Evaluating Two Cumulus Parameterization Schemes in a Cycling Ensemble Data Assimilation System with GPS RO Refractivity Profiles

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Outlines

1. Introduction
   • Applications of RO data for model error diagnostics

2. WRF-DART data assimilation experiments design

3. Results

4. Summary and plan

5. Discussions (Challenging RO DA in NWP)
   (1) A revisit --- ROPP 1D bending angle operator
   (2) A bypass --- ROPP thinner tool
Scale predictability (hour) derived by the noise-to-signal-ratio (NSR)

Where is the role of RO?

To get more accurate forecast on small scales and longer forecast on large scales for another Sandy in the future by:
1. Reduce initial error (RO data for assimilation)
2. Reduce model error (RO data for diagnostics)

- NCEP GFS 500hPa H
- 15°N~35°N, 30°W~150°W
- Isaac (2012) in August
- Sandy (2012) in October

Fang and Kuo, 2014, coming in JAS
**Objective:** Reduce model error (RO data for diagnostics)

- To assess the Tiedtke and the New Simplified Arakawa-Schubert (NSAS) cumulus parameterization (CP) schemes in a cycling ensemble data assimilation (DA) system WRF-DART, using GPS RO refractivity profiles.

**Rationale:**

1. The neutral atmosphere refractivity, as a proxy of the air density, carries thermodynamic information related to convection.
2. The GPS RO refractivity profile observations are valuable for the evaluation of model physics, given its high-quality thermodynamic information, high vertical resolution, and uniform global coverage.
3. CP, the treatment of sub-grid scale convection, is one of the most challenging model physics. The precipitation, heat and moisture distribution, and PBL-cloud-radiation interaction in a NWP model are all strongly influenced by the CP.
4. The systematic model errors related to CP can persist in a data assimilation (DA) system and impact the data assimilation performance. A cycling ensemble DA system provides a useful platform to monitor the model uncertainty, physics sensitivity, and systematic errors using retained high quality observations, like RO profiles. e.g., Torn and Davis (2012); Glen et al. (2013)
WRF-DART DA experiments design

Model system
• WRF-ARW V3.3.1 & V3.6.1
• WRF-DART (EAKF), 36km, 64 levels, 20 hPa, cycling in 3h interval
• ICBC: NCEP GEFS, 26 P-levels + data on tropopause, Oct. 15-22, 2010

Observations
✓ GTS data are assimilated, with/without SATEM thickness.
✓ GPS RO N profiles are retained for model error diagnostics:
  • Data source: atmPrf RO N profiles from COSMIC, SACC, GRACE, and TerraSAR-X.
  • Data preprocessing: RO N profiles are thinned to fixed geometric heights in 200m interval with a WRF-DART thinning program, for model verification.
  • Operator: a local N operator, with a background-based LT QC.

DA experiments:
Common physical settings: YSU, RRTM+Goddard, Goddard MP, SKEBS
3 sets of 40-member ensemble DA experiments:
(1) A single-physics ensemble (Tiedtke, ECMWF scheme implemented in WRF)
(2) A single-physics ensemble (NSAS, NCEP scheme implemented in WRF)
(3) A multi-physics ensemble (m1-m20 Tiedtke, m21-m40 NSAS)
Three modes of convective clouds

Background: Some studies suggest that shallow convections, congestus convections or deep convections may be wrongly activated or depressed in different weather and climate models, which affects the prediction of high-impact weather systems and the projection of climate modes like MJO.

Scientific questions:
• How do NSAS and Tiedtke perform for different cloud modes?
• How do the simulation of convections and the associated radiations and circulations impact the tropical cyclone track and intensity forecasts?
• Can GPS RO N profiles help diagnose the error sources?
Statistics of ensemble departures in 4 regions

Four regions:

Region 3
lat (20,40N) lon (80,130E)

Region 1
lat (-10,20N) lon (80,130E)

Region 4
lat (20,40N) lon (130,180E)

Region 2
lat (-10,20N) lon (130,180E)
GPS RO N for model error diagnostics

Normalized ME (F-O/SD)

Region 1

- Tiedtke
- model dry bias
- NSAS
- RO N negative bias

Region 2

- model cold bias
- model high height bias

Numbers of RO obs

NME (nSD) in lat (-10,20) lon (80,130)
GPS RO N for model error diagnostics

Normalized ME (F-O/SD)

Region 3
East Asia Land

- Model is strongly constrained by the GTS observations on land
- RO N negative bias
- Model cold bias
- Model high height bias

Region 4

- Tiedtke
- Model dry bias
- RO N negative bias
- NSAS
- Model cold bias
- Model high height bias
Some hypotheses for Tiedtke:
1. Shallow convections are weak in LT.
2. Moisture flux is weak from LT to MT.
3. Congestus convections are depressed in MT.
4. Broad deep convections are activated in lower HT.
5. Heights of heating and detrain are shifted down.

Some hypotheses for NSAS:
1. Shallow convections are strong in LT.
2. Moisture flux is strong from LT to MT.
3. Congestus are activated in MT.
4. Local deep convections are activated in higher HT.
5. Heights of heating and detrain are shifted up.

It may not be just the CP. Rather, it is the interaction between PBL, surface layer scheme, and the CP and shallow convection. Somehow, PBL/surface scheme does not replenish moisture in the boundary layer, after it was taken out by CP and shallow convection.
**Water vapor** $Q_v$ on level 24 (about 4600 m), member 20 at 2010101700

![Tiedtke drier](image1) ![NSAS wetter](image2)

4600m

$Q_v$ on level 13 (about 1400 m), member 20 at 2010101700

![Tiedtke wetter](image3) ![NSAS drier](image4)

1400m

Note: Similar situation for other members
Cloud fraction CLDFRA at level 26 (about 5500 m) member 20 at 2010101700

Note: Similar situation for other members
Cumulus parameterization (CP) rain (RAINC), member 20 at 2010101700

**Tiedtke**
Less coverage in environment
more concentrated at TC inner core

**NSAS**
More coverage in environment
less at TC inner core

Explicit microphysics (MP) rain (RAINNC), member 20 at 2010101700

**Tiedtke**
Scattered in environment

**NSAS**
Concentrated at TC inner core

Note: Similar situation for other members
36km 20-member 72-h Min. SLP forecasts of Typhoon MEGI (2010) initialized from EAKF analysis ensemble at 20101017 0000 UTC (Significant intensity forecast difference)
36km 20-member 72-h track forecasts of Typhoon MEGI (2010) initialized from EAKF analysis ensemble at 20101017 0000 UTC

**Different track biases**

**Tiedtke**
Small southward bias, but weaker TC
Better large scale but poor intensity?

**NSAS**
Stronger TC, but larger northward bias
Better intensity but poor large scale?
Summary

1. The vertical structure of the ensemble departure statistics in GPS RO N space could provide valuable clues to detect how shallow, congestus and deep convections are simulated by different cumulus parameterization (CP) schemes, given the vertical meteorological structure information implied by refractivity profiles.

2. The systematic model errors produced by the Tiektke and the NSAS schemes that are detected in GPS RO N space are related to the model precipitation, heat and moisture distribution, PBL-cloud-radiation interaction, and circulations, and also impact the typhoon track and intensity forecasts.
Summary (Cont.)

3. The model errors can contribute substantially to the ‘perceived’ apparent RO bias in the lower troposphere, except for the large negative RO bias near surface which are most likely caused by real RO measurement errors.

4. The large model cold bias (or higher height bias) over 20 km might be related to the coarse model vertical resolution near the model top when initialized from the NCEP GEFS data provided on coarse pressure levels.

Future plan

• To monitor and refine the DA system recursively.
• To prove the model error hypotheses, combined with dynamic diagnostics, and help improve model physics finally.