A Stochastic Perturbation Scheme (SPS)
Representing Model Related Uncertainty
in NCEP Global Ensemble Forecasting System

Dingchen Hou*, Zoltan Toth,
Yuejian Zhu and Weiyu Yang*

Environmental Modeling Center/NCEP/NOAA
5200 Auth Road, Camp Springs, MD 20746, USA
* SAIC at EMC/NCEP/NOAA

Acknowledgements:
Mark Iredell, Henry Juang, Stephane Vannitsem, Stephen Lord,
Richard Wobus, Bo Cui, Cecile Penland, Prashant Sardeshmukh,
James Purser, Mozheng Wei, Mike Young, Joe Sela and Shrinivas Moorthi.
Formulation *(Hou, Toth and Zhu 2006)*

General Expression:  \[ \dot{X}_i = T_i + S_i \quad \text{for each ensemble member } i \]

- **T**=Conventional Tendency,  
- **S**=Stochastic Tendency

Strategy: Use \( P_i = T_i - T_0 \) vectors as the basis for stochastic forcing **S**

Formulation of **S** vectors:  \[ S_i \sim \sum_j w_{i,j} P_j \]

Generate the **S** terms from (random) linear combinations of the conventional perturbation tendencies, similar to ET but applied to ensemble perturbation tendencies successively

**Generation of combination coefficients:**

An orthogonormal matrix \( W \), as a function of lead time \( t \), is generated using the methodology and software provided by James Purser. Each coefficient \( w_{i,j} \) is a random walk superimposed on a periodic function, and an example is shown.

\[ w_{14}(t) \text{ for } i=14, \text{ and } j=1,2,\ldots,14, \text{ in a 14-member ensemble} \]
The Current Version (Hou, Toth, Zhu and Yang, 2008)

Use a finite difference form for the tendency, with 6 hour time interval
The Scheme is applied every 6 hours by modifying the model state using

\[ X_i' = X_i + \gamma \sum_{j=1}^{N} w_{i,j}(t) \left[ (X_j)_t - (X_j)_{t-6h} \right] - \left[ (X_0)_t - (X_0)_{t-6h} \right] \]

For \( t=6h, 12h, \ldots \)

Where \( \gamma \) is a rescaling factor \( \gamma = \gamma_0 \gamma_1 \)

Global Rescaling \( \gamma_0 \), a logistic function of lead time \( t \):

\[ \gamma_0 = 0.03 + (0.105 - 0.03) \left( 1 - \frac{1.0}{1.0 + \exp[-0.02(t - 252h)]} \right) \]

Regional Rescaling \( \gamma_1 \), a harmonic function of latitude and season:

\[ \gamma_1 = 1.0 + A \sin(\theta) \sin \frac{2\pi(d - 91)}{364} \]

\( \Theta=\)Latitude, \( A=0.2 \)
\( d=\)Julian Day of the initial time
Implementation Under ESMF Environment

(ESMF=Earth System Modeling Framework)
Simultaneously integrating all members (Module G) and periodically applying SPS (Module Cpl)
Impact on Ensemble Forecast

- Increase in ensemble spread toward RMSE of ensemble mean;
- Reduction in systematic (domain mean) error
- Improvement in ensemble based probabilistic forecast, especially the reliability related scores;
- Improvement in ensemble pdf, measured by the CRPSS score;
- Additive impact to increase in model resolution;
- Additive impact to (off line) statistical bias correction.
Impact of SPS on Ensemble Mean Forecast
----- Reduced (Negative) Bias and Increased Spread

NH H500 Winter

SH T850 Winter
Impact of SPS on Ensemble Mean Forecast
Increased Spread, Reduced Mean Error (ME)
Reduced Mean Absolute Systematic Error (MASE)

----- Without SPS    ----- With SPS

NH 500 mb Geopotential Height
Average For 00Z01OCT2004 - 00Z31OCT2004

Solid, rmse  Dash: spread

SH 500 mb Geopotential Height
Average For 00Z01OCT2004 - 00Z31OCT2004

Solid: rmse  Dash: spread

\[
MASE = \left( \frac{f-a}{\bar{a}} \right)
\]
Impact of SPS on
Ensemble Based Probabilistic Forecast and Ensemble pdf
----- Improved verification Scores

Southern Hemisphere 850hPa Temp. Brier Skill Scores (BSS)
Average For 20060816 - 20060930

Southern Hemisphere 850hPa Temp.
Continuous Ranked Probability Skill Scores
Average For 20060816 - 20060930

BSS
Resolution
Reliability
Impact of SPS
T126L28 vs. T190L28 resolution
Additive impacts with increase in resolution

Tropical 850hPa Temp.
Continuous Ranked Probability Skill Scores
Average For 20071101 - 20071129

CRPSS

ROC

--- T126L28
--- T126L28 + SP
--- T190L28
--- T190L28 + SP
Impact of SPS

Additive Impact with Statistic Bias Correction (PP)

For RPSS Score, the positive impact of SPS and PP adds up