Estimation of aerosol direct radiative effects using TM5 and DAK

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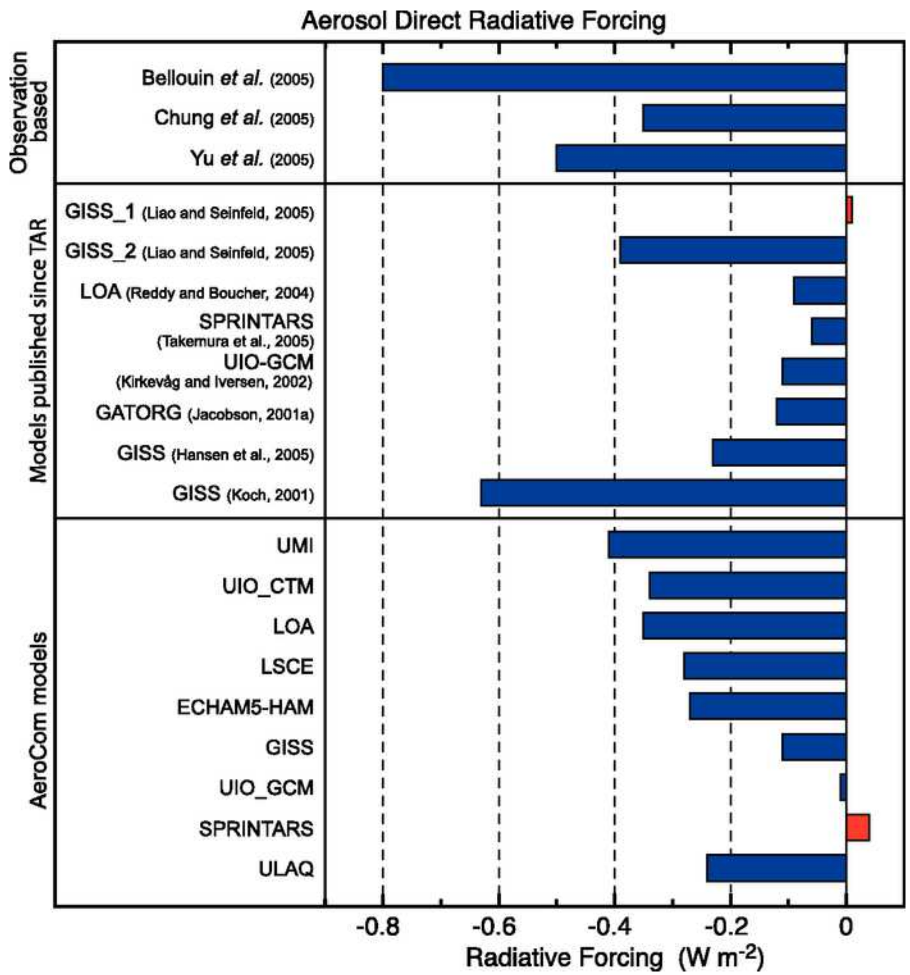
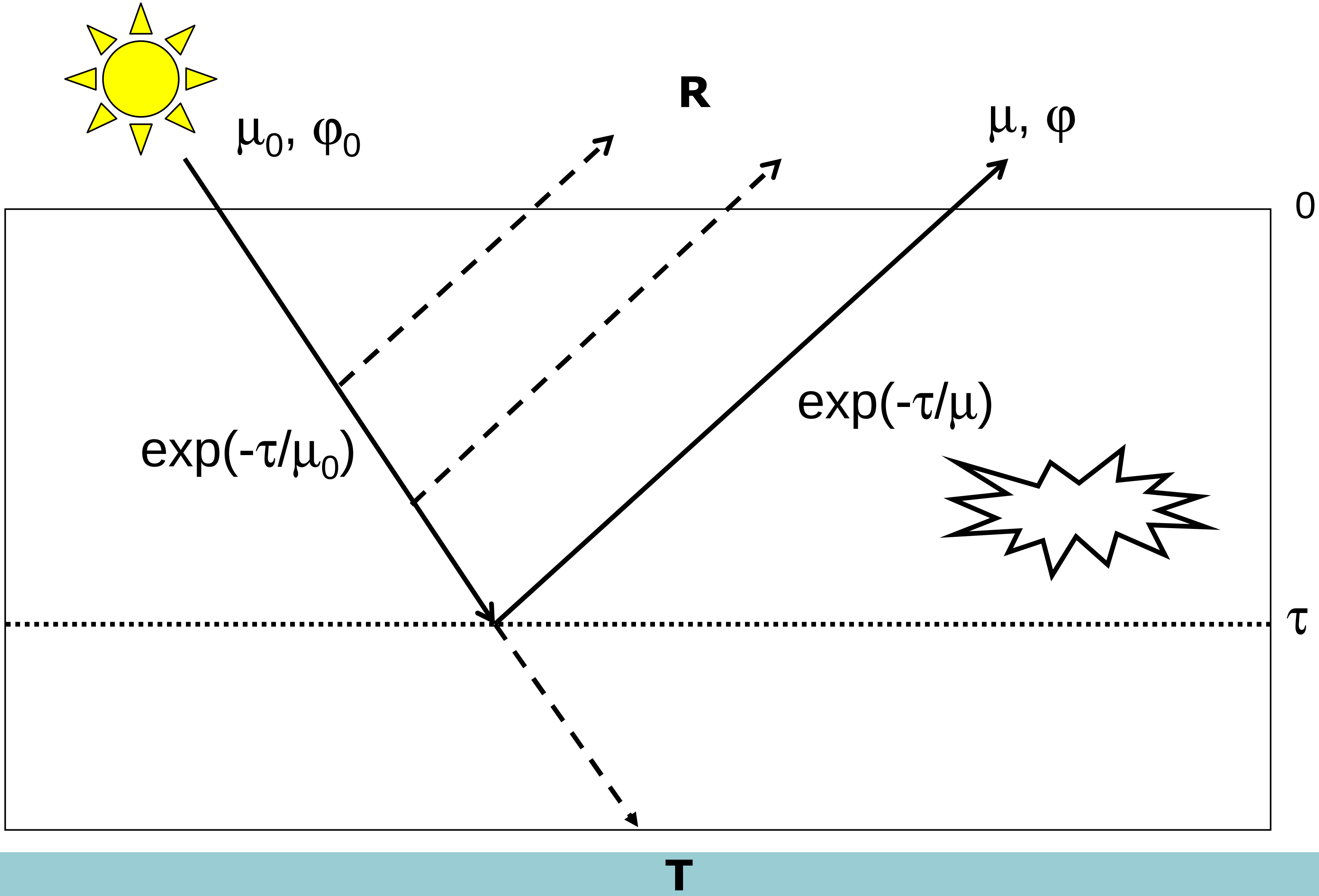
KNMI



Aerosol Direct Radiative Forcing
Observation based
Bellouin et al. (2005)
Chung et al. (2005)
Yu et al. (2005)
Models published since TAR
GISS_1 (Liao and Seinfeld, 2005)
GISS_2 (Liao and Seinfeld, 2005)
LOA (Reddy and Boucher, 2004)
SPRINTARS (Takemura et al., 2005)
UIO-GCM (Kirkevåg and Iversen, 2002)
GATORG (Jacobson, 2001a)
GISS (Hansen et al., 2005)
GISS (Koch, 2001)
AeroCom models
UMI
UIO_CTM
LOA
LSCE
ECHAM5-HAM
GISS
UIO_GCM
SPRINTARS
ULAQ
-0.8
-0.6
-0.4
-0.2
0
Radiative Forcing (W m-2)

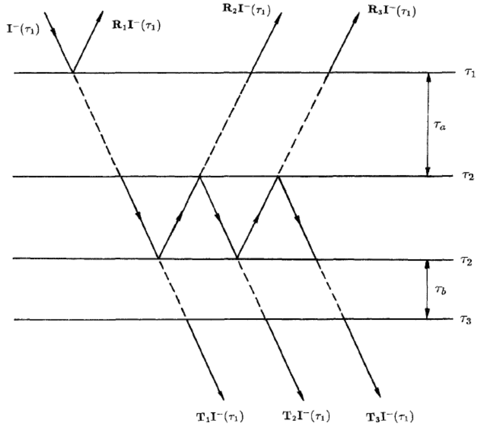
IPCC (2007)

Scattering in the atmosphere



Principle of Doubling-Adding

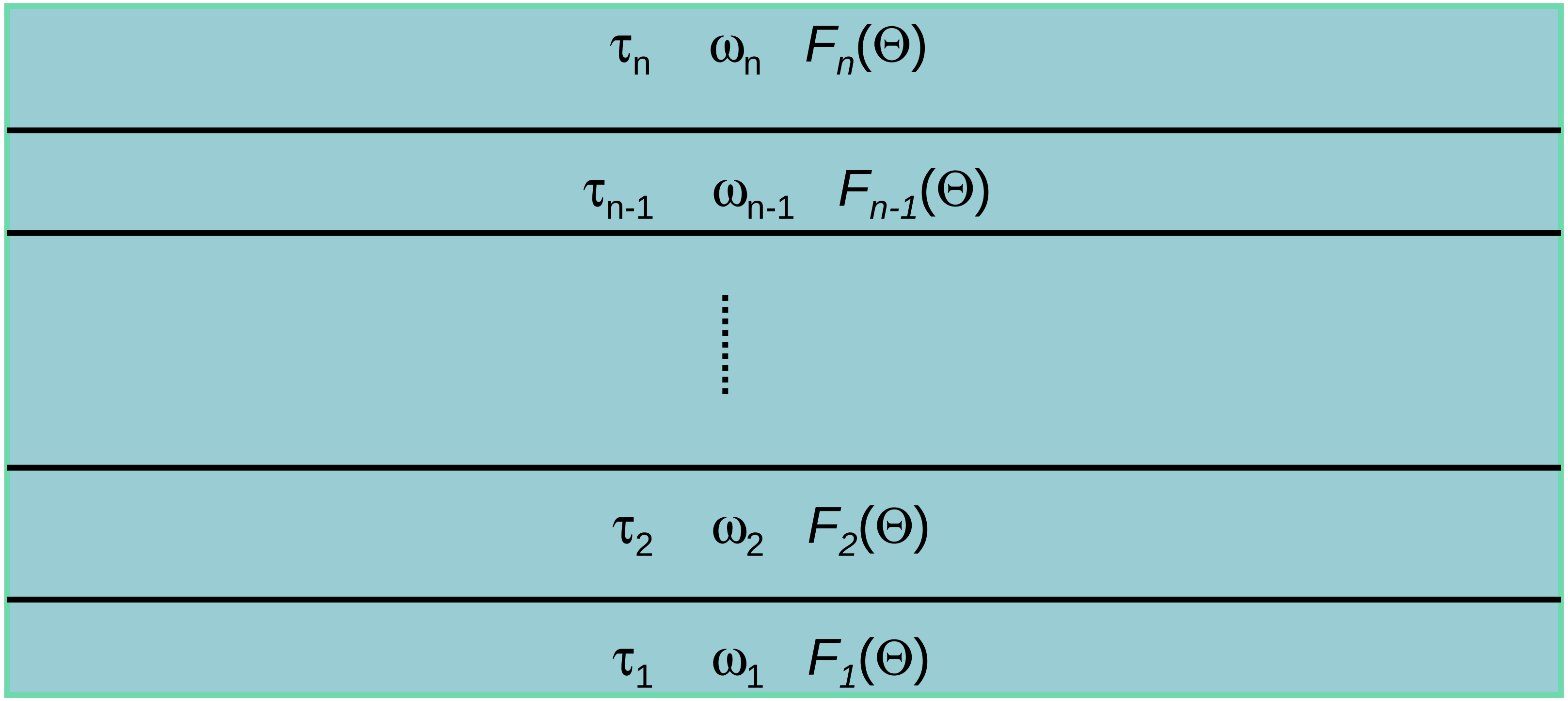
- Start with an *optically very thin layer* where only single or double scattering occurs. Calculate analytically the reflection and transmission of this layer.
- *Double this layer* repeatedly, by calculating the repeated reflections at the interface of the two layers (geometric series) and the reflection and transmission of the combined layer



- *Continue* until the (homogeneous) layer has reached the required optical thickness.
- For an inhomogeneous, stratified atmosphere: *add homogeneous layers* on top of each other, and calculate the reflection and transmission of the combined layers.

Multilayer atmosphere

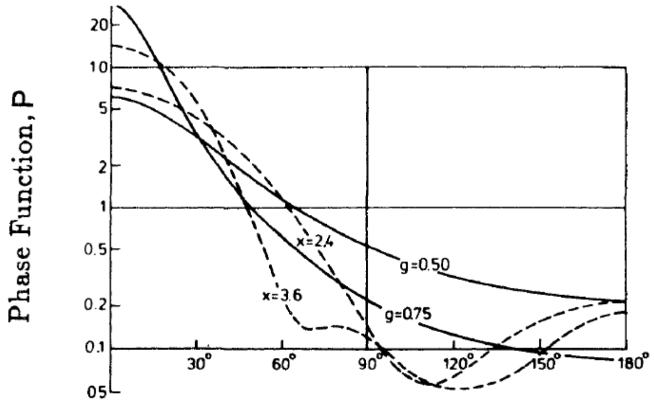
Homogeneous layers characterized by:
- Optical thickness
- Single scatter albedo
- Phase function



Surface albedo

Doubling-Adding KNMI (DAK)

- Very accurate shortwave radiation model
- Broadband version uses 32 wavelength bands (here 29)
- Atmosphere is multilayered (here 32 layers)
- UV-vis trace gases are included: O_3, SO_2, NO_2, …
- Recent additions: O_2, CO_2 for near-IR
- Clouds and aerosols can be included in each layer
- Surface albedo from GOME (spectral) and MERIS (ice/snow)
- Here using 2 x 8 Gaussian points for the angular distribution (cf. 2 x 1 and 2 x 2 in two- resp. four-stream models)
- Phase function approximated by Henyey-Greenstein function determined by 1st moment (=asymmetry factor)



Aerosol simulations:

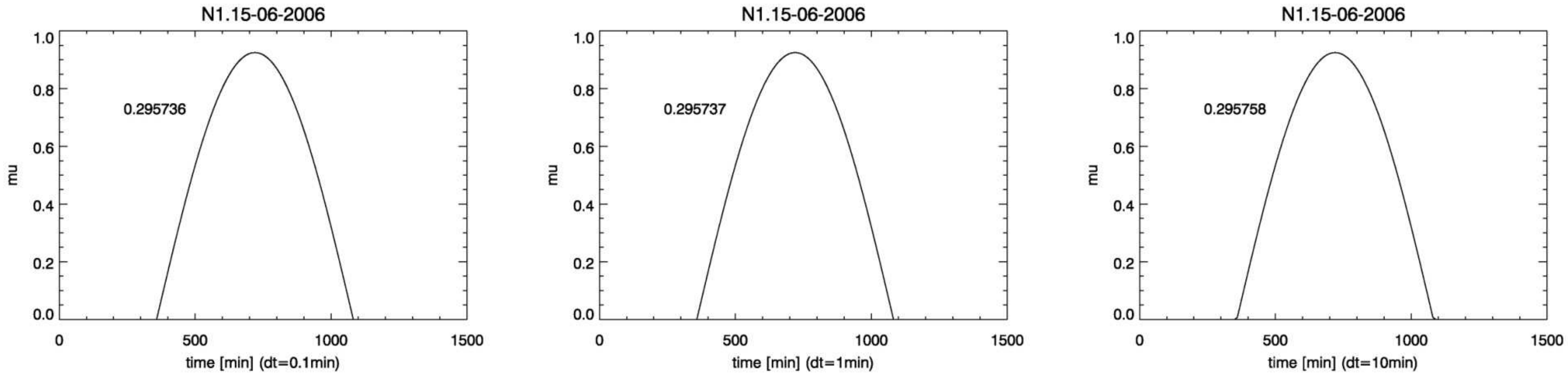
- AeroCom phase-II version using M7
- Driven by ERA-Interim meteorology
- Anthropogenic emissions for 2006 resp. 1850 (Lamarque et al., 2010)

TM5 data used in DAK:

- Monthly mean local-noon output:
  - Aerosol optical properties at the DAK wavelengths:
    - AOD
    - Single scattering albedo
    - Asymmetry factor
  - Auxilliary fields:
    - H_2O, O_3
    - Pressure
    - Air temperature
    - Orography

Numerical integration

- DAK delivers fluxes at 10 solar zenith angles
- Conversion to daily integrated values for each month and each location (post-processing in IDL)
- Monthly mean values are approximated by calculations for the 15th of each month
- Tested integration with a time steps of 0.1, 1, and 10 min.



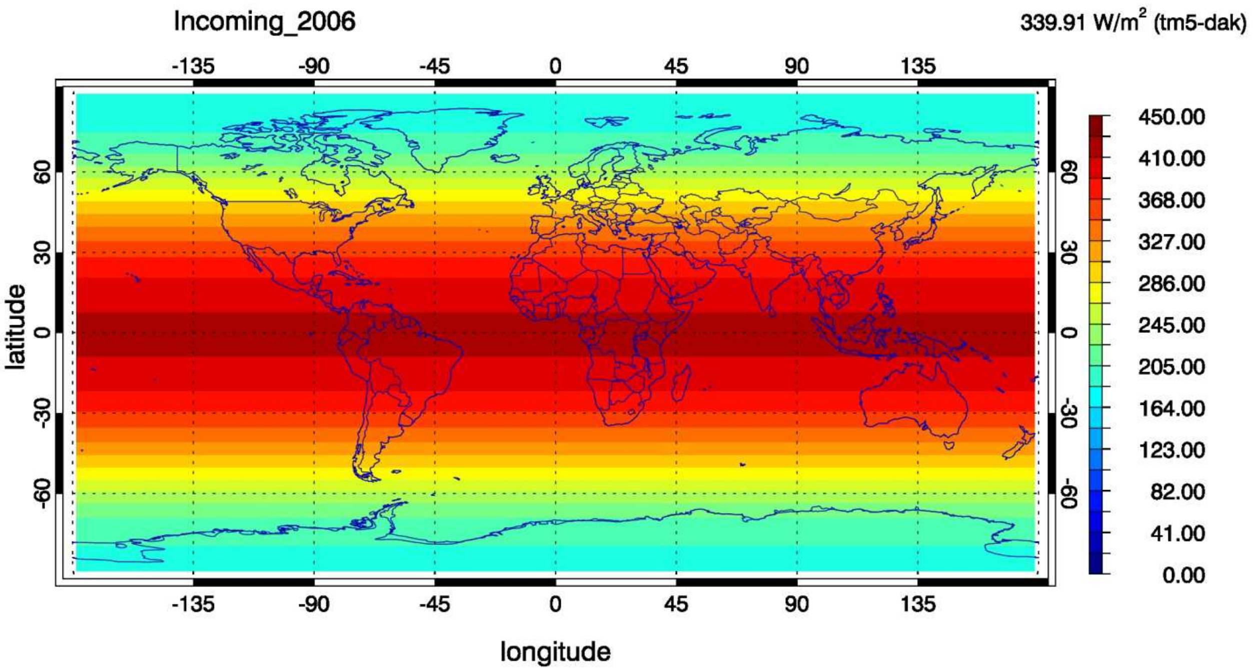
- Analytical expression for the daily integrated $\mu = \cos(\theta_o)$

$$\bar{\mu} = \frac{1}{\Delta t_{day} \pi} \left(H \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin H \right)$$

(where φ is latitude, δ declination angle, and H hour angle) gives a value of 0.295736.

→ Time step set to 1 min.

Incoming solar flux

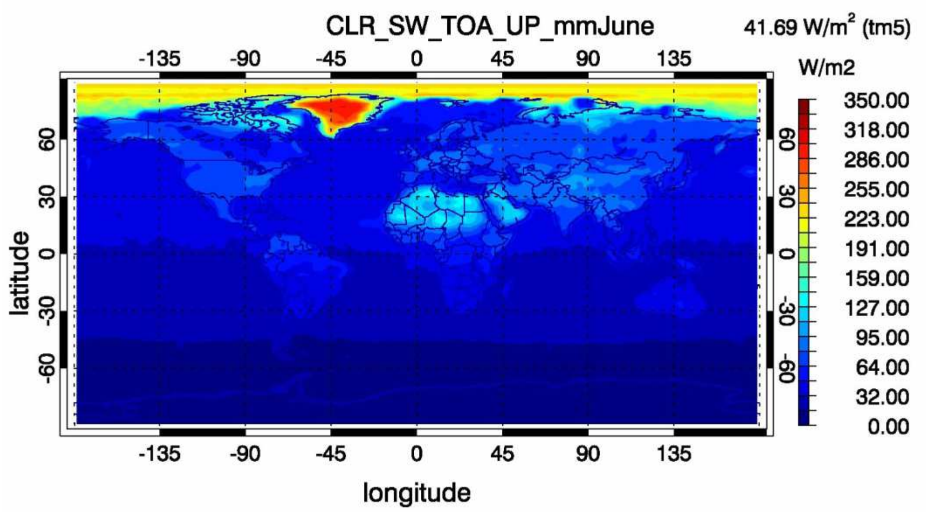


Total insolation = S/4 = 340.2 W/m^2

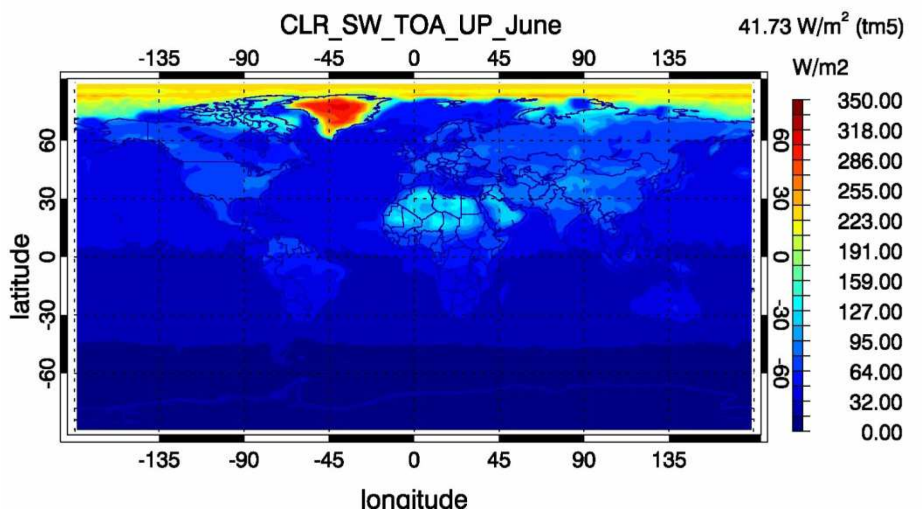
Solar constant S = 1360.8 W/m^2 (Kopp and Lean, 2011)

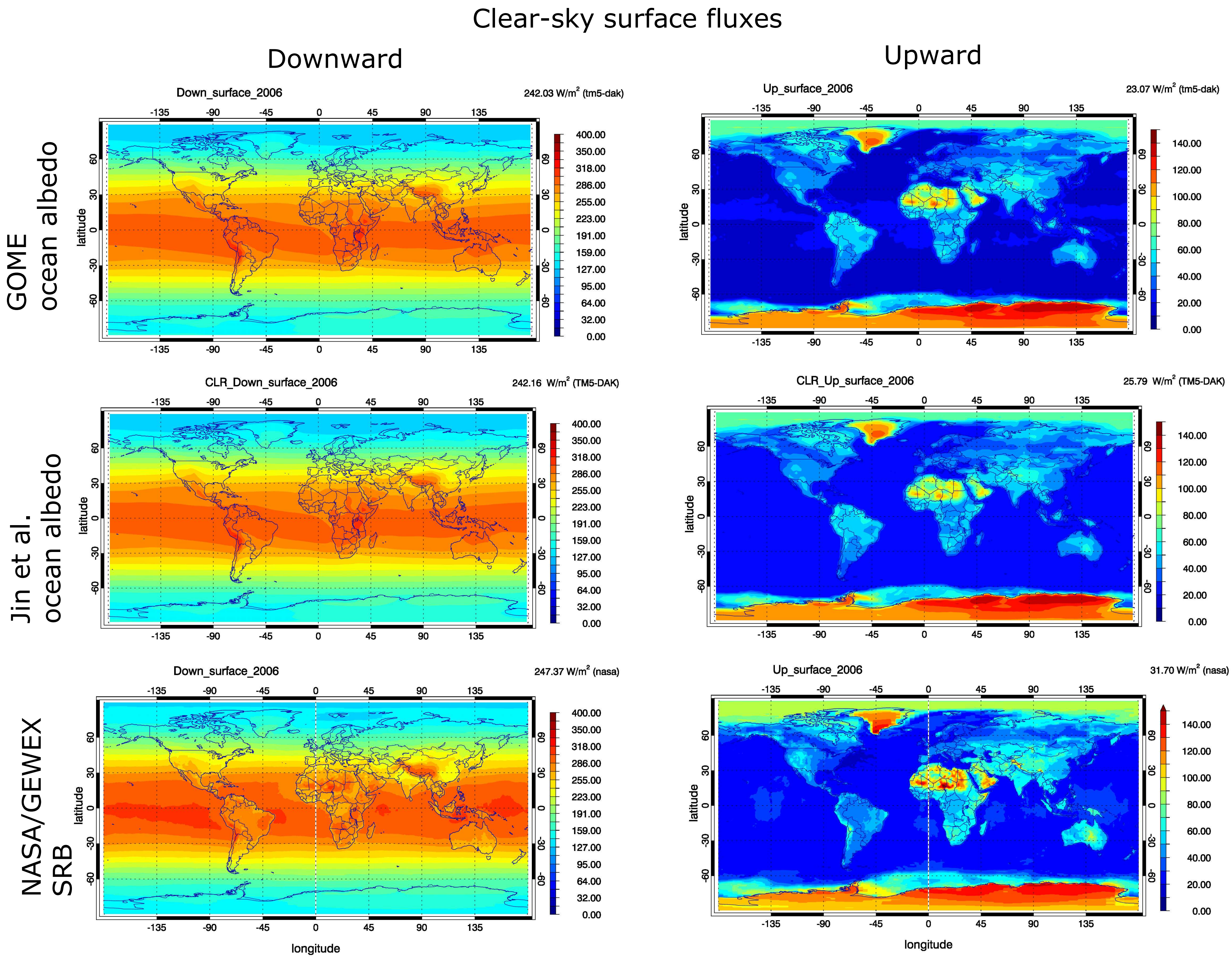
Calculation of monthly fluxes

Real monthly mean
(average over all days in the month)

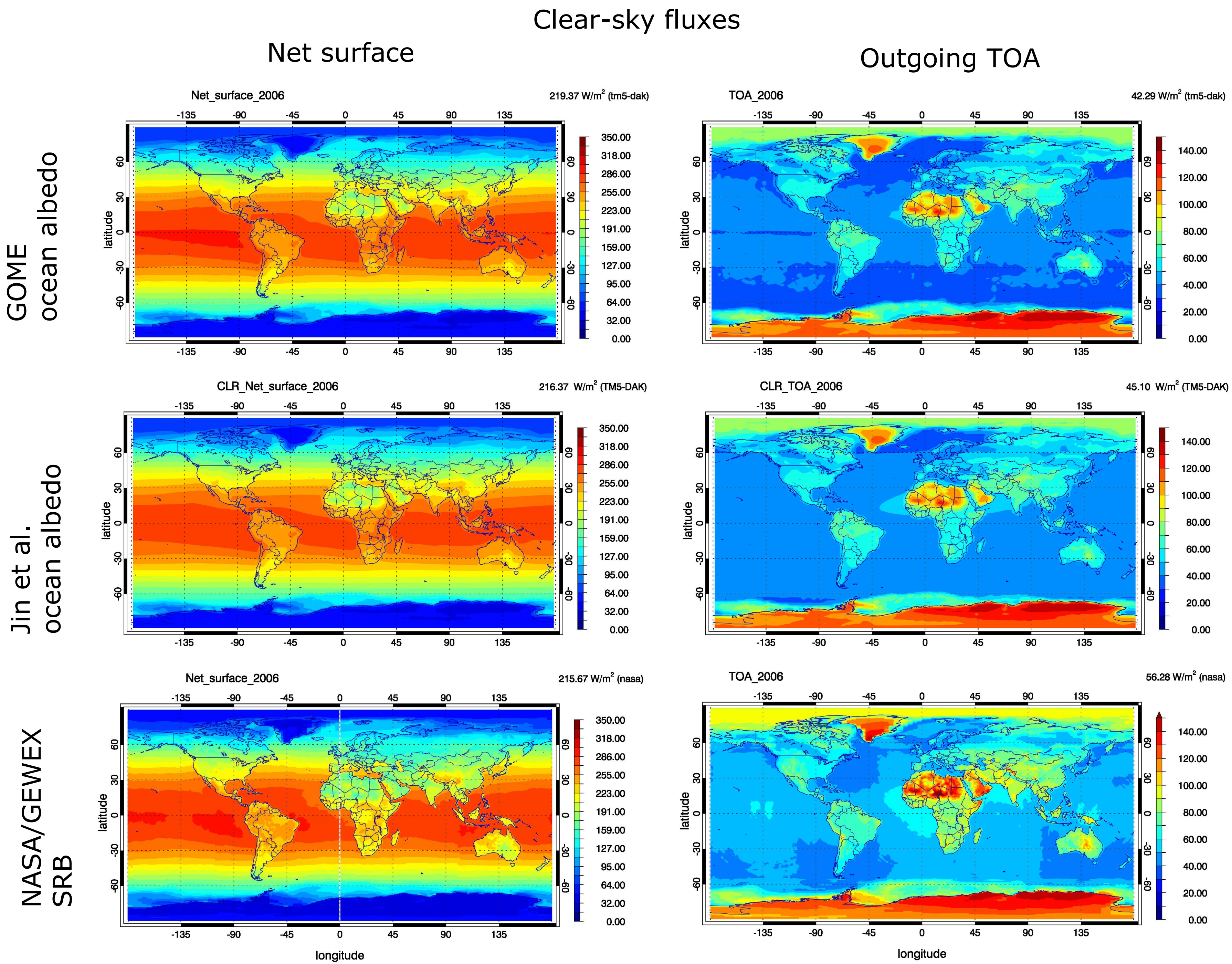


Calculation for the 15th of the month





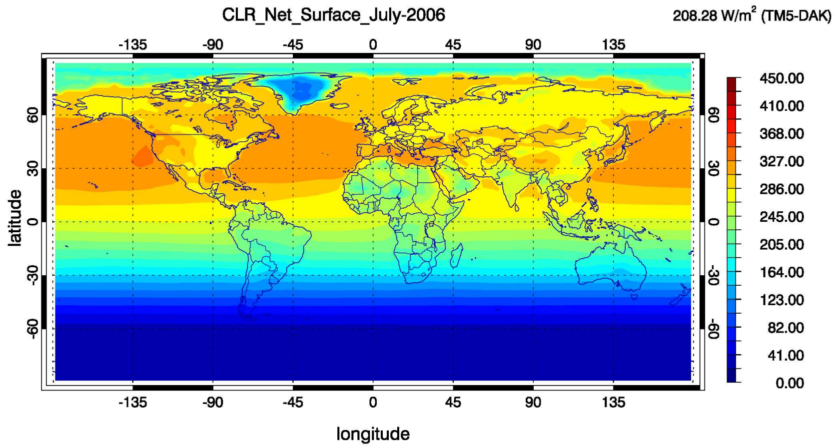
Clear-sky surface fluxes
Downward
Upward
GOME ocean albedo
Jin et al. ocean albedo
NASA/GEWEX SRB
Down_surface_2006
242.03 W/m² (tm5-dak)
Up_surface_2006
23.07 W/m² (tm5-dak)
CLR_Down_surface_2006
242.16 W/m² (TM5-DAK)
CLR_Up_surface_2006
25.79 W/m² (TM5-DAK)
Down_surface_2006
247.37 W/m² (nasa)
Up_surface_2006
31.70 W/m² (nasa)
latitude
longitude
-135 -90 -45 0 45 90 135
60 30 0 -30 -60
400.00 350.00 318.00 286.00 255.00 223.00 191.00 159.00 127.00 95.00 64.00 32.00 0.00
140.00 120.00 100.00 80.00 60.00 40.00 20.00 0.00

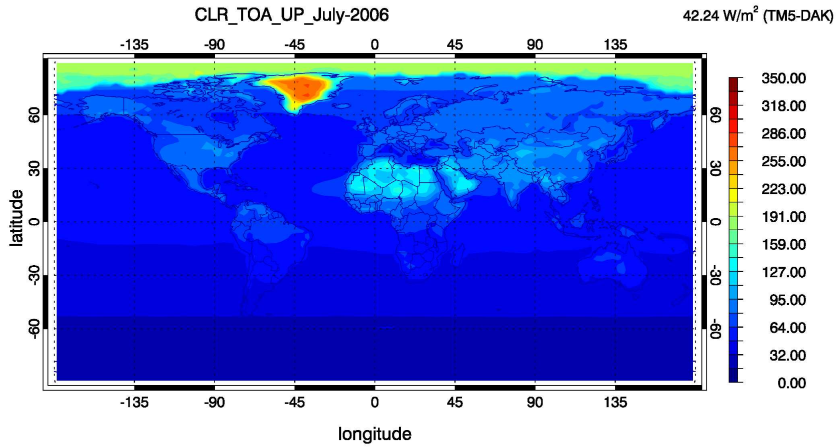


Clear-sky fluxes
Net surface
Outgoing TOA
GOME ocean albedo
Jin et al. ocean albedo
NASA/GEWEX SRB
Net_surface_2006
219.37 W/m² (tm5-dak)
TOA_2006
42.29 W/m² (tm5-dak)
CLR_Net_surface_2006
216.37 W/m² (TM5-DAK)
CLR_TOA_2006
45.10 W/m² (TM5-DAK)
Net_surface_2006
215.67 W/m² (nasa)
TOA_2006
56.28 W/m² (nasa)
-135
-90
-45
0
45
90
135
60
30
0
-30
-60
latitude
longitude
350.00
318.00
286.00
255.00
223.00
191.00
159.00
127.00
95.00
64.00
32.00
0.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00

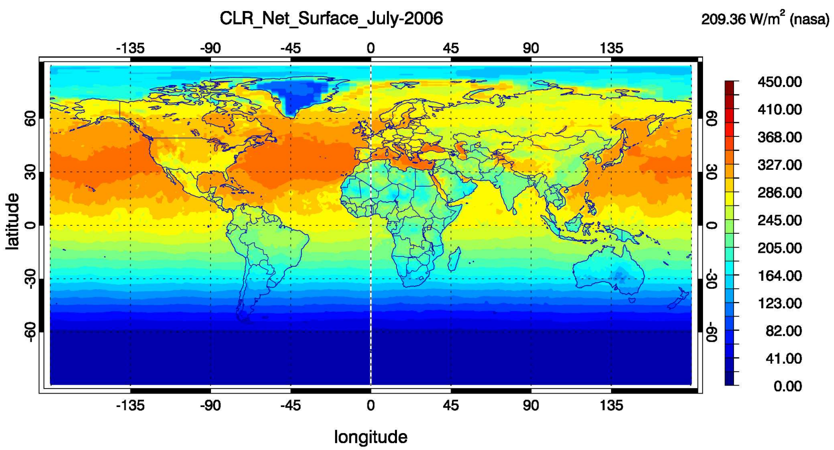
Clear-sky fluxes in summer

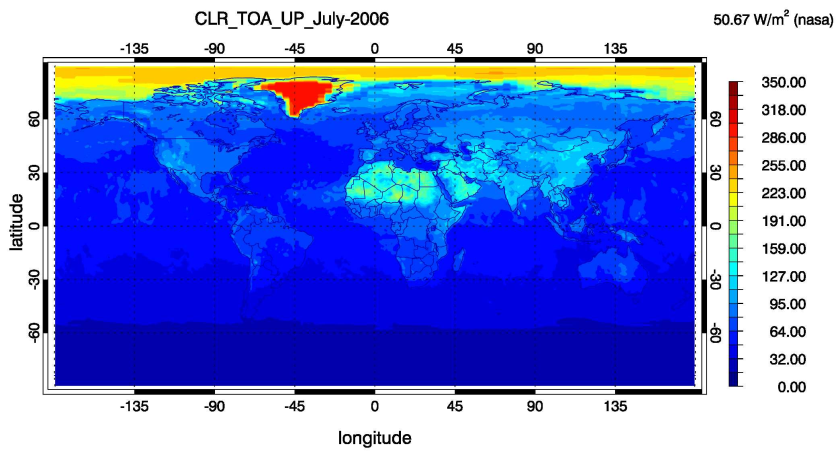
TM5/DAK





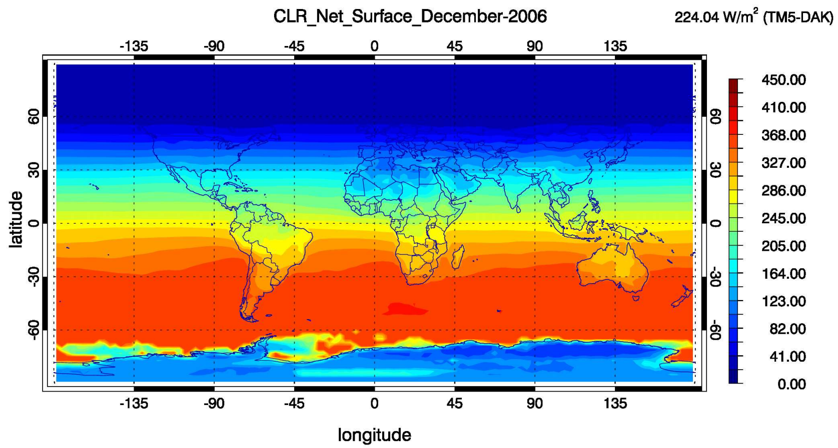
NASA/GEWEX SRB

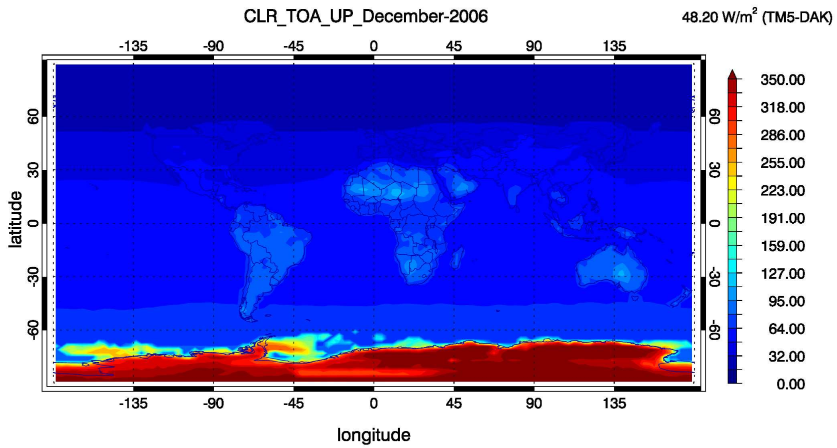




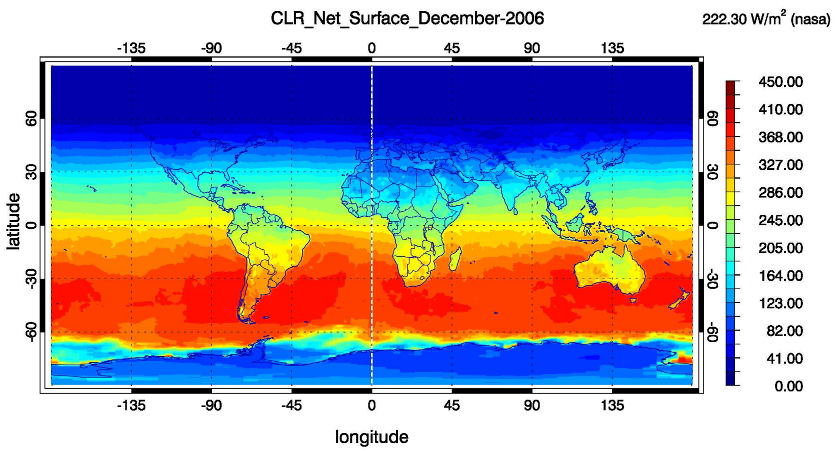
Clear-sky fluxes in winter

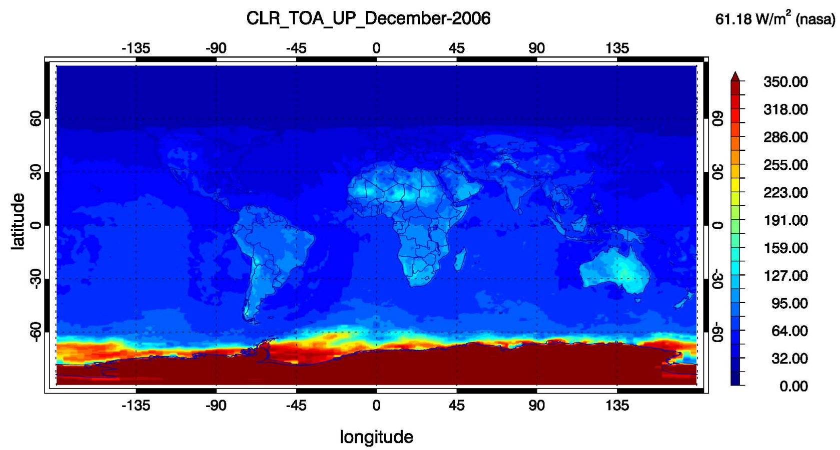
TM5/DAK



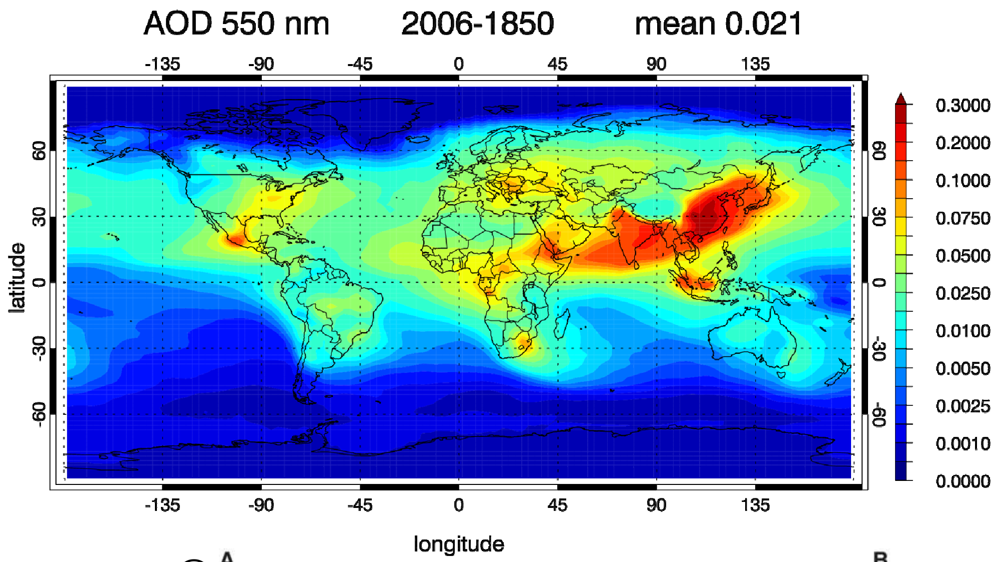


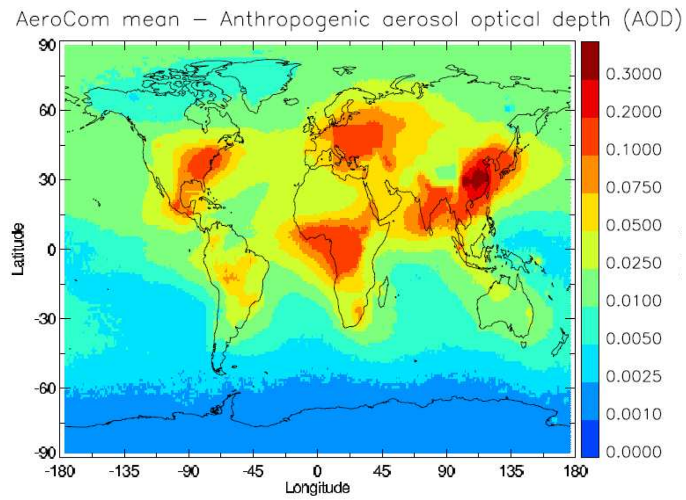
NASA/GEWEX SRB





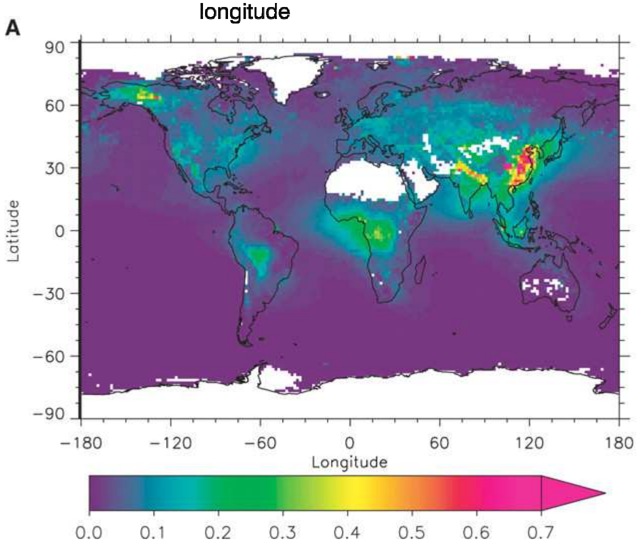
Anthropogenic AOD change: Comparison to other estimates

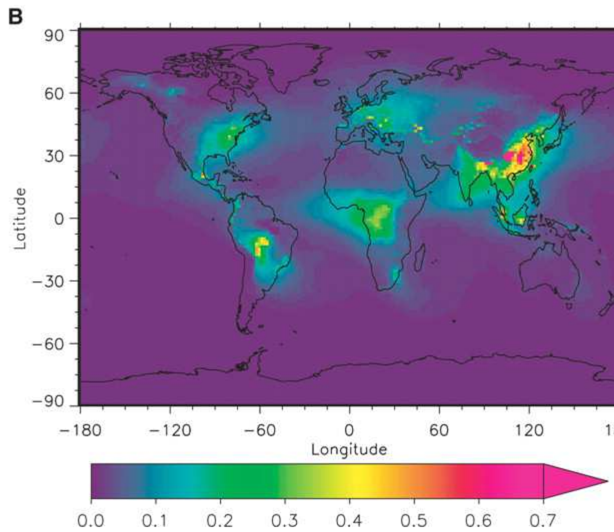




Schulz et al. (2006)

Observations based
(MODIS, AERONET, Oslo-CTM2)

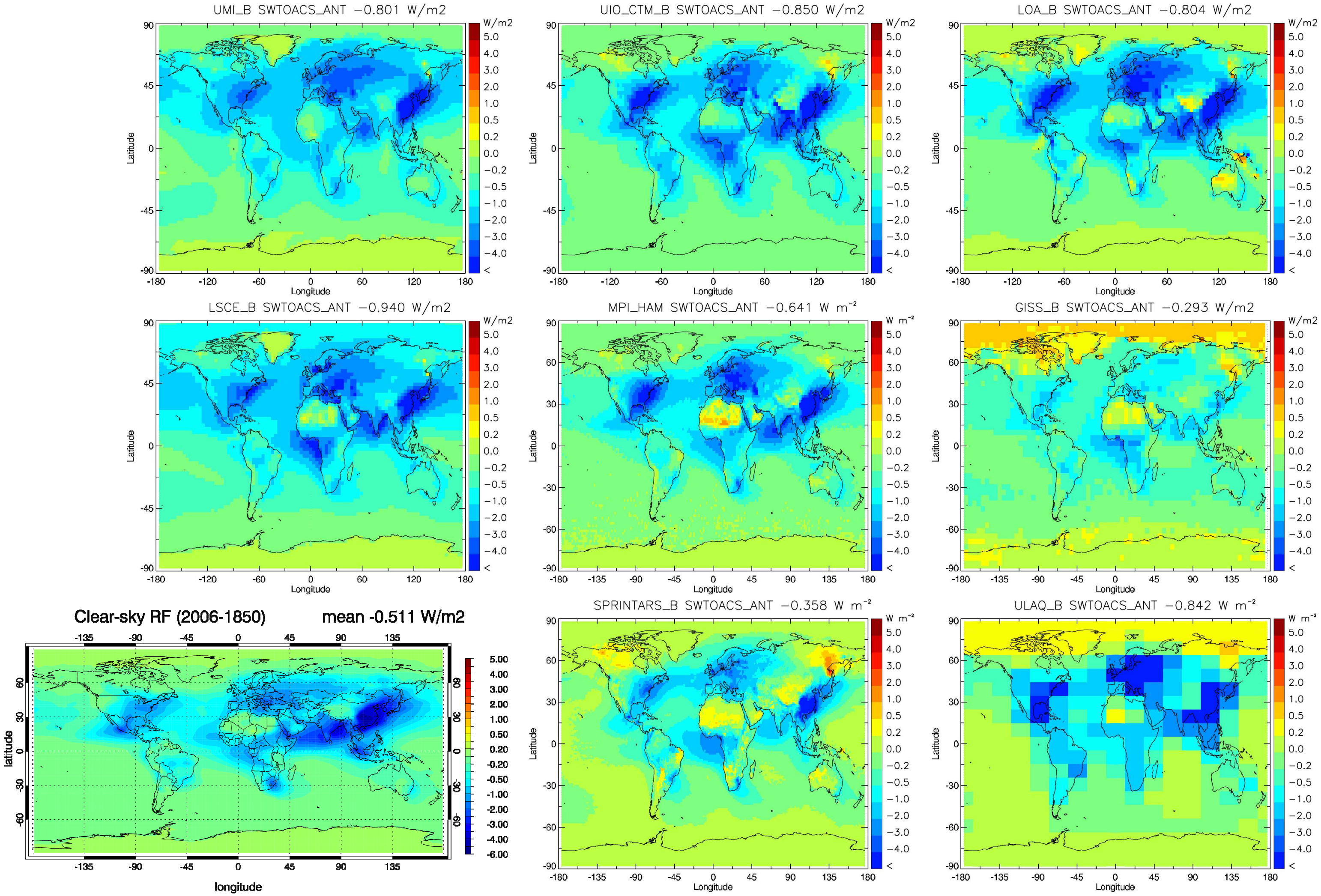




Oslo-CTM2

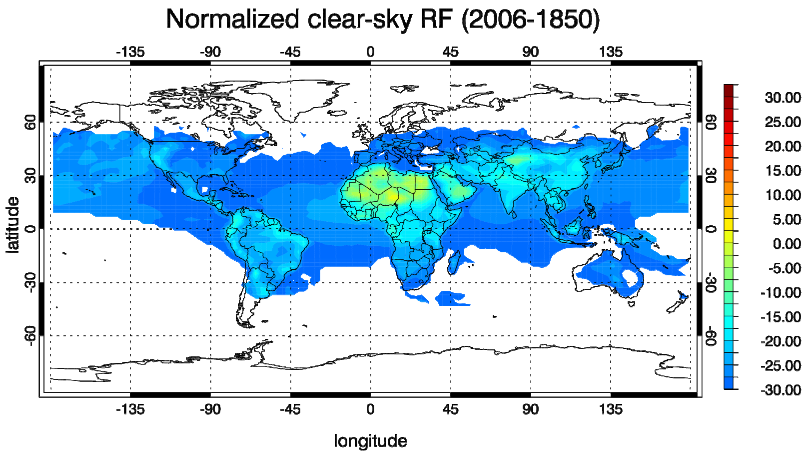
Myhre (Science, 2009)

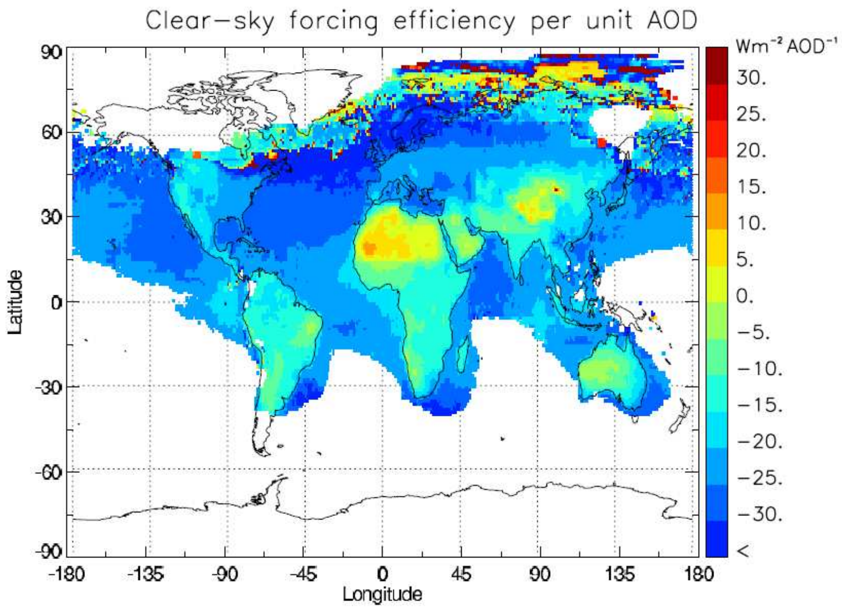
Radiative Forcing: Comparison to AeroCom models



Schulz et al. (2006)

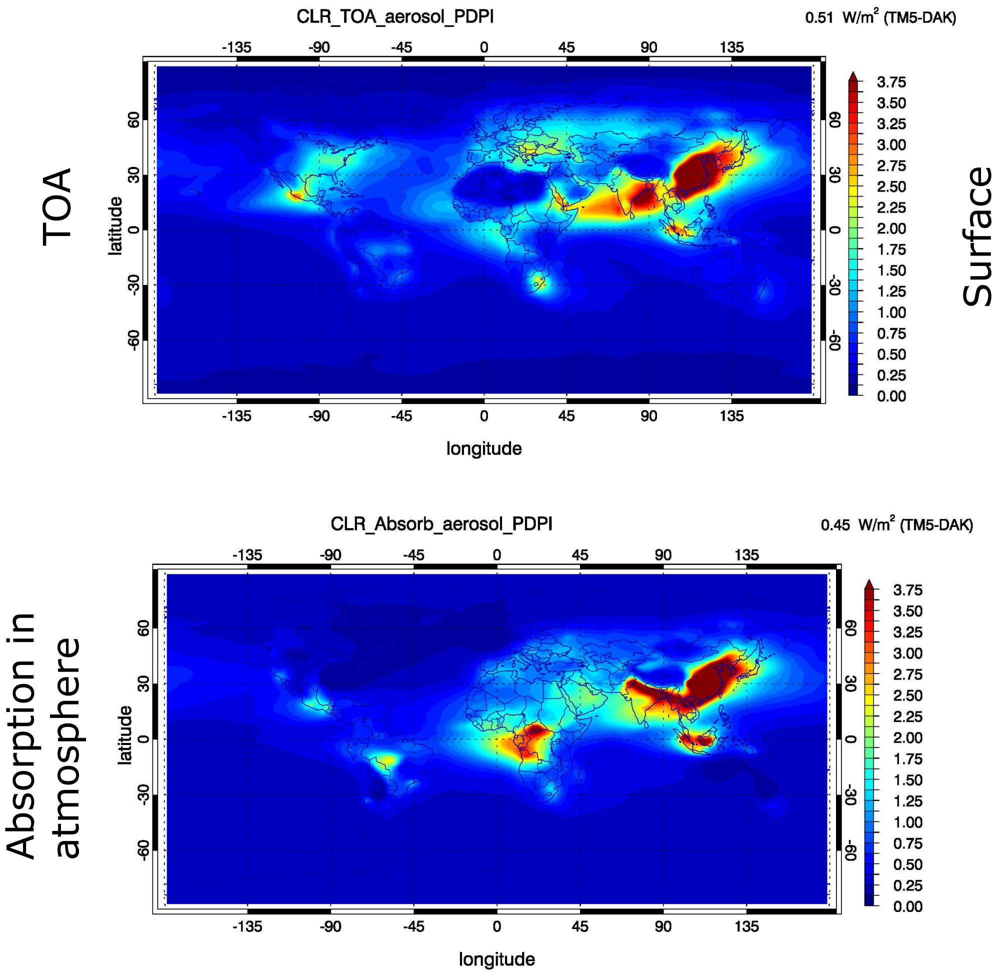
Forcing efficiency





Schulz et al. (2006)

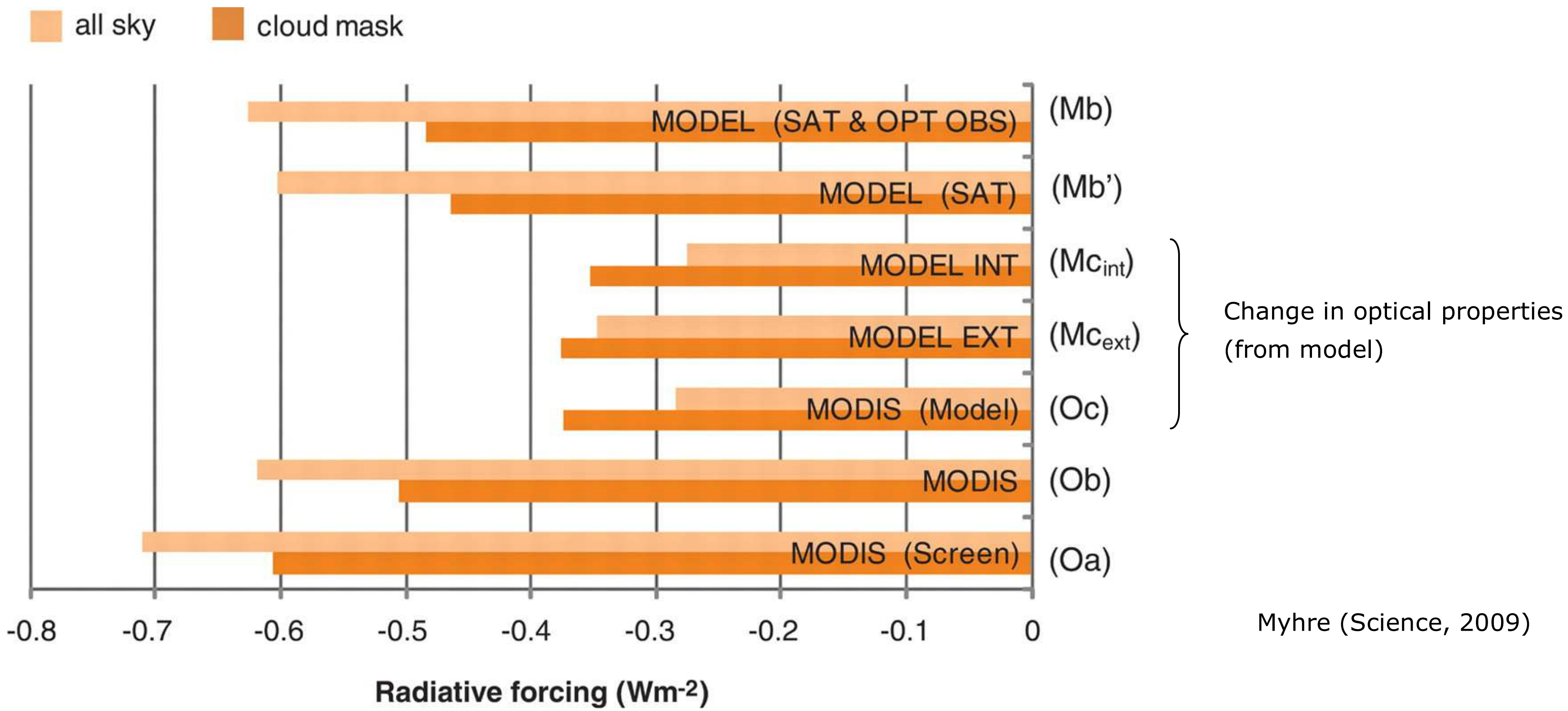
Clear-sky aerosol forcings (2006-1850)



Observation based estimates (W/m²):

TOA: -1.08
Surface: -4.44
Absorption: 3.42 (?!)

(based on MODIS, AERONET, GOCART; Chung et al., 2005)

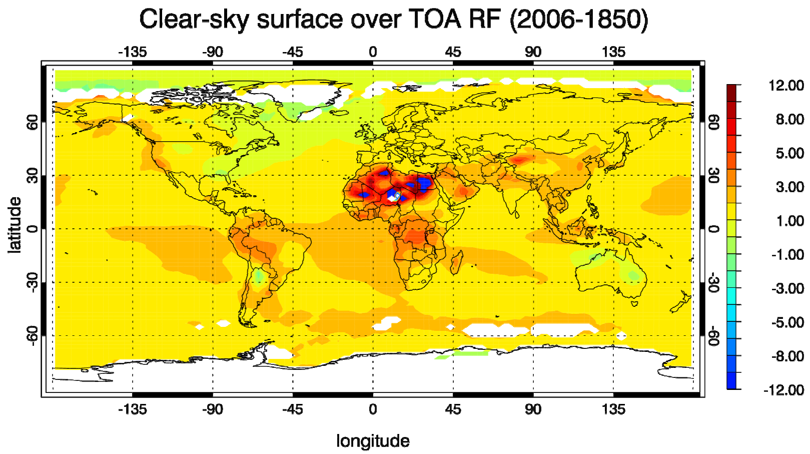


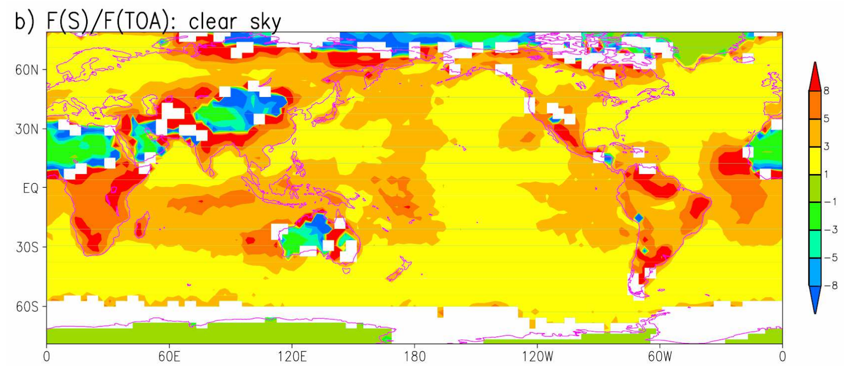
Myhre (Science, 2009)

TM5/DAK estimates cloud-masked RF: -(0.20 - 0.39) W/m^2
(using MODIS resp. FRESCO Sciamachy cloud cover)

Conclusion

- We have applied KNMI's Doubling-Adding radiation model to global TM5 output fields
- Use of the Jin et al. parameterization for ocean surface albedo instead of GOME retrieved values improves the agreement of surface and TOA fluxes with estimates from the NASA/GEWEX SRB project
- Based on TM5/DAK we estimate a global annual mean clear-sky aerosol direct RF of -0.51 W/m^2
- This is in the range of other model estimates (e.g. AeroCom) but about a factor 2 lower than the observation based estimate of Chung et al.
- The clear-sky RF efficiency per unit AOD compares well with AeroCom model estimates
- Results have been submitted to AeroCom phase-II
- As a next step we will include clouds and calculate all-sky fluxes





Chung et al. (2005)

Ocean surface albedo

- Increases with increasing solar zenith angle: specular reflection of the ocean water
- A new parametrization ocean surface albedo in DAK
- Look up table wind speed, chlorophyll concentration and zenith angle