Mesoscale Probabilistic Prediction over the Northwest: An Overview

Cliff Mass

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University of Washington

University of Washington Probabilistic Prediction Effort

- An attempt to create an end-to-end probabilistic prediction system.
- An interdisciplinary effort of the UW Departments of Statistics, Atmospheric Sciences and Psychology, as well as the Applied Physic Lab.
- Now going for ten years.

Support

- Key financial support from DOD MURI and JEFS program, and NWS CSTAR program

Major Elements

- Two mesoscale ensemble systems with 36-12 km grid spacing: UWME (15 members) and EnKF (80 members).
- Sophisticated post-processing to reduce model bias and enhance reliability and sharpness of resulting probability density functions (PDFs).
  - Stand-alone bias correction
  - Bayesian Model Averaging (BMA)
  - Ensemble MOS (EMOS)

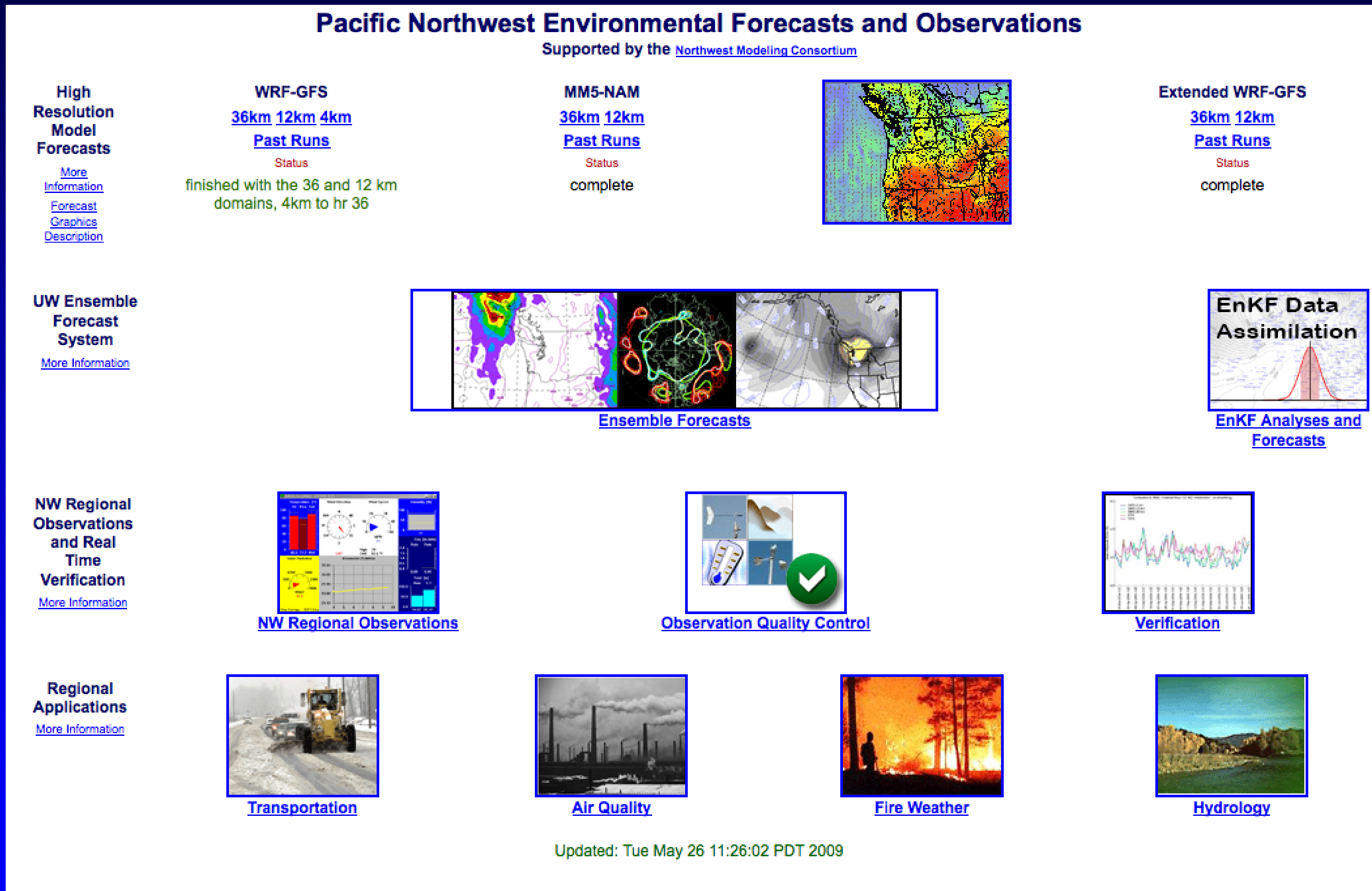
Major Elements

- Psychological research to determine the best approaches for presenting uncertainty information.
- Creation of next-generation display products providing probabilistic information to a lay audience. Example: ▪ Probcast.
- Ensemble-based data assimilation (EnKF) of 12 and 4km grid spacing

Inexpensive Commodity Clusters

- This effort has demonstrated the viability of doing such work on inexpensive Linux clusters.
- Proven to be <u>highly</u> reliable

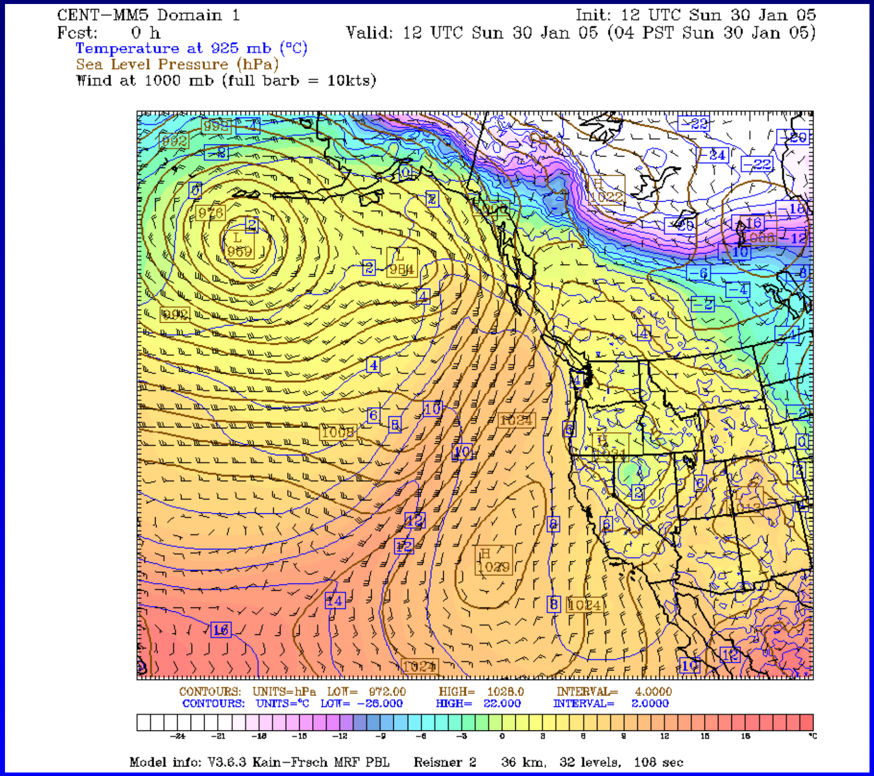
All of this has been available in real-time for years



http://www.atmos.washington.edu/mm5rt/

Mesoscale Ensembles at the UW

UWME



Core Members

- 8 members, 00 and 12Z
- Each uses different synoptic scale initial and boundary conditions from major international centers
- All use same physics
- MM5 model, will be switching to WRF.
- 72-h forecasts

“Native” Models/Analyses Available

Abbreviation/Model/Source	Type	Resolution (~ @ 45 °N) Computational	Distributed	Objective Analysis
avn, Global Forecast System (GFS), National Centers for Environmental Prediction	Spectral	T254 / L64 ~55 km	1.0° / L14 ~80 km	SSI 3D Var
cmcg, Global Environmental Multi-scale (GEM), Canadian Meteorological Centre	Finite Diff	0.9°×0.9°/L28 ~70 km	1.25° / L11 ~100 km	3D Var
eta, limited-area mesoscale model, National Centers for Environmental Prediction	Finite Diff.	32 km / L45	90 km / L37	SSI 3D Var
gasp, Global AnalysiS and Prediction model, Australian Bureau of Meteorology	Spectral	T239 / L29 ~60 km	1.0° / L11 ~80 km	3D Var
jma, Global Spectral Model (GSM), Japan Meteorological Agency	Spectral	T106 / L21 ~135 km	1.25° / L13 ~100 km	OI
ngps, Navy Operational Global Atmos. Pred. System, Fleet Numerical Meteorological & Oceanographic Cntr.	Spectral	T239 / L30 ~60 km	1.0° / L14 ~80 km	OI
tcwb, Global Forecast System, Taiwan Central Weather Bureau	Spectral	T79 / L18 ~180 km	1.0° / L11 ~80 km	OI
ukmo, Unified Model, United Kingdom Meteorological Office	Finite Diff.	5/6°×5/9°/L30 ~60 km	*same* / L12	3D Var

UWME

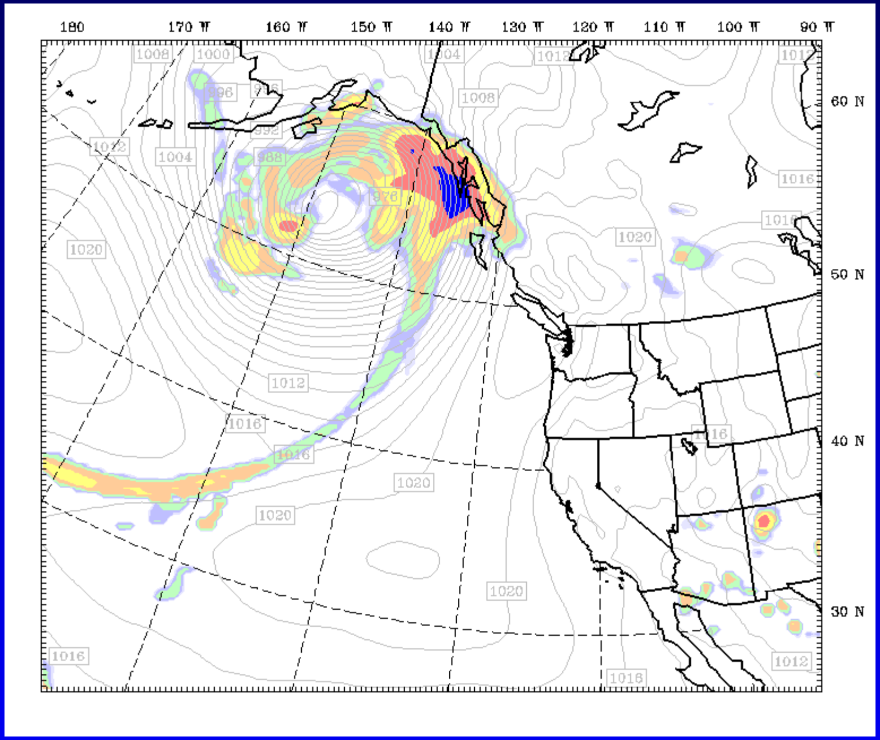
– Physics Members

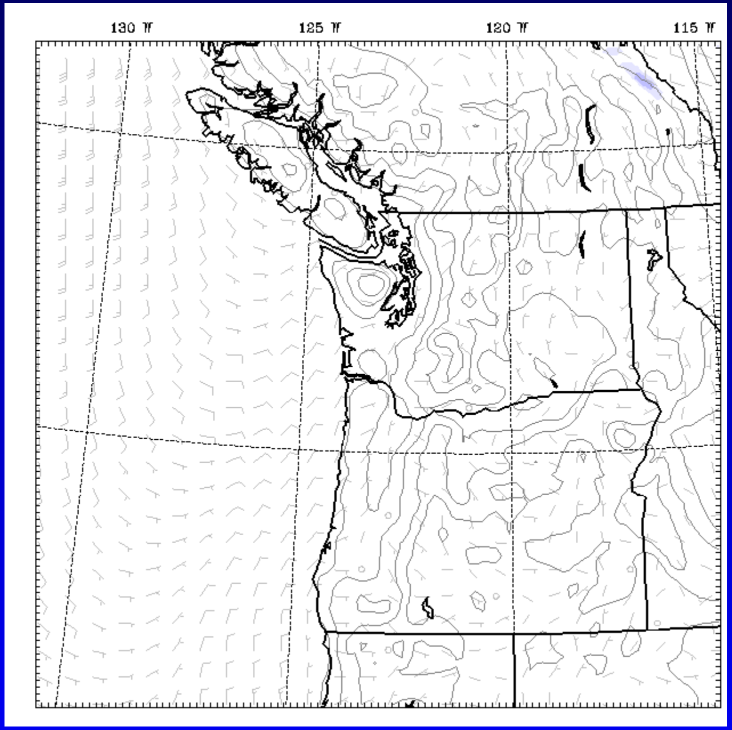
- 8 members, 00Z only
- Each uses different synoptic scale initial and boundary conditions
- Each uses different physics
- Each uses different SST perturbations
- Each uses different land surface characteristic perturbations

– Centroid, 00 and 12Z

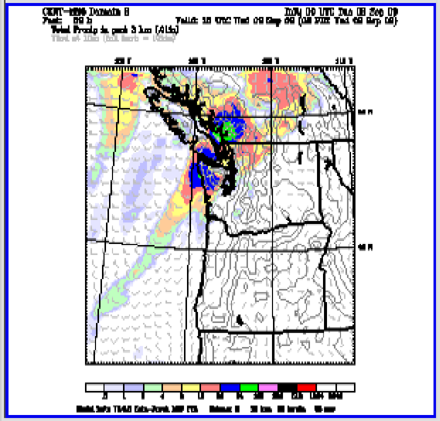
- Average of 8 core members used for initial and boundary conditions

36 and 12-km domains

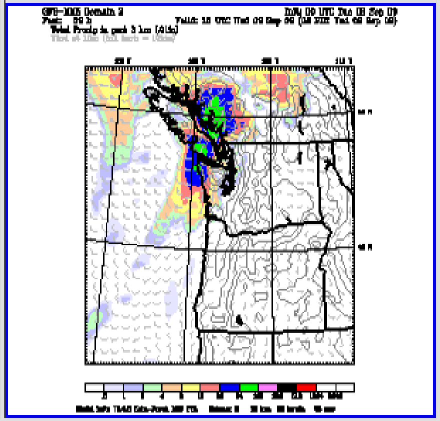




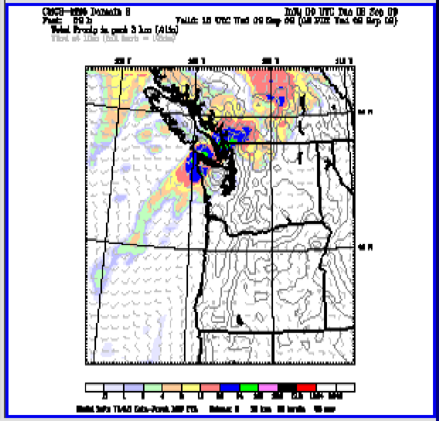
MM5 ENSEMBLE CENTROID



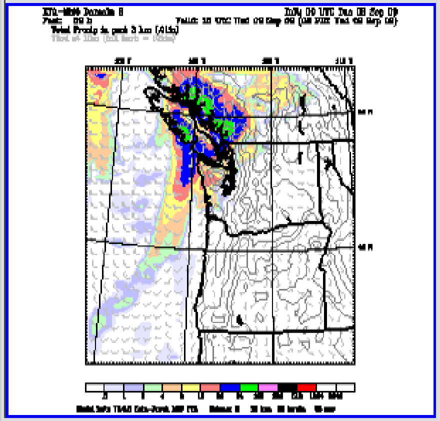
GFS-MM5



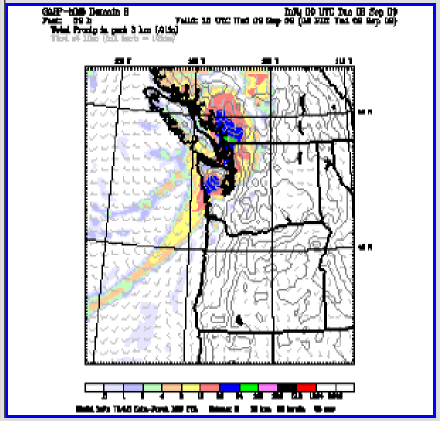
CMCG-MM5



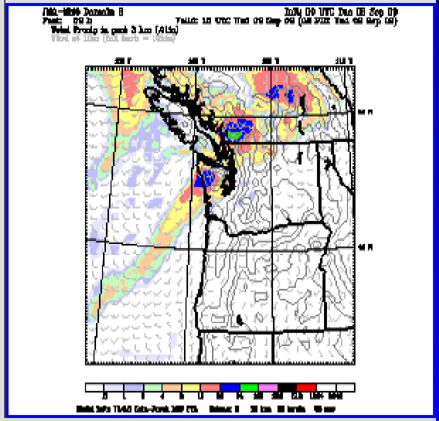
ETA-MM5



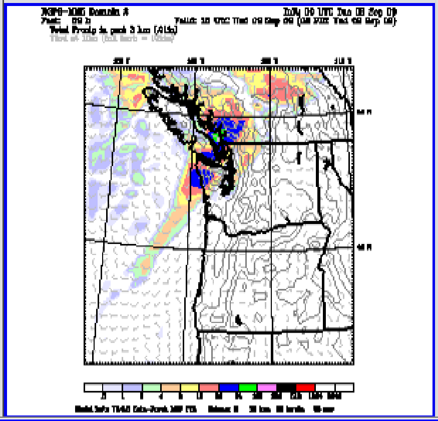
GASP-MM5



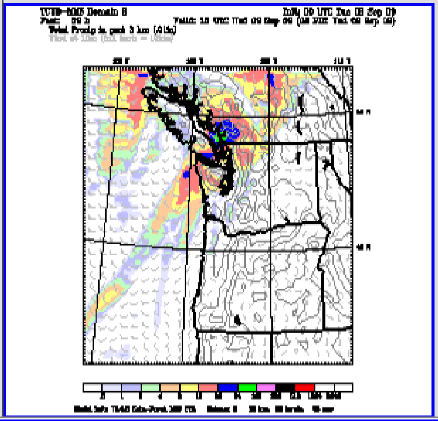
JMA-MM5



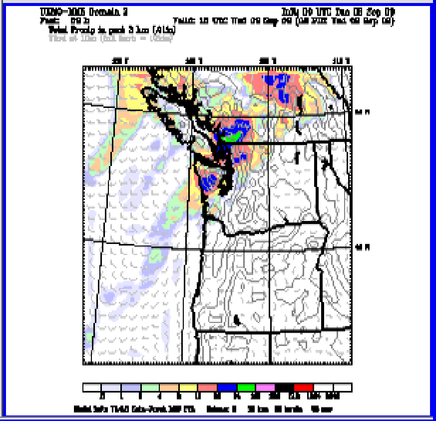
NGPS-MM5

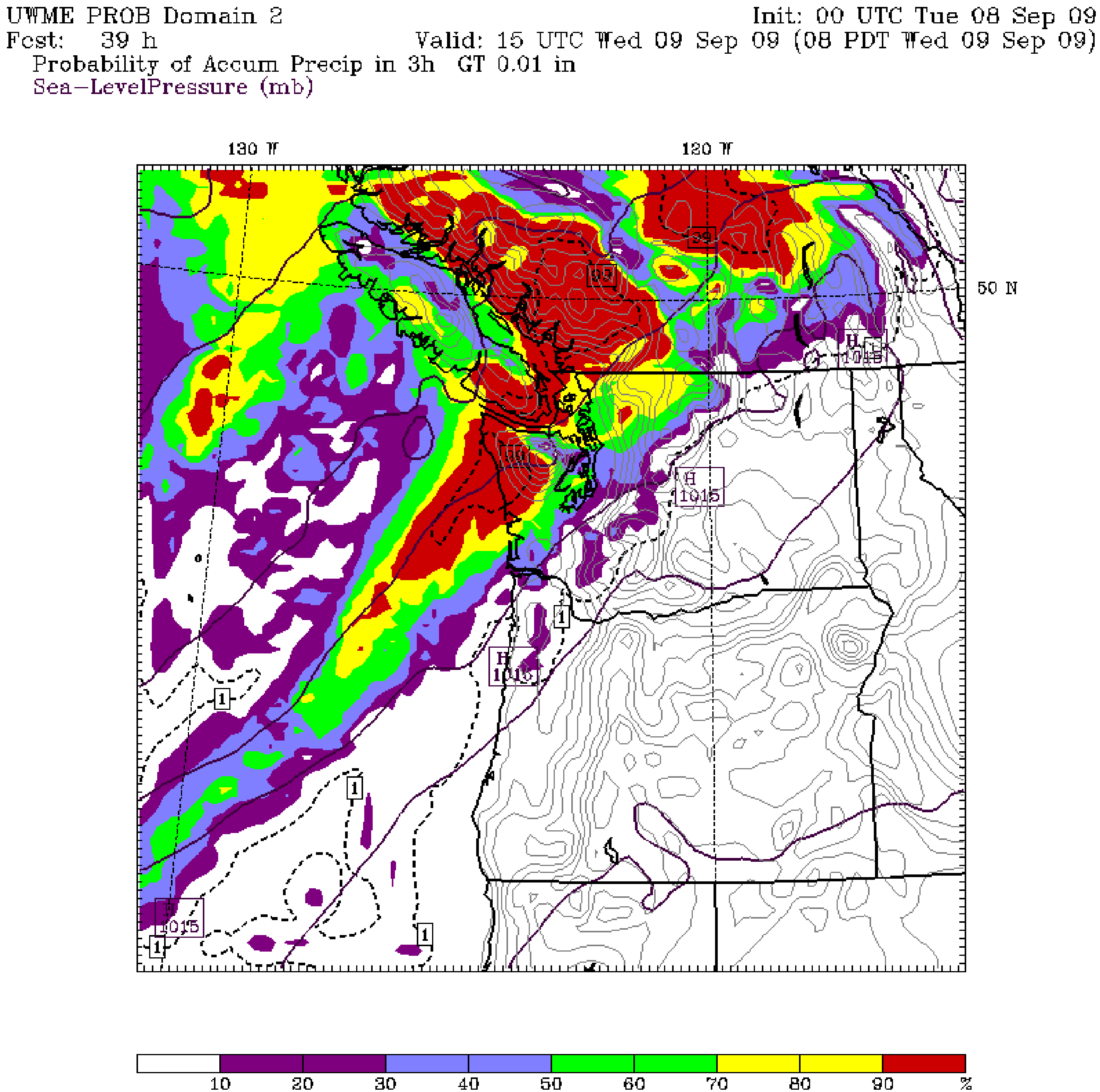


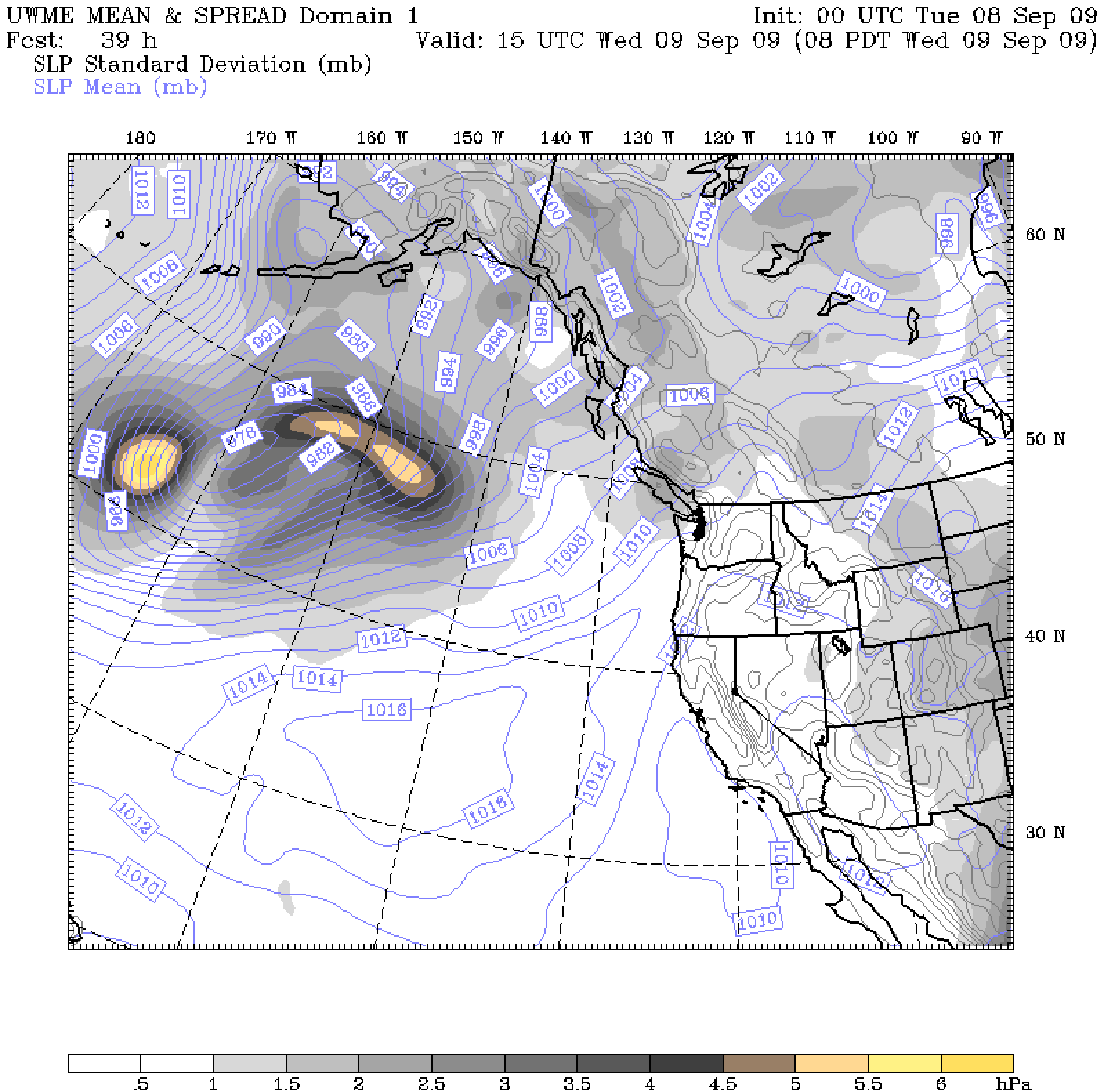
TCWB-MM5

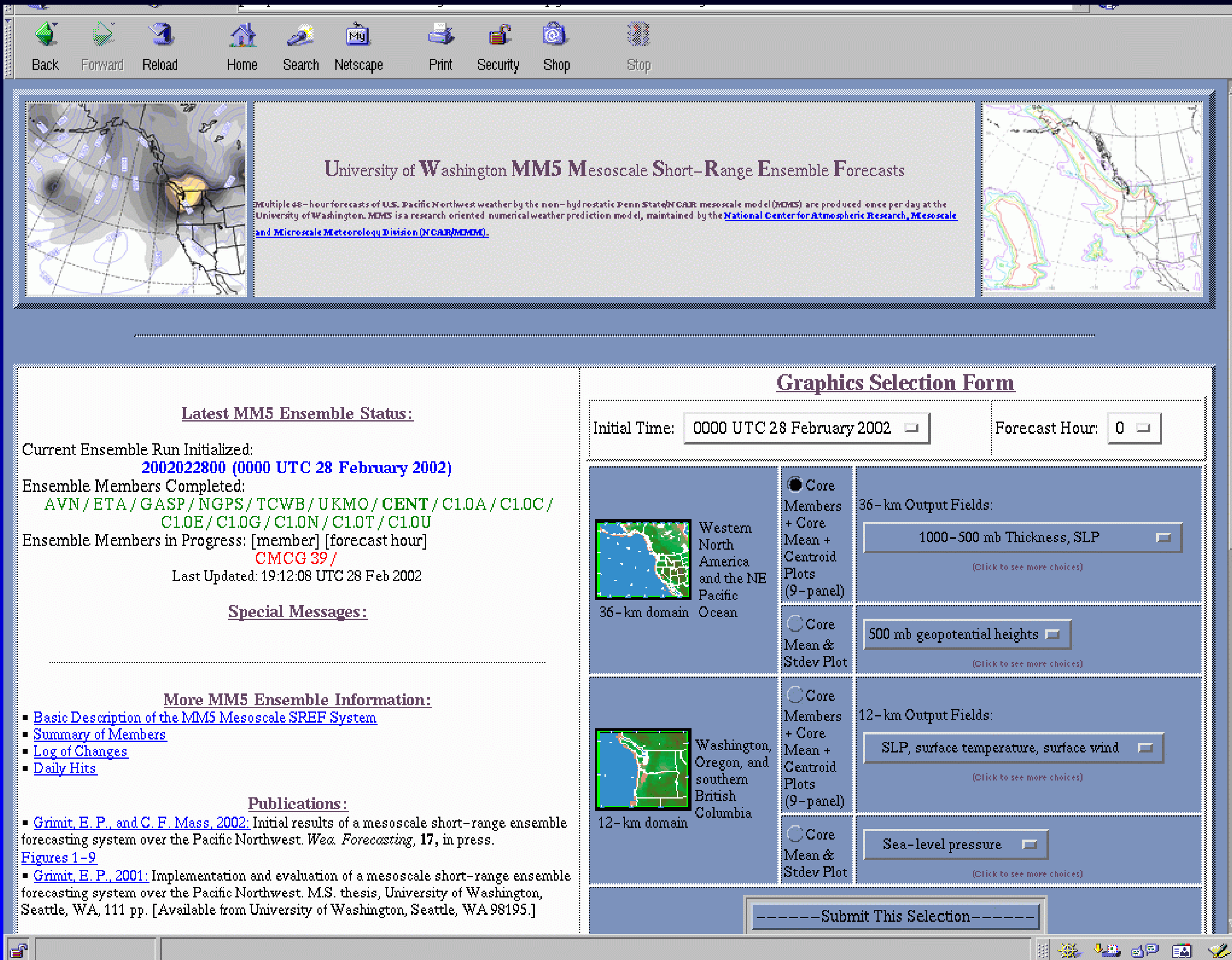


UKMO-MM5




UWME PROB Domain 2
Init: 00 UTC Tue 08 Sep 09
Fcst: 39 h
Valid: 15 UTC Wed 09 Sep 09 (08 PDT Wed 09 Sep 09)
Probability of Accum Precip in 3h GT 0.01 in
Sea-LevelPressure (mb)
130 W
120 W
50 N
H
1015
10
20
30
40
50
60
70
80
90
%


UWME MEAN & SPREAD Domain 1
Init: 00 UTC Tue 08 Sep 09
Fcst: 39 h
Valid: 15 UTC Wed 09 Sep 09 (08 PDT Wed 09 Sep 09)
SLP Standard Deviation (mb)
SLP Mean (mb)
180
170 W
160 W
150 W
140 W
130 W
120 W
110 W
100 W
90 W
60 N
50 N
40 N
30 N
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
hPa



Back
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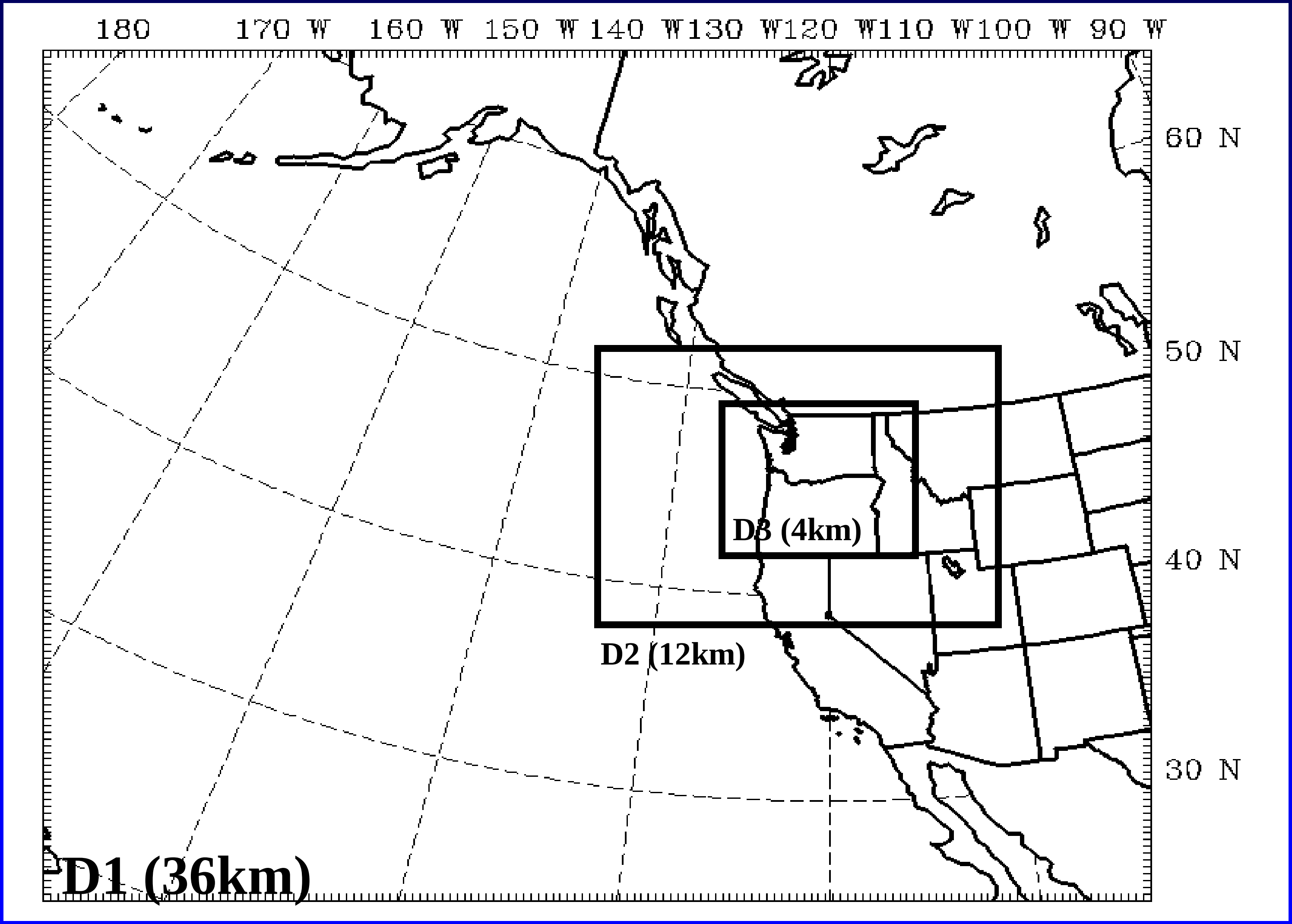
Netscape
Print
Security
Shop
Stop
University of Washington MM5 Mesoscale Short-Range Ensemble Forecasts
Multiple 48-hour forecasts of U.S. Pacific Northwest weather by the non-hydrostatic Penn State/NCAR mesoscale model (MM5) are produced once per day at the University of Washington. MM5 is a research oriented numerical weather prediction model, maintained by the National Center for Atmospheric Research, Mesoscale and Microscale Meteorology Division (NCAR/MMM).
Latest MM5 Ensemble Status:
Current Ensemble Run Initialized:
2002022800 (0000 UTC 28 February 2002)
Ensemble Members Completed:
AVN / ETA / GASP / NGPS / TCWB / UKMO / CENT / C1.0A / C1.0C / C1.0E / C1.0G / C1.0N / C1.0T / C1.0U
Ensemble Members in Progress: [member] [forecast hour]
CMCG 39 /
Last Updated: 19:12:08 UTC 28 Feb 2002
Special Messages:
More MM5 Ensemble Information:
Basic Description of the MM5 Mesoscale SREF System
Summary of Members
Log of Changes
Daily Hits
Publications:
Grimit, E. P., and C. F. Mass, 2002: Initial results of a mesoscale short-range ensemble forecasting system over the Pacific Northwest. Wea. Forecasting, 17, in press.
Figures 1-9
Grimit, E. P., 2001: Implementation and evaluation of a mesoscale short-range ensemble forecasting system over the Pacific Northwest. M.S. thesis, University of Washington, Seattle, WA, 111 pp. [Available from University of Washington, Seattle, WA 98195.]
Graphics Selection Form
Initial Time: 0000 UTC 28 February 2002
Forecast Hour: 0
36-km domain
Western North America and the NE Pacific Ocean
Core Members + Core Mean + Centroid Plots (9-panel)
36-km Output Fields:
1000-500 mb Thickness, SLP
(Click to see more choices)
Core Mean & Stdev Plot
500 mb geopotential heights
(Click to see more choices)
12-km domain
Washington, Oregon, and southern British Columbia
Core Members + Core Mean + Centroid Plots (9-panel)
12-km Output Fields:
SLP, surface temperature, surface wind
(Click to see more choices)
Core Mean & Stdev Plot
Sea-level pressure
(Click to see more choices)
------Submit This Selection------

EnKF Ensemble Configuration



EnKF Ensemble Configuration

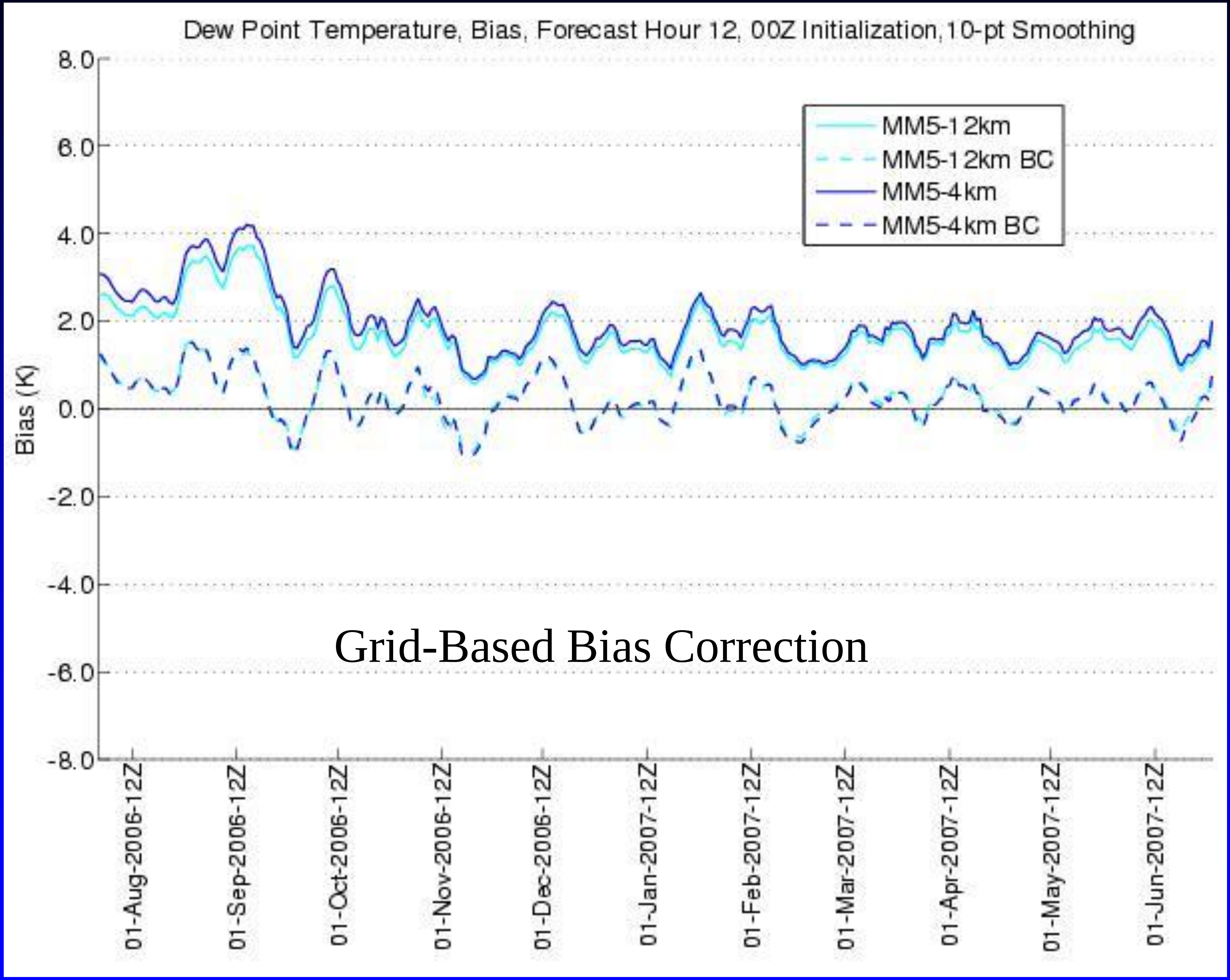
- WRF model
- 38 vertical levels
- 80 ensemble members
- 6-hour update cycle
- Observations:
    - Surface temperature, wind, altimeter
    - ACARS aircraft winds, temperature
    - Cloud-track winds
    - Radiosonde wind, temperature, relative humidity

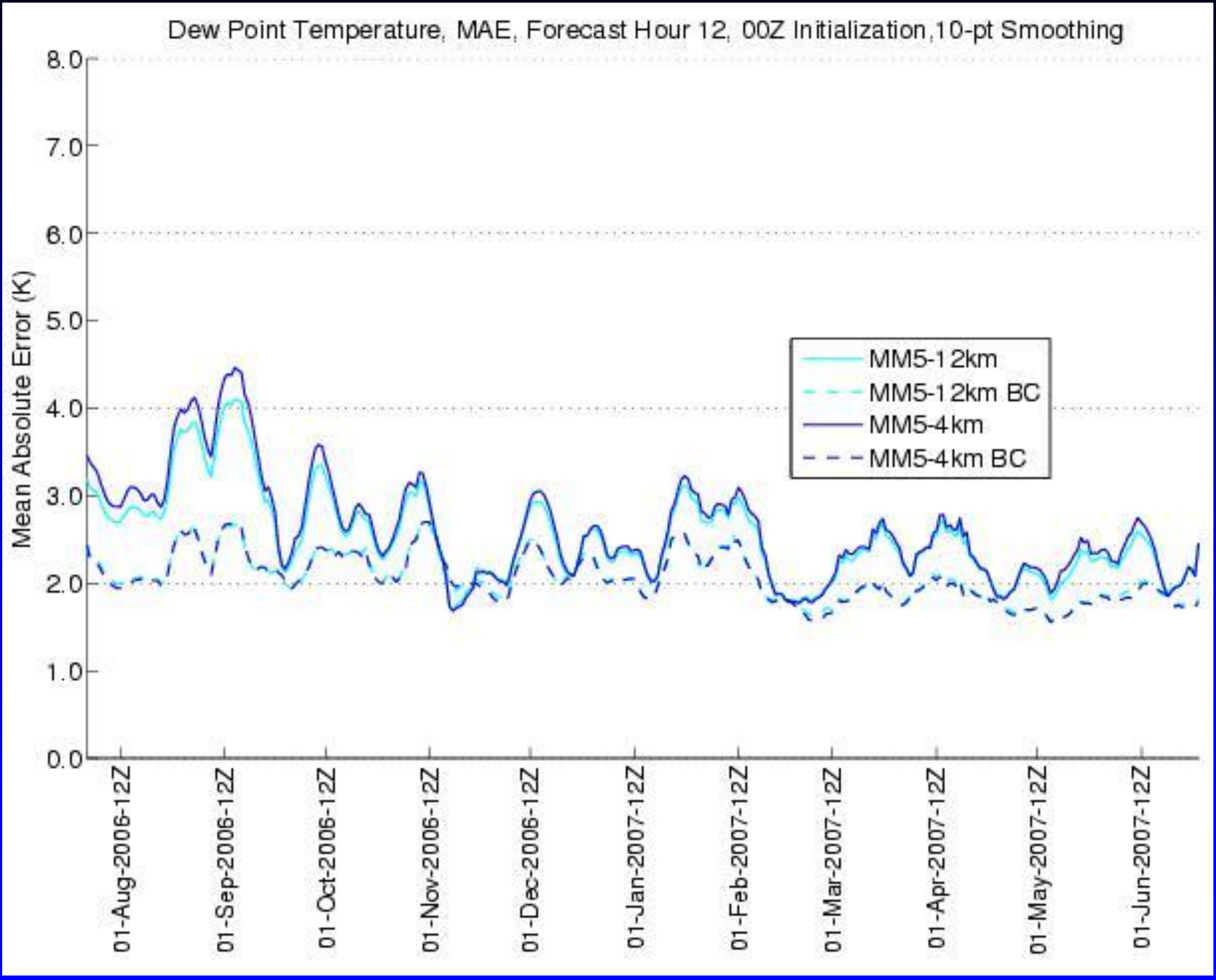
Post-Processing

- Post-processing is a critical and necessary step to get useful PDFs from ensemble systems.
- The UW has spent and is spending a great deal of effort to perfect various approaches that are applicable on the mesoscale.

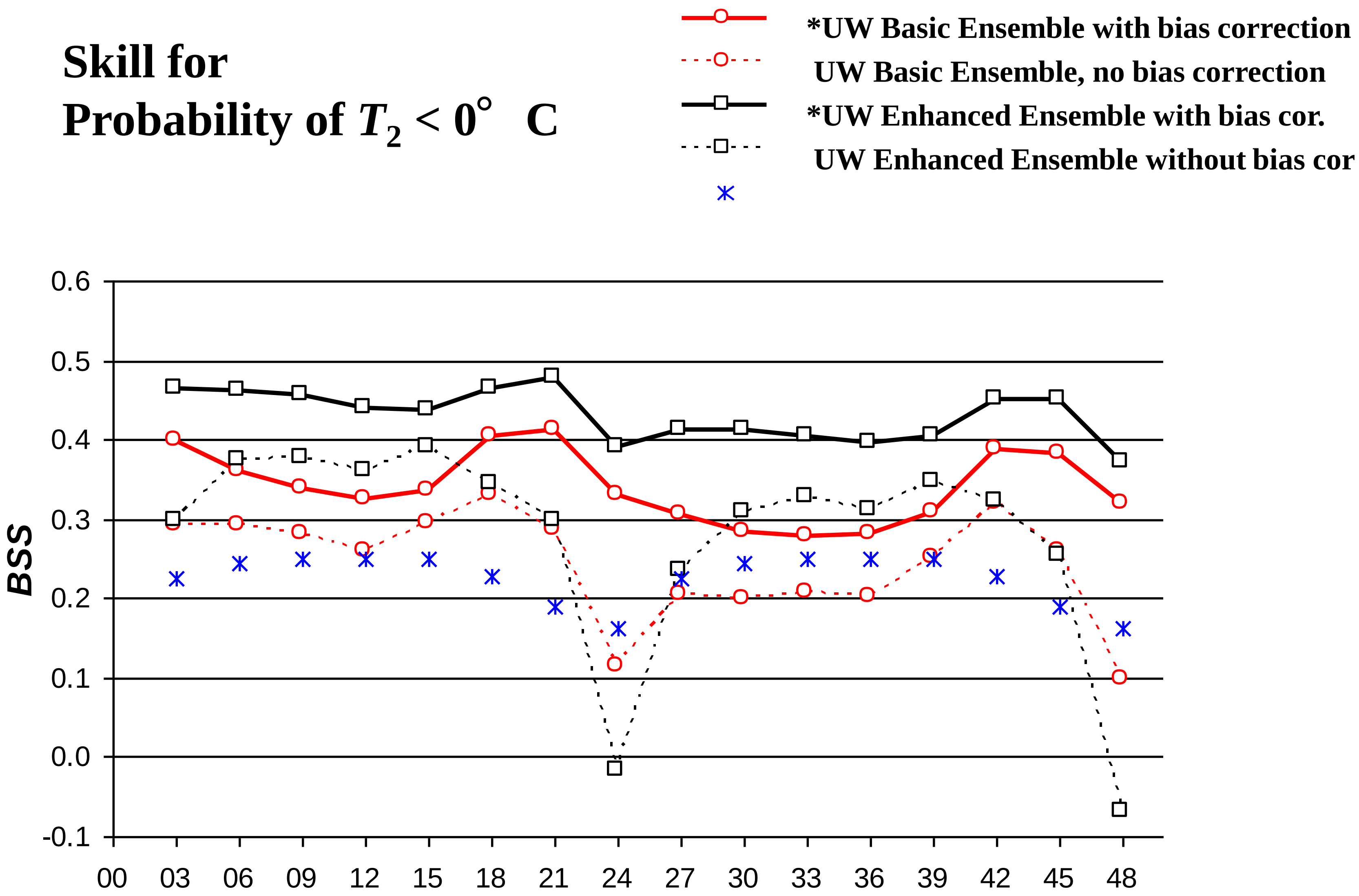
Post-Processing

- Major Efforts Include
  - Development of grid-based bias correction
  - Successful development of Bayesian Model Averaging (BMA) postprocessing for temperature, precipitation, and wind
  - Development of both global and local BMA
  - Development of ensemble MOS (EMOS)


Dew Point Temperature, Bias, Forecast Hour 12, 00Z Initialization,10-pt Smoothing
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
Bias (K)
MM5-12km
MM5-12km BC
MM5-4km
MM5-4km BC
Grid-Based Bias Correction
01-Aug-2006-12Z
01-Sep-2006-12Z
01-Oct-2006-12Z
01-Nov-2006-12Z
01-Dec-2006-12Z
01-Jan-2007-12Z
01-Feb-2007-12Z
01-Mar-2007-12Z
01-Apr-2007-12Z
01-May-2007-12Z
01-Jun-2007-12Z


Dew Point Temperature, MAE, Forecast Hour 12, 00Z Initialization,10-pt Smoothing
Mean Absolute Error (K)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
MM5-12km
MM5-12km BC
MM5-4km
MM5-4km BC
01-Aug-2006-12Z
01-Sep-2006-12Z
01-Oct-2006-12Z
01-Nov-2006-12Z
01-Dec-2006-12Z
01-Jan-2007-12Z
01-Feb-2007-12Z
01-Mar-2007-12Z
01-Apr-2007-12Z
01-May-2007-12Z
01-Jun-2007-12Z

Skill for Probability of $T_2 < 0°$ C



BSS: Brier Skill Score

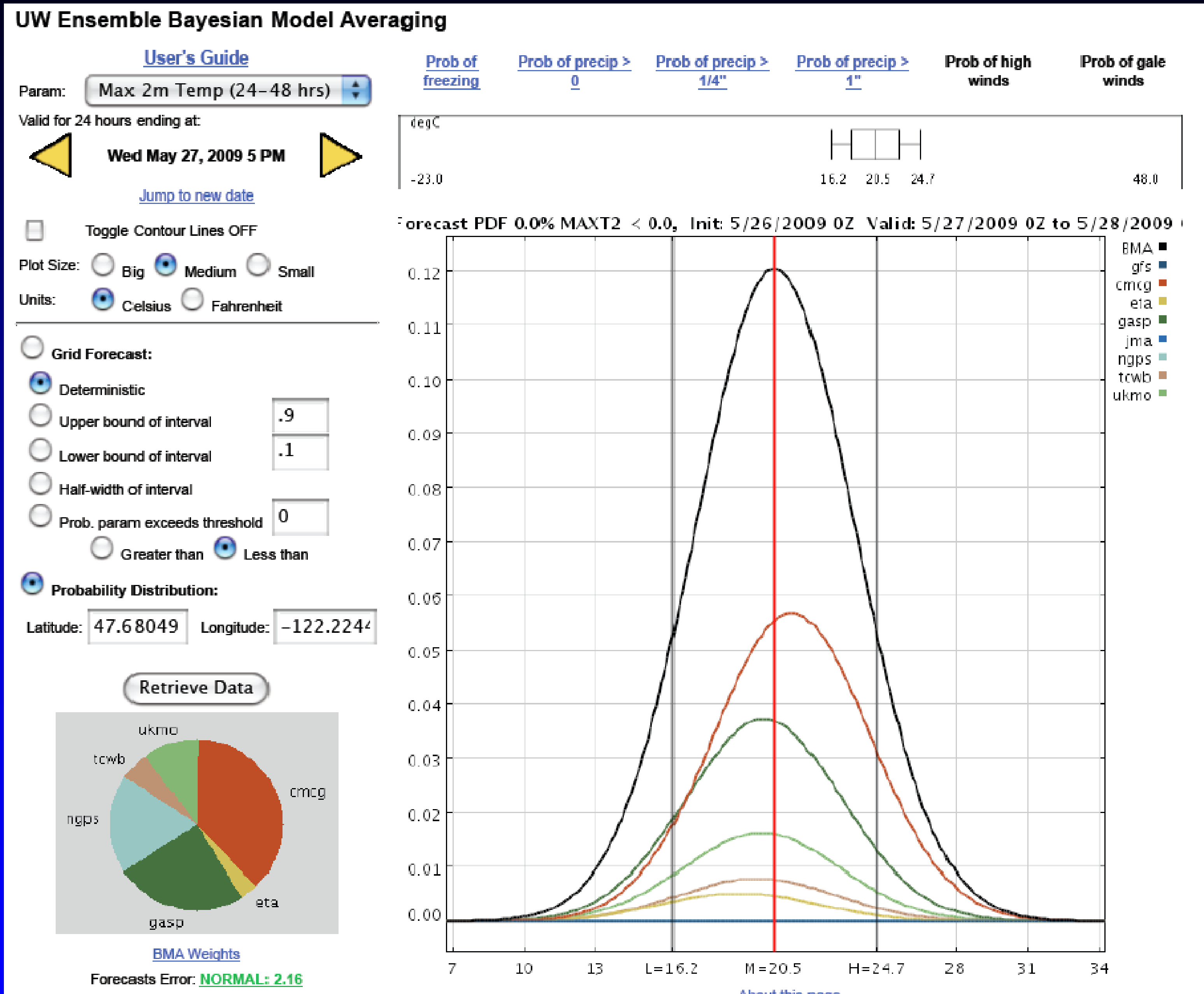
Profoundly positive effects of bias correction

BMA

- BMA model for temperature:
  - Let y be the verifying value and $\tilde{y}_k$ be the kth forecast from the ensemble.
  - The model is:

$$p(y|\tilde{y}_1, \ldots, \tilde{y}_K) = \sum_{k=1}^{K} w_k N(a_k + b_k \tilde{y}_k, \sigma^2)$$

  where $w_k \geq 0$ and $\sum_{k=1}^{K} w_k = 1$.
- The model is estimated from a training set of recent data at stations by maximum likelihood using the EM algorithm.
- Good results with a 25-day "moving window" training period.

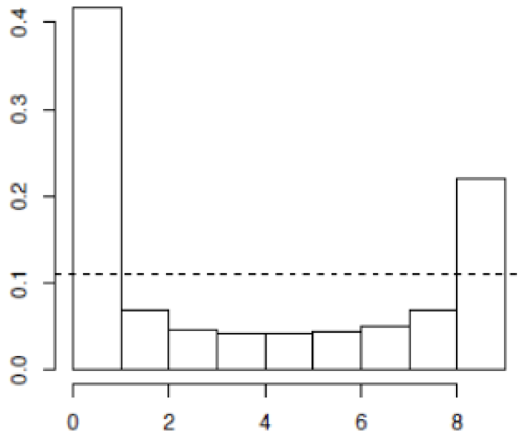

UW Ensemble Bayesian Model Averaging
User's Guide
Param: Max 2m Temp (24-48 hrs)
Valid for 24 hours ending at:
Wed May 27, 2009 5 PM
Jump to new date
Toggle Contour Lines OFF
Plot Size: Big Medium Small
Units: Celsius Fahrenheit
Grid Forecast:
Deterministic
Upper bound of interval .9
Lower bound of interval .1
Half-width of interval
Prob. param exceeds threshold 0
Greater than Less than
Probability Distribution:
Latitude: 47.68049 Longitude: -122.2244
Retrieve Data
ukmo
tcwb
cmcg
ngps
eta
gasp
BMA Weights
Forecasts Error: NORMAL: 2.16
Prob of freezing
Prob of precip > 0
Prob of precip > 1/4"
Prob of precip > 1"
Prob of high winds
Prob of gale winds
degC
-23.0
16.2 20.5 24.7
48.0
orecast PDF 0.0% MAXT2 < 0.0, Init: 5/26/2009 0Z Valid: 5/27/2009 0Z to 5/28/2009
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
7
10
13
L=16.2
M=20.5
H=24.7
28
31
34
BMA
gfs
cmcg
eta
gasp
jma
ngps
tcwb
ukmo
About this page.

Results for 2007 ($^\circ C$)

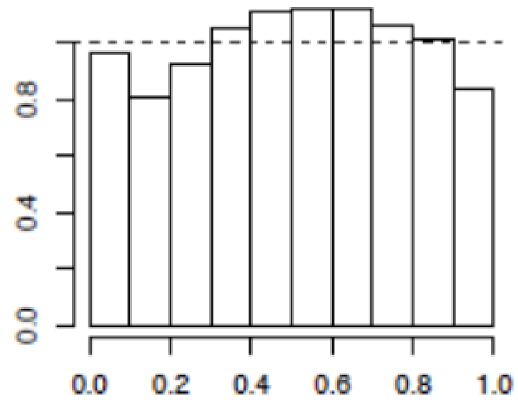
(24hr forecasts of 2m temperature at ASOS stations and buoys)

	MAE	CRPS
Raw Ensemble	2.31	1.96
BMA for UWME	2.15	1.55

Verification rank histogram for raw ensemble



PIT histogram for BMA



- BMA better calibrated and more accurate than the raw ensemble

BMA

- Testing both global BMA (same weights over entire domain) and local BMA (ensemble weights vary spatially).

EMOS

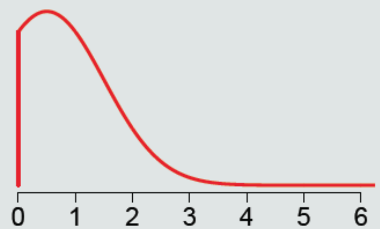
Ensemble Model Output Statistics (EMOS)

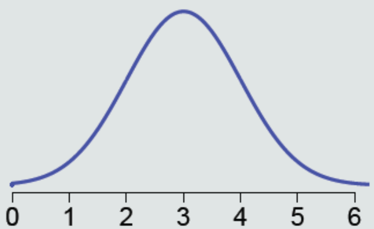
Let $X_1, \ldots, X_k$ denote an ensemble of individually distinguishable forecasts for a non-negative weather quantity Y.

We propose to use a truncated normal predictive distribution

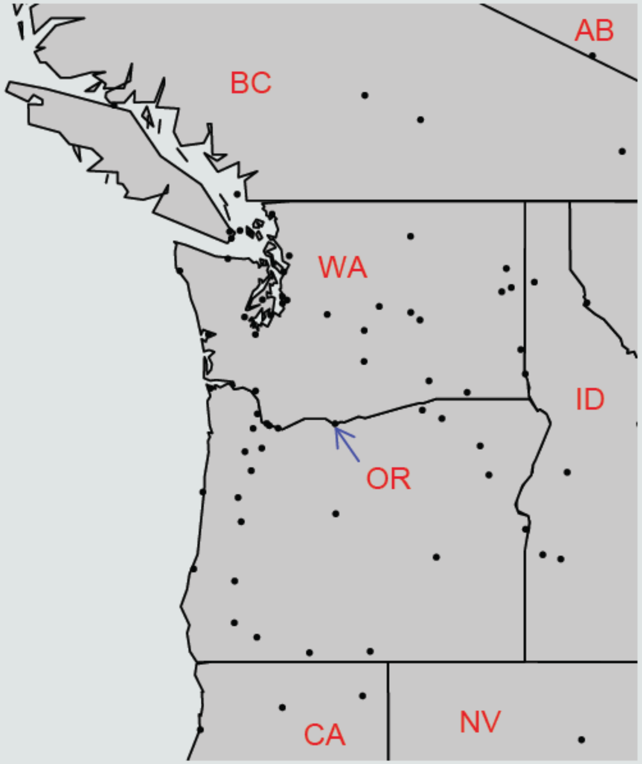
$$N^0(a + b_1 X_1 + \cdots + b_k X_k, c + dS^2),$$

where S^2 is the ensemble variance.



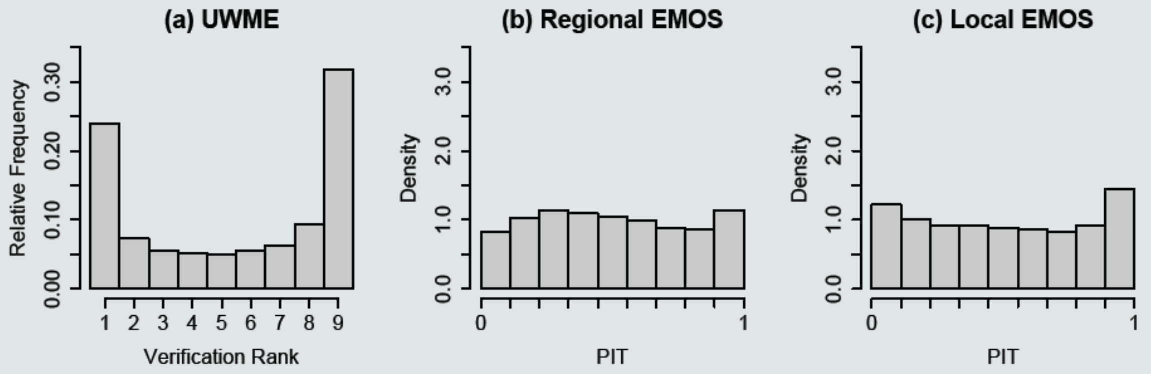


EMOS Test



- Data: forecasts for 48 hour ahead maximum wind speed and observations from 73 SAO stations in the Pacific Northwest.
- We want to create 48 hour ahead forecasts for maximum wind speed at all the stations for all available days in 2008.

EMOS Verification



Forecast	CRPS	MAE	Coverage	Width
UWME	2.47	3.15	44.3	4.7
Regional EMOS	2.16	3.00	78.1	8.9
Regional Persistence	2.85	4.01	80.8	11.7
Regional Climatology	2.79	3.92	83.1	12.2
Local EMOS	1.89	2.61	70.4	6.7
Local Persistence	2.53	3.60	76.7	10.1
Local Climatology	2.45	3.50	79.6	10.0

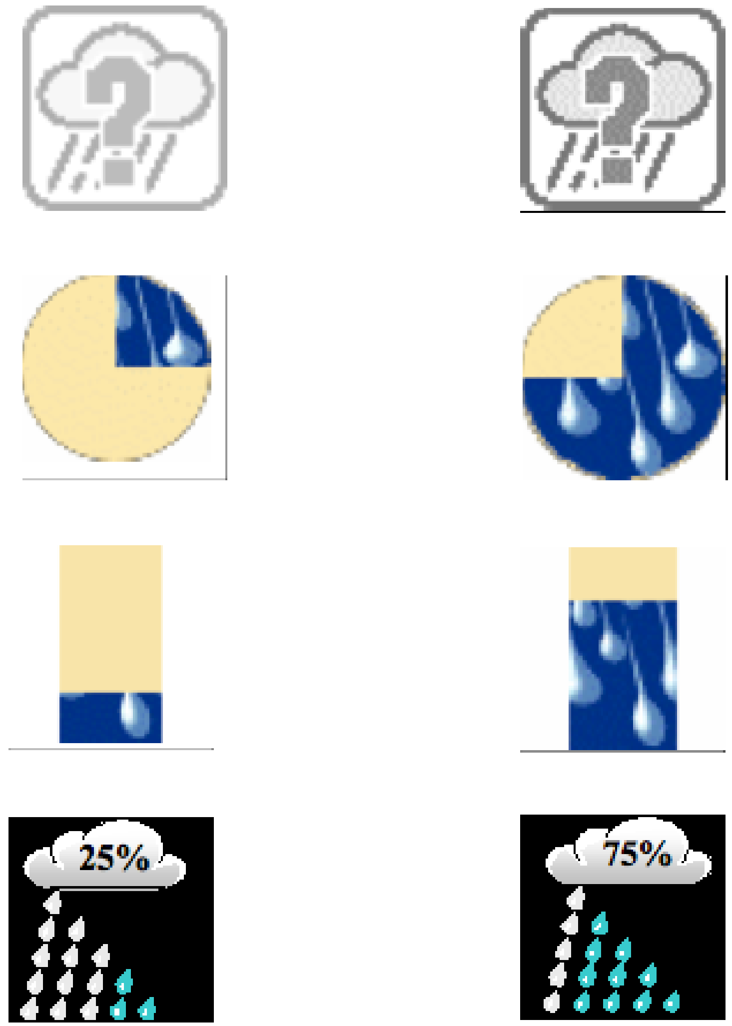
Communication and Display

- Considerable work by Susan Joslyn and others in psychology and APL to examine how forecasters and others process forecast information and particularly probabilistic information.
- One example has been their study of the interpretation of weather forecast icons.

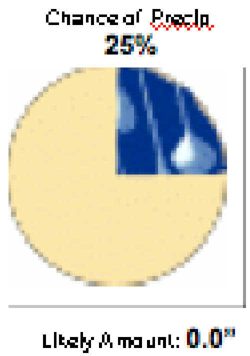
The icons used in the Precipicon study:

25% chance:

75% chance



Probability of Precipitation



Instructions:
The picture to the left displays the rain forecast for the Seattle-Tacoma Airport. Please use it to answer the following questions.

1. How likely is rain today?

(Please record your answer by drawing a vertical line (----|----) in the scale below)

Very Unlikely |--| Very Likely

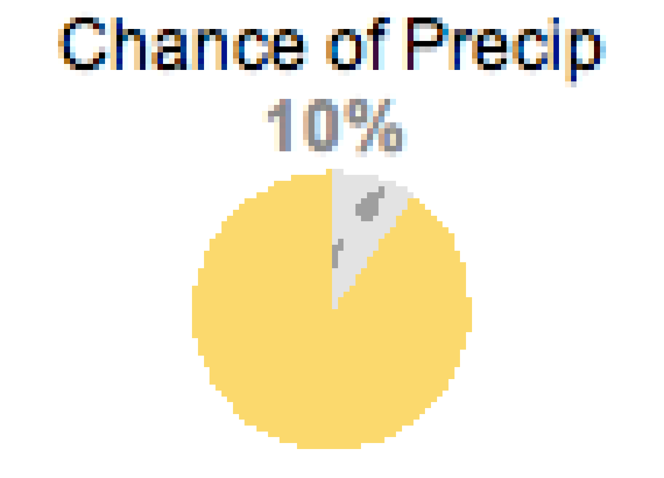
2. Would you take an umbrella with you (or wear a hooded jacket) today? (please check one answer)
___Yes ___No

3. How much will it likely rain today? (please check one answer)
___No Measurable Rain ___Less than half an inch
___More than half an inch ___Can't tell from this forecast

4. Over approximately what area of Puget Sound will it likely rain today? (please check one answer)
___None of the Area ___Less than half of the area
___More than half of the area ___Can't tell from this forecast

5. How much of the time will it likely rain today? (please check one answer)
___None of the time ___Less than half of the time
___More than half of the time ___Cant tell from this forecast

The Winner



Probcast PROBCAST

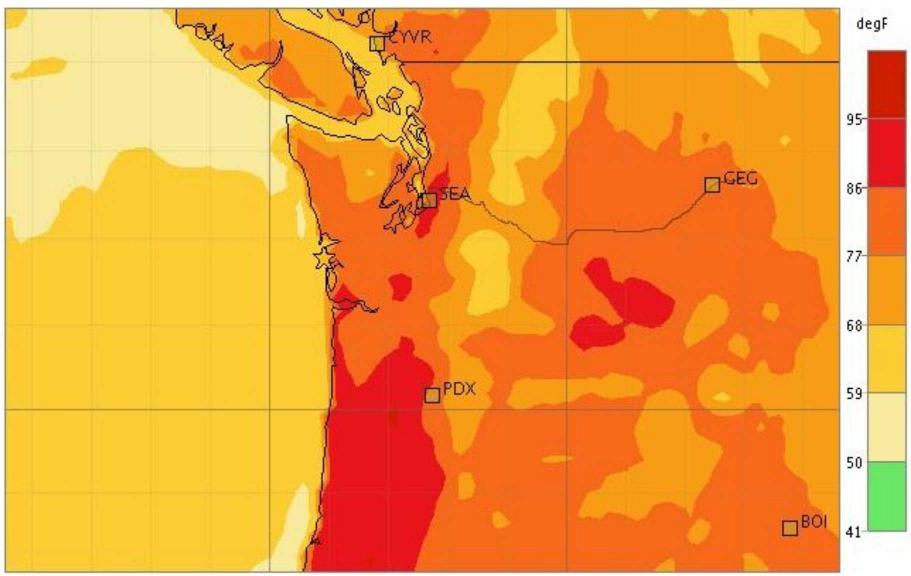
University of Washington Probability Forecast

Click a number on the table to select a new weather map; **click the weather map** or **fill in a zip code** to select a new location for the table. The yellow box shows the current map; the star shows the current location.

Grayland, WA 98547 (46.78 N, 124.08 W) — **City or Zip Code:** 98547 go

	Fri Sep 1	Fri Sep 1 Night	Sat Sep 2	Sat Sep 2 Night	Sun Sep 3
TEMP	Daytime High 66°	Nighttime Low 55°	Daytime High 62°	Nighttime Low 55°	Daytime High 63°
		Chance freeze: 0%		Chance freeze: 0%	
	As high as: 71°	As high as: 59°	As high as: 67°	As high as: 61°	As high as: 70°
	As low as: 62°	As low as: 51°	As low as: 57°	As low as: 49°	As low as: 56°
x PRECIP	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 15%
	Likely Amount: .0"	Likely Amount: .0"	Likely Amount: .0"	Likely Amount: .0"	Likely Amount: .0"
	As Much As: .0"	As Much As: .0"	As Much As: .0"	As Much As: .0"	As Much As: .03"

High temperature for Fri Daytime, Sep 1 2006 — -- Select a new weather map --



Snap to nearest zip code on map click (Improves speed)

Select exact click location (slower)

Learn more **about this page**.

This website provides uncertainty information along with a probabilistic weather forecast; move the mouse over a feature to learn more about its function.

This website was developed at the UW Applied Physics Laboratory, on the basis of research conducted at the UW departments of Atmospheric Science, Statistics and Psychology. It is funded by the Office of Naval Research.

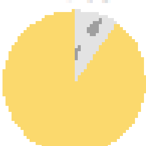
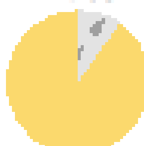
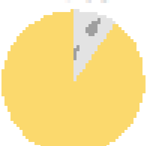
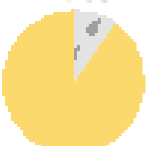
TAKE THE SURVEY

Contact **ptewson@apl.washington.edu** with questions, comments, and reports of errors.

University of Washington Probability Forecast

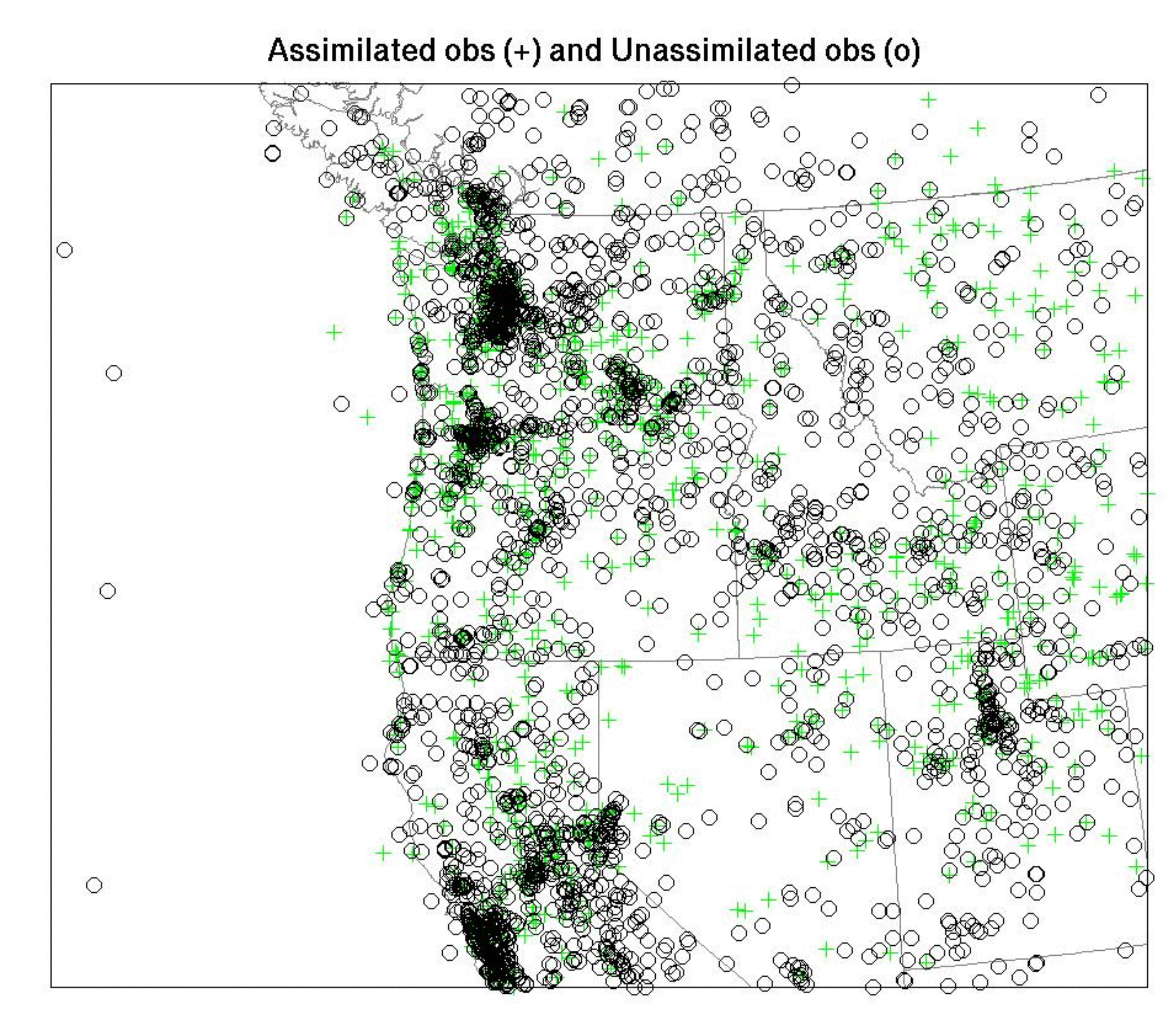
Click a number on the table to select a new weather map; **click the weather map** or **fill in a zip code** tc
the table. The yellow box shows the current map; the star shows the current locati

Grayland, WA 98547 (46.78 N, 124.08 W) **City or Zip Code:**

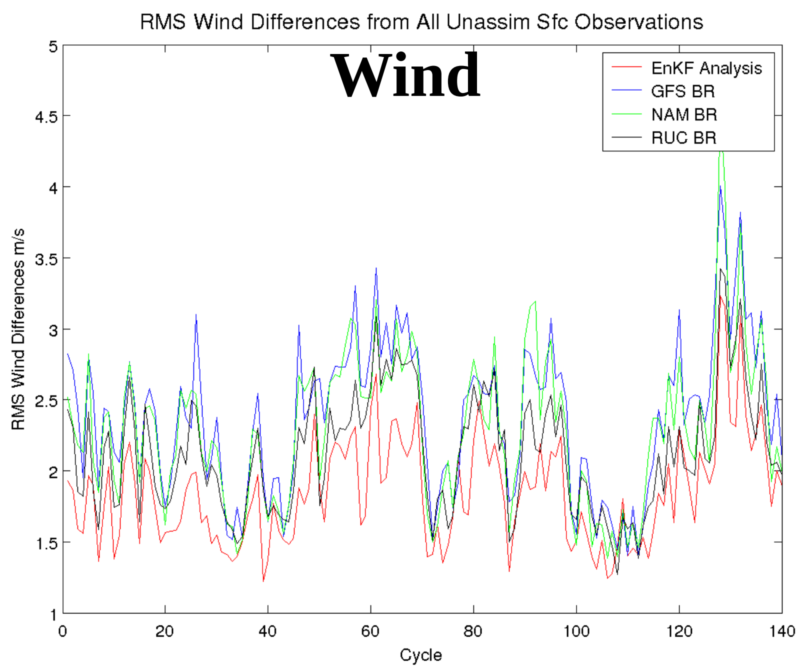
	Fri Sep 1	Fri Sep 1 Night	Sat Sep 2	Sat Sep 2 Night
TEMP	Daytime High 66° As high as: 71° As low as: 62°	Nighttime Low 55° Chance freeze: 0% As high as: 59° As low as: 51°	Daytime High 62° As high as: 67° As low as: 57°	Nighttime Low 55° Chance freeze: 0% As high as: 61° As low as: 49°
x PRECIP	Chance of Precip 10%  Likely Amount: .0" As Much As: .0"	Chance of Precip 10%  Likely Amount: .0" As Much As: .0"	Chance of Precip 10%  Likely Amount: .0" As Much As: .0"	Chance of Precip 10%  Likely Amount: .0" As Much As: .0"

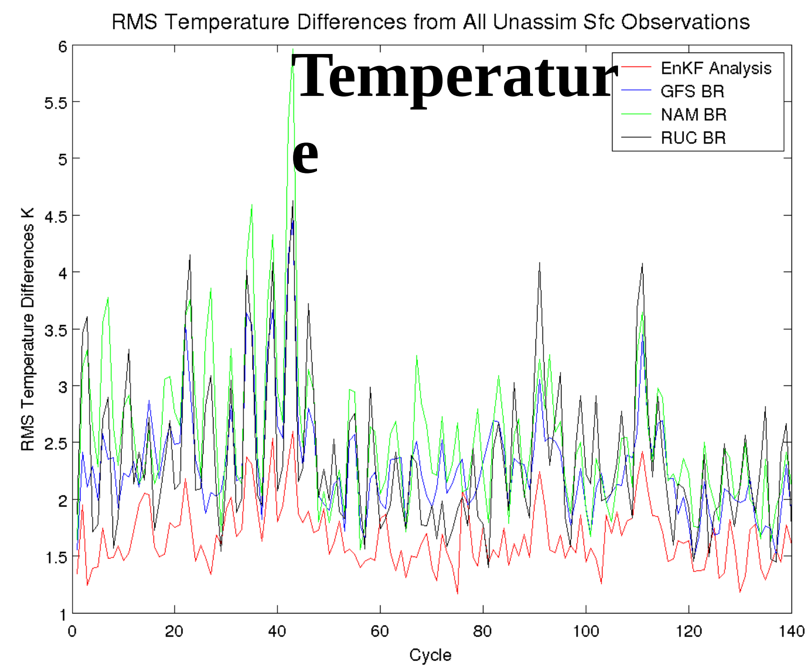
UW EnKF Data Assimilation

EnKF 12km Surface Observations



EnKF 12-km vs. GFS, NAM, RUC





RMS analysis errors

GFS	**2.38 m/s**	**2.28 K**
NAM	**2.30 m/s**	**2.54 K**
RUC	**2.13 m/s**	**2.35 K**
EnKF 12km	**1.85 m/s**	**1.67 K**

UW EnKF System Upgrades

- 4km domain
- 3-hr cycle
- Soon 1-h cycle

Summary

- The UW has attempted to build a multi-faced end-to-end ensemble prediction system
- Based on extensive research effort of several UW investigators

The END