Comparing measurements with model derived Black Carbon and AAOD based upon AEROCOM, GFED, and Kalman Filter optimized BC emissions

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Photo Taken By Jason Blake Cohen, Sept 9 2012, over Western USA

Introduction

- BC uniquely heats the atmosphere & cools the surface
- BC is heterogeneously distributed (one week lifetime)
- Top-down optimization shows greater BC emissions: especially over Southeast Asia, East Asia, & East Europe
- While mean values of AAOD and Concentration are improved, temporal and spatial discrepancies remain
- Remaining uncertainties include: urbanization and fires
- Resulting changes to atmospheric radiative forcing are (mostly) confined to the NH (Southeast Asia is complex)
- These changes lead to alteration of the large scale energy balance and dynamics of the atmosphere

Interactive Aerosol-Climate Model

- 2-moment (mass and number) aerosol module
- 3 sizes sulfate; Primary OC/BC; BC core/shell; OC internal mix
- Processing: condensation of H_2SO_4, nucleation, coagulation, water/cloud interactions, wet/dry deposition.
- Dust Climatology: CCSM Dust Model
- Inversions and comparisons with AERONET use CTM mode **driven by NCEP Reanalysis**
- Climate Runs are in GCM Mode, using a **slab ocean model**
- Effects Include Urban Processing Metamodel

Cohen, et al. GRL. 38, L10808, doi:10.1029/2011GL047417, 2011
Kim et al. JGR. 113, D16309, doi:10.1029/2007JD009756, 2008
Mahowald, et al. JGR. 108(D12), 4352, doi:10.1029/2002JD002821, 2003

Kalman Filter Optimized BC Emissions

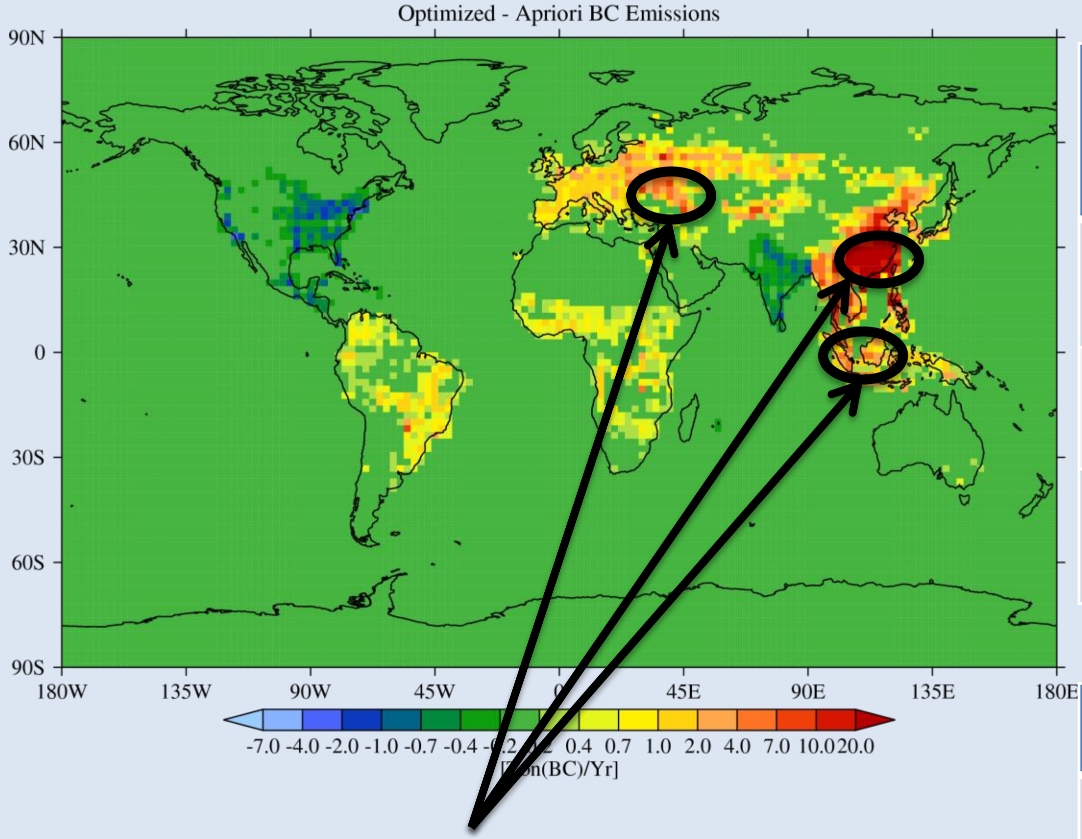
Observations: more than 130 sites, from 2002-2010
AERONET: AAOD Level 2 (AOD data, SSA inversion, AOD<0.4 not used)
EUSAAR, CAWNET, NOAA: Surface Measurements of BC

Eq1: x_k (emissions);
$Pk = x_k * x_k^T$;
R_k (model errors)
Eq2: y^o_k (measurements);
ε_k (measurement errors);
$R_k = \varepsilon_k * \varepsilon_k^T$
***Eq3:** $H_{ijk} \approx (y_{ik\text{-}pert} - y_{ik\text{-}base})/(x_{jk\text{-}pert} - x_{jk\text{-}base})$
Iterate **Eq4** to **Eq8**, until all data is assimilated
Eq4: $x^f_k = M_{k-1} * x^a_{k-1}$
Eq5: $P^f_k = M_{k-1} * P^a_{k-1} * M_{k-1}^T + Q_{k-1}$
Eq6: $K_k = P^f_k * H_{ijk}^T * (H_{ijk} * P^f_k * H_{ijk}^T + R_k)^{-1}$
Eq7: $x^a_k = x^f_k + K_k * (y^o_k - y_k)$
Eq8: $P^a_k = (I - K_k * H_{ijk}) * Pf_k$

Optimized Emissions:
17.8±5.6 Tg/year
Compared against datasets:
Bond: 7.95 (4.3 or 4.7 to 19.8 or 22) Tg/year
IPCC RCP / GFED: 7.662 (7.662 to 8.800) Tg/year
A-Priori: 14.4 Tg/year

Cohen and Wang, 2012 (under review)

Distribution of Optimized BC Emissions



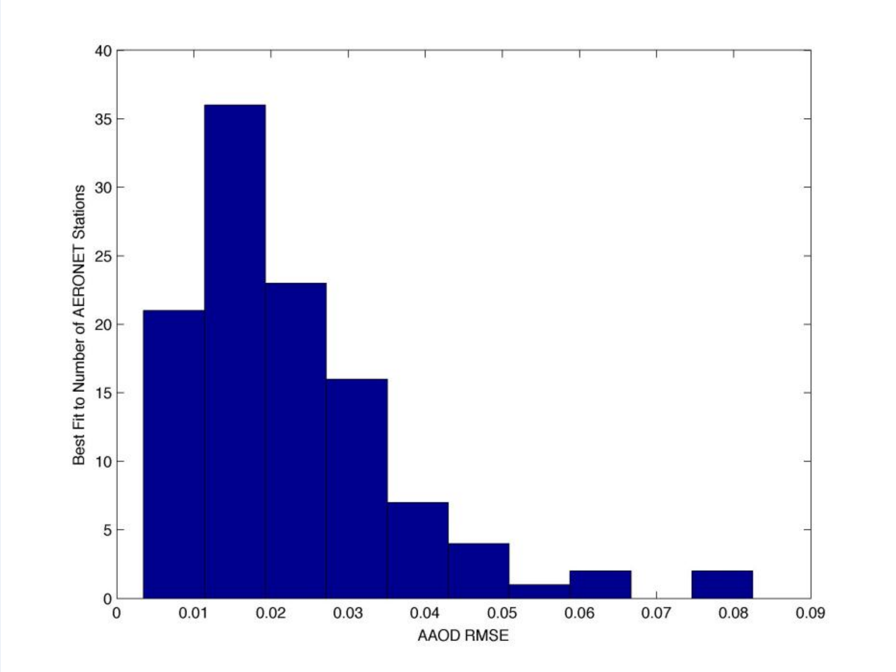
Regions of Statistically Differing Emissions

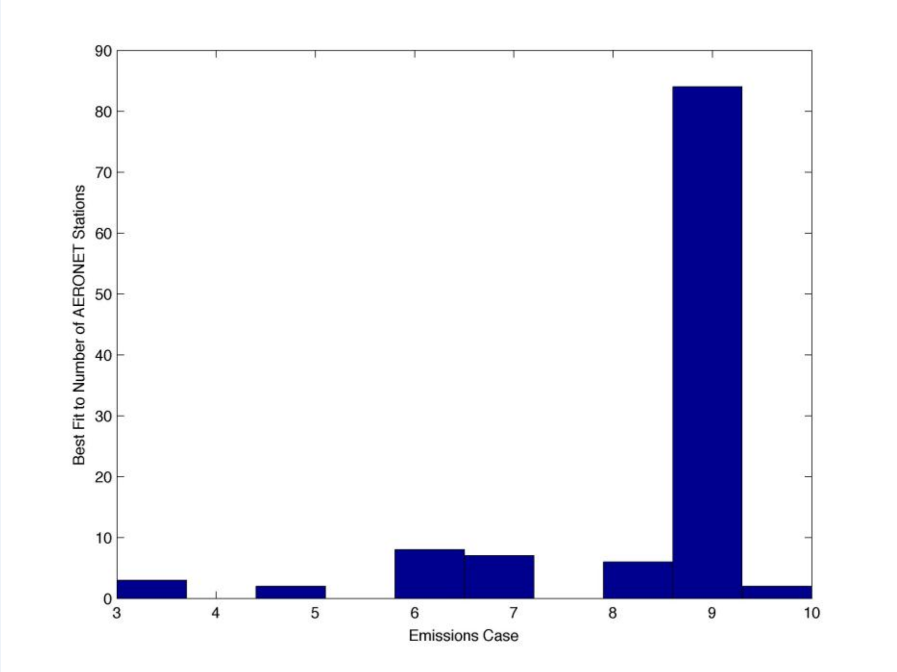
Emissions [Tg/yr]	Optimized Emissions	A-Priori Emissions
Southern East Asia	3.6±1.1	1.9
Southeast Asia	1.7±0.5	1.2
East Europe /Russia	1.2±0.4	0.7

	Computed AAOD [x10^{-3}]
Global	6.8±1.3
30^{o}S – Equator	4.1±1.0
Equator – 30^{o}N	15 (-3 +2)
30^{o}N – 60^{o}N	8.9 (-1.9 +2.1)

Cohen and Wang, 2012 (under review)

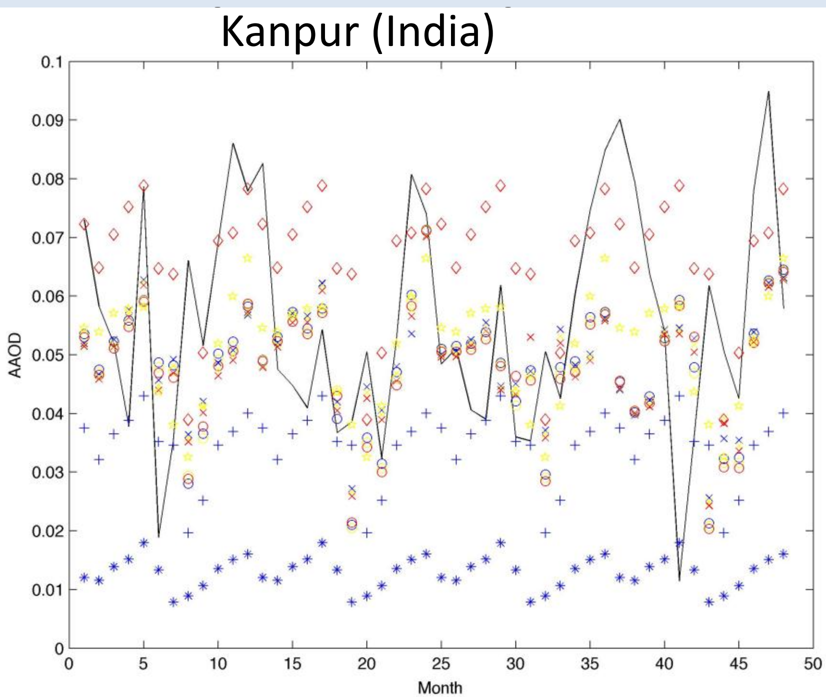
Bulk Comparisons with AERONET



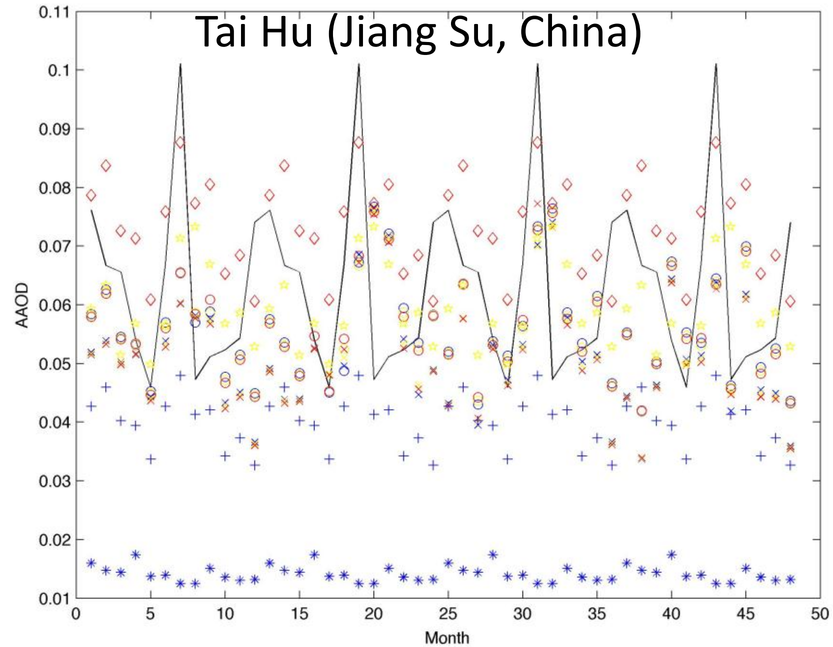


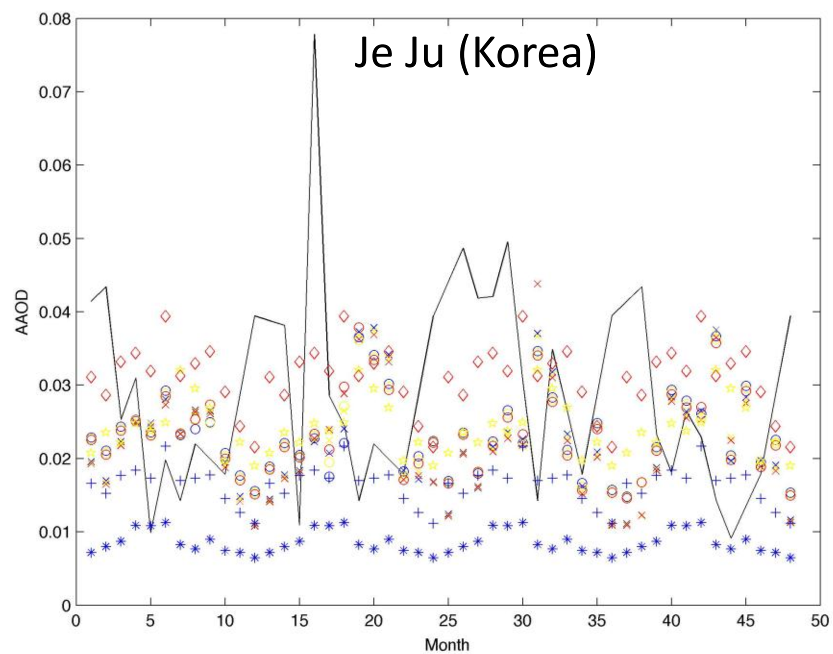
- Fractional RMSE is always less than 18%, with a mean value of 11% across all Stations.
- Highest Emissions Case has the lowest RMSE error for 84/112 stations
- Base Emissions Case with GFED Temporal Variation lowest RMSE for 13/112 stations
- AEROCOM and Unmodified GFED emissions cases never have the lowest RMSE

Specific Comparison with AERONET

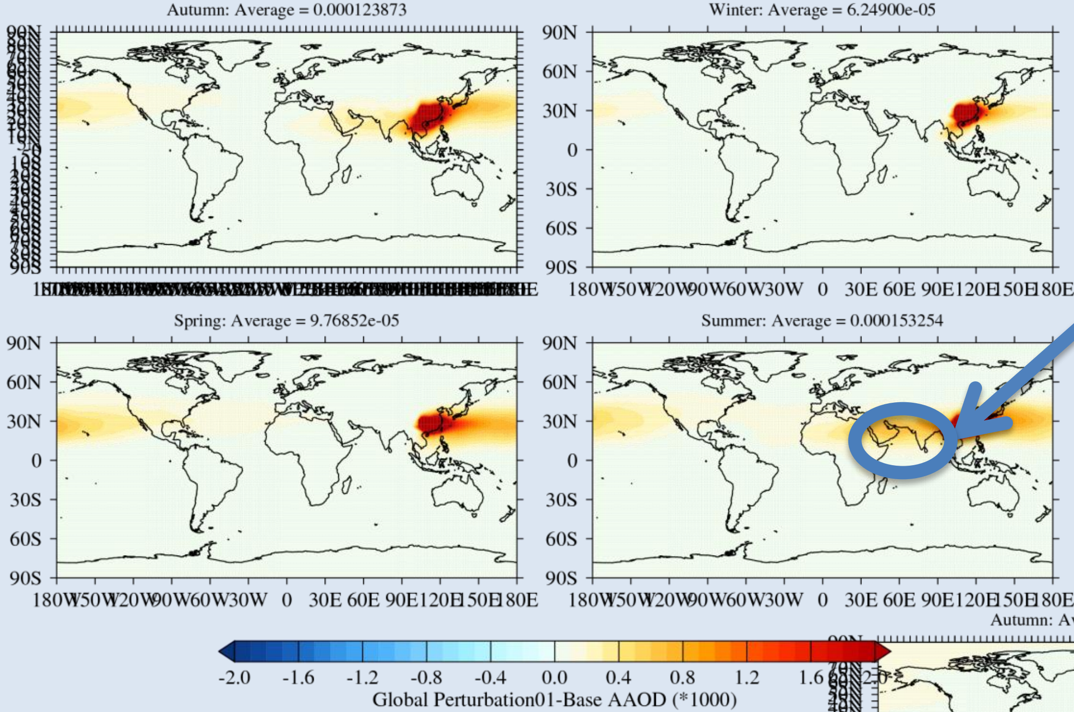


stations)

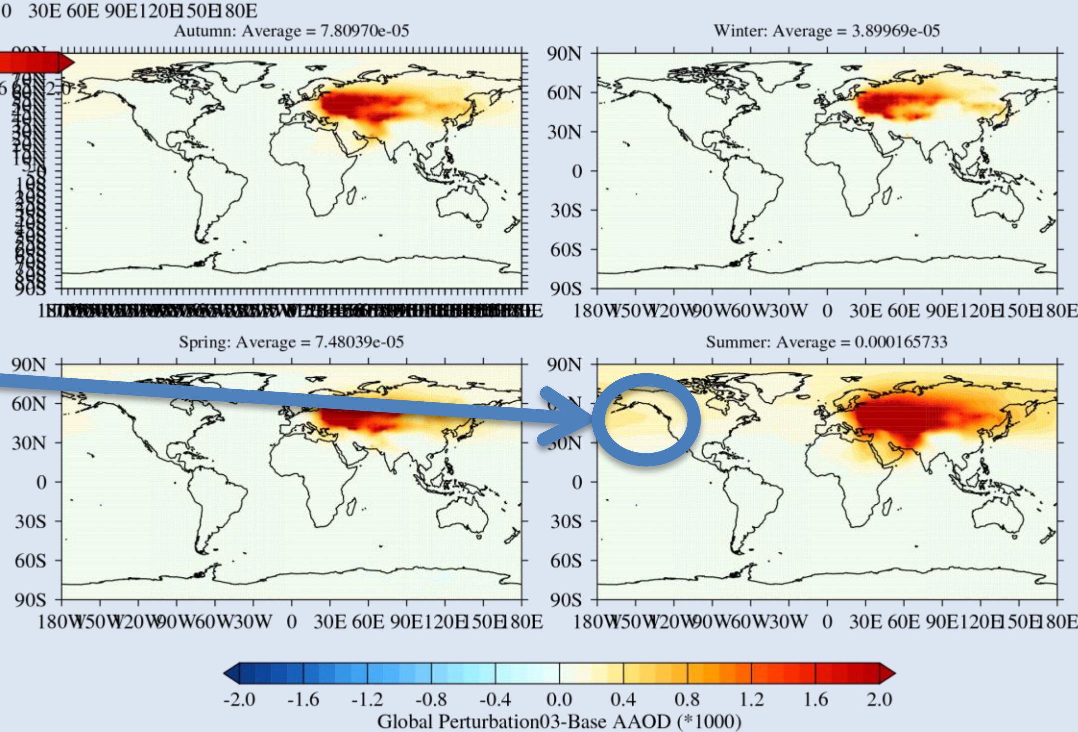




Emissions Perturbations on AAOD

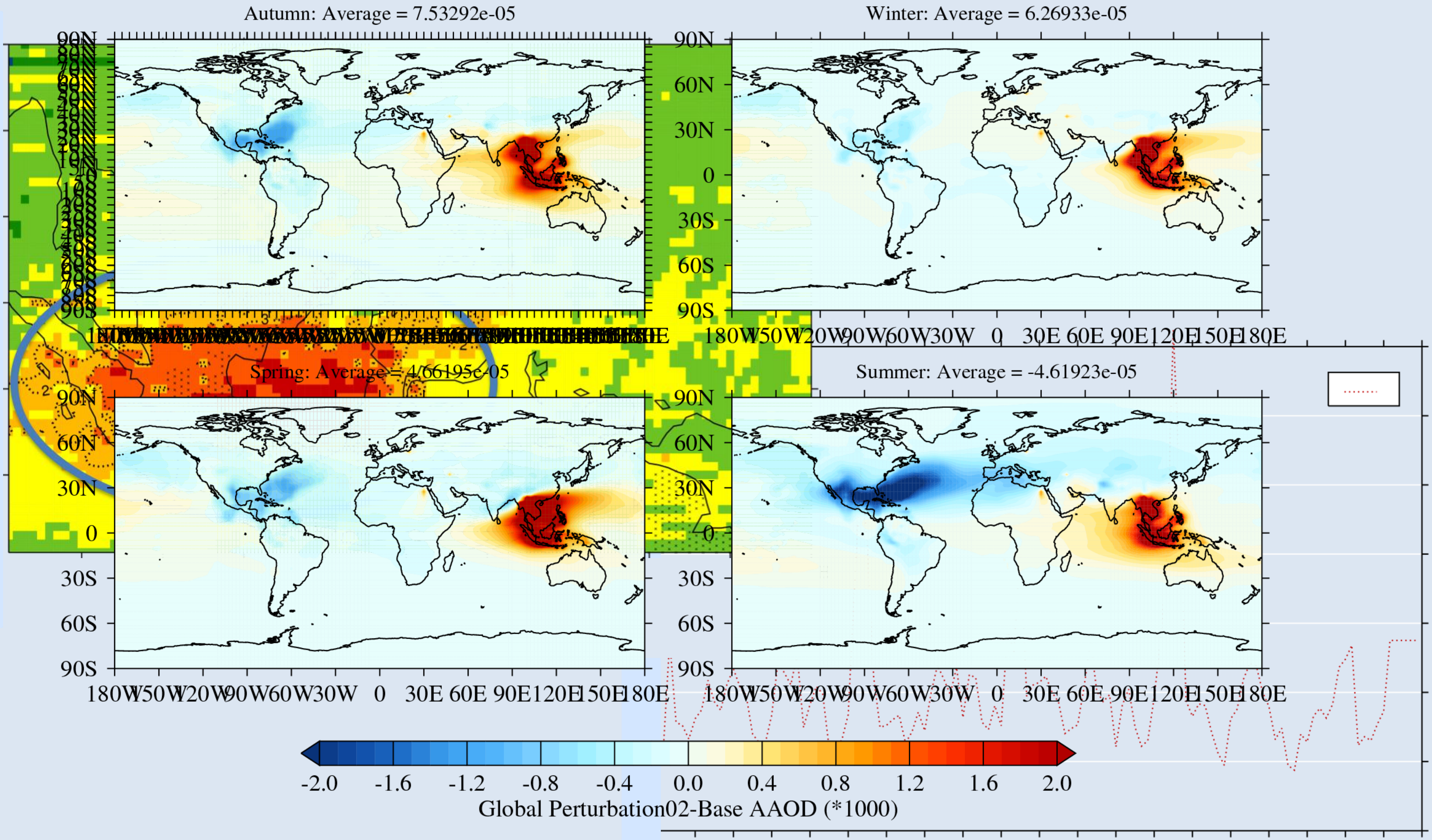


Emissions Underestimations from Southern East Asia perturb the present day AAOD mostly over East Asia and the Pacific, except for during the Summertime.



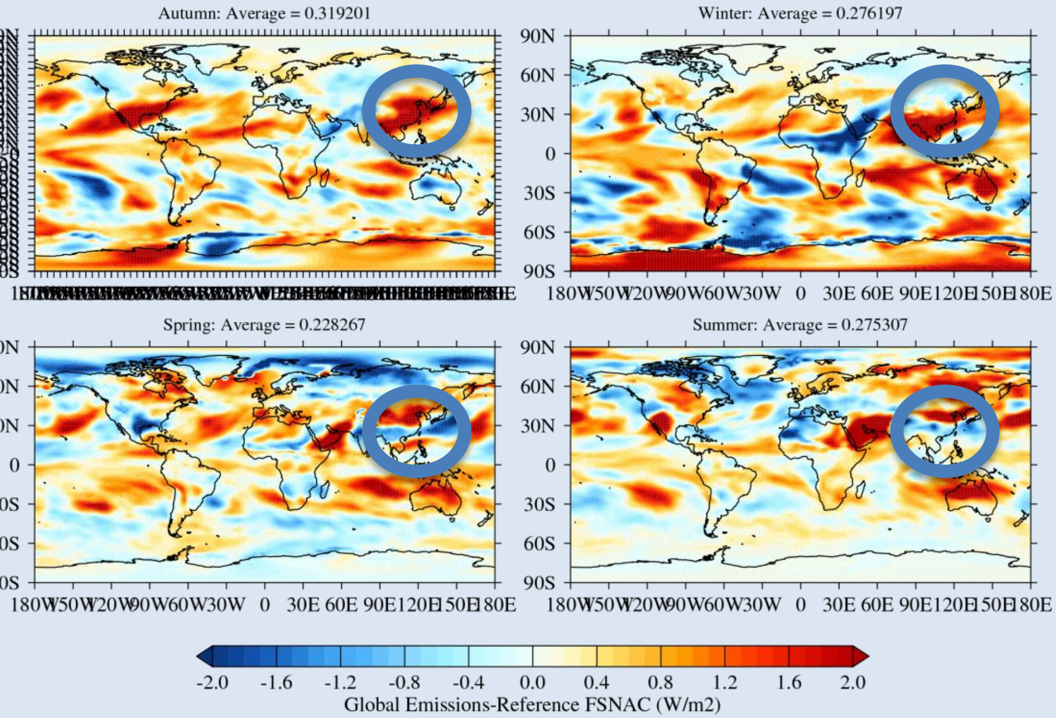
Emissions Underestimations from Eastern Europe/Russia perturb the present day AAOD mostly over Central and Northern East Asia, sometimes impacting the Pacific.

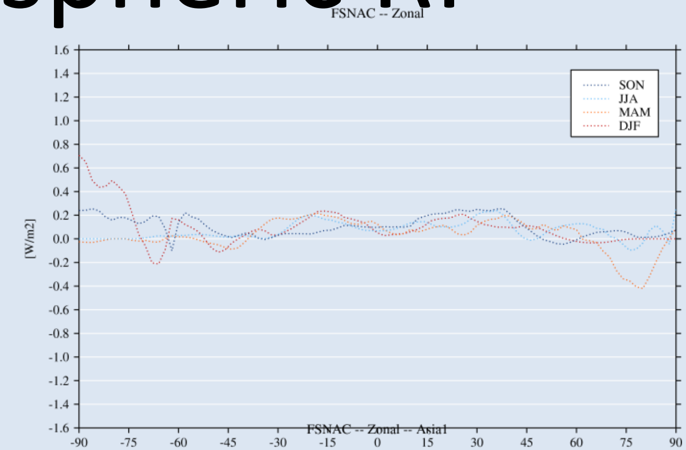
Fires Impose Spatial & Temporal Variation

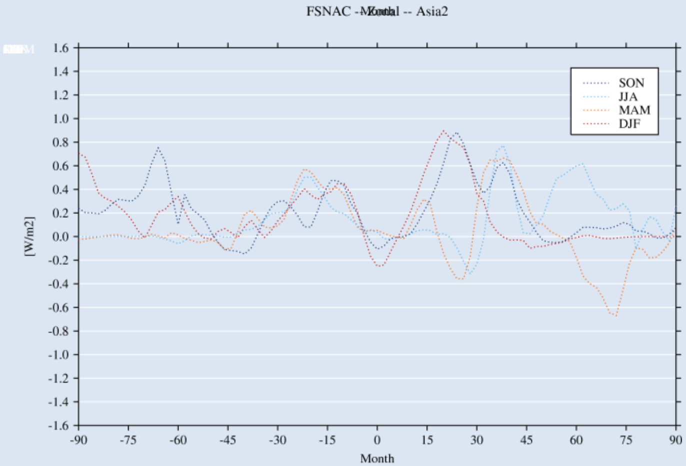


Xi and **Cohen**, 2012

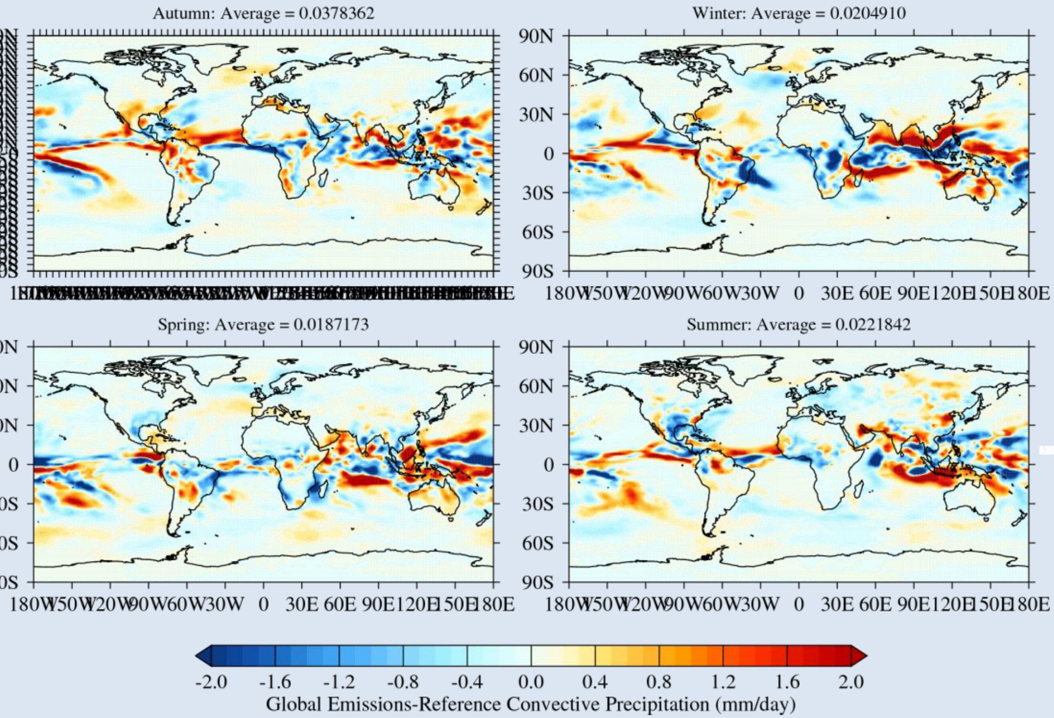
Equilibrium Atmospheric RF

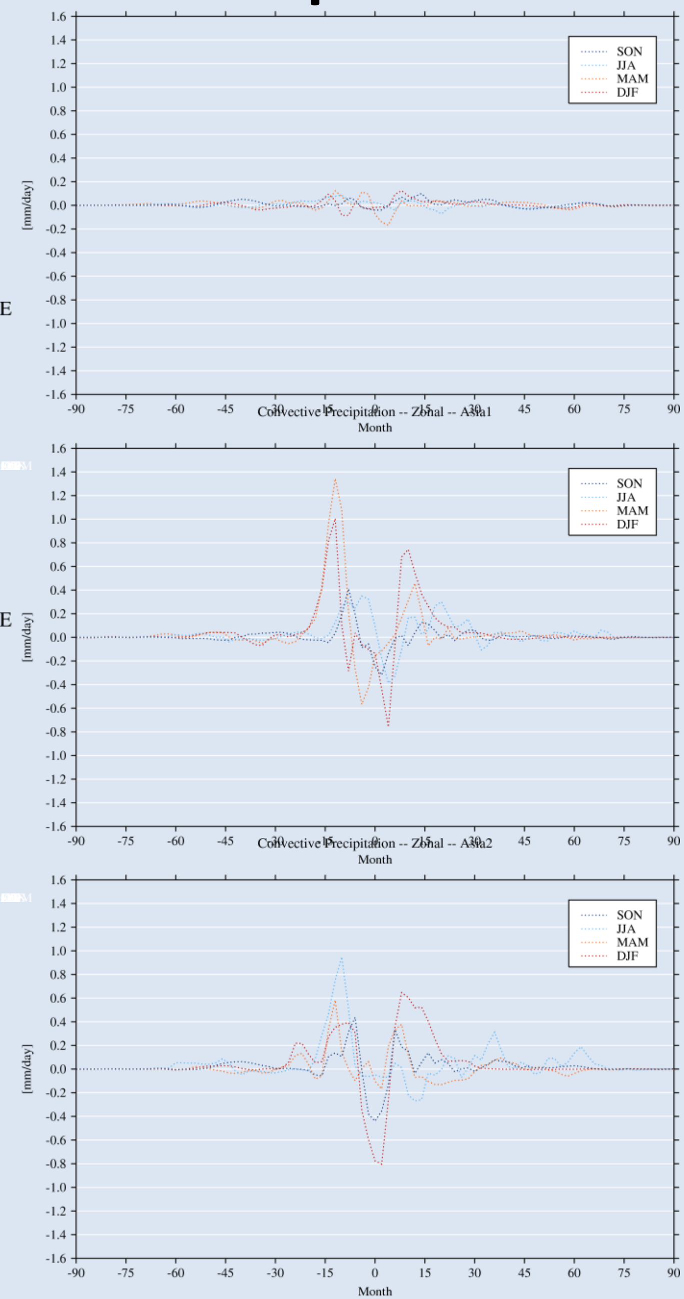






Equilibrium Convective Precipitation





Conclusions

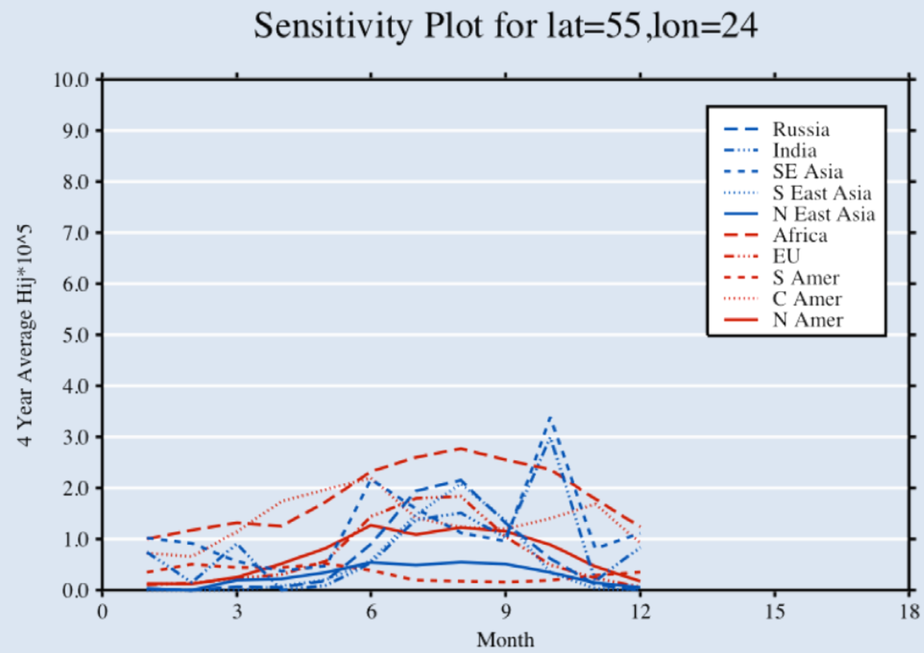
- 18Tg/yr of BC yields a chemically and energetically different climate
- Top-down methods improve the annual average modeled AAOD and surface concentrations. Still are issues in space and time.
- Optimized BC impacts optical properties of the atmosphere, mostly NH over Asia and Pacific Ocean, with SE Asia's impact wider.
- Perturbations from East Asia and Southeast Asia contribute to the atmospheric RF over South Asia during the pre-monsoon season
- The climate-adjusted profiles of atmospheric RF are far more complex than the offline, non-climate adjusted, profiles.
- Much of the energy imbalance is used to evaporate water (latent heat flux), increasing the atmospheric water column
- This leads to an increase in Tropical Asian convective precipitation, as well as a shift consistent with a change in the ITCZ

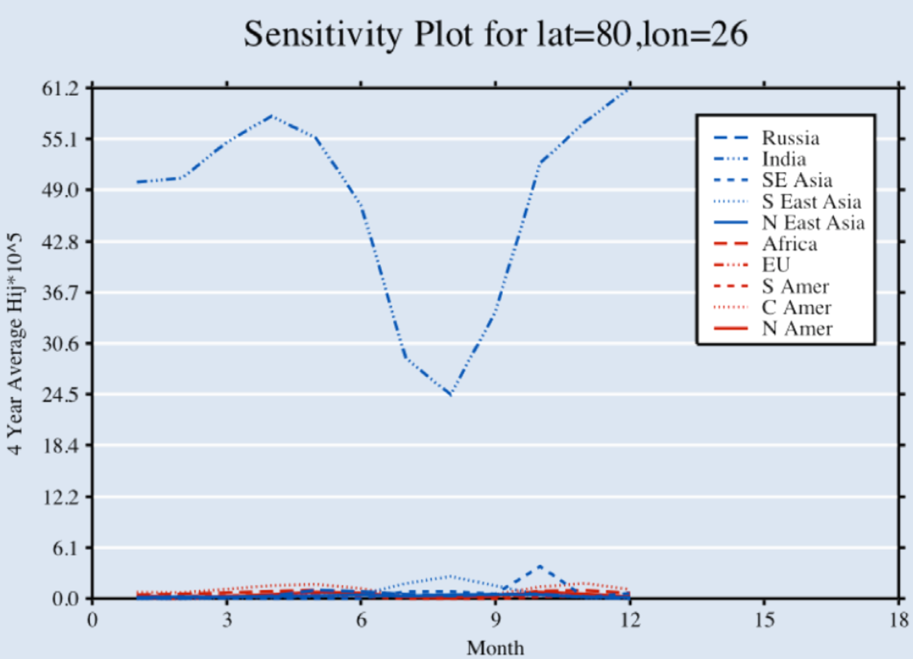
Next Steps?

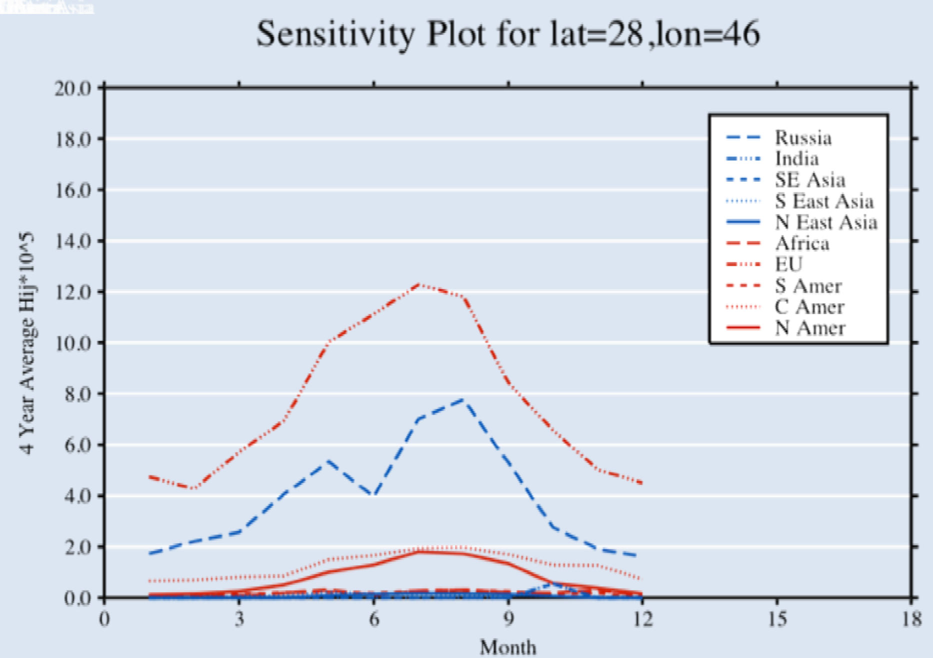
- Is anyone interested in running your models with these new emissions and making comparisons?
- Would anyone like to use their models to help study the model-dependent impact on H_{ijk}?
- Are there any other available spatial/temporal a priori data sets available for emissions?

Photo Taken By Jason Blake Cohen, April 2012, over India/Nepal

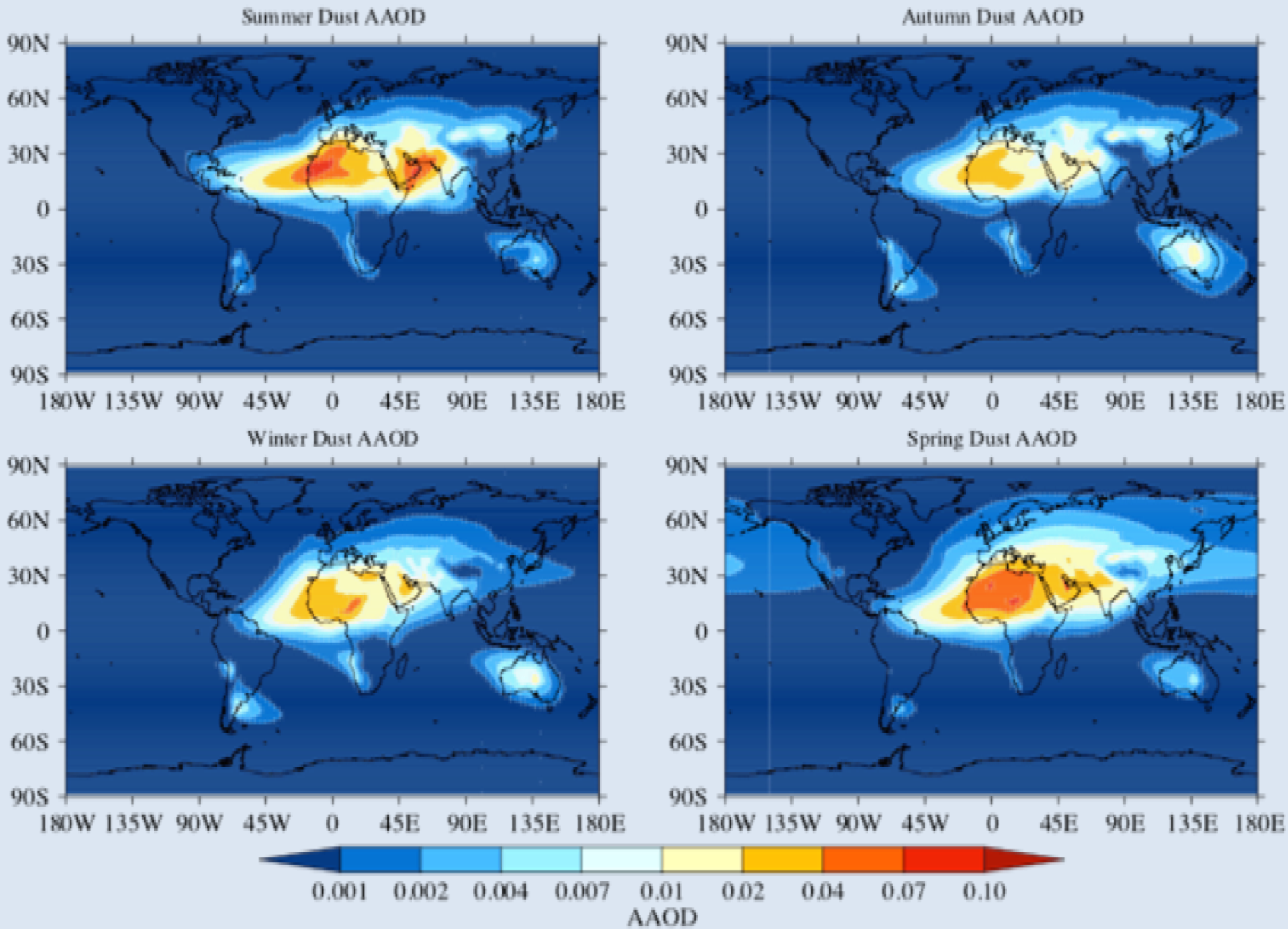
Sensitivity Matrix for Selected Stations



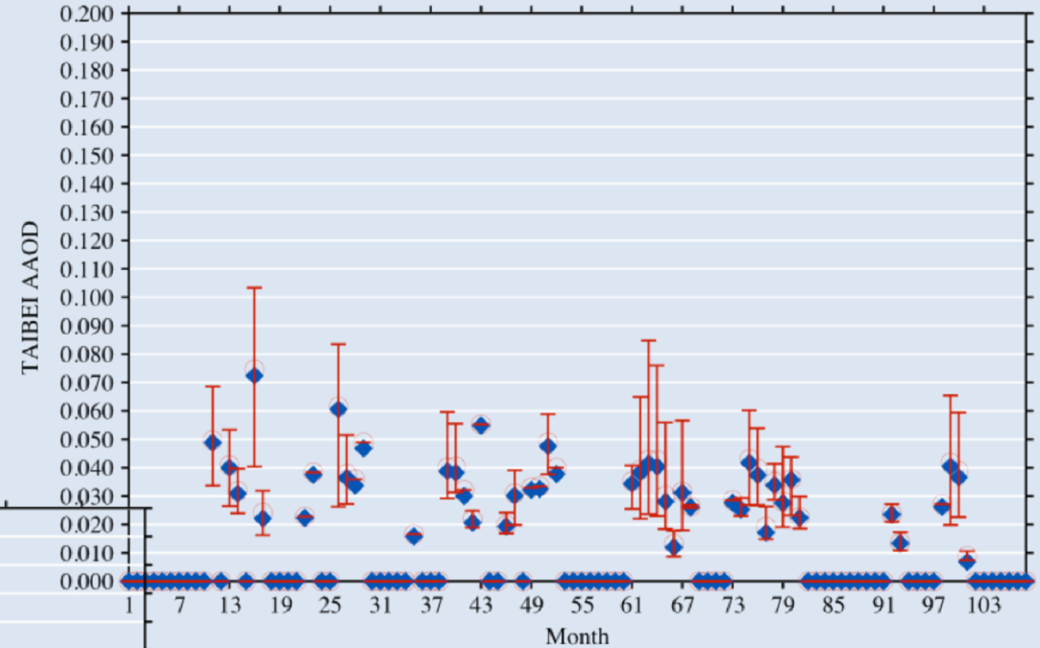


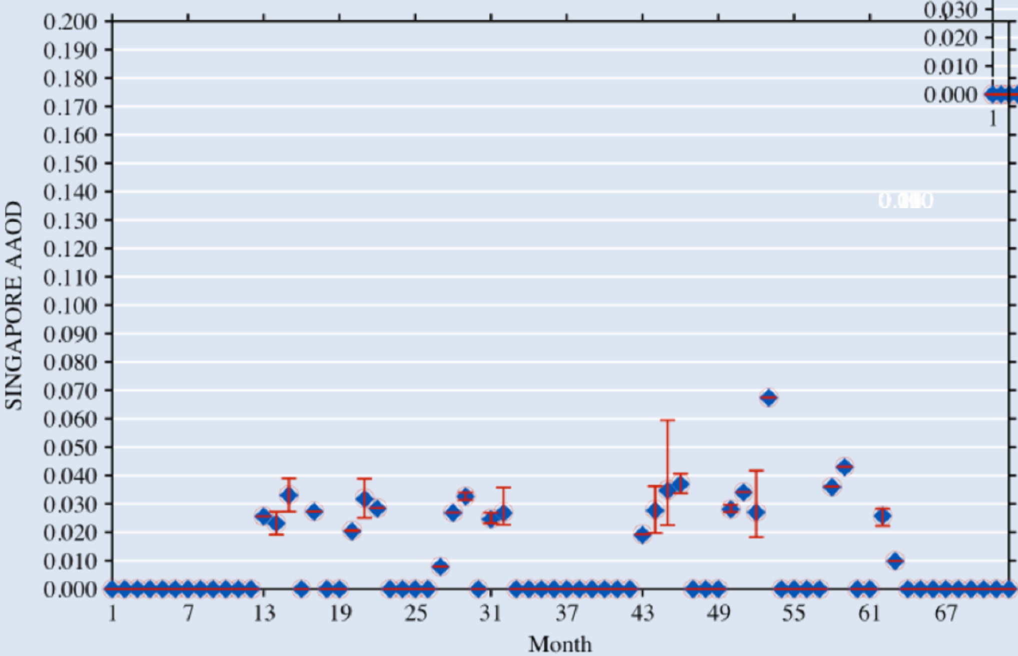


Dust Climatology



Aeronet Yields:
AOD (measured) and SSA (retrieval)





Why Do Urban Areas Matter?

- The largest 251 cities emit:
  69% BC, 62% OC, 67% SO_2.
- Urban & Background concentrations of aerosols and precursors are of different orders of magnitude.
- Processing of aerosols is non-linear, depends on Geography, Emissions, Climate.
- Regional and Urban models have short time spans, artificial boundary conditions, and require high resolution input data.
- Global models use have large spatial & temporal resolution, dilute emissions, and many processes are simplified for computational reasons.

Equilibrium Surface Temperature