December 15, 2015

Abstract

1 Background

It has been known for some time that convectively generated gravity waves feed back on the organisation of tropical convection (5). Remote momentum and temperature changes in the troposphere, communicated through the propagation of convectively generated gravity waves, condition the troposphere for further convection triggering or suppression (2). The role of gravity waves in the convection adjustment process was further investigated by Mapes (3), who details the “gregarious” nature of mesoscale tropical convection due to the evolution of gravity bores, which displace low-level parcels upward.

The work of Nicholls quantitively details the importance of mode 1 and 2 gravity waves in adjusting the neighbouring cloud-free environment. Using a 2D CRM, Lane and Reeder (ref) later showed that indeed a mode 3 gravity waves plays a large role in modifying CIN in the neighbourhood of convection.

Shutts and Gray use a numerical model investigate the role of Coriolis. Shutts and Gray examined the role of gravity waves in adjusting the environment of isolated clouds in highly rotating frames.

How gravity waves propagate into the stratosphere is well documented. (1) show how high freq gravity waves in stratosphere above a storm show good correlation between vertical wavelengths of gravity waves and depth of convective heating.

However, despite a number of idealised studies, questions remain about the role of gravity waves in the troposphere.

In an attempt to leave no stone unturned in constructing a complete picture, we revist the theory of forced gravity waves in the hope of attaining quantitive understanding in previously neglecting aspects to the problem. Using a linear, 2D, Boussinesq atmosphere, which is forced with a sensibly prescribed heating term, we find an analytic solutions for vertical velocity, w, and potential temperature, b. The effect of Coriolis are reserved for a subsequent paper. We apply a similar technique to (4), who investigates the qualtitive upward flux of energy in a system with a high rigid lid. Having an analytic solution allows us to cut computing cost, and raise the lid into a regime where we have a purely radiating solution (i.e. the group speed of the gravity waves is not large enough to rebound off the lid within our time domain). We use this toy model to address the following questions:

- What are the sensitivities to the horizontal lengthscale of heating in the far field response?

- What are the consequences of a transient heat source?

This paper directly addresses such questions, mainly through the inspection and quantification of difference plots between selected configurations of our toy model. Section 2 will detail the mathematics of our solution. Section 3 includes results from simulations probing the effect of horizontal lengthscale, and transient effects of heating respectively. Section 4 contains a summary and discussion.

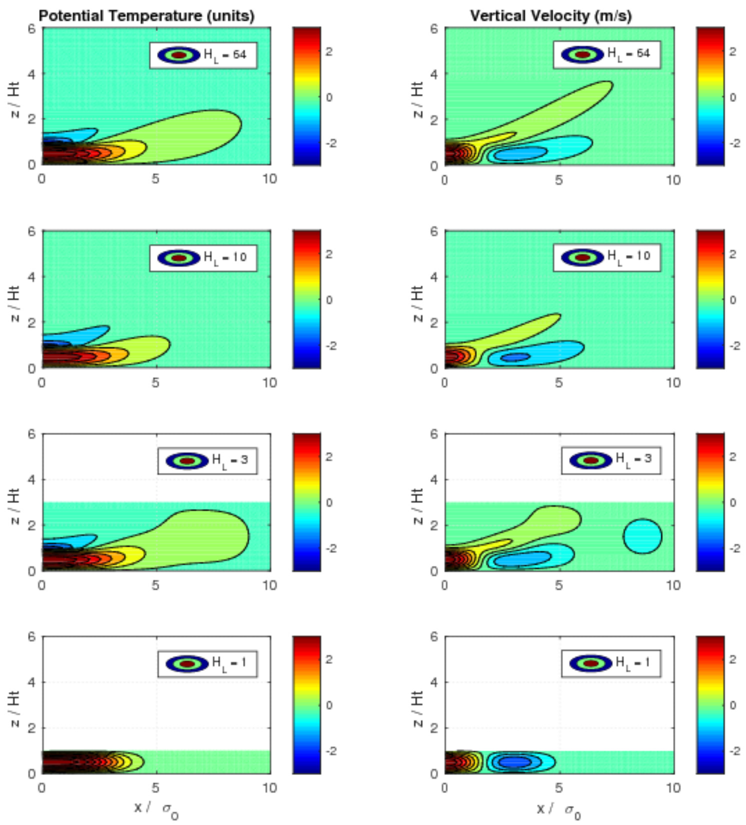
2 Results

Throughout this results section, we present model data for the vertical velocity, w, and potential temperature, b fields, since both are influential in the organisation convection. Any region with positive w, and high b is likely to trigger convection, with the opposite likely to suppress triggering.

2.1 The Effect of Raising the Position of the Rigid Lid Upper Boundary Condition

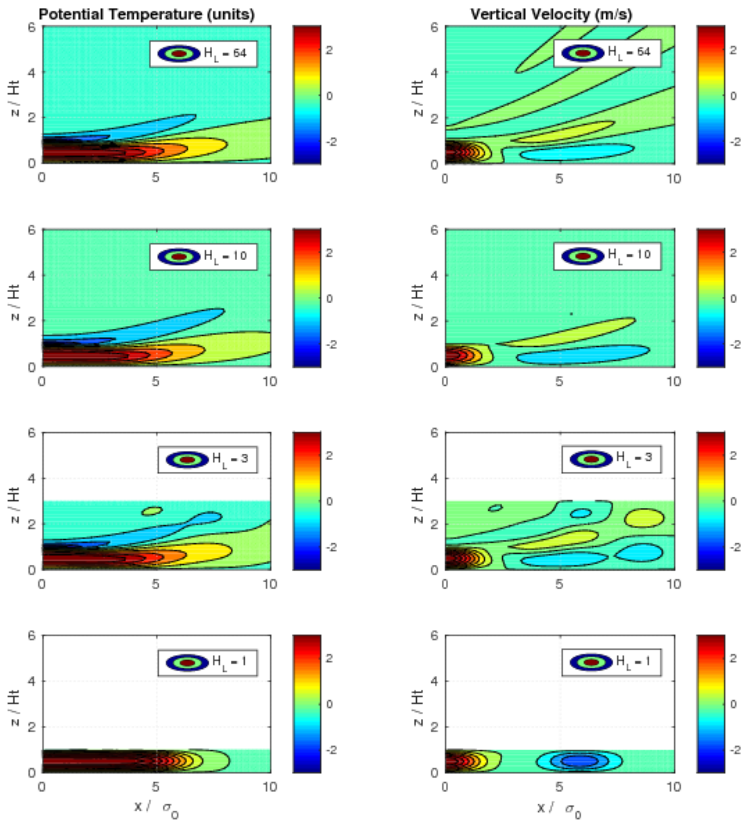
Figure (1) depicts the effect of increasing the altitude of the upper lid. We observe the distribution of energy increases aloft, indicating a radiative effect. Quantitative insights into the upward flux of energy may be obtained from this data. For example, it appears that as the lid height increases the vertical flow at the top of plot windows becomes more uniform.

Figure 1:



Along with figure (2) we note the horizontal evolution of the w-response,

Figure 2:



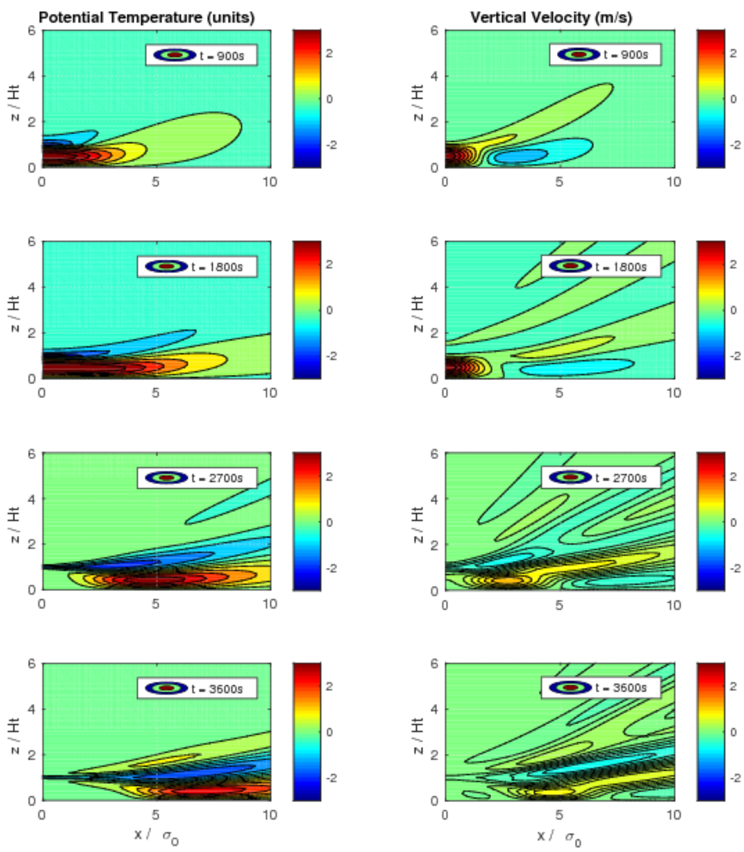
which is characterised by modes with phase speed $\frac{NH}{j\pi}$ (recall j is the vertical harmonic number) is qualitatively unaffected by the process of raising the lid. The vertical structure however varies considerably more between $H_L = 1$ and $H_L = 3$ than it does between $H_L = 10$ and $H_L = 64$ which is indicative of convergence of the w and b solution (at least in the troposphere). We also note that as the height of the lid increases the influences of the heating excite a deeper mode, characterised by a larger horizontal phase speed, as expected. The confining effect of the lid intensifies subsidence in the troposphere, meaning neighbouring convection is unlikely to be triggered. However, continuity considerations suggest enhanced triggered elsewhere. In the present case, we observe the only candidate region for this amplified ascent would be the heated region. We note that the horizontal suppression of convection is more locally intense, but less mobile, in the trapped cases.

One can better understand the time evolution of the system through figure HERE

2.2 Transient Heating

Assigning the time dependence of the heating function to be a simple boxcar function (on/off), we investigate the influence of a transient heat source. Figure (3) shows the w and b response field to such transient heating which is switched off at a time $t = 30mins$ (a reasonably realistic convection timescale, note). Advancing down the panels, we evolve at a time step of 15 minutes.

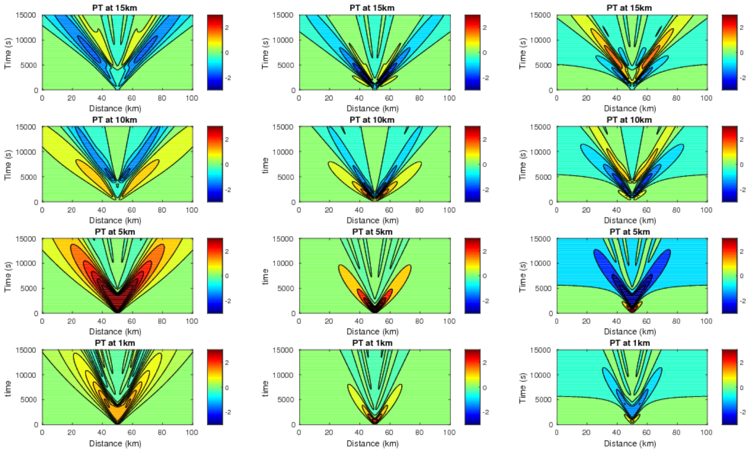
Figure 3:



The most notable effect of truncating heating is the occurrence a propagating region of ascent in the troposphere (as seen in figure (4)), which is absent in all the steady heating cases considered previously.

HERE The reader is directed to the top right hand panel of figure (2.4), in the region of $x = 2$. Counterintuitively, this bservation appears to suggest that terminating heating could trigger a weak convective event in the neighbourhood.

Figure 4:



2.3 TO INCLUDE

References

[1] Alexander, M., Holton, J. R., and Durran, D. R. The gravity wave response above deep convection in a squall line simulation. *Journal of the atmospheric sciences 52*, 12 (1995), 2212–2226.

[2] Bretherton, C. S., and Smolarkiewicz, P. K. Gravity waves, compensating subsidence and detrainment around cumulus clouds. *Journal of the Atmospheric Sciences 46*, 6 (1989), 740–759.

[3] Mapes, B. E. Gregarious tropical convection. *Journal of the atmospheric sciences 50*, 13 (1993), 2026–2037.

[4] Nicholls, M. E., Pielke, R. A., and Cotton, W. R. Thermally forced gravity waves in an atmosphere at rest. *Journal of the atmospheric sciences 48*, 16 (1991), 1869–1884.

[5] Wheeler, M., and Kiladis, G. N. Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain. *Journal of the Atmospheric Sciences 56*, 3 (1999), 374–399.

Figure 5:

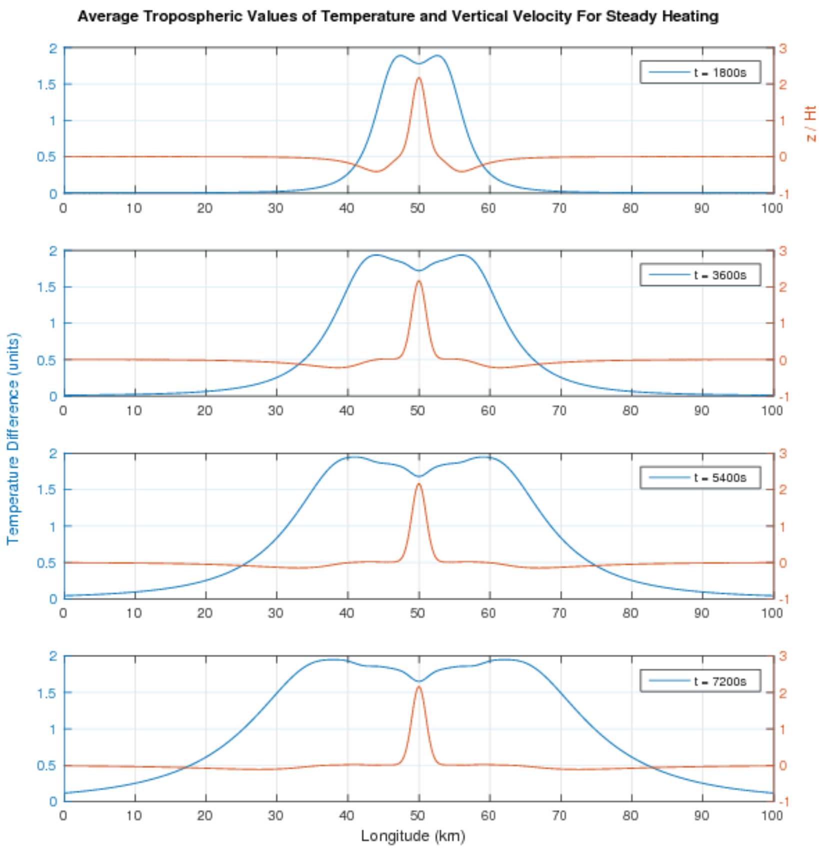
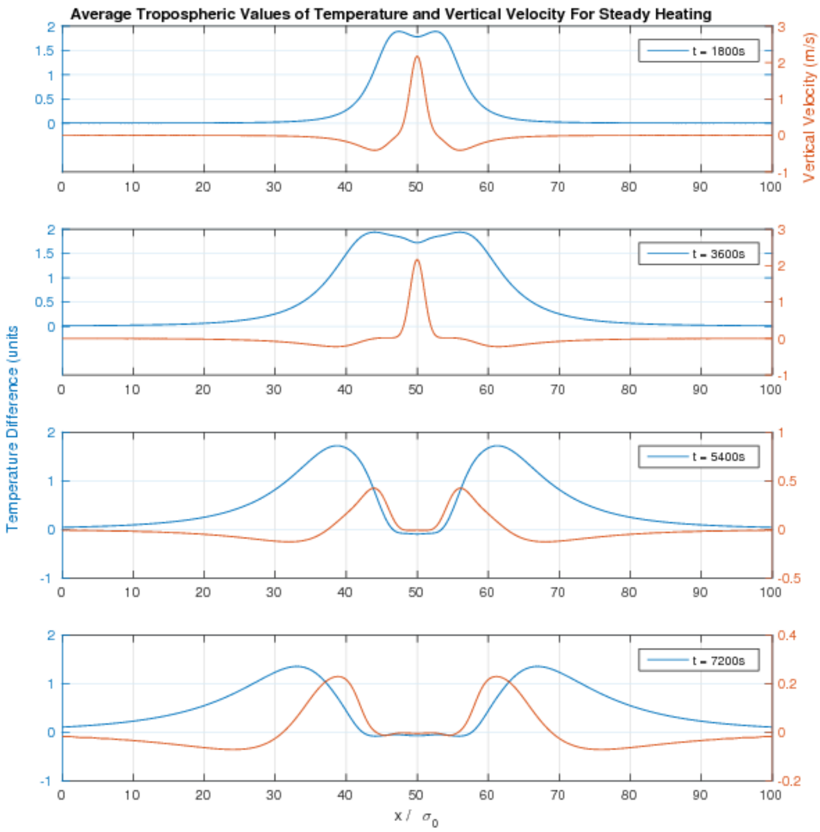
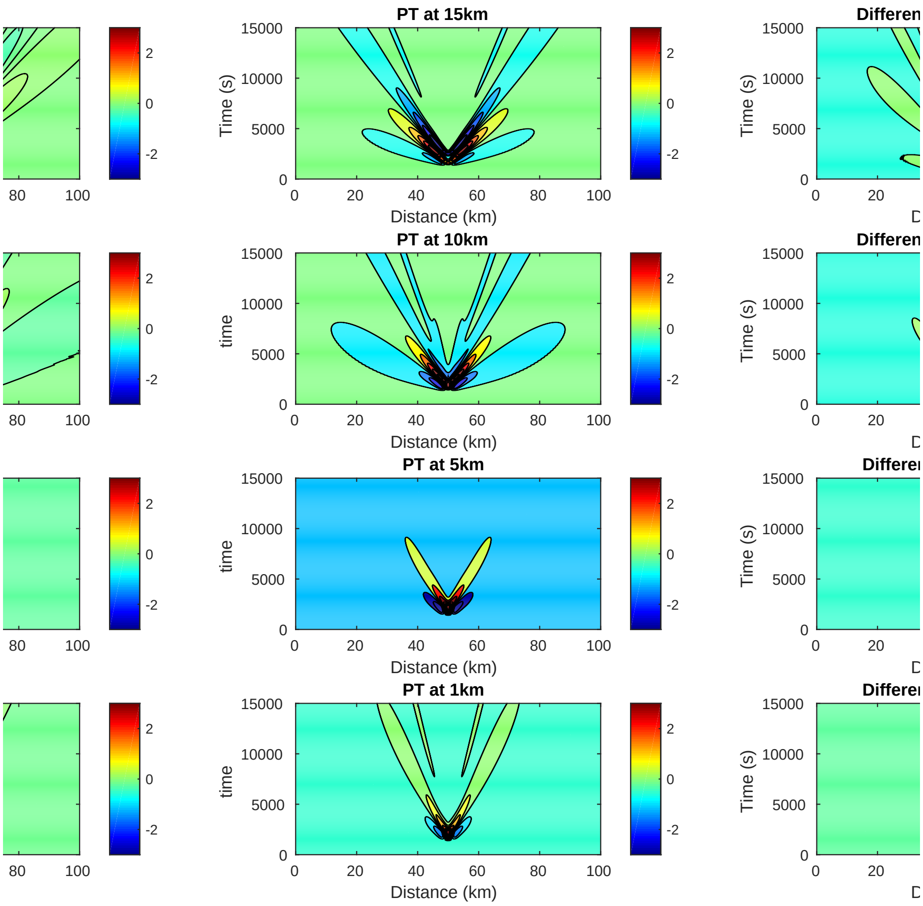

Average Tropospheric Values of Temperature and Vertical Velocity For Steady Heating
t = 1800s
t = 3600s
t = 5400s
t = 7200s
Temperature Difference (units)
z / Ht
Longitude (km)

Figure 6:



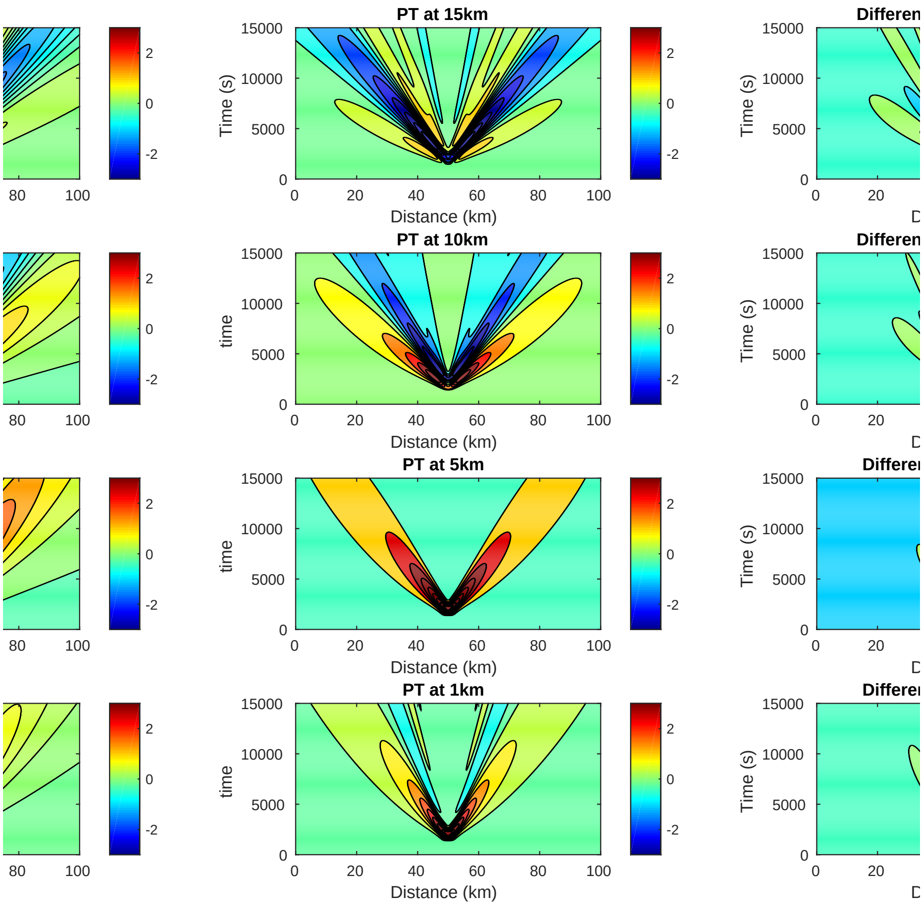
Average Tropospheric Values of Temperature and Vertical Velocity For Steady Heating
t = 1800s
t = 3600s
t = 5400s
t = 7200s
Temperature Difference (units
Vertical Velocity (m/s)
x / σ0

Figure 7:



PT at 15km
PT at 10km
PT at 5km
PT at 1km
Differen
Time (s)
time
Distance (km)

Figure 8:



PT at 15km
PT at 10km
PT at 5km
PT at 1km
Differen
Differen
Differe
Differe
Time (s)
time
Distance (km)
15000
10000
5000
0
20
40
60
80
100
2
0
-2