

The Predictability of North American Land-falling Cyclones



Brian Ancell, Texas Tech University
Lynn McMurdie, University of Washington
Rolf Langland, Naval Research Laboratory



9th Adjoint Workshop, Cefalu, Sicily, Italy October 10, 2011

Funded by the Office of Naval Research



Office of Naval Research

Background

- Atmospheric predictability has been shown to depend on different flow regimes on a variety of scales:
 - Forecast error sensitivity varies with ENSO cycle (Reynolds and Gelaro 2001)

Background

- Atmospheric predictability has been shown to depend on different flow regimes on a variety of scales:
 - Forecast error sensitivity varies with ENSO cycle (Reynolds and Gelaro 2001)
 - ETKF targeting regions vary with synoptic case (Majumdar et al. 2002)

Background

- Atmospheric predictability has been shown to depend on different flow regimes on a variety of scales:
 - Forecast error sensitivity varies with ENSO cycle (Reynolds and Gelaro 2001)
 - ETKF targeting regions vary with synoptic case (Majumdar et al. 2002)
 - SLP errors vary with large-scale, 500-hPa flow regime (McMurdie and Casola 2009)

Background

- This work aims to examine the predictability of a specific high-impact event - *land-falling North American cyclones*

Background

- This work aims to examine the predictability of a specific high-impact event - *land-falling North American cyclones*
 - Wind
 - Precipitation intensity and type (flooding, water resources, recreation, road weather...)

Research Questions

- 1) What are the general predictability characteristics of land-falling North American cyclones?

Research Questions

- 1) What are the general predictability characteristics of land-falling North American cyclones?
- 2) Are certain levels of cyclone predictability related to synoptic/mesoscale flow patterns or cyclone characteristics?

Research Questions

- 1) What are the general predictability characteristics of land-falling North American cyclones?
- 2) Are certain levels of cyclone predictability related to synoptic/mesoscale flow patterns or cyclone characteristics?
- 3) Why is the cyclone predictability for different flow patterns/cyclone characteristics the way it is?

Research Questions

The “Why” of Cyclone Predictability

- Predictability assessed with forecast uncertainty
(ensemble forecast spread)

Research Questions

The “Why” of Cyclone Predictability

- Predictability assessed with forecast uncertainty
(ensemble forecast spread)

Ensemble Forecast Spread



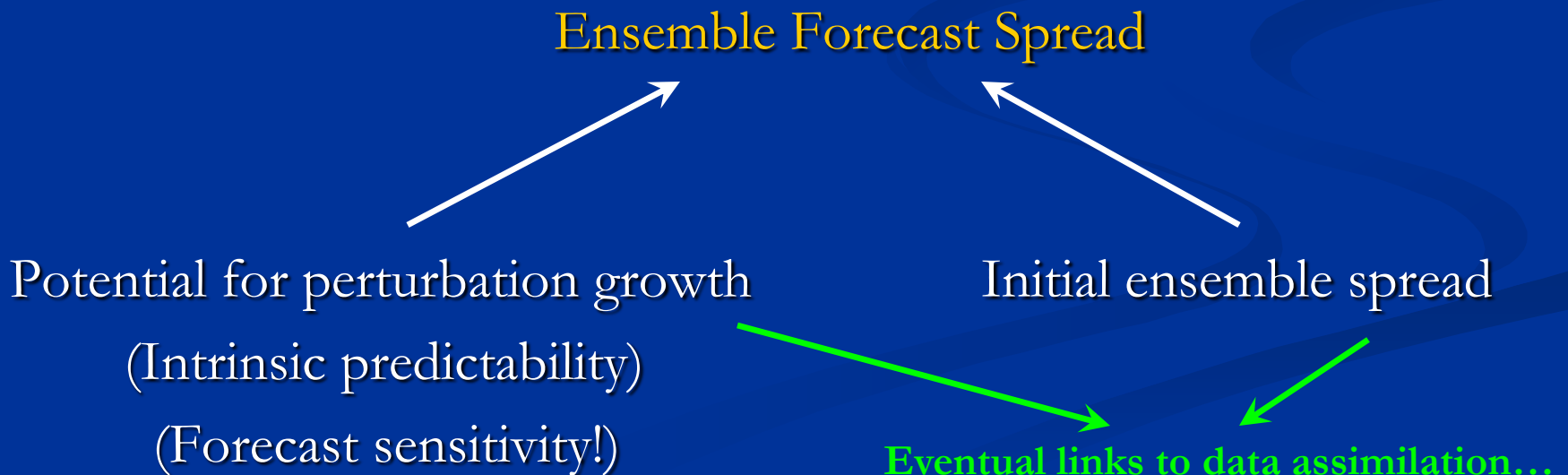
Potential for perturbation growth
(Intrinsic predictability)
(Forecast sensitivity!)

Initial ensemble spread

Research Questions

The “Why” of Cyclone Predictability

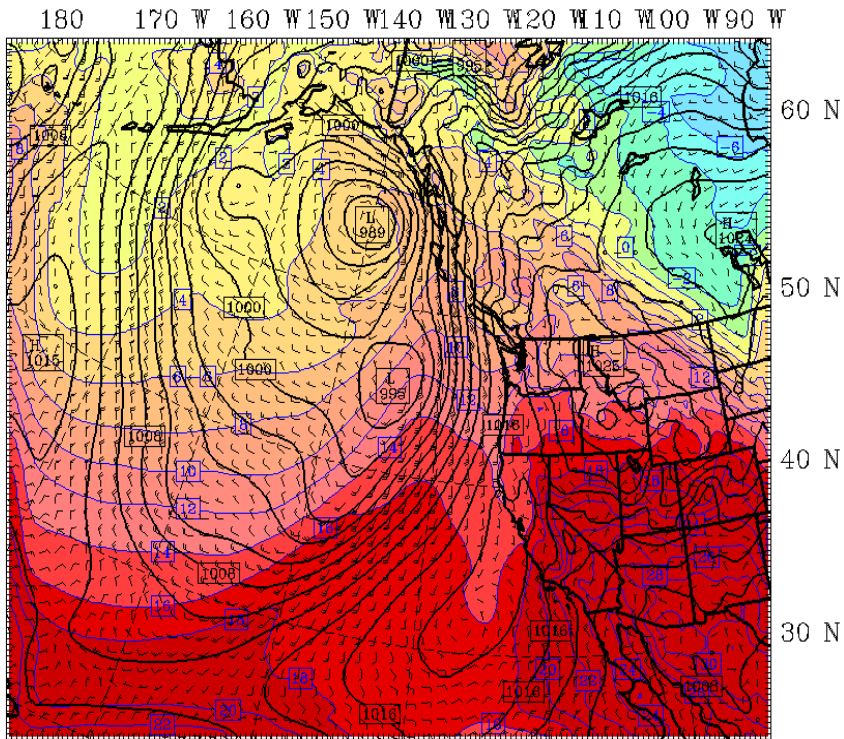
- Predictability assessed with forecast uncertainty
(ensemble forecast spread)



Methodology

- Dataset contains EnKF 48-hr forecasts of land-falling cyclones over 3 winters (2008/2009 to 2010/2011) – only 2009/2010 so far...

Methodology - EnKF



36-km Domain

- 80-member WRF-ARW EnKF
- 6-hr update cycle
- Extended forecasts to 48 hours when a cyclone makes landfall
- Extended forecast times chosen from deterministic GFS-WRF forecasts
- Assimilates cloud-track winds, ACARS, radiosonde, and surface data

Methodology

- Dataset contains EnKF 48-hr forecasts of land-falling cyclones over 3 winters (2008/2009 to 2010/2011) – only 2009/2010 so far...
- Tools used
 - 1) **Ensemble sensitivity** of the response function R
→ Characterizes the intrinsic predictability of R

Methodology

- Dataset contains EnKF 48-hr forecasts of land-falling cyclones over 3 winters (2008/2009 to 2010/2011) – only 2009/2010 so far...

- Tools used

- 1) **Ensemble sensitivity** of the response function R

—————→ Characterizes the intrinsic predictability of R

- 2) **Ensemble forecast spread** of the response function R

—————→ Characterizes the real predictability of R

Methodology

■ Ensemble sensitivity:

$$E = \frac{CV_{R,IC}}{V_{IC}}$$

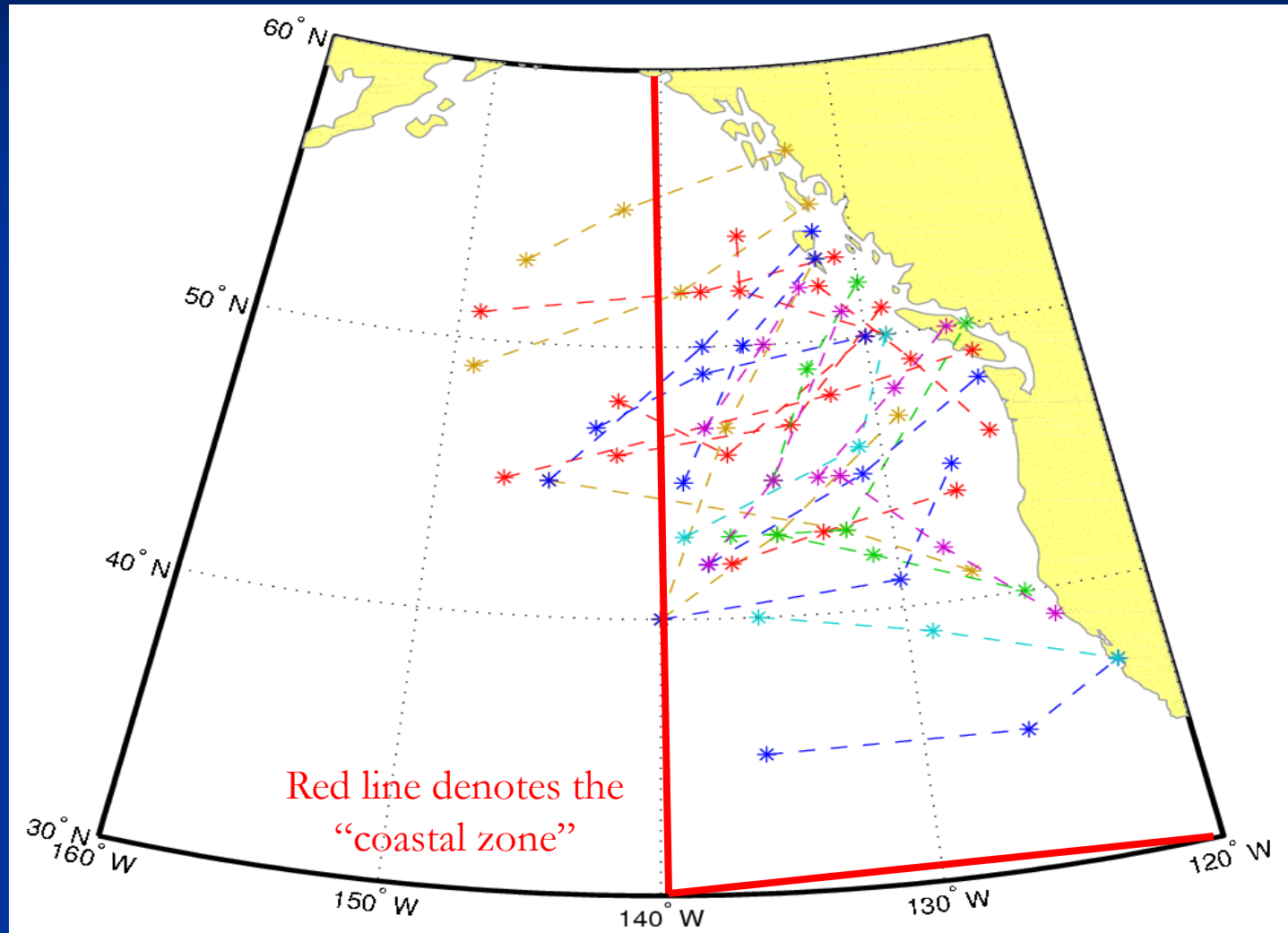
Covariance b/w response function and initial conditions

Variance of initial conditions

Response functions: Average SLP, Average U wind, Average V wind, SLP gradient

Sensitivity w.r.t.: GPH and Temperature at 300, 500, 700, 850, 925-hPa, and SLP

2009/2010 Season



27 Cyclones (cyclones can be in coastal zone at multiple times)

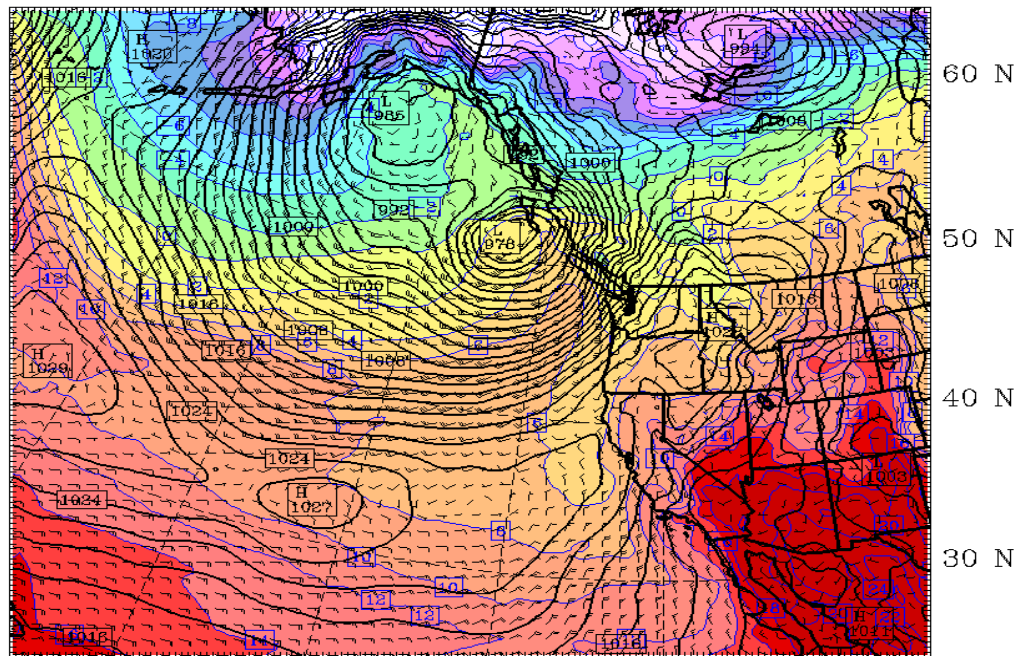
Cyclone Sensitivity Examples – Deepening

WRF 36-KM ENKF
Fest: 0 h

Init: 00 UTC Thu 19 Nov 09
Valid: 00 UTC Thu 19 Nov 09 (16 PST Wed 18 Nov 09)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 980.00 HIGH= 1028.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -28.000 HIGH= 28.000 INTERVAL= 2.0000

-28 -24 -20 -16 -12 -8 -4 0 4 8 12 16 20 24 °C
Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2009111900 - 00hr Forecast

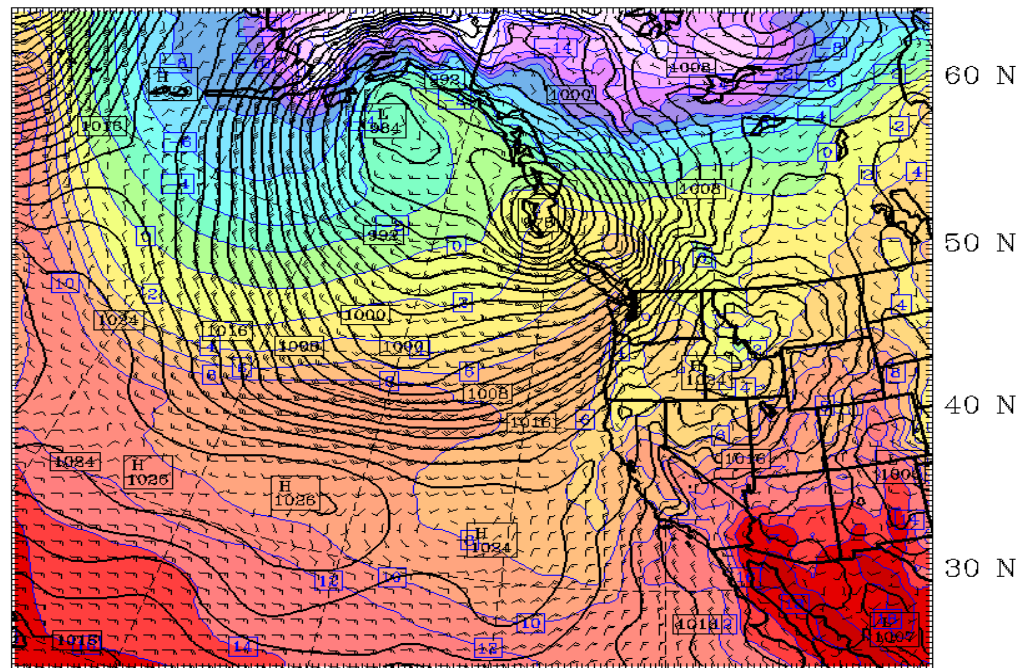
Cyclone Sensitivity Examples – Deepening

WRF 36-KM ENKF
Fest: 6 h

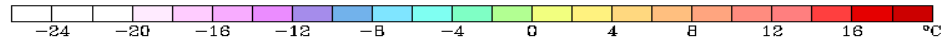
Init: 00 UTC Thu 19 Nov 09
Valid: 06 UTC Thu 19 Nov 09 (22 PST Wed 18 Nov 09)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 980.00 HIGH= 1026.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -24.000 HIGH= 18.000 INTERVAL= 2.0000



Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2009111900 - 06hr Forecast

Cyclone Sensitivity Examples – Deepening

WRF 36-KM ENKF

Fcst: 12 h

Temperature at 925 mb (°C)

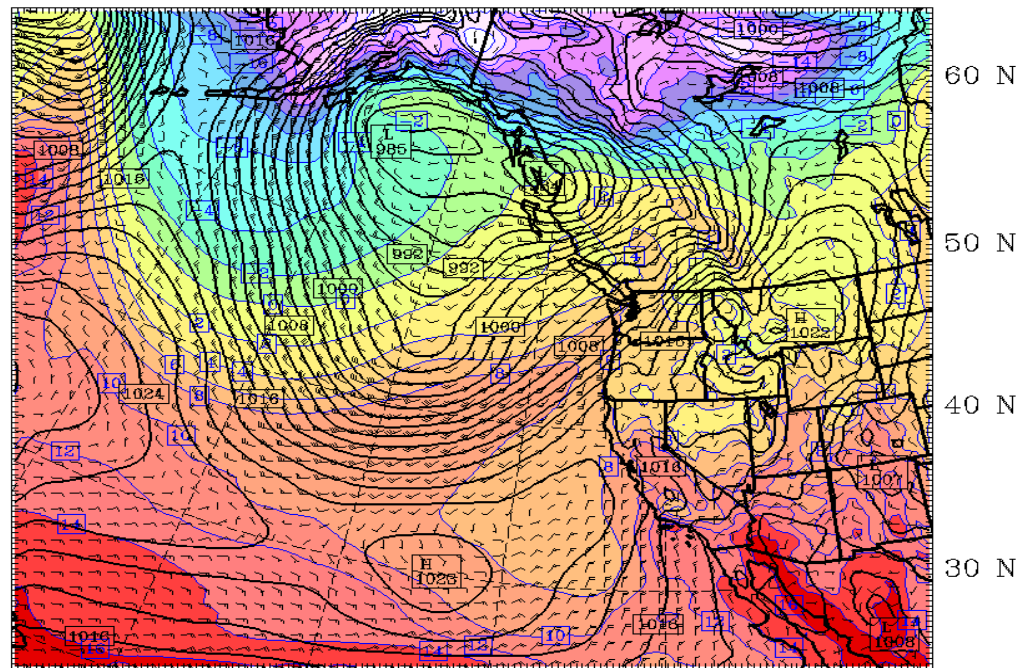
Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

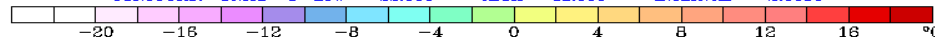
Init: 00 UTC Thu 19 Nov 09

Valid: 12 UTC Thu 19 Nov 09 (04 PST Thu 19 Nov 09)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 982.00 HIGH= 1028.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -22.000 HIGH= 18.000 INTERVAL= 2.0000



Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

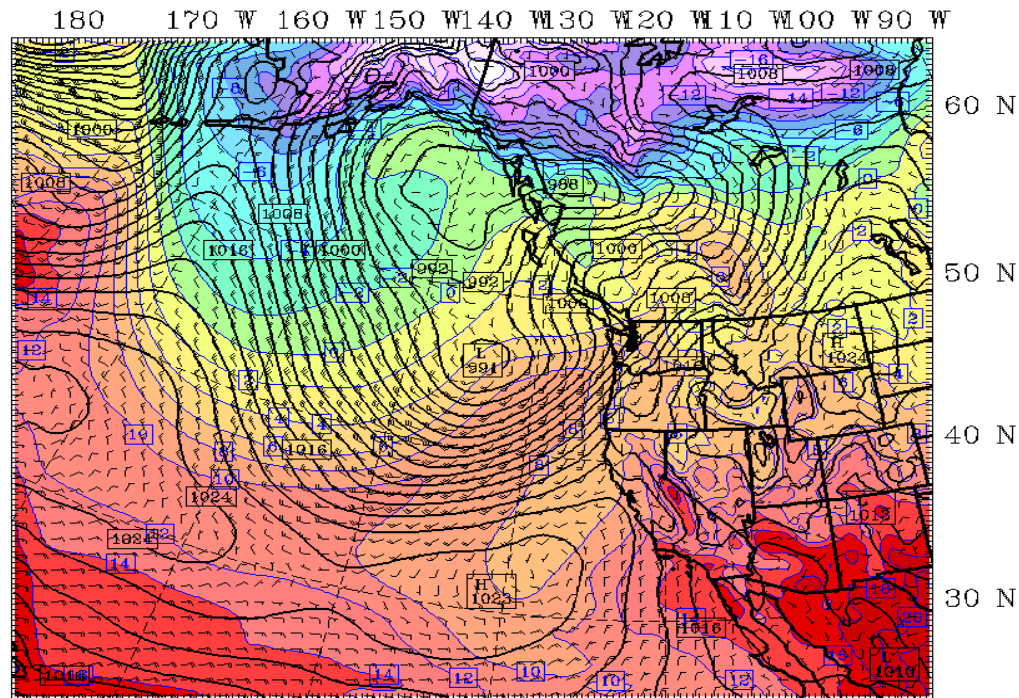
Initialized 2009111900 - 12hr Forecast

Cyclone Sensitivity Examples – Deepening

WRF 36-KM ENKF
Fest: 18 h

Init: 00 UTC Thu 19 Nov 09
Valid: 18 UTC Thu 19 Nov 09 (10 PST Thu 19 Nov 09)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)



CONTOURS: UNITS=hPa LOW= 978.00 HIGH= 1026.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -22.0000 HIGH= 24.0000 INTERVAL= 2.0000

-20 -16 -12 -8 -4 0 4 8 12 16 20 24 °C

Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2009111900 - 18hr Forecast

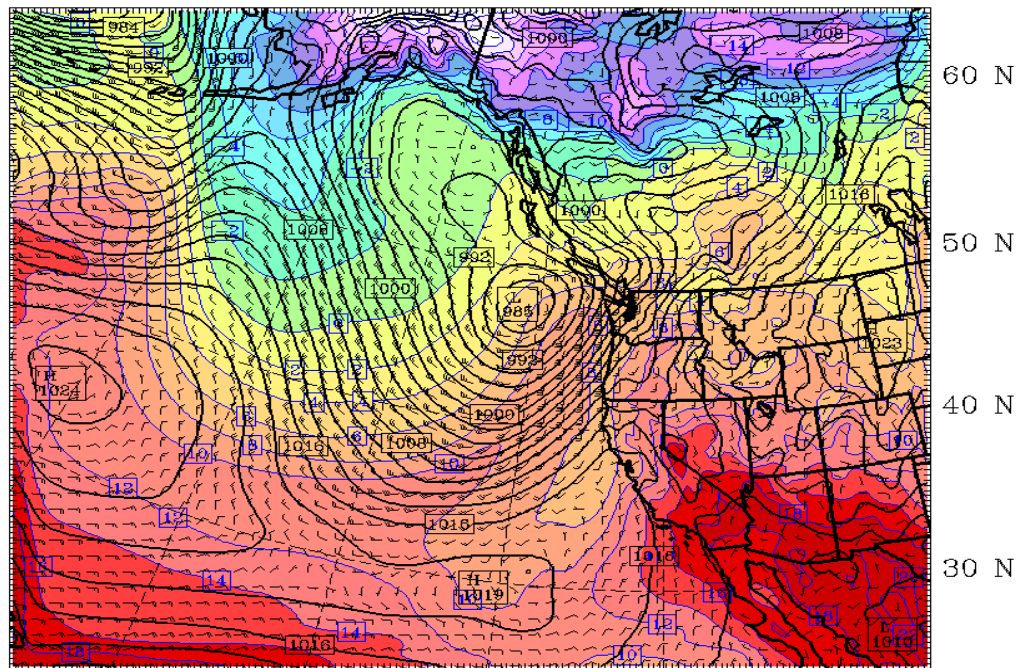
Cyclone Sensitivity Examples – Deepening

WRF 36-KM ENKF
Fest: 24 h

Init: 00 UTC Thu 19 Nov 09
Valid: 00 UTC Fri 20 Nov 09 (16 PST Thu 19 Nov 09)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 980.00 HIGH= 1024.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -24.000 HIGH= 22.000 INTERVAL= 2.0000
-24 -20 -16 -12 -8 -4 0 4 8 12 16 20 24 °C
Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2009111900 - 24hr Forecast

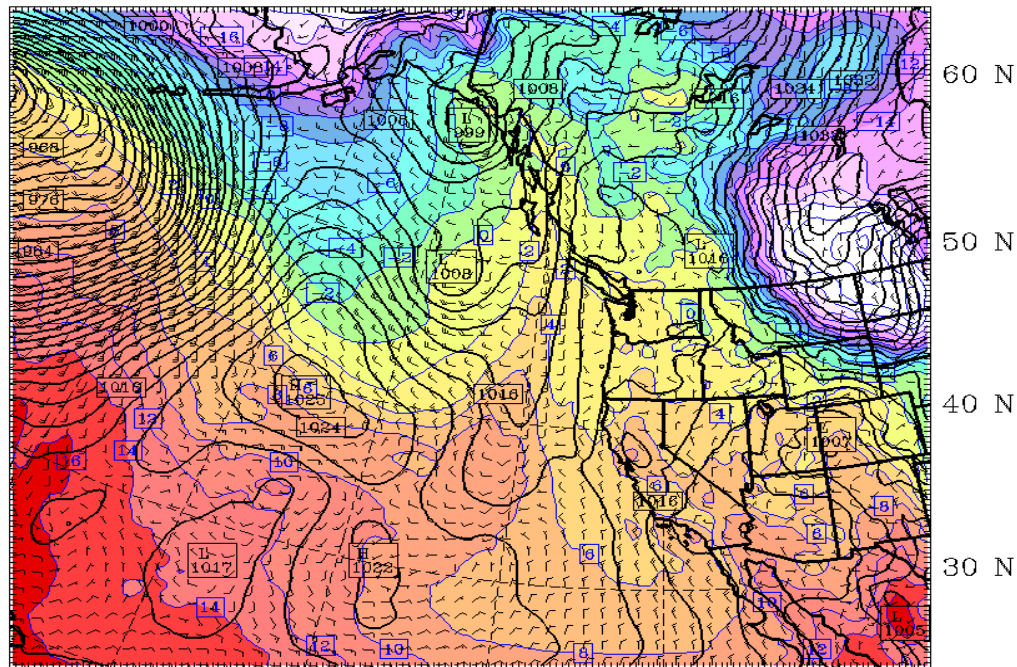
Cyclone Sensitivity Examples – Decaying

WRF 36-KM ENKF
Fest: 0 h

Valid: 06 UTC Mon 08 Feb 10 (22 PST Sun 07 Feb 10)
Init: 06 UTC Mon 08 Feb 10

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 958.00 HIGH= 1040.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -28.0000 HIGH= 16.0000 INTERVAL= 2.0000
-24 -20 -16 -12 -8 -4 0 4 8 12 16 °C

Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2010020806 - 00hr Forecast

Cyclone Sensitivity Examples – Decaying

WRF 36-KM ENKF
Fest: 6 h

Init: 06 UTC Mon 08 Feb 10

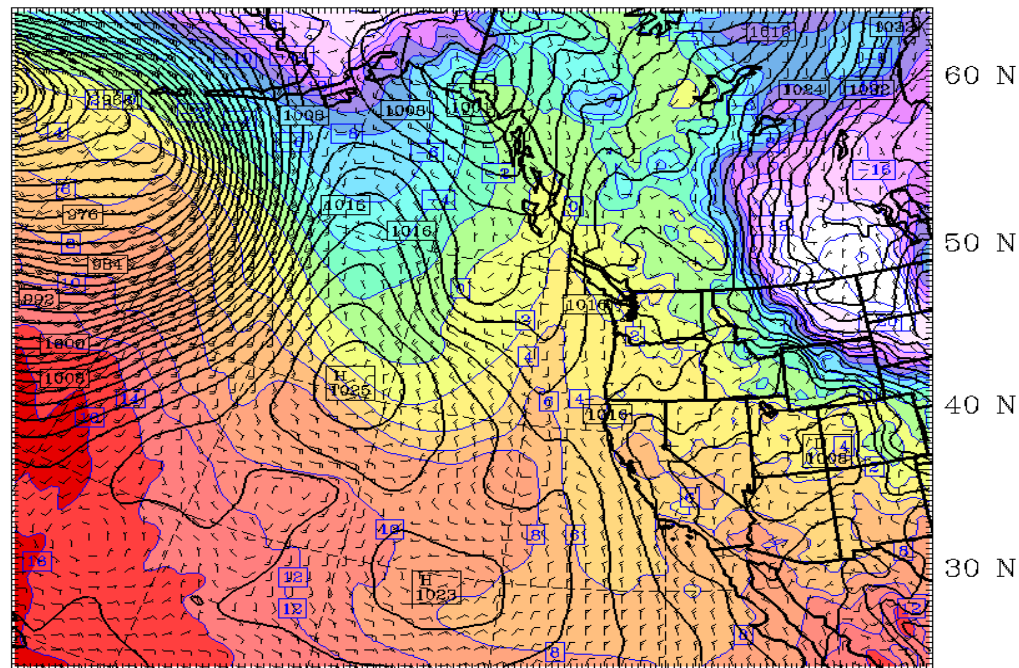
Temperature at 925 mb (°C)

Valid: 12 UTC Mon 08 Feb 10 (04 PST Mon 08 Feb 10)

Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 954.00 HIGH= 1038.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -24.000 HIGH= 16.000 INTERVAL= 2.0000

-24 -20 -16 -12 -8 -4 0 4 8 12 °C

Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2010020806 - 06hr Forecast

Cyclone Sensitivity Examples – Decaying

WRF 36-KM ENKF

Fest: 12 h

Temperature at 925 mb (°C)

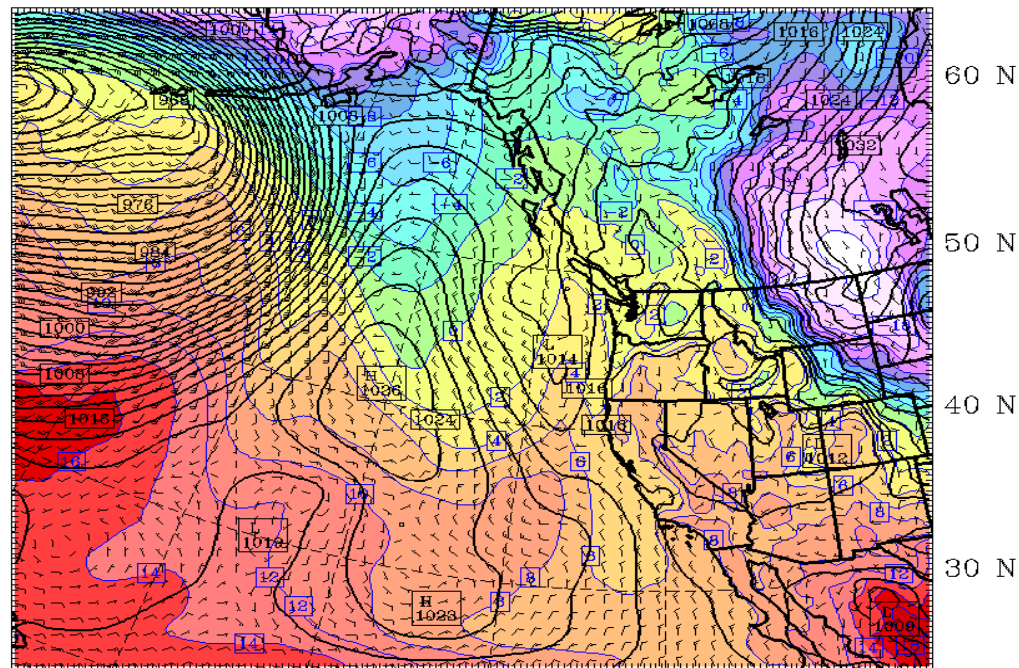
Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

Init: 06 UTC Mon 08 Feb 10

Valid: 18 UTC Mon 08 Feb 10 (10 PST Mon 08 Feb 10)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



Initialized 2010020806 - 12hr Forecast

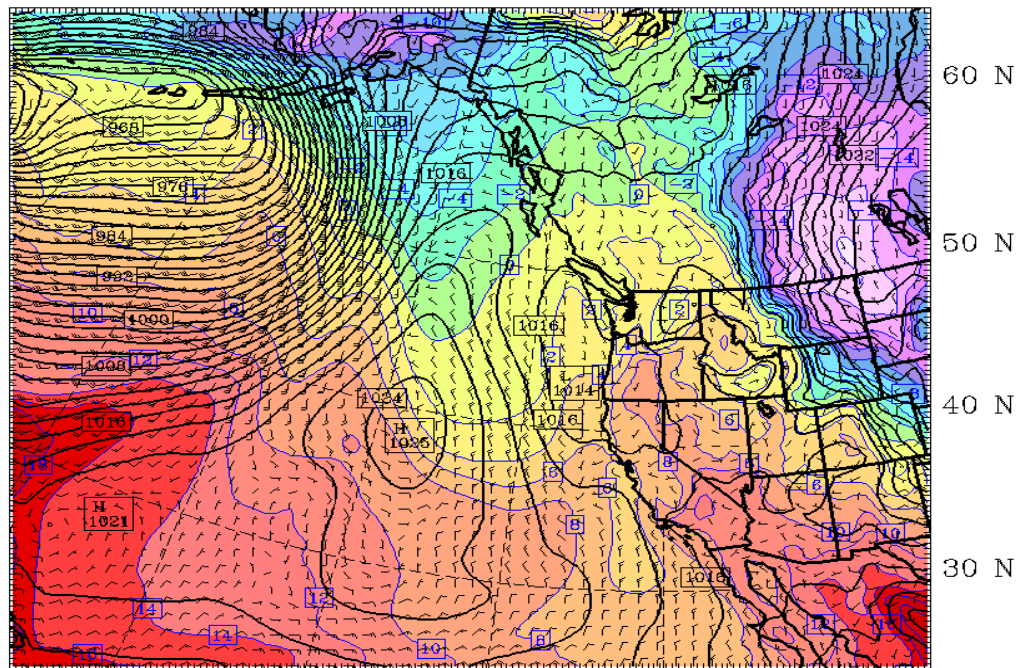
Cyclone Sensitivity Examples – Decaying

WRF 36-KM ENKF
Fest: 18 h

Init: 06 UTC Mon 08 Feb 10
Valid: 00 UTC Tue 09 Feb 10 (18 PST Mon 08 Feb 10)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 960.00 HIGH= 1036.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -18.000 HIGH= 20.000 INTERVAL= 2.0000
-16 -12 -8 -4 0 4 8 12 16 °C

Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2010020806 - 18hr Forecast

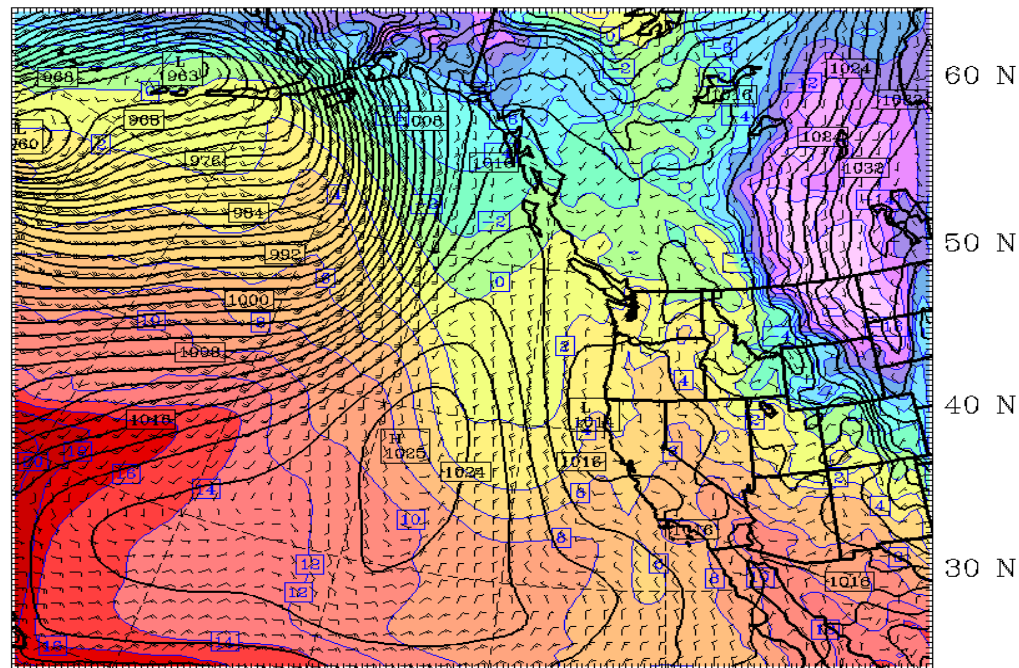
Cyclone Sensitivity Examples – Decaying

WRF 36-KM ENKF
Fest: 24 h

Init: 06 UTC Mon 08 Feb 10
Valid: 06 UTC Tue 09 Feb 10 (22 PST Mon 08 Feb 10)

Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

180 170 W 160 W 150 W 140 W 130 W 120 W 110 W 100 W 90 W



CONTOURS: UNITS=hPa LOW= 962.00 HIGH= 1034.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -16.000 HIGH= 20.000 INTERVAL= 2.0000
-16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 °C

Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Initialized 2010020806 - 24hr Forecast

Ensemble Sensitivity – Deepening

WRF 36-KM ENKF

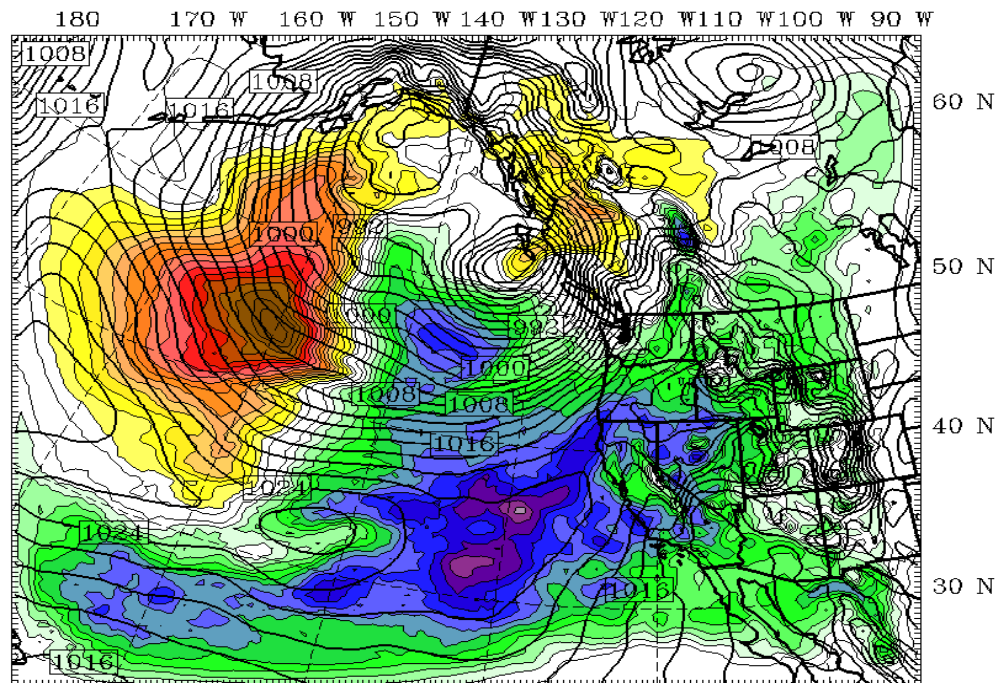
Fest: 0 h

SensitivityR1 to SLP hPa (mb/mb)

Mean Sea-level Pressure (mb)

Init: 00 UTC Thu 19 Nov 09

Valid: 00 UTC Thu 19 Nov 09 (16 PST Wed 18 Nov 09)



Ensemble Sensitivity – Decaying

WRF 36-KM ENKF

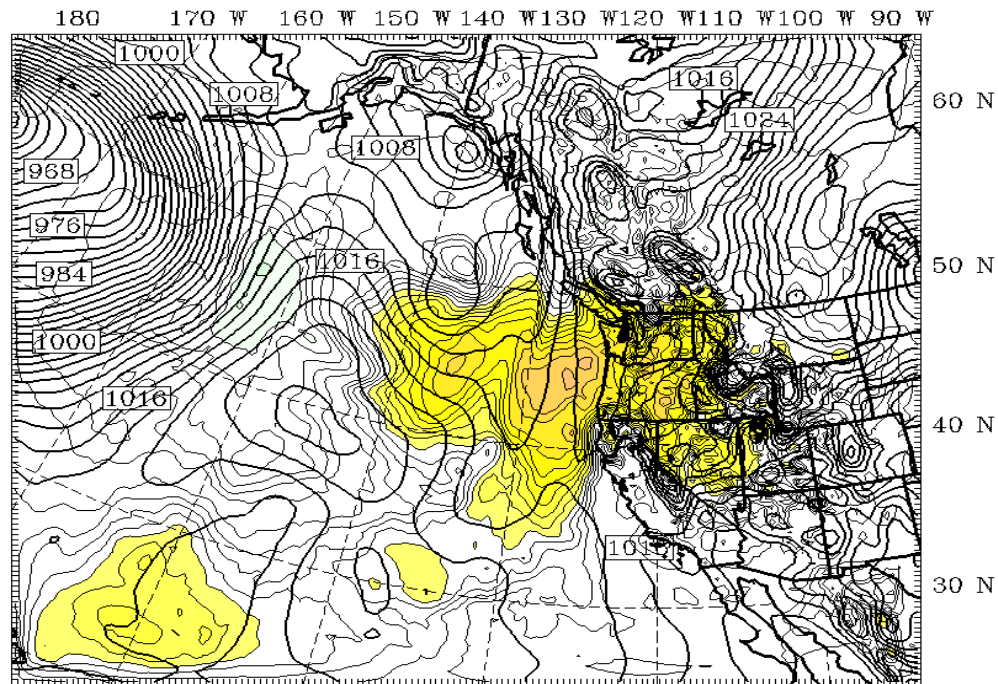
Fest: 0 h

SensitivityR1 to SLP hPa (mb/mb)

Mean Sea-level Pressure (mb)

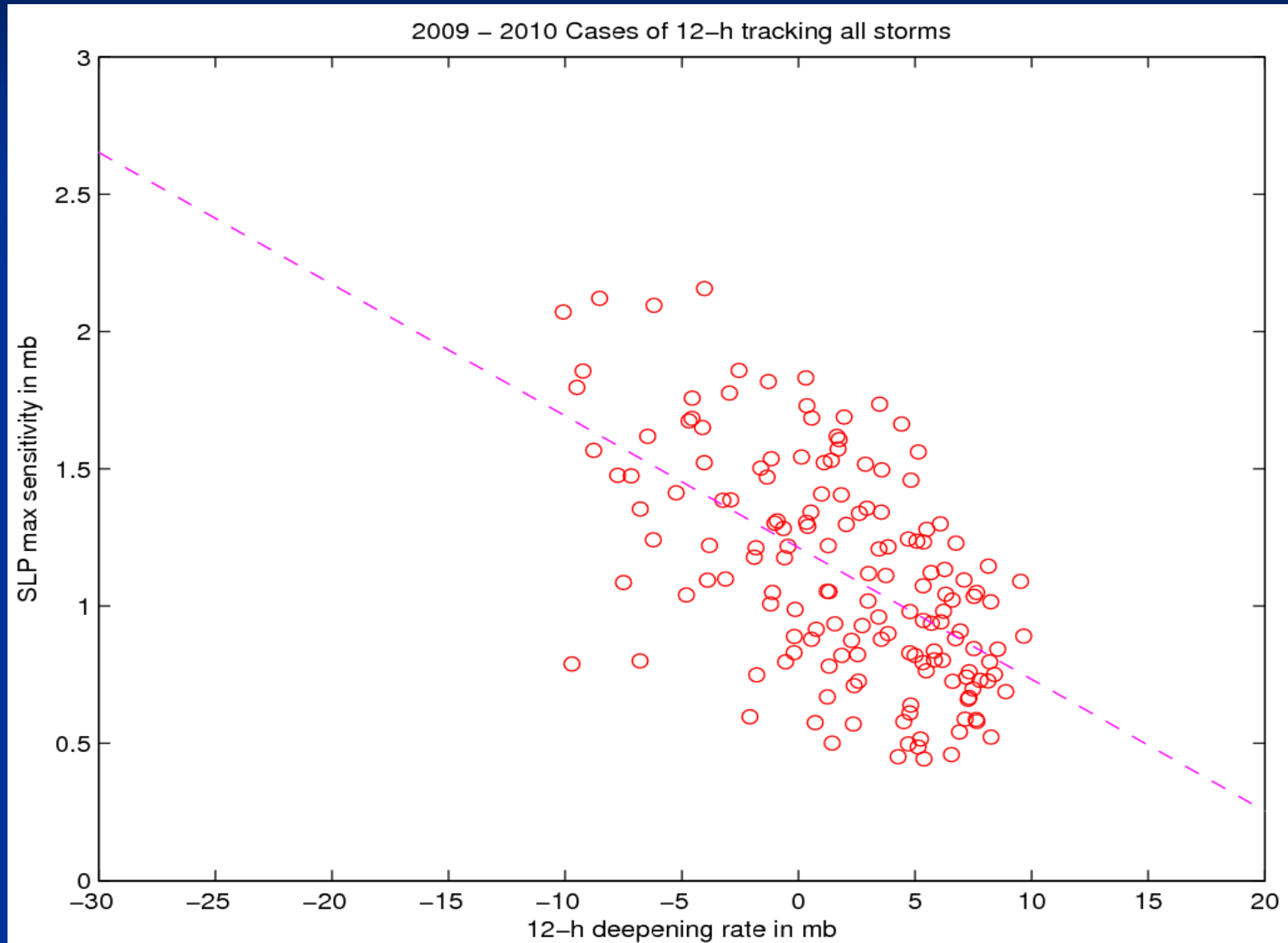
Init: 06 UTC Mon 08 Feb 10

Valid: 06 UTC Mon 08 Feb 10 (22 PST Sun 07 Feb 10)

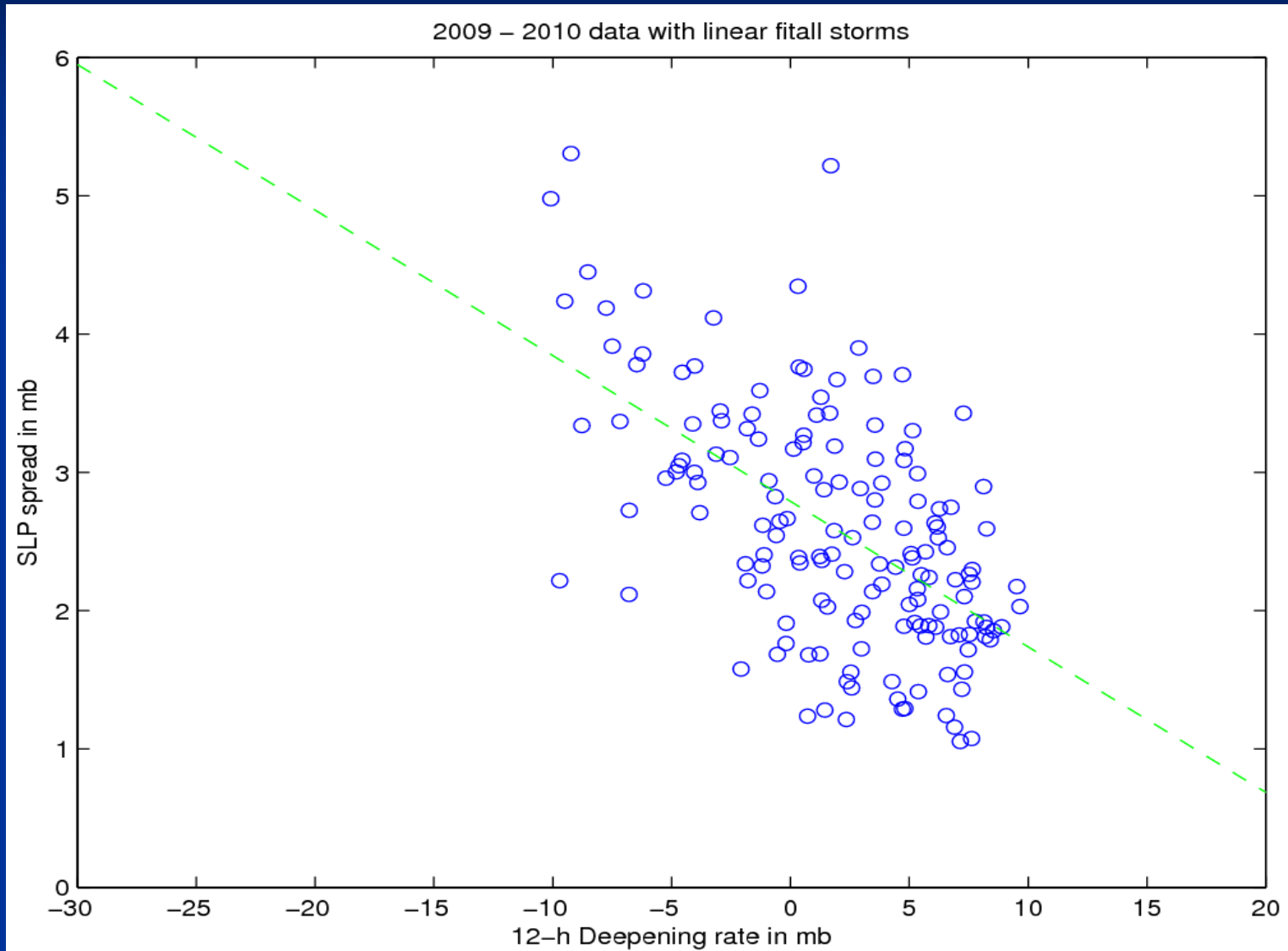


Model Info: V3.0.1.1 KF YSU PBL WSM 3class Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Duchia DIFF: simple KM: ED Smagor

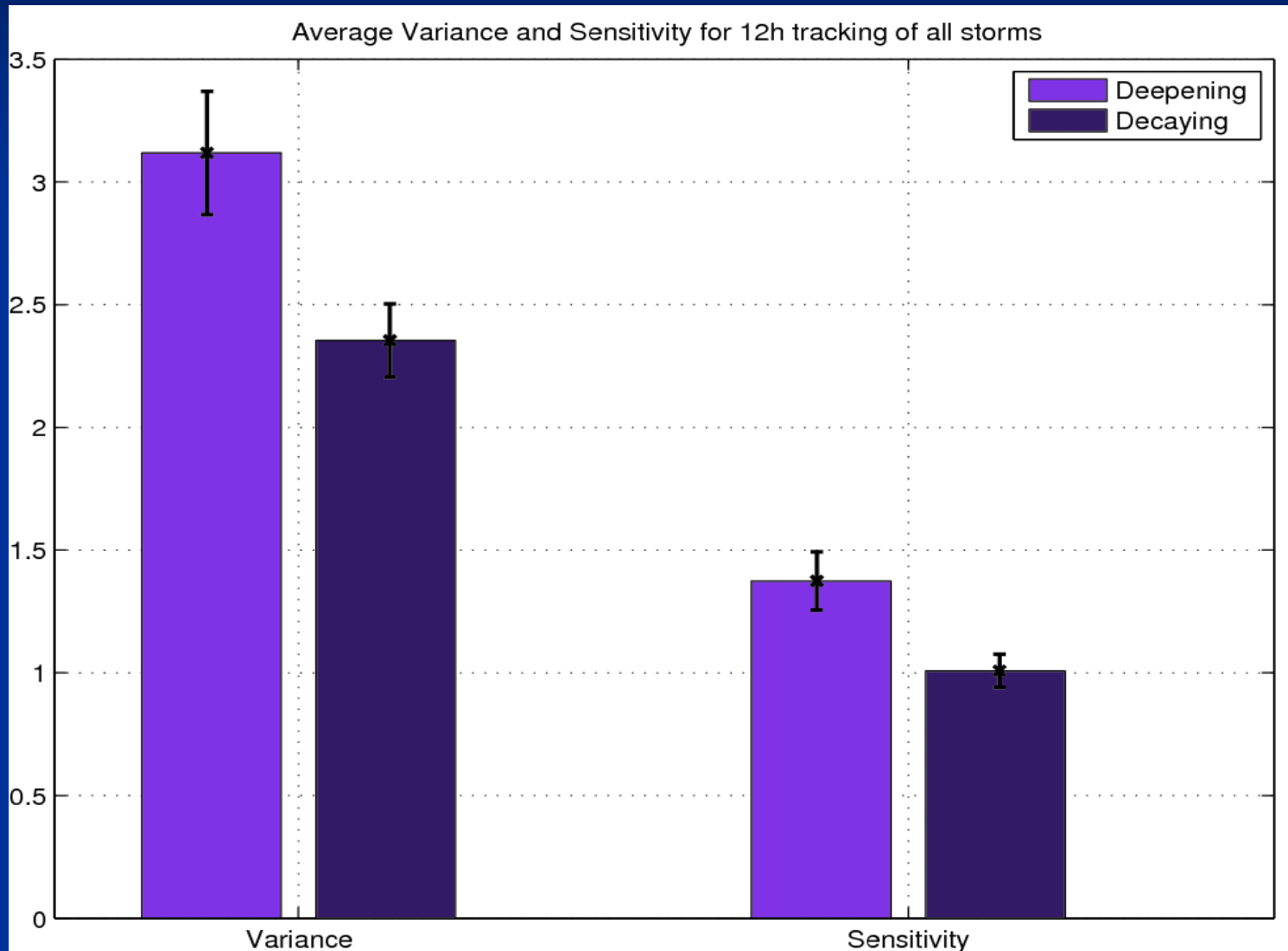
24-hr Sensitivity vs. Deepening Rate



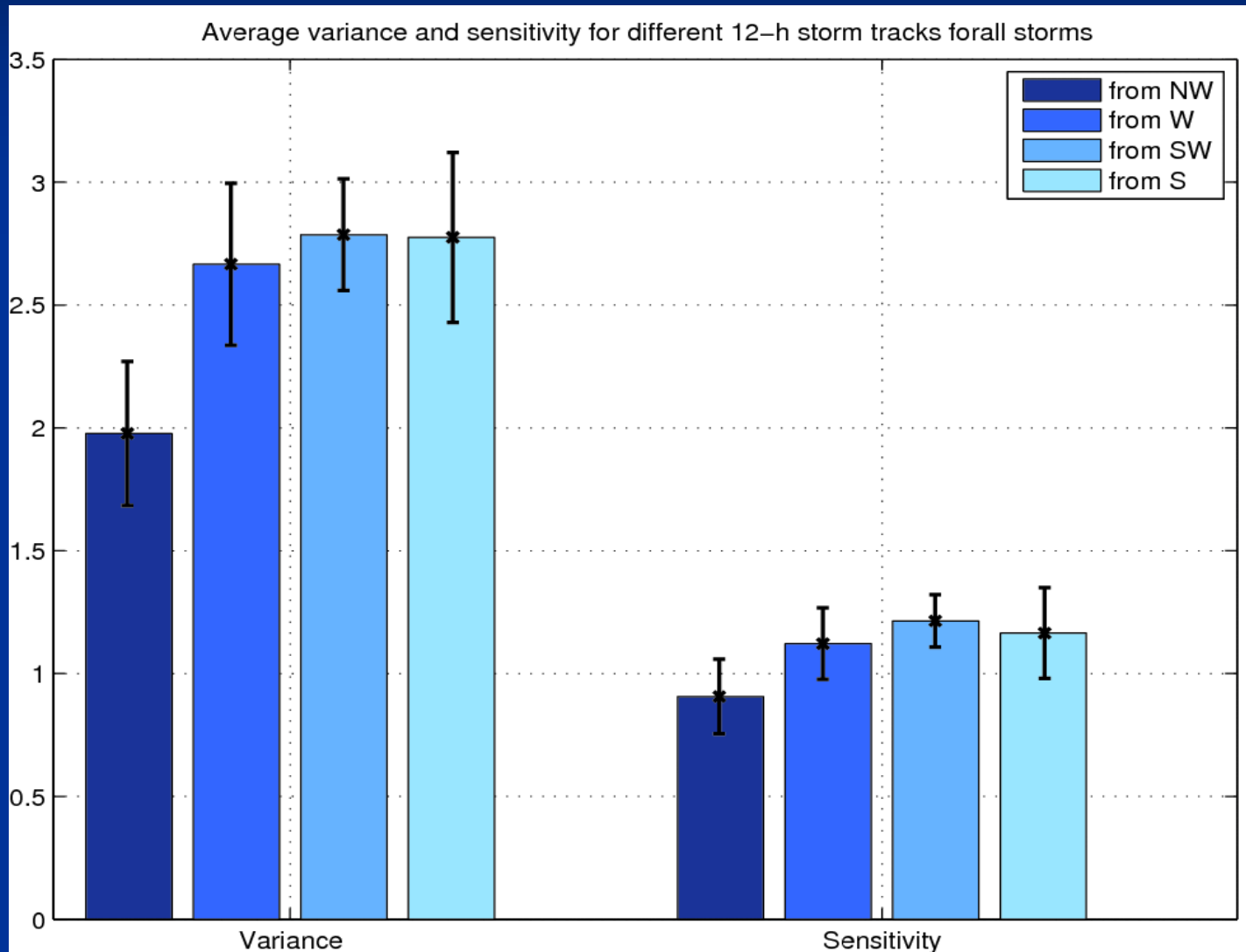
24-hr Spread vs. Deepening Rate



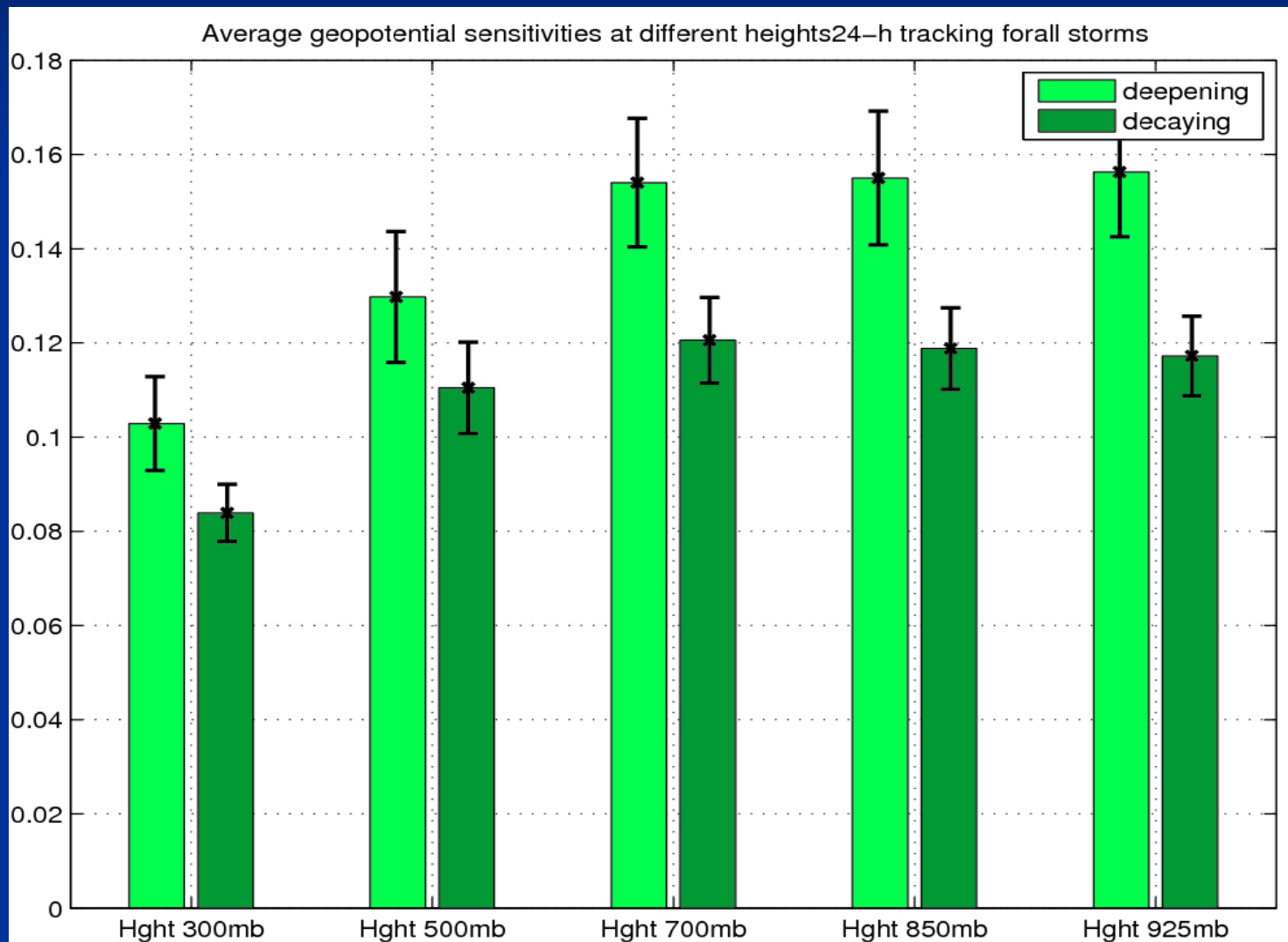
Spread/Sensitivity vs. Deepening Rate



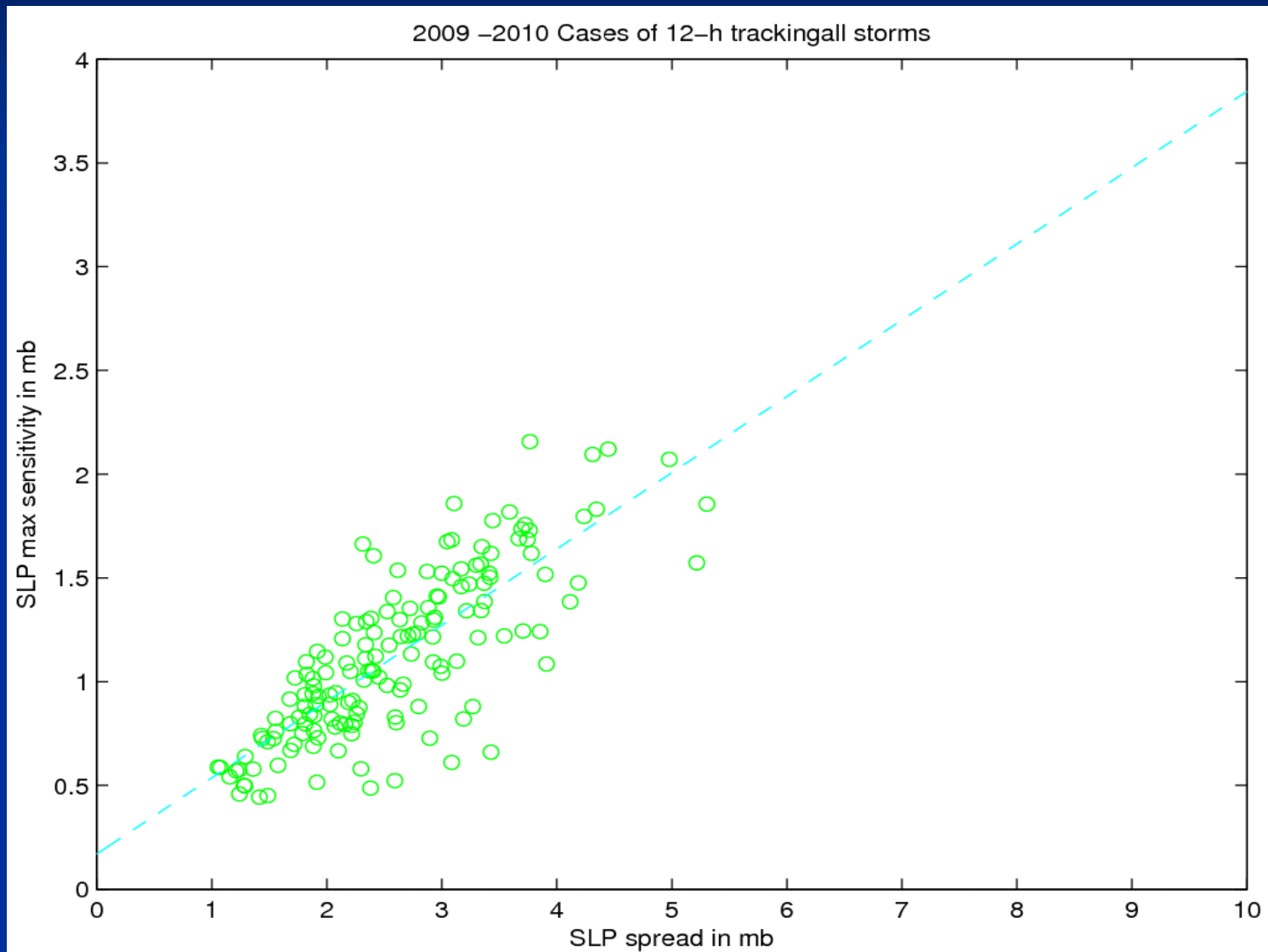
Spread/Sensitivity vs. Storm Track



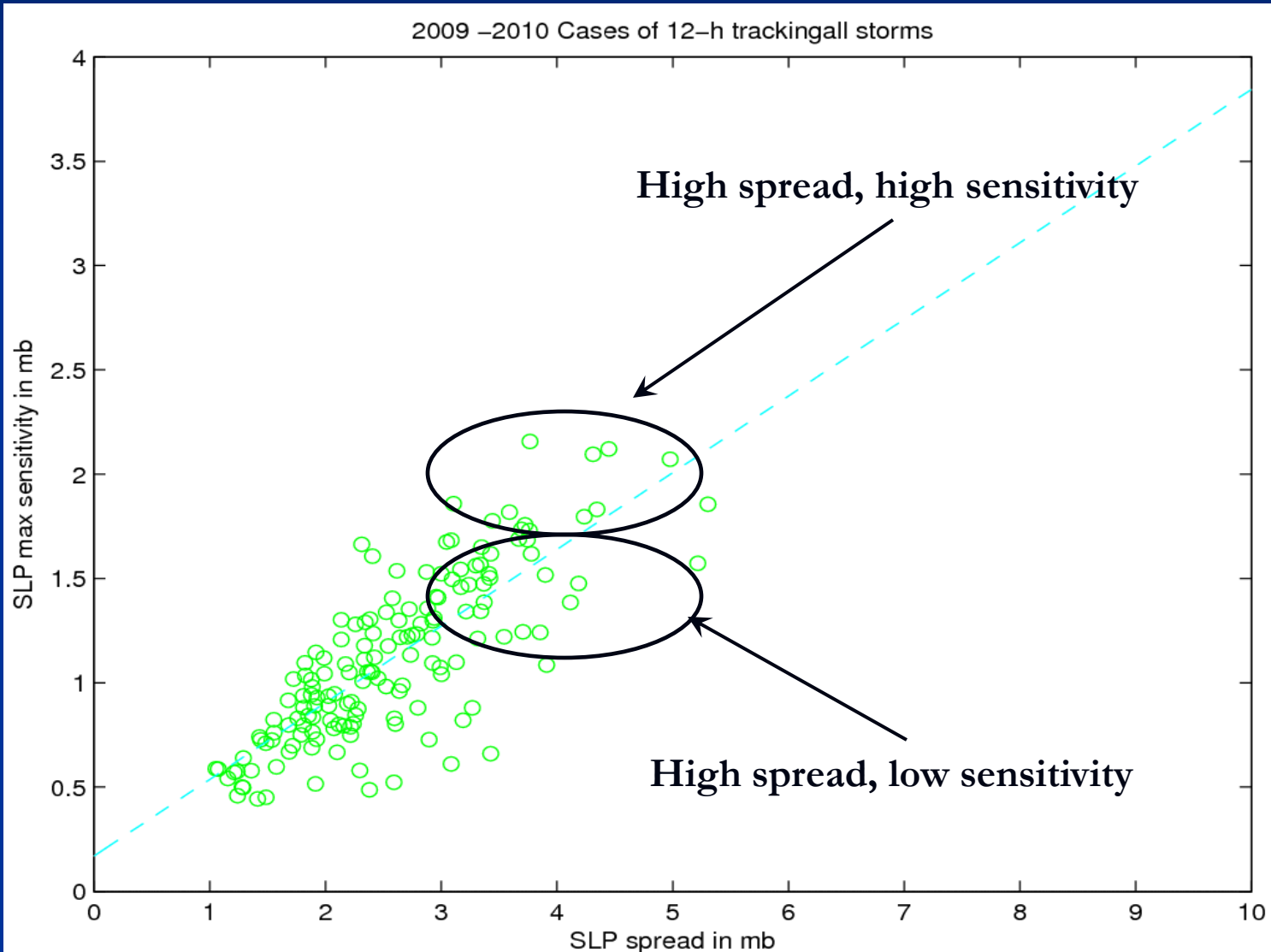
Sensitivity to GPH vs. Level



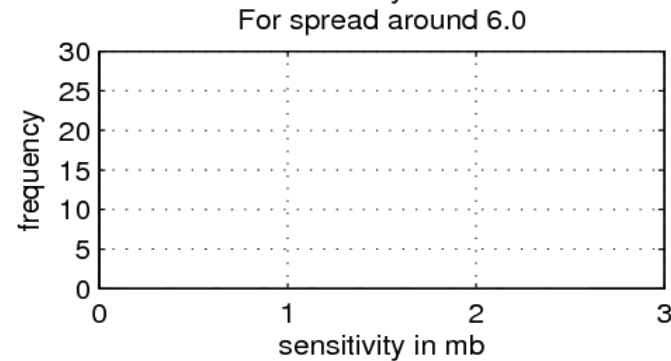
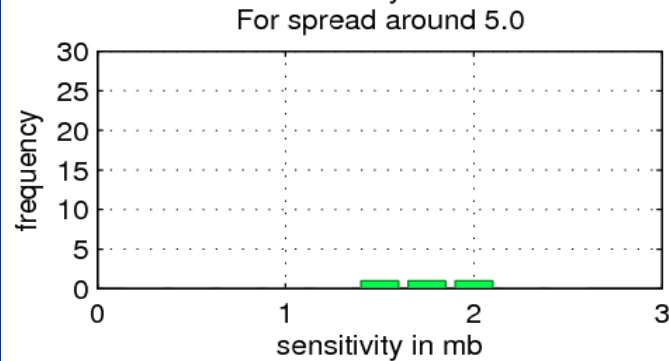
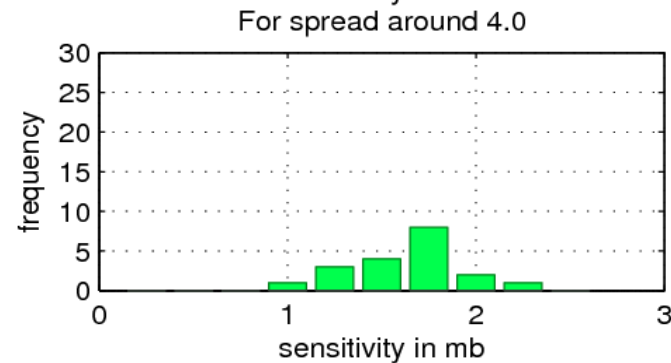
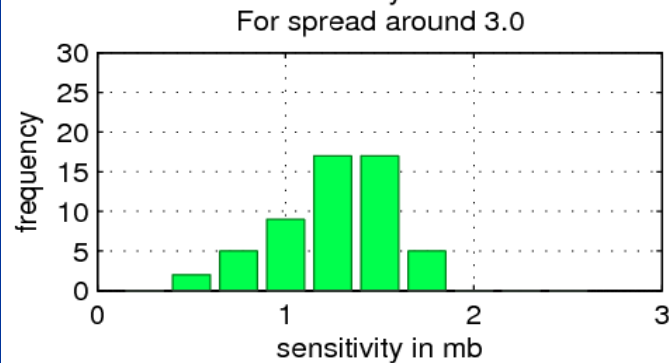
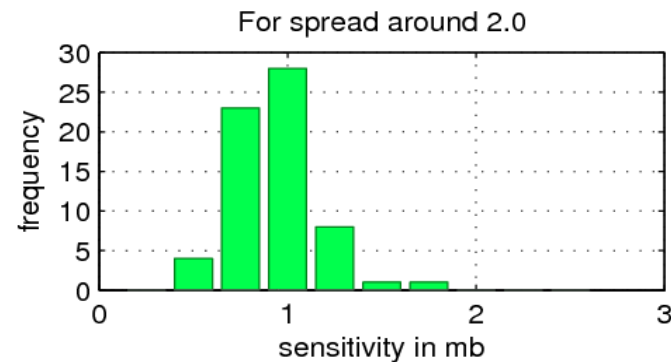
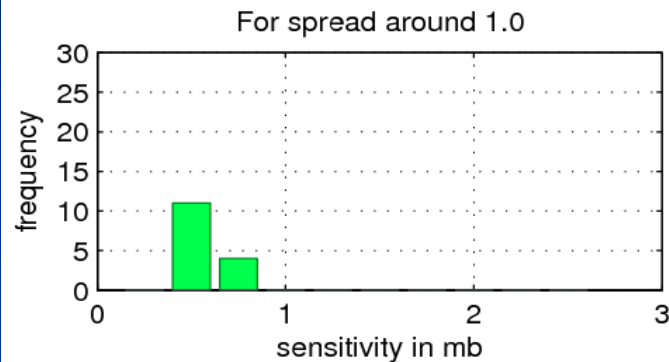
24-hr Spread vs. Sensitivity



24-hr Spread vs. Sensitivity

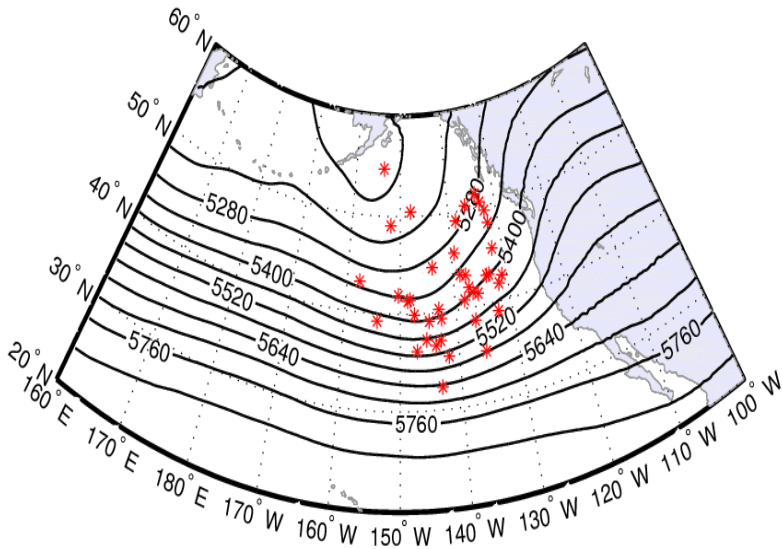


Sensitivity Distribution over Different Spread Values

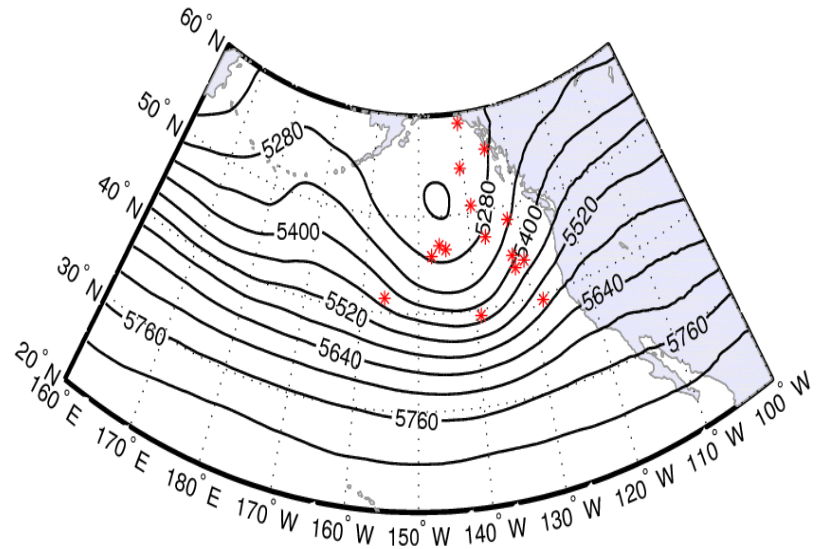


Composite 500-hPa Flow

Composite 500 hghts for high spread high sens 2009–2010. Num of cases = 40 and storm initial locations composite 500 hghts for high spread low sens 2009–2010. Num of cases = 15 and storm initial locations



High spread, high sensitivity

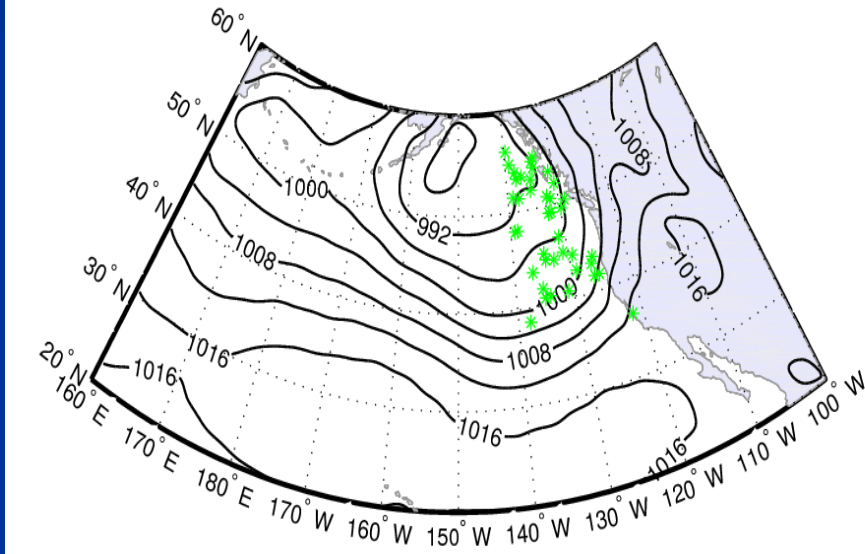


High spread, low sensitivity

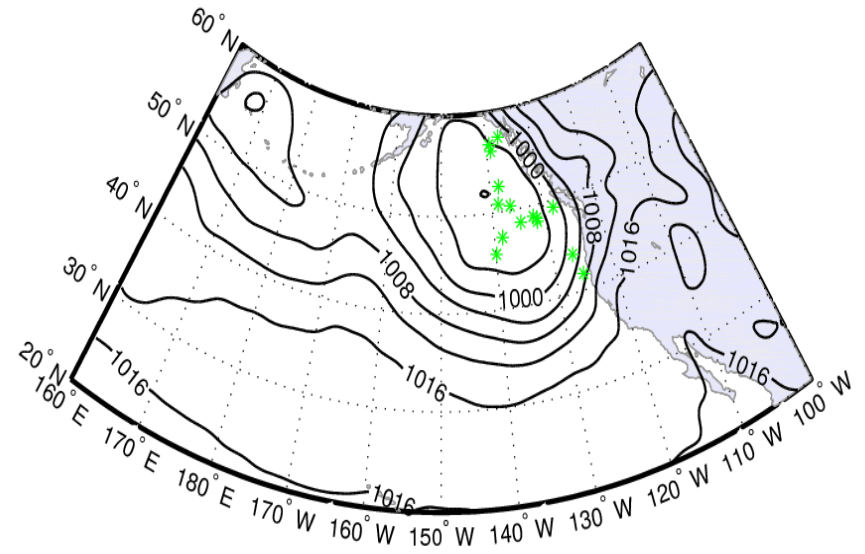
Red stars = cyclone initial position

Composite SLP

Composite SLP for high spread high sens 2009–2010. Num of cases = 40 and storm final locations Composite SLP for high spread low sens 2009–2010. Num of cases = 15 and storm final locations



High spread, high sensitivity



High spread, low sensitivity

Green stars = cyclone final position

Summary

- We aim to assess the “what”, the “how”, and the “why” of North American land-falling cyclone predictability over 3 winters

What: General characteristics of forecast uncertainty

How: Link between uncertainty and flow regime

Why: Intrinsic unpredictability vs. initial condition uncertainty

Summary

- We aim to assess the “what”, the “how”, and the “why” of North American land-falling cyclone predictability over 3 winters

What: General characteristics of forecast uncertainty

How: Link between uncertainty and flow regime

Why: Intrinsic unpredictability vs. initial condition uncertainty

- The tools we are using to do this are:
 - Ensemble sensitivity
 - Adjoint sensitivity (upcoming)
 - Ensemble forecast spread

Summary

- Early results using an SLP 24-hr response function over a single winter suggest:
 - Least predictable → Deepening cyclones from W/SW

Summary

- Early results using an SLP 24-hr response function over a single winter suggest:
 - Least predictable → Deepening cyclones from W/SW
 - Low predictability, small sensitivity → Large, deep Gulf of Alaska occluded systems

Summary

- Early results using an SLP 24-hr response function over a single winter suggest:
 - Least predictable → Deepening cyclones from W/SW
 - Low predictability, small sensitivity → Large, deep Gulf of Alaska occluded systems
 - Low predictability, large sensitivity → Occluded Gulf of Alaska system present, but secondary development apparent with stronger upstream jet (frontal waves?)

Summary

- Early results using an SLP 24-hr response function over a single winter suggest:
 - Least predictable → Deepening cyclones from W/SW
 - Low predictability, small sensitivity → Large, deep Gulf of Alaska occluded systems
 - Low predictability, large sensitivity → Occluded Gulf of Alaska system present, but secondary development apparent with stronger upstream jet (frontal waves?)
 - Sensitivity to GPH maximizes in lower troposphere just like adjoint sensitivity

Future Work

- Add other 2 winters to dataset, finish analysis
- Expand results to other response functions, forecast times
- Include adjoint sensitivity in analysis
- Include forecast error in analysis