Part II: Routine Network Design for Improved Prediction of Geophysical Fluid Flows

Analysis of Ensemble Methods

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SAMSI-IMAGE Summer School, June 2005

Adaptive $\leftrightarrow$ Routine Network Design

$$\text{ADAPTIVE} \xrightarrow{E(\text{ADAPTIVE})} \text{ROUTINE}$$

ADAPTIVE

"One-time events"

Hurricanes

Winter Storms

Thunder Storms

Tornadoes

ROUTINE

Goal: Improve

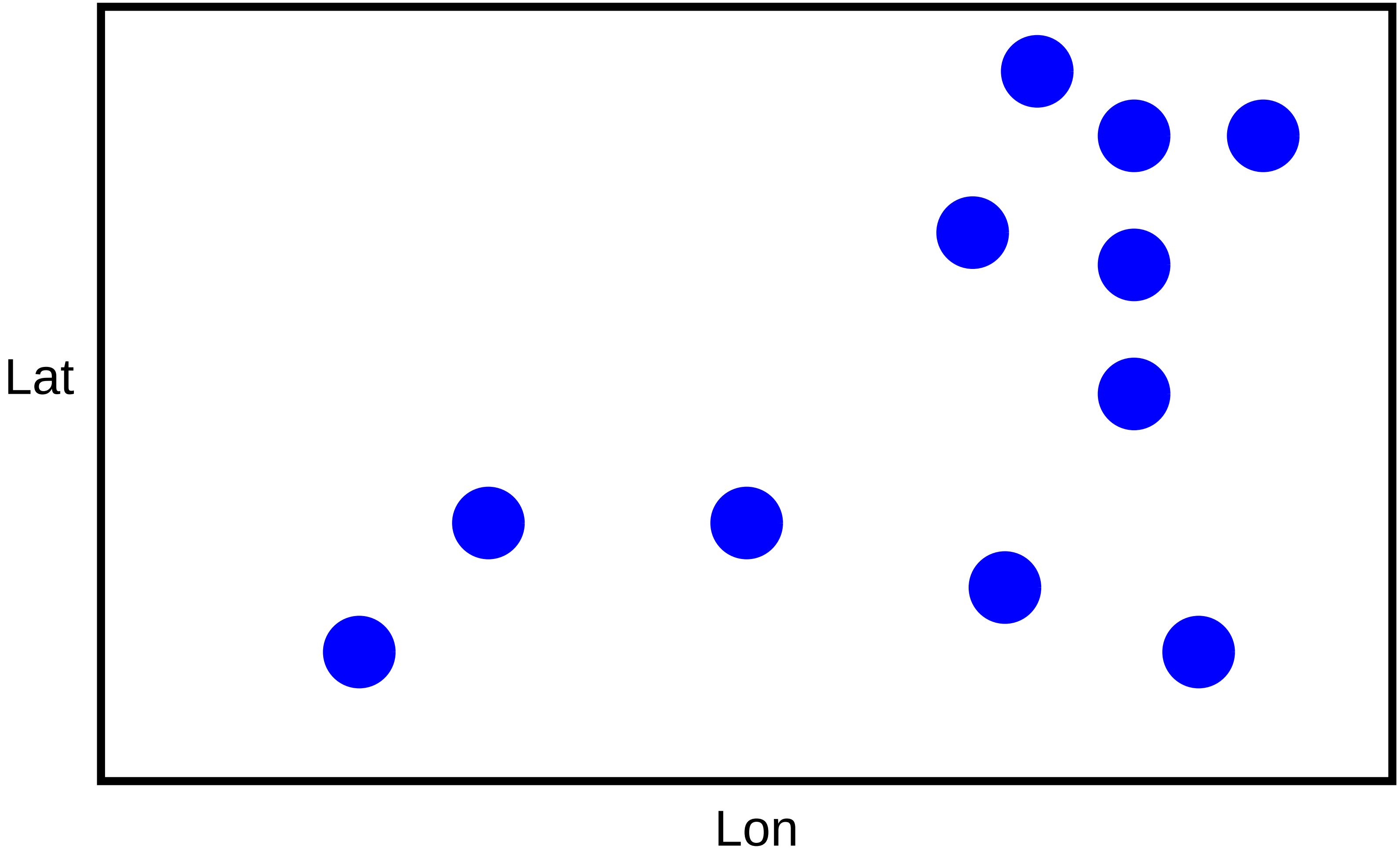
Time Mean

Predictability

Routine network design ...

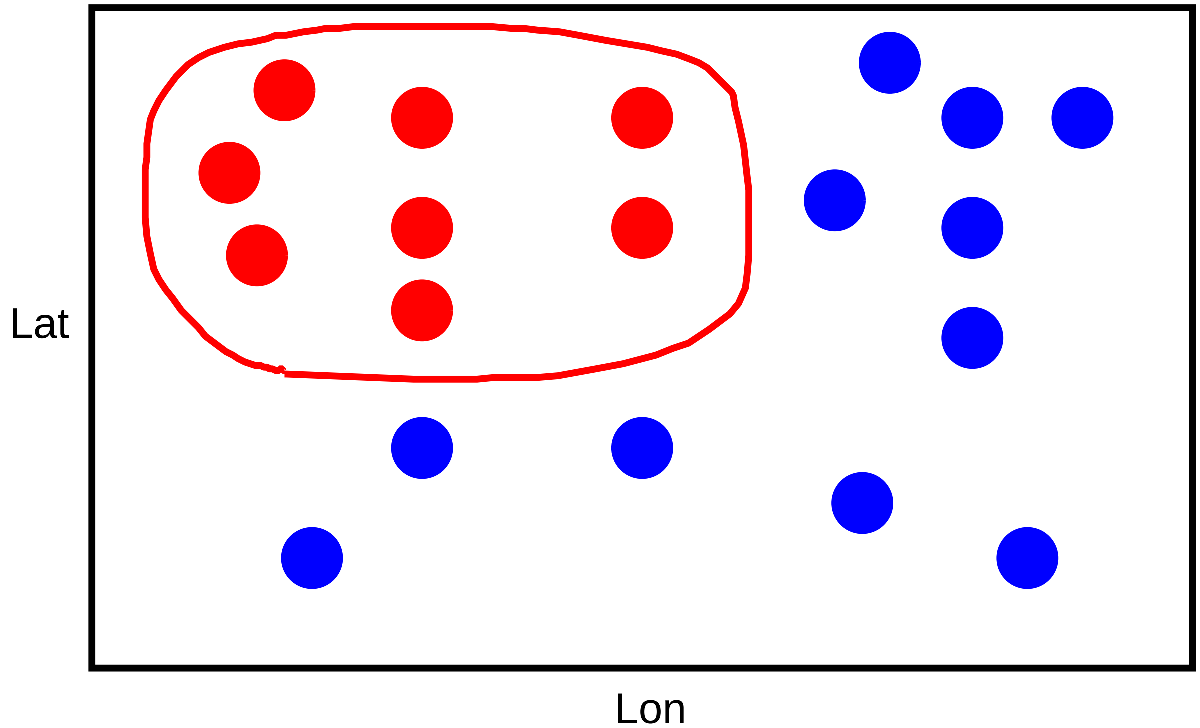
- 1. Define the problem
- 2. Observing System Simulation Experiments
- 3. My novel solution - Retrospective Design Algorithm - theory, issues, computational scaling
- 4. Demonstrate the utility of the RDA in an Atmospheric GCM

The background observing network



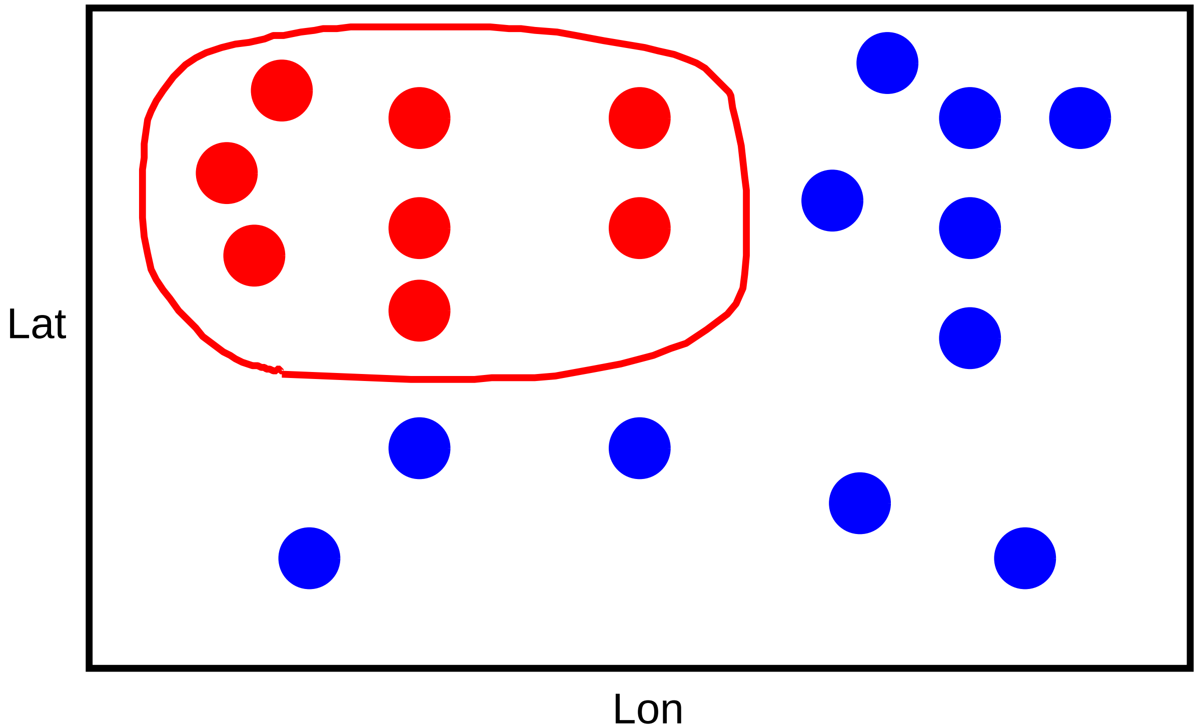
What type of problem is of interest?

The problem



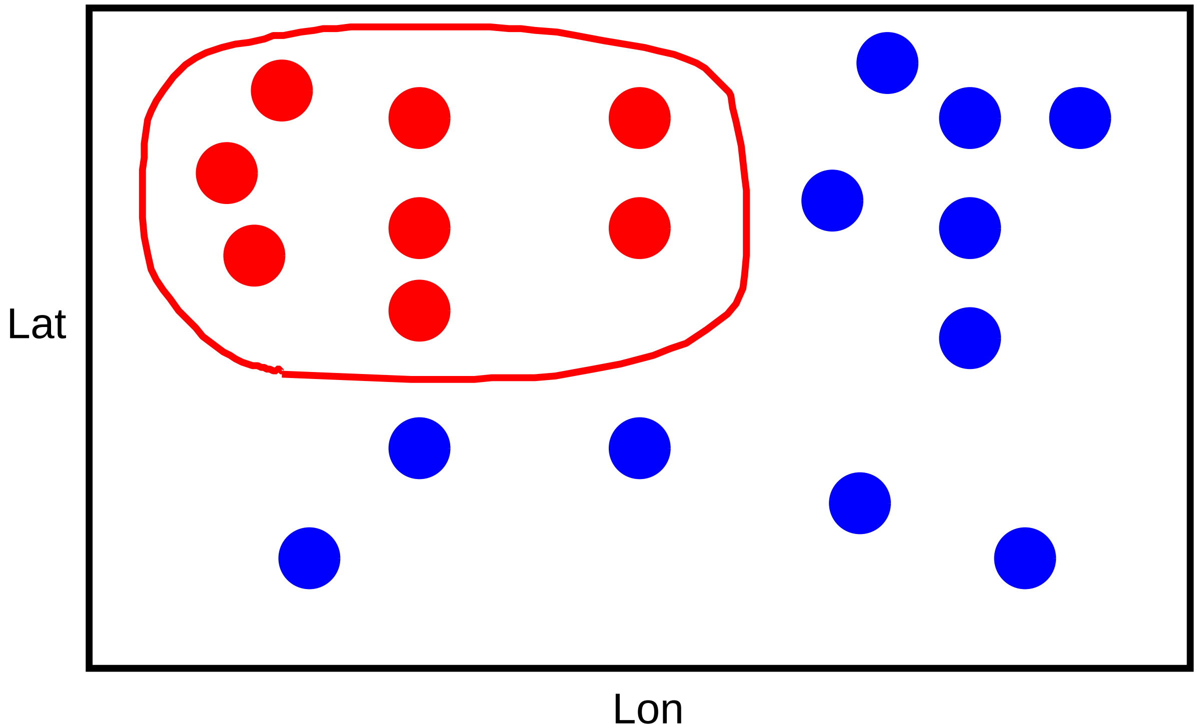
- For X dollars - can purchase 8 new RED TYPE instruments

The problem



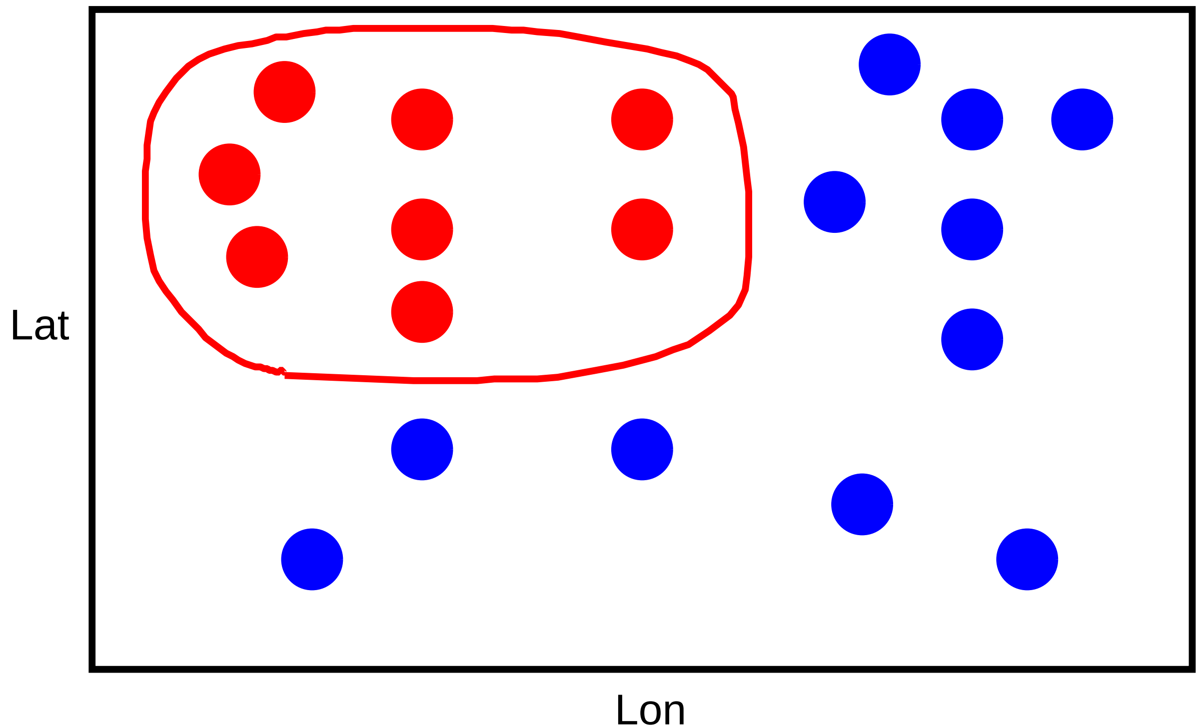
- To assess the value - must find the optimal locations of the NEW-FIXED observations given the FIXED network

The problem



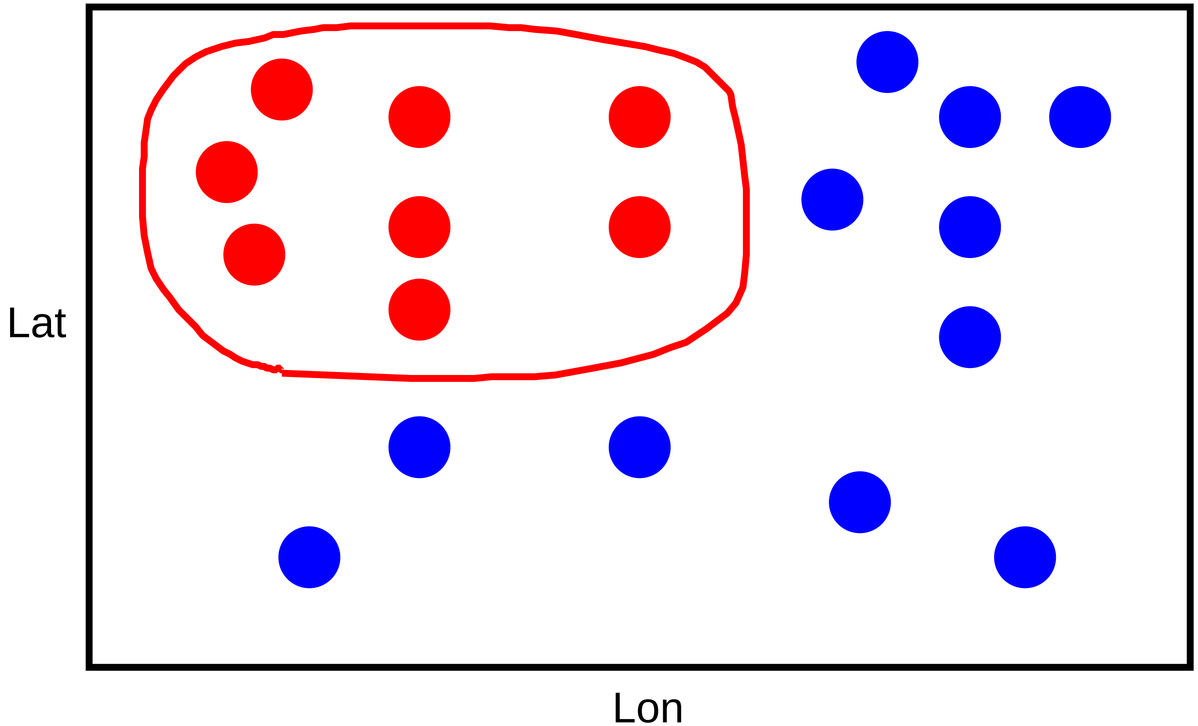
- Field experiments are often impractical, expensive and time consuming

The problem



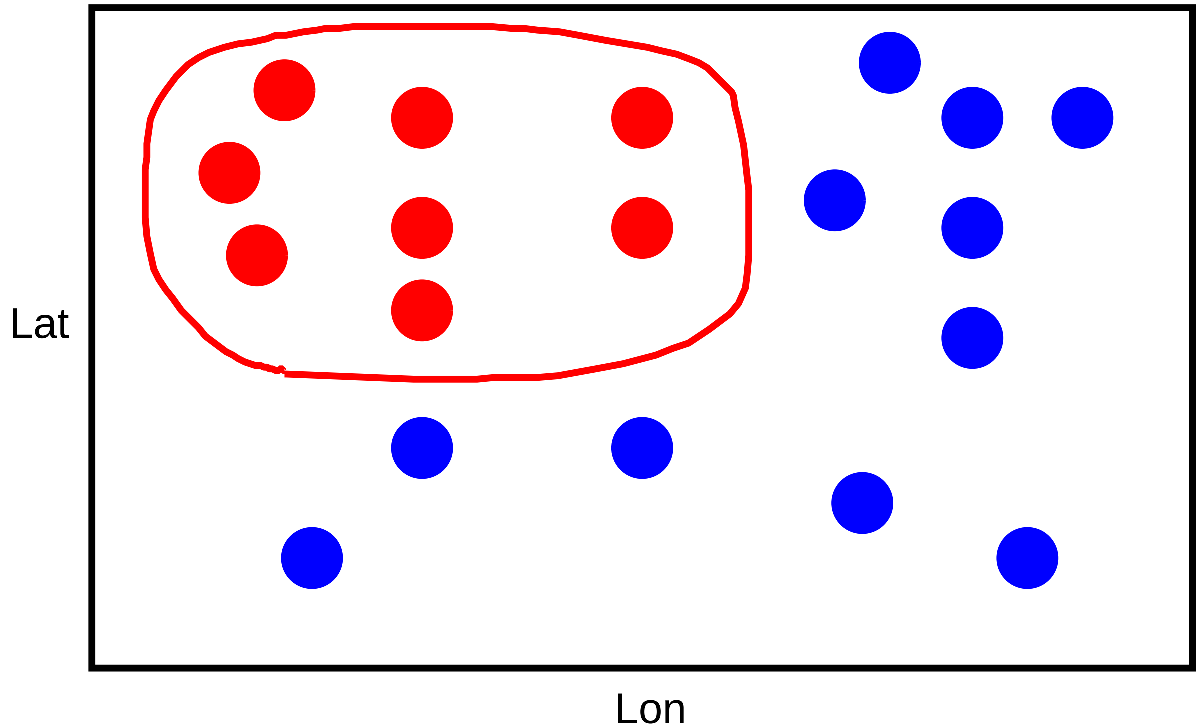
- Use simulations of the forecasting/assimilation cycle (can include economic benefit models)

The problem



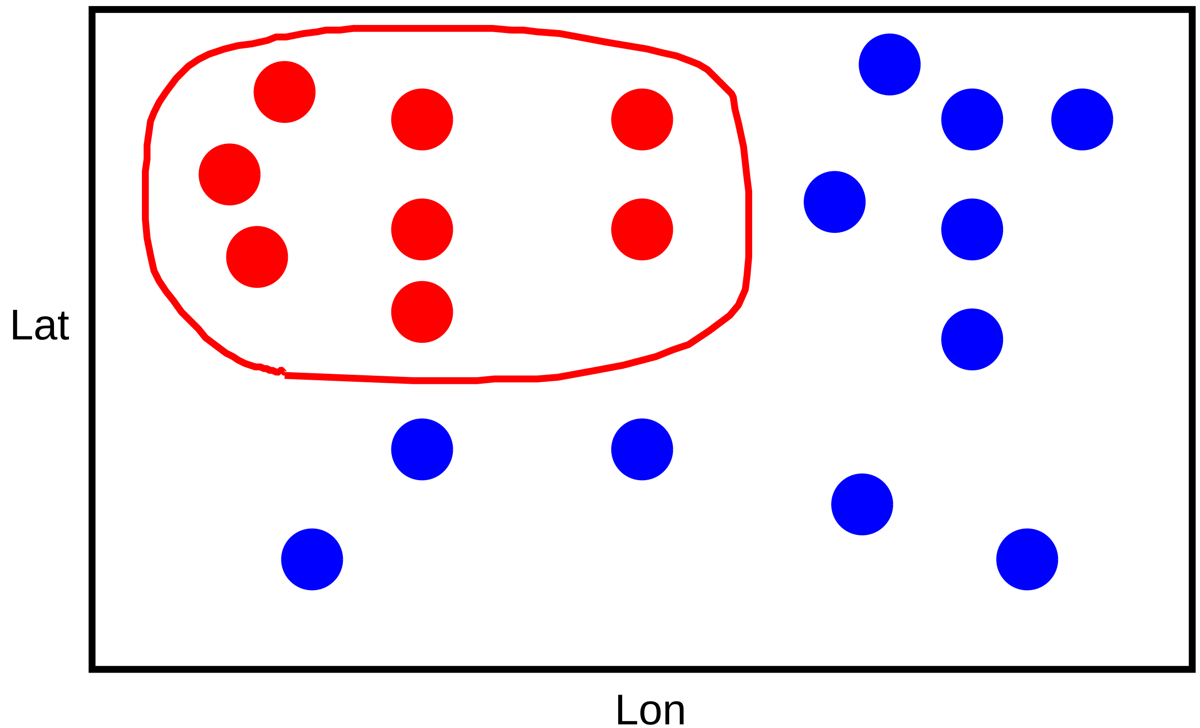
- The goal is to use the simulations as a guide in designing real networks of observations

The problem



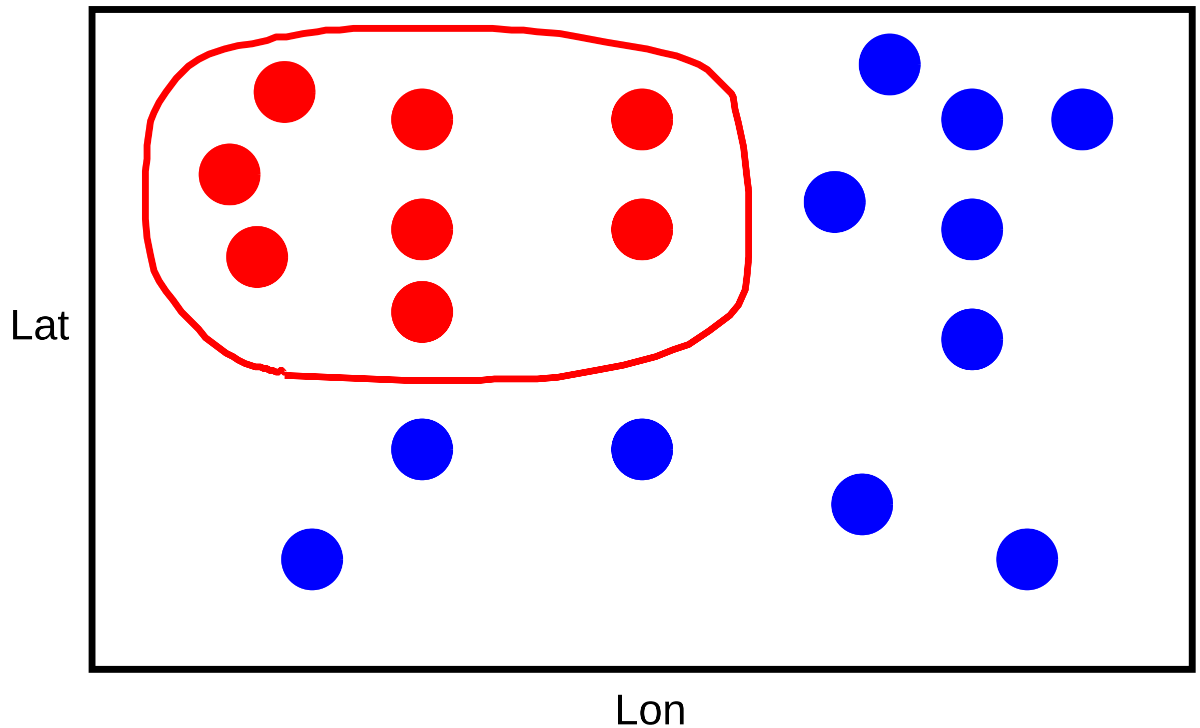
- To assess value - we must have a suitable framework for optimizing networks

The problem



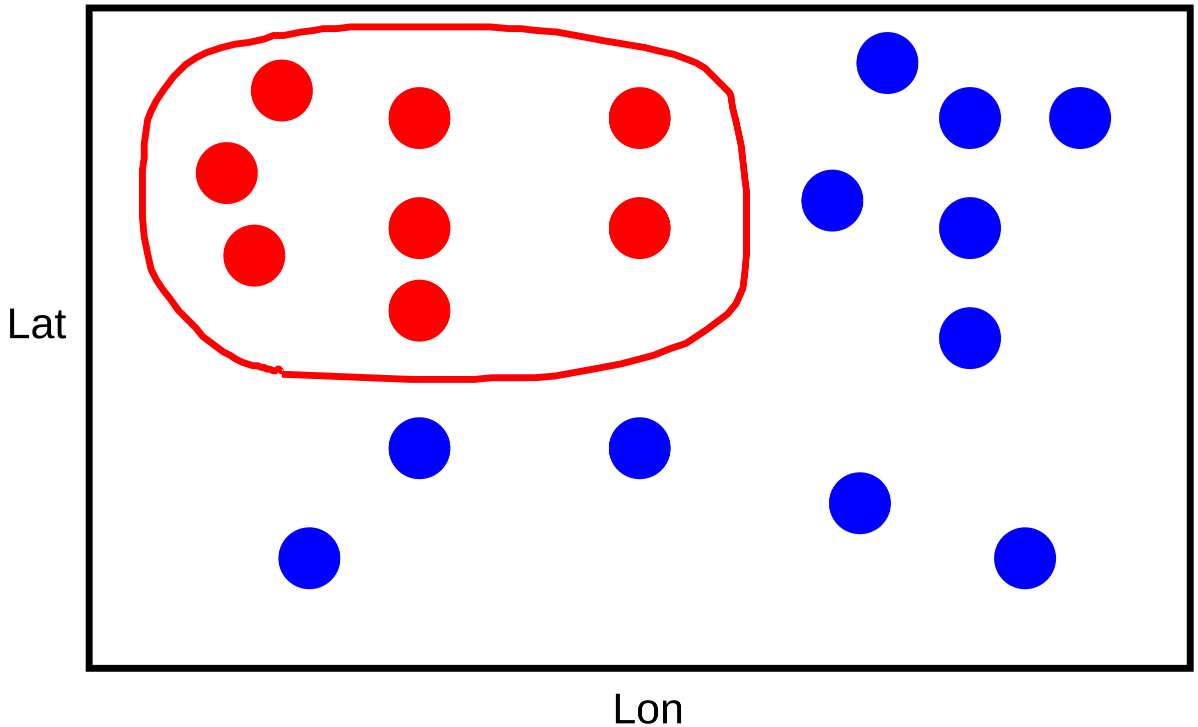
- This type of problem is central to THORPEX (a current 10 year international predictability experiment)

The problem



- These design problems are of interest to many types of prediction problems (Synoptic/Meso, Ocean/Climate, Carbon problems, ...)

The trial network H_1



- $H_1 = [H_{fixed}; H_{new-fixed}]$

Next ...

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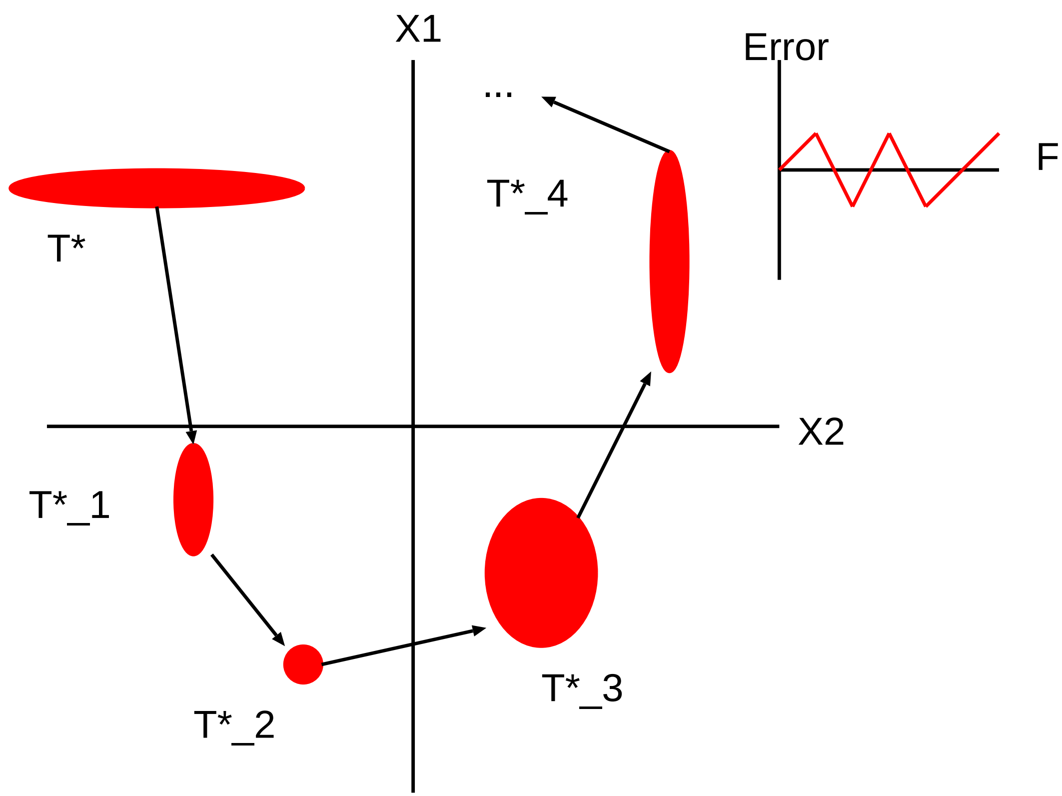
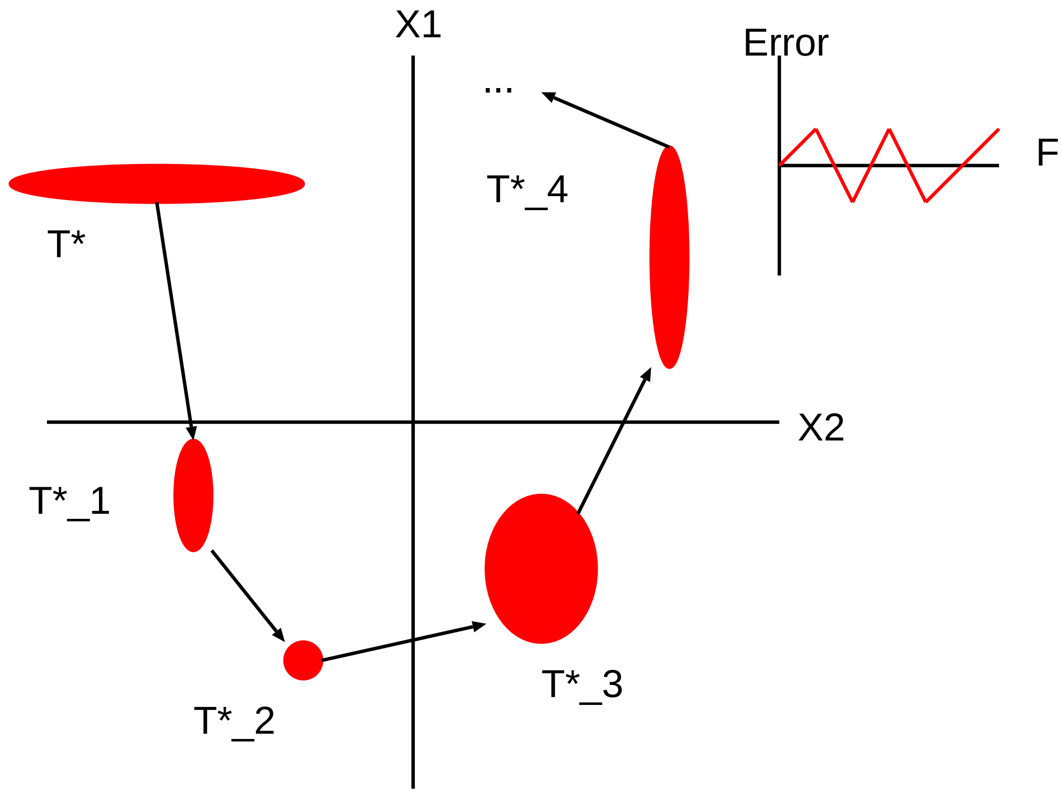
Evaluating the value of H_1 using OSSEs



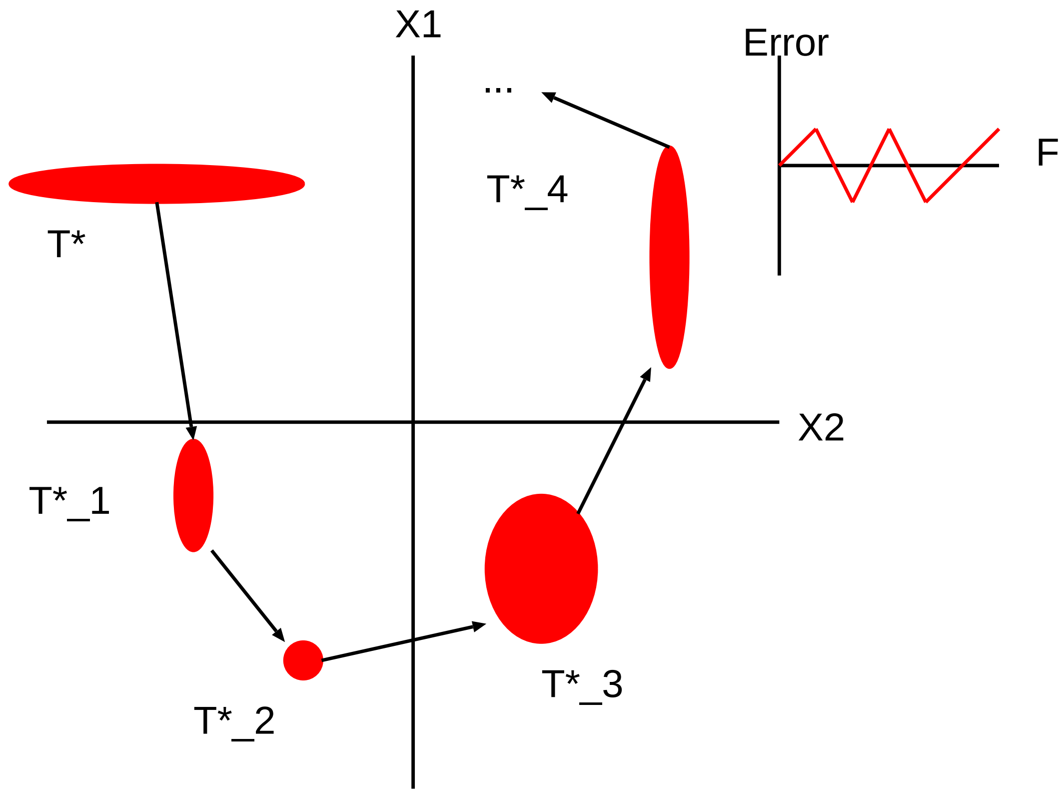
- H_1 includes both NEW-FIXED and FIXED observations

Evaluating the value of H_1 using OSSEs



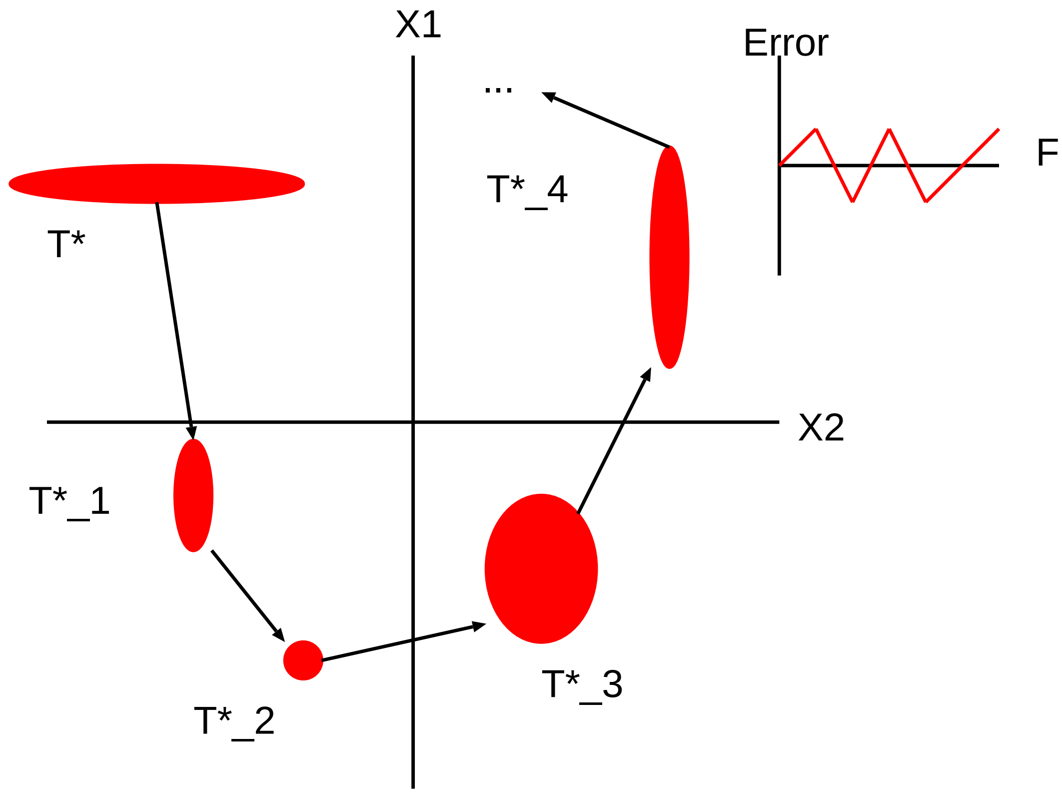
- Averaging independent error estimates amounts to an evaluation of an objective function $F(H_1)$

Evaluating the value of H_1 using OSSEs



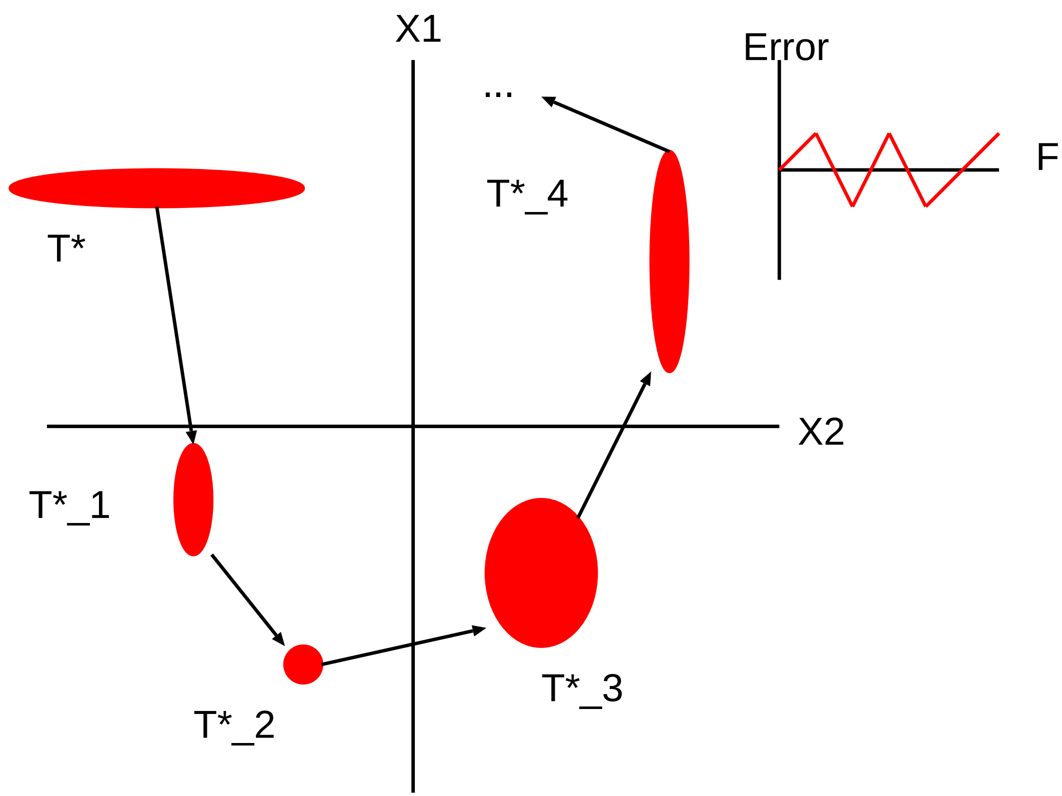
- Our objective - minimize F

Evaluating the value of H_1 using OSSEs



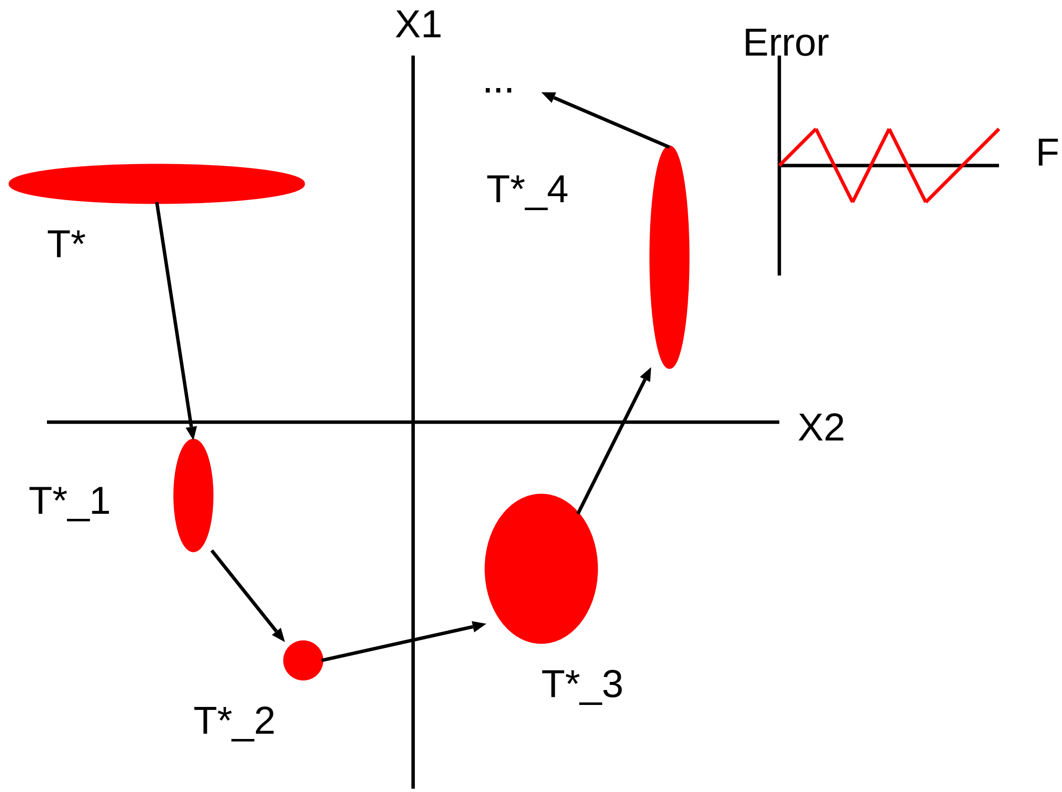
- Simple optimization method - try all conceivable configurations of H_1 and pick the minimum

Evaluating the value of H_1 using OSSEs



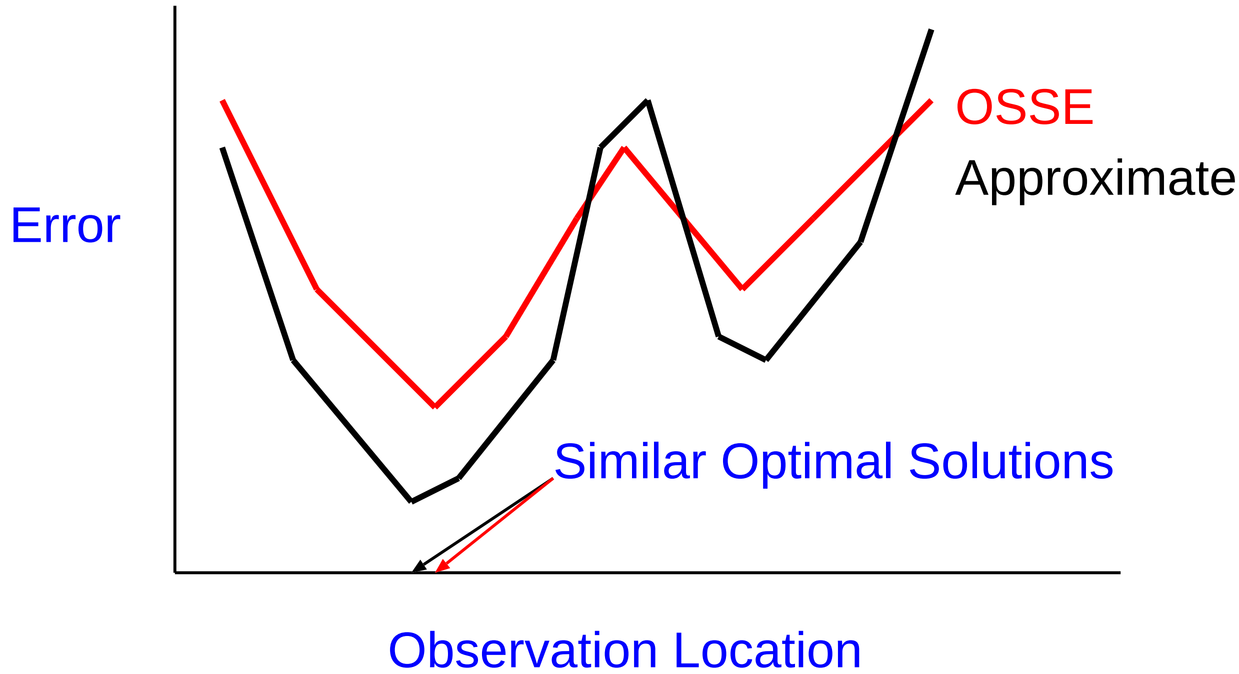
- For more advanced optimization techniques - still need to evaluate F many times and it should be smooth

Evaluating the value of H_1 using OSSEs



- For realistic GCMs - using OSSEs to optimize F is **PROHIBITIVELY EXPENSIVE**

Approximating information derived from OSSEs



- How can we obtain a statistically and dynamically significant approximation of information derived from OSSEs?

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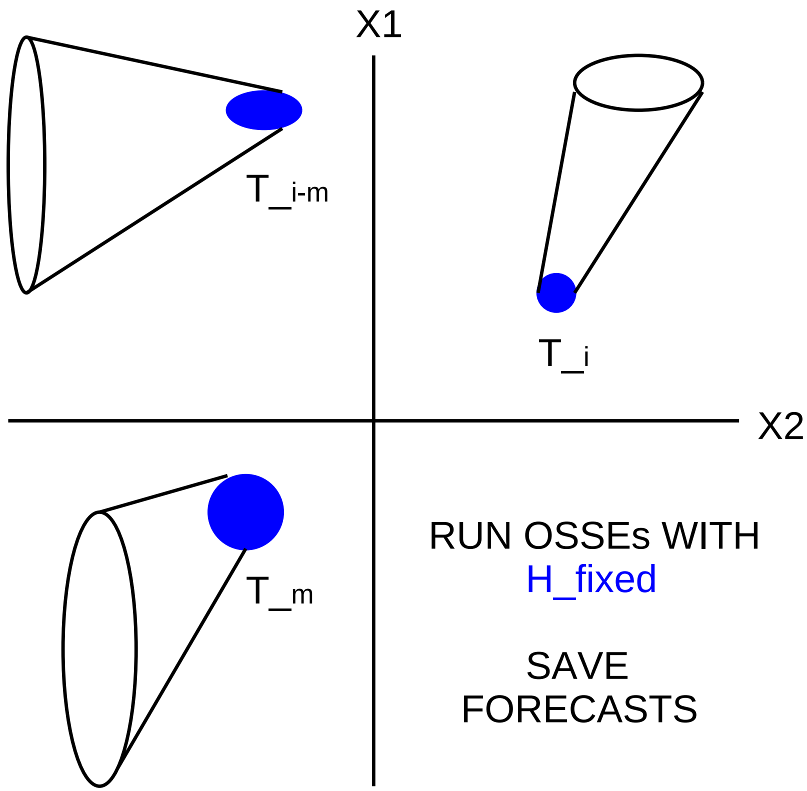
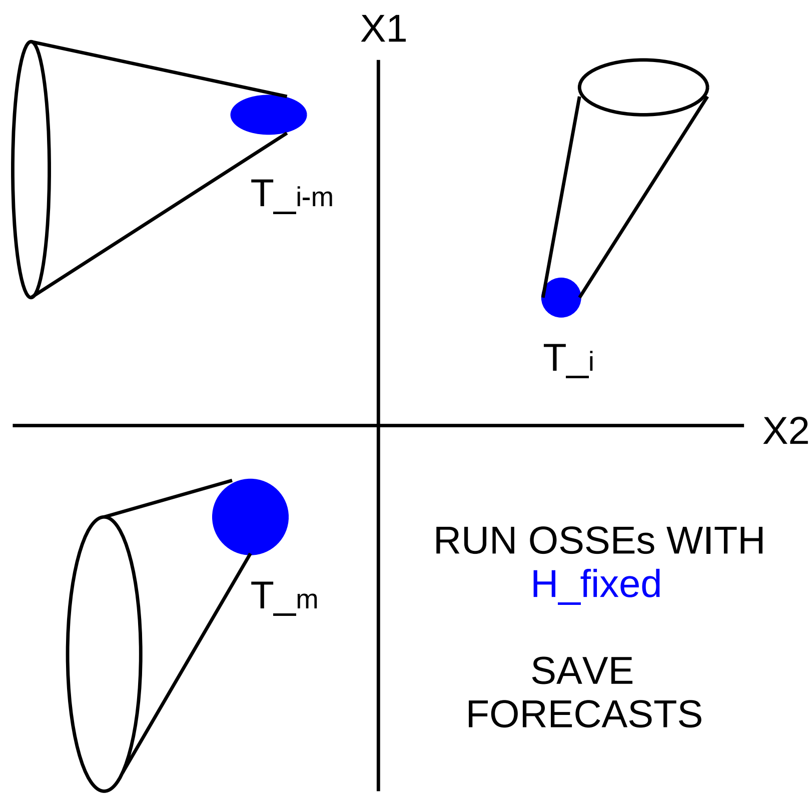
My solution - Retrospective Design Algorithm



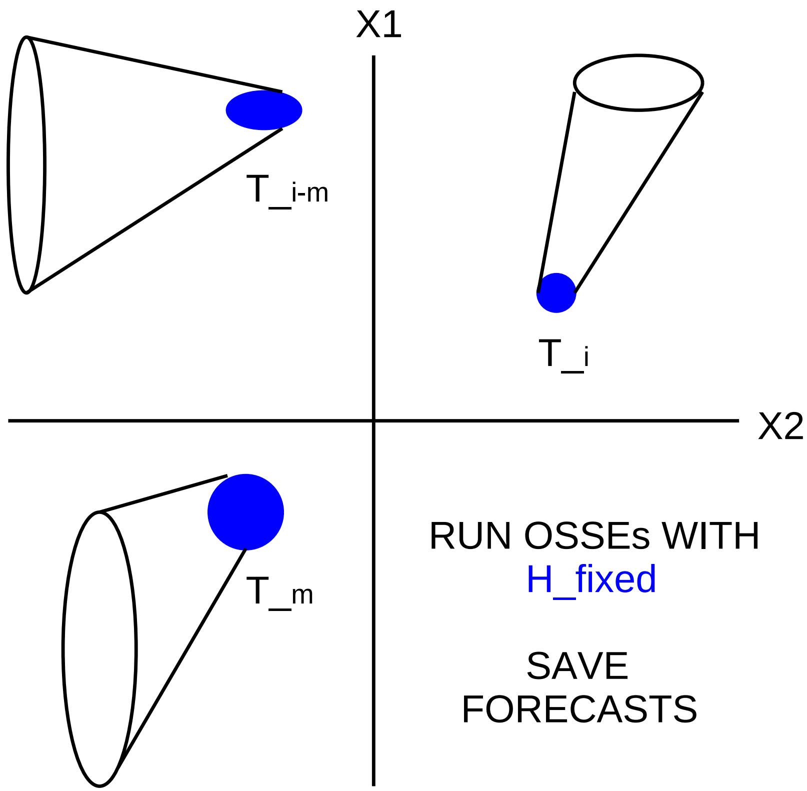
- Trial network H_1 made up of H_{fixed} and $H_{new-fixed}$

My solution - Retrospective Design Algorithm



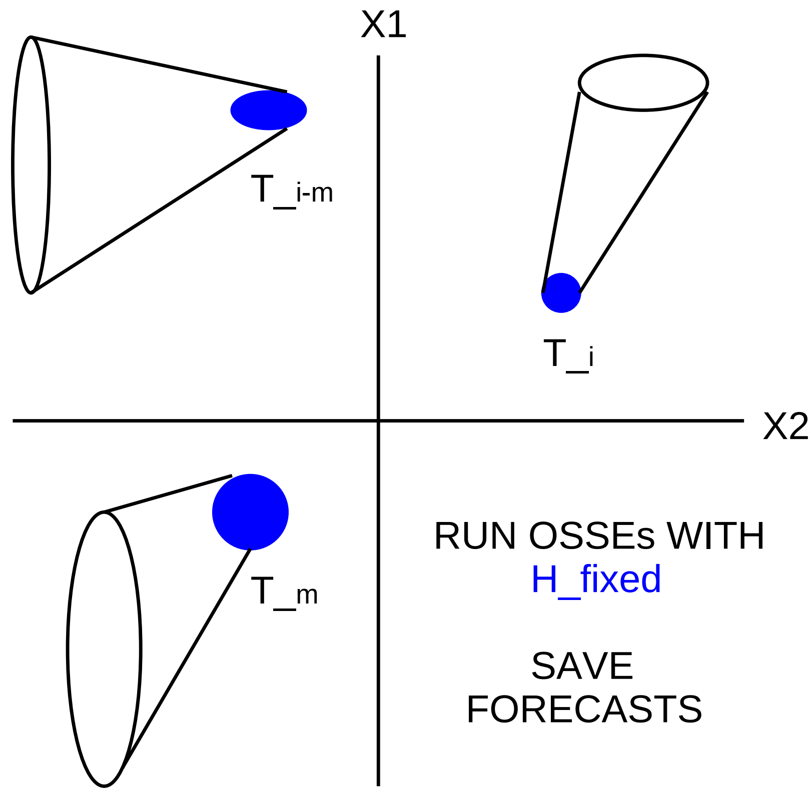
- Begin by running OSSEs with H_{fixed} and store ensemble forecasts

My solution - Retrospective Design Algorithm



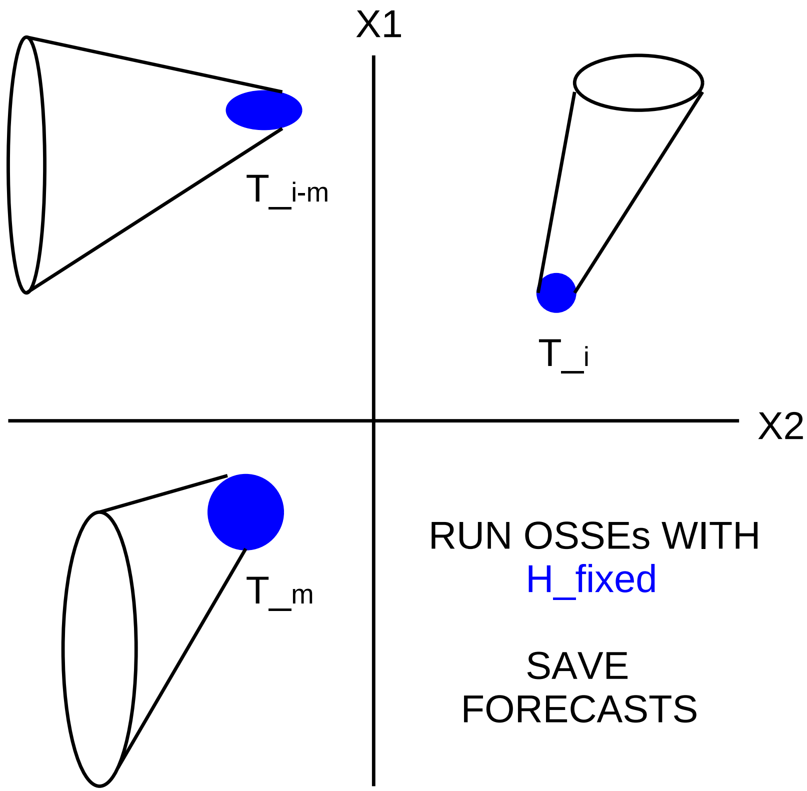
- Need to assess added information if network is switched to H_1

My solution - Retrospective Design Algorithm



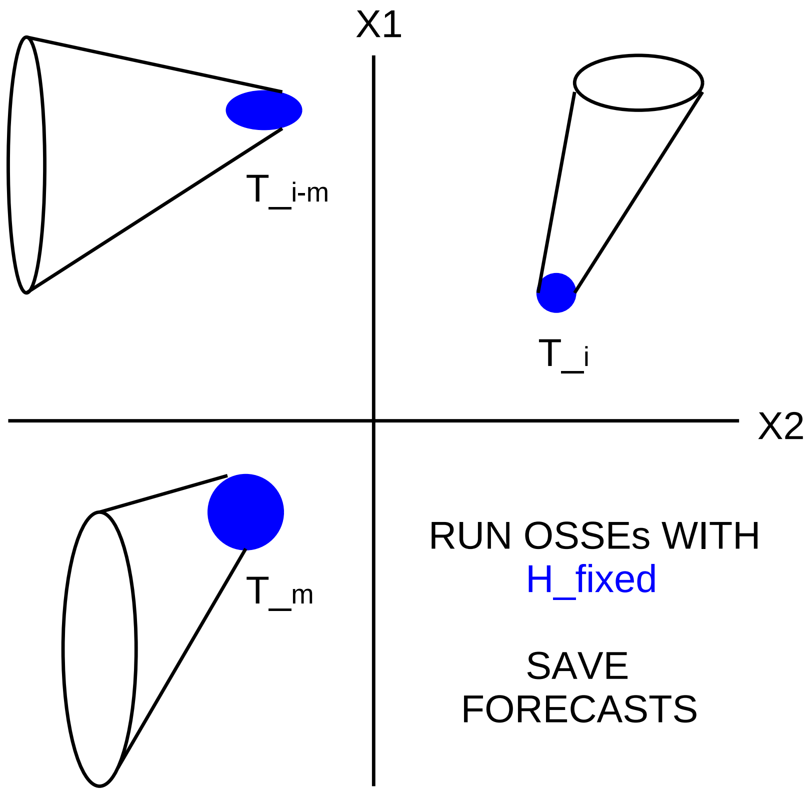
- For each initial time - could begin an OSSE under the influence of H_1 - still expensive

My solution - Retrospective Design Algorithm



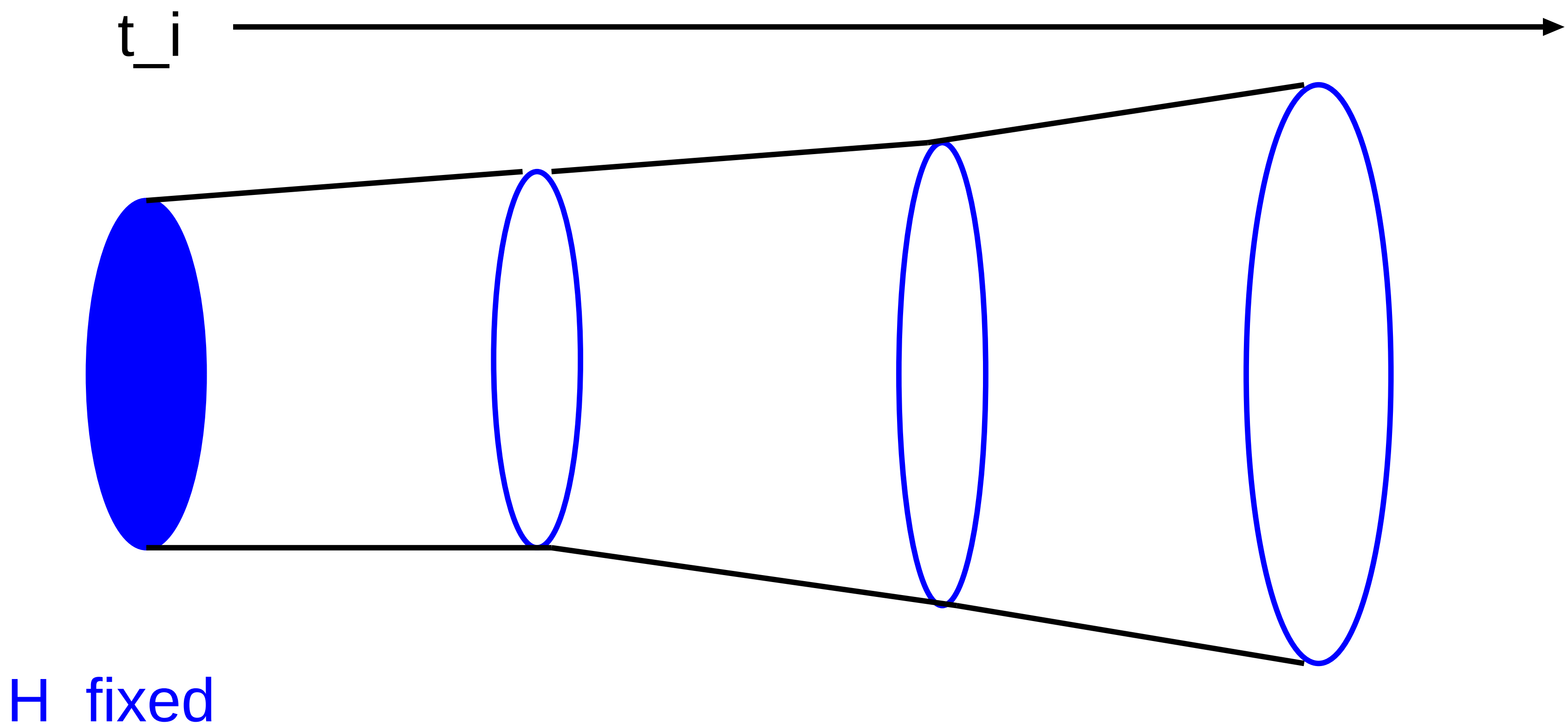
- Some approximation needs to be introduced

My solution - Retrospective Design Algorithm



- Technique makes use of ensembles generated from the OSSE with H_{fixed}

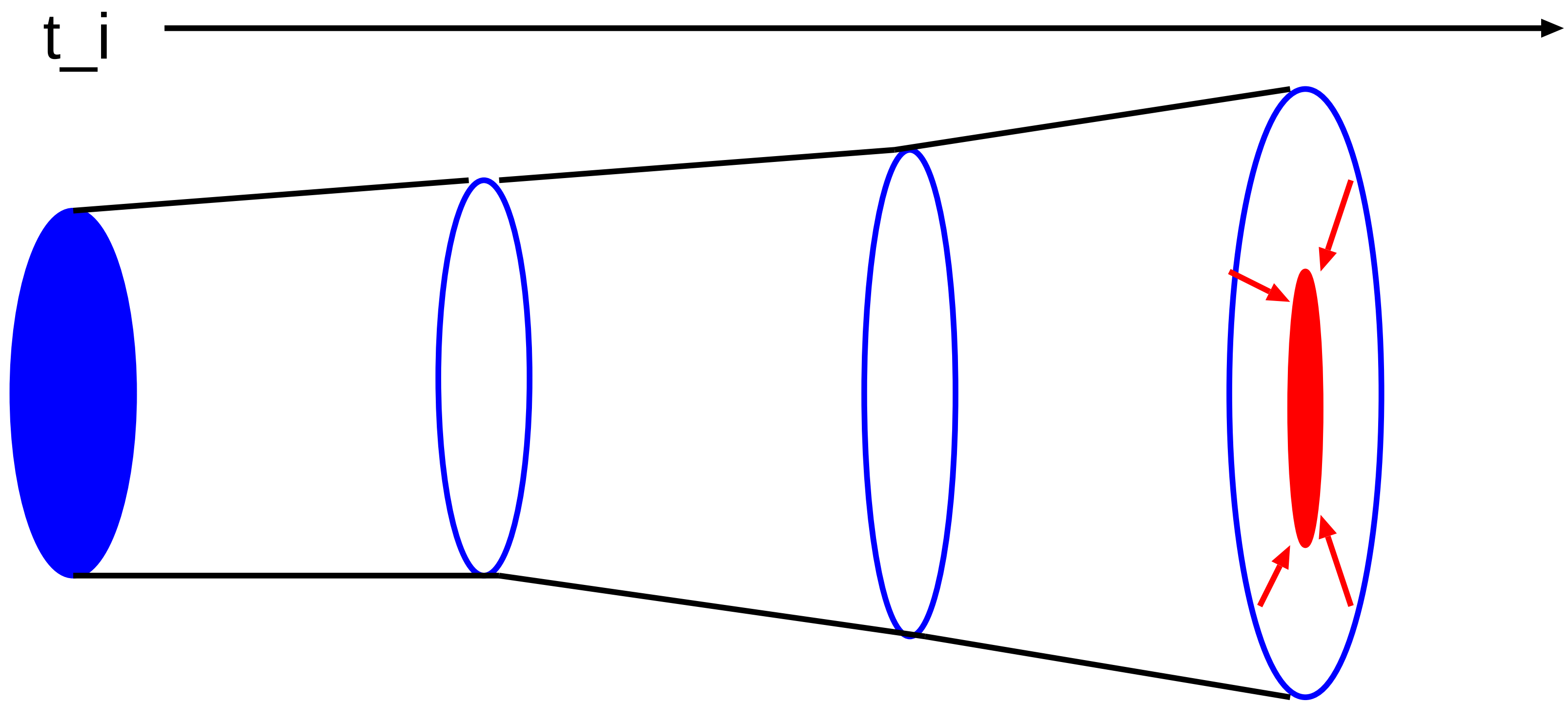
Retrospective Design Algorithm II



An ensemble forecast generated at t_i during

the OSSE with H_fixed

Retrospective Design Algorithm II



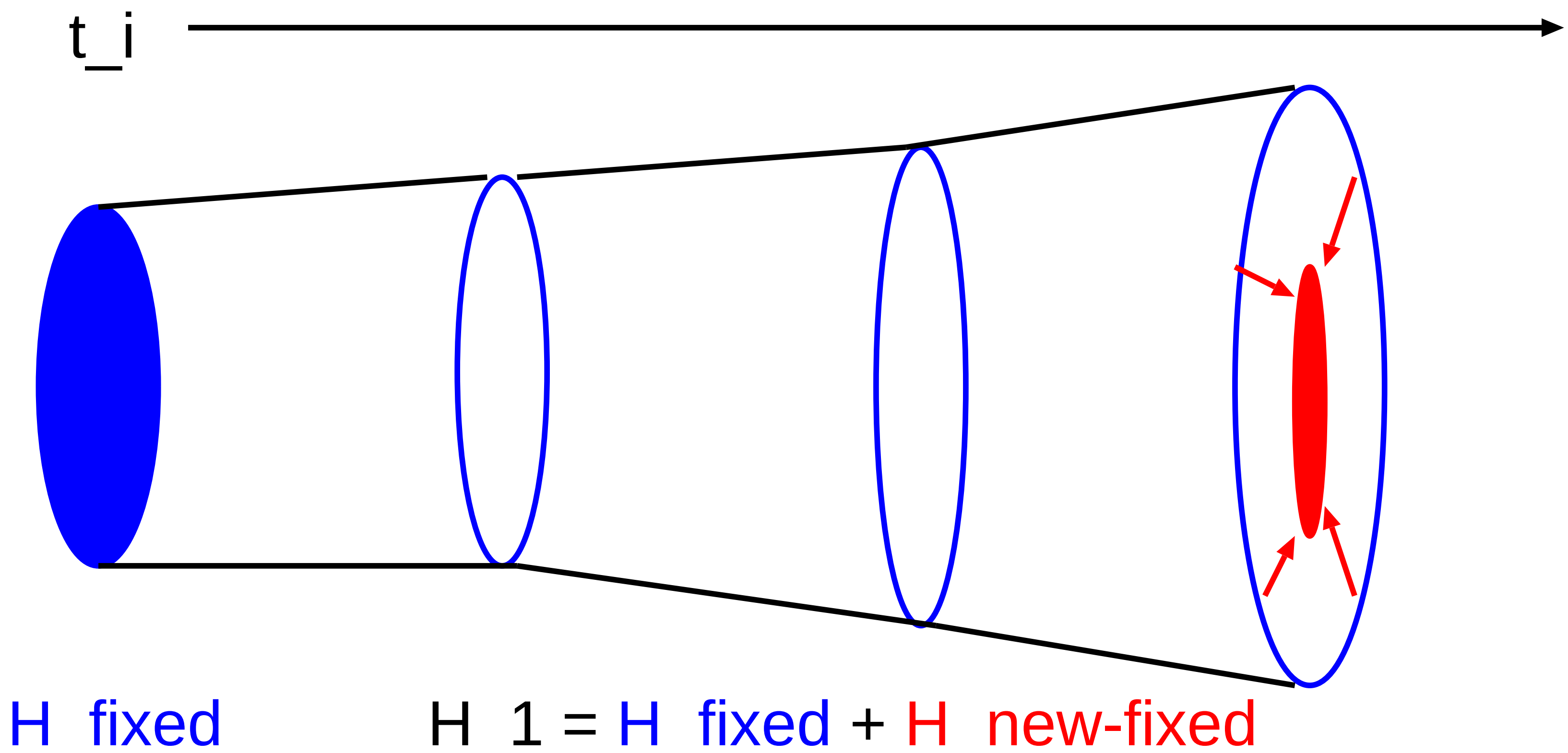
H_fixed

H_1 = H_fixed + H_new-fixed

From t_i+1 onward, assume the observing network is H_1 - the trial network

Want to compute the covariance of the atmosphere given H_1 for some time t > t_i

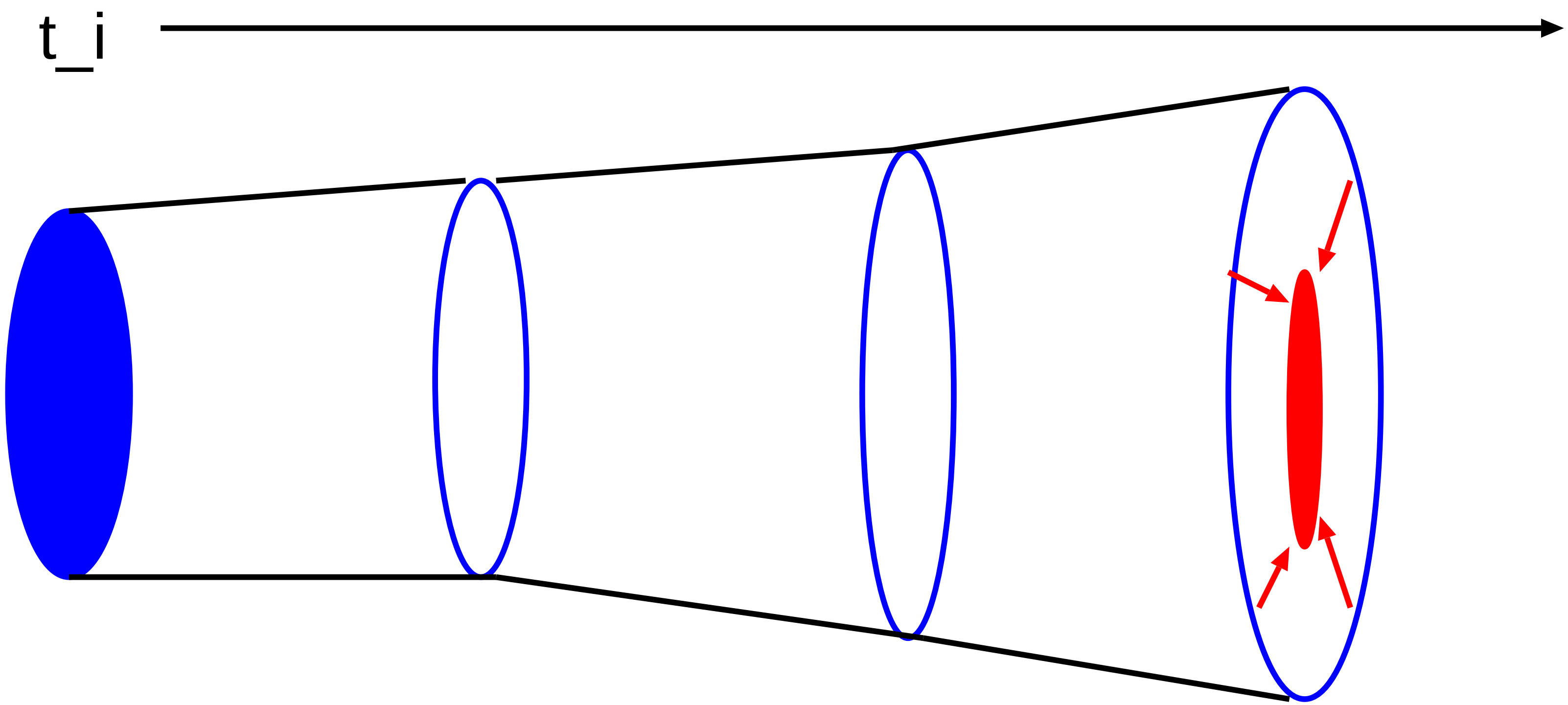
Retrospective Design Algorithm II



Without re-running the forecast model - an EnKF based algorithm exists for computing the atmosphere's covariance at t > t_i given trial network

H_1 = H_fixed + H_new-fixed - KEY POINT

Retrospective Design Algorithm II

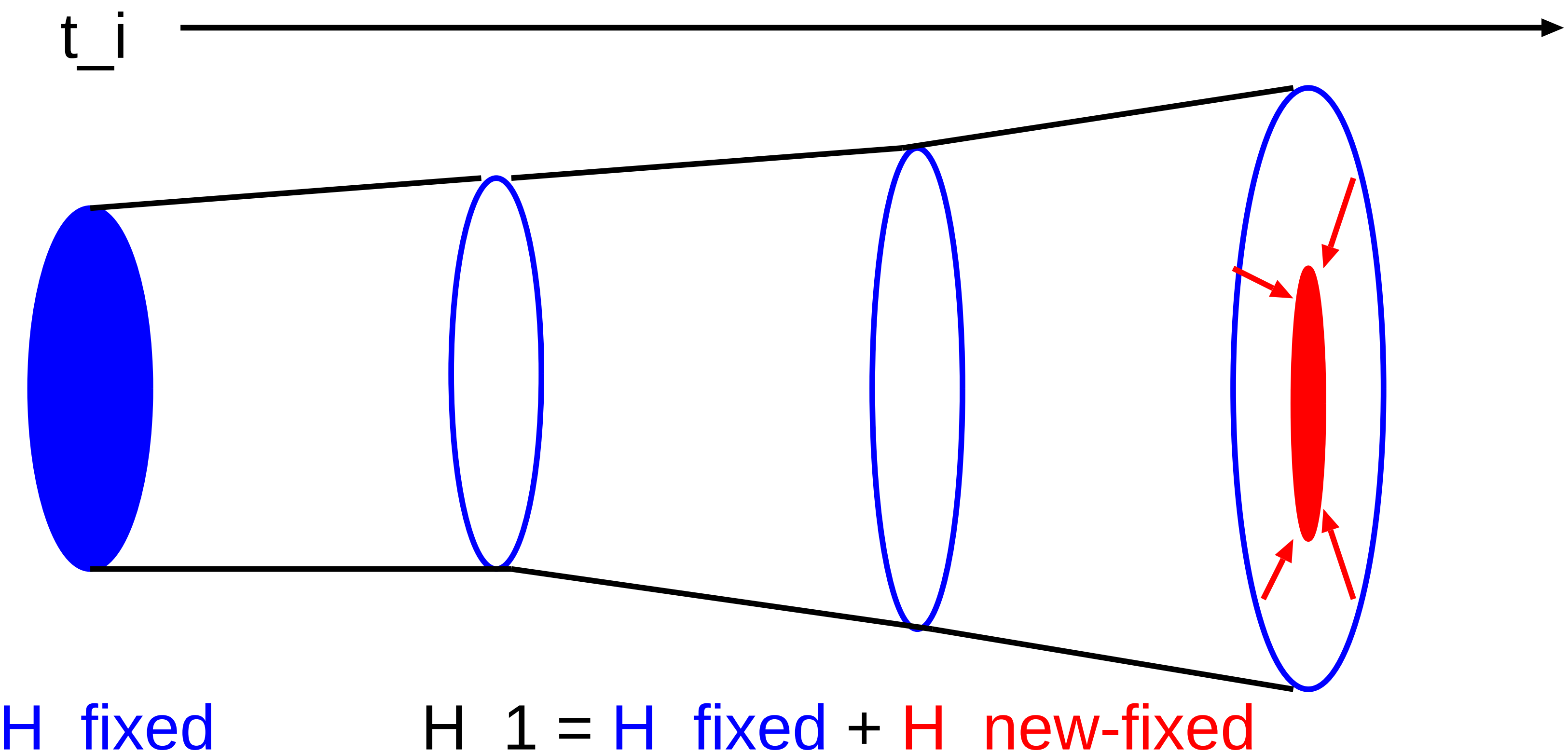


H_fixed   H_1 = H_fixed + H_new-fixed

Theory says that:
Covariance at t > t_i equivalent to what would be obtained via a sequential in time filtering procedure for linear dynamics

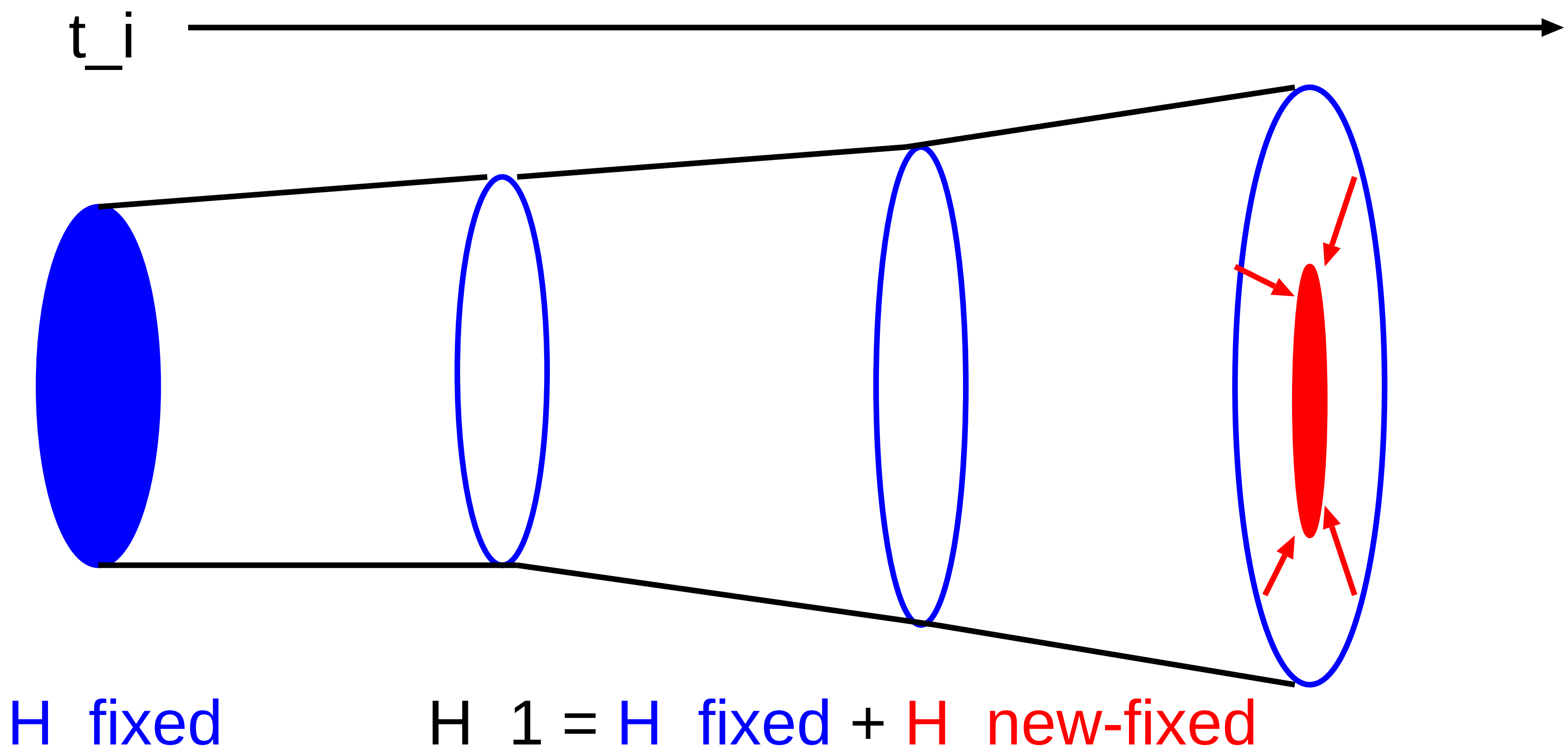
Useful information for weakly nonlinear evolution

Retrospective Design Algorithm II



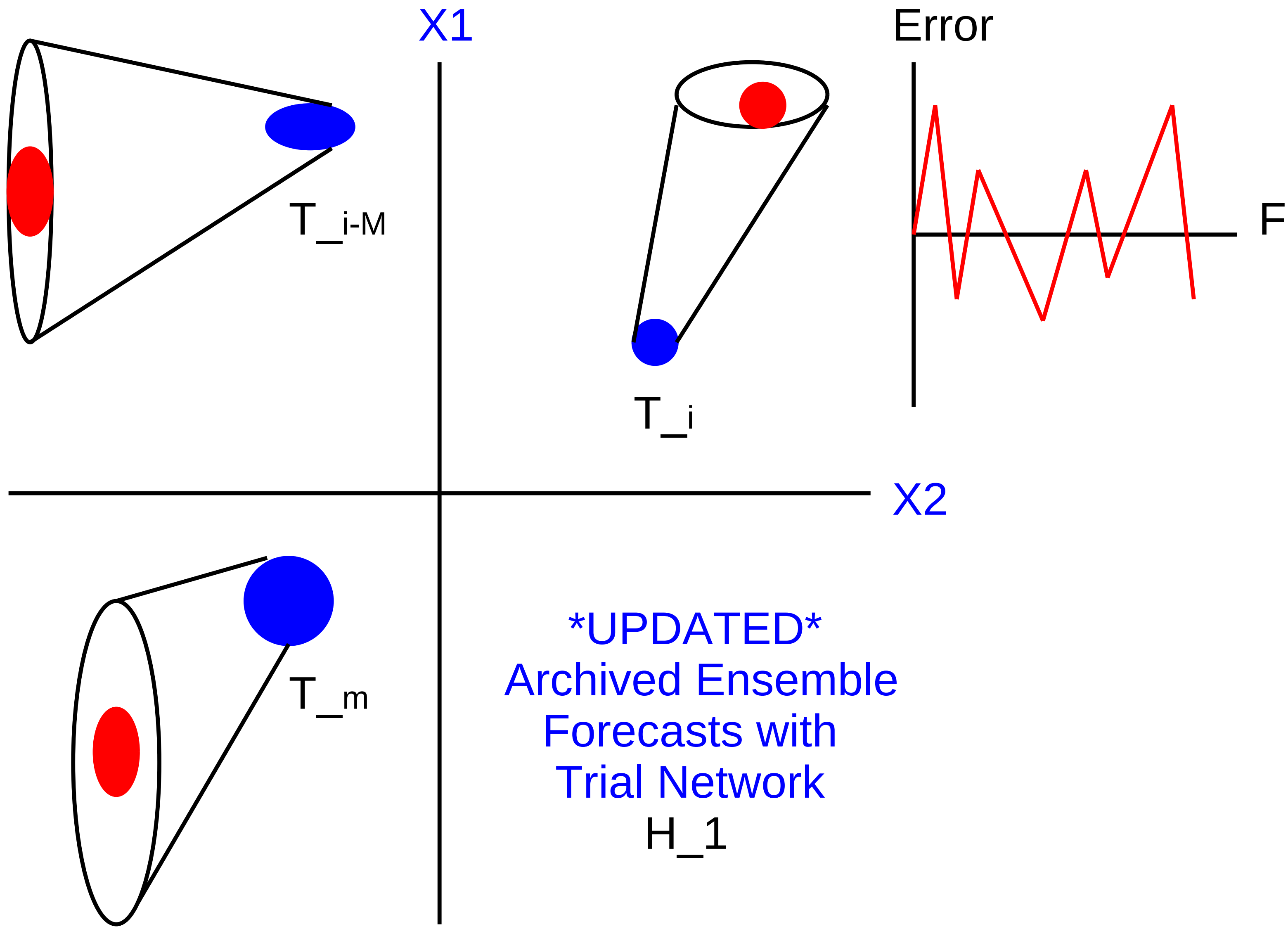
- Must consider linear dynamical time scale
- Mapping of perturbations between assimilation times should remain weakly nonlinear - otherwise influence of dynamics poorly ascertained
- Space/time sampling errors must be handled properly

Retrospective Design Algorithm II



Computational cost
~ Cost of assimilating number of MOVABLE obs
Again, no repeated integrations of model equations required - radically different from OSSEs

Evaluate the objective function using the RDA



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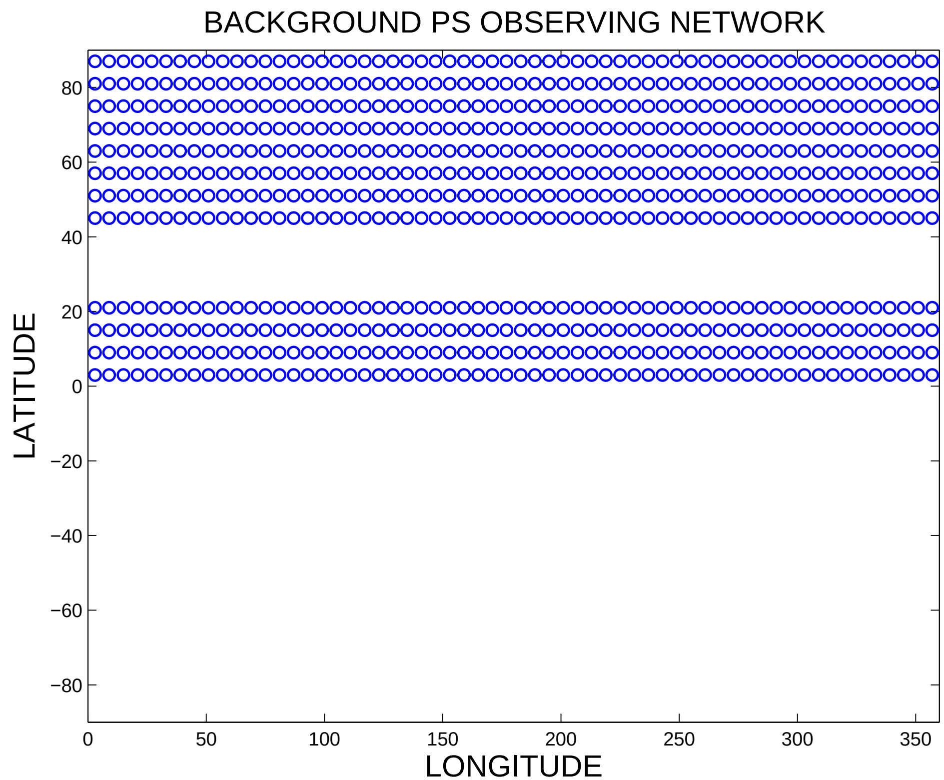
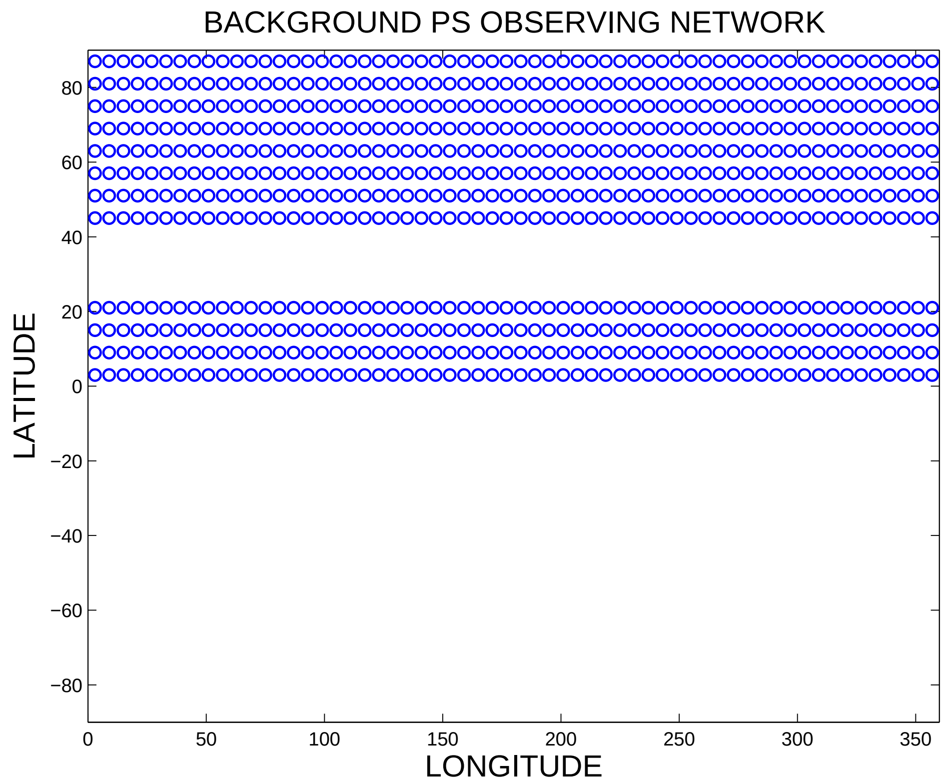
PS network design in a GCM



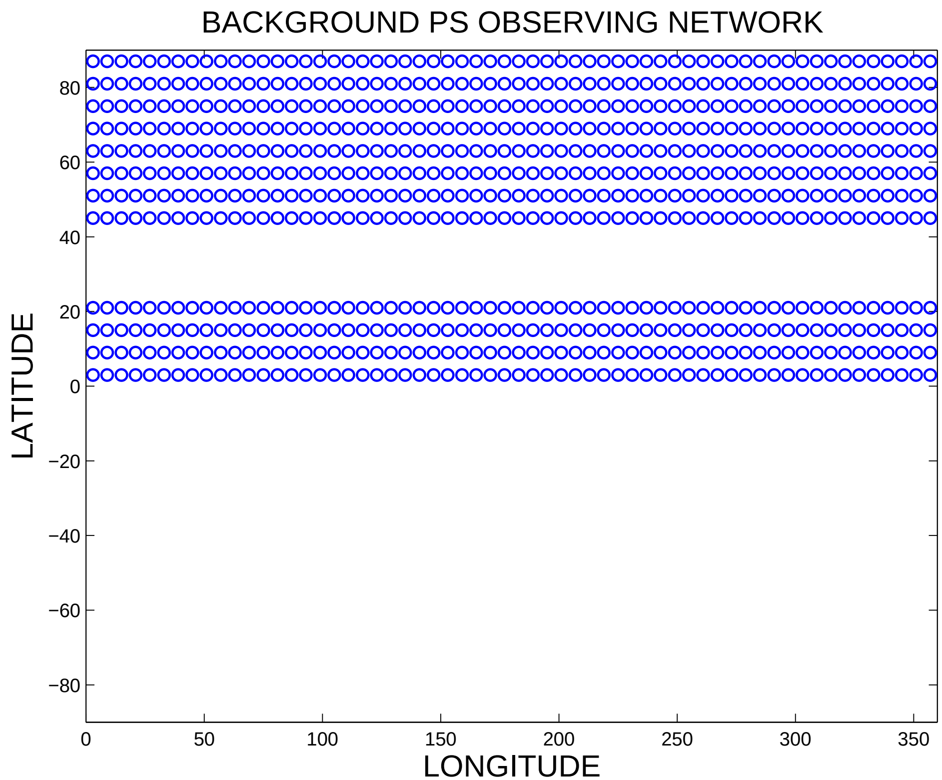
- FIXED network of surface pressure observations - $7\ mb$ observational standard deviation - assimilate every 12 hours

PS network design in a GCM



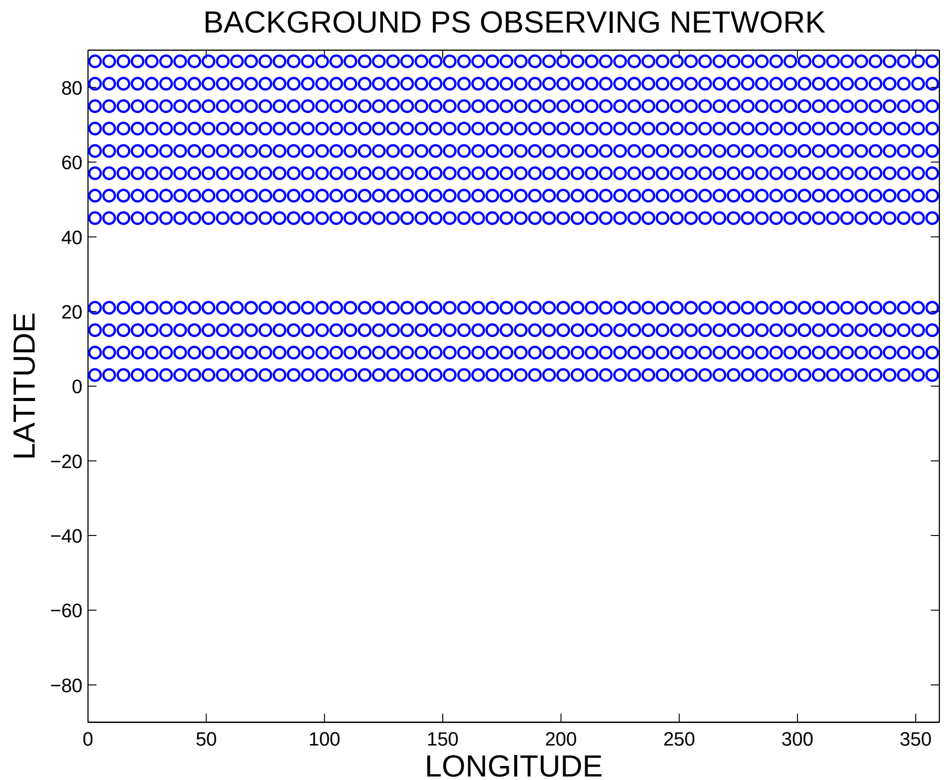
- Run an EAKF with $N = 20$ ensemble members (with localization and no inflation) in a Held-Suarez configuration of an AGCM

PS network design in a GCM



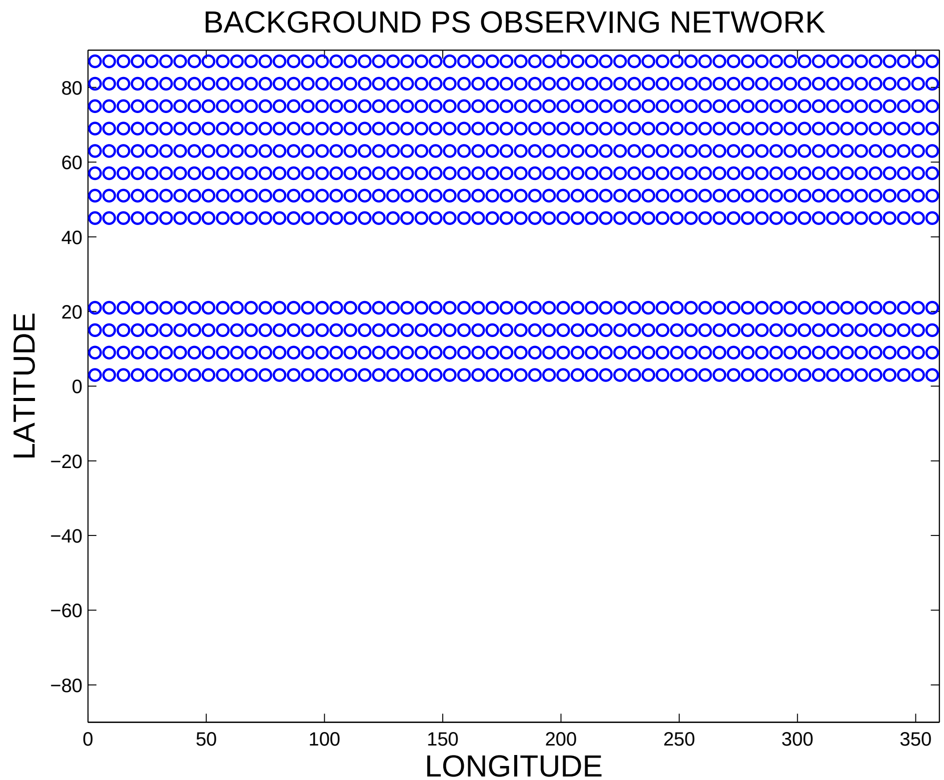
- Forcing - Newtonian cooling, Damping - Rayleigh Friction

PS network design in a GCM



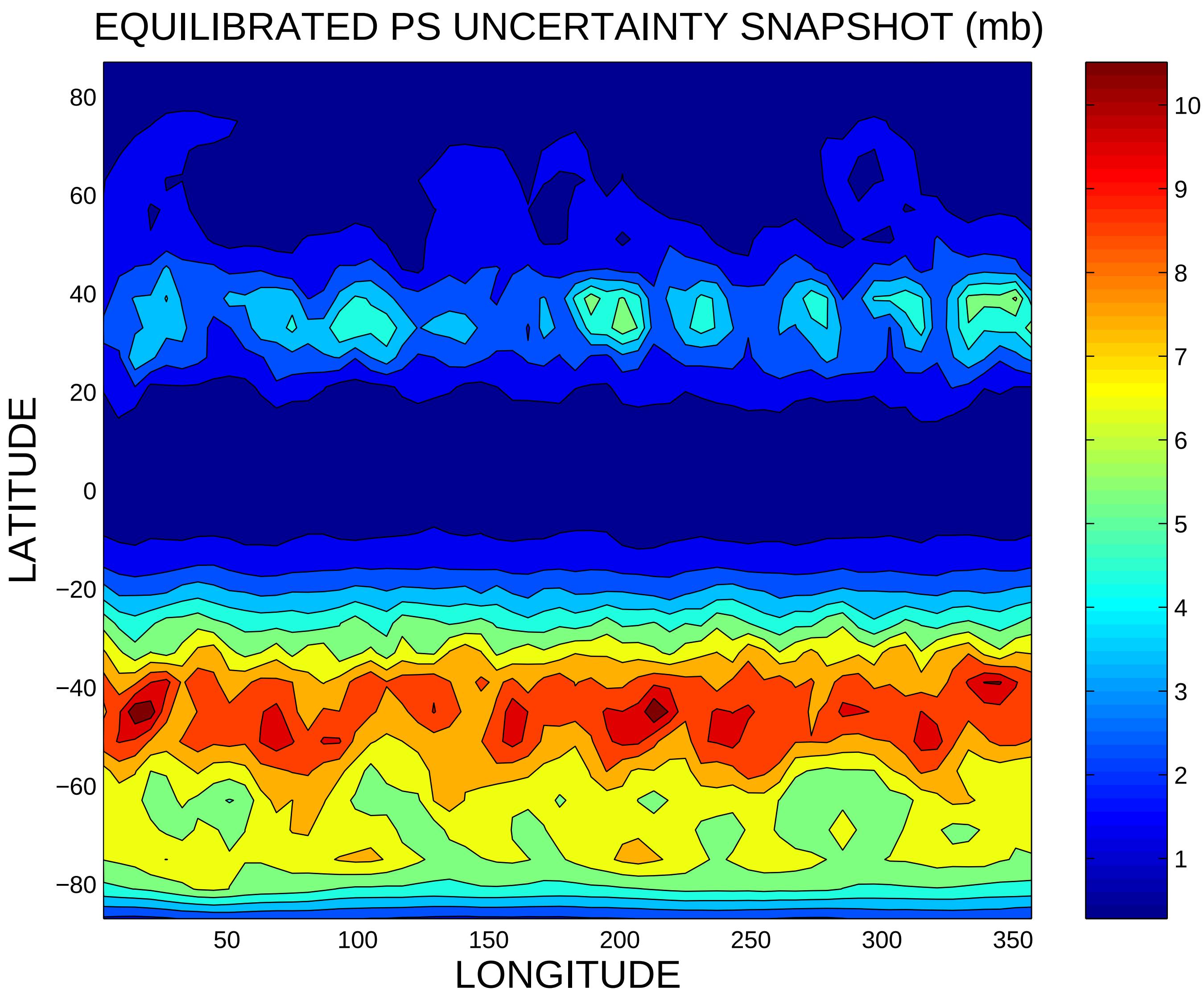
- 6 degrees horizontal resolution (60×30) - 5 vertical levels

PS network design in a GCM

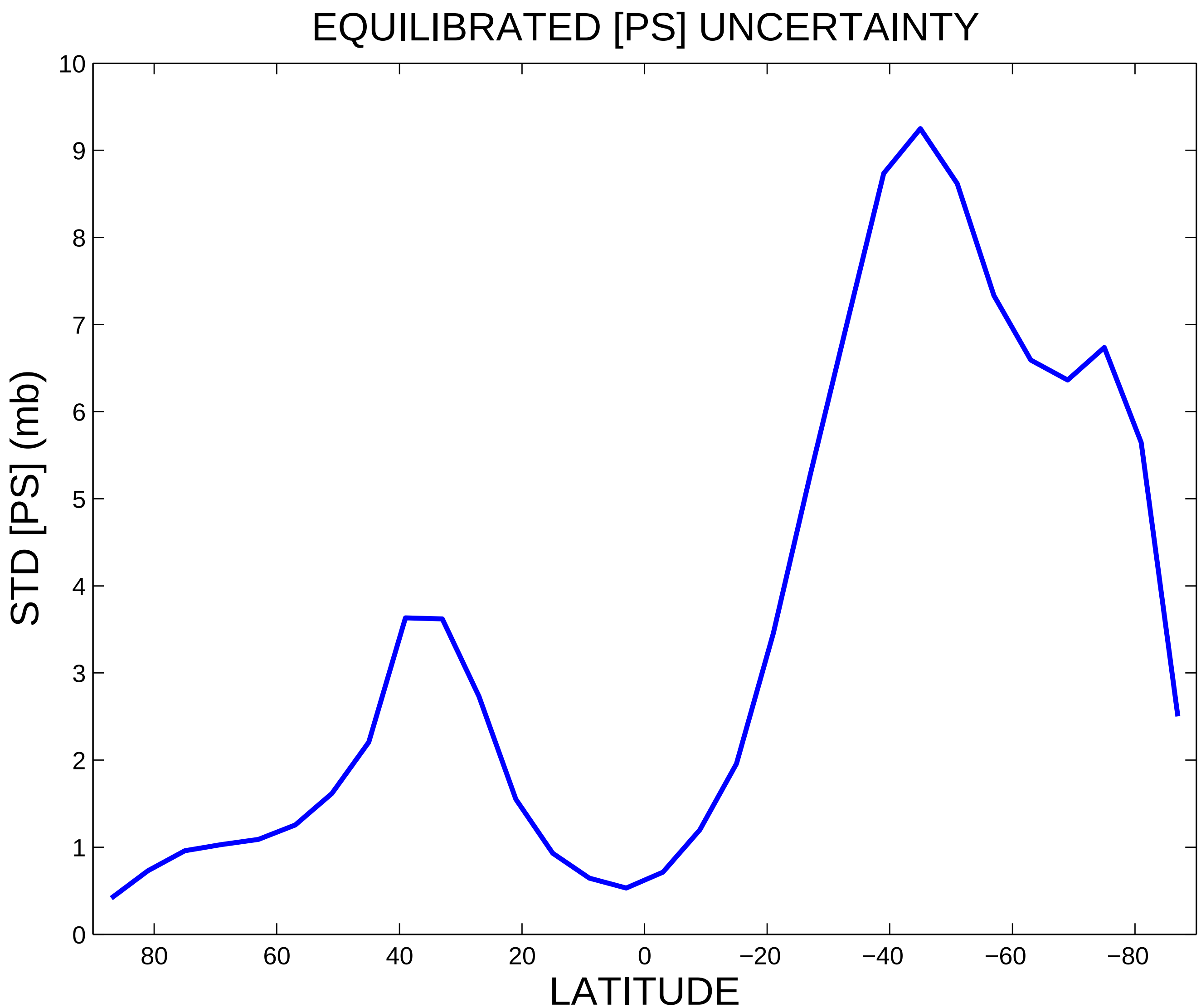


- Temperature gradient drives a baroclinically unstable flow in the mid-latitudes

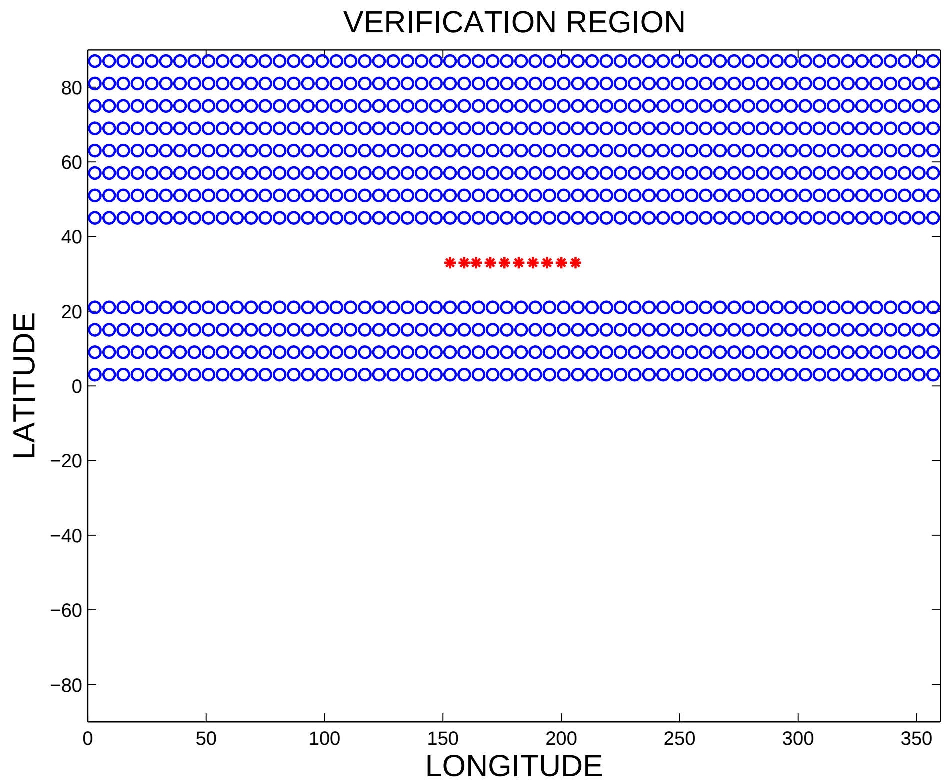
Assimilation results: posterior PS uncertainty



Assimilation results: posterior PS uncertainty

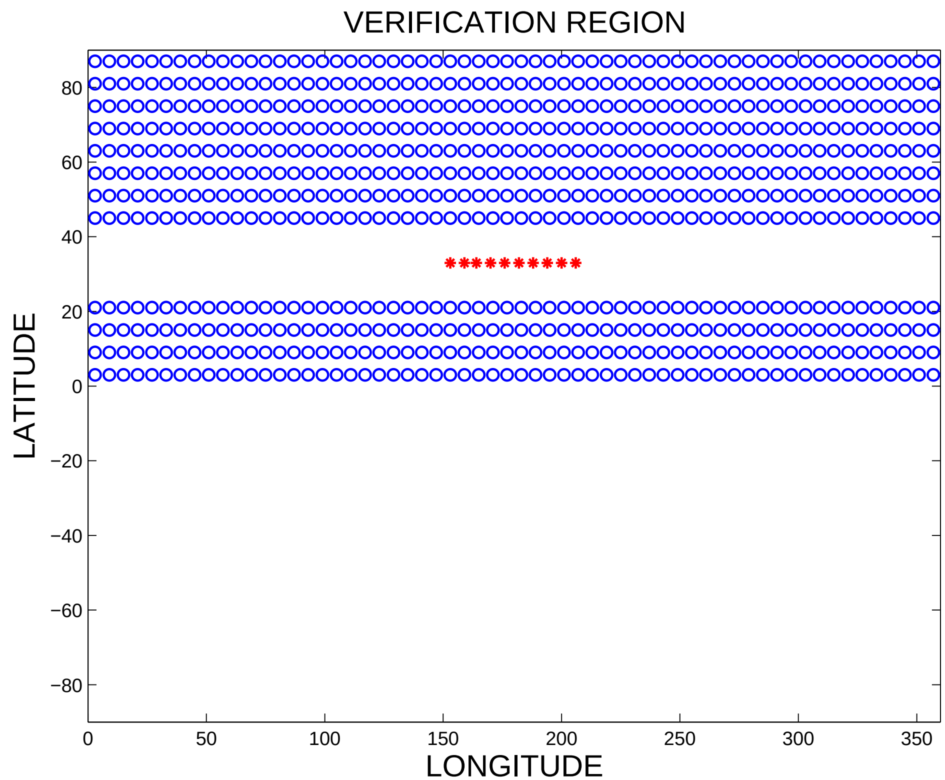


The experiment



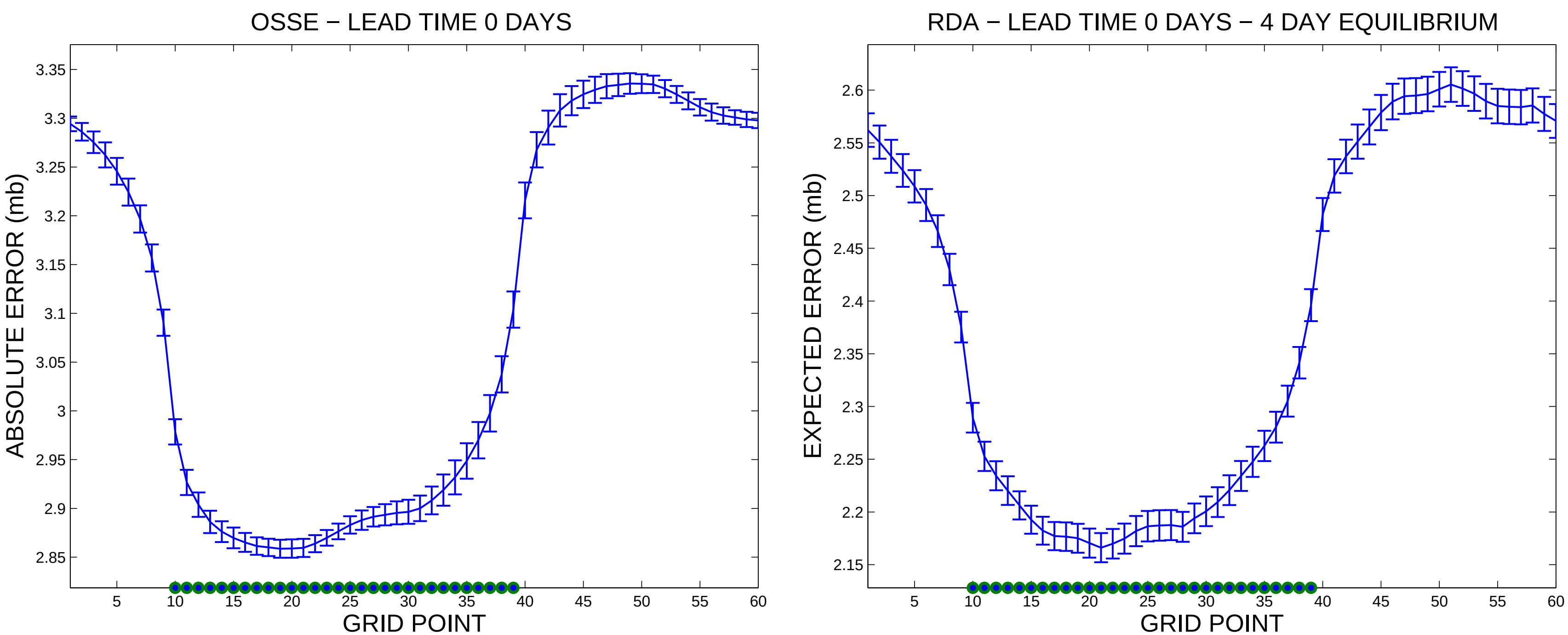
- Find the optimal placement of one *additional* accurate PS observation along the 33 degree latitude band

The experiment



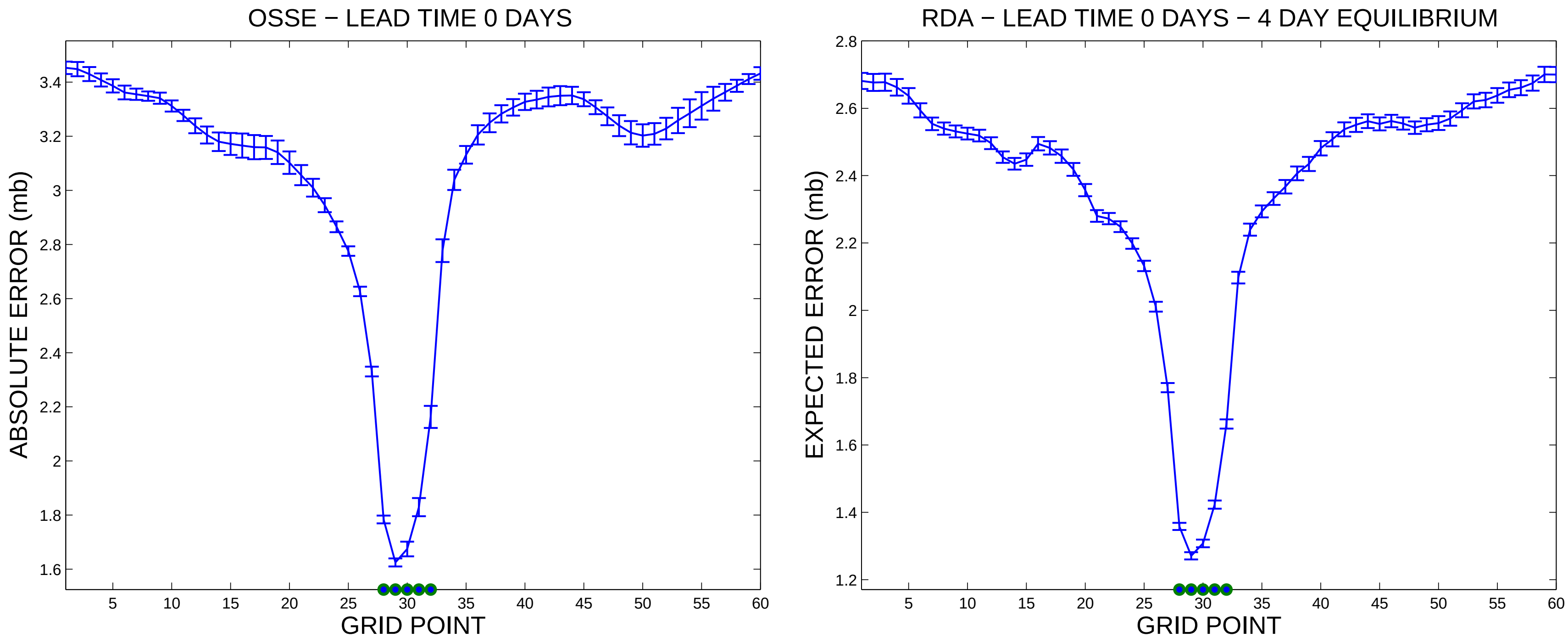
- Strong time mean winds at 33 degrees lat. ensures a strong dynamical signal in this problem

Comparison of cost functions I



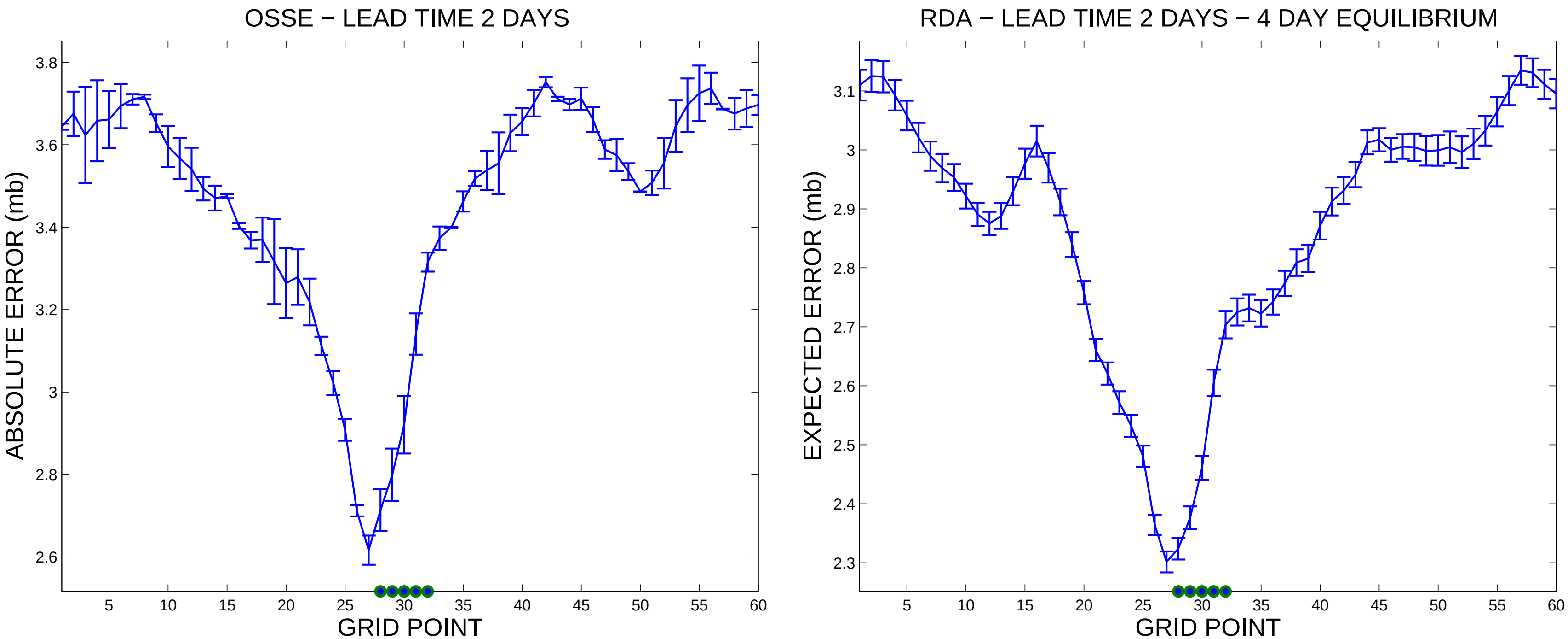
- Verification region - half the latitude band
- Forecast lead time - 0 days
- 1000 independent samples

Comparison of cost functions II



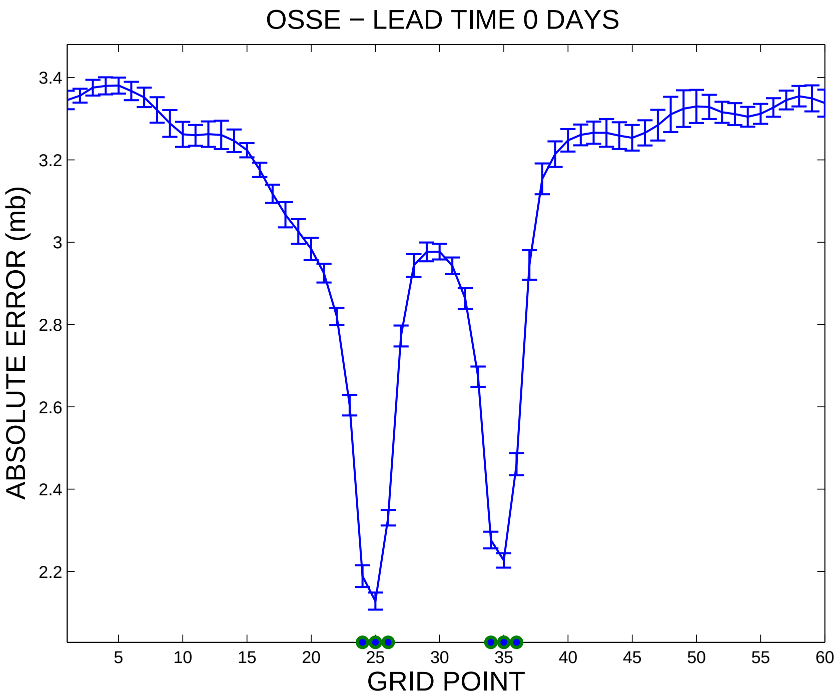
- Verification region - 5 consecutive grid points
- Forecast lead time - 0 days
- 1000 independent samples

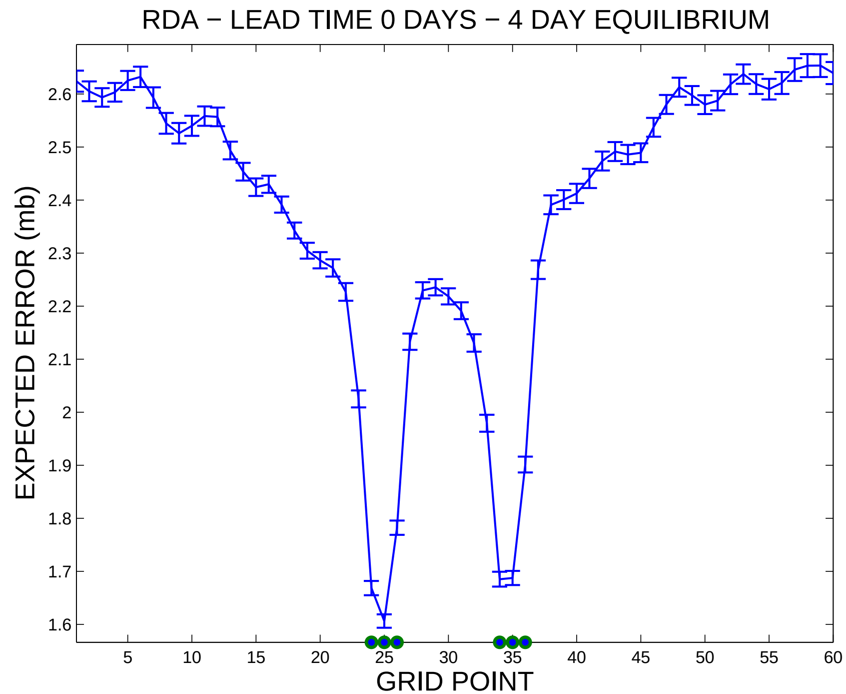
Comparison of cost functions III



- Verification region - 5 consecutive grid points
- Forecast lead time - 2 days
- 1000 independent samples

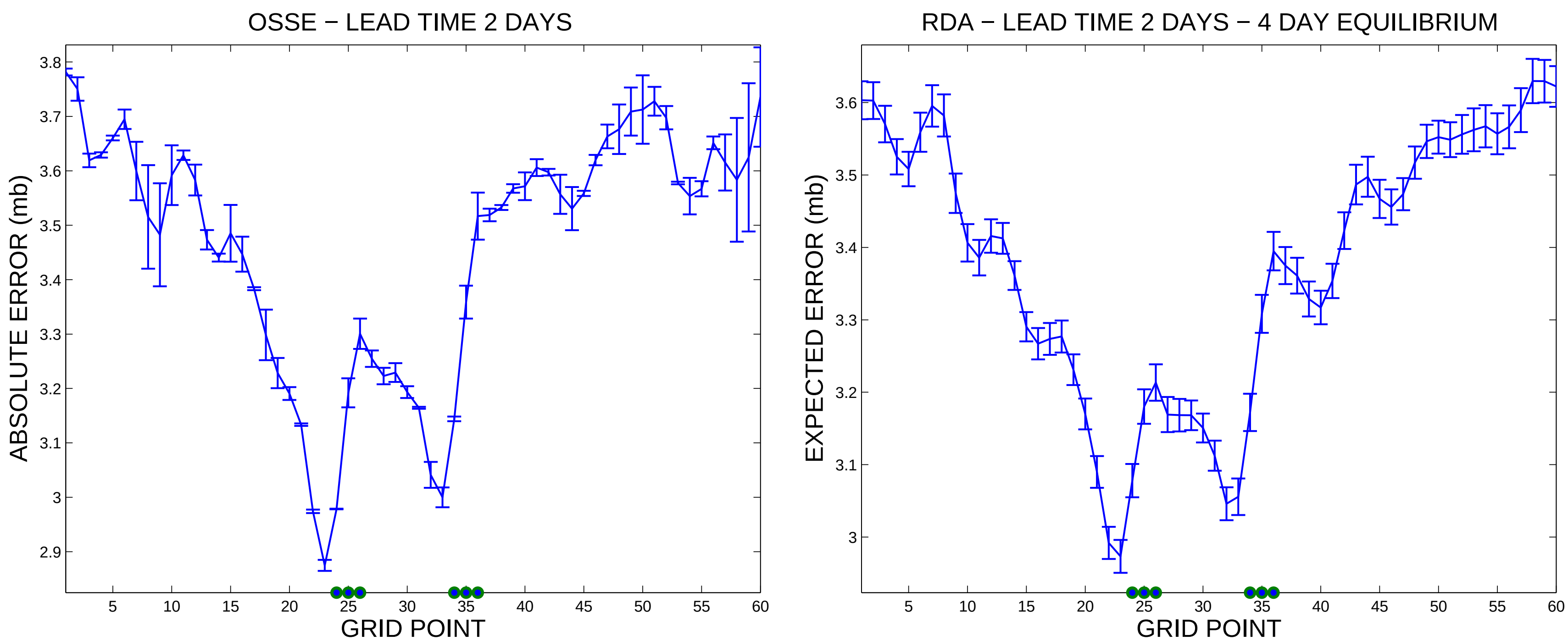
Comparison of cost functions IV





- Verification region - discontinuous
- Forecast lead time - 0 days
- 1000 independent samples

Comparison of cost functions V



- Verification region - discontinuous
- Forecast lead time - 2 days
- 1000 independent samples

Summary and conclusions

- **A method (RDA) for approximating information regarding relative placement of fixed observations derived from OSSEs has been outlined**

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Summary and conclusions

- **A method (RDA) for approximating information regarding relative placement of fixed observations derived from OSSEs has been outlined**
- **The statistical/dynamical significance has been demonstrated in an AGCM for a large variety of design problems**
- **Computational scaling of the RDA is *EXTREMELY FAVORABLE* - sophisticated optimization can be used to minimize cost functions derived from the RDA**

Key future areas in routine network design

- **Multiple observation design problems in GCMs using optimization**

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- **Applying the RDA to archived operational ensemble forecasts**

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- **Assessing value of different instrument purchases (THORPEX)**

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- **Multiple observation design problems in GCMs using optimization**
- **Applying the RDA to archived operational ensemble forecasts**
- **Economic considerations (THORPEX)**
- **Assessing value of different instrument purchases (THORPEX)**
- **Dealing/coping with model errors when using simulations**