Does Temperature Nudging Overwhelm Aerosol Radiative Effects in Regional Integrated Climate Models?

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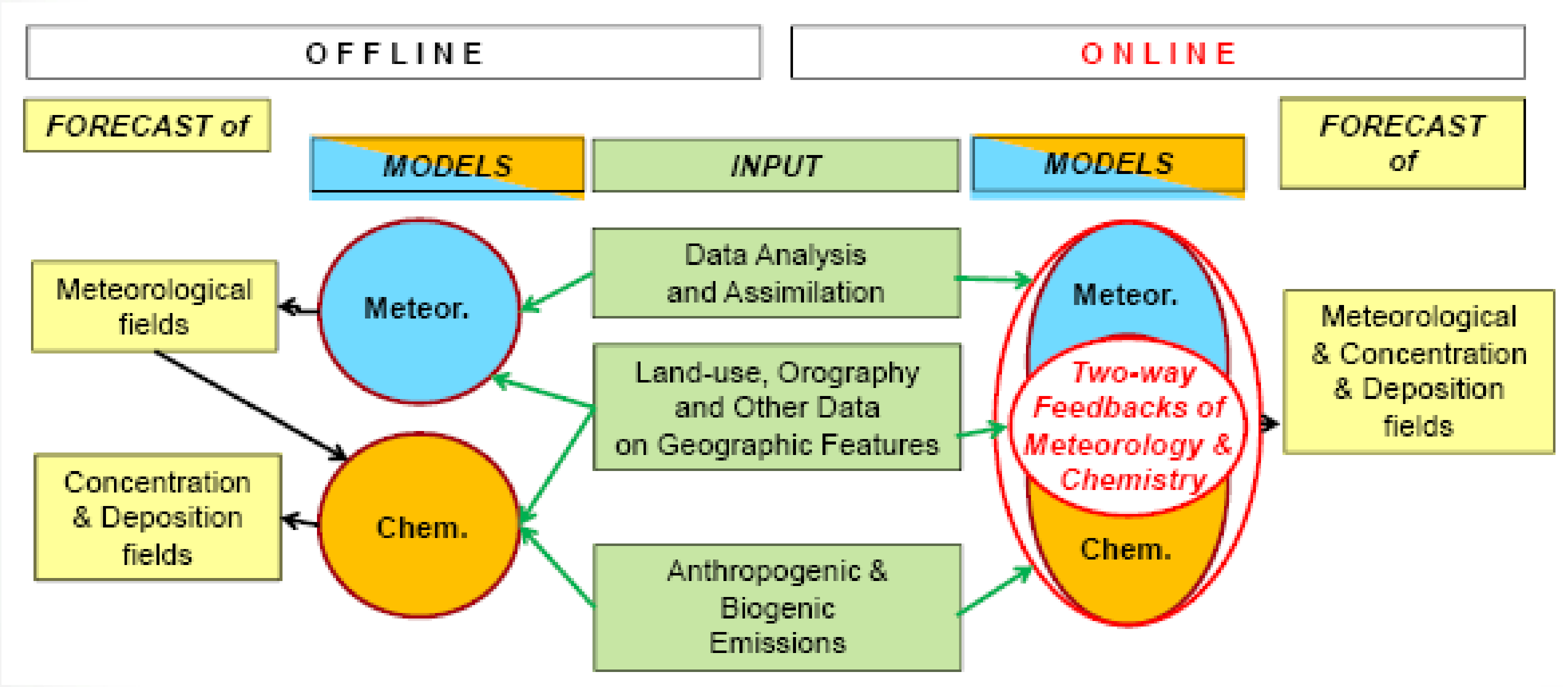
Motivation

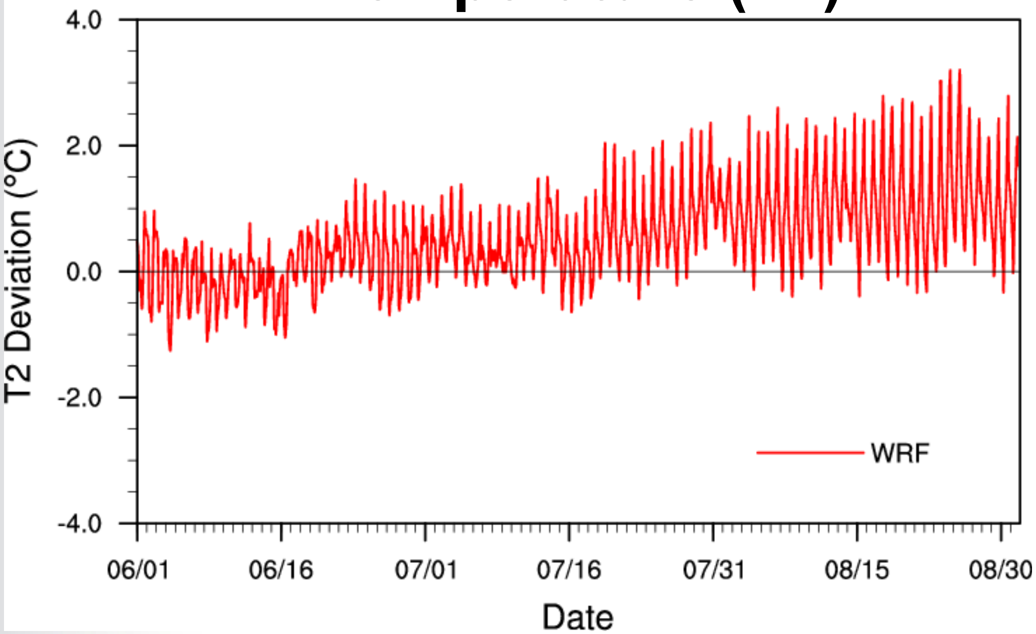
- Meteorology is an important driver for chemical transport models.



Schematic diagram of (left) offline and (right) online coupled meteorology and chemistry modelling approaches for air quality and meteorology simulation and forecasting (Baklanov et al., 2014).

Meteorological Biases

2-m Temperature (T2)



- Two Approaches

1) Frequent reinitialization
- Discontinuity
- Suppress aerosol effects

2) Data assimilation (i.e., nudging)
- Suppress aerosol effects

On-line

ΔT^{N} *vs.* ΔT^{AE} ?

Pseudo Radiative Effects (PRE)

1. Surface Effects

Flux-Adjusting Surface Data Assimilation System (FASDAS, Alapaty et al., 2008)

$$H_s^F = \rho C_p \left(\partial T_a^F / \partial t\right)\Delta z \qquad H_l^F = \rho L\left(\partial q_a^F / \partial t\right)\Delta z$$

$$PRE\_sfc = \{H_s^F - \psi_q H_l^F\}_{sfc}$$

2. Tropospheric Effects

Four-Dimensional Data Assimilation (FDDA, Stauffer and Seaman, 1990, 1994)

$$PRE\_atm = 1/n \sum_{pbl}^{top} H_s^F$$

3. TOA Effects (Effects 1 + 2)

$$PRE\_toa = PRE\_sfc + PRE\_atm$$

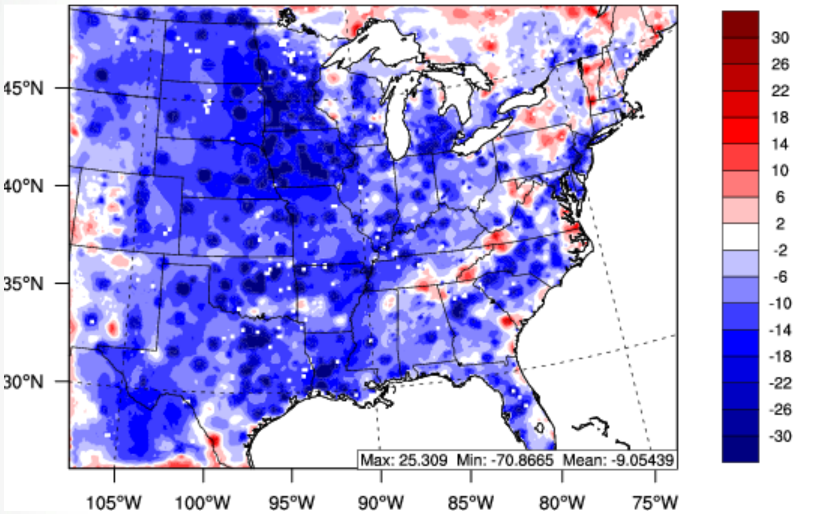
- PRE > 0: Nudging has warming effects (i.e., model underpredicts temperatures)
- PRE < 0: Nudging has cooling effects (i.e., model overpredicts temperatures)

Model Configurations

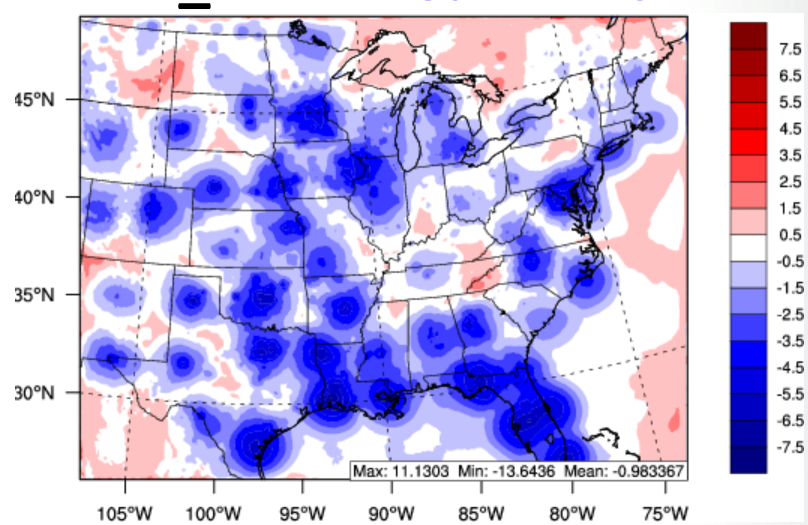
- Weather *Research and Forecasting (WRF) Model*
  - **WRF3.7.1**
  - **YSU, NOAH, MSKF, RRTMG, Morrison DMS**
  - **Mild analysis nudging of free atmosphere (u-v wind components and temperature : 5.0×10^{-5} s^{-1}; moisture: 5.0×10^{-6} s^{-1})**
  - **FASDAS for surface layer (temperature and moisture: 8.3×10^{-4} s^{-1}, see Alapaty's talk)**
  - **DX = 12 km grids; 35 layers up to 50hPa**
  - **12 km NCEP NAM, central and eastern U.S.**
  - **June, July, and August (JJA) 2006**

PRE (JJA Averages)

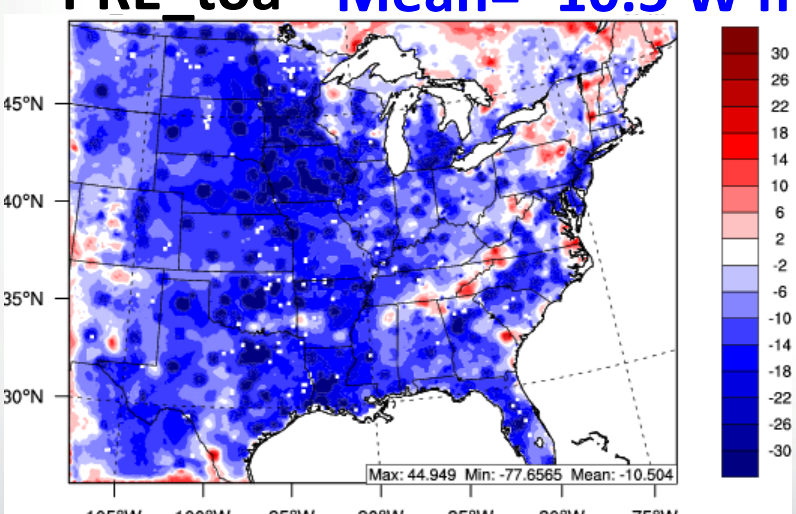
PRE_sfc **Mean= -9.1 W m^{-2}**



PRE_atm **Mean= -1.0 W m^{-2}**



PRE_toa **Mean= -10.5 W m^{-2}**



- PRE_toa is dominated by PRE_sfc.
- Nudging is cooling the surface and atmosphere.

EPA

Aerosol Radiative Effects (ARE)

SW Direct Radiative Effects (DRE)

MISR_G

MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN
0.18 -5.7	0.15 -5.7	0.14 -4.2	0.22 -7.0	0.22 -8.7	0.17 -5.8	0.25 -5.5	0.24 -5.8	0.21 -4.4	0.31 -5.4	0.24 -6.4	0.22 -4.4
0.20 -5.7	0.19 -7.0	0.15 -5.1	0.35 -6.9	0.43 -9.1	0.32 -6.9	0.37 -6.4	0.45 -7.0	0.33 -5.8	0.37 -8.0	0.32 -9.4	0.31 -7.2
			0.13 -3.9	0.10 -3.0	0.17 -4.3	0.14 -4.1	0.24 -4.6	0.23 -5.1	0.11 -3.3	0.10 -3.1	0.14 -3.8
				MAM 0.06 -4.1	JJA 0.07 -3.0	ANN 0.09 -5.8		Global Average	0.25 -5.1	0.25 -5.8	0.23 -4.9

MO_MI_GO

MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN
0.17 -5.2	0.14 -5.0	0.13 -3.9	0.20 -6.3	0.21 -7.4	0.17 -5.3	0.24 -5.4	0.23 -5.8	0.20 -4.5	0.29 -5.4	0.23 -6.4	0.21 -4.4
0.19 -5.5	0.18 -6.3	0.15 -4.7	0.31 -6.2	0.36 -7.4	0.29 -6.1	0.34 -5.6	0.38 -6.2	0.30 -5.1	0.33 -7.0	0.23 -6.5	0.25 -6.0
			0.10 -3.0	0.11 -2.9	0.13 -3.3	0.11 -3.2	0.23 -4.5	0.19 -4.2	0.08 -2.5	0.08 -2.5	0.11 -2.9
				MAM 0.07 -3.3	JJA 0.07 -2.8	ANN 0.09 -4.8		Global Average	0.21 -4.7	0.21 -5.3	0.19 -4.4

GOCART

MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN	MAM	JJA	ANN
0.14 -4.3	0.11 -4.0	0.11 -3.6	0.19 -5.8	0.19 -5.9	0.17 -4.9	0.30 -7.0	0.25 -6.3	0.23 -5.3	0.28 -5.1	0.23 -5.8	0.22 -4.4
0.15 -3.3	[illegible] -4.5	0.11 -3.2	0.29 -5.1	0.34 -6.6	0.28 -5.5	0.33 -4.7	0.34 -4.9	0.28 -4.3	0.34 -6.6	0.18 -5.0	0.25 -5.6
			0.08 -2.3	0.15 -3.1	0.12 -2.6	0.07 -2.0	0.26 -4.2	0.17 -3.0	0.06 -1.6	0.06 -1.7	0.07 -1.7
				MAM 0.07 -3.6	JJA 0.08 -3.1	ANN 0.08 -4.0		Global Average	0.22 -4.4	0.22 -4.8	0.20 -4.1

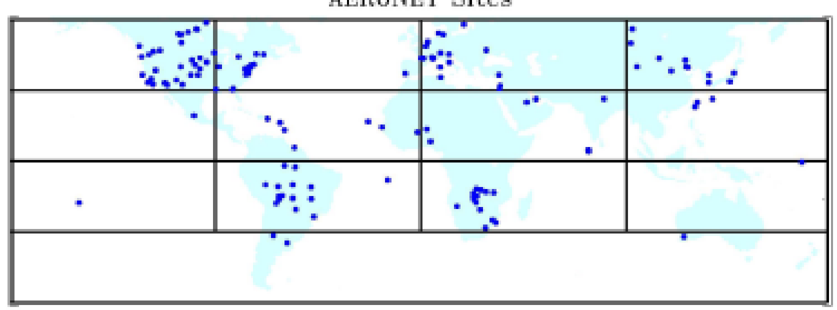
AOT (upper) and SSA (lower)

DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON
0.05/0.11/0.15/0.08 0.92/0.92/0.90/0.89	0.09/0.14/0.31/0.12 0.93/0.92/0.93/0.89	0.15/0.22/0.22/0.21 0.94/0.92/0.90/0.90	0.20/0.36/0.34/0.20 0.93/0.92/0.90/0.88
	0.26/0.34/0.33/0.28 0.96/0.96/0.94/0.94	0.30/0.38/0.38/0.32 0.92/0.94/0.93/0.93	
	0.14/0.11/0.32/0.47 0.91/0.90/0.89/0.92	0.11/0.10/0.27/0.43 0.89/0.86/0.85/0.88	

DRE (Wm^{-2}) at the TOA (upper) and surface (lower)

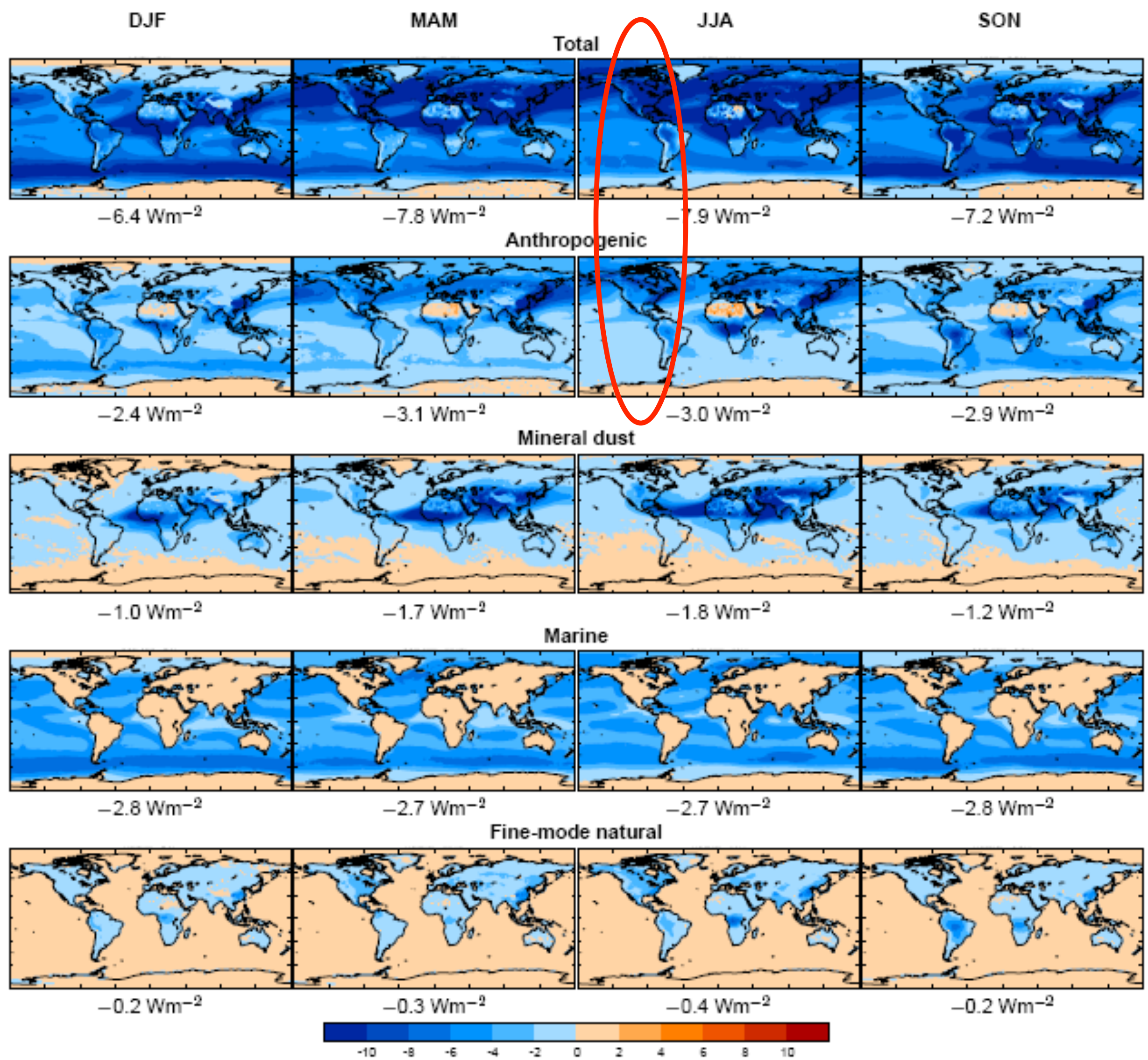
DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON	DJF/ MAM/ JJA/ SON
-1.9/-4.4/-5.2/-2.7 -3.6/-10.1/-14.4/-6.7	-2.8/[illegible]/-11.1/-4.5 -5.2/-12.8/-23.8/-10.8	-5.0/-7.0/-8.1/-5.8 -8.4/-17.6/-21.0/-14.9	-8.4/-10.7/-8.1/-5.3 -11.9/-28.2/-30.4/-15.7
	-8.4/-10.7/-10.4/-9.2 -14.5/-20.0/-23.2/-18.1	-9.1/-9.8/-9.0/-8.1 -23.8/-23.8/-24.3/-20.1	
	-3.9/-3.4/-7.2/-11.2 -11.4/-9.4/-23.3/-30.9	-2.7/-3.9/-6.4/-9.8 -10.6/-9.0/-23.5/-33.9	

AERONET Sites



JJA Model TOA: -4.0 to -8.7 W m^{-2}; Obs. TOA: -5.2 to -11.1 W m^{-2}; Obs. Surface: -14.4 to -23.8 W m^{-2} (Yu et al., 2006)

TOA DRE



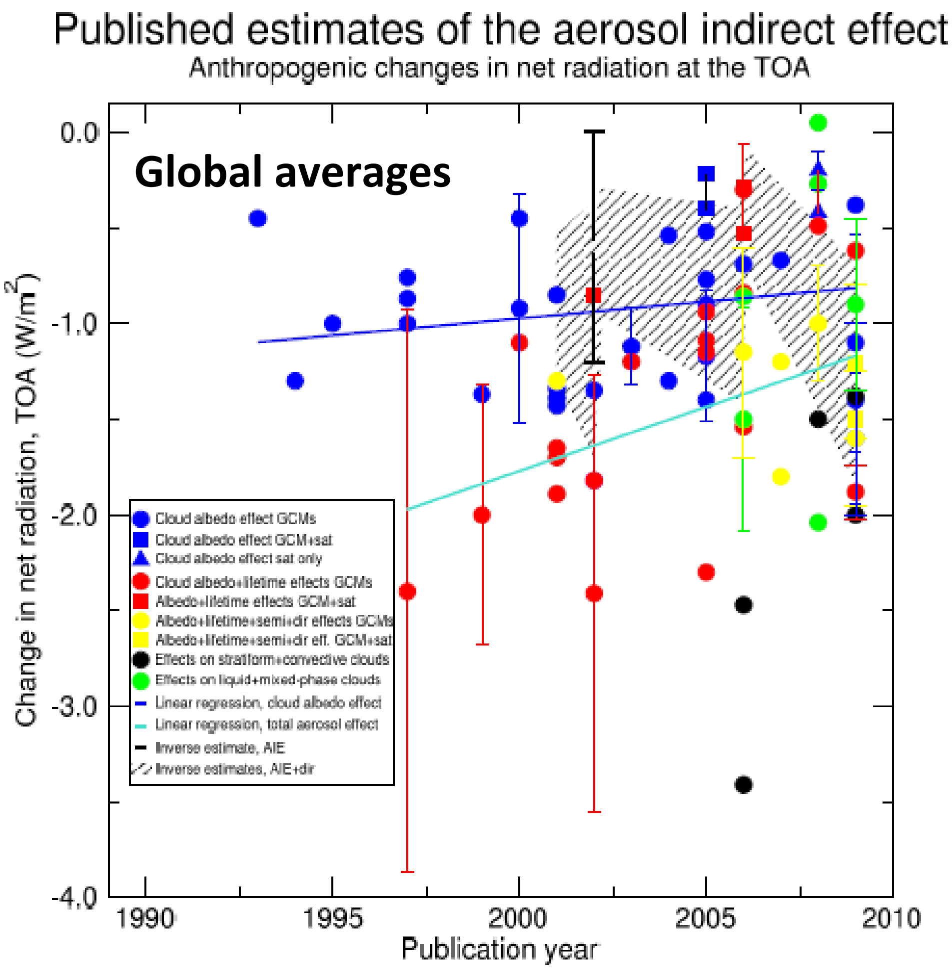
JJA (SW)
CONUS DRE < -10 W m^{-2};
Global DRE = -7.9 W m^{-2}

Anthropogenic:
CONUS: -2 to -8 W m^{-2}

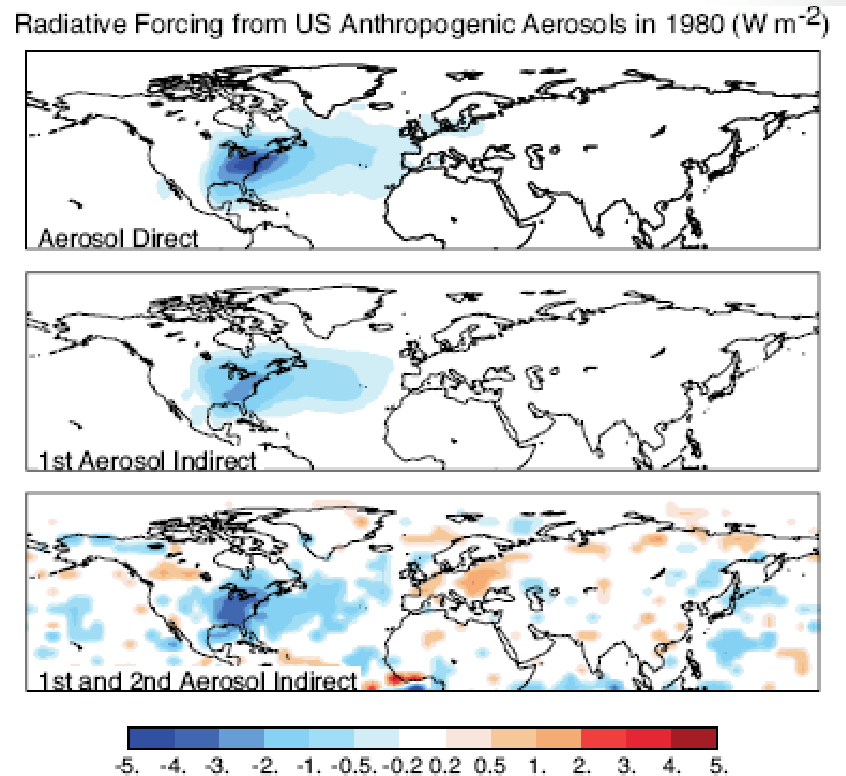
(Bellouin et al., 2013)

Anthropogenic Aerosol Indirect Effects

Aerosol Indirect Radiative Effects (large uncertainties)



Lohmann et al. (2010)



Leibensperger et al. (2012)

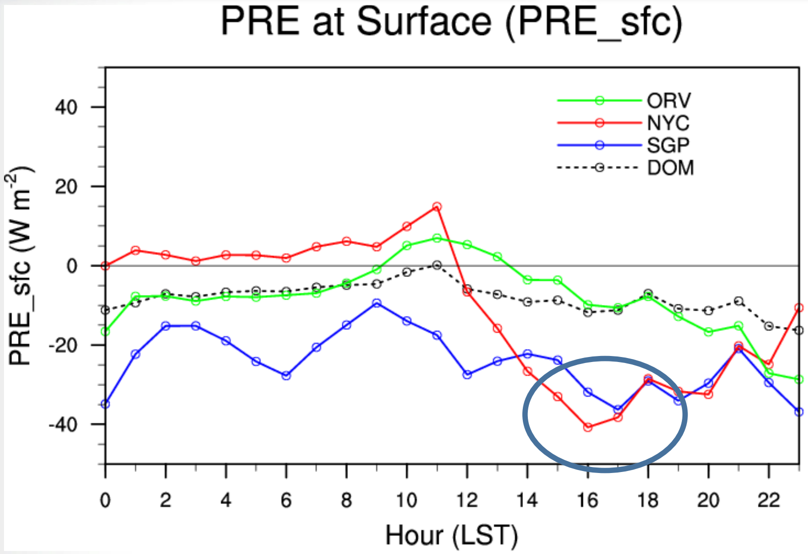
ARE…

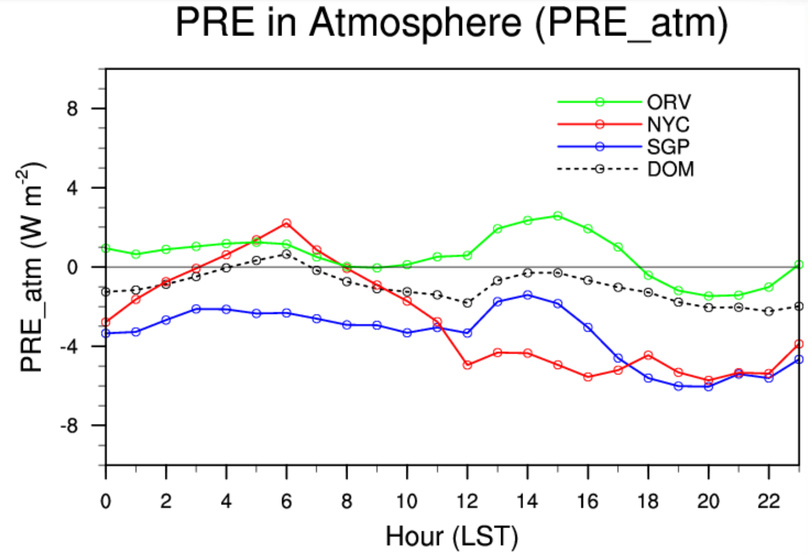
Table 1. Reported Aerosol Radiative Effects (W m^{-2})

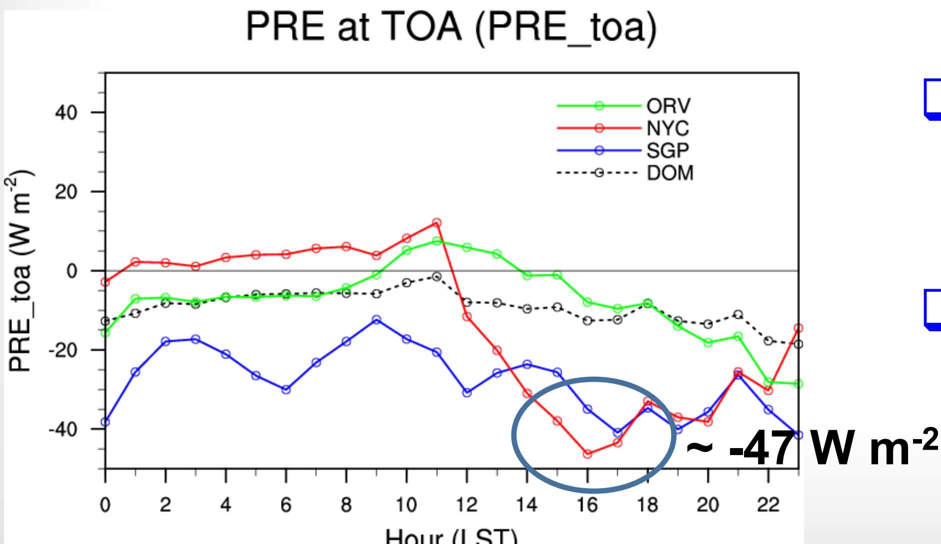
	CONUS	Globe	References
Surface	-14.4 to -23.8 (DRE) -9.1 (PRE)	-11.8±1.9 (DRE, land) -11.5±1.9 (DRE, land)	Yu et al. (2006) Bellouin et al. (2013) This work
Troposphere	-1.0 (PRE)	+5.1 (DRE, land)	Bellouin et al. (2013) This work
TOA	< -10 (DRE) -4.0 to -8.7 / -5.2 to -11.1 (DRE) ~ -4 (DRE) ~ -2.0 (anthro. DRE) ~ -2.0 (anthro. IRE) -10.5 (PRE)	-6.4±1.0 (DRE, land) -4.9±0.7 (DRE, land) -0.5 to -5 (IRE, land) −2.3±0.9 (land)	Bellouin et al. (2013) Yu et al. (2006) Heald et al. (2014) Lohmann and Feichter (2005) Leibensperger et al. (2012) Quaas et al. (2009) This work

- On regional/continental scales, PRE is close to upper limit of ARE. Using integrated modeling system (e.g., online coupled model) might reduce TOA radiative biases.

Diurnal Variation of PRE



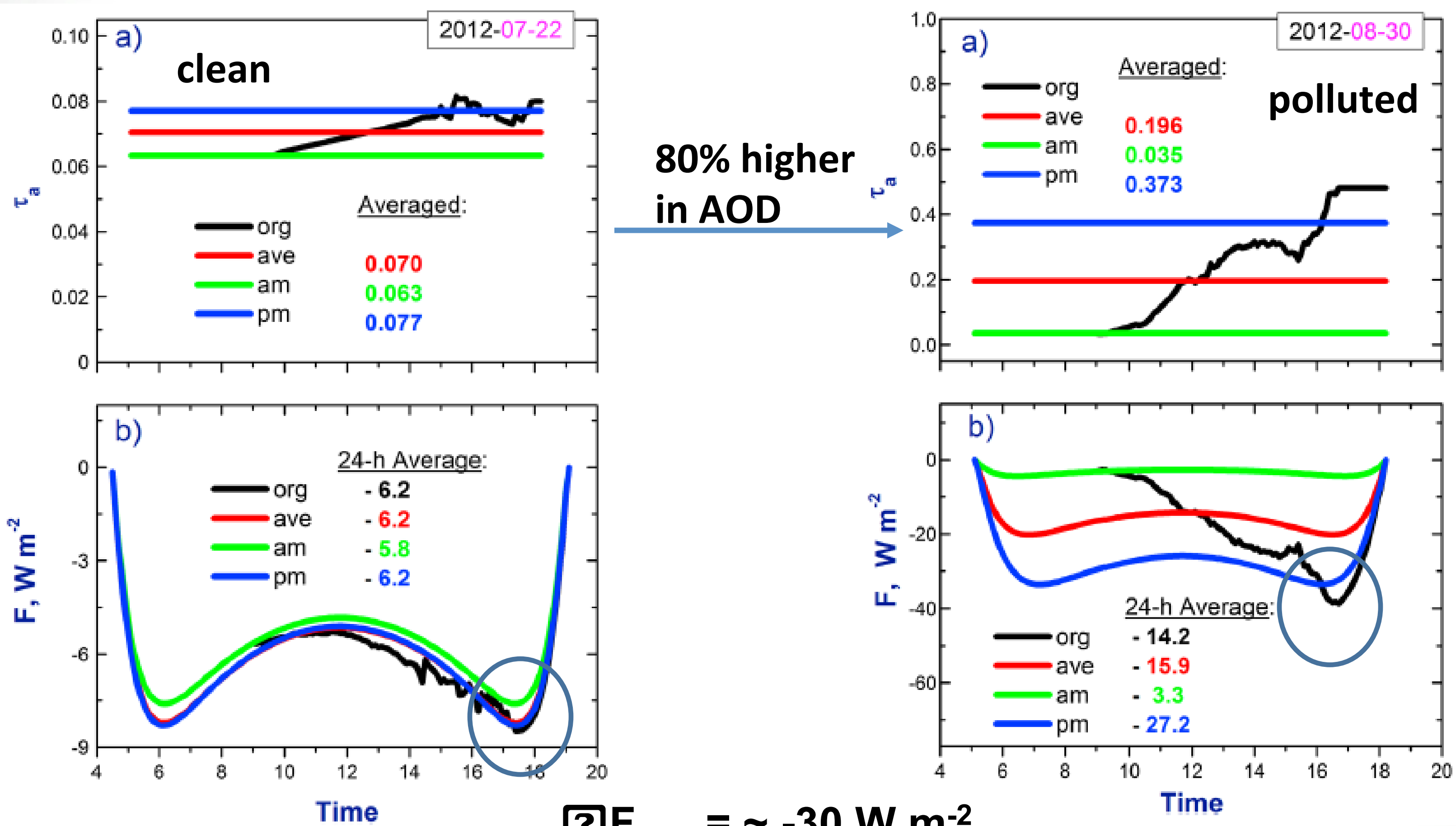




- Cooling/warming effects are much higher in local scales than large domain averages.
- Cooling/warming effects can be nonlinear depending on the sizes of model errors.

DOM: entire domain; NYC: New York City; ORV: Ohio River Valley, SGP: Southern Great Plains

Diurnal Variation of ARE (TOA)



ΔF_{max} = ~ -30 W m^{-2}

Cape Cod (Kassianov et al., 2013)

PRE could overwhelm ARE at polluted sites.

Summary

- Surface energy balance errors dominate TOA energy balance.
- Using an integrated modeling system might reduce radiative biases for large domain averages at the top of the atmosphere.
- But, PRE could overwhelm ARE at local scales in an integrated modeling system.

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