MCS cloud life cycle from merged satellite data

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An object-based approach of tropical Mesoscale Convective Systems (MCS) life cycle

Deep convective clouds and the areally extensive anvils associated with them are the dominant clouds in the Tropics, accounting for the visible appearance of the ITCZ in satellite imagery.
- more than half of total rainfall in the wet Tropics
- diabatic heating drives the Hadley & Walker circulation
- affect the energy balance (water redistribution) & large anvil size

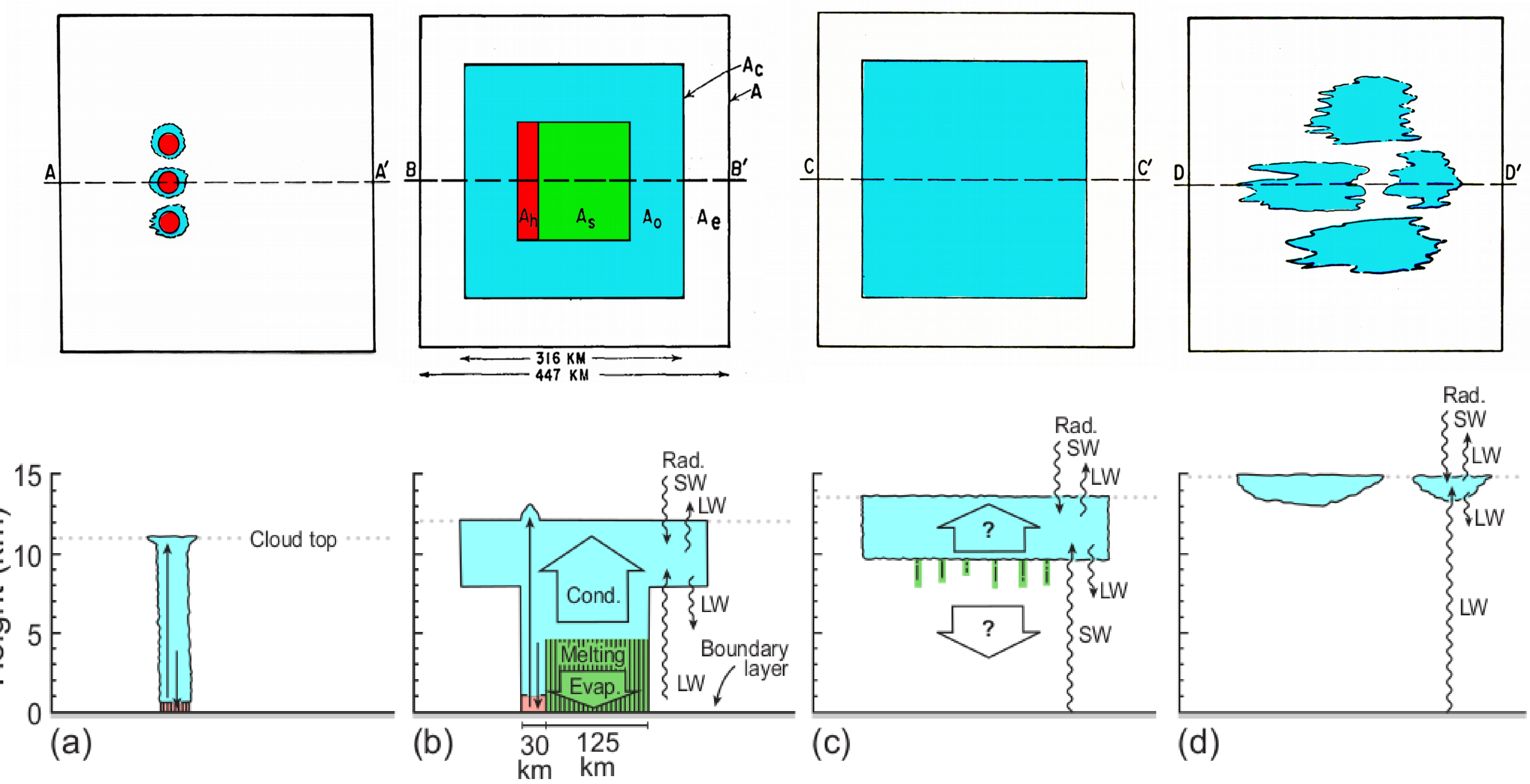
How these properties/processes evolve throughout the MCS life Cycle ?
How properties of conv and stratiform regions impact the anvil life cycle ?
Different according to the thermodynamical environment ?

An accurate representation of MCS is needed in GCM – need to represent MCS organisation (but does not exists in most GCM) & related cloud properties.

Which amount of details is needed for an accurate representation of the water & energy cycle evolution ?

MCS life cycle

Houze, 1982,2018



Importance for water cycle
Release of latent heat (conv/strat)

Importance for radiation budget
Release of radiative heating (strat/cirri)

Heating has to be weighted according the respective area : A_h, A_s, A_o

This talk

Strategy for documenting the MCS life cycle using spaceborne observations

- use of IR geostationnary imagery for detection and tracking
- take advantage of the orbiting satellites for a multivariate documentation of the MCS properties

Studied period : JJAS

Multivariate documentation

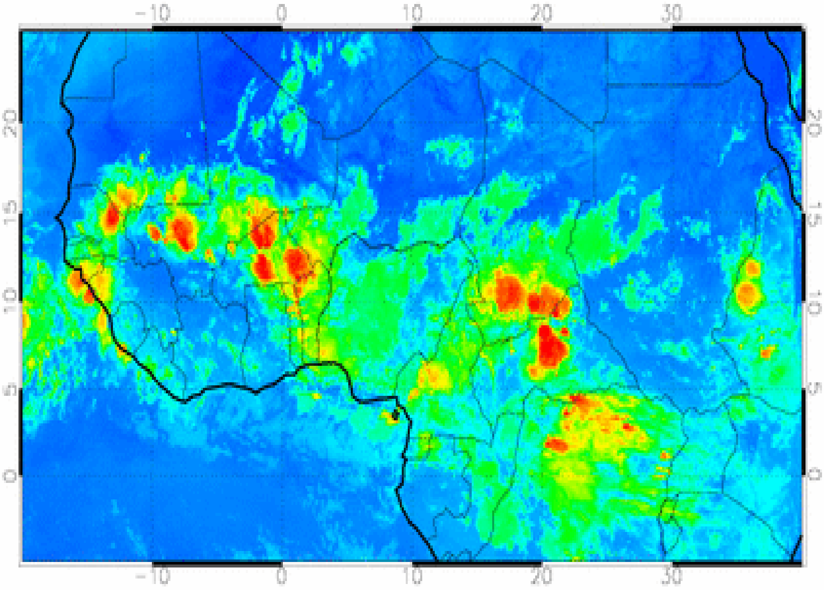
- Documentation of physical processes within the different MCS parts at regional / tropical scale
- Some technical issues

Concluding remarks

Documenting MCS Life Cycle with geostationnary images

Tracking of MCS within the geostationnary images thanks to the TOOCAN algorithm (Fiolleau & Roca 2013) at the scale of the whole Tropics

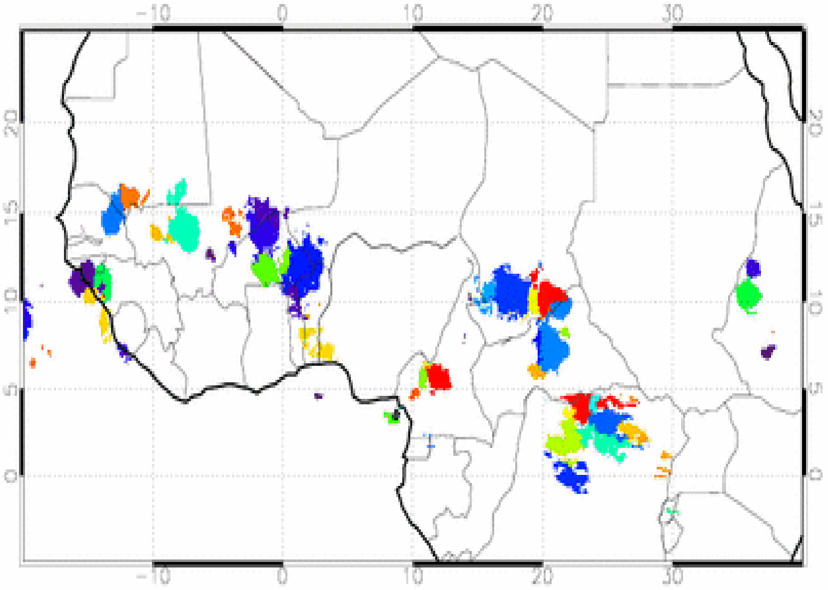
MSG IR images



2002/07/02
0000 UTC

MCS are detected and spread up to the 235K level

TOOCAN segmentation & tracking



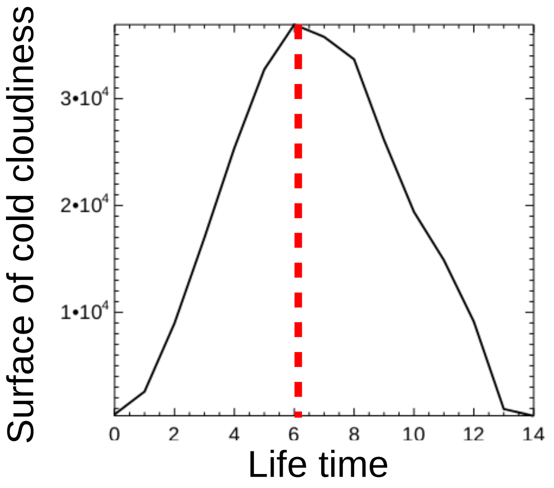
MCS scale > 1000 km^2 occasionaly sampled by an orbiting satellite

MCS sampled only once => composite strategy

Each life step is documented by aggregating observations in numerous MCS at the same life step

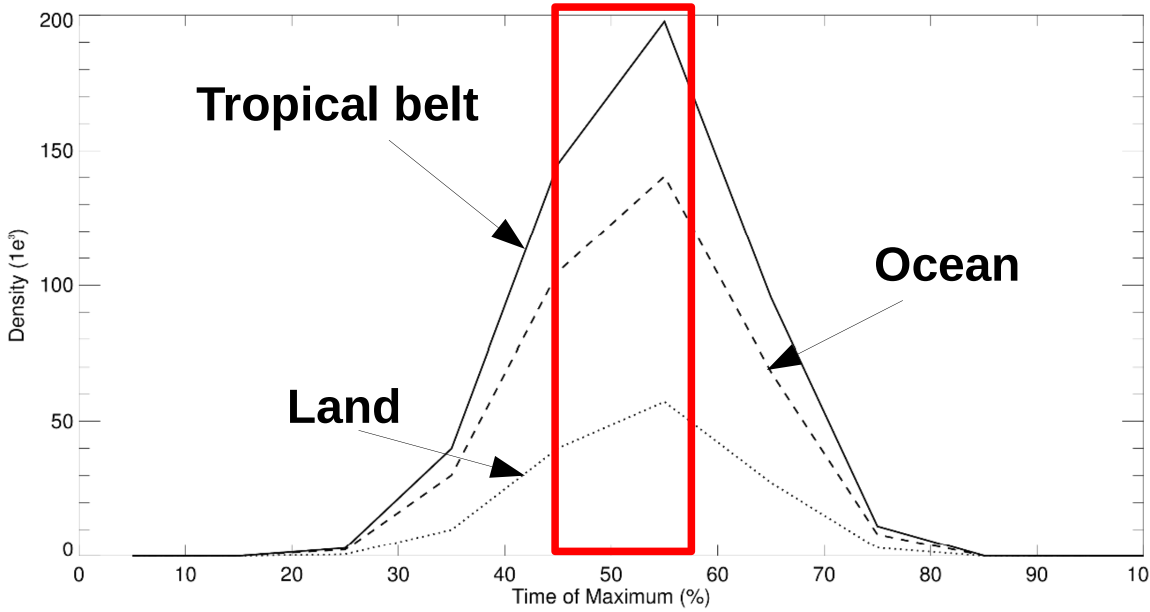
A normalised framework to document MCS life cycle

The life time is divided in 10 steps => life stage will be between 0 and 1
Life time must be longer than 5 hours (10 images)
The cloud shield must only have one phase of growth and decay



	Contribution to the total occurrence (%)			Contribution to the total cold cloudiness (%)		
	All	Land	Sea	All	Land	Sea
Number	884,063	246,080	637,983			
Life time < 5h	27	32	26	2,5	3	2
Life time > 5h simple	60	58	60	84	85	84
Life time > 5h complex	13	10	13	13,5	11	14

Maximum extend of the cold cloud shield is reached at the middle of the life cycle
=> symmetric life cycle
=> composite can be built in a normalised framework



Roca et al. (2017)

Documenting MCS Life Cycle with spaceborne observations

The composite approach provides a unified framework using the MCS tracking as a base line

MCS tracking withing geostationnary images : TOOCAN
Tropics : JJAS 2012 to 2014
Africa / Atlantic : JJAS 2007 to 2011

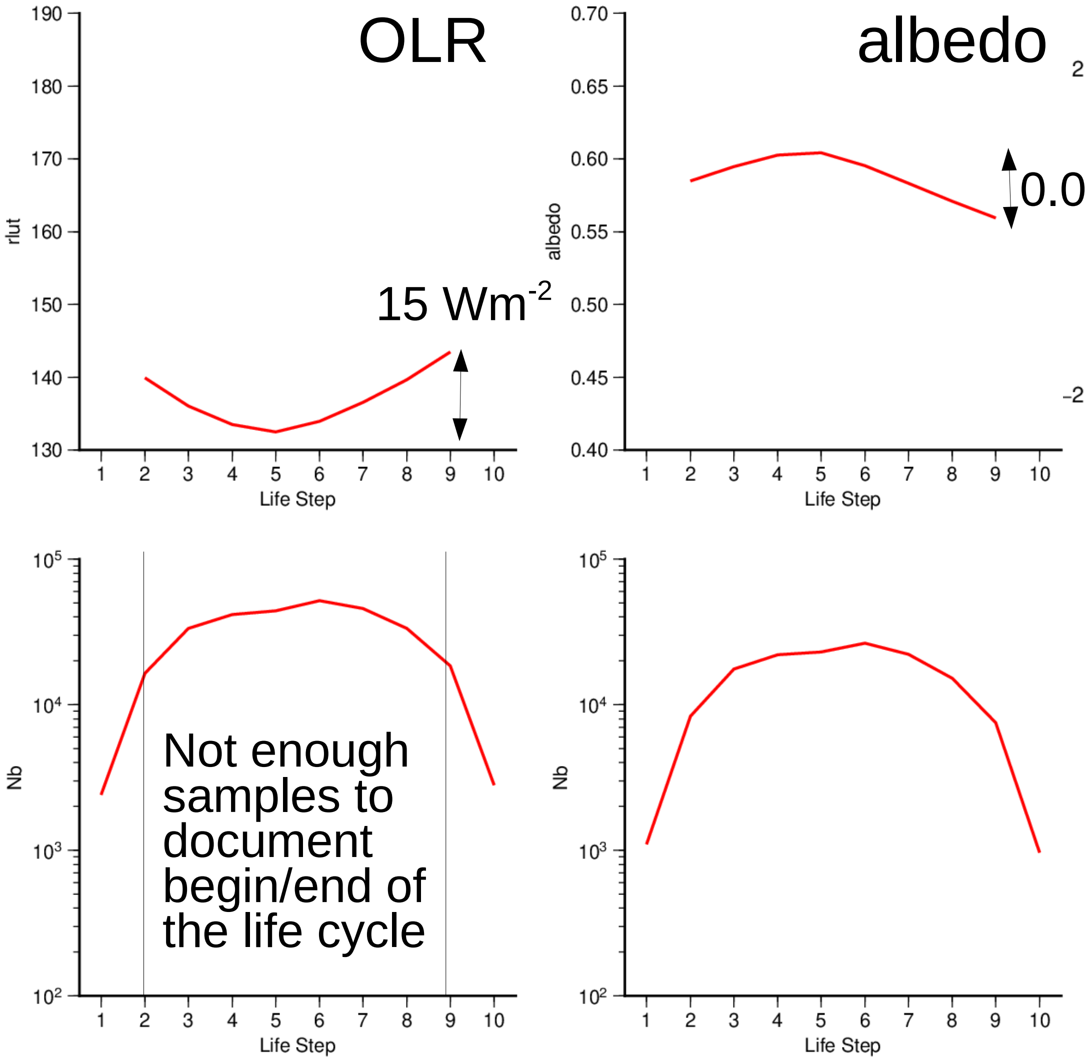
Numerous spaceborne observations but with different time spans, sampling strategy (swath or not), different resolution, sampling region

Cloud and microphysical properties, radiative heating
CloudSat/CALIPSO/CERES : 2006 to 2011 (after 2011 only day time)

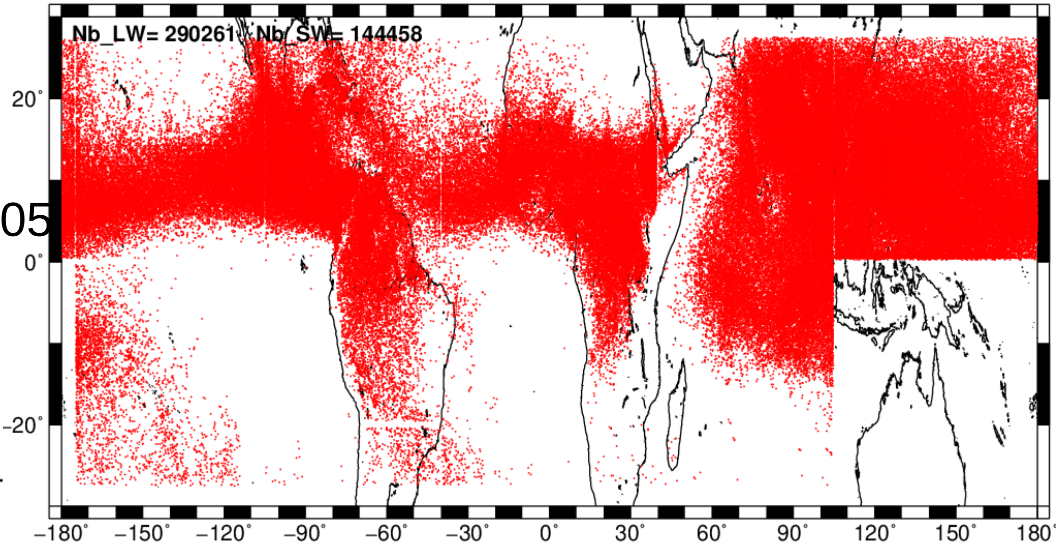
Precipitation and deep convection, latent heating
TRMM : 1998 to 2015, Spectral Latent Heating (up to 2011)

Radiative fluxes
Megha-Tropiques : since 2011

MCS radiative properties over life cycle at the scale of the Tropical Belt



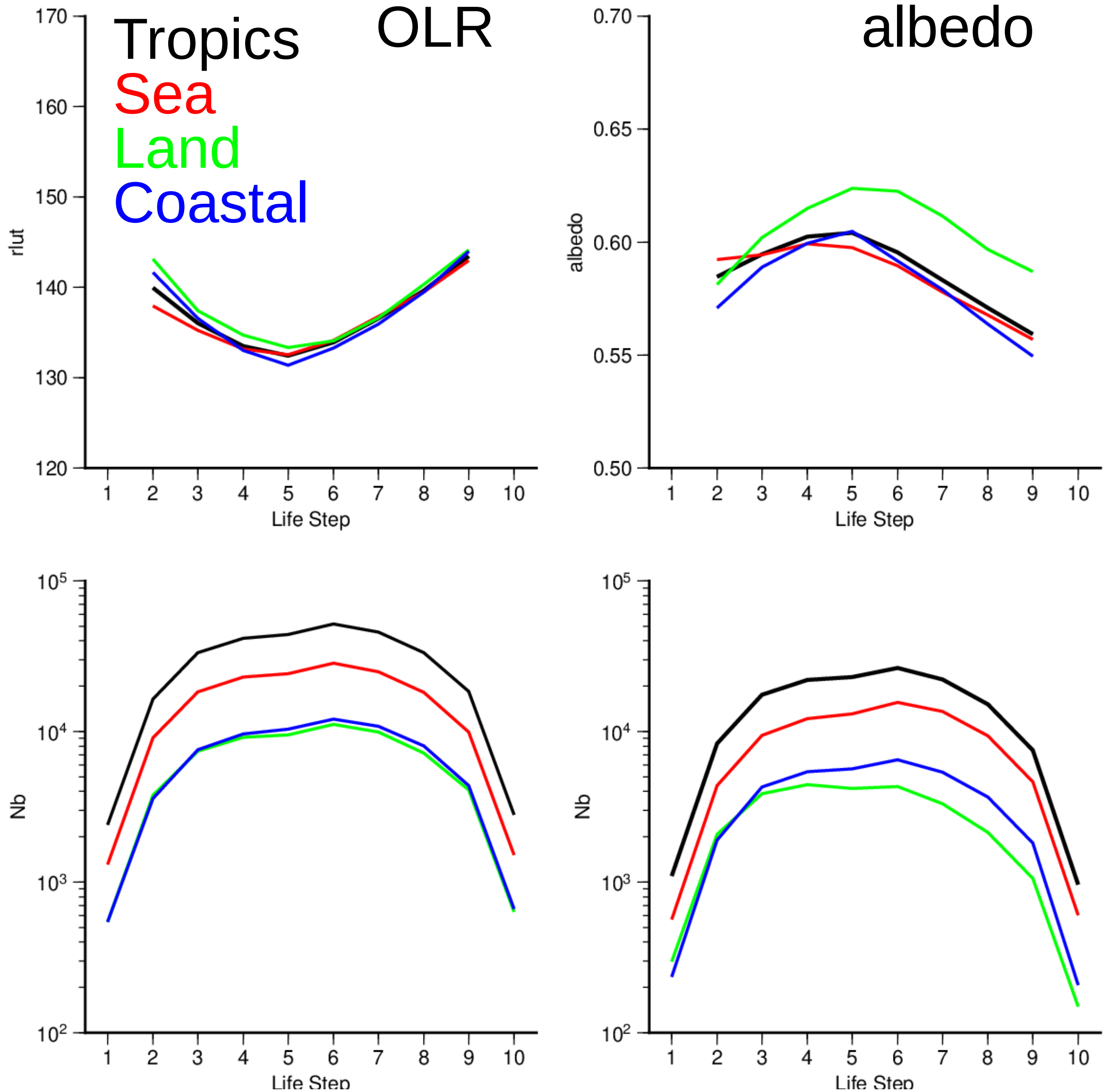
Not enough samples to document begin/end of the life cycle



JJAS 2012-2014

Variation ~ 15 Wm^{-2} / 0.05 within the life cycle
May look small but should be scaled by the size of the MCS

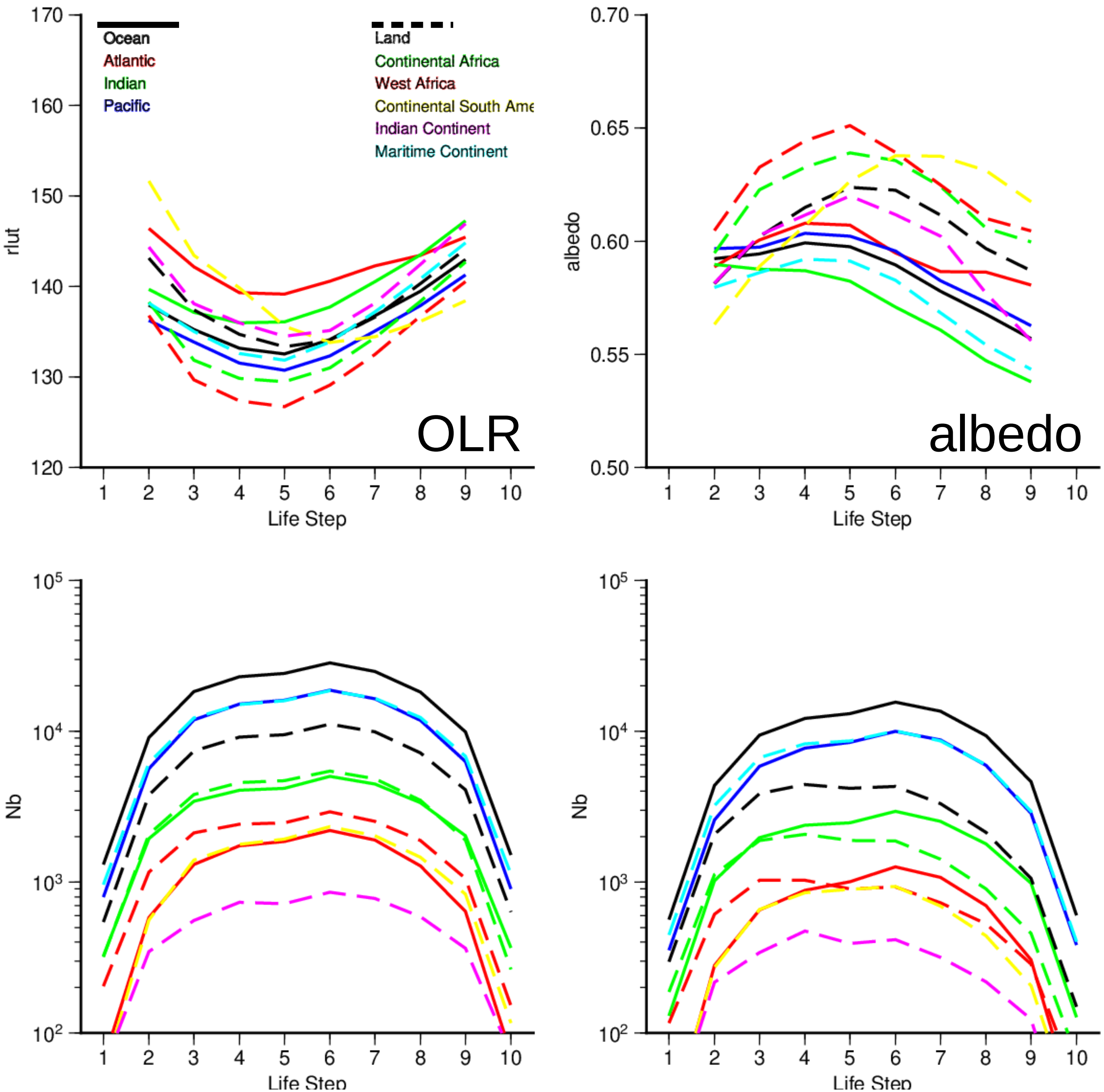
MCS radiative properties over life cycle – Land/Sea contrast

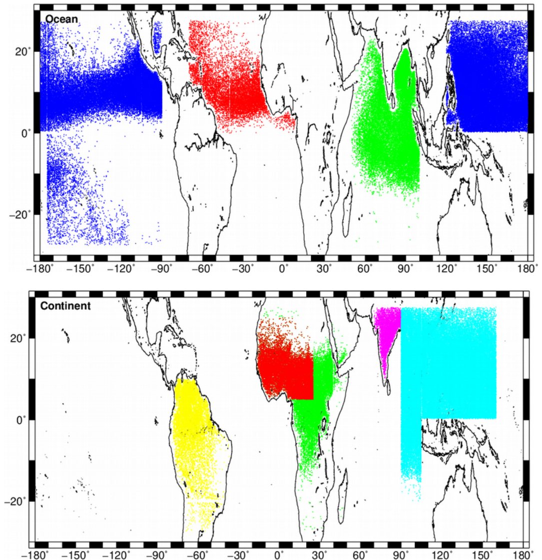


OLR :
Differences in the first half of the life cycle

Albedo :
Flat & decrease for Sea, one maximum for Land & Coastal
MCS significantly brighter over Land (whatever the life step)

MCS radiative properties over life cycle – Regional contrast





OLR & albedo have different values & life cycle according to the regions

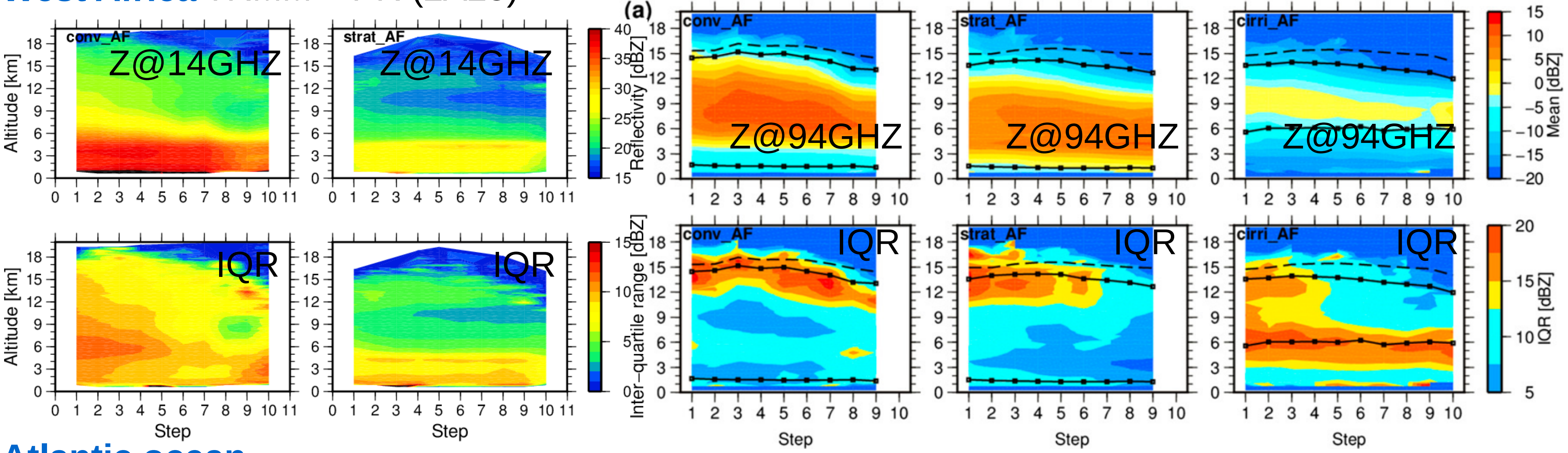
OLR :
All (-South America) have a minimum ~ middle of the life
Coldest system over WA

Albedo :
Smallest albedo over oceans (but differences among them)
Brighter MCS over WA

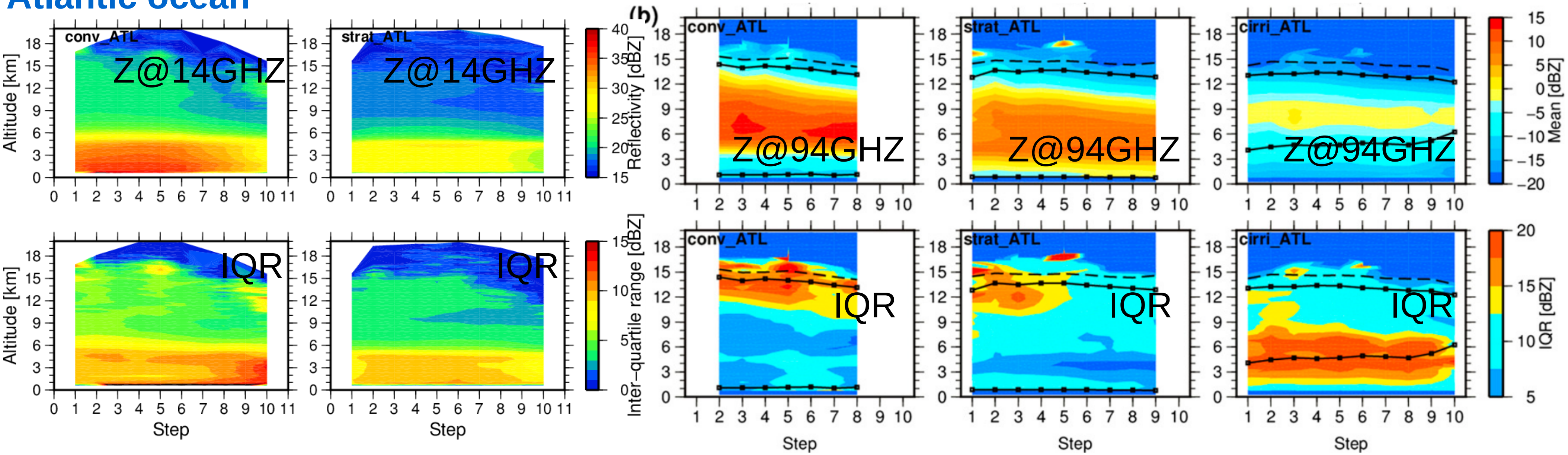
Evolution of reflectivity over the MCS life cycle

West Africa TRMM – PR (2A25)

CloudSat - CPR



Atlantic ocean



Conv Strat Conv Strat Cirri

Bouniol et al. (2016)

Evolution of reflectivity over the MCS life cycle

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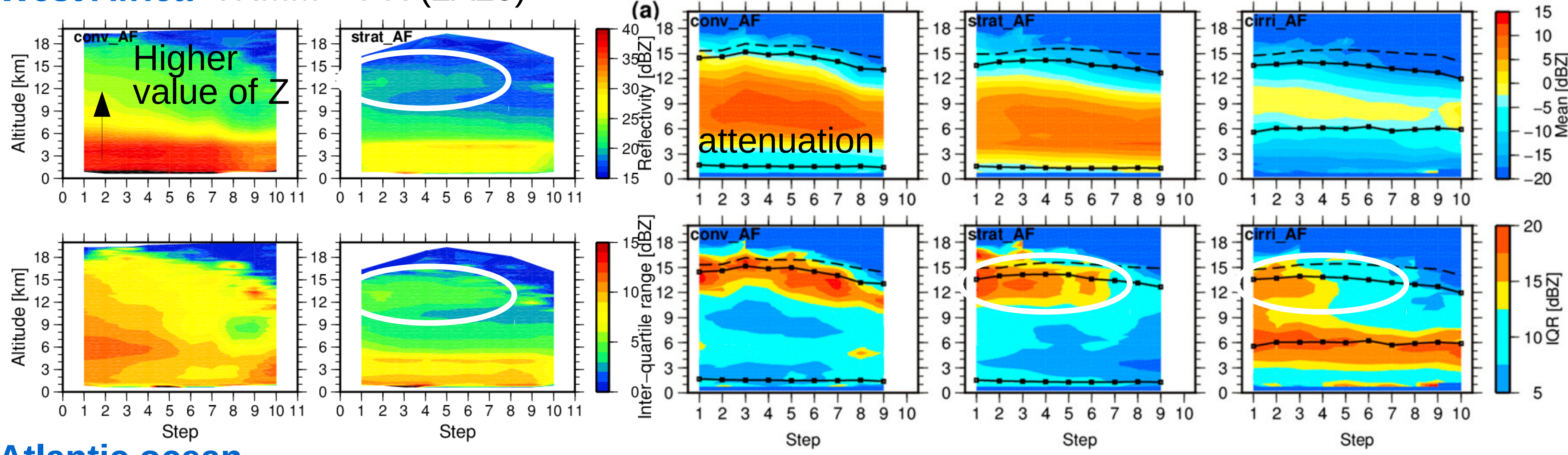
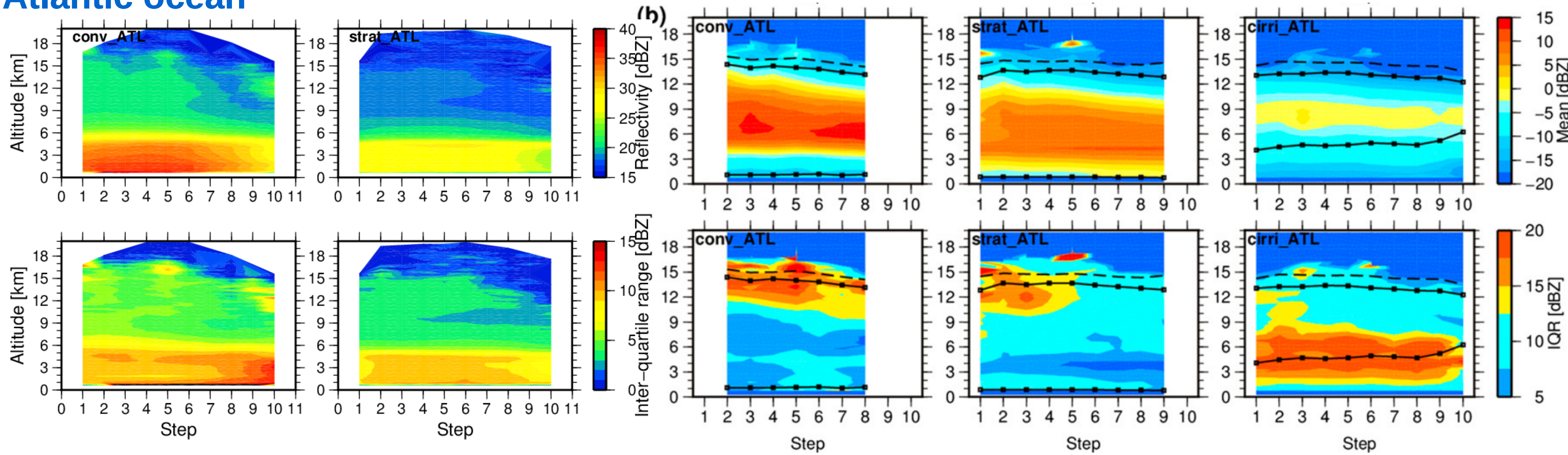


Atlantic ocean



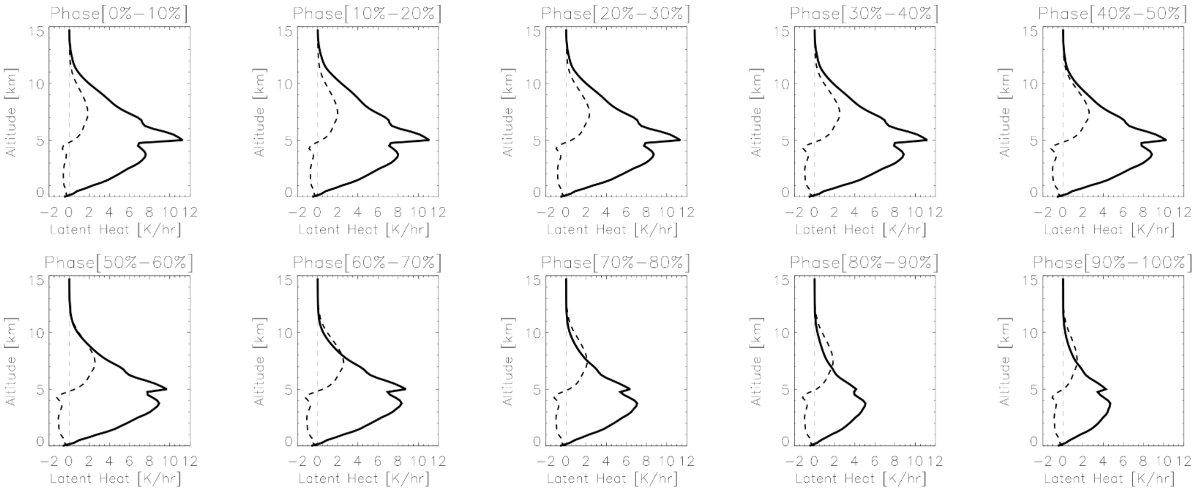
Conv : Higher reflectivity for AF in particular in the first third of the life cycle, attenuation in CloudSat
Strat : Stronger signature of detrainement toward the anvil in AF => brighter anvil over continent
Cirri : We do not observe the cloud top rises of the cirriform region

Bouniol et al. (2016)

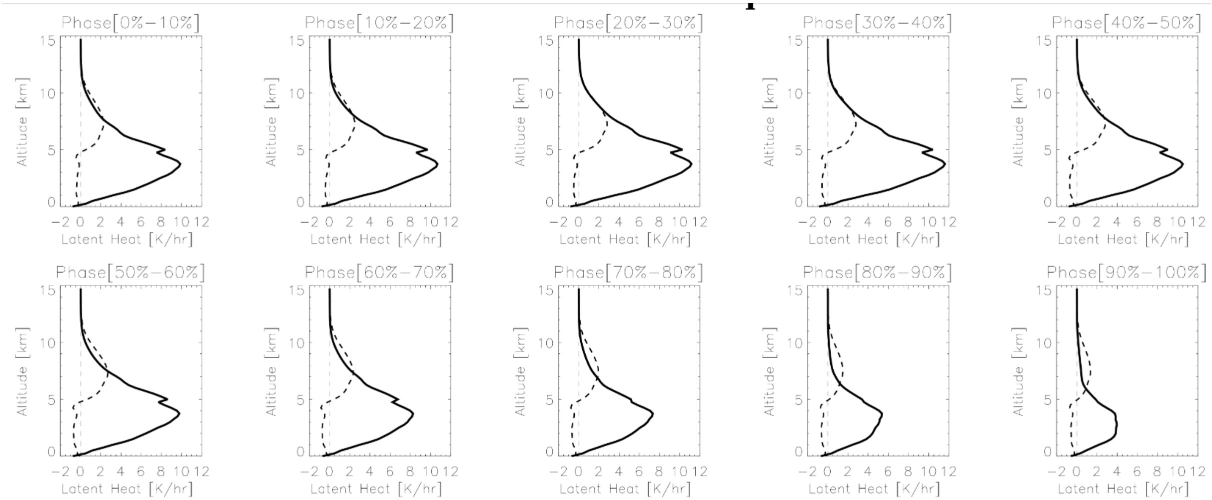
Evolution of diabatic heating profiles

SLH from Shige et al. (2007)

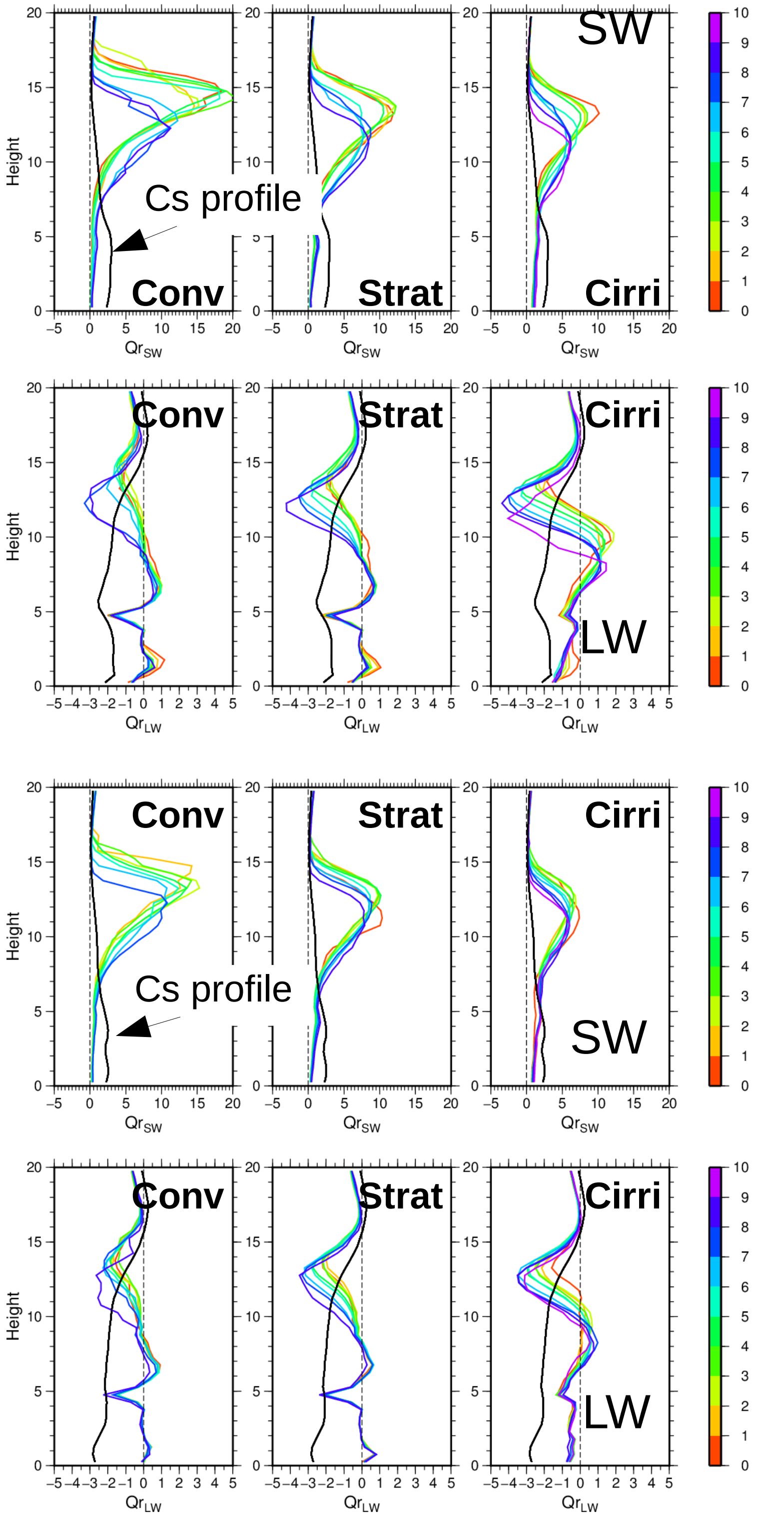
West Africa



Atlantic ocean



QR FLXHR-LIDAR



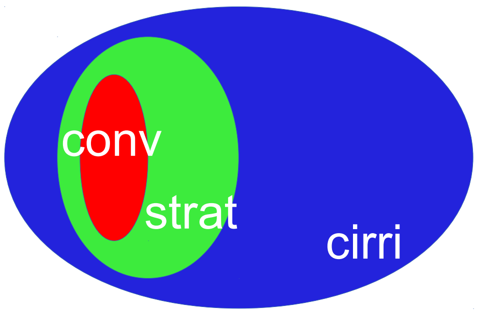
Conv LH decreases with life cycle and peaks lower than Qr, but need to be weighted by the size of the corresponding MCS part

Qr evolves throughtout the life cycle, compensating effect in SW/LW (diurnal cycle!) magnitudes are different between continent & ocean

Life cycle at the scale of the MCS

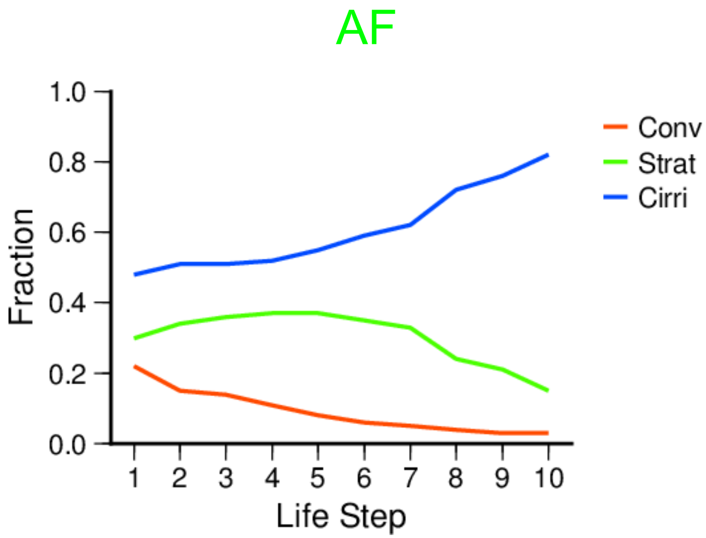
Assuming a linear recombination : $\langle Q(i)\rangle=\sum_{j=1}^{3} f_j(i)Q_j(i)$

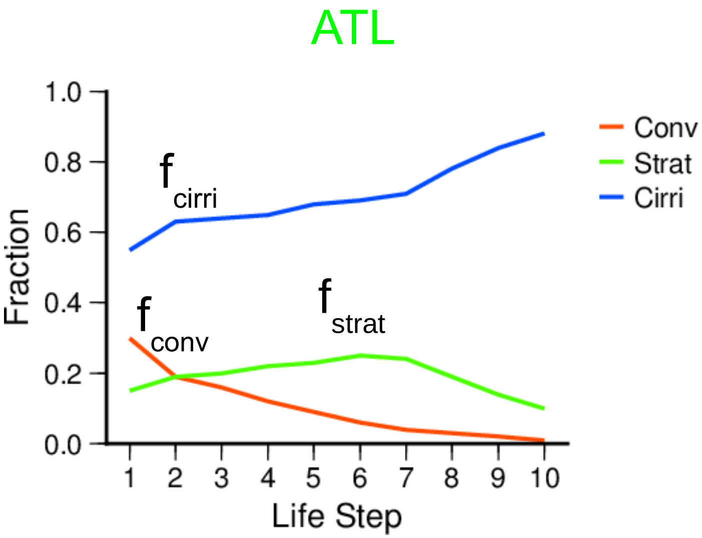
Relative evolution of each MCS sub-region :



TOOCAN MCS trajectories and TRMM-PR intersections are sought

- use of 1C21 convective/stratiform flag within the 235K area
- at least 70 % of 235 K area of the sampled MCS must be in the TRMM-PR swath





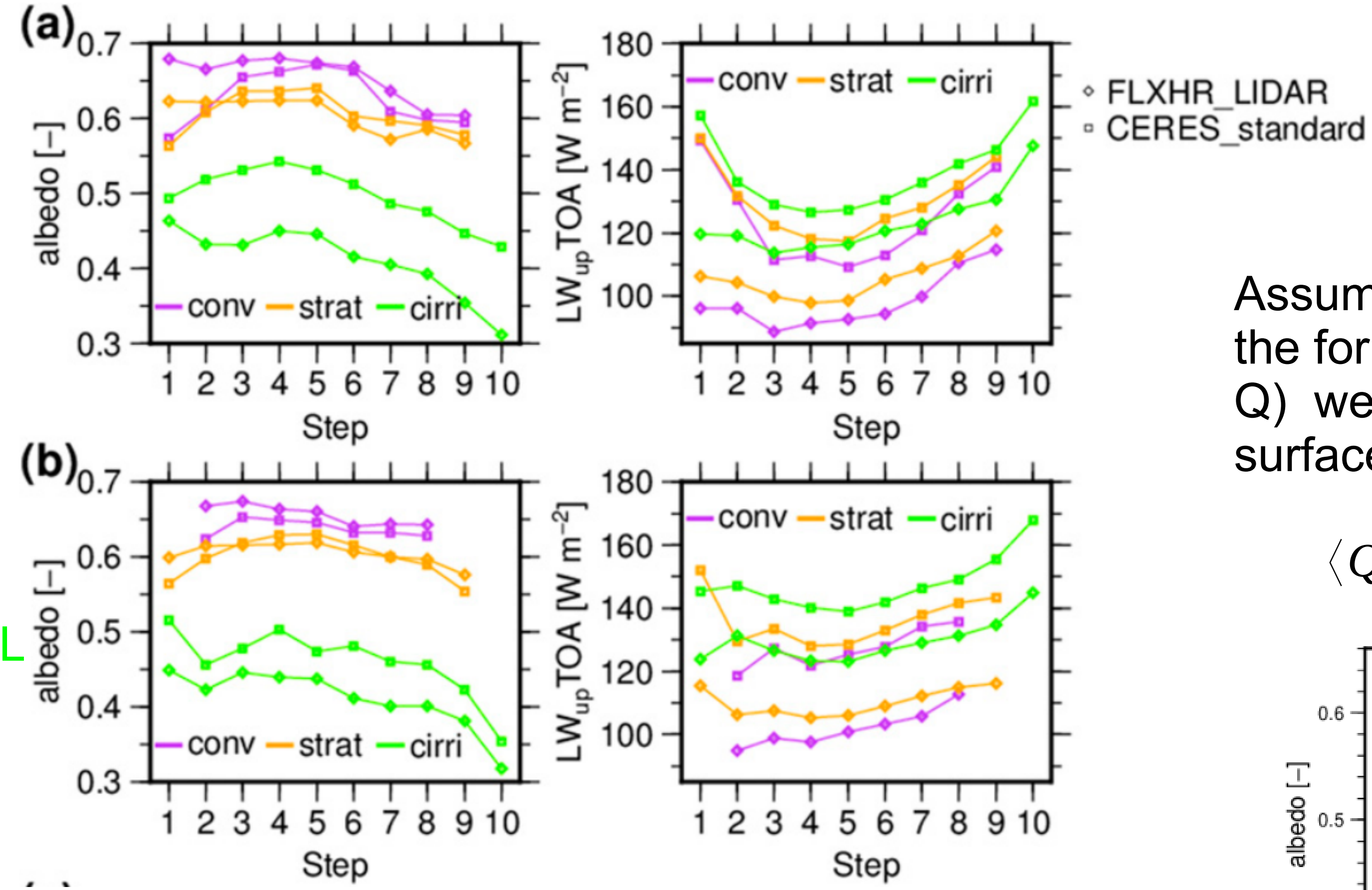
Cirriform region counts for more than half of the MCS area – only grews over the life cycle <=> the precipitating surface fraction ($f_p=f_{conv}+f_{strat}$) is only decreasing.

Convective fraction is only decreasing
Stratiform fraction ~ constant up to 2/3 of the life cycle

Evolution of the radiative properties at the scale of the MCS

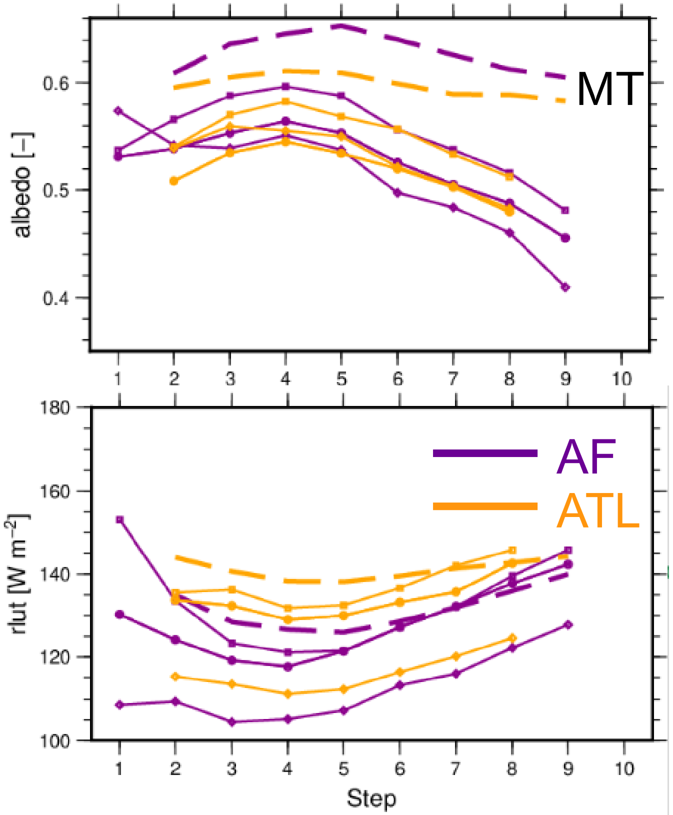
AF

ATL



Assuming a linear recombination of the former composites (parameter Q) weighted by MCS sub-region surface fraction (f) evolution

$$\langle Q(i)\rangle = \sum_{j=1}^{3} f_j(i) Q_j(i)$$



Qualitative agreement with the ScaRaB reference (dashed) :
- need to refine the surface fraction evolution
- need to include error bar
- potential impact of the diurnal cycle on albedo values

If only the cirriform region is considered, radiative parameters are changed by about 10 %
=> importance of the cirriform anvil for computation of the radiative budget, but other parts cannot be ommited in particular at the beginning of the life cycle

Comparison of convective/stratiform definition between CloudSat CPR & TRMM PR

Make use of 2D-TRMM-CloudSat products – $\Delta t < 20$ minutes
Build contingency tables [30°N-30°S] 2007 to 2009 – MODIS Tb @ 11.03 µm < 235 K

CPR : 1.5 x 1.5 km^2
PR : 5 x 5 km^2

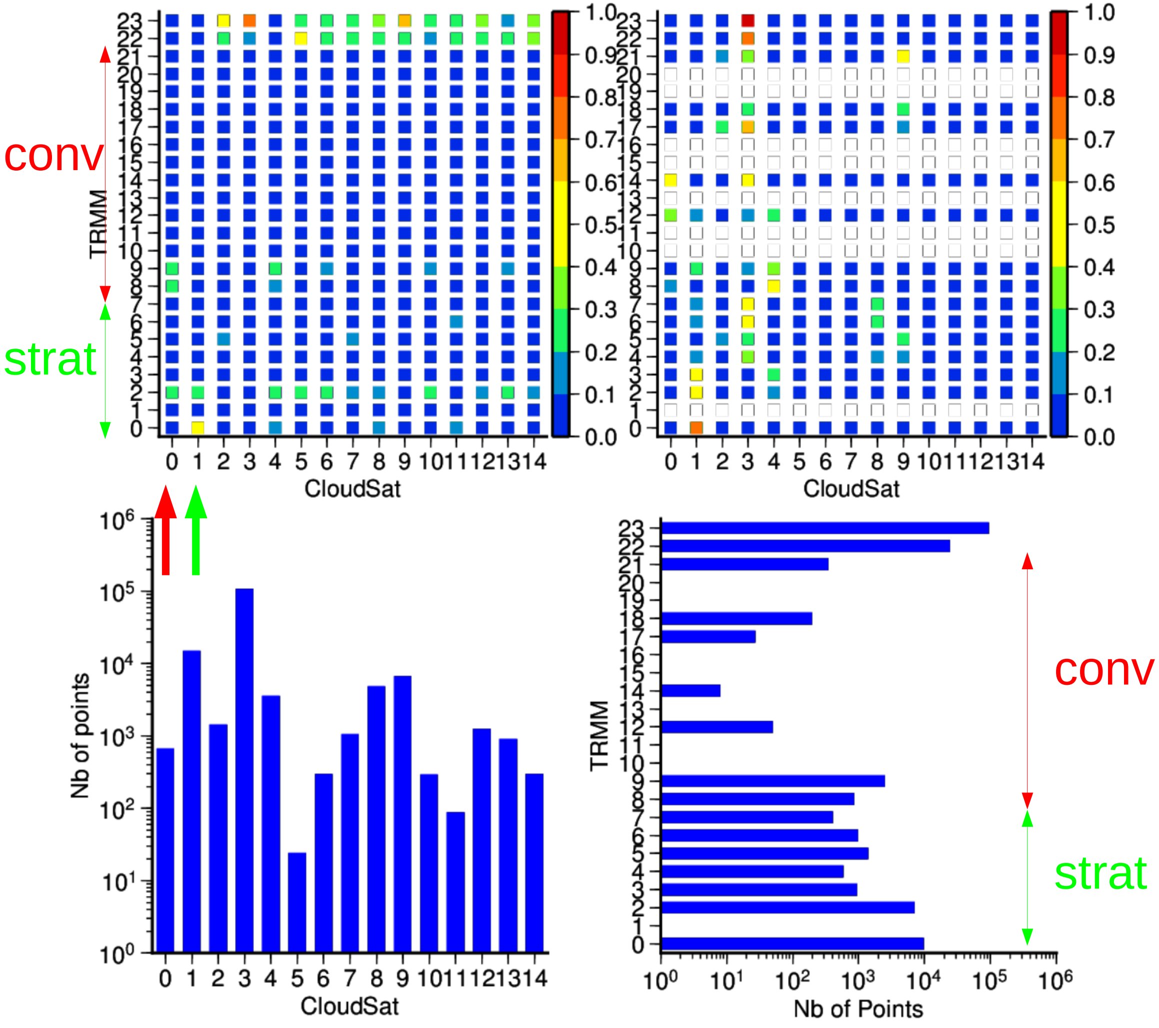
CloudSat

0 Conv
1 Strat
2 Shallow
3 Other
4 Conv+Strat
5 Conv+Shallow
6 Conv+Other
7 Strat+Shallow
8 Strat+Other
9 Shallow+Other
10 Conv+Strat+Shallow
11 Conv+Shallow+Other
12 Strat+Shallow+Other
13 Conv+Strat+Other
14 Conv+Strat+Shallow+Other

TRMM

0 100 strat V&H
1 110 ~~strat V~~
2 120 pb strat H
3 130 mb strat V
4 140 mb strat H
5 152 mb strat H
6 160 mb strat H
7 170 mb strat H
8 200 conv V&H
9 210 conv H
10 220 ~~conv V~~
11 230 ~~pb conv H~~
12 240 mb conv V
13 251 ~~conv V & H~~
14 252 conv V & H
15 261 ~~conv V & H~~
16 262 ~~conv V~~
17 271 conv
18 272 conv
19 281 ~~conv V~~
20 282 ~~conv V~~
21 291 conv
22 3XX other
23 -999

Good agreement for strat
Other=cirri
Pb for conv



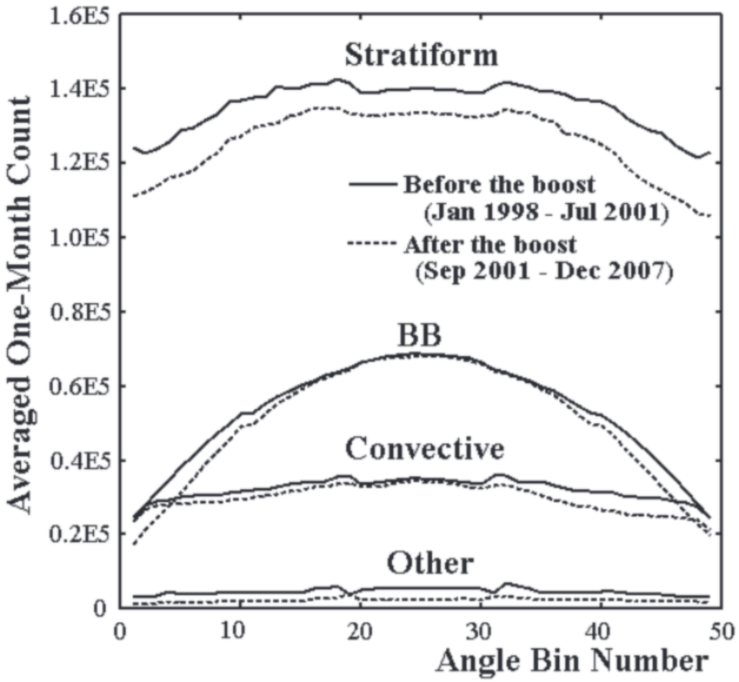
Normalised per CloudSat flag
Each column is 100

Normalised per TRMM flag
Each row is 100

Comparison of convective/stratiform definition between CloudSat CPR & TRMM PR

CloudSat – 2C-PRECIP-COLUMN conv/strat
Each profile is identified as being convective, stratiform, or shallow based on the vertical structure of reflectivity
Conv : attenuation is evident - Strat : BB detection (Z max close to 0°C) - Shallow : No Z > 0 dBZ above freezing level

TRMM PR – 2A23 conv/strat
V-method based on Okamoto et al. (1998) + H-method based on Steiner et al. (1995)
Conv : BB detected or Z high and conv in the vicinity - Strat : BB detection or Z not strong enough



Awaka et al. (2009)

BB detection sensitive to angle bin

Comparison of convective/stratiform definition between CloudSat CPR & TRMM PR

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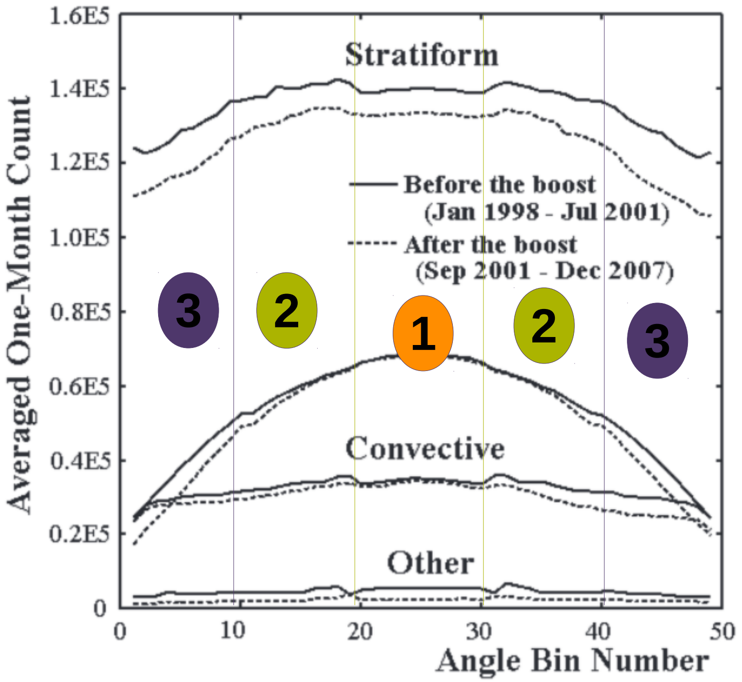
TRMM PR – 1C21

V-method based on Okamoto et al. (1998) + H-method based on Steiner et al. (1995)

Conv : BB detected or Z high and conv in the vicinity - Strat : BB detection or Z not strong enough



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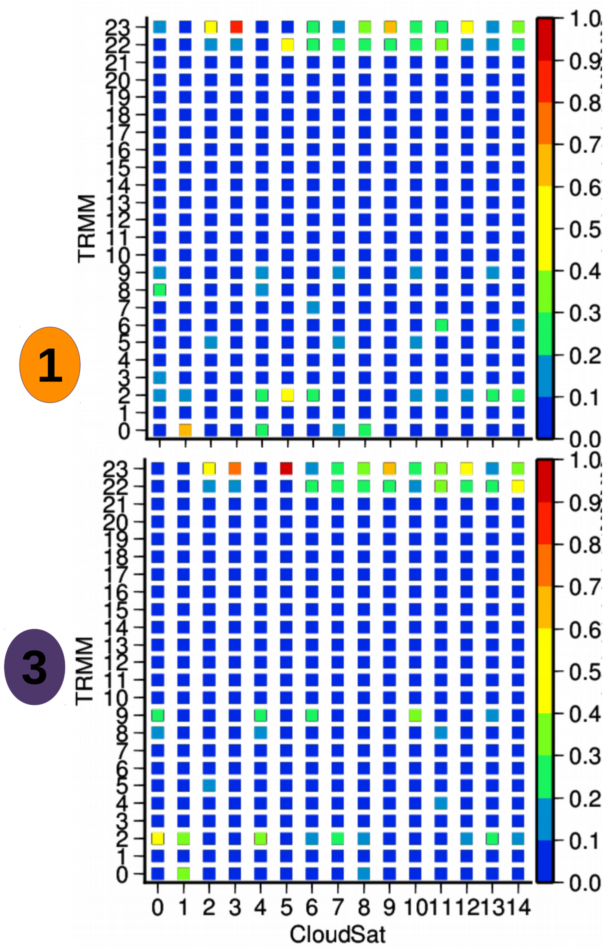

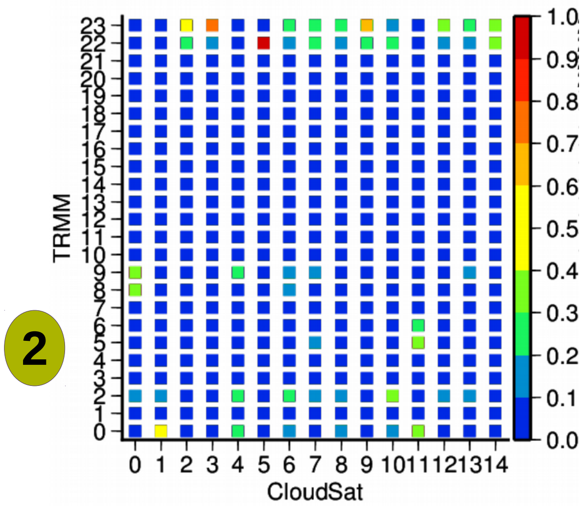

Swath edges should not be used in the composites

Cannot use 1C21 to document the size evolution of the different MCS parts

Ongoing work / conclusions

- A large number of long-lived MCS has a « simple » life cycle (*ie* one growth & decay of their cold cloud shield) => normalisation of life duration

- Different evolution of microphysical properties between continent/ocean – deeper MCS with detrainement of dense hydrometeors in the cirriform anvil

- MCS radiative property evolution at the scale of the Tropics is not representative of the regional behaviours
  - strong differences at regional scale in term of order of magnitude / life cycle => need to be cautious when using observational results for model evaluation/parameterisation development.
  - MCS are generally brighter over continent
  - Some similarities : Minimum in OLR close to the middle of life cycle. Albedo flat & decrease for Ocean / maximum close to the middle of the life cycle for Continental MCS

- TRMM-PR & CloudSat-CPR (and other : CERES, CALIOP, GPM...) data can be recombined at the scale of the MCS to document life cycle, but :
  - need to document the respective size evolution of the different MCS parts
  - some cautions need to be taken : definition of convective/stratiform regions => documentation using MW radiometer PCT (large swath) ?
  - fundamental role of the anvil cloud for the radiation budget

- Need to understand why MCS properties are different from one region to the other : thermodynamical environment