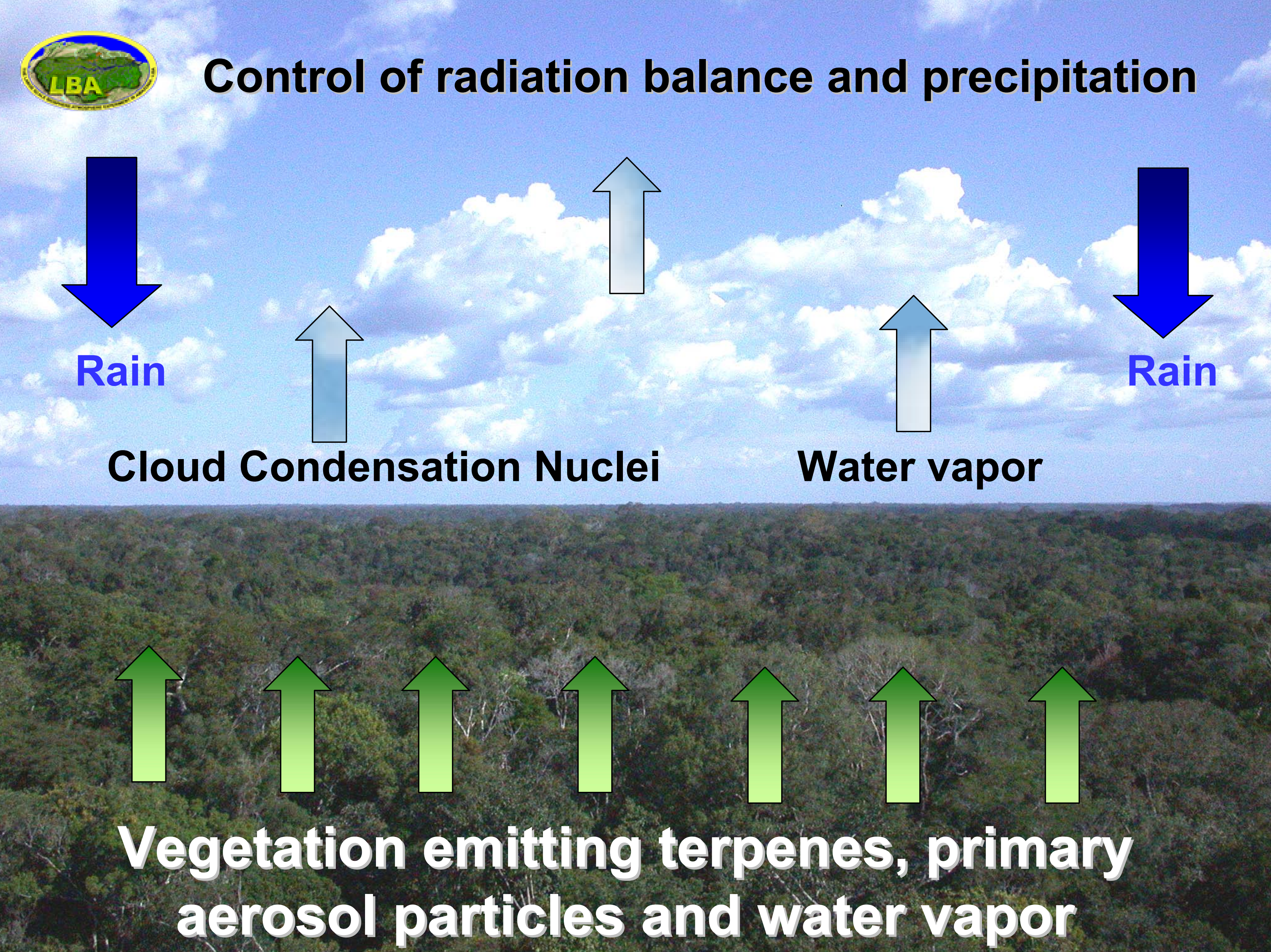
INPE/CPTEC, 19 de Outubro de 2004

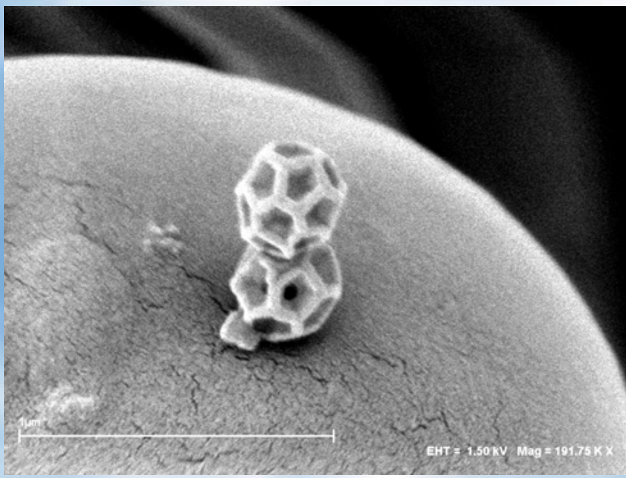
O relacionamento das partículas de aerossóis com o sistema climático terrestre

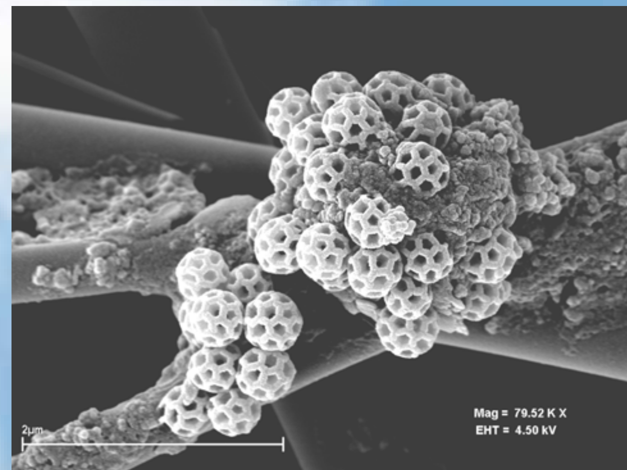
Paulo Artaxo , M. O. Andreae , M. A. Silva Dias, K. M. Longo, Saulo de Freitas, D. Rosenfeld, W. Maenhaut, S. Fuzzi, C. Facchini, S. Decesari, G. Frank , P. Guyon, M. Clayes, E. Swietlicki, Y. Rudich, e todo o time do LBA.

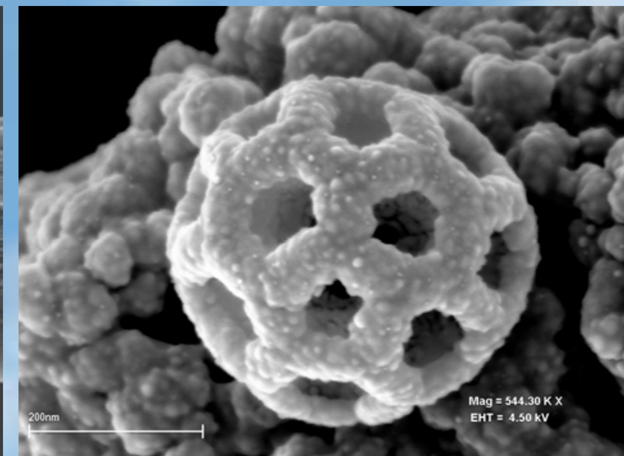
04 10 2002 21:55

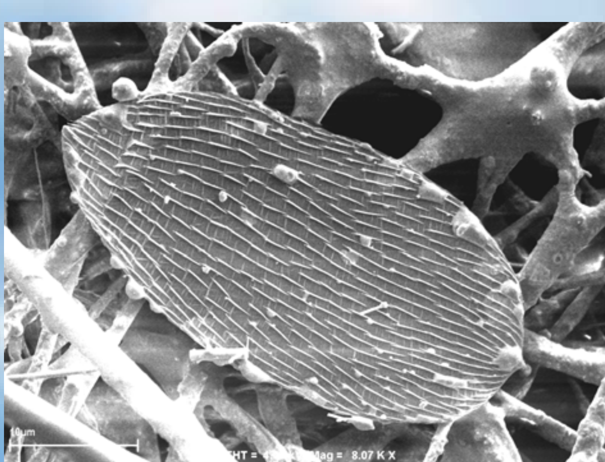

Control of radiation balance and precipitation
LBA
Rain
Rain
Cloud Condensation Nuclei
Water vapor
Vegetation emitting terpenes, primary aerosol particles and water vapor

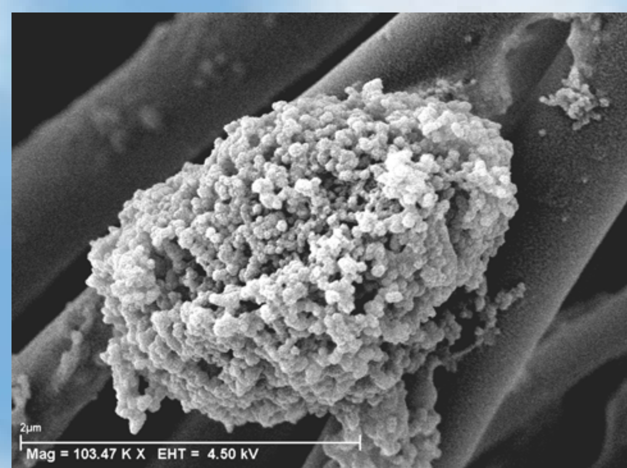
Partículas de aerossóis biogênicos naturais da floresta

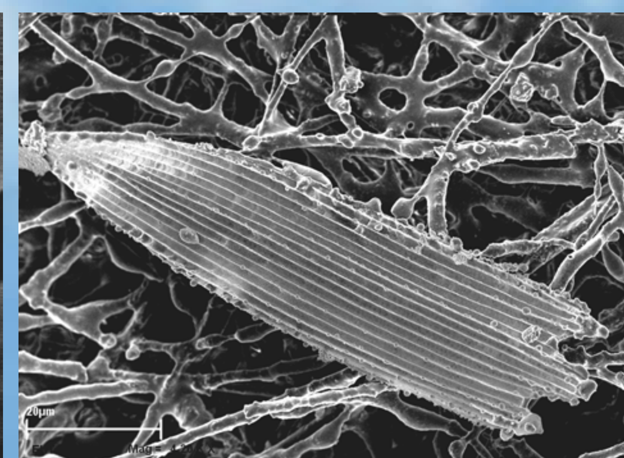












EPMA photos from Gunther Helas, MPIC

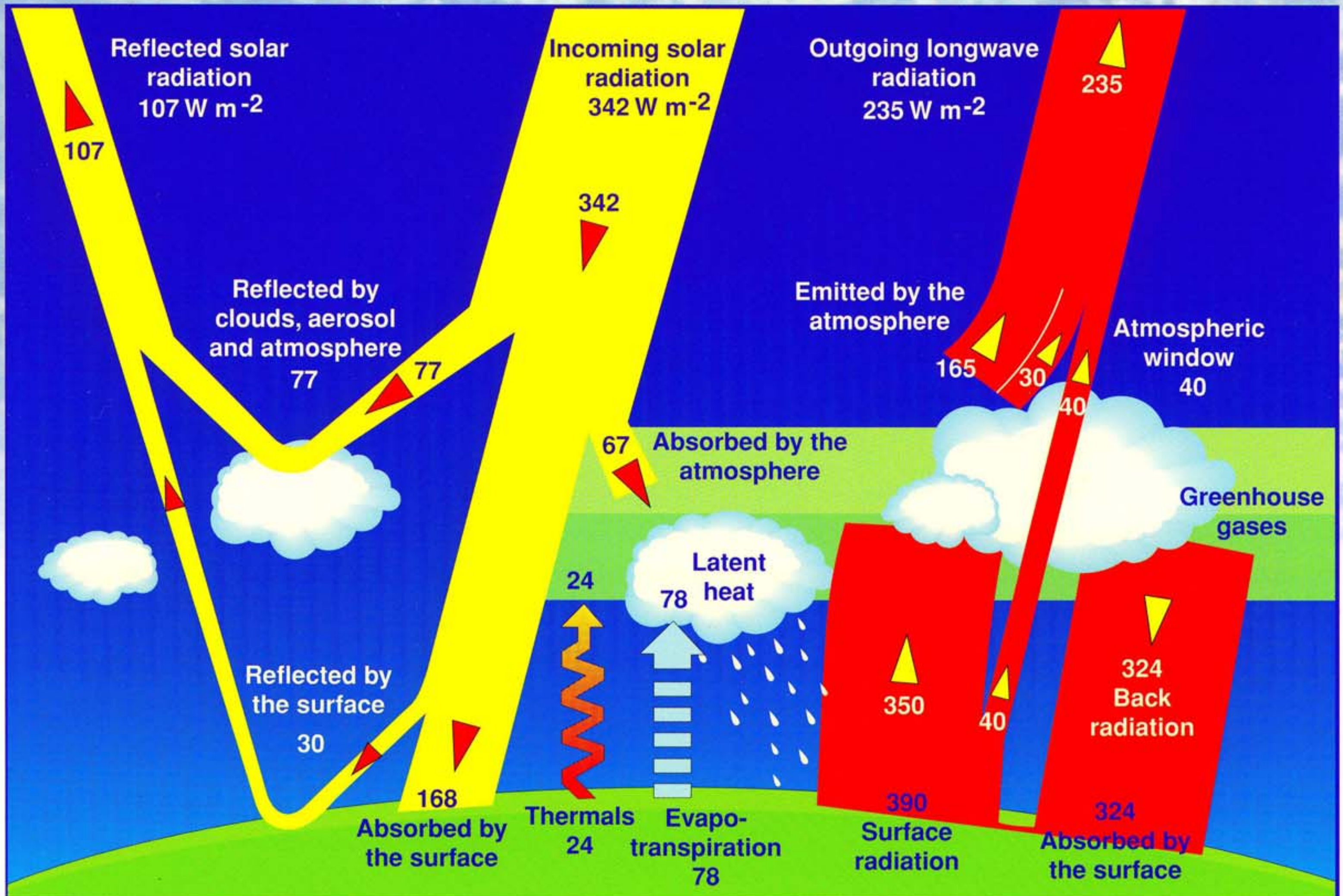
CCN production in natural conditions in Amazonia
Oxidation product of isoprene: 2-methyltetrols

Table S1. Median concentrations (ng m^{-3}) and concentration ranges of PM, OC, EC, polyhydroxylated compounds, and malic acid in 10 total filter samples collected during the LBA-CLAIRE-1998 wet season campaign (23 March - 15 April 1998) in Balbina, Brazil.

	Concentration (range)		Mean % carbon of OC
PM	7500	(4900-18300)	
OC	2700	(2100-5300)	
EC	0	(0-14)	
2-methyltetrols (*threo* + *erythro*)	31	(14-83)	0.61 ± 0.39
malic acid	7.2	(2.6-15)	0.10 ± 0.06
levoglucosan	0.46	(0-3.0)	0.02 ± 0.02
arabitol	81	(42-270)	1.36 ± 0.43
mannitol	112	(58-330)	1.79 ± 0.38
glucose	29	(12-76)	0.60 ± 0.42

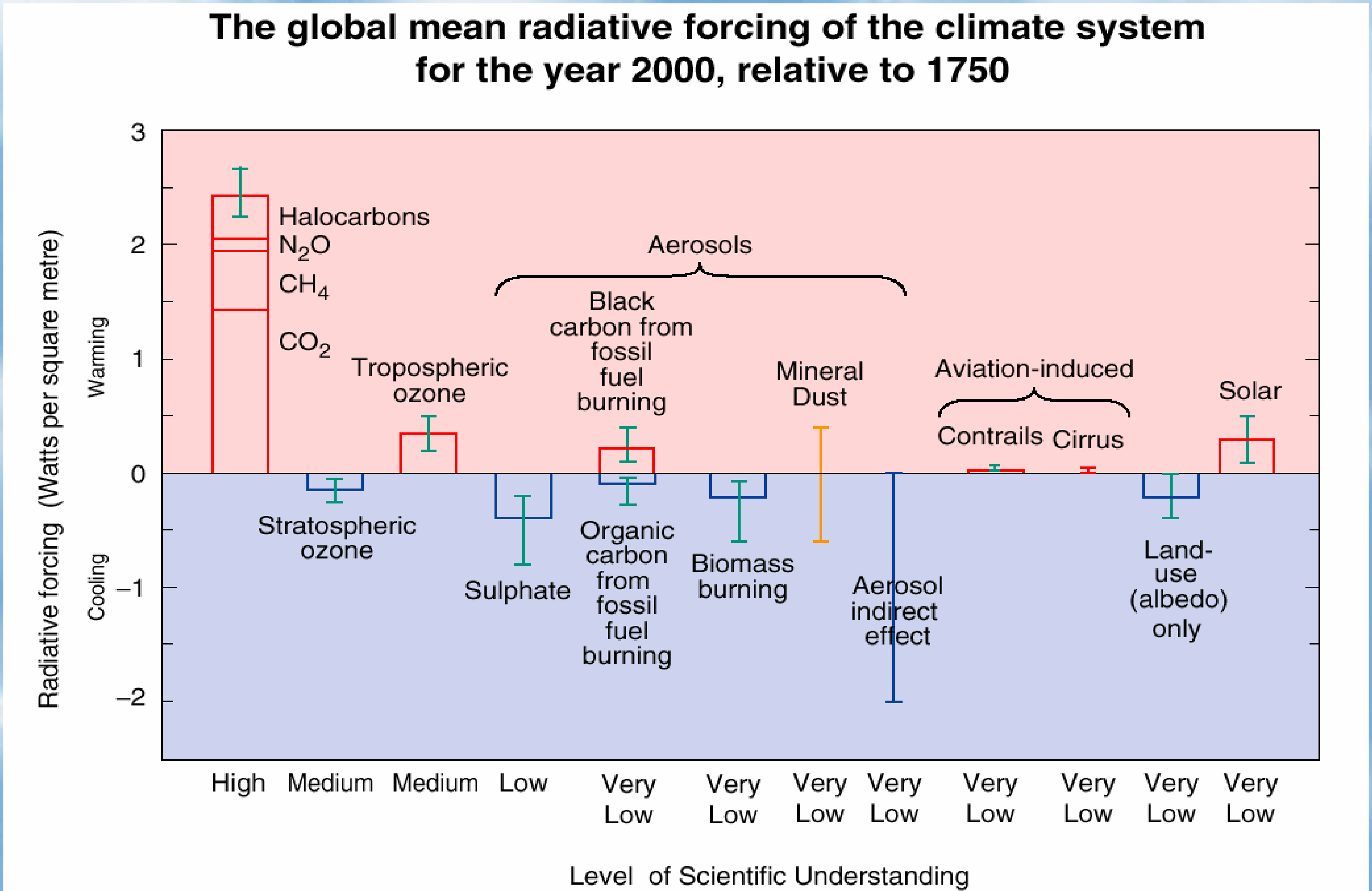
From Magda Clayes et al., 2004

Interação entre a radiação solar e a atmosfera

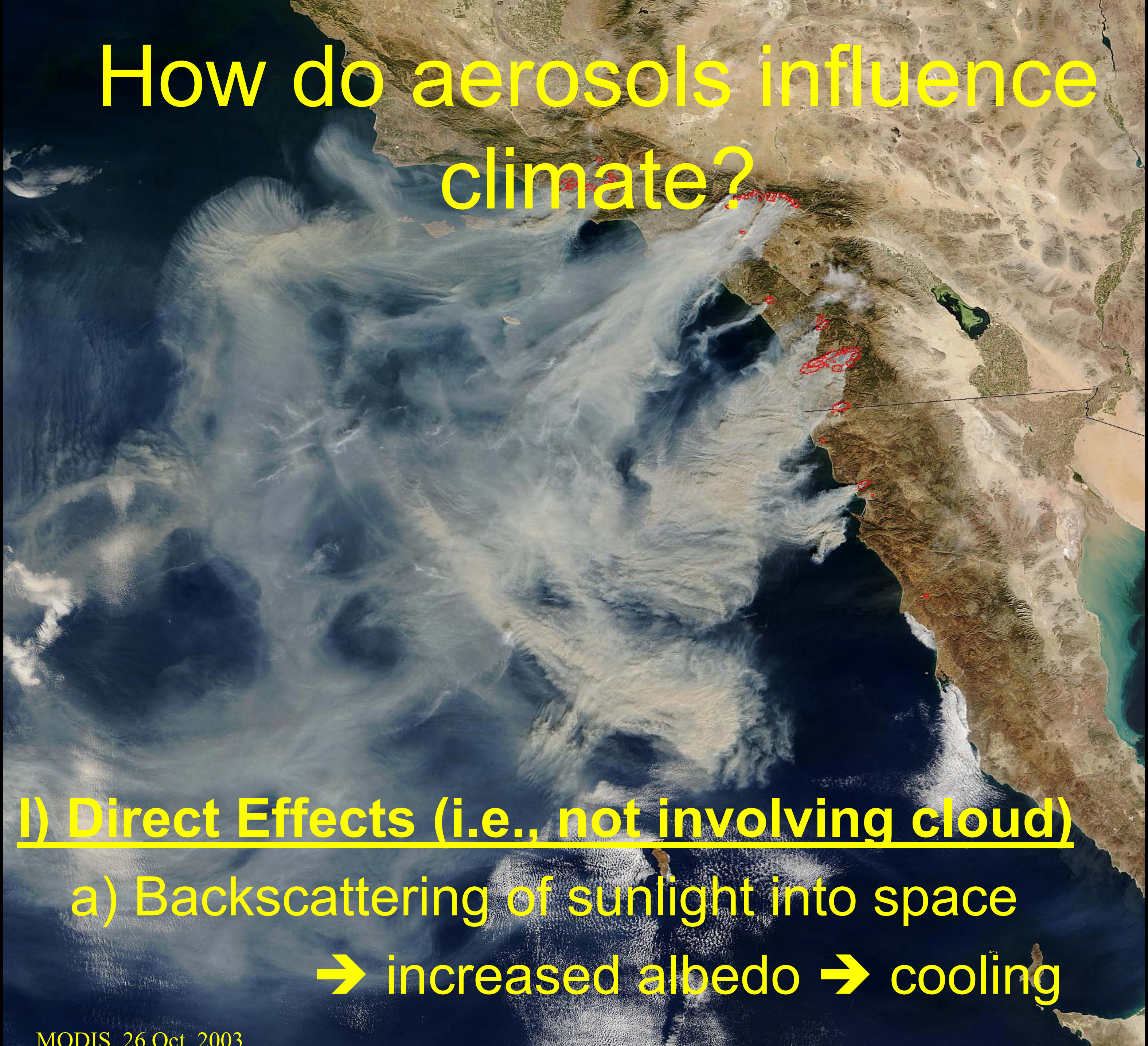


Radiation Balance of the Earth (Jeffrey T. Kiehl)

Global mean radiative forcing IPCC



How do aerosols influence climate?



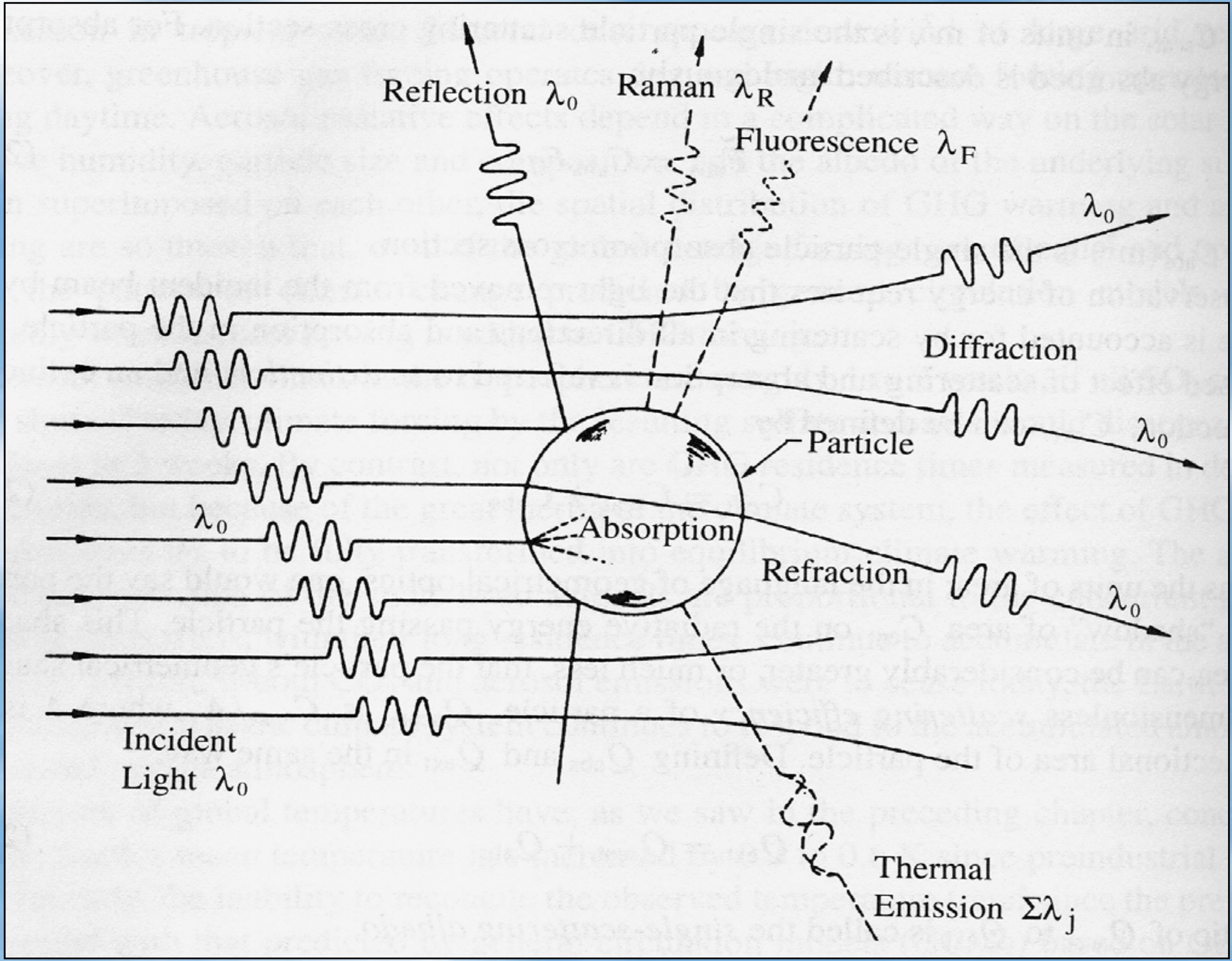
I) Direct Effects (i.e., not involving cloud)

a) Backscattering of sunlight into space

➔ increased albedo ➔ cooling

MODIS, 26 Oct. 2003

Interação entre a radiação solar e o aerossol atmosférico



Mecanismos de interação entre radiação incidente e uma partícula (Seinfeld & Pandis – 1998)

Ib) Absorption of sunlight

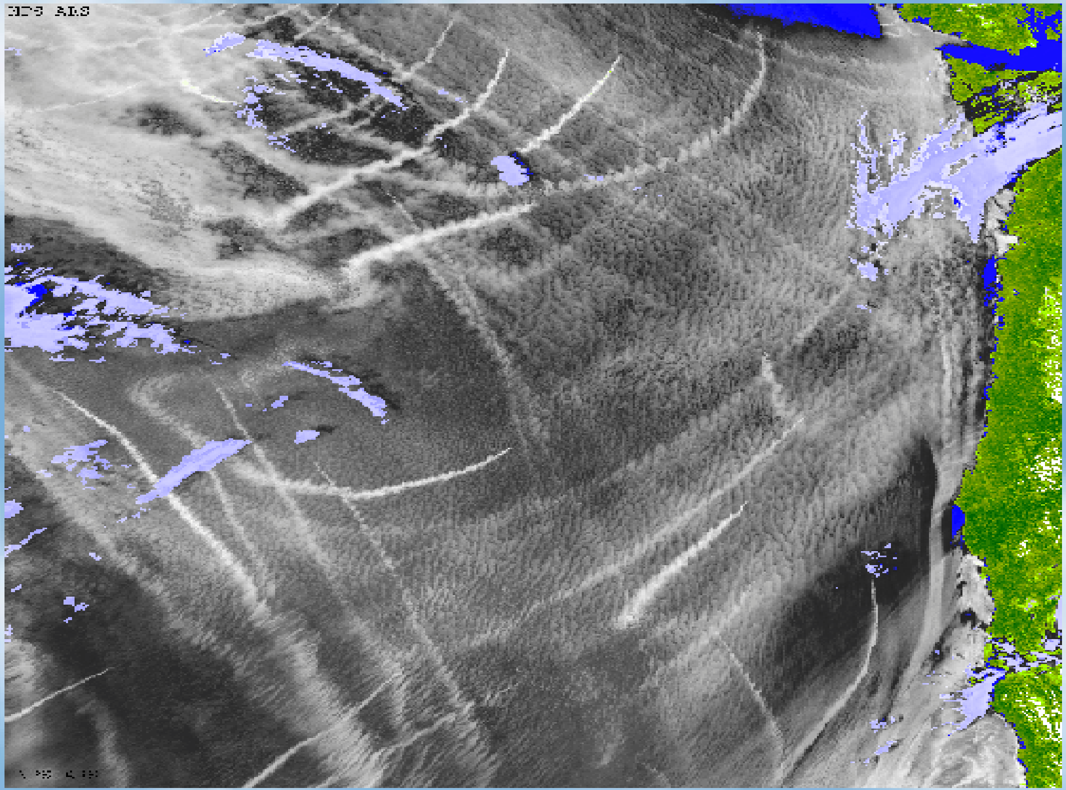
- At surface: cooling
- In atmosphere: warming
- “Semi-direct” Effects:
- reduced convection and cloudiness
- reduced evaporation
- reduced rainfall
- The key parameters are the black/brown carbon content of the aerosol and its mixing state (difficult to model and measure!!)

II) Indirect Effects

- Each cloud droplet needs a "seed" or nucleus to be able to form: "Cloud Condensation Nucleus" (CCN)
- For a given cloud, the more CCN in the air, the more droplets
- Since the water supply in a cloud is limited: more droplets means <u>smaller droplets</u>

- **More aerosol → More, but smaller droplets**

IIa) First Indirect Effect



Ship tracks off the Washington coast

- Adding CCN makes clouds with more, smaller droplets.
- These clouds are whiter, reflect more sunlight → net cooling

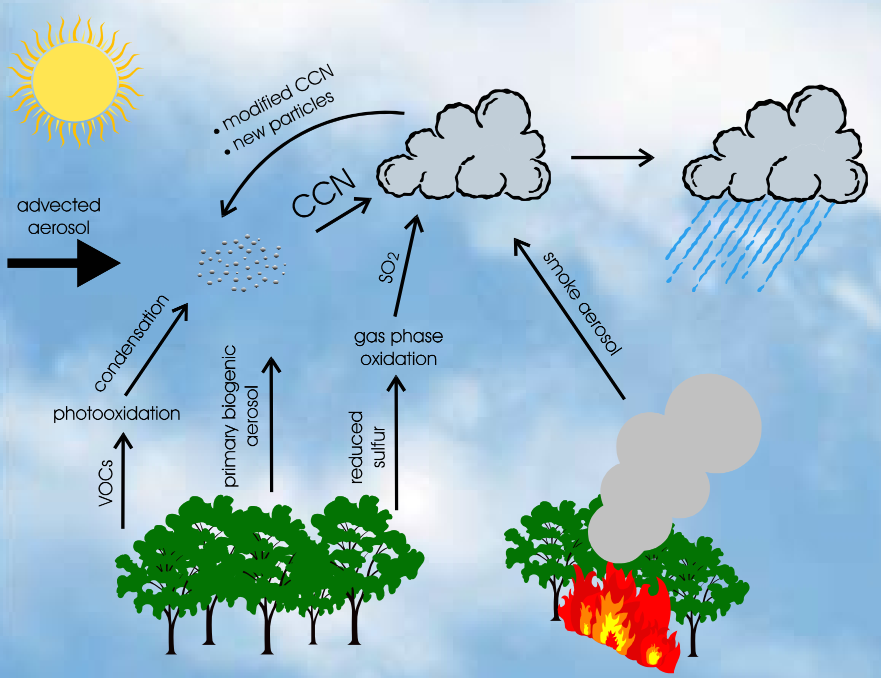
IIb) Second Indirect Effect

- “Overseeding“: To produce rain, cloud droplets need to be bigger than ~14 µm radius. When there are too many CCN, this radius is not reached and “warm” rainfall is suppressed. This occurs typically at CCN >800 cm-3.
- Therefore:
- Adding CCN increases cloud lifetime and cloud abundance ➔ Cooling

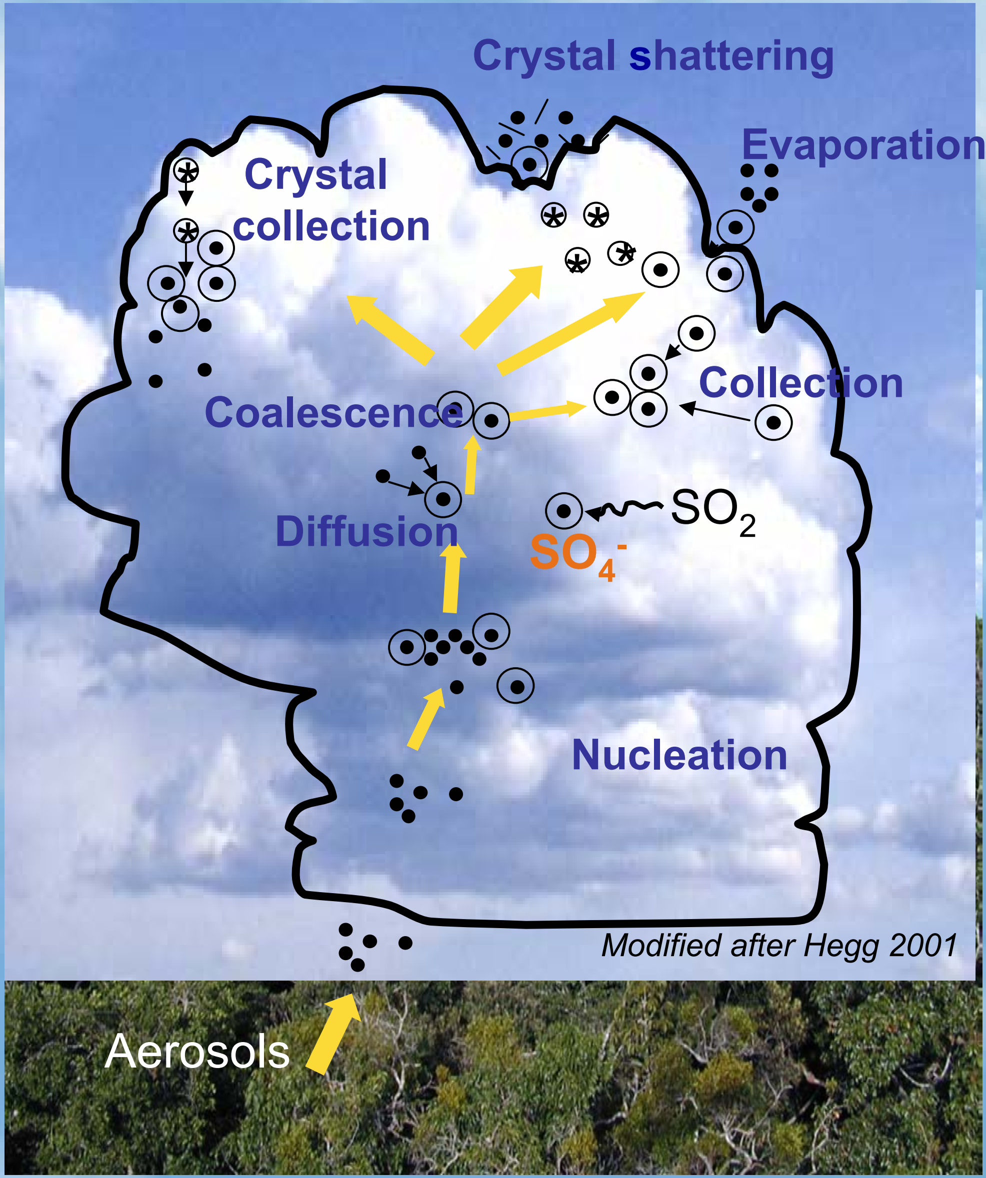
IIc) Third Indirect Effect:
Aerosol Effect on Convection Dynamics

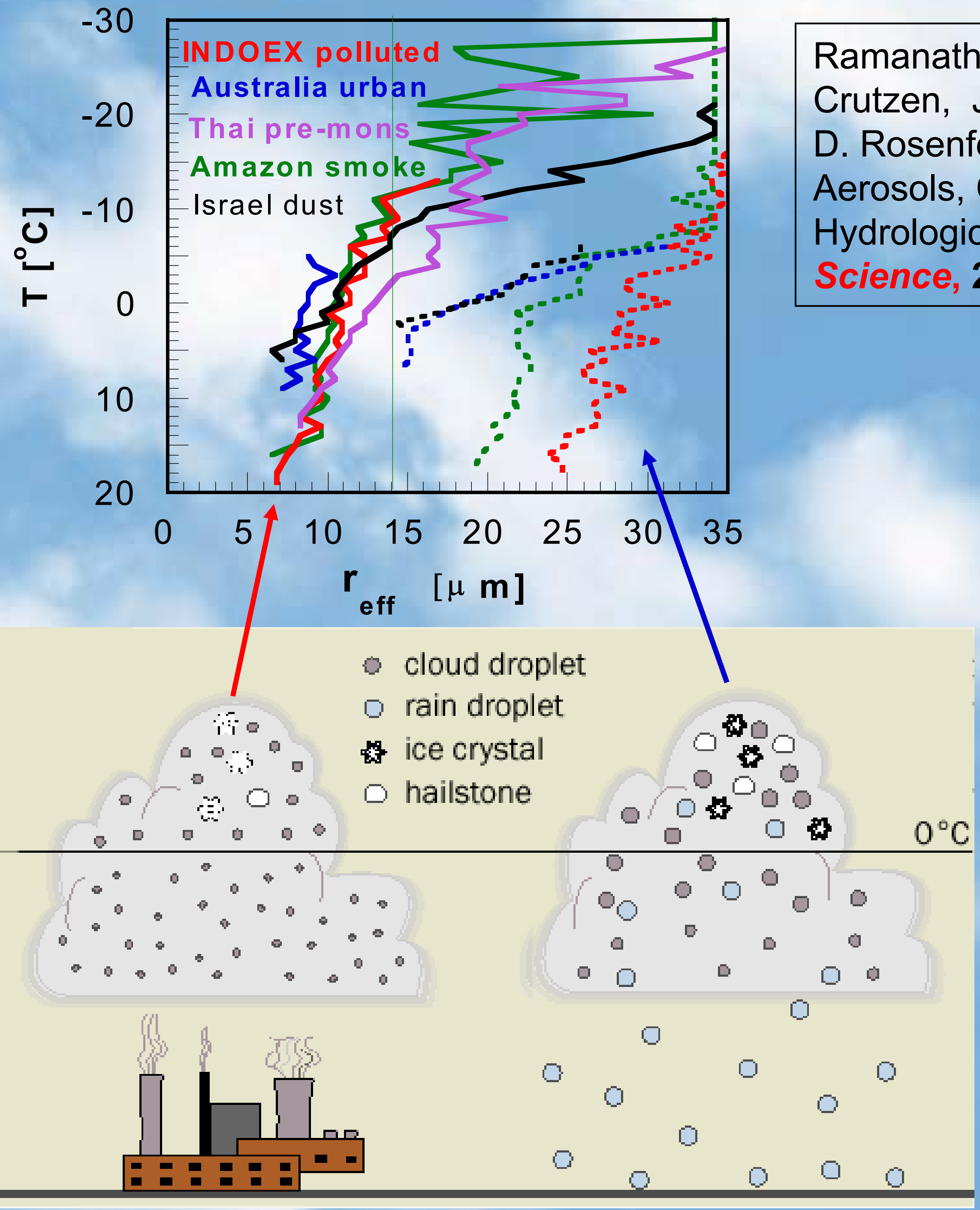
- This rain-suppression mechanism affects mainly "warm" clouds (those not containing ice phase)
- If there is enough latent heat available (tropics), the air will rise and rain-production mechanisms involving ice will take over.
- The results are
  - more wide-spread mixed phase clouds with lightning
  - a shift in the release of latent heat from lower levels (warm clouds) to upper levels in the troposphere
  - An increase in the total amount of heat released in cloud, because of ice formation
  - Enhanced vertical transport of aerosols, gaseous pollutants and water vapor to the upper troposphere and lower stratosphere

Aerosols, cloud condensation nuclei particles, clouds and precipitation

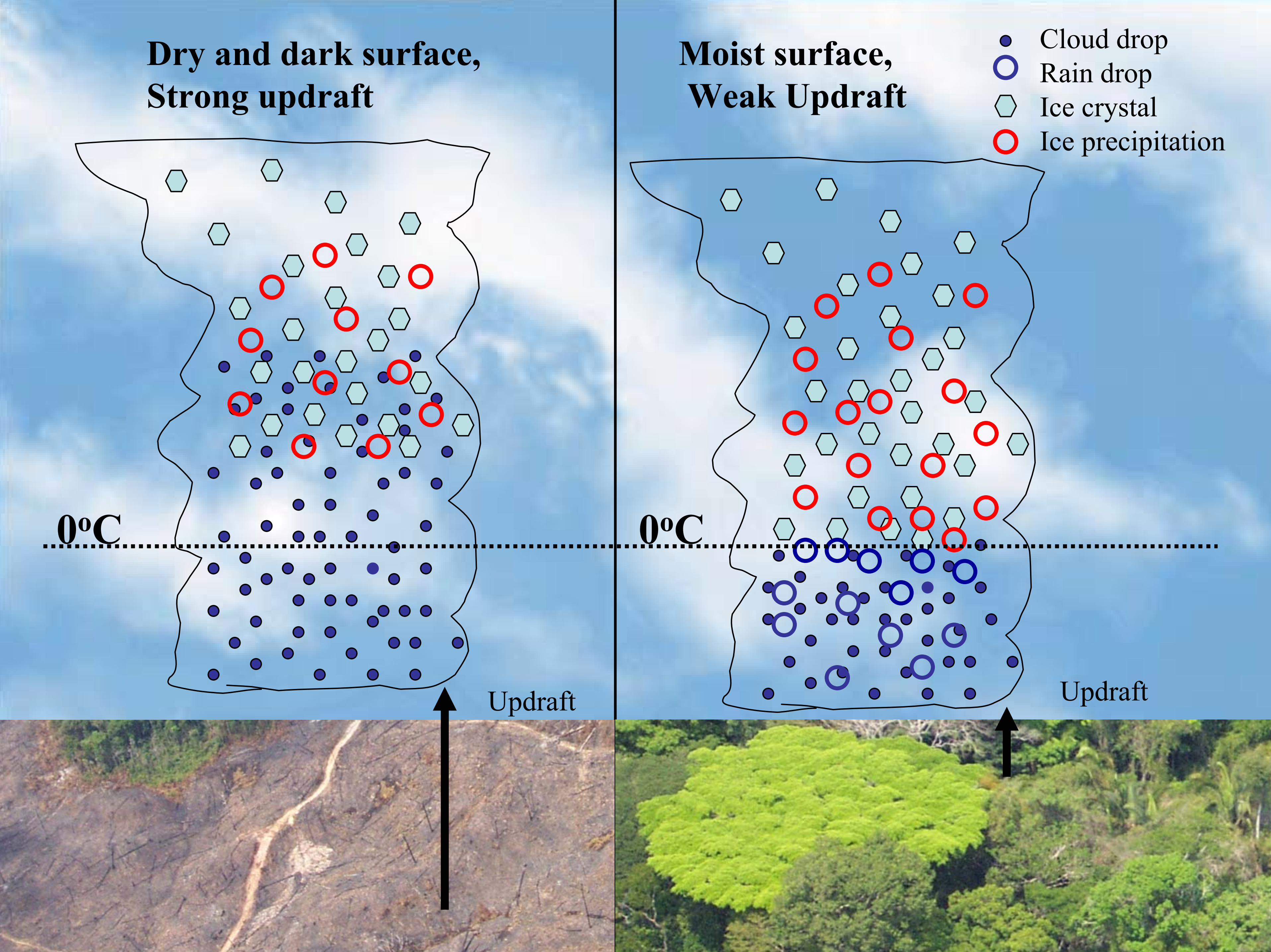


Cycle: Vegetation (VOCs) – aerosols - CCN - clouds - precipitation

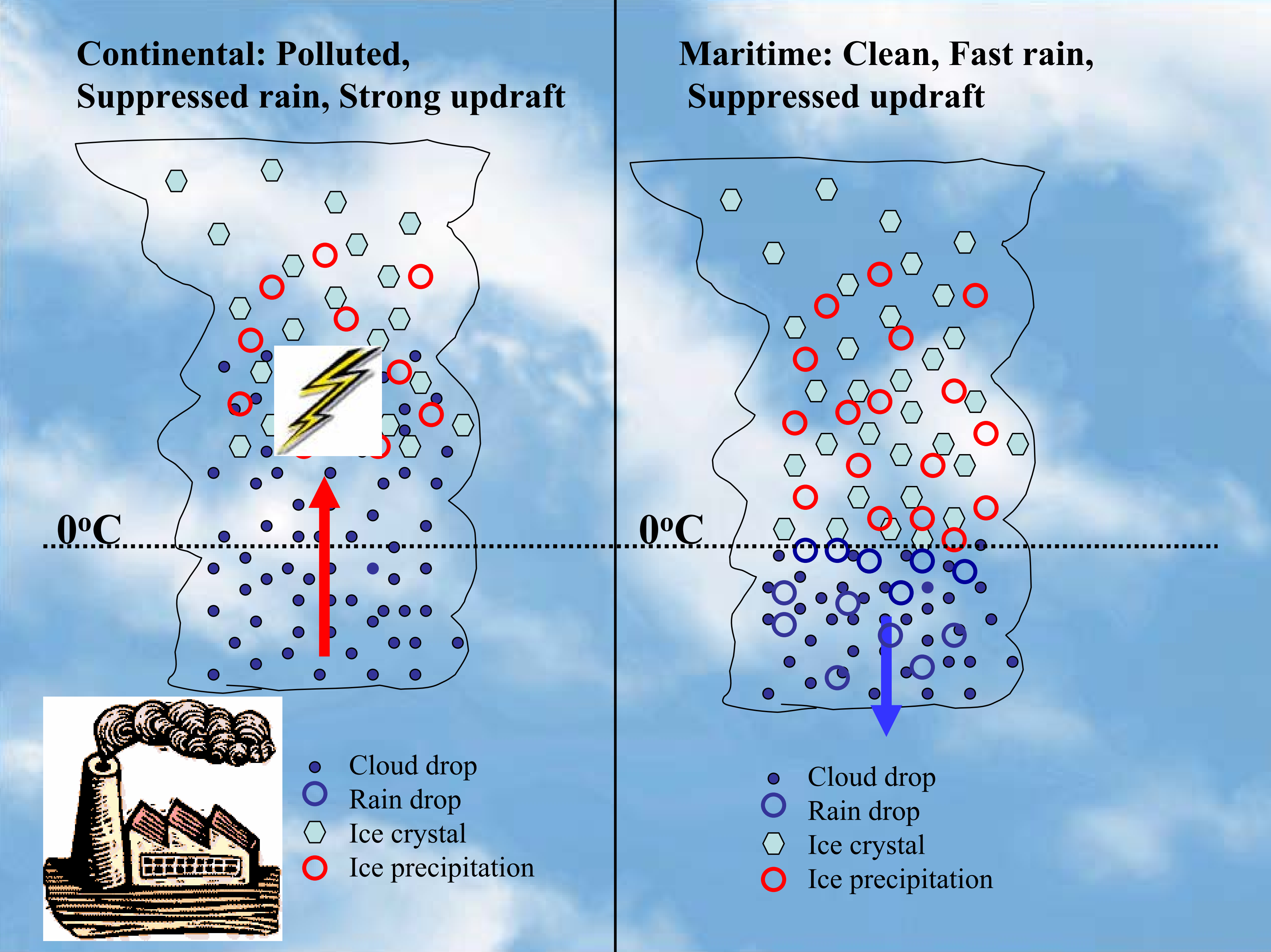




Ramanathan, V., P. J. Crutzen, J. T. Kiehl, and D. Rosenfeld, 2001: Aerosols, Climate and the Hydrological Cycle. *Science*, **294**, 2119-2124.



Dry and dark surface,
Strong updraft
Moist surface,
Weak Updraft
Cloud drop
Rain drop
Ice crystal
Ice precipitation
0°C
0°C
Updraft
Updraft


Continental: Polluted, Suppressed rain, Strong updraft
Maritime: Clean, Fast rain, Suppressed updraft
0oC
0oC
Cloud drop
Rain drop
Ice crystal
Ice precipitation
Cloud drop
Rain drop
Ice crystal
Ice precipitation

Changes in surface albedo and moisture influencing cloud dyna

Part of the atmospheric radiative loss is balanced by surface sensible and latent heat fluxes by PRECIPITATION.

This could be called the "**Thermodynamic forcing**".

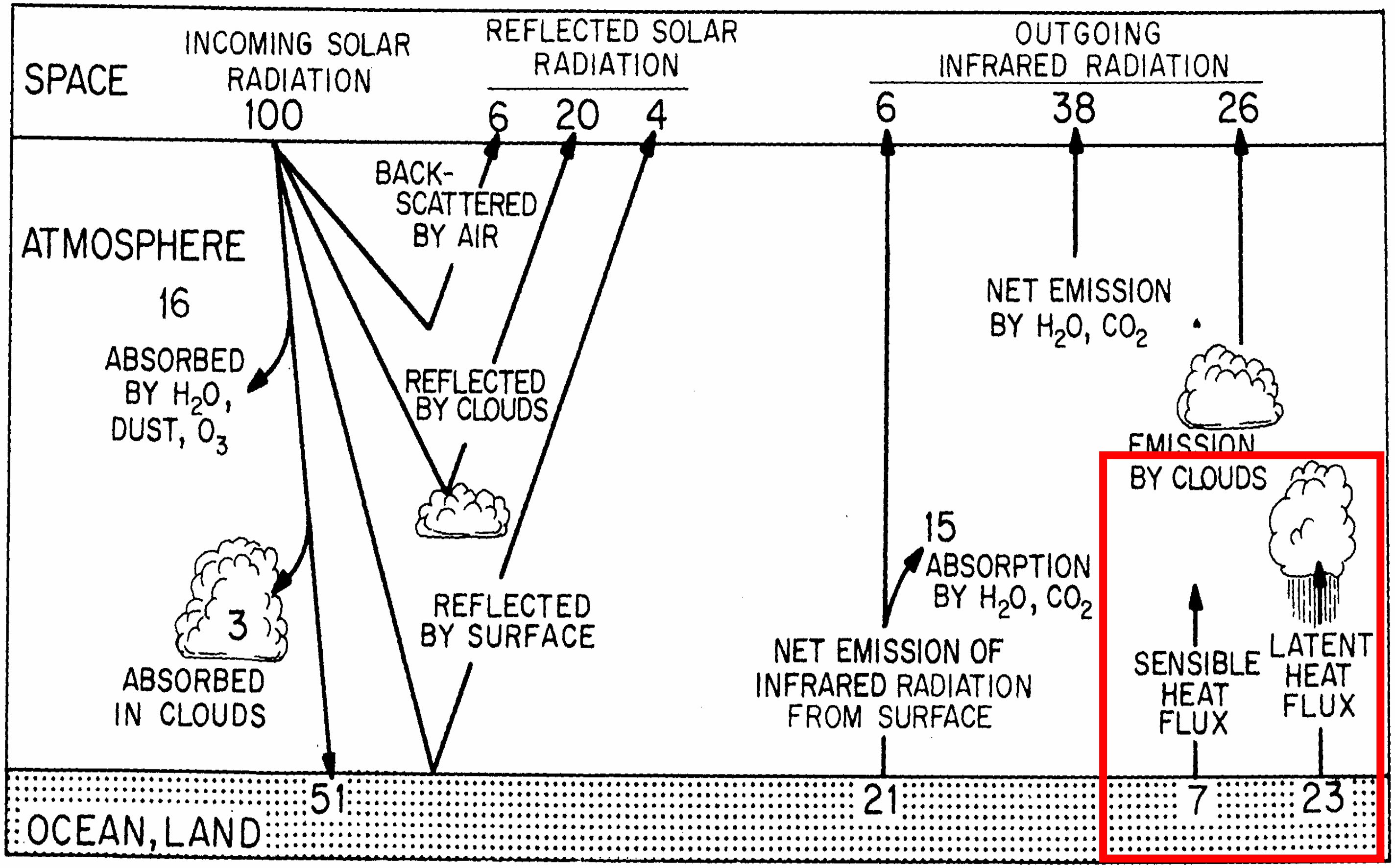
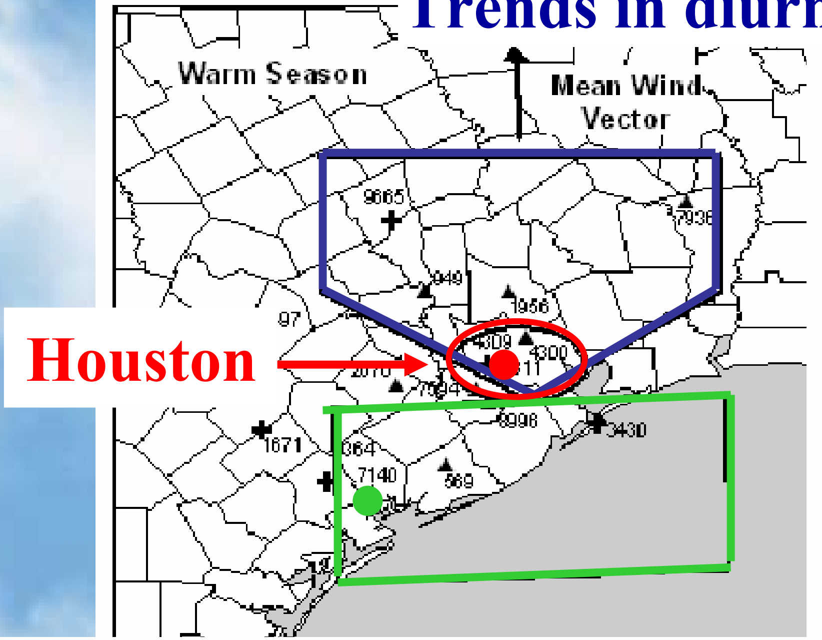
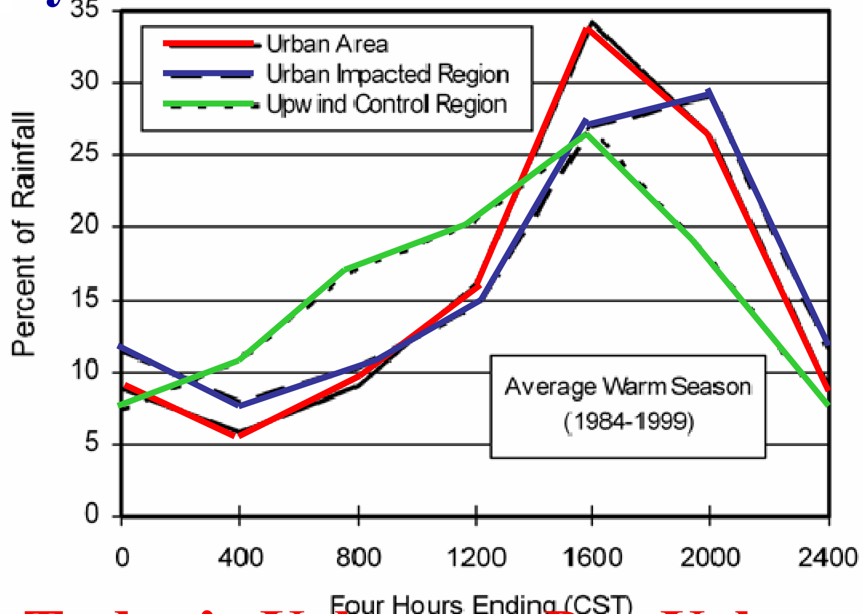


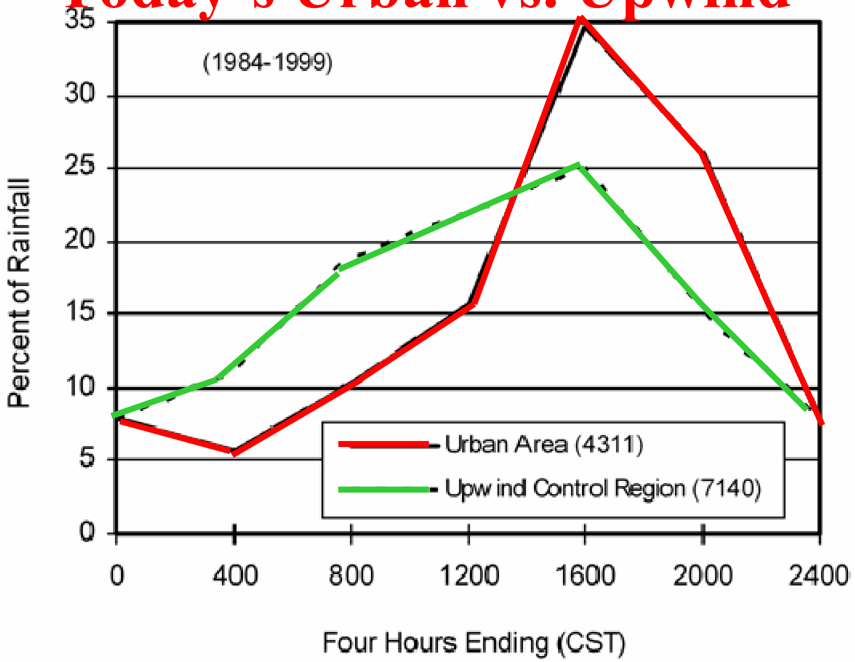
Fig. 7.1 The annual mean global energy balance for the earth–atmosphere system. (Numbers are given as percentages of the globally averaged solar irradiance incident upon the top of the atmosphere.) See text for further explanation. [Adapted from "Understanding Climatic Change," U.S. National Academy of Sciences, Washington, D.C. (1975), p. 14, and used with permission.]

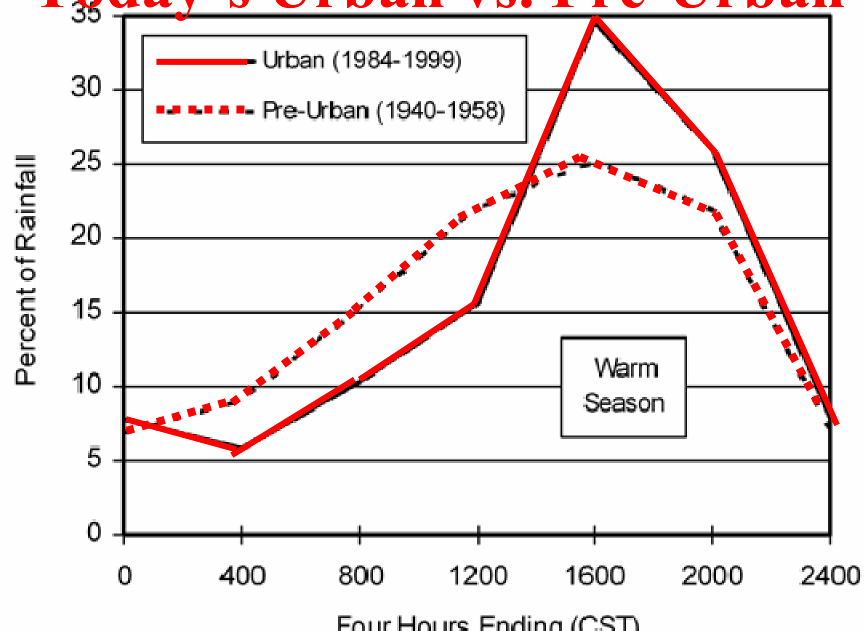
Trends in diurnal cycle of urban rainfall





Today's Urban vs. Upwind = Today's Urban vs. Pre-Urban





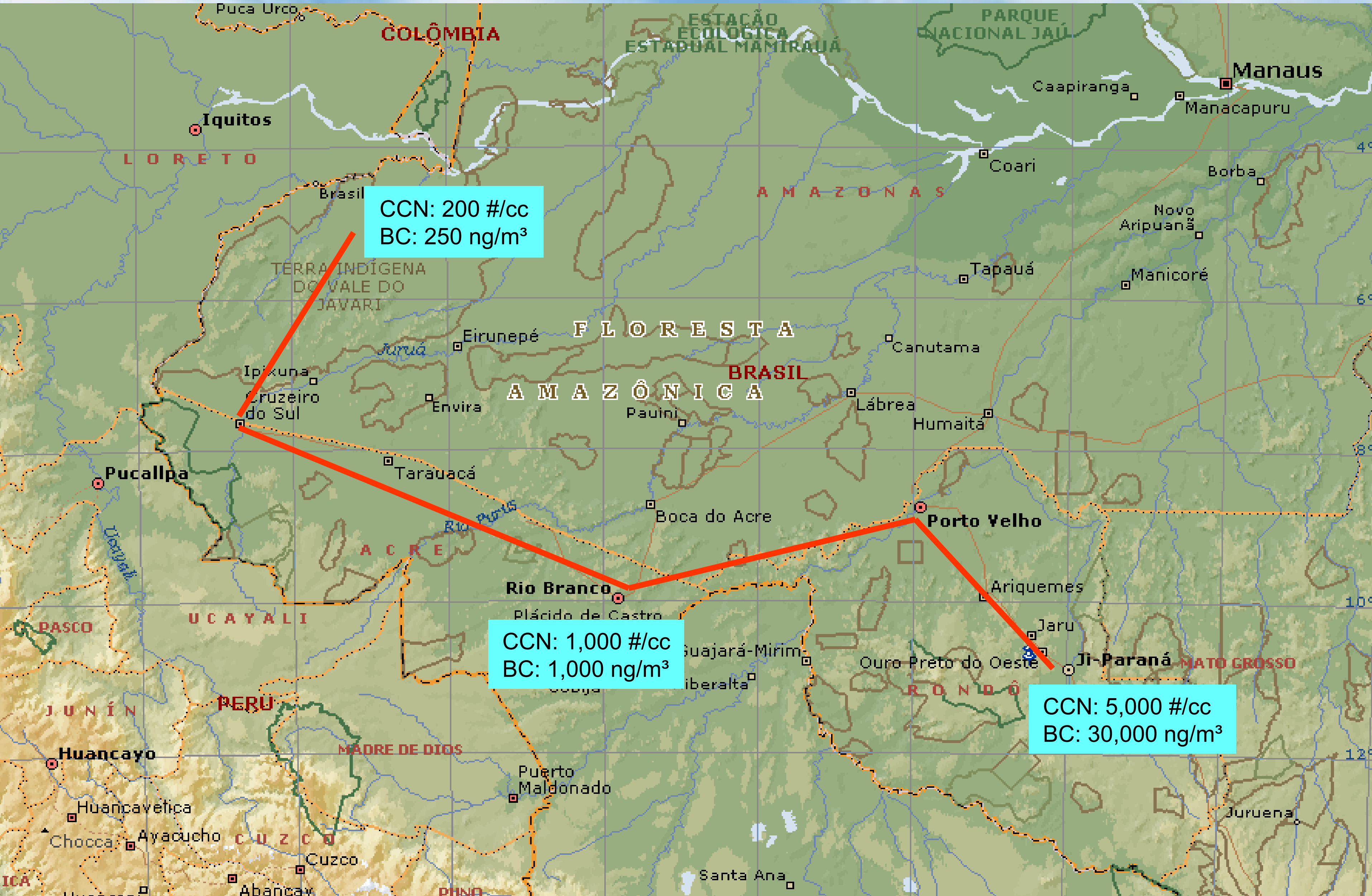
Burian and Shepherd, 2004

Hydrological cycle critical for Amazonia.
Variety of cloud structure caused by different CCN amounts and other cloud dynamic issues

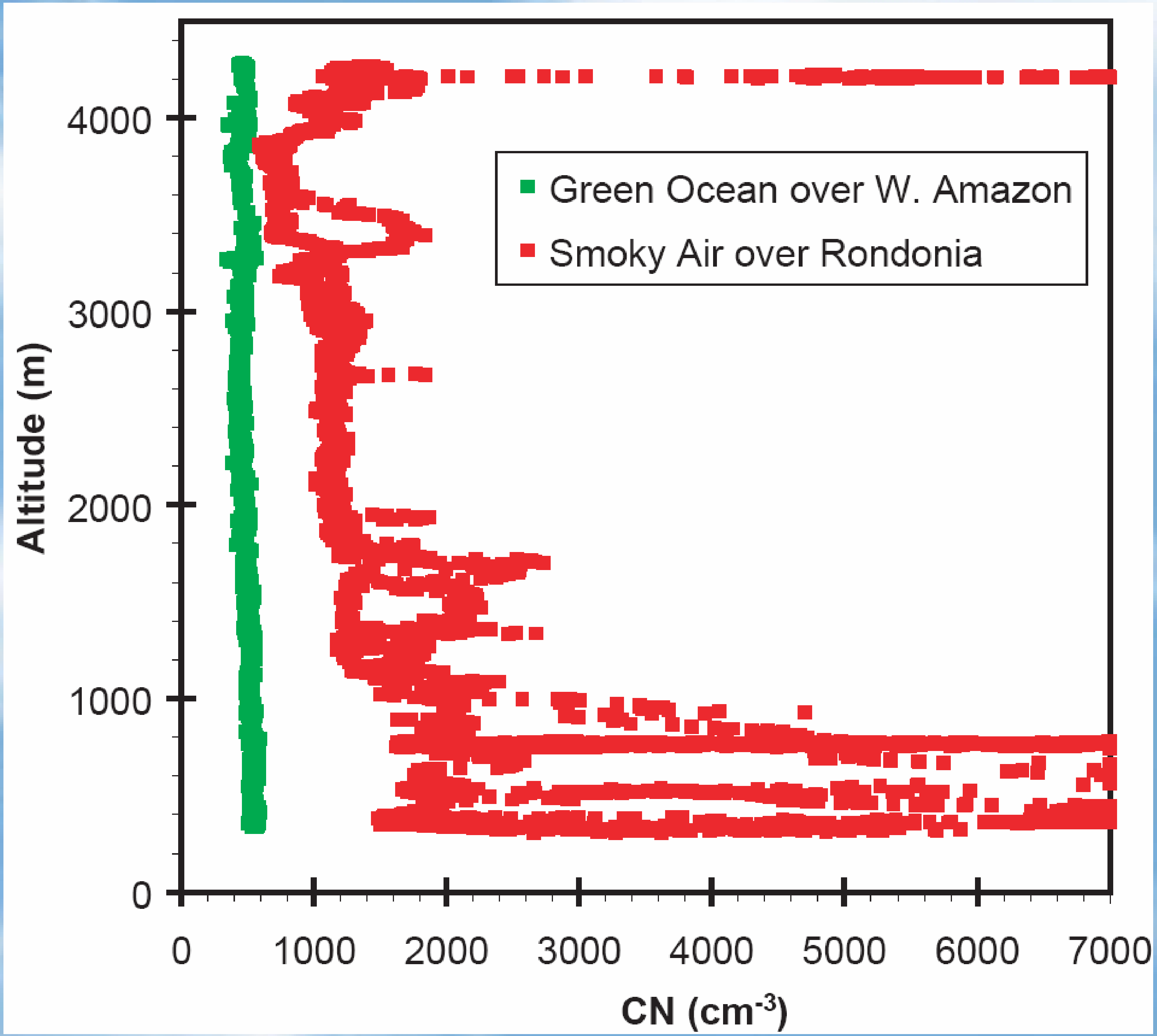
The airborne component of the SMOCC experiment

Two aircraft used in SMOCC: one for aerosol and trace gases and the second for cloud physics measurements.

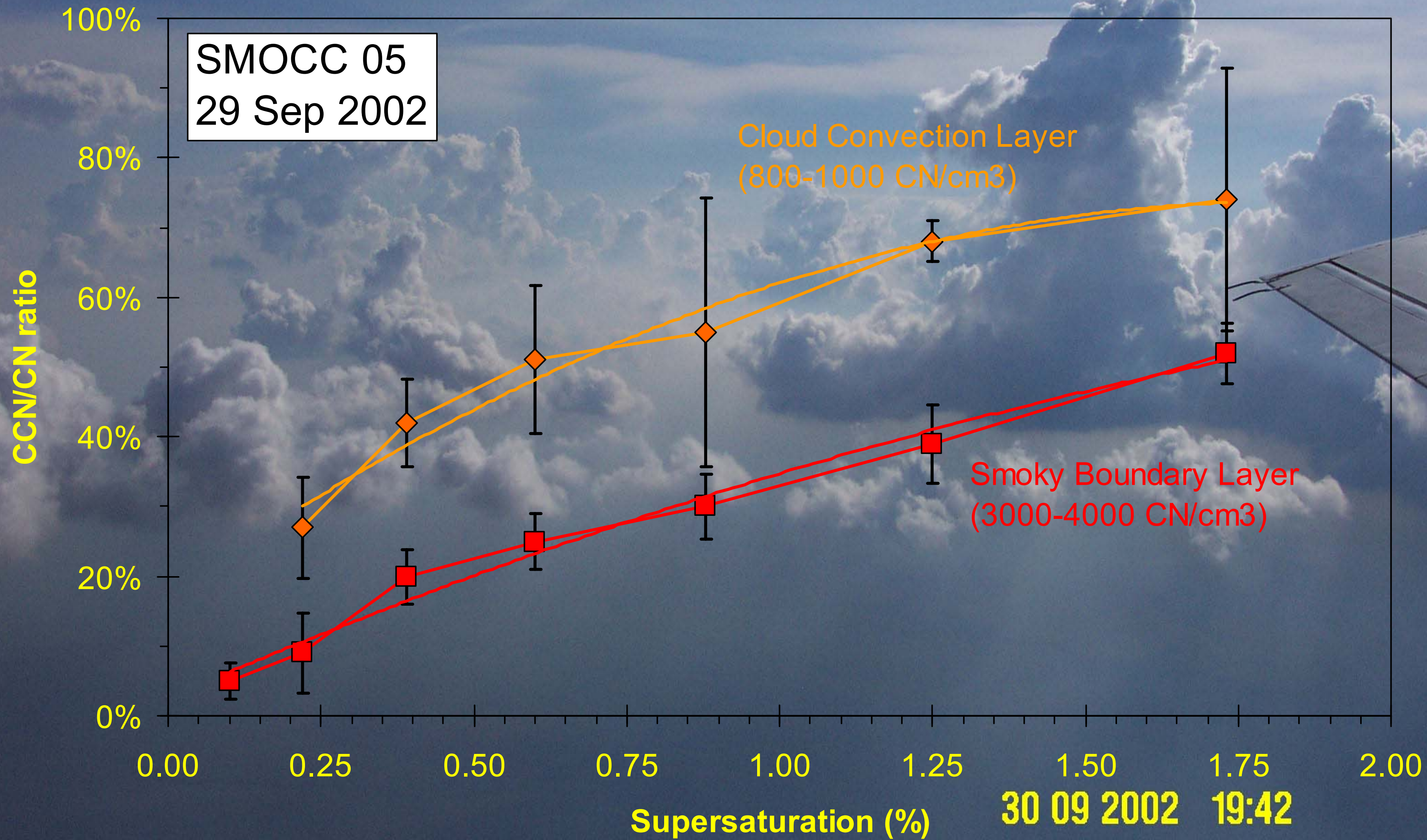
SMOCC Aircraft route from heavy smoke to clean conditions: In situ measurements of precipitation suppression



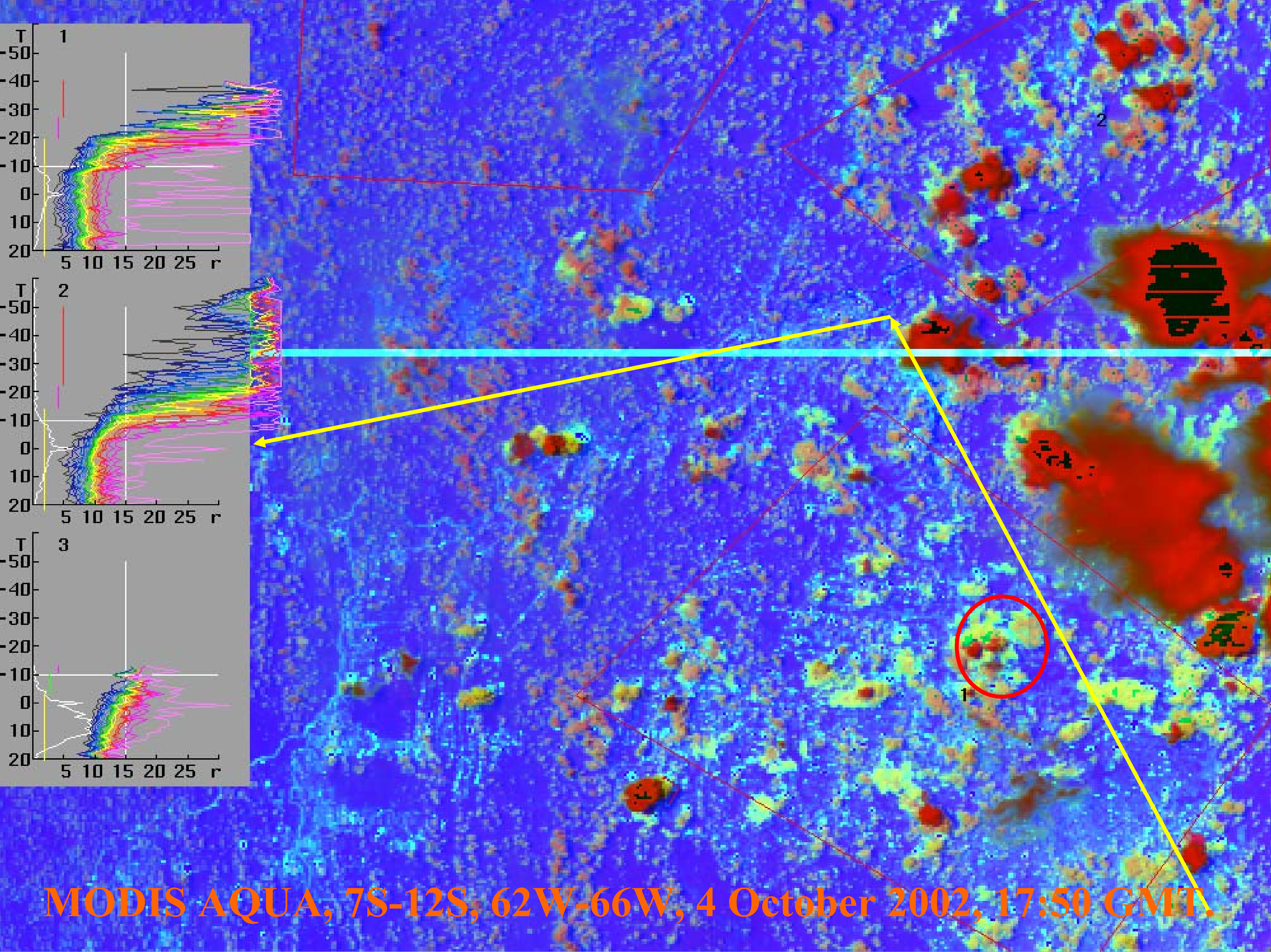
Vertical distribution of CN over the smoky region in Rondonia and the clean region in the western Amazon.



Polluted clouds grow out of the regional haze containing lots of CCN...

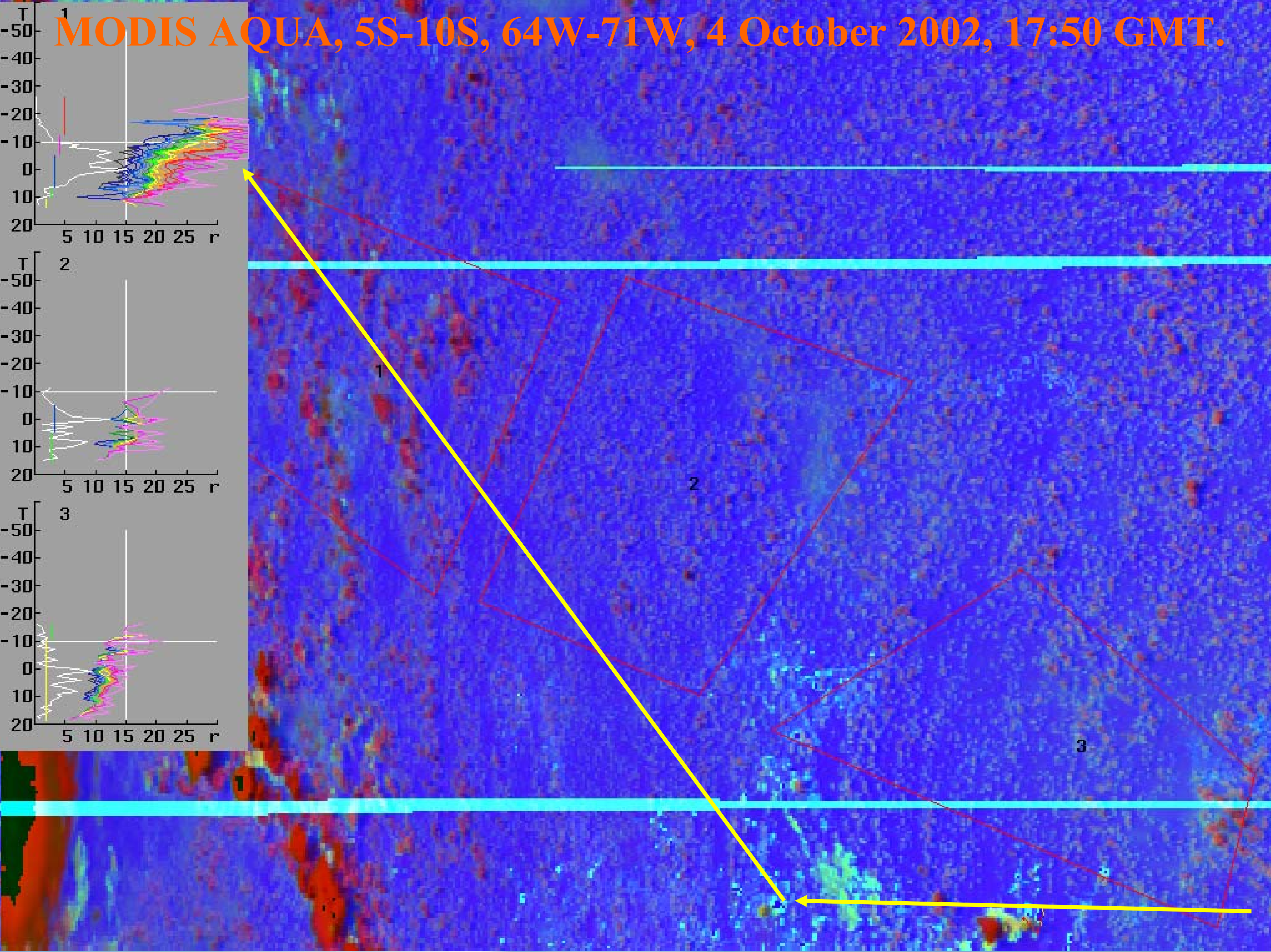



Smoke from pyrocu-type clouds blends into a smoke-laden boundary layer...
01 10 2002 19:51

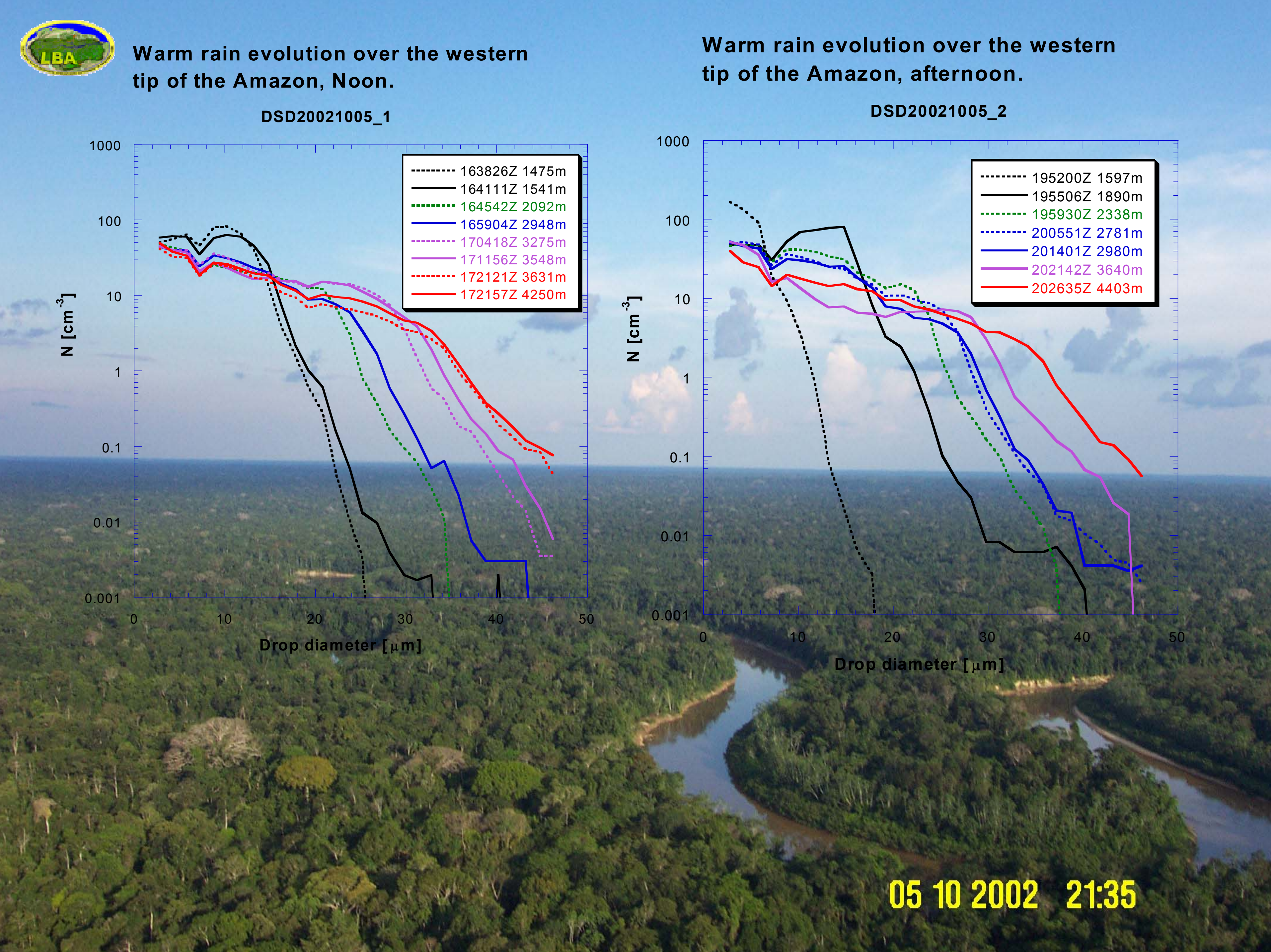


MODIS AQUA, 7S-12S, 62W-66W, 4 October 2002, 17:50 GMT.

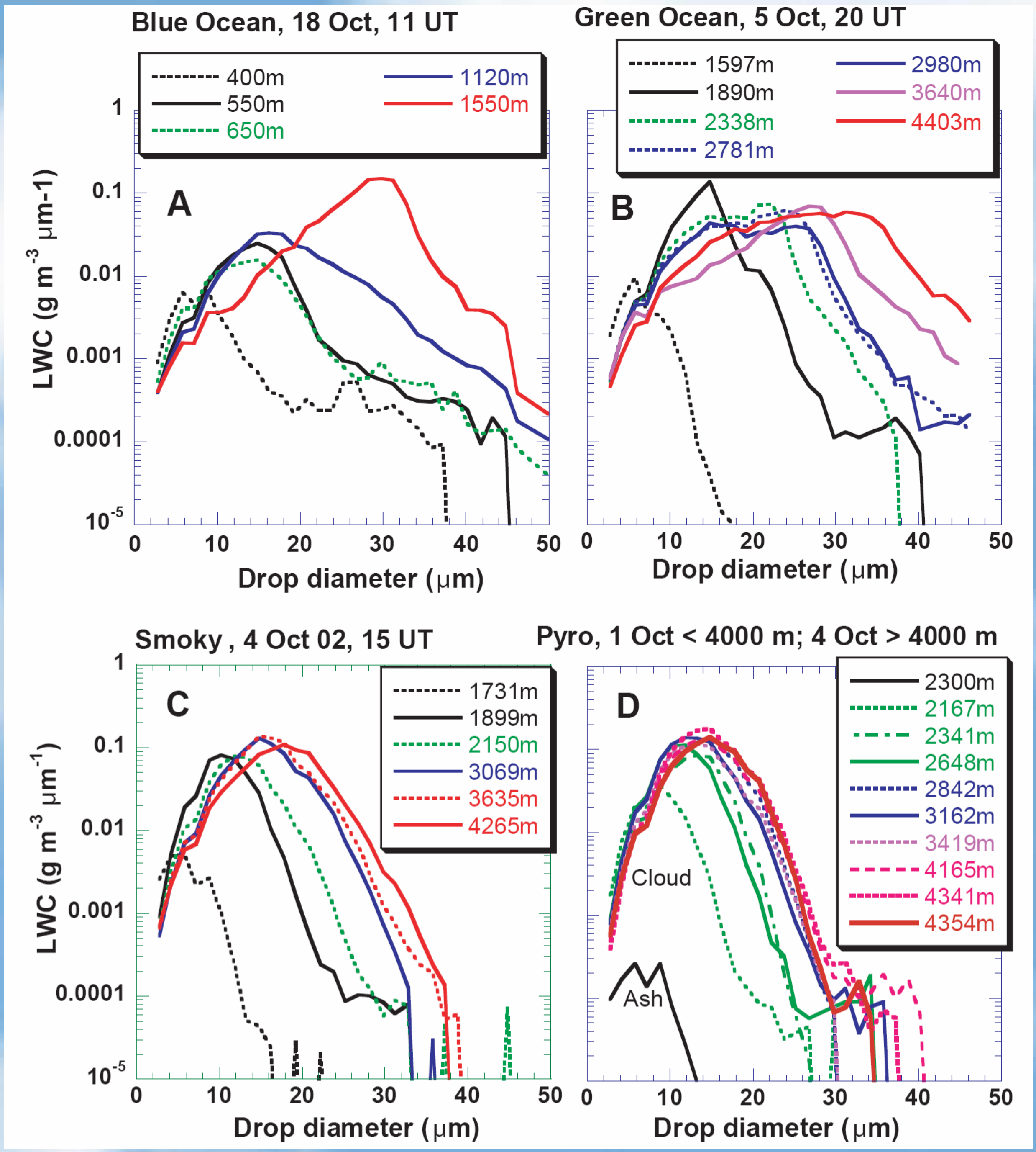
Further west, in the same airmass, we find the „Green Ocean“ - maritime-type clouds over the pristine Amazon



MODIS AQUA, 5S-10S, 64W-71W, 4 October 2002, 17:50 GMT.
T
1
2
3
r


LBA
Warm rain evolution over the western tip of the Amazon, Noon.
DSD20021005_1
163826Z 1475m
164111Z 1541m
164542Z 2092m
165904Z 2948m
170418Z 3275m
171156Z 3548m
172121Z 3631m
172157Z 4250m
N [cm-3]
Drop diameter [μm]
Warm rain evolution over the western tip of the Amazon, afternoon.
DSD20021005_2
195200Z 1597m
195506Z 1890m
195930Z 2338m
200551Z 2781m
201401Z 2980m
202142Z 3640m
202635Z 4403m
N [cm-3]
Drop diameter [μm]
05 10 2002 21:35

Addition of pyrogenic CCN has pronounced impact on cloud droplet size spectra

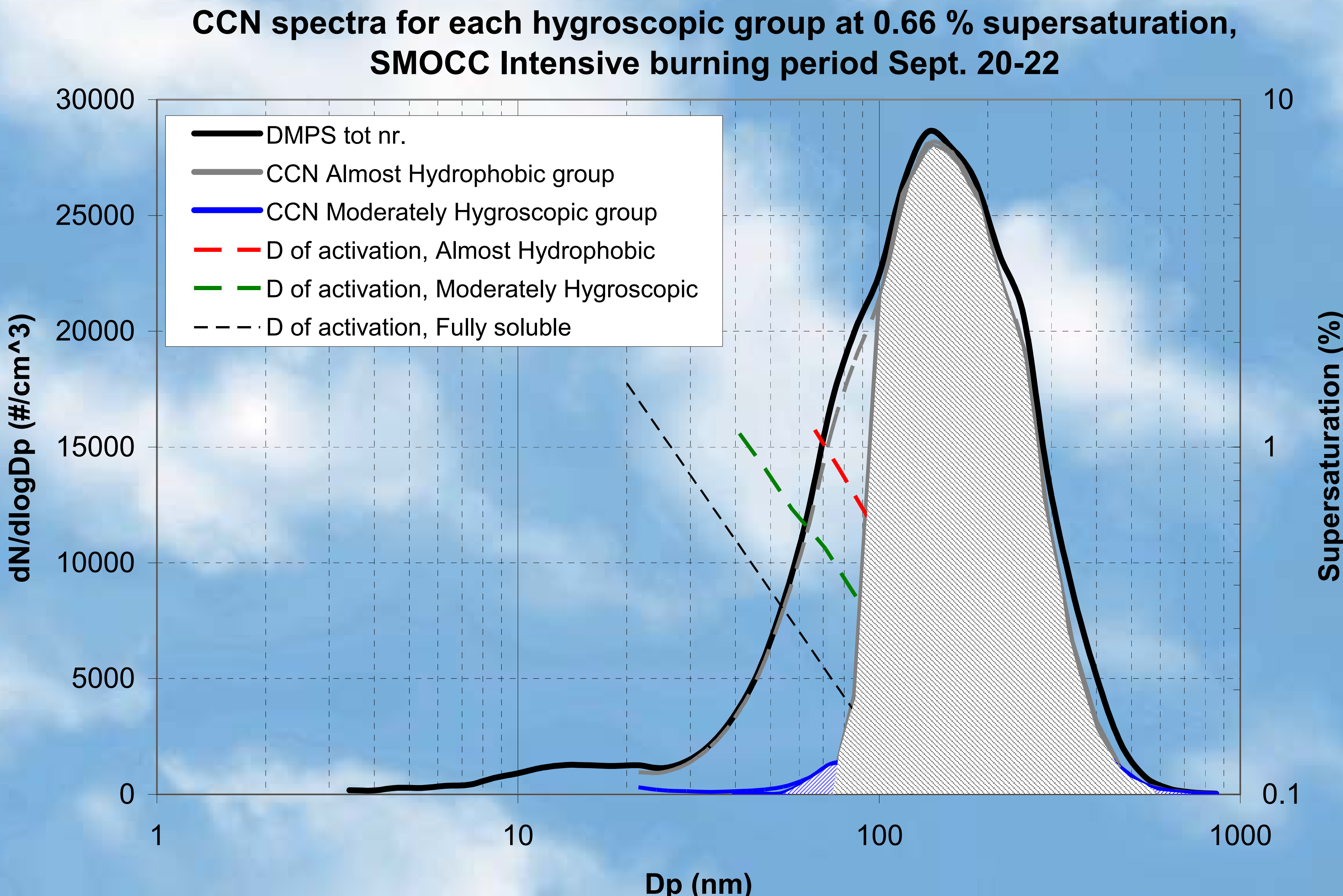


Four aerosol regimes of:
(A) *Blue Ocean*,(B) *Green Ocean*,
(C) *Smoky clouds,* (D) *Pyro-clouds*

Note that the narrowing of CDSD and the slowing of its rate of broadening with height for the progressively more aerosol rich regimes from A to D.

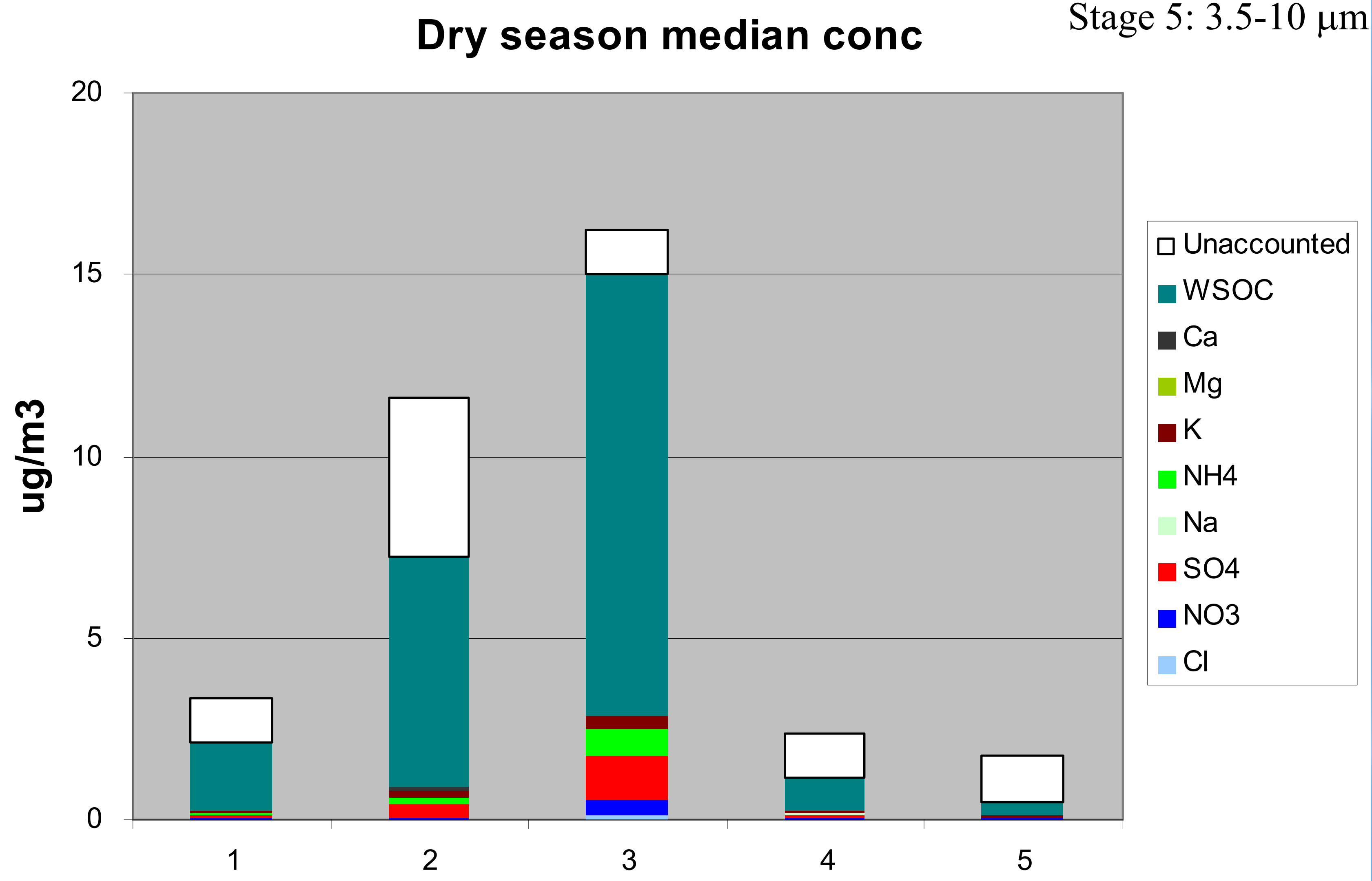
D. Rosenfeld, 2004

CCN activity is related to size...

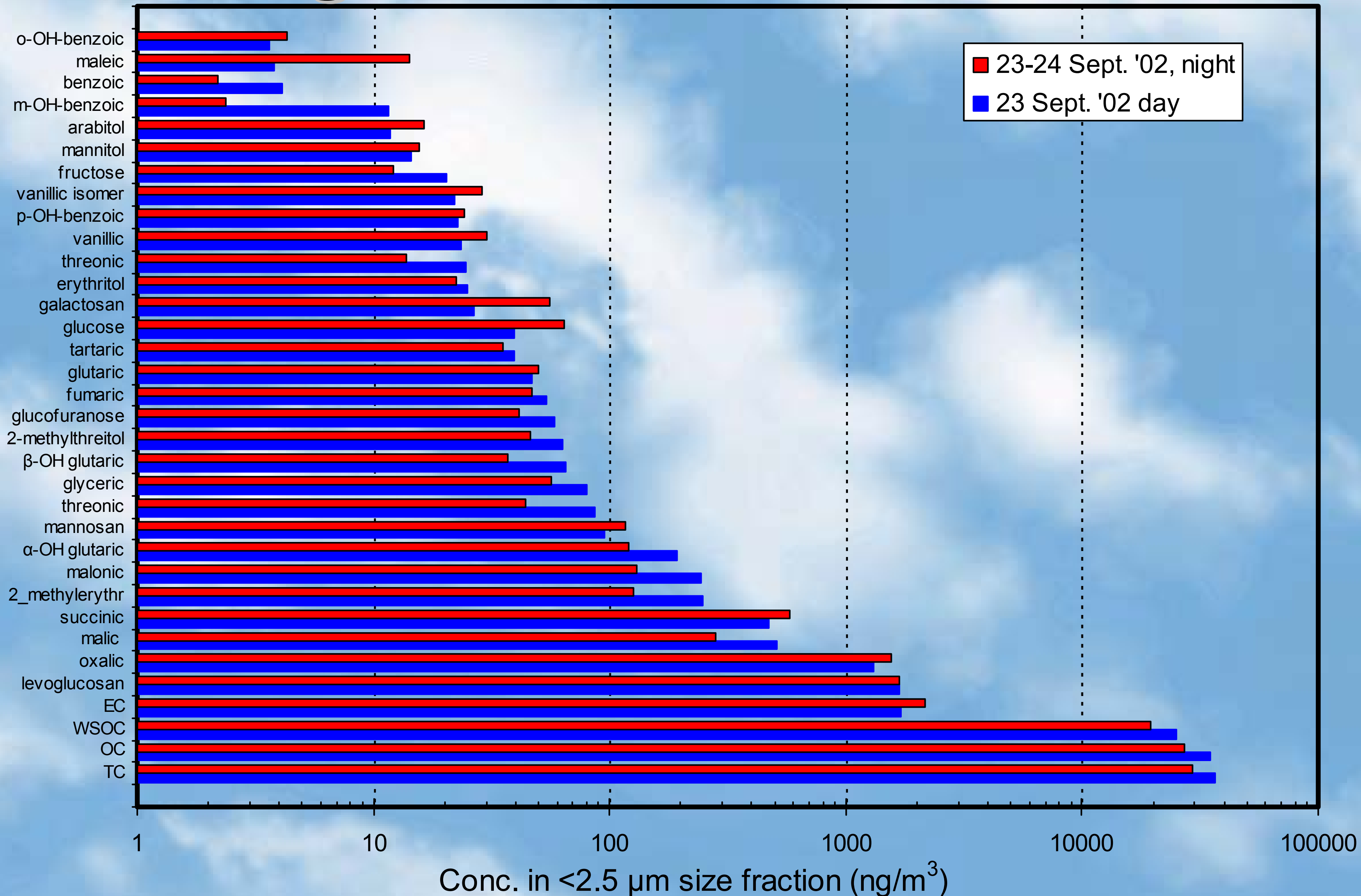


... and chemical composition

Stage 1: 0.05-0.14 µm,
Stage 2: 0.14-0.42 µm,
Stage 3: 0.42-1.2 µm,
Stage 4: 1.2-3.5 µm,
Stage 5: 3.5-10 µm

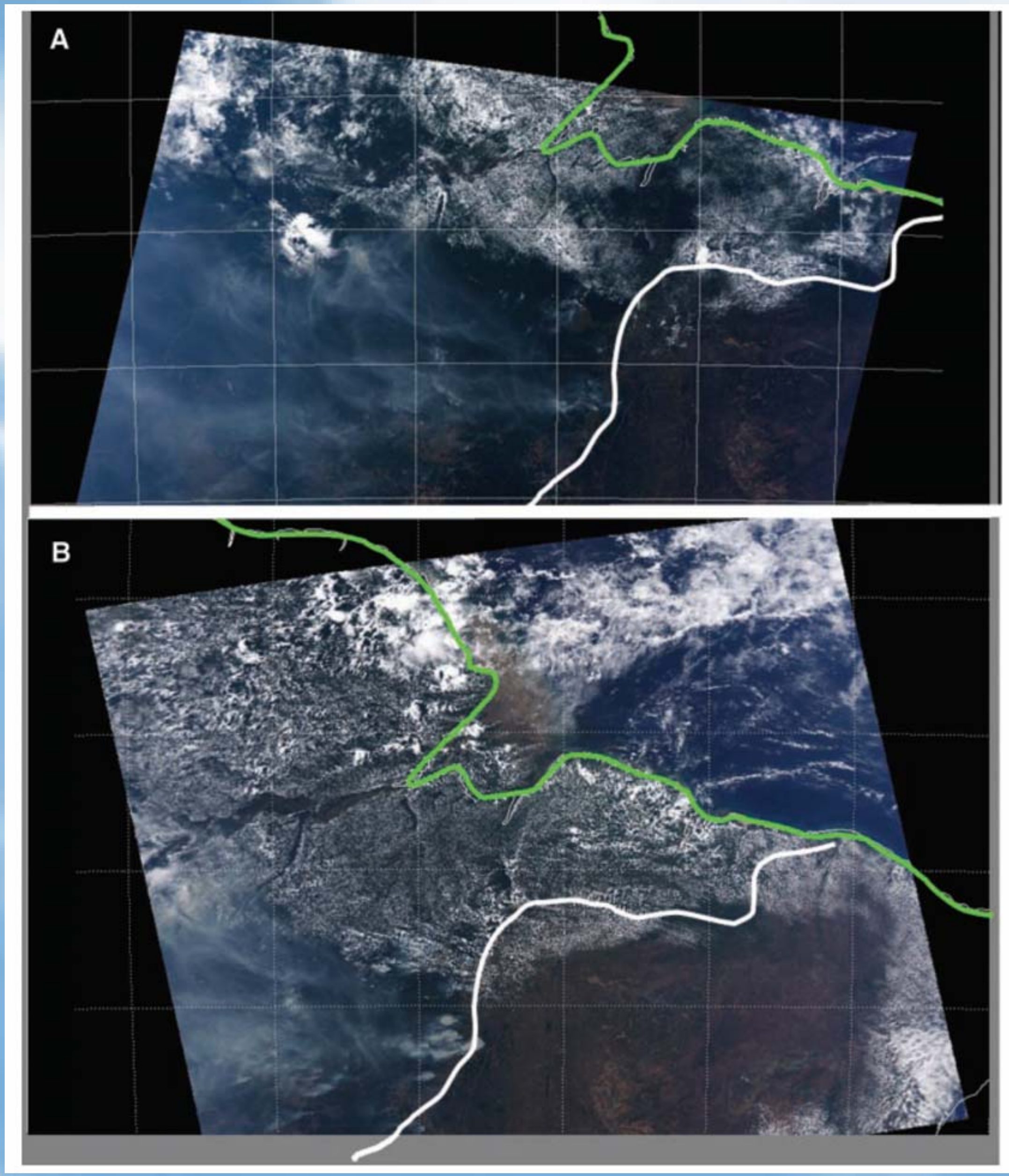


Organics in smoke aerosol

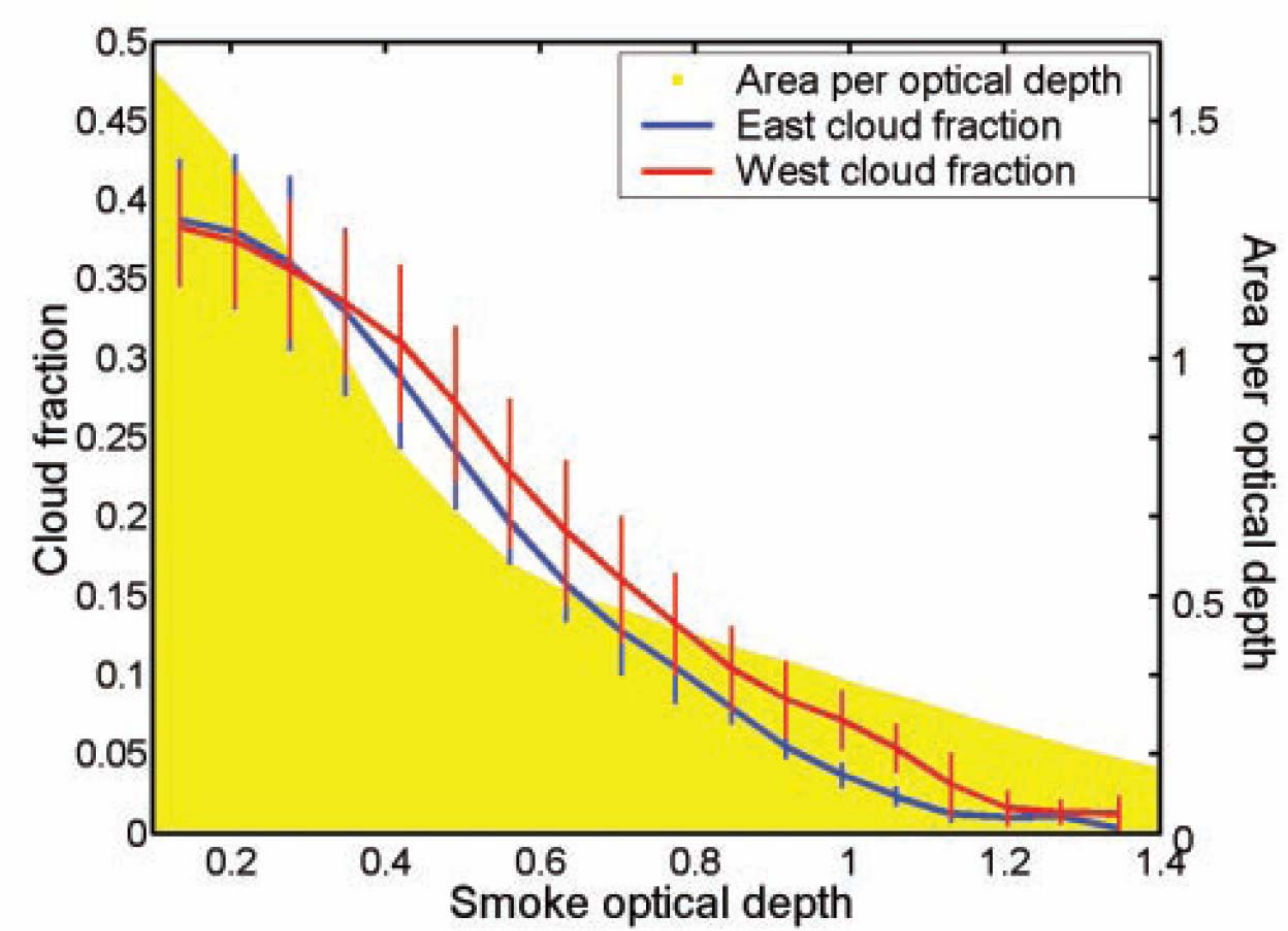


Compilation of SMOCC data by S. Decesari

Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. (**A**) The clouds (Terra, 10:00 local time) are beginning to form. (**B**) The clouds (Aqua, 13:00 local time) are fully developed and cover the whole Amazon forest except for the smoke area. The boundary between forest and Cerrado region is marked in white on both images, and the seashore is marked in green. *(From Ilan et al., Science March 2004)*

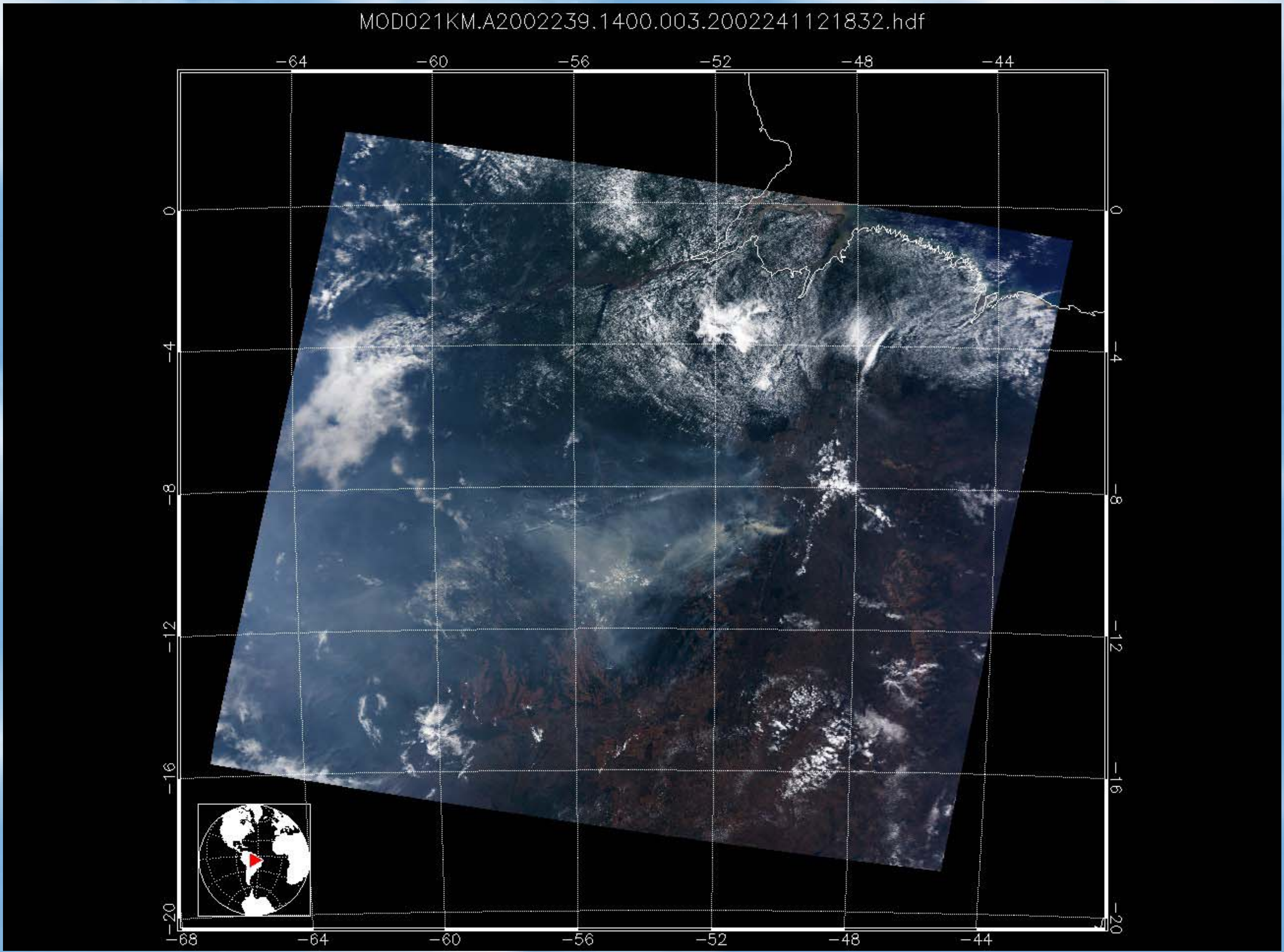


Suppression of low cloud formation by aerosols in Amazonia

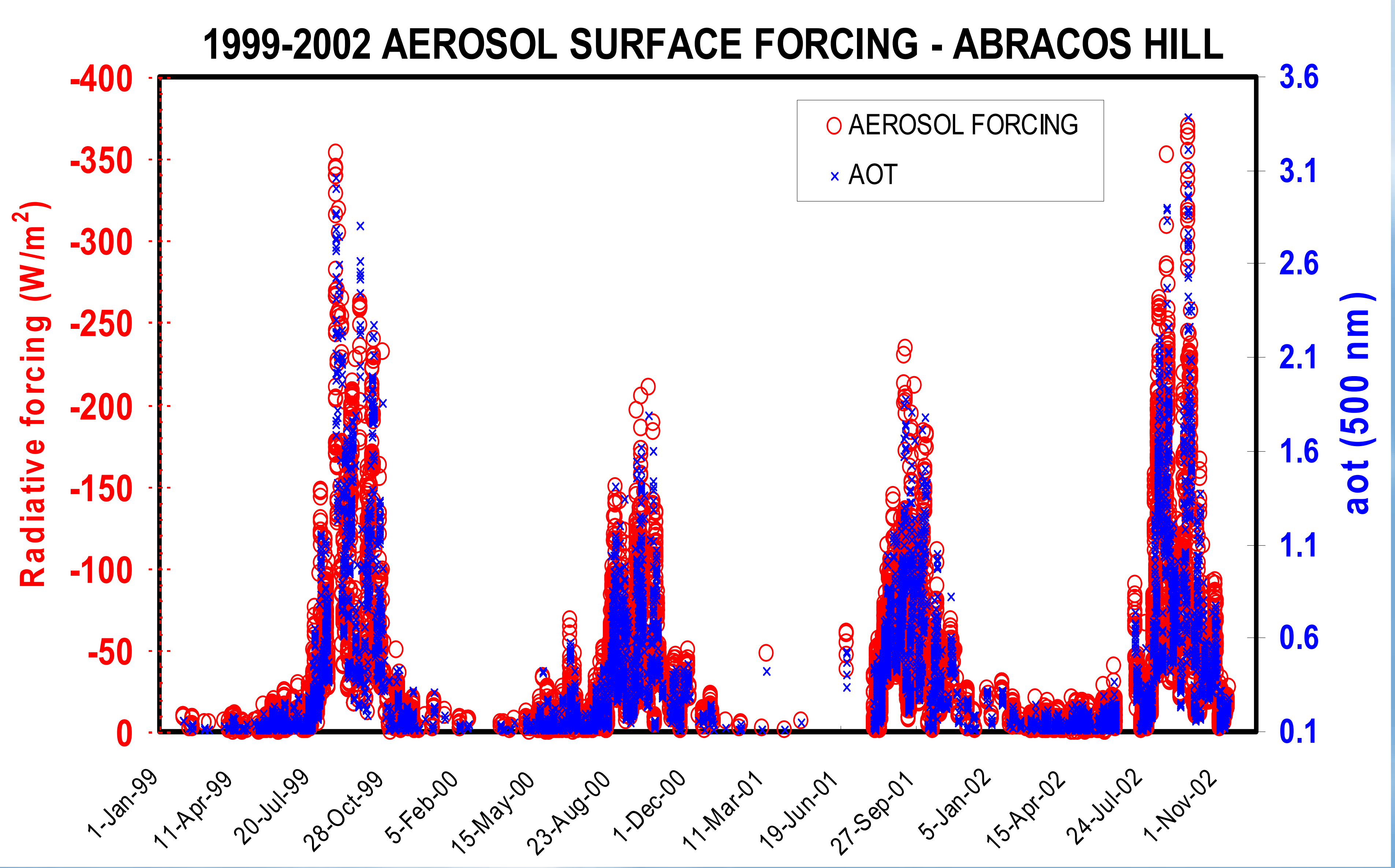


Cloud fraction as function of aerosol optical depth (OD). The cloud fraction decreases almost linearly with increasing OD. The red and blue curves denote the average of east and west areas, respectively. On average, the cloud fraction decreases to less than 1/8 of the cloud fraction in clean conditions when OD = 1. The shaded area represents the relative area covered by the respective OD, with the integral of this curve equal to one, representing the total Amazon basin. (from Ilya and Kaufman, 2004)

Large Scale aerosol distribution in Amazonia



Aerosol surface forcing in Rondonia 1999-2002



Amazonia

Average aerosol forcing clear sky

Top: - 10 w/m²

Surface: - 38 w/m²

Conditions: surface: forest vegetation
AOT (τ=0.95 at 500nm); 24 hour average
7 years (93-95, 99-02 dry season Aug-Oct)

INDOEX

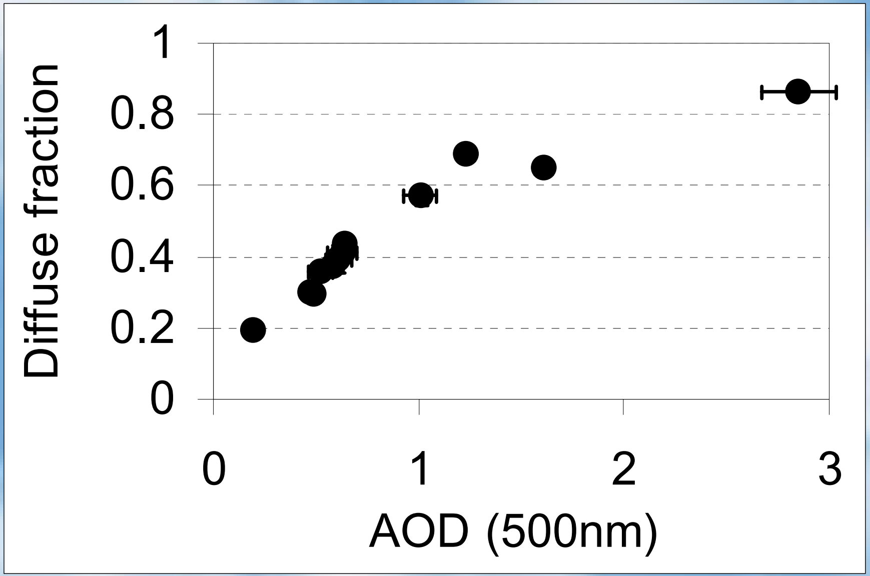
Average aerosol forcing clear sky

Top: - 7±1 w/m²

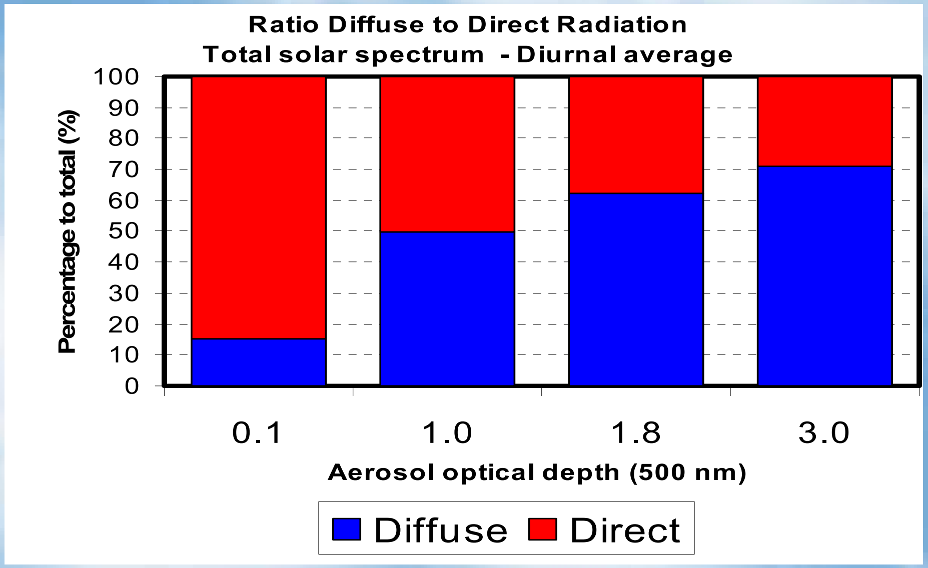
Surface: - 23±2 w/m²

Conditions: surface: ocean
AOT (τ=0.3 at 630 nm); 24 hour average
Jan-Mar 99

Measurements of the ratio diffuse to total PAR for SMOCC *(Marcia Yamasoe)*

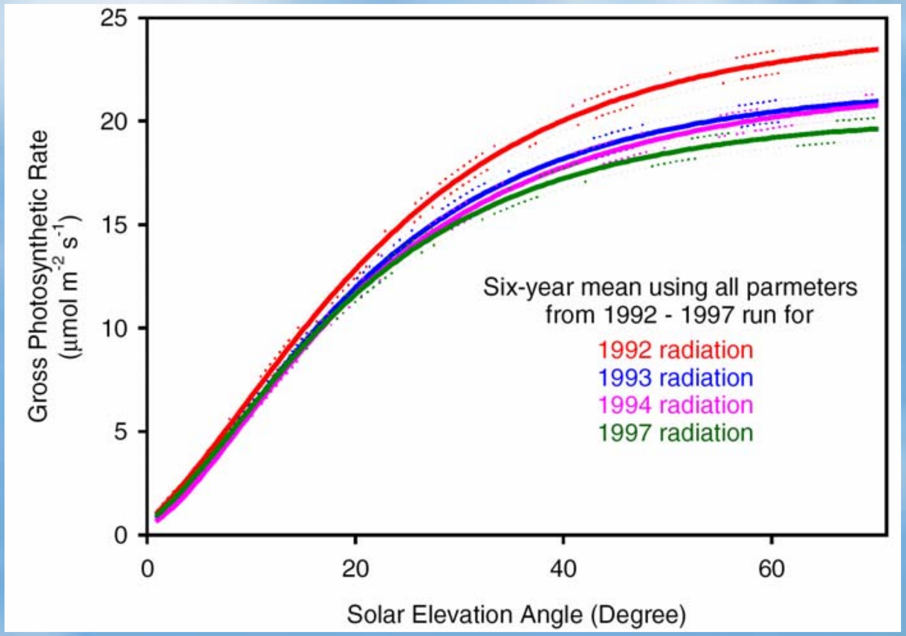


Modeling ratio diffuse and direct to total *(Aline Procopio)*

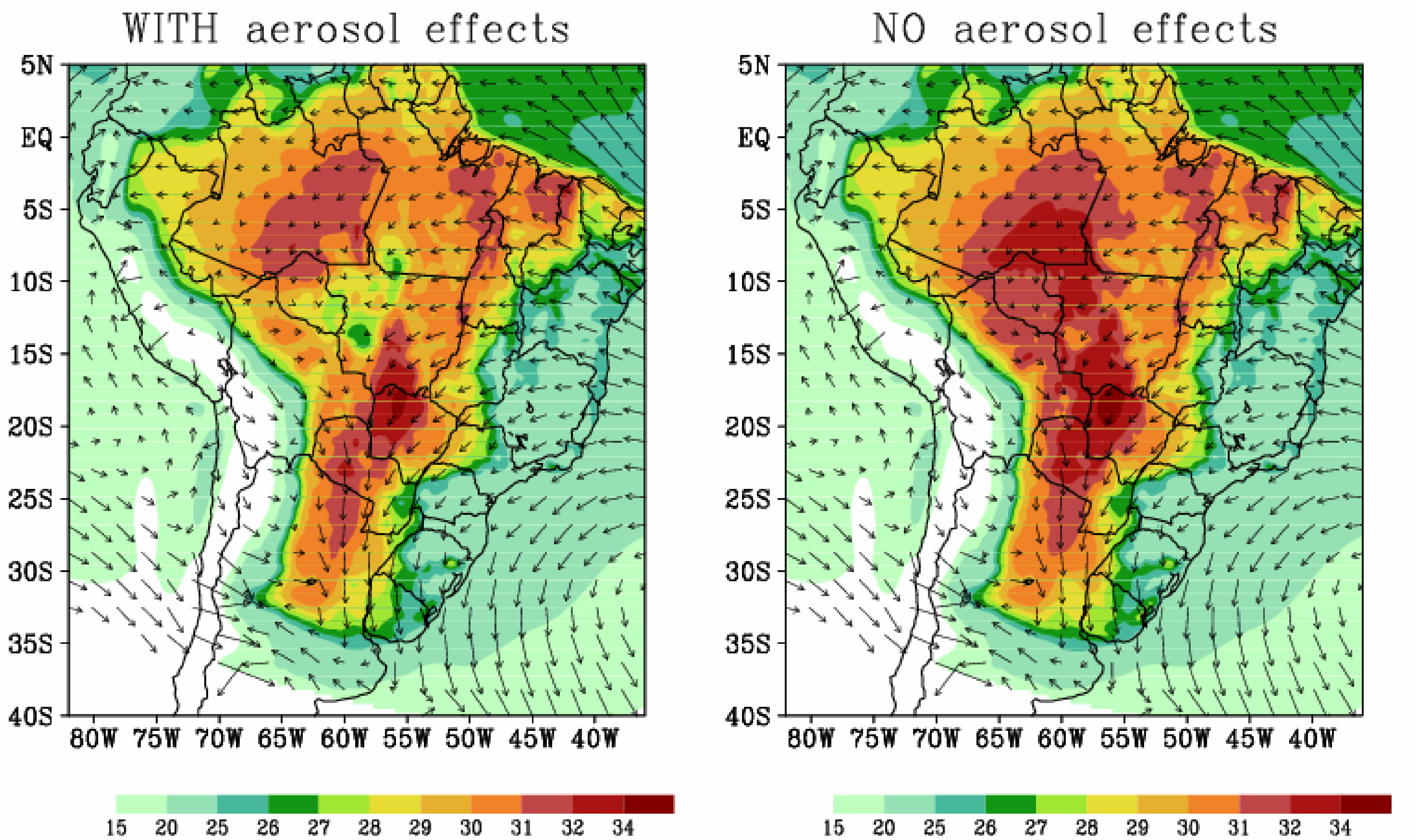


Ratio diffuse to total PAR affects Carbon Assimilation – Pinatubo Example

The mean canopy gross photosynthetic rates (solid lines) as a function of solar elevation angle for radiation conditions in 1992 (red), 1993 (blue), 1994 (pink), and 1997(dark green). *(Gu et al., Science 299, March 2003)*

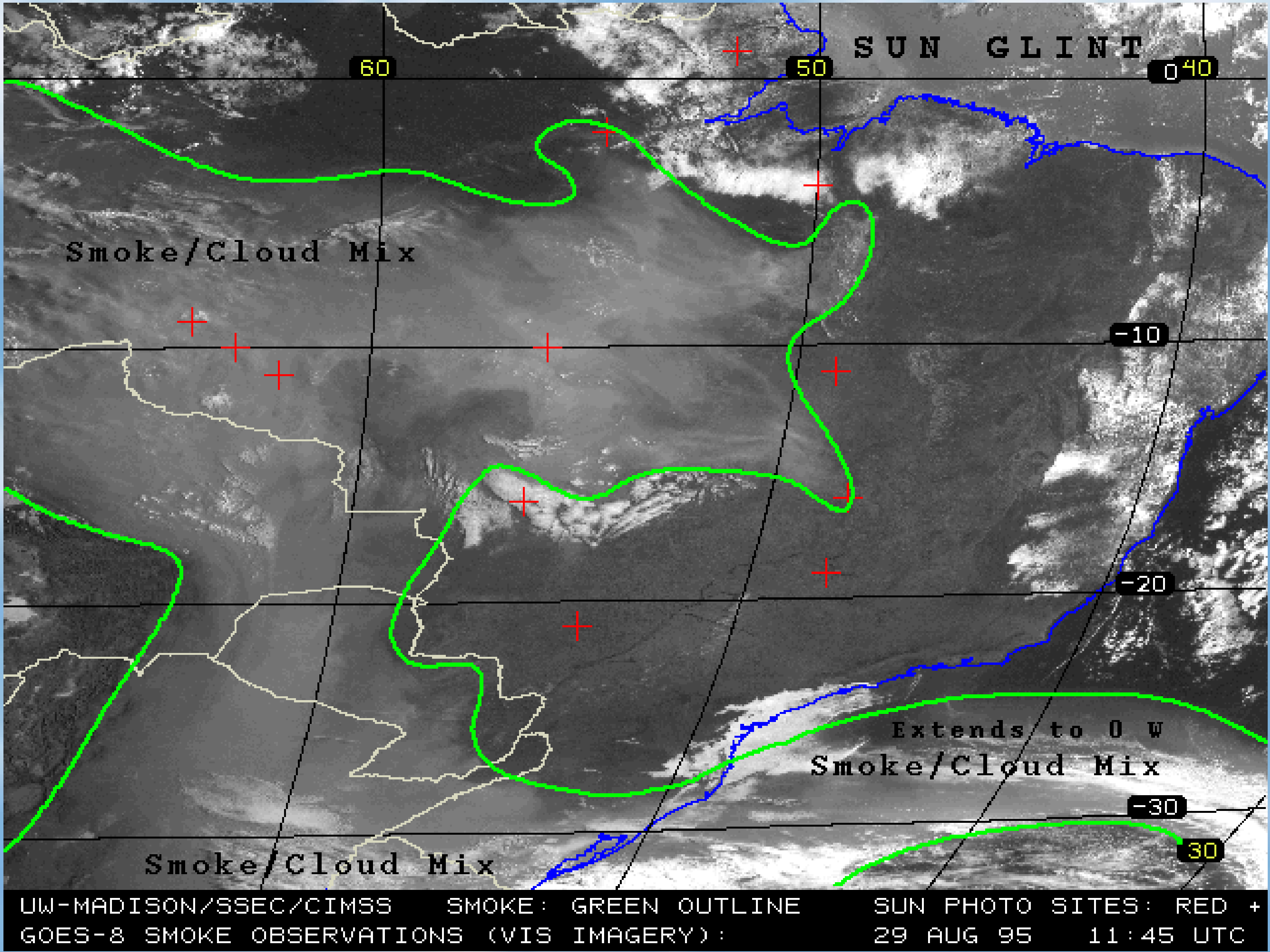


Aerosol Particles Radiative Effects on the Surface Temperature



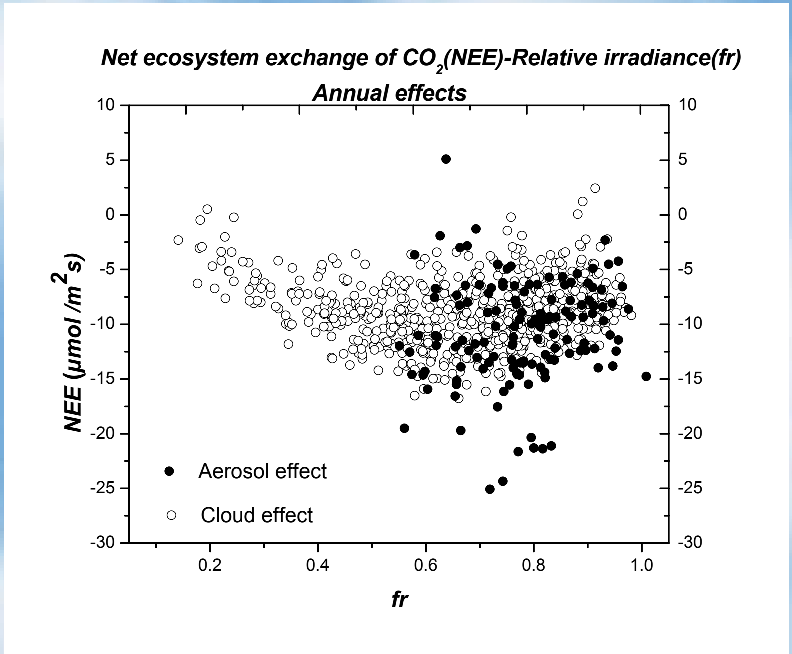
August 25, 2002, Simulations from Karla Longo and Saulo Freitas – CPTEC/INPE

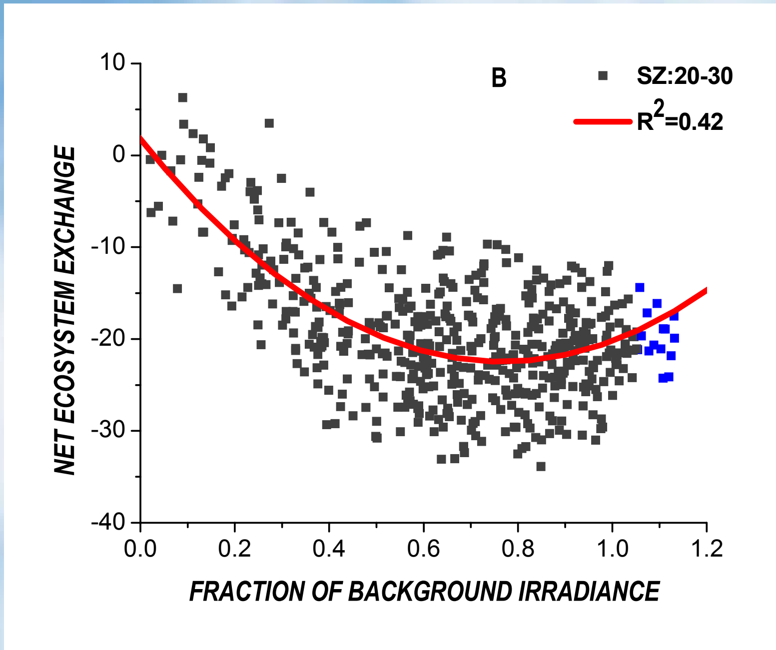
Effect of smoke aerosols and clouds over the CO2 flux in Amazonia



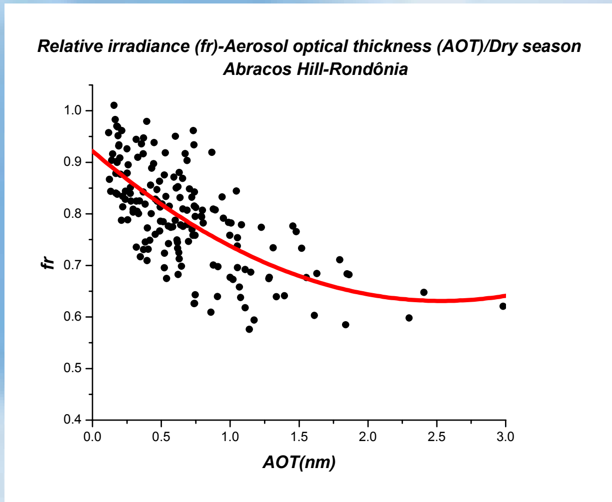
Effect of smoke aerosols and clouds over the CO_2 flux in Amazonia

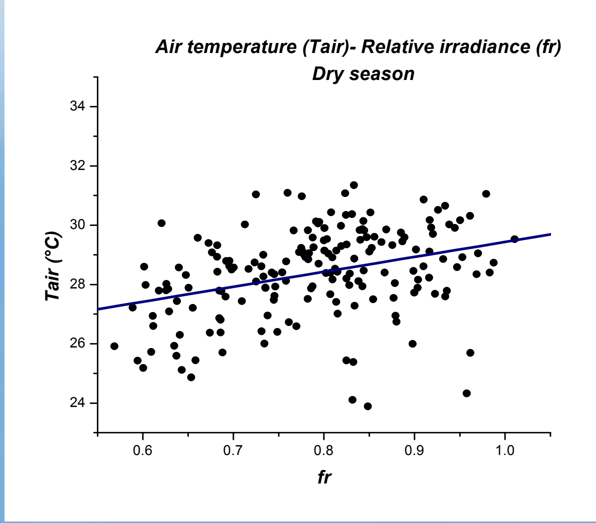
Paulo Henrique Oliveira, 2004





CO_2 assimilation is a complex interplay between: Photosynthetic active radiation, diffuse versus direct radiation, temperature, cloud coverage, and many other factors





Quantificando o efeito indireto global dos aerossóis

Table 1. Overview of the different aerosol indirect effects and range the radiative budget perturbation at the top-of-the atmosphere (F_{TOA}) [W m^{-2}], at the surface (F_{SFC}) and on the surface precipitation (PR) as estimated from Figure 2 and from the literature cited in the text.

Effect	Cloud type	Description	F_{TOA}	F_{SFC}	PR
Indirect aerosol effect for clouds with fixed water amounts (cloud albedo or Twomey effect)	All clouds	The more numerous smaller cloud particles reflect more solar radiation	-0.5 to -1.9	similar to TOA	n/a
Indirect aerosol effect with varying water amounts (cloud lifetime effect)	All clouds	Smaller cloud droplets decrease the precipitation efficiency thereby prolonging cloud lifetime	-0.3 to -1.4	similar to TOA	decrease
Semi-direct effect	Warm clouds	Absorption of solar radiation by soot may cause evaporation of cloud droplets	$+0.1$ to -0.5	larger than TOA	decrease
Glaciation indirect effect	Mixed-phase clouds	More ice nuclei increase the precipitation efficiency	?	?	increase
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets delay the onset of freezing	?	?	increase or decrease
Surface energy budget effect	All clouds	Increased aerosol and cloud optical thickness decrease the net surface solar radiation	n/a	-1.8 to -4	decrease

U. Lohmann *and* J. Feichter *2005, submitted*

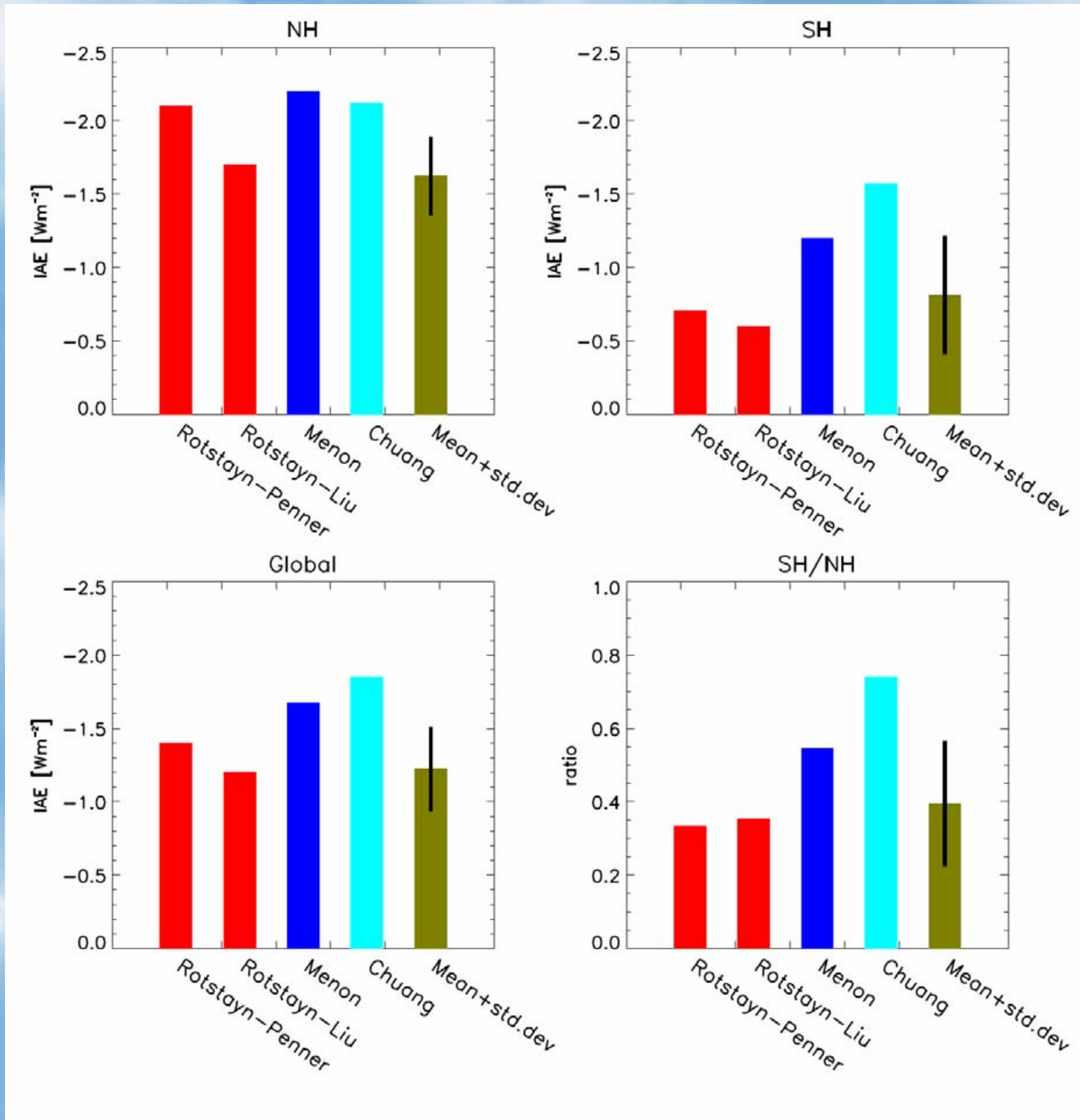
Total forcing for trace gases aerosols and clouds

Table 2. Instantaneous Forcings F (W m^{-2}), surface temperature response T_{sfc} (K), climate sensitivities λ (K m^2 W^{-1}), efficacies E and effective forcings F_e as defined in the text for different forcing agents and from different coupled equilibrium climate model/mixed-layer ocean simulations

Experiment	F	T_{sfc}	λ	E	F_e	Reference
Well mixed greenhouse gases from 1860 to 1990	2.12	1.82	0.86	1	2.12	Roeckner, pers. comm.
Tropospheric ozone	0.37	0.34	0.91	1.06	0.39	Roeckner, pers. comm.
Sulfate aerosols, direct effect	-0.34	-0.24	0.71	0.83	-0.28	Roeckner, pers. comm.
Sulfate aerosols, Twomey effect	-0.89	-0.78	0.87	1.01	-0.90	Roeckner, pers. comm.
All aerosol effects (direct and indirect on water clouds)	-1.4	-0.87	0.62	0.72	-1.01	Feichter et al. (2004), Lohmann and Feichter (2001)
All aerosol effects and GHG effect	-1.4+ 2.1 = +0.7	0.57	0.81	0.94	0.66	Feichter et al. (2004), Lohmann and Feichter (2001)

U. Lohmann *and* J. Feichter *2005, submitted*

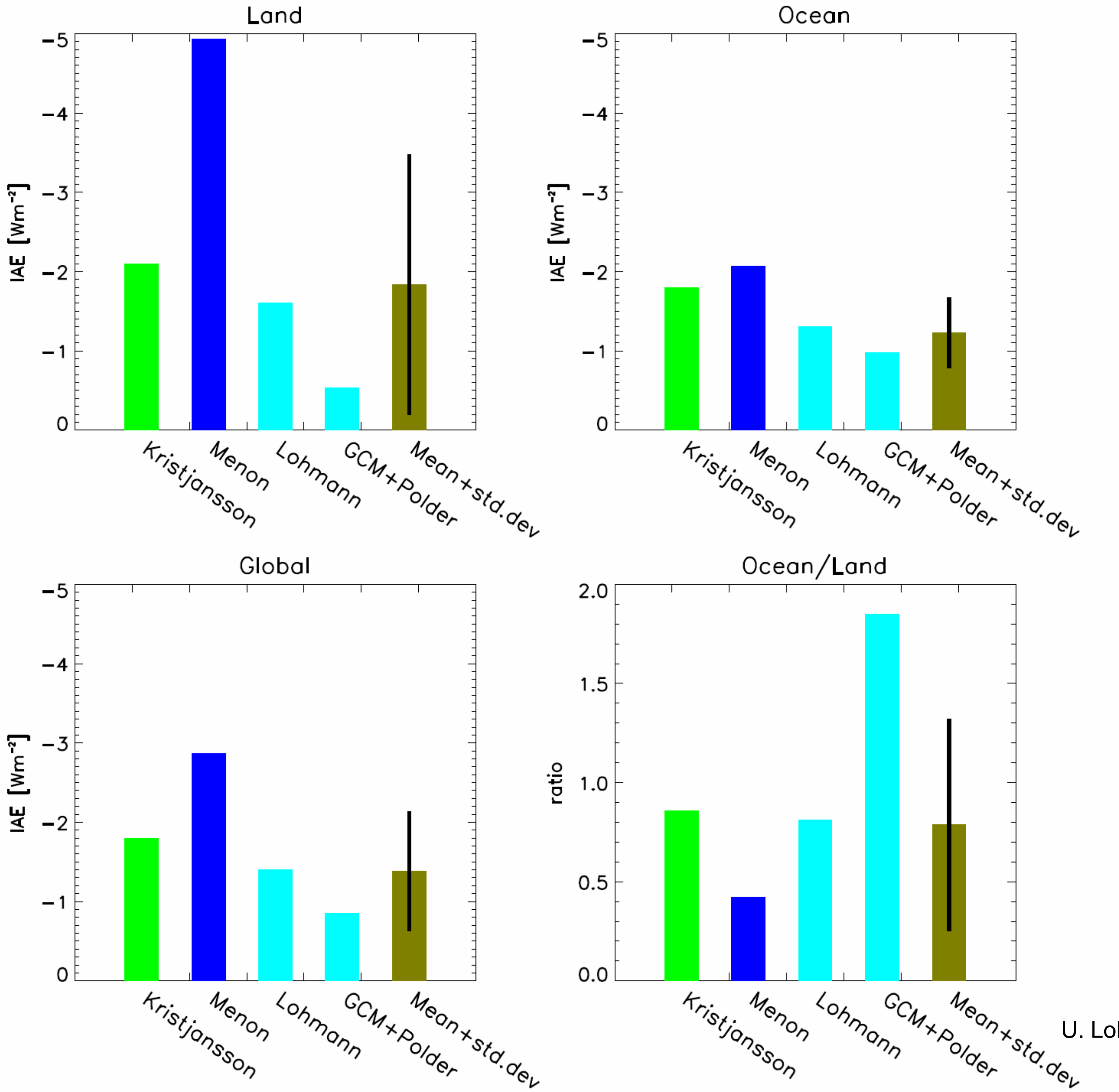
Global mean Twomey effect



Global mean Twomey effect and its contribution on the Northern and Southern Hemisphere (NH, SH) of anthropogenic sulfate aerosols from Rotstayn and Penner (2001) and Rotstayn and Liu (2003) (red bars), of anthropogenic sulfate and black carbon (blue bars) from Menon et al. (2002a), of anthropogenic sulfate and black, and organic carbon from Chuang et al. (2002) (turquoise bars) and the mean plus standard deviation from all simulations (olive bars).

U. Lohmann *and* J.Feichter *2005, submitted*

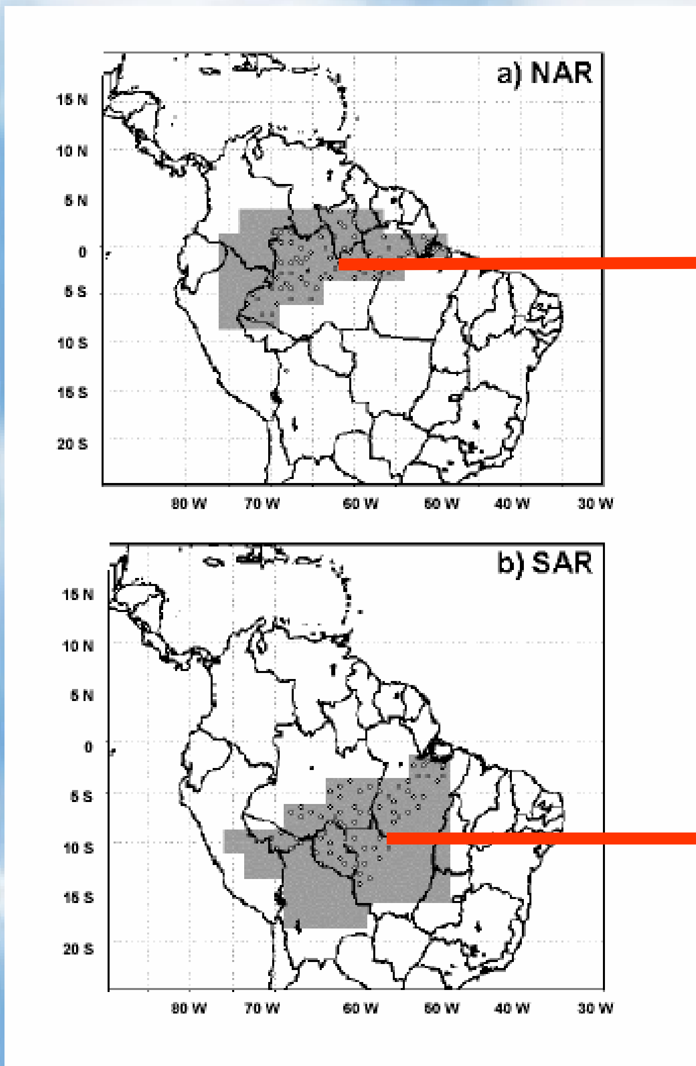
Global mean total indirect aerosol effects

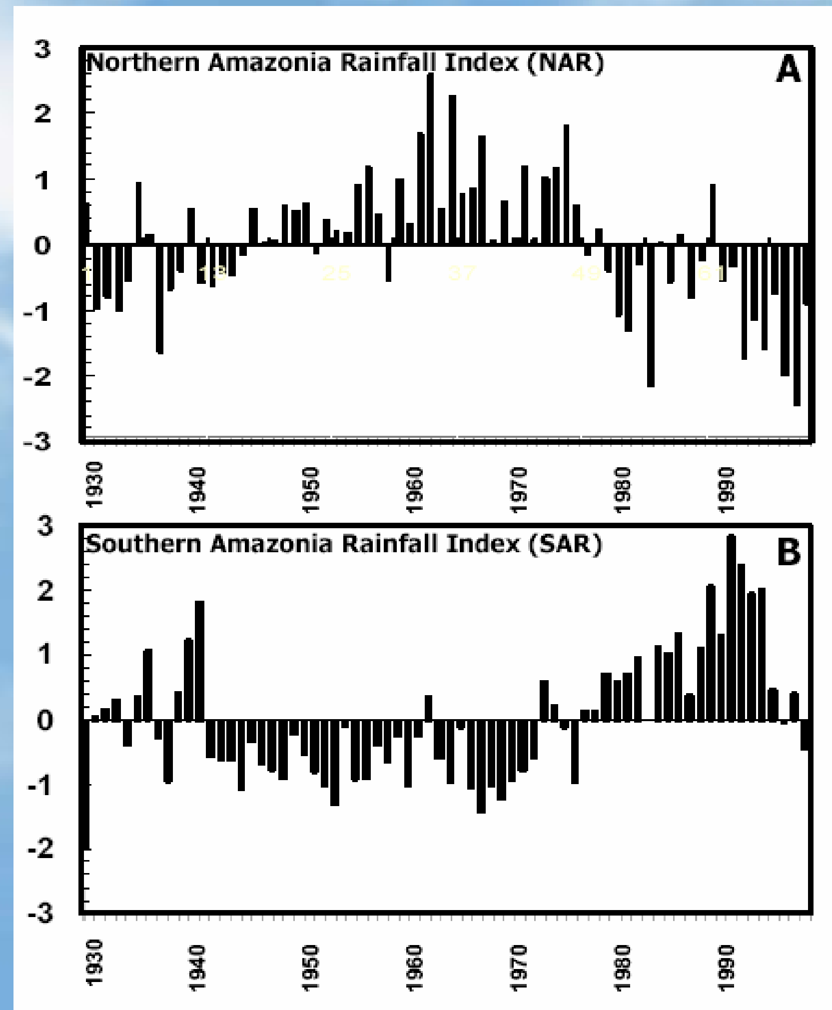


Global mean total indirect aerosol effects and their contribution over the oceans and over land, respectively of anthropogenic sulfate and black carbon (green bars) from Kristjansson (2002), of anthropogenic sulfate and black carbon (blue bars) from Menon et al. (2002a), of anthropogenic sulfate and black, and organic carbon from Lohmann and Lesins (2002), from a combination of ECHAM4 GCM and POLDER satellite results Lohmann and Lesins (2002) (turquoise bars) and the mean plus standard deviation from all simulations (olive bars).

U. Lohmann *and* J. Feichter *2005, submitted*

Precipitation in Amazonia 1930-1990: Interannual and interdecadal variability

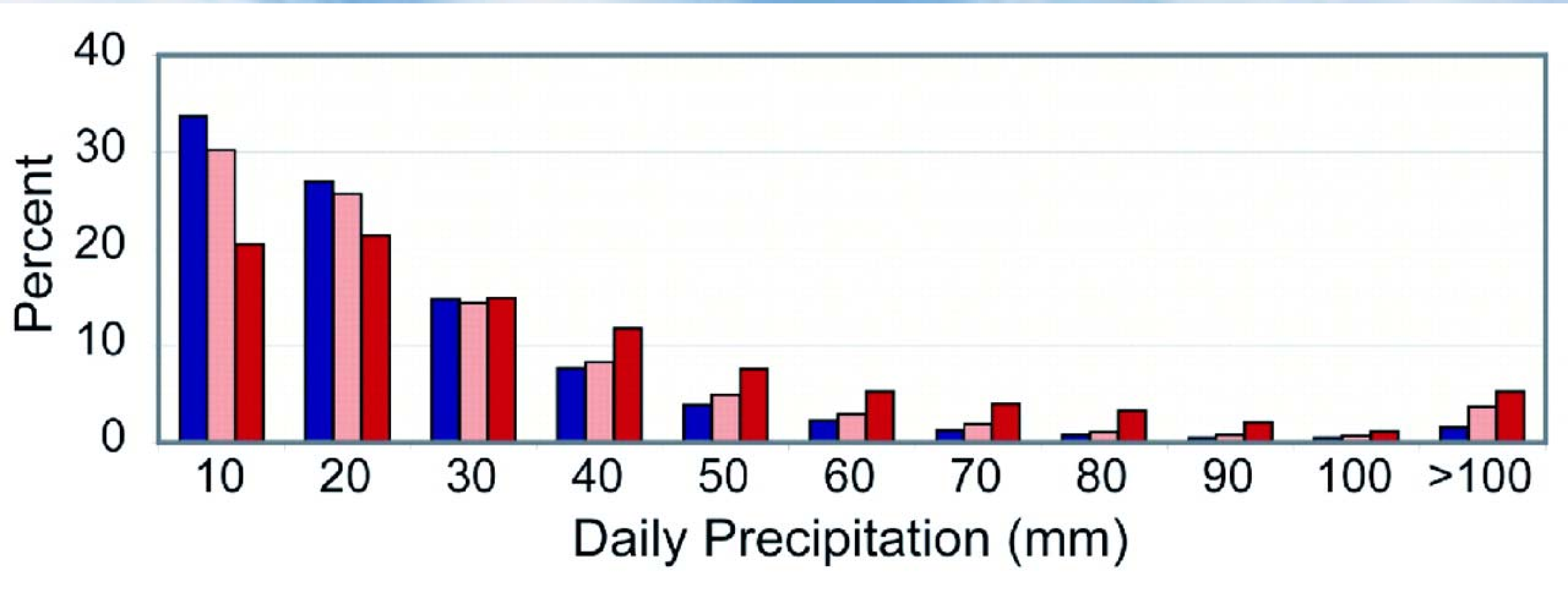




Marengo, 2003

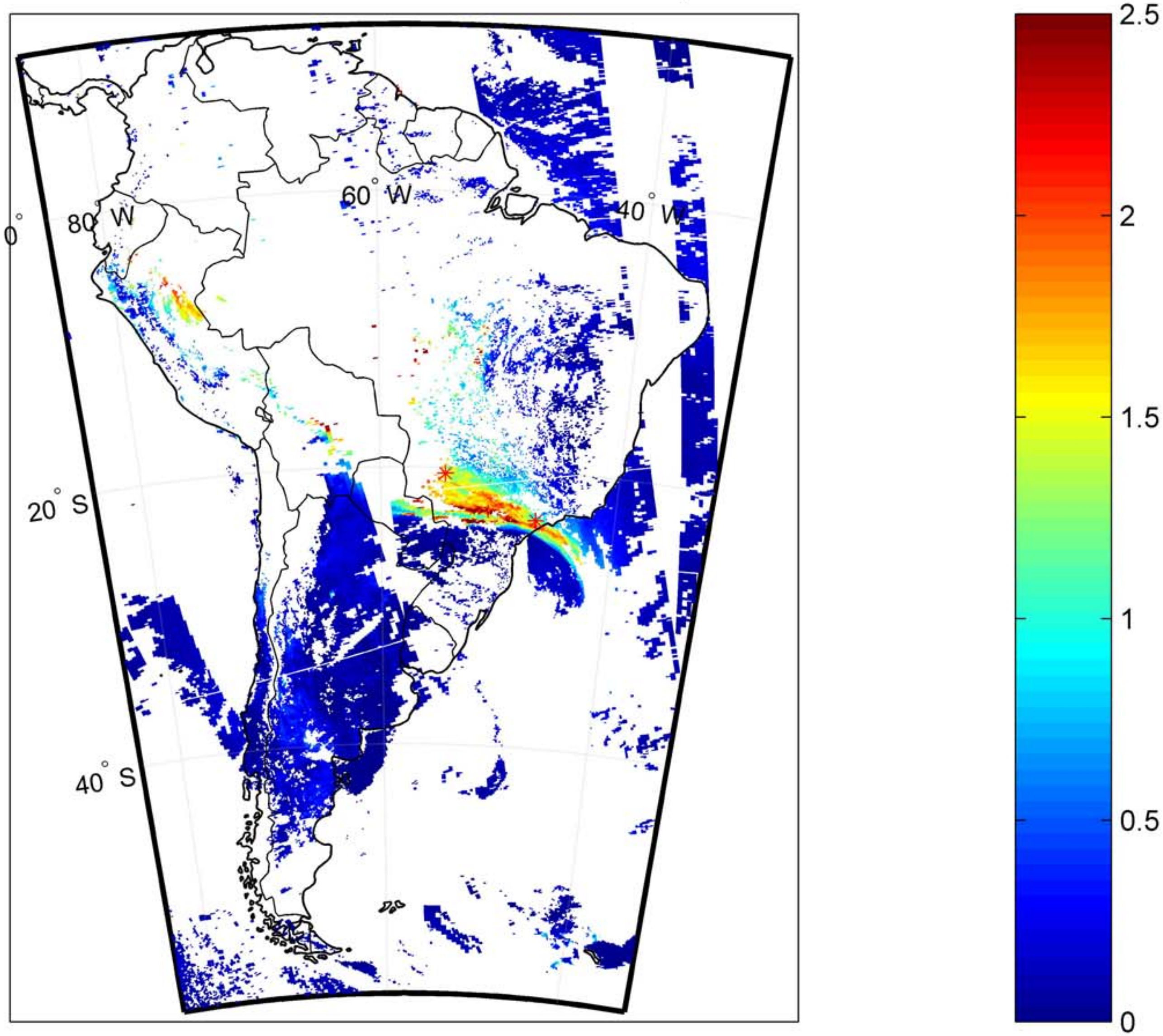
Rainfall indices in northern (NAR) and southern Amazonia (SAR) from 1929=30 to 1998=99. Indices are expressed as departures normalized by the standard deviation, from the reference period 1949–1998. From Marengo et al., Theor. Appl. Climatol. 2004.

Intensity of daily precipitation as a percentage of total amount

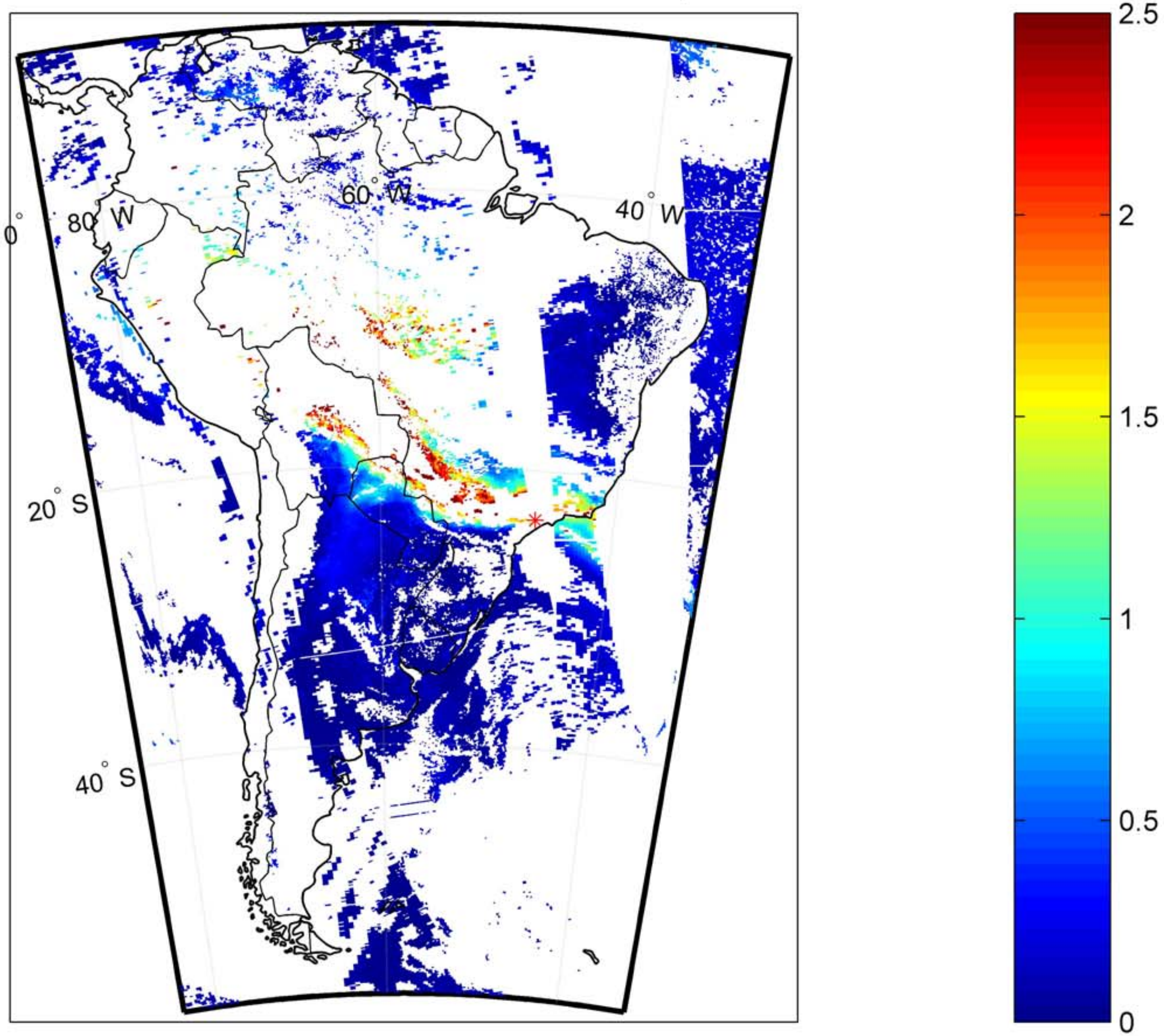


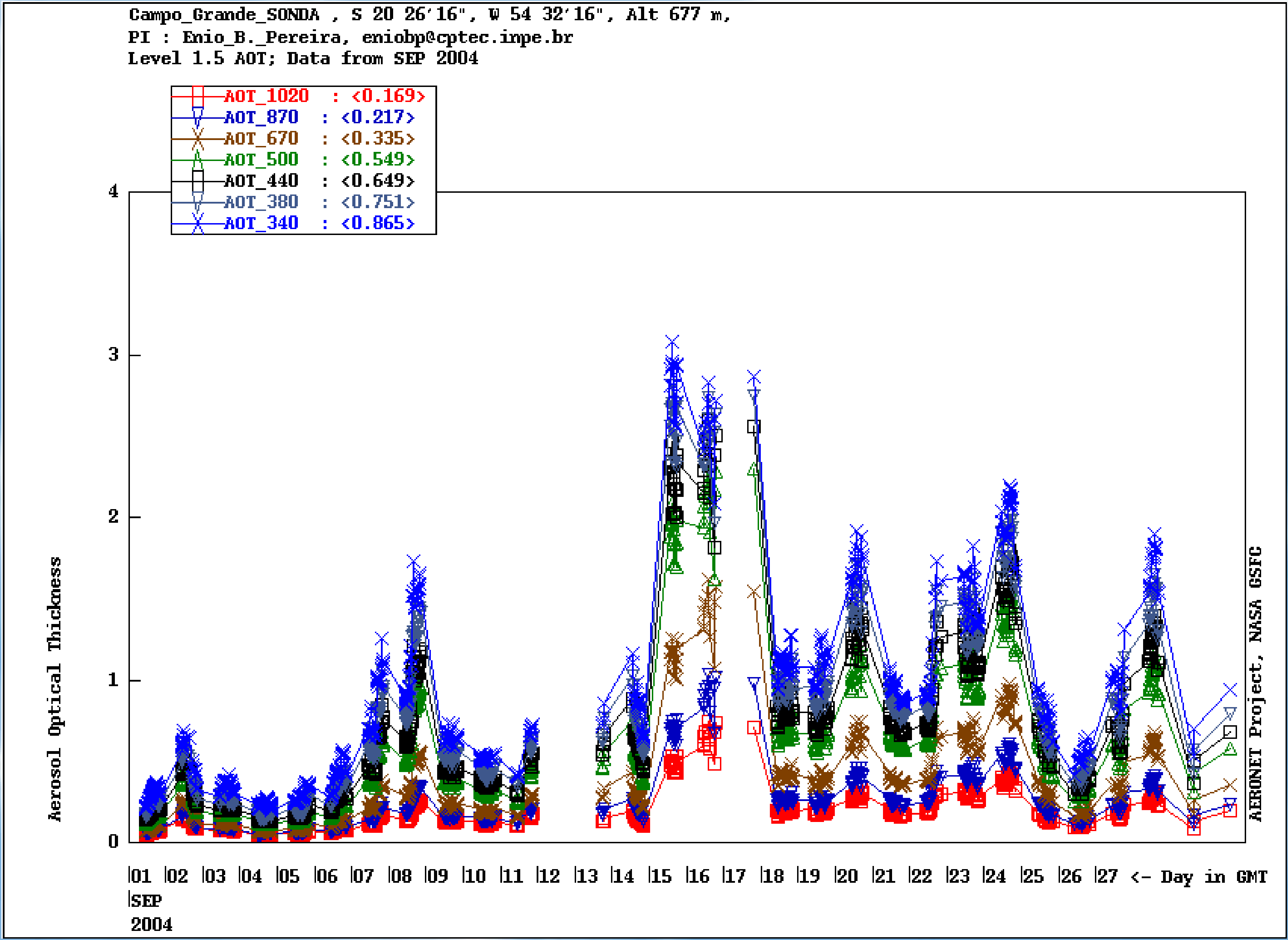
Climatology of the intensity of daily precipitation as a percentage of total amount in 10 mm/day categories for different temperature regimes, based on 51, 37, and 12 worldwide stations, respectively: blue bars, –3°C to 19°C; pink bars, 19°C to 29°C; dark red bars, 29°C to 35°C. By selection, all stations have the same seasonal mean precipitation amount of 230 ± 5 mm. As temperatures and the associated water-holding capacity of the atmosphere (*15*) increase, more precipitation falls in heavy (more than 40 mm/day) to extreme (more than 100 mm/day) daily amounts. (*Science 302, 1719, 2003*)

America do Sul AOT550 2004 AQUA15Sep2004

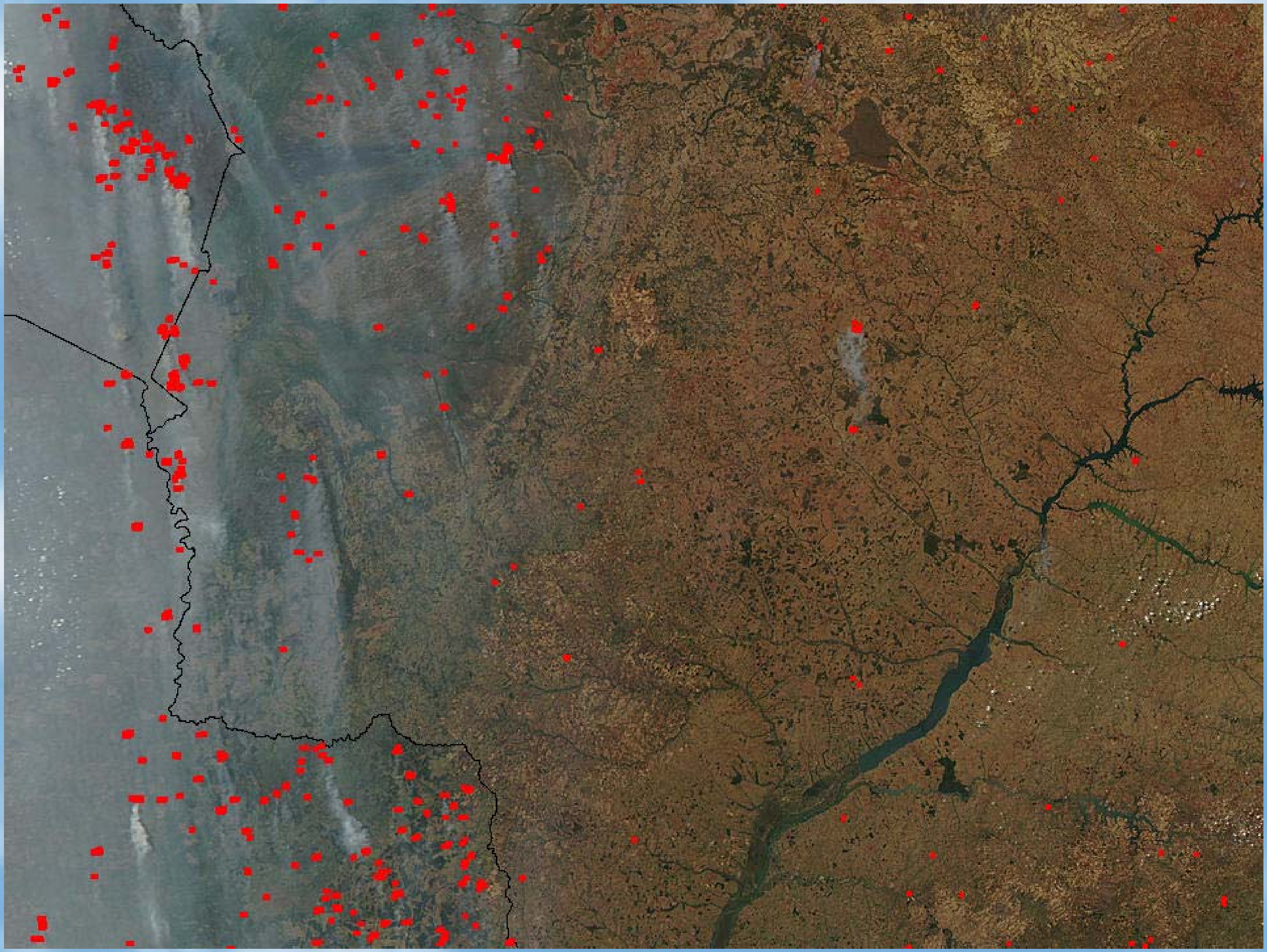


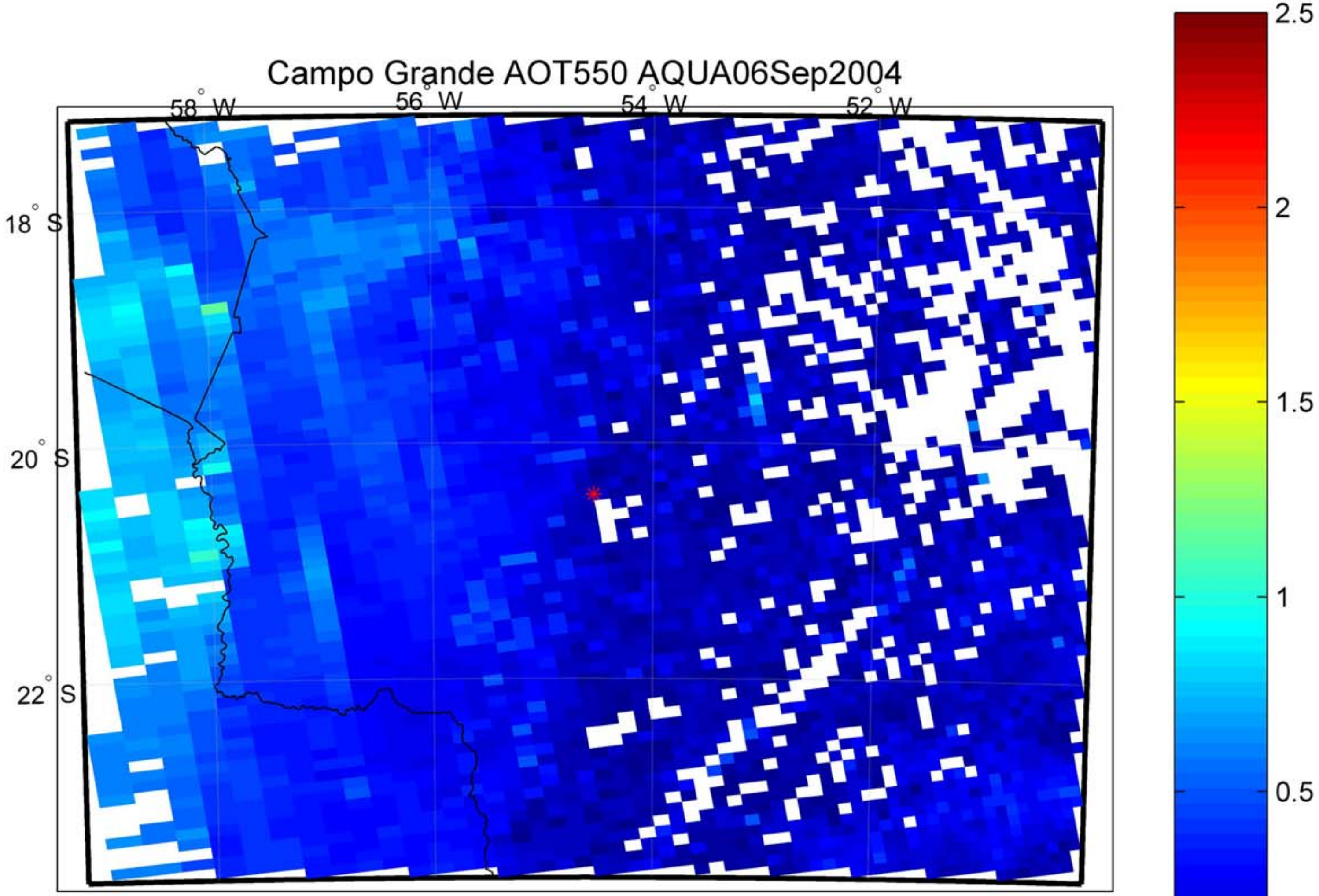
America do Sul AOT550 2004 AQUA16Sep2004




Campo_Grande_SONDA , S 20 26'16", W 54 32'16", Alt 677 m,
PI : Enio_B._Pereira, eniobp@cptec.inpe.br
Level 1.5 AOT; Data from SEP 2004
AOT_1020 : <0.169>
AOT_870 : <0.217>
AOT_670 : <0.335>
AOT_500 : <0.549>
AOT_440 : <0.649>
AOT_380 : <0.751>
AOT_340 : <0.865>
Aerosol Optical Thickness
0
1
2
3
4
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 <- Day in GMT
SEP
2004
AERONET Project, NASA GSFC

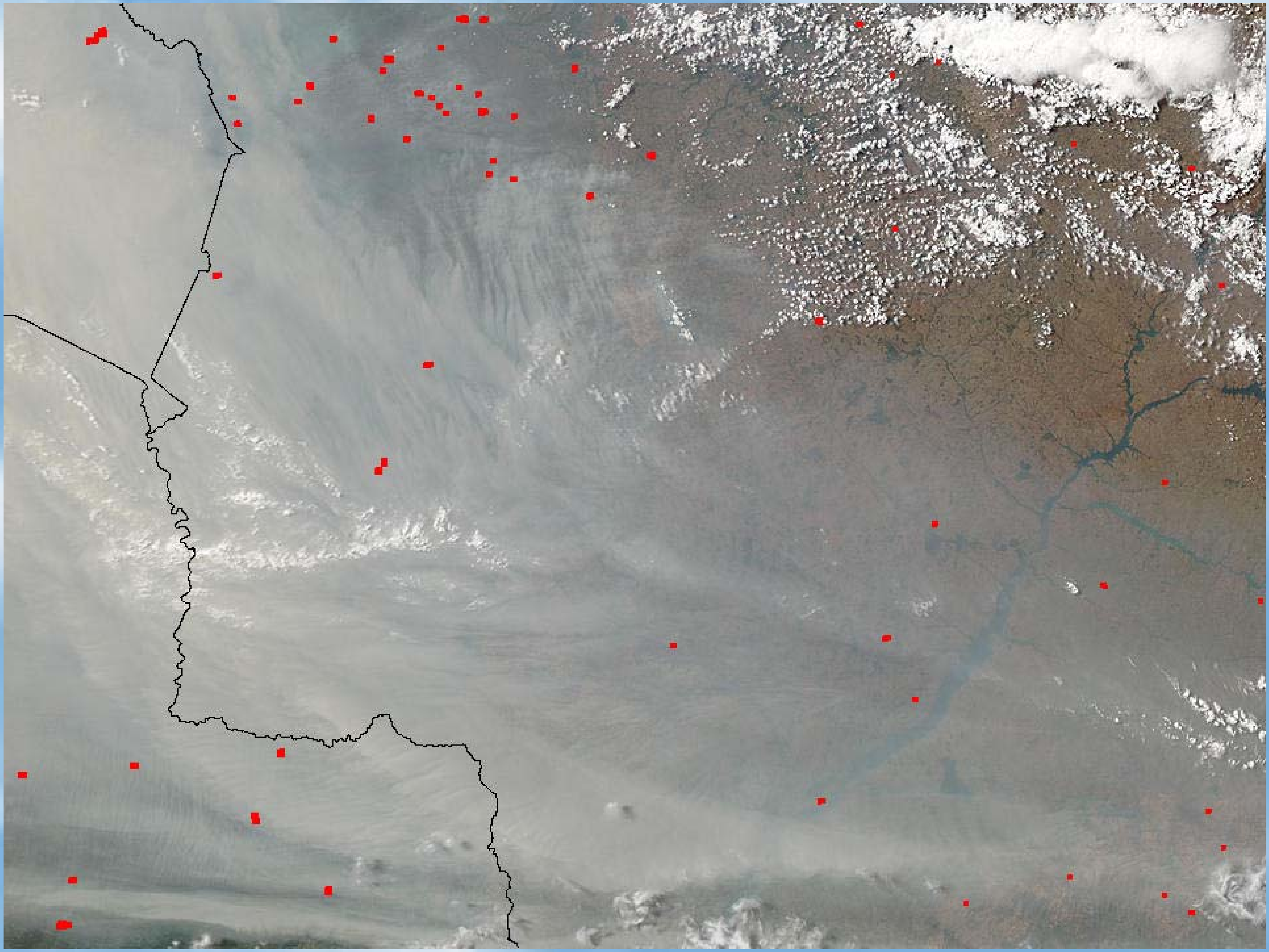
Campo Grande – 06 de setembro de 2004

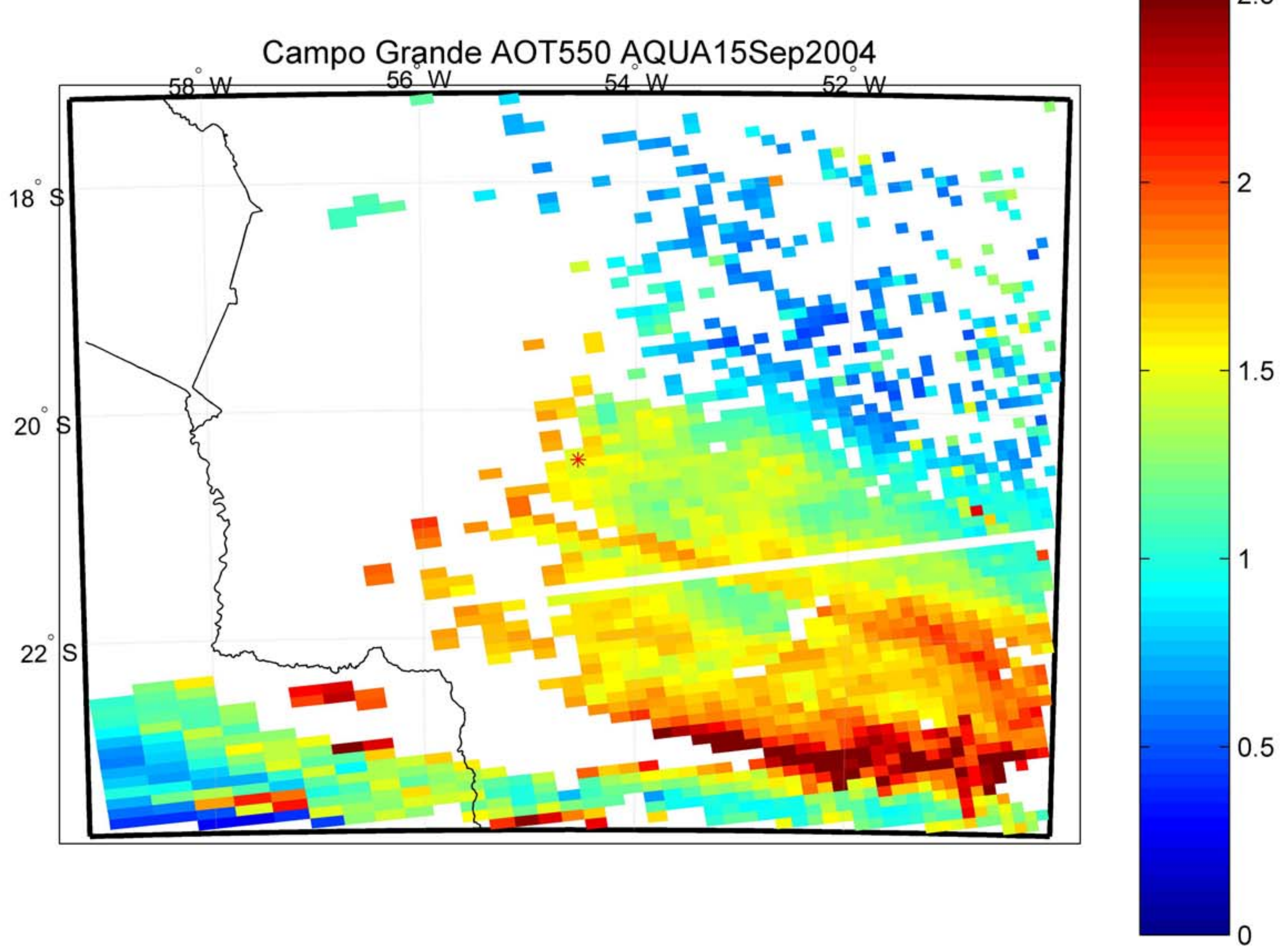




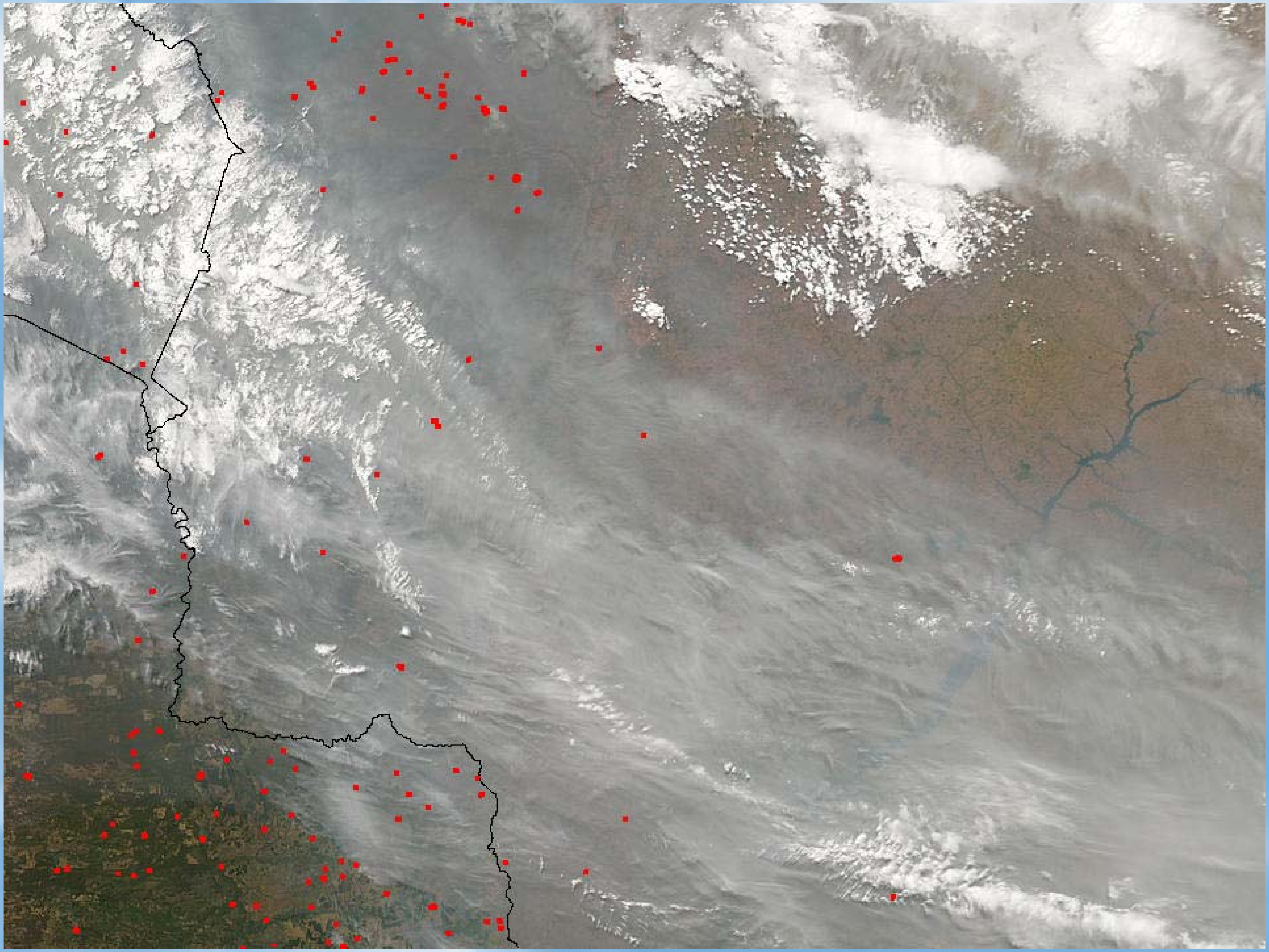
Campo Grande AOT550 AQUA06Sep2004
58° W
56° W
54° W
52° W
18° S
20° S
22° S
2.5
2
1.5
1
0.5
0

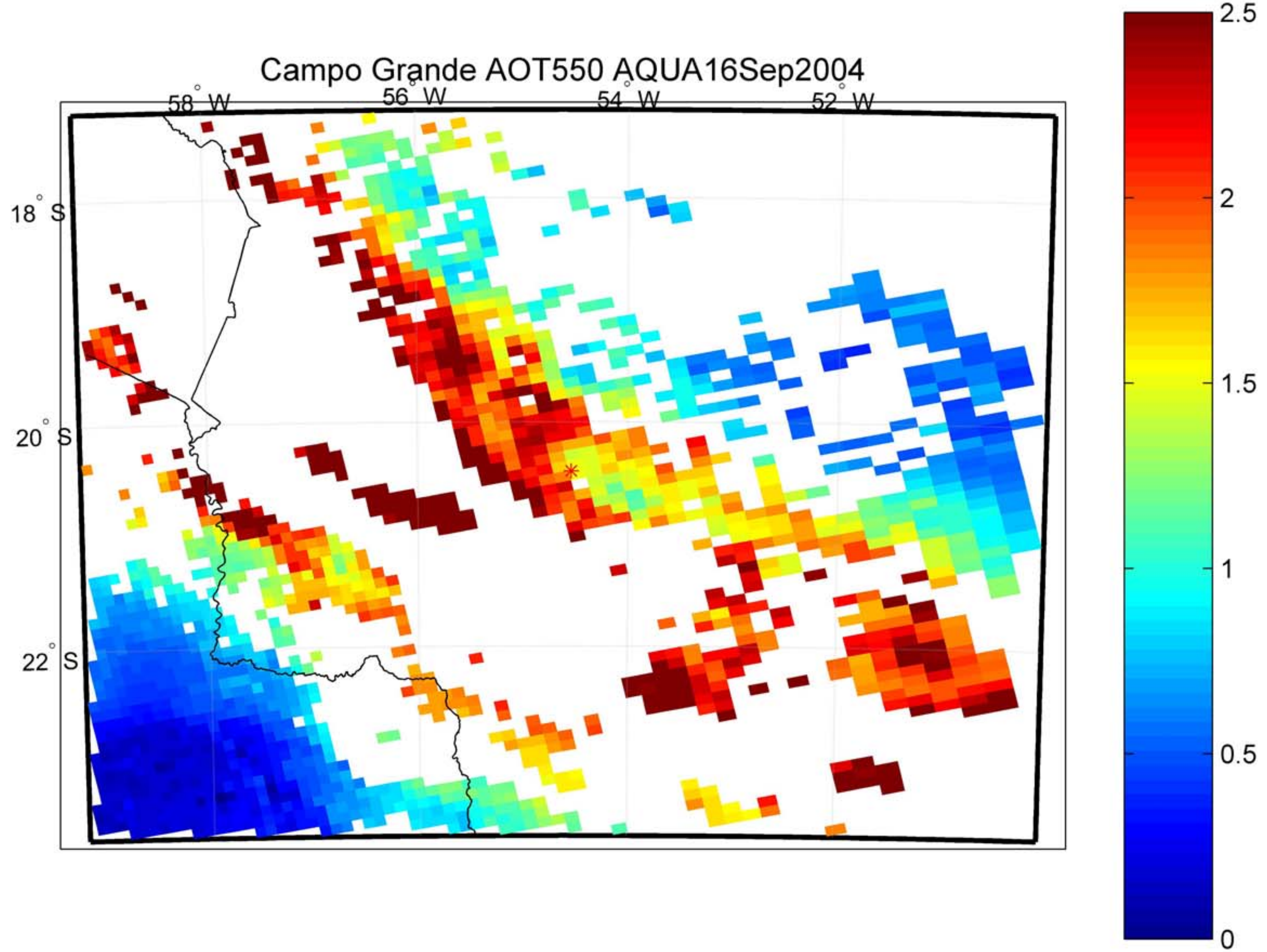
Campo Grande – 15 de setembro de 2004

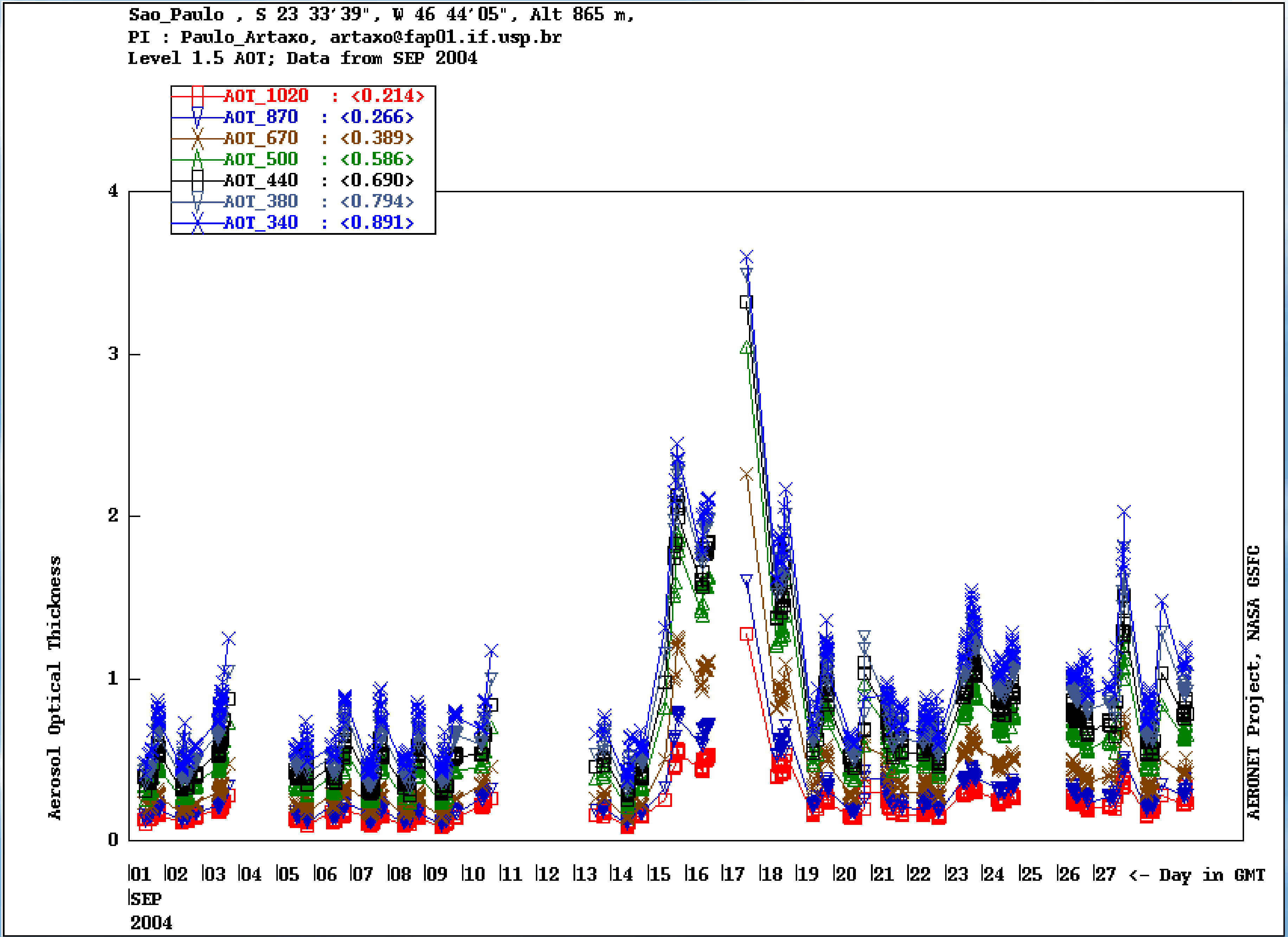



Campo Grande AOT550 AQUA15Sep2004
58° W
56° W
54° W
52° W
18° S
20° S
22° S
2.5
2
1.5
1
0.5
0

Campo Grande – 16 de setembro de 2004

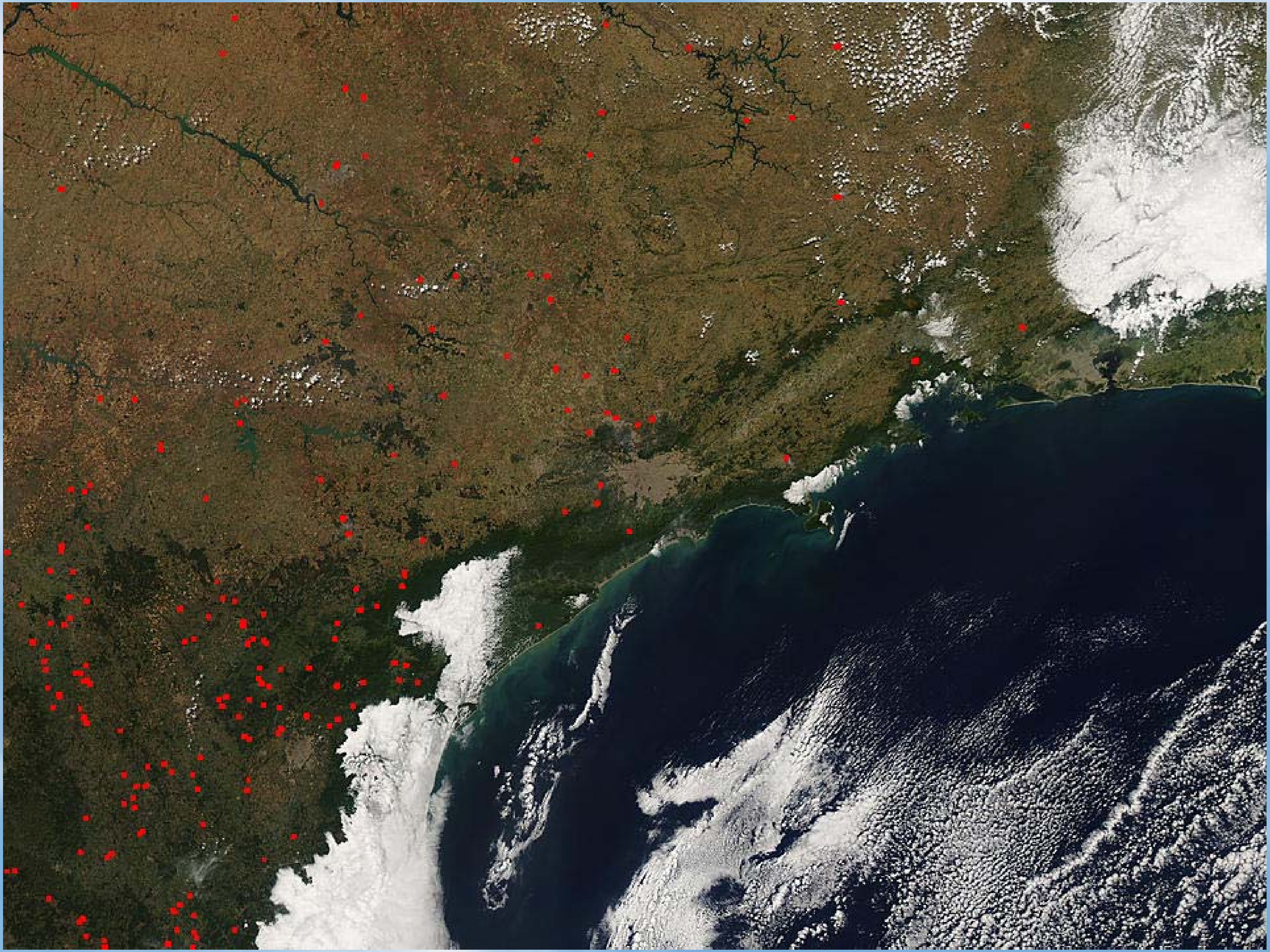


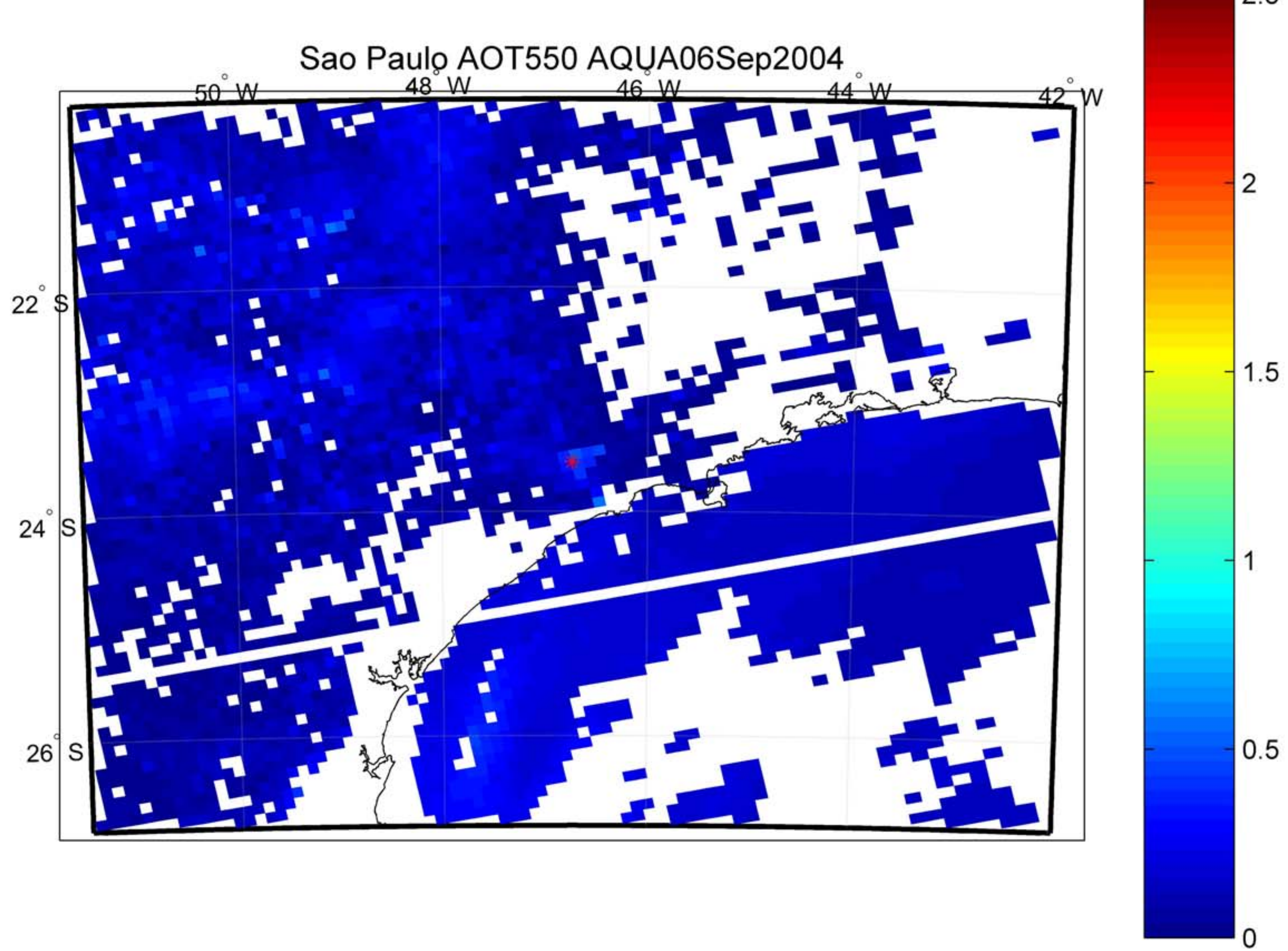

Campo Grande AOT550 AQUA16Sep2004
58° W
56° W
54° W
52° W
18° S
20° S
22° S
2.5
2
1.5
1
0.5
0



Sao_Paulo , S 23 33'39", W 46 44'05", Alt 865 m,
PI : Paulo_Artaxo, artaxo@fap01.if.usp.br
Level 1.5 AOT; Data from SEP 2004
AOT_1020 : <0.214>
AOT_870 : <0.266>
AOT_670 : <0.389>
AOT_500 : <0.586>
AOT_440 : <0.690>
AOT_380 : <0.794>
AOT_340 : <0.891>
Aerosol Optical Thickness
0
1
2
3
4
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 <- Day in GMT
SEP
2004
AERONET Project, NASA GSFC

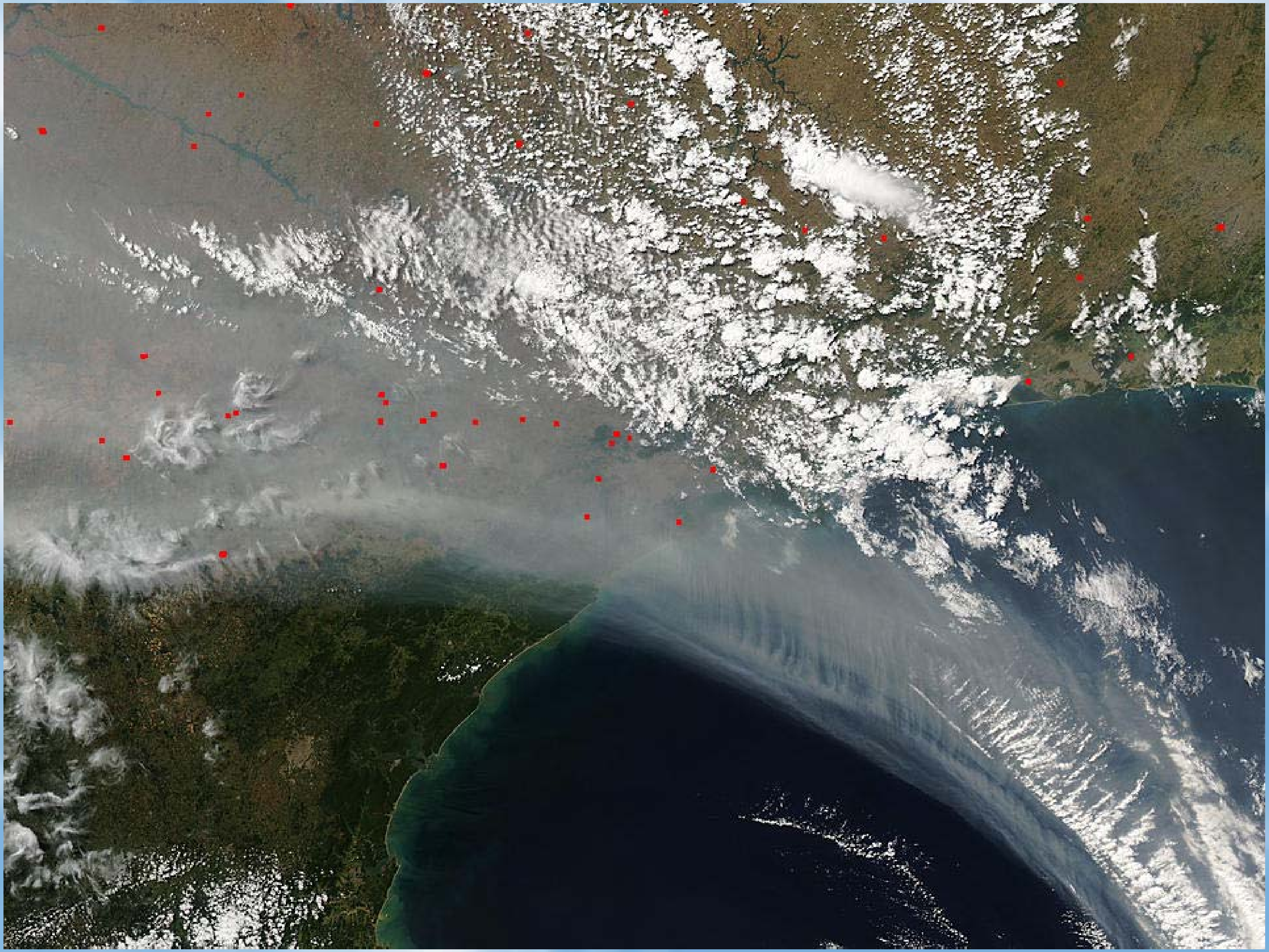
São Paulo LIMPO – 06 de setembro de 2004

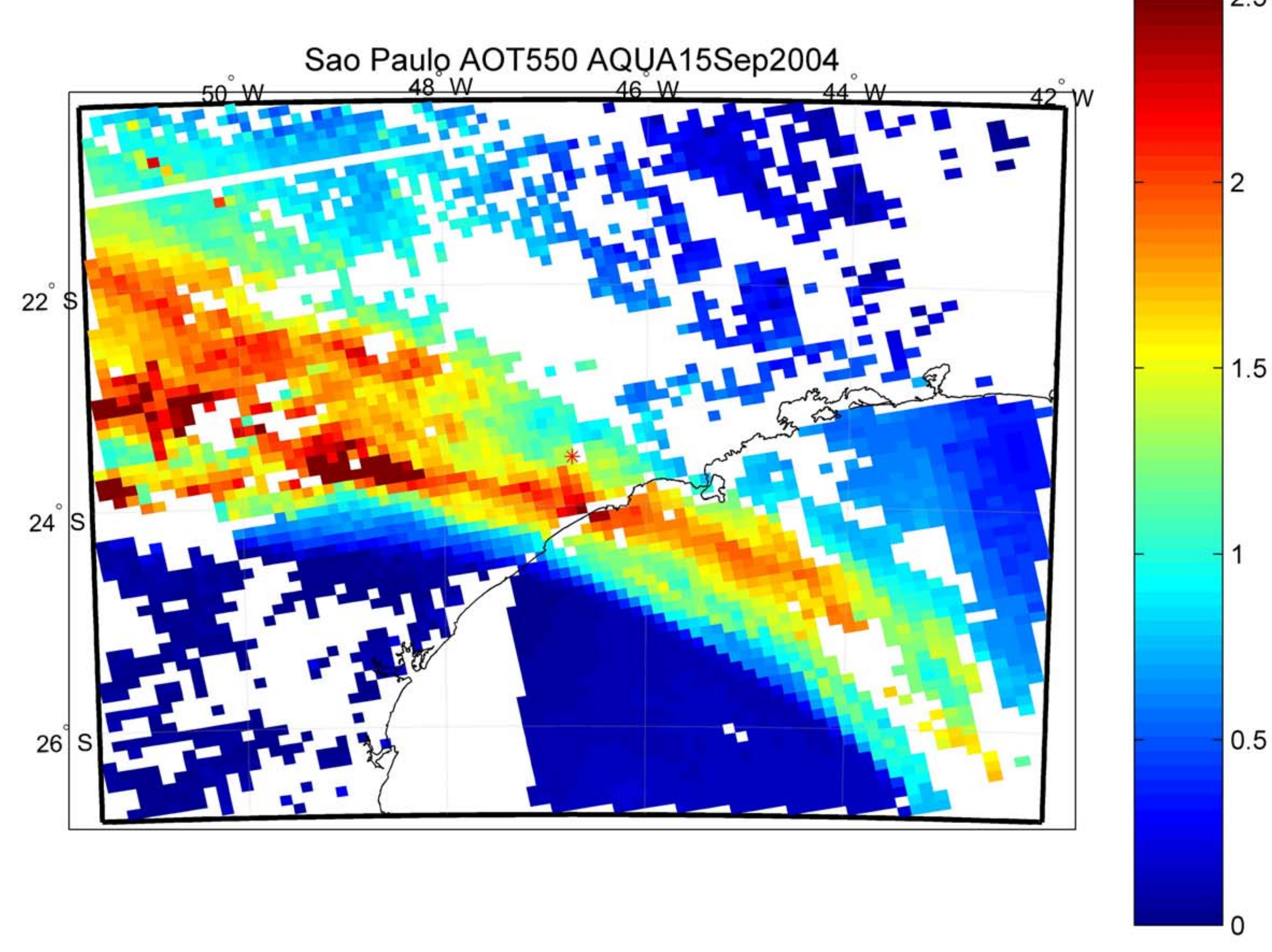


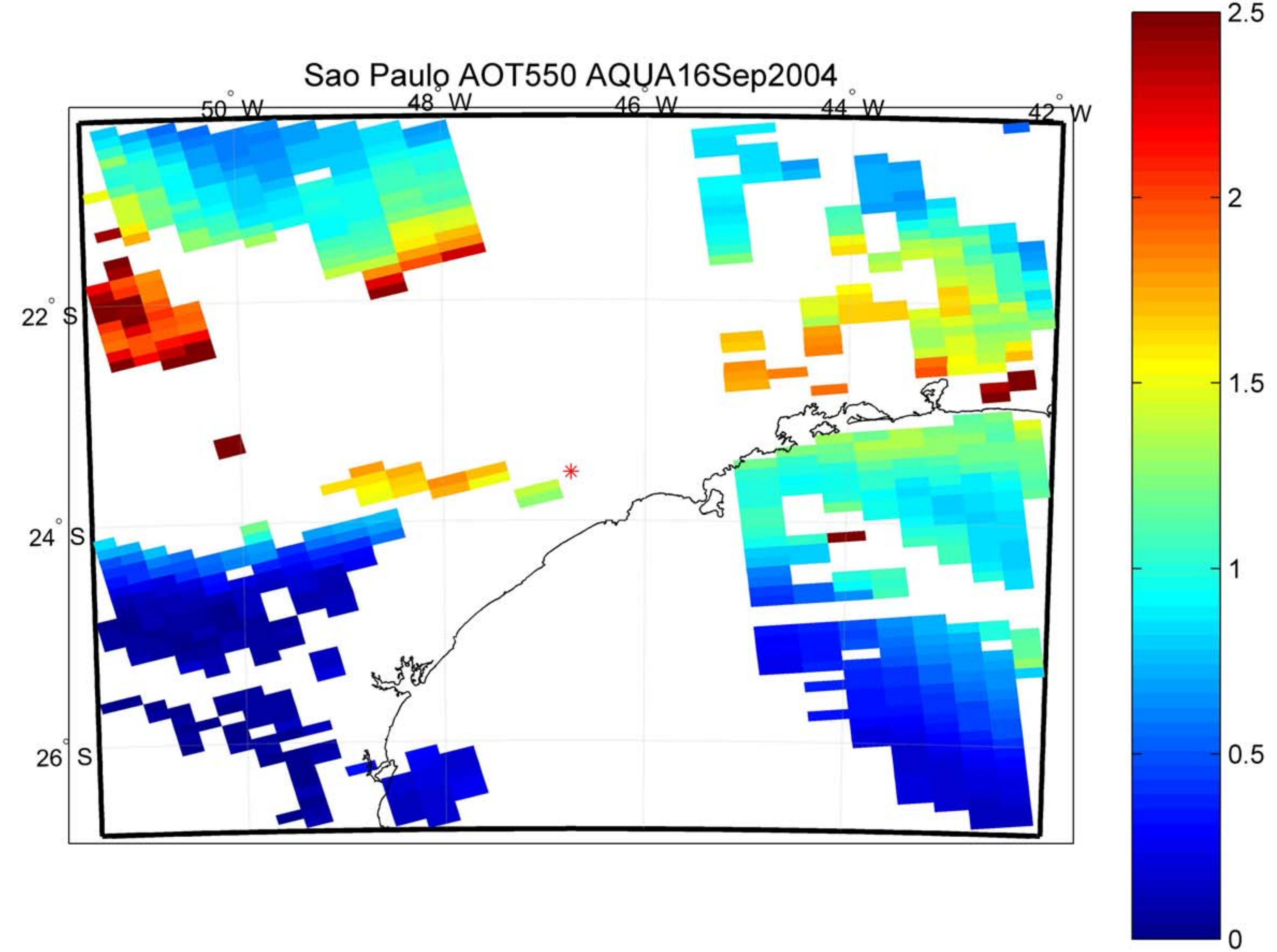


Sao Paulo AOT550 AQUA06Sep2004
50° W
48° W
46° W
44° W
42° W
22° S
24° S
26° S
2.5
2
1.5
1
0.5
0

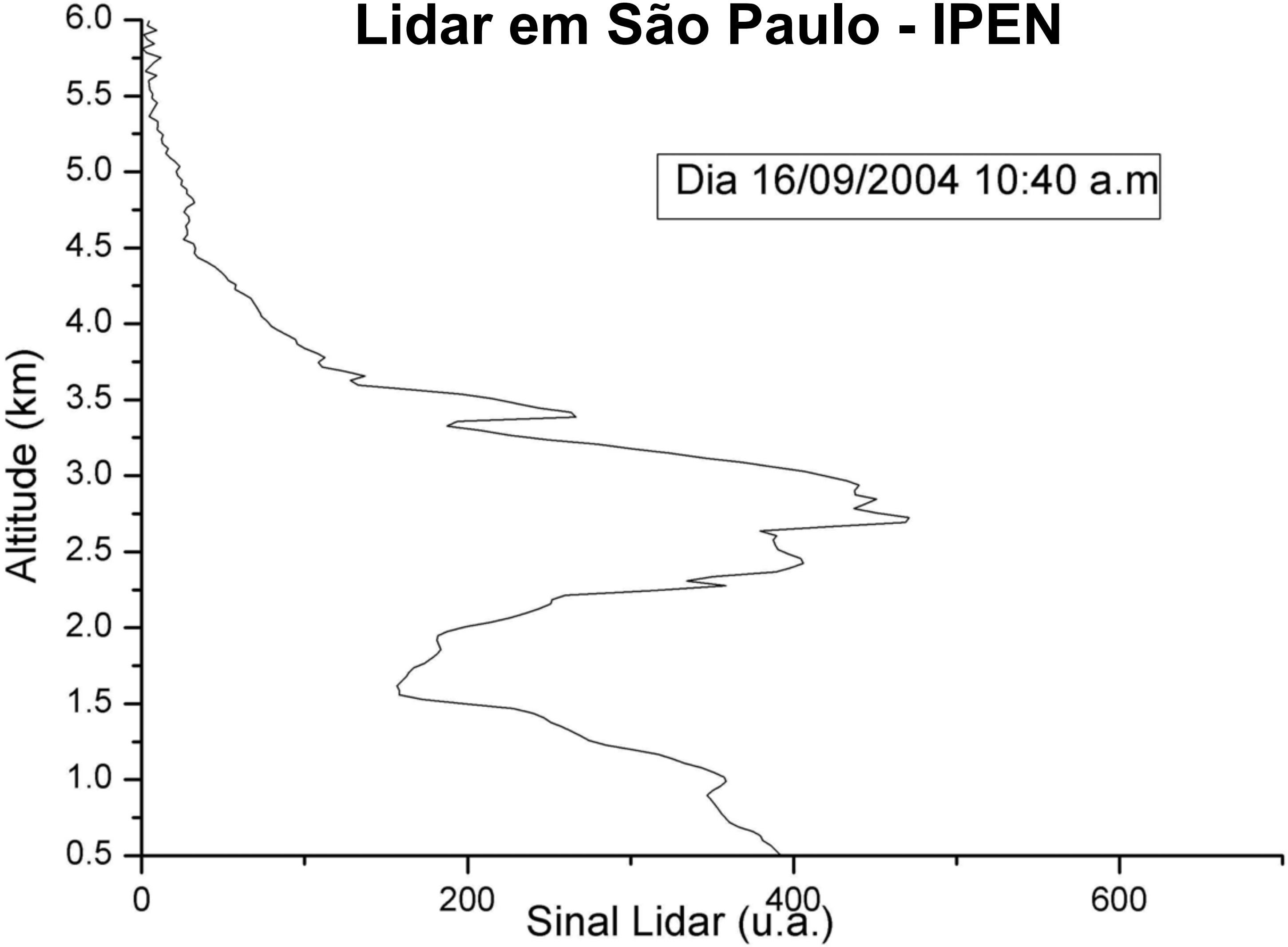
São Paulo – 15 de setembro de 2004




Sao Paulo AOT550 AQUA15Sep2004
50° W
48° W
46° W
44° W
42° W
22° S
24° S
26° S
2.5
2
1.5
1
0.5
0


Sao Paulo AOT550 AQUA16Sep2004
50° W
48° W
46° W
44° W
42° W
22° S
24° S
26° S
2.5
2
1.5
1
0.5
0

Lidar em São Paulo - IPEN



Conclusões:

- Existem inúmeras incertezas na evolução do clima global
  - Uma das maiores incognitas é o efeito indireto de aerossóis no clima
  - forçantes sócio econômicas imprevisíveis
  - o sistema dinâmico é complexo, não linear e com componente caótica
- é preciso compreender profundamente os processos de interação biosfera-atmosfera em especial aqueles que envolvem a formação de nuvens e de chuvas, e o balanço de radiação
- modelos devem enfocar o sistema físico-químico-hidrológico-biológico completo de modo integrado