From desert dust to nucleation, aerosols and their climate impact

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Outline

Aerosol sources

Direct and indirect effects

Experimental results

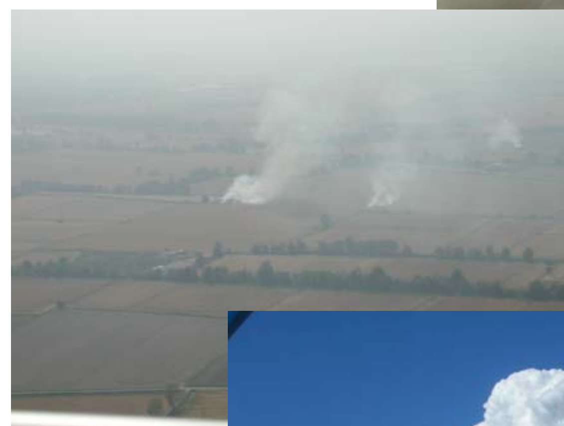
Summary

Aerosol sources

coarse

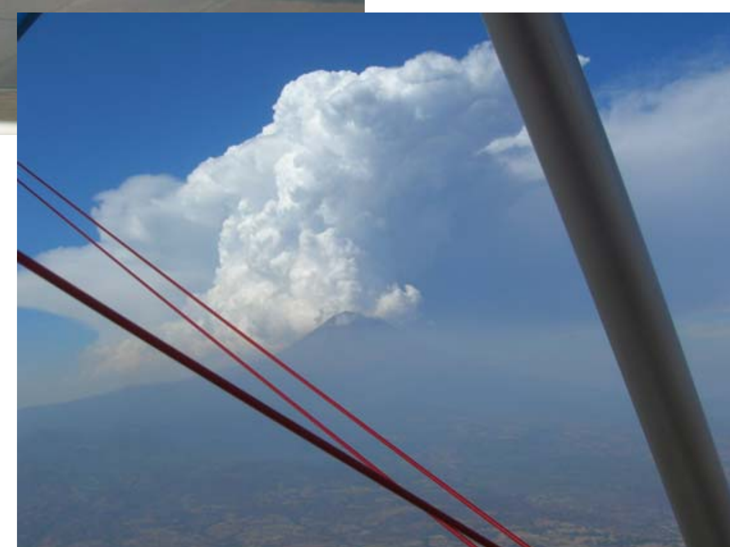
Sea salt

Resuspension of aerosols, desert dust



fine

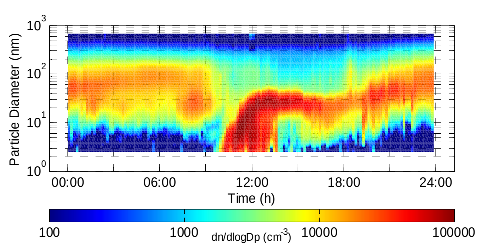
Emission (BB + anthr.)



Cloud processing

ultrafine

Nucleation



Climate effects

1) direct

coarse

fine

2) indirect

cloud-

albedo

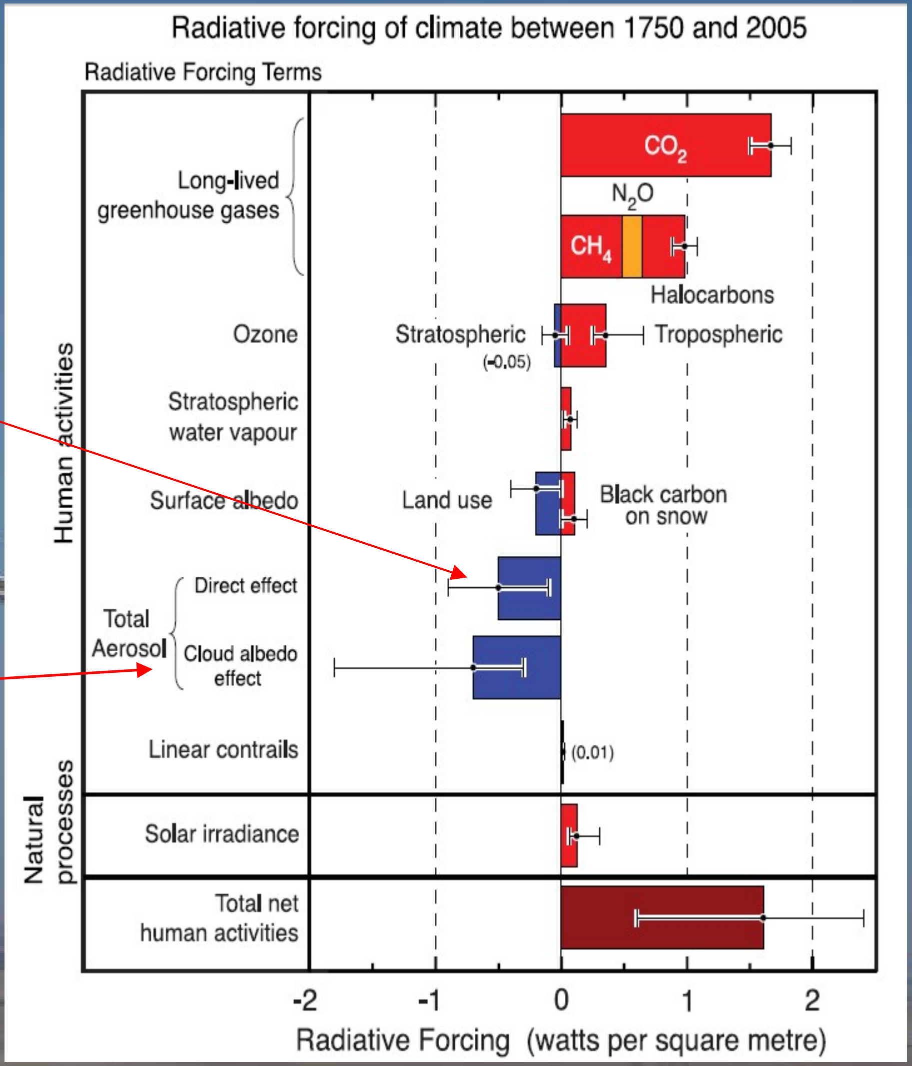
lifetime ?

precipitation ?

(ultra)fine

water related

coarse?



Direct effects (Scattering, absorption)

Reduction of shortwave radiation at the earth‘s surface

Redistribution of energy in the lower troposphere

Indirect response

Modification of the vertical stability -> Clouds

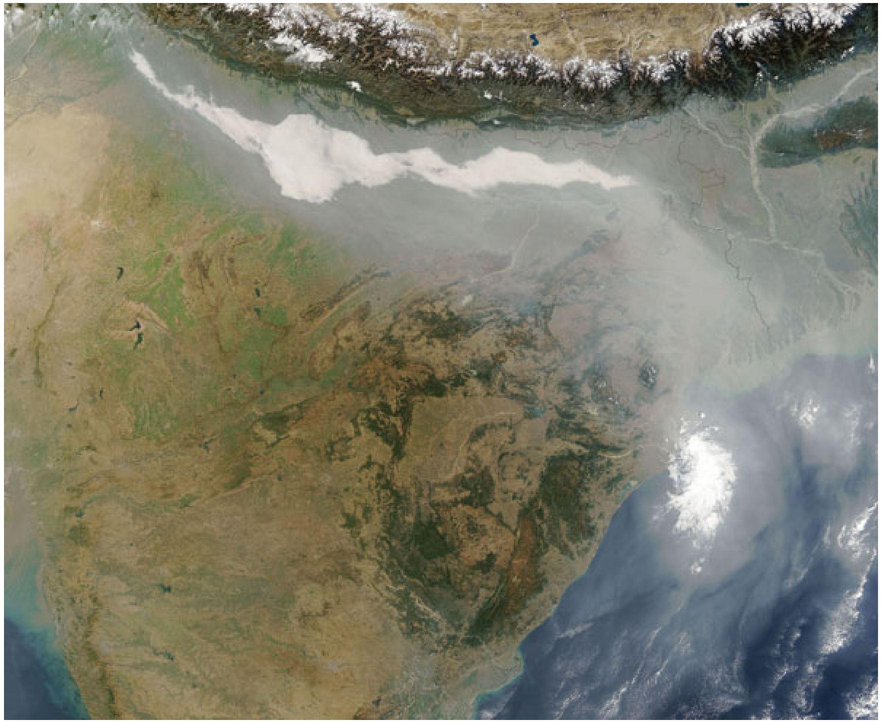
Reduction / modification of photolysis rates

Modification of the 3D distribution of greenhouse gases (O_3....)

Direct effects (scattering, absorption)

Prominent examples

Smog drifts down India's populous Ganges valley and out into the Bay of Bengal. This is the source of 'atmospheric brown clouds' over the Indian Ocean, and the climatic effect of its constituent aerosol particles is investigated by Ramanathan and colleagues
NASA/GODDARD SPACE FLIGHT CENTER/J. SCHMALTZ



Climate change: **Aerosols heat up**
Peter Pilewskie

Solid particles suspended in the atmosphere have long played second fiddle to greenhouse gases as agents of climate change. A study of atmospheric heating over the Indian Ocean could provoke a rethink.

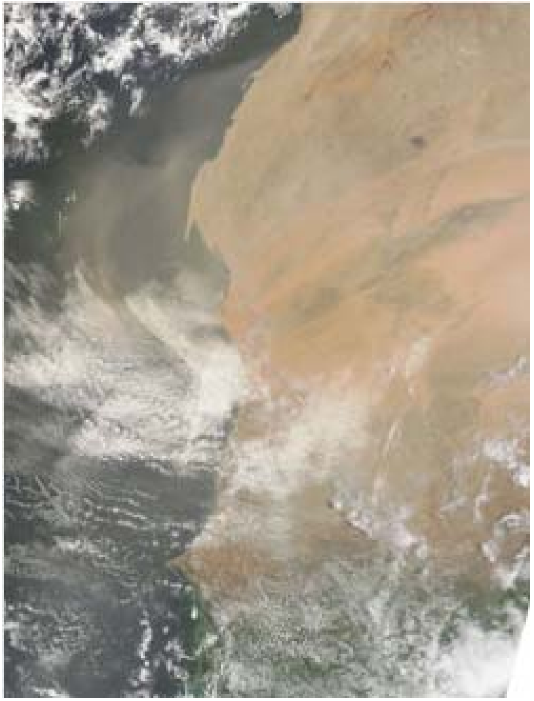
Nature Vol. 448, 2007

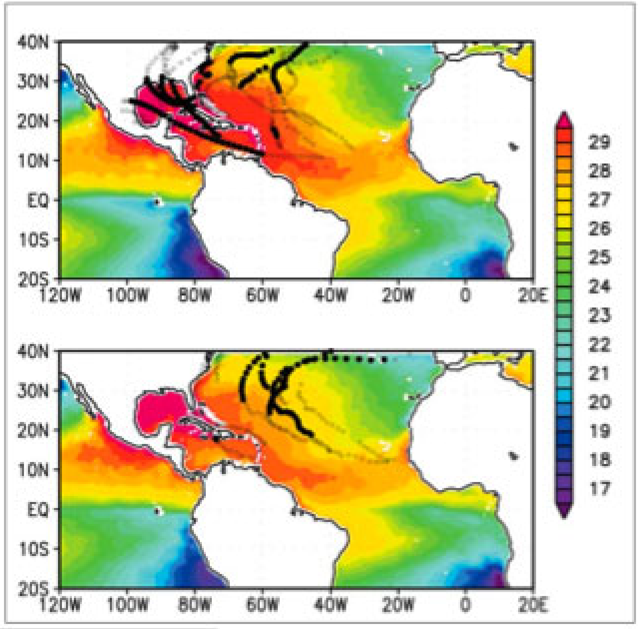
Direct effects (scattering, absorption)

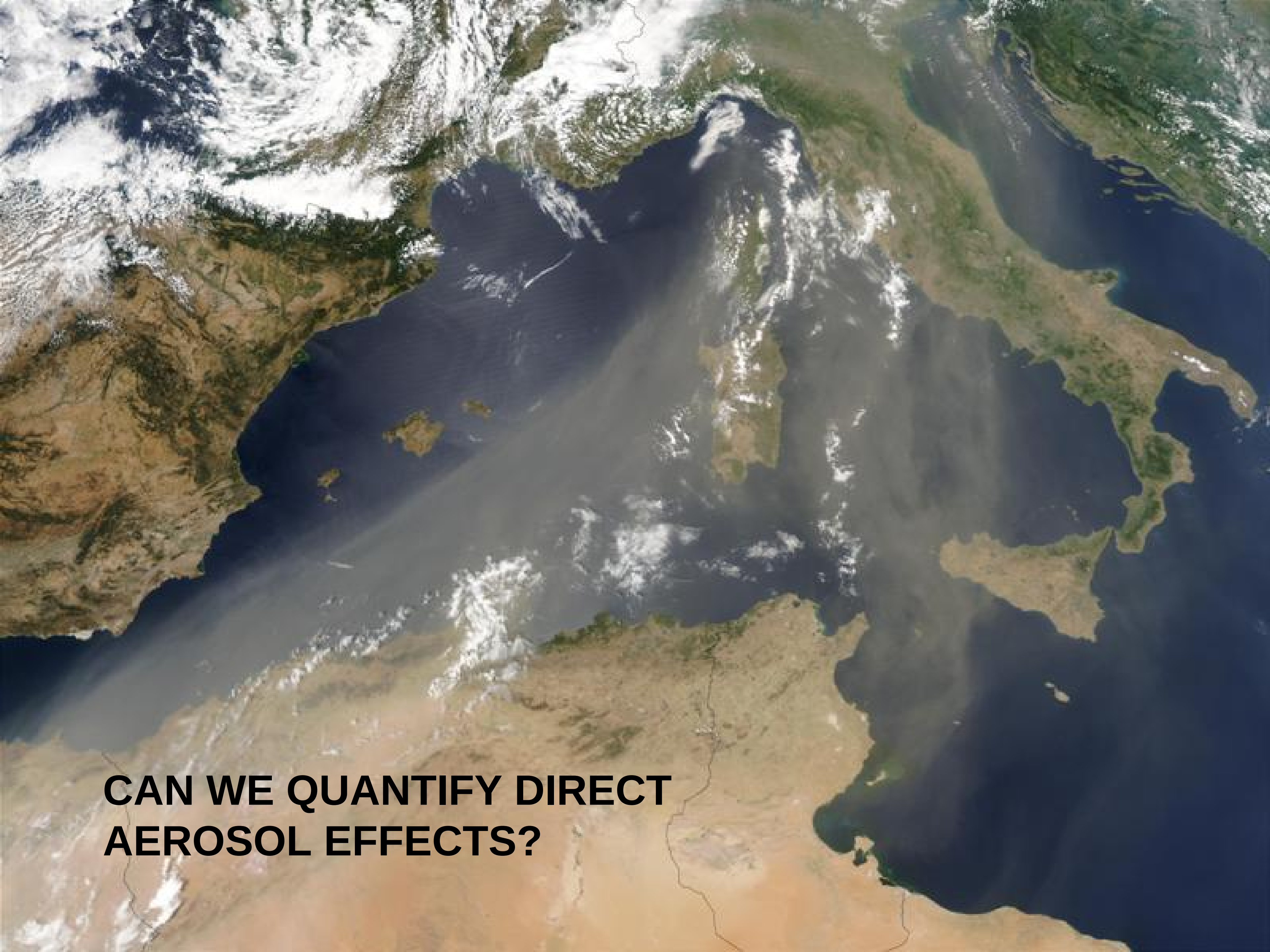
Prominent examples

Reduction of sea surface temperature in the north atlantic leading to lower hurricane activity

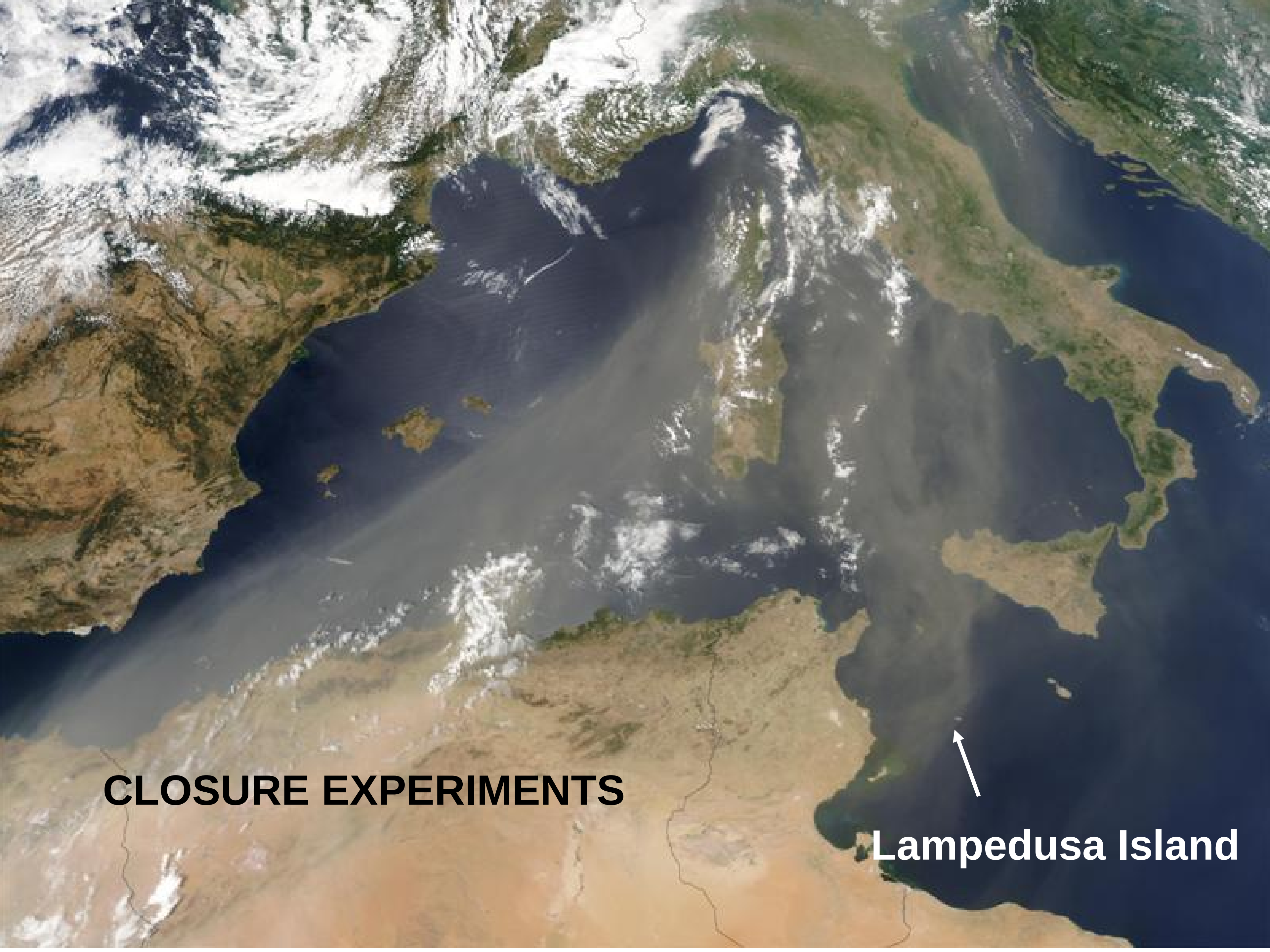
http://www.nasa.gov/mission_pages/hurricanes/archives/2007/hurricane_dust.html

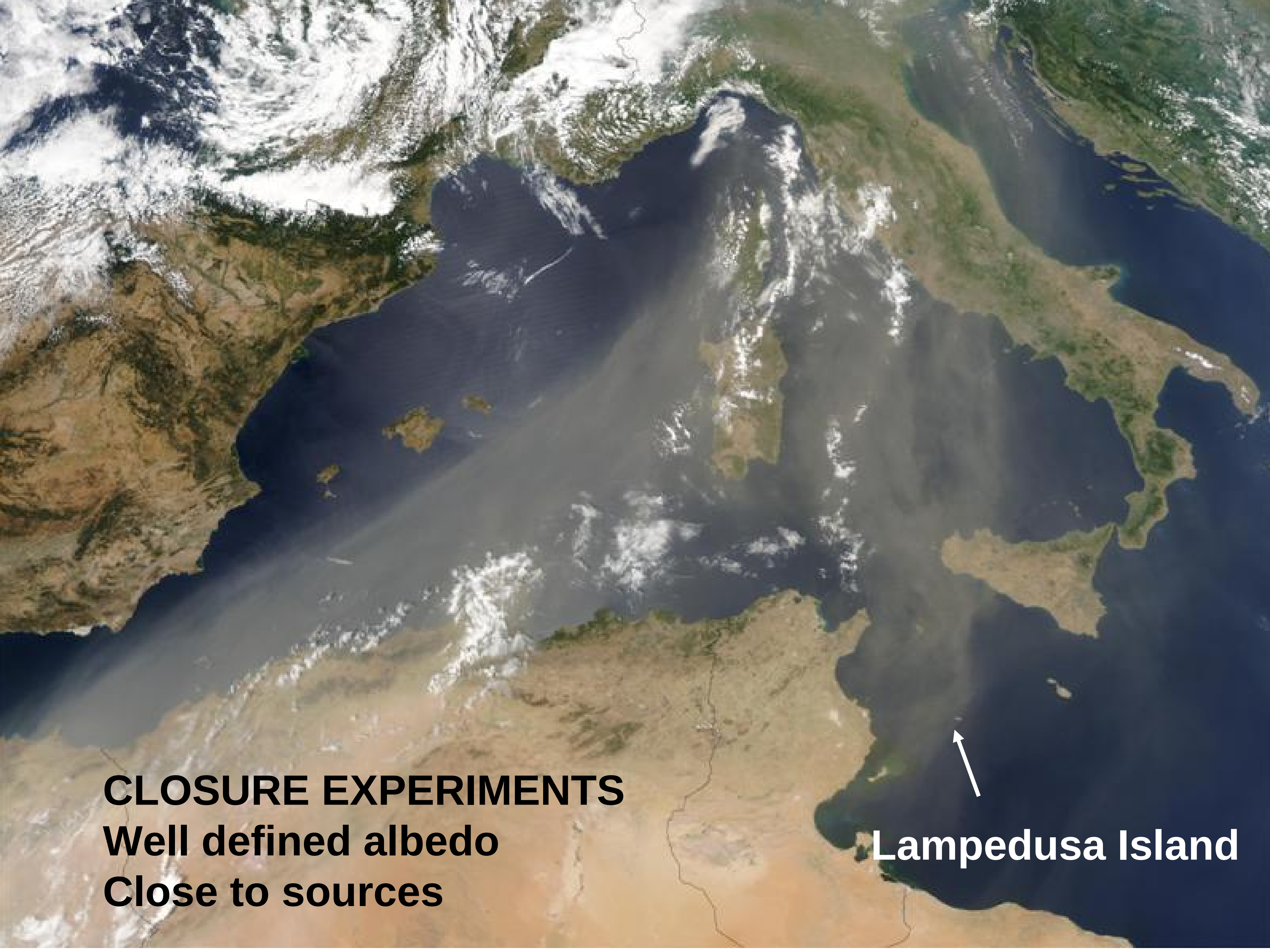






CAN WE QUANTIFY DIRECT AEROSOL EFFECTS?


CLOSURE EXPERIMENTS
Lampedusa Island


CLOSURE EXPERIMENTS
Well defined albedo
Close to sources
Lampedusa Island

Parameter list for closure studies

Spectral Actinic Flux
Act. Rad. 300 nm JO1D
Act. Rad. 380 nm JNO2
Global Irradiance
Spectral Albedo
Infrared irradiance

Temperature (air)
Humidity
Pressure
Surface Temperature

Aerosol number
Aerosol / size distribution
Scatt. coeff. / visibility
Absorption coefficient

Ozone

Table 1. Aerosol measurements for direct forcing of climate.

Extensive Properties

$\sigma_{sp}(\lambda)(m^{-1})$:	Scattering component of extinction, scattering coefficient
$\sigma_{bsp}(\lambda)(m^{-1})$:	Hemispheric backscatter coefficient
$\sigma_{ap}(\lambda)(m^{-1})$:	Absorption coefficient *
m:	Mass concentration
m_i:	Species mass concentration (chemical composition as f(r))
$\beta_{180}(m^{-1}\sigma\rho^{-1})$:	Lidar backscatter coefficient

Intensive Properties

å:	$d \log \sigma_{sp} / d \log \lambda$	Wavelength dependence (Ångström exponent)
f(RH):	$\sigma_{sp}(RH)/\sigma_{sp}(\text{low RH})$	Humidity dependence
B:	σ_{bsp}/σ_{sp}	Backscatter ratio
ω:	$\sigma_{sp}/(\sigma_{sp}+\sigma_{ap})$	Single scatter albedo *
α_m:	$\partial\sigma_{sp}/\partial m(m^2 g^{-1})$	Mass scattering efficiency
α_i:	$\partial\sigma_{sp}/\partial m_i$ (mg)	Species scattering efficiency
S(sr):	$(\sigma_{sp}+\sigma_{ap})/\beta_{180}$	Lidar ratio
	______	Ratios of chemical components

* Most uncertain property

From Charlson, 1987

Parameter list for closure studies

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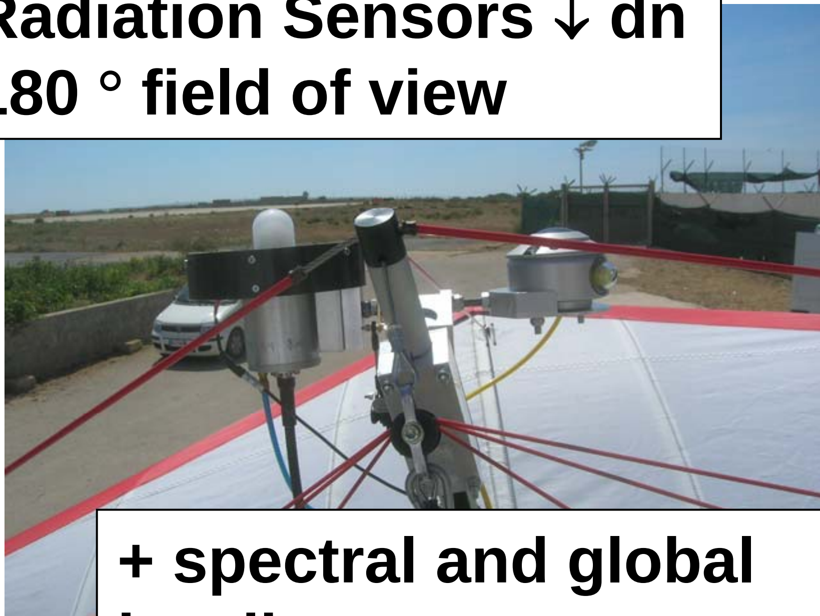
Ozone

Preferred platform

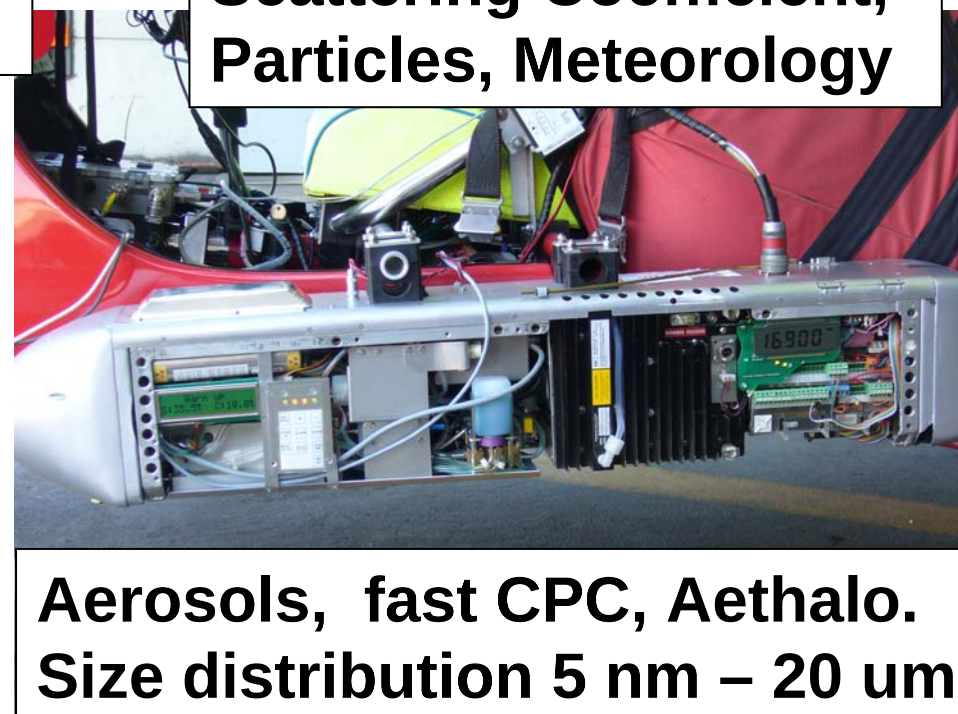
D-MIFU, microlight aircraft

Radiation Sensors ↓ dn
180 ° field of view



+ spectral and global irradiance

Ozone, Radiation ↑ up, Scattering Coefficient, Particles, Meteorology



Aerosols, fast CPC, Aethalo.
Size distribution 5 nm – 20 um

Radiation Sensors for GAMARF installed on gimballed platforms

+- 0.2 degrees

Upwelling, IR, irradiance, spectral actinic flux

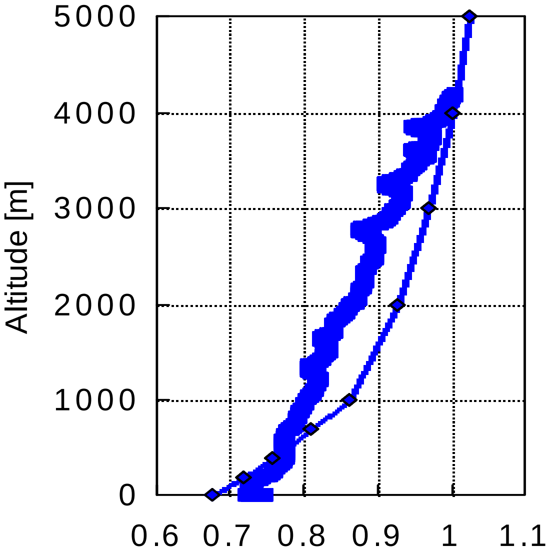
VERTICAL PROFILES OVER THE SEA UP TO 4000 m

LAMPEDUSA ISLAND (~50 m)

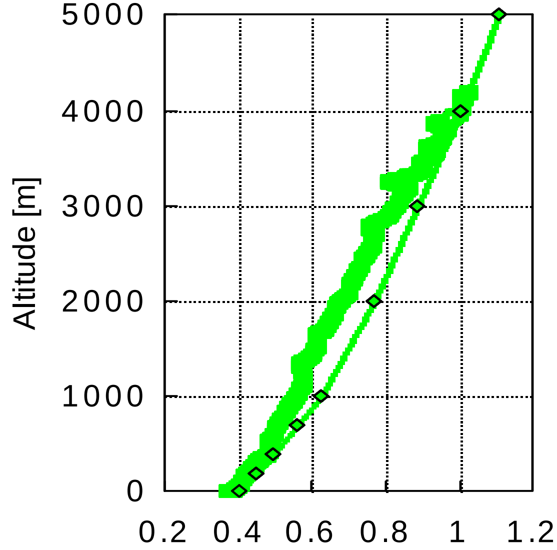
10 km * 3 km

LAMPEDUSA 1999

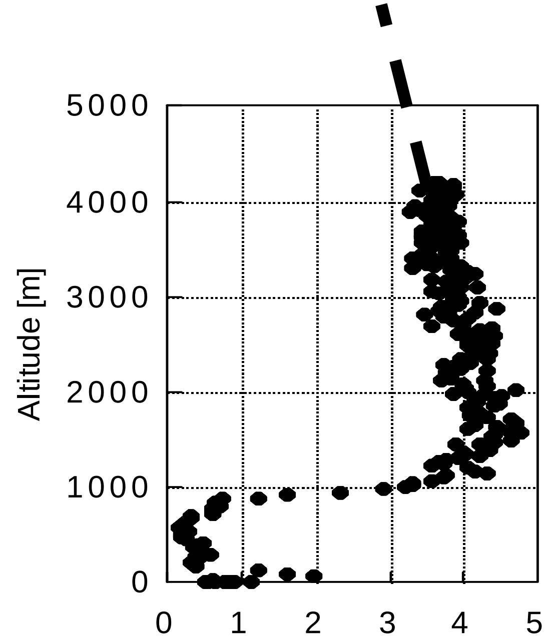
Dust layer up to 7 km out of reach for the ULM



380 nm



300 nm



Large particles (FSSP)

normalized actinic radiation and 1 dimensional model calculation (STAR)

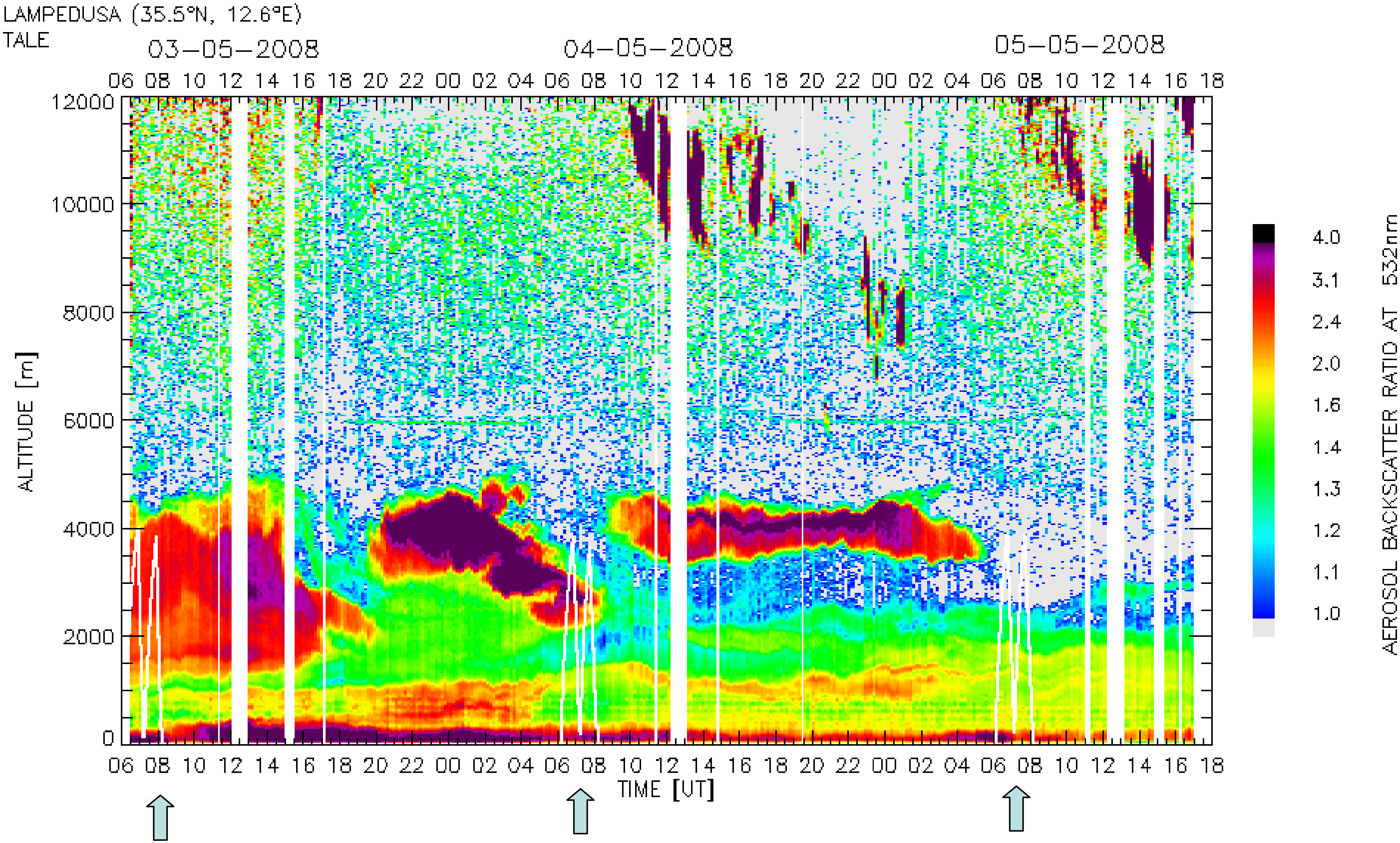
SHORTWAVE RADIATION

The GAMARF Project

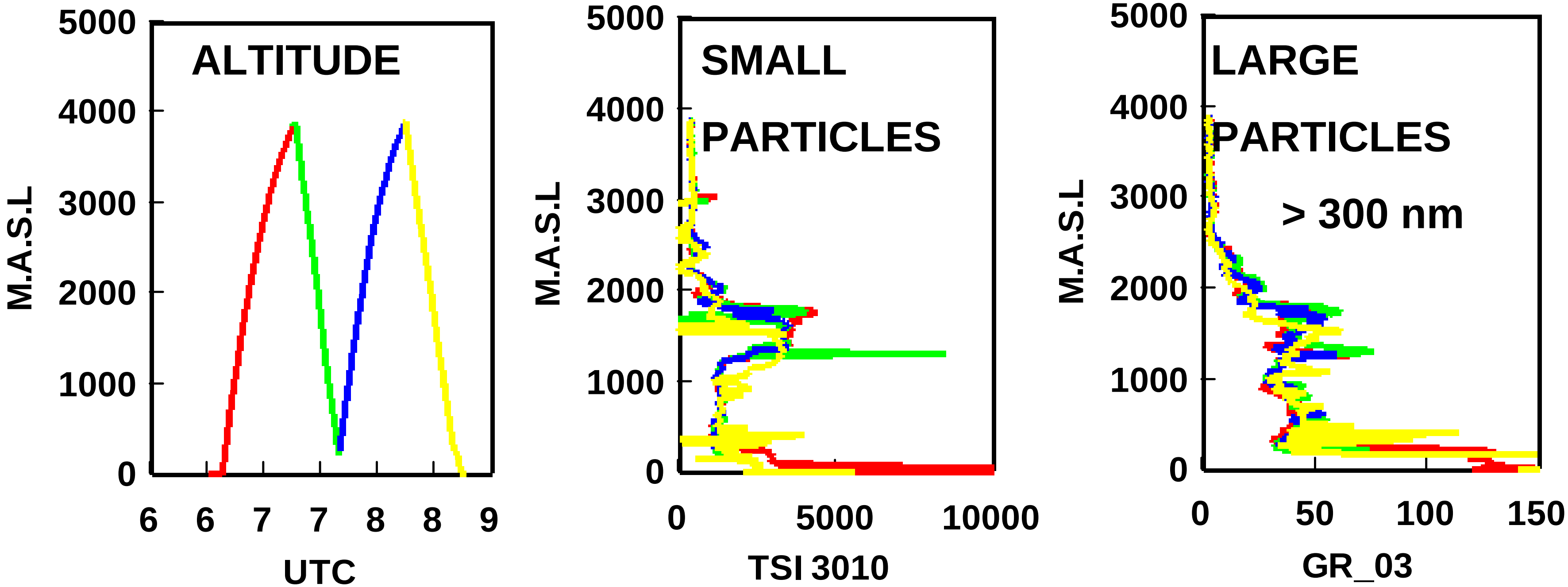
Wolfgang Junkermann[1], Daniela Meloni[2], Tatjana Di'Iorio[2], Alcide DiSarra[2]

[1] KIT Karlsruhe, [2]ENEA, ROME

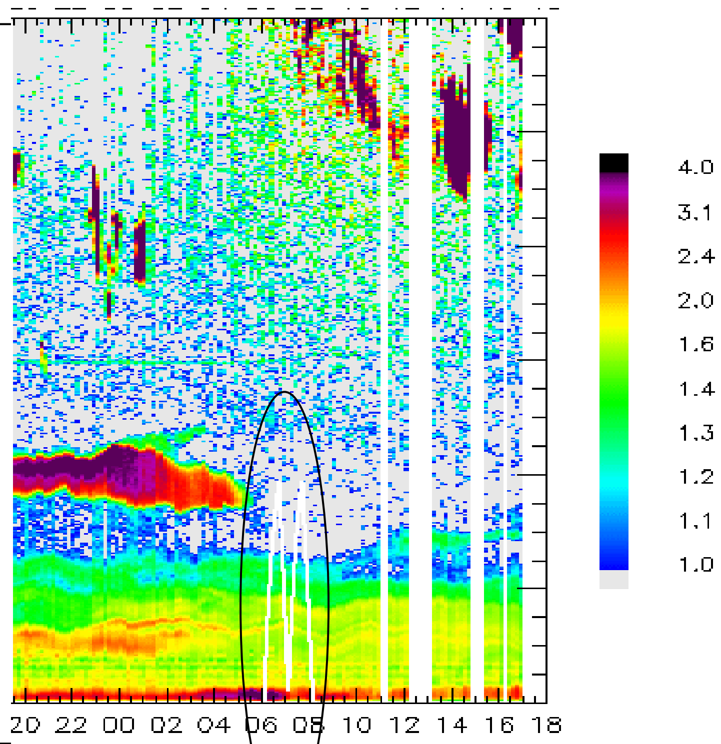
LONGWAVE RADIATION

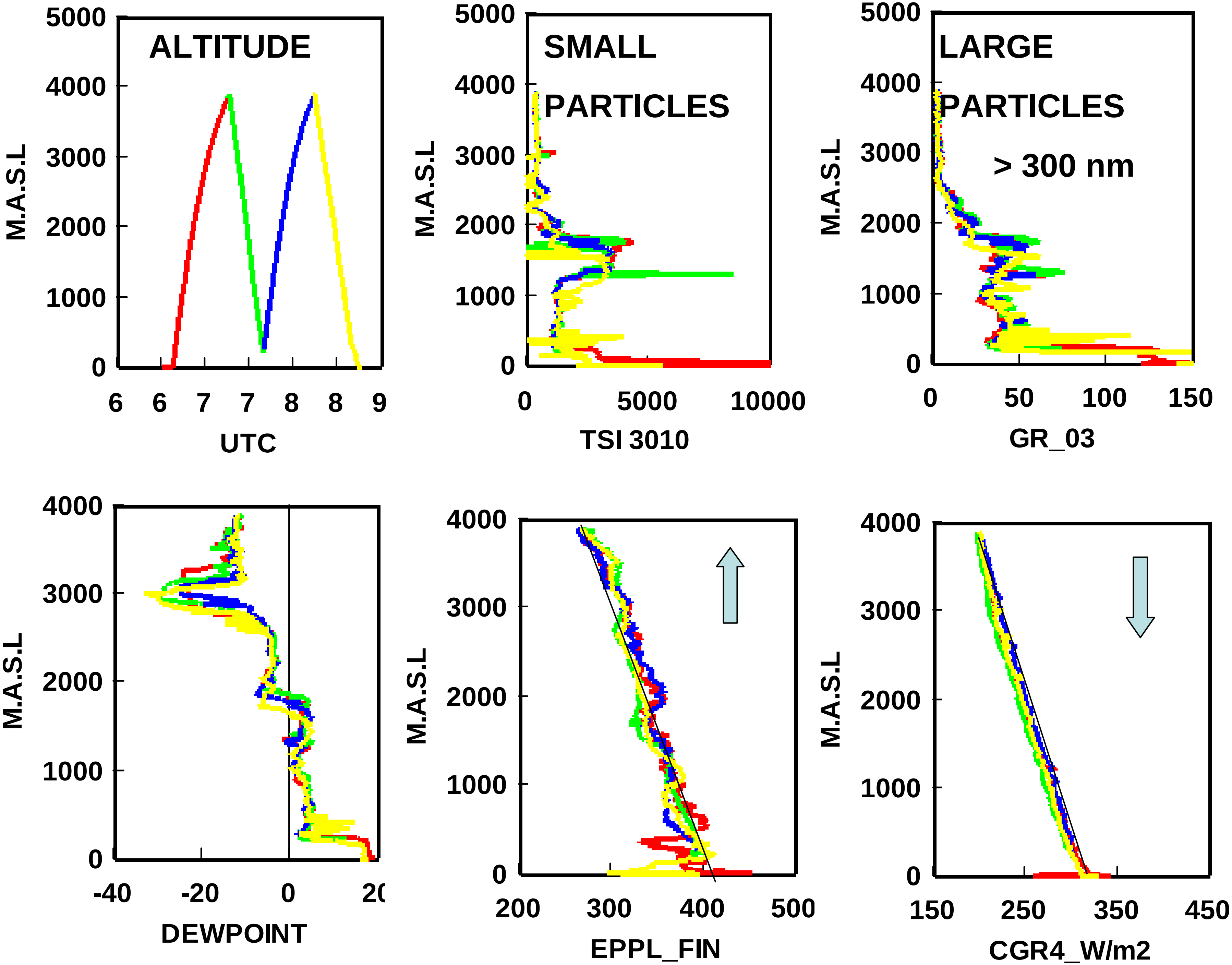


AIRCRAFT PROFILES

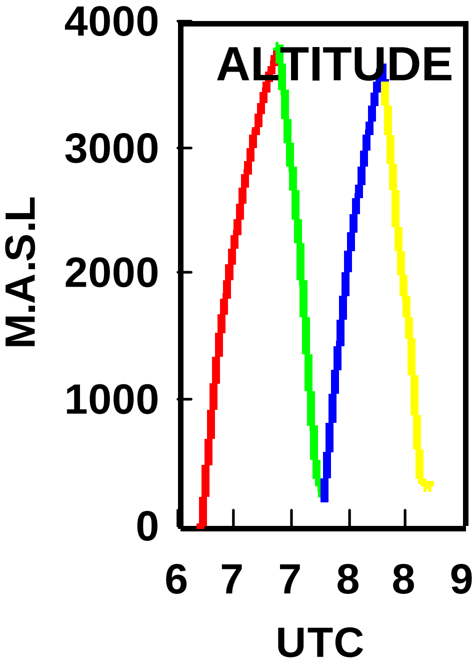


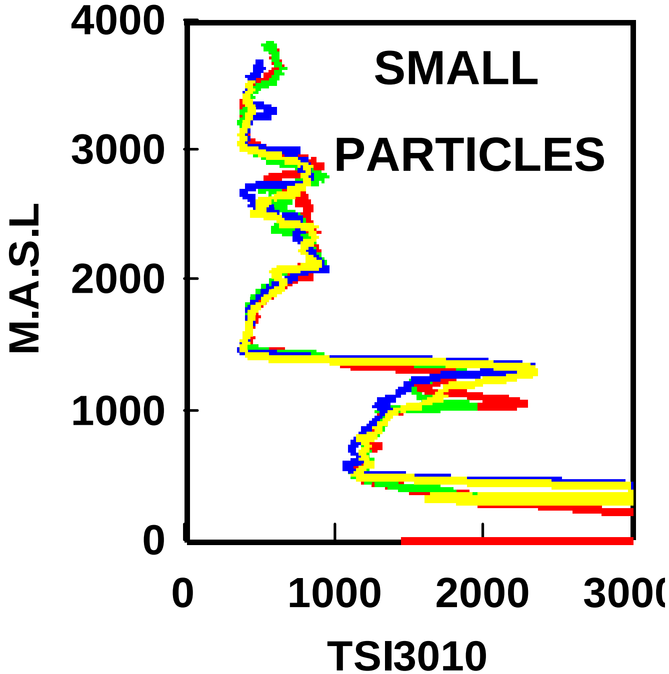
LIDAR PROFILE
ALT

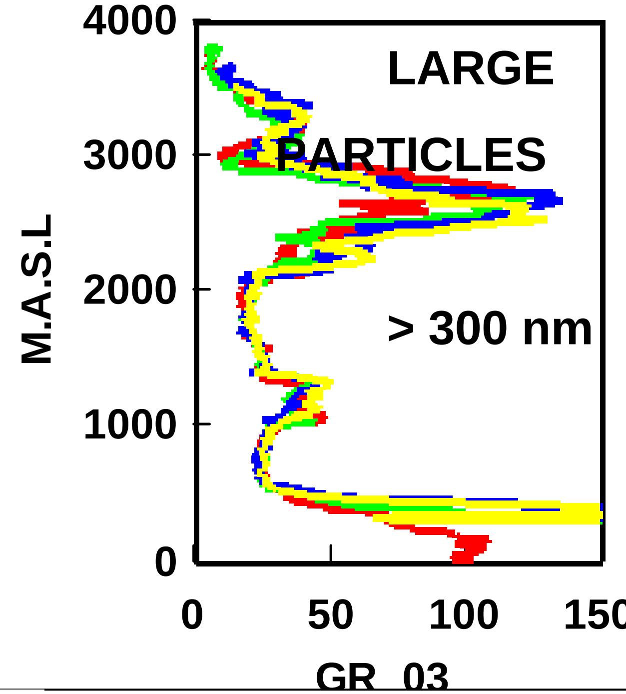




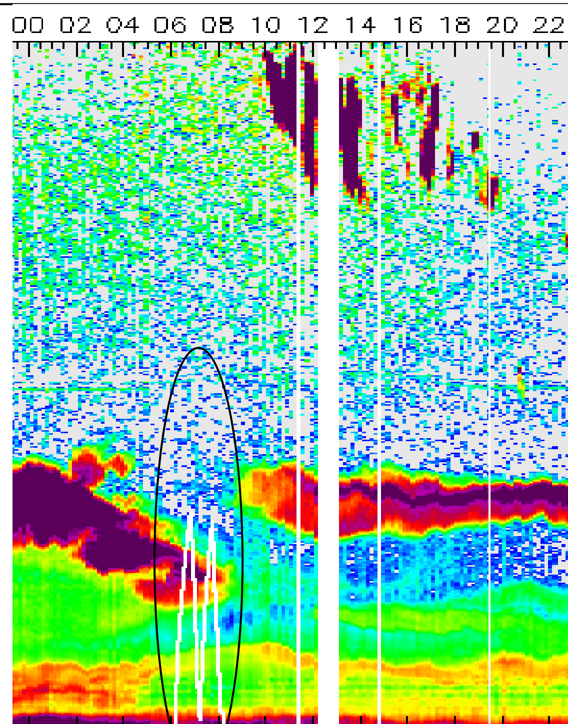
ALTITUDE
M.A.S.L
5000
4000
3000
2000
1000
0
6
6
7
7
8
8
9
UTC
SMALL
PARTICLES
M.A.S.L
0
5000
10000
TSI 3010
LARGE
PARTICLES
> 300 nm
M.A.S.L
0
50
100
150
GR_03
M.A.S.L
4000
3000
2000
1000
0
-40
-20
0
20
DEWPOINT
M.A.S.L
200
300
400
500
EPPL_FIN
M.A.S.L
150
250
350
450
CGR4_W/m2

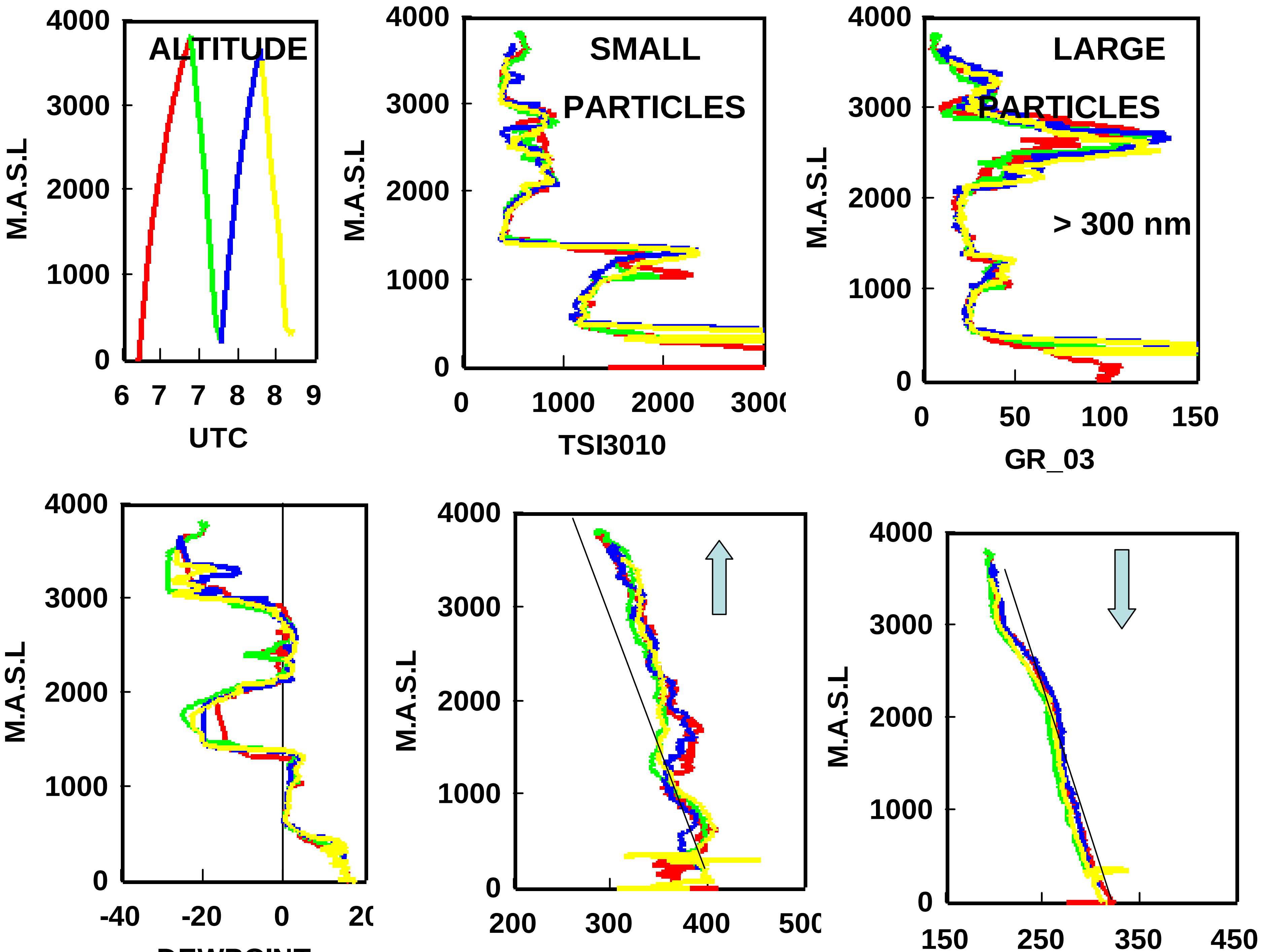




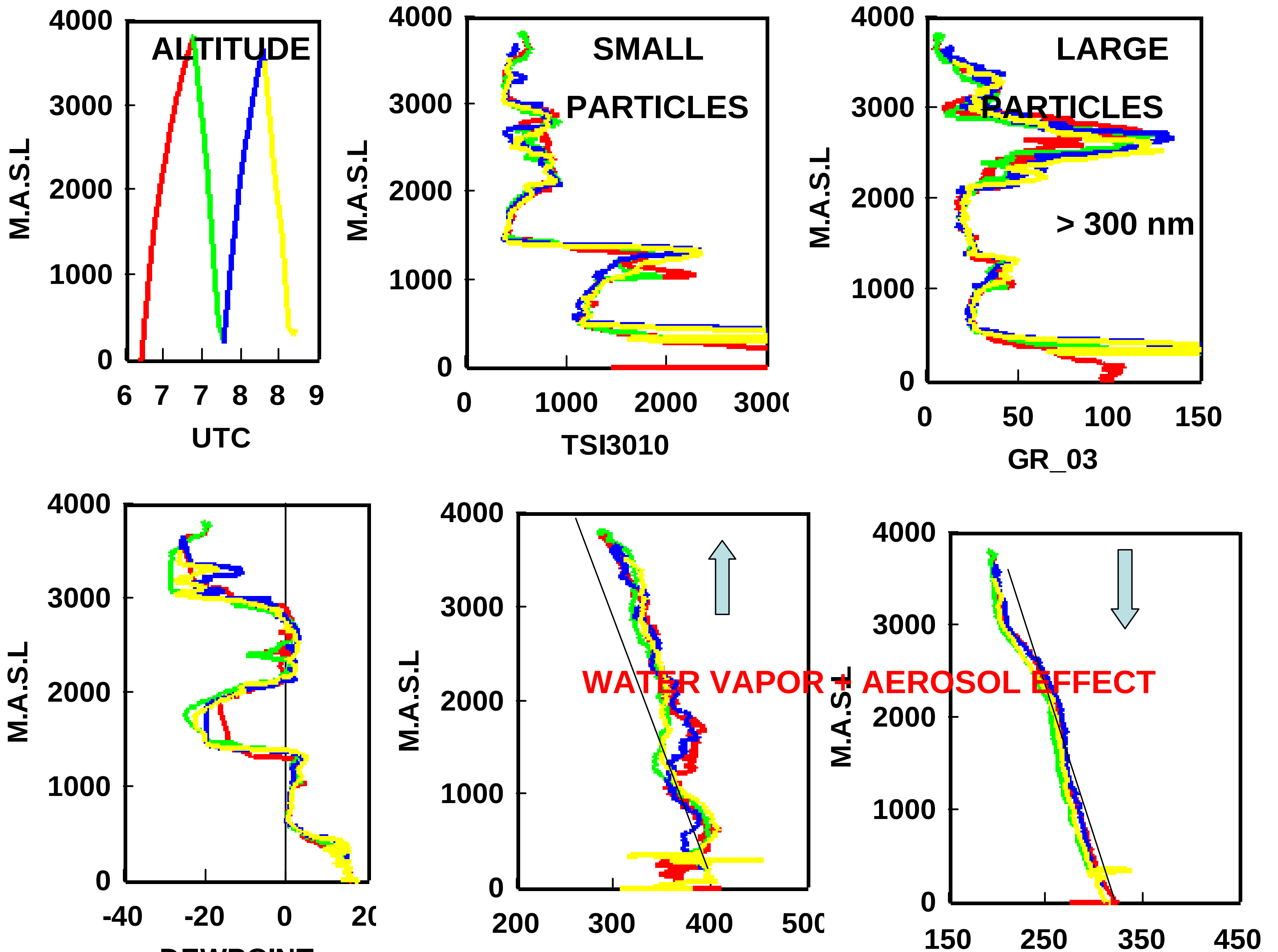


LIDAR PROFILE
ALT





ALTITUDE
M.A.S.L
UTC
6 7 7 8 8 9
0 1000 2000 3000 4000
SMALL
PARTICLES
TSI3010
0 1000 2000
LARGE
PARTICLES
> 300 nm
GR_03
0 50 100 150
-40 -20 0
200 300 400
150 250 350 450

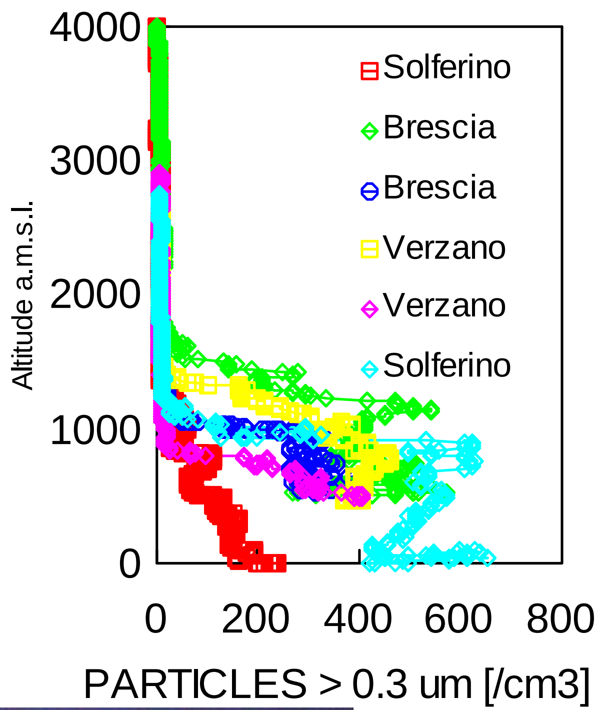


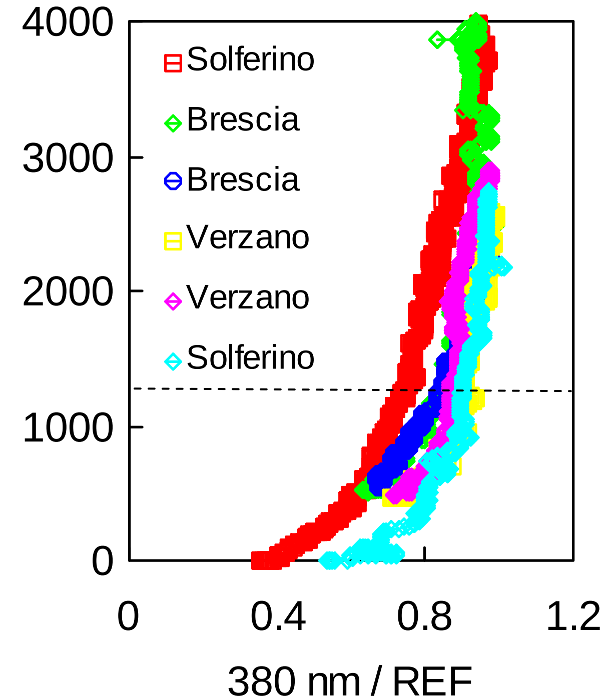
ALTITUDE
M.A.S.L
UTC
SMALL
PARTICLES
TSI3010
LARGE
PARTICLES
> 300 nm
GR_03
DEWPOINT
WATER VAPOR + AEROSOL EFFECT

Continental situation Po-Valley, Northern Italy

Small particles < 300 nm
~ 8000-30000 / cm^3

SHORTWAVE RADIATION



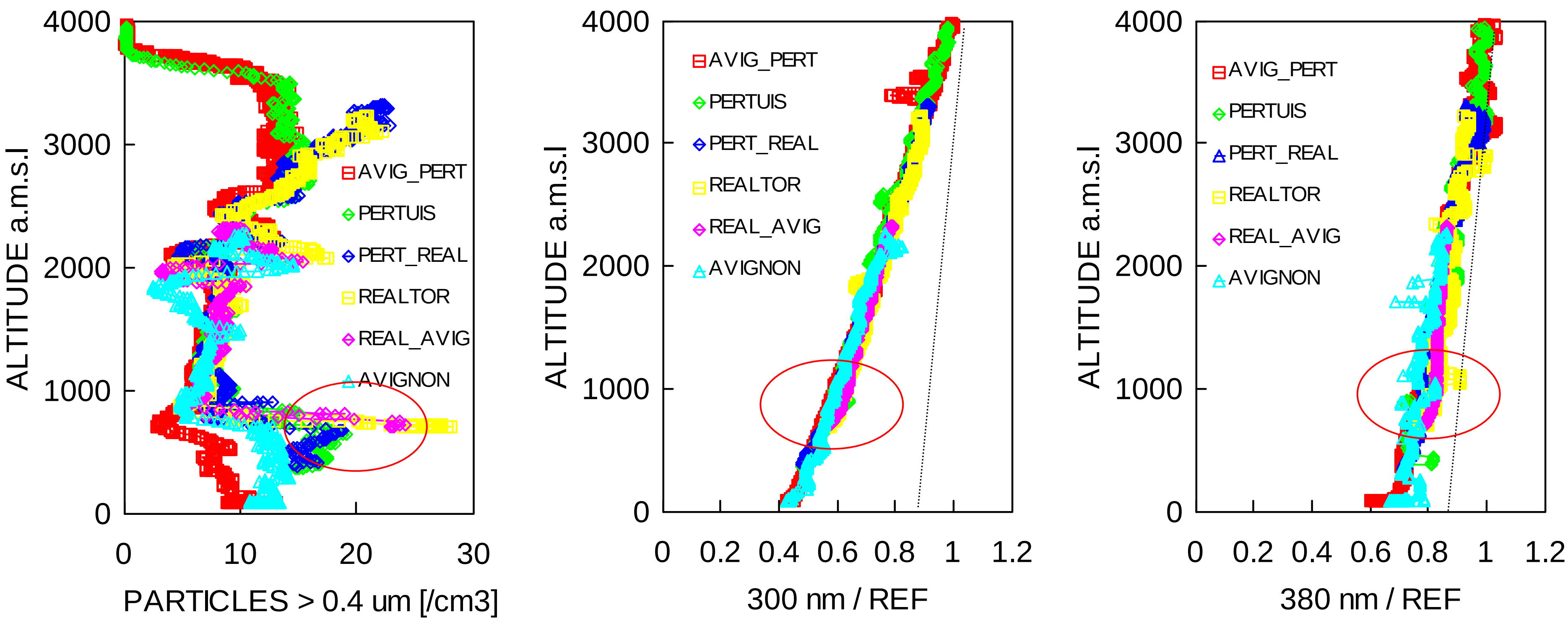


‚Typical‘ -belly shaped- actinic radiation profiles in the anthropogeneously polluted region,

enhancement above and within upper range of PBL, absorption close to the ground

Southern France, Provence, hazy, ESCOMPTE 2001
AOT 300 nm 0.48, 500 nm 0.42

SHORTWAVE RADIATION



Several layers of particles up to ~ 4000 m, uppermost layer aged air mass from Spain, reduction of UVB to ~ 50 % of clean - aerosol free (mistral) situation.

Radiation profile controlled by aerosol vertical distribution

Enhanced scattering at TBL

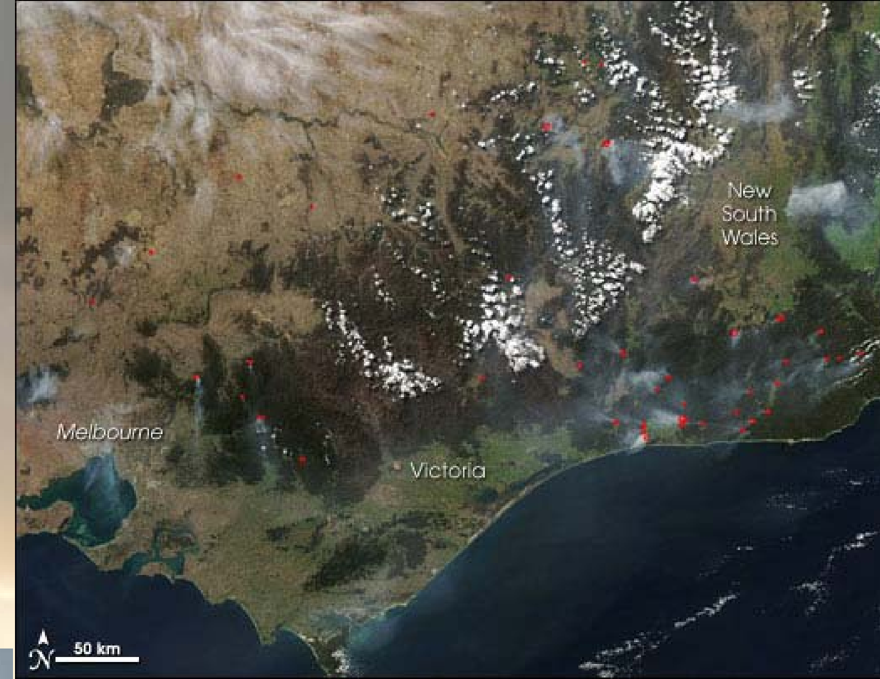
Biomass burning aerosols

Volcanic ash

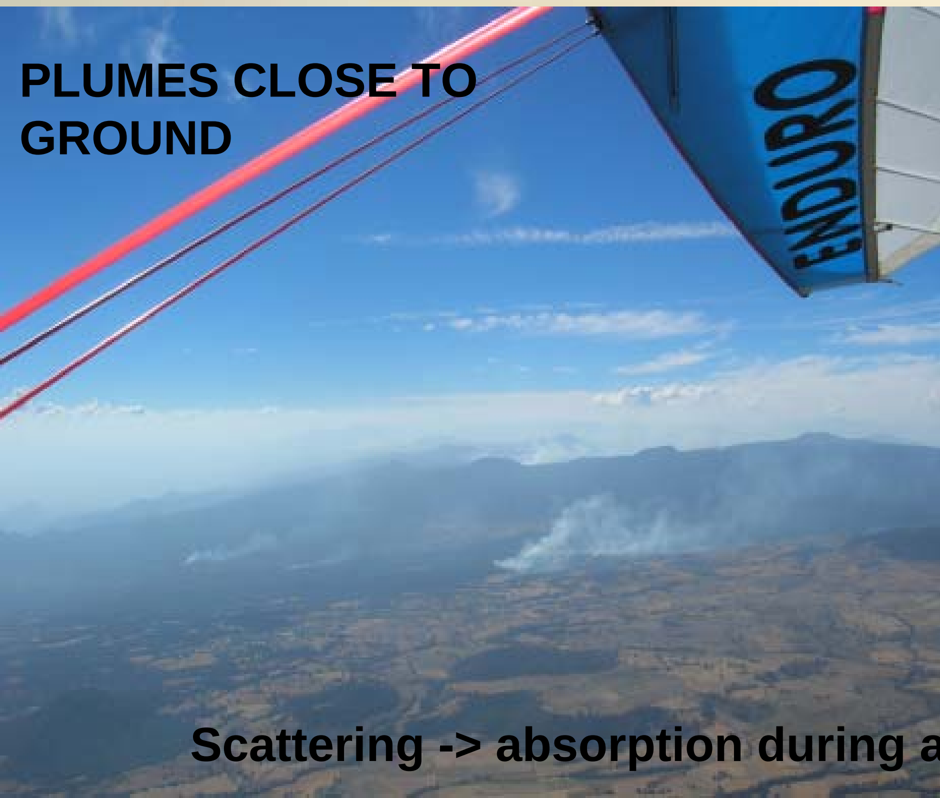
Karlsruhe Institute of Technology

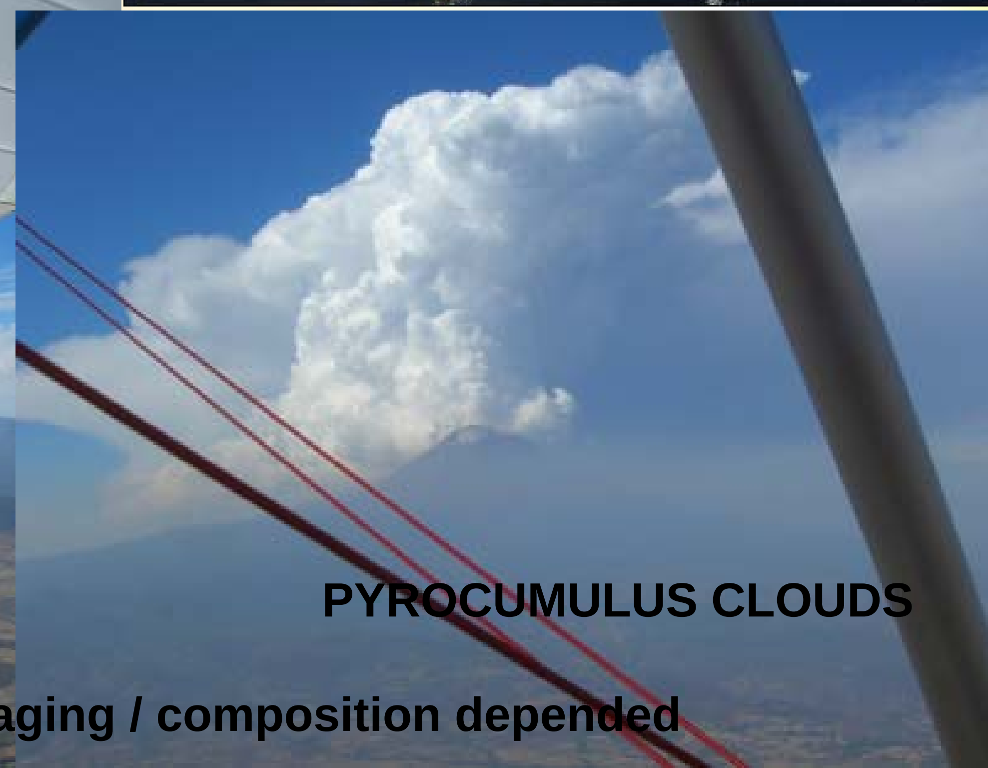
Biomass burning aerosols

PROBLEMS



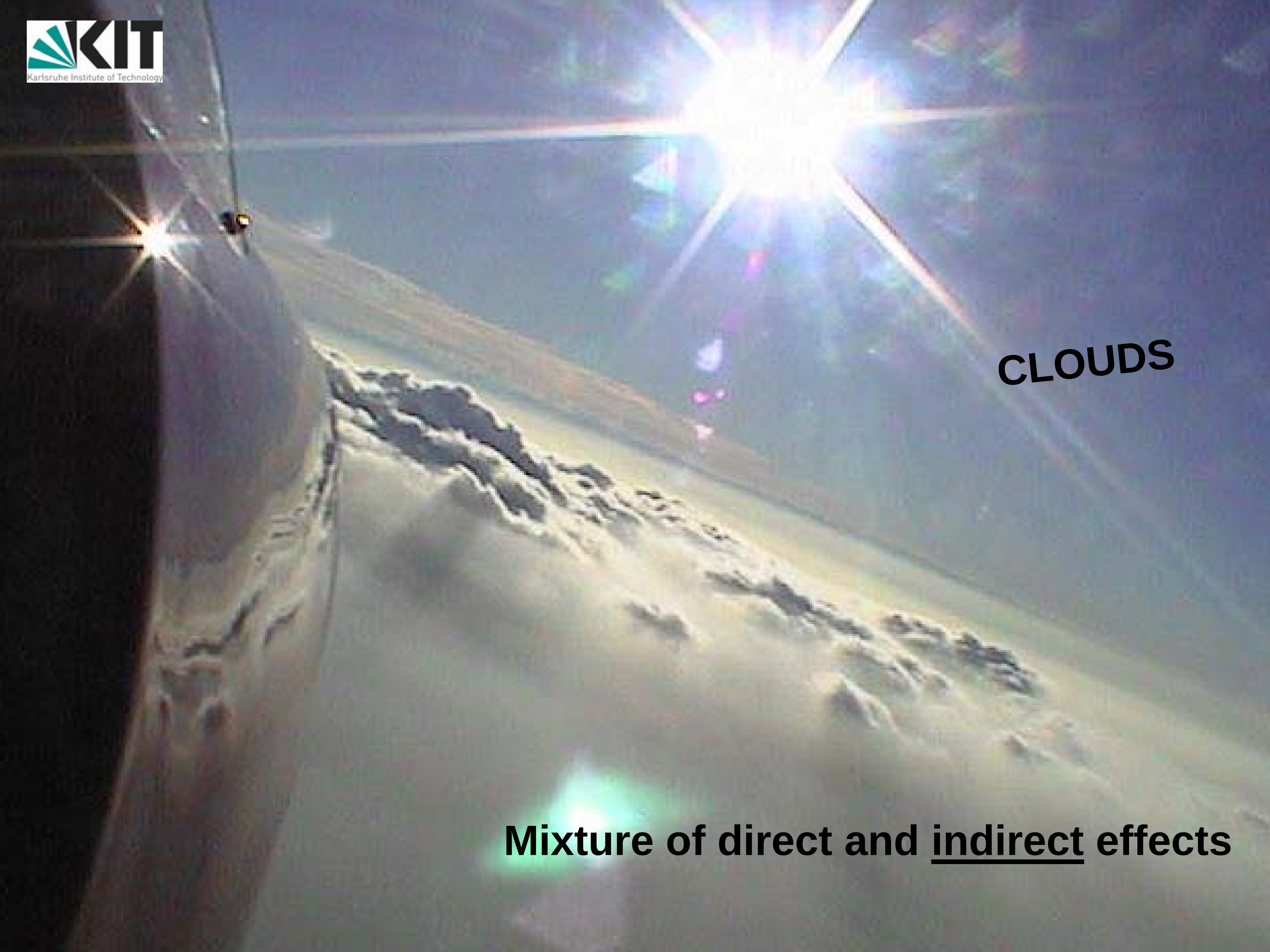
PLUMES CLOSE TO GROUND





PYROCUMULUS CLOUDS

Scattering -> absorption during aging / composition depended


CLOUDS
Mixture of direct and indirect effects

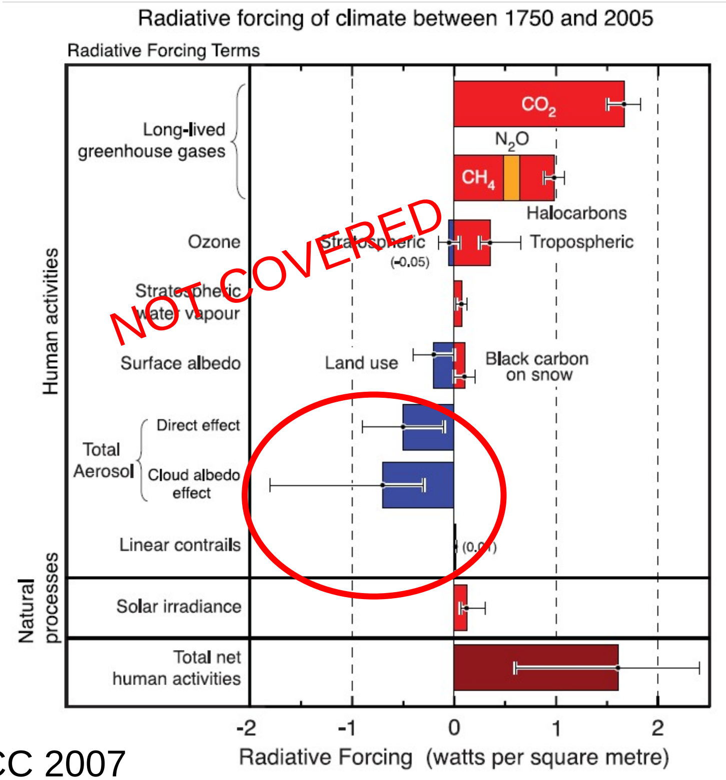
Reducing the uncertainties

⇩

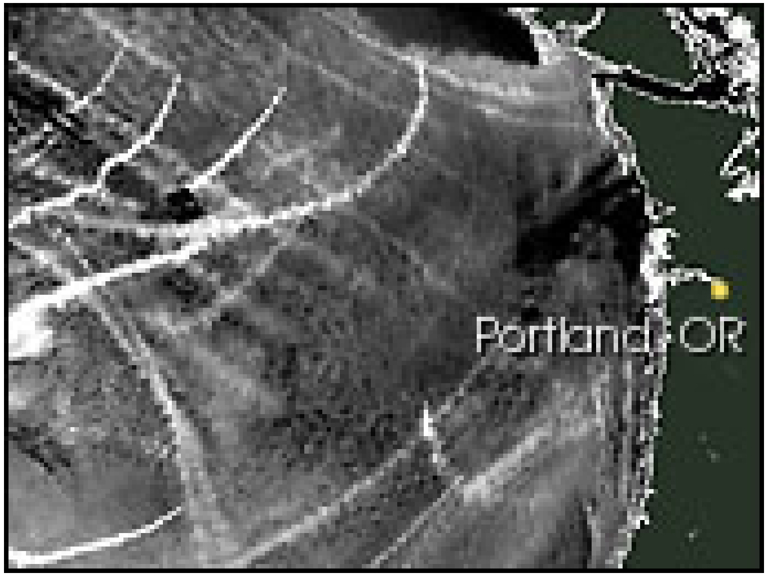
cloud albedo

cloud lifetime

precipitation



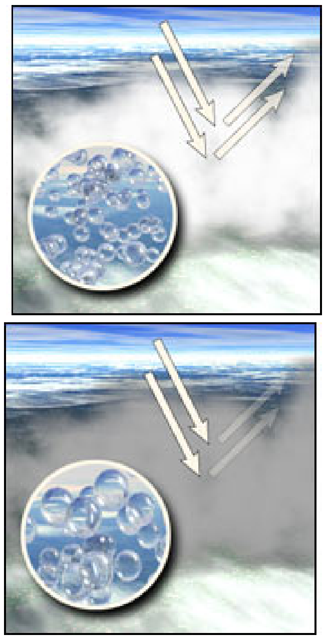
IPCC 2007

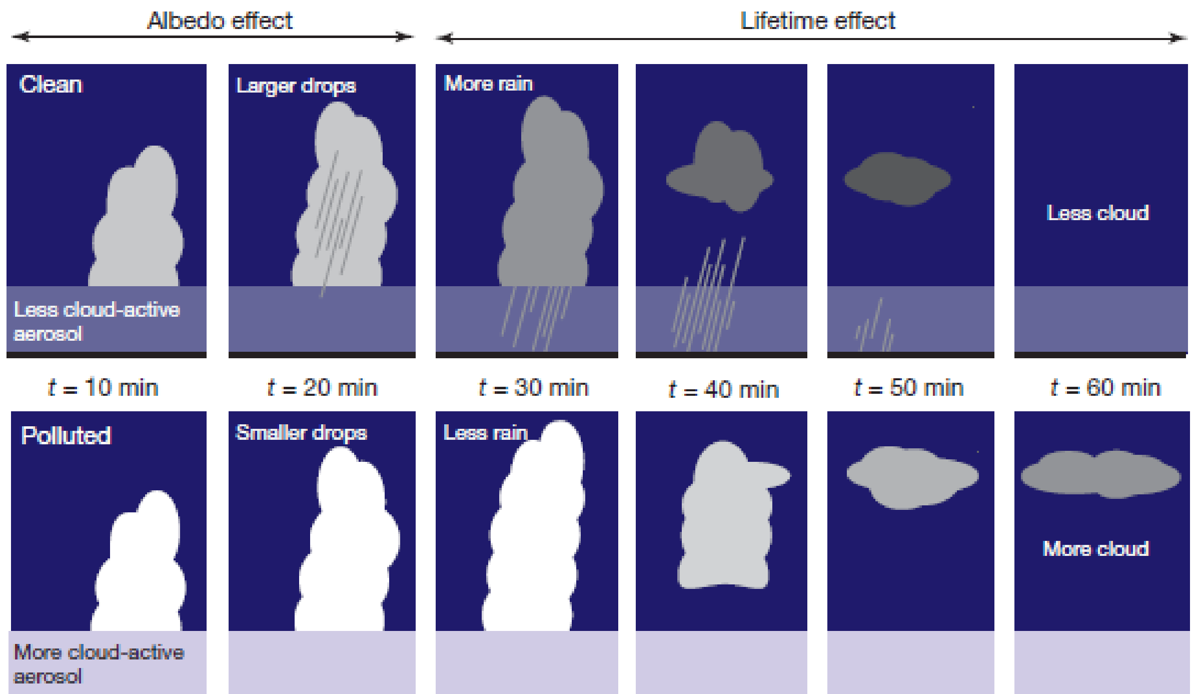


Cloud albedo affects the shortwave radiation (-> radiative forcing),

smaller droplets increase lifetime ? (-> radiative forcing)

smaller droplets reduce rain rate?





Cloud condensation nuclei (CCN)

Updraft velocity

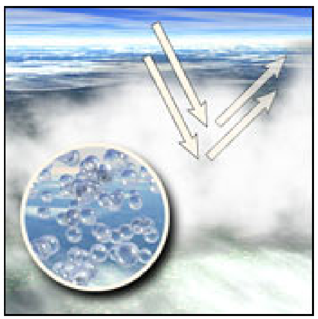
CCN chemistry?

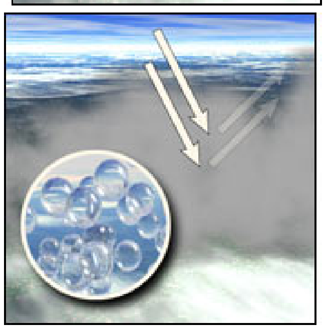
Cloud albedo affects the shortwave radiation (-> radiative forcing),

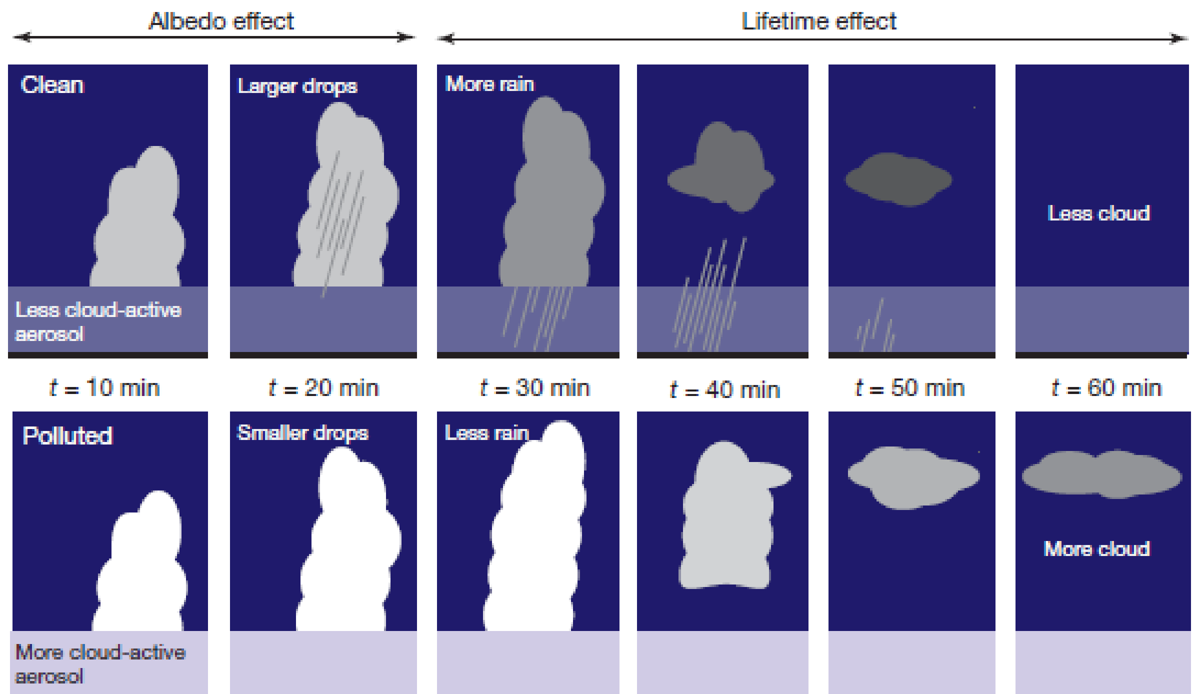
smaller droplets increase lifetime ? (-> radiative forcing)

smaller droplets reduce rain rate?

MEASURABLE ??





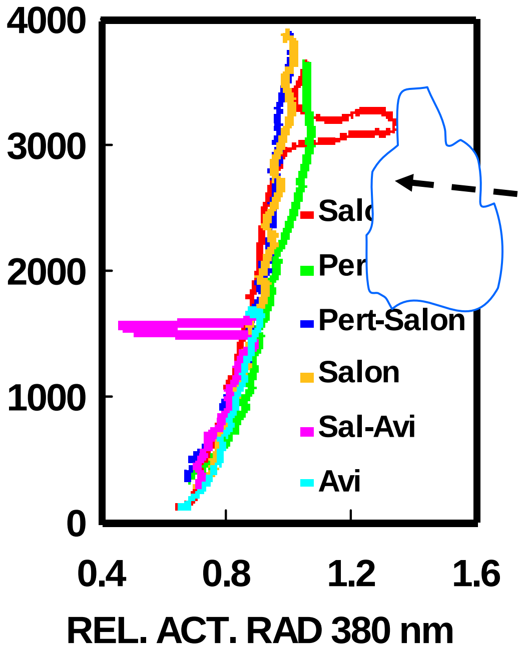


Cloud condensation nuclei (CCN)

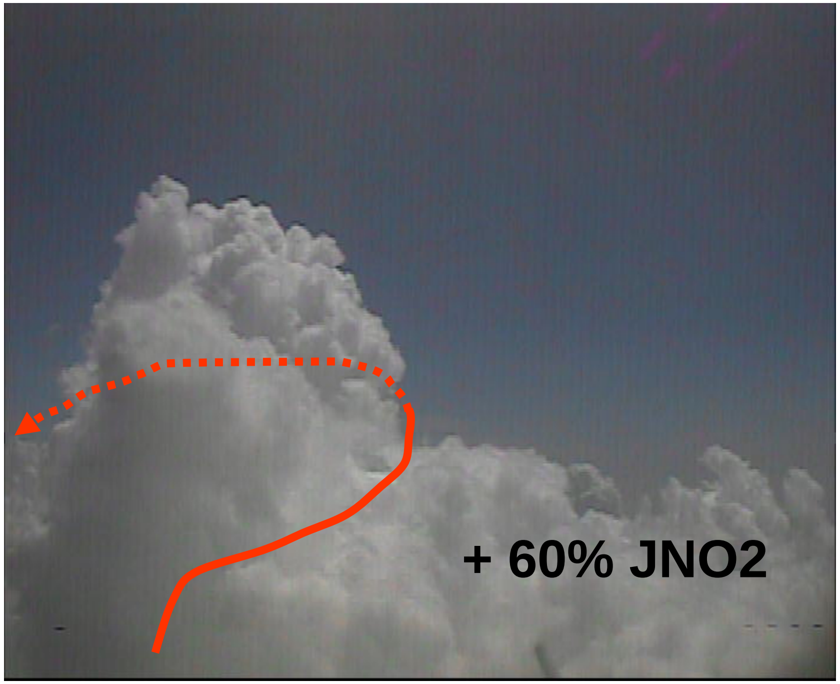
Updraft velocity

CCN chemistry?

RADIATION MEASUREMENT, ACTINIC FLUX (ALL PHOTONS IN AN AIR VOLUME)



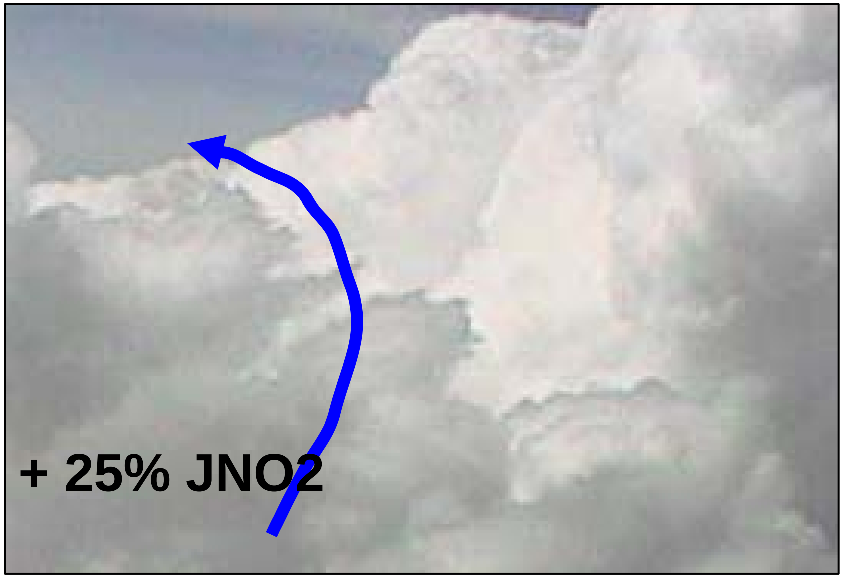
normalized to 1 at 4000 m



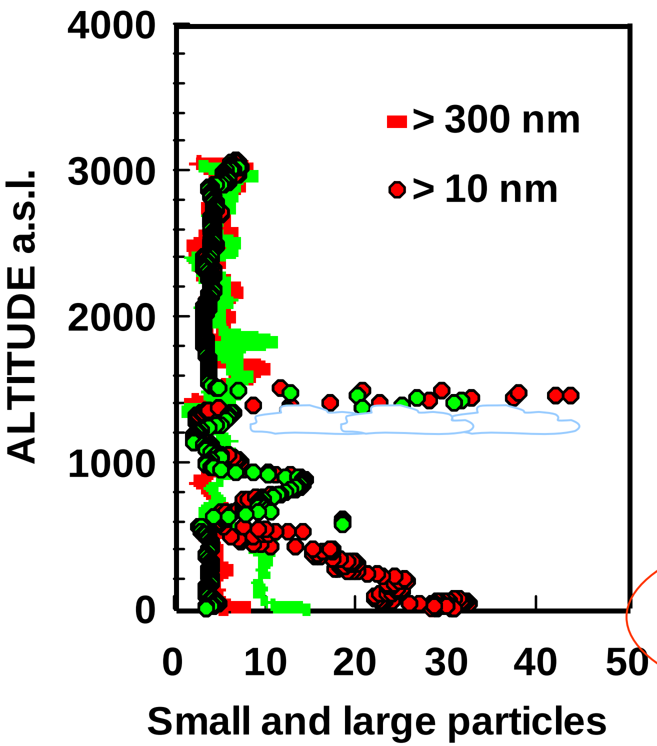
High albedo above cloud in clean conditions, reduced albedo (< 0.25) above aged cloud

FOR COMPARISON

3D Model without any aerosol ~ + 60%



Aerosol lining on top of a stratiform cloud layer



High number of small particles up to 5000 / cm^3 (symbols / 100), no large ones (lines) on top of a stratiform cloud layer in clean maritime conditions

Reduced albedo to 0.4 at 380 nm

QUESTIONS: AEROSOL PRODUCTION MECHANISM

After a few hours :

Cumuli embedded in aged aerosol layers

decreasing influence of clouds on radiation

Radiation profile dominated by aerosols, cloud albedo effect reduced

After a few hours :

Cumuli embedded in aged aerosol layers

decreasing influence of clouds on radiation

Radiation profile dominated by aerosols, cloud albedo effect reduced

CLOUD ALBEDO AND LIFETIME EFFECTS MEASURABLE ?

ALBEDO EFFECTS

DIFFICULT TO QUANTIFY DUE TO UNHOMOGENITIES OF CLOUDS AND MISSING REFERENCE AREA‘S (CLOUD FIELDS)

LIFETIME

EFFECTS

NOT CONFIRMED UP TO NOW WITH CURRENT DATA BASE

PRECIPITATION

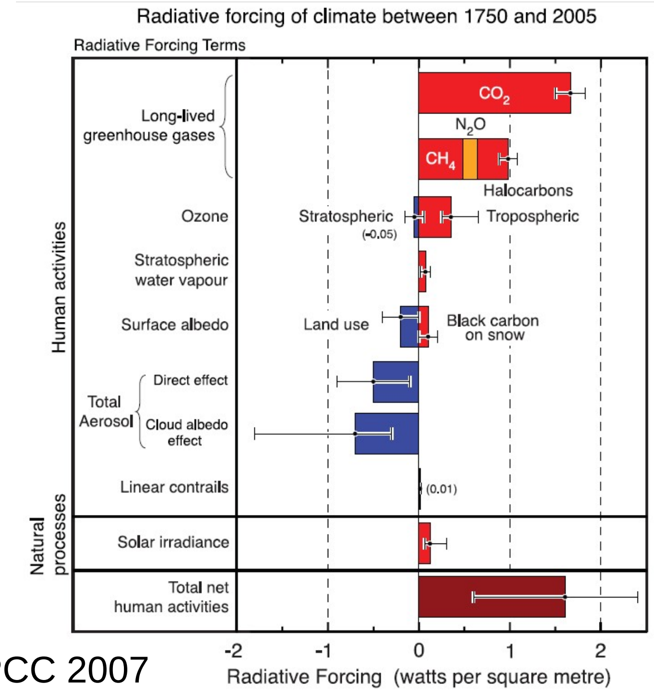
EFFECTS

POSSIBLY ACCESSIBLE FOR EXPERIMENTS IN SELECTED AREAS WITH CONCURRENT LONG TERM DATA RECORDS LINKING CCN TO RAIN RATES

Reducing the uncertainties in model input parameters

⇓

measurement of cloud microphysics relevant aerosols +.....



IPCC 2007

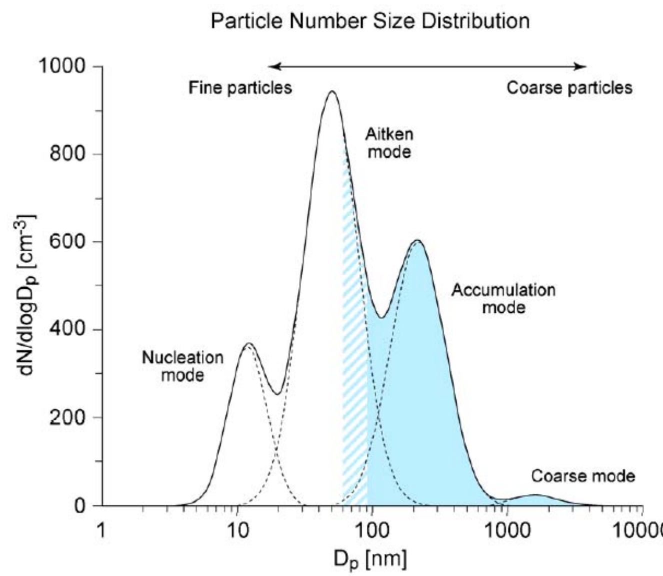
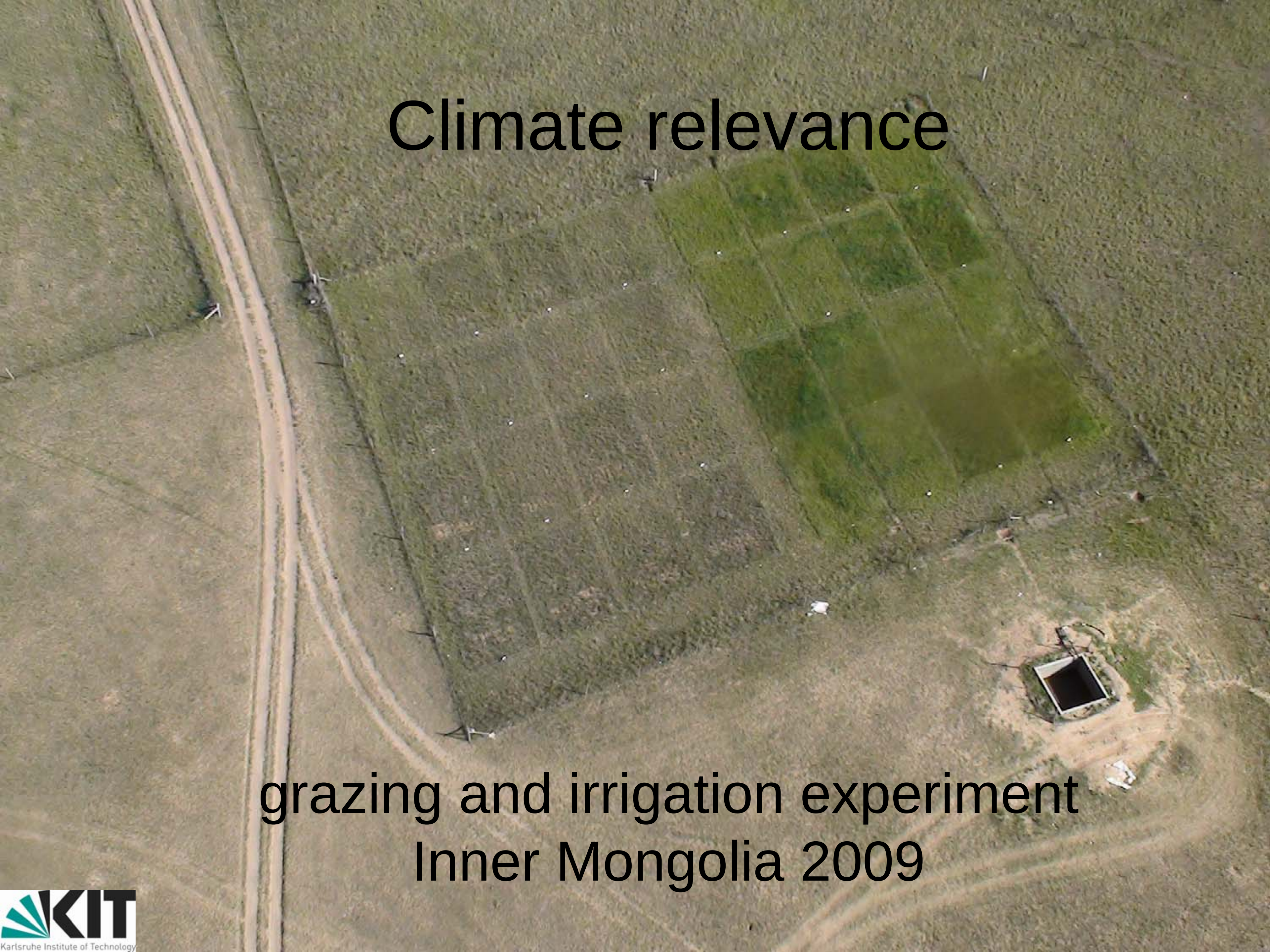


Figure 3-1: *Typical particle number size distribution. The shaded band represents the range of sizes activated as CCN at 0.3% SS, a typical median SS in clouds.*

Z. Levin, Aerosol Pollution Impact on Precipitation: A Scientific Review, 2007

Climate relevance



grazing and irrigation experiment
Inner Mongolia 2009

Karlsruhe Institute of Technology

Measurements require both, well defined environmental conditions and long term data sets

two examples ‚natural laboratories‘

Western Australian wheat belt

Steppe, Inner Mongolia (> 1000 km)

Western Australia

regional scale production of ultrafine aerosol following drastic land cover change and > rising ground water table

TWO EFFECTS: CLOUDS (meteo) + RAIN (aerosol)

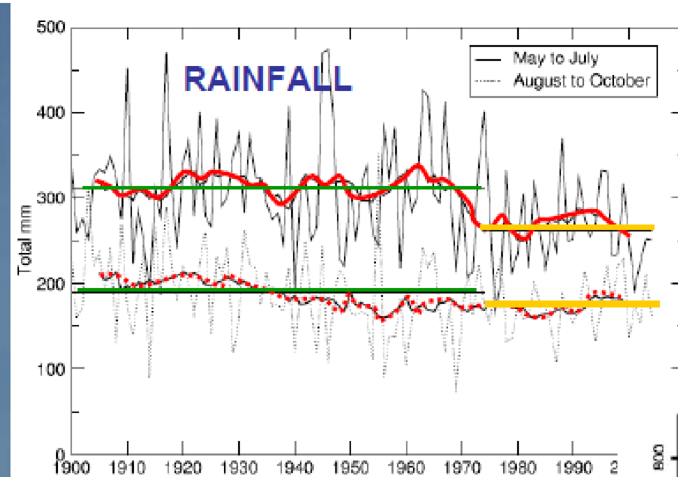


Fig. 4 Time series of Southwest Western Australia rainfall (mm). Solid trace depicts early w July) totals and dotted trace late winter (August to October) totals. Means for the periods 190 1975 to 2004 are represented by horizontal lines

Bates et al.
Climatic Change, 89, 2008, 339-354

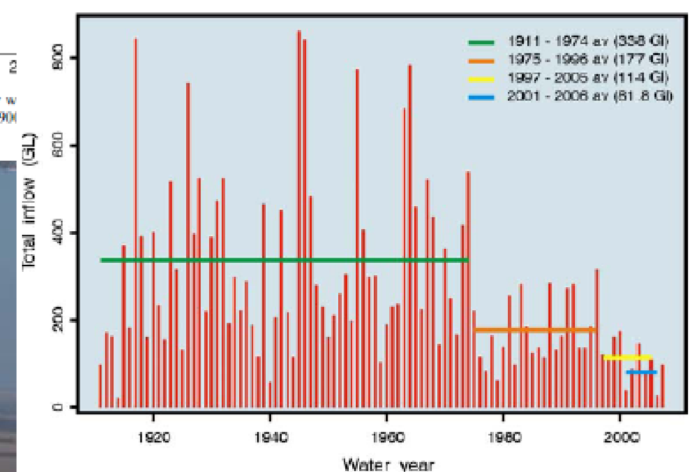


Fig. 5 Annual (May to April) inflow series (GL) for the Integrated Water Supply System. Source: http:// www.watercorporation.com.au

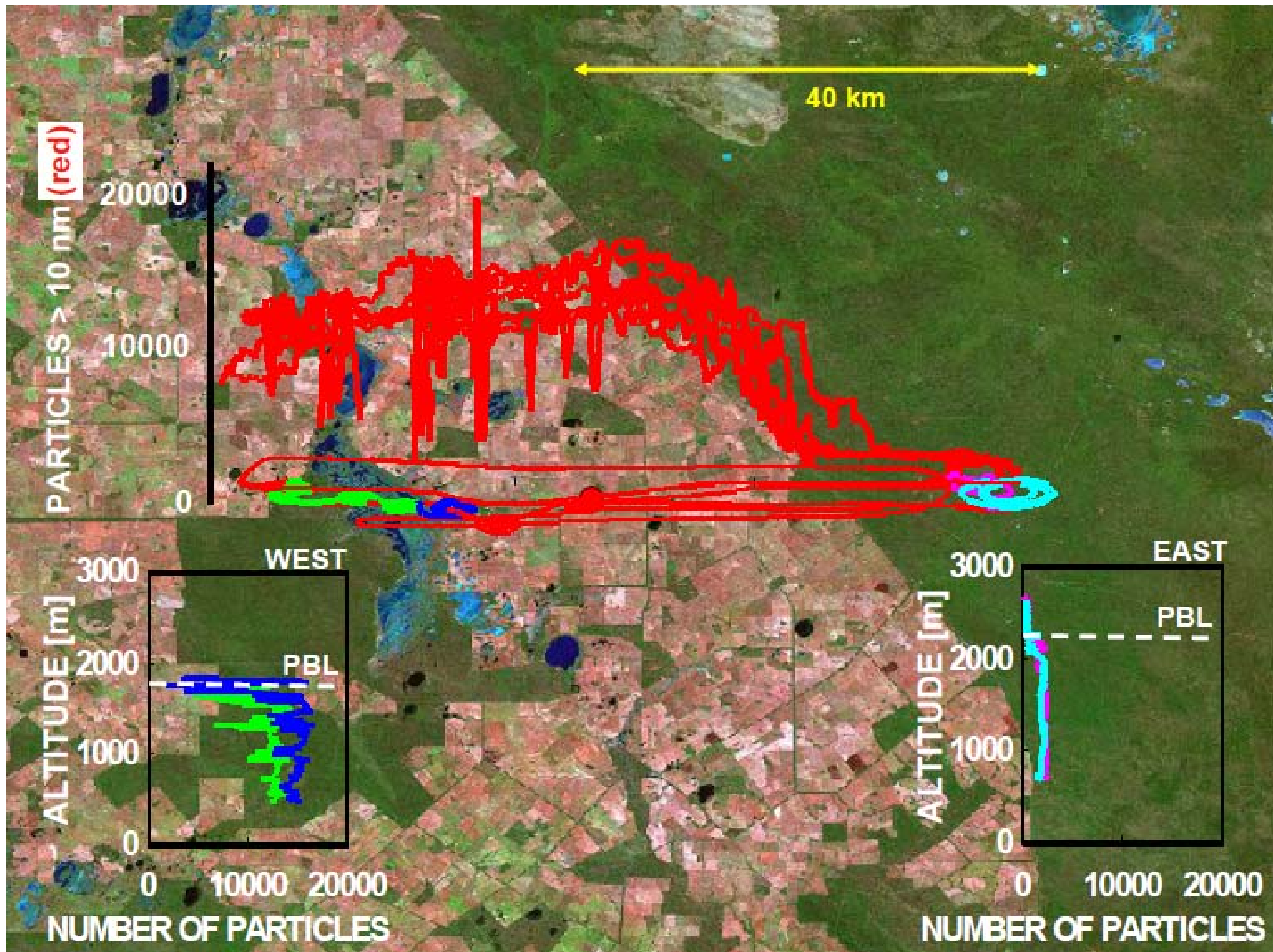
Western Australia

regional scale production of ultrafine aerosol following drastic land cover change and > rising ground water table

AEROSOL > 10 nm

 # / cm3

SOURCES?



Western Australia

regional scale production of ultrafine aerosol following drastic land cover change and > rising ground water table

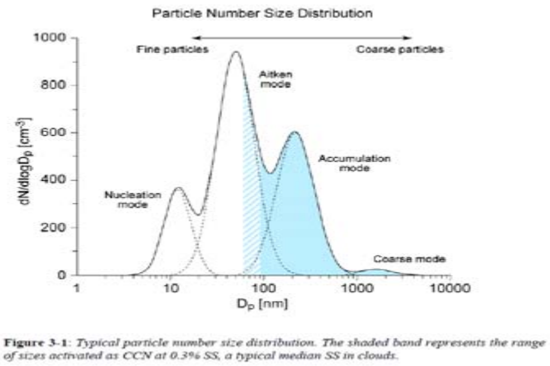
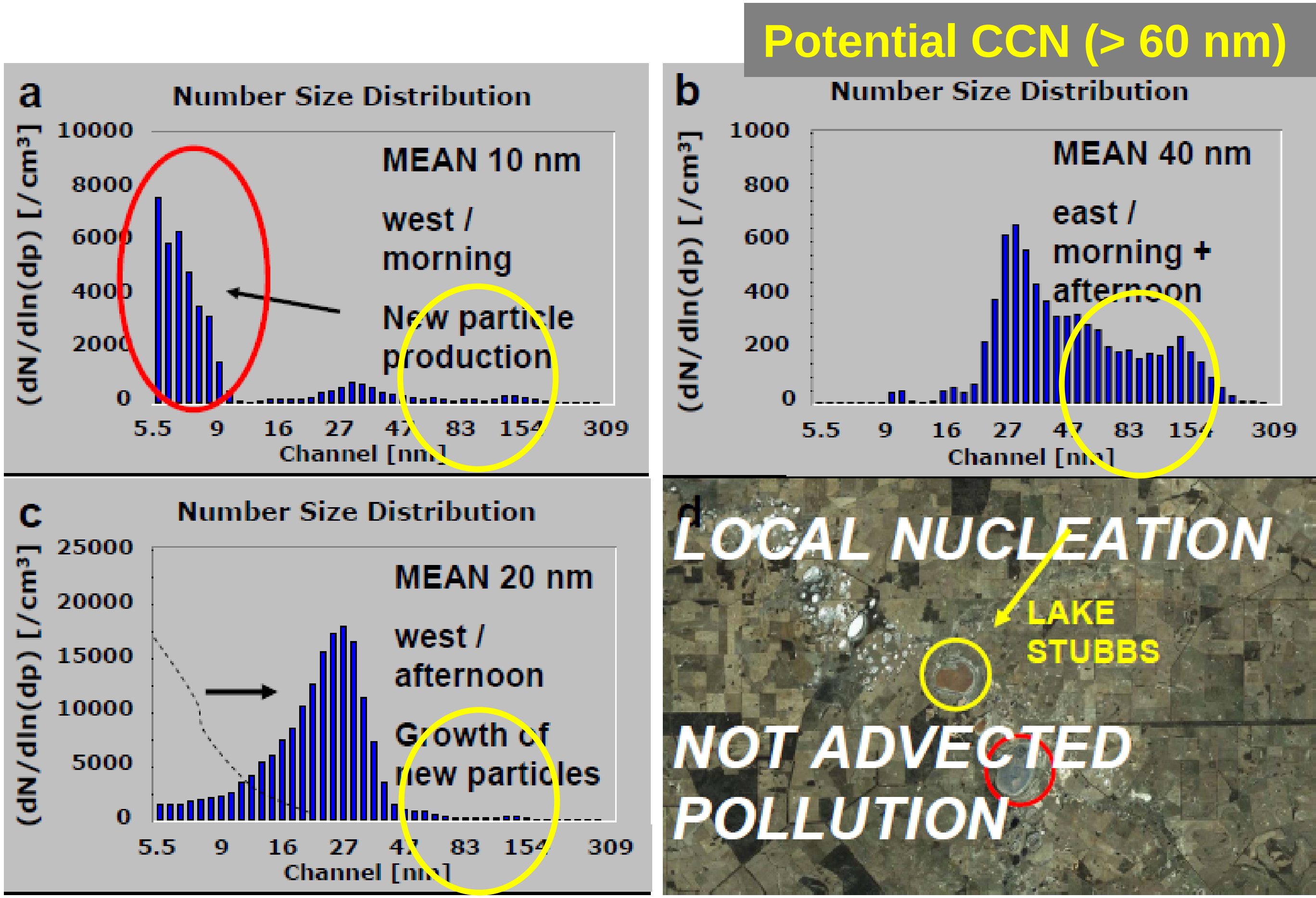


Figure 3-1: Typical particle number size distribution. The shaded band represents the range of sizes activated as CCN at 0.3% SS, a typical median SS in clouds.



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Parameter	West (agriculture) ground	West (agriculture) cloud base	East (natural vegetation) ground	East (natural vegetation) cloud base
Temperature [°C]	16	10	20	6
Pressure [hPa]	975	900	975	800
Dewpoint [°C]	11	9	6	3.5
Water [g/m3]	9.9	8.8	6.9	6.1
Potential CCN	~350		~250	
Cloud droplets [/cm3]	247		198	
Average diameter [um]	8.3		9.5	
Liquid water content [g/m3]	0.10		0.15	

Note the difference of water vapor converted into LWC

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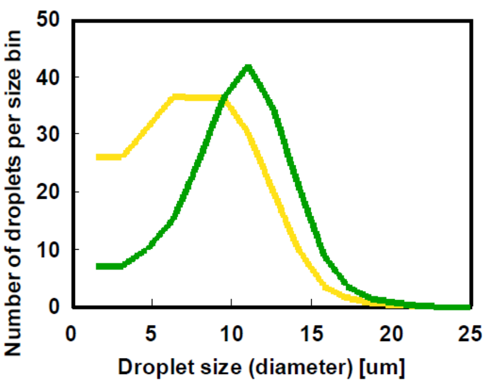

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$$R \sim LWP^{\alpha} N_d^{-\beta}$$

R = rain rate (cloud base)
LWP = liquid water path (macro)
N_d = drop conc (microphysical)

$\alpha \sim 1.50$
$\beta \sim 0.67$

Wang and Feingold, 2009a

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F = 2.3

Wang and Feingold, 2009a

KIT — MURDOCH UNIVERSITY PERTH WESTERN AUSTRALIA — UAH — ARA

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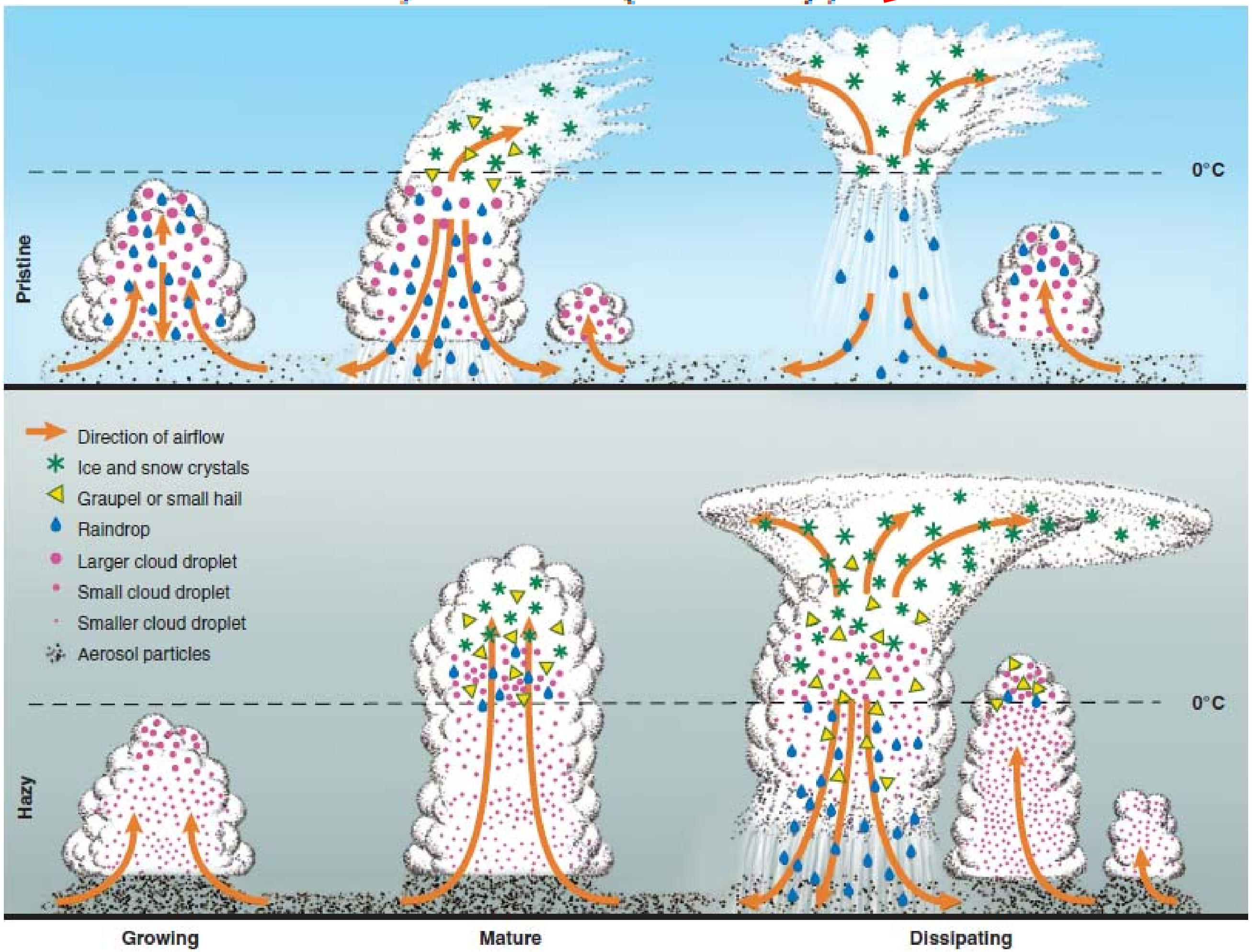
Flood or Drought: How Do Aerosols Affect Precipitation?

Daniel Rosenfeld, *et al.*

Science **321**, 1309 (2008);

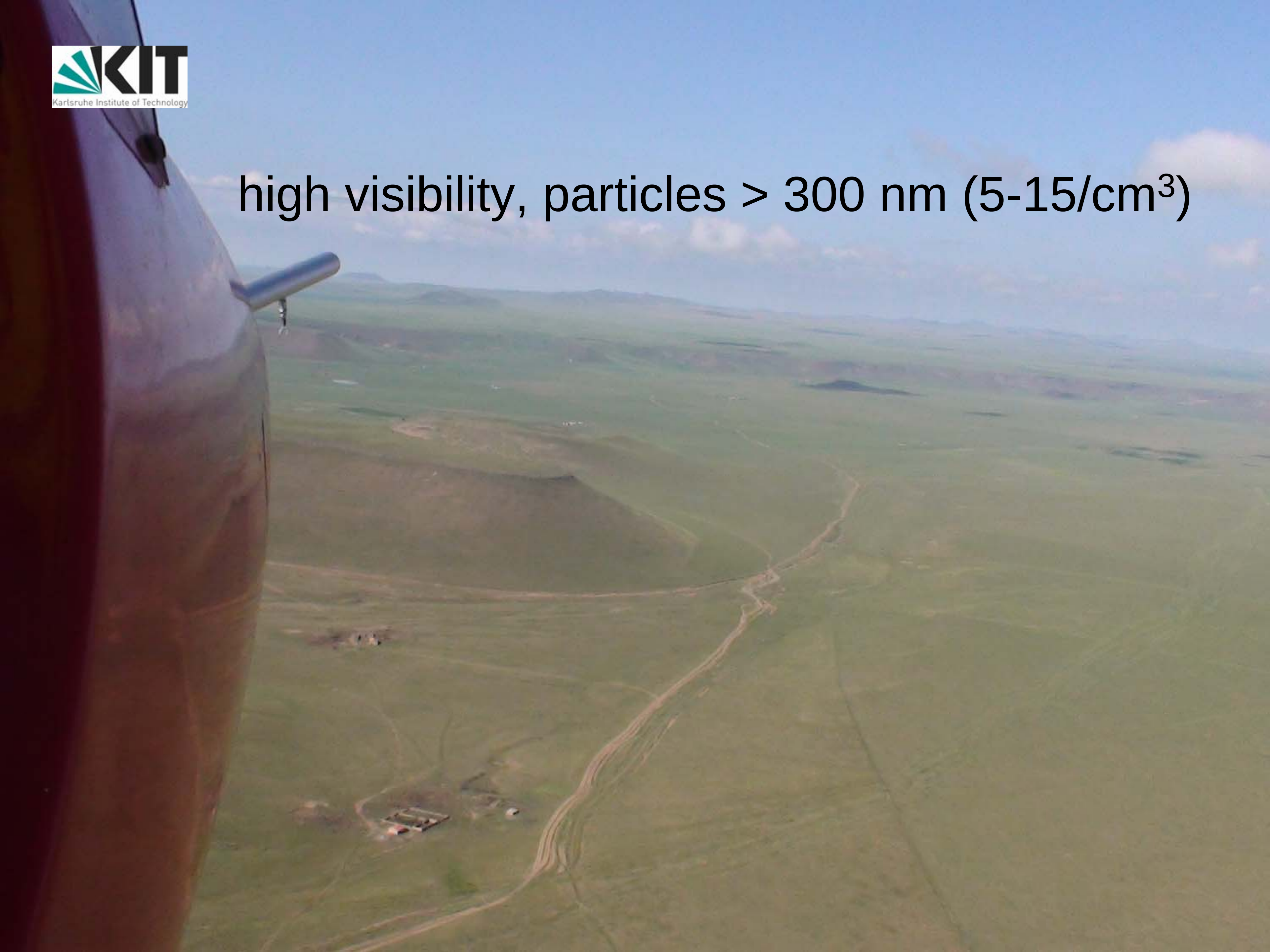
BOTH



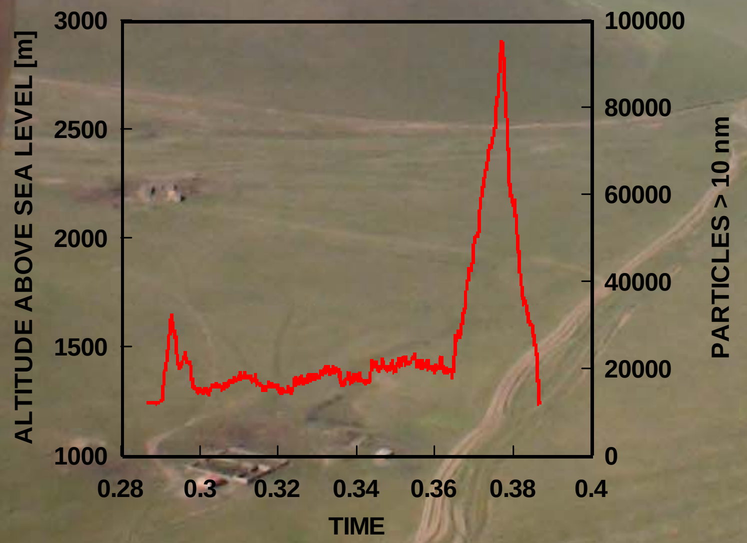
Inner Mongolia, summer 2009

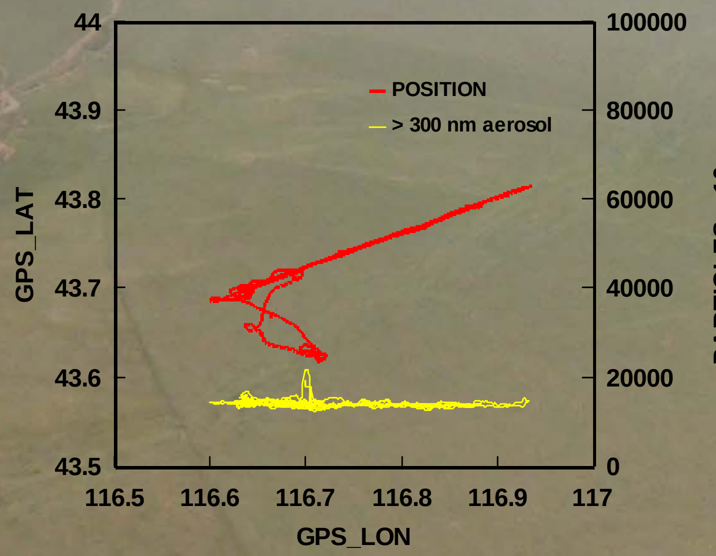
KIT Karlsruhe Institute of Technology

high visibility, particles > 300 nm (5-15/cm^3)

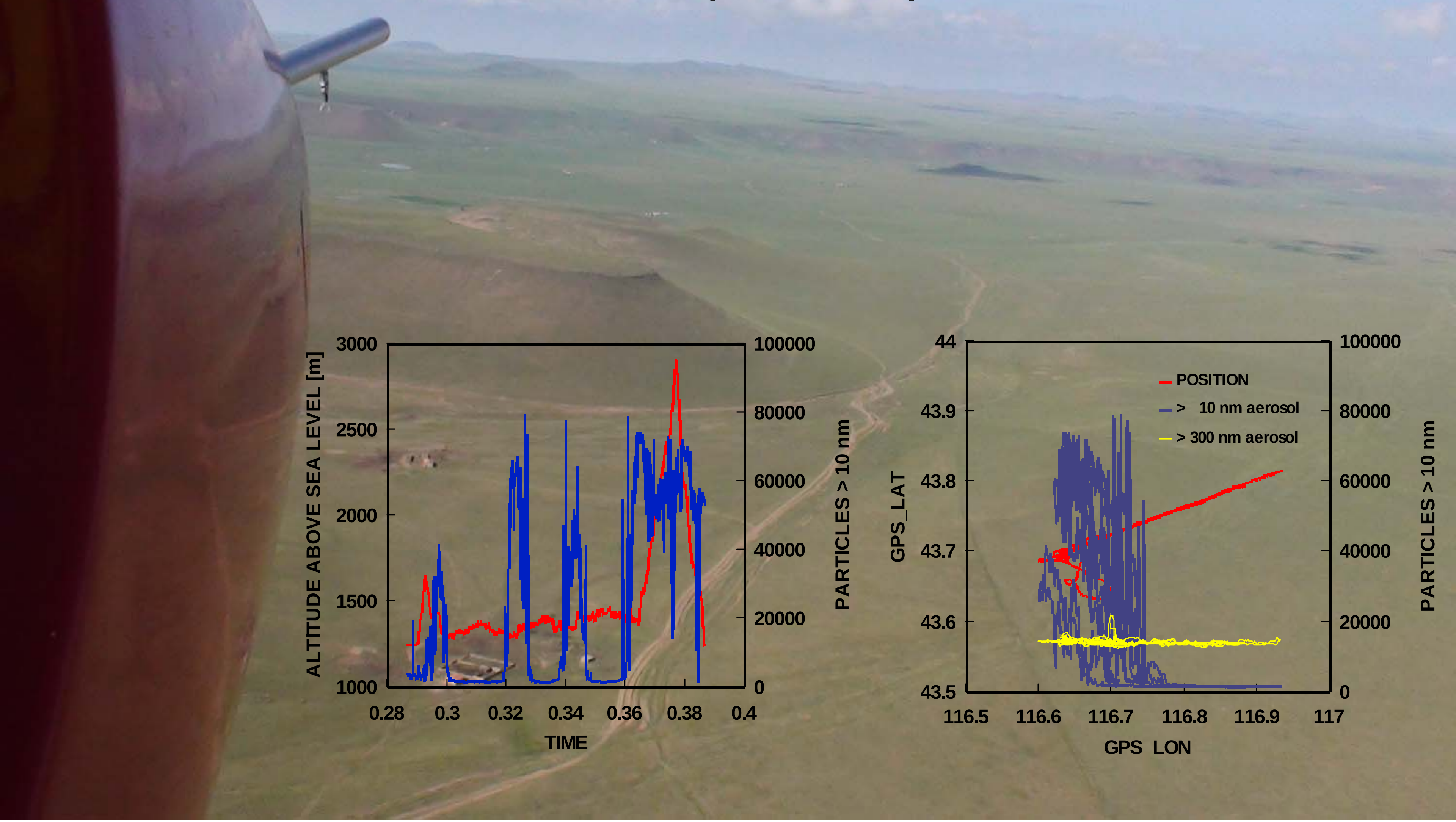


Turbulence flights (50-150 m) + vertical sounding



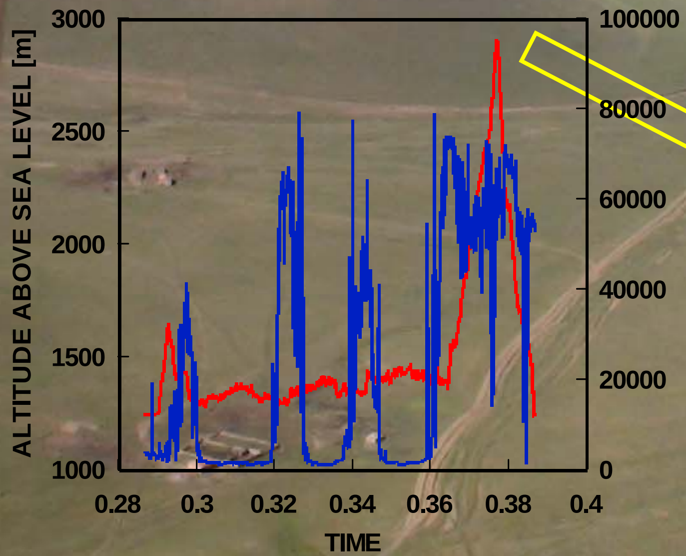


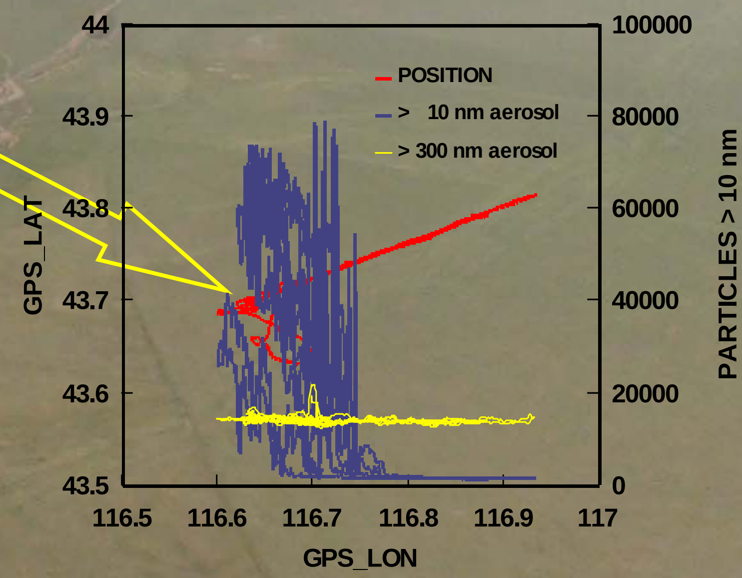
ultrafine particle production?



ultrafine particle production?

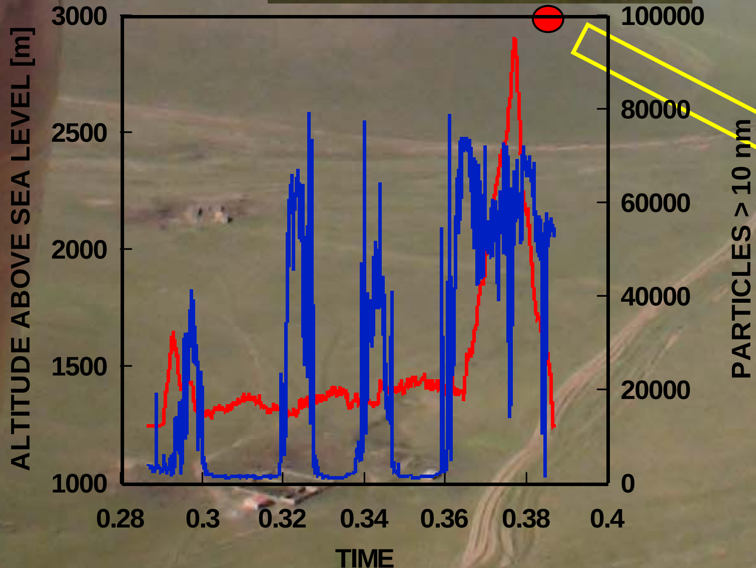
WIND 310 °, 8 m/sec, 55 km distance

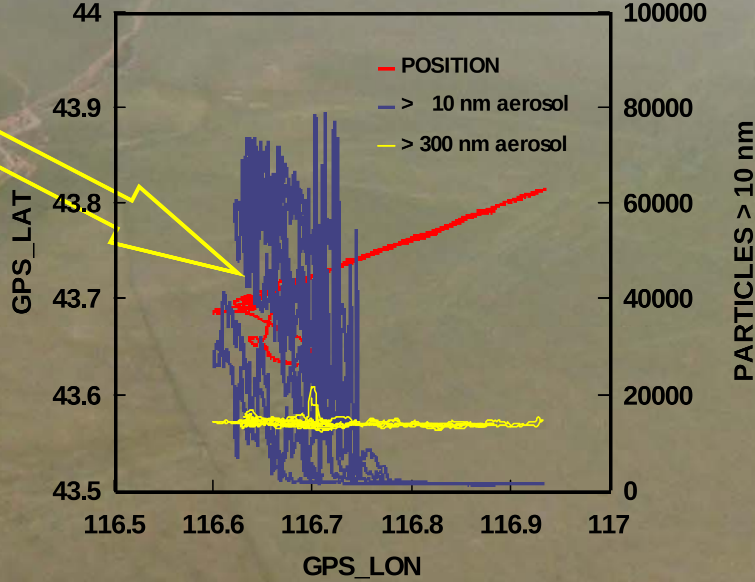


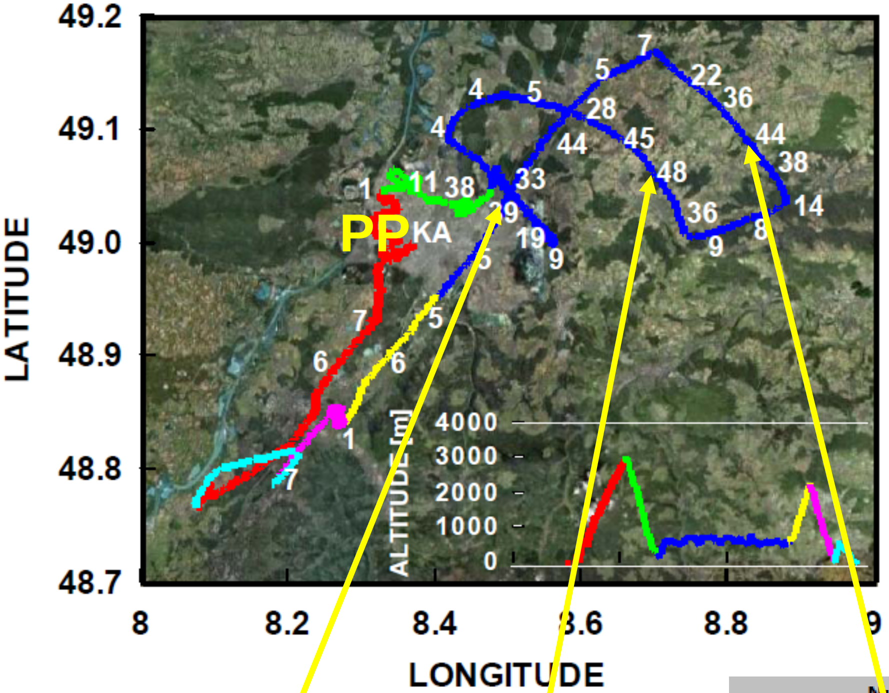


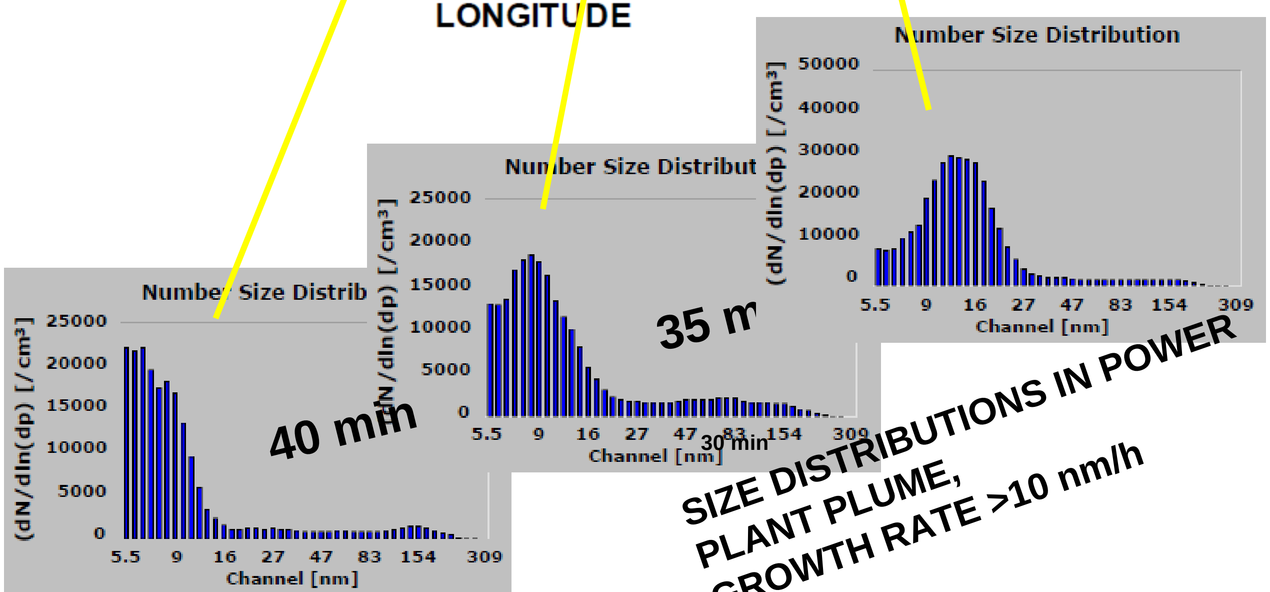
ultrafine particle production
yes from SO2

XILINHOT WIND 310 °, 8 m/sec, 55 km distance



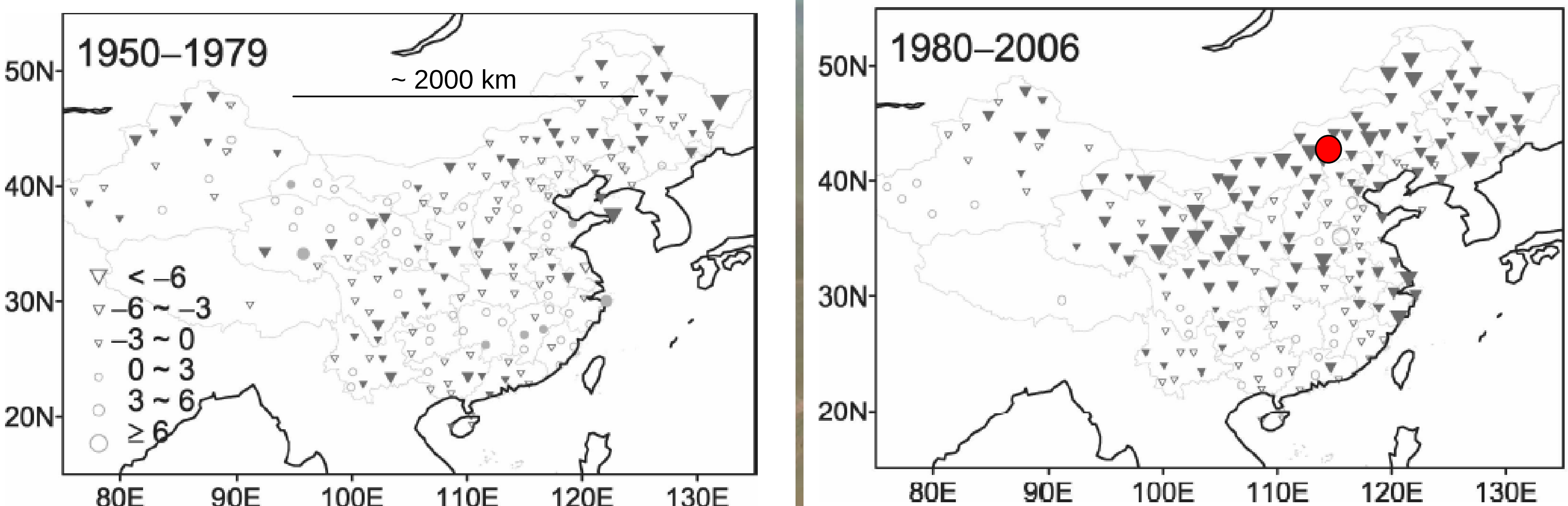






SIZE DISTRIBUTIONS IN POWER PLANT PLUME,
GROWTH RATE >10 nm/h

Precipitation effect: long term data sets, frequency of rainy days in summer

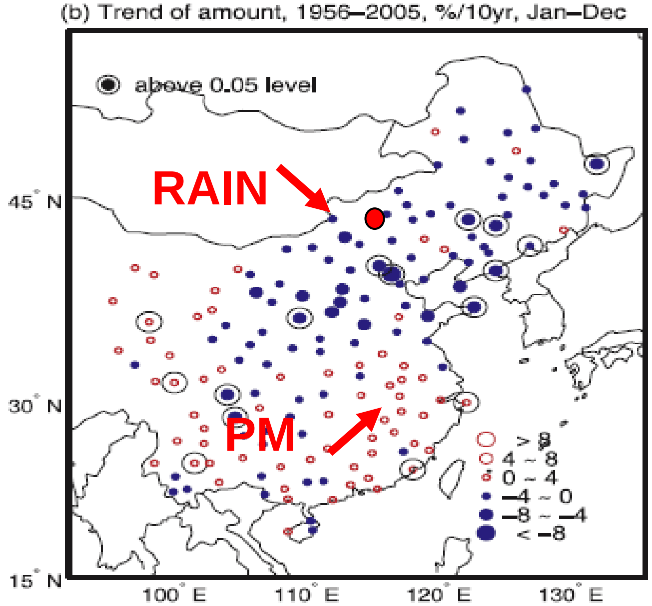


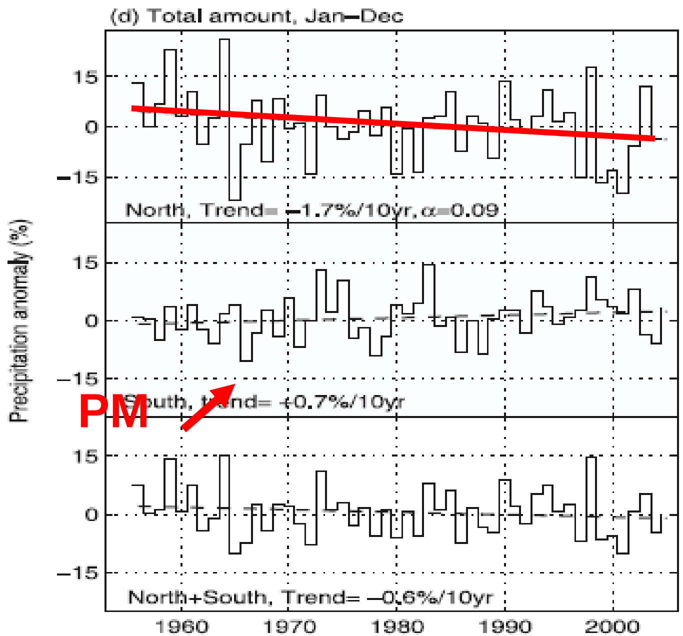
The Impact of Aerosols on the Summer Rainfall Frequency in China

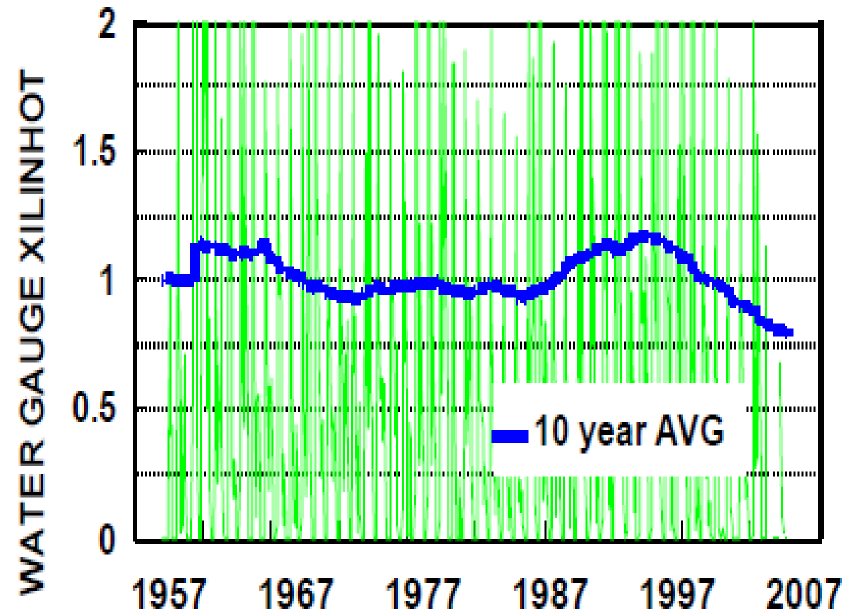
Yong-Sang Choi and Chang-Hoi Ho

JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY

Fig. 6. The trend of the rain frequency [days $(10\ yr)^{-1}$] in summer for (top) 1955–79 and (bottom) 1980–2005. Stations significant at the 90% level are indicated by filled symbols. In contrast to the situation before 1979, the rain frequency has rapidly decreased since 1980.







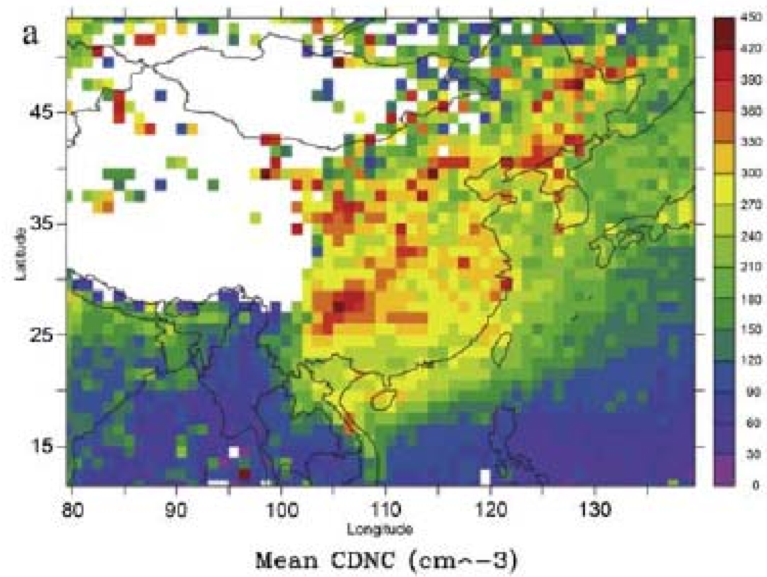
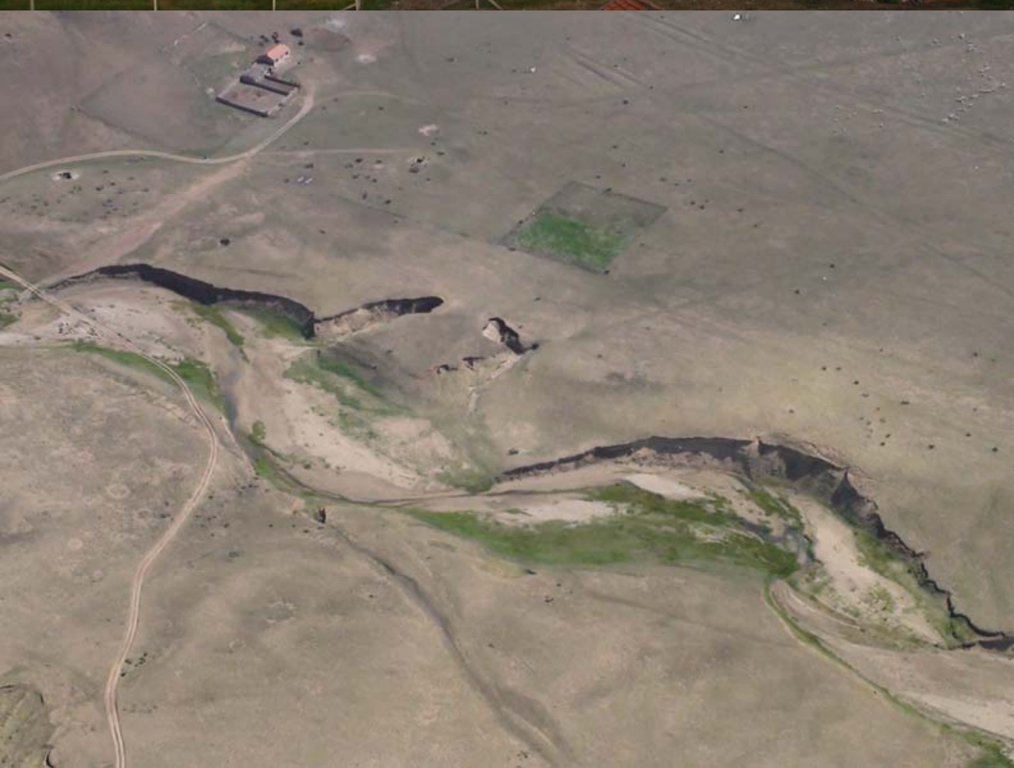
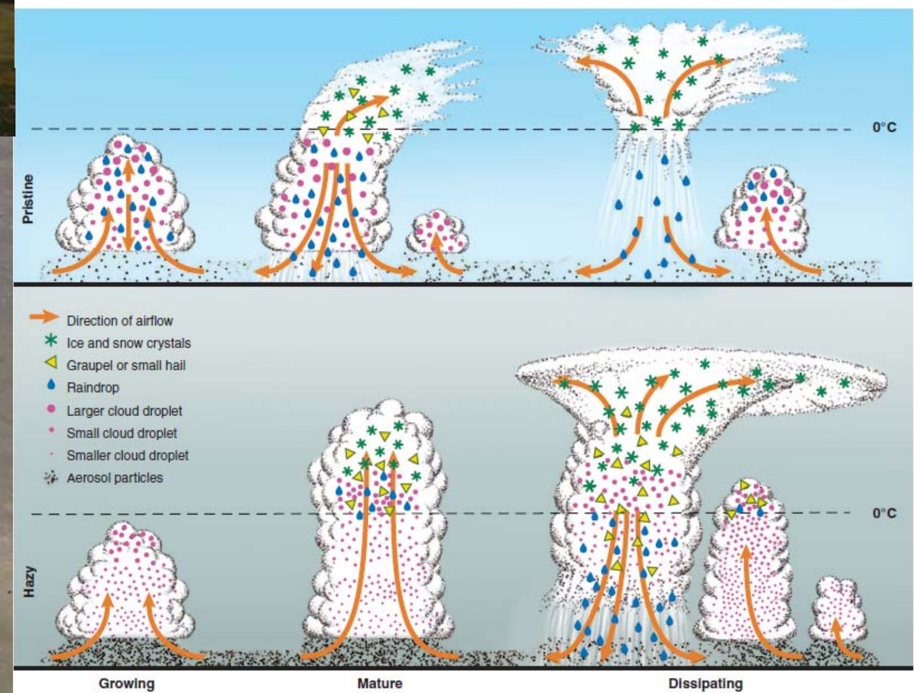


Figure 10. The spatial distribution for cloud droplet number concentration (CDNC, cm^3) and cloud effective radius for water clouds (CERW, μm) averaged for 2003–2006.

erosion from one event
in 2007
/ desertification





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SUMMARY (1/3)

Desert dust

RF + over land, - over the ocean
altitude, albedo and chemistry dependent

closure experiments
Samum, Lampedusa …

SUMMARY (2/3)

Biomass burning aerosol

high local and spatial variability, optical properties dependent on biomass type / humidity

Climate impact very uncertain

SUMMARY(3/3)

nucleation mode derived CCN

relevant for regional scale precipitation

point or distributed sources

Main climate effects in semiarid climates / remote agricultural areas

SUMMARY(3/3)

nucleation mode derived CCN

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Main climate effects in semiarid climates / remote agricultural areas

MODELS OR MEASUREMENTS ??

NOVEMBER 5. 2009

Thank you for your attention