Mesoscale Ensemble Prediction System:

What is it?

What does it take to be effective?

What are the impacts of shortcomings?

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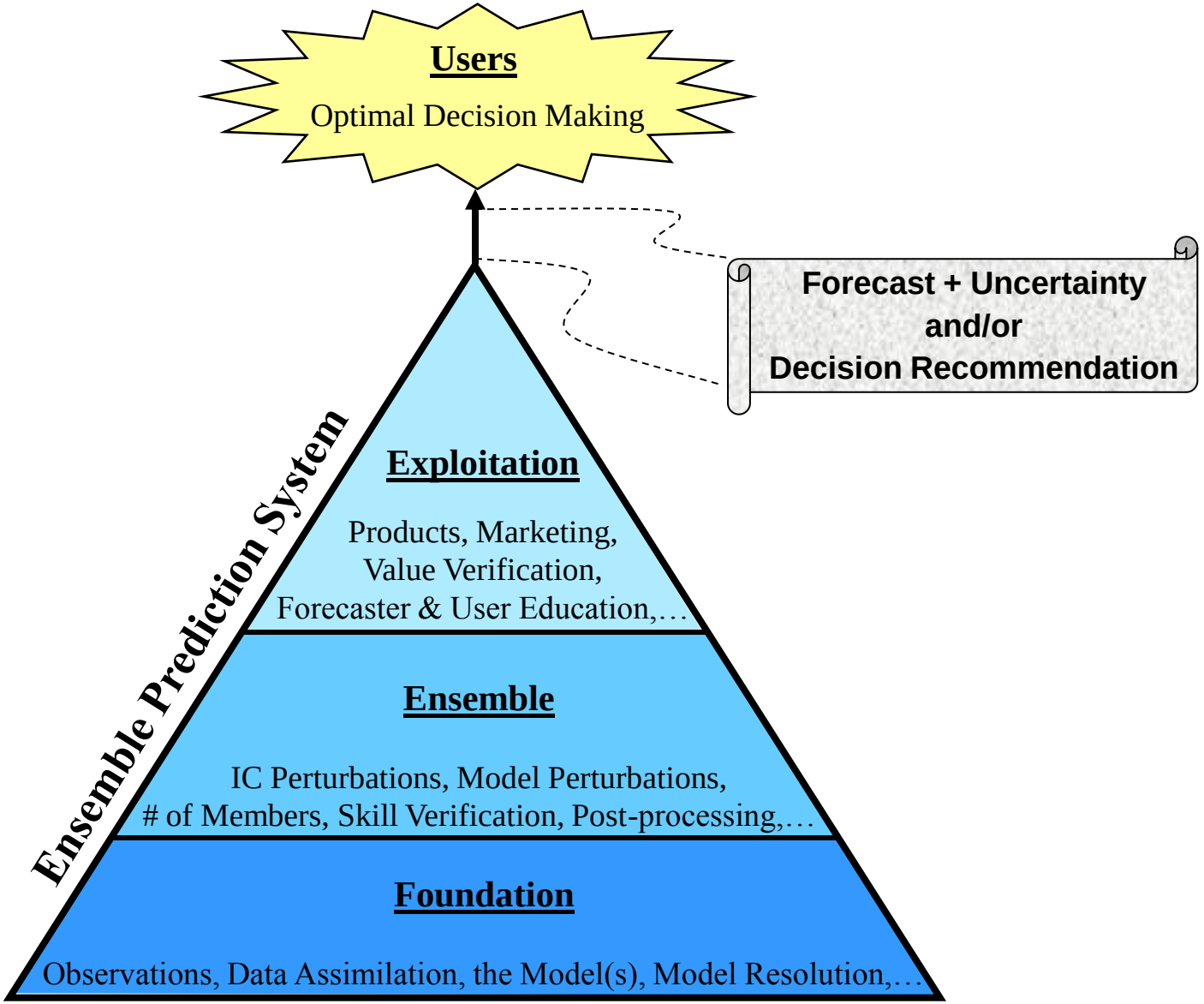
What is it?


Users
Optimal Decision Making
Forecast + Uncertainty
and/or
Decision Recommendation
Ensemble Prediction System
Exploitation
Products, Marketing,
Value Verification,
Forecaster & User Education,…
Ensemble
IC Perturbations, Model Perturbations,
# of Members, Skill Verification, Post-processing,…
Foundation
Observations, Data Assimilation, the Model(s), Model Resolution,…

Sources of Uncertainty in NWP

External

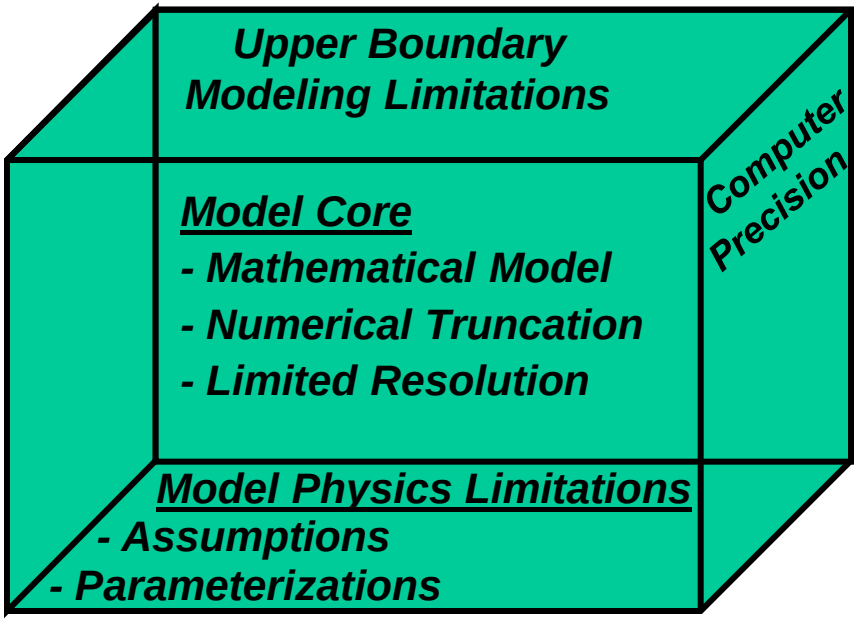
Initial Conditions
- *Erred Observations*
- *Incomplete Observations*
- *Limitations to Data Assimilation*

Lateral Boundary Conditions
- *Inaccuracies*
- *Coarse spatial & temporal resolution*

NWP Model

Lower Boundary Conditions
- *Incomplete and Erred Surface Temperature, Soil Moisture, Albedo, Roughness Length, …*

Internal

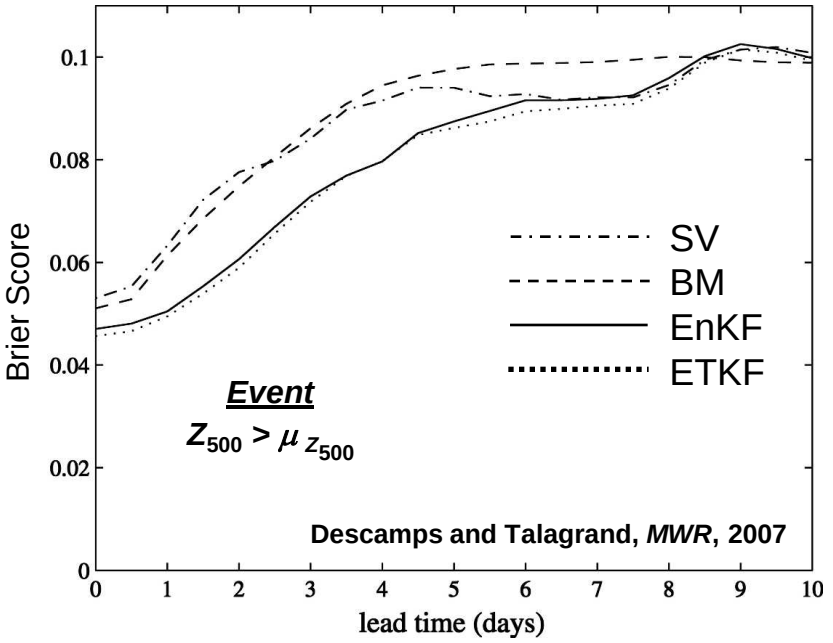


What does it take to be effective?

- - - Robust IC Perturbations - - -

- **Goal:** ***n*** **dynamically consistent and equally likely analyses that span the analysis error subspace**

- **Methods:**
  - **Bred Modes (BM)**
  - **Singular Vectors (SV)**
  - **Ensemble Kalman Filter (EnKF)**
  - **Ensemble Transform Kalman Filter (ETKF)**

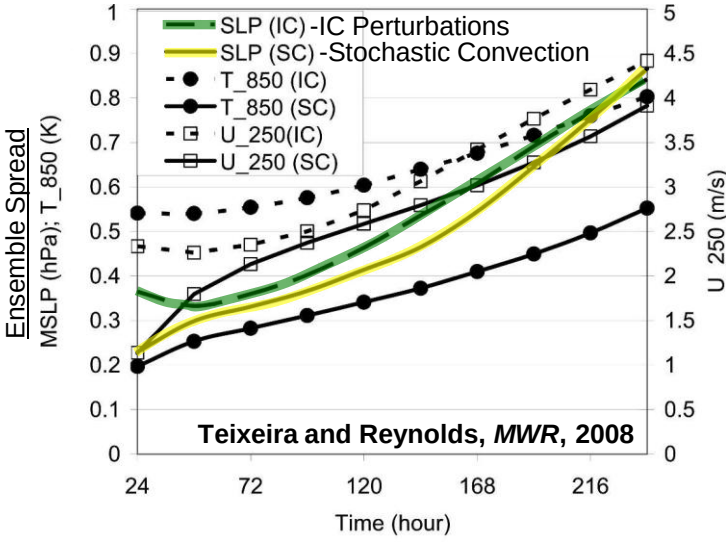


- **Questions:**
  - **Special considerations for mesoscale, short-range ensemble?**
  - **Importance of Scale?**
  - **Cold vs. Warm Start?**

What does it take to be effective?

- - - Robust Model Perturbations - - -

- **Goal**: **Diversity in members' attractors to attempt to span true attractor, or at least aim for a statistically consistent forecast PDF**
- **Methods**:
  - **Multi-model** – *different models and/or different physics schemes*
  - **Stochastic Physics** – *structured perturbations to state variables' tendency during model integration*
  - **Stochastic Backscatter** – *return dissipated energy via scale-dependent perturbations to wind field*
  - **Random Parameters** – *randomly perturb parameters (e.g., entrainment rate) during integration*
  - **Perturbed Parameters** – *" "*, *but hold constant during integration*
  - **Perturbed Field Parameters** – *SST, albedo, roughness length, etc.*
  - **Stochastic Parameterizations** – *explicitly model stochastic nature of subgrid-scale processes*
  - **Perturbed Lateral Boundary Conditions**
    - *Smaller domain, Longer forecast → Bigger issue*
- **Questions**:
  - **Combinations?**
    - *Which methods may be used together?*
  - **Other Methods?**
    - *Stochastic Field Parameters*
    - *Couple to Ocean Model Ensemble and/or LSM Ensemble*
    - *…?*

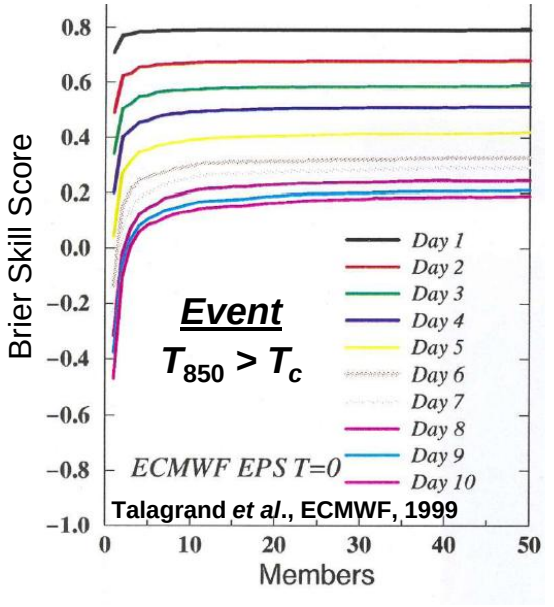


What does it take to be effective?

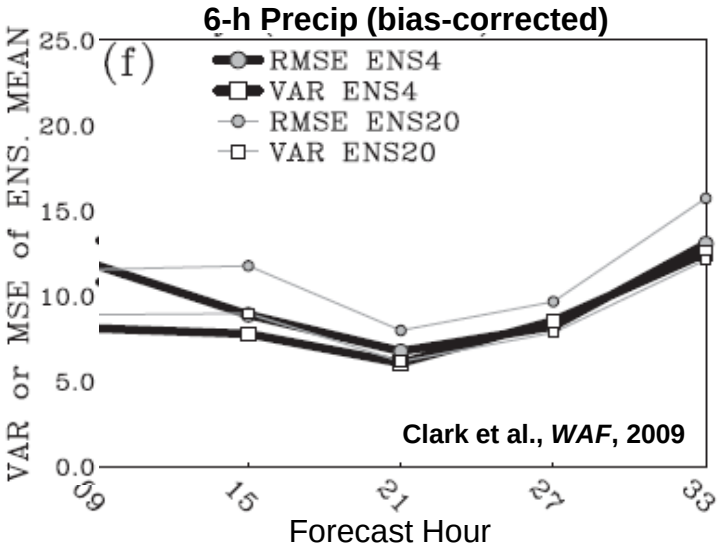
- - - Powerful Processors - - -

Primary Drivers…

- **Ensemble Size**: Need to consistently depict PDF from which members are drawn
  - 8-10 for decent ensemble mean
  - 20-30 for skilled forecast probability
  - 50+ to capture low probability events (PDF tails)



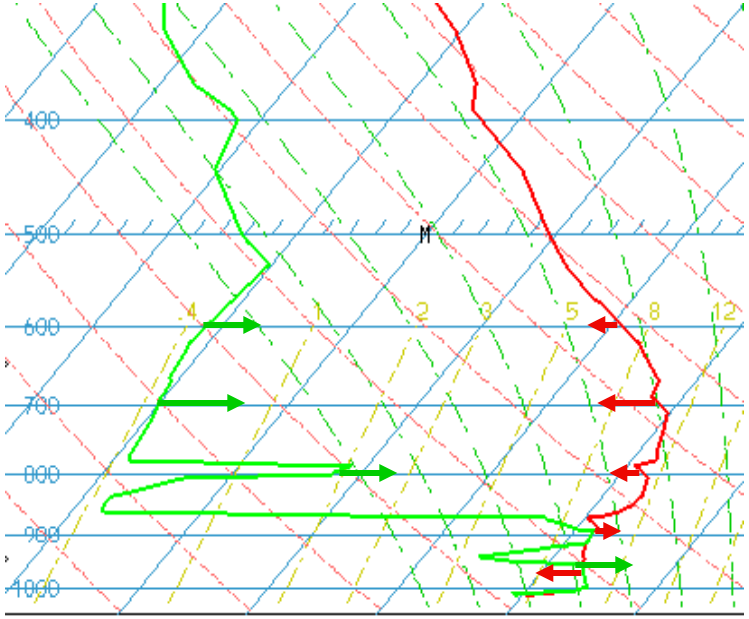
- **Model Configuration**: Need to meet user requirements
  - Forecast Length
  - Domain Coverage
  - Forecast Update Frequency
  - Timeliness
  - $ $ $ **Resolution** $ $ $
    - *Can only estimate uncertainty of resolved scales*
    - *Benefits of finer resolution:*
      1) Increased spread
      2) Reduced fcst error
      } improved statistical consistency
      3) Increased VALUE
    - *Resolving convection (grid<4km) is key*

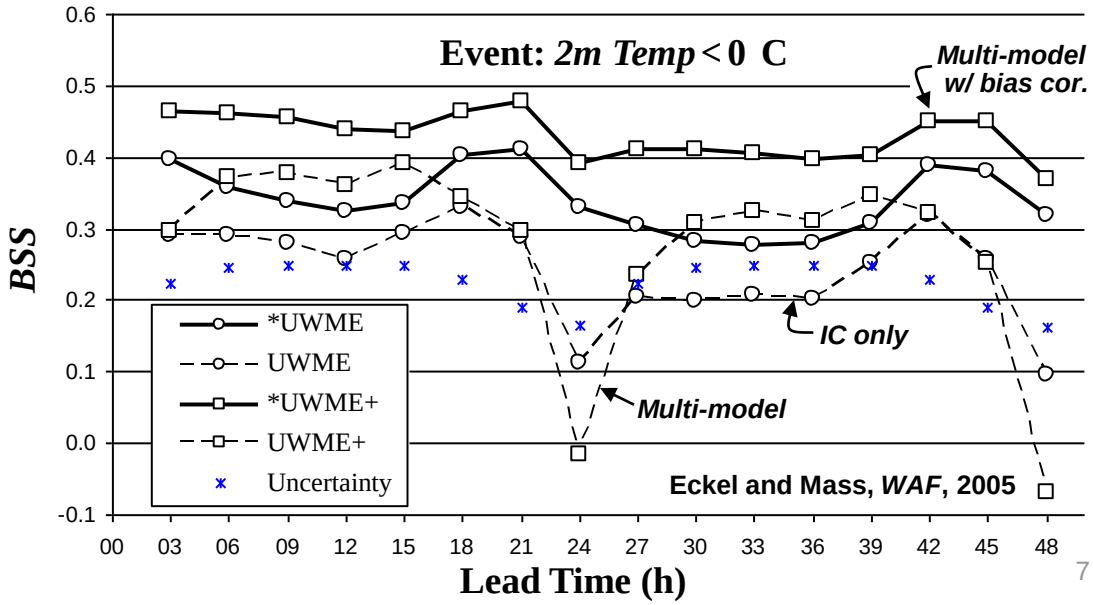


What does it take to be effective?

- - - Robust Post-processing - - -

- **Calibration**: **Need to maximize skill & value**
  - **Obtain Reliability** – *account for systematic errors (significant model biases in meso. models)*
  - **Boost Resolution via Downscaling** – *can greatly improve value of information*
  - **Reforecast Dataset** – *needed to calibrate low frequency events*
  - **Adaptable to variety of state and derived variables**
  - **Practical** – *easy to maintain*
  - **Preserve Meteorological Consistency?**





What does it take to be effective?

- - - Comprehensive Verification - - -

- **Parameters** – *emphasis on sensible weather and user requirements*
- **Ground Truth** – *emphasis on observations vs. model analysis*
- **Skill Metrics (*VRH, BSS, CRPS, etc.*)** – *focus on ensemble performance*
- **Value Metrics (*ROCSS, VS, etc.*)** – *focus on benefit to user*

Both feed back into R&D

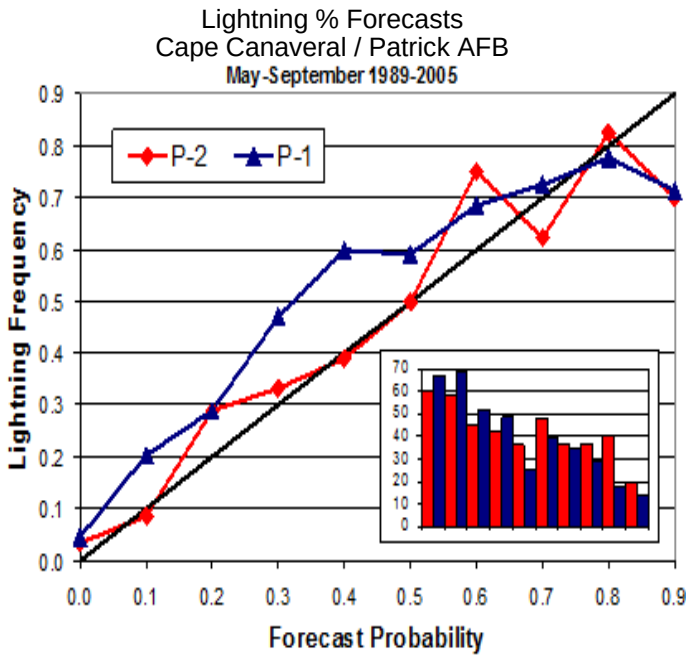
- **Accessible to Users**
  - ***Interactive, web-based interface***
  - ***Frequent updates***
  - ***Link into products and education***

Shuttle Endeavor
12 Jul 2009

Contingency Table Statistics Updated (P-2) and Phase 1 tools (P-1)			
Statistic	*P-2 (0.47)*	*1-Day Persistence*	*P-1 (0.35)*
POD	0.68	0.62	0.66
FAR	0.21	0.23	0.23
HR	0.74	0.71	0.73
CSI	0.52	0.46	0.50
HSS	0.47	0.40	0.44

Lambert and Roeder, *NASA*, 2007

http://science.ksc.nasa.gov/amu/briefings/fy08/Lambert_Probability_ILMC.pps



What are the impacts of shortcomings?

- **Poor Dispersion** – Failure to simulate error growth
- **Poor Skill** – Weak Reliability & Resolution
- **High Ambiguity** – Large random error in uncertainty estimate

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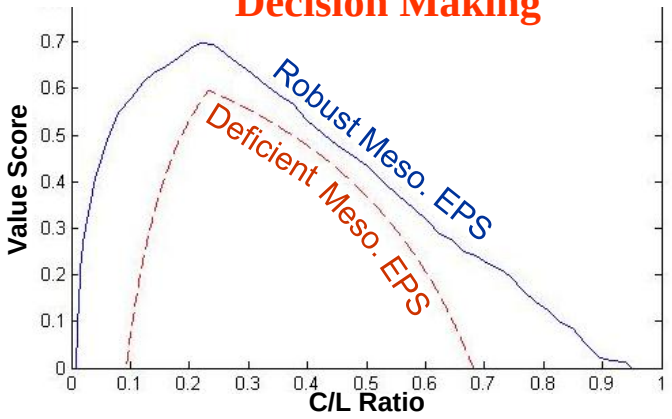
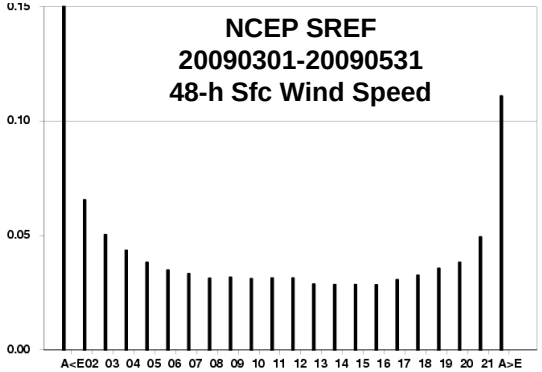
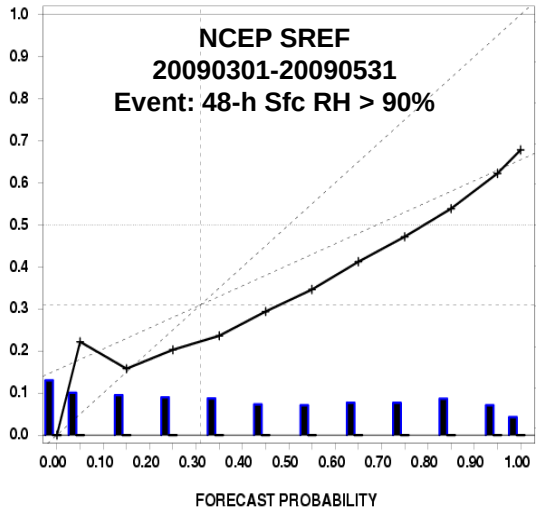
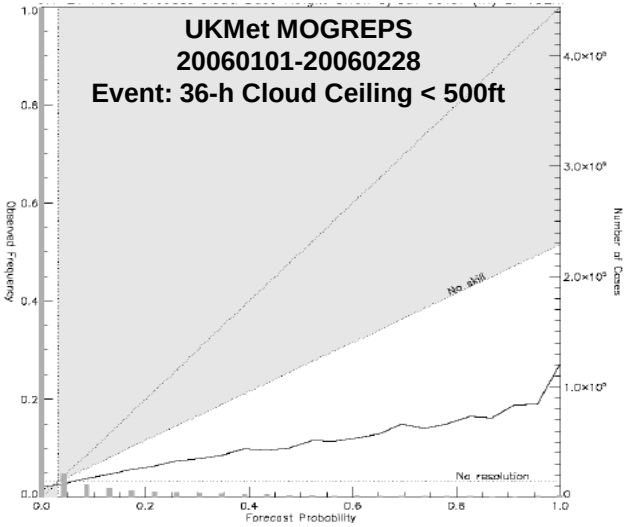
Degraded Value for Decision Making

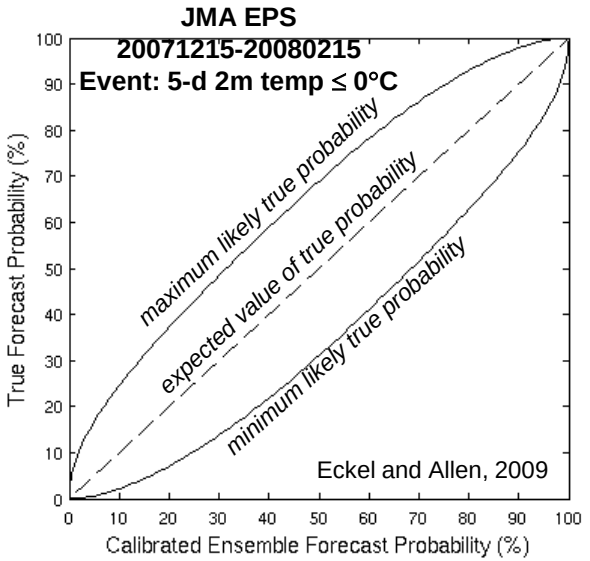








Bowler et al., *MetOffice*, 2007



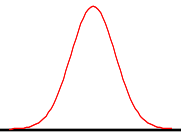
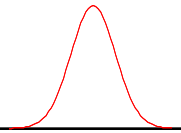
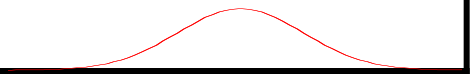
Backup Slides

True Forecast PDF

True forecast PDF recipe for lead time τ in the current forecast cycle:

1) Look back through an infinite history of forecasts produced by the analysis/forecast system in a stable climate
2) Pick out all instances with the same analysis (and resulting forecast) as the current forecast cycle
3) Pool the verifying true states at τ to construct a distribution

Not absolute -- depends on uncertainty in ICs and model (better analysis/model = sharper true PDF)

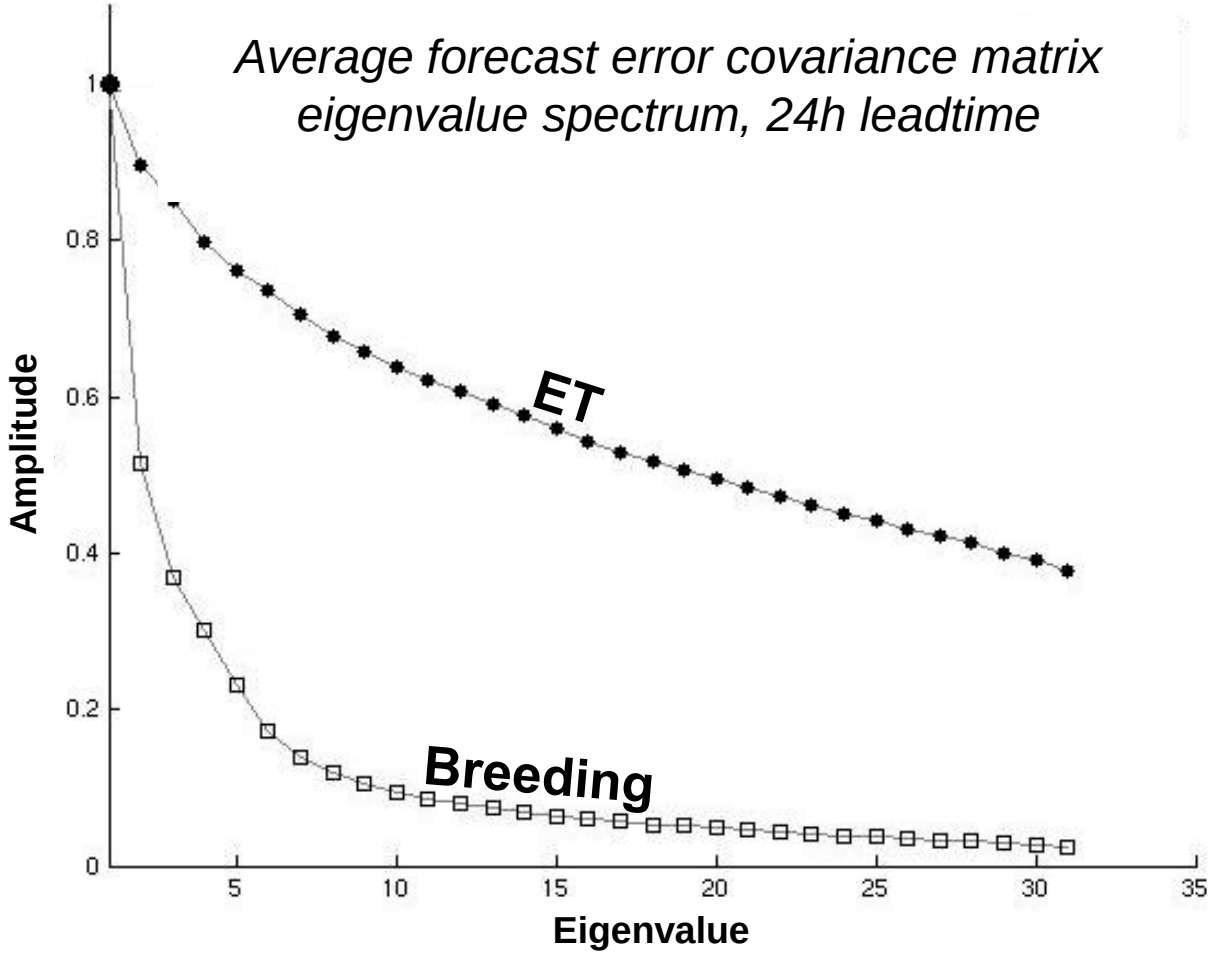
Analysis	Model	True Forecast PDF (at a specific τ)
Perfect	Perfect	Only one possible true state, so true PDF is a delta function. 
Erred	Perfect	Each historical analysis match will correspond to a different true initial state, and a different true state at time τ. 
Perfect	Erred	While each matched analysis corresponds to only one true IC, the subsequent forecast can match many different true states due to grid averaging at τ=0 and/or lack of diffeomorphism. 
Erred	Erred	Combined effect creates a wider true PDF. Erred model also contributes to analysis error. 

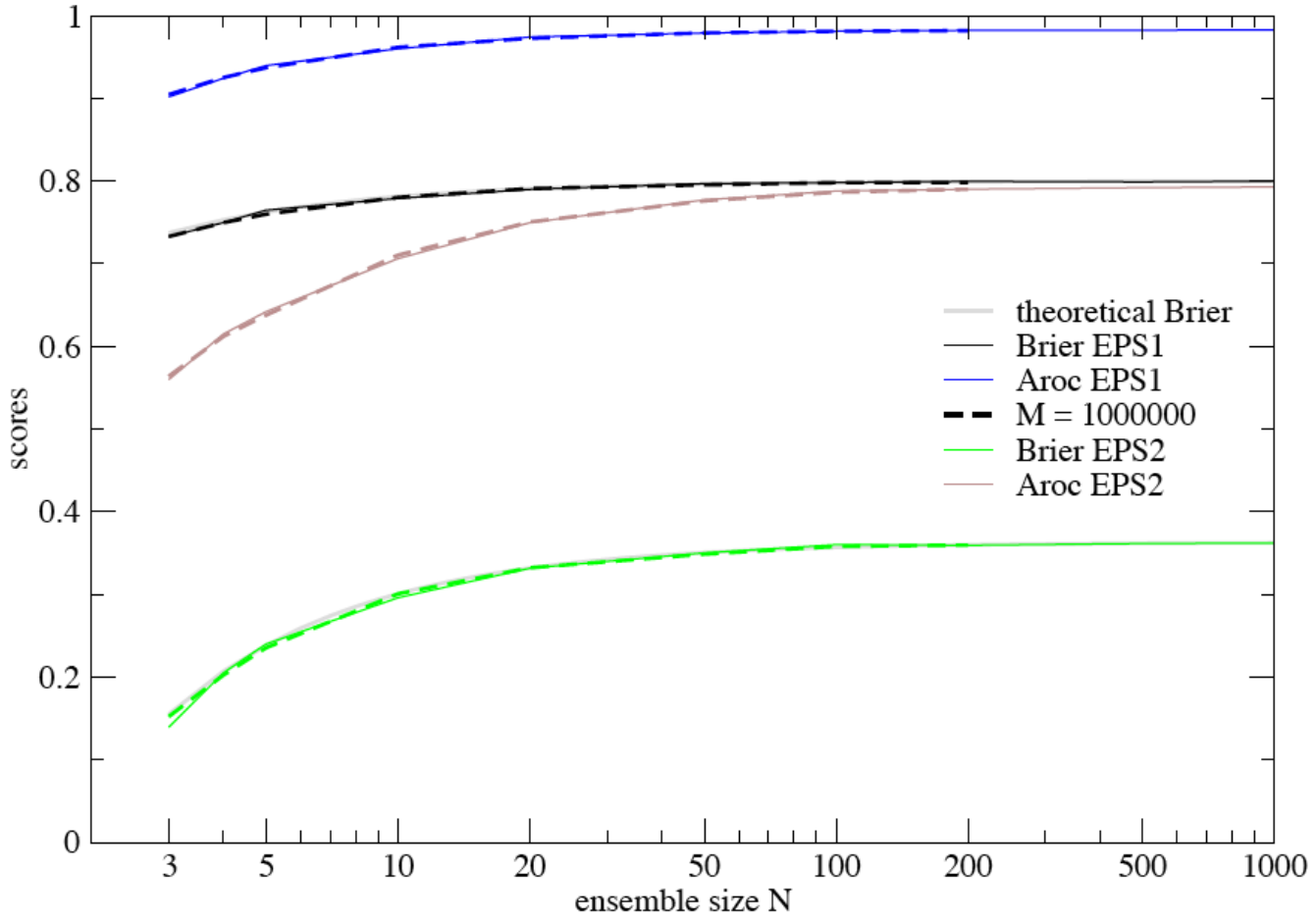
Perfect → exactly accurate (with infinitely precision)

Erred → inaccurate, or accurate but discrete

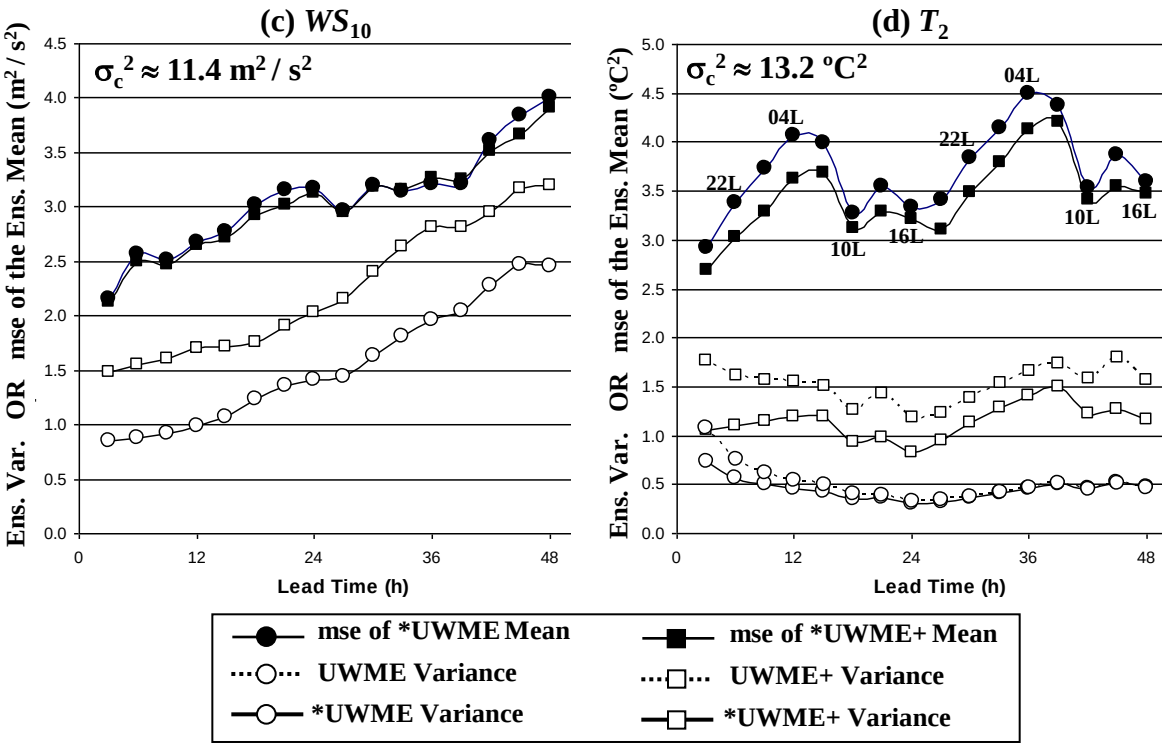
ICs by Ensemble Transform (ET)
(from Craig Bishop, NRL)

ET maintains error variance in more directions than breeding…





O. Talagrand and G. Candille, Workshop *Diagnostics of data assimilation system performance* ECMWF, Reading, England, 16 June 2009



Eckel and Mass, *WAF*, 2005