Impact of Cycled 3DVAR Assimilation of COSMIC Observations on Nor’east’er Simulations

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Introduction

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) mission is a joint operation of the National Space Organization of Taiwan and UCAR that currently produces about 1800+ Global Positioning System (GPS) radio occultation (RO) profiles daily. To advance global coverage, the six polar-orbiting satellites (which make up COSMIC) observed and recorded the phase and amplitude of occulted GPS signals that are used to generate vertical profiles of ionosphere and reflection. These profiles are then inverted via an Abel transform to obtain vertical density profiles of refractivity and bending angle as a function of height (Caulfield et al. 2008). These data can then be assimilated by numerical weather prediction models, such as the Weather Research and Forecasting (WRF) model, in both data-dense and data-sparse regions where these data can potentially better model simulations of temperature, pressure, and other dependent variables.

This project aims to improve prognostic weather simulations via the assimilation of GPS RO data has attracted interest from ECMWF (Healy and Thapliyal 2006) and NCEP/Cauffiel et al. (2008) who both commissioned studies on the merits of assimilating GPS RO data into their own operational weather models. Their results demonstrated that 3DVAR data assimilation produces significant improvements in both temperature and pressure. In the ECMWF and WRF models, respectively. Motivated by these results, we hypothesize that cycled COSMIC RO data assimilation into the Advanced Research WRF (WRF-ARW) will better enable it to simulate eight intense cyclogenetic events (nor’easters) impacting the Northeastern United States. Additionally, the relative importance of COSMIC RO data assimilation in the pre-cyclogenesis phase of each of our cases will be demonstrated via a data detailed experiment.

Methods

- All cases after April 2006 (COSMIC launch)
- Cases over several months (October – April)
- “Nor’eaстер cases” (Jacobs et al. 2009)
- Creates wide array of unique weather situations where a nor’easter later develops
- 3 model domains (45km, 15km, 5km)
- Domain sizes sufficient to track each case from development through rapid cyclogenesis
- 27 vertical levels with a 50 hPa model top
- Sufficient model error to make COSMIC influence apparent
- Energy norm analysis of Nor’easter Cases Relative to “Ground Truth” (GFS 003 Model Analysis)
- Over-intensification (14 runs), under-intensified (4 runs), within ± 5 hPa (22 runs)
- Tracking timing biases
- Leftward track tendency bias in WRF runs (5/8 cases) – Exceptions 2/6, 10/12, 22/23 cases
- Sufficient model error to make COSMIC influence apparent
- Allows simulations of the crucial pre-rapid cyclogenesis for each nor’easter case (Kuo et al. 1991; Yue et al. 2008)

Impact on WRF Simulated Storm Track

- 5 WRF Model Runs (1 non-COSMIC, 4 with COSMIC RO)
- COSMIC RO Observation Periods
  - 1 assimilation (18Z)
  - 7 assimilations (24 hrs)
  - 17 assimilations (48 hrs)
  - 61 assimilations (180 hrs)

- High total energy norm values from upper troposphere (~200-350 hPa or model levels 16-21)
- Domain 2 results
  - Energy norms notably higher in domain 1 than domains 2 and 3
  - Domain 3: Consistent – Energy norm results in rough agreement (more variability than domain 2)

- Domain 1: Not consistent – Energy norm much worse for all COSMIC cases (possible forced boundary errors)

- Inter-case variability
  - Case 2 – 19/31 (61.3%) versus Case 5 – 29/31 (96.77%)

- Similar to RMSE, smaller energy norm values denote better performance versus “Ground Truth” (51.5%)

Energy Norm Analysis of Nor’eaステRS Cases Relative to “Ground Truth” (GFS 003 Model Analysis)

- Positive values denote improved performance versus WRF 3.2 (differences shown are WRF 3.2 – experimental run)
- All model runs show little variability during the first 48 hours
- Energy norm results not directly proportional to number of COSMIC RO observations (Location most important)
- Average Domain 2 energy norm differences (all times)
  - WRF 0.0 hr – 2.125 ± 1.392 (51.5% of cases positive)
  - WRF 24 hr – 0.62 T ± 1.98 m (18.8% of cases positive)
  - WRF 48 hr – 1.085 ± 0.5 m (19.5% of cases positive)

- Assimilating COSMIC during each nor’easter (hours 72-120) was beneficial (improvement in at least 44 of 72 times)

Difference in Energy Norm Compared to WRF 3.2 (No COSMIC)

- Domain 1: No consistent – Energy norm much worse for all COSMIC cases (possible forced boundary errors)
- Domain 2: Consistent – Energy norm results in rough agreement (exception WRF-COSMIC 0 hr) [see above]
- Domain 3: Consistent – Energy norm results in rough agreement (more variability than domain 2)

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References


