Quantifying Dynamical Inconsistencies in Convective Ensemble Data Assimilation

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Motivation

Problem

Spurious convection after Radar data assimilation of thunderstorms
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Cause
Dynamically inconsistent DA analyses as initial states of forecasts
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Cause
Dynamically inconsistent DA analyses as initial states of forecasts

Method
1. Proper characterization and quantification of spurious convection (this talk)
2. Development and testing of methods to increase “dynamical consistency” of analyses (future work)
Outline

1. LETKF OSSEs with varying length scales
   - Fine and Coarse Analysis Schemes
   - Spurious Convection

2. Quantifying Dynamical Consistency
   - Gravity Wave Noise
   - Coldpool Coupling

 Retrieval of Perturbation Pressure (in abstract, but dropped)
OSSE Setup

- Perfect model experiment:
  - 2 km horizontal resolution, sounding with high CAPE and shear
  - 1 Nature Run, 50 Members
OSSE Setup

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  - 1 Nature Run, 50 Members
- Long-lived (> 6h) mesoscale convective systems
  - randomly located in background ensemble
  - similarity of storms (shape, strength) due to identical sounding
Perfect model experiment:
- 2 km horizontal resolution, sounding with high CAPE and shear
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Long-lived (> 6h) mesoscale convective systems
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LETKF Data Assimilation
- COSMO-KENDA System (German Weather Service)
- Simulated observations of reflectivity and Doppler wind
- 3 hour assimilation cycling
- 3 hour ensemble forecast
- Varying analysis scales to study scale dependent error growth
LETKF OSSEs with varying length scales
Quantifying Dynamical Consistency

Fine and Coarse Analysis Schemes
Spurious Convection

Multicell Storm Structure

Storm Motion

L8: 2 km

L32: 8 km

Lange et al.
Dynamical Inconsistencies in convective DA
LETKF OSSEs with varying length scales
Quantifying Dynamical Consistency

Fine and Coarse Analysis Schemes

**L8**
- 8 km localization
- 2 km observations
- 5 minute cycling

**L32SOCG20**
- 32 km localization
- 8 km observations
- 20 minute cycling

First Forecast Hour: Spurious Storm Evolution

- Top: Member of $L8$
- Bottom: Nature
First Forecast Hour: Spurious Storm Evolution

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LETKF OSSEs with varying length scales
Quantifying Dynamical Consistency

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1h Forecasts in L32

Less spurious convection in L32 → more “dynamical consistency”?
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Gravity Wave Noise (last analysis)

Nature Run

W at 17 UTC, level 35 (3500 meters) Nature

W from (j,i)-gridpoint (70, 0) to (160, 196) Nature at 17 UTC
Gravity Wave Noise (last analysis)

L32 Member

W at 17 UTC, level 35 (3500 meters) L32SOCG20m1

\[
\begin{array}{ccccccc}
\text{Distance (km)} & 0 & 50 & 100 & 150 & 200 & 250 & 300 & 350 \\
\text{Height (m)} & 0 & 5000 & 10000 & 15000 & 20000 \\
\end{array}
\]

W from (j,j)-gridpoint (70, 0) to (160, 196) L32SOCG20m1 at 17 UTC

\[
\begin{array}{ccccccc}
\text{Distance (km)} & 0 & 50 & 100 & 150 & 200 & 250 & 300 & 350 & 400 \\
\text{Height (m)} & 5000 & 10000 & 15000 & 20000 \\
\end{array}
\]

Lange et al.
Dynamical Inconsistencies in convective DA
Gravity Wave Noise (last analysis)

L8 Member

W at 17 UTC, level 35 (3500 meters)

W from (j,i)-gridpoint (70, 0) to (160, 196) L8m1 at 17 UTC

Lange et al.

Dynamical Inconsistencies in convective DA
Surface Pressure Tendencies during cycling and first FC hour

L8
L8 init
L32SOCG20
L32SOCG20 init
Surface Pressure Tendencies Results

Surface pressure tendencies

- larger in L8, especially at first analysis
- incomplete relaxation within the cycling (L8 and L32)
- only bulk indication for “dynamical consistency”
LETKF OSSEs with varying length scales
Quantifying Dynamical Consistency
Gravity Wave Noise
Coldpool Coupling

Vertical Acceleration Histograms

Vertical Acceleration $dW/dt$ before/after first analysis (14 UTC)

- Pre Ana
- Post Ana L8
- Post Ana L32
- Post Ana L32SOCG20

Dynamical Inconsistencies in convective DA 15 / 22

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Cold Pool Coupling

Question

“How closely is the future convection coupled to the present cold pool edges?”
Cold Pool Coupling

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“How closely is the future convection coupled to the present cold pool edges?”

Method

Compute the spatio-temporal correlation $C(\vec{x}, t)$:

- $C(\vec{x}, t)$ of field $|\vec{\nabla} T(\vec{x}, t_0)|$ with field $\frac{d\text{Cond}}{dt} (\vec{x}, t)$
- moving frame of reference: $|\vec{\nabla} T(\vec{x}, t_0)|$ shifted with storm propagation vector
- regard correlation parallel to storm movement
Cold Pool Coupling: 1 hour Ensemble Forecasts

Correlation of Temperature-Gradient to Condensation Rate

direction parallel to storm propagation, moving frame of reference

a) Nature

b) L8

c) L32

Top to bottom:
- Nature
- L8
- L32

Left: behind storm
Right: ahead of storm

Lange et al.
Dynamical Inconsistencies in convective DA
Cold Pool Coupling Results

Measure for "dynamical inconsistency":
New storms uncoupled to cold pool edges and their gust fronts.

Spurious convection in L8:
- triggering of long lived spurious cells immediately (< 5 min) after initialization
- mostly ahead of "true" storms
- no trace of hypothetical perturbations that "radiate" from true storms
- apparently caused by precursor cells:
  - shallow convergence patterns without rain
  - below observation threshold
  → not fully suppressed during cycling
Impact on Cold Pool Coupling: Perturbed Nature Run

Nature Run

instantaneously perturbed with layerwise perturbations of background ensemble

Top to bottom:
- Nature
- Nature + Perturbed $T$
- Nature + Perturbed $U, V, W, PP$

Left: behind storm
Right: ahead of storm
Outlook: Assimilation Plans

Influence of EnKF-DA relaxation methods on spurious convections

- Vary localization (vertically, horizontally) and observation resolution
- Give observations less weight (inflated observation error covariance, RTPP)
- Spatial smoothing of increments
- Relating spatio-temporal parameters to GW phase speed
- Assimilate wind-only
- Gaussian anamorphosis of reflectivity observations
Summary and open questions

Statement:
Spurious convection: An embarassment for convective scale DA.

Unknown:
Present OSSE setup: Sensible or chasing its own errors?

Done so far:
- Metrics for gravity wave noise and unbalanced storm dynamics
- Surface Pressure Tendencies
- Coldpool Coupling

Need help with:
- Instantaneous measures for balanced states?
- Other possibilities, e.g. using ensemble sensitivities?
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Quantifying Dynamical Consistency

Surface Pressure Tendencies: Perturbed Nature Run

Surface Pressure Tendencies of Perturbed Nature Run

NatPert with
- $t \times 10.0$
- $tBL \times 10.0$
- $uvwpp \times 10.0$
- $uvwppBL \times 10.0$
- $uvwtppp \times 10.0$
- $uvwtpppBL \times 10.0$
- Nature

$dps/dt$ [Pa/s]

Time (UTC)