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 state climate (water vapor, energy fluxes)?

If not, climate feedbacks may also be associated with convective organization changes.

Datasets used to conduct the study: CLAUS (0.5x0.5, 3x hourly; Brightness Temperature); HOAPS2 (1x1, twice-daily; rain/precipitable water/surface fluxes/SSST); ERAInterim (0.75x0.75, 4x daily, relative humidity), NCEP (2.5x2.5, 4x daily, 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)

30 September 1997 6:00 UTC

Segregated Brightness Temperature CLAUS (240K images) (not shown)

Synoptic domains: 10°-11°

SCAI ≤ 11.3

N = 3 (aggregation)

Do = 454 km

SCAI > 11.3

N = 0 (scatter)

Do = 10

The domains A and B are characterized by similar large-scale forcings (Sea Surface Temperature, dynamics) and a small domain-averaged precipitation rate (11 mm/3x3) but a different degree of convective aggregation.

SCAI-composites of the large-scale variables (10°-11°) over tropical oceans (spanned period: 1988-2005)

Humidity

Convective aggregation and tropospheric humidity are anti-correlated:

- 10% (a few kg/m³) 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 rate, SST (28°C) and comparable large-scale circulation

Convective aggregation and surface (latent and sensible) heat fluxes intensity are correlated:

- ~ 20 W/m² 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/m² 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).

Variability of the degree of convective aggregation: the intraseasonal scale

January 1990 Intraseasonal Event over Indian Ocean

Domain: 75E-100E/0-10N

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 (not shown).

- 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.

  - Convective aggregation 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? (convective-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).