis Fry, 708, 759, 762, 764  
ridges (see also midlatitude), 332  
  axis symbols on weather maps, 281, 367, 391, 399  
  formation and characteristics, 367-376, 391  
  highs, relationship to, 390  
  in Easterly waves, 611-612  
  in Rossby waves, 353, 367-376  
right  
  hand rule for ageostrophic wind direction, 455  
  moving supercells, 518-520  
  quadrant of  
    hurricane, 627  
    jet streak, 454-456  
RIJ (rear inflow jet), 488-491  
riming of ice crystals, 199, 202, 546  
rings of light in the sky (see optics), 833-868  
rising  
  air parcels, 129  
  motion in cyclones (lows), 356  
  pressure in cyclones, 463  
  symbol on weather map, 278  
risk of severe weather (convective outlook), 528-530  
roads, as threat during storm chasing, 517  
  mirages on, 862  
robust statistics, 502  
ROC curve and diagram, 783-785  
  skill score, 784-785  
rocketsonde, 134  
Rocky Mountains, chinook winds, 676-677  
ROCOB code, 269  
  SHIP, 269  
ROFOR code, 269  
roll  
  cloud (undular bore; wave, volutus cloud), 169  
  vortices, horizontal, 167  
root-mean-square (RMS) error, 778-779  
  of 50 kPa geopotential heights, 778  
rope shaped tornado, 577, 583  
rosette shaped ice crystals, 199  
Rossby  
  deformation radius, 344  
  and geostrophic adjustment, 344  
  external radius of deformation, 405-406, 665  
  internal radius of deformation, 319-320, 344, 665  
  use in baroclinic waves, 372-373  
  use in coastal jets, 664-665  
  number, 306  
  curvature, 306  
  defined, 306, 313  
  frontogenesis issues, 411  
  vs. geostrophy, 306  
  wave(s) (also called planetary waves), 332, 353, 367-376  
  characteristics, 373-374  
  definition, 367  
  forecasts, 370  
  heat transport, 339, 374-375, 378  
  highs associated with, 391  
  instability, 367-376

momentum transport, 375-376  
size (wavelength; wavenumber), 367, 369  
stationary (lee side), 443-444  
Rossby, Carl-Gustav, 399, 749, 759  
rotating  
  planet; boundary layer growth on, 689  
  storms (also see vortices)  
    cyclones, extratropical lows, 425-480  
    hurricanes, typhoons, tropical cyclones, 603-644  
    mesocyclones (thunderstorms), 492-495, 587-592  
    tornadoes, 577-592  
rotation  
  angular momentum, 360-361, 617  
  forces, 296-299  
  hurricane, 617-619, 626-629  
  lines in spectra, 221  
  rate of Earth, 297, 879  
  changes of, 376  
  solid body, 363, 577  
  supercell thunderstorms, 483, 586-587  
  tornadic origin of, 586-587  
  wind-vector, in sea breeze, 656-657  
rotational invariance, 320  
rotation-angle of Earth, 229, 268-299  
rotor circulations, 165, 667  
rotor clouds, 165, 667  
roughness length, 677, 700-702  
  Davenport-Wieringa classification, 700  
round-off error, 759  
rule(s) for  
  determining static stability, 138, 688-689  
  determining unstable regions, 138  
  drawing isopleths on weather maps, 280-281  
runaway feedback, 807  
Runge-Kutta method, 757  
running average, 599  
runway  
  direction, 646-647  
  visual range (RVR), 270  
  change criterion for SPECI, 270  
  in METAR, 270

## S

S band radar, 242  
S time zone (Central & Mexico), defined, 5  
safe room (above-ground tornado shelter), 529  
safety  
  hurricane, 638-639  
  index, livestock weather, 117  
  lightning, 567-571  
  when storm chasing, 485, 517, 567, 570, 583-584  
Saffir, Herbert, 607  
Saffir-Simpson hurricane wind scale, 605-607  
Sagan, Carl, 415, 869  
sails on frigate, 635  
salt, 188, 190-192  
saltation, 562  
sample volume, radar, 240  
sand, 170  
  lithometeors, 205  
  saltation, 562  
  storm (haboob), 562  
    weather-map symbols for, 275-276  
San Francisco (advection) fog, 173-175  
Santa Maria volcano eruption, 805  
SAR (synthetic aperture radar), 230  
SARAD code, 269  
SAREP code, 269  
satellites, 219-239  
  16 satellite, 222-235  
  ABI (advanced baseline imager), 222-235  
  channels, 222-223, 230-233  
  geostationary (GOES), 227  
  humidity observation from, 112  
  hurricane tracking, 637  
  image interpretation, 231-235  
  imager, 230-235  
  locations of weather observations from, 272-273  
  loop (of images), 227  
  low-light-level cameras, 569  
  Meteosat images, 228  
  observed Total Solar Irradiance, 39  
  observations of hurricanes, 603-605, 608, 614, 616, 620  
  optical transient detectors, 569  
  orbits, 227-229  
  photos of Earth, 228, 232-233  
  polar orbiting (POES), 228-229  
  radiative transfer, concepts for, 220-226  
  remote sensing from, 219  
  retrievals, 235-239  
    difficulties, 239  
  sensors, 273  
  sounder, 235-239  
  sounding pre-thunderstorm, 496  
  triangulation, 291  
  types, 227-229  
  SATEM code, 269, 273  
  SATO code, 269, 272-273  
  SATRAD observation locations, 273  
  saturated (see also moist)  
    adiabat on thermo diagrams, 119-158  
    adiabatic lapse rate, 101-106  
    plot using spreadsheet, 103  
    for determining static stability, 139-141  
  air, 87-98  
  air parcels, 130  
  absolutely unstable, 140  
  neutral stability, 140  
  saturation (see also equilibrium), 87-90  
  absolute humidity, 91  
  humidity, 87-96  
    vs. air temperature, 88, 92, 100  
  in clouds, 159-161  
  level (also see Lifting Condensation Level), 93-94, 130  
  mixing ratio, 91-92  
  processes causing, 159-161  
    cooling, 159  
    moisture addition, 160  
    mixing, 160-161  
  relative humidity, 92  
  specific humidity, 91  
  vapor pressure, 87-90  
    ice vs. water, 88, 201-202  
  savings time, daylight, 5, 6  
  sawtooth shape of Rossby waves, 374-376  
  Sawyer-Eliassen circulation, 412, 415  
  SB-CAPE, 503-505  
  sc (stratocumulus clouds), 168  
  scalar equation, 293  
  scale  
    analysis, 623  
    height  
      for density, 10  
      for pressure, 8  
    length  
      buoyancy, 733  
      dissipation, 709  
      momentum, 733  
    velocity  
      buoyancy, 68-69, 109, 703-704  
      mechanical turbulence, 701-703  
  scales of motion, 315  
    vs. forecast skill, 768  
  scan strategies and angles for radar, 241-242  
  scattered  
    cloud cover, 170, 279  
    light, 33, 219-222, 856-858  
    rain showers, 545-546  
  scattering, 856-858  
    backward, forward, 219, 857-858  
    blue sky, 857  
    by aerosols, 221, 805, 857-858  
    from volcanic SO<sub>2</sub> in stratosphere, 805, 858  
    by air molecules, 220-222, 857  
    directional variation (forward vs. backward), 219, 857  
    geometric, 857  
    Mie, 858  
    of energy from radar, 240-241  
    of radiation, 219-222, 856-858  
    of visible light, 856-858  
    optical depth/thickness, 805, 856  
    polarization, 856  
    Rayleigh, 857  
    transmitted light, 856  
    twilight, 857-858  
    types, 856-858  
    visibility, 856-858  
    vs. wavelength, 857-858  
    white clouds, 857  
  scatterometer sensors on satellites, 230  
    locations of observations, 272  
  schedule, forecast, 762  
  Scheiner, Christopher, 855  
  Scheiner's 28° halo, 855  
  Schwarzschild's equation for radiative transfer, 224-225  
  Science Graffiti and Graffiti, scattered in most chap-



- ters
  - anonymous, 16, 31
- science
  - atmospheric, 205, 877
  - fundamentals, 869-878
  - high-risk, high-gain, 863
  - on doing, 877
  - philosophies, 877
- scientific
  - basis for numerical weather forecasts, 746-751
  - laws (see Laws)
  - method, 2, 26, 343, 680
  - mistakes & pitfalls, 863, 877
  - notation for numbers or values, 870
  - paradigm shifts, 863
  - paradox, 293
  - philosophies, 167, 293, 680, 877
  - problem solving methods, 72
  - revolutions, 26, 773, 863
  - thought, expert vs. novice, 72
  - tools, 877
- scientists, 877
  - mistakes made by great scientists, 863
  - passion, 877
  - responsibilities as a citizen, 738
  - young, 293
- score, forecast skill, 777-785
- scorpion analogy (sting jet), 414-415
- scour of beaches by ocean waves, 634-635
- screen, Stevenson, 115
- scrolls on ice crystal plates, 199
- sct (scattered) cloud cover, 170
- scud (cumulus fractus), 483
  - weather-map symbol for, 277
- sea breeze, 654-657
  - front, 655-656
    - radar observations of, 249
    - thunderstorms triggered by, 525, 654-655
  - head, 655
  - high-pressure associated with, 391, 654-655
- sea-level
  - density, 10
  - pressure
    - change, as plotted on weather maps, 277-278
    - cyclone-intensity measure, 426, 463-467
    - in various units, 7
    - mean, 267
    - METAR, 270
    - on weather maps, 275, 434
    - reduction methods, 267
    - tendency, 277-278, 463-467
  - rise due to hurricane, 632-634
  - temperature (average), 7
- sea-spray rainbow, 841
- sea surface temperature (SST), 608-609, 616
  - climate variations, 818
  - role of cold temperatures in hurricane death, 616
  - warm anomaly, 818
  - ENSO, 818-820
  - PDO, 818-820
- sea water density, 880
- season(s)
  - Earth, 30, 797-802, 879
  - hurricane, 630
- seasonal
  - averages (months used for), 330, 333
  - differences in atmospheric boundary layer, 695-696
  - forecast models, 768
  - heating cycle, 30-33, 40-41, 332-333, 354-358
- seasonality of hurricanes, 630
- second, 870
- secondary
  - circulation (Sawyer-Eliassen) at fronts, 412
    - associated with jet streaks, 455-456
  - fields, 772
  - rainbow, 838, 840-841
  - variables in NWP, 771-772
  - wavelets, 859
- sector plate ice crystals, 198-199
- seeding of clouds, 195-196, 218, 553-554
  - cavum (hole in cloud layer from seeding), 169
- self-development of cyclones, 468-471
- semi-
  - Lagrangian method of NWP, 761
  - log graph, 873-874
  - major axis of Earth's orbit, 28, 800-802
    - precession, 800
  - minor axis of Earth's orbit, 28
  - transparent (=translucent), 42, 169, 220
- Seneca, 523
- sense (direction) of circulation, 456, 377-378
- sensible heat (enthalpy), 58, 671
  - flux at the surface, 73-76
- sensitive dependence to initial conditions, 773-776
- sensitivity, 350, 810
  - climate, 810, 812
  - definition, 350, 810
  - factor, 812
  - magnitudes, 812
  - studies, 350
- sensors (see weather instruments)
- in situ (direct)
  - definition, 219
  - list of, 219
  - remote, 219-266
    - definition, 219
    - radar, 240-260
    - satellites, 220-239
- separation of variables, 89
- sequestered carbon dioxide (CO<sub>2</sub>), 812
- set of data, reporting, 875
- setting sun, shape of, 862
- severe
  - hail, 548
  - thunderstorm
    - definition, 528
    - environment, 496
    - intensity forecasting, 501, 507, 516, 521-522, 524, 530-531
    - probabilistic forecasts, 529
    - watches and warnings, 528-530
  - weather
    - forecasting & risks, 528-530
    - Storm Prediction Center (SPC), 532
    - SWEAT index, 531
- SFAZI code, 269
- SFAZU code, 269
- sferics, 568
- SFLOC code, 269
- shadows
  - aircraft, glory optical phenomena around, 860
  - radar, 241
  - rain, 397, 472
- shaft
  - hail-, 553
  - work, 672
- shallow, weather-map symbol for, 276
- shallow water wave speed, 633
- shapes of
  - clouds, 171
  - tornadoes, 577
- Shapiro-Keyser cyclone model, 414-415
- shear (also see wind shear), 509-522
  - bulk Richardson number, 522, 530-531
  - components, 509
  - direction, 509
  - frontal, 407-412
  - frontogenesis, 407-412
  - generation of TKE, 708-710, 727
  - geostrophic wind, caused by thermal wind, 345-349
  - hodograph usage to determine, 509-522
  - isoshar, 18
  - line, 281, 399
  - local (single layer), 514
  - magnitude, 509, 515-516
  - mean vector, 514
  - production of turbulence, 704, 710
  - single-layer, 514
  - speed, 509-510
  - surrogate using wind difference, 509
  - total magnitude, 515-516
  - turbulence production, 704, 710
  - units, 509
  - vorticity, 362
  - wind, 706
    - radar observations of, 254
    - hurricane environment, 610
    - thunderstorm environment, 496, 509-522
- shearing deformation, 320-321
- sheath ice crystals, 198-199
- sheet lightning, 567
- sheets of clouds, 168
- shelf clouds, 562
- shield of stratiform clouds, 425-428
  - from hurricanes, 604
  - from thunderstorm MCS, 488
- shifting winds, 349, 400-401
- shimmering mirages, 862
- SHIP
  - code, 269, 271
  - parameter, 530-531
- shock
  - front, from lightning, 571-574
- 1-D normal, 572
- wave, 571-574
- short
  - gap winds, 661-662
  - range weather forecast models, 768
  - scale number prefixes (for USA), 870
  - waves (see also planetary waves), 369-370, 372
- short-wave
  - radiation (see also radiation, solar), 37, 220, 793
  - Rossby, 369-370
  - transmitted, 805
- shoulder region of window, 220-223
- Showalter stability index (SSI), 531
- showers, symbols on weather maps, 275-276
- SI (Système Internationale) - international system of units, 8, 870
- Siberian
  - high, 354-356
  - traps, 805
- sidereal (relative to the stars)
  - day, 227, 297
  - Earth year period, 29
  - moon orbital period, 27
- sigma (s)
  - coordinates, 746
  - model, 746
  - plume spread standard deviation, 729
  - velocity standard deviation, 727
- sign
  - coefficient (centrifugal force), 296
  - positive or negative, in scientific notation, 870
- signals, 219-220
- signal strength from radar, 245-246
- signature
  - damage to crops and forests, 593
  - horizontal divergence (downburst outflow), 253, 561
  - tornado vortex (TVS), 253
- significant
  - hail, 548
    - parameter (SHIP), 530-531, 551-552
  - levels, 134-135, 147
  - tornadoes, 501, 507, 516, 522, 530-531, 580
    - parameter (STP), 530-531, 592
- silicon window on IR radiometers, 45
- silver iodide, 195-196, 553-554
- similarity theory, 699-704
- simple is best (Occam's razor), 680
- simplified (toy) models, 330
  - of global circulation, 330-334
  - of hurricanes, 626-629
- Simpson, Robert, 607
- sine law of radiation, 40
- singing wires (aeolian tones), 560
- single-cell thunderstorms, 486
- single-layer shear, 514
- sink, level of free (LFS), 557
- sinking, 135
- sirens, civil-defense, 529
- sizes of
  - clouds, 170
  - hydrometeors, 187
- skc (sky clear), 170
- skeletal shaped ice crystals, 199
- skew-T log -P diagram, 121-158
  - components, 124
  - creation of, 124-125
- skewness factor, 125
- ski runs, 209
- skill
  - climatology, 780
  - forecast (NWP), 752, 777-785
  - persistence, 780
  - scores, 777-785
  - vs. forecast time, 775, 780
  - vs. scale of event, 768
  - vs. spread of ensemble forecasts, 777
- skin of air parcel, 57
- sky
  - color, 857-858
  - cover, 170
    - weather-map symbols for, 279
  - transmissivity, net, 44
- slab model, 697-698
- slalom ski snow, 209
- slanting data, 826
- sleet (ice pellets), 199, 276
- slight thunderstorm risk, 530
- sling psychrometer, 94
- slope
  - definition, 396
  - on log-log graph, 215
  - flows (anabatic, katabatic), 649-653

- force of katabatic winds, 396, 651-653
- of storm surge, 633
- statistical calculation, 770
- SLP, sea-level pressure, units, 7
- small
  - disturbance errors, 875
  - nuclei, 188
- smog (see also pollution), 193
  - brown cloud, 857-858
- smoke, 170
  - concentration distribution, 734, 737
  - dispersion, 710, 723-744
  - lithometeors, 205
  - plumes, 710, 724
    - edge, 730
    - footprint, 733
  - stack, 723-724
    - clouds, 166
  - weather-map symbol for, 276
- smoothing data, 826
- smoothness, Lipschitz, 761
- snapshot of smoke plume, 728
- Snell, Willebrod van Royen, 841
- Snell's Law
  - for light, 834-837
    - 3-D, 836
  - for sound, 575
- Snelling, 765
- snow
  - accumulation and liq. water equivalent, 107, 208-209
  - banner cloud, 165
  - capped mountains, viewed from satellite, 234
  - characteristics, 209
  - condensation onto, 110
  - dendrites, 198-199
  - density, 209
  - depth sensor, 210
  - eater, 676
  - formation in cold clouds, 201-202
  - grain classification, 199, 209
    - weather-map symbols for, 276
  - melting into rain, 206
  - optics (ice-crystal optics), 163, 842-855
  - pellets (graupel), 199, 546
    - weather-map symbols for, 276
  - pillow, 210
  - powder, 209
  - shapes, 198-199
  - strength, 209
  - swath on the ground, 163
  - symbols on weather maps, 208, 275-279
  - thunder-, 207
- snowball Earth, 811
- snowfall rates, 208-209
- snowflakes as aggregates of many crystals, 200
- SO (Southern Oscillation), 818-819, 824
- social aspects of hurricane hazards, 631
- sodar, 219
- sodium chloride (salt), 190-192
- SOI (Southern Oscillation Index), 818-819, 824
- solar
  - activity variations, 803
  - azimuth angle, 33
  - blackbody radiation emitted, 37, 39
  - cells (photovoltaics), 46
  - constant (total solar irradiance), 39-45, 793-794, 879
    - kinematic, 879
    - variations, 803
  - declination angle, 30-31, 802
  - downwelling radiation, 793
  - elevation angle, 32
    - vs. latitude, 40, 334
  - emission of radiation, 37-39
  - faculae, 803
  - forcing ratio, 813-815
  - heating and cloud formation, 162
  - incoming radiation, 39, 334-337, 793, 797, 801-802
  - input, net, 795
  - insolation, 40, 336, 793, 797, 801-802
  - irradiance, 37-39, 793-794, 879
  - luminosity parameter, 813-815
  - net input to Earth, 795
  - output variations, 803
  - radiation, 37-39, 220
    - astronomical influences, 797-803
    - driving the global circulation, 329, 334-339
    - transmitted, 805
  - radiative forcing, 40
  - radius, 33
  - tides, 376
  - total solar irradiance (TSI), 39, 793-794, 803, 879
  - upwelling radiation, 44-47, 220-226, 230-239, 797
  - variability, 39
  - wind, 376
    - zenith angle, 33
- Solberg, H., 399
- solenoid
  - on weather maps, giving max advection, 458
  - term, in the circulation equation, 366
- solid
  - angle, dimension and units, 870
  - body rotation
    - in tornado core, 577-578
    - quasi-geostrophic vorticity, 449
    - relative vorticity, 363
- solitary wave (bore; roll cloud), 169, 656
- solstice, summer and winter, 30-31, 801, 879
- solute, 190-192
- solute effect, 189-193
- solution to pollution, 724
- solutions
  - in water droplets, 190
  - to atmospheric equations, 749
- solving problems, 72, 869
- sonde (instrument to make soundings), 134
  - dropsonde, 134
  - radiosonde, 134
  - rawinsonde, 134
  - rocketsonde, 134
  - weather balloon, 134
- sonic
  - anemometer, 321
  - thermometer, 78
- soot, 151
- sound
  - howling in storms (aeolian tones), 560
  - rays in air, 575-576
  - refraction of, 575-576
  - speed/velocity, 572, 575-576, 674, 880
  - supersonic thunder shock wave, 571-574
  - waves, 571, 575-576
    - transition from shock waves, 571
- sounder
  - channels on satellites, 222-223, 226, 235
  - operation on satellites, 235-239
- soundings, 119
  - environmental, 59, 134
  - locations worldwide, 271
  - mandatory levels, 134, 772
  - methods, 134-135, 496
  - pre-thunderstorm, 496-499, 503-508
  - retrieval by satellite, 235-239
  - significant levels, 134, 147
    - to determine boundary layer depth, 143
    - to determine CAPE, 503-508
    - to determine clouds, 162-164
    - to determine tropopause height, 143, 496
- source
  - height of pollutant emissions, 723
  - latitudes for angular momentum, 361, 375
  - location for parcels, 360-361, 711
  - of pollution, 724
  - of turbulence, 69-71, 138-142, 666-668, 705-715
  - of weather data, 271-273
    - point, 724
    - receptor framework, 724
- south direction (opposite north), 2
- South
  - Atlantic subtropical high, 354
  - Pacific subtropical high, 354
  - Pole, 4
- Southern
  - annular mode (SAM), 824
  - Hemisphere, 4
    - defined, 4
    - continental low, 354
    - global circulation, 332, 339, 343, 350-358
    - midlatitude cyclones (lows), 426, 430-432
    - semi-permanent monsoon names, 354
    - sign of Coriolis force, 297, 301
    - sign of centrifugal force, 296
  - Indian Ocean High, 354
  - oscillation index (SOI), 818-819, 824
- SO<sub>2</sub>, sulfur dioxide, 7, 725, 804, 858
- space
  - dust, 376
  - outer, satellite images of, 234
- Space Science and Engineering Center (SSEC), 232
- spatial
  - distribution of pressure /temperature, 280, 343, 359
  - gradients; finite-difference approximations, 754-755
- SPCLI code, 269
- special crystal orientations, 855
- species of clouds, 168
- SPECI code (special meteor. aviation report), 269-271, 275-279
  - criteria that trigger issuance of, 270
- specific
  - differential phase, 256
  - heat
    - air, 53, 55-56, 58, 880
    - at constant pressure, Cp, 53-56, 880
    - at constant volume, Cv, 55, 880
    - of humid air, 56
    - of liquid water, 54, 56, 880
    - of water vapor, 880
    - ratio, 880
  - humidity, 91
    - saturation value of, 91
  - volume, 11, 121
    - isostere, 18
  - work, 121
- spectral
  - absorption, 222-223
    - hygrometer, 111
    - lines, 221
  - dispersion, 834
  - radiance constants, 221, 879
  - transmittance, 222-223
- spectrometer, 46-47
- spectrum
  - electromagnetic, 220-223
  - light (colors), 37, 222, 834-835, 862
  - width, 254
- speed (see also velocity)
  - airspeed, indicated with pitot-static system, 674
  - constant (isotach), 18
  - equation, 2-3, 314-315, 746
  - difference in jet stream, 450-453
  - group, 658
  - of dry line movement, 417
  - of electromagnetic radiation, 243
  - of light, 36, 240, 243, 834-837, 879
  - of rain drops (see terminal velocity), 202-204
  - of sea-breeze front, 655-656
  - of sound, 572, 575-576, 674, 880
  - of wind, 2, 3, 302-314
    - around highs and lows, 307
    - Beaufort scale, 635-636
    - in hurricanes, 605-607, 626-629
    - in tornadoes, 577-580
    - total (rotation + translation), 578, 627-628
  - phase, 369-370, 658
  - shear (shear magnitude), 509-510
  - updraft, 649
  - wave, 658
- spheres, layers in atmosphere (e.g., troposphere), 12-13, 563
  - electrosphere and ionosphere, 565
- spherical
  - coordinates, 747
  - cow, 330
- spider lightning, 567
- spin (see vorticity), 320-321
- spin down
  - of cyclone, 429
  - of Earth, 376
  - of global circulation, 388
- spin-up
  - rate of cyclones, 446-451, 617
  - of global circulation, 388
  - of hurricanes, 617
  - of tornadoes, 586-587
  - of vorticity, 446-451, 586-587
- spinning forces, 296-299
- spiral
  - bands in tropical depressions & hurricanes, 604-605, 613-615
  - Ekman (in ocean), 378
  - pattern (waterspout evolution), 582
- spissatus/spi, 168
- Spörer minimum in solar activity, 803
- spotters, storm, 529
- spray, 170, 276
  - ring (waterspout evolution), 582
- spread
  - parameter, Weibull distribution, 646
  - interquartile range (IQR), 502
  - smoke plume, 729-730
  - temperature-dew-point, 92
  - vs. skill, 777
- spreadsheet
  - programs and samples, 20-21
  - thermodynamics, 63, 103
  - thermo diagrams, 63, 100, 103, 125

- springs (illustrating Brunt-Vaisala oscillation), 136  
 Spring (vernal) equinox, 30-31, 801  
 sprite, red, 563, 568  
 squall, weather-map symbol for, 276  
 squall line of thunderstorms, 488, 490-491  
   predicting, by using total shear magnitude, 516  
   radar image of, 243  
   tornadoes (landspouts) from, 582  
   weather-map symbols for, 281  
 SR (storm relative), 584  
 SRH (storm relative helicity), 530-531, 588-592  
 SSM/I (Special Sensor Microwave Imager), 230, 273  
 SST (sea surface temperature), 608-610, 616  
 st (stratus clouds), 168  
 stability, 119-158  
   absolute, 140  
   airmass, 391-396  
   cloud type vs., 161-164  
   conditionally unstable, 140  
   cyclogenesis, impact of stability on, 426  
   dry absolutely unstable, 140  
   dry neutral, 140  
   dynamic, 141-142  
   flow, 138-142  
   in stratosphere, 143-144  
   in troposphere, 143-144, 688-690  
   indices for thunderstorm & tornado forecasting, 530-531  
   neutral, 138-140  
   nonlocally unstable, 138-139  
   numerical, 759-761  
   Paquill-Gifford classification, 727-728  
   rules for determining, 138-141  
   saturated absolutely unstable, 140  
   saturated neutral, 140  
   smoke dispersion, vs., 732-737  
   static, 138-141  
   turbulence determination, 142  
   unstable, 138  
 stable  
   absolutely, 140  
   air, 138-142  
   boundary layer (SBL), 692, 696  
     cold airmass genesis, 393  
     depth, 696  
     e-folding height, 696  
     smoke plume rise within, 733  
     strength, 696  
     temperature, 692-696  
     turbulence, 707-710  
     velocity standard deviations, 707  
   Brunt-Väisälä frequency, 136-137  
   definition, in flow stability, 138  
   equilibrium of droplets, 191  
   regions, 138-140  
   surface-layer wind, 702-703  
 stably-stratified  
   flow, 657-661, 688-689  
   turbulence related to PG types, 710  
 staccato lightning, 568  
 stack height, smoke emission, 723  
 stacking of pressure characteristics  
   hurricane, warm core, 622  
   low-pressure, role in cyclolysis, 432-433  
 stages of evolution of  
   thunderstorm cells, 485  
   tornadoes, 583  
 staggered arrangement of grid points, 753  
   Arakawa grids, 753  
 stagnation  
   events for air pollution, 741  
   point, 672  
   pressure, 673  
   streamline, 672-675  
 standard  
   atmosphere, 11-13, 688-690  
     definition, 11-13  
     density, 10-13  
     in thermo diagram, 135, 688-690  
     lapse rate, 11-13, 70, 688-690  
     static stability, 688-690  
     temperature, 11-13, 688  
   deviation, 706-707, 727, 875-877  
     of pollutant location, 729-730  
     of wind components, 706-708, 727  
     propagation in equations, 876-877  
     variation with height, 707  
   isobaric surfaces (upper air), 772  
   pressure, 7, 107, 880  
     levels (mandatory), 772  
   refraction of radar beam, 244-245  
   scientific notation, 870  
   STP, 7, 107, 880  
   temperature, 7, 107, 880  
   time, 5  
   uncertainty, 875  
 standardized wave shape for lightning surge, 569-570  
 standards, air-quality, 725  
 standing lenticular clouds, 165, 666-668, 684-685  
   optical phenomena caused by, 859-860  
 start shaped ice crystals, 199  
 star(s)  
   red giant, 803  
   visible at night, 33  
   white dwarf, 803  
 state  
   equation of, defined, 14-15  
   of air, 2  
   of parcel, 128  
   thermodynamic, defined, 2, 6  
   on a thermo diagram, 100, 128  
   USA, in, 431  
 static  
   AM radio, 568  
   definition, 16  
   electricity, 564  
   hydrostatic, 15-16, 340, 651, 747  
   instabilities and circulations, 132  
     cumulus cloud formation, 162  
     -pitot system for air speed, 674  
     pressure, 7, 672-674  
     stability, 138-141, 687-689  
     airmass, 391-396  
     air parcel method, 138-139, 687-688  
     apex method for determining, 138-139  
     atmospheric boundary layer, 687-689  
     cloud formation within, 162-163  
     estimation, 728-729  
     forced vs. free convection, 710  
     frontal, 414  
     layer method for determining, 140-141  
     misinterpretation, 729  
     neutral, 139-140, 688-689, 710  
     nonlocal, 138-139  
     parcel method for determining, 138-139  
     rules for determining, 138-139, 688-689  
     smoke dispersion in, 710, 723-744  
     stable, 136-137, 139-140, 688-689, 710  
     thunderstorm, 496-499, 503-508  
     unstable, 138-139, 688-689, 710  
     temperature, 672-674  
   statically stable air, 136-140  
     clouds that form in, 163, 165  
     mirages in, 861-863  
   statically unstable air, 128-142  
     clouds that form in, 161-162, 164  
     mirages in, 861-863  
     smoke plume dispersion in, 735-737  
 station  
   ID or weather station code (ICAO), 270  
   Papa, 288  
   plot model on weather maps, WMO, 274-279  
 stationary  
   environment, 688  
   flow, 669  
   turbulence, 708  
   front(s), quasi-stationary, 404  
   weather-map symbols for, 281, 399  
   mountain waves & lenticular clouds, 666-668  
   planetary waves (& lee cyclogenesis), 443-444  
   north-south amplitude & wavelength, 444  
   quasi-, 281, 399  
 statistical methods  
   adaptive, 771  
   average (mean), 502, 705, 726, 875  
     running, 599  
   bell curve, 729-730  
   biases (mean, systematic errors), 770, 778  
   binary event verification, 780-782  
   box-and-whisker diagram, 538  
   calibrated ensemble forecasts, 777  
   categorical event verification, 780-782  
   central-limit theorem, 184  
   correlation coefficient, 711, 779  
     anomaly, 779-780  
   cost function, 766-767  
   covariance, 711, 821-822  
     matrix, 822  
   cumulative probability threshold, 777  
   data reduction, 502  
   dice, 184  
   discriminator of thunderstorm intensity, 507  
   eigenvalues and eigenvectors, 822  
   empirical orthogonal function (EOF) analysis, 820-823  
   error, 778, 875-877  
     propagation, 876-877  
   forecasts, 816  
   Gaussian distribution, 184, 729-730, 875  
   intercept, 770  
   interquartile range (IQR), 502  
   Kalman filtering & gain, 770  
   least squared error, 770  
   linear regression, 770  
   matrix, 822  
   mean (average), 502, 726, 875  
     absolute error (MAE), 778  
     error (ME), 778, 875  
     squared error (MSE), 778  
     squared error skill score (MSESS), 778  
   median, 502  
   method of moments, 730  
   model output statistics, 770-771  
     updateable, 771  
   normal distribution, 729-730  
   outliers, 502  
   percentiles, quartiles, 502  
   predictands and predictors, 770  
   perfect prog method (PPM), 770-771  
   principal component analysis (PCA) methods, 820-823  
   probabilistic forecasts, 777  
   propagation of errors, 876-877  
   random number generator, 184  
   rank, 502  
   recursive, 771  
   regression, 770  
   root mean square error (RMSE), 778  
   running average, 599  
   slope, 770  
   standard  
     deviation, 502, 706-708, 727, 875-877  
     uncertainty, 875  
   thunderstorm & tornado likelihood, 501-502, 507, 516, 522, 538, 588-592  
   trace of matrix, 822  
   variance, 706-708, 727, 821  
   verification of weather forecasts, 777-785  
 statistical theory (Taylor's) for pollutant dispersion, 731-732  
 statistics  
   dispersion, pollutant, 728-730  
   non-parametric, 502  
   resistant & robust, 502  
   turbulence, 706-708, 726-728  
   verification of forecasts, 777-785  
   vs. life, 726  
 Steadman, R.G. Heat Index, 77, 117  
 steady pressure symbol on weather map, 278  
 steady state  
   atmosphere (radiative equilibrium), 795  
   definition, 302  
   flow, 669  
   radiation balance of Earth system, 794  
   winds, 302-314  
     in ABL, 699  
 steam  
   engines, 89  
   fog, 173  
 steering winds  
   hurricanes, 607-608  
   thunderstorm (normal storm motion), 487, 516-518  
 Stefan-Boltzmann  
   constant, 37, 337, 879  
   law, 37-39, 337, 794  
 stellar shaped ice crystals, 199  
 stencil, 757-758  
 stepped leader, 566  
 steps for problem solving, 869  
 steradian, unit of solid angle, 221-224, 870  
 stereographic map projections, 748  
 Stevenson screen, 115  
 Stewart, George R., 775  
 sting jet, 414-415  
 Stokes Drag Law, 202-203  
 Stokes, George, 759  
 Stone, Alex, 315  
 storm (also see thunderstorms, cyclones or hurricanes)  
   case-study of extratropical cyclone, 433-466  
   cells, 485  
   chasing, 484, 532  
     core punching, 583  
     safety, 485, 517, 567, 570, 583-584  
   convective (see Thunderstorms), 496-499

- damage scales (tornado), 579-580  
 data for case-study cyclone, 434-435  
 downslope wind, 667, 675-677  
 dust, 562  
 evolution, 484-485  
 hazards, for thunderstorms, 545-602  
 hail, 548-554  
 helicity, 587-592  
 hurricanes, 603-644  
 intensity forecasting (indices for), 530-531, 588-592  
 lightning, 563-571  
 motion/movement of thunderstorms, 483, 488, 510  
   normal, 516-518  
   left- and right-moving, 518-520  
   winds relative to, 584-585  
 movement of hurricanes, 615  
 Prediction Center (SPC), 532, 580  
 pre-storm environment, 496-499  
 radar identification and observations of, 248  
 relative (SR), 584  
   effective helicity (eSRH), 590  
   helicity (SRH), 530-531, 588-592  
   winds, 584-585  
 reports, 532  
 rotation, origin of, 586-587  
 sand (haboob), 562  
   sounds, 560  
 spotters, 529  
 strength, indices for forecasting, 530-531  
 surge, 615, 632-634, 669  
   heights, 633  
 supercell, 483, 492-495  
 system, 426  
 thunderstorms, 481-602  
 total rainfall accumulations, 257  
 track  
   hurricanes, 607-608, 615  
   extratropical cyclones (Lows), 429-431  
   thunderstorms and tornadoes, 483, 516-520, 584, 593  
   tropical, 614-615, 635-636  
   typhoons, 603-644  
   weather-map symbols for, 276, 426, 614-615  
   winds (Beaufort scale), 635-636  
     downslope, 667, 675-677  
 stormy-weather heat flux, 70-71  
 STP, standard temperature & pressure, 7, 107, 880  
 straight-line winds (also see derecho), 489, 491, 494, 554, 560-563  
   downburst generated, 554-563  
   radar observations of, 253, 560-561  
 strange attractors, 773-776  
 stratified  
   air layers at night, 653  
   fogs, 176-177  
   system, 657-661  
 stratiform/stratiformis (advection) clouds, 94, 162-164, 168  
   clouds in thunderstorm MCS, 488  
   drizzle from, 546  
   formed at frontal boundaries, 160, 425-428  
   radiative effects in, 132, 160  
   shield at warm fronts, 425-426  
 stratocumulus, 161, 164  
 stratopause, 12-13  
 stratosphere, 12-13, 143  
   isentropic potential vorticity in, 415  
   pressure gradient in, 359  
   temperature reversal in, 359  
   tight packing of isentropes, 143, 414  
   winds in, 359  
 stratospheric  
   aerosols, 804-805, 858  
   air, 414-415  
   clouds, 166  
   ozone, 364  
     destruction, 724  
 stratus, 162-163  
   in satellite images, 234  
 streaklines, 668-669  
 streaks  
   hail, 552  
   jet, 454  
     role in upward motion & cyclogenesis, 454-456  
 streamer (lightning), 566  
 streamlines, 611-612, 668-675  
   stagnation, 672-674  
 streamwise vorticity, 518, 587-592  
 streets  
   clouds, 167  
   urban, 678-679  
 strength of  
   fronts, 408-412  
   stable boundary layer, 696  
 stress, 700-702, 712-715  
   dimension of, 870  
   kinematic, 701, 712-713  
   molecular, 701  
   Reynolds, 701, 712-713  
     vs. momentum flux, 712-713  
   turbulent (Reynolds), 701  
   units, 870  
 stretching  
   deformation, 320-321  
   in typical weather patterns, 447-451  
   self-development of cyclones, 468-471  
   term in vertical vorticity eqn., 447-451, 586-587  
 striations, cloud, 483  
 strike, lightning, 566  
 strokes, lightning, 567-568  
 structure of  
   atmosphere, 11-13  
   boundary layer, 13, 692  
   hurricanes, 604  
 Stull, Roland - about the author, XIV  
 Stüve diagrams, 121-158  
 subadiabatic  
   lapse rate, 140  
   region, 144  
 subanthelic arc, 855  
 subcategories of clouds, 168-169  
 subcircumzenith arc, 855  
 subcritical flow, 659  
 subgeostrophic wind, 304, 455, 699-700  
 subgrid scale, 750, 816  
 subhelic arc, 854-855  
 subhorizon halos, 855  
 subjective (hand) analysis of weather maps, 279-281  
  
 sublimation, latent heat of, 56  
 subparhelia (subsun dogs), 842, 851, 854-855  
 subparhelic circle, 855  
 subpolar  
   lows, 330  
   zone, 330  
 subranges of turbulence, 315, 708  
 subrefraction of radar beam, 244-245  
 subsidence  
   air pollution episodes and exceedences, 691  
   around clouds including thunderstorms, 161, 545-546  
   at top of atmospheric boundary layer, 691  
   by Ekman or boundary layer pumping, 319-320  
   in anticyclones (highs), 356, 390-396, 691  
   in Hadley cell, 351  
   in hurricanes, 629  
   in troposphere of high, 390  
   on weather maps, 433, 437, 448, 451, 471  
   estimated from convergence/diverg., 441, 449, 452, 455-456, 461-462  
   radar estimates of, 252-253  
   trapping of air pollutants, 691  
 subsun, 842, 844, 854-855  
 subsun dog, 842, 851, 854-855  
 subsurface heat and water parameterizations for NWP, 751  
 subtropical, 330  
   deserts, 351  
   highs (anticyclones), 331, 351, 391  
     Southern Hemisphere, 354  
   jet, 233, 331-332, 350-351, 357-361  
     angular momentum, 360-361  
     latitude dependence on Earth rotation, 351  
   zone, 330  
 suction vortices, 593  
 sulfates, 188, 811, 858  
 sulfur dioxide, SO<sub>2</sub>, 7, 725, 858  
   aerosols and emissions from volcanoes, 804-805, 858  
   stratospheric, 804-805, 858  
 sulfuric acid, 188, 190-192  
 sultriness, 77  
 summer, 330  
   atmospheric boundary layer, 695-696  
   simmer index, 117  
   solstice, 30, 801-802, 879  
   year without (1816), 805  
 sun (also see solar)  
   apparent  
     rise and setting times, 33, 861-862  
     shape during rise and set, 862  
     azimuth angle, 33  
     blackbody radiation emitted, 37, 39  
   blue, 858  
   crimson, 858  
   distance to earth, 30, 802, 879  
     aphelion, average, and perihelion, 879  
   dog, 842, 850-851, 854-855  
     sub, 842, 851, 854-855  
   elevation angle, 32  
   emission of radiation, 37-39  
   evolution: red-giant star; white dwarf star, 803  
   faculae (surrounding sunspots), 803  
   green flash, 862  
   halos around, 842-855  
   optical phenomena around, 163  
   output variations, 803  
   pillar, 842-843, 854-855  
   radius angle as viewed from Earth, 33  
   red, 858  
   shape when rising or setting, 862  
   subsun, 842, 844, 854-855  
   synchronous orbit, 227-229  
   younger, 803  
   zenith angle, 33  
 sundial time, 34  
 sunlight, 131-132  
 sunrise  
   apparent & geometric, 33-34, 861-862  
   time, 33-34  
 sunset  
   apparent & geometric, 33-34, 861-862  
   blue color, 858  
   red color, 858  
   time, 33-34  
 sunshine, constant (isohel), 18  
   and cloud formation, 162  
 sunspot  
   activity or cycle, 39, 803  
   faculae, 803  
   number, 803  
   superadiabatic lapse rate, 139-140  
 supercell  
   thunderstorm, 482-484, 492-495  
     classic (CL), 492-494, 549, 553  
     composite parameter (SCP), 530-531, 592  
     effective (eSCP), 591  
     high-precipitation (HP), 495  
     hybrid, 492  
     indices for forecasting, 530-531, 588-592  
     intensity forecasting, 501, 507, 516, 521-522, 524, 530-531  
     likelihood, 516, 530-531  
     low-precipitation (LP), 495  
     motion, 518-520  
     normal storm motion, 516-518  
     right- and left-moving, 518-520  
     rotation (as a mesocyclone), 586-592  
     storm-relative wind statistics, 585  
   tornadoes, 577, 582, 588-592  
 supercontinents (Pangea, Gondwana, Laurasia), 804  
 supercooled liquid water, 88, 98, 186, 194-195, 201-202  
   glaciation of, 554  
   lightning creating, role in, 564-566  
 supercritical flow, 659  
 supergeostrophic wind, 304, 311, 455, 699-700  
 supergradient wind, 643  
 superior  
   airmass code, 392  
   mirages, 862-863  
 supernumerary bows, 838, 860-861  
 superposition of light rays, 845  
 superrefraction of radar beam, 244-245  
 supersaturated, 88  
   air, 88  
 supersaturation, 185-187  
   activating nuclei, 195  
   available, 187  
   background, 197  
   critical, 192  
   droplet growth rate, 190-192  
   fraction, 186, 196-197  
   gradient, 196-197  
   percentage, 186, 196-197  
   reduction of, in WBF, 201-202  
   water availability to make droplets, 186-187  
 supersonic  
   flight, 88  
   shock waves in thunder, 571-574  
 supertyphoon, 607  
 supplementary cloud features, 168-169  
 suppression of hail, 553  
 supralateral arc, 854-855  
 surf, 635

- surface (also see near-surface)  
 albedo feedback (snow & ice cover), 810-812  
 based CAPE, 503-506  
 budget of radiation, 44-45, 797  
 drag, 300-301, 319, 447-448, 625, 632-634, 700-701  
 emissivity, 42  
 energy budget, global, 797  
 fluxes, 67-69  
 front, 399-412  
   attributes, 399  
   glyphs (lines) on weather maps, 399  
   horizontal structure, 400-402  
   vertical structure, 403-407  
 heat budget, 73-76, 797  
   Bowen ratio, 74-76  
   daily variation of, 74  
   units, 74  
 heat flux  
   airmass modification by, 397-398  
   bulk transfer relationships, 397-398  
   calm days, 68  
   effective turbulent, 68  
   measurement, 75  
 isobaric, 290-291  
 latent heat flux, 108  
 layer, 308, 692, 700  
   depth, 308, 692  
   log wind profiles, 702-705  
   neutral, 702  
   stable, 702-703  
   temperature profile, 692-694  
   turbulence, 705, 709  
   unstable, 703-705  
   winds, 692, 700-705  
 moisture flux, 108-111  
 observations, 270-271  
   automatic (ASOS and AWOS), 271  
 parameterizations in NWP models, 750  
 radiation budget, 44-45  
   longwave (IR), 45  
   net radiation, 45, 797  
   solar, 44  
 roughness, 677-678, 700-703  
 sensible heat flux, 73-76, 797  
 skin temperature, 67-68  
 solar radiation, 44  
 temperature  
   gradients, 66-75, 872  
   max, for thunderstorms, 506, 523  
   tension of pure water, 189, 215, 880  
   weather maps, 435, 437-438, 466  
   waves (in open channel hydraulics), 658-661  
   winds, 701  
   wind-waves, 634-636  
 surfaces of constant  
   height above ground (= 0 for surface maps), 437  
   height above mean sea level (= 0 at MSL), 436  
   potential temperature, 437  
   potential vorticity, 437  
   pressure, 436  
   thickness, 436  
 surge(s)  
   power, due to lightning, 569-570  
   probabilities, 569  
   storm, due to hurricanes, 632-634  
 surplus radiation, 338  
 surrogate vertical velocity, for mass budget, 463-464  
 Sutcliffe development theorem (for cyclogenesis), 456  
 Sverdrup, H.U., 399  
 swamp coolers, 116  
 swaths of hail or snow, 163, 548, 552  
 sweat, 93  
   index (severe weather threat), 531  
 swell, 635  
 swirl ratio, 530-531, 592-593  
 switching axes of graphs, 3  
 symbols and notation, 481  
   for ice crystals, 199  
   for fronts, 399  
   for weather maps, 168-170, 208, 274-279, 614-615  
 SYNOP code, 269, 271  
 MOBIL, 269  
 synoptic  
   definition, 268, 274  
   observations, 268-273  
   meteorology, 353, 444  
   scale, 315, 444  
   cross-mountain pressure gradient, 661-664  
   divergence, 393-396  
   vorticity needed for hurricanes, 610  
   weather, 274, 444  
   times for NWP forecasts, 758  
   weather maps, 274-281, 444  
 synopticians, 444  
 synoptics, the field of, 444  
 synthesis  
   PCA reconstruction of data, 823  
   questions at end of each chapter, explained, 25  
 synthetic aperture radar (SAR), 230  
 Syracuse, 150  
 systematic errors (biases), 770, 777, 875
- T**  
 T time zone (Mountain), defined, 5  
 T-phi thermo diagram (tephigram), 122  
 table-driven code formats (TDCF), 268  
 TAF (terminal aerodrome forecast) code, 269  
 tail  
   beaver, 483  
   cloud (cauda), 169, 483  
   winds, aircraft, 563  
 tailored weather forecasts, 772  
 Talmud, 523  
 Tambora, Mt., 805  
 tangent arcs, 851-855  
   lower, 851-8532, 854-855  
   upper, 842, 851-852-854-855  
 tangential  
   component, 249, 304-312, 320-321, 362-364, 577-581, 626-627  
   velocity  
     hurricane model, 626-627  
     hurricane winds, 622-623  
     of earth, 298-299, 360-361  
     tornado, 577-580  
     winds near surface, 622-623  
     winds varying with altitude, 618-623  
 Tarantian age, 799  
 tax, 711  
 Taylor, G.I., 731  
 Taylor series, 754-755  
   finite differencing schemes, 754-755  
   truncation order, 754-755  
 Taylor's hypothesis, 731  
 Taylor's statistical theory for pollutant dispersion, 731  
 TCU (see towering cumulus, or cumulus congestus), 161-162, 165-166, 168, 482-485, 582  
 tectonic influences on climate, 804-805  
 teleconnections, 832  
 telescope, reflecting, 293, 862  
 TEMP code, 269, 271  
 DROP, 269  
 MOBIL, 269  
 SHIP, 269  
 temperature, 6-7, 54, 870  
   absolute, 7  
   absolute virtual, 14-15  
   absolute zero, 7  
   advection, 65-67  
   in grid cells, 750, 754-761  
   role in self development of cyclones, 468-469  
   airmass, 391-397  
   apparent, 76-78  
   brightness, 211, 221-224  
   Celsius, Centegrade, defined, 7  
   change with height, 11-13, 129-144  
   city (urban heat island), 678-679  
   climate, radiative balance, 794-797  
   constant (isotherm), 18  
   contrasts between land and water, 356  
   convective condensation, 526-527  
   conversion formulae, 7  
   correction for dynamic warming, 673-674  
   definition, 6-7  
   dew-point, 92-93  
   isodrosotherm, 18  
   distribution over hurricane depth, 621-625, 629  
   dynamic, 672-674  
   Earth effective radiative, 794, 879  
   equivalent potential, 104-106  
   errors, 766  
   evolution, 72-73, 746  
   excess in cities, vs. population, 649  
   Fahrenheit, defined, 7  
   field, 280, 343, 359  
   forecast equations, 746  
   frost-point, 92  
   global warming, 796  
   gradient  
     derivation of equation, 336  
     equator to pole, 336  
     horizontal; meridional, 335  
     in troposphere, 335-336  
     near the ground, 335-336  
   heat index, 77-78, 117  
   humidex, 77-78, 117  
   humidity index, 77-78, 117  
   hurricane model, 621-622, 629  
   ice-albedo feedback, 808-812  
   instruments, 78-79  
     correction for dynamic warming, 673  
   inversion, 139, 144, 687-691  
   isotherm, isothermal, 18  
   Kelvin, defined, 7  
   lapse rate, 59-60  
   latitude variation of, 335  
   layers of atmosphere, 12  
   lightning, of, 563  
   liquid-water potential, 104, 500  
   max surface, for thunderstorms, 506, 523  
   measurement, 78-79  
     correction for dynamic warming, 673  
   meridional gradient, 335-336  
   METAR, 270  
   mixed layer, 692-698  
   modification in airmasses, 397-399  
   molecular velocity, 6  
   of planets in the solar system, 22  
   potential, 61-64, 500  
   profile, 3  
     evolution of boundary layer, 694-696  
     hypothetical, 3  
     vs. geopotential height, 11-12  
   radiative  
     emission, effective, 794  
     equilibrium, 794-797  
   reversal in stratosphere, 359  
   sea-level, 7  
   sensible energy, 54  
   sensors, 78-79  
   sounding locations from satellite, 273  
   stable boundary layer, 696  
   standard, 7  
     STP, 7, 107, 880  
   static, 672-674  
   stratospheric, 359  
   surface, 12, 794-797  
   tendency, 64, 72, 746  
   thermo diagram, 119-158  
   threshold for ice nucleation, 195  
   units, defined, 7, 870  
   urban-rural difference, 679  
   variation of saturation humidity, 88-90  
 virtual, 14-15  
   constant, 880  
 virtual potential, 61-62  
   vs. height, 11-12, 127-145  
   near surface, 335  
   weather maps, 274-275, 438-440  
   wet-bulb, 94-96, 500  
   wind chill, 76-77  
   zonally averaged, 335-336  
 temperature influence on albedo (modeled), 808  
 temperature-dew-point spread, 92  
 temperature-humidity index (THI), 77-78  
 tempest, 607  
 tendency, 18  
   height, 463  
   in forecast verification, 778  
   pressure, at MSL, 463-467  
   term, 747  
   temperature, 746  
 tephigrams (also see thermo diagrams), 121-158  
 tera ( $10^{12}$ ), 870  
 terminal velocity of, 202-204  
   cloud droplets, 202  
   hydrometeors, 202-204  
   rain drops, 203, 555  
     causing downbursts, 555  
   hailstones, 204, 549  
 terminology, process, 18  
 terrain (also see mountains), 365, 397-398  
   following coordinate system, 746, 753  
   influence on cyclogenesis, 443-446  
 terrestrial radiation (or IR or longwave), 37-39, 223  
 tertiary rainbow, 840  
 TESAC code, 269  
 Tetens' formula, 90  
 Texas, USA, 416, 431, 560  
 theoretical  
   meteorology, 872  
   winds, 302-313  
 thermal(s)

- belt for crops on mountain slopes, 653  
 circulations, 341-342, 356, 648-657  
   in hurricanes, 613  
   in local winds (e.g., sea breezes), 655  
 clouds, in, 162  
 convective, 649, 694, 710  
 diameters, 648-649  
 drag, felt by, 648-649  
 energy transferred, 58, 672  
 internal boundary layer (TIBL), 654-657  
 lidar image of, 649  
 low, 341-342, 356, 430-431  
 rise, 649, 710  
 scales of motion, 315  
 stress index, 117  
 updraft, 648-649  
 upside-down, cold-air sinking, 177, 396  
 wind, 345-348  
   African easterly jet, creation by, 611  
   advection of vorticity (cyclogenesis), 456-462  
   case study, 348-349  
   components, 347  
   cyclone propagation direction, 469  
   direction, 347-348  
   effect, 345-346, 352  
   magnitude, 347  
   wind relationship, 345-349  
   in hurricanes, 621-623  
   thermal wind, 346-348  
   thickness, 345-346, 436
- thermally driven circulations, 341-342, 648-657  
 anabatic wind, 649-652  
 direct, 351, 412  
 hydrostatic, 341-342  
 katabatic wind, 652-653  
 monsoons, 356  
 sea-breeze, 654-657  
 thermals, 68, 648-649
- thermister, 78  
 thermocline, 610  
 thermocouple, 78  
 thermo diagram (see thermodynamic diagram), 119-158
- thermodynamic diagram, 63, 119-158  
 airmass modification over mountains, 398-399  
 applications, 127-133  
   chinook and foehn winds, 676-677  
 blanks, 151-158  
 boundary layer, for, 144, 157-158  
 building/creating, 119  
 cloud base height, 130, 162, 164, 496-498  
 cloud diagnosis, 134  
 cloud top, 162, 164, 496-498  
 complete/full/large, 121, 151-158  
 components, 119-121  
   adiabats, 63, 103  
   buoyancy, 135-136, 498, 503-508  
   cloud base, 130, 162, 164, 496-498  
   dry adiabats, 63, 119-128  
   environmental lapse rate, 134-136, 138, 496-498, 503-508  
   height contours, 121  
   isentropes, 63  
   isobar, 63, 100, 119-128  
   isohume, 100-102, 119-128  
   isotherm, 63, 100, 119-128  
   lifting condensation level, 93-96, 105-107, 130, 138, 162, 164, 483, 496-501, 522-527, 530-531  
   moist adiabats, 102-106, 119-128, 496-499, 503-506, 522-527  
   convective inhibition (CIN) determination, 523-526  
   dew-point temperature, 128  
   dry (unsaturated) processes, 129  
   environment, 134  
   excess water, 186  
   for boundary layer, 157-158  
   humidity, 128  
   hurricane thermodynamics, 624-625  
   identifying different types of, 126-127  
   isohumes of mixing ratio, 100-101  
   locate stable layers, 733-734  
   masters, 151-158  
   misinterpretation, 729  
   mixing ratio, 128  
   moist (saturated) processes and liquid water, 101-106, 129  
   mountains, lifting over, 398-399  
   parcels vs environment, 134  
   partial water fallout from clouds, 130-131  
   plotting on, 128  
   pressure, 128  
   processes, 100-106, 121, 129-133  
   dry (unsaturated) lifting/lowering, 129  
   moist (saturated) lifting/lowering, 130  
   precipitation, 130-131  
   radiative heating/cooling, 131-132  
   relative humidity, 133  
   saturated adiabats, 102-106  
   saturated (cloudy or foggy) air, 128, 130  
   saturation mixing ratio, 128  
   soundings, 134-135  
   spreadsheet construction of, 63, 103  
   state, 100, 121  
   temperature, 128  
   thunderstorm thermodynamics, 496-526, 557-558  
   total water mixing ratio, 128  
   types, 121-123  
   emagram, 119-123, 127, 152  
   P vs. alpha diagram, 121  
   pseudoadiabatic diagram, 121-123, 153  
   skew-T log-P diagram, 121-125, 154, 157  
   Stüve diagram, 121-123, 153  
   tephigram, 121-123, 155  
   T - log P (emagram), 119-123, 127, 152  
   theta-height diagram, 121-123, 156, 158  
   unsaturated air, 128  
   wind, plotted on, 510
- thermodynamic  
 method of mixed layer growth, 394-395, 697-698  
 state, defined, 6  
   density, 10  
   on a thermo diagram, 128  
   pressure, 7  
   temperature, 6  
   within a hurricane, 624-625
- thermodynamics  
 first law of, 53, 58-59, 64-65  
 frontogenesis, 411  
 heat, 53-86  
 hurricane, 620-625  
 thunderstorm, 496-508, 522-526  
 topics, 1
- thermohaline circulations in ocean, 804  
 thermometers, 75, 78-79, 219  
 thermopause, 13  
 thermosphere, 12-13  
 thermostat, 78  
 theta (q) - (potential temperature), 61-63, 103-106  
 theta-height (z) thermodynamic diagram, 121-158  
 theta-w vs theta-e, 105
- thickness, 17  
 100 to 50 kPa chart, 346-348, 436, 439, 442  
 contours, 346-348, 458  
 definition, 17, 345-346  
 in high pressure center, 390-391  
 of clouds, 161-162  
 on weather maps, 346-348, 436, 439  
 optical, 43, 805, 856  
 related to thermal wind, 345-349, 436  
 temperature relationship for, 79
- threads (see end of each chapter)  
 threat score, 781-782  
 equitable, 782
- three-band general circulation, 329, 376-378
- threshold  
 for binary/categorical forecasts, 780  
 for probability forecasts, 777  
 temperatures for ice nucleation, 195
- thunder, 571-576  
 3-second rule, 575  
 audibility, 575-576  
 creation mechanism by lightning, 571  
 distance away, 576  
 force of, 571  
 ray paths, 575-576  
 shock wave, 571-574  
 sound wave, 575-576
- thunderhead, 482  
 thundersnow, 207  
 thunderstorm(s), 481-602  
 airmass, 486  
 altitudes, 496-499  
 appearance, 482  
 aspect ratio of, 485  
 attributes, 481-495  
 base at LCL, 497-498  
   elevated inflow, 522  
 basic, 486-487  
 bear's cage, 495  
 beaver-tail cloud, 492, 494-495  
 bookend vortex, 490-491  
 bow echo, 490-491  
 bursticane, 602  
 CAPE, 503-508, 530-531, 590  
 cauda (tail cloud), 169  
 cells, 484-485  
 change criterion for SPECI, 270  
 chasing, 484  
   safety, 485, 517, 567, 570, 583-584  
 CIN (convective inhibition), 522-526, 590  
 classic supercell, 492-494, 549, 553  
 cloud shield, 488  
 clouds associated with, 482, 488, 494  
 cold-pool of air, 488  
 conditional instability, 141, 498, 503-508  
 convective available potential energy (CAPE), 503-508, 530-531  
 convective conditions, 496-499, 530-531  
   high humidity in the ABL, 499-502  
   instability (nonlocal conditional), 503-508  
   trigger mechanisms causing lifting, 522-526  
   wind shear in the environment, 509-521  
 convective inhibition (CIN), 522-526, 530-531  
 Coriolis force, effect on, 490-492  
 CPTP = cloud physics thunder parameter, 530  
 cumulonimbus cloud, 161-162  
 daily cycle, 528  
 damage scales, tornado, 579-580  
 derecho, 491, 494  
 development, 484-485  
 difficulties in forecasting, 527-528, 547  
 direction (see movement), 516-520  
 downbursts and gust fronts, 554-562  
   downdraft CAPE, 530-531, 557-559  
   evaporative cooling, 556  
   gust fronts, 560-563  
   precipitation drag, 555  
   pressure perturbation, 559-560  
   radar observations of, 253  
 downdraft CAPE (DCAPE), 530-531, 557-559  
 downdrafts, 483, 492-494  
 duration/lifetime, 486  
 echo-free vault, 493  
 effective  
   bulk shear, 522  
   bulk wind difference, 522  
   depth, 522  
   inflow layer & inflow base, 590  
   layer, 522  
   storm relative helicity (eSRH), 590  
   supercell composite parameter (eSCP), 591  
 elevated inflow, 522  
 energy helicity index, 530-531  
 energy released by, 499  
 environment, 141, 496-499  
   pre-storm, 496-531  
 equilibrium level (EL; storm top), 497-506  
 evolution, 484-485  
 flanking line, 492, 494  
 flow stability, causing, 138  
 flumen (inflow cloud bands), 169  
 forecasting, 527-532, 547  
 formation conditions, 496-527  
 forward-flank downdraft (FFD), 483, 492-493  
 frequency/activity (isoceraunic), 18  
 frontal, 400, 525  
 graupel, 493  
 gust fronts, 494, 554-562  
 hail, 493, 548-553  
   significant hail parameter (SHIP), 530-531  
 hazards, 481, 545-602  
 heat  
   flux profile, 70-71  
   released, 546-548  
 helicity, 587-592  
   storm-relative (SRH), 530-531  
   updraft (UH), 530  
 high-precipitation (HP) supercell, 492, 495  
 highs (anticyclones) associated with, 391  
 hook echo, 494  
 humidity, 499-502  
 hurricanes, in, 604, 613-615, 620-621, 637  
 hybrid supercell, 492  
 in cold fronts, 400, 525  
 indices for forecasting, 530-531  
 inflow bands (flumen), 169  
 inflow of humid air from ABL, 546-547  
 influence on mixed layer, 510  
 instability, 496-508  
 intensity forecasting, 501, 507, 516, 521-522, 524, 530-531  
 key altitudes, 496-499  
 latent heating inside, 546-548  
 level of free convection (LFC), 497-506, 530

- lifting condensation level (LCL; storm base), 497-506, 530-531
- lifting needed to trigger, 522-527
- lightning and thunder, 563-576
  - global lightning mapper, 235
- limit of convection (LOC; see equil. level), 498
- line-end vortices, 490
- long-lasting, 509-510
- low-precipitation (LP) supercell, 492, 495
- main updraft, 483, 492, 495
- MCC (see mesoscale convective complex), 491
- MCS (see mesoscale convective system), 488-492
- mesocyclone, 481, 483, 492-495, 510, 582, 586-591
- meso-high, 391, 488
- meso-low, 489
- mesoscale convective
  - complex (MCC), 491
  - systems (MCS), 488-492
  - vortex (MCV), 492
- midlatitude-cyclone related, 425-428, 434, 438, 466
- mixed layer, 496-503
- movement, 483, 510
  - normal storm motion, 516-518
  - left- and right-moving, 518-520
- multicell, 486-487
- muris (wall cloud), 170
- nighttime, 590
- nonlocal conditional instability (NCI), 498, 503-508
- organization, 486-495
- orographic, 487, 526, 547-548
- outflow winds, 560-562
- outlook forecasts of convection, 528-530
- overshooting dome (penetrative convection), 498
- parameterization in NWP models, 751
- path (see movement), 516-520
- precipitation, 206, 486, 493, 495, 545-554
- precursor clouds (altocumulus castellanus), 165
- pressure perturbations, 559
- propagation of, 485, 494
- pulse, 486
- radar images of, 243, 248, 253-254, 482-483, 486-488, 490-495, 552-553
- radiative effects, 131-133, 624-625
- rain, heavy, 545-548
- rainfall rate, 546
- random effects in thunderstorm development, 527
- rear-flank downdraft (RFD), 492-494
- rear inflow jet (RIJ), 489
- risk of, 528-530
- rotation, 586-591
- safety, 485, 517, 567, 570, 575, 583-584
- satellite images of, 234
- sequence of events, 484
- severe thunderstorm
  - definition, 528
  - environment, 496-502
  - watches and warnings, 528-530
- severity forecasting, 501, 507, 516, 521-522, 524, 530-531
- significant hail parameter (SHIP), 530-531
- significant tornado parameter (STP), 530-531
- single-cell, 486
- size, 481-498
- soundings, pre-storm environmental, 496-499
- squall line, 243, 488, 490, 582
- SR (storm relative), 584
  - winds, statistics for, 585
- stability indices, 530-531
- stages of evolution, 485
- storm-relative helicity (SRH), 530-531, 590
- straight-line winds, 489-490, 554, 560-563
  - derecho, 491, 494
- stratiform clouds, 488-489, 492
- strength forecasting, 501, 507, 516, 521-522, 524, 530-531
- supercell, 482-484, 492-495, 549, 553
  - composite parameter (SCP), 530-531
  - effective (eSCP), 591
  - tornadoes, 577, 582
  - wind statistics, 585
- steering-level winds, 487
- suppression of neighboring storms, 547
- swirl ratio, 530-531, 592-593
- symbols on weather maps, 275-276, 481
- tail cloud (cauda), 169
- thunder, 571-576
- timing, 528, 546
  - effect of mountains on, 528
- top
  - cold, 546
  - equilibrium level (EL), 498
- tornadoes, 494, 577-593
  - significant tornado parameter (STP), 530-531
  - triggering, 496, 522-526
  - tropical, 331-332, 350-351
  - tropopause vs. storm top, 496-506
  - turbulence (see updrafts & downbursts), 111, 508, 527-530
  - types, 486-495
  - UH = updraft helicity, 530
  - unfavorable conditions for, 499
  - updrafts, 483, 498, 503-508, 649
    - helicity (UH), 530
  - upslope, 526
  - vault (echo-free), 493
  - venting of boundary layer air, 691-692
  - violent, 492, 498
  - warming rate due to condensation, 546
  - warnings and watches, 528-530
  - watch-box, 528-529
  - weak echo region (WER), 493
  - weakly forced (airmass), 486
  - weather-map symbols, 275-276, 481
  - wind shear in pre-storm environment, 509-521
- Tibetan low, 354-356
- TIBL (thermal internal boundary layer), 654-657
- tidal bulge of solid earth, 229
- tides, lunar and solar, 376, 635
- tight packing of isopleths, 143
- tiling method for finding CAPE & CIN areas, 504-505, 524
- tilt of
  - earth axis (obliquity), 30, 798-803, 879
  - variations and climate, 798-803
  - high pressure with altitude, 390-391
  - low-pressure with altitude, 432
  - mountain waves with altitude, 668
  - troughs with altitude, 432
- tilted
  - coordinate system, 124-125, 650-653
  - isobars, 345-349, 359
- tilting
  - effect on frontal zone strength, 409
  - of cold-core cyclone, 622
  - of front, 412
  - of tropopause, 415
  - of trough, role in cyclogenesis, 432, 622
  - of vertical temp gradient, 409
  - of wave crests with altitude, 668
  - term in vertical vorticity eqn, 447-448, 586-587
- time, 870
  - airmass thickness, max, 395
  - astronomical values that determine time, 34
  - constant (isochrone), 18
  - daylight (summer), 5
  - differencing in NWP, 757
  - e-folding, 9, 393-396
  - equation of, 34
  - GMT, 5
  - isochrone, 18
  - lead, 762
  - line, numerical, 757
  - scales, 315
    - Lagrangian turbulence, 732
  - standard, defined, 5
  - step, 750
  - sunrise & sunset, 33-34
  - twilight starts and ends, 33-34
  - units, 870
  - UTC, defined, 5
  - valid, 762
  - zones, defined, 5
  - Zulu, defined, 5
- tipping bucket rain gauge, 210
- tips for doing homework exercises, 20-26
- TiROS (Television and Infrared Operational System), 273
- TKE (see turbulence kinetic energy), 708-710
- Toba, Lake, 805
- tongue, dry air, 429
- tonne mass units (or metric ton), 870
- tools, scientific, 877
- top of
  - atmosphere, observations of, 220
  - clouds, 162
  - mixed layer, 497
  - thunderstorm (equilibrium level, EL), 497
- topographic formation of highs, 391
- tornado, 483, 494, 577-593
  - appearance, 581-583
  - bait, 592
  - blowdown of trees, 593
  - boundary layer of, 586
  - breakdown bubble, 592-593
  - bulk Richardson number shear, 522
  - Burgers-Rott vortex (BRV), 599
  - change criterion for SPECI, 270
  - cold-air funnels, 582
  - cone shape, 577
  - core pressure deficit, 577-578
  - cylinder shaped, 577
  - damage
    - exploding houses, 674
    - paths, 584
    - scales, 579-580
  - debris cloud, 581-583
  - developing stage, 583
  - dissipating, 583
  - dust swirl, 583
  - evolution, 583
  - family, 584
  - forecasting, indices for, 530-531, 588-592
  - frequency in USA & Canada, 579
  - funnel cloud, 483, 581-583
  - hourglass shaped, 577
  - in hurricanes, 584, 627, 637
  - intensity scales, 579-580
    - enhanced Fujita (EF) scale, 578-580
    - forecasting, 501, 507-508, 516, 522, 530-531
    - Fujita (F) scale, 579
    - Torro (T) scale, 579-580
  - irrotational winds around, 385
  - landspouts, 582
  - life cycle, 583
  - likelihood, 591
  - mature stage, 583
  - mesocyclones and helicity, 582, 587-592
  - multiple vortex, 592-593
  - origin of rotation, 586-587
  - outbreaks, 583-584
    - in hurricanes, 637
  - intensity scales, 579-580
  - origin of rotation, 586-587
  - pressure
    - decrease in core, 577-578
    - increase due to wind stagnation, 672-674
  - Rankine combined vortex wind model, 577-578, 599
  - reports, 532
  - rope shape/stage, 577, 583
  - rotation, 577-578
    - direction, 578-579, 586
    - origin, 586-587
  - safety, 583-584
  - scales, 579-580
  - shapes, 577
  - significant vs. weak, 501, 507-508, 516, 522, 530-531, 580
  - significant tornado parameter (STP), 530-531, 592
  - spin-up, 586-587
  - stages in evolution, 583
  - suction vortices, 592-593
  - supercell, 582
  - swirl ratio, 530-531, 592-593
  - tangential velocity vs. intensity, 577-580
  - thunderstorms, relationship to, 577
  - total speed, 578
  - translation speed, 578, 582
  - types, 582-583
  - V-shaped, 577
  - vortex signature, 251, 253, 599
  - vortices that are not tornadoes, 582-583
    - dust devils, 582
    - gustnadoes, 582
    - steam devils, 583
    - firewhirls, 583
  - wall cloud (muris), 170, 483
  - watches and warnings, 528-530
  - waterspouts, 582
  - weather-map symbols, 276
  - wedge, 577
  - winds
    - cyclotrophic, 311-312
    - dynamic warming, 673
    - exploding houses, 674
    - irrotational, 385, 577
- torque on
  - atmosphere, 366
  - Earth, 376
  - satellite orbit, 229
- Torr, 7
- TORRO scale for hailstone diameter, 548

- tornado intensity (T), 579-580
- total
- deformation, 321
  - derivative, 872
  - entropy, 624-625
  - meridional heat transport, 378
  - shear magnitude, 515-516
    - distribution of, 515
  - solar irradiance (TSI), 39, 793-794
    - variations, 803
  - totals index (TT), 531
  - water, 94, 97-99
    - conservation of, 99-111
    - content in a column of air, 211
    - fallout from cloud, 108
    - in fogs, 176
    - in thermo diagram, 128-133
    - mixing ratio, 97-99, 186
    - reduction in thermo diagrams, 130-133, 397-398, 676
- TOVS (TIROS Operational vertical sounder), 273
- tower
- hot convective, 644
  - updraft, 482
- towering cumulus (tcu), 162, 168, 483
- stage of thunderstorm-cell evolution, 485
- toy model(s) of, 330
- airmass formation, 393-396
  - climate processes, 793-796
  - differential heating (global), 334-339
  - extratropical cyclone, 450-451
  - global circulation, 330-334
  - hurricanes, 626-629
  - jet stream, 359-360
  - MSL pressure tendency, 464-467
  - transmittance of radiation, 225-226
- trace
- matrix, 822
  - rainfall rate, 208
- tracers, passive, conservative, 731
- TRACKOB code, 269
- tracks
- extratropical cyclones (lows), 429-431
  - tropical cyclones (hurricanes), 607-608, 615
  - thunderstorms and tornadoes, 483, 516-520, 584, 593
- trade
- inversion, 351
  - winds, 330-332, 351
    - cumuli, 351
    - role in steering hurricanes, 607-608, 615
    - role in triggering hurricanes, 610-612
    - Walker circulation, 820
- trading, emissions, 742
- trajectories, 668-669
- backward, 724
  - forward, 724
  - of hailstones, altering, 553-554
  - path lines, 669
- transfer of electric charge, 564-566
- transformations: inertial or Newtonian, 715
- transient turbulence theory (T3), 714, 716
- transition
- hurricane extratropical, 615
  - winds: anabatic vs. katabatic, 654
- translation of
- hurricanes, 627-628
  - thunderstorms, 516-520
  - tornadoes, 578, 582
- translucent, 42
- translucidus, 169
- transistors, 752
- transmission of radiation, 41-43
- transmissivity, 42
- net sky, 44
- transmittance of atmosphere, 220-226
- profiles, 225-226
- transmitted solar radiation, 805, 856-858
- transparency of
- atmosphere, 220-223
    - reduction due to volcanic eruptions, 805
  - clouds, 169
  - windows on radiometers, 45
- transpired (CO<sub>2</sub> from plants), 812
- transport
- coefficients
    - bulk heat, 68
    - bulk moisture, 109
    - convective coefficient, 68, 109
    - Ekman, hurricane, 610, 633-634
    - energy, 53, 499-502, 708-709
    - heat, 68
      - global, 338-339
      - planetary waves, by, 374-375
    - mixed layer coefficient, 68
    - momentum, global, 375-376
    - turbulent, 709
      - of heat, 67-71
      - of moisture, 109-111
      - velocity of turbulence, 300
  - transverse (cross-frontal) circulation, 412, 415
  - trapped low-level barrier jet, 664-665
  - trapping of
    - pollutants, 725
    - radar beam, 244-245
  - tree
    - blowdown by downbursts & tornadoes, 593
    - ring dating (dendrochronology), 803
  - Trenberth omega equation (see omega equation), 456-458
  - Trenberth, Kevin, 339, 458, 797
    - omega equation, 458
  - triangle shaped ice crystals, 199
  - Tricker arc, 854-855
  - trigger mechanisms for
    - hurricanes, 610-613
    - thunderstorms, 485, 496, 522-526
  - trigonometric conversions, 650
  - trimming data, 826
  - triple point, 414
  - trof (see trough)
  - trop (see tropopause)
  - Tropic of
    - Cancer, 31
    - Capricorn, 31
  - tropical
  - airmass
    - code, 392
    - genesis, 393-395
  - cloud heights, 163
  - convection variations due to ENSO & PDO, 820
  - convergence
    - in easterly waves, 611-612
    - zone (ITCZ), 330-332, 351, 610-612
  - cyclogenesis (birth of hurricanes), 608-610
  - cyclolysis (death of hurricanes), 616
  - cyclones (see hurricanes), 330, 427, 603-644
  - cumulus, 351
  - depression, 613-614
  - disturbance, 613
  - easterly jet and waves, 611-612
  - forecasters/meteorologists, 343, 611, 613
  - geostrophic & gradient winds, 611-612
  - hurricane, 603-644
    - monsoon, 333-334, 356, 612
    - Prediction Center, 638
    - rainfall, 209-211, 351
    - storm, 614-615, 635-636
      - watches & warnings, 638
    - streamlines, 611-612
    - thunderstorms, 331-332, 351-352
  - trade inversion, 351
  - trade winds, 331, 351, 358, 376, 610, 612, 615
  - tropopause, 163
  - typhoon (see hurricanes), 603-644
  - upper tropospheric trough (TUTT), 612-613
  - winds, 611-612
  - year, 31
- tropics, 330
- intertropical convergence zone (ITCZ), 233
- tropopause, 12-13, 414-415
- folding
    - fronts, upper-level, 414-415
    - isentropic potential vorticity, 364, 441-443
    - of cyclone case study, 441-443
    - on weather maps, 364, 441-443
    - ozone injection by, 364, 414-415
    - radionuclide injection by, 364, 414-415
    - satellite observations of, 234
  - height, 143
    - determination, 143, 496
    - variation with latitude, 163, 353
  - pressure, 163
  - thunderstorm tops near, 497-498
  - winds near (also see jet stream), 331-332, 357-362
- troposphere, 12-13
- average density, 72
  - average depth, 12
  - coupling with daily heating cycle, 687-692
  - depth, 12, 143
    - variation with latitude, 163
  - folds, 364, 414-415
  - upper trough, tropical (TUTT), 612-613
- tropospheric constraints on atmos. boundary layer, 689-690
- trough(s) (see also midlatitude), 332
- axis, 281, 367
    - of cyclone case study, 433
    - symbols on weather map, 281, 399
  - circumpolar, 432
  - formation & characteristics, 367-376
  - in tropical easterly waves, 611-612
  - in Rossby waves, 353, 367-376
  - monsoon (MT), 612
  - tilt with altitude, 432
  - tropical upper-tropospheric (TUTT), 612-613
  - upper-level disturbance, 433
- TROWAL (trough of warm air aloft), 281, 399, 413-414
- true
- anomaly, 29, 802
  - longitude, 802
  - skill score, 781
- truncation error, 754-755, 760
- trunk space, 677-678
- TSI = total solar irradiance, 39-45
- tuba, 169
- tumble of small falling ice crystals, 842
- turbine, wind
- efficiencies, 647-648
  - pressure change across, 671
- turbulence, 705-716
- atmospheric boundary layer (ABL), 687, 705-716
    - above ABL, 110, 687
    - airmass characteristics of, 391-396
      - role in evolution, 393-396
  - buoyant, 704, 705
    - generation, 709-710
  - cascade, 315
  - clear-air (CAT), 141-142, 165
  - closure, 713-716
  - closure types, 714-716
    - K-theory, 714-716
    - transient turbulence theory, 716
  - clouds created by, 165-166
  - conservation, 706, 708-709
  - covariances, 711-713
  - convection
    - forced, 710
    - free, 710
  - convective, 705
    - mixed-layer, 704
    - thunderstorm, 508, 527-530
  - correlation coefficients, 711-713
  - defined, 705
  - determination, 138-142
  - dispersion of pollutants, caused by, 723-744
  - dissipation, 706, 709
  - existence, 142
  - fair-weather, 69-70
  - flux
    - as a covariance, 711-713
    - from advection terms, 714
    - divergence terms, 747
    - gradient, 65, 67-71, 107-111, 698, 711-716, 746-747
    - heat, 711-714
      - momentum, 713
    - forced convection, 710
    - free convective/convection, 704, 710
    - heat budget, in, 69, 713-716
    - heat flux, 711-712
    - in air masses, 397-398, 691-692
    - in cloud
      - rotor clouds, 165
      - thunderstorms, 481-602
    - in neutral static stability
    - inertial subrange of, 708
    - intensity, 710
    - intermittent, 692
    - isotropy, 707, 710
    - kinetic energy (TKE), 708
      - advection, 708
      - budget equation, 708
      - buoyant production or consumption, 709
      - cascade, 315
      - dissipation, 709
      - generation, 708-709
      - shear generation, 708-709
      - tendency, 708
    - mean and turbulent parts, 705-706
    - mechanical, 704, 705
    - microscale, 708
    - momentum flux, 713
    - mountain wave, 667
    - onset, 142
    - parameterization in NWP models, 751
    - production, 708-709
      - scales of motion, 315



- radar observations of CAT, 242  
 radar spectrum width in, 254  
 raindrop growth affected by, 206  
 scales of motion, 315  
 shear, 704, 705  
   generation, 708-710  
 stability dependence, 119, 138-142, 688, 707-708, 710  
 stably-stratified (SST), 710  
 stationary, 708  
 statistics, 706-708, 726-728  
 stormy-weather, 70-71  
 terms, derivation, 714  
 thermal, 134-140, 144, 648-657, 704, 708-710, 716  
 thunderstorm, 111, 508, 527-530  
 transient, 714-716  
 transport, 300, 709  
 types, Pasquill-Gifford, 727-728  
 velocity scales, 68-69  
 wake, behind mountains, 667
- turbulent**  
 continuity equation, in flux form, 714  
 convective mixing, 69-71, 108-111, 138-139, 144, 704, 710, 735-737  
 dispersion of pollutants, 724  
 drag, 300  
   above the boundary layer, 300, 687-690  
   atmospheric boundary layer, 300, 699-701  
   force, 300-301  
   term in vertical vorticity equation, 447-448, 586  
 eddies, 706, 708  
 flow, 660, 705  
 heat flux, effective, 68  
 flux  
   divergence, 715  
   variation with height, 70, 698, 715-716  
 gusts, 705-706  
 kinematic moisture flux, 108-109  
 kinematic heat flux, 68  
 mixing  
   frontolysis, 411  
   by thunderstorms, 70-71, 111  
 parts, 705-706  
 Reynolds stress, 701  
 stress, 701  
 surface layer, 709  
 transport, 709  
   of heat, 67-71  
   of moisture, 109-111  
 transport velocity, 300  
 velocity variances, 706-708  
 vertical heat flux divergence, 64-65, 69-71, 698, 711-716  
 wake, 165, 667  
 whirls (eddies), 708  
 turret (shaped clouds), 168  
 TUTT (tropical upper tropospheric trough), 612-613
- TV (television), severe weather reporting, 529-532  
 TVS = tornado vortex signature, 253, 599  
 twilight, 11, 33-34  
   astronomical, civil & military, 33-34  
 twinned rainbows, 841  
 twister (see tornado), 577-593  
 two-layer system of fluids, 657-661  
 two-way nesting of NWP grids, 752  
 types of  
   clouds, 168-169  
   fog, 173  
   thunderstorms, 486-495  
 typhoons (see hurricanes), 330, 426, 603-644  
 damage potential (CDP), 607  
 international forecast organizations, 607  
 intensity scales, 607  
 super-, 607
- U**  
 U time zone (Pacific), defined, 5  
 $u^*$  (see friction velocity), 378, 700-704, 709  
 U velocity definition, 2, 3  
   determination using hodographs, 513  
 UHF = ultra high frequencies, 259  
 UK air quality objectives, 725  
 ultrafine aerosols, 188  
 ultrasonic snow depth sensor, 210  
 ultraviolet light (see also radiation), 222, 857  
   haze filters for cameras, 857  
 uncertainty in weather forecasts, 776  
 uncinus/unc, 168
- uncontrolled experiments, 554  
 understanding & critical evaluation, exercises explained, 23  
 undulatus, 169  
 undular bore (roll cloud), 169  
 unidata IDV, 772  
 United Nations, 268  
 units, 870  
   component of scientific notation, 870  
   concentration of pollutants, 724  
   conversion, 871  
   density, 10  
   force per mass, 292-300  
   metric (SI), 7, 870  
   MKS system, International System (SI), 7, 870  
   potential vorticity (PVU), 364  
   pressure, 7, 19  
   scientific, 8, 870  
   temperature, 7, 870  
   water vapor pressure, 87
- universal**  
 constants, 879  
 observation codes, 268  
 theories, 107, 877
- universities and NWP, 772**
- unsaturated (see also dry), 57, 87, 92**  
 air, 87  
 air parcel, 128-129  
 definition, 87  
 heat budget, 57  
 humidity, 87-96  
 lapse rate, 60, 129
- unstable**  
 absolutely, 140  
 air (regions), 138-139, 688-689  
 clouds in, 161-162, 164-165  
 dispersion of smoke in, 710  
 determining, 138-139  
 velocity standard deviations, 707  
 atmospheric boundary layer (ABL), 692  
 turbulence, 707-710  
 baroclinically, 371  
 barotropically, 368  
 boundary-layer wind, 308  
 conditionally, 140-141, 498  
   nonlocal, 496-499, 503-508  
 drag, turbulent, 300  
 dry absolutely, 140  
 equilibrium of droplets, 191  
 flow, definition, 138  
 mixed layer, 692  
 nonlocally, 138-144  
   conditionally, 496-499, 503-508  
 saturated absolutely, 140  
 statically, 138, 688-689  
   cumulus cloud formation in, 162  
 up, definition of, 4, 298  
 updateable MOS (model output statistics), 771  
 updraft(s)  
   bubble, 482  
   cloud, 162  
   helicity (UH), 530  
   main, 483  
   rotating, 492  
   , instability & CAPE in thunderstorms, 503-508  
   thermals, 648-649  
   tower, 482  
   velocity in  
     cyclones, 446, 451-462  
     easterly waves, 612  
     hurricanes, 605, 612, 620, 628  
     of buoyant thermals, 648-649  
     thunderstorms, 508, 649
- upper-air**  
 jet  
   streaks, 454-456  
   streams, 357-361, 405-407, 414-415, 452-453  
 mandatory levels, 134, 772  
 significant levels, 134, 147  
 soundings, 134  
   locations worldwide, 271  
   Pacific data void, 288  
 weather maps and charts, 291  
 winds vs. thunderstorm strength, 510
- upper-level**  
 charts, in case-study of cyclone, 433-466  
   reason for using, 291, 436-437, 442  
   20 kPa, 440-443, 452, 455-456  
   50 kPa, 433, 442, 448, 451  
   70 kPa, 439, 442  
   85 kPa, 439, 442, 449, 459-462  
   100 kPa, 438, 463  
 disturbance, 433
- divergence  
 due to jet streak ageostrophic flow, 454-456  
 due to jet stream curvature, 453  
 related to pressure tendency, 464-467  
 fronts, 414-415  
 trough, position that causes cyclogenesis, 432, 450-453, 467  
 winds, 331-332
- upper**  
 atmosphere, 13  
 quartile, 502  
 suncave Parry arc, 854-855  
 sunvex Parry arc, 854-855  
 tangent arcs, 842, 851-855  
 tropospheric  
   fronts, 414-415  
   winds, 331-332  
 Wegener arc, 855
- upside-down cold thermals, 177**
- upslope**  
 flow (anabatic), 649-652  
 fog, 173  
 rain, 398-399  
 thunderstorms, 526
- upward motion**  
 at cold fronts, 470-471  
 in extratropical cyclones, 425, 451-462
- upward velocity in extratropical cyclones, 425, 426, 451-462**
- upwelling**  
 ocean water in hurricanes, 610  
 radiation, 44-45, 220
- urban**  
 breezes, 679  
 canopy, 678-679  
 canyon, 678-679  
 cloud formation over, 162  
 heat island, 678-679  
 plume, 678-679, 742  
 smog, 193
- U.S. (USA)**  
 air quality standards, 725  
 geography, 431  
 Joint Typhoon Warning Center, 607  
 National Hurricane Center (NHC), 608, 638  
 National Inst. for Standards & Tech. (NIST), 51, 879  
 national lightning detection network (NLDN), 568-569  
 National Oceanic & Atmos. Admin. (NOAA), 637  
 National Weather Service (NWS), 532  
 short scale number prefixes, 870  
 standard atmosphere, 11-13  
 states & their postal abbreviations, 431  
 Storm Prediction Center, 532  
 Supreme Court, quotation, 470  
 symbols for clouds on weather maps, 168  
 Tropical Prediction Center, 638  
 usage of probability scores for forecasts, 785  
 UTC (Coordinated Universal Time), 5, 268  
 uv (see ultraviolet), 222
- V**  
 V shaped tornado, 577  
 V time zone (Alaska), defined, 5  
 V-velocity definition, 2, 3  
   determination using hodographs, 513  
 vacuum, 19  
   speed of light in, 834  
 VAD = velocity azimuth display, 252-253  
 Väisälä (in Brunt-Väisälä frequency), 136-137  
 valid time, 762  
 valley  
   circulations, 649-654, 660-670, 675-676  
   fog, 177  
   gap winds, 661-664  
   pollutants trapped in, 654  
   subsidence into, 654  
   winds, 649-654, 660-670, 675-676
- value**  
 components in scientific notation, 870  
 of forecasts, economic, 784-785
- Vancouver**  
 International Airport (CYVR), 646-647  
 solar azimuth & elevation, 32-33
- vanes, wind, 219, 321**
- van't Hoff factor, 190**
- vapor pressure, 14, 87**  
 definition, 87

- over curved droplets, 189-192
- over flat surface of water, 87-90
- reference, 88, 880
- saturation, 87-90
- supersaturation, 186
- units, 87
- variation with temperature, 14, 88
- vapor, water feedback, climate, 810
- vaporization, latent heat of, 54, 56, 88-90, 108, 880
- variance, 706, 727
  - smoke plume spread, 726-732, 735-737
  - velocity, 706-708, 727
- variable(s)
  - conserved, 61
  - continuous, verification of, 777-780
  - dependent, 872
  - independent, 872
  - gases in the atmosphere, 7
  - grids and grid meshes, 752-753
  - italicized notation for, 870
- variant pi, 801
- variational data assimilation (3DVar & 4DVar), 273, 767
- varieties of clouds, 168-169
- vault, echo-free, 493, 552-553
- vector
  - equation, 292
  - force, 292
  - operators
    - cross product, 299
    - dot product, 239
  - sum, 292
  - wind
    - difference (surrogate for shear), 509
    - shear, 509
    - velocity, 292, 509
- veering wind, due to warm-air advection, 349, 511, 520
- vegetation
  - greenness, 230, 751
  - parameterizations, 749-751
- veils of clouds, 168
- velocity (see also speed), 2-3
  - azimuth display, 252-253
  - buoyancy scale, 68-69, 110, 704
  - components, 2-3, 293, 314-315, 746
  - convective, 68-69, 704
  - Deardorff, 69, 703-704
  - downburst, 554-557
  - entrainment, 697-698
  - friction, 378, 677, 700-713
  - group, 658
  - horizontal, 2-3
    - scales, buoyant, 68-69, 109, 300, 703-704
    - scales, mechanical, 68-69, 109, 700-703, 708-709
  - hurricane
    - radial, 627-628
    - tangential, 605-607, 622-623, 626-627
    - vertical, 628-629
  - mean wind, 705-706, 726-727
  - of air parcel relative to earth, 360-361
  - phase, 658
  - radial, 249-254
  - standard deviation, 706-708, 727, 731-732
  - tangential
    - in hurricane, 605-607, 622-623, 626-627
    - in tornado, 577-580
  - terminal, 202-204, 555
  - thermals, 649
  - thunderstorm updrafts, 508
  - tornado, 577-580
  - turbulent transport, 68-69, 109, 300, 703-704
  - variance, 706-708, 727, 731-732
  - vertical, 2-3, 252, 448, 451-462, 628-629, 746
    - max up- and down-drafts, 508, 557-559
    - omega, 451, 456-462
    - Q-vectors, 460-462, 469-471
  - wave, 658
  - winds, summary of, 314
- velum, 169
- venting of atmos. boundary layer air, 691-692
- venturi effect, 674-675
- verification of forecasts, 777-785
  - binary variables, 780-782
  - categorical events, 780-782
  - continuous variables, 777-780
  - cost-loss decision models, 784-785
  - probabilistic forecasts, 782-784
  - scores, 752, 777-785
- verifying analysis, 769, 777
- vernal equinox (Spring), 30-31, 801-802
- angle from perihelion, variation of, 799-801
- angle from Earth, 802
- vertebratus, 169
- vertical
  - advection of
    - heat, 67, 72, 714
    - mass, 317-318
    - momentum, 295, 315
    - vorticity, 447-448
  - axis on graphs, 3
  - cell circulation, 377
  - circulations (global), 332-333, 377-378
  - effective, 377-378
  - component of the equations of motion, 315-317
  - coordinates, alternative, 746
  - cross section of
    - atmosphere, 143-144, 332, 357, 359, 373, 432
    - cyclone (case study), 441
    - dry line, 416
    - fronts, 403-407, 412-416
    - hurricanes, 605, 618, 620-621, 624, 629
    - storm surge, 632-635
    - thunderstorms, 482-490, 496, 510, 525-526, 553-554, 563, 566, 575
    - troughs, 432
  - density profile, 10
  - direction, 4
  - equation of motion, 315-317, 746
    - applied to thunderstorms, 649, 554
    - for thermals, 649
  - flux divergence, 65-73, 109-110, 746
  - flux of water vapor, 108
    - during free convection, 109-110
  - forces as cause vertical motion, 315-317
  - frontal structure, 403-404
  - gradient, 872
    - geostrophic wind (thermal wind), 345-349
    - IR flux, 71
    - mixing ratio, 75, 110, 692
    - potential temperature, 67, 75, 110, 688, 690, 692, 695-698
    - pressure, 8-9, 12-13, 15-17, 554, 621-623
  - mean temperature advection, 72
  - motion, 66, 451-462
  - omega, 451, 456-462
  - pressure gradient, 15
  - profiles, 119
    - pressure, 9
    - potential temperature, 67, 75, 110, 688, 690, 692, 695-698
    - weather variables, 119, 134
  - shear, 509-521, 699-704
  - structure
    - anticyclone (highs), 391
    - atmosphere, 11-13
    - cold front, 403-404
    - warm front, 403-404
  - temperature gradient definition, 872
  - turbulent flux, 67-71, 108-111, 711-716
  - velocity, 2-3, 252, 448, 451-462, 628-629, 746
    - constant, 17
    - continuity effects that drive, 452-459
    - clones, in extratropical, 446, 451-462
    - downbursts, in, 554-562
    - equations for, 315-320
    - hurricane model, 628-629
    - omega, 451, 456-459, 462
    - Q-vectors, 460-462, 469-471
    - radar, 252-253
    - standard deviation, 706-711, 731-732
    - subsidence, 545-546
    - synoptic scale, 448
    - thermals, in, 649
    - thunderstorms, in, 508, 545-546, 557-559
    - top of boundary layer, 319-320
    - top of hurricane, 612, 618, 628
    - typical, 318
    - vorticity, effect of, 448
    - weather map of, 448
  - visibility, 170
  - wave propagation, 668
  - wind speed, 318, 451-462
    - Ekman pumping, 319-320
    - isanabat, 18
    - thermals, 648-649
- very
  - fine particulate matter (PM<sub>2.5</sub>), 725
  - low frequency (VLF) radio waves, 568
- VHF = very high frequencies, 258-259
- vibration lines is spectra, 221
- vicinity, weather map symbol for, 276
- viewing angle, 838, 846
  - for rainbow rays, 839-840
  - minimum, 846
- vs. cloud droplet for diffraction fringes, 858-860
- violent stage of thunderstorms, 485
- violet color defined (also see optics chapter), 37
- virga, 169, 185, 482-484, 547
  - weather-map symbol for, 276
- virtual
  - potential temperature, 61-62
    - in buoyancy, 135-136
    - in downbursts & DCAPE, 555-563
    - in katabatic flow, 649-653
  - temperature
    - average, as measure of thickness, 17-18
    - constant, 14-15, 880
    - defined, 14-15
    - in buoyancy, 135-136
    - in CAPE, 503-504
    - in gust fronts, 562-563
- vis5D, 772
- viscosity, eddy, 715
- viscous dissipation rate of TKE, 315, 709
  - scales, 315
- visibility, 43, 170, 270, 275, 867
  - airmass characteristics, 391
  - change criterion for SPECI, 270
  - definition, 43, 867
  - haze, 193, 856-858
  - in precipitation, 208-209
  - MÉTAR, 270
  - minimum (in METAR), 270
  - reduced, 170, 193, 270, 275
  - runway visual range (RVR), 270
  - weather-map codes, 275
  - vertical, 170
- visible
  - light, 220, 222
  - satellite images (photos), 230-233
- visual
  - geometric albedo, 879
  - range (also see runway visual range, RVR), 43
- visualization programs for NWP output, 772
- void, Pacific data, 287-288
- volatile hydrocarbons, 193
- volcanic
  - ash & aerosols, 170, 276, 804-805, 858
  - climate change processes, 804-805, 810
  - eruption(s), 804-805
    - Agung, 805
    - change criterion for SPECI, 270
    - Cotopaxi, 805
    - Deccan traps, 805
    - El Chichon
    - Krakatau, 805
    - Lake Toba, 805
    - Mt. Tambora, 805
    - Pinatubo, 805
    - Santa Maria, 805
    - Siberian traps, 805
    - Yellowstone caldera, 805
  - red skies caused by, 858
  - winter, 805
    - The Year Without Summer, 805
- volcanism influences on climate, 804-805, 810
- volt, unit of electric potential, 564, 870
- voltage breakdown potential in air, 566
- voltage difference, 564-566
- volume
  - density, 10
  - extinction coefficient, 43
  - fraction of gases in air, 7
  - grid, 750-756
  - sampled by radar, 240
  - scans by radar, 241
  - specific, 10
    - isostere, 18
- von
  - Freiberg, Theodor, 841
  - Goethe, 249
  - Kármán constant, 677, 701
  - Neumann, John, 624, 669, 749, 759
- vort max (see also vorticity maximum), 457
- vortex / vortices
  - book-end, 490-491
  - Burgers-Rott (BRV), 599
  - cold-air funnels, 582
  - debris cloud, 581
  - dust devil, 582
  - firewhirl, 582
  - funnel cloud, 581
  - gustnado, 582
  - landspouts, 582
  - line-end, 490
  - mountain-lee, 165
  - multiple-vortex tornadoes, 592-593

- polar, 397, 824  
 Rankine combined, 577-578, 599  
 roll, horizontal, 167  
 spray, 582  
 steam devil, 582  
 stretching, 447-451, 586  
 suction, 593  
 tornado, 577-593  
   signature (TVS) on Doppler radar, 253, 599  
   supercell, 582  
 tube, 166, 447, 518, 586-587  
 waterspouts, 582  
 wing-tip, 166  
 vorticity, 320-321, 362-365  
   absolute vorticity, 363, 448  
   advection, 447-451, 458  
     PVA & NVA, 447-448, 459  
   beta effect, 447-451  
   cascade, 586  
   charts, for case-study cyclone, 439-441, 448  
   circulation, 365-366  
   conservation, 363, 397, 445  
   curvature-induced, 362  
   cyclogenesis indicator, 426  
   cyclonic, along fronts, 407  
   definition, 320-321, 362-365  
   divergence effect, 447-449  
   drag effect, 447-449  
   forecast equation for, 447-449  
   frontal, 407  
   geostrophic, 319, 449-451  
     relative, 319  
   helicity, 587-592  
   horizontal (streamwise), 518  
     advection, 447-449  
     circulation, 365-366  
   hurricane environment, 610  
   isentropic potential vorticity, 364-365  
   maximum (vort max), 457  
     of cyclone case study, 459  
     on weather maps, 457-458  
   negative advection (NVA), 447-448  
   planetary, 363-364  
   positive advection (PVA), 447-448, 459  
   potential vorticity, 363-365, 397  
     conservation, 445  
     isentropic, 364-365  
   quasigeostrophic approx., 449-451  
   relative vorticity, 319-321, 362-363, 577, 586-588  
   shear-induced, 362  
   solid body, 363  
   spin-up, 447-449  
   streamwise, 518, 587-592  
   stretching, 447-451, 586-590  
   swirl ratio, 592-593  
   tendency equation, 447-449, 586  
   tilting effect, 447-449, 586-588  
   tornado, 577-578, 586-588  
   turbulent drag, 447-449, 586  
   vertical advection, 447-449  
   wave, 368
- clouds at, 162-164  
 definition, 404  
 drizzle from, 546  
 extratropical cyclones, attached to, 425-428  
 halos, 401, 842  
 horizontal structure, 401  
 horizontal winds, 401  
 occlusion, 413-414  
 rain from, 546  
 stratiform clouds, 162-164, 401, 425-428  
 sundogs, 401, 842  
 thunderstorm triggers, 525  
 weather map symbol, 281, 399  
 wind shifts, 401  
 low-pressure centers, 621-623  
 mode rainfall estimates, 257  
 rain, 115  
 sector, 425-428  
 vs. cold core cyclones, 622  
 winds, 66, 349, 511, 520, 676
- warming  
 dynamic, 672-674  
 global (climate), 150, 796  
 thunderstorm latent heat release, 546-548
- warnings (forecasts)  
 hurricane, 631, 638  
 thunderstorm/severe-storm, 528-530  
 tropical storm, 638
- watches (forecasts), 528-530, 638
- water, 87-118  
 availability for droplet formation, 186-187  
 barometer, 7  
 budget, 99-111  
   at surface, 108-109  
   Eulerian, 107-111  
   Lagrangian, 99-101  
   thunderstorm, 547  
   total water, 99-100  
   zonally averaged, 210  
 characteristics, constants, and parameters, 880  
 conservation, 99-101  
 content, 97  
 density vs. temperature, 835, 880  
 depth, constant (isobath), 18  
 depth of constant temperature (isobathytherm), 18  
 droplet clouds, 163  
   in cold airmasses, 393-397  
 index of refraction, 834-835  
 latent heats, 54  
 liquid  
   content, 97  
   depth, 210-211  
   depth vs pressure, 7  
   loading, 15, 555  
   mixing ratio, 15, 97-98  
   specific heat, 880  
 mixing ratio, 15, 75, 91, 97-98  
 molecular arrangement & electric charge transfer, 565  
 molecule content, 188-189  
 phases, 198  
 precipitable, 98  
 reflection from, 838  
 saturation vapor pressure, 87-90  
 specific heats, 54, 880  
 supercooled, 186  
 surface tension, 189, 880  
 thermo diagram, 99-105  
 total, 97-100  
 vapor, 7, 87-118  
   absorption of radiation, 221-223  
   channel on satellites, 112, 226, 231  
   cloud feedbacks, 810-811  
   density, 91  
   density excess, 198  
   feedback, 810  
   gas constant, 88-92, 880  
   greenhouse gas, 811  
   holding capacity, 87-90  
   in air, 7  
   mixing ratio, 89-98  
   molecular weight, 7  
   pressure, 87  
   specific heats, 880  
   vertical flux, 108-110  
   volcanic eruptions of, 805
- waterspout tornadoes, 582  
 change criterion for SPECI, 270  
 cyclostrophic winds, 311-312  
 life cycle, 582  
 weather-map symbol for, 276
- Watson, Andrew, 813
- watt, unit of power, 870  
 wave, 705  
 African easterly wave, 611-612  
 amplitude, 368-374, 443-444, 634, 666-668  
 atmospheric, 705, 710  
 battering of structures by ocean waves, 634-635  
 bore, 656  
 boundary layer, 710  
 buoyancy, 666-668, 710  
   thunderstorm triggering, 526  
 chaotic clouds, 169  
 clouds (see lenticular, or standing lenticular), 165, 168, 666-667  
   chaotic (asperitas), 169  
   optics caused by, 859-860  
   roll cloud (undular bore wave), 169  
 crests, 658, 668  
   tilt with altitude, 668  
 curvature, 375  
 definition, 705  
 drag, 668  
   parameterization in NWP, 751  
 easterly, 611-612  
 electromagnetic, 219  
 energy, 658  
 equations, 368-374, 634, 666  
 flux of heat meridionally, 375  
   effect on circulation, 377  
 formation in jet stream, 357, 367-376, 443-445  
 fronts/frontal, 427-428, 837, 859  
 gravity, 666-668, 710  
   thunderstorm triggering, 526  
 group speed, 658  
 heat transport by Rossby waves, 374-375, 378  
 height of ocean waves, 634-636  
 interfacial (surface), 658  
 internal, 658  
 intrinsic phase speed, 658  
 jet stream (Rossby), 367-376  
 Kelvin, in ocean, 633-634  
 Kelvin-Helmholtz, 142, 165, 710  
 lee, 666-668  
 long, IR, 37-39, 45, 220-226, 230-239, 751, 794-797, 810  
 long Rossby, 369  
 mountain, 666-668  
   drag parameterization in NWP, 751  
 momentum  
   effect on circulation, 377  
   transport by Rossby waves, 375-376  
 or density current (bore), 655-656  
 phase speed, 658-661  
 planetary (see Rossby waves), 367-376  
 prefrontal, 656  
 propagation, 36, 369-370, 611-612  
   for remote sensing, 219-226  
 ridge, 443  
 Rossby, 329, 332, 353, 367-376  
   amplitude & other characteristics, 373-374  
   scour by ocean waves, 634-635  
   shallow-water, 658  
   shape of lightning surge, 569-560  
   short Rossby, 369  
   short, solar, 37-46, 220-223, 230-234, 334-339, 693, 793-815  
   solitary (bore), (volutus cloud), 169, 656  
   sound, 219  
   speed (see phase speed), 367-374, 611, 834-837  
     shallow-water, 633, 658  
   stationary lee-side Rossby, 443-444  
   surf, 635  
   surface, 658  
   swell, 635  
   tilt, 372-376, 611, 668  
   tops sheared off by hurricane winds, 634  
   trough, 443, 658  
   vapor, 87-118  
     channel of satellites, 226  
     feedback in climate, 810  
     thunderstorm environment, 499-502  
 velocity, 658  
 vorticity, 368  
 westward propagation of, 369-372, 611-612  
 wind-driven ocean, 634-636
- wavelength(s), 36-37, 221-226, 230, 242-243, 329, 367-376, 427, 468  
 bands of visible and IR sensors, 45  
 bands for satellite sensors, 222-223, 230  
 natural, 666  
 of easterly waves, 611  
 of electromagnetic radiation, 222-223  
 of light, 36, 222, 834-857  
   for different colors, 37, 834-835, 862

## W

W time zone (Hawaii, Aleutian), defined, 5

w\* (see Dearthoff velocity), 69, 110, 703-704, 736

W-velocity definition, 2, 451

wake turbulence behind mountains, 667

waldsterben (forest death), 742

Walker circulation, 820

wall

cloud (tornadoic), 483, 581-583

Foehn, 676-677

murus, 169

warm

air

advection (& veering wind), 66, 349, 511, 520

conveyor belt, 433

rises, 135

sector of extratropical cyclone, 425-428

airmass formation (genesis), 393-395

anafront, 404

cloud precipitation processes, 204-206

conveyor belt, 433

core system, 426

of hurricanes, 614, 621-625

vs. cold core, 426, 622

frontogenesis, 281, 399

frontolysis, 281, 399

fronts, 399-401

aloft, weather-map symbol for, 281, 399

- of max growth rate for Rossby waves, 372
- of mountain waves, 666
- of planetary Rossby waves, 367, 369
- of planetary stationary lee waves, 444
- of wind waves, ocean, 634-636
- wavelets, 837
- wavenumber, 36
  - of Rossby waves, 367, 369
- WAVEOB code, 269
- WBF (Wegener-Bergeron-Findeisen) process, 201-202
- weak
  - echo region (WER), 493
  - tornadoes vs. significant, 501, 507, 516, 522, 530-531
- weakly forced (airmass) thunderstorms, 486
- weather, 1
  - altitudes, 143
  - analysis
    - hand (manual; subjective), 280-281
    - objective (automated), 765-767
  - anomaly (isnormal), 18
  - anticyclonic, 390
  - associated with warm katafront, 404
  - balloon, 134
  - briefing procedure, 765
  - codes & code modifiers, 268-273, 276
  - control, 218
  - data sources, 271-273
  - definition, 1
  - forecast(s)
    - agencies (Nat. Weather Service NWS), 532
    - computerized (see numerical), 745-792
    - medium-range, 768, 775
    - numerical, 745-792
    - topics, 2
  - forecast models, 751
    - heirarchy, 768
  - frontal, 400-401
  - glyphs (symbols on weather maps), 276, 282
  - highs, in, 390
  - instruments for measuring
    - errors of, 875
    - humidity, 97, 111-112, 219
    - precipitation, 219
    - pressure, 19, 219
    - temperature, 78-79, 219
    - radiation, 45-47
    - remotely, 219-266
    - soundings, 134-135
    - wind, 219, 321-322
  - map(s)
    - airmass codes, 391-392
    - analysis methods, 274-281, 402
    - CAPE, 506-508
    - case-study examples of, 433-466
    - global pressure patterns, 354-355
    - humidity, pre-storm, 500-501
    - max advection, finding, 458
    - NWP output, 772
    - solenoids, finding, 458
    - station plot model, 274-279
    - symbols for cloud genera, 168
    - symbols for hurricanes, 614-615
    - symbols for precipitation rate, 208
    - synoptic, 274-281
    - thunderstorm environment, 500-501, 506-508, 522-525, 532
    - vorticity advection, 459
    - winds on, 290-291
  - METAR, 270
  - observations, 268-273
    - at airports, 268-271
    - locations, 271-273
    - METARS, 268-271
    - using satellites, 227-239, 272-273
  - Pacific Northwest, 288, 398, 472, 765
  - past and present, as plotted on maps, 275-276
  - predictability limit, 773-775
  - prediction, numerical, 745-792
    - Richardson's 1922 book, 764
  - radar, 211, 240-260, 322
  - radio, NOAA, 529, 638
  - reports, 267-273
  - station
    - ID or code (ICAO), 270
    - plot model on weather maps, 274-279
  - satellites, 112, 219-239
    - locations of weather obs. From, 272-273
    - sensors, 273
    - services, radars used by, 243
    - symbols (glyphs) on weather maps, 276, 282
  - web-enhanced questions, explained, 24
  - wedge angles, 843, 845-847, 855
  - Wegener arc, 854-855
  - Wegener-Bergeron-Findeisen (WBF) process, 201-202, 546
  - Weibull distribution for wind speeds, 645-646
  - weighing rain gauge, 210
  - weighting functions for radiative transfer, 226, 237-239
    - for GOES satellites, 226
  - weights, 15
    - air, 8
    - person, 8, 15
    - pressure, 7
  - well-mixed fog, 176-177
  - WER (weak echo region), 493
  - west
    - Coast weather, 288, 397-399, 472, 765
    - direction, 2
    - Gregory, 765
    - westerlies (winds in global circulation), 331, 353
    - Western Hemisphere, 4
      - defined, 4
    - westward tilt, 432
    - wet-bulb, 94
      - depression, 94
      - globe temperature, 117
      - mixing ratio, 95
      - potential temperature, 103-106
        - in fogs, 176
      - weather maps of, 500
      - temperature, 94, 96, 111
        - weather maps of, 500
    - what scientists do, 470
    - whirls, big and little, 708
    - whiskers, box-and- (statistics), 539
    - whistling through trees and wires, 560
    - white, 862
      - clouds, 856-858
      - dwarf star, 803
      - out (in blowing snow), 208
    - Wien's Law, 37
    - Wieringa, Davenport - roughness length classification, 700
    - wild fire and CO2 release, 812
    - Wilde, Oscar, 523
    - wind(s), 302-314
      - ageostrophic, 304, 343, 454-456
      - anabatic, 649-652
      - anemometer, 321-322
      - anticyclonic, 306
      - antitriptic, 312-313, 663
      - aspre, 676
      - astru, 676
      - average, global circulation, 330-334, 358
      - barbs on station-plot model, 278, 291
      - Beaufort scale, 635-636
      - Bora, 675-676
      - boundary-layer gradient (BLG) wind, 309-311, 613-615, 618-619
      - boundary-layer wind, 307-309
      - breeze, 635-636
      - canopy, 677-679
      - ceaseless, 329
      - channeled, 664
      - chill temperature index, 76-77
      - Chinook, 675-676
      - circulation, 329-388
      - coastal, 654-657, 661-665
      - cold-air drainage, 177, 652-653
      - components (U, V, W), 2, 3
        - conversion to speed and direction, 2
        - graphical determination (hodograph), 513
        - conversion, 3
        - cyclonic, 306
        - cyclostrophic wind, 311-312, 618
      - damage by
        - downbursts of air and gust fronts, 554-563
        - downslope windstorms, 667, 675-677
        - hurricanes, 605, 626-636
        - tornadoes, 579-580, 592-593
        - wind waves and coastal flooding, 631-637
      - difference (surrogate for shear), 509
        - magnitude, 509
        - vector, 509
      - direction, 2, 314
        - change criterion for SPECI, 270
        - constant (isogon), 18
        - conversion to components, 3
        - defined, 2
        - frequency, 646-647
        - instruments to measure, 219
        - naming, 2, 513
        - radar observations of, 252-253
        - rose, 646
        - variability in METAR, 270
      - dispersion of pollutants, 724
      - Doppler-radar measured, 249-254, 322
      - downburst, 554-563
      - downslope, 652-653, 675-677
        - storm, 667, 675-677
      - driven
        - by forces, 289-328
          - ocean currents, 610, 632-633, 701
      - easterlies, 330-332
        - jet (African), 611
      - electrical generation by, 647-648
      - equations of motion, 301, 314-315, 554, 746-749
      - equatorial, 343
      - errors, 766
      - exponential profile, 678
      - extratropical cyclonic, 425
      - field, 343
        - adjustment to mass field, 344
      - Foehn, 676-677
      - forces that drive, 302
      - forecast equations, 746
      - forest canopy, 677-678
      - frontal, 400-407
      - gale, 635-636
      - gap, 661-664
        - geostrophic, 663
          - long, 662-664
          - short, 661-662
      - general circulation, 330-334
      - geostrophic wind, 302-304, 343-349
        - African easterly jet, 611
      - global circulation, 330-334
      - gradient wind, 304-307, 617-618
      - gust duration, 605, 607
      - gust-front, 560-563
      - high-altitude (upper-tropospheric), 330-331
      - hodograph, for plotting winds, 510-513
      - horizontal, 302-314
      - hurricane
        - exploding houses, 674
        - force winds (Beaufort scale), 635-636
        - radial, 627-628
        - stages of life cycle, 614
        - tangential, 614, 622, 626-627
      - idealized, 302-314
      - inertial, 312
        - oscillation, 304, 311-312, 700
      - inflow, 618-619
      - instruments for measuring, 321-322
        - pitot-static system, 674
      - irrotational, 385
      - jet stream, 357-362
        - low level, 664-665
      - katabatic, 652-653
      - local, 645-686
      - log wind profile, 677, 702-703
      - magnitudes, 314
      - mean vs. instantaneous (turbulent), 705-706, 726
      - measuring, 321-322
        - height, 701
      - METAR, 270
      - mountain, 649-654, 660-670, 675-676
      - names of (at steady state), 302, 314, 654
      - near-surface, global, 330-331
      - noise, 560
      - non-equilibrium, 618-619
      - outflow, 554, 560-563, 618-619
      - plotting on weather maps, 291
      - power, 647-648
        - average, 647
        - theoretical available, 647-648
        - vs. wind speed, 647-648
      - profile
        - convective radix layer, 703-705
        - exponential, 678
        - instruments to measure, 134, 321-322, 701
        - logarithmic, 677, 702-703
        - stable surface layer, 702-703
        - neutral surface layer, 677, 702
        - unstable radix layer, 703-705
      - profilers, 257-258, 322
        - locations worldwide, 272
      - reports of damage from, 532
      - rose, 646-647
      - Saffir-Simpson hurricane scale, 605-607
      - scale, Beaufort, 635-636
      - sensors for measuring, 321-322
        - arrays for airport wind shear, 556, 563
      - shear (also see shear), 509-522
        - components, 509
        - constant (isoshear), 18

- definition, 509, 706  
 direction, 509  
 frontal, 404-407  
 in hurricane environment, 610  
 in thunderstorm environment, 496-499, 509-522, 586-592  
 magnitude, 509  
 radar observations of, 254  
 sensors at airports, 563  
 thermal-wind effect, causing, 345-349  
 tornado formation, role in, 586-592  
 turbulence generation, 706, 708-709  
 units, 509  
 vs. stability, 141  
 shield around rain gauges, 210  
 shift in fronts, 349, 400-401  
 slope, 649-653  
 sounds, 560  
 speed, 2, 3, 314  
   around highs and lows, 307  
   constant or equal, 17  
   conversion to components, 3  
   decrease across a wind turbine, 647-648  
   defined, 3  
   Doppler radar measurement of, 252-253  
   for gap winds at constant depth, 661-663  
   frequency, 645-646  
   instruments to measure, 219, 321-322  
   isotach, 17  
   latitude, variation with, 359  
   mean, 705, 726-727  
   probability, 645  
   probability distribution - Weibull, 645-646  
   profile, 702-705  
   radial speed, 249-253  
   relative frequency, 645-646  
   weather-map symbols, 278  
   Weibull distribution, 645-646  
 speed profile, 699-705  
 storm  
   downslope, 667, 675-677  
   force winds (Beaufort scale), 635-636  
 storm-relative, 584-585  
 straight-line (also see derecho), 489, 491, 494, 554, 560-563  
 stress, 700-713  
   ocean currents driven by, 701  
 subgeostrophic, 304, 455, 699  
 summary of, horizontal, 302, 313-314  
 supergeostrophic, 304, 455, 699-700  
 supergradient, 643  
 superposition of mean, waves & gusts, 705-706  
 surface  
   layer, 699-705  
   measuring height, 701  
 thermal, 345-349  
   African easterly jet, 611  
   derived, 346  
 thunder shock front, associated, 572-574  
 -torn clouds (fractus), 165-166  
 tornadic, 385, 577-580  
   exploding houses, 674  
 total (rotational + translational), 578, 627-628  
 trade, 330-331  
 tropopause (jet stream), 357-362  
 tunnels, boundary-layer growth in, 689  
 turbines and power generation, 647-648  
   efficiency, 647-648  
   power output curve, 648  
   pressure change across, 671  
 turbulent part, 705-706  
 upper-tropospheric, global, 331-332  
 upslope, 649-652  
 urban canopy, 678-679  
 valley winds, 649-654, 660-670, 675-676  
 vane, 219, 321-322  
 variance of, 706-711, 727  
 vector weather map case study, 438, 440  
 veering, 349, 511, 520  
 vertical speed  
   downburst, 554-559  
   in extratropical cyclones, 451-462  
   in hurricanes, 628-629  
   in thunderstorms, 508, 557  
   omega, 451, 456-459  
 waves on ocean, 634-636  
 weather maps, 290-291, 440  
 westerlies, 331-332  
 whistling wires (aeolian tones), 560  
 zonally averaged at 20 kPa, 358  
 zonda, 676  
 window  
   absorption, 43  
   atmospheric, 43, 796-797  
   dirty, 220-223  
   radiative, 43, 220-221, 796-797  
   transmittance, 220-221  
   visible and IR radiometers, 45  
 wing(s)  
   aircraft, 88  
   tip vortices, 166  
 WINTEM code, 269  
 winter, 330  
   atmospheric boundary layer, 695-696  
   nuclear, 151  
   solstice, 30-31, 801  
 wires, sounds from wind (aeolian noise), 560  
 WMO = world meteorological organization, 149, 169, 268, 615  
   station plot model, 275  
 Wolf minimum in solar activity, 803  
 work, 54, 58, 503, 526  
   shaft, 672  
 World Meteorological Organization (WMO), 149, 268  
   cloud classification, 168-169  
   cloud height definitions, 163  
   cloud symbols on weather maps, 168  
   hurricane and typhoon names, 615  
   identification of upper-air stations, 149  
   mandatory (upper-air) levels, 772  
 world  
   circulations (global), 329-388  
   climate processes (natural), 793-832  
   map of annual precipitation, 209  
   record rainfall rates, 208, 545-548  
 Wreck of the Hesperus, 847  
 WRF (weather research & forecasting) model, 751  
 WSR-88D weather surveillance radar, 243  
 wstar ( $w^*$ ; see Deardorff velocity), 69, 110, 703-704, 736
- ## X
- X band radar, 242  
 x direction definition, 2  
   change to match mean wind direction, 649-653, 727  
 xenon, Xe, 7  
 x rays, 222
- ## Y
- y-direction definition, 2  
 year  
   leap, 31  
   sidereal, 29  
   tropical, 31  
   without summer, 1816, 805  
 yellow color defined (also see optics chapter), 37  
 Yellowstone caldera, 805  
 yocto ( $10^{-24}$ ), 870  
 Yogi Berra (see Berra)  
 yotta ( $10^{24}$ ), 870  
 Young-Laplace equation, 215
- ## Z
- z direction definition, 2  
 Z (radar reflectivity factor), 245-246  
 Z time zone, defined (see UTC), 5  
 Z-R relationship, 247  
 zenith  
   angle defined, 4-5  
   circumzenith arcs, 848-849  
   point, 854  
 zepto ( $10^{-21}$ ), 870  
 zero  
   absolute, 879  
   buoyancy, 135, 688  
   isodop, 250, 253-254  
   set, 171  
   zetta ( $10^{21}$ ), 870  
 zi = mixed layer depth, 143-144  
 Zinsser, William, 863  
 zo = roughness length, 677-678  
 zonal  
   average  
     heat transport, 339, 378  
     insolation, radiation, 336-338  
   temperature, 335  
   flow, 330  
     breakdown, 367  
     defined, 330  
     perturbed, 367-368  
   propagation of baroclinic waves, 369-374  
   velocity from source latitudes, 361  
   wavenumber, 367  
 zonally averaged  
   evaporation vs. precipitation, 210  
   radiative forcings, 338-339  
   winds at 20 kPa, 358  
 zonda wind, 676  
 zone, frontal, 280-281, 400-412  
 zones, time, 5  
 zoning for hurricanes, 631  
 Zulu Time, Z, defined (see UTC), 5  
 Zworykin, Vladimir, 759

