A Comparison of Ensemble Perturbations Generated by Breeding and Ensemble Kalman Filter Schemes

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Motivations

• Background
  – BV-ETR: It is NCEP Global Ensemble Forecast System (GEFS) initialization since 1992 – which is dynamically breading orthogonal fast growing perturbation in region with high baroclinicity.
  – HVEDAS: Hybrid Variation Ensemble Data Assimilation System will be implemented by May 22\textsuperscript{nd}, to deliver better quality of analysis (or initial condition of forecast).
  – EnKF: Ensemble Kalman Filter data assimilation will be implemented by May 22\textsuperscript{nd} for HVEDAS, which evolves an ensemble over data assimilation, updated at successive observation times.

• Motivations
  – To compare BV-ETR and EnKF initialized ensemble forecast
  – To take advantages of BV-ETR and EnKF, improving ensemble initial perturbations and forecast
Experiment design

• Period: 07/01 – 10/17/2011
• Forecast resolutions: T254L42/T190L42
• Forecast lead time: 8/16 days
• Initial condition: hybrid analysis (latest version)
• Perturbed initial conditions: ETR and EnKF
  – ETR is using current operational version
  – EnKF is using 6-hour forecasts from previous cycle
• Verification against: hybrid analysis
• Statistics:
  http://www.emc.ncep.noaa.gov/gc_wmb/xzhou/EnKF_ETR_16d.HTML
NH 500hPa height

RMS and Spread

CRPS

Reliability and Resolution

Anomaly Correlation
NH 850hPa Temperature

Northern Hemisphere 850hPa Temp.
Continuous Ranked Probability Skill Scores
Average For 20110701 – 20111017

CRPS

Northern Hemisphere 850hPa Temp. Brier Skill Scores (BSS)
Average For 20110701 – 20111017

Reliability and Resolution

NH 850hPa Temperature

Northern Hemisphere 850hPa Temp.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20110701 – 20111017

RMS error and Spread

Anomaly correlation
North American 2 Meter Temp.
Continued Ranked Probability Skill Scores
Average For 20110701 - 20111017

- CRPS
- Reliability and resolution
- RMS error and Spread
- Anomaly correlation
Preliminary summary

• **NH 500hPa height:**
  – The score differences are very small or insignificant.
  – BSS are similar, looks EnKF is more reliable, and ETR has more resolution for short lead time.
  – EnKF has a little over dispose (spread) for short lead time

• **NH 1000hPa height:**
  – EnKF has better CRPS score for day 5-10
  – EnKF has better reliability for short lead time (day 2-8)
  – EnKF has better error/spread ratio for short lead time

• **NH 850hPa temperature:**
  – EnKF has better CRPS and BSS score for first week
  – The scores for ensemble mean are very similar or insignificant

• **Tropical 850 u:**
  – EnKF has better score for short and longer lead time
  – ETR has a little better for reliability for short lead time
  – ETR is over dispose (spread) for initial time

• **Tropical 250 u:**
  – ETR has better score for CRPS and ensemble mean for day 3-8, but not week-2
  – EnKF is over dispose (spread) for initial time

• **Northern American Surface u (10-m):**
  – EnKF has better CRPS and BSS for day 1-3
  – The scores of ensemble mean are all similar or insignificant

• **Northern American Surface t (2-m):**
  – All score difference are small or insignificant
  – EnKF has better reliability for very short lead time
Please note that EnKF runs without applying TS relocation.

GFS – T574L64 (GSI analysis)
GEFS – T254L42 (GSI analysis)
EnKF – T254L42 (hybrid analysis)
ETR – T254L42 (hybrid analysis)

Forecast hours

#CASES 232 218 187 171 150 118 89 66

Courtesy of Jiayi Peng
Summary of TS track forecast

• TS track forecast for ensemble mean:
  – Both of ETR and EnKF is improving TS track forecast from initial hybrid analysis when comparing initial GSI analysis.
  – ETR has smaller track errors than EnKF for all lead times
    • 6.4% (24h); 5.2% (48h); 7.5% (72h); 4.0% (96h) and 8.3% (120h)
    • May be insignificant, or less samples
  – Possible reasons:
    • EnKF experiments do not run TS relocation?
    • Due to larger initial perturbations (over dispose)?
    • Will test this if it is possible

• GEFS track forecast is a very important NWP guidance for NHC hurricane forecast
  – Will compare ETR and EnKF for 2012 hurricane season closely
PECA (Pert versus Error Correlation Analysis)
NH Z500 error growth for different lead times

NorthH z500 FCST ERROR Growth Rate (/day) at Day 2

Meridonal Wavenumber

2-day

NorthH z500 FCST ERROR Growth Rate (/day) at Day 5

Meridonal Wavenumber

5-day

Convective scale – saturated earlier

NorthH z500 FCST ERROR Growth Rate (/day) at Day 10

Meridonal Wavenumber

10-day

NorthH z500 FCST ERROR Growth Rate (/day) at Day 16

Meridonal Wavenumber

16-day
NH Z500 perturbation (spread) growth for different lead times

ETR is different from EnKF
NH T850 error growth for different forecast lead times

NorthH t850 FCST ERROR Growth Rate (/day) at Day 2

NorthH t850 FCST ERROR Growth Rate (/day) at Day 5

NorthH t850 FCST ERROR Growth Rate (/day) at Day 10

NorthH t850 FCST ERROR Growth Rate (/day) at Day 16

Meridional Wavenumber
NH T850 perturb (spread) growth for different lead times

NorthH t850 Ensemble Perturb. Growth Rate (/day) at 2-day

NorthH t850 Ensemble Perturb. Growth Rate (/day) at 5-day

NorthH t850 Ensemble Perturb. Growth Rate (/day) at 10-day

NorthH t850 Ensemble Perturb. Growth Rate (/day) at 16-day
Summary of diagnostic study

• PECA evaluation:
  – Correlations are very similar for most domains and variables.
  – EnKF is a little better for ensemble mean at Northern hemisphere region.

• Ensemble error and spread growth:
  – ETR has slower growth for both error and spread for short lead time (day 1-3), but get faster and faster from medium range to extended range. This may be from ETR cycling and rescaling to filter out some of quickly growth (saturated) mode, such as convective mode.
  – Main contribution to spread growth is from wave 1-5 for extended range.
  – Short waves (>10) is saturated earlier
  – This diagnostic study (analysis) will help us for tuning stochastic perturbations in the future.
Plan

- To run EnKF experiment with TS relocation, to find out why TS track errors for EnKF are larger than ETR.
- To run ETR (or rescaling only) over EnKF (f06) which will allow both ETR and EnKF have similar (reasonable) sizes of ensemble initial perturbations, to find out if EnKF is still better for short lead time probabilistic forecasts.
- Preliminary conclusion will be presented after above two experiments
Background !!!
NH Anomaly Correlation for 500hPa Height

Period: January 1st – December 31st 2010

Anomaly Correlation vs Forecast (days)

- **GFS**: 8.0d
- **GEFS**: 9.7d
- **NAEFS**: 10.2d

0.6 skill line
RTMA Region 2m Temperature
Averaged From 2007090100 to 2007093000

NCEP/GEFS raw forecast

4+ days gain from NAEFS

NAEFS final products

From
Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Combination of NCEP and CMC
Down-scaling (NCEP, CMC)
NAEFS NDGD Probabilistic 2m Temperature Forecast Verification For 2007090100 – 2007093000

Continuous Ranked Probability Score (C)

Forecast Lead Time (Days)

From Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Combination of NCEP and CMC
Down-scaling (NCEP, CMC)

NCEP/GEFS raw forecast

8+ days gain

NAEFS final products
Atlantic, AL01~19 (06/01~11/30/2011)

- GEFSo---GEFS T190 (operational run)
- GEFSx---GEFS T254 (parallel run)
- GFS ------GFS T574 (operational run)

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ETR – T254L42 (hybrid analysis)

Please note that EnKF runs without applying TS relocation

Forecast hours

#CASES 232 218 187 171 150 118 89 66

Track error(NM)

Courtesy of Jiayi Peng
Flow Chart for Hybrid Variation and Ensemble Data Assimilation System (HVEDAS) - concept

Lower resolution

Ensemble fcst (1)  
$t=j-1 \rightarrow j$

Ensemble fcst (2)  
$t=j \rightarrow 16\text{ days}$

EnKF assimilation  
$t=j$

Ensemble fcst  
$t=j, \rightarrow j+1$

EnKF assimilation  
$t=j+1$

Estimated Background Error Covariance from Ensemble Forecast (6 hours)

Replace Ensemble Mean

1. Using EnKF f06 as initials

2. Using current ETR

Compare?

GSI/3DVAR  
$t=j$

Hybrid Analysis?

Higher resolution

Hybrid Analysis?
Fig. 6. Schematic of the time evolution of the rms amplitude of high-energy baroclinic modes and low-energy convective modes. Note that although initially growing much faster than the baroclinic modes, convective modes saturate at a substantially lower level.

Early study from Zoltan Toth: BAMS 1992
Two-scale Lorenz ‘96 model

\[
\frac{dx_i}{dt} = x_{i-1}(x_{i+1} - x_{i-2}) - x_i + F - \frac{hc}{b} \sum_{j=1}^{J} y_{i,j},
\]

\[
\frac{dy_{i,j}}{dt} = cby_{i,j+1}(y_{i,j-1} - y_{i,j+2}) - cy_{i,j} + \frac{c}{b} F_y + \frac{hc}{b} x_i,
\]

slow large-scale variables \( x_i \) (i=1,2,...I)

fast small-scale variables \( y_{i,j} \) (i=1,2,...I; j=1,2,...J)

Let \( I=36 \) and \( J=10 \) in this study.

Thus, the slow large-scale variables \( x_i \) could be thought of some atmospheric quantity in 36 sectors of a latitude circle, so that each large sector covers 10 degrees of longitude, while the fast small-scale variables \( y_{i,j} \) can represent the values of some other quantity in 36*10 sectors, so that each small sector covers 1 degree of longitude in one large sector.
Results from Lorenz experiments

- **h=0**
  - No interaction
  - Slow mode
  - Fast mode

- **h=0.1**
  - Slow mode
  - Fast mode

- **h=0.5**
  - Slow mode
  - Fast mode

- **h=0.8**
  - Slow mode
  - Fast mode

**Lead time (hr)**

**RMSE**

*Courtesy of Jessie Ma*