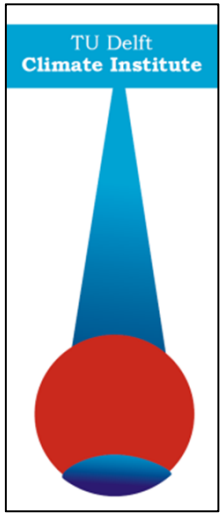
Clouds, climate, challenges

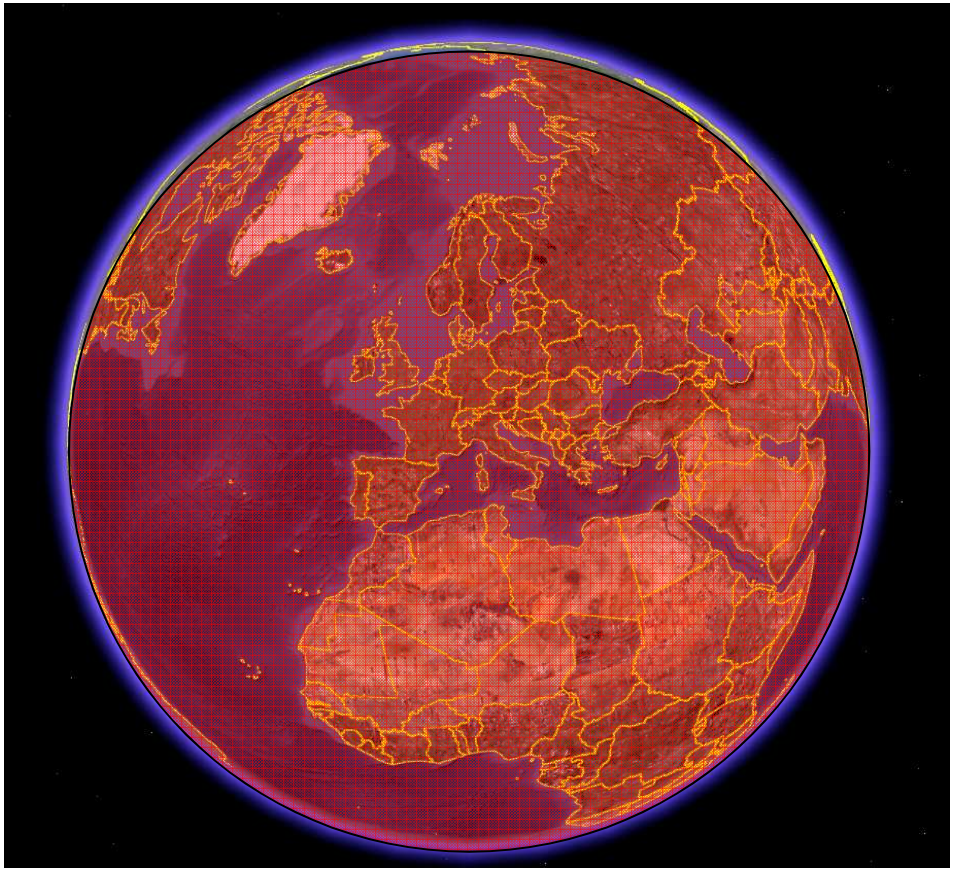
Herman Russchenberg

Remote Sensing of the Atmosphere



Our Earth

is slowly warming



The world population

is moving into the cities



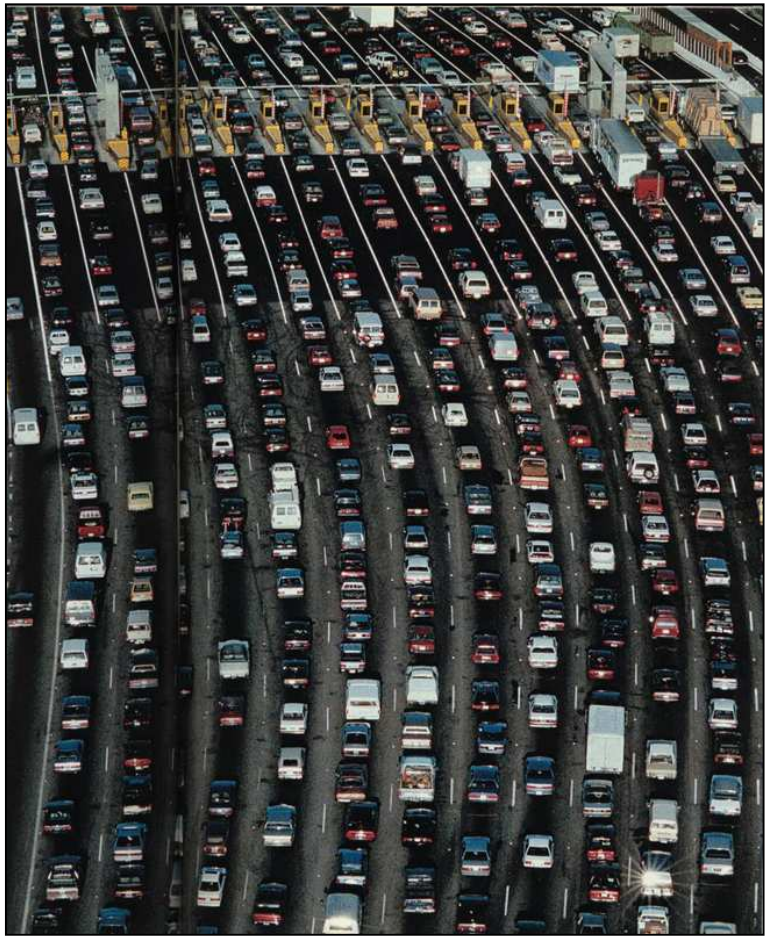
and gets prone to

… severe weather



and gets prone to

… infrarcts



and gets prone to

… heat



and gets prone to

… air pollution



‘Gets prone’

… does not mean ‘will experience’



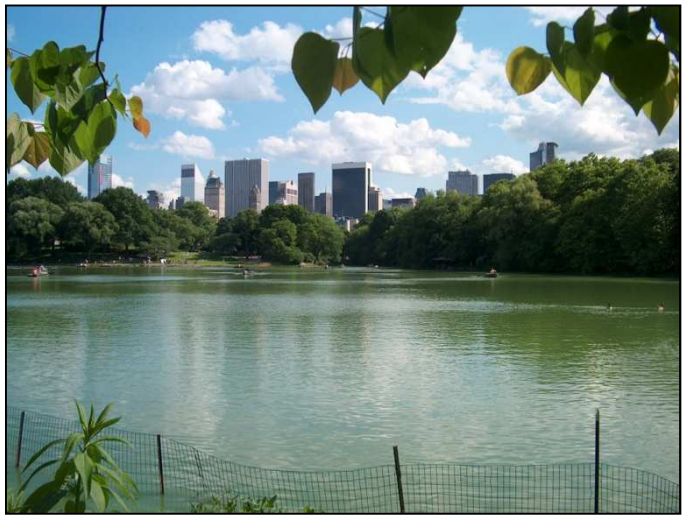
The challenge is

… to make cities a nice place to live

… for 60 % of the world population

… summer, spring, autumn and winter





What is climate?

Long term averaged weather (30 yrs)

What is climate change?

Changes of long term averaged weather (30 yrs)

What is anthropogenic climate change?

Man-induced changes of long term averaged weather (30 yrs)

What drives a climate?

Inflow and outflow of energy

Distribution of energy over the globe

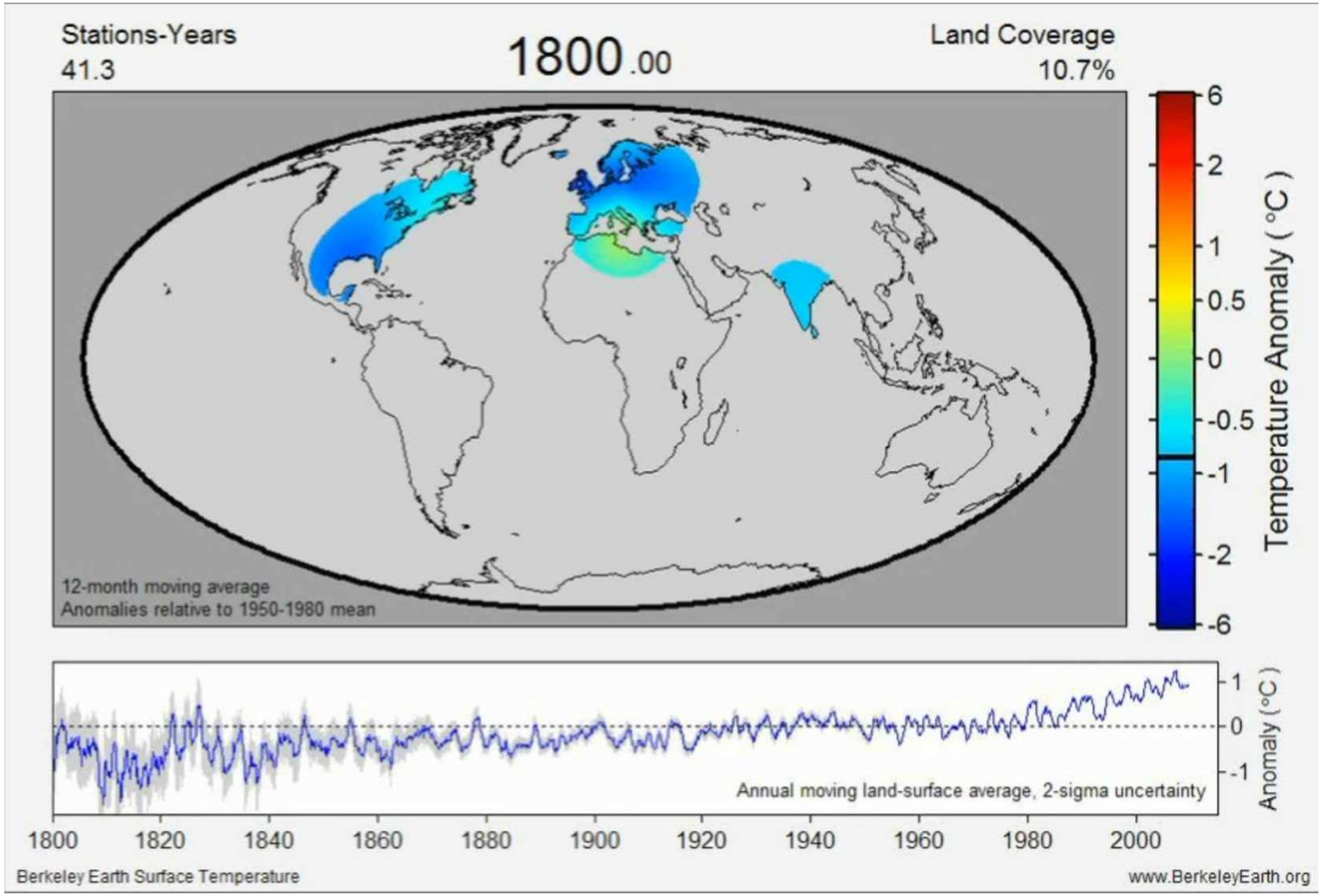
Atmosphere:
- **radiation**
- **phase changes**
- **circulation**

Forcings and feedbacks

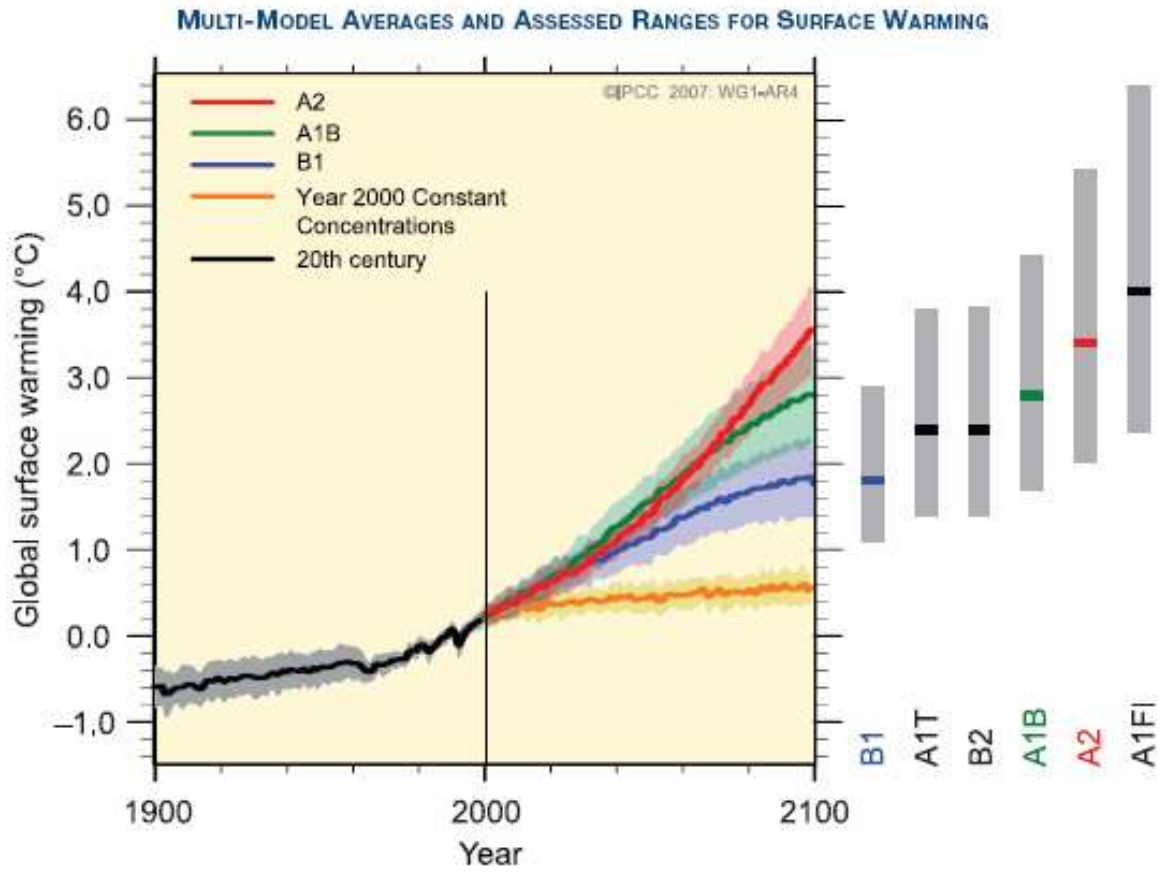
Forcings: external factors that can change the climate
Solar variability, earth orbit, manmade greenhouse gases, volcanic eruptions…

Feedbacks: factors that can change the climate in response to climate change
Clouds, water vapour, melting ice, ocean currents…

Development of global temperature

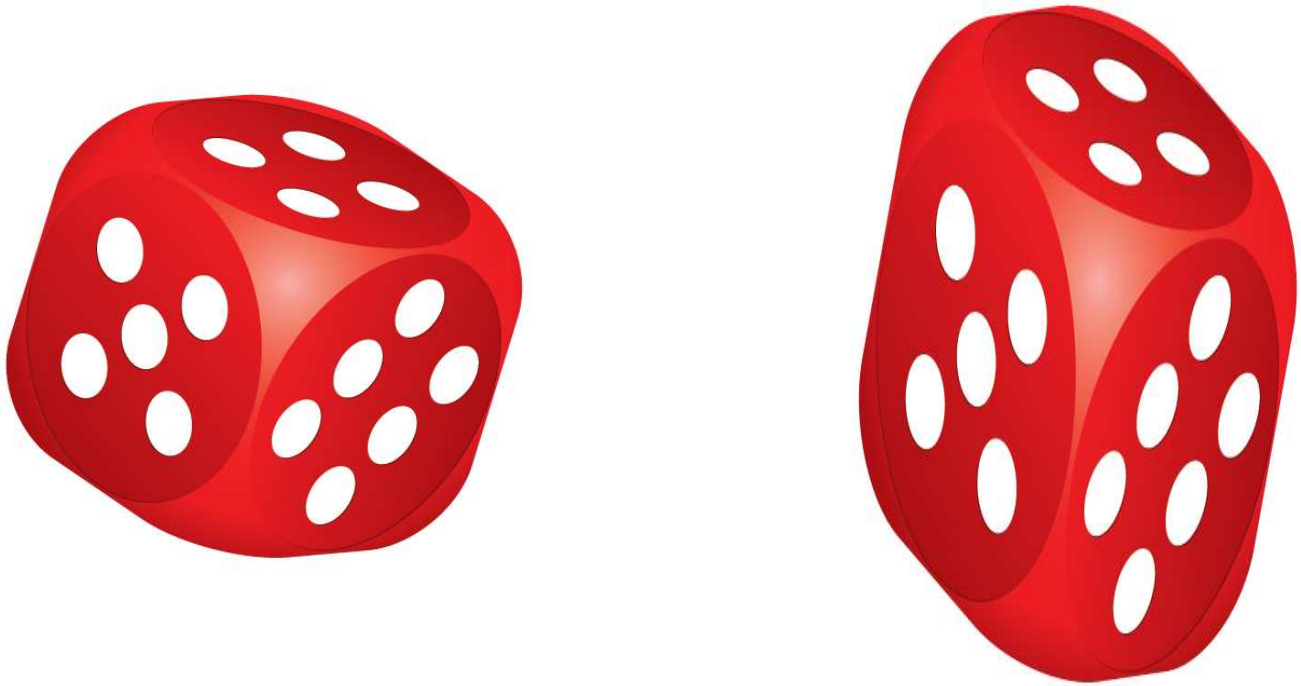


IPCC climate scenarios

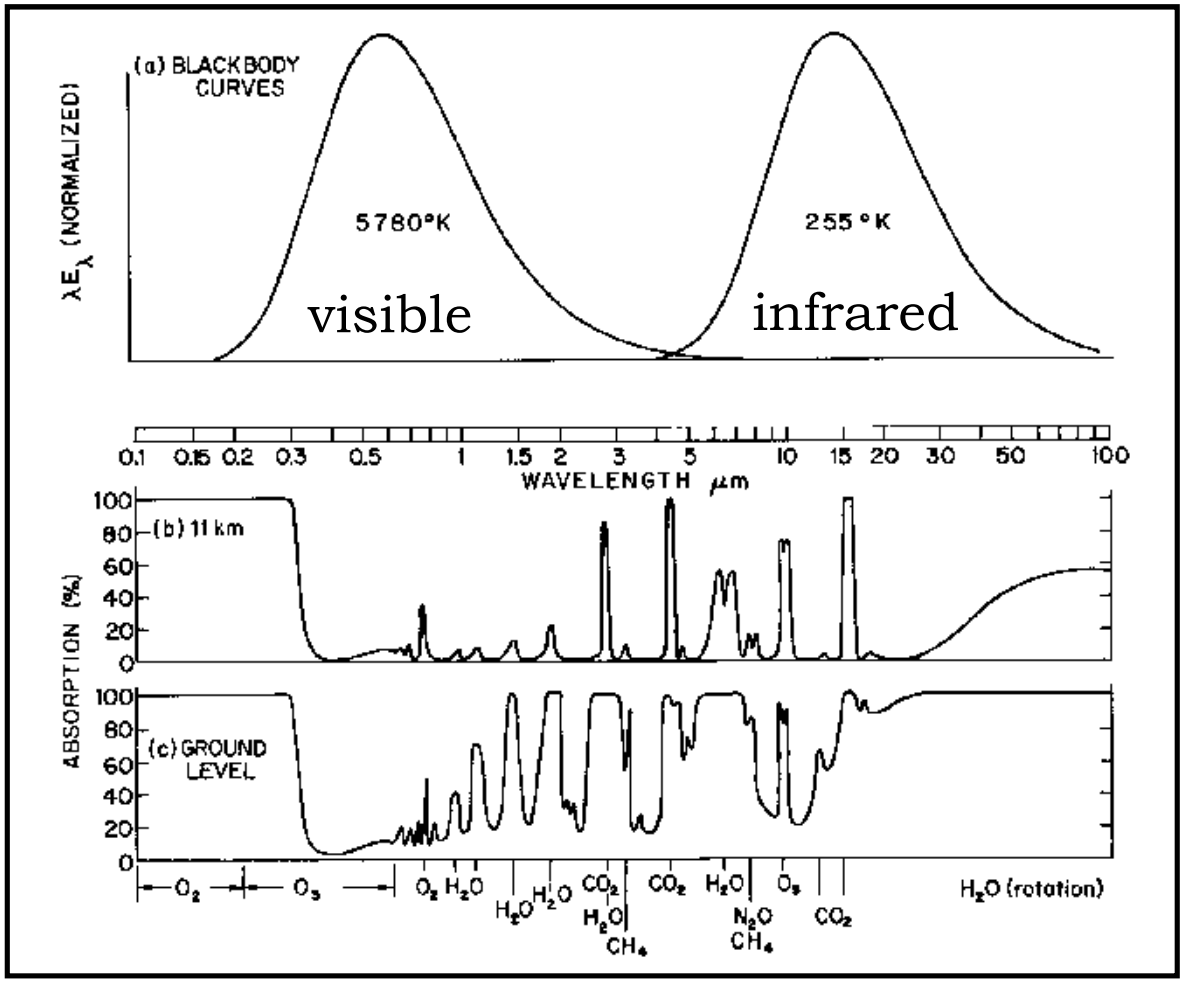


Source: IPCC

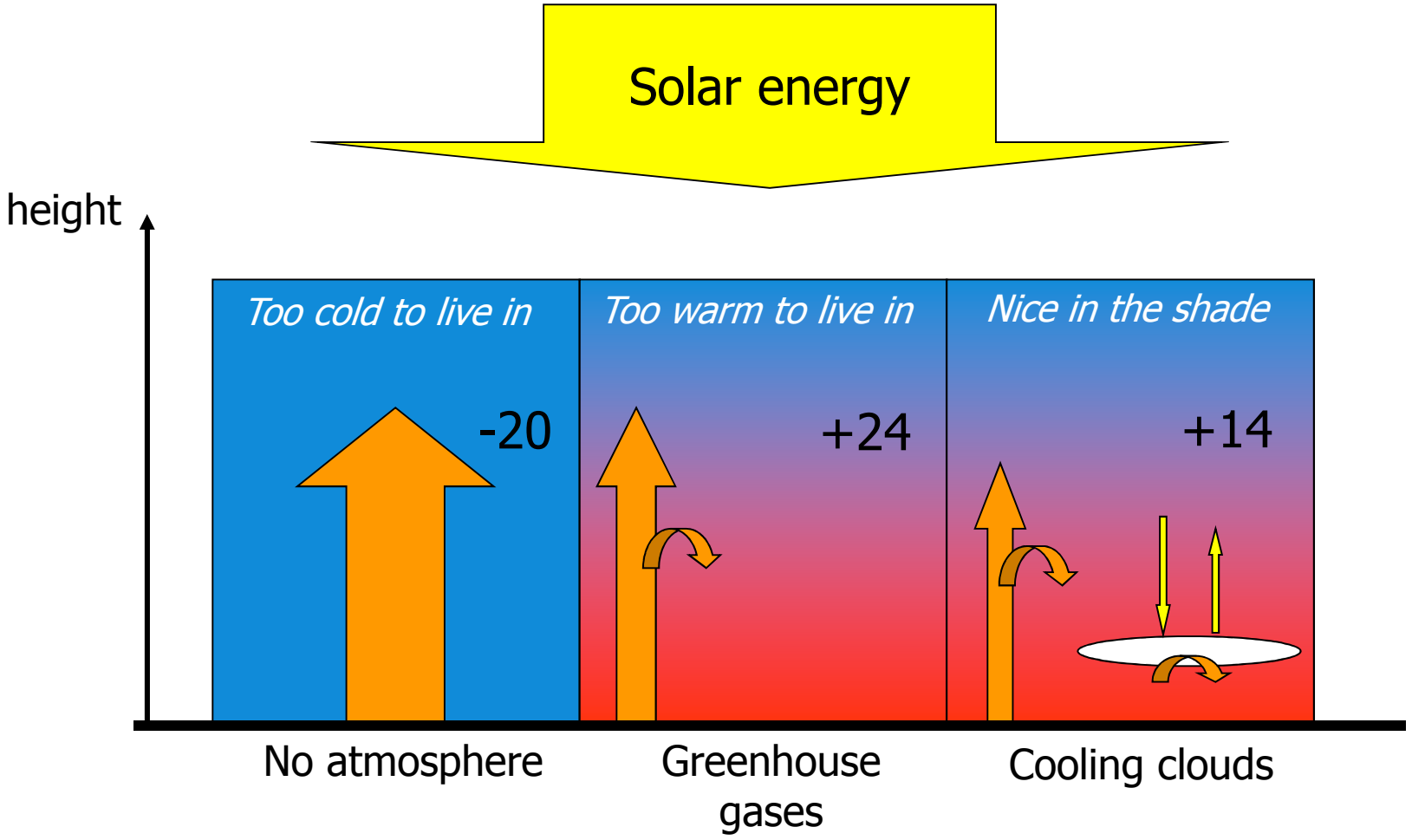
Understanding climate change



Short and long wave radiation



The radiation balance: a status quo

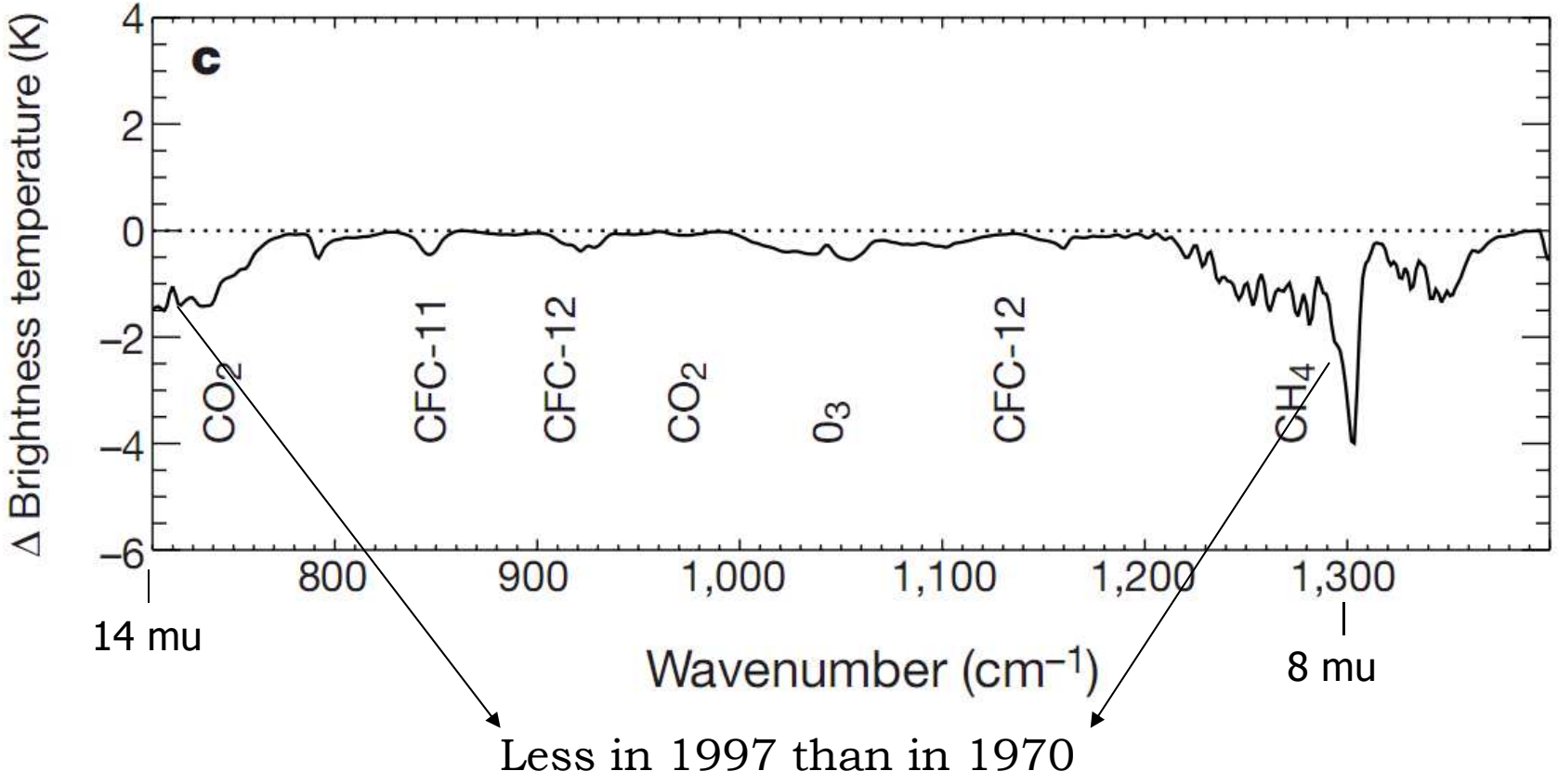


Spectrum change 1970-1997

Comparison of satellite measurements: outgoing radiation

Harris et al

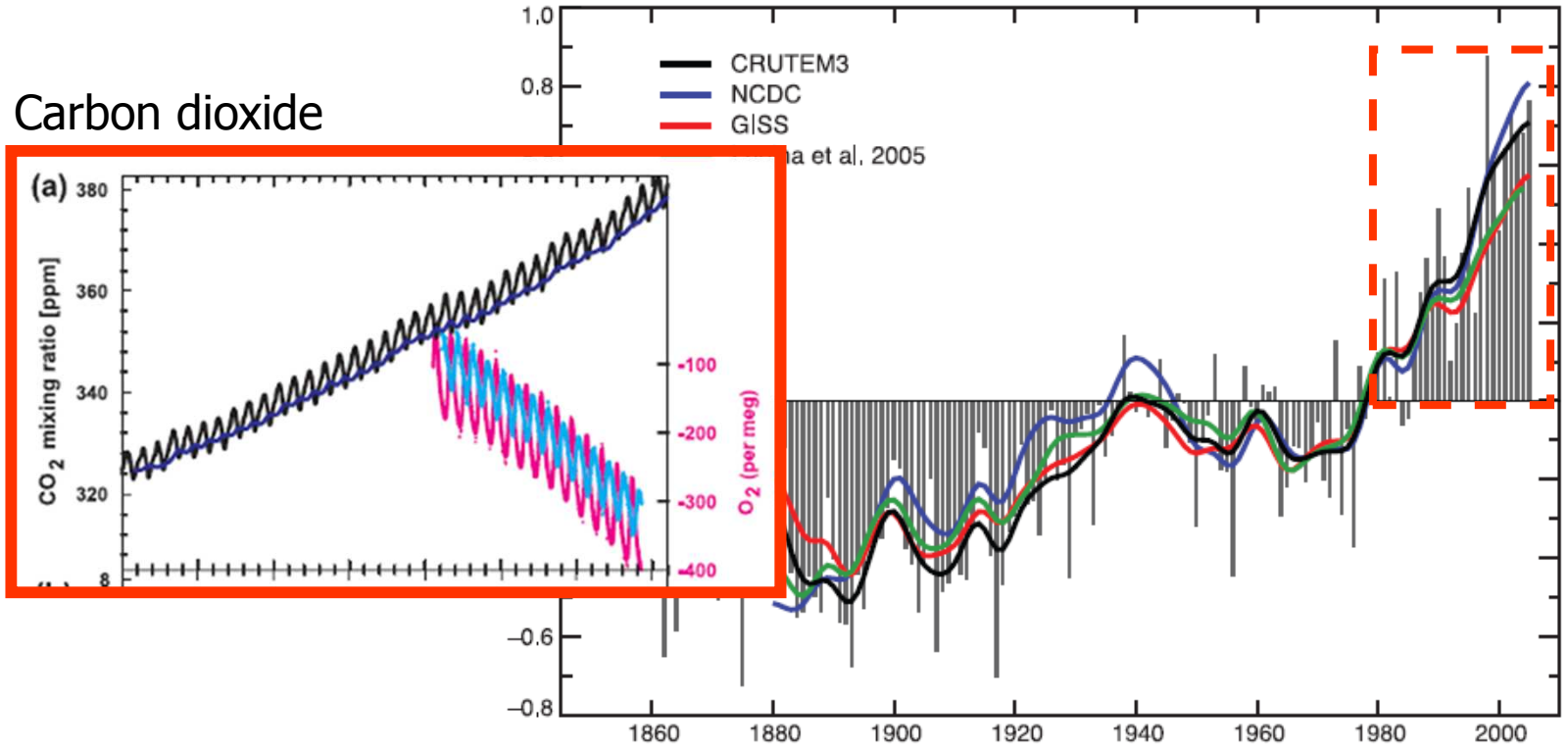
NATURE | VOL 410 | 15 MARCH 2001 | www.nature.com



Less in 1997 than in 1970

Observations of climate change

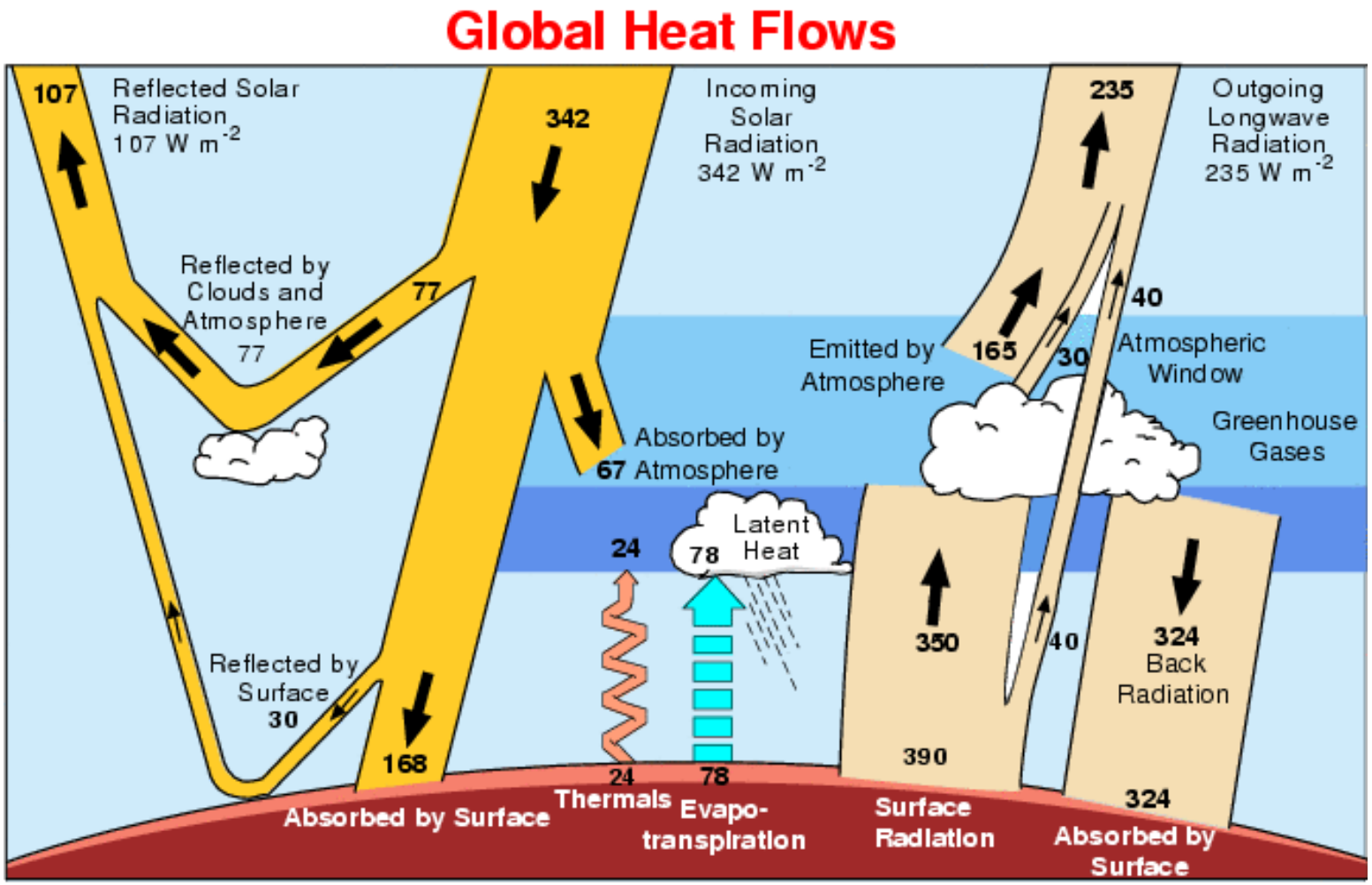
Temperature in the last 160 year



Carbon dioxide

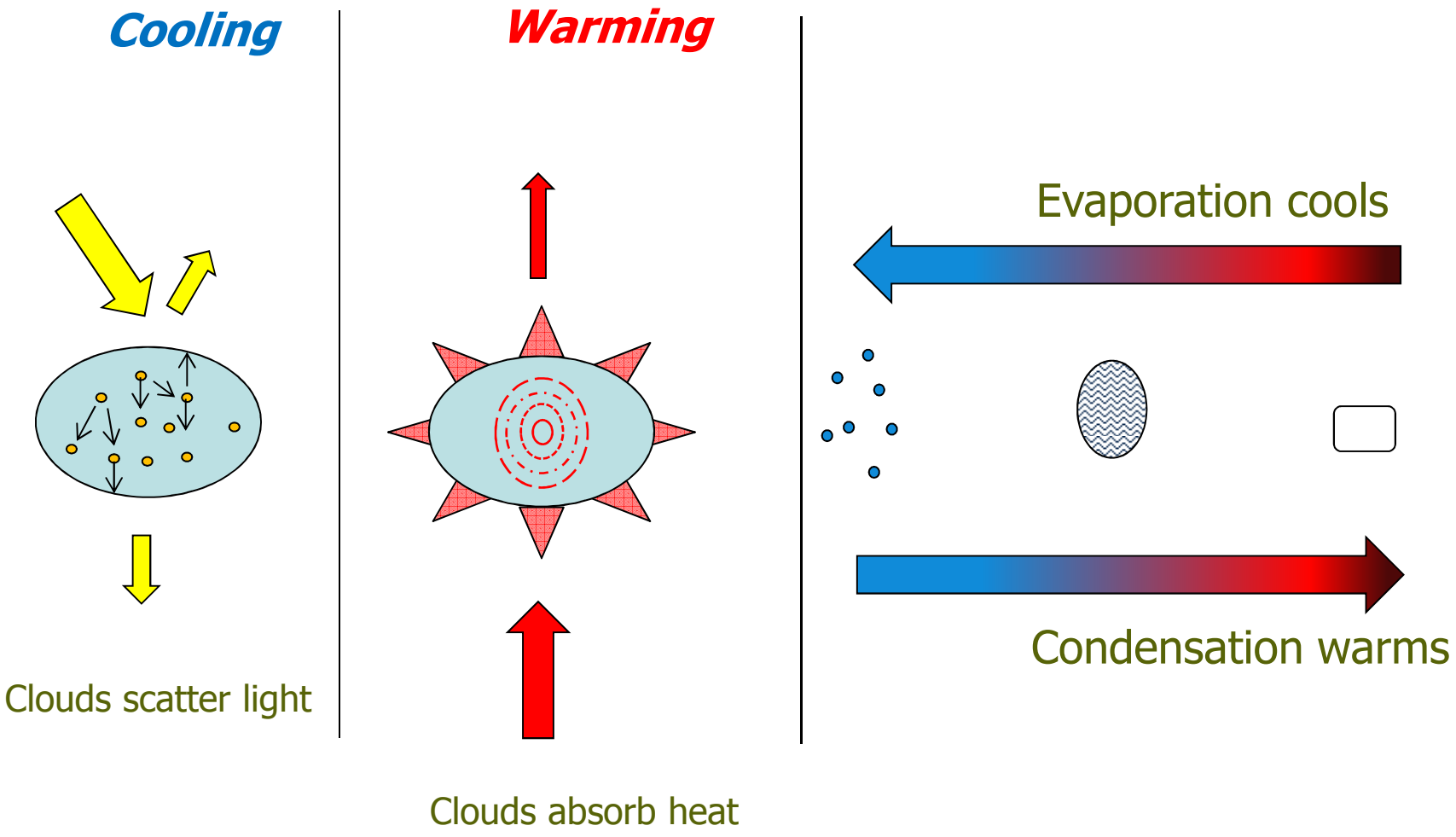
Source: IPCC

Earth-atmosphere energy balance



Kiehl and Trenberth 1997

Clouds and climate



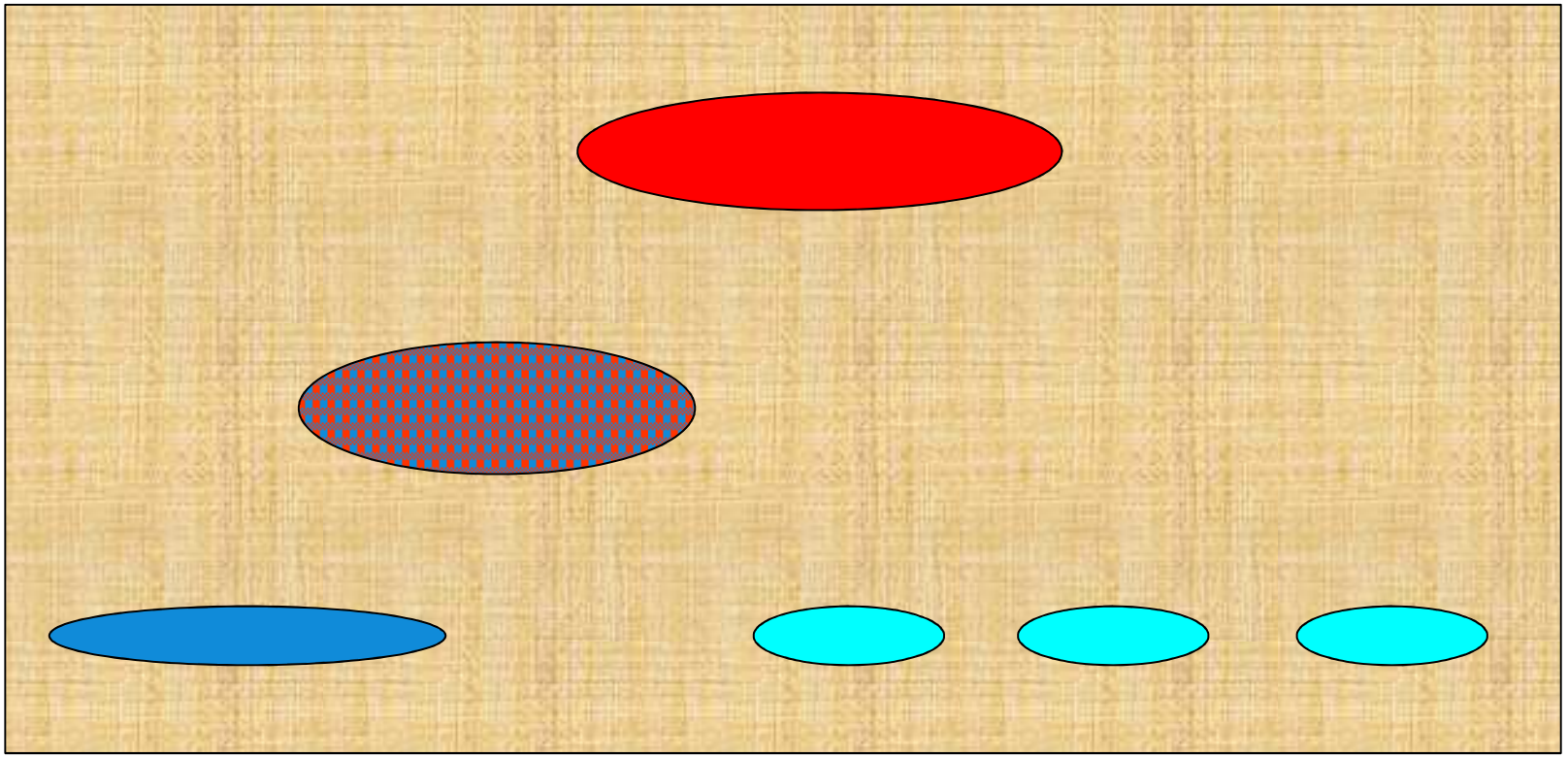
- Higher temperatures lead to more water vapour in the atmosphere leads to more clouds lead to trapping of heat from the earth leads to higher temperatures: **warming**



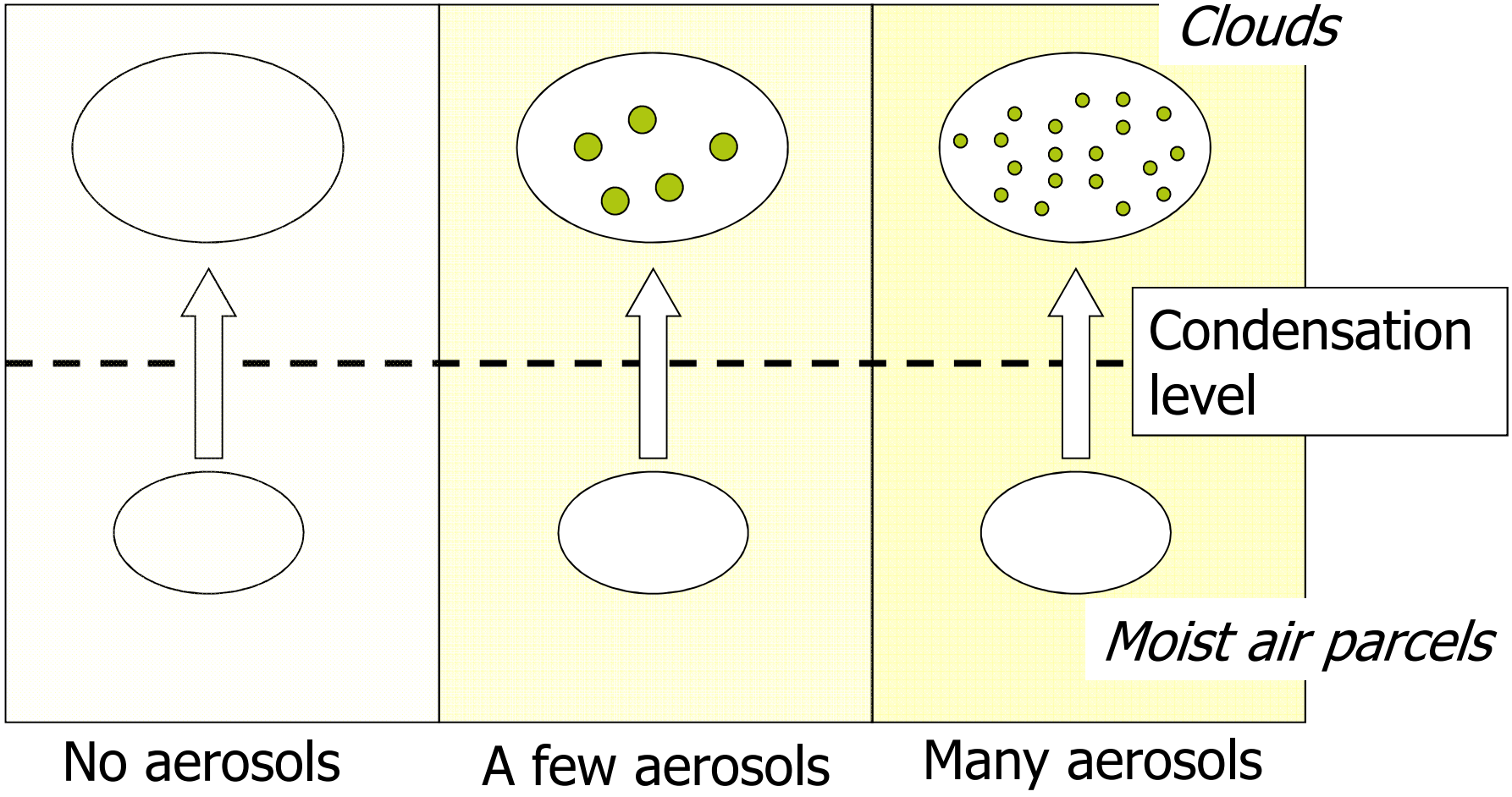
The radiation balance: a status quo?

- Higher temperatures lead to more water vapour in the atmosphere leads to more clouds lead to more reflection of sun light: **cooling**

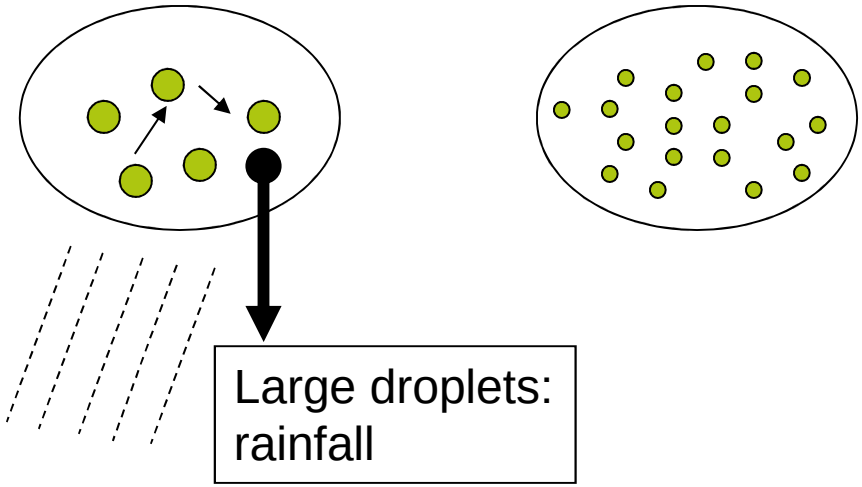
What will happen to the clouds?



A bit about cloud formation



rainfall formation



More aerosols

↓

Delayed rainfall

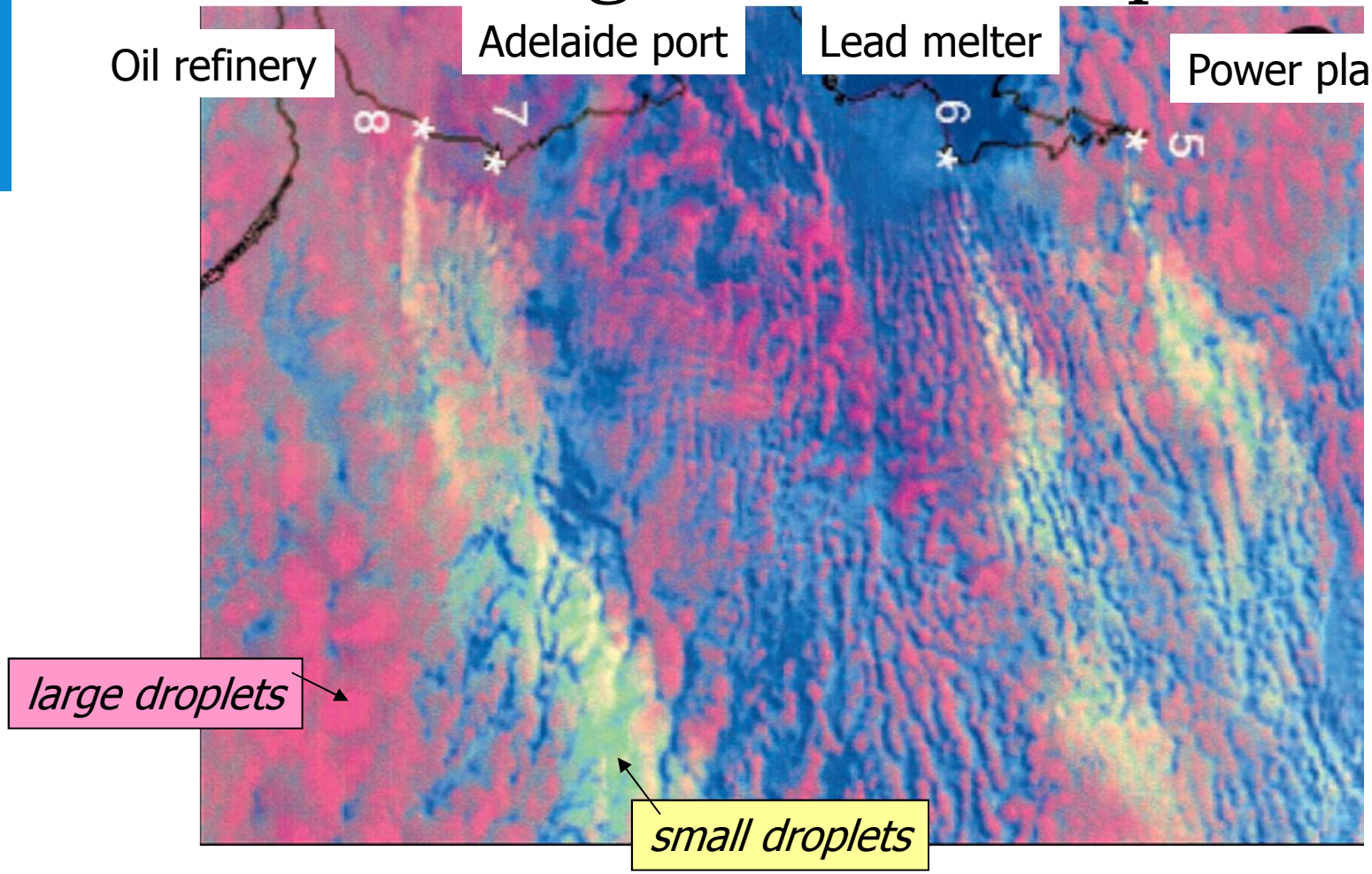
↓

Longer cloud lifetime

↓

Sustained impact
on radiation

Cloud changes due to air pollution



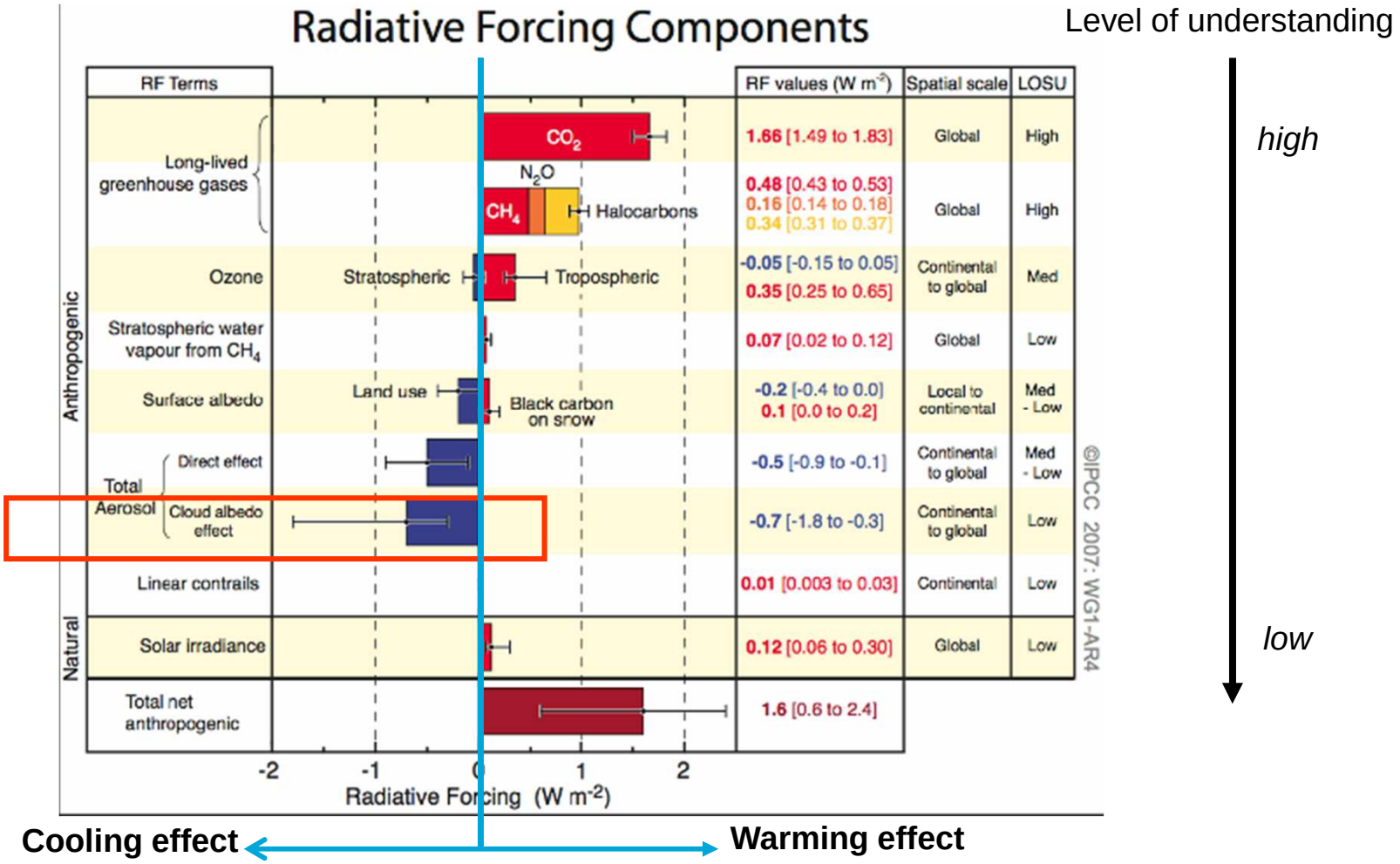
Source: NASA

Cloud modulation by ship exhausts



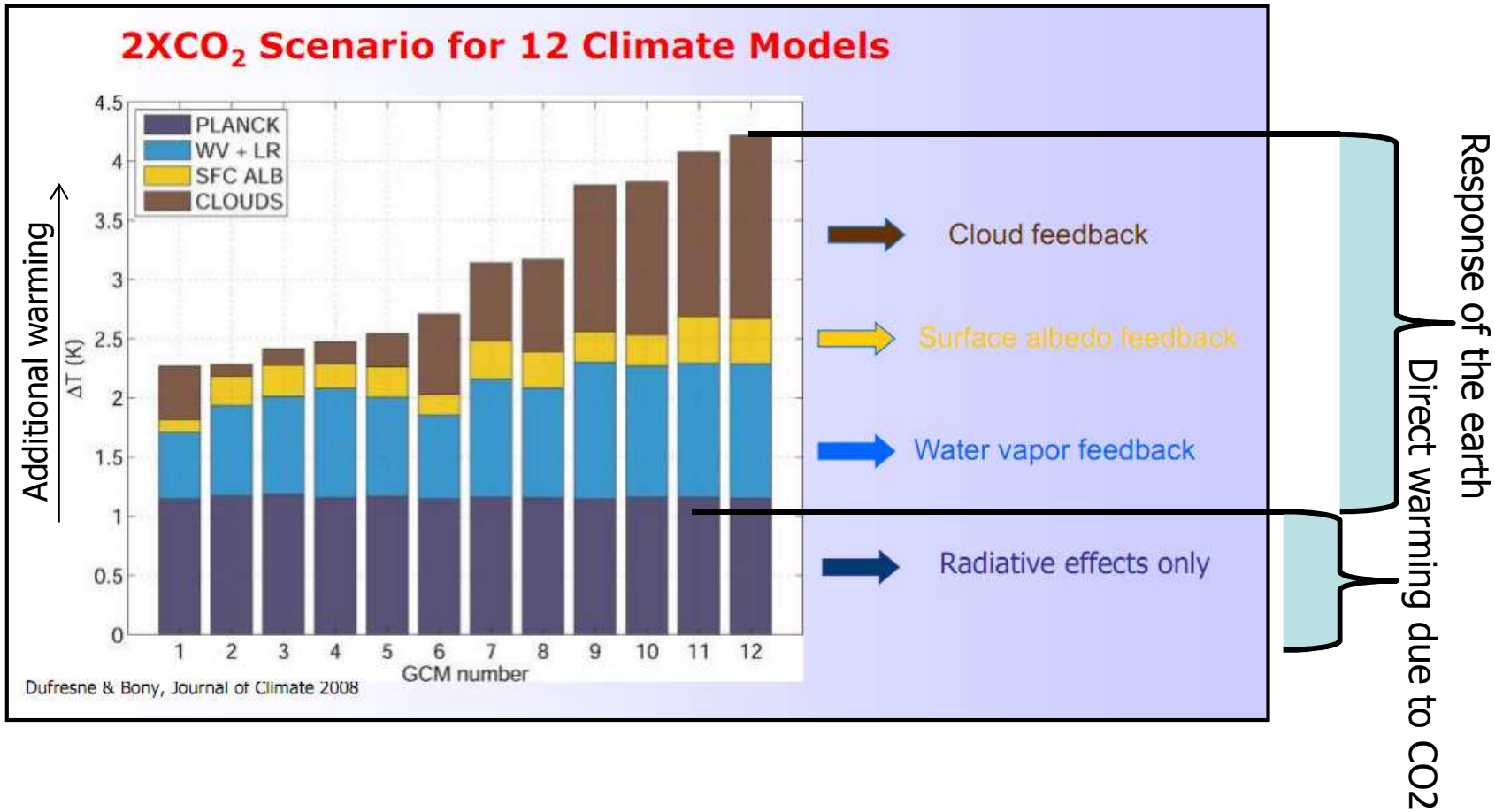
http://earthobservatory.nasa.gov/IOTD/view.php?id=5488

State of the atmospheric art in climate research

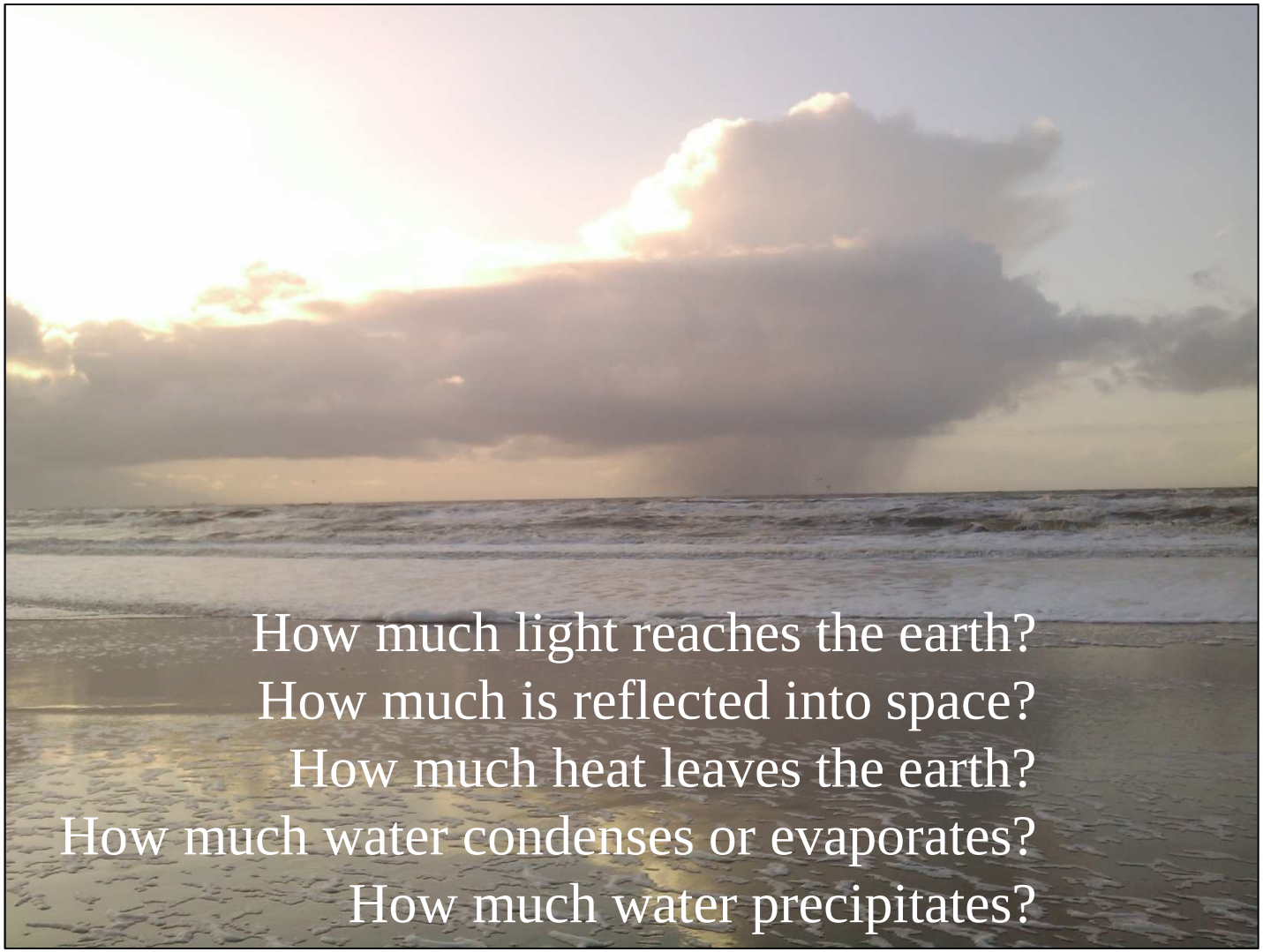


Source: IPCC

Global warming: state of the art

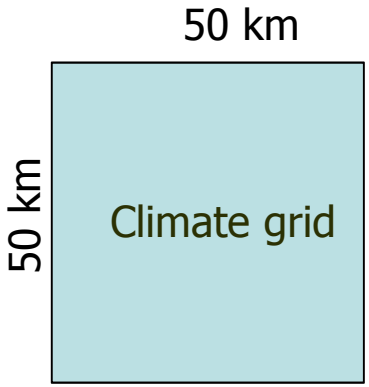


The cloud questions



Why are clouds so difficult?





Complexity of the problem

Large variety of cloud types

Global information needed

A large range of temporal and spatial scales

A multitude of different physical parameters

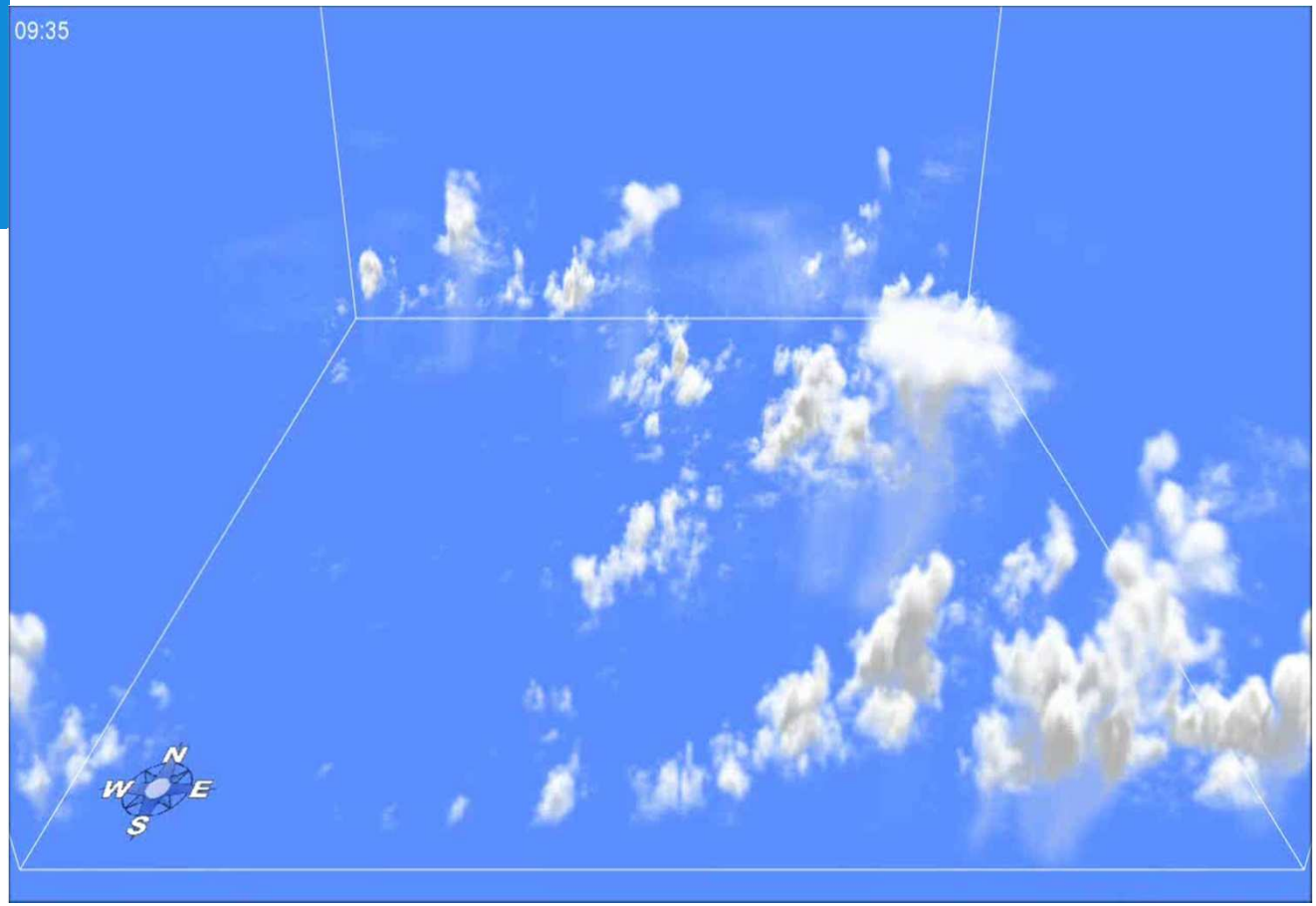
How to solve this problem?

Models



Observations

Cloud simulations



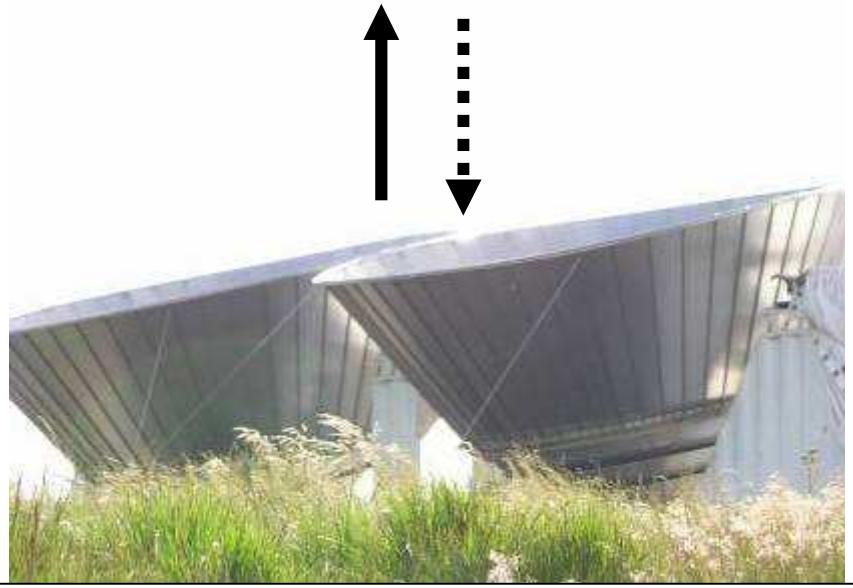
Courtesy of Harm Jonker, Stephan de Roode, Pier Siebesma, Jerome Schalkwijk, Gerwin de Haan

physics meets computer science

How to measure clouds?

Atmospheric properties: gases, aerosols clouds, rainfall, wind, thermo-dynamics, radiation

Reflection properties of the atmosphere as function of time and place



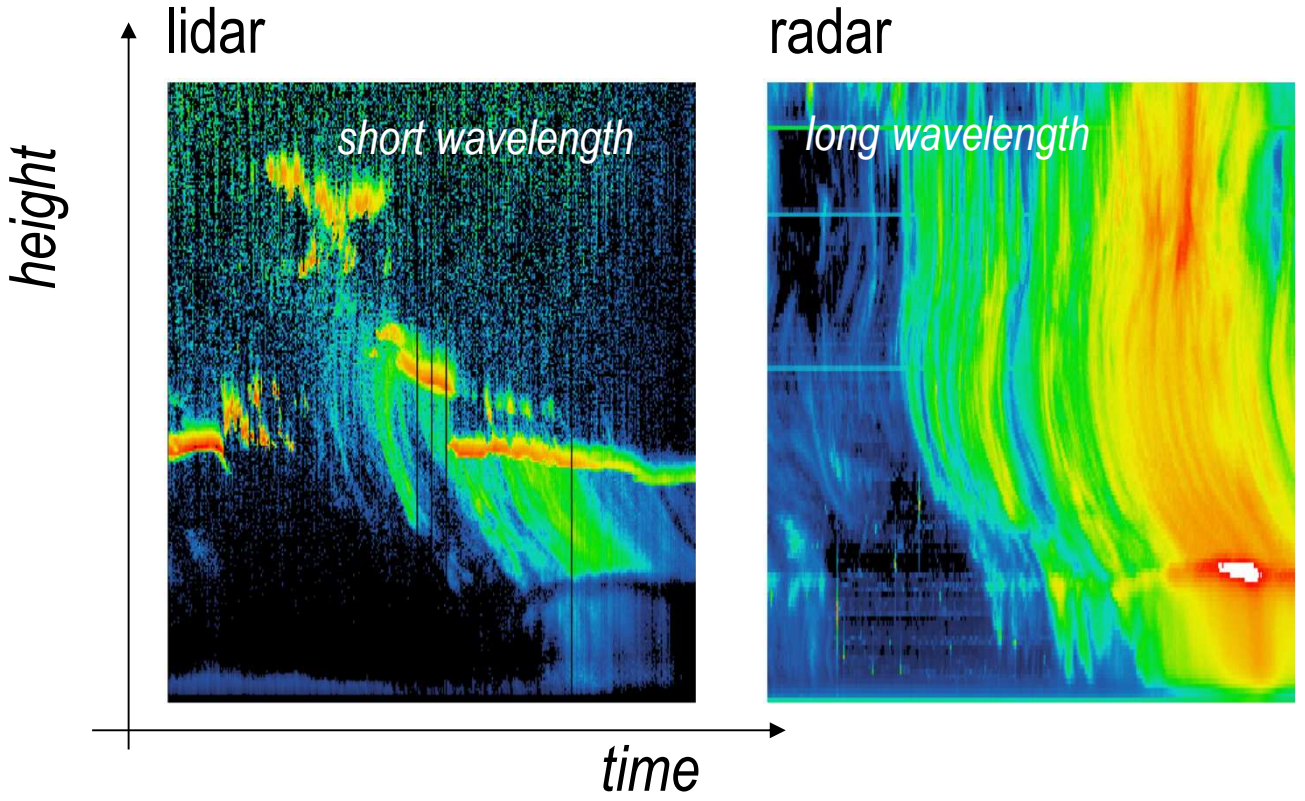
Cesar Observatory



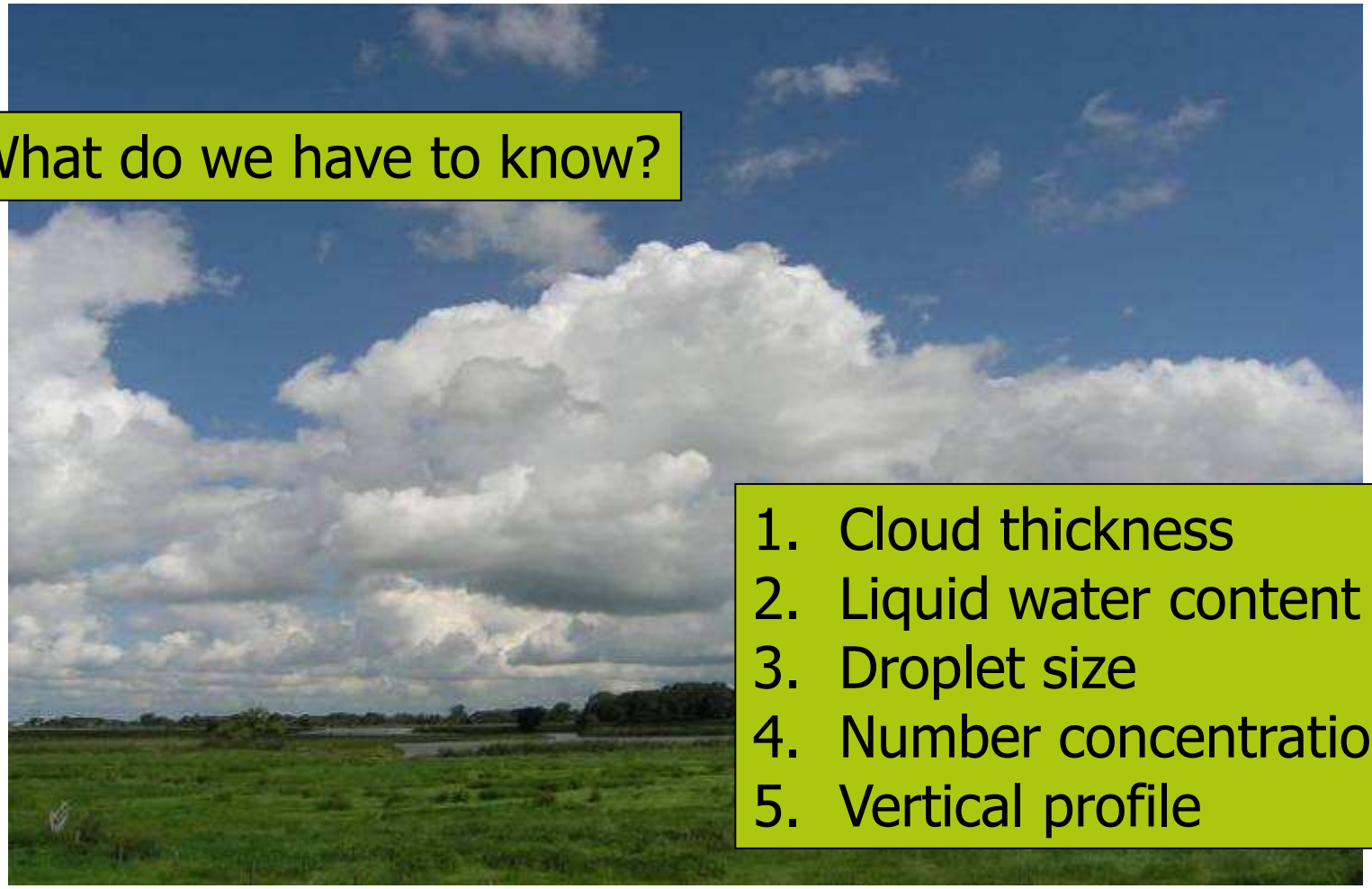
Delft University of Technology, KNMI, Wageningen University and Research
Utrecht University, RIVM, ECN, TNO , European Space Agency

Why multi-sensor strategies?

Observation of light rain with different instruments



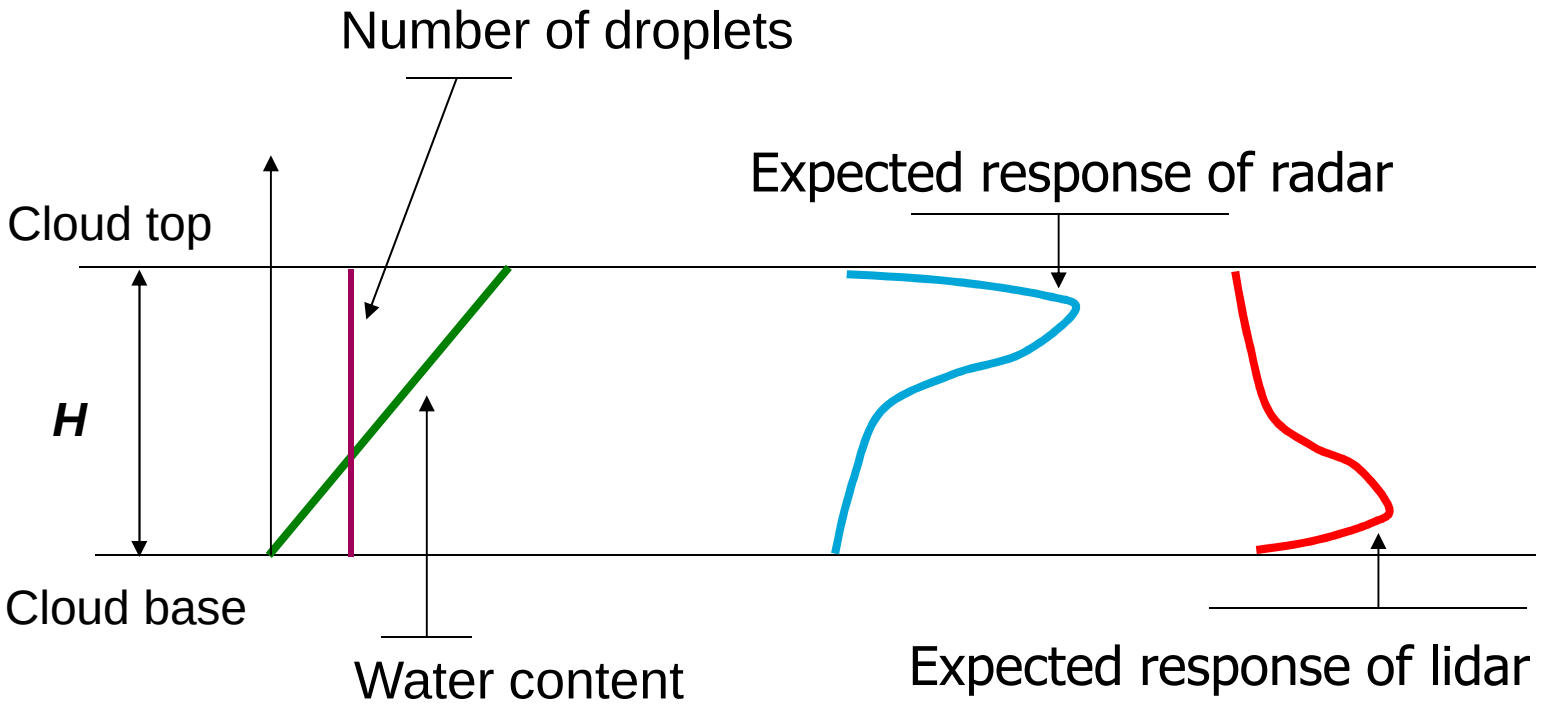
Case study: water clouds



What do we have to know?

1. Cloud thickness
2. Liquid water content
3. Droplet size
4. Number concentration
5. Vertical profile

Assume a cloud model



The retrieval technique

$$LWC(h) = f(h)LWC_{ad} = a\left(f(h)Z_{ad}\right)^{\frac{1}{2}} = aZ^{\frac{1}{2}}(h)$$

$$a = \frac{LWP}{\sum_{i=h_{cb}}^{i=h_{ct}} Z^{\frac{1}{2}}(h_i)\Delta h}$$

$$r_{eff}(h) = k_2^{-1}k_6^{-\frac{1}{3}}\left(\frac{\pi\rho_w}{48}\right)^{\frac{1}{3}}\left(\sum_{i=h_{cb}}^{i=h_{ct}} Z^{\frac{1}{2}}(h_i)\Delta h\right)^{\frac{1}{3}} LWP^{-\frac{1}{3}}Z^{\frac{1}{6}}(h)$$

Frisch et al, 2002

From microphysics to optics

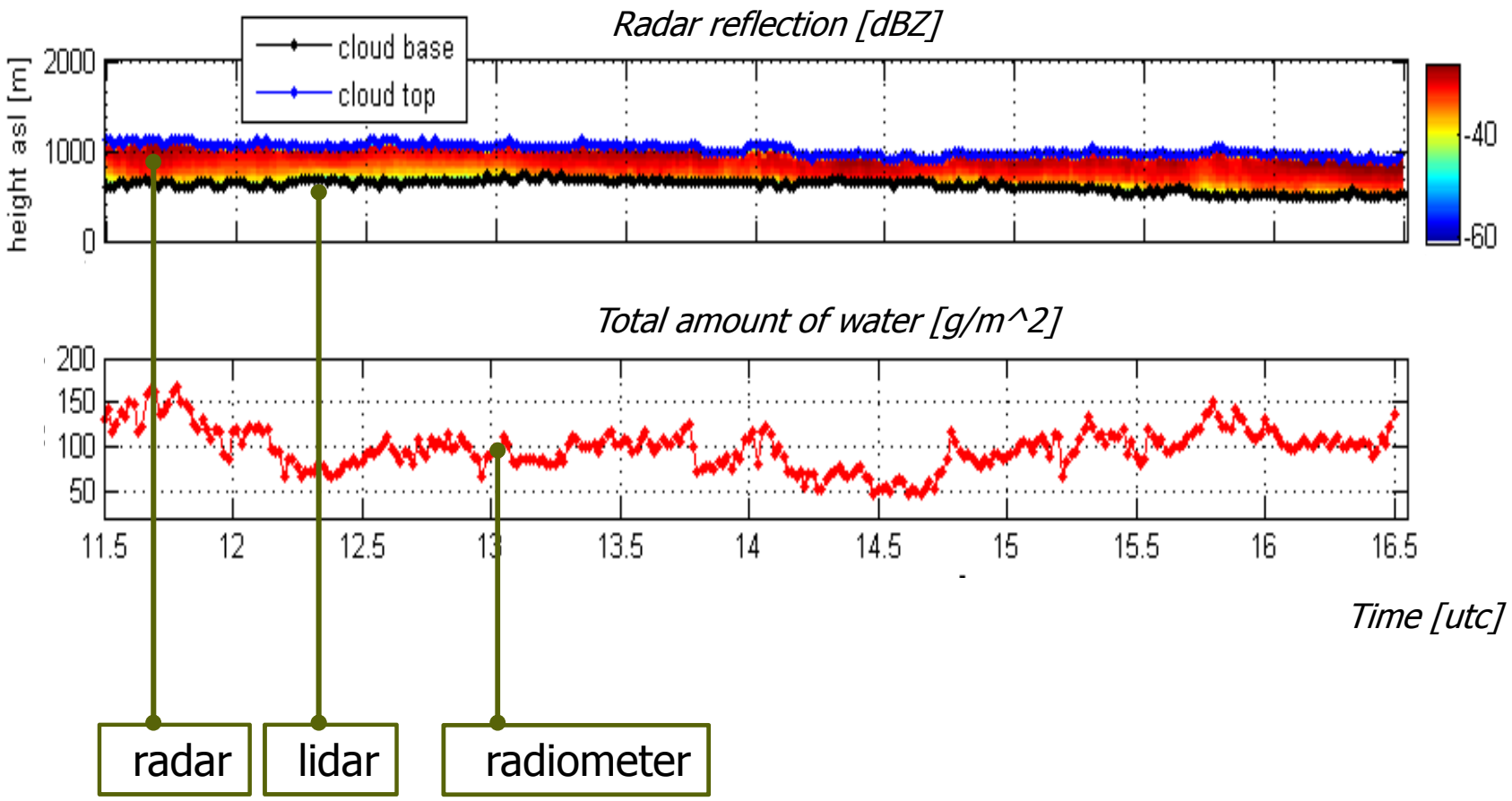
$$\sigma_{ext}(h) = \frac{3}{2\rho_w}\frac{LWC(h)}{r_{eff}(h)}$$

Exctinction profile

Optical thickness

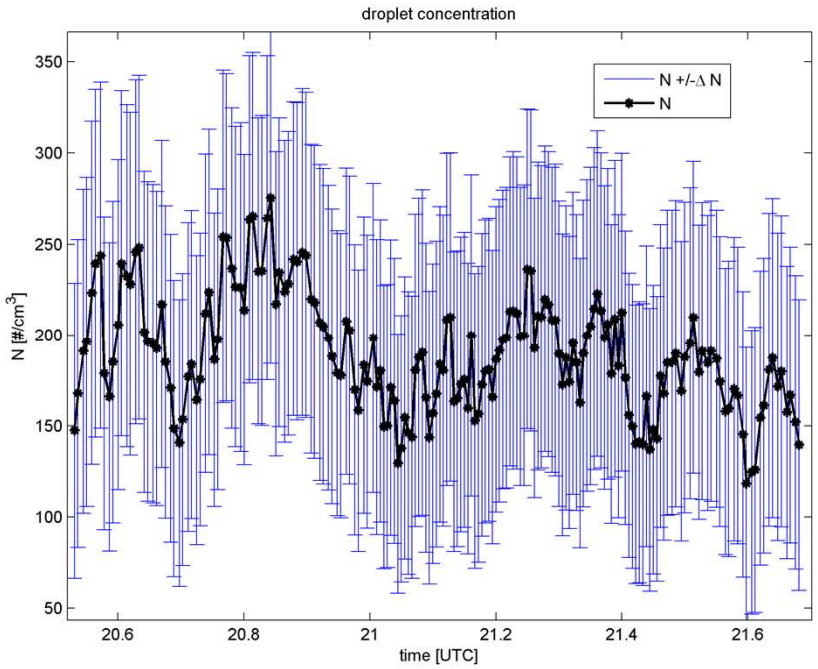
$$\tau = \int_{h_{cb}}^{h_{ct}} \sigma(h)dh = \frac{3}{2\rho_w}\int_{h_{cb}}^{h_{ct}} \frac{LWC(h)}{r_{eff}(h)}dh$$

Inside stratocumulus

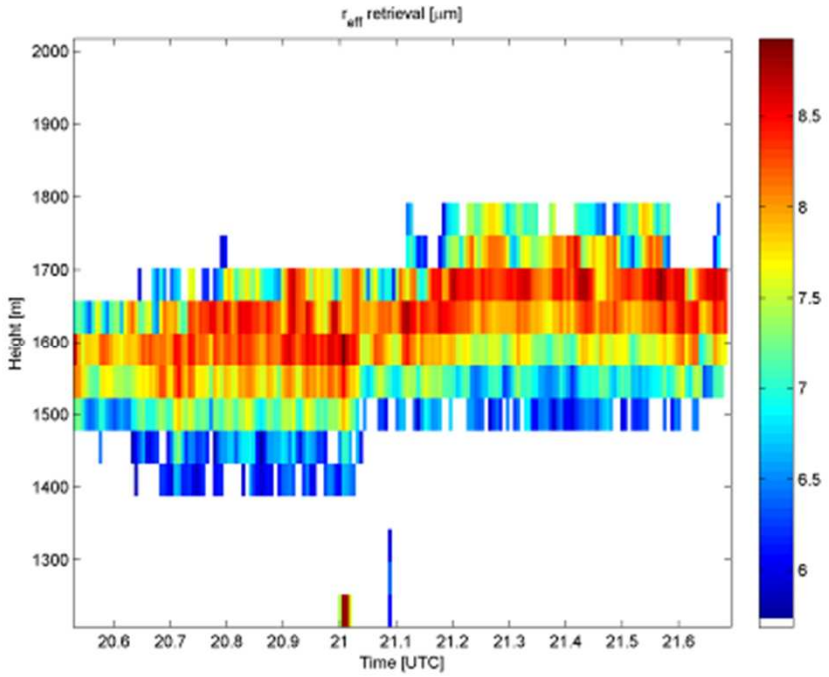


estimate cloud parameters

Droplet concentration



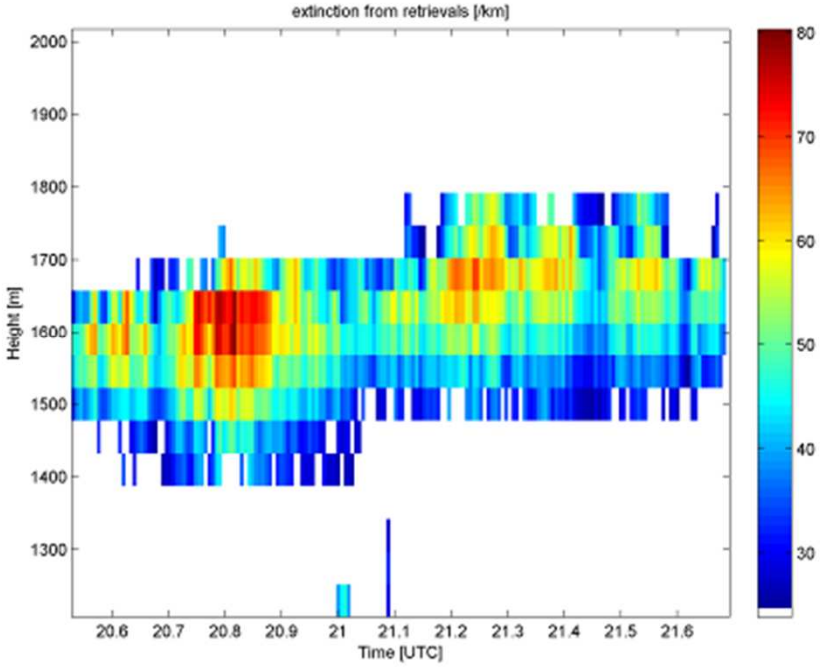
Profile particle size



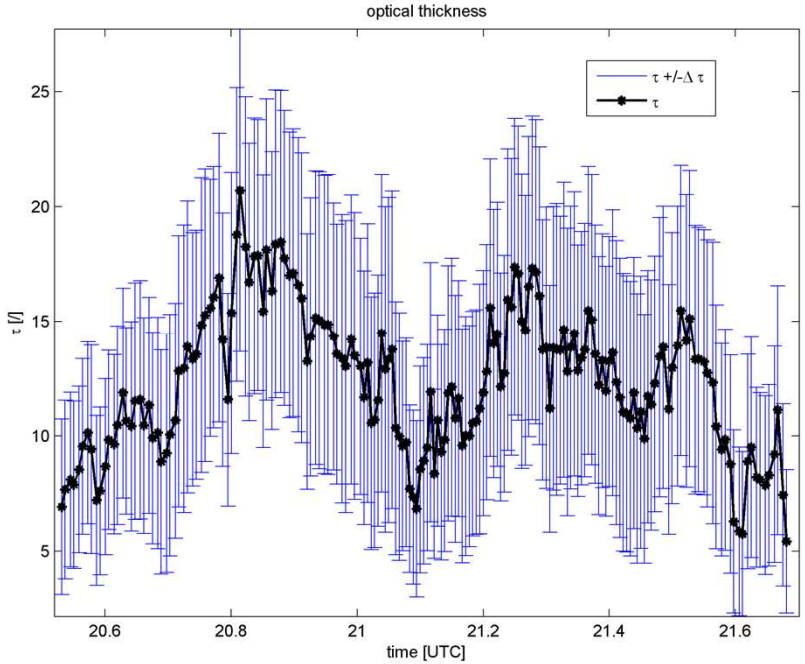
Courtesy: Christine Brandau

radiative properties

Extinction



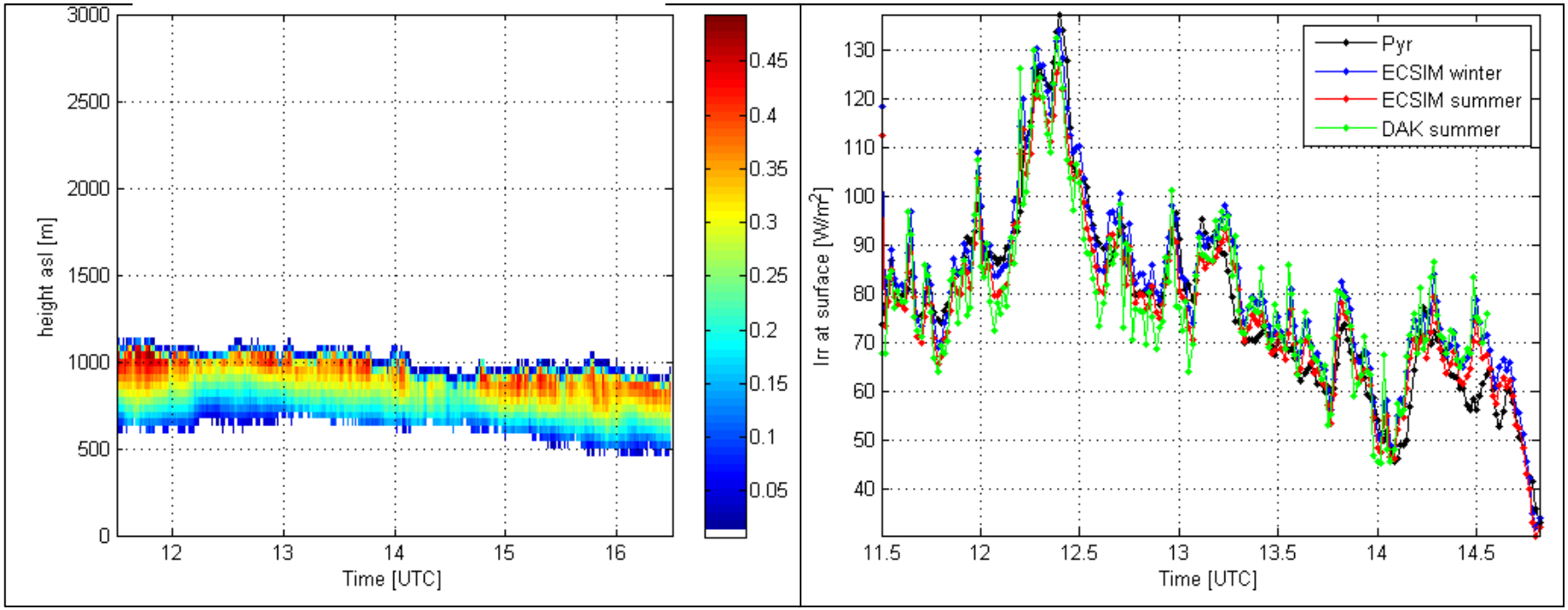
Optical thickness



Clouds and their shadow

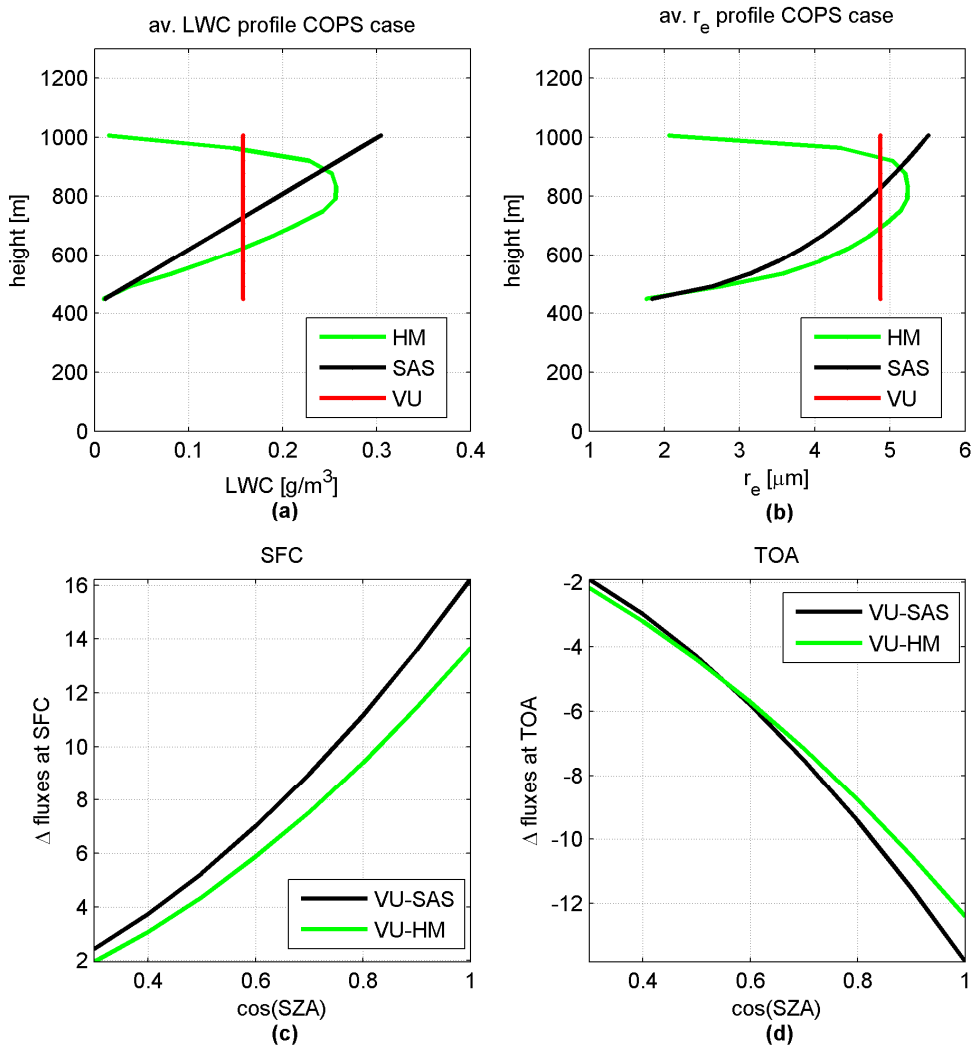
Distribution of water in the cloud [g/m^3]

Amount of sunlight at the surface [W/m^2]

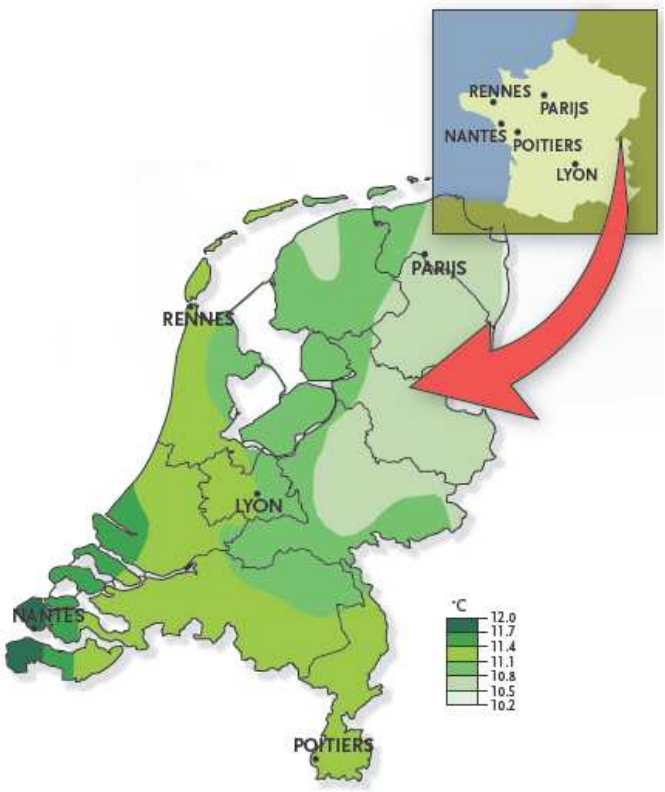


Courtesy of Christine Brandau, Simone Placidi, Dave Donovan, Wouter Knap

Impact of the vertical cloud structure



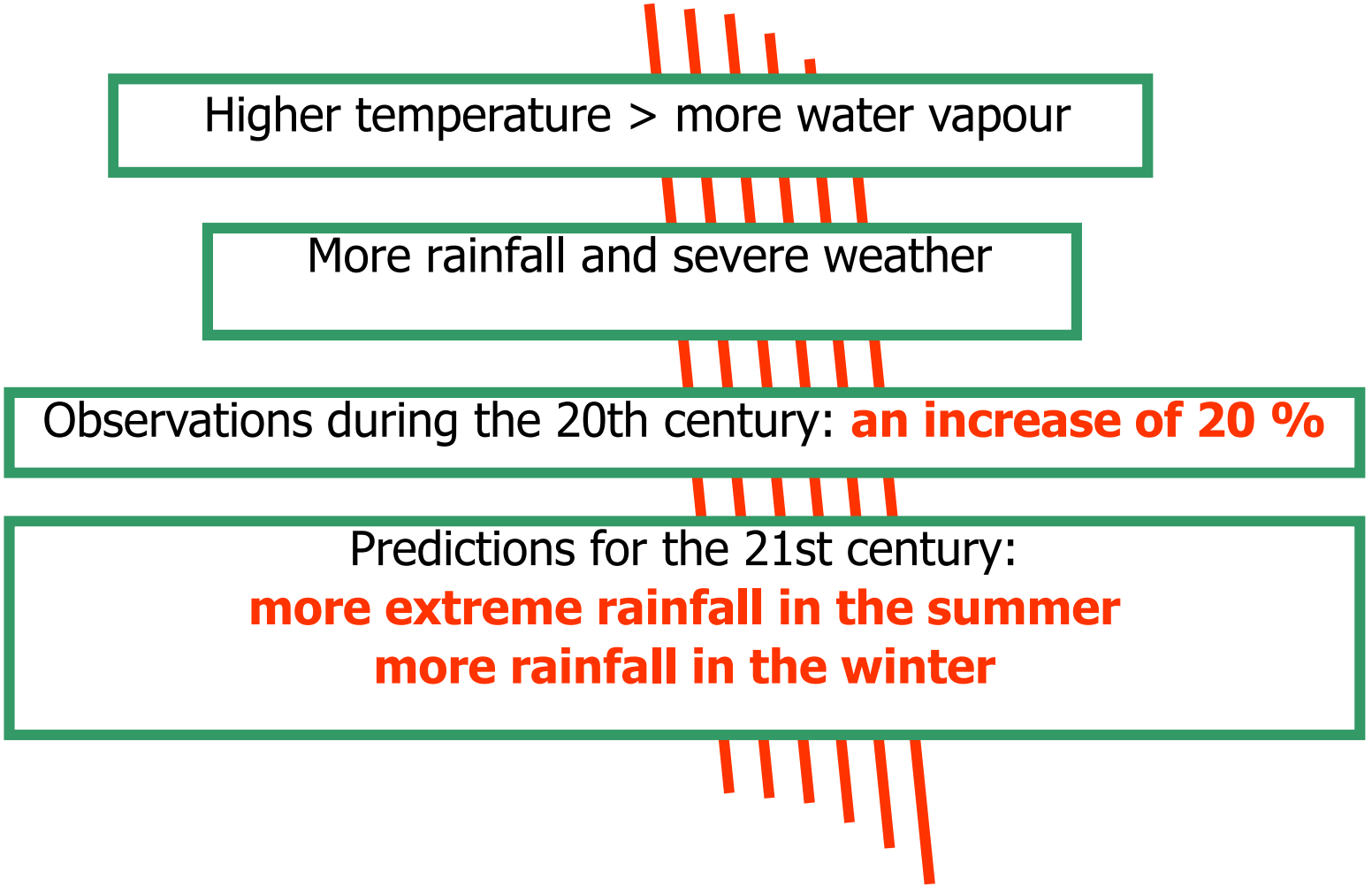
What to expect in The Netherlands?





Source: KNMI

Rainfall in a changing climate

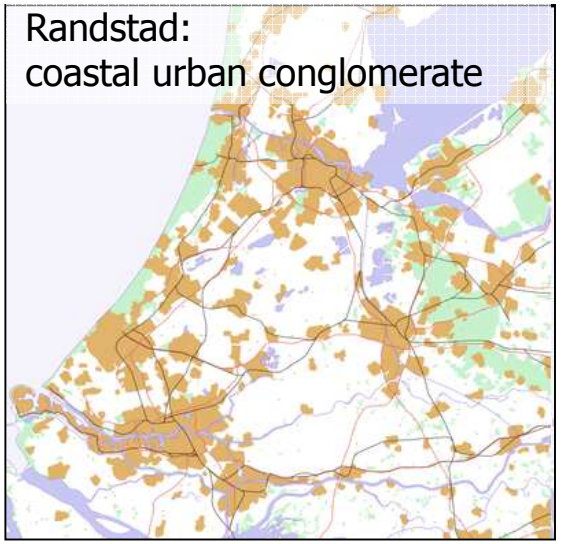


Extreme rainfall in a metropolis

Larger vulnerability modern society
(flooding, transport, communication)

Accurate information needed

Integrated model-observation warning systems
Better understanding rainfall formation
Detailed observations of microphysics needed



Population: 7 million
Economy: 4th region of Europe
Dense infrastructure



Philosophy: composite sat-lo-hi-res model

to improve forecasts: *street level hourly basis*

RAINGAIN – high resolution rainfall data in cities



RainGain

Xband/Improved Cband radars in 4 Pilots:

- Rotterdam (NL)
- Leuven (B)
- Paris (F)
- London (UK)

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

nwe INTERREG IVB

TU Delft

Provincie Zuid Holland

Gemeente Rotterdam

Nouvelle Université Leuven

Aquafin

École des Ponts ParisTech

Val de Marne

Seine Saint Denis

Météo France

Imperial College London

Met Office

Flood Forum

Veolia Environnement Recherche & Innovation

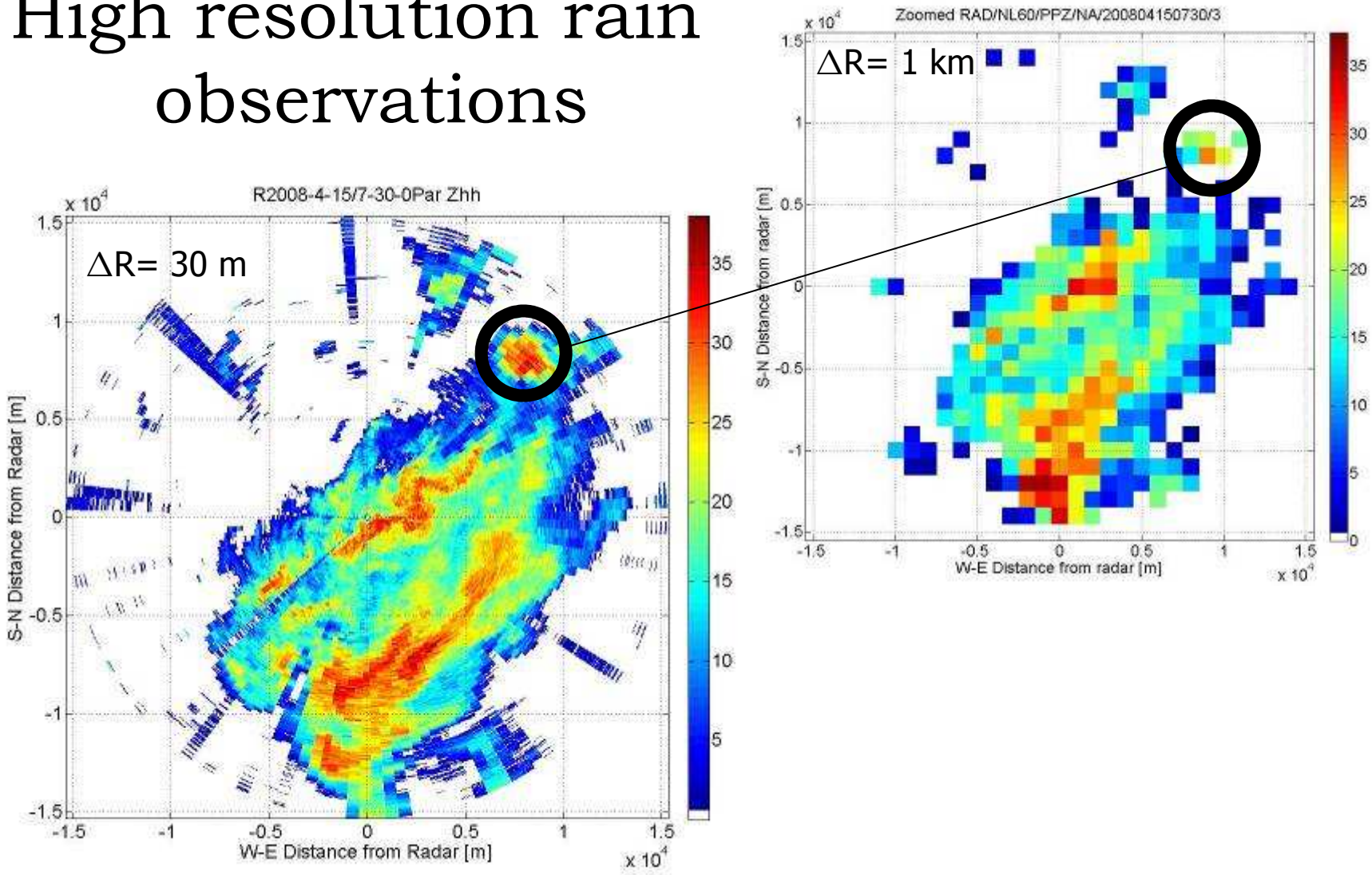
Rainfall radars at CESAR Observatory





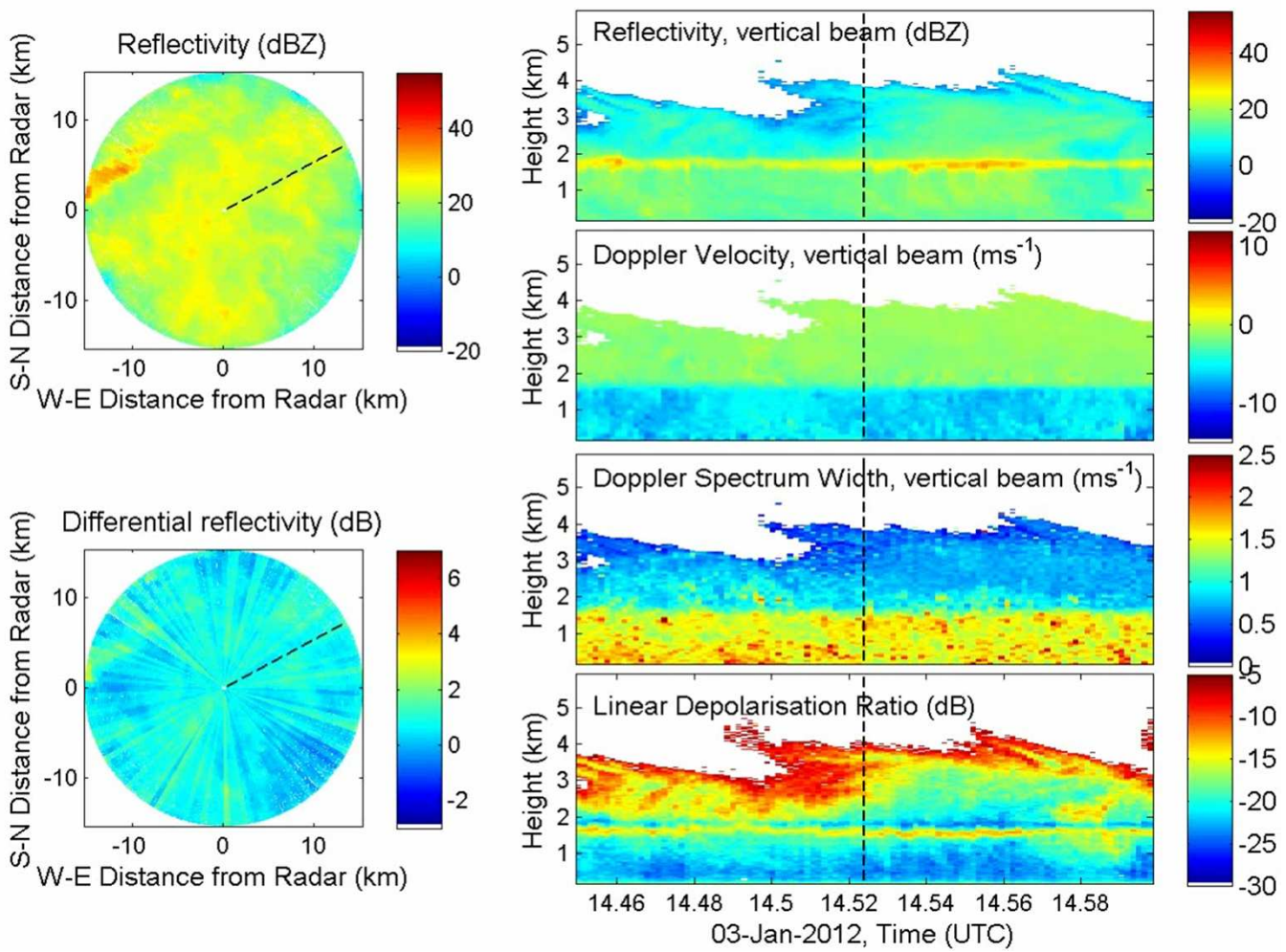


High resolution rain observations



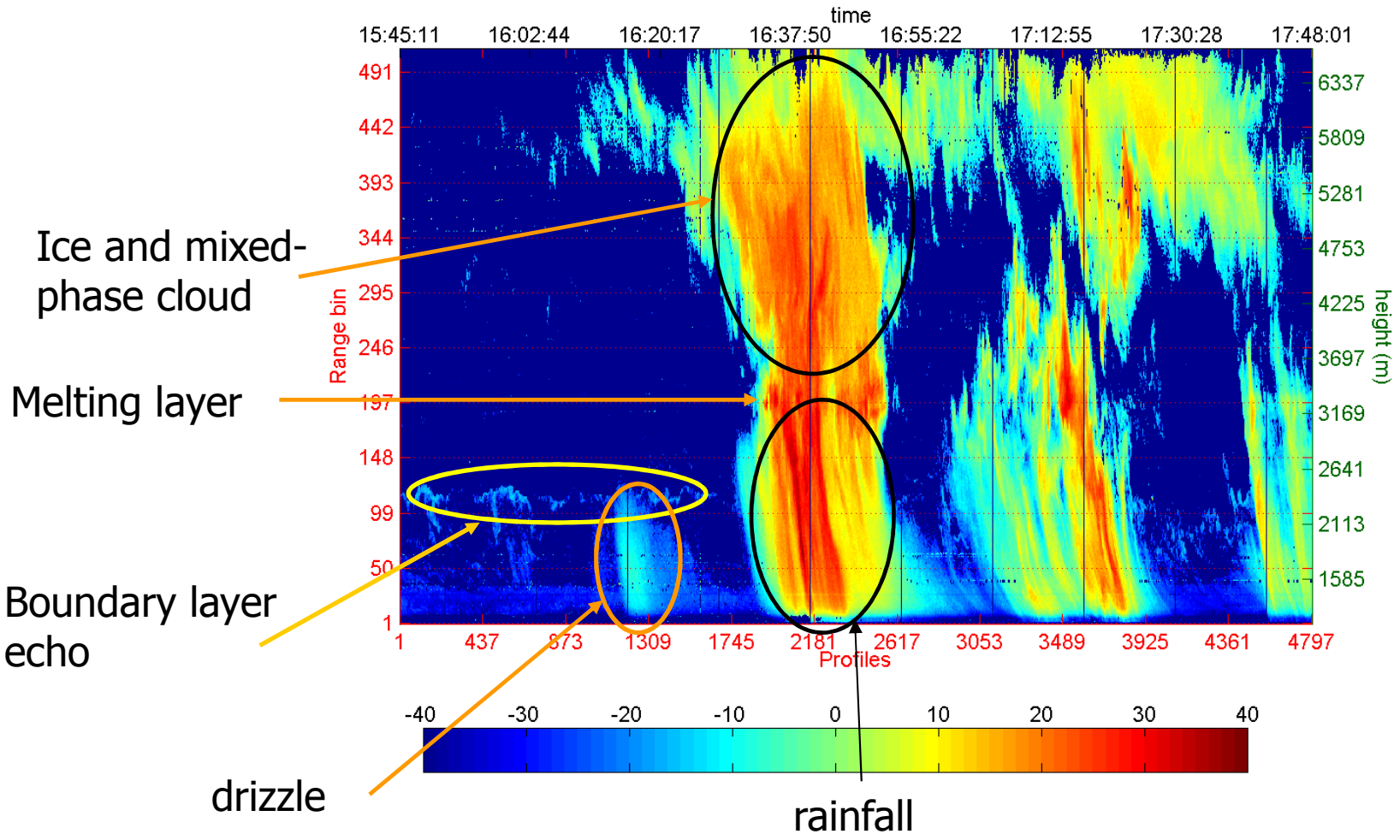
Courtesy: KNMI

Clouds and rainfall



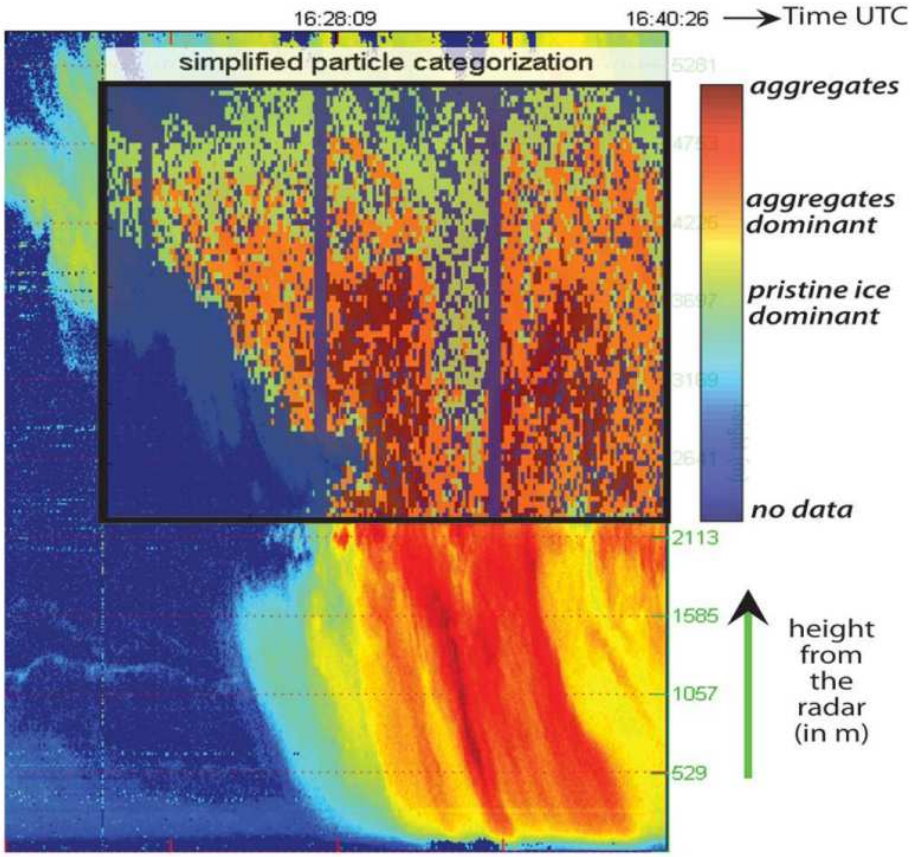
Courtesy of Tobias Otto, Yann Dufournet, Christine Unal

Rain through radar eyes



Courtesy: Yann Dufournet

Spectral-polarimetric classification



Courtesy Durfournet

Way of the future:
put the content into its context

