Az előrejelzési bizonytalanság dinamikájának vizsgálata a THORPEX Interactive Grand Global Ensemble (TIGGE) adatbázis segítségével

Szunyogh István

Texas A&M University
Department of Atmospheric Sciences

OMSz, Budapest, június 19, 2015

Outline

1. TIGGE Data Set
2. Methods of Investigation and Results
   - Spectral Analysis
   - Local Diagnostics
   - Lorenz-Curve Diagnostics
3. Conclusions

Based on the Manuscript

Herrera, M. A., I. Szunyogh, and J. **Tribbia,** 2015: The dynamics of forecast uncertainty in the THORPEX Interactive Grand Global Ensemble. To be submitted.

TIGGE Data Set–Operational Ensemble Forecast Data for Research

- **ECMWF**–European Centre for Medium-Range Weather Forecasts
- **NCEP**–US National Centers for Environmental Prediction (NCEP)
- **UKMO**–UK Met Office
- **CMA**– China Meteorological Administration
- **JMA**–Japan Meteorological Administration
- **KMA**–Korean Meteorological Administration
- **CMC**–Meteorological Service of Canada
- **Météo France**
- **BoM**–Australian Bureau of Meteorology–data not available
- **CPTEC**–Centro de Previsão de Tempo e Estudos Climáticos–data not used

Key Features of the TIGGE Ensembles

NWP Center	Model Error	Initial Perturbation
ECMWF	SKEB/SPPT	SV & EDA
NCEP	SPPT	ET
UKMO	SKEB	ETKF
CMA	None	BV
CMC	SKEB/SPPT	EnKF
KMA	None	BV
JMA	SPPT	SV
Météo-France	Multi-Physics	SV & ESV

The Opportunity (for Predictability Research)

Because the TIGGE ensembles use a wide variety of

- models
- data assimilation schemes
- initial perturbation generation techniques and
- methods for the representation of the effect of model errors,

common behavior typically indicates fundamental properties of the uncertainty dynamics

Experiment Design

- **Data:** TIGGE data on a $2.5° \times 2.5°$ resolution horizontal grid at the main pressure level from 1000 hPa to 200 hPa
- **Forecasts:** All forecasts started in January-February 2012
- **Diagnostics of the atmospheric flow:** Based on ECMWF analyses of January-March 2012
- **Norm:** Combines the temperature and wind grid point variables, such that it has dimension of $(J/kg)^{1/2}$
- **Inner Product:** Defined in accordance with norm
- **Proxy for true atmospheric states:** ECMWF analyses, except when ECMWF forecasts are verified, when NCEP analyses are used

Methods of Investigation

An arbitrary local state vector **x** can be decomposed as

$$\mathbf{x} = \bar{\mathbf{x}} + \delta\mathbf{x},$$

where $\delta\mathbf{x}$ is the difference between **x** and the ensemble mean $\bar{\mathbf{x}}$

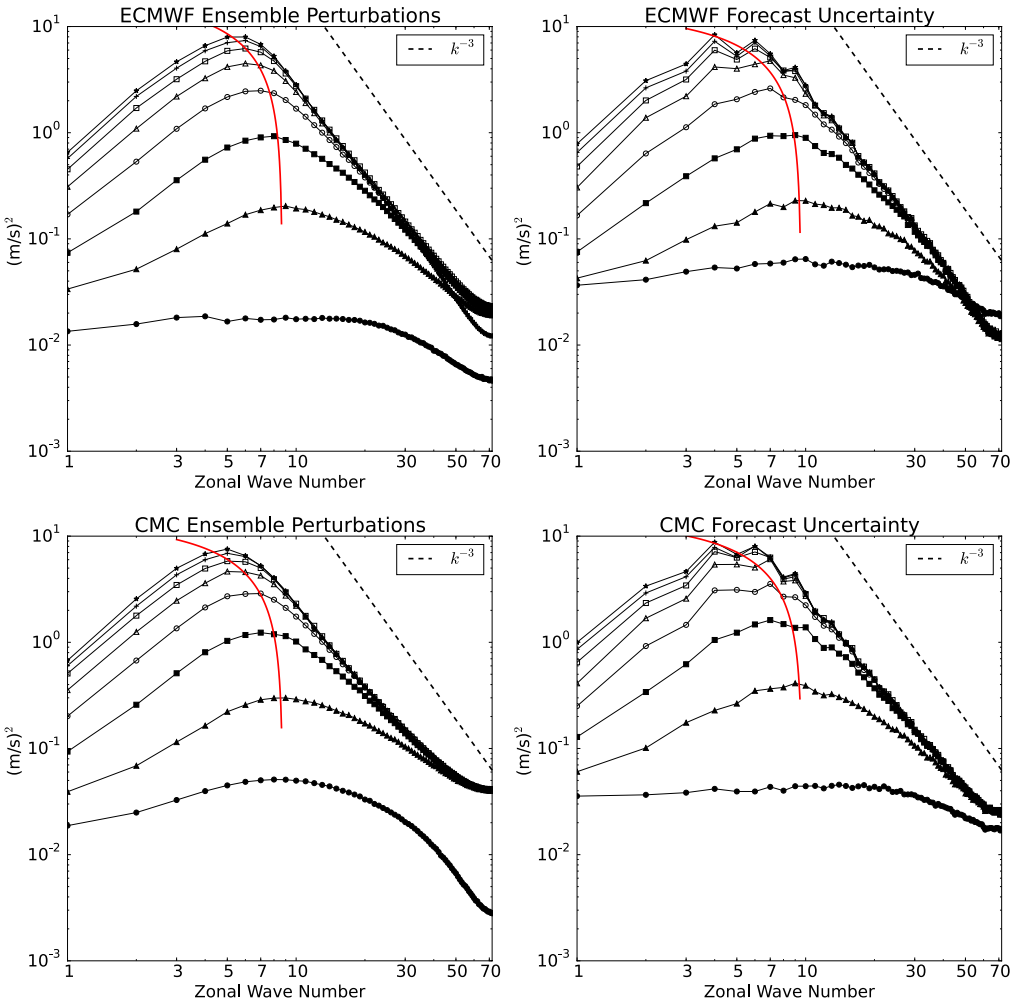
Forecast uncertainty: $\delta\mathbf{x}$, if **x** is a **proxy for the true state**

Ensemble perturbation: $\delta\mathbf{x}$, if **x** is an ensemble member

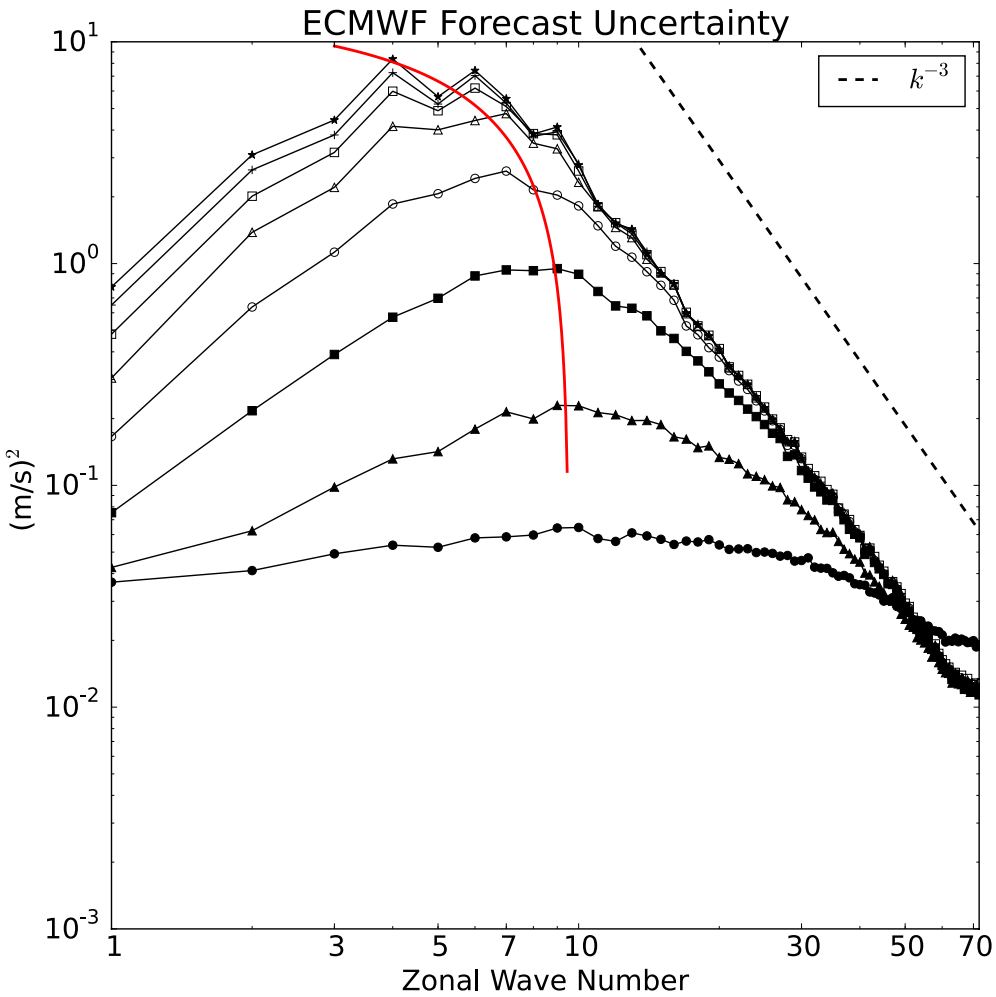
The forecast uncertainty and the ensemble perturbations are examined by

- Spectral analysis (with respect to zonal wave number)
- Local diagnostics
- Lorenz-curve analysis

Power Spectra of the Uncertainty and the Ensemble Perturbations (v-wind at 500 hPa



A Closer Look at the Dynamics of the Power Spectra of the Uncertainty (v-wind at 500 hPa, ECMWF)



The Concept of the Local Space of Ensemble Perturbations

Definition: The local space of ensemble perturbations $\mathbb{S}_\ell$ at grid point ℓ is the linear (vector) space spanned by the ensemble perturbations in a local neighborhood of ℓ

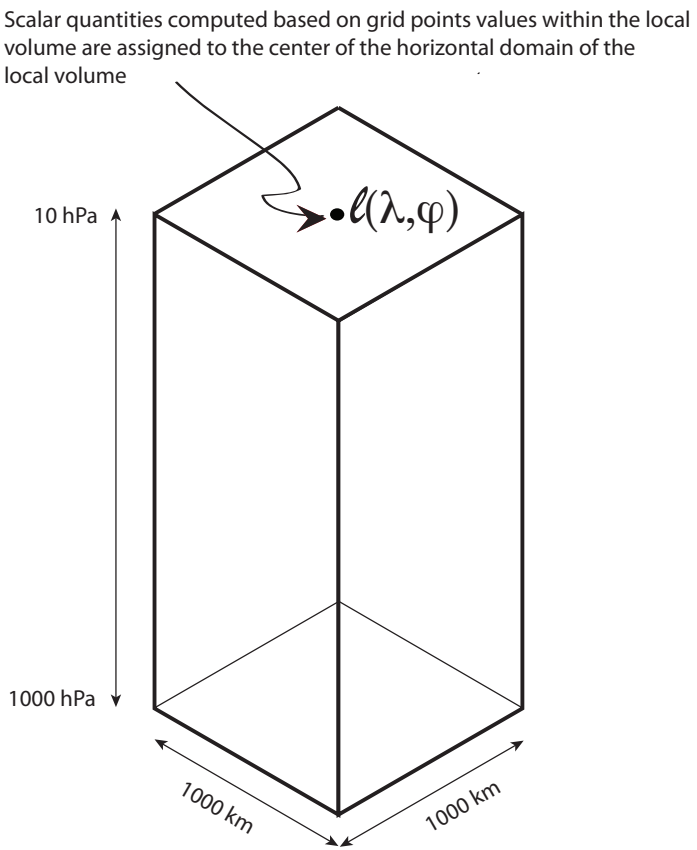
Purpose: to investigate the ability of the ensemble in capturing the patterns of uncertainty in addition to the magnitude of the uncertainty

Notation:

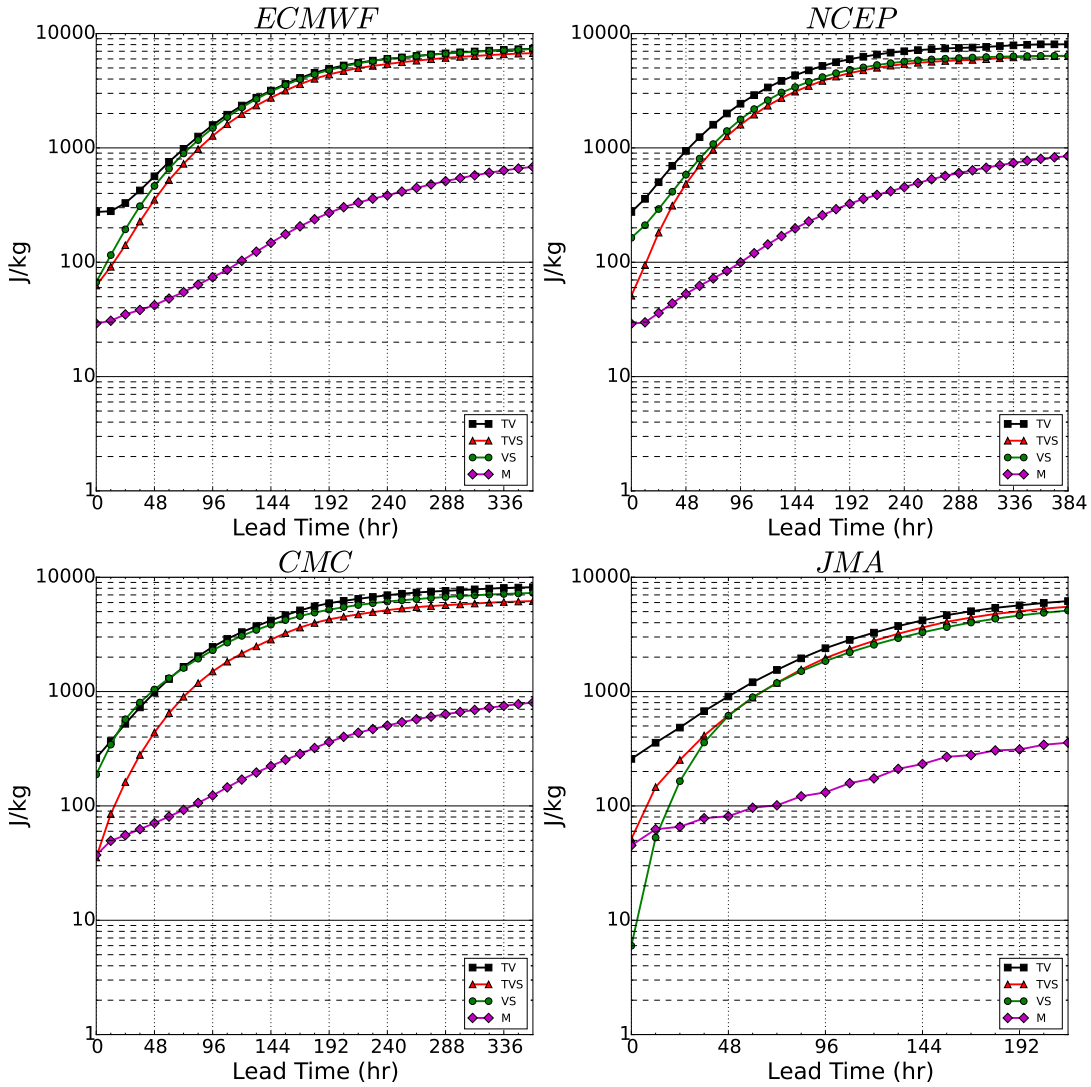
- TV–mean-square of the local forecast uncertainty
- M–squared-mean of the local forecast uncertainty
- TVS–mean-square of the local forecast uncertainty in $\mathbb{S}_\ell$ (ideally, $TVS \approx TV$)
- VS–variance of the local ensemble perturbations (ideally, $VS \approx TV$)

Illustration of a Local State Vector

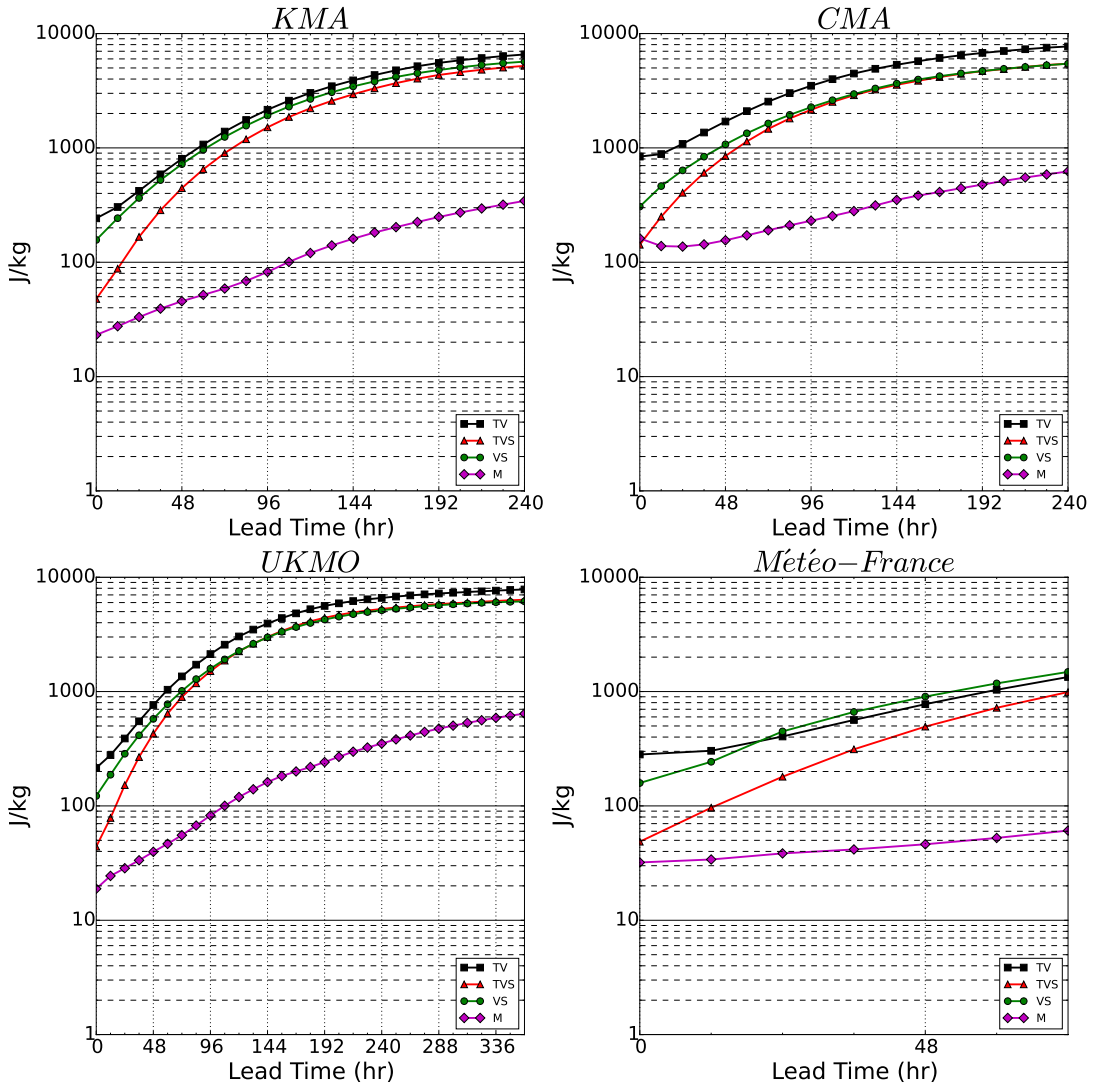
We define a **local state** vector $\mathbf{x}_\ell$ with all N state variables of the model that represent the state within a local volume centered at location (grid point) ℓ



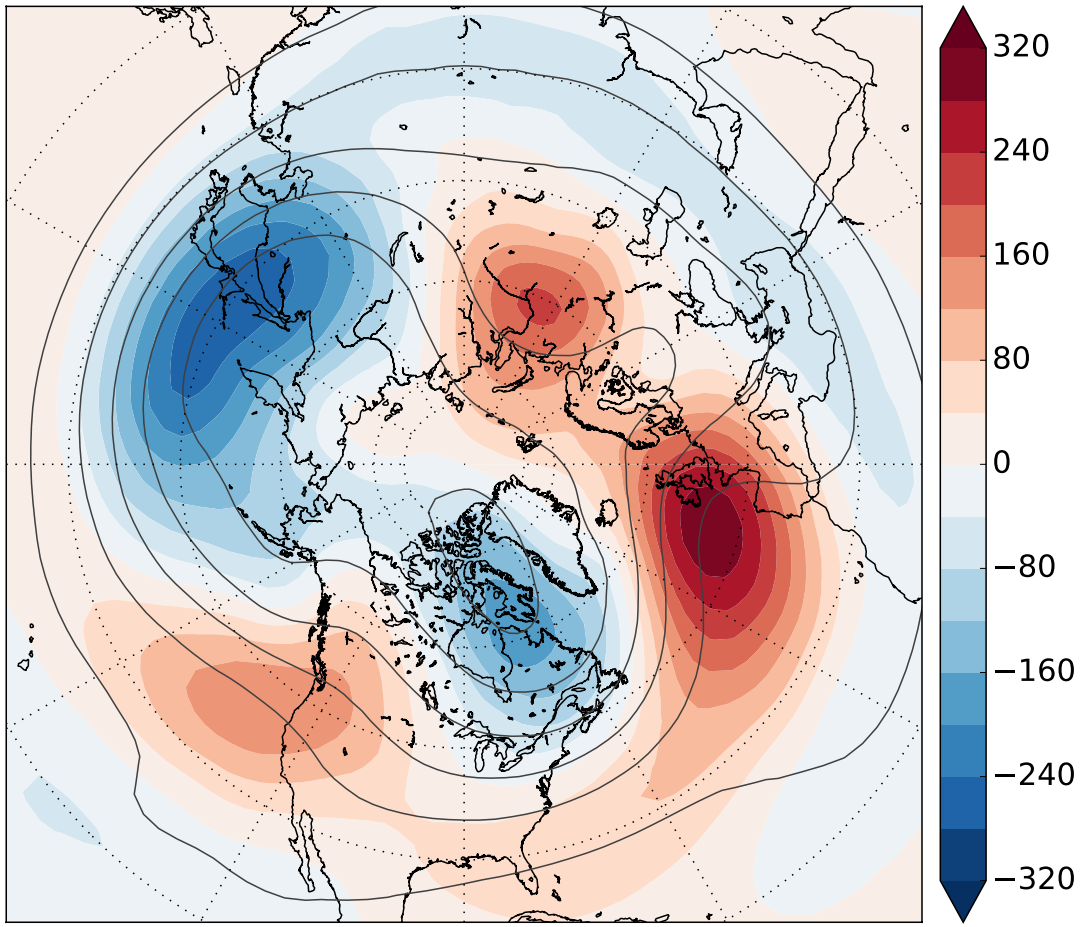
Results I



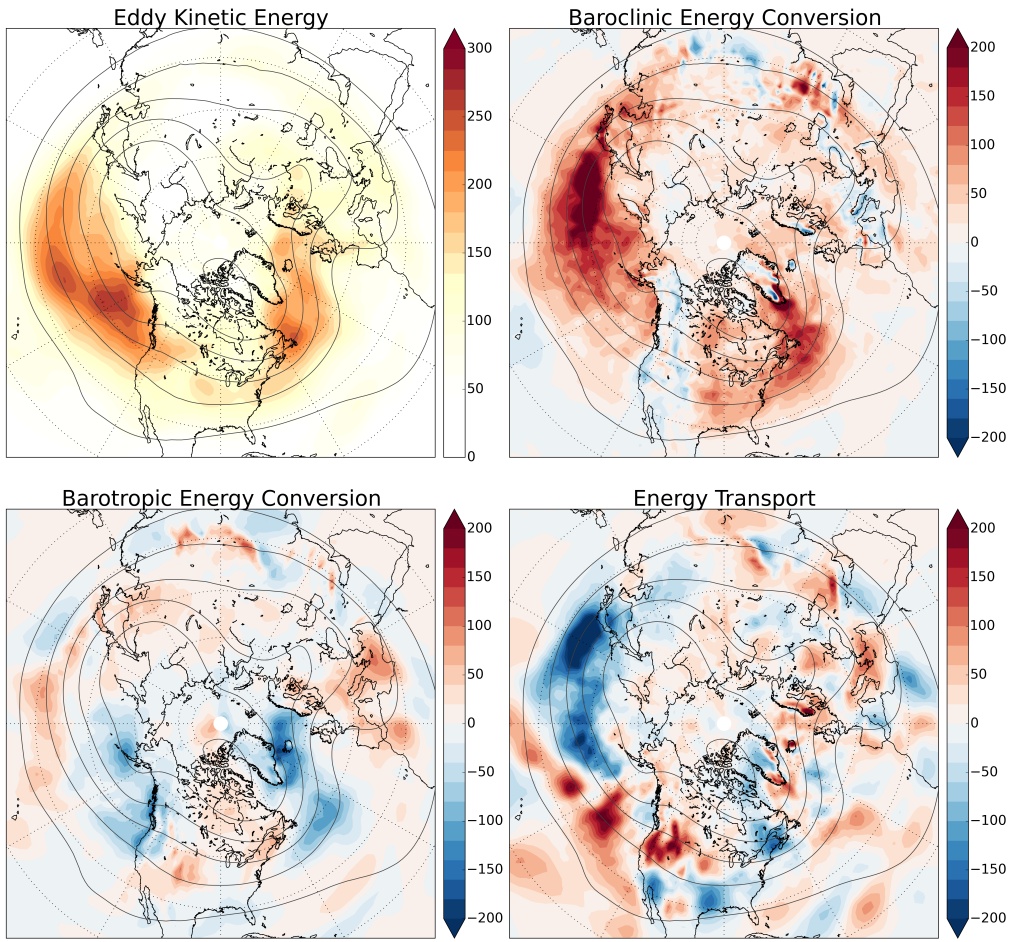
Results II



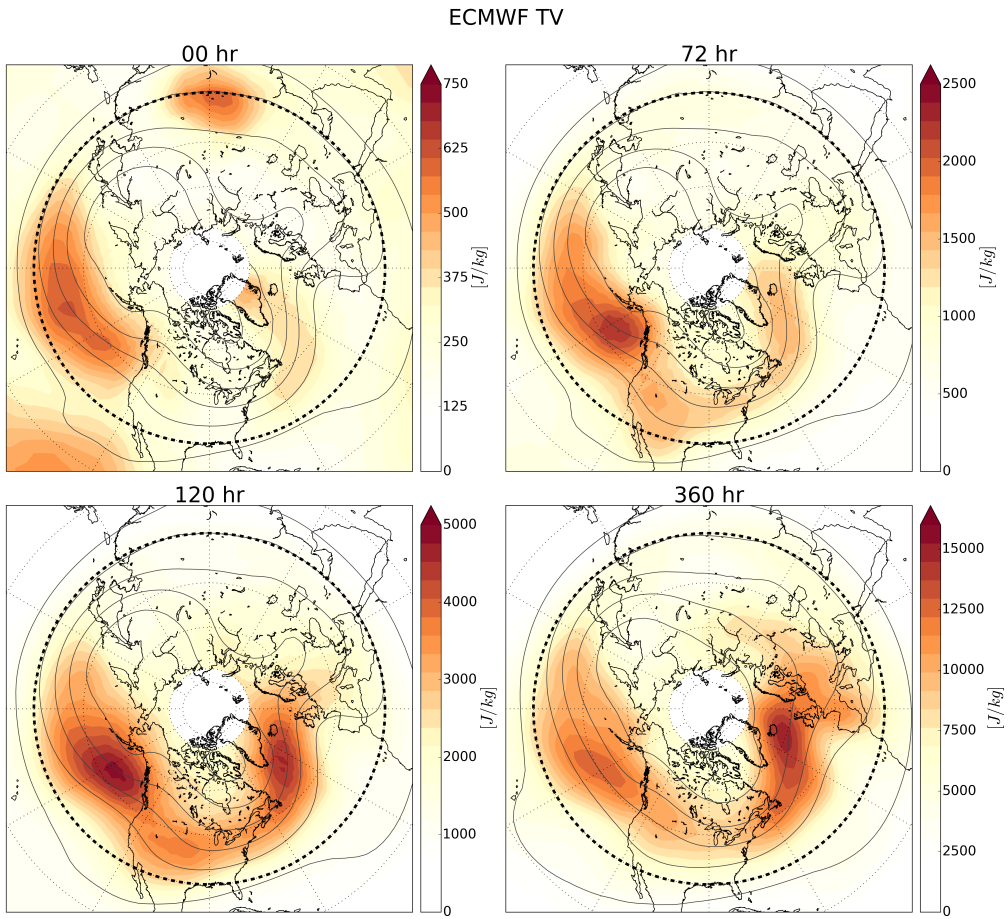
Geopotential Height Anomalies of the Time-mean Flow at 500 hPa



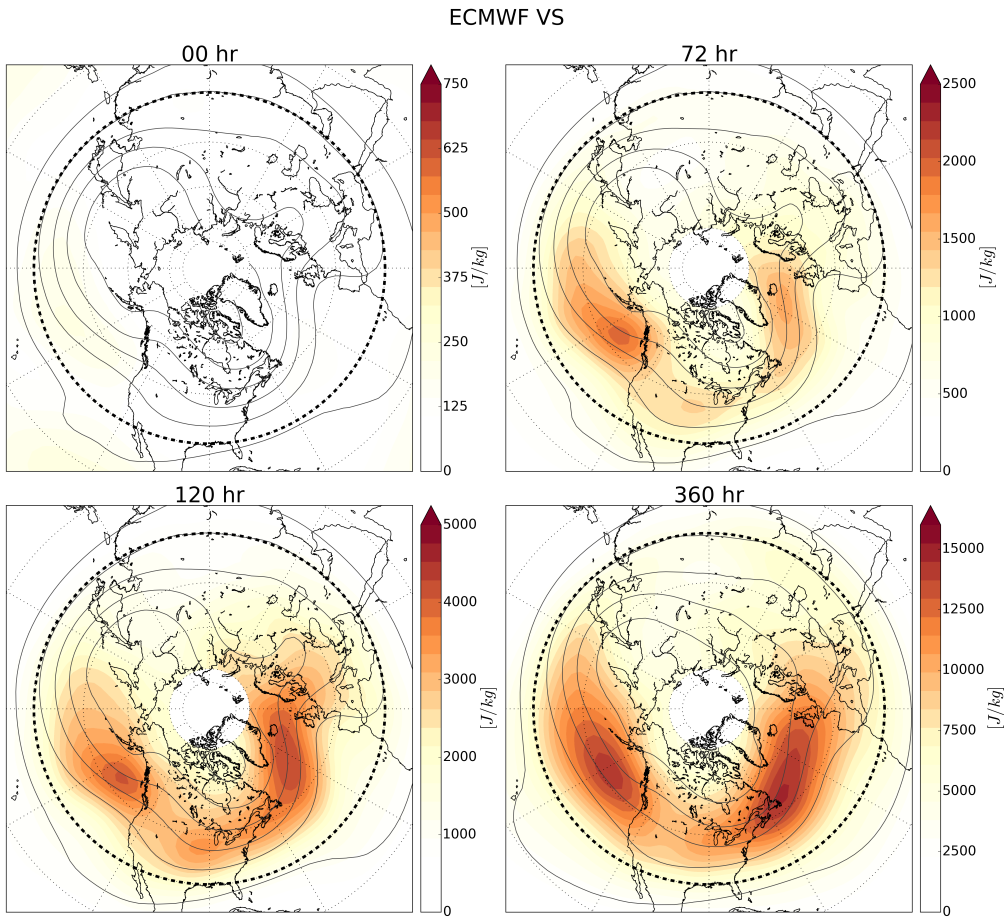
Eddy Kinetic Energy Balance for the Investigated Period



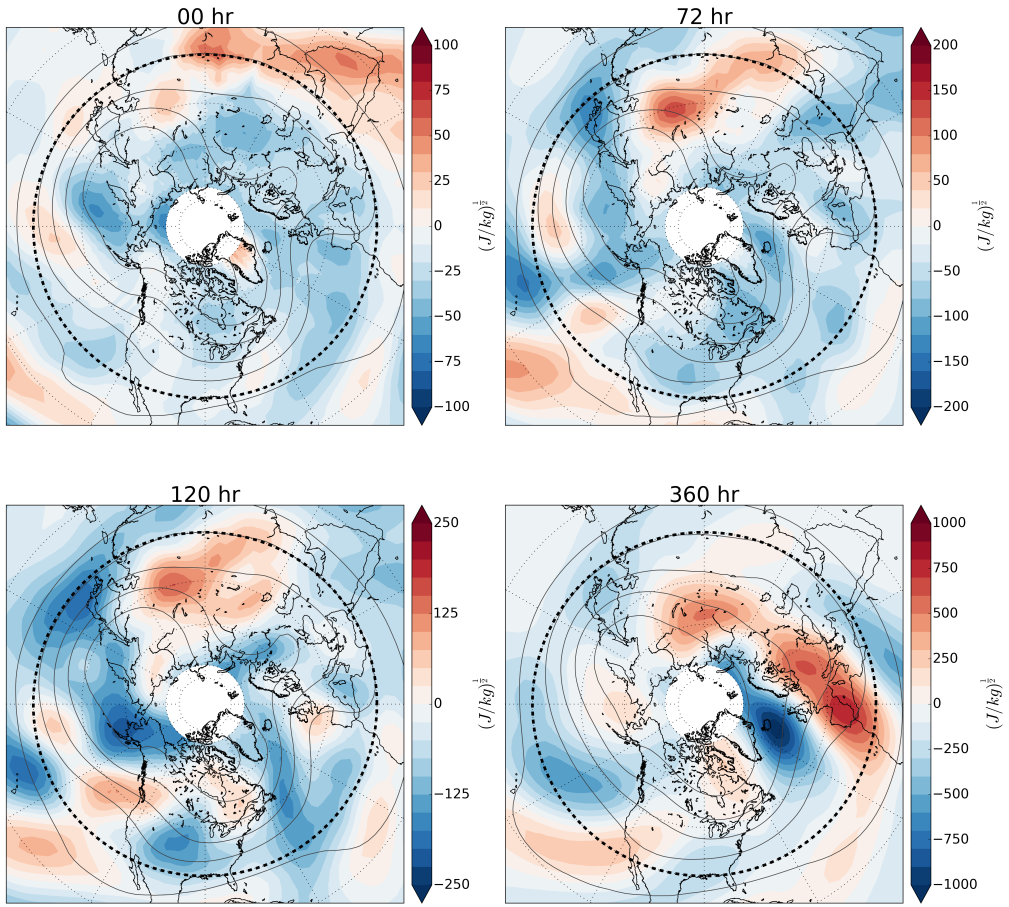
Spatio-temporal Evolution of TV in the Forecasts for the ECMWF Ensemble



Spatio-temporal Evolution of VS in the Forecasts for the ECMWF Ensemble



Spatio-temporal Evolution of M in the Forecasts for the ECMWF Ensemble

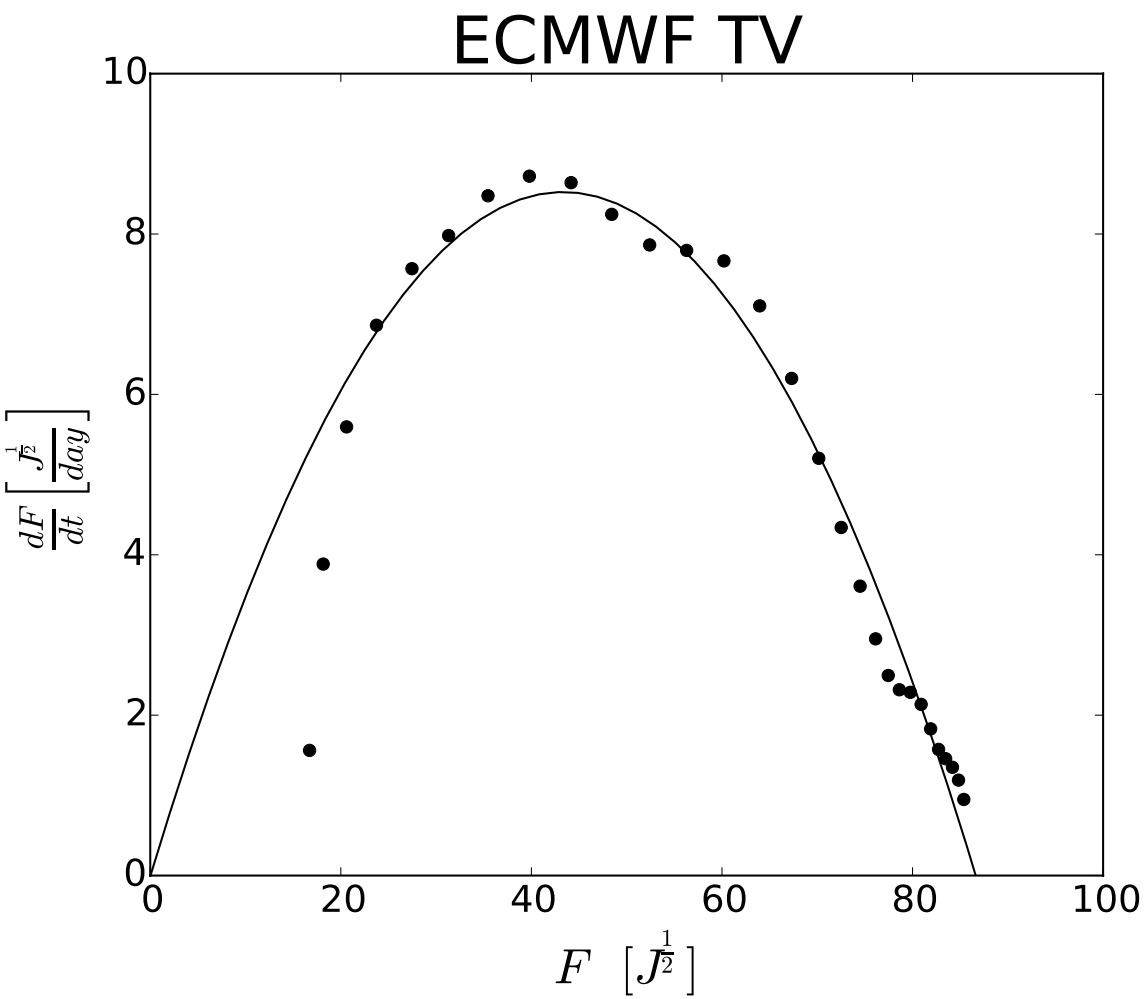


Lorenz-Curve Diagnostics

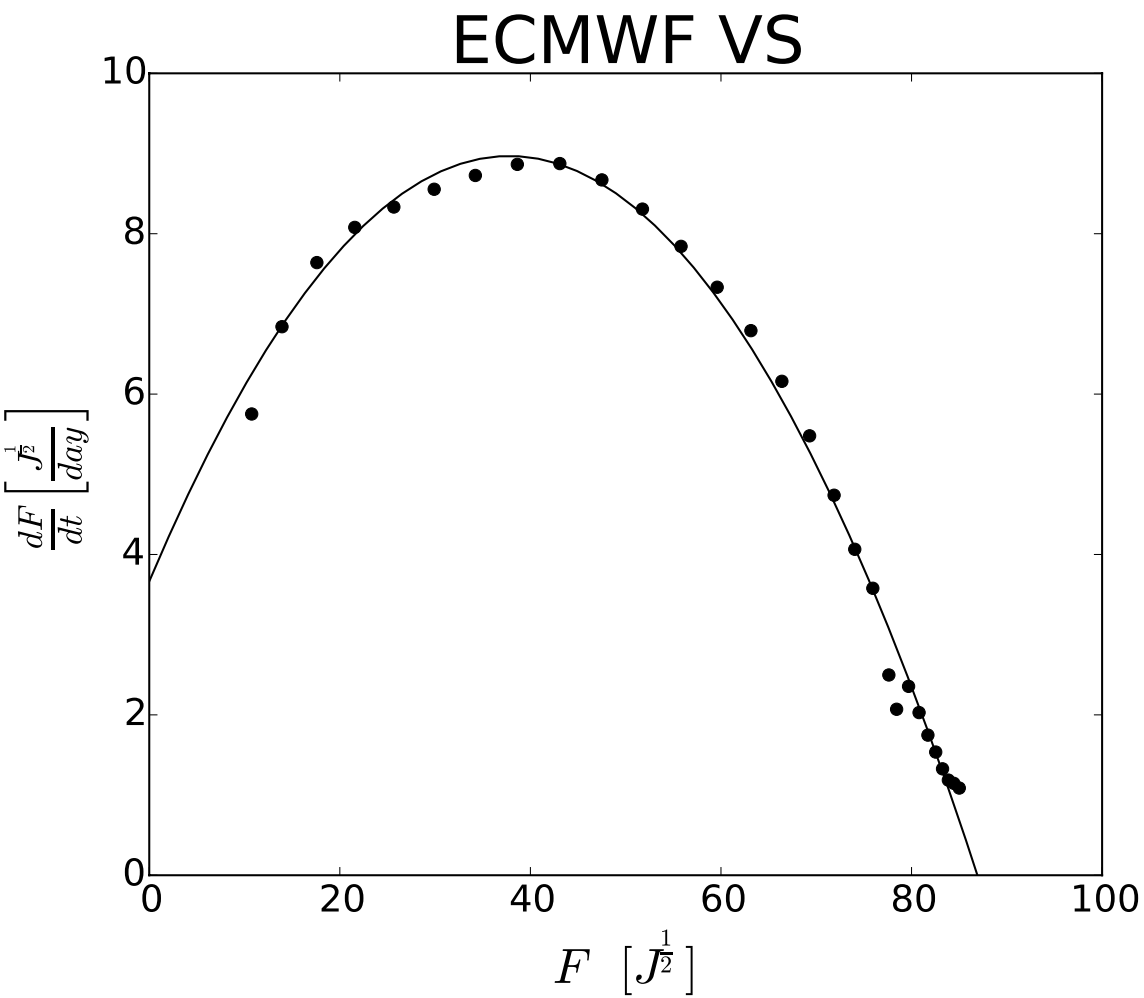
$$\frac{dF}{dt} = (\alpha F + \beta)\left(1 - \frac{F}{F_\infty}\right),$$

- F is either $\sqrt{TV}$ or $\sqrt{VS}$
- the three parameters to estimate are
  - α–**linear growth rate**
  - β–**model error forcing**
  - F_∞–**asymptotic value of uncertainty** (or ensemble spread) at long forecast lead times
- α, β, and F_∞, in principle, can be estimated by fitting a second-order polynomial to pairs of $(\sqrt{F}, d\sqrt{F}/dt)$ data

The Lorenz-curve for TV for the ECMWF ensemble



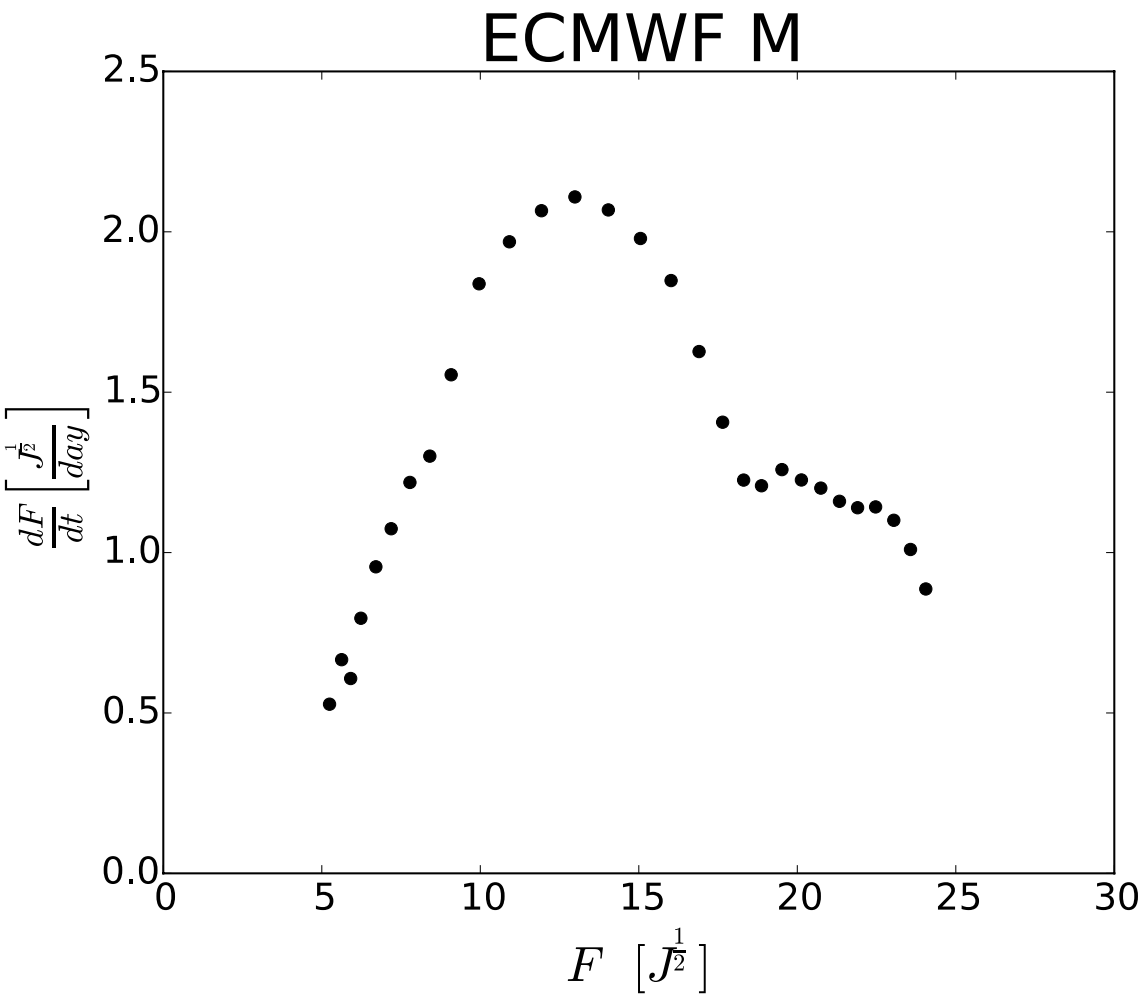
The Lorenz-curve for VS for the ECMWF ensemble



Key Findings Based on the Lorenz Curves

- For the **ECMWF**, **NCEP** and **UKMO** ensembles, the **daily linear growth** ($e^{\alpha t}$, t=24h), for **TV** is 1.3-1.5
- Fort the **ECMWF**, **NCEP** and **UKMO** ensembles, the daily growth rates for **TV** and **VS** are in good agreement
- For the rest of the ensembles, the daily growth rate of the uncertainty is underestimated by the ensembles; but the difference is not large for the CMC, JMA, and KMA ensembles
- the NCEP ensemble underestimates β, while the CMC ensemble slightly overestimates β
- all ensembles, except for the ECMWF ensemble, underestimates the asymptotic value of TV_∞ ($VS_\infty < TV_\infty$)

Lorenz Curve Type Diagram for the Mean Uncertainty (M)



Conclusions

1. We identified some **specific strengths and weaknesses** of each ensemble included in TIGGE
2. The following **general picture** also emerges from the results:
   1. **initially**, the growth is the fastest at the scales most sensitive to baroclinic instability;
   2. **the growing and saturating** synoptic scale uncertainties form a wave-packet-like pattern, whose envelop extends from the entrance region of the Pacific storm track to the exit region of the Atlantic storm track;
   3. the large-scale structure of the packet envelope is controlled by the slowly varying large-scale flow;
   4. the carrier wave number of the wave packet gradually shifts from the synoptic to the large scales,
   5. at the **sub-synoptic scales**, the uncertainty evolves as predicted by Lorenz's classic theory.