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The WRF-CMAQ Two-Way Coupled Modeling System:

Development, Testing, and Initial Applications

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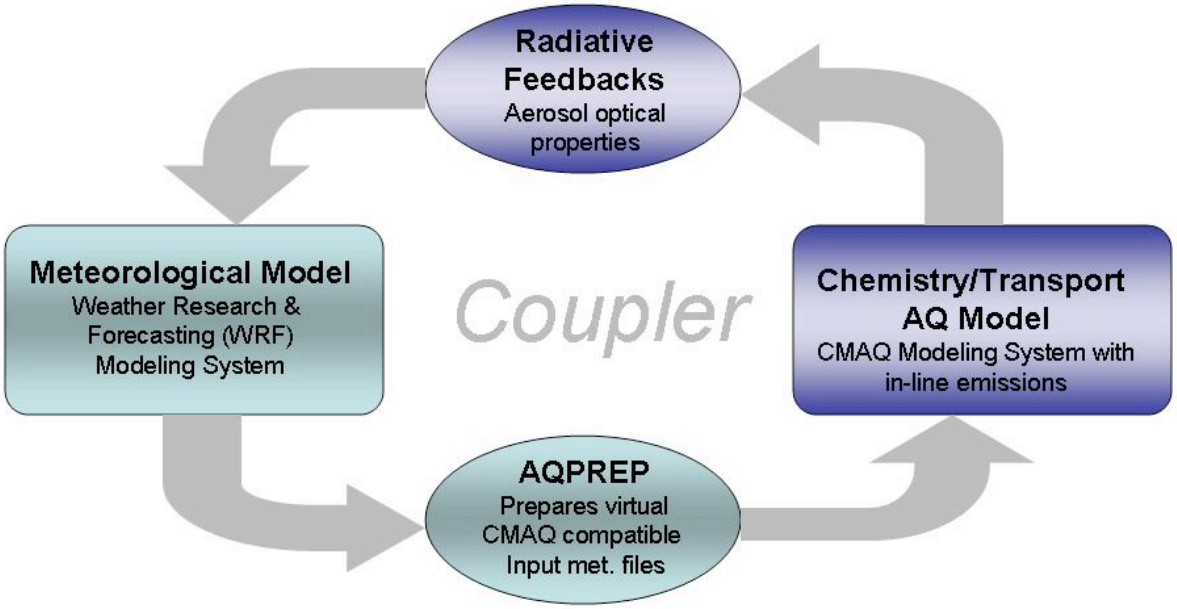
2-Way Coupled Meteorology/Air Quality Modeling: Rationale

- Concurrent meteorology and chemistry-transport calculation
  - ***High frequency communication*** between dynamical and chemical calculations
    - Requisite for finer scale urban modeling/exposure applications
      - Higher temporal integration (Dt << 1 hour) is necessary at finer horizontal grid resolutions (Dx < 10 km).
      - *Such high rates of data exchange are not practical using I/O disk files*
- Represent and assess the potentially important ***radiative effects of pollutant loading*** on simulated dynamical features and air quality
  - Framework to study Air Quality-Climate interactions
    - Direct feedbacks on shortwave radiation (this talk)
    - Direct feedbacks on photolysis rates
    - Indirect feedbacks on cloud microphysics
- ***Consistent treatment*** of dynamical processes in meteorological and AQ models; reduces redundant calculations

Two-Way Coupled WRF-CMAQ Modeling System:
Design and Model Features



Aerosol Optics & Feedbacks

- Volume weighted refractive indices for 19 wavelength intervals based on
  - Composition and size distribution
  - SO_4^{2-}, NO_3^-, NH_4^+, Na^+, Cl^-, EC, POA, anthropogenic and biogenic SOA, other primary, water
- CAM Shortwave radiation scheme in WRF
- Effects of aerosol scattering and absorption on photolysis
- Effects of O_3 on long-wave radiation

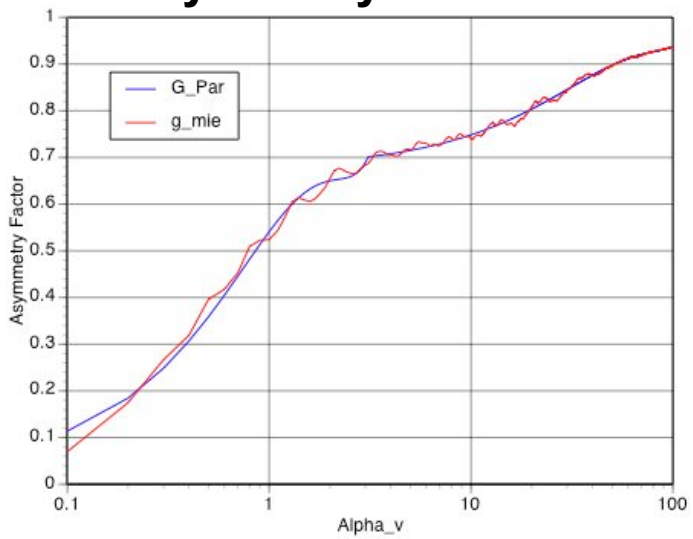
***Flexible* design of model coupling allows**

- data exchange through memory resident buffer-files
- flexibility in frequency of coupling
- identical on-line and off-line computational paradigms with minimal code changes
- both WRF and CMAQ models to evolve independently;
  ➡ *Maintains integrity of WRF and CMAQ*

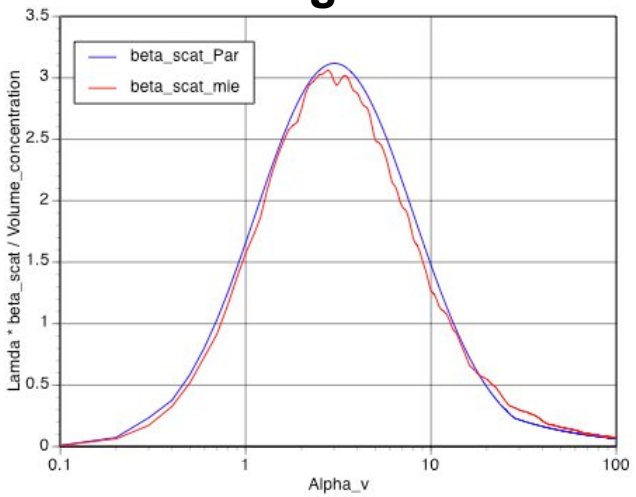
Mie approximation

Mie Parameterized

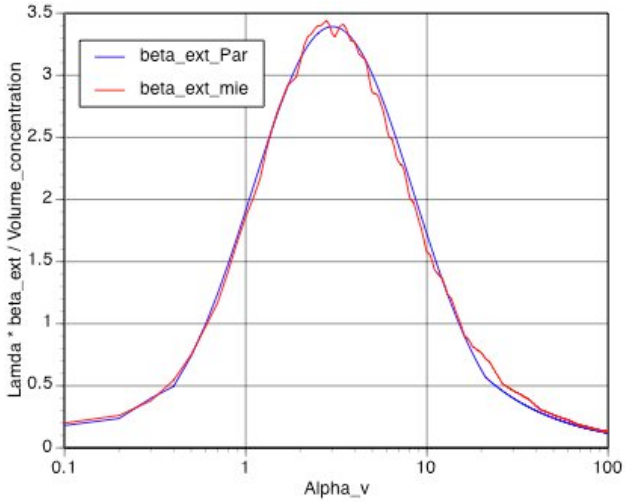
Asymmetry Factor



Scattering coefficient



Extinction coefficient



$$\alpha = \frac{\pi D}{\lambda}$$

Evan and Fournier, *Appl. Optics*, 1990

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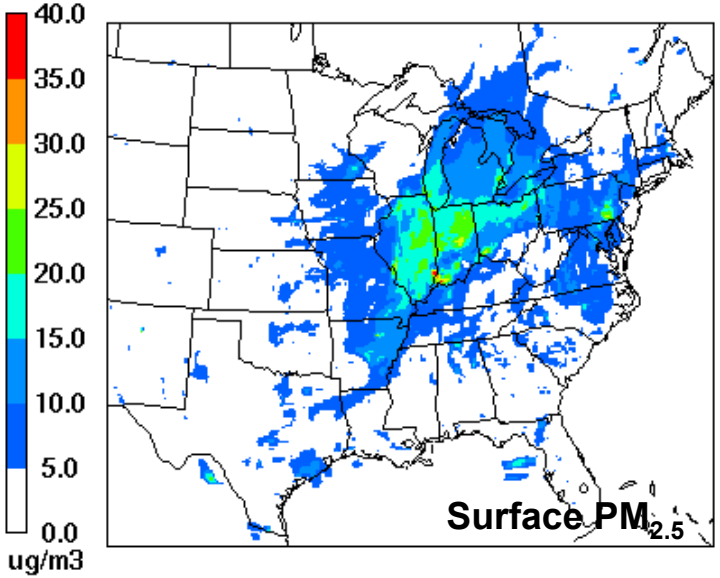
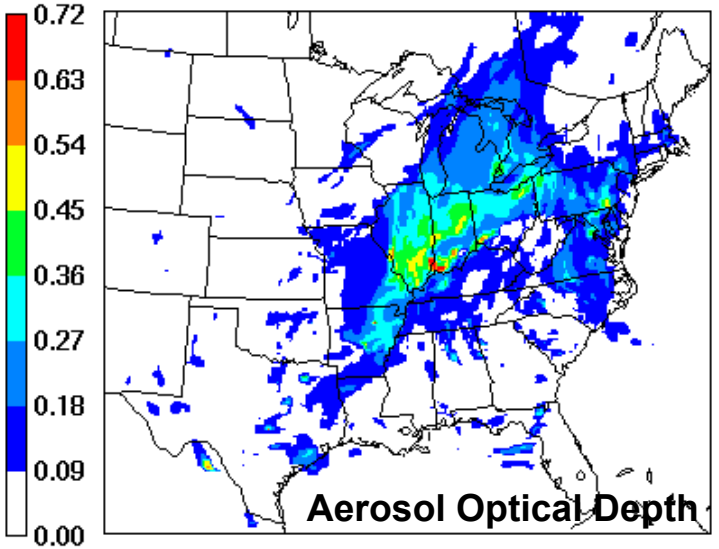
2-way test results: Case 1

- WRF-CMAQ
  - Dx = 12km, 34 layers
  - 4:1 CMAQ/WRF timestep ratio
  - Eastern US
  - August 2-10, 2006
- Direct feedback of aerosol effects on CAM SW radiation
  - Compare the optical effects of CMAQ's aerosol characteristics to CAM default aerosol characteristics

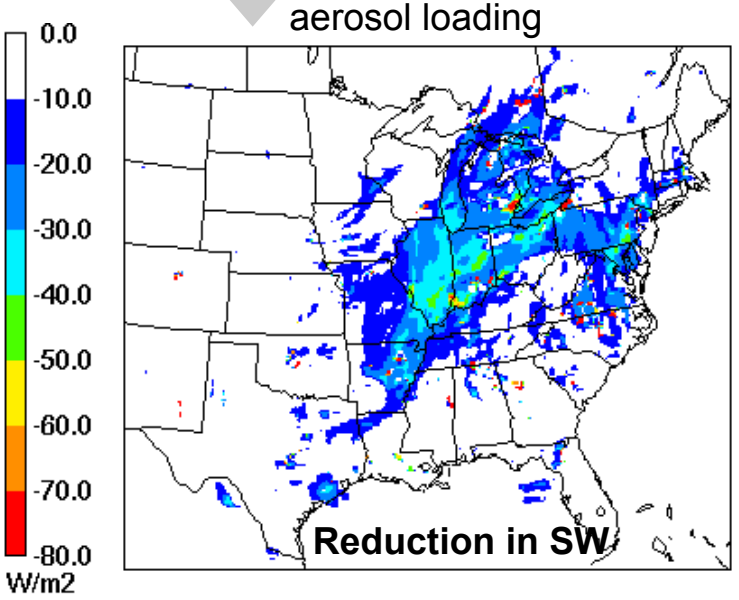
2-Way Coupled WRF-CMAQ Modeling System: Early Results (8/6/06: 22Z)



Optical properties of aerosols

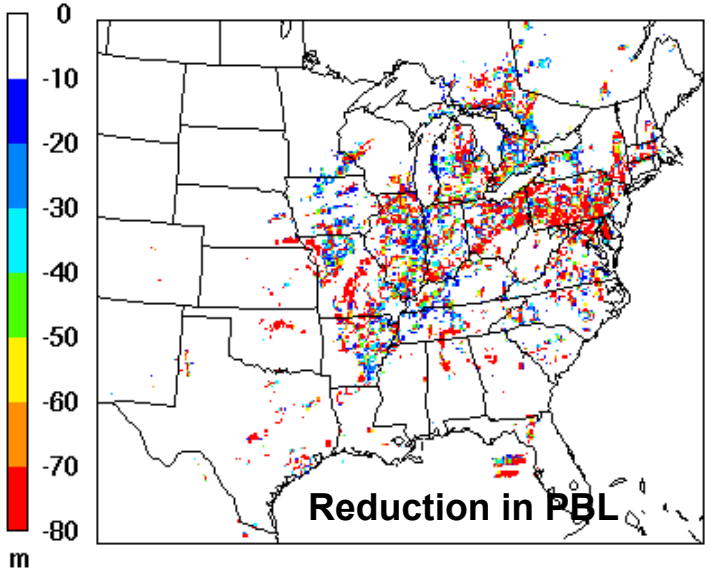


Reduction in shortwave radiation reaching the surface in regions of aerosol loading



Changes in radiation impact simulated dynamical features

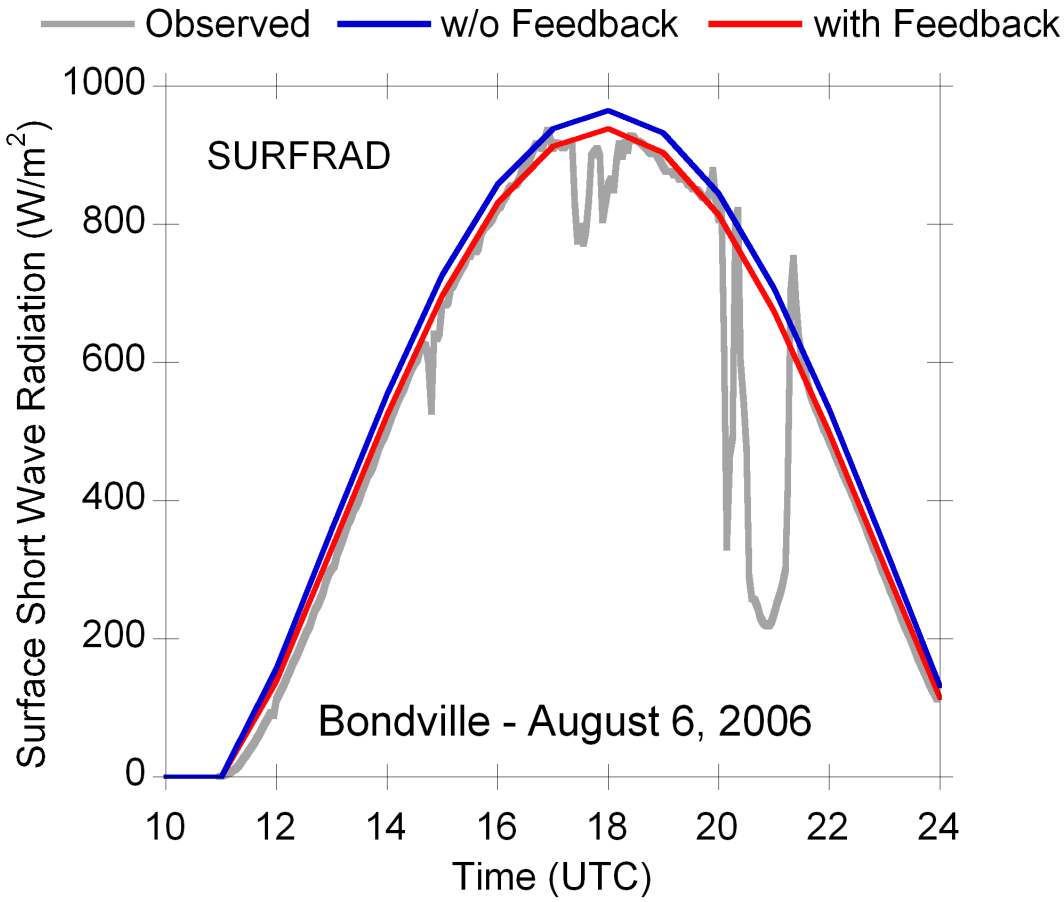
(also a reduction In temperature)



Direct Effects on Shortwave Radiation Reaching the Surface

With and Without Feedbacks

Is the signal detectable relative to measurements?



Slight cooling and better agreement with measurements noted in simulation with aerosol feed-backs

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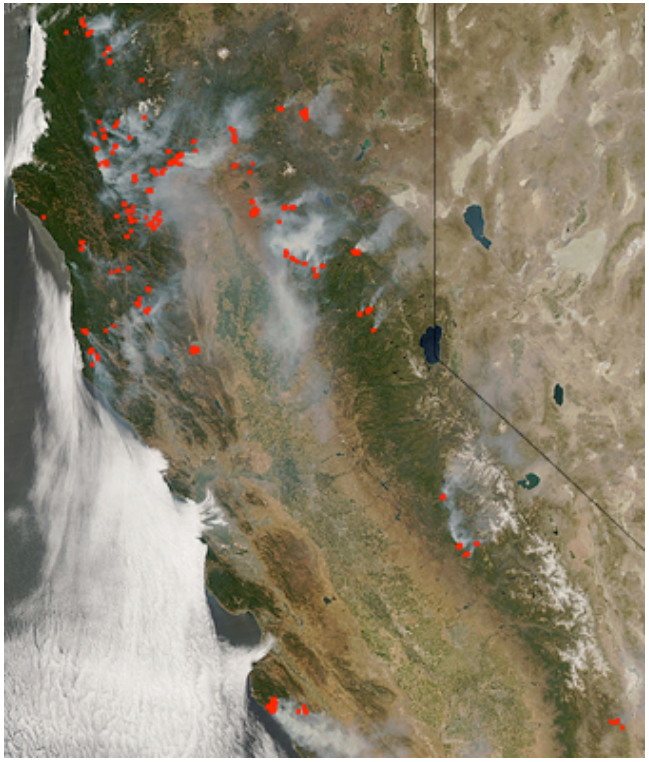
Case 2: California Wildfires



- June 20-30, 2008
- Dx = 12km, 34 layers
- 4:1 CMAQ/WRF timestep ratio
- Wildfire emission estimates from CMAQ real-time air quality forecasting
  - Emissions =

    (fuel loading) x

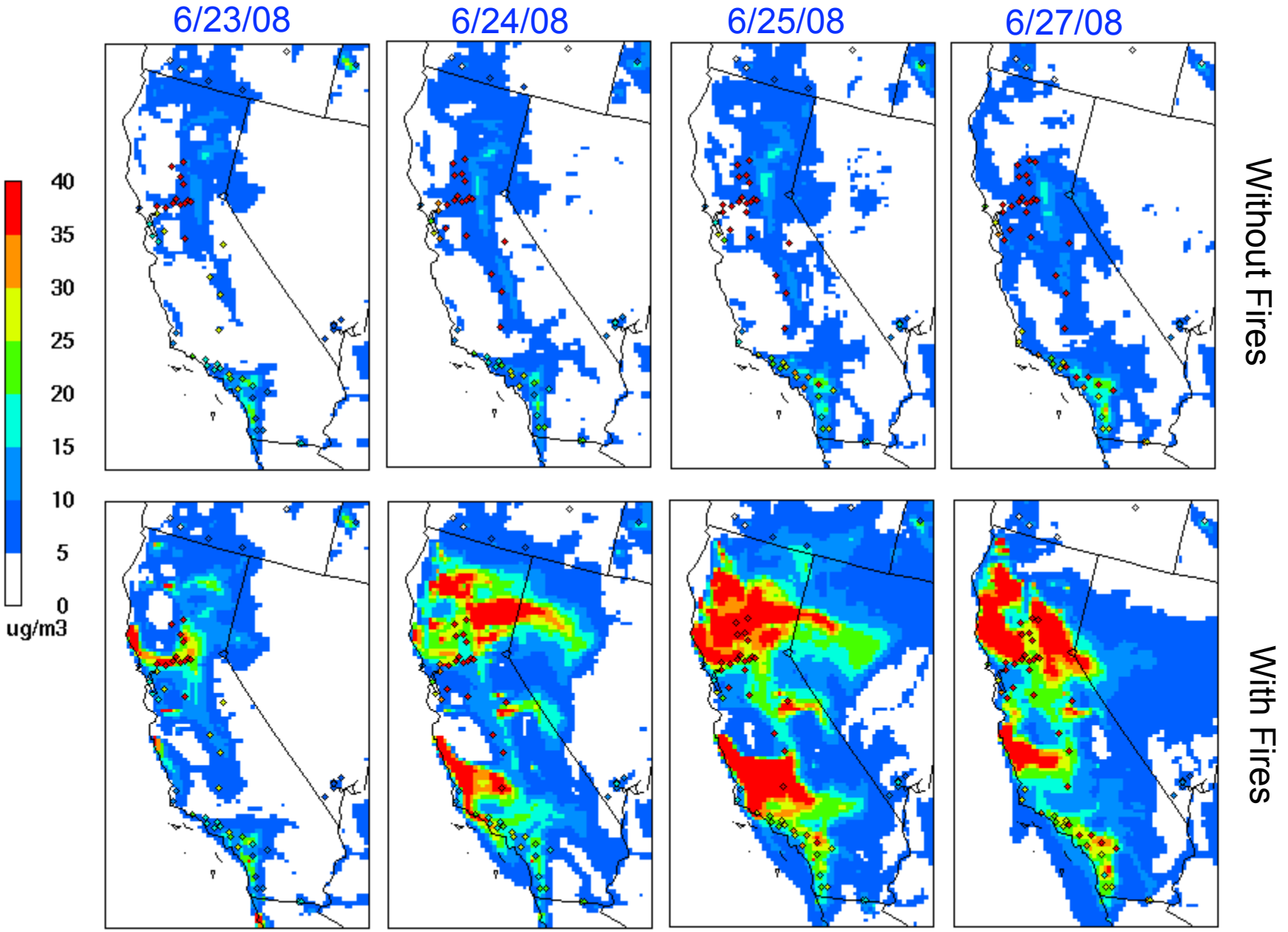
    (area burned) x

    (emission factor)

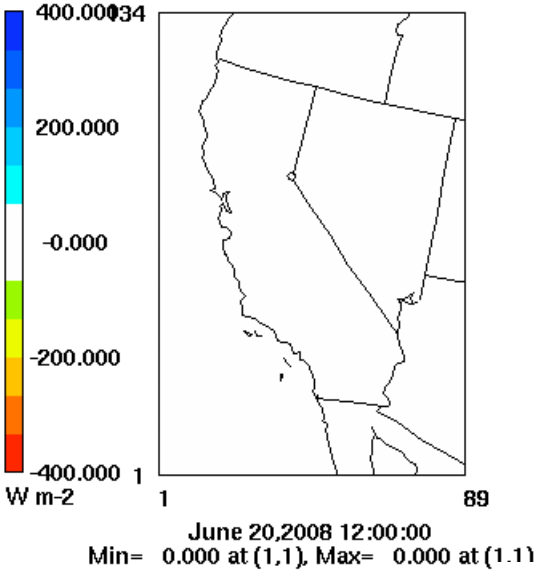
Widespread wildfires resulted in significant PM pollution during mid/late June 2008 in California and surrounding states

- Fuel loading: National Fire Danger Rating (NFDR) system
- Emission Factors: Fire Emission Production Simulator (FEPS) Function of fuel class

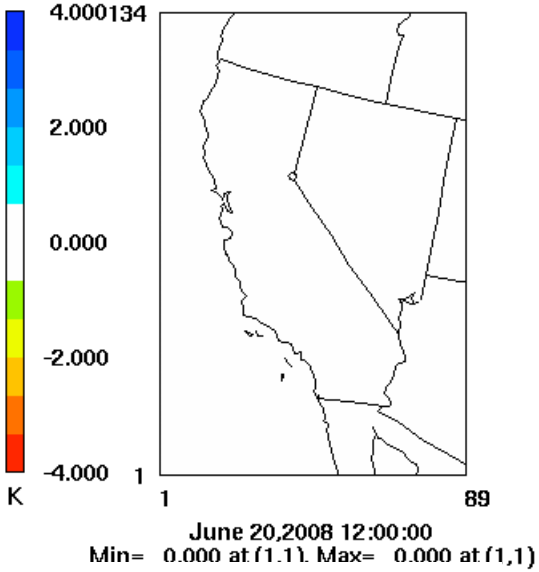
Impacts of Wildfire Emissions on Daily-avg. $PM_{2.5}$



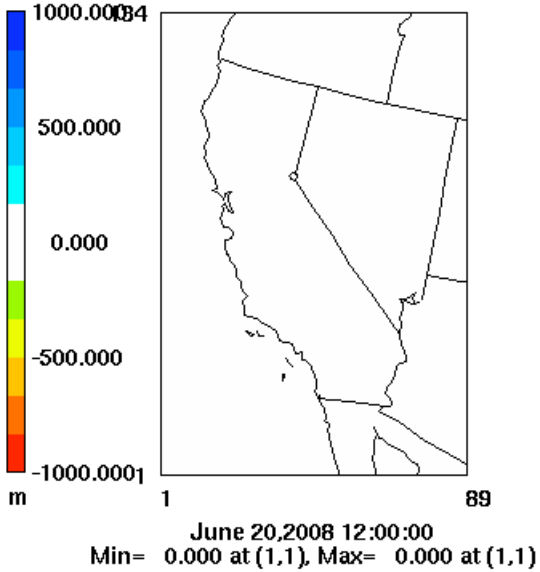
Shortwave Radiation



2-m Temperature

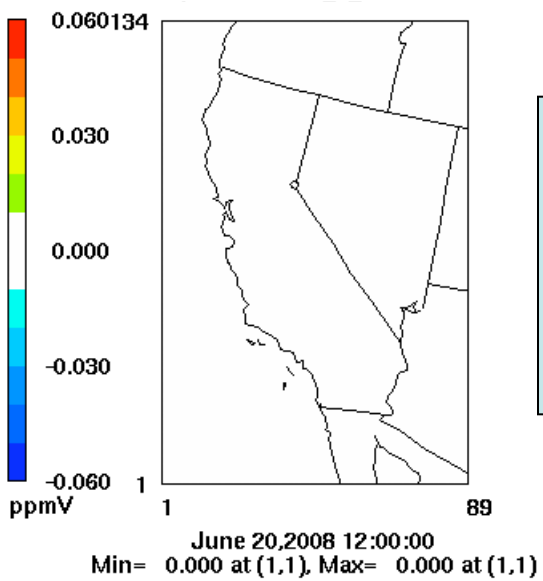


PBL Height



June 20-28, 2008
(with feedbacks)
minus
(without feedbacks)

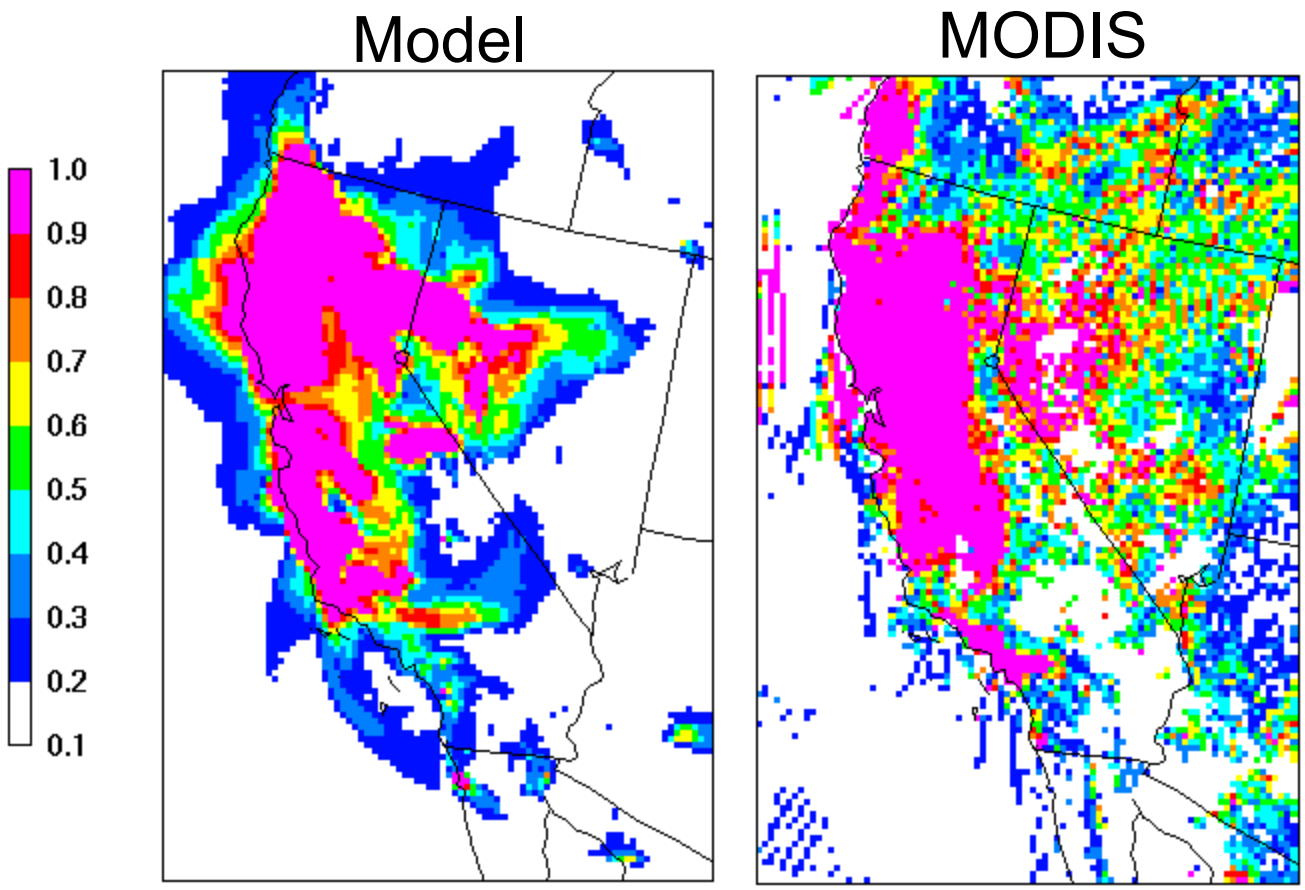
Surface O_3



- **Substantial changes are evident in the predicted ozone concentrations due to changes in radiation and its effect on the PBL evolution**
- ***Inclusion of photolysis modulation will further alter these effects***

Aerosol Optical Depth Comparisons

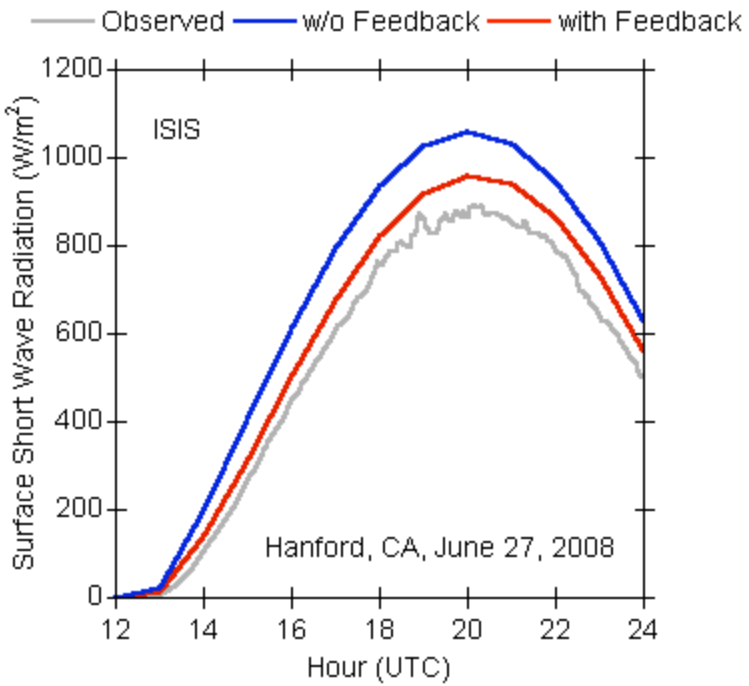
Maximum Values: June 23-30, 2008

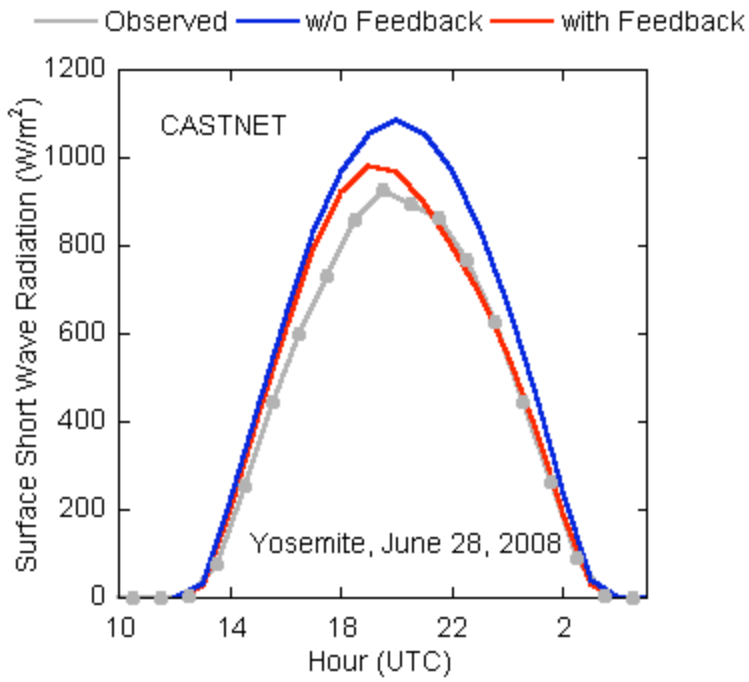


Shortwave Radiation Reaching the Surface

With and Without Feedbacks

Comparison with measurements at California Sites

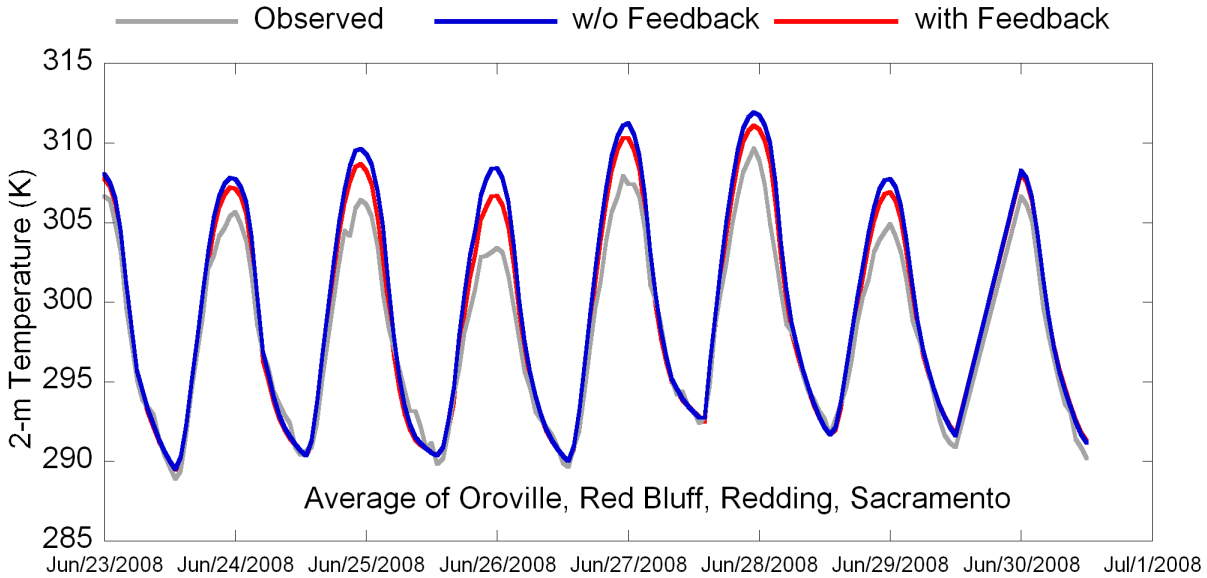


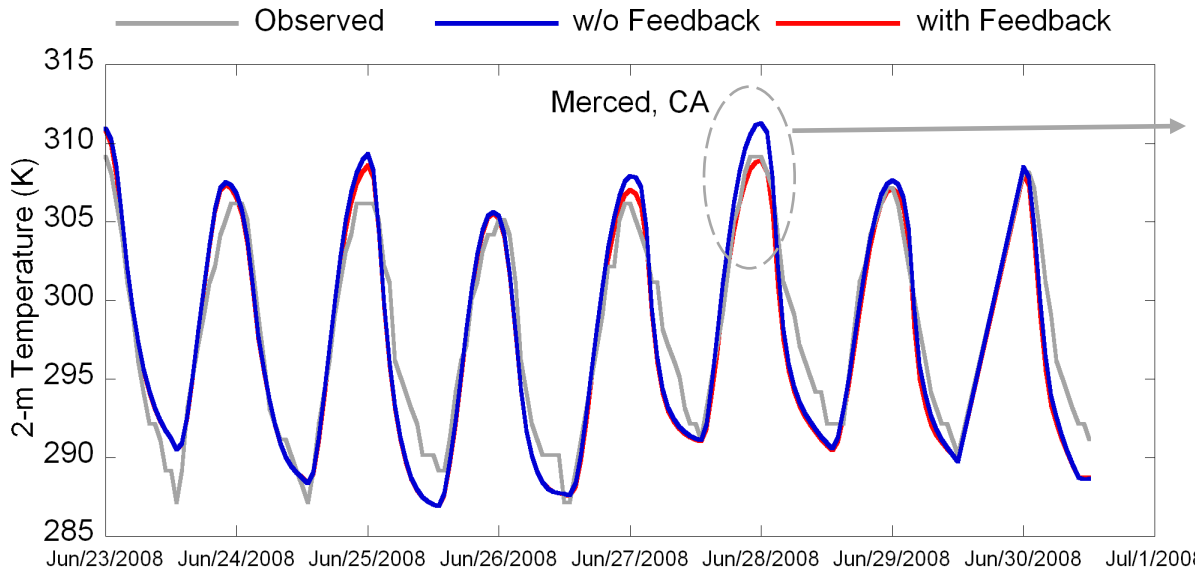


- Significant reduction in shortwave radiation reaching the surface due to aerosol loading
- Including aerosol direct forcing improves simulation of SW radiation

Comparison of 2-m Temperature with Measurements

Simulations with and without aerosol feedbacks; California sites; June 2008





Site impacted by wildfire plume; noticeable cooling due to attenuation of radiation

- **Cooling effects noticeable; Including aerosol direct forcing improves simulation**

Diurnal Temperature Range (DTR)

Proxy for variability in surface solar radiation

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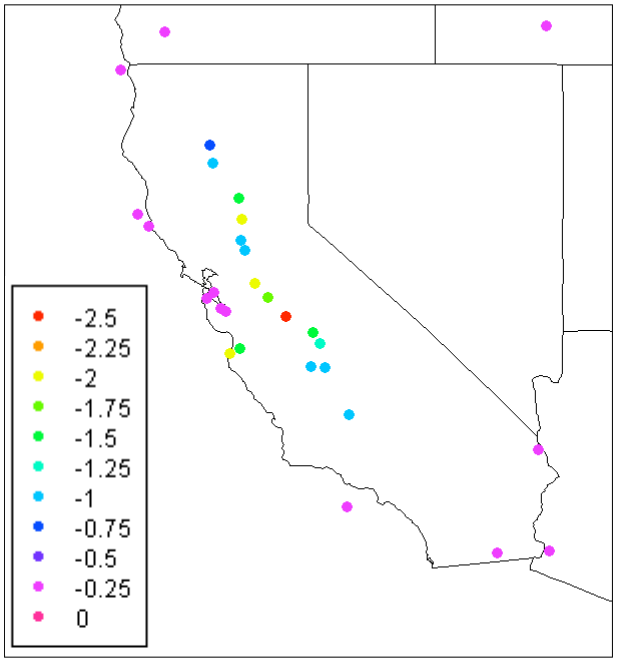
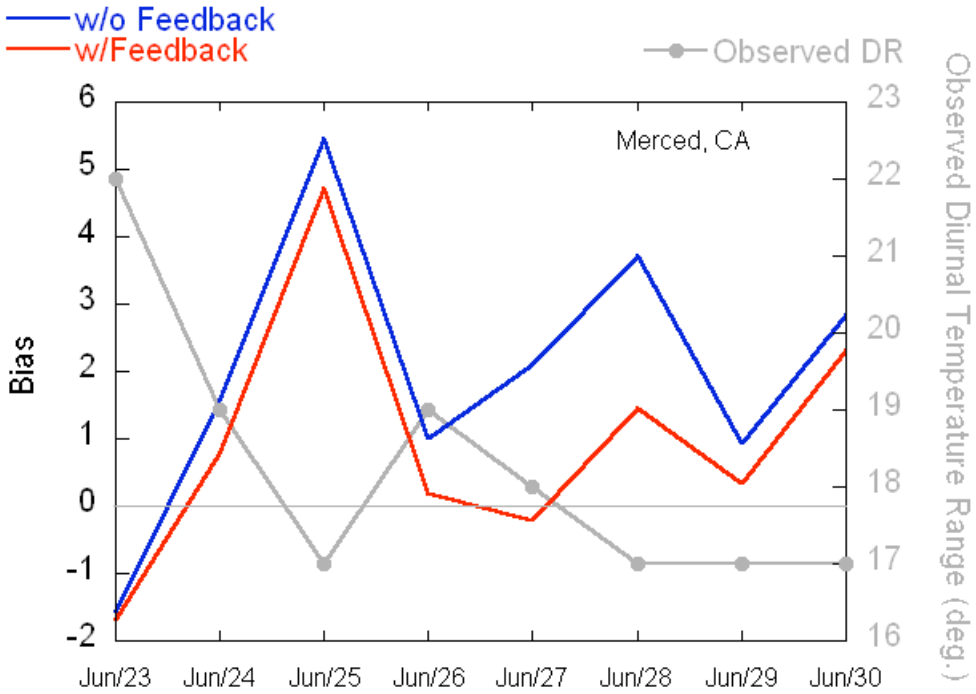
Difference in DTR

w/Feedback – w/o Feedback
June 28, 2008



Comparison with observed range at site impacted by wildfire plume



Reduction in bias in simulated DTR

- **More widespread observations of DTR could be used to assess aerosol effects**

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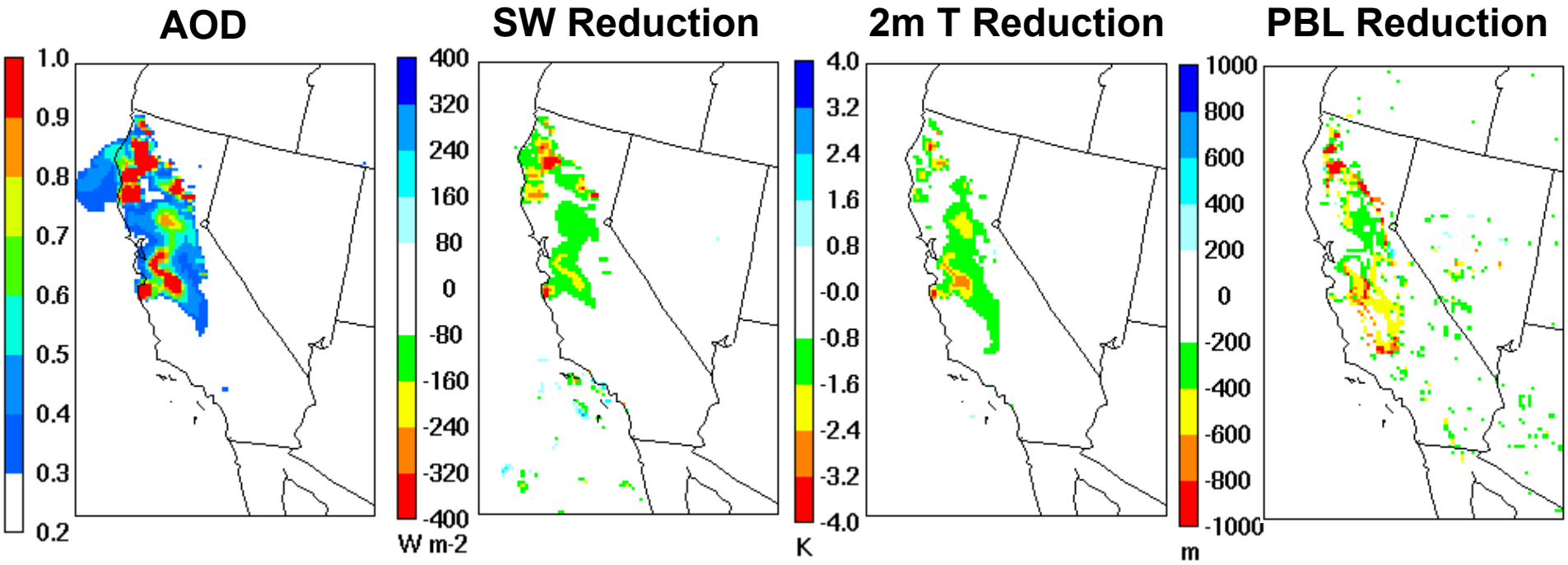
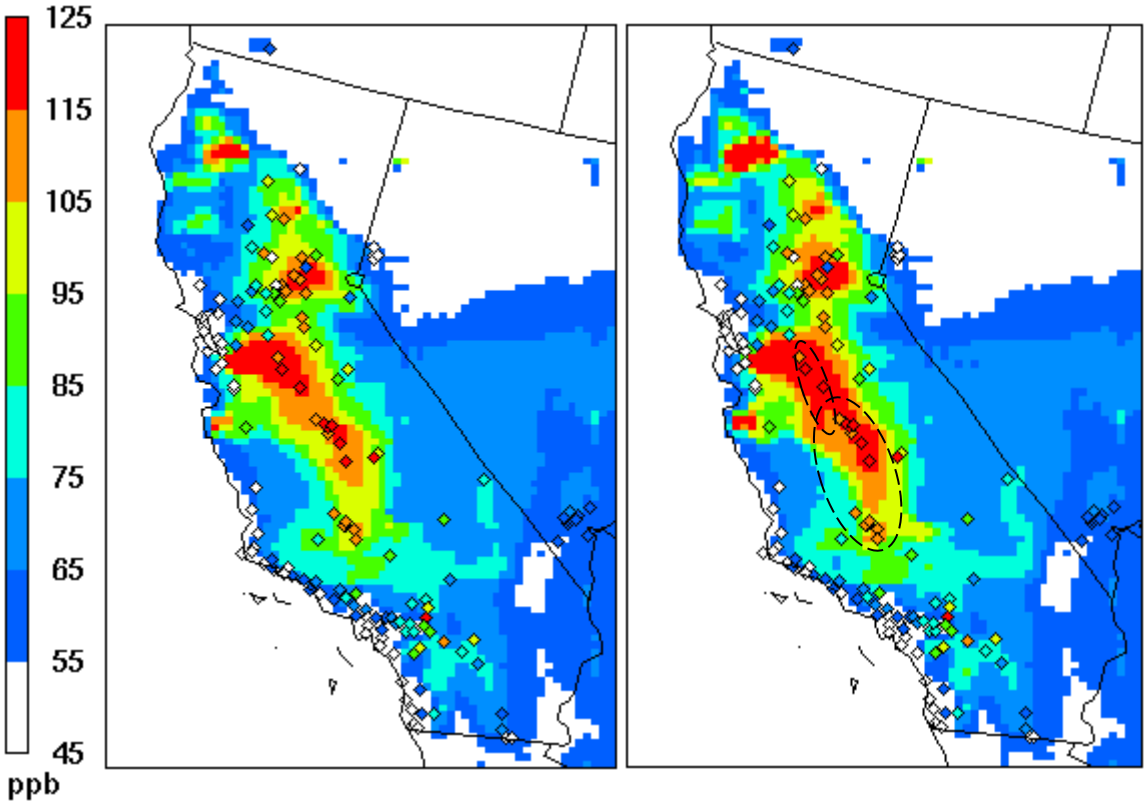
June 27, 23Z

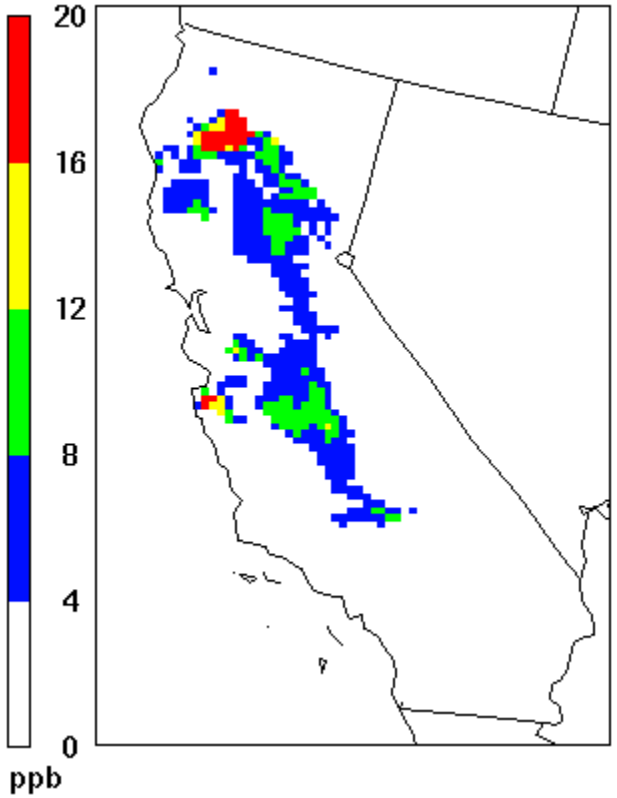


Maximum 8-hr. O_3: June 27 2008



Without Feedbacks

With Feedback



Enhancement due to feedback at locations where [O_3] > 75ppb

Reduction in PBL heights results in increased O_3

➡ **Feedback effects could have important air quality impacts**

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Computational Efficiency: 1-day test

Run	**Exec. Time**
WRF only	2:15:23
MCIP	0:04:21
CMAQ	2:25:18
Total uncoupled system	**4:45:02**
Coupling system w/o feedback 4:1	**5:13:50**
Coupling system w/o feedback 4:1	**5:20:57**
Coupling system w/ feedback 1:1	9:34:29

Looking Ahead: Air Quality - Climate Interactions

Extension to Hemispheric Scales: *Preliminary Results*, March 15-30, 2006

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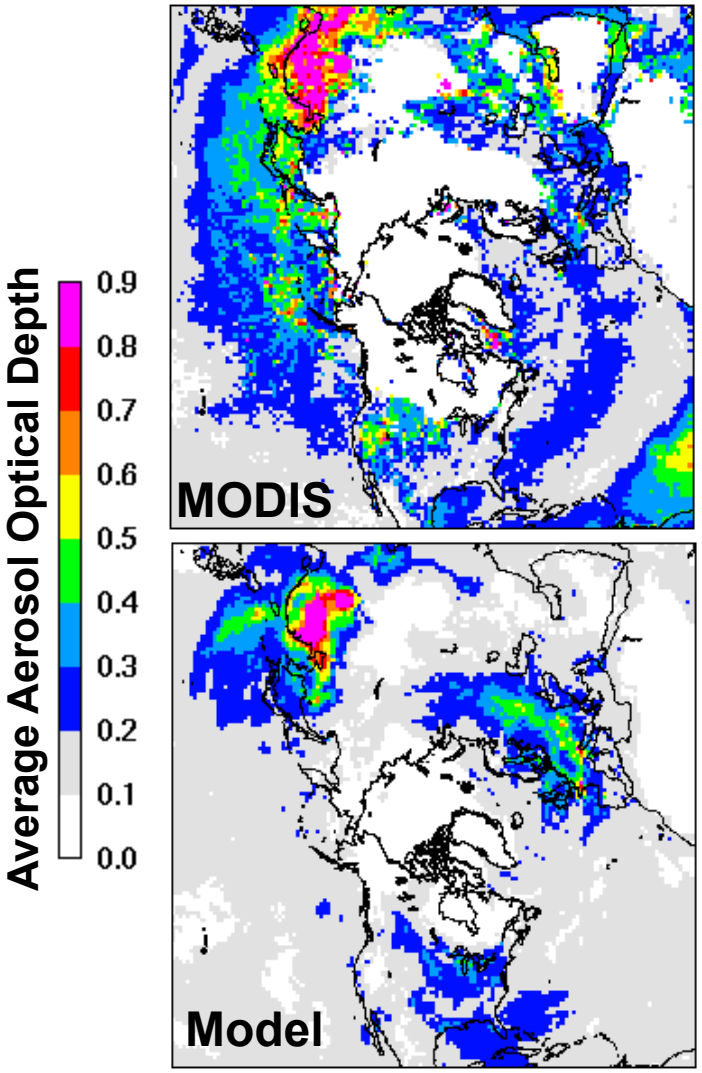

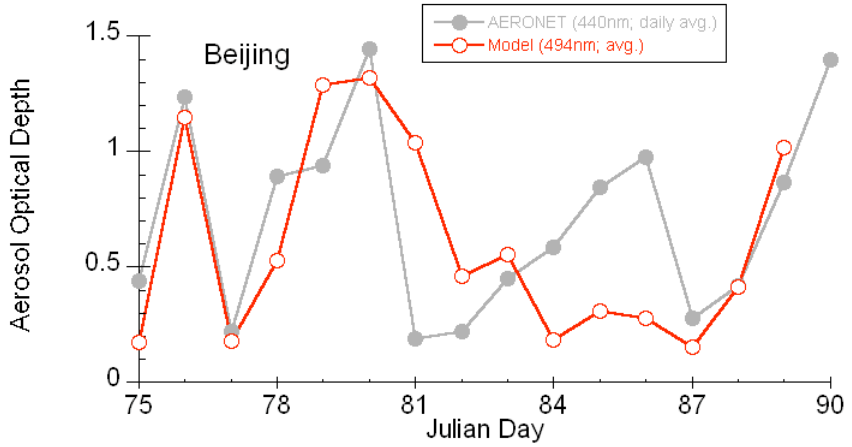

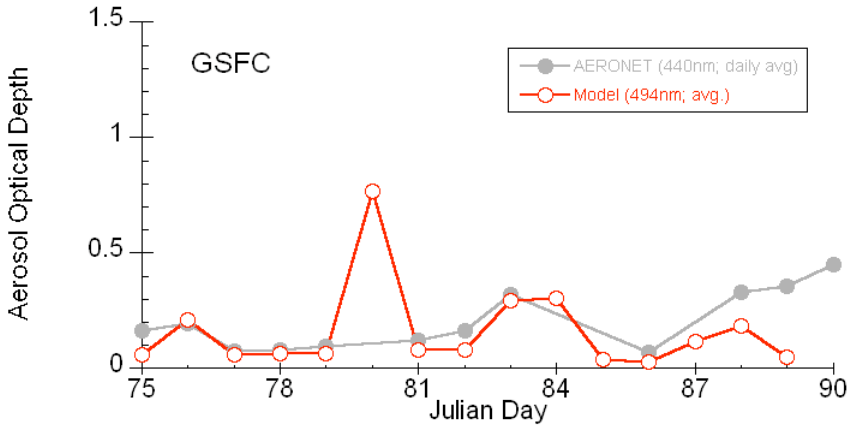

Significant spatial heterogeneity in aerosol loading which is captured reasonably well by the model

Spatial Heterogeneity in Dimming and Cooling Effects

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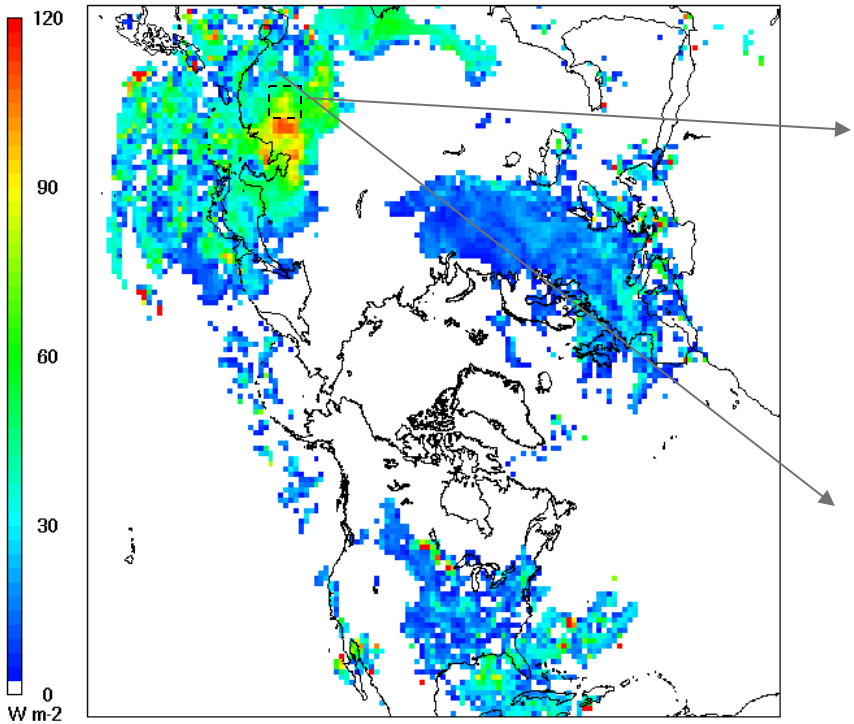
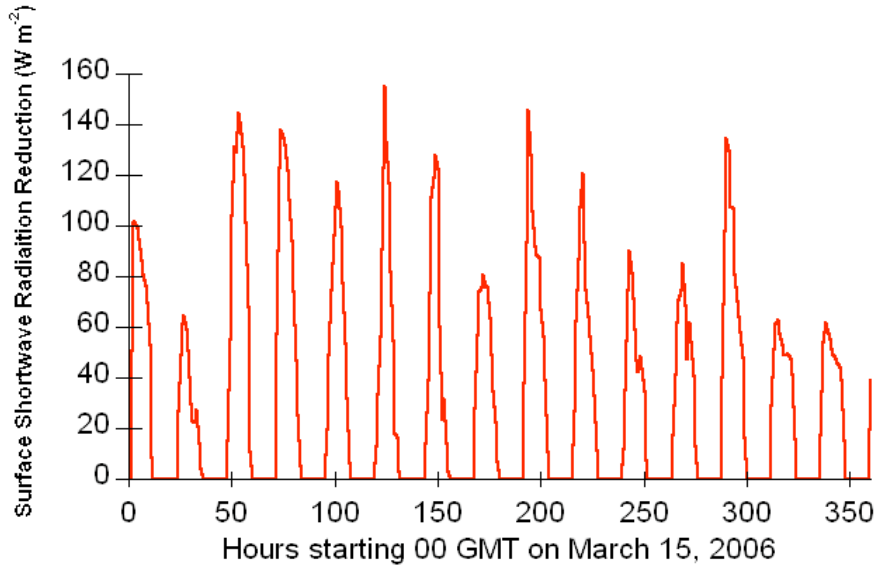
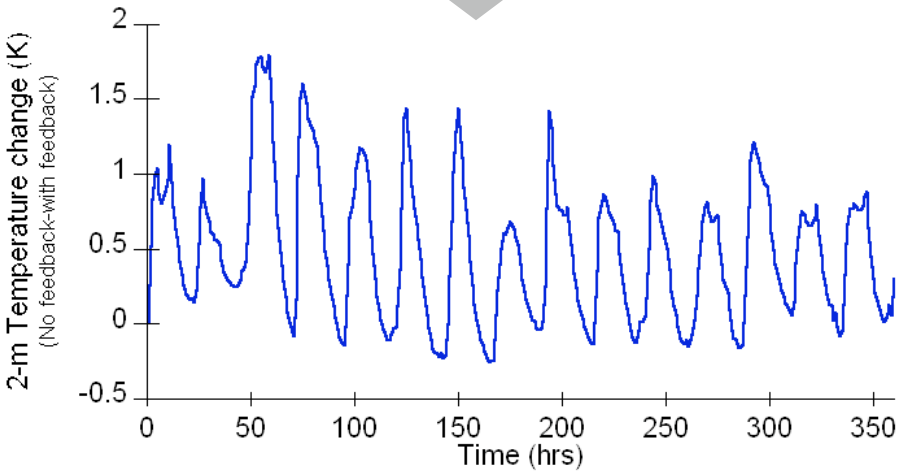
Avg. Reduction in SW Radiation: "Dimming"







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Summary

- A computationally efficient and flexible coupled meteorology-atmospheric chemistry modeling system based on the WRF and CMAQ models has been developed.
- Direct feedback of aerosols on SW radiation has been tested
  - Effects can be large in regions with significant aerosol loading
  - Preliminary comparisons with limited measurements show improvements in simulation skill for SW radiation and 2m T
- ***Challenge***: Assessing the magnitude and directionality of feedback effects on simulated air quality

Next Steps

- Additional testing of aerosol effects on photolysis rates
- Additional testing of effects of pollution on long-wave radiation
- Verification of results for longer simulations
- Investigation of “indirect effects”: effects on CCN and resolved cloud microphysics

Looking Ahead: Air Quality - Climate Interactions

Extension to Hemispheric Scales: *Preliminary Results*, March 15-30, 2006

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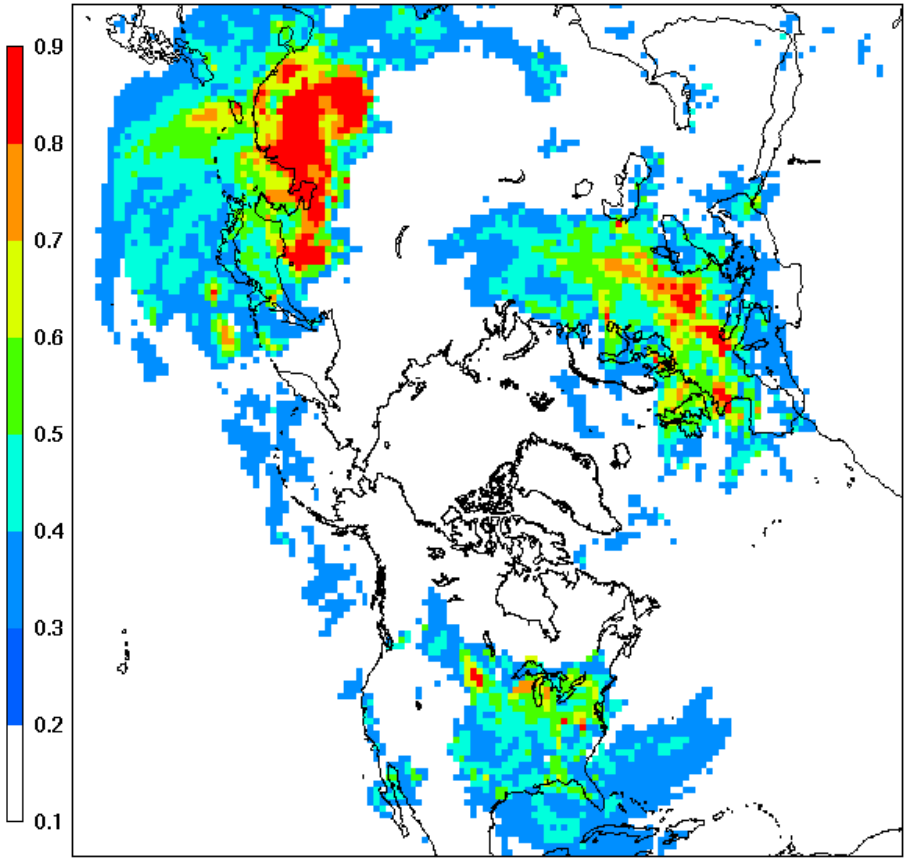
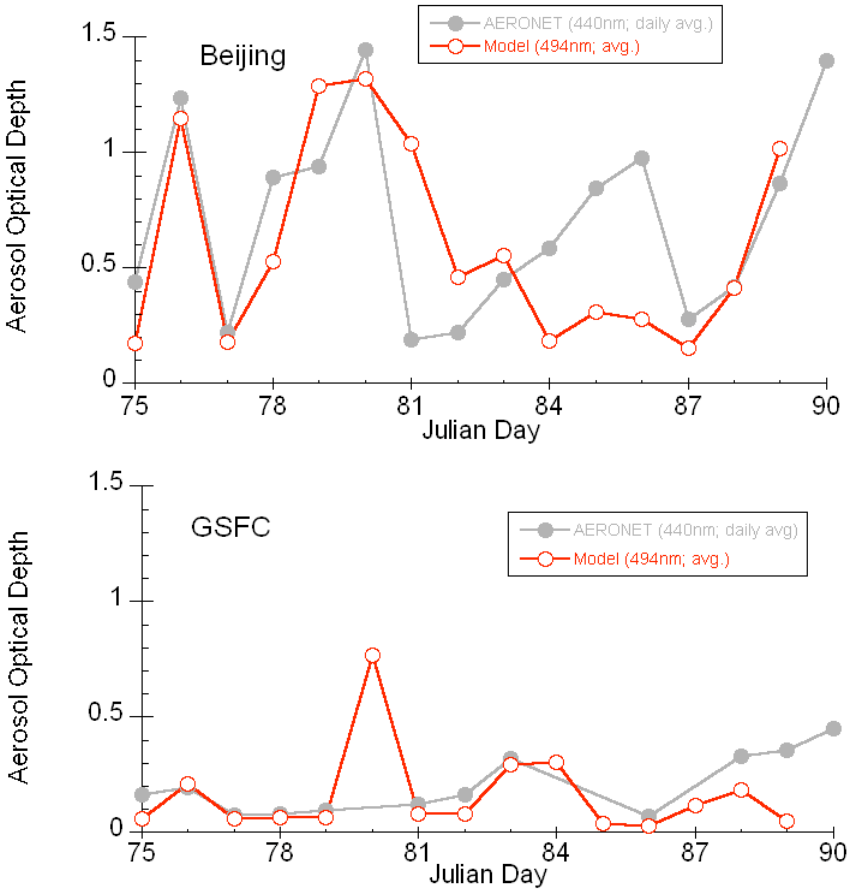
Average Aerosol Optical Depth





Significant spatial heterogeneity in aerosol loading which is captured reasonably well by the model

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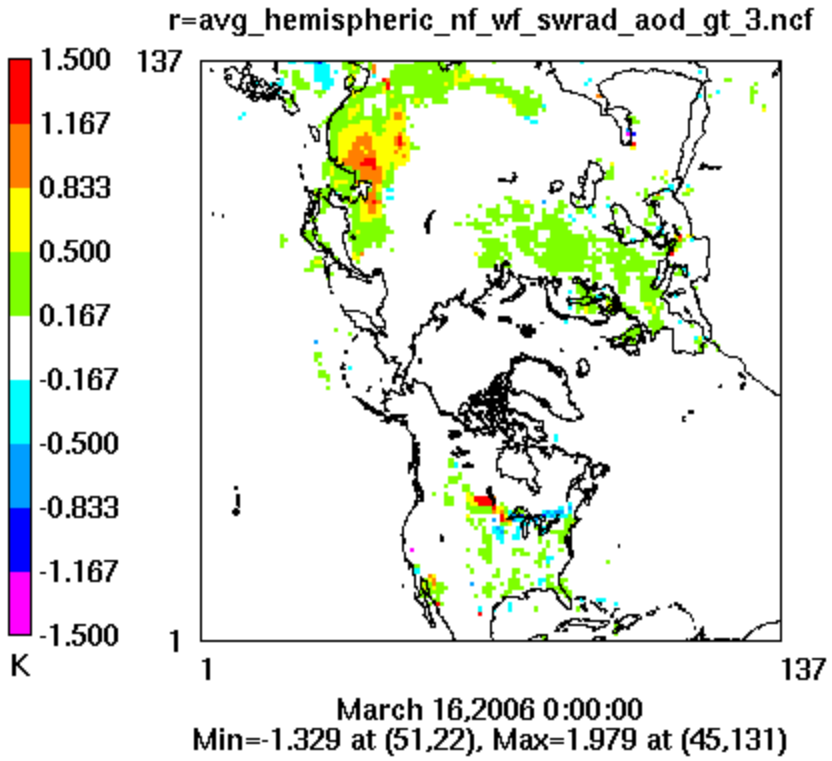
Layer 1 T2_NFr-T2_WFr



Flexible Time-stepping and Coupling

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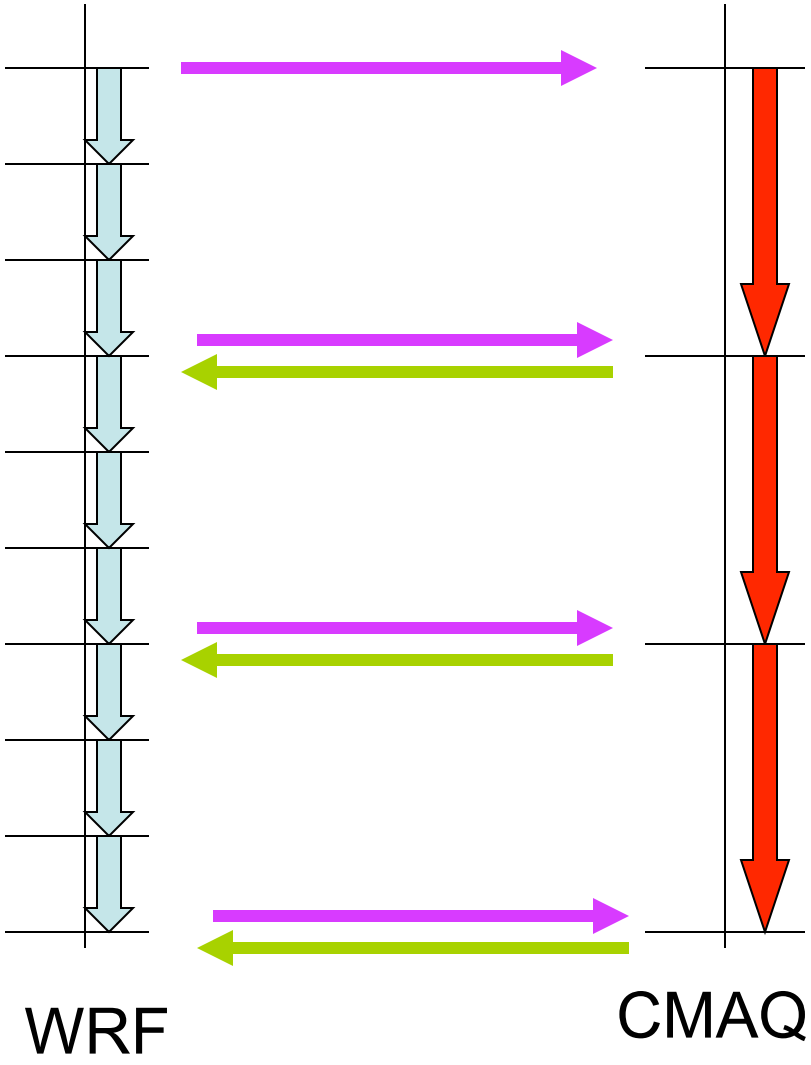
Example:

$Dt_c = 3Dt_w$



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