Observational evidence for a systematic dependence of water vapor, surface fluxes and radiation on the degree of aggregation of deep convection

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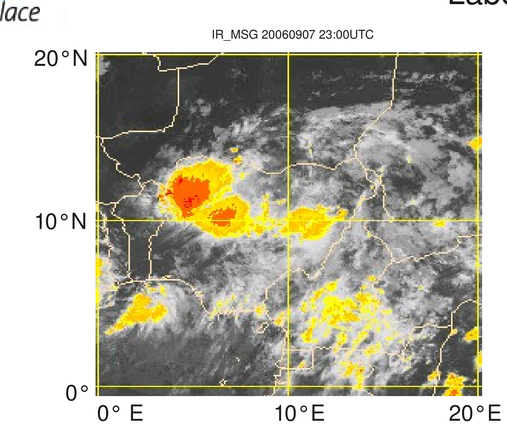
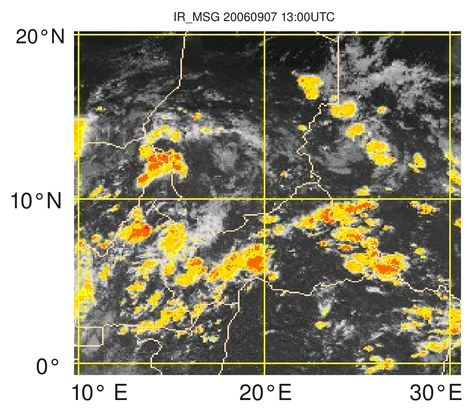
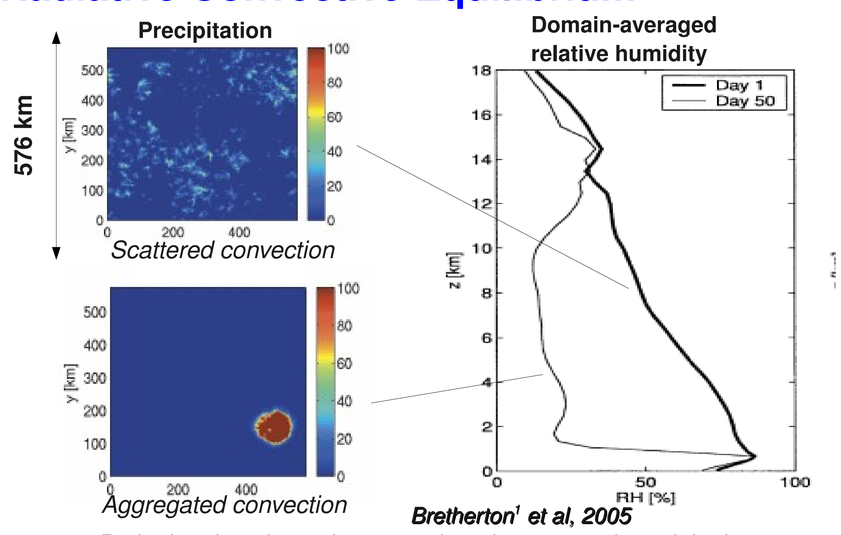




Tropical deep convection exhibits various forms of organization on a large range of scales, from mesoscale to planetary scale (Mesoscale Convective Systems, Madden Julian Oscillation…)

Questions : What are the implications of convective organization for the large-scale atmospheric state ? For given large-scale forcings and « amount of convection », are two different states of convective organization equivalent with regard to the mean climate state (water vapor, energy fluxes) ?
If not, climate feedbacks may also be associated with convective organization changes.

Previous studies : Cloud Resolving Models in Radiative Convective Equilibrium



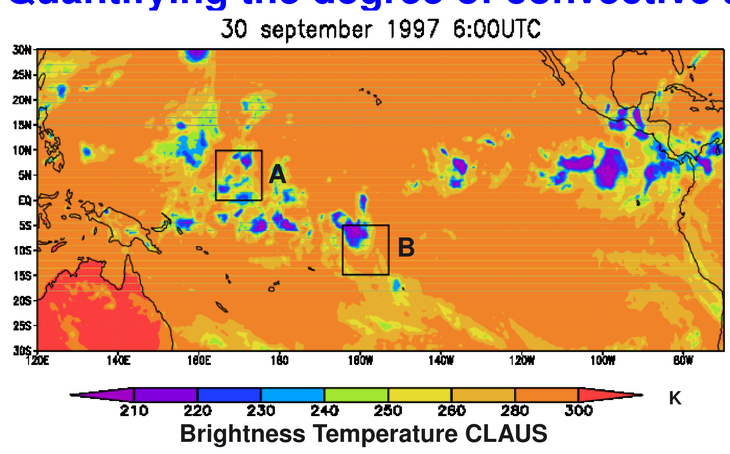
Bretherton[1] et al, 2005

Both situations have the same domain-averaged precipitation rate

When convection is more aggregated, the large-scale atmosphere is much Drier than when convection is scattered.

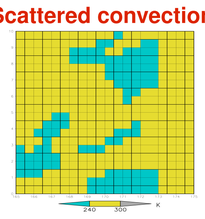
Datasets used to conduct the study : CLAUS *(0.5x0.5, 3xhourly ; Brightness Temperature)* ; HOAPS[2] *(1x1, twice-daily, rain/precipitable water/surface fluxes/SST)* ; ERAinterim (*0.75x0.75, 4xdaily, relative humidity*), NCEP (*2.5x2.5, 4xdaily, relative humidity, vertical velocity*), AIRS (*1x1, twice-daily, relative humidity*) , OLR-NOAA *(2.5x2.5, daily, OLR)*, CERES (*5x5, daily, LW+SW radiative fluxes*)

Quantifying the degree of convective aggregation : a Simple Convective Aggregation Index (SCAI)



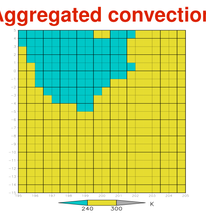
Segmented Brightness Temperature CLAUS (240K) Images (240K defines deep convective cloudiness)
Synoptic domains : 10°*10°

Scattered convection — **A**



SCAI = 11.3
N = 5 (4-connectivity)
Do = 454 km

Aggregated convection — **B**



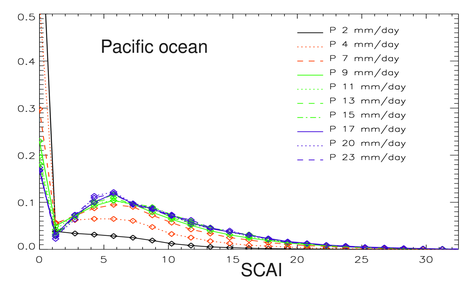
SCAI = 0
N = 1
Do = 0

Two relevant parameters :
- ***N***, number of convective zones within a 10°*10° box *(clustering algorithm)*
- ***Do***, order zero diameter, measure of scattering of an ensemble of *n* points (*Gauvrit et Delahaye[3], 2006*) : $Do = \sqrt[n]{do*dl..di.*dn}$ (*di*, distance between the centers of mass of clusters in pairs)

$$SCAI = \frac{N}{Nm} \times \frac{Do}{L} \times 1000$$

L, characterictics length of the domain (~1000 km)
Nm = L/a (a, resolution of the pixel) : number of a potential maximum convective « disaggregation »

Range : 0-30 (very aggregated to highly scattered)

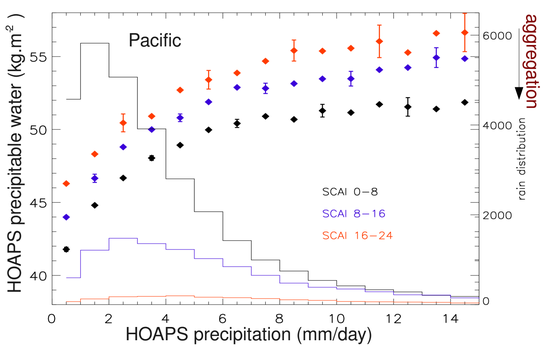


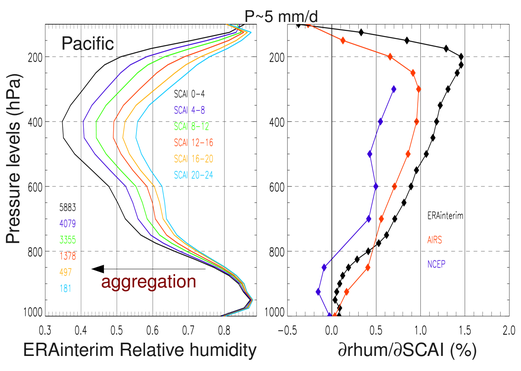
Probability density functions of the SCAI parameter sorted by domain-averaged HOAPS precipitation regimes for the period 1988-2005.

The domains A and B are characterized by similar large-scale forcings (Sea Surface Temperature, dynamics) and a same domain-averaged precipitation rate (11mm/d) but a different degree of convective aggregation.

SCAI-composites of the large-scale variables (10°*10°) over tropical oceans (spanned period : 1988-2005)

Humidity





Fixed domain-averaged rain rate, SST (28°C) and comparable large-scale circulation

Convective aggregation and tropospheric humidity are anti-correlated :
~ 10% (a few kg.m^{-2}) difference in precipitable water for SCAI between 0 and 20
~ 20% absolute difference in ERAinterim relative humidity for SCAI between 0 and 20

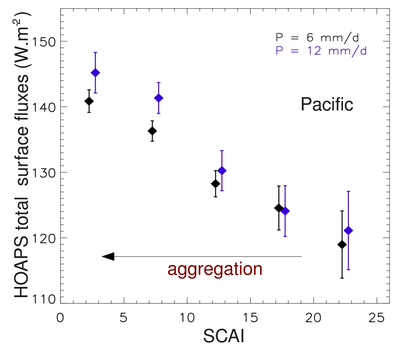
It holds for all precipitation regimes

The dependence of humidity on the degree of convective aggregation is maximum in the middle and upper troposphere.

All datasets (AIRS data, ERAinterim and NCEP reanalyses) reveal this anti-correlation in the free-troposphere, but with different sensitivities.

This anti-correlation stems from the environment outside convective areas (not shown)

Surface turbulent fluxes



Fixed domain-averaged rain rates, SST (28°C) and comparable large-scale circulation

Convective aggregation and surface (latent and sensible) heat fluxes intensity are correlated :
~ - 20 W/m^2 for SCAI between 0 and 24

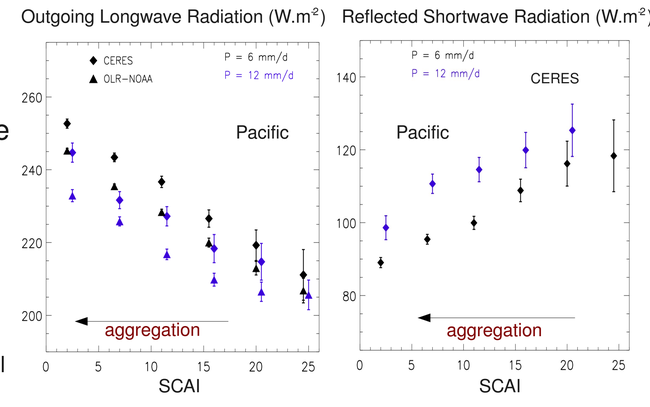
Cold pools, gust-winds, air-sea differences affected by convective organization ?

Top Of the Atmosphere Radiative fluxes

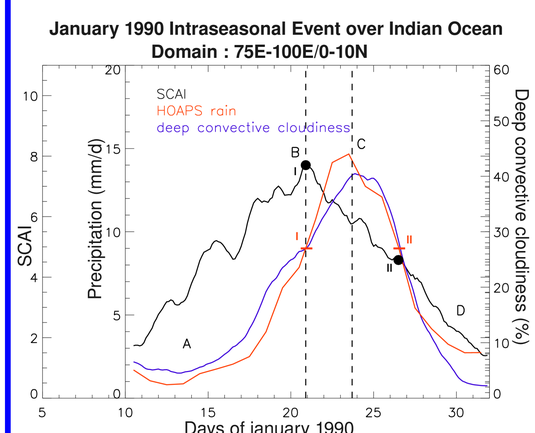
Convective aggregation and OLR flux intensity are strongly correlated :
~ -40 W/m^2 for SCAI between 0.and 24
Convective aggregation and reflected shortwave radiation are anti-correlated :
~+20W/m^2 for SCAI between 0 and 24

→ The TOA net radiative budget is much less affected by convective aggregation than the LW and SW components separately.
The sensitivity of TOA radiation to the degree of convective aggregation is mainly caused by changes in cloudiness at all altitudes (not shown).

Outgoing Longwave Radiation (W.m^2) — Reflected Shortwave Radiation (W.m^2)



Variability of the degree of convective aggregation : the intraseasonal scale



During the active phase, variations of SCAI and those of the convective activity (precipitation, cold cloudiness) are not in phase:
• Shortly before the maximum convective intensity, convective systems starts to aggregate.
• Asymmetry between the intensifying and decaying stages with regard to aggregation state : for given convective activity, the 2nd stage is more aggregated than the 1st stage

→ Role of the convective aggregation dynamics in the development of an MJO event through interacting with atmospheric humidity and thus modulating the convection-moisture feedback intensity ?

- For given large-scale forcings and convective activity, a systematic dependence of water vapor, surface fluxes and TOA radiation on the degree of convective aggregation is observed at the synoptic scale :
  - Humidity and convective aggregation are anti-correlated
  - Aggregated convection is associated with intensified surface fluxes
  - The OLR increases with convective aggregation while reflected shortwave radiation decreases : the TOA net radiative budget is much less affected than the LW and SW components separately.
- Underlying mechanisms ? (convection-humidity feedback, precipitation efficiency, cold pools and gust-winds, cloud amount changes at all altitudes...)
- A convective organization feedback may play a role in climate variability and sensitivity : examination of the variability of the degree of convective aggregation at different scales (intraseasonal, interannual, decadal) (work in progress)
- Deficiencies in the representation of convective organization in general circulation models : source of systematic biases ?
- .SCAI analyses : a diagnostic tool for evaluating the representation of convective organization and its interaction with water vapor and energy fluxes in models (GCM,CRM).

1-Bretherton, C, P.Blossey and M.Khairoutdinov, 2005 : An energy balance analysis of deep convective self-aggregation above uniform SST.*J.Atmos.Sci.*,**62**,4273-4292.
2-Andersson,A.,K.Fennig,C.Klepp,S.Bakan,H.Gassl,and J.Schulz,2010: The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data-HOAPS-3.Earth Syst.Sci.Data Discuss.,3,143-194.
3-Gauvrit N. and J.P.Delahaye,2006:order 0 diameter, a natural measure of scattering.Math. & Sci. Hum. année 44,n°175,p41-51.
Tobin,I., S.Bony, R.Roca : Observational evidence for a systematic dependence of water vapor, surface fluxes and radiation on the degree of aggregation of deep convection (manuscript submitted to J. Climate)