Indirect and Semi-Direct Effects of South Asian Aerosols: Why are they Unique?

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Aerosol Effects: Visually See Difference
Pristine Conditions
Polluted Conditions

0310 20 FEB
Lidar also shows big difference between regions

Pristine

Polluted
Outline

1. Background
   - INDOEX observations
   - In-situ observations of indirect effects

2. Remote sensing field observations
   - Estimating indirect/semi-direct effect

3. Difficulties in interpreting observations
   - Varying meteorology

4. The role of cloud-resolving models

5. Summary
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Semi-Direct & Indirect Effects

- Carbonaceous aerosols absorb solar radiation
  - May desiccate cloud layers
  - Stabilize b.l.
  - Reduce convection, spin-down
  - Hydrological cycle

Anthropogenic emissions

Continent
Aerosol Gradients

- Definite increase in aerosols closer to India (e.g., optical depth), Ramanathan et al. 2001

Plate 4. The latitudinal variation of $\tau_v$ (0.5 $\mu$m) measured by the Indian research vessel Sagar Kanya during 1996 to 1999. The multiwavelength Sun photometer used for this data is described by Jayaraman et al. [1998]. The precision of the measurement is $\pm$0.03 or 20%, whichever is smaller. Each color represents a different year.
Gradient flights transects from Male to south of Equator allowed sampling of pristine & polluted air remotely

5 such flights conducted on days trade cumuli dominated
Distributions of LWC and vertical velocity similar between pristine and polluted clouds

(Heymsfield and McFarquhar 2001)
Droplet concentrations 3.5 times higher in polluted regions

Heymsfield and McFarquhar 2001
Cumulative cross-sectional area, proportional to extinction coefficient, 55% higher in polluted clouds
INDOEX Radiometer Observations

- In-situ data provide information only at 1 cloud level and limited sample volume ⇒ use remote sensing!
- 0.64 μm radiance recorded by NCAR’s MCR at ~ 30 m resolution for 4 such gradient flights
- τ retrieved using GSFC algorithm developed for MAS
- See how cloud coverage, cloud size, and optical depth vary for pristine & polluted conditions
On average, polluted clouds seem to appear less frequently.
Cumulative cloud coverage greater for pristine (8.5%) than polluted (5.6%) conditions

Clouds smaller than 2 km make big contributions to area

McFarquhar et al. 2004
Retrieved $\tau_c$ 75% higher for polluted clouds than for pristine

Suggests action of indirect effect?

McFarquhar et al. 2004
Which dominates: semi-direct or indirect effect?

- Use $\tau_c$ and coverage as function of cloud size, with radiative transfer model, to estimate CRF for pristine/polluted clouds.

- Change in CRF associated with polluted conditions is $+7(+1) \text{ W m}^{-2} \text{ m}^{-1}$ at TOA (surface) at 0.64 $\mu$m.
  
  Estimate critically depends on $\tau_c$, $\tau_a$, and $\omega_0$ for aerosols.

- Suggests semi-direct effects dominating in Indian Ocean region.
BUT...
Norris (2001) shows cloud cover increasing in Northern Indian Ocean from 1952-1999

Chameides et al. (2002) find weak/inconsistent relationship between aerosols and cloud cover

And satellites tell us ….
Analysis of cloud mask data from # of scenes collected over Indian Ocean by MISR in Feb. 2001-2003 suggest greater cloud coverage for polluted clouds!

(in collaboration with Di Girolamo and Zhao)
Need to look at meteorological conditions in different regions

- have done so for INDOEX cases
- May be stronger gradient in $\tau_a$ for INDOEX (weaker cross-equatorial flow)
Red: $\tau_a > 0.2$
Yellow: $0.1 < \tau_a < 0.2$
Blue: $\tau_a < 0.1$

In collaboration with Di Girolamo and Zhao
Feb 24

-7.4, 72.2
Less vapor near top of boundary layer for polluted conditions

Otherwise, thermodynamic profiles do not show large differences between pristine and polluted conditions: similar meteorology?

McFarquhar et al. 2004
Need Process Study to Determine Semi-Direct Effects on Cloud Cover

- **Primary effect** of aerosols is redistribution of solar heating within atmosphere:
  - Causes surface cooling
  - Alters stability & vertical motions
  - Changes in latent & sensible heat flux
  - Modifies planetary boundary layer height
  - Ultimately affects large-scale circulation

- Use fine resolution (100 m) NCAR EULAG CRM model, initialized with INDOEX dropsondes, to investigate
Simulations of Diurnal Cycle

- semi-direct effect dominates 2\textsuperscript{nd} indirect effect
- cloud coverage less than seen in Ackerman et al. (2000) study—how important is effect in Indian Ocean?
- need to examine what affects cloud cover

McFarquhar, Wang and Grabowski 2004
Experiments with different vertical distributions of aerosol (above, within or below cloud layer) give very different cloud coverage statistics.
Stronger up/downdrafts in cloud layer when soot below cloud layer

Weaker up/downdrafts when soot within cloud layer (SOOTC, SOOTT)

Changing up/downdrafts has big effect on cloud fraction, and on cloud bases and tops

Critically need to know location of aerosol layer as big impact on semi-direct effect
From soundings, estimate cloud base similar for pristine/polluted clouds

For clouds below 2 km, pristine clouds have higher heights; may be thicker

Consistent with lower boundary layer from semi-direct effect; more consistent with soot aerosol within cloud
Summary

1. In-situ observations show cloud properties affected by aerosols.
2. Radiometer observations show aerosol effects on cloud coverage, $\tau_c$, and on CRF.
3. For INDOEX, semi-direct effects dominate giving CRF of $\sim +7 (+1) \text{ W m}^{-2}$ at TOA (surface).
4. Satellite studies may show different trends in how cloud cover affected by aerosols.
5. Observed diurnal cycle of trade cumuli replicated by simulations:
   - profile of aerosol extinction critical: impacts feedback on thermodynamic structure which affects heating budget, convection & precipitation.
Future

- Add bin-resolved microphysics into CRM
- Extend satellite analysis to include more cases and regions
  - Better understand linkage to meteorology and vertical profile of aerosols
- Look at fine resolution retrievals of LWP, \( r_e \), and \( \tau_c \) from satellites
Model Setup

- NCAR EULAG model used
  - doubly periodic, 100/40 m horizontal/vertical resolution, 6.4 by 6.4 by 3.0 km
  - Initialized by dropsondes released during gradient flights
- Simulations investigate dependence on:
  - aerosol properties (amount & profile)
  - thermodynamic profiles (4 days)
  - surface fluxes, inversion height