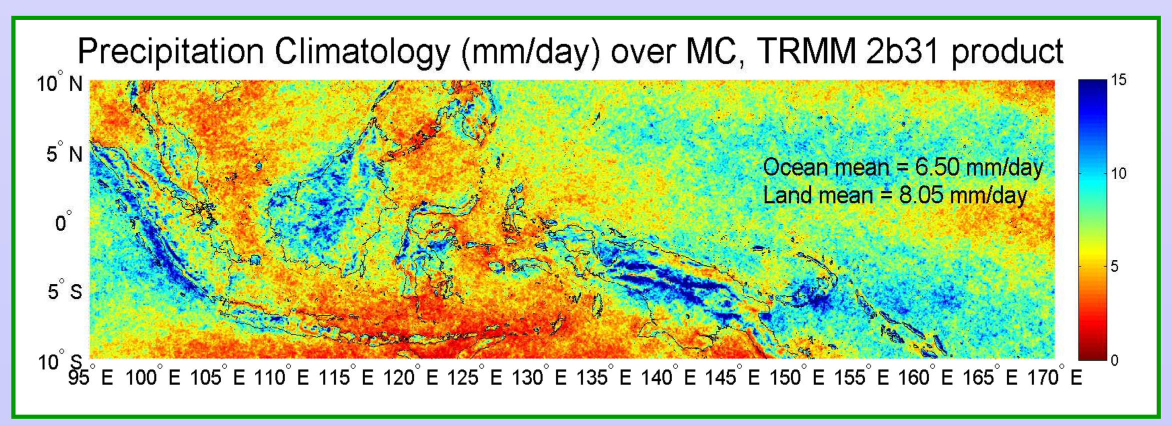
Rectification of the Diurnal Cycle over Small Islands in Radiative-Convective Equilibrium

Timothy W. Cronin*, Kerry A. Emanuel

*Program in Atmospheres, Oceans, and Climate, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge 02139; (*twcronin@mit.edu)*

Introduction

- Tropical islands and continents are substantially rainier than nearby ocean areas (figure below; Sobel et al., 2011)
- Studies of lightning flash rates also show that convection is more vigorous over islands and continents (e.g. Williams et al., 2004)
- General Circulation Models (GCMs) often suffer a dry bias over tropical land regions
- GCMs also tend to poorly represent the diurnal cycle of convection (Dai, 2006)
- Are these biases linked?
- Is the elevated convective vigor and time-mean precipitation a consequence of “rectification” of the diurnal cycle?
- Does the diurnal cycle have a significant impact on the tropical precipitation distribution on climate timescales?



Long-term climatology of precipitation over the Maritime Continent (MC) region. The islands are substantially rainier than the nearby ocean.

Rainfall data: Mulligan (2006) database: http://www.ambiotek.com/1kmrainfall

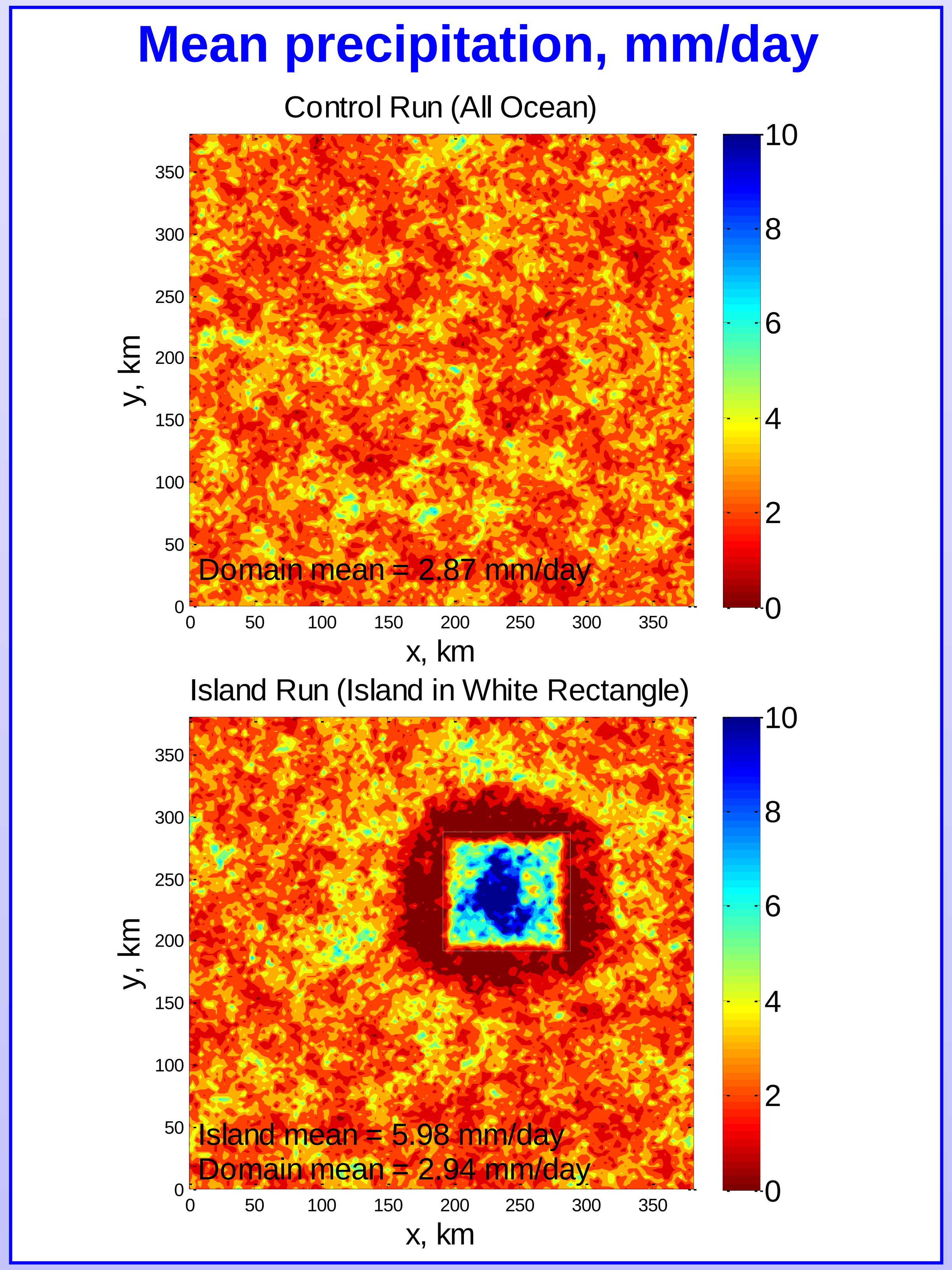
land mask: https://www.ghrsst.org/data/ghrsst-data-tools/navo-ghrsst-pp-land-sea-mask/

Experimental Design

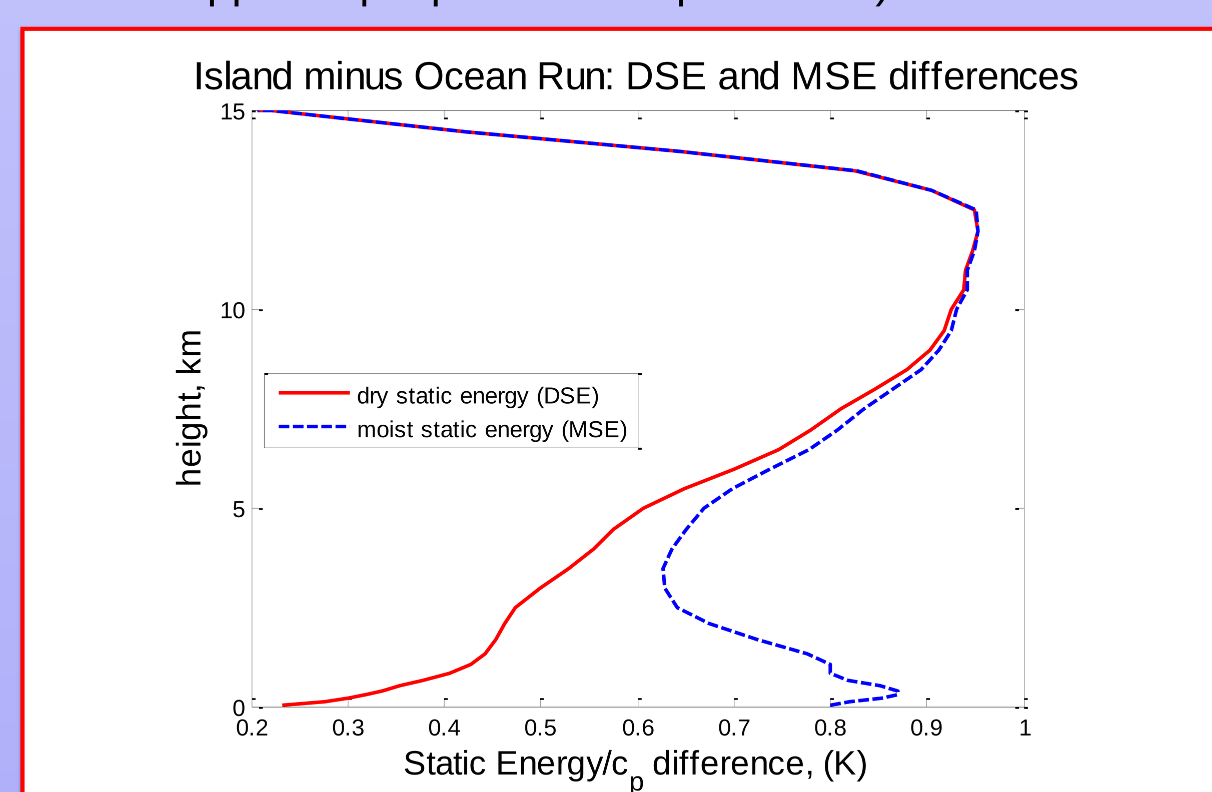
- Simulate Radiative-Convective Equilibrium (RCE) in a cloud-system resolving model with a mixed lower boundary
- System for Atmospheric Modeling (SAM) – Khairoutdinov and Randall (2003)
- Doubly periodic domain
- 384 x 384 km, 3 km resolution; 64 vertical levels
- Non-rotating; no background wind
- TOA diurnally varying insolation for March 20, 45 N
- Average insolation: 310.3 W m^{-2}
- Surface temperature interactive everywhere
- Ocean: 1 m slab; Land: 5 cm slab (no surface heat sink)
- **Only difference between the land and ocean grids is that the land has a lower heat capacity**
- Simulations of all-ocean domain, or with 96 x 96 km island
- Figures show results averaged over last 40 days of 250-day simulations

Results

- Island is much rainier than the surrounding ocean in SAM RCE simulation
- Mean precip. → island: 5.98 mm/day, ocean: 2.74 mm/day

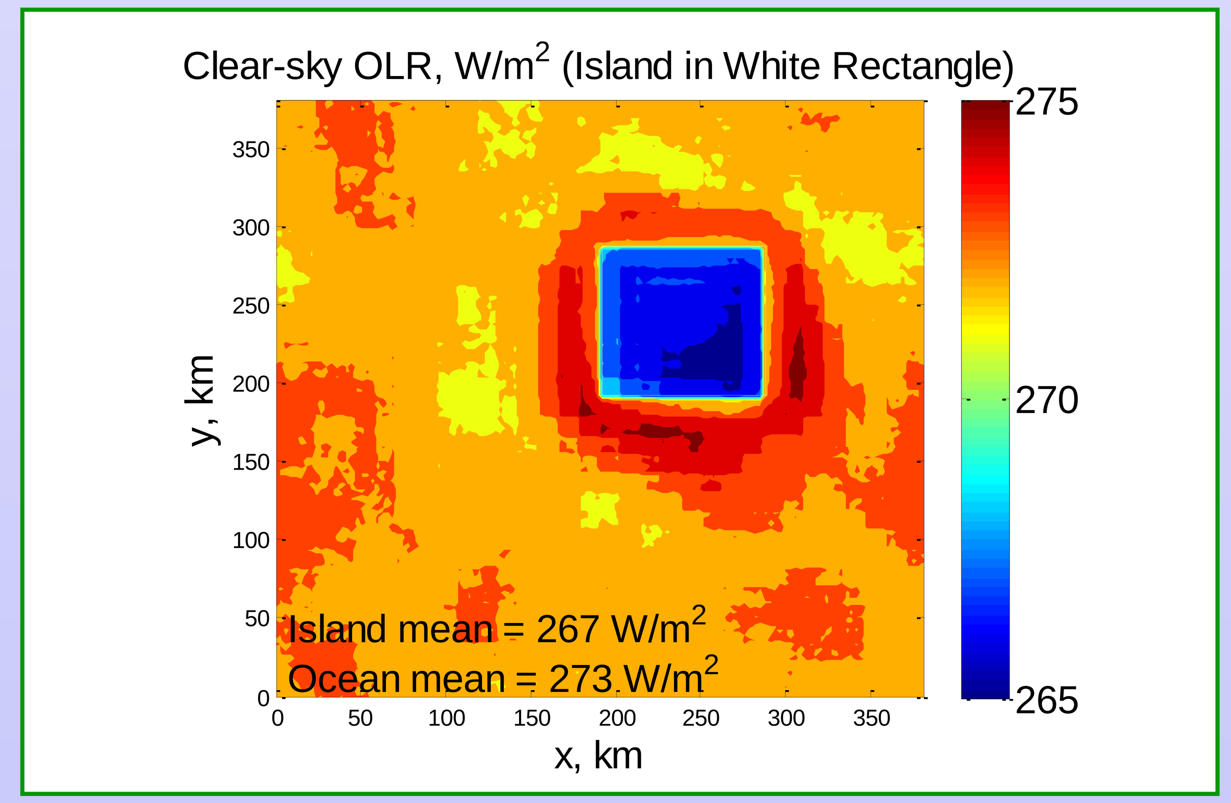


- Island Run is slightly warmer than Control Run (by roughly 1 K in upper troposphere – see plot below)

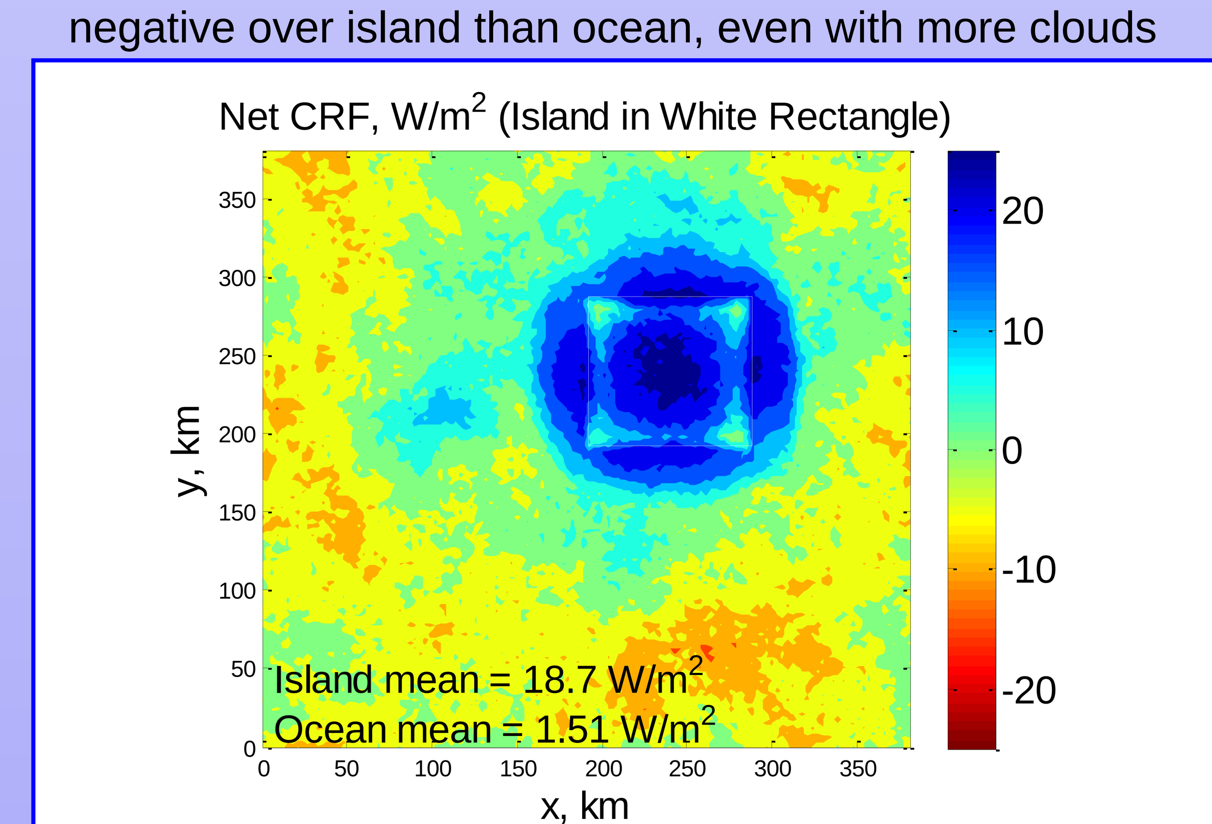


Mechanisms

- What mechanisms in the simulation lead to rectification of the diurnal cycle and cause the island to be rainier than the ocean?
- **1) Clear-sky mechanism** of Randall et al. (1991): nonlinear dependence of surface enthalpy fluxes on surface temperature disequilibrium
- As a consequence, average surface skin temperature is cooler for island (291.7 K) than ocean (295.8 K)
- Thus the time-mean clear-sky outgoing longwave radiation (OLR) is lower over island than ocean (figure below)
- Lower OLR implies a column-integrated radiative surplus, which provides forcing for ascent

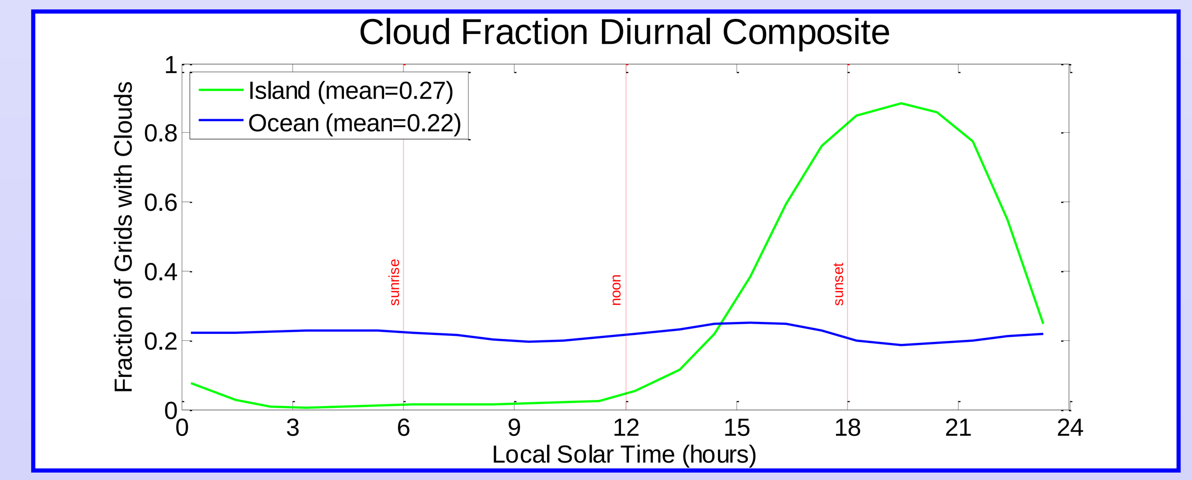


- **2) Cloud mechanism**: greater cloud cover, along with phase lag of clouds relative to solar heating over island
- Leads to positive net cloud radiative forcing (Net CRF = LW CRF + SW CRF), which also provides forcing for ascent Greater cloud fraction over island (0.27) than ocean (0.22) leads to larger longwave cloud radiative effect
- But diurnal cycle of cloud cover over the island is peaked after sunset (see discussion), so shortwave forcing is less negative over island than ocean, even with more clouds



Discussion

- Cloud radiative forcing is key to the magnitude of the island precipitation enhancement, and overall warming
- LW CRF: island: 36.6 W/m^2, ocean: 25.5 W/m^2
- SW CRF: island: -17.9 W/m^2, ocean: -24.0 W/m^2
- How robust is this phase lag of island cloud fraction?



Conclusions and Future Work

- This study suggests that island precipitation enhancement can occur solely as a result of the lower heat capacity of land surfaces and rectification of the diurnal cycle
- We find two column-energetic mechanisms; one a clear-sky radiative effect, the other a cloud radiative effect
- Both provide forcing for time-mean ascent and enhanced precipitation over the island
- Impacts of warmer atmosphere in a domain with an island on the large-scale tropical circulation?
- How to compare column-energy balance mechanisms from this study to other mechanisms – e.g. gravity wave resonance (Robinson et al., 2008) or land-sea and mountain-valley circulations followed by cumulus merger (Qian, 2008)?
- Scaling of precipitation enhancement with island size/geometry?

Acknowledgments

Thanks to Marat Khairoutdinov for supplying me with the model code, and to Allison Wing for teaching me how to use it. This work has been supported by NSF Grant #1136480, “The Effect of Near-Equatorial Islands on Climate,” which is a collaboration with Peter Molnar.

References

- **Dai**, A., 2006. *Precipitation Characteristics in Eighteen Coupled Climate Models*. J. Clim., 19, pp. 4605-4630.
- **Khairoutdinov**, M.F., and D.A. Randall, 2003. *Cloud Resolving Modeling of the ARM Summer 1997 IOP: Model Formulation, Results, Uncertainties, and Sensitivities*. J. Atmos. Sci., 60, pp. 607-625.
- **Mulligan**, M., 2006. *Global Gridded 1km TRMM Rainfall Climatology and Derivatives. Version 1.0*. Database: http://www.ambiotek.com/1kmrainfall
- **Qian**, J., 2008. *Why Precipitation is Mostly Concentrated over Islands in the Maritime Continent*. J. Atmos. Sci., 65, pp. 1428-1441.
- **Randall**, D.A., Harshvardhan, and D.A. Dazlich, 1991. *Diurnal Variability of the Hydrologic Cycle in a General Circulation Model*. J. Atmos. Sci, 48, pp. 40-62.
- **Robinson**, F.J., S.C. Sherwood, and Y. Li., 2008. *Resonant Response of Deep Convection to Surface Hot Spots*. J. Atmos. Sci., 65, pp. 276-286.
- **Sobel**, A.H., C.D. Burleyson, and S.E. Yuter, 2011. *Rain on Small Tropical Islands*. J. Geophys. Res., 116, D08102.
- **Williams**, E., T. Chan, and D. Boccipio, 2004. *Islands as Miniature Continents: Another Look at the Land-Ocean Lightning Contrast*. J. Geophys. Res., 109, D16206.