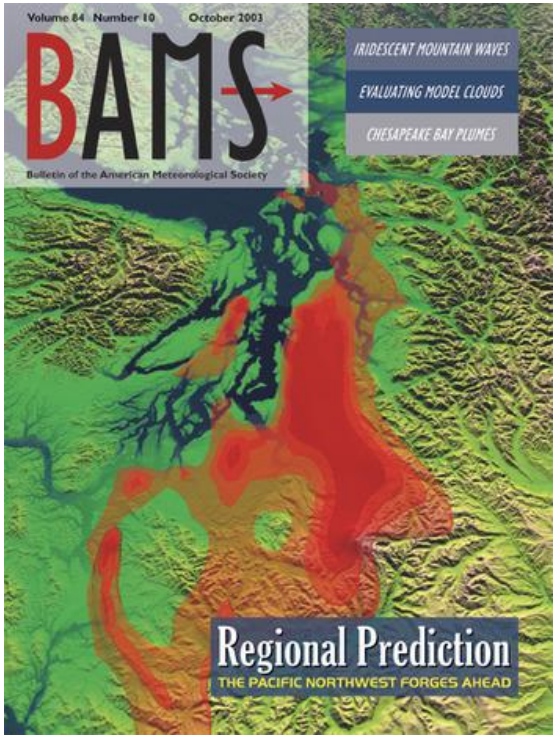
An Emergency Response Asset: High-Resolution Regional Weather Modeling for the Pacific Northwest

Cliff Mass

University of Washington



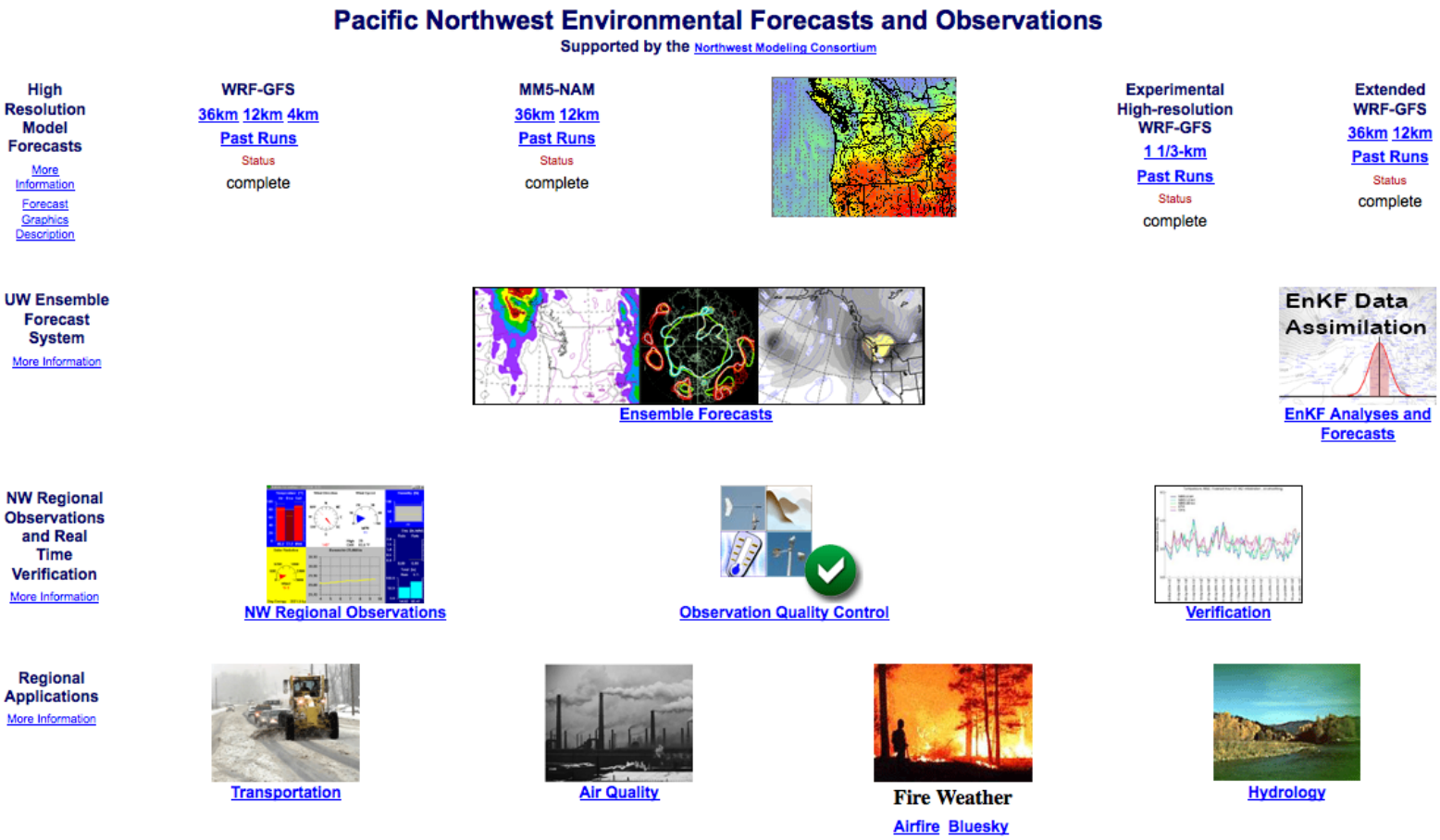
High-Resolution Regional Environmental Forecasting

- Needed to prepare for and respond effectively to severe weather.
- Required to determine trajectories of plumes and pollutants.
- Necessary for adaptation to global climate change.

The Northwest Real-Time Prediction Effort

- Supported by the NW modeling consortium, a collection of local, state, and Federal agencies…as well as private sector firms…a relatively unique funding approach.
- Nearly two decades old.
- End-to-end environmental prediction.

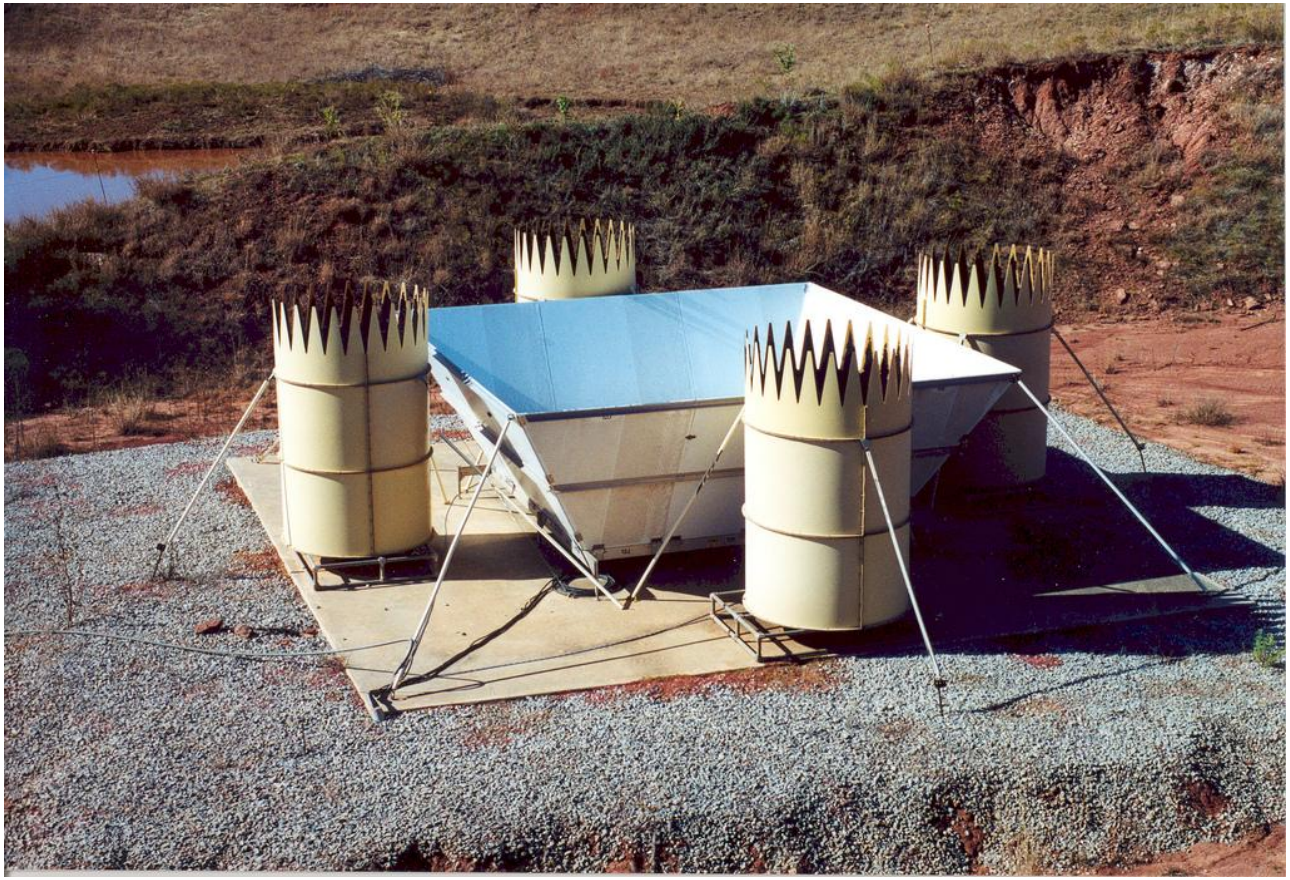
End-to-End Regional Environmental Modeling



History

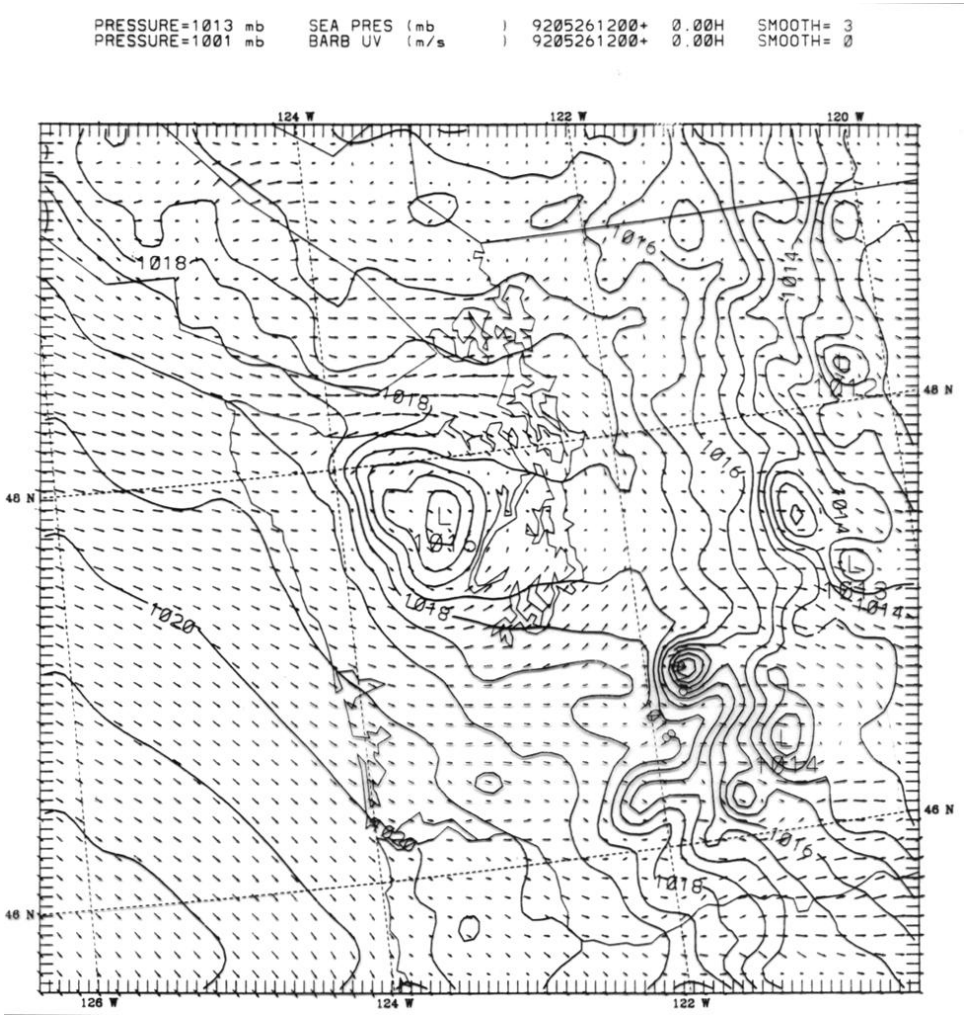
- The NW modeling consortium can be traced back to the early 1990s when regional air quality agencies, the UW, and the NWS started meeting about another problem…the lack of upper air soundings over the Puget Sound region.

The solution: a 915 Mhz Profiler supported by several agencies



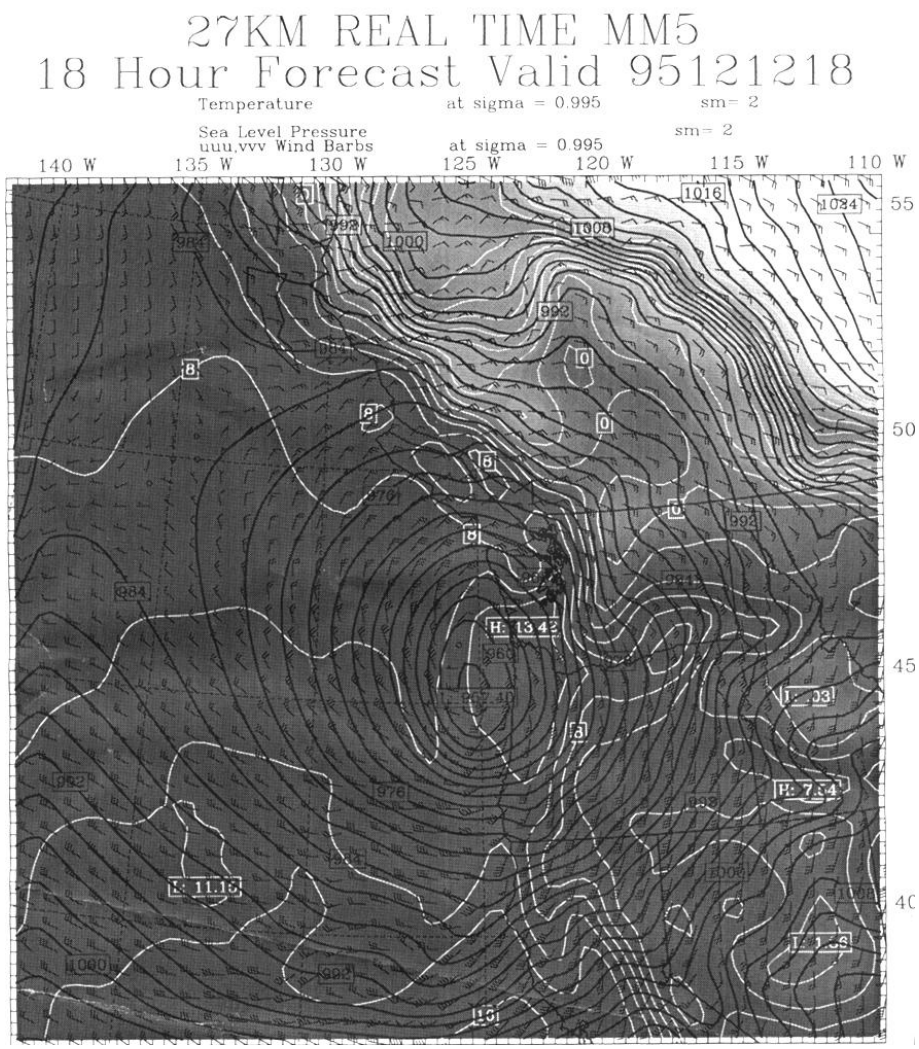
Consortium Phase II: Regional Modeling

- During the 1980s and early 1990s, my group was doing extensive experimentation with first RAMS and then MM4/5.
- It became clear that with sufficient resolution, mesoscale models could simulate and predict many local weather features of importance to the air quality and other communities.



Early MM4 simulation (10 km) of a Puget Sound convergence zone (Jim Steenburgh)

- In 1995, with consortium support, created a real-time system: running MM5 once a day at 27 km over the Northwest
- With very promising results, the agencies decided to invest in a far larger computer and to jump to much higher resolution. **The NW modeling consortium was formed**.



Early Members of the Consortium

- Puget Sound Air Pollution Control Agency
- UW
- National Weather Service
- EPA
- Washington State Depts. of Ecology and Transportation
- U.S. Forest Service
- US Navy
- Seattle City Light

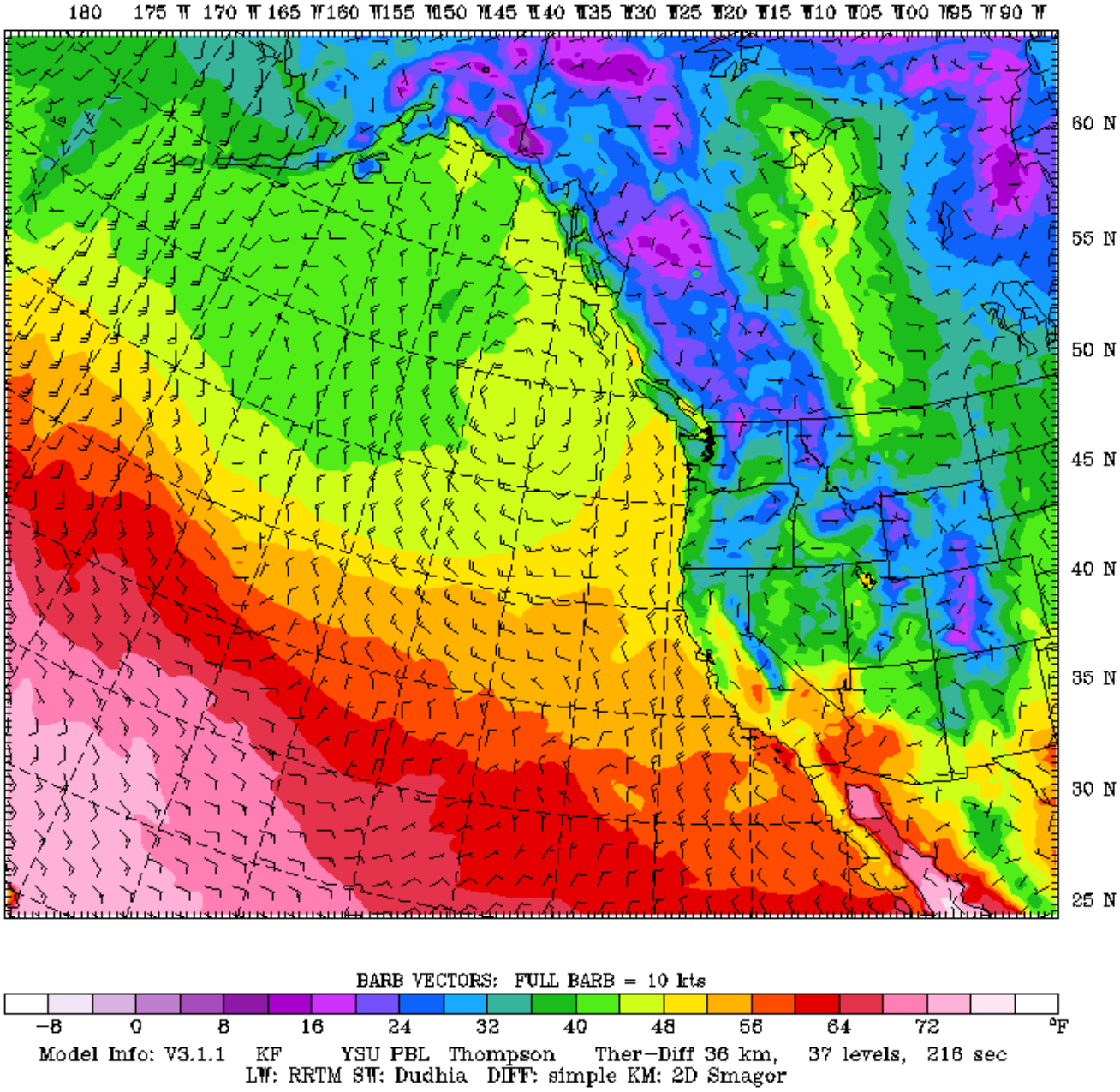
Naydene Maykut, PSCAA, First Chair, NW Modeling Consortium

Regional High Resolution Forecasting: Fast Forward to 2012

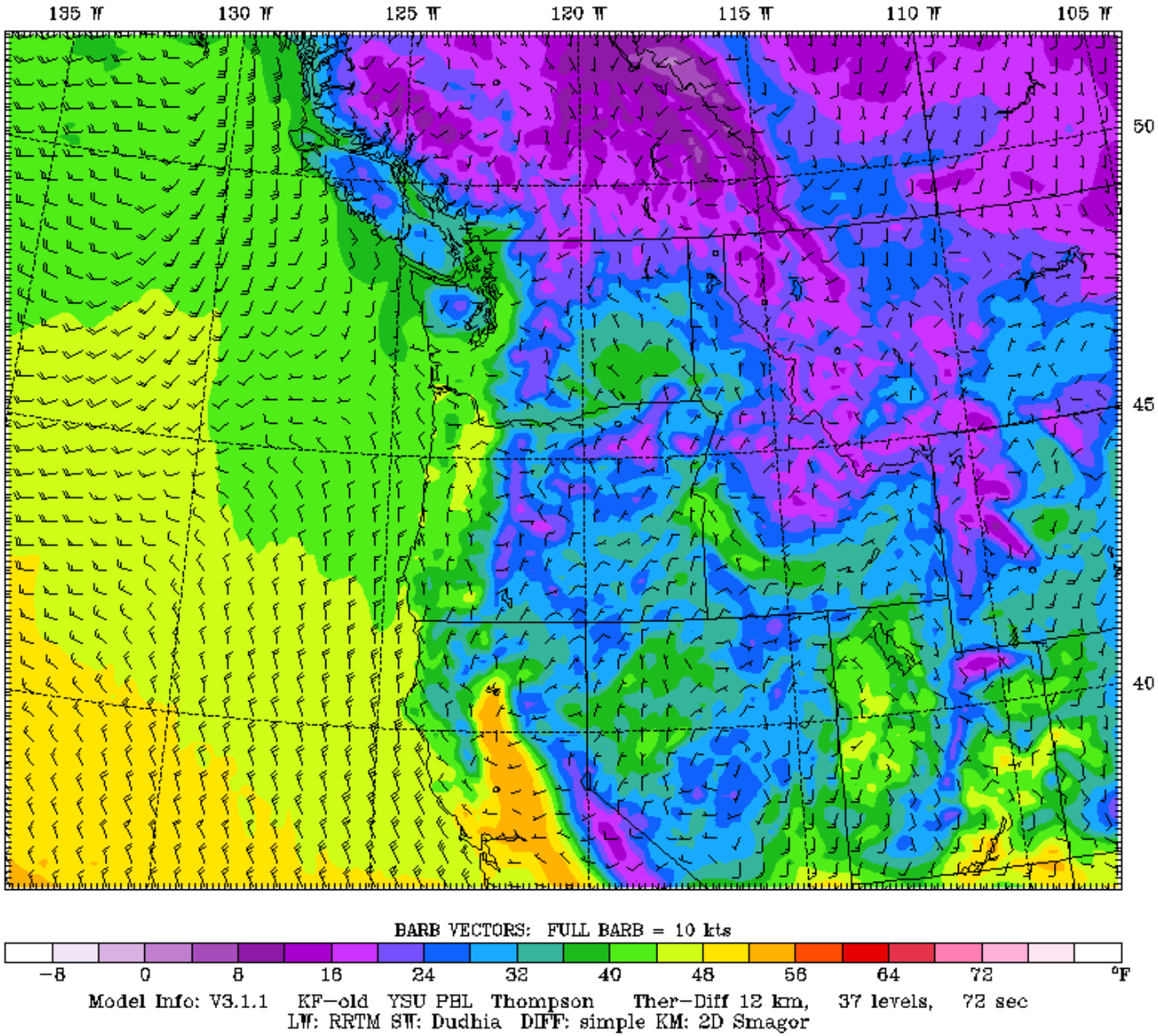
- MM5 replaced by WRF
- Larger domains … plus a new 1.3 km inner nest—perhaps the highest resolution operational NWP in the U.S.
- Model run on 136-core SAGE cluster using commodity (Intel Xeon) chips. Highly parallelized using 40 Gbit per sec. Infinitband
- Over 100 TB of disk storage

SAGE Cluster

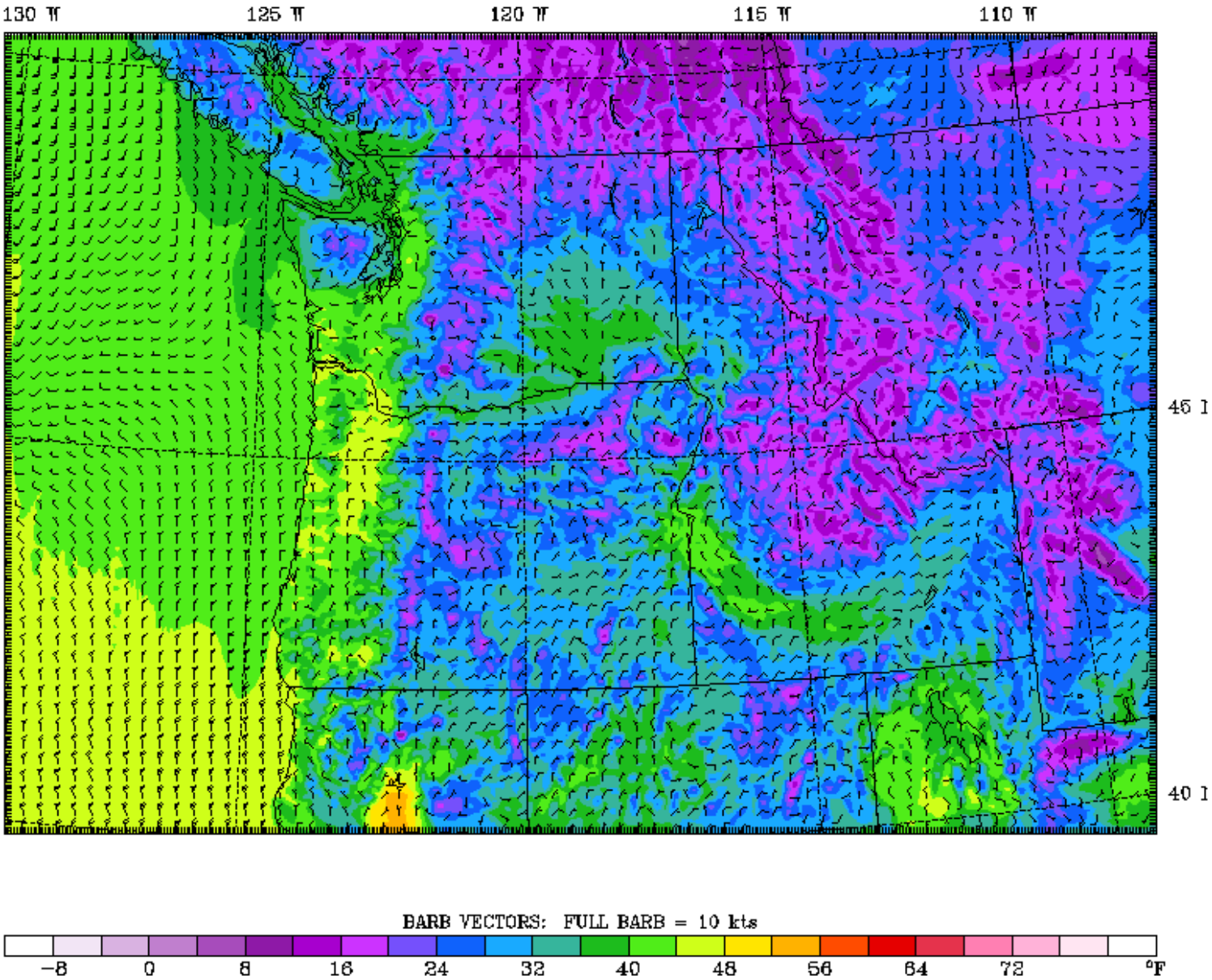
36 km


180 175 W 170 W 165 W 160 W 155 W 150 W 145 W 140 W 135 W 130 W 125 W 120 W 115 W 110 W 105 W 100 W 95 W 90 W
60 N
55 N
50 N
45 N
40 N
35 N
30 N
25 N
BARB VECTORS: FULL BARB = 10 kts
-8 0 8 16 24 32 40 48 56 64 72 °F
Model Info: V3.1.1 KF YSU PBL Thompson Ther-Diff 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

12 km


135 W
130 W
125 W
120 W
115 W
110 W
105 W
50
45
40
BARB VECTORS: FULL BARB = 10 kts
−8
0
8
16
24
32
40
48
56
64
72
°F
Model Info: V3.1.1 KF−old YSU PBL Thompson Ther−Diff 12 km, 37 levels, 72 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

4 km


130 W
125 W
120 W
115 W
110 W
45 N
40 N
BARB VECTORS: FULL BARB = 10 kts
-8
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8
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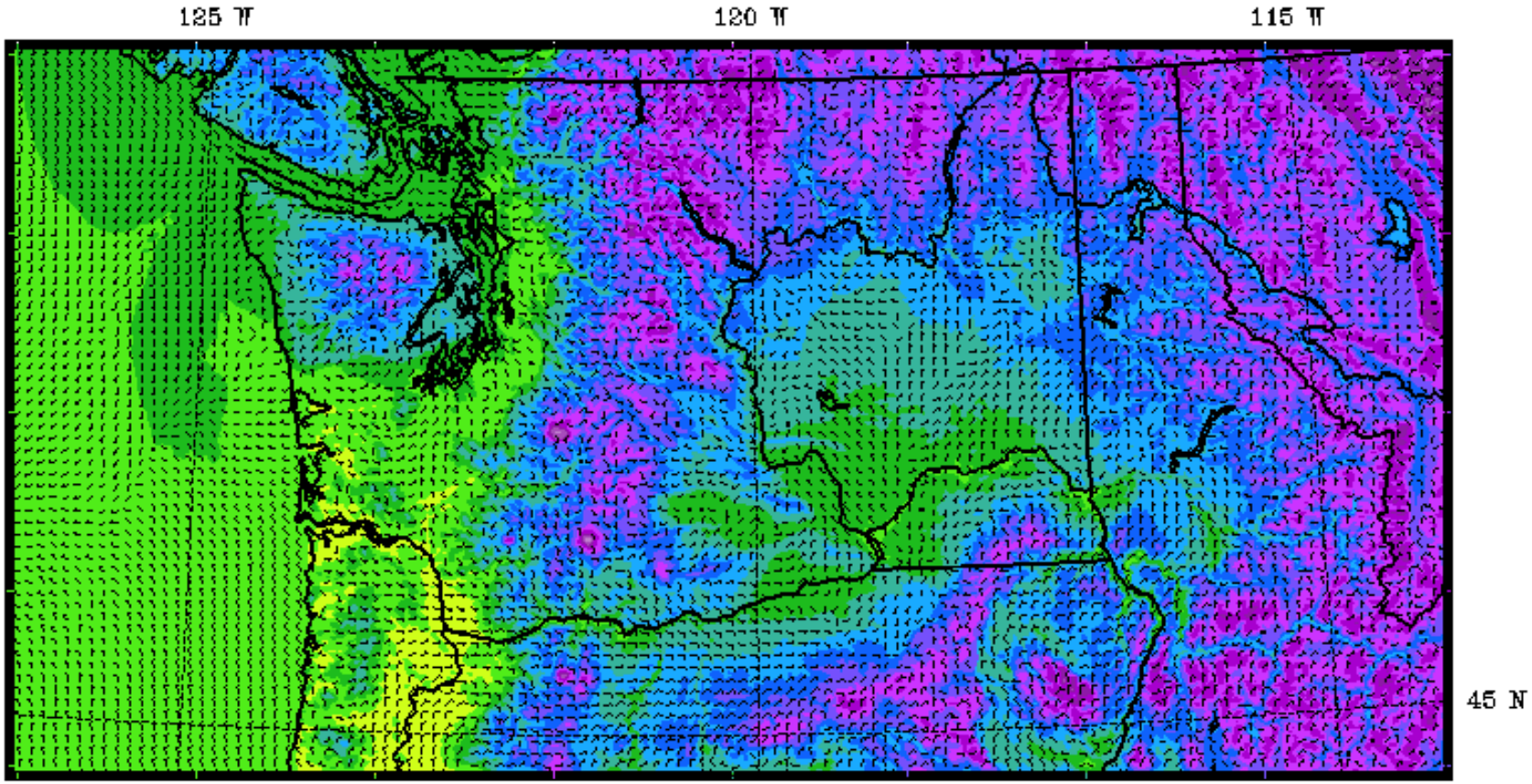
56
64
72
°F



1.33 km

Current Real Time Runs

- WRF driven by NWS GFS model
  - 36-12 km out to 180h, twice a day
  - 4 km, 84 h, twice a day
  - 1.33 km, 48h, twice a day
- MM5 driven by NWS NAM model (early look)
  - 36-12 km, 72 h, twice a day

Reliability: 99% plus.

2012 Consortium

- Rob Elleman, Chair (replaced Rob Wilson)
- Members:
  - Private Sector (Iberdrola, King)
  - UW
  - Puget Sound Clean Air Agency
  - EPA
  - State of Washington (Ecology, Transportation, DNR)
  - NWS
  - Forest Service
  - City of Seattle (SPU, City Light)

Output is available on the web and in gridded form (to consortium members)

WRF-GFS Page Navigation

Home
Go to MM5-NAM Run
Go to Extended Run

Top
36 km
12 km
4 km
1 1/3 km
WRF-GFS Runs for Other Dates
UW Atm. Sci. Home Page

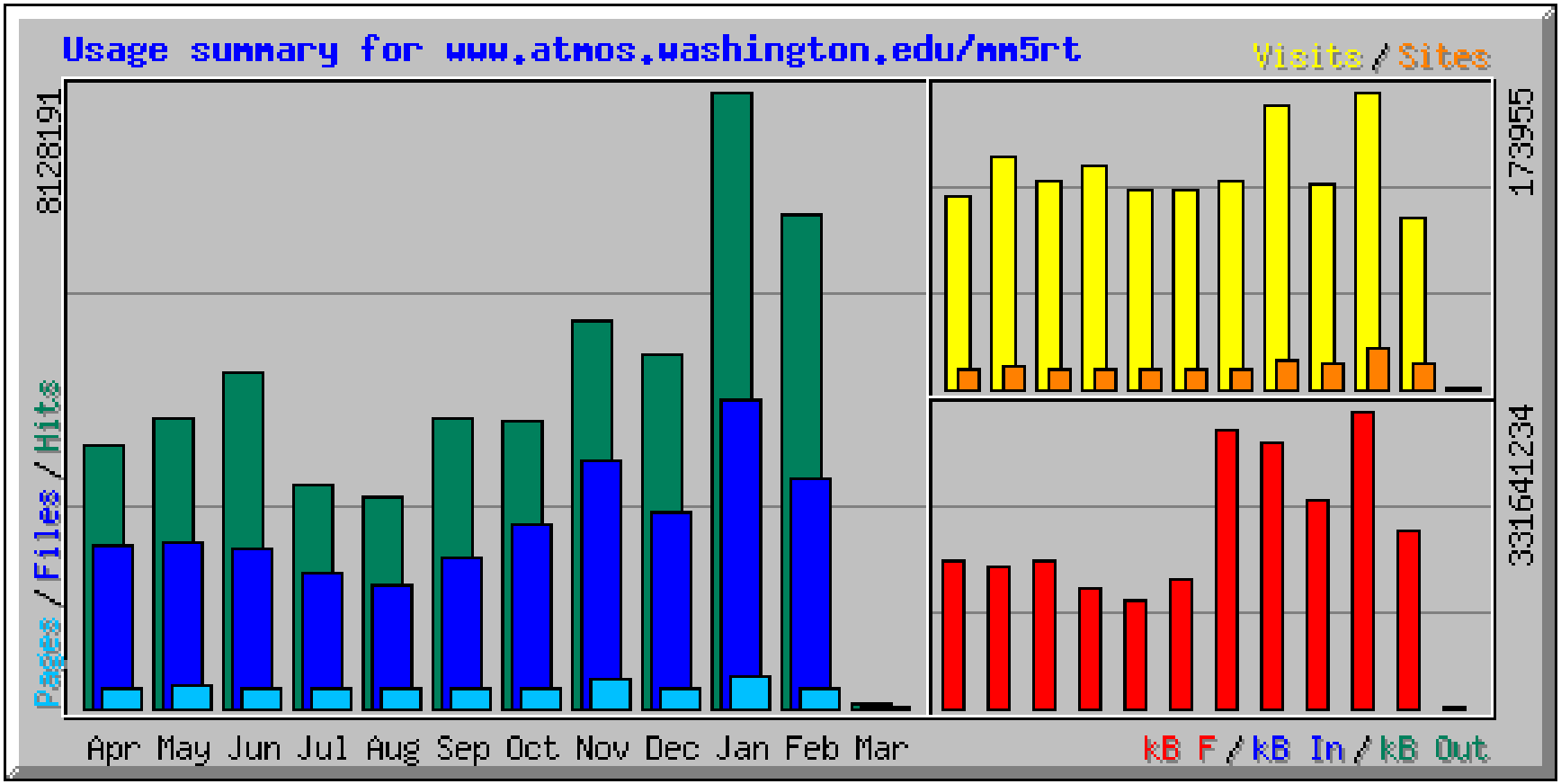
More Graphics

Display All Hours
Soundings
12 4 1 1/3
Sounding Generator
Meteograms
12 4 1 1/3
Meteogram Generator
Time-Heights
12 4 1 1/3
Time-Height Generator
Air Quality
12 4 1 1/3

WRF-GFS 12 km Domain
Initialized 2012042012 UTC
5 am PDT Fri 20 Apr 2012

	Product	Loop By Type	Forecast Hour																				
12km All Types	Loop by Hour Now excludes soundings		L0	L3	L6	L9	L12	L15	L18	L21	L24	L27	L30	L33	L36	L39	L42	L45	L48	L51	L54	L57	L60
12km Surface	**SLP**, 10 m winds, and temp	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Subdomain WA **SLP**, 10m winds, and temp	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Western WA **SLP**, 10m winds, and temp	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Columbia Gorge **SLP**, 10m winds, and temp	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	925 mb temperature, winds	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Thickness 1000-500 mb	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	CAPE (Convective available potential energy)	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Temperature	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	WA Surface (2m) temperature	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Columbia Gorge Surface (2m) temperature	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Bias-corrected Surface (2m) temperature	LOOP	6	12	18	24	30	36	42	48	54	60	66	72									
	Surface (2m) temperature bias	LOOP	6	12	18	24	30	36	42	48	54	60	66	72									
	Surface (2m) dew point temperature	LOOP	6	12	18	24	30	36	42	48	54	60	66	72									
	Bias-corrected Surface (2m) dew point temperature	LOOP	6	12	18	24	30	36	42	48	54	60	66	72									
	Surface (2m) dew point temperature bias	LOOP	6	12	18	24	30	36	42	48	54	60	66	72									
	10m Wind Speed	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Western WA **10m Wind Speed**	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Columbia Gorge **10m Wind Speed**	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	10m Wind Gusts	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Western WA **10m Wind Gusts**	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Columbia Gorge **10m Wind Gusts**	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Relative Humidity	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	Solar radiation	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	WA **Solar radiation**	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
12km Constant Height Western	1000 ft, pressure, winds	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	2000 ft, pressure, winds	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
	3000 ft, pressure, winds	LOOP	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60

How many are looking?



A Number of Organizations Are Getting the Model Grids

- **National Weather Service**: brought into their interactive system
- **Forest Service**: to support wildfire and smoke operations.
- **Washington State Univ**: Air quality and smoke modeling
- **Washington State**: to force air quality models
- **KING-5 TV** for on-air graphics
- …and others.

WSU Air Quality Modeling

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

Air-quality forecasting for the Pacific Northwest
AIRPACT

AIRPACT Home
Graphics Products
LAR Home

Intro to AIRPACT
Domain
Collaborators
Background
Change Log
News
Disclaimer
Contact

Activities/Related Programs:

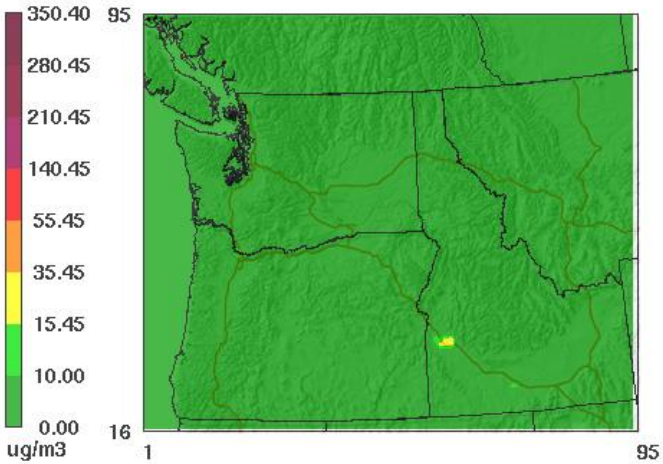
NW-AIRQUEST
AIRNow
BioEarth
BlueSky
CEREO
ClearSky
WRF Forecasting
NSPIRE
WSU Laboratory for Atmospheric Research

Today's PM2.5 Modeling Prediction

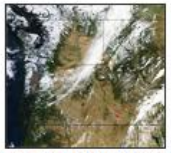
(click here for today's OZONE modeling prediction)

AQI-colored Rolling 24-hr Avg PM2.5

from two AIRPACT-3 CMAQ runs:
2012041600 and 2012041700



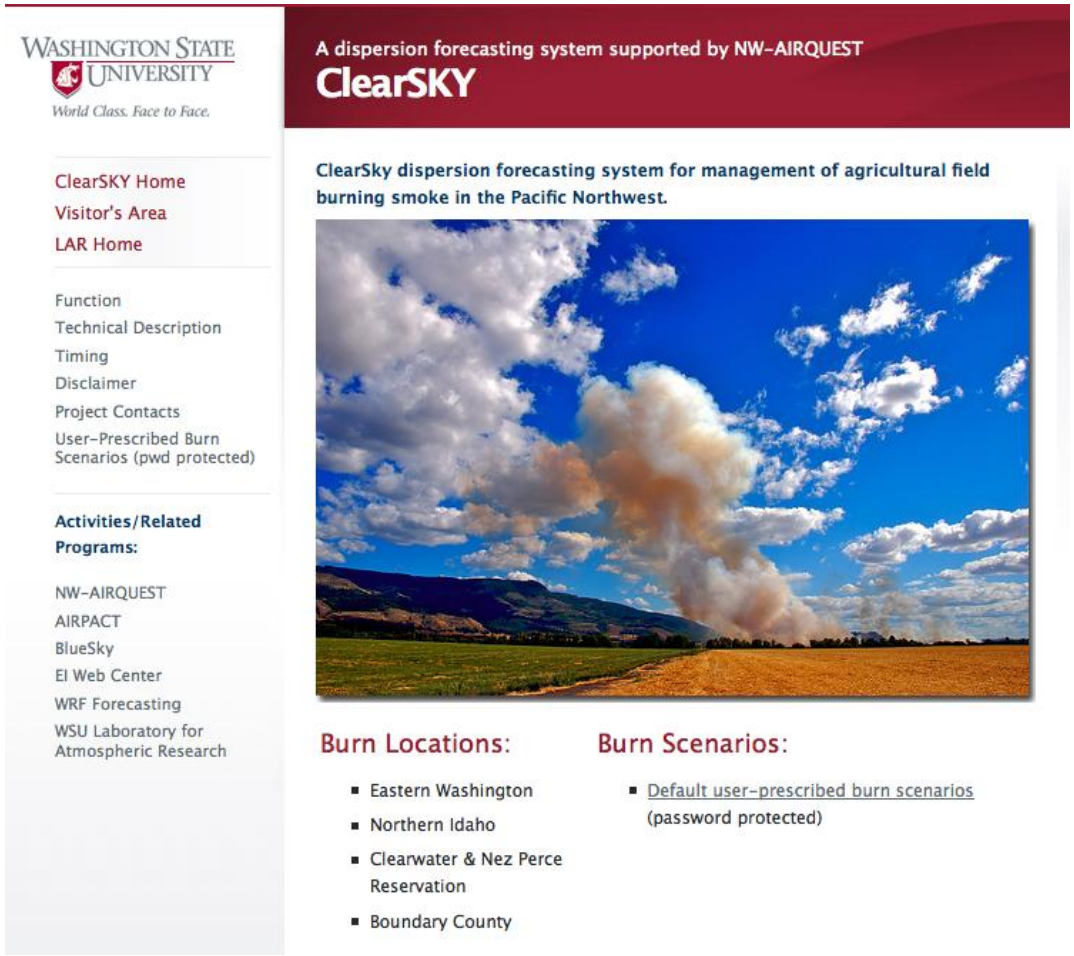
April 19,2012 2:00:00 (PST)
Min= 0.19 at (14,70), Max= 21.85 at (60,33)



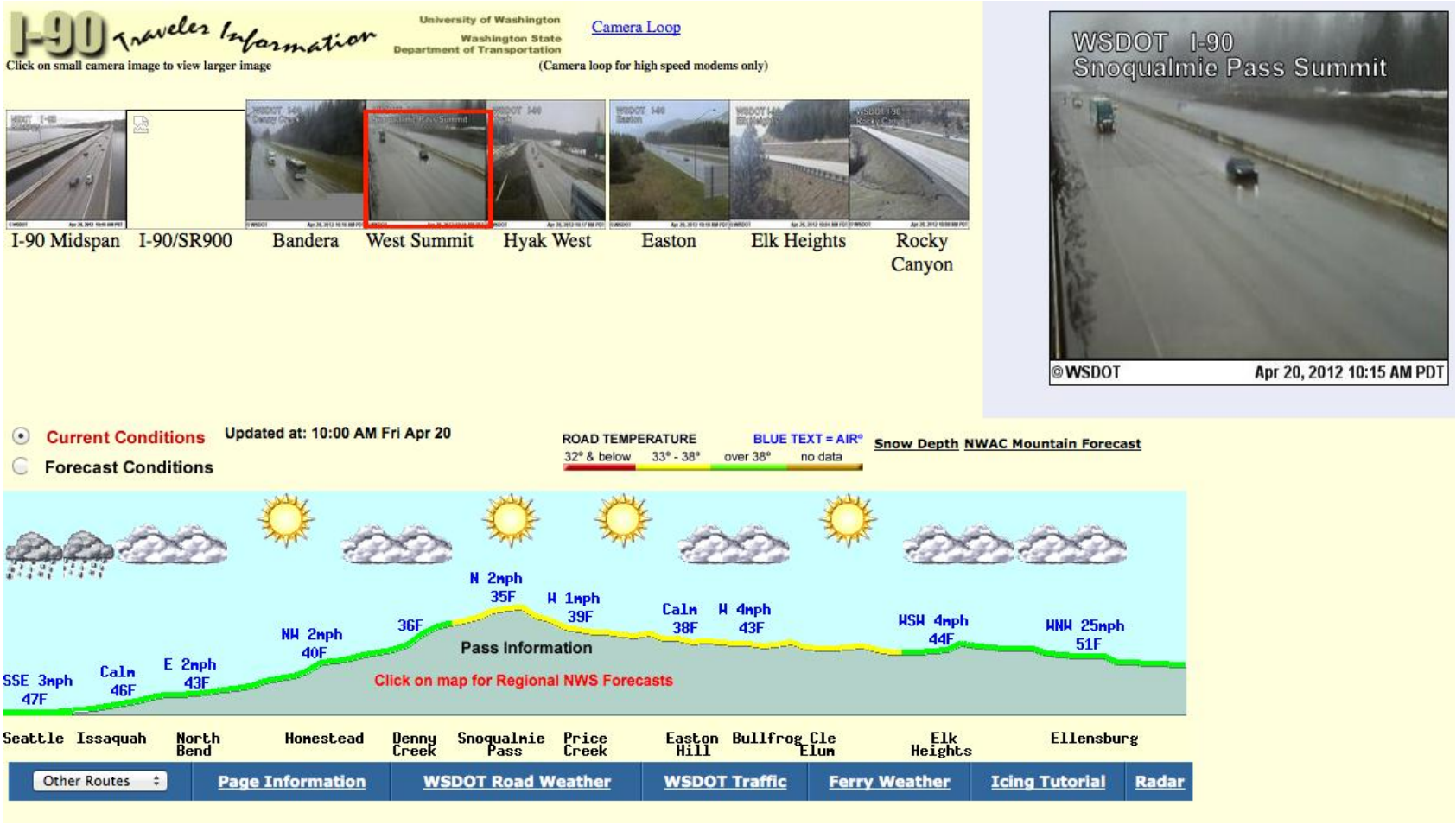
Daily MODIS imagery

Flash Animation Products

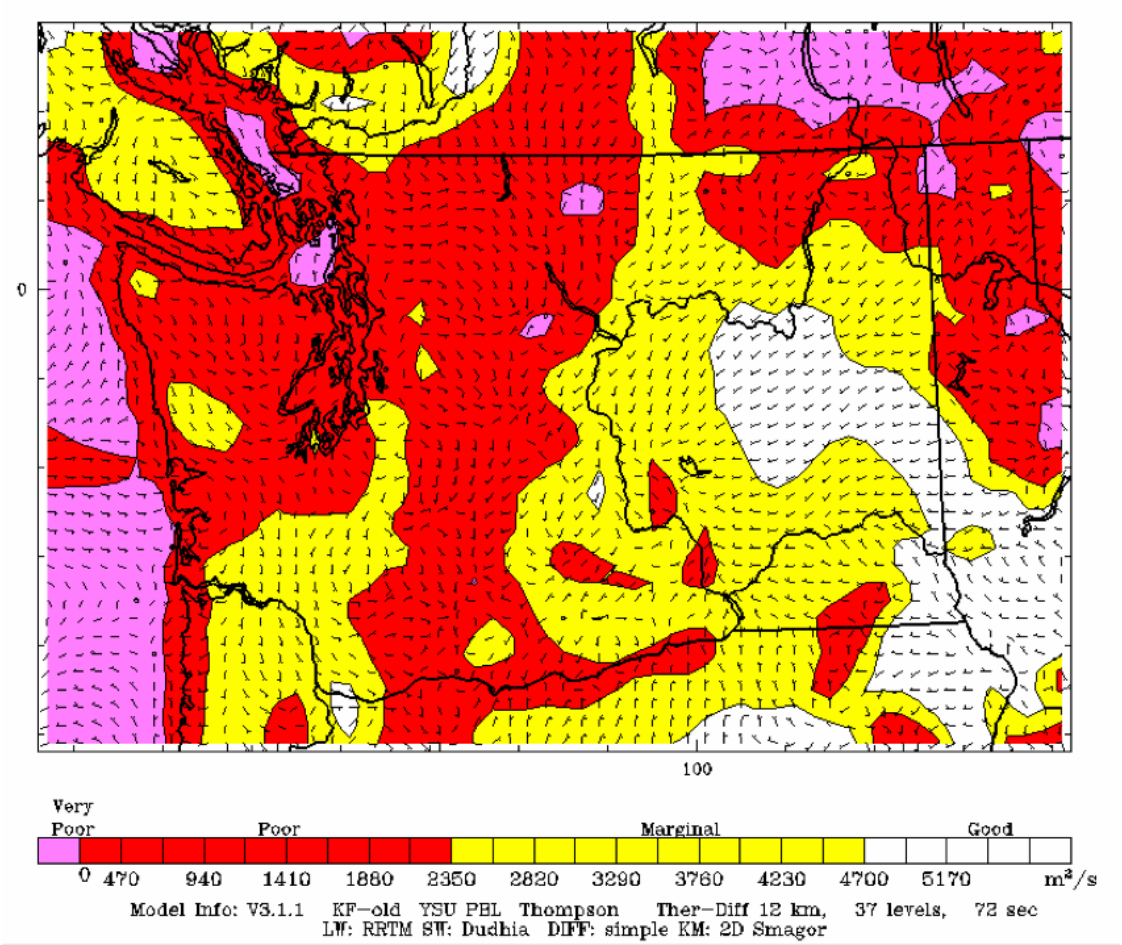
Managing Field Burning



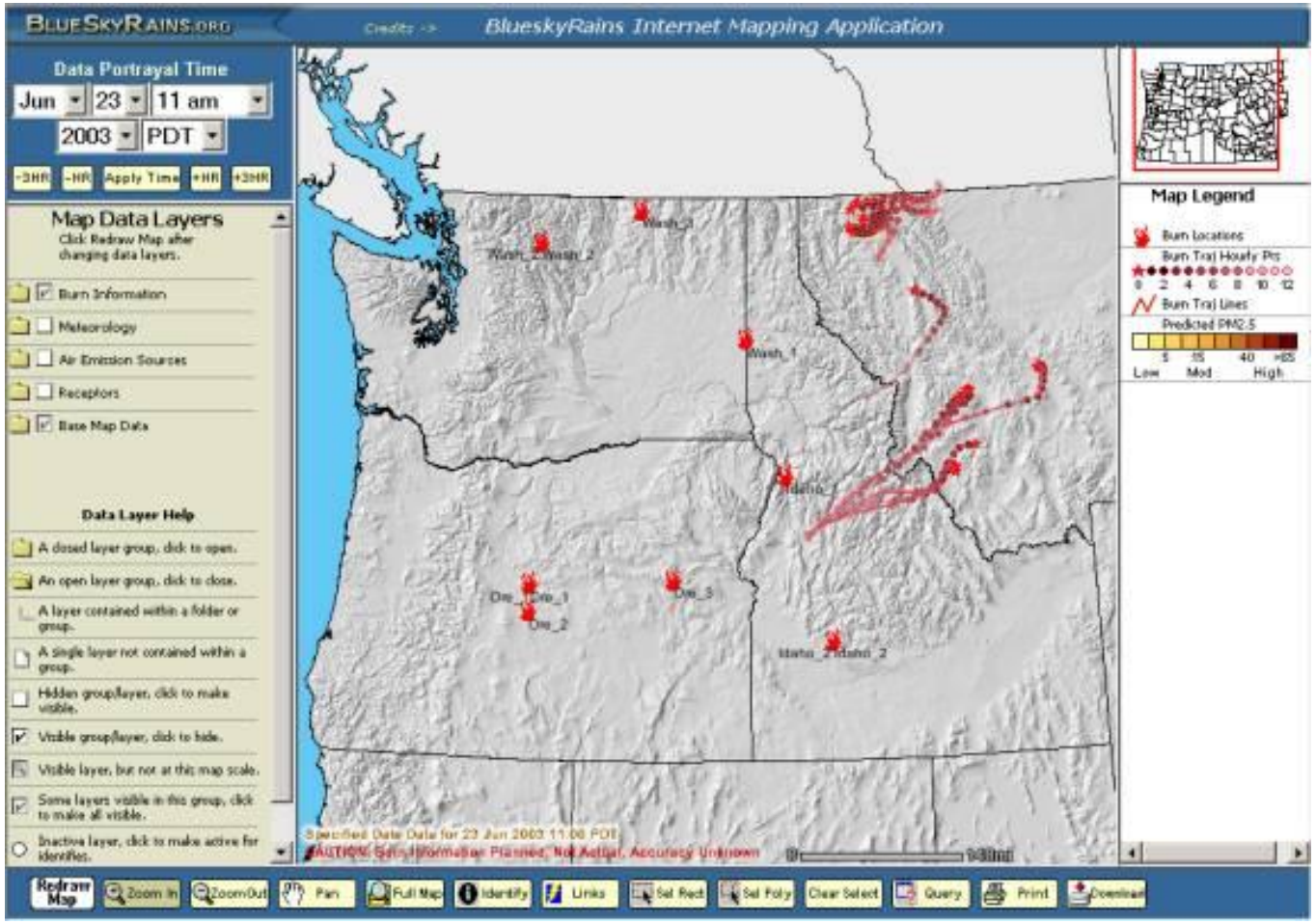
WSDOT


I-90 Traveler Information
University of Washington
Washington State Department of Transportation
Camera Loop
Click on small camera image to view larger image
(Camera loop for high speed modems only)
I-90 Midspan
I-90/SR900
Bandera
West Summit
Hyak West
Easton
Elk Heights
Rocky Canyon
WSDOT I-90
Snoqualmie Pass Summit
©WSDOT
Apr 20, 2012 10:15 AM PDT
Current Conditions
Updated at: 10:00 AM Fri Apr 20
Forecast Conditions
ROAD TEMPERATURE
32° & below
33° - 38°
over 38°
no data
BLUE TEXT = AIR°
Snow Depth
NWAC Mountain Forecast
SSE 3mph 47F
Calm 46F
E 2mph 43F
NW 2mph 40F
36F
N 2mph 35F
W 1mph 39F
Calm 38F
W 4mph 43F
WSW 4mph 44F
WNW 25mph 51F
Pass Information
Click on map for Regional NWS Forecasts
Seattle
Issaquah
North Bend
Homestead
Denny Creek
Snoqualmie Pass
Price Creek
Easton Hill
Bullfrog
Cle Elum
Elk Heights
Ellensburg
Other Routes
Page Information
WSDOT Road Weather
WSDOT Traffic
Ferry Weather
Icing Tutorial
Radar

Ventilation Index for AQ Agencies

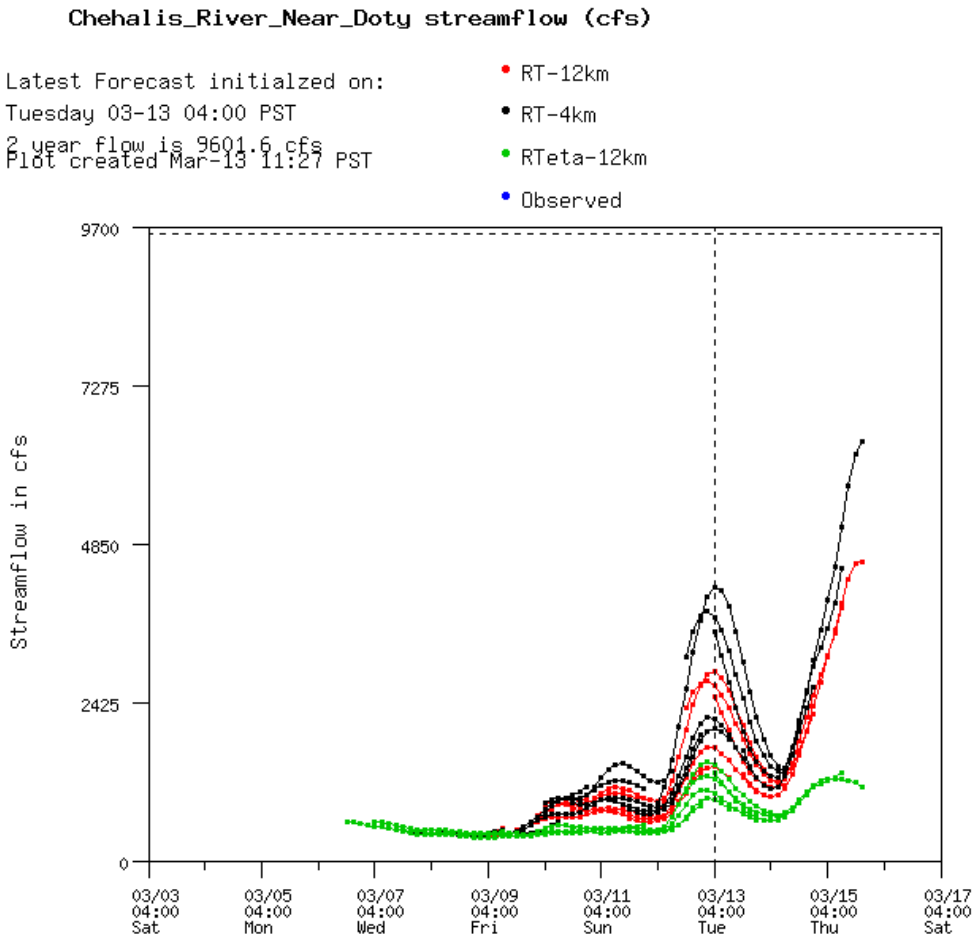


U.S. Forest Service



King-5 Futurecasts Driven by UW WRF

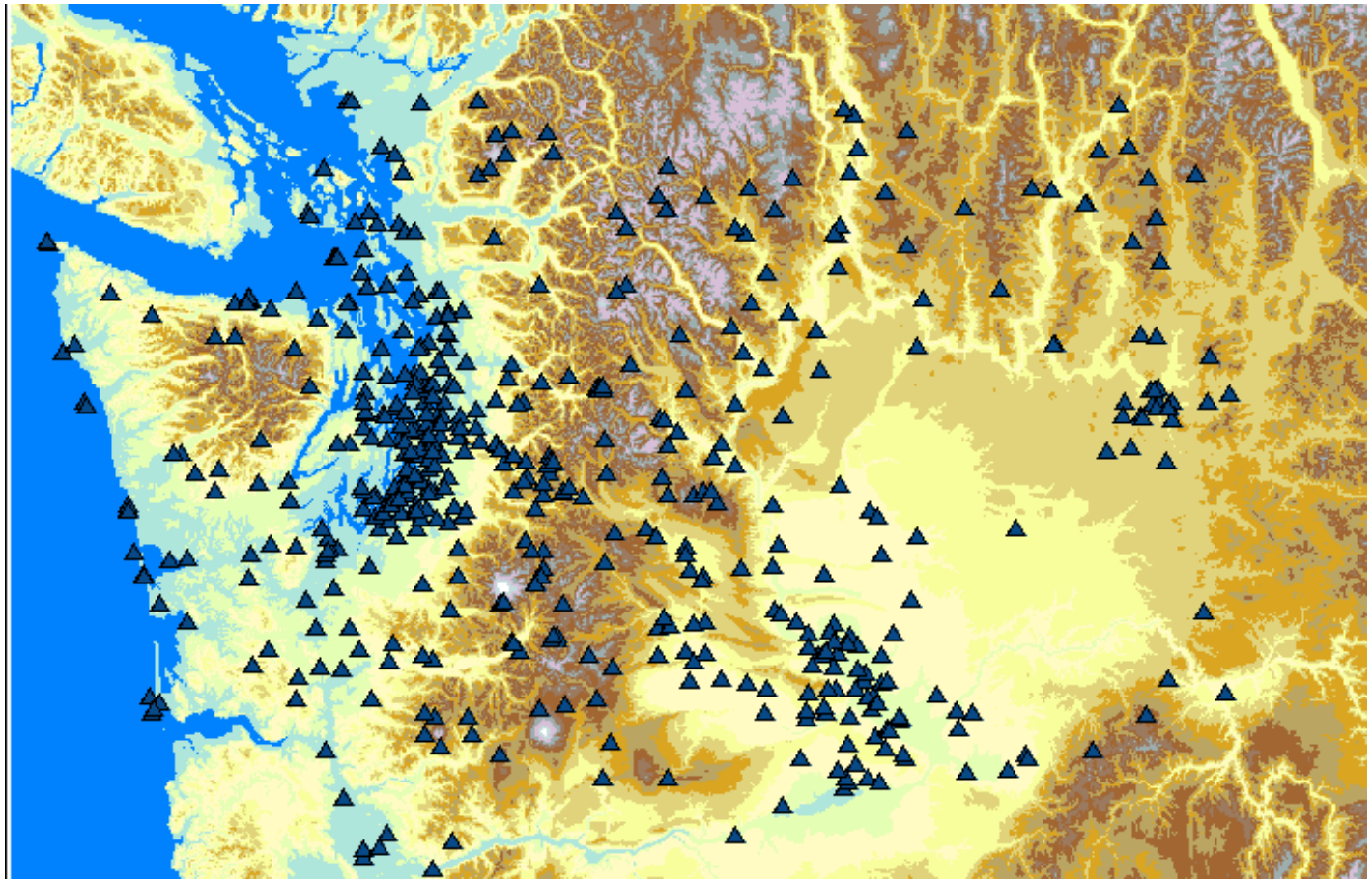
Real-Time Hydrological Prediction: WRF Driving DHSVM



Data Everywhere

- In support of the nascent modeling effort in the mid-1990s, we needed a lot more data than was available as NWS/FAA airport sites.
- During that period a number of groups established observing networks, whose data was available over the nascent Internet (Puget Sound Clean Air Agency, Schoolnet, etc.)
- Why not collect these networks, decode them, and combine to create a dense mesonet?

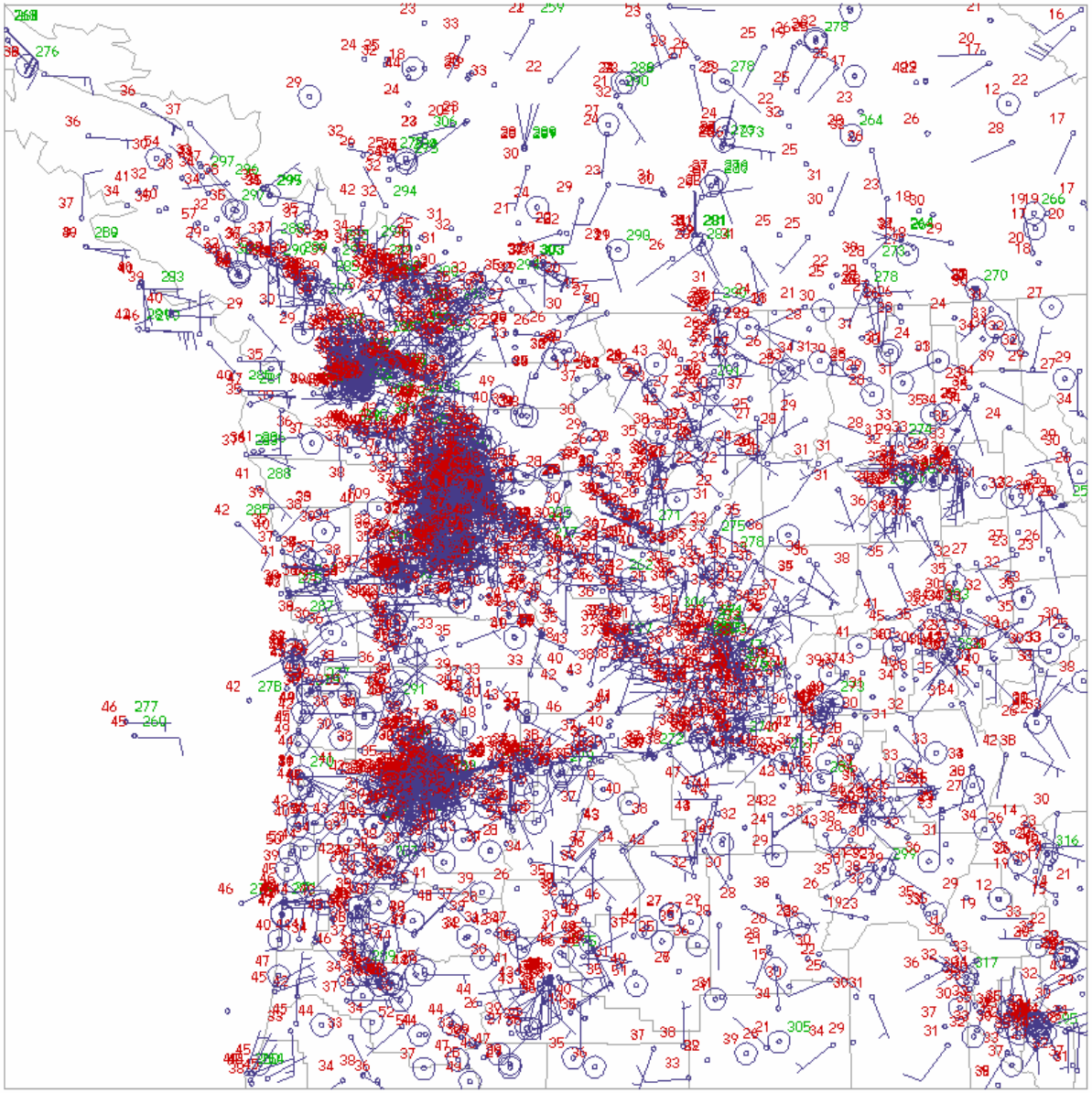
NorthwestNet was born



Today

Over 72 different networks

3000-4000 observations per hour over WA and OR



Probabilities

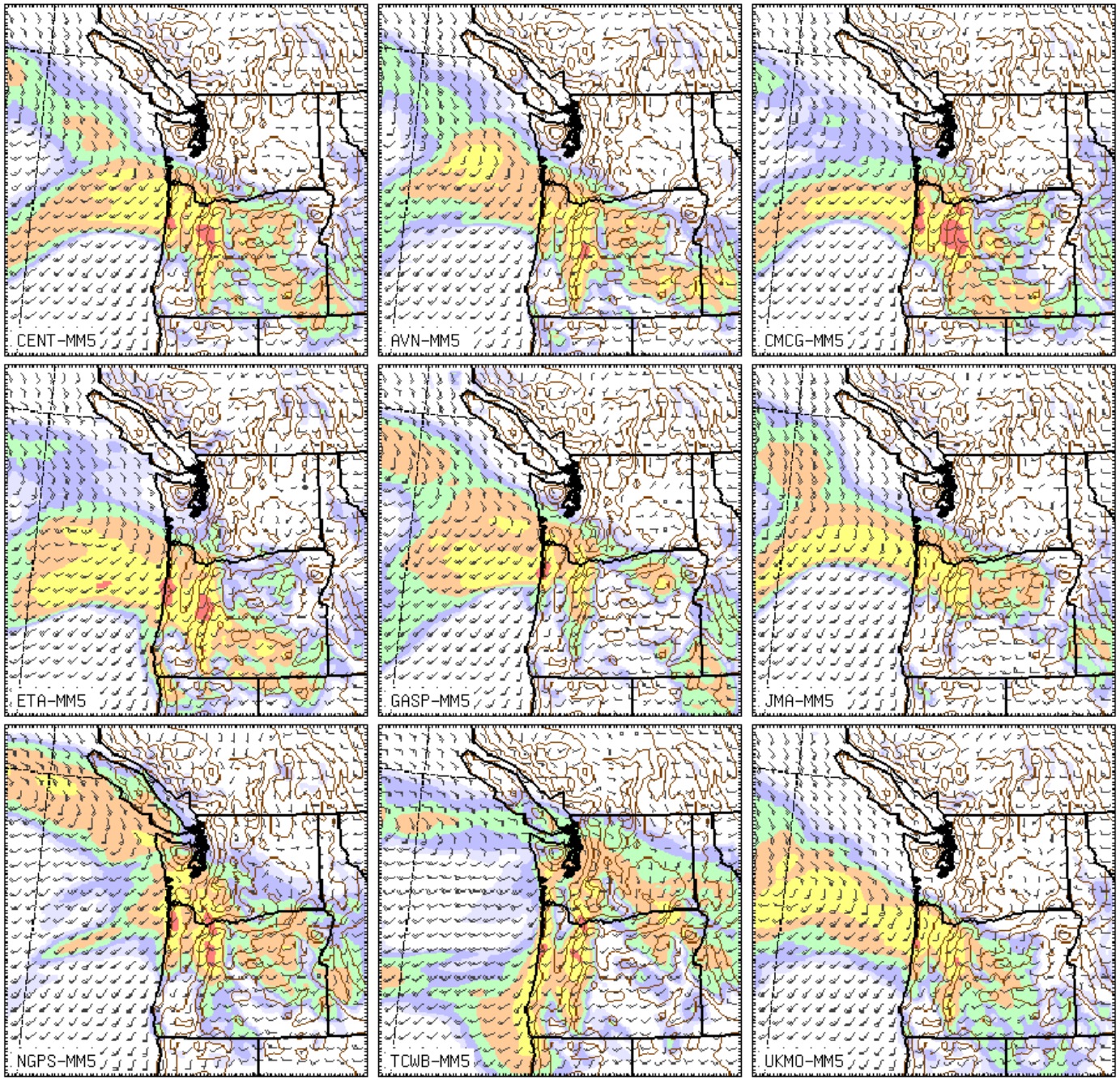
- Probabilistic prediction is the future.
- Clearly needs to be done at high-resolution for regional applications.
- Based on high-resolution ensembles.
- But little had been done before 2000.
- Starting at that time, the UW built the highest-resolution regional ensemble system in the U.S.
- With UW statistics created a sophisticated post-processing system to get reliable probabilistic information.

The UW Mesoscale Ensemble Prediction System (UWME)

Abbreviation/Model/Source	Type	Resolution (~ @ 45 °N) Computational	Distributed	Objective Analysis
avn, Global Forecast System (GFS), National Centers for Environmental Prediction	Spectral	T254 / L64 ~55km	1.0° / L14 ~80km	SSI
cmcg, Global Environmental Multi-scale (GEM), Canadian Meteorological Centre	Spectral	T199 / L28 ~100km	1.25° / L11 ~100km	3D Var
eta, Eta limited-area mesoscale model, National Centers for Environmental Prediction	Finite Diff.	12km / L45	90km / L37	SSI
gasp, Global AnalysiS and Prediction model, Australian Bureau of Meteorology	Spectral	T239 / L29 ~60km	1.0° / L11 ~80km	3D Var
jma, Global Spectral Model (GSM), Japan Meteorological Agency	Spectral	T106 / L21 ~135km	1.25° / L13 ~100km	OI
ngps, Navy Operational Global Atmos. Pred. System, Fleet Numerical Meteorological & Oceanographic Cntr.	Spectral	T239 / L30 ~60km	1.0° / L14 ~80km	OI
tcwb, Global Forecast System, Taiwan Central Weather Bureau	Spectral	T79 / L18 ~180km	1.0° / L11 ~80km	OI
ukmo, Unified Model, United Kingdom Meteorological Office	Finite Diff.	5/6°×5/9°/L30 ~60km	*same* / L12	3D Var

UWME
36 and 12 km
Grid spacing

Precipitation

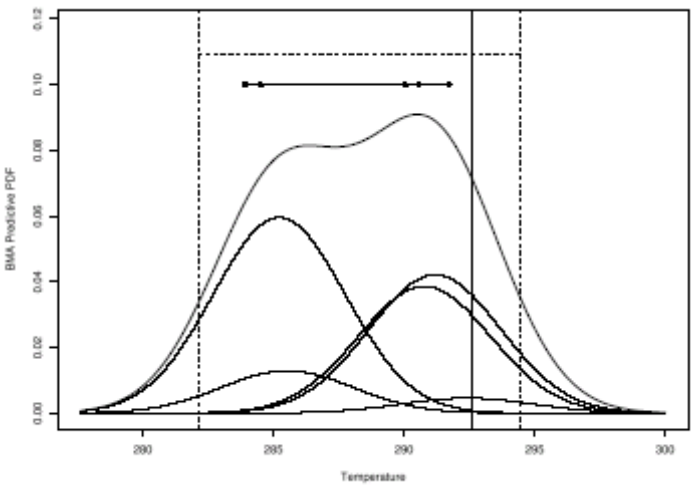


Ensemble Post-Procssing: Bayesian Model Averaging (BMA)

- The predictive PDF is a mixture of PDFs, each one centered on one of the forecasts after bias correction.
- Let y be the observed value.
- Let $\tilde{y}_k$ be the kth forecast from the ensemble
- The BMA 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 by maximum likelihood using the EM algorithm.



[c.f. Raftery et al. 2005, Mon. Wea. Rev.]

PROBCAST

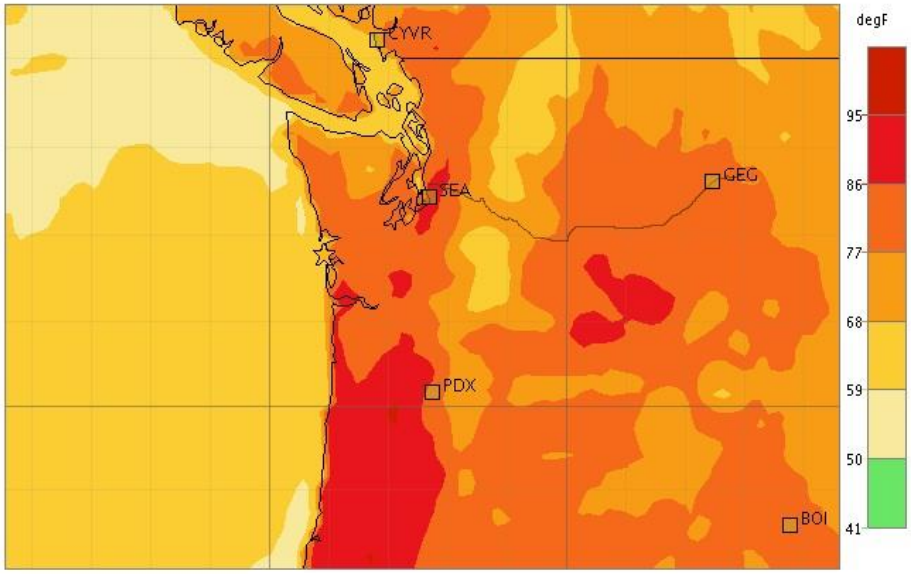
University of Washington Probability Forecast

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°
	As high as: 71° As low as: 62°	Chance freeze: 0% As high as: 59° As low as: 51°	As high as: 67° As low as: 57°	Chance freeze: 0% As high as: 61° As low as: 49°	As high as: 70° As low as: 56°
xPRECIP	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 10%	Chance of Precip 15%
	Likely Amount: .0" As Much As: .0"	Likely Amount: .0" As Much As: .0"	Likely Amount: .0" As Much As: .0"	Likely Amount: .0" As Much As: .0"	Likely Amount: .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

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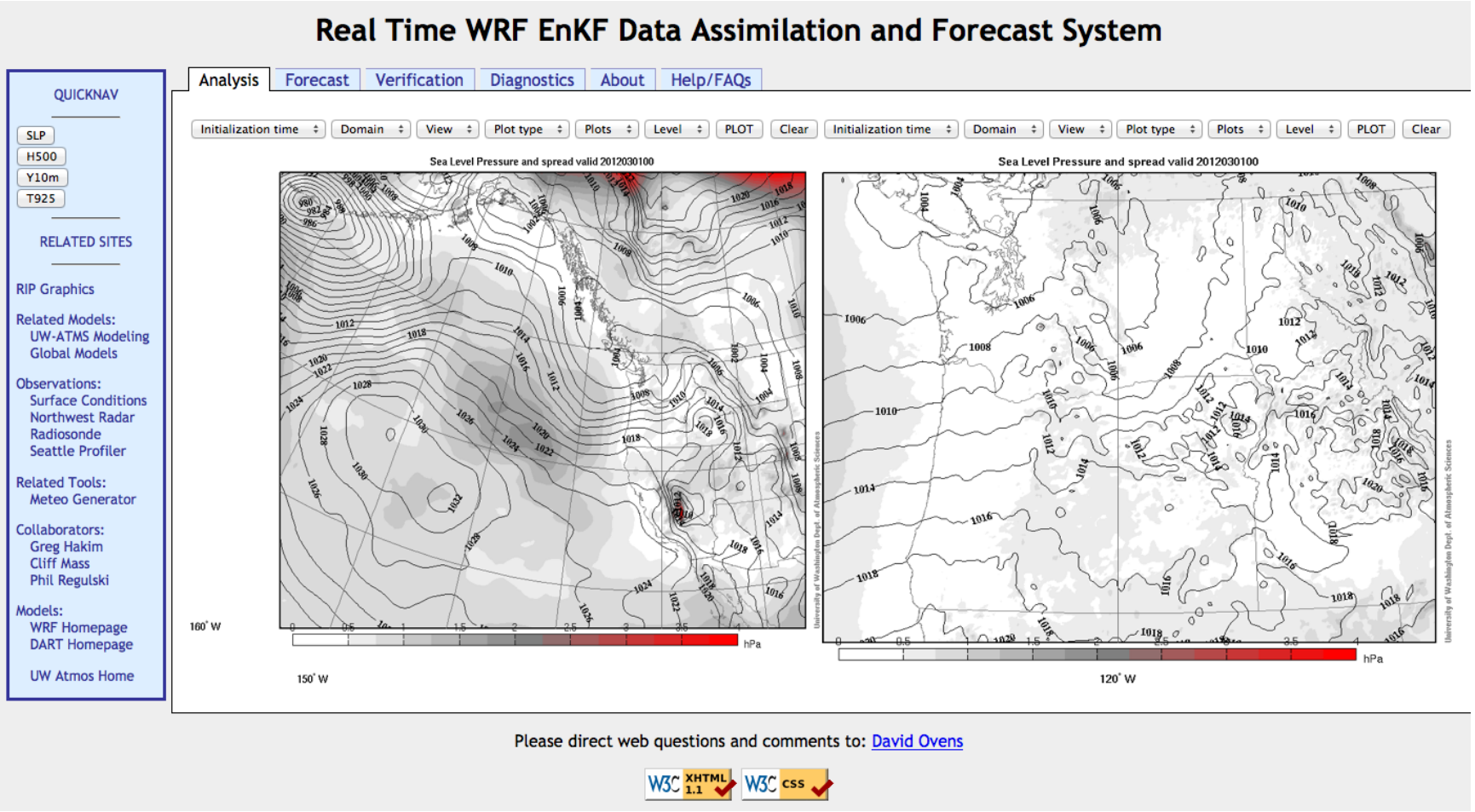
Contact ptewson@apl.washington.edu with questions, comments, and reports of errors.

Regional Probabilistic Data Assimilation and Forecasting



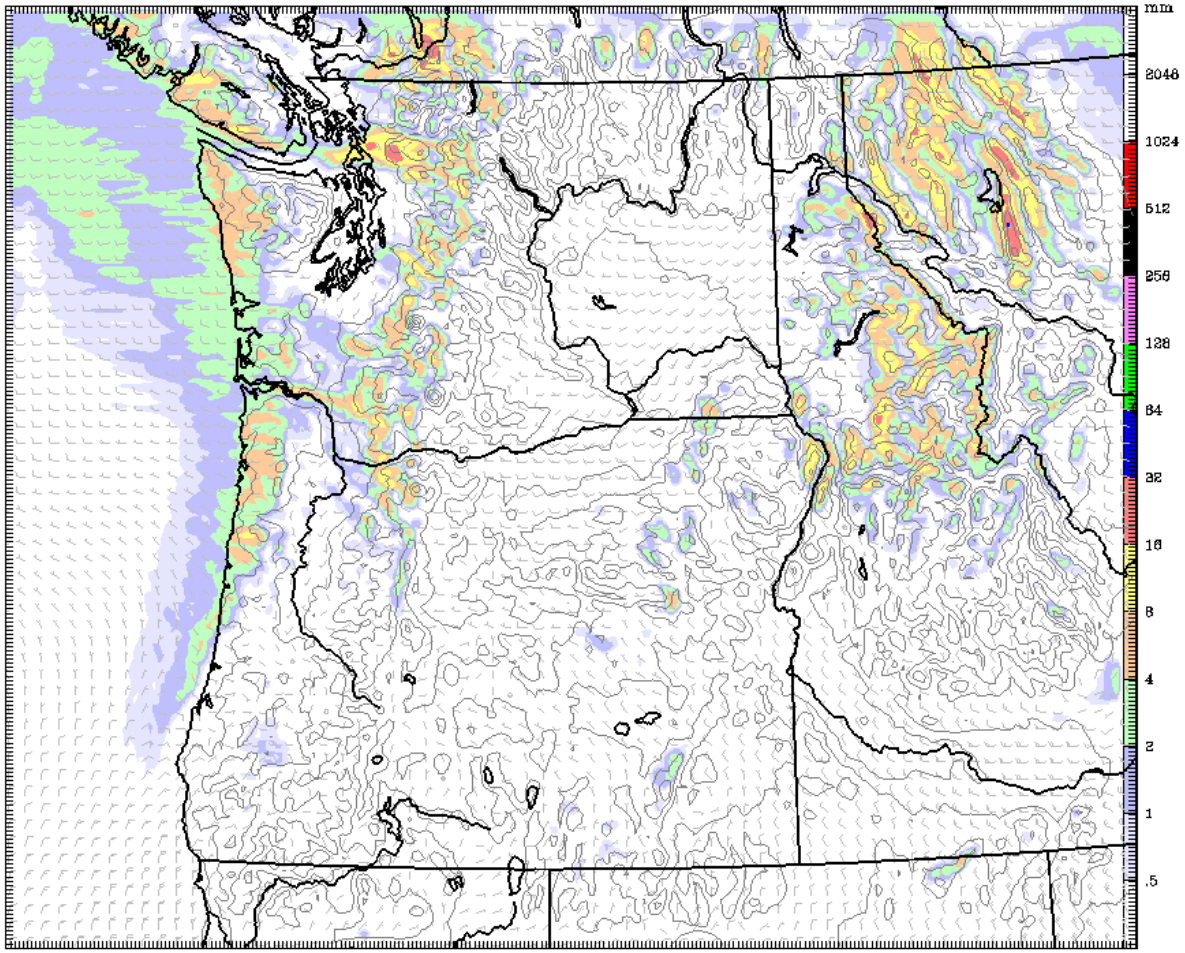
The Long Term Future of the UW Modeling Effort

- Based on a 64-member ensemble of forecasts at 36 and 4 km grid spacing. WRF model and DART Ensemble Kalman Filter (EnKF) System
- Every three hours assimilate a wide range of observations to create 64 different analyses.
- Then we forecast forward for 3 hours and then assimilate new observations.
- Thus, we have a continuous cycle of probabilistic <u>analyses.</u>

EnKF Ensemble Forecasting System

- We can run ensemble of forecasts forward to give us probabilistic forecasts for any period we want. Now doing 24h, four times a day.
- Planning to go to a 1-hr cycle and to use more observations (e.g., more surface pressure obs).
- This will be the way to produce the best analyses and short-term forecasts for a variety of needs.

UW WRF EnKF 4km Domain Init: 12 UTC Sat 05 May 12
Fcst: 3 h Valid: 15 UTC Sat 05 May 12 (08 PDT Sat 05 May 12)
Total Precip in past 3 hrs (.01in)
Wind at 10m (full barb = 10kts)

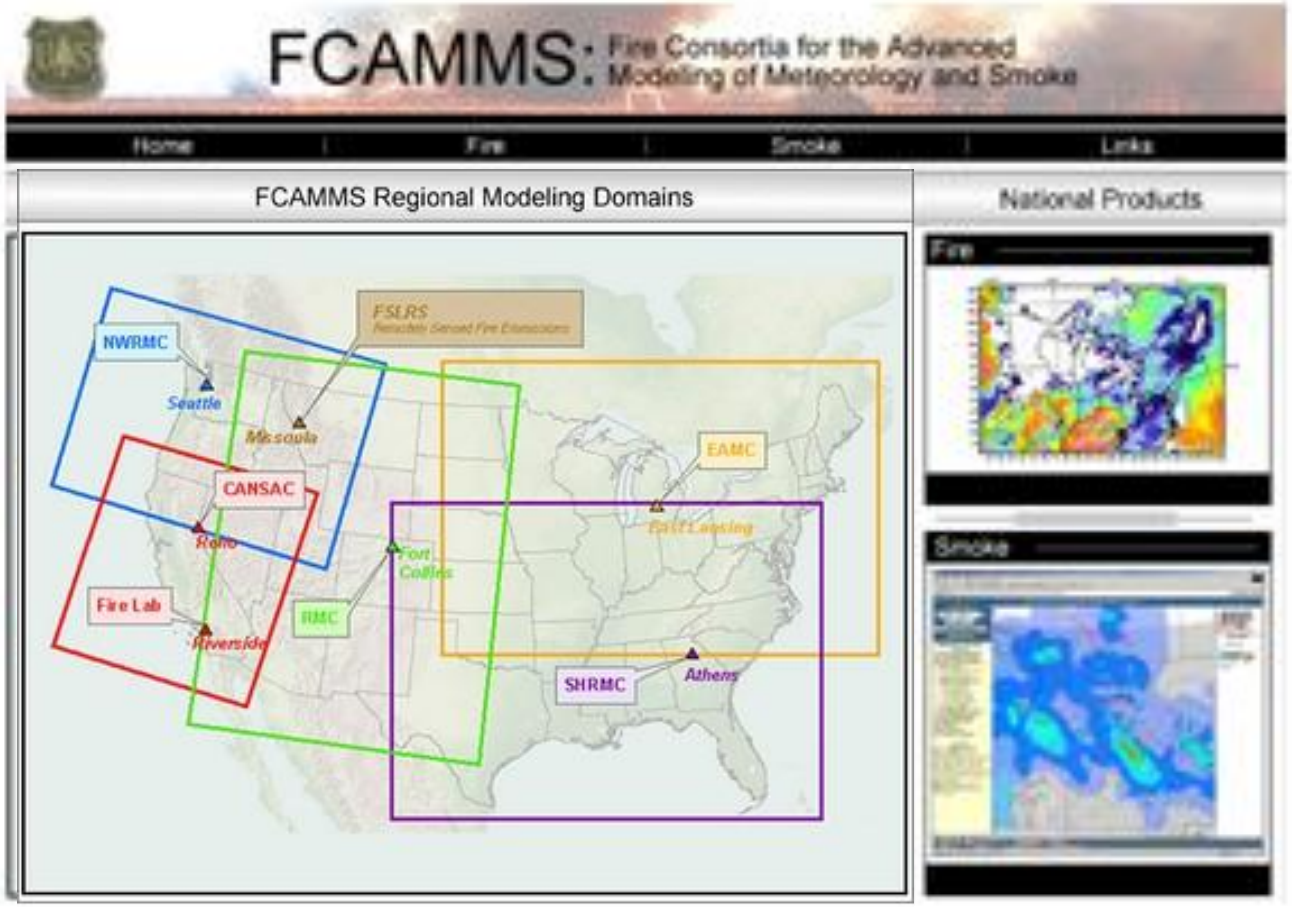


Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 4.0 km, 37 levels, 24 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

UW Regional NWP Effort Serves As A Model

- Based on the success of the UW NW modeling and consortium approach, a number of others tried to clone or duplicate it.
- A major example: the U.S. Forest Service FCAMS (*Fire Consortia for Advanced Modeling of Meteorology and Smoke*) effort:

FCAMMS


FCAMMS: Fire Consortia for the Advanced Modeling of Meteorology and Smoke
Home
Fire
Smoke
Links
FCAMMS Regional Modeling Domains
National Products
Fire
Smoke
NWRMC
Seattle
FSERS
Missoula
CANSAC
Reno
Fire Lab
Riverside
RMC
Fort Collins
EAMC
East Lansing
SHRMC
Athens

A Different Model

- Regional high-resolution environmental prediction is viable.
- Combined with a national backbone effort, it offers an alternative to completely centralized environmental prediction.

The End or ….