Uncertainty of numerical weather prediction (NWP)

Henrik Feddersen, DMI
Numerical weather prediction

Observations → Analysis → Atmospheric model → Forecast

\[
\begin{align*}
\frac{\partial U}{\partial t} + \frac{1}{a \cos \theta} \left( U \frac{\partial U}{\partial x} + V \cos \theta \frac{\partial U}{\partial \theta} \right) + \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta (U^2 + V^2) \right) &= 0 \\
\frac{\partial V}{\partial t} + \frac{1}{a \cos \theta} \left( U \frac{\partial V}{\partial x} + V \cos \theta \frac{\partial V}{\partial \theta} \right) &= 0 \\
\frac{\partial T}{\partial t} + \frac{1}{a \cos \theta} \left( U \frac{\partial T}{\partial x} + V \cos \theta \frac{\partial T}{\partial \theta} \right) &= \frac{\partial \phi}{\partial \eta} \\
\frac{\partial q}{\partial t} + \frac{1}{a \cos \theta} \left( U \frac{\partial q}{\partial x} + V \cos \theta \frac{\partial q}{\partial \theta} \right) &= \frac{\partial \phi}{\partial \eta} \\
\frac{\partial}{\partial \theta} \left( \frac{\partial p}{\partial \theta} \right) + \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \frac{\partial p}{\partial \theta} \right) &= 0
\end{align*}
\]
Uncertainties

- Observations
- Model
- Nonlinearity and chaos
Uncertainties

• Observations
  - Accuracy
  - Errors
  - Coverage

• Model

• Nonlinearity and chaos
Uncertainties

• Observations
  – Accuracy
  – Errors
  – Coverage

• Model
  – Unresolved scales
  – Theory
  – Numerics
  – Bugs

• Nonlinearity and chaos
Initial condition uncertainty

- Specify initial probability density
- Use Monte Carlo method to sample initial probability density and integrate model for every sample
Initial condition uncertainty

- Specify initial probability density
- Use Monte Carlo method to sample initial probability density and integrate model for every sample
In practice: Ensemble forecasting

- Perturb the analysis
- Run a limited number of ensemble members (~10 – 100) using perturbed analyses as initial conditions
Model uncertainty
Multi-scheme ensemble

NWP model physics

- Condensation 1
- Condensation 2
- Radiation
- Turbulence
- Surface 1
- Surface 2
DMI ensemble setup

Observations

Analysis → atmospheric model

Forecast
DMI ensemble setup

Observations

ECMWF

Analysis → Global atm model → Forecast

Boundary conditions

Observations

DMI

Analysis → Limited-area atm model → Forecast

Boundary condition perturbations

Initial condition perturbations

Model perturbations
DMI ensemble configuration in the MUD, MESO and FAUNA projects

- HIRLAM model
- Horizontal resolution $0.05^\circ$
- 40 vertical levels between surface and 10hPa
- Forecast length: 48-54h; 4 runs per day
- 21-25 ensemble members per run
Model domains

MUD and MESO

FAUNA
Ensemble spread, MESO experiment

- Ensemble mean wind and precipitation
- “Spaghetti” and ensemble mean mean sea level pressure
Ensemble spread, MESO experiment

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Precipitation, 850hPa wind, MSLP 2016042712+18h
Ensemble spread, MESO experiment

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Ensemble spread, MESP experiment

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Ensemble point forecasts, MESO experiment

Skrydstrup air base

Karup air base
Ensemble point forecasts, FAUNA experiment

Fukushima

Mito
Precipitation spread, FAUNA experiment

Precipitation min, max
2011031400+12h
Valid on Monday 14 Mar 12:00 UTC

3h precip, mbr002

3h precip, mbr013