Impact of Lightning Data Assimilation in Northeast Pacific Tropical Cyclone Remnants

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Introduction

- Development of a technique to incorporate GOES-R Geostationary Lightning Mapper (GLM) observations using a hybrid variational-ensemble data assimilation system
- Evaluate the impact of lightning flash rate on multi-scale data assimilation (DA) applications

Completed Milestones

- Benchmark system

WRF-NMM at 27, 9km, and 6-hr DA frequency (SEMI-OPERATIONAL)
Ferrier microphysics
Vertical updrafts and total condensate lightning observation operator
WWLLN data as a proxy for GLM

Ongoing Project

-Enhanced system

WRF-ARW at 9, 3, 1 km resolution, 6, 3, 1-hr assimilation frequency
WSM6 Microphysics
Lightning observation operator based on hydrometeor-flash rate link (McCaul et al. 2009)
WWLLN and/or Earth Networks Total Lightning Network (IC+CG)

Data Assimilation System

- CSU – Maximum Likelihood Ensemble Filter (MLEF) is used as a hybrid (variational-ensemble) DA system.
- 32-ensembles
- 3-hr assimilation frequency (currently testing 1-hr)
- Control variables: T, P, U, V, W, Cloud hydrometeors (cloud, vapor, rain, graupel, snow, and ice).

Lightning Observation Operator

- Lightning flash rate from McCaul et al. (2009) lightning threat forecast algorithm currently used operationally in NOAA High Resolution Rapid Refresh (A version of WRF-ARW)

- Combination of upward flux of graupel in mixed phase region (-15 C)

$$F_1 = k_1 \left(w q_g \right)_m$$

- with gridded-vertically integrated ice-phase hydrometeors (graupel, ice, and snow)

$$F_2 = k_2 \int \rho \left(q_g + q_s + q_i \right) dz$$

- F_3 is a blended threat thus improving temporal and areal coverage of lightning activity

$$F_3 = r_1 F_1 + (1 - r_1) F_2$$

Parameter	Description
w	Vertical velocity
r	Local air density
q_g, q_s, q_i	Graupel, snow and ice mixing ratios
k_1, k_2	0.042, 0.20 – Calibration coefficients of peak flash density
r_1	0.95 – From sensitivity of various weights

Lightning Observation Operator

- The goal is to minimize the following cost function:

$$J(x) = \frac{1}{2}\left[x - x^f\right]^T P_f^{-1}\left[x - x^f\right] + \left[y - h(x)\right]^T R^{-1}\left[y - h(x)\right]$$

- Control variables: T, U, V, P, W, and cloud mixing ratios (water, rain, snow, vapor, ice, graupel)

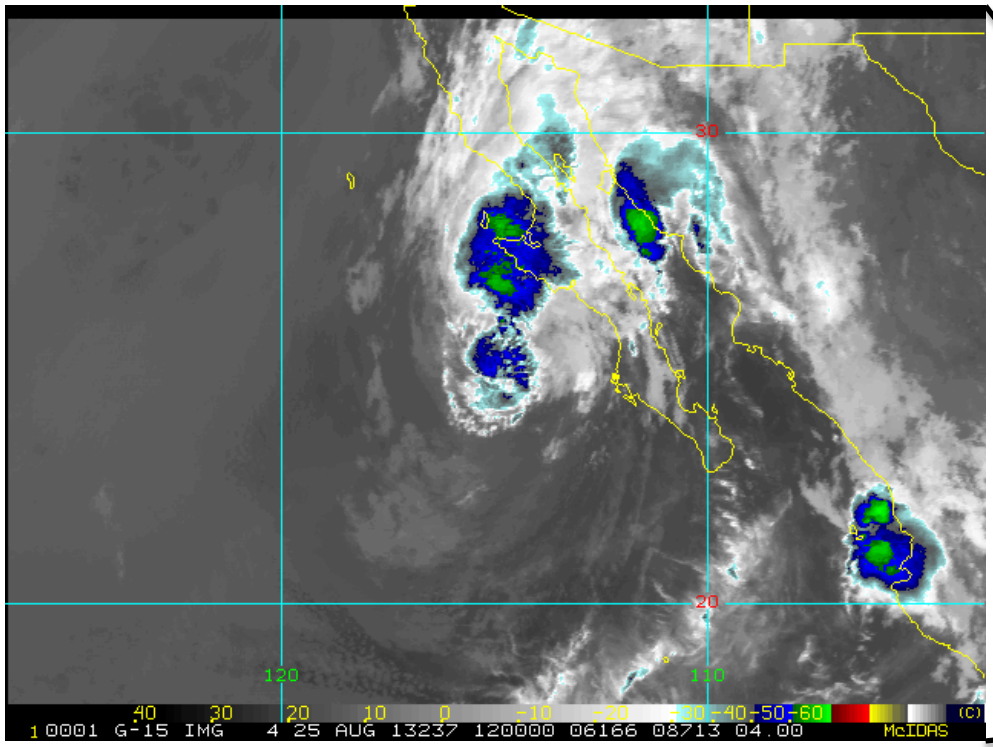
- F_3 is the observation operator (h)

Parameter	Description
r_1	0.95 – From sensitivity of various weights
x	Control Variables (CV)
P_f	Error covariance of CV
f	Denotes forecast guess
y	Lightning flash rate observations
R	Error covariance of observations

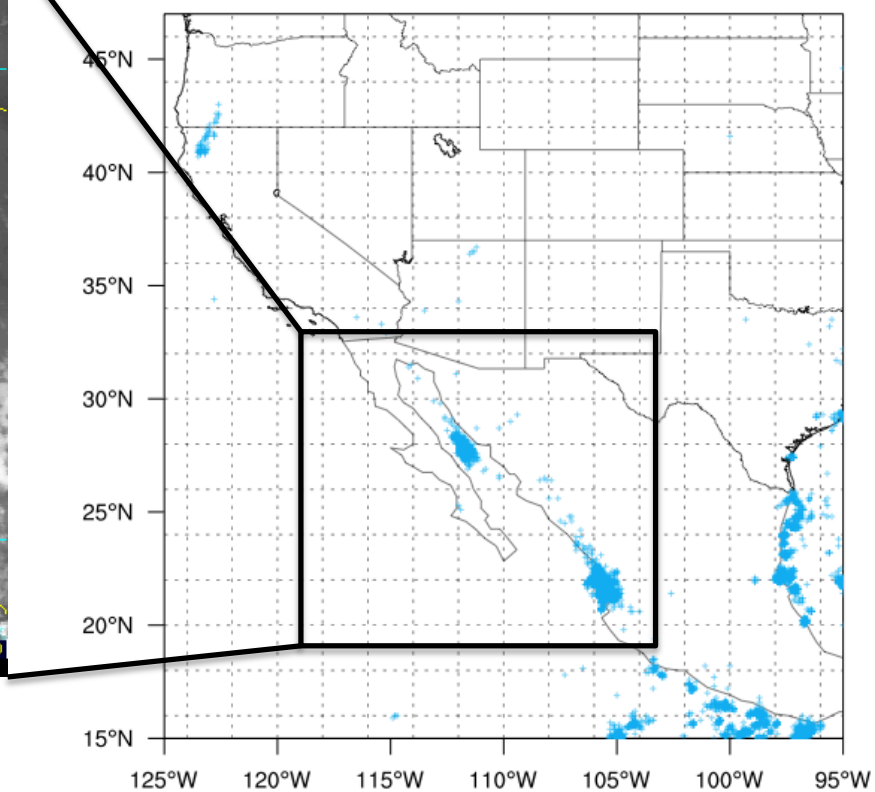
Case Study: Tropical Cyclone Ivo – August 22-25, 2013

Valid: 2013-08-25_12:00:00

GOES-15 Infrared



WWLLN lighting observations

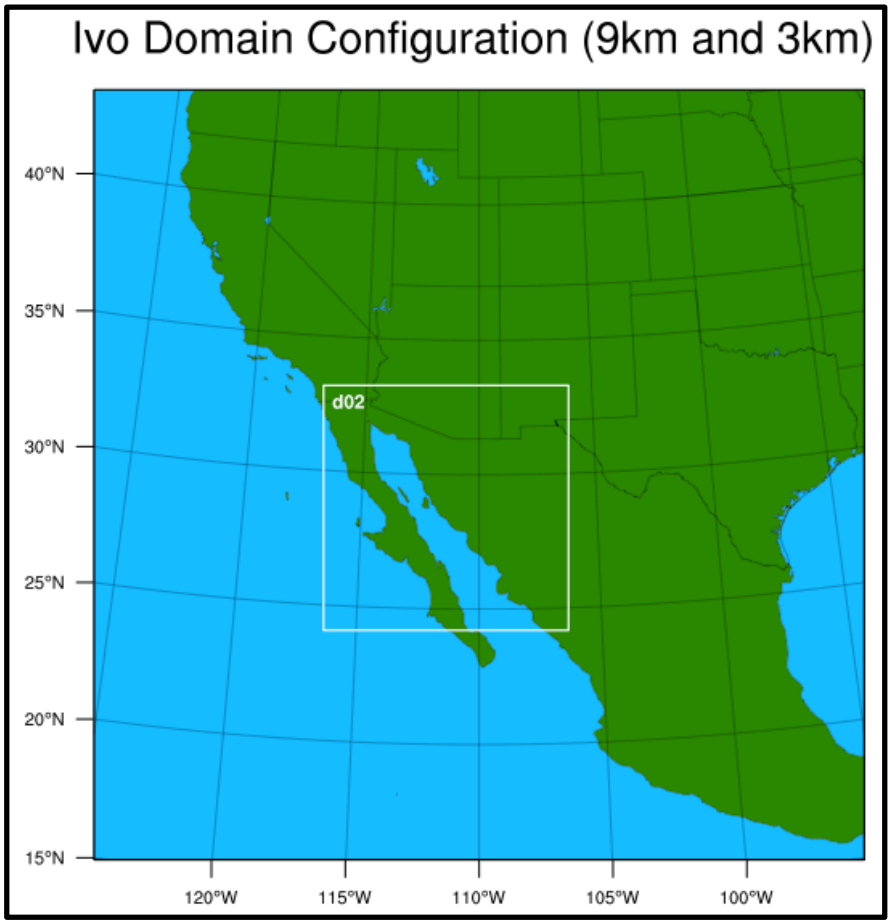


- Ivo hit the Baja California Peninsula during late NAM season
- Moisture from the storm triggered flash floods over the Southwest US

Modeling System Setup

WRF-ARW

PARAMETER	CHOICE
Horizontal resolution	9km and 3km
Sigma Levels	35
PBL scheme	YSU
Short & long wave radiation	Dudhia and RRTM
Land Surface	Noah
Microphysics	WRF 1-Moment 6-class
Initial & lateral BC	Global Forecast System (GFS)



Experiments

- Assimilation of conventional observations (GSI)

  - Control experiment
  - PREPBUFR data

- Assimilation of conventional observations and lightning (GSI+LIGHT)

  - PREPBUFR
  - WWLLN data

Preliminary Results

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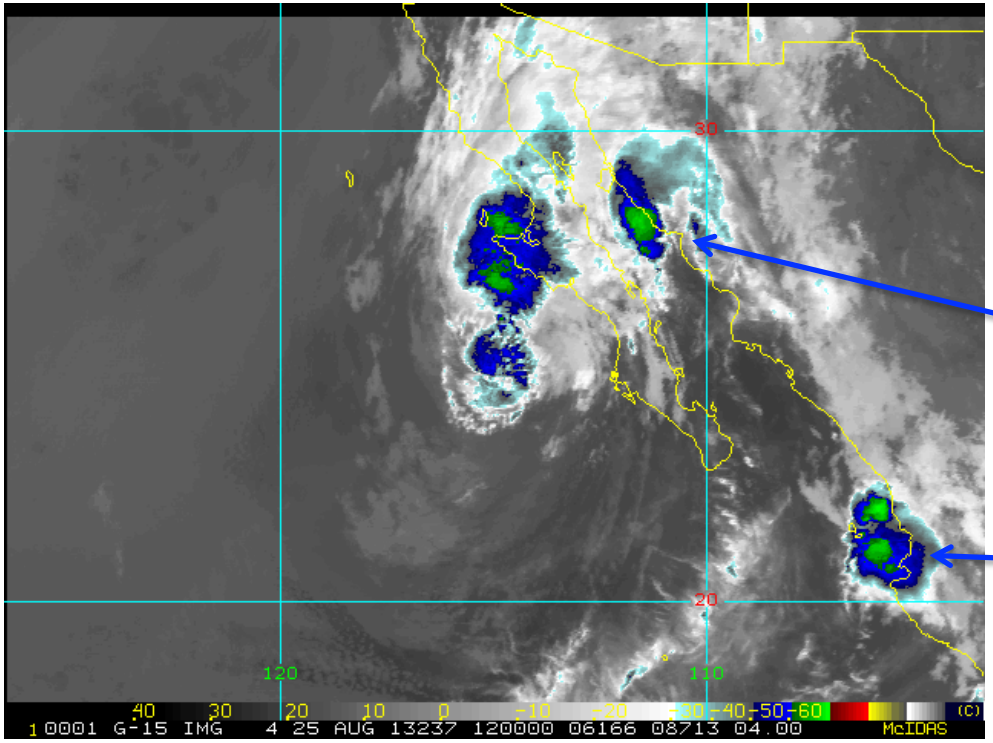
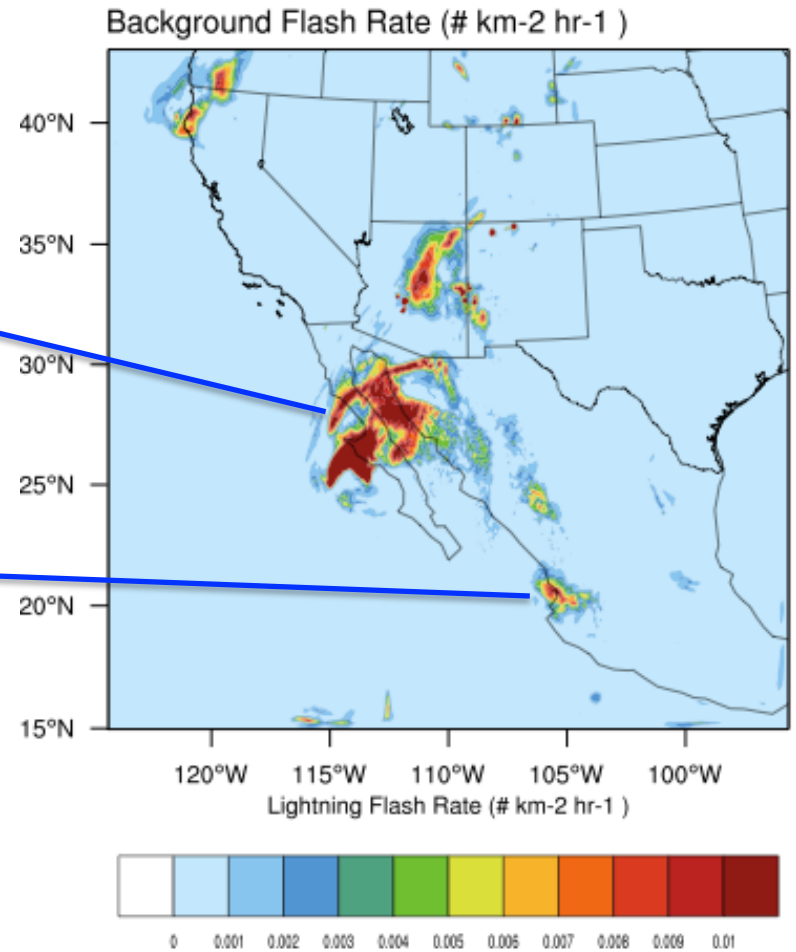
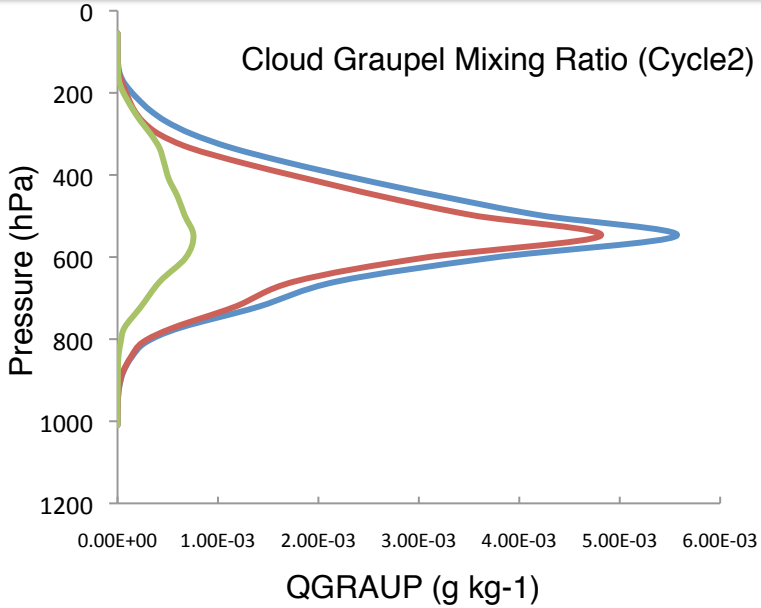
GOES-15 Infrared

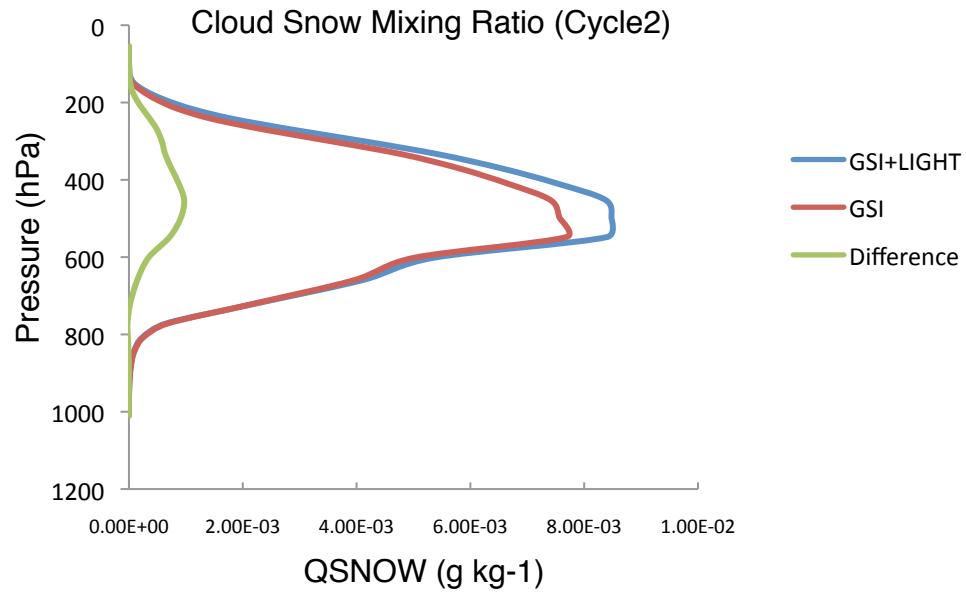


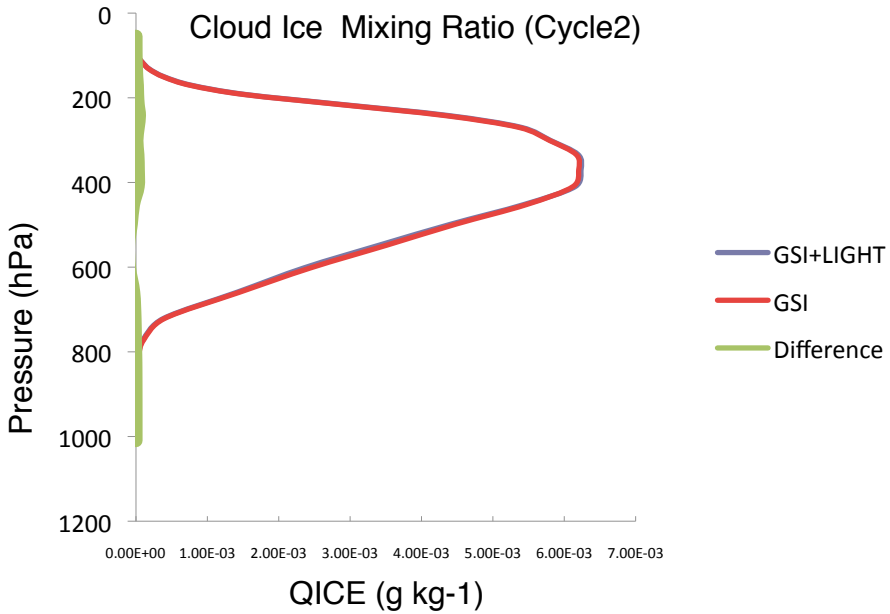
Forecast Lightning Flash Rate



Preliminary Results: Vertical Profiles

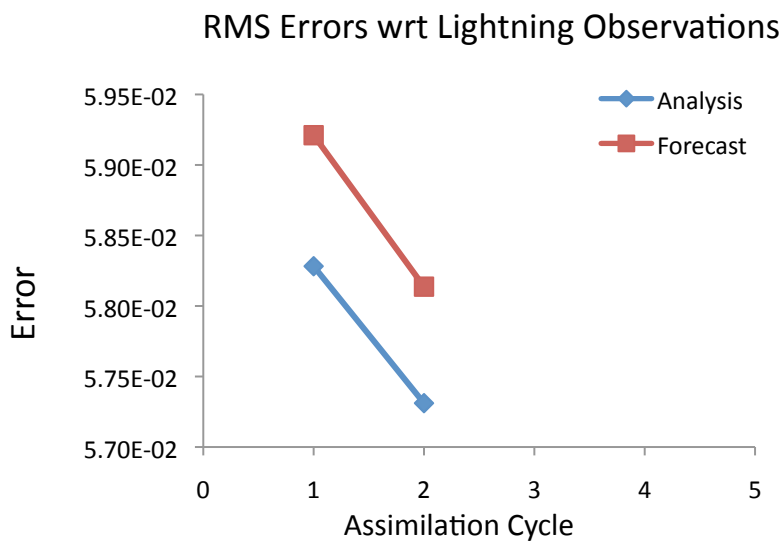


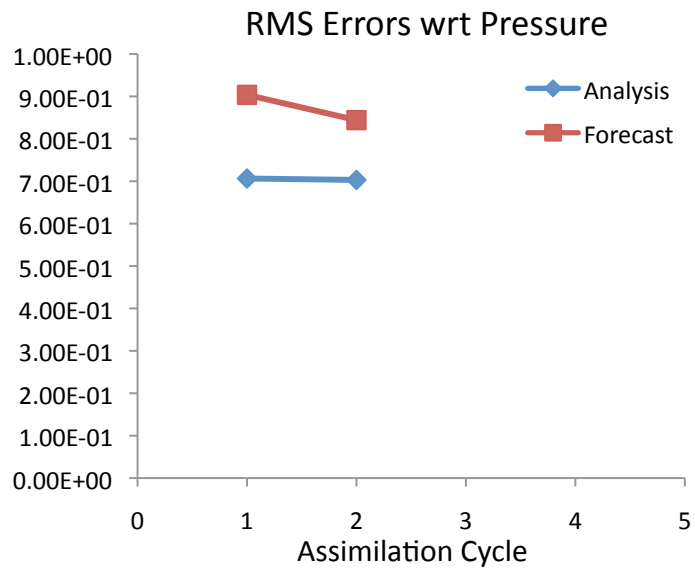


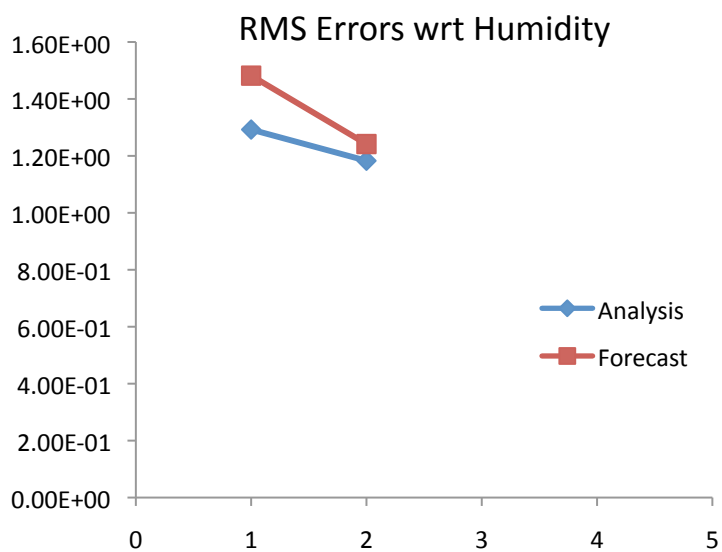


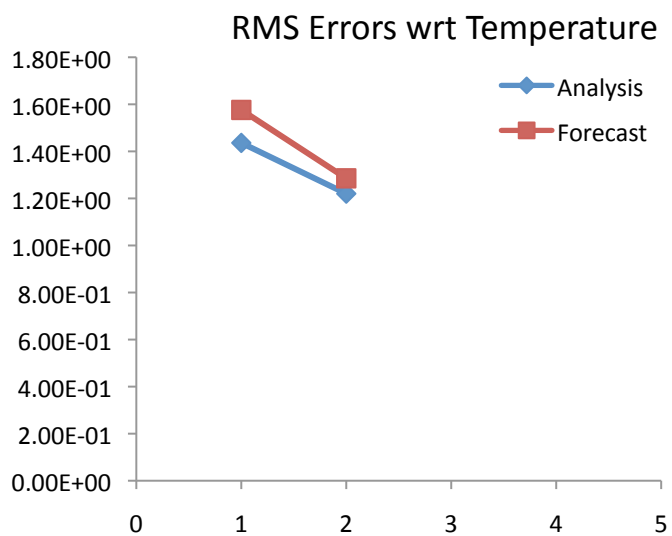
Preliminary Results: RMS Errors

RMS errors wrt to lightning and control variables: $x = (T, P, Q, U, V)^T$









Summary and Future Work

- Continue both experiments (more cycles)
- Modify weights and de-correlation lengths
- Test the effect of combined GOES-R ABI and GLM observations
- DA experiments with combined lightning, conventional observations and All-Sky satellite radiances using NOAA codes (GSI and CRTM)

Other Applications:

- Test the lightning DA methodology developed for WRF-NMM for hurricane inner-core with HWRF
- Test the lightning DA methodology developed for WRF-ARW for lightning NO_x production with WRF-Chem

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