Aerosol Distributions and Direct Radiative Forcing – Estimates from a Global Aerosol Analysis with MODIS Assimilation

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Introduction

Aerosols are particles in the atmosphere that can absorb and reflect solar radiation.

Aerosol Radiative Forcing → Climate Response

"It is unlikely that satellites can directly supply the required aerosol information; rather success will depend upon appropriate combinations of satellite data, models, field measurements and surface monitoring. These considerations apply to investigation of the effect of aerosols on clouds, that is, the 'indirect' aerosol climate forcing, as well as the direct aerosol forcing."

Executive Summary of the NASA Global Aerosol Climatology Project

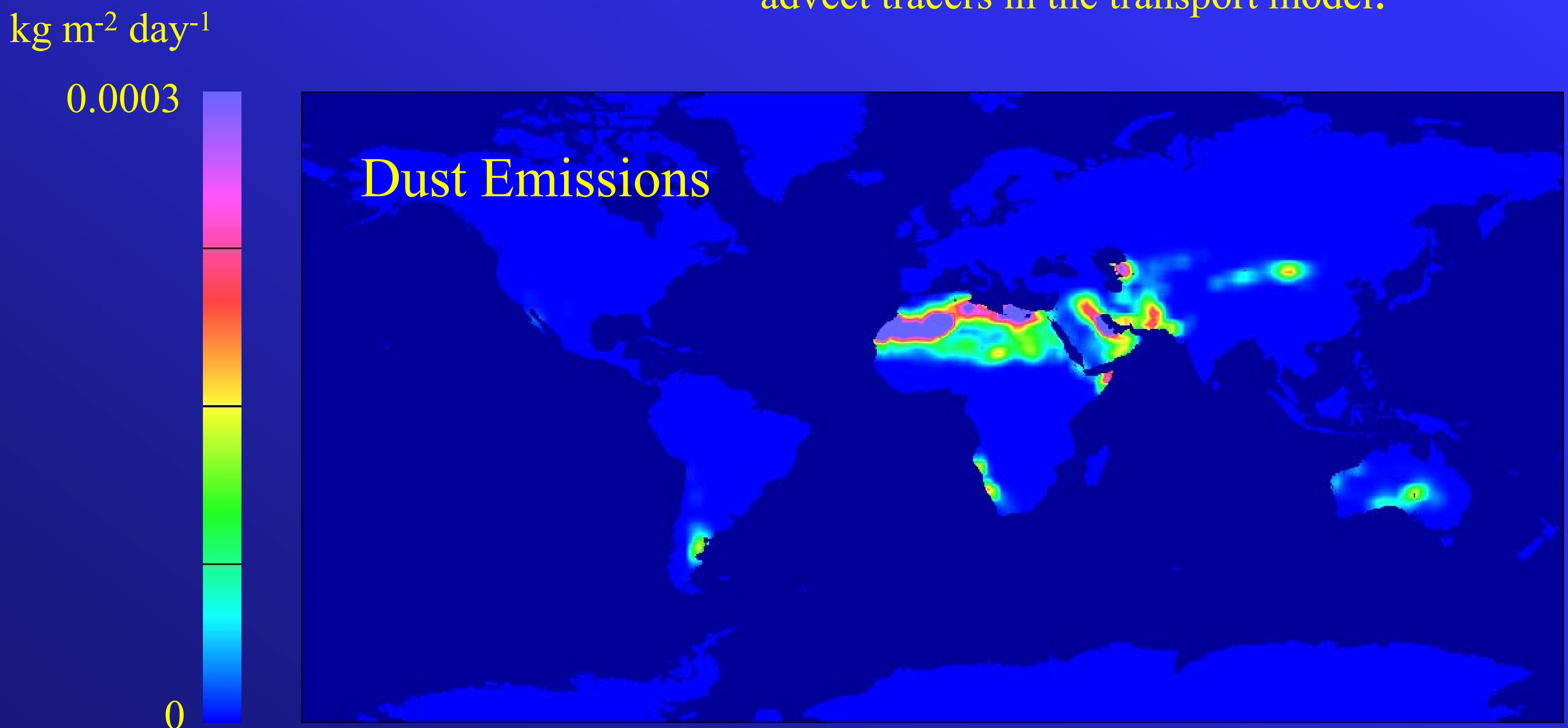
Aerosol Optical Depth (AOD) Assimilation is a method of blending model simulated aerosol fields with satellite observations.

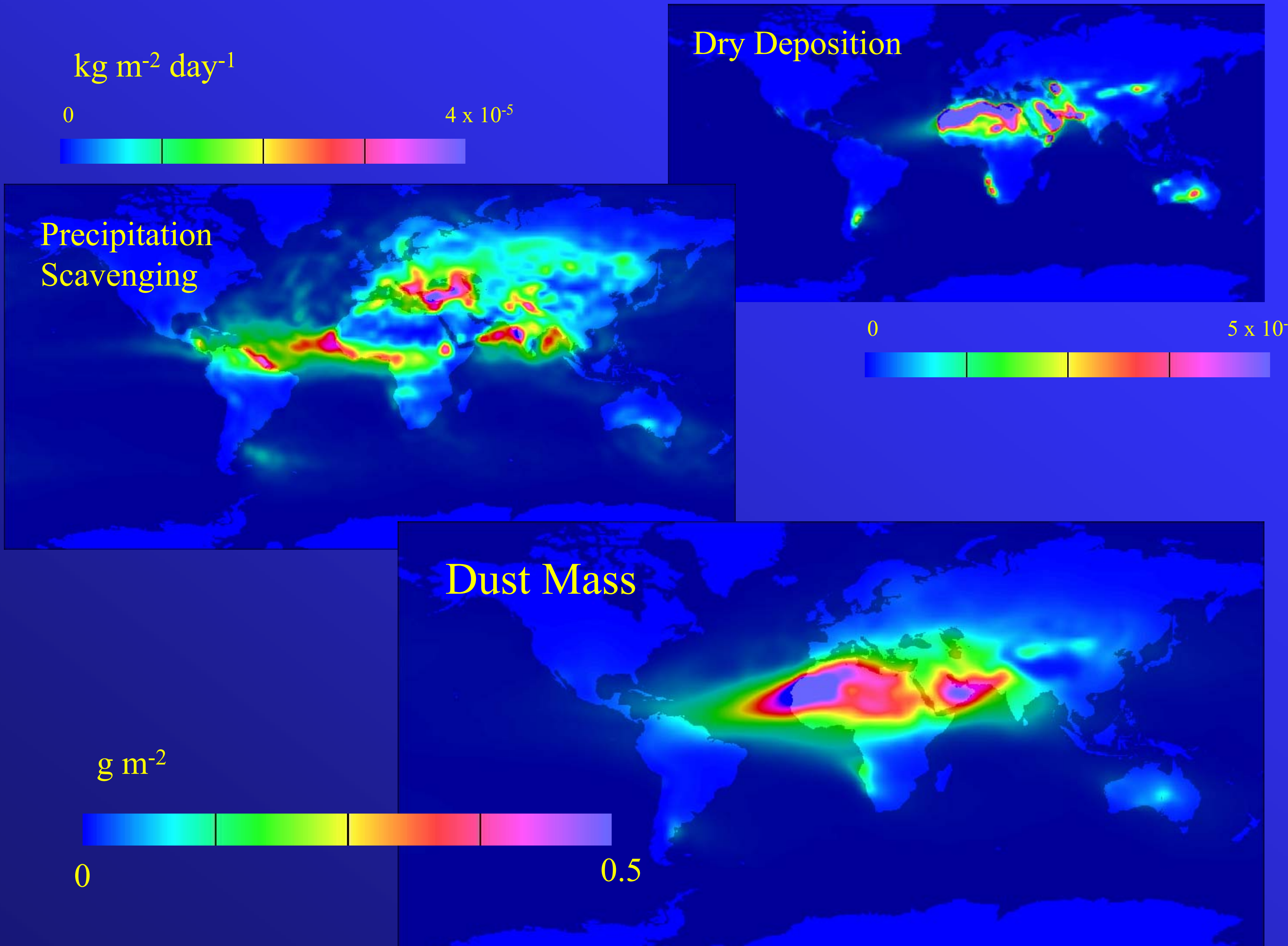
Constraining a global transport model in this way
may lead to improved estimates of aerosol radiative forcing.

Chemical Transport Models

Dust Aerosol Example

Winds from Weather Forecasts/Analyses advect tracers in the transport model.





kg m-2 day-1
0
4 x 10-5
Precipitation Scavenging
Dry Deposition
0
5 x 10-5
Dust Mass
g m-2
0
0.5

AOD Assimilation
AVHRR Advanced Very High Resolution Radiometer
OR
MODIS Moderate Resolution Imaging Spectrometer

Meteorological fields
NCEP/NCAR Reanalysis
resolution T62 ~ 1.9°, 28 levels
OR **NCEP Aviation Analysis**
resolution T126, 42 levels
OR **CAM** (NCAR Community Atmosphere Model)
resolution T42, 28 levels

AOD
λ = 630 nm
OR 550 nm
Optimal Interpolation

1° by 1° gridded aerosol product
Stowe et al 1997
Kaufman et al 1998

MATCH
Model for Atmospheric Transport and Chemistry
Rasch et al 1997

SO_2/DMS/Carbon Aerosol Emission Inventories
monthly climatologies
Benkovitz et al 1996
Cooke et al 1999
Liousse et al 1996

MATCH Configuration

Sulfur Cycle/ Sulfate Aerosol

Gas phase/aqueous chemistry

Barth et al 2000

tracers DMS, SO_2, SO_4, H_2O_2

monthly climatologies for O_3, OH, HO_2, NO_3

from MOZART (Model for Ozone and its Precursors in the Troposphere)

Dust Aerosol

Mobilization and deposition

Zender et al 2003

Mahowald et al 2003

4 size categories

0.005 – 0.5 µm (radius), 0.5 – 1.25 µm, 1.25 – 2.5 µm, 2.5 – 5.0 µm

Diagnosed sea-salt aerosol

Blanchard and Woodcock 1980

No nitrate aerosol

Carbon Aerosol

Black Carbon (Soot)

Organic Carbon hydrophobic ⇨ hydrophilic

Cooke and Wilson 1996

Hydrological Cycle

Prognostic cloud water

Rasch and Kristjansson 1997

Vertical convection

Zhang and McFarlane 1995

Precipitation - bulk microphysical

Flatau 1989

Aerosol Optics

Sulfate*, Sea-Salt, Organic Carbon, Soot

Optical Properties of Aerosols and Clouds

Hess et al 1998

Dust

Zender et al 2003

*Currently based on $(NH_4)_2SO_4$

How does AOD assimilation work?

Assimilation adjusts model aerosol mass so that model AOD more closely matches satellite observed AOD.

$$\tau_\lambda = \Sigma_s \Sigma_k [\Delta p_k / g \quad k_\lambda(RH)] \, q_{sk}$$

Single wavelength assimilation scales aerosol mass mixing ratios independent of vertical level and species

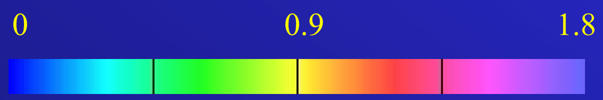
$q_{sk} \Rightarrow \alpha \, q_{sk}$ through *Optimal Interpolation*, with a spatial correlation length of ~ 100 km .

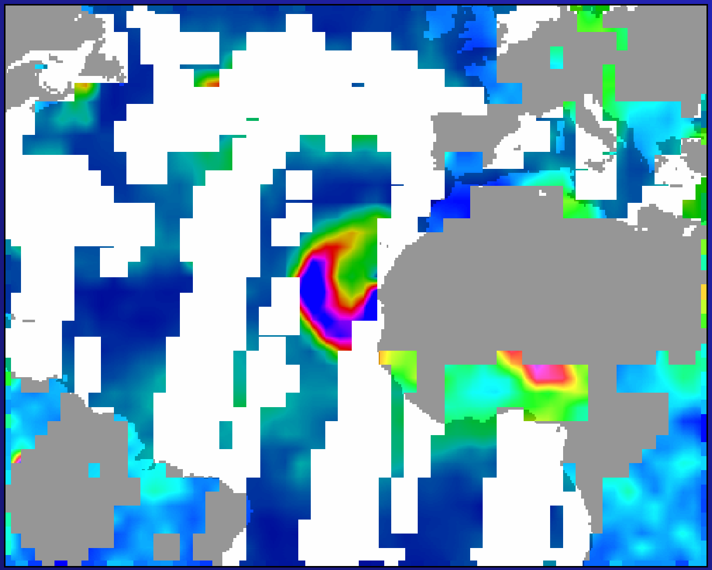
An example illustrates the subsequent model propagation of this mass correction …

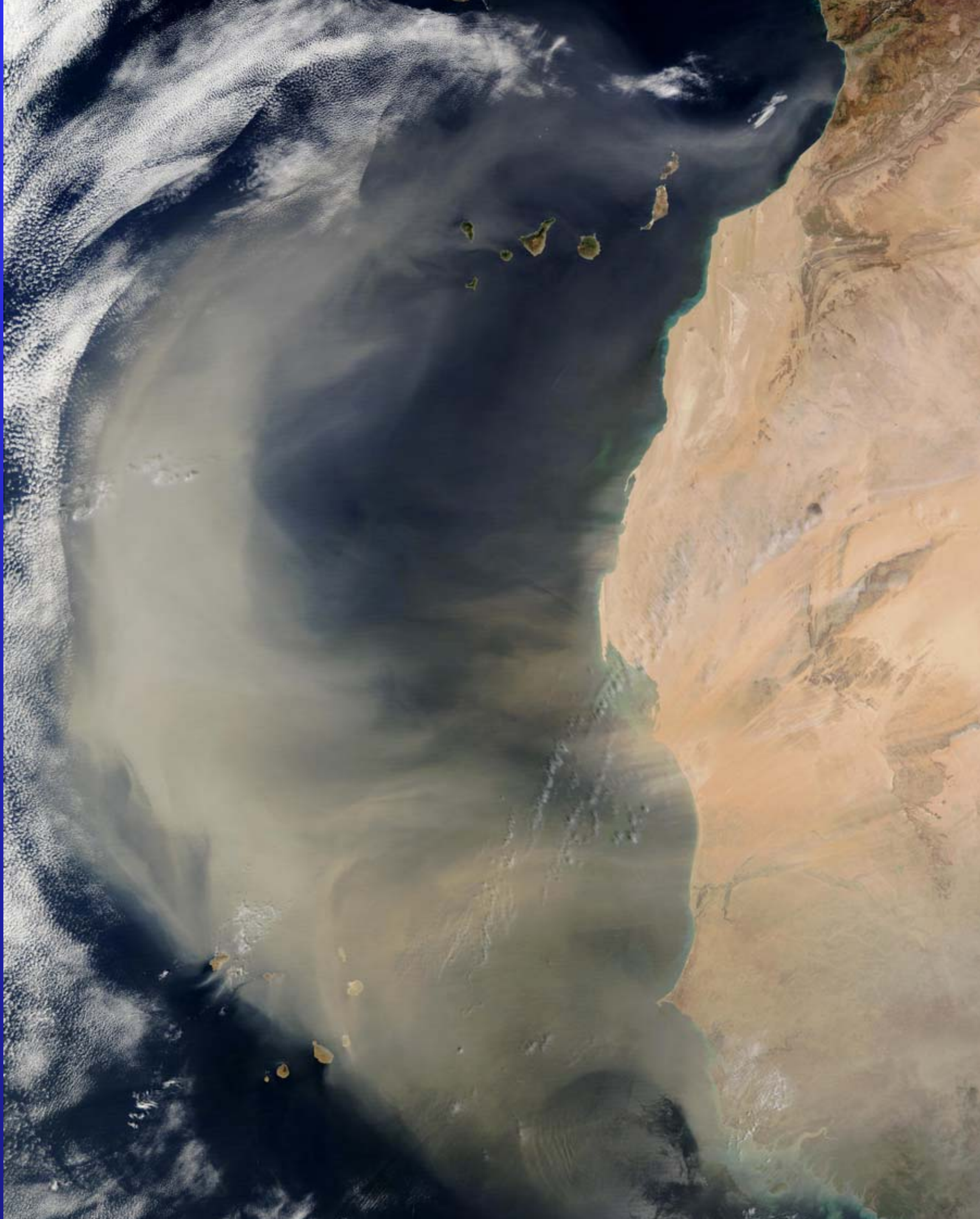
Aerosol Assimilation Example

Saharan Dust Storm March 2, 2003

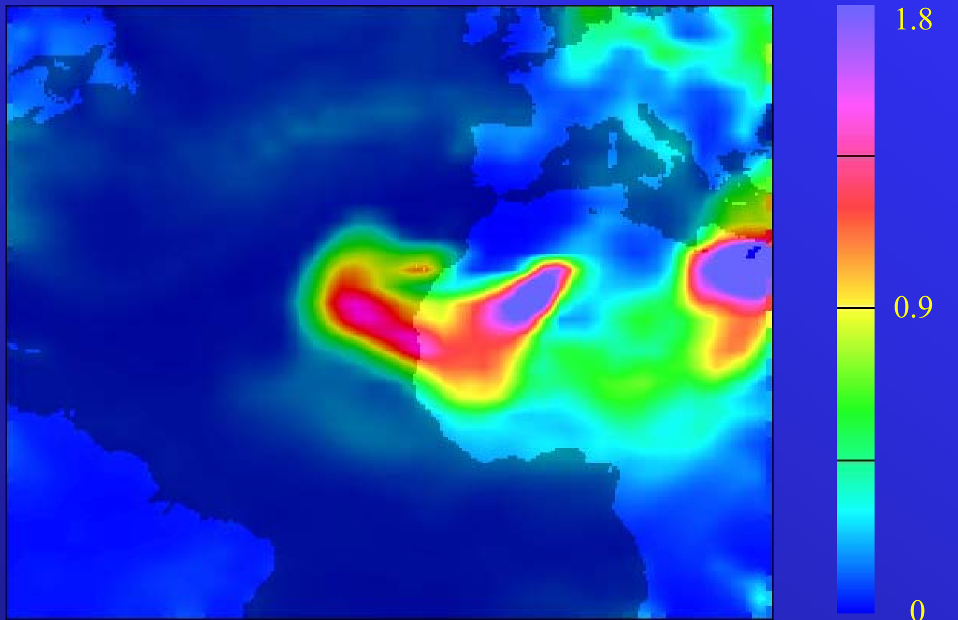
MODIS AOD at
MATCH 1.9° resolution



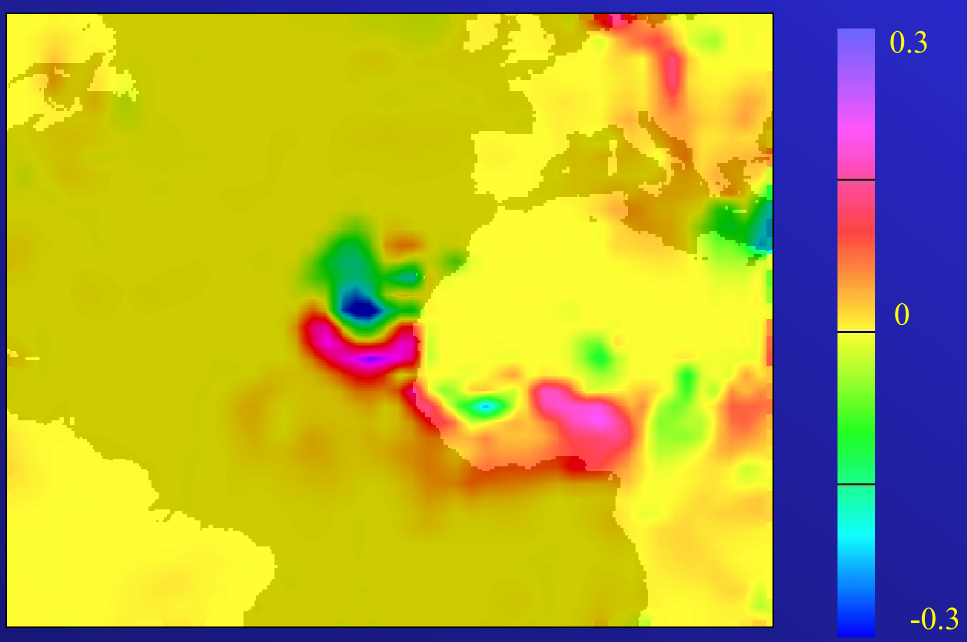




March 2



MATCH AOD

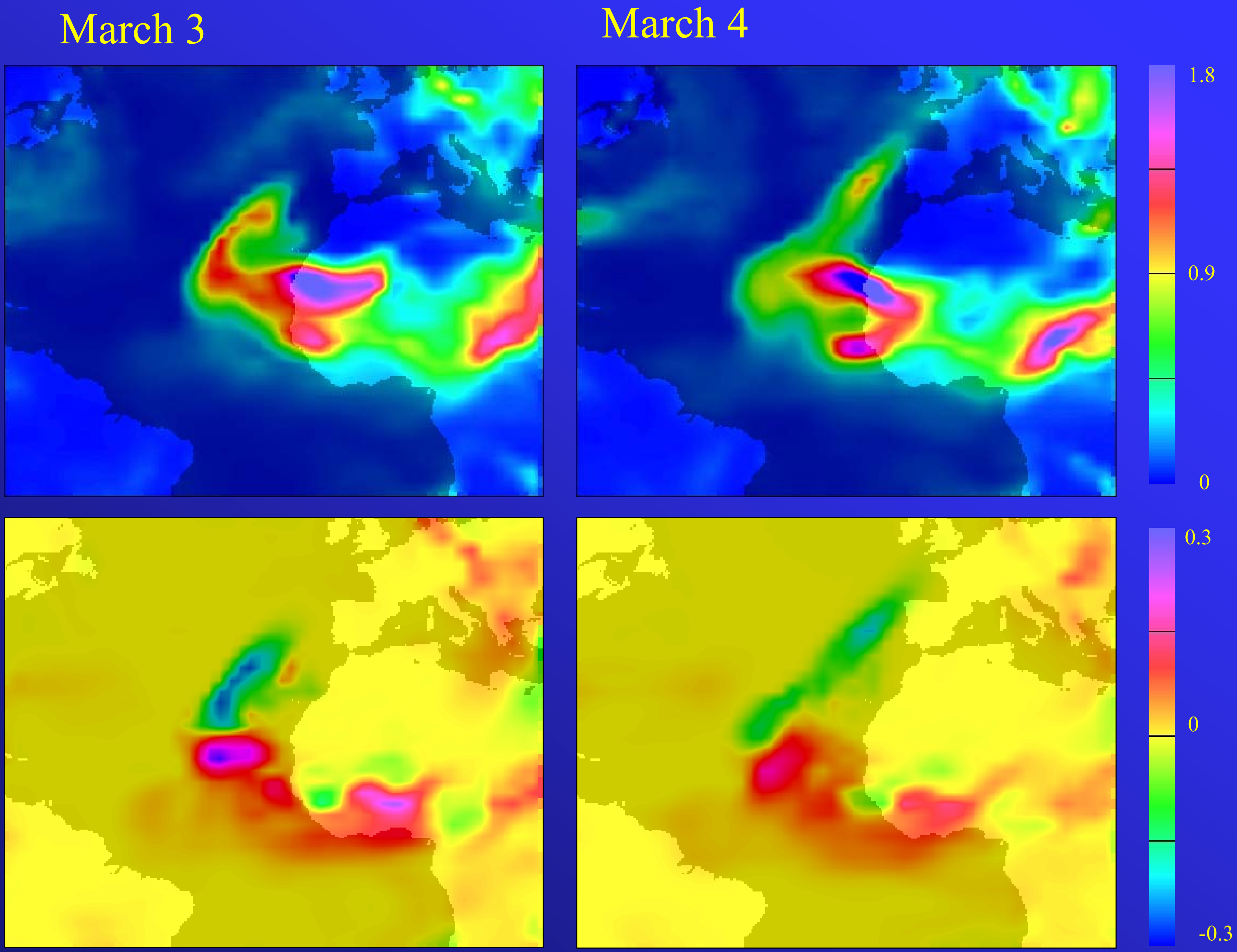


AOD Difference

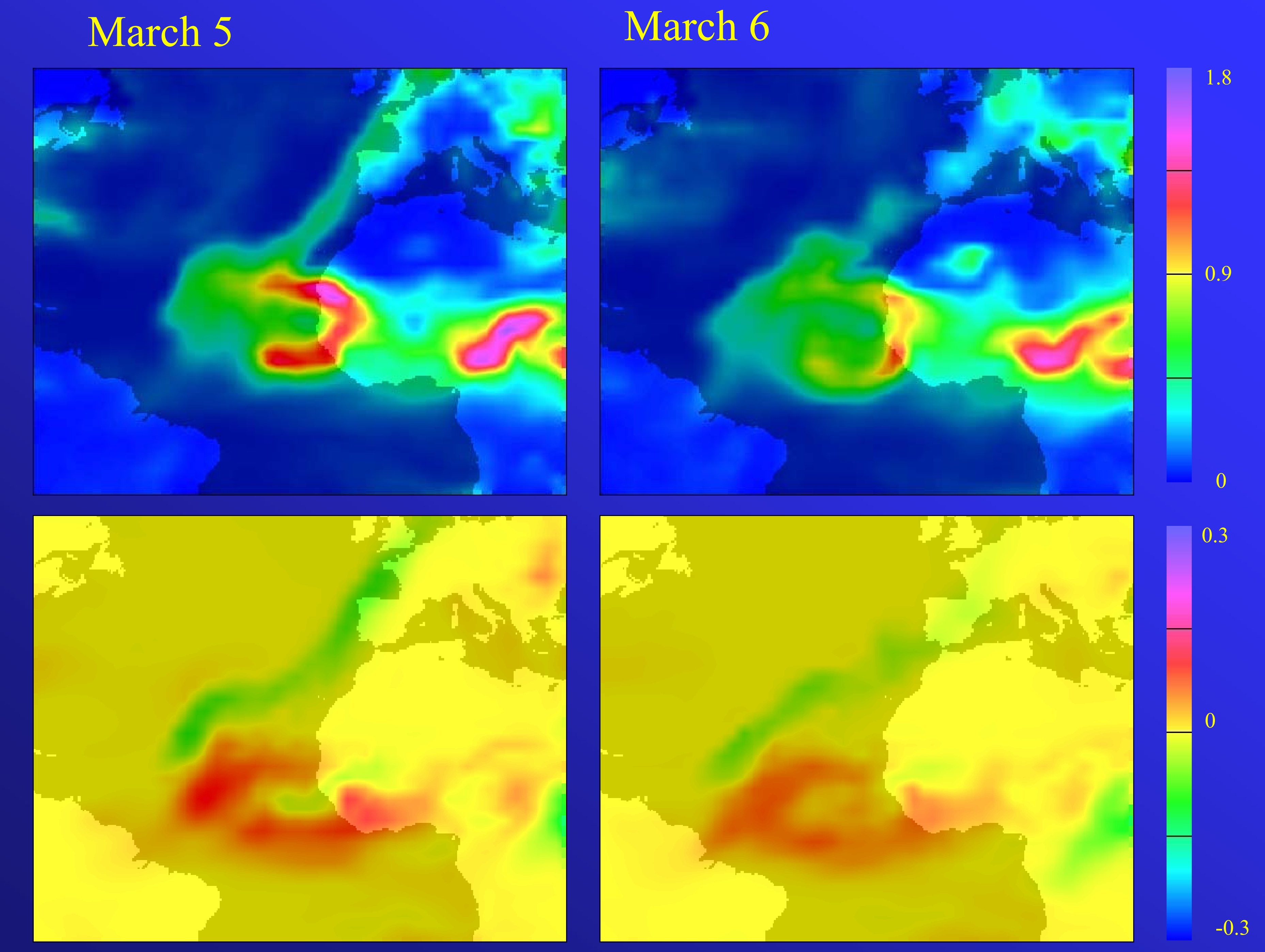
MATCH with
MODIS Assimilation
(on March 2 only)

-

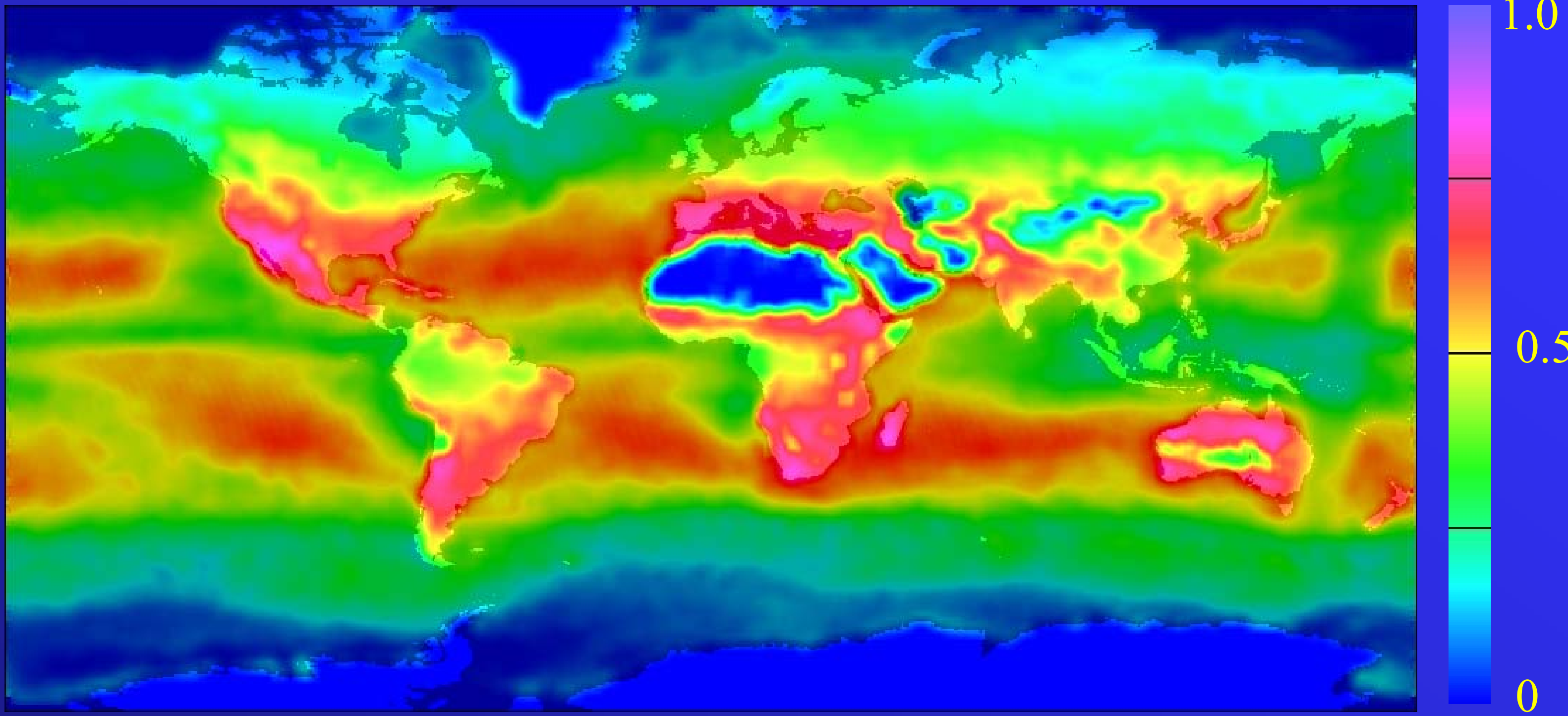
MATCH



March 3
March 4
1.8
0.9
0
0.3
0
-0.3

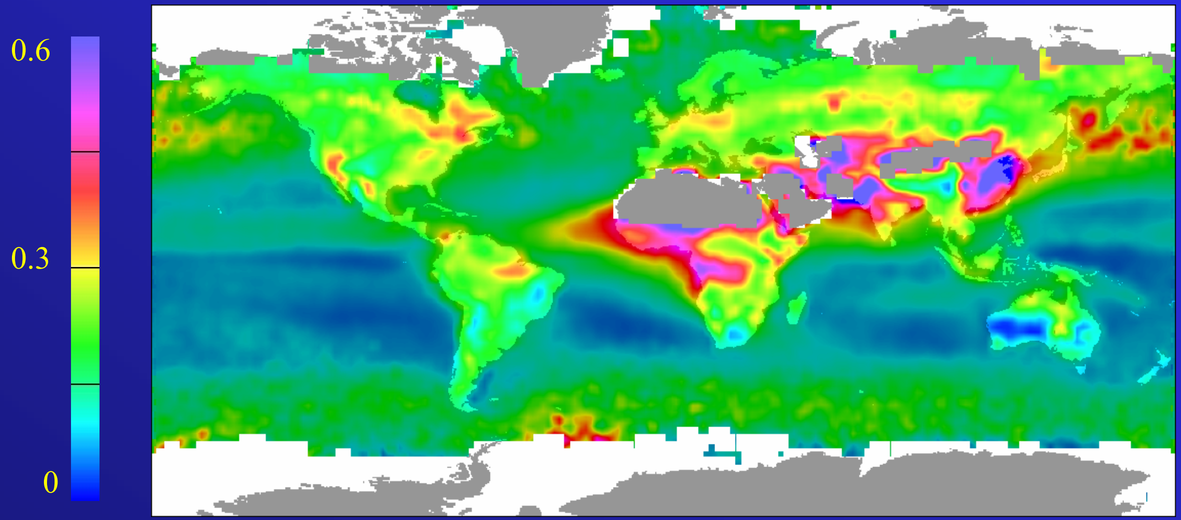

March 5
March 6
1.8
0.9
0
0.3
0
-0.3

MODIS Sampling 2001

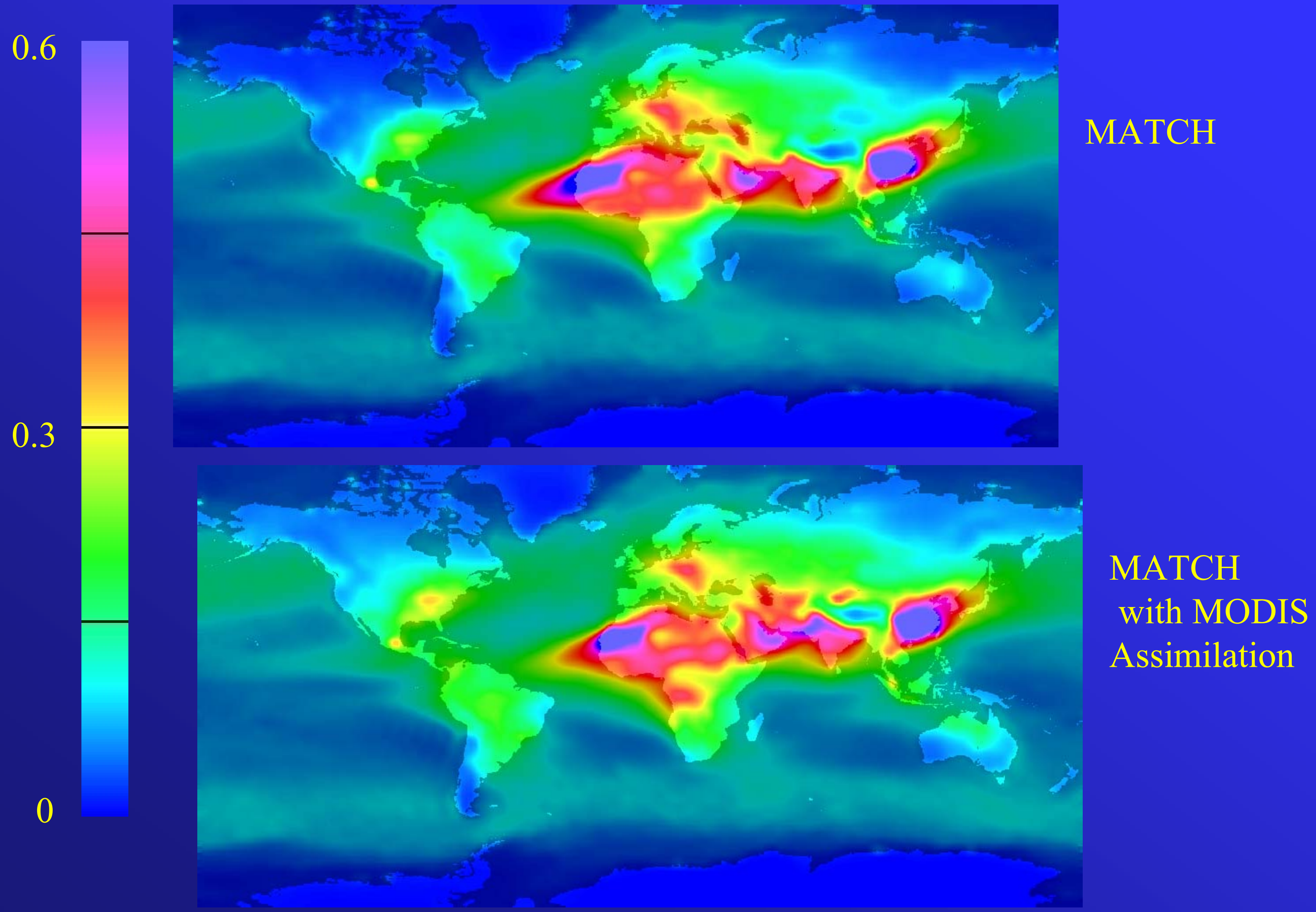


fraction of days with MODIS AOD measurement

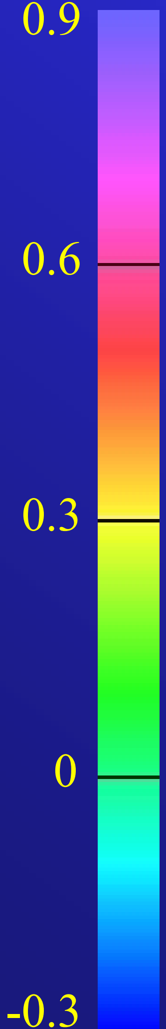
MODIS AOD 2001

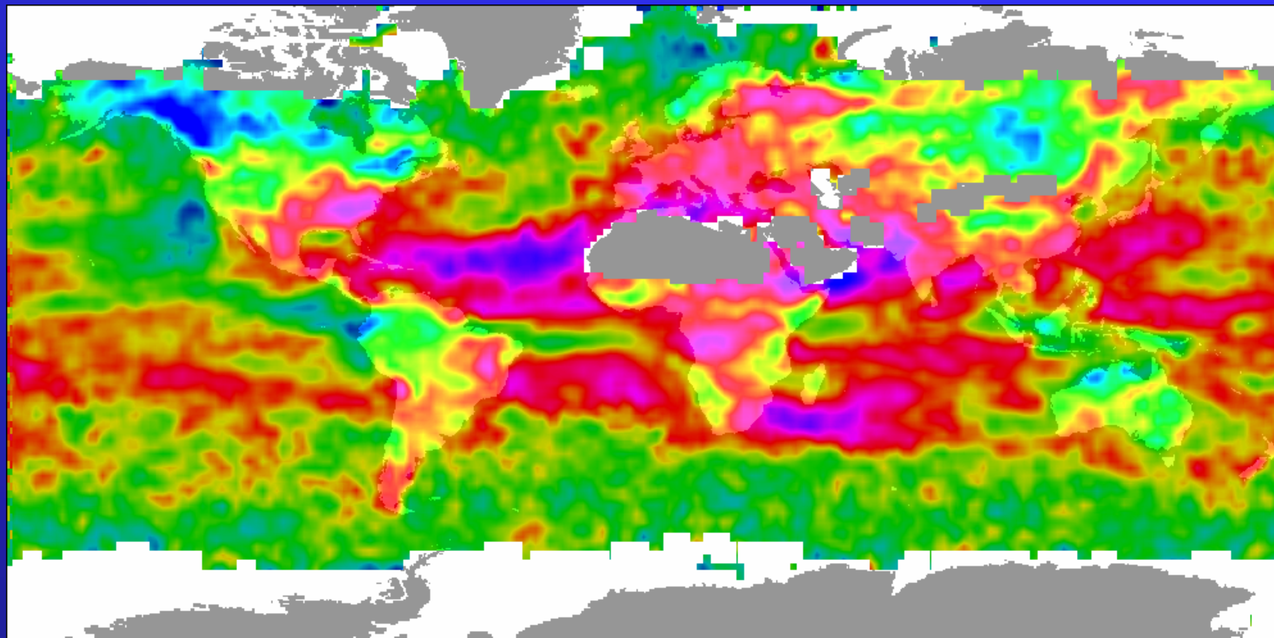


Aerosol Optical Depth 2001



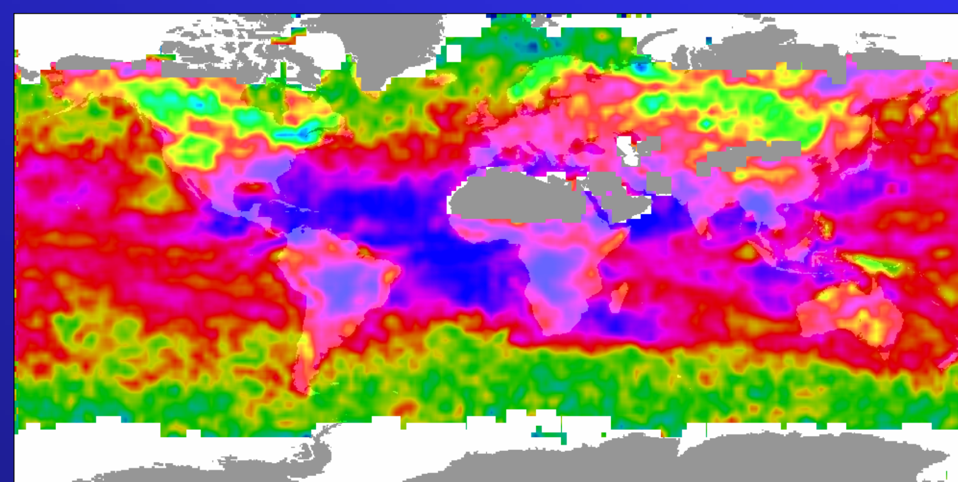
Aerosol Optical Depth MATCH/MODIS Correlation 2001



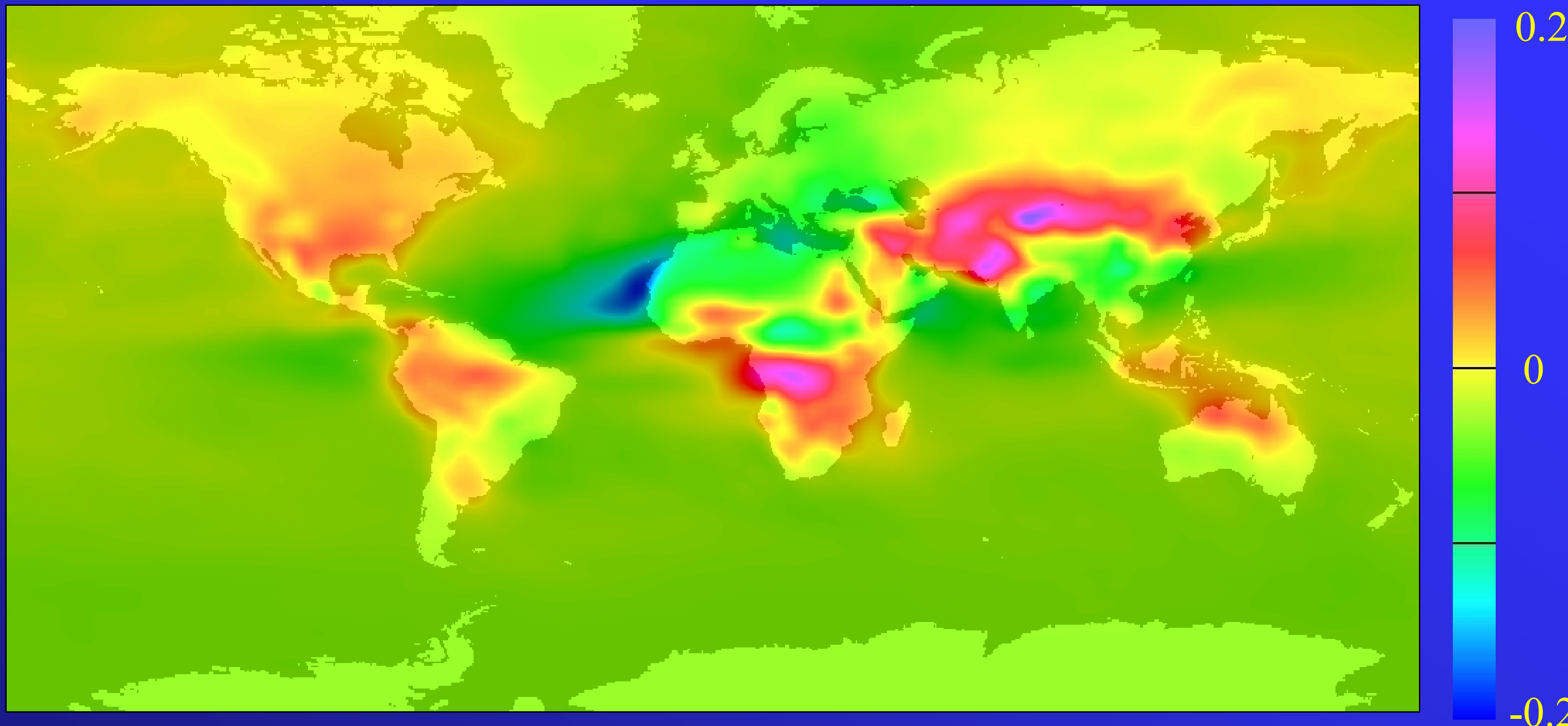


5-day running mean

with Assimilation



AOD Assimilation Correction 2001



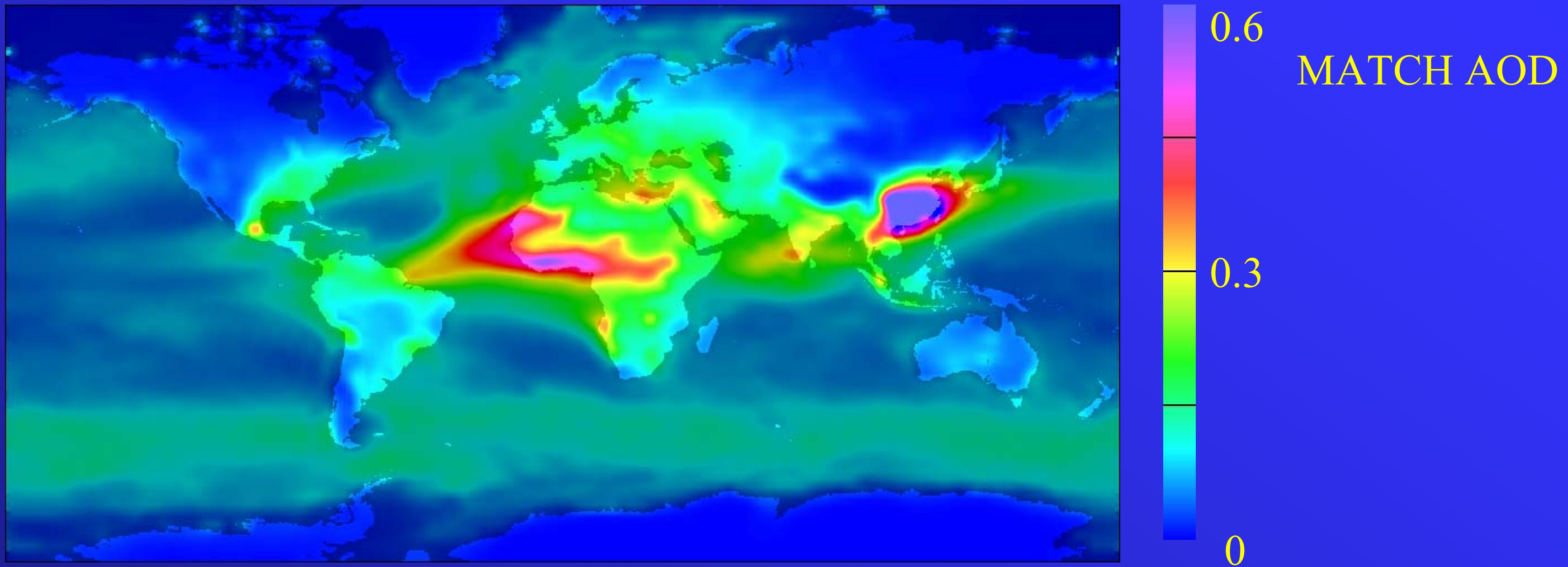
AOD Difference

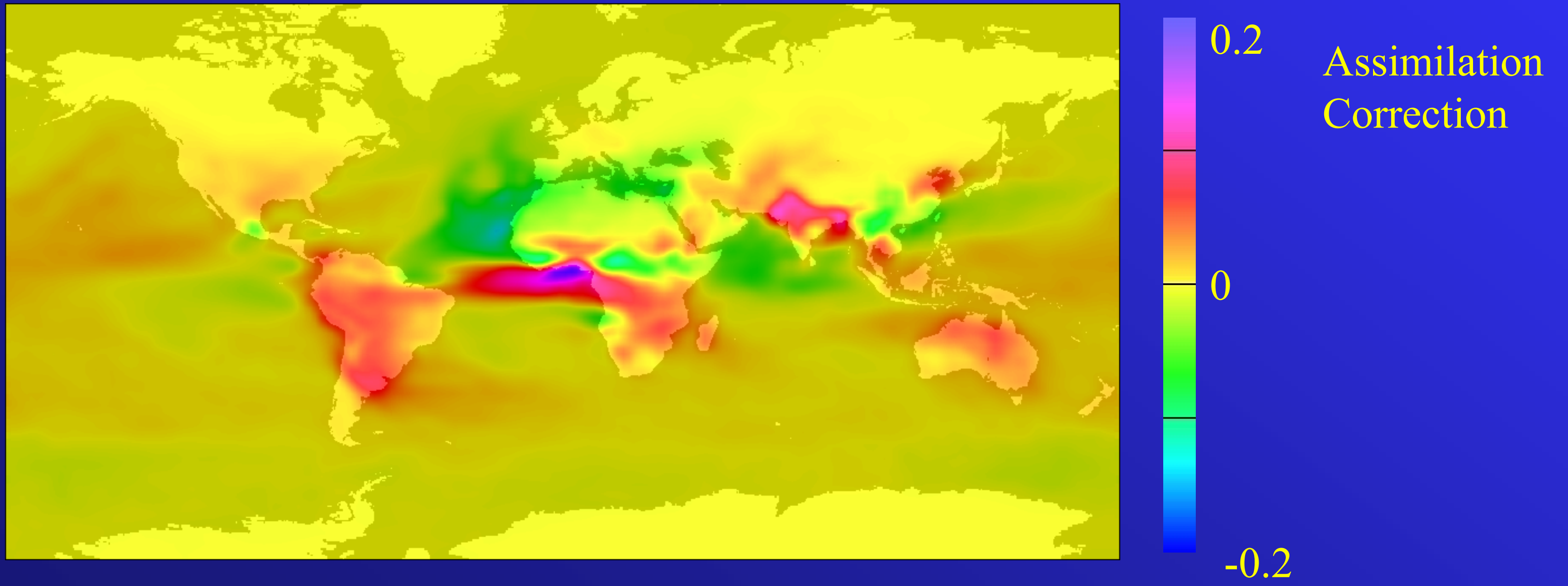
MATCH with MODIS Assimilation

-

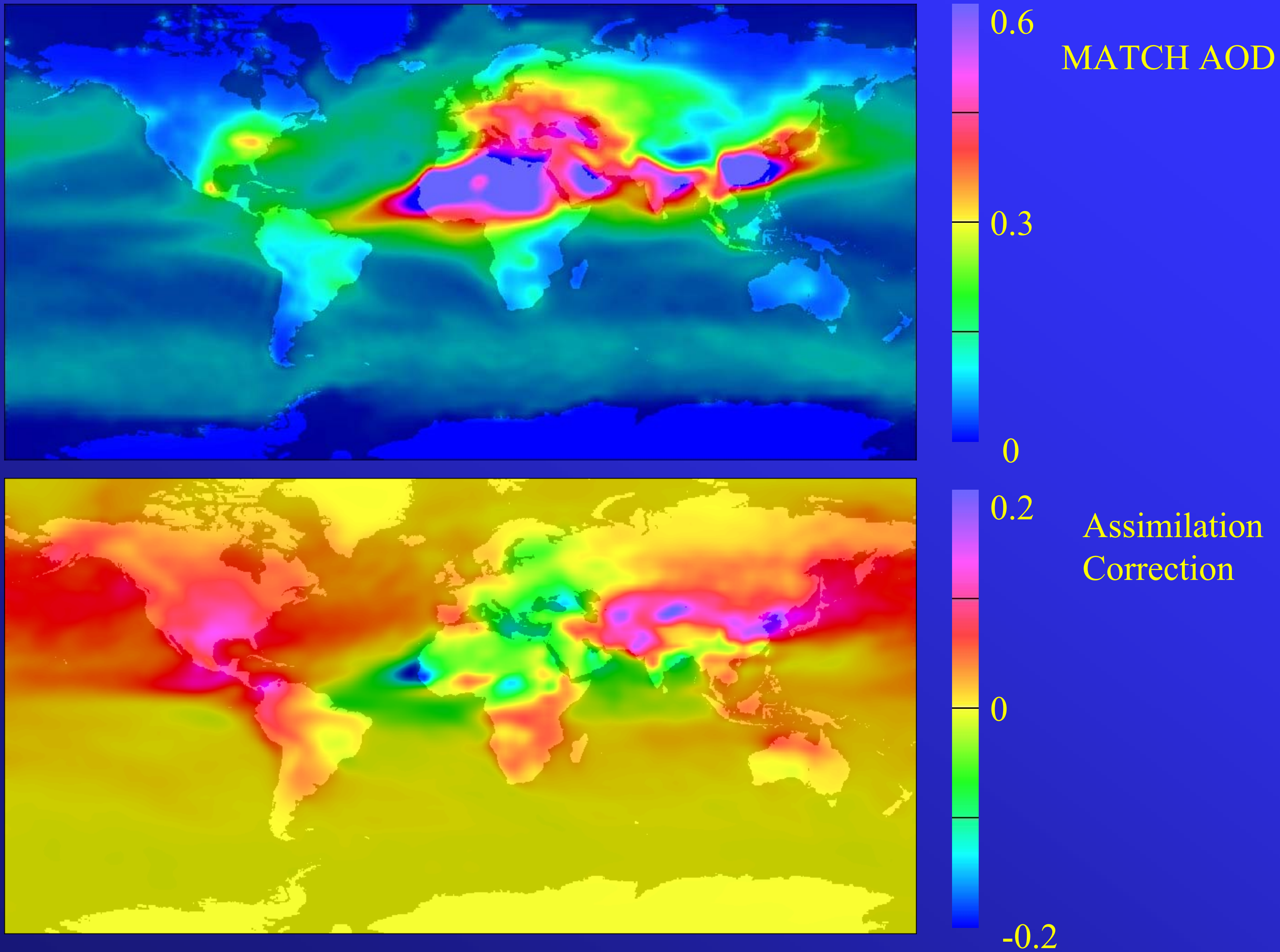
MATCH

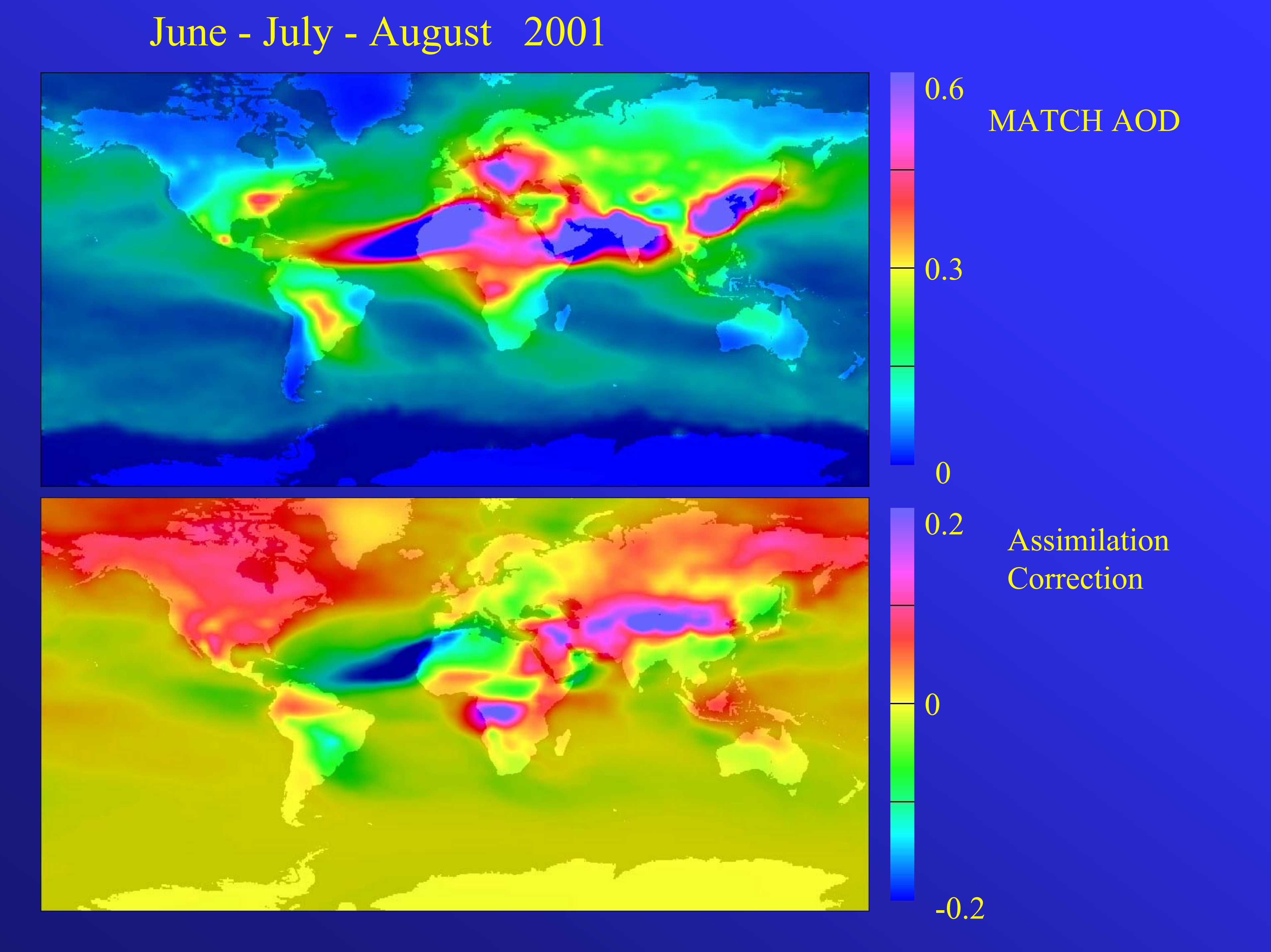
December - January - February 2001



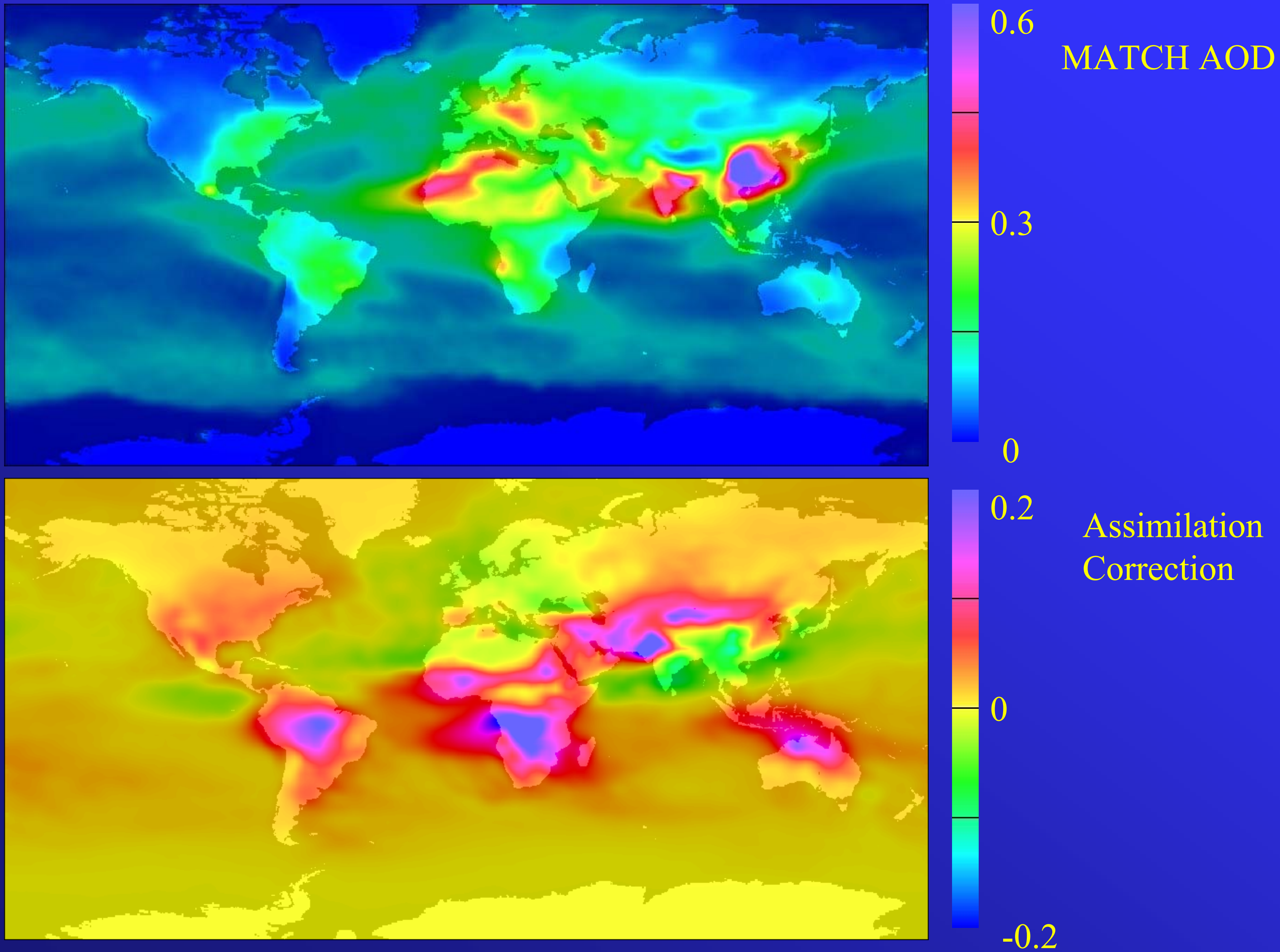


March - April - May 2001

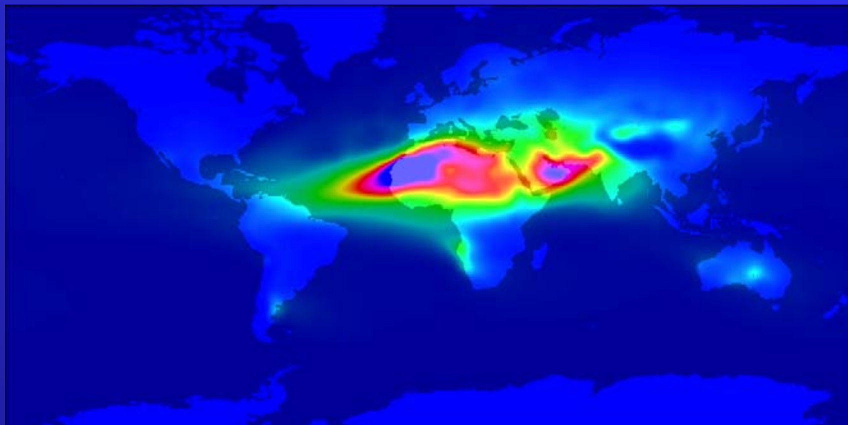



June - July - August 2001
0.6
MATCH AOD
0.3
0
0.2
Assimilation
Correction
0
-0.2

September - October - November 2001



Dust Mass Budget

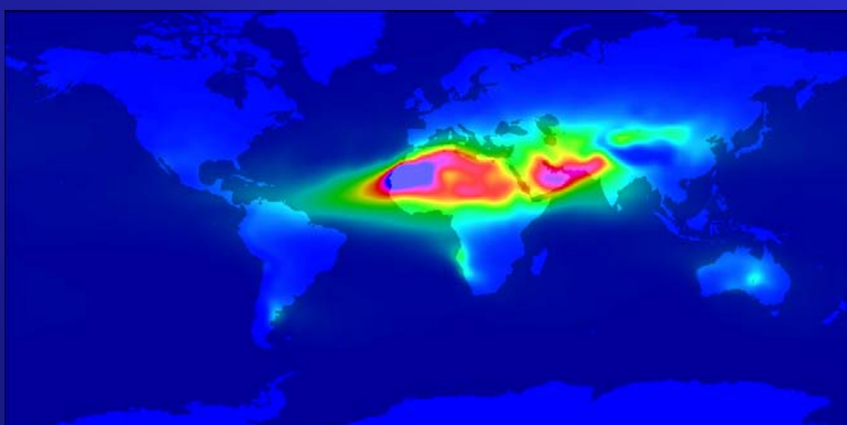


MATCH

Mass ~ 18.6 Tg
Emissions ~ 2.7 Tg day^{-1}
Dry Deposition ~ 1.2 Tg day^{-1}
Wet Deposition ~ 1.5 Tg day^{-1}

τ ~ 7.0 days

MATCH with MODIS Assimilation



Mass ~ 16.8 Tg
Emissions ~ 2.7 Tg day^{-1}
Assimilation ~ - 0.3 Tg day^{-1}
Dry Deposition ~ 1.1 Tg day^{-1}
Wet Deposition ~ 1.3 Tg day^{-1}

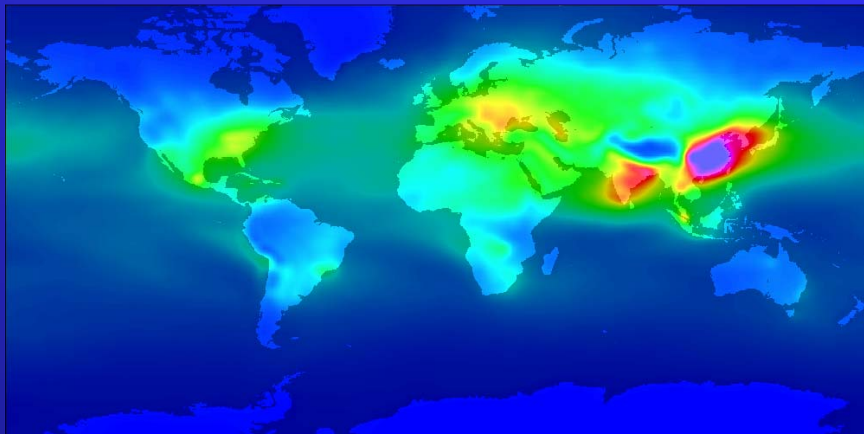
τ ~ 7.0 days

Dust Mass

0 0.5

g m^{-2}

Sulfate Mass Budget

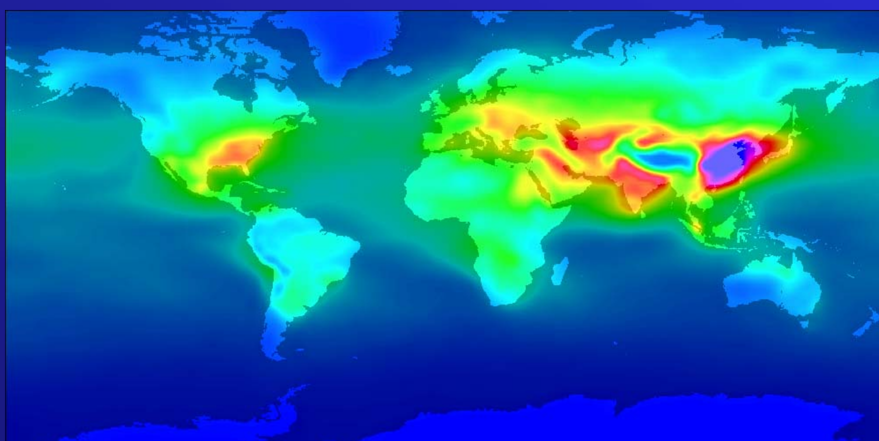


MATCH

Mass ~ 0.6 Tg(S)
Emissions ~ 0.005 Tg(S) day^{-1}
Gas Phase ~ 0.02 Tg(S)
Aqueous Phase ~ 0.125 Tg(S)
Dry Deposition ~ 0.02 Tg(S) day^{-1}
Wet Deposition ~ 0.13 Tg(S) day^{-1}

$\tau \sim 3.9$ days

MATCH with MODIS Assimilation



Mass ~ 0.73 Tg(S)
Emissions ~ 0.005 Tg(S) day^{-1}
Gas Phase ~ 0.02 Tg(S)
Aqueous Phase ~ 0.125 Tg(S)
Assimilation ~ 0.02 Tg day^{-1}
Dry Deposition ~ 0.025 Tg(S) day^{-1}
Wet Deposition ~ 0.145 Tg(S) day^{-1}

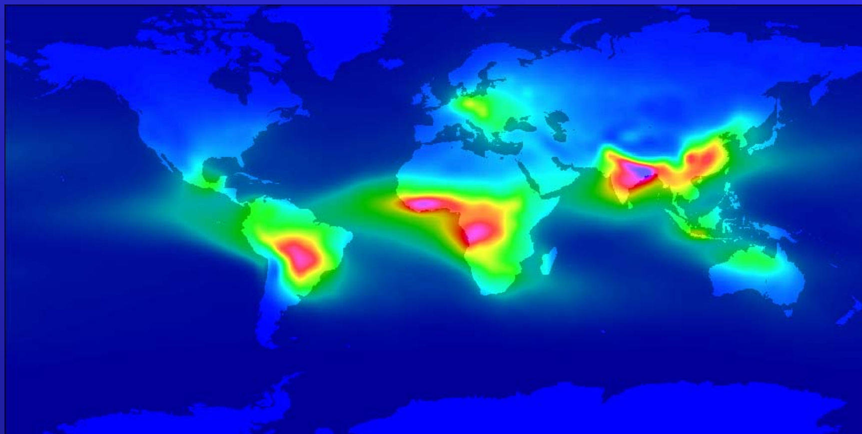
$\tau \sim 4.3$ days

Sulfate Mass

0 0.008

g (S) m^{-2}

Organic Carbon Mass Budget



MATCH

Mass ~ 1.7 Tg

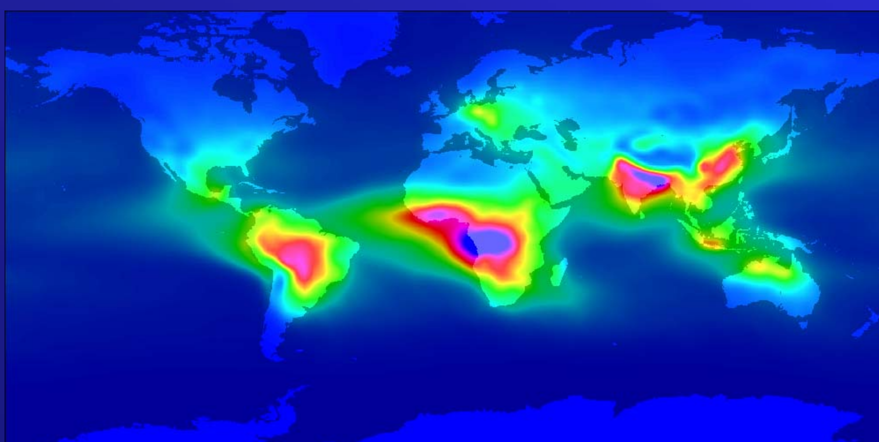
Emissions ~ 0.24 Tg day^{-1}

Dry Deposition ~ 0.06 Tg day^{-1}

Wet Deposition ~ 0.18 Tg day^{-1}

τ ~ 7.2 days

MATCH with MODIS Assimilation



Mass ~ 2.2 Tg

Emissions ~ 0.24 Tg day^{-1}

Assimilation ~ 0.04 Tg day^{-1}

Dry Deposition ~ 0.06 Tg day^{-1}

Wet Deposition ~ 0.22 Tg day^{-1}

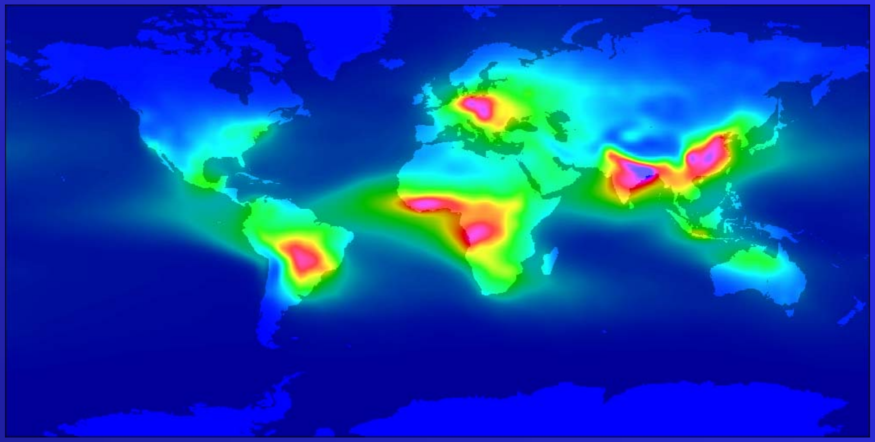
τ ~ 7.6 days

Organic Carbon Mass

0 0.03

g m^{-2}

Black Carbon Mass Budget

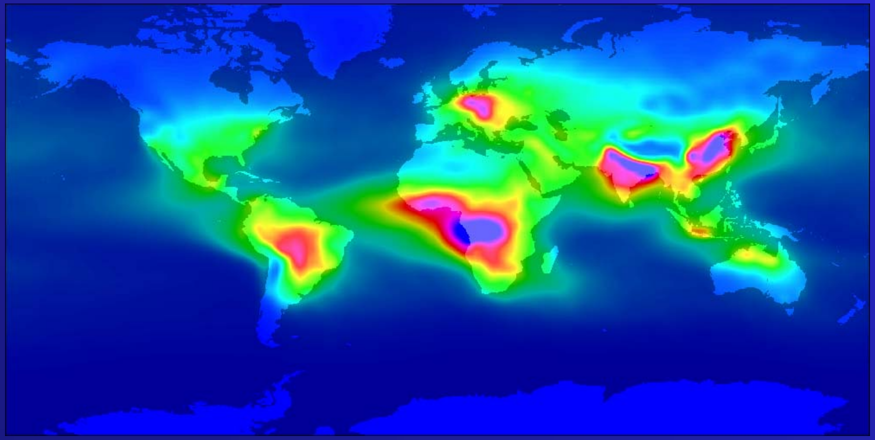


MATCH

Mass ~ 0.19 Tg
Emissions ~ 0.03 Tg day^{-1}
Dry Deposition ~ 0.01 Tg day^{-1}
Wet Deposition ~ 0.02 Tg day^{-1}

τ ~ 6.6 days

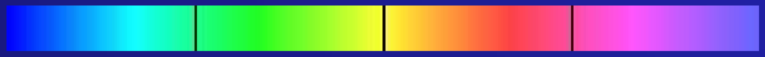
MATCH with MODIS Assimilation



Mass ~ 0.25 Tg
Emissions ~ 0.03 Tg day^{-1}
Assimilation ~ 0.005 Tg day^{-1}
Dry Deposition ~ 0.01 Tg day^{-1}
Wet Deposition ~ 0.025 Tg day^{-1}

τ ~ 7.1 days

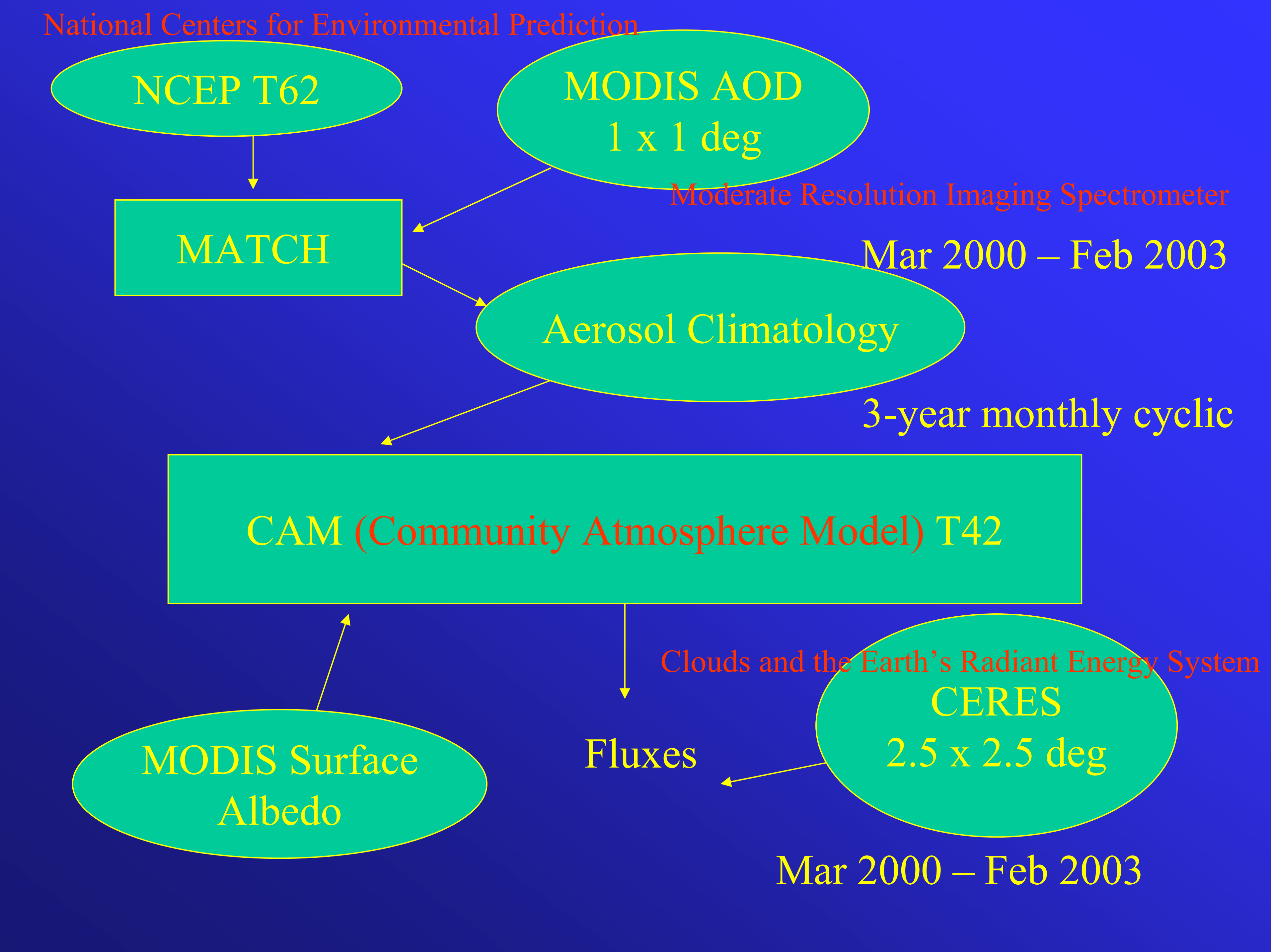
Black Carbon Mass



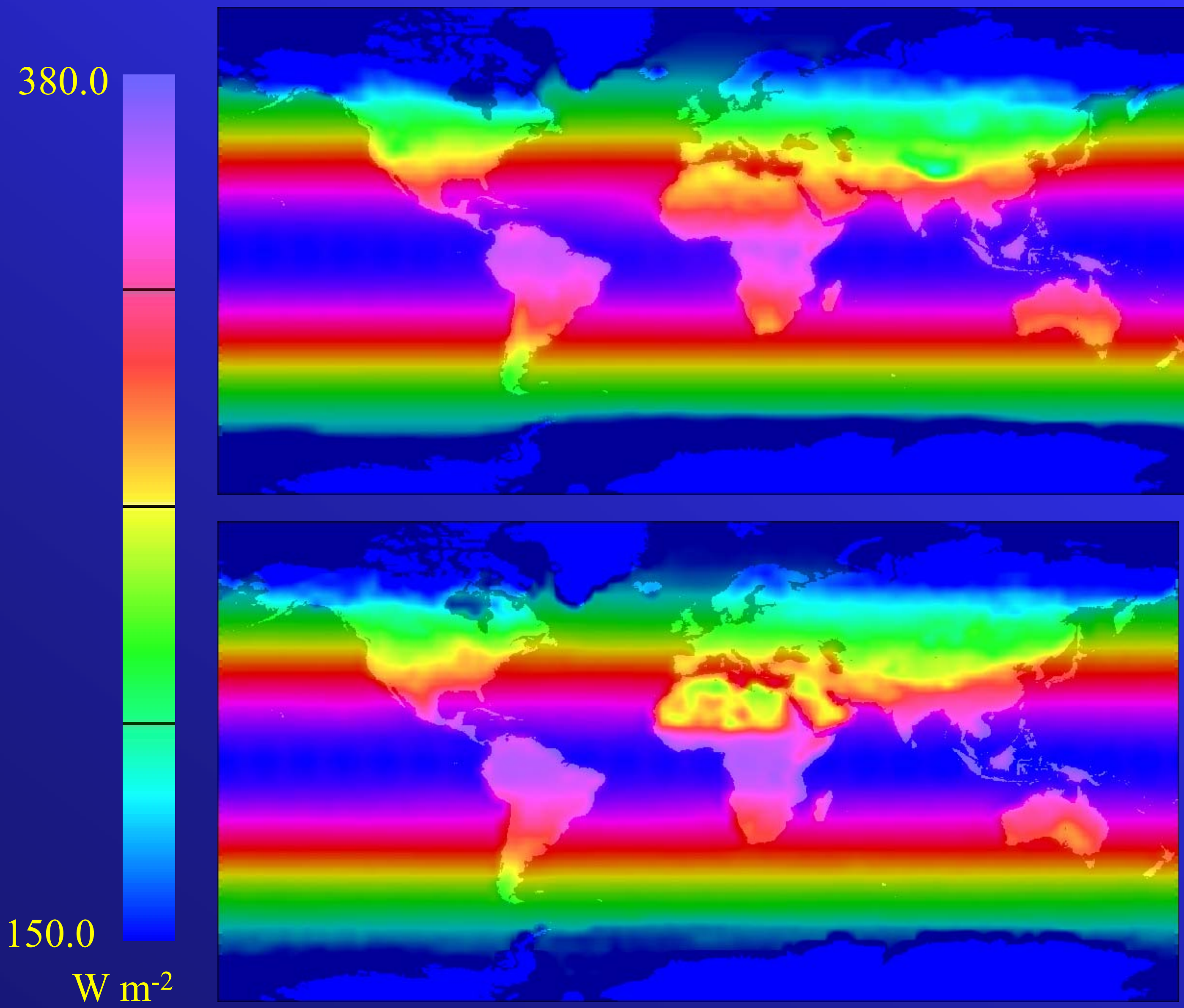
0 — 0.003

g m^{-2}

Aerosol Radiative Forcing


National Centers for Environmental Prediction
NCEP T62
MODIS AOD
1 x 1 deg
Moderate Resolution Imaging Spectrometer
MATCH
Mar 2000 – Feb 2003
Aerosol Climatology
3-year monthly cyclic
CAM (Community Atmosphere Model) T42
Clouds and the Earth's Radiant Energy System
CERES
2.5 x 2.5 deg
Fluxes
MODIS Surface
Albedo
Mar 2000 – Feb 2003

Top-of-Atmosphere Net Shortwave Flux (Clear-Sky)



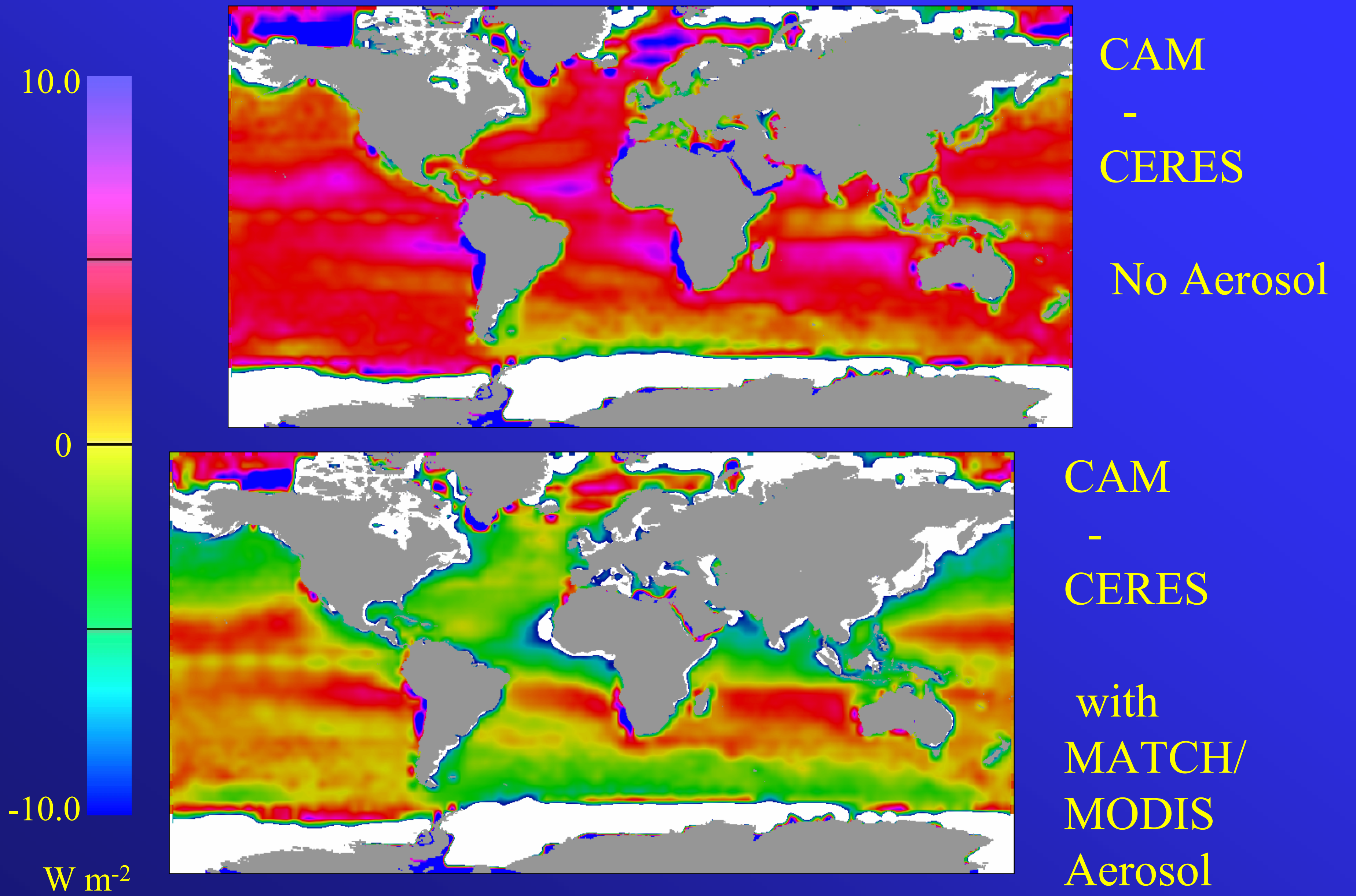
CAM

CERES*
Satellite

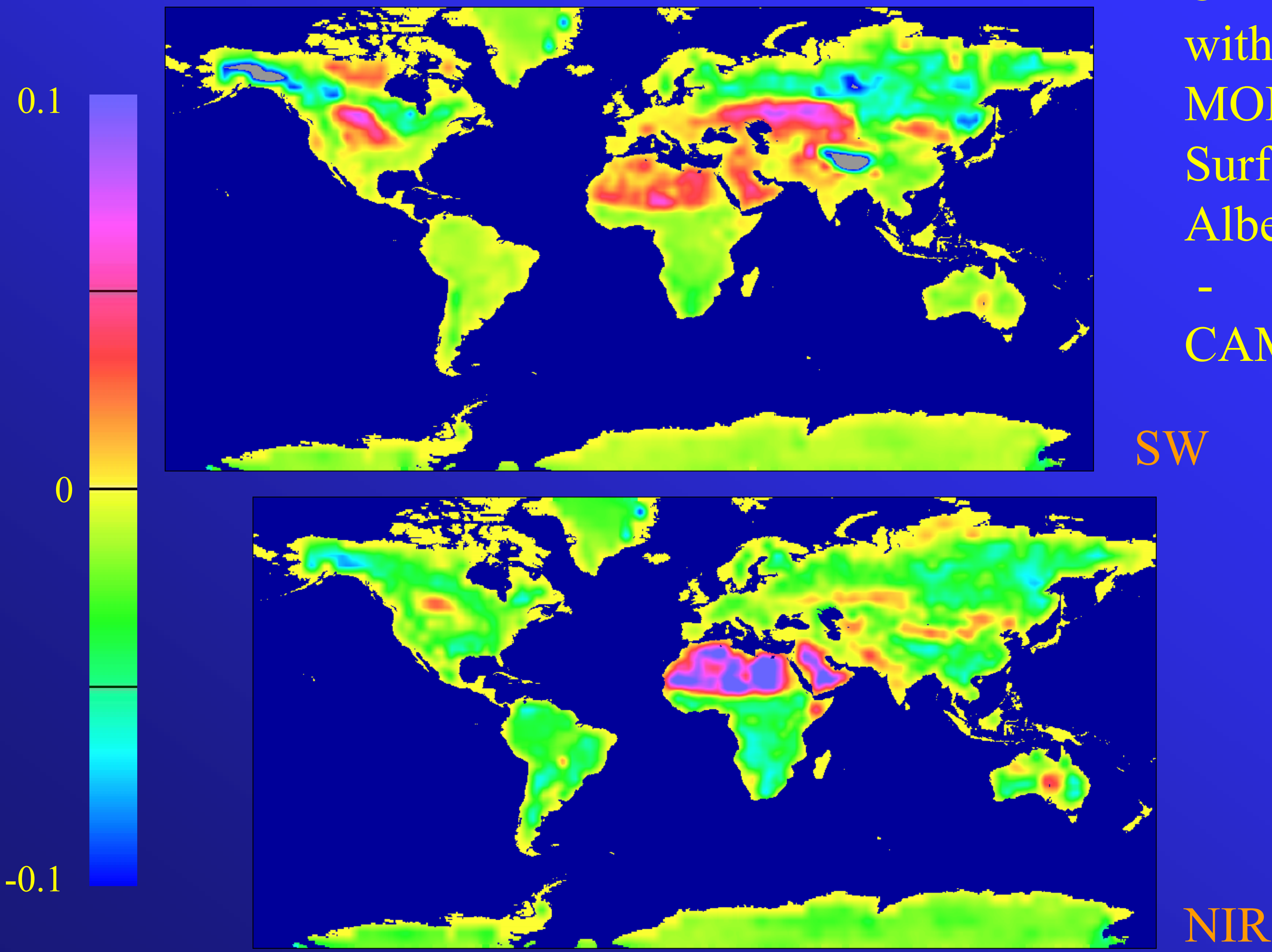
*ERBE-Like
Algorithm

(Earth Radiation
Budget Experiment)

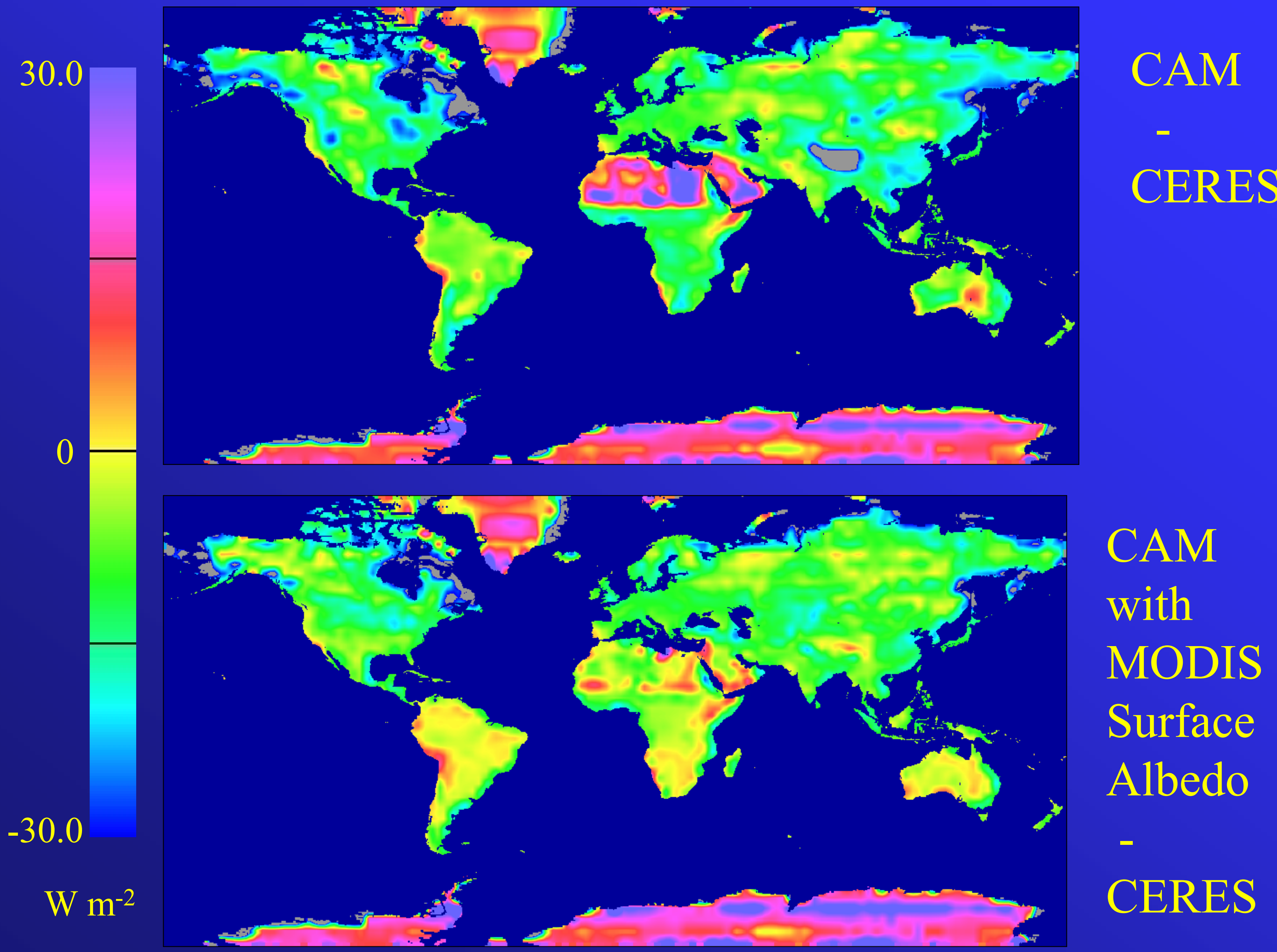
TOA Net SW Flux Bias over Oceans



Diffuse Land Surface Albedo Differences

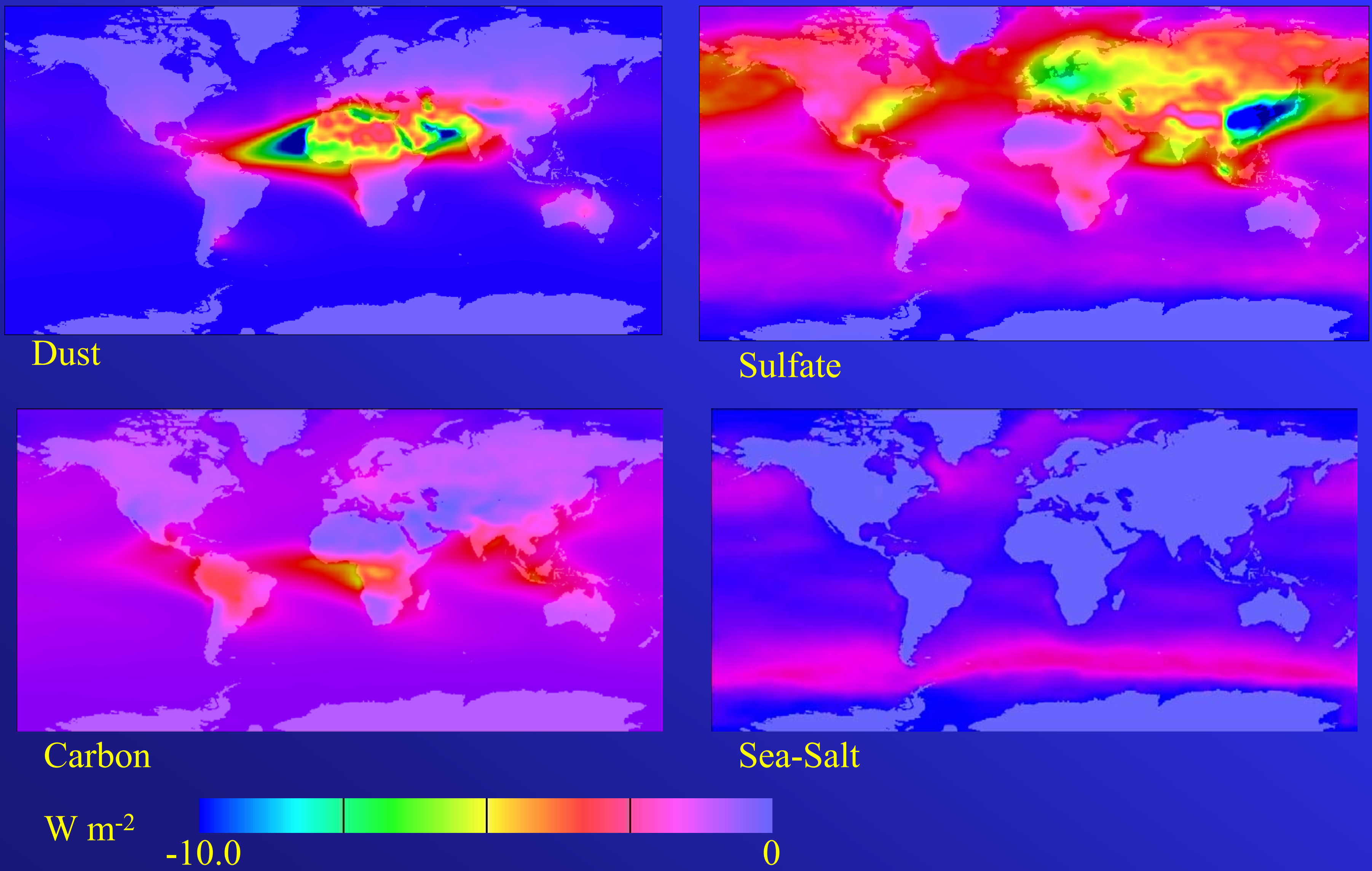


TOA Net SW Flux Bias over Land

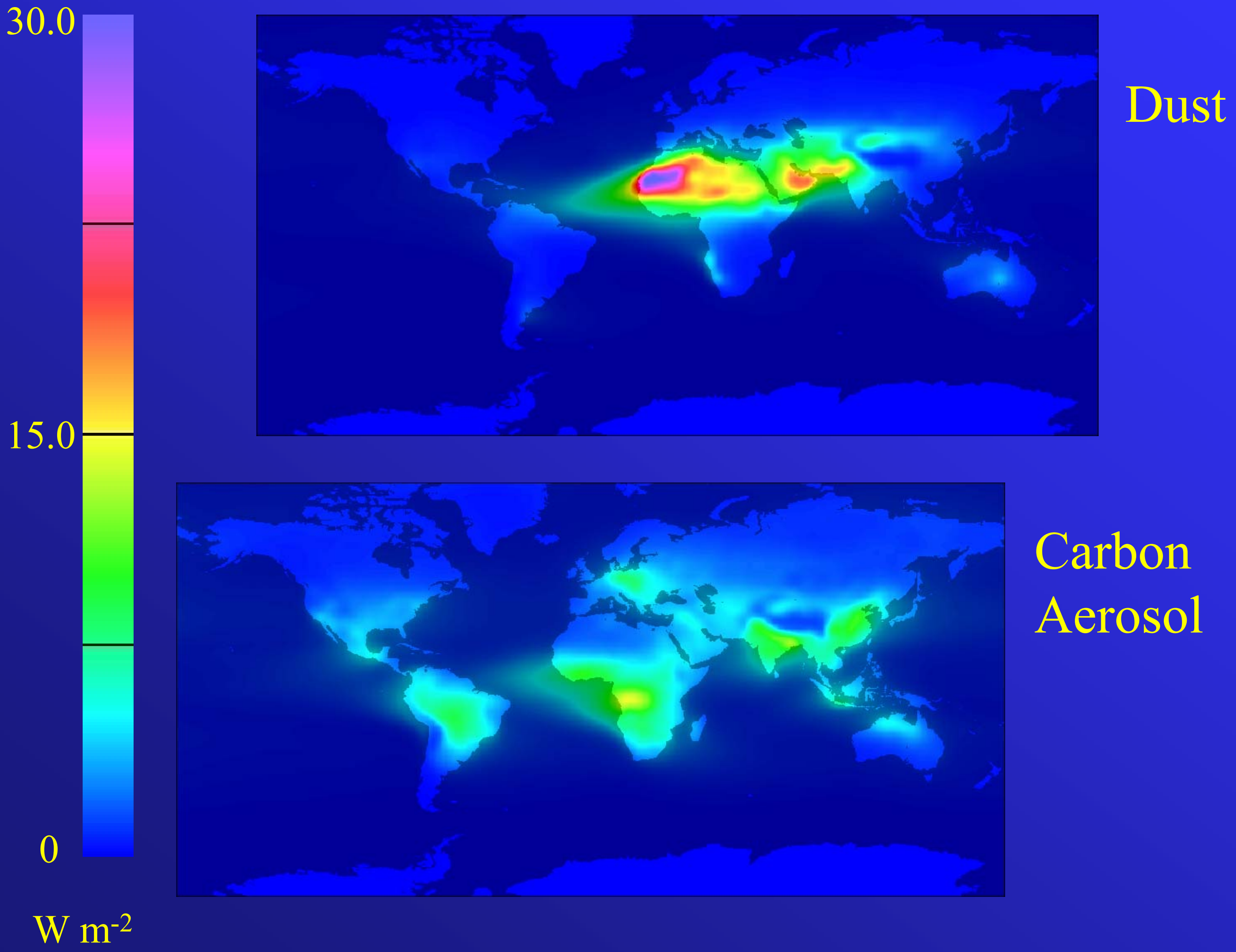


Aerosol TOA SW Radiative Forcing (Clear-Sky)

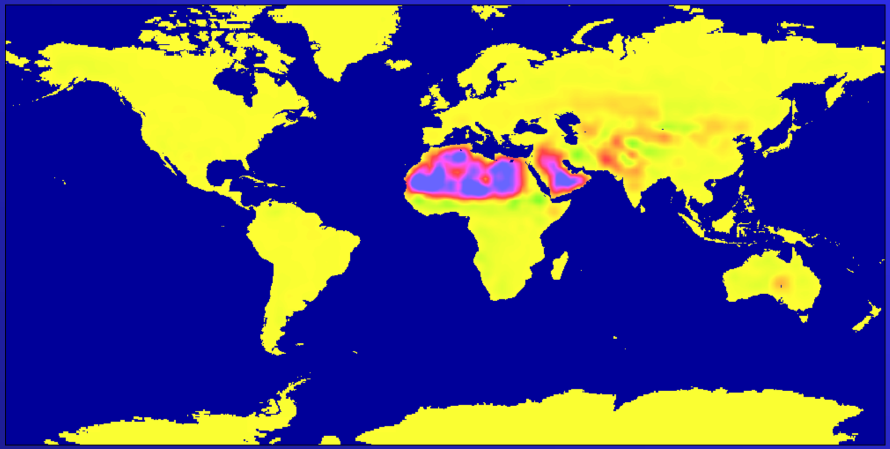
from CAM with MATCH/MODIS Aerosol Climatology



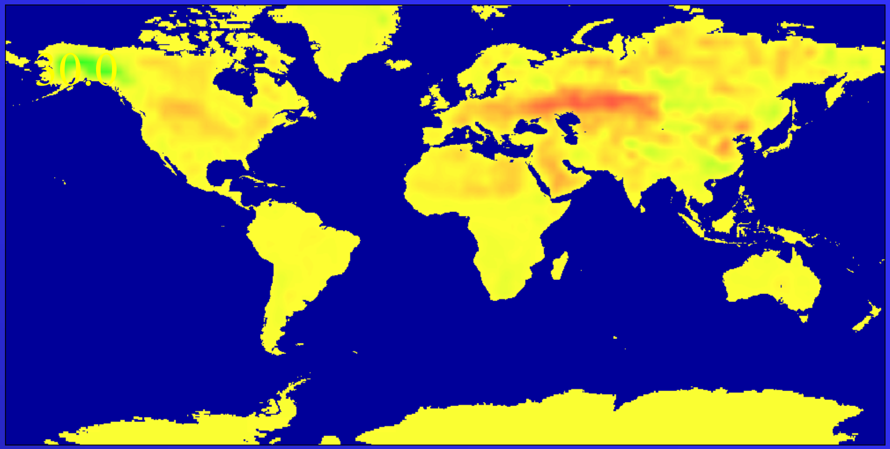
Aerosol Atmospheric Absorption



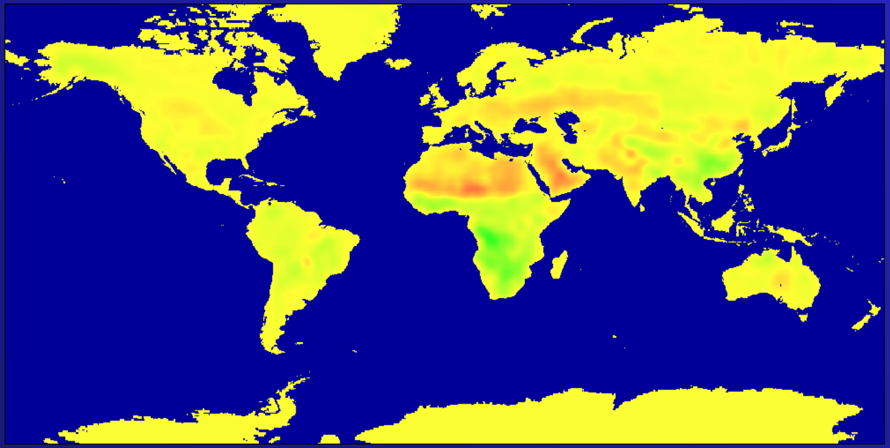
Change in Forcing CAM Surface Albedo ⇨ MODIS/CAM Surface Albedo



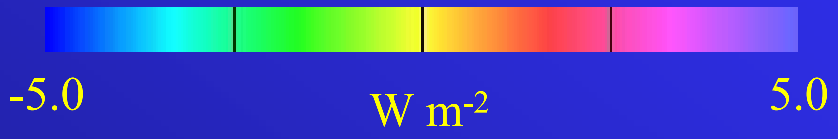
Dust



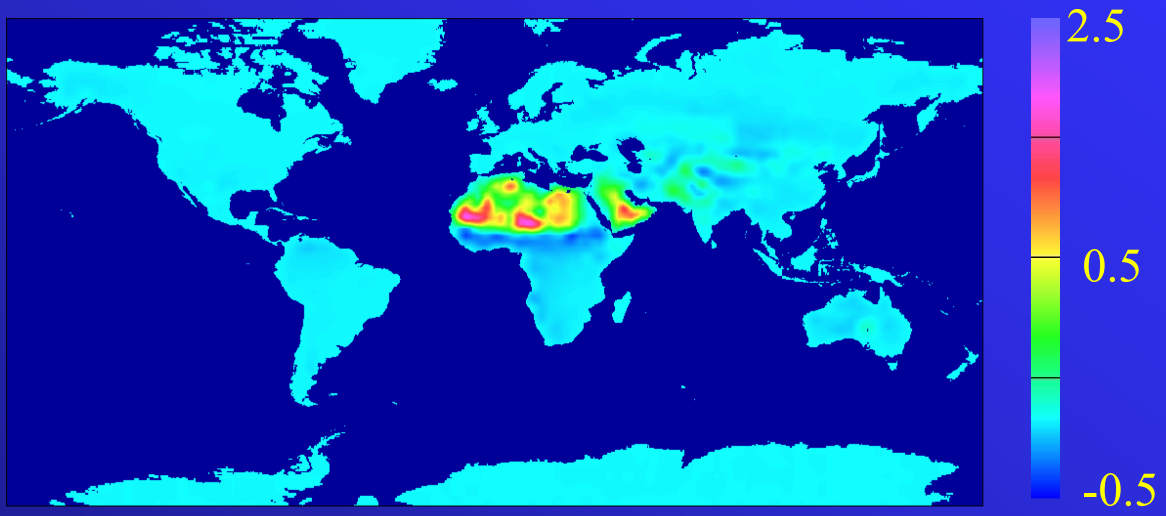
Sulfate



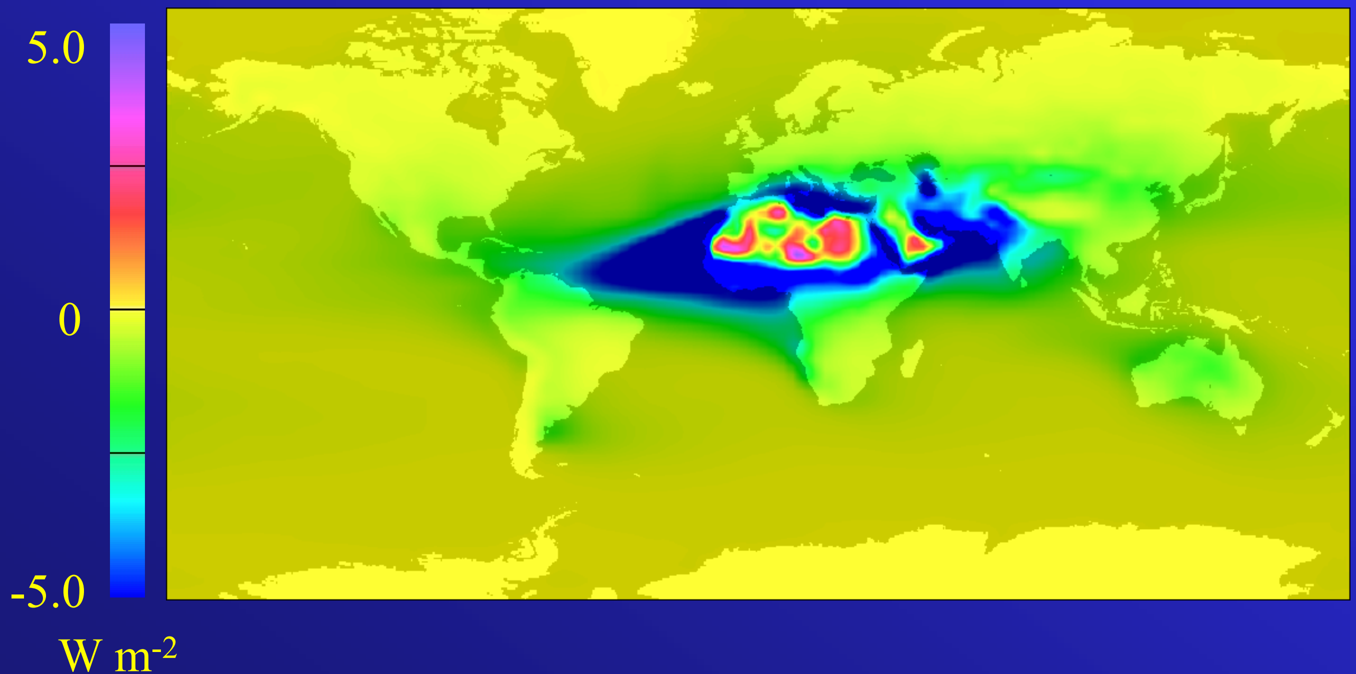
Carbon



Dust TOA Forcing > 0 over Sahara?



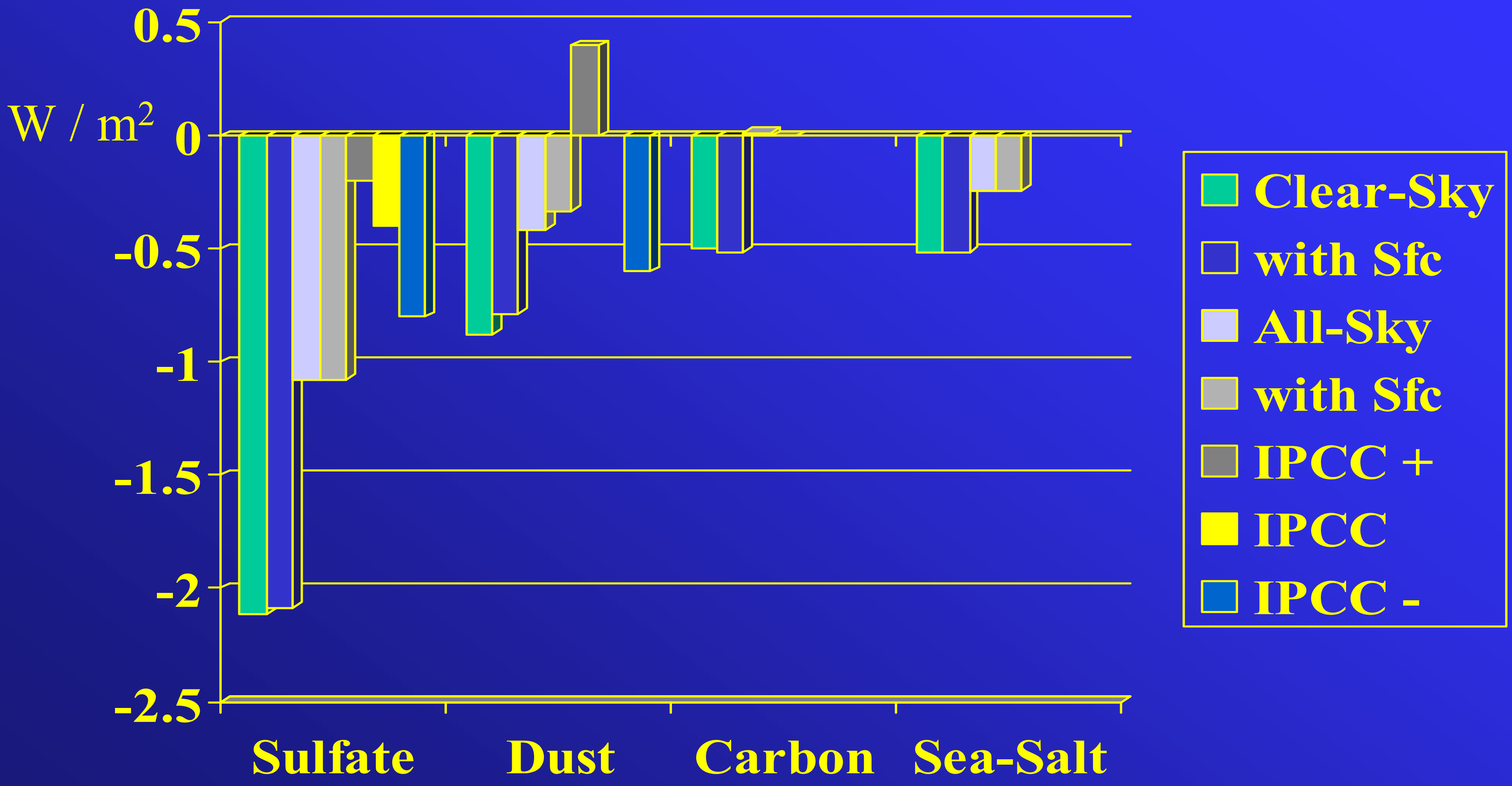
Change in Dust Absorption



Dust TOA Forcing

with MODIS Surface Albedo

Global Mean TOA Aerosol Forcing



Conclusions/Future Work

- The MATCH/MODIS Aerosol Dataset provides estimates of aerosol mass and radiative forcing directly constrained by satellite observations.

- Validation of this Dataset will occur in the next few weeks through the AEROCOM (Aerosol Inter-Comparison) project.

- The CERES (ERBE-Like Algorithm) for satellite measured fluxes does not detect regional aerosol signatures over oceans.

- However, this Dataset will be an integral part of the NASA CERES-SARB (Clouds and the Earth's Radiant Energy System – Surface Atmosphere Radiation Budget) project, which will estimate top and in-atmosphere fluxes constrained by the CERES measurements using improved CERES/MODIS cloud and scene algorithms.

- MISR (Multi-Angle Imaging Spectro-Radiometer) flux and radiance assimilation.

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P. Rasch & N. Mahowald,
A. Conley & D. Bundy

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