Predictability of extra-tropical cyclones: initial condition and model uncertainty

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Uncertainties in numerical weather prediction:

1. Initial condition uncertainty
   • Inaccuracy in the observations.
   • Errors in background forecast.
   • Approximations in data assimilation systems.

2. Model uncertainty
   • Imperfect numerical methods
   • Uncertainties in parameterization schemes.
Initial Jet Stream
Initial Upper Level Perturbation
Experiment Design

Control Experiment:
Expt. 1: Gridlength=90 km, CP grid.

Initial condition uncertainties:
Expt. 2: Amplitude of PV' is increased by 25 %.
Expt. 3: Amplitude of PV' is decreased by 25 %.

Model uncertainties:
Expt. 4: L-Grid
Expt. 5: Gridlength=45km
Initial condition uncertainty

- Growth rate of cyclones
- Growth rate of differences between two forecasts with different initial conditions – “forecast error”.
Growth Rate \( (\sigma_{\delta P} = \frac{\ln(\frac{\delta P_{t+\delta t}}{\delta P_t})}{\delta t}, \delta P = P_{\text{surf}} - 1000 \text{ mb}) \)

Unit: \( S^{-1} \)

- Initial rapid growth
- Exponential growth
- Decaying stage
Central surface pressure difference (hPa) of Expt. 2 and Expt. 3 to Expt. 1
Error Growth Rate (\( \sigma_{\Delta P} = \frac{\ln(\frac{\Delta P_{t+\delta t}}{\Delta P_t})}{\delta t} \))

**Unit:** \( S^{-1} \)

- **Initial rapid growth**
- **Exponential growth**
- **Decaying stage**

**Expt. 2**

**Expt. 3**
Model uncertainty

• Growth rate of cyclones

• Growth of differences between two forecasts with different model settings – “forecast error”.
Growth Rate \( \left( \sigma_\delta P = \frac{\ln \left( \frac{\delta P_{t+\delta t}}{\delta P_t} \right)}{\delta t} \right) \), \( \delta P = P_{\text{surf}} - 1000 \text{ mb} \)
Central surface pressure difference (hPa) of Expt. 4 and Expt. 5 to Expt. 1
Model error ($\Delta P$) with fitting curve ($n=3.7$ and $t_1=60$)

Error growth rate: $S^{-1}$

\[ \Delta P(t) = \Delta P(t_1) \left( \frac{t}{t_1} \right)^n, \quad 0 < t < t_1 \]

\[ \sigma_{\Delta P} = \frac{\ln\left( \frac{\Delta P_{t+\delta t}}{\Delta P_t} \right)}{\delta t} \]
Model error ($\Delta P$) with fitting curve ($n=3.0$ and $t_1=50$)

Error growth rate: $S^{-1}$

$$\Delta P(t) = \Delta P(t_1) \left( \frac{t}{t_1} \right)^n, \quad 0 < t < t_1$$

$$\sigma_{\Delta P} = \frac{\ln\left( \frac{\Delta P_{t+\delta t}}{\Delta P_t} \right)}{\delta t}$$
Summary 1

- Both the cyclone and the forecast error associated with initial uncertainties have three growth phases: initial rapid growth, exponential growth and decay. The exponential growth rates of the cyclone and forecast error are similar.
Summary 2

• The approximately cubic time dependence of the forecast error resulting from two different sources of model uncertainty is suggestive of a potentially general relationship.

• We hypothesize that no matter whether the error is originally caused by initial condition or model uncertainty, after a certain time the exponential growth of the normal mode dominates.
Future work

1. Extend to models with uncertainties resulting from different physical parameterization schemes and the inclusion of stochastic physics.

2. Repeat the calculations starting from a flow that already contains developed cyclones (this is more representative of the NWP process).

3. Investigate the development of forecast spread originating from the interaction between initial condition and model uncertainties.