Mid-Level Vorticity, Moisture, and Gross Moist Stability in the Tropical Atmosphere

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Showers and rains:

- Ramage (1971) divides tropical precipitation into two regimes:
  - Showers: Fine weather with relatively dry conditions, high CAPE, low shear;
  - Rains: Cloudy weather with moist conditions, low CAPE, higher shear;
  - The rains regime produces more average rainfall;
  - The showers regime produces higher peak rainfall.

- Williams et al. (1992) make similar distinction and correlate higher lightning rates with the showers regime.

- Is low CAPE and high moisture a cause or an effect of convection with higher average rainfall?
In situ measurements:

- TPARC/TCS08 (2008) project in western Pacific
  - ELDORA radar (NRL P-3)
  - Dropsondes from 10 km (Kessler C-130Js)
- PREDICT/GRIP/IFEX (2010) project in western Atlantic and Caribbean
  - Dropsondes from 12-13 km (NSF/NCAR G-V, NASA DC-8)
Two examples; Hagupit2 and Nuri2:

3-5 km absolute vorticity (ks$^{-1}$) and relative wind (20 m/s/deg)
Thermodynamic Effect of Vortices

West Pacific wave
Reed and Recker (1971)

Developing disturbance
warm
PV anomaly
cool

PV anomaly
Hagupit 2 dynamics:

![Graphs showing Hagupit 2 dynamics](image-url)
Nuri2 profiles:

- Circulation (km²/s)
- Height (km)
- Total and planetary
- Entropy (J/K/kg)
- Mass flux (10⁹ kg/s)
Thermodynamics:

Instability index:

\[ I = s^*_lo - s^*_hi \]

\( s^*_lo \): average \( s^* \) over [1, 3] km
\( s^*_hi \): average \( s^* \) over [5, 7] km

Saturation fraction:

\[ F = \frac{\int r dp}{\int r_S dp} \approx \frac{\int (s - s_d) dp}{\int (s^* - s_d) dp} \]

\( r \): mixing ratio
\( r_S \): saturation mixing ratio
\( s_d \): dry entropy
\( s \): moist entropy
\( s^* \): saturated moist entropy
Instability index:

Mean Soundings

- Nuri2
- Hagupit2

I-H2
I-N2
I = instability index

Height (km)

Moist entropy (J/K/kg)
Mean Nuri2 - Hagupit2 temperatures:

Temperature difference: nuri2 - hagupit2

- z vs dtemp
- z vs dtvirt
Differences quantified:

<table>
<thead>
<tr>
<th></th>
<th>Nuri2</th>
<th>Hagupit2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instability index</td>
<td>$11 \text{ J/ K/ kg}$</td>
<td>$27 \text{ J/ K/ kg}$</td>
</tr>
<tr>
<td>Saturation fraction</td>
<td>0.88</td>
<td>0.82</td>
</tr>
<tr>
<td>Normalized GMS</td>
<td>$-0.01$</td>
<td>0.64</td>
</tr>
<tr>
<td>Mass flux</td>
<td>bottom-heavy</td>
<td>top-heavy</td>
</tr>
<tr>
<td>Vorticity maximum</td>
<td>middle levels</td>
<td>surface (weak)</td>
</tr>
<tr>
<td>Fate</td>
<td>rapid devel</td>
<td>delayed devel</td>
</tr>
</tbody>
</table>
TCS08/PREDICT: Instability index vs mid-level vorticity

![Graph showing the relationship between mid-level absolute vorticity and instability index. Points are scattered across the graph, with stars indicating specific data points for N2 and H2.](image-url)
TCS08/PREDICT: Saturation fraction vs instability index
Normalized Gross Moist Stability (NGMS)

\[ \text{NGMS} = -\left( \frac{T_R}{L} \right) \left( \frac{\nabla_h \cdot (\rho \mathbf{v}_h s)}{\nabla_h \cdot (\rho \mathbf{v}_h r)} + \rho \mathbf{v}_z s \bigg|_{\text{top}} \right) \]

- \([\chi] \): Horizontal average and vertical integral of \(\chi\).
- \(\overline{\chi} \bigg|_{\text{top}} \): Horizontal average of \(\chi\) at domain top.
- \(T_R\): Constant reference temperature; \(L\): Latent heat constant; \(\rho\): Density; \(s\): Specific moist entropy; \(r\): Water vapor mixing ratio; \(\mathbf{v}_h\): System-relative horizontal wind; \(\mathbf{v}_z\): Vertical wind.
NGMS and the mass flux profile:

- High NGMS: Top-heavy
- Low NGMS: Bottom-heavy

Diagram showing the relationship between height and mass flux with different NGMS conditions.
TCS08/PREDICT: NGMS vs mid-level vorticity
TCS08/PREDICT: NGMS vs instability index
TCS08/PREDICT: NGMS vs saturation fraction
Rain and mass flux profiles from WTG cloud simulations:

(Raymond, D. J. and S. L. Sessions, 2007)
Rain and Mass Flux Profiles (cont...)

A

- unperturbed
- $\delta \theta = \pm 0.5$ K
- $\delta \theta = \pm 1.0$ K
- $\delta \theta = \pm 2.0$ K

$\nu_y = 7$ m/s

B

- unperturbed
- $\delta r = 0.25$ g/kg
- $\delta r = 0.5$ g/kg
- $\delta r = 1.0$ g/kg

$\nu_y = 7$ m/s
Chain of causality

Increased mid-level vorticity

Decreased instability index

Convective dynamics

Horizontal and vertical shear

Increased saturation fraction

Decreased NGMS

Increased rain and energy transfer to the large scale
References

