Analysis of Convective Aggregation from CERES Cloud Object Data

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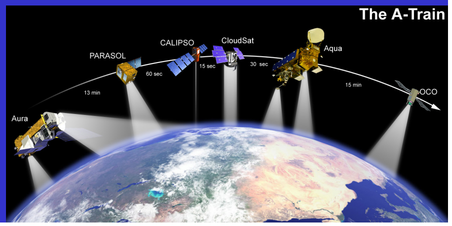
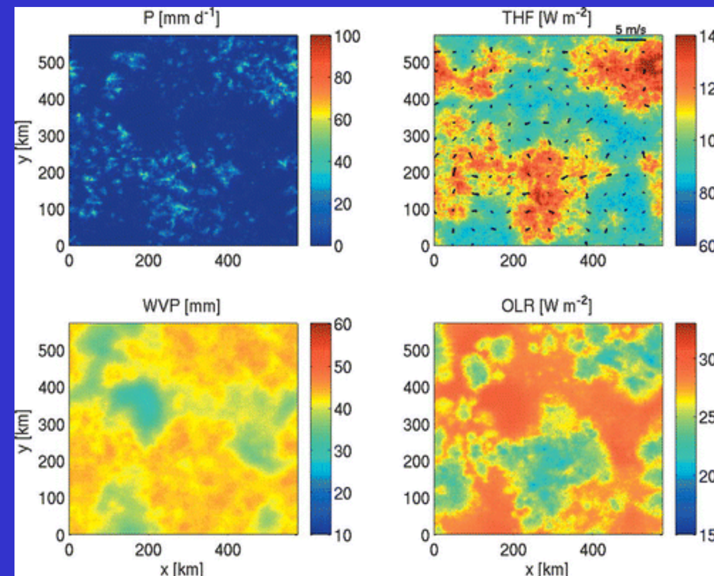
Objective: To provide an observational understanding of convective aggregation

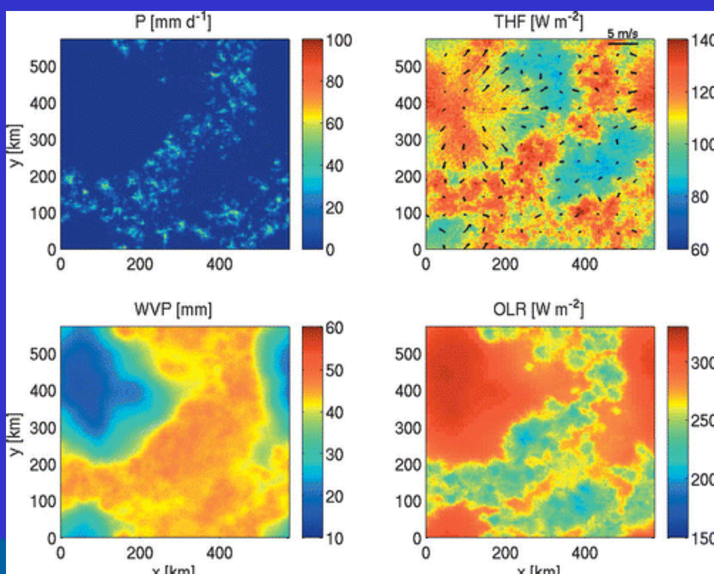


What is convective aggregation?

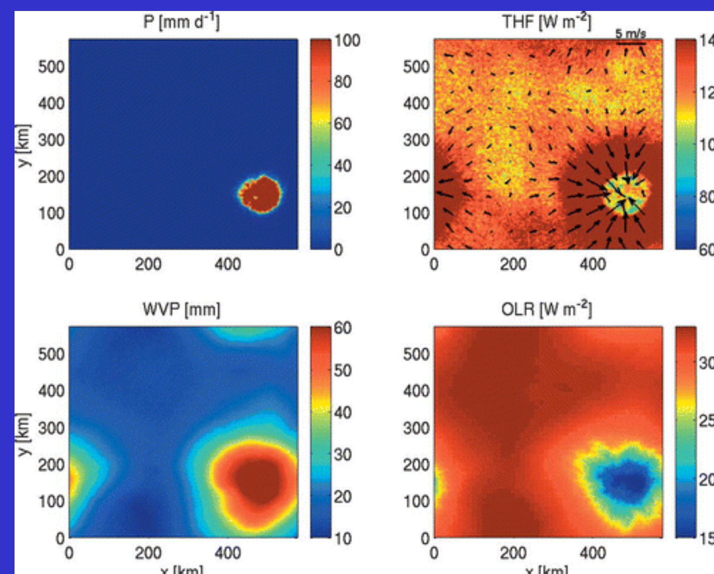
- A self-aggregation phenomenon in idealized radiative-convective equilibrium (cloud-resolving model) simulations under constant, uniform sea surface temperature (SST)
- It is linked to feedbacks between convection, moisture, clouds, radiation, and surface fluxes



Day 10

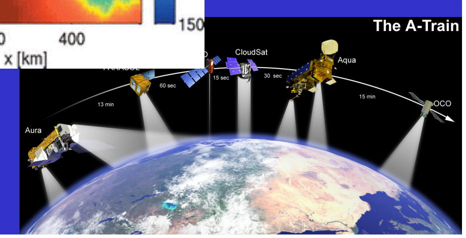


Day 20



Day 30

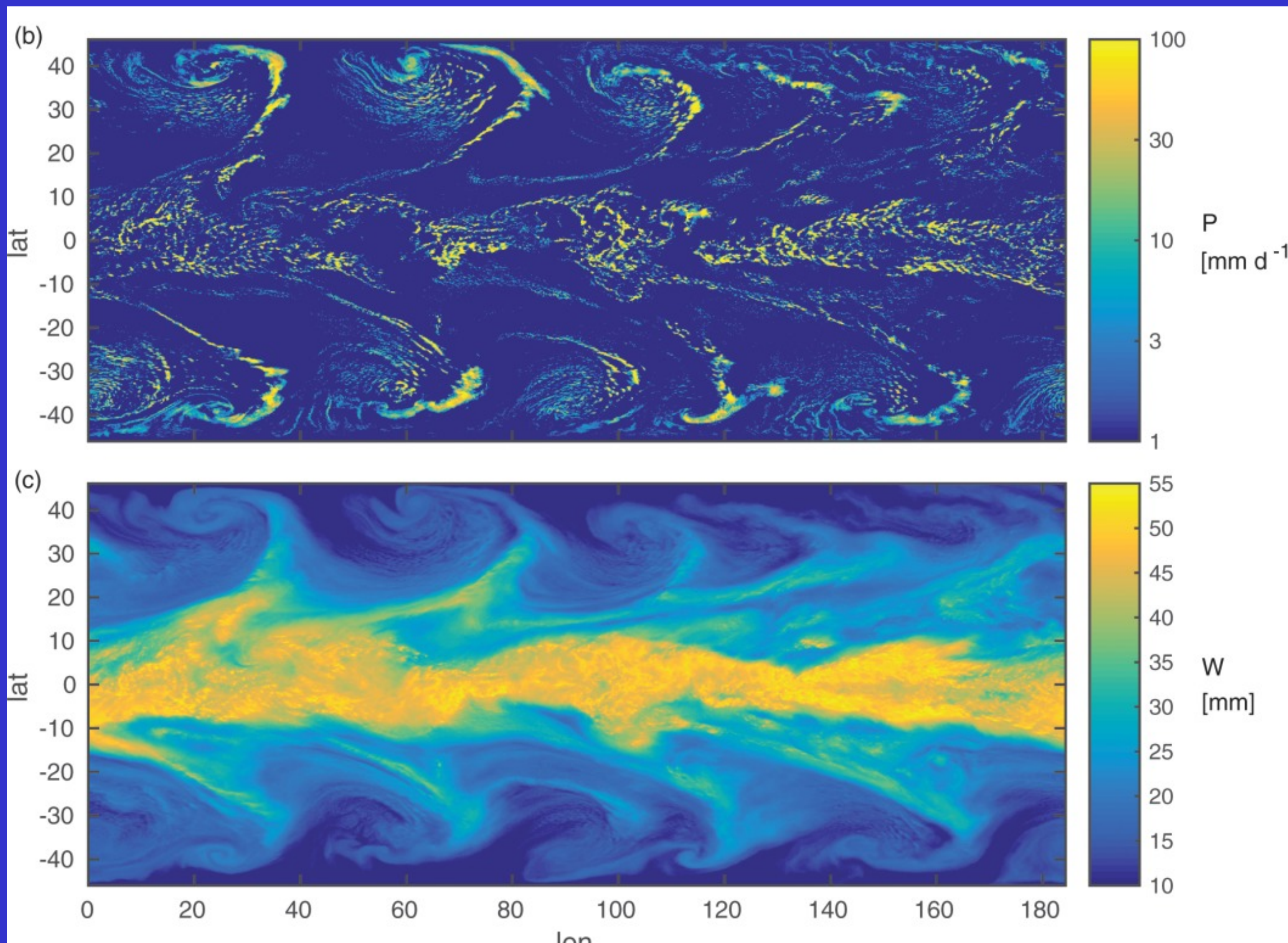
Bretherton *et al.* (2005)



Convective aggregation: more examples, 1

Near-global cloud-resolving simulation (dx=4 km), latitudinally varying SSTs

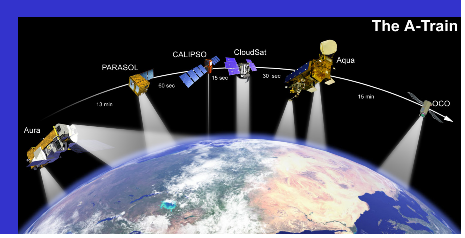
Aqua planet



Precipitation

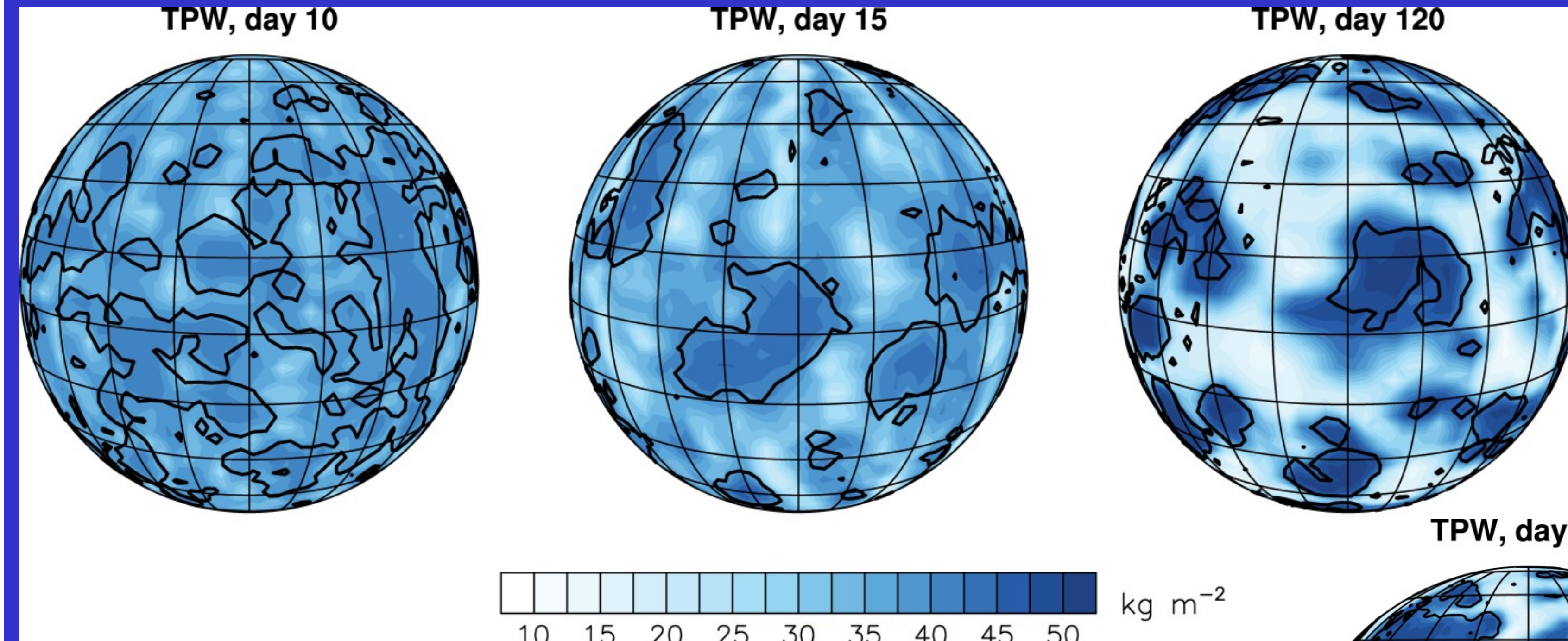
Precipitable water

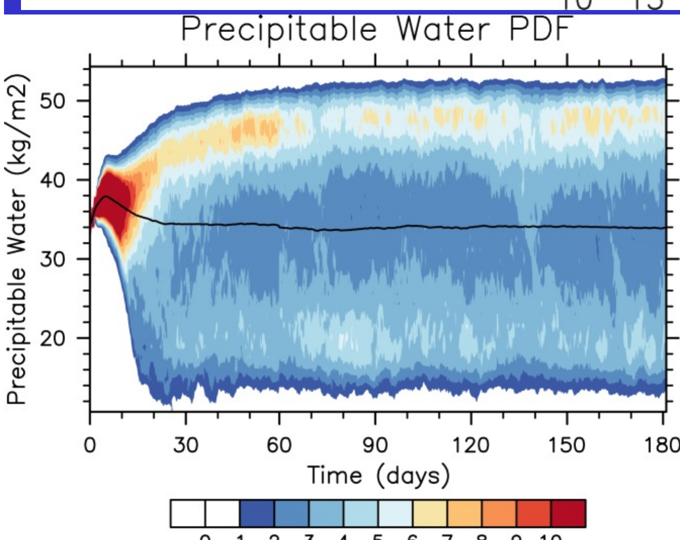
Bretherton & Khairoutdinov (2015)



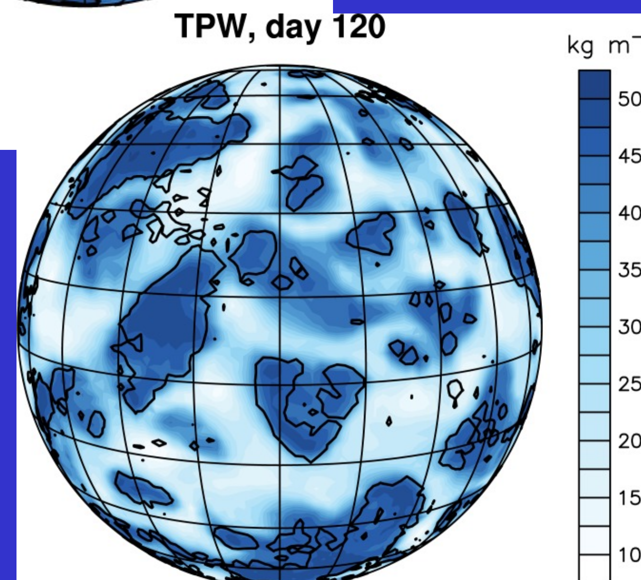
Convective aggregation: more examples, 2

Super-parameterized GCM or MMF (T42 & T85, dx=4 km), uniform SSTs (27C)

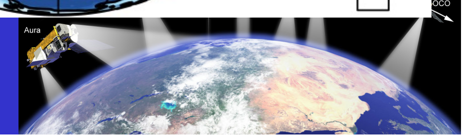




Total precipitable water

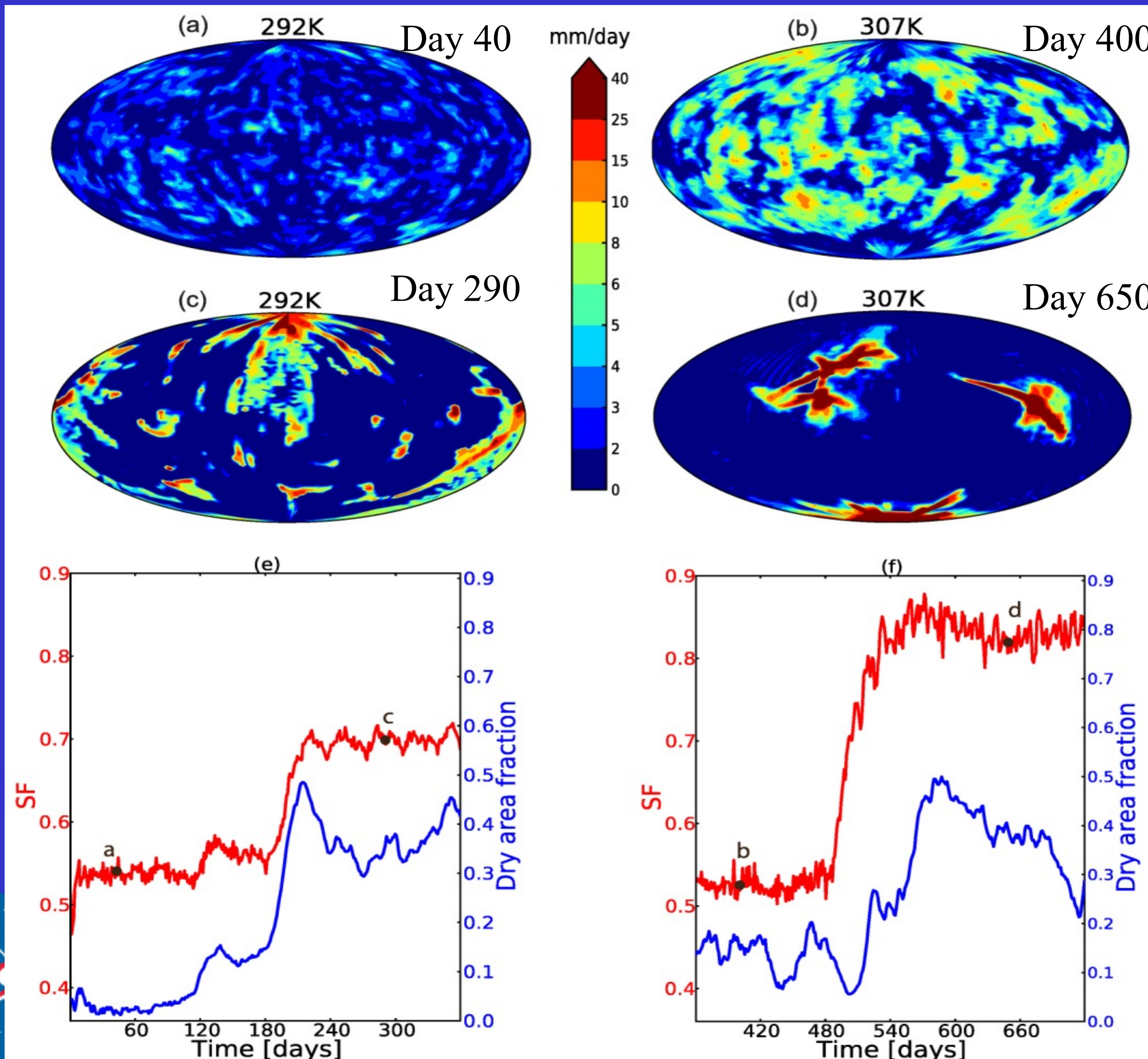


Arnold & Randall (2015)

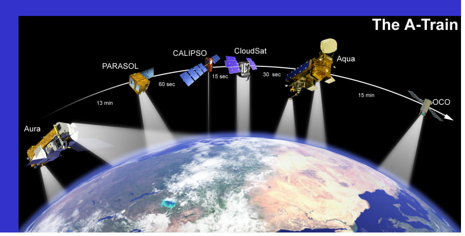


Convective aggregation: more examples, 3

Conventional global climate model (GCM) (3.75° × 1.875°)



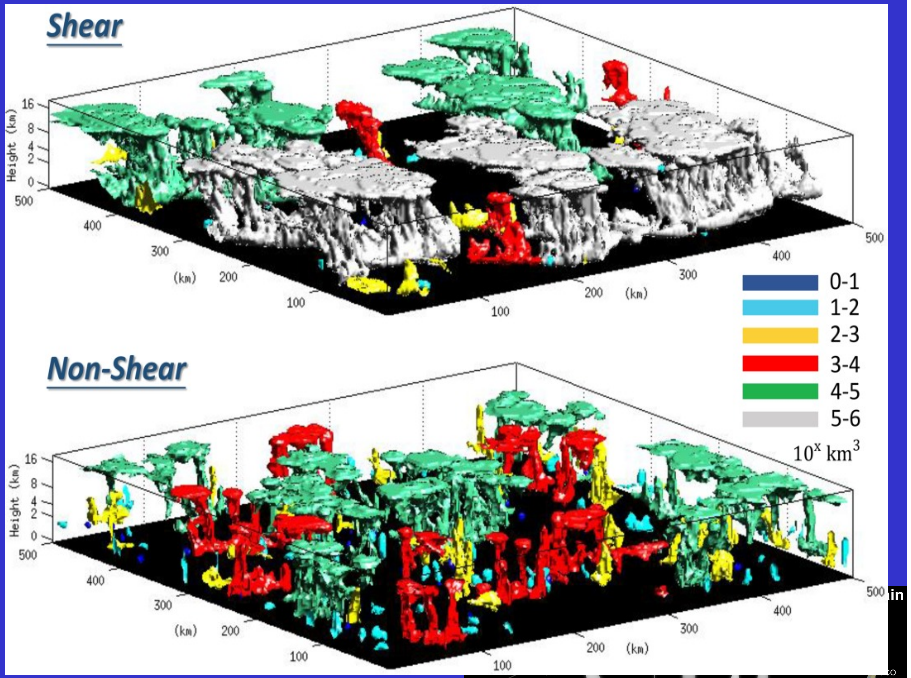
Coppin & Bony (2015)

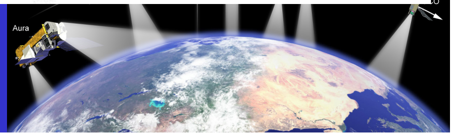


Relevance of self-aggregation to observed convection

- How relevant is self-aggregation physics to real-world convective organization?
  - Radiative-convective equilibrium over small domains are rarely observed (Jakob et al., 2018)
  - Sea surface temperatures (SSTs) are not uniformly distributed over large domains (e.g., the entire globe) where radiative-convective equilibrium have been simulated with uniform SST by conventional GCMs, MMF, and global CRMs
  - Convective clusters are organized by many processes; e.g., wind shear, cool pools, cloud-radiation interactions

- How can observations be used to help understand convective aggregation?
  - Can a physically meaningful index be defined? SCAI or COP (next slide)
  - How can observations be analyzed? e.g., stratified by SCAI/COP and large-scale environmental measures? (will be addressed in a future study)





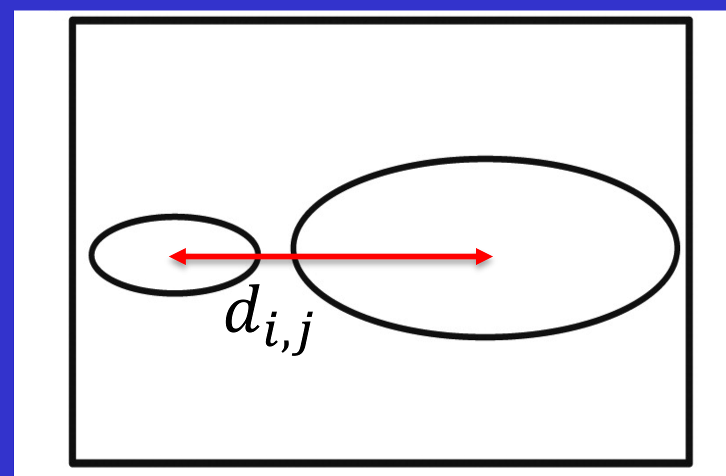
Definition of convective aggregation indices

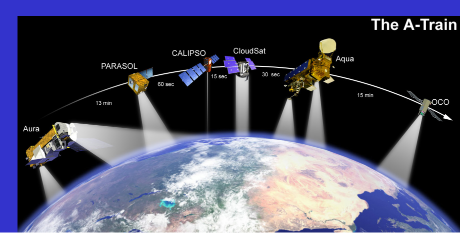
- Simple Convective Aggregation Index (SCAI) (Tobin *et al.* 2012)
- $SCAI = \frac{N}{N_{max}} \frac{D_0}{L} \times 1000$
- N: number of cloud objects; L domain lengthscale
- N_{max}: maximum of cloud objects within a domain
- D_0 is the geometrical mean of distances ($d_{i,j}$) between objects; $D_0 = \sum_{i=1}^{N} \sum_{j=i+1}^{N} d_{i,j} \Big/ \frac{1}{2}N(N-1)$

- Convective Organization Potential (COP) (White *et al*. 2018)
- Interaction potential: $V(i,j) = \frac{\sqrt{A_i} + \sqrt{A_j}}{d(i,j)\sqrt{\pi}}$
- $COP = \sum_{i=1}^{N} \sum_{j=i+1}^{N} V(i,j) \Big/ \frac{1}{2}N(N-1)$
- A_i, A_j are areas of i^{th} and j^{th} objects, respectively

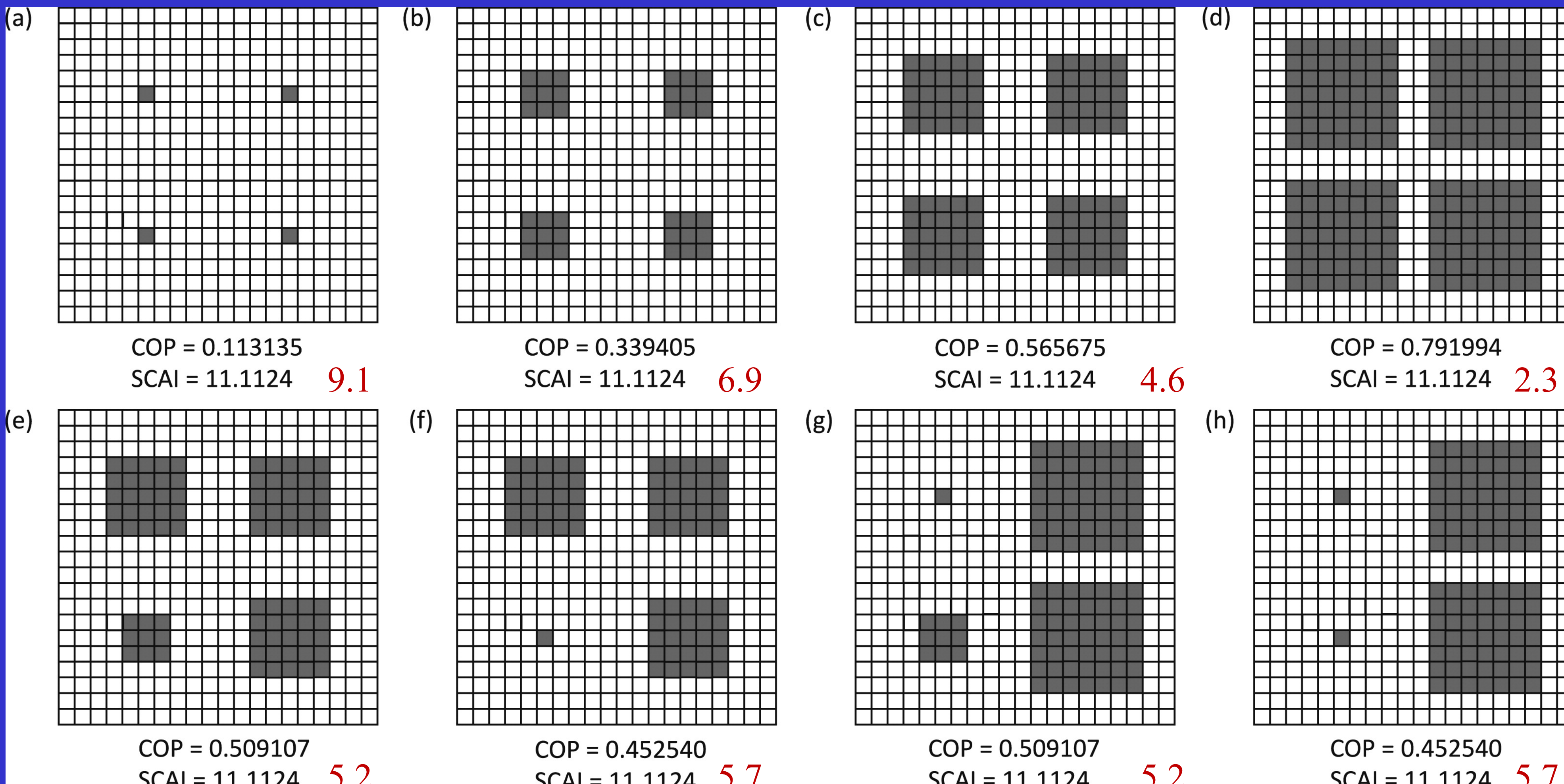
  $0 \leq$ COP ≤ 1 (maximum aggregation)

- A modification to SCAI (this study)
- Reduce the distances ($d_{i,j}$) between two objects by the sum of their radii
- $d'_{i,j} = d_{i,j} - (\sqrt{A_i} + \sqrt{A_j})/\sqrt{\pi}$
- Modified SCAI → 0 if $D_0(d'_{i,j})$ → 0
- SCAI = 0 (maximum aggregation)



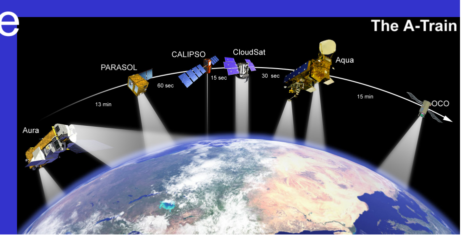


Comparison of different aggregation indices



An increase in cloud object size increases the degree of aggregation; Convective organization potential (COP) and the modified SCAI are consistent with each other while the original SCAI does not.

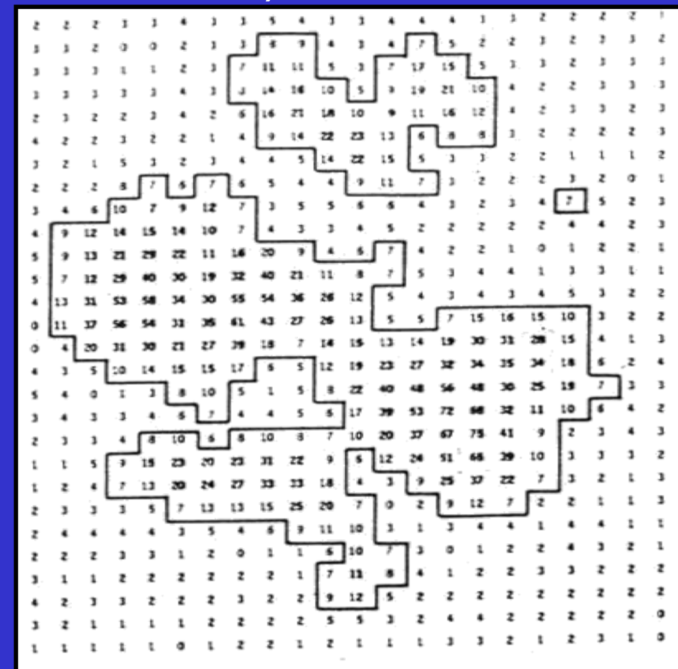
White *et al.* (2018)

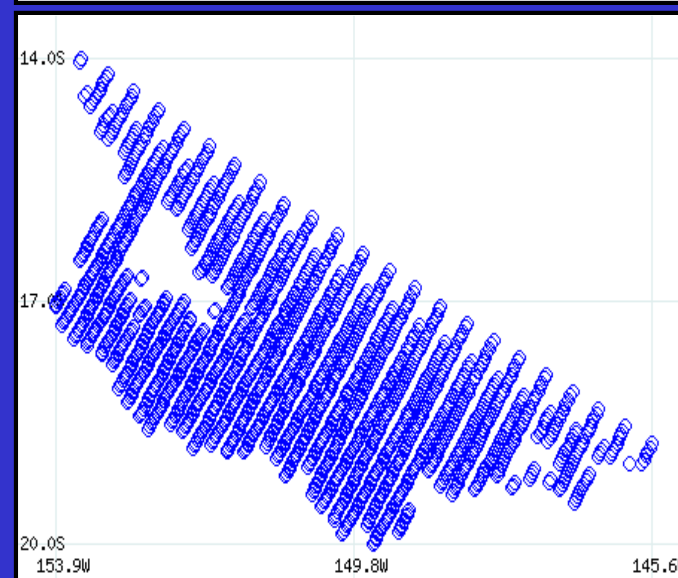


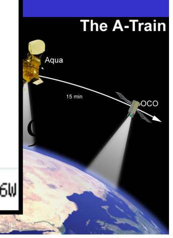
Selection of convective cloud objects

(Xu *et al.* 2005, 2007, 2008, 2016, 2017)

- A contiguous patch of cloudy regions with a single dominant cloud-system type; no mixture of different cloud-system types
- The shape and size of a cloud object is determined by
  - the satellite footprint data
  - the footprint selection criteria
- Selection criteria for deep convective cloud objects:
  - Cloud optical thickness $\tau > 10$, and
  - Cloud top height $z_{top} > 10$ km, and
  - Overcast

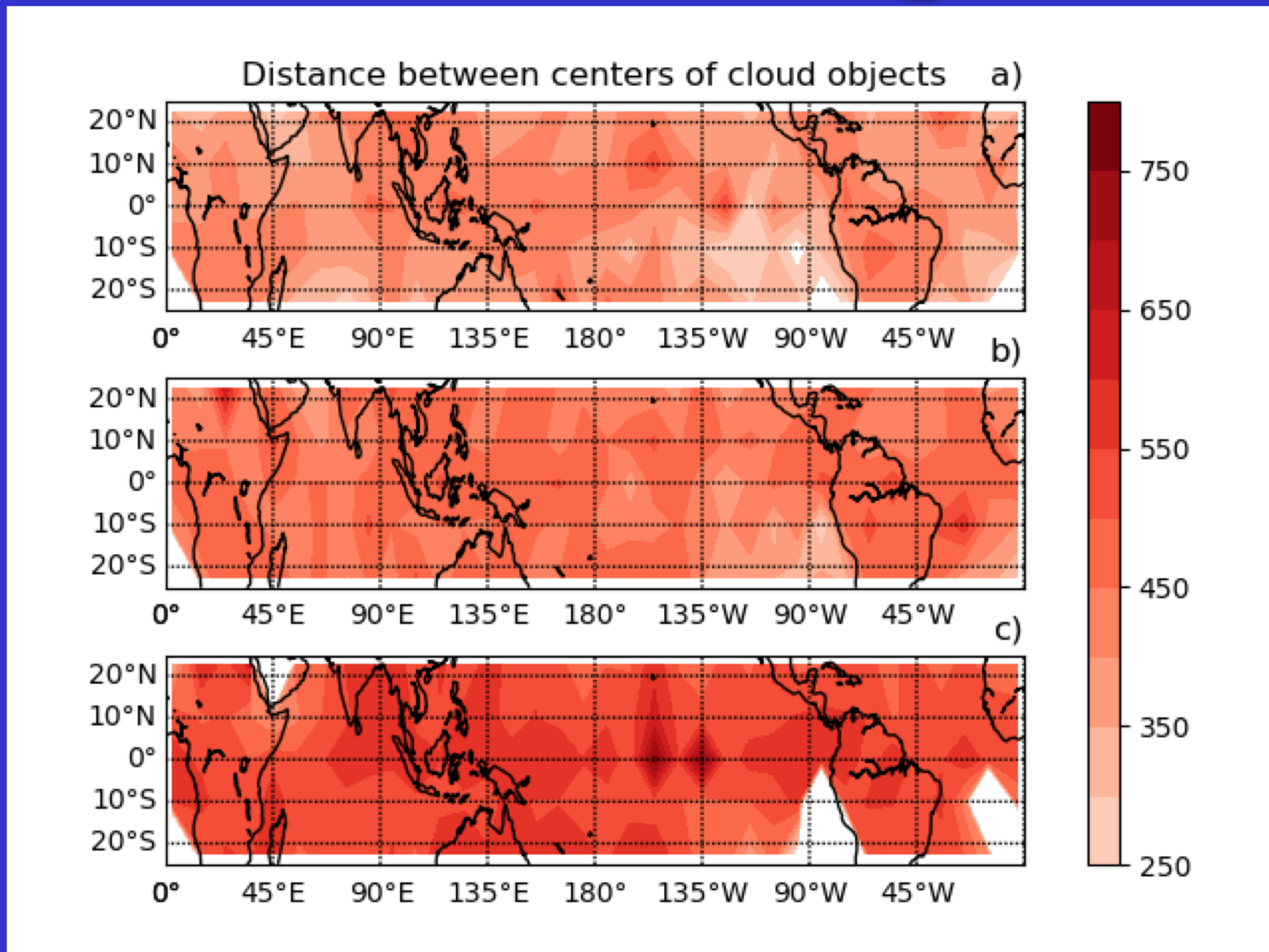






Mean distances between cloud objects – SCAI_Tobin

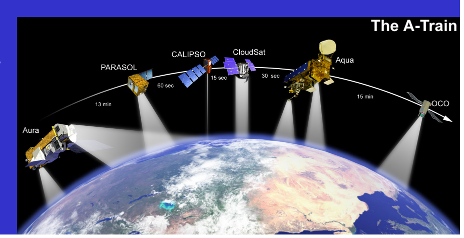
75-150 km; 150-300 km; >300 km



July 2006 –
June 2010
Aqua data

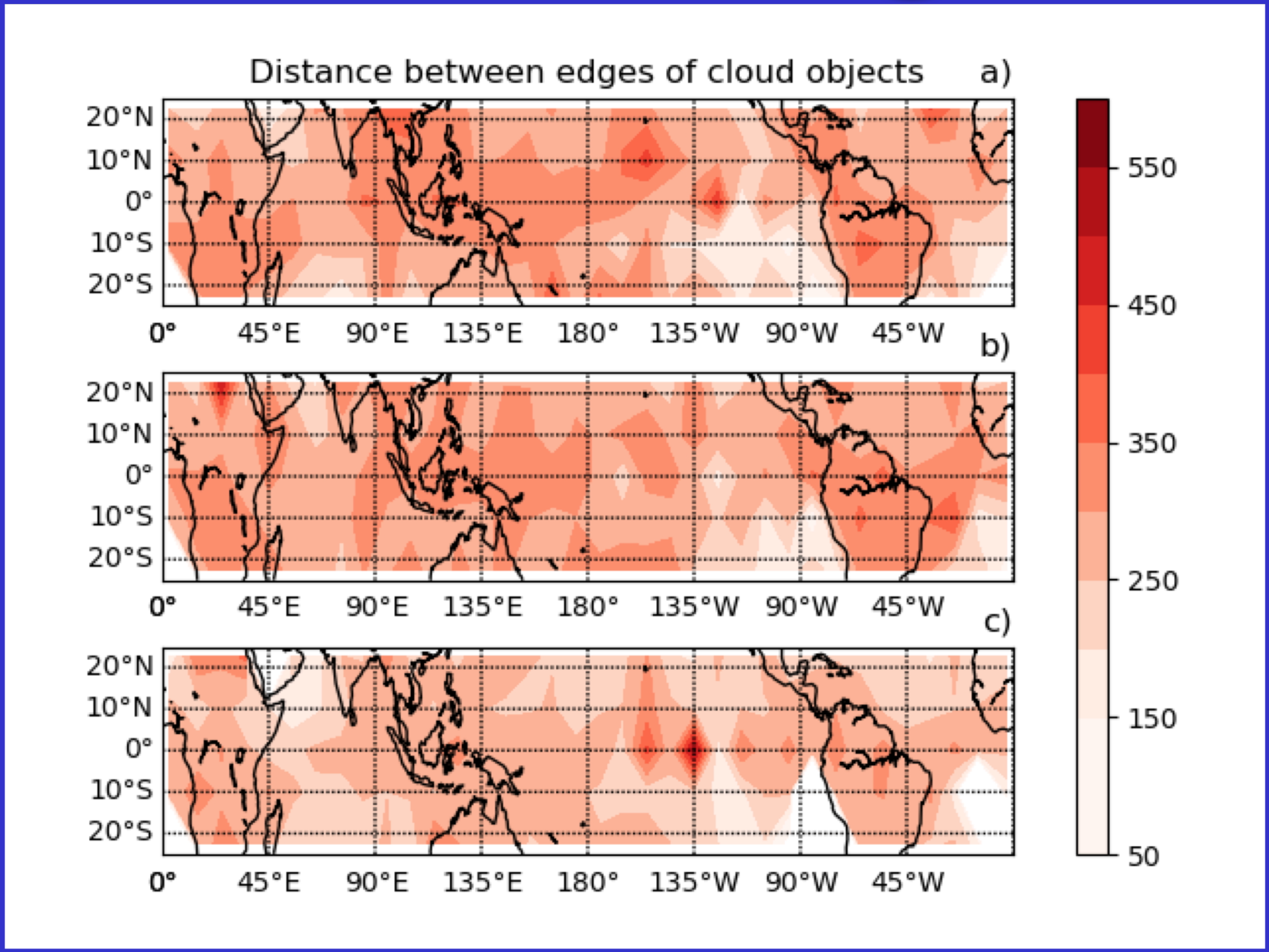
10 ° x10 ° grids

The mean distances for the large clusters are the largest

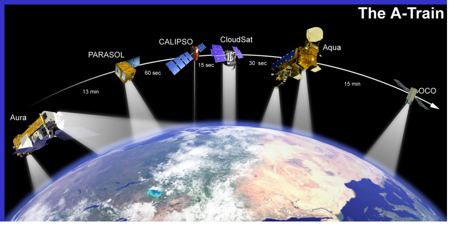


Mean distances between cloud objects – SCAI_Modified

75-150 km; 150-300 km; >300 km

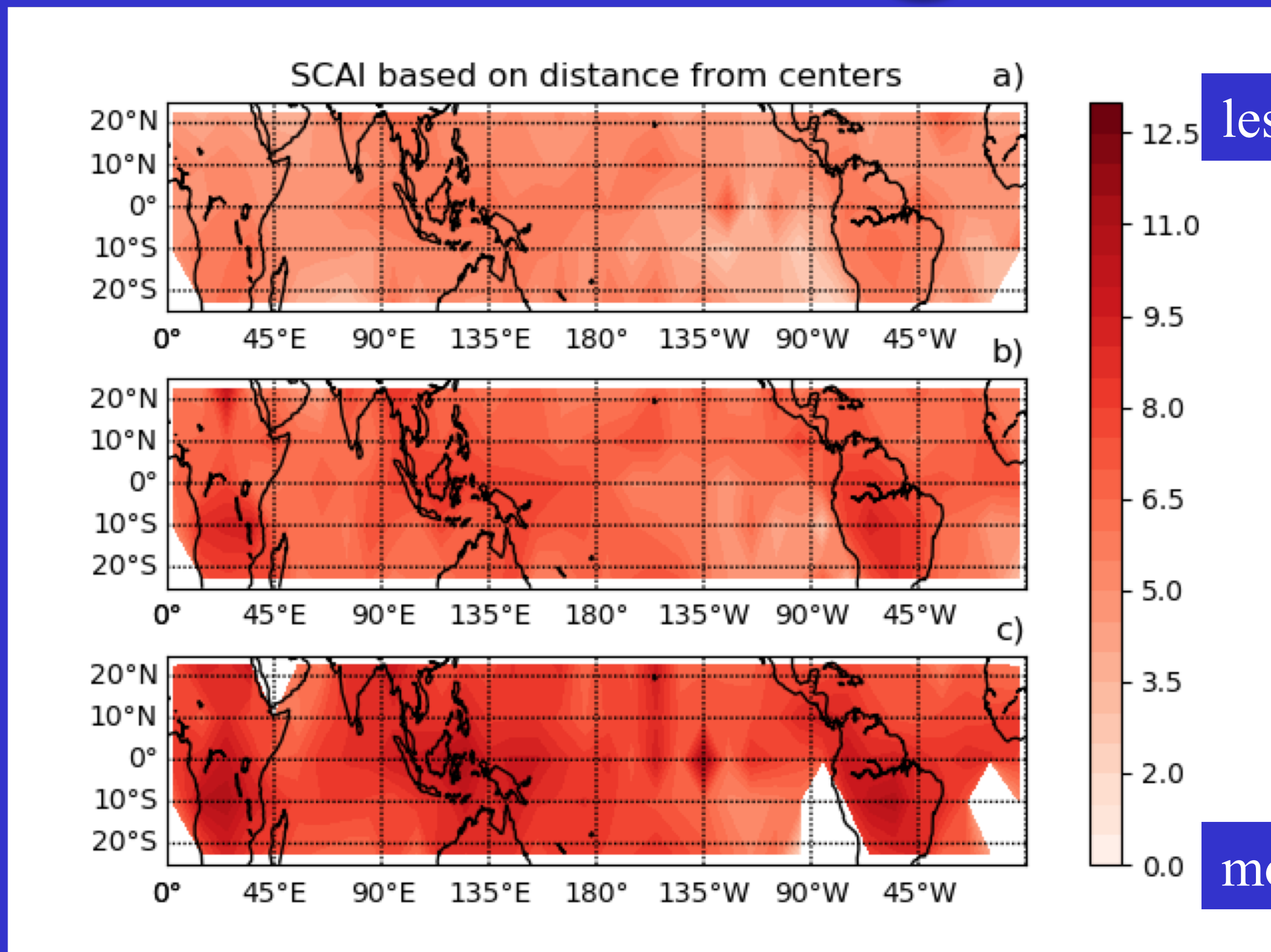


The mean distances are reduced for the modified SCAI, with the largest reduction for the large clusters



Simple convective aggregation index (SCAI_Tobin)

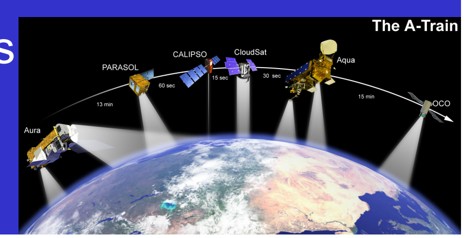
75-150 km; 150-300 km; >300 km



less aggregated

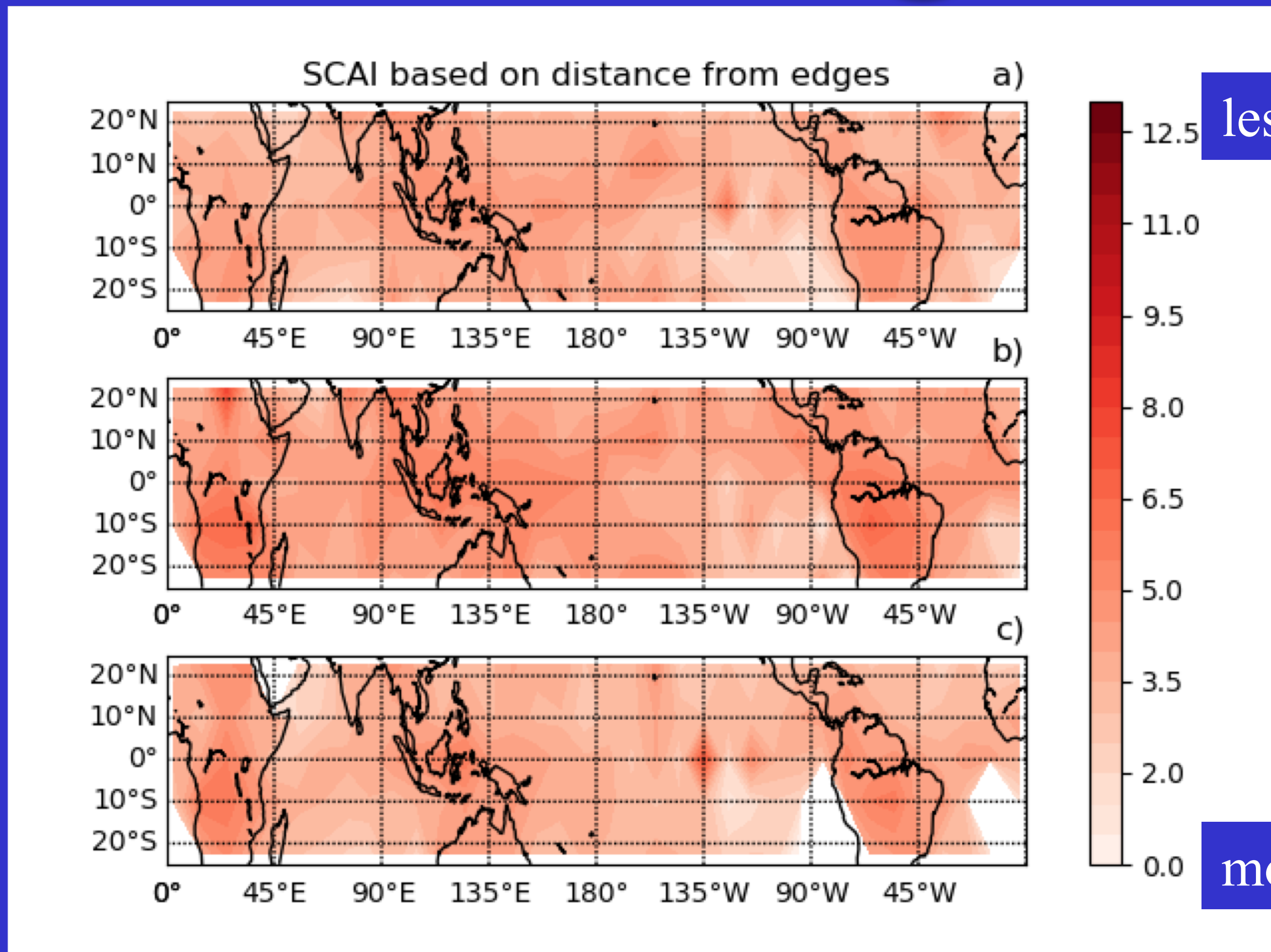
more aggregated

Large clusters are *less* aggregated than small clusters



Simple convective aggregation index (SCAI_Modified)

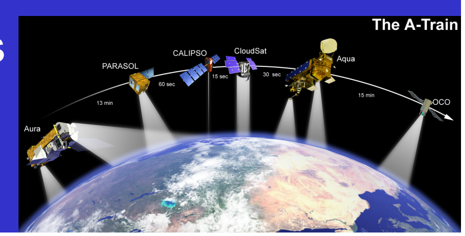
75-150 km; 150-300 km; >300 km



less aggregated

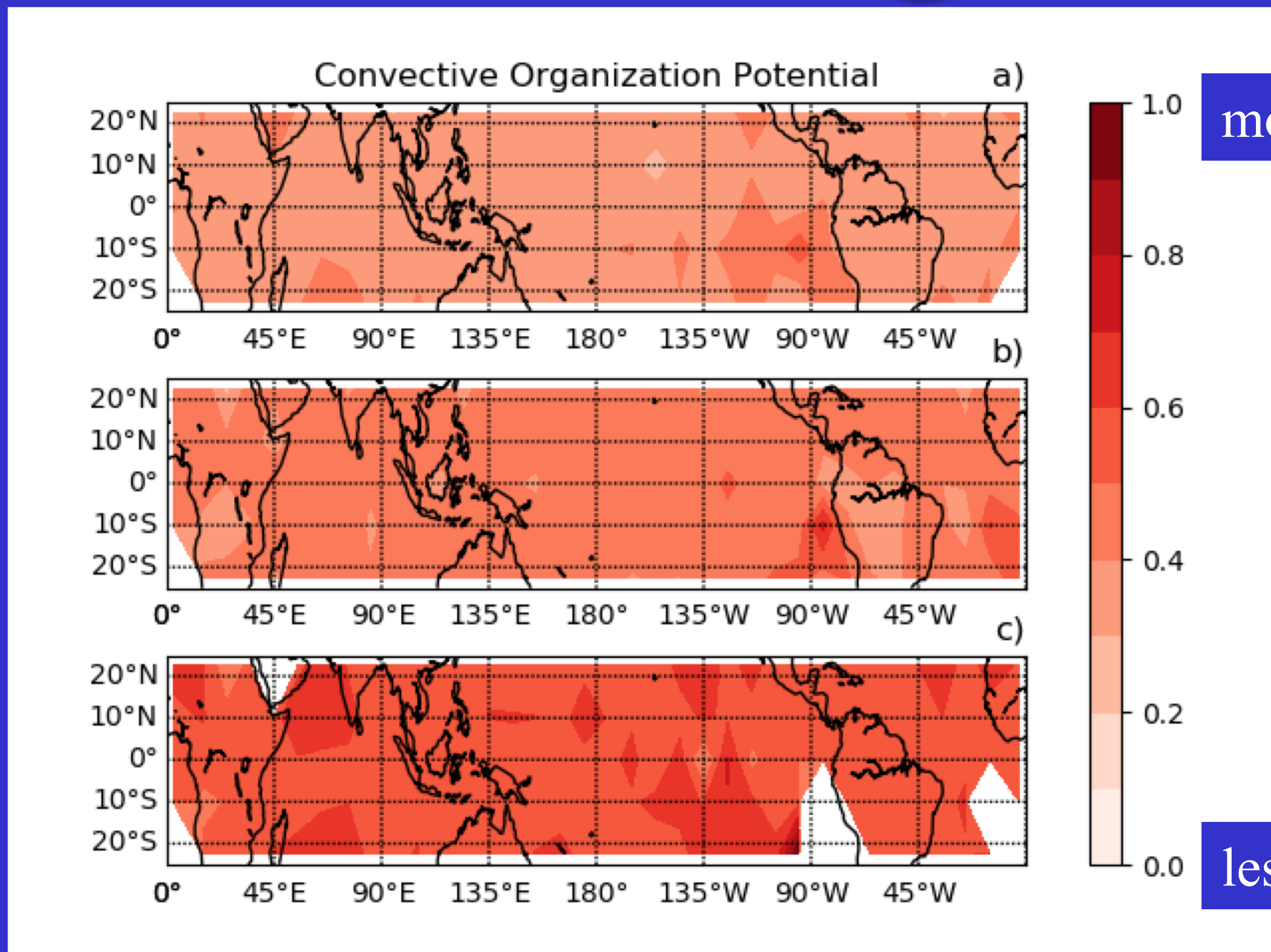
more aggregated

Large clusters are *slightly more* aggregated than small clusters



Convective organization potential (White *et al.* 2018)

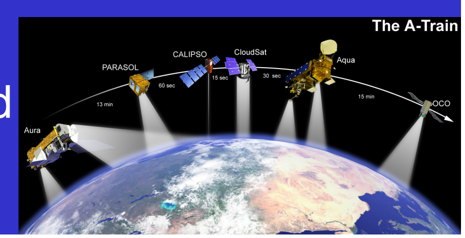
75-150 km; 150-300 km; >300 km



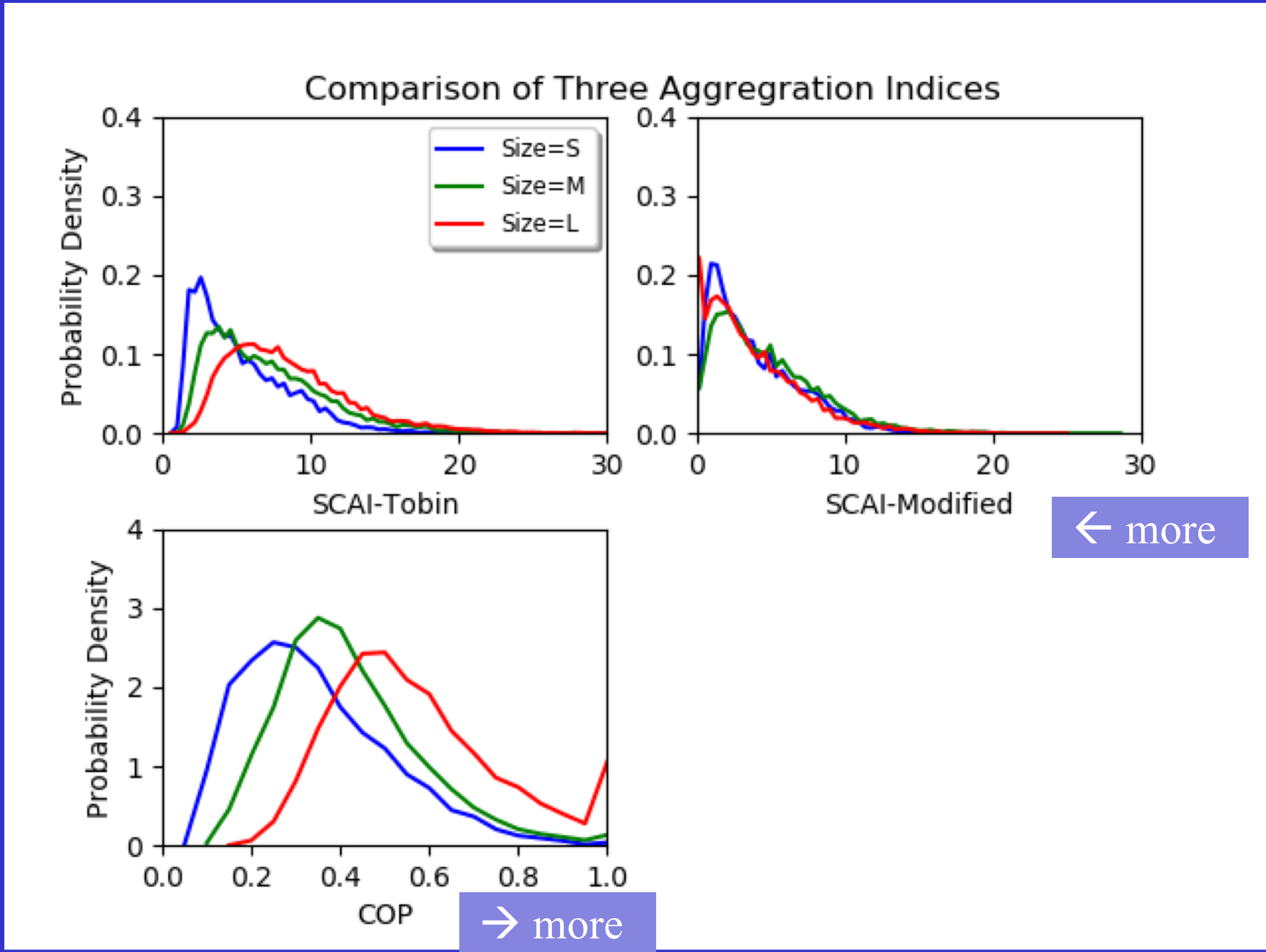
more aggregated

less aggregated

Large clusters are *more* aggregated than small clusters;
But the index biases towards the large clusters, compared to the modified SCAI.



All size categories of convective clusters

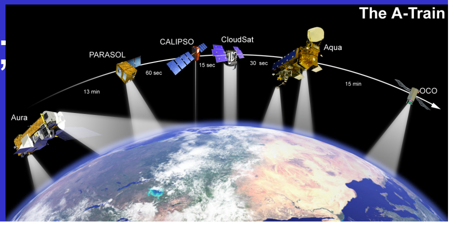


← more

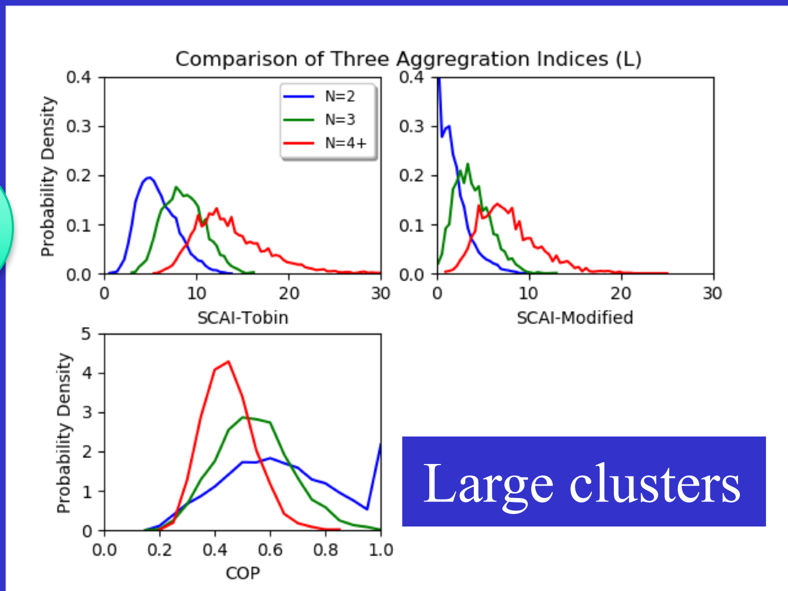
→ more

For every 10°x10° grid with 2 or more cloud objects

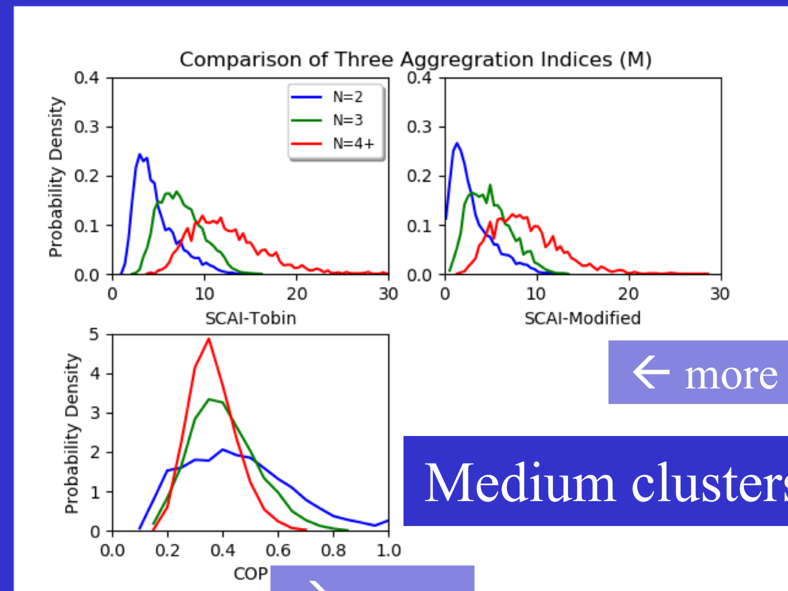
As in spatial distributions, large clusters are less aggregated according to SCAI-Tobin, but more aggregated according to COP; only slightly more aggregated according to the modified SCAI.



Dependency on numbers of convective objects in a cluster



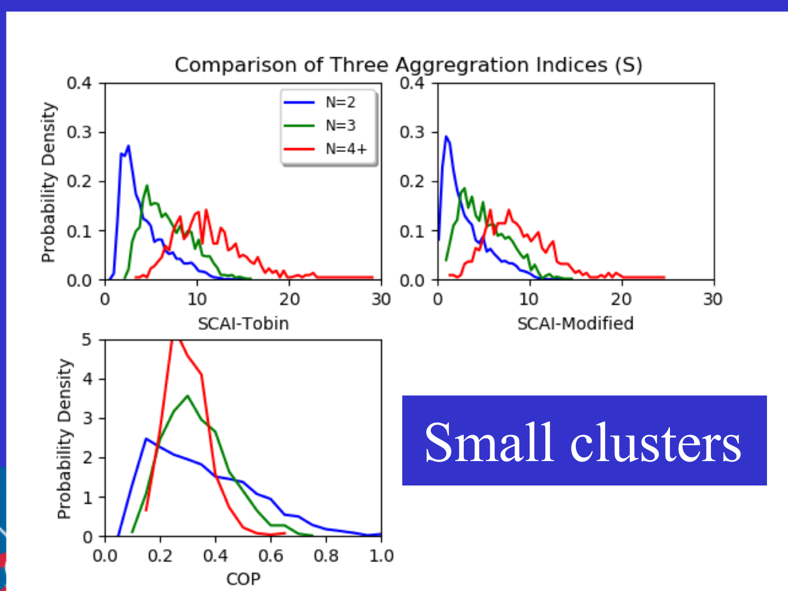
Large clusters



← more

Medium clusters

→ more

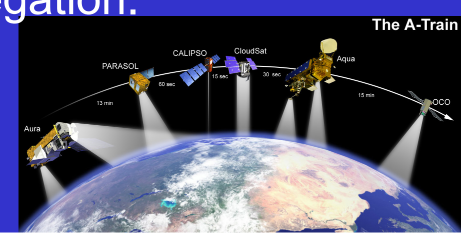


Small clusters

More cloud objects, less aggregated for both SCAIs
The dependency is weaker for COP, esp. small cluster.

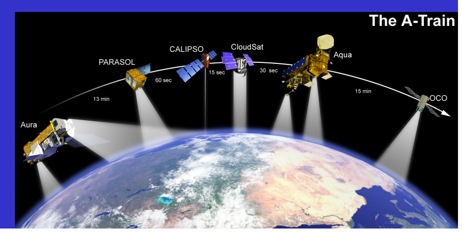
The latter is seen from larger overlapped areas underneath two curves for COP.

Number of convective objects is not the only factor for determining the degree of aggregation.



Summary

1) As a first step for providing an observational understanding of convective aggregation, convective aggregation indices are evaluated with cloud object data in this study
2) The problem with the Tobin et al. (2012) SCAI, i.e., ignoring the size of cloud objects, can be solved with either a simple modification (this study) or using convective organization potential (COP)
3) The degree of aggregation obtained from the modified SCAI is slightly larger for large clusters, but it is much larger according to COP
4) The dependency of aggregation on the number of cloud objects within a cluster is much weaker for COP
5) The number of cloud objects are not the only factor for determining the degree of aggregation (mistakenly used in several previous studies)



“aa train” for measuring convective aggregation

- The aa-Train utilizes two 6U CubeSats flying in formation.
- The Leader carries an infrared imaging instrument that identifies clouds in the scene and communicates their location to a Follower carrying a cloud top/water phase lidar.
- The Leader spacecraft calculates an optimal path and sends pointing commands to maneuver the Follower spacecraft to point the lidar to measure cloud heights.
- When combined, the volume of aggregating tropical clouds will be measured.