Impacts of Different Aerosol Types on Convective Clouds as Observed by CALIPSO/CloudSat

Jonathan H. Jiang, Lei Huang, Hui Su

Jet Propulsion Laboratory, California Institute of Technology

Steven Massie

University of Colorado at Boulder, Boulder, Colorado, U.S.A.

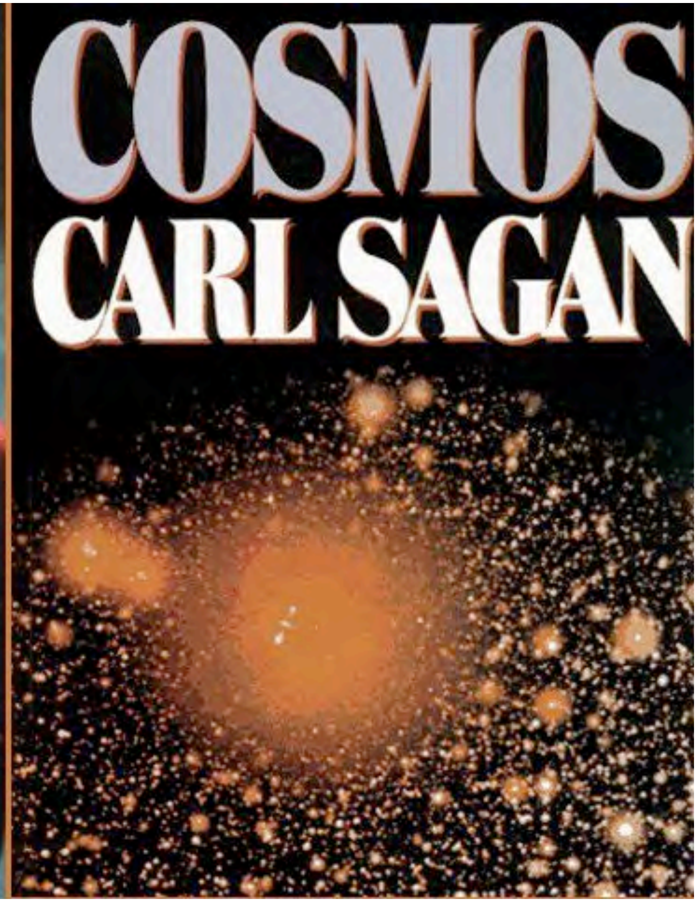
Ali Omar

NASA Langley Research Center

Zhien Wang

Department of Atmospheric Science, University of Wyoming

For Bill Rossow Symposium, June 6, 2017



Microwave Boundary Conditions on the Atmosphere and Clouds of Venus[1]

WILLIAM B. ROSSOW AND CARL SAGAN

Laboratory for Planetary Studies, Cornell University, Ithaca, N. Y. 14853

(Manuscript received 13 December 1974, in revised form 3 March 1975)

ABSTRACT

The dielectric properties of H_2O and H_2SO_4 at microwave frequencies have been calculated from the Debye equations. The derived frequency and temperature dependence agrees well with existing data. The dielectric properties of H_2O/H_2SO_4 mixtures are deduced and, for a well-mixed atmosphere, the structure of H_2O and H_2O/H_2SO_4 clouds is calculated. With the COSPAR model atmosphere and the calculated cloud models, the microwave properties of the atmosphere and clouds are determined. The 3.8 cm radar reflectivity of the planet, the Mariner 5 S-band occultation profile, and the passive microwave emission spectrum of the planet together set an upper limit on the mixing ratio by number of H_2O of $\sim 10^{-2}$ in the lower Venus atmosphere, and of H_2SO_4 of $\sim 10^{-5}$. The polarization value of the real part of the refractive index of the clouds, the spectroscopic limits on the abundance of water vapor above the clouds, and the microwave data together set corresponding upper limits on H_2O of $\sim 2\times10^{-4}$ and on H_2SO_4 of $\sim 9\times10^{-6}$. Upper limits on the surface density of total cloud constituents and of cloud liquid water are, respectively, ~ 0.1 g cm^{-2} and ~ 0.01 g cm^{-2}. The infrared opacities of 90 bars of CO_2, together with the derived upper limits to the amounts of water vapor and liquid H_2O/H_2SO_4, may be sufficient to explain the high surface temperatures through the greenhouse effect.

1. Introduction

Water vapor is a spectroscopically detected constituent of the Venus atmosphere above the clouds [for a review, see L. D. G. Young (1972)] and water is an effective absorber of microwave radiation in both its vapor and liquid phases. Because of the temperature structure of the atmosphere and the presence of sulfuric acid in the clouds, the water vapor abundance must be greater below than above the Venus clouds. Microwave observations constitute the only remote method for investigating the water content of the deep atmosphere of Venus. Direct spacecraft observations of water have so far been restricted to the middle atmosphere. Microwave observations also set an upper limit on the integrated abundance of liquid water and other absorbers. The first such calculation set an upper limit of ~ 0.1 g cm^{-2} to the liquid water in the Venus clouds (Sagan and Giver, 1961). Previous attempts to place an upper limit on the total abundance of water on Venus from the microwave spectrum have assumed either the presence of uniformly mixed water vapor alone (Pollack and Morrison, 1970; Janssen *et al.*, 1973) or the presence of uniformly mixed water vapor and a relatively thin, isothermal, liquid water cloud (Sagan and Giver, 1961; Barrett and Staelin, 1964). In the first case, the derived upper limit on the water vapor mixing ratio by number, a value between 2×10^{-4} and 5×10^{-3}, was below the minimum amount of water needed to condense liquid water clouds, assuming no impurities; it was therefore concluded that liquid water could be ignored as a source of microwave opacity. In the second case, details of cloud structure and the relation of vapor pressure to cloud thickness were ignored since the calculations were performed at a time when the atmospheric structure was poorly known; the authors concluded that high water vapor abundances and relatively thick liquid water clouds might be compatible with the microwave data.

Recently, Hansen and Hovenier (1974) have deduced two important properties of the upper cloud particles from an analysis of the polarization of light reflected from Venus:

1) The particles are spherical with a mean radius of 1 μm. Therefore, the cloud particles are liquid down to temperatures between 230 and 250 K.

2) The real part of the refractive index for visible light is 1.44.

The only material so far proposed that can remain liquid at these temperatures and that has this refractive index is sulfuric acid solutions with concentration by mass of about 75%. This composition, suggested by A. T. Young (1973), explains the previously puzzling 11.2 μm band (A. T. Young, 1973), and is consistent, while many other materials are not, with the 3 μm absorption feature (Pollack *et al.*, 1974).

Since there is strong evidence supporting a cloud composed of sulfuric acid solution and since the composition and structure of the noncondensing part of the Venus atmosphere is better known, detailed cloud models can now usefully be compared to the microwave

[1] Presented at the Conference on the Atmosphere of Venus, Goddard Institute for Space Studies, 15–17 October 1974.

John C. McConnell
(1945-2013)


Steinman Hall

Clouds in the Smoke Environment

Smoke during biomass burning season in Amazon
http://earthobservatory.nasa.gov

Clouds in the Dust Environment

Saharan dust storm http://earthobservatory.nasa.gov

Clouds in the Polluted Environment

Pollution in Asia www.conservationmagazine.org

Smoke

Biomass burning → soot, black carbon and organic carbon.

→ darker colored readily absorbs sunlight

→ warm the atmosphere and shading the surface

Dust

Sandstorms → mineral dust.

→ colors depending on the properties of the minerals that comprise the dust grains, and whether they have darker or brighter colors.

Sea-Salt

Sea sprays → sea-salt.

→ Bright-colored

→ reflect most sunlight they encounter and cooling the atmosphere and surface.

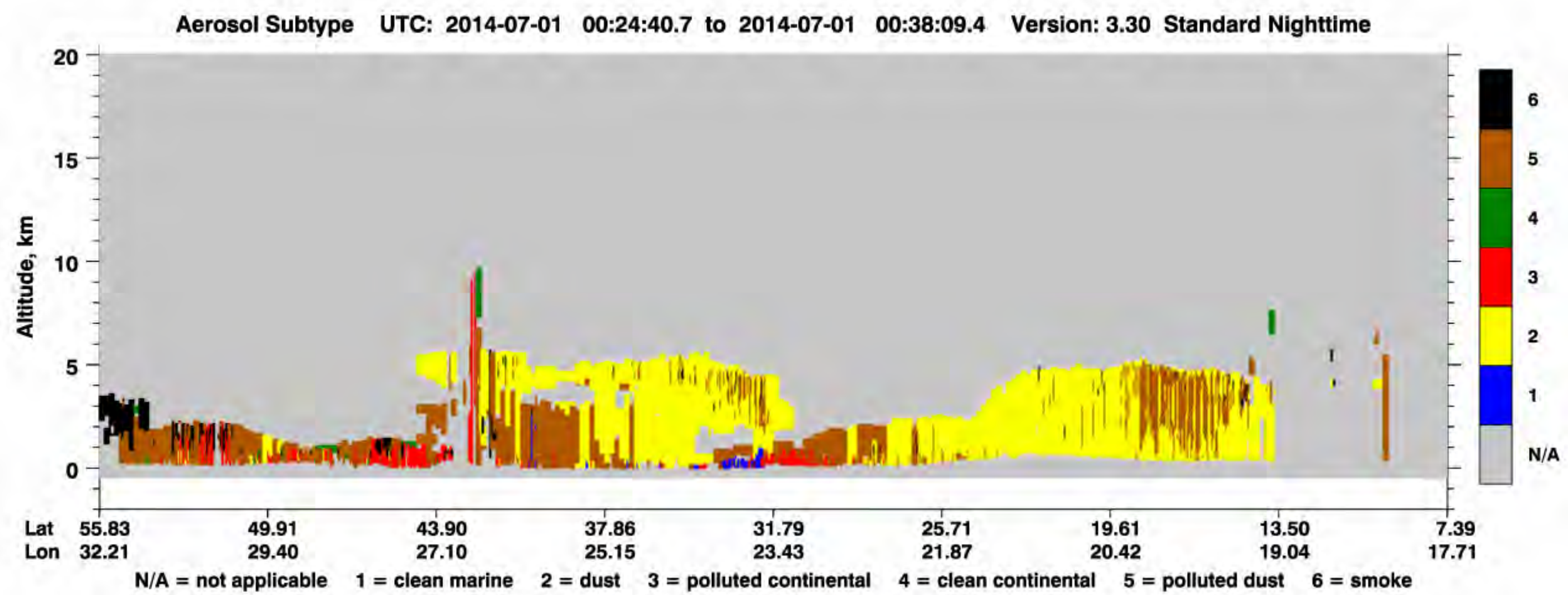
Anthropogenic

Mixture of aerosols → Automobiles, incinerators, power plants, constructions

→ black carbon, sulfate, and nitrate particles, etc.

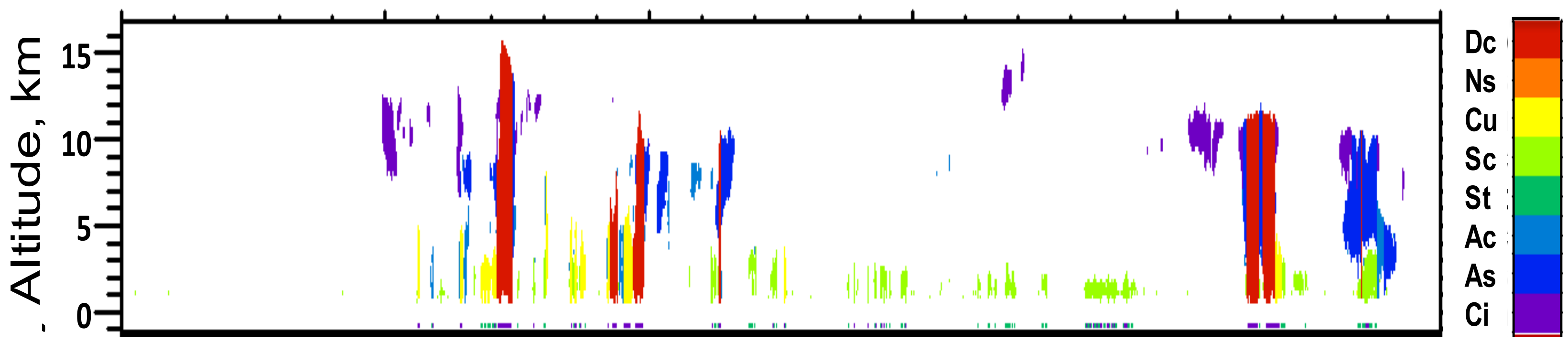
CALIPSO Aerosol Types

- CALIPSO aerosol profile data (CAL-LID-L2-05kmAPro), aerosol layer data (CAL-LID-L2-05kmALay), both including aerosol-type classification
  - There are 7 aerosol types:
    - **Smoke,**
    - **Dust,**
    - Polluted Continental,
    - Polluted Dust,
    - Clean Continental,
    - Clean Marine,
    - Dusty Marine



CloudSat Cloud Types

- CloudSatCALIPSO combined cloud profiles (2C-ICE, 2B-CLDCLASS-LIDAR) and radar-visible combined retrieval 2B-CWC-RVOD. These data include cloud water content, cloud optical depth, cloud fraction, cloud layer top/base height and cloud-type classification
  - There are 8 cloud type
    - **Deep convective (Dc),**
    - Cirrus (Ci),
    - Nimbostratus (Ns),
    - Altostratus (As),
    - Altocumulus (Ac),
    - Cumulus (Cu),
    - Stratus (St),
    - Stratocumulus (Sc).



Science question

- How do different types of aerosol affect the microphysical and macrophysical properties of different types of cloud?
  - **Convective Clouds in Smoke and Dust Environment**

Aerosol may inhibit convection [Ramanathan et al. 2005; 2007]

→ Absorptive aerosols warm the first several kilimoters of the temperature profile, thereby stabilizing temperature profiles, and stabilization inhibited convection.

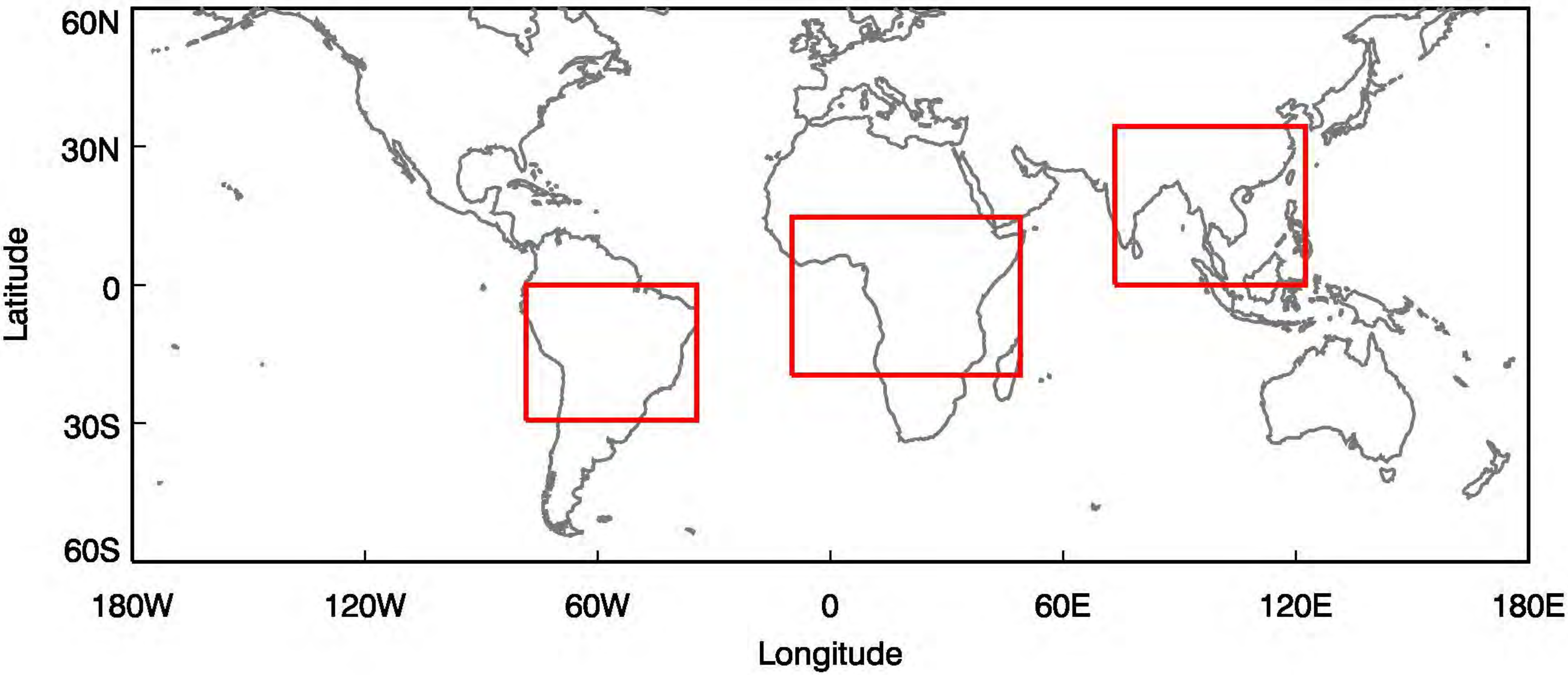
→ Increasing drought may occur in the coming decades of this century

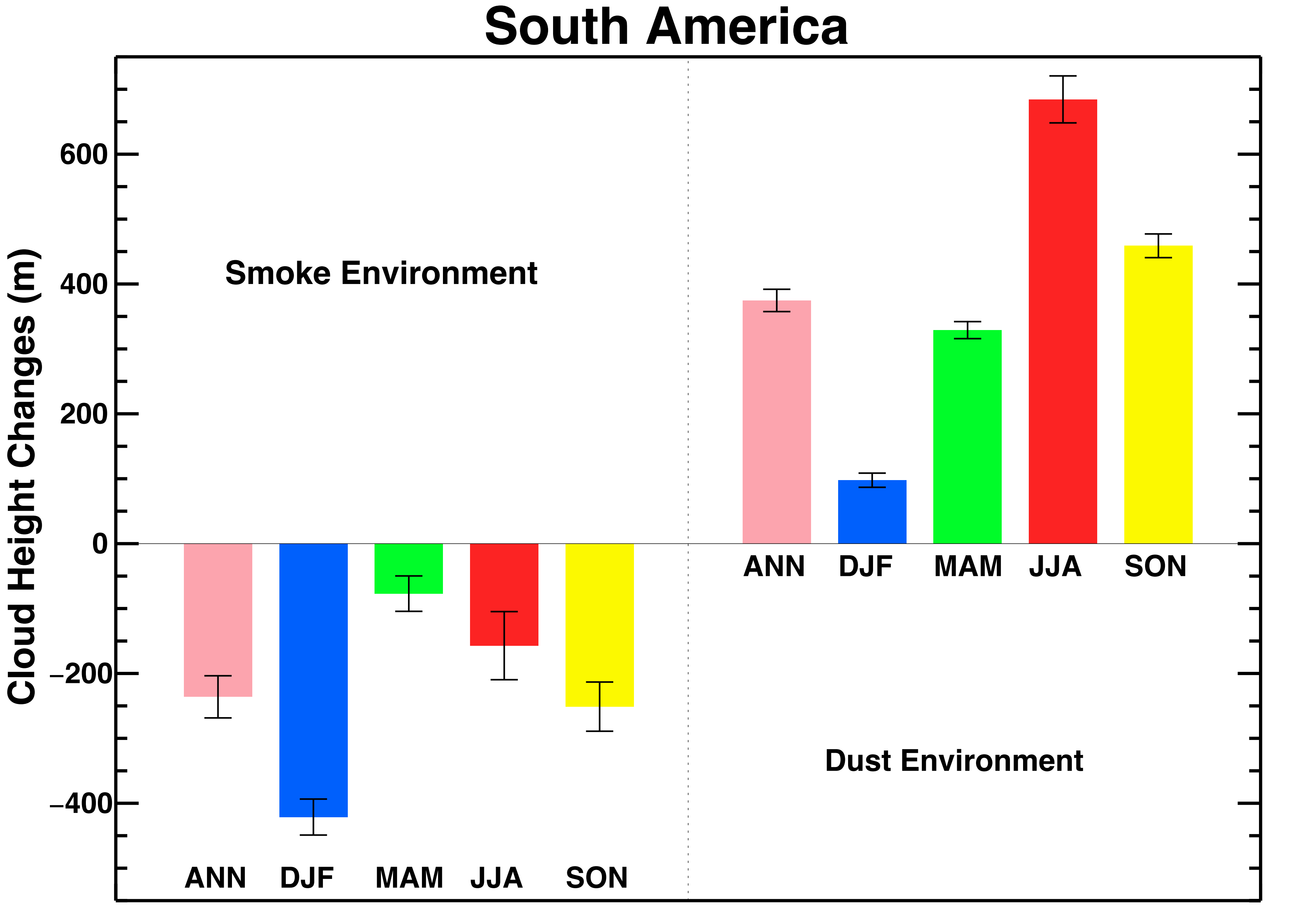
.

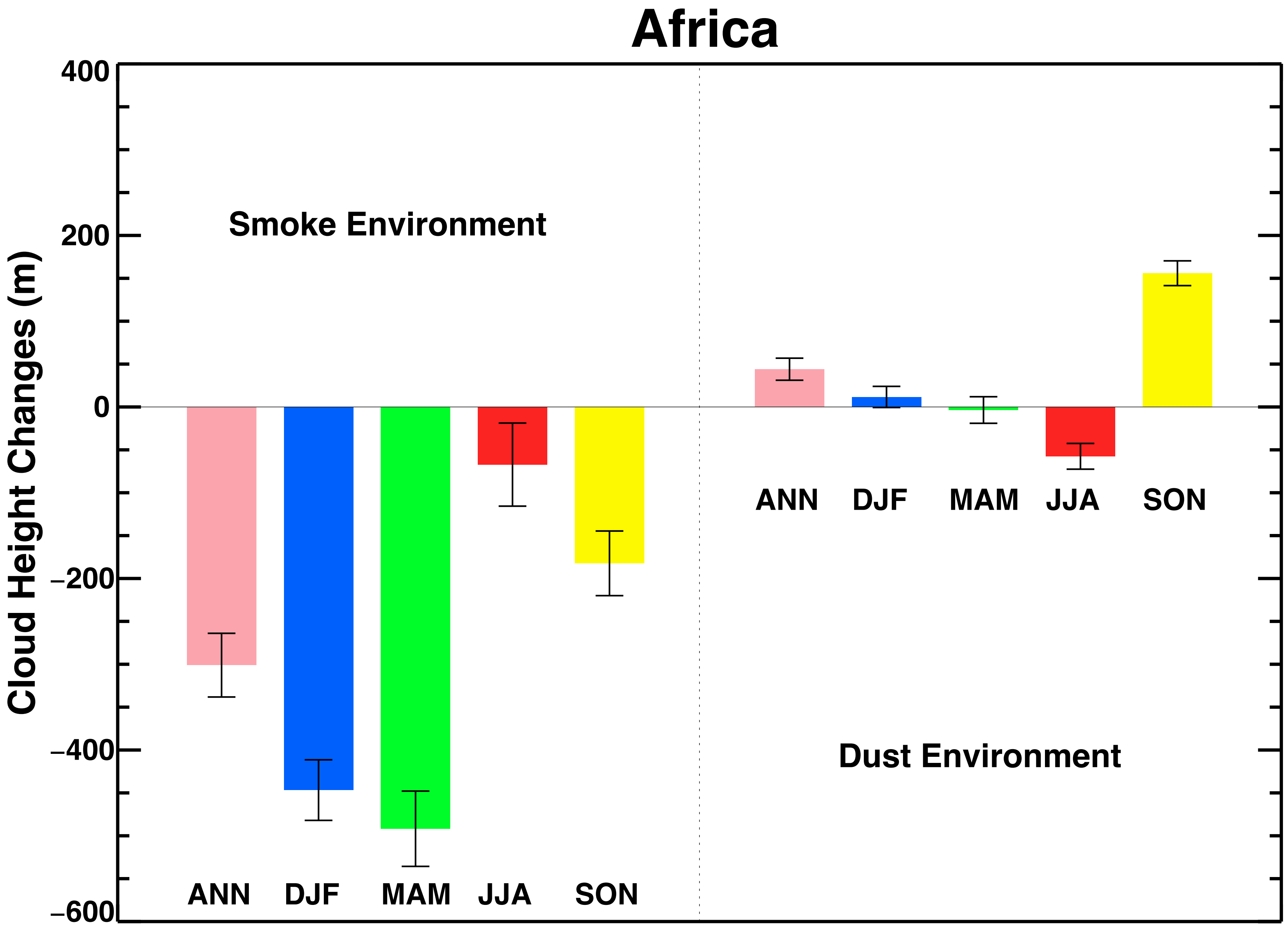
Aerosol may enhance convection: [*Khain et al*., 2005; *Rosenfeld et al*., 2008]

→ Increase in aerosols suppress warm rain processes, permitting more liquid water to reach the freezing level, and thereby enhance latent heat release in the upper portions of clouds.

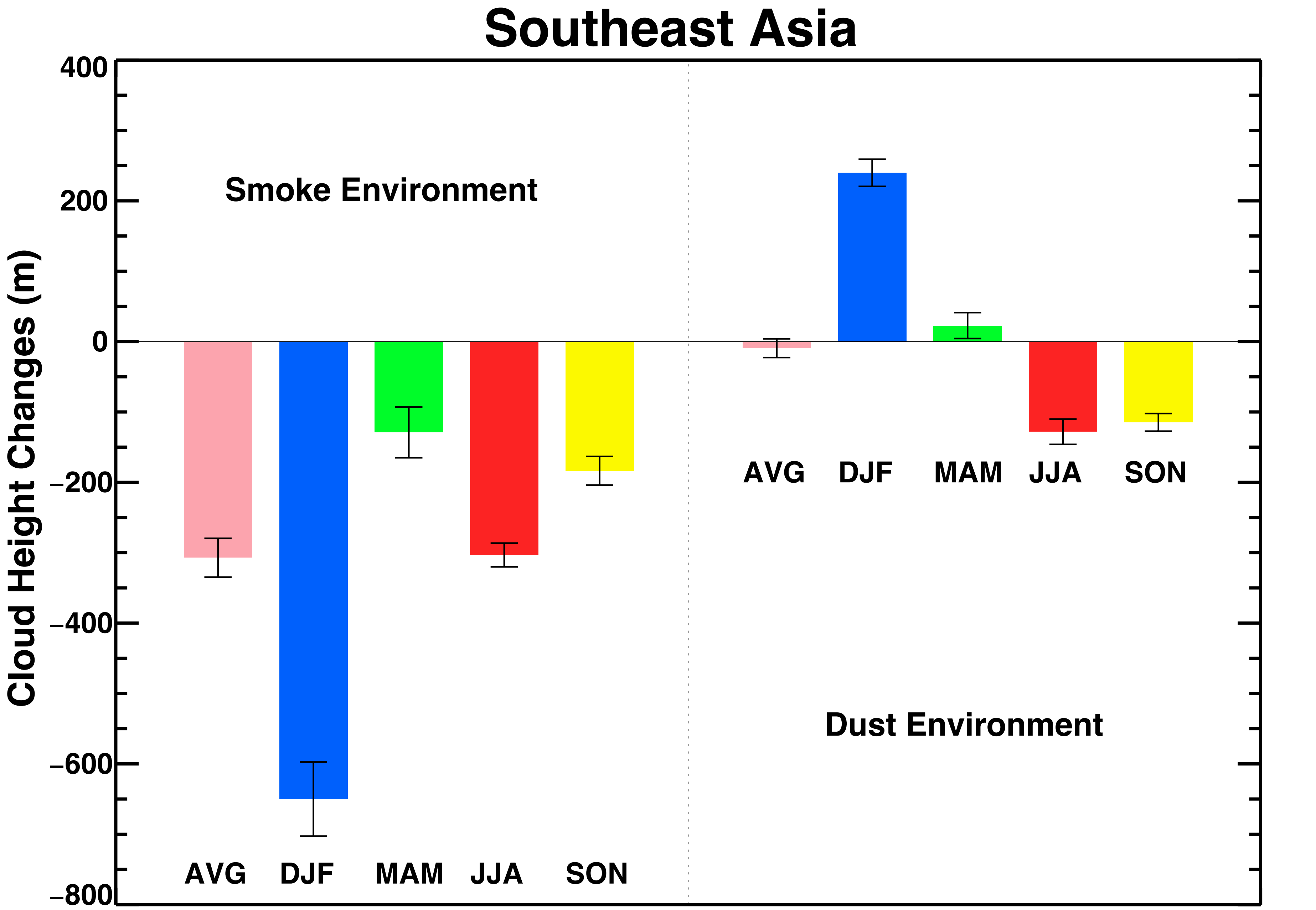
→ Convective invigoration

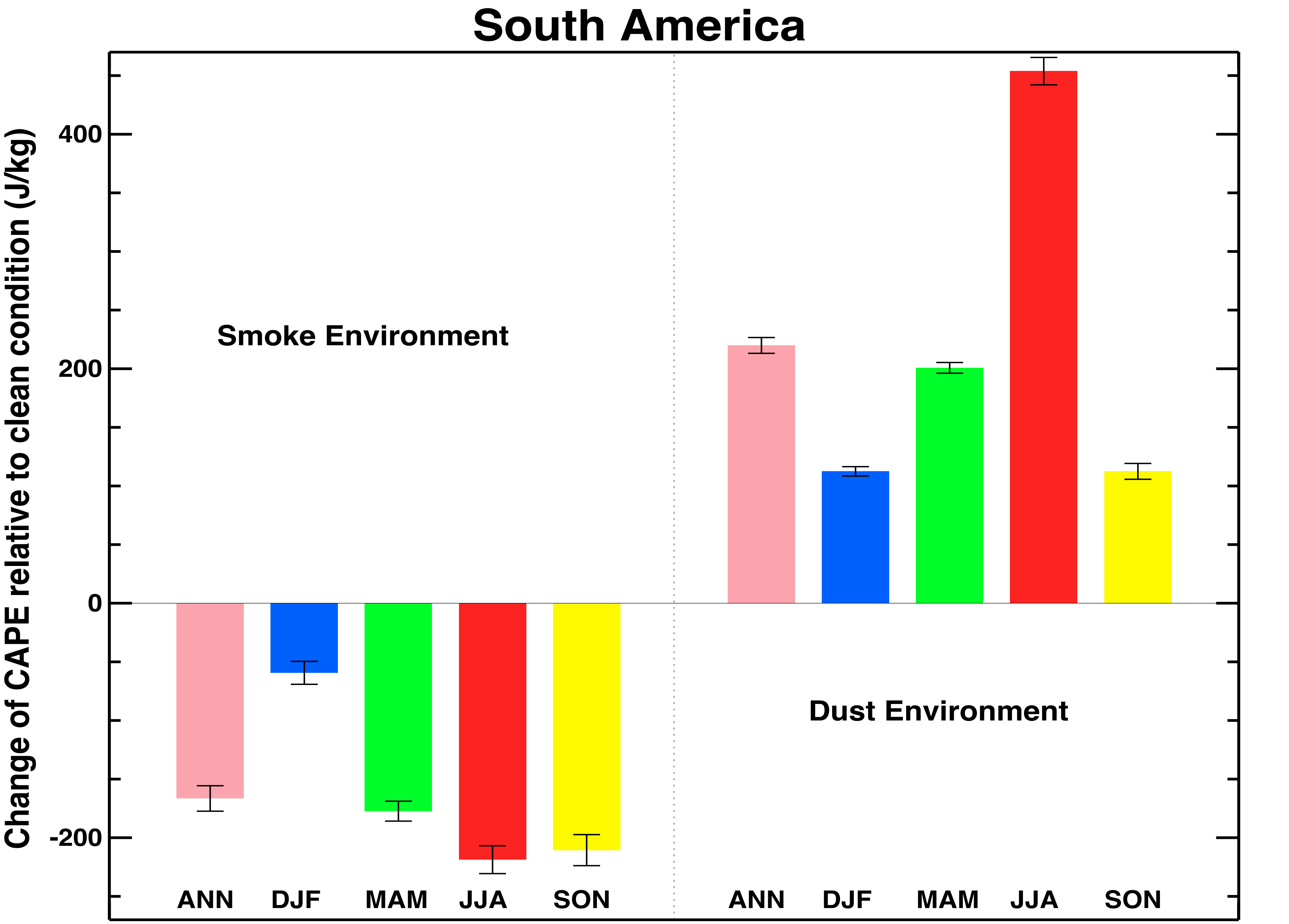

60N
30N
0
30S
60S
Latitude
180W
120W
60W
0
60E
120E
180E
Longitude


South America
Cloud Height Changes (m)
600
400
200
0
–200
–400
Smoke Environment
Dust Environment
ANN
DJF
MAM
JJA
SON
ANN
DJF
MAM
JJA
SON

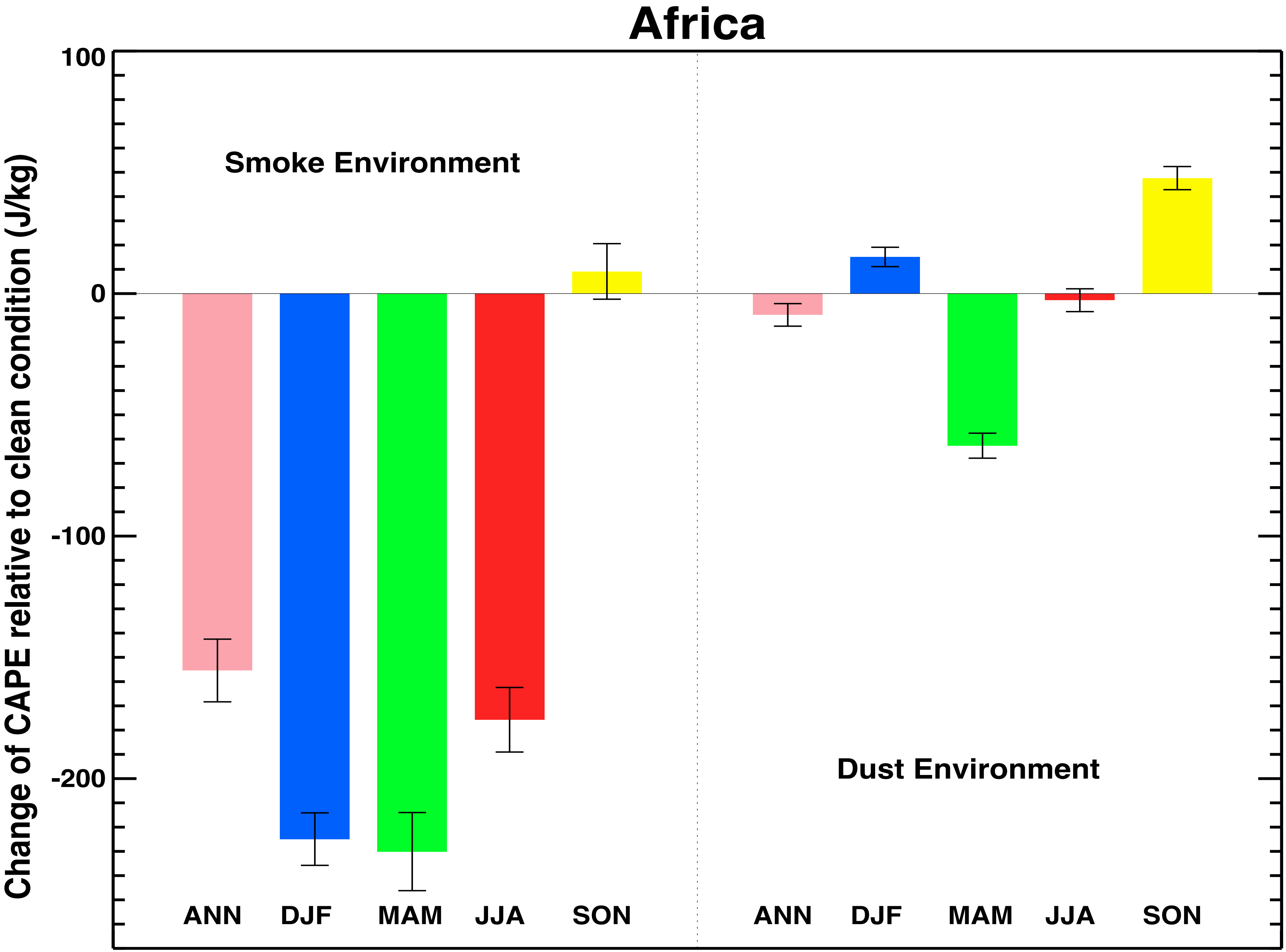


Africa
Cloud Height Changes (m)
400
200
0
−200
−400
−600
Smoke Environment
ANN
DJF
MAM
JJA
SON
Dust Environment
ANN
DJF
MAM
JJA
SON

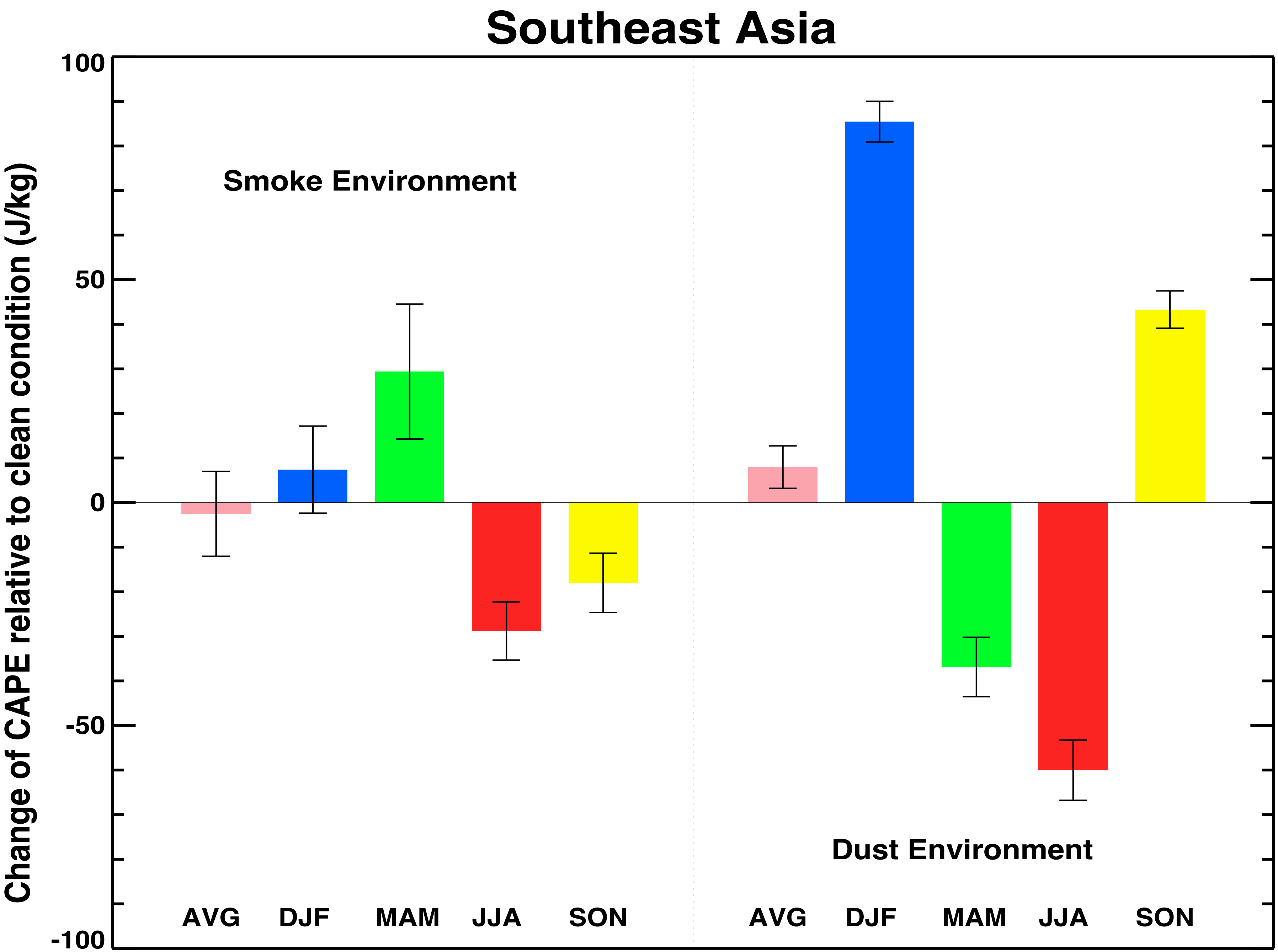

Southeast Asia
Cloud Height Changes (m)
400
200
0
−200
−400
−600
−800
Smoke Environment
AVG
DJF
MAM
JJA
SON
Dust Environment
AVG
DJF
MAM
JJA
SON

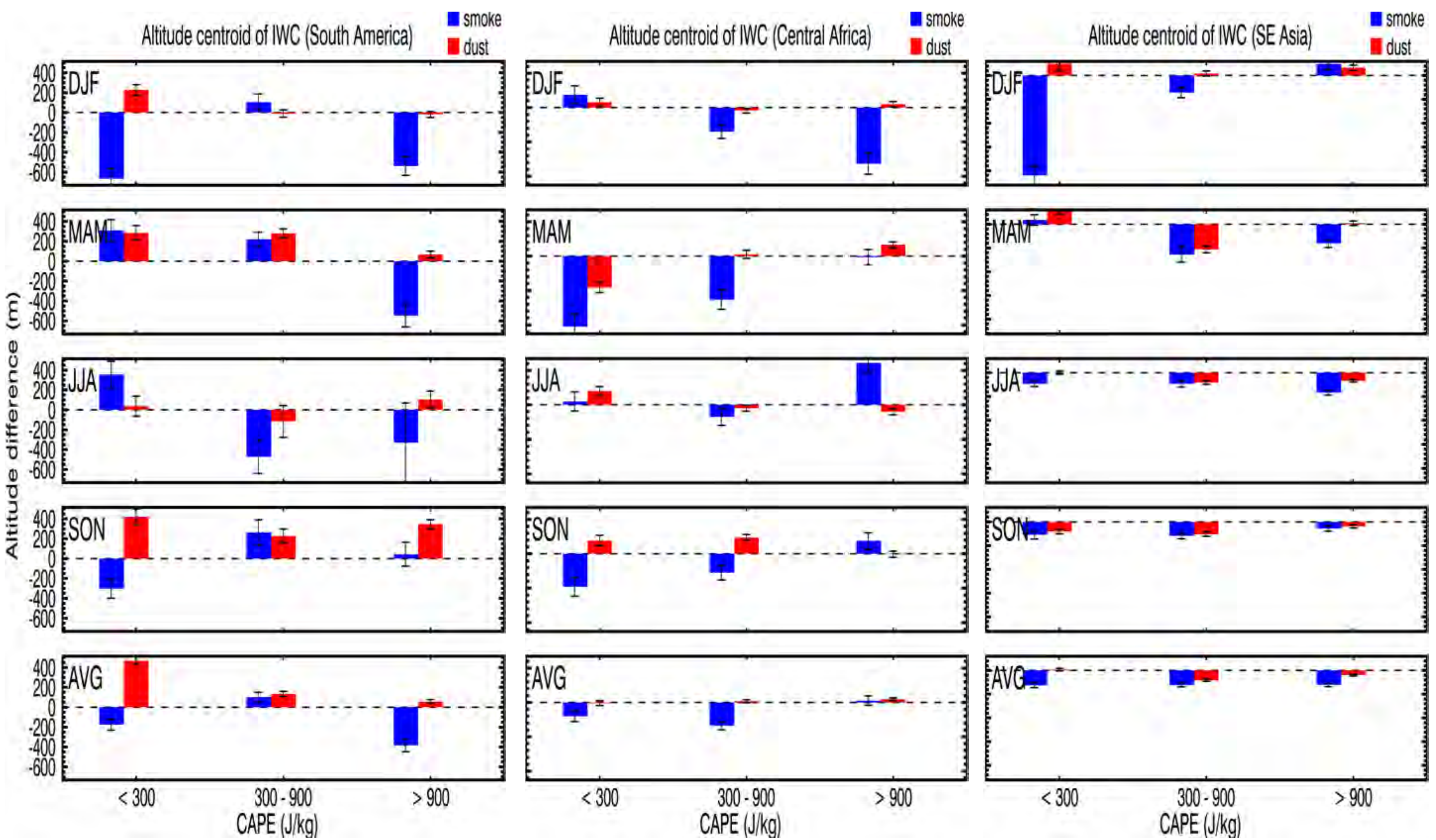


South America
Change of CAPE relative to clean condition (J/kg)
400
200
0
-200
Smoke Environment
Dust Environment
ANN
DJF
MAM
JJA
SON
ANN
DJF
MAM
JJA
SON



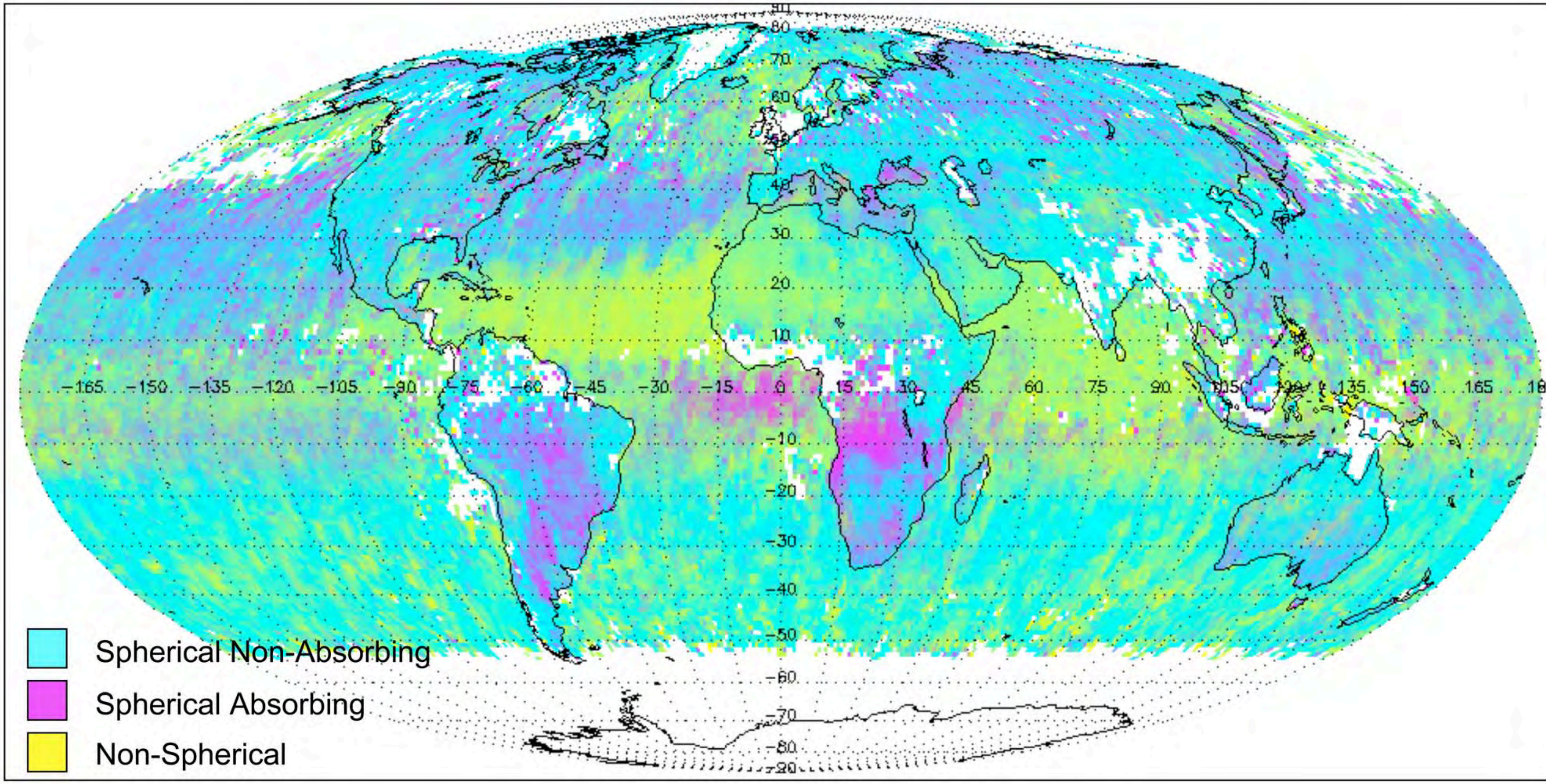
Africa
100
0
-100
-200
Change of CAPE relative to clean condition (J/kg)
Smoke Environment
Dust Environment
ANN
DJF
MAM
JJA
SON
ANN
DJF
MAM
JJA
SON


Southeast Asia
Change of CAPE relative to clean condition (J/kg)
100
50
0
-50
-100
Smoke Environment
Dust Environment
AVG
DJF
MAM
JJA
SON
AVG
DJF
MAM
JJA
SON



Altitude centroid of IWC (South America)
Altitude centroid of IWC (Central Africa)
Altitude centroid of IWC (SE Asia)
smoke
dust
DJF
MAM
JJA
SON
AVG
Altitude difference (m)
400
200
0
-200
-400
-600
< 300
300 - 900
> 900
CAPE (J/kg)

MISR Observed Aerosol types in July 2007



Key

- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical

From: Kahn et al. 2010, JGR, doi:10.1029/2010JD014601

Summary

- Over the three study regions of South America, Africa, and South East Asia, the results show:
  - Convective clouds developed in *Smoke* environment have lower cloud height and associated with smaller CAPE, suggesting smoke aerosols (from biomass burning) may affect cloud developments by suppressing the convective development.
  - Convective clouds developed in *Dust* environment have higher cloud height and associated with larger CAPE, suggesting dust aerosols may enhance the deep convection.