Ensemble-based Sensitivity for MPEX

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Forecast Sensitivity

- Forecast sensitivity analysis has been successfully used to understand the growth of errors and identify regions for additional “targeted” observations
- Many of these methods use linearized error growth version of model
- Ensemble-based approach uses ensemble of forecast states to determine sensitivity, does not suffer from linearized model assumptions

Ensemble Sensitivity

$$\frac{\partial J_e}{\partial x_j} \equiv cov(\delta J, \delta \mathbf{x}_{o,j})\mathbf{D}_j^{-1} = \frac{cov(\mathbf{J}, \mathbf{X}_j)}{var(\mathbf{X}_j)}$$

Ancell and Hakim 2007, Torn and Hakim 2008

- Ensemble-based method of computing the sensitivity to the initial conditions
- Above equation is linear regression based on ensemble:
  - Dependent variable is ensemble estimate forecast metric
  - Independent variable is ensemble estimate of state variable
- Works best when the forecast metric is more continuous
- Can also compare subset of members that have particular metric properties.

MPEX Products

- To support MPEX operations, three different types of forecast sensitivity will be computed from 30 member ensemble being run at NCAR
  - Sensitivity (change in metric per change in earlier forecast fields)
  - Composite differences based on 8 members with highest/lowest metric values
  - Hypothetical observation impact
- Forecast Metric will be precipitation averaged over area (more later)

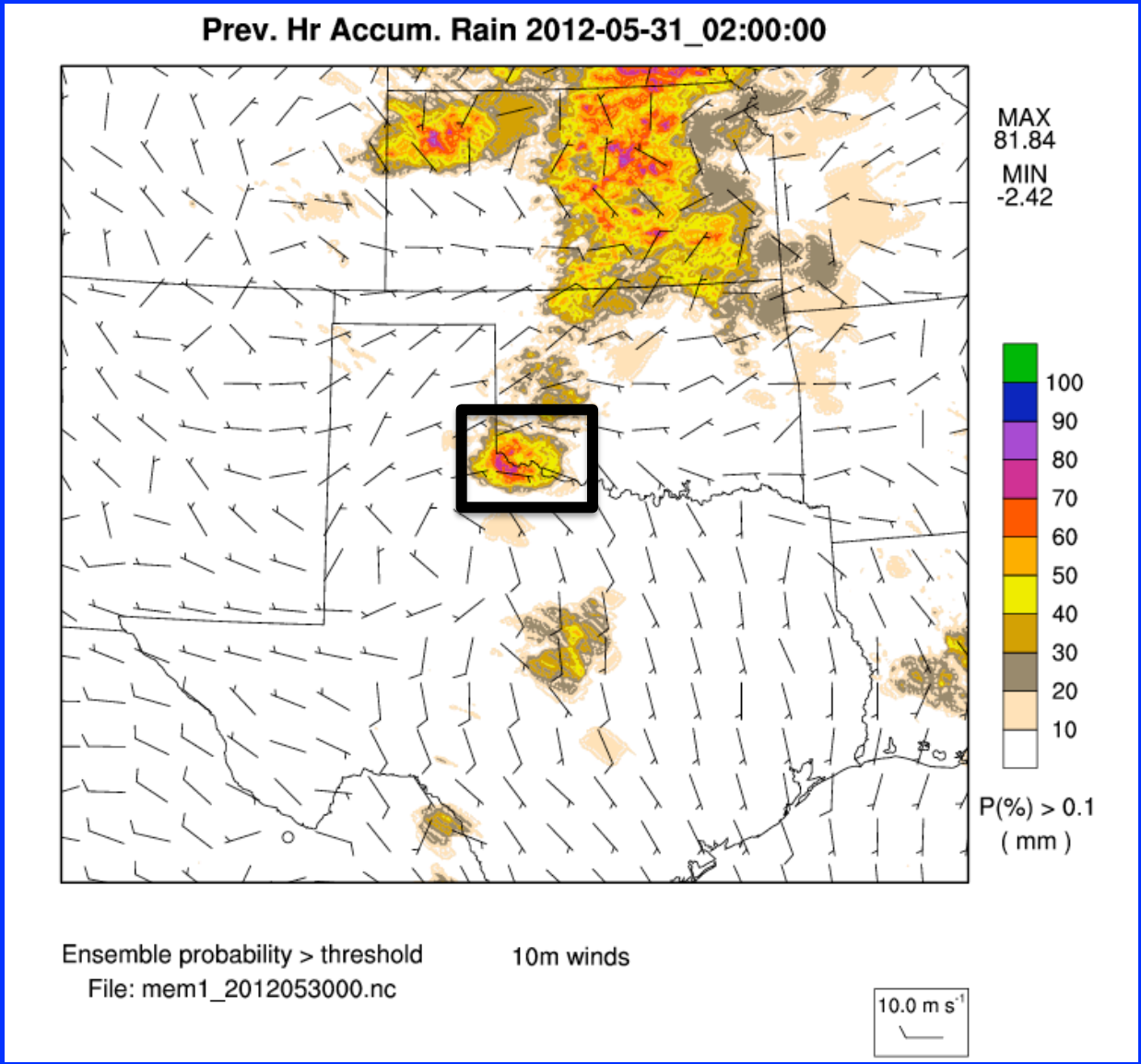
Signal vs. Noise

- Given small ensemble, it can be difficult to distinguish between signal and noise
- For sensitivity, compute error bounds on slope. If zero slope is not within 95% confidence error bounds, sensitivity is deemed statistically significant (see Wilks 6.2.4)
- For composites, test differences based on student t test based on two sample means and standard deviations.

Sensitivity Fields

- 2-6 km Theta-e
- Precipitable water
- 500-800 hPa water vapor mixing ratio
- Water vapor mixing ratio in lowest 1 km
- Theta-e in lowest 1 km
- 500 hPa vorticity
- Wind in lowest 1 km
- 330 K potential vorticity
- CAPE/CIN
- Static stability in lowest 1 km
- 400-800 hPa static stability
- Others??????

Forecast Example



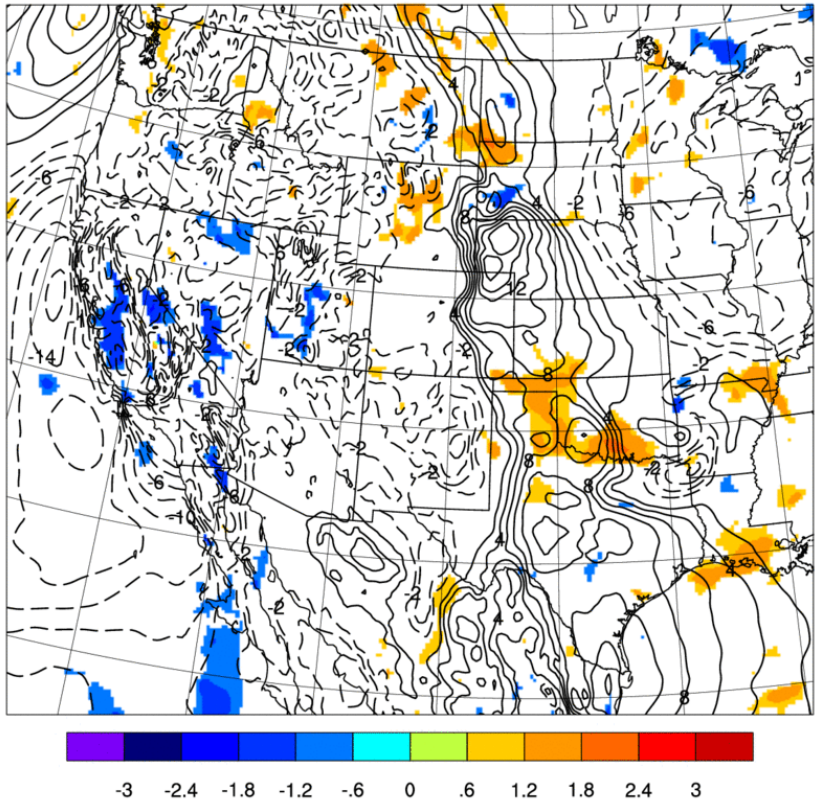
Look at forecast initialized 0000 UTC 30 May 2012

Forecast metric is precipitation averaged over box 0000-0300 UTC

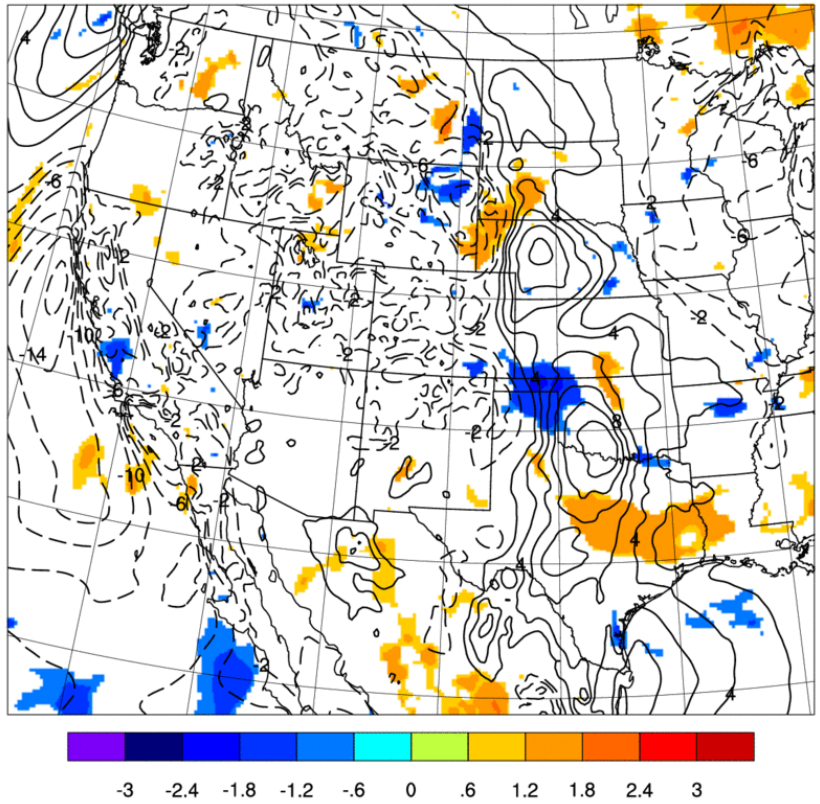
Region also identified through automated sensitivity approach

V-wind Sensitivity Plots

Sensitivity to 1200 UTC fields (-12-15 h)

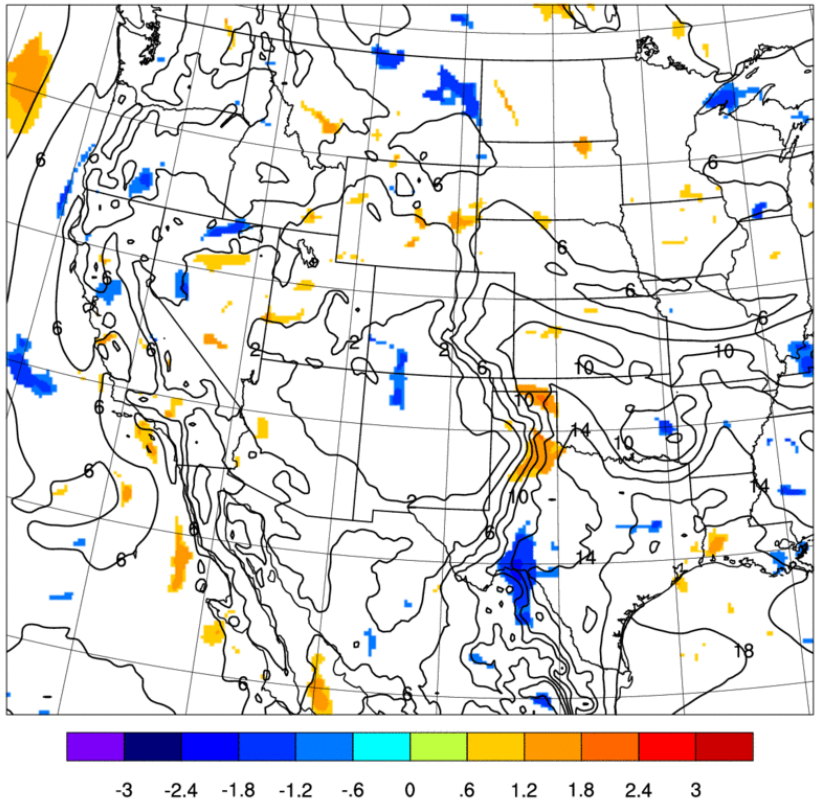


Sensitivity to 1800 UTC fields (-6-9 h)

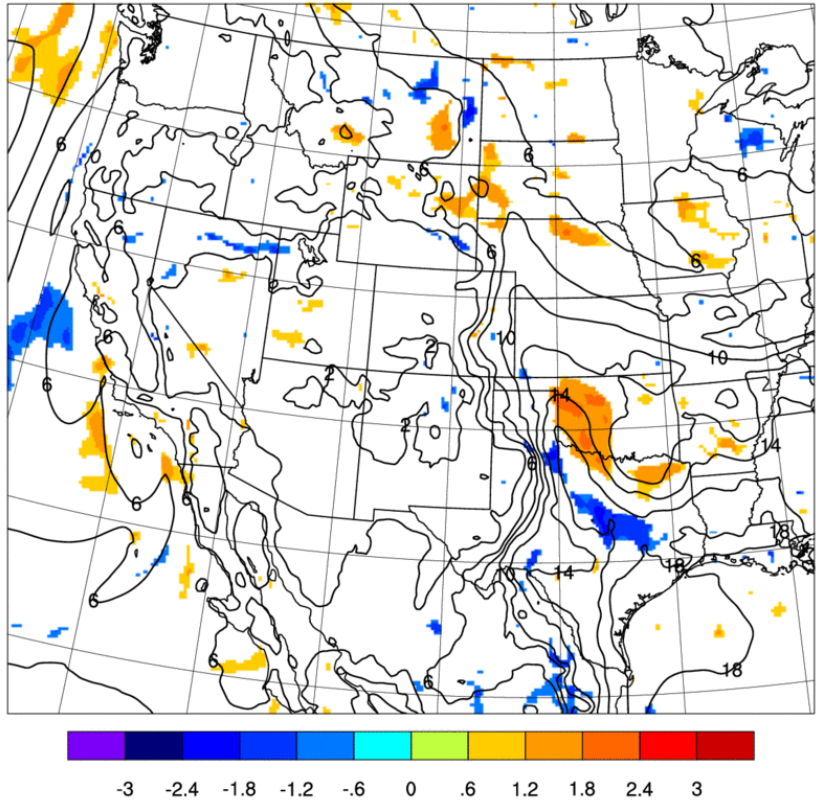


Water Vapor Sensitivity Plots

Sensitivity to 1200 UTC fields (-12-15 h)

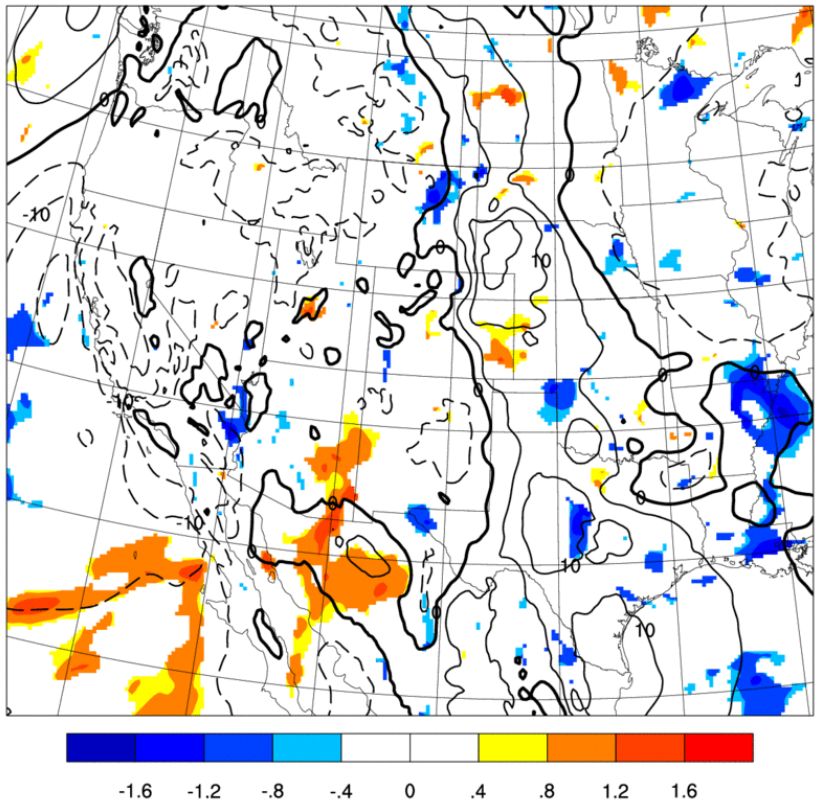


Sensitivity to 1800 UTC fields (-6-9 h)

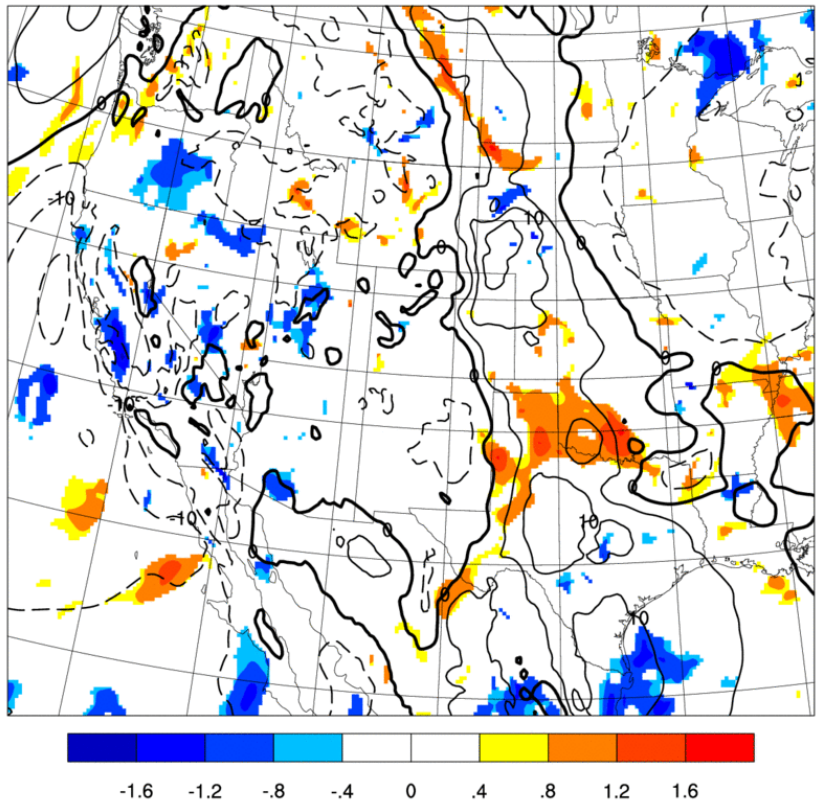


Composite Plots

Lowest Precipitation Members



Highest Precipitation Members



Observation Impact

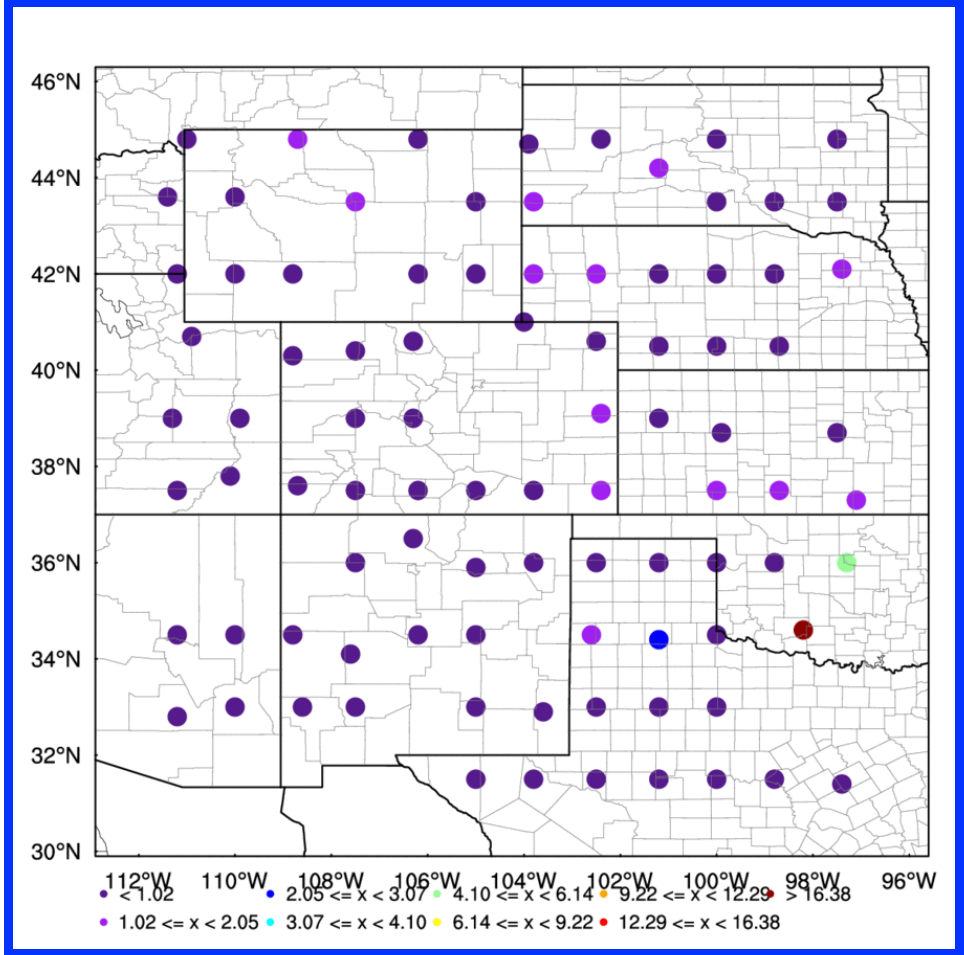
- Ensemble-based method allows for estimate of observation impact
  - Can get change in metric value if you know observation properties, ensemble metric values and observation value itself
  - Can get reduction in variance knowing first two above (no need for observation)

$$\delta J = \mathbf{J}(\mathbf{H}\mathbf{X}^b)^{\mathrm{T}}(\mathbf{H}\mathbf{P}^b\mathbf{H}^{\mathrm{T}} + \mathbf{R})^{-1}[\mathbf{y} - \mathcal{H}(\mathbf{x}^b)],$$

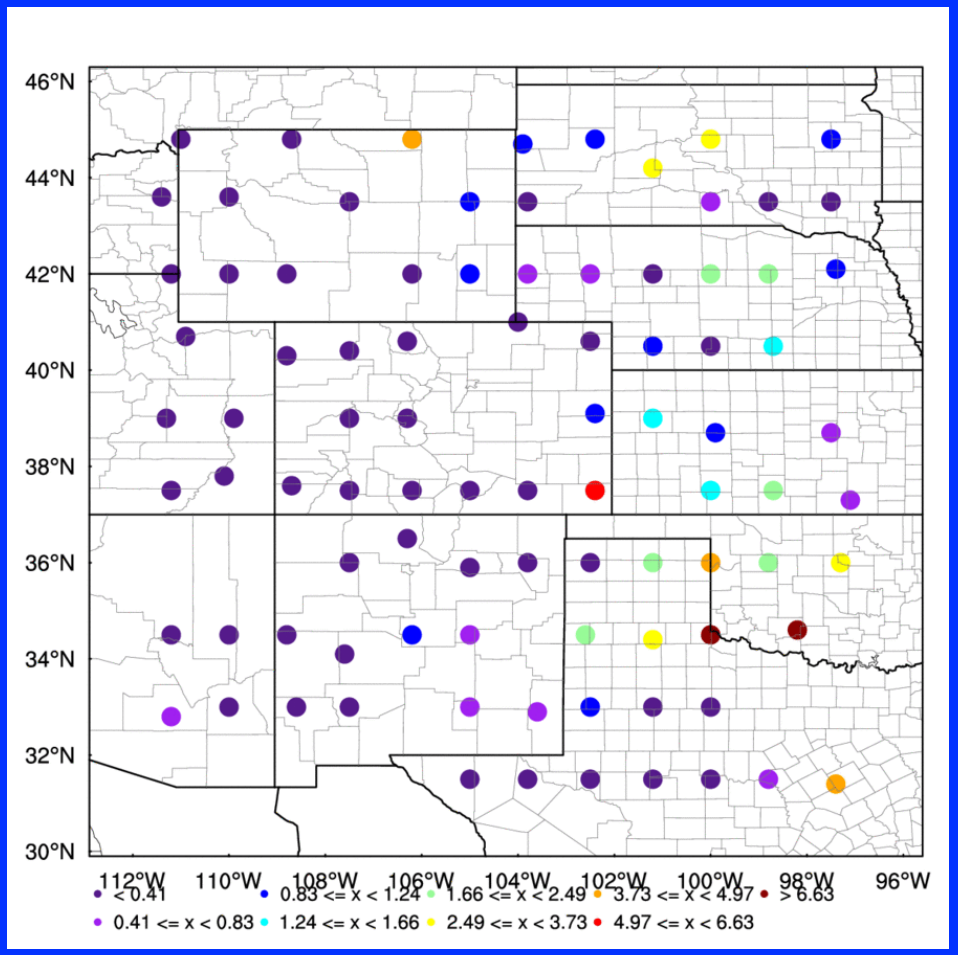
$$\delta\sigma = -\mathbf{J}(\mathbf{H}\mathbf{X}^b)^{\mathrm{T}}(\mathbf{H}\mathbf{P}^b\mathbf{H}^{\mathrm{T}} + \mathbf{R})^{-1}\mathbf{H}\mathbf{X}^b\mathbf{J}^{\mathrm{T}}.$$

Observation Impact

1200 UTC dropsondes

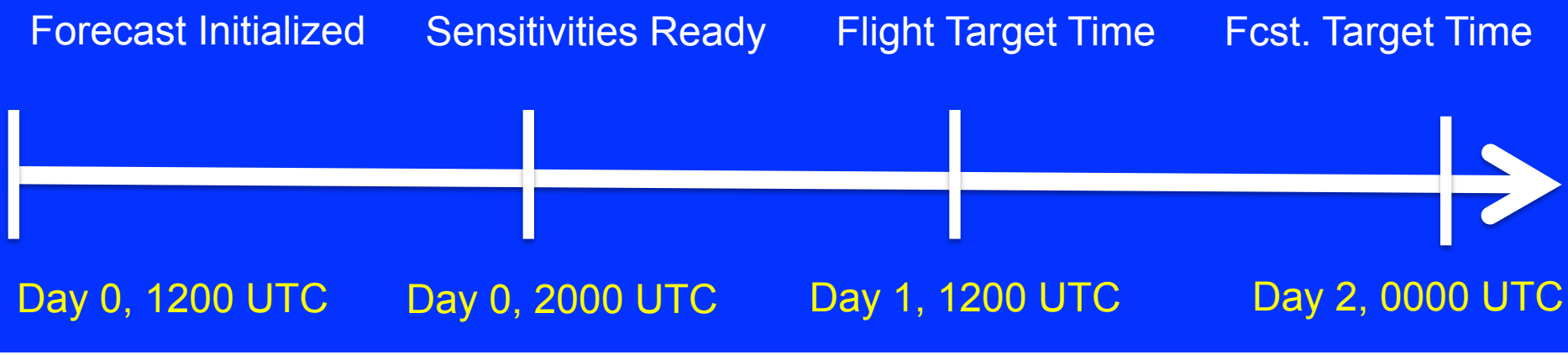


1800 UTC dropsondes



Dropsonde Operations Timeline

- Need to determine sensitivity prior to daily planning meeting
- Instead of computing sensitivity to IC, will do sensitivity to earlier forecast lead time.
  - Likely sensitivity of 36 h forecast to 24 h forecast.

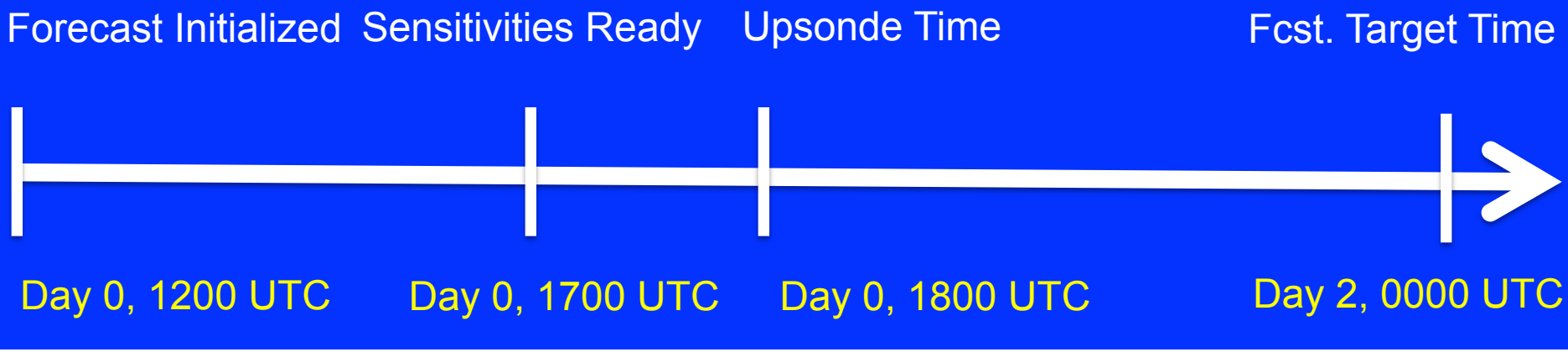


Upsonde Ops. Timeline D-1

- Compute sensitivity of 36 h forecast to 30 h forecast. Goal to provide general guidance on location for next day
- Will follow same format as dropsondes, except target time is moved

Upsonde Ops. Timeline Day of

- Will confirm sensitive region by computing sensitivity from 1200 UTC forecast on day of convection



Questions for Others

- Any suggestions for metrics?
- Any other suggestions for fields?
- Additional Plots?
- Case studies from 2012 will be posted on the web shortly (will likely be incorporated or linked into Glen's forecast page)
  - http://www.atmos.albany.edu/facstaff/torn/MPEX_sens
- Papers describing these approaches and their applications are available upon request