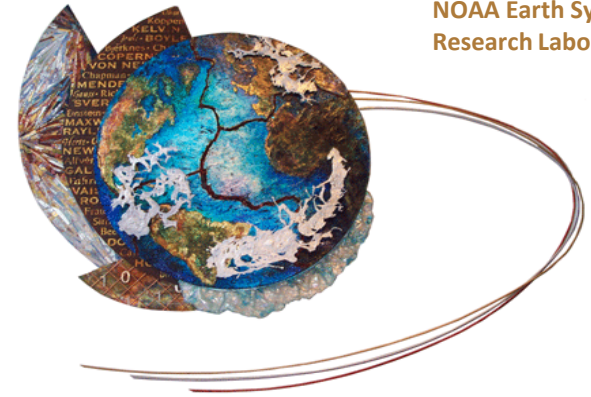




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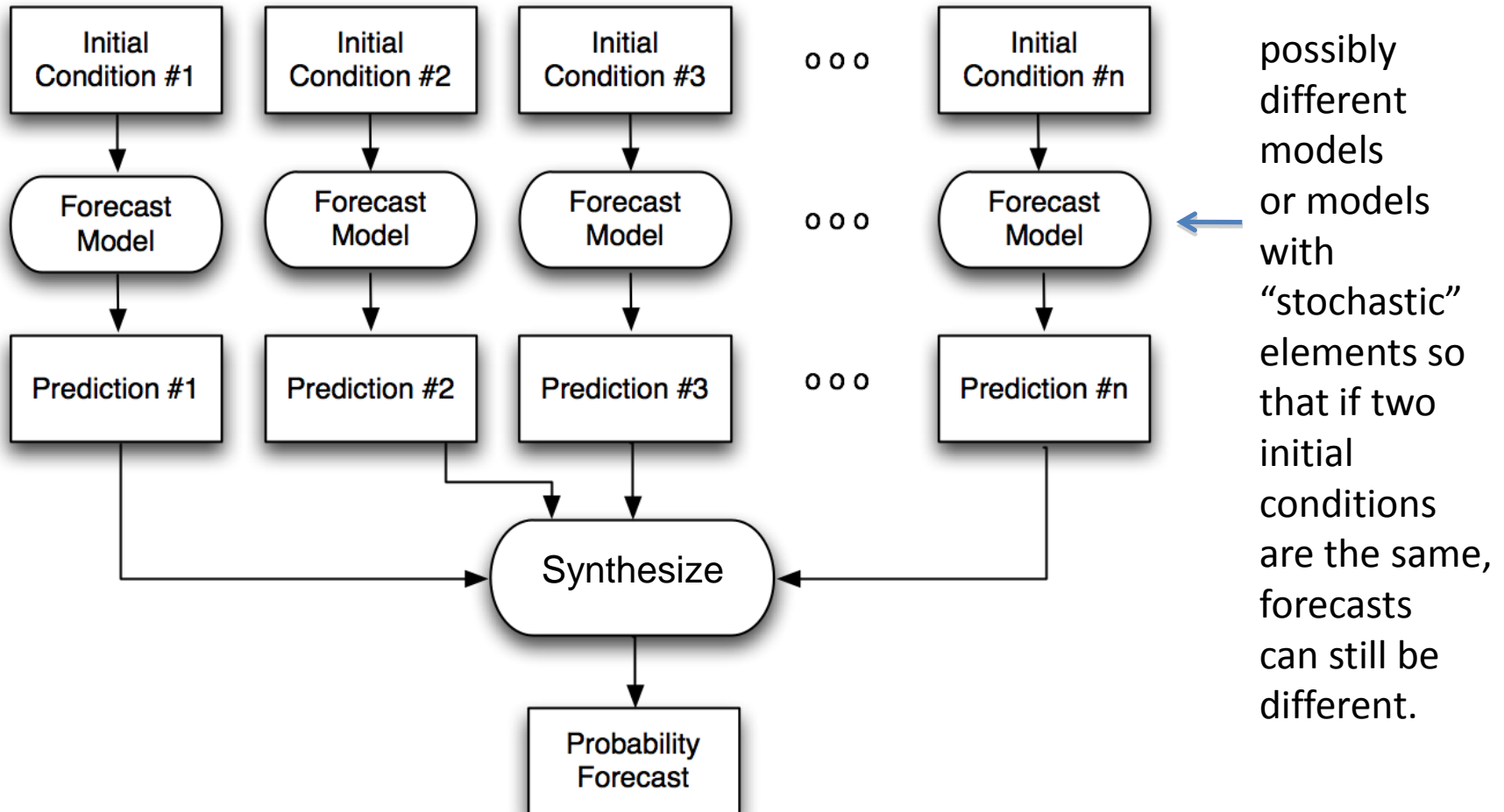
# Review of ensemble prediction fundamentals

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# “Ensemble weather prediction”



# Topics

- Brief primer on chaos theory
- Desired properties of ensembles
- Initializing ensembles
- Dealing with model error
  - mostly in Carolyn Reynolds' talk
- Ensembles & hurricanes
- Some product ideas

# “Chaos” – why we use ensembles

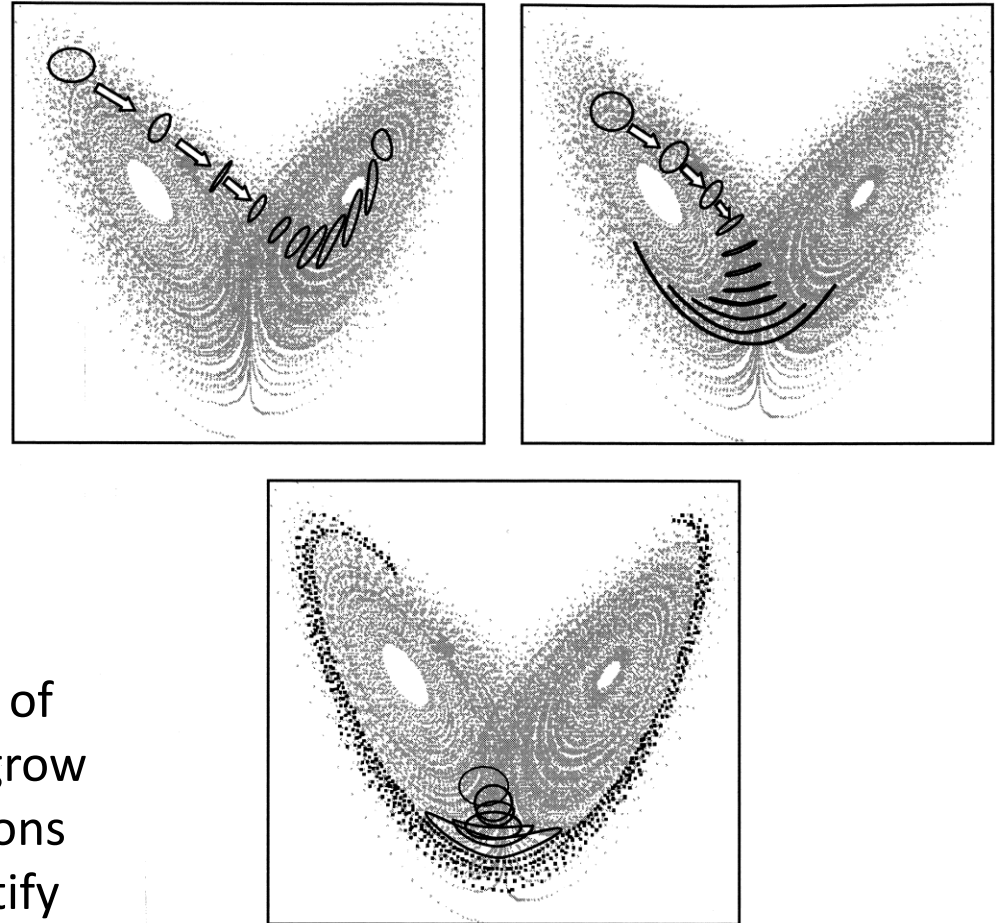
A toy dynamical system that has some characteristics of the weather

$$\begin{aligned}\frac{dx}{dt} &= \sigma(y - x) \\ \frac{dy}{dt} &= x(\rho - z) - y \\ \frac{dz}{dt} &= xy - \beta z\end{aligned}$$

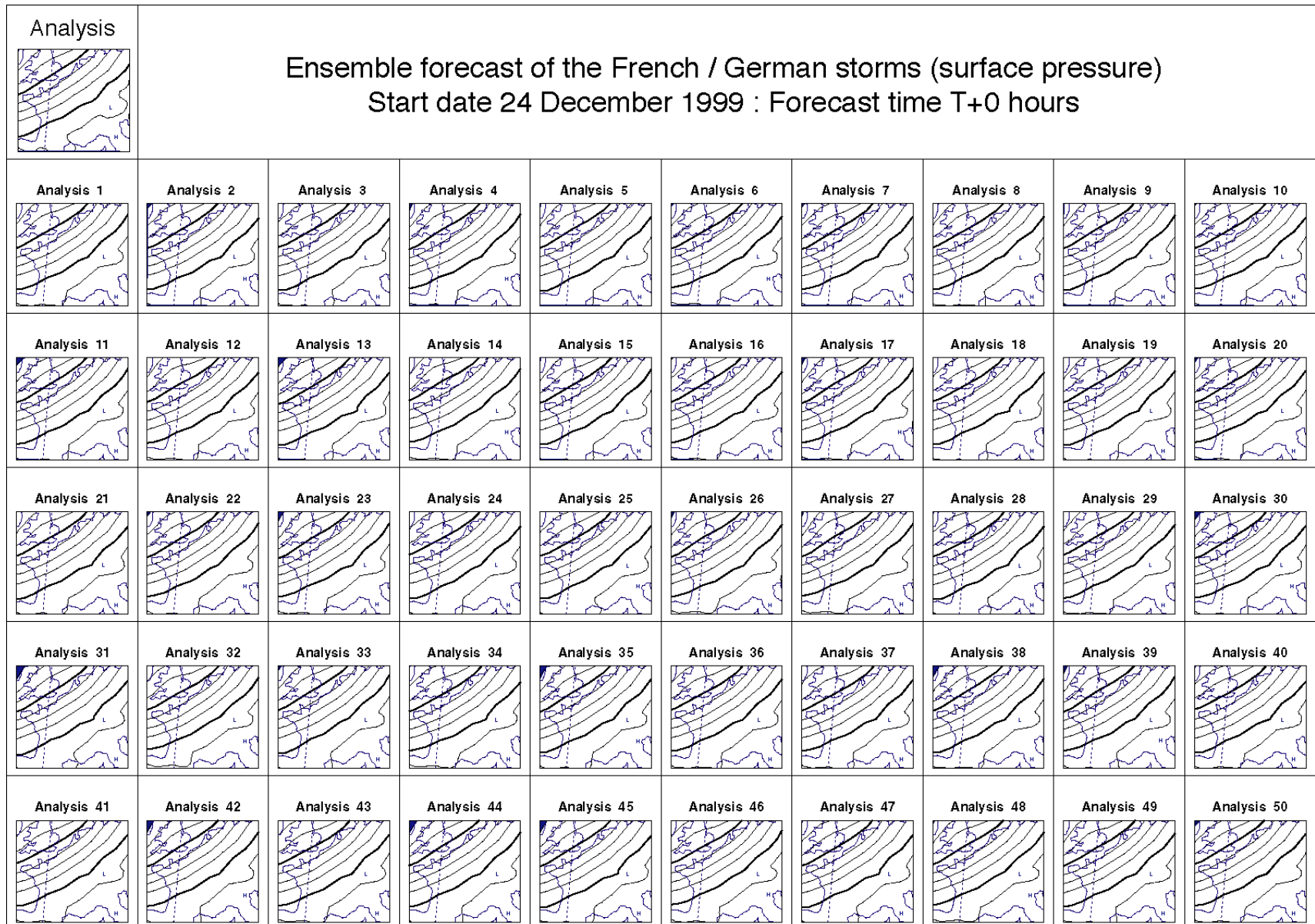
$\rho, \beta, \sigma$  αρε φικεδ.

Select initial conditions within range of analysis uncertainty. Result: errors grow more quickly for some initial conditions than others. Would be nice to quantify situational uncertainty.

The Lorenz (1963) model

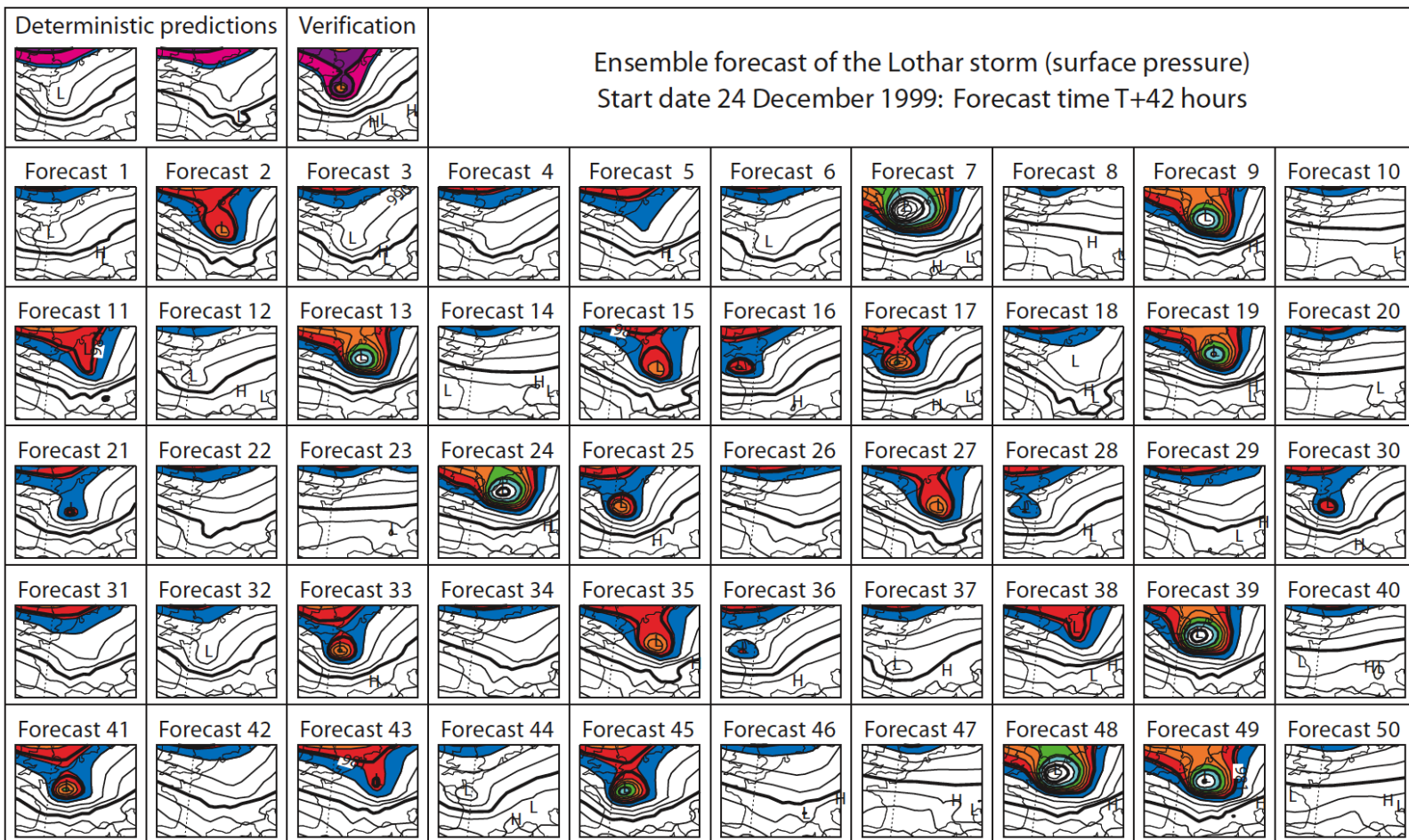


# Initial conditions for “Lothar” ensemble forecasts

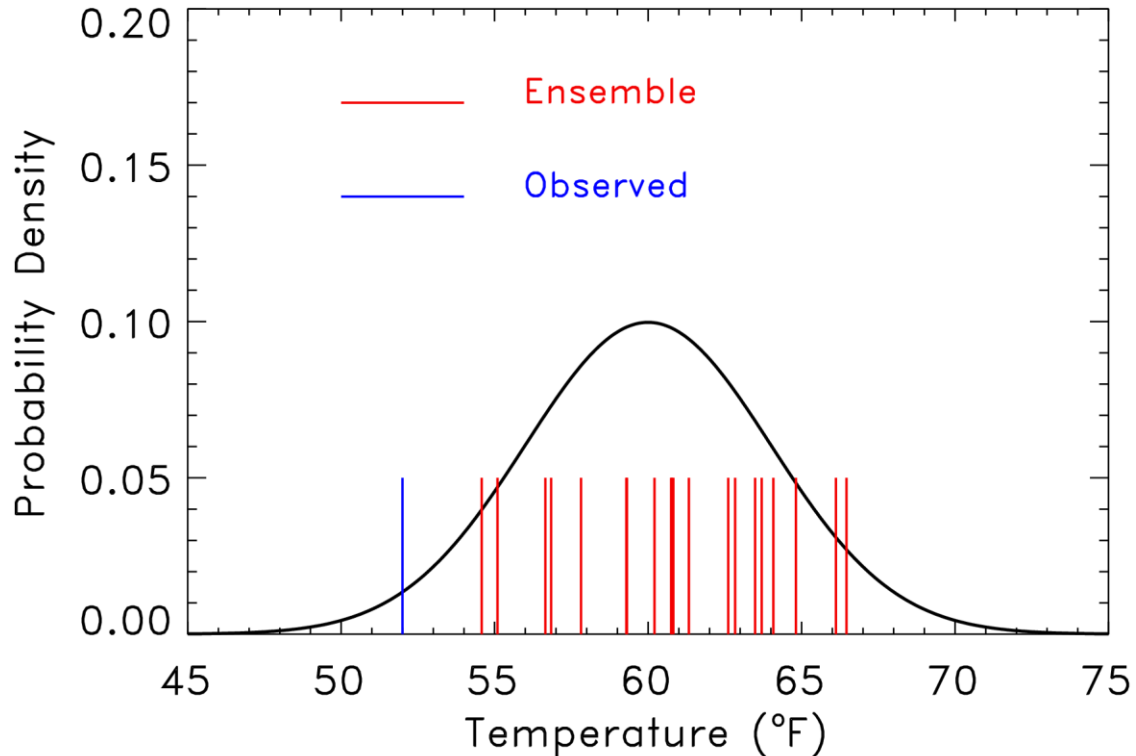


# Lothar 42-h MSLP forecasts

deterministic forecast → totally misses damaging storm over France; some ensemble members forecast it well.

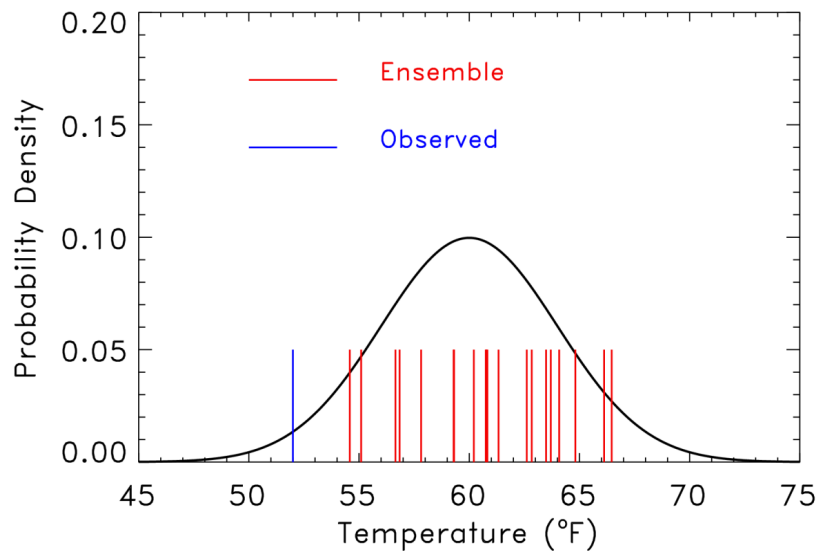


# Question: what constitutes a “good” ensemble forecast?

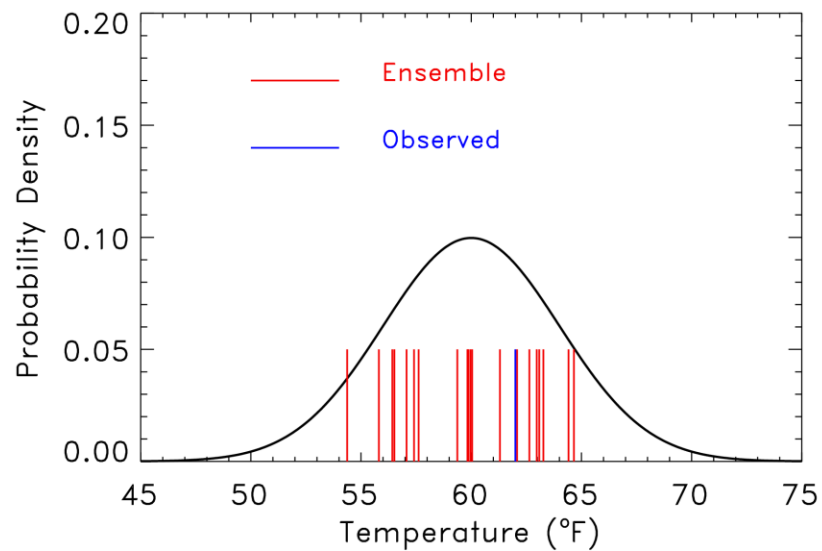


Here, the observed is outside of the range of the ensemble, which was sampled from the pdf shown. **Is this a sign of a poor ensemble forecast?**

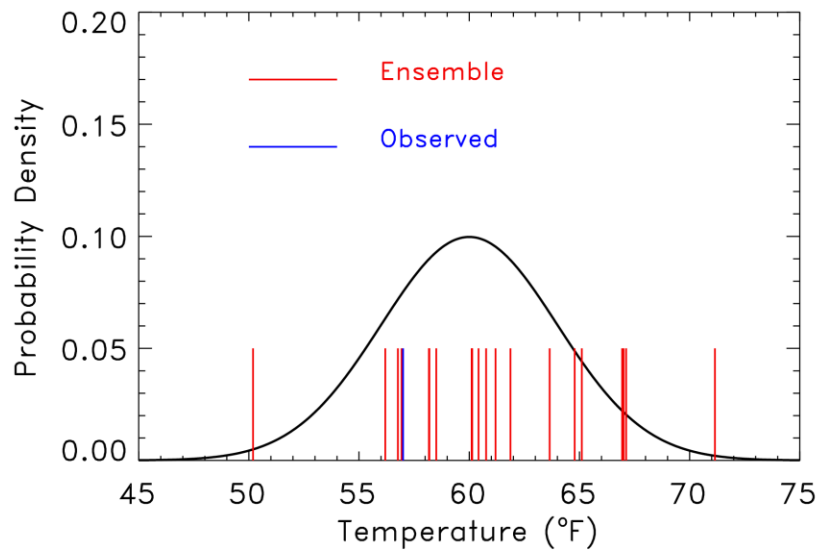
Rank 1 of 21



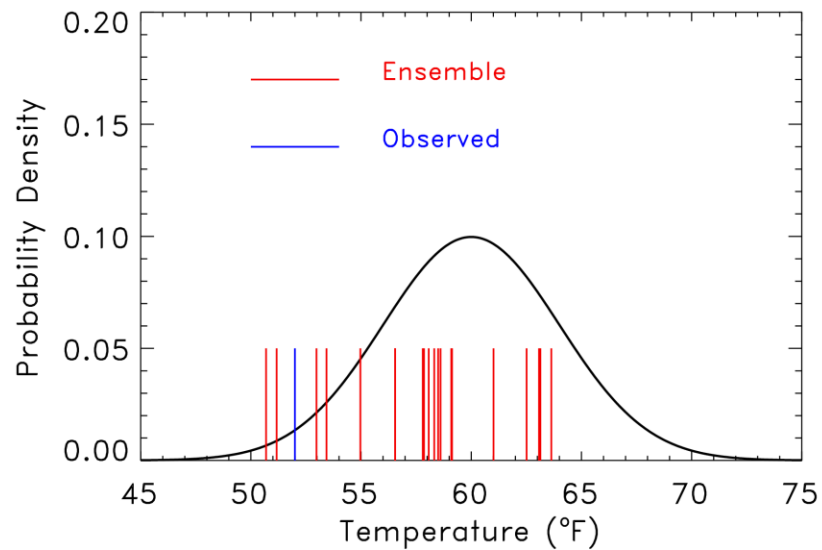
Rank 14 of 21



Rank 5 of 21



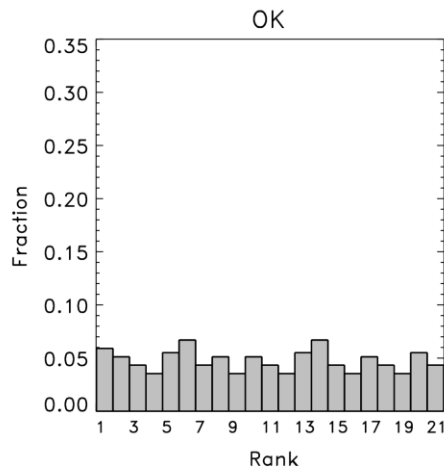
Rank 3 of 21



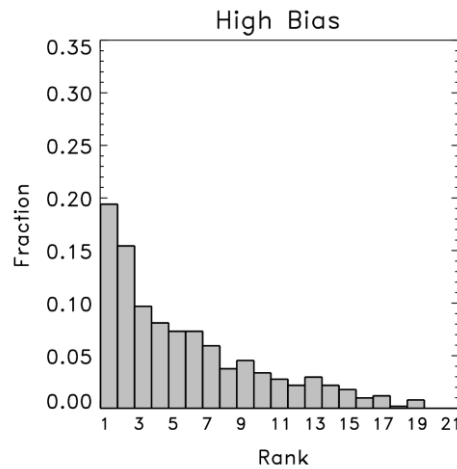


# Ensembles and truth should be draws from the same distribution

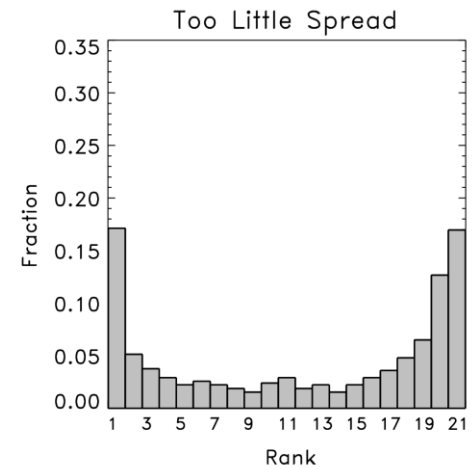
We can only evaluate the quality of an ensemble when we have lots of samples from many situations to evaluate the characteristics of the ensemble.



↑  
Happens when truth is indistinguishable from any other member of the ensemble.

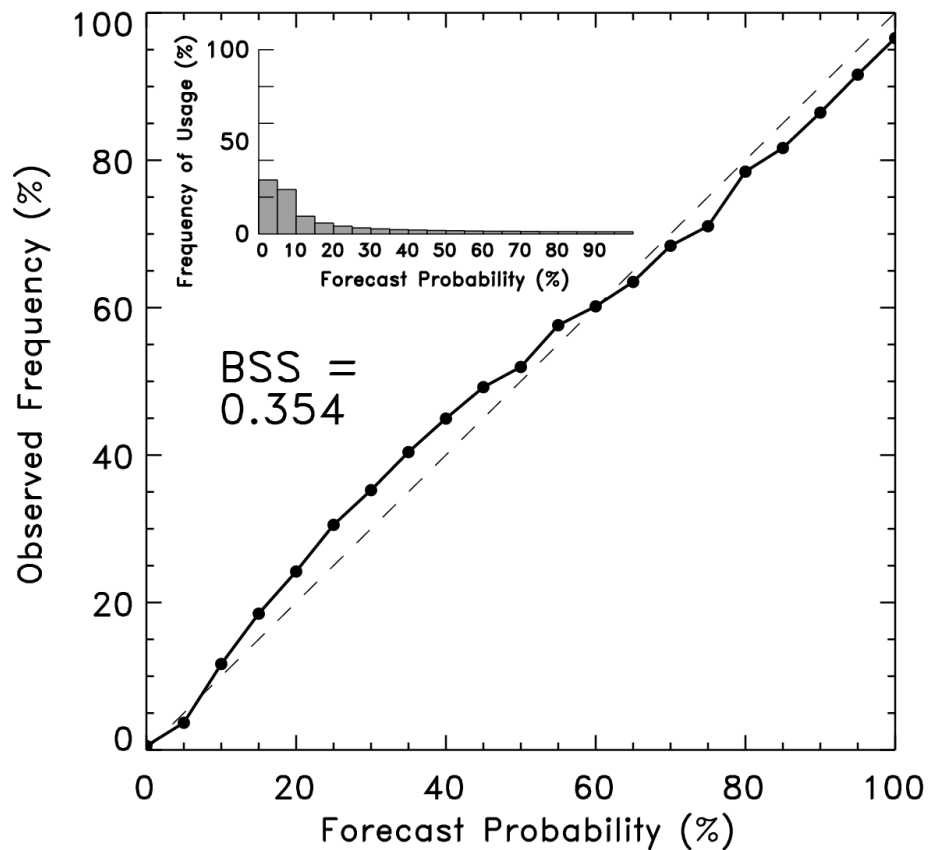


↑  
Happens when observed too commonly is lower than the ensemble members.



↑  
Happens when there are either some low and some high biases, or when the ensemble doesn't spread out enough.

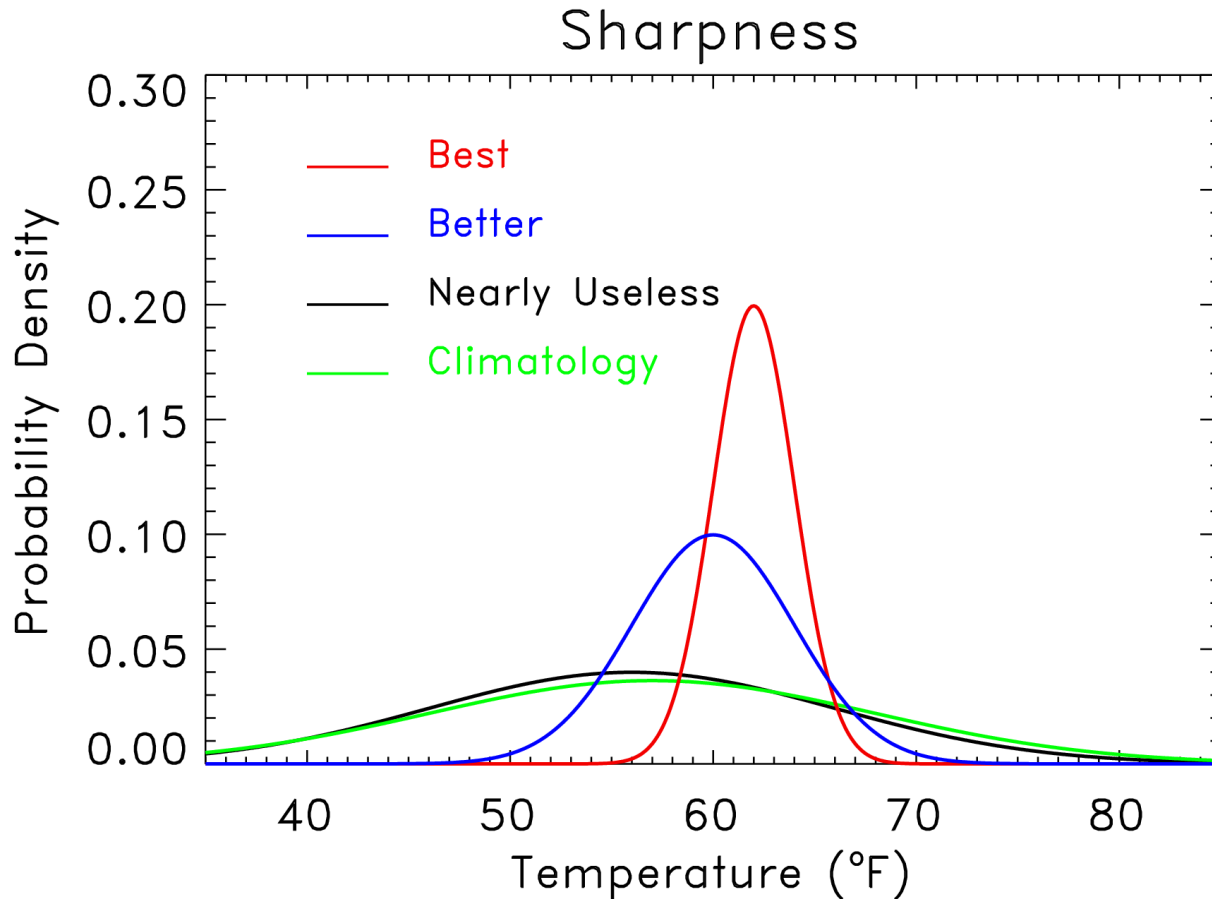
# Such ensemble forecasts will be “reliable” (if there are enough members)



In a reliable forecast, the event occurs at the same relative frequency as the probability you forecast.

Note: even if the ensemble and the truth are drawn from the same distribution, with a small ensemble you won't get reliable probabilities due to sampling error (Richardson, QJRM, 2001)

# “Sharpness” another desired characteristic of ensembles

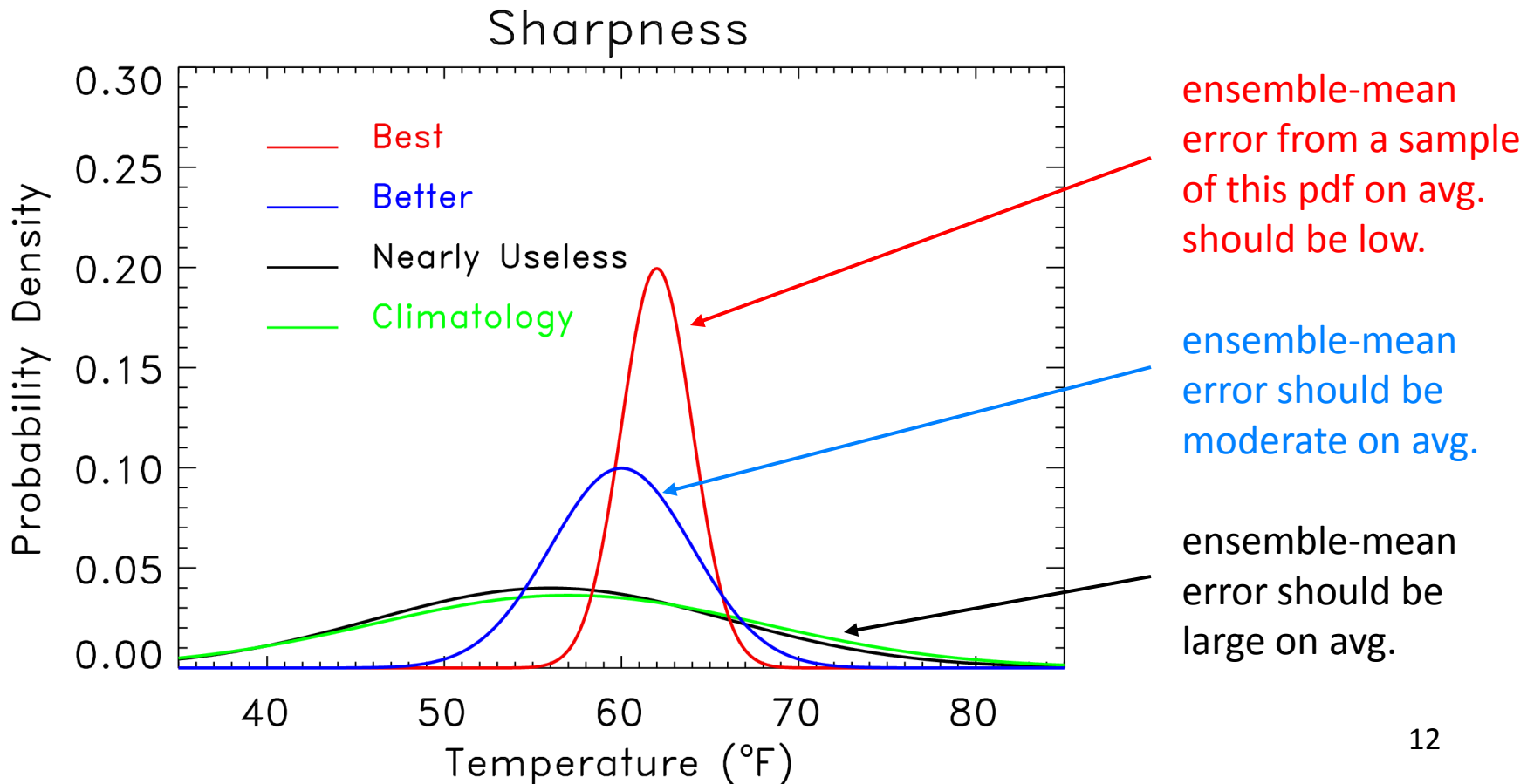


“Sharpness” measures the specificity of the probabilistic forecast. Given two reliable forecast systems, the one producing the sharper forecasts is preferable.

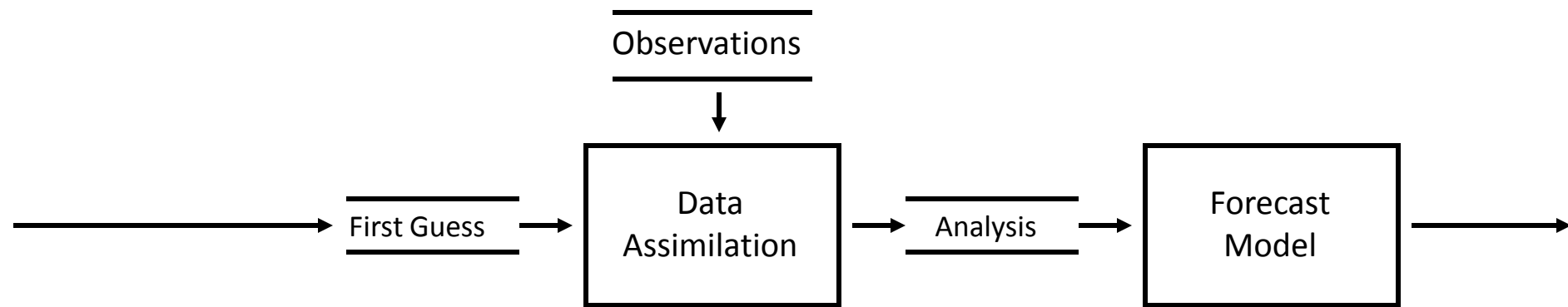
But: don’t want sharp if not reliable. Implies unrealistic confidence.

# “Spread-skill” relationships

Small-spread ensemble forecasts should have less ensemble-mean error than large-spread forecasts. Demonstrate that ensembles can quantify situational uncertainty.

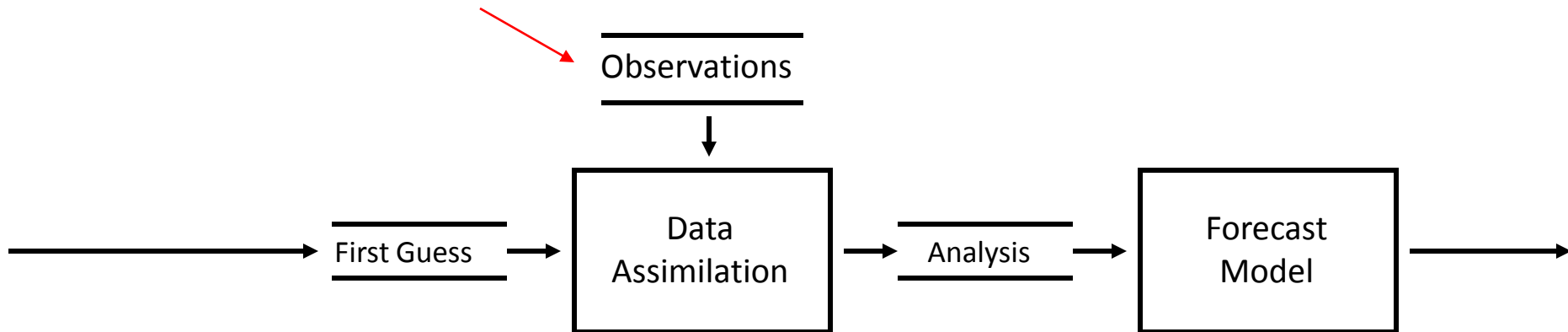


# How we think about the process of generating an initial ensemble



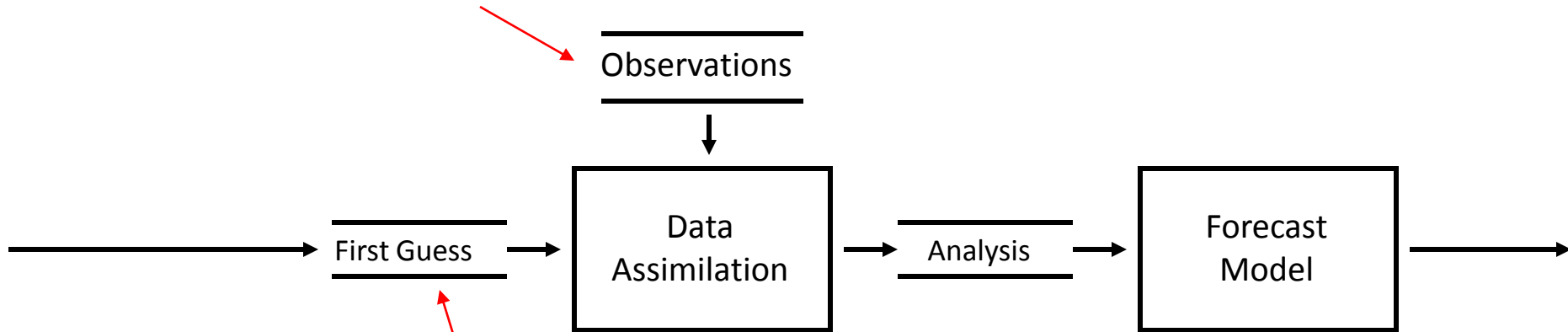
# How we think about the process of generating an initial ensemble

observations have errors,  
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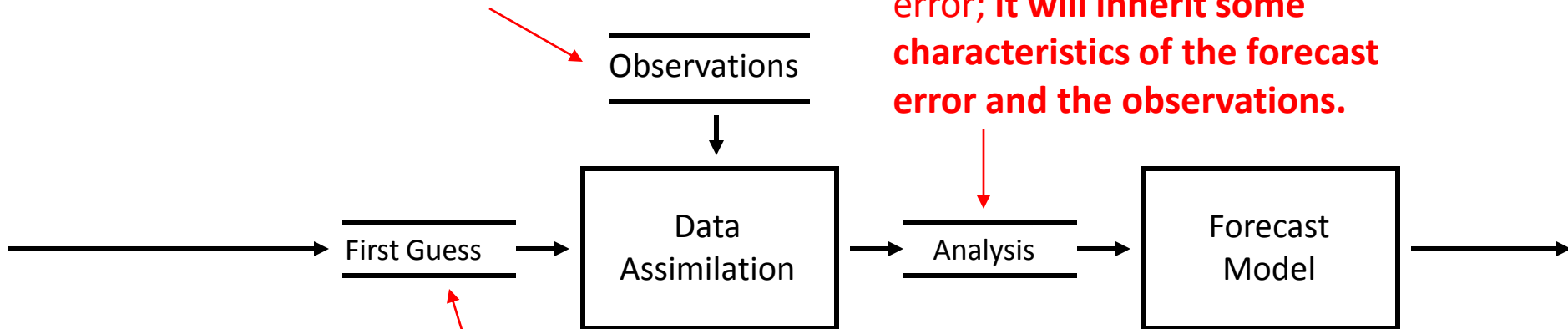


this will inevitably have some errors, else  
why assimilate new observations?

# How we think about the process of generating an initial ensemble

observations have errors,  
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hence the "initial condition"  
will inevitably have some  
error; **it will inherit some  
characteristics of the forecast  
error and the observations.**



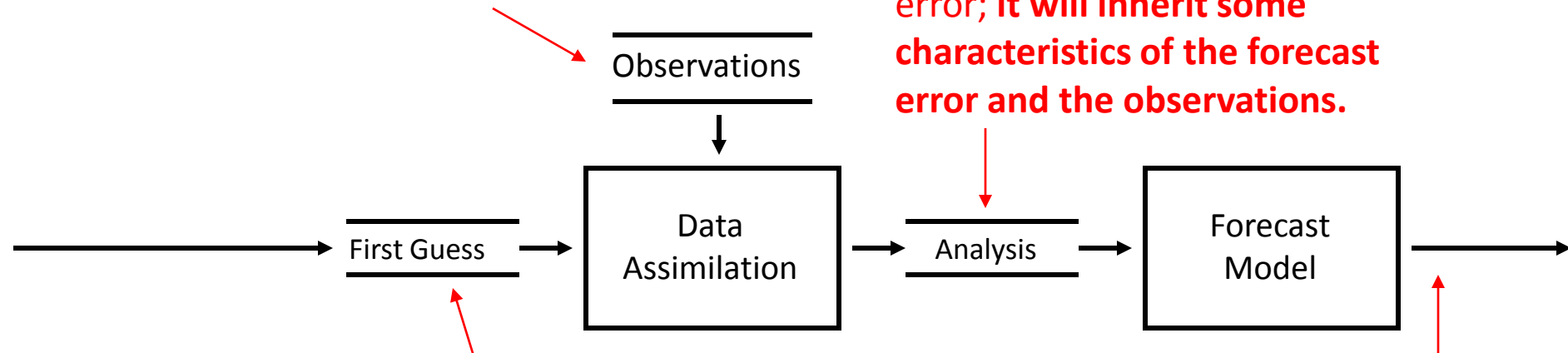
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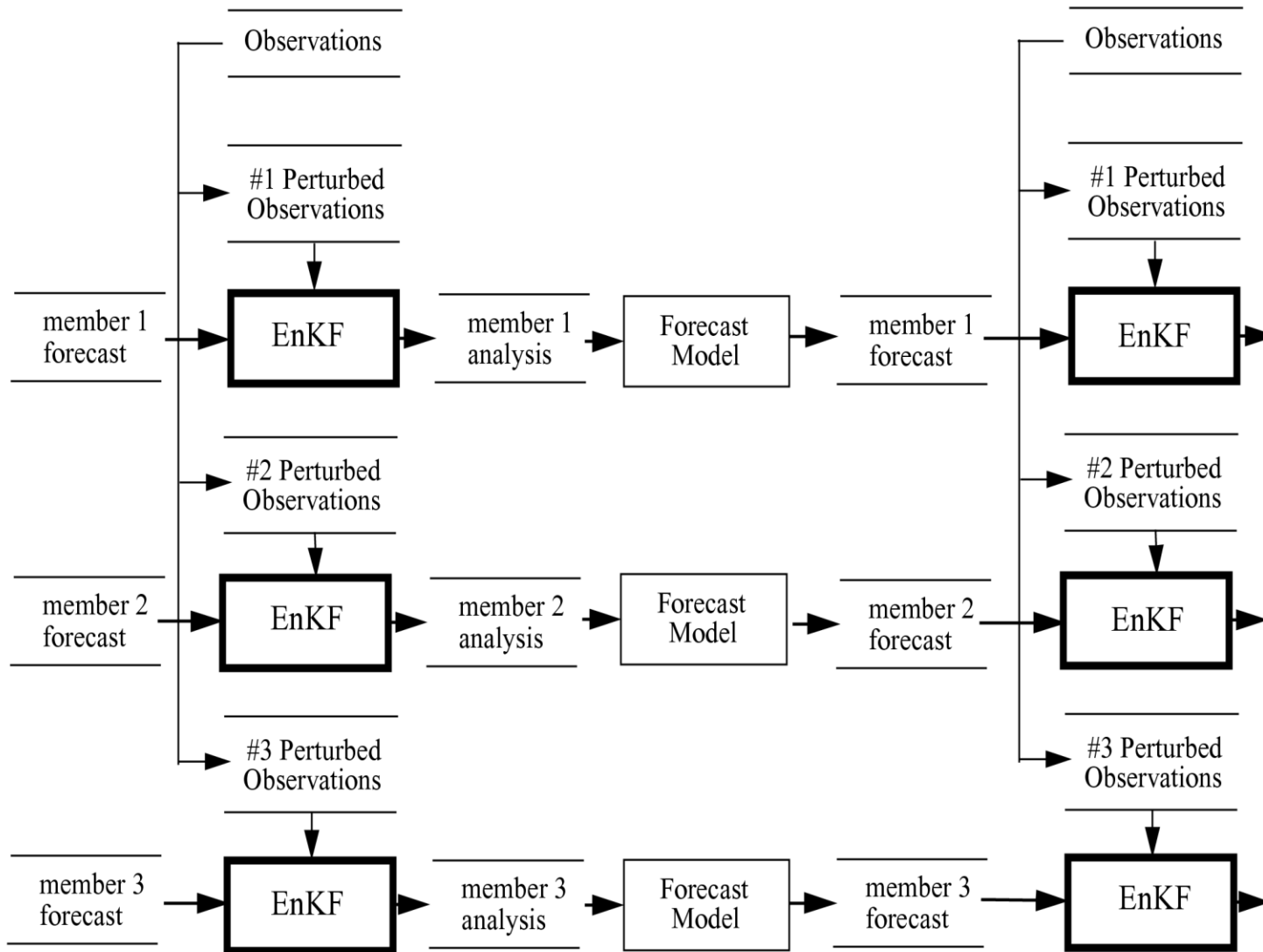


this will inevitably have some errors, else  
why assimilate new observations?

and of course  
errors tend to  
grow with time,  
so it'd be helpful  
to have a sense  
of the diversity of  
possible outcomes

# EnKF (Ensemble Kalman Filter)

naturally simulates uncertainty in observations, prior forecast

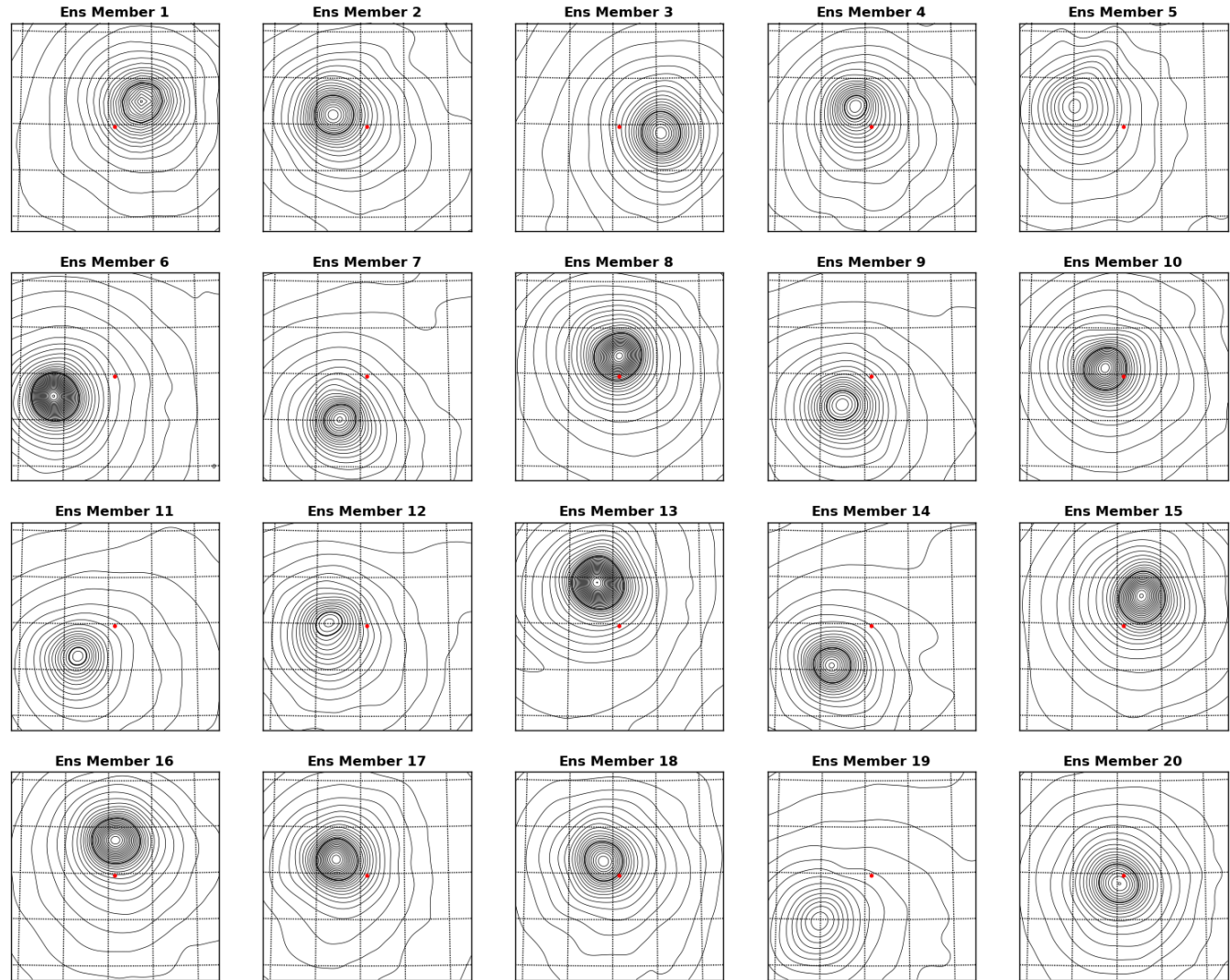


(This schematic is a bit of an inappropriate simplification, for EnKF uses every member to estimate background-error covariances)

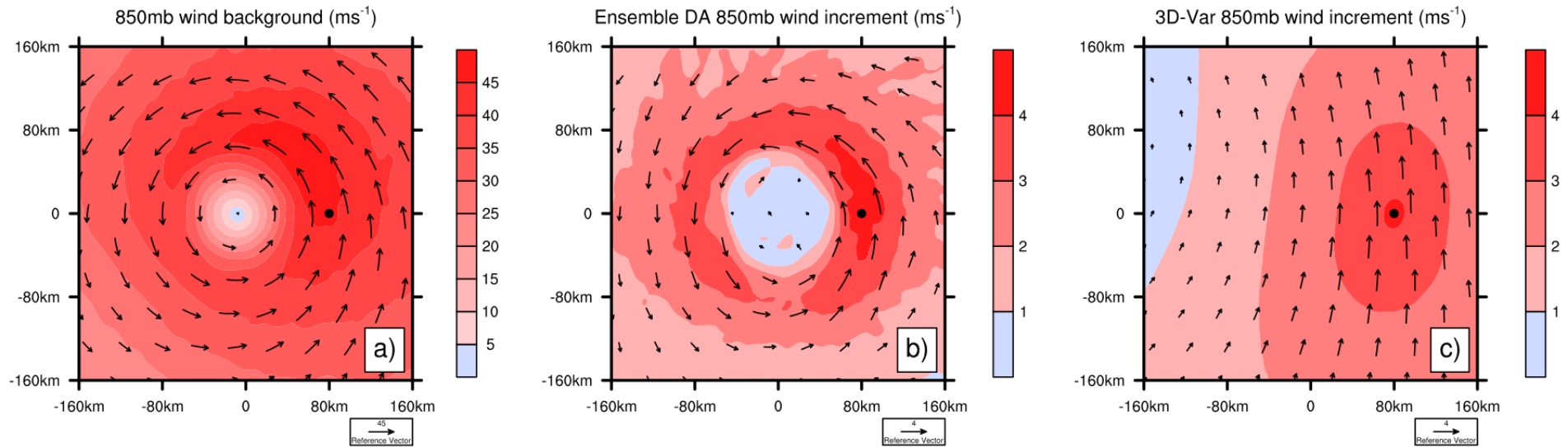
# Ensembles provide estimates of forecast error & their correlation structure in the EnKF

here, 20-member ensemble of short-term forecasts, showing uncertainty in the forecast position and structure of a hurricane vortex.

Note, for example, more spread in MSLP in center of domain than on the edges.



# An example of “analysis increment” from EnKF and 3D-Var



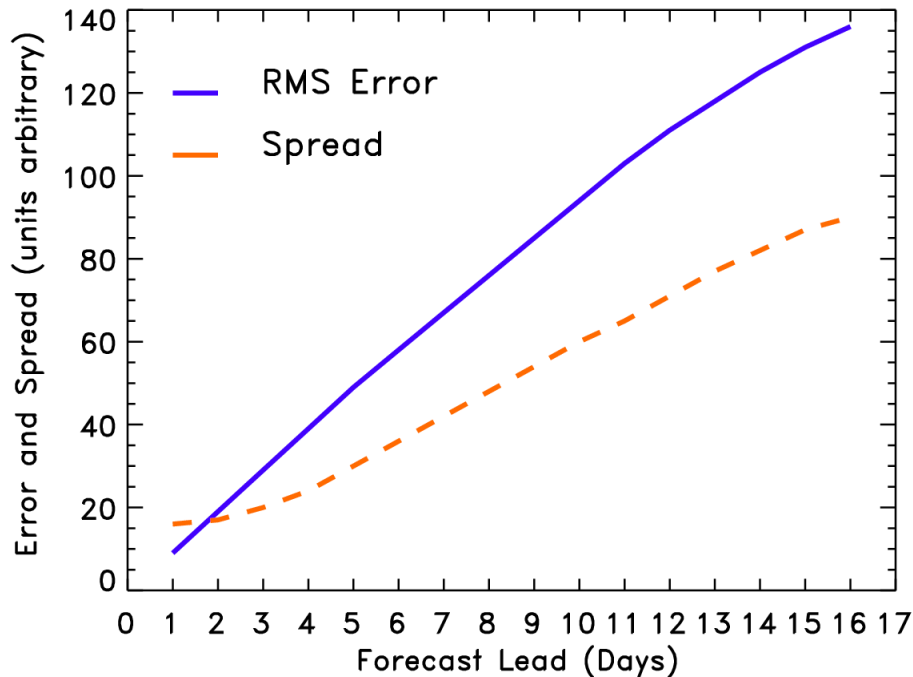
This shows the adjustment to a wind observation 1 m/s greater to the background (at dot) in EnKF and in more classical “3D-Var”

# Desirable properties for ensembles of initial conditions

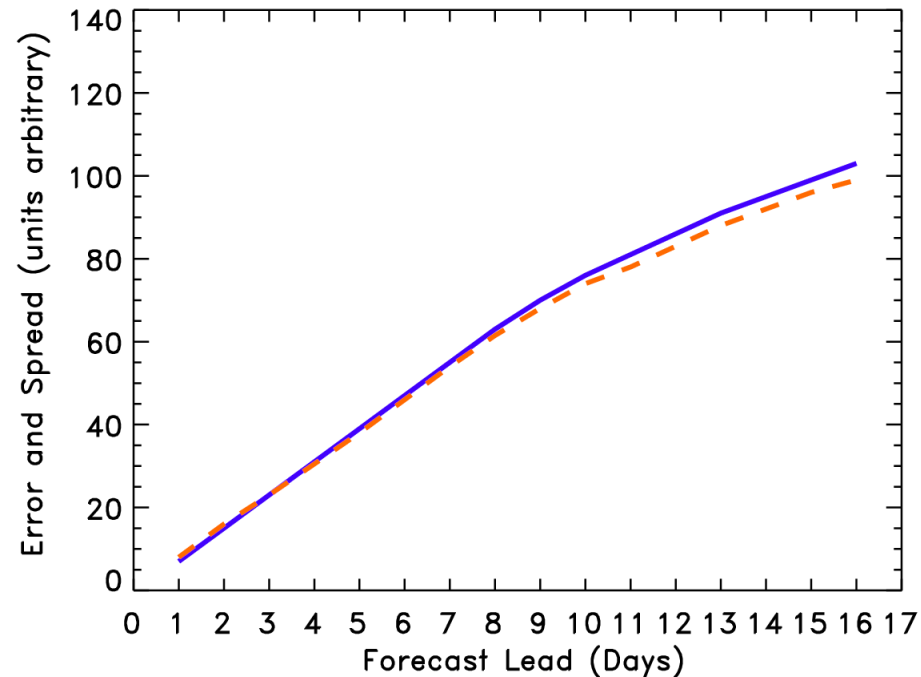
- (1) true model state and ensemble are random draws from the same distribution (same as before).
  - i.e., ensemble samples “analysis uncertainty.”
  - implies larger differences between members in data voids, or where prior forecast differences were growing.
  
- (2) differences between subsequent forecasts ought to grow quickly enough that ensemble-spread consistent with ensemble mean error.
  - with perfect forecast model, (2) will happen naturally if you take care of (1)

# Spread-error consistency

(a) Inconsistent: Large Error & Slower Spread Growth

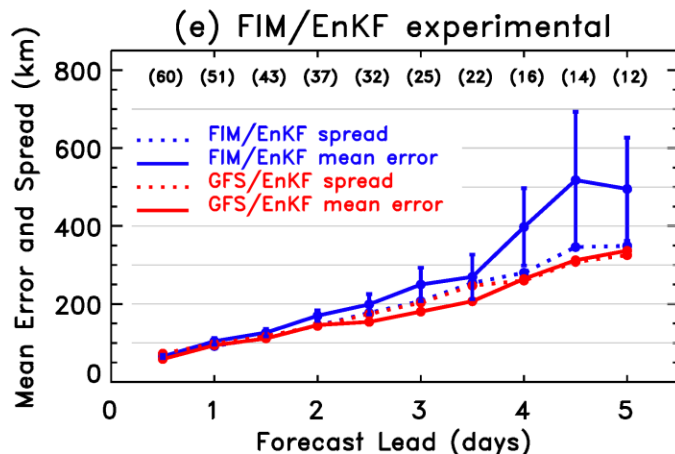
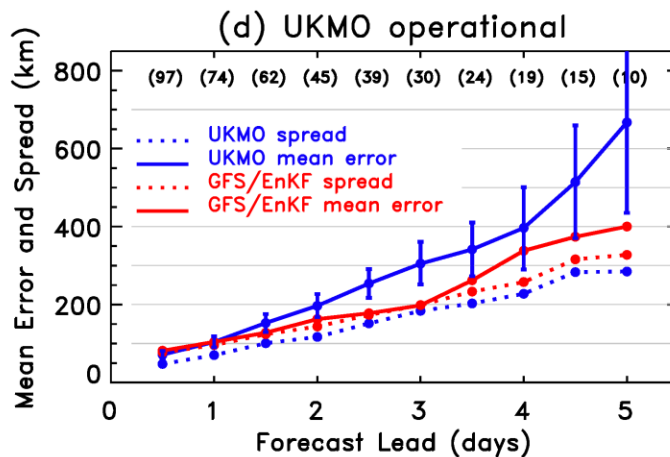
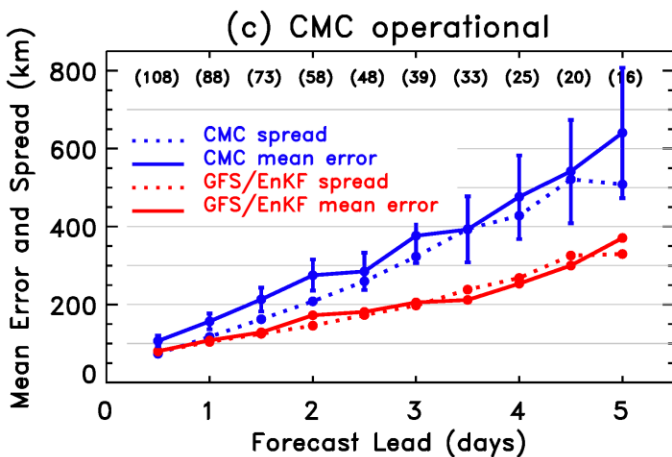
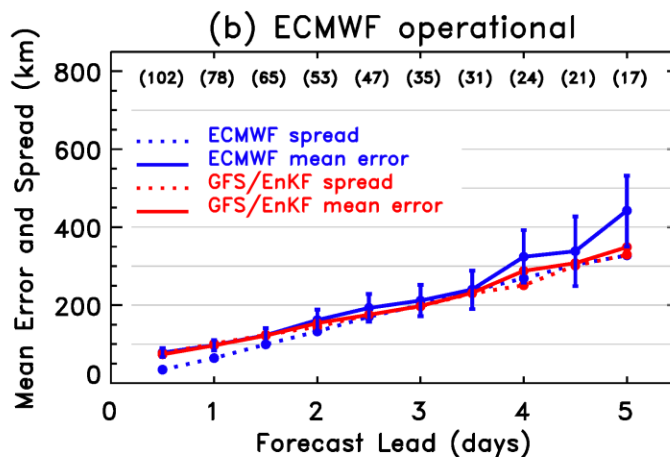
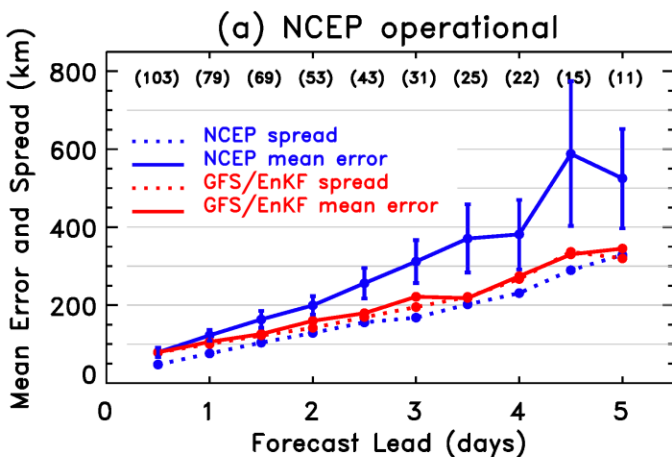


(b) Consistent: Smaller Error & Faster Spread Growth



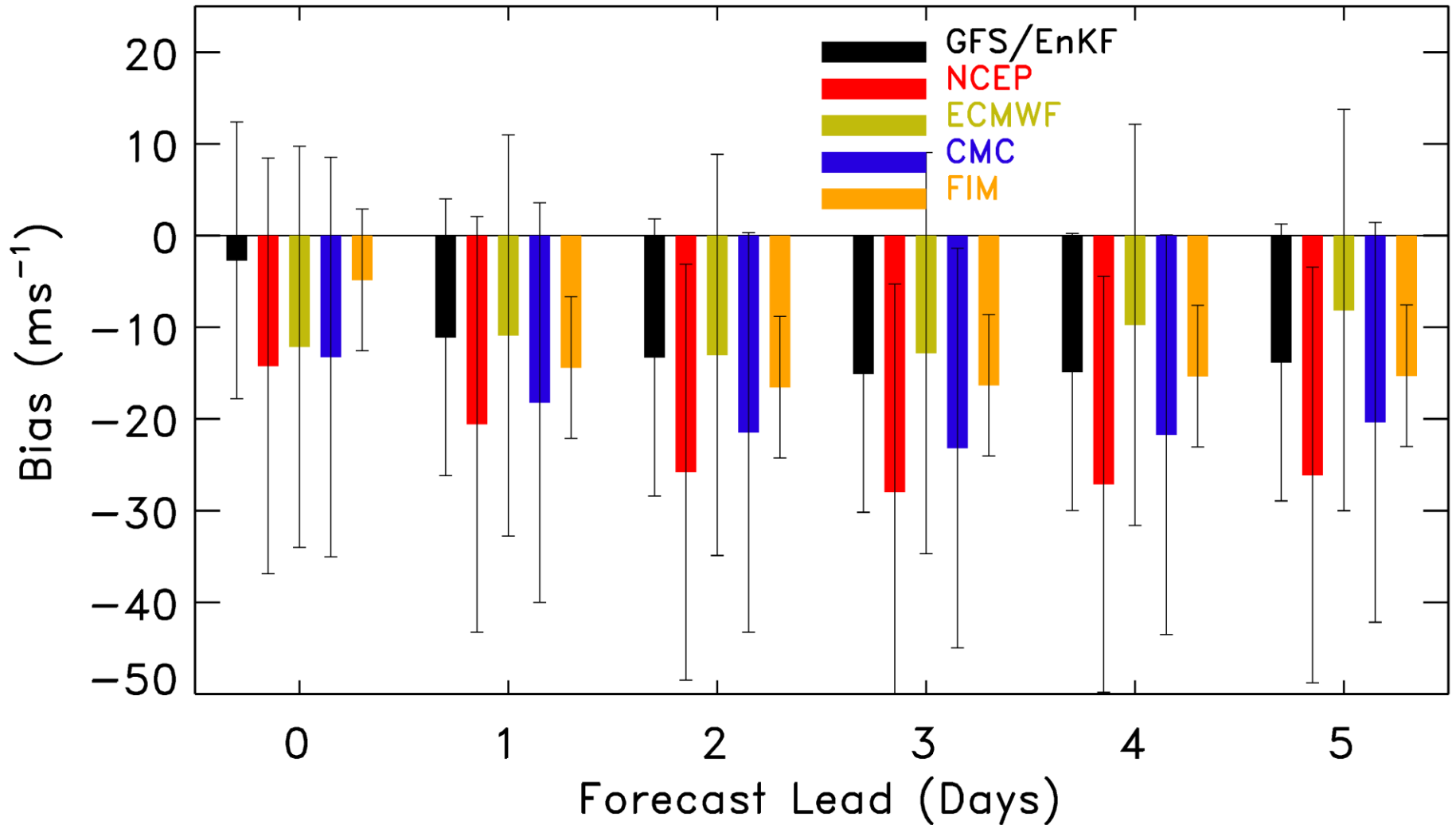
**Spread should grow as quickly as error;** part of spread growth from manner in which initial conditions are generated, some due to the model (e.g., stochastic physics, higher resolution increases spread growth). Focus on initial-condition aspect.

from recently submitted  
Hamill et al. (2012) MWR  
manuscript



For most models, spread  
of hurricane tracks is  
smaller than track  
ensemble-mean error.

# Maximum Wind Speed Bias



Global ensemble forecast models have systematic under-estimation of maximum wind speed. Lesson: we're far from conquering model error in NWP and ensembles.



# “Model error”

- Imperfections in the forecast model, due to:
  - inadequate resolution
  - unduly simple physical parameterizations
    - deterministic may be inappropriate
  - coding bugs
  - lack of coupling, e.g., ocean-atmosphere
  - use of limited-area nested model
    - boundary-condition imperfections
    - one-way nesting of outer domain, lack of ability for resolved scales to interact with planetary scales
  - etc.

# Addressing model error

(Carolyn Reynolds will review further)

- Improve your model
- Incorporate stochastic parameterizations where appropriate
- Multi-parameterization
- Multi-model
- Post-processing using prior forecasts, obs
  - upcoming talk by Zoltan Toth

# Ensemble products (what we're here to discuss)

- For the fields where we are starting to have some confidence in ensemble guidance, what can we do to convey that information in useful ways to the forecaster and to the public?

# Example: Hurricane Bill

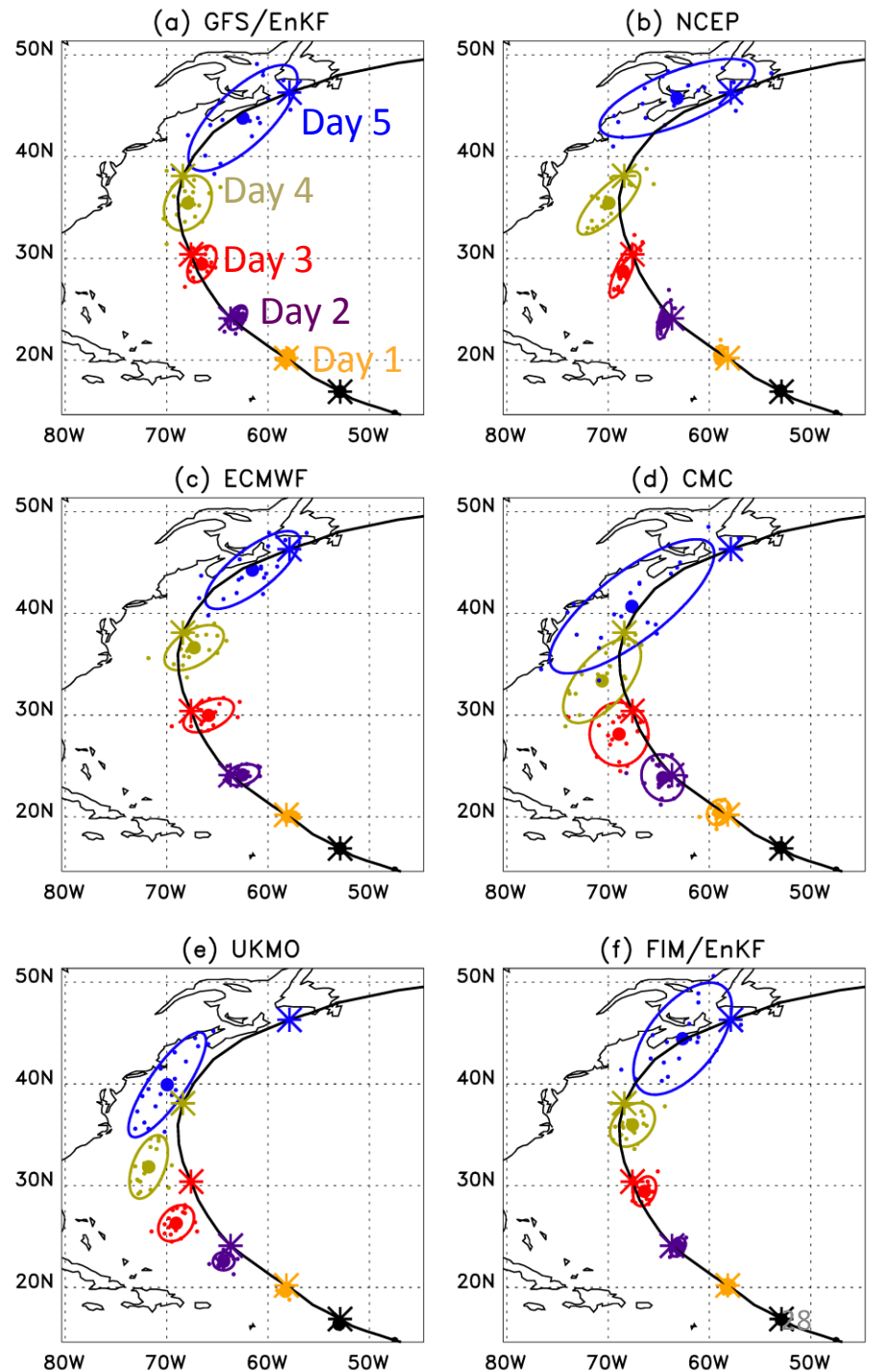
Initialized 00 UTC 19 August 2009.

Contours provide fit of bivariate normal to ensemble data. Encloses 90% of the probability.

All models slow, to varying extents.

GEFS/EnKF, ECMWF, NCEP, FIM tracks decent.

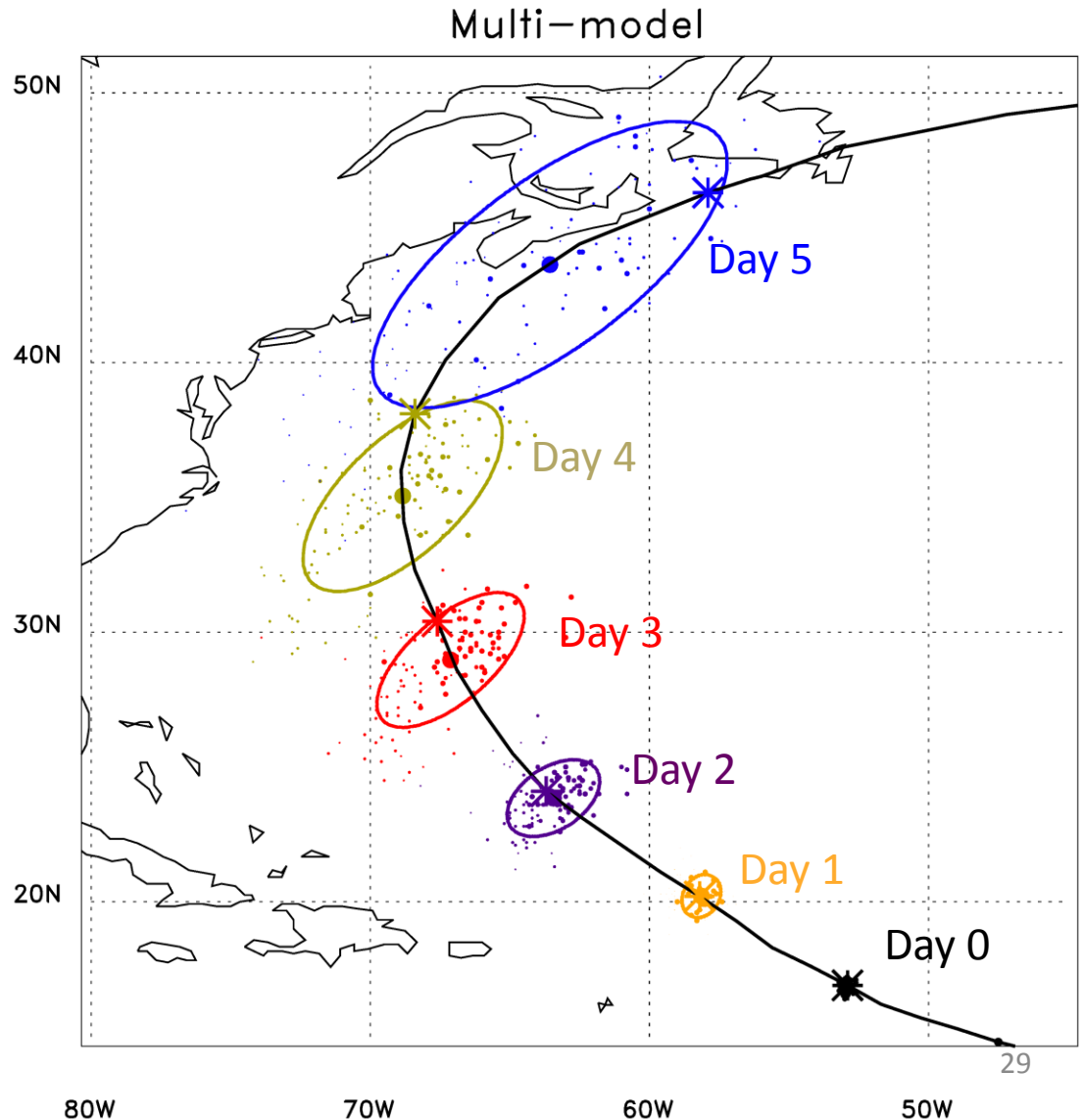
UKMO, CMC have westward bias.



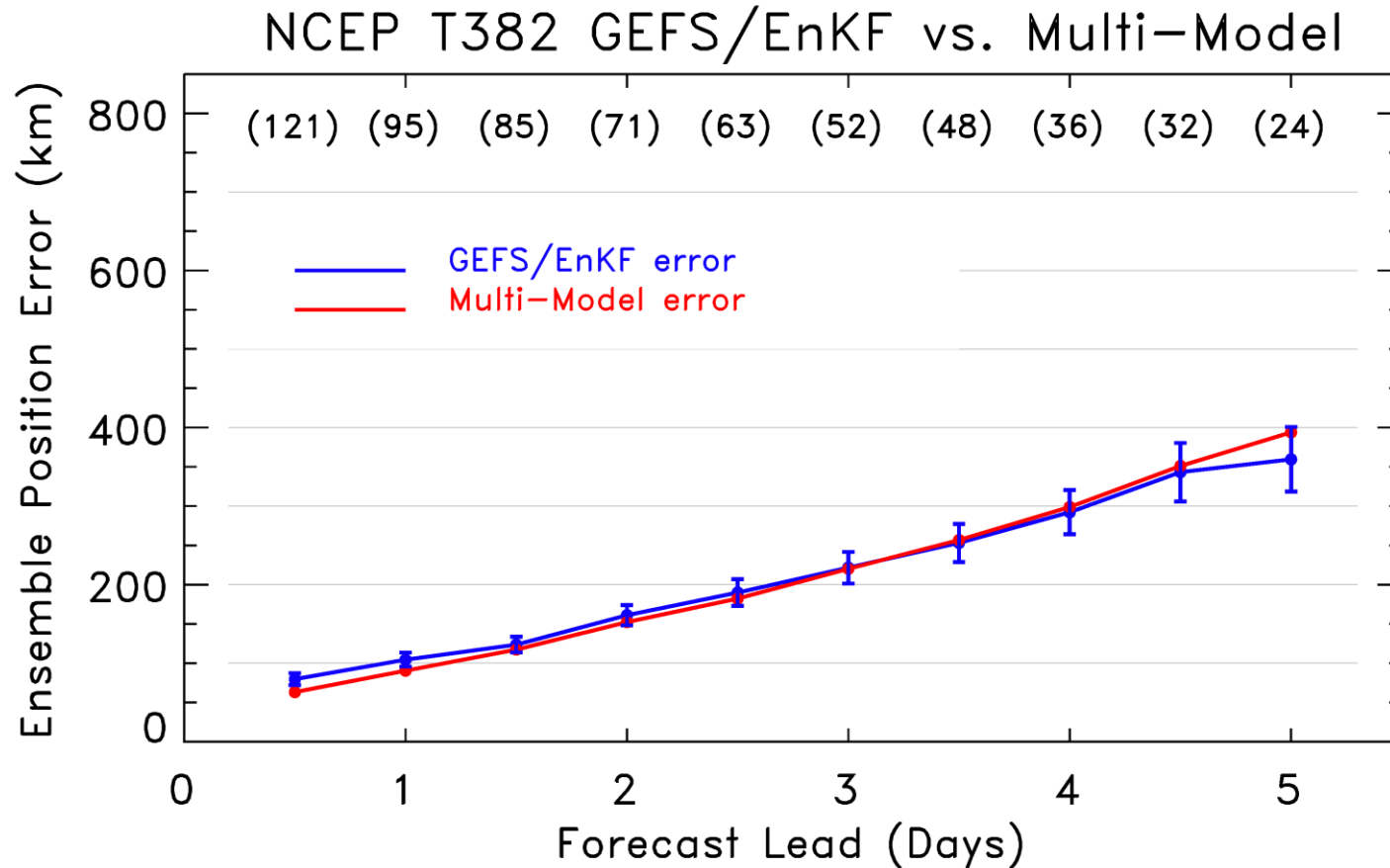
# An experimental multi-model product

Dot area is proportional to the weighting applied to that member

- = ens. mean position
- \* = observed position

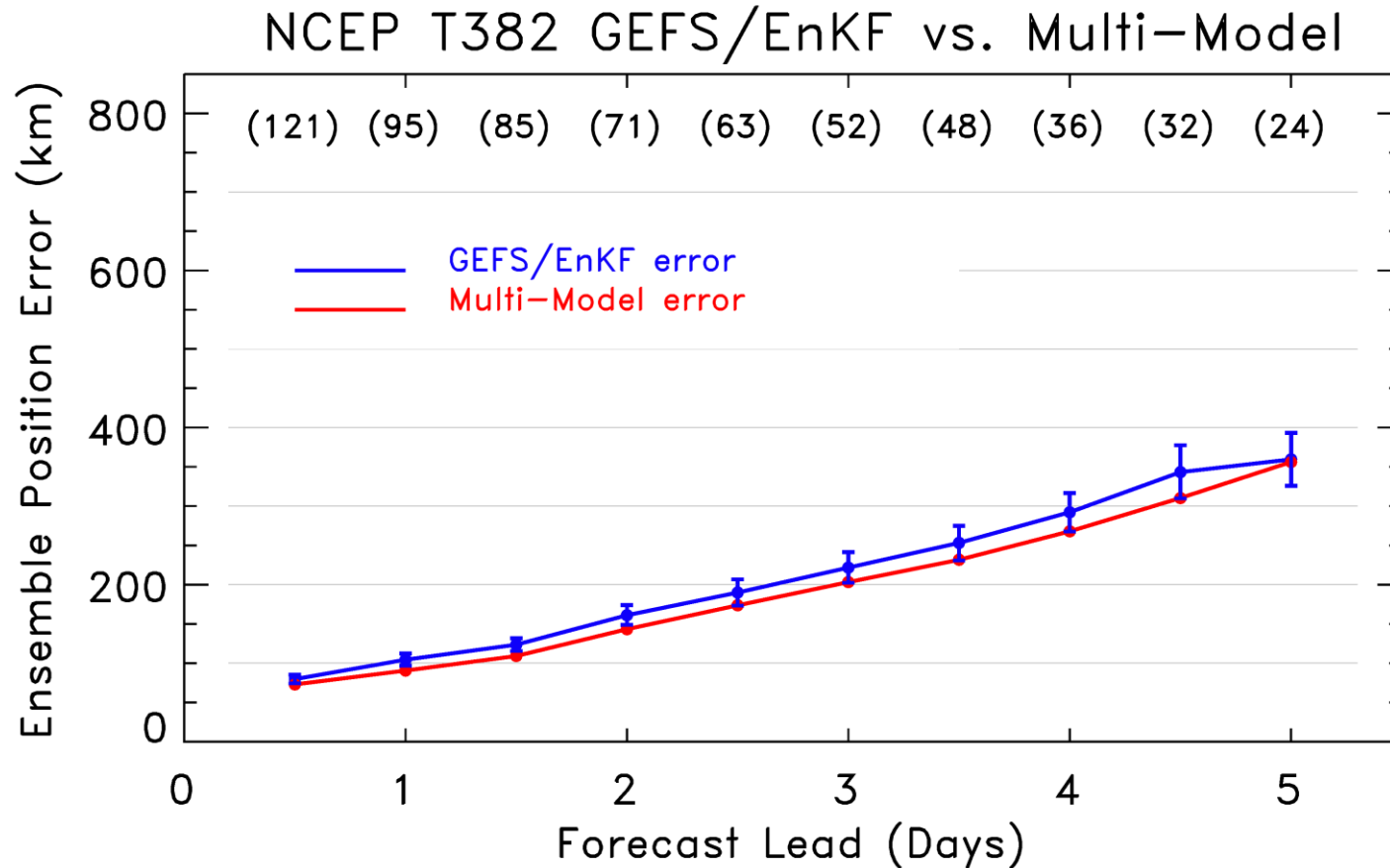


# Multi-model error (GEFS/EnKF, ECMWF, FIM, UKMO, CMC, NCEP)



Not much improvement from multi-model (poorer models don't seem to help much here)

# Multi-model error (GEFS/EnKF, ECMWF only)



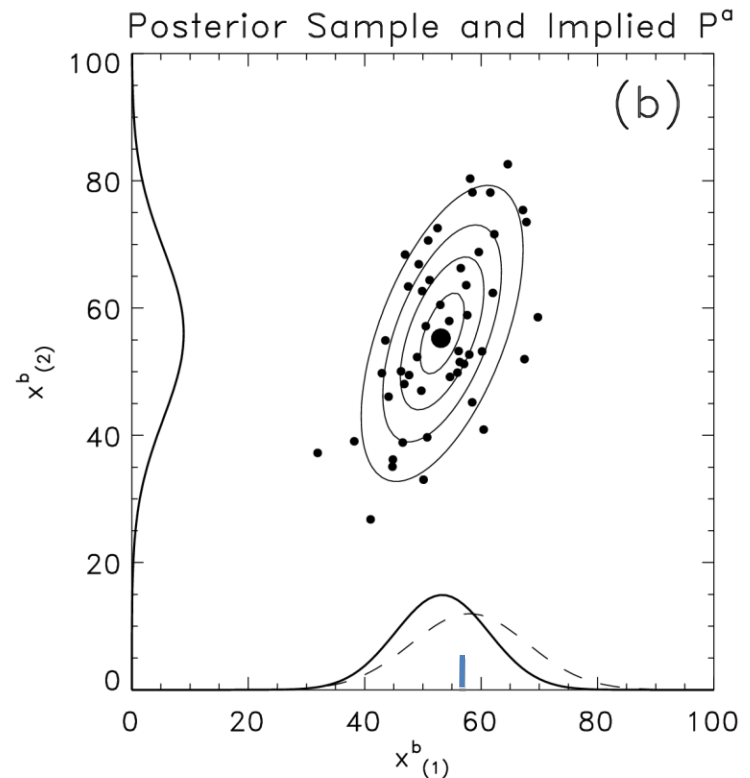
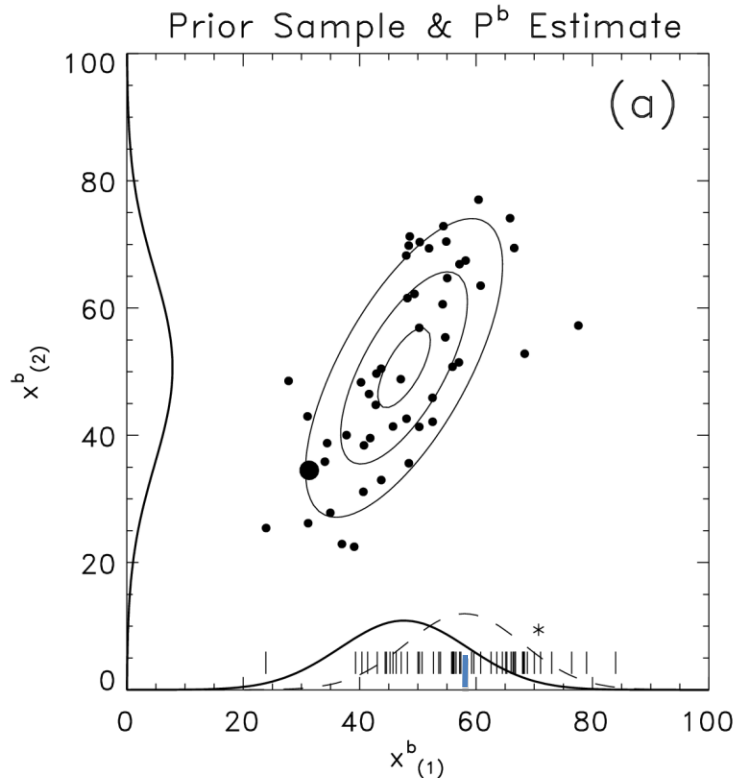
Now some improvement, ~ 6 - 9 hours lead.

# Questions

- Mine:
  - Are ellipses, colors useful way of conveying ensemble information?
  - Are products like the multi-model synthesis shown here potentially useful to forecasters?
  - Should we only develop products just for hurricane aspects where we have some confidence (track), or also for those where we lack confidence (intensity)?
- Yours



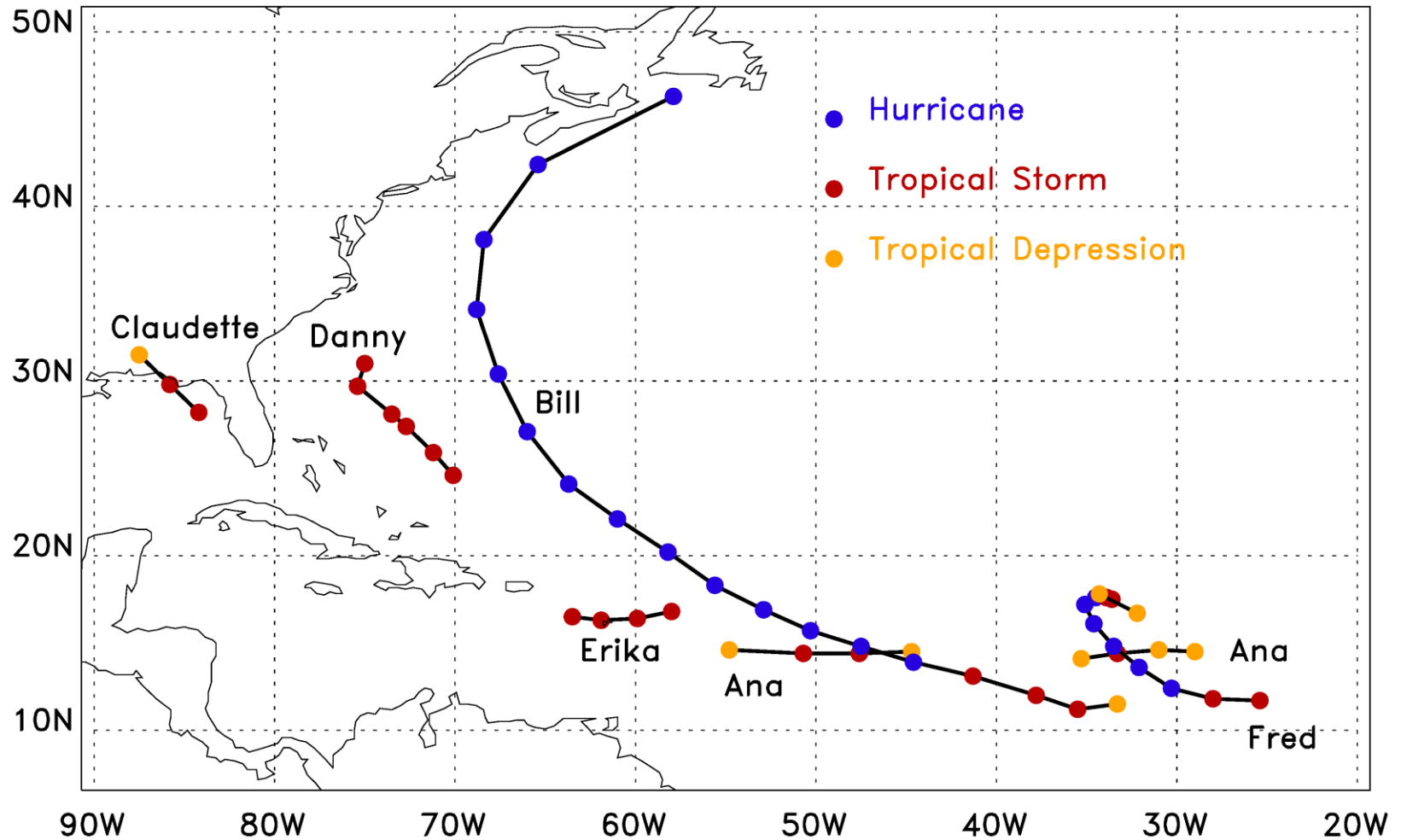
# How the EnKF works: 2-D example



Start with a random sample from bimodal distribution used in previous Bayesian data assimilation example. Contours reflect the Gaussian distribution fitted to ensemble data.

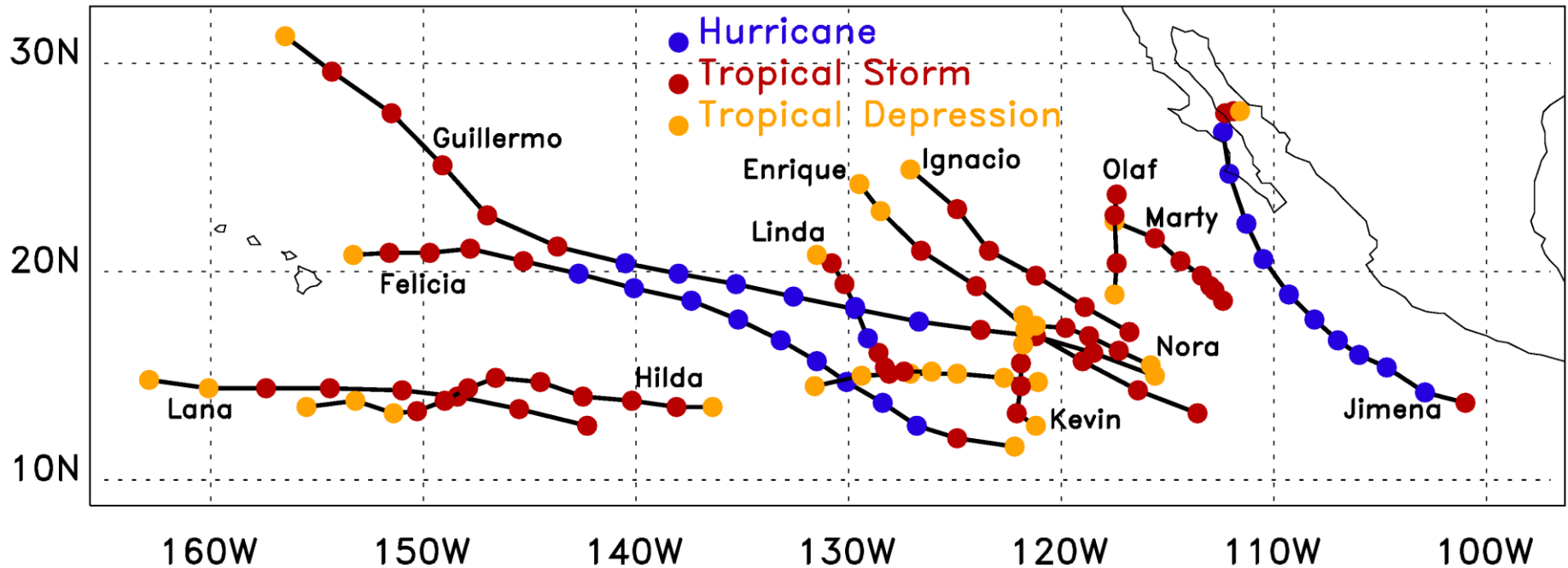
# Review of Atlantic Basin activity

Atlantic Basin Storms, 31 Jul 2009 to 03 Oct 2009



# Review of Eastern-Pacific activity

Eastern Pacific Storms, 31 Jul 2009 to 03 Oct 2009



# Review of Western-Pacific activity

Western Pacific Storms, 31 Jul 2009 to 03 Oct 2009

