National Aeronautics and Space Administration

Observational System for Constraining Clouds and Precipitation in Atmospheric Models

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(Topic Area RTD)

Project Objective:

- **Representation of turbulence, clouds and convection are one of the most uncertain parts of climate and weather prediction models.**

Questions to be answered:

- **What physical variables should future observational systems measure to constrain these highly uncertain processes in climate and weather prediction models?**
- **What is the minimum requirements (i.e. vertical resolution and error characteristics) for these measurements to provide meaningful constrain for atmospheric models?**

Benefits to NASA and JPL (or significance of results):

- **Help define priorities for future Earth observing capabilities driven by the need to improve important aspects of atmospheric models and understanding of the Earth's atmosphere**
- **Help define the need for observational technology development**

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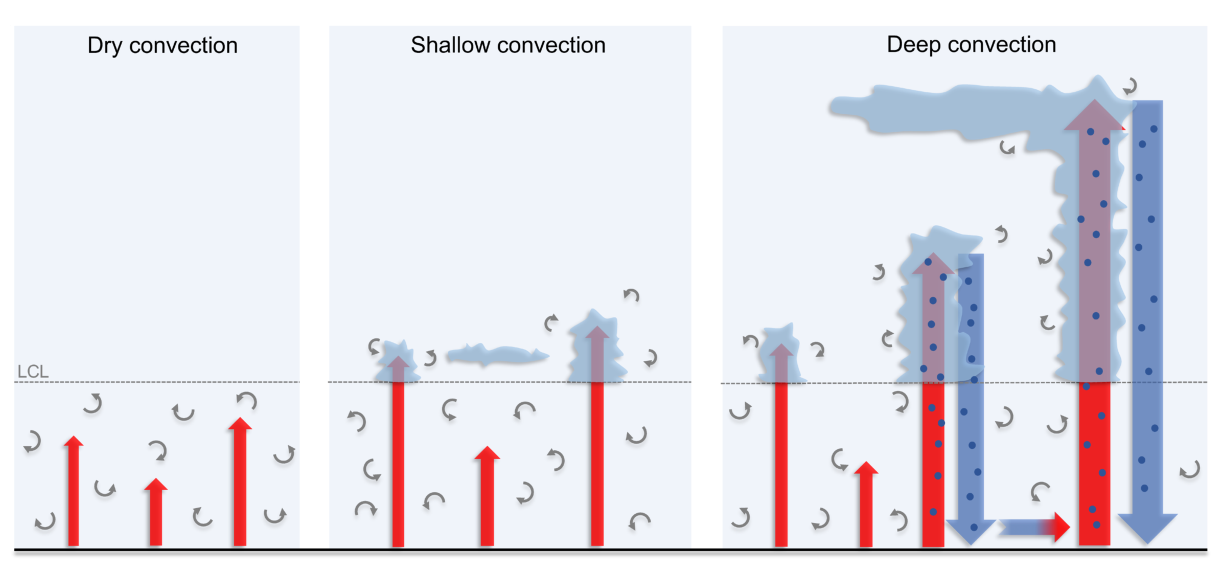
FY18/19 Results:

Ingredients:

1. JPL Stochastic multi-plume Eddy-Diffusivity/Mass-Flux (EDMF) parameterization, represents unified boundary layer, shallow, deep convection and microphysical parameterization (Suselj et al., 2019a,b):

- Decomposition of subgrid-scale motion into (i) multiple convective plumes (surface-forced updrafts and evaporatively-driven downdrafts) and (ii) non-convective environment
- Microphysical processes coupled to subgrid scale dynamics
- Strong interaction between convective microphysics and plume dynamics, consistent assumptions about subgrid-scale distributions of thermodynamic and kinematic variables
- 14 model parameters with (somewhat) uncertain values associated with uncertainty of subgrid-scale processes (see table below)

Schematics of the three convective types represented by the EDMF parameterization.



Model parameters in the EDMF parameterization.

Parameter	Range	Default	Short description
			Mass-Flux component
a_u	0.05 - 0.5	0.15	Updraft area at the surface
ϕ	0 - 6	2	Factor in lateral entrainment rate parameterization (Eqs. 7 and 8)
N	2 - 100	10	Number of updrafts
s_f	0.5 - 2	1	Factor representing intermittence of entrainment rate (Eq. 7)
$c(w, q_t)$	0.2 - 1	0.32	Correlation coefficient between w and q_t in the surface layer
$c(w, \theta_v)$	0.2 - 1	0.58	Correlation coefficient between w and θ_v in the surface layer
w_b	0 - 3	1.5	Coefficient in updraft vertical velocity equation (Eq. 5). Parameter w_a is constrained with Eq. 6.
α_w	0.3 - 3	1	Factor in surface σ_w equation
α_{q_t}	0.3 - 3	1	Factor in surface q_t equation
α_{θ_v}	0.3 - 3	1	Factor in surface θ_v equation
			Eddy-Diffusivity component
a_N	10^{-3} - 10^{-1}	0.07	Coefficient in stability dependent formulation for diffusive length scale.
a_{diff}	0.5 - 5	3	Coefficient for diffusive length scale.
a_{diss}	0.5 - 5	1	Coefficient in dissipative length scale (Eq. 14)
			Condensation routine
a_s	0.1 - 5	1	Dissipation rate for momentum and Thermodynamic variables used in $\overline{s's'}$ equation

2. Case study - Diurnal cycle of non-precipitating continental convection (ARM case, Brown et al., 2002)
3. Proxy for measurements – large-eddy-simulation (LES) data for the studied case.

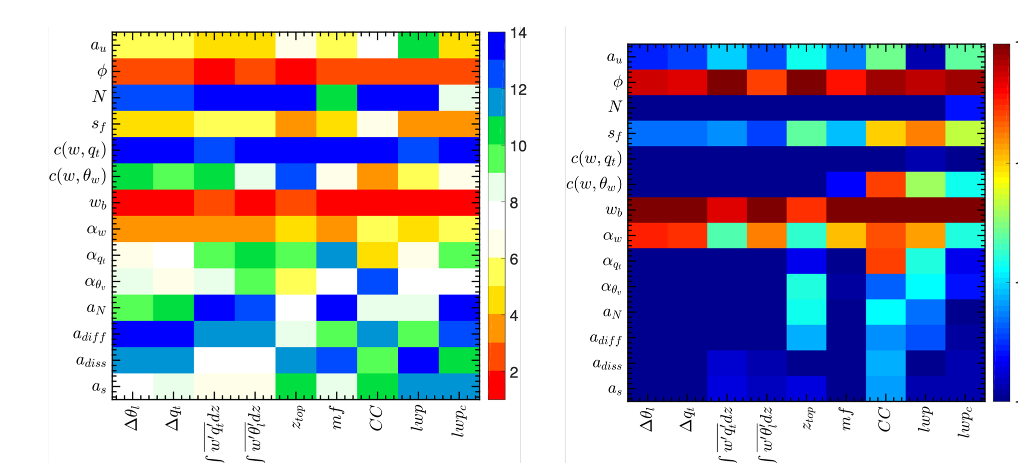
References:

- Brown, A., et al. (2002). Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land. Q J Royal Met Soc. 128, 1075-1093
- Posselt, D. He, F., Bukowki, J. and Reid, J. (2019). On the Relative Sensitivity of a Tropical Deep Convective Storm to Changes in Environment and Cloud Microphysical Parameters. J. Atmos. Sci. 76(4), 1163-1185
- Suselj,K., Kurowski, M. & Teixeira. (2019a). On the Factors Controlling the Development of Shallow Convection in Eddy-Diffusivity/Mass-Flux Models. J. Atmos. Sci., 76(2), 433-456
- Suselj,K., Kurowski, M. & Teixeira. (2019b). A Unified Eddy-Diffusivity/Mass-Flux Approach for Modeling Atmospheric Convection. J. Atmos. Sci., 76(8), 2505-2537

Methodology and results:

1. **Parameter screening**. To which key parameters are the EDMF results most sensitive to?
   - Computationally efficient monte-Carlo based Morris-one-at-the-time method (MOAT, Posselt et al., 2019), result value μ - impact of parameter on the *quantity of interest* (QI).
   - For each QI compute rank of μ and μ value normalized by its range ($R\mu$)

Rank of μ (left) and normalized range $R\mu$ corresponding to model parameters for different QIs (x-axis)

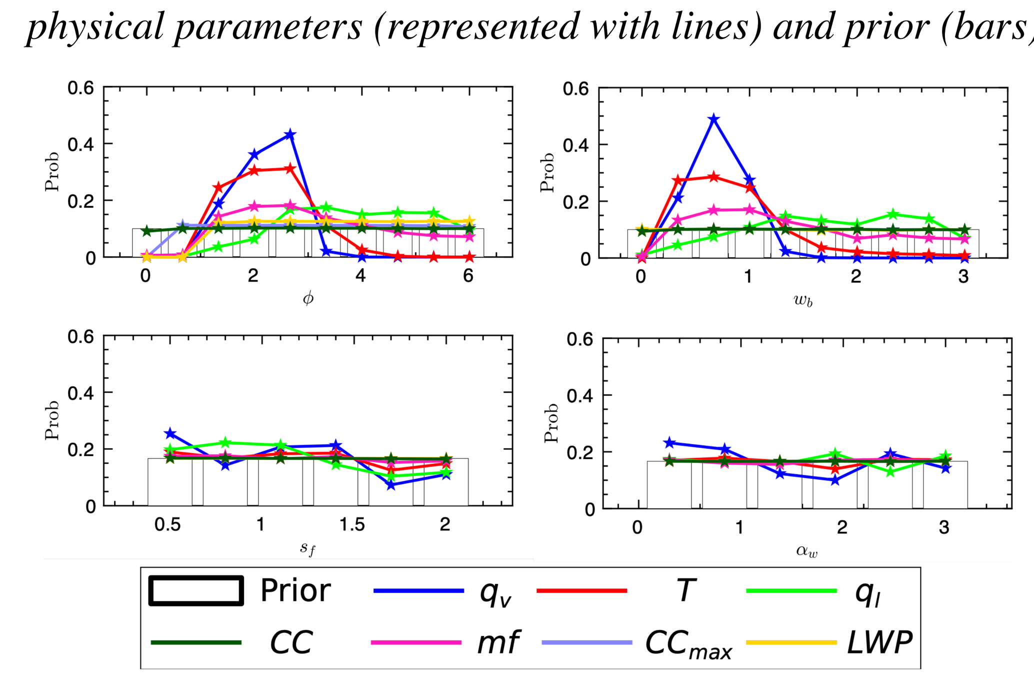


Main results:

- All QIs are highly sensitive to the values of parameters controlling updraft properties (ϕ and w_b).
- Most QIs are moderately sensitive to parameters s_f and α_w.

2. **Measurement constrain for parameter values**. Which physical variable best constrains influential EDMF parameters?
   - Perform EDMF simulation for the parameter space defined by four influential parameters
   - For each EDMF simulation compute probability that simulated quantity is consistent with measurement, assign distribution to parameter values
   - Estimate posterior distribution of parameter value given the uniform prior

Posterior parameter distribution given measurements of certain physical parameters (represented with lines) and prior (bars)

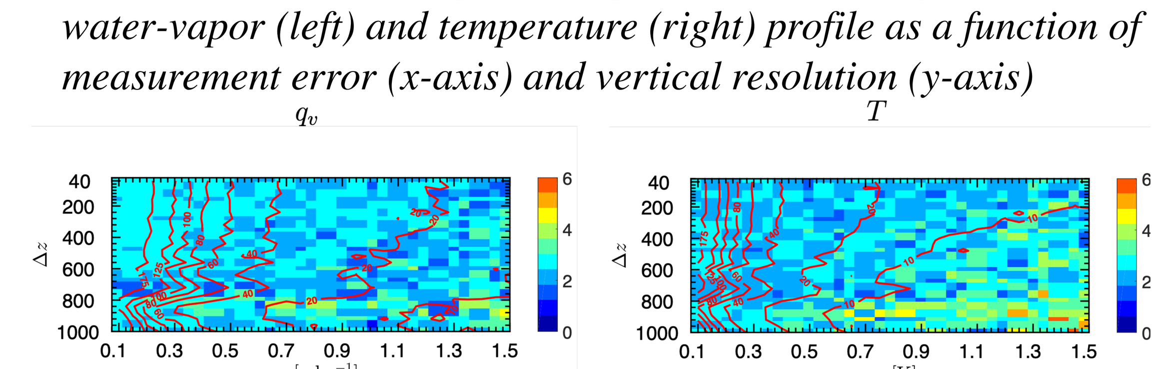


Main results:

- Parameters ϕ and w_b can be well constrained with observation of temperature and water vapor profile, other potential observations provide little constrained.
- Most observations cannot constrain parameters s_f and α_w (their impact on model results is too low).

3. **Measurement requirements.** What is the required vertical resolution and error of measurements?
   - Repeat parameter estimation (step 2) with decreased vertical resolution and random error of measurements
   - Criteria characterizing impact of measurements: (i) Most probable value of parameter, (ii) $dP = 100 * \max[(P_{post} - P_{prior})/P_{prior}]$ where P_{prior} and P_{post} are prior and posterior parameter distributions.

dP (red lines) and most probable parameter values given observation of water-vapor (left) and temperature (right) profile as a function of measurement error (x-axis) and vertical resolution (y-axis)



Main results:

- For $dP \gtrsim 20$ the measurements seem to provide reasonable constrain to model parameters.
- Error characteristics and vertical resolution of measurements seem to be related.

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