Clouds & Radiations

About the remote sensing of clouds

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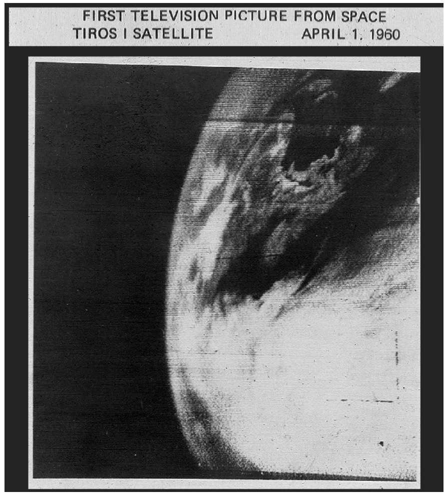
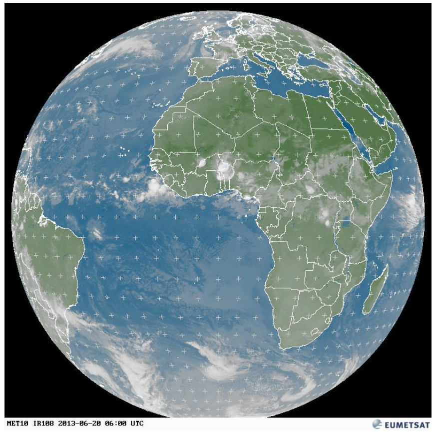
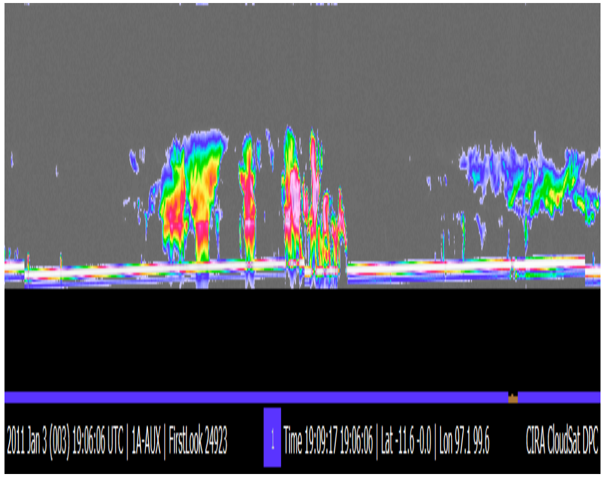
Satellites & Clouds

From TIROS 1960 → To ISCCP (1980') → To the train: A-train 2006 & EarthCare (2016) → And the future







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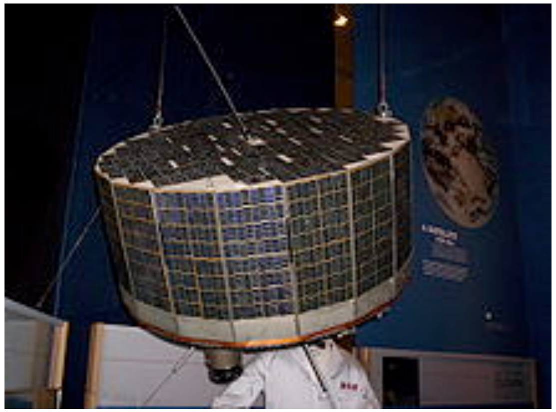
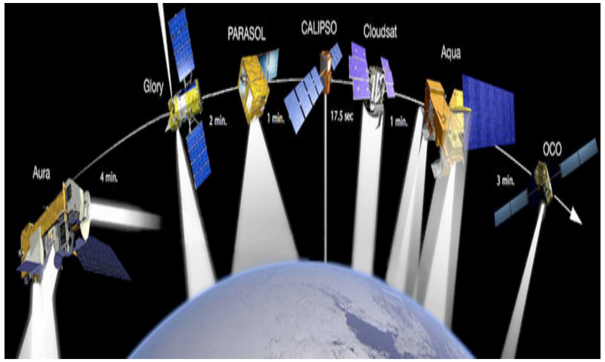




What do we want ? shopping list

- Where and when are the clouds ?
  Cloud macrophysical properties:
  « cloud cover », vertical distribution

- What kind of cloud particles are in the clouds ?
  Cloud microphysical and optical properties :
  effective radius, liquid/ice water content (or path), precip

- How do the clouds warm/cool the Earth, the atmosphere, the surface ?
  Cloud radiative properties , fluxes, …

- The atmospheric environment of the cloud…

At what spatial and temporal resolution ?

Every where
Every time

Space scale:
At the scale of the cloud particle, as well as global scale

Time scale:
Instantaneously, hourly, diurnal, seasonal, interannual, and over several decade

And also:

All the variables simultaneously to study how cloud properties vary together

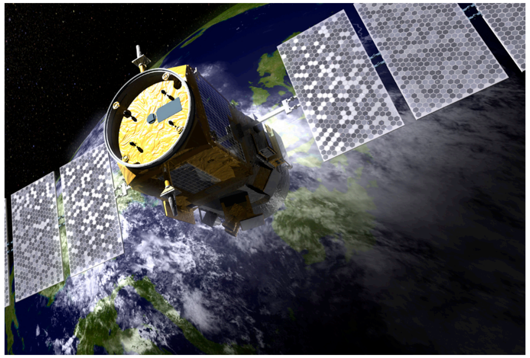
And also:

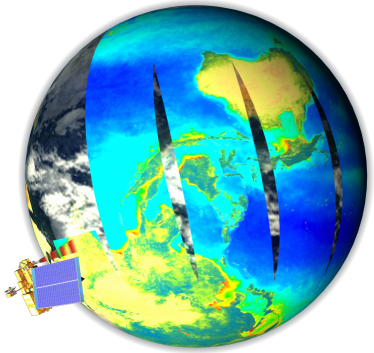
Simultaneous observations of the environment of the cloud to understand links between clouds and their environement

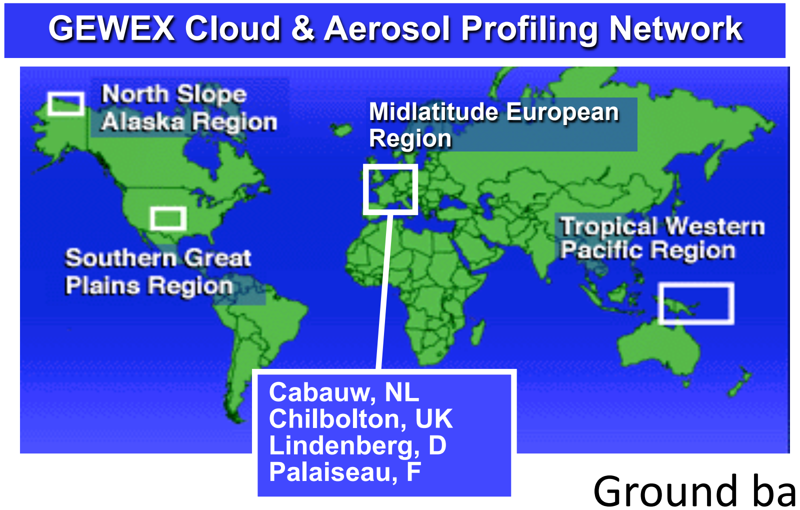
Outline

- How do we observe the cloud variables ?
  - Some elements of the physical basis for remote sensing of clouds
- What have we learned so far about clouds from satellite remote sensing ?
  - few examples
- What is still missing ?

How do we observe the clouds ?



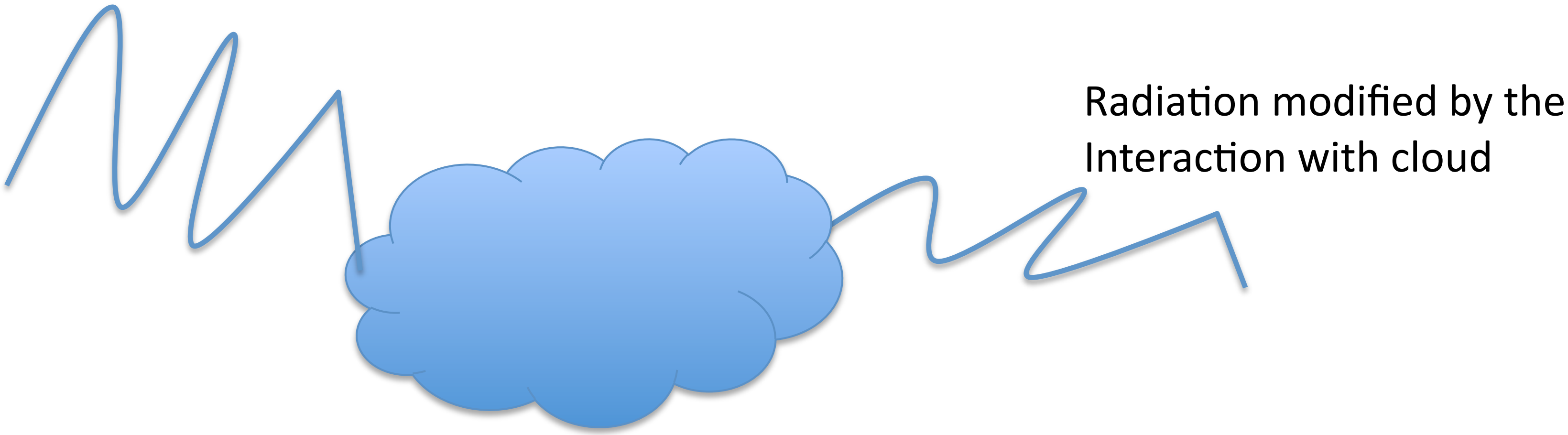




Ground base sites

Remote sensing

Incident radiation
natural: passive remote sensing
artificial: active remote sensing



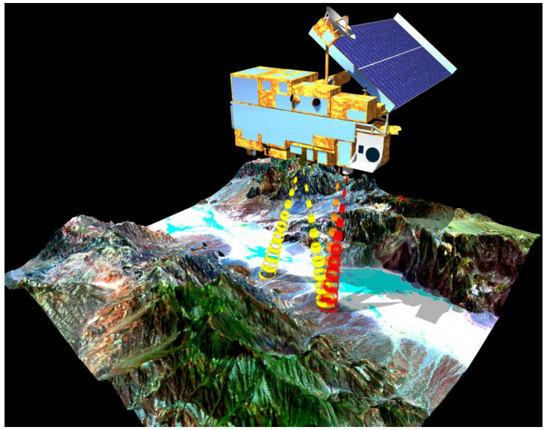
⇒Deduce cloud properties from the differences between the « incident radiation » and the « modified radiation »

⇒ The « incident radiation » and « the modified radiation » are linked by the radiative transfer equation

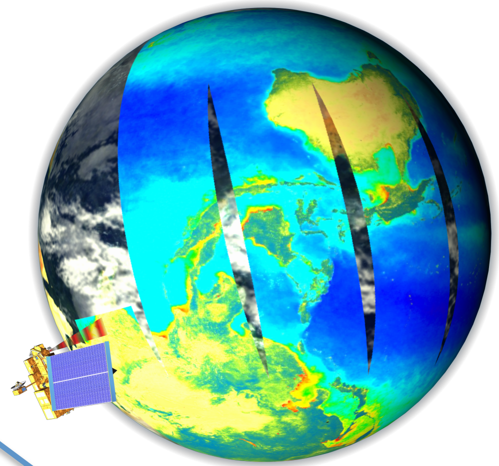
What is behind (and influences) the cloud properties retrieved from satellites ?

Objective: clouds

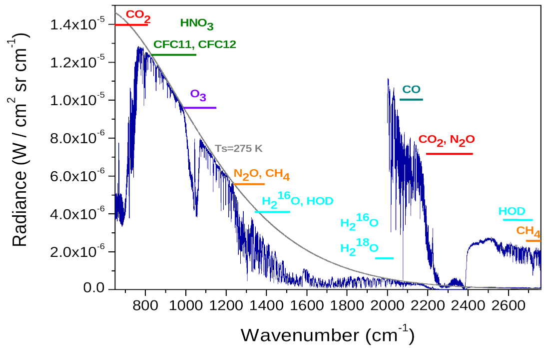
Viewing direction



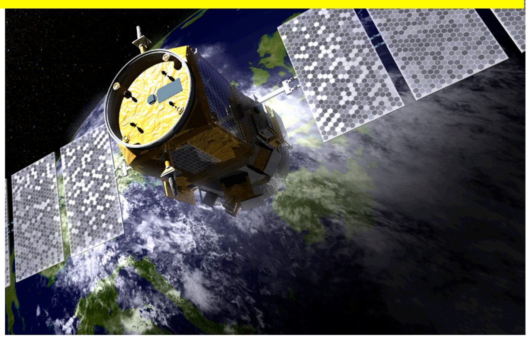
Orbit of the satellite



Wavelength



Instrument sensitivity & resolution

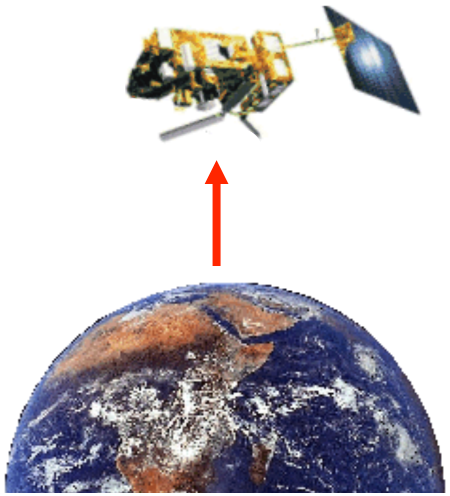


Sampling

Viewing direction

Cloud is a dense media compared to others atmospheric components (gaz, aerosols)

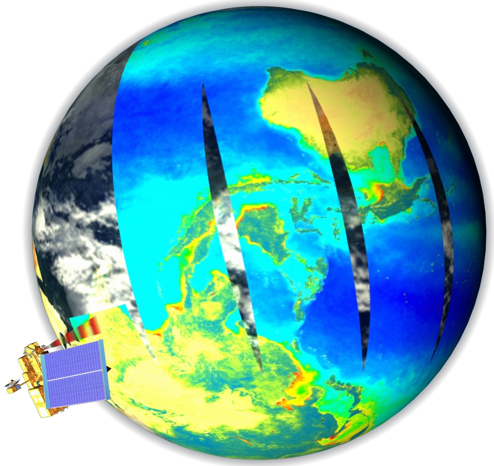
=> Nadir (or Nadir Like) viewing
with some exception for optically thin clouds (cirrus)



+ high horizontal resolution
+ good global coverage

Orbits

Sunsynchroneous

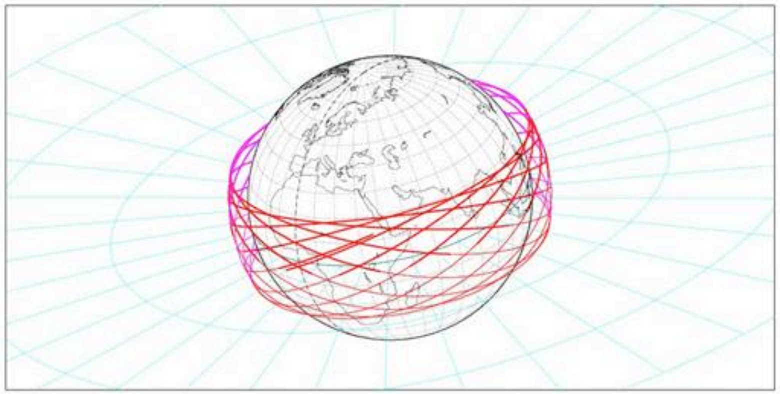


⇒ - 1 over pass per day at constant local time
Preclude access to cloud diurnal cycle

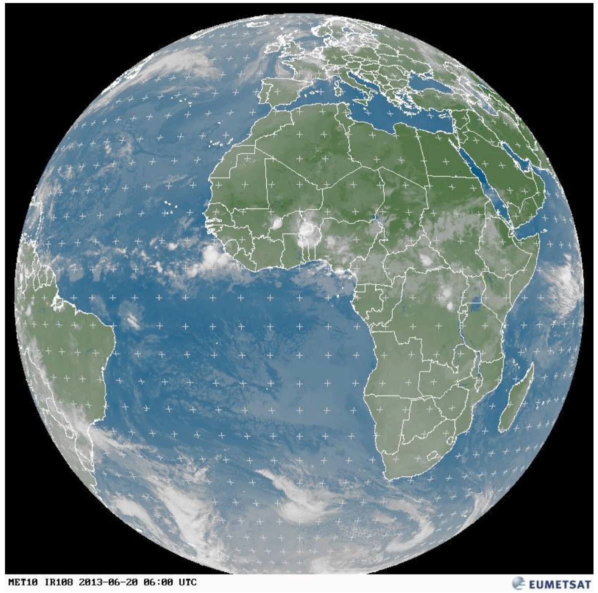
⇒ + Allow high spatial resolution and new generation of instrument (active remote sensing)

A-train

LEO Megha Tropique (orbit for one day)



Geostationnary



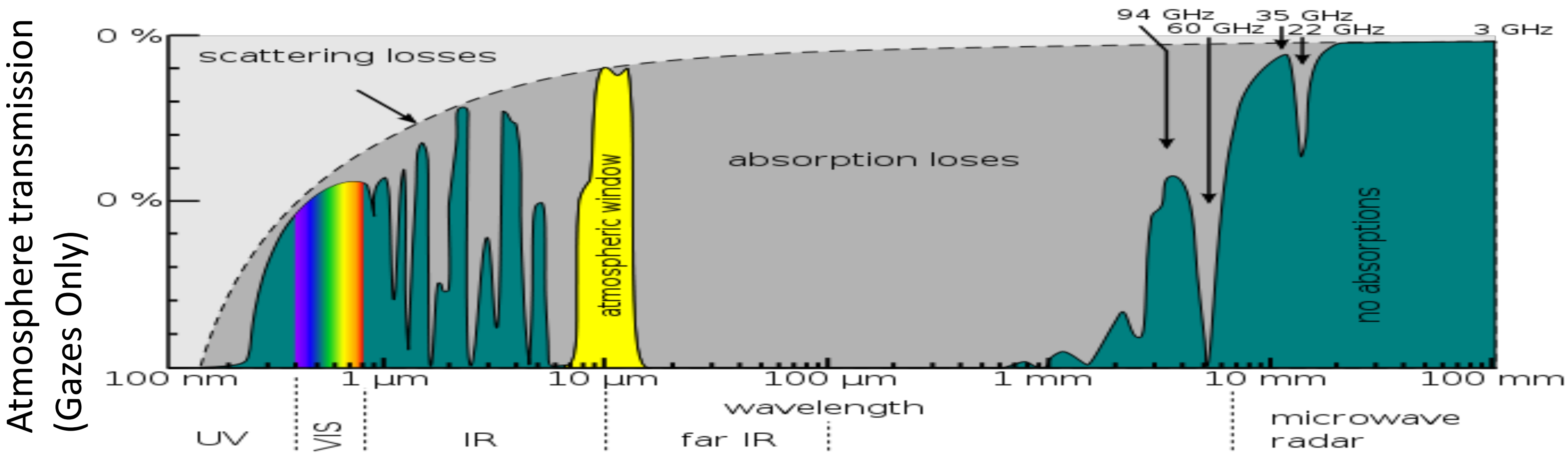
⇒ + Powerfull at low latitudes

⇒ - Preclude access to high spatial resolution and new generation of instruments and polar regions

=> + Only way to access cloud diurnal cycle from space

ISCCP

Wavelength

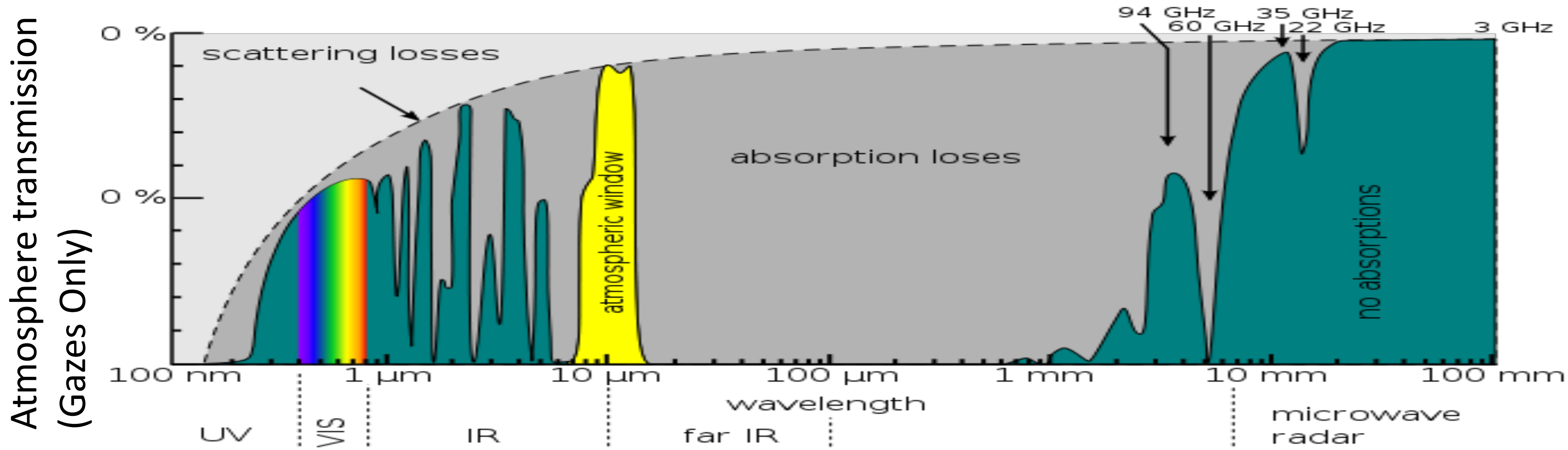


Interaction with clouds: SCATTERING ABSORPTION/ EMISSION

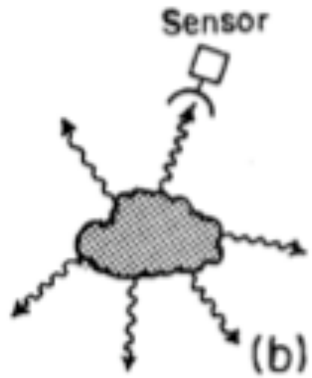
Natural source of emission: SUN SURF/ATM

Artificial source of emission: LASER (LIDAR) RADAR

Passive remote sensing of clouds in the thermal infrared

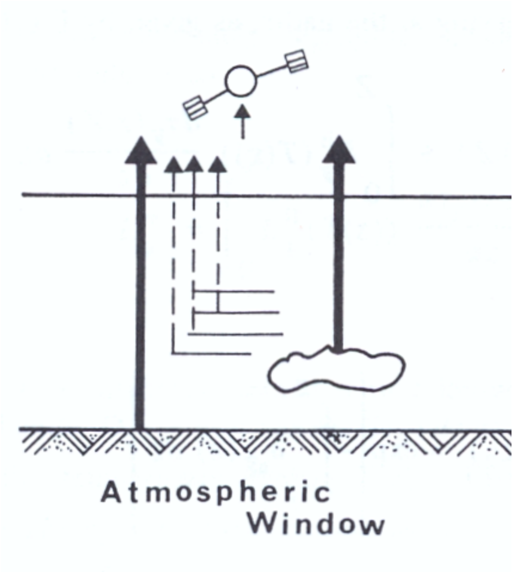


Interaction with clouds: SCATTERING ABSORPTION/ EMISSION



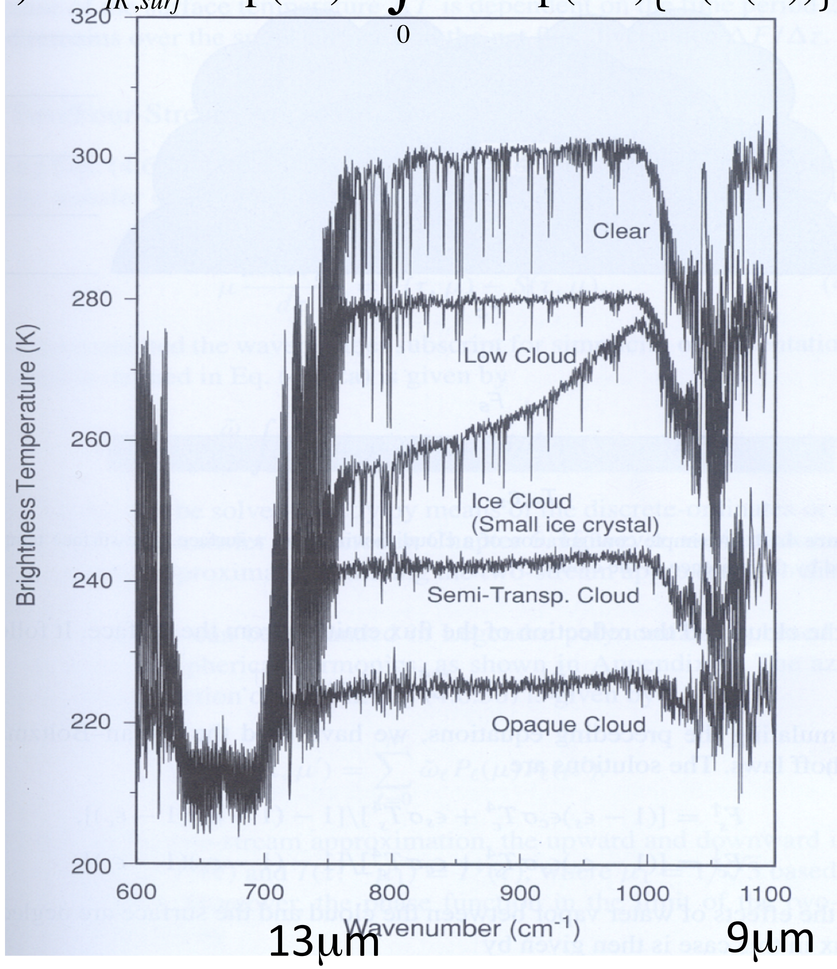
Natural source of emission: TELLURIC

Passive Remote sensing of clouds in the thermal infrared



τ_IR ,Tcloud, Tsurf drive L_IR

$$L_{IR,up}(\tau) = L_{IR,surf}.\exp(-\tau) + \int_0^{\tau} d\tau'.\exp(-\tau')\{B(T(\tau'))\}$$



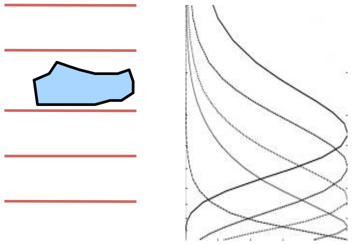
C. Crevoisier

2 channels => ε and estimate of r_{ice} when small

Spectrum => more contrains

Spectrum +CO2 absorption band (15μm)

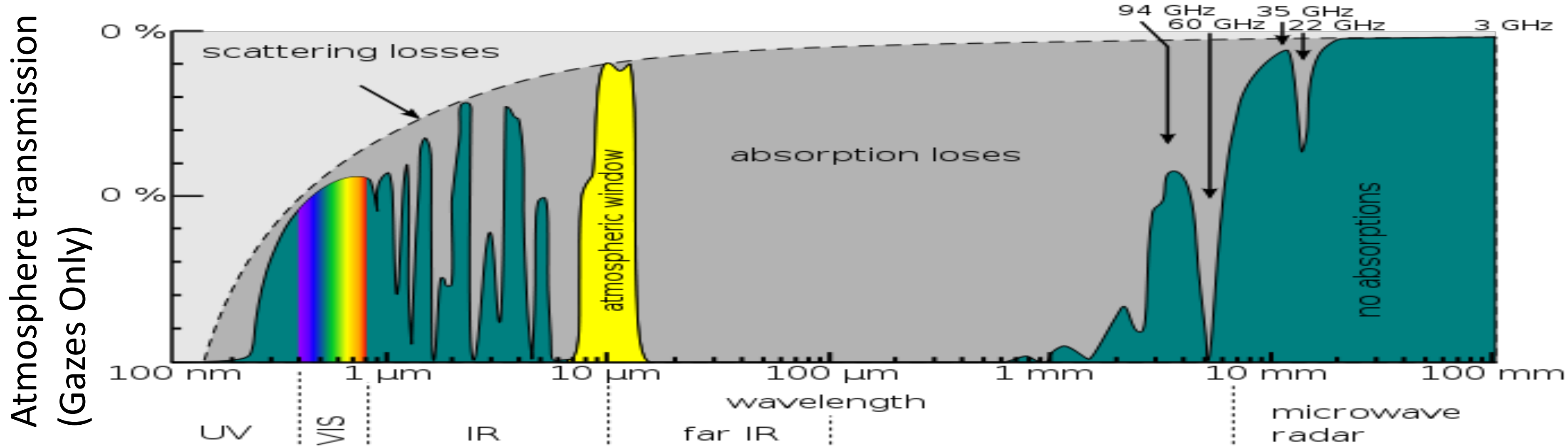
=> Cloud height constrain



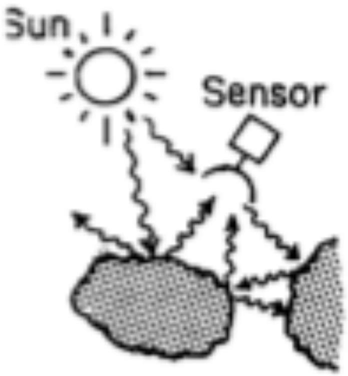
AVHRR, MODIS , ISCCP

IASI, AIRS, TOVS => spectrum (sounders)

Passive remote sensing of clouds in the visible and nIR



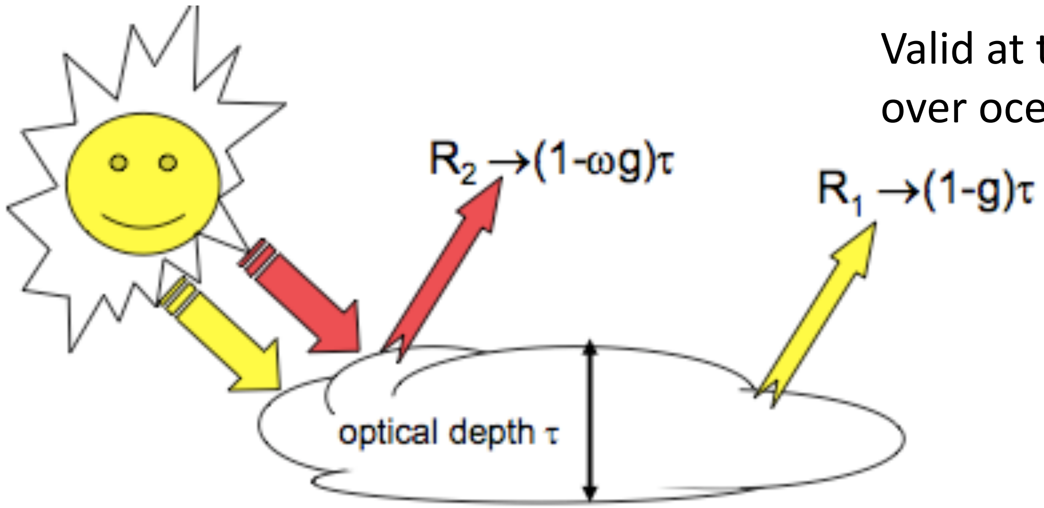
Interaction with clouds: SCATTERING ABSORPTION/ EMISSION EMISSION



Natural source of emission: SUN

Passive remote sensing of clouds in the visible and nIR

Twomey & Cocks, 1980's
Nakajima & King, 1990s



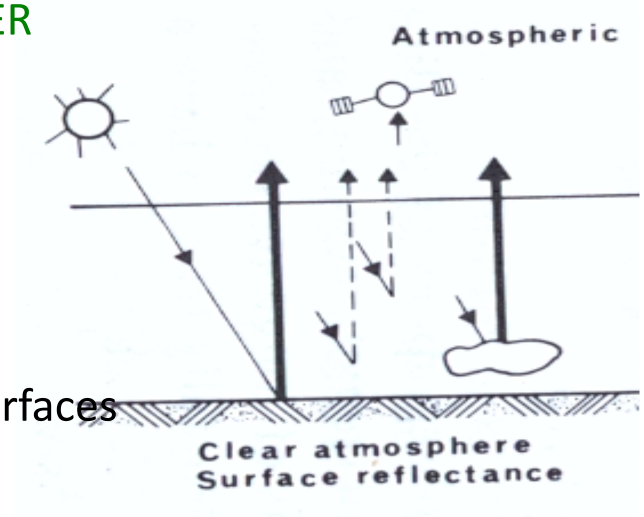
Valid at the cloud top over ocean

$$LWP \rightarrow \frac{2}{3}\tau r_e$$

1 viewing direction Vis and pIR radiometers: ISCCP, PATMOS, ATSR
Multi angles VIS radiometers: MISR and PARASOL/POLDER

Day time only

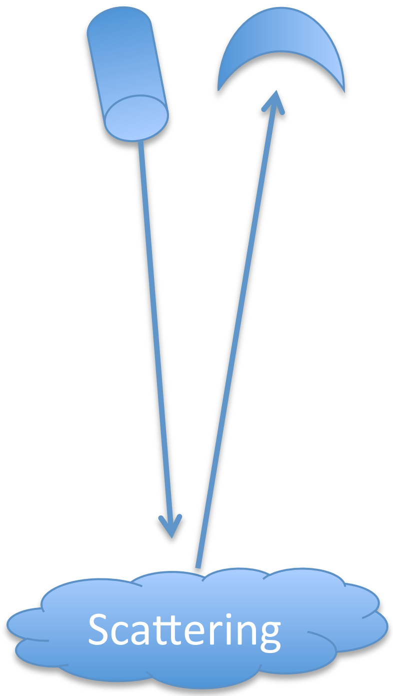
Difficult to use above reflecting surfaces



Active remote sensing

Source of radiation

Transmitter (I_rec)   Receiver (I_rec)



Backscattering $\Theta = \pi$

Pulses : the source is not continuous (=/ natural radiation)

$\Rightarrow$Distance Transmitter-Receiver : $d = c\ (t1 - t0)\ /2$

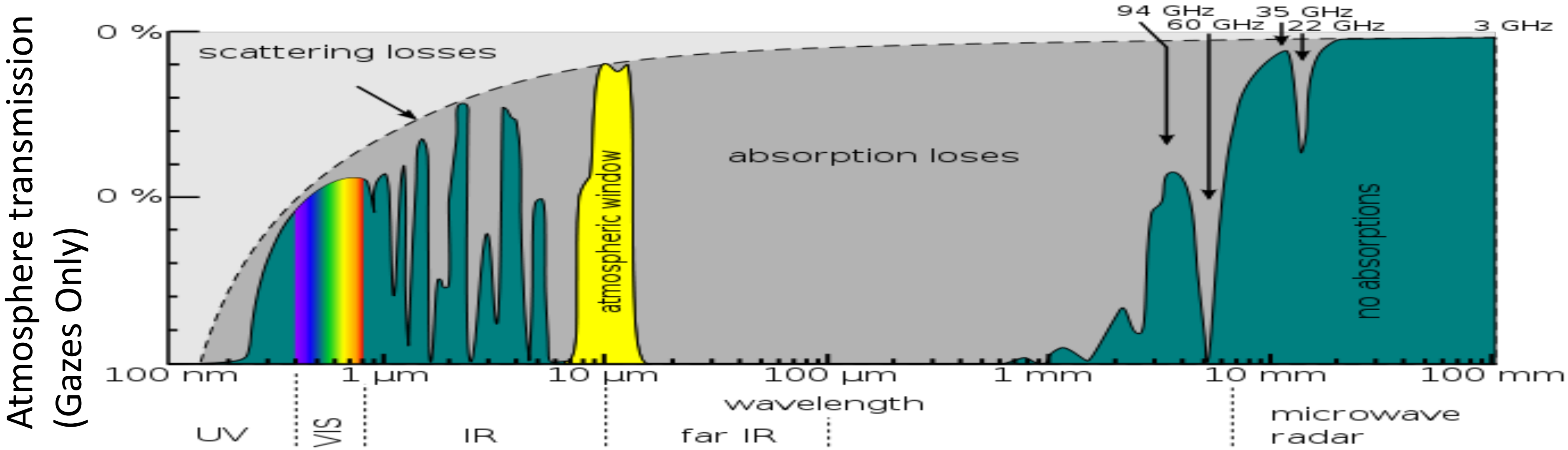
$\Rightarrow$ cloud detailed vertical structure !!

Backscattering only:

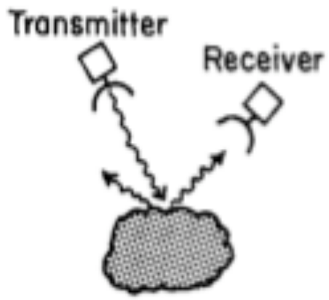
=> $I\_rec = I\_inc\ .\ \beta.\ T^2(d)$

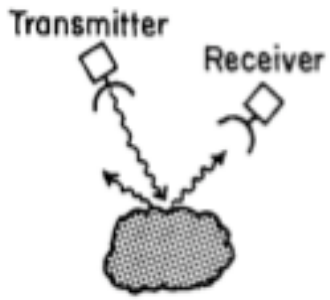
Limit : a curtain

Active remote sensing of clouds



Interaction with clouds: SCATTERING | ABSORPTION/ EMISSION | SCATTERING



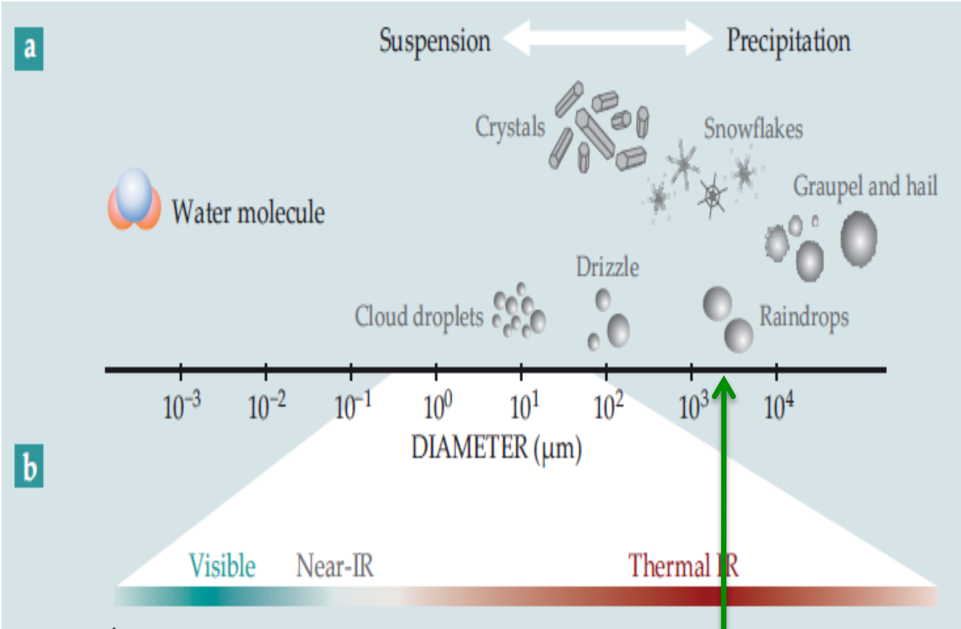


Artificial source of emission: LASER (LIDAR) | RADAR

What drives interactions between an ensemble of cloud particles and radiation?

1) When do an ensemble of cloud particles and radiation interact?

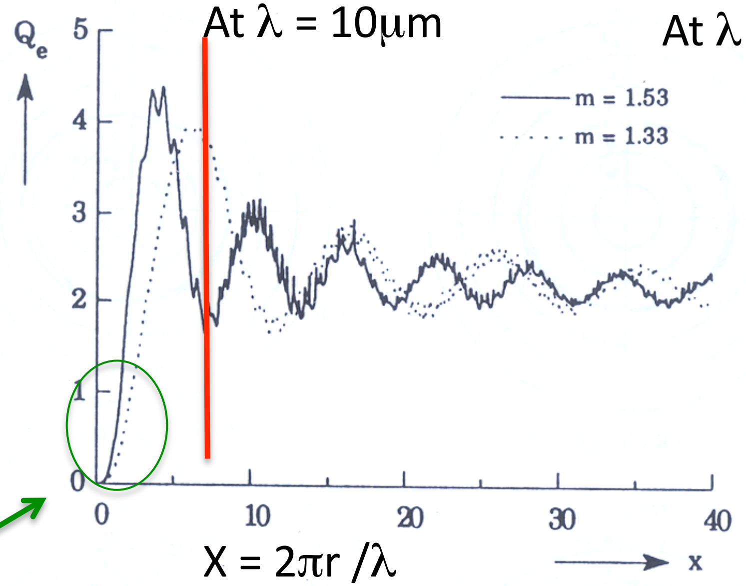
=> Particle size .vs. Wavelength: the extinction efficiency



Stevens, Bony

r = 10µm
At λ = 10µm

r = 10µm
At λ = 1µm



60

$X = 2\pi r / \lambda$

Lidar :
λ = 0.5 µm

Cloud Radar
λ = 3.2 mm

Active remote sensing : wavelengths

	Transmitter	Advantage	Disadvantage
CALIPSO	Laser (visible, infrared wavelengths; 0.5-10 X 10^{-6} m)	Sees* all particles of a few 0.1 X 10^{-6} m and greater, able to provide high resolution	Attenuates heavily in moderately thick cloud, multiple scattering confuses ranging (from space)
	Mirowave		
CLOUDSAT	mm wavelength (e.g. 3mm)	Sees* all particles of a few ~5 X 10^{-6} m (most cloud particles) and greater. No multiple scattering effects	Attenuation in moderate to heavy rainfall ms for rains > 3-5 mm/hr from space
TRMM	cm wavelength (1-10 cm)	Less attenuated under heavy rain	Unable to see majority of cloud

* Depends also on volume concentration of particles sees ice and water particles with almost equal sensivity

G. Stephens

$$I(z) \approx Io.\frac{P(\pi)}{4\pi}\sigma_{sca}.\exp[-2\eta\tau(z,TOA)]$$

Z => N.D^6

See Lebstock papers for precipitations

Active remote sensing : wavelengths

More Calipso advantages :
-opticall very thin clouds (subvisible)
- very fractionnated clouds (shallow cu)
- Clouds close to the surface
- Clouds over continents

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CALIPSO	Laser (visible, infrared wavelengths; 0.5-10 X 10^{-6} m)	Sees* all particles of a few 0.1 X 10^{-6} m and greater, able to provide high resolution	Attenuates heavily in moderately thick cloud, ~~multiple scattering confuses ranging (from space)~~
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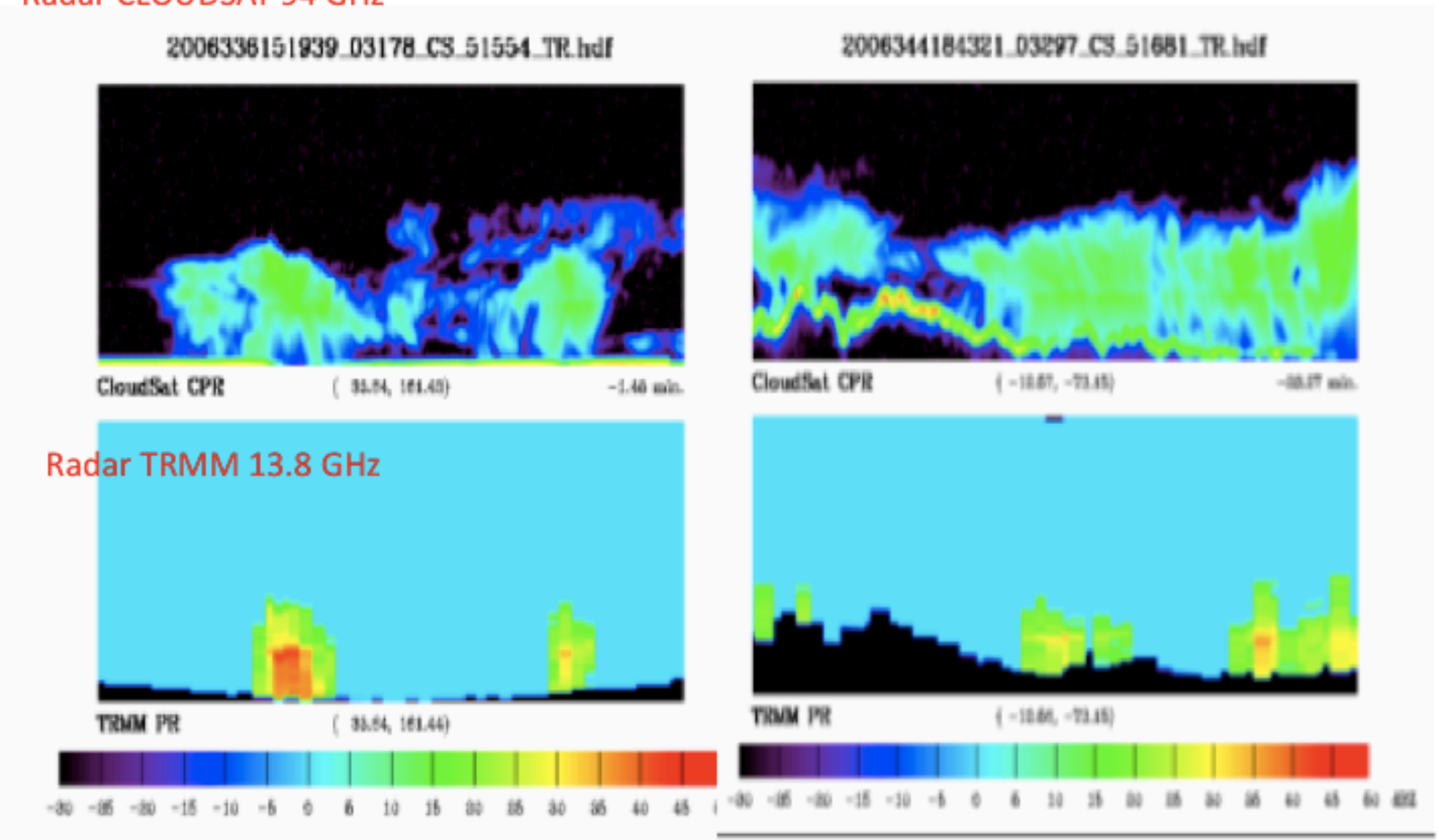
Radar CLOUDSAT 94 GHz



How do we observe these cloud variables ?

- Instruments onboard satellite observe Radiances (NOT fluxes) at a given wavelength, spatial resolution and temporal resolution

-The spatial resolution (pixel, footprint) varies from one instrument to another (250m to 20km)

=> the radiance is an average over the surface of the footprint

=> clouds smaller that the spatial resolution are mixed with clear regions

-Each wavelength observes a different part of the clouds (radiative transfer eq)

None of the wavelength can observe completely the cloud (radiative transfer eq)

-The observed radiance are used to

1) detect the presence of clouds

2) retrieve the optical depths (or emissivity),

3) which are used to derive Re and LWP

Consequence:

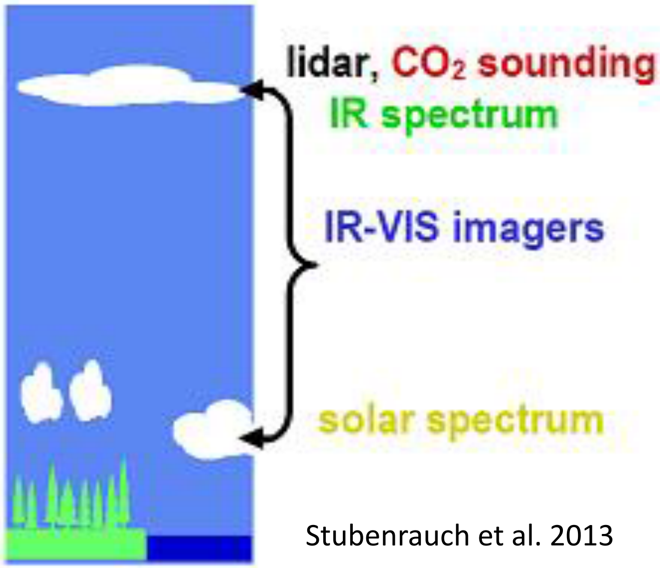
If a couple (wavelength&resolution) is sensitive to a certain part of the cloud, then, steps 1-3 will concern only this part of the cloud

=> Step 1 « detect the presence of a cloud » (or « cloud cover ») determines the next steps

Is there a cloud ? …. again … but this time from a satellite point of view

« The cloud detection »

=> The « cloud cover »



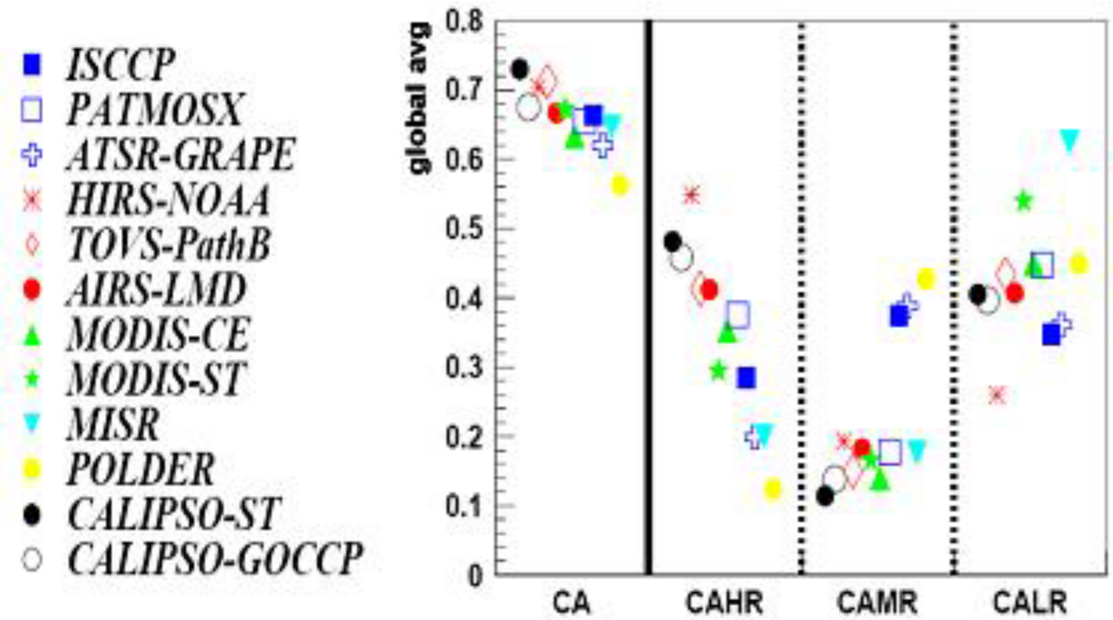
Stubenrauch et al. 2013

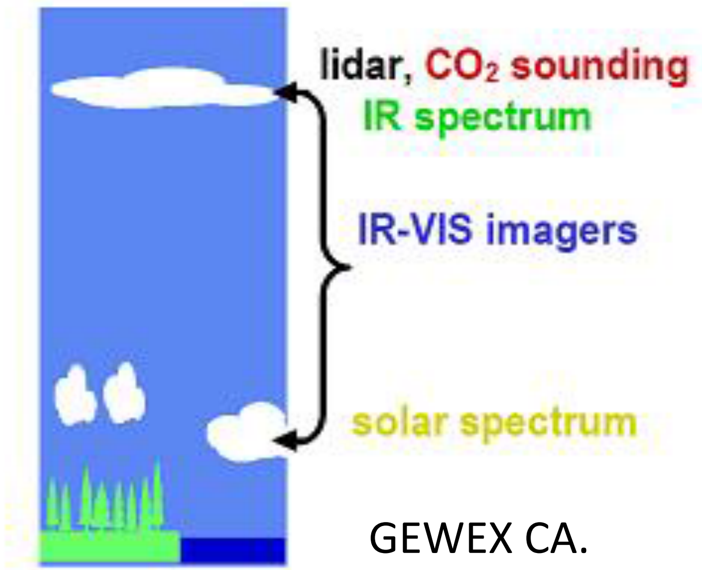
- How do we observe these cloud variables ?
  - physical basis for remote sensing of clouds

- What have we learned so far about clouds from satellite remote sensing ?
  - Some example of Results

- What is still missing ?

About the cloud cover





GEWEX CA.
Stubenrauch et al.

The cloud covers observed at different wavelengths are different , which is consistent with the radiative transfer equation

NB: in a model, the cloud cover does not depend on the wavelength => the « model cloud cover » and « observed cloud cover » are not the same thing
=> (LWP, T, Re) in models and (LWP, T, Re) in observations are a priori not the same things

Time series of

cloud amount & Tcloud

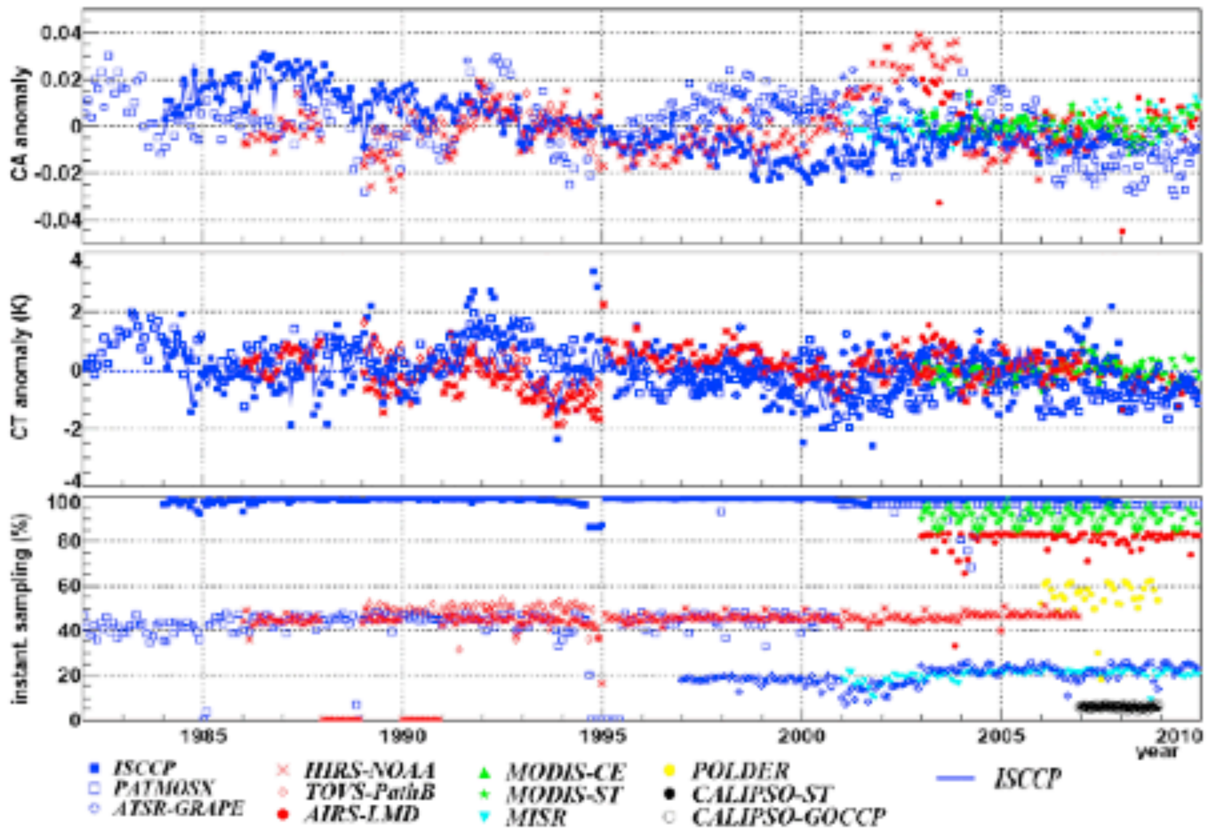
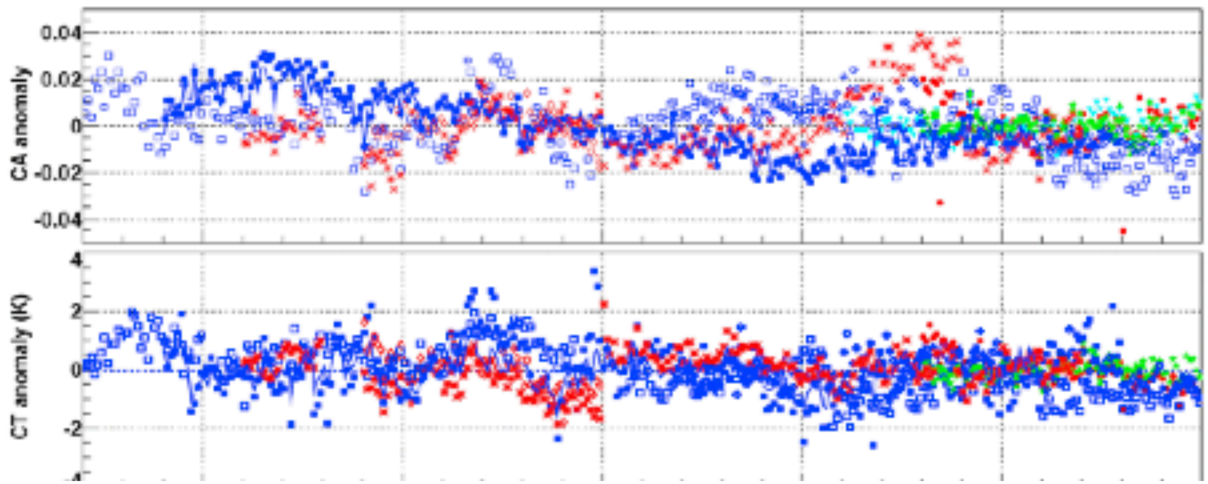


Figure 6: Time series of global cloud amount (CA) and cloud temperature (CT) anomalies as well as of monthly mean 'instantaneous' sampling fraction of the globe (at a specific local observation time) of the participating datasets. For each dataset the period covered in the GEWEX cloud assessment database is shown, with local observation time at 1:00 PM (3:00 PM for ISCCP, 10:00 AM for ATSR-GRAPE and 10:00 AM for MISR). ISCCP anomalies are also shown using the whole diurnal time statistics (blue line).

GEWEX CA.
Stubenrauch et al.

Time series of

cloud amount & Tcloud



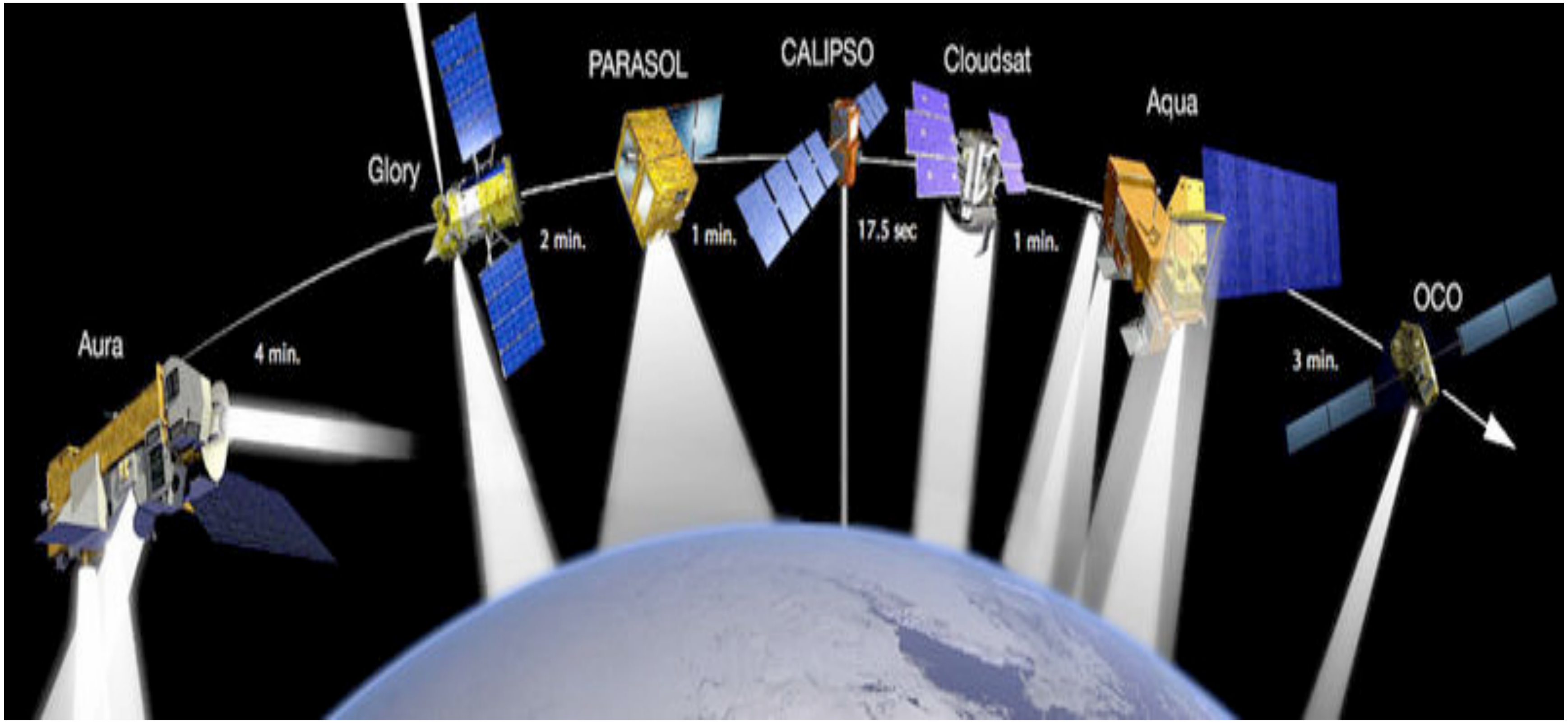
« Global interannual variability lies between 2-3% in cloud amount, and 2K in cloud temperature

ISCCP exhibit a slowvariation over 1984-2008, that is not reflecting in any other dataset (coarser time sampling). Spurious changes in calibration and sampling do affect the magnitude but do not eliminate this slow variation

A present, on can only conclude that global monthly mean cloud amount is constant over the last 25 yeras to within 2.5%, within the range of interannual variability »

GEWEX Cloud Assesment.

About the A-train

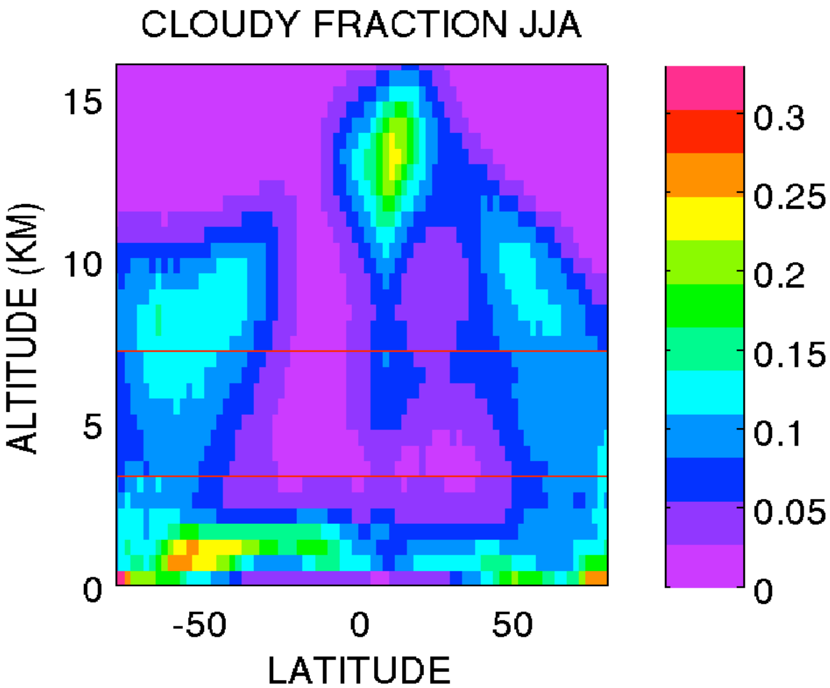


Since 2006: the golden age of cloud's satellite observations ?

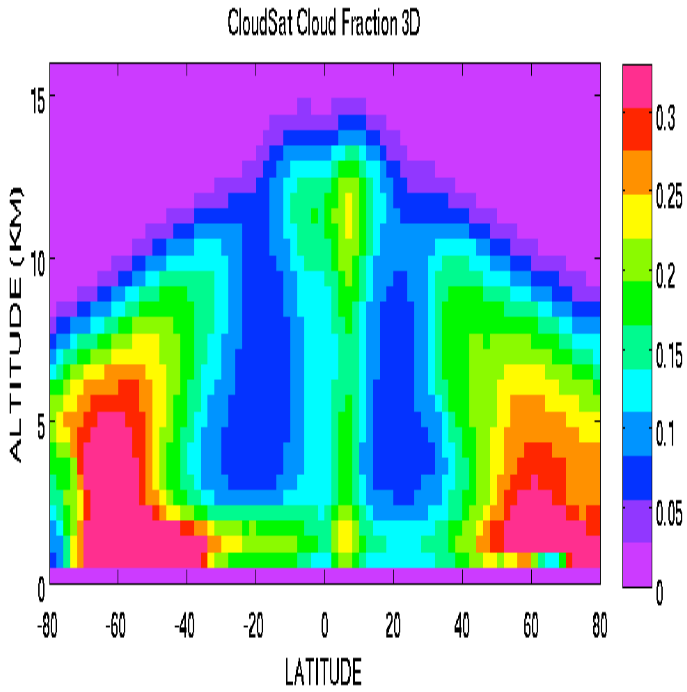
hundreds of papers => visit the CALIPSO and CloudSat publication webpage
http://www-calipso.larc.nasa.gov/resources/bibliographies.php
http://cloudsat.atmos.colostate.edu/publications/journal_articles

The zonal mean cloud fraction profile

LIDAR CALIPSO



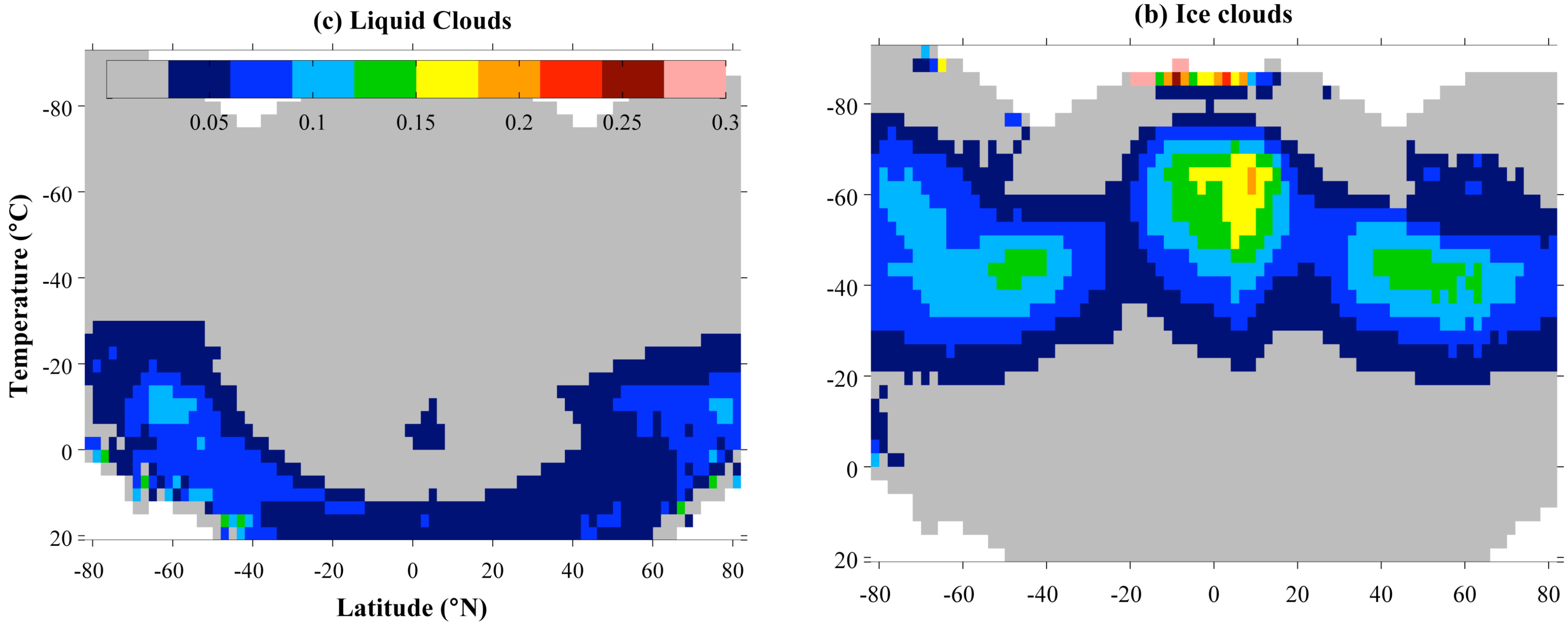
RADAR CLOUDSAT



CFMIP-OBS

Cloud Phase

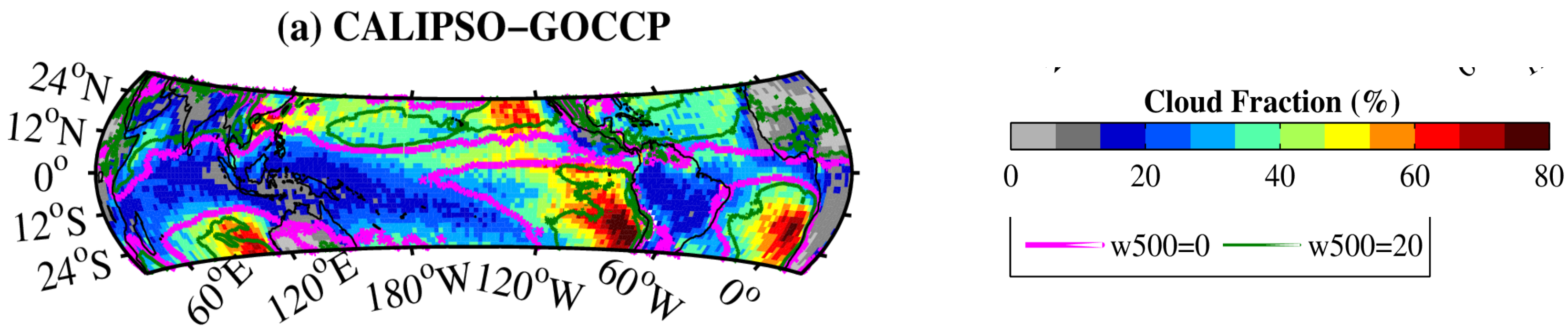
LIDAR CALIPSO



CFMIP-OBS

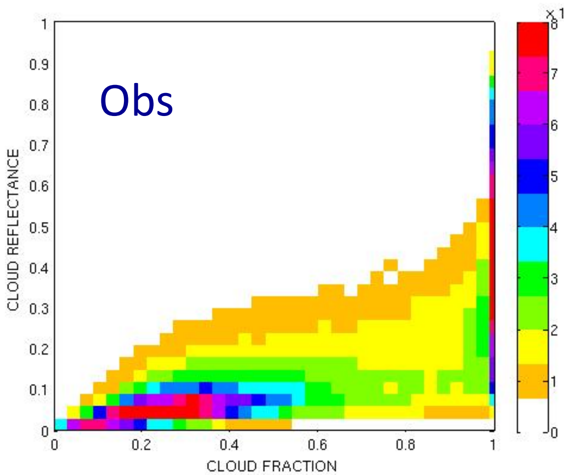
Cesana 2012

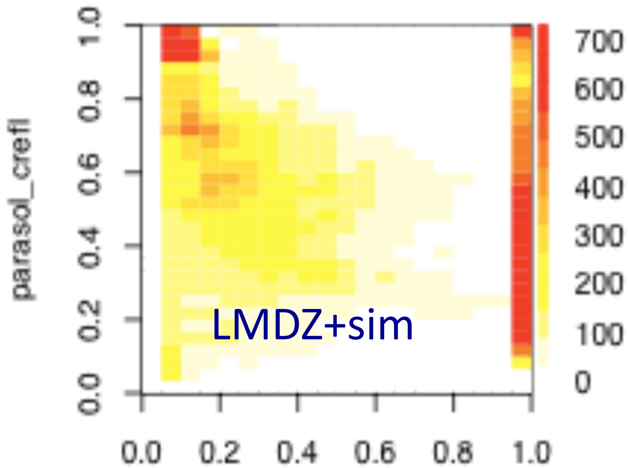
In tropical boundary layer clouds, synergy between A-train instruments : the instantaneous statistical relationship between cloud cover and optical depth



Corrélation between instantaneous variables

Cloudy Reflectance PARASOL





Konsta et al., 2012

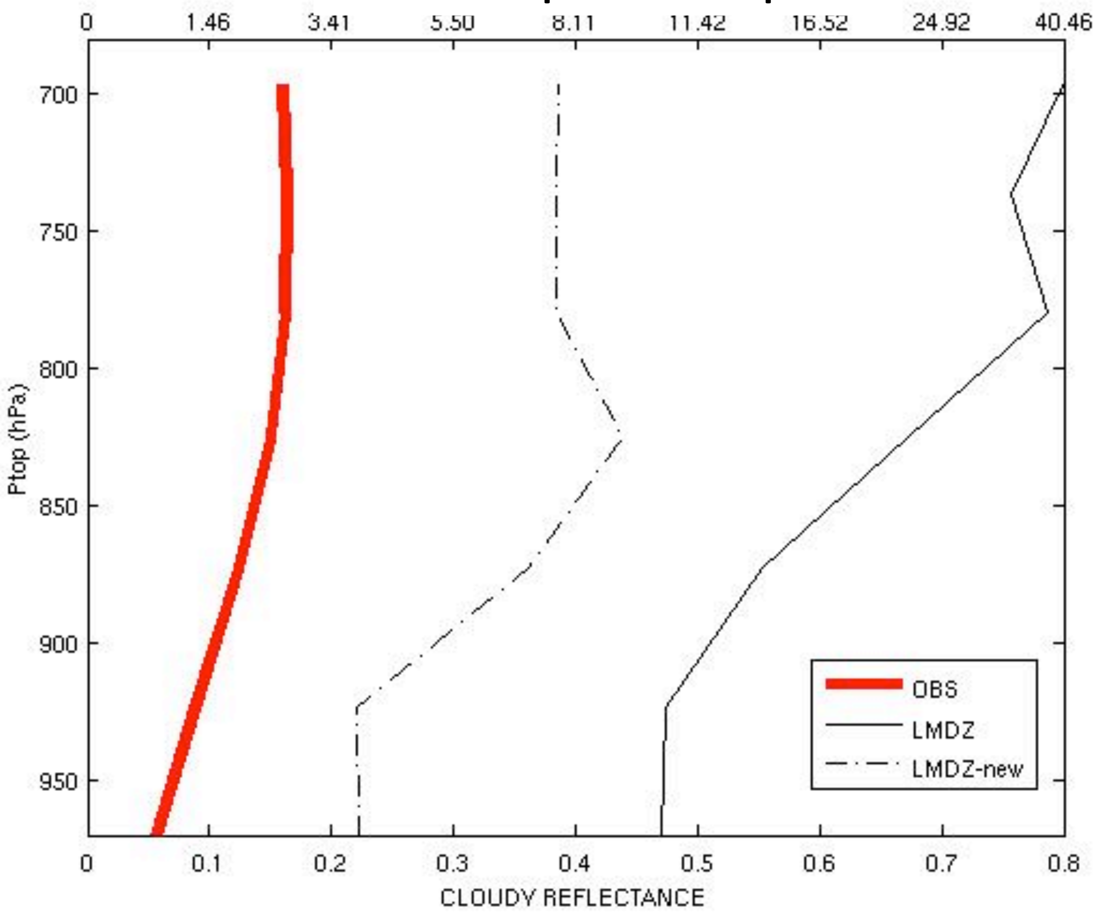
Cloud fraction (CALIPSO-GOCCP)

Statistics over 2 years

In tropical boundary layer clouds, synergy between A-train instruments shows that:
Cloud top gets higher with optical depth (2 years of obs)

Cloud Optical depth

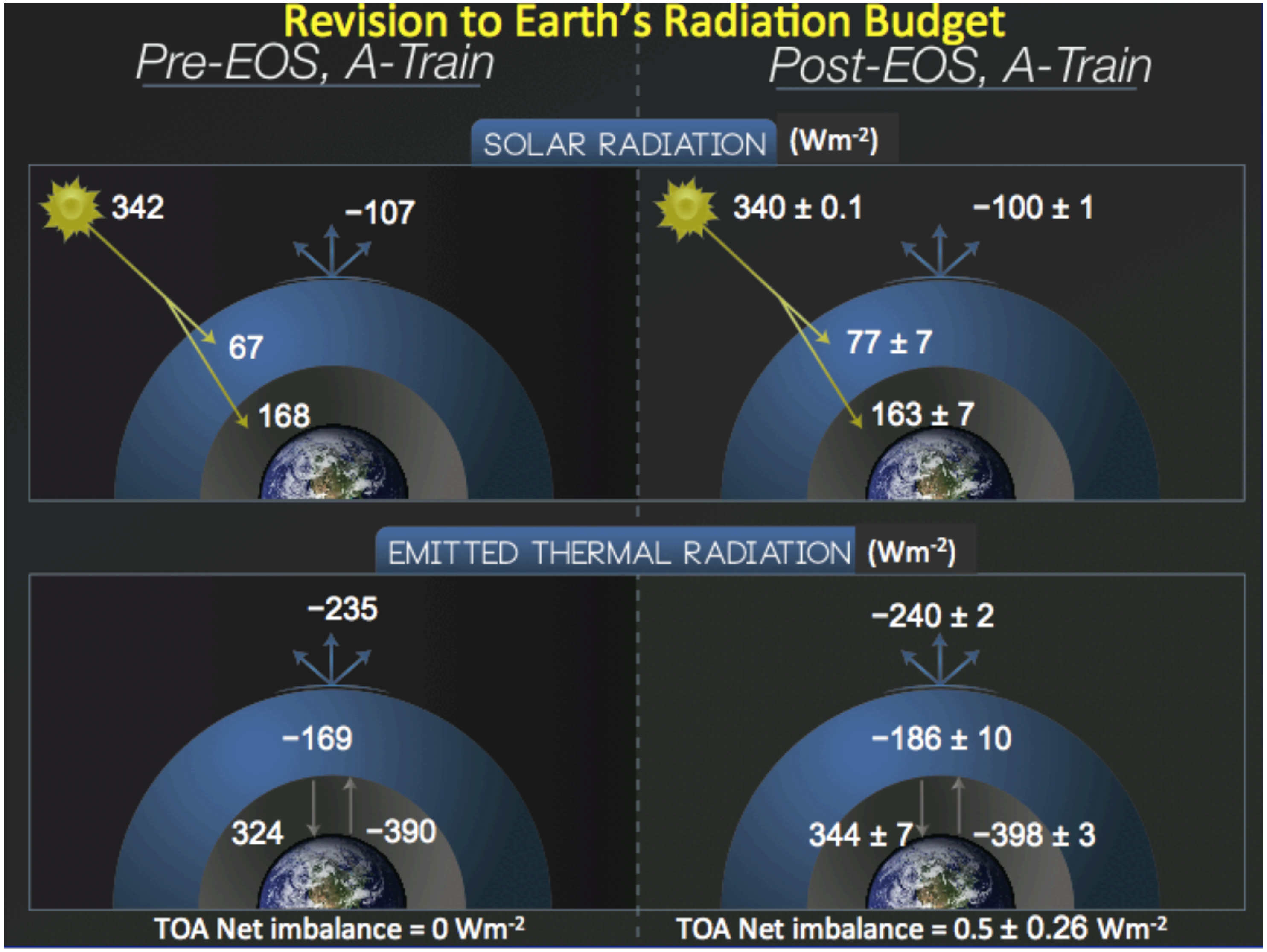
Cloud Top Pressure Calipso-GOCCP



Cloud Reflectance

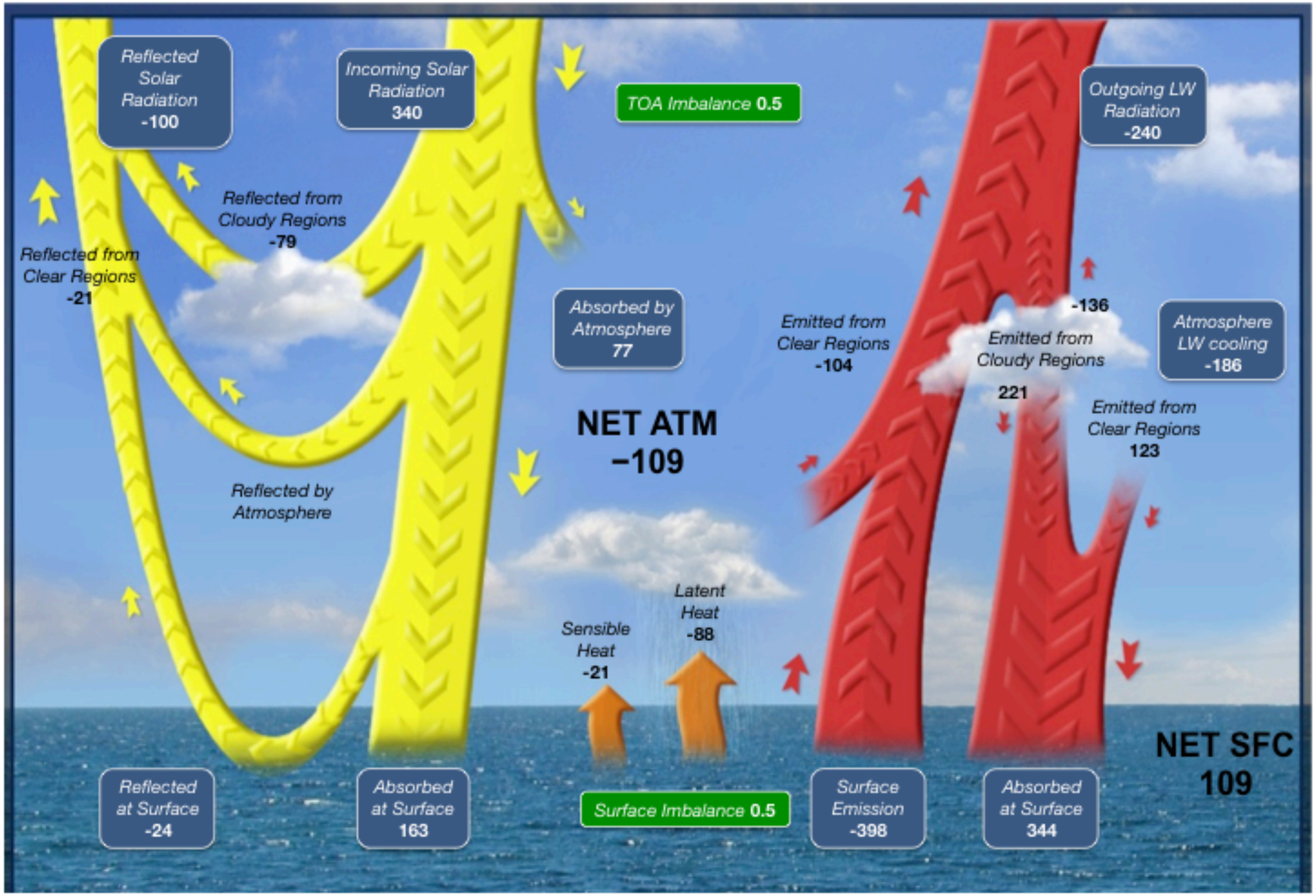
(Konsta et al. 2012)

For 0.2 <Cloud Fraction < 0.5
Statistics over 2 years


Revision to Earth's Radiation Budget
Pre-EOS, A-Train
Post-EOS, A-Train
SOLAR RADIATION (Wm-2)
342
-107
67
168
340 ± 0.1
-100 ± 1
77 ± 7
163 ± 7
EMITTED THERMAL RADIATION (Wm-2)
-235
-169
324
-390
-240 ± 2
-186 ± 10
344 ± 7
-398 ± 3
TOA Net imbalance = 0 Wm-2
TOA Net imbalance = 0.5 ± 0.26 Wm-2

Loeb & Kato

Radiative budget



Loeb and Wielicki, in press

Some recomendations

- Check the temporal and spatial resolution of the observational dataset you are using (cloud diurnal cycles, small clouds, …)
- Long time series for clouds are still ….
- Be careful above continent and mountains and ice/snow
- Observations are always dependent on the instrument sensitivity, and for clouds on the optical properties .vs. Wvl => check what wvl you are using
- Observations are not models: need to understand the difference in the definition of variables

- Recent observations (A-train and future E-Care) : « the golden age of cloud observations ??? » take this opportunity

- The remote sensing community has done significant effort to make cloud observations easier to understand for non remote sensing researchers:
  - Use CFMIP simulators (COSP) to « practice » cloud remote sensing
    - http://cfmip.metoffice.com/COSP.html
  - Use CFMIP-OBS + COSP for model evaluation
    - http://climserv.ipsl.polytechnique.fr/cfmip-obs/
  - Use Gewex Cloud assesment to learn about instruments sensitivity and products
    - http://climserv.ipsl.polytechnique.fr/gewexca/

What is still missing for clouds ?

- Long term series (current and new variables: eg. Vertical structure)
- Co variance of cloud variables at interesting spatio temporal resolution (process studies) & statistically representative
- Diurnal cycle .vs. Global coverage
- Low level atmos at global scale
- Light precipitations
- Clouds variables within their environment

- New ways to « think »/analyze obs (remove cloud cover ? LWC ? …) define the relevant diagnostics

LWC

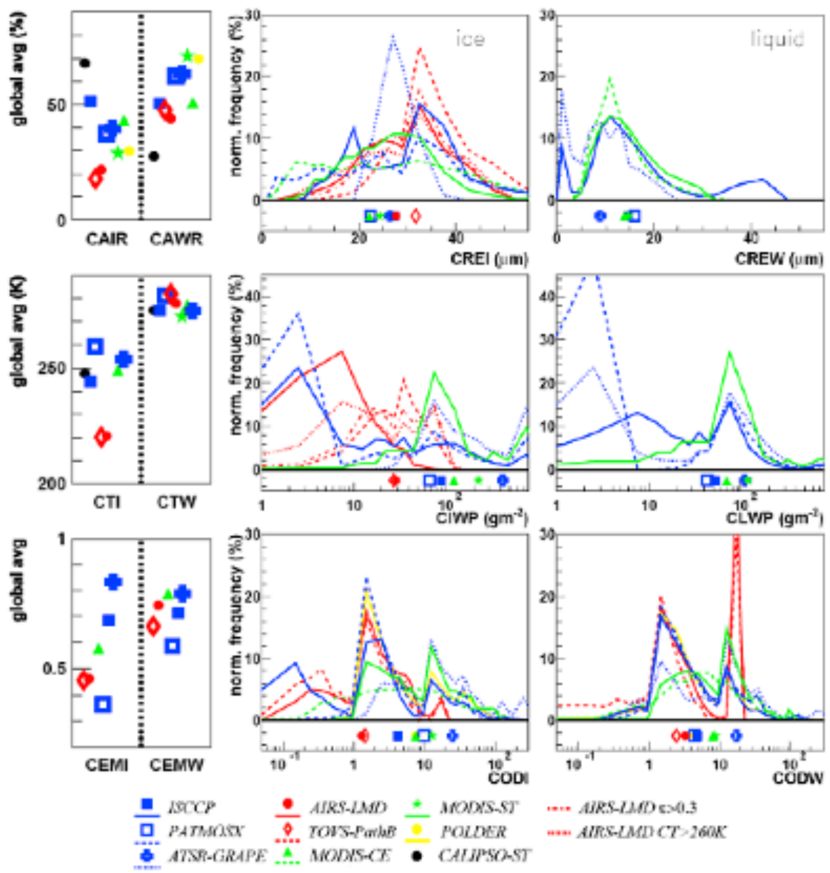


Figure 4: Left: Global averages of cloud properties of ice clouds (I) and of liquid clouds (W): relative amount (CAR), temperature (CT) and IR effective emissivity (CEM). CAWR + CAIR = 100%, except AIRS-LMD and TOVS Path-B for which the missing 35% correspond to clouds of mixed phase (230 K < CT < 260 K). Right: Normalized frequency distributions of cloud properties of ice clouds (I) and of liquid clouds (W): effective radius (CRE), water path (CWP) and optical depth (COD). Their global averages are indicated below the distributions. Statistics are averaged over daytime measurements (1:30 – 3:00 PM LT, except ATSR-GRAPE at 10:30 AM LT).Seasonal cycle of selected cloud properties

GEWEX CA