Probabilistic weather forecasting

ATSC 507

Thomas Nipen
University of British Columbia

Outline

- Why probabilistic forecasts?
- Measures of forecast uncertainty
- Producing prob forecasts
- Calibrating prob forecasts

Intro to prob. forecasts

- States the likelihood of all weather outcomes
- Gives a sense of forecast uncertainty
- A way for meteorologists to never be wrong (… or right)
- Useful for aiding economic decision making

Reservoir management

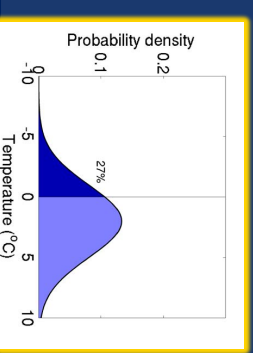Road maintenance

Wildfire risk assesment

…

Planning a picnic?

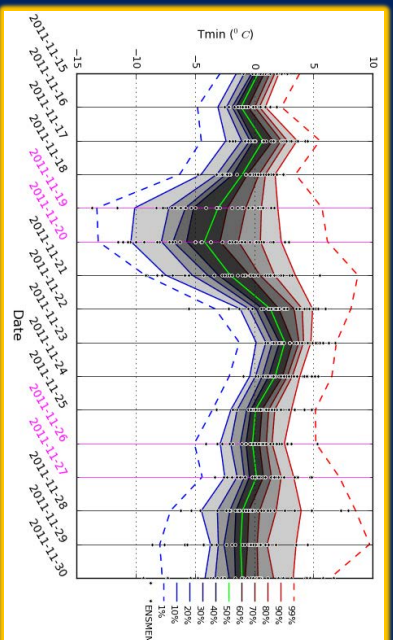# Intro to prob. forecasts

- Deterministic:
  – Shows single value
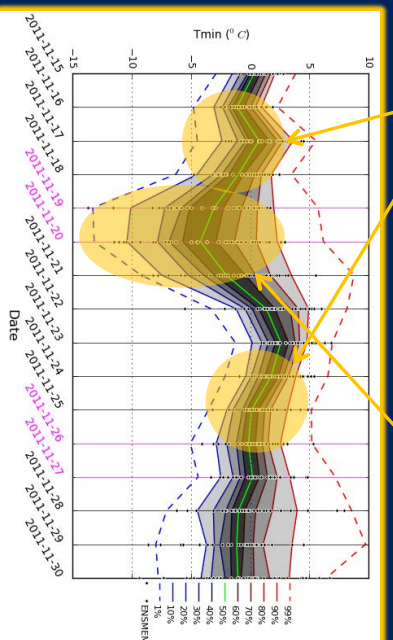
- Probabilistic:
  – All outcomes
  – Shows uncertainty

Slide 5

Intro to prob. forecasts

- Cumulative distribution function (CDF) plot

Slide 6

Intro to prob. forecasts
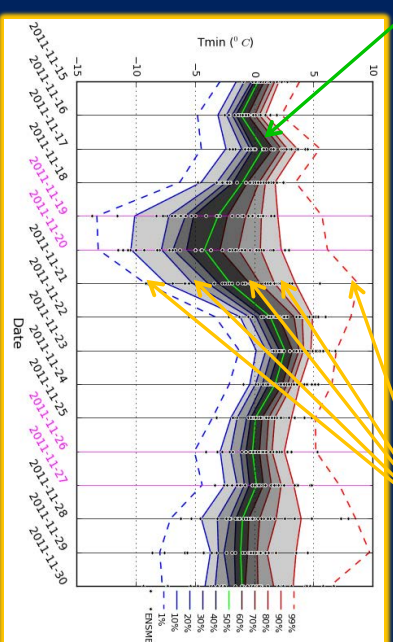
- Cumulative distribution function (CDF) plot

Central tendency

Probability lines

Slide 7

Intro to prob. forecasts

- Cumulative distribution function (CDF) plot

More certain

Less certain

Slide 8

Road maintenance

Prevention cost

		Observed	
		Freezing	Warm
Forecasted	Freezing	$100k	$100k
	Warm	$10M	$0

Slide 11

⑪

Slide 9

Road maintenance

Prevention cost

Loss

		Observed	
		Freezing	Warm
Forecasted	Freezing	$100k	$100k
	Warm	$10M	$0

⑨

Slide 12

Measures of uncertainty

- The ensemble variance used as measure of uncertainty

- Greater spread → greater uncertainty

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Slide 10

Road maintenance

- Optimal strategy:
  - **act** when prob(freezing) > 1%
  - **risk** a loss otherwise
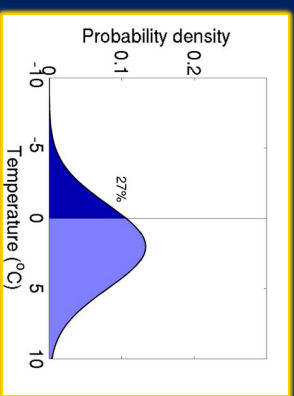
		Observed	
		Freezing	Warm
Forecasted	Freezing	$100k	$100k
	Warm	$10M	$0

Probability density

27%

⑩

Slide 13
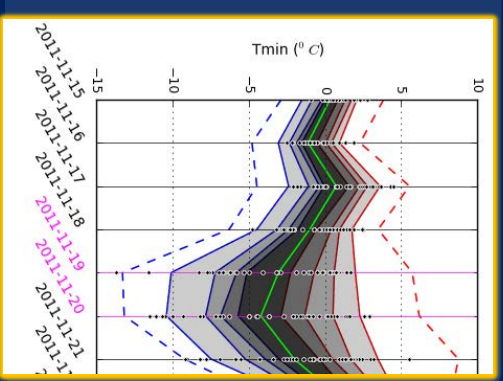
Measures of uncertainty

- The ensemble variance used as measure of uncertainty
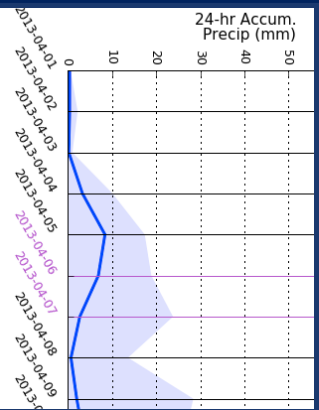- Greater spread → greater uncertainty
- Requires a spread-skill relationship
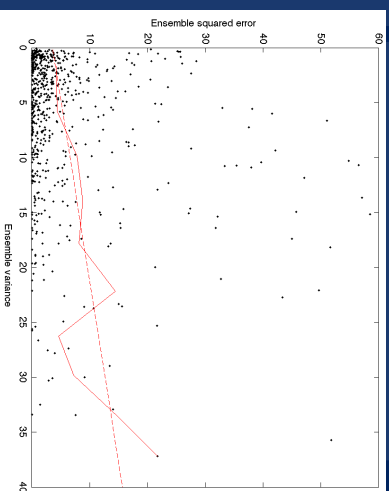
Ensemble squared error

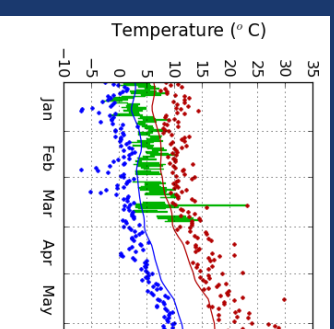Ensemble variance

Slide 14

Measures of uncertainty

- Ensemble variance
- Ensemble mean
- Anomaly
- Analysis increment
- Local gradient
- Analog

Slide 15

Measures of uncertainty

- Ensemble variance
- **Ensemble mean**
- Anomaly
- Analysis increment
- Local gradient
- Analog

- Often used for precip
- Days with greater precip has more uncertainty

24-hr Accum. Precip (mm)

2013-04-01
2013-04-02
2013-04-03
2013-04-04
2013-04-05
2013-04-06
2013-04-07
2013-04-08
2013-0

Slide 16

Measures of uncertainty

- Ensemble variance
- Ensemble mean
- **Anomaly**
- Analysis increment
- Local gradient
- Analog

- Forecasts further from climatological mean are more uncertain

Temperature (^{o} C)

Jan Feb Mar Apr May

Slide 17

Measures of uncertainty

- Ensemble variance
- Ensemble mean
- Anomaly
- **Analysis increment**
- Local gradient
- Analog

- Analysis increment:
  – Difference between today's analysis and yesterday's forecast for today
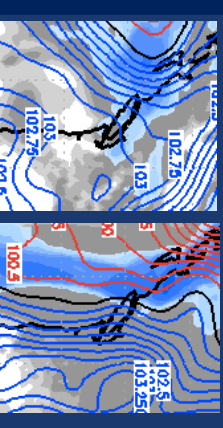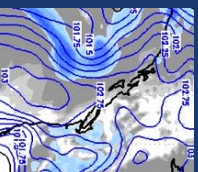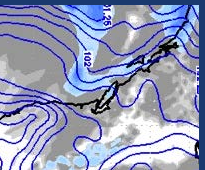
Yesterday's NWP
Obs
Analysis

⑰

Slide 19

Measures of uncertainty

- Ensemble variance
- Ensemble mean
- Anomaly
- Analysis increment
- Local gradient
- **Analog**

- Use uncertainty from similar cases in past

Similar   Not similar

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Slide 18

Measures of uncertainty

- Ensemble variance
- Ensemble mean
- Anomaly
- Analysis increment
- **Local gradient**
- Analog

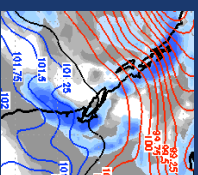- Greater gradient means greater impact if positioned wrong

Weak   Strong

⑱

Slide 20

- Why probabilistic forecasts?
- Measures of forecast uncertainty
- Producing prob forecasts
- Calibrating prob forecasts

⑳

Slide 21

Producing prob forecasts

- Moments
- Count ens members
- Bayesian model avg.

Slide 22

Producing prob forecasts

- **Moments**
- Count ens members
- Bayesian model avg.

- Pick a distribution
  - Gaussian
  - Gamma
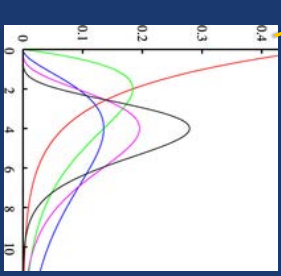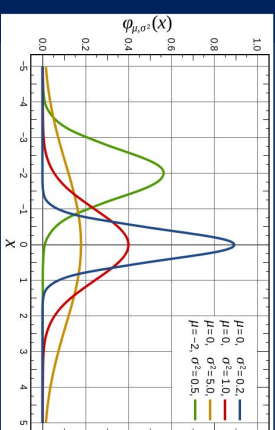

Slide 23

Producing prob forecasts

- **Moments**
- Count ens members
- Bayesian model avg.

- Pick a distribution
  - Gaussian
  - Gamma
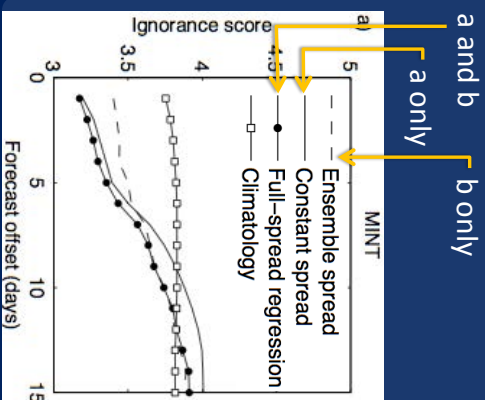- Adjust its moments based on past data
  - mean
  - variance

Slide 24

Producing prob forecasts

- **Moments**
- Count ens members
- Bayesian model avg.

- Pick a distribution
  - Gaussian
  - Gamma
- Adjust its moments based on past data
  - mean
  - variance

$$\sigma^2 = a + b\mu$$

Variance ← σ^2

Offset ← a

Scaling ← b

Uncertainty measure → μ

Producing prob forecasts

- **Moments**
- Count ens members
- Bayesian model avg.

$$\sigma^2 = a + b\mu$$

Uncertainty measure

Variance — Offset — Scaling

a and b — a only — b only

Ignorance score

MINT
— Ensemble spread
— Constant spread
• Full–spread regression
□ Climatology

Forecast offset (days)

25

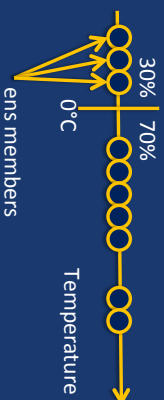
Producing prob forecasts

- Moments
- **Count ens members**
- Bayesian model avg.

- How many members are below threshold?

30% 70%
0°C
ens members
Temperature

27

Producing prob forecasts

- **Moments**
- Count ens members
- Bayesian model avg.

$$\sigma^2 = a + b\mu$$

Uncertainty measure

Variance — Offset — Scaling

Spread-skill less useful

More useful

Ignorance score

MINT
— Ensemble spread
— Constant spread
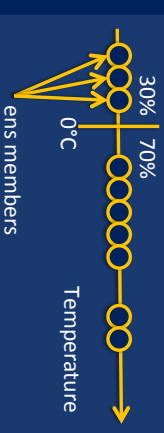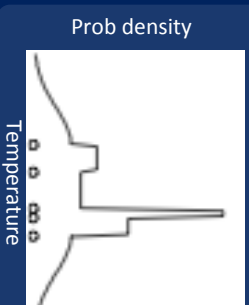• Full–spread regression
□ Climatology

Forecast offset (days)

26
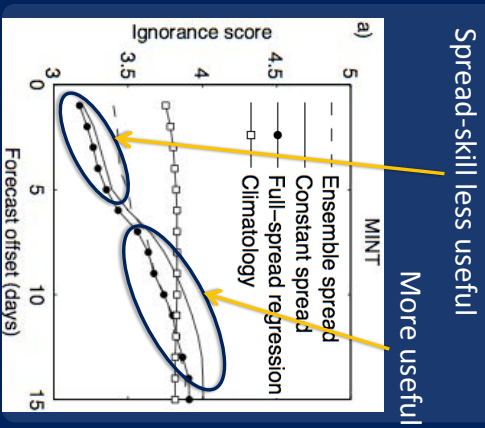
Producing prob forecasts

- Moments
- **Count ens members**
- Bayesian model avg.

- How many members are below threshold?
- Sampling error
- 100% spread-skill
- Uneven PDF

Prob density
Temperature

30% 70%
0°C
ens members
Temperature

28

- Why probabilistic forecasts?
- Measures of forecast uncertainty
- Producing prob forecasts
- Calibrating prob forecasts

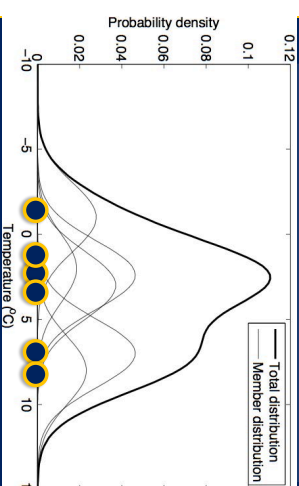# Producing prob forecasts

- Moments
- Count ens members
- **Bayesian model avg.**

- Pick a distribution
  – Gaussian
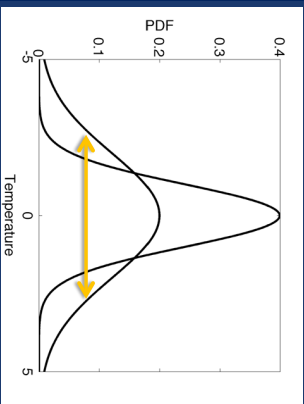 – Gamma
- Park one on each ensemble member
- Add up (using weights)

Why calibrate?

- Use of Gaussian when errors are non-Gaussian
- S-shaped rank histogram
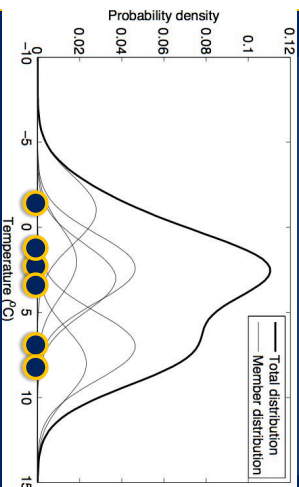
Producing prob forecasts

- Moments
- Count ens members
- **Bayesian model avg.**

- Pick a distribution
  – Gaussian
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- Park one on each ensemble member
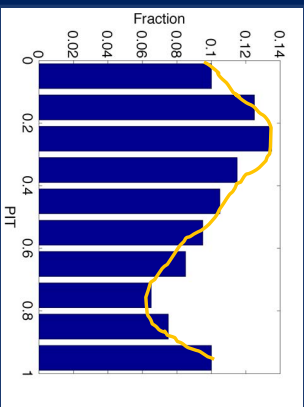- Add up (using weights)
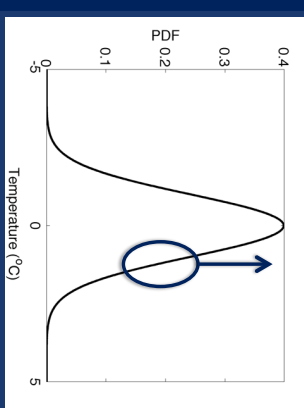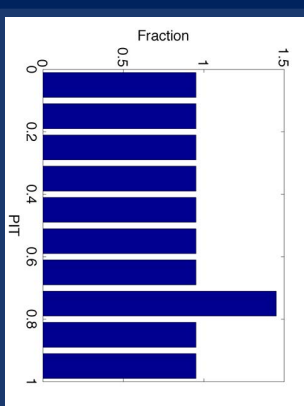- Built in spread-skill assumption

Why calibrate?
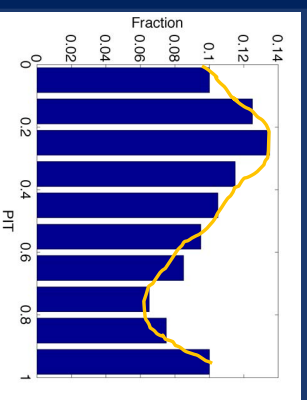
- Use of Gaussian when errors are non-Gaussian
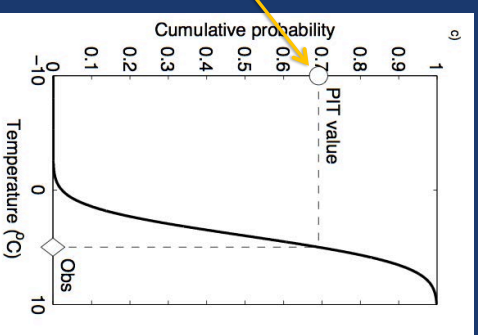- S-shaped rank histogram
- Changing spread doesn't help

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How to calibrate

1. Use past distribution of verifying PIT values

PIT: Probability integral transform = verifying CDF

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Why calibrate?

- Correcting histogram leads to lower ignorance

�34

How to calibrate

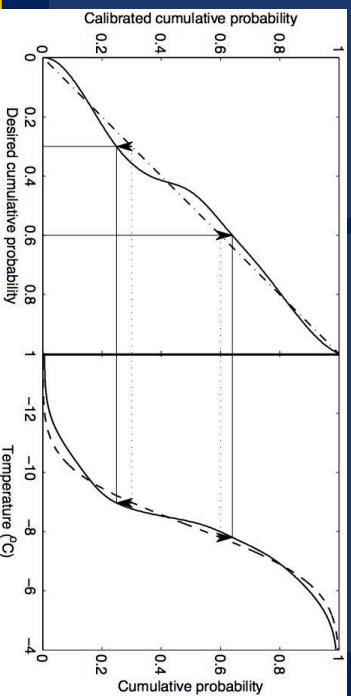1. Use past distribution of verifying PIT values
2. Turn histogram into calibration curve

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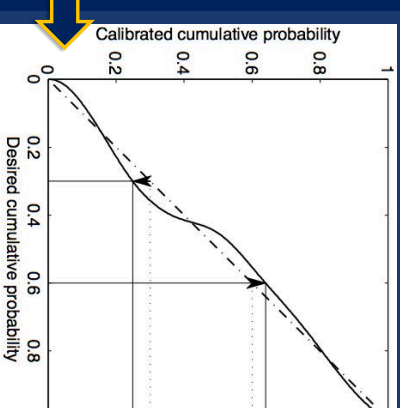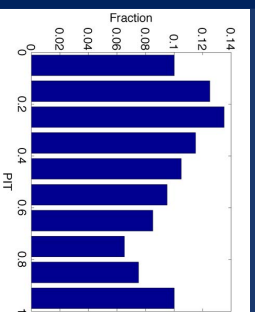
How to calibrate

1. Use past distribution of verifying PIT values
2. Turn histogram into calibration curve

3. Calibrate!

Calibration

- Watch out:
  – Don't calibrate if already calibrated
  – Calibration curve should be **smoothed**
  – Calibration curve must be **monotonic**

Summary

- Why probabilistic forecasts?
- Measures of forecast uncertainty
- Producing prob forecasts
- Calibrating prob forecasts