NAGOYA UNIVERSITY

ISEE Institute for Space-Earth Environmental Research

Satellite data analysis of convective and UT cloud variabilities

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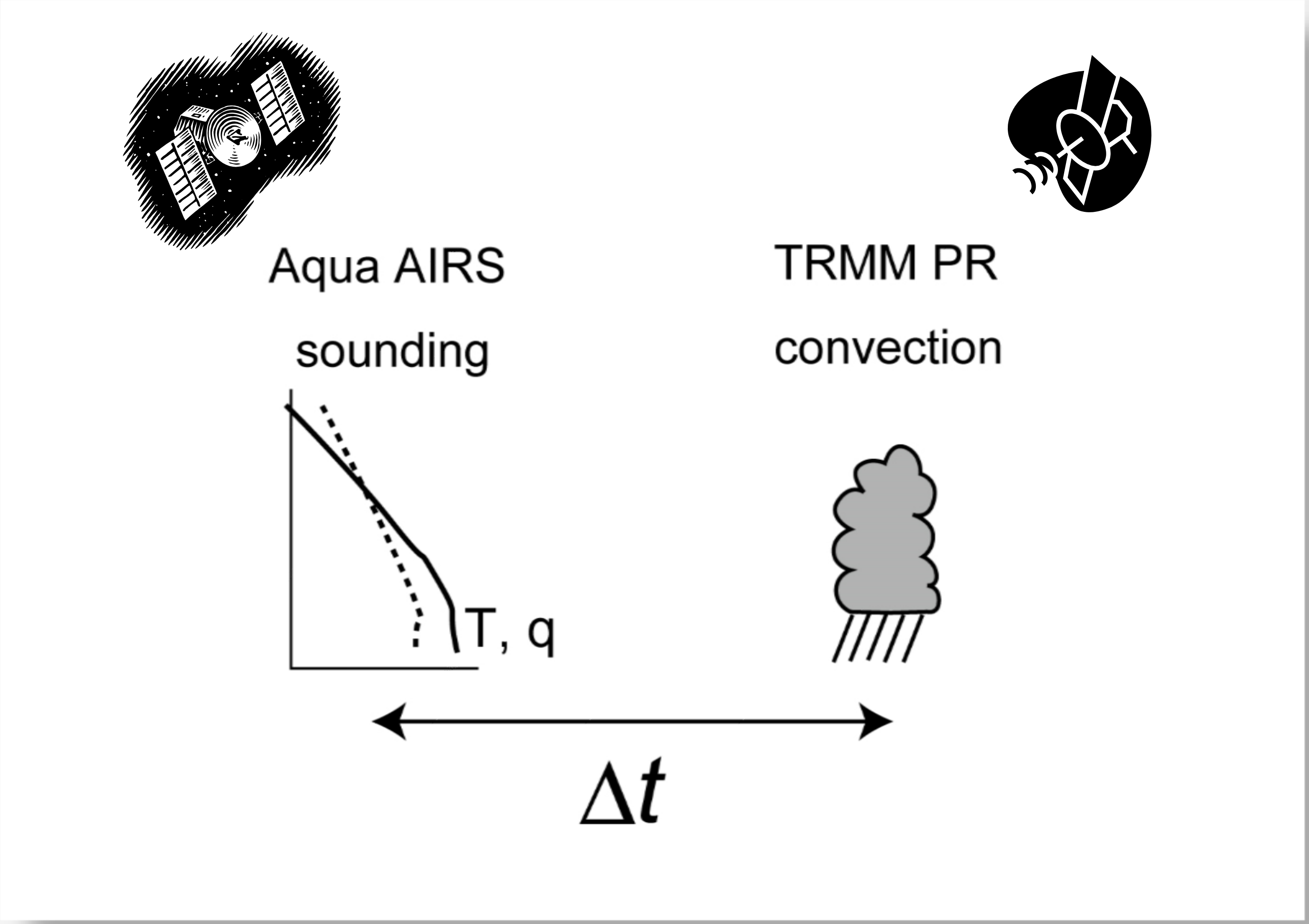
Plans for PROCES UTCC

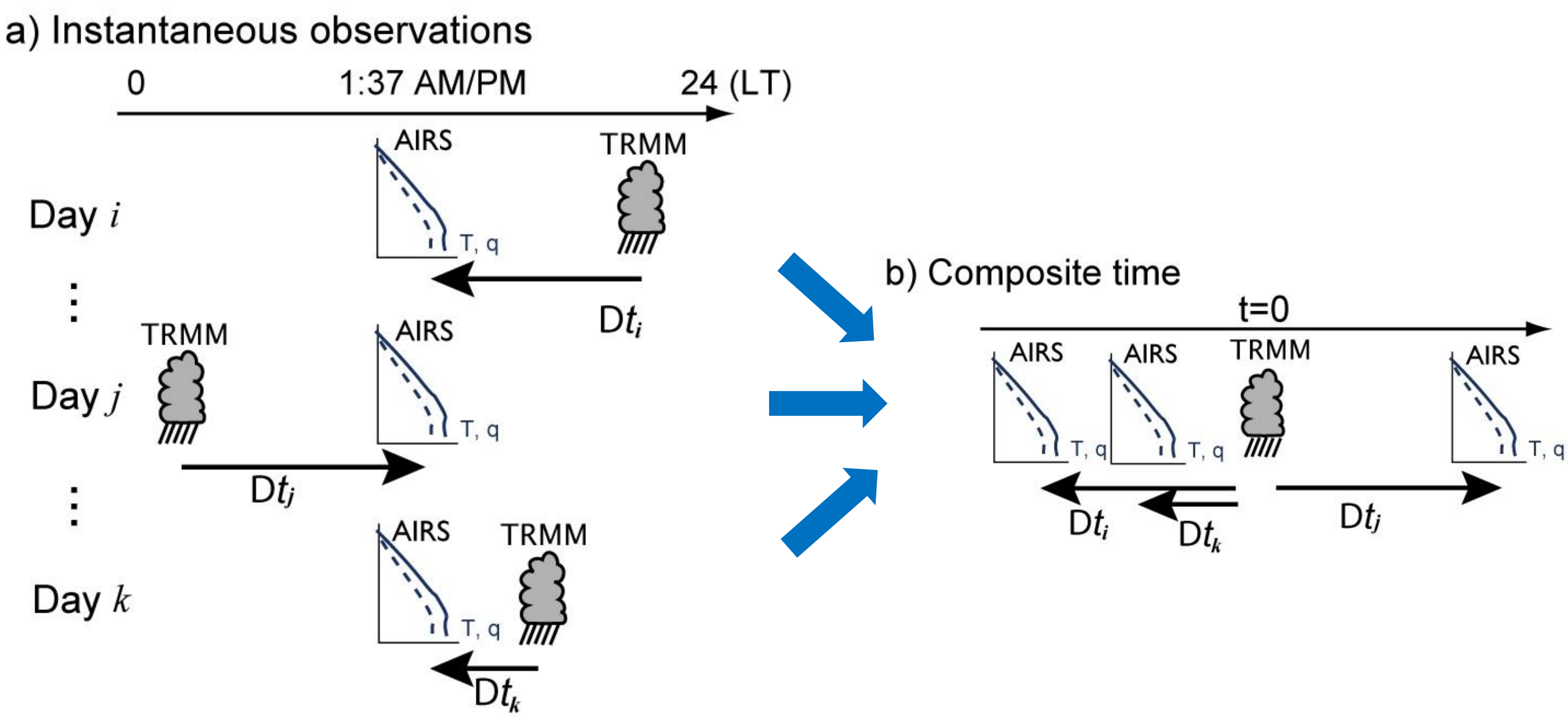
- What has been done so far.
  - Satellite data analyses to study the evolution of tropical convection over hourly to daily time scales.
    - Composite time series (Masunaga, 2012)
    - Thermal and moisture budget analysis (Masunaga, 2013)
    - LS-mean vertical motion (Masunaga and L'Ecuyer, 2014)
    - Convective mass flux (Masunaga and Luo, 2016)
- What can be done in the PROES UTCC framework.
  - Satellite-based datasets to study…
    - The variability of UT clouds over the convective life cycle
    - UT convective detrainment

Satellite observations of *T*/*q* and convection

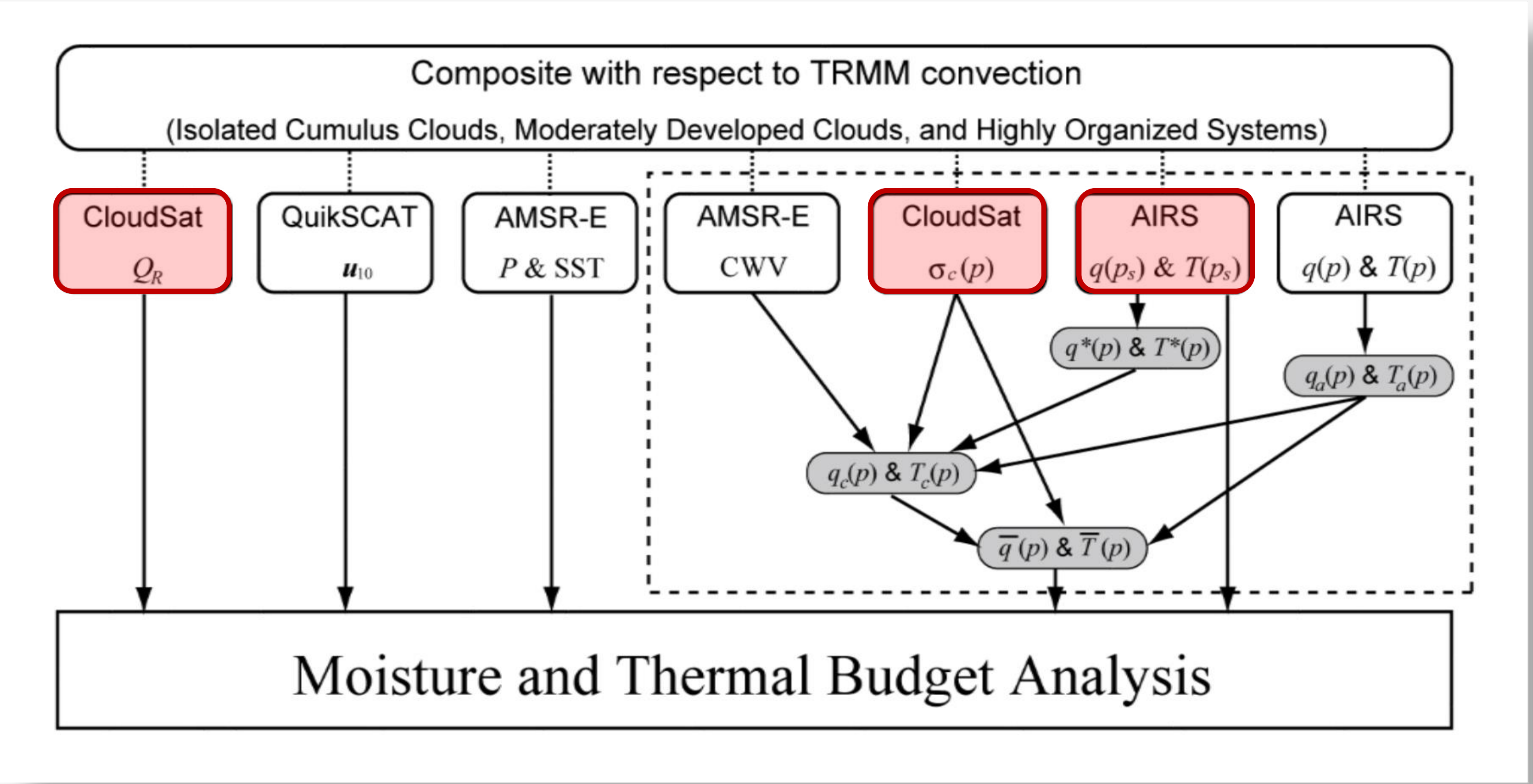


Making a composite time series

- AIRS *T* & *q* composited against TRMM convection

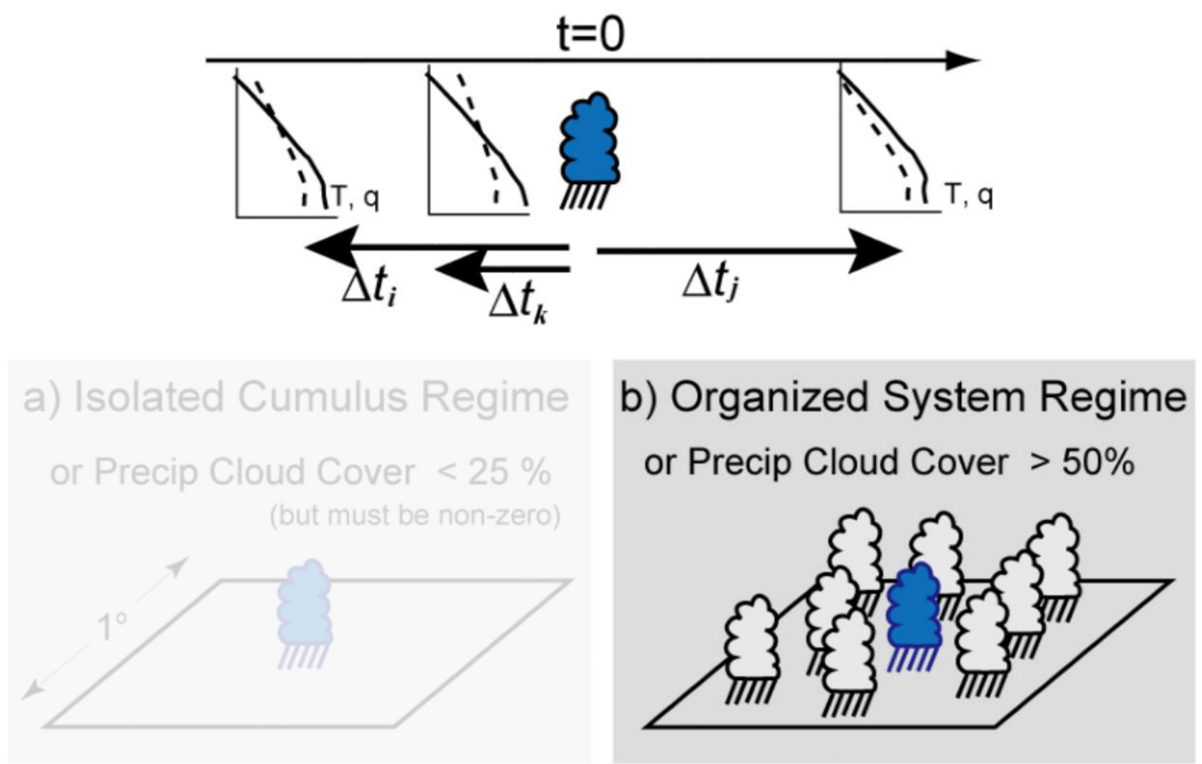


Satellite observation: strategy



- AMSR-E precipitation is from CSU GPROF2010 product and SST is from RSS.
- Radiative heating rate is from the CloudSat 2B FLXRH product.
- QuikSCAT u_{10} is from the SeaWinds Level3 daily gridded product (JPL PO.DAAC).

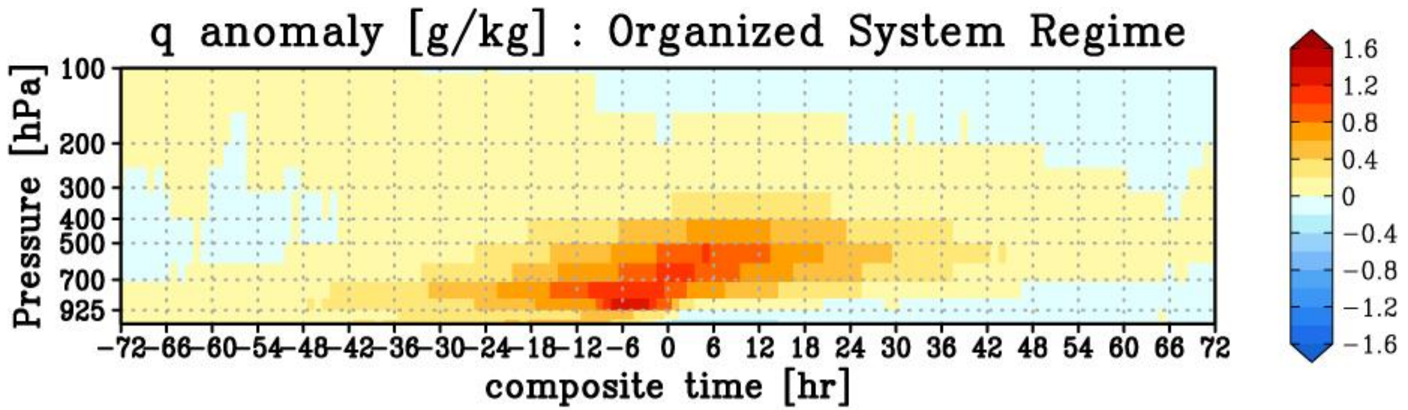
Breakdown by different convective regimes

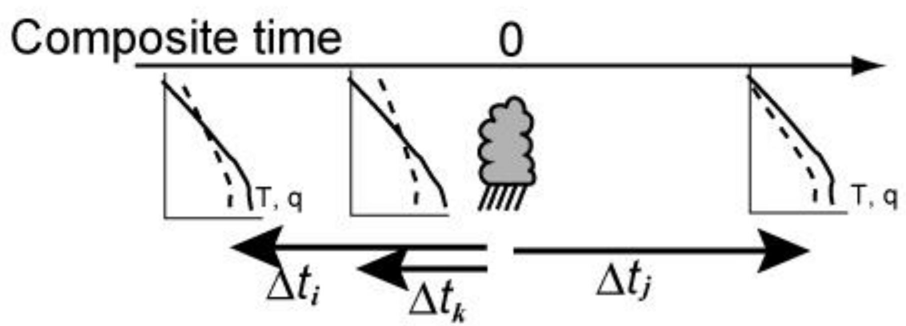


* Precipitation Cloud Cover is defined as the fractional area covered with PR-detected rainfall.

Composite for organized convective systems

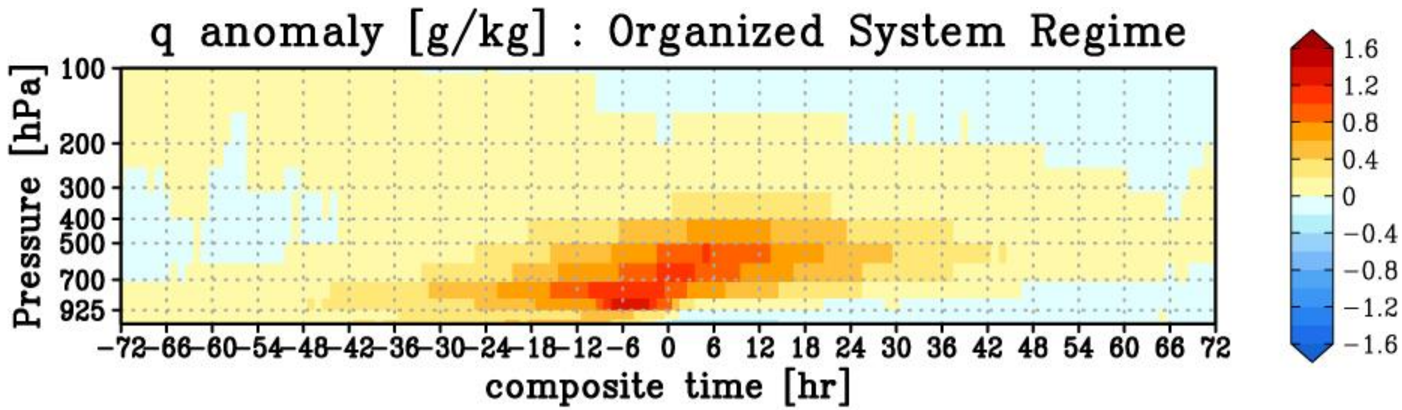
- Evolution of moisture and cloud structures

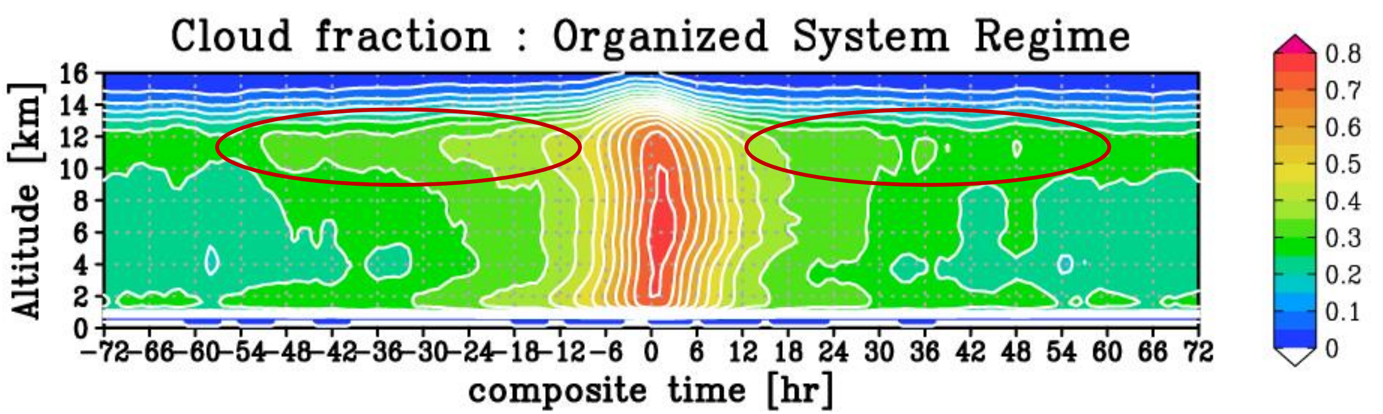




Composite for organized convective systems

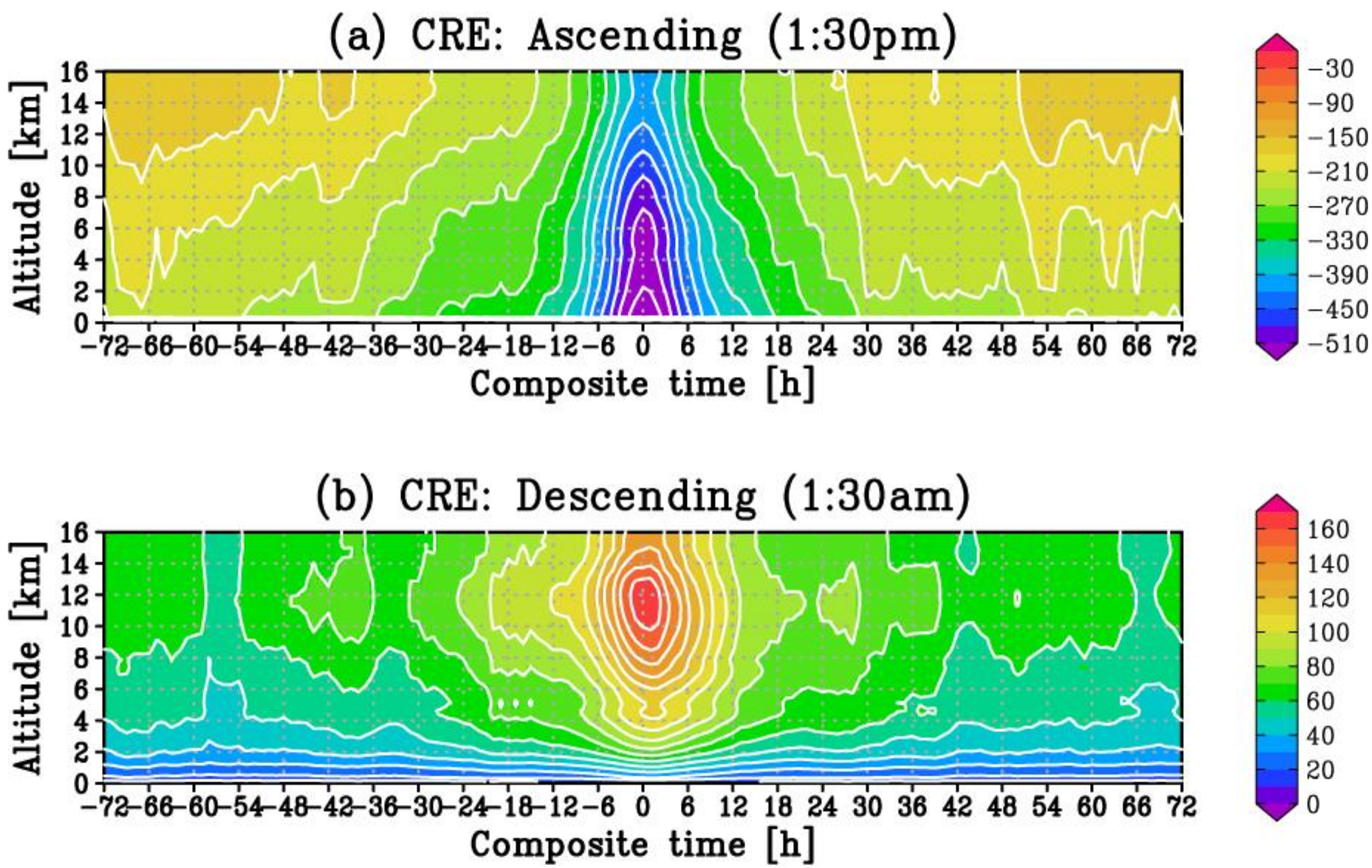
- Evolution of moisture and cloud structures





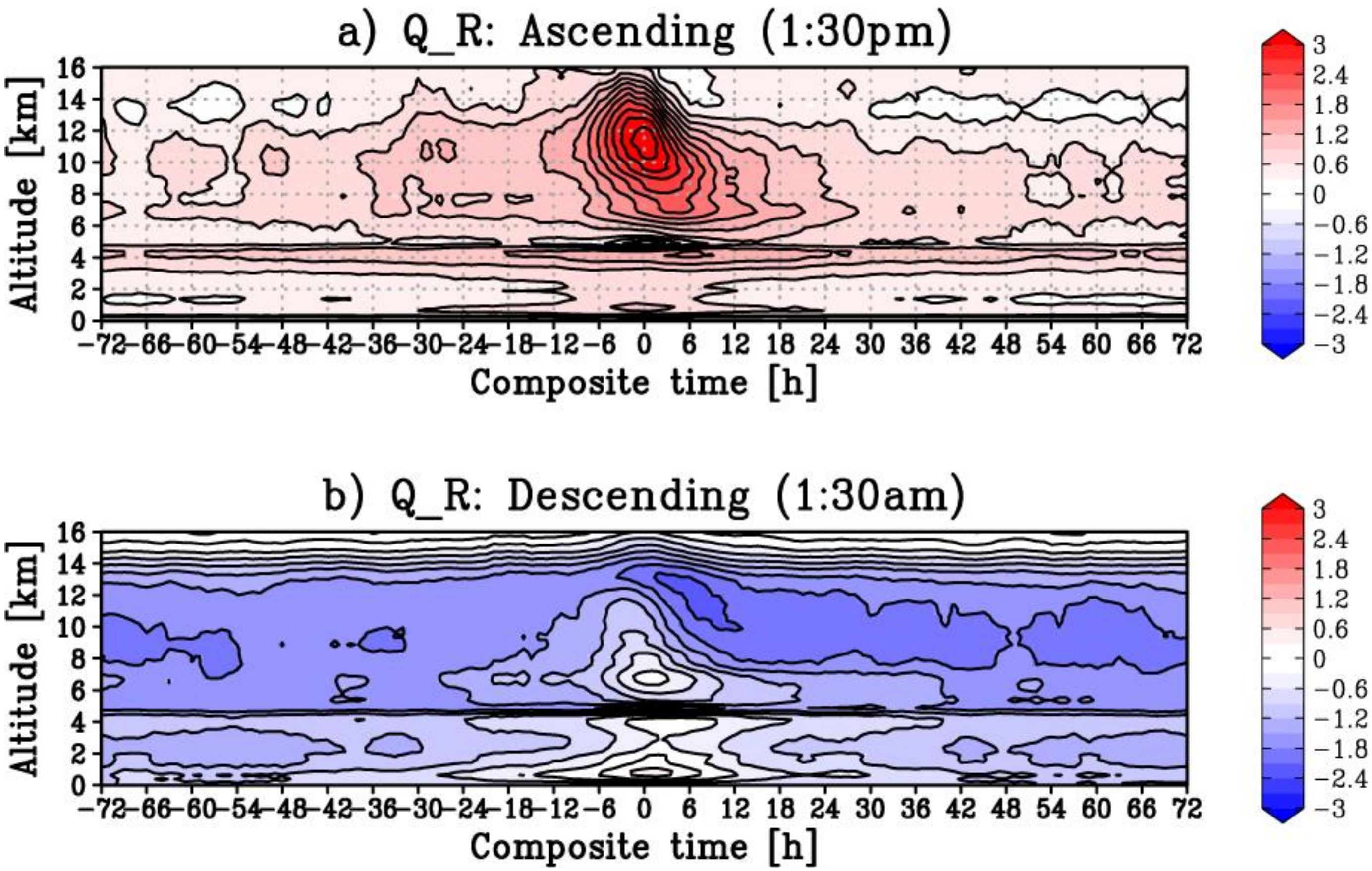
Composite for organized convective systems

- Evolution of $\mathrm{CRE} = (F^{\uparrow}_{\mathrm{clr}} - F^{\downarrow}_{\mathrm{clr}}) - (F^{\uparrow}_{\mathrm{all}} - F^{\downarrow}_{\mathrm{all}})$

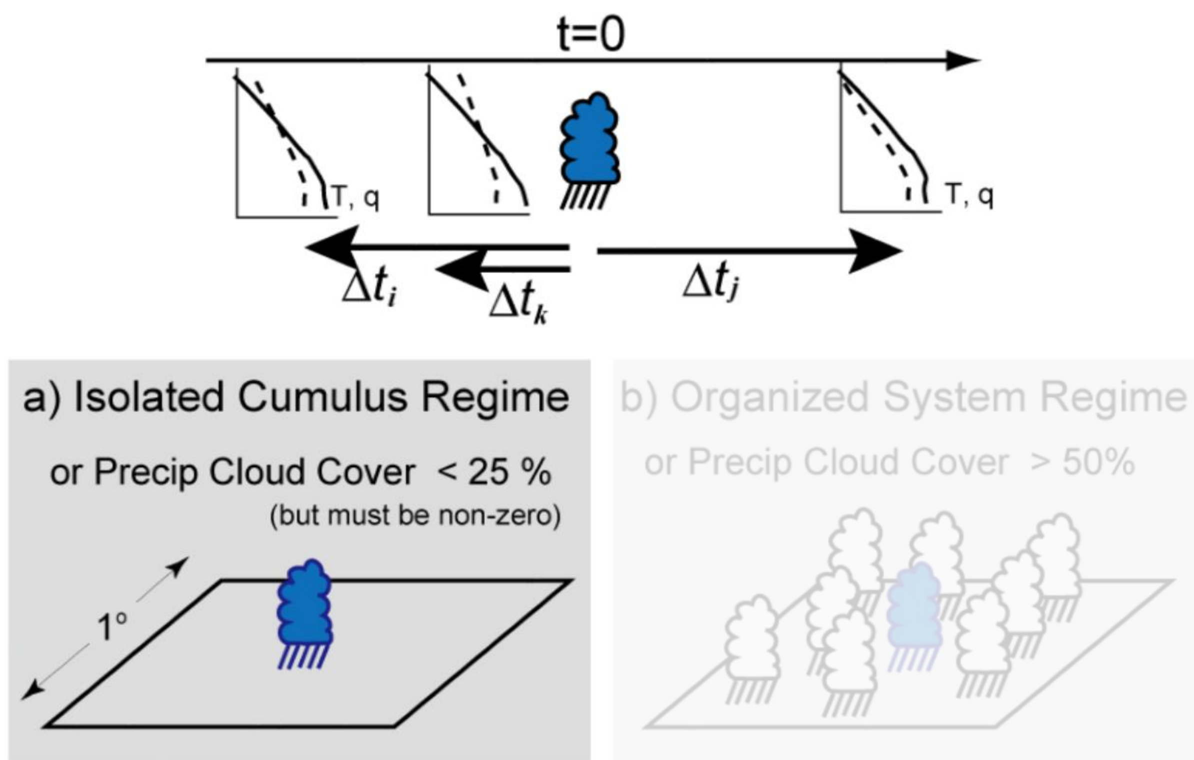


Composite for organized convective systems

- Evolution of Q_R



Breakdown by different convective regimes



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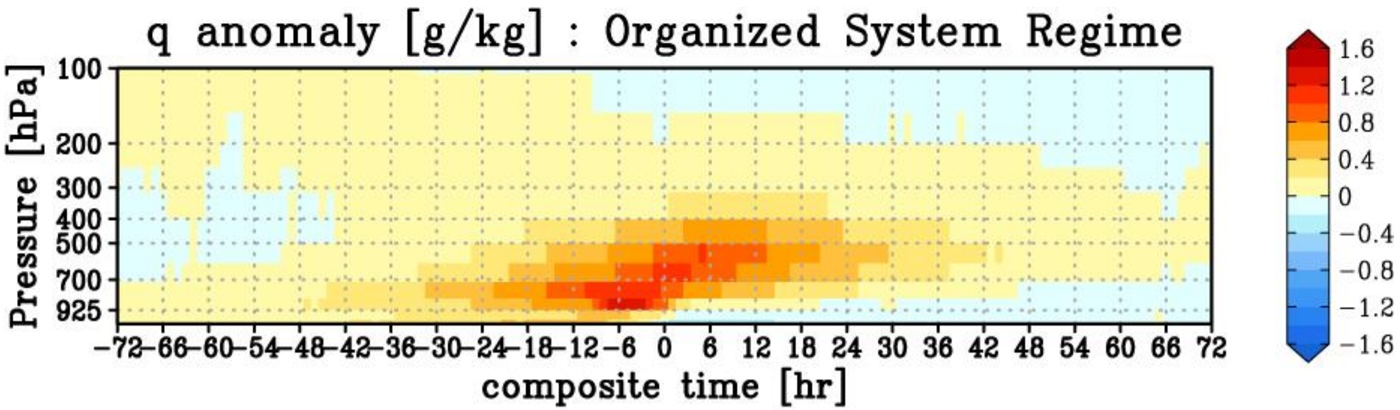
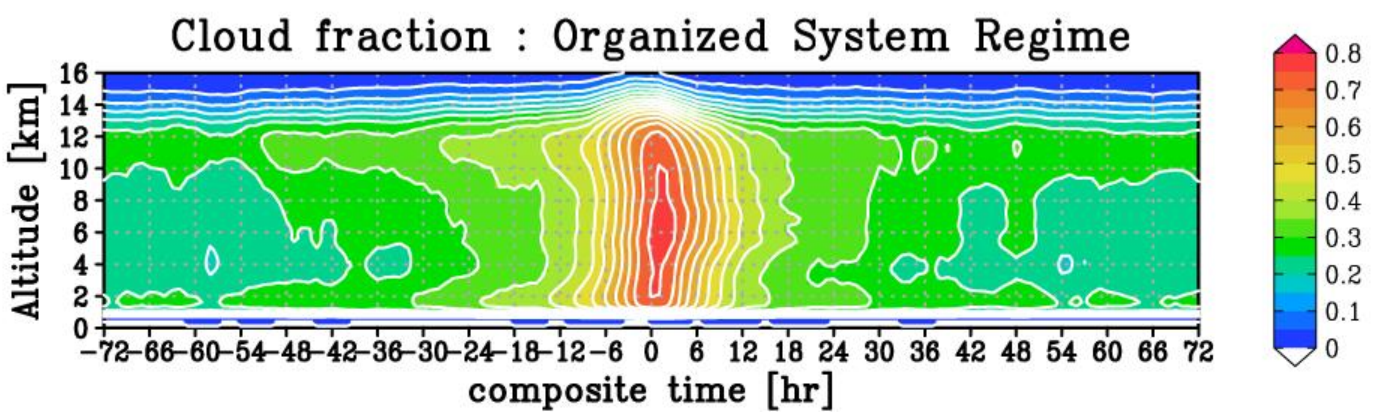
Composite for organized convective systems

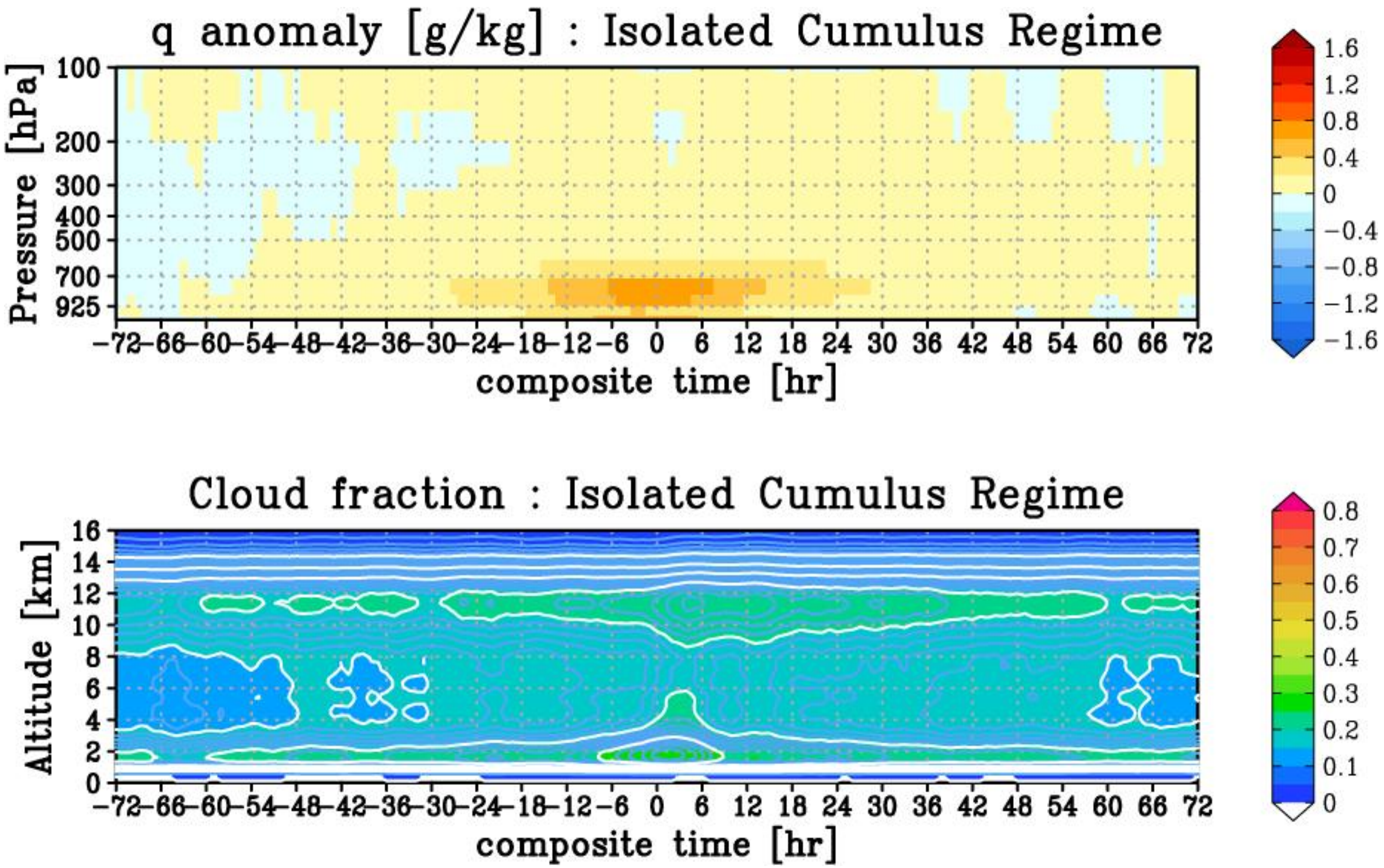
- Evolution of moisture and cloud structures





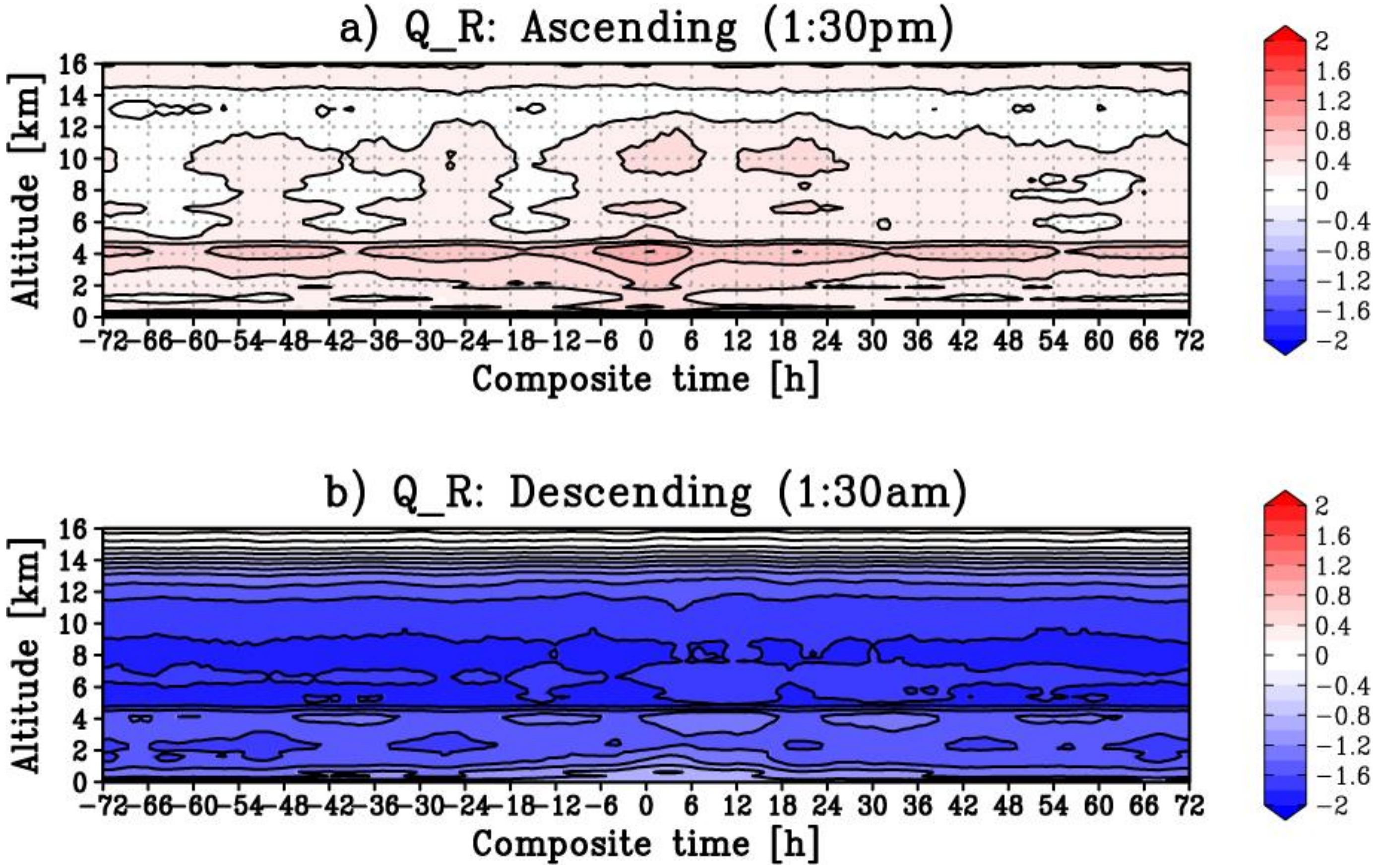
Composite for isolated cumuli

- Evolution of moisture and cloud structures



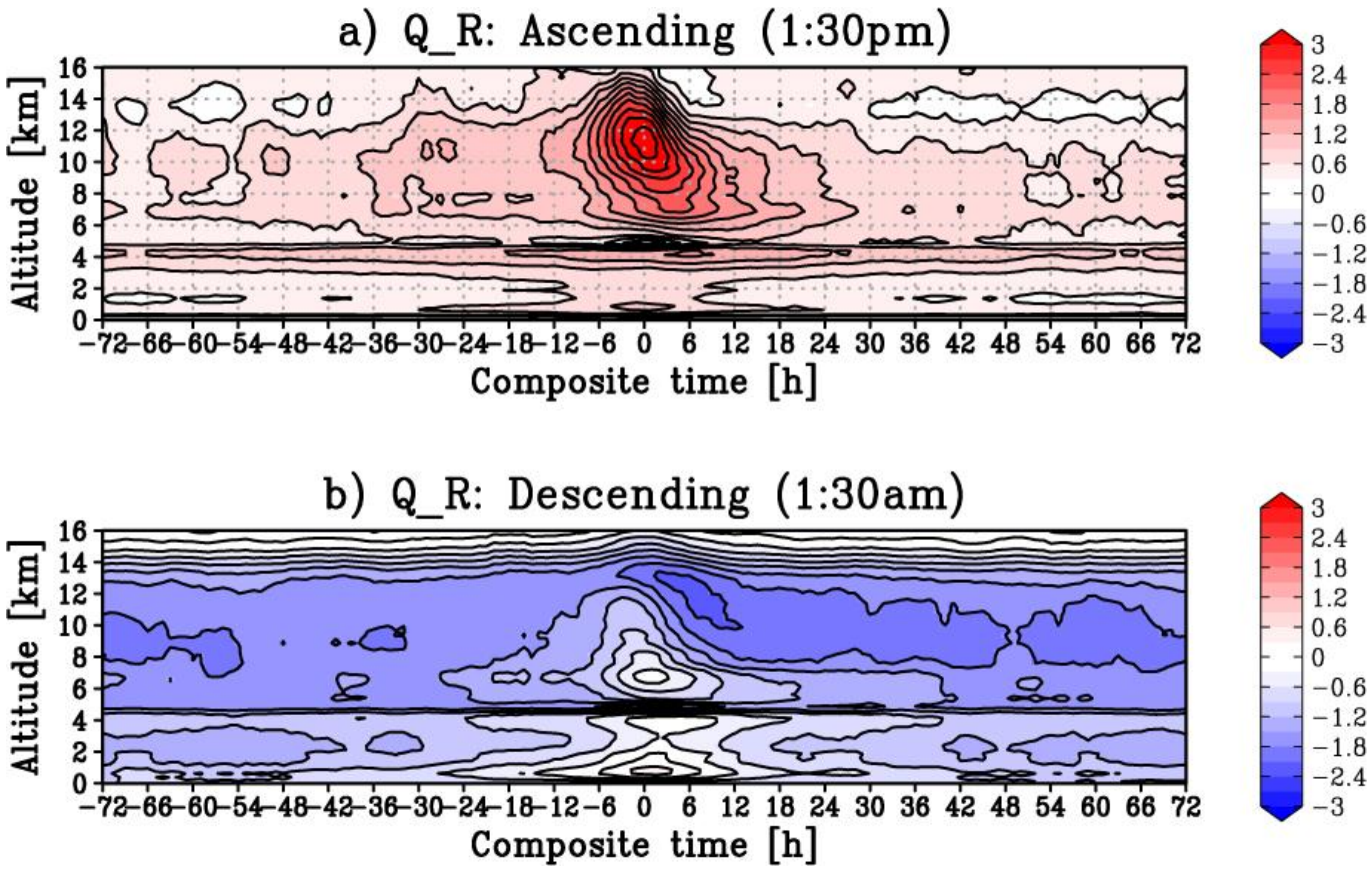
Composite for isolated cumuli

- Evolution of Q_R



Composite for organized convective systems

- Evolution of Q_R



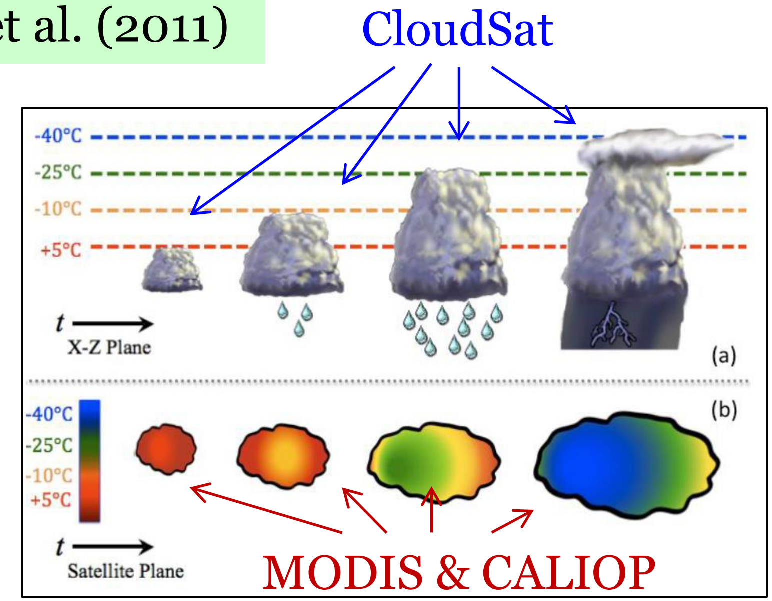
UT cloud cover begins to enhance even ~2 days before a vigorous convective system develops.

Detrainment from scattered deep convection present in the background?

The satellite data input: cloud-top w_c

Cloud-top buoyancy
Luo et al. (2010); Wang et al. (2011)

$$B = g\frac{T_{parcel} - T_{env}}{T_{env}}$$



Needs vertical extrapolation to obtain full in-cloud profiles.

A single-column plume model

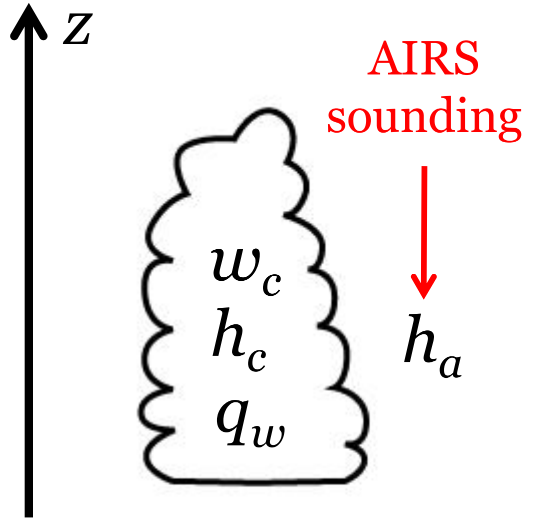
- Basic and ancillary equations

Basic equations

$$\frac{1}{2}\frac{\partial w_c^2}{\partial z} = a_B B - \epsilon w_c^2 - c_D w_c^2,$$

$$\frac{\partial (h_c - L_i q_i)}{\partial z} = -\epsilon(h_c - L_i q_i - h_a),$$

$$\frac{\partial q_w}{\partial z} = -\epsilon q_w + \frac{1}{w_c}(\dot{q}_{\mathrm{cond}} - \dot{q}_{\mathrm{auto}}),$$



Anc. eqs.

$$B = g\left(\frac{T_{v,c} - T_{v,a}}{T_{v,a}} - q_w\right), \quad q_i = f_i q_w, \quad \text{where } f_i = \frac{2 - \tanh[(T_c - T_{0,i})/dT_i]}{2}$$

$$\dot{q}_{\mathrm{auto}} = \frac{1}{\tau_{\mathrm{auto}}}(q_w - q_{w,crit})H(q_w - q_{w,crit}), \quad \dot{q}_{\mathrm{cond}} = -w_c\left[\frac{\partial q_{v,c}}{\partial z} + \epsilon(q_{v,c} - q_{v,a})\right].$$

A single-column plume model

- Entrainment and detrainment

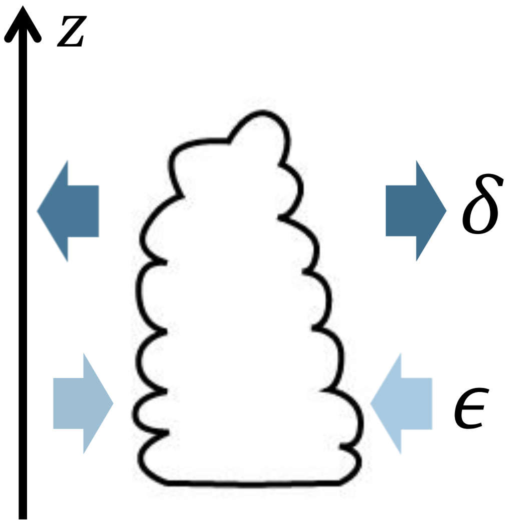
Entrainment/ Detrainment

$$\epsilon = \epsilon_{\rm dyn} + \epsilon_{\rm tur}, \quad \delta = \delta_{\rm dyn} + \delta_{\rm tur},$$

† Dynamic component ($\epsilon_{\rm dyn}$, $\delta_{\rm dyn}$):
Constrained with w_c by continuity eq.

$$\epsilon_{\rm dyn} = \frac{1}{\rho w_c}\frac{\partial(\rho w_c)}{\partial z} H\left[\frac{\partial(\rho w_c)}{\partial z}\right], \quad \delta_{\rm dyn} = -\frac{1}{\rho w_c}\frac{\partial(\rho w_c)}{\partial z} H\left[-\frac{\partial(\rho w_c)}{\partial z}\right]$$

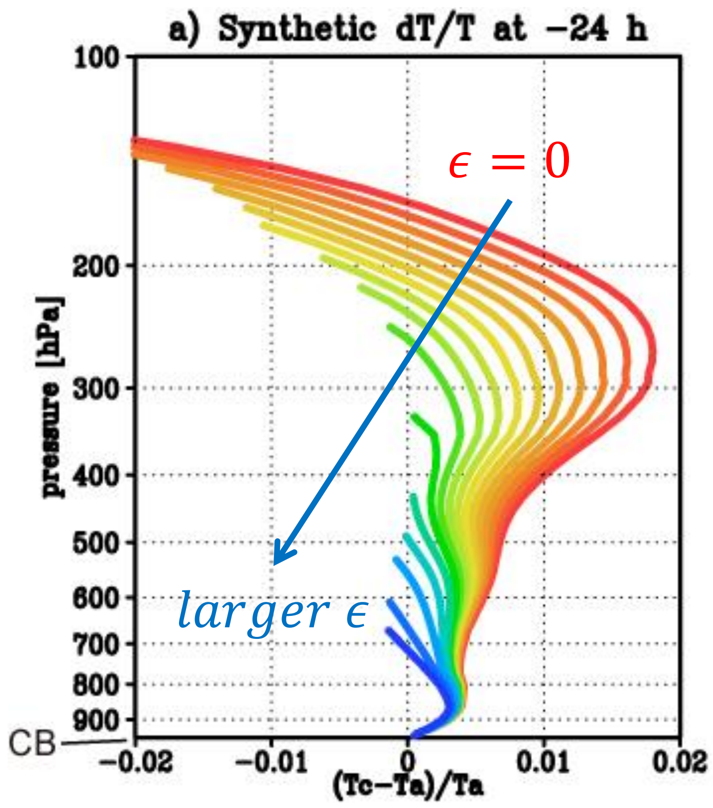
† Turbulent component ($\epsilon_{\rm tur}$, $\delta_{\rm tur}$):
Prescribed below



$\epsilon_{\rm tur}$=0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.12, 0.15, 0.2, 0.3, 0.4 $\rm km^{-1}$

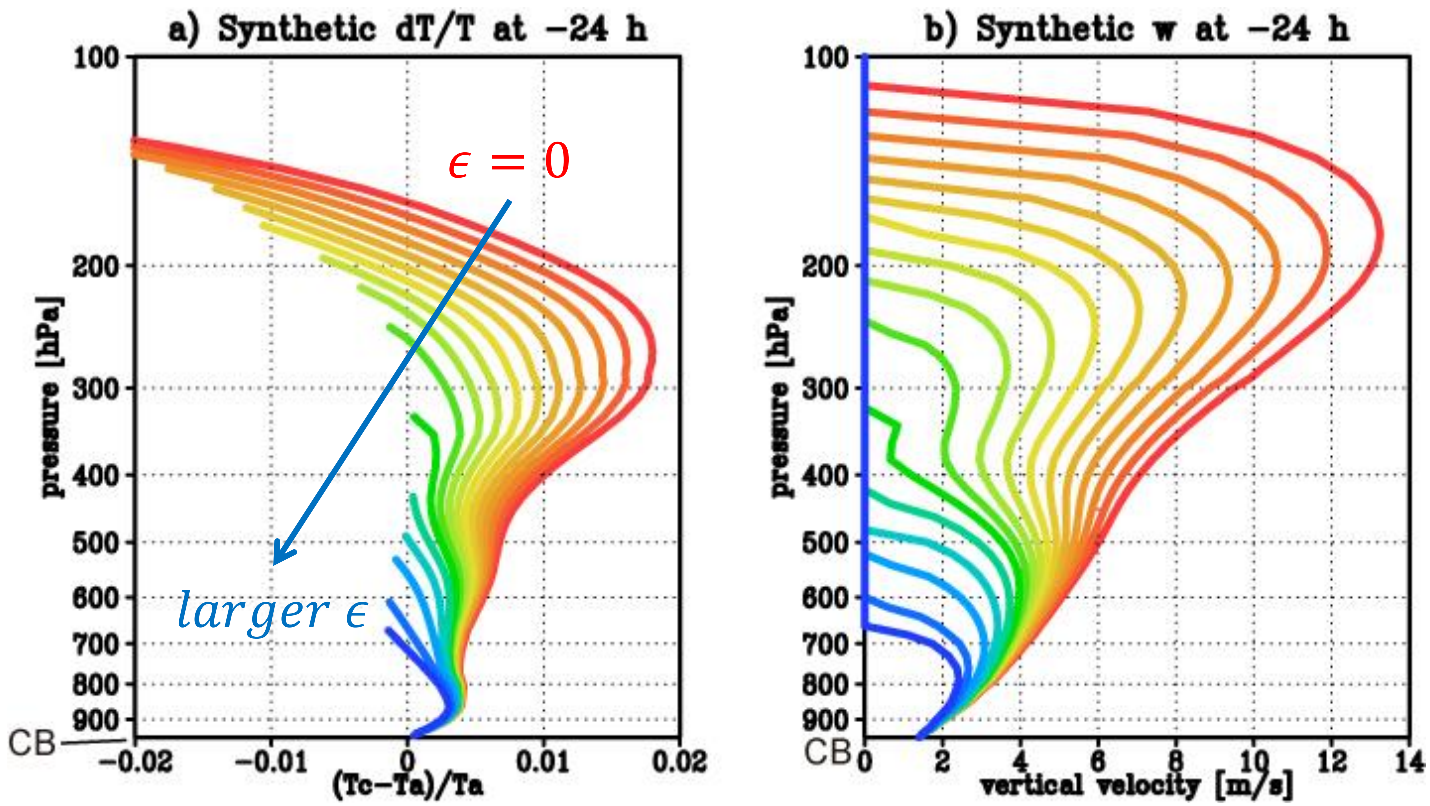
Plume model solutions

- Simulated buoyancy ($\Delta T / T_a$)



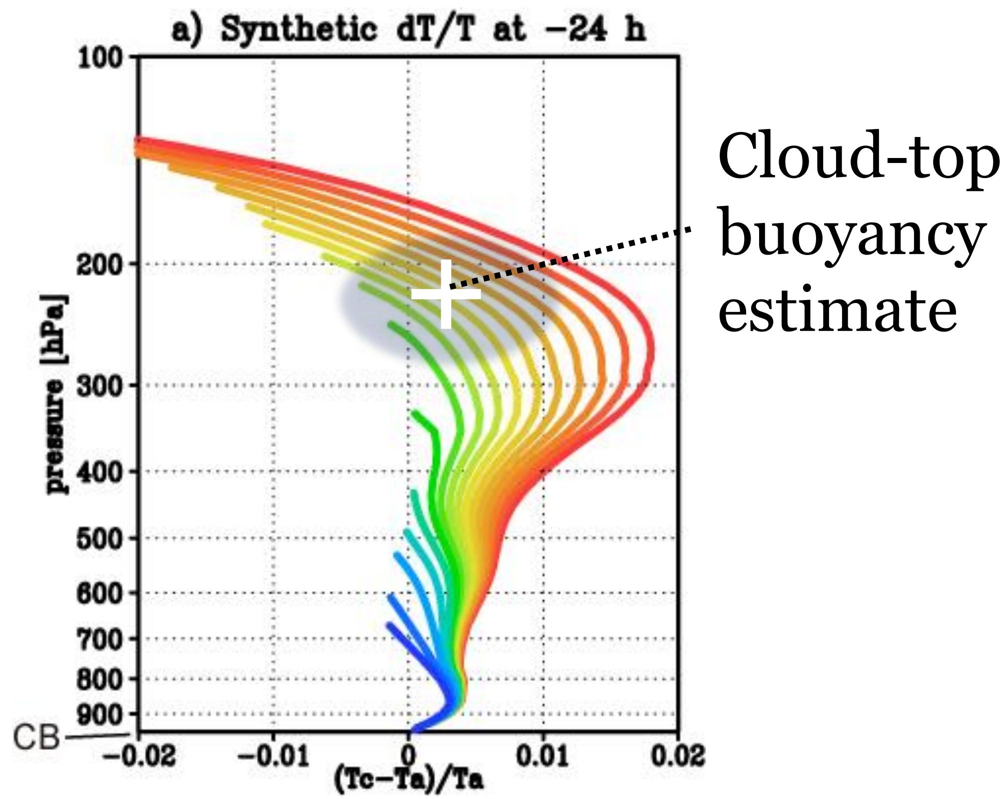
Plume model solutions

- Simulated buoyancy ($\Delta T/T_a$) and w_c profiles



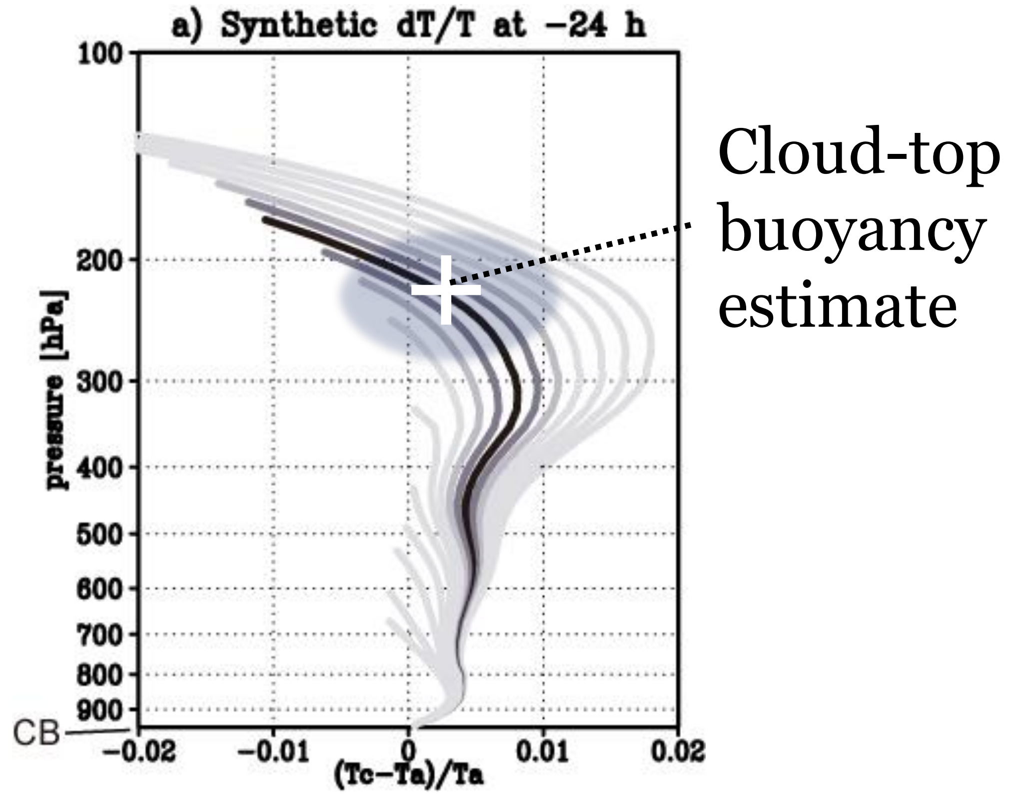
Candidate buoyancy profiles

- Bayesian retrieval with cloud-top buoyancy estimates
  - Applied to plume-model solutions as candidate profiles



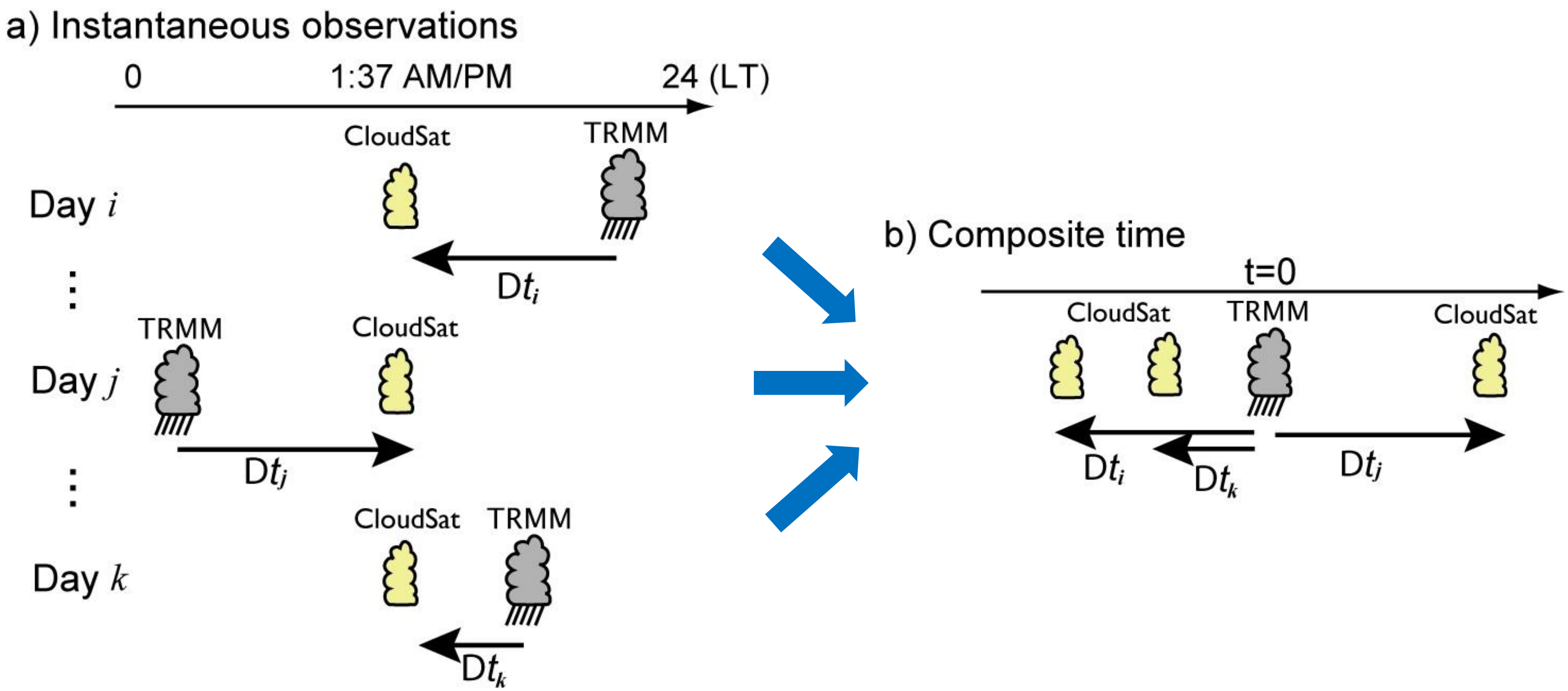
Selection of the best matched profiles

- Bayesian retrieval with cloud-top buoyancy estimates
  - $\hat{w}_c(z) \equiv \sum_i p(\epsilon_{\mathrm{tur},i}|z_T, \Delta T_T) w_{c,i}(z) = \sum_i p(\epsilon_{\mathrm{tur},i}) p(z_T, \Delta T_T|\epsilon_{\mathrm{tur},i}) w_{c,i}(z),$



Making a composite time series

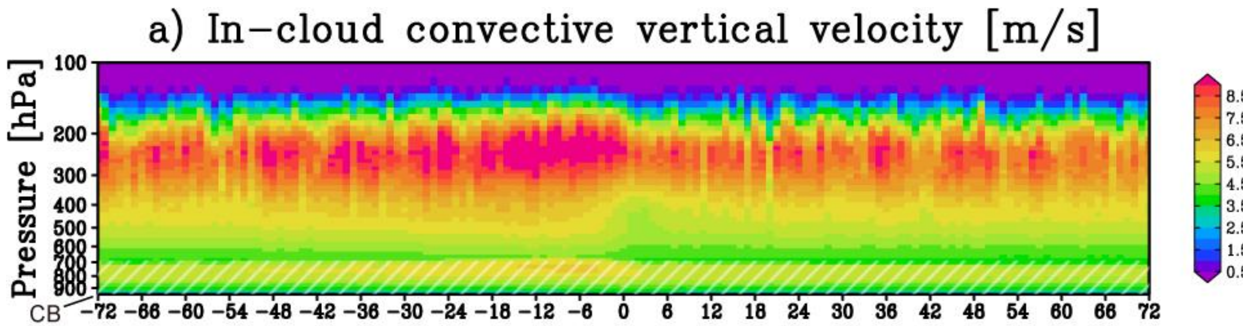
- CloudSat w_c composited against TRMM convection

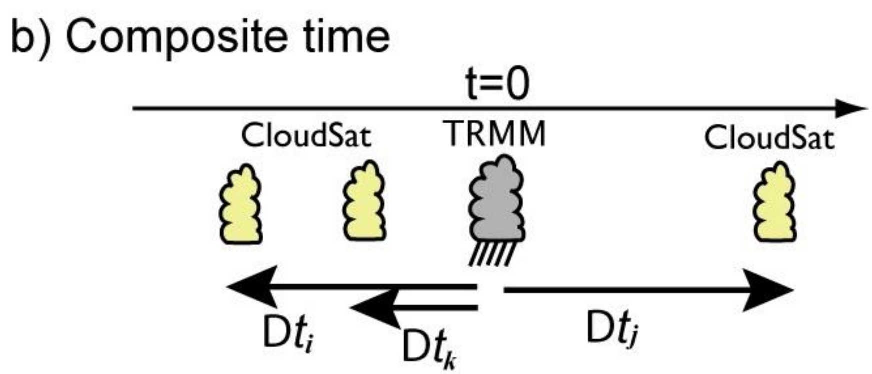


Composite time series of w_c

$\boldsymbol{w_c}$

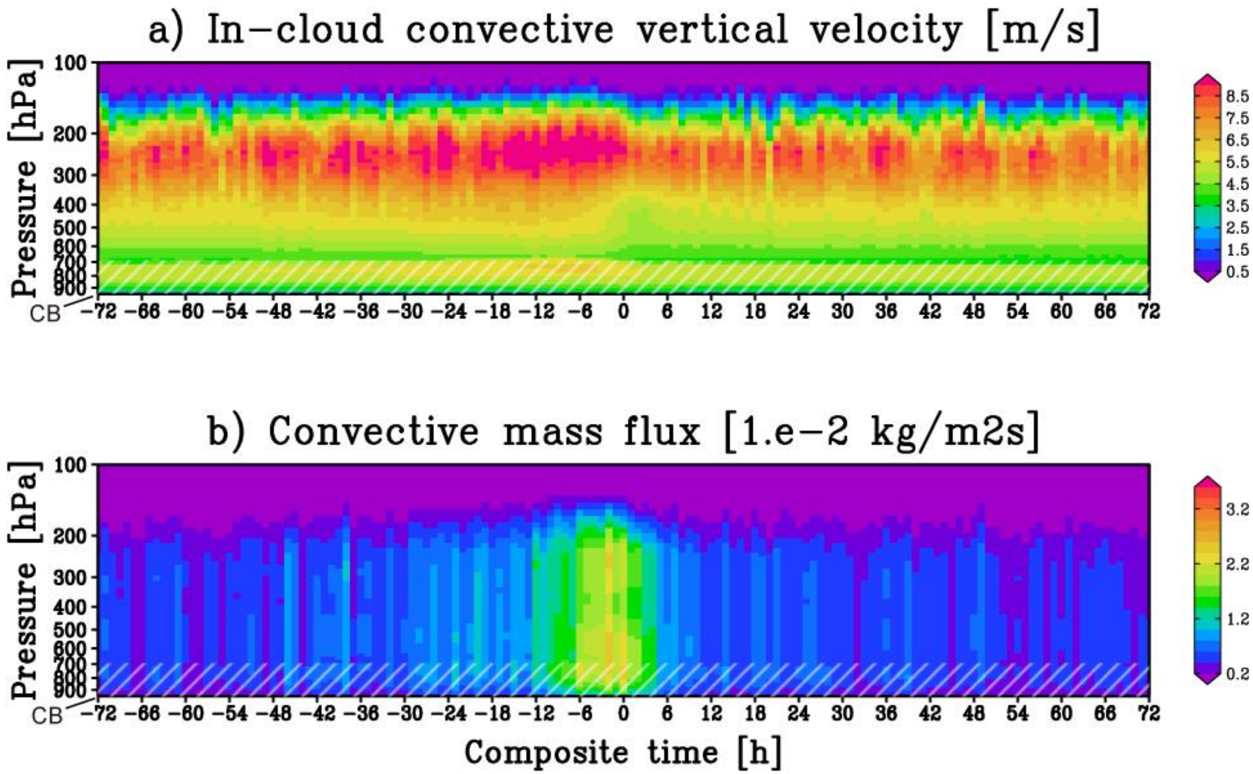
nearly invariant over time





Convective intensity: $$\overline{\hat{w}_c} = \frac{1}{A_w} \sum_{\in A_w} \hat{w}_c,$$

Composite time series of w_c and M_c



w_c
nearly invariant over time

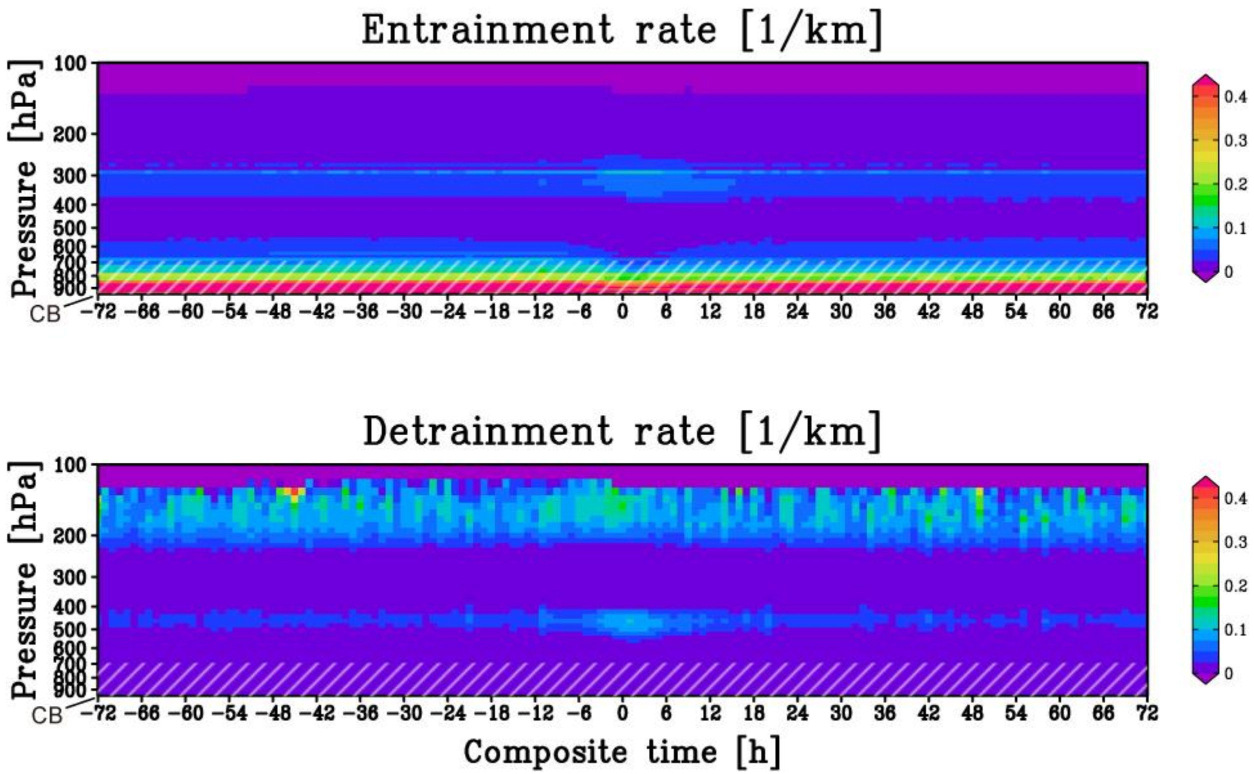
M_c
largely varies over time

Convective mass flux: $\overline{M_c} = \frac{1}{A_0} \sum_{\in A_w} \rho \hat{w}_c,$

Composite time series of ε and δ

$\boldsymbol{\varepsilon}$
largest near cloud base

$\boldsymbol{\delta}$
consistent near tropopause



Entrainment and detrainment rates:

$$\frac{1}{\rho w_c}\frac{\partial(\rho w_c)}{\partial z} = \epsilon - \delta,$$

Dataset available for the PROES community

- Composite time series of …
  - AIRS T and q
  - CloudSat (w CALIPSO) cloud cover
  - CloudSat/CAPLISO radiative flux and heating rate
  - Large-scale mean vertical velocity
  - Convective vertical velocity and mass flux
  - Entrainment/detrainment rate (and mass flux)
  - P, E, u_{10}, etc.

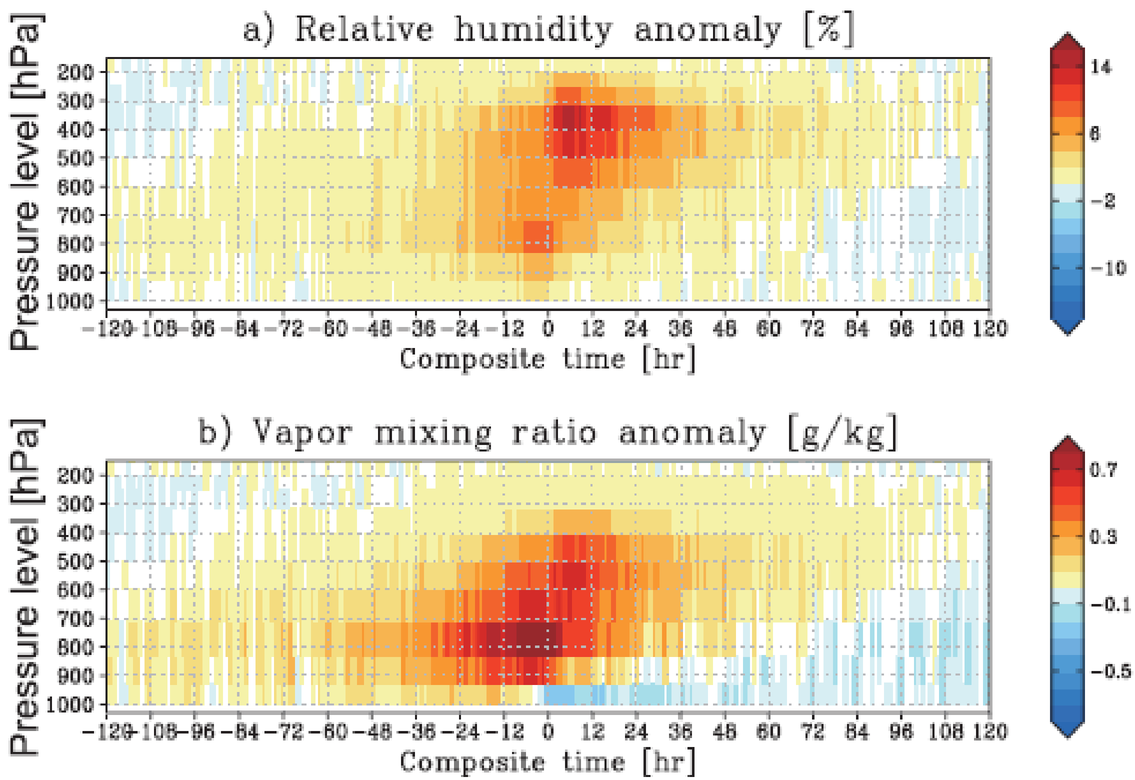
Backup slides

Analysis design

- Target region and period
  - Global tropical oceans (15°S-15°N)
  - 7 years from Dec. 1, 2002-Nov. 30, 2009
    - except for CloudSat with the beginning date of Jul. 1, 2006.
- Satellite instruments

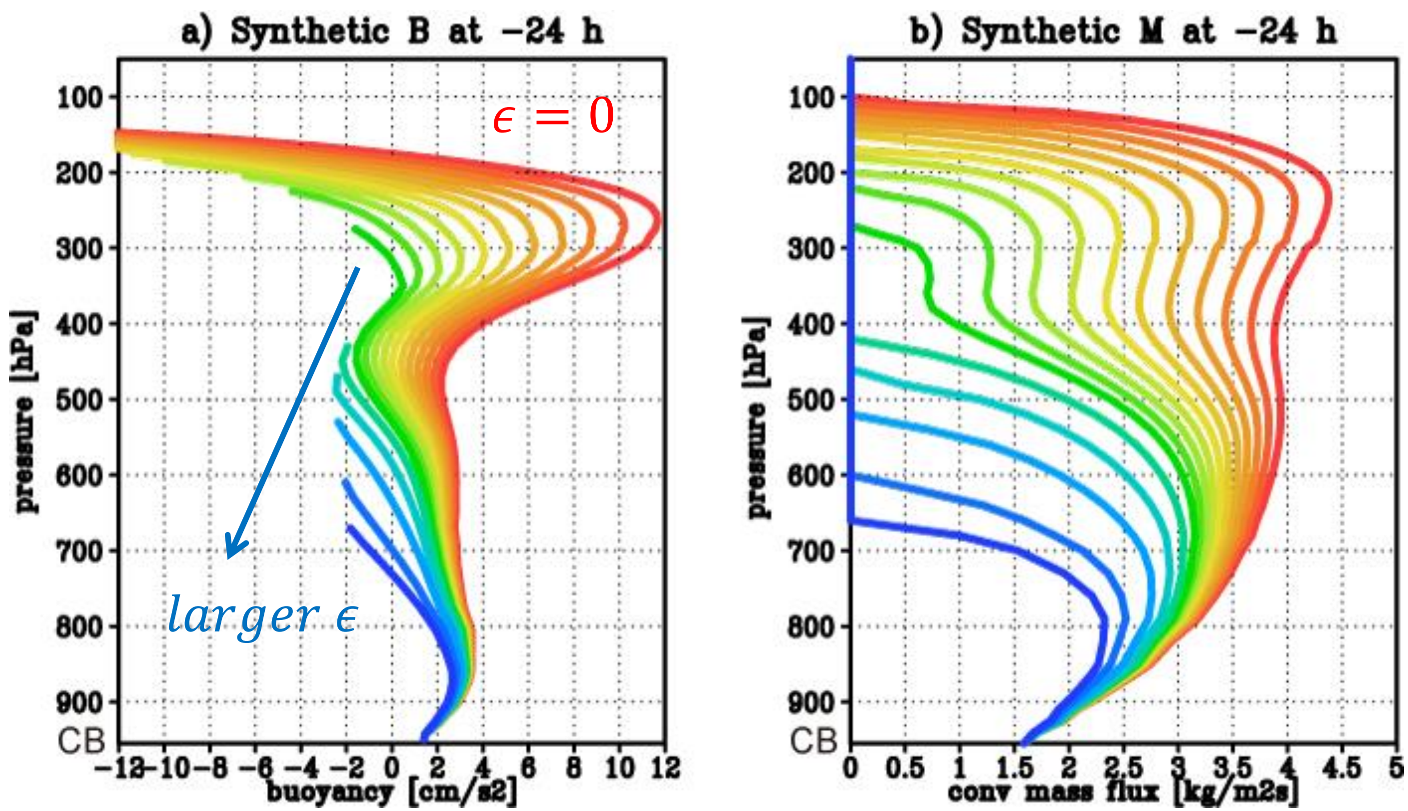
Satellite	Instruments	Local time of obs.	Parameters to be derived
TRMM	PR	Variable	Convection
Aqua	AIRS/AMSU	1:30 am/pm	$T(p)$ and $q(p)$
Aqua	AMSR-E	1.30 am/pm	CWV and P
CloudSat	CPR	1:30 am/pm	$\sigma_c(z)$
QuikSCAT	SeaWinds	6:00 am/pm	$\mathbf{u}_{10}$

Relative humidity versus vapor mixing ratio



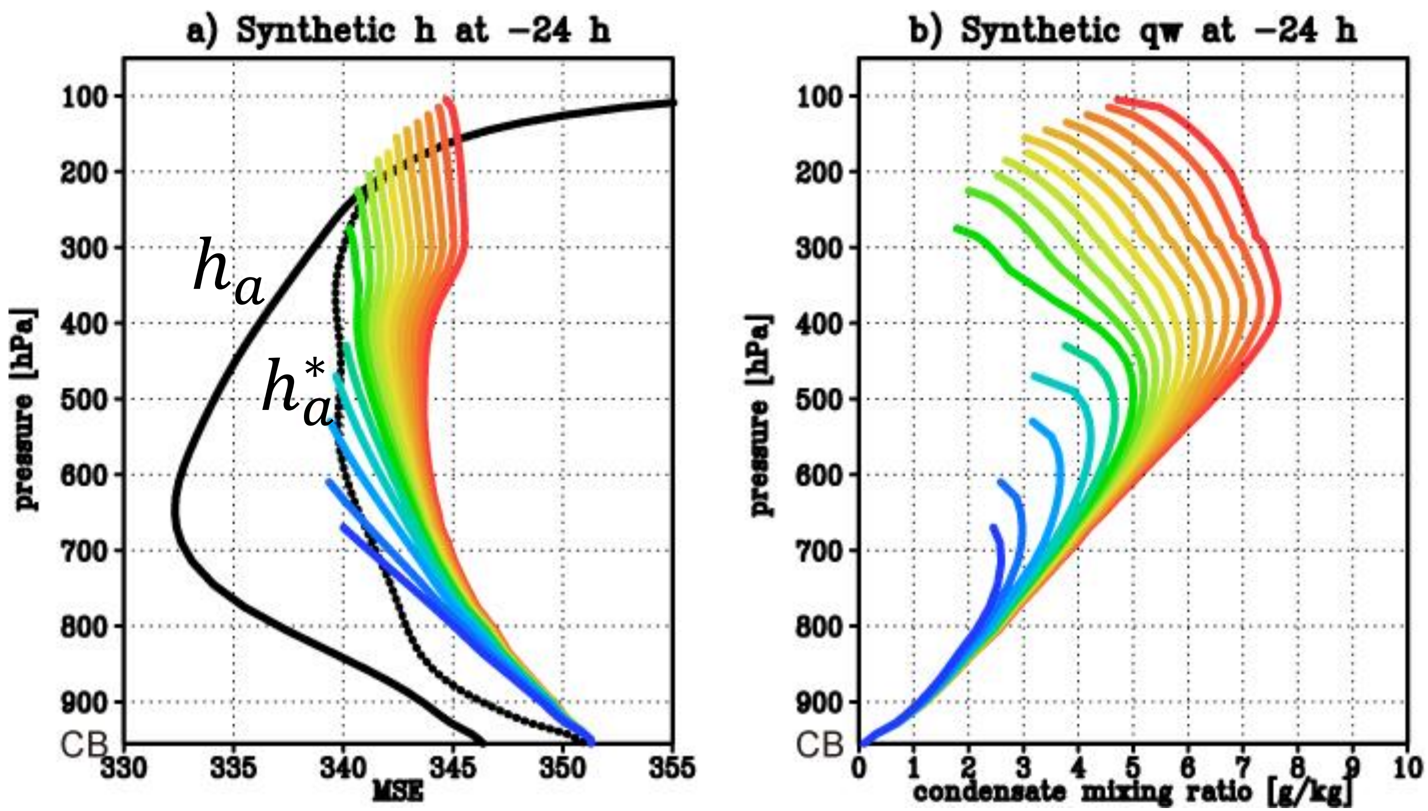
Plume model solutions

- Simulated buoyancy (actual) and M_c profiles



Plume model solutions

- Simulated h_c (with h_a and h_a^*) and q_w profiles



Plume model solutions

- Simulated ϵ and δ profiles (incl. dynamic comp.)