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Stochastic Parametrization of Deep Convection in a Regional Ensemble Prediction System

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Rationale for stochastic parametrizations

- Stochastically Perturbed Parametrization Tendencies scheme (SPPT ; Buizza et al. 1999, Charron et al. 2010) is very efficient method to represent model error but rather unsatisfactory from a more fundamental perspective.

- In the long-term, SPPT should be ideally replaced by more physically based approaches to error simulation – inherently stochastic schemes.

- At RPN-A/CMC, we are currently working on a stochastic deep convection scheme and investigating its application in the REPS.

Stochastic deep convection scheme at RPN/CMC

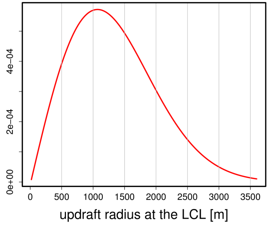
- **Approach is based on the Plant-Craig (PC) stochastic deep convection scheme** (Plant and Craig, 2008).

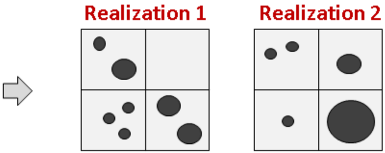
- **Plume model adopted from Bechtold scheme (Bechtold, 2001) :**
  - A bulk mass-flux parametrization very similar to Kain-Fritsch (KF ; used in the original PC scheme)
  - CAPE-type closure – based on the assumption that 90% of CAPE is removed within a specified adjustment period $\sim$ 60 min
  - The plume model used with this scheme, however, differ to some extent from KF (e.g., triggering mechanism, conservation of enthalpy and mixing ratio).

- **Rationale for the use of Bechtold scheme :**
  - Modular structure
  - Consistent deep and shallow convection representation – possible extension to shallow convection.

Stochastic deep convection scheme at RPN/CMC

- **Deterministic version of the Bechtold scheme :** A single plume represents the mean properties of the entire subgrid-scale population of clouds.
- **Stochastic version :** in a given grid cell a cluster of convective activity with different intensities and sizes occurs.
  - Multiple plumes are randomly drawn from the radius distribution
  - Population size scaled by the closure assumptions.





Plume sampling function

- The clouds are generated based on the **Plume sampling function** – on average <N> plumes is generated during the specified cloud life time T (45 min in our case) :

$$p(r)dr = \langle N \rangle \frac{\Delta t}{T} \frac{2r}{\langle r^2 \rangle} exp\left(-\frac{r^2}{\langle r^2 \rangle}\right)$$

  where $\langle N \rangle$ is the expected number of plumes generated over time T :

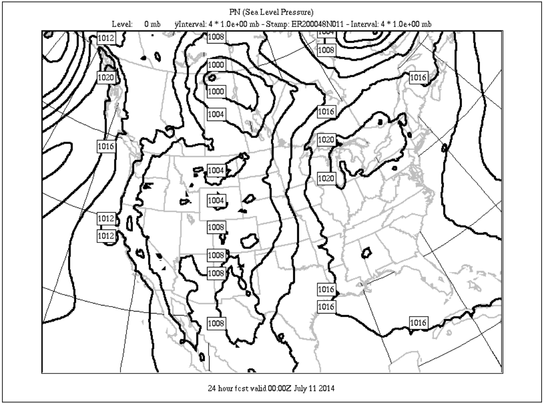
$$\langle N \rangle = \frac{\langle M \rangle}{\langle m \rangle}$$

- $\langle M \rangle$ is obtained from CAPE closure assumptions in the deep-convection scheme. In other words <N> number of clouds act to remove 90$\%$ of the CAPE in time T. This is equivalent to as having one single plume in the given area but with mass flux M.
- $\langle N \rangle$ can be changed by the tuneable $\langle m \rangle$ but if $\langle m \rangle$ is reduced the scheme becomes more costly. Therefore, larger grid areas could be problematic.

Preliminary results

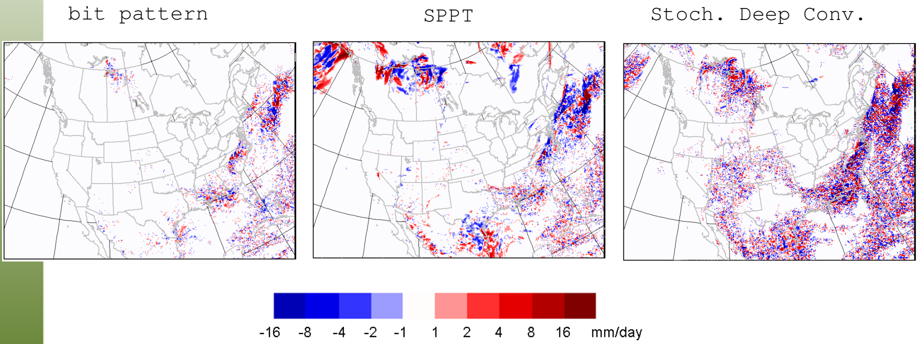
- Case of REPS forecast for *0000Z 10 July 2014*
- REPS domain zoomed over the US (24-hr forecast valid 0000Z 11 July)

surface pressure



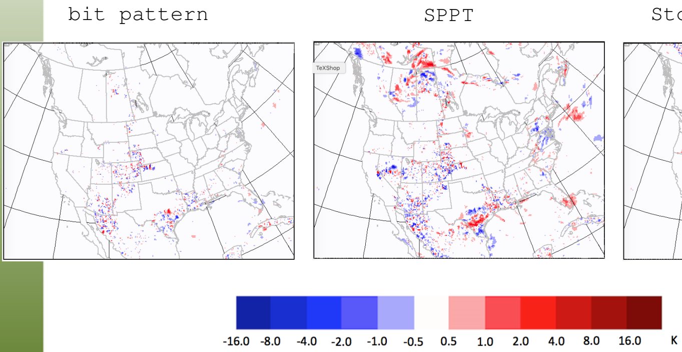
Preliminary results

- Impact of various perturbations on **00-24h pcp accumulation** (valid *0000Z 11 July 2014)*
- One source of perturbations at a time.



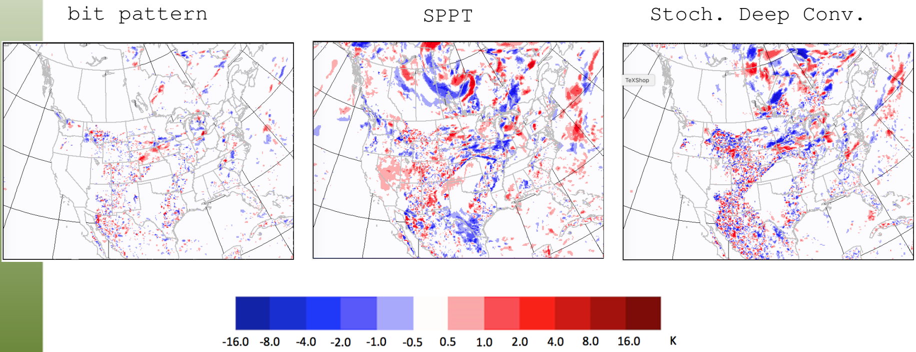
Preliminary results

- Impact of various perturbations on **24h screen-level temperature** (valid *0000Z 11 July 2014)*
- One source of perturbations at a time.



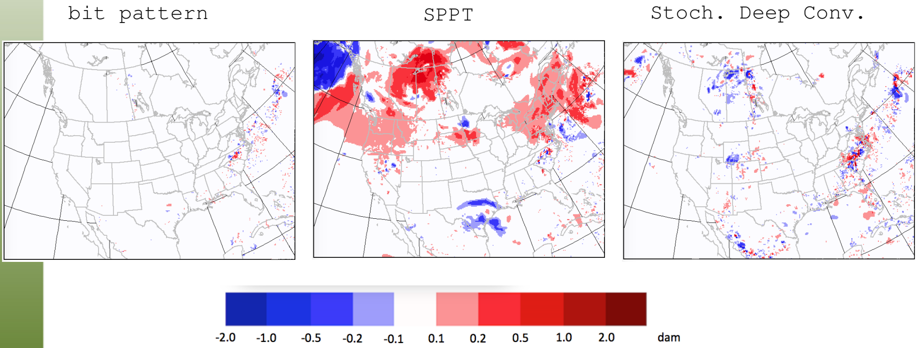
Preliminary results

- Impact of various perturbations on **72h screen-level temperature** (valid *0000Z 13 July 2014)*
- One source of perturbations at a time.



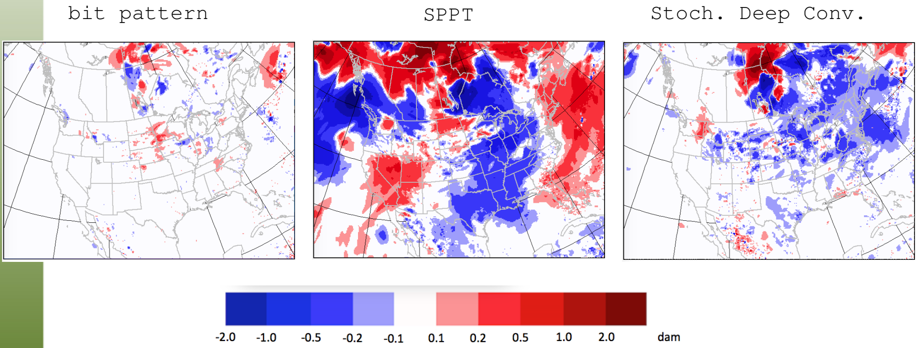
Preliminary results

- Impact of various perturbations on **24h GZ 500 hPa** (valid *0000Z 11 July 2014)*
- One source of perturbations at a time.



Preliminary results

- Impact of various perturbations on **72h GZ 500 hPa** (valid *0000Z 13 July 2014)*
- One source of perturbations at a time.



Scale analysis of regional REPS error

- EPS field : $x = x_m(i, j, k, t, \tau)$
  i, j and k are horizontal and vertical grid indices, m ensemble member, t forecast issue time and τ lead time.

- Analysis : $y = y(i, j, k, t + \tau)$.

- Model error $\varepsilon_m \equiv x_m - y$ is decomposed as

$$\langle \varepsilon \rangle = \langle x \rangle - y$$

$$\varepsilon_m{}^* = x_m - \langle x \rangle,$$

  where

$$\langle x \rangle = \frac{1}{N_m} \sum_{m=1}^{N_m} x_m.$$

  is the ensemble mean.

Scale analysis of REPS error

- Using the Discrete Cosine Transform (Denis *et al.* 2002), the spatial variance of model error ε can be decomposed into contributions from different spatial scales λ :

$$\sigma^2_{\varepsilon\varepsilon}(k, m, t, \tau) \equiv \overline{(\varepsilon - \overline{\varepsilon})^2} = \sum_{q=1}^{N_q} \hat{\sigma}^2_{\varepsilon\varepsilon}(\lambda_q, k, m, t, \tau)$$

  where

$$\overline{(\,\cdot\,)} = \frac{1}{N_i N_j} \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} (\,\cdot\,)$$

  is the spatial average.

- It can be shown that the expectation of the error variance over the ensemble is additive in terms of error components :

$$\langle \hat{\sigma}^2_{\varepsilon\varepsilon} \rangle = \hat{\sigma}^2_{\langle\varepsilon\rangle\langle\varepsilon\rangle} + \langle \hat{\sigma}^2_{\varepsilon^*\varepsilon^*} \rangle$$

Error variance components

- The two error variance components can be conveniently expressed in the form of the law of cosines :

$$\hat{\sigma}^2_{\langle\varepsilon\rangle\langle\varepsilon\rangle} = \hat{\sigma}^2_{yy}\left(1 + (\hat{\gamma}\hat{\rho})^2 - 2\,(\hat{\gamma}\hat{\rho})\,\hat{r}\right) \qquad (1)$$

$$\langle\hat{\sigma}^2_{\varepsilon*\,\varepsilon*}\rangle = \hat{\sigma}^2_{yy}\left(\hat{\gamma}^2(1 - \hat{\rho}^2)\right). \qquad (2)$$

- Here $\hat{\gamma}$ represents the spectral ratio of variances, $\hat{\rho}$ is the inter-member coherence and $\hat{r}$ is the coherence between the ensemble mean and analyses :

$$\hat{\gamma}^2 \equiv \frac{\langle\hat{\sigma}^2_{xx}\rangle}{\hat{\sigma}^2_{yy}}, \qquad \hat{\rho}^2 \equiv \frac{\hat{\sigma}^2_{\langle x\rangle\langle x\rangle}}{\langle\hat{\sigma}^2_{xx}\rangle}, \qquad \hat{r} \equiv \frac{\hat{\sigma}^2_{\langle x\rangle y}}{\left(\hat{\sigma}^2_{\langle x\rangle\langle x\rangle}\,\hat{\sigma}^2_{yy}\right)^{1/2}}.$$

- The role of $\hat{\rho}$ is twofold – it represents :
  1. Smoothing effect of averaging in the ensemble mean (Eq. 1)
  2. Ensemble spread (Eq. 2)

Modern-Era Retrospective analysis for Research and Applications (MERRA)

DA System

- Goddard Earth Observing System Model version 5 (GEOS-5) atmospheric DA system.
- Integrates a AGCM with grid-point statistical interpolation.
- 1/2 $^\circ$ x 1/3 $^\circ$ horizontal grid, 72 levels.

Dataset

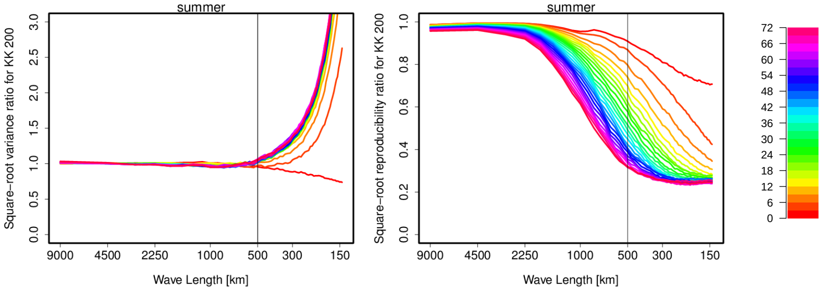
- Fields : GZ, UU, VV, TT @ 500 and 250 hPa.
- Three-hourly time series (instantaneous values).
- Lat-lon grid 0.5° x 0.625° interpolated to the REPS grid (0.1375°).

Verification period

- Winter : January 01 – 31, 2014.
- Summer : July 01 – 31, 2014.

Variance Ratio and Reproducibility, EKIN 200 hPa, summer)

$$\hat{\gamma} \equiv \left(\frac{\langle \hat{\sigma}^2_{xx} \rangle}{\hat{\sigma}^2_{yy}} \right)^{1/2}, \qquad \hat{\rho} \equiv \left(\frac{\hat{\sigma}^2_{\langle x \rangle \langle x \rangle}}{\langle \hat{\sigma}^2_{xx} \rangle} \right)^{1/2}$$



Spread-to-error ratio

- Members of a perfect EPS and perfect analyses would be statistically indistinguishable. Hence :

  $$\langle \varepsilon \rangle = \langle x \rangle - y \quad \sim \quad \langle x \rangle - x = \varepsilon^*$$

  which yields

  $$\hat{\sigma}^2_{\langle \varepsilon \rangle \langle \varepsilon \rangle} = \langle \hat{\sigma}^2_{\varepsilon^* \varepsilon^*} \rangle$$

  or

  $$1 + (\hat{\gamma}\hat{\rho})^2 - 2\,(\hat{\gamma}\hat{\rho})\,\hat{r} = \hat{\gamma}^2(1 - \hat{\rho}^2).$$

- *In the spectral range* in which we have confidence in the analyses we require :

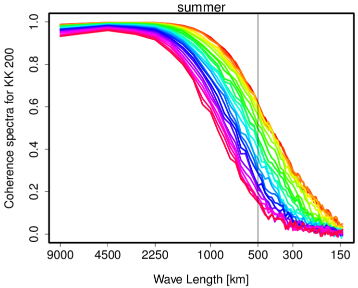
  $$\hat{\gamma} \approx 1$$

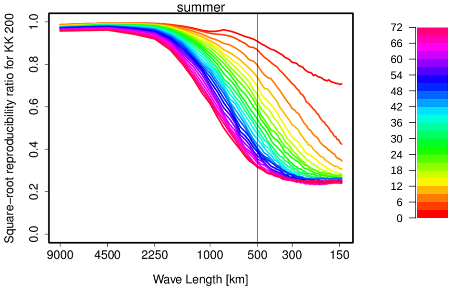
  which yields the following necessary condition for an EPS to be balanced :

  $$\hat{\rho} \approx \hat{r}.$$

Coherence vs. Reproducibility Ratio, EKIN 200 hPa, summer

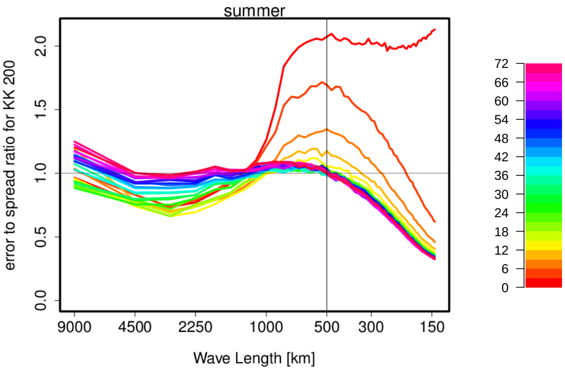
$$\hat{r} \equiv \frac{\hat{\sigma}^2_{\langle x \rangle y}}{\left(\hat{\sigma}^2_{\langle x \rangle \langle x \rangle}\ \hat{\sigma}^2_{yy}\right)^{1/2}} \qquad \hat{\rho} \equiv \left(\frac{\hat{\sigma}^2_{\langle x \rangle \langle x \rangle}}{\langle \hat{\sigma}^2_{xx} \rangle}\right)^{1/2}$$





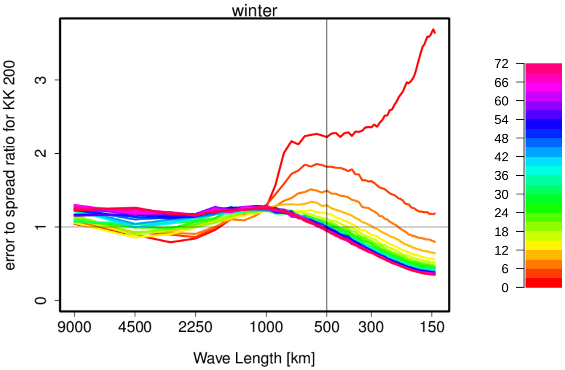
Error-to-Spread Ratio, EKIN 200 hPa, summer

$$\left(\hat{\sigma}^2_{\langle\varepsilon\rangle\langle\varepsilon\rangle}/\langle\hat{\sigma}^2_{\varepsilon^*\varepsilon^*}\rangle\right)^{1/2}$$



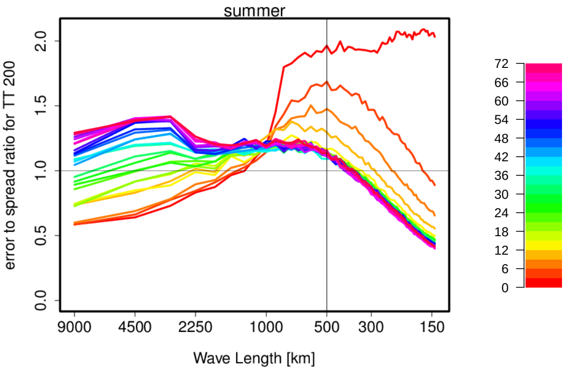
Error-to-Spread Ratio, EKIN 200 hPa, winter

$$\left(\hat{\sigma}^2_{\langle\varepsilon\rangle\langle\varepsilon\rangle} / \langle\hat{\sigma}^2_{\varepsilon*\varepsilon*}\rangle\right)^{1/2}$$



Error-to-Spread Ratio, TT 200 hPa, summer

$$\left(\hat{\sigma}^2_{\langle\varepsilon\rangle\langle\varepsilon\rangle} / \langle\hat{\sigma}^2_{\varepsilon^*\varepsilon^*}\rangle\right)^{1/2}$$



Applications of the scale analysis method

- **Study the contribution of different sources of perturbations**
  - Use to study the impact of perturbations in initial and lateral boundary conditions, SPPT
  - Contrubution of stochastic parametrizations to the spread.

- **Uncertainty in the reanalyses**
  - Use other renalaysis (ERA-Interim, NARR - higher spatial resolution (35 km), 3-hourly
  - Use CMC analyses.

- **Apply to the Global EPS**
  - The method can be easily adapted to allow spectral transformations on the sphere
  - More degrees of freedom for PTP and stochastic parametrizations than in the REPS.

Conclusions and Future Work

- **Expectations from the stochastic deep convection scheme :**
  - Contribute to ensemble spread in weather situations with **weak large-scale forcing** – convection driven with the diurnal cycle.
  - Increase the spread at scales **below 1000 km** in the **early** stages of the forecast.
  - Hasten the **upscale propagation** of the inter-memember differences.
  - It is not expected to have a large impact in situations with strong large-scale forcing.

- **Future work :**
  - Scheme adds fine-scale variability (grainy precipitation patterns) – how this impacts the quality of the forecasts ?
  - A systematic evaluation of the scheme in REPS and proper scoring.
  - Introducing stochasticity in other schemes (e.g., shallow convection, PBL vertical diffusion, gravity wave drag).