Improving Air Quality Simulation for 2016 Summer Ozone Episode by Assimilating Geostationary Satellite Observations

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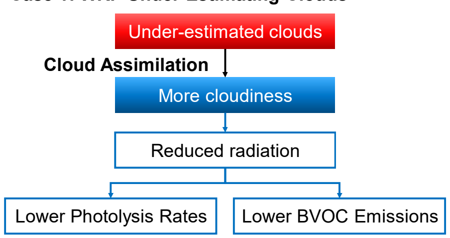
1. Motivation

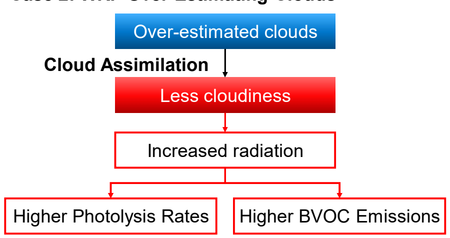
A reliable estimate of biogenic emission rates and photolysis rates (or photodissociation reaction rates) is crucial in numerical air quality models when simulating ozone and other harmful chemical species (Mathur et al. 1998; Pour-Biazar et al. 2007). These rates can be effectively modified by temperature and incident solar radiation flux, which may be inaccurately estimated in numerical weather prediction (NWP) models due to errors in cloud fields (Pour-Biazar et al. 2007). Studies (e.g., Guenther et al. 2012) have shown that air quality models may perform better by assimilating satellite-based solar radiation data.

A cloud assimilation technique introduced by White et al. (2018) has shown improvements in the simulated cloud fields by correcting spatial and temporal cloud placement through assimilation of Geostationary Operational Environmental Satellite (GOES) observations. In this study, attempts are made to apply White's method to the Weather Research and Forecasting (WRF) coupled with Chemistry (WRF-Chem) model.

Case 1: WRF Under-Estimating Clouds



Case 2: WRF Over-Estimating Clouds



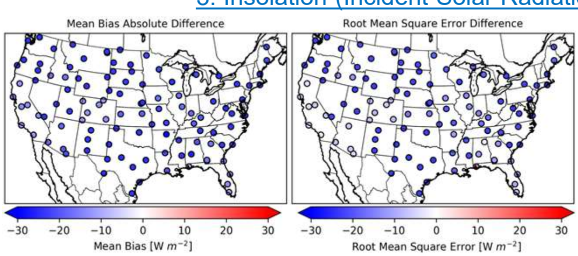
2. Model Setup

Two simulations are conducted using WRF-Chem (v4.1). The first is a control simulation, which does not implement the cloud assimilation technique; while the other simulation applies White's method using insolation and cloud albedo products derived from GOES-13 data.

The simulations are performed on a 12-km domain covering the contiguous United States (CONUS) over the June 2016 period. The model's meteorological initial and boundary conditions are provided by the North American Mesoscale Forecast System (NAM) 12-km analysis and forecast. The chemistry boundary conditions are based on the Model for Ozone and Related Chemical Traces (MOZART) outputs. For chemical emissions, the EPA's 2016 beta emissions are used for anthropogenic sources, biogenic and fire emissions come from the Model of Emissions of Gases and Aerosols from Nature (MEGAN) and the Fire Inventory from NCAR (FINN) version 1.5. A 10-day spin-up run is conducted to initialize the chemical fields. The important physical and chemical options used in this study are summarized in the table.

Physics/Chemistry	Option
Horizontal Resolution	12 km
Microphysics	Thompson
Cumulus	Kain-Fritsch
Longwave Radiation	RRTMG
Shortwave Radiation	RRTMG
Surface Layer	Monin-Obukhov
Land Surface	Noah
PBL	YSU
Chemical Mechanism	T1-MOZCART

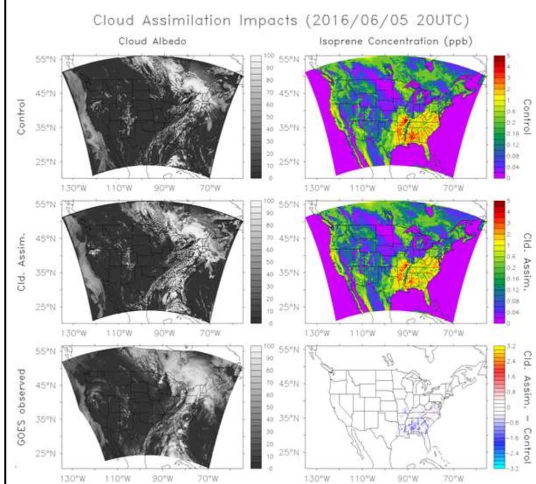
3. Insolation (Incident Solar Radiation) Statistics

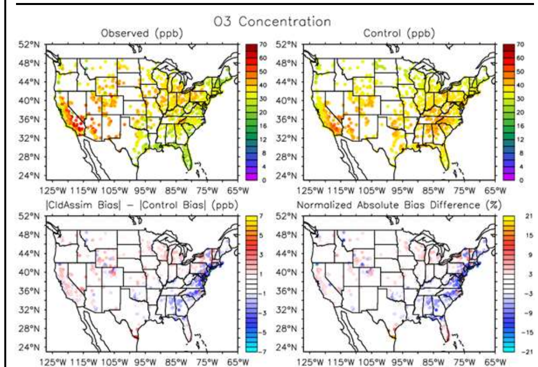


Note: the insolation field is improved throughout the domain!

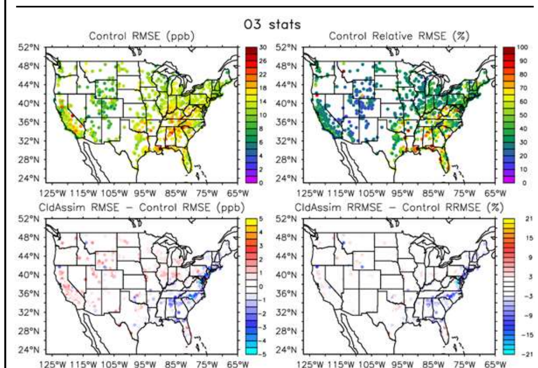
	Mean Bias [W m^{-2}]	RMSE [W m^{-2}]
All-sky statistics		
Control	86.38	171.25
Cloud Assimilation	65.39	153.75
Clear-sky statistics		
Control	76.22	141.04
Cloud Assimilation	70.30	135.65
Cloudy statistics		
Control	103.87	214.60
Cloud Assimilation	56.42	181.60

4. Preliminary Results

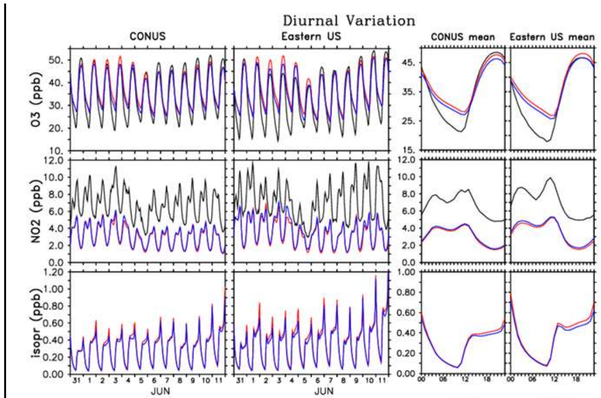




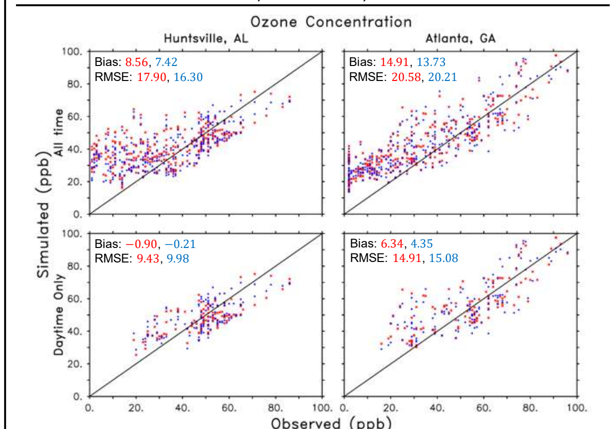
Note: Blue indicates improvements; red means degradation



Note: Problems were found in preliminary runs. Need further investigation.



Note: Black – observation; Red – Control; Blue – Cloud Assimilation



Note: Red – Control; Blue – Cloud Assimilation

5. Take Away Messages

- Cloud assimilation can positively impact the simulated cloud fields and thereby improve biogenic emissions and photolysis rates.
- For this case study, cloud-assimilation reduced simulated surface ozone levels by increasing cloudiness. This improved model performance in the East but degraded the performance in the West.
- **There are problems in the preliminary runs**. It showed high ozone over night, and a large consistent NO_2 under-estimation. Possible reasons:
  - Error in emission inputs/species mapping
  - Error in deposition velocity
  - Error in nighttime PBL mixing
- **Future plan**:
  - Correct emission inputs/species mapping
  - Switch to WRF-CMAQ for more versatility.

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