Investigation of Multi-decadal Trends in Aerosol Direct Radiative Effect from Anthropogenic Emission Changes over North America and Northern Hemisphere by Using the Multi-scale Two-way Coupled WRF-CMAQ Model

Chao Wei[1,*], Jia Xing[1,*], Jonathan Pleim[1], Rohit Mathur[1], David Wong[1], George Pouliot[1], Christian Hogrefe[1], Chuen-Meei Gan[1,*], ST Rao[1] and Francis S. Binkowski[2]

[1]Atmospheric Modeling and Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, U.S.A.

[2]The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, U.S.A.

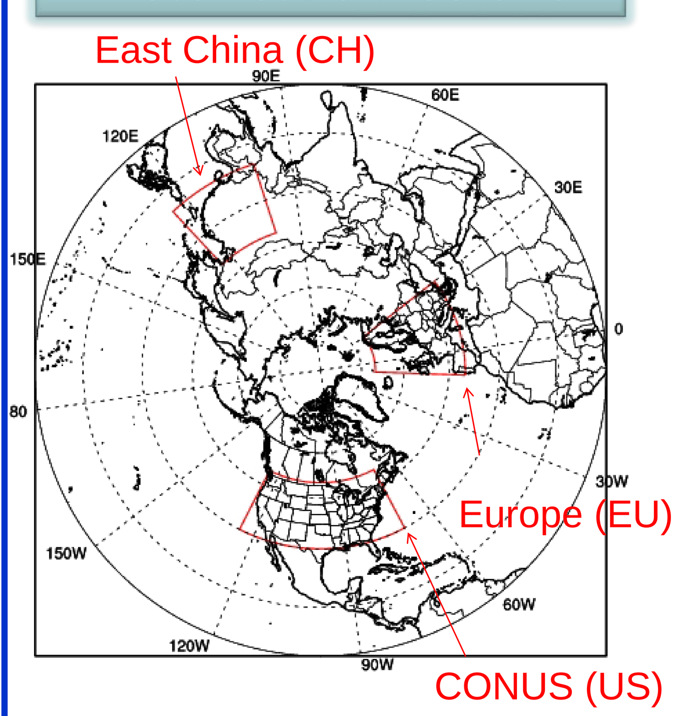
[*]National Research Council

Introduction

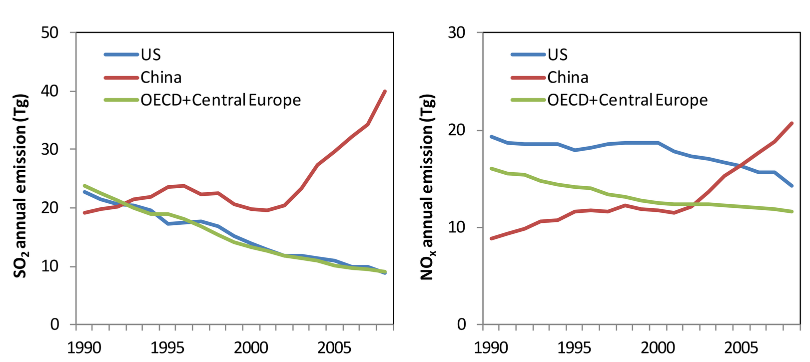
Anthropogenic aerosols play a dominant role in the surface solar radiation "dimming or brightening" trends observed across the globe. However, the simulations of Global Climate Models (GCMs) generally underestimate the decadal changes in surface radiation, compared to the observed "diming" and "brightening" trends during the 20th century. Therefore it is important to further reduce the uncertainties and to improve the model's ability of reproducing the decadal changes in surface radiation. A new two-way coupled meteorology and atmospheric chemistry model, i.e., Weather Research and Forecast (WRF) model coupled with the Community Multiscale Air Quality (CMAQ) model has been developed by U.S. Environmental Protection Agency. This model system can be applied as an integrated regional climate and chemistry model (RCCM) which is an important tool for downscaling future projections of global climate to higher resolution, and assessing the interactions between atmospheric chemistry and climate forcing and the effects of air pollutants on atmospheric radiation and secondary effects on meteorology and air concentrations.

In this study, we extend the applicability of the two-way WRF-CMAQ model to hemispheric scales and high-resolution. Results of with and without aerosol feedback simulations are presented and discussed.

Historical emissions



Significant reductions in emission SO_2 and NO_x in the United States and Europe;
but sharp increases of emissions in China from 1990 – 2010



Method

High-resolution WRF-CMAQ two-way model

–WRF3.3: NCLD land-use type, RRTMG radiation scheme, ACM2 (Pleim) PBL, PX LSM.

–CMAQ5.0: CB05-AERO6 chemistry, inline photolysis, inline dust emission module.

•Meteorological input data

NCEP North America Regional Reanalysis (NARR) data with 32×32km spatial and 3-hour temporal resolution; NCEP ADP Operational Global Surface/ Upper Air Observations with 6 hour intervals,

•Emission Inventory

A newly developed 20-years emission inventory is used in order to accurately reflect the emission trends resulting from progressively more stringent air quality regulations as well as population trends, economic conditions, and technology changes in motor vehicles and electric power generation.

•Domain

12×12 km resolution over most of North America; 35 layers from surface to 100mb.

Hemispheric WRF-CMAQ two-way model

–WRF3.3: MODIS land-use type, RRTMG radiation scheme, ACM2 (Pleim) PBL, PX LSM.

–CMAQ5.0: CB05-AERO6 chemistry, tropopause ozone calculated from PV (potential vorticity), inline photolysis, inline dust emission module.

•Meteorological input data

NCEP/NCAR Regional Reanalysis data with 2.5 degree spatial and 6-hour temporal resolution; NCEP ADP Operational Global Surface/ Upper Air Observations with 6-hour intervals,

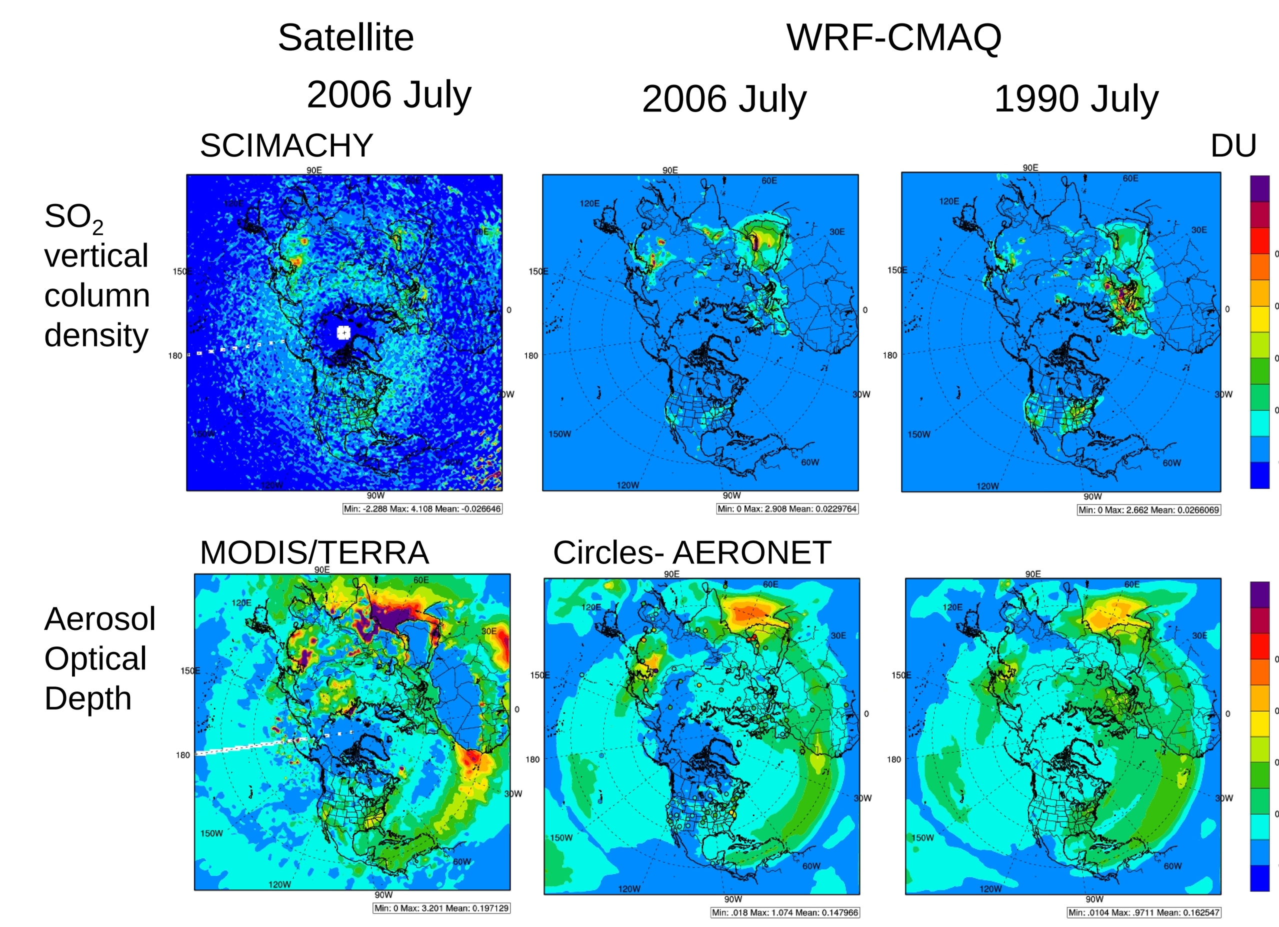
•Emission Inventory

A newly developed 20-years emission inventory for US is used. The anthropogenic emissions were derived from EDGAR (Emission Database for Global Atmospheric Research) and biogenic VOC and lightning NOx emissions were obtained from GEIA (Global Emission Inventory Activity). Temporal distribution was referred to EDGAR default profile, speciation was referred to SMOKE profile, vertical allocation was referred to SMOKE plume-rise and EMEP profile.

•Domain

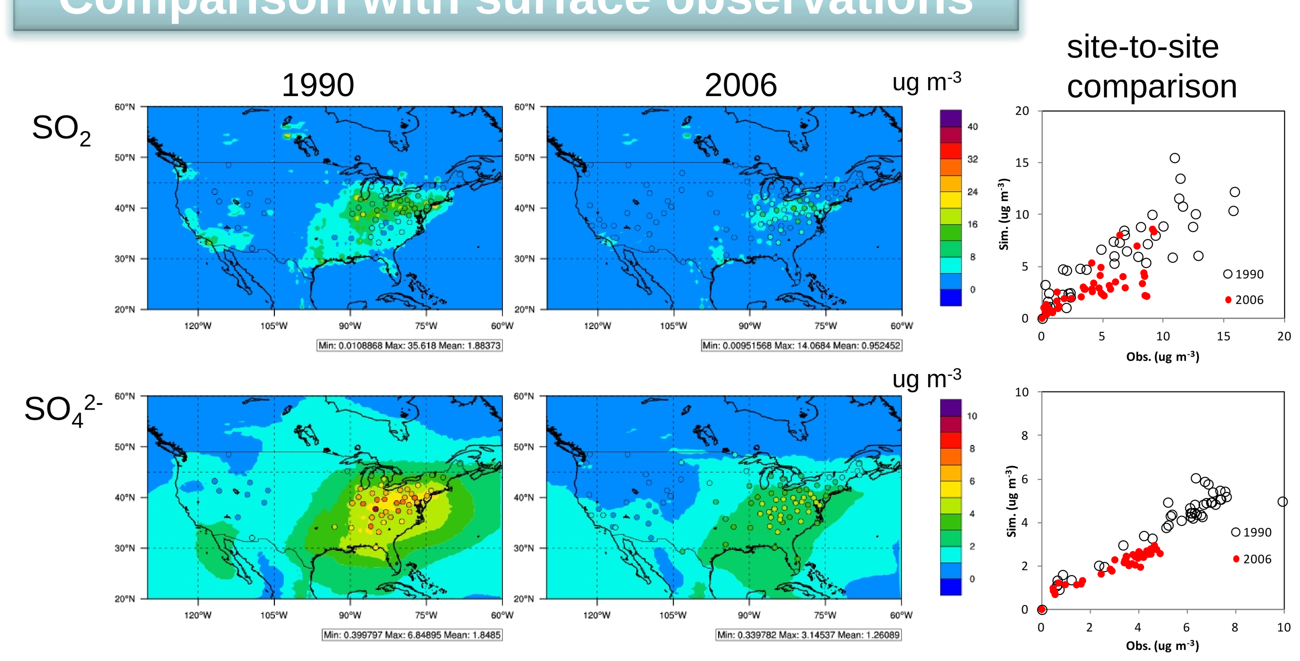
108×108 km resolution over north hemisphere; 44 layers from surface to 50mb.

Comparison with satellite retrieval



Model roughly represents and spatial distributions of aerosols

Comparison with surface observations



Annul mean of surface concentration; observation-CASTNET

Nudging for soil and atmosphere

nudging for atmosphere in summer (2006 Jun)

cases	mean bias	mean abs error	correlation	std
strong soil nudging				
strong air coef. (NF)	0.087826	1.6527	0.94407	2.2141
small air nudging coef. (NF)	0.13726	1.6562	0.944	2.2158
small air nudging coef. (F)	0.095295	1.6566	0.94396	2.2196
delta T (NF-F)	**0.042**	-0.0004		
weak soil nudging				
small air nudging coef. (F)	0.16646	1.7178	0.94076	2.2811
small air nudging coef. (NF)	0.22337	1.7208	0.94077	2.2809
delta T (NF-F)	**0.057**	0.003		
no air nudging (NF)	0.7675	2.5323	0.86776	3.3428
no air nudging (F)	0.70258	2.4704	0.87232	3.2862
delta T (NF-F)	**0.065**	0.062		

nudging for temperature, water vapor, and wind speed above PBL

- **base case** (weak nudging)
  - guv,gt = 0.00005 (~6 hours)
  - gq = 0.00001
- strong nudging
  - guv,gt = 0.0003 (~1 hour)
  - gq = 0.00001

soil nudging in summer (2006 Jun)
(weak nudging in atmosphere)

cases	mean bias	mean abs error	correlatio n	std
big soil nudging coef. (NF)	0.13726	1.6562	0.944	2.2158
big soil nudging coef. (F)	0.095295	1.6566	0.94396	2.2196
delta T (NF-F)	**0.042**	-0.0004		
small soil nudging coef. (NF)	0.22337	1.7208	0.94077	2.2809
small soil nudging coef.(F)	0.16646	1.7178	0.94076	2.2811
delta T (NF-F)	**0.057**	0.003		

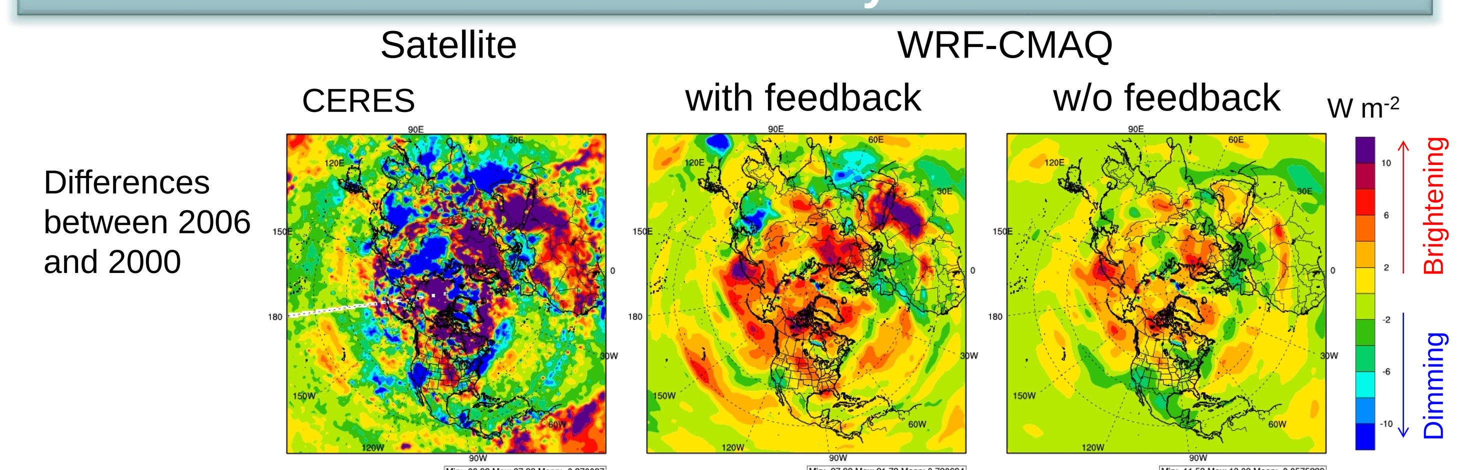
nudging for soil temperature in Pleim-Xiu land-surface model

- **base case** (weak nudging): T2NUDF = 1.5E-6 (~7.7 days)
- strong nudging: T2NUDF = 1.0E-5 (~27 hours)
- medium nudging: T2NUDF = 3.0E-6 (~3.8 days)

soil nudging in winter (2006 Jan)
(weak nudging in atmosphere, NF)

cases	mean bias	mean abs error	correlatio n	std
small soil nudging coef.	0.11701	1.8888	0.95769	2.4910
big soil nudging coef.	0.089634	1.8253	0.96066	2.4043
mid soil nudging coef.	0.10844	1.8673	0.9587	2.4617

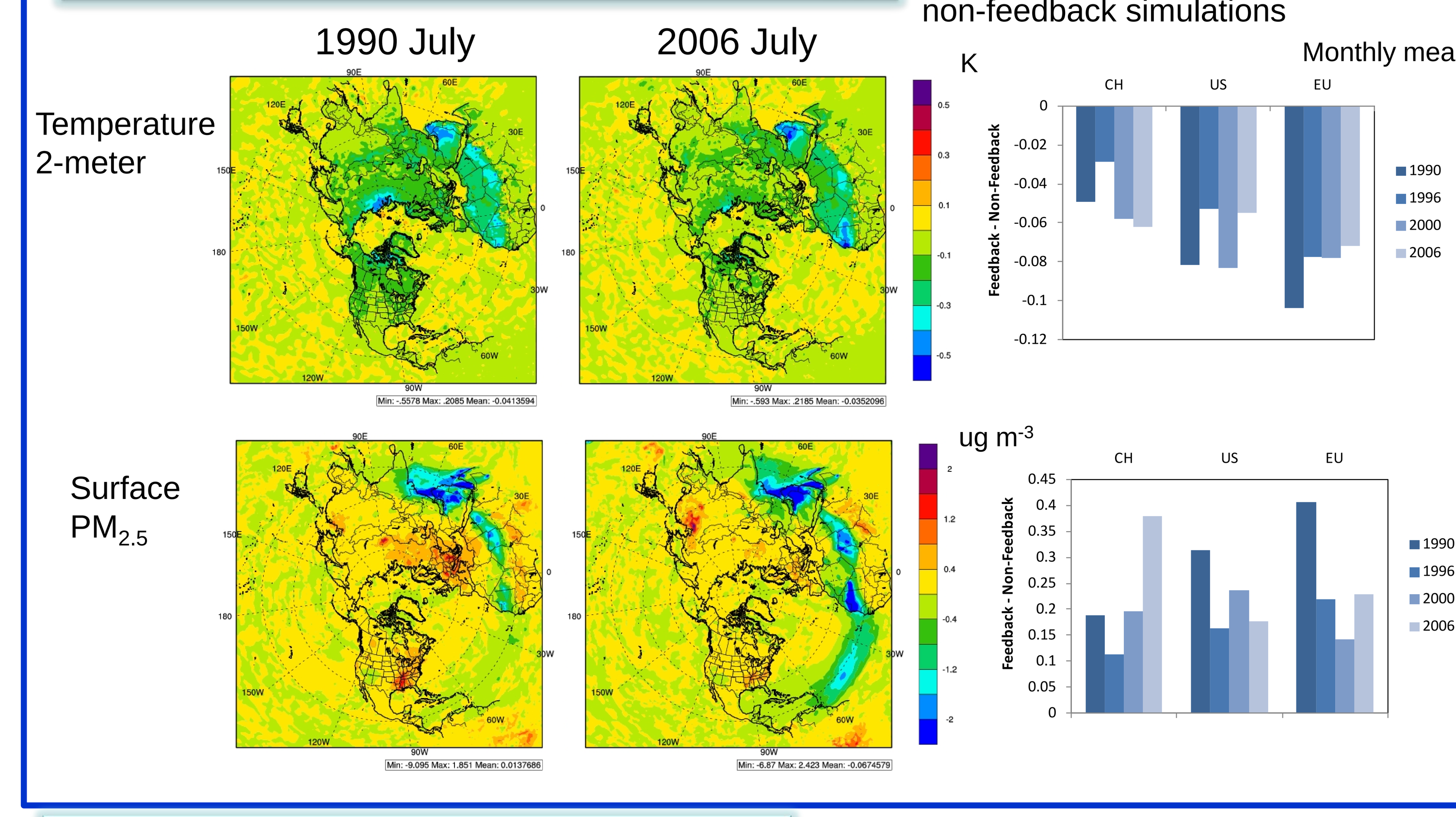
Aerosol Direct Effects on Clear sky shortwave Radiation



Significant dimming effects caused by heavy aerosol burden in east China and downwind area of Middle East

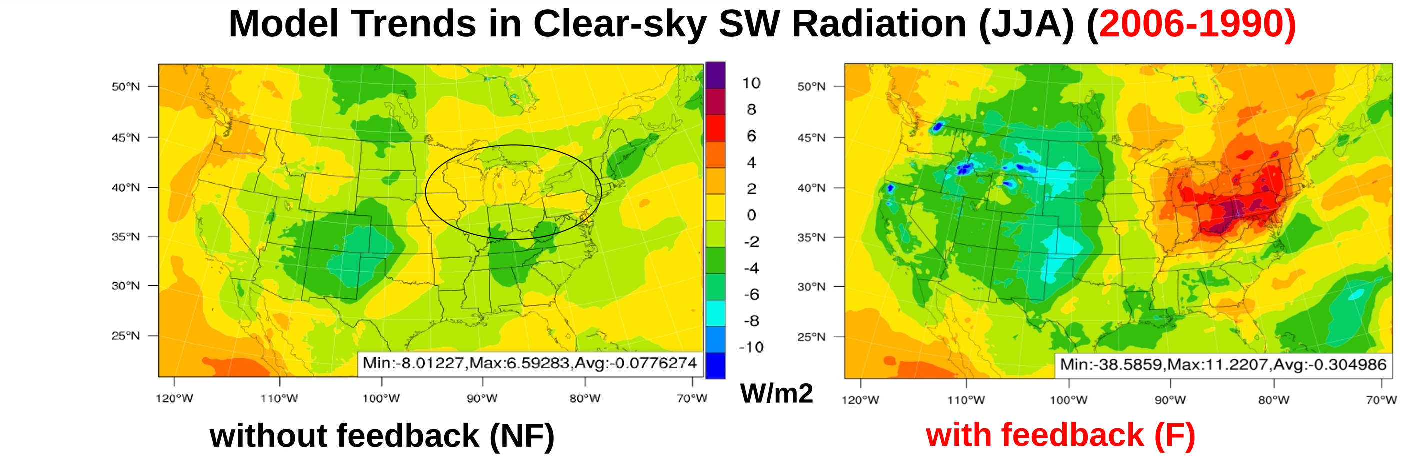
Aerosol impacts on Met and $PM_{2.5}$

Differences between feedback and non-feedback simulations

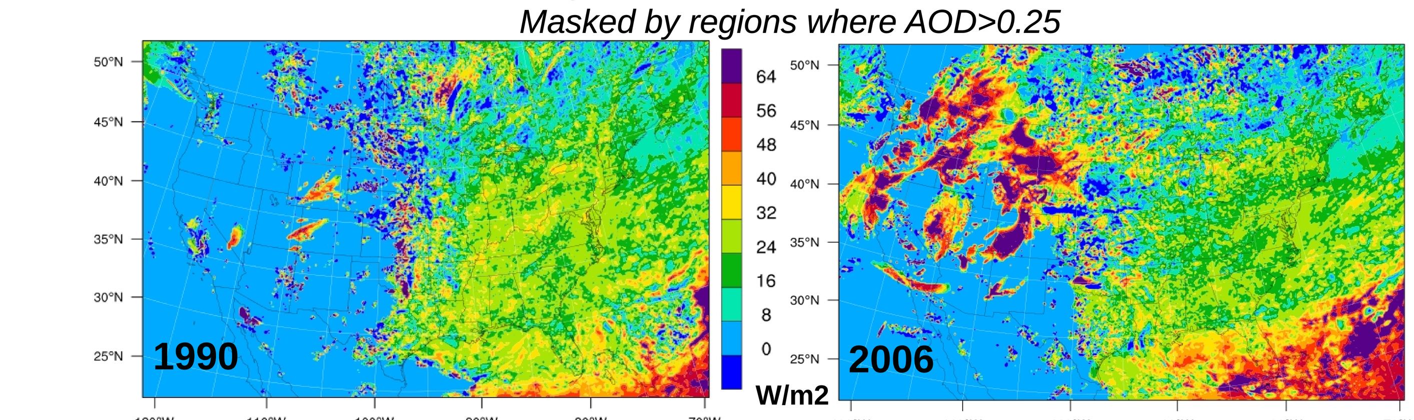


High-resolution modeling

Model Trends in Clear-sky SW Radiation (JJA) (2006-1990)



Reduction in Average Surface Solar Radiation During Aerosol Events (JJA) (NF-F)
Masked by regions where AOD>0.25



Conclusions & Acknowledgement

1. Hemispheric and high-resolution WRF-CMAQ model system were successfully set up and are ready for 20-year simulations..
2. A preliminary examination of the capability of two-way coupled WRF-CMAQ model to represent the aerosol direct effects and to reproduce the observed changes in radiation was performed through comparison with CERES satellite retrieval. Future comparisons will involve more long-term observations (e.g., AERONET, SURFRAD, WRDC).
3. With coupled aerosol direct impacts, the ground temperature, surface solar radiation trends to be reduced over the domain. $PM_{2.5}$ will be enhanced in industrial regions, but reduced in windblown dust area.
4. Sensitivity studies on nudging strategies show using a well-chosen nudging scheme can help model get a balance between strong signal of aerosol effects and good performance.

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