AEROSOL EFFECT on CLIMATE:

The MODIS connection

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1. **The direct aerosol forcing**
2. **The indirect aerosol forcing**
3. Remote sensing of aerosol from present satellites
4. Application to aerosol-cloud interaction
5. **How can MODIS do it better ?**
6. **Measurements (SCAR experiment, sun/sky radiometers)**

1. The direct aerosol forcing

Sulfates:

SO_2 -----> $SO_4^{=}$ (particles) -----> Radiation -----> Climate

Smoke:

fire -----> smoke particles -----> Radiation -----> Climate

REMOTE SENSING — CLIMATE

Radiance to space	atmosp. radiance	attenuated surface reflectance	Flux to space	atmosp. flux

$$L^* = L_o + F_d T\rho/\pi \qquad F^* = F_o + F_d \tilde{T}\rho$$

$$L_o \propto P(\Theta)\tau_a \qquad F_o \propto \beta\tau_a$$

Phase function — aerosol optical thickness — back-scattering ratio

SCATTERING ANGLE

ρ — SURFACE REFLECTANCE

$$\beta \cong \int_{90^\circ}^{180^\circ} P(\Theta)\, d\cos\Theta$$

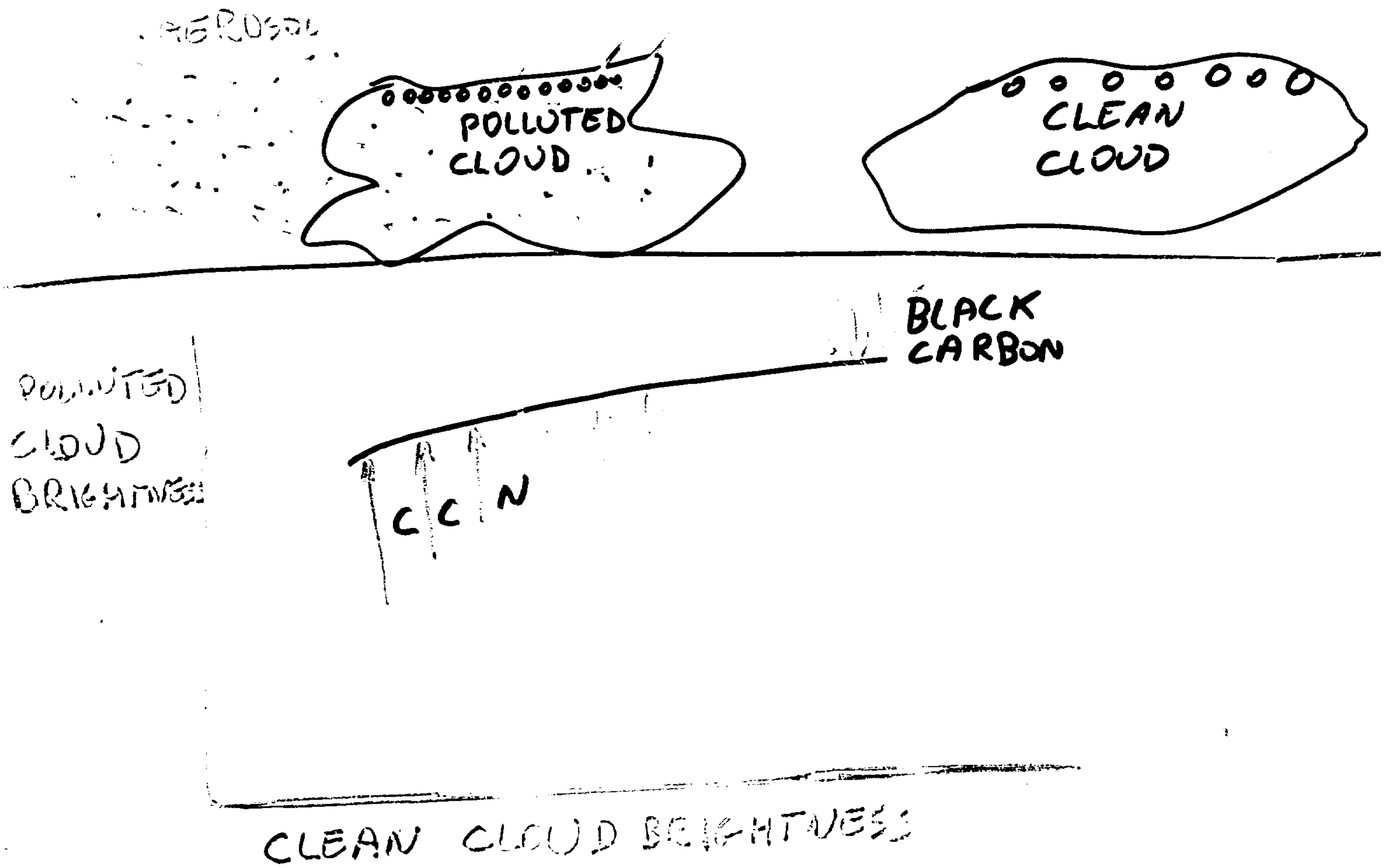
2. The indirect aerosol forcing

Anthropogenic Aerosol Particles

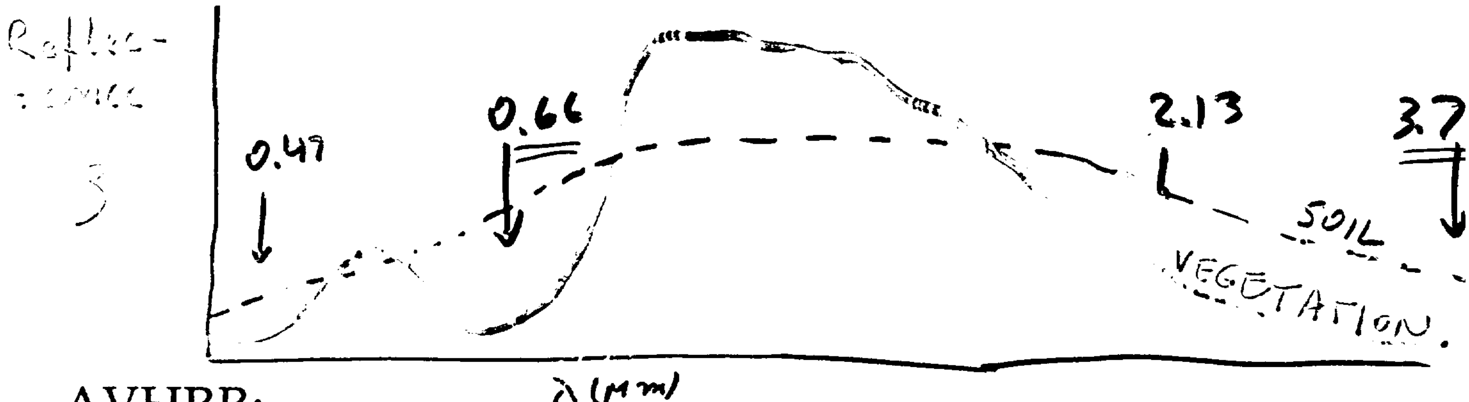
---------> Extra Cloud Condensation Nuclei

---------> Numerous Cloud Drops

---------> Brighter clouds



3. Remote sensing of aerosol from present satellites

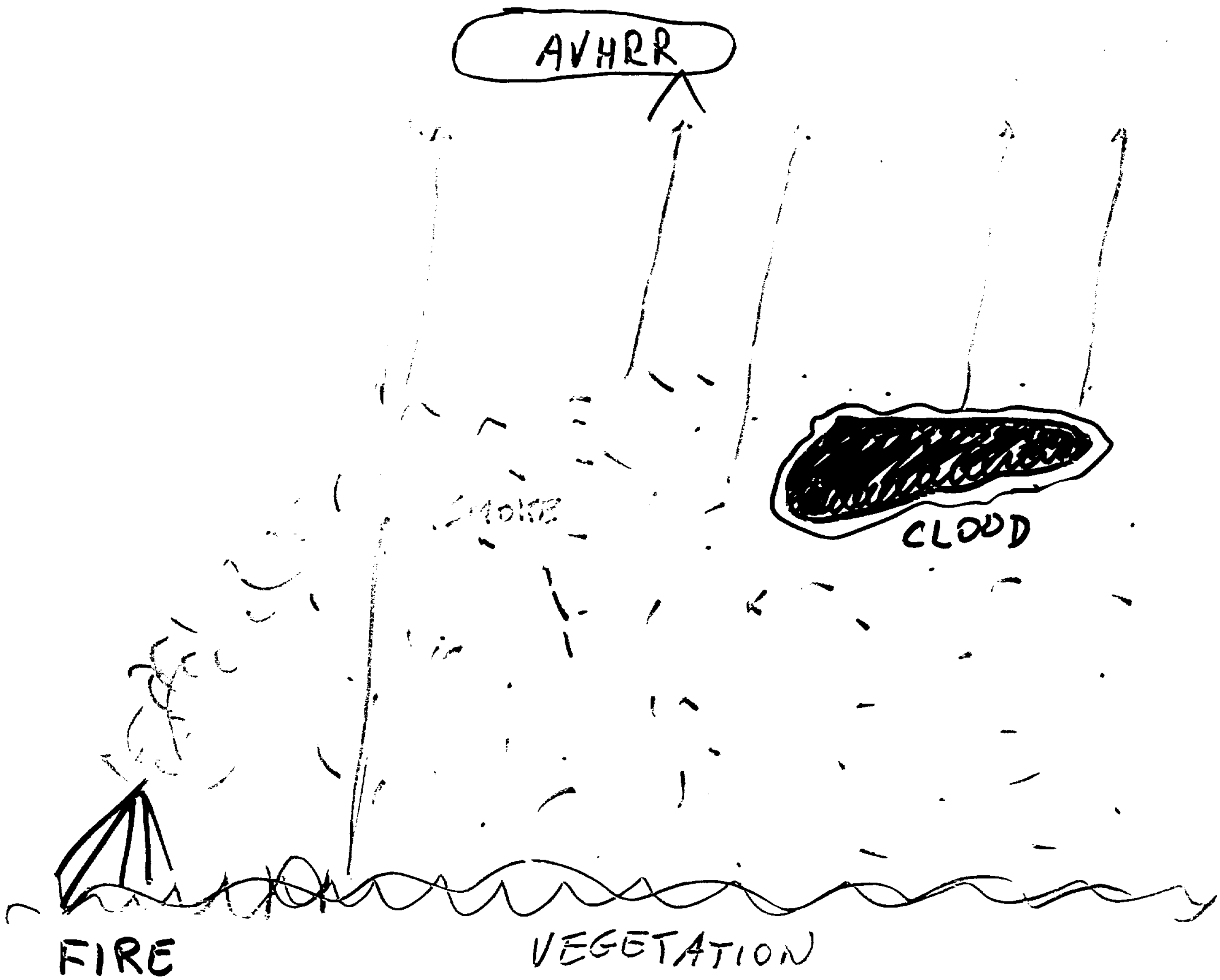


AVHRR:

- Detect dark pixels (using the 3.75 μm channel)
- Determine surface reflectance
- Find the aerosol optical thickness in the red channel

The method works for dense vegetation as the dark target

REMOTE SENSING OF SMOKE & CLOUDS



CLOUD REMOTE SENSING

ORTHOGONALITY OF τ_c x r_c

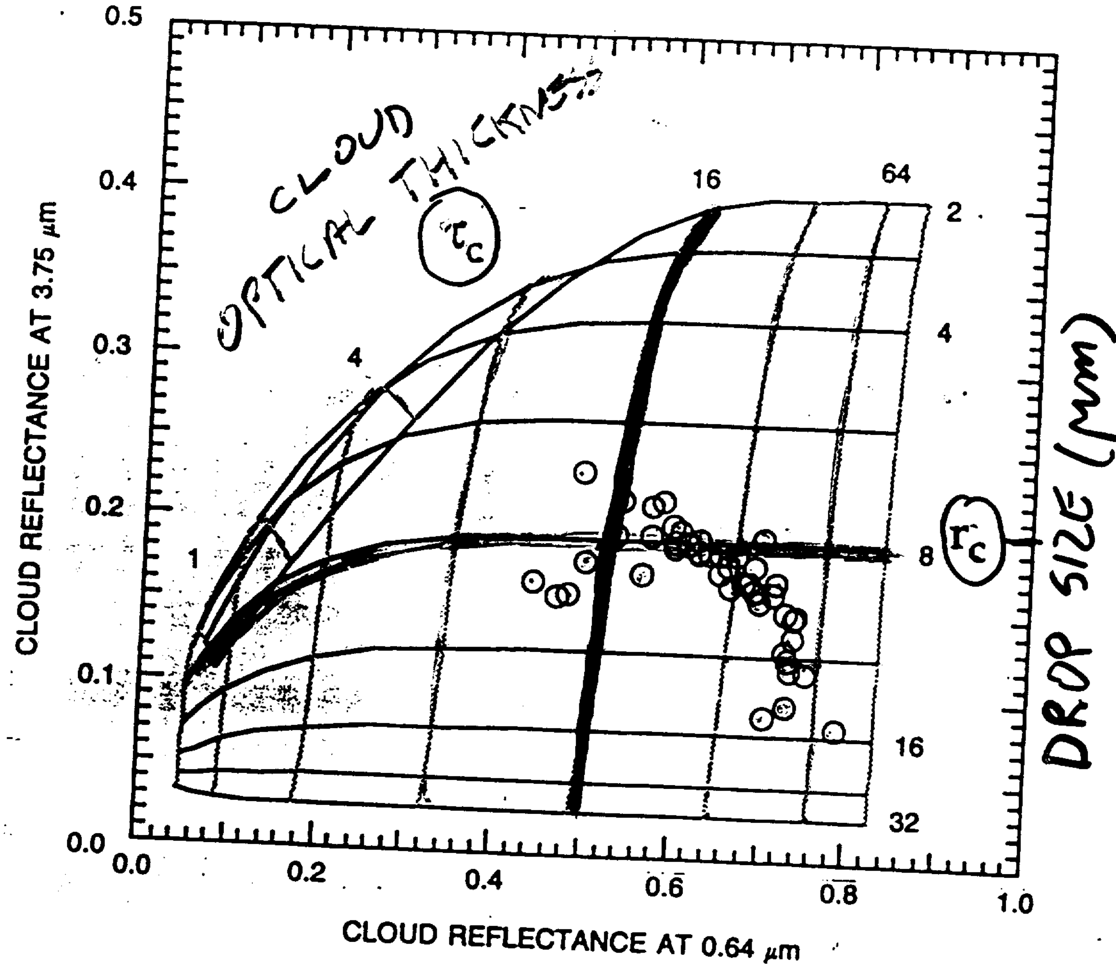
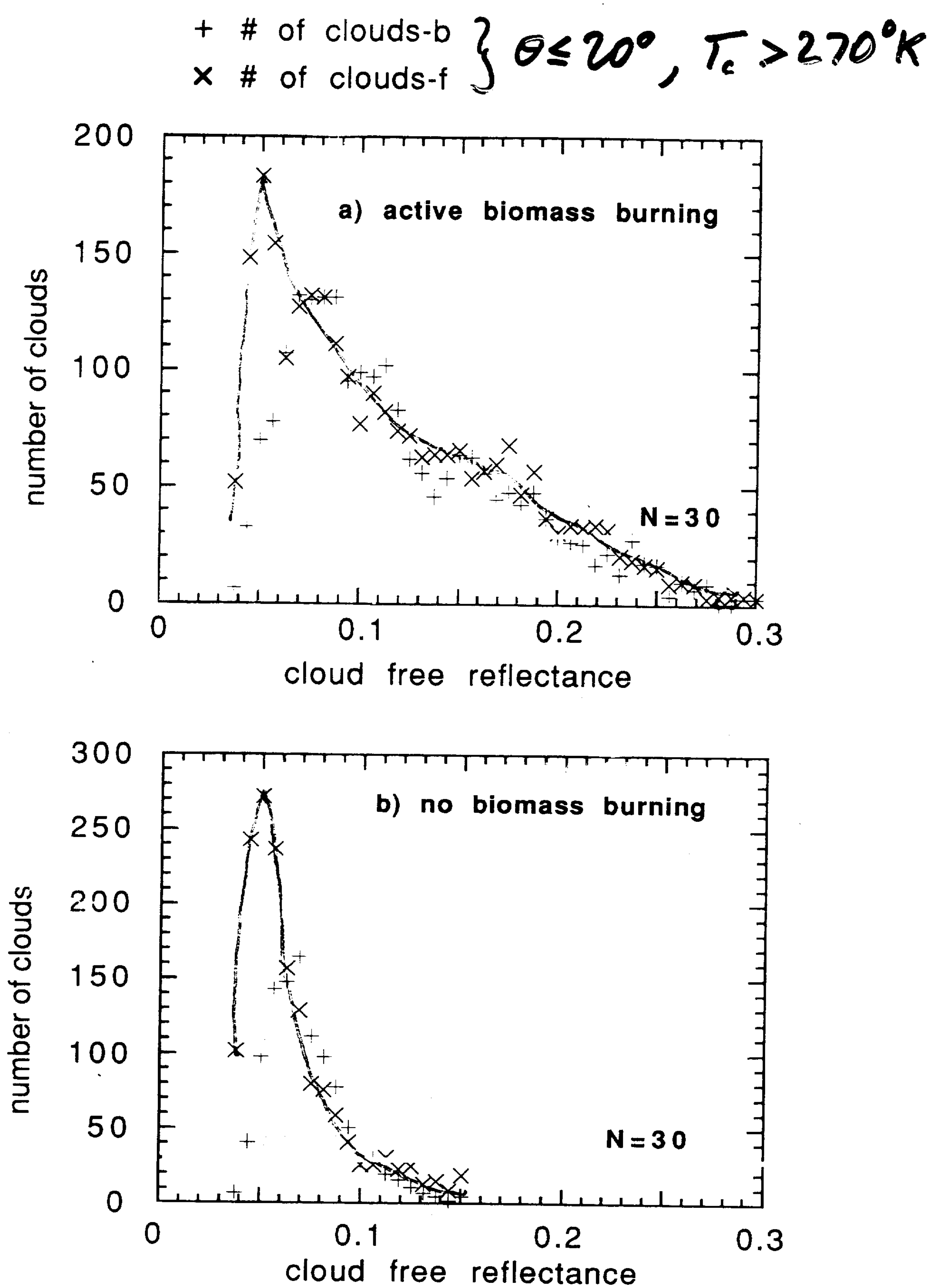
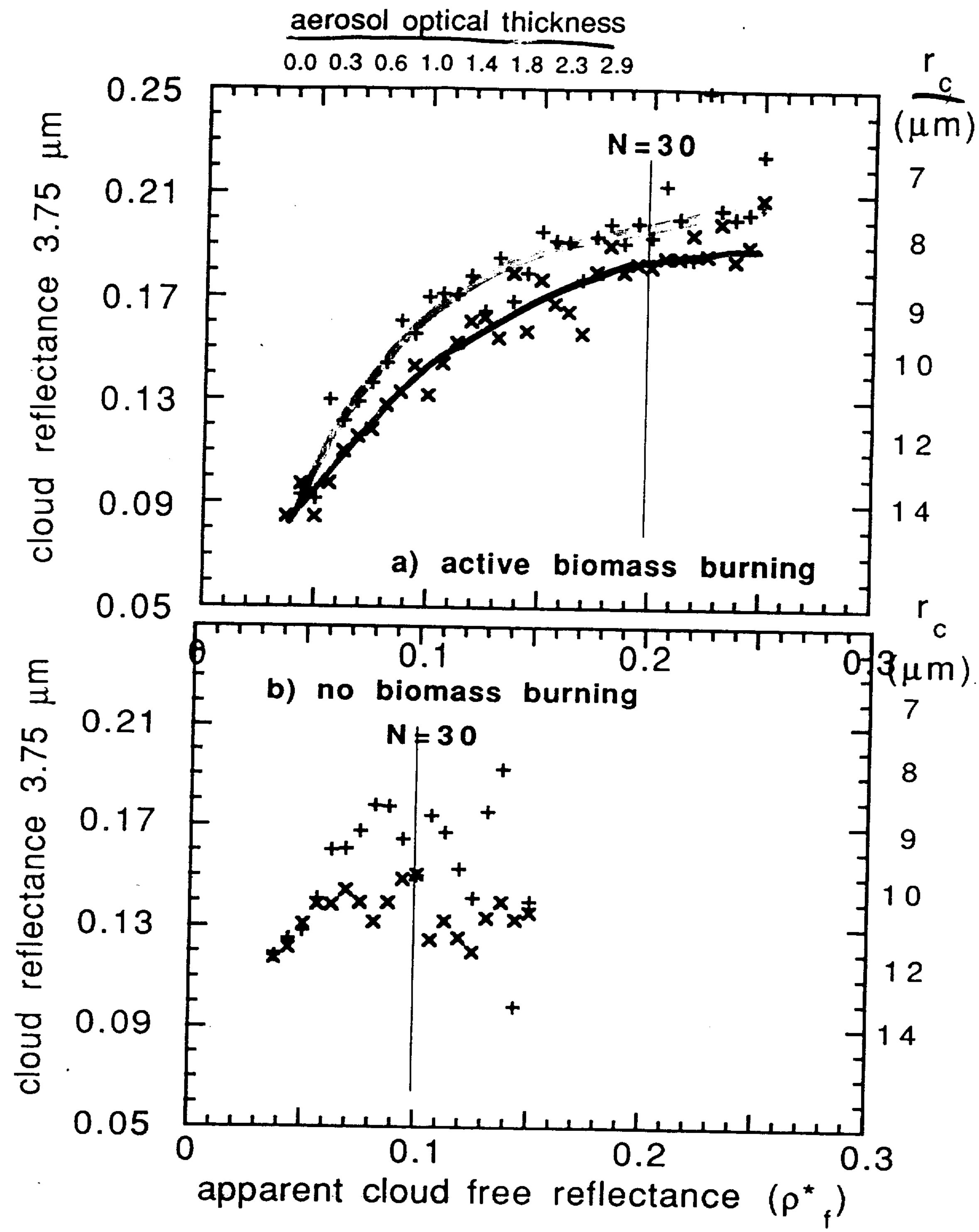


Fig. 1: Counter lines of equal cloud optical thickness (τ_c - gray lines) and equal average drop radius (r_c - black lines), in coordinates of the cloud reflectance in channel 1 (0.64 μm) and channel 2 (3.75 μm). Except for small drop size or small cloud optical thickness the lines are almost orthogonal, indicating the capability to detect the optical thickness and the drop size from these two AVHRR channels. The AVHRR data for clouds in Brazil, averaged for equal steps of the cloud-free radiance (indicating the density of smoke) are also plotted (o). The theoretical data and the measurements are averaged for the two azimuths (30° and 150°) and are give for the conditions during an AVHRR pass with solar zenith angle of 60° and average view direction of 10°.

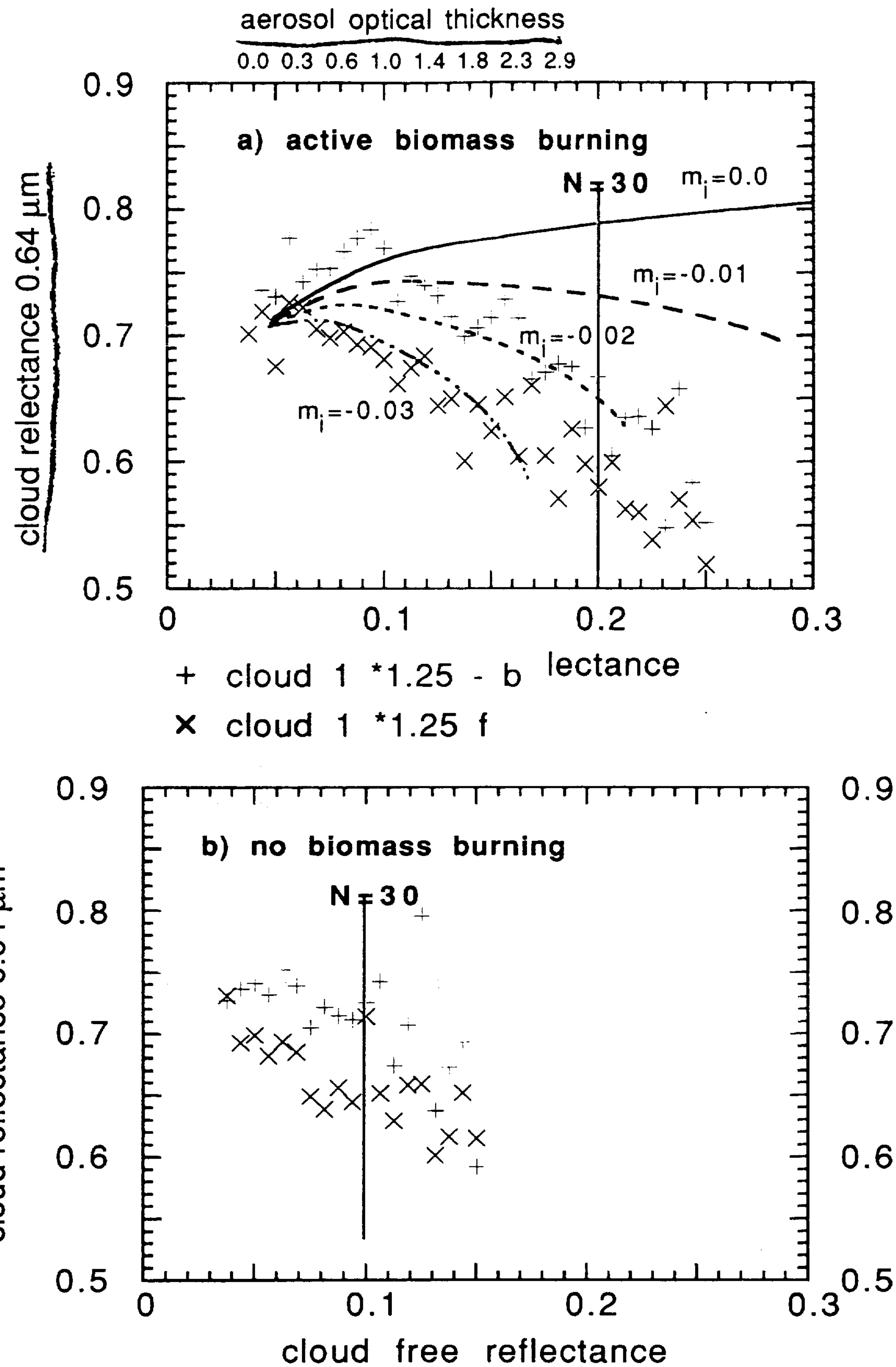

+ # of clouds-b
× # of clouds-f
θ≤20°, T_c >270°K
a) active biomass burning
N=30
number of clouds
cloud free reflectance
b) no biomass burning
N=30
number of clouds
cloud free reflectance

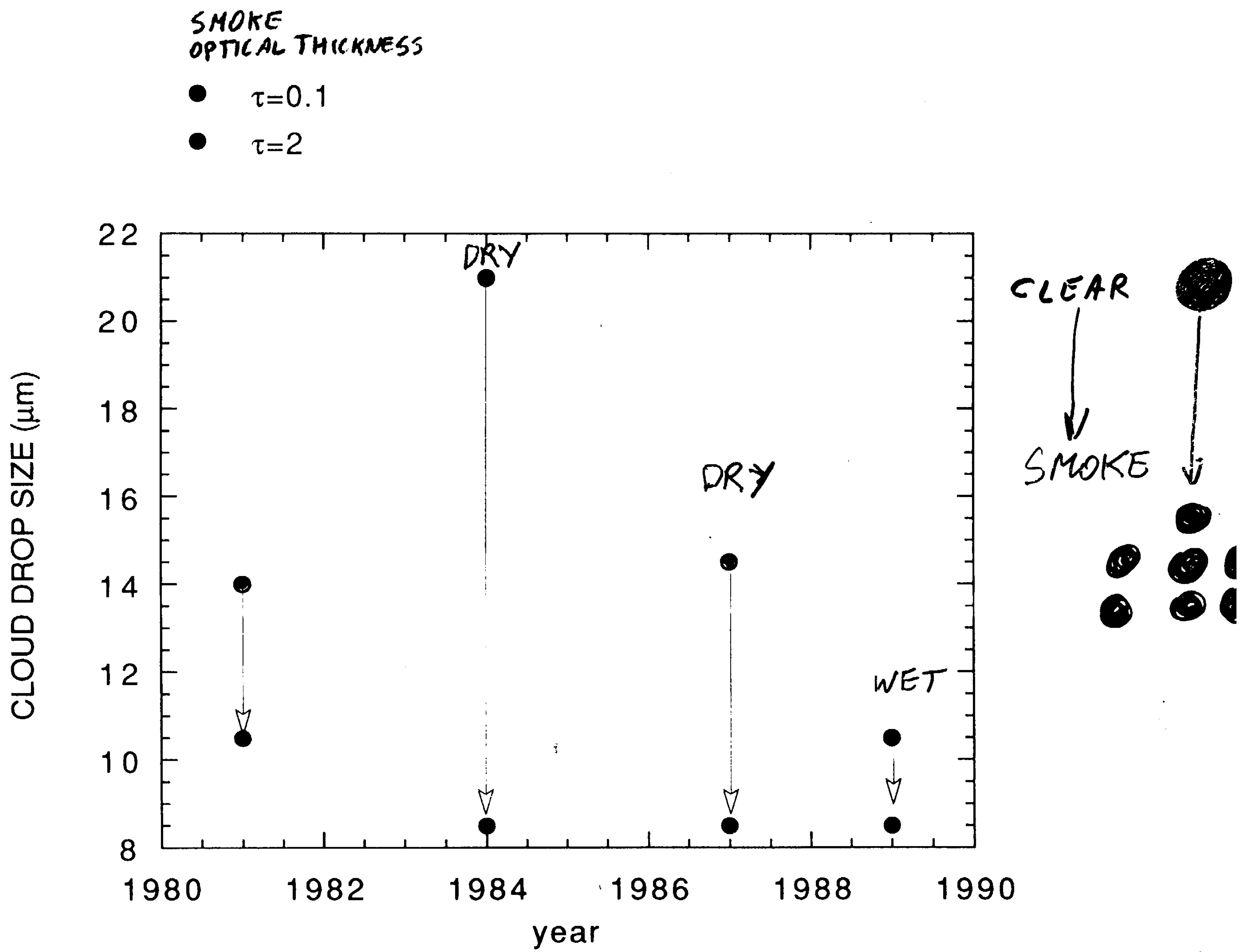
+ - BACK SCATTERING
X - FORWAD scattering } $\theta \le 20°$, $T_c \geq 270°K$



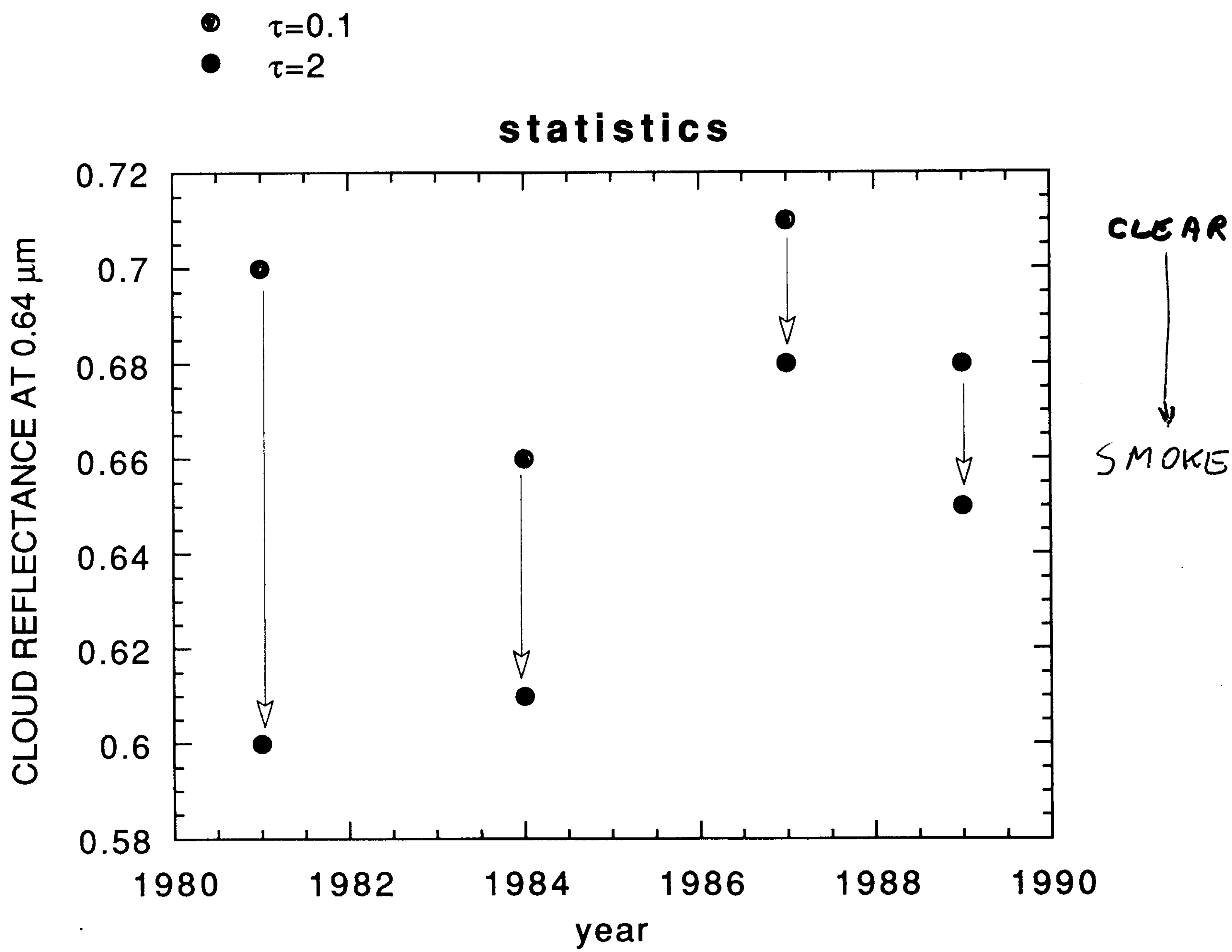
SMOKE → SMALLER DROP SIZE

CLOUD REFLECTIVITY





SMOKE OPTICAL THICKNESS
τ=0.1
τ=2
DRY
DRY
WET
CLEAR
SMOKE
CLOUD DROP SIZE (µm)
year
22
20
18
16
14
12
10
8
1980
1982
1984
1986
1988
1990

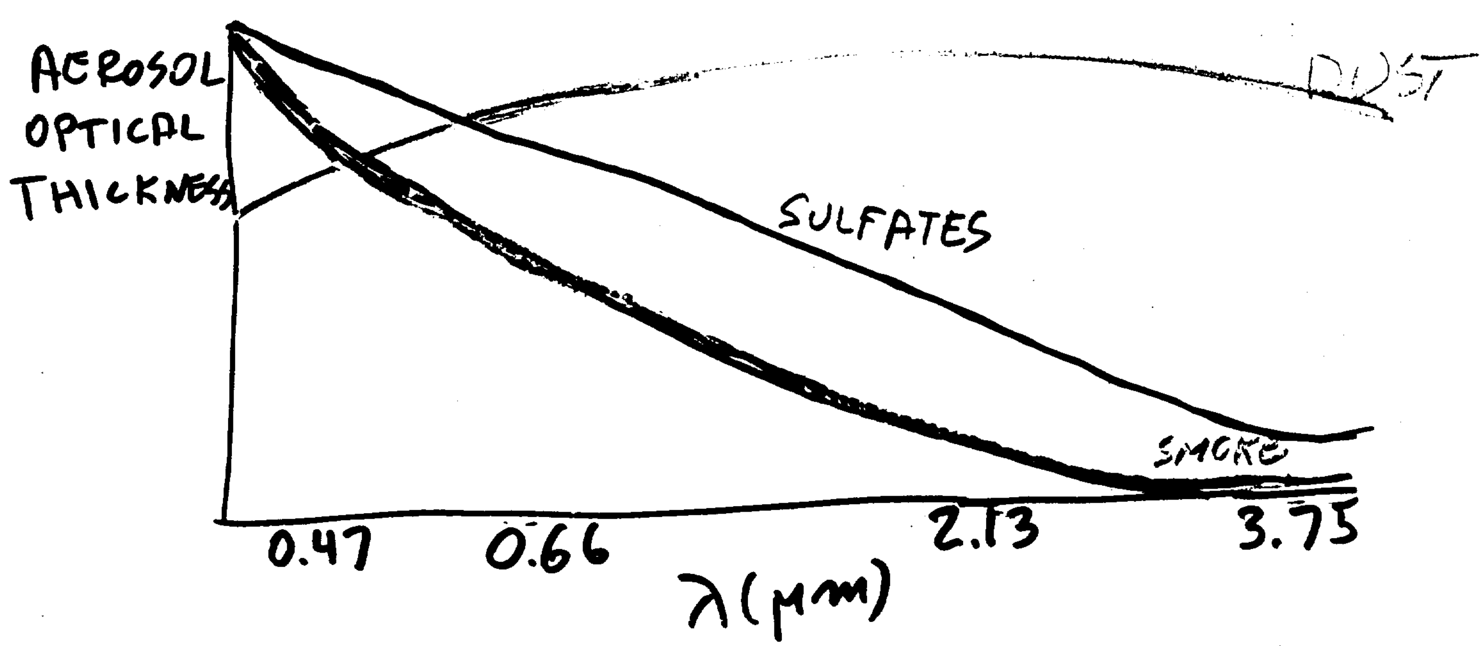


τ=0.1
τ=2
statistics
CLOUD REFLECTANCE AT 0.64 μm
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
1980
1982
1984
1986
1988
1990
year
CLEAR
SMOKE

5. How MODIS will do it better ?

retrieved parameter	AVHRR	MODIS
cloud drop size	3.75 µm	3.95 µm, 2.13 µm
determine dark targets	3.75 µm	3.95 µm, 2.13 µm
aerosol optical thickness	0.64 µm	0.47 µm 0.64 µm 2.13 µm
resolution	1 km	250m -1km
water vapor	affects retrieval	measured
surface parameters	--------------	retrieved

calibration, registration, noise...............



oxidation of sulfur in clouds is represented by adding a fraction of the SO_2 mass ($[0.5-f_1]S_o/N$) to a fraction f_p (f_p=10/N, 10 is the assumed number of cycles through clouds[11]) of particles that are large enough to be activated for that supersaturation. It is assumed that each cloud drop can oxidize the same amount of SO_2[16], thus neglecting effects of drop size and acidity, which can be of significant importance[17]. Coagulation between particles and in-cloud scavenging was introduced using size dependent rates developed by Hoppel[11]. These account for the particle Brownian diffusion and gravitational collection of interstitial particles by cloud droplets.

To test the model we simulated measured aerosol size distributions[11,12]. Figure 1a shows the time evolution of the size distribution for maritime conditions: low initial particle concentration (120 particles·cm^{-3}), supersaturation based on a square probability distribution and SO_2 concentration of S_o=0.5 μgS/m^3. In Fig. 1b the final size distribution is shown for a variety of computational conditions. It shows the effect of replacing the square distribution of S_c with a Gausian distribution and the effect of adding a nuclei mode to the initial size distribution. The size distribution is compared with measurements of Maritime air by Hoppel et al. (Figs. 7 and 10 in [11]). We were able to reproduce the measured two accumulation modes found in the measurements[11,12], one at 0.015-0.03 μm for particles generated in the gas phase, and a second at 0.08-0.12 μm for particles that grew in the aqueous phase in clouds (Fig. 1b). The measured gas phase mode was smaller than in the simulation (Fig. 1b). For a polluted environment: high initial particle concentration (800 cm^{-3}) and larger SO_2 concentration S=1 μgS/m^3 only one accumulation mode appears at 0.06-0.08 μm, also in agreement with measurements[11,12] (Fig. 2). The remaining nuclei mode is also shown in the figure. Recent laboratory measurements of the in-cloud growth of acid and salt sulfates

Aerosol cooling vs. Greenhouse warming

Sulfate direct forcing 0.3-1 W/m^2

Sulfate indirect forcing 0-1 W/m^2

Biomass burning direct forcing 0.3-1 W/m^2

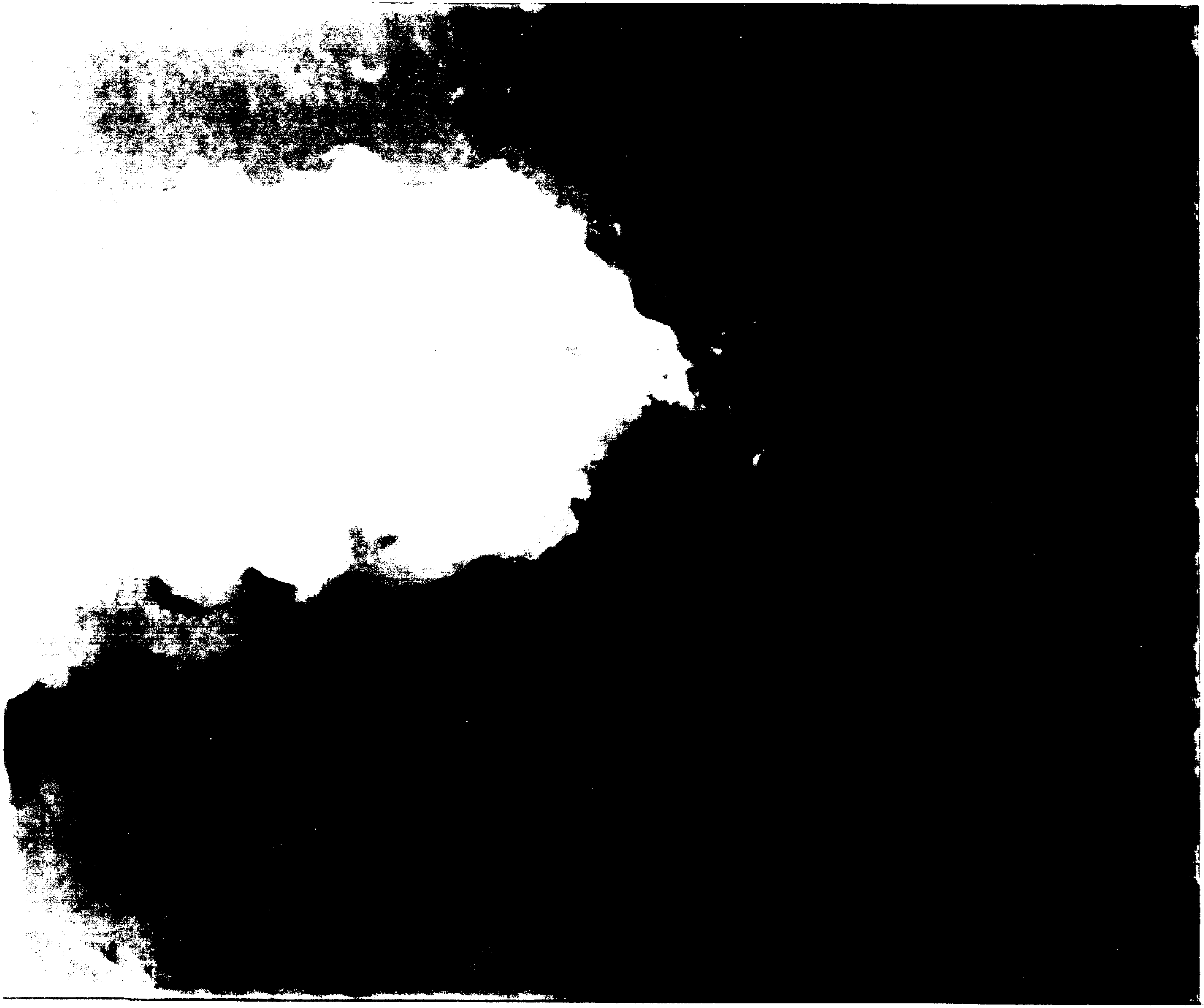
Biomass burning indirect forcing 0-1 W/m^2

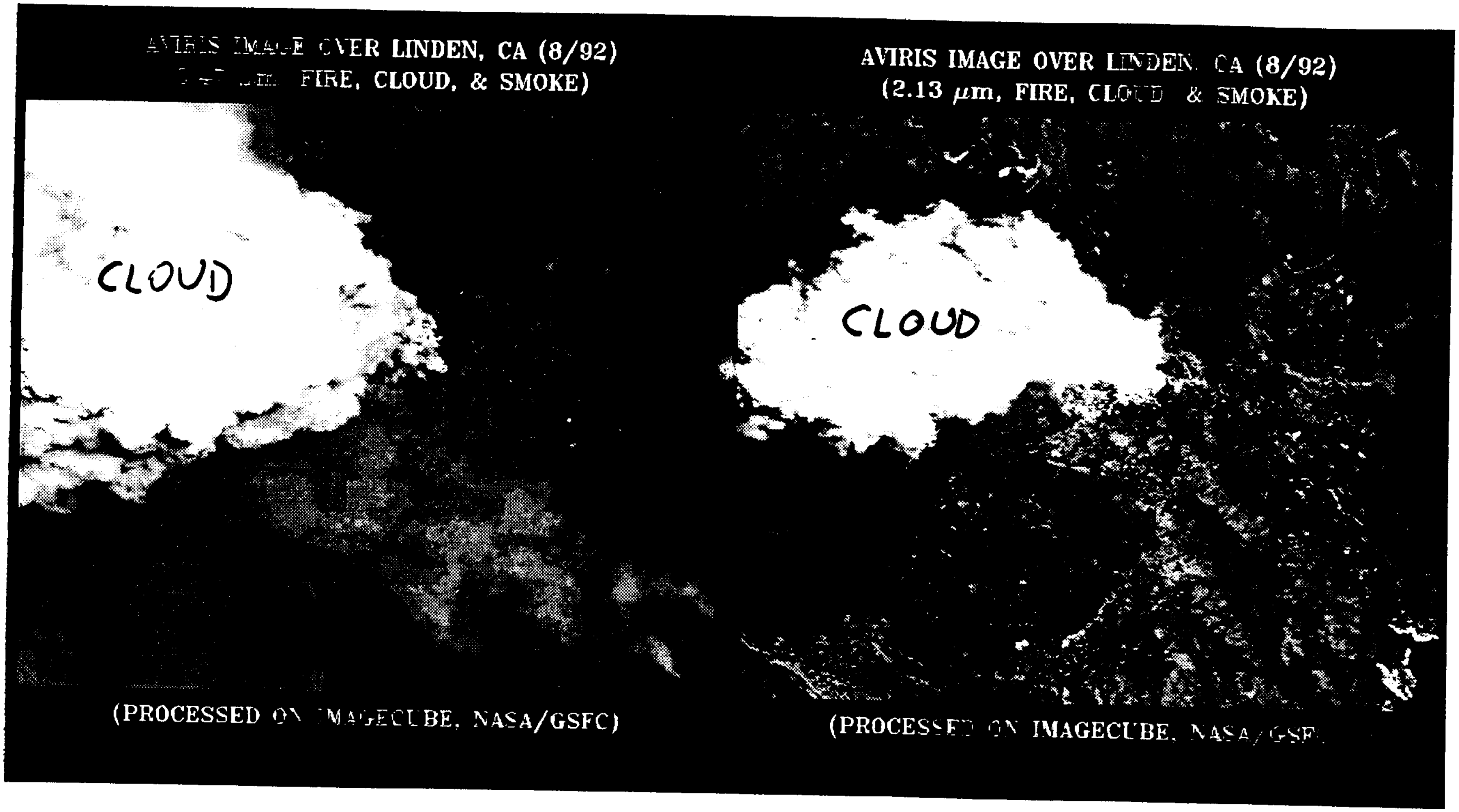
Total cooling	0.6-4 W/m^2

Greenhouse effect of CO_2+trace g.	3 W/m^2

NITRATES ?

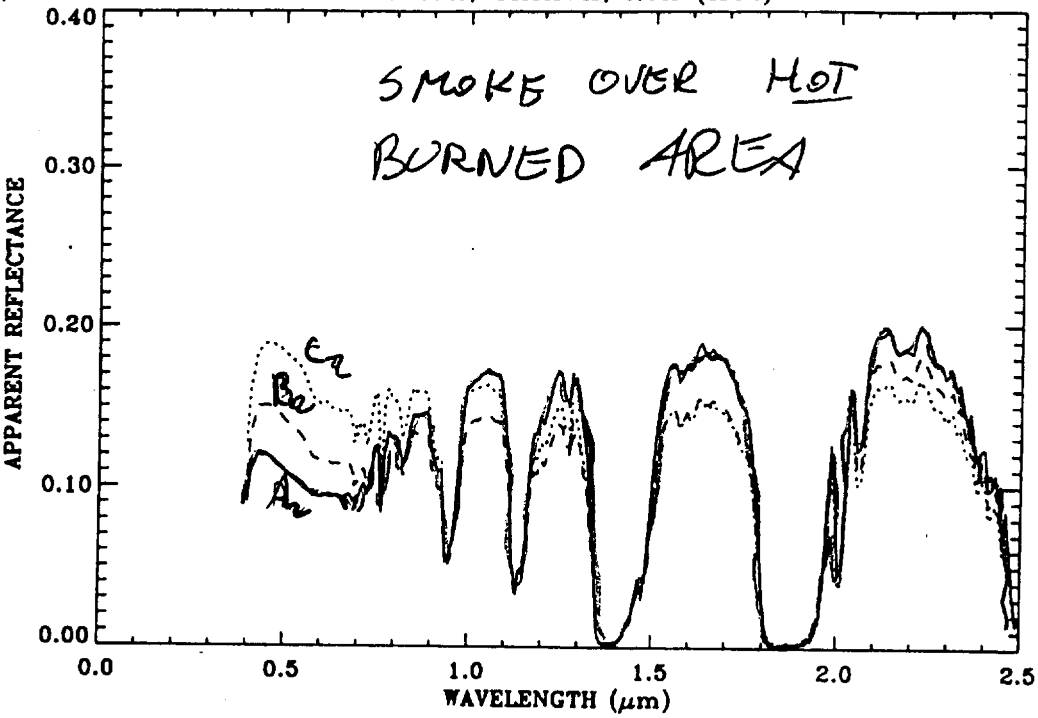
INDUSTRIAL CARBON ?




OVER LINDEN, CA (8/92)
FIRE, CLOUD, & SMOKE)
CLOUD
(PROCESSED ON IMAGECUBE, NASA/GSFC)
AVIRIS IMAGE OVER LINDEN, CA (8/92)
(2.13 μm, FIRE, CLOUD & SMOKE)
CLOUD
(PROCESSED ON IMAGECUBE, NASA/GSFC)

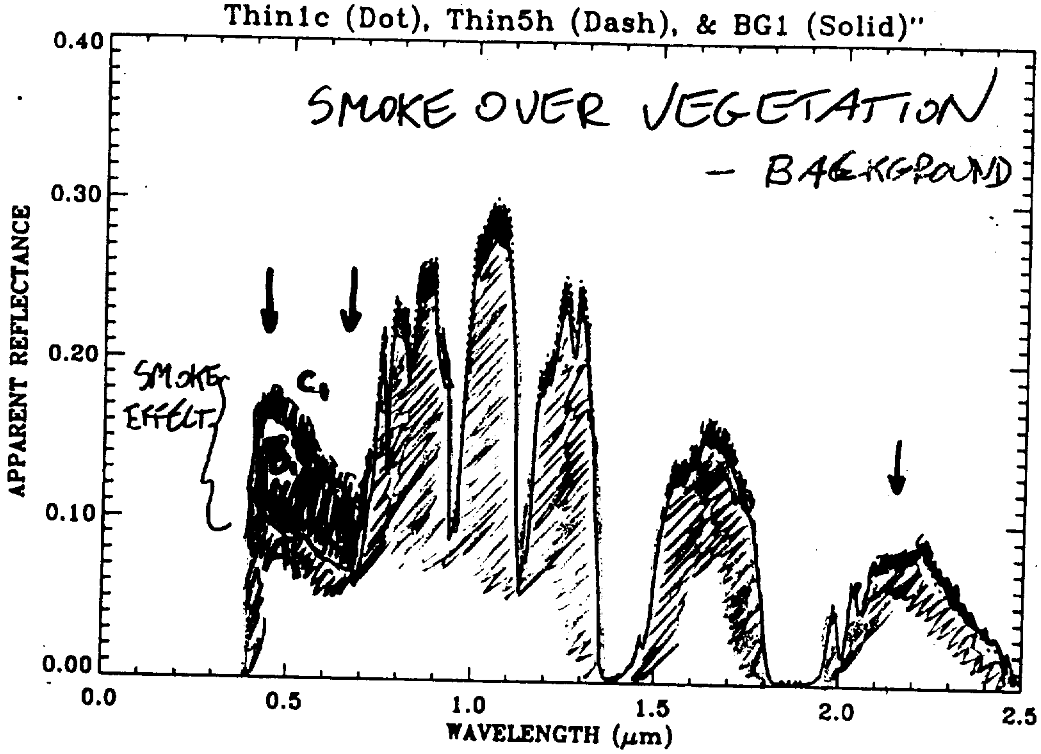
SMOKE OVER BURNED AREAS

Thin6h, Thin7h, Ash (Hot)



COLD SMOKE OVER VEGETATED AREAS (LOWER PART OF THE IMAGE)

Thin1c (Dot), Thin5h (Dash), & BG1 (Solid)"



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6. Measurements:

Smoke/Sulfates Cloud and Radiation experiment

A- July 1993, Atlantic coast of US: **Sulfates**

8 days of operation
  clear --> hazy days
  cloud free ----> low level cumulus to cirrus
5 Landsat TM images of clear and hazy conditions
MAS and AVIRIS images from the ER-2
U. Washington C-131A for aerosol, cloud chemistry and radiation
Network of sun/sky radiometers

Aerosol formation and properties
Aerosol optical properties
Cloud CCN and drops
Remote sensing of aerosol
Remote sensing of clouds and cirrus
Remote sensing of surface properties
Remote sensing of water vapor
Atmospheric corrections

B- 1994, 1995, Brazil: **Smoke and clouds**

C- 1994 California **Fires**, surface reflectance

(See poster in back of the room)

network of sun/sky radiometers

Sample of the global variation of aerosol:

- optical thickness
- size distribution
- scattering phase function
- ground truth for experiments and satellite retrievals

1992: Brazil (B. Holben) - 2 weeks
1993: Brazil (B. Holben) - dry season
1993: East US (SCAR-A) - 12 weeks
1994: One year of sampling in
Bermuda, Barbados, Tel Aviv,
SCAR-B and C
LTER stations in the US+
1995: One year of sampling in China,

1998-----> Stations around the world that represent remote sensing conditions and aerosol types for ground truth and fine tune.

Summary and conclusions

1. Aerosol can affect climate by directly reflecting sunlight to space and indirectly by increasing cloud reflectance.

2. Satellite data can be used to analyze cloud-aerosol relation on a large scale.

3. MODIS can sense clouds and aerosol better due to the better spectral and spatial resolution and radiometric performance.

   Additional aerosol and cloud parameters can be sensed.

4. Network of sun/sky radiometers on representative geographical locations is very important to assess the aerosol optical properties and for ground truth to MODIS

- The End -