U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION

OFFICE NOTE 420

PROCEEDINGS OF THE
FASTEX UPSTREAM OBSERVATIONS WORKSHOP
NCEP, Camp Springs, MD, April 10–11, 1997

COMPILED BY: Zoltan Toth
GSC at the ENVIRONMENTAL MODELING CENTER

JULY 1997

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FASTEX UPSTREAM OBSERVATIONS WORKSHOP
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COVER PAGE, CONTENT, SUMMARY, PROGRAM, PARTICIPANTS – 5 pages

A COLLECTION OF TRANSPARENCIES PRESENTED BY

Kerry Emanuel	MIT	3 pages
Ron Gelaro	NRL	20
Zhao–Xia Pu	NCEP/UCAR	3
Craig Bishop	Penn State University	20
Thierry Bergot	Meteo France (Shown by C. S.)	3
Istvan Szunyogh	NCEP/NCAR/MIT	3
Zoltan Toth	NCEP/GSC	10
Chris Snyder	NCAR/MMM	8
Peter Houtekamer	RPN, Canada	10
Jeffrey Anderson	GFDL	8
Stephen Lord	NCEP	18
Jon Talbot	US Air Force	20

A total of 131 pages

ADDITIONAL COPIES AVAILABLE FROM:
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SUMMARY

On April 10–11, 1997, NCEP/EMC hosted a workshop on FASTEX Targeted Observations. Beyond NCEP personnel, 17 people attended from universities, research institutes and funding agencies from across the US and Canada. The workshop had 3 focus areas: (1) Review of upstream targeting operations and methods used during the FASTEX field experiment; (2) Discussion of evaluation methods of the data impact and early results; (3) Consideration of a smaller field experiment over the Pacific for the winter of 1997/98 and/or the following winter. As to the operations, the presentations and the ensuing discussions focused on problem areas that resulted mainly from the broad spectrum of interests/observations followed up during FASTEX. The potential advantages of a smaller field experiment focusing mainly on upstream applications, became clear. A few results were already presented showing that the extra upstream observations during FASTEX had an impact on the forecasts in the desired area. However, it also became evident that the impact of the data strongly depends on the particulars of the analysis scheme used and therefore possible modifications/improvements to the analysis scheme should also be considered along with targeting research in general. It was also pointed out that during FASTEX, most targeted observations were taken just off the well observed east coast of north America, thus their impact may be rather limited. Discussing plans, participants from NRL and NCEP expressed a strong interest in pursuing the possibility of organizing a smaller scale targeting field experiment during the next winters over the Pacific. The Pacific, with its large domain, offers more potential for improving weather forecasts verifying over land – therefore we can expect direct impact on US weather forecasts. Other participants stressed the need for carefully analyzing the FASTEX and regular observational data in a research mode to best prepare for future field experiments. The upstream targeting component in FASTEX got organized within a relatively short period of time; FASTEX played an inspiring and galvanizing role in all the research and development efforts that brought together this new field within meteorology. The targeting community will be much better prepared for a possible Pacific experiment after the FASTEX experience and such a challange would definitely give an invaluable momentum leading to improvements in all methods involved. A more detailed report on the workshop is under preperation; a copy of transparencies shown are attached.

AGENDA FOR THE
FASTEX UPSTREAM OBSERVATIONS WORKSHOP
NCEP, Camp Springs, MD, April 10–11, 1997, Room 209

Thursday, April 10

9:00 WELCOME REMARKS — Eugenia Kalnay, Director of EMC

1) OVERVIEW OF UPSTREAM OPERATIONS

9:10 Activities based at NCEP — Kerry Emanuel (MIT)
9:30 Activities based in Shannon — Mel Shapiro (NOAA)
10:05 Break

2) TARGETING METHODS USED: SIMILARITIES & DIFFERENCES

10:20 NRL adjoint methods — Ron Gelaro (NRL)
10:50 NCEP adjoint and tangent linear methods — Zhao–Xia Pu (NCEP)
11:20 Ensemble–based SVD — Craig Bishop (PSU)
11:50 French adjoint methods — (Presented by Chris Snyder, NCAR)

12:00–14:00 Lunch Break
13:00 EMC/Global Modeling Branch Briefing (Open; Short work–in–progress reports)

3) EVALUATION METHODS AND EARLY RESULTS: DO'S AND DONT'S

14:00 Genaral remarks — Kerry Emanuel (MIT)
14:10 Ensemble–based SVD — Istvan Szunyogh (NCEP)
15:10 NCEP adjoint/linear tangent methods — Zhao–Xia Pu (NCEP)
16:10 NRL adjoint methods — Ron Gelaro (NRL)
16:20 Discussion
18:00 Adjourn

Friday, April 11

4) ISSUES IN ADAPTIVE OBSERVATIONS

8:00 Statistical design for adaptive observations — Chris Snyder (NCAR)
8:20 Determination of the value of observations — Peter Houtekamer (RPN)
8:40 Detection of signal in Monte Carlo evaluations of functions of random variables: Implications for targetted observations — Jeff Anderson (GFDL)
9:00 Targeting experiments using existing data — Zoltan Toth (NCEP)
9:30 Break

5) A POSSIBLE PACIFIC FIELD EXPERIMENT: LESSONS LEARNT FROM FASTEX

10:00 Past Pacific reconnaissance experiments — Steve Lord (NCEP)
10:30 Improved Wea. Recon. System of the AF WC–130s — Jon Talbot (USAF)
11:00 Experiences from the Newfoundland upstream observations outpost — Rebecca Morss (MIT)
11:15 What do we want from a Pacific experiment? — Mel Shapiro (NOAA)
11:30 Discussion
12:30 Recommendations

13:00 Lunch
14:00–17:00 Informal group discussions

PARTICIPANTS:

Jeffrey Anderson	GFDL
Craig Bishop	Penn State University
Nick Bond	NOAA
Simon Chang	NRL
Kerry Emanuel	MIT
Ron Gelaro	NRL
Paul Hirschberg	NOAA/NWS
Peter Houtekamer	RPN, Canada
Sharanya Majumdar	Penn State University
Rebecca Morss	MIT
Steven Nelson	NSF
Steven Payne	ONR
Scott Sandgathe	ONR
Mel Shapiro	NOAA
Chris Snyder	NCAR/MMM
Pamela Stephens	NSF
Jon Talbot	US Air Force

FROM NCEP:

Henry Juang	NCEP/GSC
Eugenia Kalnay	NCEP
Steve Lord	NCEP
Zhao–Xia Pu	NCEP/UCAR
Istvan Szunyogh	NCEP/NCAR/MIT
Zoltan Toth	NCEP/GSC
Jack Woolen	NCEP/GSC
Wan–Shu Wu	NCEP/GSC

NCEP Operations During FASTEX

Kerry Emanuel, MIT

- **Objective:** Field test various adaptive sampling strategies in aid of forecasting for FASTEX domain
- **Resources:**

  1 Learjet (Flight International)

  Range: $\simeq$ 2400 nm

  Ceiling: $\simeq 41,000$ ft.

  Base: St. Johns, Newfoundland

  2 USAF C–130's

  Range: $\simeq$ 6000 km

  Ceiling: $\simeq$ 28,000 ft.

  Base: St. Johns, Newfoundland

  1 Gulfstream IV

  Range: $\simeq$ 2800 nm

  Ceiling: $\simeq$ 45,000 ft.

  Base: Shannon, Ireland; St. Johns

  3 Dedicated ships with rawinsondes

Lear and G4 equipped with GPS-based dropsondes

C–130's equipped with Omega-based dropsondes

- **Input:**

  NCEP Singular-Value Decomposition Sensitivity: Mostly tailored to verification area, lead time.

  NCEP Adjoint Sensitivity: Mostly fixed verification region, lead time range.

  NCEP Inverse Tangent Linear Model: Mostly fixed verification region, lead time range.

  NCEP SVD-Based, but using ECMWF Ensemble: Variable verification region, lead time; used only toward end of project.

  Penn-State SVD based on Canadian or mixed NCEP-Canadian Ensemble: Fixed verification region, lead time range. Only used toward end of project.

  ECMWF Singular-Vector: Used very little, owing to inappropriate lead times during most of project.

  NRL Adjoint Sensitivity, Singular Vectors: Some flights based on products using fixed verification region; some using variable regions.

  French adjoint sensitivity; Singular Vectors: Mostly tailored verification region, lead time.

- Summary:

  13 successful Lear missions

  6 successful C-130 missions

	"Complete" coverage	"Partial" coverage	"Some" coverage	Null
NCEP SVD	12	2	0	3
NCEP Adjoint	9	0	5	0
NCEP Inverse TLM	5	1	6	1
NCEP SVD-ECMWF	4	1	1	0
PSU SVD	3	0	0	0
ECMWF	9	0	2	0
NRL Adjoint	10	1	1	1
French Adjoint	7	0	2	0

The NRL Method for Adaptive Observations in FASTEX

Ron Gelaro, NRL

Navy Global Model (NOGAPS)

Nonlinear Trajectory T79L18: full physics
Tangent Linear and Adjoint: dry, simplified boundary layer

Verification Area: defined to include main area of cyclone and associated frontal features (generally close to but not identical to FASTEX MSA).

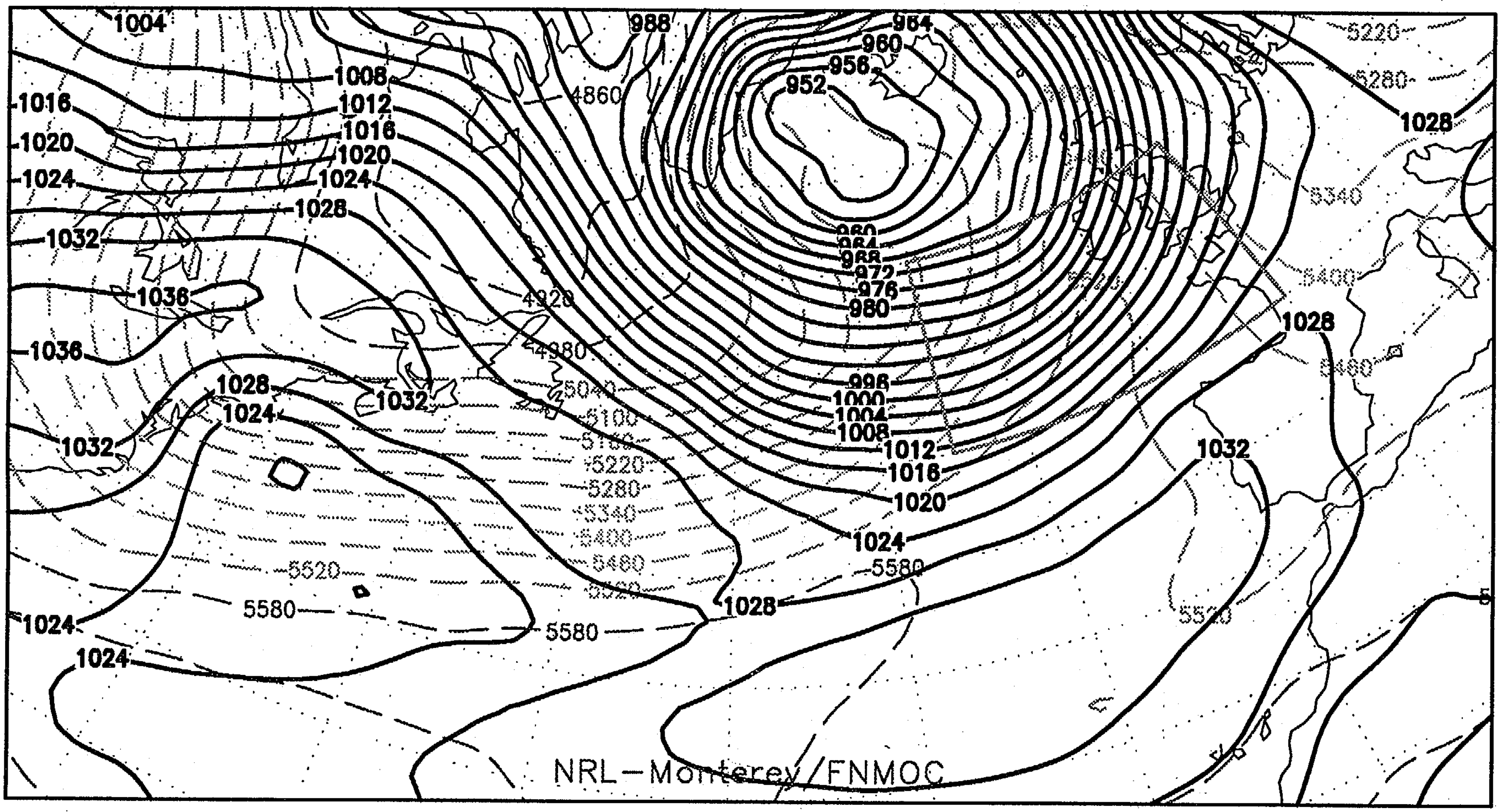
Time Configuration: generally 24-48 hr upstream of cyclone verification, with lead time of 24-36hr for mission planning and aircraft ferry to target area.

Singular Vectors:
T47L18, three leading SVs: maximize total perturbation energy within verification area between surface and 1 mb.

Sensitivity Gradients:
T79L18, gradients (∇J), with J defined as relative vorticity between surface and 650mb in verification area.

Note: the singular vector and sensitivity methods provide essentially the same results for targeting of mid-latitude cyclones, and are not considered to be separate methods.

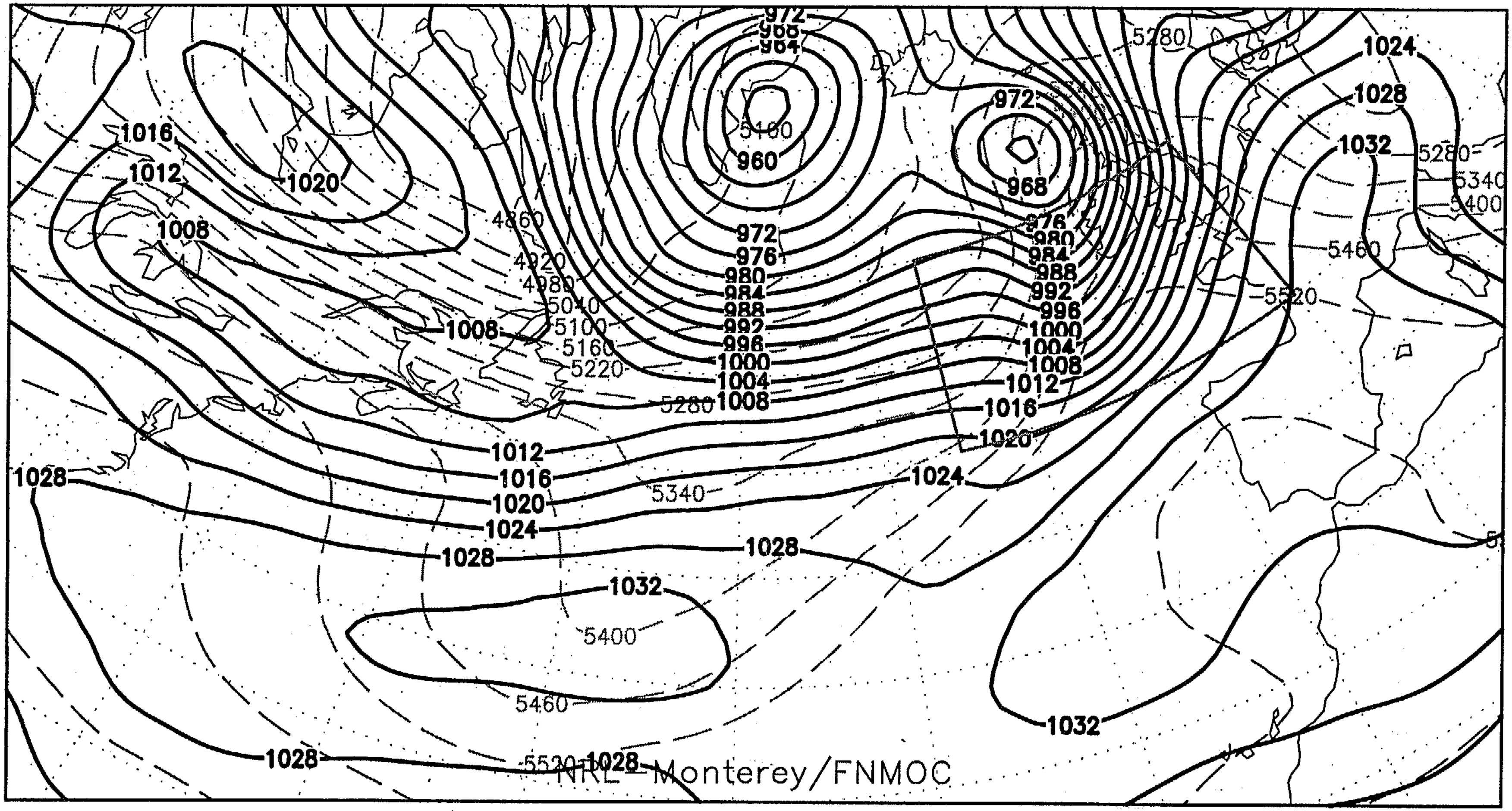
MSLP & 500–1000hPa THICKNESS ci=4.0mb, 60.0m



NOGAPS Nonlinear Analysis T79L18 Initial State:1997021712 Tau= 0

Analysis Valid: 1997021712

MSLP & 500-1000hPa THICKNESS ci=4.0mb, 60.0m

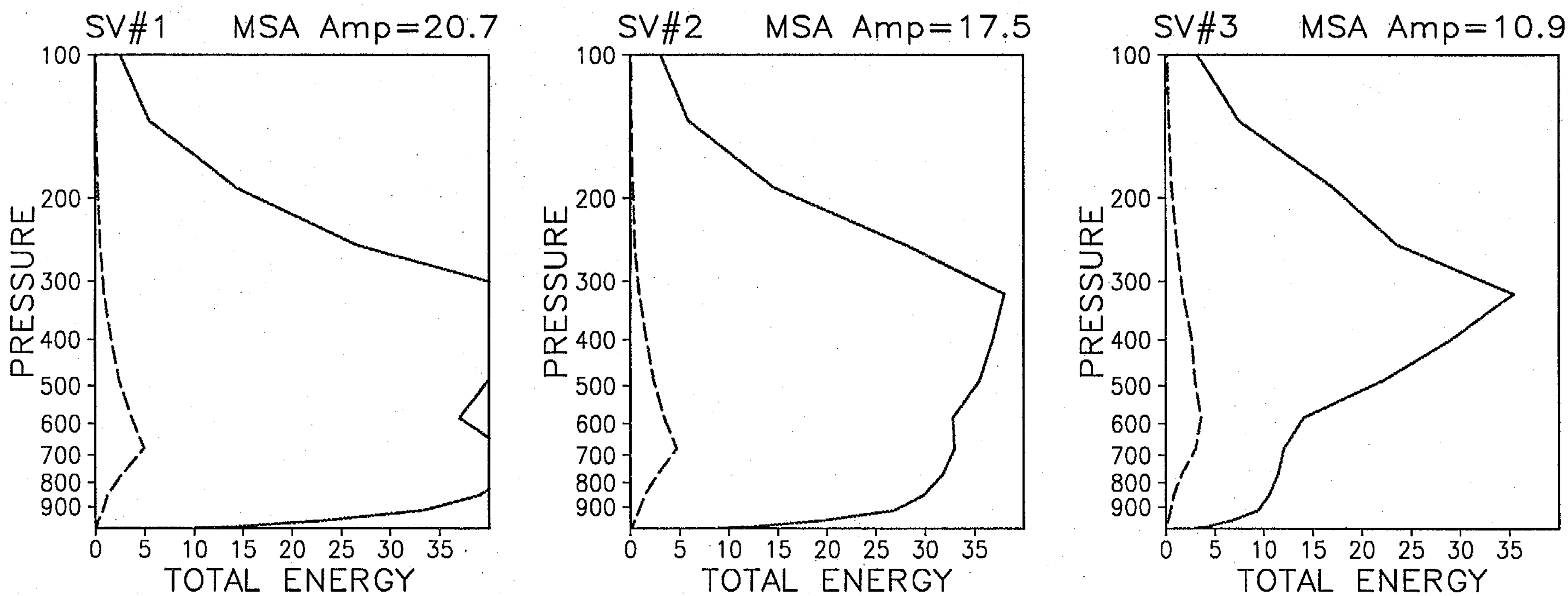


NOGAPS Nonlinear Analysis T79L18 Initial State:1997021912 Tau= 0

Analysis Valid: 1997021912

ENERGY VERTICAL PROFILES: 3 LEADING SINGULAR VECTORS

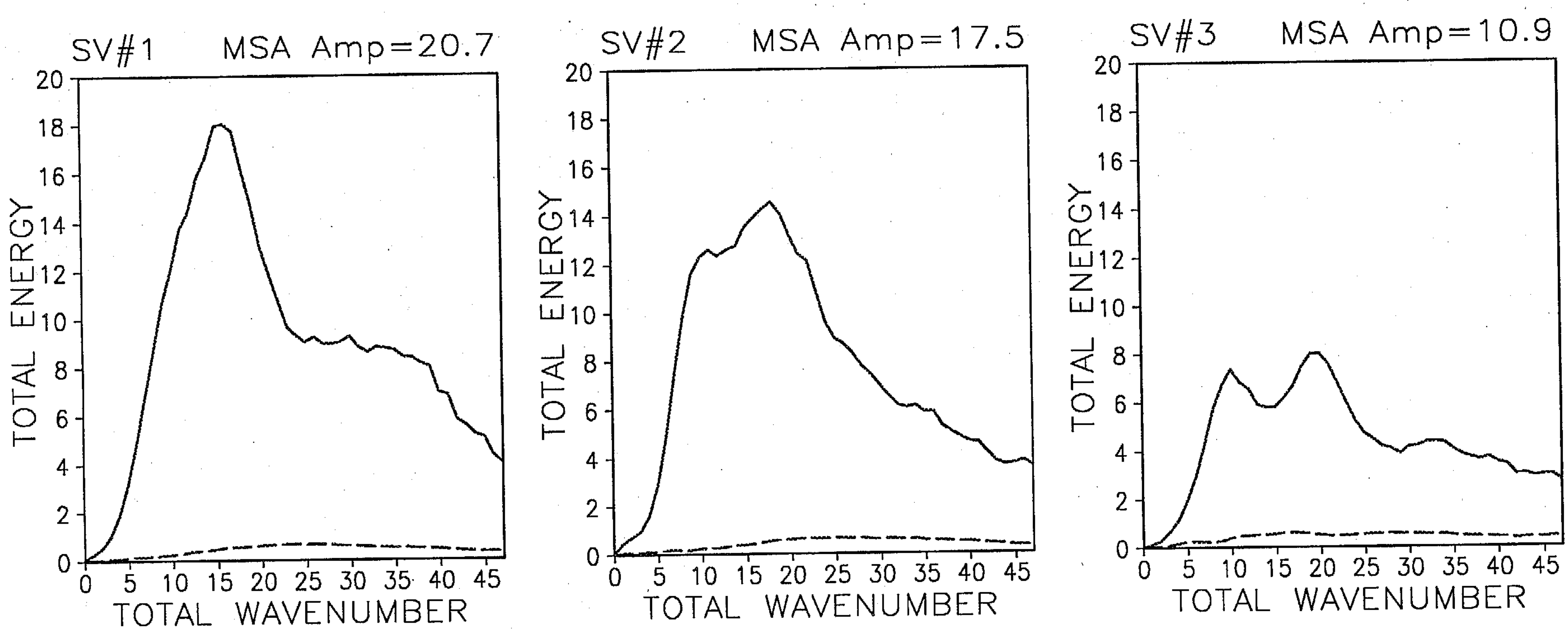
Global Energy(x20) at Initial (Target) Time (DASH)
Global Energy at Final (Fcst Verification) Time (SOLID)



NOGAPS Singular Vectors T47L18 (+84h,−48h) Targets Valid 1997021712
Forecast Valid 1997021912

TOTAL WAVENUMBER SPECTRA: 3 LEADING SINGULAR VECTORS

Global Energy(x20) at Initial (Target) Time (DASH)
Global Energy at Final (Fcst Verification) Time (SOLID)

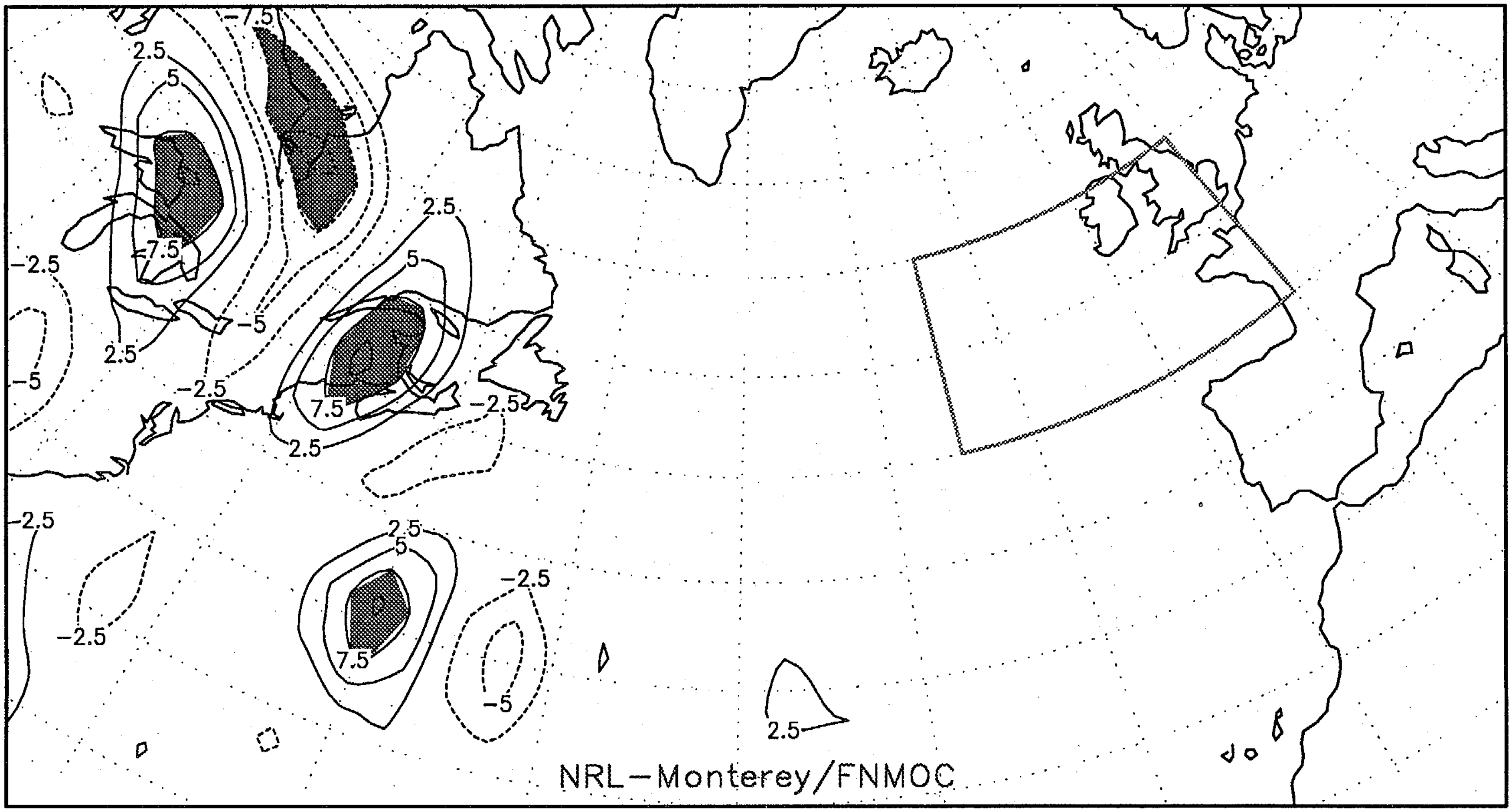


NOGAPS Singular Vectors T47L18 (+84h,−48h)

Targets Valid 1997021712
Forecast Valid 1997021912

SINGULAR VECTOR at TARGETED OBSERVING TIME

SV#1 Initial TEMP 490hPa MSA Amp=20.7

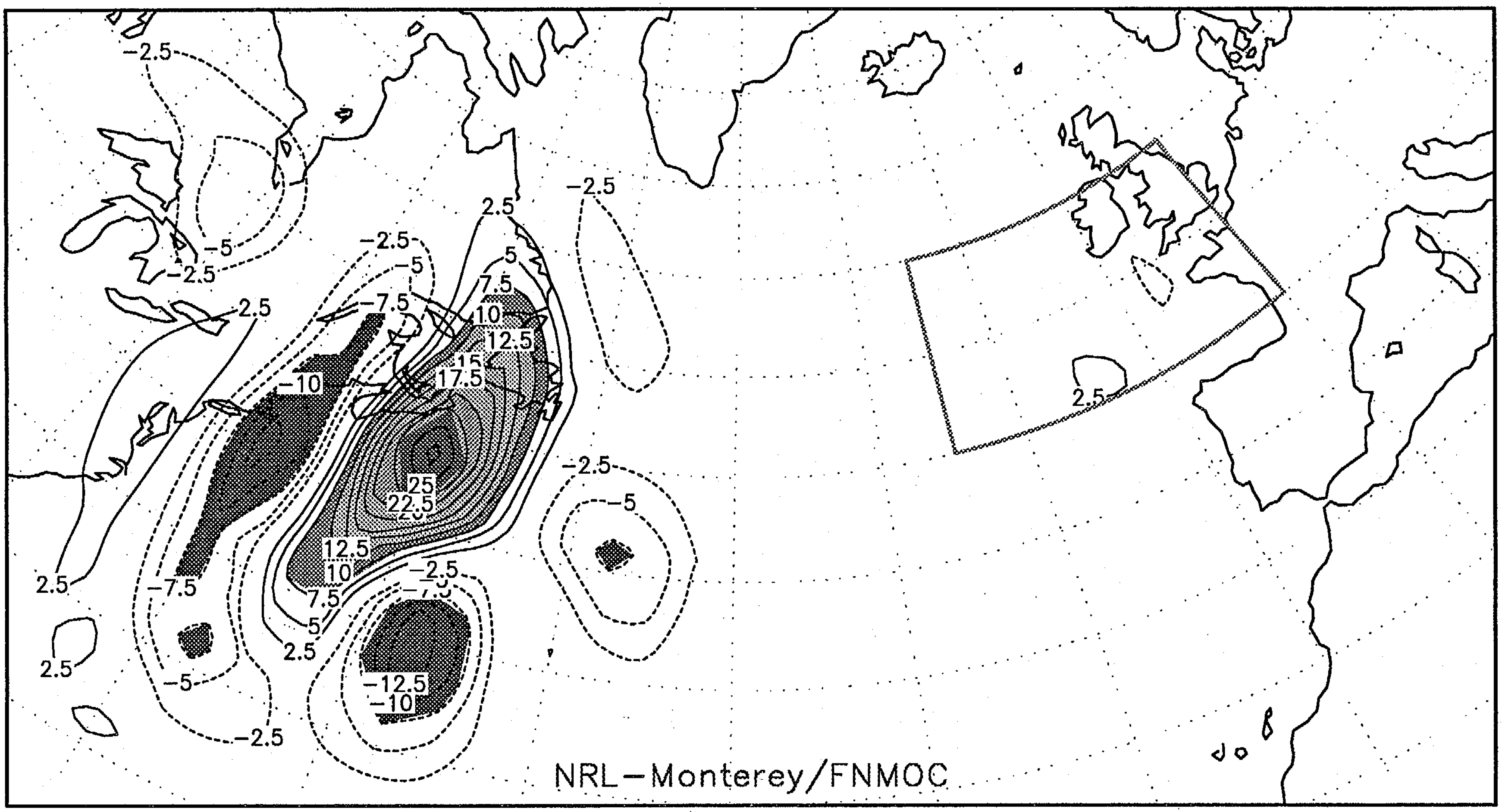


NOGAPS Singular Vector T47L18 (+84h,–48h)

Valid 1997021712
From 1997021600

SINGULAR VECTOR at TARGETED OBSERVING TIME

SV#1 Initial TEMP 680hPa MSA Amp=20.7

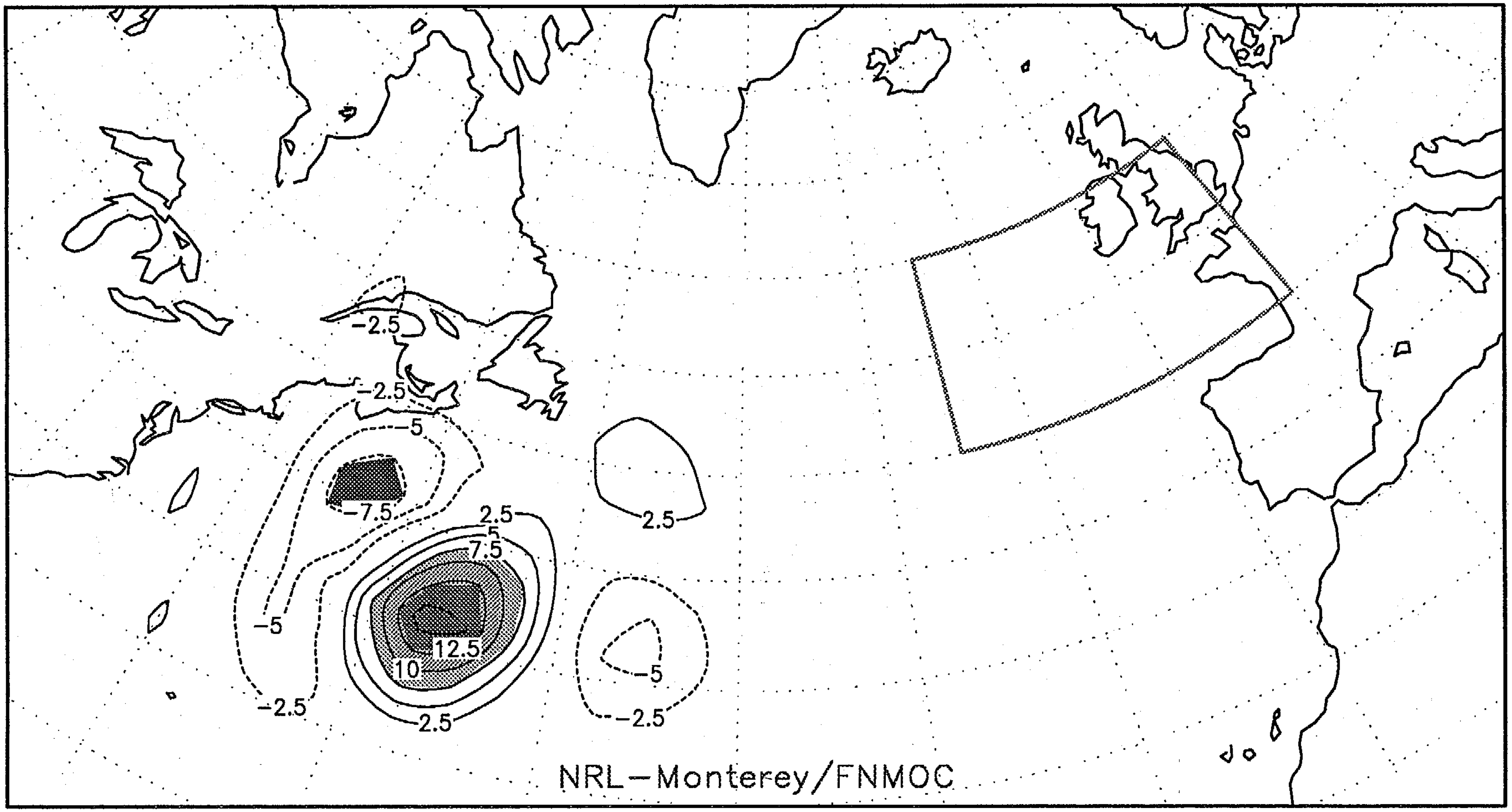


NOGAPS Singular Vector T47L18 (+84h,-48h)

Valid 1997021712
From 1997021600

SINGULAR VECTOR at TARGETED OBSERVING TIME

SV#1 Initial TEMP 850hPa MSA Amp=20.7

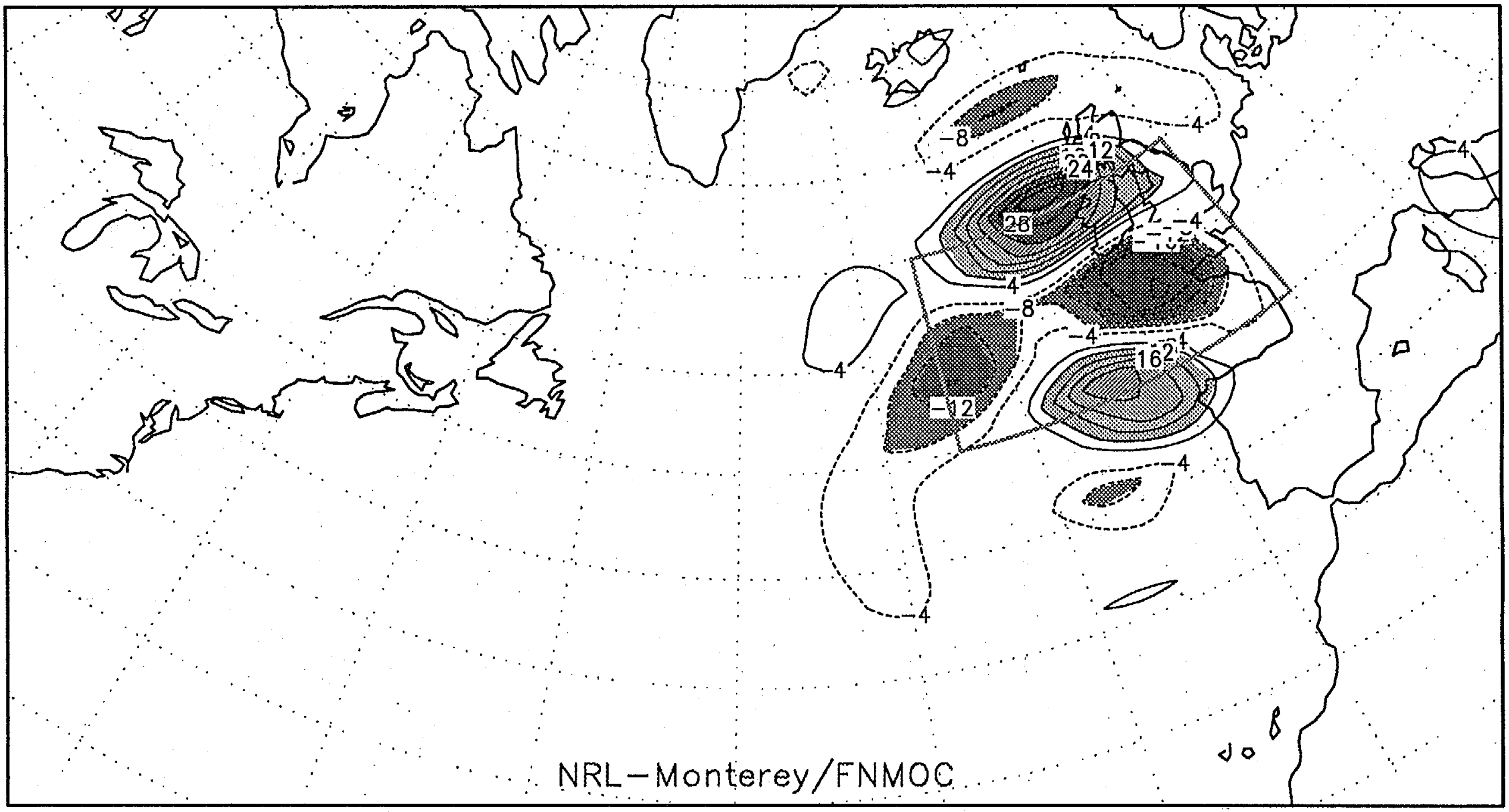


NOGAPS Singular Vector T47L18 (+84h,-48h)

Valid 1997021712
From 1997021600

SINGULAR VECTOR at FORECAST VERIFICATION TIME

SV#1 Final VOR($x10^4$) 850hPa MSA Amp=20.7

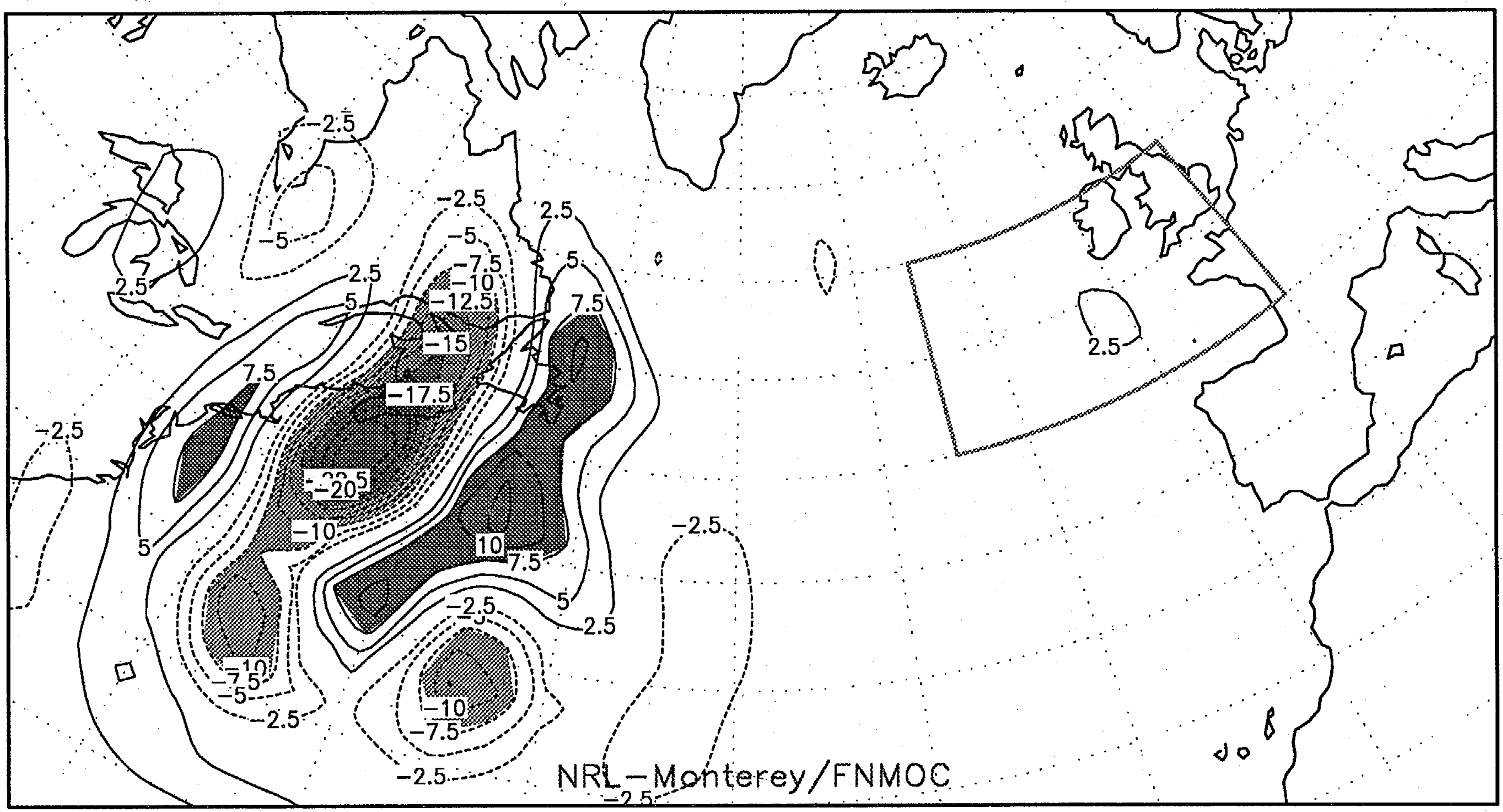


NOGAPS Singular Vector T47L18 (+84h,−48h)

Valid 1997021912
From 1997021600

SINGULAR VECTOR at TARGETED OBSERVING TIME

SV#2 Initial TEMP 680hPa MSA Amp=17.5

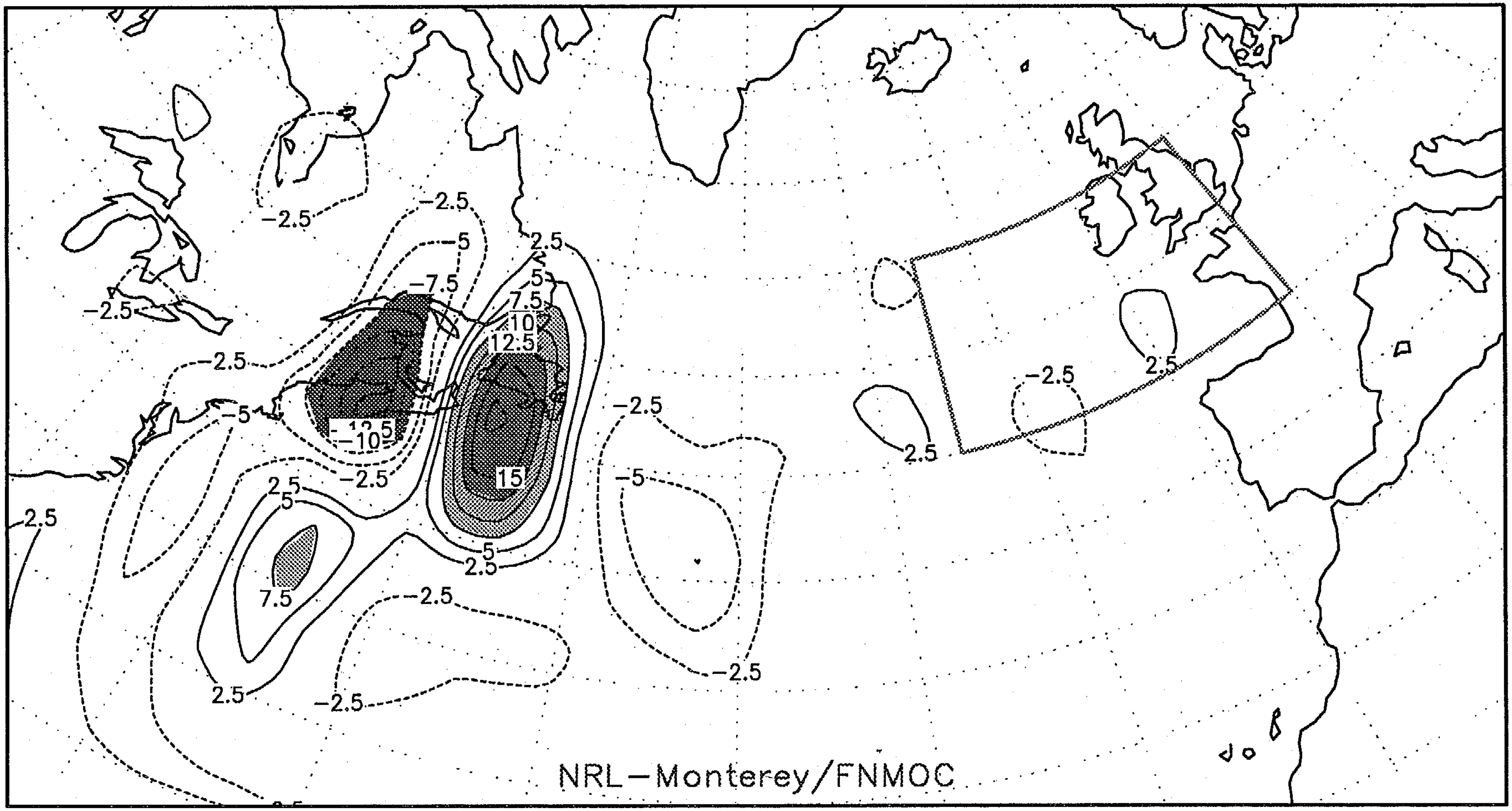


NOGAPS Singular Vector T47L18 (+84h,-48h)

Valid 1997021712
From 1997021600

SINGULAR VECTOR at TARGETED OBSERVING TIME

SV#3 Initial TEMP 680hPa MSA Amp=10.9

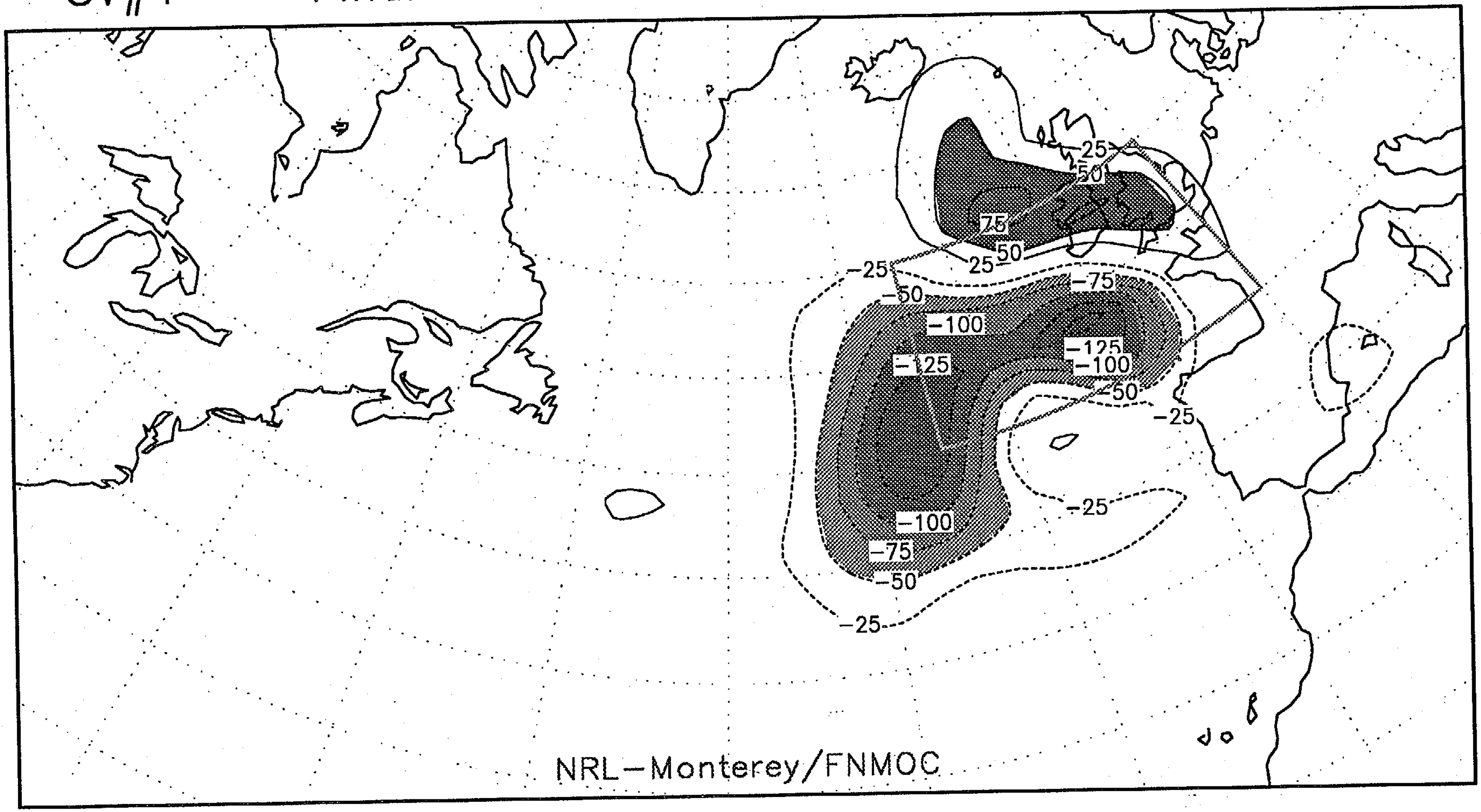


NOGAPS Singular Vector T47L18 (+84h,-48h)

Valid 1997021712
From 1997021600

SINGULAR VECTOR at FORECAST VERIFICATION TIME

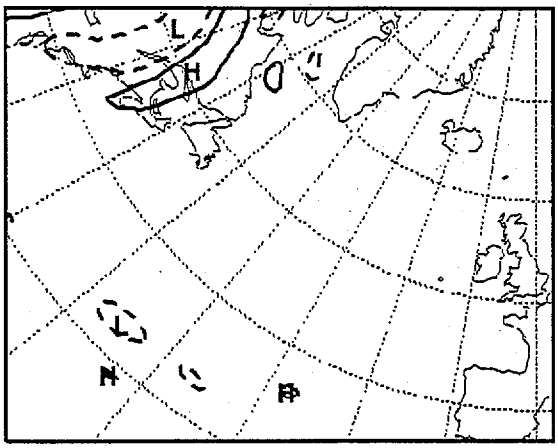
SV#1 Final TEMP 850hPa MSA Amp=20.7



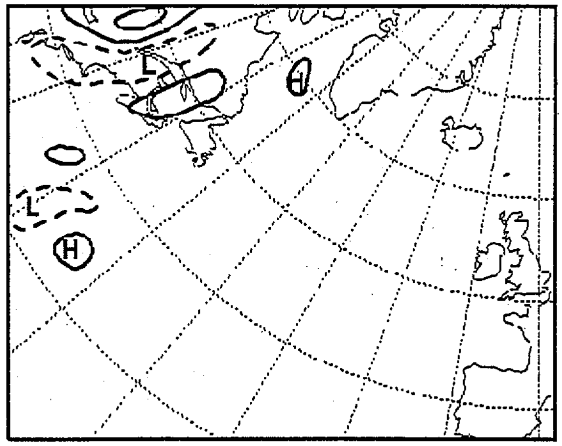
NOGAPS Singular Vector T47L18 (+84h,-48h)

Valid 1997021912
From 1997021600

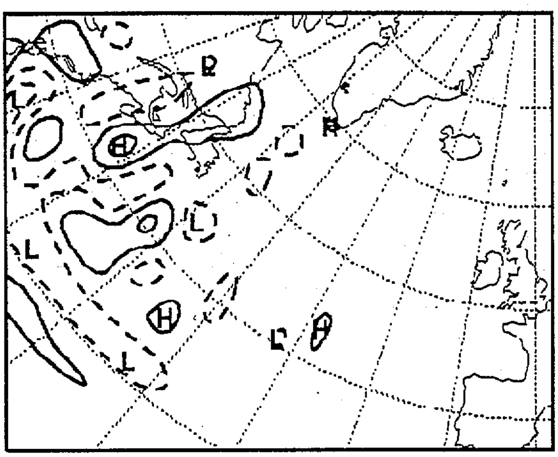
17 FEB 97 12Z - 48h OTI - VOR -SV= 1-H- 7000 m



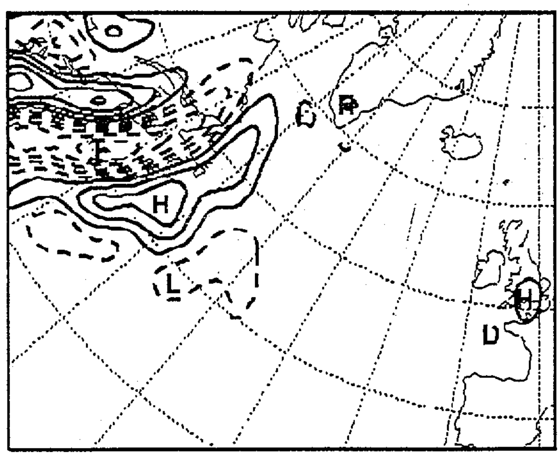
17 FEB 97 12Z - 48h OTI - T -SV= 1-H- 7000 m



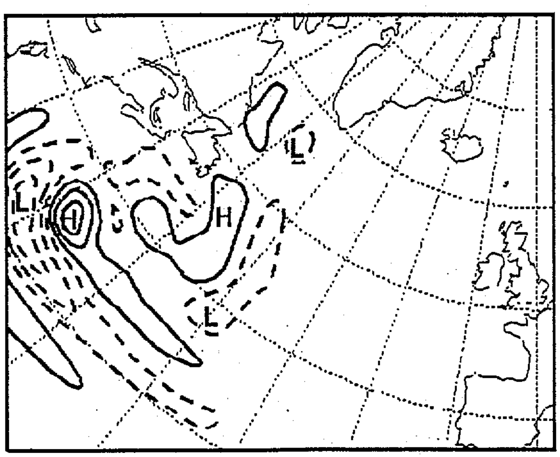
17 FEB 97 12Z - 48h OTI - VOR -SV= 1-H- 3100 m



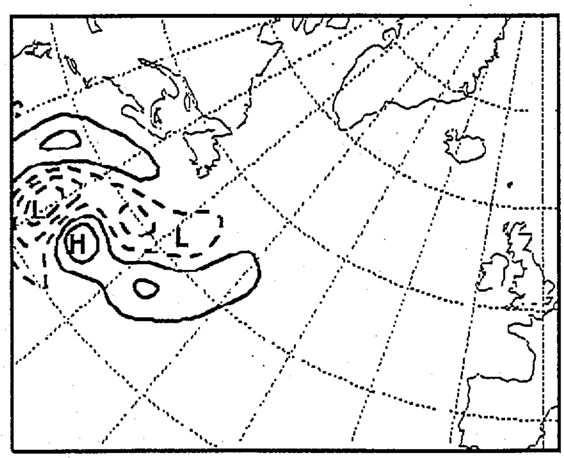
17 FEB 97 12Z - 48h OTI - T -SV= 1-H- 3100 m



17 FEB 97 12Z - 48h OTI - VOR -SV= 1-H- 000 m

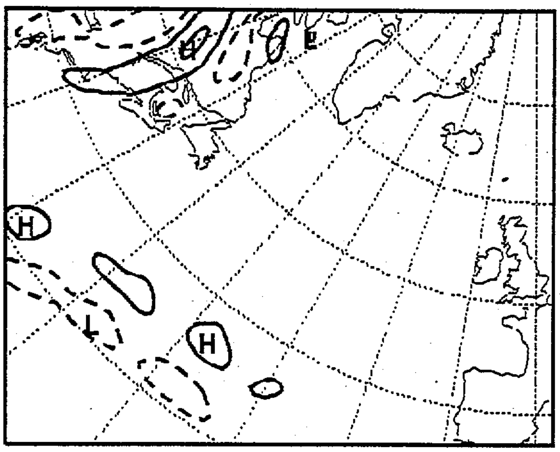


17 FEB 97 12Z - 48h OTI - T -SV= 1-H- 000 m

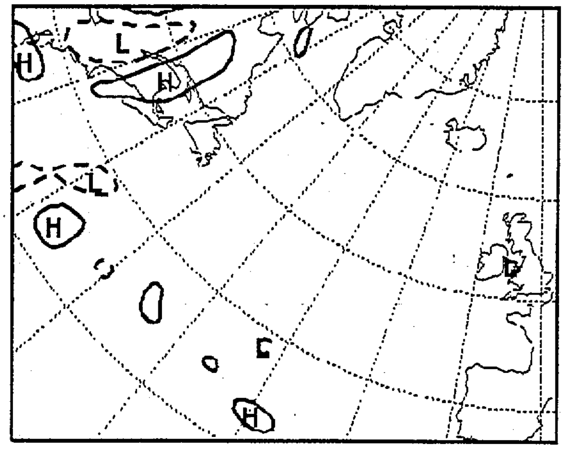


MAGICS 5.2 munin - emos Sun Feb 16 00:22:51 1997 - AMRB-svifs970217 48h

17 FEB 97 12Z - 48h OTI - VOR -SV= 2-H- 7000 m



17 FEB 97 12Z - 48h OTI - T -SV= 2-H- 7000 m



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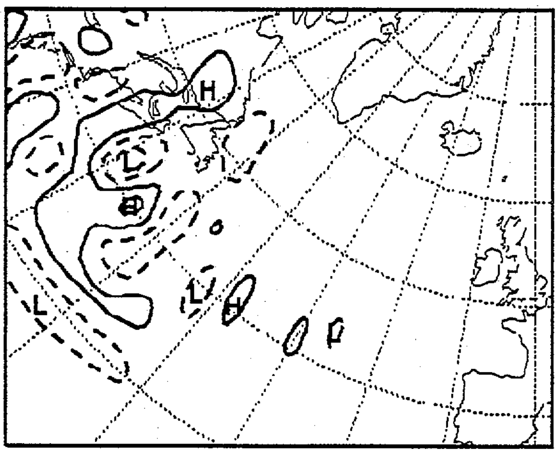
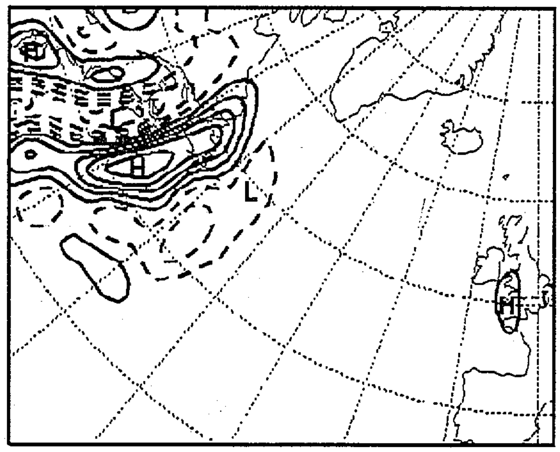


17 FEB 97 12Z - 48h OTI - T -SV= 2-H- 3100 m



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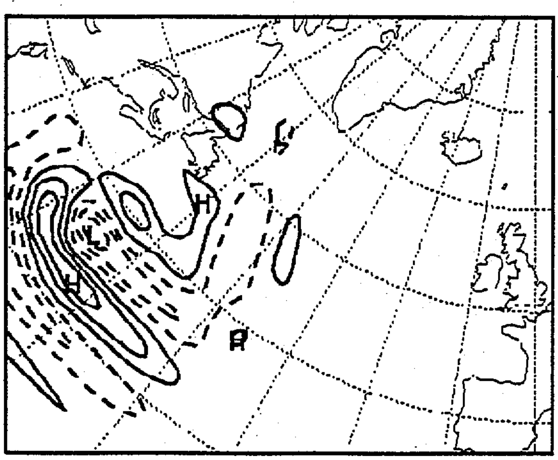

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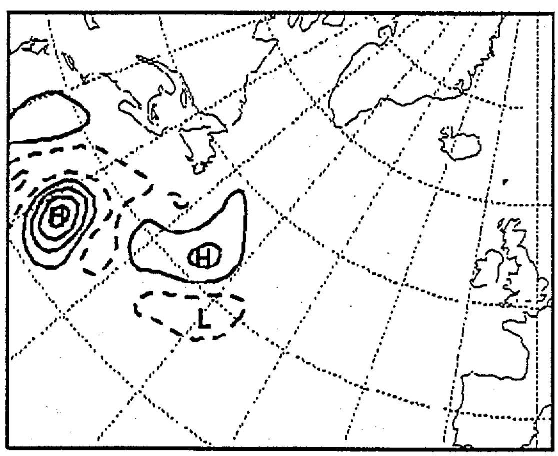

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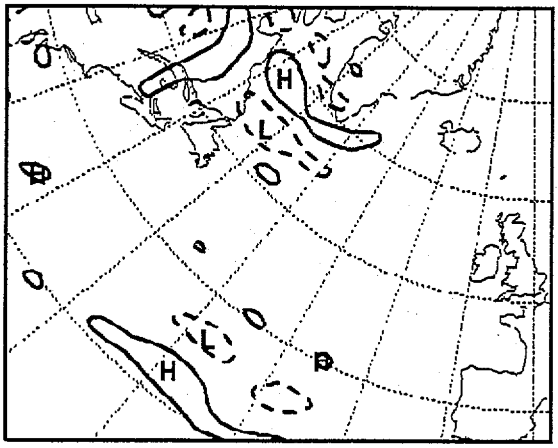

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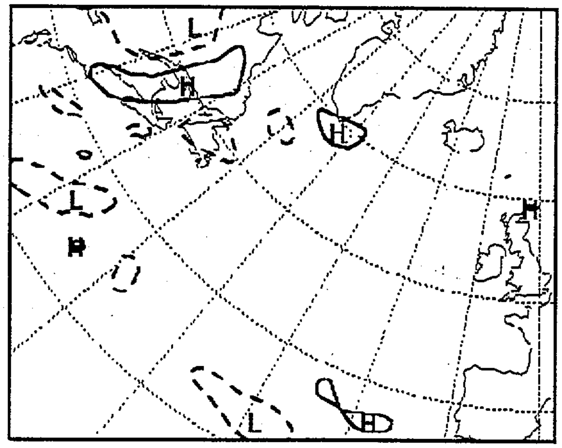

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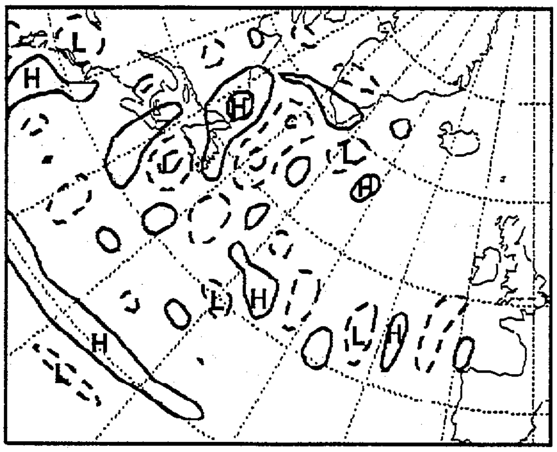
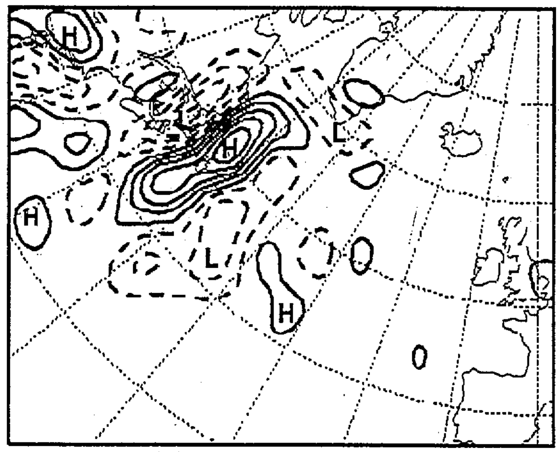


17 FEB 97 12Z - 48h OTI - T -SV= 3-H- 3100 m



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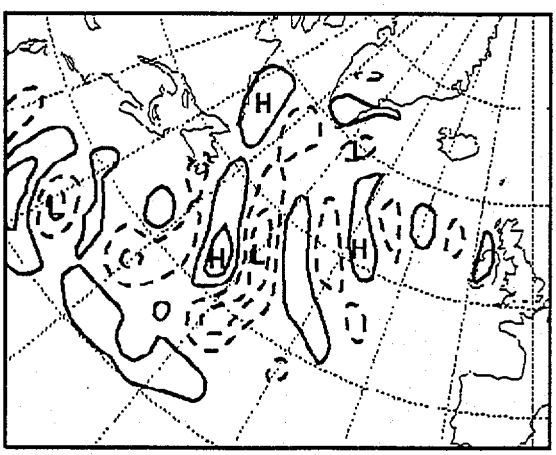

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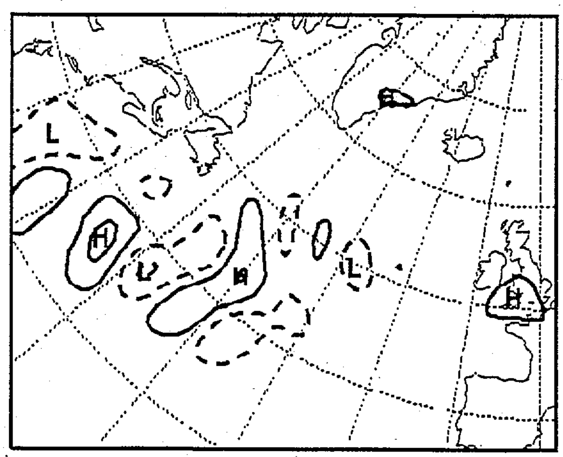
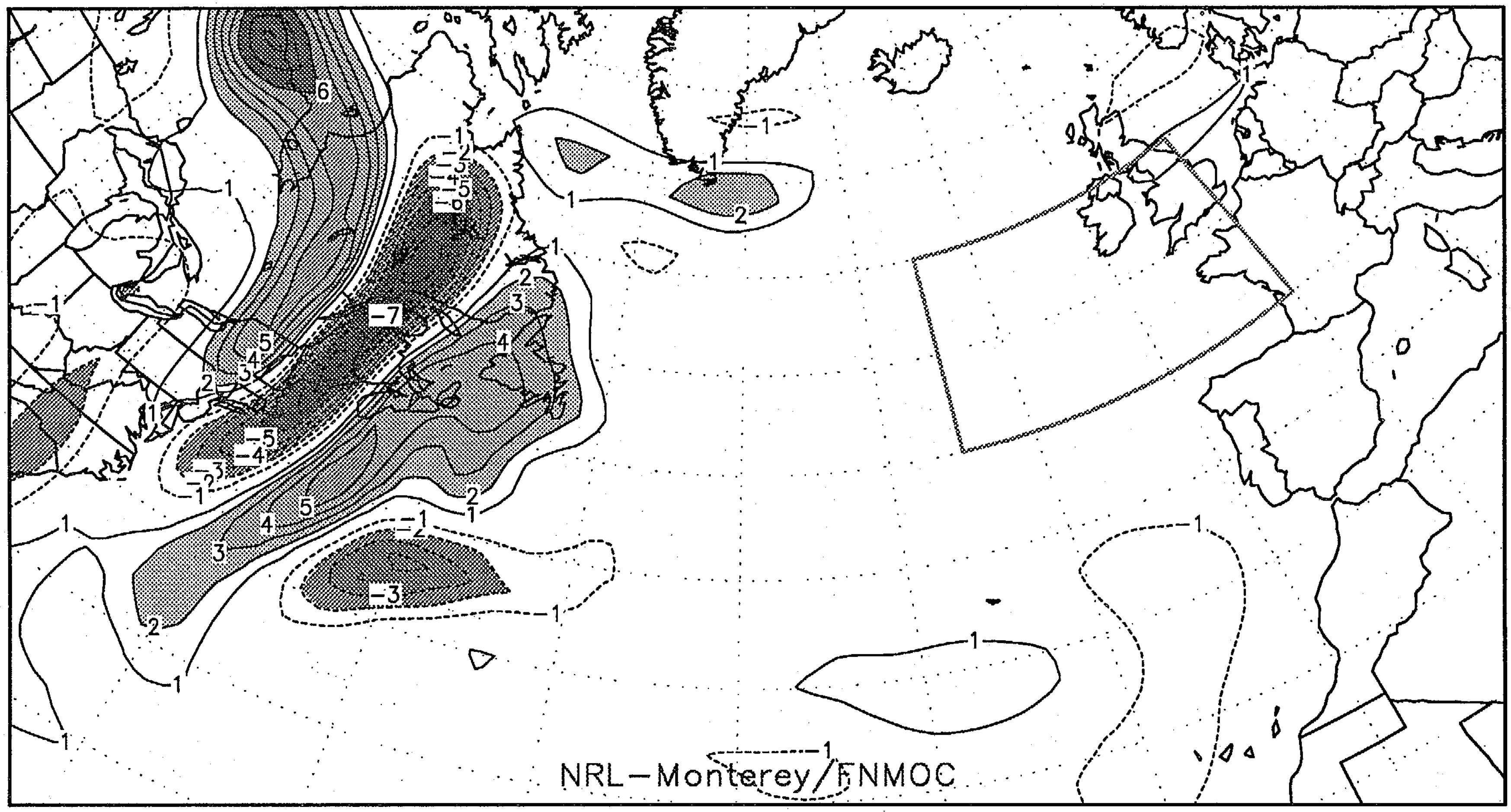


MAGICS 5.2 munin - emos Sun Feb 16 00:20:04 1997 - AMRD-svifs970217 48h

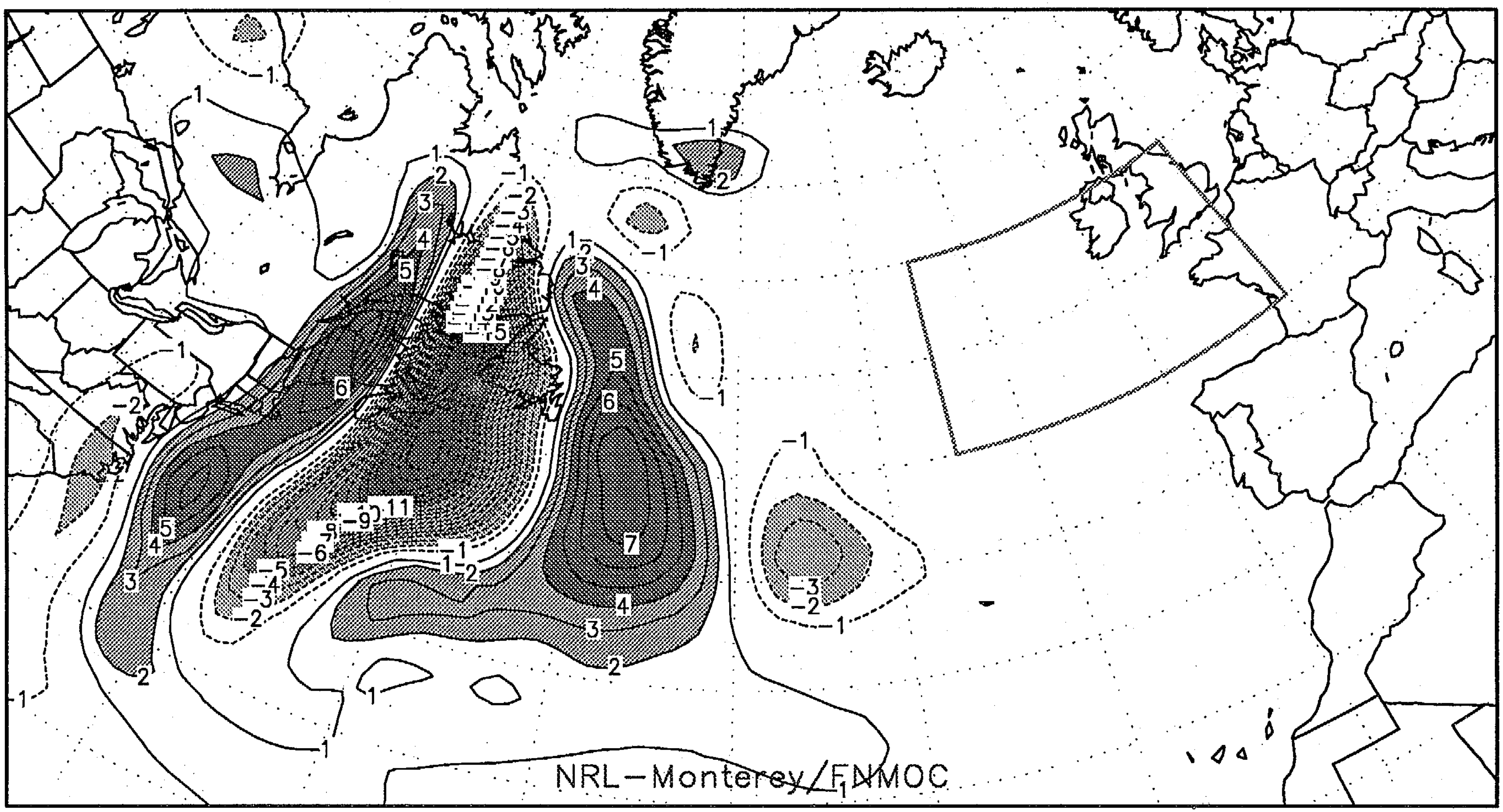
490hPa dJ/d(TEMPERATURE) ci=1.0×10^{-7}



NOGAPS Adjoint Sensitivity T79L18 (+84h,-48h) Target Valid: 1997021712

Forecast Valid: 1997021912

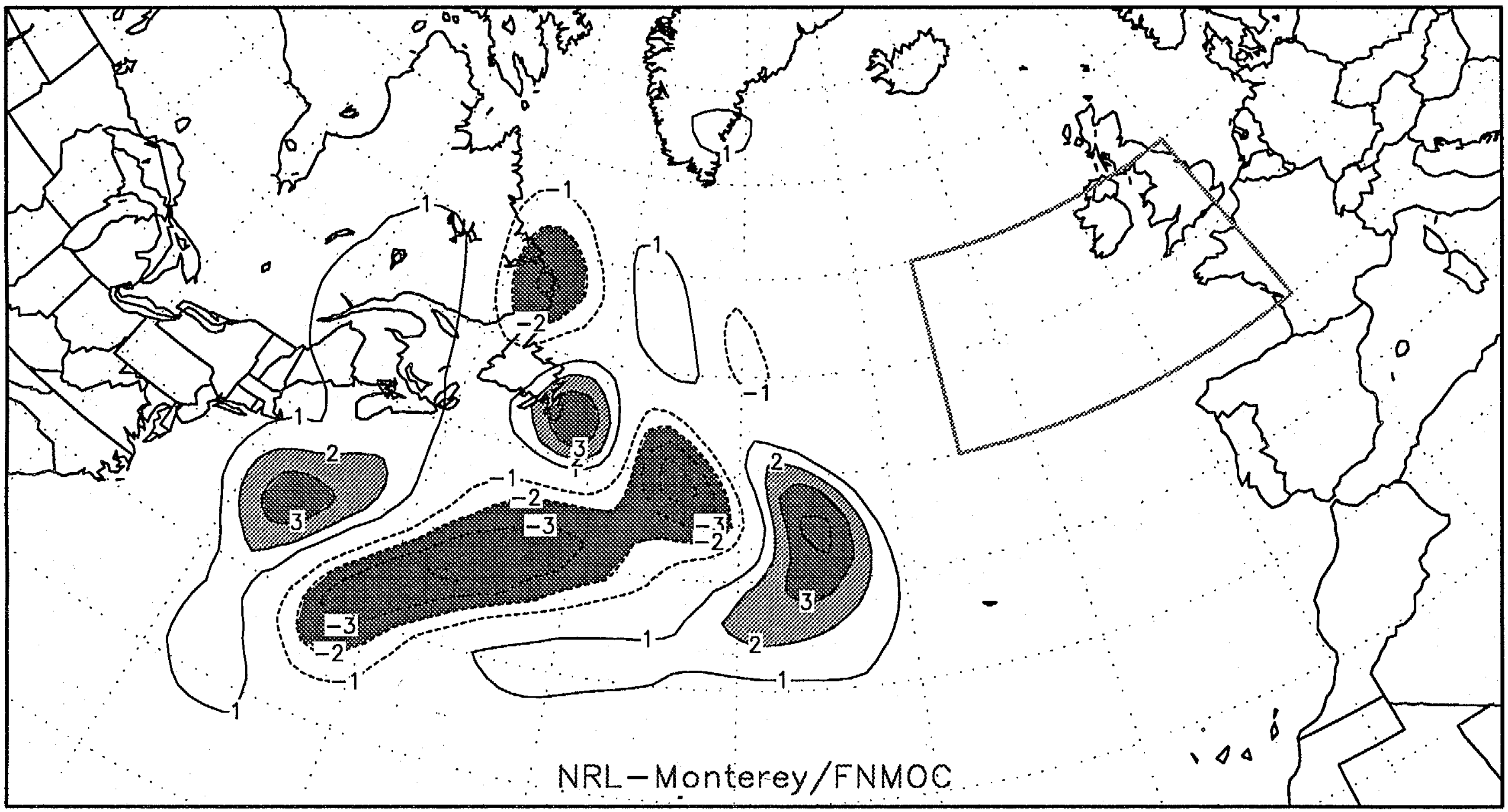
680hPa dJ/d(TEMPERATURE) ci=1.0×10^{-7}



NOGAPS Adjoint Sensitivity T79L18 (+84h,−48h) Target Valid: 1997021712

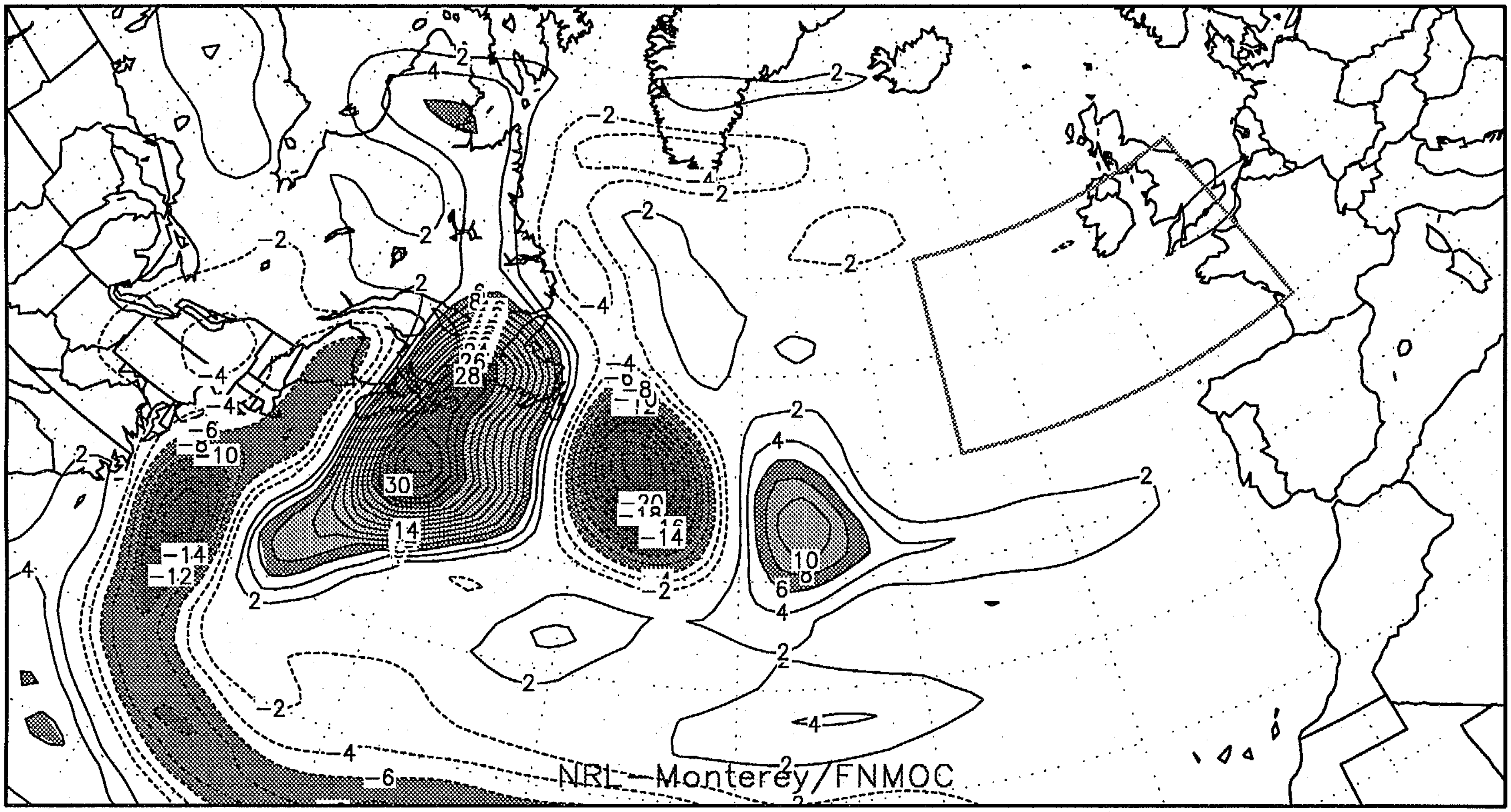
Forecast Valid: 1997021912

850hPa dJ/d(TEMPERATURE) ci=1.0×10^{-7}



NOGAPS Adjoint Sensitivity T79L18 (+84h,-48h) Target Valid: 1997021712
Forecast Valid: 1997021912

680hPa dJ/d(U-COMP) ci=2.0x10^{-8}



NOGAPS Adjoint Sensitivity T79L18 (+84h,−48h) Target Valid: 1997021712

Forecast Valid: 1997021912

Adjoint Model and A Quasi-inverse Linear Model
of NCEP Global Spectral Model
in FASTEX Experiment

Zhaoxia Pu and Eugenia Kalnay
EMC/NCEP

Thanks to: ***Tim Marchok, Zoltan Toth and***
I. Szunyogh and Mark Iredell

● Goal

Determine the location where the observations are most needed.

● Method

Take forecast difference between ensemble members at final time ($\delta x = X^a_T - X^b_T$, $X_T = M(X(t_0))$) . Mask targetted area (FASTEX). Trace back this area to observational time using adjoint and quasi-inverse method.

❶ ADJOINT Method

define a cost function based on total energy norm (error norm) as:

$J = \| \delta x \|^2$

Gradient of J ----- sensitivity patterns

method similar to NRL, French.

❷ The "quasi-inverse" Linear Method (new)

The TLM approximation:

$$M_t(X_0+\delta X_0)-M_t(X_0)=L_t\delta X_0+O(\delta X_0)^2$$

Quasi-inverse linear

$$\delta X_0 \approx L_t^{-1}(M_t(X_0+\delta X) - M_t(X_0))$$

We approximate L^{-1}, the inverse operator, by integrating the TLM backwards in time. i.e., with a negative time step. Since the sign of the diffusive processes cannot be integrated backwards, we change the sign of the surface friction and diffusion term.

● The Model

❍ Nonlinear forecast model

NCEP operational global medium range forecast model. With lower resolution T62 and 28 vertical sigma levels.

❍ Adjoint and tangent linear model

Navon et al. 1992, adiabatic version
Pu et al. 1995,
-------- An adiabatic version with surface friction and vertical mixing (Buizza 1993).

❍ Quasi-inverse Linear Model (Pu & Kalnay 1996)

TLM with negative time step and reversed sign of a diffusion term

● Performance for FASTEX

During January ----- February of 1997

❒ Procedure

At 00Z and 12Z
T+72 h
Global Ensemble
Forecast Spread

↓

Mask Filter
O(10W, 50N)
R=1000km

"Basic Flow"
Every 6h forecast

↓

Spread in
" Verification area"

↓

Adjoint and/or Quasi-inverse
Linear Method

↓

Sensitivity Field
at T+24, T+36, T+48, T+60h → Discussion

ENSEMBLE TRANSFORMATION AND ADAPTIVE OBSERVATIONS

Craig H. Bishop, Pennsylvania State University.

Zoltan Toth, Istvan Szunyogh, NCEP.

Sharanya Majumdar, Pennsylvania State University.

April 1997

(Many thanks to NCEP and RPN)

ENSEMBLE TRANSFORM TECHNIQUE.

Uses linear combinations of ensemble perturbations to transform an ensemble that is appropriate for one particular observational network into an ensemble that would be appropriate for *any* other observational network.

Utilizes singular vector decompositions of *nonlinear* ensemble perturbations to rapidly estimate the prediction error variance associated with a wide range of different possible deployments of observational resources. Optimal deployment minimizes the estimate of prediction error variance.

If the ensemble perturbations were linear and if they spanned the state vector of the model, the ensemble transform technique would produce identical perturbations to the optimal SVs discussed in Ehrendorfer and Tribbia (1997).

Useful for directing mobile observing platforms to locations where they will have a positive impact on forecast error, deciding which observations will have minimal impact on forecast accuracy, diagnosing forecast busts and ensemble construction.

Any Ensemble, Full Physics, Very Fast.

OVERVIEW

Matching ensemble perturbations to observational networks

(a) The perfect but impractical prototype calculation

(b) The practical calculation

The moderation of aliasing problems via SV decomposition

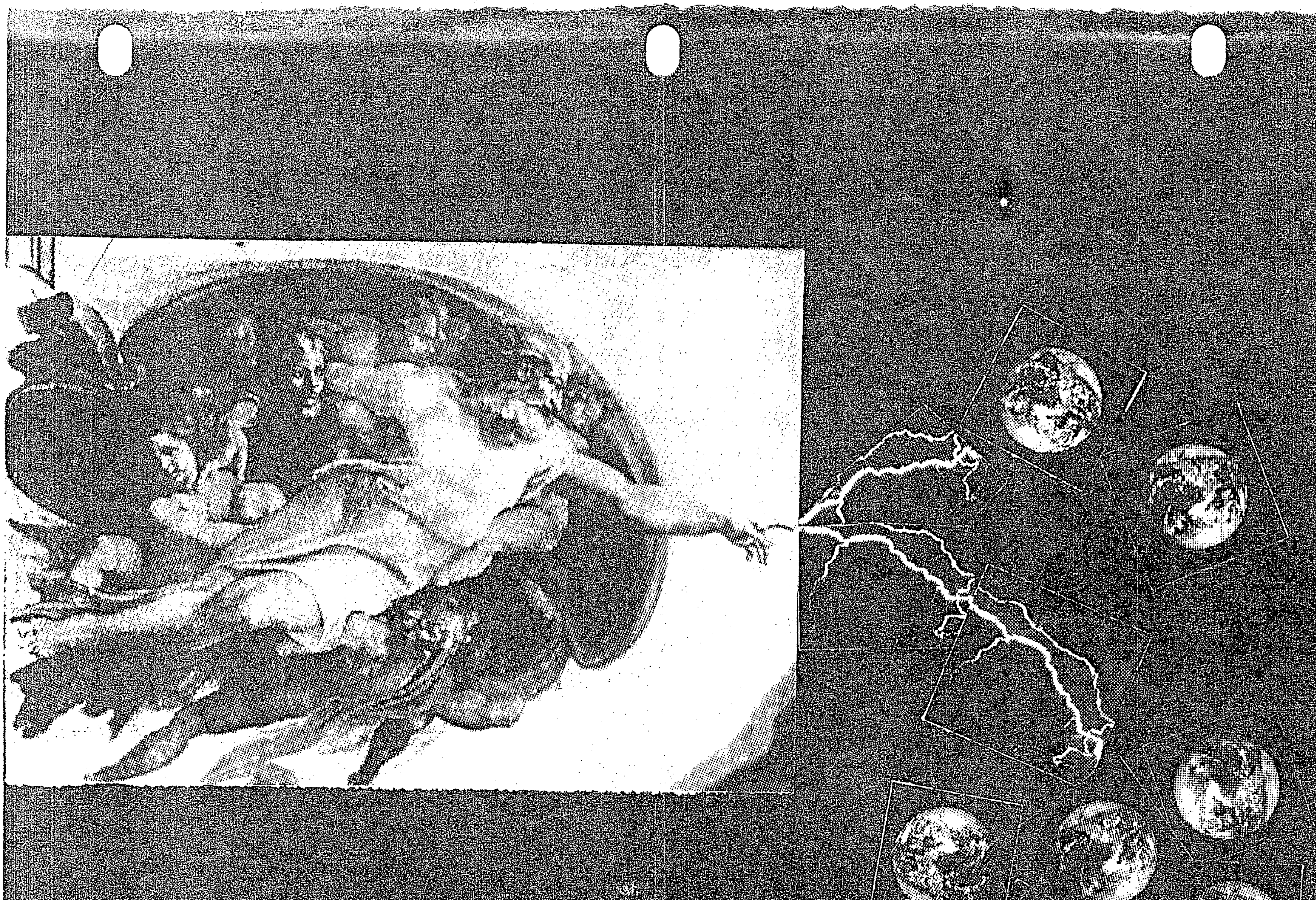
Time continuity of data sensitive region

Tests

(a) Idealized model

(b) A data denial experiment from NCEP

Conclusions



The perfect but impractical calculation

$$\lambda_i = \mathbf{e}_i^T \left(\frac{\underline{\underline{\mathbf{V}}}(t_a) \ \underline{\underline{\mathbf{V}}}(t_a)^T}{N} \right) \mathbf{e}_i$$

$$= \mathbf{e}_i^T \ \underline{\underline{\mathbf{A}}}(t_a) \ \mathbf{e}_i .$$

$\underline{\underline{\mathbf{V}}}(t_a)$ is the matrix whose *N* columns are realisations of analysis error. Each analysis error has dimension *M.*

$\mathbf{e}_i$ is the ith vector of orthonormal basis

c_{ni} = projection of nth realisation onto $\mathbf{e}_i$

=coefficient of $\mathbf{e}_i$ in nth realization

λ_i is mean value of c_{ni} over all realisations

$\underline{\underline{\mathbf{A}}}(t_a)$ is the *MxM* analysis error covariance matrix

$\underline{\underline{\mathbf{P}}}(t)$ is the *MxM* *prediction* error covariance matrix; it is given by replacing t_a by t in the definition of $\underline{\underline{\mathbf{A}}}(t_a)$

$$\underline{\underline{\mathbf{P}}}(t) = \frac{\underline{\underline{\mathbf{V}}}(t) \ \underline{\underline{\mathbf{V}}}(t)^T}{N} .$$

Let $\underline{\underline{X}}_e(t)$ be the *MxM* matrix whose columns are *any* set of *M* independent ensemble perturbations.

Let $\underline{\underline{Y}}_e(t)$ be the matrix of transformed ensemble perturbations; i.e.

$$\underline{\underline{Y}}_e(t) = \underline{\underline{X}}_e(t) \; \underline{\underline{C}},$$

where $\underline{\underline{C}}$ is the transformation matrix. If the $\underline{\underline{C}}$ matrix is chosen so that

$$\underline{\underline{Y}}_e(t_a)^T \underline{\underline{A}}^{-1}(t_a) \underline{\underline{Y}}_e(t_a) = \underline{\underline{I}}$$

then

$$\underline{\underline{A}}^{-1}(t_a) = \left(\underline{\underline{Y}}_e(t_a)^T\right)^{-1}\left(\underline{\underline{Y}}_e(t_a)\right)^{-1}$$

hence

$$\underline{\underline{A}}(t_a) = \underline{\underline{Y}}_e(t_a)\underline{\underline{Y}}_e(t_a)^T = \underline{\underline{X}}_e(t_a)\underline{\underline{C}}\underline{\underline{C}}^T\underline{\underline{X}}_e(t_a)^T$$

and

$$\underline{\underline{P}}(t) = \underline{\underline{Y}}_e(t)\underline{\underline{Y}}_e(t)^T = \underline{\underline{X}}_e(t)\underline{\underline{C}}\underline{\underline{C}}^T\underline{\underline{X}}_e(t)^T$$

Interestingly, there are an infinite number of appropriate transformations. If $\underline{\underline{B}}^T = \underline{\underline{B}}^{-1}$ then

$$\underline{\underline{X_e}}(t)\,\underline{\underline{CBB}}^T\underline{\underline{C}}^T\underline{\underline{X_e}}(t)^T = \underline{\underline{Z_e}}(t)\,\underline{\underline{Z_e}}(t)^T = \underline{\underline{P}}(t)\,.$$

where

$$\underline{\underline{Z_e}}(t) = \underline{\underline{X_e}}(t)\,\underline{\underline{C}}\;\underline{\underline{B}} = \underline{\underline{Y_e}}(t)\,\underline{\underline{B}}\,.$$

This is an extremely useful property as it allows us to find appropriately transformed ensembles whose members are orthogonalized and ordered with respect to some measure of error, ϵ.

For example, could find a $\underline{\underline{B}}$ such that the transfomed ensemble perturbations, $\underline{z_e}(t)$, are orthogonal with respect to the following measure of forecast error.

$$\epsilon = \underline{z}(t_v)^T \underline{\underline{F}}^{-1} \underline{z}(t_v)$$

Such vectors are the singular vectors (SVs) of this measure of prediction error variance.

The SVs which maximize this measure of prediction error are "optimal" in the sense that they explain more prediction error variance than any other SV, Ehrendorfer and Tribbia (JAS, 1997, p.286)

If one is solely interested in a normalized prediction error over some localized verification region, one could obtain a normalized prediction error covariance matrix, $\underline{\underline{P}}^*(t)$, by replacing, $\underline{\underline{Y}}_e(t)$ by $\underline{\underline{F}}^{-1/2}\underline{\underline{Y}}_e(t)$ where $\underline{\underline{F}}^{-1/2}$ is a positive definite diagonal matrix operator which normalizes variables and sets them to zero in regions outside of the verification region. In algebraic terms,

$$\underline{\underline{P}}^*(t) = \underline{\underline{F}}^{-1/2}\underline{\underline{Y}}_e(t)\,\underline{\underline{Y}}_e(t)^T\underline{\underline{F}}^{-1/2} = \underline{\underline{F}}^{-1/2}\underline{\underline{P}}(t)\,\underline{\underline{F}}^{-1/2}.$$

The practical calculation

Use available ensemble perturbations and all available information on analysis error covariance matrix in a direct application of above technique.

Illustration from Fastex

8 NCEP members and 9 RPN members in ensemble

Analysis error covariance matrix is assumed to be diagonal

Values of diagonal elements of analysis error covariance matrix are estimated from spread of RPN ensemble at initialization time.

Outside the target region,

a_{ii}=
1.5x(mean square of ensemble perturbations over whole globe)

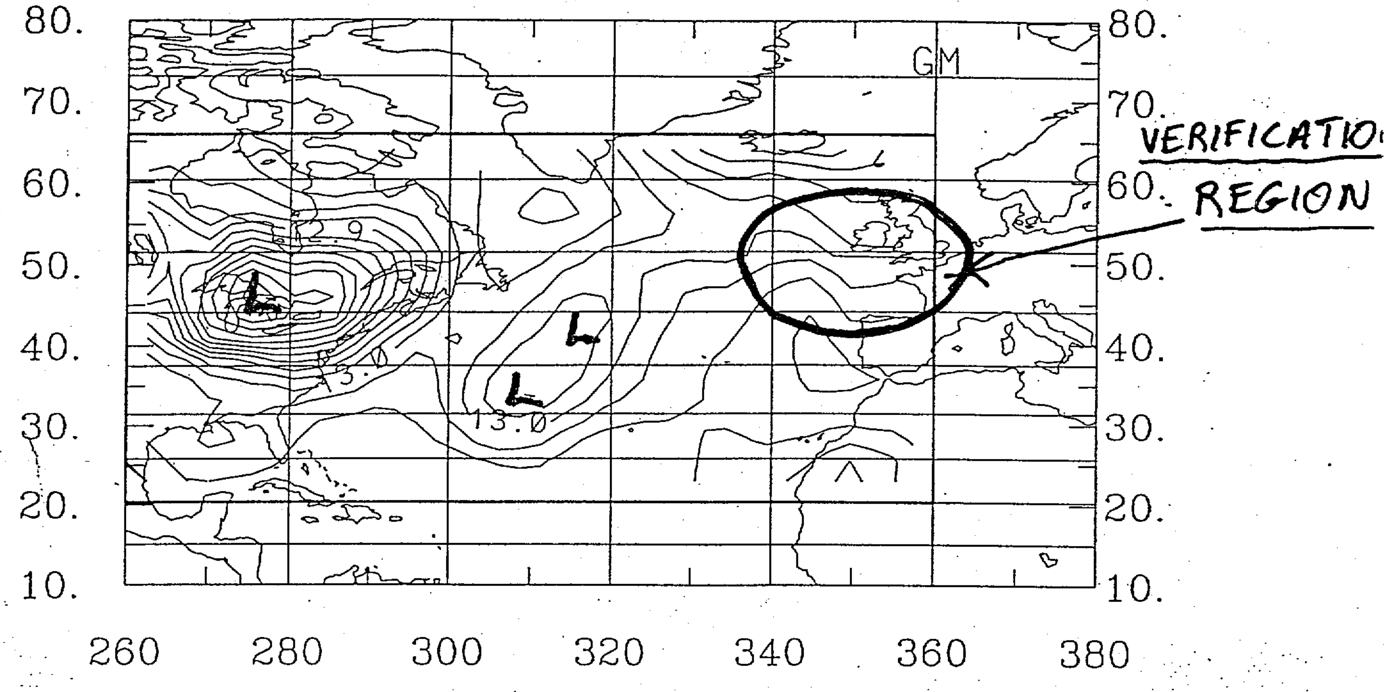
+0.5x(smoothed mean square of ensemble perturbations)

Inside the target region

a_{ii}=
1.0x(mean square of ensemble perturbations over whole globe)

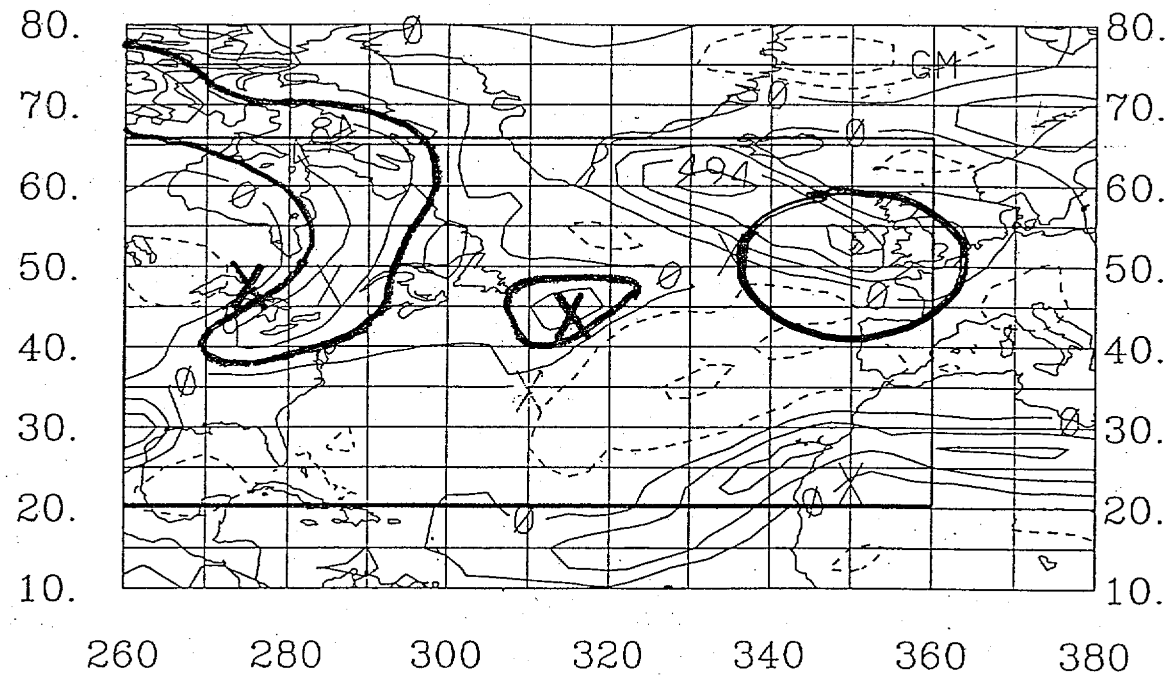
State vector only contains vorticity and streamfunction at 850mb, 500 mb and 250 mb

12.74(275.0E 47.7N),12.77(285.0E 47.7N),12.92(310.0E 34.4N),



ERRØR EXPLAINED BY 4 LEADING SV S ØF TRANSFØRMED ENS

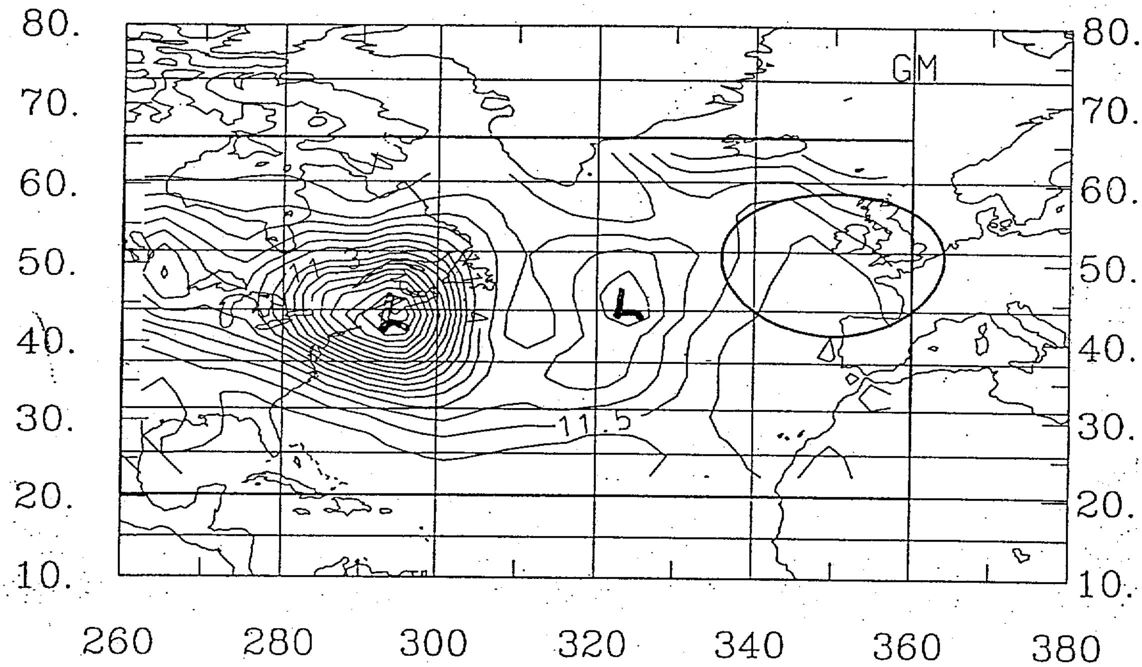
48 X FØR 48-108 1997021100



500 MB VØRTICITY. X S MARK IDEAL TARGET AREAS

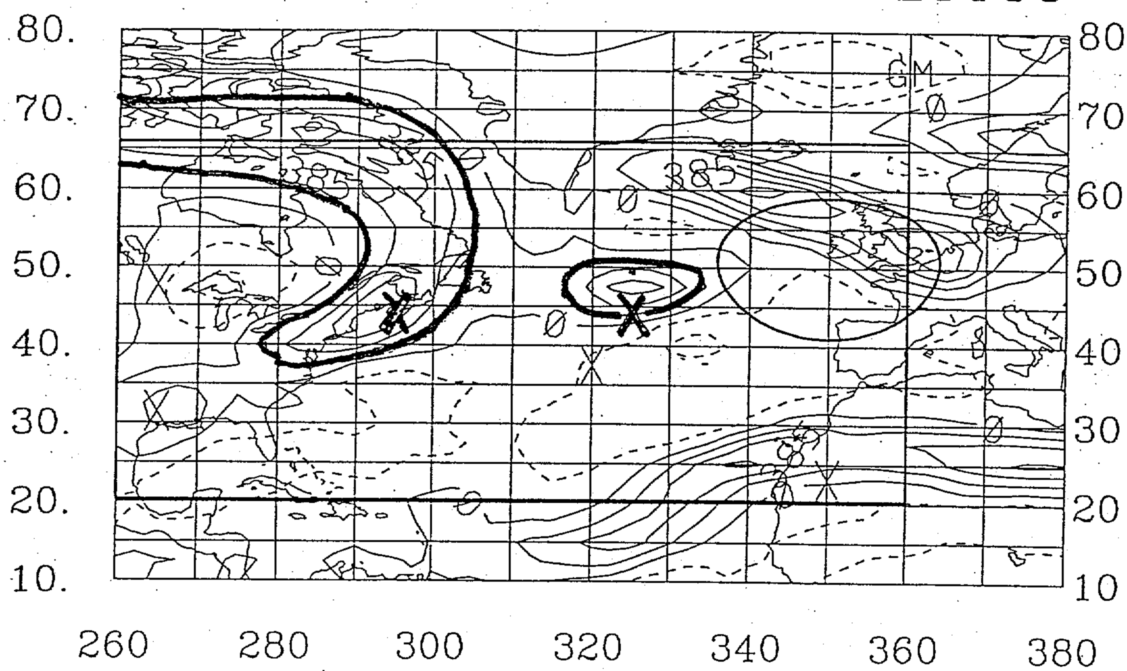
The estimate of prediction error was based on a forecast initialized at 0Z 11 Feb. 97.

11.13(295.0E 44.1N),11.33(265.0E 47.7N),11.37(325.0E 44.1N),



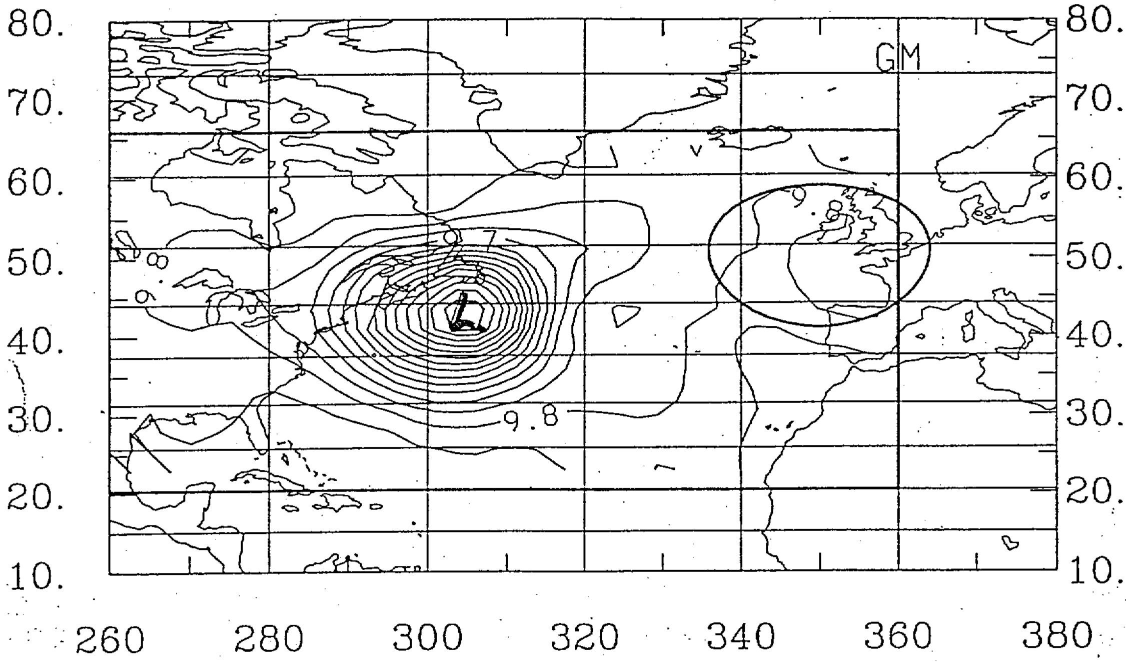
ERRØR EXPLAINED BY 4 LEADING SV S ØF TRANSFØRMED ENS

60 X FØR 60-108 1997021100



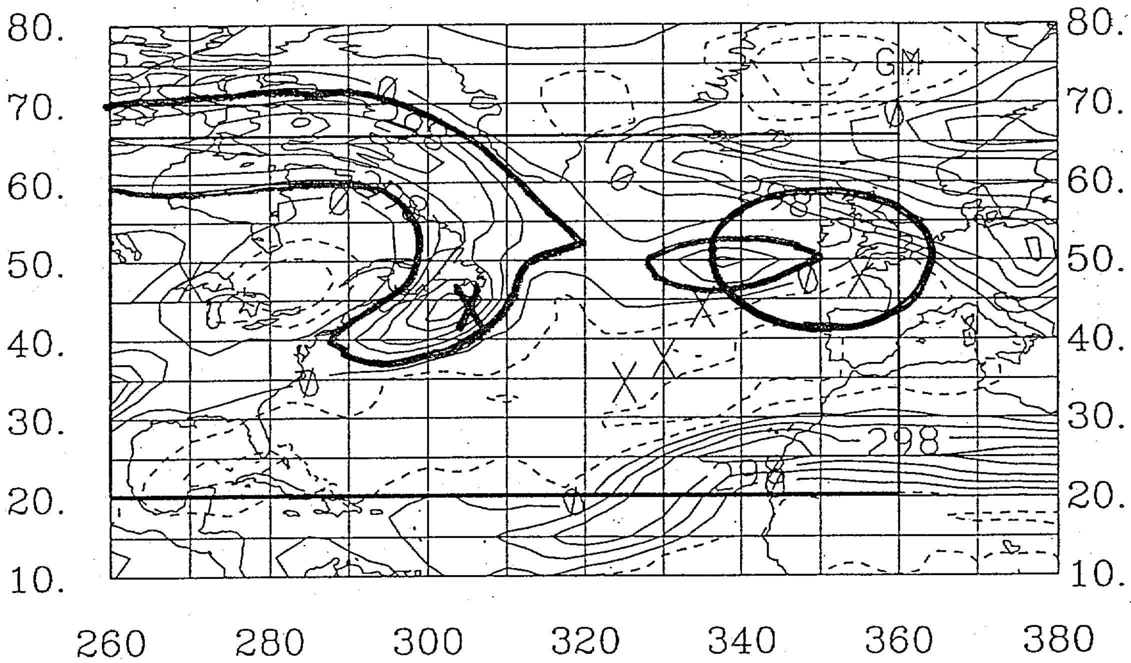
500 MB VØRTICITY. X S MARK IDEAL TARGET AREAS

9.31(305.0E 44.1N), 9.72(270.0E 47.7N), 9.73(355.0E 47.7N).



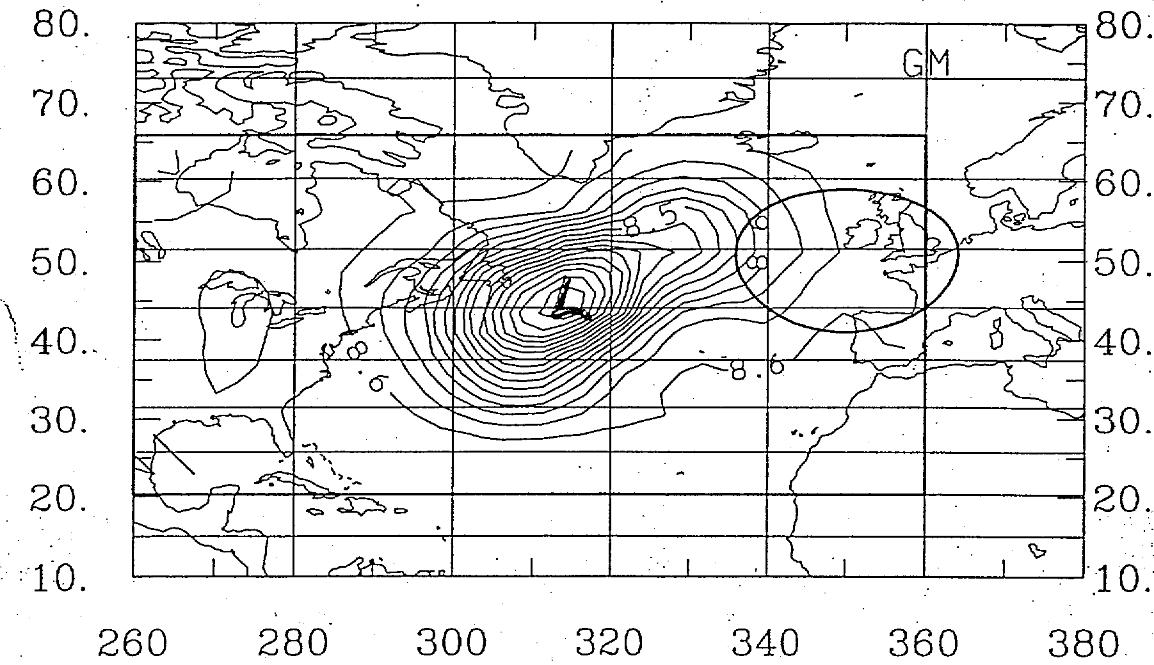
ERRØR EXPLAINED BY 4 LEADING SV S ØF TRANSFØRMED ENS

72 X FØR 72-108 1997021100



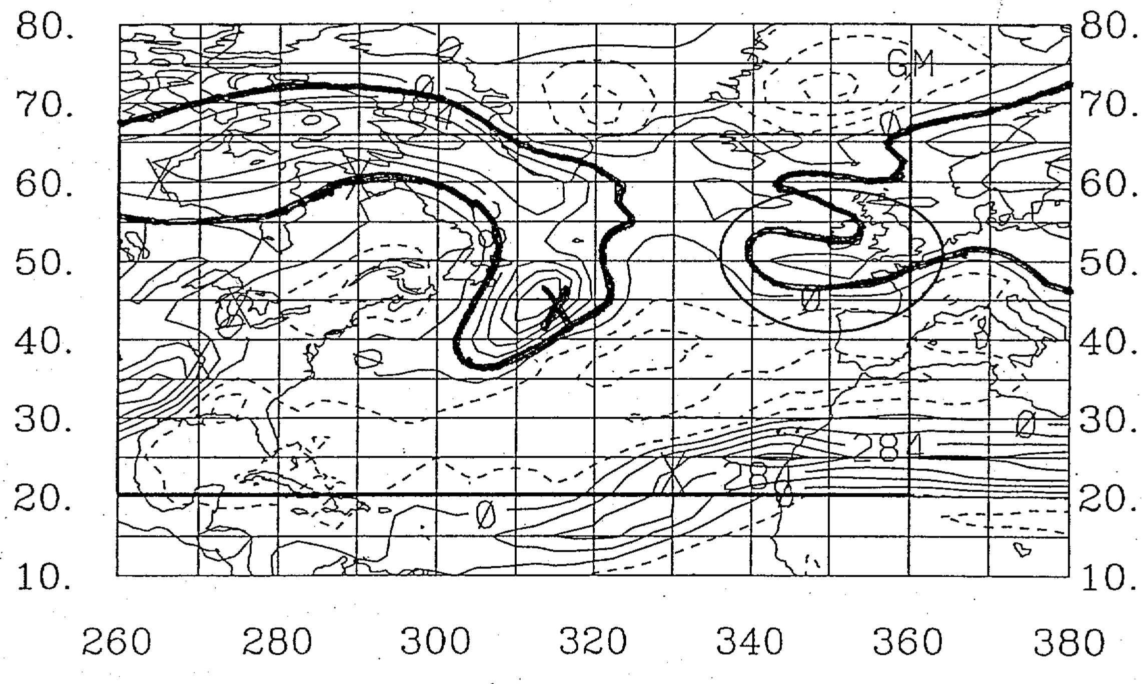
500 MB VØRTICITY. X S MARK IDEAL TARGET AREAS

8.12(315.0E 44.1N), 8.61(265.0E 60.4N), 8.63(275.0E 44.1N),



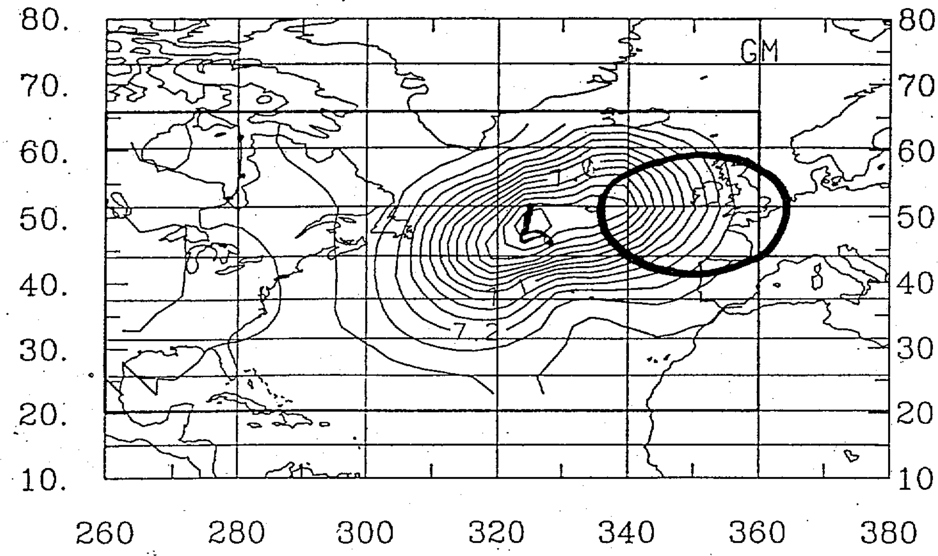
ERRØR EXPLAINED BY 4 LEADING SV S ØF TRANSFØRMED ENS

84 X FØR 84-108 1997021100



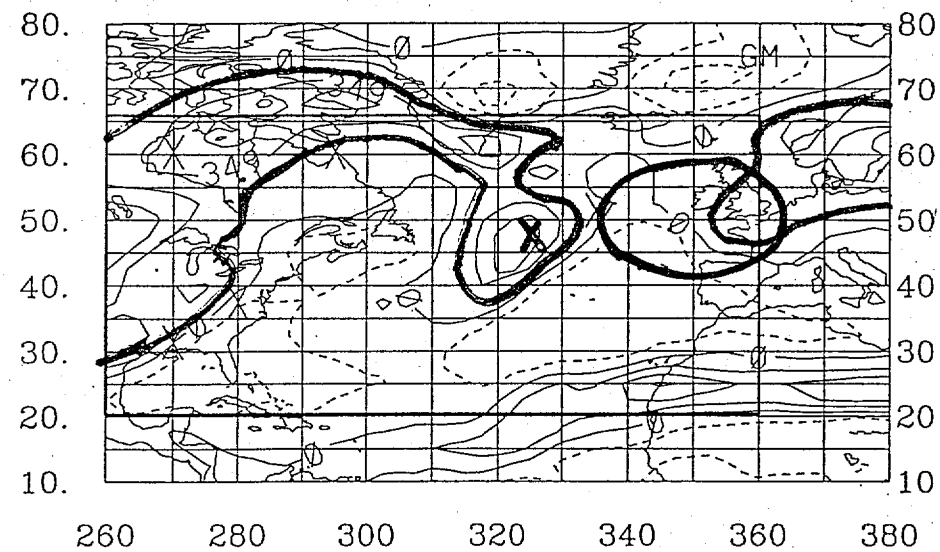
500 MB VØRTICITY. X S MARK IDEAL TARGET AREAS

6.78(325.0E 47.7N). 6.82(335.0E 51.5N). 7.19(270.0E 60.4N).

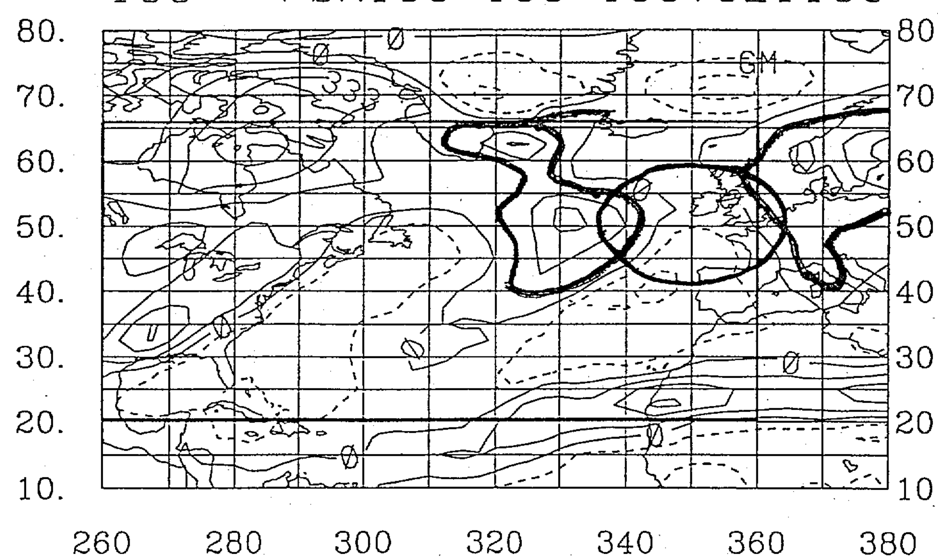


ERRØR EXPLAINED BY 4 LEADING SV S ØF TRANSFØRMED ENS

96 X FØR 96-108 1997021100



108 FØR108-108 1997021100



500 MB VØRTICITY. X S MARK IDEAL TARGET AREAS

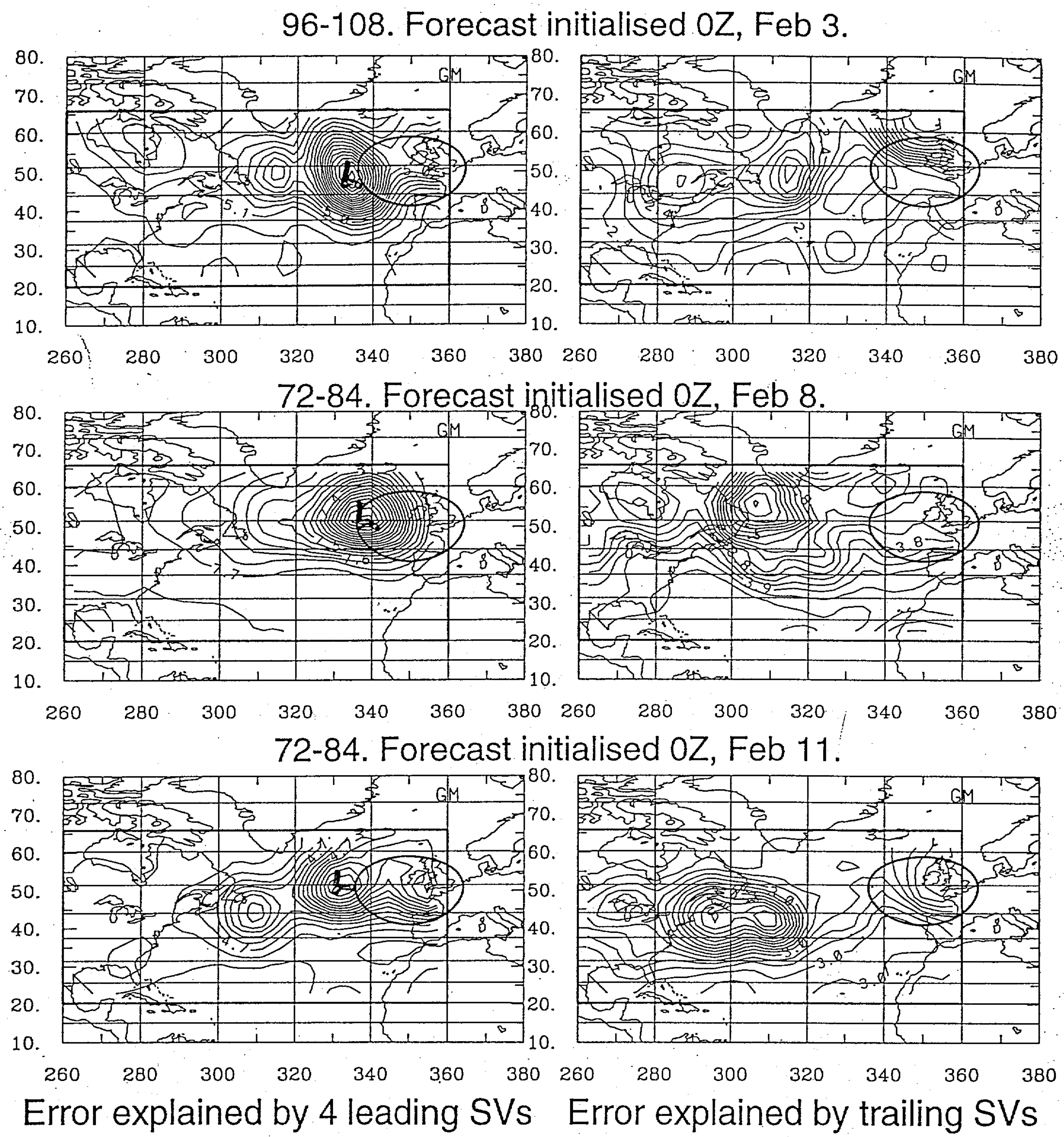
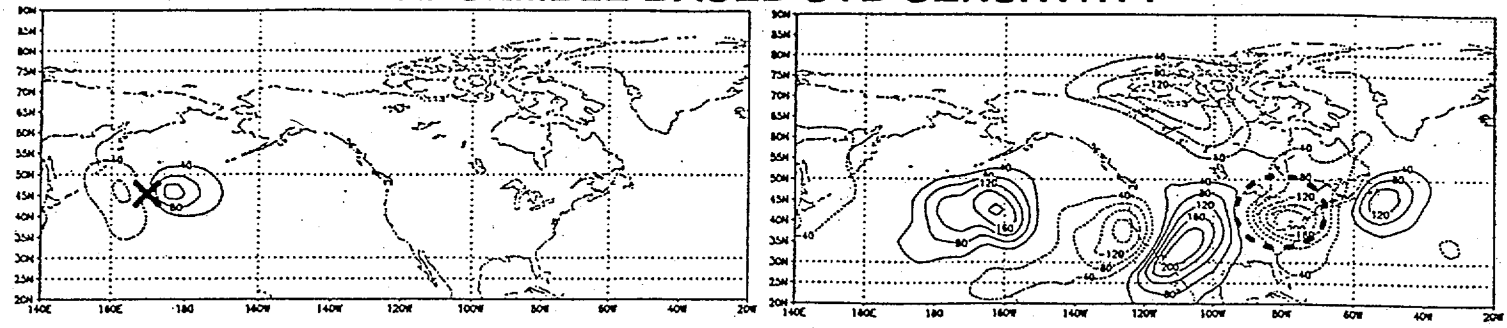


Fig. 1. The square root of the scaled prediction error variance has been plotted as a function of the center of a 750 km**2 region of high quality observations. With only a 12 h difference between analysis time and verification time, the optimal sites for supplementary observations ought to lie reasonably close to the verification region.

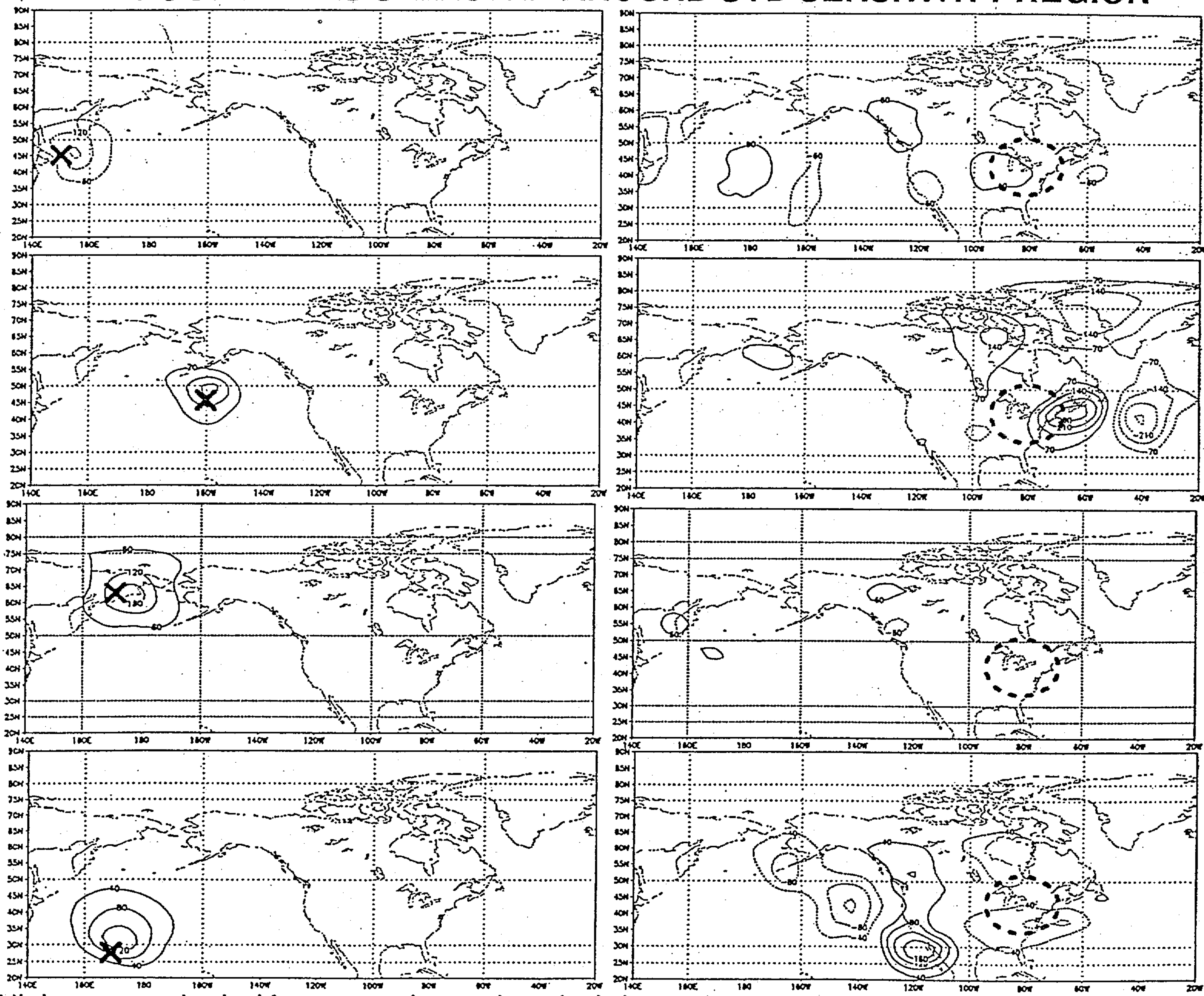
HEIGHT DIFFERENCE BETWEEN CONTROL AND DATA-INVENTED

ANALYSIS, 1997/01/03/00 108–HR FCST VALID AT 97/01/07/12

ENSEMBLE BASED SVD SENSITIVITY

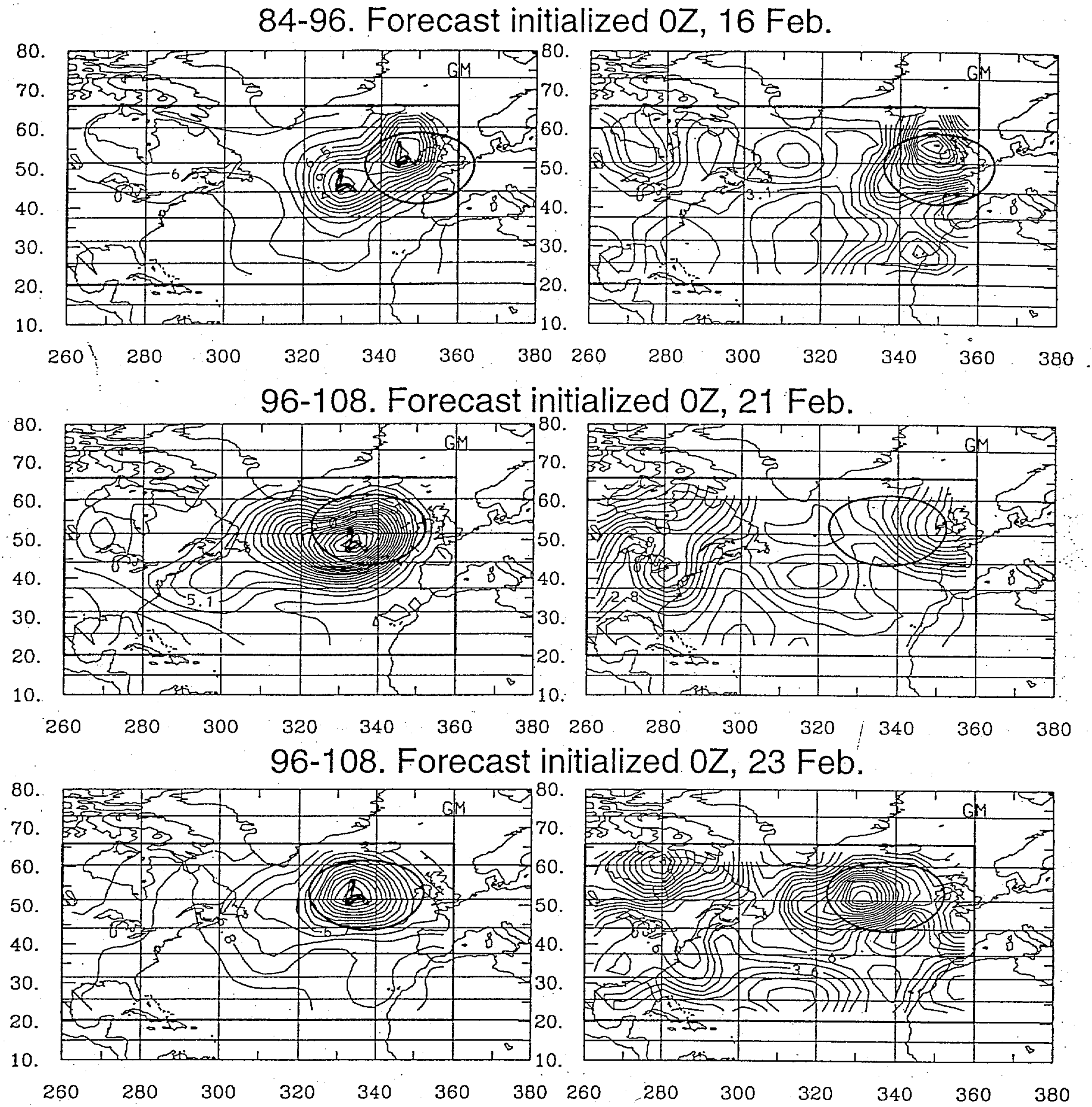


FOUR AREAS SELECTED AROUND SVD SENSITIVITY REGION



All data were denied from experimental analysis in 300 km radius vicinity of most sensitive area indicated by ensemble based SVD sensitivity calculations. In addition, data were invented and introduced into experimental analysis from 24–hour control forecast valid at analysis time, over same sensitive region. Effectively this amounts to denying all observations up to 24 hours prior to analysis time that had an impact on control analysis over the sensitive area. Verification area where amplification is maximized at 108–hour lead time is marked by a dashed ellipsoid on right panels. Four areas surrounding the most sensitive area were also tested similarly.

TOTH Z I SZUNYOGH C BISHOP J WOOLEN AND T MARCHOK



Error explained by 4 leading SVs   Error explained by trailing SVs

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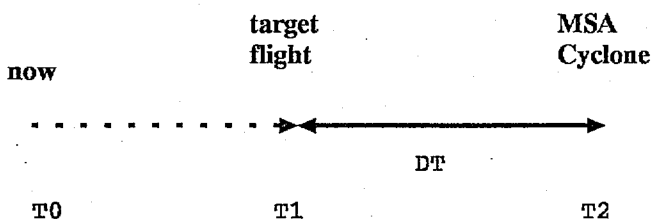
Any Ensemble, Full Physics, Very Fast

The French adjoint methods used during FASTEX

Thierry Bergot
METEO FRANCE

- Modele : ARPEGE / IFS
  - truncature T63, 19 vertical levels
  - tangent linear and adjoint : model with simplified physics
  - trajectory : model with the full physics. trajectory truncated at T21
- flexibility : T1, T2, area of interest



- sensitivity :
  - J = enstrophy inside the area of interest
  - gradient with respect to euclidean norm
- singular vectors :
  - Resolution of the Dual problem :
    - computation of the eigenvectors (W_i) of the lower dimensional product operator LL^*
    - computation of the singular vectors : $V_i = L^* W_i / \lambda_i$
  - Initial norm (at T1) : energy
  - Final norm (at T2) : enstrophy inside the area of interest

Targetting experiments using FASTEX data

- Main goal :

  study the growth of forecast errors for different FASTEX IOPs. And precisely for FASTEX cyclones poorly forecasted.

- Pre-FASTEX results :

  It is necessary that the initial error don't project onto the most unstable structure, typically the 2 first SVs, to really improve the forecast. (Bergot and al, 1996, 7th Mesoscale conference)

- tools :
  - FASTEX targets
  - FASTEX data (soundings)
  - assimilation : ARPEGE / IFS 3DVAR and 4DVAR
  - forecast model : ARPEGE / IFS

The futur work :

define the best strategy to control the growth of the forecast errors

- time parameters :
  - strategy 1 : many observations in sensitive area at one time. questions :
    * observations 48h before the mature phase are sufficient? (if only a small error project onto the most unstable structure, this error will growth super-exponentionally, and the forecast is not very well improved - pre-Fastex results)
    * how many observations are needed to correct the initial errors with the actual assimilation system?
  - strategy 2 : some observations in sensitive area at different times during the lifecycle of the cyclone. questions :
    * observations every 6h, 12h, 18h, 24h?
    * how many observations are needed to have a good forecast?
  - comparison of the 2 strategies.
- space parameters :
  - observations only around the most sensitive levels
  - importance of the upper levels
- comparison of subjective and objective targets

EARLY RESULTS FOR NCEP
PART I

ISTVAN SZUNYOGH
ZOLTAN TOTH
JACK WOOLEN
WAN-SHU WU
TIM MARCHOK
DAVE PARRISH

April 10 1997

Main goals

i) Find advantages and disadvantages of the different targeting strategies

ii) Identify the synoptic regimes whose prediction can be improved by targeting

- Sensitivity patterns are localized enough
- Sensitivity to the initial conditions dominates over the impact of model errors
- The time window between targeting and verification is within the predictability limit of a particular system

iii) Verify the forecasts using the extra data in MSA

Conclusions

i) Each targeting strategy worked well for the investigated cases, the signal from the extra observations always got to the verification region!

ii) There are cases when the sensitive area covers a large geographical region. In these cases the benefits from targeting is questionable.

iii) The problem of targeting and that of data assimilation cannot be investigated independently. Extra data may not improve the forecast skill for a particular case due to problems in the analysis. Targeting strategies should take into account the specifics and limitations of the data assimilation systems and the NWP models. Assimilation of targeted observations, on the other hand, is a new challange for the developement of advanced analysis schemes.

REVIEW OF THE USE OF ECMWF ENSEMBLE DATA FOR TARGETING UPSTREAM OBSERVATIONS DURING THE FASTEX FIELD EXPERIMENTS

ZOLTAN TOTH [1] AND ISTVAN SZUNYOGH[2]
EMC/NCEP

OVERVIEW. In this report, four of the six FASTEX cases where the ensemble based SVD method was used with ECMWF ensemble data are reviewed briefly. These four cases correspond with A5, A6, L8 and L11 in the accompanying summary table. In each case, we apply the ensemble based SVD technique (Bishop and Toth, 1996) on the 10–member NCEP ensemble (00Z runs) and compare the sensitivity fields with those based on the 50–member ECMWF ensemble (12Z runs from previous day), using the same technique.

It is clear from the figures (figure pages/fp 1, 3, 5, and 7) that the location of maximum sensitivity (crosses mark the maximum NCEP sensitivity) in the 10–member NCEP and 50–member ECMWF ensemble based calculations is identical in most cases. Considering also the other cases in February 1997 (not shown) one can conclude that the location of maximum sensitivity from calculations based on the two different ensembles is either identical or within a distance equivalent to the resolution of these sensitivity calculations (5 degrees lat–lon). The similarity of the sensitivity results is even more compelling given the substantial differences between the behavior of the two models and ensembles (see below).

RESULTS. *CASE 1.* In addition to the comparison between sensitivity results based on the 10–member NCEP and 50–member ECMWF ensembles, for the first two cases we also computed sensitivity fields based on different 10–member subsets of the ECMWF ensemble. For A5, the full 50–member ECMWF ensemble indicates two areas of sensitivity, corresponding reasonably well with the 10–member NCEP ensemble results (fp. 1). The location of the absolute minimum is identical while there is a north–south displacement with respect to the sensitivity over eastern Canada. This is despite the fact that the NCEP and ECMWF control forecasts are markedly different at verification time. For example, the ridge at the surface just north of the verification area (marked with a dotted ellipsoid at final time, fp. 2) is at 20W in the NCEP control forecast while it is at 30W in the ECMWF run.

The agreement between results based on the whole ECMWF ensemble and its subsets is not so strong as those between the whole ECMWF ensemble and the 10–member NCEP ensemble. For example, the secondary minimum over eastern Canada is completely missing from the 2nd and 5th subsets while the location of the absolute minimum is substantially shifted in other cases (e. g., 1st subset). In any case, if we accept the 50–member ECMWF ensemble based results as a good estimate of sensitivity, almost all 10–member calculations (except the 3rd ECMWF subset) have spurious areas indicated as sensitive. This is because in a small set of ensemble perturbations there can be far–field correlations occuring just by chance. Consider a case when perturbations in a real sensitive area correlate well with those in an area far away that is not sensitive. In this case if, through a linear combination of the initial perturbaitons, we reduce the initial ensemble spread in the far away insensitive area, the initial ensemble perturbations in the real sensitive area will also be reduced due to the far–field correlation. Judging from the results on fp. 1, this problem is apparently much reduced or eliminated with the use of more ensemble members.

CASE 2. For A6 (fp. 3), the sensitivity results for the 10–member NCEP and 50–member ECMWF ensembles are again rather similar with an absolute maximum in sensitivity over the eastern part of the Hudson Bay. (Maximum sensitivity is indicated by low values on the charts, showing, at each point, the level of expected forecast error variance at verification time in the verification region after taking extra observations in the vicinity of the gridpoint, as a fraction of the expected error variance *without* taking the extra observations.) Again, most of the 10–member subsets of the ECMWF ensemble show less correspondence to the results from the full 50–member ensemble. For example, in none of the five subsets the location of the absolute minimum corresponds with that found in the full 50–member ECMWF ensemble (and the 10–member NCEP ensemble). The message again is that a larger ensemble can effectively eliminate spuriously sensitive areas. The similarity between the NCEP and ECMWF ensemble based sensitivity results come despite the noticable differences between the ensemble forecasts themselves. There are substantial differences in the spread between the two ensembles both at initial and final time. For example, at final time the maximum spread for the NCEP ensemble is in the northern part of the verification area (centered at about 12.5W, 56N) while it is northwest of that for the ECMWF ensemble (22.5W, 57N).

CASE 3. For L8 (fp. 5–6) the 50–member ECMWF ensemble indicates two centers of large sensitivity, the northeastern one being somewhat stronger. In the 10–member NCEP results

1. GSC at NCEP
2. NCAR/MIT

the absolute minimum is far to the northwest of these two centers (and most probably represents a spuriously sensitive area). The two, equally deep secondary minima on the NCEP chart corresponds well with the ECMWF minima. The southwestern center is identically positioned in the two sensitivity charts while the norhteastern center on the NCEP chart is 5 degrees east of that on the ECMWF chart. The sensitivity calculations based on both ensembles on fp. 5 indicate that the most sensitive areas are the southwestern and northeastern parts of the surface low (see targeting area marked by dashed ellipsoids on the 1000 hPa forecast height maps, corresponding to areas of maximum sensitivity), and that these areas overlap with high uncertainty in the mid– to upper troposphere, indicated by large spread again in both ensembles (fp. 6). Clearly, the objective targeting guidance based on the two ensembles is confirmed and corroborated by subjective considerations of either the time evolution of the ensemble spread or the synoptic situation itself.

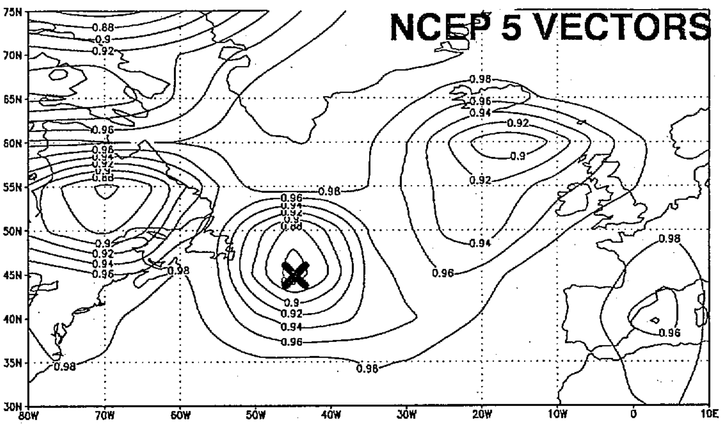
The difference in the position of the northeastern sensitivity center may actually be partly explained by the fact that the NCEP forecasts (both for the surface low and for the northeastern ensemble spread maximum at 500 hPa) are 4–7 degrees ahead (further to the east) of the features in the ECMWF forecasts – both at initial and final (verification) times. For example, the center of the surface low is at 26W, 50N in the NCEP, while at 21W and 55N in the ECMWF control forecast, resulting in a different flow configuration over the verification region. Beyond positional differences, there is also a large difference in the evolution of the spread in the two ensembles. At the initial time of the SVD calculations (36 and 48 hrs lead time for the NCEP and ECMWF ensembles respectively) there are two centers of large spread over the western Atlantic, associated with the uncertainty in the position and intensity of a deep low pressure system. Of these two centers, the southwestern is the more pronounced in the NCEP and the northeastern in the ECMWF ensemble. This pronounced difference is still present at the next time level shown, while the two spread plots become more similar at the last two time levels. Even at the verification time, however, there is an 8 degrees difference in the longitudinal position of the spread maximum in the verification area. It is also possible that the sensitivity results, despite differences in the ensembles, would still fully converge if more members were added to both ensembles.

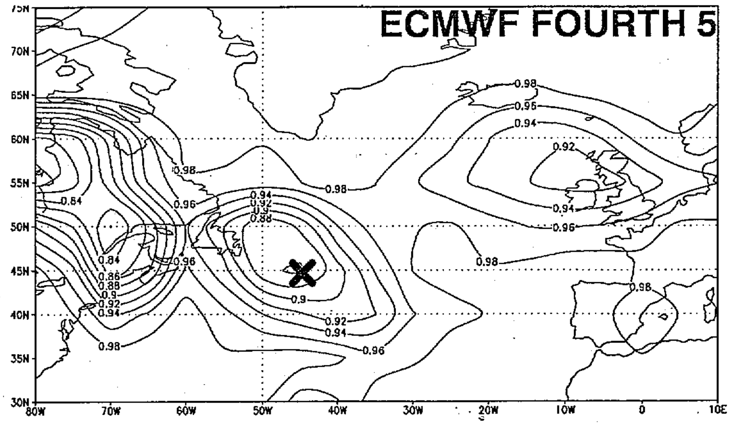
CASE 4. L11 offers perhaps the most striking example for the effect of using a larger ensemble. Here again the absolute minimum on the 10–member NCEP and 50–member ECMWF sensitivity charts are located identically (fp. 7). The 10–member NCEP ensemble, however, has at least four secondary minima of different intensity. These are all eliminated by using the 50–member ECMWF ensemble, suggesting that all the other minima are spurious (as was suspected in real time operations based on subjective considerations such as time evolution of sensitivity charts and ensemble spread fields). The most striking difference in spread between the two ensembles is also found for L11 (fp. 8). North of 45N, there may even be a negative correlation between the two spread charts for the first two time levels. Note, for example, that at 36 (for NCEP) and 48 (for ECMWF) hours lead time, near the area of largest sensitivity (50W, 50N) the NCEP 500 hPa height spread has a minimum (20 m) while the ECMWF ensemble has a maximum (60 m). The difference becomes less pronounced by the verification time – at least for the location of the absolute spread maximum. However, there are still differences. In particular, the maximum spread in the verification region is 120 m for the ECMWF ensemble while it is only half of that (60 m) for the NCEP ensemble. The difference in the amplitude of local spead maximum is even more striking for a feature centered at 57.5W, 47.5 N: in the ECMWF ensemble, the maximum is 100 m, while in the NCEP ensemble it is only 20 m. These differences must be associated with the nature of the initial ensemble perturbations (singular vector vs. bred perturbations) and deserve further investigation.

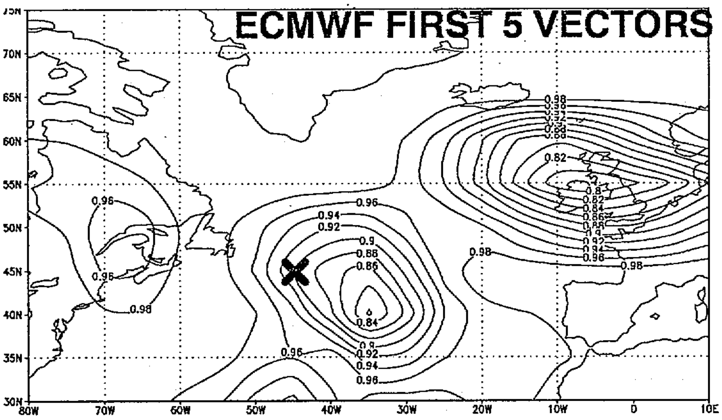
SUMMARY. We found the 50–member ECMWF ensemble, along with the 10–member NCEP ensemble, extremely useful for ensemble based upstream targeting during the second half of the FASTEX field experiments (February 1997). In particular, in most cases the sensitivity results from the 50–member ECMWF ensemble confirmed those based on the much smaller NCEP ensemble, giving more credibility to the SVD method. Moreover, the larger ECMWF ensemble always clarified the results by largely reducing or often eliminating spurious sensitivities that result from far–field random correlations present in smaller ensembles. The fact that these results were achieved with two ensembles that substantially differ in the control analysis, model formulation, resolution and initial perturbation technique, resulting in often substantially different forecasts and associated uncertainty, further attest to the robustness of the ensemble based SVD technique. Note that both ensembles are based on dynamically conditioned initial perturbations, though the evolution of the ensemble spread (which is an indicator of perturbation growth in the ensemble) is rather different from time to time. Nevertheless it seems that with an ensemble of 10–50 members, that are dynamically constrained, it is possible to extract useful sensitivity information that can be used for upstream targeting observations. As a further test of the SVD method the impact of real and "synthetic" data on forecasts, collected in sensitive regions, will be analyzed.

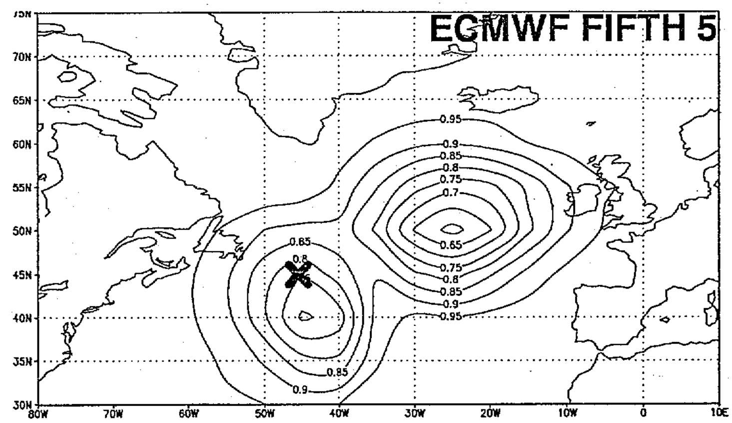
THE USE OF THE ECMWF ENSEMBLE FOR TARGETING OBSERVATIONS DURING FASTEX

Sensitivity of +84 hr forecast error in the FASTEX region (centered at 23W 43N with a radius of 1000 km) to errors at +48 hr (valid at 970206 00Z) based on 970204 00Z NCEP ensemble of 5 vectors.

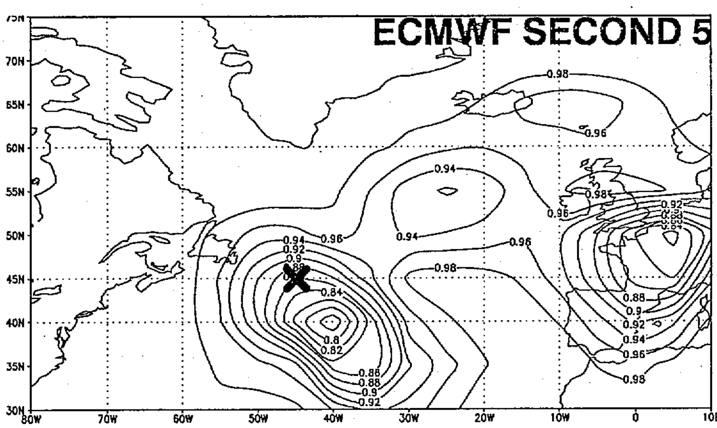


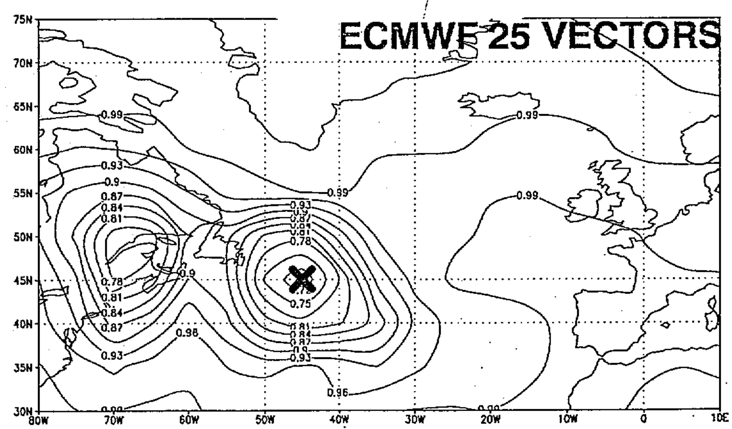




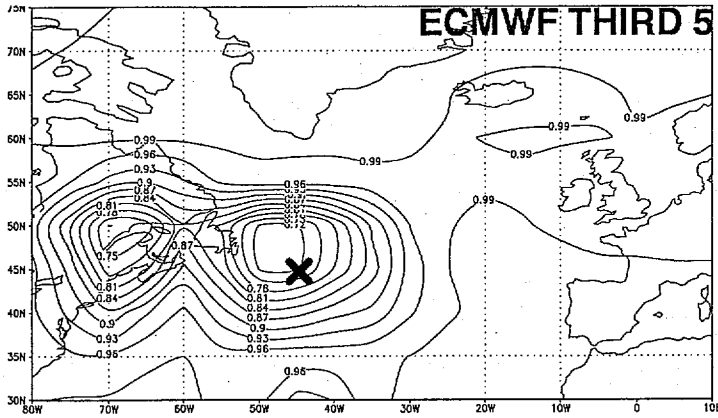


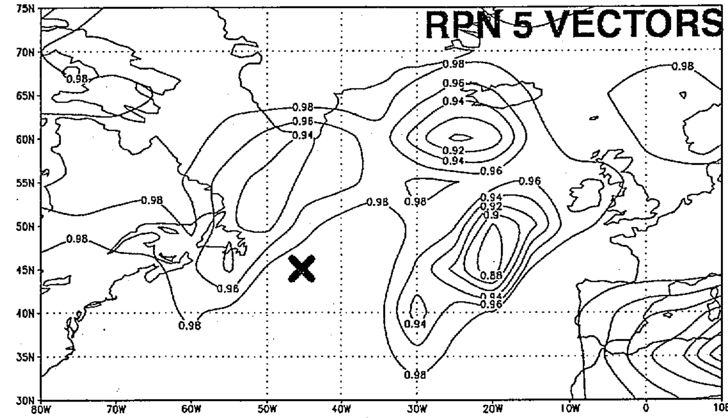
Sensitivity of +96 hr forecast error in the FASTEX region (centered at 23.0W 43.0N with a radius of 1000 km) to errors at +60 hr (valid at 970206 00Z) based on 970203 12Z NCEP ensemble of 25 vectors.



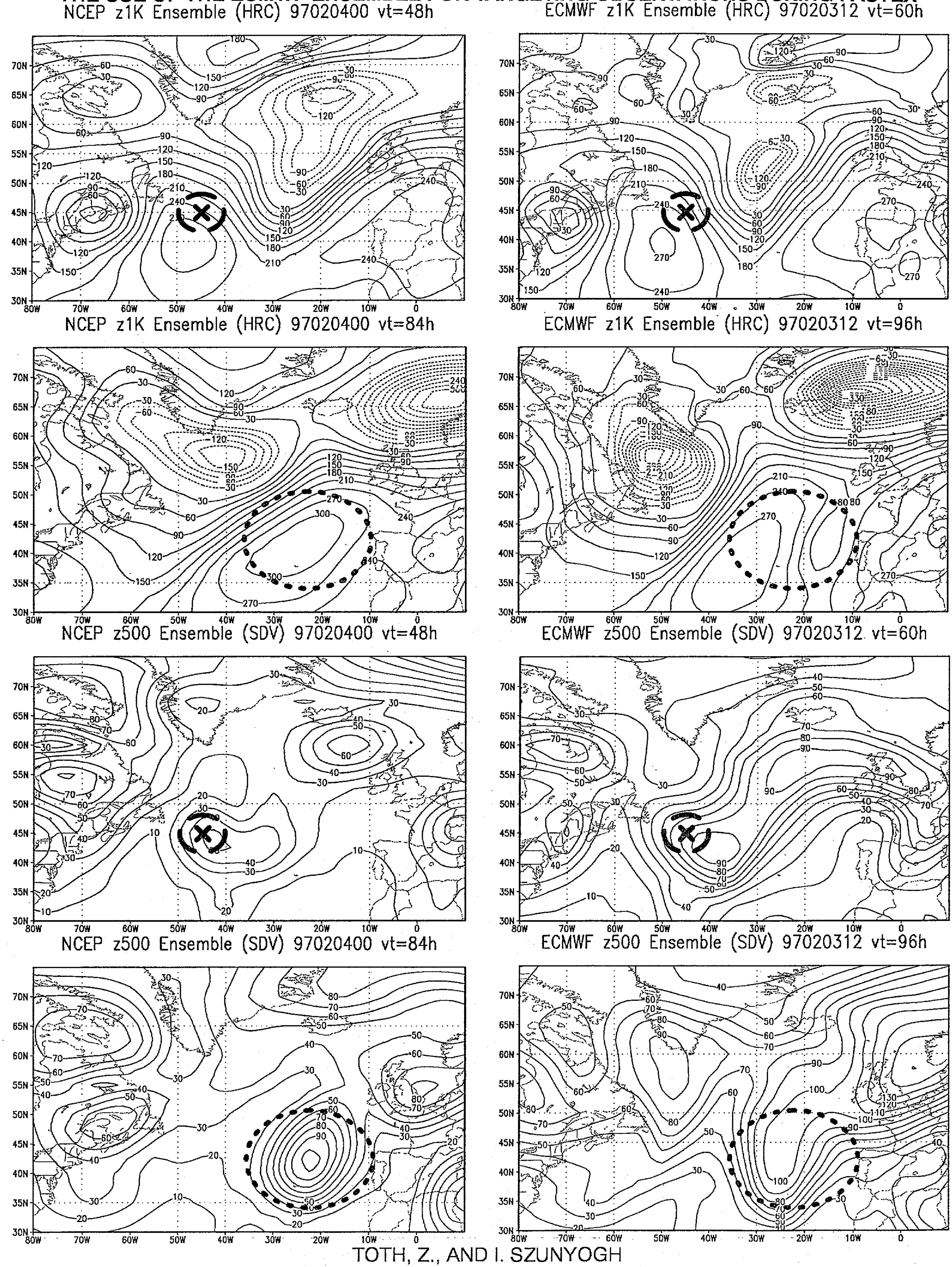


Sensitivity of +84 hr forecast error in the FASTEX region (centered at 23.0W 43.0N with a radius of 1000 km) to errors at +48 hr (valid at 970206 00Z) based on 970204 00Z RPN ensemble of 5 vectors.





THE USE OF THE ECMWF ENSEMBLE FOR TARGETING OBSERVATIONS DURING FASTEX



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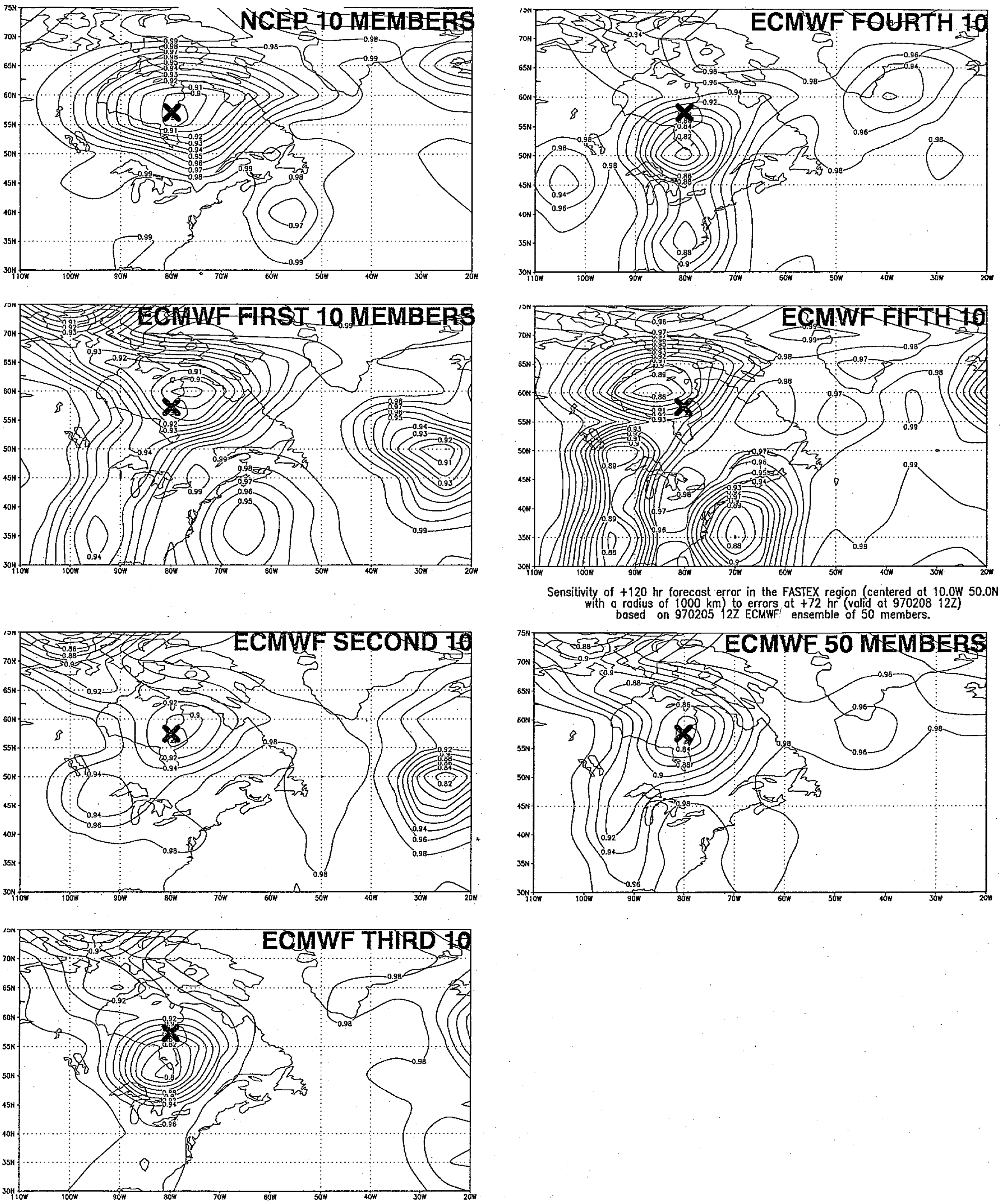
THE USE OF THE ECMWF ENSEMBLE FOR TARGETING OBSERVATIONS DURING FASTEX

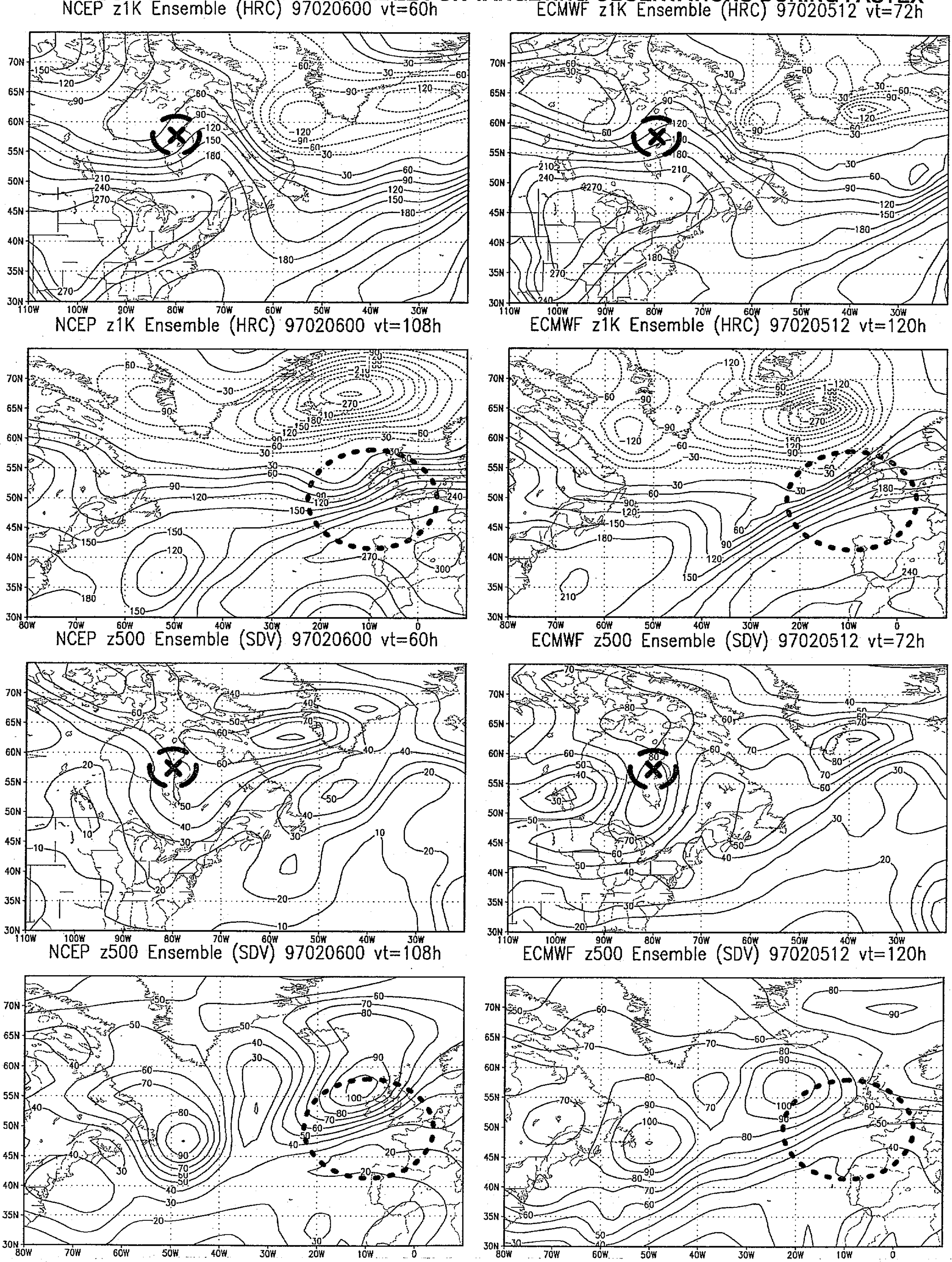
Sensitivity of +108 hr forecast error in the FASTEX region (centered at 10.0W 50.0N with a radius of 1000 km) to errors at +60 hr (valid at 970208 12Z) based on 970206 00Z NCEP ensemble of 10 members.



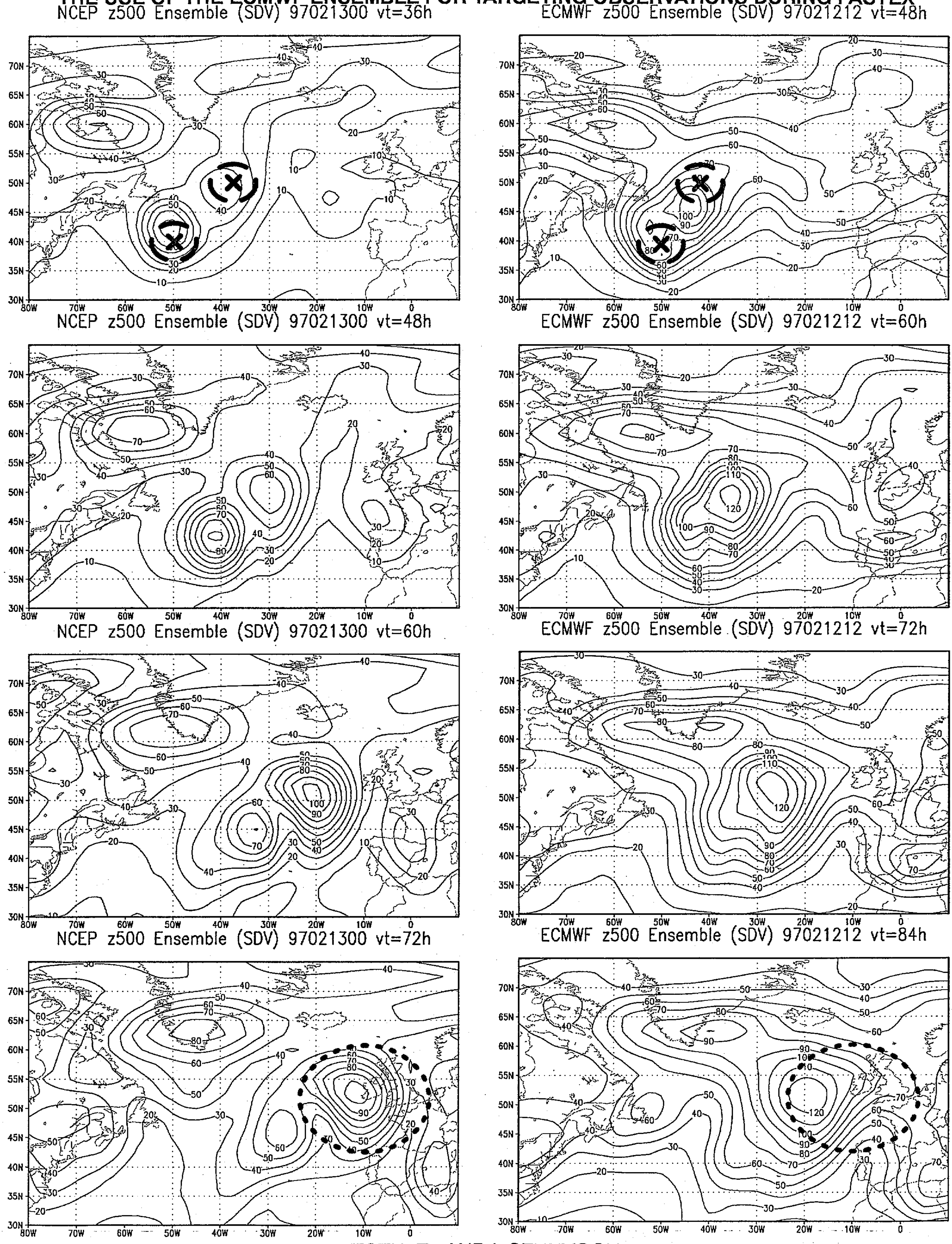
Sensitivity of +120 hr forecast error in the FASTEX region (centered at 10.0W 50.0N with a radius of 1000 km) to errors at +72 hr (valid at 970208 12Z) based on 970205 12Z ECMWF ensemble of 50 members.

TOTH, Z., AND I. SZUNYOGH

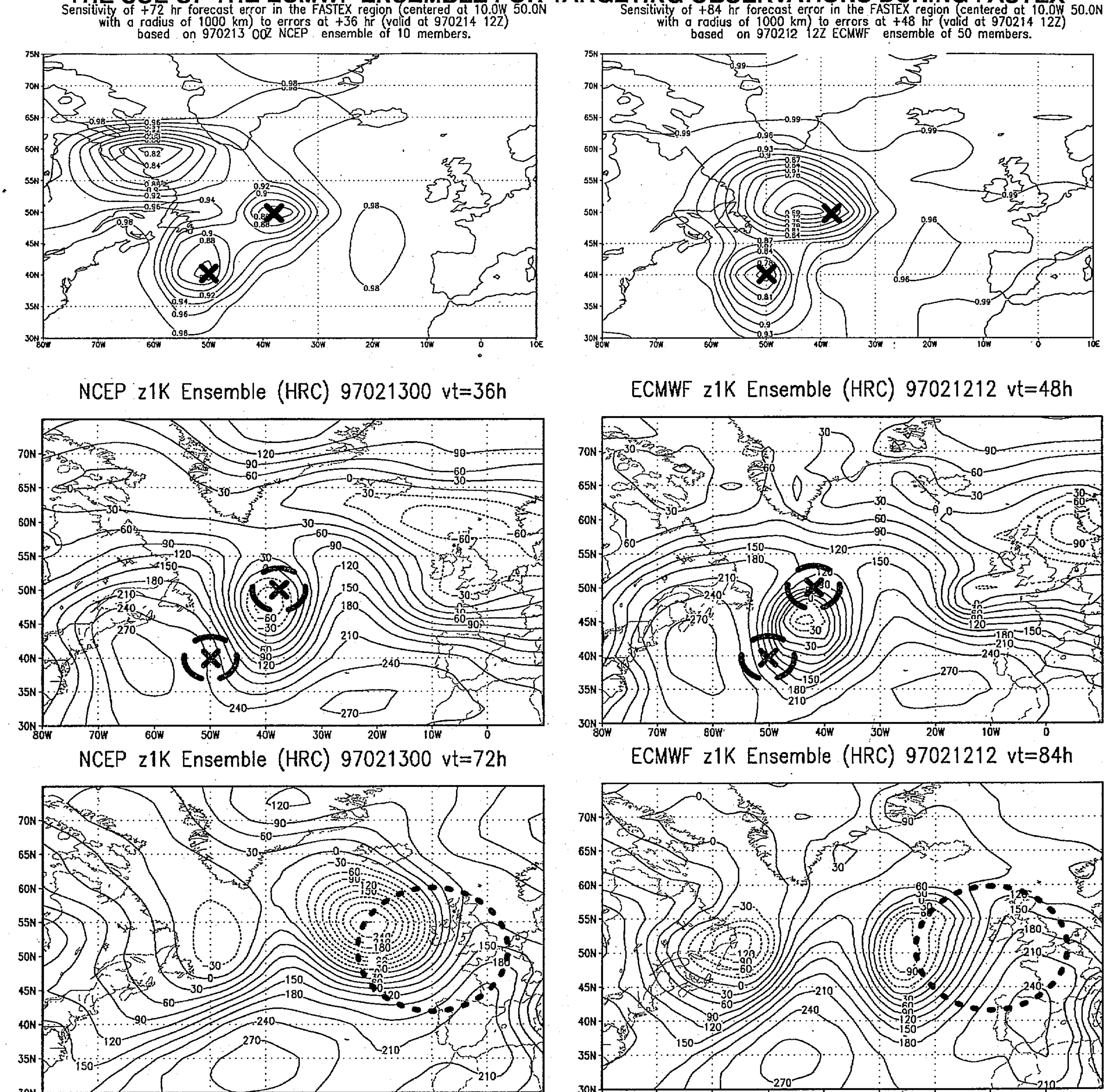
THE USE OF THE ECMWF ENSEMBLE FOR TARGETING OBSERVATIONS DURING FASTEX



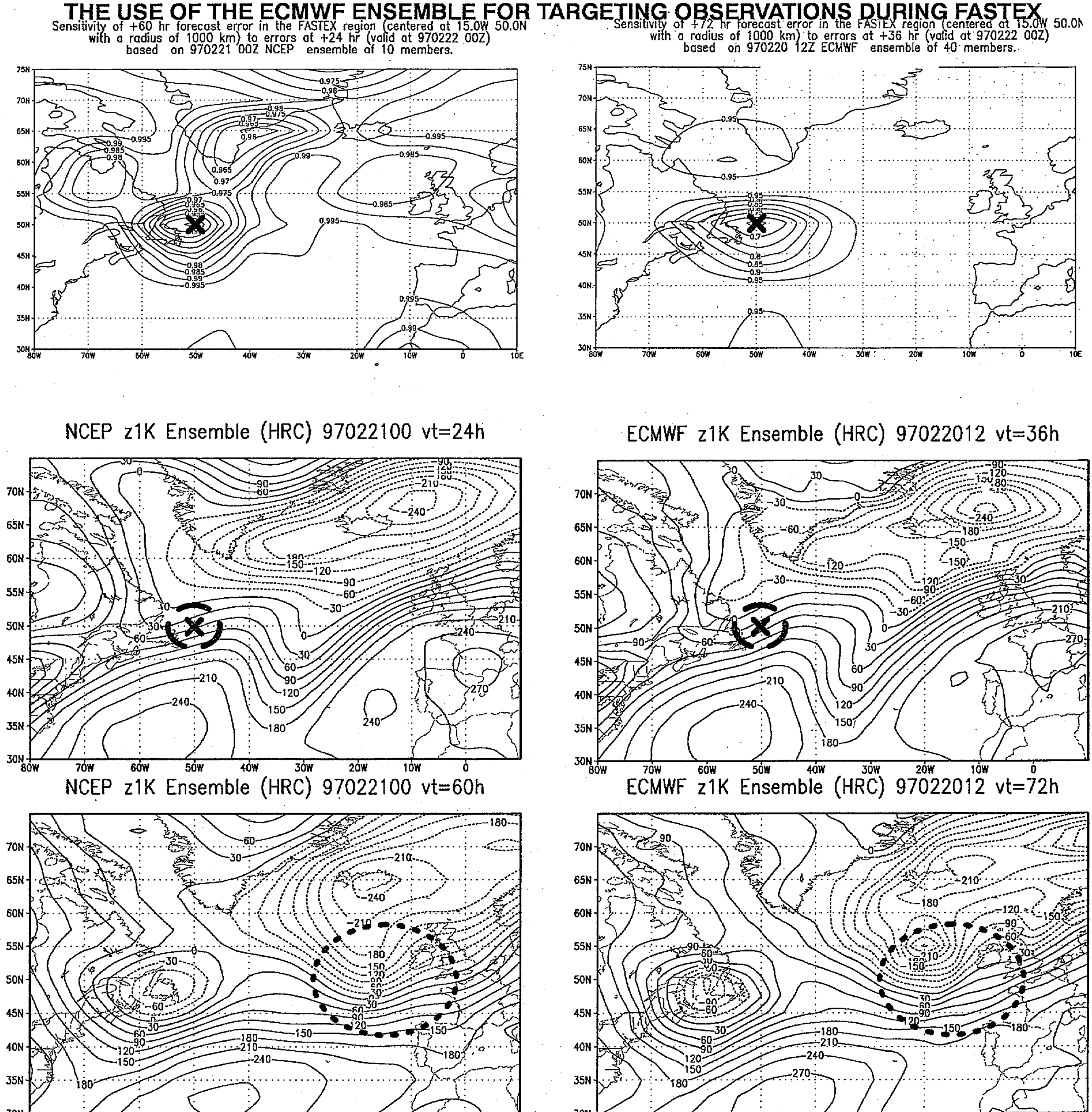
TOTH, Z., AND I. SZUNYOGH

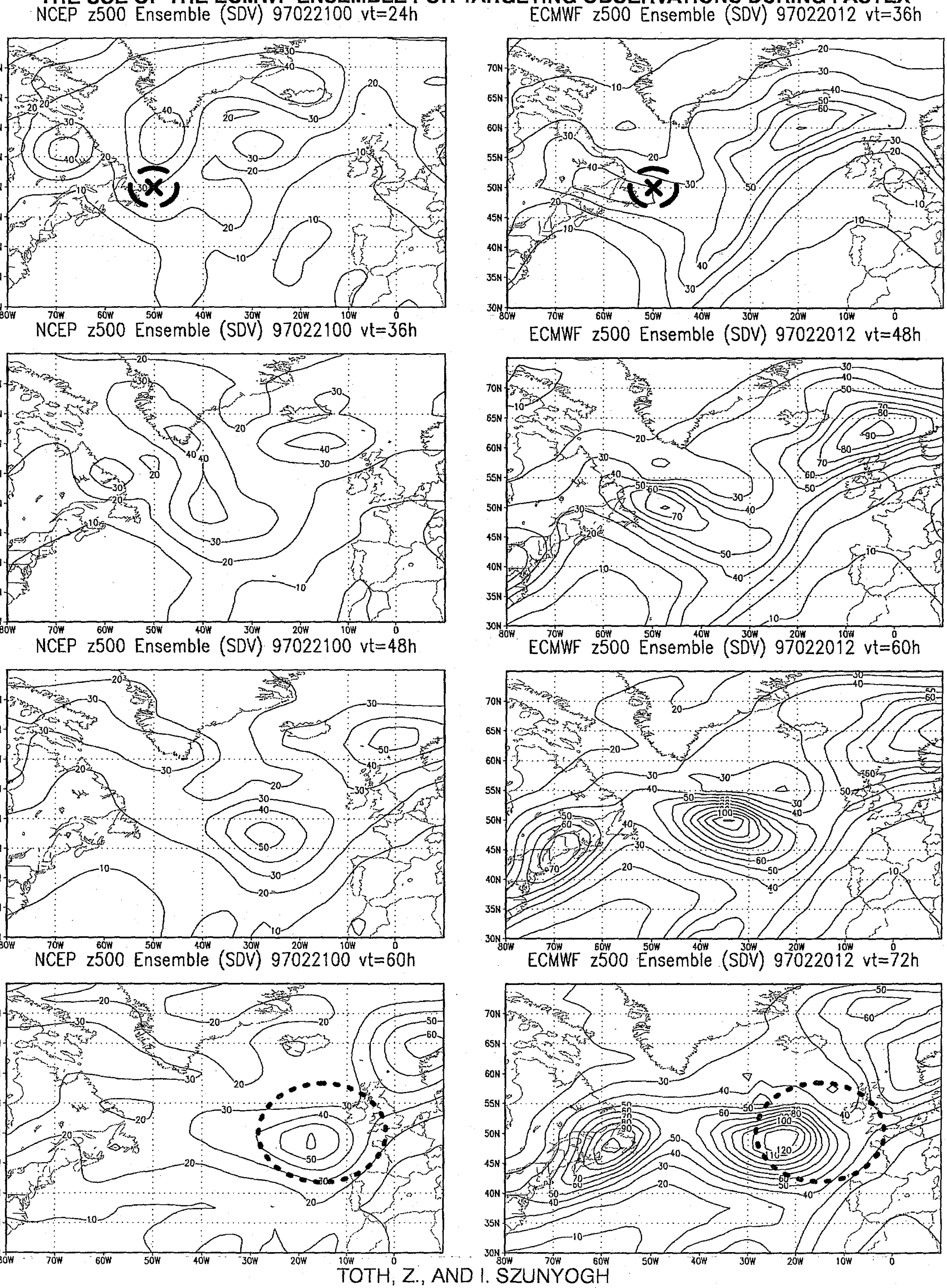

NCEP z500 Ensemble (SDV) 97021300 vt=36h
ECMWF z500 Ensemble (SDV) 97021212 vt=48h
NCEP z500 Ensemble (SDV) 97021300 vt=48h
ECMWF z500 Ensemble (SDV) 97021212 vt=60h
NCEP z500 Ensemble (SDV) 97021300 vt=60h
ECMWF z500 Ensemble (SDV) 97021212 vt=72h
NCEP z500 Ensemble (SDV) 97021300 vt=72h
ECMWF z500 Ensemble (SDV) 97021212 vt=84h

THE USE OF THE ECMWF ENSEMBLE FOR TARGETING OBSERVATIONS DURING FASTEX



TOTH, Z., AND I. SZUNYOGH


Sensitivity of +60 hr forecast error in the FASTEX region (centered at 15.0W 50.0N with a radius of 1000 km) to errors at +24 hr (valid at 970222 00Z) based on 970221 00Z NCEP ensemble of 10 members.
Sensitivity of +72 hr forecast error in the FASTEX region (centered at 15.0W 50.0N with a radius of 1000 km) to errors at +36 hr (valid at 970222 00Z) based on 970220 12Z ECMWF ensemble of 40 members.
NCEP z1K Ensemble (HRC) 97022100 vt=24h
ECMWF z1K Ensemble (HRC) 97022012 vt=36h
NCEP z1K Ensemble (HRC) 97022100 vt=60h
ECMWF z1K Ensemble (HRC) 97022012 vt=72h


NCEP z500 Ensemble (SDV) 97022100 vt=24h
ECMWF z500 Ensemble (SDV) 97022012 vt=36h
NCEP z500 Ensemble (SDV) 97022100 vt=36h
ECMWF z500 Ensemble (SDV) 97022012 vt=48h
NCEP z500 Ensemble (SDV) 97022100 vt=48h
ECMWF z500 Ensemble (SDV) 97022012 vt=60h
NCEP z500 Ensemble (SDV) 97022100 vt=60h
ECMWF z500 Ensemble (SDV) 97022012 vt=72h

Statistical Design for Adaptive Observations

M. Berliner, Z.-Q. Lu
NCAR/CGD

C. Snyder
NCAR/MMM

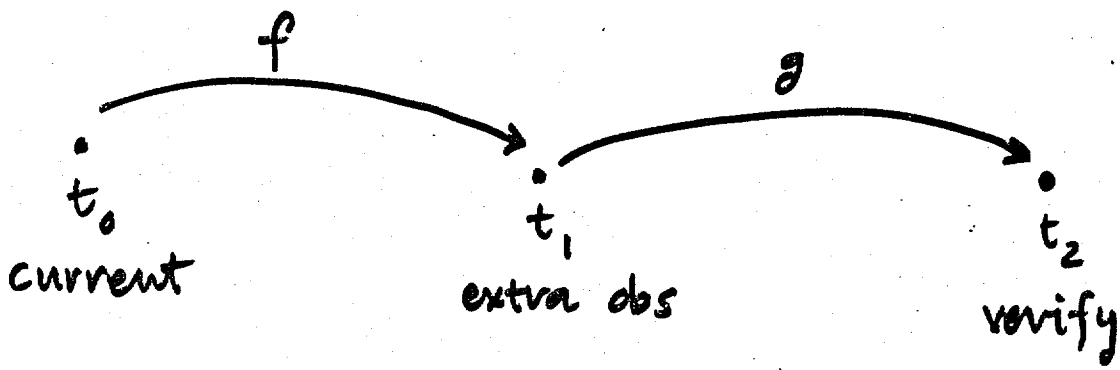
FORMULATION

Times: t_0 = current t_1 = extra obs. t_2 = verify (from t_1)

Let $\underset{\sim}{X}$ = model state vector (random variable)

$\underset{\sim}{Y}$ = observations

f, g = forecasts of length $t_1 - t_0$, $t_2 - t_1$



Assume:

$$\underset{\sim}{X} \sim N(\underset{\sim}{\nu}, A), \quad \underset{\sim}{X}_i = \underset{\sim}{X}(t_i)$$

$$\underset{\sim}{y} = k(\underset{\sim}{X}_1) + \varepsilon, \quad \varepsilon \sim N(0, \Sigma)$$

⇝ Forecasts, obs have normal distrib's

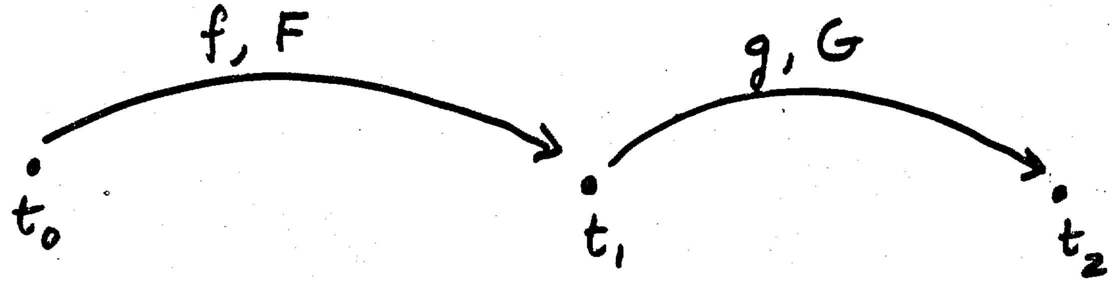
$$f(\underset{\sim}{X}) \approx f(\underset{\sim}{\nu}) + F(\underset{\sim}{X} - \underset{\sim}{\nu})$$

$$g(\underset{\sim}{X}) \approx g(\underset{\sim}{\nu}) + G(\underset{\sim}{X} - \underset{\sim}{\nu})$$

$$k(\underset{\sim}{X}) = k(\underset{\sim}{\nu}) + K(\underset{\sim}{X} - \underset{\sim}{\nu})$$

⇝ "Errors are linear/small"

Then



analysis:

$$X_0 \sim N(v_0, A_0)$$

t_1 extra obs: $\underset{\sim}{Y} = \underset{\sim}{y}$

Forecast:

$$X_1 \sim N(\mu_1, B_1)$$

$$\begin{cases} \mu_1 = f(v_0) \\ B_1 = F A_0 F^T \end{cases}$$

After obs, analysis:

$$X_1 \,\big|_{Y=y} \sim N(v_1, A_1)$$

Kalman Filter ⟷

$$\begin{cases} v_1 = A_1 (B_1^{-1} \mu_1 + K^T \Sigma^{-1} y) \\ A_1 = (B_1^{-1} + K^T \Sigma^{-1} K)^{-1} \end{cases}$$

Forecast:

$$X_2 \sim N(\mu_2, B_2)$$

$$\begin{cases} \mu_2 = g(v_1) \\ B_2 = G A_1 G^T \end{cases}$$

Key results

$$A_1 = (B_1^{-1} + K^T \Sigma^{-1} K^T)^{-1}$$

$\leadsto$ A_1 independent of y,
depends on "locations" of obs (K)

$$B_2 = G A_1 G^T$$

Design Criteria

Want: obs. at t_1 for "best" forecast at t_2

$\Longrightarrow$ seek K s.t. $fn(B_2) = \min$

1) minimize forecast error variance
$\Longrightarrow \min_K [\, tr(B_2) \,]$

2) other possibilities: $\min_K \det(B_2)$
minimize leading e-value

NOTE: K depends on dynamics, DA, initial analysis error.

SIMPLE ~~MODEL~~ EXAMPLE:

Single-site design, minimize $tr(B_2)$

K^T = vector, same dim'n as X

$$tr(B_2) = tr(G A_1 G^T)$$

$$= tr(G B_1 G^T) - \frac{tr(G B_1 K^T K B_1 G^T)}{\sigma^2 + K B_1 K^T}$$

[since $A_1 = B_1 - B_1 K^T K B_1 / \sigma^2 + K B_1 K^T$]

Suppose σ^2 is negligible. Then, min $tr(B_2)$ equivalent to maximizing

$$\frac{K^T B_1 G^T G B_1 K}{K^T B_1 K},$$

or, find max e-value of

$$\boxed{G^T G B_1 \underset{\sim}{x} = \lambda \underset{\sim}{x}} \quad (K^T = \underset{\sim}{x})$$

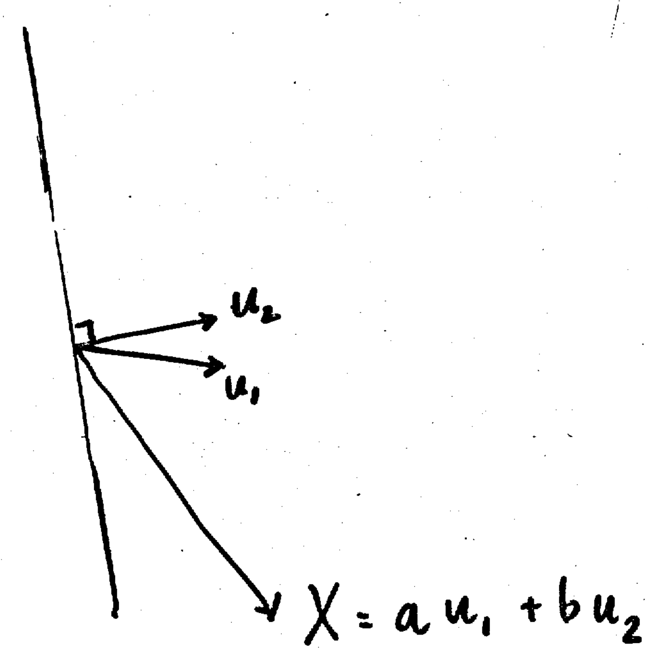
Let $\underset{\sim}{u} = B_1 \underset{\sim}{x}$: $\quad G^T G \underset{\sim}{u} = \lambda B_1^{-1} \underset{\sim}{u}$, $\quad K^T = B^{-1} \underset{\sim}{u}$

(c.f. Houtekamer, Ehrendorfer & T, Bishop & Toth, ...)

Why is design based on $B_1^{-1}\underset{\sim}{u}$ rather than on $\underset{\sim}{u}$?

⇝ $\underset{\sim}{u}$ is "most dangerous" error

<u>BUT</u> $B_1^{-1}\underset{\sim}{u}$ is orthogonal to all other e-vectors of $GG^T\underset{\sim}{v} = \lambda B^{-1}\underset{\sim}{v}$



- Adaptive obs naturally formulated as problem in statistical design

- ⇒ minimize (say) forecast error variance over all feasible networks

- Design need not resemble structure to be "removed" from data (if B's, A's not diagonal)

Conundrum: assumptions (and thus targeting?) work best when forecast needs <u>least</u> improvement.

Determination of the value of observations

Peter Houtekamer (RPN)
Louis Lefaivre (CMC)
Montreal

In Montreal we are running an 8 member ensemble (T63 or T95), each day at 00Z, out to forecast day 10. During FASTEX we were still running on the private account of Louis Lefaivre. Management wants to have 16-member ensembles run by "operations".

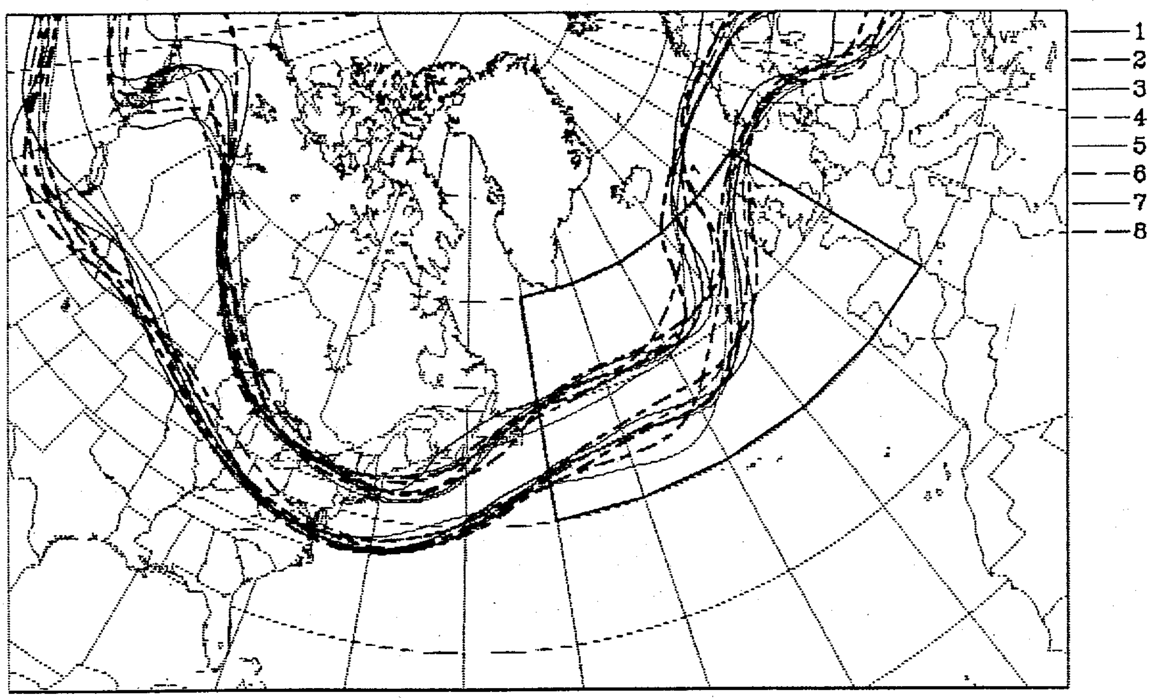
- The Canadian ensembles were sent to Craig Bishop who combined them with the NCEP ensembles.
- Two of our forecasters (Allan Rahill and Suzanne Roy) went to Shannon. They did receive a special RPN-targeting product with big delays. The product was not used.

Targeting using correlations

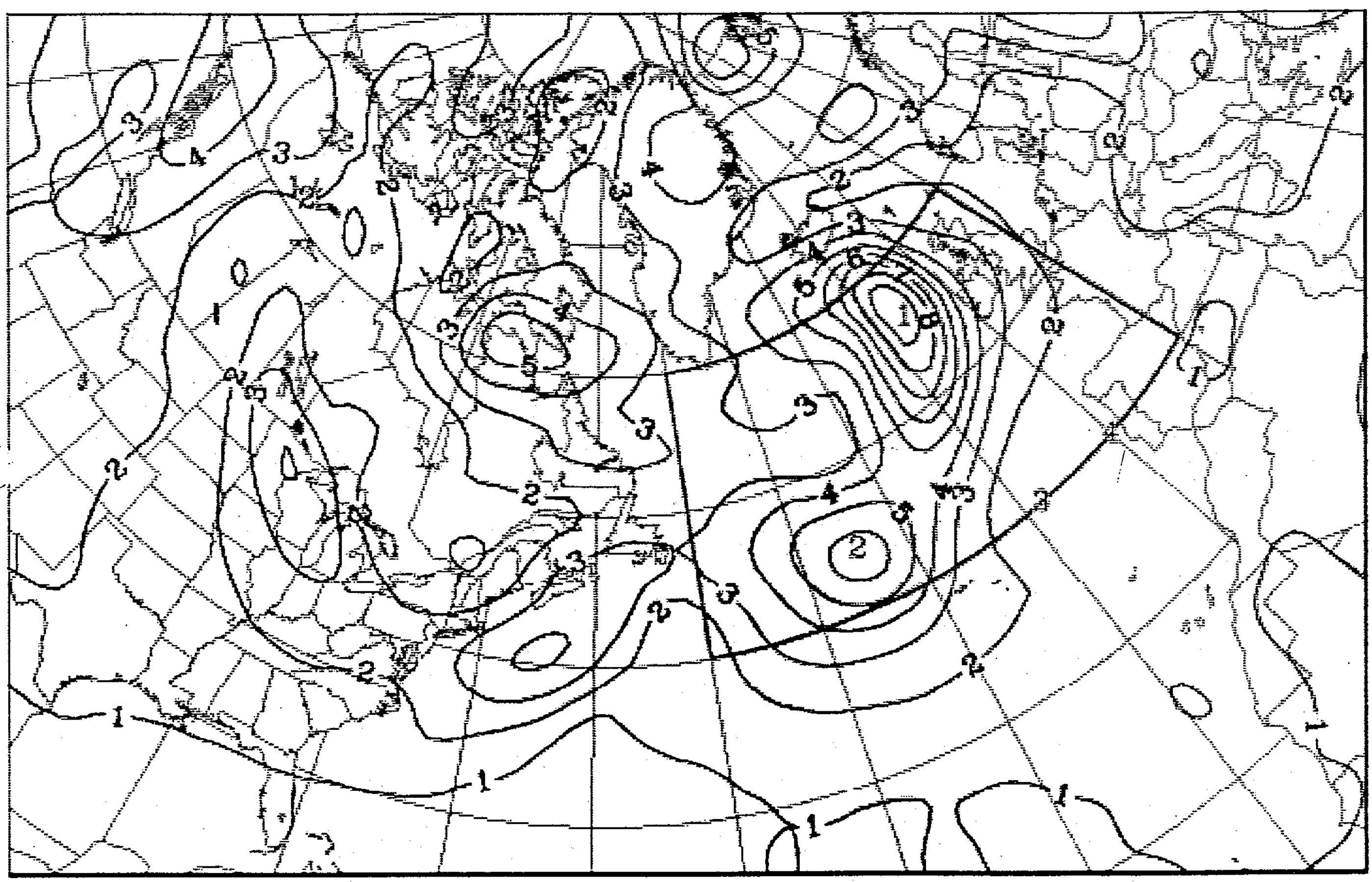
For 48 and for 72 hour forecasts and for the 500 mb height and the 1000-500 mb thickness we did the following:

1. Wait until the ensemble forecast is available.
2. Find the upto 6 places in the target region where the forecast error (ensemble spread) has a local maximum.
3. Correlate the forecast error with the error for the same variable at 24 hours.
4. Recommend that observations be done where the correlation has extreme values.

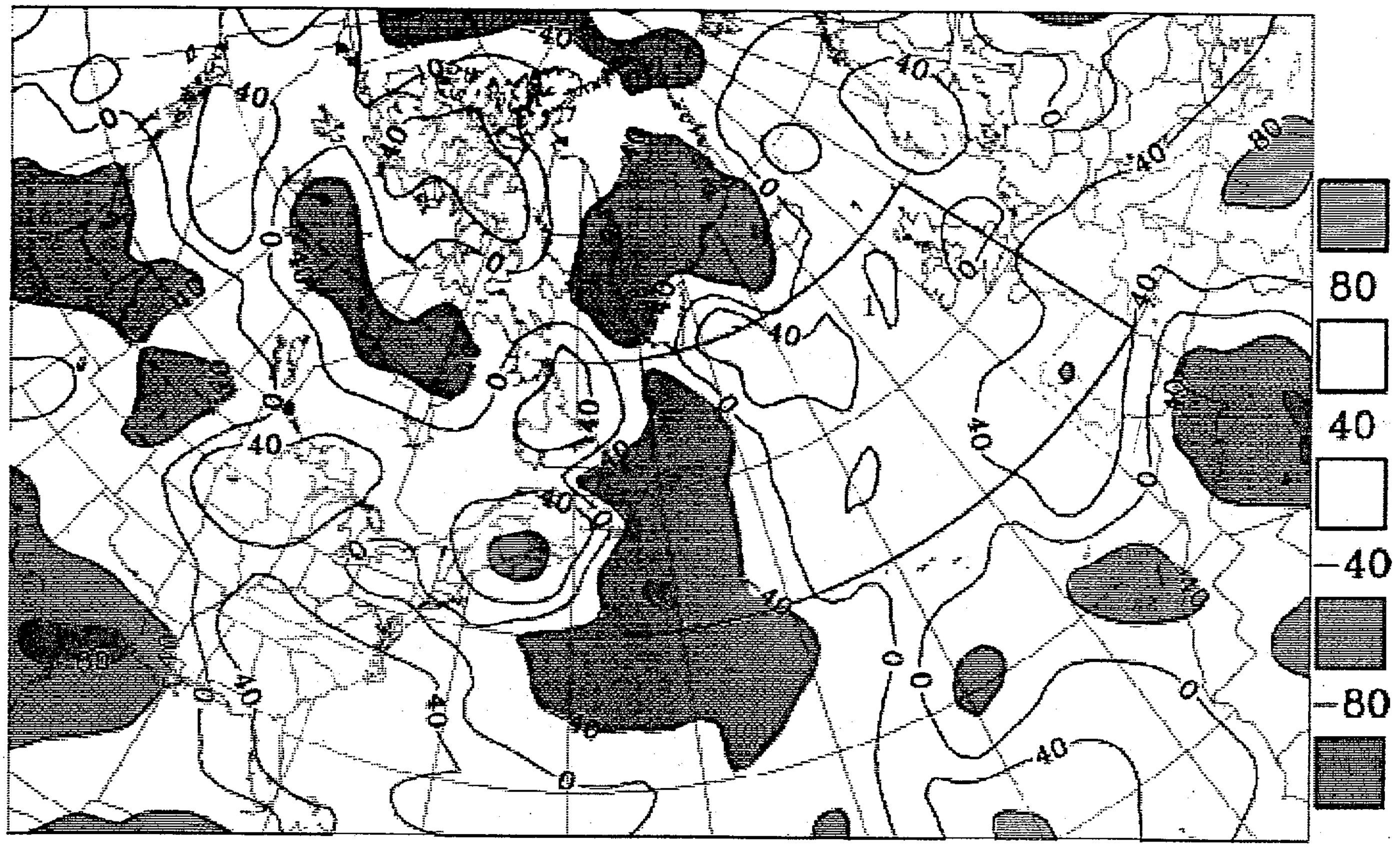
Forecast starting March 4, 00 UT
72h
528 dam - 500 hPa &
552 dam - 500 hPa



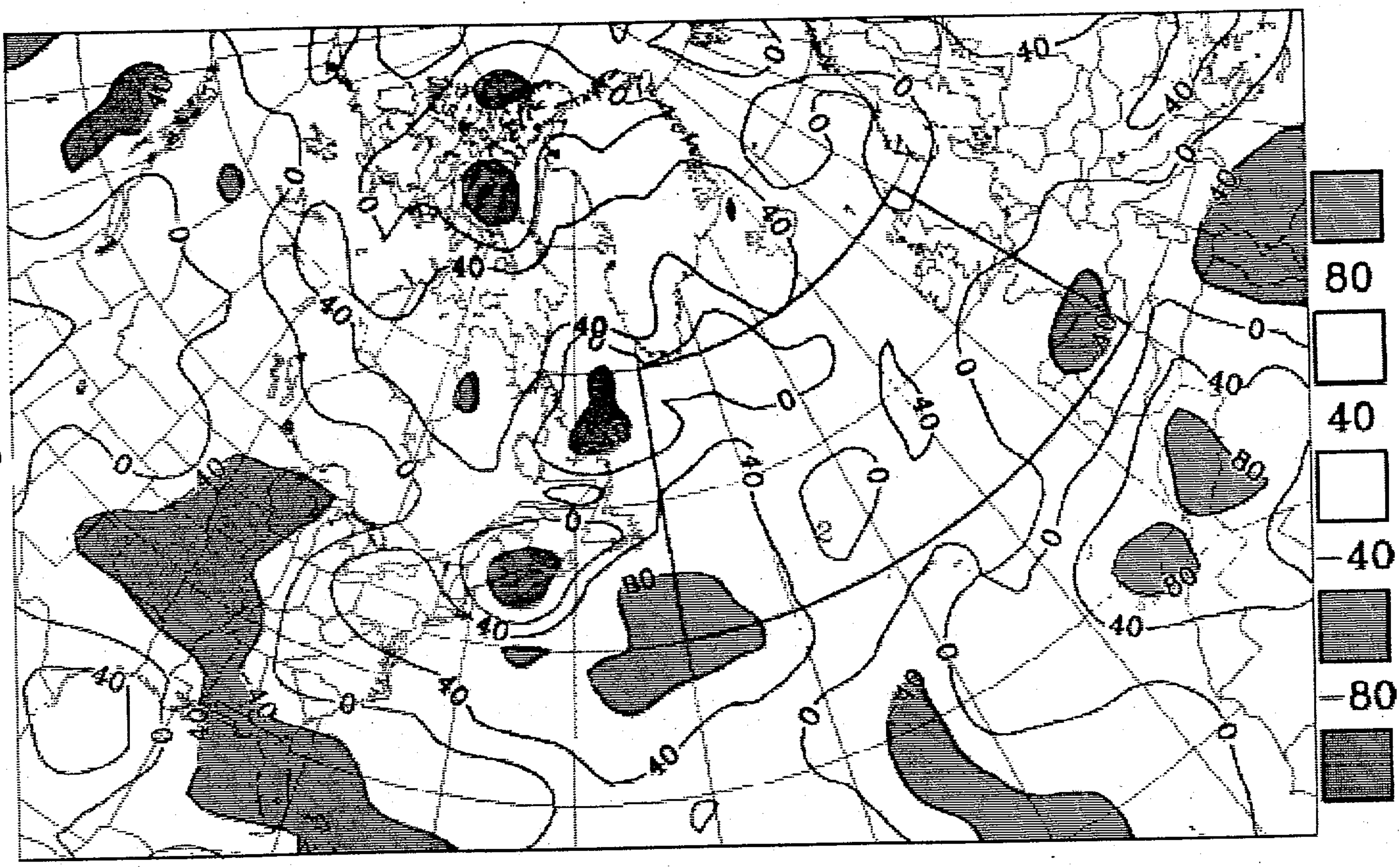
Spread at 72h (heights)



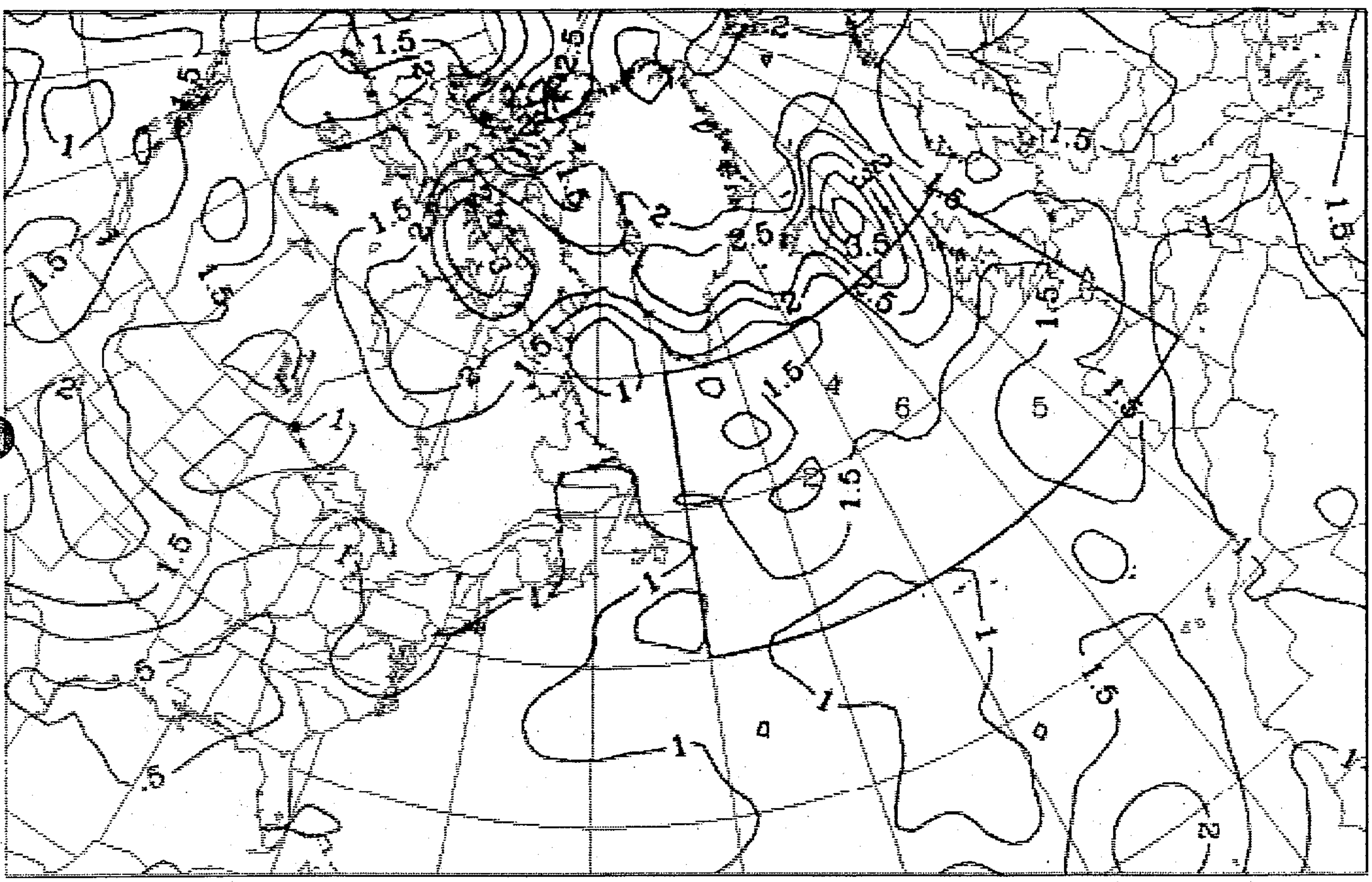
ρ(24h, 72h)



ρ(24h, 72h)



Spread at 24 h (heights)



How to select a target?

Targeting assumes one has a target like

1. Short-range forecasts for the Olympics.
2. Accurate 48 hour forecasts for southern Ireland.
3. Accurate analyses.

The selection of the targets would seem arbitrary.

If one goes for accurate analyses one eliminates one step of the preparation. According to the breeding philosophy first guess errors are big where they are rapidly growing. If this is true the only important thing is to reduce first guess errors by as much as possible where they are largest.

Prediction of the impact

For a very small network one may evaluate:

$$
\begin{aligned}
K &= P^f H^T (H P^f H^T + R)^{-1} \\
P^a &= (I - KH) P^f
\end{aligned}
$$

One may then minimize P^a for different locations of the additional observation. This will be feasible if only the 3 to 5 most important observations are included in the analysis.

Link with NAOS:

If the impact of additional observations can be quantified one may also quantify the impact of existing observations.

Early warning time

A rigorous scheme having an early warning time of about 2 hours could be as follows (all steps):

1. Wait for most available observations for the previous analysis to come in (about 2 hours).
2. Perform the data-assimilation step (at t-6) for the ensemble. (about 45 minutes).
3. Integrate the ensemble to obtain a first guess valid at t=0 (30 minutes).
4. Perform an analysis of where the observations should be taken (30 minutes).
5. Communicate the targeting advice to a flight planner (15 minutes).
6. Repeat step 2 and 3 as more observations become available.

Need for 4D assimilation schemes

If one has a 4D-var scheme or ensemble Kalman filter one can take full advantage of the additional observations. In particular:

1. The assimilation scheme will be aware of the big uncertainty in the first guess.
2. A longer correlation length may be used over the oceans.

A 4D-scheme will also lead to a better use of currently already available observations.

An adaptive ensemble Kalman filter is being developed by Peter Houtekamer and Herschel Mitchell for a T21L3 QG-model.

Plans for the future

1. Estimate and introduce parametrized model error into 6 hour ensemble forecasts with the T95L23 model.
2. Revise the analysis code to take advantage of the correlations in the ensemble.
3. Run an ensemble Kalman filter with about 100 members

FASTEX related

We may get the perfect person to work on NAOS OSSE or targeting work.

We would like to be involved in Pacific follow-up experiments if any are organized.

Detection of Signal in Functions of Random Variables
Implications for Targeted Observations

Jeff Anderson, GFDL

Given multi-normal random variable $x = (x_1, x_2, \ldots, x_k)$

Scalar function $S(x)$

Generate set of random samples of x and corresponding S (ensemble)

<u>Question: what component(s) of x have largest 'impact' on S?</u>

Reducing uncertainty in this component(s) maximally reduces uncertainty in S.

<u>Simple method for answering question:</u>

Do a univariate regression of S onto each component of x (cheap)

Find the x-components with the largest F-value from regression

More sophisticated methods would involve partial correlations, etc. (expensive)

Simple Example

x is 10000 dimension unit multi-normal

$$S = \sum_{i=1}^{k} w_i x_i$$

Weights w_i determine impact of x components on S

First case: $w_1 = 100$, all other w's are 1

How often is w_1 identified as most important, second most important...

Table 1:

Sample Size	Largest F-test	Second Largest	Third Largest
50	100%		
25	96%	1%	2%
20	83%	7%	3%
15	52%	8%	4%
10	16%	9%	4%

Simple Example

x is 10000 dimension unit multi-normal

$$S = \sum_{i=1}^{k} w_i x_i$$

Weights w_i determine impact of x components on S

Second case: $w_i = a^i$ $i = 1, ..., 100$
$w_i = 1$ otherwise

Series of progressively more important components

Sample size 50;
How often is w_{100} identified as most important, second most important...

Table 1:

Variance Factor, a	Largest F-test	Second Largest	Third Largest
2.0	100%		
1.5	98%	2	
1.4	89%	8%	1%
1.25	71%	9%	2%
1.2	59%	15%	4%

These are very rigorous tests with 10000 independent degrees of freedom. GCMs certainly have far fewer independent degrees of freedom.

What can one do with realistic ensemble sizes?

Barotropic Precursor (Targeting?) Example

Random variable x; gridpoint initial conditions for T21 barotropic model (2112)

Random variable $y = G(x)$; state of model after n-hour integration

Scalar function $S(y) = S(G(x))$; value at one gridpoint after (n+p)-hour integration
(or any scalar function of model variables from all times)

Do random sample of x (ensemble)

Get corresponding random sample of y and S(y) by integrating model

Do regression of S on each component of y

Sample results:

Initial condition is observed 300mb from 14 January, 1987

'Observational' error distribution; normal, 5e5 variance IID at each gridpoint

Target point is (54N, 6E) at lead time 96 hours

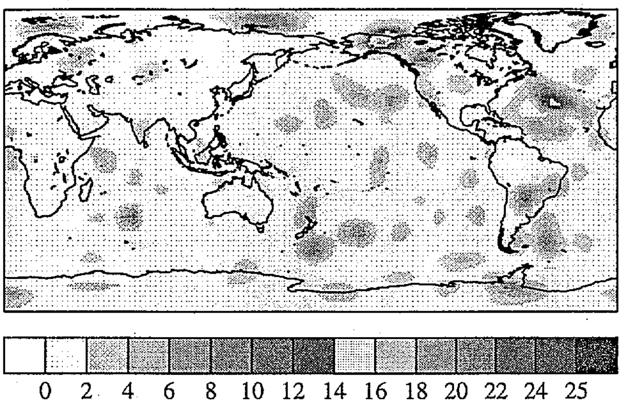
Look at precursors for p = 12, 24, 36, 48, 60, 72, 84 hours

Plot value of F-test for each gridpoint; large F gives points with large impact

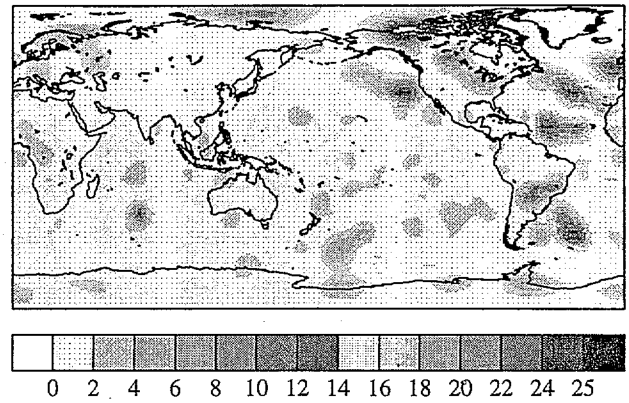
Better resolving values at these precursor points would reduce uncertainty in S

Target to reduce uncertainty at these precursor points

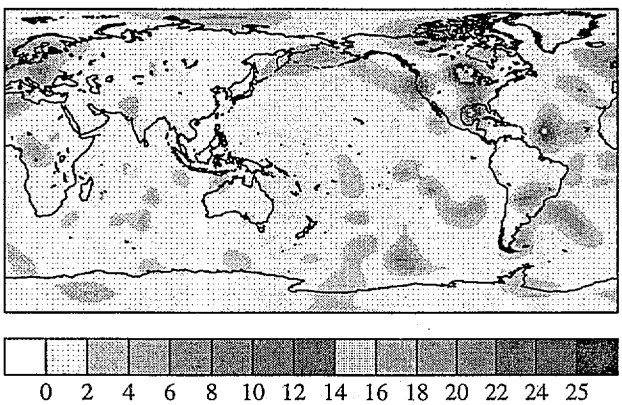
84 Hour Precursor F-test



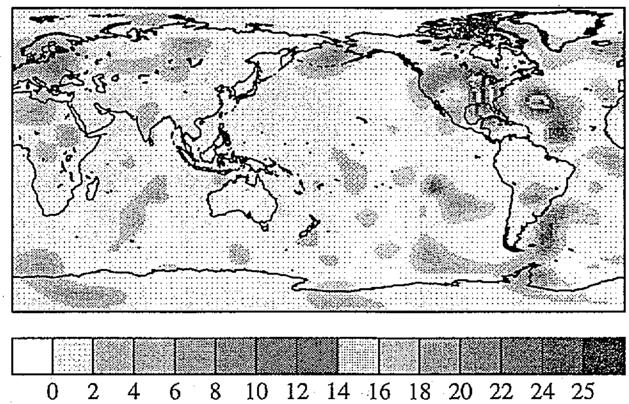
72 Hour Precursor F-test



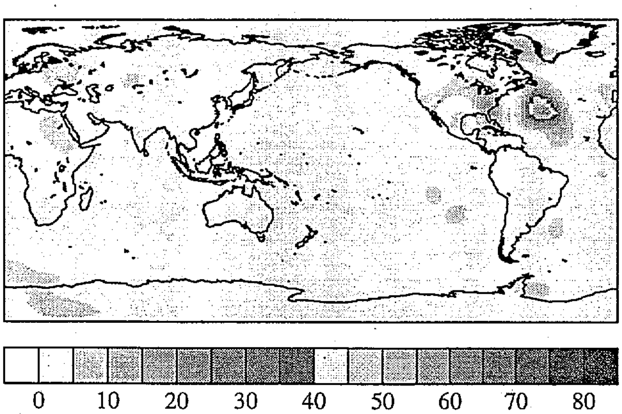
60 Hour Precursor F-test



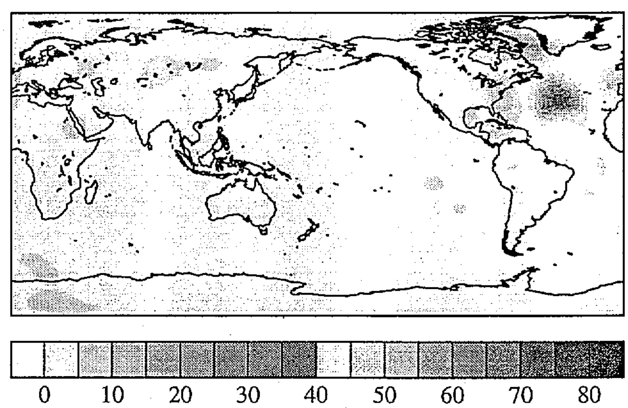
48 Hour Precursor F-test



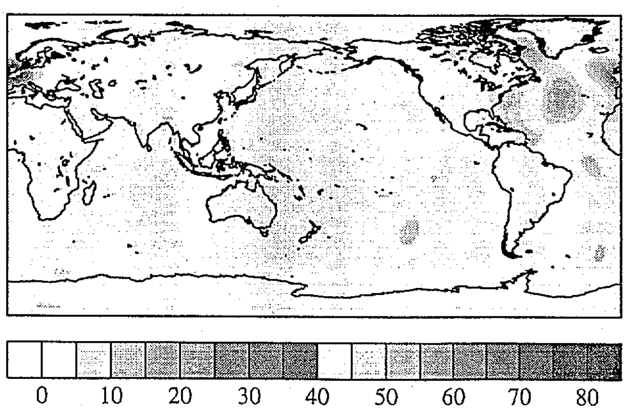
36 Hour Precursor F-test



24 Hour Precursor F-test

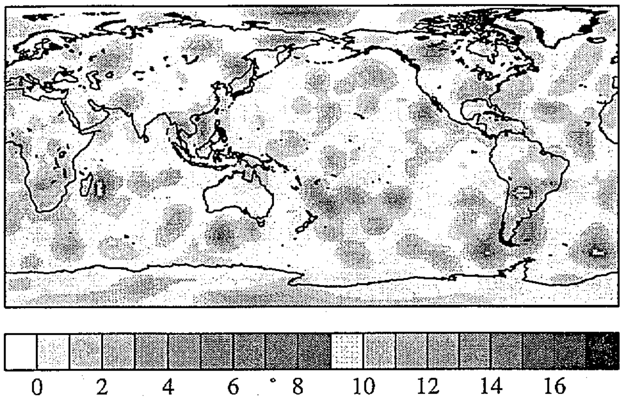


12 Hour Precursor F-test

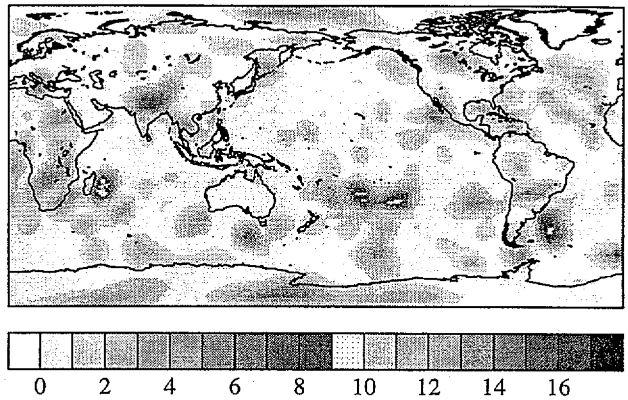


T21 50-member; Target (54N, 6E)

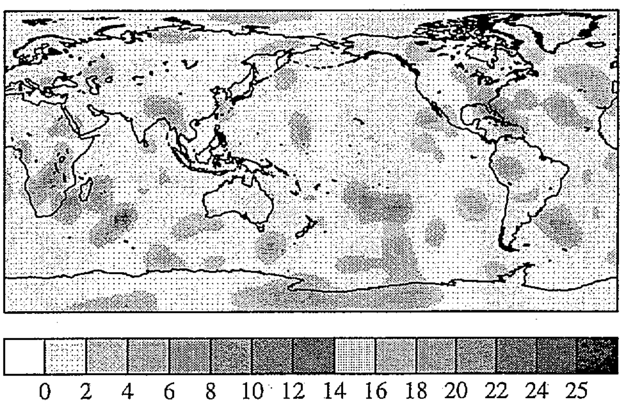
84 Hour Precursor F-test



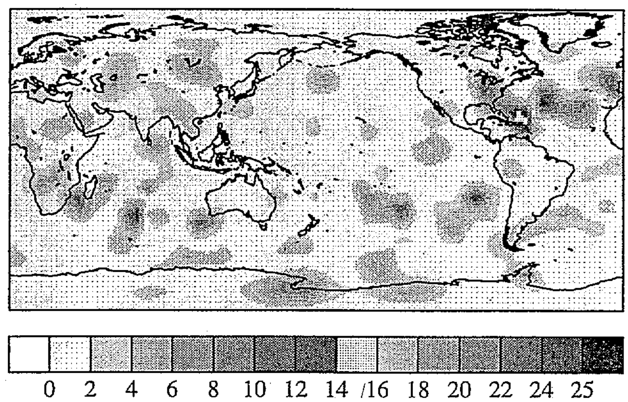
72 Hour Precursor F-test



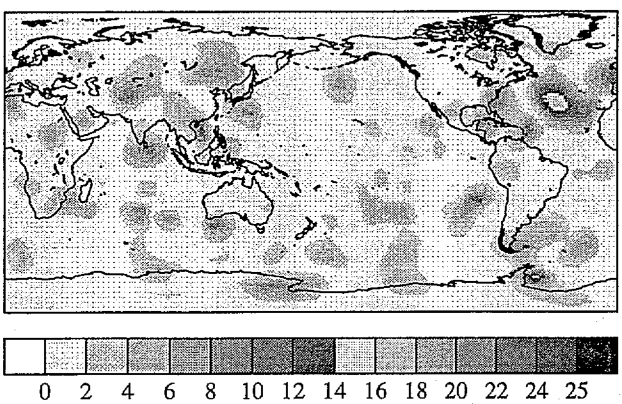
60 Hour Precursor F-test



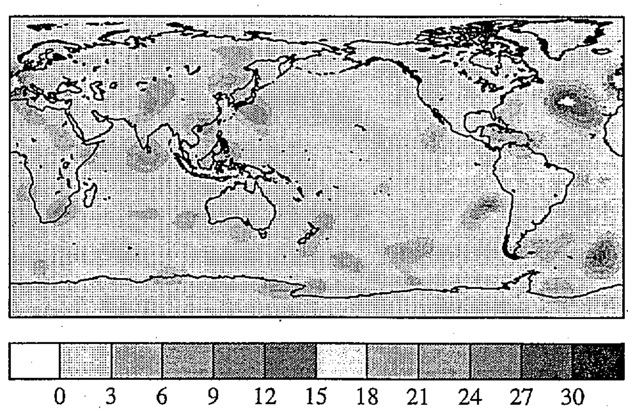
48 Hour Precursor F-test



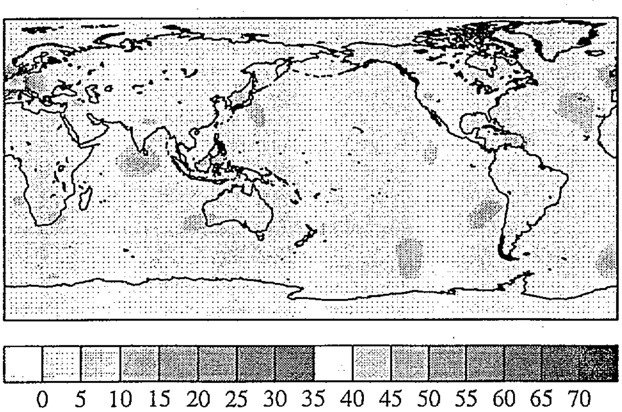
36 Hour Precursor F-test



24 Hour Precursor F-test

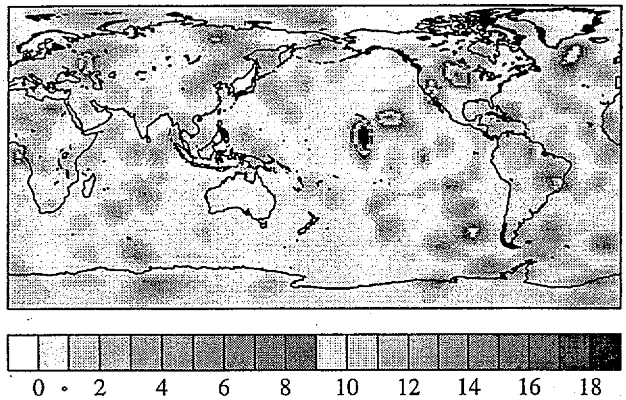


12 Hour Precursor F-test

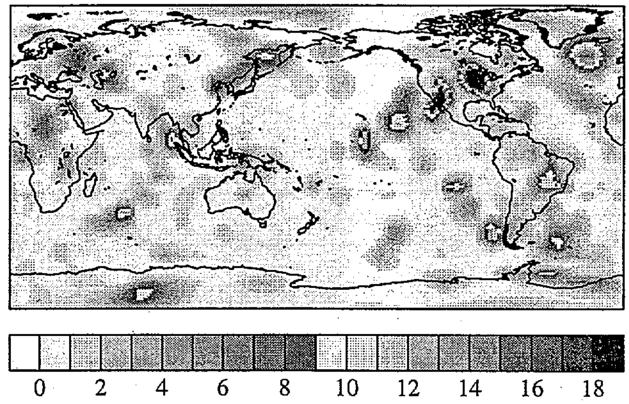


T21 25-member; Target (54N, 6E)

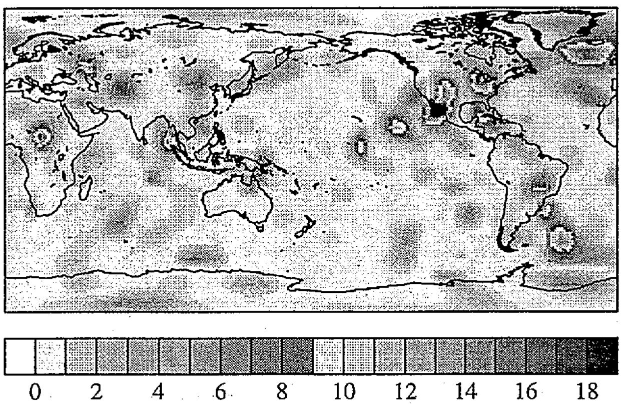
84 Hour Precursor F-test



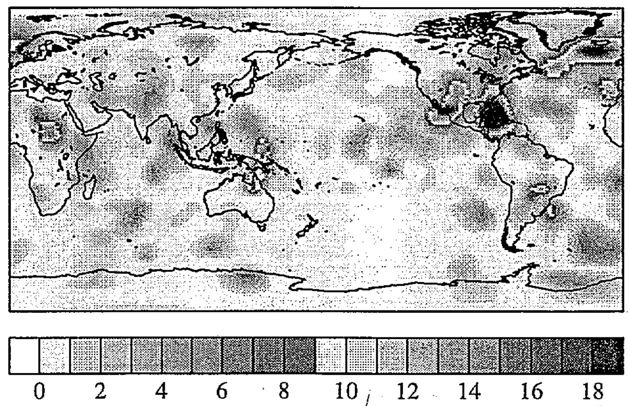
72 Hour Precursor F-test



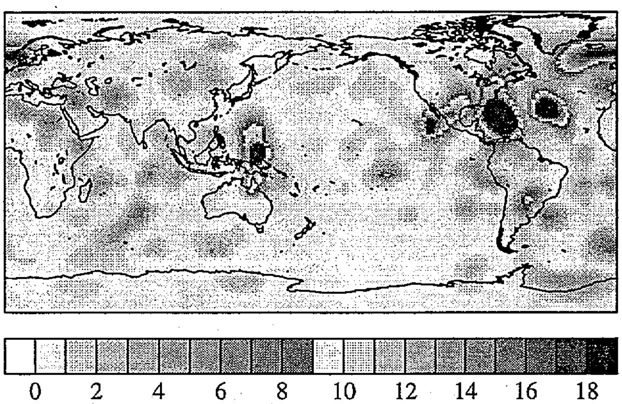
60 Hour Precursor F-test



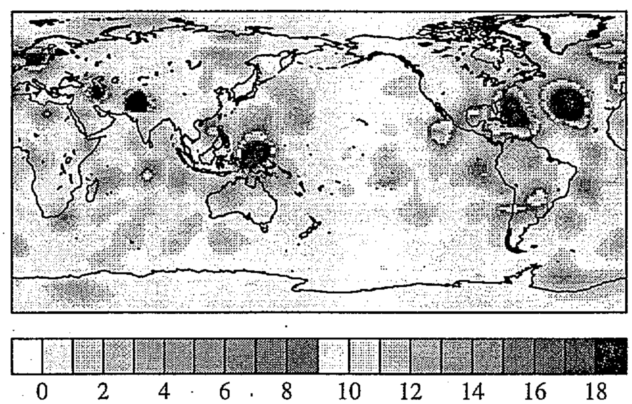
48 Hour Precursor F-test



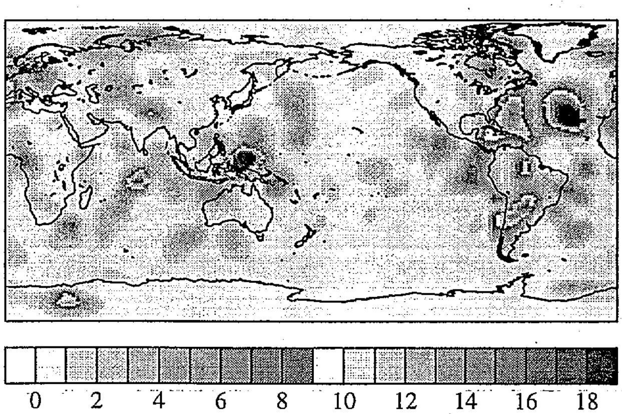
36 Hour Precursor F-test



24 Hour Precursor F-test



12 Hour Precursor F-test



T21 10-member; Target (54N, 6E)

Extension to Real Targeted Observations Problems

Multi-normal random variable x becomes initial condition distribution
Poorly known but may not matter

Random variable y = G(x) is state of GCM after n-hours of integration

Scalar function S(y) is scalar forecast quantity of interest after (n+p)-hours

Note: Can do this for any number of target S's using same ensemble
- Can do this for any number of precursor periods with same ensemble
- Can be same ensemble used for operational prediction
- Possibility that current ensemble sizes are nearly sufficient
- No need for any reduced subspace sampling, non-random sampling, etc.
- Fancier statistics can better extract importance
- Bounds on confidence exist, also get controls for free

Interesting Point: Can do this for model uncertainties at same time (Houtekamer)
- Can do for LARGE set of parameters (1000's ?) with current ensemble sizes
- Most important parameters for given scalar functions (targets) could be found
- Tested in barotropic model context
- Plan to try this in coupled GCMs

The Impact on Synoptic–Scale Forecasts Over the United States of Dropwindsonde Observations Taken in the Northeast Pacific Ocean

Stephen J. Lord
National Centers for Environmental Prediction/NWS
Washington, D. C.

Collaborators:
Steve Tracton (NCEP)
Bert Katz (GSC, NCEP)

I. Introduction

II. Results

Data sensitivity experiments

Interpretation using NCEP Ensemble runs

III. Conclusions

Introduction

- **Hurricane Omega Dropwindsonde Experiments**
  - **Burpee et al (BAMS, May 1996)**
  - **Franklin and DeMaria (MWR, March 1992)**

- **U. S. Air Force Reserve 53rd Weather Reconnaissance Squadron Missions routinely flown for East and Gulf Coast Severe Winter Weather**

- **Purpose: To investigate the impact of similar reconnaissance missions in the Northeast Pacific (NEP) Ocean**
  - **Little prior experience in NEP reconnaissance**
  - **Acknowledge cooperation of:**

    U. S. Air Force Reserves 53rd Weather Reconnaissance Squadron

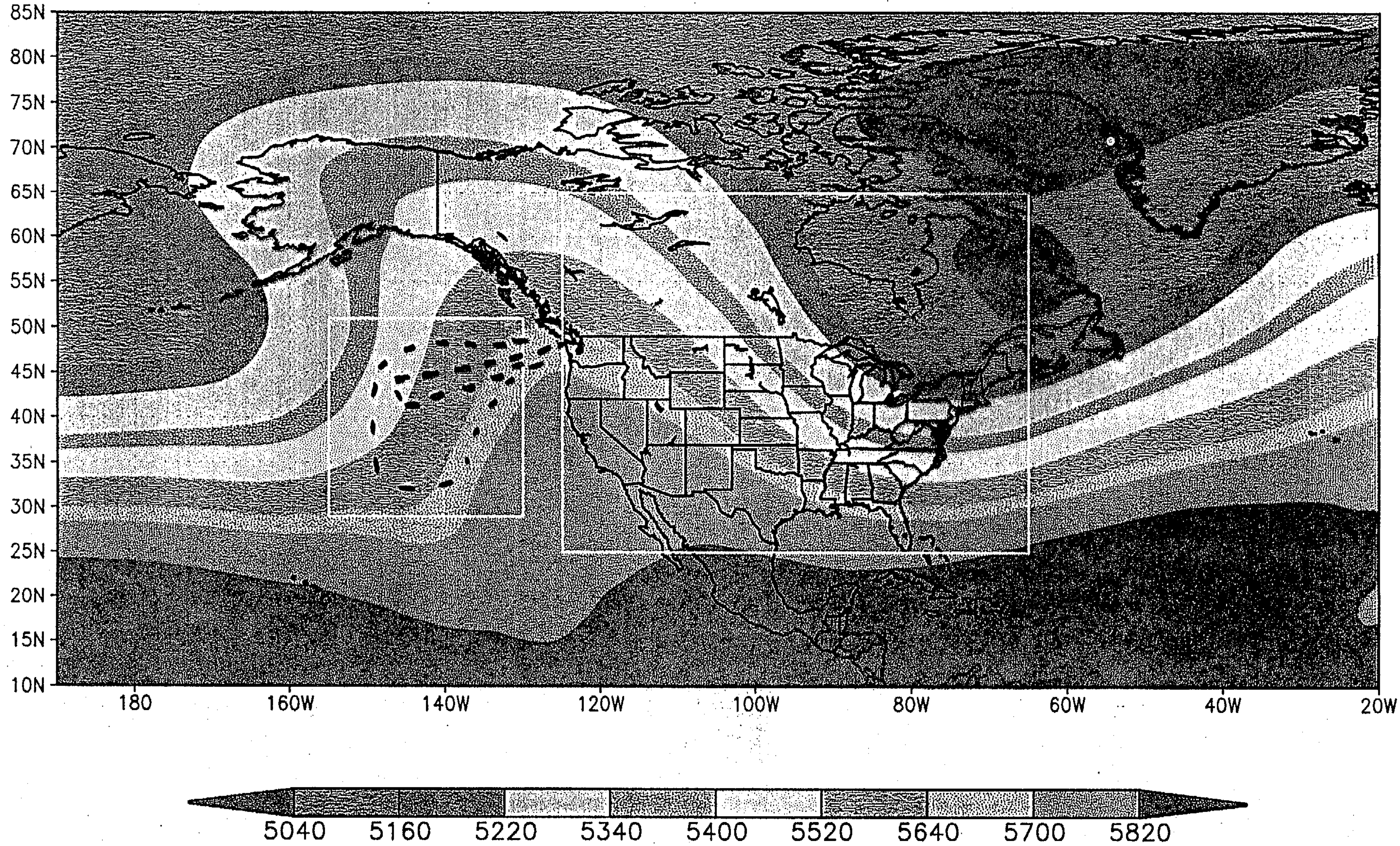
    George Frederick (Radian Corporation)

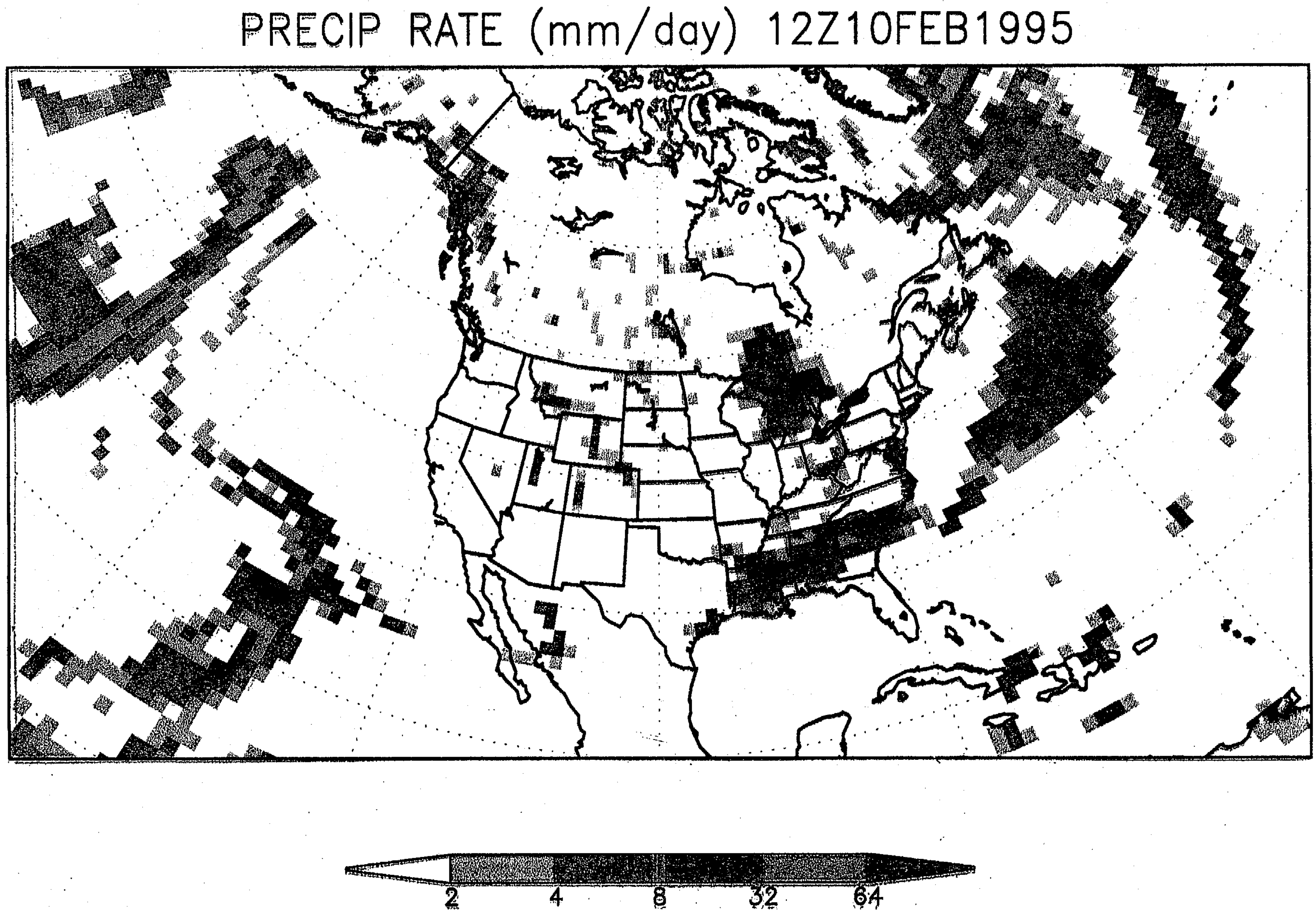
U. S. Air Force Reserve 53rd Weather Reconnaissance Squadron Missions

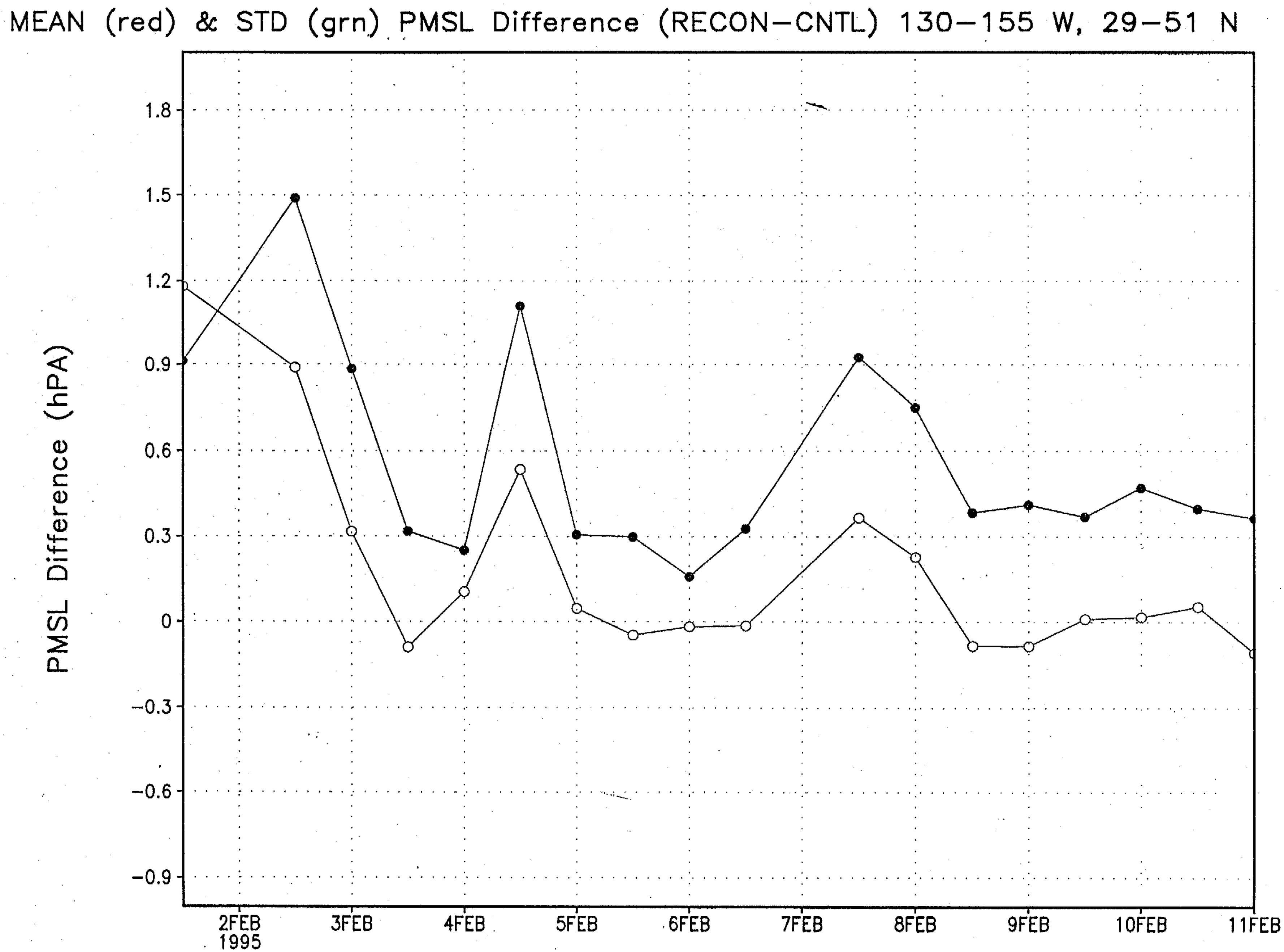
- 31 January – 11 February 1995
- 10 Missions into Northeast Pacific Ocean and Gulf of Alaska, area bounded by 130–155 W, 29–51 N
- Flight tracks planned in advance by forecasters at the NWS WFO (Seattle) and NCEP Operations
- Mission duration approximately 10 hours
- Total of 126 dropwindsondes
  - 38 conventional Omega Dropwindsondes
  - 86 Radian/NCAR Lightweight Omega Digital Dropwindsondes (LOD2)
  - 2 Radian/NCAR Lightweight Global Positioning System Digital Dropwindsondes (LGPSD2)
- Soundings of Wind, Temperature and Humidity (WTH) from approximately 7 km (400 mb) to surface
- Observations used in operational NCEP analyses
- Reruns with NCEP Global Data Assimilation System and without soundings
  - With and without WTH soundings
  - Wind–only soundings
  - Mass–only soundings

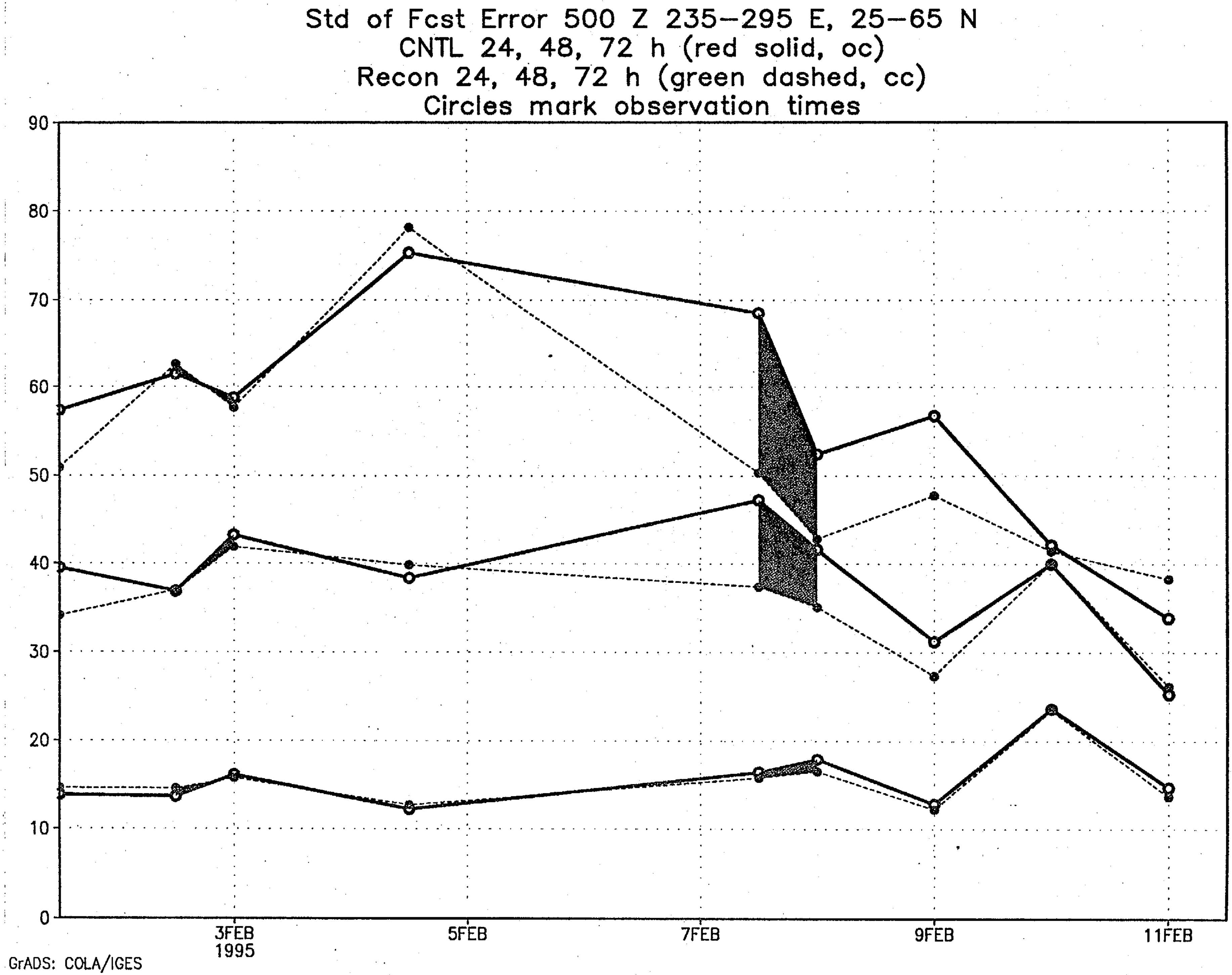
500 hPa Height ANALYSIS

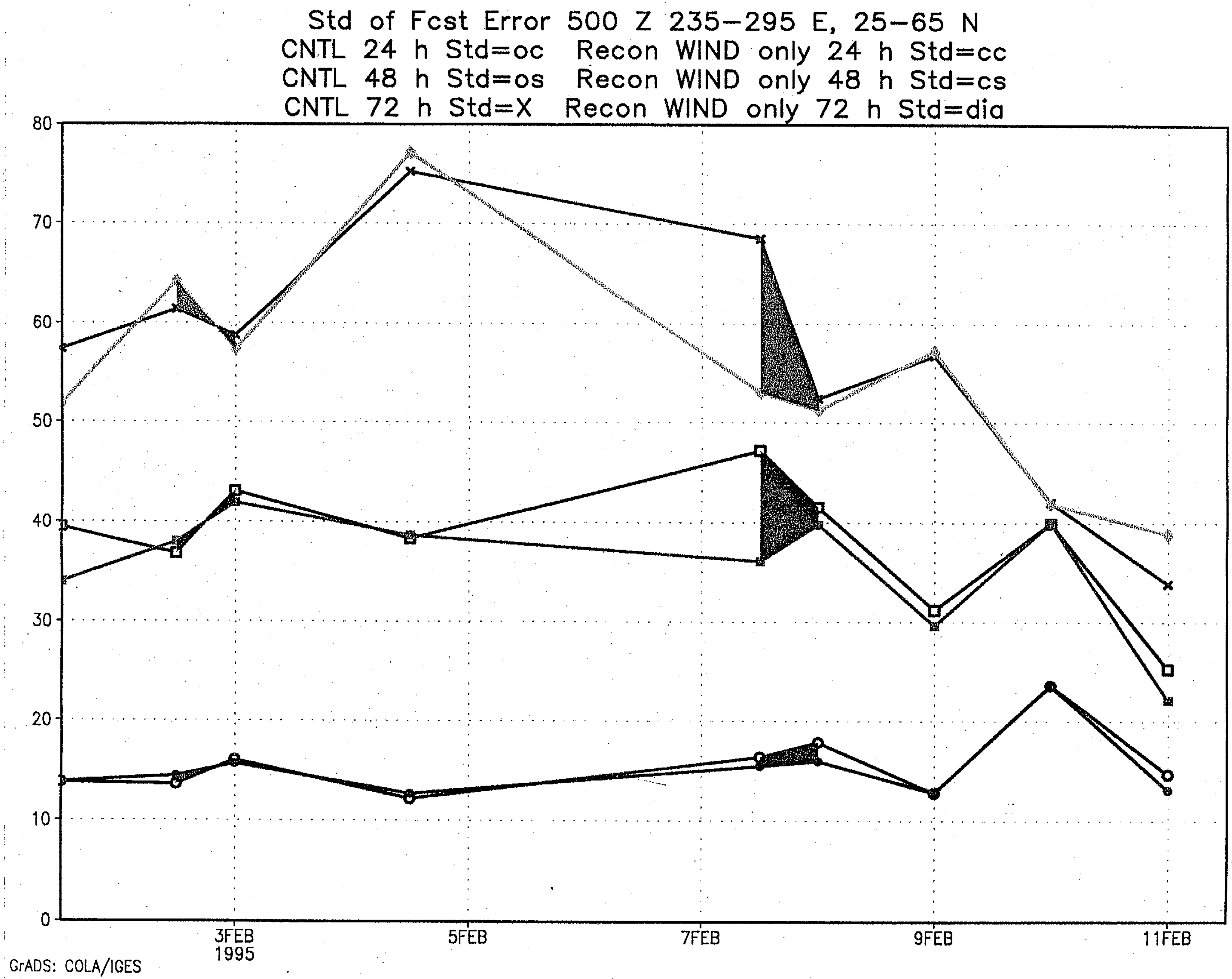
Time Average: 12 UTC 1 February 1995 to 00 UTC 11 February

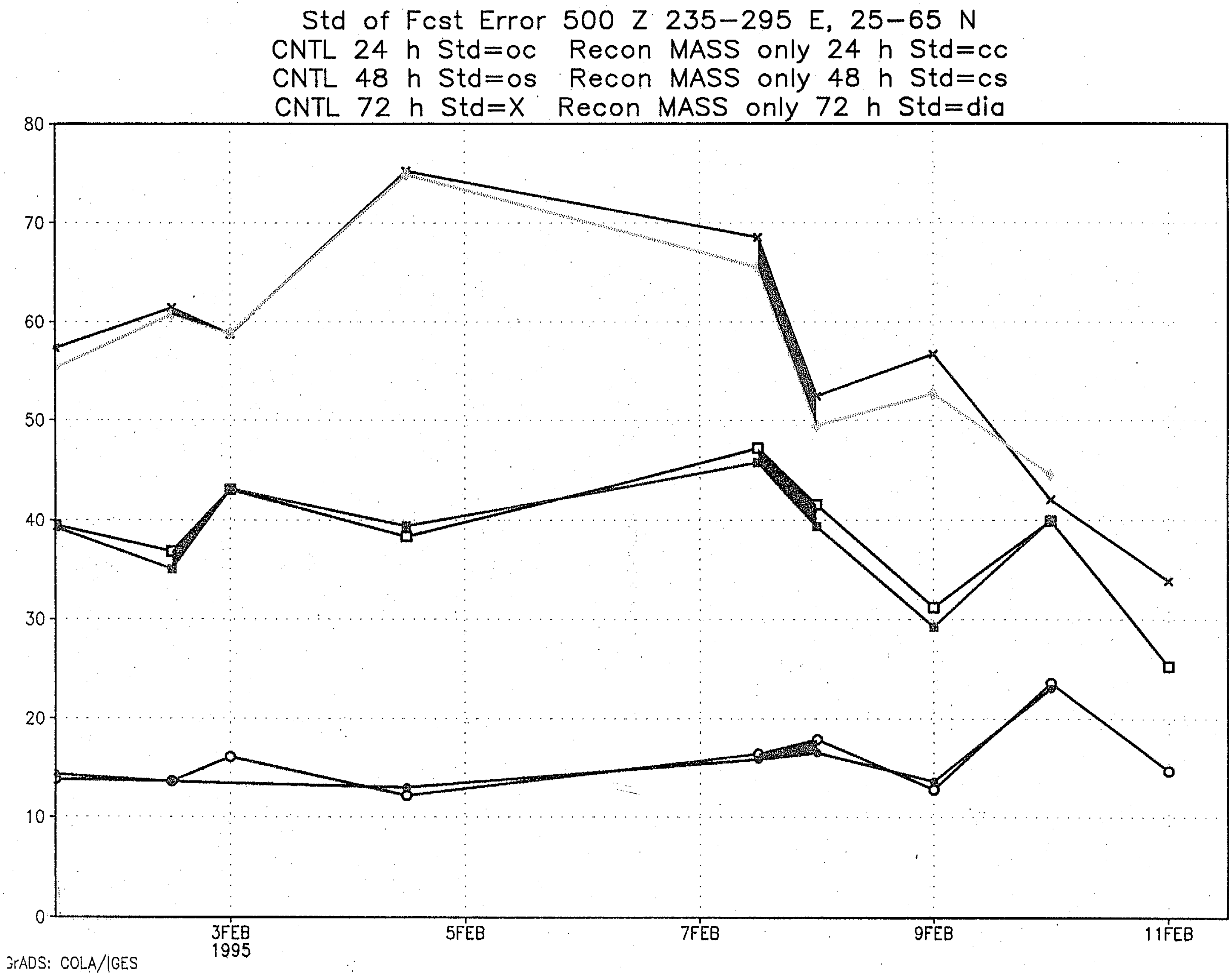



PRECIP RATE (mm/day) 12Z10FEB1995
2
4
8
32
64


MEAN (red) & STD (grn) PMSL Difference (RECON−CNTL) 130−155 W, 29−51 N
PMSL Difference (hPA)
1.8
1.5
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
2FEB
1995
3FEB
4FEB
5FEB
6FEB
7FEB
8FEB
9FEB
10FEB
11FEB

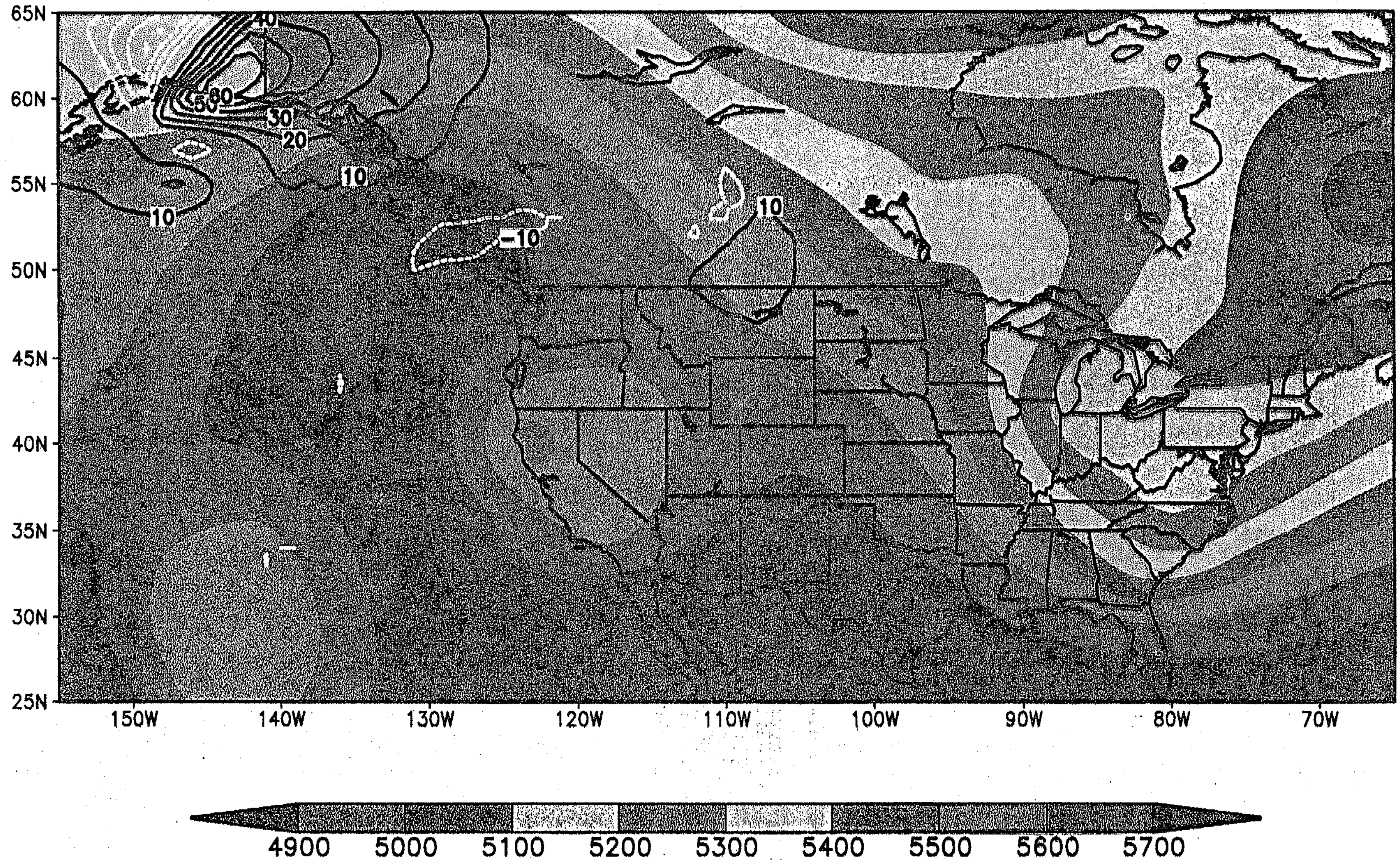

Std of Fcst Error 500 Z 235–295 E, 25–65 N
CNTL 24, 48, 72 h (red solid, oc)
Recon 24, 48, 72 h (green dashed, cc)
Circles mark observation times
90
80
70
60
50
40
30
20
10
0
3FEB
1995
5FEB
7FEB
9FEB
11FEB
GrADS: COLA/IGES


Std of Fcst Error 500 Z 235–295 E, 25–65 N
CNTL 24 h Std=oc Recon WIND only 24 h Std=cc
CNTL 48 h Std=os Recon WIND only 48 h Std=cs
CNTL 72 h Std=X Recon WIND only 72 h Std=dia
80
70
60
50
40
30
20
10
0
3FEB
1995
5FEB
7FEB
9FEB
11FEB
GrADS: COLA/IGES


Std of Fcst Error 500 Z 235-295 E, 25-65 N
CNTL 24 h Std=oc Recon MASS only 24 h Std=cc
CNTL 48 h Std=os Recon MASS only 48 h Std=cs
CNTL 72 h Std=X Recon MASS only 72 h Std=dia
80
70
60
50
40
30
20
10
0
3FEB
1995
5FEB
7FEB
9FEB
11FEB
GrADS: COLA/IGES

RECON Anal & Improvement=abs(ctlerr)−abs(recerr) for 24 h Fcst 95020712

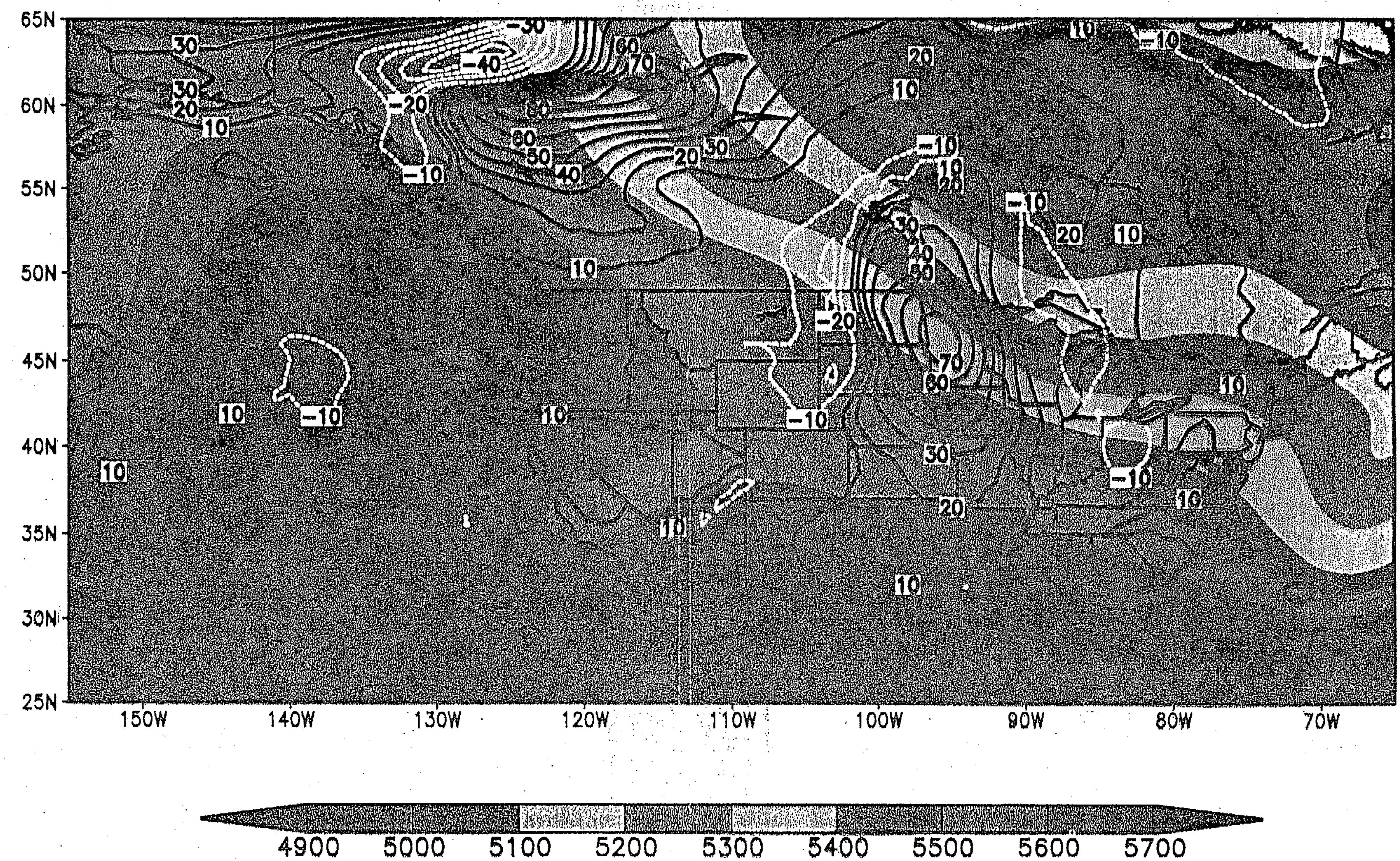
Improvement: Min=−41, Max=70, Area Mean=1.74511



GrADS: COLA/IGES

RECON Anal & Improvement=abs(ctlerr)-abs(recerr) for 48 h Fcst 95020712

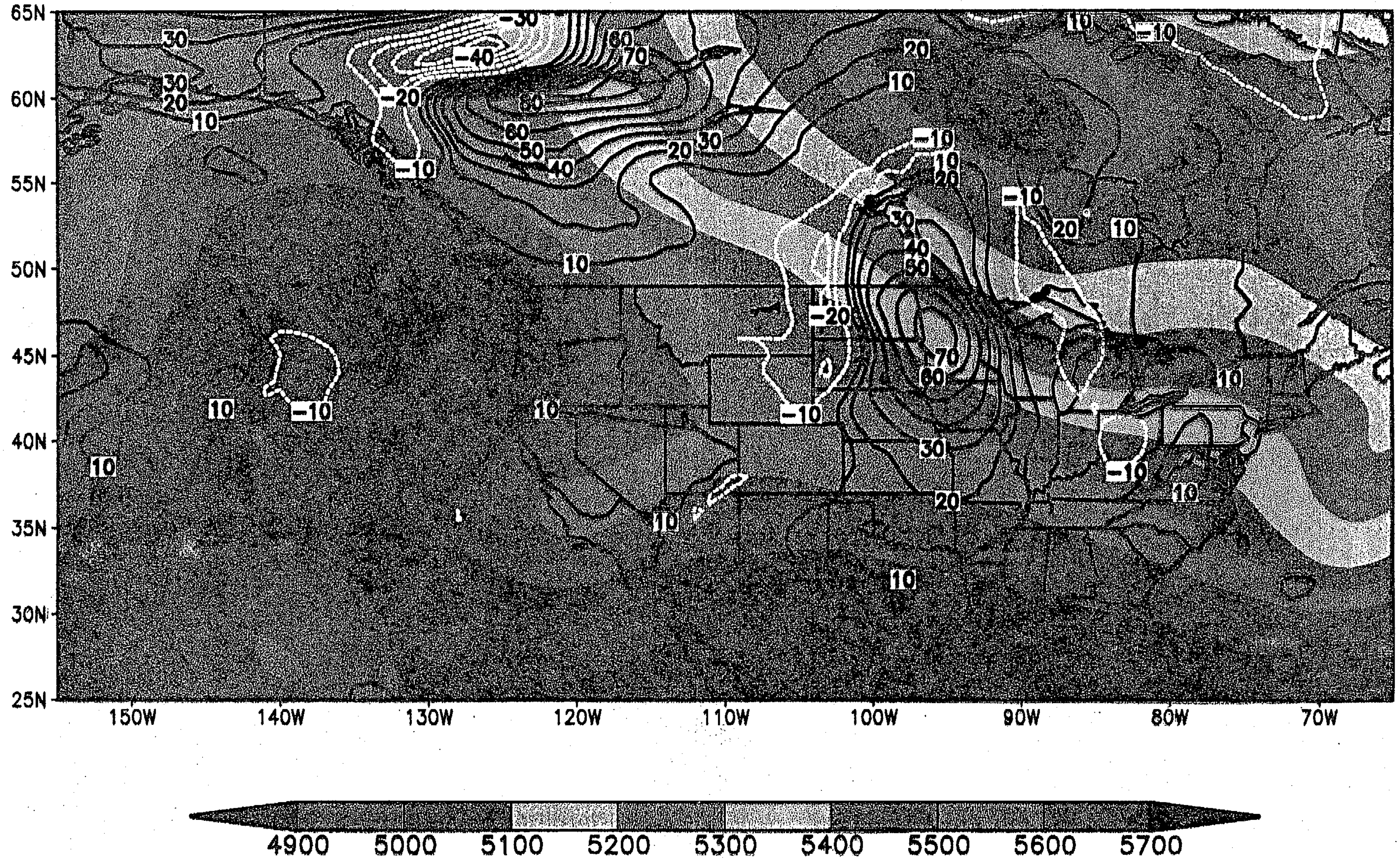
Improvement: Min=-60, Max=87, Area Mean=7.16242



GrADS: COLA/IGES

RECON Anal & Improvement=abs(ctlerr)-abs(recerr) for 48 h Fcst 95020712

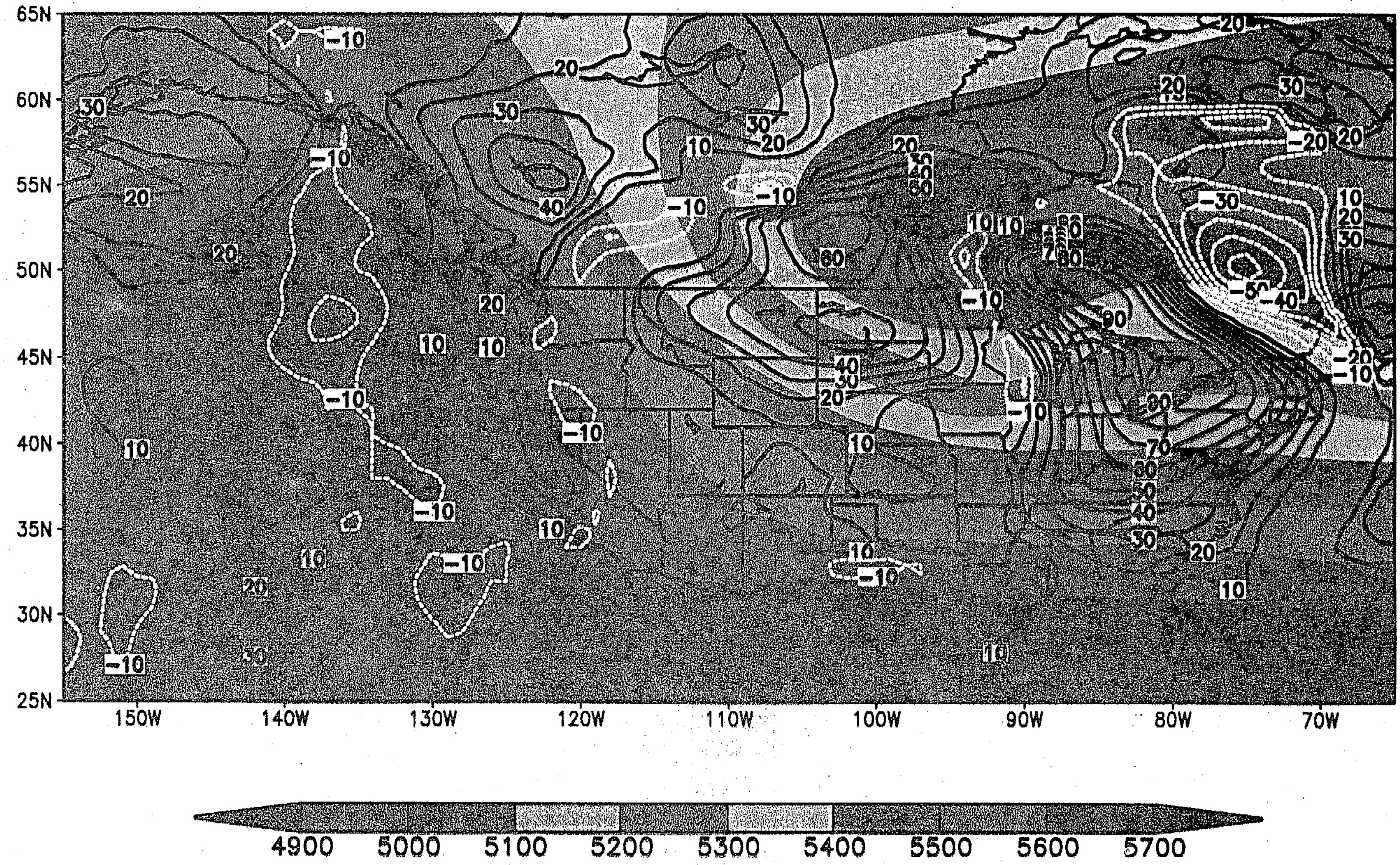
Improvement: Min=-60, Max=87, Area Mean=7.16242



GrADS: COLA/IGES

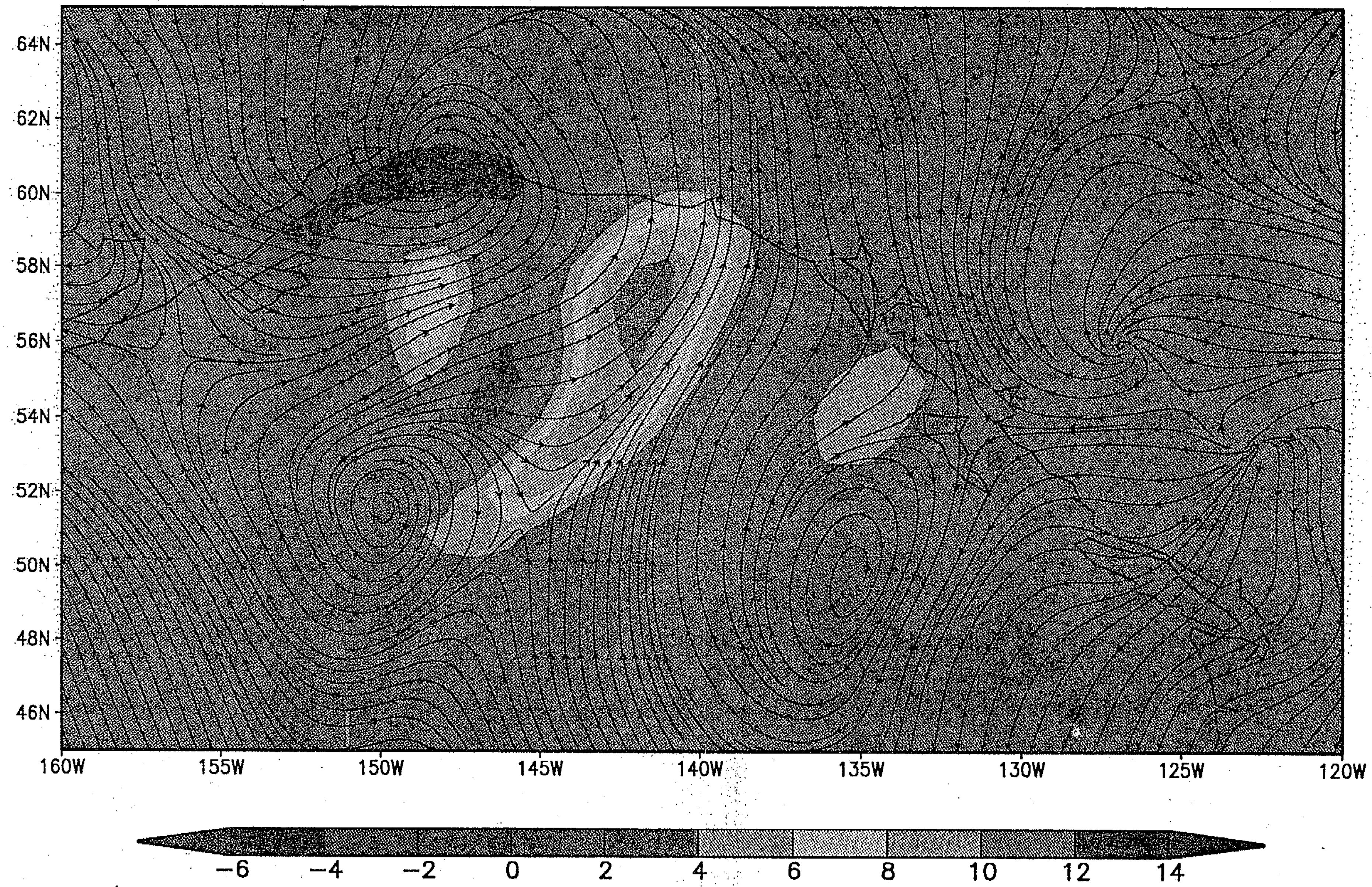
RECON Anal & Improvement=abs(ctlerr)−abs(recerr) for 72 h Fcst 95020712

Improvement: Min=−63, Max=96, Area Mean=11.446



GrADS: COLA/IGES

1000 hPa Wind Error Diff (ctl-recon) 12Z 8 Feb 1995

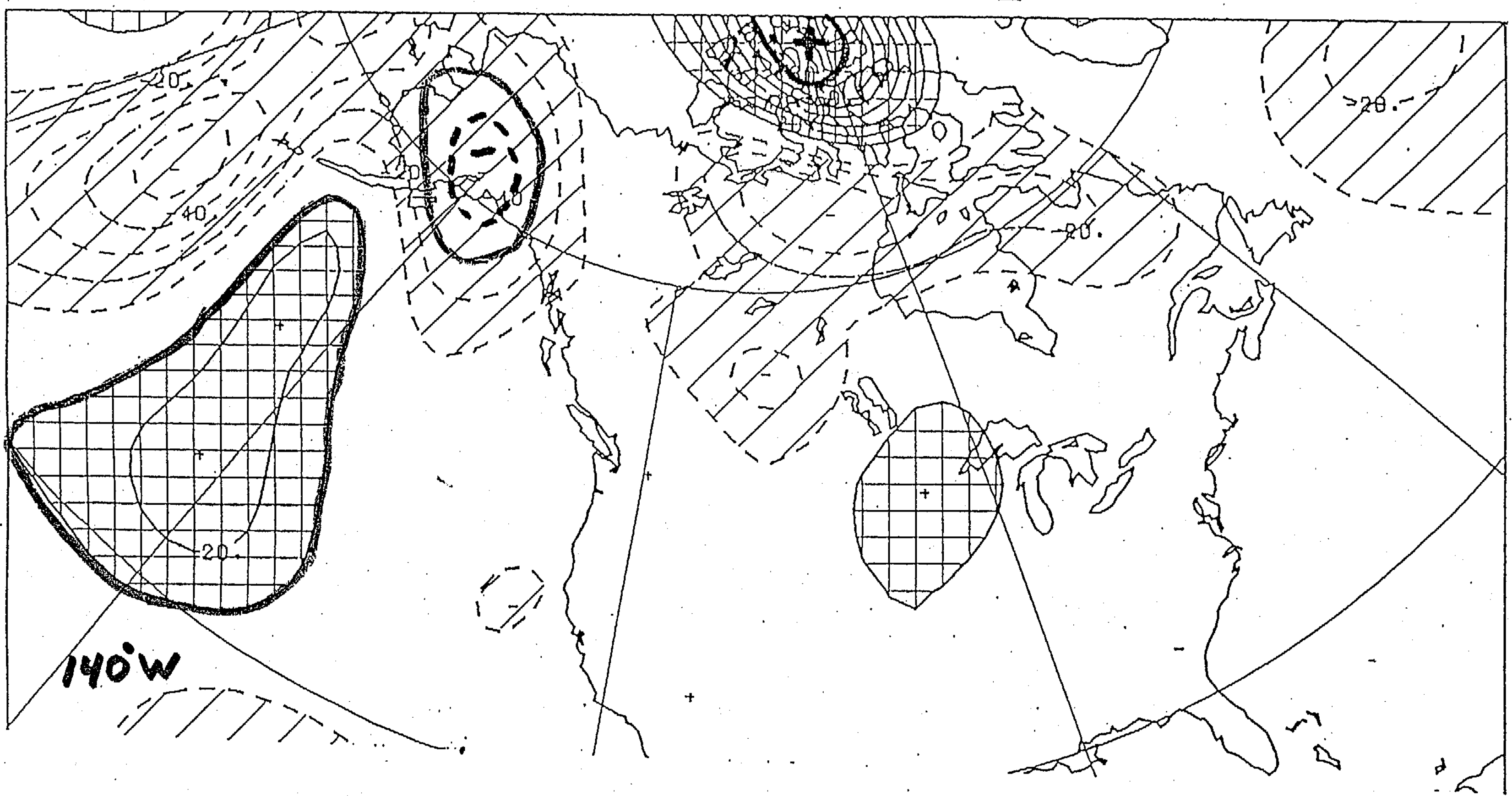


GrADS: COLA/IGES

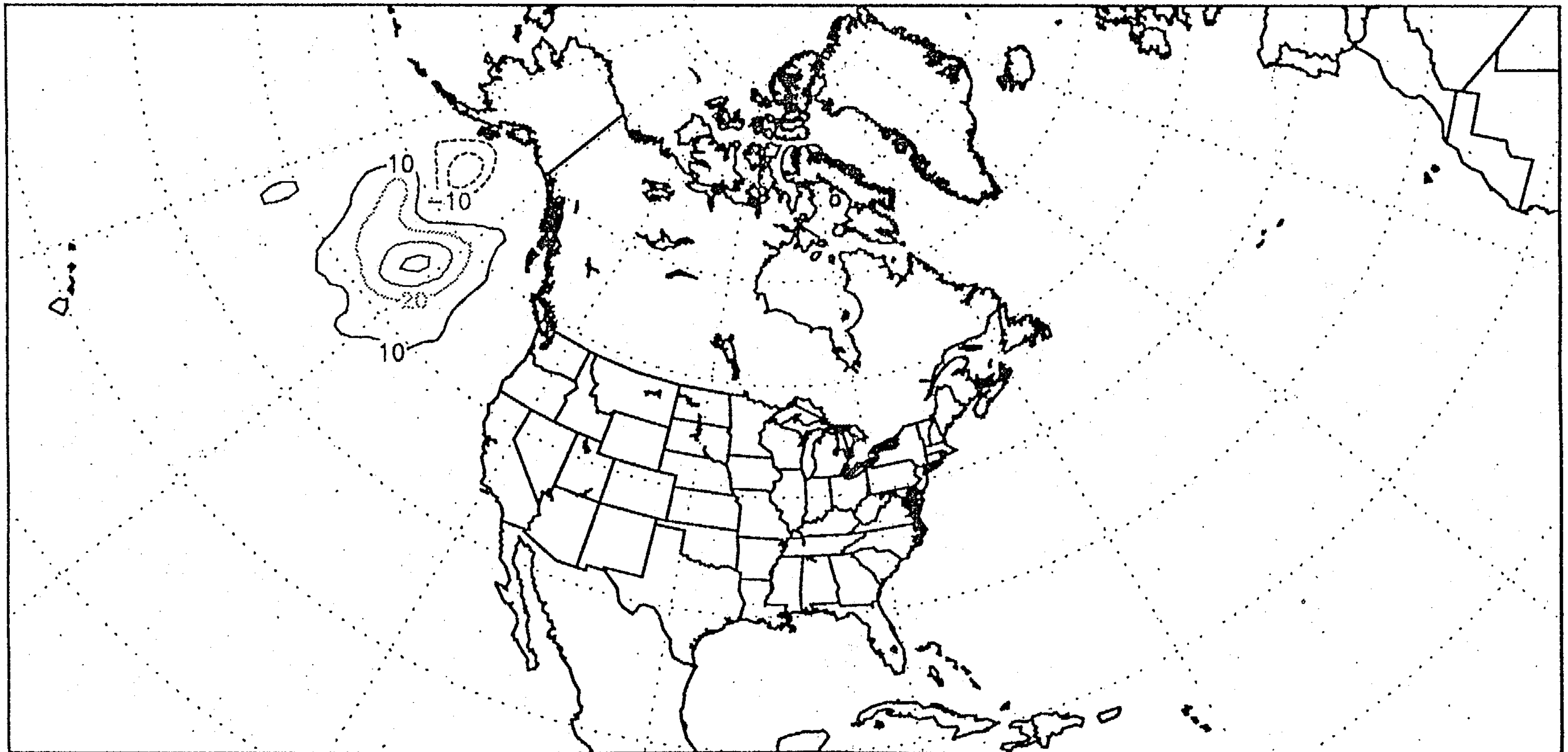
Interpretation Strategies Using NCEP Operational Ensembles

- **Positive Impact Case:**
  - IC – 00 UTC 8 February
  - Demonstrate that perturbation of ensemble member with (subjectively) the best forecast over continental US resembles that induced by Recon soundings
  - Conclude that Recon soundings affected the development of major weather system downstream over central and eastern US
- **Neutral Impact Case:**
  - IC – 00 UTC 3 February
  - Demonstrate that perturbation of ensemble member that most resembles that induced by Recon soundings is irrelevant to forecast errors over continental US
  - Conclude that analysis differences due to Recon soundings should not affect the development of forecast errors downstream

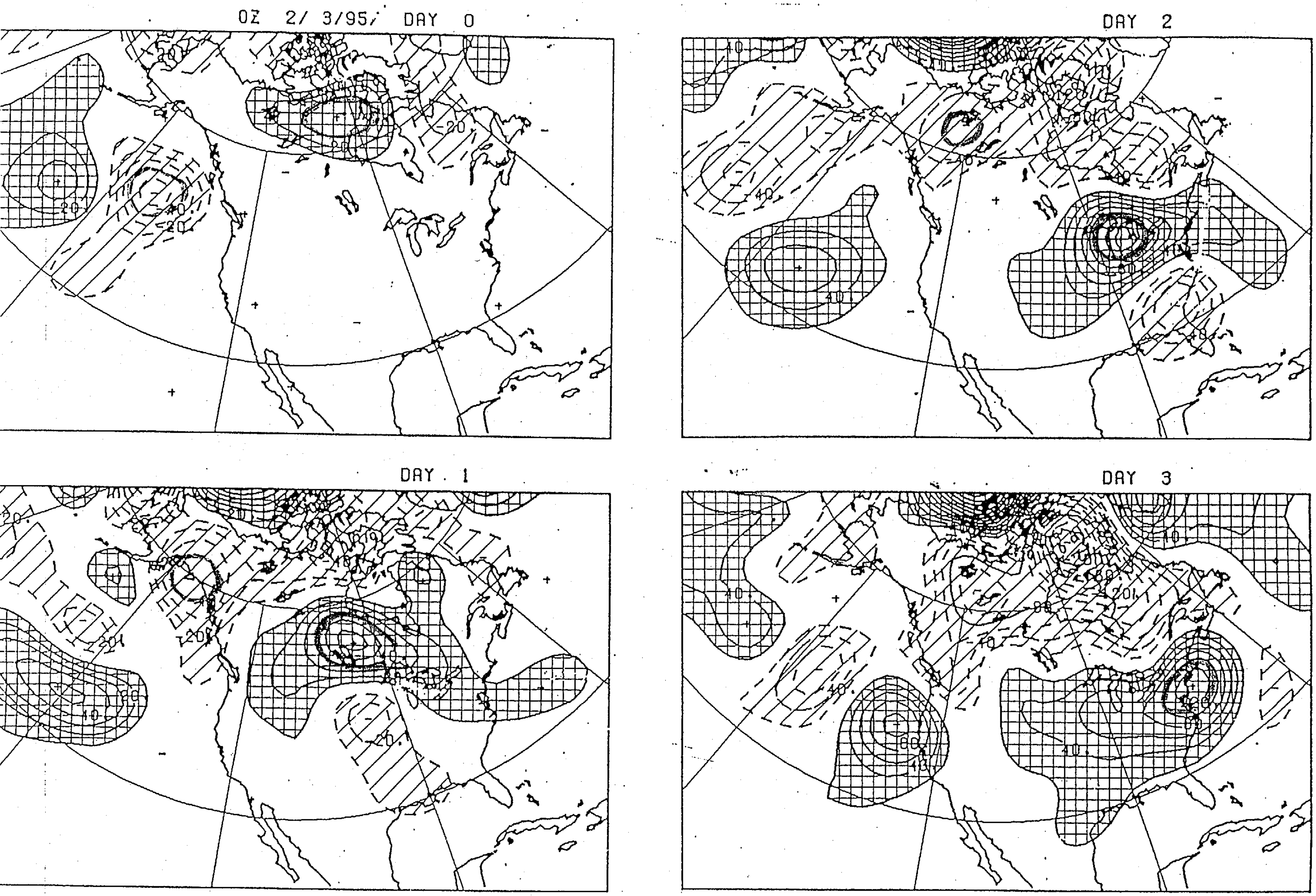
BFM–CNTL 500 hPa Z Anal_95020800



RECON-CNTL 500 hPa Z Anal_95020800



Closest Perturbation to RECON–Induced Soundings



Conclusions

- Offshore observations have a strong potential for improving synoptic–scale forecasts over the continental US

BUT

- Observations must be obtained in a cost–effective and efficient manner
- Wind observations are more effective than mass obs. at reducing forecast errors in these cases
- Ensemble techniques can be used to determine regions with greatest potential for reducing most rapidly growing analysis errors
  - Techniques under evaluation now in context of 1996 hurricane season by Hurricane Research Division/ AOML and National Hurricane Center, Miame
  - Evaluations for mid–latitude cases will certainly point to need for observations in Canada, Mexico and other offshore regions, depending on the synoptic situation

Future Work

- Investigate Data Sensitivity using Linear Tangent Model & Adjoint Methods
- Refine Deployable Observation Strategies Using Ensemble Techniques

WC-130H Improved Weather Reconnaissance System

Major Jon Talbot

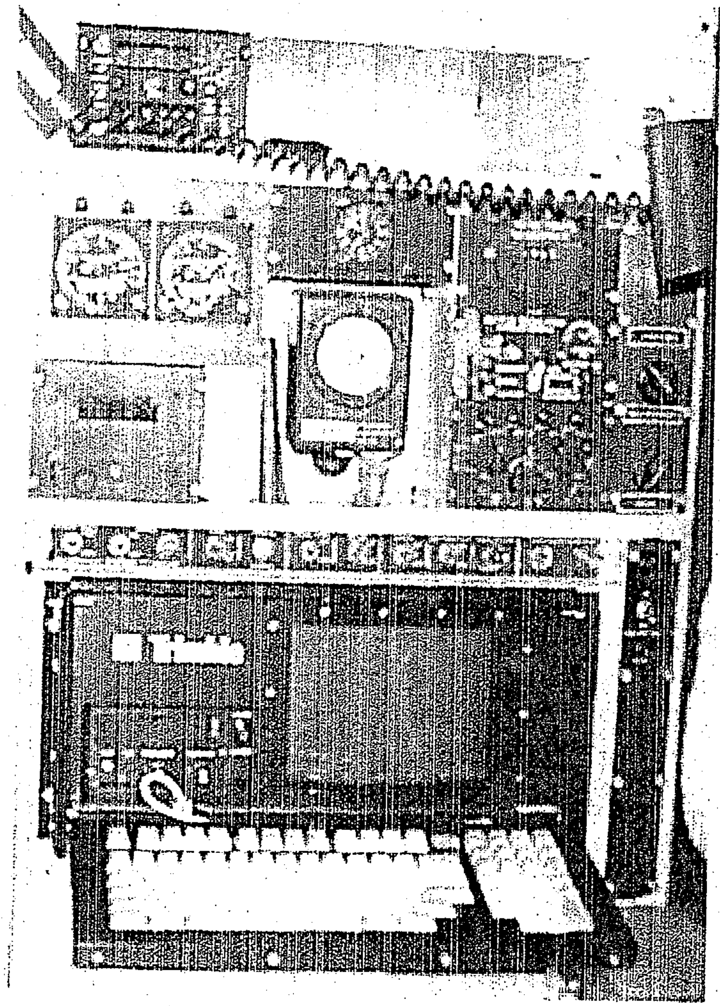
Topics of Discussion

- Brief overview of the Improved Weather Reconnaissance System
- Data Accuracy's
- How to interprete archived data

Improved Weather Reconnaissance System (IWRS)

- Comprised of three subsystems
  - Atmospheric Distributed Data System
  - Satellite Communications System
  - Omega Dropwindfinding System
- Developed by NOAA in early 80's
  - prototype installed in P-3's
- Installation complete in WC-130 in 1991

Atmospheric Distributed Data System



- Collects data from aircraft sensors, navigation system, and dropsonde system
- Computes higher level parameters
- Sends data to satellite communications system

Atmospheric Distributed Data System

- Collects data at eight times per second
- User selectable archive rate.
  - 1 second
  - 10 second
  - 30 second
  - 1 minute
  - 2 minute

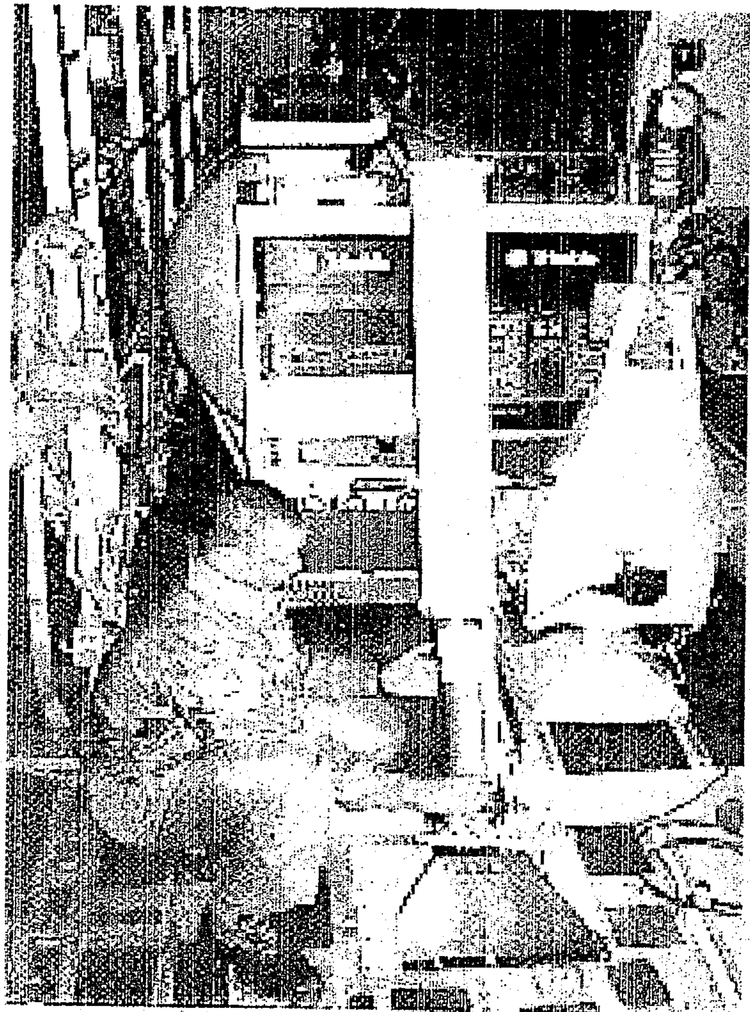
Atmospheric Distributed Data System

- Sensors
  - Temperature
  - Dewpoint
  - Radar Altitude
  - PressureAltitude
  - Dynamic Pressure
  - Side Slip
- Data from Navigation System
  - Latitude, Longitude
  - Velocity North, Velocity East
  - True Heading

Satellite Communication System

- Sends data through AFSATCOM
- Ground station at CARCAH located at the Tropical Prediction Center
  - Allows real time data transfer to TPC
  - Allows onboard meteorologist to communicate with hurricane forecaster
- Portable ground station allows communications at deployed locations

Omega Dropwindfinding System



- Receives and processes sonde data
- Able to track two sondes at a time
- Draws sounding on screen as sonde falls
- AVAPS GPS system expected in late 97

Data Accuracy's

- Total Air Temperature: +\- 0.25C +0.5%C
- Dew Point: +/- 0.5C above 0C, +/- 1.0C below 0C
- Radar Altitude: +/- 2ft (0-100ft), +/- 2% (100-5000ft), +/- 100ft (5000-10,000ft), +\- 1% above 10,000ft
- Pressure Altitude: +\- 10 ft (sea level - 80,000ft)
- Wind speed/Direction: Usually 5 Deg/5 Knots

Interpreting Archive Data

- Units
  - Lat/Long: Deg, neg for lat south of equator/west of Greenwich
  - Temp (tt,ta): Deg C
  - Dewpoint (td): Deg C
  - Dynamic Pressure (dp),Probe Transducers (paa,pal,pb,pss), Flight level Pressure (flp):Millibars
  - Radar altitude, Pressure Altitude (ra,pa)Height of Standard Surface (hss) Geopotential Altitude (ga) D-Value (dv): Meters
  - Side Slip (ss): Degrees
  - Height of standard surface (hss): Meters

time	lat	lon	slp	flp	pa	ra	ga	dv	hss	tt	ta	td	wd	ws	thd	trk	tas	gs	vn	ve	dp	pb	pss	ss
15:32:00	54.178	53.008	998.8	978.7	291	161	149	-142	-100	-18.2	-22.5	-26.2	256	31	170	161	181	182	-172	61	64.3	7	149	-0.5
15:32:01	54.177	53.008	999	978.8	291	162	150	-141	-100	-18.4	-22.7	-26.3	258	29	170	160	181	182	-172	61	64	0	149	0
15:32:02	54.176	53.007	998.9	978.6	292	163	151	-141	-100	-18	-22.4	-26.4	254	29	170	160	182	182	-172	61	65	-1	149	0.1
15:32:03	54.176	53.007	998.9	978.5	293	163	152	-142	-100	-18.2	-22.5	-26.4	260	29	169	160	179	182	-172	61	62.8	2	149	-0.2
15:32:04	54.175	53.006	998.9	978.4	294	165	153	-141	-100	-18	-22.2	-26.3	260	29	169	160	179	182	-172	61	62.8	6	149	-0.4
15:32:05	54.174	53.006	998.9	978.2	296	165	153	-142	-100	-18.4	-22.6	-26.4	261	28	169	160	179	182	-172	62	62.6	4	149	-0.3
15:32:06	54.173	53.006	998.8	978.1	297	166	154	-143	-100	-18.2	-22.5	-26.4	259	29	169	160	180	182	-171	63	63.3	4	149	-0.3
15:32:07	54.172	53.005	999	978.2	296	166	155	-142	-100	-18.2	-22.6	-26.3	256	29	169	160	182	183	-171	63	64.5	2	149	-0.2
15:32:08	54.172	53.004	998.9	978.2	296	166	154	-142	-100	-18.2	-22.6	-26.2	254	28	169	160	183	183	-171	63	65.3	-4	149	0.3
15:32:09	54.171	53.004	998.9	978.2	296	166	154	-142	-100	-18.4	-22.7	-26.1	258	30	169	160	181	183	-171	63	63.8	7	149	-0.5
15:32:10	54.17	53.003	998.9	978.2	296	165	153	-142	-100	-18.4	-22.7	-26.1	260	30	168	160	180	183	-171	63	63.3	9	149	-0.7
15:32:11	54.169	53.003	999	978.3	295	166	154	-141	-100	-18.6	-22.8	-26.1	261	29	168	160	180	183	-172	63	63.1	6	149	-0.5
15:32:12	54.169	53.002	999	978.4	294	165	153	-141	-100	-18.3	-22.7	-26.1	258	28	169	160	181	183	-172	64	64.1	-2	149	0.1
15:32:13	54.168	53.002	998.9	978.4	294	164	152	-142	-100	-18.4	-22.7	-26	260	29	169	160	180	183	-172	64	63.5	0	149	0
15:32:14	54.167	53.002	999	978.6	292	163	151	-141	-100	-18.4	-22.6	-25.9	263	30	168	160	179	183	-172	63	62.5	9	149	-0.7
15:32:15	54.166	53.001	999	978.8	291	162	150	-141	-100	-18.4	-22.6	-25.9	263	28	168	160	179	183	-172	63	62.5	7	149	-0.6
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15:32:17	54.165	53	998.9	979	289	160	148	-141	-100	-18.3	-22.6	-25.8	262	29	169	160	179	183	-172	64	62.8	2	149	-0.2
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15:32:20	54.163	52.999	998.9	979.2	288	158	147	-141	-100	-18	-22.4	-25.7	255	26	169	160	183	184	-173	63	65.5	-4	149	0.3
15:32:21	54.162	52.998	998.9	979	289	160	149	-141	-100	-17.8	-22.2	-25.7	260	29	168	160	181	184	-173	63	63.8	9	149	-0.7
15:32:22	54.16	52.997	998.9	978.7	292	162	150	-141	-100	-17.8	-22.2	-25.6	259	28	168	160	182	184	-173	63	64.3	9	149	-0.7
15:32:23	54.16	52.997	998.9	978.5	294	163	152	-142	-100	-18.2	-22.6	-25.6	259	28	168	160	181	184	-173	63	64.3	8	149	-0.6
15:32:24	54.159	52.997	999	978.5	293	164	152	-141	-100	-18	-22.4	-25.5	258	29	168	160	182	184	-173	63	64.6	8	149	-0.6
15:32:25	54.159	52.996	998.9	978.5	293	163	152	-142	-100	-18.2	-22.5	-25.3	259	29	168	160	181	183	-172	63	64.3	8	149	-0.6
15:32:26	54.158	52.995	999	978.5	293	164	152	-141	-100	-18.2	-22.5	-25.2	259	29	169	160	181	183	-172	63	64	6	149	-0.4
15:32:27	54.156	52.995	998.9	978.5	294	164	152	-142	-100	-18	-22.3	-25.1	262	28	169	160	180	184	-173	62	63.1	3	149	-0.2
15:32:28	54.156	52.995	998.9	978.4	294	164	152	-142	-100	-18.6	-23	-25.1	258	28	169	160	182	184	-173	62	65	2	149	-0.2
15:32:29	54.155	52.994	998.9	978.3	295	165	153	-142	-100	-18	-22.5	-25.1	255	29	169	160	184	184	-173	62	66	9	149	-0.7
15:32:30	54.154	52.993	999.1	978.4	294	165	153	-141	-100	-18.2	-22.7	-25	253	26	169	160	184	184	-173	62	66.5	-3	149	0.3
15:32:31	54.154	52.993	998.9	978.2	296	166	154	-142	-100	-18.2	-22.6	-24.9	256	28	169	160	183	184	-173	62	65.3	3	149	-0.2
15:32:32	54.153	52.992	998.9	978.1	297	166	155	-142	-100	-17.8	-22.2	-24.8	258	28	168	160	182	184	-173	62	64.6	9	149	-0.7
15:32:33	54.152	52.992	999.1	978.3	295	166	154	-141	-100	-18.4	-22.8	-24.8	255	26	168	160	184	184	-173	62	66	3	149	-0.2
15:32:34	54.151	52.992	998.9	978.3	295	165	153	-142	-100	-18.2	-22.6	-24.8	258	27	168	160	182	184	-173	62	64.8	2	149	-0.2
15:32:35	54.15	52.991	999.1	978.5	293	165	153	-140	-100	-18.4	-22.8	-24.8	258	26	169	160	182	184	-173	62	64.6	-3	149	0.2
15:32:36	54.149	52.991	999	978.4	294	165	153	-141	-100	-18.2	-22.5	-24.8	262	28	168	161	180	184	-173	61	63.3	9	149	-0.7
15:32:37	54.149	52.991	998.8	978.1	297	166	154	-143	-100	-18	-22.5	-24.8	255	26	168	161	184	184	-174	61	66.2	8	149	-0.6
15:32:38	54.148	52.99	999.2	978.4	295	166	155	-140	-100	-18.2	-22.6	-24.8	257	25	168	160	183	184	-174	62	65.7	5	149	-0.4
15:32:39	54.147	52.989	999.2	978.4	294	166	155	-140	-100	-18.2	-22.6	-24.8	259	28	168	160	182	184	-174	62	64.8	13	149	-1
15:32:40	54.146	52.989	999.1	978.4	294	166	154	-140	-100	-18.4	-22.7	-24.8	262	28	168	160	181	184	-173	63	64	13	149	-1
15:32:41	54.146	52.988	999.1	978.4	294	166	154	-140	-100	-18.2	-22.6	-24.9	260	27	168	160	182	185	-173	64	64.5	6	149	-0.5
15:32:42	54.145	52.988	999	978.4	294	165	153	-141	-100	-18.6	-23	-25	260	27	168	159	182	185	-173	65	64.5	-1	149	0.1
15:32:43	54.144	52.987	999	978.7	292	163	151	-141	-100	-18.6	-22.9	-25	262	28	167	159	181	185	-173	66	63.8	4	149	-0.3
15:32:44	54.143	52.987	999.1	978.9	290	162	150	-140	-100	-18.4	-22.8	-25.2	260	27	167	159	182	185	-173	67	64.8	5	149	-0.4
15:32:45	54.142	52.986	999.1	979	289	162	150	-140	-100	-18.3	-22.7	-25.2	261	27	167	159	181	185	-173	67	64.3	9	149	-0.7
15:32:46	54.141	52.986	999.2	979.1	288	160	149	-139	-100	-18.4	-22.8	-25.5	257	27	167	159	183	185	-173	67	65.8	4	149	-0.3
15:32:47	54.141	52.985	999.1	979.4	286	158	147	-139	-100	-18.2	-22.6	-25.6	259	26	167	159	182	185	-172	68	65	1	149	-0.1
15:32:48	54.14	52.985	999.1	979.4	286	158	147	-139	-100	-18.2	-22.4	-25.7	264	29	167	158	180	185	-172	68	62.9	9	149	-0.7
15:32:49	54.139	52.984	999	979.4	286	158	146	-140	-100	-18.6	-22.8	-26	264	29	167	158	180	185	-172	68	63.1	9	149	-0.7

FLTLVL10

time	lt	lg	ta	td	wd	ws	dv	pa	ra	flag
10:32:10	47 37.3N	52 44.2W	-8.2	-11.3	359	24	-121.4	108	0	280
10:32:20	47 37.3N	52 44.2W	-8.2	-11.4	359	24	-121.4	108	0	280
10:32:30	47 37.3N	52 44.2W	-8.2	-11.1	359	24	-121.7	108	0	0
10:32:40	47 37.3N	52 44.2W	-8.2	-10.9	356	24	-122.4	109	0	280
10:32:50	47 37.3N	52 44.2W	-8.2	-10.9	358	24	-122	109	0	280
10:33:00	47 37.3N	52 44.2W	-8.2	-10.9	357	24	-122.4	109	0	0
10:33:10	47 37.3N	52 44.2W	-8.1	-11	356	24	-122.2	109	0	280
10:33:20	47 37.3N	52 44.2W	-8.1	-10.9	360	24	-121.8	109	0	280
10:33:30	47 37.3N	52 44.2W	-8.3	-10.8	352	21	-122.1	109	0	280
10:33:40	47 37.3N	52 44.2W	-8.3	-10.7	323	19	-121.8	108	0	0
10:33:50	47 37.3N	52 44.2W	-8.5	-10.6	299	18	-122.2	109	0	0
10:34:00	47 37.4N	52 44.2W	-8.7	-10.4	299	18	-122.5	109	0	0
10:34:10	47 37.4N	52 44.2W	-8.8	-10.2	298	18	-122.9	110	0	280
10:34:20	47 37.4N	52 44.3W	-8.8	-10	295	18	-123.4	110	0	0
10:34:30	47 37.4N	52 44.3W	-8.8	-9.9	297	18	-124.2	111	0	0
10:34:40	47 37.4N	52 44.3W	-8.8	-10	325	16	-125	111	0	280
10:34:50	47 37.5N	52 44.3W	-8.6	-9.8	6	16	-125.1	112	0	280
10:35:00	47 37.5N	52 44.3W	-8.4	-9.8	333	18	-125.4	112	0	0
10:35:10	47 37.5N	52 44.3W	-8.6	-9.5	280	20	-125.2	112	0	280
10:35:20	47 37.5N	52 44.3W	-8.6	-9.4	271	23	-126.6	113	0	280
10:35:30	47 37.5N	52 44.3W	-8.5	-9	267	25	-128.1	115	0	0
10:35:40	47 37.5N	52 44.3W	-8.5	-9.6	267	27	-129.4	116	0	0
10:35:50	47 37.5N	52 44.3W	-8.5	-9.2	271	25	-129.7	116	0	280
10:36:00	47 37.5N	52 44.4W	-8.8	-9.6	274	21	-129.8	117	0	0
10:36:10	47 37.5N	52 44.6W	-8.7	-11.7	273	16	-128.5	115	0	0
10:36:20	47 37.4N	52 45.0W	-8.8	-12.6	275	16	-126.2	113	0	0
10:36:30	47 37.4N	52 45.5W	-8.7	-13.3	282	12	-109.4	97	0	0
10:36:40	47 37.4N	52 46.0W	-8.6	-13.9	284	16	-116.6	121	16	0
10:36:50	47 37.3N	52 46.6W	-8.9	-14.2	284	19	-117.7	168	63	0
10:37:00	47 37.3N	52 47.1W	-9	-14.3	283	20	-114.8	226	123	0
10:37:10	47 37.3N	52 47.8W	-9.5	-14.3	289	18	-130.6	258	139	0
10:37:20	47 37.2N	52 48.5W	-9.8	-14.3	294	18	-162.2	287	136	0
10:37:30	47 37.2N	52 49.2W	-10	-14.5	290	19	-166	352	198	0
10:37:40	47 37.1N	52 49.9W	-10.8	-14.8	291	19	-137.8	456	330	0
10:37:50	47 37.0N	52 50.6W	-11.9	-15.3	286	20	-139.8	579	454	0
10:38:00	47 37.0N	52 51.3W	-12.8	-15.6	276	21	-193.2	700	526	0
10:38:10	47 37.0N	52 52.0W	-13.5	-15.8	273	24	-144.6	828	702	0
10:38:20	47 37.1N	52 52.5W	-14	-17.7	274	25	-51.7	941	908	0
10:38:30	47 37.5N	52 53.0W	-14.7	-21.7	265	22	-53.8	1061	1025	0
10:38:40	47 38.0N	52 53.0W	-15.4	-22.9	249	21	-55.8	1152	1111	0
10:38:50	47 38.5N	52 52.7W	-15.6	-26.1	242	24	-62.7	1230	1181	0
10:39:00	47 38.9N	52 52.0W	-16.6	-28.2	260	28	-72.8	1315	1256	0
10:39:10	47 39.3N	52 51.3W	-16.9	-29.6	269	30	-82	1433	1365	0
10:39:20	47 39.6N	52 50.7W	-17.1	-30.6	268	34	-141.4	1537	1410	0
10:39:30	47 40.0N	52 50.0W	-17.1	-31.4	266	38	-280.5	1610	1344	0
10:39:40	47 40.4N	52 49.3W	-17.4	-31.9	264	40	-258.9	1660	1415	0
10:39:50	47 40.8N	52 48.6W	-16.3	-32.3	265	43	-263.3	1712	1462	0
10:40:00	47 41.1N	52 47.9W	-15.3	-32.6	264	45	-282.5	1749	1480	0
10:40:10	47 41.5N	52 47.1W	-14.2	-32.9	262	45	-276.4	1777	1514	0
10:40:20	47 41.9N	52 46.4W	-14	-33.1	262	47	-271.5	1799	1542	0
10:40:30	47 42.3N	52 45.6W	-13.8	-33.3	260	46	-301.4	1844	1556	0
10:40:40	47 42.7N	52 44.8W	-13.6	-33.5	258	45	-260.7	1892	1645	0
10:40:50	47 43.1N	52 44.0W	-13.4	-33.7	257	44	-218	1932	1728	0

day	time	td	tt	dp	pal	paa	pb	pss	hc1	hc2	flp	ra	lt	lg	vn	ve	thd	ss	atk	gs	trk	ta	pa	ga	dv	hss	slp	tas	wd	ws	mxw	
8	10325	-10.9	-8.1	1	-0.7	0	-1	1.4	0	0	1000.2	-1.5	47.6223	-52.7364	0	0	4.9	7.9	0	0	45	-8.2	109	-13.5	-122.3	-100	998.5	23.7	357	23.6	23.7	0
8	10330	-10.9	-8.1	1	-0.5	0	-1	1.4	0	0	1000.3	-1.3	47.6223	-52.7364	0.8	-0.1	3.8	8	0	0.8	352.3	-8.2	108.7	-13.3	-122	-100	998.5	23.7	356	22.8	23.6	0
8	10335	-10.6	-8.4	1	0.3	0	-2.1	1.8	0	0	1000.3	-1.5	47.6223	-52.7364	4	-3.6	322.5	12.8	0	5.3	318.1	-8.5	108.7	-13.5	-122.2	-100	998.5	23.4	307.2	18.2	21.3	0
8	10340	-10	-8.7	1.1	0.3	0	-2.1	1.9	0	0	1000.1	-1.5	47.623	-52.7378	5.2	-5.1	315.1	13	0	7.3	315.6	-8.8	110.3	-13.5	-123.6	-100	998.4	25.1	296.7	18.1	18.5	0
8	10345	-9.9	-8.5	1	-0.1	0	-1.9	1.7	0	0	999.9	-1.5	47.6244	-52.7378	6.4	0	358.7	12.4	0	6.3	359.7	-8.6	111.5	-13.5	-125.2	-100	998.2	22.4	340.8	15.9	18.1	0
8	10350	-9.3	-8.5	1	-0.6	0	-0.1	1.6	0	0	999.7	-1	47.6244	-52.7385	-0.1	-1.4	272.4	0.6	0	1.4	268	-8.6	113.5	-13	-126.7	-100	998	23.7	272.2	22.5	24.8	0
8	10355	-9.4	-8.5	1.9	-1.5	0.7	0.4	2.2	0	0	999.3	-1.3	47.6244	-52.7385	-0.5	-6.9	267.1	-2.1	3.6	6.9	266.1	-8.6	116.5	-13.3	-129.7	-100	997.6	31.2	270.2	24.2	27.3	0
8	10360	-12.6	-7.2	20.3	-11.8	16.2	2.8	23.5	0	0	1000.3	-1	47.6237	-52.7467	-6.3	-88.2	266.1	-1.4	8.7	88.5	266	-8.7	108.5	-13	-121.4	-99.5	998.6	102.9	276.4	14.6	20.6	0
8	10365	-14.1	-5.6	44.7	-34.3	37.2	5.1	53.9	0	0	992.8	67.5	47.6223	-52.7715	-10.8	-138.5	266.5	-1.1	10.4	139	265.5	-8.9	172	55.5	-116.4	-97.7	999.9	156.6	283.5	18.4	19.8	0
8	10370	-14.4	-5.2	61.9	-43.1	51.1	7.9	76.6	0	0	977.9	157.7	47.6209	-52.8024	-18.1	-167.5	265.9	-1.2	9.8	168.3	264.5	-9.8	299	146	-153	-97.3	996.5	184.8	291.2	18.3	19.8	0
8	10375	-15.2	-7.1	63.3	-45	52.2	9.3	79	0	0	945.7	436.5	47.6182	-52.8381	-19.9	-169	264.1	-1.3	9.8	170.1	263.3	-11.8	578.2	421.3	-157	241.5	998.9	188.8	283.9	19.8	21	0
8	10380	-18.4	-9.6	57.9	-33.9	47.2	9	73.4	0	0	905	878.3	47.6168	-52.8717	60	-135.3	289.4	-1.4	8.1	148	293.9	-14.1	943.5	860	-83.4	714.5	1012.3	170.2	270.7	23.6	25.2	0
8	10385	-25.7	-11.4	57.6	-30.6	46.8	6.5	72.8	0	0	873.7	1182.5	47.6381	-52.8813	169.9	77.1	17.6	-1	7.4	186.6	24.4	-15.9	1232.2	1168.5	-63.8	1375.2	1018	169.6	250.7	24	28	0
8	10390	-30.5	-12.6	55.3	-29.9	45.1	-0.5	68.3	0	0	842.8	1373	47.658	-52.8504	131.6	163.4	44.9	0.1	7.5	209.8	51.1	-17.1	1526.8	1358.7	-168	1294.7	1007.2	183.5	267.5	34	37.7	0
8	10395	-32.3	-11.7	55.7	-32	45.4	5.1	69.5	0	0	824.3	1452.8	47.6759	-52.8168	133.7	176.5	45.2	-0.8	8	221.4	52.8	-16.3	1706.7	1438.5	-268.3	1207	994.7	186.6	264.5	42.4	45.1	0
8	10400	-33.1	-8.9	59.7	-35.9	48.9	3.8	73.1	0	0	814.2	1537.5	47.6951	-52.779	140.9	187	46	-0.6	8.3	234.1	53	-14	1806.5	1523.5	-283.1	1196	991.6	195	261.4	45.9	46.5	0
8	10405	-33.7	-8.2	61.7	-37.2	50.7	0.7	74.8	0	0	801.5	1721.5	47.715	-52.7399	143.9	189.8	47	-0.1	8.4	238.2	52.8	-13.5	1934.3	1707.5	-226.7	1258	998.6	199.7	259.6	44.2	46	0
8	10410	-34	-9.1	61.5	-37.2	50.6	1.4	74.6	0	0	783	1989.8	47.737	-52.7042	177.1	149.6	31.3	-0.2	8.4	231.8	40.2	-14.5	2122.5	1976	-146.6	1592.7	1010.1	201.1	262.8	44.8	45	0
8	10415	-34.3	-10.9	60.3	-37.8	49.4	4	73.2	0	0	759.6	2236	47.7631	-52.6767	200.5	107.8	17.3	-0.6	8.7	227.6	28.3	-16.4	2364.8	2222.2	-142.4	2831.8	1012.8	204	262	45.5	46.3	0
8	10420	-34.5	-11.9	61.2	-38.6	50.2	3.4	73.9	0	0	740.3	2419.8	47.7919	-52.6568	210.2	85.9	10.6	-0.5	8.8	227.1	22.2	-17.6	2569.7	2406	-163.8	2822.5	1011.5	207.7	262.1	46.4	46.5	0
8	10425	-34.8	-12.5	59.3	-35.7	48.5	3	71.8	0	0	723.4	2596.5	47.8214	-52.6403	212	79	8.6	-0.5	8.4	226.3	20.4	-18.2	2753	2582.8	-170.3	2827.2	1011.3	206.7	260.3	47.1	47.3	0
8	10430	-35	-12.7	58.2	-34	47.5	3.5	70.8	0	0	709.7	2743.2	47.851	-52.6238	214.8	82.4	9.7	-0.6	8.1	230	21	-18.4	2903.5	2729.5	-174.1	2832.2	1011	206.7	256	47	47.3	0
8	10435	-35.4	-13.1	57.8	-33.6	47.2	3.7	70.5	0	0	696.9	2878.7	47.8812	-52.6067	218.3	85.7	10.2	-0.6	8.1	234.5	21.4	-18.9	3046.8	2865	-181.8	2832.2	1010.4	207.7	253	48.8	49.3	0
8	10440	-35.6	-14.1	57.8	-33.5	47.2	3.5	70.5	0	0	684.6	3010.2	47.9114	-52.5888	221.2	86.9	10.1	-0.6	8.1	237.6	21.5	-19.9	3186.8	2996.7	-190	2831.5	1010.5	209	251.9	50.7	51.4	0
8	10445	-36	-14.4	56.9	-31.9	46.3	3.1	69.5	0	0	671.8	3153	47.9423	-52.571	221.5	86.7	9.3	-0.5	7.8	237.9	21.4	-20.2	3337	3139.3	-197.6	2831	1009.6	209.3	253.4	53.3	54.2	0
8	10450	-36.3	-15.1	53.6	-27.3	43.3	3.5	66.1	0	0	656.7	3318.7	47.9732	-52.5531	217.3	84.2	7.7	-0.6	7.2	233	21.2	-20.7	3511	3305	-206.1	2830	1008.6	205.3	255.5	56.4	57.7	0
8	10455	-36.6	-16	51.2	-23.4	41.1	3.2	63.4	0	0	642.5	3469	48.0027	-52.5359	214.4	81.9	6.6	-0.6	6.5	229.6	20.9	-21.4	3680.5	3455.2	-225.2	2818.5	1006.7	202.5	256.7	58.3	59.2	0
8	10460	-37	-16.7	49.5	-21.1	39.5	2.8	61.5	0	0	629.3	3625.5	48.0322	-52.5188	214.9	82	5.4	-0.5	6.1	230.1	20.9	-22	3840.3	3611.8	-228.7	2821.3	1006.6	201.1	258.3	63	63.9	0
8	10465	-37.3	-16.7	49.5	-20.9	39.6	3	61.7	0	0	619.8	3741.8	48.0624	-52.5016	221	83.4	5.5	-0.5	6	236.2	20.7	-22.2	3958	3727.7	-230.1	2823	1006	202.6	252.6	65.1	65.6	0
8	10470	-37.7	-16.9	50.9	-23	40.9	2.9	63	0	0	611.4	3842	48.094	-52.4838	227	87.8	6.4	-0.5	6.4	243.4	21.1	-22.5	4062.5	3828	-234.3	2822.3	1005.5	206.5	250.6	66.5	68.4	0
8	10475	-38	-17.3	51.8	-24.4	41.7	3.3	64.1	0	0	602.5	3947.5	48.1256	-52.4659	231.1	89.3	6	-0.6	6.6	247.8	21.1	-23.1	4174.2	3936.5	-237.8	3314.5	1005.3	209.1	250.3	69.4	70.3	0
8	10480	-38.3	-17.6	51	-23.2	41	3.2	62.3	0	0	593.8	4054.3	48.1579	-52.4467	233.2	90.4	6	-0.6	6.4	250.1	21.2	-23.3	4285.8	4054.5	-231.3	5291.7	1005.8	206.9	247.4	72.1	72.8	0
8	10485	-38.6	-18.3	50.9	-22.9	40.9	3.1	62.2	0	0	585	4162.5	48.1908	-52.4281	235	90.5	5.7	-0.6	6.4	251.9	21.1	-24	4399.3	4162.8	-236.7	5291	1005.6	207.9	247.2	73.5	73.7	0
8	10490	-39	-19	49	-20.3	39.2	2.9	60.2	0	0	576.3	4271.7	48.2231	-52.4096	236.4	90.6	5.7	-0.6	5.9	253.2	21	-24.6	4513.3	4271.7	-241.4	5291	1005.4	205.3	244.7	75.5	76.4	0
8	10495	-39.3	-19.5	49.2	-20.2	39.3	2.8	60.4	0	0	569	4363.5	48.2561	-52.3904	239.3	91.7	5.8	-0.5	5.8	256.3	21	-25.2	4609.8	4363.5	-246.3	5290.2	1005.2	206.7	243.9	76.9	77.5	0
8	10500	-39.6	-20	47.8	-18.4	38	2.7	58.8	0	0	561.4	4459	48.2897	-52.3711	240.5	92.2	5	-0.5	5.5	257.6	21	-25.6	4710.5	4459	-251.4	5289.8	1004.5	205.1	243.3	81	83	0
8	10505	-39.9	-19.9	48.1	-18.4	38.3	2.1	59.3	0	0	554.8	4543.7	48.3234	-52.3519	243.1	93.9	4.6	-0.4	5.4	260.6	21.1	-25.6	4799.2	4543.7	-255.5	5290.8	1003.2	206.8	244	84.5	84.6	0
8	10510	-40.2	-20.5	48.6	-19.2	38.8	2.5	59.5	0	0	548.2	4627.2	48.357	-52.332	245.4	96.6	4.6	-0.5	5.6	263.7	21.5	-26.3	4889.5	4627.2	-262.2	5287	1003.1	208.7	244.3	86.6	87.3	0
8	10515	-40.6	-21.4	48.6	-19.4	38.8	2.5	59.5	0	0	541.3	4717	48.3913	-52.3121	247.3	97.3	4.6	-0.5	5.7	265.8	21.5	-27.2	4985.2	4717	-268.3	5283.8	1003.6	209.8	244	87.5	87.8	0
8	10520	-40.9	-22.2	48.2	-19	38.4	3	59.3	0	0	534.3	4804.8	48.4257	-52.2915	248.1	95.1	4.3	-0.6	5.6	265.8	21	-28	5082.2	4804.5	-277.7	5277.5	1003.3	209.9	243.3	86.7	87.5	0
8	10525	-41.2	-23.2	48.2	-18.7	38.3	2.8	59.1	0	0	527	4885	48.46	-52.2723	248.2	95.2	4	-0.5	5.6	265.8	21	-29	5184.8	4884.7	-300	5258.5	1002	210.8	244.2	87.4	88.2	0
8	10530	-41.5	-24.1	47.5	-18	37.8	2.7	58.5	0	0	518.9	4978.3	48.4943	-52.2524	246.9	95.3	3.5	-0.5	5.4	264.6	21.1	-29.9	5299.2	4978	-321.2	5242	1000.4	210.5	245.3	88.4	88.6	0
8	10535	-41.8	-24.8	47.8	-18.3	38	2.4	58.5	0	0	512.4	5074	48.5287	-52.2324	247.3	95.9	3.7	-0.5	5.5	265.2	21.2	-30.8	5394	5073.8	-320.3	5246.5	1001.7	212.1	246	87.9	88.6	0
8	10540	-42.1	-24.8	51.6	-23.9	41.3	3.9	62.7	0	0	509.4	5116.2	48.563	-52.2118	255.1	99.3	4.6	-0.7	6.5	273.7	21.3	-31.3	5437	5116.2	-320.9	5247.8	1002.4	220.4	245.8	86.8	87.6	0
8	10545	-42.4	-23.9	56.5	-31.2	45.4	4.9	67.7	0	0	508.9	5125.5	48.5994	-52.1906	267.1	103.9	5.4	-0.8	7.8	286.7	21.3	-30.9	5444.8	5125.2	-319.6	5249.5	1001.6	230.6	244.3	87.5	87.8	0
8	10550	-42.6	-23.3	63.2	-41.7	51.3	5.6	74.4	0	0	508.5	5132	48.6372	-52.1686	279.1	107.8	5.9	-0.9	9.2	299.2	21.1	-31.1	5450	5131.8	-318.2	5251	1002.2	243.5	244.7	87.4	87.8	0
8	10555	-43	-22.3	69.6	-49.3	56.6	4.2	80.6	0	0	508.4	5133.8	48.677	-52.1459	290.9	108.4	6.2	-0.6	9.9	310.4	20.4	-30.9	5450.8	5133.5	-317.3	5252	1001.8	255	244.4	87	87.4	0
8	10560	-43.2	-21.8	75	-56.8	61.3	4.4	85.7	0	0	508.6	5130.5	48.7182	-52.1233	301.6	106.6	5.8	-0.6	10.5	319.9	19.5	-31	5448.8	5130.3	-318.6	5250.5	1002	264.2	243.1	86.4	86.8	0
8	10565	-43.3	-21.4	79.8	-63.1	65.1	5	90.7	0	0	508.8	5125.7	48.7601	-52.1006	309.1	109.6	6.4	-0.6	11	328	19.5	-31.3	5446	5125.7	-320.3	5248.7	1002.4	272	242.9	85.9	86.3	0
8	10570	-43.4	-20.9	84.2	-67.5	68.8	1.8	94.3	0	0	508.8	5122.8	48.8033	-52.0752	310.3	137.5	12.1	-0.2	11.1	339.4	23.9	-31.2	5445	5122.5	-322.3	5246.5	1001.9	278.9	244.2	86.8	87.1	0
8	10575	-43.5	-21	84.1	-69.4	68.6	6.3	95.2	0	0	509.4	5115	48.8466	-52.0443	307.2	146.8	13.4	-0.8	11.5	340.5	25.6	-31.3	5437.5	5114.8	-322.7	5245.8	1002.3	278.6	244.8	87	87.4	0
8	10580	-43.4	-21.6	80.5	-64.7	65.7	6.9	91.9	0	0	509.1	5115.7	48.8892	-52.0148	304.1	135.5	11.3	-0.9	11.2	332.9	24	-31.4	5441	5115.5	-325.4	5243.2	1002.3	273	244.5	86.5	87.4	0
8	10585	-43.3	-21.7	79.6	-62.3	65	4.2	91	0	0	509.8	5102.7	48.931	-51.9873	304.2	118.6	7.8	-0.5	10.9	326.5	21.3	-31.5	5431.5	5102.7	-328.6	5239.5	1002	271.2	245.7	87.2	87.3	0
8	10590	-43.3	-22	78.2	-59.6	63.8	2.5	89.8	0	0	510	5096.5	48.9729	-51.9653	303.5	101.2	4.3	-0.3	10.6	320	18.4	-31.6	5428	5096.5	-331.5	5236.3	1002	268.9	245.9	87	87.4	0
8	10595	-43.3	-22.3	76.8	-57.9	62.7	3.3	88.4	0	0	510.2	5089.5	49.0155	-51.944	303.2	102.5	4.8	-0.4	10.5	320.1	18.7	-31.7	5425.3	5089.5	-335.6	5232	1001.8	266.4	244.1	86.9	87.1	0
8	11000	-43.3	-22.5	75.6	-57	61.7	3.4	86.6	0	0	508.6	5108.2	49.0574	-51.9214	299.2	114.3	7	-0.5	10.5	320.3	20.9	-31.7	5448.5	5108.2	-340.4	5228.5	1001.1	264.7	245.4	88.2	88.5	0
8	11005	-43.3	-22.7	75.6	-57.8	61.7	5.5	86.8	0	0	508.2	5111.3	49.0986	-51.896	298.4	121.2	8.2	-0.7	10.6	322	22.1	-32	5454.5	5111.3	-343.2	5225.7	1001.3	264.9	245.4	88.3	88.4	0
8	11010	-43.3	-22.7	78.5	-62.6	64	6.9	89.7	0	0	507.9	5112.5	49.1398	-51.8706	303.7	116.7	6.9	-0.9	11.1	325.4	21	-32.3	5458.3	5112.5	-345.8	5223.3	1001.9	269.5	245.4	88.2	88.6	0
8	11015	-43.4	-22.6	81	-65.3	66.1	5.7	91.8	0	0	507.5	5116.2	49.1824	-51.8465	308	114.8	6.9	-0.7	11.2	328.7	20.4	-32.6	5465	5116.2	-348.9	5220.2	1002	273.5	244.8	86.6	87.7	0
8	11020	-43.5	-22.7	83.1	-67.5	67.8	4.6	93.6	0	0	507	5120.8	49.2256	-51.8218	309.9	121.5	8.1	-0.6	11.3	332.9	21.4	-32.9	5471.7	5120.8	-350.9	5218.5	1002.6	276.9	245.5	87.4	87.8	0
8	11025	-43.5	-22.8	84	-68.4	68.5	4.5	94.1	0	0	506.9	5119	49.2689	-51.795	310.6	127.6	9.3	-0.5	11.4	335.8	22.3	-32.9	5473.3	5119	-354.2	5215.3	1002.2	276.5	244.6	88.9	89.1	0
8	11030	-43.6	-22.4	84.5	-69.7	68.9	5.4	95.3	0	0	507.3	5110.5	49.3114	-51.7676	313.1	126.6	8.5	-0.6	11.5	337.7	22	-32.6	5468	5110.7	-357.4	5212	1001.1	276.9	244.3	91.5	91.8	0
8	11035	-43.6	-22.3	85.9	-71.4	70.1	5.5	98	0	0	508.4	5093.2	49.3554	-51.7415	315.8	121.6	7.8	-0.6	11.6	338.5	21.1	-32.8	5451.5	5093.2	-358.2	5210.2	1001.7	281.4	245	88.7	91.5	0
8	11040	-43.7	-22.6	86.2	-71	70.3	4.1	97.7	0	0	508.1	5094.3	49.3993	-51.7161	315.9	120.6	7.8	-0.5	11.5	338.1	20.9	-33.1	5455.5	5094.5	-361	5207.5	1002	281.5	245	88.2	89.4	0
8	11045	-43.7	-22.7	86.8	-71.9	70.9	3.8	98.1	0	0	507.9	5093	49.4433	-51.69	316.2	126.2	8.8	-0.4	11.5	340.5	21.8	-33.3	5458.3	5093.2	-364.9	5203.5	1002	282.4	245.2	89.2	89.7	0
8	11050	-43.8	-22.8	87.1	-72.4	71.1	4.2	98.3	0	0	507.9	5089.2	49.4872	-51.6625	316.8	129.6	9.2	-0.5	11.6	342.3	22.2	-33.3	5458	5089.5	-368.5	5200	1001.8	282.8	245.2	90.6	91.2	0
8	11055	-43.8	-22.6	86.9	-72.3	70.9	4.7	98.1	0	0	507.8	5089	49.5312	-51.6351	318.4	128.5	8.7	-0.5	11.6	343.3	22	-33.2	5460.7	5089.2	-371.6	5197.2	1000.8	282.7	244.6	91.9	92	0
8	11060	-43.9	-22.5	88	-73.4	71.8	4.1	98.8	0	0	507.7	5087.7	49.5751	-51.6076	321.1	126.7	8.3	-0.5	11.6	345.1	21.5	-33.2	5462	5088	-374.2	5194.8	1000.7	284.3	244.3	92.3	92.7	0
8	11065	-43.9	-22.8	89.1	-75.2	72.6	4.9	99.9	0	0	507.4	5084.2	49.6198	-51.5808	321.6	125	8.2	-0.6	11.8	345.1	21.2	-33.7	5466	5084.5	-381.4	5187.5	1000.9	285.8	244.3	90.3	92.1	0

439//

SXXX50 KNHC 060237
AF968 WX FASTEX05 HDOB 01 KNHC
0217 4737N 05244W 00025 5038 000 000 053 053 000 00000 0000000000
0218 4737N 05244W 00026 5039 000 000 053 053 000 00000 0000000000
0219 4737N 05244W 00028 5041 000 000 051 057 000 00000 0000000000
0220 4737N 05244W 00030 5044 139 012 053 053 013 00000 0000000000
0221 4737N 05244W 00033 5046 265 005 059 059 014 00000 0000000000
0222 4737N 05245W 00062 5076 281 010 059 059 018 00000 0000000000
0223 4738N 05245W 00037 5051 134 020 057 057 024 00000 0000000000
0224 4737N 05244W 00035 5042 148 012 061 065 024 00005 0000000000
0225 4735N 05242W 00322 0022 191 019 061 077 022 00356 0000000000
0226 4734N 05238W 00860 0042 233 029 059 081 032 00921 0000000000
0227 4731N 05237W 01379 0022 234 026 081 153 028 01416 0000000000
0228 4728N 05235W 01784 0009 257 038 069 091 040 01806 0000000000
0229 4725N 05233W 02026 0005 271 040 063 083 042 02044 0000000000
0230 4722N 05232W 02278 5001 273 031 075 091 040 02292 0000000000
0231 4718N 05230W 02536 5014 272 026 085 115 029 02536 0000000000
0232 4715N 05229W 02780 5015 268 031 101 123 032 02778 0000000000
0233 4712N 05228W 03057 5021 260 031 115 147 033 03050 0000000000
0234 4709N 05225W 03367 5023 259 043 125 157 044 03358 0000000000
0235 4705N 05223W 03619 5026 264 043 139 173 044 03607 0000000000
0236 4702N 05222W 03889 5028 268 041 153 193 042 03876 0000000000

SXXX50 KNHC 060257
AF968 WX FASTEX05 HDOB 02 KNHC
0237 4659N 05220W 04149 5027 274 044 163 201 044 04134 0000000000
0238 4655N 05219W 04432 5021 279 050 175 203 051 04412 0000000000
0239 4652N 05217W 04786 5026 276 052 191 217 053 04760 0000000000
0240 4648N 05215W 04988 5043 277 055 203 227 055 04947 0000000000
0241 4645N 05214W 05214 5041 276 059 215 235 059 05174 0000000000
0242 4641N 05212W 05435 5041 278 062 229 241 062 05395 0000000000
0243 4638N 05210W 05662 5041 275 065 231 253 066 05622 0000000000
0244 4634N 05208W 05836 5039 276 068 235 255 068 05799 0000000000
0245 4631N 05207W 05995 5037 277 069 243 265 069 05960 0000000000
0246 4627N 05205W 06145 5036 277 073 253 271 074 06112 0000000000
0247 4623N 05203W 06318 5036 275 077 263 277 078 06286 0000000000
0248 4620N 05201W 06457 5043 277 080 269 269 080 06429 0000000000
0249 4616N 05159W 06562 5040 277 081 277 277 081 06538 0000000000
0250 4612N 05158W 06682 5038 276 081 285 285 081 06658 0000000000
0251 4608N 05156W 06787 5034 276 082 295 295 083 06768 0000000000
0252 4605N 05154W 06876 5033 277 081 297 297 083 06859 0000000000
0253 4601N 05152W 06976 5030 277 080 305 305 080 06962 0000000000
0254 4558N 05150W 07093 5028 276 080 319 319 080 07081 0000000000
0255 4553N 05149W 07183 5027 279 079 325 325 080 07172 0000000000
0256 4550N 05147W 07253 5024 280 078 333 333 079 07245 0000000000

sonde number: 22588
launch day,hour,min: 8 13 0
launch lat, lng: 55 4.1N 49 52.0W
launch stns: DABC/H

PTH data

time	pr	temp	hum
0	485	-43.8	19
10	490	-41.3	12
20	496	-42.4	13
30	499	-42.4	13
40	504	-42.3	14
50	508	-42.1	14
60	512	-41.7	14
70	515	-41.5	14
80	520	-41.3	15
90	524	-41.1	16
100	530	-40.5	18
110	533	-40.1	20
120	537	-39.9	19
130	541	-39.4	21
140	545	-38.9	22
150	550	-38.6	23
160	555	-38.1	24
170	558	-37.8	26
180	563	-37.4	28
190	567	-37.4	29
200	571	-37.4	31
210	574	-37.0	33
220	579	-36.6	34
230	584	-36.2	35
240	588	-35.9	36
250	591	-35.8	38
260	595	-35.6	40
270	599	-35.5	43
280	604	-35.1	46
290	607	-35.0	49
300	611	-34.8	54
310	616	-34.6	58
320	620	-34.3	62
330	624	-34.2	69
340	628	-33.9	73
350	632	-33.5	75
360	637	-33.3	76
370	641	-33.0	77
380	645	-32.7	78
390	650	-32.8	77
400	653	-32.7	76
410	659	-32.8	76
420	662	-32.7	75
430	667	-32.5	75
440	672	-32.4	75
450	676	-32.4	74
460	681	-32.3	75

1010 957 -15.7 98
1020 961 -15.2 98
1030 963 -15.0 98
1040 966 -14.7 98
1050 969 -14.6 98
1060 972 -14.5 98
1070 978 -14.3 98
1080 982 -13.8 98
1090 988 -13.3 98
1100 992 -13.1 93
1106 995 -12.7 95

wind data
time pr wd ws qual
0 485 231 58 9
110 533 224 49 9
140 545 221 46 9
170 558 219 44 9
200 571 218 44 9
230 584 219 41 9
260 595 220 40 9
290 607 221 40 9
320 620 224 40 9
350 632 227 38 9
380 645 229 36 9
410 659 231 34 9
440 672 233 32 9
470 685 231 31 9
500 699 229 30 9
530 714 227 29 9
560 729 224 27 9
590 744 223 25 9
620 759 225 24 9
650 774 224 23 9
680 789 225 23 9
710 801 224 23 9
740 815 224 23 9
770 833 227 24 9
800 852 229 25 9
830 868 235 26 9
860 880 240 26 9
890 895 243 26 9
920 909 245 25 9
950 925 243 27 9
980 942 237 31 9
1010 957 236 33 9

2 sec data
time pr temp hum
1078 982 -13.8 98
1080 982 -13.8 98
1082 984 -13.6 98
1084 985 -13.4 98
1086 986 -13.3 98

1088	986	-13.4	98
1090	988	-13.3	98
1092	988	-13.3	98
1094	989	-13.4	96
1096	990	-13.3	94
1098	990	-13.3	93
1100	992	-13.1	93
1102	992	-13.0	95
1104	994	-12.7	96
1106	995	-12.7	95
1108	994	-12.1	95
1110	994	-12.1	95
1112	994	-12.1	95
1114	994	-12.1	95
1116	994	-12.1	95
1118	994	-12.1	95
1120	994	-12.1	89

mandatory heights

pr	hgt
485	5120
500	4909
700	2575
850	1182
925	557
996	0

encoded message
UZNT13 KNHC 081547 COR
AF968 LABSEA02 OB 18 COR KNHC
XXAA 58135 99551 70499 18559 99996 12706 ///// 00531 ///// /////
92557 17704 24028 85182 23504 23524 70575 32129 23029 50491 427//
23055 88999 77999
XXBB 5813/ 99551 70499 18559 00996 12706 11988 13303 22797 27906
33779 28729 44689 32529 55645 32725 66588 35960 77537 39980 88485
439//
21212 00/// ///// 11957 23533 22909 24525 33774 22523 44672 23532
55571 22044 66485 23058

URNT10 KNHC 060307
AF968 WX FASTEX05 OB 01 KNHC
97779 03074 50451 51500 73200 28073 8487/ /5719

URNT10 KNHC 060333
AF968 FASTEX05 OB 02 KNHC
97779 03334 50432 50500 73300 28058 8389/ /5725

URNT10 KNHC 060405
AF968 FASTEX05 OB 03 KNHC
97779 04054 50426 49000 73300 27049 8392/ /5726

UZNT13 KNHC 060351
AF968 FASTEX05 OB 04 KNHC
XXAA 56034 99439 70508 15030 99031 002// ///// 00241 011// /////
92864 013// 22523 85536 033// 24028 70060 085// 24033 50562 207//
26055 40723 321// 27564 88999 66391 28066 431//
XXBB 5603/ 99439 70508 15030 00031 002// 11004 013// 22982 002//
33807 047// 44776 043// 55651 115// 66630 119// 77620 105// 88565
163// 99537 169// 11417 307// 22391 32958
21212 00/// ///// 11960 22021 22752 25535 33700 24033 44684 22038
55588 28560 66461 24553 77446 25053 88391 28066

UZNT13 KNHC 060418
AF968 FASTEX05 OB 05 KNHC
XXAA 0604/ 99420 70500 15020 99033 01226 ///// 00261 00243 92884
01959 85556 01760 70091 06161 50566 207// 40728 311// 88999 77999
XXBB 0604/ 99420 70500 15020 00033 01226 11919 02160 22826 01561
33702 06161 44638 09958 55616 11304 66561 14124 77470 243// 88392
31962

URNT10 KNHC 060432
AF968 FASTEX05 OB 06 KNHC
97779 04324 50439 46800 73500 28061 8492/ /5720

URNT10 KNHC 060502
AF968 FASTEX05 OB 07 KNHC
97779 05024 50454 44200 73400 29088 8490/ /5712

UZNT13 KNHC 060453
AF968 FASTEX05 OB 08 KNHC
XXAA 56044 99435 70476 14937 99031 01636 ///// 00245 00919 /////
92864 02761 24516 85533 04760 25521 70055 08761 27034 50561 21903
32564 40723 31760 27558 88999 77999
XXBB 5604/ 99435 70476 14937 00031 01636 11975 02907 22968 01559
33961 01561 44864 04960 55793 04360 66709 07961 77663 11958 88641
12358 99604 13503 11561 14136 22522 19500 33501 22100 44490 20933
55454 24929 66391 32962
21212 00/// ///// 11968 22014 22890 26517 33831 25023 44758 25034
55686 27534 66506 28564 77391 27558

UZNT13 KNHC 060511
AF968 FASTEX05 OB 09 KNHC
XXAA 56054 99448 70454 14945 99031 01650 ///// 00245 00737 /////

HCL	1 LT	2 LG	3 HSS	4 TA	5 TD	6 WD	7 WS
0%	28 7.6N	89 8.5W	7489.8	-21.6	-32.0	252.8	36.1

	VALUE	DEF. VAL	DEF. BASE	OPR LOCK		VALUE	DEF. VAL	DEF. BASE	OPR LOCK
LT	28 7.6N				GS	248.9			
LG	89 8.5W				TAS	246.5			
RA	7527.4				THD	162.1			
PA	7199.1				TRK	154.9			
FLP	399.2				DTA	343.0			
GA	7504.1				CC	-172.0			
DV	305.0				DPR	48.3			
HSS	7489.8				PBT	6.0			
SLP	1012.9				PSS	57.1			
TA	-21.6				SS	-1.2			
TD	-32.0				ATK	5.1			
WD	252.8				TT	-13.5			
WS	36.1				VE	105.5			
MXW	35.8				VN	-225.4			
					HC1	0			
					HC2	0			

DATA STATUS

:ommand:

AF967 WX

97/03/12
0:49:05

HCL	1 LT	2 LG	3 HSS	4 TA	5 TD	6 WD	7 WS
0%	27 46.9N	88 58.3W	7494.7	-22.0	-25.5	254.6	36.6

	VALUE	DEF. VAL	DEF. BASE	OPR LOCK		VALUE	DEF. VAL	DEF. BASE	OPR LOCK
LT	27 46.9N				GS	255.1			
LG	88 58.3W				TAS	252.7			
RA	7543.8				THD	164.4			
PA	7210.1				TRK	156.8			
FLP	398.6				DTA	345.0			
GA	7520.3				CC	-172.0			
DV	310.3				DPR	50.8			
HSS	7494.7				PBT	3.1			
SLP	1014.3				PSS	59.3			
TA	-22.0				SS	-0.6			
TD	-25.5				ATK	5.0			
WD	254.6				TT	-13.5			
WS	36.6				VE	100.5			
MXW	36.8				VN	-234.4			
					HC1	0			
					HC2	0			

DATA STATUS

:ommand:

AF967 WX

97/03/12
0:32:15

Future

- WC-130J expected in 1998
  - more capability
  - ceiling near 200mb
  - increase in data types/frequency
  - New doppler radar should allow vertical wind profile generation/archive while in flight
  - new sensors to remotely sense sfc wind dir/spd