The Role of Gravity Waves in the Formation and Organization of Clouds During TWPICE

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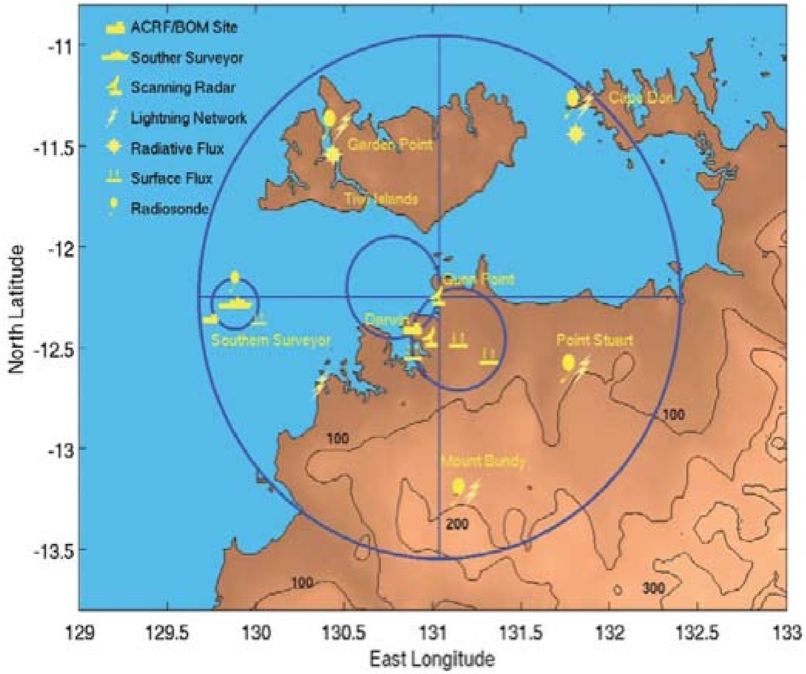
Background and Aims

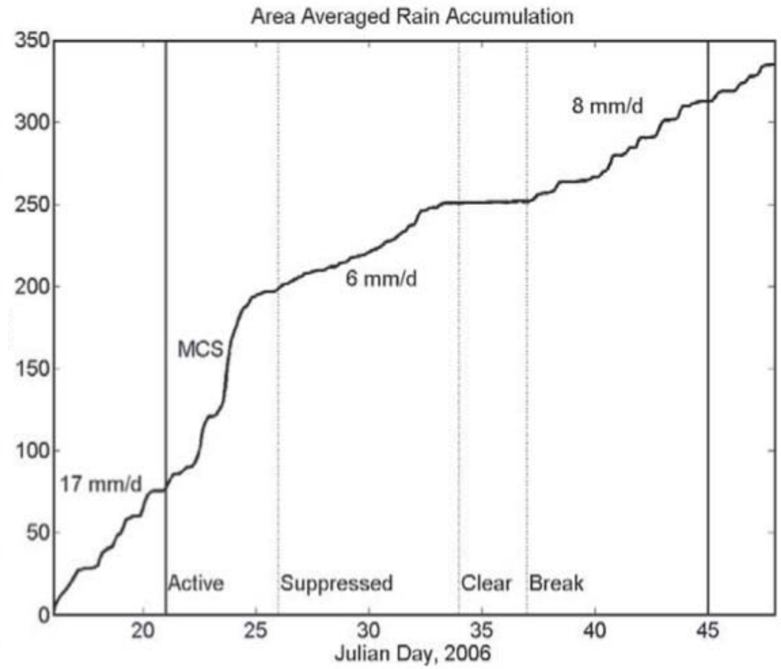
- Gravity waves generated by clouds displace air parcels vertically as they propagate away, possibly producing further cloud.
- Gravity waves transport momentum and energy large distances from the site of their generation, exerting a stress on the atmosphere wherever they dissipate.
- The project examines the part played by convectively generated gravity waves:

i. in the formation of cirrus, and
ii. in the subgrid-scale momentum transport and associated large-scale stresses imposed on the troposphere and stratosphere.

TWPICE

The project is centered on the observations taken during TWPICE.

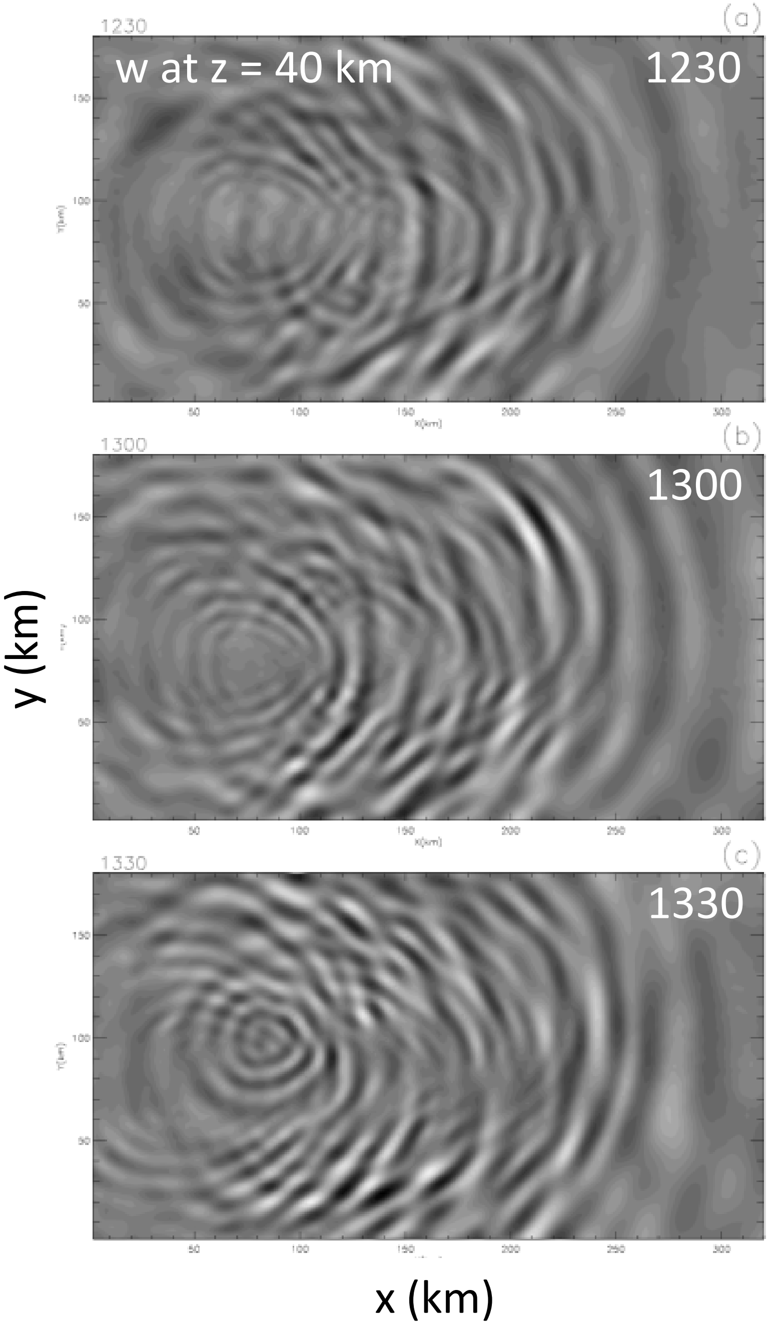




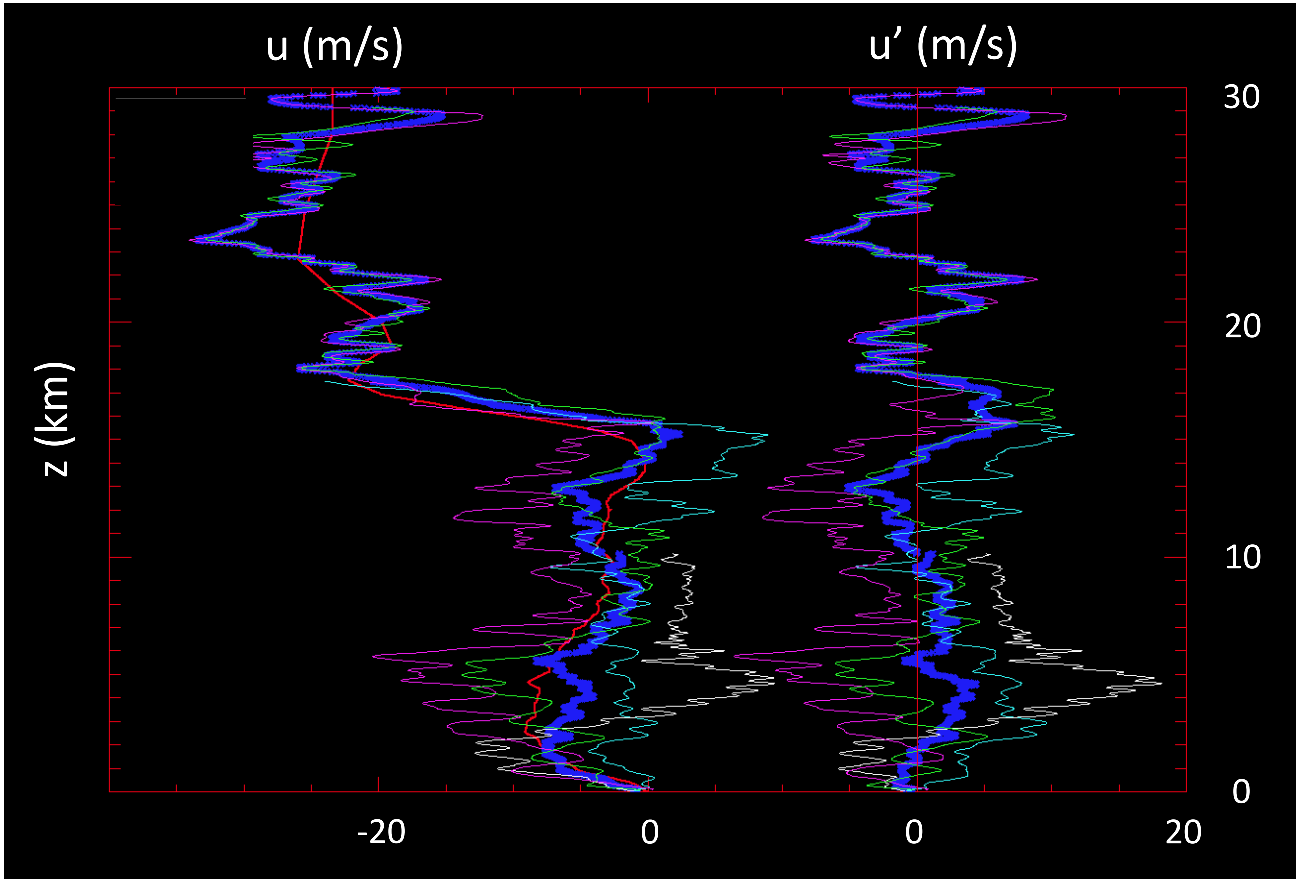
May, P. T., J. H. Mather, G. Vaughan, C. Jakob, G. M. McFarquhar, K. N. Bower, and G. G. Mace, 2008: The Tropical Warm Pool International Cloud Experiment. Bull. Amer. Meteor. Soc, 89, 629-645.

Convectively Generated Gravity Waves

- Horizontal cross section through idealized three-dimensional simulation of convection above the Tiwi Islands off Northern Australia.
- The vertical velocity at a height of 40 km is shown at (a) 1230 LST, (b) 1300 LST and (c) 1330 LST. (From Lane, Reeder and Clarke., 2001, JAS, 58, 1249 - 1274.)

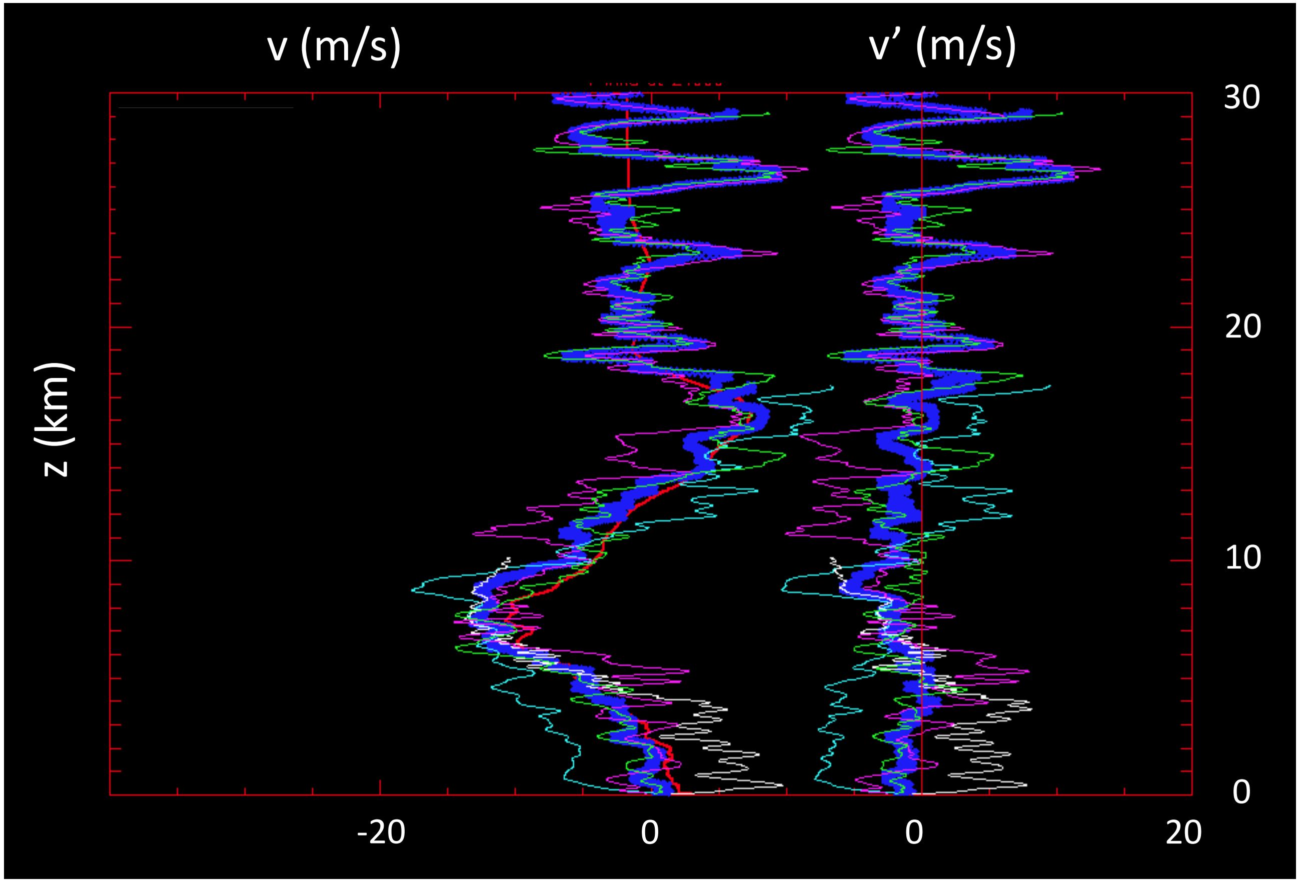


Radiosondes from TWPICE



- The perturbation profile is defined as the difference between the radiosonde profile that from the ARM variational analysis (Shaocheng Xie).
- A basic assumption is that the perturbations represent gravity waves.

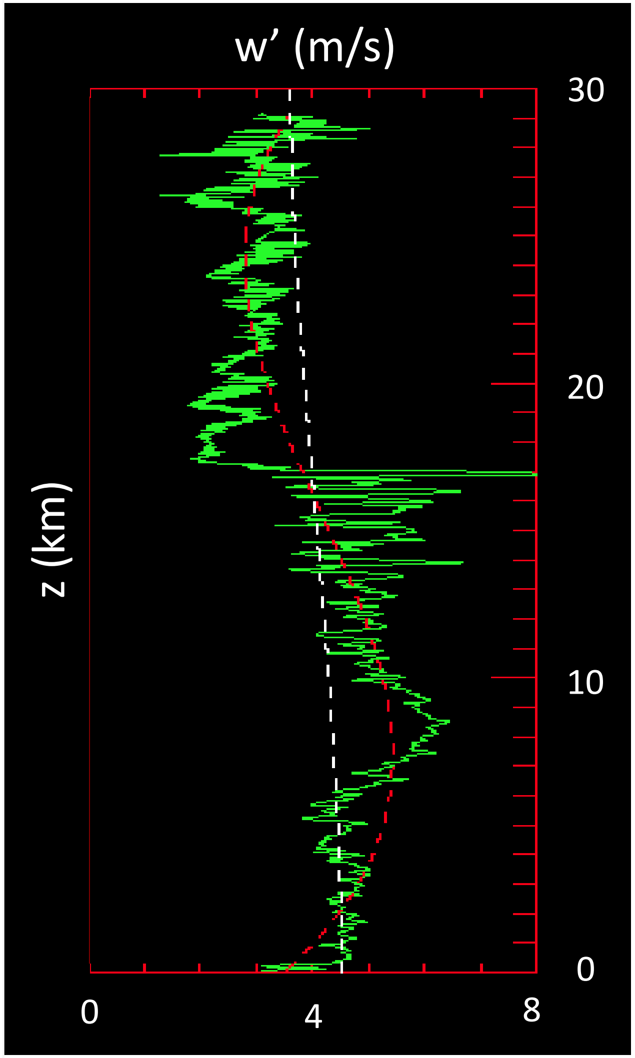
Radiosondes from TWPICE



- Gravity waves are more easily detected in the stratosphere because: (i) the density decreases with height, and (ii) the waves are marked in the troposphere by convective circulations and other weather systems.

Radiosonde from TWPICE

- The ascent rate of the radiosonde is calculated from the time derivative of the hydrostatically calculated radiosonde height.
- A cubic polynomial is fitted to and removed from each vertical profile.
- The amplitude of the vertical motion in the upper troposphere is typically 2 m/s.



Radiosonde Ascent Rate

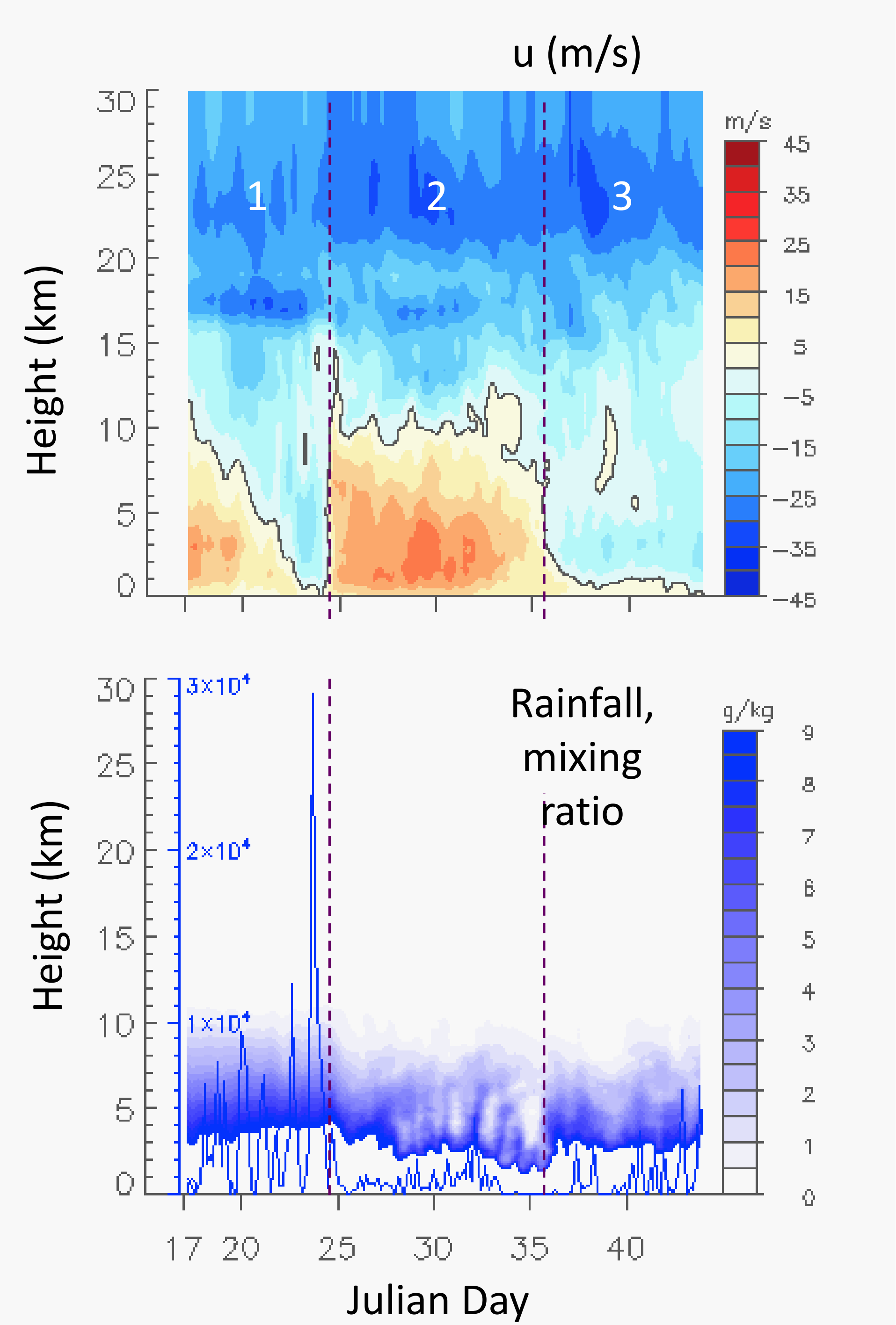
Let $$(u, v, w) = (A_u, A_v, A_w)\exp\left[i(kx + ly + mz - \omega t)\right]$$

Then $$A_w = -\frac{(kA_u + lA_v)}{m}$$

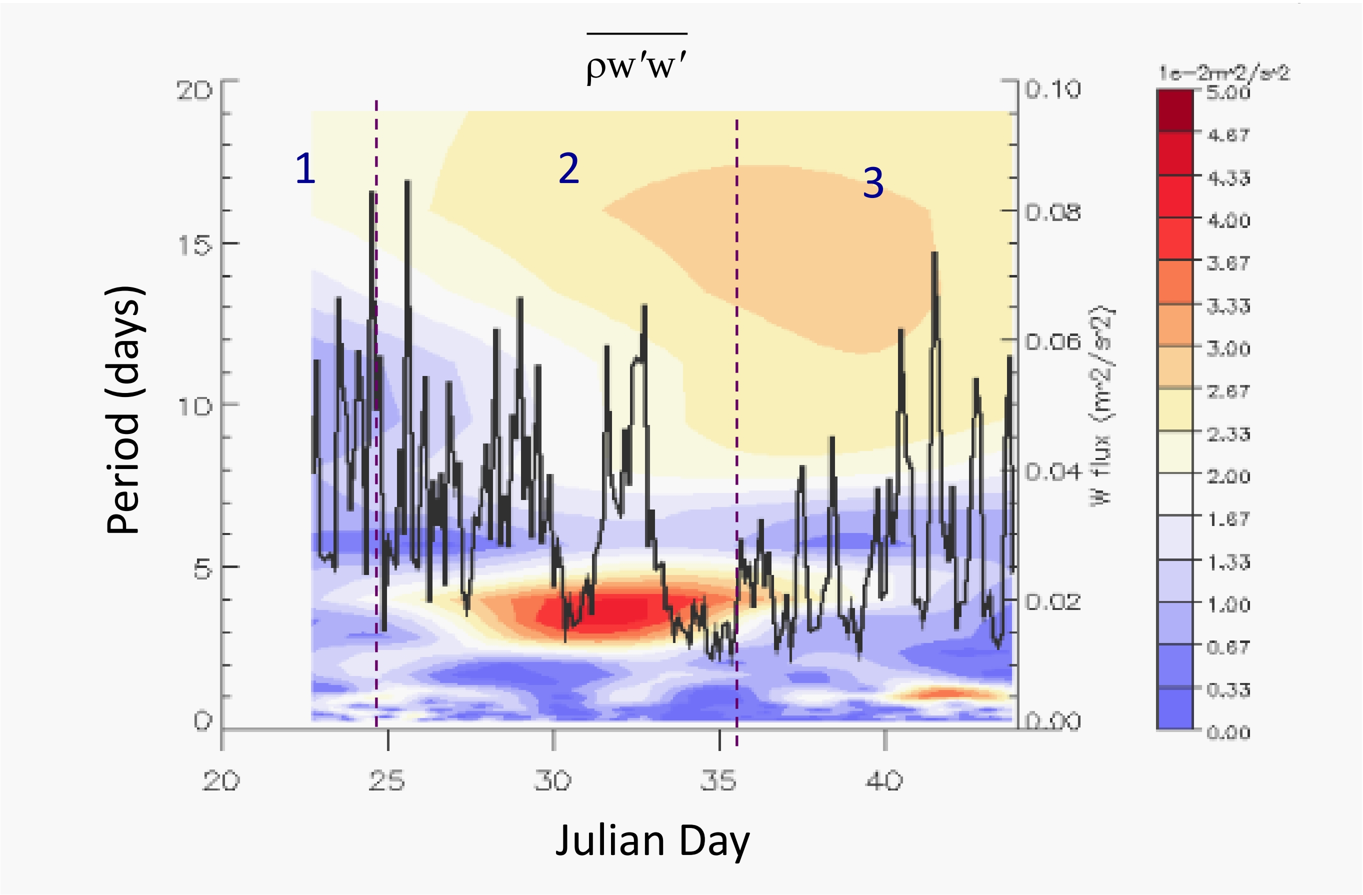
- If A_u and A_v are fixed, then $|A_w|$ increases with decreasing vertical wave number and increases with increasing horizontal wave number.
- Consequently, measurements of u and v emphasize long horizontal wavelengths, whereas measurements on w emphasize short horizontal wavelengths.

Convective Regimes

- Regime 1 – Active monsoon convection.
- Regime 2 – Suppressed convection. Strong westerlies associated with deep tropical low to the south.
- Regime 3 – Break convection. Deep easterlies.
- These periods do not coincide exactly with those defined by May et al. (2008)

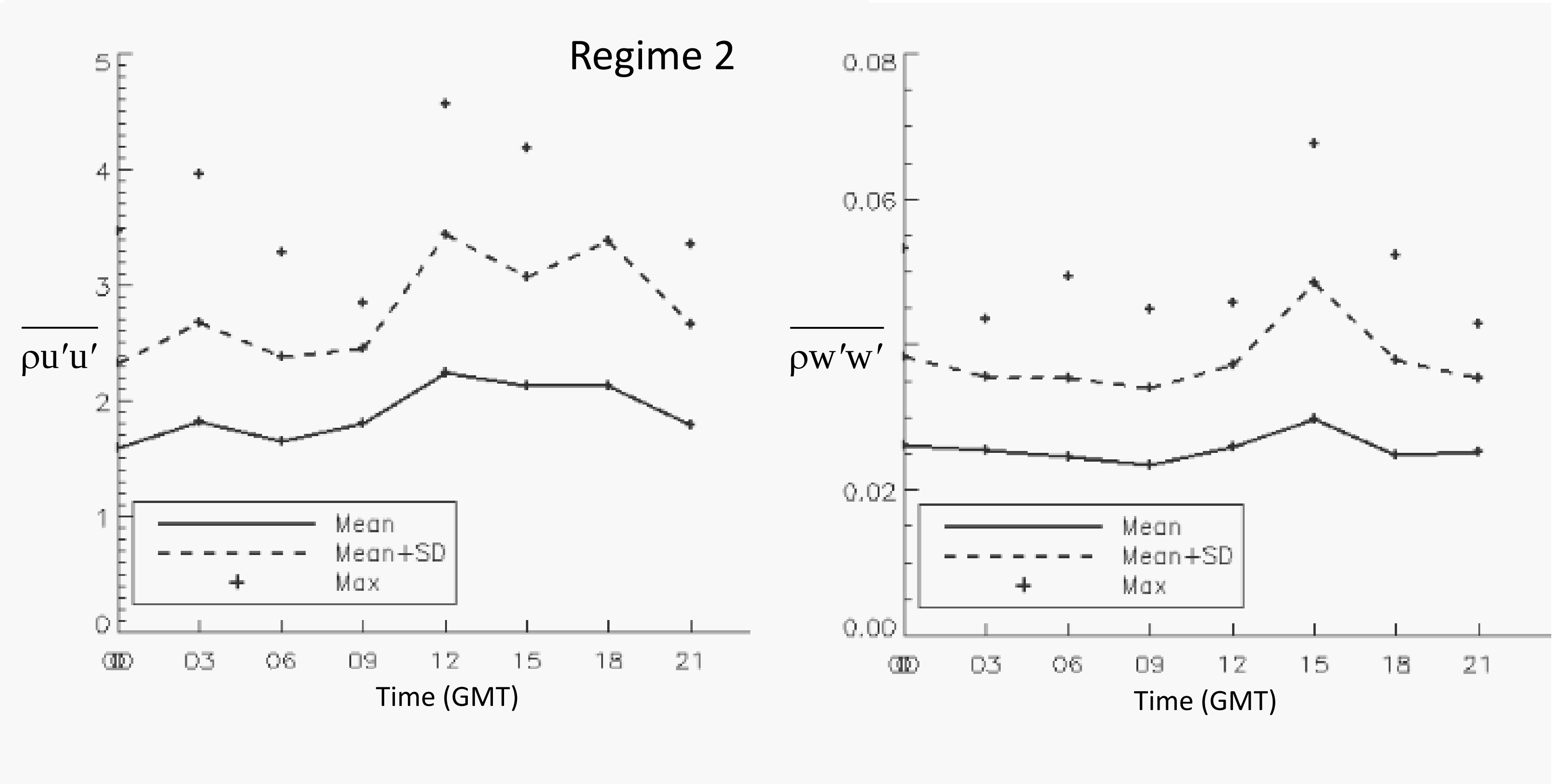


Morlet Wavelet Analysis



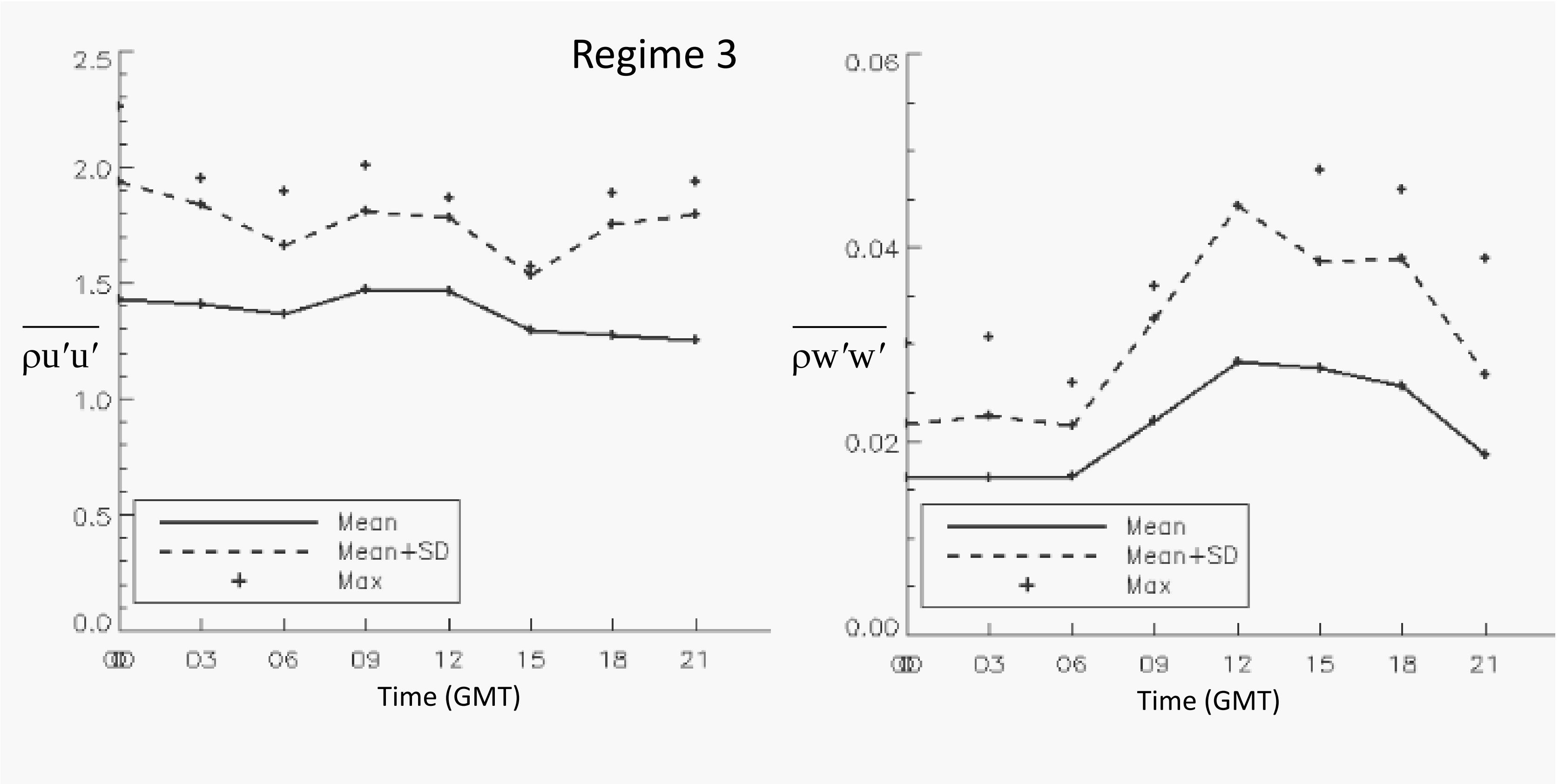
- Regime 2. The high frequency wave activity is modulated on a time scale of 3 – 4 days.
- Coincides with the passage of a very large amplitude inertia-gravity wave.
- Regime 3. Peak at 1 day.

Wave Variance from Radiosondes



- ρu'u' reflects inertia-gravity wave activity and varies little diurnally.
- ρw'w' reflects higher frequency gravity wave activity and has strong diurnal variation.

Wave Variance from Radiosondes



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Convective Generation of Gravity Waves

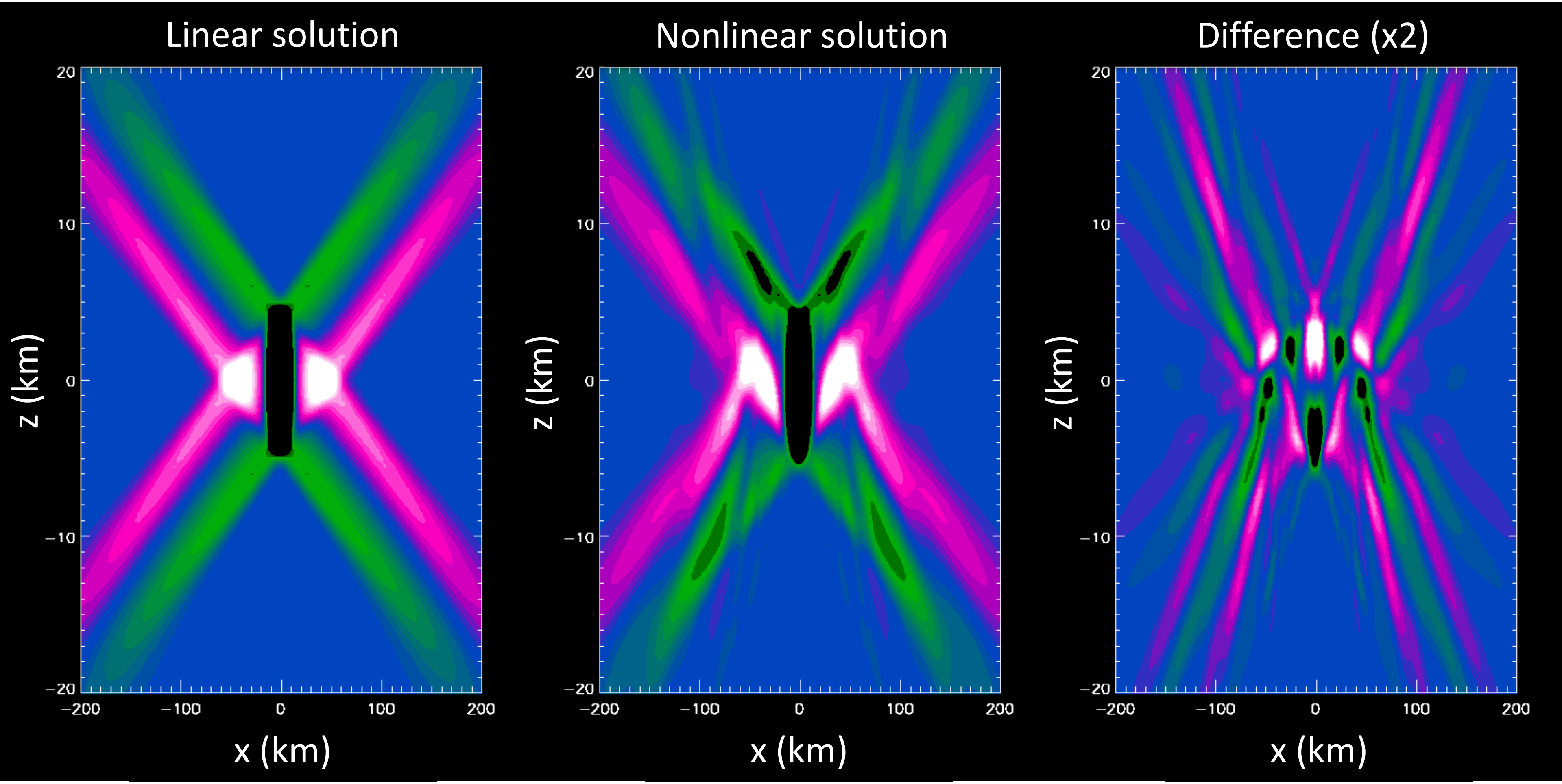
- Hypothesis: Large-amplitude, high frequency gravity waves are excited as the convective updrafts overshoot, and subsequently oscillate about, their level of neutral buoyancy (LNB).

- To the extent that the background flow is steady and horizontally homogeneous, the waves conserve their ground-based frequency and horizontal wavelength as they propagate upwards.

- Then the intrinsic frequency varies along a ray as

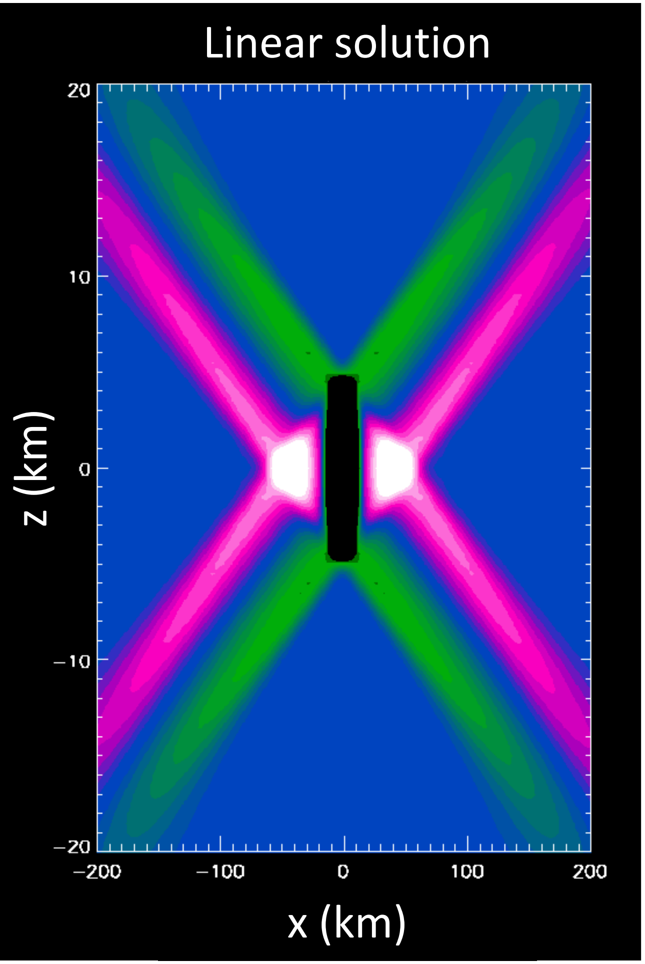
$$\hat{\omega} = \hat{\omega}_{LNB} - k\left(U - U_{LNB}\right)$$

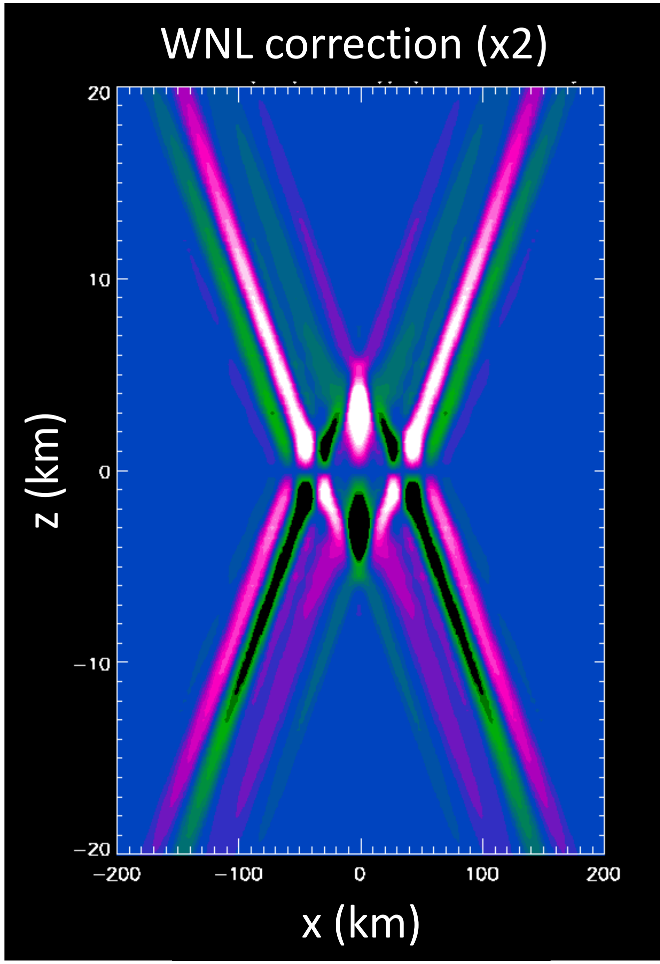
Nonlinear Theory



- Idealized 2-D, nonlinear model forced by a (periodic) diabatic heat source. (source period: 2 hours, width: 20 km, depth 10 km)
- Vertical velocity (black/green +ve, white/pink –ve)

Weakly Nonlinear (WNL) Theory





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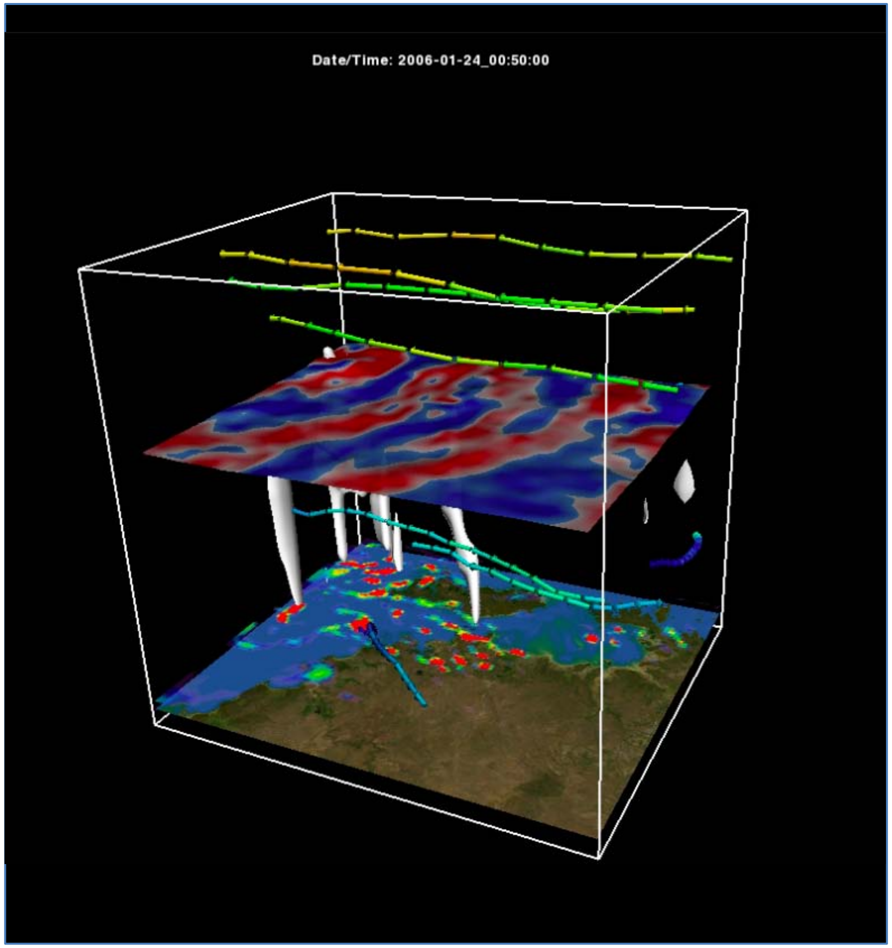
Ensemble Simulations of TWPICE

- The project uses a combination of detailed numerical simulation and analysis of the observations taken during TWP-ICE. As an example, see the numerical simulation.

- Output from the simulation will be used to drive an offline detailed microphysics calculation describing the production of cirrus.



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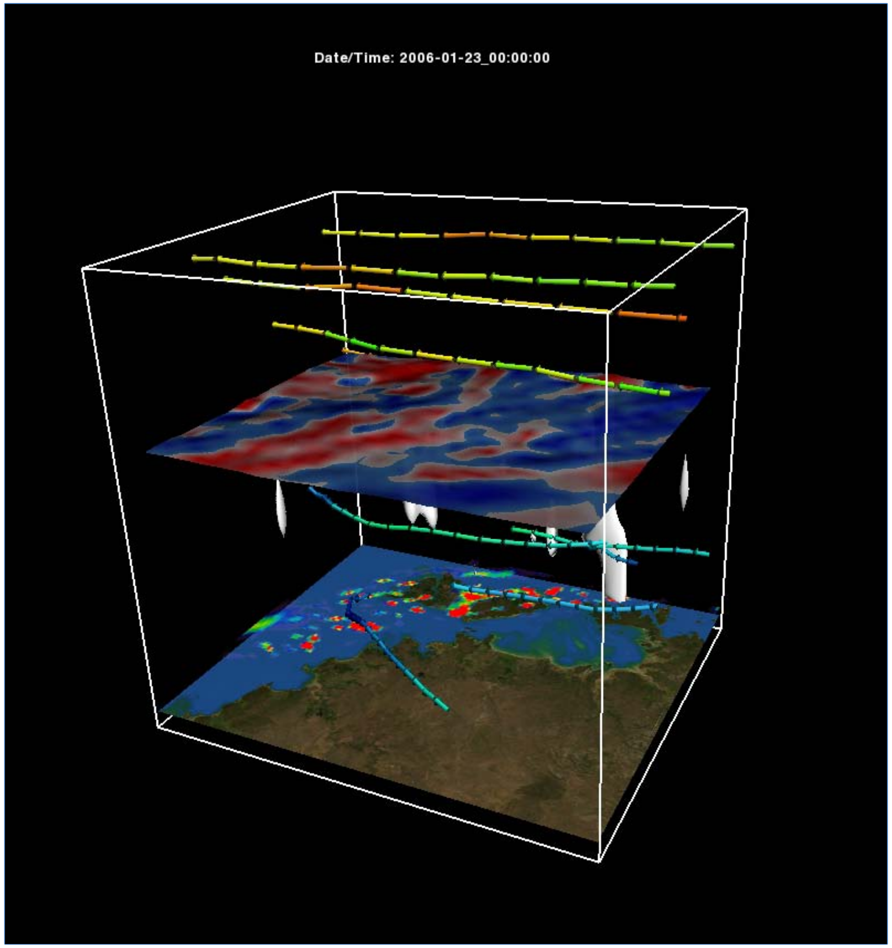
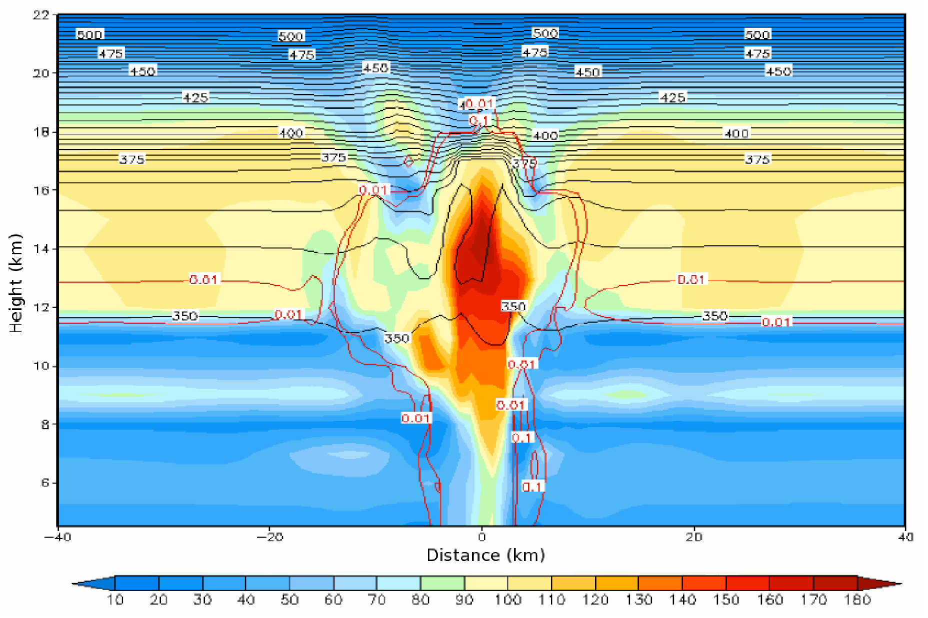


Future Direction - Formation of Cirrus

- Gravity waves have the potential to lift moist layers in the upper troposphere to produce extensive layers of cirrus.
- The vertical velocity perturbations may lead to supersaturation near the tropopause, which in turn can lead to cirrus nucleation.
- Relative humidity with respect to ice (colored) from an idealized three-dimensional WRF simulation of a deep convective cloud in a background environment observed during TWP-ICE.
- Total cloud mixing ratio (cloud water plus all ice types) contoured at 0.01 and 0.1 g/kg (red contours) with potential temperature (black contours).



Connection with the Cloud Life Cycle WG

- The project integrates:

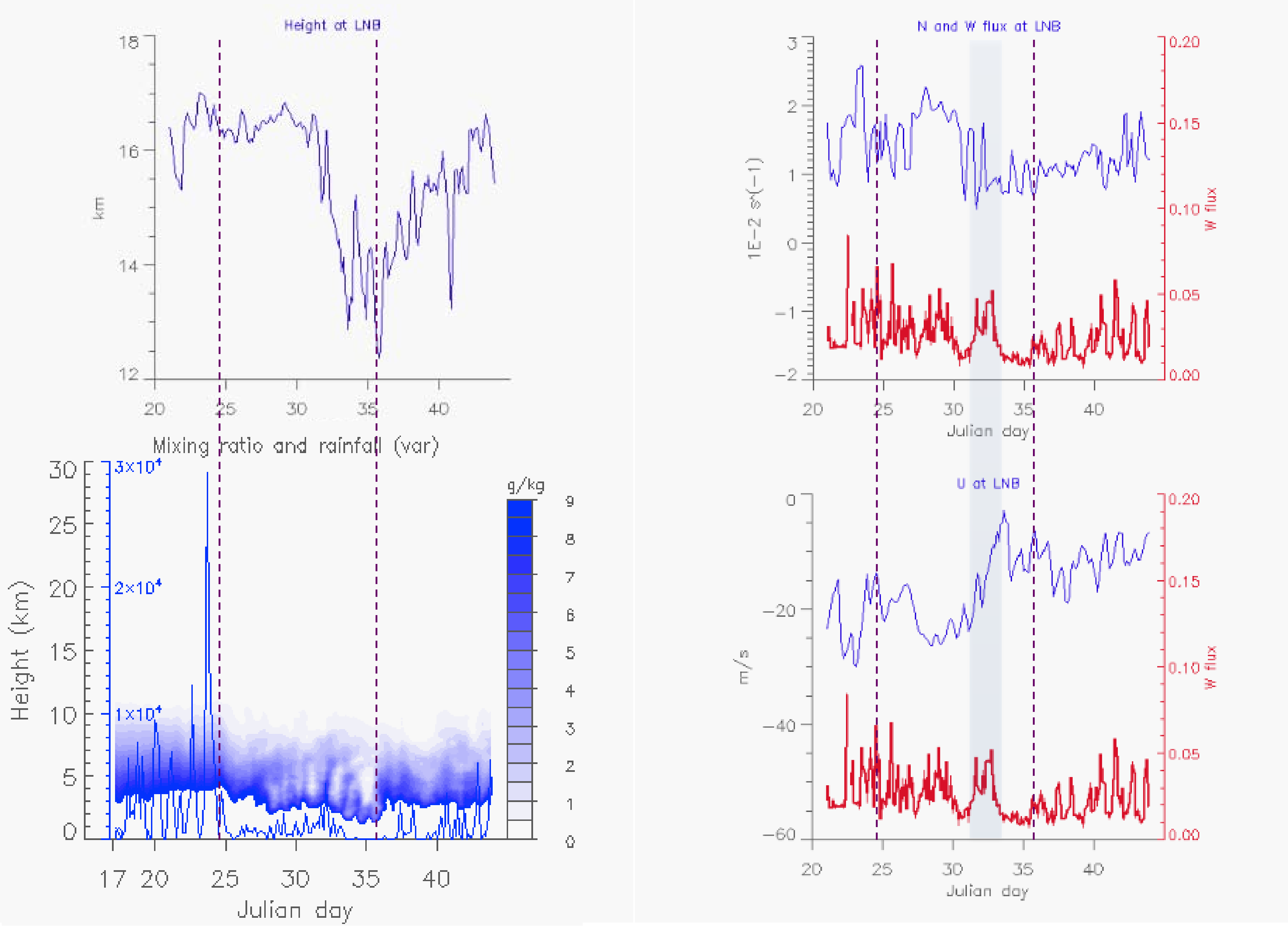
i. Observations from TWPICE
ii. Theory
iii. Numerical modeling (WRF).

- The project spans (at least) two cloud types:

i. Deep convection
ii. Cirrus.

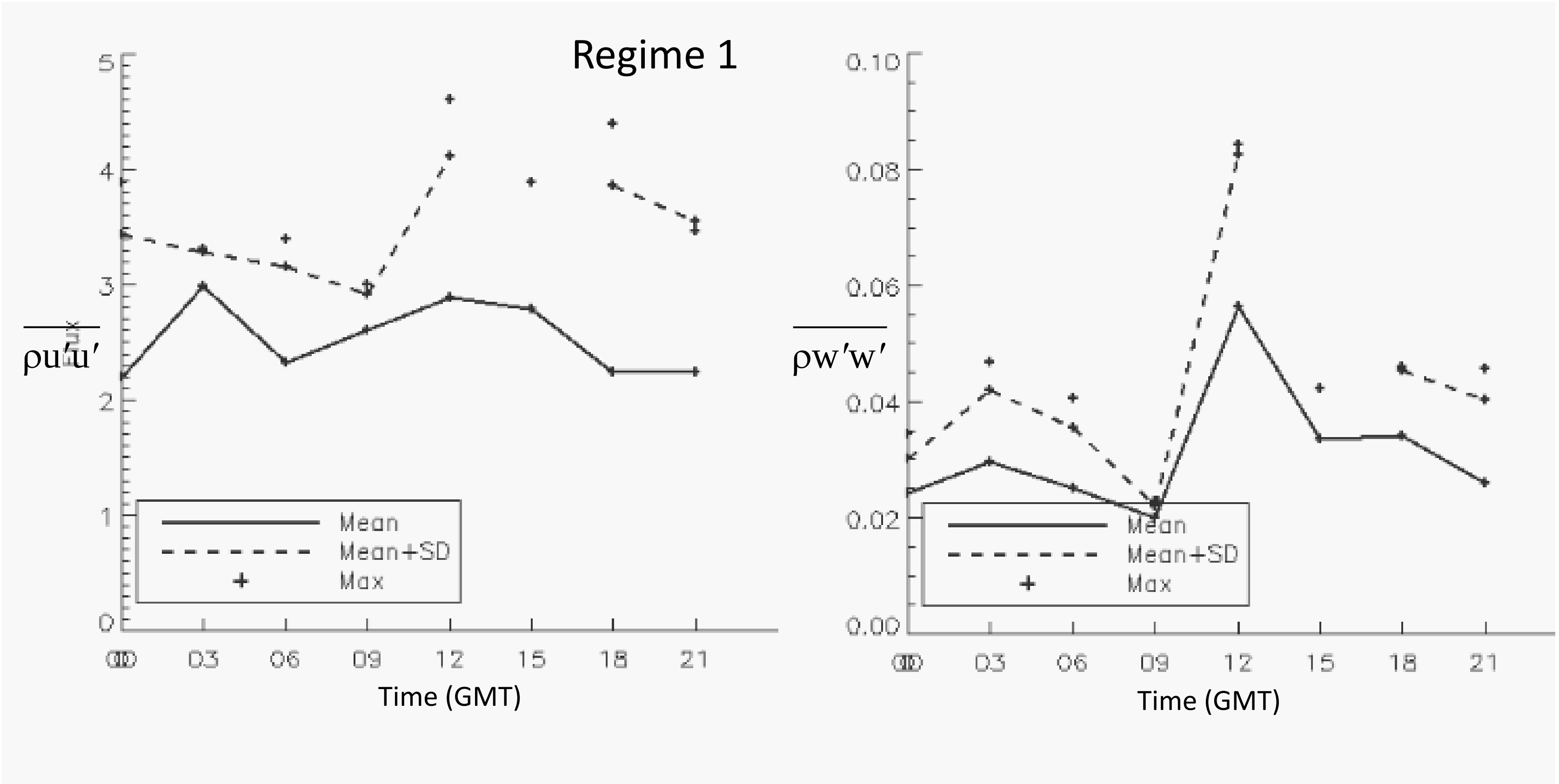
- The project informs the parameterization of:

i. Nonorographic gravity-wave drag
ii. Cirrus.



Height at LNB
km
Mixing ratio and rainfall (var)
Height (km)
g/kg
3x10⁴
2x10⁴
1x10⁴
Julian day
N and W flux at LNB
1E-2 s^(-1)
W flux
Julian day
U at LNB
m/s
W flux
Julian day

Wave Variance from Radiosondes



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