Using Geostationary Satellite Observations to Improve Air Quality Simulation for the 2016 Ozone Season

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Background

- Clouds affect atmospheric chemistry by modifying dynamics and chemical processes:
  - Planetary boundary layer (PBL) development and vertical mixing
  - Cloud-aerosol-radiation interactions
  - Surface insolation and temperature
    - Further affect biogenic emissions of volatile organic compounds (VOCs) and photochemical reaction rates
  - Lightning-induced nitrogen oxides (NOx) emissions
  - Wet deposition of trace gases and aerosols

- White et al. (2018) assimilates GOES cloud observations into WRF model improves cloud and surface radiation fields
  - Model performance of surface wind speed, temperature, and mixing ratio does not degrade

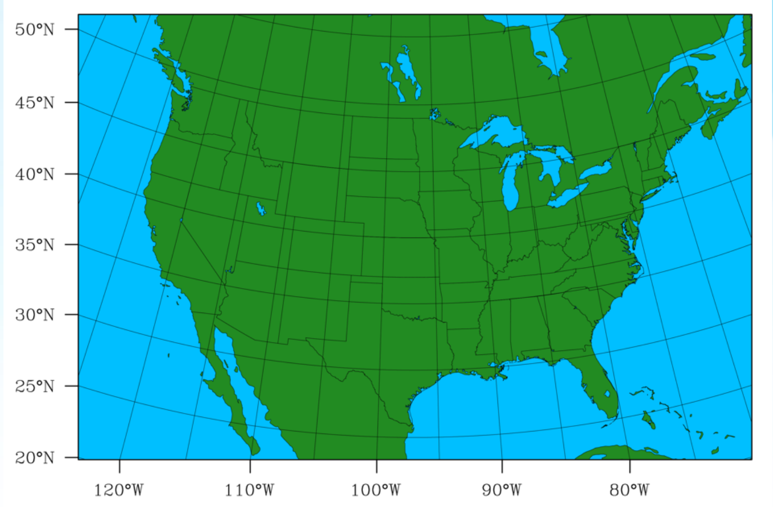
Objective

- Hypothesis
  - Impacts on model clouds and surface insolation can change biogenic VOC emissions and photochemical reactions, leading to improvements in daytime peak ozone concentration

- Evaluate the impacts of cloud assimilation technique on air quality simulations
  - Preparing two sets of meteorological background data from WRF
    - Control (no satellite data)
    - Cloud assimilation (uses GOES cloud observations)
  - Processing gridded emissions (except biogenic emissions) through SMOKE using meteorological data from the control run
  - Conducting two air quality simulations using CMAQ
    - Biogenic emissions are calculated inline in CMAQ

Model configuration

- Study period: June-September 2016 (10-day spin up in May)
- WRF domain: 12 km CONUS (472 x 312), 35 vertical levels (model top at 50 hPa)
- SMOKE/CMAQ domain: EPA 12US2 (396 x 246)
- Emissions: EPA 2016v1 modeling platform

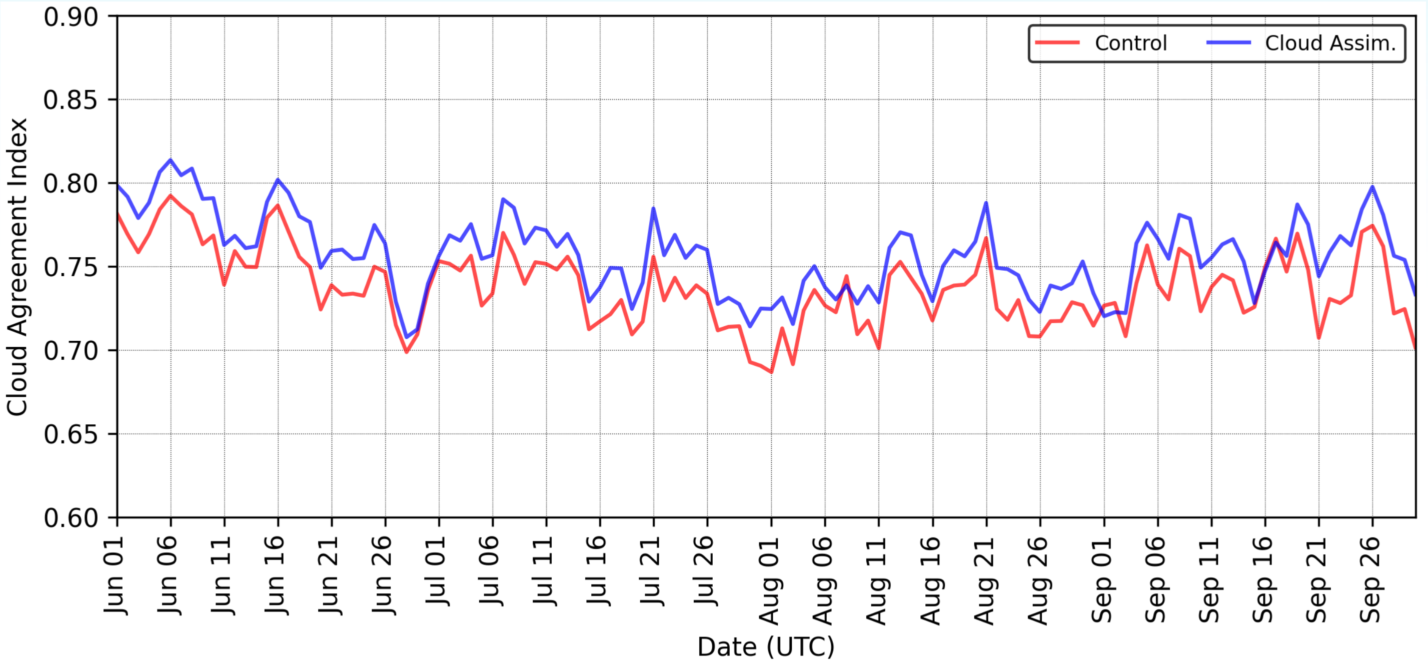


WRF	Version 4.1.4
LAND COVER	NLCD 2011 9s
INITIALIZATION	12 km NAM
MICROPHYSICS	Morrison
CUMULUS	Multiscale Kain-Fritch
LW RADIATION	RRTMG
SW RADIATION	RRTMG
SURFACE LAYER	Pleim-Xu
LAND SURFACE	Pleim-Xu
PBL	ACM2
NUDGING	Above the PBL or the 18th model level (~1665 m), whichever is higher
NUDGING COEFFICIENTS	U,V: $3\times10^{-4}s^{-1}$; T: $3\times10^{-4}s^{-1}$; Q: $1\times10^{-5}s^{-1}$
OTHER	Observations from MADIS

CMAQ	Version 5.2.1
MECHANISM	cb6r3_ae6_aq
CTM_WB_DUST	Y
CTM_ERODE_AGLAND	N
CTM_LTNG_NO	N
CTM_WVEL	Y
KZMIN	Y
CTM_ILDEPV	Y
CTM_MOSAIC	N
CTM_FST	N
CTM_ABFLUX	N
CTM_HGBIDI	N
CTM_SFC_HONO	Y
CTM_GRAV_SETL	Y
CTM_BIOGEMIS	Y
CTM_PT3DEMIS	N
CTM_ZERO_PCSOA	N

National cloud/radiation stats

Cloud agreement index quantifies how well model cloud agrees with GOES observation
NOTE: Cloud assimilation showed less improvements when used with Pleim-Xu/ACM2 scheme compared to Noah-YSU WRF configuration in prior sensitivity study



Surface insolation (W m^{-2}) compared to USCRN

		CONTROL		CLOUD ASSIMILATION	
		Bias	RMSE	Bias	RMSE
PX-UAH	All	48.5	144.2	42.0	129.4
	Clear	35.5	102.3	35.2	92.3
	Cloudy	64.9	183.9	50.5	164.7

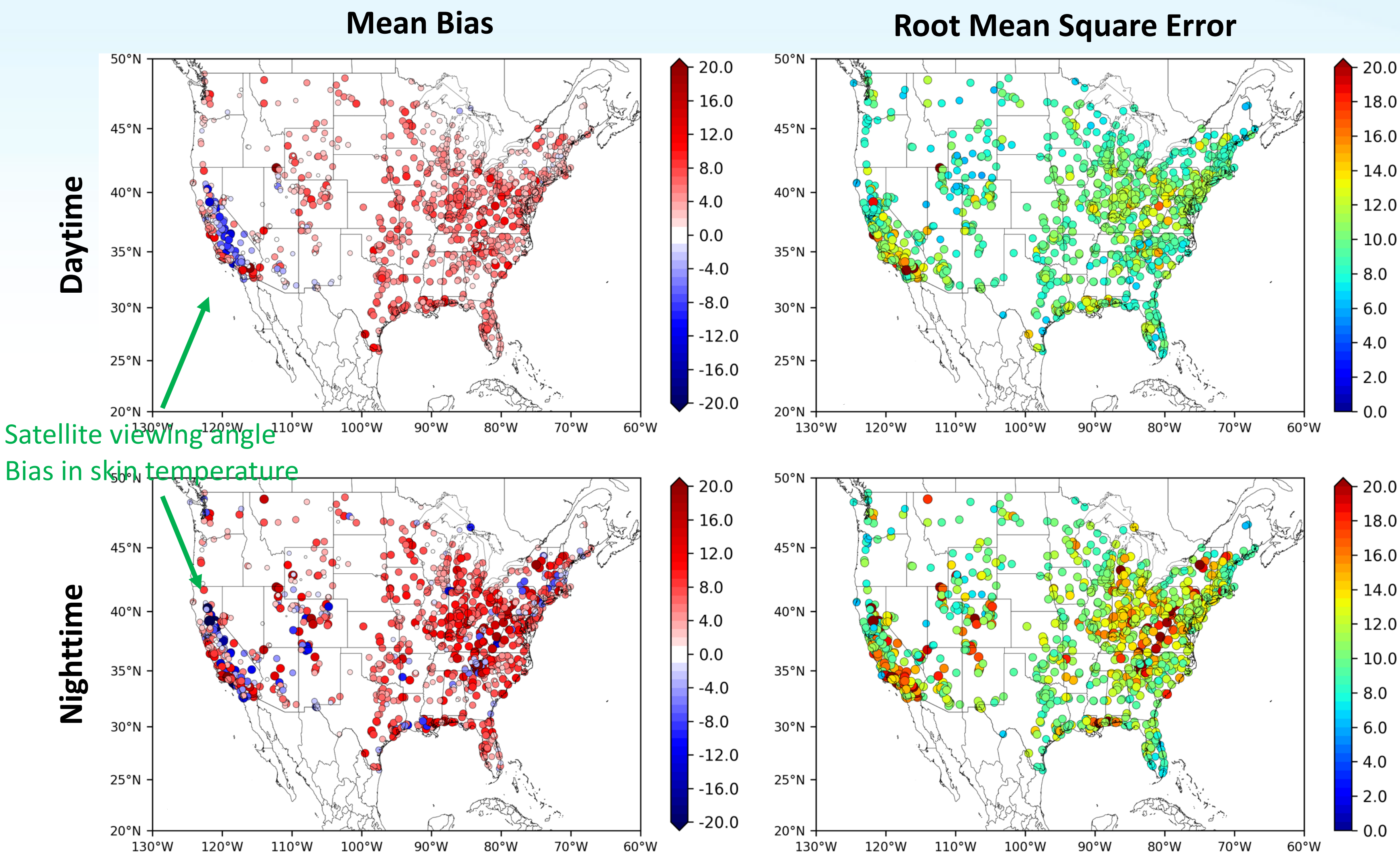
A 10% cloud albedo threshold is set to distinguish between clear and cloudy sky conditions

Domain-wide stats of surface O3

Hourly observations from the Air Quality System (AQS) were used to evaluate CMAQ results.
Day and night were separated according to solar elevation.

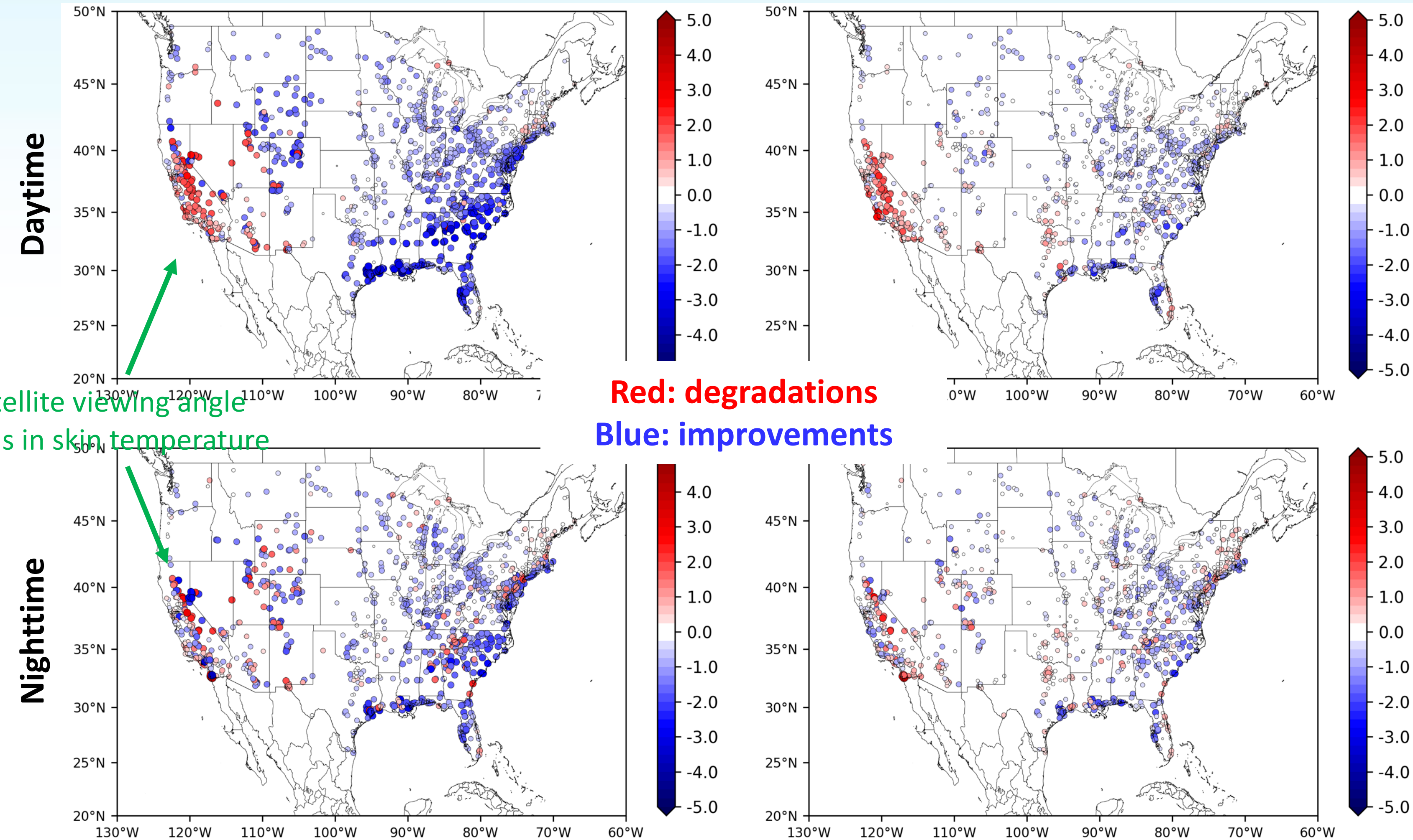
		Mean bias (ppb)	RMSE (ppb)	R^2
Control	All	3.4	11.3	0.691
	Daytime	3.3	10.5	0.696
	Nighttime	3.6	12.3	0.566
Cloud Assimilation	All	2.4	11.2	0.695
	Daytime	2.2	10.4	0.699
	Nighttime	2.7	12.2	0.569

Spatial stats of Control surface O3



Cloud Assim. impacts on surface O3

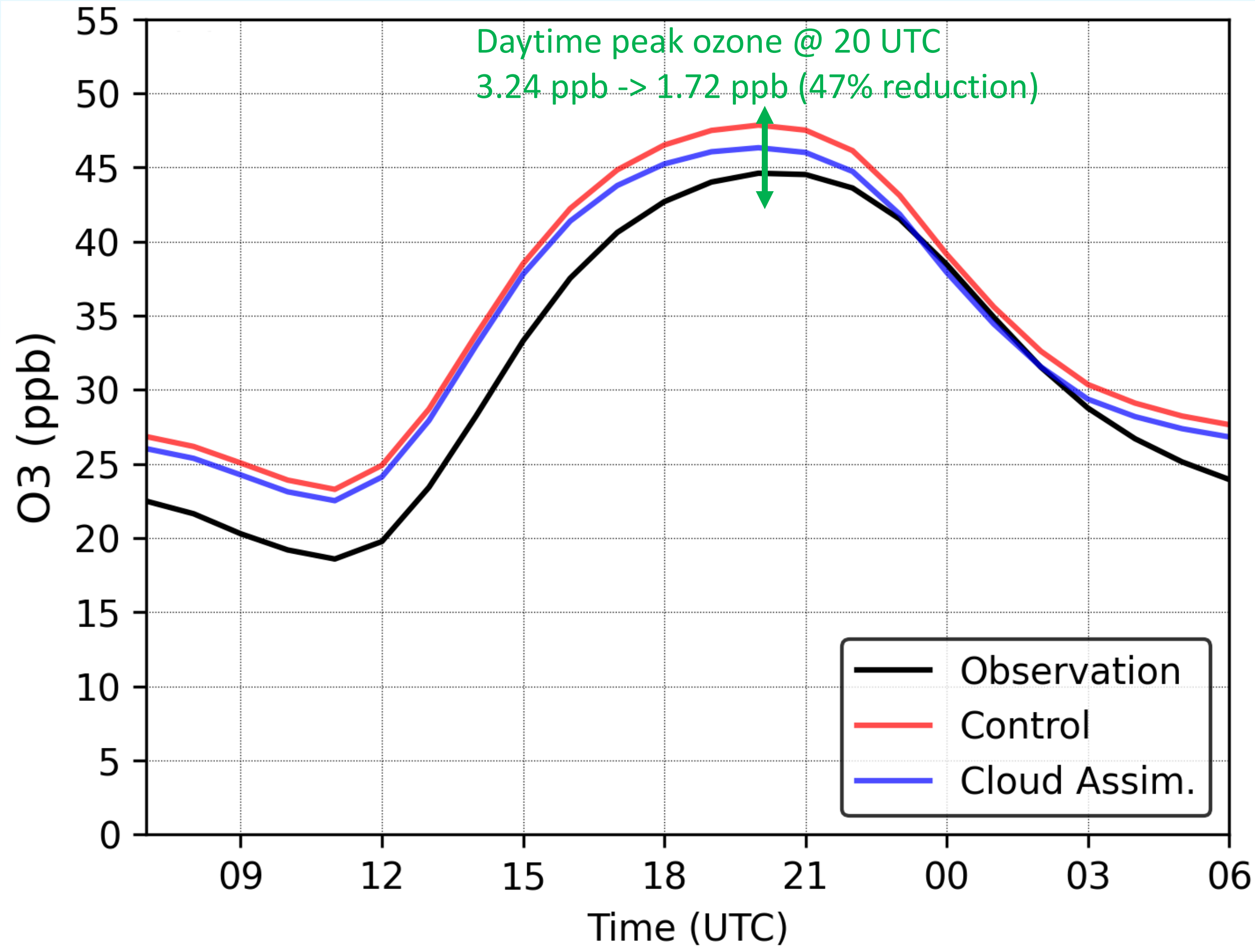
Absolute Mean Bias Difference **Error Difference**



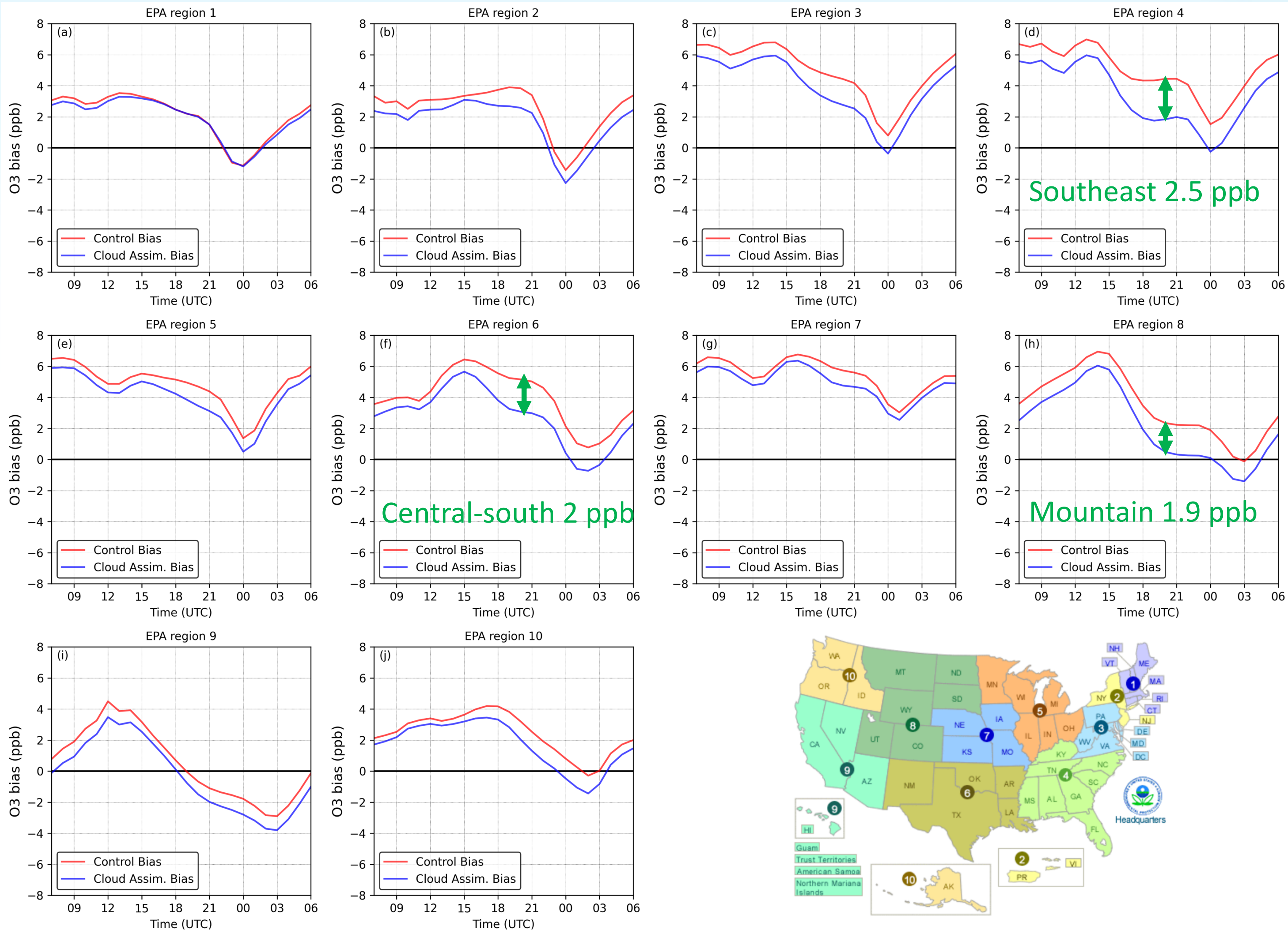
Satellite viewing angle
Bias in skin temperature

Red: degradations
Blue: improvements

Diurnal cycle of domain-wide surface O3

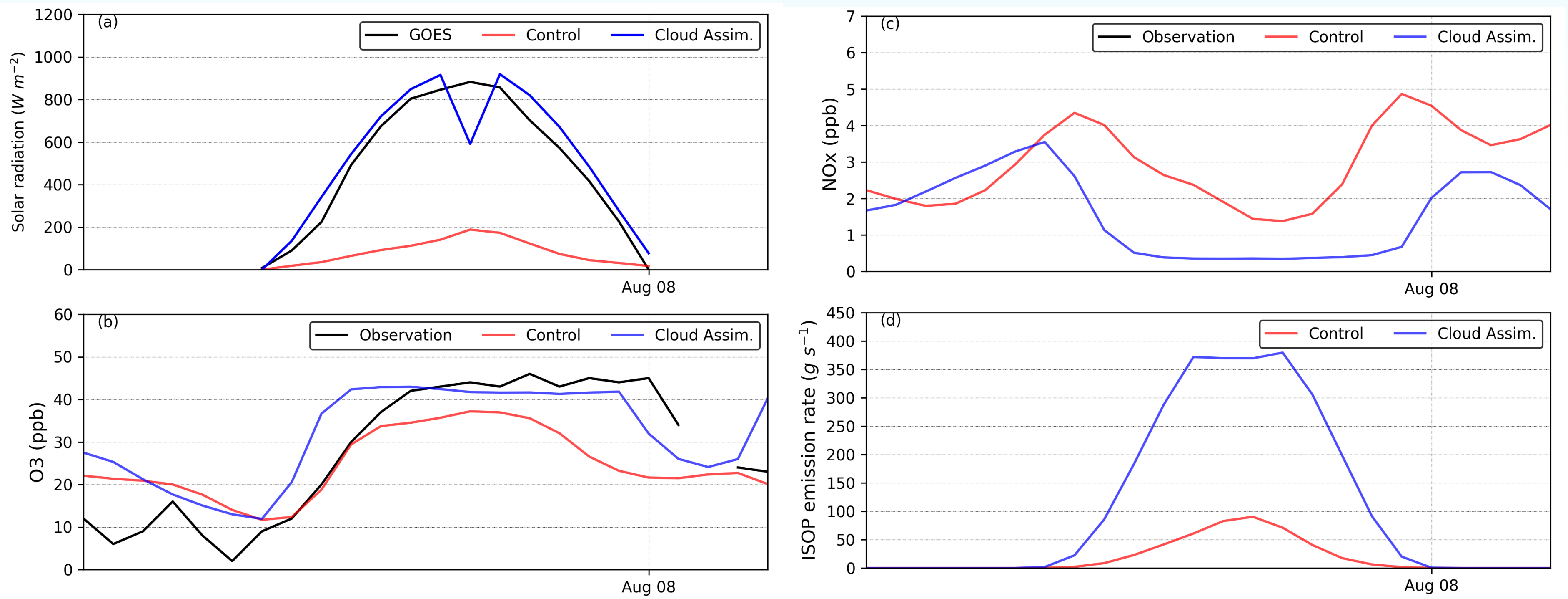


Diurnal cycle of regional surface O3



Case study – Yorkville, Atlanta, GA

The monitor is typically used as the background monitor for the area



Summary

- In this case, cloud assimilation improves cloud agreement index by ~2.4% on average.
  - Note that a Noah-YSU configuration may yield a higher improvement in cloud agreement than Pleim-Xu/ACM2.
- Mean bias and error of model predicted surface insolation are reduced by 13% and 10%, respectively.

- Domain averaged overprediction in surface ozone is reduced by ~1 ppb.
  - From ~3.4 ppb to ~2.4 ppb.
  - Exceptions were found in California where model skin temperature may be biased. A skin temperature assimilation may improve model performance.
- Domain averaged daytime peak ozone is reduced by ~47%
  - From 3.24 ppb to 1.72 ppb
- Regional daytime peak ozone is reduced most effectively in the southeast, central-south, and mountain states.
  - The southeast and central-south have intense BVOC emissions and more transient convective clouds
  - Reasons for large improvement in the mountain need further investigation

Acknowledgement

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