The Value of Weather Observations for Numerical Weather Prediction

Topics:
1. NWP Overview
2. Ensemble Fcsts.
3. Nowcasting
4. Applications
5. Weather Obs. Sites

Roland Stull & Rosie Howard
University of British Columbia (UBC)
Vancouver, Canada
Aug 2017

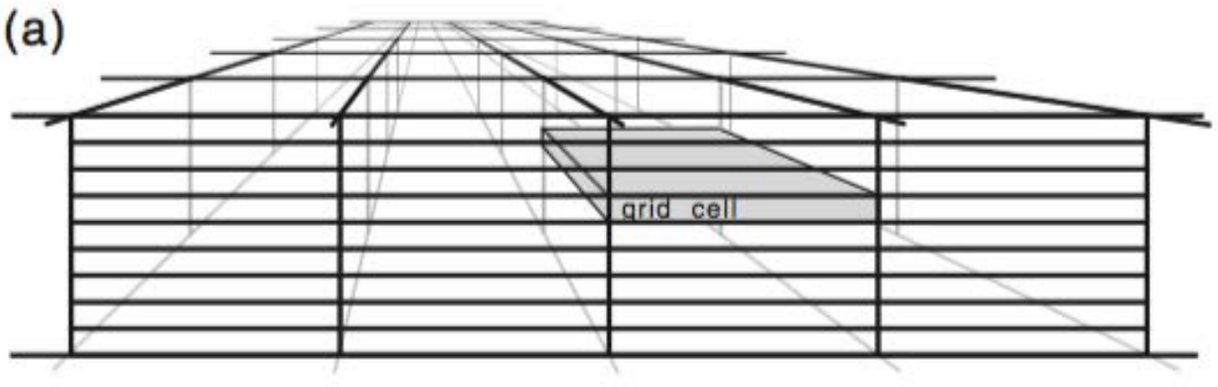
Colleagues:
Dominique Bourdin
Maggie Campbell
Tim Chui
Anthony DiStefano
Maria Frediani
Matt Fung
Rosie Howard
Yu Ito
Bryan Jansens
Julia Jeworrek
Henryk Modzelewski
Nadya Moisseeva
Pedro Odon
Kyle Sha
Roland Schigas
David Siuta
Greg West

1. Overview of Numerical Weather Prediction (NWP)

= computation fluid dynamics (CFD) of the atmosphere

Method

- Divide atmosphere into 3-D array of cells or grid points



- Insert initial conditions (ICs) at each point, based partly on **observations**.

- Integrate the fluid-dynamics eqs. forward in time by finite difference

$$\frac{\Delta U}{\Delta t} = -U\frac{\Delta U}{\Delta x} - V\frac{\Delta U}{\Delta y} - W\frac{\Delta U}{\Delta z} \qquad (20.1)$$

$$-\frac{1}{\rho}\cdot\frac{\Delta P}{\Delta x} + f_c \cdot V - \frac{\Delta F_{z\,turb}(U)}{\Delta z}$$

$$\frac{\Delta V}{\Delta t} = -U\frac{\Delta V}{\Delta x} - V\frac{\Delta V}{\Delta y} - W\frac{\Delta V}{\Delta z} \qquad (20.2)$$

$$-\frac{1}{\rho}\cdot\frac{\Delta P}{\Delta y} - f_c \cdot U - \frac{\Delta F_{z\,turb}(V)}{\Delta z}$$

$$\frac{\Delta W}{\Delta t} = -U\frac{\Delta W}{\Delta x} - V\frac{\Delta W}{\Delta y} - W\frac{\Delta W}{\Delta z} \qquad (20.3)$$

$$-\frac{1}{\bar{\rho}}\frac{\Delta P'}{\Delta z} + \frac{\theta_{vp} - \theta_{ve}}{\bar{T}_{ve}}\cdot|g| - \frac{\Delta F_{z\,turb}(W)}{\Delta z}$$

From the Heat Budgets chapter is a forecast equation for temperature T (modified from eq. 3.51):

$$\frac{\Delta T}{\Delta t} = -U\frac{\Delta T}{\Delta x} - V\frac{\Delta T}{\Delta y} - W\left[\frac{\Delta T}{\Delta z} + \Gamma_d\right] \qquad (20.4)$$

$$-\frac{1}{\rho\cdot C_p}\frac{\Delta \mathbb{F}^*_{z\,rad}}{\Delta z} + \frac{L_v}{C_p}\frac{\Delta r_{condensing}}{\Delta t} - \frac{\Delta F_{z\,turb}(\theta)}{\Delta z}$$

From the Water Vapor chapter is a forecast equation (4.44) for total-water mixing ratio r_T in the air:

$$\frac{\Delta r_T}{\Delta t} = -U\frac{\Delta r_T}{\Delta x} - V\frac{\Delta r_T}{\Delta y} - W\frac{\Delta r_T}{\Delta z} \qquad (20.5)$$

$$+\frac{\rho_L}{\rho_d}\frac{\Delta Pr}{\Delta z} - \frac{\Delta F_{z\,turb}(r_T)}{\Delta z}$$

From the Forces & Winds chapter is the continuity equation (10.60) to forecast air density ρ: (20.6)

$$\frac{\Delta \rho}{\Delta t} = -U\frac{\Delta \rho}{\Delta x} - V\frac{\Delta \rho}{\Delta y} - W\frac{\Delta \rho}{\Delta z} - \rho\left[\frac{\Delta U}{\Delta x} + \frac{\Delta V}{\Delta y} + \frac{\Delta W}{\Delta z}\right]$$

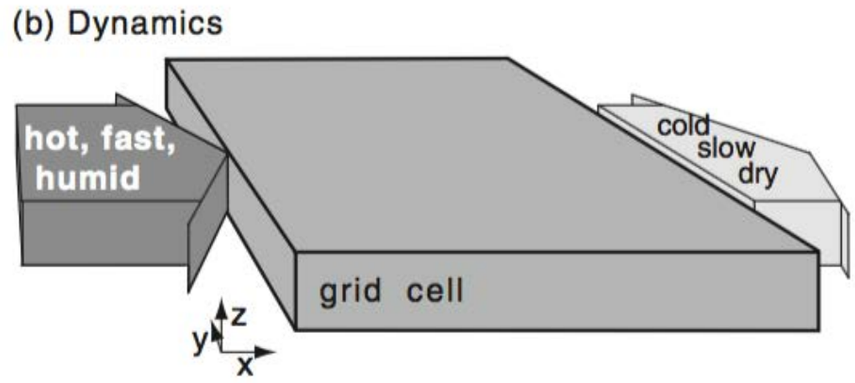
For pressure P, use the equation of state (ideal gas law) from Chapter 1 (eq. 1.23):

$$P = \rho\cdot\Re_d\cdot T_v \qquad (20.7)$$

NWP Dynamics & Physics

Resolvable components are “dynamics”

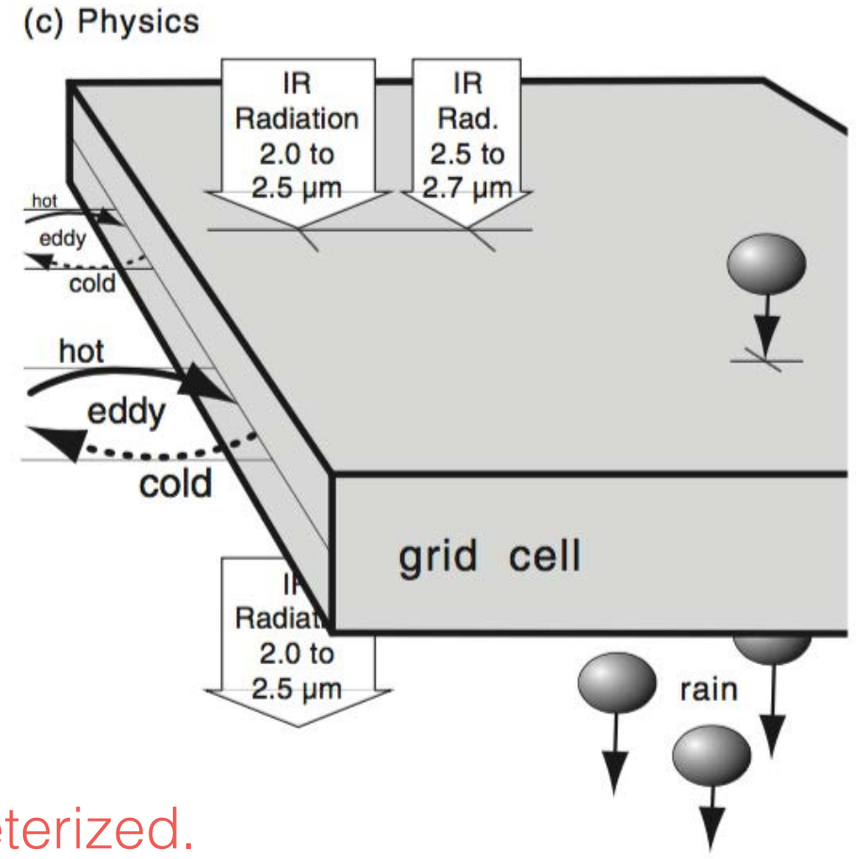
- pressure-gradient force
- advection (transport by wind; illustrated at right)
- Coriolis force
- large-scale buoyancy/stability



Sub-grid components are “physics”

- cloud microphysics (raindrops, snowflakes)
- deep convection (thunderstorms)
- boundary layer & turbulence (eddies)
- solar and IR radiation
- vegetation & land/ocean/ice surface
- topographic effects (mountain waves)

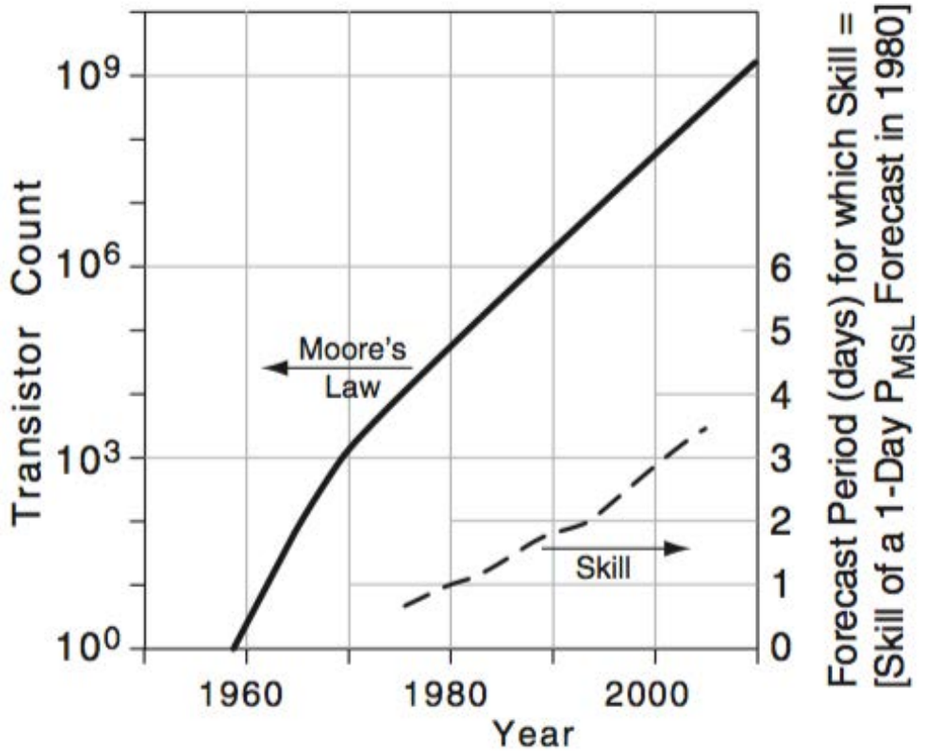
All these have resolvable effects that must be parameterized.



Numerical Stability vs. Grid Resolution

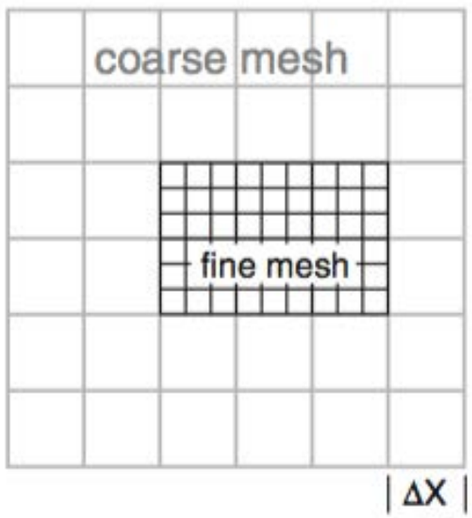
Grid-size Issues

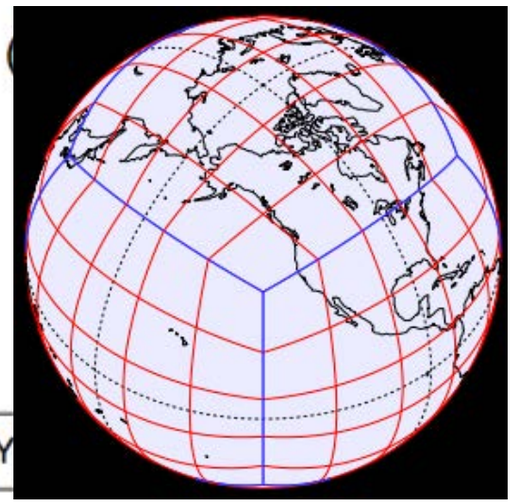
- complex terrain requires finer grid resolution
- takes longer to run on computers
- but to have value, the forecast must finish before the weather happens. ("need for speed")



Solutions / Alternatives

- nested grids (often used in horizontal)
- variable grids (often used in vertical)
- finite volume (FV3 recently adopted by NWS)
- spectral (current GFS model by NWS)





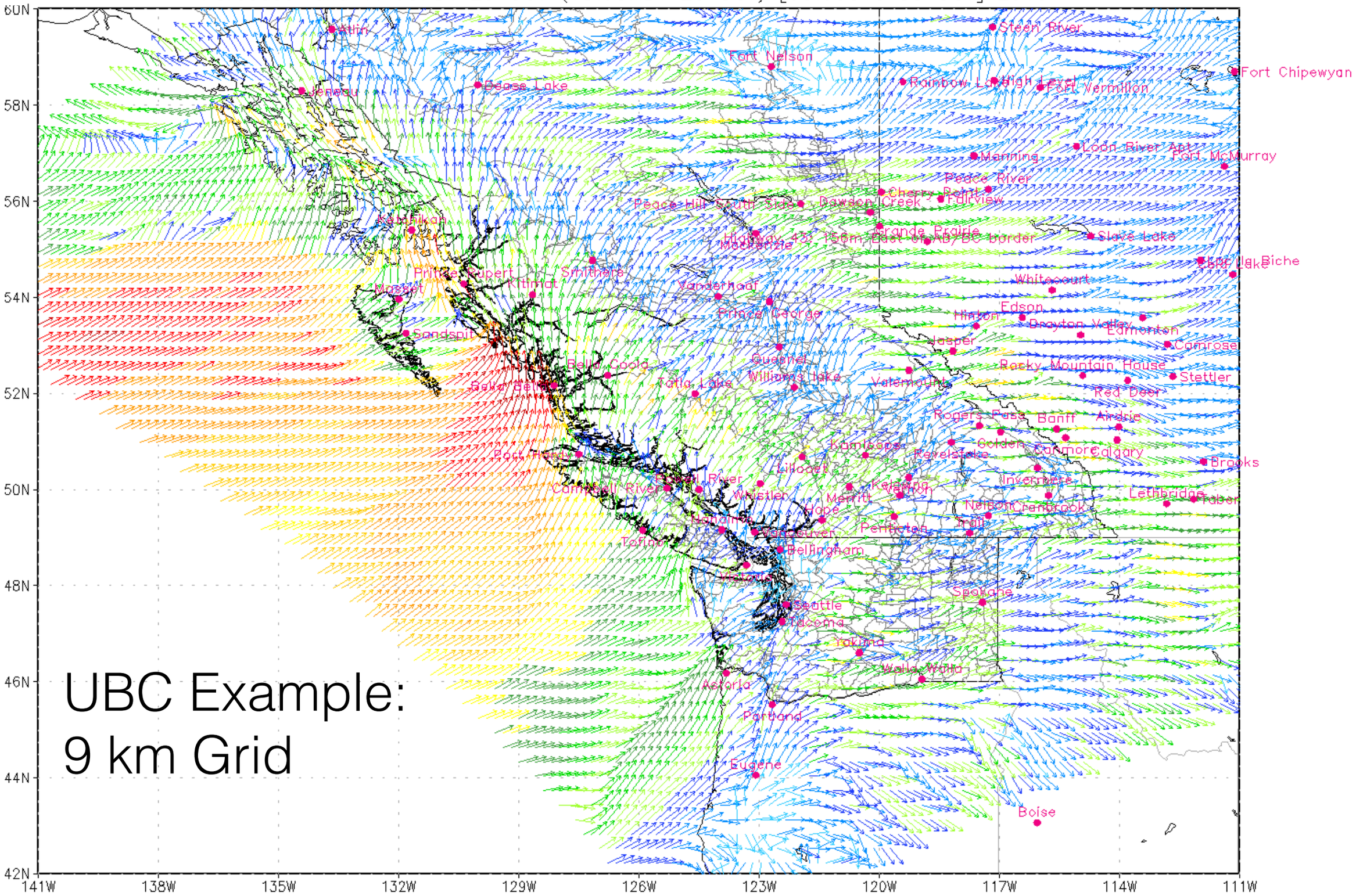
Model/IBC: WRF3/GFSgc01

9 km grid

Coloured Surface Winds

Grid initialized: 3UTC, 29 OCT 2015

Forecast valid 17:00PDT 29 OCT (18:00MDT 29 OCT) [00:00UTC 30 OCT] 2015



UBC Example: 9 km Grid

Forecast valid 17:00PDT 29 OCT (18:00MDT 29 OCT) [00:00UTC 30 OCT] 2015

3 5 8 11 13 16 19 22 24 27 30 32 35 38 43

5 10 15 20 25 30 35 40 45 50 55 60 65 70 80

colour bar: Wind Speed marked in knots above bar and km/hr below bar

arrows: Wind Direction

2 Degrees Longitude is
128 km at 55 latitude
143 km at 50 latitude
157 km at 45 latitude

photo credit: David Siuta & Henryk Modzelewski

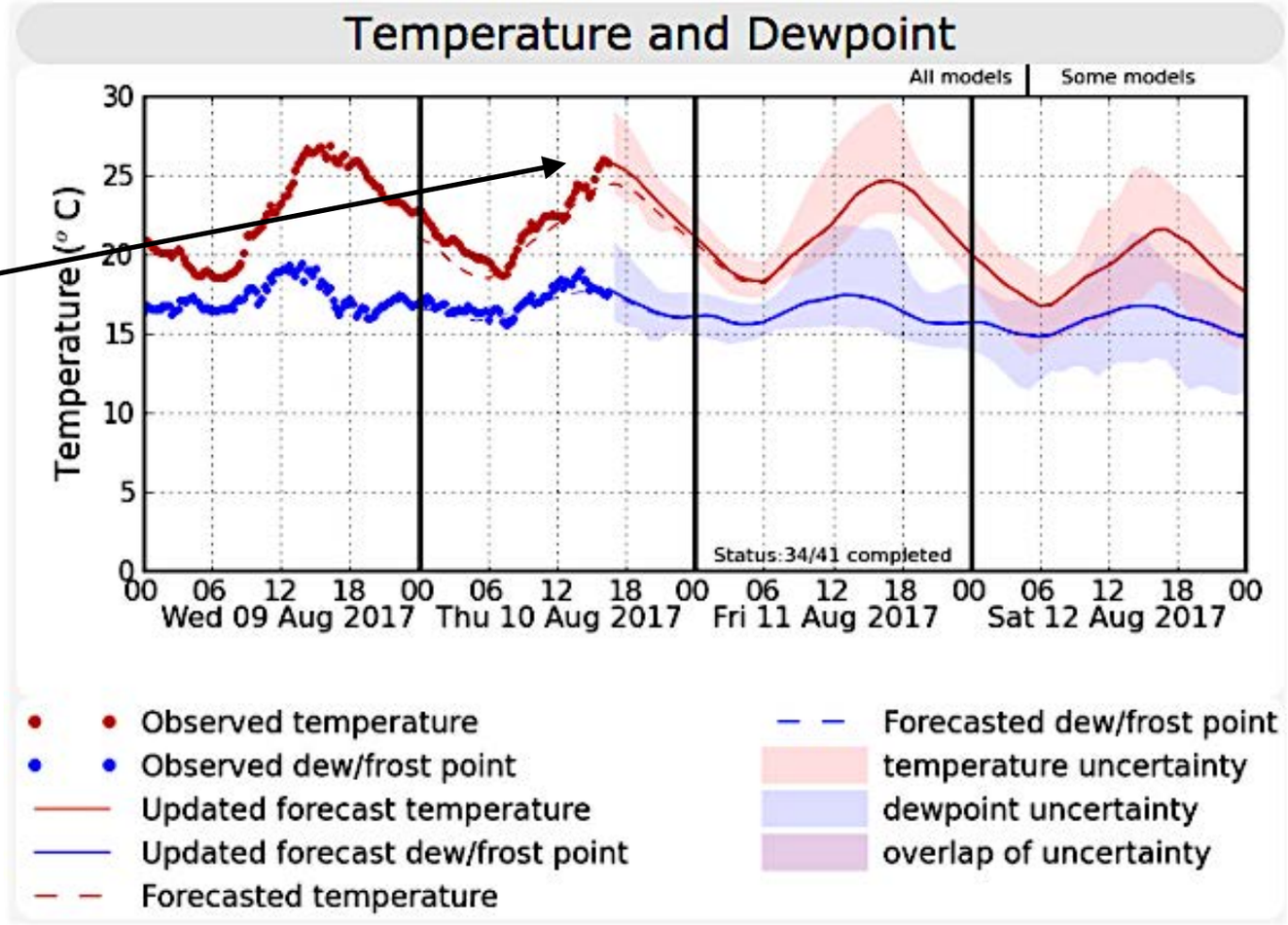
Forecast Improvement

- Systematic error reduction via post-processing bias correction, based on **observations**. (Kalman filters, running avg., instant bias correction)

- Random error reduction via an **ensemble** of forecasts.

- Probabilistic forecast calibration using **observations.**

- Merging new weather **observations** with previous forecast to produce new analyses (data assimilation & nowcasting)

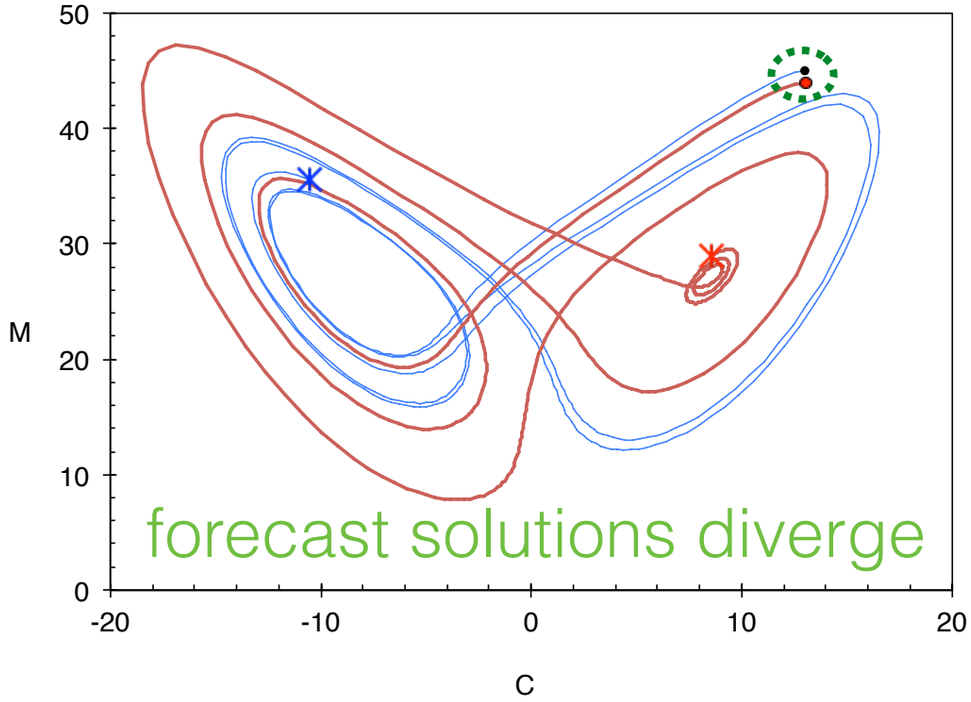


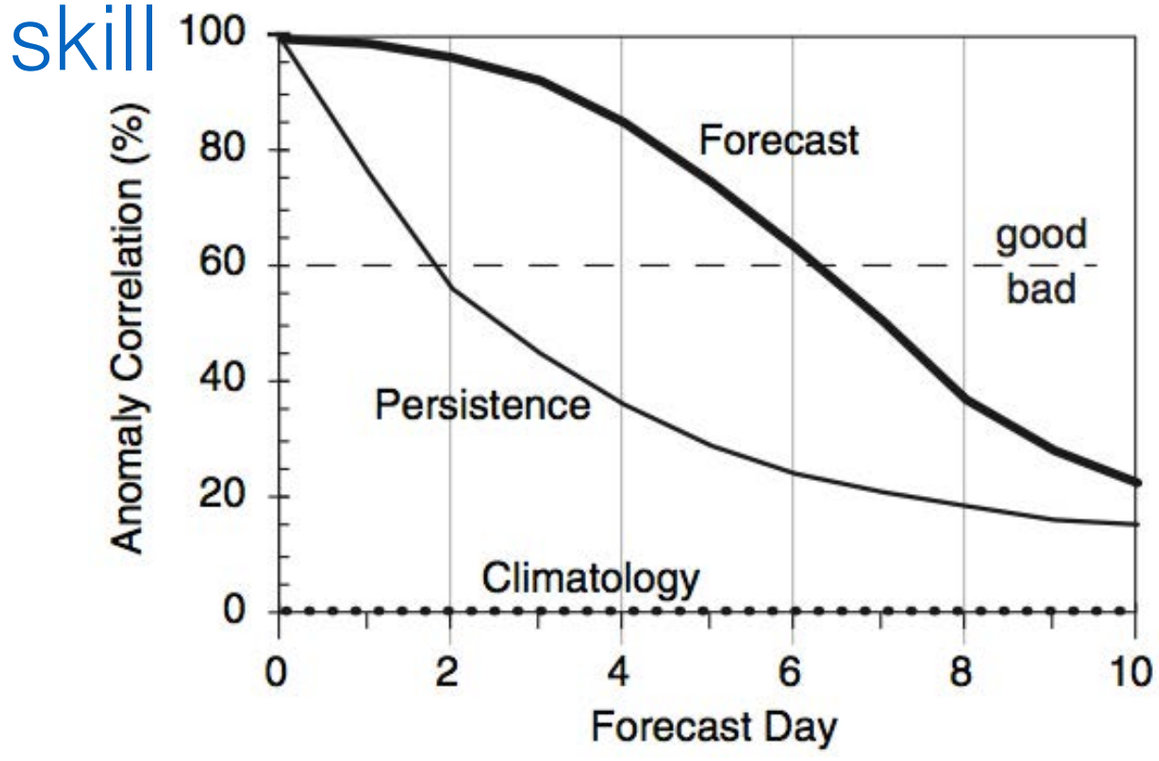
Chaos vs. Predictability

Atmosphere is like Lorenz strange attractor, only worse.

- Highly nonlinear (many degrees of freedom).
- Sensitive dependence to ICs.
- If modelled IC is different than real atmos. IC, then forecast weather diverges from actual weather.
- Skill decreases with increasing forecast horizon.

CCArray weather obs. can give better ICs and better forecasts.





2. Ensemble Approach

Reduces random errors associated with chaotic atmosphere

<u>UBC Example</u>: 42 ensemble members run each day on our 448 core computer cluster + additional members run on cloud computers

- Multi NWP models
  WRF, MM5
- Multi model versions
  WRF-ARW, WRF-NMM
- Multi Initial Conditions (ICs)
  GFS, NAM, GEM, NAVGEM, ARPEGE
- Multi grid sizes
  108, 36, 27, 12, 9, 4, 1.3 km horiz.
- Multi boundary-layer physics
  YSU, ACM2, & more

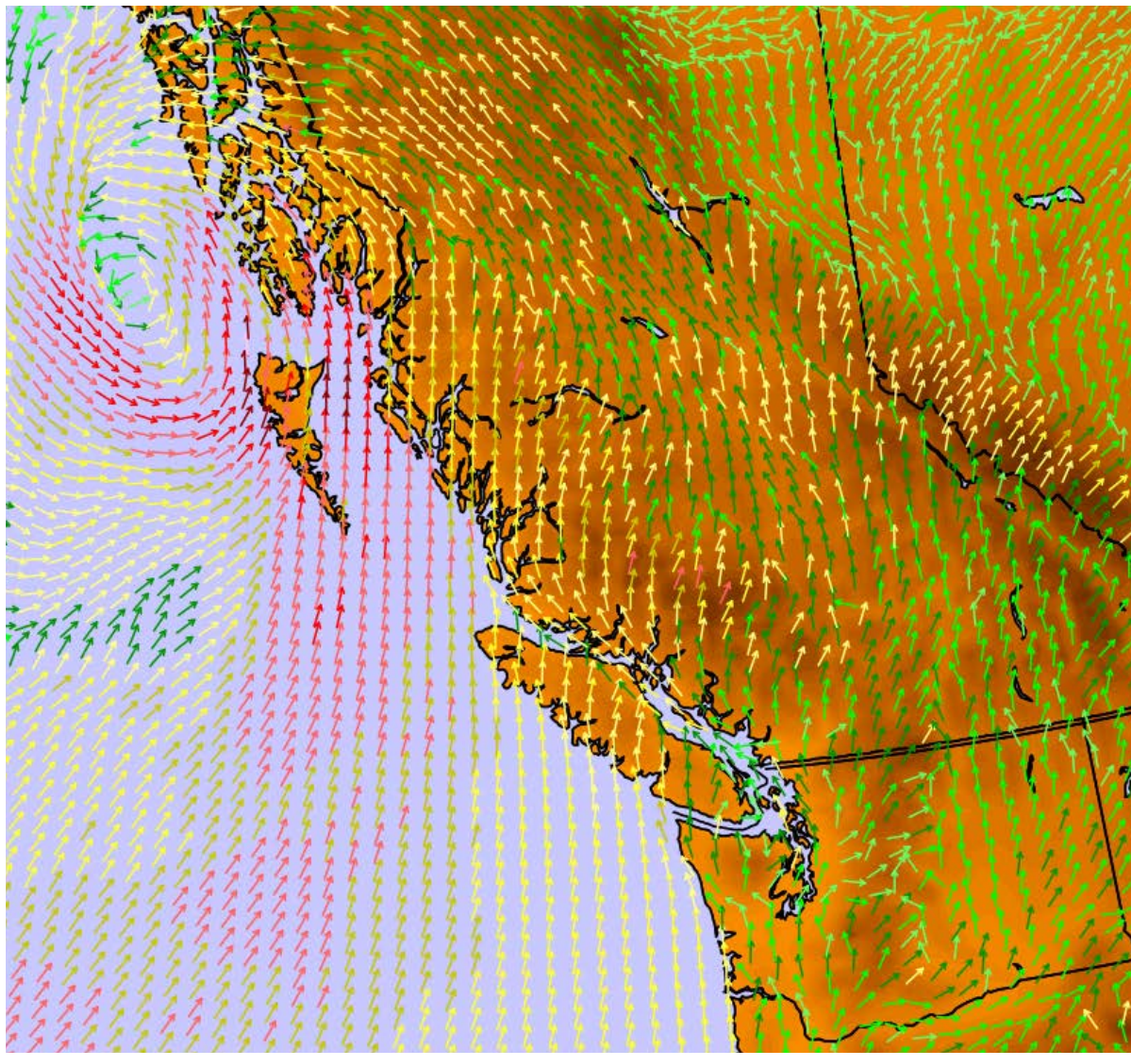


photo credit: Greg West

Ensemble Spread

Gives one estimate of forecast uncertainty.

Generic Methods:

(But uncalibrated spread has little value.)

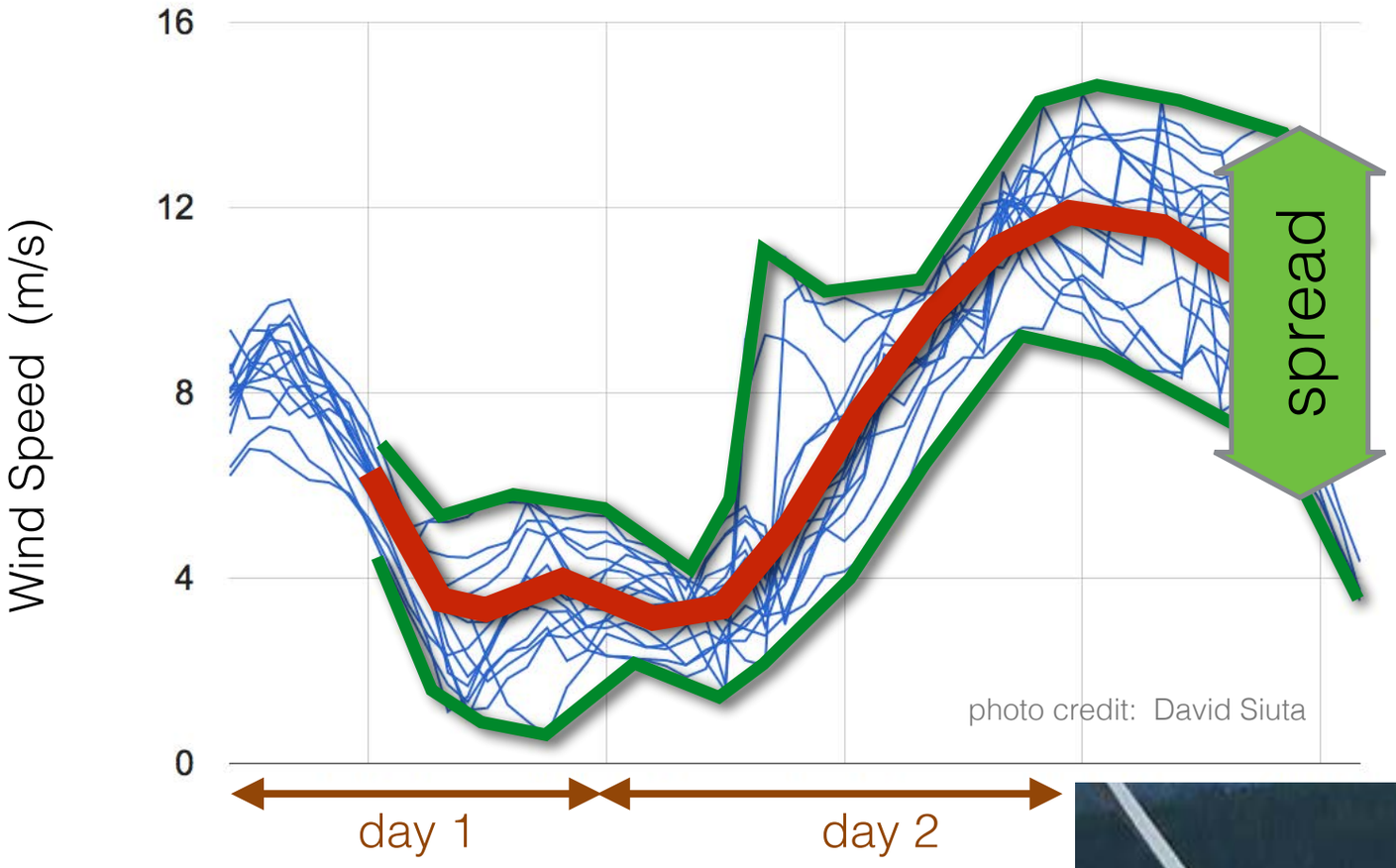


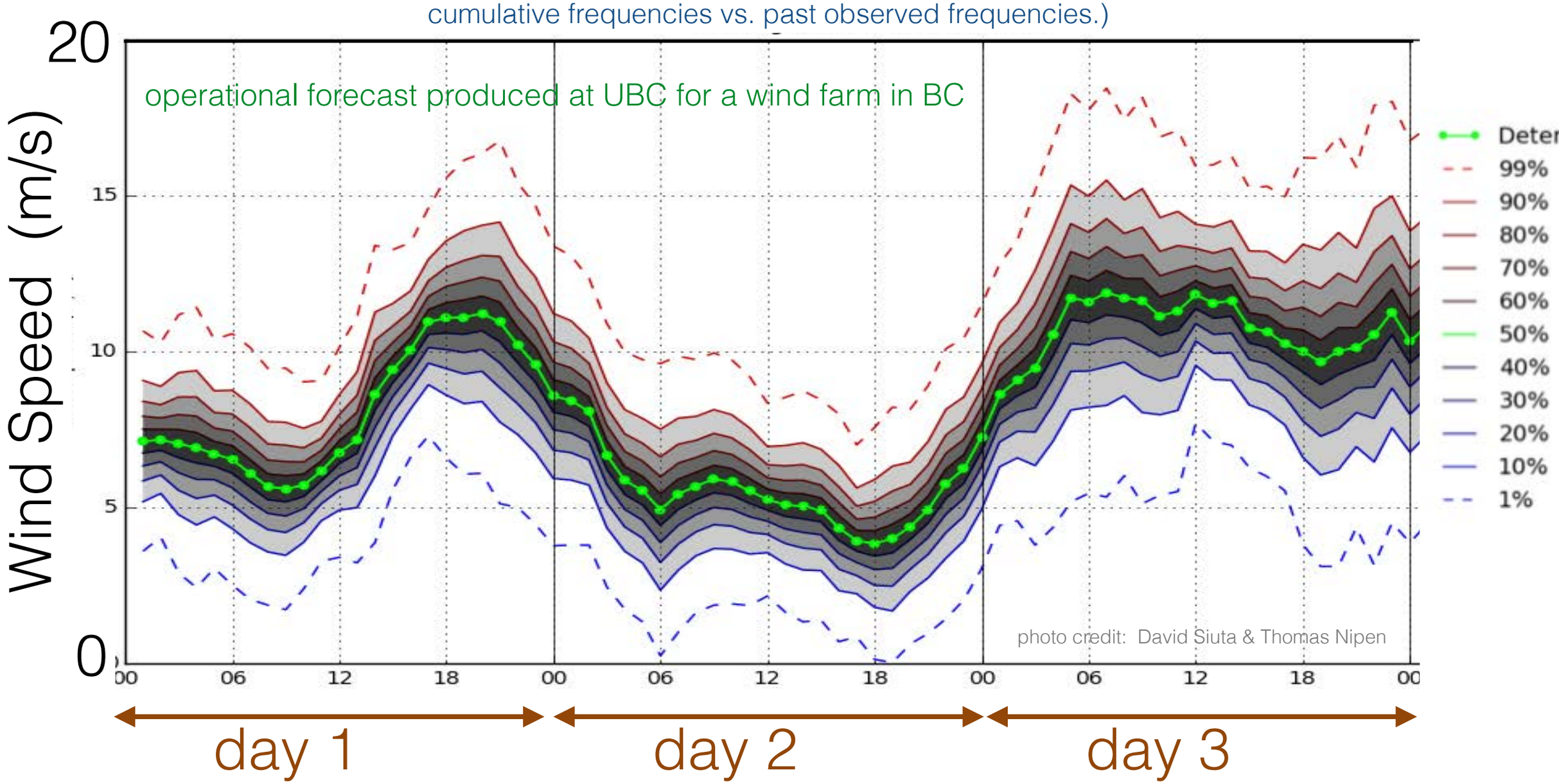
photo credit: David Siuta

Ensemble Probabilities

Finally, calibrate the probabilities:

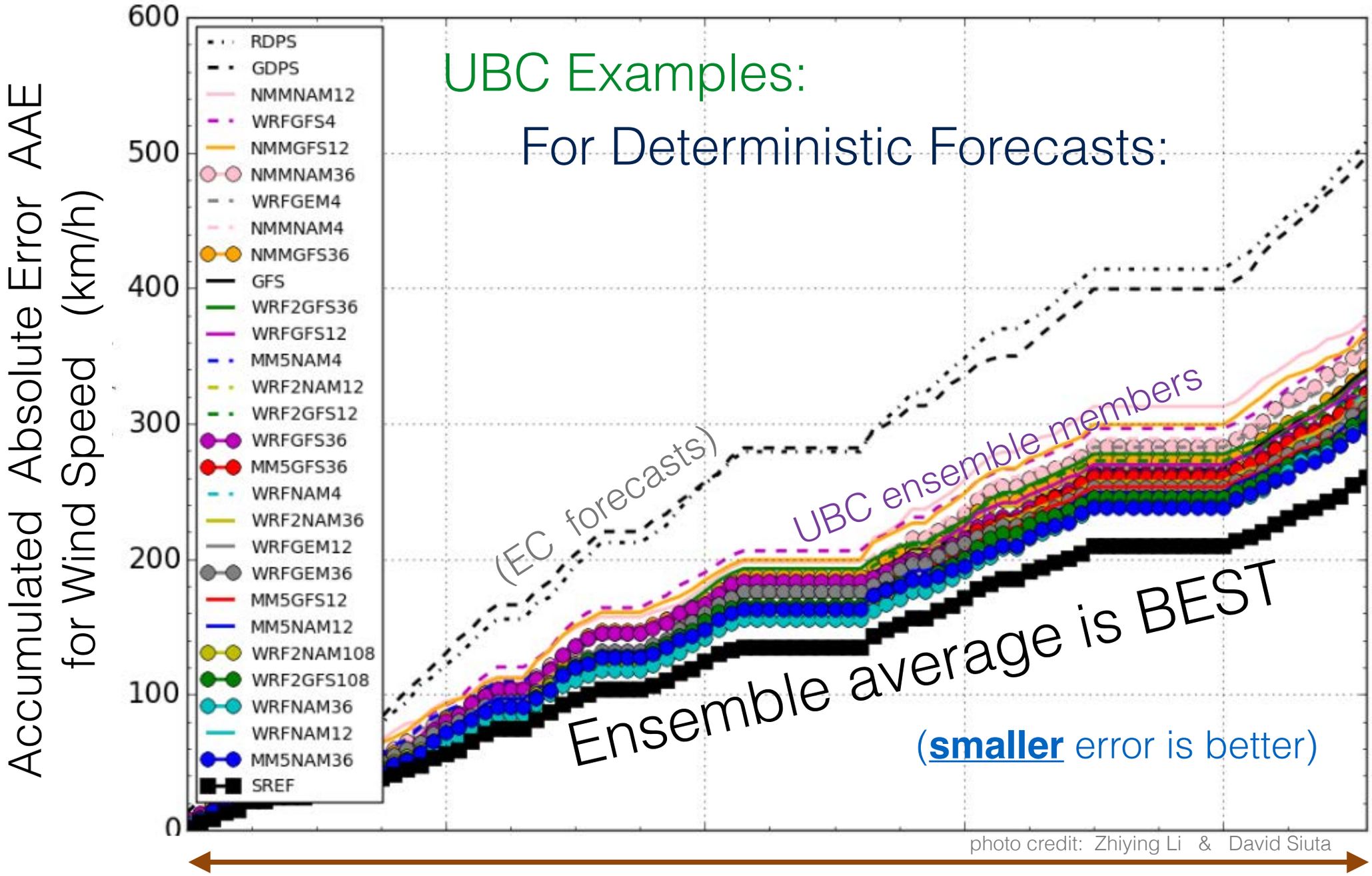
Calibration means the predicted probability matches the observed frequency.

(Calibrated using the Nipen method: based on a mapping of past forecast cumulative frequencies vs. past observed frequencies.)



Ensemble Verification

Measures skill & identifies potential problems



3. Nowcasting

- Combine gridded NWP output (i.e., forecast)
- With sparse irregularly located weather **observations**

- To make an updated “nowcast”.

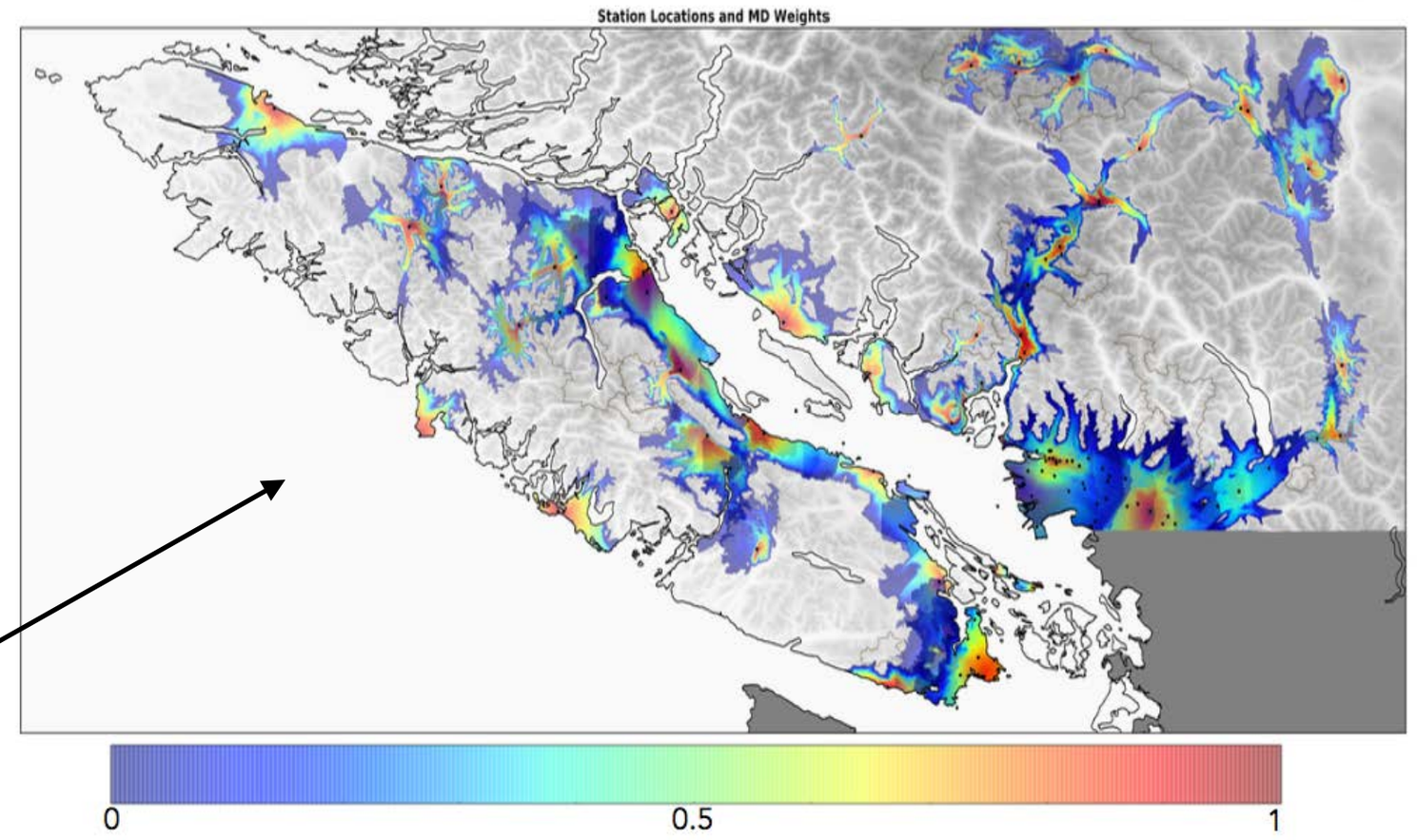
Observation Locations in EmWxNet

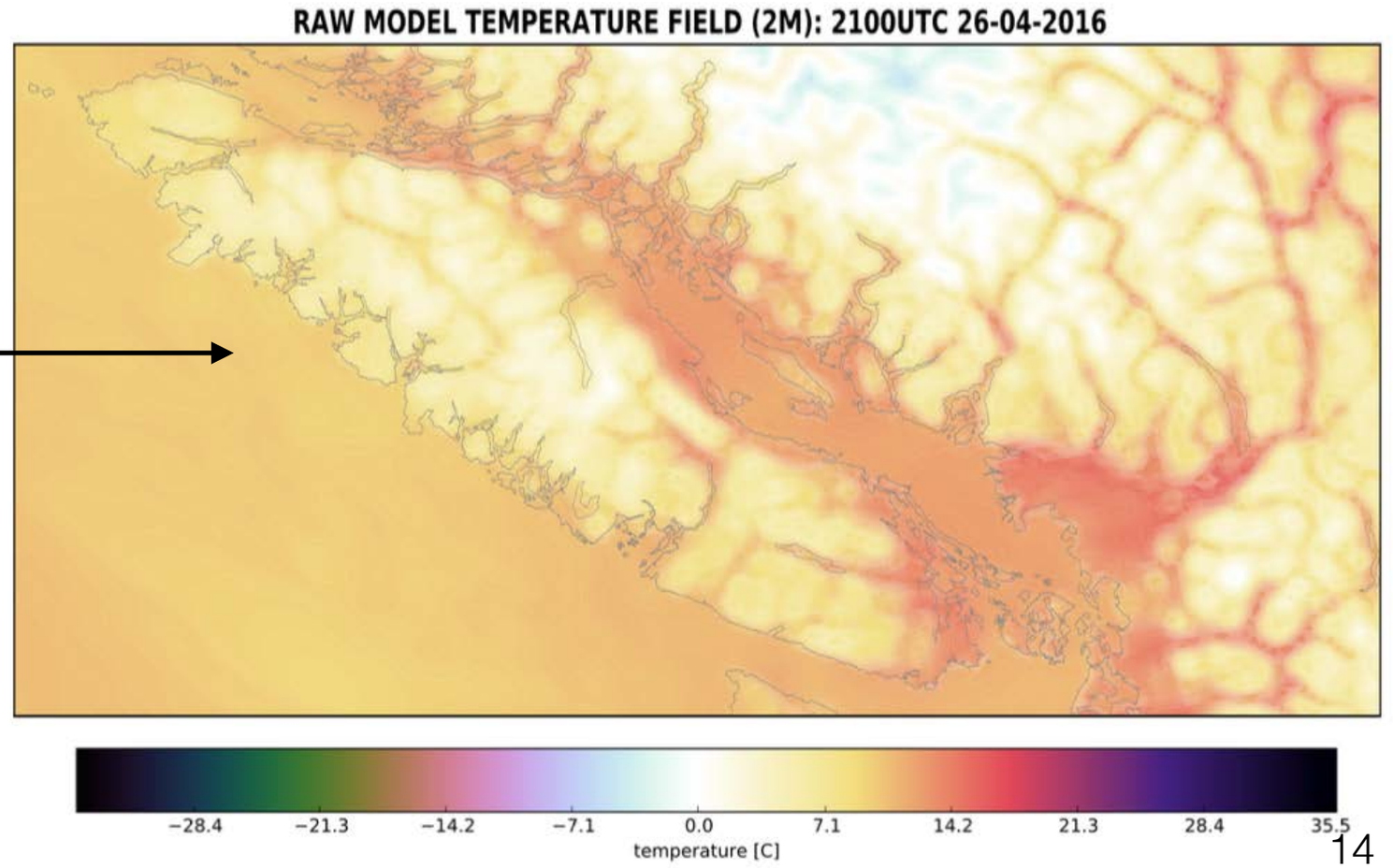
Take the sparse weather observations from EmWxNet,

spread them with due regard to topography,

and combine them with the raw gridded forecast

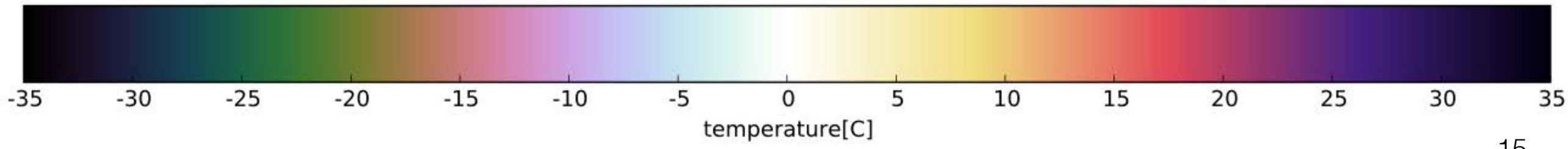
to yield … (see next slide)





HIGH-RESOLUTION TEMPERATURE ANALYSIS (2M) | 2100UTC 26-04-2016 | MD DA

Resulting Nowcast of Temperature



4. Applications

Examples of Applied Research & Service at UBC.

- Clean Energy
- Transportation
- Hazards
- Special Projects

Geophysical Disaster Computational Fluid Dynamics Center

• University of British Columbia – Vancouver • Dept. of Earth, Ocean & Atmospheric Sciences • Weather Forecast Research Team • Directed by Prof. Roland Stull •

What we do.

Weather Forecasts for Clean Energy

- Hydroelectricity
- Wind power
- Solar power
- Biomass energy

Bennett Dam & Williston Lake photo by R. Stull

Sponsor:
BC Hydro

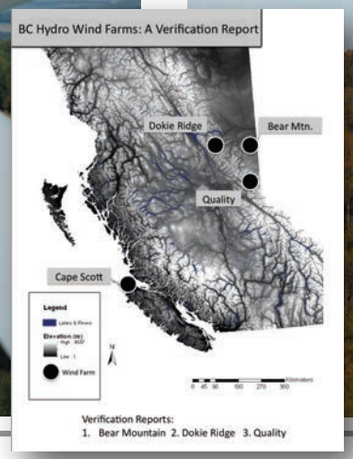
Region:
British Columbia

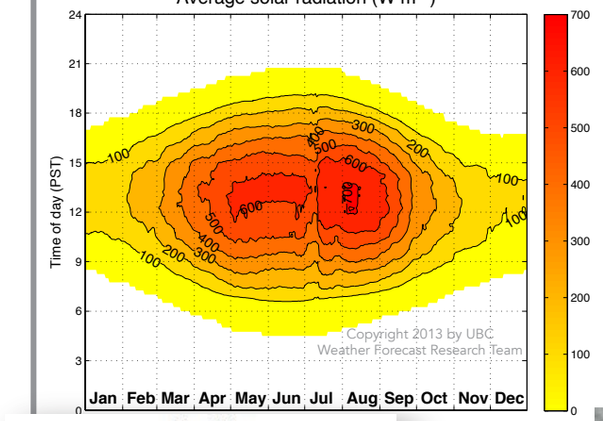
Ensemble forecasts out to 16 days of precipitation, temperature, & freezing level for 30 hydro electric facilities

Sponsor:
BC Hydro

For 4 BC Wind Farms:
- Bear Mountain
- Dokie
- Quality
- Cape Scott

Bear Mountain Wind Park photos by AltaGas

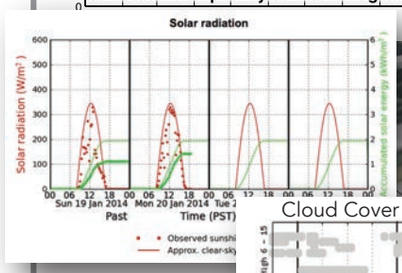




Sponsor: BCIT

Region: Burnaby

Solar-radiation forecasts for GAIT solar-panel oasis.



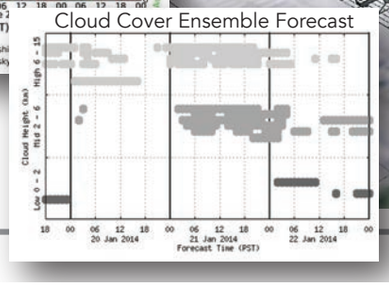


photo by BCIT

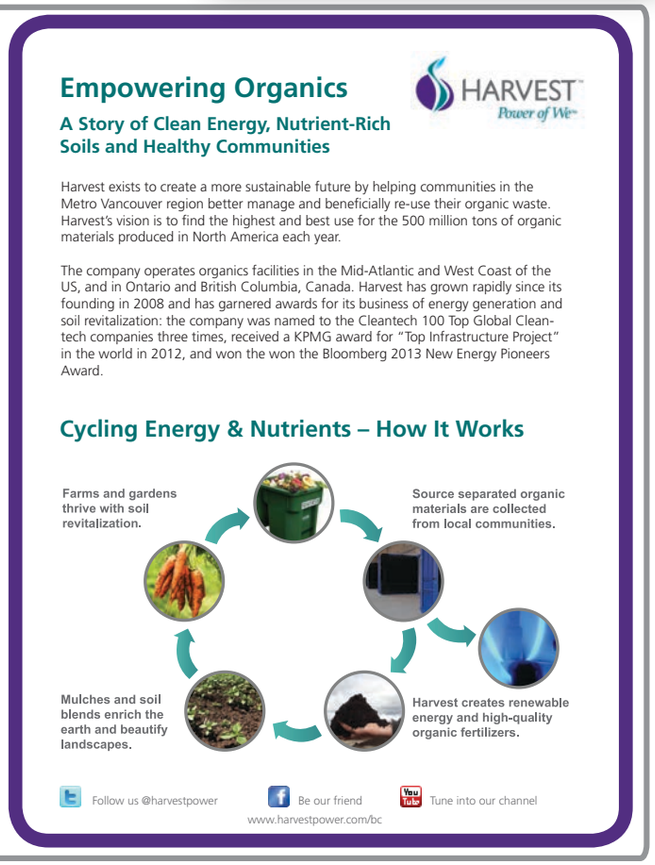
For more info, contact:

Prof. Roland Stull
UBC EOAS Dept.
2020-2207 Main Mall
Vancouver, BC V6T 1Z4
Canada
rstull@eos.ubc.ca
604-822-5901

Sponsor:
Harvest Power

Region:
Richmond

Wind and stability (gustiness) fore-casts & email alert messages.



Empowering Organics

A Story of Clean Energy, Nutrient-Rich Soils and Healthy Communities

HARVEST Power of We

Harvest exists to create a more sustainable future by helping communities in the Metro Vancouver region better manage and beneficially re-use their organic waste. Harvest's vision is to find the highest and best use for the 500 million tons of organic materials produced in North America each year.

The company operates organics facilities in the Mid-Atlantic and West Coast of the US, and in Ontario and British Columbia, Canada. Harvest has grown rapidly since its founding in 2008 and has garnered awards for its business of energy generation and soil revitalization: the company was named to the Cleantech 100 Top Global Clean-tech companies three times, received a KPMG award for "Top Infrastructure Project" in the world in 2012, and won the won the Bloomberg 2013 New Energy Pioneers Award.

Cycling Energy & Nutrients – How It Works

Follow us @harvestpower Be our friend Tune into our channel
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What we do.

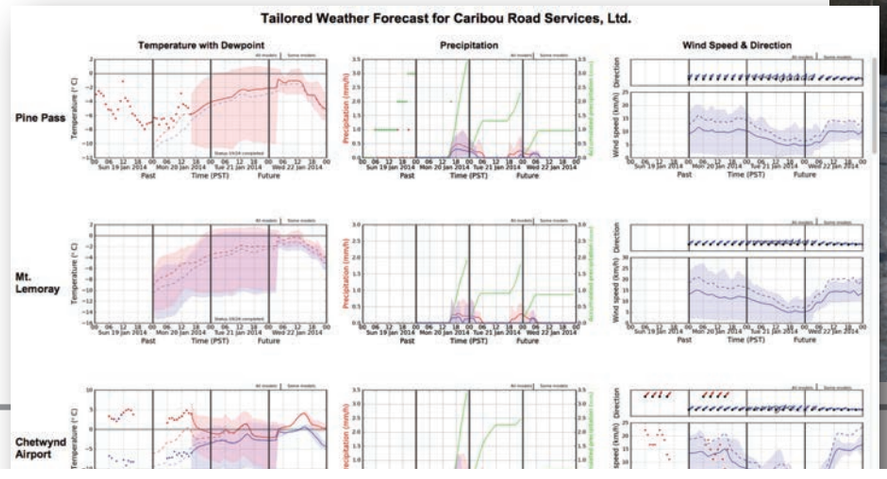
Weather Forecasts for Transportation

- Highway Maintenance
- Electric Bus/Trolley
- Sea Ports
- Railroads

Sponsor: Caribou Road Services

Peace Region in N.E. Brit. Col.

Snowfall, temperature, wind, humidity, and cloudcover forecasts out 2.5 days



photos by Caribou Road Services

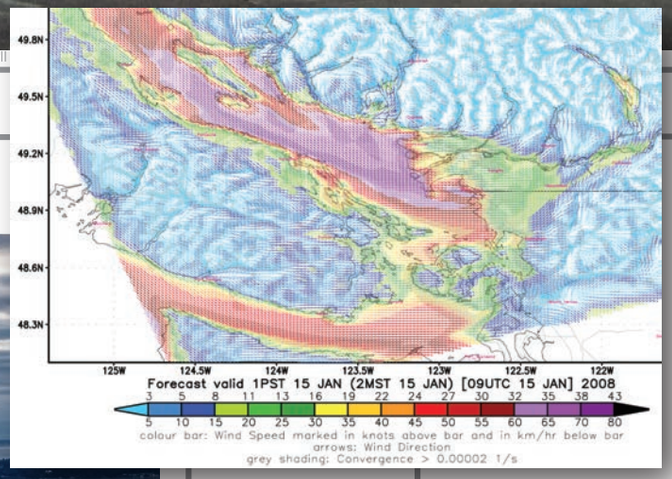
photo by R. Stull

photos by R. Stull

Sponsor: Coast Mountain Bus Co.

Region: Greater Vancouver

Temperature, humidity for frost & ice formation on trolley overhead lines.
Also deployed weather stations.



Sponsors: Deltaport & Westport

Wind & gust forecasts for safer ship loading.

photo by TSI Deltaport

Deltaport is Port Metro Vancouver's largest container terminal, located at Roberts Bank.

For more info, contact:

Prof. Roland Stull
UBC EOAS Dept.
2020-2207 Main Mall
Vancouver, BC V6T 1Z4
Canada
rstull@eos.ubc.ca
604-822-5901

Sponsor: RadHyPS.
Region: W. Canada

Weather-station data in support of Canadian Pacific Railway operations.

http://www.cpr.ca/en/news-and-media/photo-gallery/merchandise/PhotoGallery/Attachments/7/merch_007_hr.jpg

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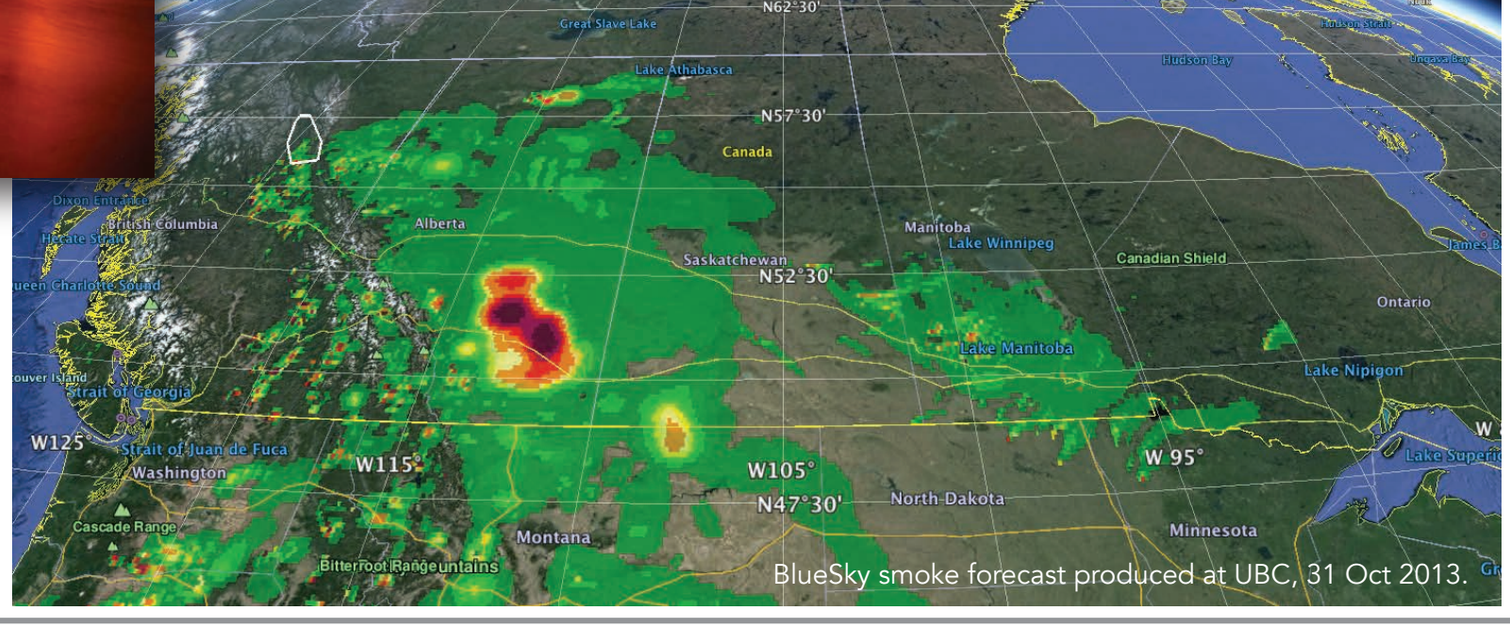
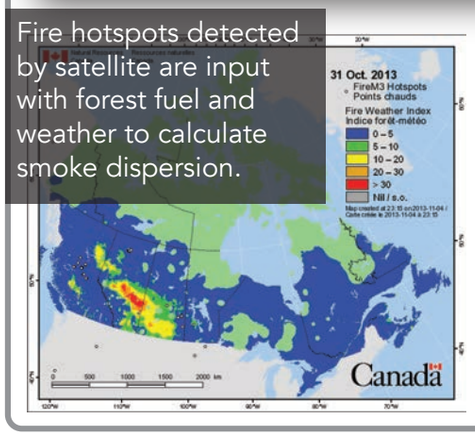
What we do.

Forecasts for Weather-related Hazards

- Forest Fire Smoke
- Flooding
- Avalanches
- Emergency Weather Net



BlueSky smoke forecast produced at UBC, 31 Oct 2013.



Fire hotspots detected by satellite are input with forest fuel and weather to calculate smoke dispersion.

Sponsors: CSSP & Environment Ministries from many provinces.

Name: BlueSky

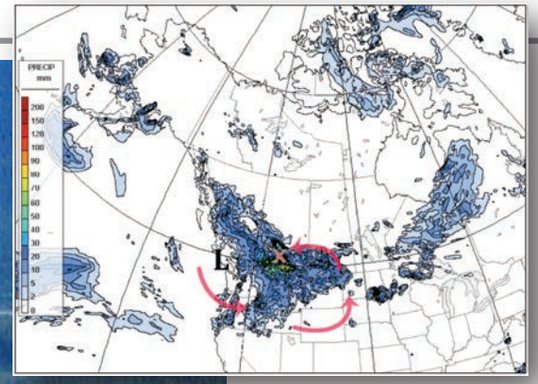
Region: Canada

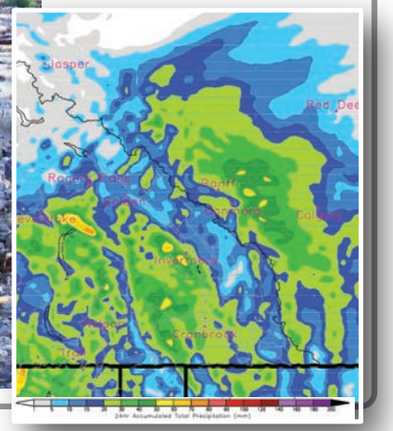
Spread of smoke from wild fires.

Sponsor: Town of Canmore, AB, and BGC Engr.

Region: Alberta

Analysis of storm conditions that caused flooding in 2013.





Sponsor: BC Ministry of Transportation

Region: BC. Avalanche weather data.

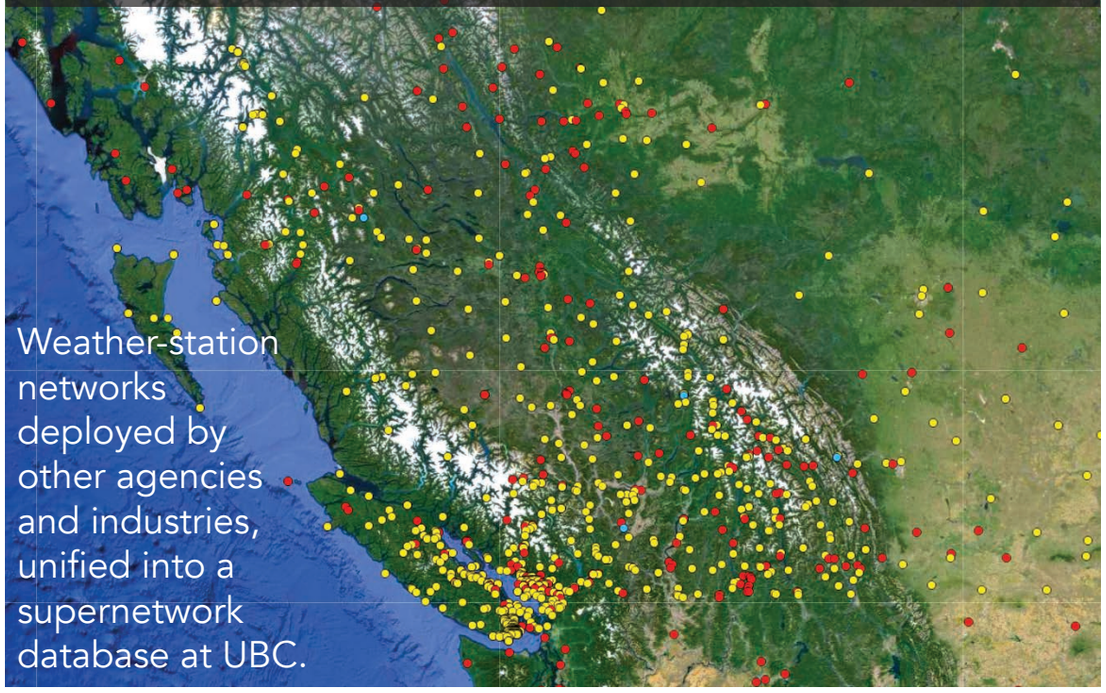
photo of Pine Pass cleanup
by Caribou Road Services

photos by BC Min. of Transportation & Infrastructure. East of Revelstoke, 2011.

For more info, contact:

Prof. Roland Stull
UBC EOAS Dept.
2020-2207 Main Mall
Vancouver, BC V6T 1Z4
Canada
rstull@eos.ubc.ca
604-822-5901

Emergency Weather Network
Weather support for emergency managers



Weather-station networks deployed by other agencies and industries, unified into a supernetwork database at UBC.

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What we do.

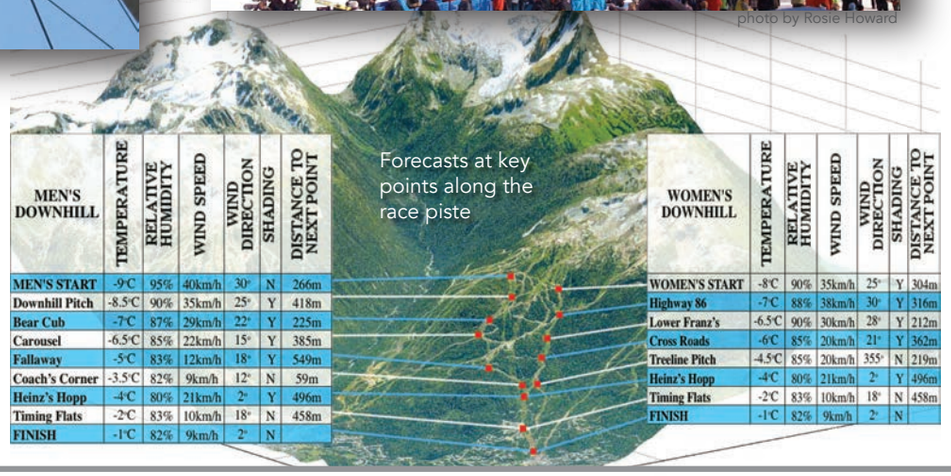
Weather Forecasts for Special Events/Projects

- 2010 Winter Olympics
- Project Firestorm
- Rocketsonde Buoys
- Canadian Arctic

Deployment of sophisticated sensors

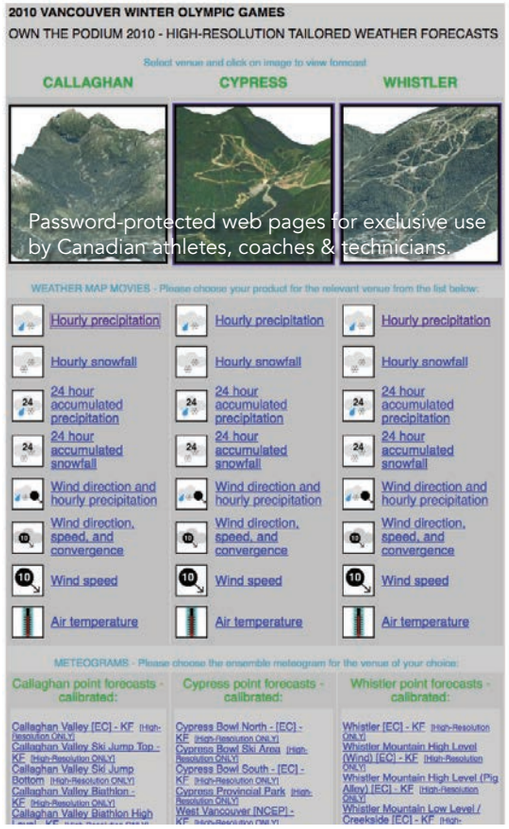
photo by Rosie Howard

photos by R. Stull



MEN'S DOWNHILL	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED	WIND DIRECTION	SHADING	DISTANCE TO NEXT POINT
MEN'S START	-9°C	95%	40km/h	30°	N	266m
Downhill Pitch	-8.5°C	90%	35km/h	25°	Y	418m
Bear Cub	-7°C	87%	29km/h	22°	Y	225m
Carousel	-6.5°C	85%	22km/h	15°	Y	385m
Fallaway	-5°C	83%	12km/h	18°	Y	549m
Coach's Corner	-3.5°C	82%	9km/h	12°	N	59m
Heinz's Hopp	-4°C	80%	21km/h	2°	Y	496m
Timing Flats	-2°C	83%	10km/h	18°	N	458m
FINISH	-1°C	82%	9km/h	2°	N	

WOMEN'S DOWNHILL	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED	WIND DIRECTION	SHADING	DISTANCE TO NEXT POINT
WOMEN'S START	-8°C	90%	35km/h	25°	Y	304m
Highway 86	-7°C	88%	38km/h	30°	Y	316m
Lower Franz's	-6.5°C	90%	30km/h	28°	Y	212m
Cross Roads	-6°C	85%	20km/h	21°	Y	362m
Treeline Pitch	-4.5°C	85%	20km/h	355°	N	219m
Heinz's Hopp	-4°C	80%	21km/h	2°	Y	496m
Timing Flats	-2°C	83%	10km/h	18°	N	458m
FINISH	-1°C	82%	9km/h	2°	N	



Password-protected web pages for exclusive use by Canadian athletes, coaches & technicians.

Sponsor: 2010 Vancouver Olympic Committee & OTP

Region: Whistler, Callaghan, Cypress Ski Resorts, BC.

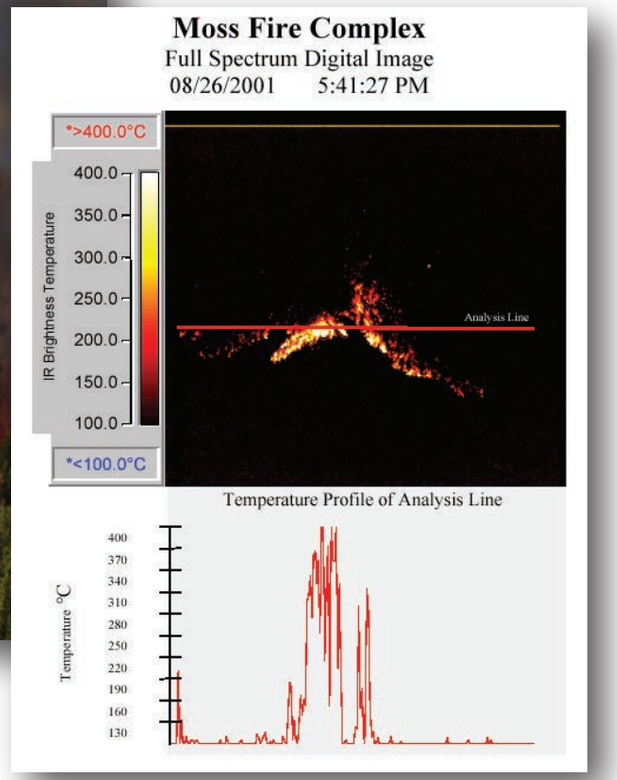
Tailored weather forecasts for athletes & technicians, and research on snow race surfaces.

Sponsor: Forest Renewal BC

Region: BC.

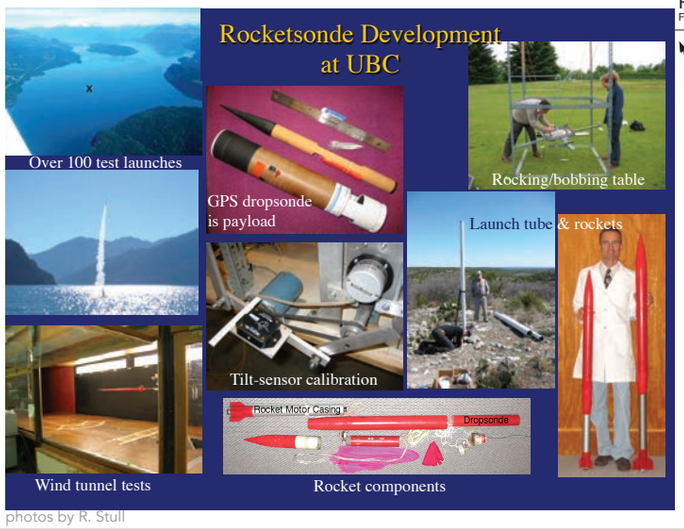
Research aircraft observations of active forest fires to verify our coupled forest-fire / weather-forecast models.

photos by R. Stull

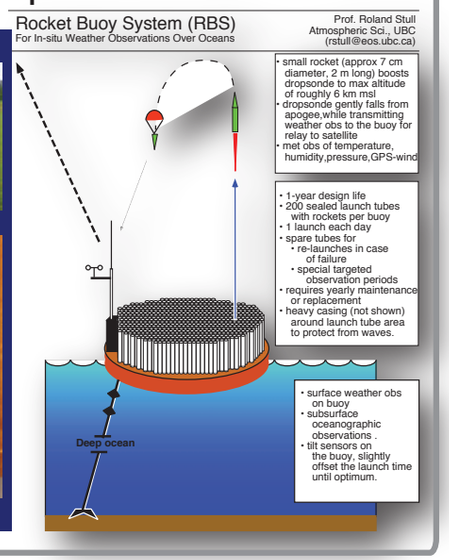


Sponsor: Canadian Foundation for Climate & Atmospheric Science (CFCAS)

Prototyping of an autonomous rocket sounding system for data upwind of BC.

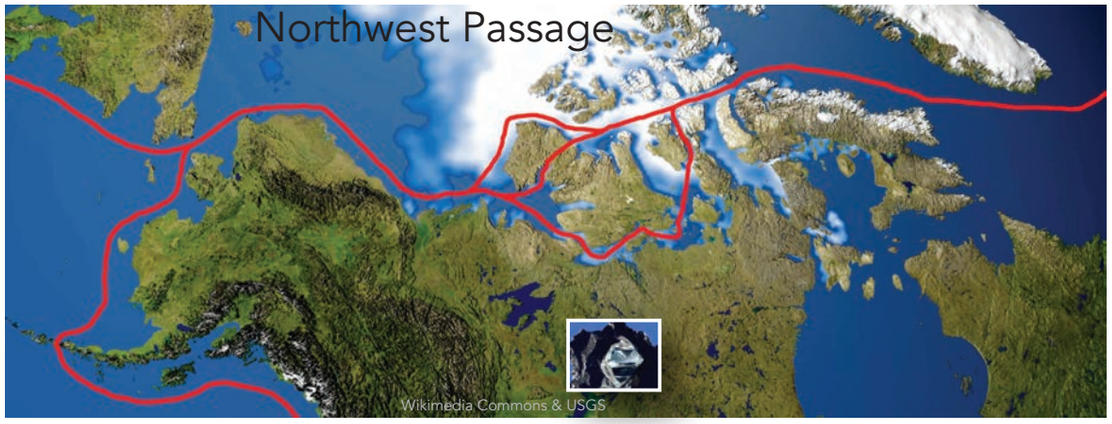


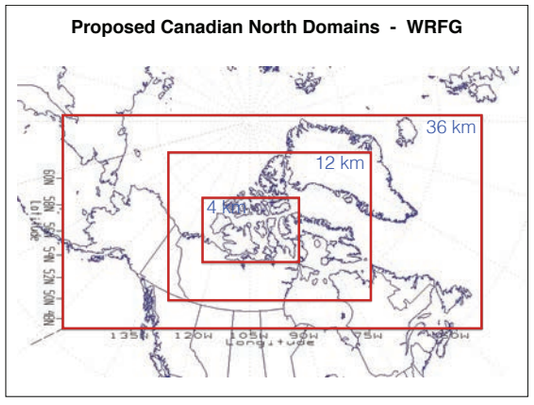
photos by R. Stull



For more info, contact:

Prof. Roland Stull
UBC EOAS Dept.
2020-2207 Main Mall
Vancouver, BC V6T 1Z4
Canada
rstull@eos.ubc.ca
604-822-5901





Strategic Expansion into Canadian Arctic to serve northern communities, diamond exploration, shipping, & aviation.

Arctic Canada forecasts that you can use during your field work.

http://weather.eos.ubc.ca/arctic/

5. Weather Observation Networks

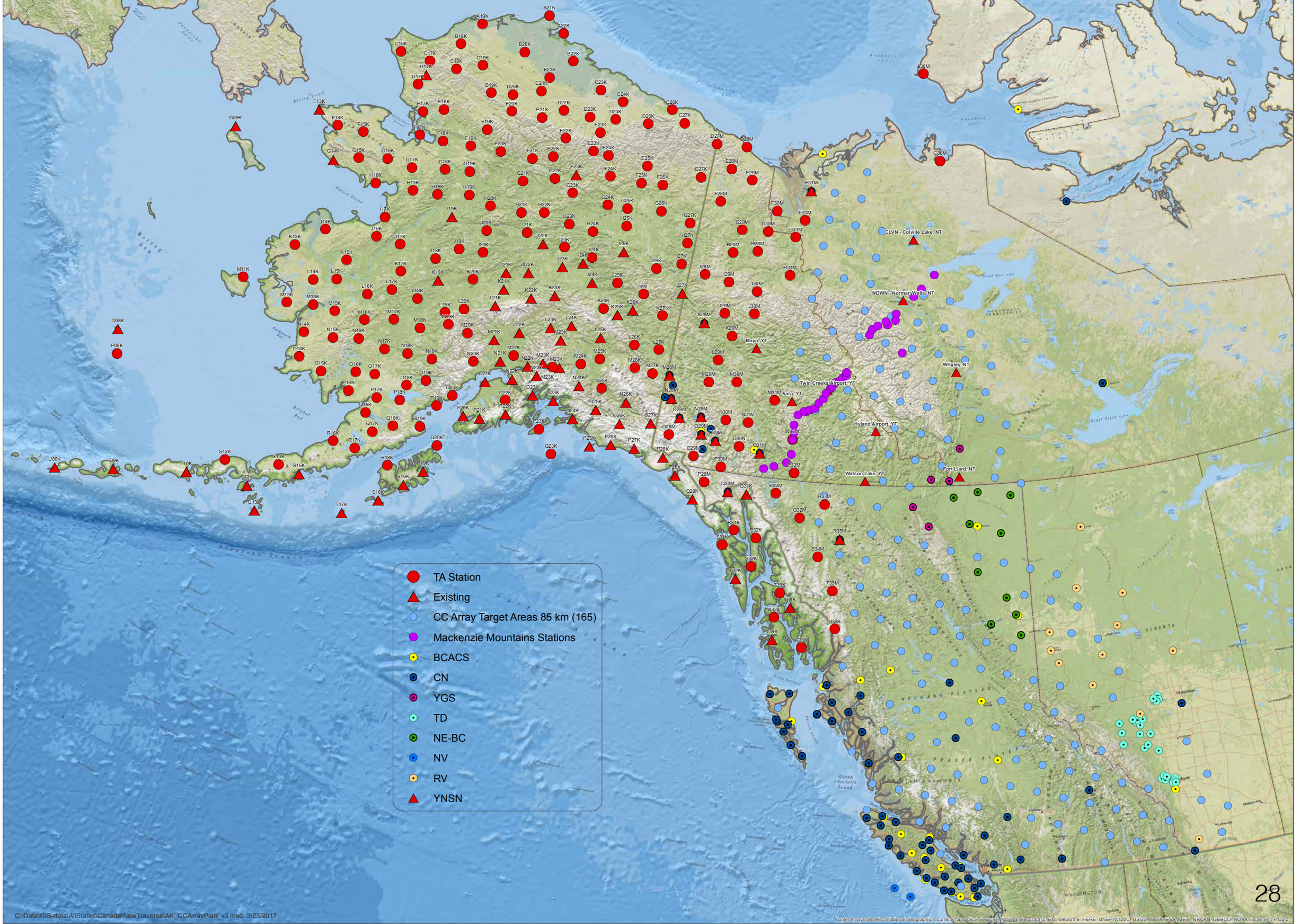
- Emergency Weather Network (EmWxNet), operated by UBC as a network of networks
- CCArray
- Recommendations on which CCArray locations could also have weather sensors.

Network of Networks

- BC Ministry of Transportation and Highways
- BC Ministry of Water, Land and Air Protection, Air Resources Branch
- Environment Canada Marine
- BC Ministry of Forests
- BC Hydro
- Greater Vancouver Regional District
- BC Ministry of Water, Land and Air Protection, Rivers
- Environment Canada BC and Yukon Stations
- National Center for Environmental Prediction
- CN Rail
- Canadian Pacific Railway
- UBC (AB)
- UBC (RS)
- Westshore Terminals
- BGC Engineering Inc.
- UVic School-Based Weather Stations
- CAA Alberta Motor Association
- Coast Mountain Bus Company
- TSI Deltaport
- Wunderground
- Harvest Power
- Wood Buffalo Environmental Association
- Dummy agency for testing
- NAV CANADA
- Zero Emission Energy Developments
- Metro Vancouver Regional District

EmWxNet

USArray TA Alaska and Planned CCArray



C:\Data\GIS-data\AllStates\Canada\NewTraverse\AK_CCArrayPlan_v3.mxd 3/23/2017

Possible Sites for Weather Sensors

TA Station
Existing
CC Array Target Areas 85 km (165)
Mackenzie Mountains Stations
BCACS
CN
YGS
TD
NE-BC
NV
RV
YNSN

Recommended Weather Stations
Top 10
Next 10
Next 10
Next 10

The Value of Weather Observations for Numerical Weather Prediction

Roland Stull & Rosie Howard
University of British Columbia (UBC)
Vancouver, Canada
Aug 2017

Topics:
1. NWP Overview
2. Ensemble Fcsts.
3. Nowcasting
4. Applications
5. Weather Obs. Sites

rstull@eoas.ubc.ca

rhoward@eoas.ubc.ca

The End. Questions?