Balanced Dynamics and Convection in the Tropical Atmosphere[1]

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How Do We Separate "Convection" from "Large Scale"? (Ooyama, 1982)

- Total atmospheric flow = balanced part + unbalanced part.
- Convection included in unbalanced part and is tightly coupled to it. This part of the flow is chaotic and unpredictable in detail.
- Balanced flow is much simpler and much more predictable.
- Only that aspect of convection controlled by the balanced part of the flow is predictable.

Adjustment to Balance by Inertia-Gravity Waves

Plane wave

$$amplitude \propto \exp[i(kx + mz - \omega t)]$$

Dispersion relation

$$\omega^2 = f_{eff}^2 + \frac{k^2 N^2}{m^2} \Rightarrow \omega^2 \geq f_{eff}^2$$

Balance time scale $< 1/$Coriolis parameter. At 10 N
$f^{-1} \approx 10$ hr.
Effective Coriolis parameter

$$f_{eff} = \zeta_a = absolute\ vorticity$$

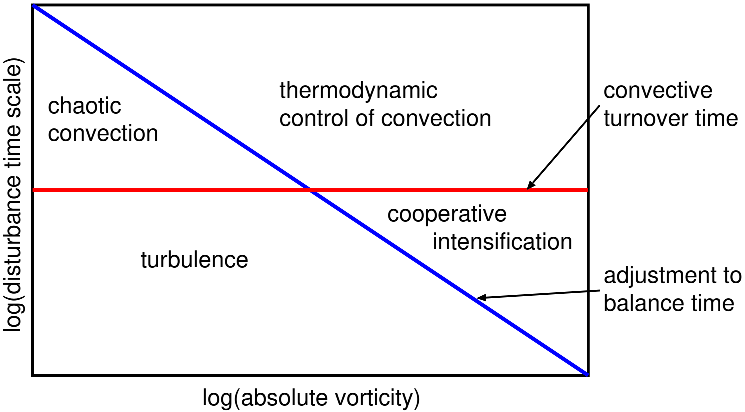
Time Scales of Convection

- Convective cell overturning time $\approx$ 1 hr
- Mesoscale convective system 2-20 hr
- Ensembles of tropical convection (easterly waves, cyclones) $>$ 1 day

Convective time scale $=$ time scale for changing vorticity $\approx 1/$mean divergence (area-dependent)

Convective time scale $>$ adjustment time scale $\Rightarrow$ balance

Regime Diagram (Inspired by Ooyama)



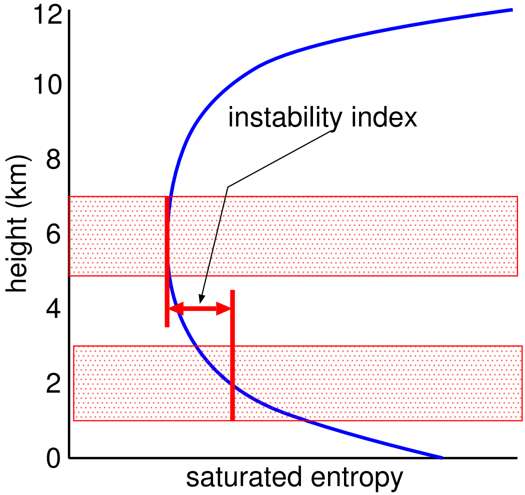
Thermodynamic Control of Convection

From Raymond and Sessions (2007); Sessions et al. (2015); in weak temperature gradient models, rain increases as:

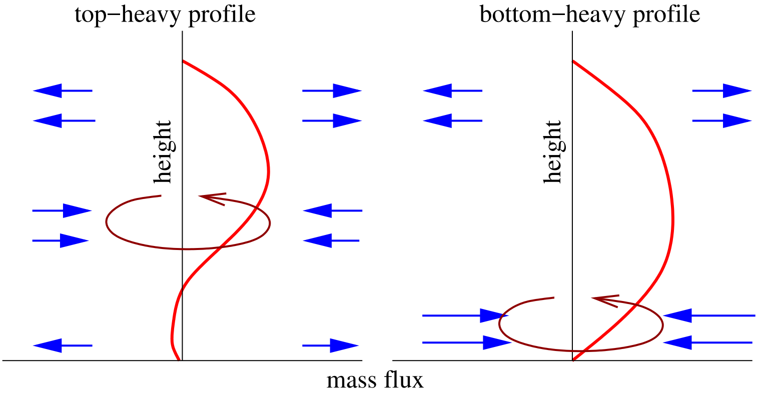
- surface moist entropy flux increases;
- saturation fraction (a measure of column relative humidity) increases;
- instability index (a measure of lower to upper-tropospheric moist convective instability) decreases (within limits).

Instability index decreases as mid-level vorticity increases.

Instability Index = saturated moist entropy 1-3 km minus saturated moist entropy 5-7 km



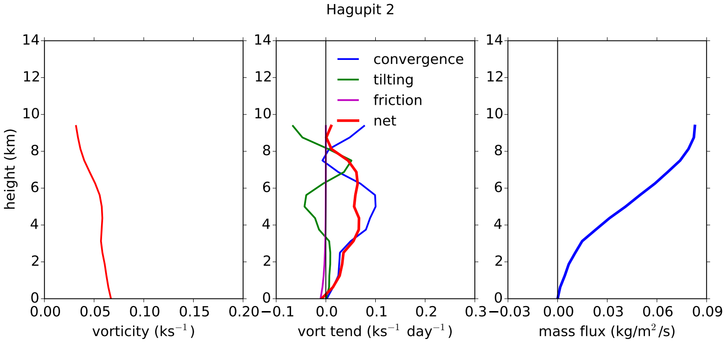
Instability Index and Convection



large instability index
strong entropy detrainment

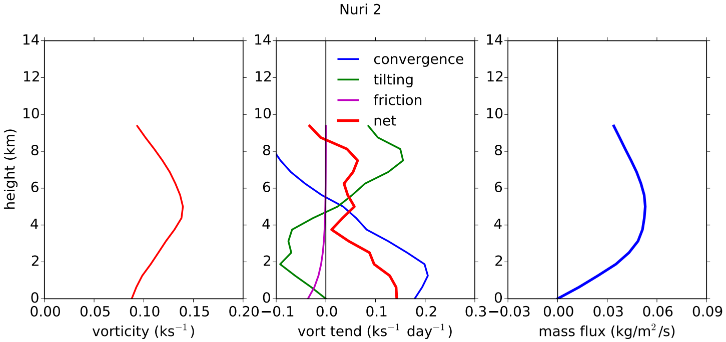
small instability index
weak entropy detrainment

Hagupit 2 – Non-Developing Wave



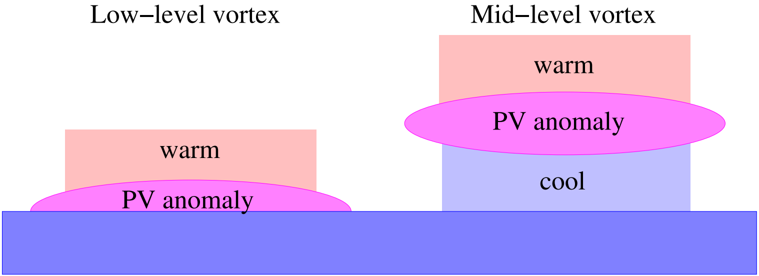
Instability index = 27 J/K/kg

Nuri 2 – Rapidly Developing Cyclone

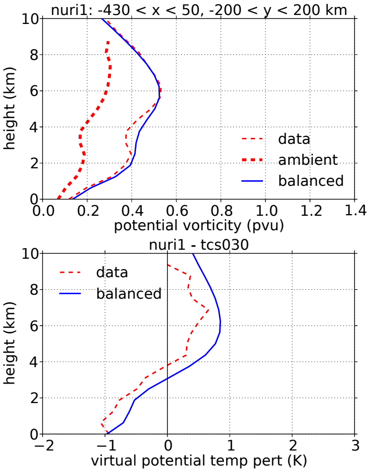


Instability index = 11 J/K/kg

Potential Vorticity and Temperature Perturbations (Balanced State)



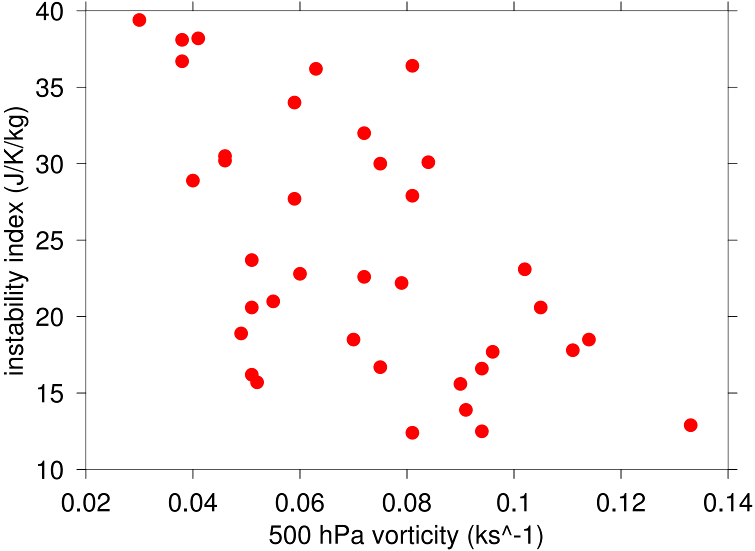
Nuri1 and Nuri2 PV Inversions



Vorticity and Convection

- Mid-level vorticity produces a temperature dipole with a warm anomaly aloft and a cool anomaly at low levels.
- This temperature dipole results in lower instability index.
- Lower instability index produces bottom-heavy convective mass fluxes, which increases precipitation and aids in tropical cyclone spinup.
- It also results in weaker moist entropy detrainment or even entropy entrainment.

Instability Index and Mid-Level Absolute Vorticity (TPARC/TCS08 and PREDICT)

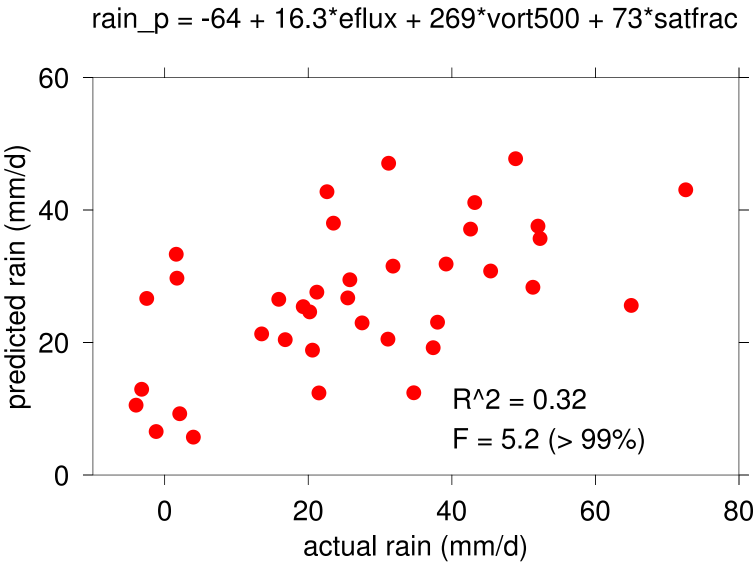


Can We Predict Rainfall? Measure of Strength of Convection

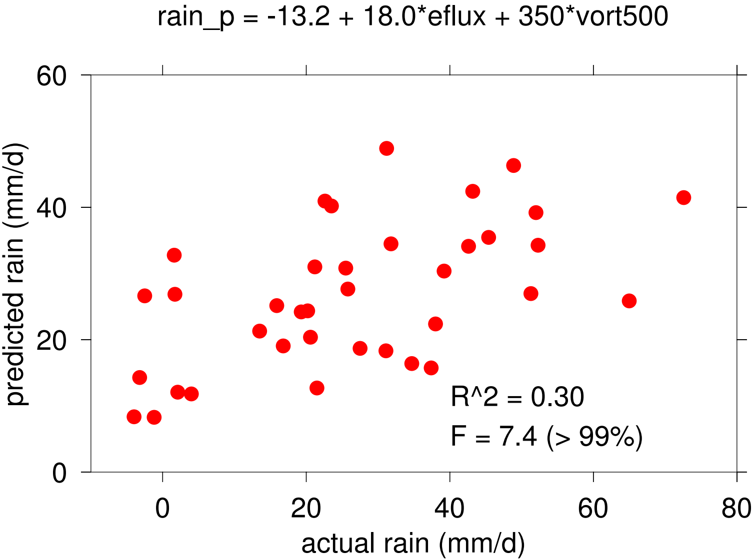
- Recipe: Linear combination of...
  - Surface moist entropy flux (eflux)
  - 500 hPa vorticity (surrogate for instability index; vort500)
  - Saturation fraction (column relative humidity; satfrac)
- Inspired by Raymond and Flores (2016).

$$\text{rain} = \text{A} + \text{B*eflux} + \text{C*vort500} \; (+ \text{D*satfrac})$$

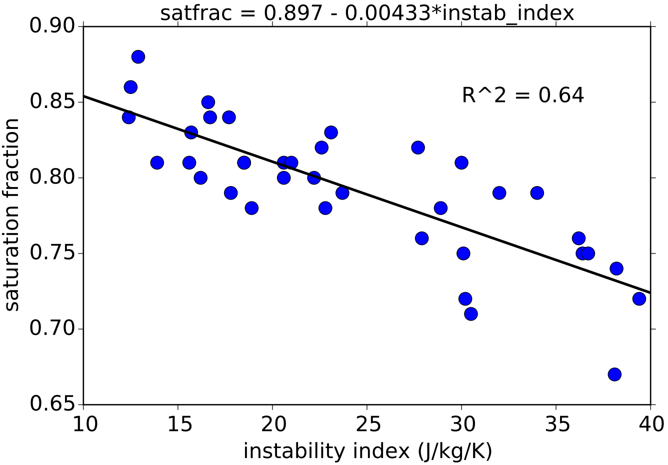
Predicted vs. Actual Rainfall (with humidity)



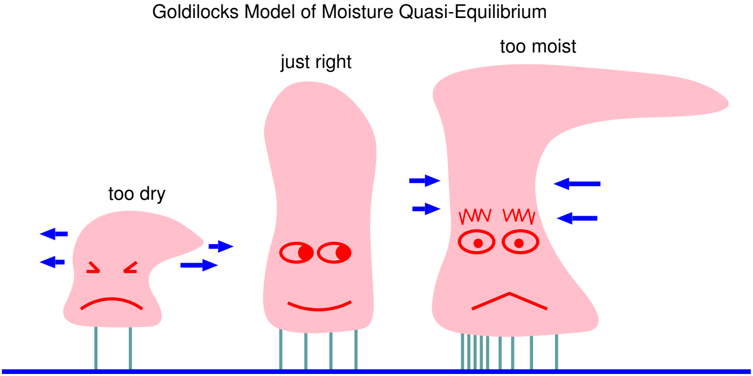
Predicted vs. Actual Rainfall (no humidity)



Moisture Quasi-Equilibrium



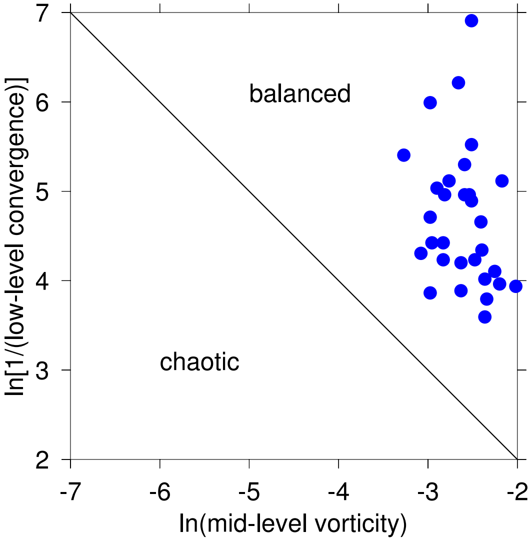
How Does MQE Work? (Singh and O'Gorman, 2013)



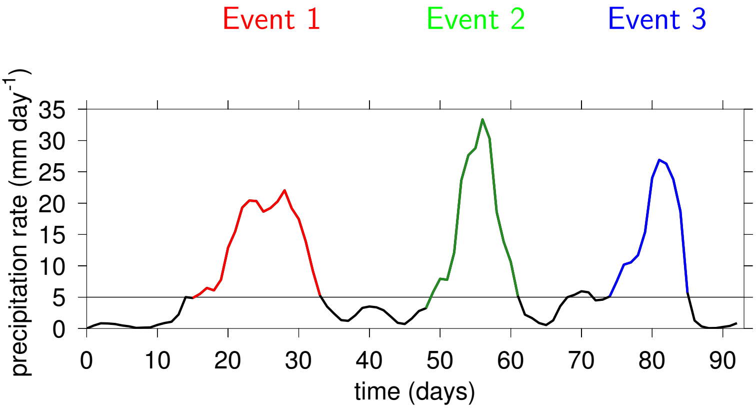
Summary of Forcing of Tropical Oceanic Rainfall

- Three controlling variables
  - Surface moist entropy flux
  - Strength of mid-level vorticity (instability index)
  - Saturation fraction
- However: Saturation fraction is slaved to mid-level vorticity as long as convection is strong and environmental ventilation is weak.

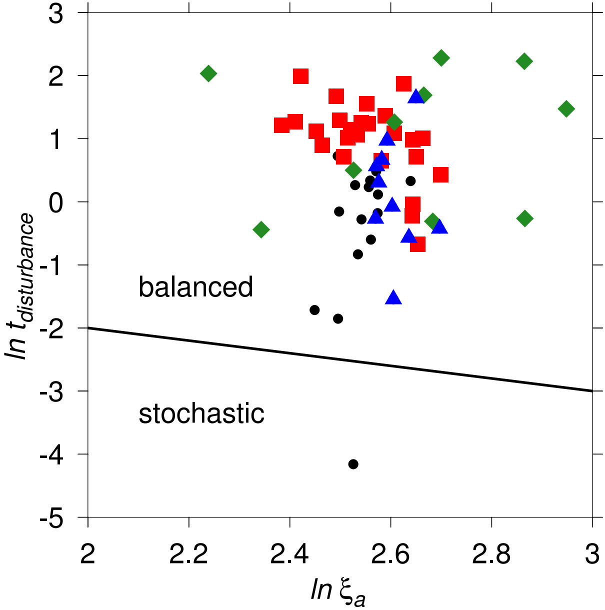
TCS08-PREDICT Regime Diagram (300 km scale)



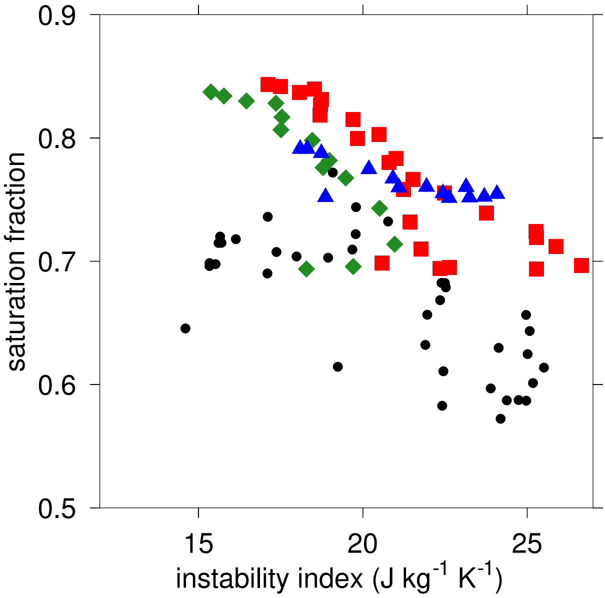
Examples from DYNAMO



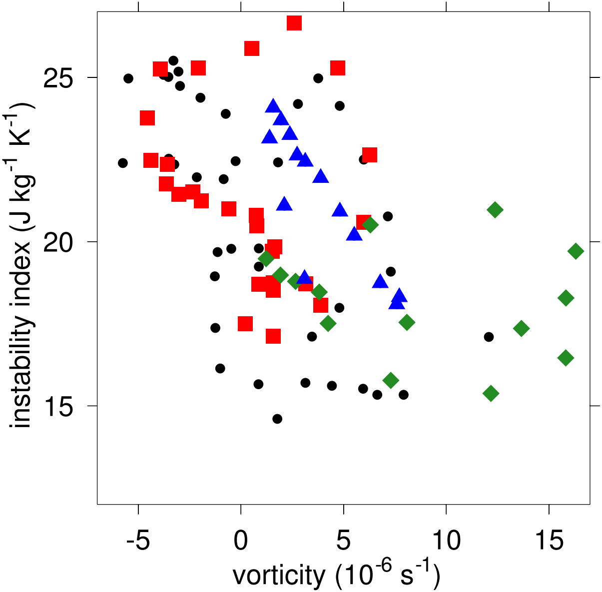
Dynamo Regime Diagram (500-1000 km scale)



Moisture Quasi-Equilibrium in DYNAMO



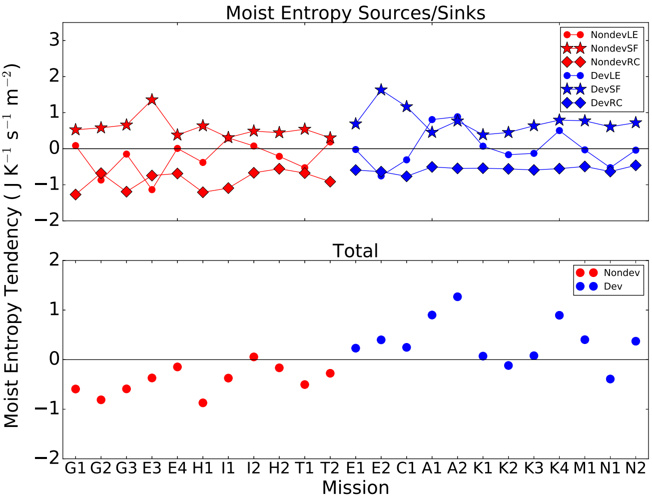
Instability Index vs. Mid-Level Relative Vorticity



Entropy Budget and Intensification of Tropical Cyclones

- Case studies of tropical cyclones in various phases from HS-3, PREDICT/IFEX, and TCS-08
- Arrays of dropsondes and satellite data used to compute entropy budget
- Storm intensification correlated with positive column entropy tendency
- This test could be done operationally with G-V dropsonde arrays around TCs

Entropy Tendency and TC Intensification (Ana Juračić)



Interaction of Convection and Balanced Disturbances