Predicting uncertainty in the global ICON Ensemble

• Perturbation Methods in global Ensembles
• The ICON-EPS
• The ECMWF-EPS
• Spread-Skill properties

by Michael Denhard
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SPPT  \rightarrow  stochastic perturbed physical tendencies  
SKEB \rightarrow  stochastic kinetic energy backscatter  
RPA/RPP \rightarrow  random parameters  
Rphys \rightarrow  random physics
 ICON EPS

operational suite (will start November 2017)

• 40 Member
• Global, 40 km ( -> +180h)
• 00/12 UTC → +180h and 06/18UTC → +120h
• ICON-EU Nest, 20 km ( -> +120h)
• ETKF
• Focus is on short range up to +72h
• Boundary Conditions for COSMO-DE-EPS (2.8km, +27h)
• LETKF (Localized Ensemble Transform Kalman Filter, Hunt et.al. 2007)
• 40 Members (→ 80 Members)
• 3h Assimilation Cycle
• 40 km (20 km Europa)

• Covariance Inflation
  - multiplicative factor
  - additive Inflation $+0.25B_{3dVar}$ (NMC Method)
  - „relaxation to the prior“
  - SST 1°K random perturbations with spatial correlations of 100km/1000km and 1 day
Ensemble Data Assimilation (EDA)

Ensemble of independent 12-hour 4D-Var assimilations at T399L91 with two minimizations at T95 and T159 by perturbing observations.

Stochastic Physics (SPPT)

model physics perturbations

Singular Vector perturbations

Eigenvalue Problem \[ M^* EMx = \lambda Dx \]

where \( M \) is the tangent linear Operator and \( D, E \) define the Norm at initial (D) and evolved (E) time.
Kinetic energy spectra of IFS M001 at 100 hPa
2016081000-2016081700 steps 0 - 120 h (8 fcts.)

Kinetic energy spectra of ICON M001 0195 at 100 hPa
2016081000-2016081700 steps 0 - 120 h (8 fcts.)

LETKF covariance inflation?

Perturbed Observations?
Forecasts | ICON-EPS (ice)  
| ECMWF-EPS (ece)  

Verification | Mai, June, July, August, September (2016)  

Lead times | up to +180h  

Resolution | 1,5° x 1,5° regular lat/lon (aggregated from finer grids)  
| 0,5° x 0,5° regular lat/lon  

Domains | Northern Mid Latitudes (20° - 65°N, NML)  

Parameter | 500hPa Geopotential
Time Series

RMSE, Spread
+24h

ICON-EPS

ECMWF-EPS

rmse & spread

May               Jun                Jul                  Aug               Sep              Oct

time

May       |       Jun   |       Jul   |       Aug    |       Sep     |       Oct    |
-----------------|----------------|-----------------|-----------------|-----------------|-----------------|
4.0          | 4.5          | 5.0            | 5.5            | 6.0            | 6.5            |
4.5          | 5.0          | 5.5            | 6.0            | 6.5            | 7.0            |
5.0          | 5.5          | 6.0            | 6.5            | 7.0            | 7.5            |
5.5          | 6.0          | 6.5            | 7.0            | 7.5            | 8.0            |
6.0          | 6.5          | 7.0            | 7.5            | 8.0            | 8.5            |
6.5          | 7.0          | 7.5            | 8.0            | 8.5            | 9.0            |
7.0          | 7.5          | 8.0            | 8.5            | 9.0            | 9.5            |
7.5          | 8.0          | 8.5            | 9.0            | 9.5            | 10.0           |
8.0          | 8.5          | 9.0            | 9.5            | 10.0           | 10.5           |
8.5          | 9.0          | 9.5            | 10.0           | 10.5           | 11.0           |
9.0          | 9.5          | 10.0           | 10.5           | 11.0           | 11.5           |
9.5          | 10.0         | 10.5           | 11.0           | 11.5           | 12.0           |
10.0         | 10.5         | 11.0           | 11.5           | 12.0           | 12.5           |
10.5         | 11.0         | 11.5           | 12.0           | 12.5           | 13.0           |
11.0         | 11.5         | 12.0           | 12.5           | 13.0           | 13.5           |
11.5         | 12.0         | 12.5           | 13.0           | 13.5           | 14.0           |
12.0         | 12.5         | 13.0           | 13.5           | 14.0           | 14.5           |
12.5         | 13.0         | 13.5           | 14.0           | 14.5           | 15.0           |
13.0         | 13.5         | 14.0           | 14.5           | 15.0           | 15.5           |
13.5         | 14.0         | 14.5           | 15.0           | 15.5           | 16.0           |
14.0         | 14.5         | 15.0           | 15.5           | 16.0           | 16.5           |
14.5         | 15.0         | 15.5           | 16.0           | 16.5           | 17.0           |
15.0         | 15.5         | 16.0           | 16.5           | 17.0           | 17.5           |
15.5         | 16.0         | 16.5           | 17.0           | 17.5           | 18.0           |
16.0         | 16.5         | 17.0           | 17.5           | 18.0           | 18.5           |
16.5         | 17.0         | 17.5           | 18.0           | 18.5           | 19.0           |
17.0         | 17.5         | 18.0           | 18.5           | 19.0           | 19.5           |
17.5         | 18.0         | 18.5           | 19.0           | 19.5           | 20.0           |
18.0         | 18.5         | 19.0           | 19.5           | 20.0           | 20.5           |
18.5         | 19.0         | 19.5           | 20.0           | 20.5           | 21.0           |
19.0         | 19.5         | 20.0           | 20.5           | 21.0           | 21.5           |
19.5         | 20.0         | 20.5           | 21.0           | 21.5           | 22.0           |
20.0         | 20.5         | 21.0           | 21.5           | 22.0           | 22.5           |
+24h

**ICON-EPS**

**ECMWF-EPS**
+72h

**ICON-EPS**

**ECMWF-EPS**
Spread-Skill properties

\[
E\left(\|f_{i,t,k} - \langle f_{i,t} \rangle_q\|_q\right) = E\left(\|a_{i,t} - \langle f_{i,t} \rangle_q\|_q\right) \quad \forall k \in K
\]

Forecast \( f_{i,t,k} \) with \( k = 1, \ldots, K \) ensemble members

Analysis \( a_{i,t} = h(o_{i,t}) \)

Observation \( o_{i,t} \)

Time steps \( t = 1, \ldots, T \)

Grid points \( i = 1, \ldots, N \)

\( q \)-Norm
ICON EPS vs. Observations

provided by Felix Fundel

Geopotential [20160801, 20161005]

Spread/Skill ratio

Feedbackfile Verification by Felix Fundel

… using forward operators from data assimilation
500hPa Geopotential, NML

![Graph showing rmse & spread over lead time](image)

![Graph showing rmse & spread over time](image)
30. September 2016  0,5° x 0,5°

Error [Pa]

+24h ICON Ensemble 0.5° x 0.5°

+168h ICON Ensemble 0.5° x 0.5°

ICON-EPS

Spread [Pa]

+24h ECMWF-EPS 0.5° x 0.5°

+168h ECMWF-EPS 0.5° x 0.5°

ECMWF-EPS
→ 1.5° x 1.5° grid

+24h ICON Ensemble

+168h ICON Ensemble

+24h ECMWF-EPS

+168h ECMWF-EPS

30. September 2016

Spread [Pa]
Spread-Skill Reliability

Leutbecher, M., 2009: Diagnosis of Ensemble Forecasting Systems, ECMWF

Linear Regression Model
Spread Skill Reliability

slope of linear regression model

Calibration:
- multiplicative inflation and deflation
- mean spread equals mean error (dotted lines)

perfect = 45°
lead time is colour coded

ECMWF-EPS

ICON-EPS

slope of spread/error regression [°]
The ICON EPS …

… has reasonable spread/skill properties

… but it takes to long to develope a proper spread skill relation.

→ outside the forecast range of LAM ensembles
Stochastic non-dynamical forcing pushes the model state away from its stable manifold!

\[ \text{\textup{spectral pattern generator}} \]

"Stochasticity should be introduced only where appropriate and not in every part of the model physics, otherwise physical meaning is lost."

SRNWP workshop on physical parametrisation and ensemble prediction 18-20 June 2013, Madrid Spain