Observational understanding of aerosols and climate

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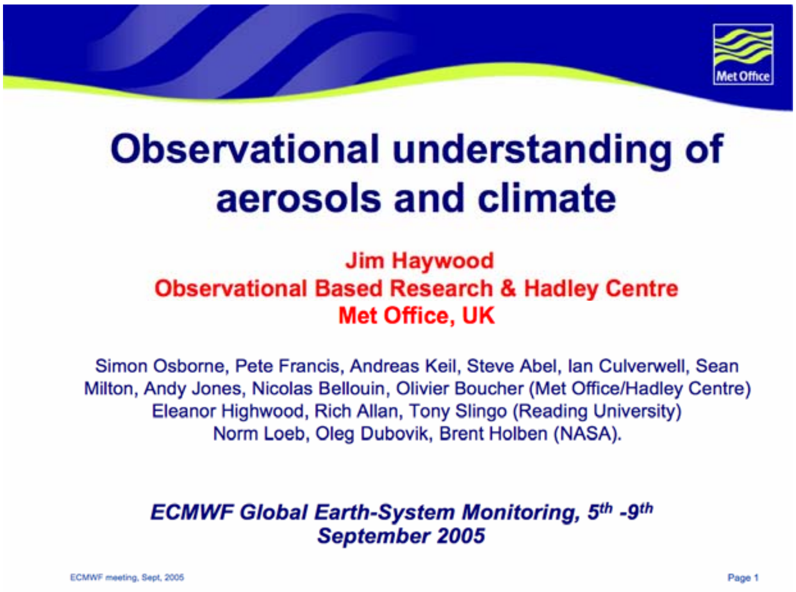

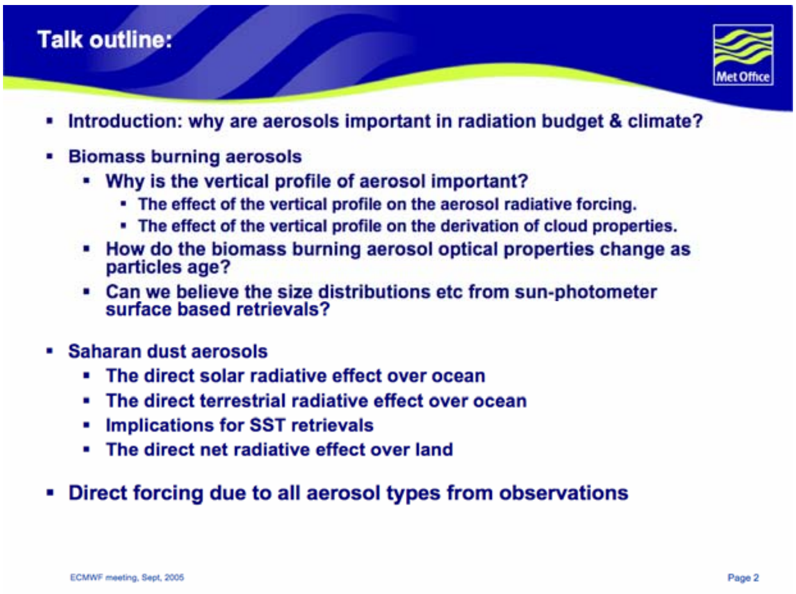

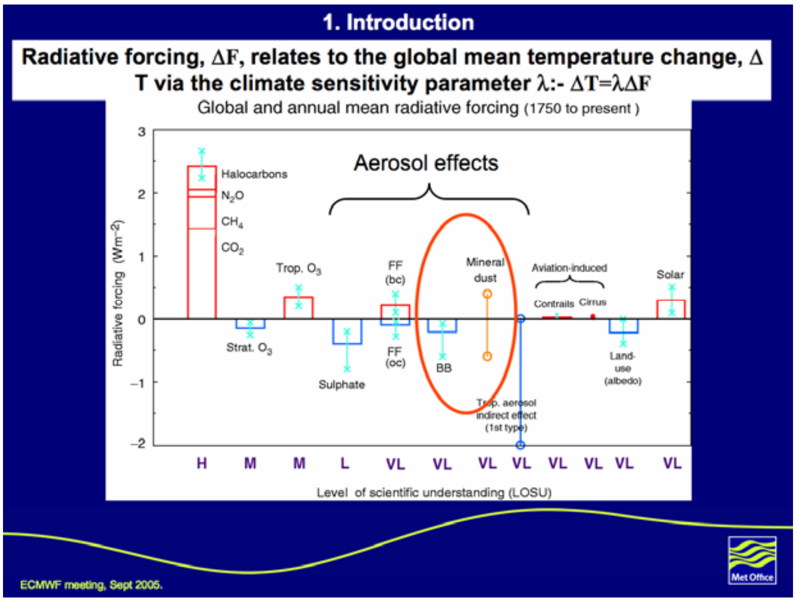
1. Introduction
Radiative forcing, ΔF, relates to the global mean temperature change, ΔT via the climate sensitivity parameter λ:- ΔT=λΔF
Global and annual mean radiative forcing (1750 to present)
Aerosol effects
Halocarbons
N2O
CH4
CO2
Trop. O3
Strat. O3
Sulphate
FF (bc)
FF (oc)
BB
Mineral dust
Trop. aerosol indirect effect (1st type)
Aviation-induced
Contrails
Cirrus
Land-use (albedo)
Solar
Radiative forcing (Wm-2)
H M M L VL VL VL VL VL VL VL VL
Level of scientific understanding (LOSU)
ECMWF meeting, Sept 2005.
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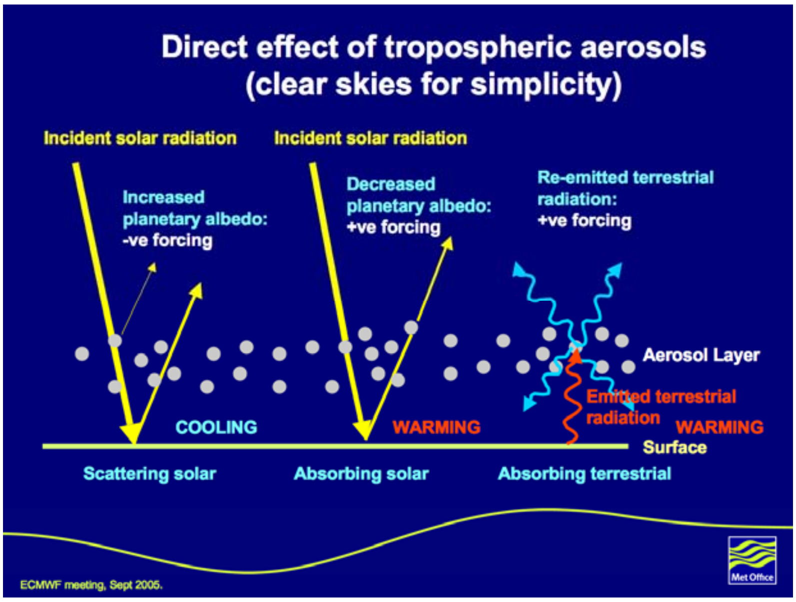
Direct effect of tropospheric aerosols
(clear skies for simplicity)
Incident solar radiation
Incident solar radiation
Increased planetary albedo: -ve forcing
Decreased planetary albedo: +ve forcing
Re-emitted terrestrial radiation: +ve forcing
Aerosol Layer
Emitted terrestrial radiation
COOLING
WARMING
WARMING
Surface
Scattering solar
Absorbing solar
Absorbing terrestrial
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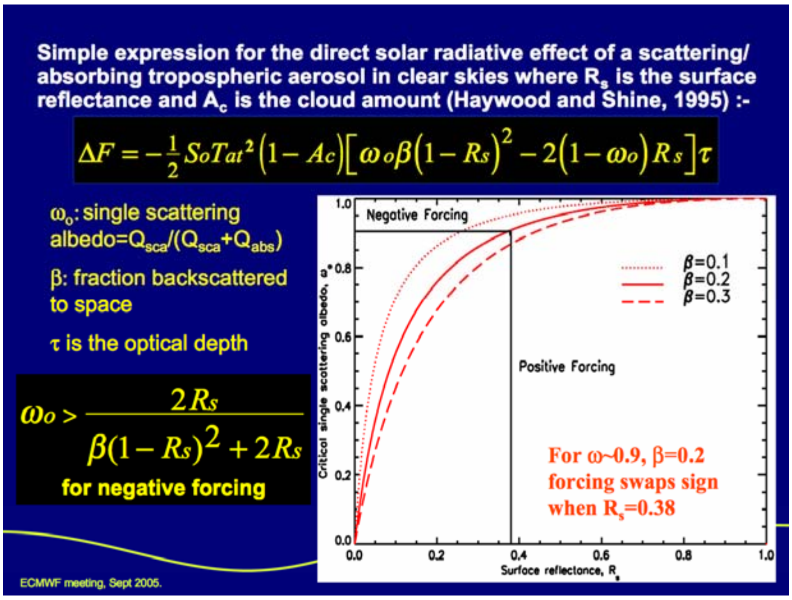
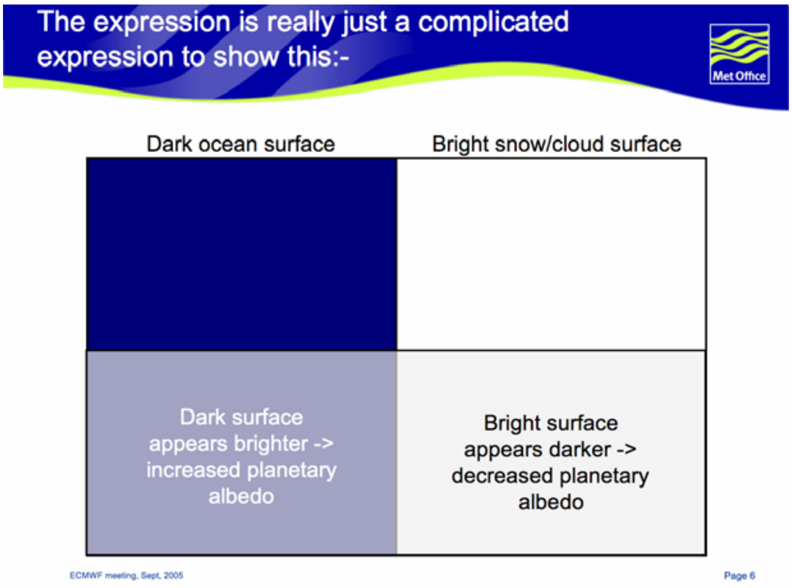
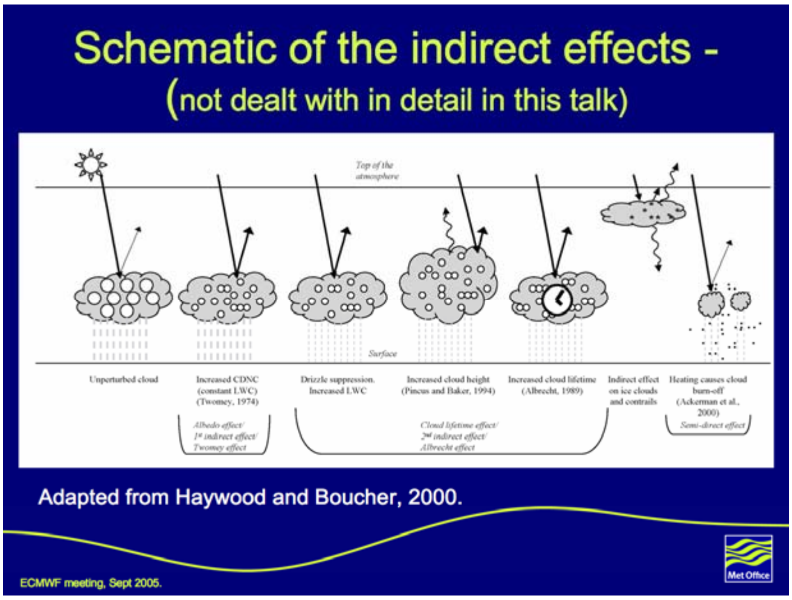
Met Office


Simple expression for the direct solar radiative effect of a scattering/absorbing tropospheric aerosol in clear skies where Rs is the surface reflectance and Ac is the cloud amount (Haywood and Shine, 1995) :-
$\Delta F = -\frac{1}{2} S_o T_{at}^2 (1-A_c)[\omega_o \beta (1-R_s)^2 - 2(1-\omega_o) R_s]\tau$
ωo: single scattering albedo=Qsca/(Qsca+Qabs)
β: fraction backscattered to space
τ is the optical depth
$\omega_o > \frac{2R_s}{\beta(1-R_s)^2 + 2R_s}$
for negative forcing
Negative Forcing
Positive Forcing
β=0.1
β=0.2
β=0.3
Critical single scattering albedo, ωo
Surface reflectance, Rs
For ω~0.9, β=0.2 forcing swaps sign when Rs=0.38
ECMWF meeting, Sept 2005.





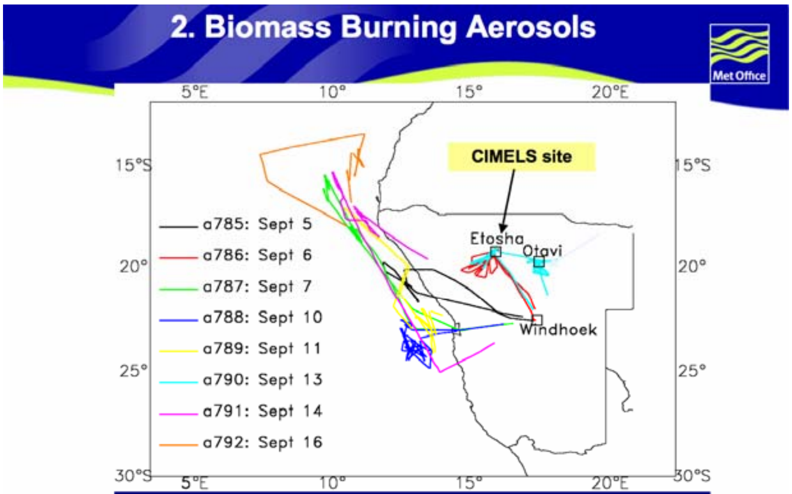
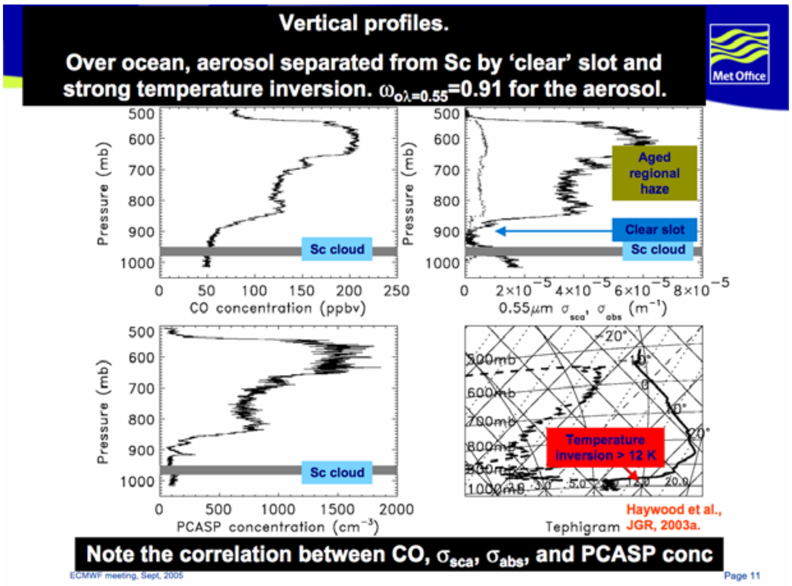


Figure 1: Map showing the geographical location of the flights performed by the C-130 during SAFARI 2000. The approximate positions of Windhoek, Etosha, and Otavi are marked. The geopolitical outline of Namibia is also shown.


Vertical profiles.
Over ocean, aerosol separated from Sc by 'clear' slot and strong temperature inversion. $\omega_{o\lambda=0.55}$=0.91 for the aerosol.
Met Office
Pressure (mb)
Sc cloud
CO concentration (ppbv)
Aged regional haze
Clear slot
Sc cloud
0.55μm σ_{sca}, σ_{abs} (m^{-1})
Sc cloud
PCASP concentration (cm^{-3})
Temperature inversion > 12 K
Tephigram
Haywood et al., JGR, 2003a.
Note the correlation between CO, σ_{sca}, σ_{abs}, and PCASP conc
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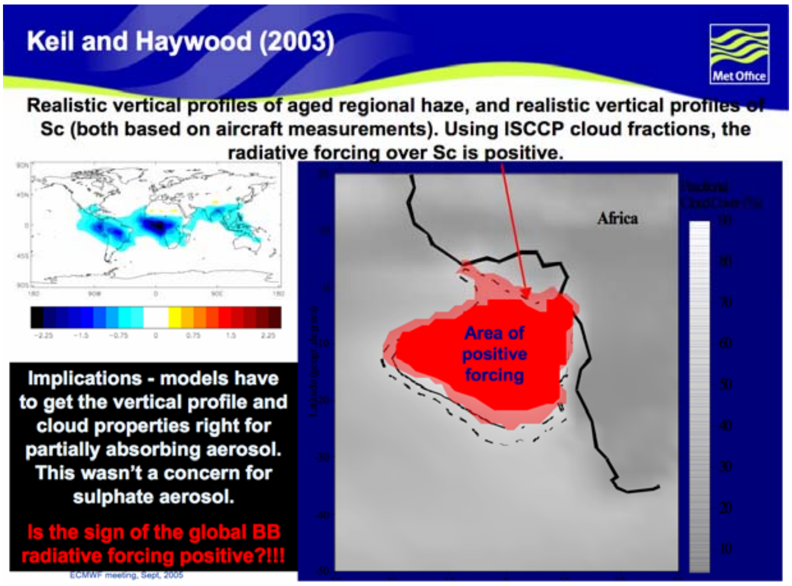
Keil and Haywood (2003)
Met Office
Realistic vertical profiles of aged regional haze, and realistic vertical profiles of Sc (both based on aircraft measurements). Using ISCCP cloud fractions, the radiative forcing over Sc is positive.
Africa
Area of positive forcing
Implications - models have to get 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?!!!
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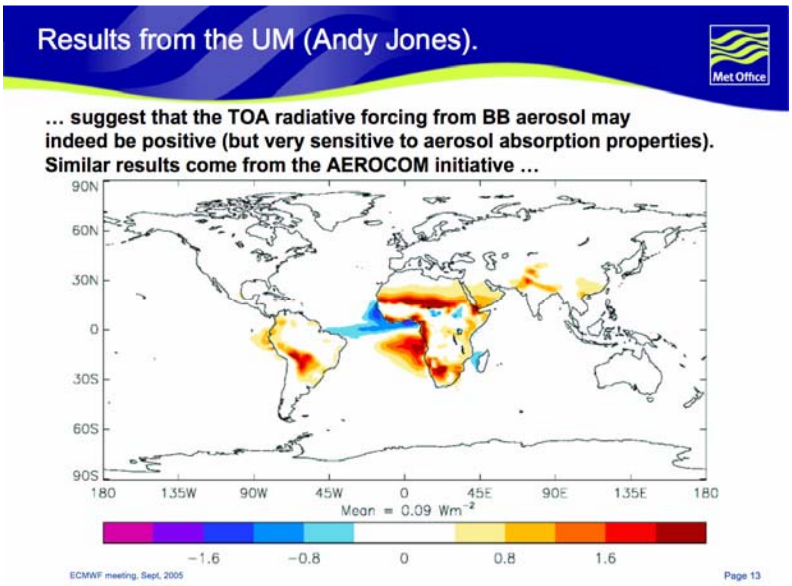
Results from the UM (Andy Jones).
Met Office
… suggest that the TOA radiative forcing from BB aerosol may indeed be positive (but very sensitive to aerosol absorption properties). Similar results come from the AEROCOM initiative …
Mean = 0.09 Wm^{-2}
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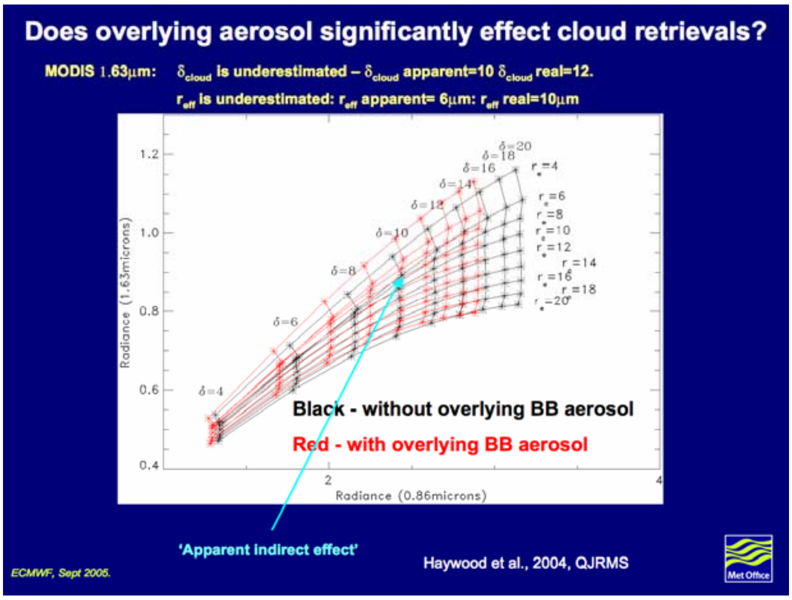
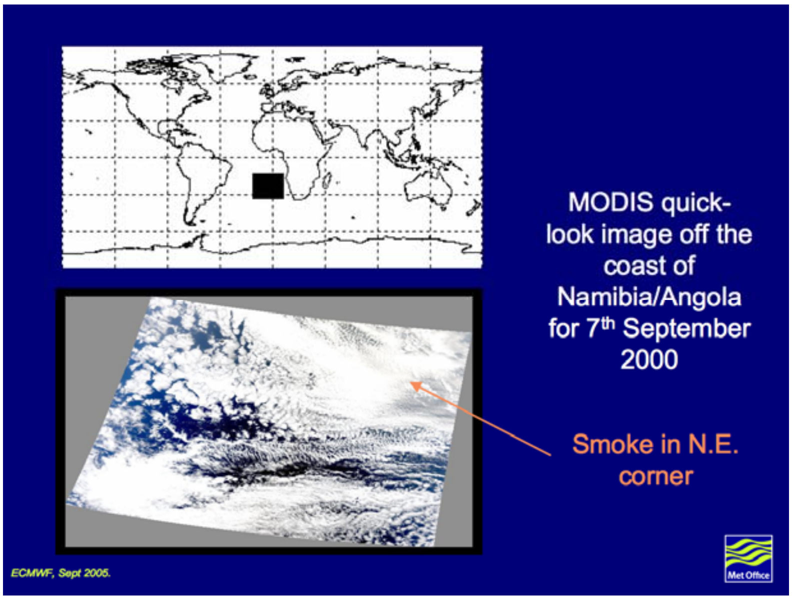
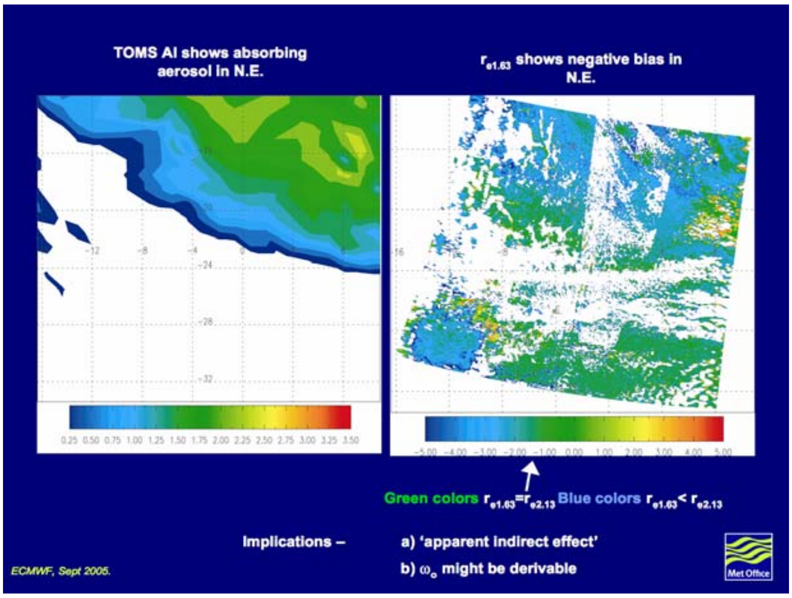

Does overlying aerosol significantly effect cloud retrievals?
MODIS 1.63µm: δcloud is underestimated – δcloud apparent=10 δcloud real=12.
reff is underestimated: reff apparent= 6µm: reff real=10µm
Black - without overlying BB aerosol
Red - with overlying BB aerosol
Radiance (1.63microns)
Radiance (0.86microns)
'Apparent indirect effect'
Haywood et al., 2004, QJRMS
ECMWF, Sept 2005.
Met Office


MODIS quick-look image off the coast of Namibia/Angola for 7th September 2000
Smoke in N.E. corner
ECMWF, Sept 2005.
Met Office


TOMS AI shows absorbing aerosol in N.E.
re1.63 shows negative bias in N.E.
Green colors re1.63=re2.13 Blue colors re1.63< re2.13
Implications –
a) 'apparent indirect effect'
b) ωo might be derivable
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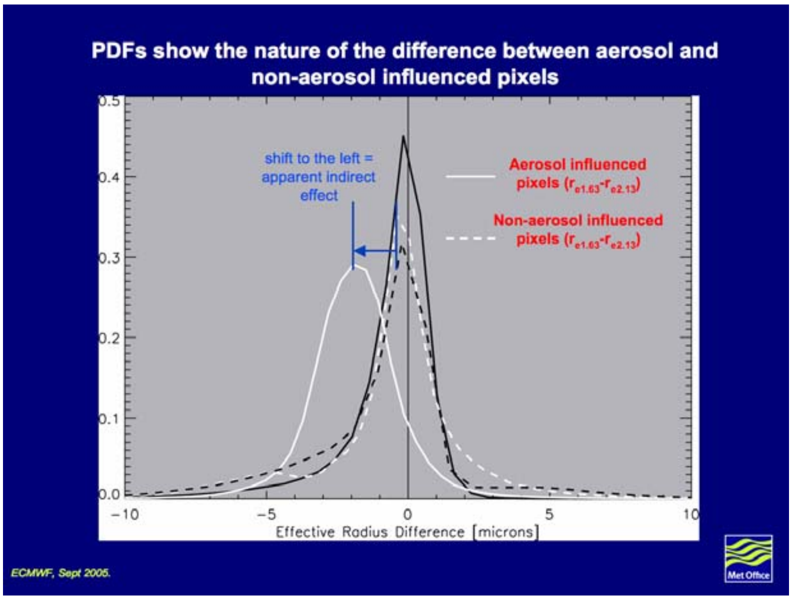
Met Office


PDFs show the nature of the difference between aerosol and non-aerosol influenced pixels
shift to the left = apparent indirect effect
Aerosol influenced pixels ($r_{e1.63}$-$r_{e2.13}$)
Non-aerosol influenced pixels ($r_{e1.63}$-$r_{e2.13}$)
0.5
0.4
0.3
0.2
0.1
0.0
−10
−5
0
5
10
Effective Radius Difference [microns]
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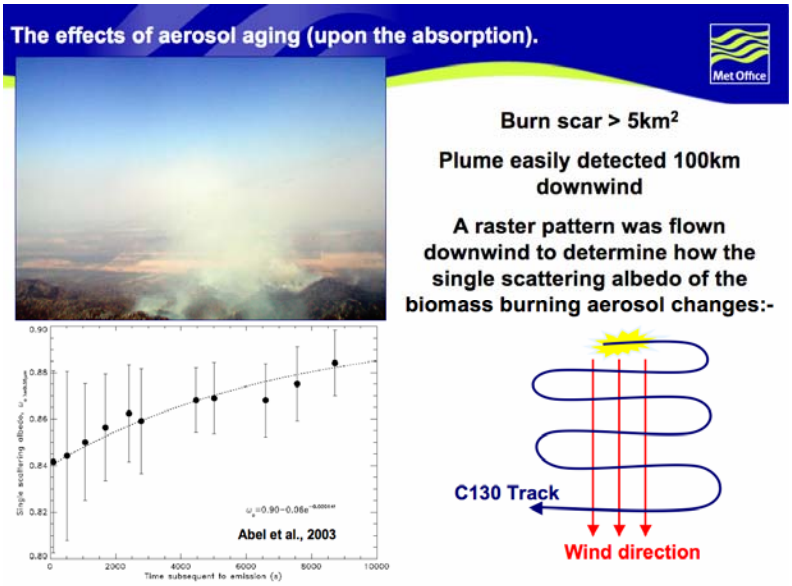
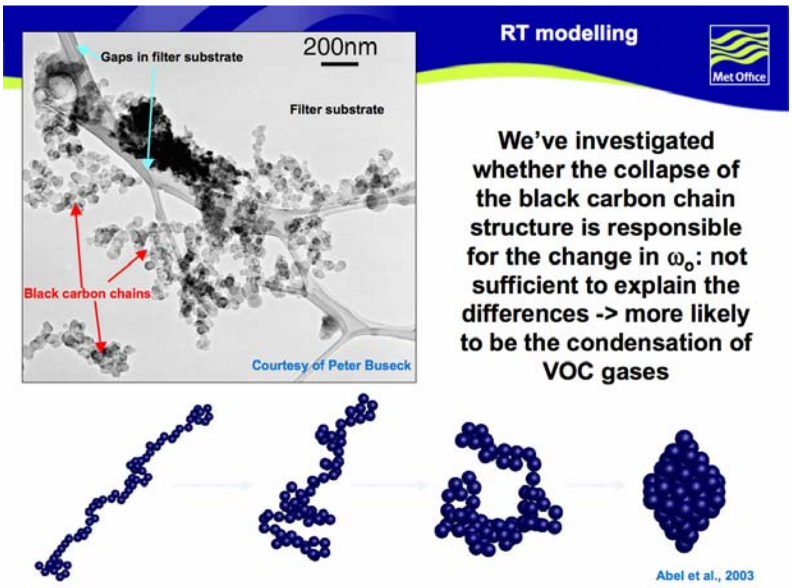
Met Office


The effects of aerosol aging (upon the absorption).
Met Office
Burn scar > 5km²
Plume easily detected 100km downwind
A raster pattern was flown downwind to determine how the single scattering albedo of the biomass burning aerosol changes:-
Abel et al., 2003
C130 Track
Wind direction


RT modelling
Met Office
200nm
Gaps in filter substrate
Filter substrate
Black carbon chains
Courtesy of Peter Buseck
We've investigated whether the collapse of the black carbon chain structure is responsible for the change in ω_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.
Met Office
Retrievals of $\tau_{aer\lambda}$, size distribution, absorption
SeaWiFS composite
LDOPE / MODLAND
But do we believe them?
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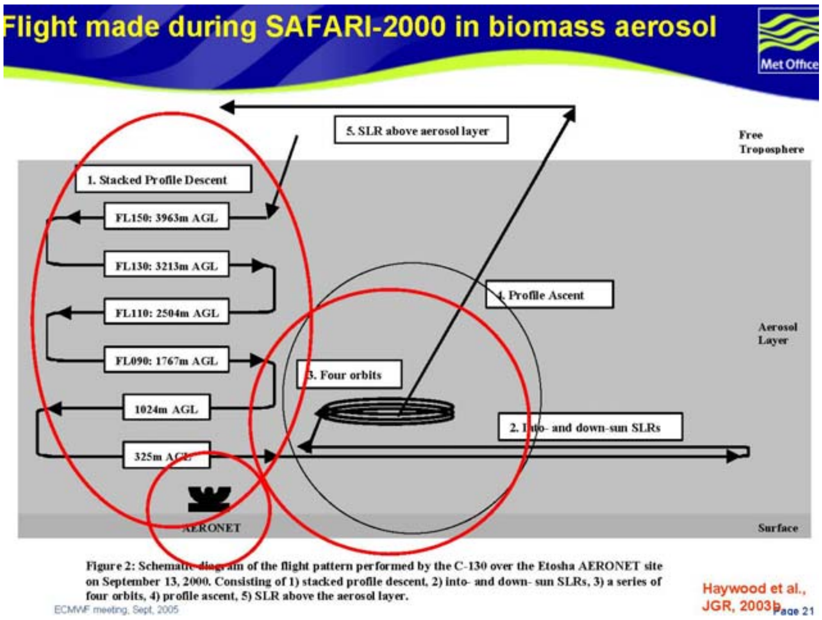
Flight made during SAFARI-2000 in biomass aerosol
Met Office
5. SLR above aerosol layer
Free Troposphere
1. Stacked Profile Descent
FL150: 3963m AGL
FL130: 3213m AGL
FL110: 2504m AGL
FL090: 1767m AGL
1024m AGL
325m AGL
4. Profile Ascent
3. Four orbits
2. Into- and down-sun SLRs
Aerosol Layer
AERONET
Surface
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
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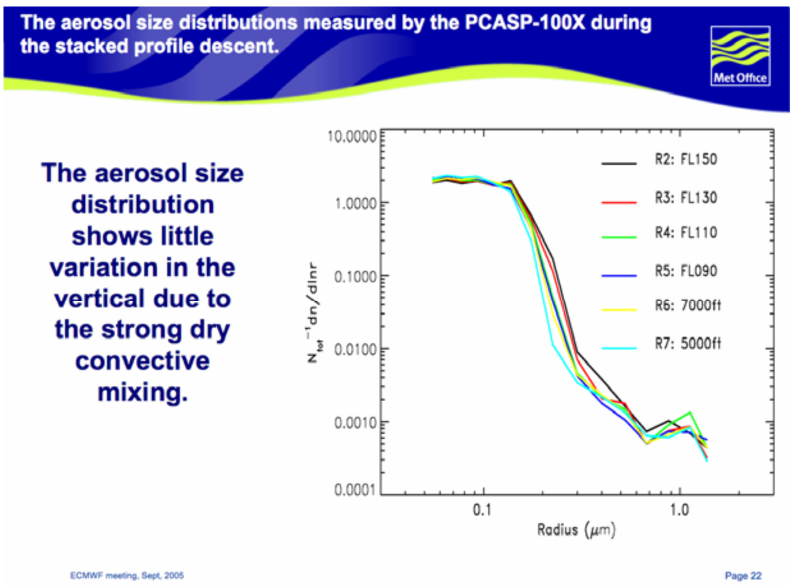
The aerosol size distributions measured by the PCASP-100X during the stacked profile descent.
Met Office
The aerosol size distribution shows little variation in the vertical due to the strong dry convective mixing.
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
$N_{tot}^{-1}dn/dlnr$
R2: FL150
R3: FL130
R4: FL110
R5: FL090
R6: 7000ft
R7: 5000ft
0.1
1.0
Radius (μm)
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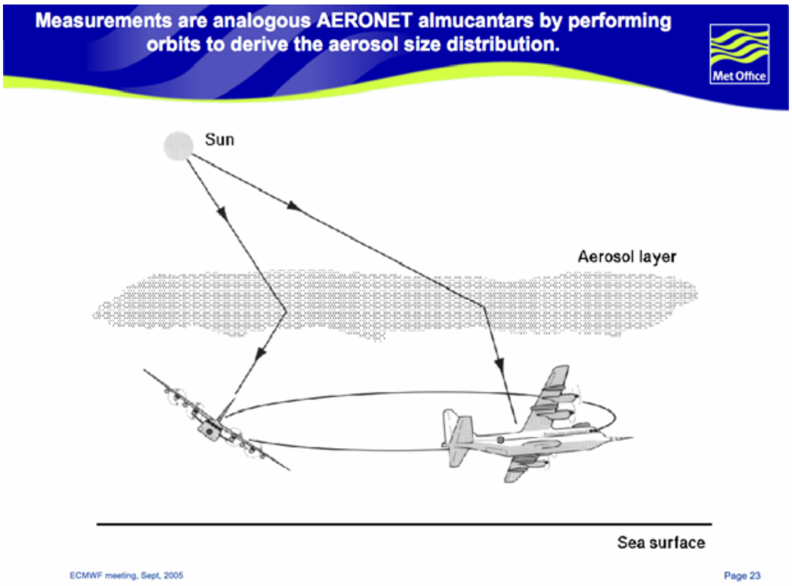
Measurements are analogous AERONET almucantars by performing orbits to derive the aerosol size distribution.
Met Office
Sun
Aerosol layer
Sea surface
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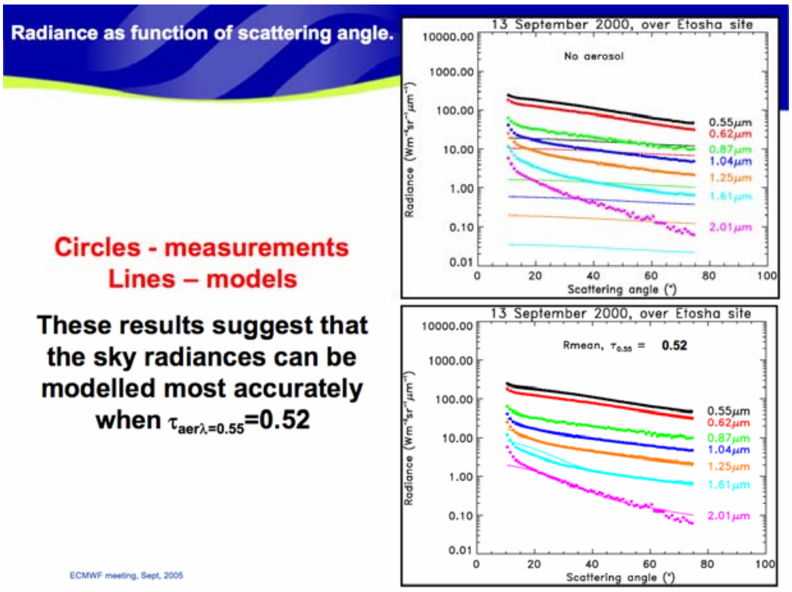
Radiance as function of scattering angle.
Circles - measurements
Lines – models
These results suggest that the sky radiances can be modelled most accurately when $\tau_{aer\lambda=0.55}$=0.52
13 September 2000, over Etosha site
No aerosol
Rmean, $\tau_{0.55}$ = 0.52
Radiance (Wm^{-2}sr^{-1}µm^{-1})
Scattering angle (°)
0.55µm
0.62µm
0.87µm
1.04µm
1.25µm
1.61µm
2.01µm
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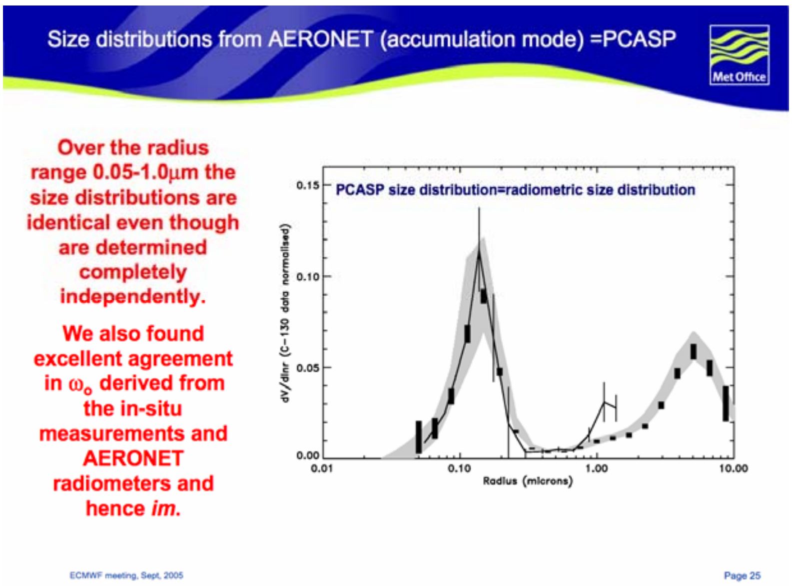
Size distributions from AERONET (accumulation mode) =PCASP
Met Office
Over the radius range 0.05-1.0µm the size distributions are identical even though are determined completely independently.
We also found excellent agreement in ω_o derived from the in-situ measurements and AERONET radiometers and hence *im.*
PCASP size distribution=radiometric size distribution
dV/dlnr (C−130 data normalised)
Radius (microns)
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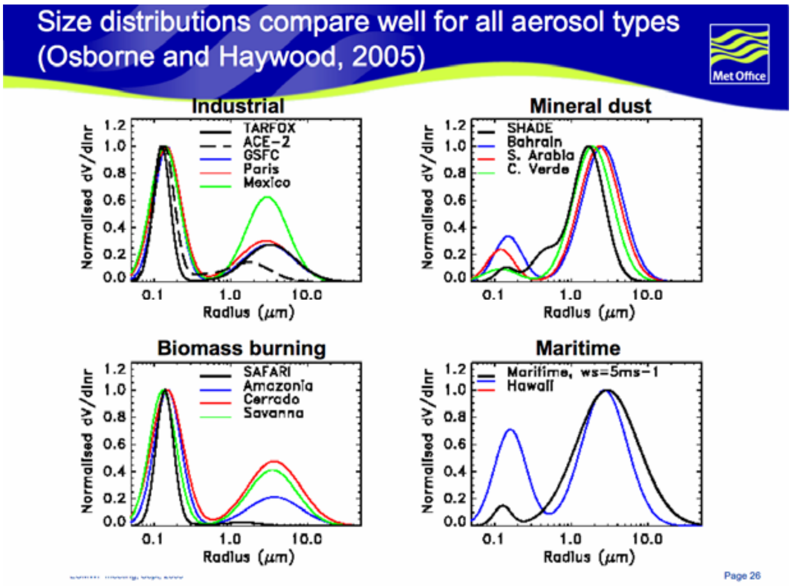
Size distributions compare well for all aerosol types
(Osborne and Haywood, 2005)
Met Office
Industrial
TARFOX
ACE-2
GSFC
Paris
Mexico
Mineral dust
SHADE
Bahrain
S. Arabia
C. Verde
Biomass burning
SAFARI
Amazonia
Cerrado
Savanna
Maritime
Maritime, ws=5ms-1
Hawaii
Normalised dV/dlnr
Radius (μm)
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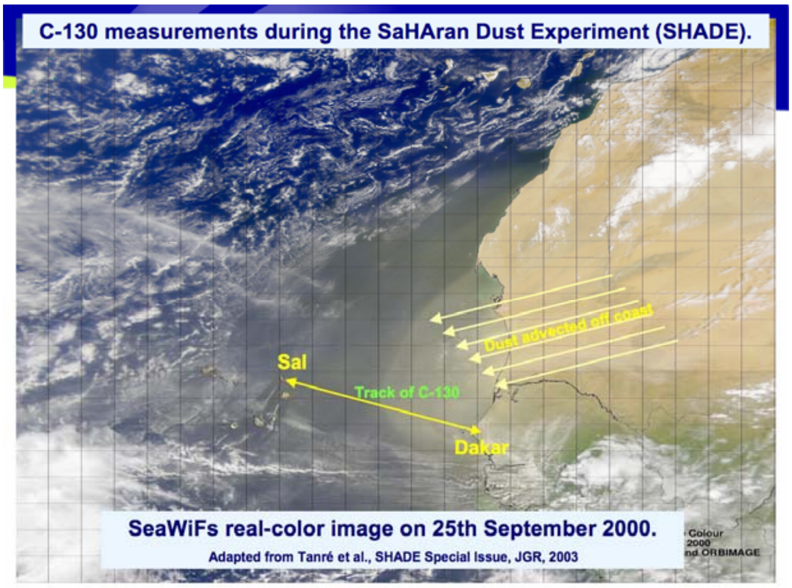
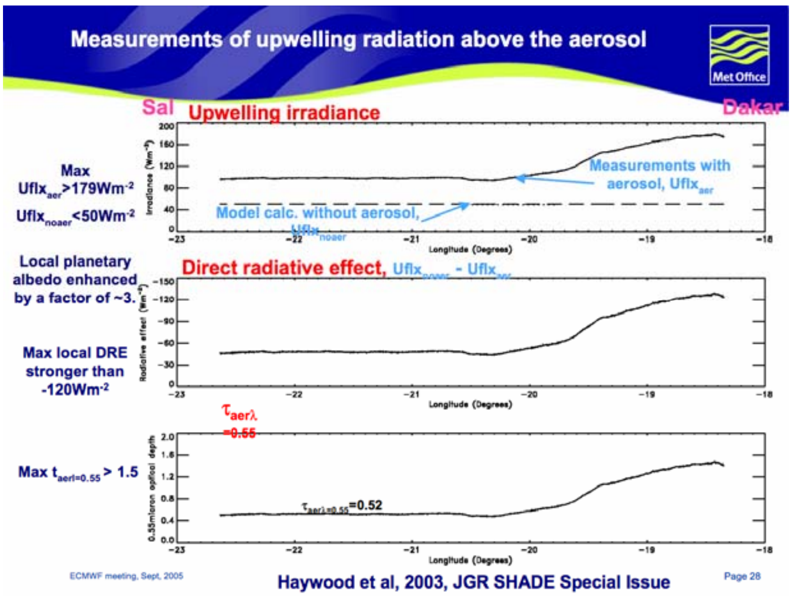

C-130 measurements during the SaHAran Dust Experiment (SHADE).
Dust advected off coast
Sal
Track of C-130
Dakar
SeaWiFs real-color image on 25th September 2000.
Adapted from Tanré et al., SHADE Special Issue, JGR, 2003


Measurements of upwelling radiation above the aerosol
Met Office
Sal
Upwelling irradiance
Dakar
Max
Uflx_aer>179Wm-2
Uflx_noaer<50Wm-2
Measurements with aerosol, Uflx_aer
Model calc. without aerosol, Uflx_noaer
Longitude (Degrees)
Local planetary albedo enhanced by a factor of ~3.
Direct radiative effect, Uflx_noaer - Uflx_aer
Max local DRE stronger than -120Wm-2
τ_aerλ=0.55
Max τ_aerλ=0.55 > 1.5
τ_aerλ=0.55=0.52
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Haywood et al, 2003, JGR SHADE Special Issue
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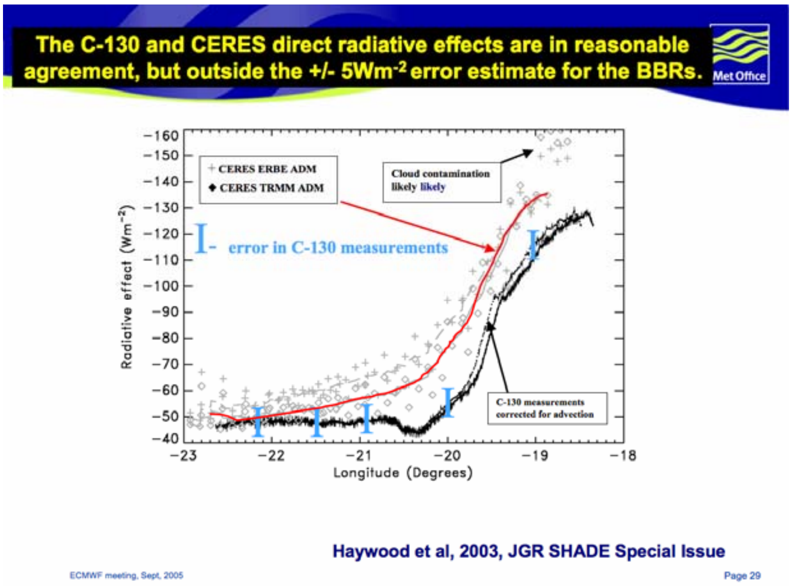
The C-130 and CERES direct radiative effects are in reasonable agreement, but outside the +/- 5Wm-2 error estimate for the BBRs.
Met Office
CERES ERBE ADM
CERES TRMM ADM
Cloud contamination likely
error in C-130 measurements
C-130 measurements corrected for advection
Radiative effect (Wm-2)
Longitude (Degrees)
Haywood et al, 2003, JGR SHADE Special Issue
ECMWF meeting, Sept, 2005
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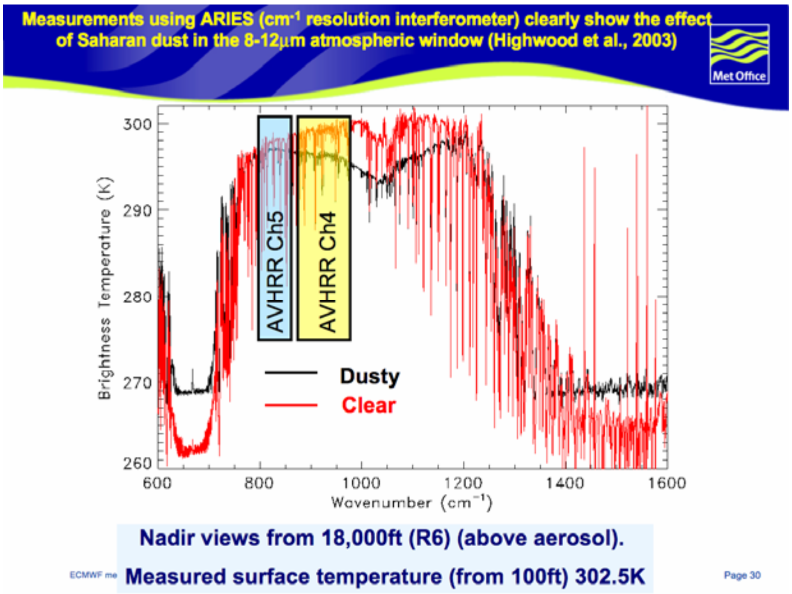
Measurements using ARIES (cm-1 resolution interferometer) clearly show the effect of Saharan dust in the 8-12μm atmospheric window (Highwood et al., 2003)
Met Office
AVHRR Ch5
AVHRR Ch4
Dusty
Clear
Brightness Temperature (K)
Wavenumber (cm-1)
Nadir views from 18,000ft (R6) (above aerosol).
Measured surface temperature (from 100ft) 302.5K
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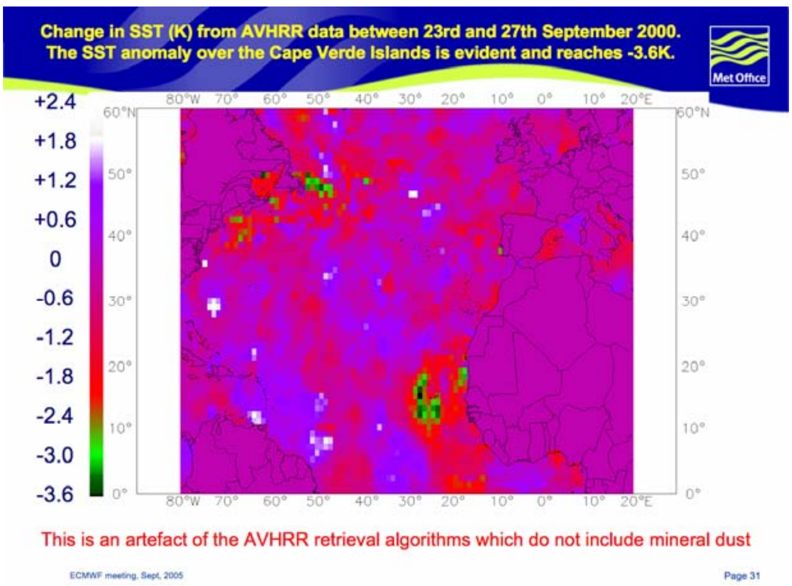
Change in SST (K) from AVHRR data between 23rd and 27th September 2000.
The SST anomaly over the Cape Verde Islands is evident and reaches -3.6K.
Met Office
+2.4
+1.8
+1.2
+0.6
0
-0.6
-1.2
-1.8
-2.4
-3.0
-3.6
This is an artefact of the AVHRR retrieval algorithms which do not include mineral dust
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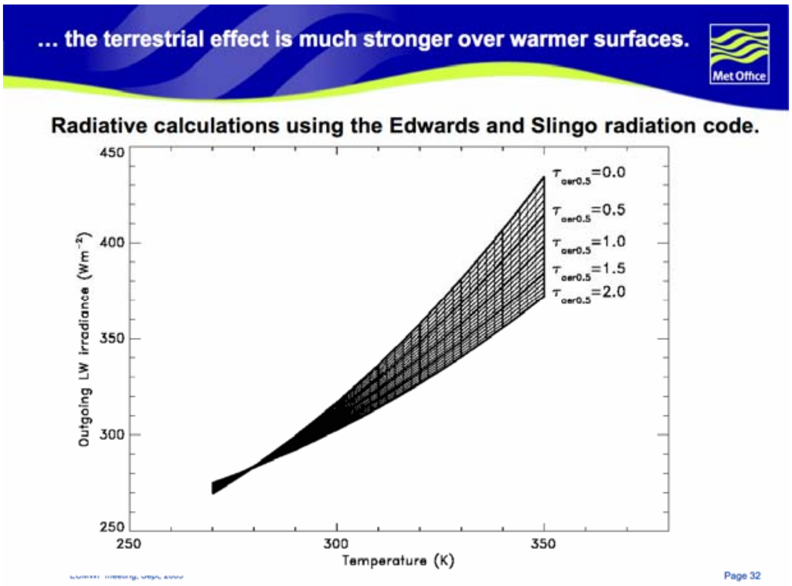
… the terrestrial effect is much stronger over warmer surfaces.
Met Office
Radiative calculations using the Edwards and Slingo radiation code.
Outgoing LW irradiance (Wm⁻²)
Temperature (K)
τaer0.5=0.0
τaer0.5=0.5
τaer0.5=1.0
τaer0.5=1.5
τaer0.5=2.0
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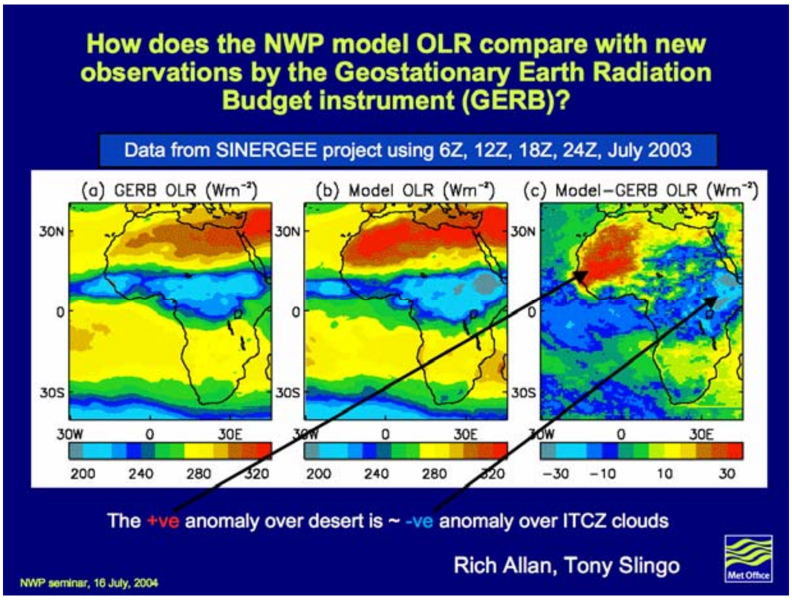
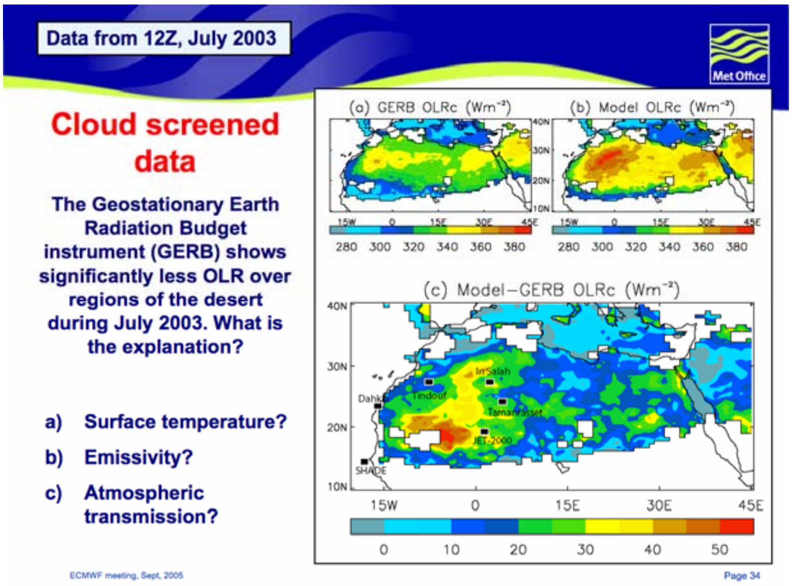

How does the NWP model OLR compare with new observations by the Geostationary Earth Radiation Budget instrument (GERB)?
Data from SINERGEE project using 6Z, 12Z, 18Z, 24Z, July 2003
(a) GERB OLR (Wm⁻²)
(b) Model OLR (Wm⁻²)
(c) Model−GERB OLR (Wm⁻²)
The +ve anomaly over desert is ~ -ve anomaly over ITCZ clouds
Rich Allan, Tony Slingo
NWP seminar, 16 July, 2004
Met Office


Data from 12Z, July 2003
Met Office
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?
(a) GERB OLRc (Wm⁻²)
(b) Model OLRc (Wm⁻²)
(c) Model−GERB OLRc (Wm⁻²)
In Salah
Tindouf
Tamanrasset
JET-2000
SHADE
ECMWF meeting, Sept, 2005
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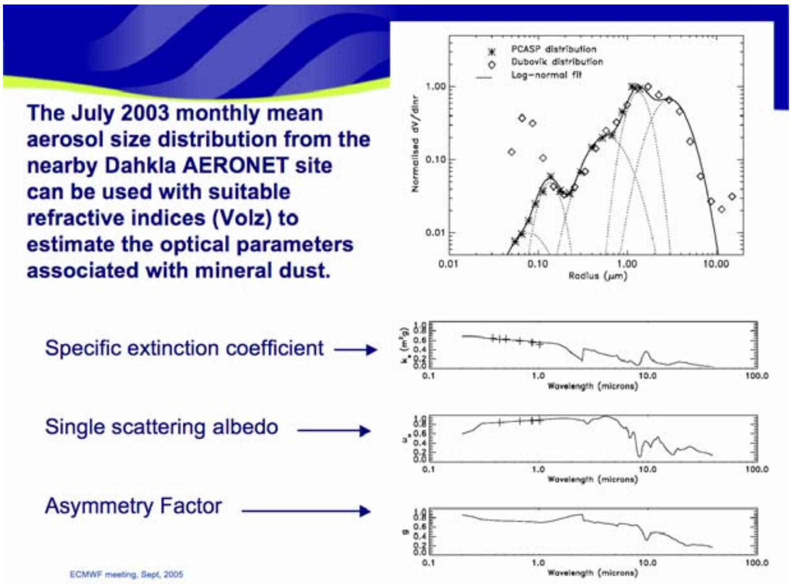
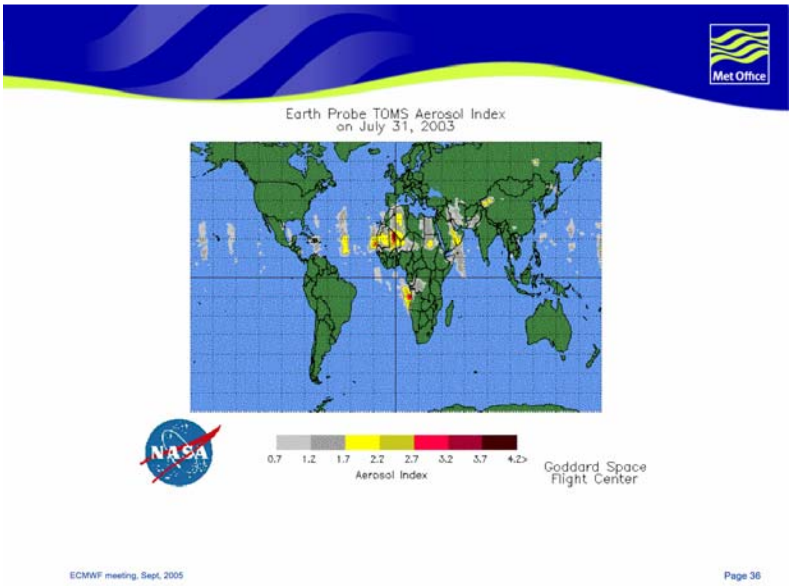

The July 2003 monthly mean aerosol size distribution from the nearby Dahkla AERONET site can be used with suitable refractive indices (Volz) to estimate the optical parameters associated with mineral dust.
PCASP distribution
Dubovik distribution
Log-normal fit
Normalised dV/dlnr
Radius (μm)
Specific extinction coefficient
Single scattering albedo
Asymmetry Factor
Wavelength (microns)
ECMWF meeting, Sept, 2005


Met Office
Earth Probe TOMS Aerosol Index on July 31, 2003
NASA
Aerosol Index
Goddard Space Flight Center
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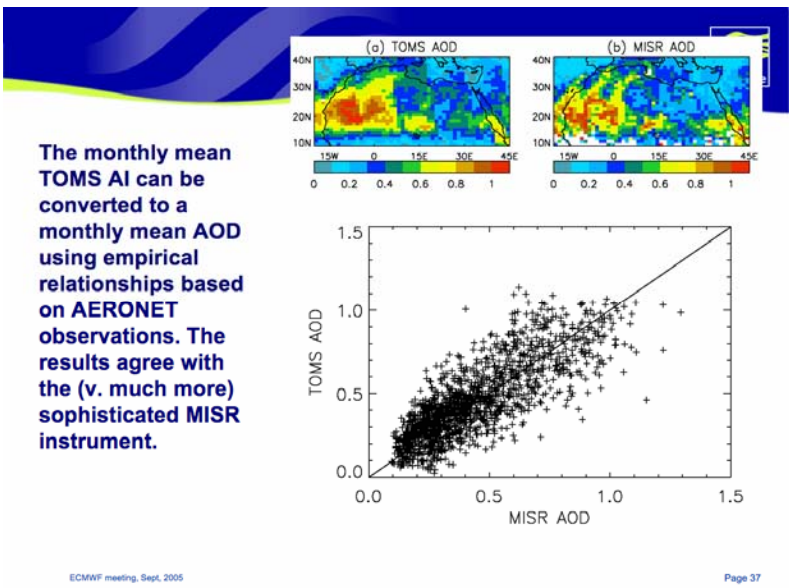
The monthly mean TOMS AI can be converted to a monthly mean AOD using empirical relationships based on AERONET observations. The results agree with the (v. much more) sophisticated MISR instrument.
(a) TOMS AOD
(b) MISR AOD
TOMS AOD
MISR AOD
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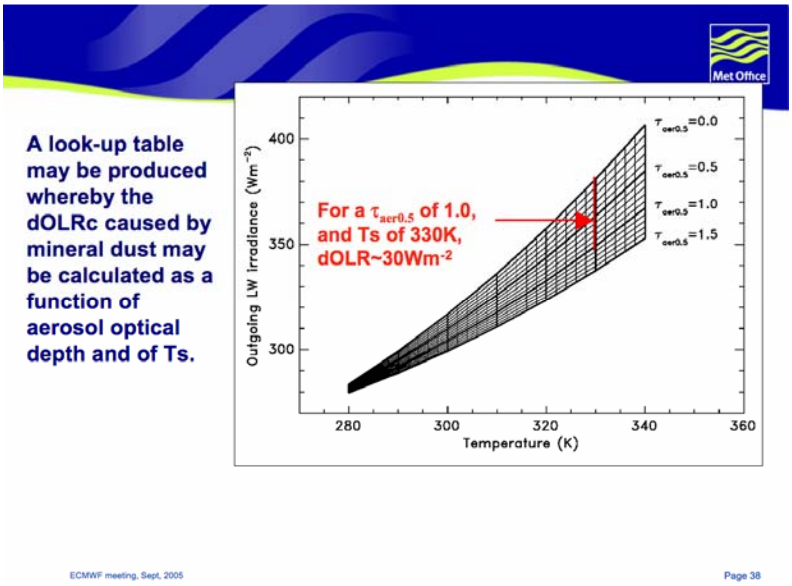
A look-up table may be produced whereby the dOLRc caused by mineral dust may be calculated as a function of aerosol optical depth and of Ts.
For a $\tau_{aer0.5}$ of 1.0, and Ts of 330K, dOLR~30Wm^{-2}
Outgoing LW Irradiance (Wm^{-2})
Temperature (K)
$\tau_{aer0.5}$=0.0
$\tau_{aer0.5}$=0.5
$\tau_{aer0.5}$=1.0
$\tau_{aer0.5}$=1.5
Met Office
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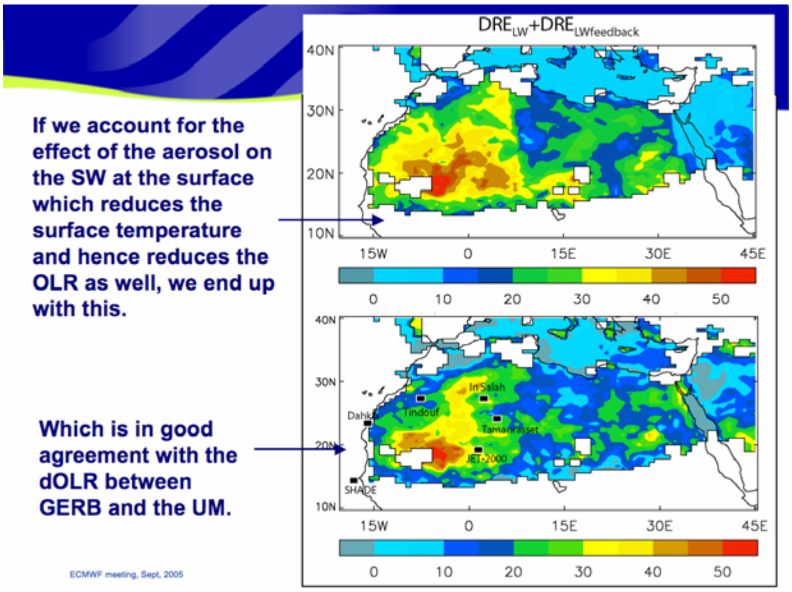
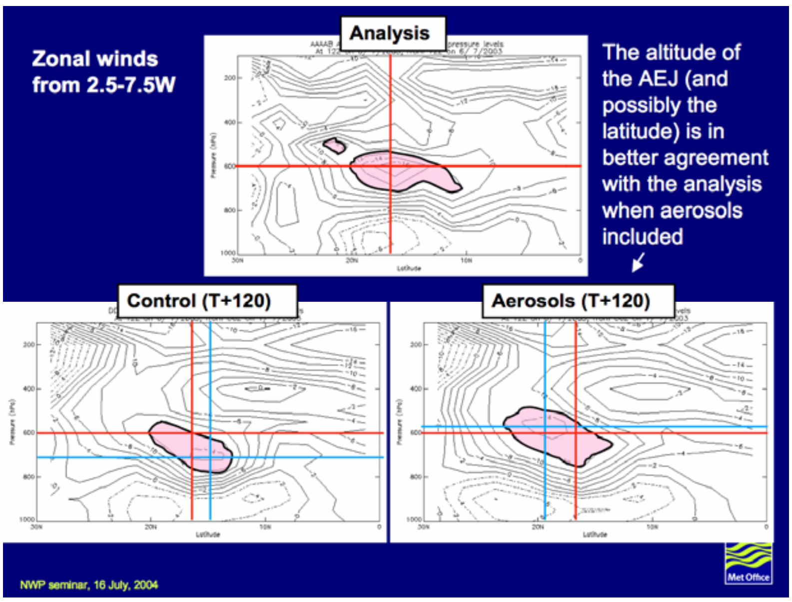
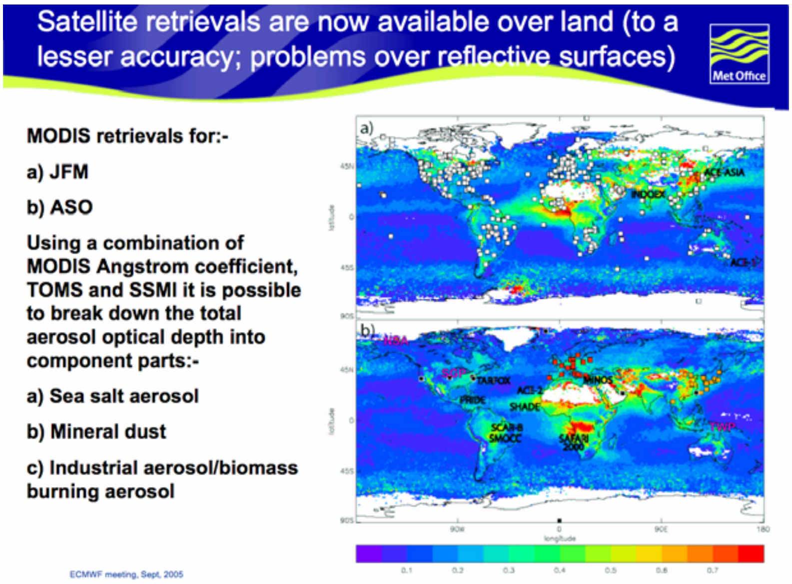
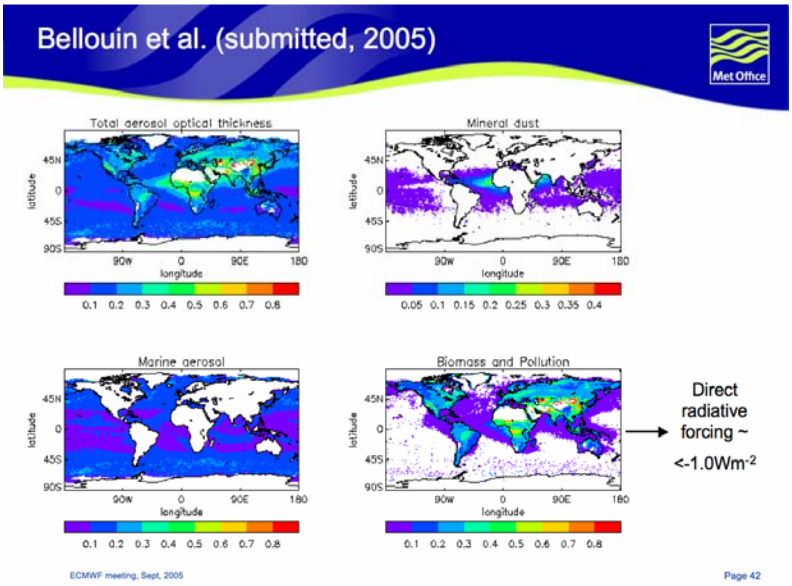

DRE$_{LW}$+DRE$_{LWfeedback}$
If we account for the effect of the aerosol on the SW at the surface which reduces the surface temperature and hence reduces the OLR as well, we end up with this.
Which is in good agreement with the dOLR between GERB and the UM.
In Salah
Tindouf
Dahkla
Tamanrasset
JET-2000
SHADE
ECMWF meeting, Sept, 2005


Zonal winds from 2.5-7.5W
Analysis
The altitude of the AEJ (and possibly the latitude) is in better agreement with the analysis when aerosols included
Control (T+120)
Aerosols (T+120)
Latitude
Pressure (hPa)
NWP seminar, 16 July, 2004
Met Office


Satellite retrievals are now available over land (to a lesser accuracy; problems over reflective surfaces)
Met Office
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
a)
ACE-ASIA
INDOEX
b)
TARFOX
ACE-2
PRIDE
SHADE
MINOS
SCAR-B
SMOCC
SAFARI 2000
ECMWF meeting, Sept. 2005


Bellouin et al. (submitted, 2005)
Met Office
Total aerosol optical thickness
Mineral dust
Marine aerosol
Biomass and Pollution
latitude
longitude
45N
0
45S
90S
90W
0
90E
180
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
Direct radiative forcing ~ <-1.0Wm-2
ECMWF meeting, Sept. 2005
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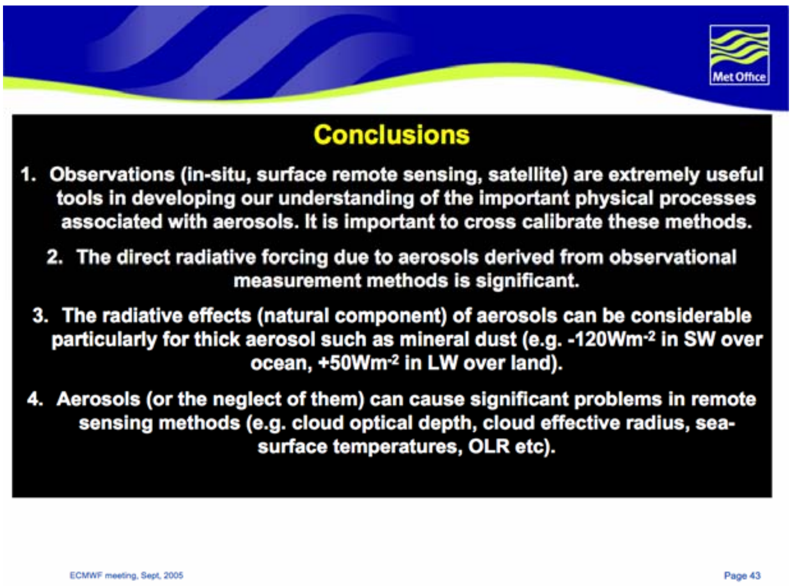
Met Office
Conclusions
1. Observations (in-situ, surface remote sensing, satellite) are extremely useful tools in developing our understanding of the important physical processes associated with aerosols. It is important to cross calibrate these methods.
2. The direct radiative forcing due to aerosols 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. -120Wm-2 in SW over ocean, +50Wm-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).
ECMWF meeting, Sept. 2005
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