Observational understanding of aerosols and climate

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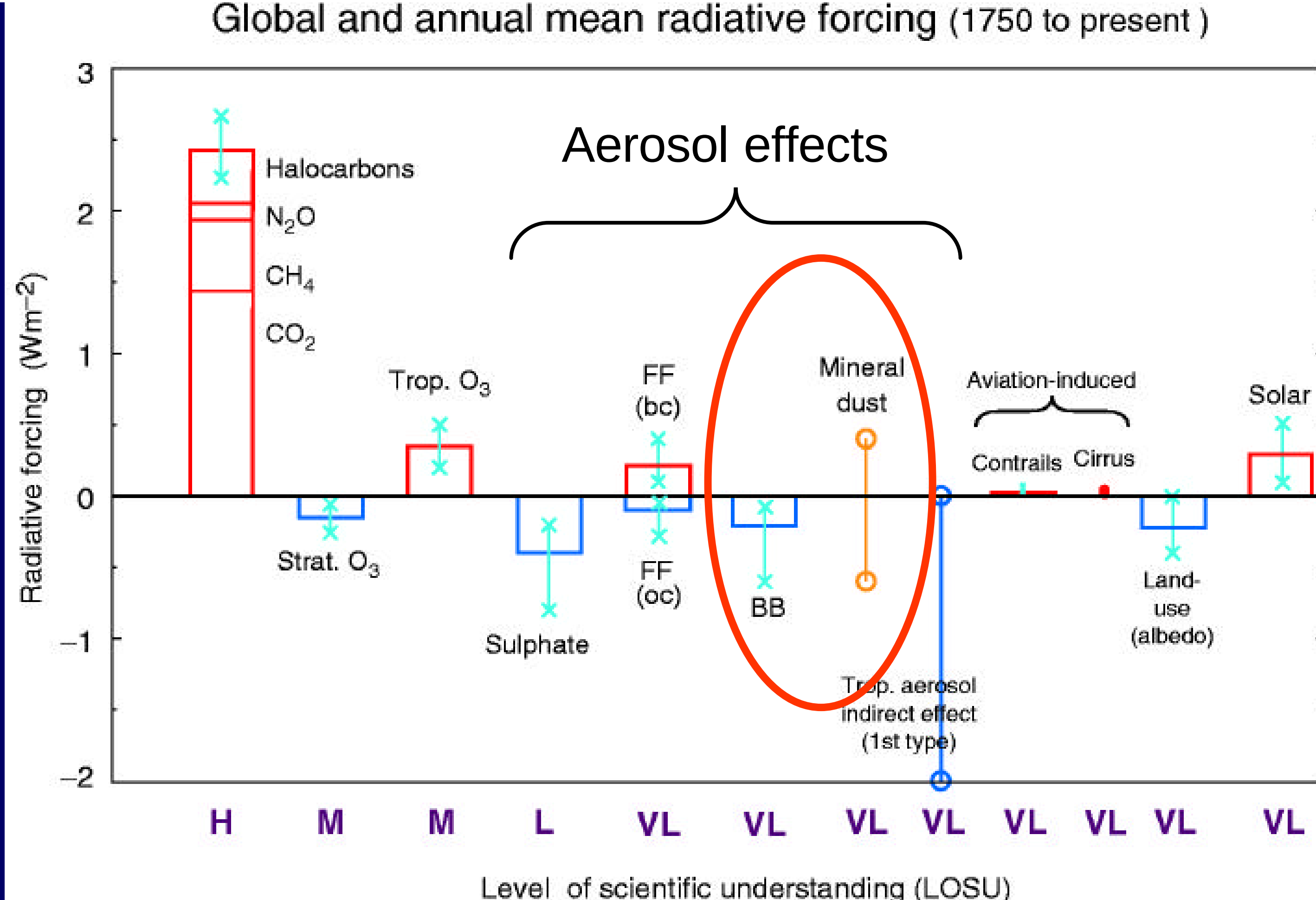
ECMWF Global Earth-System Monitoring, 5th -9th September 2005

Talk outline:

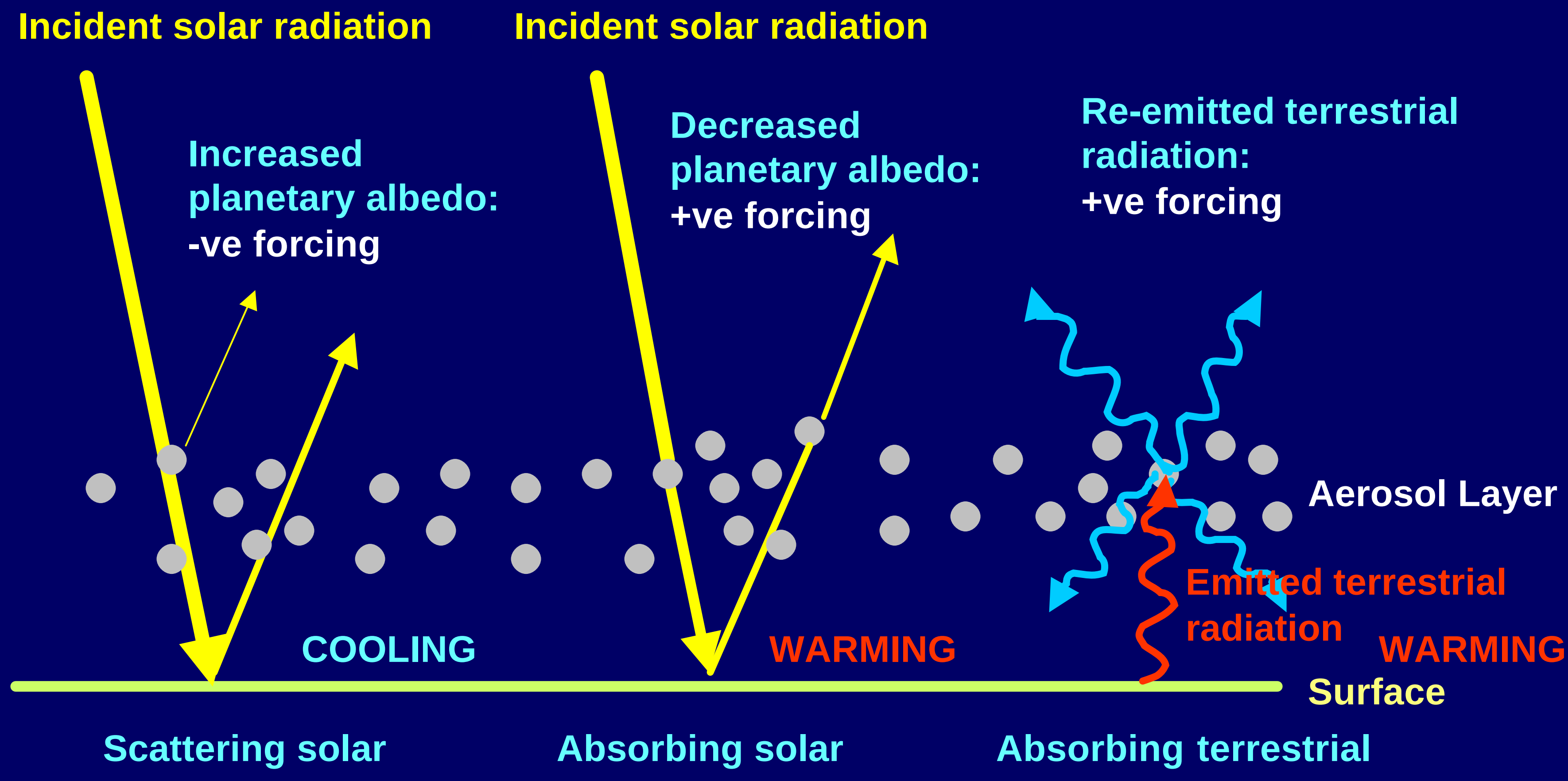
- Introduction: why are aerosols important in radiation budget & climate?
- Biomass burning aerosols
  - Why is the vertical profile of aerosol important?
    - The effect of the vertical profile on the aerosol radiative forcing.
    - The effect of the vertical profile on the derivation of cloud properties.
  - How do the biomass burning aerosol optical properties change as particles age?
  - Can we believe the size distributions etc from sun-photometer surface based retrievals?
- Saharan dust aerosols
  - The direct solar radiative effect over ocean
  - The direct terrestrial radiative effect over ocean
  - Implications for SST retrievals
  - The direct net radiative effect over land
- Direct forcing due to all aerosol types from observations

1. Introduction

Radiative forcing, DF, relates to the global mean temperature change, DT via the climate sensitivity parameter l :- DT=lDF



Direct effect of tropospheric aerosols (clear skies for simplicity)



Simple expression for the direct solar radiative effect of a scattering/ absorbing tropospheric aerosol in clear skies where R_s is the surface reflectance and A_c is the cloud amount (Haywood and Shine, 1995) :-

$$\Delta F = -\tfrac{1}{2} S_o T_{at}^{2}(1 - A_c)\left[w_o b(1 - R_s)^2 - 2(1 - w_o)R_s\right]t$$

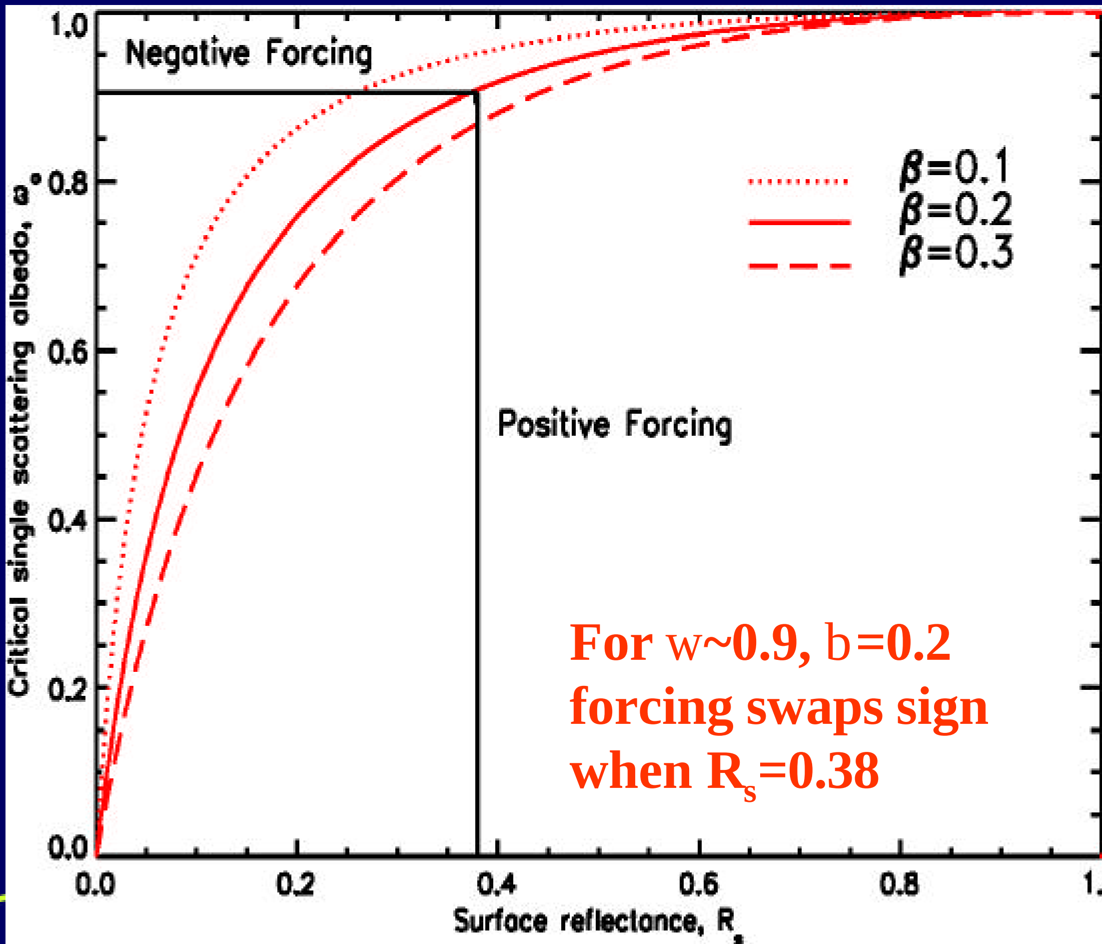
ω_o: single scattering albedo=$Q_{sca}/(Q_{sca}+Q_{abs})$

β: fraction backscattered to space

τ is the optical depth

$$w_o > \frac{2R_s}{b(1-R_s)^2 + 2R_s}$$

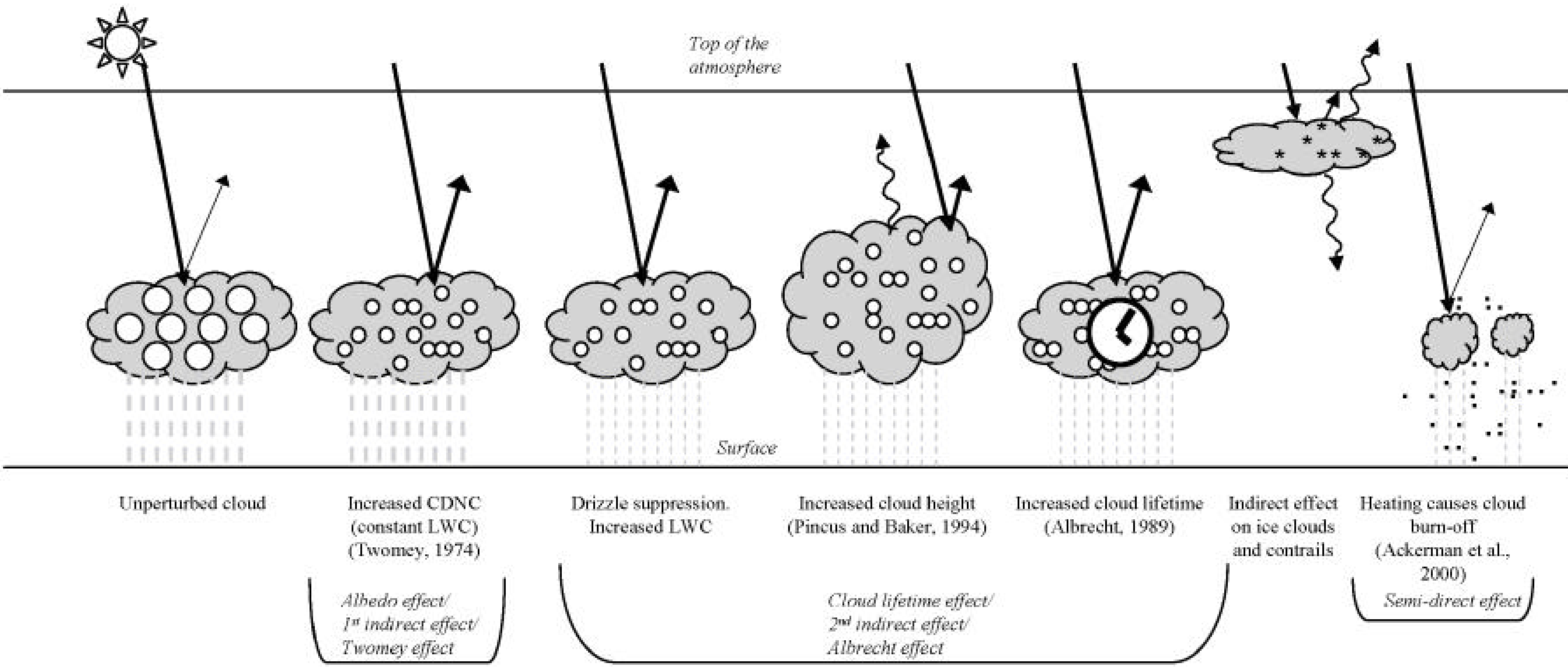
for negative forcing



The expression is really just a complicated expression to show this:-

Dark ocean surface	Bright snow/cloud surface
Dark surface appears brighter -> increased planetary albedo	Bright surface appears darker -> decreased planetary albedo

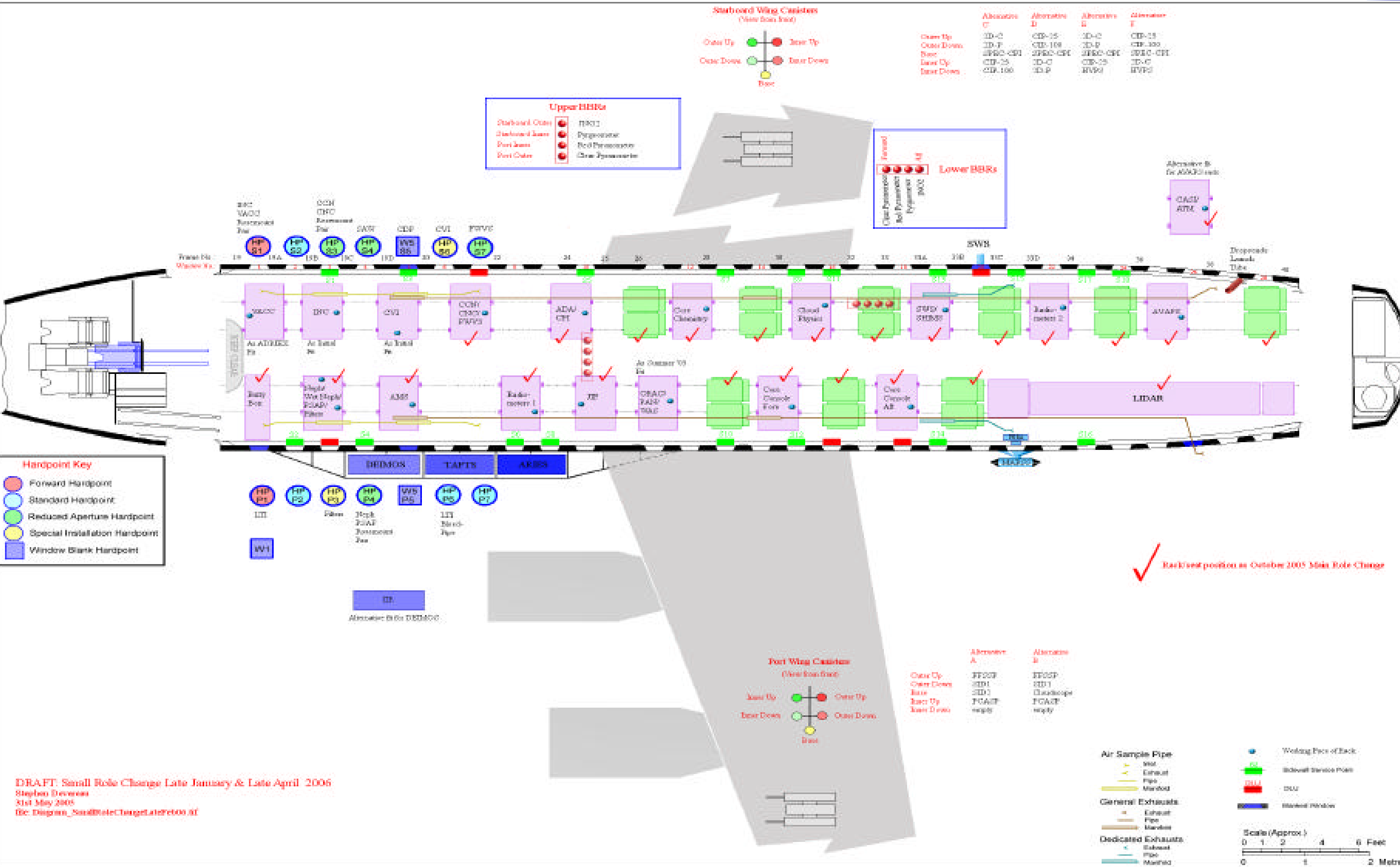
Schematic of the indirect effects - (not dealt with in detail in this talk)



Adapted from Haywood and Boucher, 2000.

The Met Office/NERC/FAAM aircraft

The layout of the BAe146 (interchangeable)



2. Biomass Burning Aerosols

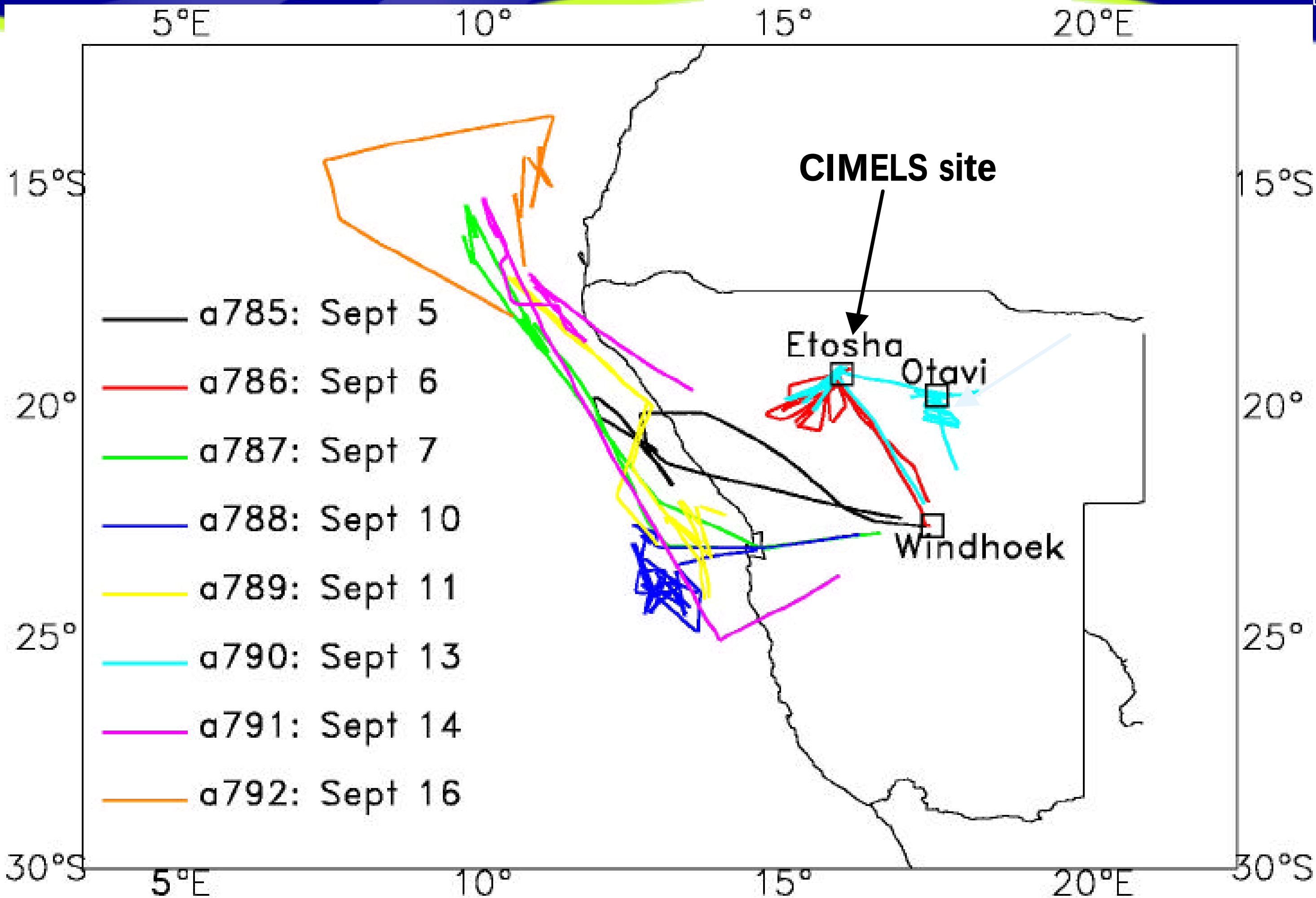
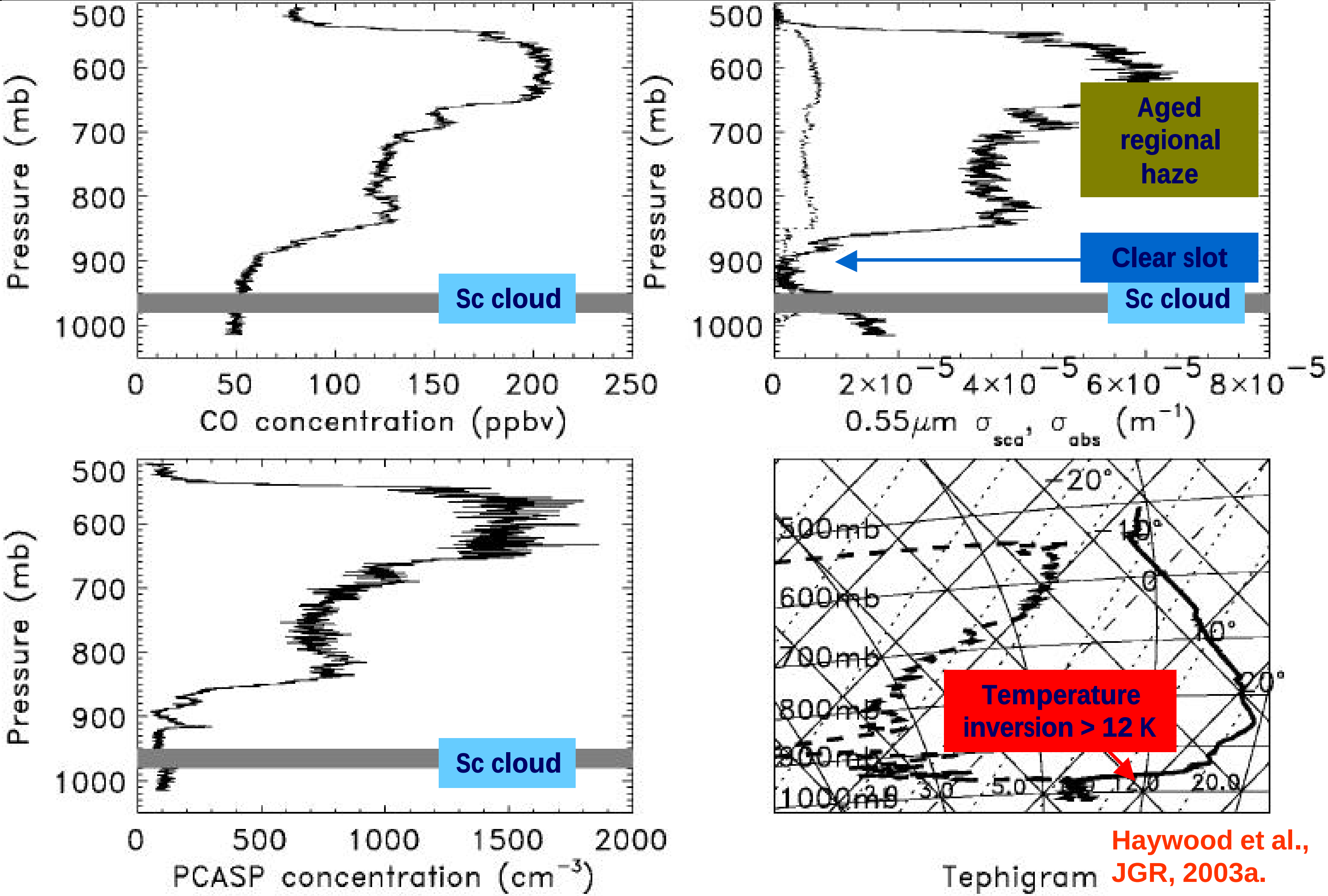


Figure 1: Map showing the geographical location of the flights performed by the C-130 during SAFARI 2000. The approximate positions of Windhoek, Etosha, and Otavi are marked. The geopolitical outline of Namibia is also shown.

Vertical profiles:

Over ocean, aerosol separated from Sc by 'clear' slot and strong temperature inversion. $\omega_{0\lambda=0.55}$=0.91 for the aerosol.

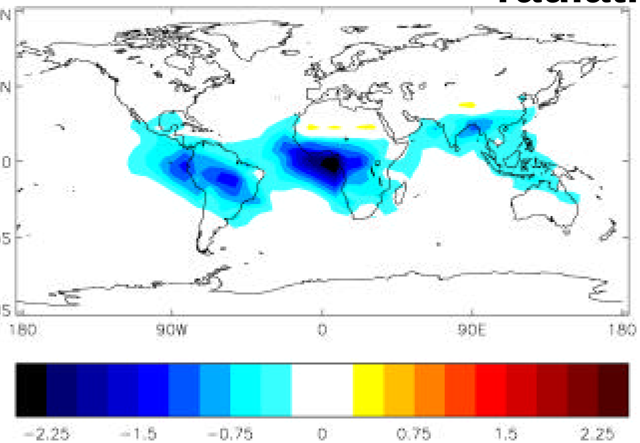


Haywood et al., JGR, 2003a.

Note the correlation between CO, σ_{sca}, σ_{abs}, and PCASP conc

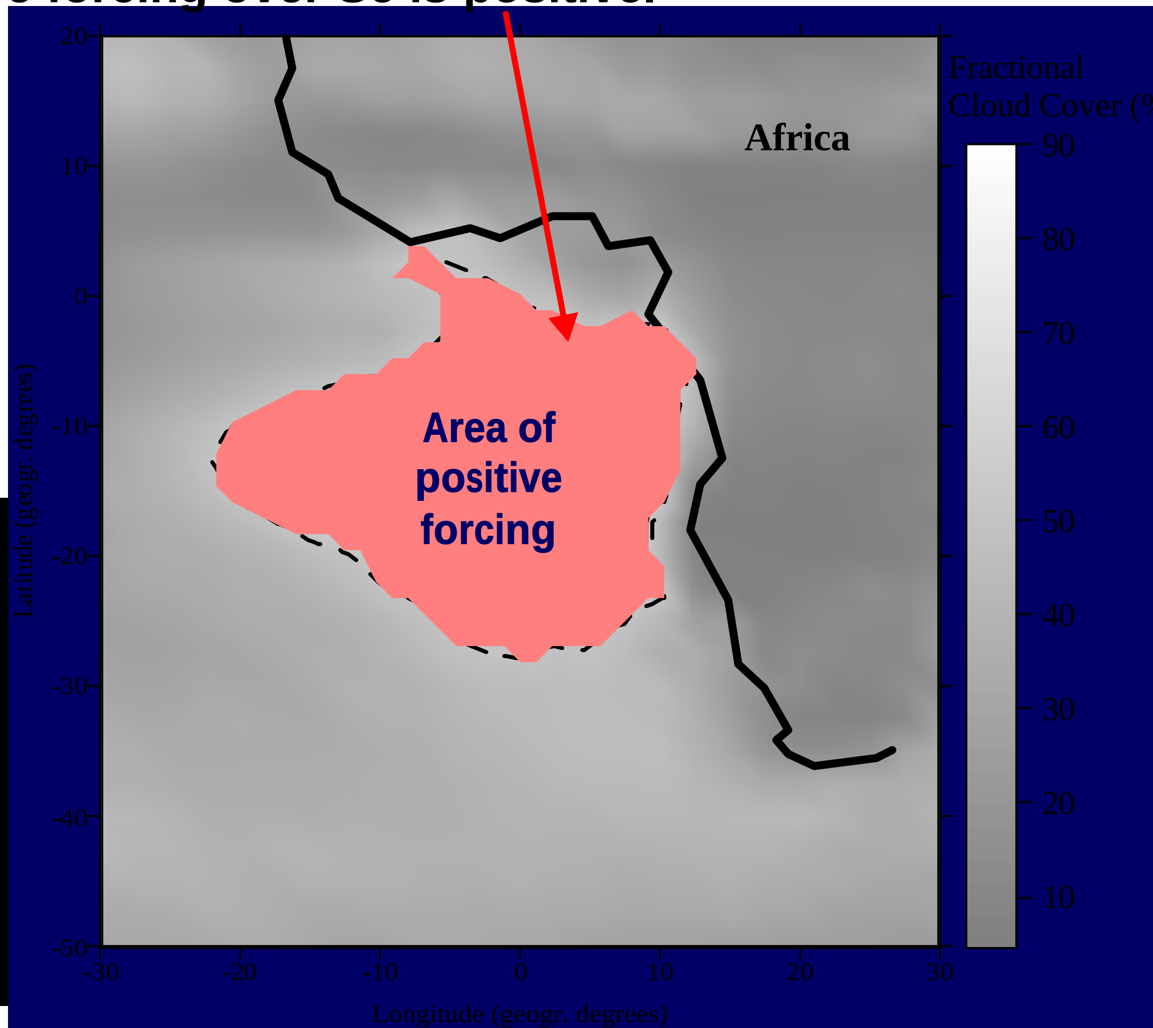
Keil and Haywood (2003)

Realistic vertical profiles of aged regional haze, and realistic vertical profiles of Sc (both based on aircraft measurements). Using ISCCP cloud fractions, the radiative forcing over Sc is positive.



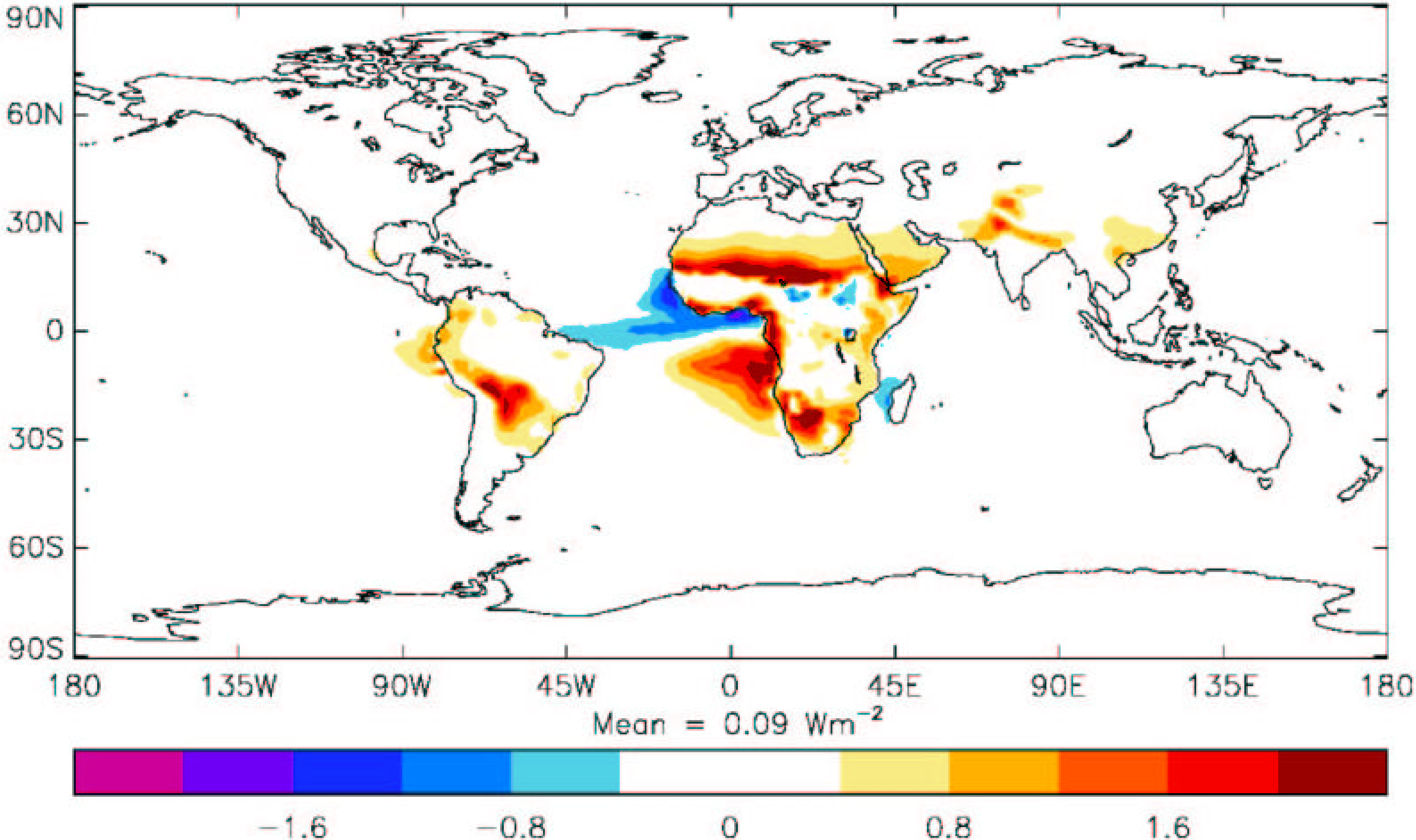
Implications - models have to get the vertical profile and cloud properties right for partially absorbing aerosol. This wasn't a concern for sulphate aerosol.

Is the sign of the global BB radiative forcing positive?!!!



Results from the UM (Andy Jones).

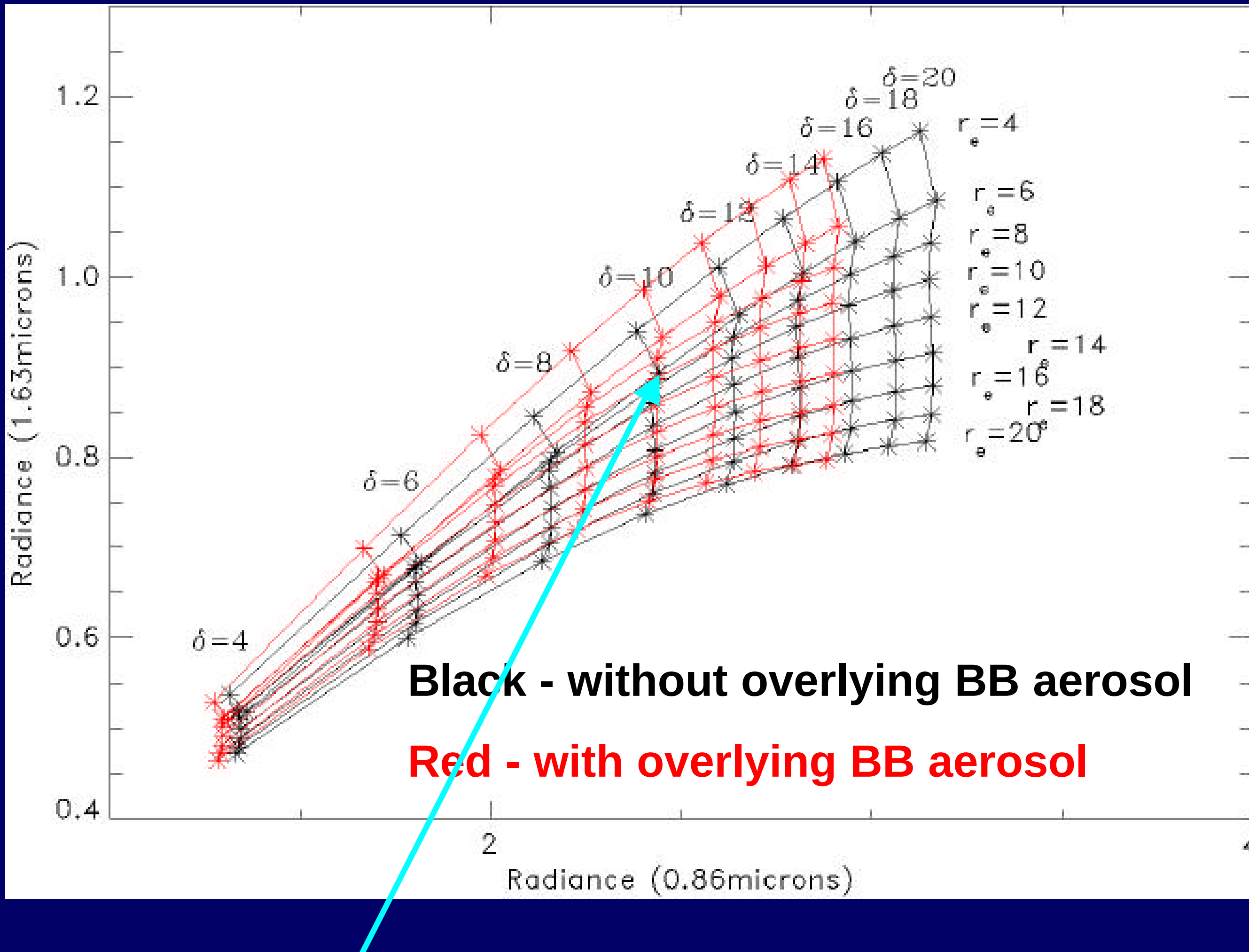
………..suggest that the TOA radiative forcing from BB aerosol may indeed be positive (but very sensitive to aerosol absorption properties). Similar results come from the AEROCOM initiative ……..



Does overlying aerosol significantly effect cloud retrievals?

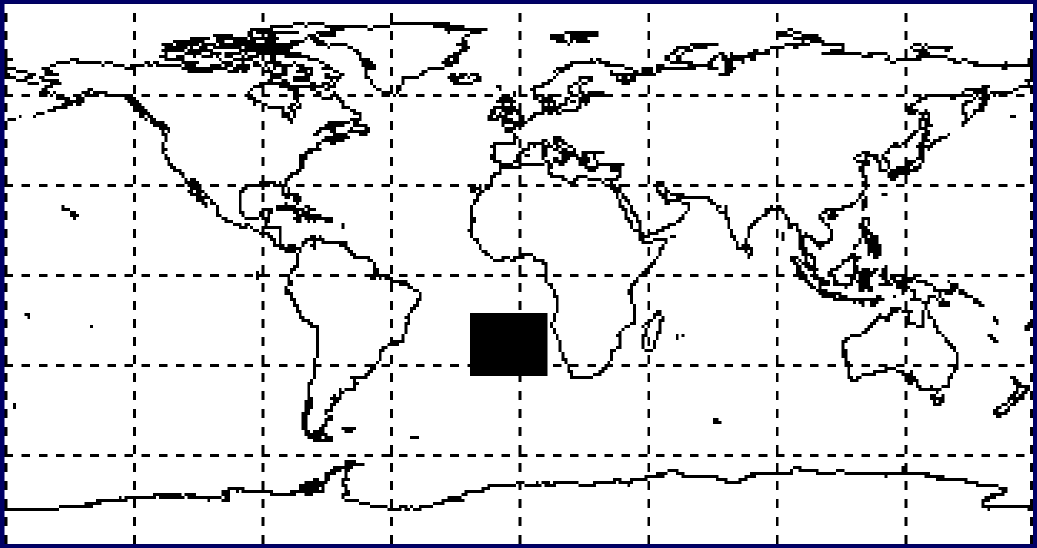
MODIS 1.63mm: d_{cloud} **is underestimated –** d_{cloud} **apparent=10** d_{cloud} **real=12.**

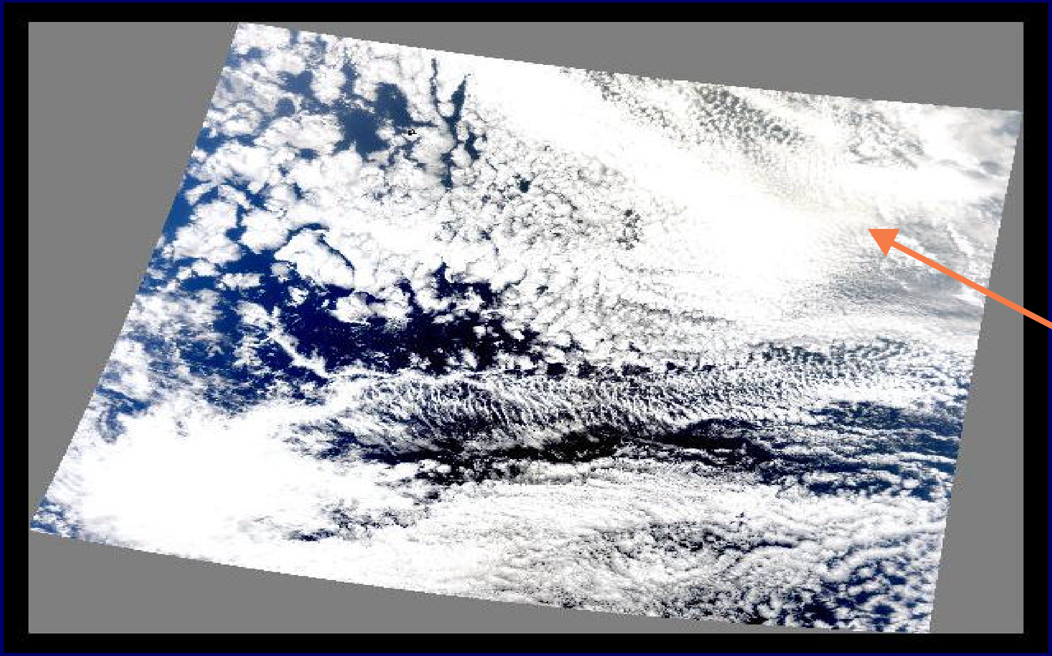
r_{eff} **is underestimated:** r_{eff} **apparent= 6mm:** r_{eff} **real=10mm**



'Apparent indirect effect'

Haywood et al., 2004, QJRMS

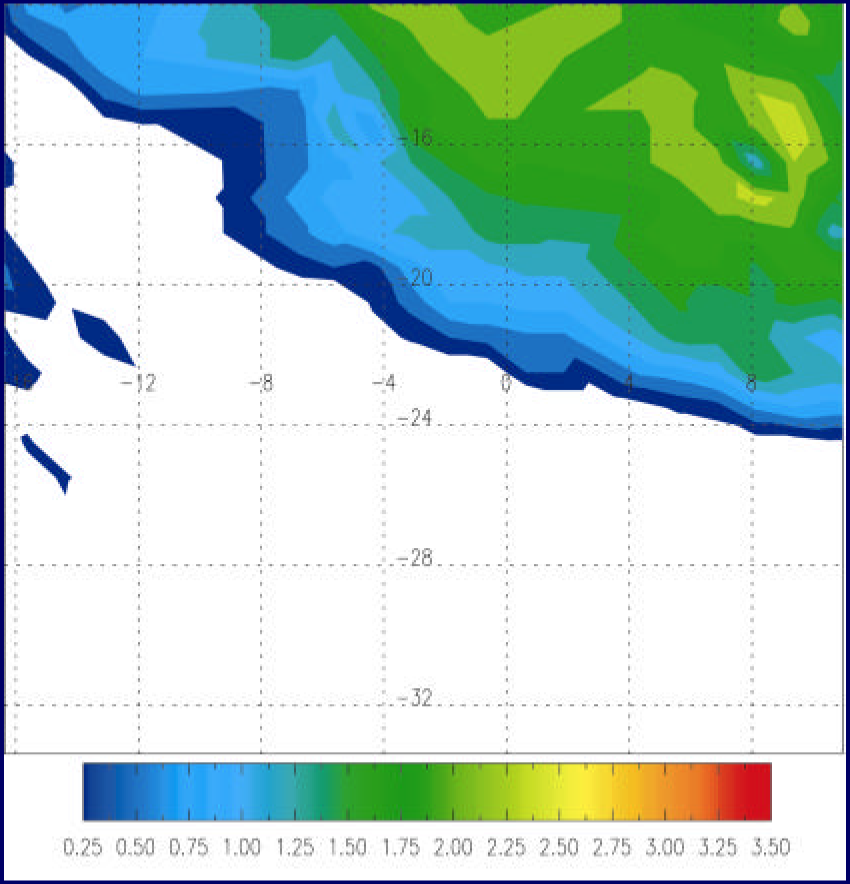




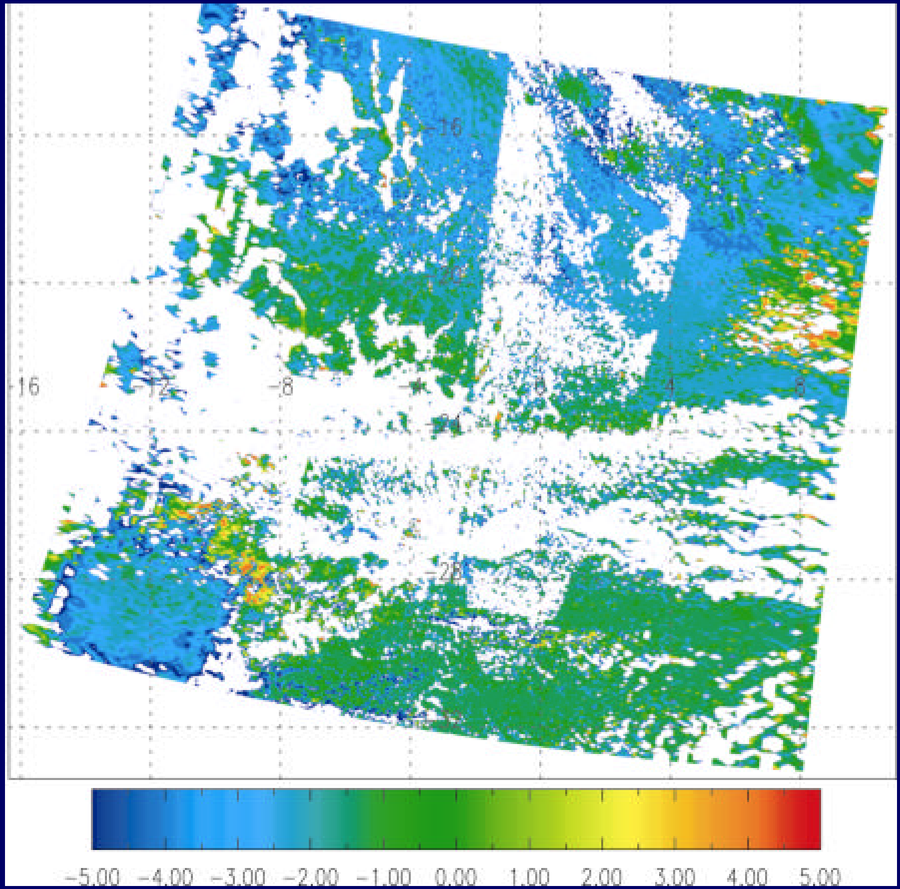
MODIS quick-look image off the coast of Namibia/Angola for 7th September 2000

Smoke in N.E. corner

TOMS AI shows absorbing aerosol in N.E.



$r_{e1.63}$ shows negative bias in N.E.



Green colors $r_{e1.63}=r_{e2.13}$ Blue colors $r_{e1.63}< r_{e2.13}$

Implications –

a) 'apparent indirect effect'

b) w_o might be derivable

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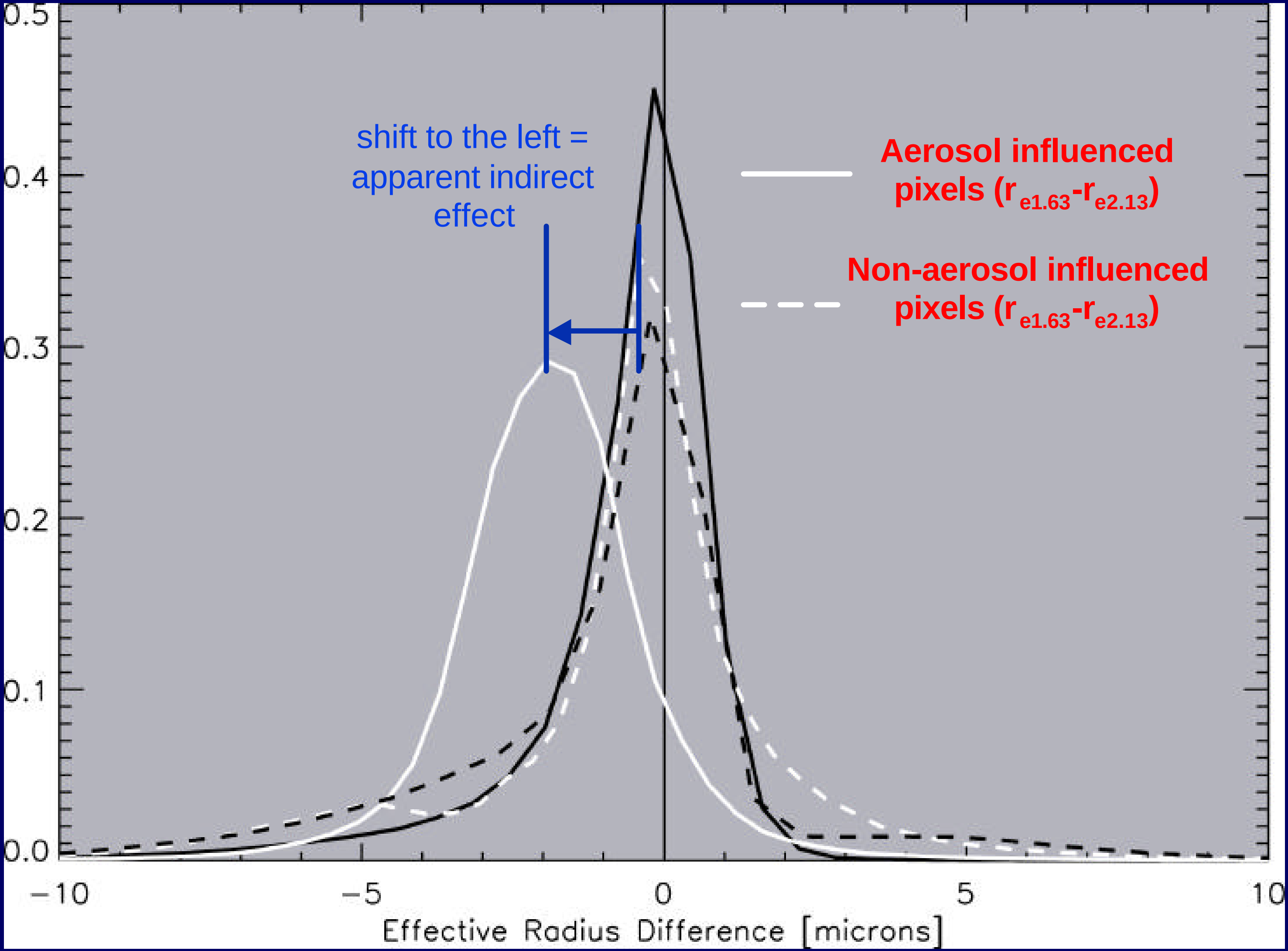
PDFs show the nature of the difference between aerosol and non-aerosol influenced pixels



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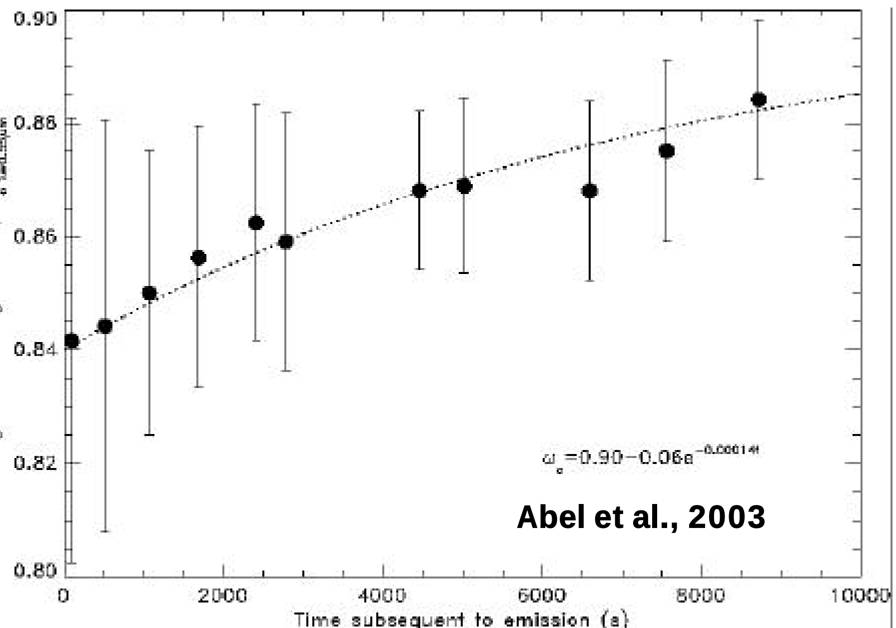
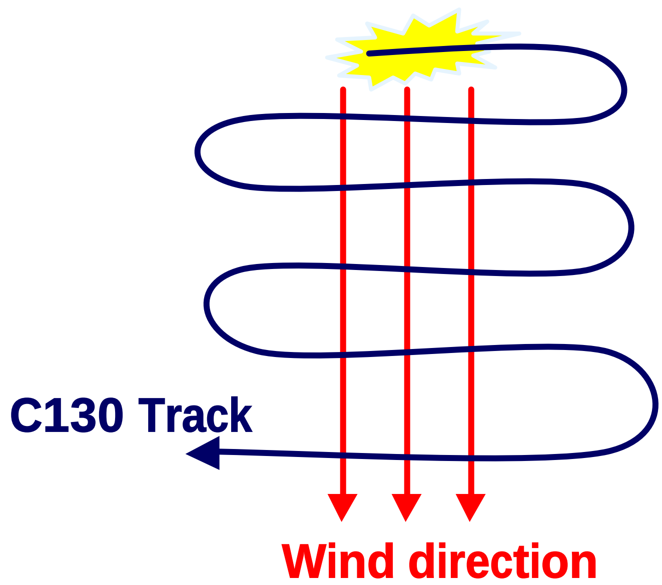
he effects of aerosol aging (upon the absorption).

Burn scar > 5km²

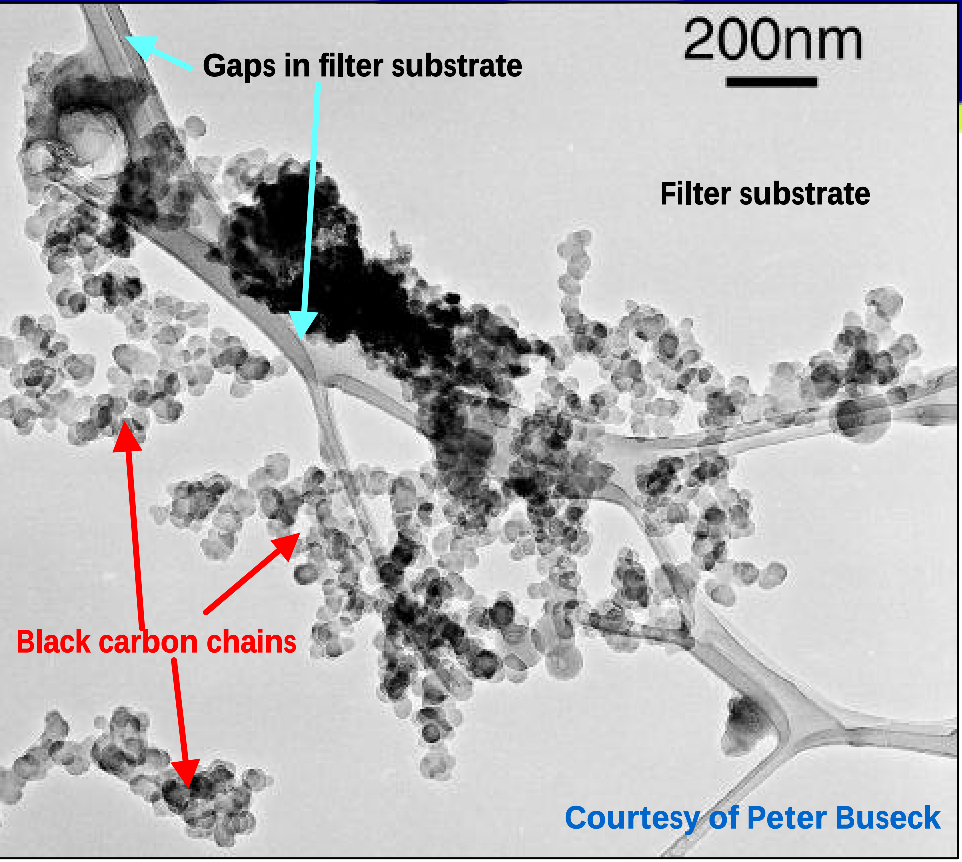
Plume easily detected 100km downwind

A raster pattern was flown downwinc to determine how the single scatterin albedo of the biomass burning aerosc changes:-

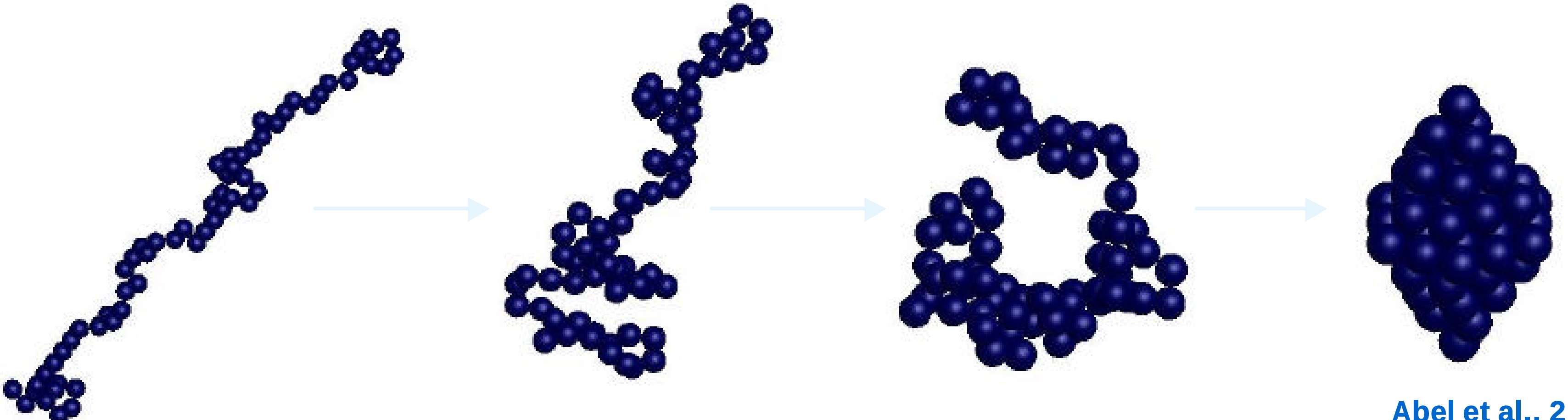




RT modelling



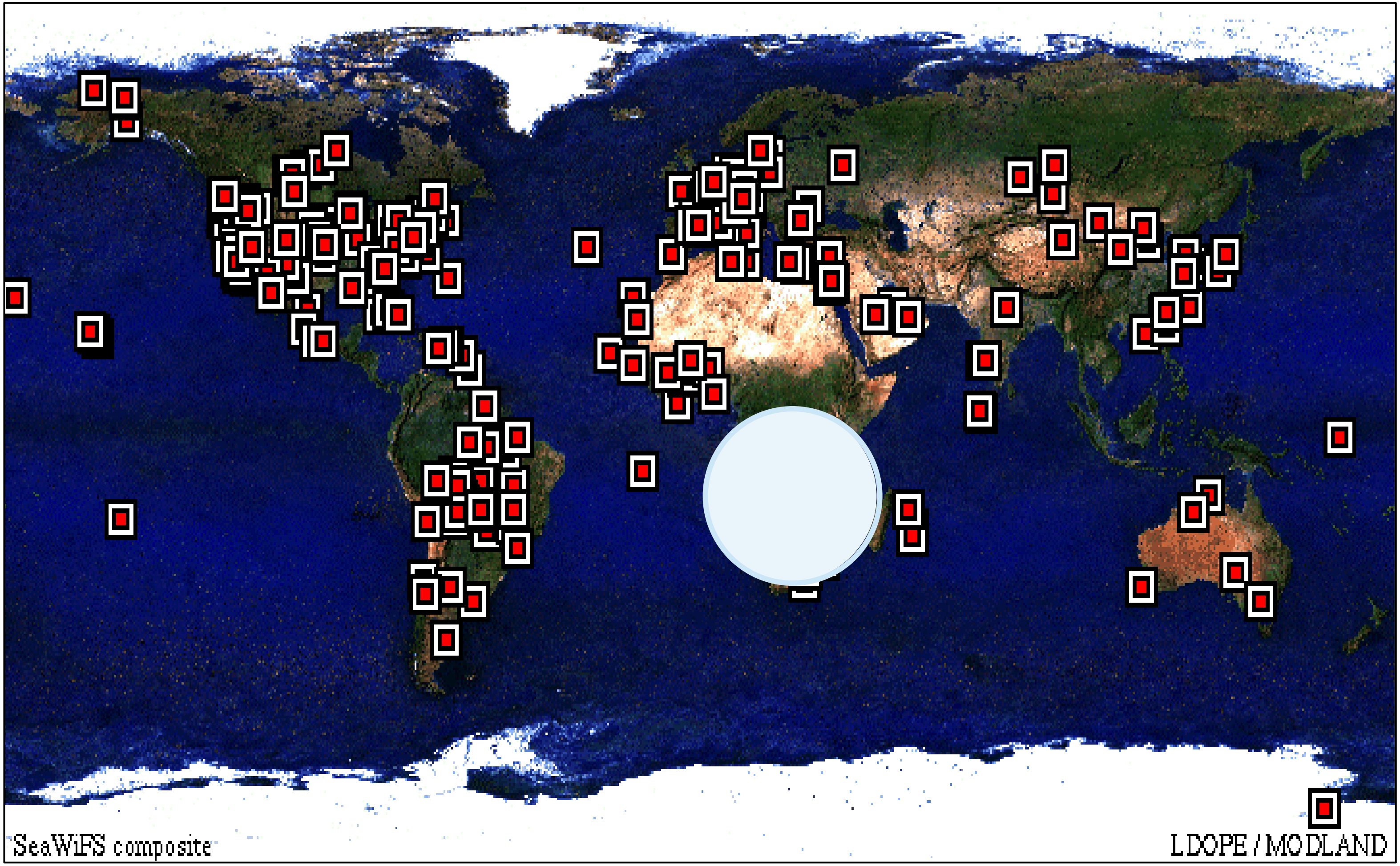
We've investigated whether the collapse of the black carbon chain structure is responsible for the change in w_o: not sufficient to explain the differences -> more likely to be the condensation of VOC gases



Abel et al., 2003

AERONET - over 150 surface sites.

Retrievals of $\tau_{aer\lambda}$, size distribution, absorption



But do we believe them?

Flight made during SAFARI-2000 in biomass aerosol

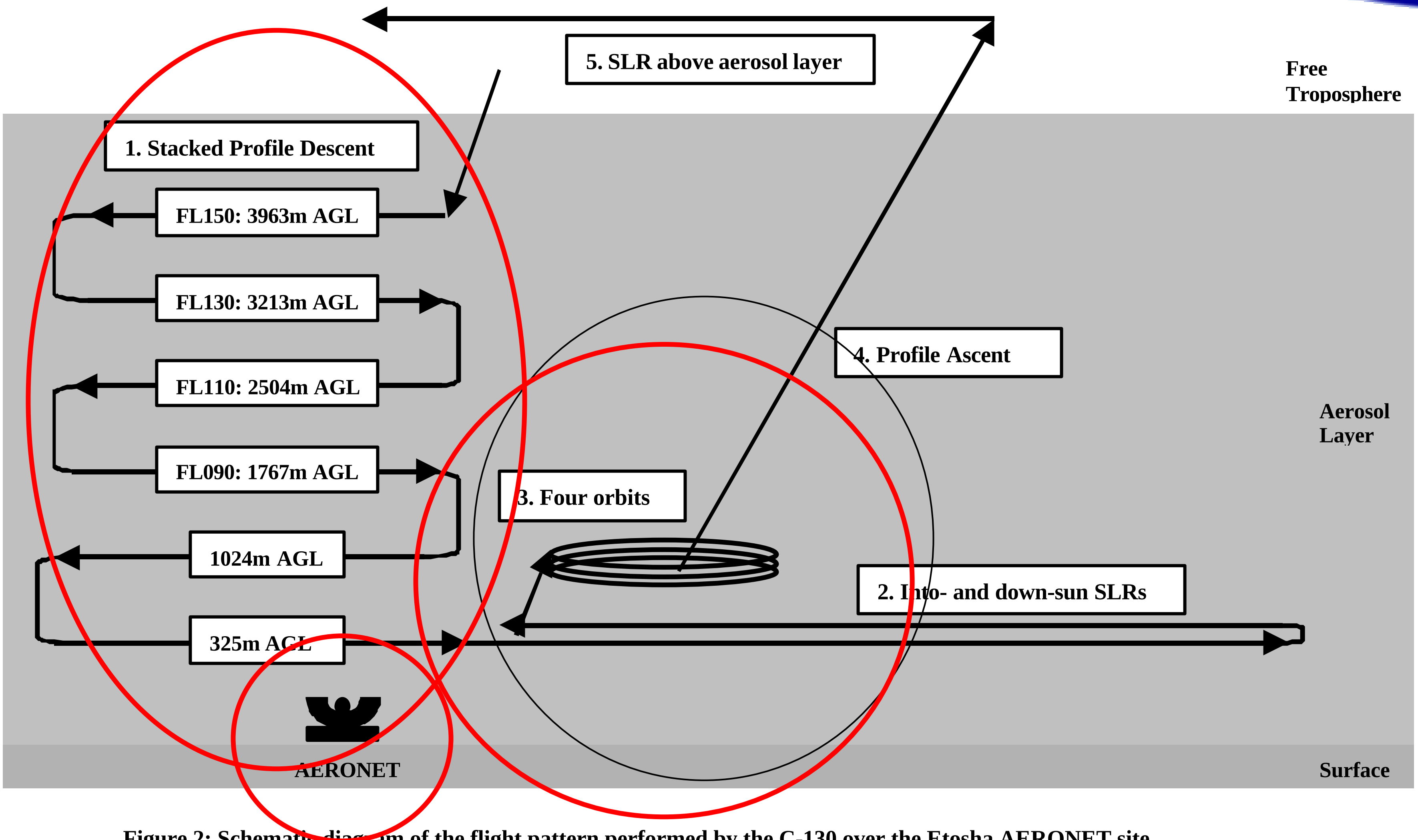
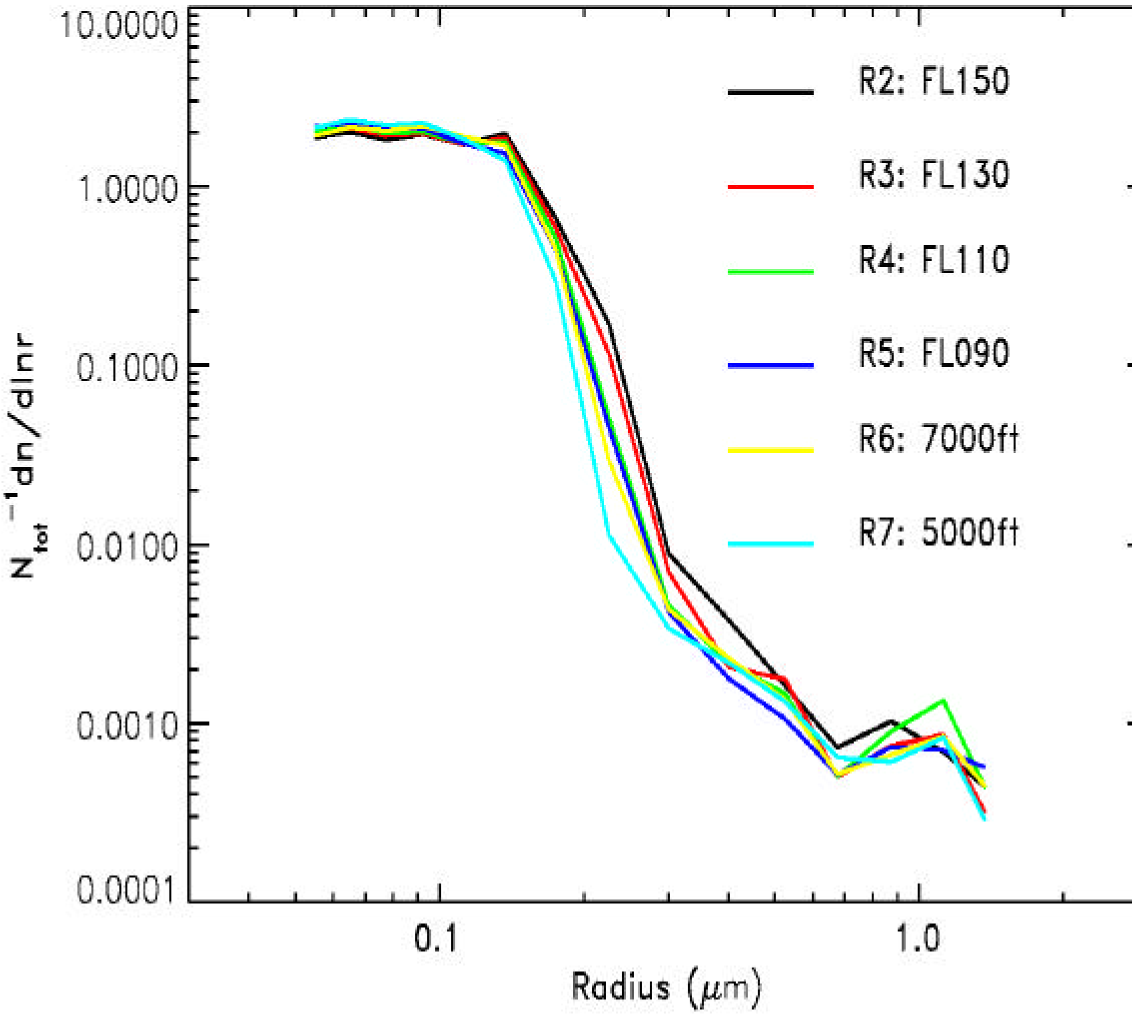


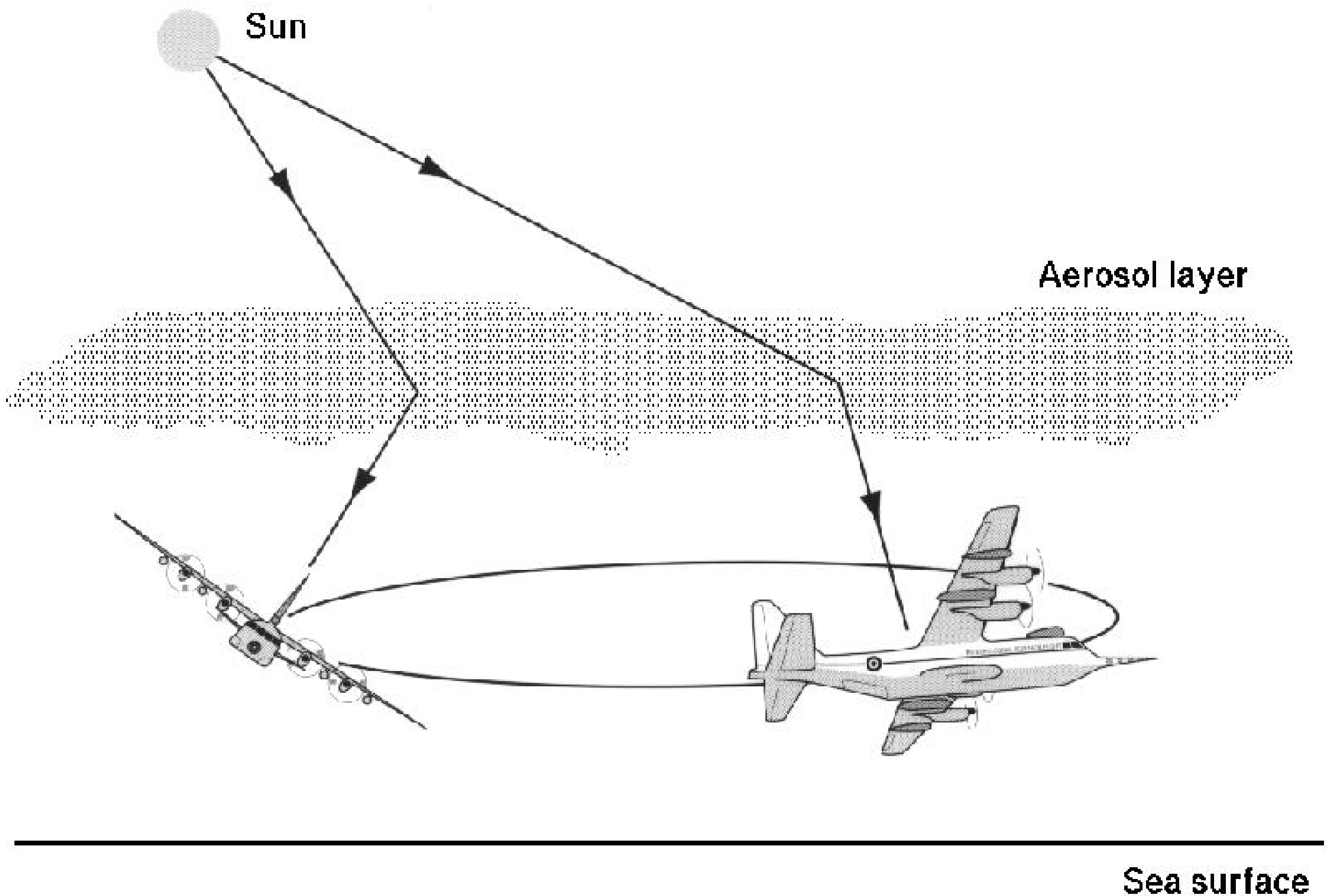
Figure 2: Schematic diagram of the flight pattern performed by the C-130 over the Etosha AERONET site on September 13, 2000. Consisting of 1) stacked profile descent, 2) into- and down- sun SLRs, 3) a series of four orbits, 4) profile ascent, 5) SLR above the aerosol layer.

Haywood et al., JGR, 2003b.

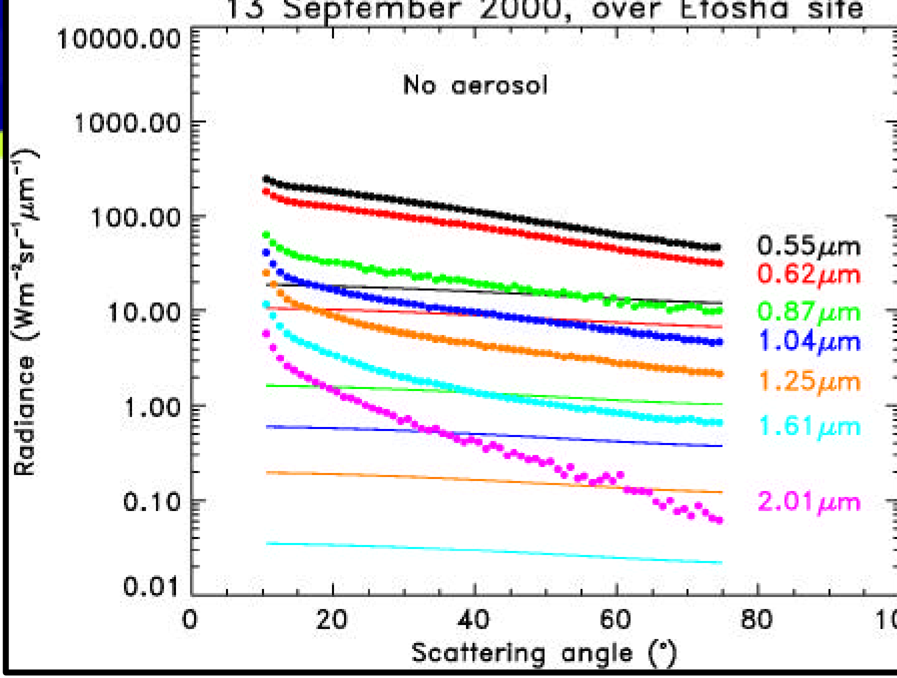
The aerosol size distribution shows little variation in the vertical due to the strong dry convective mixing.

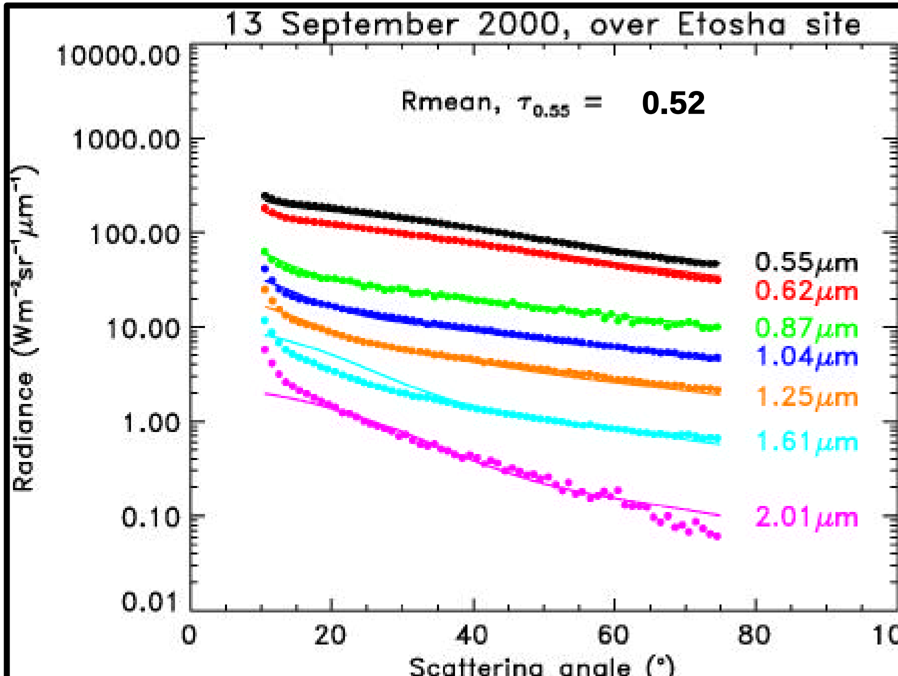


Measurements are analogous AERONET almucantars by performing orbits to derive the aerosol size distribution.



Radiance as function of scattering angle.





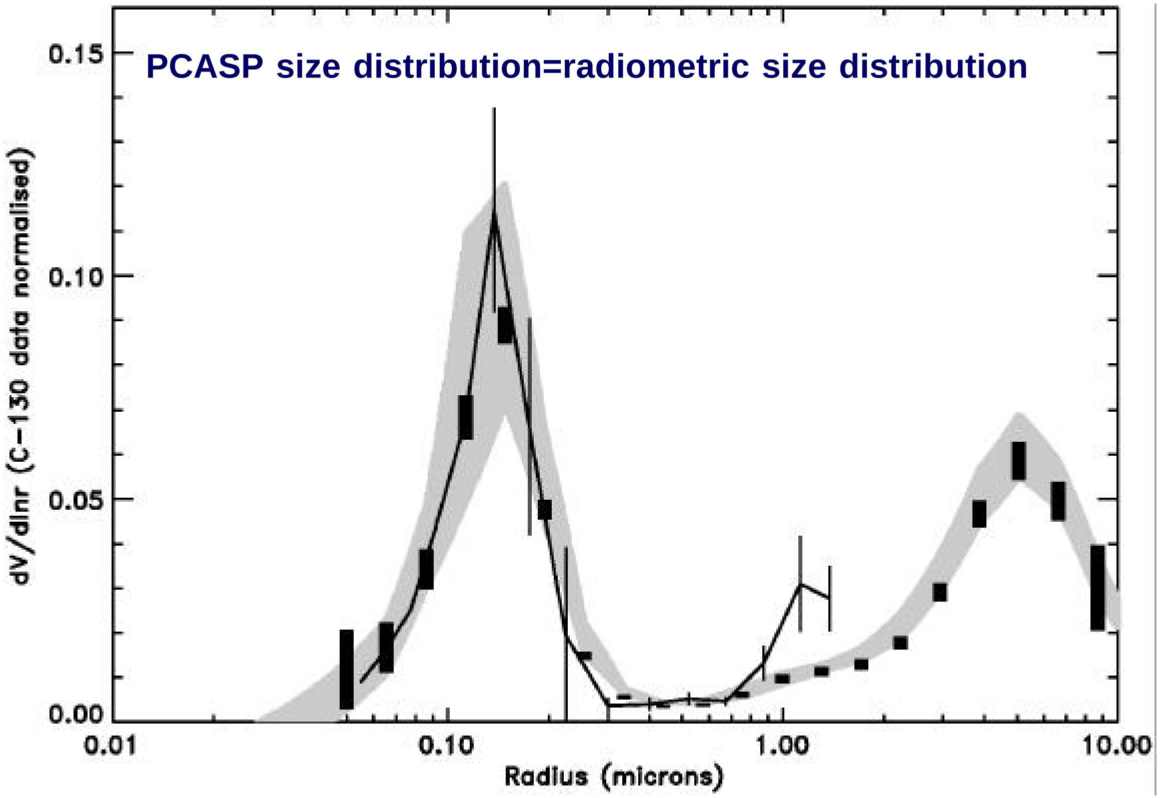
Circles - measurements
Lines – models

These results suggest that the sky radiances can be modelled most accurately when $\tau_{aer\,\lambda=0.55}$=0.52

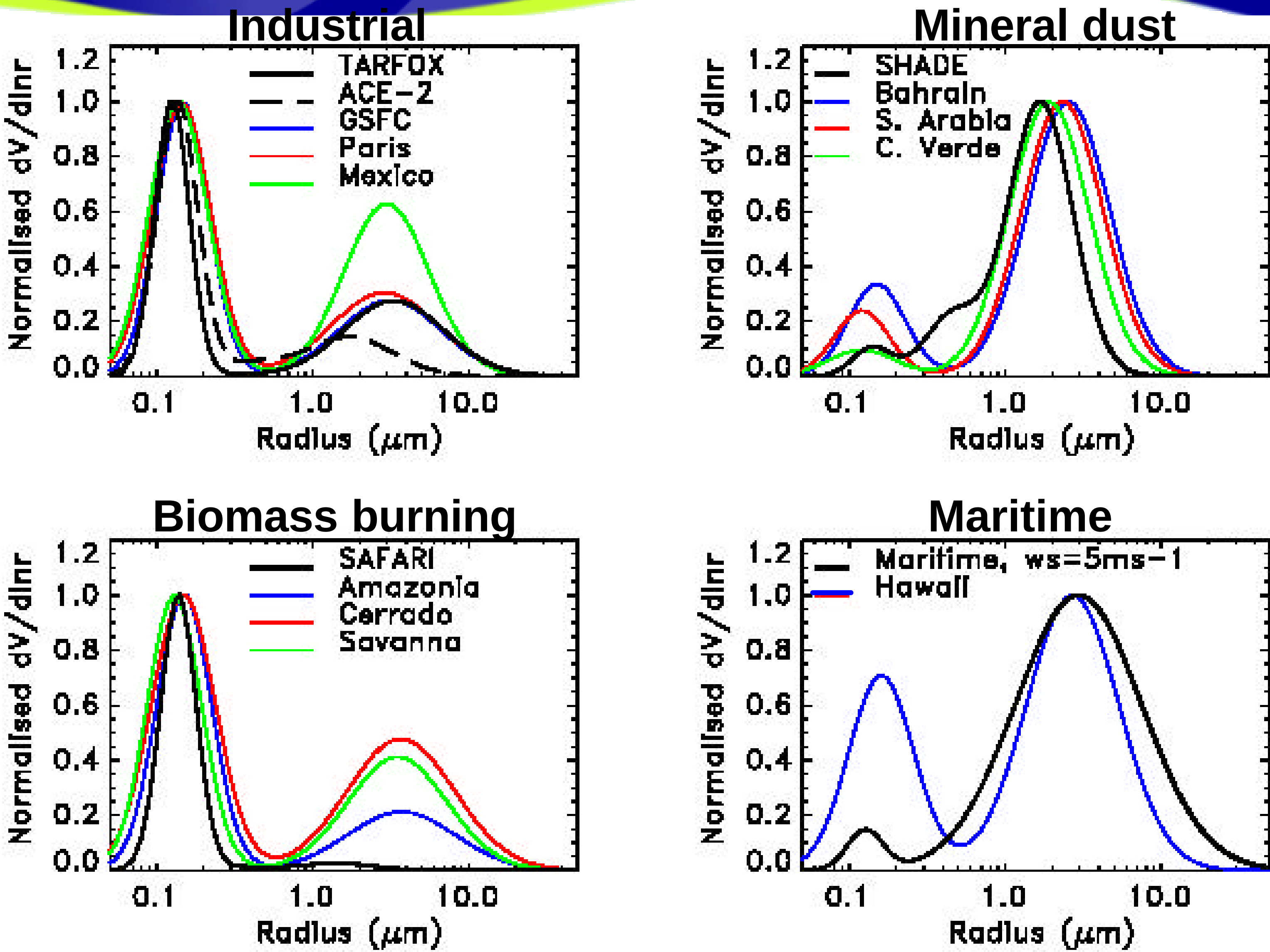
Size distributions from AERONET (accumulation mode) =PCASP

Over the radius range 0.05-1.0μm the size distributions are identical even though are determined completely independently.

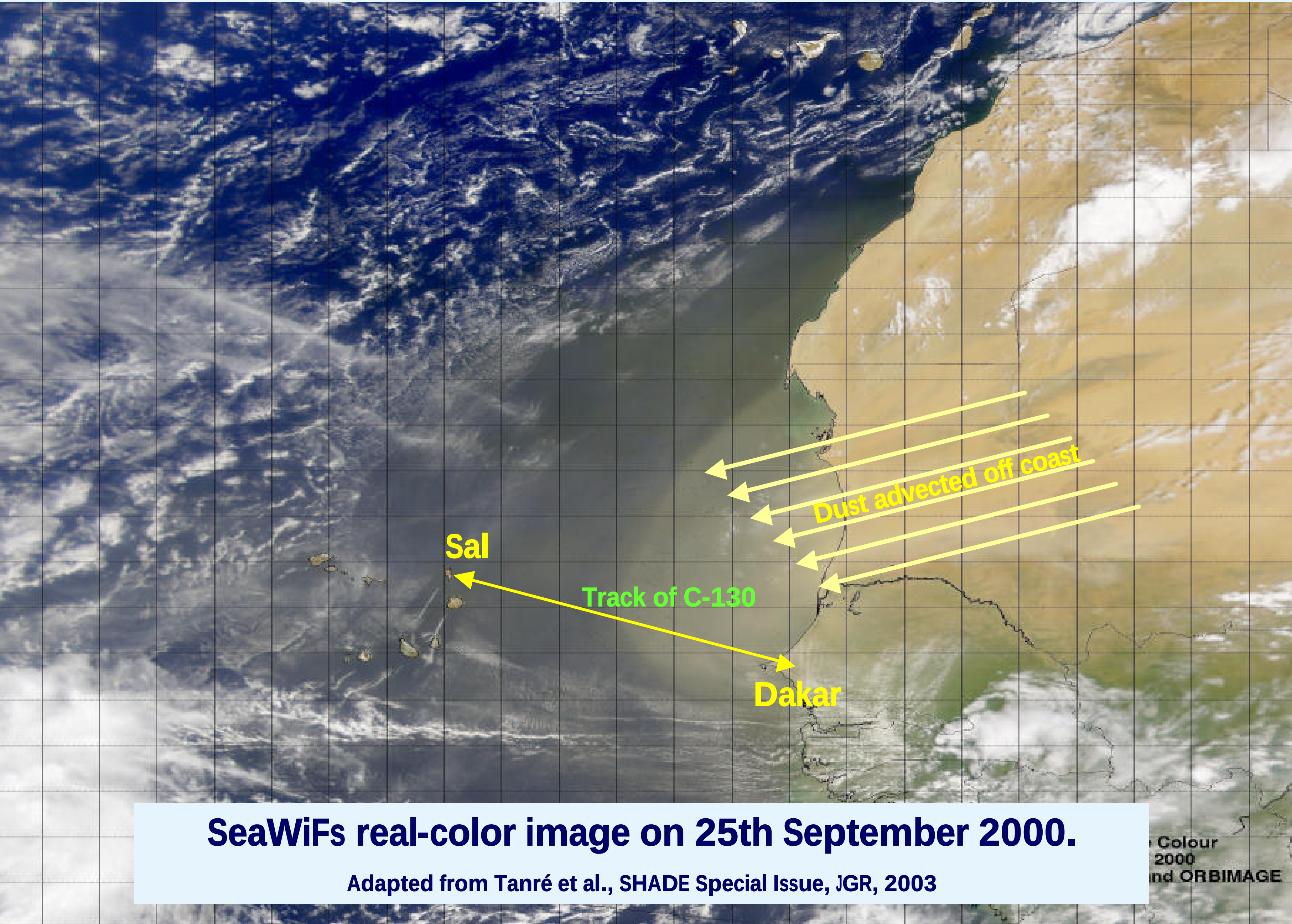
We also found excellent agreement in w_o derived from the in-situ measurements and AERONET radiometers and hence *im*.



Size distributions compare well for all aerosol types (Osborne and Haywood, 2005)



C-130 measurements during the SaHAran Dust Experiment (SHADE).



SeaWiFs real-color image on 25th September 2000.

Adapted from Tanré et al., SHADE Special Issue, JGR, 2003

Measurements of upwelling radiation above the aerosol

Max

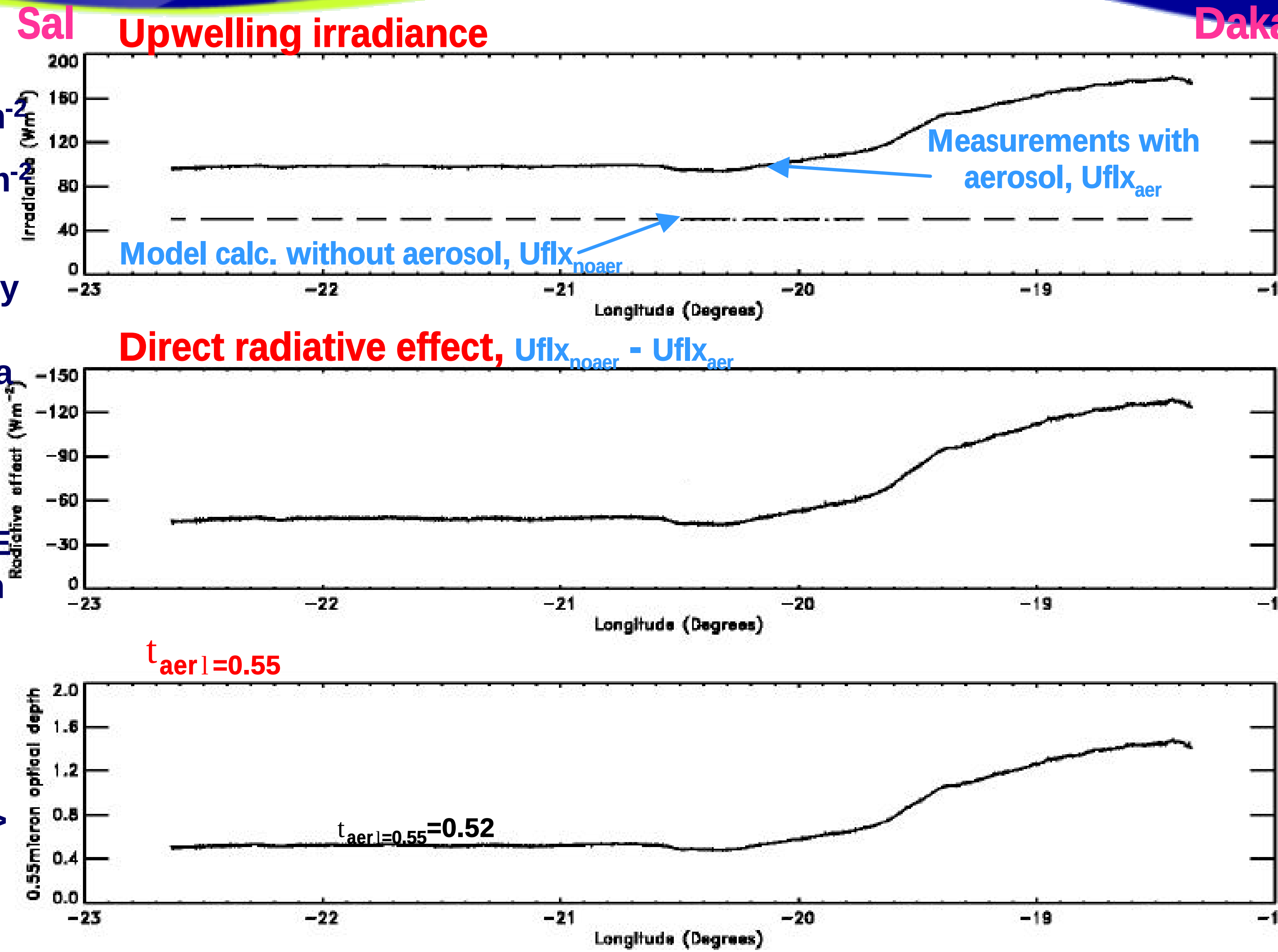
$Uflx_{aer}$>179Wm^{-2}

$Uflx_{noaer}$<50Wm^{-2}

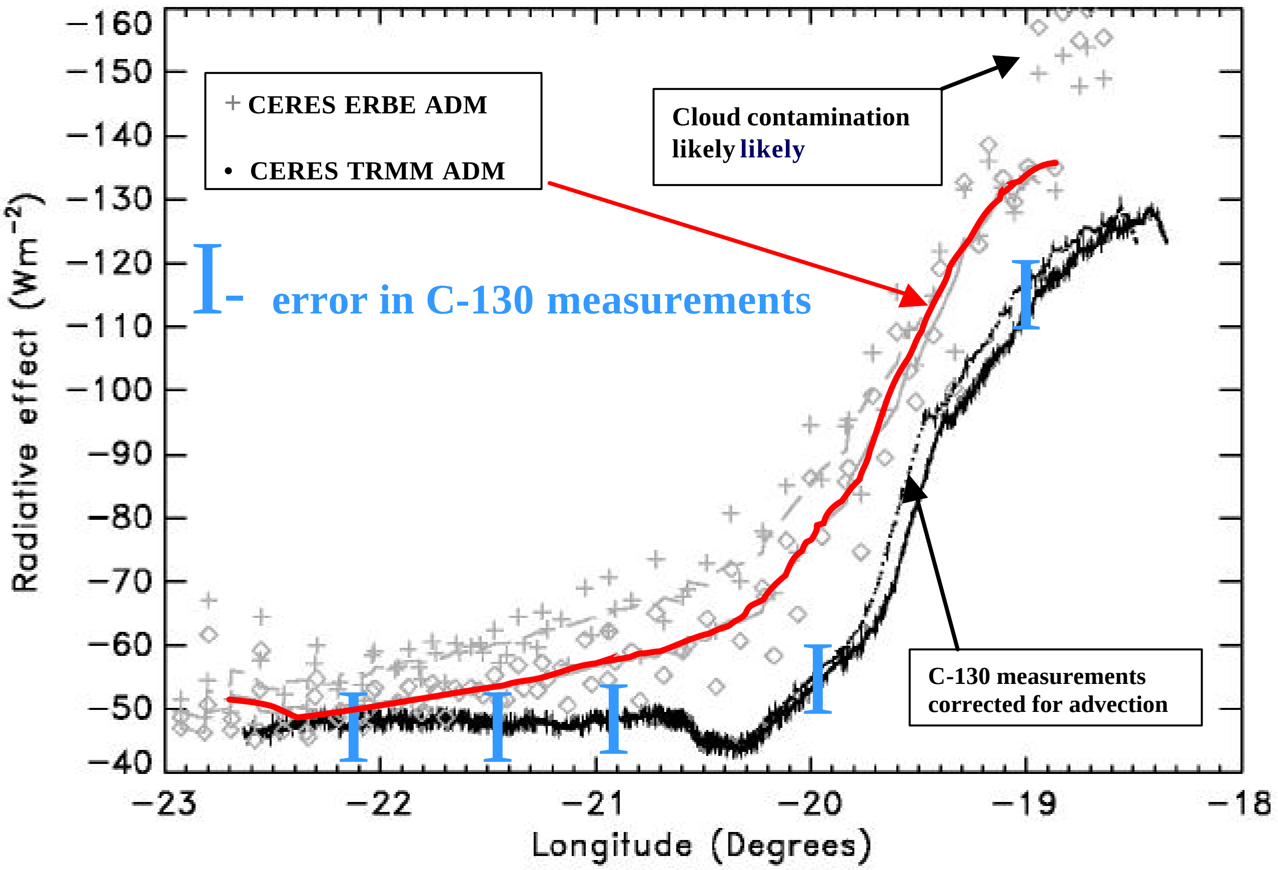
Local planetary albedo enhanced by a factor of ~3.

Max local DRE stronger than -120Wm^{-2}

Max $t_{aer l=0.55}$ > 1.5

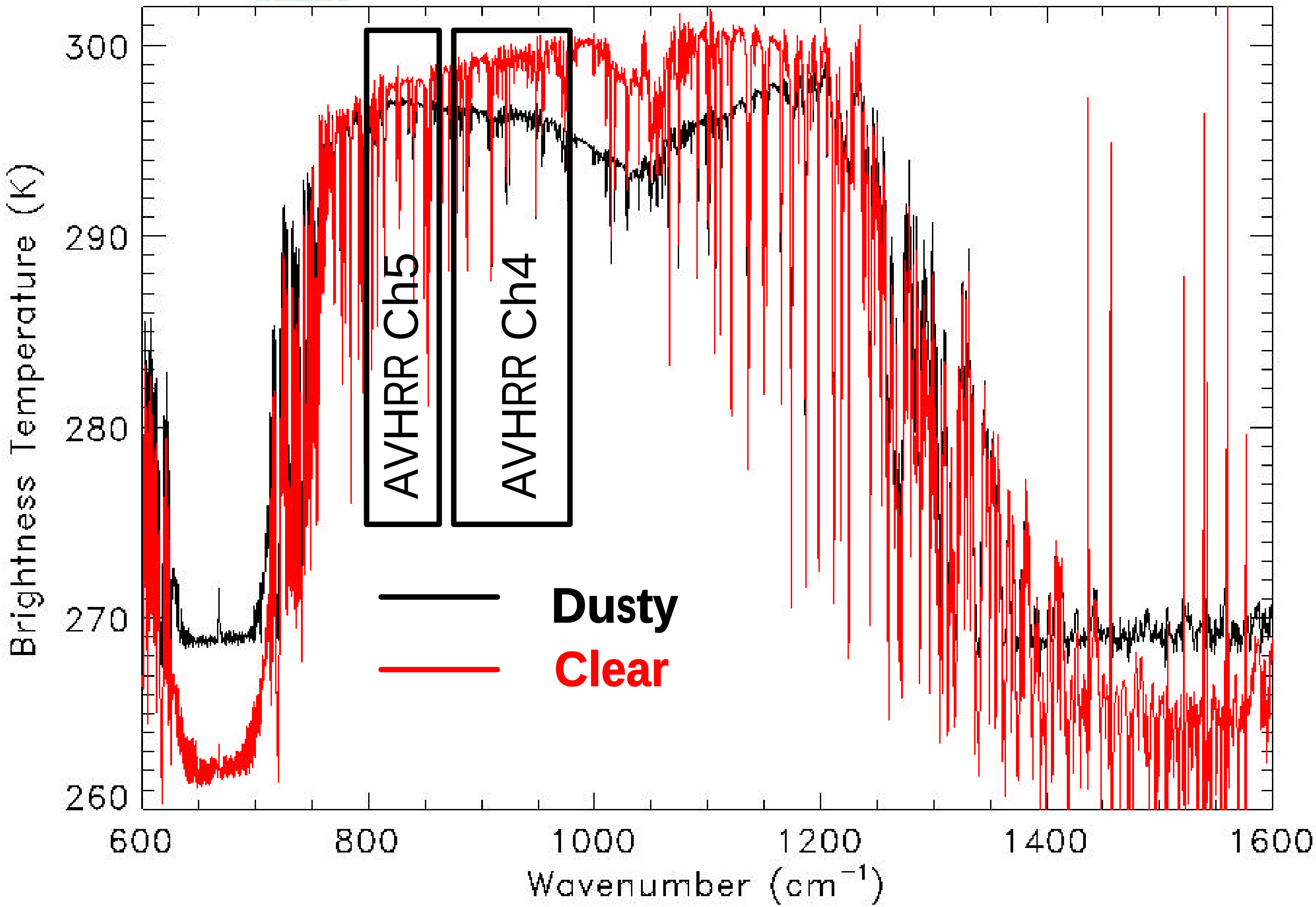


The C-130 and CERES direct radiative effects are in reasonable agreement, but outside the +/- 5Wm^{-2} error estimate for the BBRs.



Haywood et al, 2003, JGR SHADE Special Issue

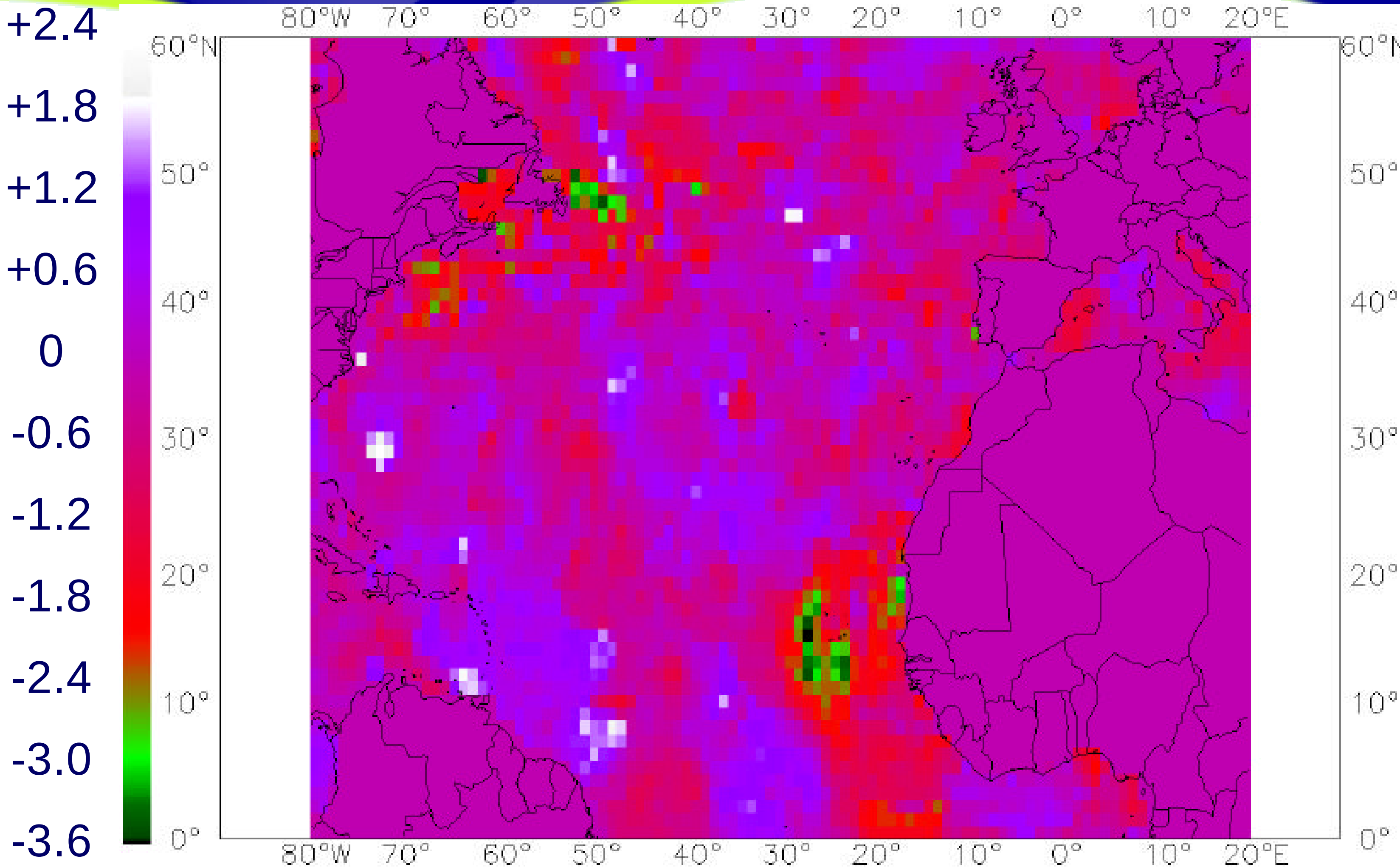
Measurements using ARIES (cm⁻¹ resolution interferometer) clearly show the effect of Saharan dust in the 8-12mm atmospheric window (Highwood et al., 2003)



Nadir views from 18,000ft (R6) (above aerosol).

Measured surface temperature (from 100ft) 302.5K

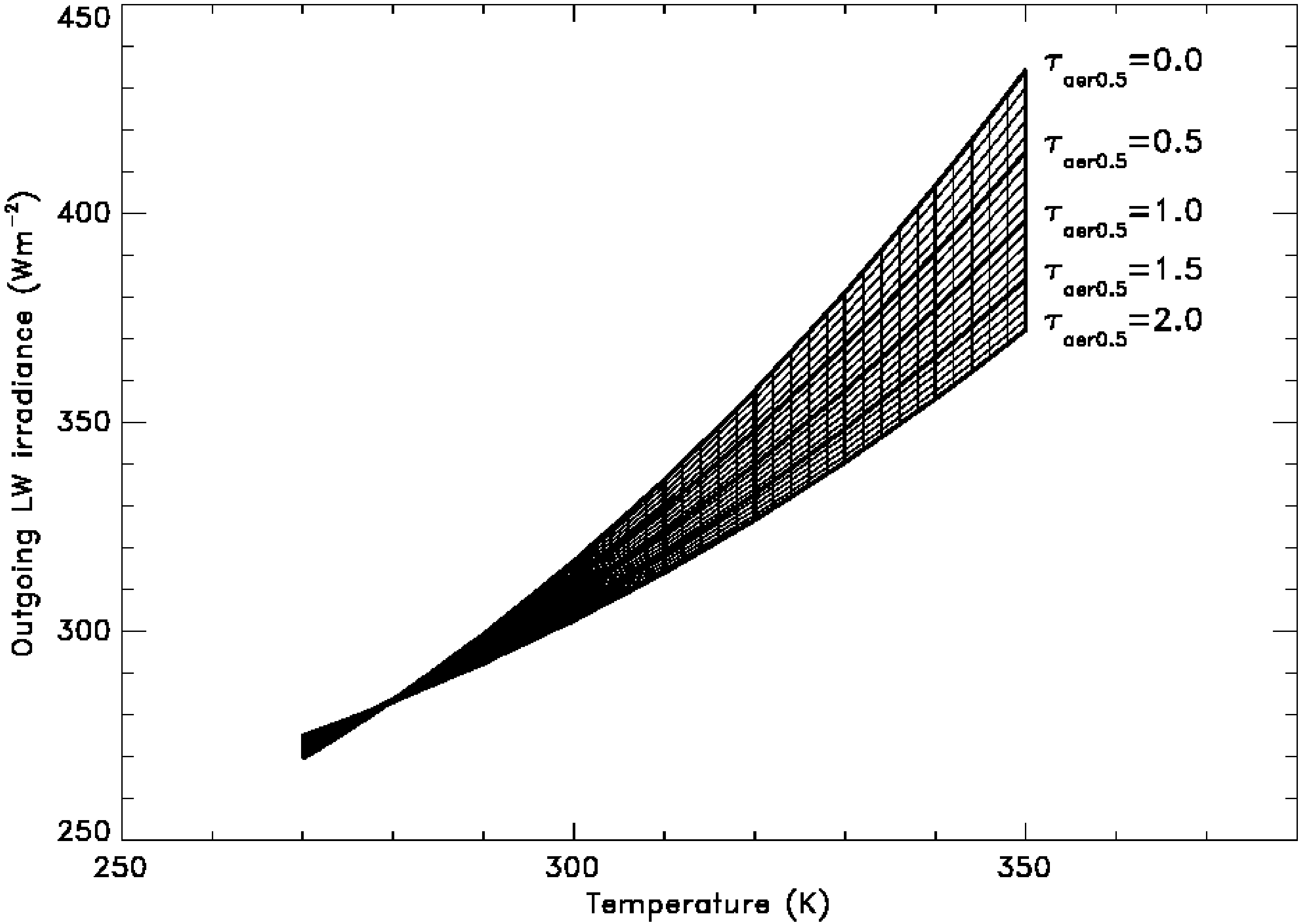
Change in SST (K) from AVHRR data between 23rd and 27th September 2000. The SST anomaly over the Cape Verde Islands is evident and reaches -3.6K.



This is an artefact of the AVHRR retrieval algorithms which do not include mineral dust

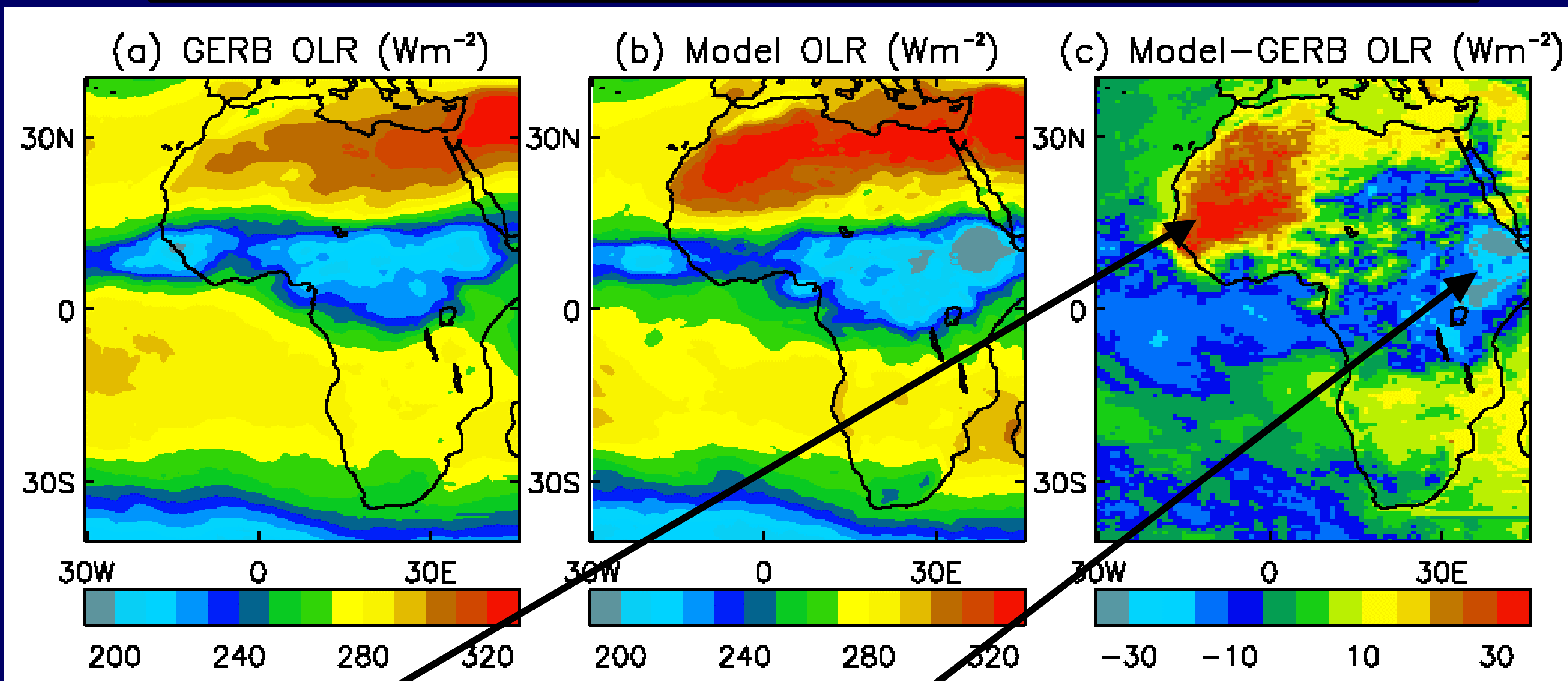
… the terrestrial effect is much stronger over warmer surfaces.

Radiative calculations using the Edwards and Slingo radiation code.



How does the NWP model OLR compare with new observations by the Geostationary Earth Radiation Budget instrument (GERB)?

Data from SINERGEE project using 6Z, 12Z, 18Z, 24Z, July 2003



The +ve anomaly over desert is ~ -ve anolmaly over ITCZ clouds

Rich Allan, Tony Slingo

Data from 12Z, July 2003

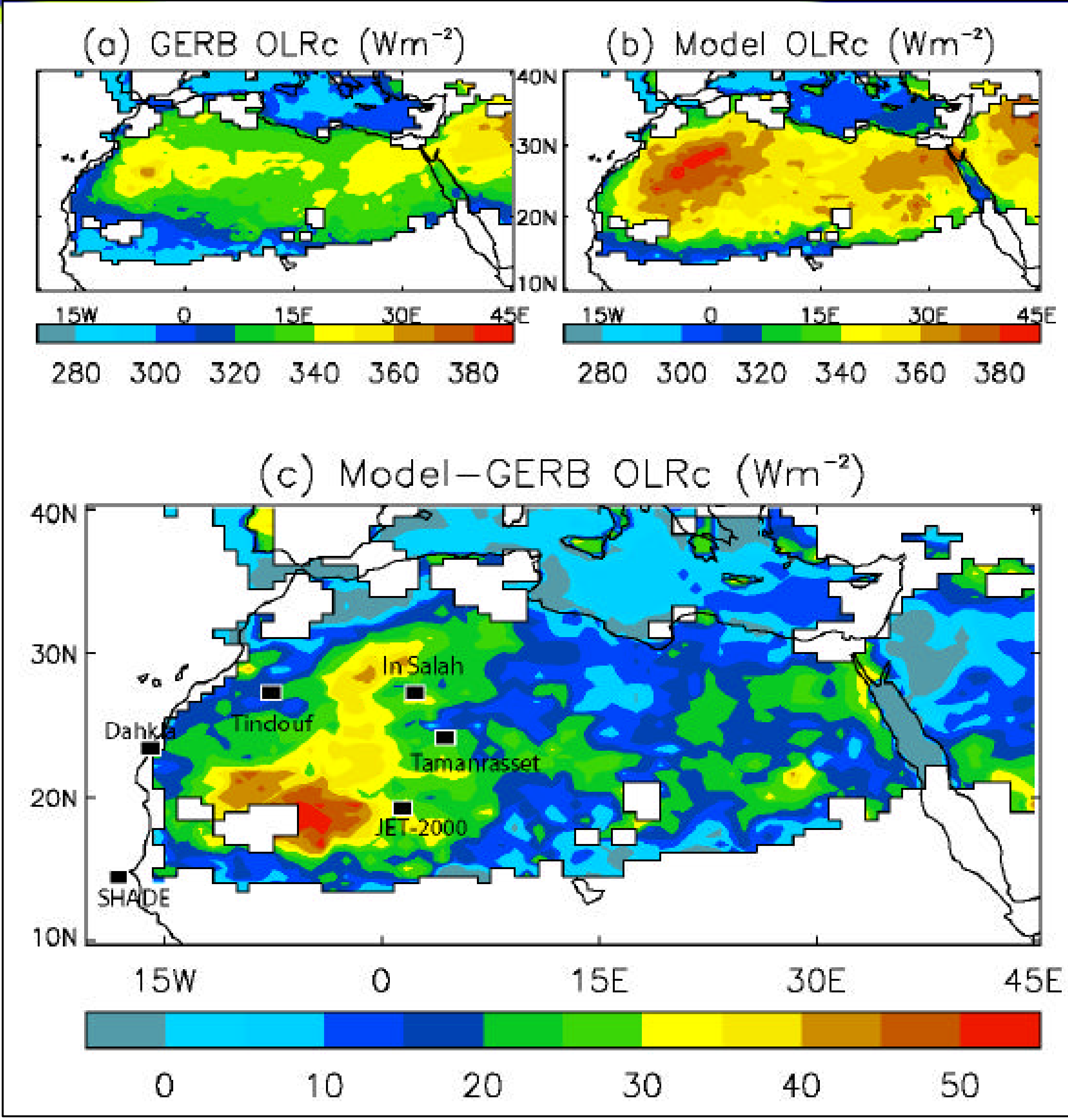
Cloud screened data

The Geostationary Earth Radiation Budget instrument (GERB) shows significantly less OLR over regions of the desert during July 2003. What is the explanation?

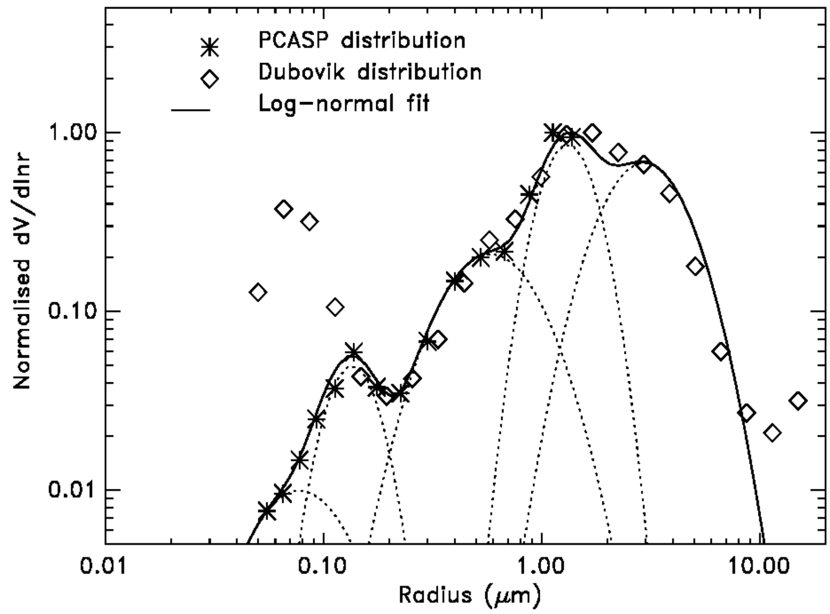
a) **Surface temperature?**

b) **Emissivity?**

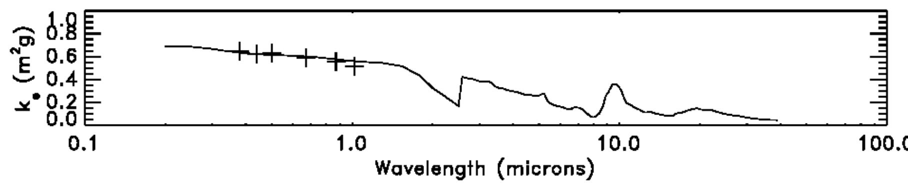
c) **Atmospheric transmission?**



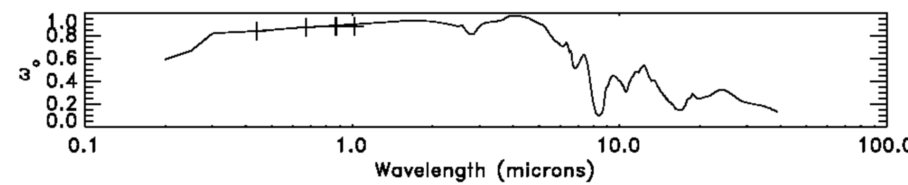
The July 2003 monthly mean aerosol size distribution from the nearby Dahkla AERONET site can be used with suitable refractive indices (Volz) to estimate the optical parameters associated with mineral dust.



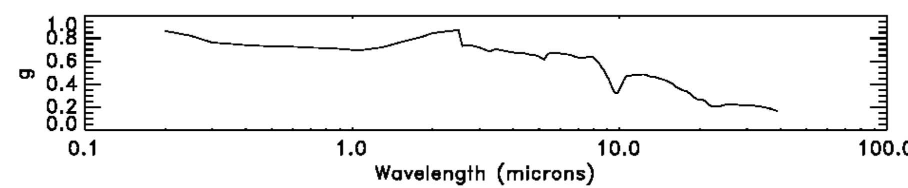
Specific extinction coefficient →

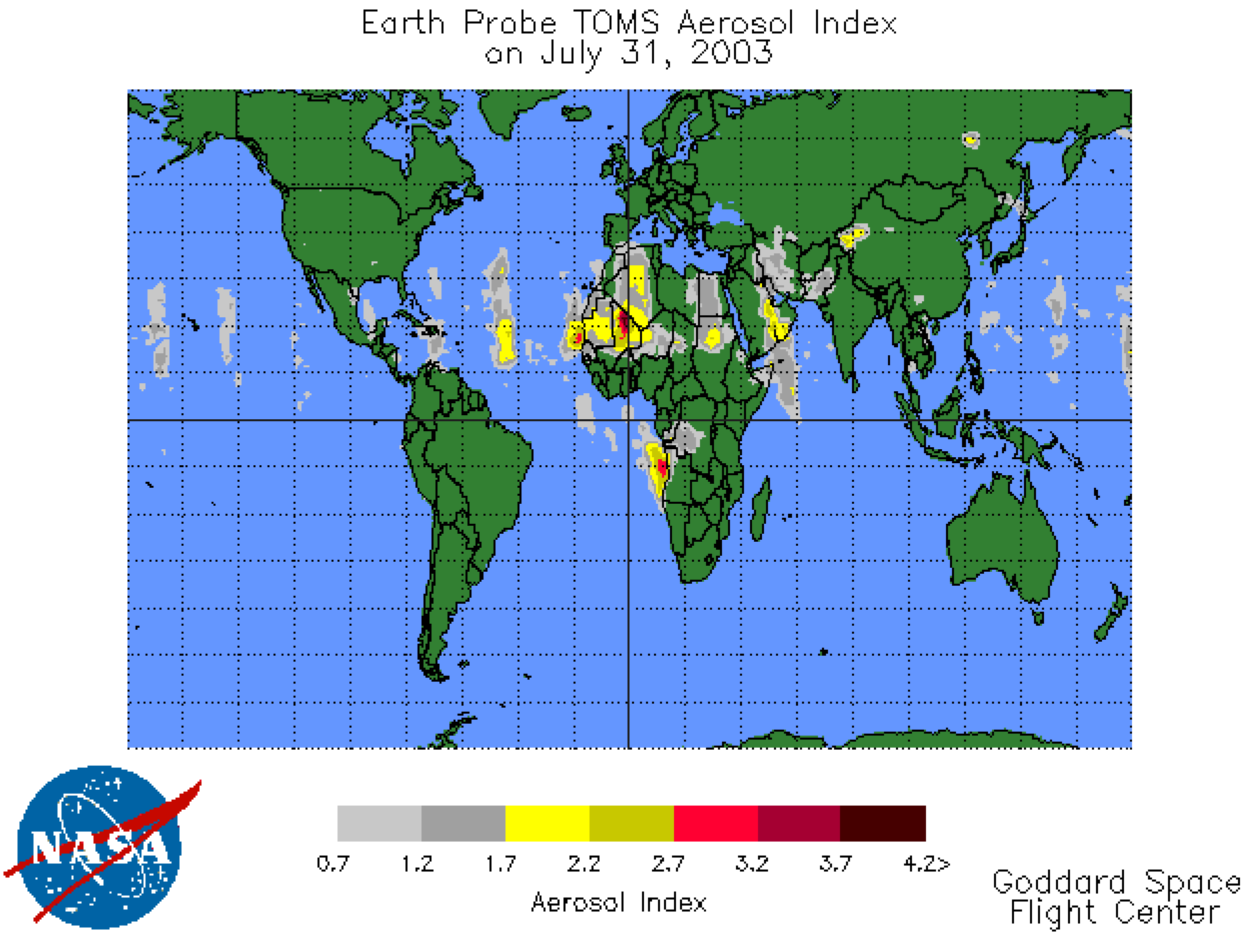


Single scattering albedo →

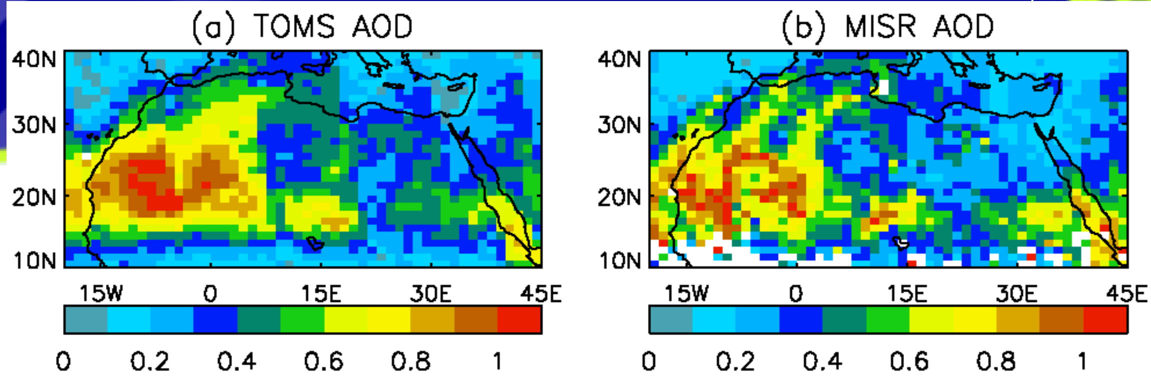


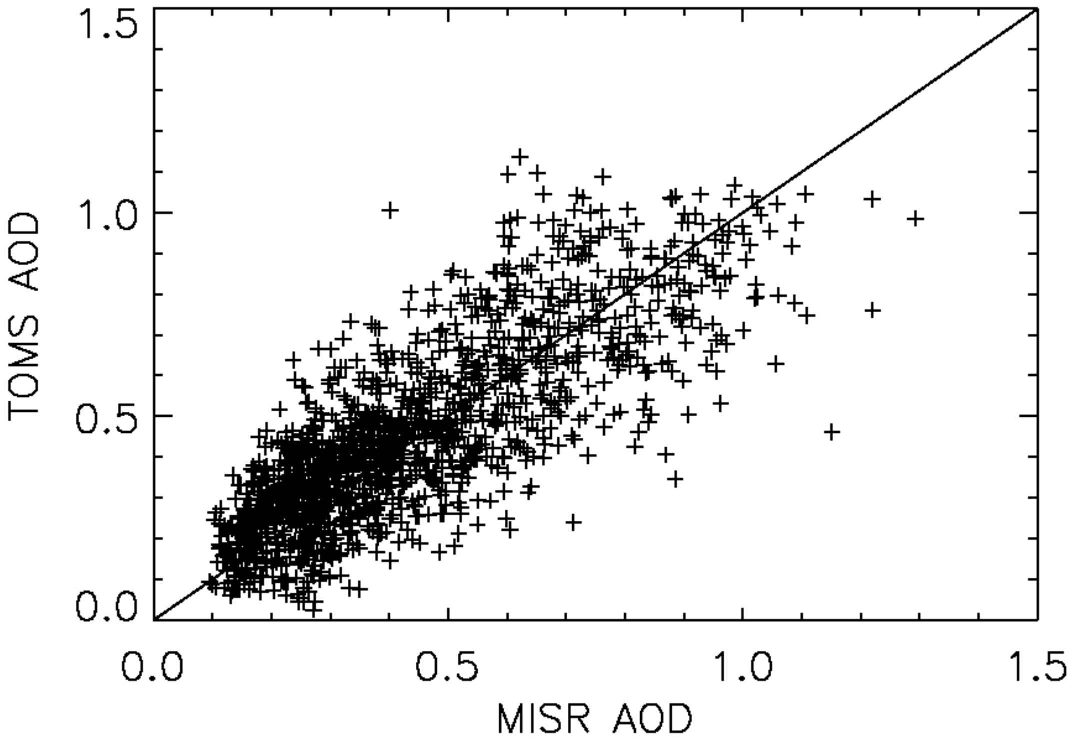
Asymmetry Factor →



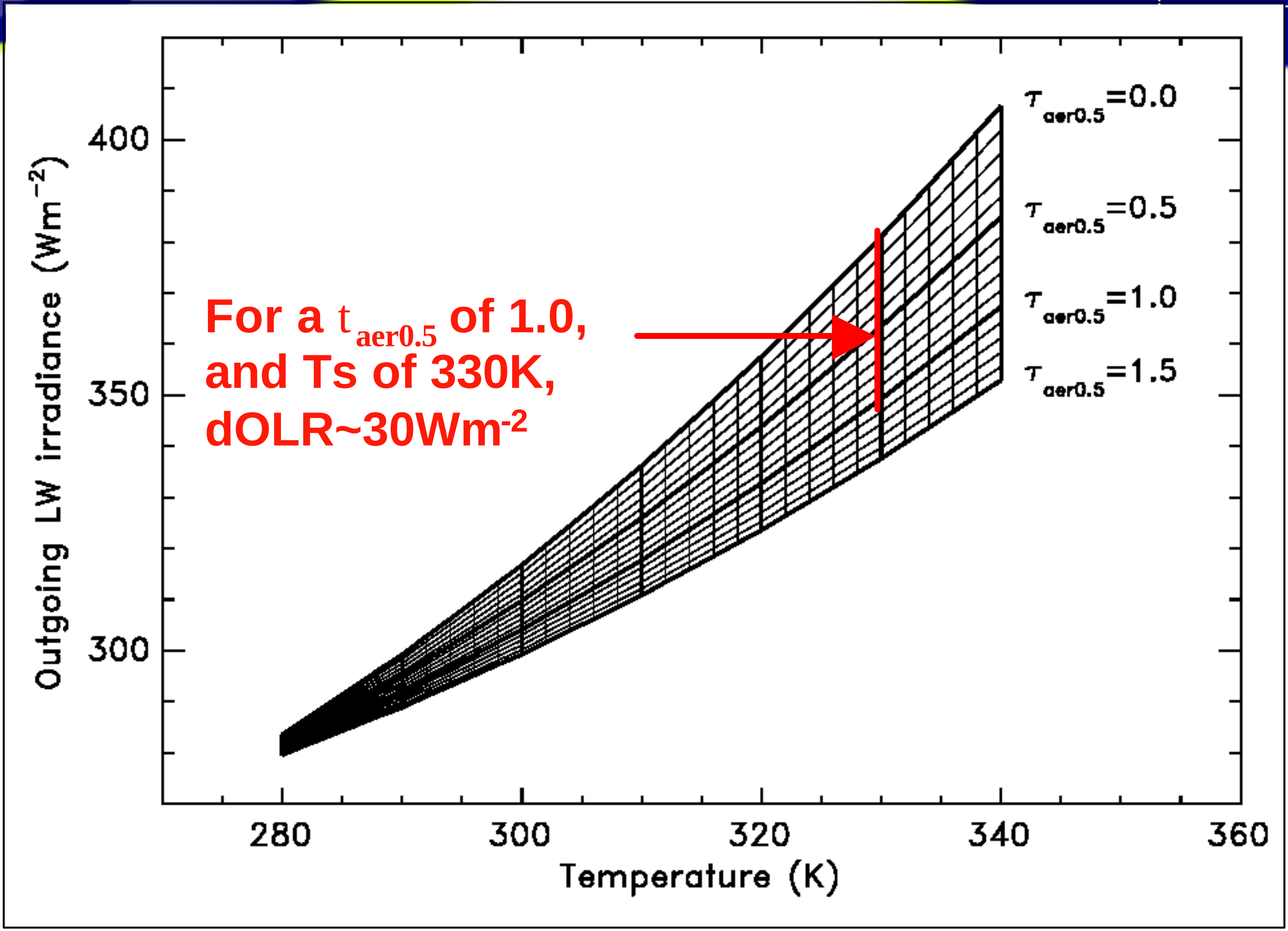

Earth Probe TOMS Aerosol Index
on July 31, 2003
0.7
1.2
1.7
2.2
2.7
3.2
3.7
4.2>
Aerosol Index
Goddard Space
Flight Center

The monthly mean TOMS AI can be converted to a monthly mean AOD using empirical relationships based on AERONET observations. The results agree with the (v. much more) sophisticated MISR instrument.

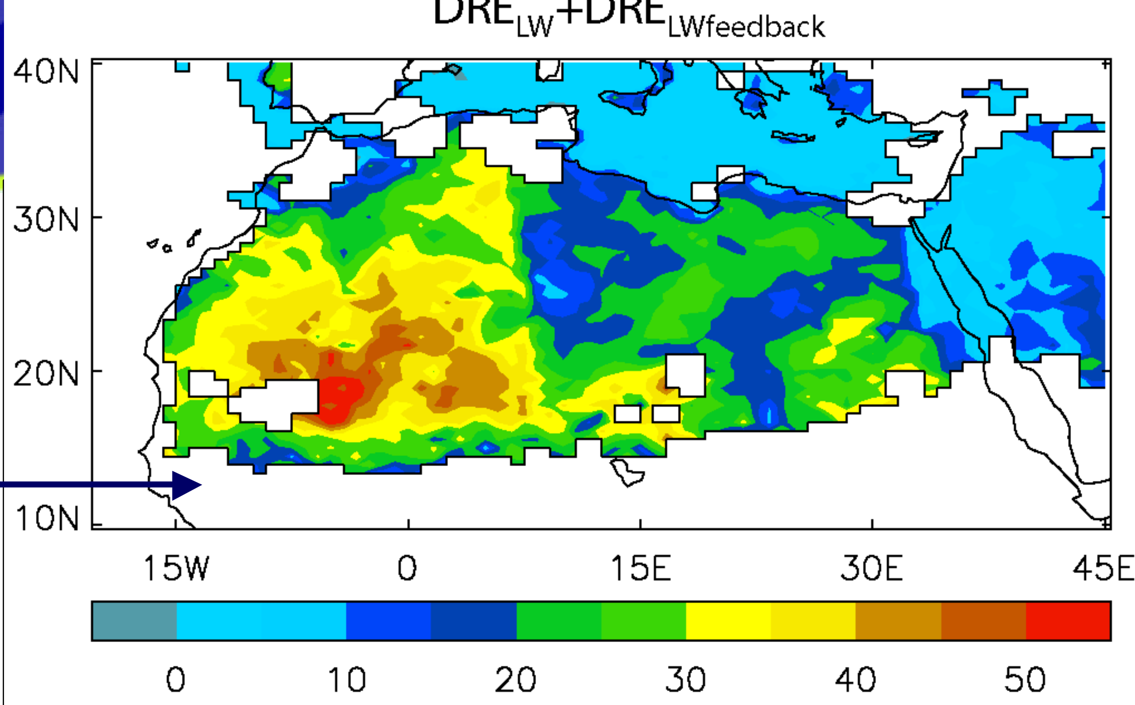




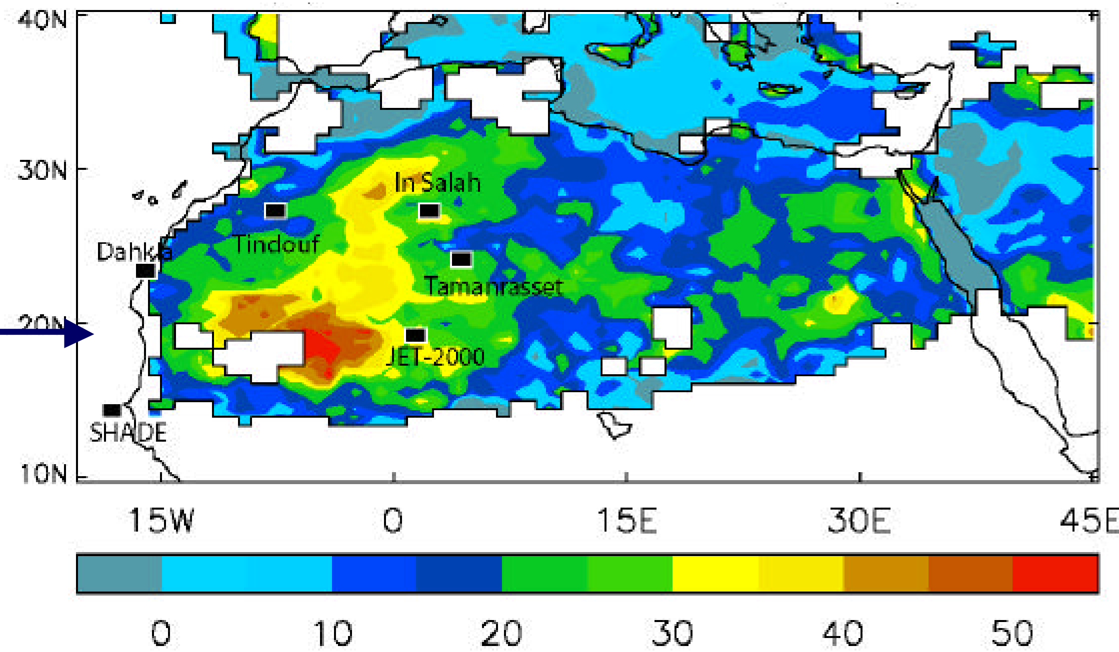
A look-up table may be produced whereby the dOLRc caused by mineral dust may be calculated as a function of aerosol optical depth and of Ts.



If we account for the effect of the aerosol on the SW at the surface which reduces the surface temperature and hence reduces the OLR as well, we end up with this.



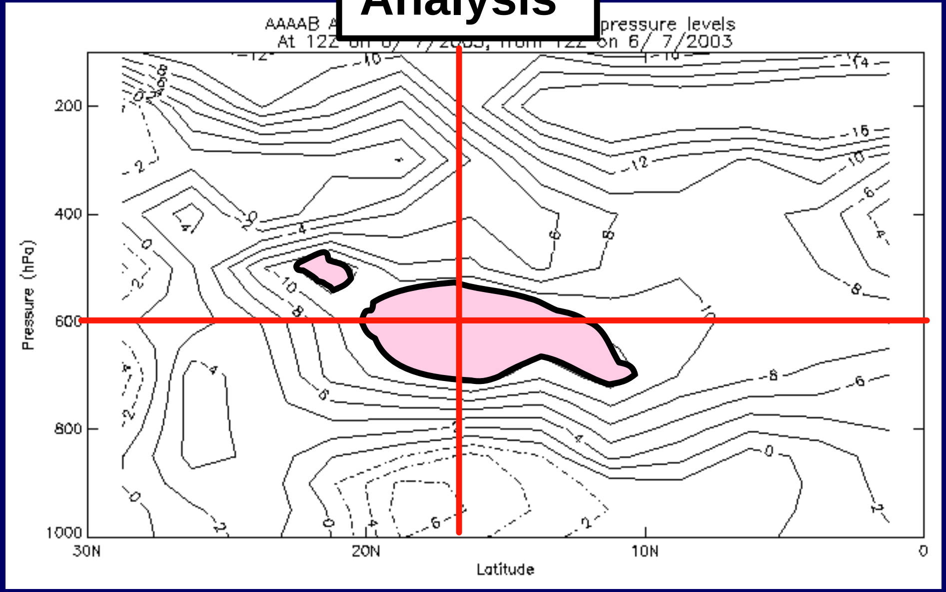
Which is in good agreement with the dOLR between GERB and the UM.



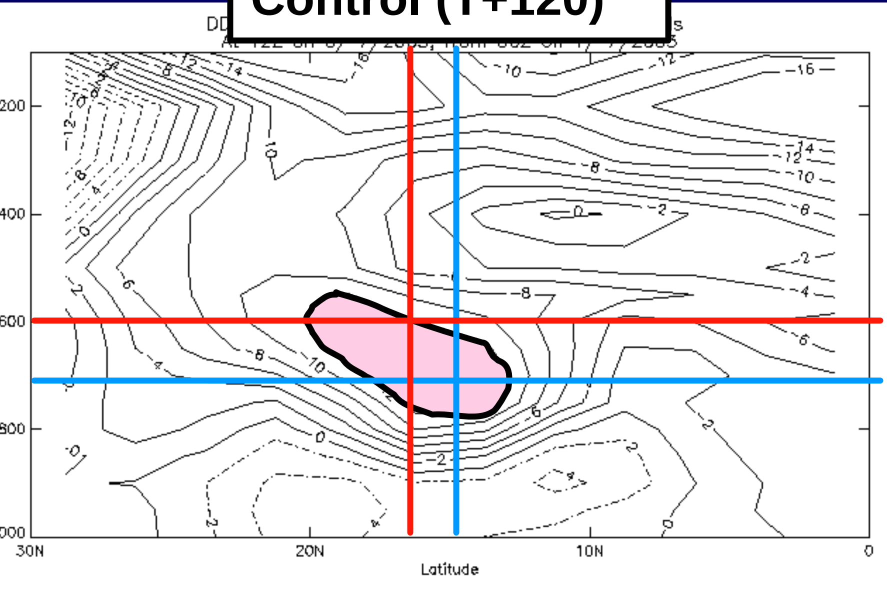
Zonal winds from 2.5-7.5W

The altitude of the AEJ (and possibly the latitude) is in better agreement with the analysis when aerosols included

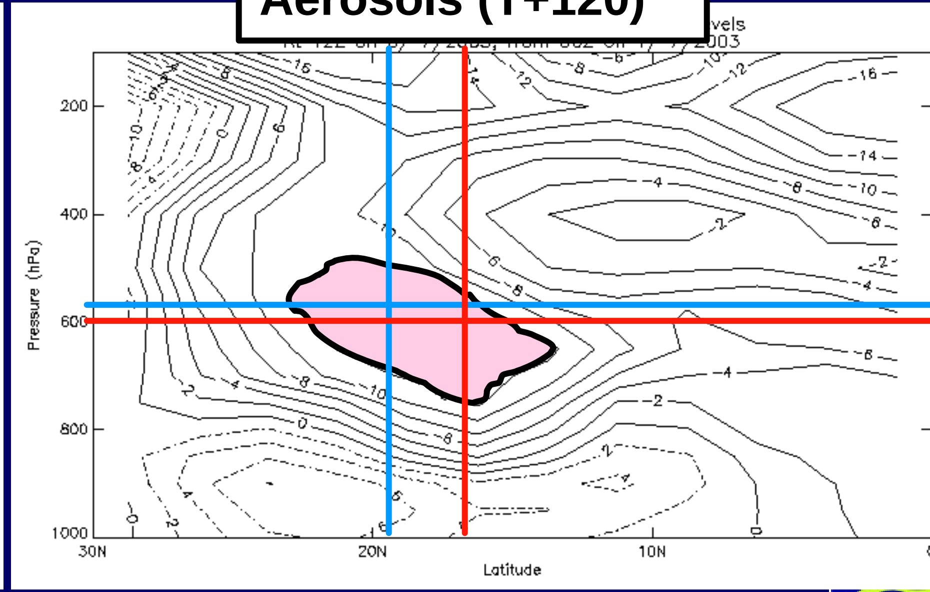
Analysis



Control (T+120)



Aerosols (T+120)



Satellite retrievals are now available over land (to a lesser accuracy; problems over reflective surfaces)

MODIS retrievals for:-

a) JFM

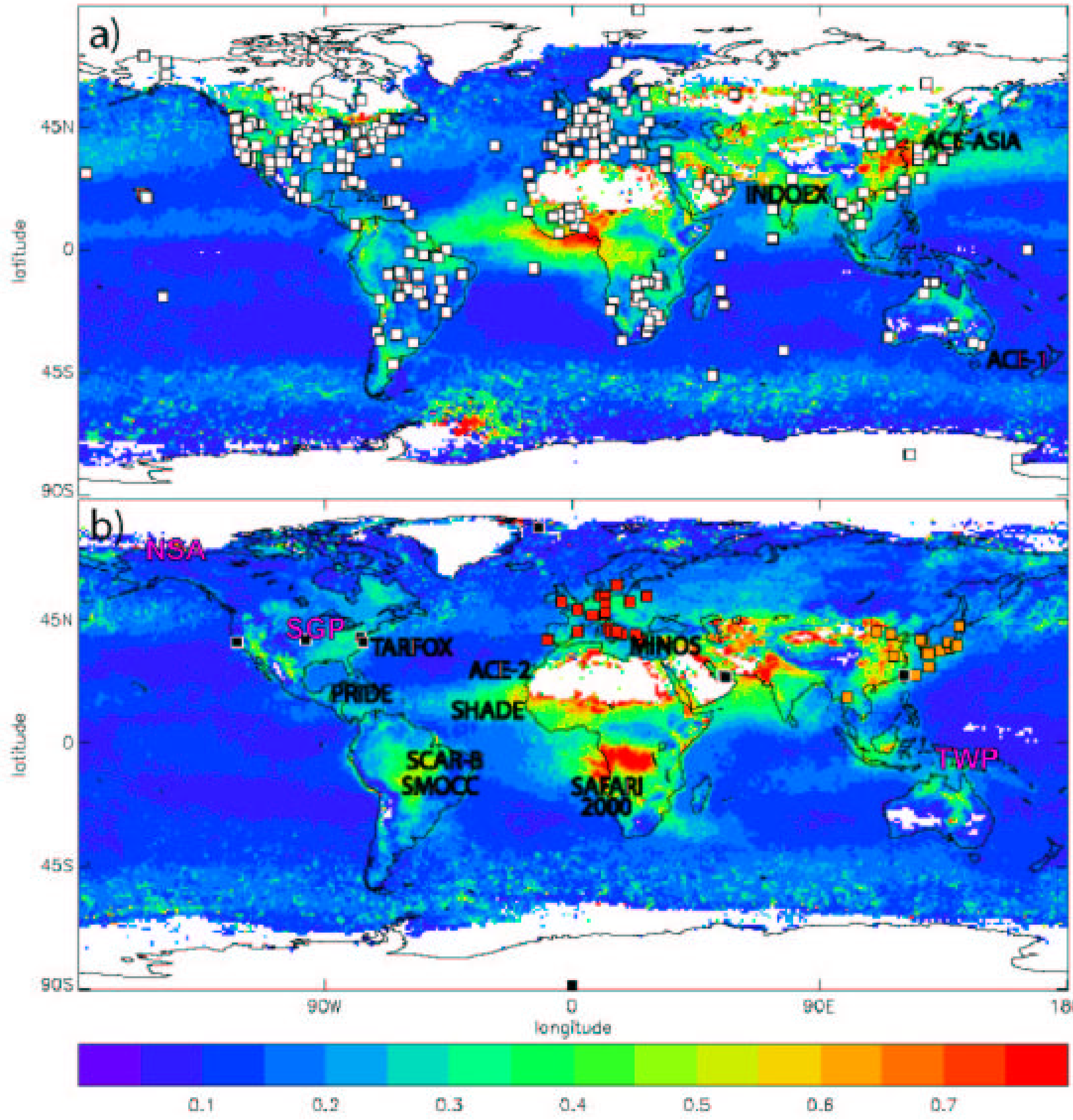
b) ASO

Using a combination of MODIS Angstrom coefficient, TOMS and SSMI it is possible to break down the total aerosol optical depth into component parts:-

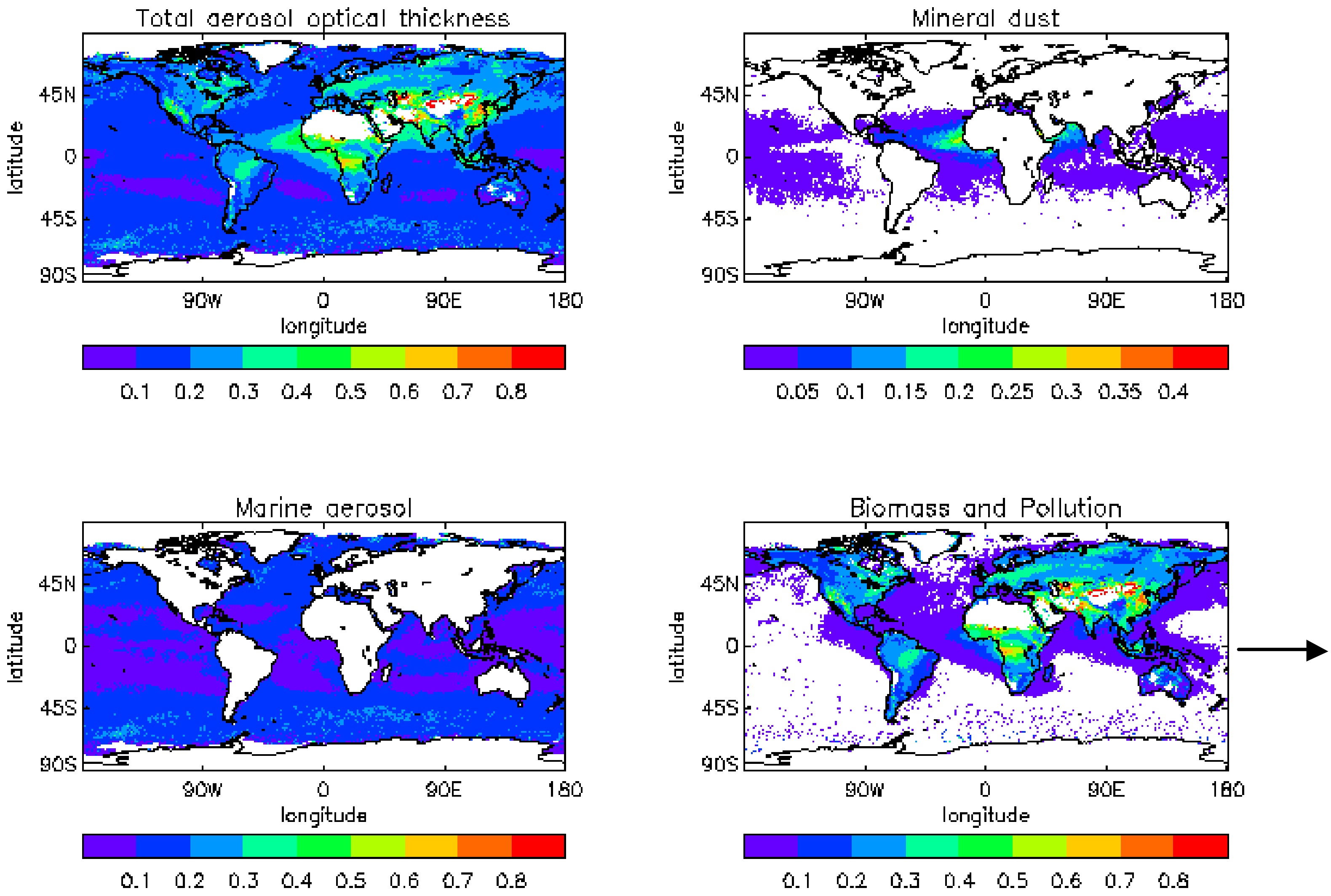
a) Sea salt aerosol

b) Mineral dust

c) Industrial aerosol/biomass burning aerosol



Bellouin et al. (submitted, 2005)



Direct radiative forcing ~ <-1.0Wm^{-2}

Conclusions

1. Observations (in-situ, surface remote sensing, satellite) are extremely useful tools in developing our understanding of the important physical processes associated with aerosols. It is important to cross calibrate these methods.
2. The direct radiative forcing due to aerosols derived from observational measurement methods is significant.
3. The radiative effects (natural component) of aerosols can be considerable particularly for thick aerosol such as mineral dust (e.g. $-120 Wm^{-2}$ in SW over ocean, $+50 Wm^{-2}$ in LW over land).
4. Aerosols (or the neglect of them) can cause significant problems in remote sensing methods (e.g. cloud optical depth, cloud effective radius, sea-surface temperatures, OLR etc).