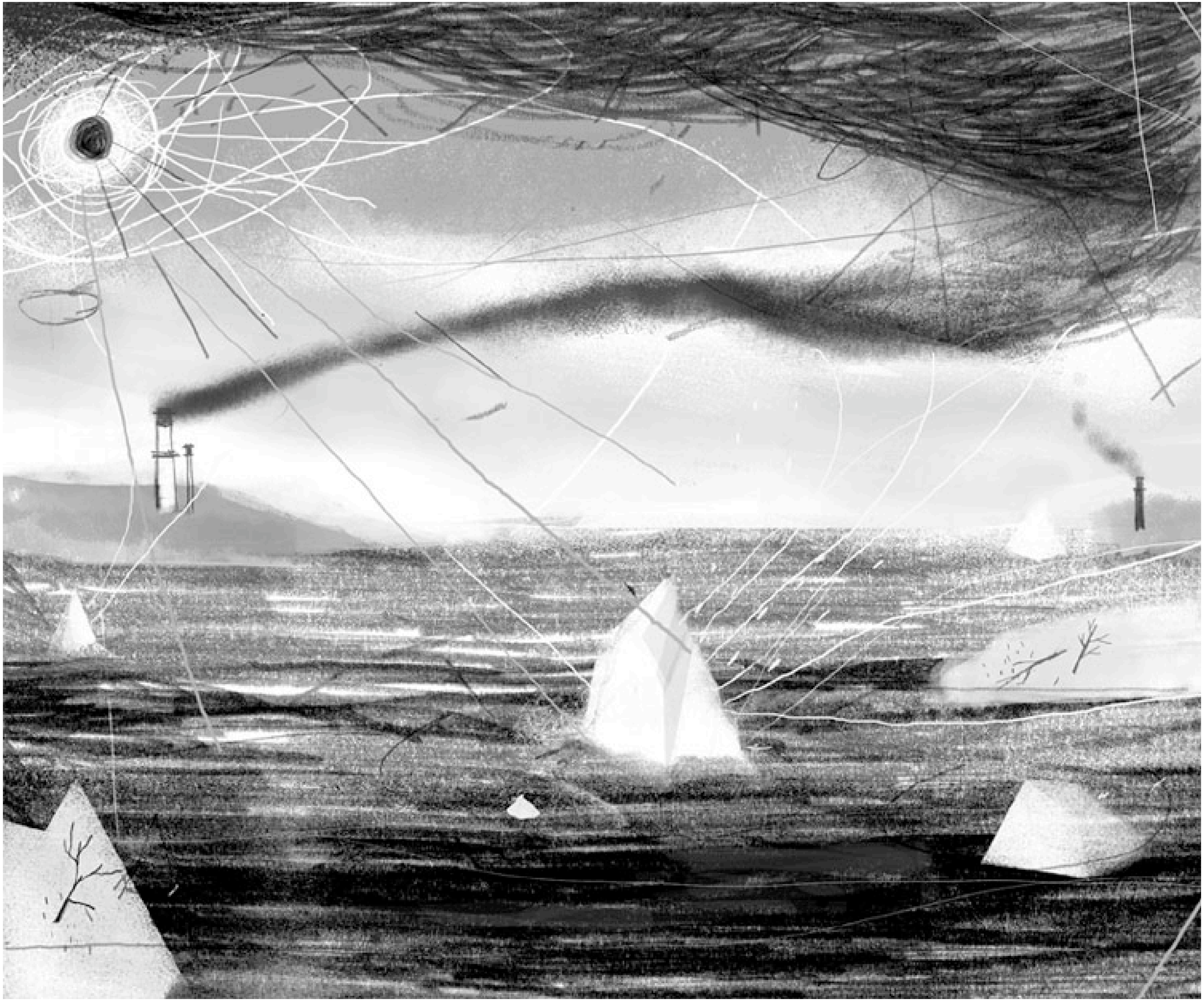
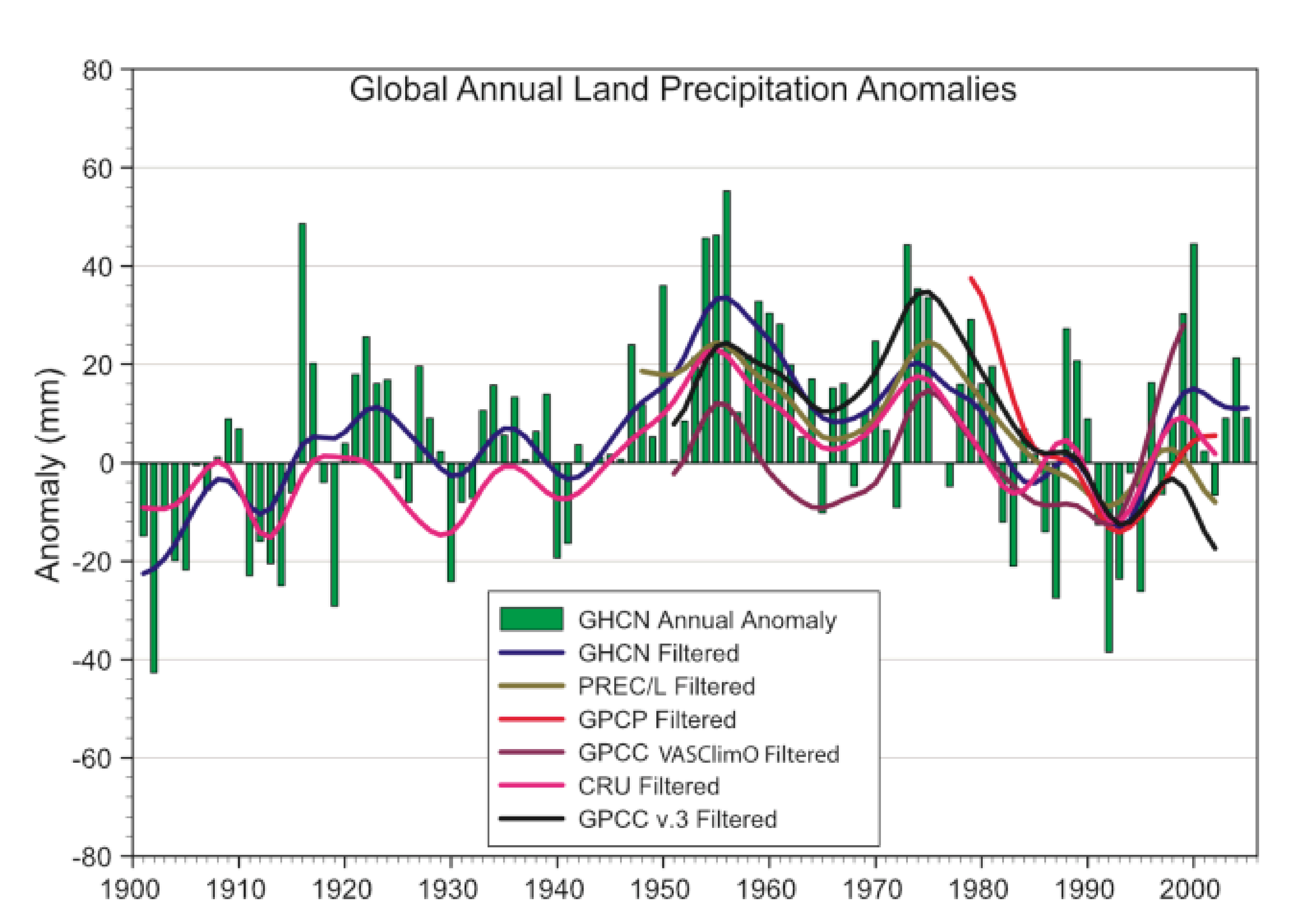
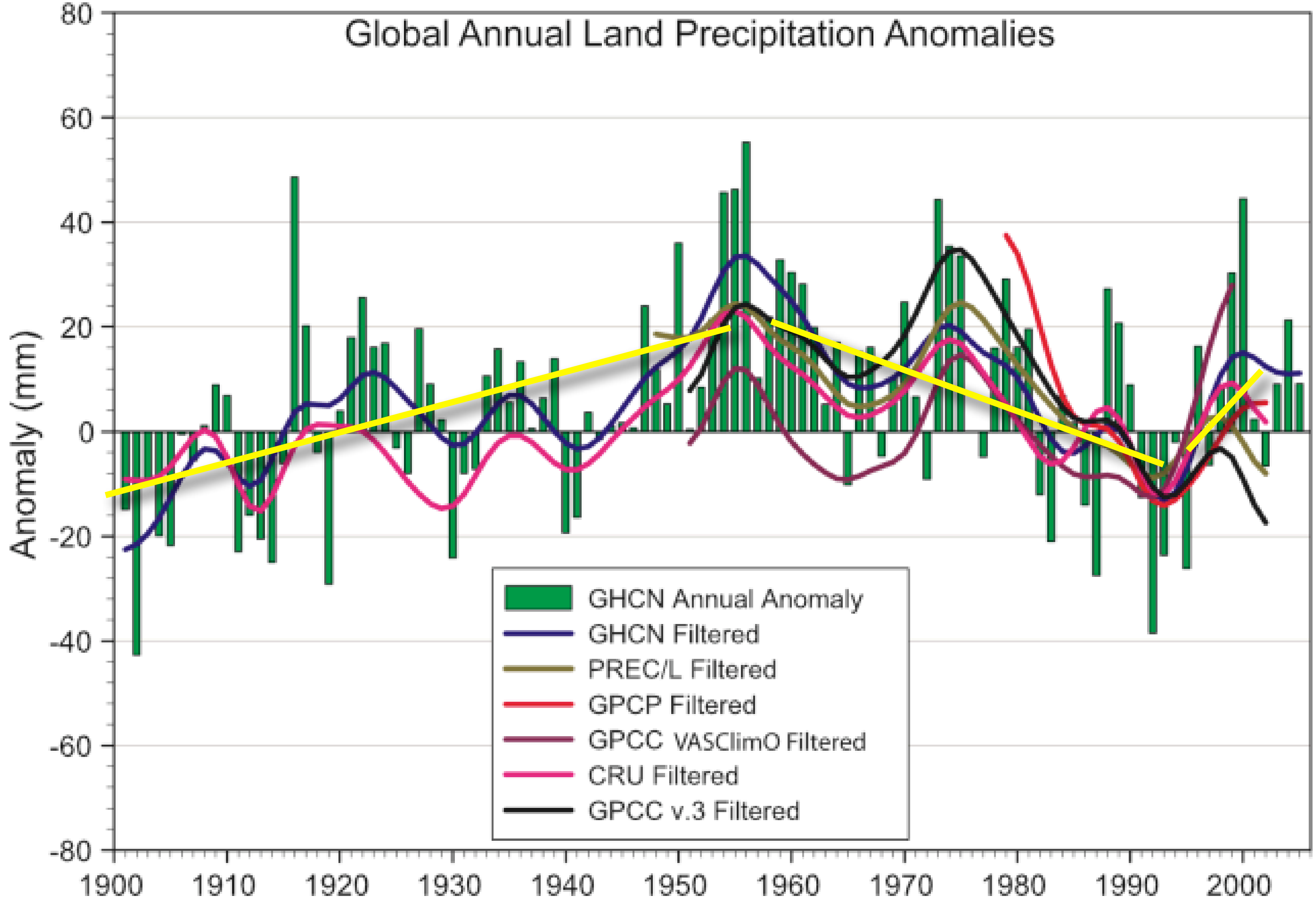


Jon Han


Global Annual Land Precipitation Anomalies
Anomaly (mm)
80
60
40
20
0
-20
-40
-60
-80
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
GHCN Annual Anomaly
GHCN Filtered
PREC/L Filtered
GPCP Filtered
GPCC VASClimO Filtered
CRU Filtered
GPCC v.3 Filtered


Global Annual Land Precipitation Anomalies
Anomaly (mm)
80
60
40
20
0
-20
-40
-60
-80
1900
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1950
1960
1970
1980
1990
2000
GHCN Annual Anomaly
GHCN Filtered
PREC/L Filtered
GPCP Filtered
GPCC VASClimO Filtered
CRU Filtered
GPCC v.3 Filtered

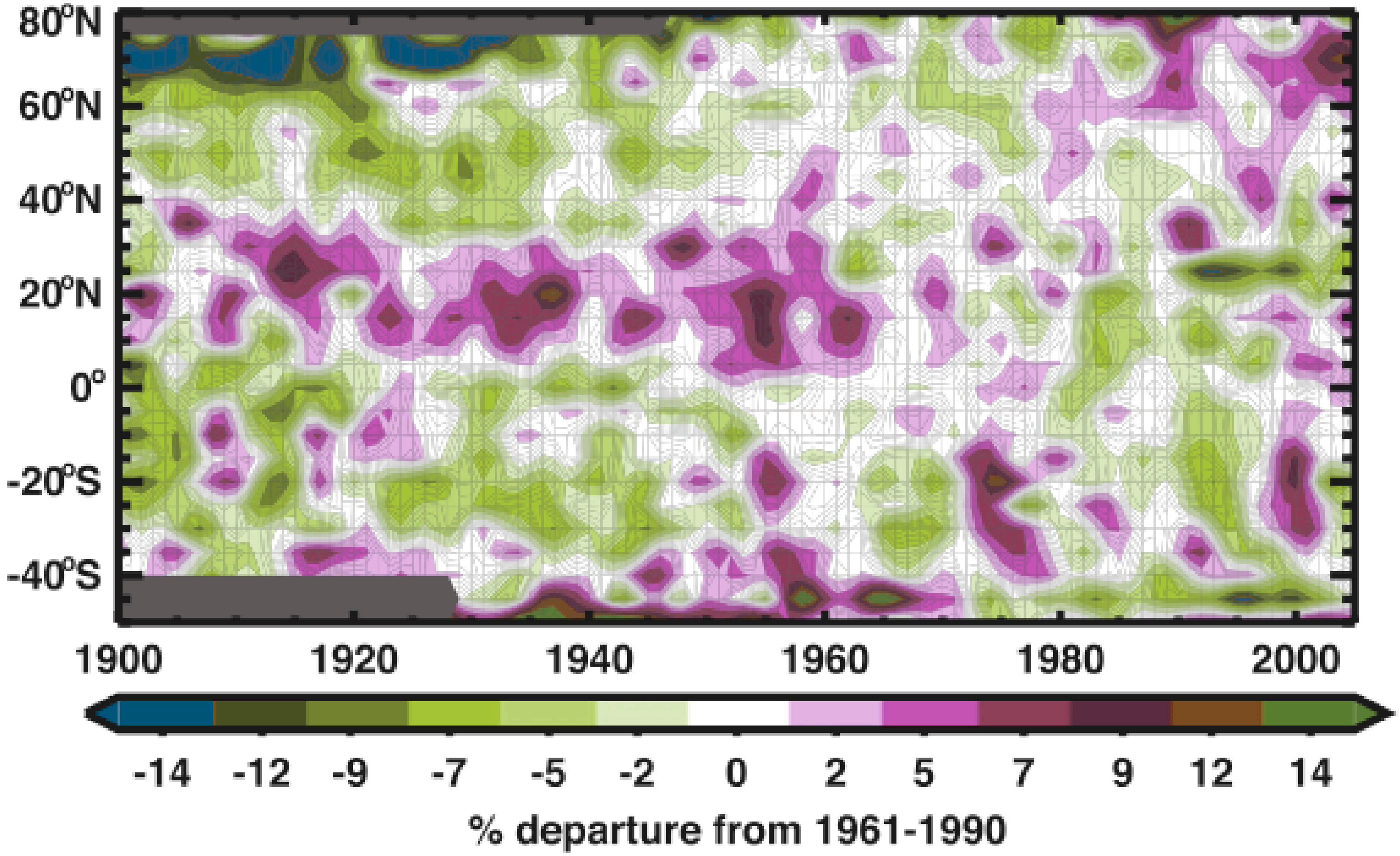
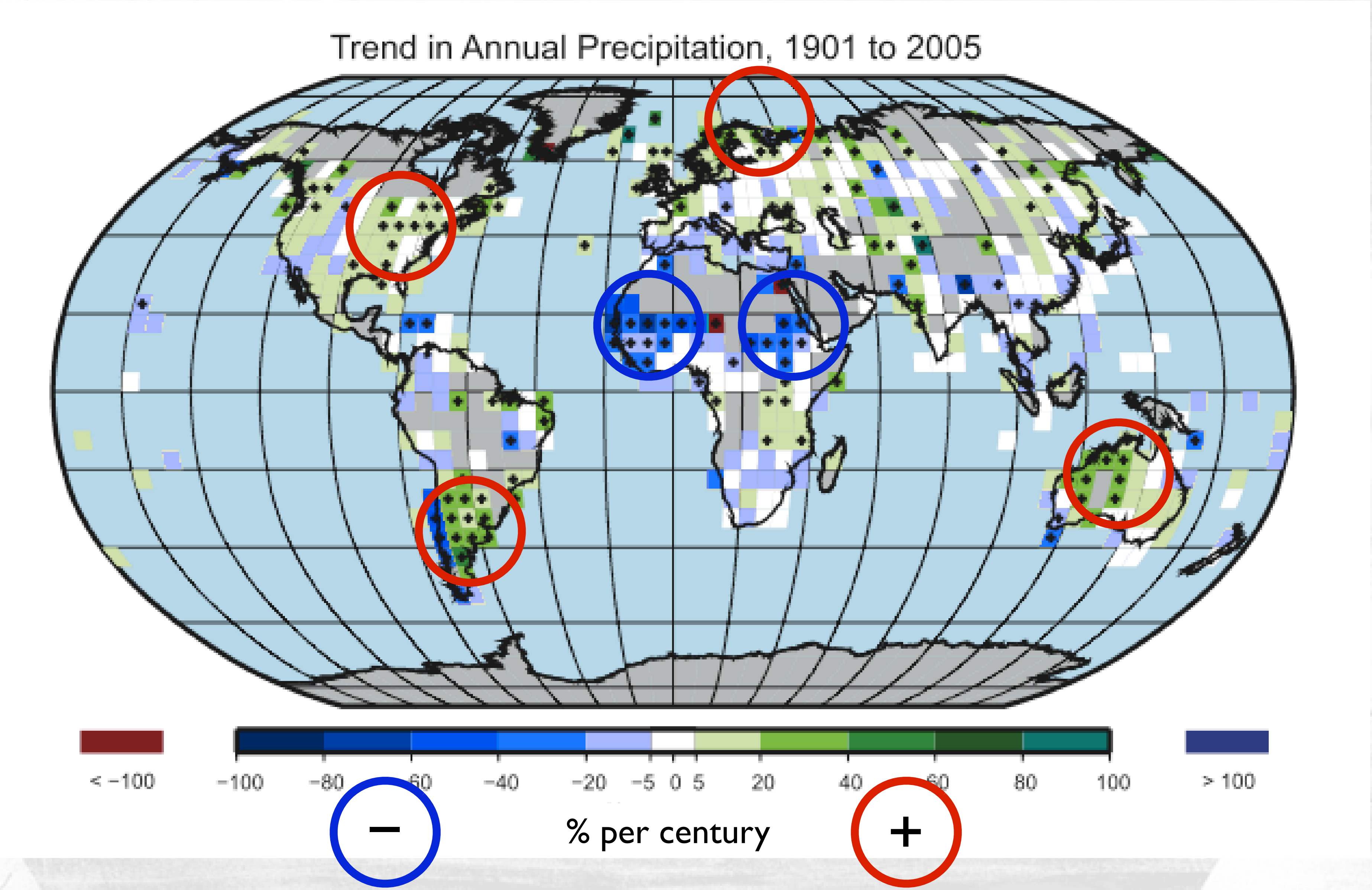
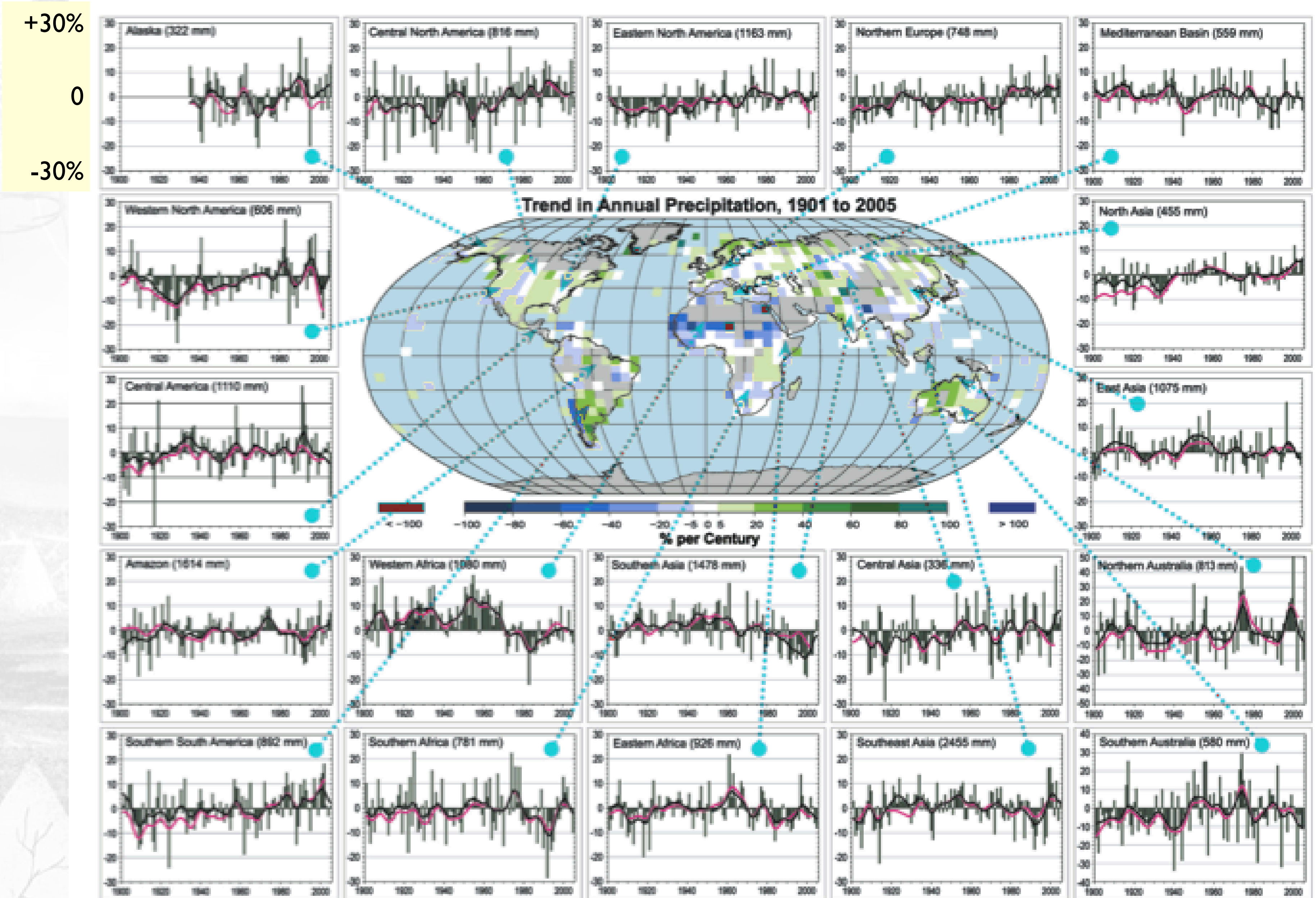


Figure 3.15. *Latitude-time section of zonal average annual anomalies for precipitation (%) over land from 1900 to 2005, relative to their 1961 to 1990 means. Values are smoothed with the 5-point filter to remove fluctuations of less than about six years (see Appendix 3.A). The colour scale is nonlinear and grey areas indicate missing data.*



Trend in Annual Precipitation, 1901 to 2005
< −100
−100
−80
−60
−40
−20
−5
0
5
20
40
60
80
100
> 100
−
% per century
+

Figure 3.14. *Precipitation for 1900 to 2005. The central map shows the annual mean trends (% per century). Areas in grey have insufficient data to produce reliable trends. The surrounding time series of annual precipitation displayed (% of mean, with the mean given at top for 1961 to 1990) are for the named regions as indicated by the red arrows. The GHCN precipitation from NCDC was used for the annual green bars and black for decadal variations (see Appendix 3.A), and for comparison the CRU decadal variations are in magenta. The range is +30 to –30% except for the two Australian panels. The regions are a subset of those defined in Table 11.1 (Section 11.1) and include: Central North America, Western North America, Alaska, Central America, Eastern North America, Mediterranean, Northern Europe, North Asia, East Asia, Central Asia, Southeast Asia, Southern Asia, Northern Australia, Southern Australia, Eastern Africa, Western Africa, Southern Africa, Southern South America, and the Amazon.*



Aerosol Pollution Impact on Precipitation - Scientific Review

The WMO/IUGG International Aerosol Precipitation Science Assessment Group (IAPSAG)

Z. Levin - Chair
W. Cotton - Vice-Chair

Initial work was under the leadership of Prof. Peter Hobbs.

summary, plus personal perspective, by Gabor Vali


The WMO/IUGG
INTERNATIONAL AEROSOL
PRECIPITATION SCIENCE
ASSESSMENT GROUP
(IAPSAG)
World
Meteorological
Organization
Weather • Climate • Water
IAMAS
Aerosol Pollution Impact on
Precipitation:
A Scientiific Review
Z. Levin, Chair
W. Cotton, Vice-Chair

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Chairperson: Dr. George Isaac, Environment Canada

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Vali, Gabor	University of Wyoming	USA
Yau, Peter	McGill University	Canada
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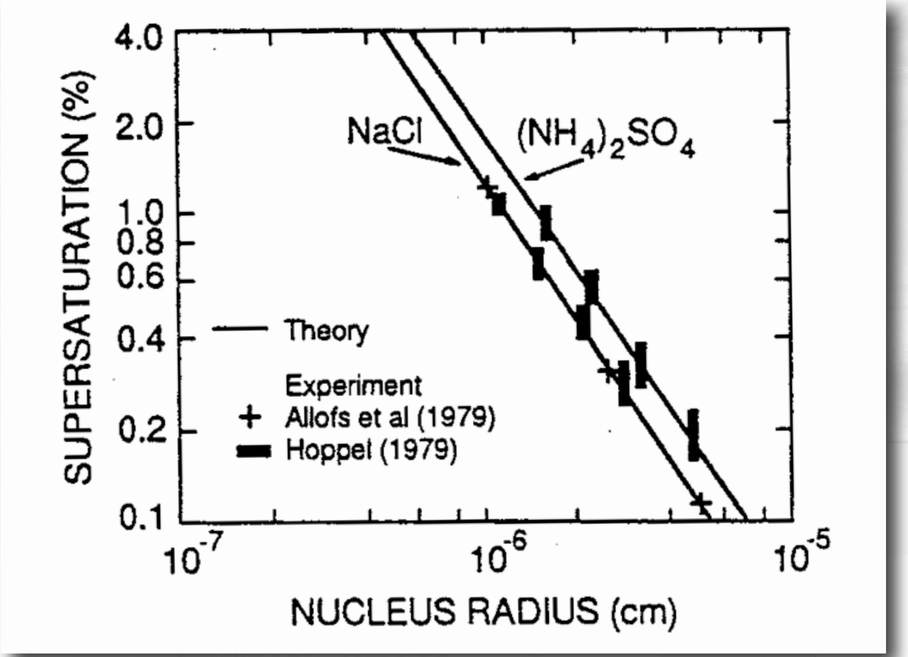
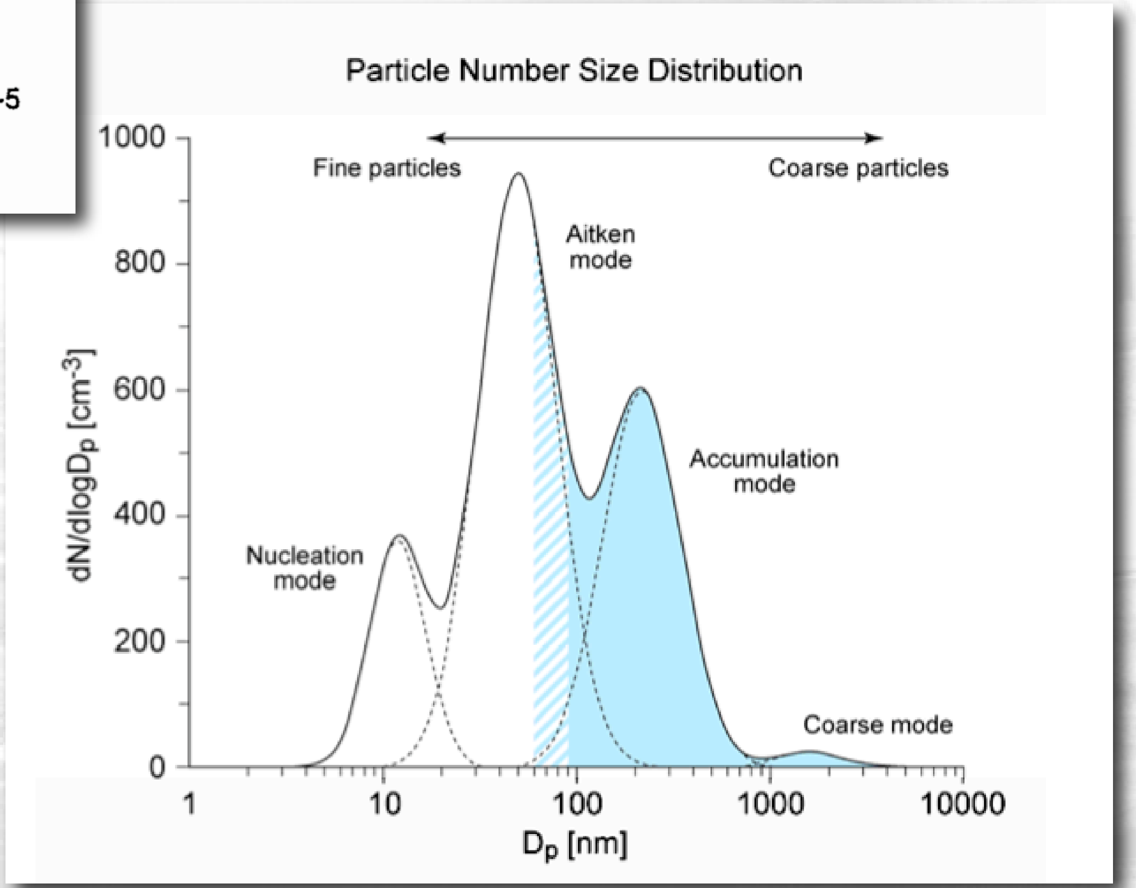
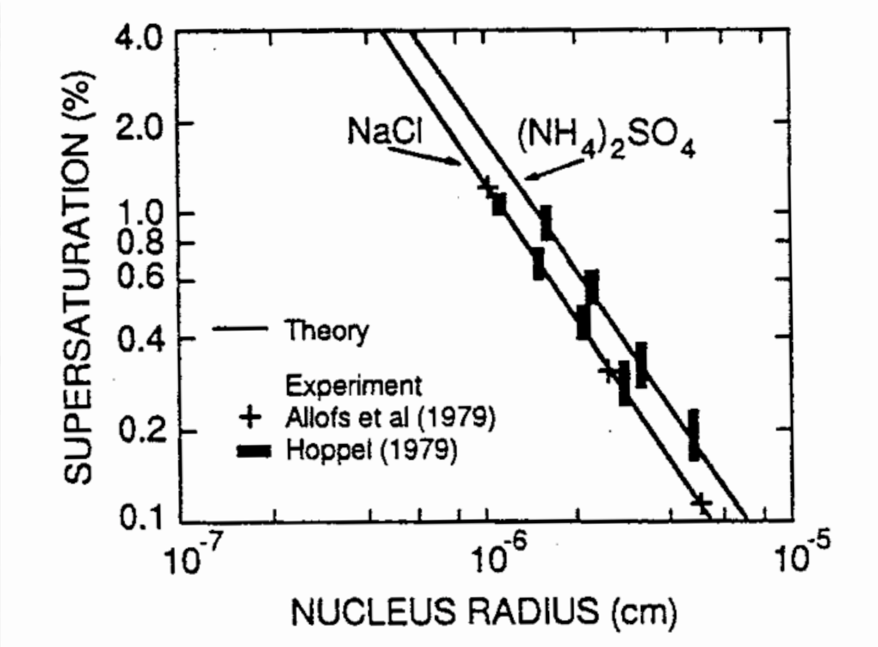


from Pruppacher and Klett, 1997 (pg. 186)





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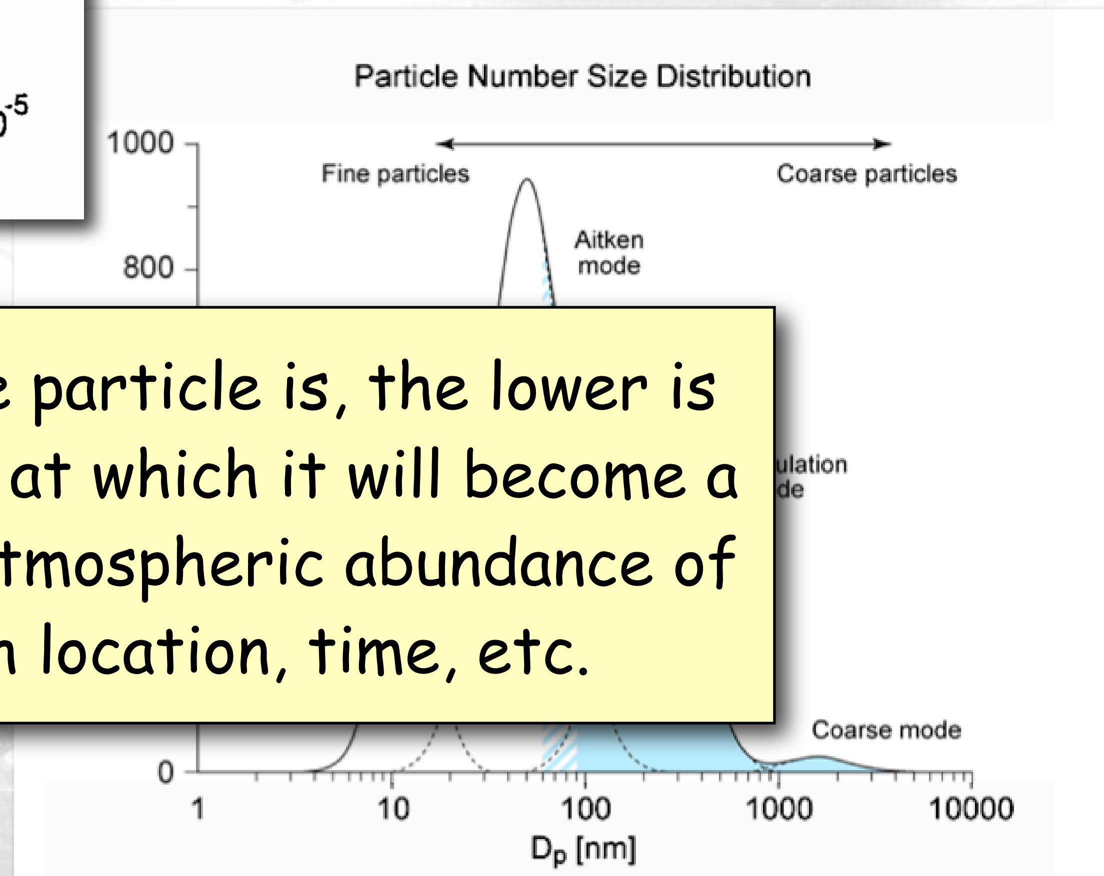
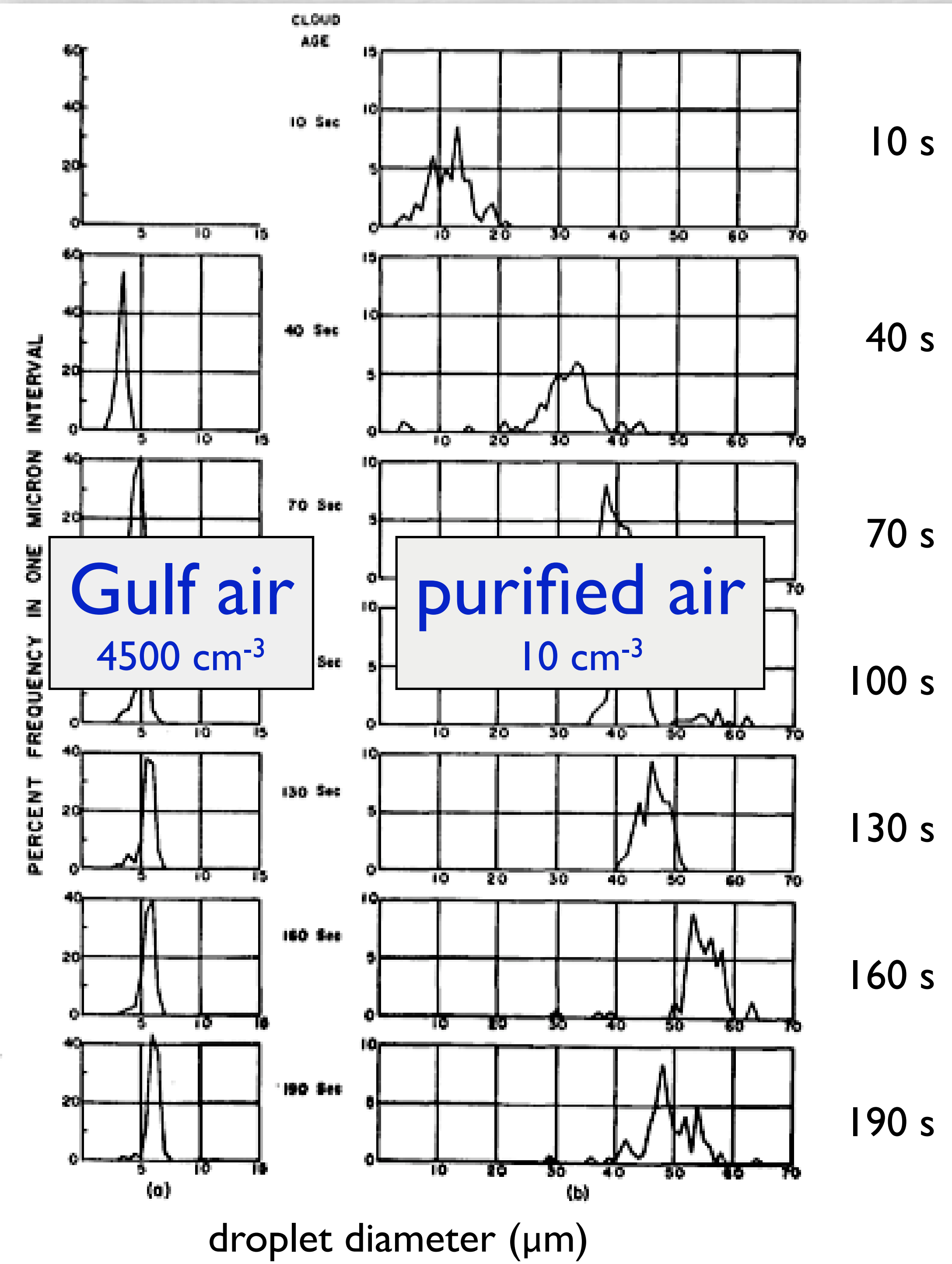
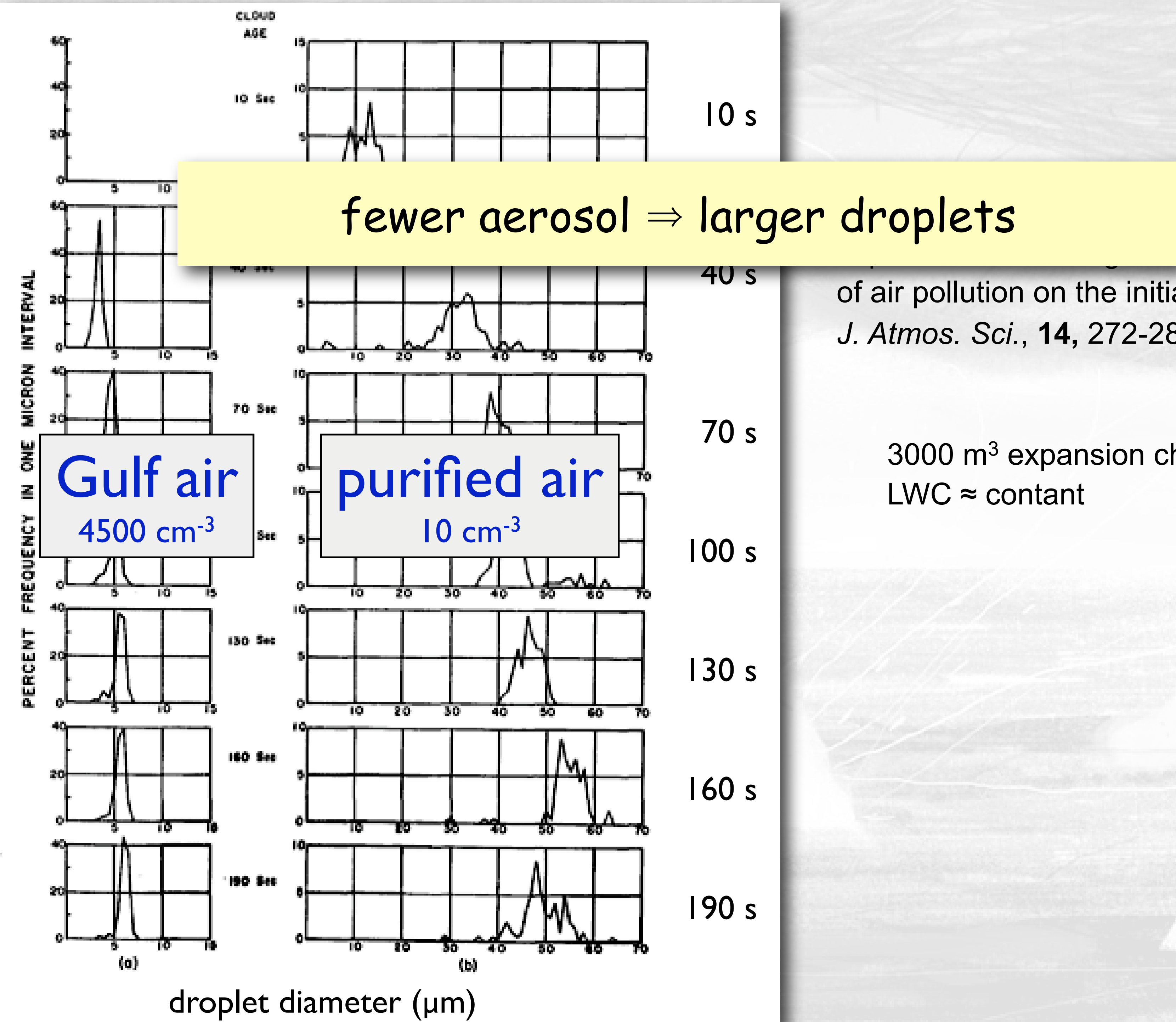


The larger a soluble particle is, the lower is the supersaturation at which it will become a cloud droplet. The atmospheric abundance of CCN varies with location, time, etc.



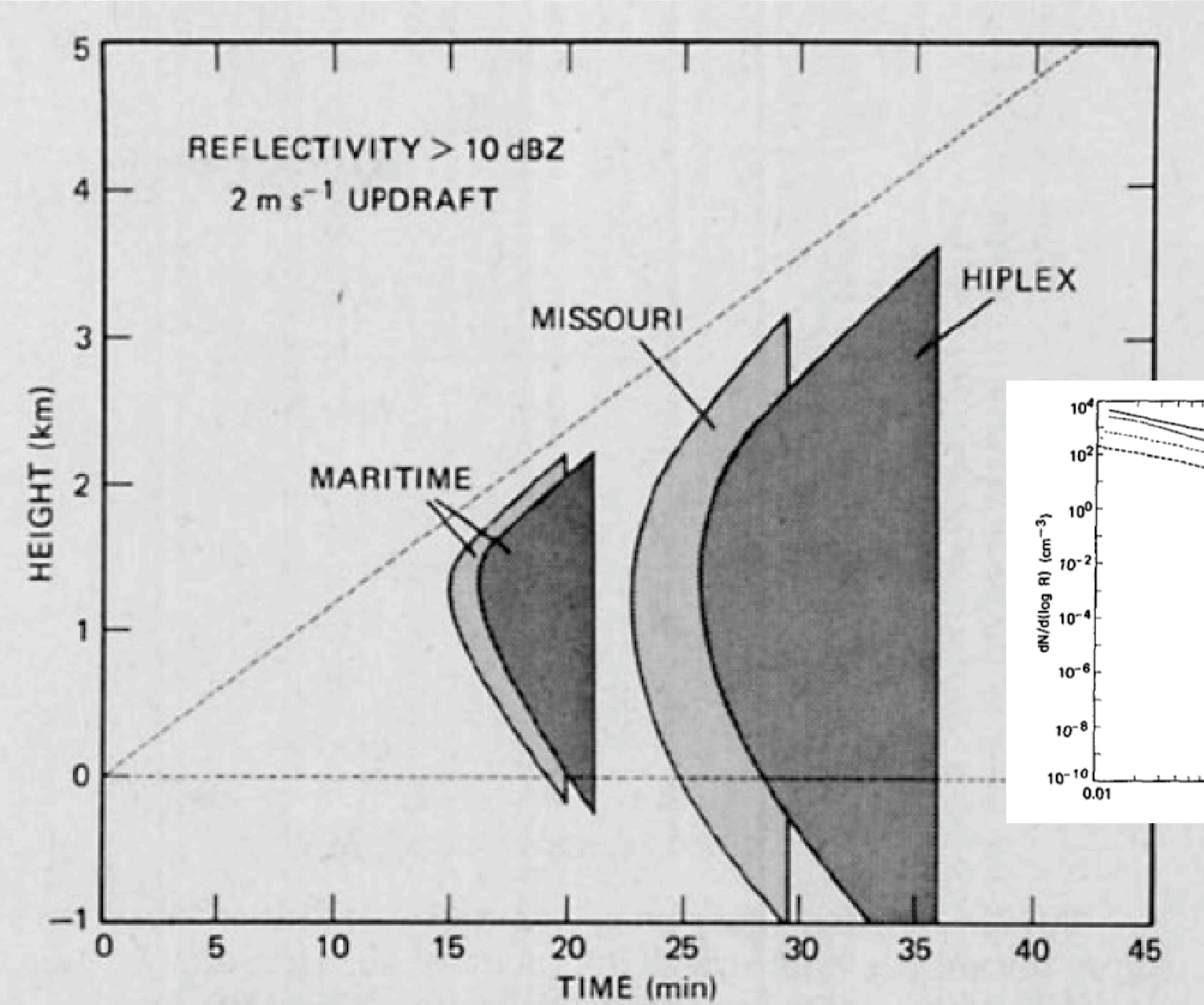
Gunn, R and B. B. Phillips, 1957: An experimental investigation of the effect of air pollution on the initiation of rain. *J. Atmos. Sci.*, **14,** 272-280

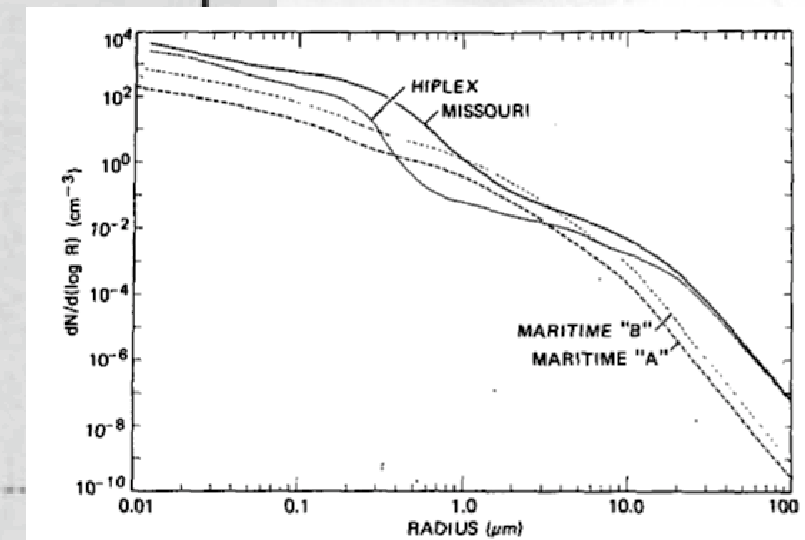
3000 m^3 expansion chamber
LWC ≈ contant



…s, 1957: An … of the effect of air pollution on the initiation of rain. *J. Atmos. Sci.*, **14,** 272-280

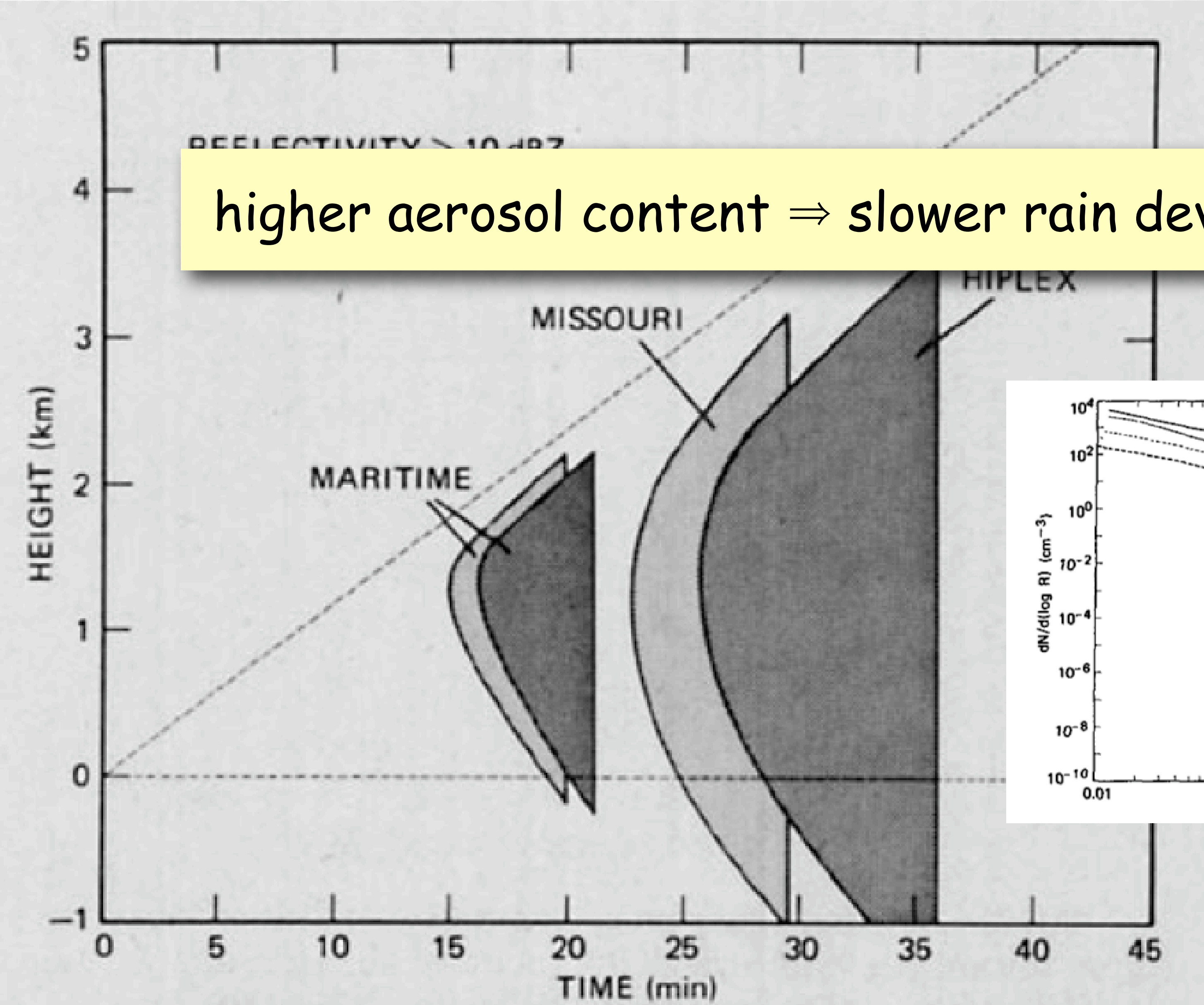
3000 m^3 expansion chamber
LWC ≈ contant

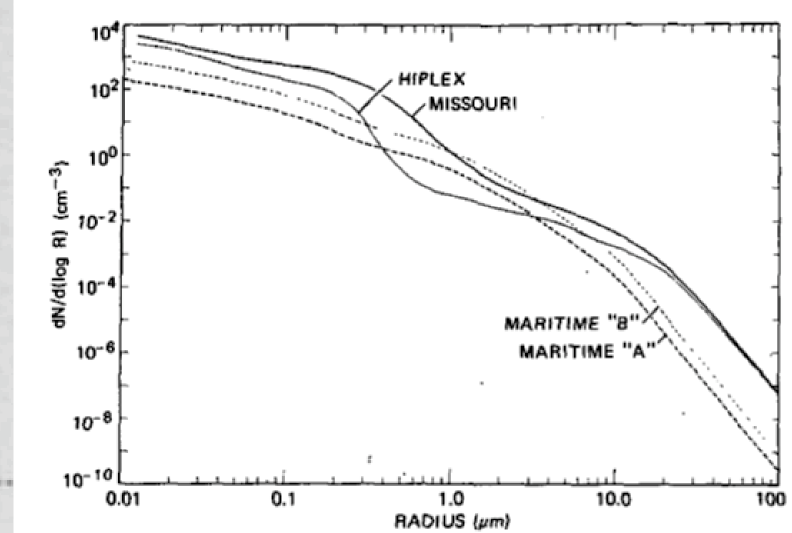




Johnson, 1982

higher aerosol content ⇒ slower rain development





Johnson, 1982

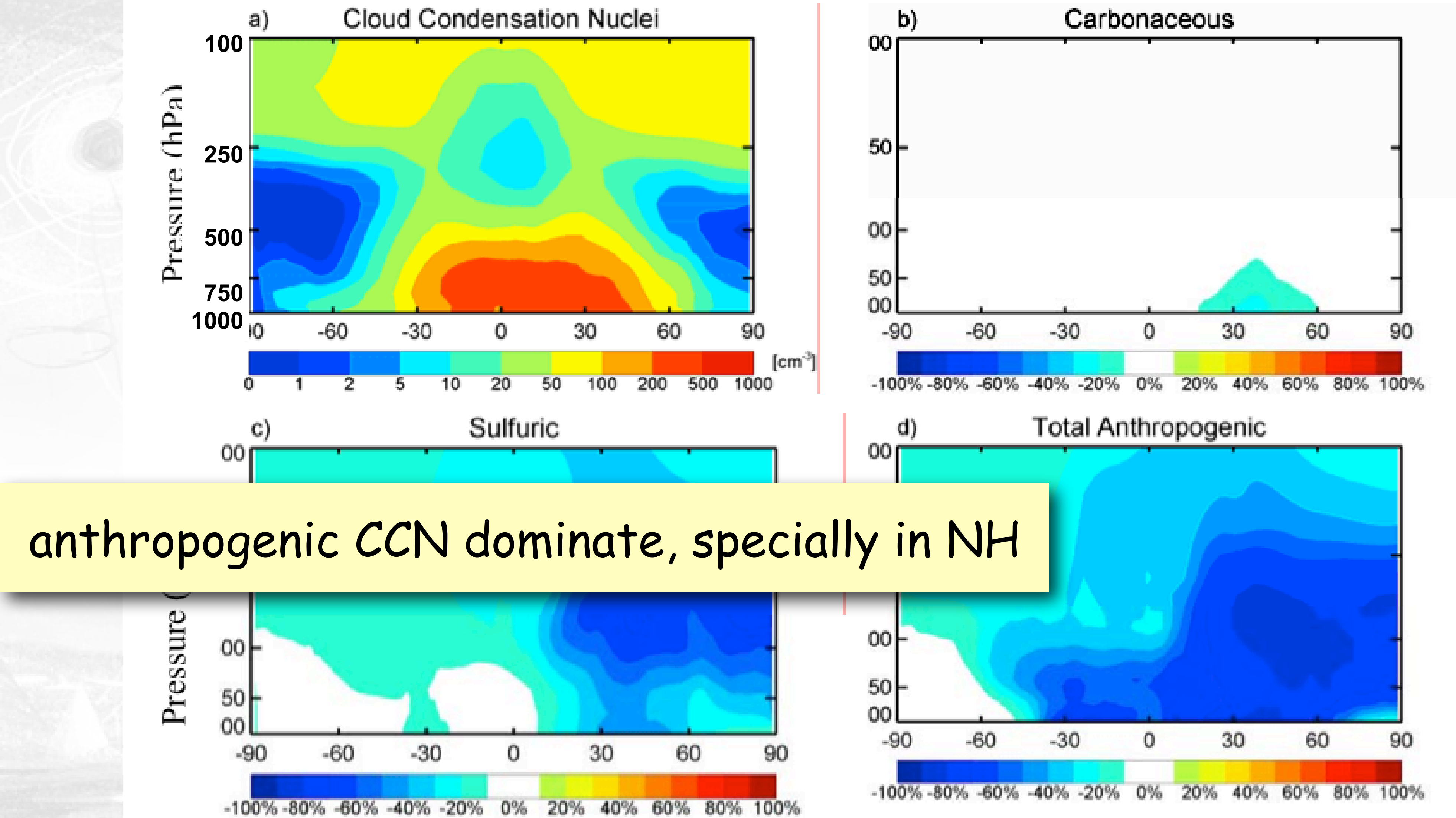


Figure 3-6. *a) Total zonal annual-mean cloud condensation nuclei (cm^{-3} STP{1013hPa, 273.15K}) as simulated by the ECHAM5-HAM aerosol model. CCN are defined here as hygroscopic accumulation and coarse mode aerosol particles. Change in CCN due to the omission of b) carbonaceous emissions from fossil-fuels and industry, c) sulfur emission from fossil-fuels, industry, and bio-fuels, d) all anthropogenic emissions including fossil-fuels, industry, bio-fuels, and vegetation fires (adapted from Stier et al.[2005,2006]).*

1. Source of the aerosol matters

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Indicators elements in rain vary according to airmass trajectory.

Anker et al., 2007
J. Geophys. Res., **112**, D03306, doi:10.1029/2006JD007517

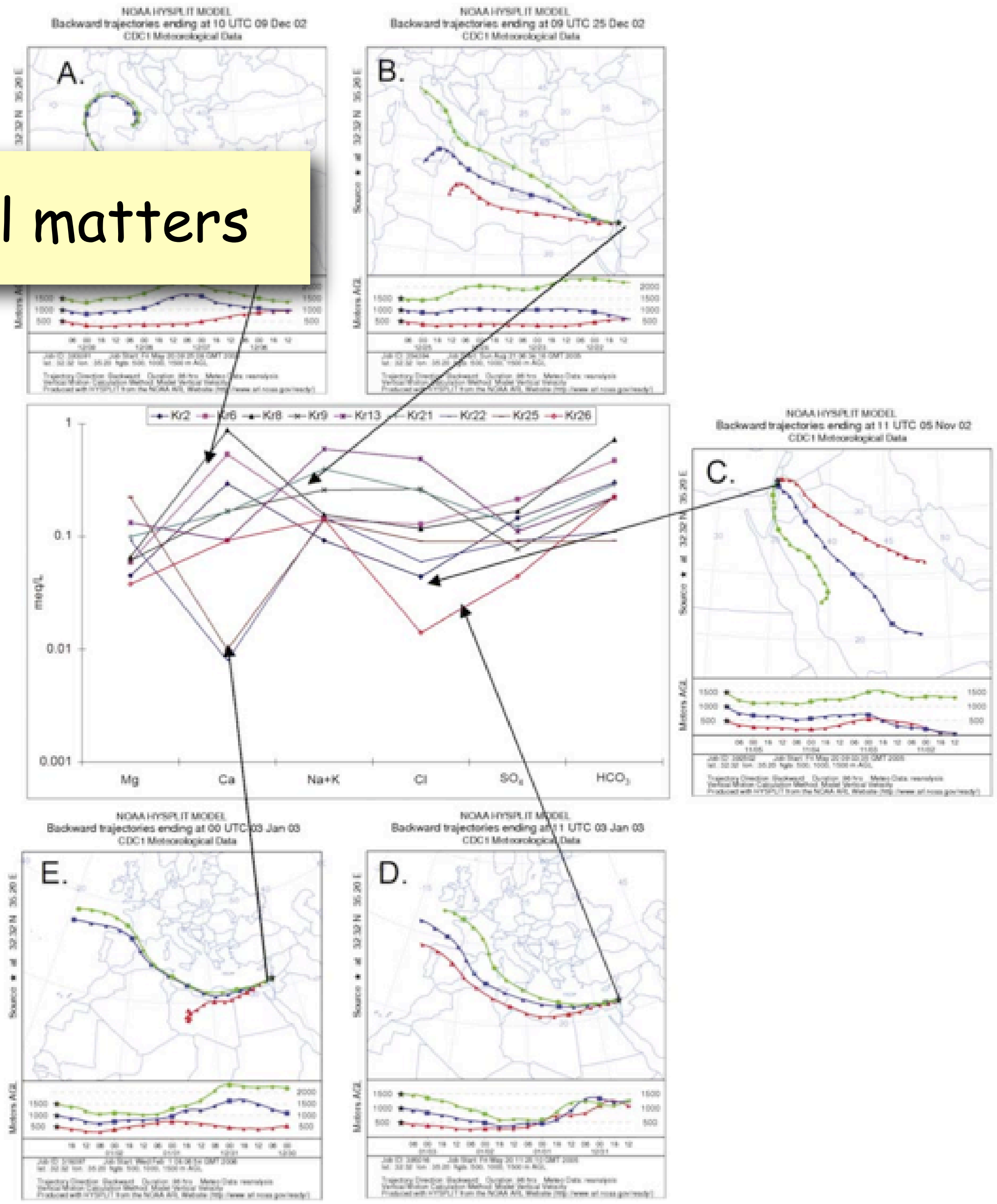
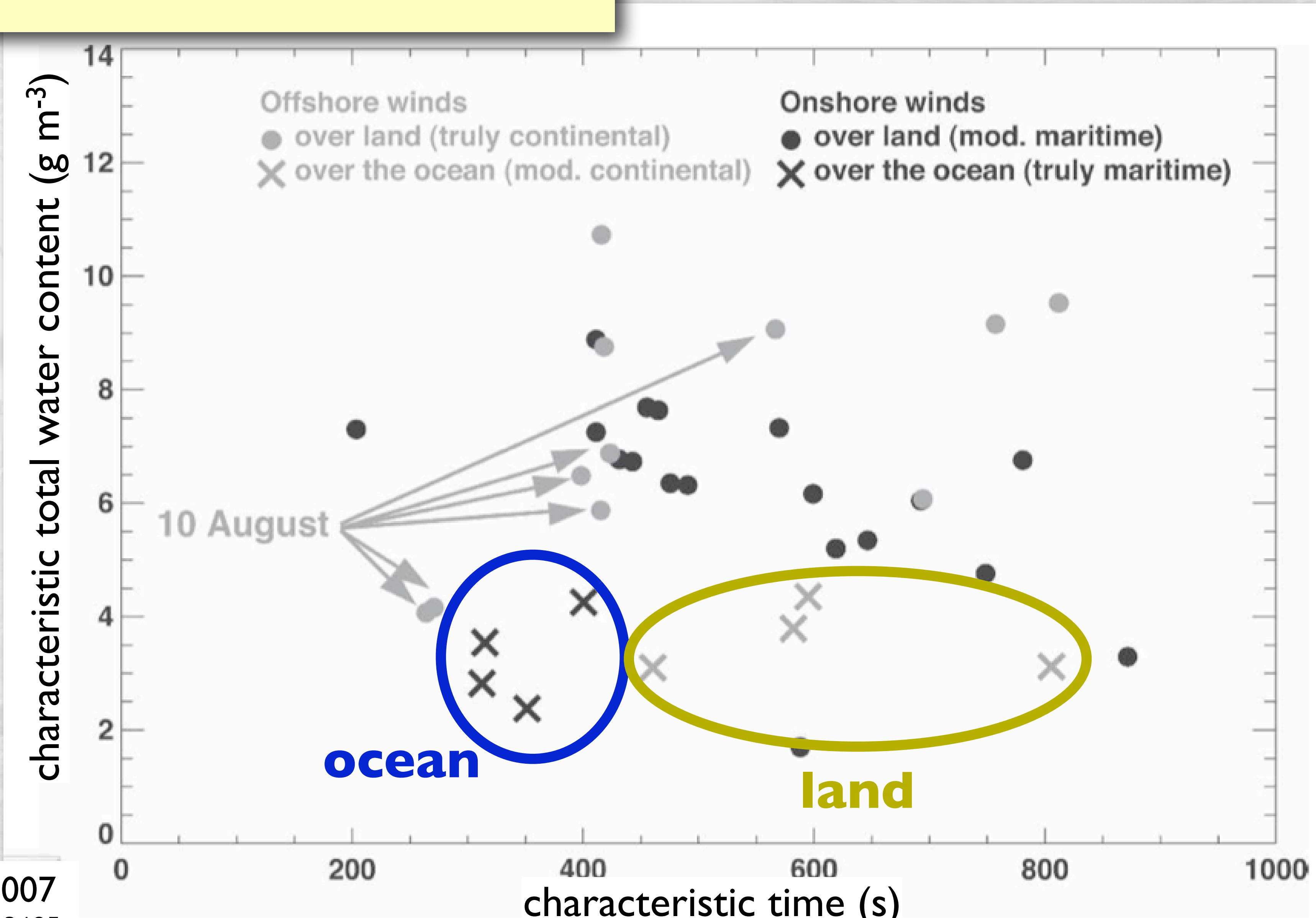
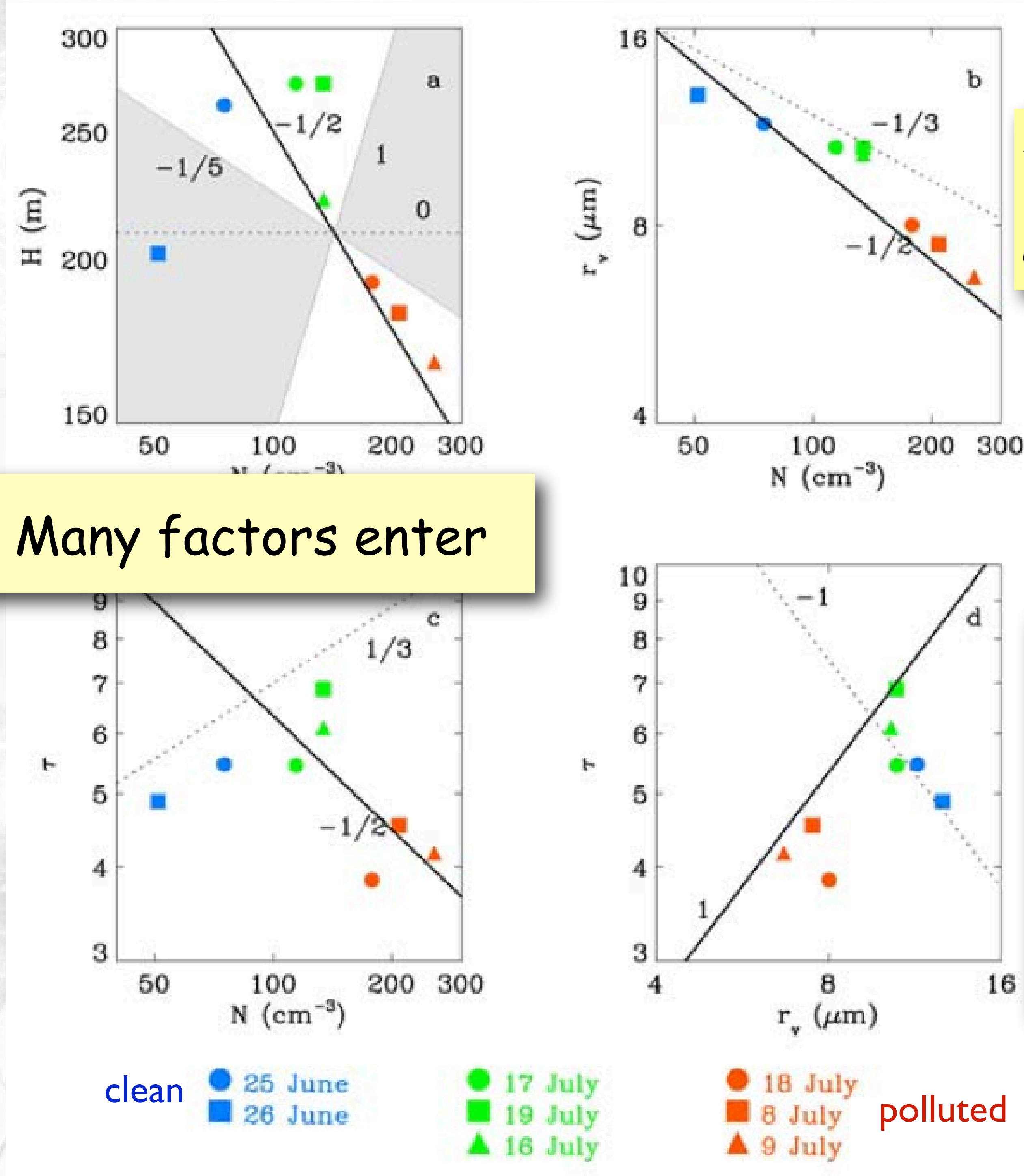


Figure 6. Schoeller diagram of rainwater from Yizre'el, cross linked with typical air mass parcel trajectories: (a) Kr 8 representing cSW trajectories, (b) Kr 21 representing mW trajectories, (c) Kr 2 representing cSE trajectories, (d) Kr 26, and (e) Kr 25 representing two stages in SW (tropical).

1. Source of the aerosol matters



Göke et al., 2007
J. Atmos. Sci., **64**, 3695



← r_v vs. N is close to expected

2. Many factors enter

ACE-2

← tau vs. r_v is contrary to expected because polluted clouds were also thinner due to their passage over land

Brenguier, Pawlowska and Schuller, 2003

3. Effects on precipitation are sensitive to detail

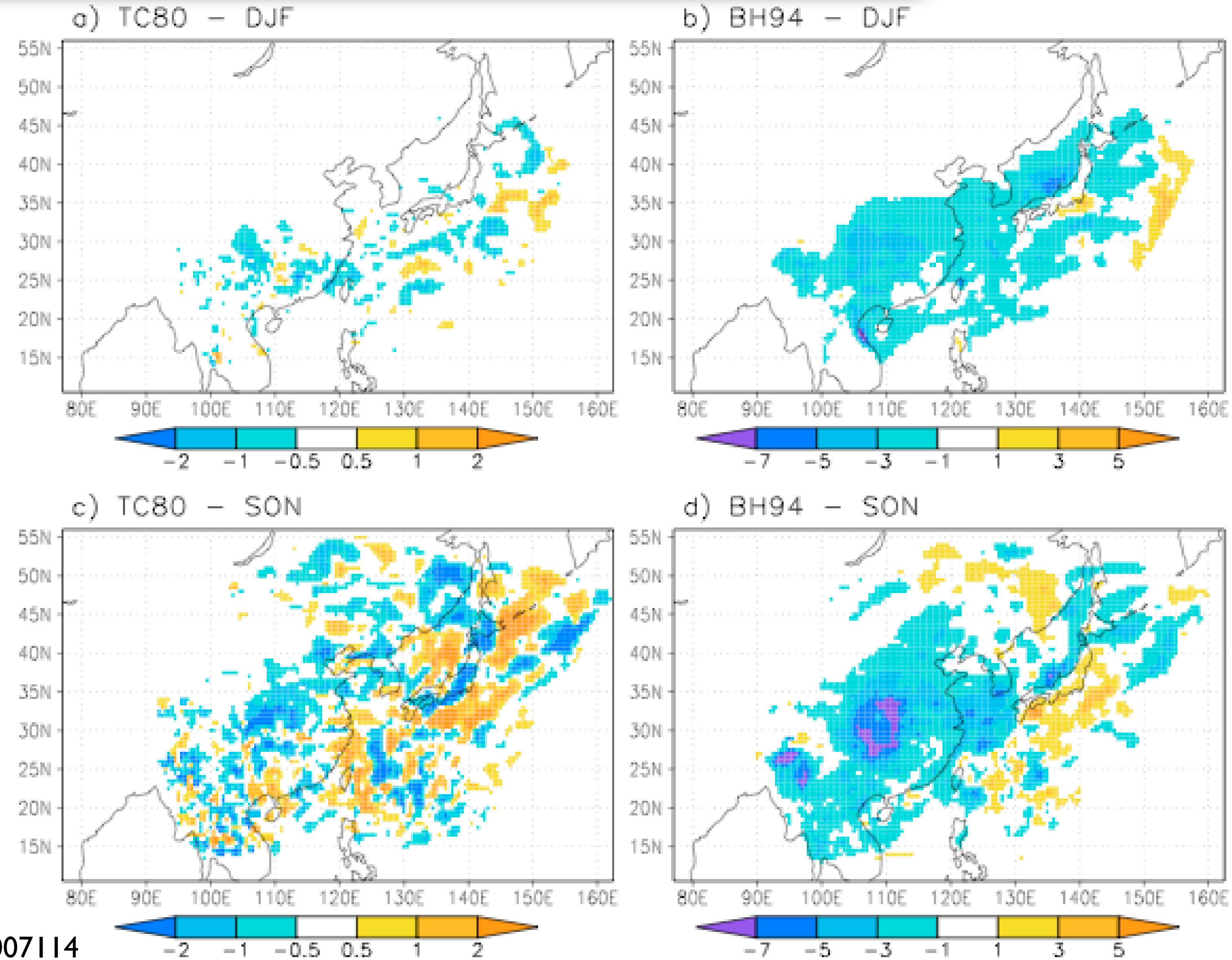


Figure 6. Spatial distribution of seasonal precipitation change (10 mm month^{-1}) in DJF and SON from second indirect effect only experiments using the TC80 and BH94 schemes: (a) TC80 – DJF, (b) BH94 – DJF, (c) TC80 – SON, and (d) BH94 – SON. Note different scales.

Huang, Chameides and Dickinson, 2007
J. Geophys. Res. , **112**, D03212, doi:10.1029.2006D007114

Expectation is that polluted clouds develop less precipitation via the coalescence process. This results from larger droplet concentrations, smaller cloud droplets and slower development of large drops while the clouds are getting diluted and may be dissipating.

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Evidence for the connection between sub-cloud aerosol (CCN) and droplet number and size is fairly solid from both in situ, remote sensing measurements and form models in maritime boundary layer clouds.

SOCEX: Boers et al. 1996, 1998
ACE2: Snider et al. 2003
DYCOMS: Twohy et al. 2005

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SOCEX: Boers et al. 1996, 1998

ACE2: Snider et al. 2003

DYCOMS: Twohy et al. 2005

Even in marine Sc, the evidence for precipitation decrease at the ground as a result of increased CCN content is elusive. Additional factors become significant: cloud depth, temperature, stability, etc.

It isn't possible to ideally separate the impacts of aerosols on cloud microphysics and precipitation from:

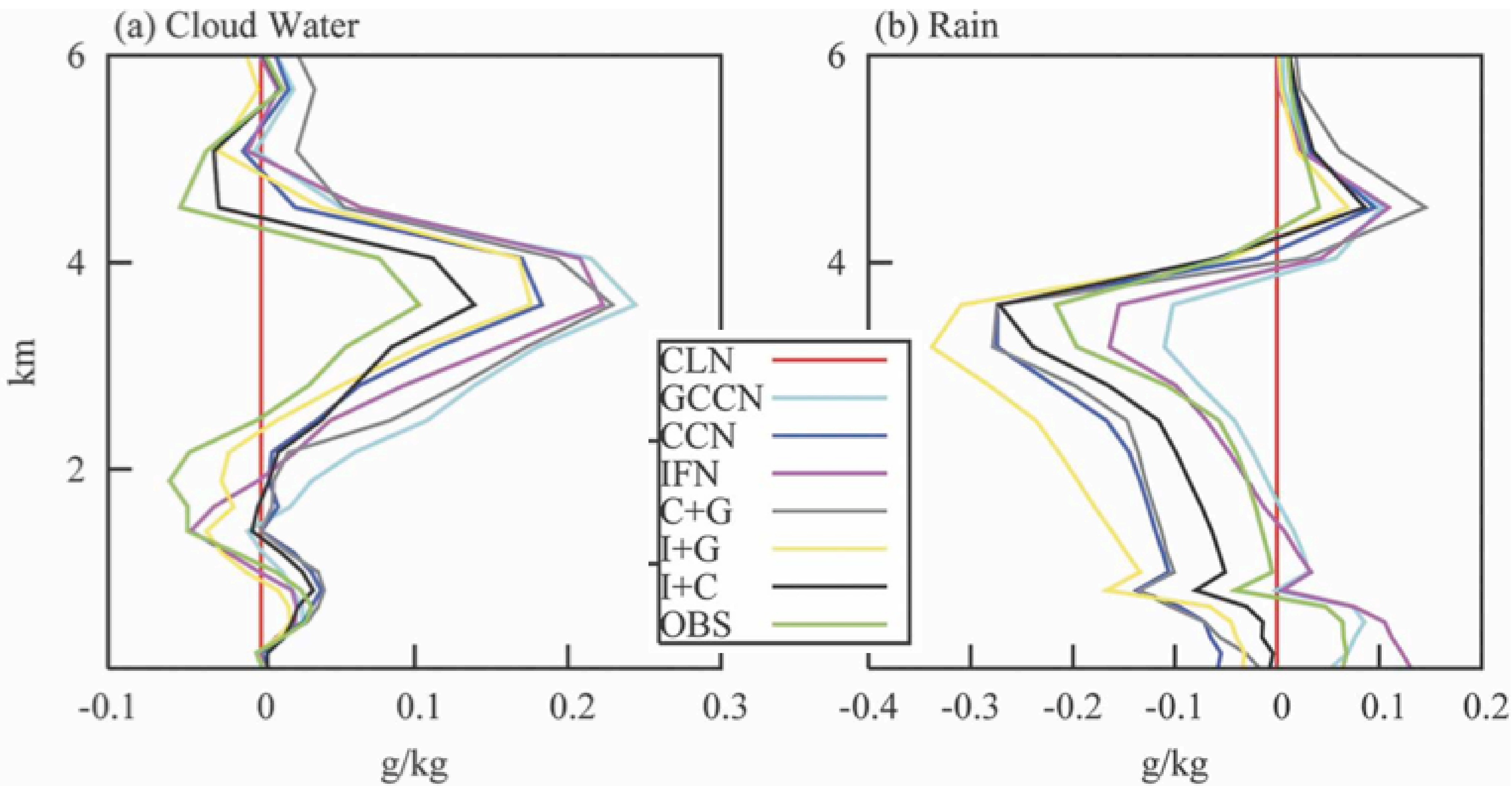
- coincident alterations of dynamical, thermodynamical and other factors,
- direct, and semi-direct aerosol effects, with their associated changes in dynamics and hydrology,
- feedbacks resulting from the indirect effects.

As a result, the search continues to isolate causes and quantify the outcomes in the empirical data, and in models.

Other potential aerosol impacts on 'warm rain'

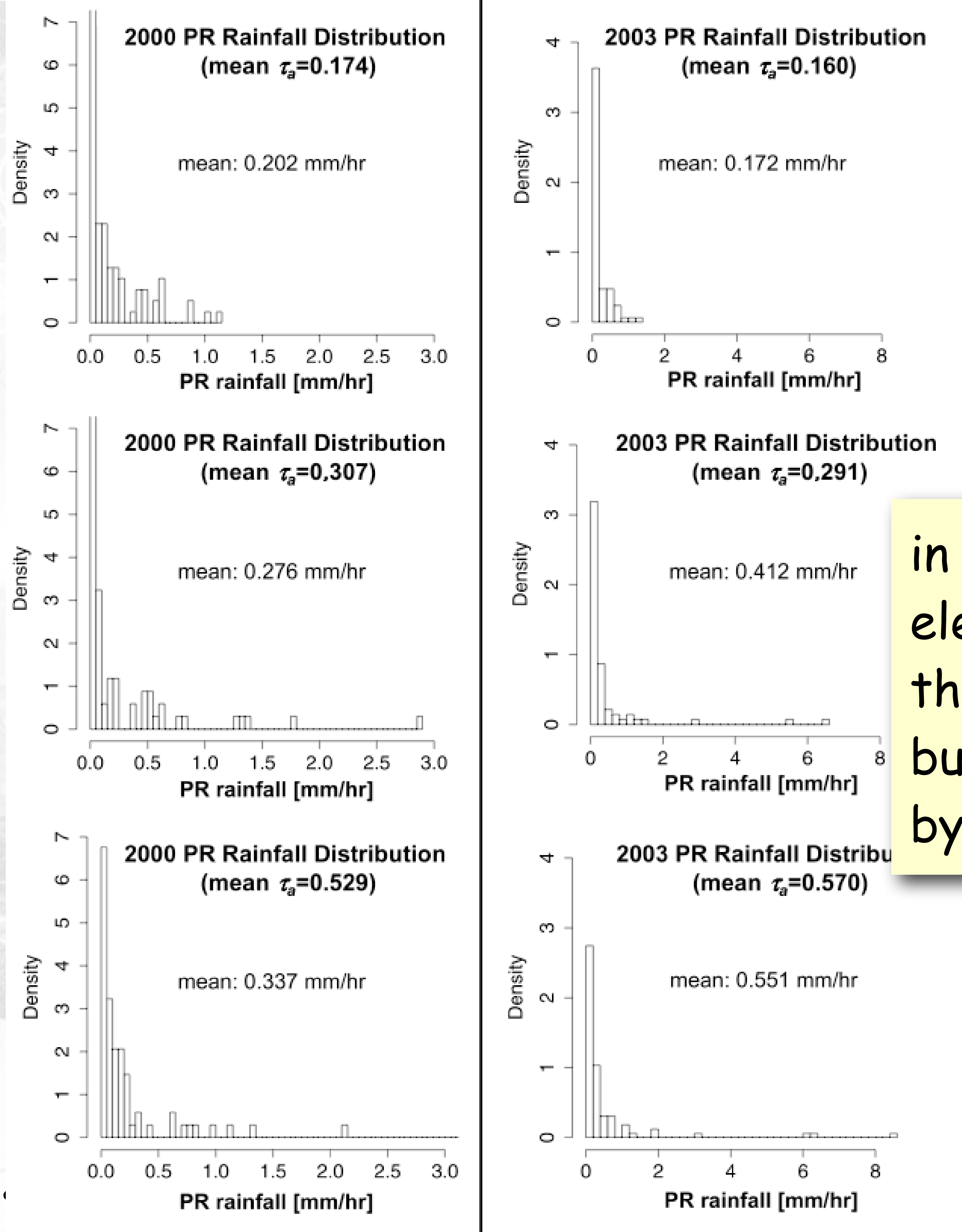
- GCCN (giant CCN) accelerate coalescence
- increased CCN → less loading → more vigorous updrafts → taller clouds

etc., etc.



van den Heever et al., 2006
J. Atmos. Sci. **63**, 1752

model calculations show that precipitation from deep convection in Florida increases with higher IN, or GCCN content and decreases with more CCN



Lin et al., 2006

J. Geophys. Res., 111, D19204

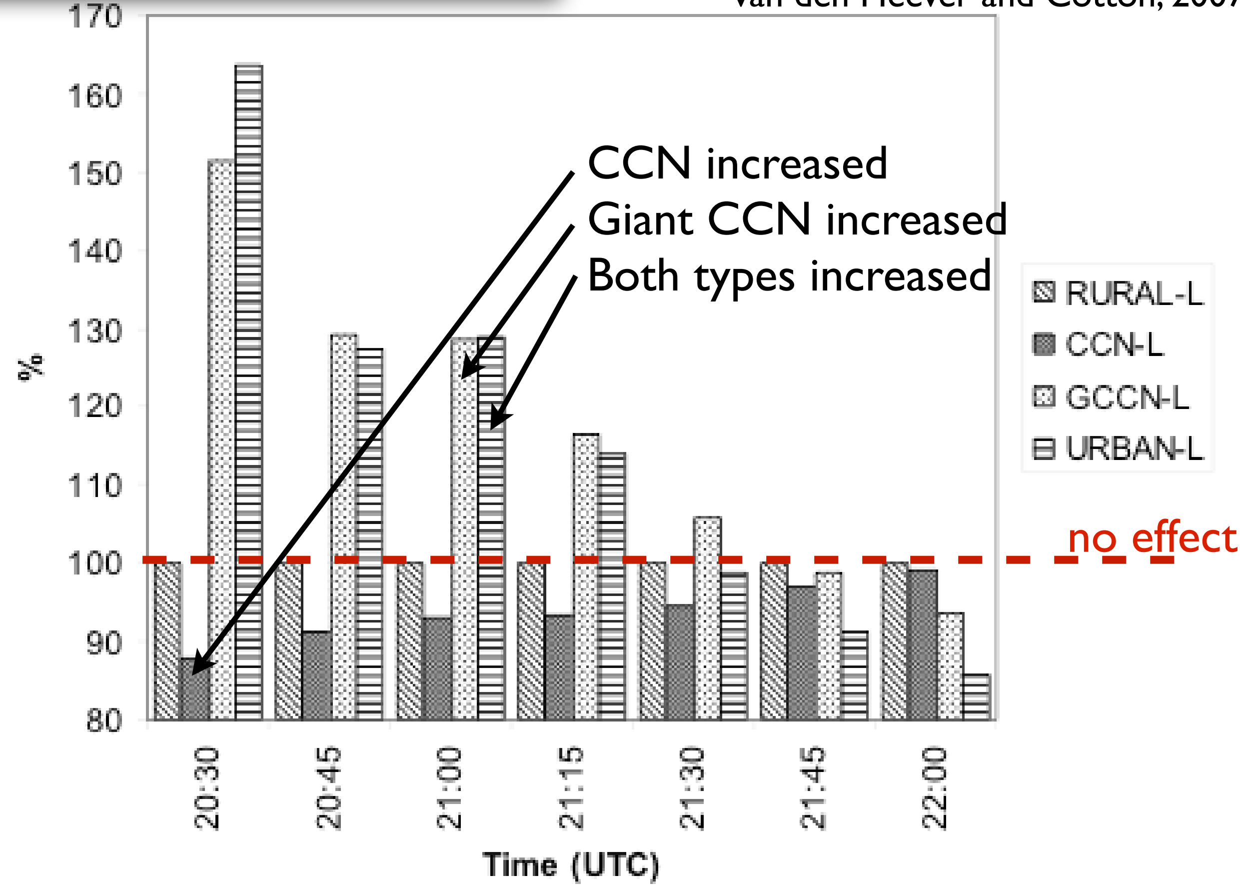
in the Amazon Basin, elevated aerosol optical thickness (biomass burning) is accompanied by higher precipitation

Urban precipitation anomalies:

roughness, convergence
heat island
aerosol pollution

IPCC AR4WG1 Ch.3

van den Heever and Cotton, 2007



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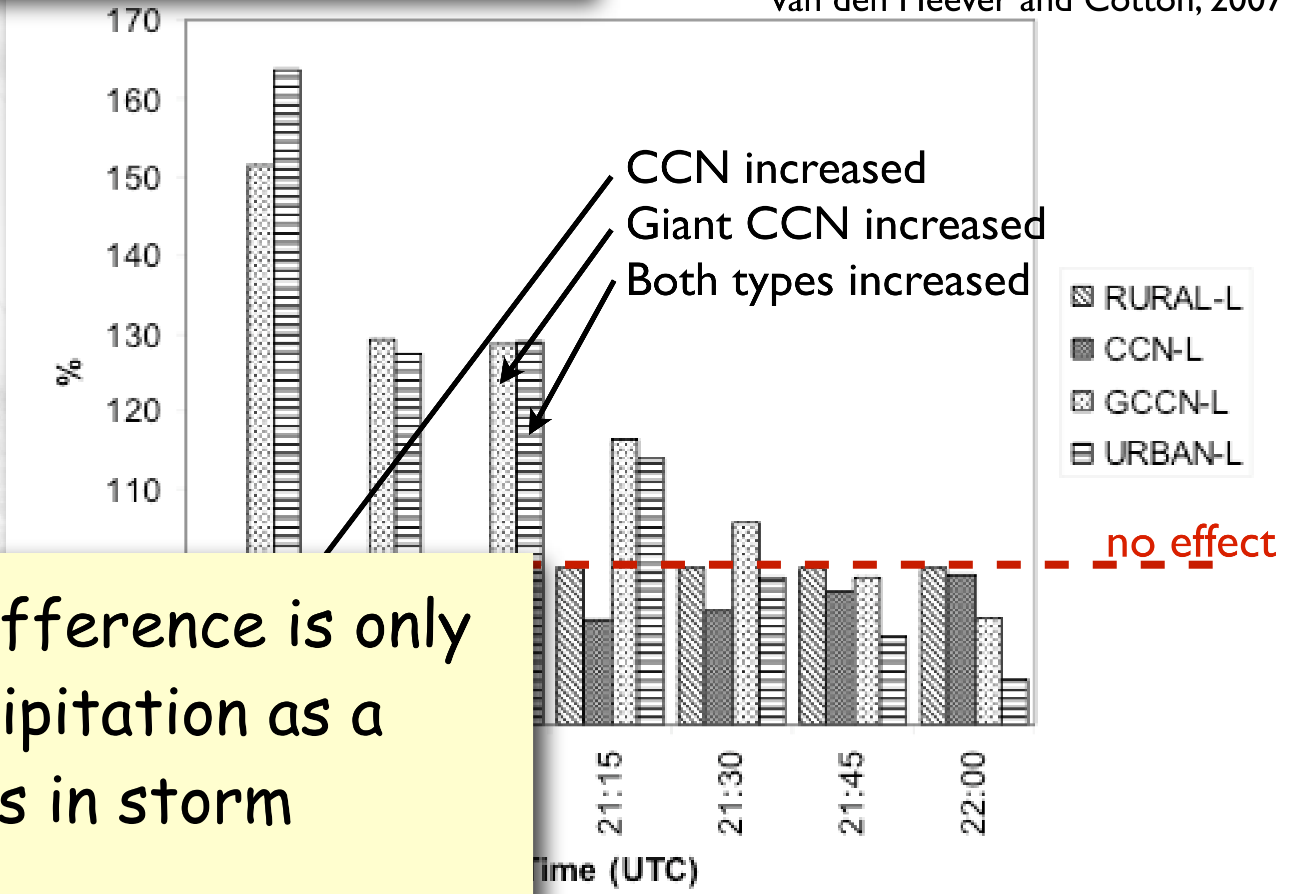


urban to rural difference is only in timing of precipitation as a result of changes in storm characteristics

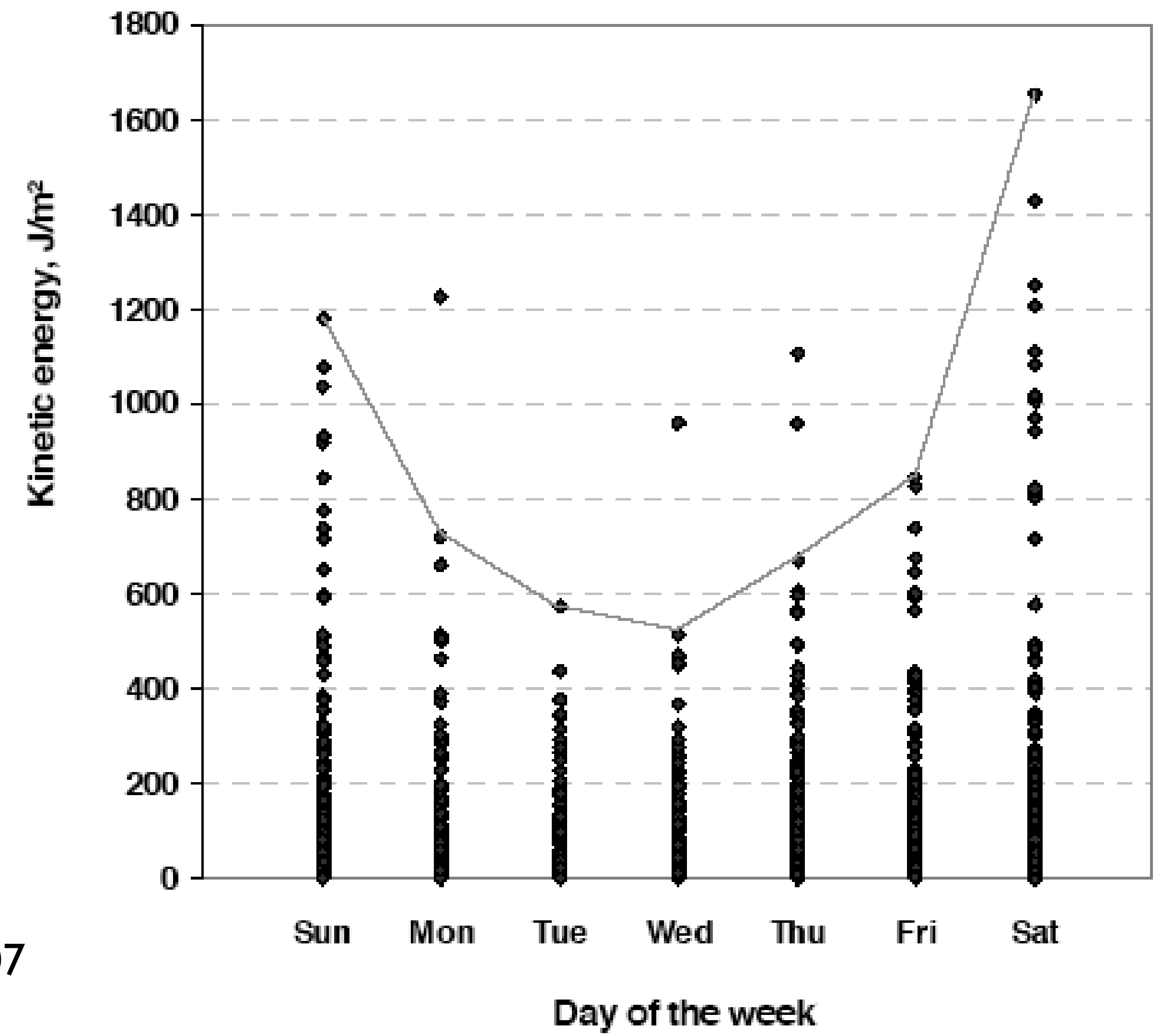
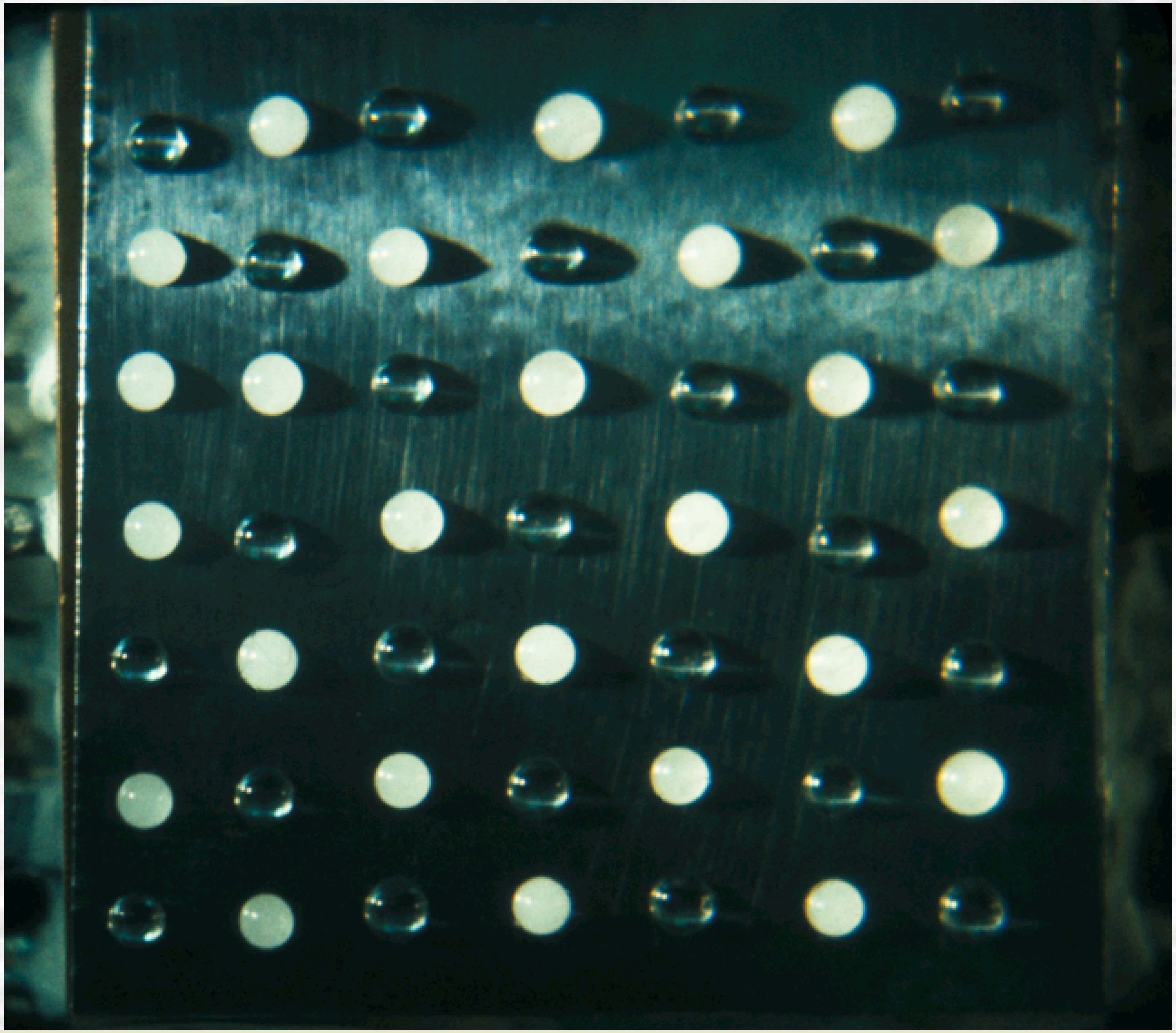


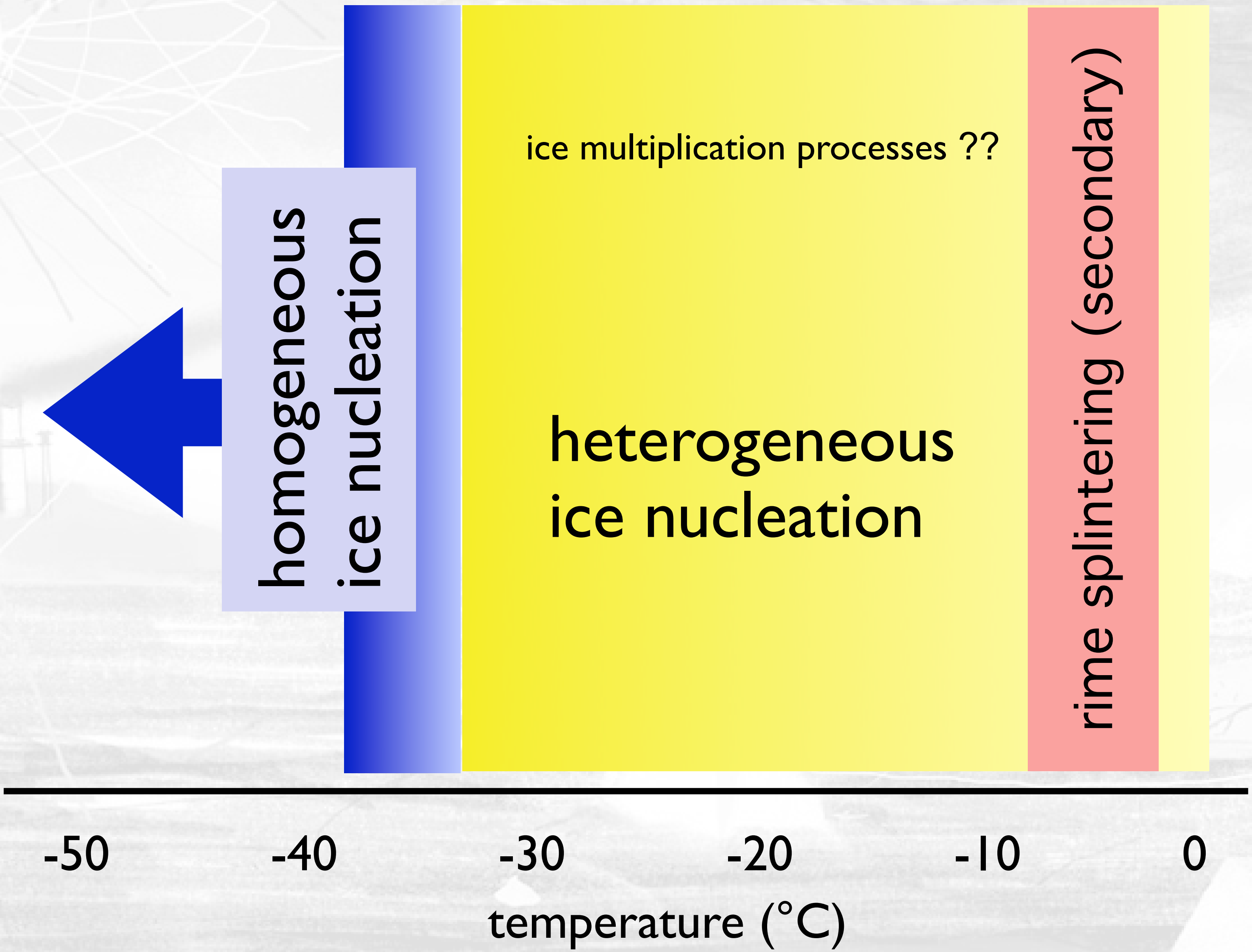
Fig. 1. Kinetic energy of 2,269 point hailfalls in the Midi Pyrénées region from 1989 to 2006 according to the day of the week. The curve is hand drawn.

Dessens et al., 2007
9th Wx. Mod. Conf.

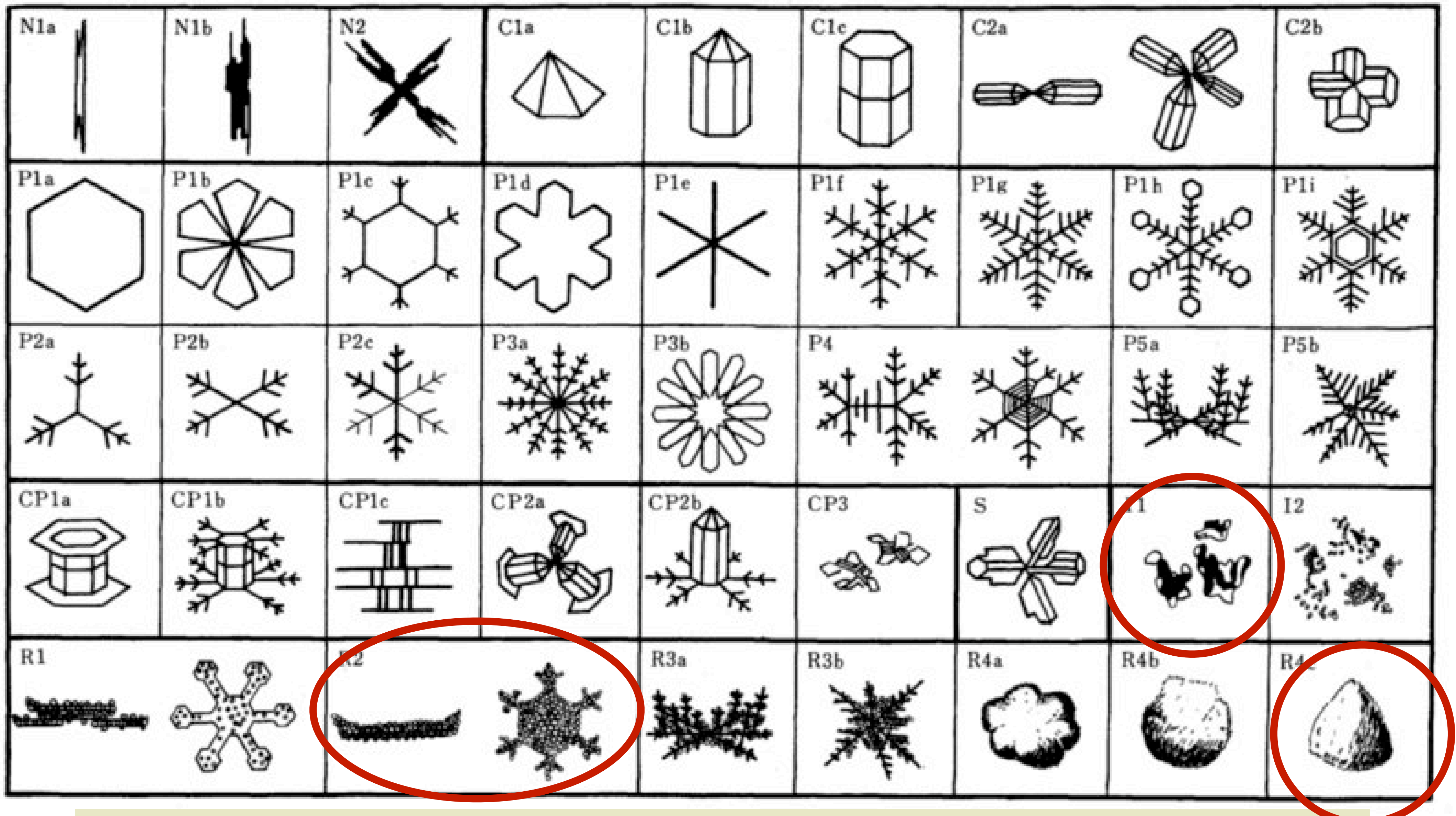
ICE



water drops freeze at different temperatures, depending on the ice nuclei (IN) they contain

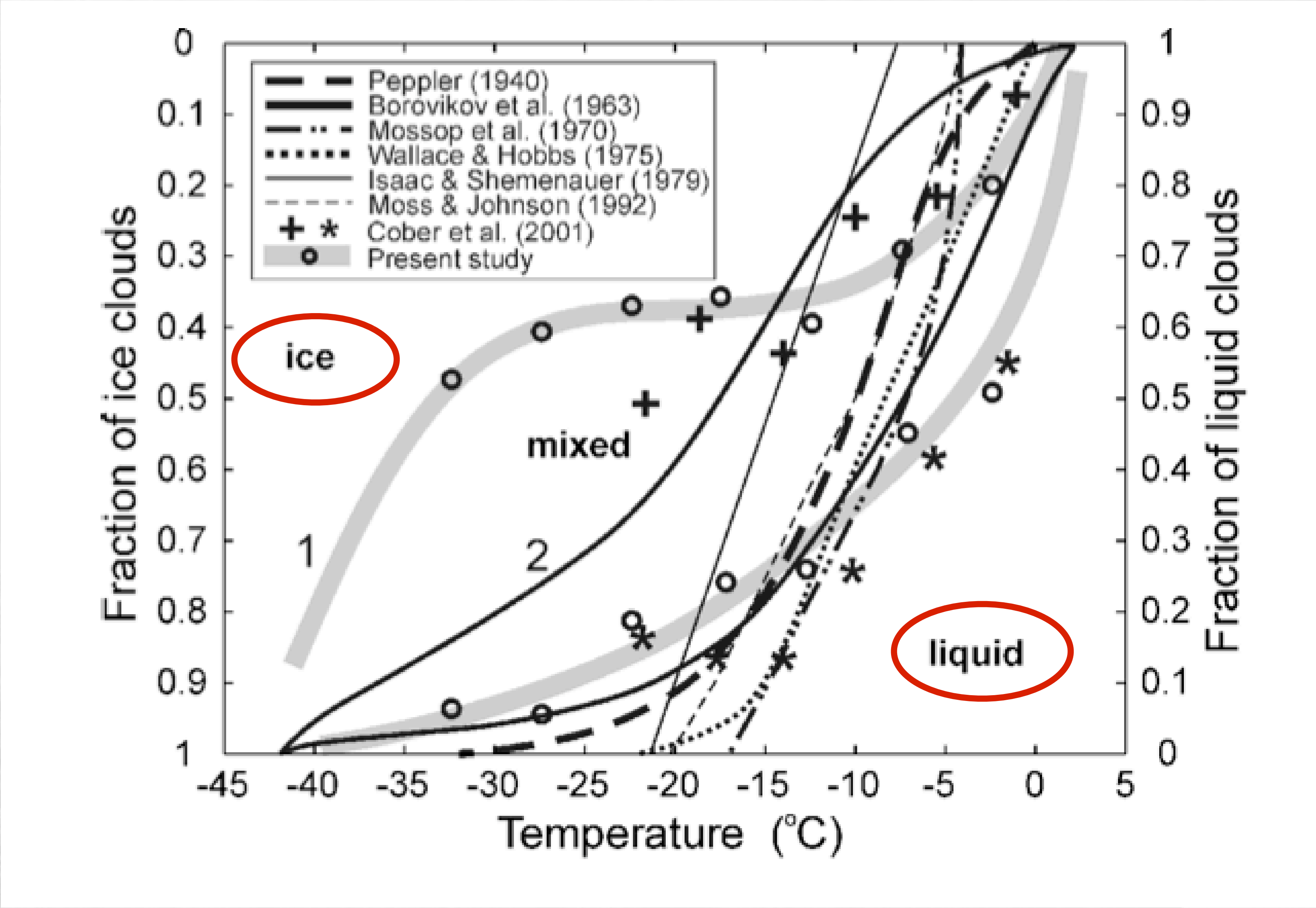

ice multiplication processes ??
heterogeneous
ice nucleation
homogeneous
ice nucleation
rime splintering (secondary)
-50
-40
-30
-20
-10
0
temperature (°C)

Nakaya, 1954



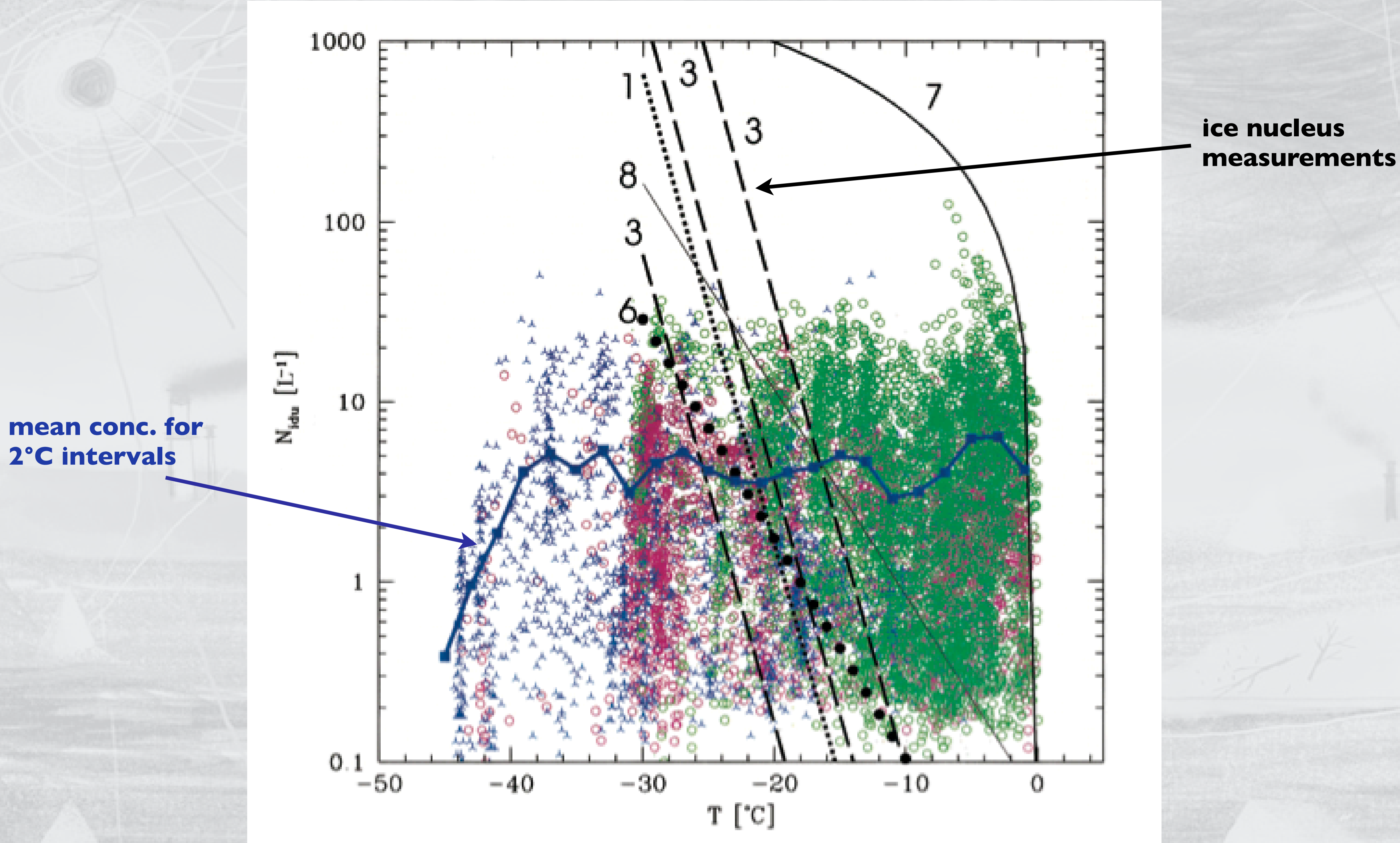
ice particles in the atmosphere develop in many different forms - a significant complication in observation and modeling

Source: Korolev et al., 2003 (Quart. J. Roy. Meteor. Soc.)

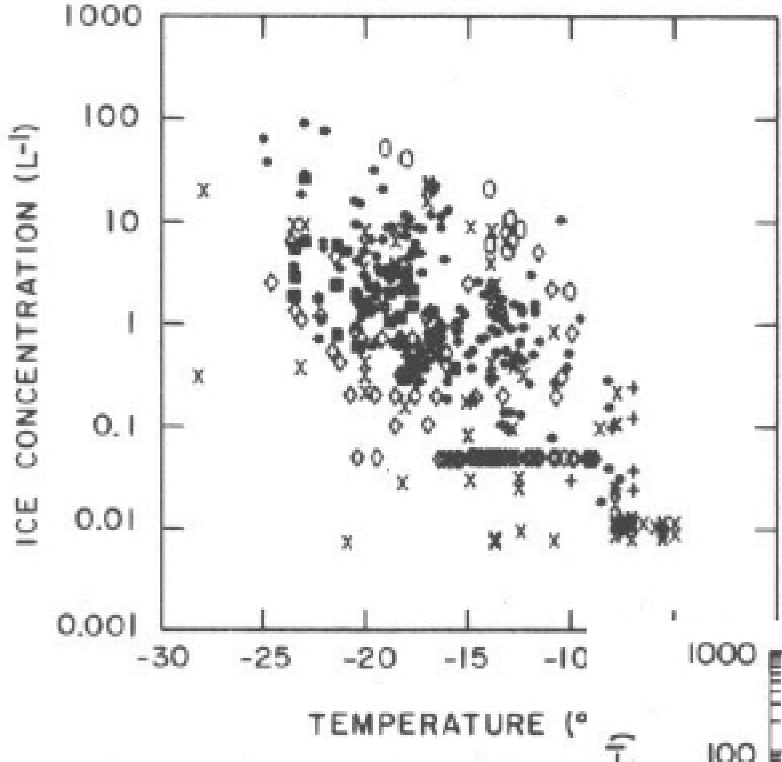


Zones of ice and liquid clouds by temperature.

Source: Gultepe et al., 2001(Int'l J. Climat.)

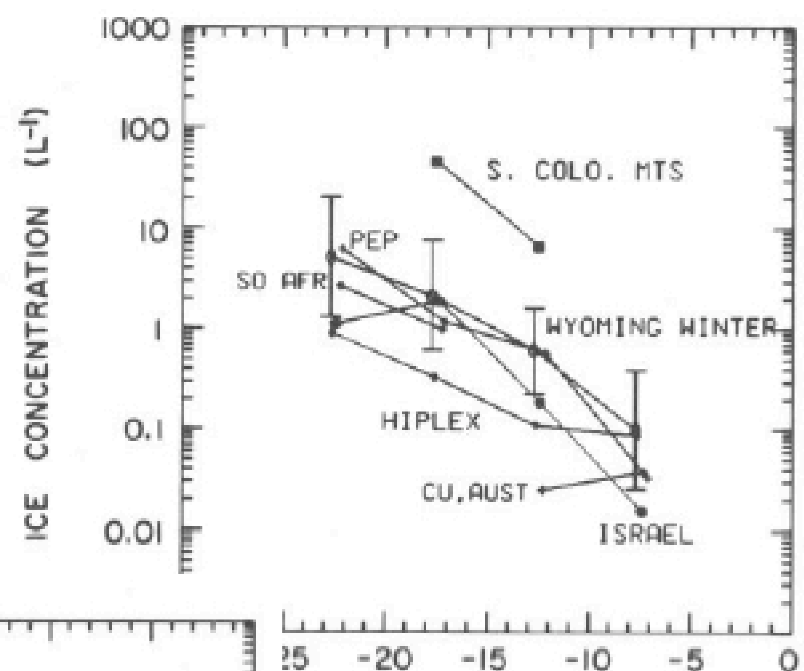


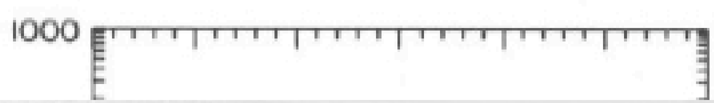
Ice particle concentrations from aircraft measurements (2D-C probe) in various projects

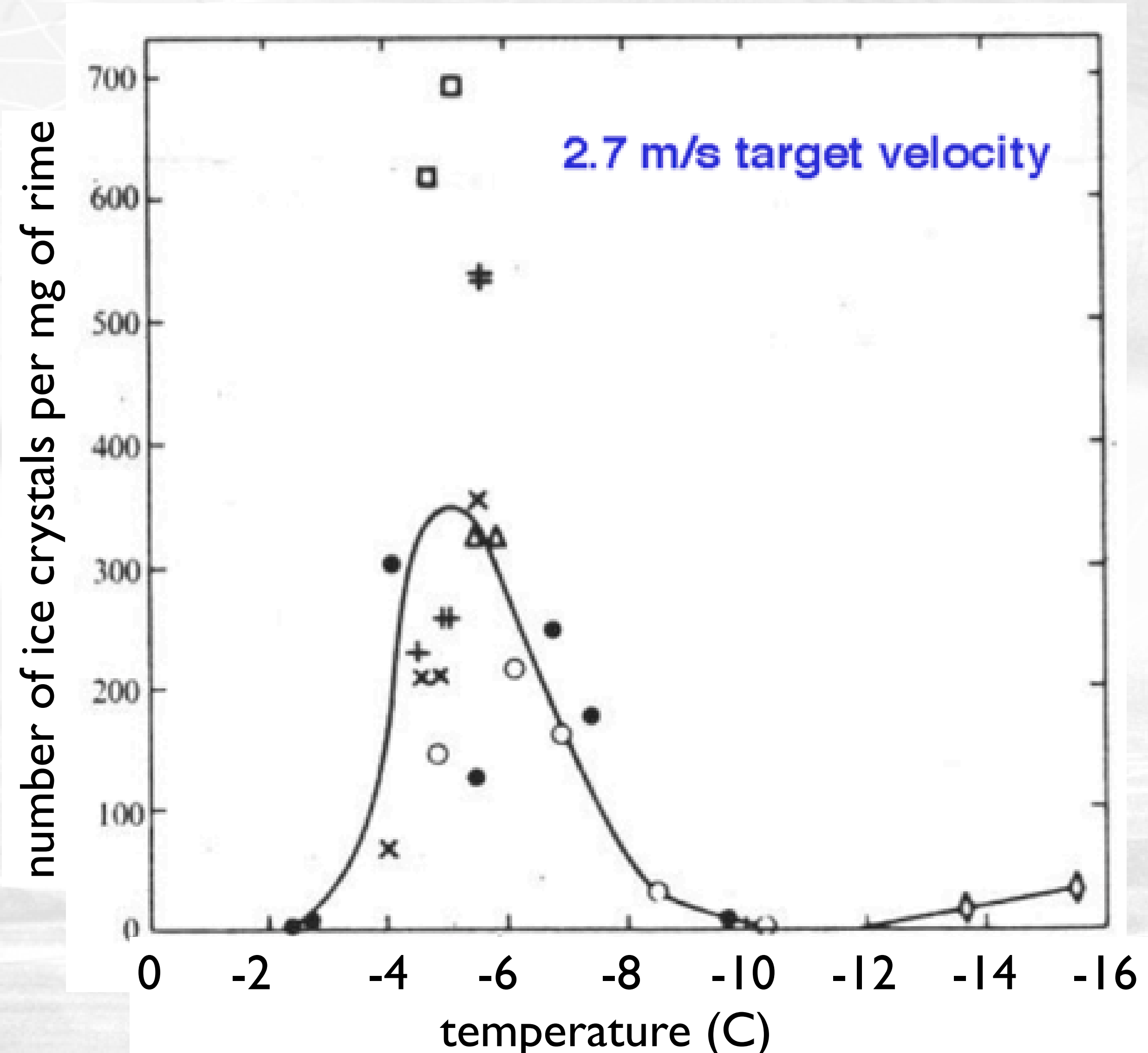


Cooper,1986

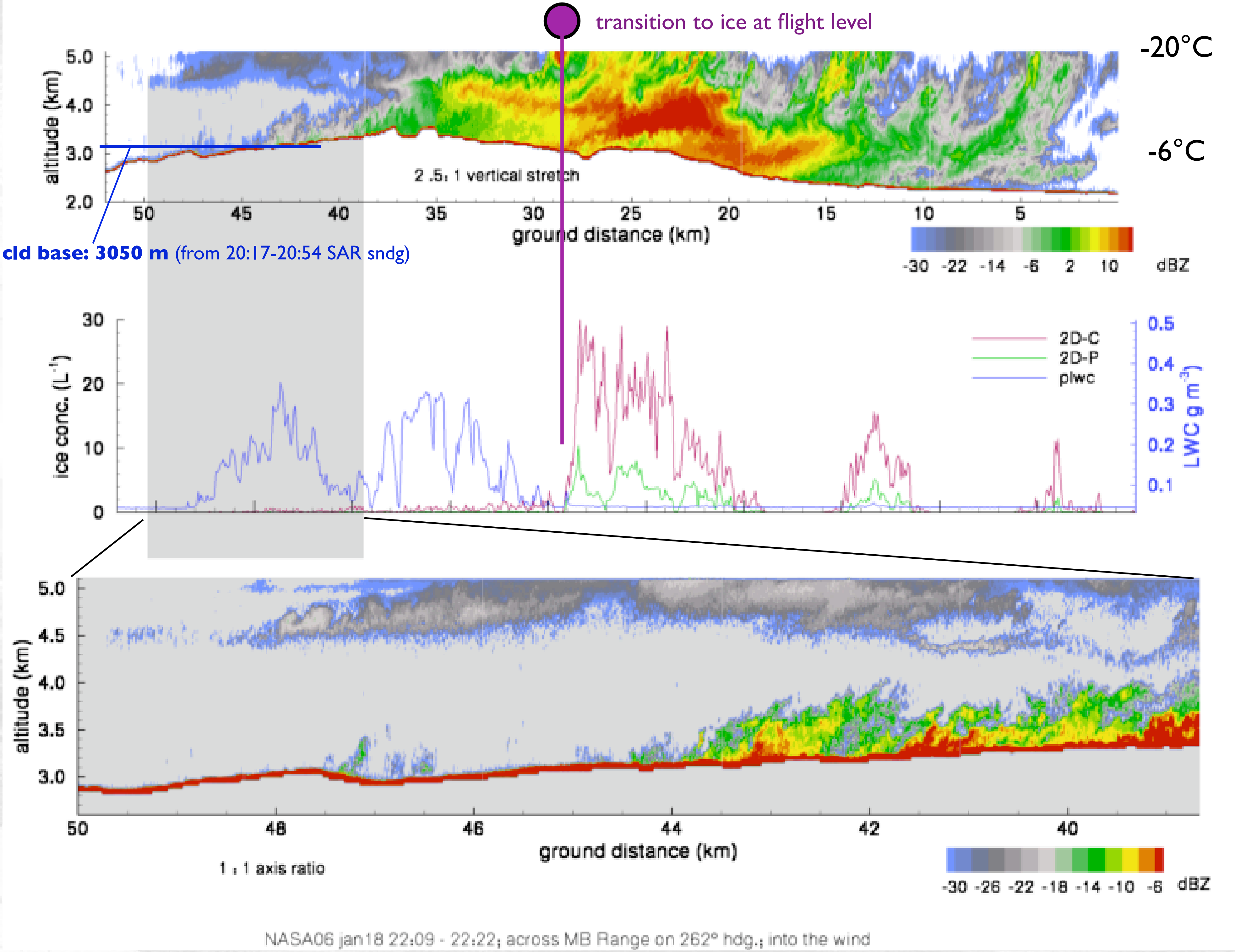
for cases where ice concentration can be attributed to nucleation







Hallett and Mossop, 1974



transition to ice at flight level
-20°C
-6°C
altitude (km)
2 .5: 1 vertical stretch
ground distance (km)
cld base: 3050 m (from 20:17-20:54 SAR sndg)
-30 -22 -14 -6 2 10 dBZ
ice conc. (L-1)
LWC g m-3
2D-C
2D-P
plwc
1 : 1 axis ratio
-30 -26 -22 -18 -14 -10 -6 dBZ
NASA06 jan18 22:09 - 22:22; across MB Range on 262° hdg.; into the wind

With few exceptions, there is no reliable way to predict ice concentrations in clouds from aerosol or ice nucleus measurements.

This is a major missing element in cloud and climate models. Here, fundamental understanding of processes is the problem, even before the complexities introduced by other factors are considered.

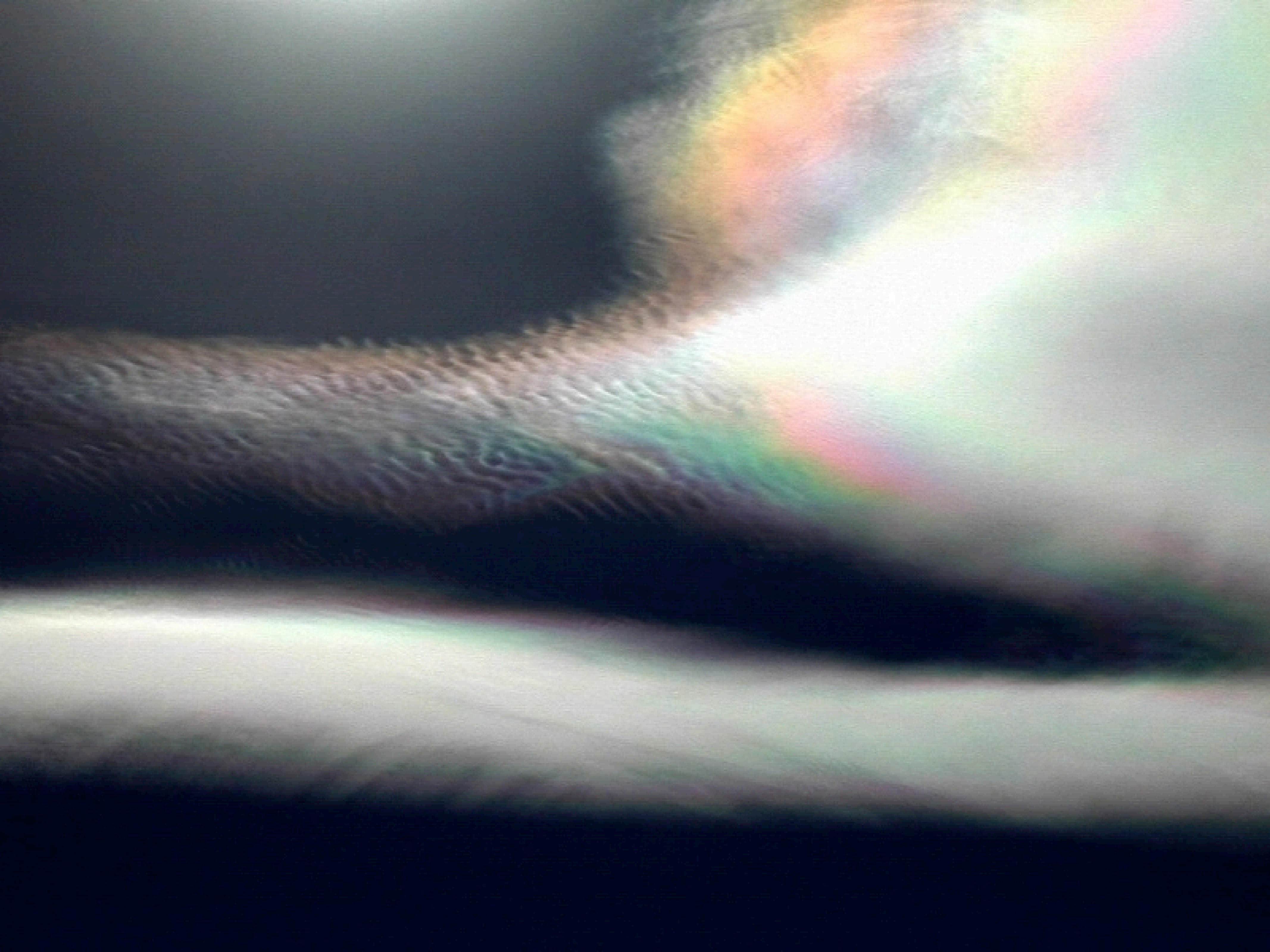
IAPSAG recommendations:

Series of international projects and workshops:

- **Better characterization of aerosols:**
  - **emission inventories**
  - **chemical processes, physical properties and instrumentation**
- **The effects on clouds and precipitation**

Immediate action items:

- **CCN measurements at monitoring stations**
- **IN and ice particle measurement strategy**
- **workshop on aerosol effects on orographic clouds**
- **modeling workshop**
- **generate global data sets**
- **develop statistical tools**
- **WMO web page**



cloud seeding —— **aerosol impacts on precipitation**

cloud seeding

- known aerosol type: hygroscopic or ice nucleating
- point or line sources
- “static” or “dynamic” seeding
- convective clouds
- orographic clouds
- decades of research
- target/control designs

aerosol impacts on precipitation

- mixtures of aerosols
- gaseous pollutant also present
- widespread sources
- no randomized design

- large, continuous sources
- new installations
- weekday/weekend comparisons

same basic physics, similar observational and modeling challenges, similar societal issues

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cloud seeding

aerosol impacts on precipitation

- kn
  hy
- po
- “st
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resent

same pitfalls of rapid judgments and inadequate rigor in the scientific work; same exposure to political pressure

- large, continuous sources
- new installations
- weekday/weekend comparisons

same basic physics, similar observational and modeling challenges, similar societal issues

cloud seeding

aerosol impacts on precipitation

- kn
  hy
- pc
- “st
- convective clouds
- orographic clouds
- decades
- target/cc

resent

- large, continuous sources

s

same pitfalls of rapid judgments and inadequate rigor in the scientific work; same exposure to political pressure

same needs for inventive thinking, for the use of evolving technical possibilities, for the education of young scientists

Greater difficulties:

- mixture of many aerosol sources vs. single agent
- change in aerosol composition downwind
- no randomization possible

Advantages:

- continuous sources (paper mills, ...)
- effect of new source may be contrasted with historical record
- day of week variation may be explored

Examples of problems where immediate efforts overlap:

- measurement of precipitation
- ice nucleus measurements
- remote sensing of cloud structure
- model development
- discussion of concept and realization of "proof"