ADAPTIVE OBSERVATIONS AT NWS: THE WINTER STORM RECONNAISSANCE PROGRAM

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http://sgi62.wwb.noaa.gov:8080/ens/target/wsr.html

1 SAIC at NCEP

OUTLINE / **CONCLUSIONS**

1) ATMOSPHERIC OBSERVATIONS

TRADITIONAL AND ADAPTIVE APPROACHES

2) TARGETED OBSERVATIONAL TECHNIQUE

FCST CASE SECLECTION, SENSITIVE AREA, DATA COLLECTION

3) PAST PROGRAMS

EIGHT RESEARCH & OPER. PROGRAMS BETWEEN 1997–2002

4) WINTER STORM RECONNAISSANCE 2001 PROGRAM

OPERATIONALLY IMPLEMENTED AT NWS; POSITIVE RESULTS

5) PLANS

EXPAND WSR PROGRAM IN TIME/SPACE; THORPEX RESEARCH

ATMOSPHERIC OBSERVATIONS

CURRENT PRACTICE:

Most observations are taken

1) At fixed times and locations (in situ obs)

2) As opportunities arise (aircraft ascent/descent; satellite overpass)

3) Based on FEATURE (hurricane, heavy precip & its environment)

ADAPTIVE APPROACH:

Obs. taken adaptively to maximize analysis and/or forecast impact

TARGETED OBSERVATIONS

IMPROVE PARTICULAR FCST FEATURE:

Eg, 3–day precip fcst over ne US

QUESTION: Can targeting observations improve fcst performance?

PROBLEM: Fcst feature

may not exist at observation time

may undergo major changes till verification time =>

Feature based technique is not applicable at longer lead times

TARGETED OBSERVATIONS

1) How to select fcst feature?

a) Uncertainty/information content in fcst

b) Societal impact: Is uncertainty tolerable?

2) How to identify sensitive area to be observed?

(i) Adjoint sensitivity calcuations

(ii) Ensemble transform technique

3) How to take observations?

(i) Dropsondes released from manned aircraft

(ii) Unmanned aircraft

(iii) Balloons

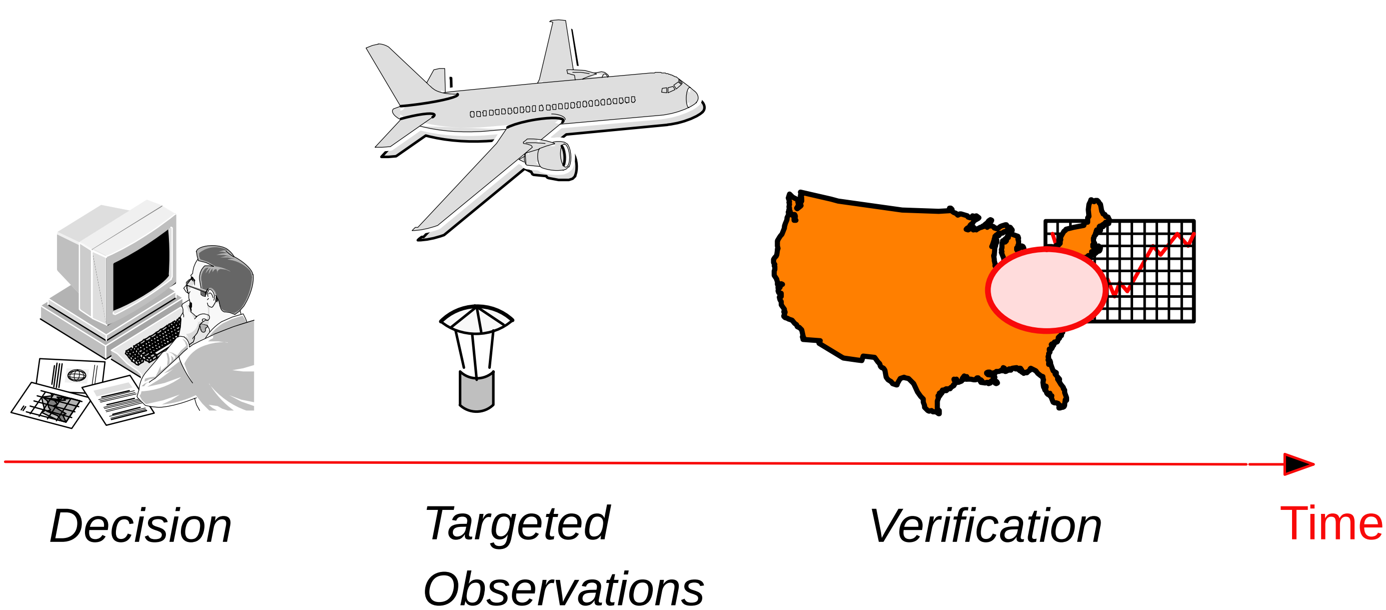
(iv) Satellite

4) How to evaluate technique?

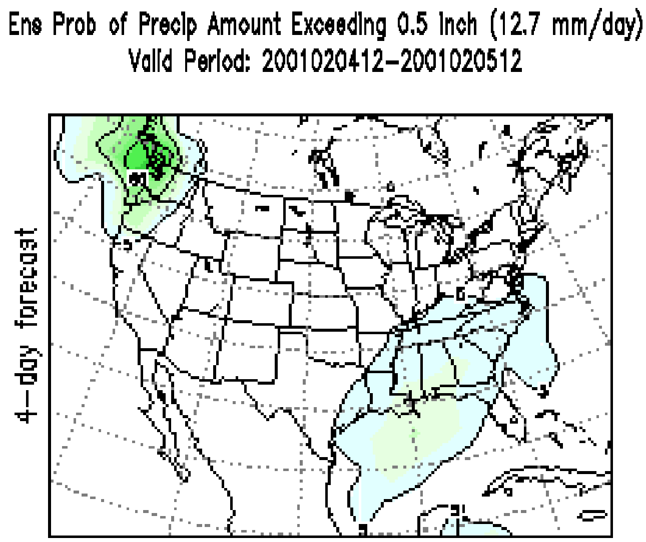
(i) Data impacts desired fcst feature?

(ii) Impact positive (ie, fcst improved)?

(iii) Societal impact – Cost effective?

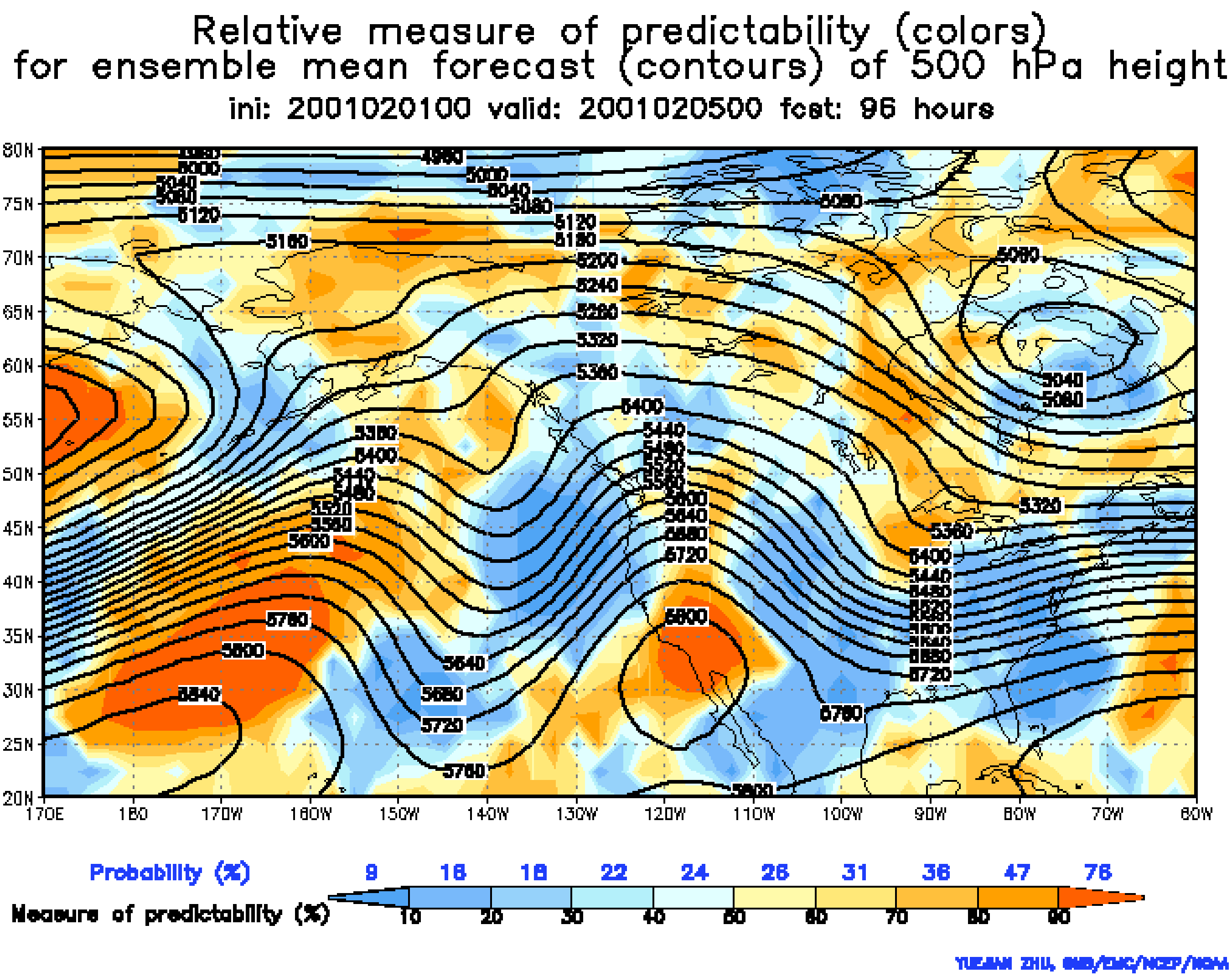


CASE SELECTION



CASE 1:

Decision time: 2001020100
Observation time: 2001020300
Verification time: 2001020500
Longitude: 123W
Latitude: 48N
Priority: HIGH
Comments: nw precip



ENSEMBLE TRANSFORM TECHNIQUE

GOAL:

Try to reduce expected fcst error at time *t2*, location *V(erif)*

PROBLEM:

<u>Locate sens area</u> where extra obsv. at *t1* best achieve goal

METHOD:

Based on **nonlinear ensemble** – *Bishop and Toth, 1996*

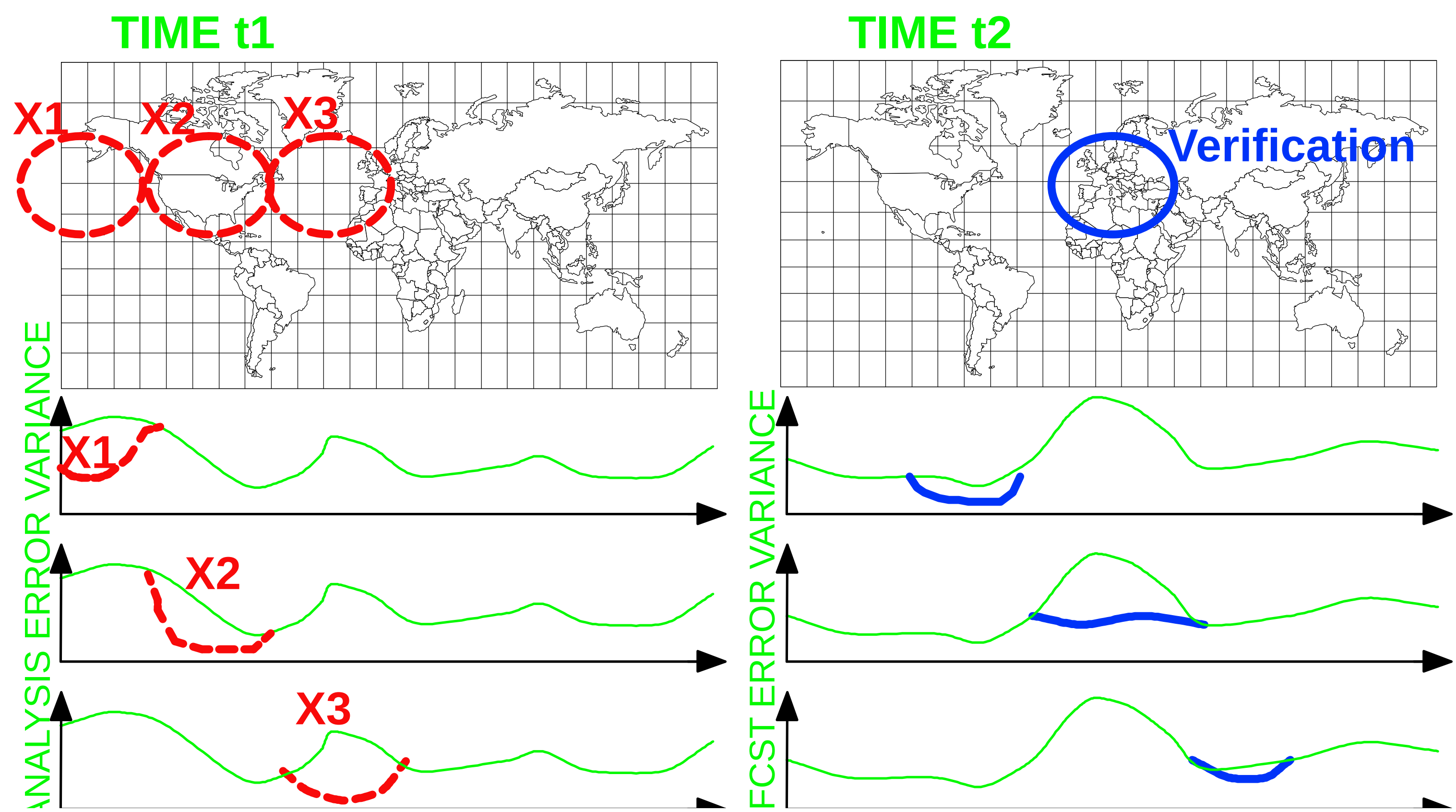
Esemble Trasform Kalman Filter *Bishop and Majumdar, 2000*

Variance = uncertainty under standard observational network

TRANSFORM ENSEMBLE to see effect of extra observations

Variance = uncertainty with extra obs. added at location X

MOVE X to see if variance at t2 optimally reduced at Verif area



TRANSFORMATION:

Linear combination of ensemble perturbations –

SVD in vector space of ensemble perturbations at *t1* and *t2*

<u>***COMPUTATIONALLY VERY EFFICIENT***</u>

DAILY DECISION PROCESS FOR TAKING TARGETED OBSERVATIONS

FORECASTERS: List of significant fcst events: Time, Lat/Lon

PRIORITIZE

Objective guidance can be developed based on ensemble

SDM: Sensitivity computations for each event:

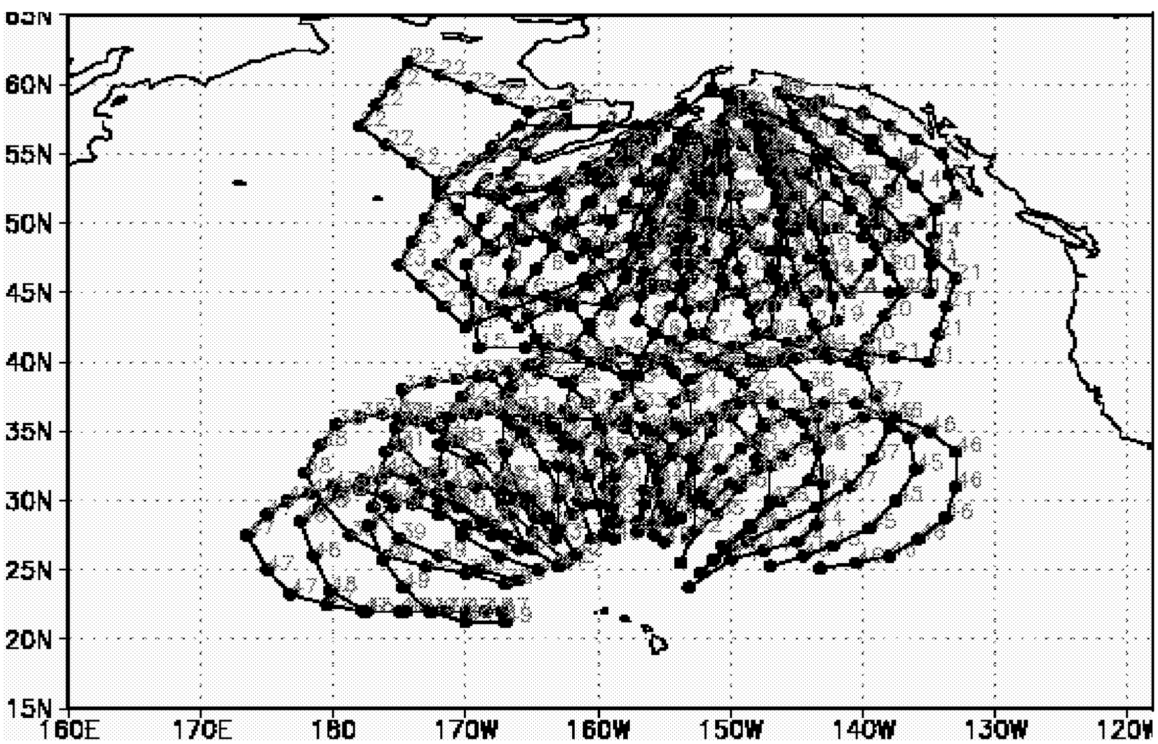
General guidance
Best flight tracks
Expected data impact

Based on results and priority of each event and available resources,

DECIDE WHETHER TO FLY, AND WITH WHICH PLANE(S)

Can be fully automated for other observing systems

WSR PREDESIGNED FLIGHT TRACKS



OVERVIEW OF FIELD PROGRAMS

PROGRAM	*TIME PERIOD*	*OBS.AREA*	*VERIF.AREA*

FASTEX Jan–Febr 1997, W–Atlantic Europe
First field test of targeted observations. Research mode, collaboration with MIT, NCAR and others. International cooperation.

NORPEX Jan–Febr 1998 NE–Pacific W–US
First test over Pacific. Collaboration with NRL. Comparison of different techniques.

CALJET March 1998 NE–Pacific CA
First test of mesoscale targeting. Targeting technique modified for mesoscales. Collaboration with ERL and others.

WSR99 Jan–Febr 1999 NE–PAcific CONUS, AL
Quasi–operational program. Case selection by NWS forecasters.

WSR2000 Jan–Febr 2000 NE–Pacific CONUS, AL
Training of operational personnel

WSR2001 Winter 2001 NE–Pacific CONUS, AL
Operational implementation

PACJET Winter 2001 NE–Pacific W–US
Meso–scale research program

WSR2002 Winter 2002 NE–Pacific CONUS, AL
Fully operational

THORPEX–TOST Winter 2003 Atlantic & Pacific – Obs. system tests

WINTER STORM RECONNAISSANCE PROGRAM

January 15 – February 20, 2001

BASED ON: WSR 2000 & earlier field programs

NEW ELEMENT: **Transition into operations**

COLLABORATIVE EFFORT:

Forecast feature	Sensitive area	Aircraft operations
Regions => HPC =>	EMC/SDM	=> AOC/USAF Reserve

EACH MISSION:

Requested by field/HPC forecasters to support critical weather fcsts
Operational needs

Among predisigned flight tracks, best is selected objectively
SDM training

Dropsonde flight missions carried out by AOC & USAF Reserve

TOTAL OF 17 MISSIONS, 360 DROPSONDES:
8 NOAA G–IV (from Honolulu) and
10 USAF C–130 (from Anchorage) flights

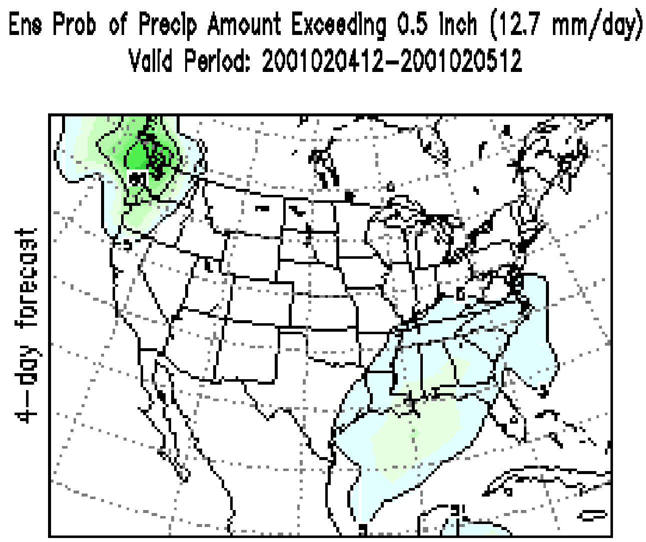
ALL DATA USED OPERATIONALLY

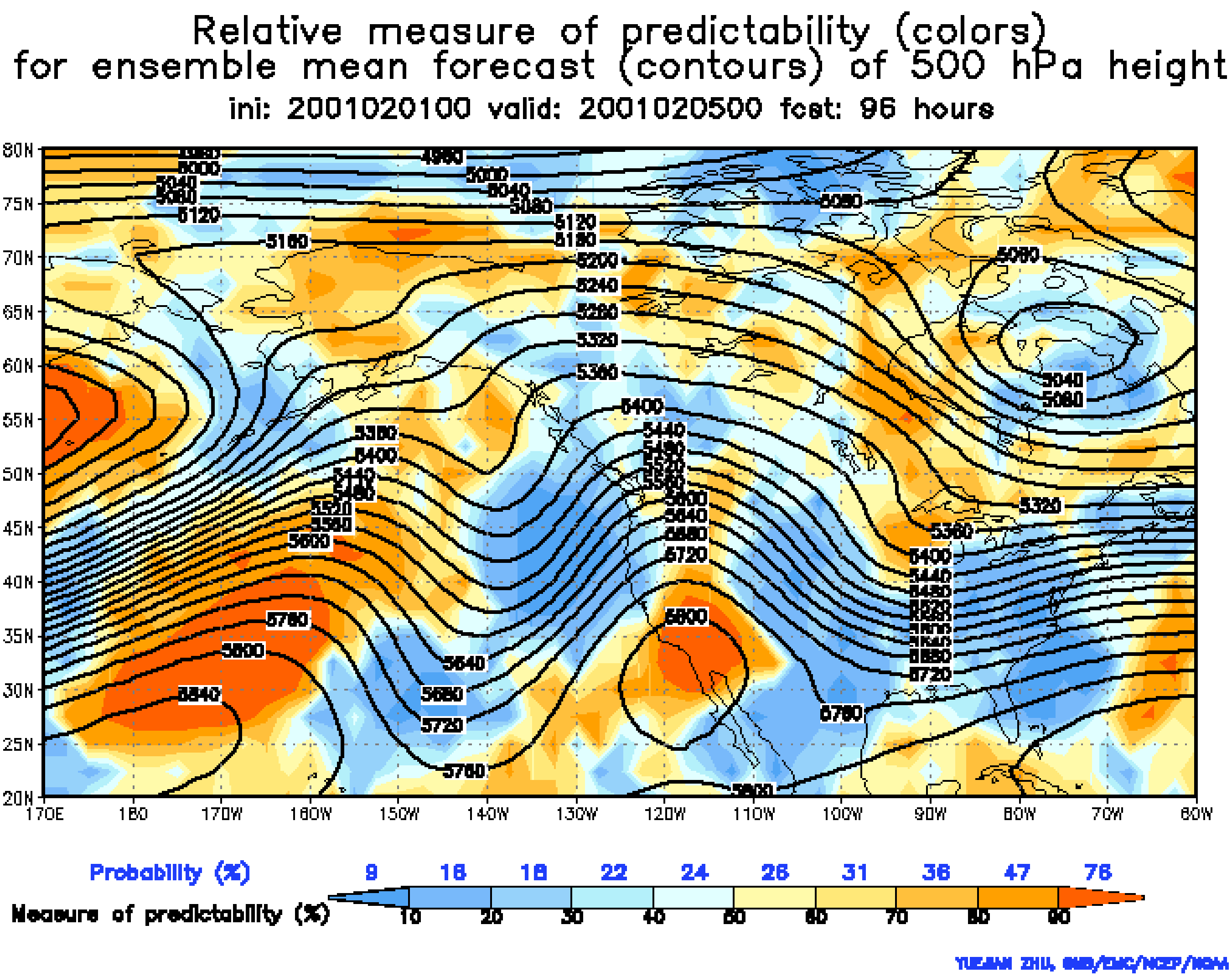
DATA IMPACT EVALUATION:
Near real time *parallel assimil. fcst cycle* with dropsonde data excluded:

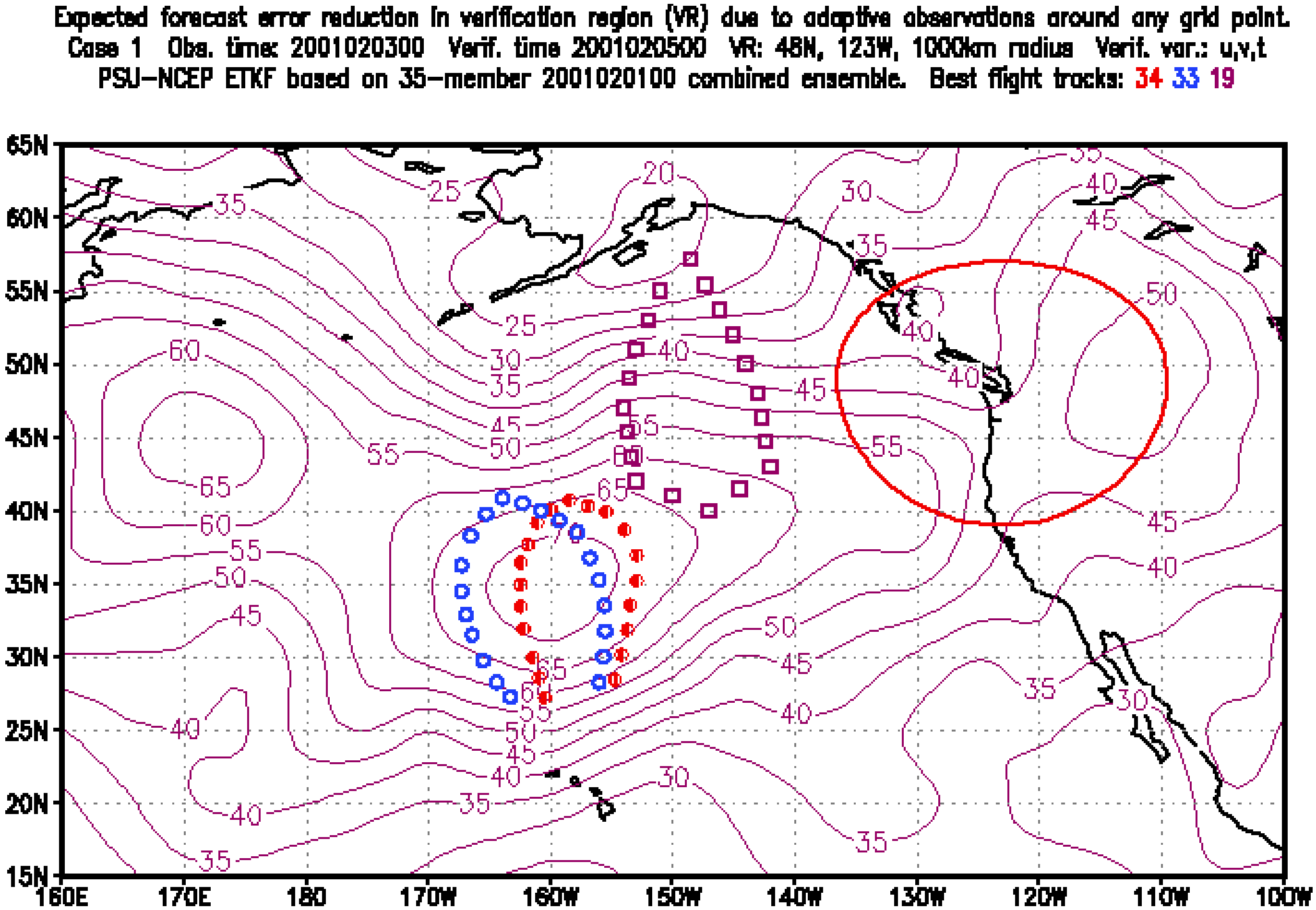
http://sgi62.wwb.noaa.gov:8080/ens/target/wsr2001.html

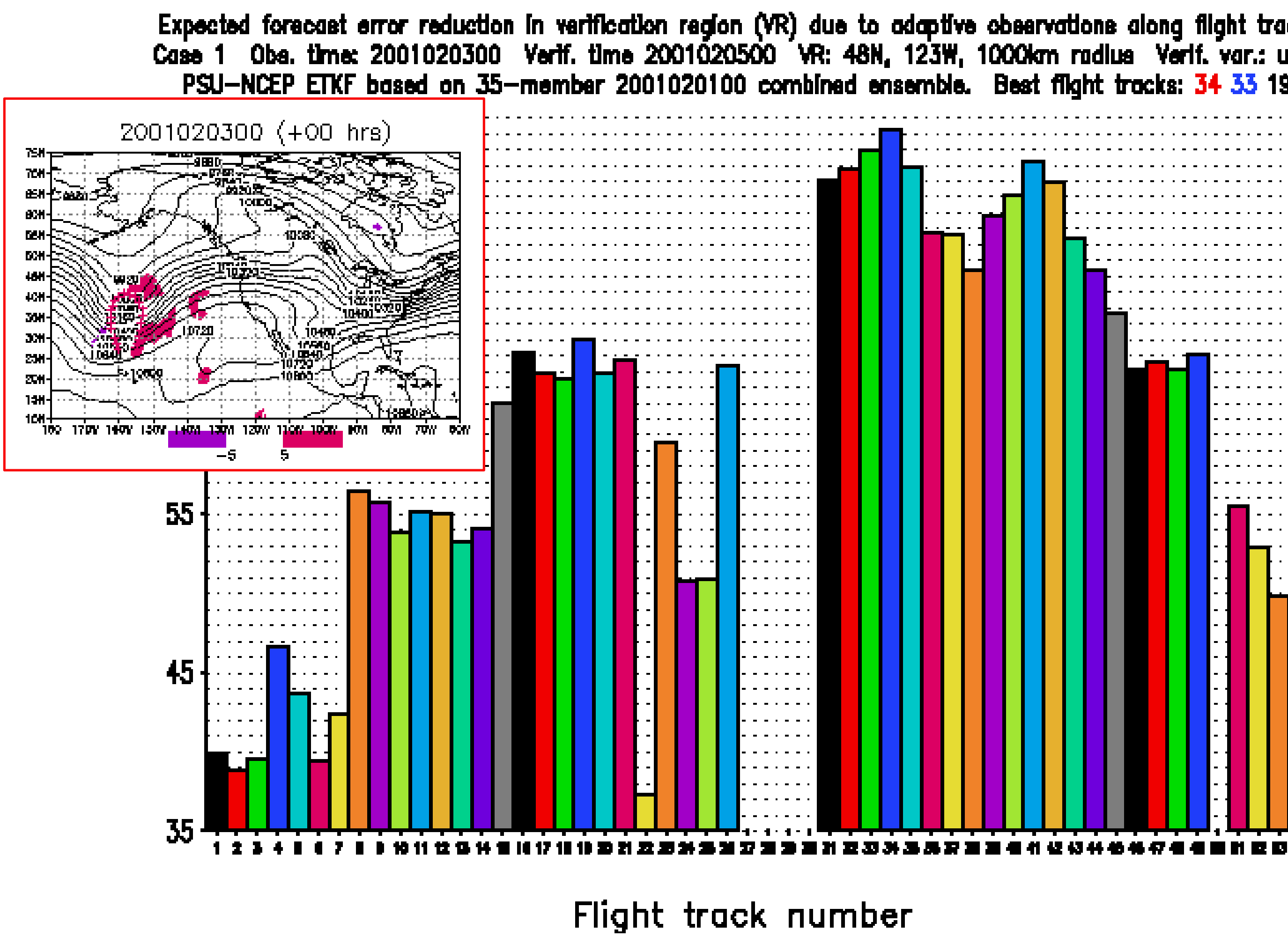
AN EXAMPLE: PACIFIC NW STORM

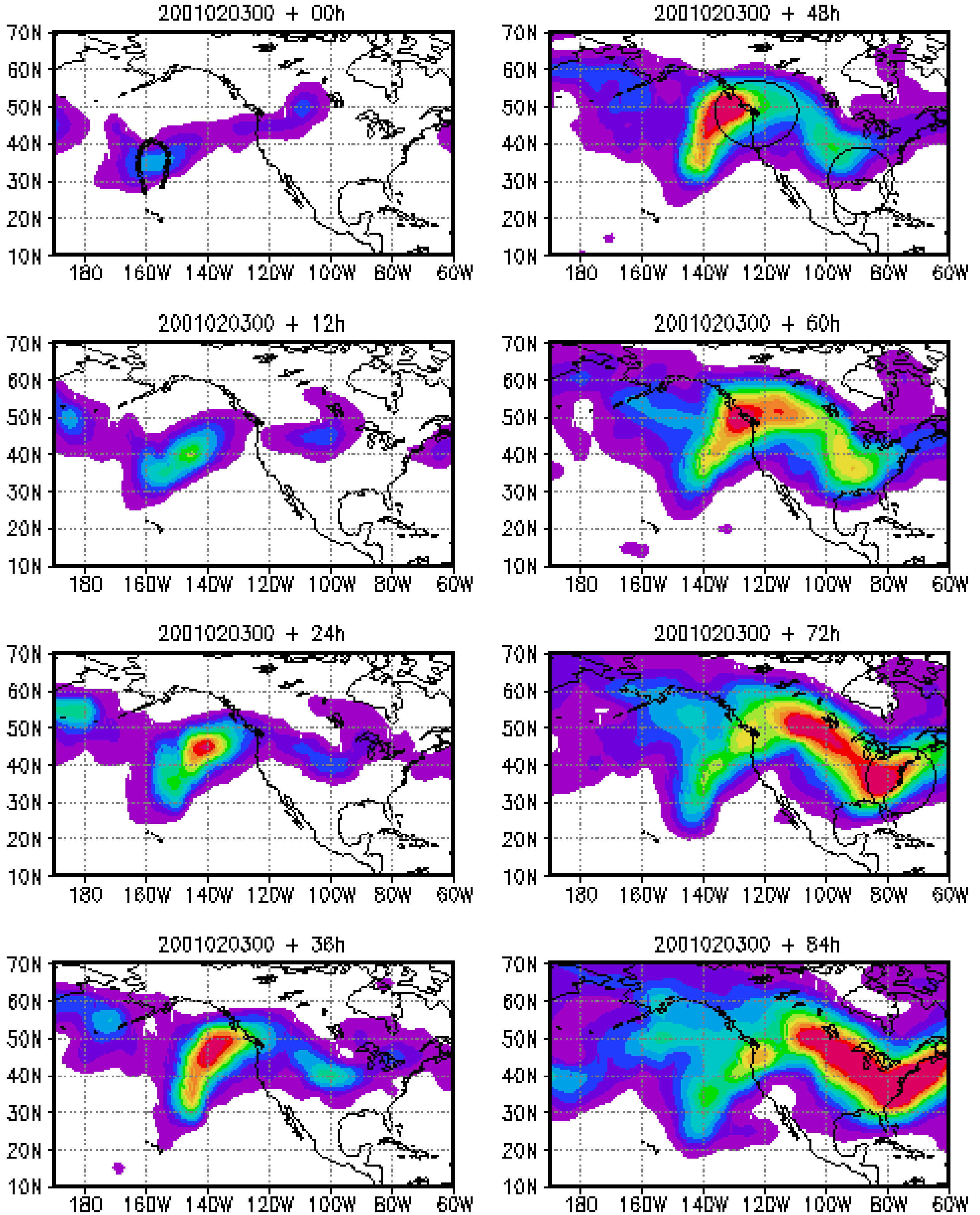
CASE 1:
Observation time: 2001020300
Verification time: 2001020500
Longitude: 123W
Latitude: 48N
Priority: HIGH
Comments: nw precip



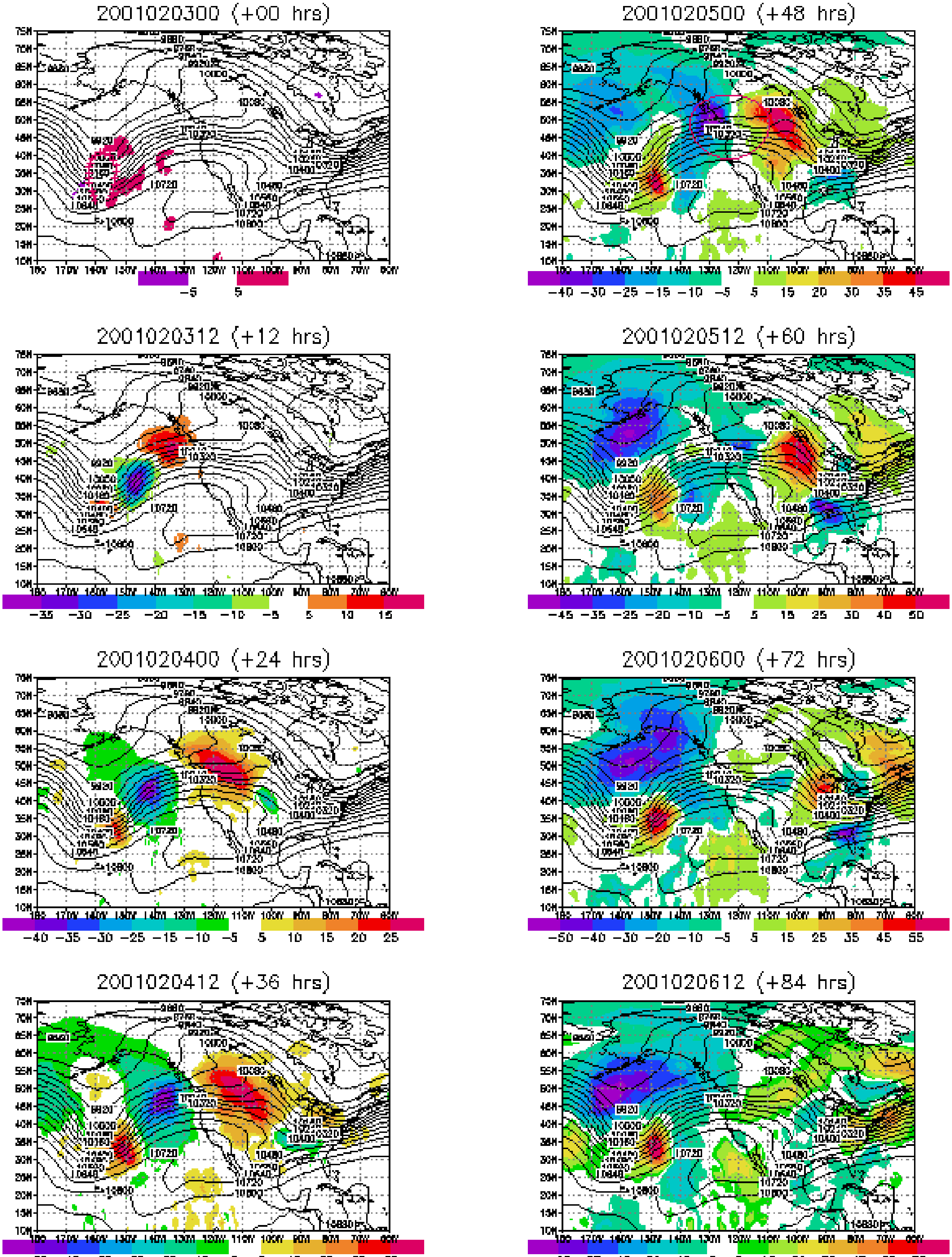



Expected forecast error reduction in verification region (VR) due to adaptive observations around any grid point.
Case 1 Obs. time: 2001020300 Verif. time 2001020500 VR: 48N, 123W, 1000km radius Verif. var.: u,v,t
PSU-NCEP ETKF based on 35-member 2001020100 combined ensemble. Best flight tracks: 34 33 19
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
160E
170E
180
170W
160W
150W
140W
130W
120W
110W
100W

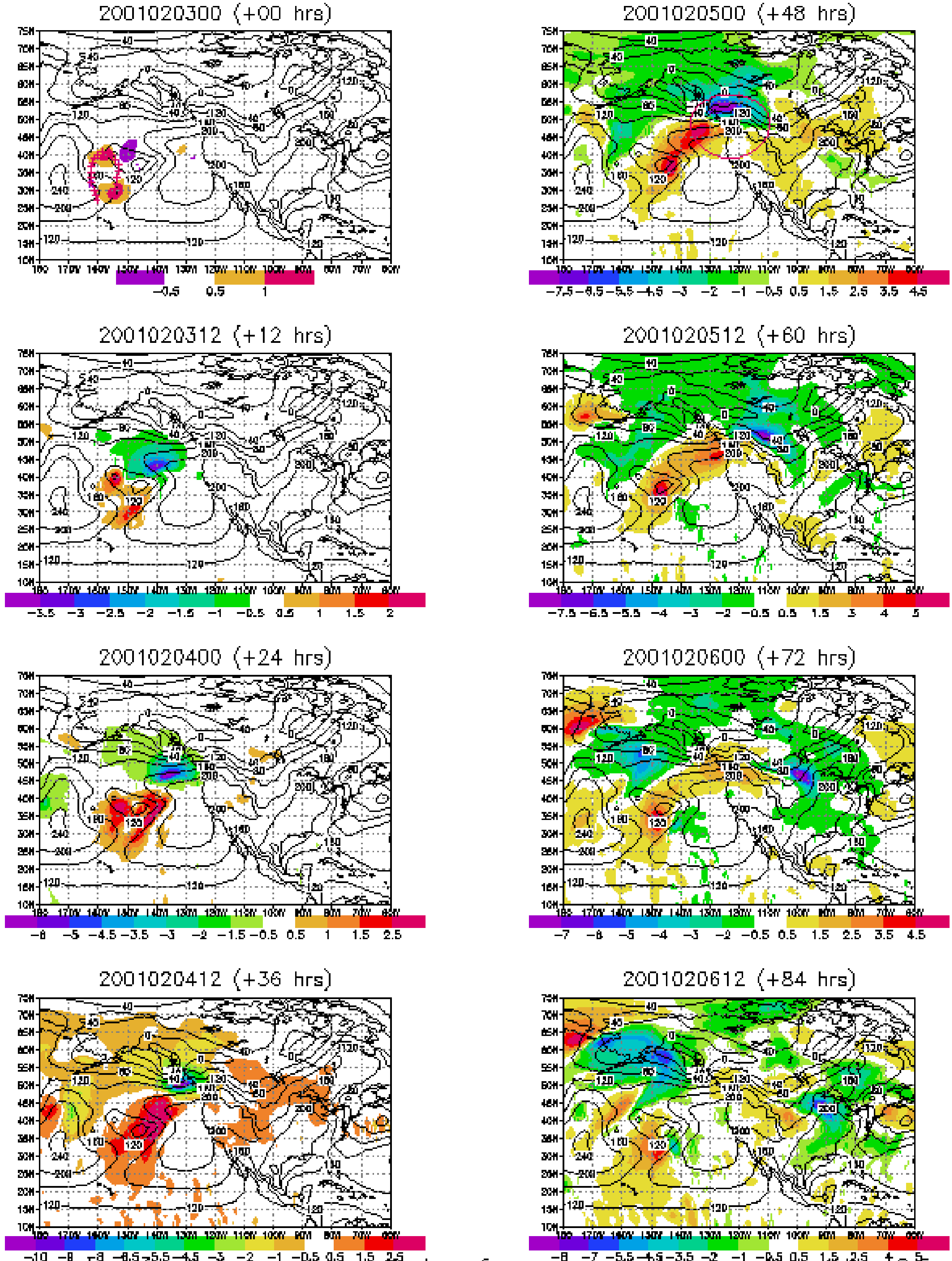

Expected forecast error reduction in verification region (VR) due to adaptive observations along flight track
Case 1 Obs. time: 2001020300 Verif. time 2001020500 VR: 48N, 123W, 1000km radius Verif. var.: u,v
PSU-NCEP ETKF based on 35-member 2001020100 combined ensemble. Best flight tracks: 34 33 19
2001020300 (+00 hrs)
55
45
35
Flight track number



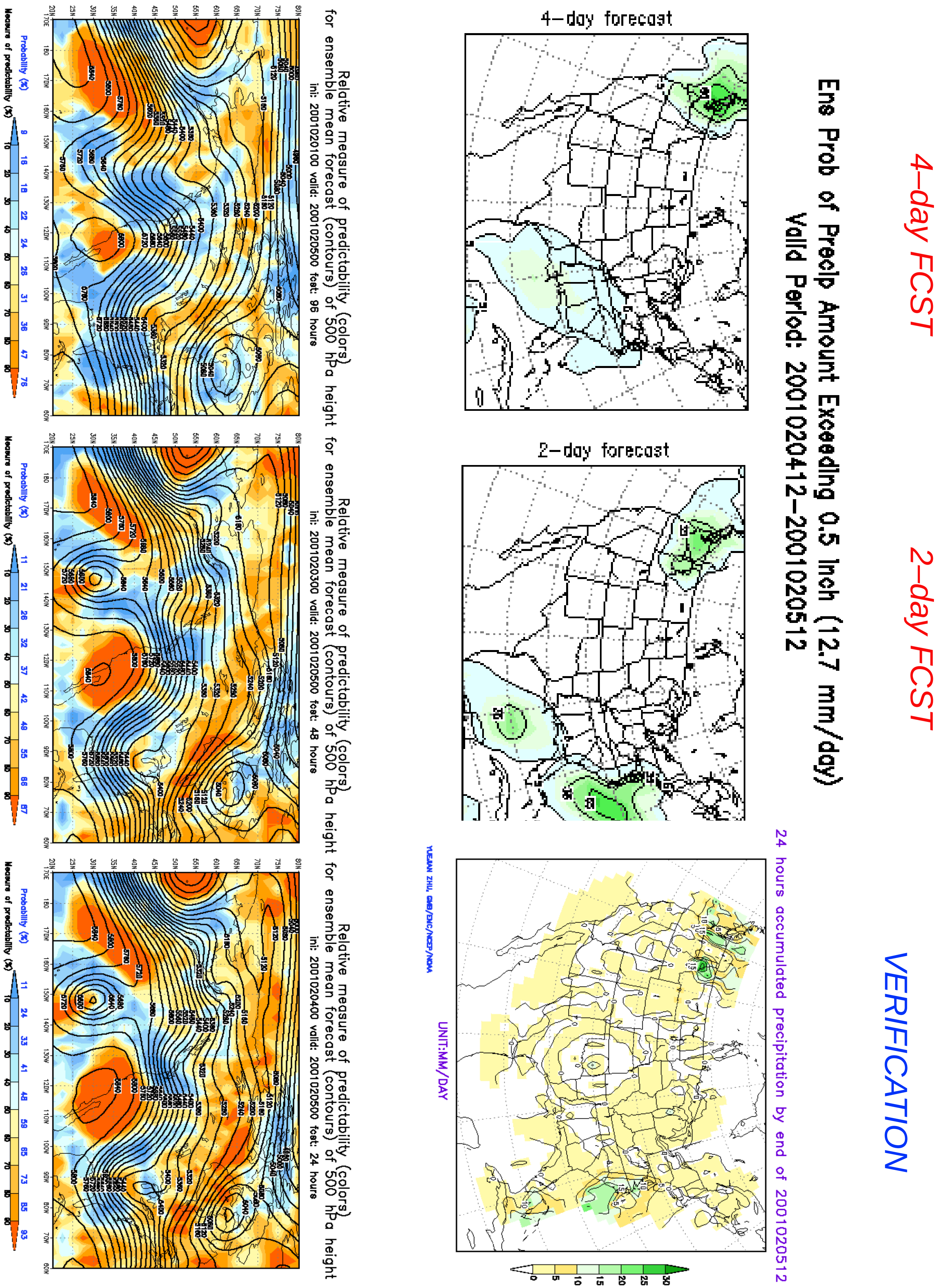
Signal Variance for u,v,t. Flight 34. Observation time 2001020300. 2001020100 ensemble.

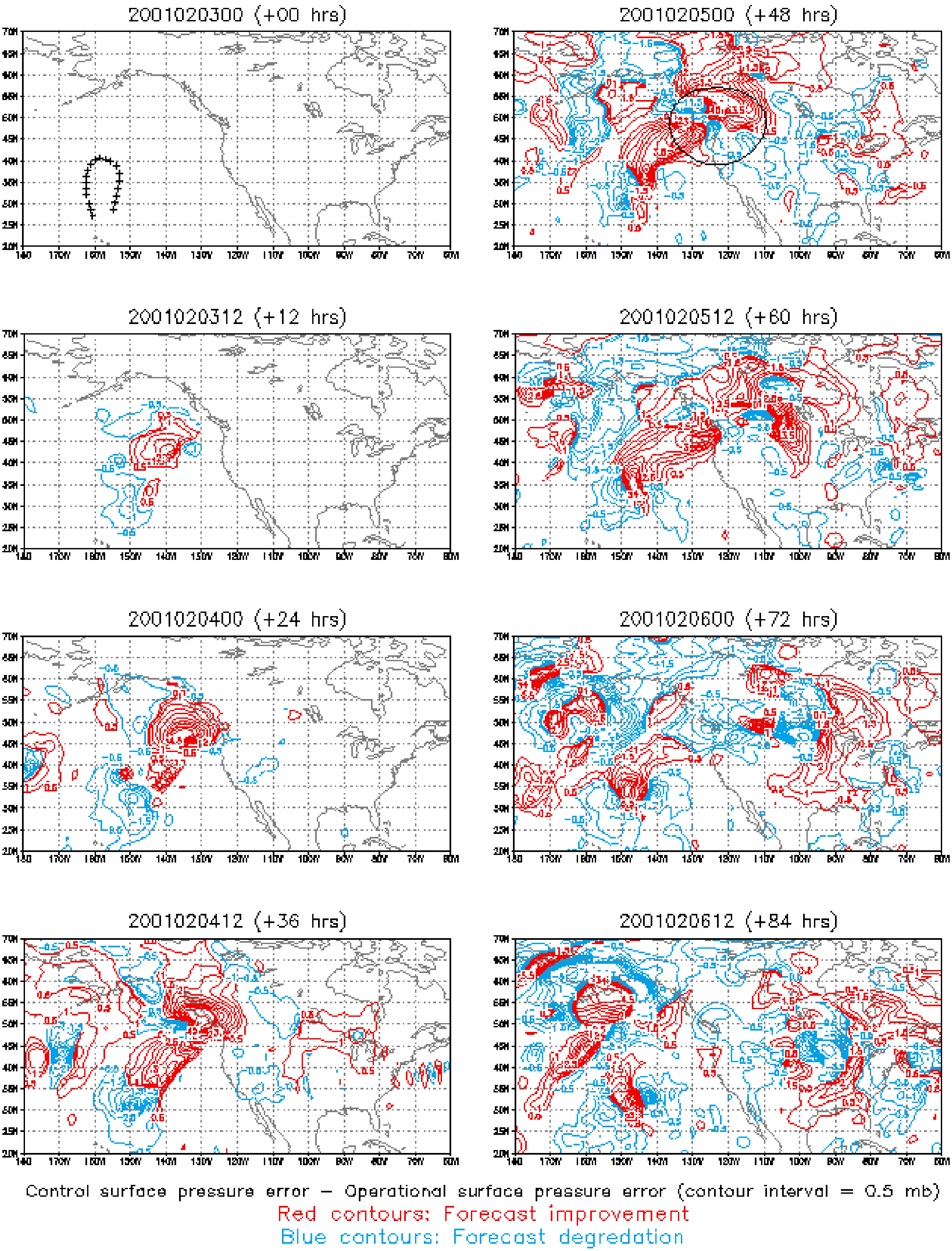


Operational 250mb height – control 250mb height (contour interval = 5 m)



Operational surface pressure − control surface pressure (contour interval = 0.5 mb)


4-day FCST
2-day FCST
VERIFICATION
Ens Prob of Precip Amount Exceeding 0.5 inch (12.7 mm/day)
Valid Period: 2001020412–2001020512
4-day forecast
2-day forecast
24 hours accumulated precipitation by end of 2001020512
UNIT:MM/DAY
Relative measure of predictability (colors) for ensemble mean forecast (contours) of 500 hPa height
ini: 2001020100 valid: 2001020500 fcst: 96 hours
Relative measure of predictability (colors) for ensemble mean forecast (contours) of 500 hPa height
ini: 2001020300 valid: 2001020500 fcst: 48 hours
Relative measure of predictability (colors) for ensemble mean forecast (contours) of 500 hPa height
ini: 2001020400 valid: 2001020500 fcst: 24 hours
Probability (%)
Measure of predictability (%)


2001020300 (+00 hrs)
2001020500 (+48 hrs)
2001020312 (+12 hrs)
2001020512 (+60 hrs)
2001020400 (+24 hrs)
2001020600 (+72 hrs)
2001020412 (+36 hrs)
2001020612 (+84 hrs)
Control surface pressure error – Operational surface pressure error (contour interval = 0.5 mb)
Red contours: Forecast improvement
Blue contours: Forecast degredation

WINTER STORM RECONNAISSANCE PROGRAM 2001

JAN. 15– FEBR. 20

DATE/FLIGHTS YYMMDD (AT 00Z)		VERIFICATION LEAD TIME HRS	CENTER OF 1000 KM DISC N	W	VERIICATION. SP	WND	PRC	SUM
010128	21	48	36	91	+	+		+
		72	39	77	–	+		0
010131	20+31	24	50	124	+	+		+
		48	50	124	+	+		+
		108	35	96	–	–		–
010201	20+35	24	50	124	+	+		+
		96	30	87	+	–		0
010203	34	48	48	123	+	+		+
010204	21+S	36	48	124	+	0		+
		96	35	95	+	+		+
		24*	21	158	+	+		+
010205	37	96	35	88	+	+		+
010206	9	72	36	91	+	+		+
		96	40	80	+	+		+
010207	8	48	42	123	–	–		–
		72	39	86	+	+		+
010210	H	24	21	157	+	+		+
		48	21	157	0	+		+
		72	21	157	0	+		+
010217	45	36	39	124	0	+		+
		48	41	91	0	+		+
010219	46	24	40	122	+	+		+
010220	37	48	39	121	0	+		+
		72	36	76	0	+		+
010226	F	24	35	112	0	0		0
		48	35	92	–	0		–
		72	34	86	–	–		–
010301	P	24	49	123	–	+		0
010303	P	24	40	123	+	0		+
		36	38	120	+	+		+

WINTER STORM RECONNAISSANCE PROGRAM 2001

	SP	WND	SUM
PERCENT OF FORECASTS IMPROVED:	***52***	***74***	***74***
PERCENT OF FORECASTS DEGRADED:	***19***	***15***	***15***

TOTAL OF 27 ***FORECAST VERIFICATION CASES:***

IMPROVEMENT 20
NEUTRAL IMPACT 3
DEGRADATION **4**

RESULTS STATISTICALLY SIGNIFICANT AT 0.1% – 5% LEVEL

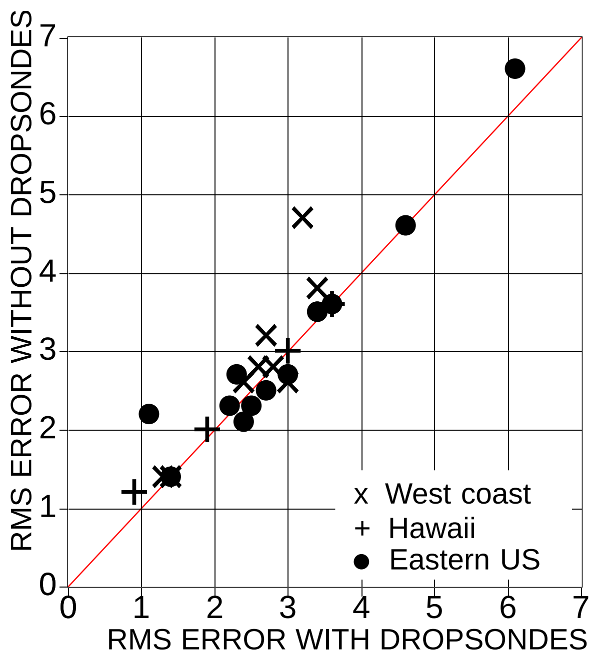


FIG. 2: RMS error of 24–84 hours targeted surface pressure forecasts, measured against observations within predefined verification regions over the west coast, Hawaii, and the eastern US, with (horizontal axis) and without (vertical axis) the use of dropsonde data for the 27 Winter Storm Reconnaissance Program 2001 cases.

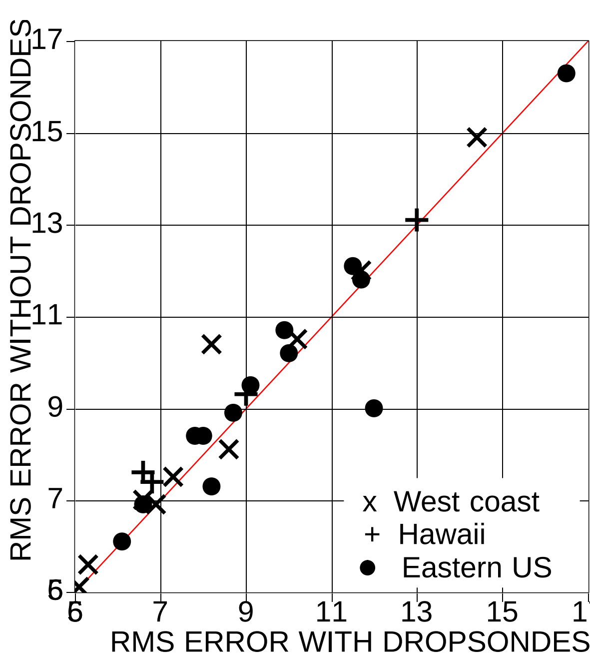


FIG. 3: Same as Fig. 2 except for wind vector errors integrated for the 1000–250 hPa layer.

WINTER STORM RECONNAISSANCE PROGRAM

January 22 – March 20, 2002

BASED ON: Earlier field programs

NEW ELEMENT: **Fully Operational**

COLLABORATIVE EFFORT:

Forecast feature	Sensitive area	Aircraft operations
Regions => HPC =>	SDM =>	AOC/USAF Reserve

EACH MISSION:

Requested by field/HPC forecasters to support critical weather fcsts
Operational needs

Among predisigned flight tracks, best is selected objectively
SDM personnel trained

Dropsonde flight missions carried out by AOC & USAF Reserve

TOTAL OF 22 MISSIONS, 500–600 DROPSONDES:
18 NOAA G–IV (from Anchorage & Honolulu) and
7 USAF C–130 (from Honolulu) flights

ALL DATA USED OPERATIONALLY

DATA IMPACT EVALUATION:
P*arallel assimil. fcst cycle* with dropsonde data excluded, see later at:

http://sgi62.wwb.noaa.gov:8080/ens/target/wsr2001.html

SUMMARY OF TARGETED OBSERVATIONS RESULTS

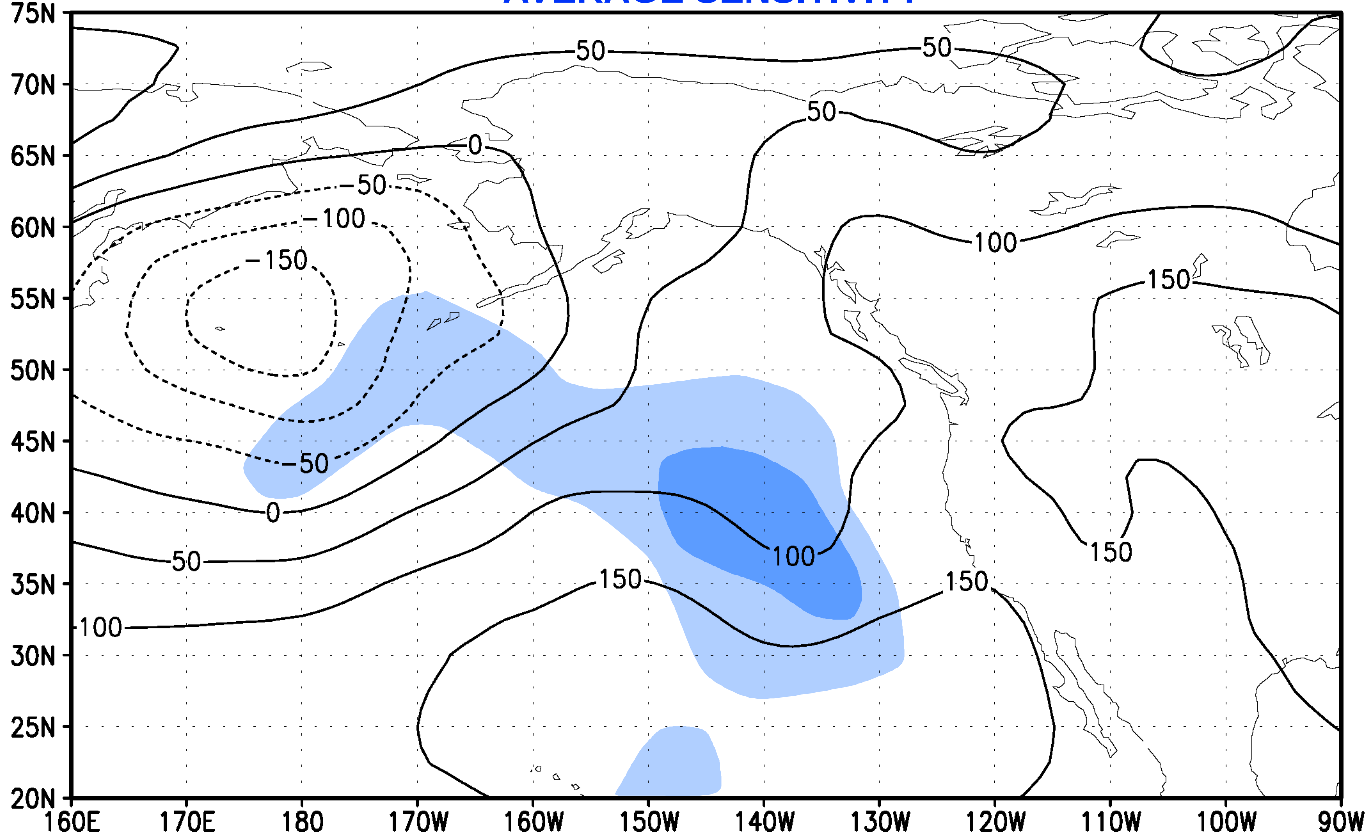
	SIGNAL		MOD/	VERIFICATION			
	sp	prc	NULL	sp	wnd	prc	SUM
FASTEX	7+1–0		*12/3*		3–2		3–2
NORPEX	8–2	7+1–2		7–2	7–1	7–0	7–0
CALJET	3+1–1	4+1	*1*	5–0	3–1		4–0
WSRP–99	21+4–0	24+1–0		16–5	15–8	13–2	18–5
WSRP–00				16–2	15–8		15–3
WSRP–01				14–5	20–4		20–4
TOTAL	**39+6–3**	**35+3–2**	***12/4***	**58–14**	**63–24** **60–22**	**20–2**	**67–14** **64–12**
% SUCC.:	***81–94***	***87–95***		***81***	***73***	***91***	***84***
STAT. SIGN.:				*	*	*	*

1) **Max. signal is in verif. area in most cases –**
   12–84 hrs lead time, Continental US + Alaska
2) **Moderately sensitive areas contribute less**
3) **Nonsensitive areas virtually have no impact**
4) **Forecasts improve in 70–90% cases**
5) **10–20% average error reduction in verif area**
6) **Targeted forecasts gain 12–24 hrs in lead time**

TECHNOLOGY TRANSFERRED INTO OPERATIONS

1000 HPA MEAN FLOW, JAN–FEBR 2000

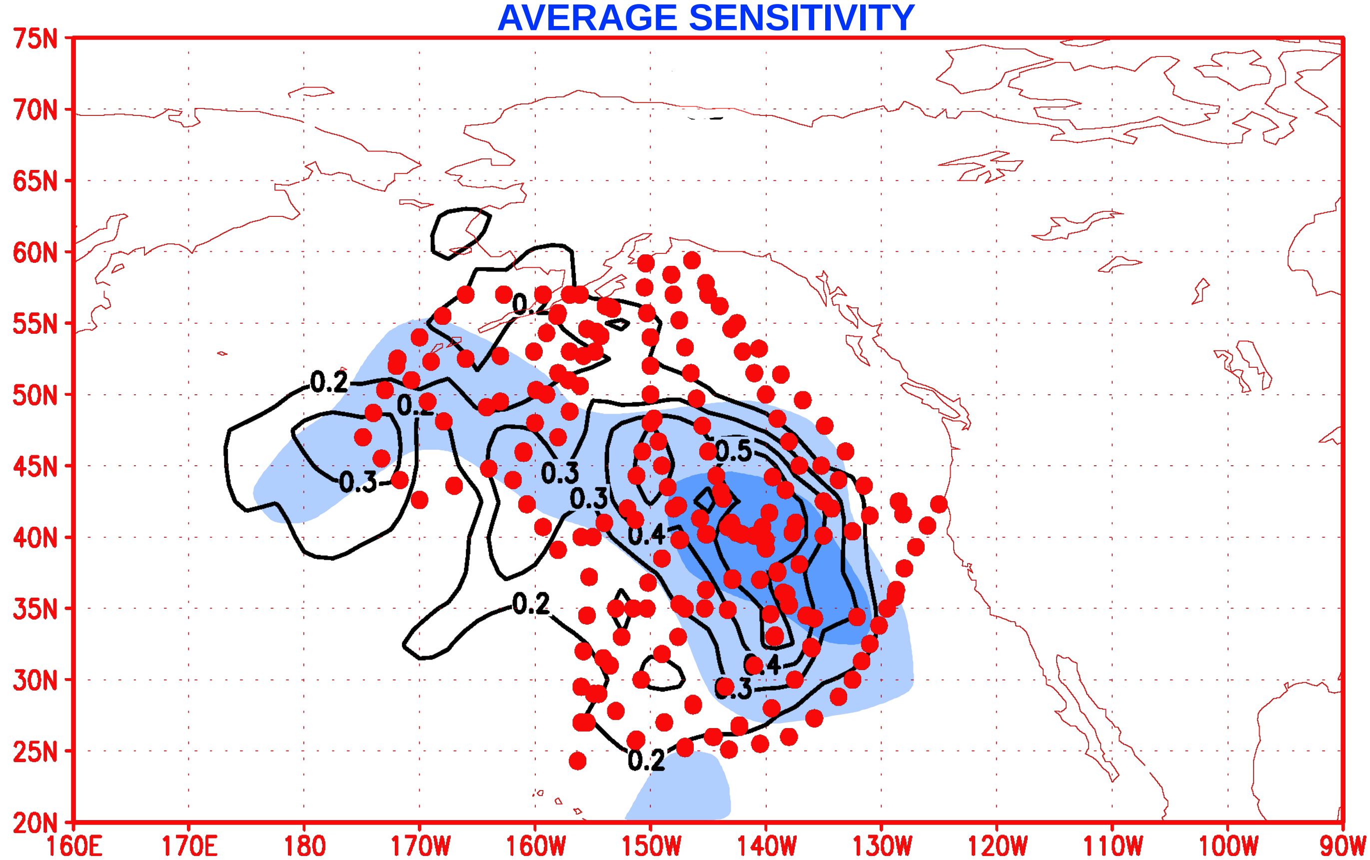
AVERAGE SENSITIVITY



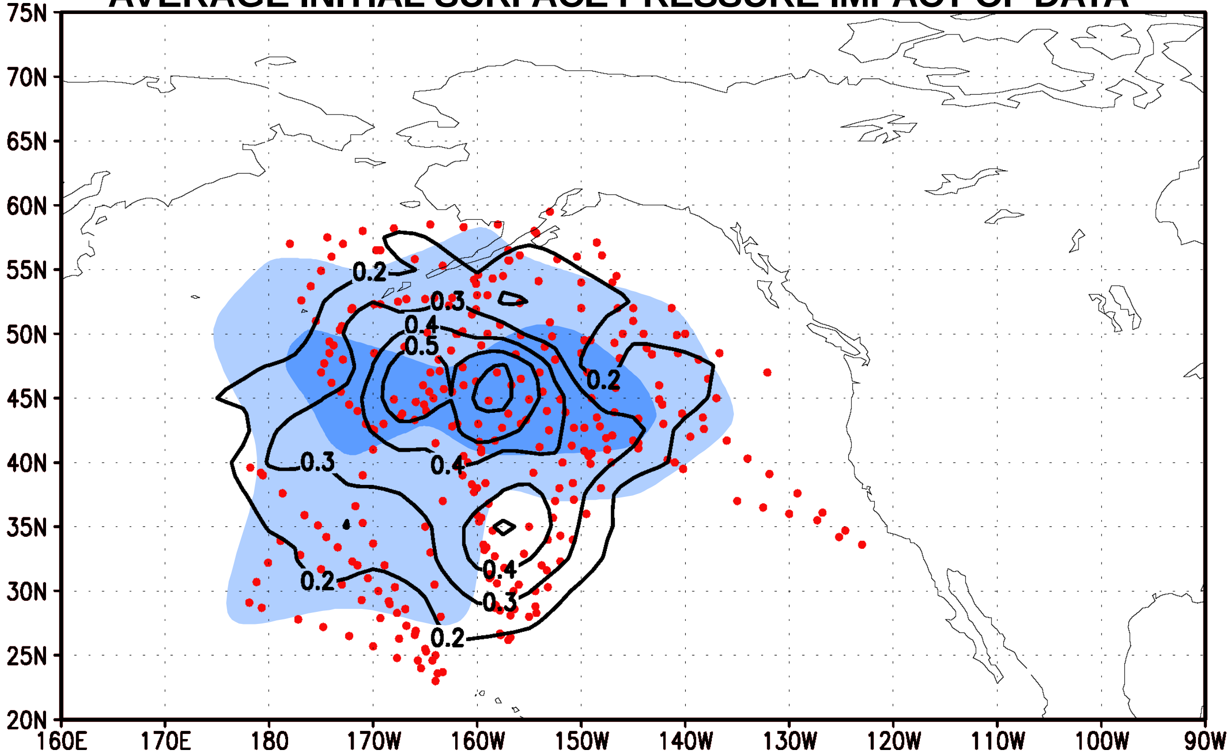
AVERAGE INITIAL IMPACT OF DATA

DROPSONDE LOCATIONS

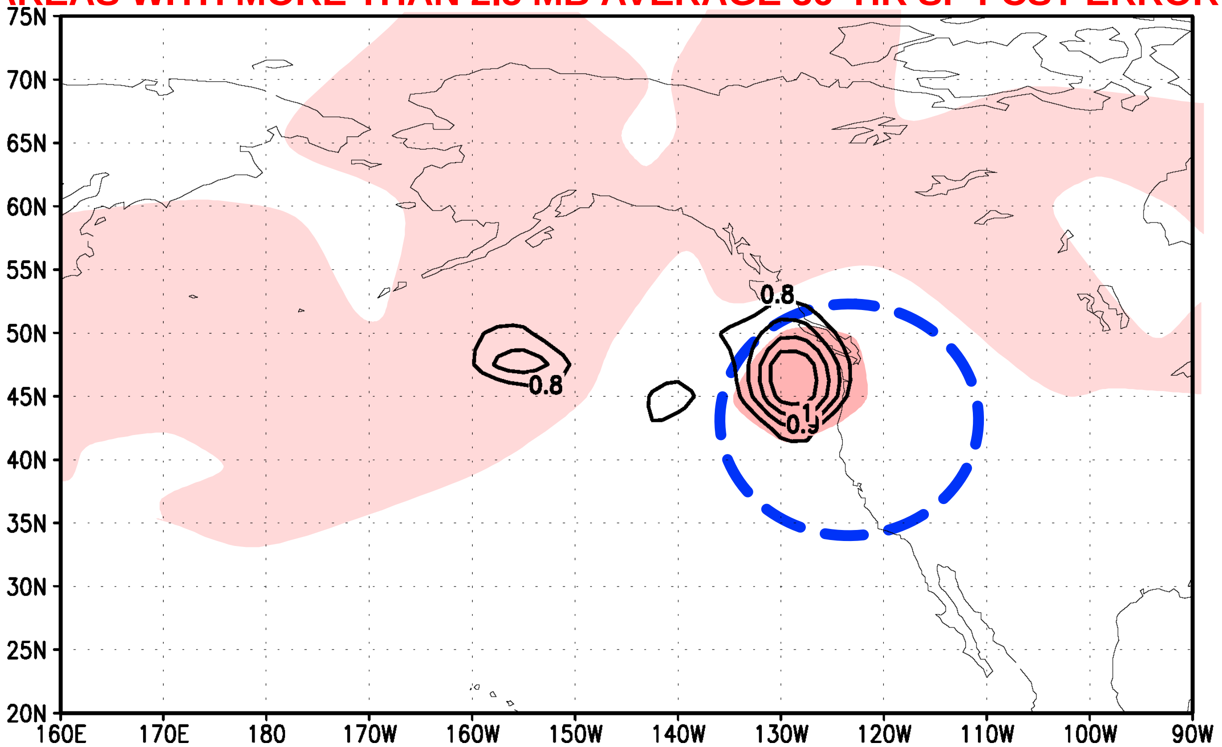
AVERAGE SENSITIVITY



AVERAGE SENSITIVITY OF 36–HR FORECASTS TO INITIAL CONDITIONS
DROPSONDE LOCATIONS
AVERAGE INITIAL SURFACE PRESSURE IMPACT OF DATA

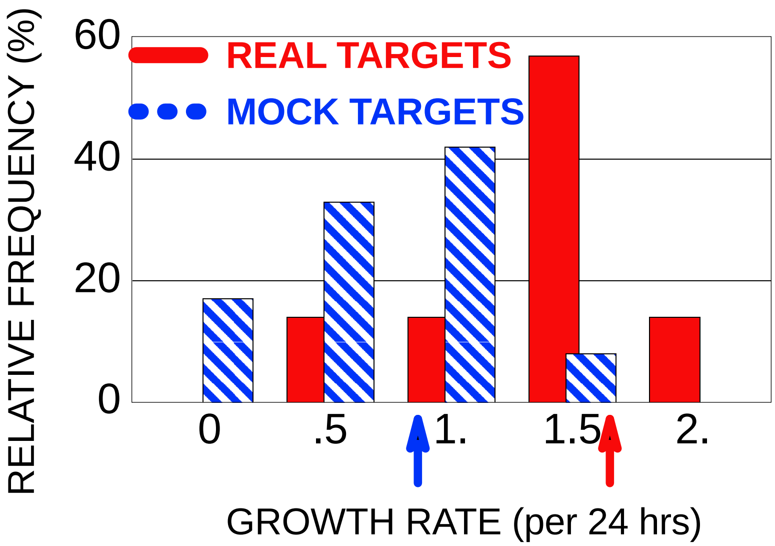


AVERAGE SURFACE PRESSURE IMPACT OF DATA AT 36–HR FCST LEAD TIME
AVERAGE LOCATION OF VERIFICATION REGION AT 36–HR LEAD TIME
AREAS WITH MORE THAN 2.5 MB AVERAGE 36–HR SP FCST ERROR

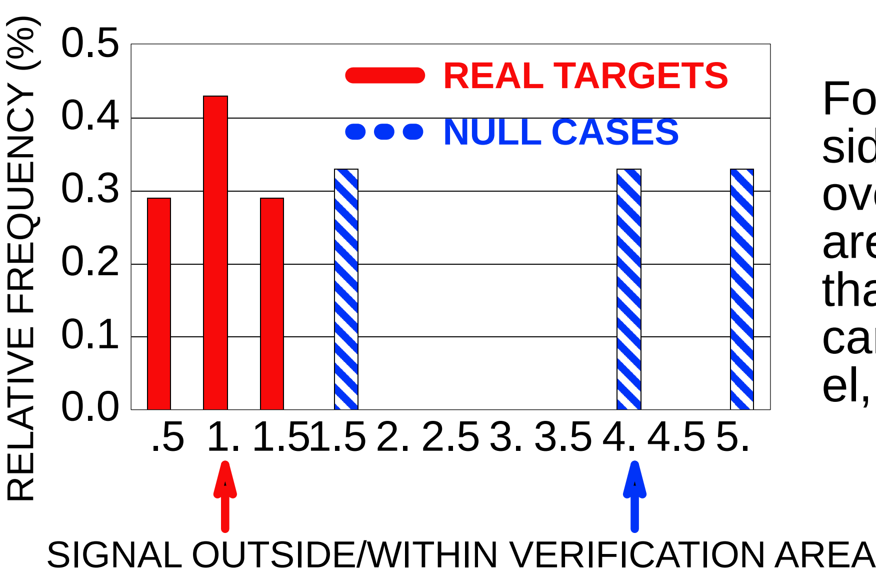


Average pattern of sensitivity in initial conditions to errors in a 36–hour forecast over the west coast for the 15 Winter Storm Reconnaissance Program 1999 cases in 36–hr forecasts (top, shades of blue). The surface pressure impact of the dropsonde data (red dots) is shown in black contours at initial time (top, contour interval is 0.1 mb, starting at 0.2 mb), and at 36–hr lead time (bottom, first contour is at 0.8 mb). Note that the maximum average forecast impact of the targeted data is within the area of preselected verification regions (averaged location shown as a blue ellipsoid), right over the area of large (greater than 2.5 mb) control surface pressure forecast error shaded in pink.

FASTEX RESULTS



Signal from real targeted areas amplifies much more than that from adjacent, less sensitive areas (significant difference at 0.5% level, Wilcoxon rank sum test)

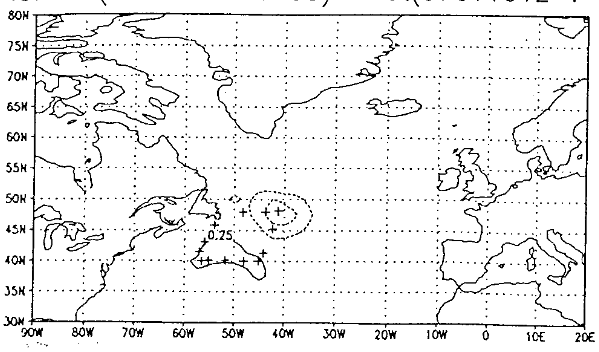


For null cases signal outside of verification area over that within verification area is much larger than that for real cases (significant difference at 0.5% level, Wilcoxon rank sum test)

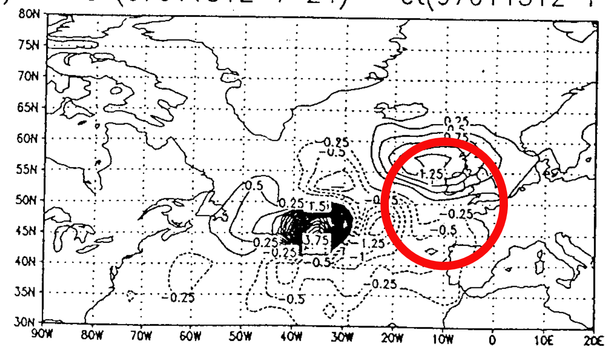
Based on 11 out of 14 FASTEX cases

NULL–1

IOP 3 (97011312 + 00) − ct(97011312 + 00)

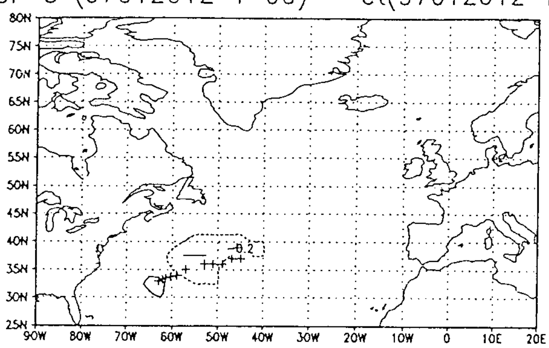


e) IOP 3 (97011312 + 24) − ct(97011312 + 24)

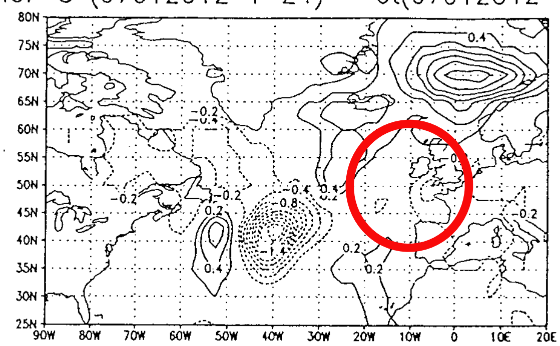


NULL–2

IOP 5 (97012012 + 00) − ct(97012012 + 00)

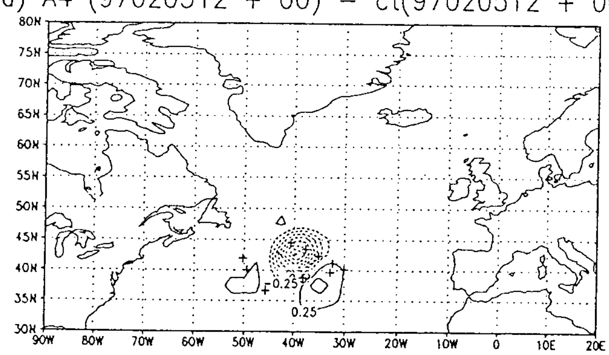


e) IOP 5 (97012012 + 24) − ct(97012012 + 24)

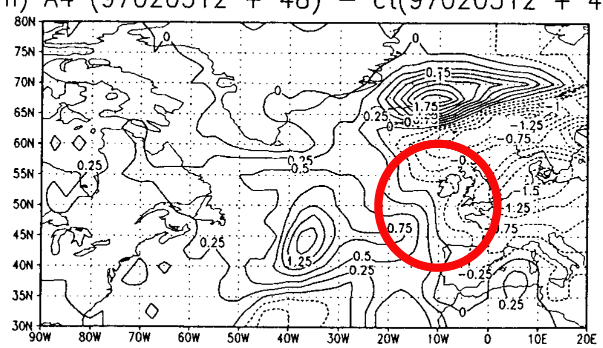


NULL–3

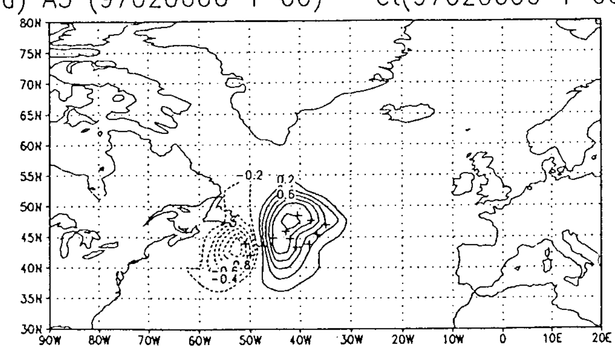
a) A4 (97020512 + 00) − ct(97020512 + 00)



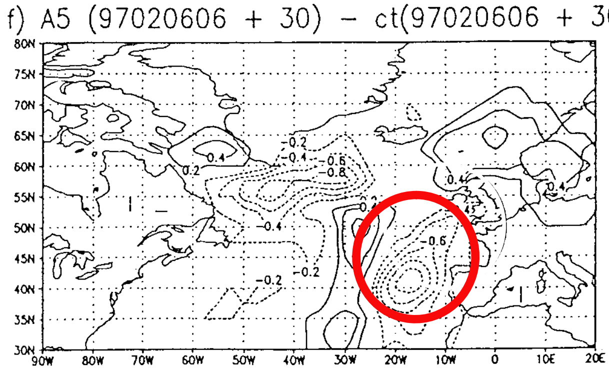
h) A4 (97020512 + 48) − ct(97020512 + 48)

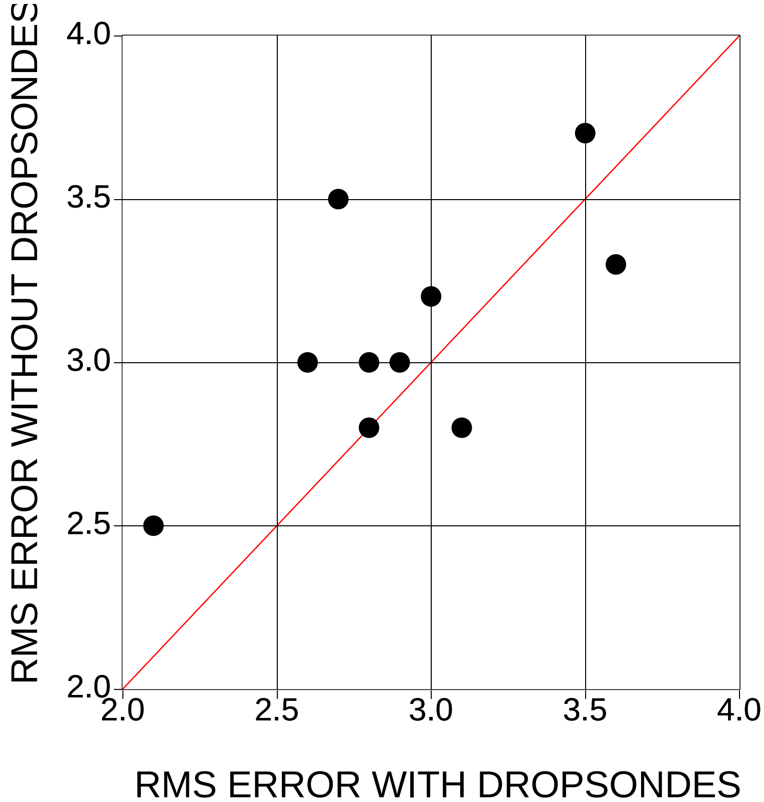


a) A5 (97020606 + 00) − ct(97020606 + 00)

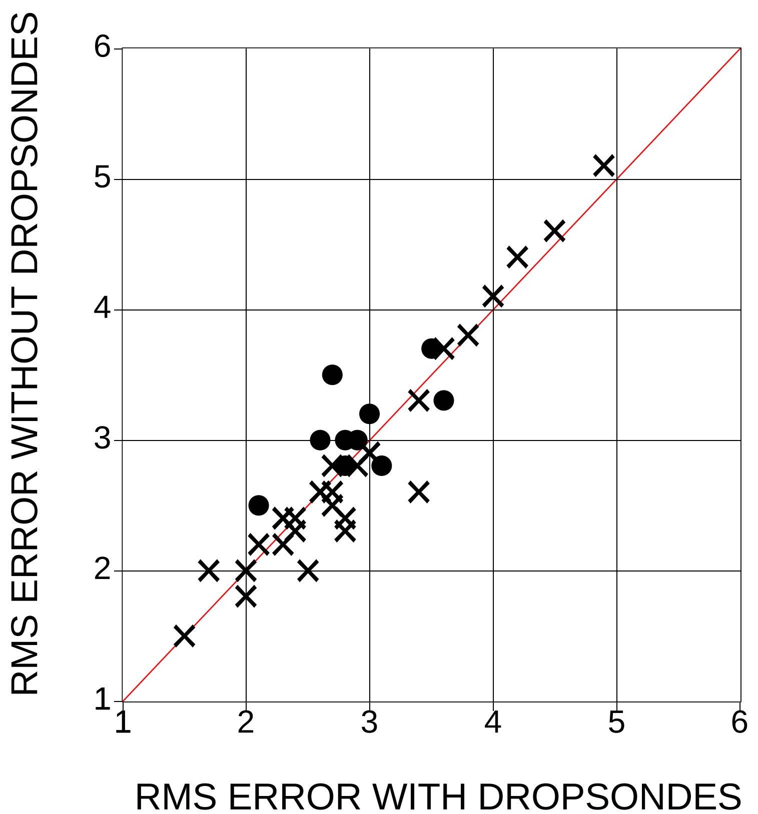


f) A5 (97020606 + 30) − ct(97020606 + 30)



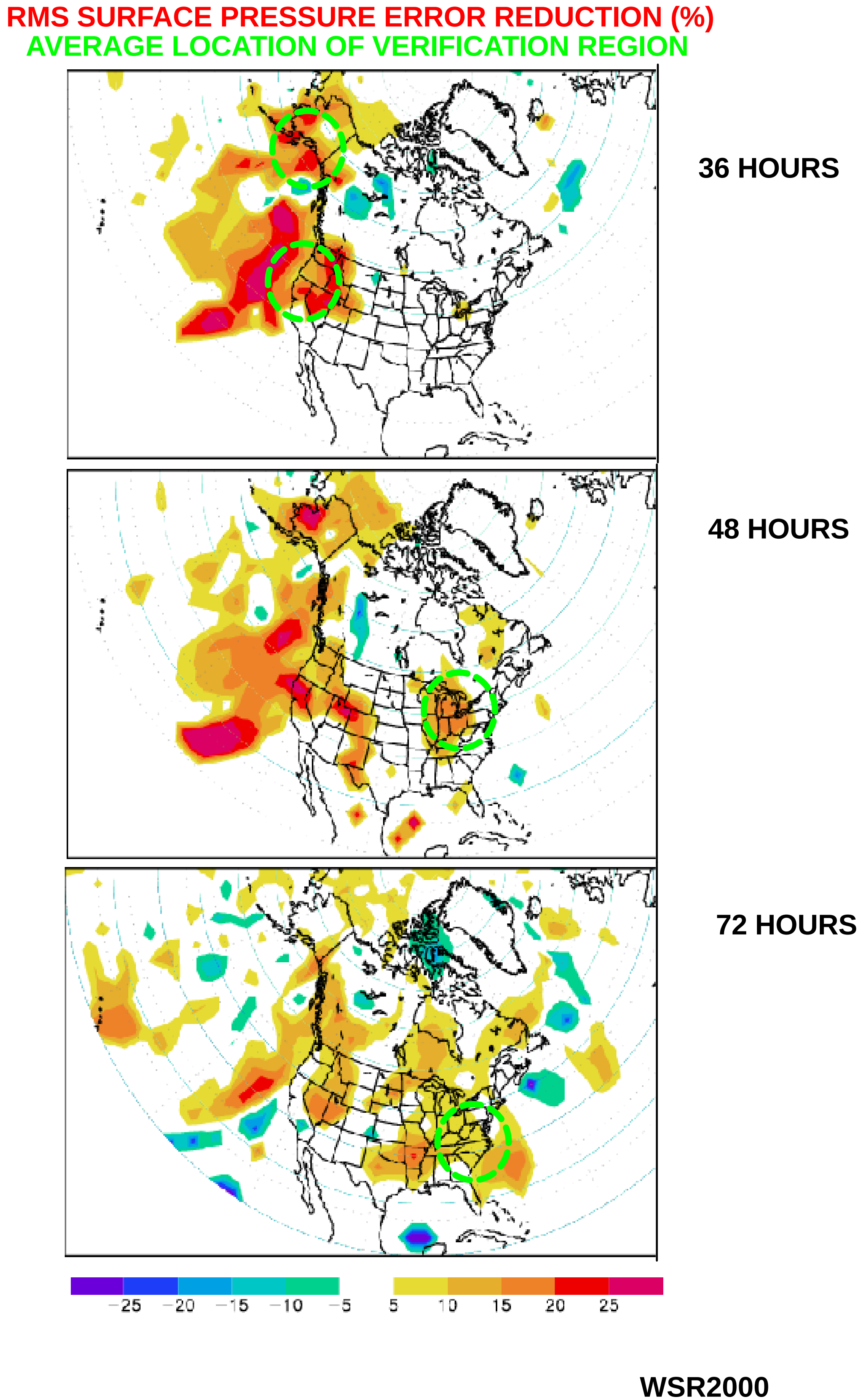


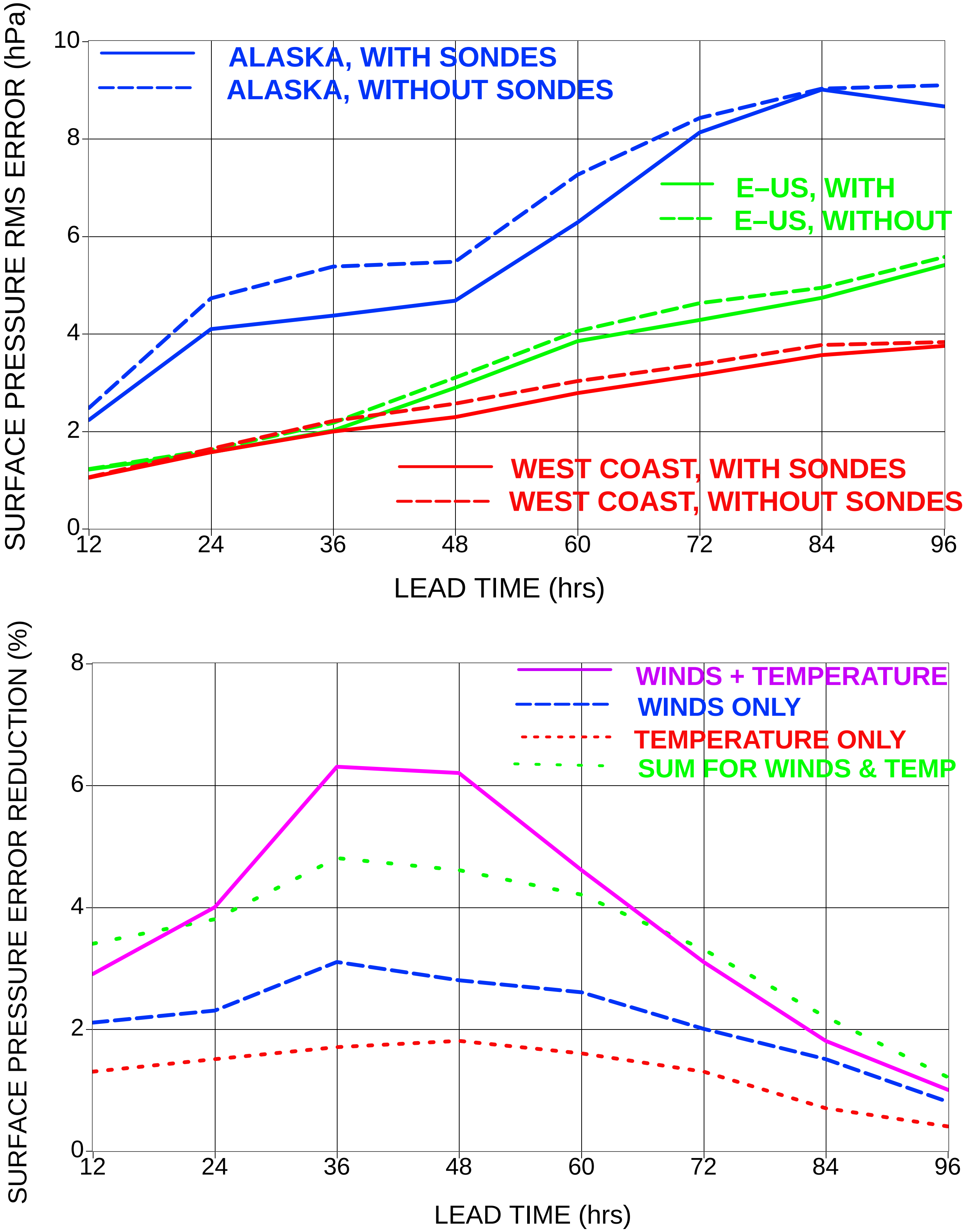
2–day surface pressure fcsts improved 7 out of 8+2 cases (statistically significant at 10% level)



NCEP flight days have higher skill than all other days (or other flight days); statistically significant at 5% level

RMS error (measured against observations) of 2–day surface pressure forecasts with (horizontal axis) and without (vertical axis) of dropsonde data for the 10 NORPEX–98 cases (top) where the NCEP targeted guidance was used, over western north America (230–260 E, 30–60 N). On the bottom panel errors for all other days in the NORPEX–98 period (January 16 – February 27, except for missing data on Febr. 16, 17 and 19, where no flights were taken) are shown with crosses whereas the NCEP flight days are repeated with dots.

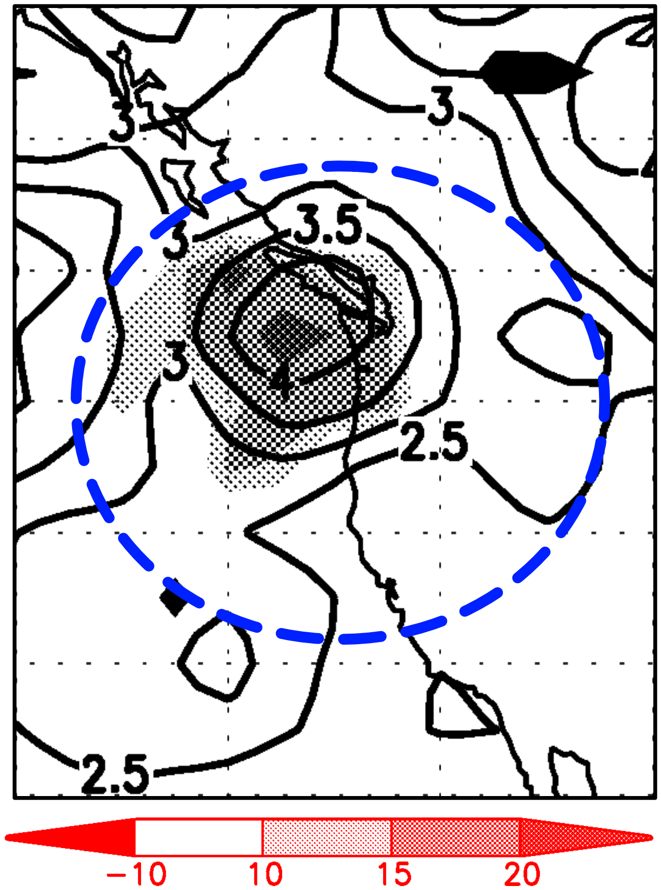

RMS SURFACE PRESSURE ERROR REDUCTION (%)
AVERAGE LOCATION OF VERIFICATION REGION
36 HOURS
48 HOURS
72 HOURS
−25 −20 −15 −10 −5 5 10 15 20 25
WSR2000



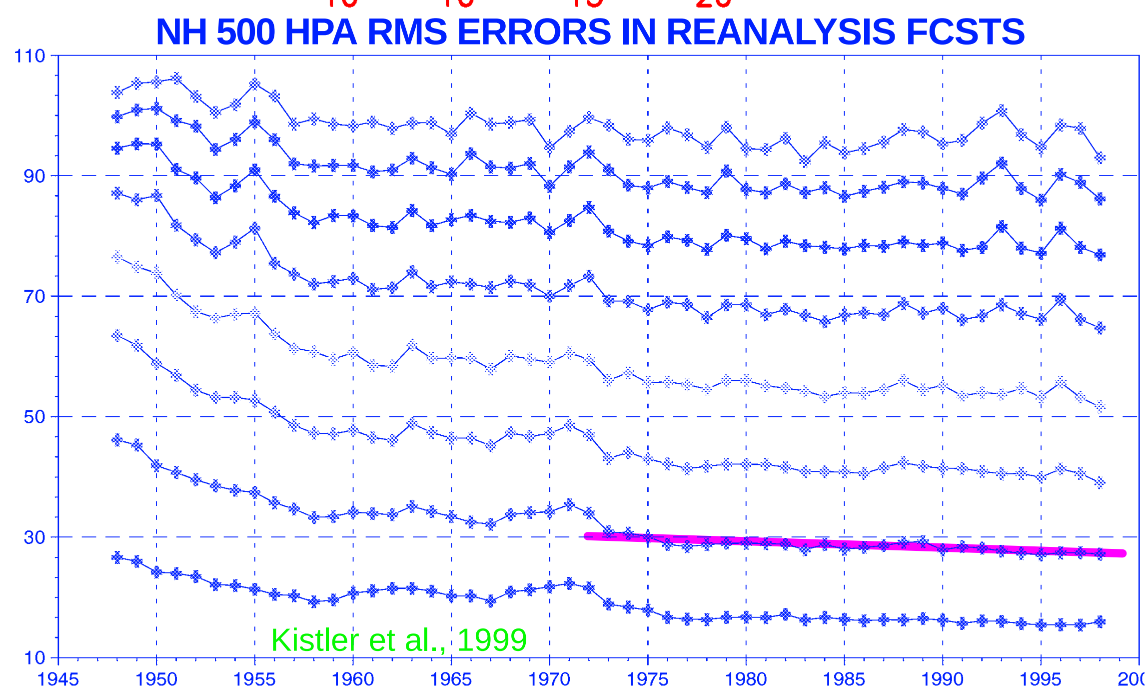
RMS error (upper panel) of surface pressure forecasts with (continuous lines) and without (dashed lines) dropsonde data for the 12 WSR2000 cases, over the US (25–50N, 125–70W), West coast (25–50N, 125–100W), Eastern US (25–50N, 100–70W), and Alaska (55–70N, 165–140W). RMS error reduction (lower panel) in surface pressure over western half of Northern Hemishpere extratropics due to winds and temperature, or separately winds only or temperature only targeted dropsonde data for the 12 WSR2000 cases. The sum of the separate winds and temperature only error reduction values is also shown.

AVERAGE % ERROR REDUCTION IN 48–HR SURFACE PRESSURE FORECASTS

AVERAGE 48–HR SURFACE PRESSURE FORECAST ERROR



MAXIMUM 48–HR SP ERROR IS REDUCED BY AN AVERAGE OF 10–20% WITHIN VERIFICATION REGION



IT TOOK 25 YRS TO REDUCE 2–DAY FCST ERRORS BY 10 % DUE TO IMPROVEMENTS IN THE NH OBSERVING SYSTEM

Average reduction in 48–hr surface pressure forecast error for 15 Winter Storm Reconnaissance Program 1999 cases (top, shades of red, %), along with the average 48–hr control surface pressure forecast error (black contours). Note that the use of the dropsonde data reduced forecast errors on average by 10–20% over the area of maximum forecast errors within the average location of the verification regions at 48–hr lead time (blue dashed ellipsoid). In comparison, improvements in the Northern Hemispheric observing system produced a 10% rms error reduction in 2–day 500 hPa reanalysis forecasts during the most recent 25 years (bottom right).

QUALITATIVE COMPARISON OF *ENSEMBLE TRANSFORM* AND *ADJOINT* SENSITIVITY RESULTS, JAN. 25 2000 STORM

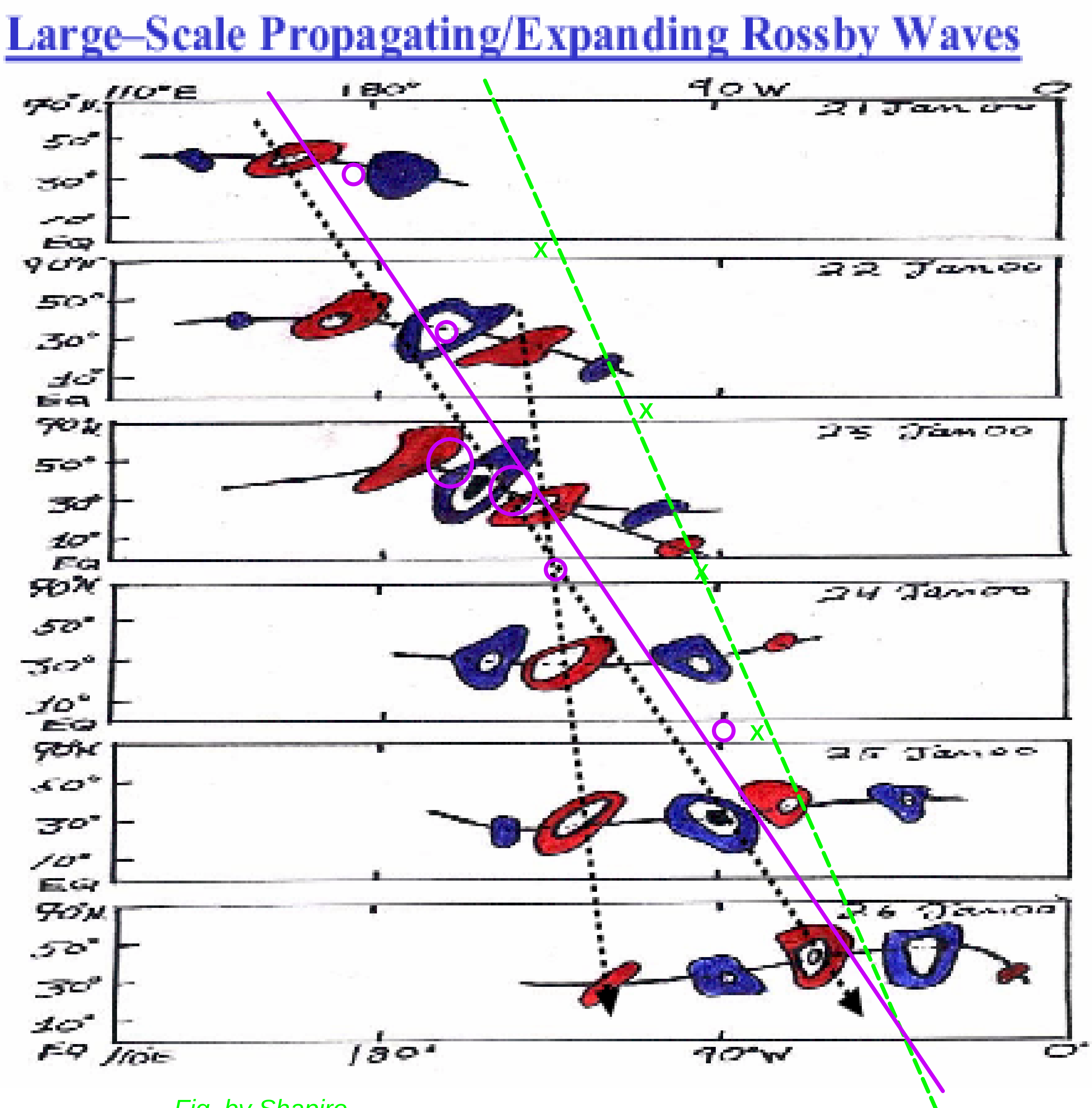
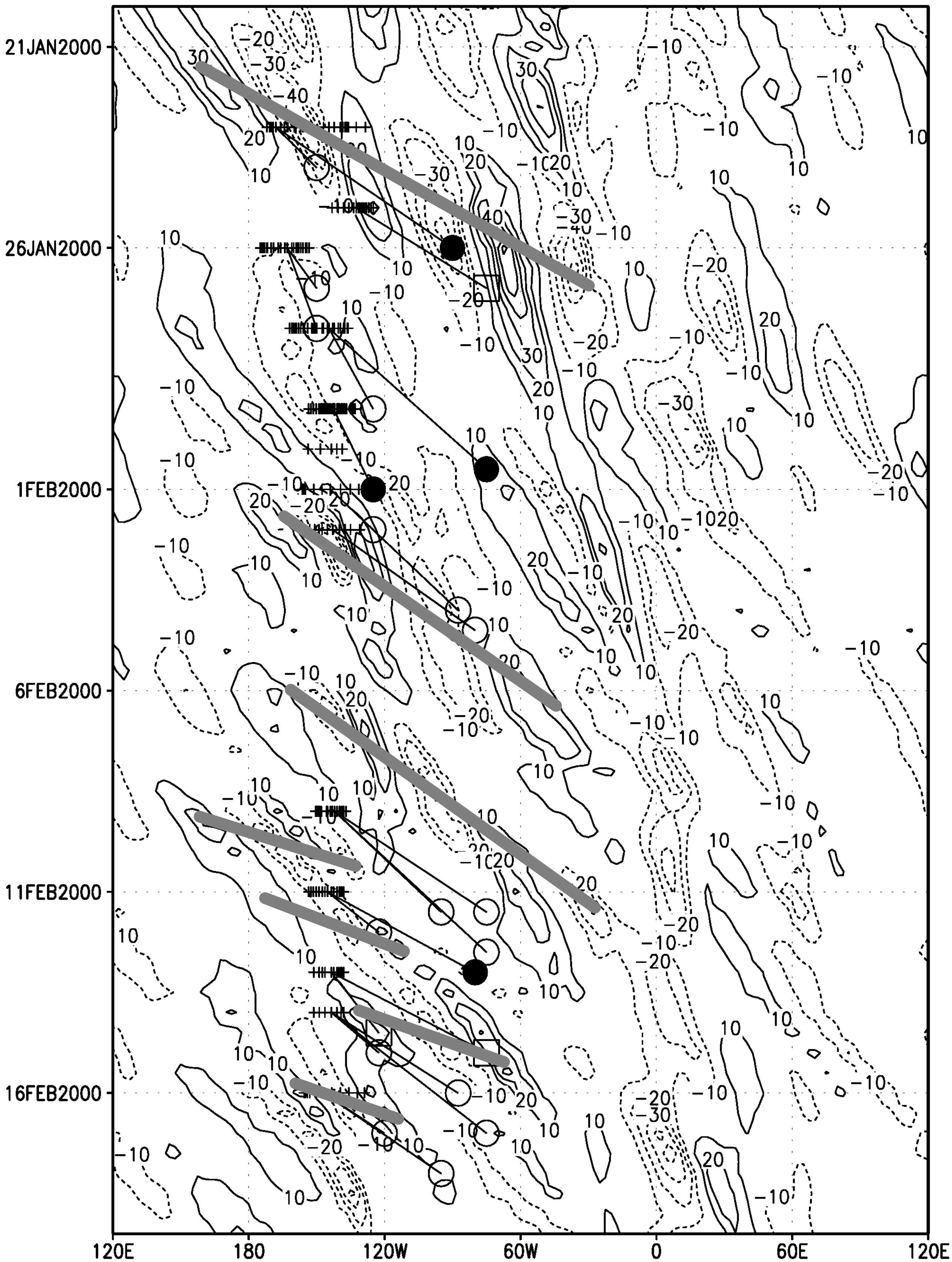


Fig. by Shapiro


21JAN2000
26JAN2000
1FEB2000
6FEB2000
11FEB2000
16FEB2000
120E
180
120W
60W
0
60E
120E

ADAPTIVE OBSERVATIONAL PLANS

1) EXPAND OPERATIONAL WSR PROGRAM

a) Cover full winter (4 instead of 2 mos.)

b) Fold East Coast Winter Storm program under WSR

c) Establish West Coast mesoscale program under WSR

2) THORPEX RELATED RESEARCH

a) Study adaptive obs approach on larger (global) domain

b) Explore targeting longer (4–6–day) range fcsts

c) Test use of new LIDAR wind, aerosonde, driftsonde obs.

d) Compare traditional vs. adaptive approach in OSSEs

e) Refine sensitivity analysis – increase resol./ens. members

f) Automate case selection based on ensemble fcsts

g) Study economic impact

OUTLINE / CONCLUSIONS

1) ATMOSPHERIC OBSERVATIONS

TRADITIONAL AND ADAPTIVE APPROACHES

2) TARGETED OBSERVATIONAL TECHNIQUE

FCST CASE SECLECTION, SENSITIVE AREA, DATA COLLECTION

3) PAST PROGRAMS

EIGHT RESEARCH & OPER. PROGRAMS BETWEEN 1997–2002

4) WINTER STORM RECONNAISSANCE 2001 PROGRAM

OPERATIONALLY IMPLEMENTED AT NWS; POSITIVE RESULTS

5) PLANS

EXPAND WSR PROGRAM IN TIME/SPACE; THORPEX RESEARCH

QUESTIONS – 4

4) CAN AN ENSEMBLE PREDICT VARIATIONS IN FCST UNCERTAINTY?

REPHRASED QUESTION:

What are the typical **variations in foreseeable forecast uncertainty?**
What variations in predictability can the ensemble resolve?

METHOD:

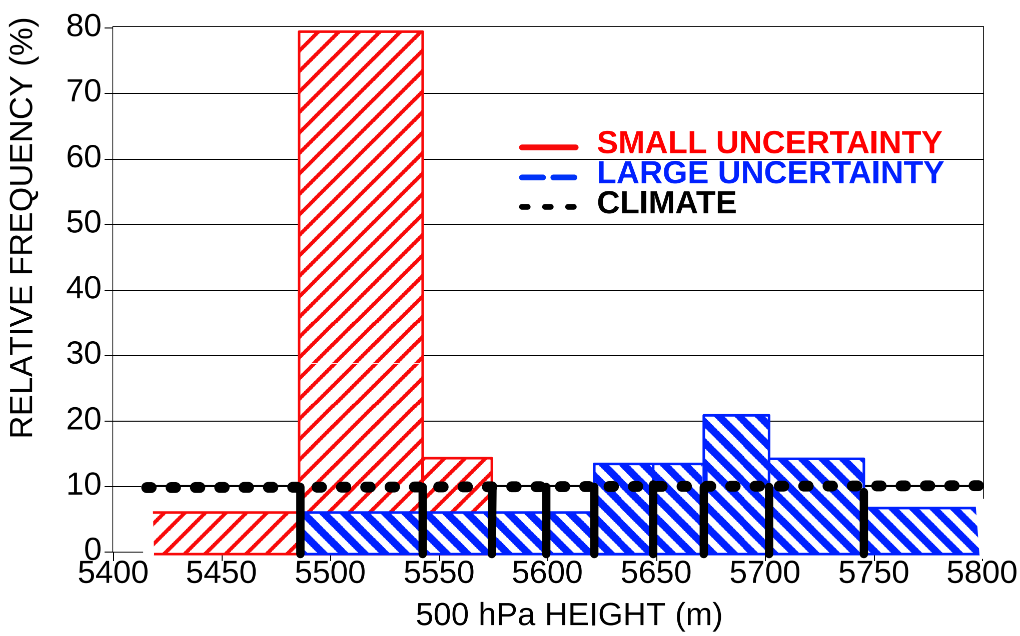
Ensemble mode value to distinguish high/low predictability cases
Stratify cases according to ensemble mode value –
Use 10–15% of cases when ensemble is highest/loewest

DATA:

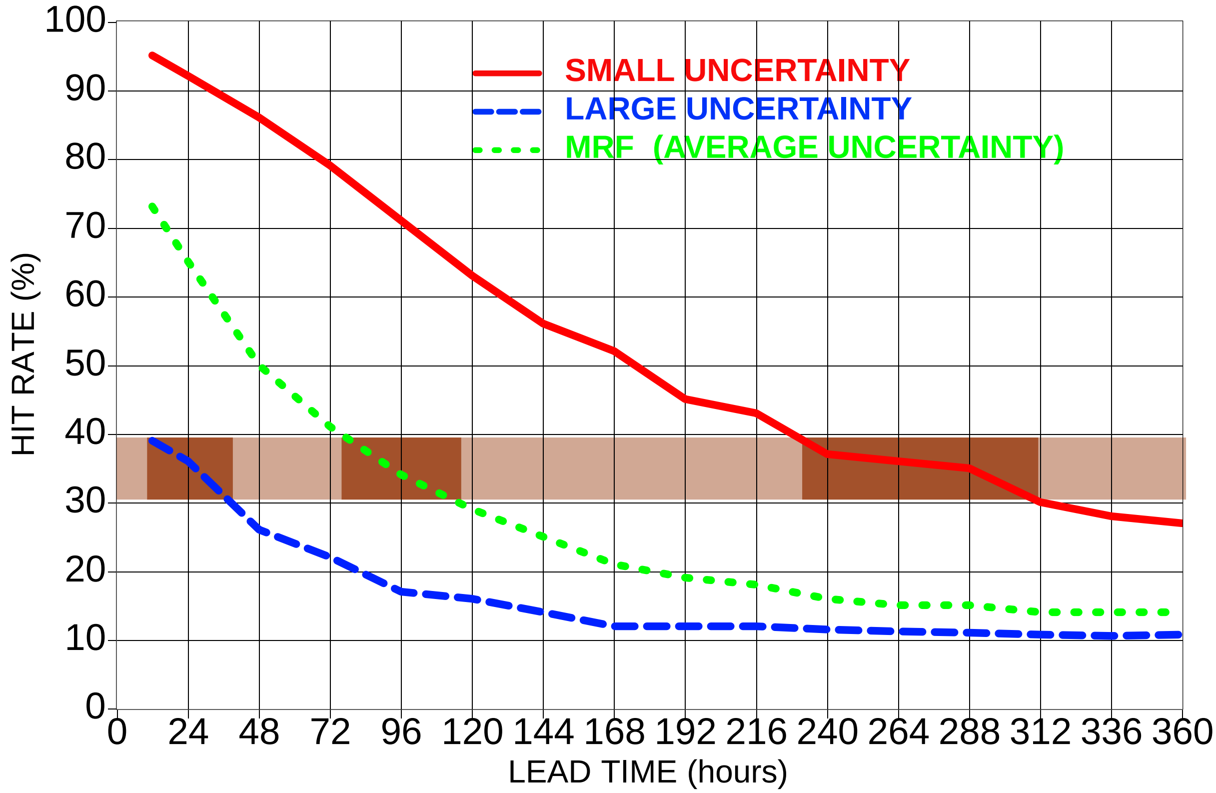
NCEP **500 hPa NH extratropical ensemble fcsts** for March–May 1997
14 perturbed fcsts and high resolution control

VERIFICATION:

Hit rate for ensemble mode and hires control fcst



SEPARATING HIGH VS. LOW UNCERTAINTY FCSTS



THE ***UNCERTAINTY OF FCSTS*** *CAN BE* ***QUANTIFIED IN ADVANCE***

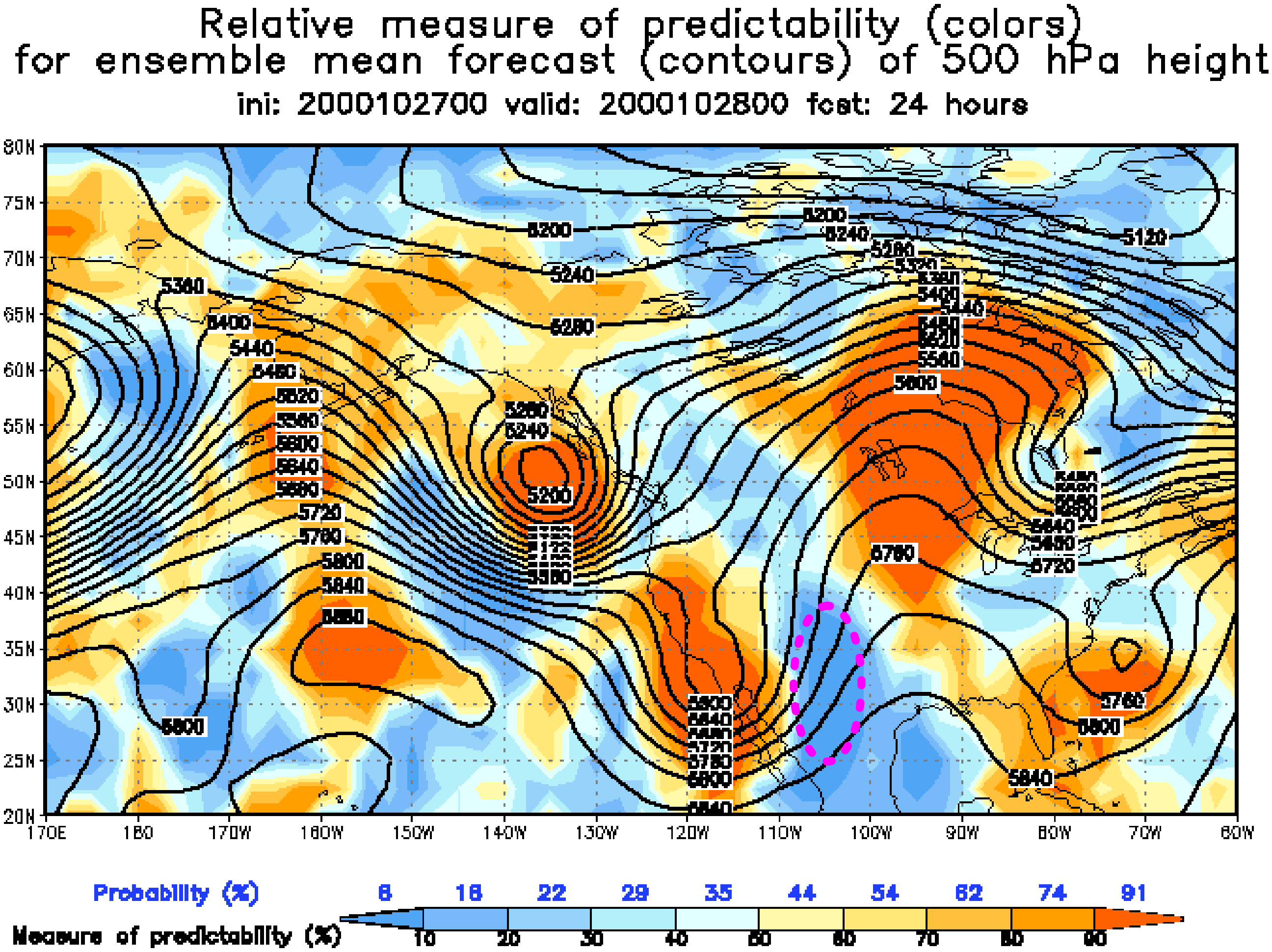
HIT RATES FOR 1–DAY FCSTS

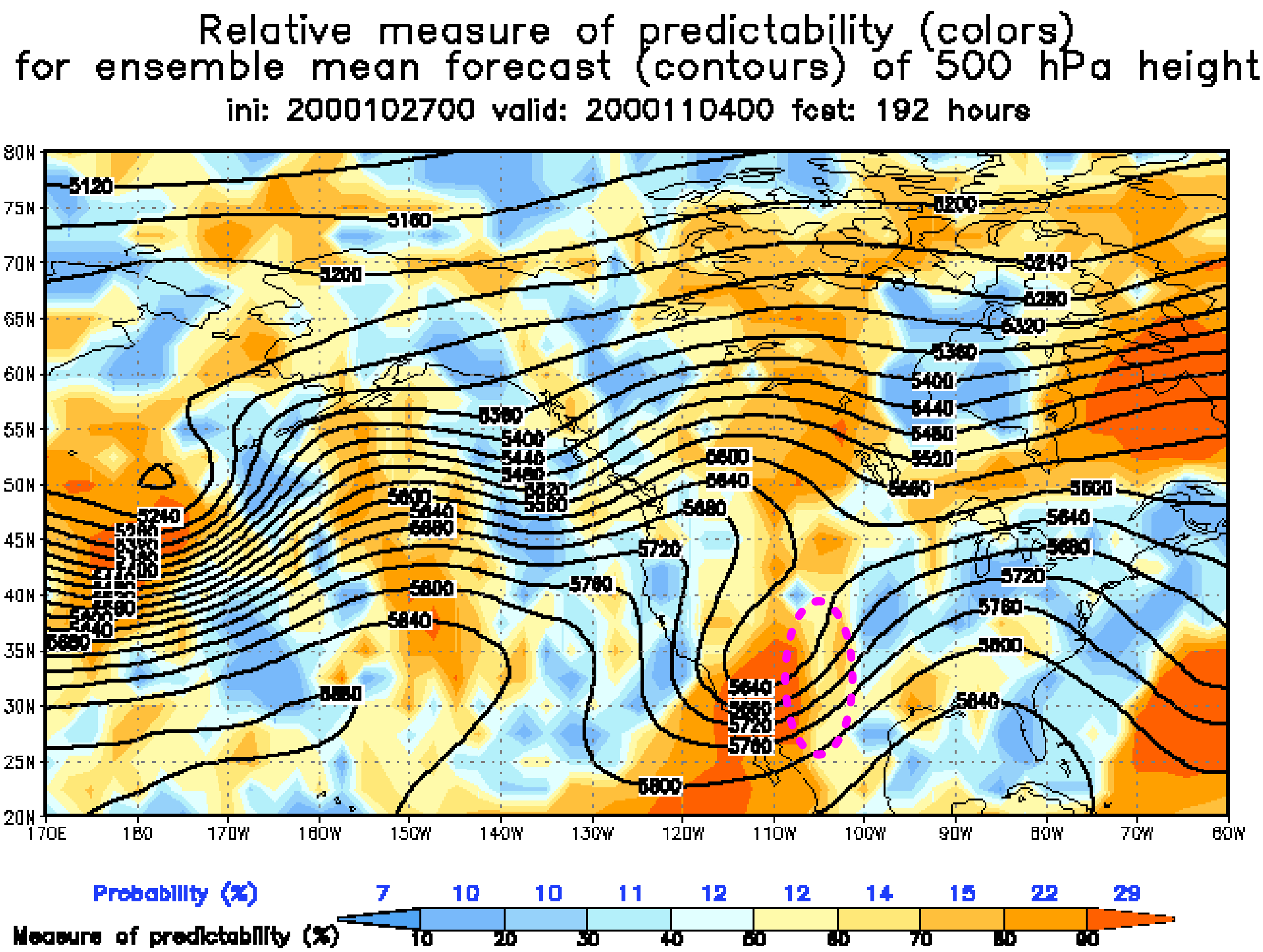
CAN BE ***AS LOW AS 36%****, OR* ***AS HIGH AS 92%***

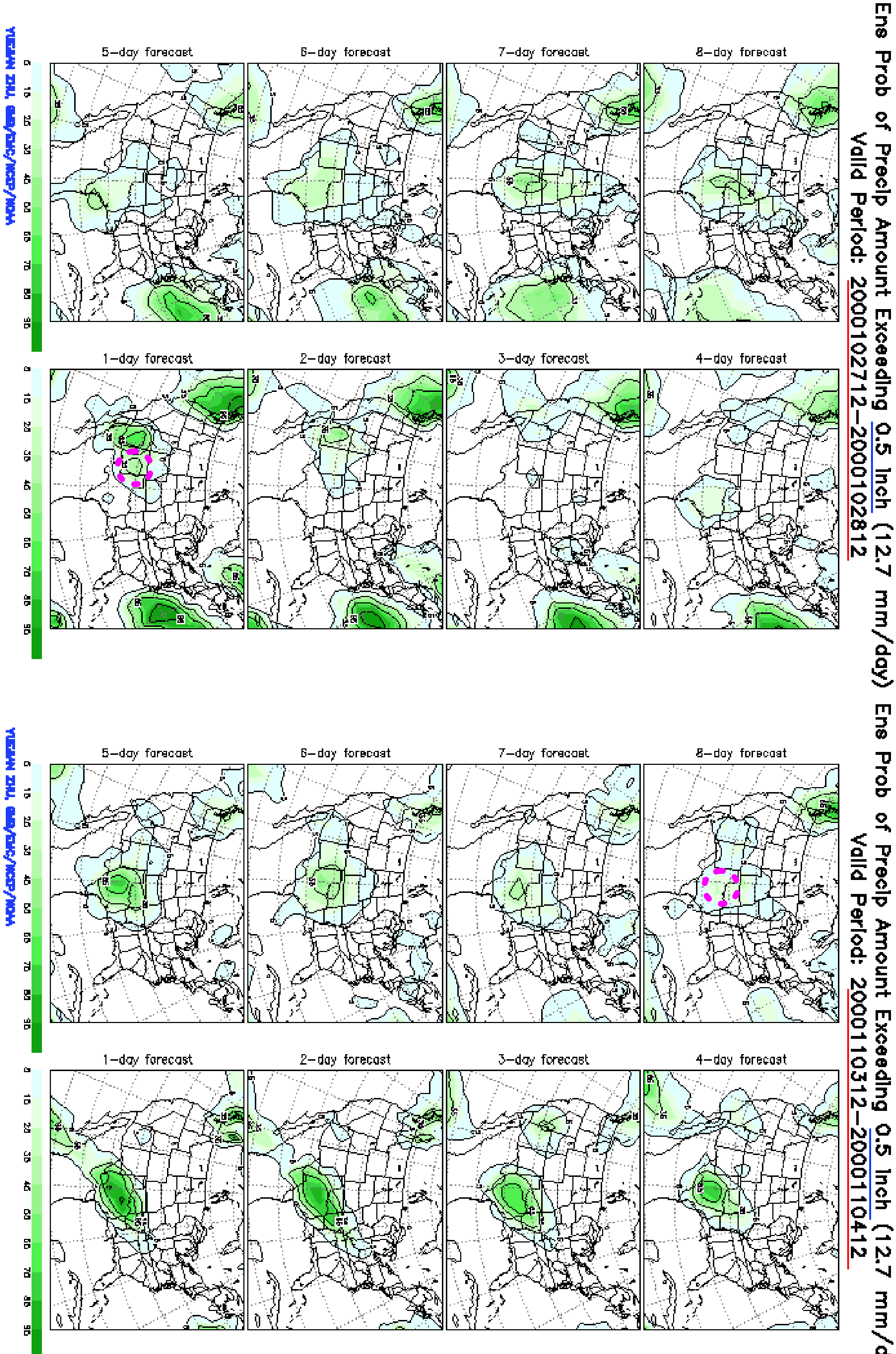
10–15% OF THE TIME A 12–DAY FCST CAN BE AS GOOD, OR A 1–DAY FCST CAN BE AS POOR AS AN AVERAGE 4–DAY FCAST

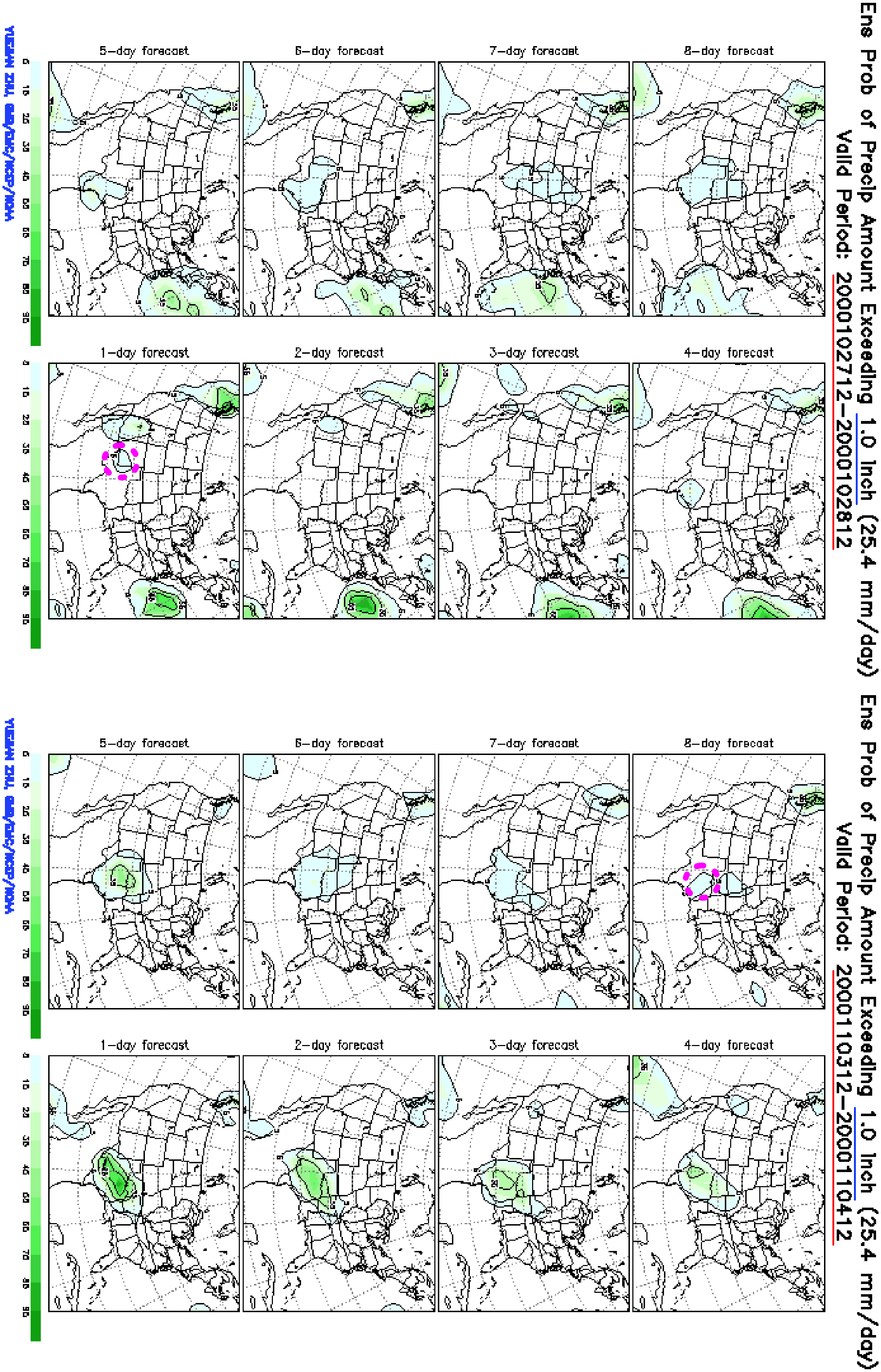
1–2% OF ALL DAYS THE 12–DAY FCST CAN BE MADE WITH MORE CONFIDENCE THAN THE 1–DAY FCST

AVERAGE HIT RATE FOR EXTENDED–RANGE FCSTS IS LOW –
VALUE IS IN KNOWING WHEN FCST IS RELIABLE


Relative measure of predictability (colors)
for ensemble mean forecast (contours) of 500 hPa height
ini: 2000102700 valid: 2000102800 fcst: 24 hours
80N 75N 70N 65N 60N 55N 50N 45N 40N 35N 30N 25N 20N
170E 180 170W 160W 150W 140W 130W 120W 110W 100W 90W 80W 70W 60W
Probability (%) 6 16 22 29 35 44 54 62 74 91
Measure of predictability (%) 10 20 30 40 50 60 70 80 90


Relative measure of predictability (colors)
for ensemble mean forecast (contours) of 500 hPa height
ini: 2000102700 valid: 2000110400 fcst: 192 hours
80N 75N 70N 65N 60N 55N 50N 45N 40N 35N 30N 25N 20N
170E 180 170W 160W 150W 140W 130W 120W 110W 100W 90W 80W 70W 60W
Probability (%) 7 10 10 11 12 12 14 15 22 29
Measure of predictability (%) 10 20 30 40 50 60 70 80 90


Ens Prob of Precip Amount Exceeding 0.5 Inch (12.7 mm/day)
Valid Period: 2000102712–2000102812
1–day forecast
2–day forecast
3–day forecast
4–day forecast
5–day forecast
6–day forecast
7–day forecast
8–day forecast
Ens Prob of Precip Amount Exceeding 0.5 Inch (12.7 mm/day)
Valid Period: 2000110312–2000110412
1–day forecast
2–day forecast
3–day forecast
4–day forecast
5–day forecast
6–day forecast
7–day forecast
8–day forecast


Ens Prob of Precip Amount Exceeding 1.0 Inch (25.4 mm/day)
Valid Period: 2000102712–2000102812
5–day forecast
6–day forecast
7–day forecast
8–day forecast
1–day forecast
2–day forecast
3–day forecast
4–day forecast
Ens Prob of Precip Amount Exceeding 1.0 Inch (25.4 mm/day)
Valid Period: 2000110312–2000110412
5–day forecast
6–day forecast
7–day forecast
8–day forecast
1–day forecast
2–day forecast
3–day forecast
4–day forecast

WHAT MAKES FCSTS BETTER / MORE USEFUL?

1) **More / better quality data** – within 25 years:
10% 2D error reduction, 6–hr gain

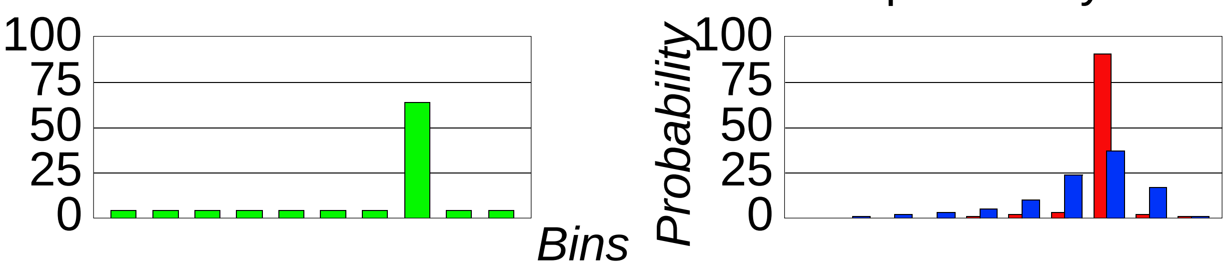
2) **Improved analysis schemes** – within 6 years:
10% 5D AC improvement, 12–hr gain

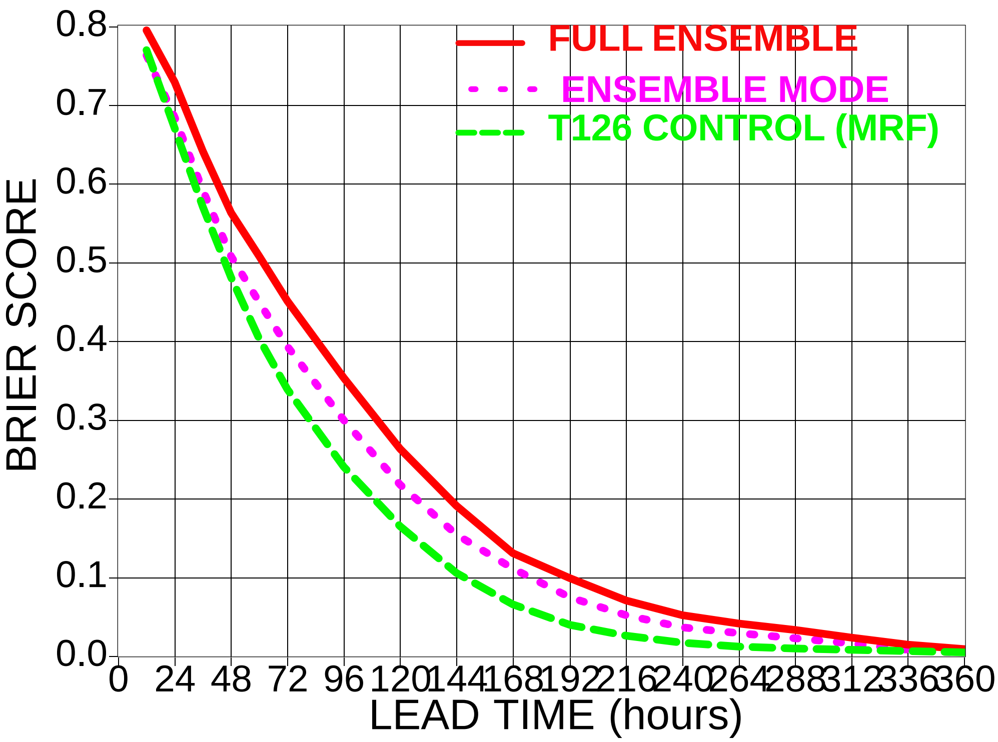
3) **Better fcst models**

4) **Use of ensembles:** 25–30% 5D Brier score imprvm.,24–hour gain

CONTROL
Yes or No fcst for an event

ENSEMBLE
Full probability distribution

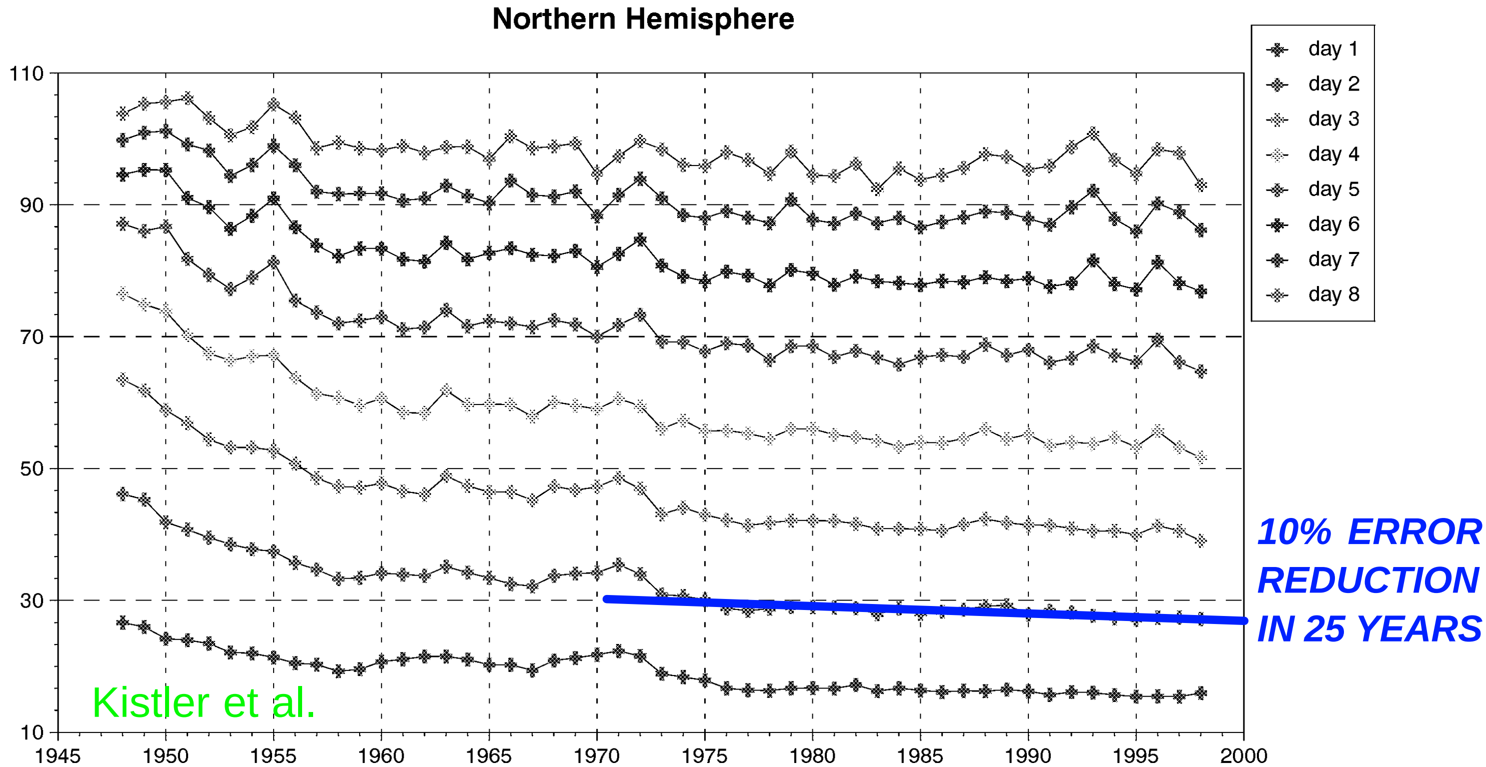




Control forecast always predicts same level of reliability whereas ensemble indicates flow dependent level of reliability

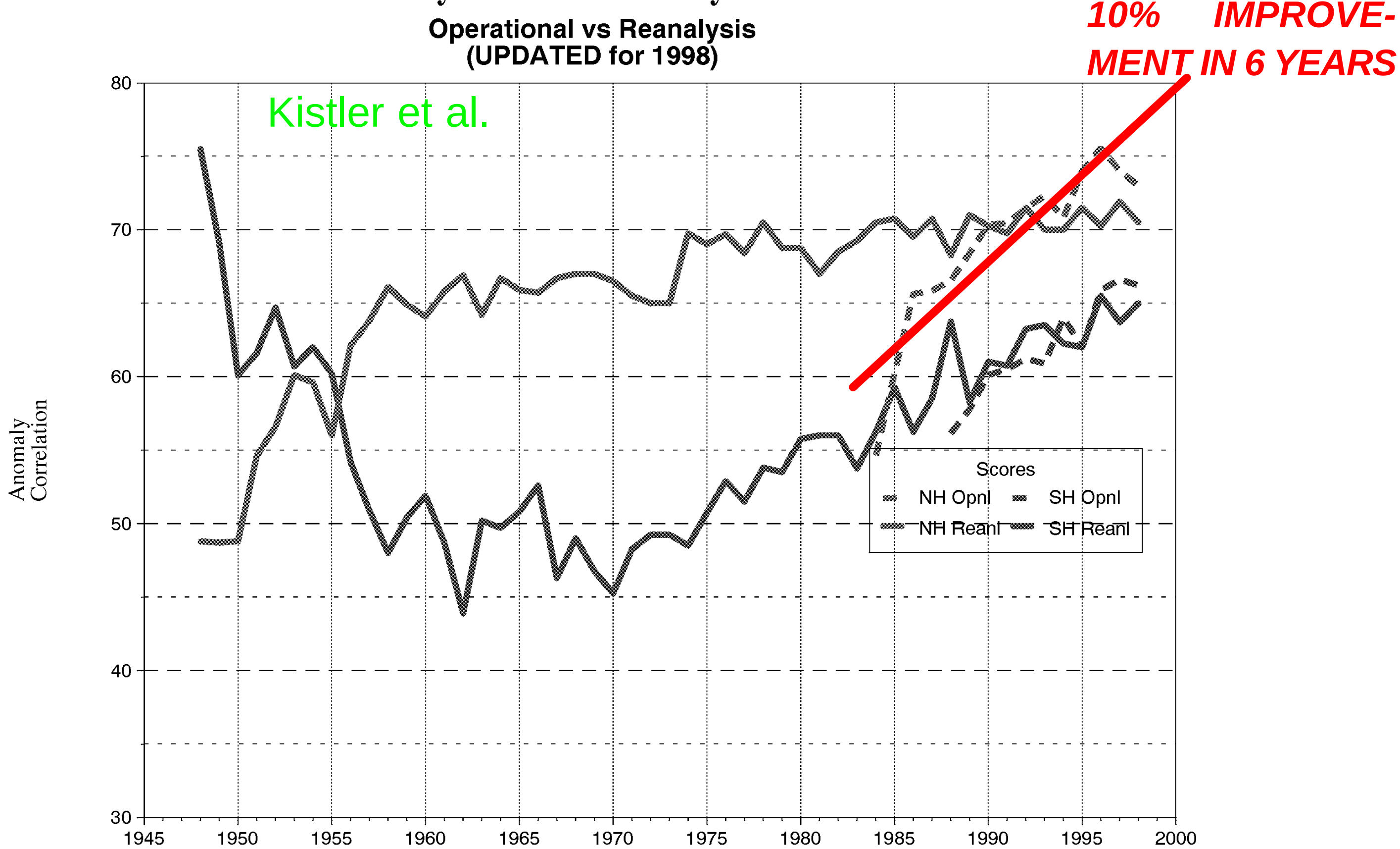
IMPROVEMENTS IN DATA ONLY

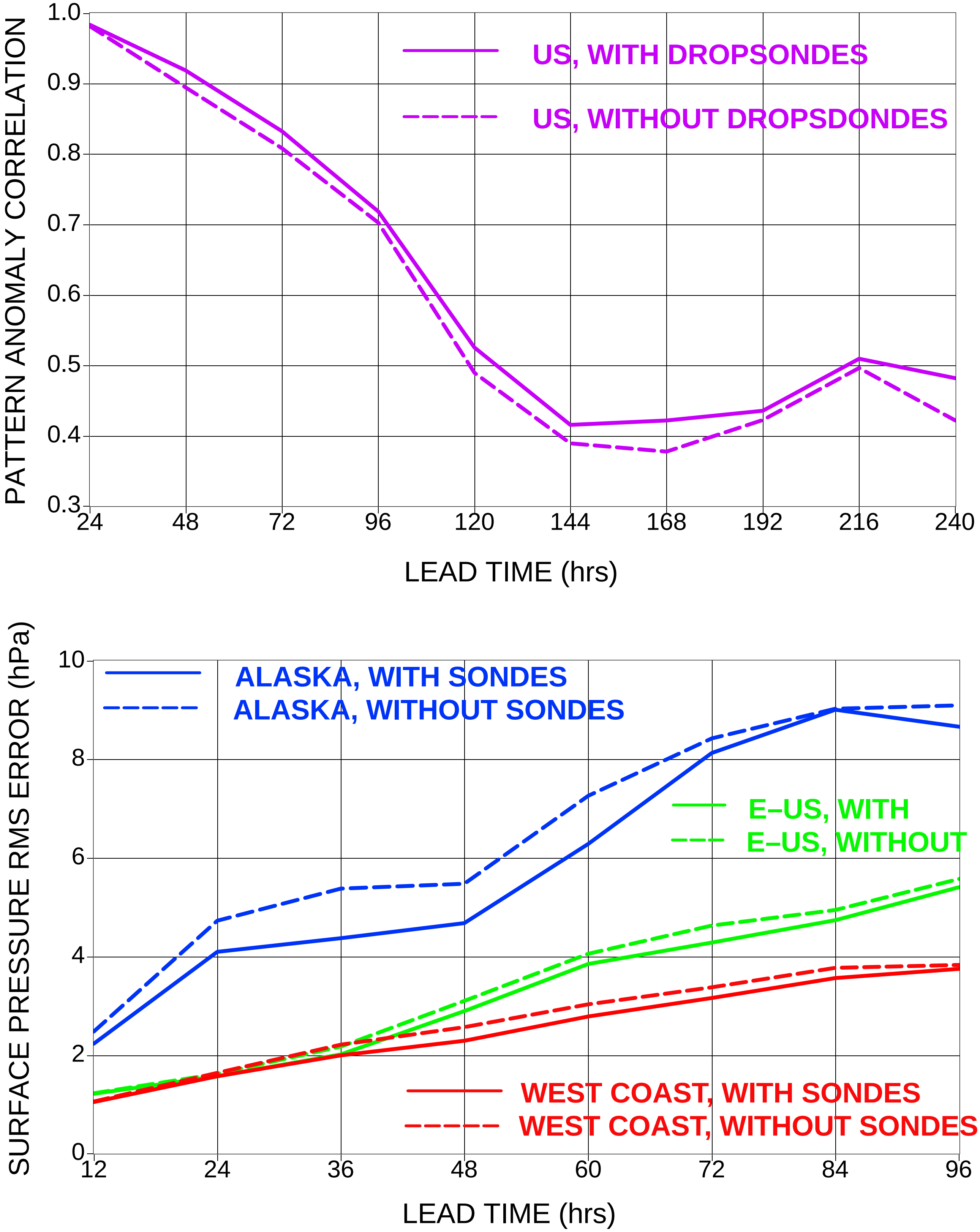
Reanalysis Forecast 500 mb Height RMS



IMPROVEMENTS IN DATA + ASSIMILATION + MODEL

NCEP 5-Day Forecast Anomaly Correlations





Pattern Anomaly correlation (PAC, upper panle) and RMS error (lower panel) oF surface pressure forecasts with (continuous lines) and without (dashed lines) dropsonde data for the 12 WSR2000 cases, over the US (25–50N, 125–70W), West coast (25–50N, 125–100W), Eastern US (25–50N, 100–70W), and Alaska (55–70N, 165–140W).