Mesoscale Gravity Wave – Convection Coupling

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1. Introduction

• Observations and numerical simulations often identify the emergence of deep convection with quasi-regular spacing of O(100 km).

• Coupling between mesoscale gravity waves and the convective cloud population is one candidate mechanism for this spacing.

• Gravity waves in the troposphere with deep vertical wavelengths are known to influence the development of deep convection through their modification of the stability of the environment (e.g., Mapes, *J. Atmos. Sci.*,1993).

• Many previous studies represented the convection as a steady heat source, which generates bore-like disturbances. In this situation, no discrete horizontal scales emerge in the cloud environment.

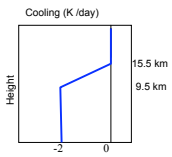
• If the convective source is assumed to be transient (which it is) then discrete horizontal wavelengths emerge.

2. Model simulation

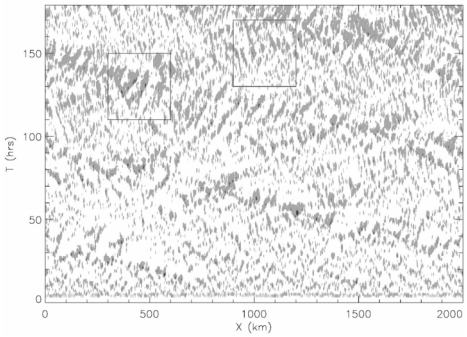
MODEL CONFIGURATION:

Idealized two-dimensional cloud-system resolving simulations similar to the configuration in Lane and Moncrieff (2008, *J. Atmos. Sci.*).

Model: Clark anelastic model (Clark 1977, *J. Comp. Phys.*)
Sounding: 1330 26/11/95 MCTEX sounding (Tiwi Is, Australia)
Domain: 2000 km wide
40 km high (top 10 km sponge)
1 km horizontal grid spacing
200 m vertical grid spacing
Periodic lateral boundaries
Surface: Free slip
Constant sensible heat flux (10 W / m^2)
Constant latent heat flux (100 W / m^2)
Simple background conditions:
Zero background wind
Imposed tropospheric cooling:

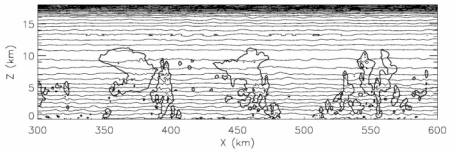


Modeled Rain Rate



• The cloud population becomes 'self organized' as it evolves, selecting its preferred regimes of organization and propagation.

• Clouds are relatively weak and extend over about 2/3 of the depth of the troposphere - similar to oceanic convection.

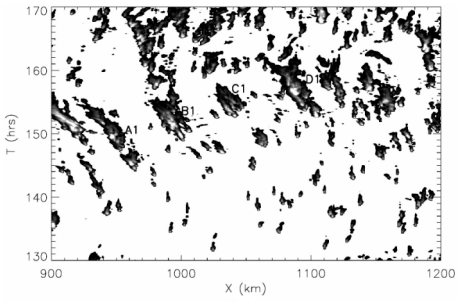


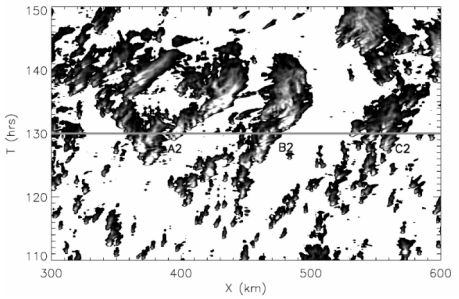
Cross-section in region of active convection (left box above).

3. Emergent characteristic scales

• Quasi-regular horizontal cloud spacing emerges at many times and locations in the model simulation, embedded within broader scale regions of organization / propagation.

• E.g., cloud water mixing ratio at 5 km for two periods / locations:

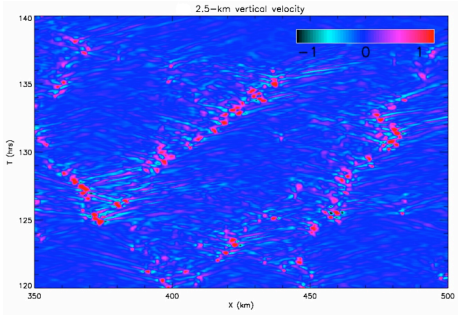




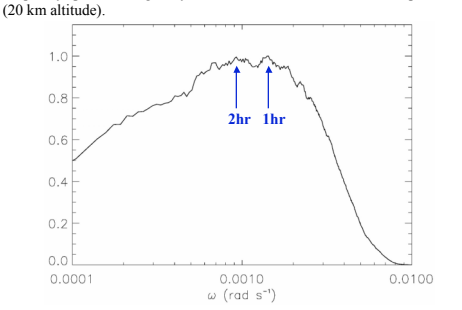
• Shorter lived systems emerge with a spacing ~50 km, longer lived systems are spaced ~100 km apart.

• The vertical velocity identifies the prevalence of a characteristic convective timescale from 1-2 hours. This timescale is presumably determined by the thermodynamics.

• The convective timescale is defined by the lifecycle of convective updrafts within the convective system. It also helps define the frequency of gravity waves generated by the convection.

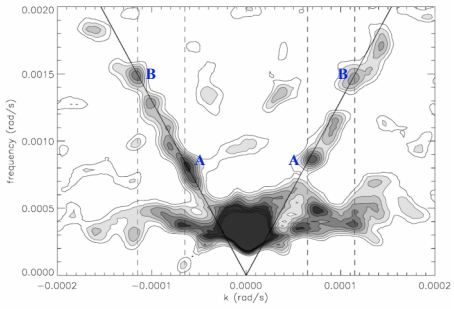


• The characteristic convective timescale defines the peaks in the frequency spectrum of gravity wave momentum flux in the stratosphere (20 km altitude).



4. Gravity wave – convection coupling

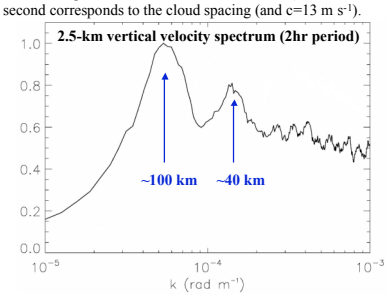
• To explore the characteristics of the cloud field, it is analyzed using a similar method to Wheeler and Kiladis (1999, *J. Atmos. Sci.*). The frequency-wavenumber spectrum of the 5-km cloud water is calculated and divided by a smoothed version of this spectrum to identify the peaks.



• At timescales less than ~5 hours, the peaks in the cloud spectrum occur along the lines in frequency / wavenumber space that correspond to c = ω/k =±13 m s^{-1}. The convection is coupled to gravity waves with this speed.

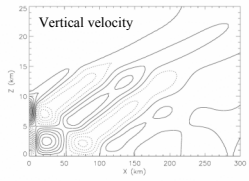
• Isolated peaks in the spectrum exist at:
A. Period: ~2 hr, Wavelength: 120 km
B. Period: ~1 hr, Wavelength: 60 km
These are consistent with the spacing of the longer-lived and shorter-lived systems, respectively.

• At these periods, each vertical velocity spectra features a double peak. The first corresponds to twice the width of clouds (i.e., the wave source), the second corresponds to the cloud spacing (and c=13 m s^{-1}).



• Using the hydrostatic dispersion relation, c=13 m s^{-1} corresponds to a vertical wavelength of about 10 km in the troposphere. This wavelength is approximately equal to the depth of the convection and 2/3 of the depth of the troposphere. It is often referred to as the n=3 mode.

• Wave theory and idealized simulations show that an isolated transient source, like that of the individual clouds in the moist simulation, will readily generate these n=3 modes. The horizontal wavelength of the n=3 mode is constrained by the vertical wavelength and the source period (convective lifecycle) via the dispersion relation.



Idealized simulation:
Source period: 2hrs
Source width: 20 km
Source depth: 10 km
Stratiform heating / cooling

Summary of wave - convection coupling process:
• Clouds in the population all have similar convective lifecycles & depths.
• These clouds generate deep tropospheric gravity waves with periods equal to the convective lifecycle and vertical wavelengths that are harmonics of the depth of the troposphere and partly determined by the depth of the convection.
• In this case, 10 km vertical wavelength waves (n=3) with periods of 2 hours were dominant.
• With the period and vertical wavelength determined, the horizontal wavelength is constrained by the dispersion relation (100 km in this case).
• As the cloud population evolves, the clouds becomes self-organized so that their separation matchs the wavelength of the deep tropospheric modes; they then become coupled.
• Work is continuing, examining other scenarios and the influence of 3D.