Cloud modeling, aircraft observations, and the development of cumulus parameterizations[1]

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Abstract

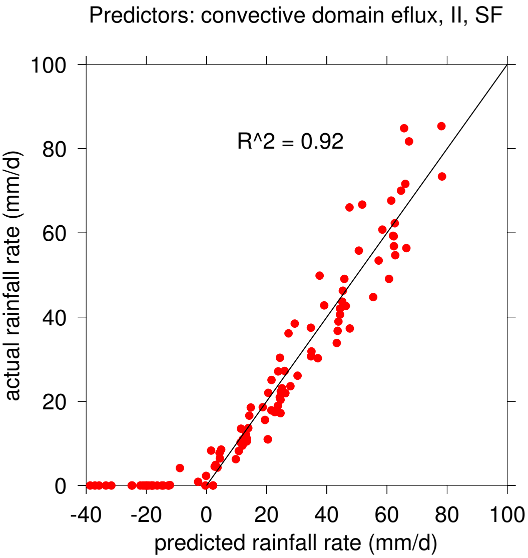
The poor treatment of convection in global models is a major obstacle to weather and climate predictions in the tropics. I outline a method for improving cumulus parameterizations in these models employing a combination of cloud modeling and in situ observations from aircraft-based dropsondes and radars. Such observations cannot be made from satellites using current technology. The recent development of weak temperature gradient cloud modeling allows us to capture the dependence of convective properties such as convective heating profiles and precipitation on the convective environment. The use of gridded dropsonde deployments and radar observations of convection from high altitude aircraft makes possible the direct comparison between real-world convection and these model results. High resolution regional modeling is also useful.

Hypothesis: Mean convection is controlled by thermodynamics

Controlling factors derived from weak temperature gradient cloud modeling:

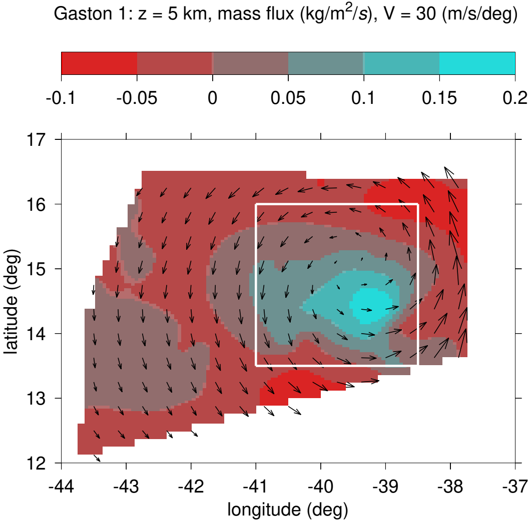
- Surface total moist entropy flux (*eflux*: heat flux/BL temperature)
- Saturation fraction (*SF*: precipitable water divided by saturated precipitable water)
- Instability index (*II*: low to mid-tropospheric moist convective instability)

$$\mathrm{Rain} = -251 + 45.8\,eflux + 362\,SF - 1.02\,II$$



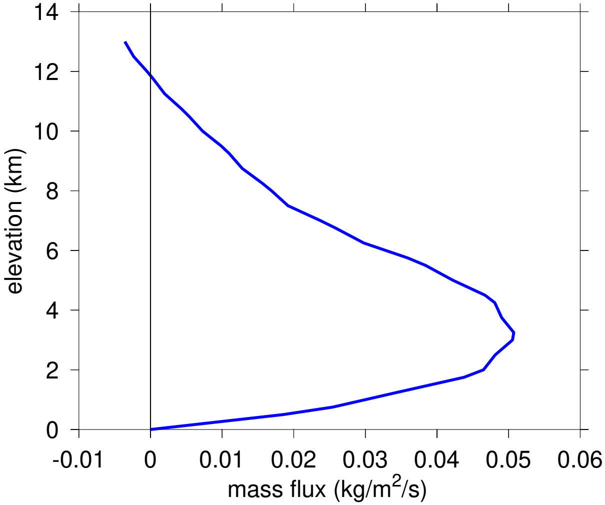
Raymond and Flores (2016)

Example of 1 deg grid dropsonde observations

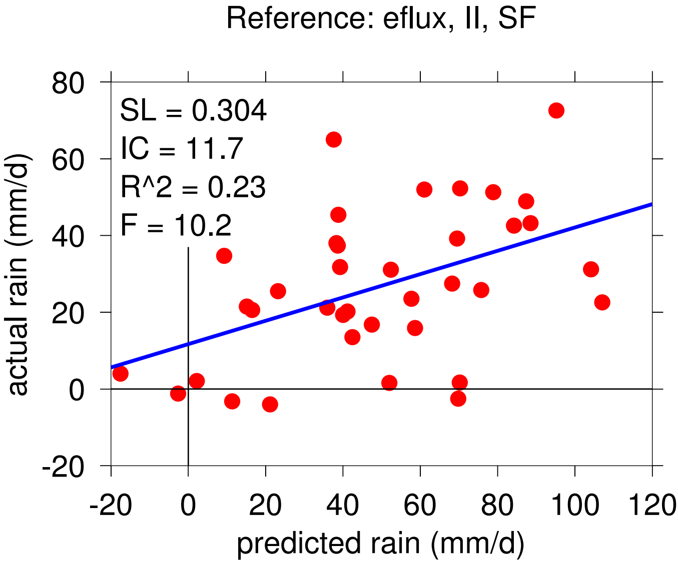


Gjorgjievska and Raymond (2014)

Vertical profile of mass flux in white box



Comparison of WTG modeling with 37 case studies



Raymond and Flores (2016)

Results of comparison

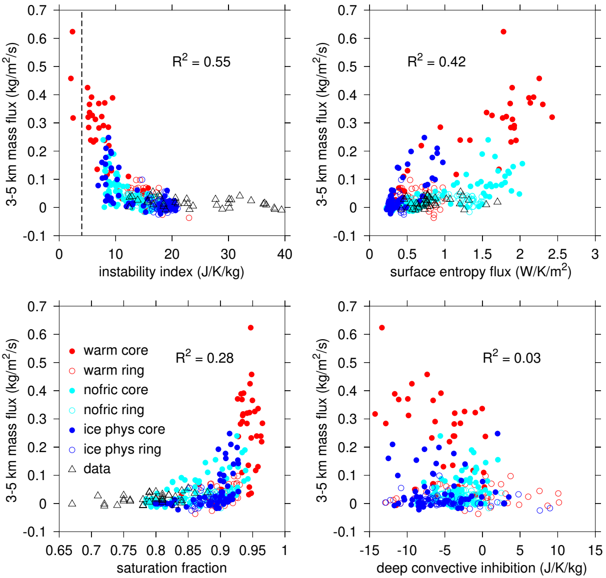
- Results are noisy
- Too much rain predicted
- However, the correlation is highly significant ($F = 10.2$)

Further test in extreme tropical cyclone conditions

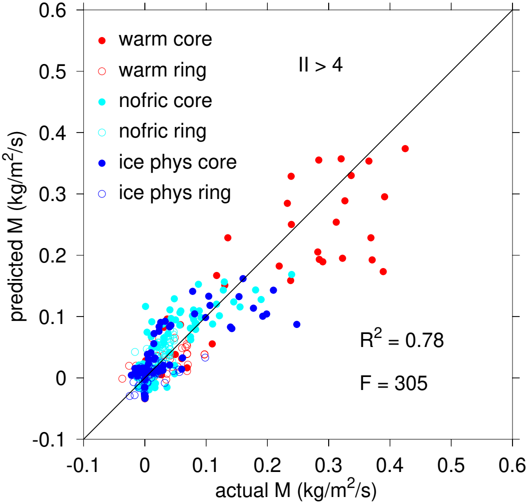
- High resolution modeling of tropical cyclone formation (Gerard Kilroy, Roger Smith, Michael Montgomery)
- Diagnosed convection in inner core $0 < R < 50$ km and outer ring $50 < R < 100$ km
- Three cases:
  - Warm rain cloud physics
  - Full ice cloud physics
  - Warm rain but no surface friction
- Add deep convective inhibition ($DCIN$) as a predictive variable to account for frictional convergence
- Regression is no longer linear
- Predict lower tropospheric mass flux rather than rain

Raymond and Kilroy (2019)

Scatter plots over all cases



$$\text{Mflux} = -0.080 + 6.9/II^2 + 0.0050/(1 - SF) + 0.033 eflux - 0.0028 DCIN$$



Conclusions

- The surface entropy flux, the saturation fraction, the instability index, and the deep convective inhibition are sufficient to predict the mean convective rainfall and lower tropospheric mass flux even in extreme conditions.
  - The rain and mass flux increase with increasing surface fluxes and saturation fraction.
  - Surprisingly, the rain and mass flux increase with decreasing instability index.
  - The rain and mass flux increase with decreasing convective inhibition as expected.
- Any cumulus parameterization should obey these constraints.