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The Ups and Downs of Tropical Updrafts and Downdrafts

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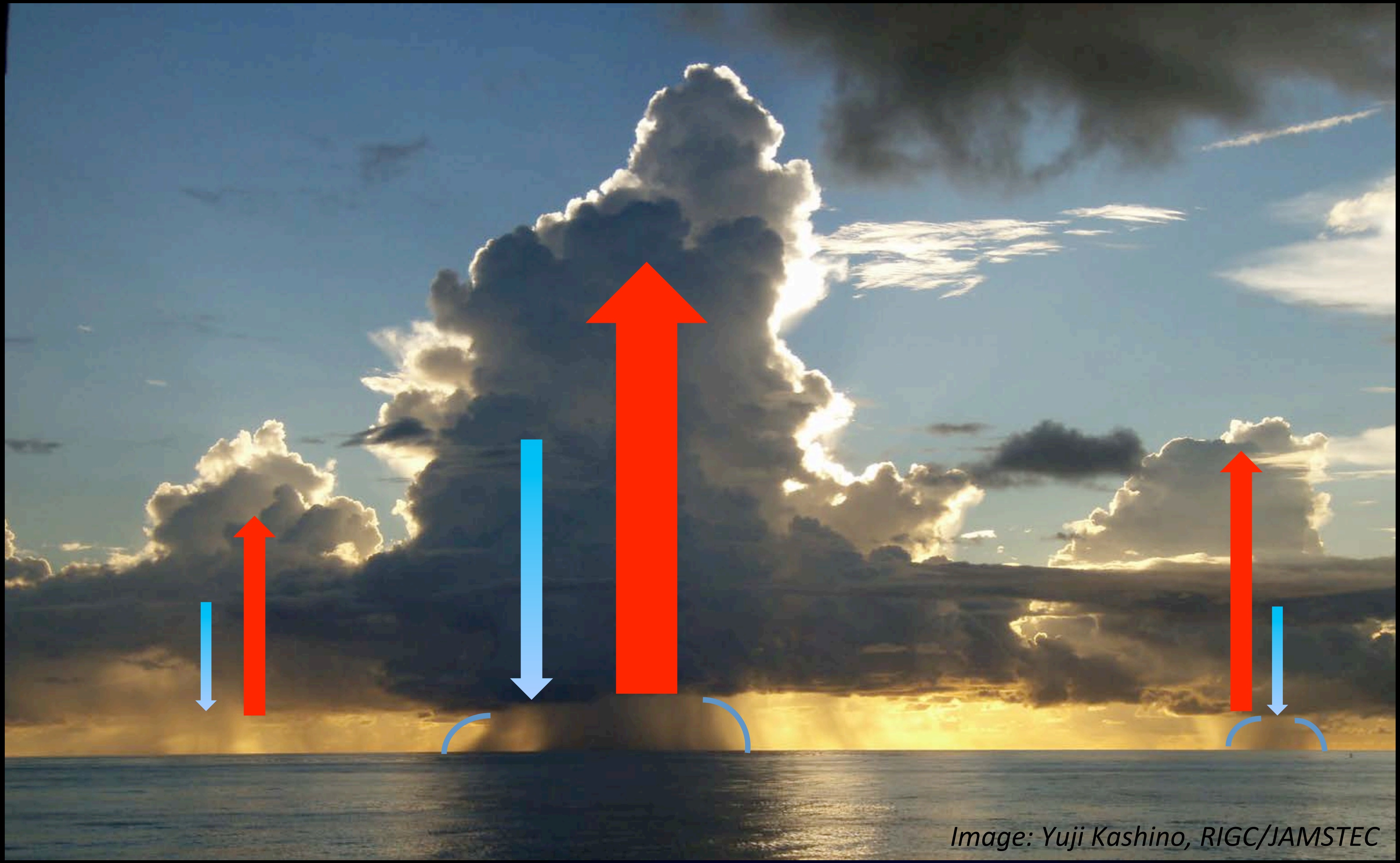
Image: *Yuji Kashino, RIGC/JAMSTEC*

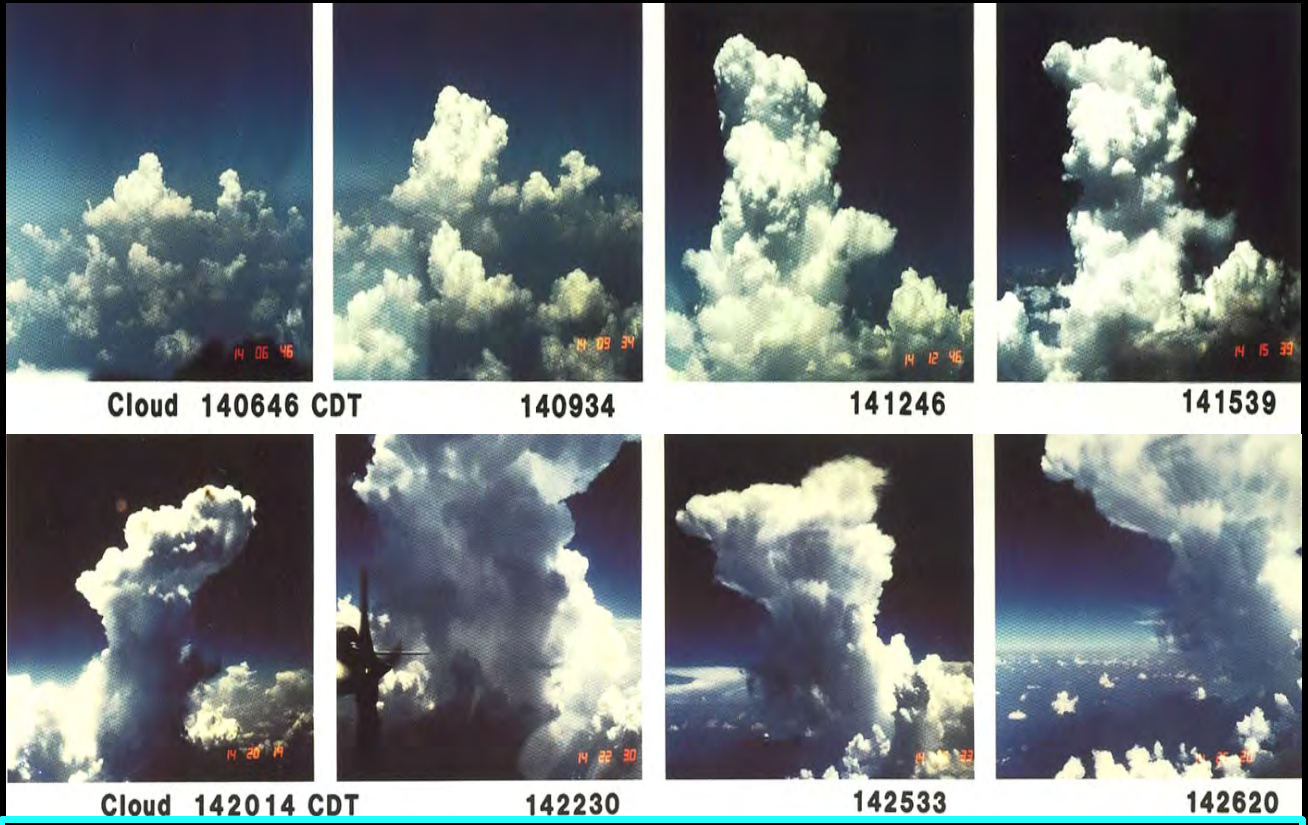
FOCUS: (1) Updrafts, Downdrafts and (2) Cold Pools



1. What do we not know
2. Modeling challenges
3. Useful observables and associated platforms

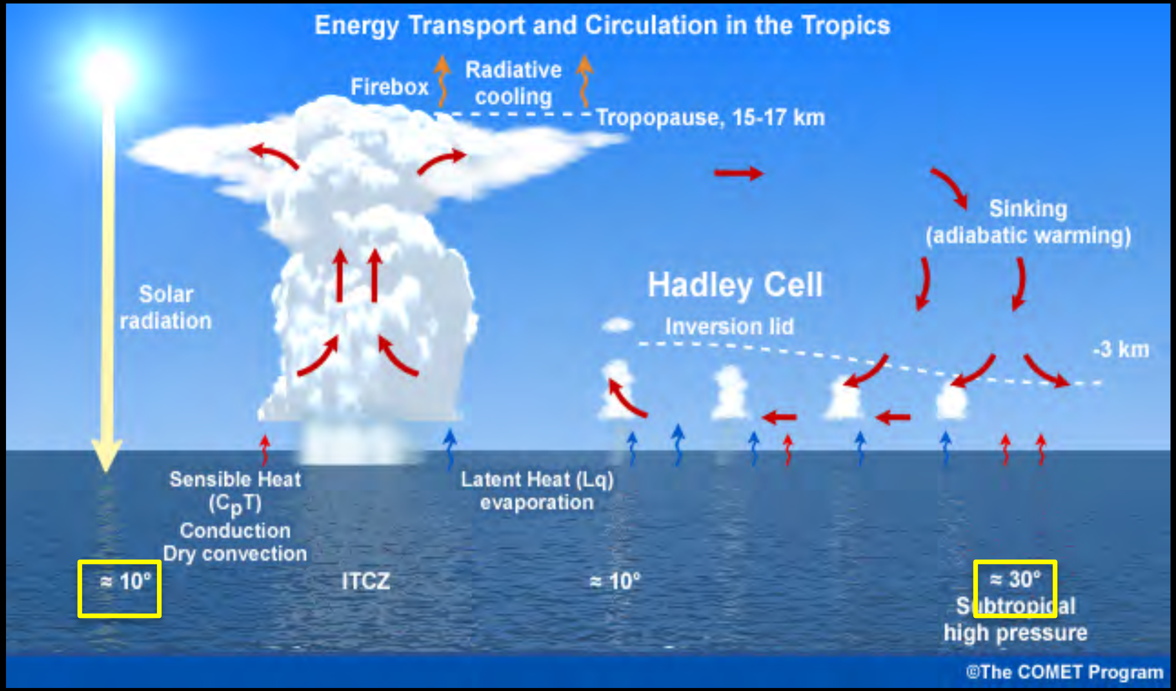
1.1 Updrafts and Downdrafts – What we Don't Know

(1) Transport of water, air, energy, aerosols



- How does CMF vary as a function of environment (CAPE, shear, SST, RH)?

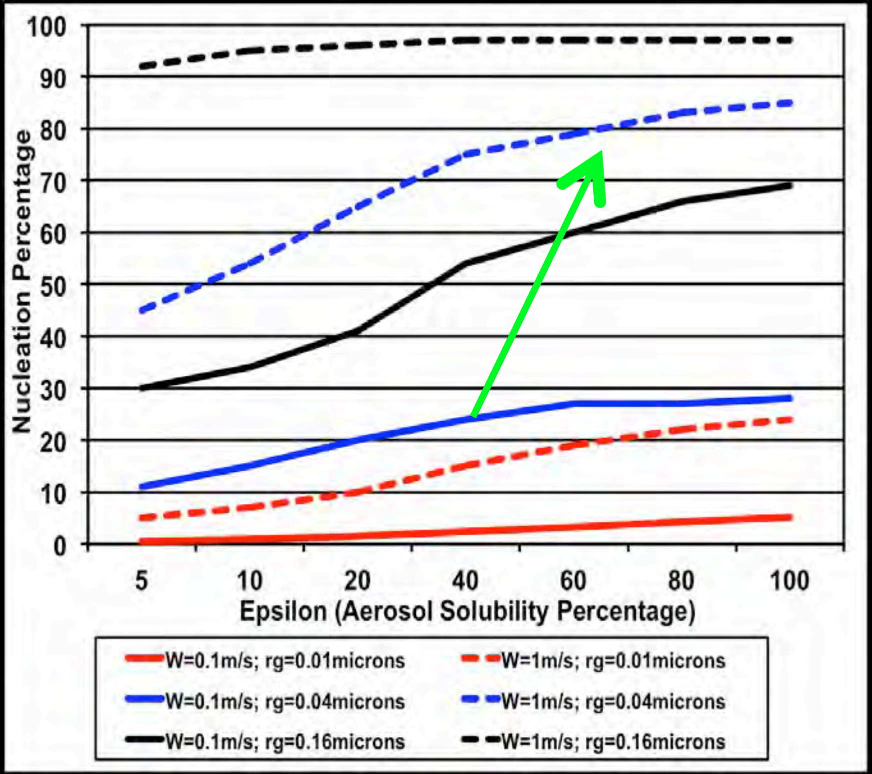
(2) Large-scale circulation



- How are climate-induced changes to deep CMF impact the large-scale circulation?

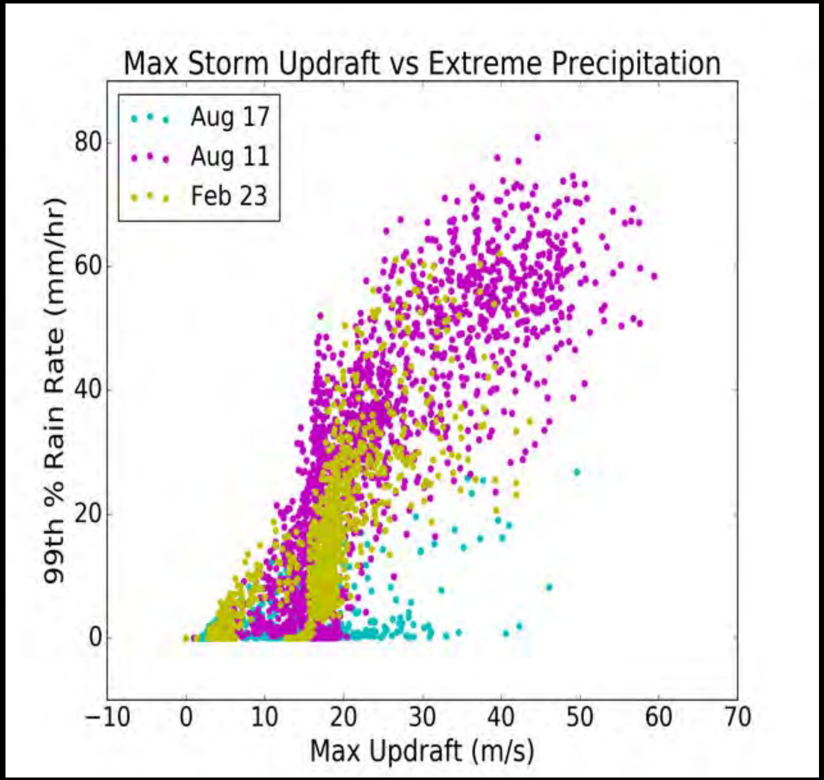
1.1 Updrafts and Downdrafts – What we Don't Know

(3) Supersaturation and activation



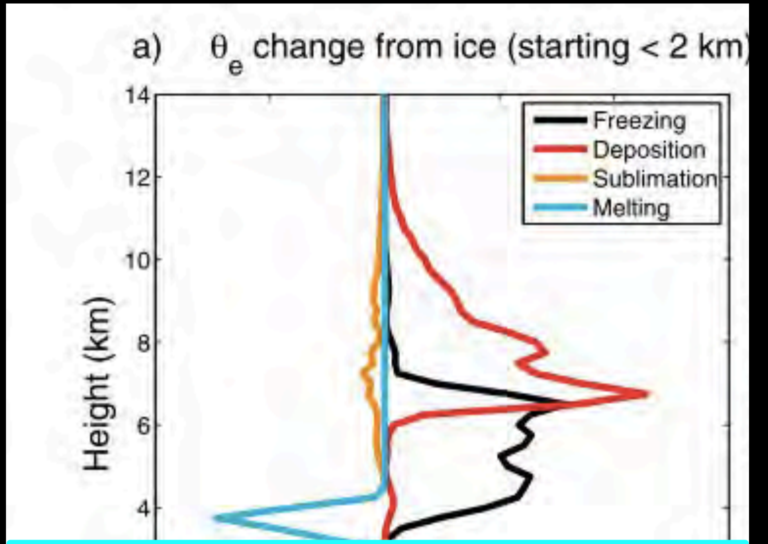
- What supersaturations are achieved in deep trop convection?

(4) Precipitation rates



- What controls the relationship between storm updrafts and extreme precipitation?

(5) Latent heating feedbacks

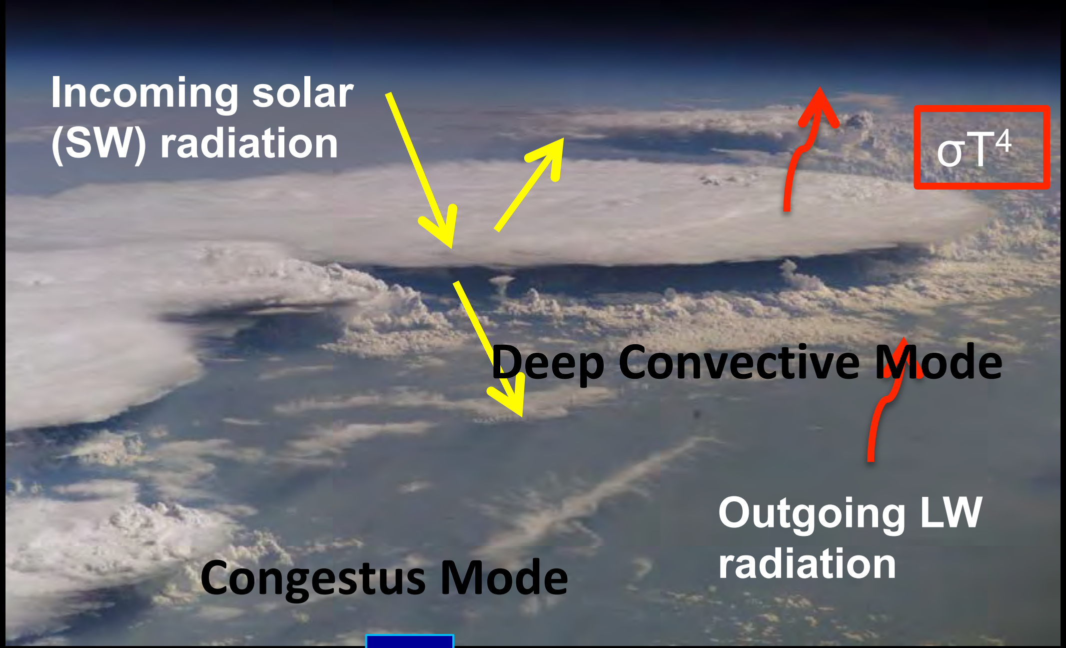


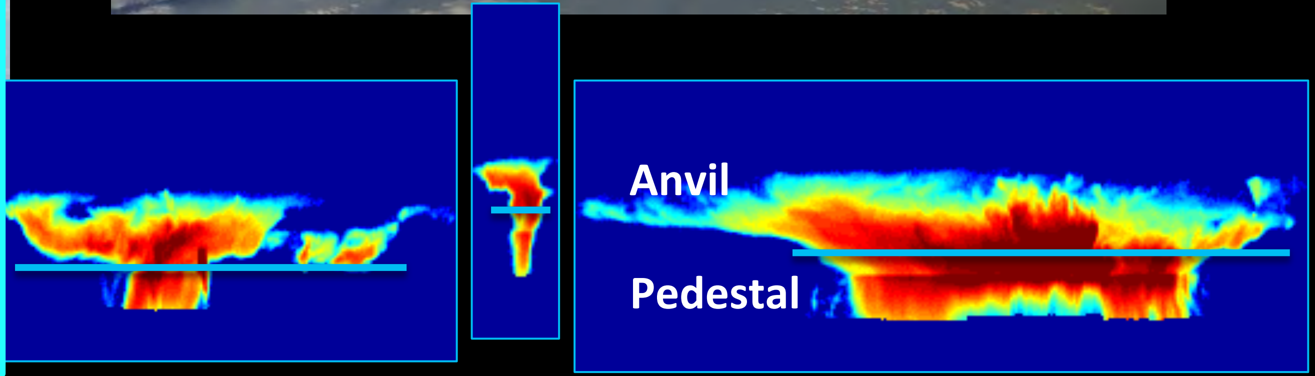
- How are ice processes, latent heating and vertical velocity related, and how does vary with ice species?

1.1 Updrafts and Downdrafts – What we Don't Know

(6) Vertical and horizontal cloud location and extent

- What is the relationship between convective anvils and pedestals?
- How is this relationship impacted by environmental variables (CAPE, shear, RH, SSTs, aerosols)?

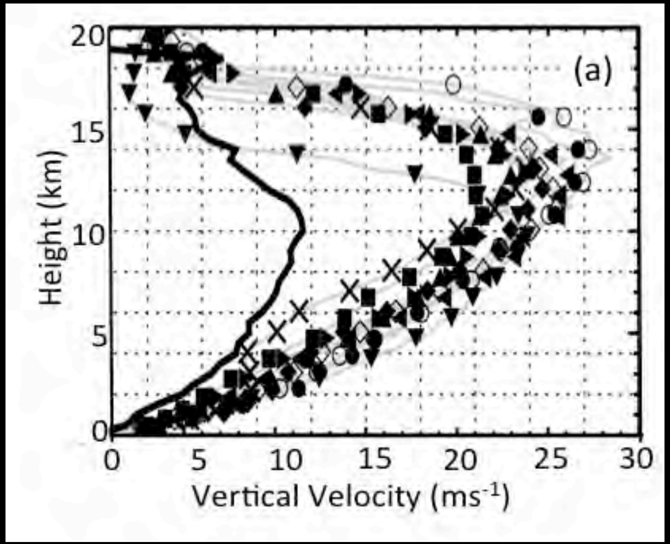




van den Heever et al., CLIVAR Convection Air-Sea Interaction Workshop, Boulder, CO, 2019

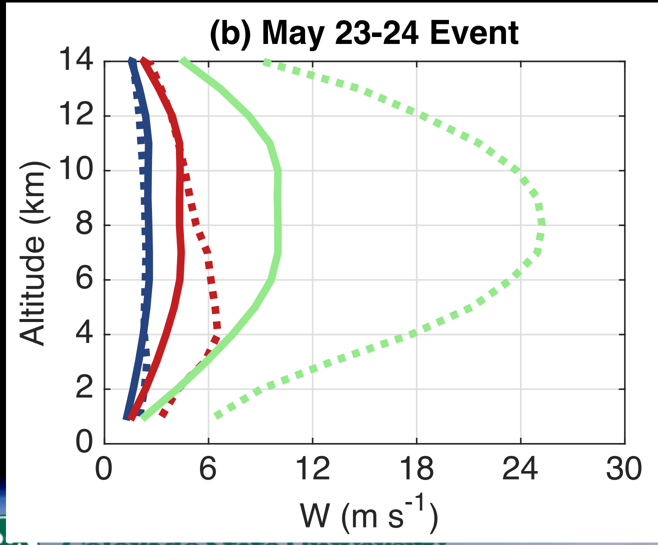
1.2 Modeling Updrafts and Downdrafts

Tropical Convection

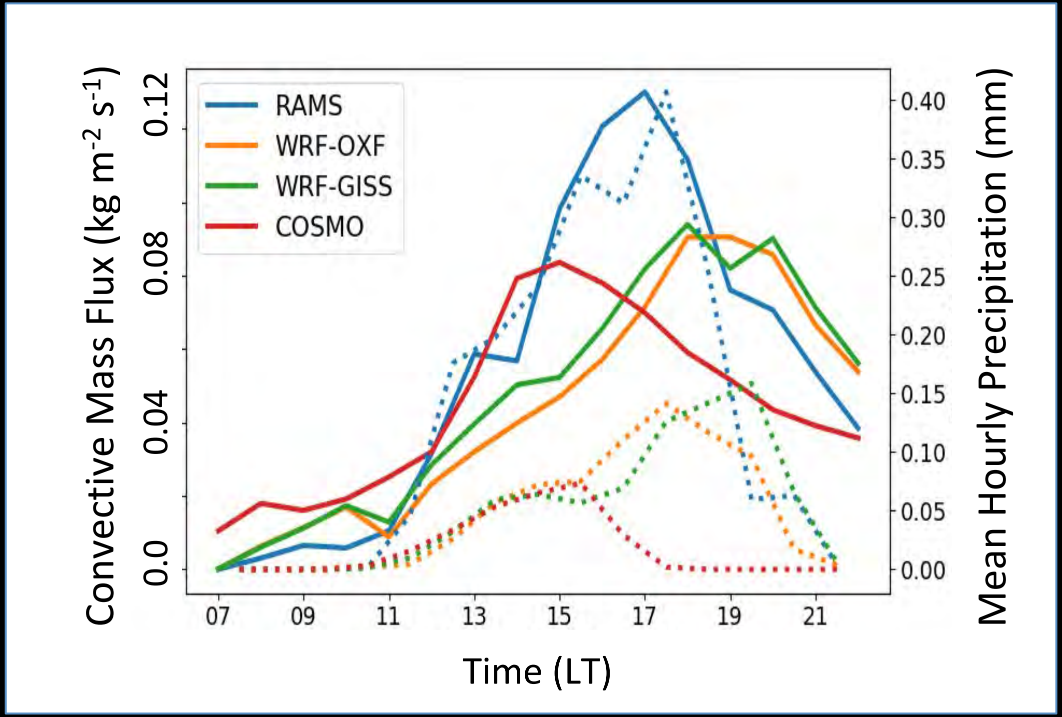


CRMs (symbols) compared with radar (solid curve) (after Varble et al 2014).

Midlatitude Squall Lines (MC3E)

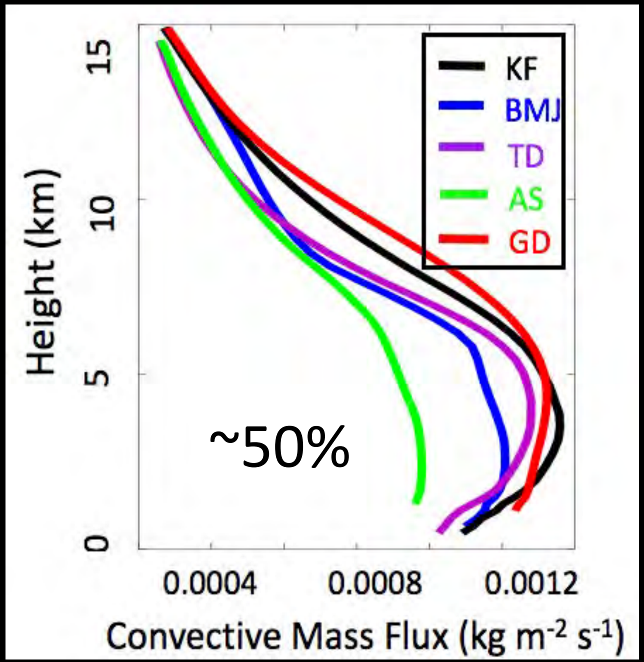


CRMs (dotted) compared with radar (solid curve) (after Marinescu et al 2016).



ACPC Inter-model Comparison Study: state-of-the-art CRMs produce significant differences in CMF and associated precipitation rates (after van den Heever et al 2019)

IMPLICIT → Cu Parameterizations

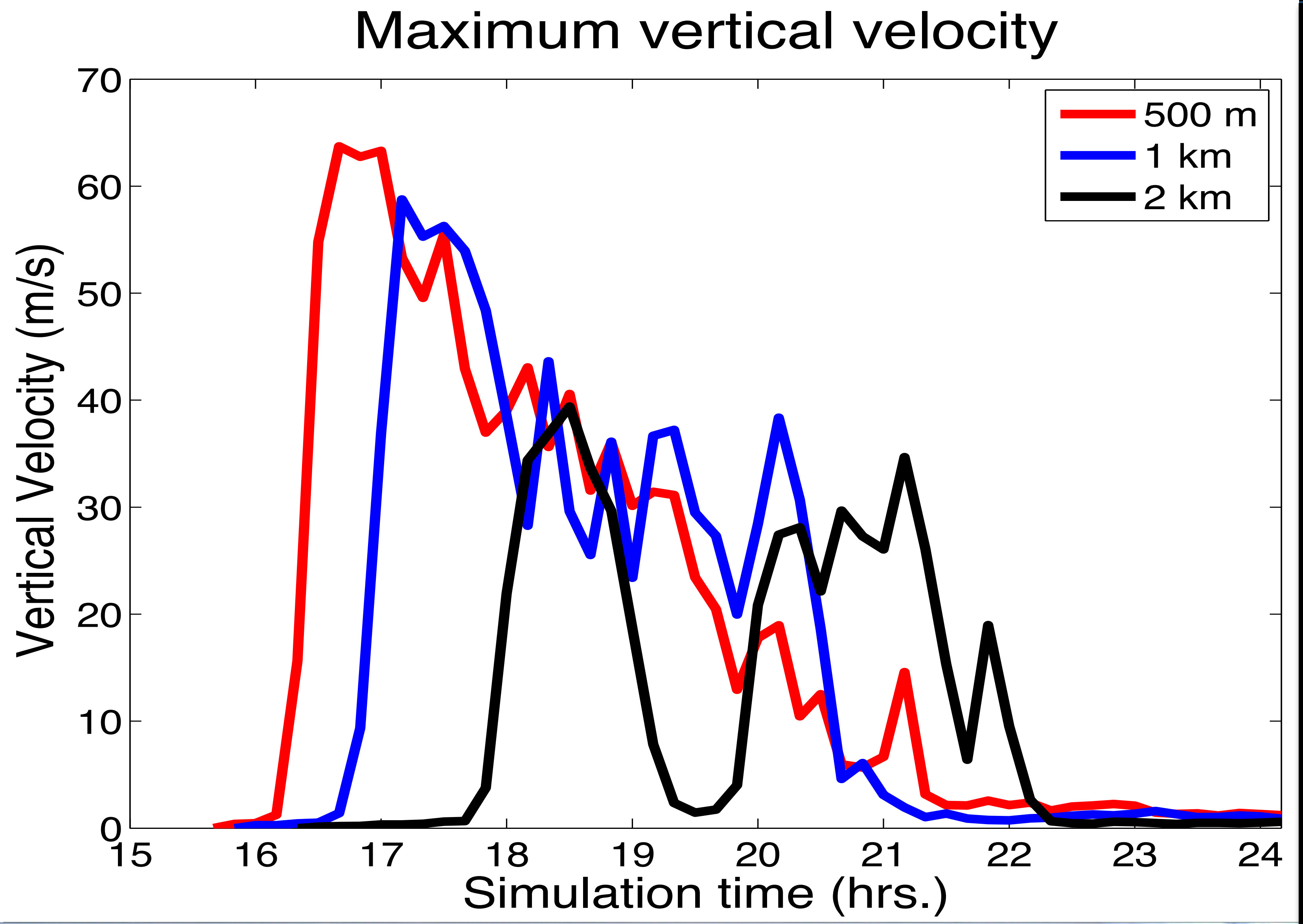


CMF from a simulation of the same convective storms using the same model (WRF) but different convective paramerizations

1.2 Modeling Updrafts and Downdrafts

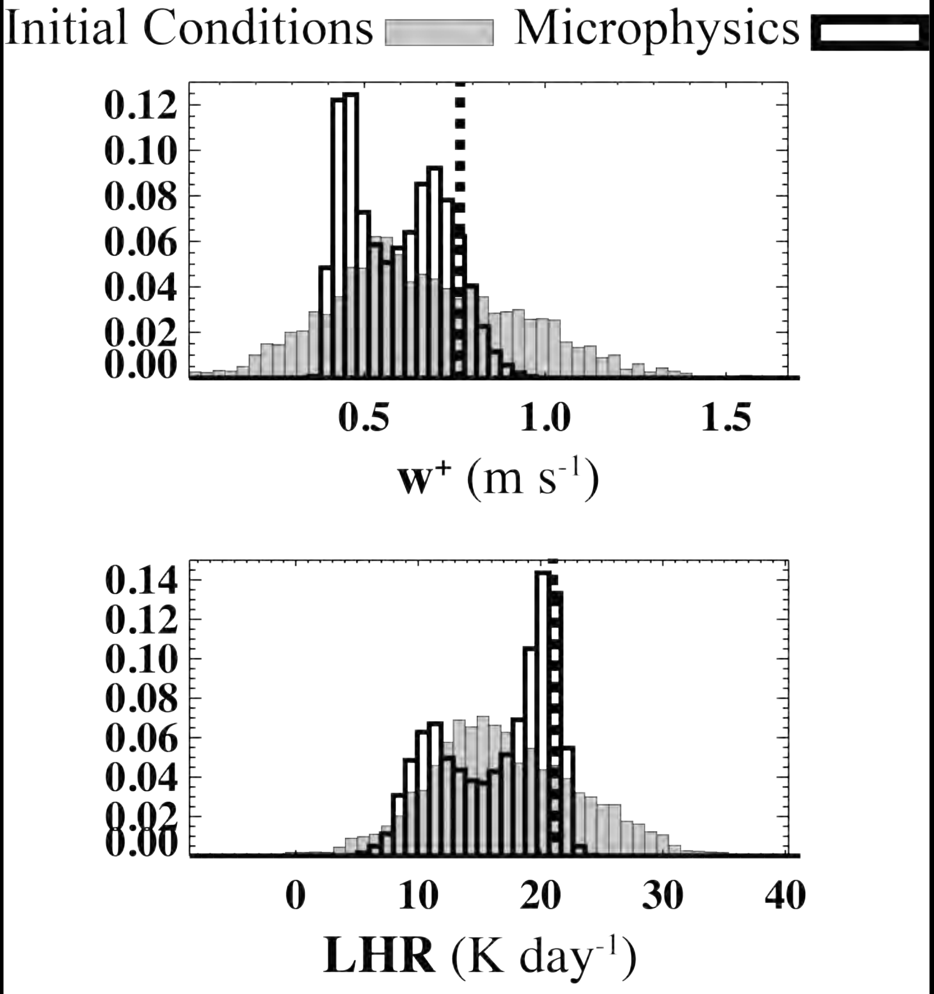
Challenges when modeling vertical motion:

- Numerous processes, phase changes and feedbacks → parameterization of process rates
- Grid spacing



(after McGee and van den Heever 2015)

1.2 Modeling Updrafts and Downdrafts - Challenges in Representing Vertical Motion



Convective ensemble generated via perturbations to initial conditions and microphysical parameters exhibits quite large variability in transport and heating (Posselt et al. 2019)

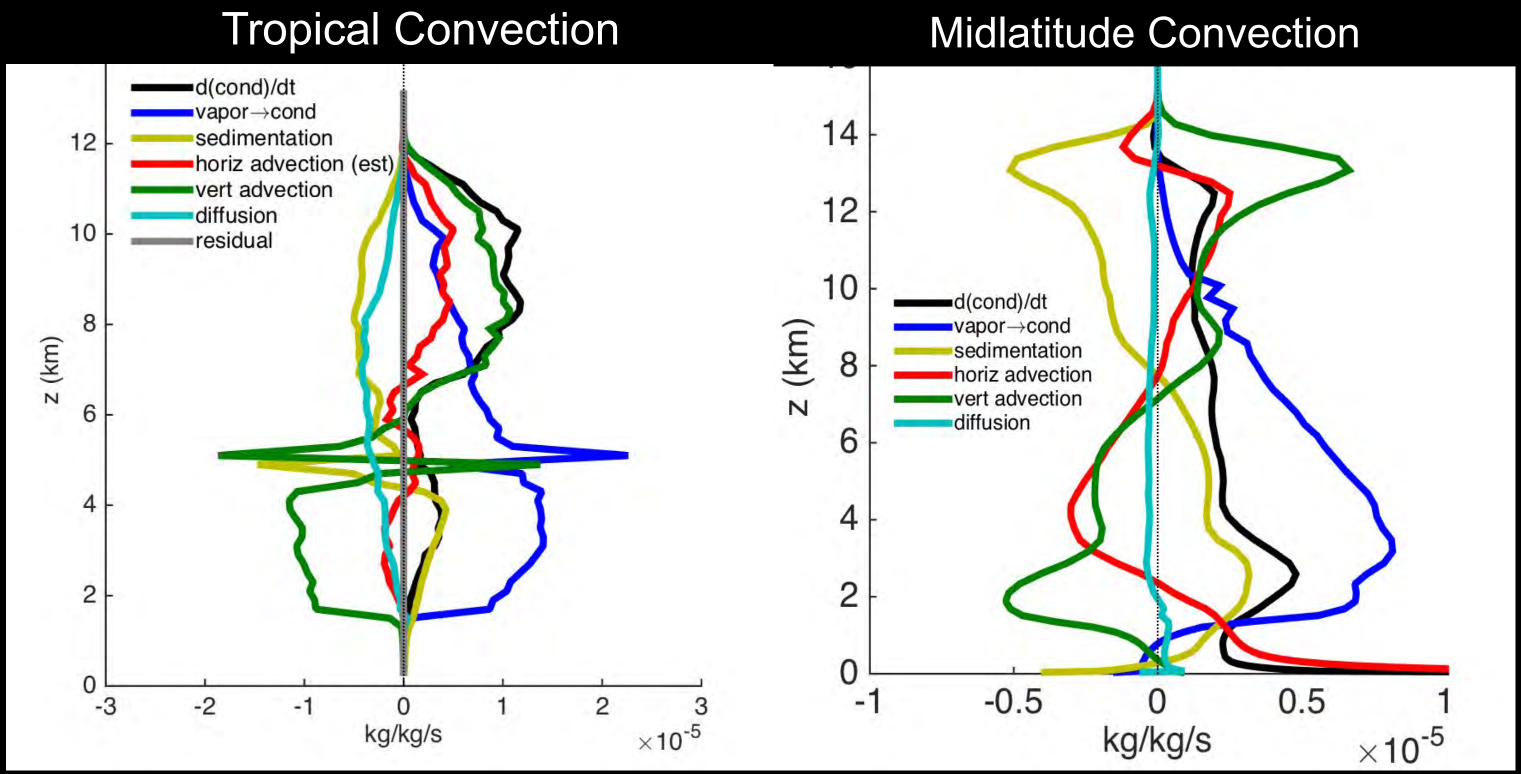
Histograms of upward of mean (averaged over space and time) upper-tropospheric (8-16 km) upward vertical velocity (m s^{-1}) and (bottom panel) latent release (K day^{-1}) for the mature phase of a tropical squall line as a function of microphysical parameter perturbations (unfilled), initial conditions (gray filled) and the control simulation (dotted black line) (after Posselt et al 2019)

1.2 Modeling Updrafts and Downdrafts - Potential Sources of Error in Simulating W

$$\frac{\partial w}{\partial t} = -\vec{V}\cdot\vec{\nabla}w - \frac{1}{\rho}\frac{\partial p}{\partial z} + B + D$$

$$B = g\frac{\theta'_\rho}{\theta_{\rho 0}} \approx g\left(\frac{\theta'}{\theta_0} + 0.61r_v - r_c\right)$$

$$\frac{\partial r_c}{\partial t} = -\vec{U}_h\cdot\vec{\nabla}_h r_c - [w - v_t]\frac{\partial r_c}{\partial z} + M + D$$



Contributions of different terms in condensate equation to time changes in condensate mixing ratio in simulations of different convective storms. Budget terms are analyzed over grid points with w > 1 m s^{-1} for both cases (van den Heever et al 2018)

1.3 Updraft and Downdraft Observables

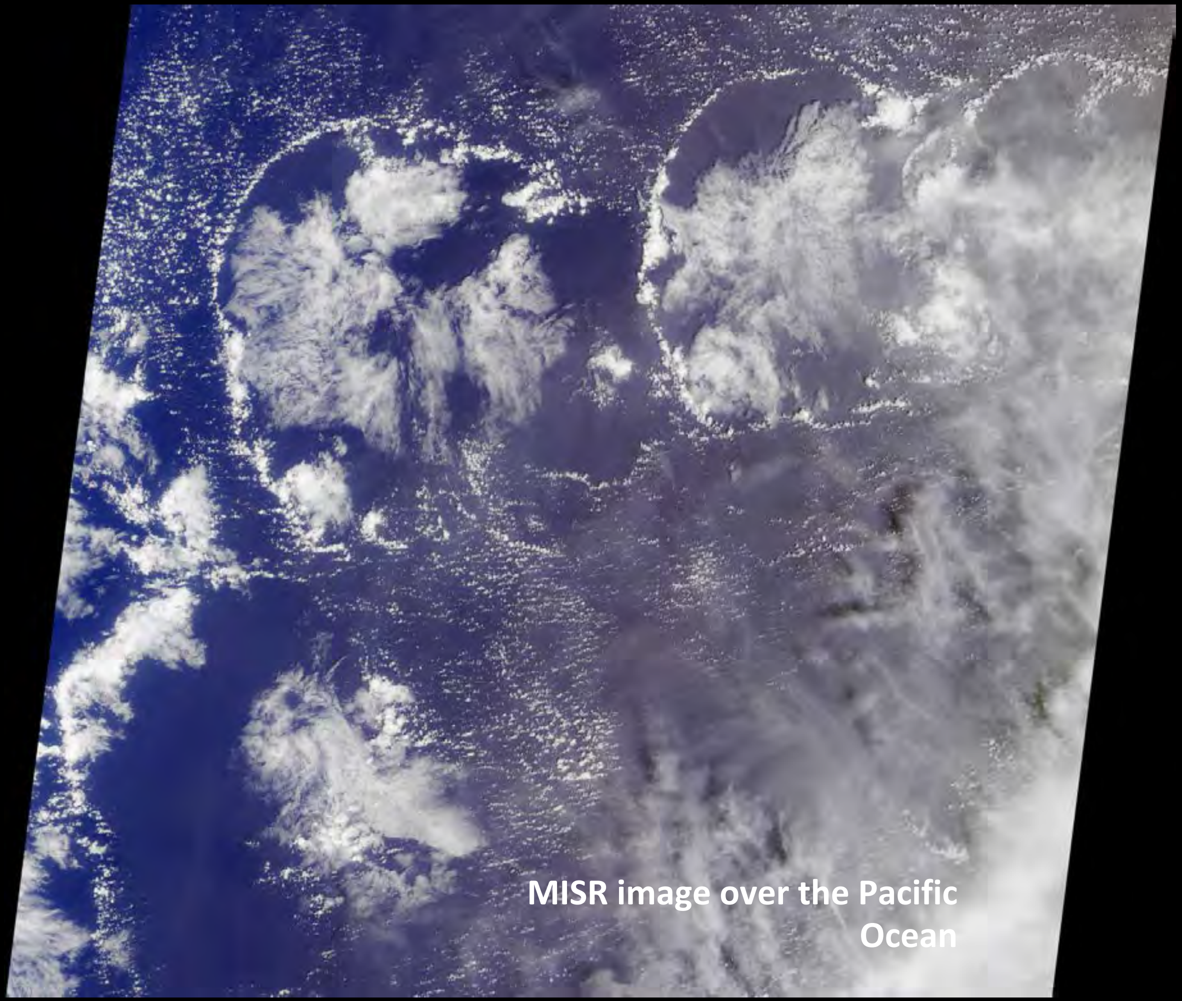
We need:

- Co-located vertical velocities and microphysical process information (including supersaturation)
  - as a function of environmental variables (CAPE, shear, RH, SST, aerosols), storm life cycle and diurnal cycle
  - globally

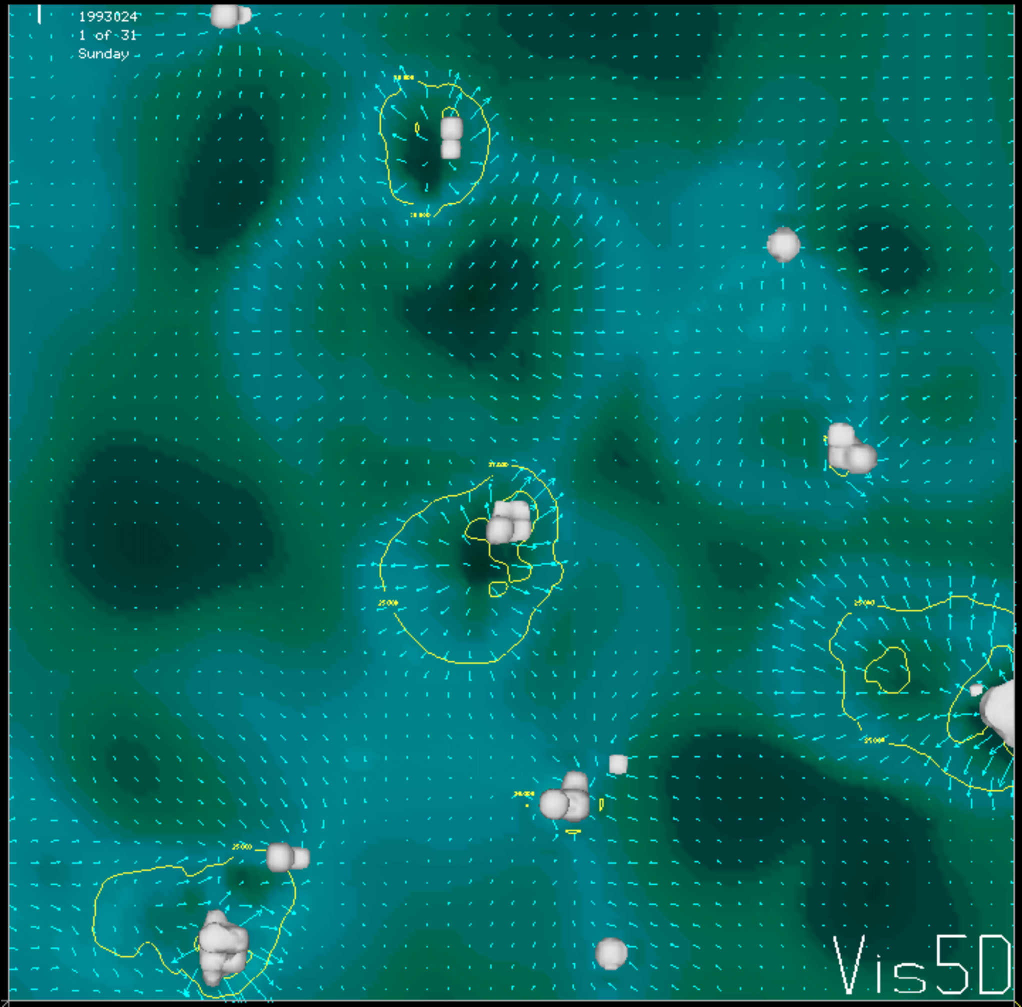
1. Numerous long-term field campaigns in a range of environments
   → start – measure – repeat
2. Satellite based platforms

   → Implementation of NAS DS (A-CCP)

2. Cold Pools



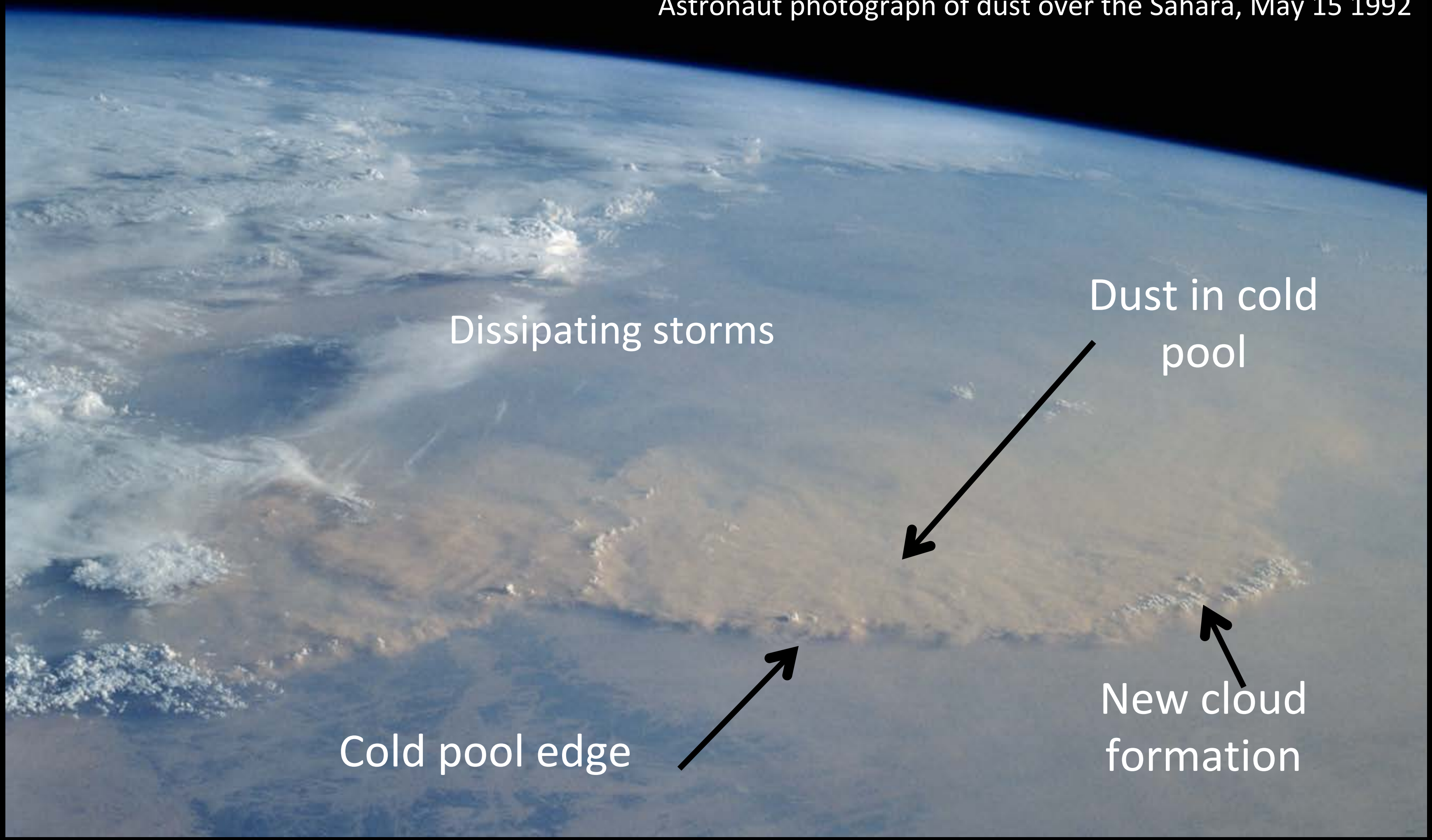
MISR image over the Pacific Ocean



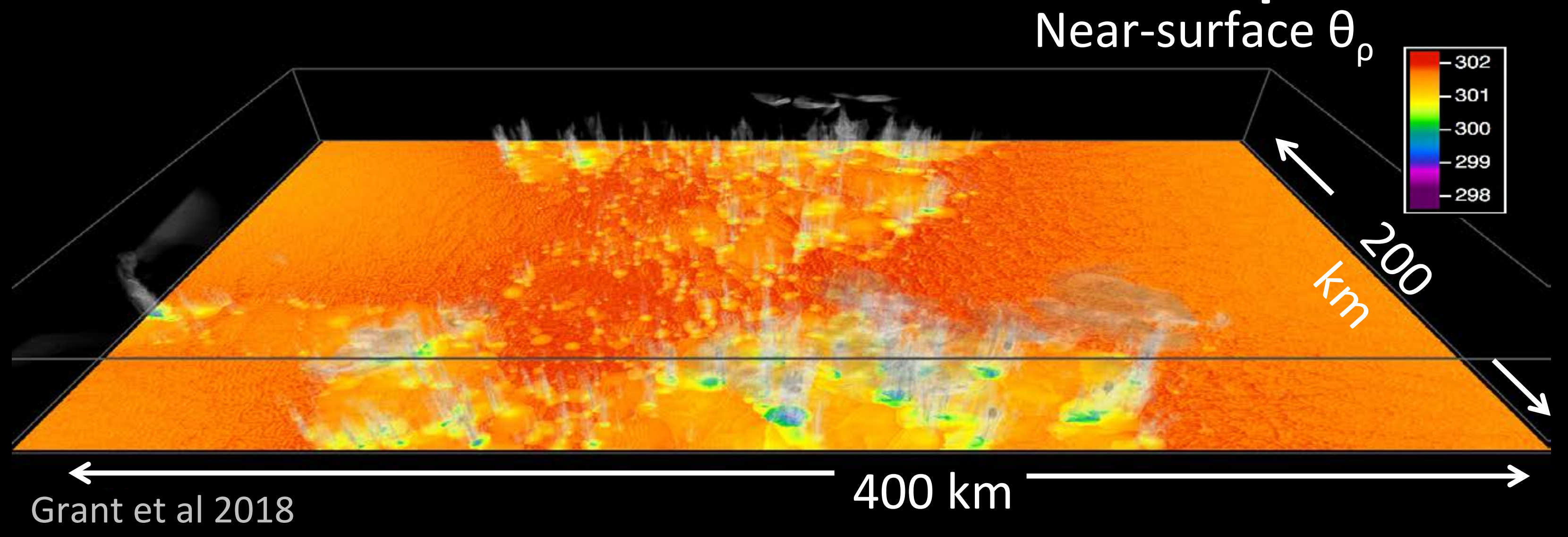
2.1 Role of Cold Pools in Tropical Convection

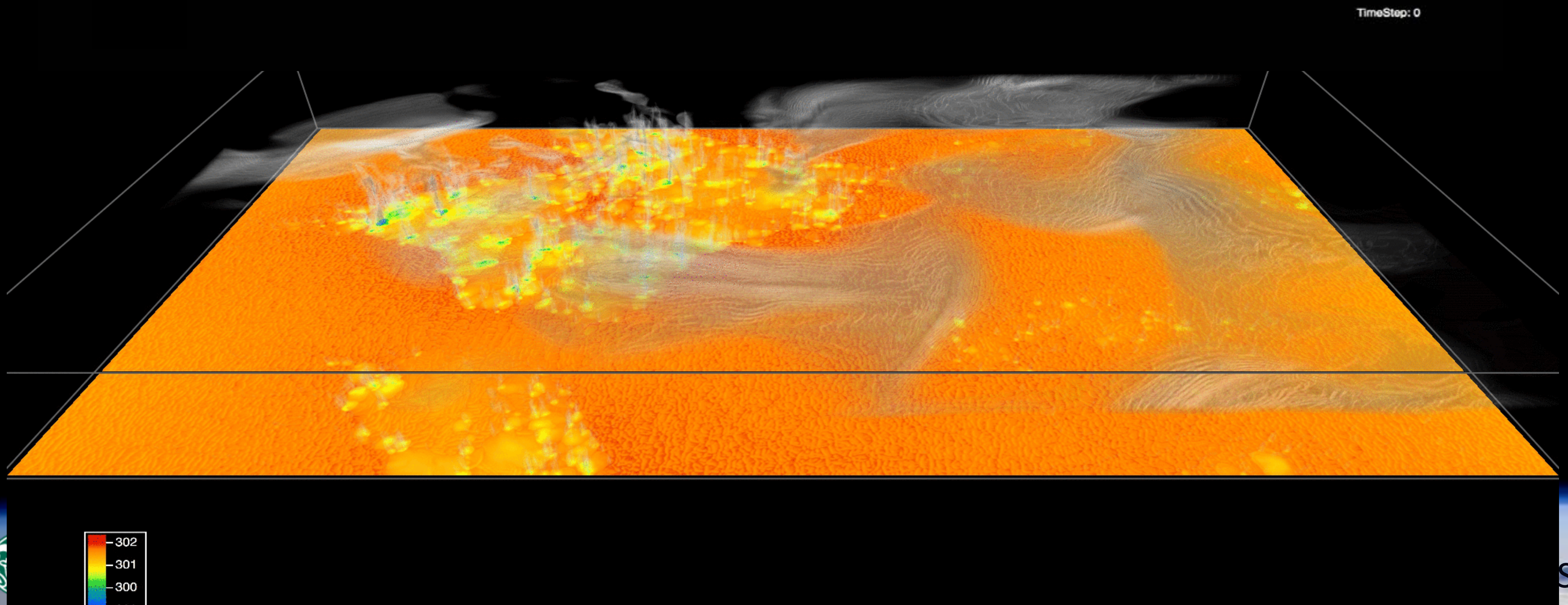
- Storm
  - initiation
  - intensity
  - maintenance
  - Propagation
- Dust transport
- Parameterizations

Astronaut photograph of dust over the Sahara, May 15 1992



2.1 Role of Cold Pools in Tropical Maritime Systems



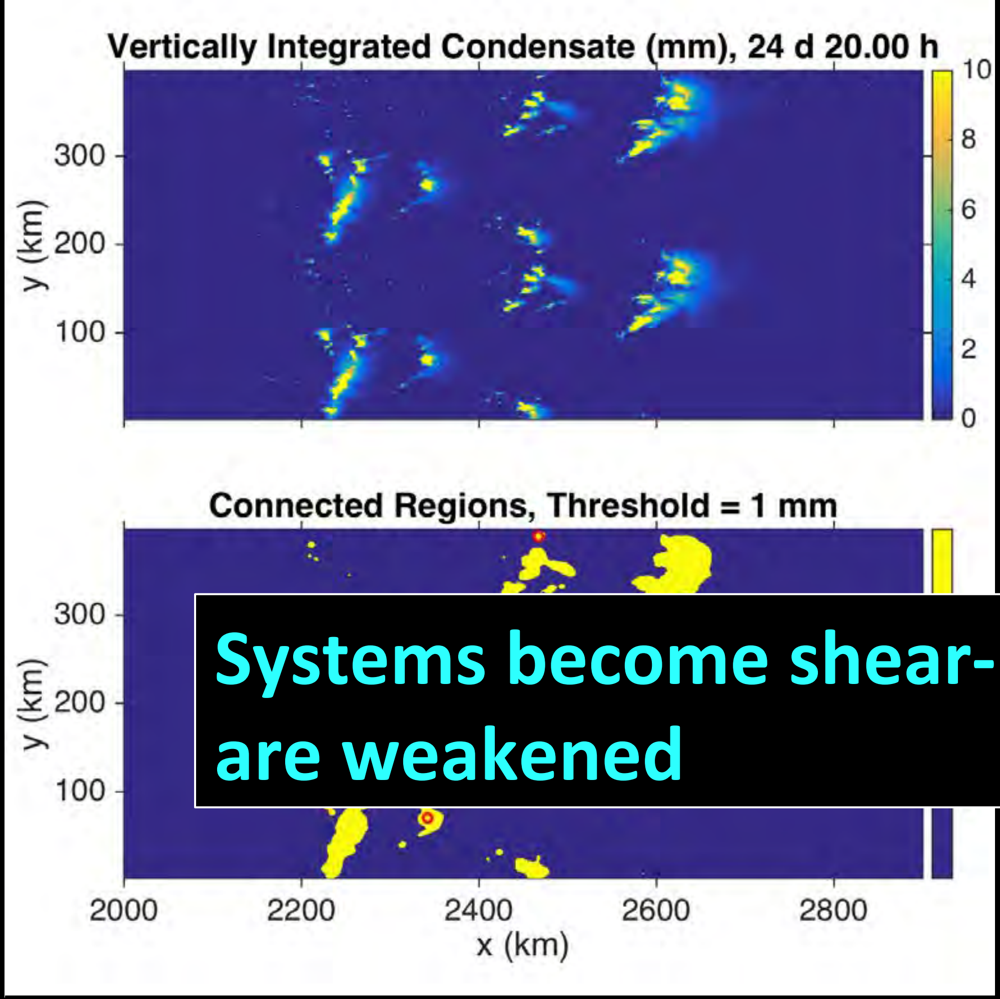


- Idealized RCE experiments
- A dynamically self-consistent framework to study physics of idealized tropical convective systems with realistic properties
- Linear system
- Cluster system

2.1 Role of Cold Pools in Tropical Maritime Convection

- weaken cold pools under Sheared Environments

shear →



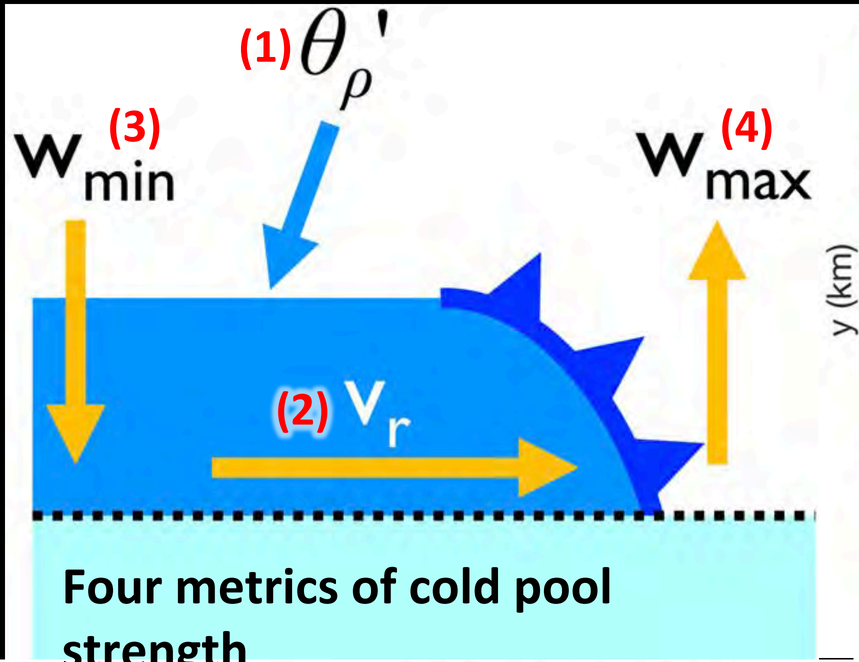
Systems become shear-parallel as cold pools are weakened

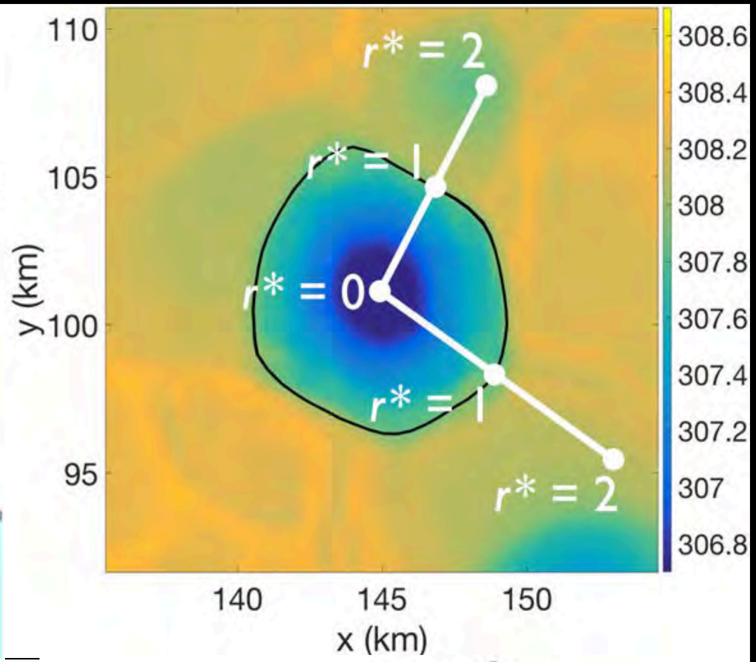
U10_CONTROL

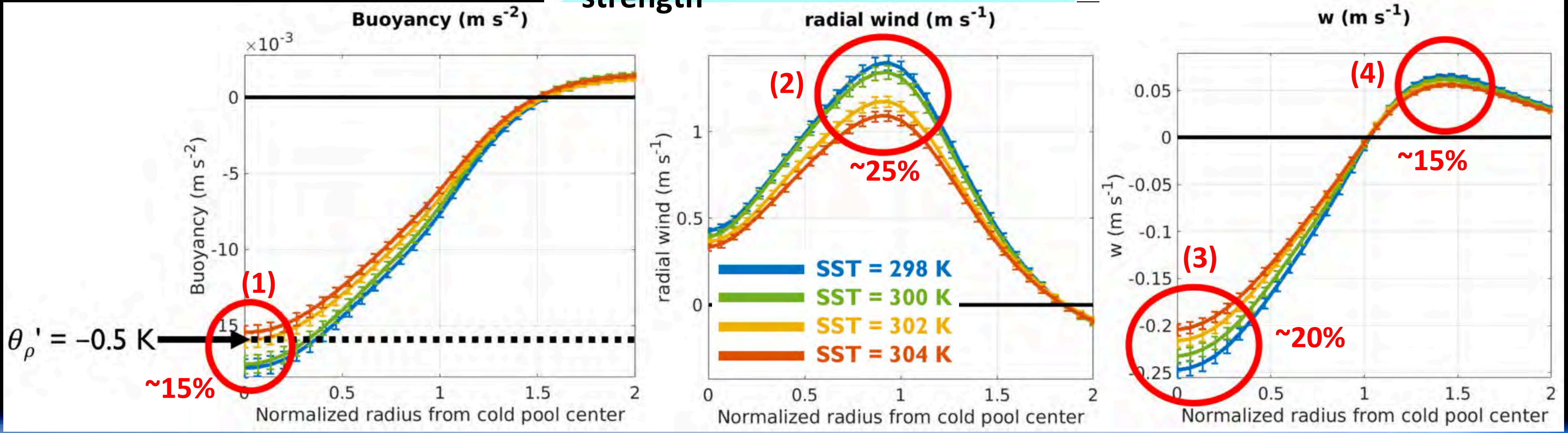
(after Grant et al 2019)

Surface Flux Impacts on CPs

Models suggest that as SST increases from 298 K to 304 K, cold pools become ~15-25% weaker.

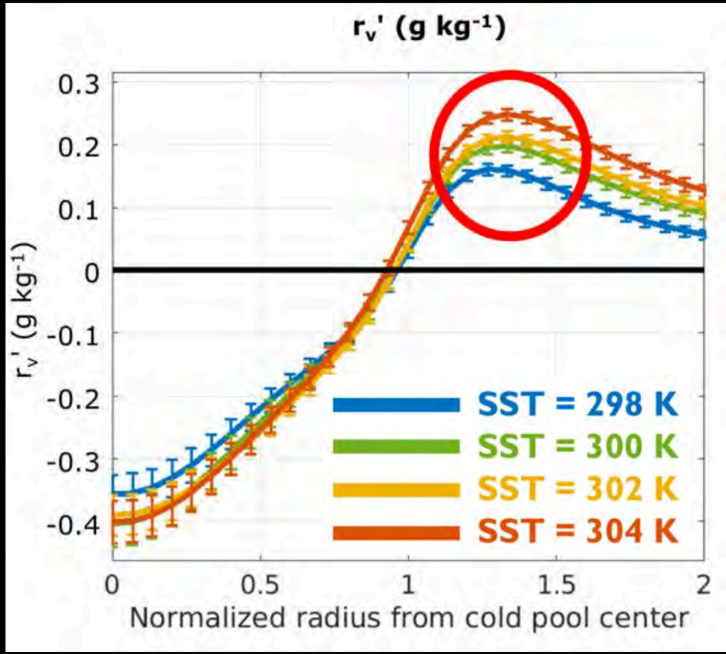


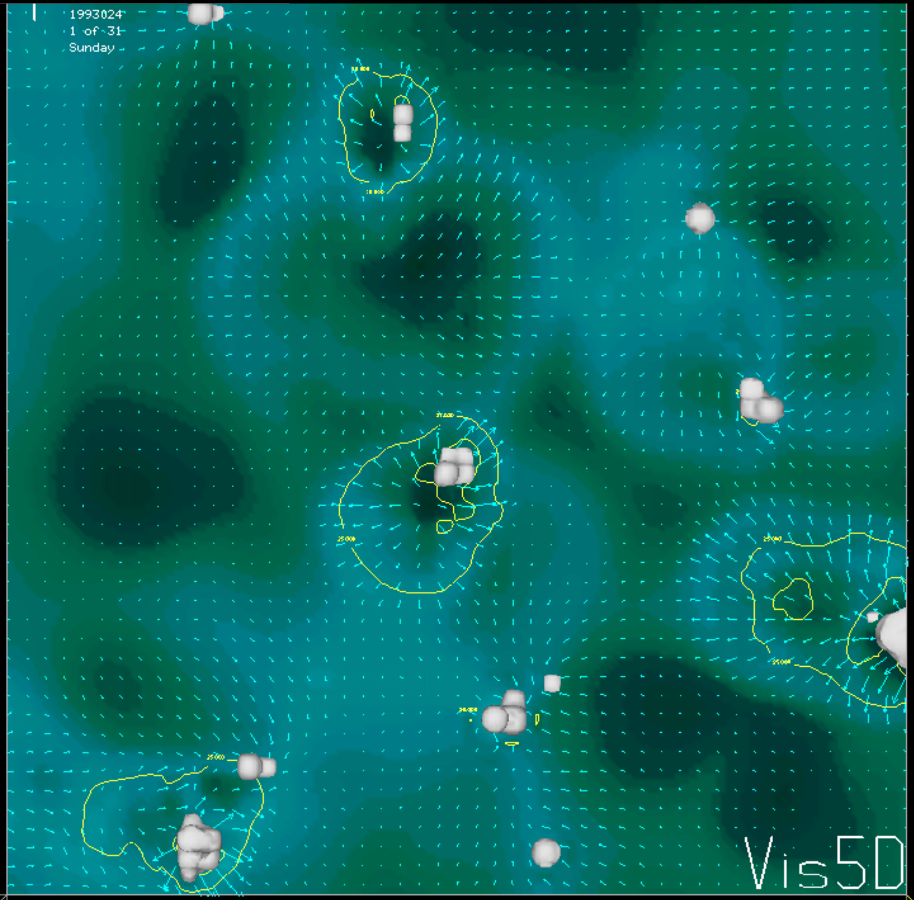




Surface Flux Impacts on Water Vapor Rings

Models also show that as SST increases from 298 K to 304 K, water vapor rings become ~50% stronger → implications for convective initiation





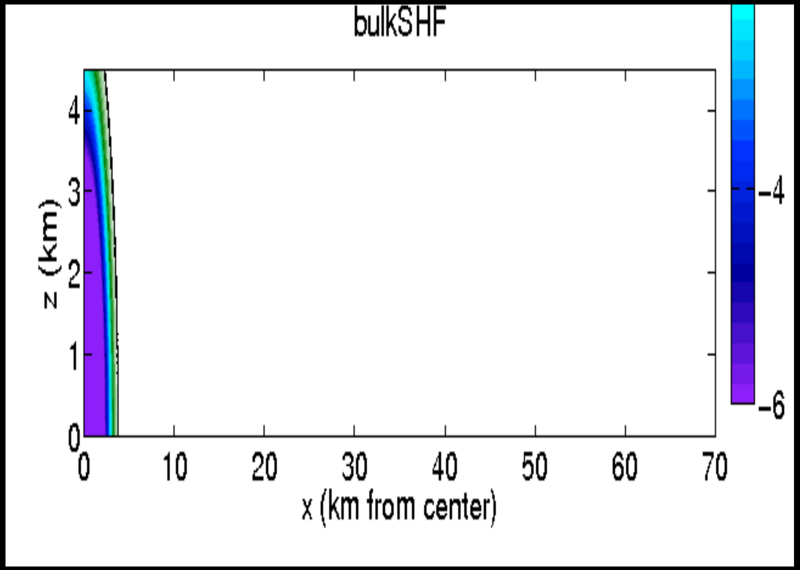
Overall conclusion:

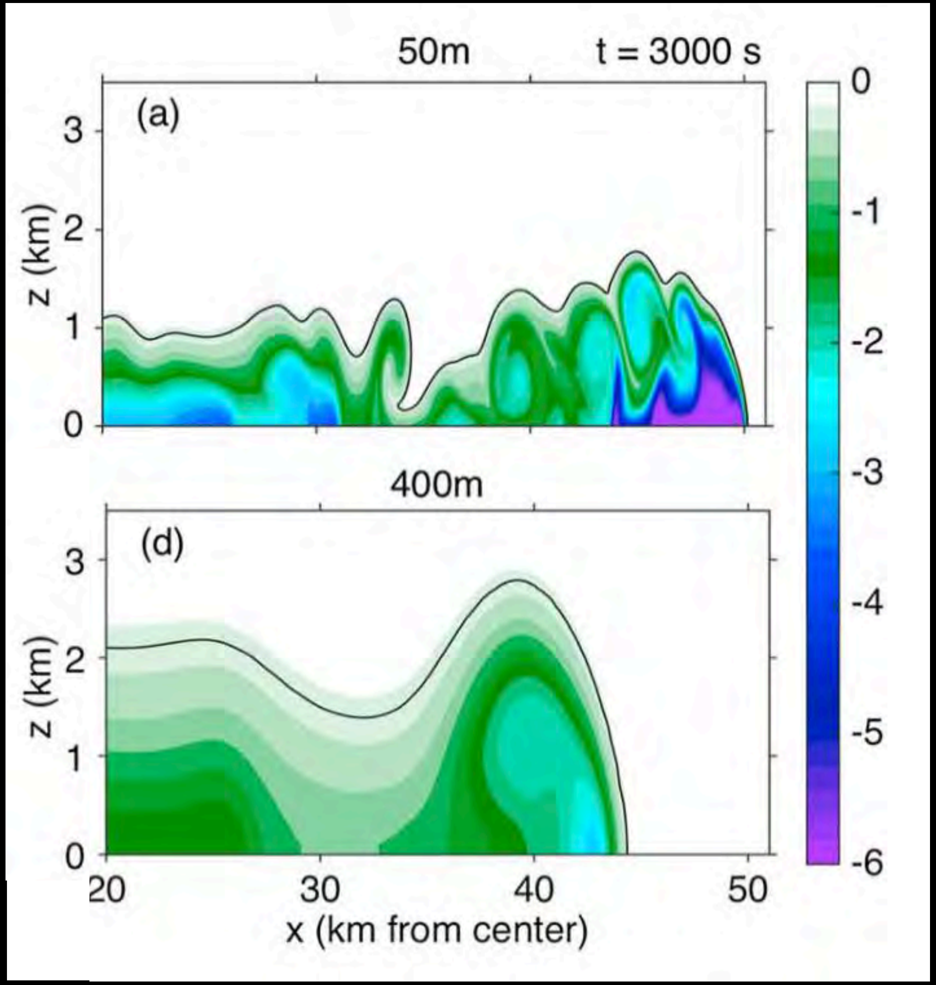
In a warmer climate, we might expect that the processes by which cold pools trigger and organize convection may change, with a lesser role for mechanical forcing and a greater role for thermodynamic/moisture forcing (after Drager and van den Heever 2019)

2.2 Modeling Cold Pools

- Challenges arising from Grid Spacing and Surface Flux Representation

- What are the spatial and temporal scales critical to cold pool processes?



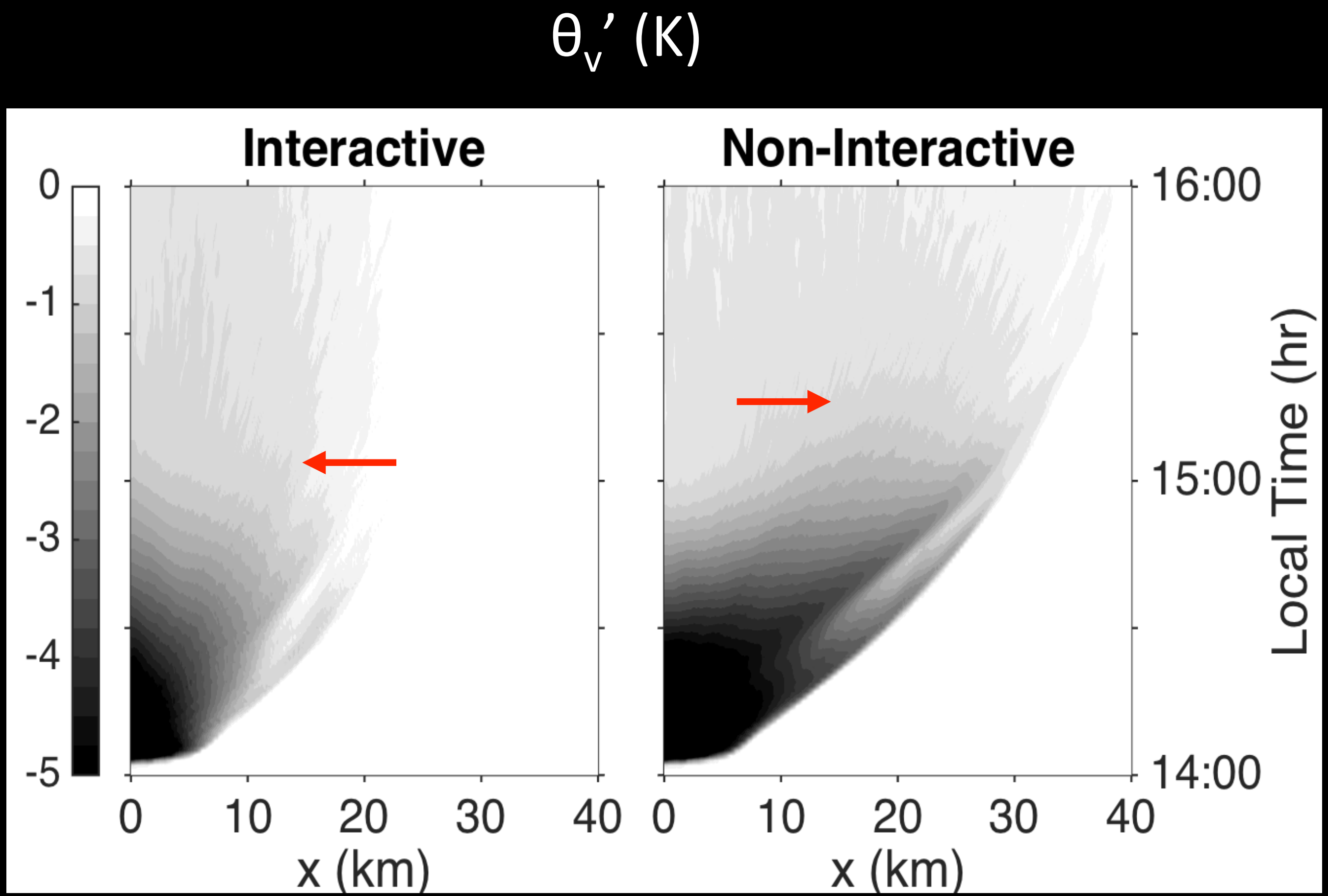


Grid spacing

(after Grant and van den Heever 2016)

2.2 Modeling Cold Pools
- Importance of Interactive Surface Fluxes

- Non-interactive surface case:
  - Cold pool intensity (+30%)
  - Extent (+60%)
  - Lifetime (+100%)
  - Pattern of dissipation



(After Grant and van den Heever 2018)

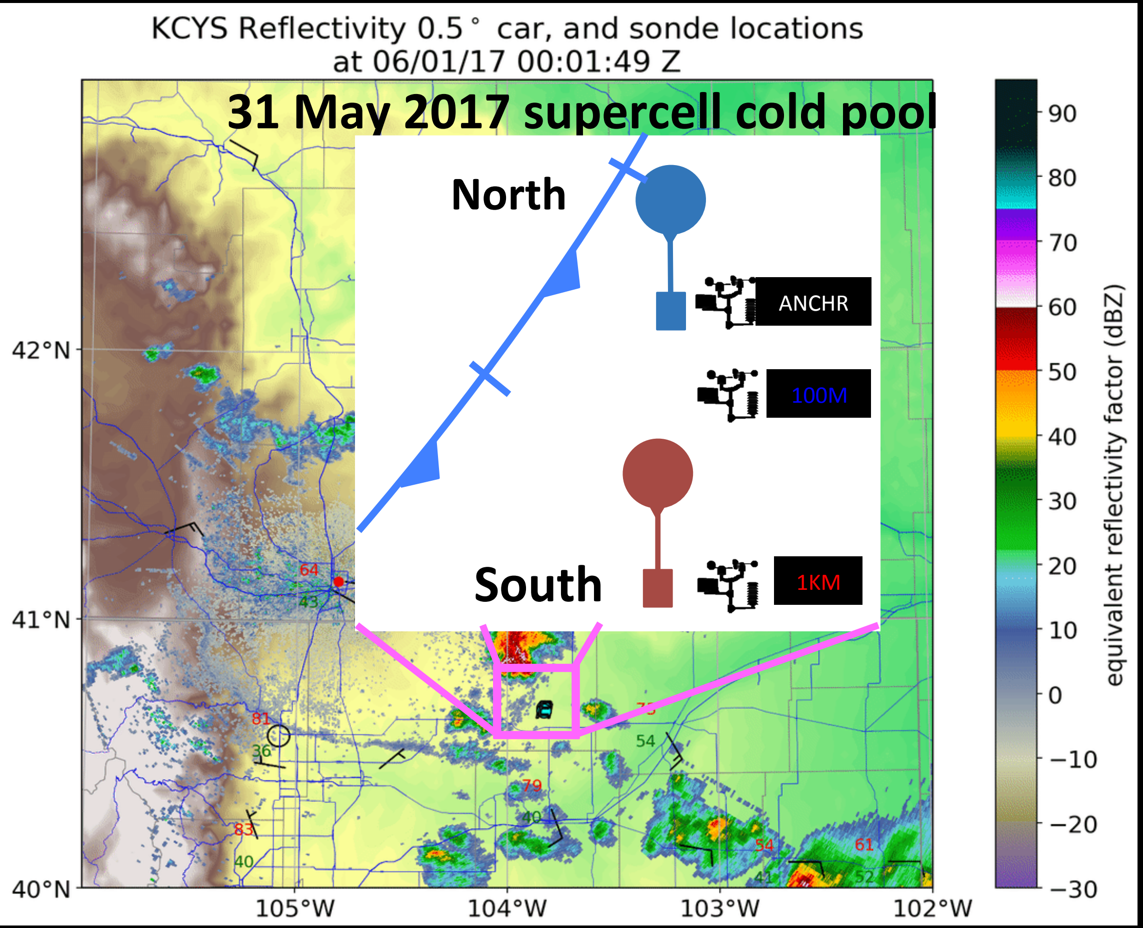
2.3 Cold Pool Observables

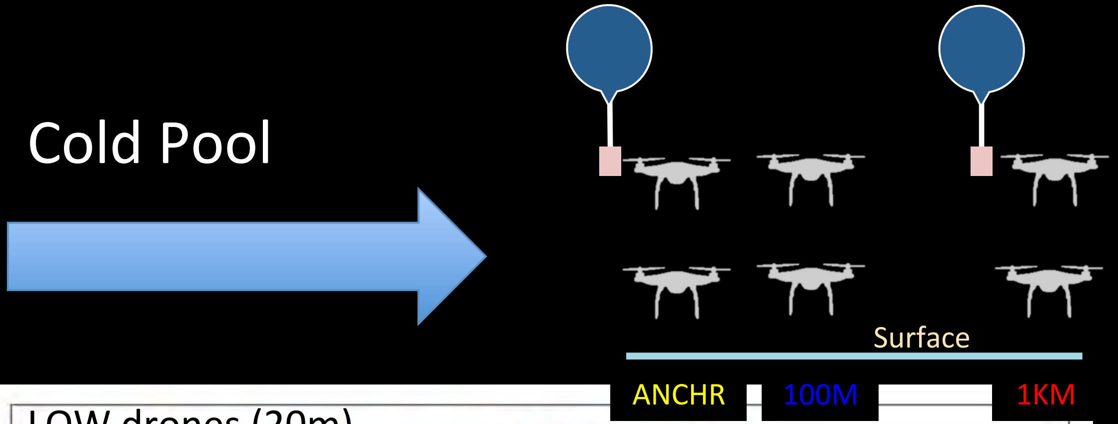
- High spatial and temporal resolution measurements of cold pool properties (temperature, RH, wind, aerosols) as well as LHFs and SHFs
  - throughout the entire depth of the cold pool
  - as a function of environment (including surface fluxes, precipitation rate and surface characteristics

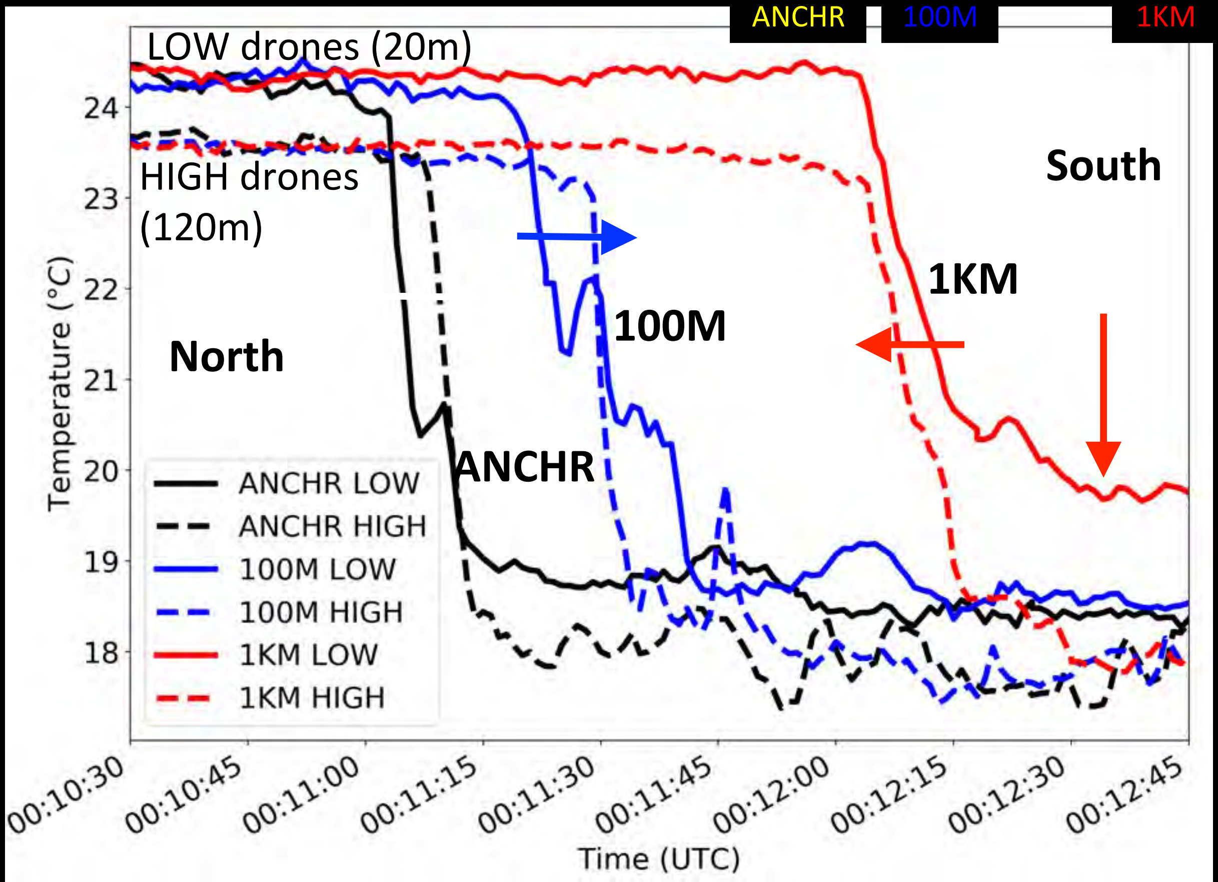
- UAVs

2.4 Cold Pool - Platforms

(after van den Heever et al 2019 BAMS)







Temperature data from 6 drones over 3 minutes

Summary

1. **Updrafts and downdrafts observables**:

- Co-located vertical velocities and microphysical process information (including supersaturation)
  - as a function of environmental variables (CAPE, shear, RH, SST, aerosols), storm life cycle and diurnal cycle
  - globally

2. **Cold pools observables:**

- High spatial and temporal resolution measurements of cold pool properties (temperature, RH, wind, aerosols) and LHFs and SHFs
  - throughout the entire depth of the cold pool
  - as a function of environment (including LHFs and SHFs), precipitation rate and surface characteristics