Indirect and semi-direct Forcing:
Is it a warming or a cooling effect?
Observations from MODIS

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It is cooling, and may be even more than we thought!

Content

• MODIS observations of aerosols and clouds
• Smoke inhibition of clouds over the Amazon
• Aerosol enhancement of clouds over the Atlantic Ocean
• New aerosol-cloud observations from space: Glory and ACE-3DI
MODIS wide spectral range:

- Distinguish dust from smoke / pollution aerosol
- Distinguish aerosol from land reflectance

Kaufman et al., Nature 2002

MODIS: Saharan dust, Jan. 2002

Fires in Australia, Dec 2001
Testing...
MODIS aerosol validation 2000-2002

66% of MODIS aerosol retrievals over ocean fall within expected uncertainty

71% of MODIS aerosol retrievals over land fall within expected uncertainty

Ichoku et al. 2002
Chu et al. 2002
Remer et al. 2002
Remer et al. (2004)
Koren, Kaufman, Remer & Martins, Measurement of the effect of Biomass Burning Aerosol on Inhibition of Cloud Formation over the Amazon

Shuttle mission STS 076
Koren et al Science, 2004; Cloud fraction as function of aerosol optical depth (OD). The cloud fraction decreases almost linearly with increasing OD.
Impacts:

- Smoke instantaneous forcing: $-28 \text{W/m}^2 \rightarrow +8 \text{W/m}^2$
- Smoke 24 hours forcing: $-11 \text{W/m}^2 \rightarrow -5 \text{W/m}^2$
- Less radiation at the surface $\Rightarrow$ less evaporation
- Smaller boundary layer cloud fraction
Aerosol effect on cloud development - MODIS data over the Atlantic Ocean:

Kaufman, Koren, Rosenfeld, Remer, Rudich

Aerosol Optical thickness  Cloud fraction

Precipitable water vapor

June-Aug. 2003
July 2002-clean: AOT<0.2

water cloud fraction

ice cloud fraction

July 2002-hazy: AOT>0.2

water cloud fraction

ice cloud fraction
Data evaluation:
Cloud and aerosol retrievals reliable for AOT<0.4,
mostly reliable for AOT <0.6,
aerosol is identified as clouds for AOT>0.8

Classification to convective and stratiform clouds

Establish cause and effect using multiple regression with meteorological parameters.
June-Aug. 2002 STRATIFOM CLOUDS:
June-Aug. 2002 STRATIFOM CLOUDS: longitudinal variation
Stratiform clouds:

- CLOUD FRACTION
- EFFECTIVE RADIUS (µm)
- CLOUD OPTICAL THICKNESS
- AEROSOL OPTICAL THICKNESS
- CLOUD TOP TEMPERATURE (K)

Graphs showing the relationship between cloud fraction, effective radius, cloud optical thickness, aerosol optical thickness, and cloud top temperature across different latitudinal bands (30S-20S, 20S-5N, 5N-30N, 30N-60N).

- Blue line: 30S-20S
- Orange line: 20S-5N
- Green line: 5N-30N
- Black dashed line: 30N-60N
**SEA SALT** - AOT: 0.02 (5th) -> 0.20 (95th) => Δcl.fr.=0.41!, ΔR_{eff} = -4.2 μm Δτ_e=2.5

1/2 of Δcl.fr. ∝ aerosol; part of Δcl.fr. = 0.13 ∝ Δcl.temp.

Most of ΔR_{eff} ∝ aerosol. Δτ_e*ΔR_{eff} increased by 23%

**SMOKE BELT** – AOT: 0.03 - 0.51 => Δcl.fr.=0.32!, ΔR_{eff} = -6.4 μm Δτ_e=0.3

Most Δcl.fr., ΔR_{eff} ∝ aerosol. Half ∝ AOT, half ∝ aerosol type
Δτ_e*ΔR_{eff} decreased by 30%

**DUST BELT** – AOT: 0.03 - 0.62 => Δcl.fr.=0.70!, ΔR_{eff} = -1.6 μm Δτ_e=0.3.

3/4 of the Δcl.fr., ∝ aerosol. Δτ_e*ΔR_{eff} increased by 8%

**POLLUTION BELT** – AOT: 0.03 - 0.62 => Δcl.fr.=0.72!, ΔR_{eff} = -1.9 μm Δτ_e=0.9

2/3 Δcl.fr., ΔR_{eff} ∝ aerosol. Δcl.fr=0.20 ∝ Δcl.temp, half ∝ aerosol type
Δτ_e*ΔR_{eff} increased by 8%

Radiative effects: Smoke ΔF=-6 W/m² out of which -1 W/m² ∝ Δτ_c
Dust ΔF=-9 W/m² out of which -0.4 W/m² ∝ Δτ_c
Pollution ΔF=-5 W/m² out of which -1 W/m² ∝ Δτ_c
Convective clouds over the Atlantic Ocean:

Cascading impact of the presence of aerosols on convective clouds: $R_{\text{eff}}$: decrease in the size of the cloud water droplets (by 0-20%), \textbf{ICE}: decrease in the fraction of ice in the clouds (50% to 15%), \textbf{Height}: increase in the altitude of the cloud tops (by 200mb), and \textbf{Coverage}: increase in the coverage (by 10-30%).

Analysis of co-variability of the aerosol and meteorological parameters that affect clouds and aerosols show that 70-100% of these effects are due to variability in the concentration of aerosol.

Detailed results---->
Clear and Polluted vs. pressure for Convective Clouds - Water

$0 < \text{AOD} < 0.15$  $0.15 < \text{AOD} < 0.6$

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30-45N  15-30N  0-15N
Clear and Polluted vs. pressure for Convective Clouds - Ice

0<AOD<0.15  0.15<AOD<0.6

AOD  REff  CFrac  COD

North

30-45N

Mid-West

15-30N

ITCZ

0-15N
Future aerosol-clouds satellites: Plans and whishes:

The Glory mission - Mishchenko et al

The ACE-3DI mission - Martins et al
Conclusions