Diagnosis of analysis and forecast ensembles by using normal modes

N. Žagar, J. Tribbia, J. Anderson, K. Raeder, L. Isaksen and D. Tan

Questions

- How large part of the global atmospheric forecast errors pertains to the divergent motion i.e. inertia-gravity (IG) waves?
- How is the analysis uncertainty split between the balanced (ROT) and IG motion? How is it dependent on the assimilation system and the assimilation methodology (4D-Var versus the ensemble Kalman filter (EnKF))?
- How important are the large-scale tropical waves for the global data assimilation? How are the tropical forecast errors in the IG motion spread across the scales, time and motion types?
- What is the real potential of the EnKF due to flow-dependent background-error covariances in comparison to 4D-Var, especially in the tropics?

Datasets

Two ensembles of global analyses and forecasts for July 2007:
- ECMWF EnKF system DART/CAM (http://www.image.ucar.edu/DARTs/DARTs/): 80-member CAM ensemble on the horizontal resolution T85, 26 vertical levels up to 3.5 hPa. Limited number of observations (conventional observations and AMVs). The covariance localization and a time constant, spatially varying covariance levels.
- DART/CAM 4D-Var ensemble: 21-member ensemble with 12 hour 4D-Var and model cycle 32r3. It uses operational 91 levels up to 0.01 hPa (80 km) the horizontal resolution T85, 26 vertical levels up to 3.5 hPa. Limited (http://www.image.ucar.edu/DAReS/DART/): 80-member CAM ensemble on the horizontal resolution T85, 26 vertical levels up to 3.5 hPa. Limited number of observations (conventional observations and AMVs). The covariance localization and a time constant, spatially varying covariance levels.

Normal mode expansion

3D orthogonal modes of Kasahara and Puri (MWR, 1981). Basic idea is to select the subset of modes which provides the optimal fit to the input vector X for each ensemble member. Differences between the ensemble members are analyzed in the space of modes (k,n,m).

\[ X(\lambda, \phi, z) = \sum_{k=0}^{N_k} \sum_{n=0}^{N_n} \sum_{m=0}^{N_m} (S_k n m) \Phi_k(n m)(\lambda, \phi) P_m(z) \]

\[ \Phi_k(n m)(\lambda, \phi) = H_{knm} \Psi_k(n m) \]

Summary

- Application of normal modes offers a physically attractive approach to quantification of uncertainties in analyses and forecasts. It can point out the scales and motion types most affected by the inflation, localization, observations and model biases.
- Two very different ensembles show an increased uncertainty in mid-July 2007. Its exact origin and implications to be studied.
- Among various IG motion, the greatest uncertainty is found in the Kelvin wave in both systems.
- The fact that there is more IG motion in the increment fields than in the prior ensemble spread in the DART/CAM system is possibly an indication of the noise introduced by the assimilation step.

Contact information:
Nedjeljka Žagar, University of Ljubljana, Slovenia nedjeljka.zagar@fmf.uni-lj.si
Joe Tribbia, Jeff Anderson, Kevin Raeder
National Center for Atmospheric Research, Boulder, CO tribbia@ucar.edu, janderson@ucar.edu
Lars Isaksen, David Tan
European Centre for Medium-Range Weather Forecasts, UK lars.isaksen@ecmwf.int, david.tan@ecmwf.int

Analysis increments average spectra

ECMWF 3-h fc ensemble: average spread vs. its variability

Half of the 3-hour forecast ensemble spread is associated with the IG motion. Long scales dominate; k=1 Kelvin wave (n=0) for the eastward IG (EIG) motion and k=6, n=1 for the westward IG (WIG) motions. The error amplitude variability is large, factor 2-3 in the balanced (ROT) modes. The origin of the large error increase on 9-10 July 2007 and its importance for the initialization still unclear.

ECMWF 3-h fc ensemble: average spread vs. its variability

Kelvin wave fc-error evolution

The ensemble spread is related to the impact of inflated covariances, the observation coverage and flow properties. The reduction of uncertainties does not necessarily coincide with the structure of the forecast ensemble spread. Uncertainties reduce where the observations exist. Little observation available in the tropics => the Kelvin wave spread cannot be maintained.