Non-stationery trapped gravity lee waves, and their impact on the large-scale

Matt Hills and Dale Durran

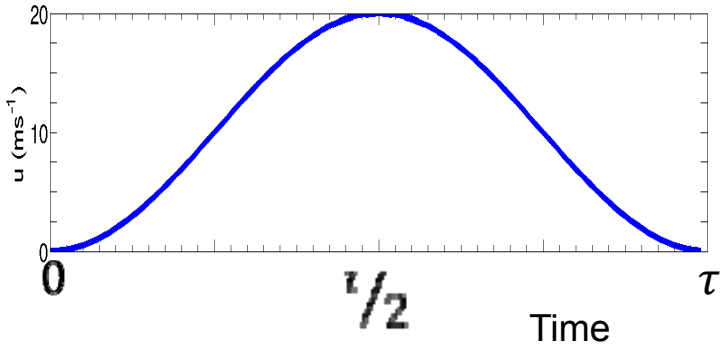
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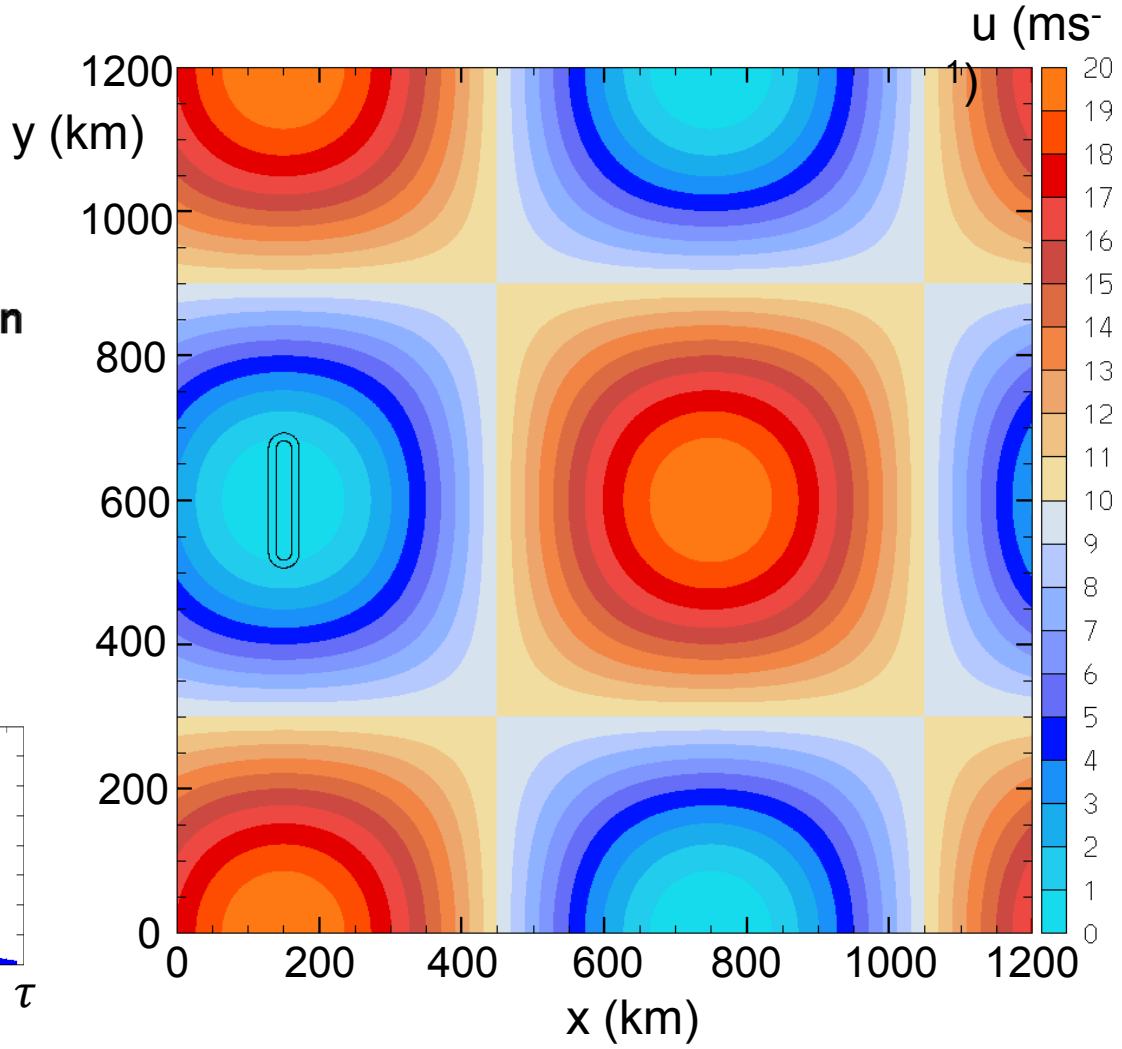
Introduction

- Possible ways for trapped lee waves to decay:
  - Dissipation
  - Leakage
  - Untrapping (ie. become vertically propagating)
- Impact on large scale depends on type of decay
- Goals:
  - How trapped waves evolve in a time-varying flow.
  - How the large-scale flow is modified by the waves.

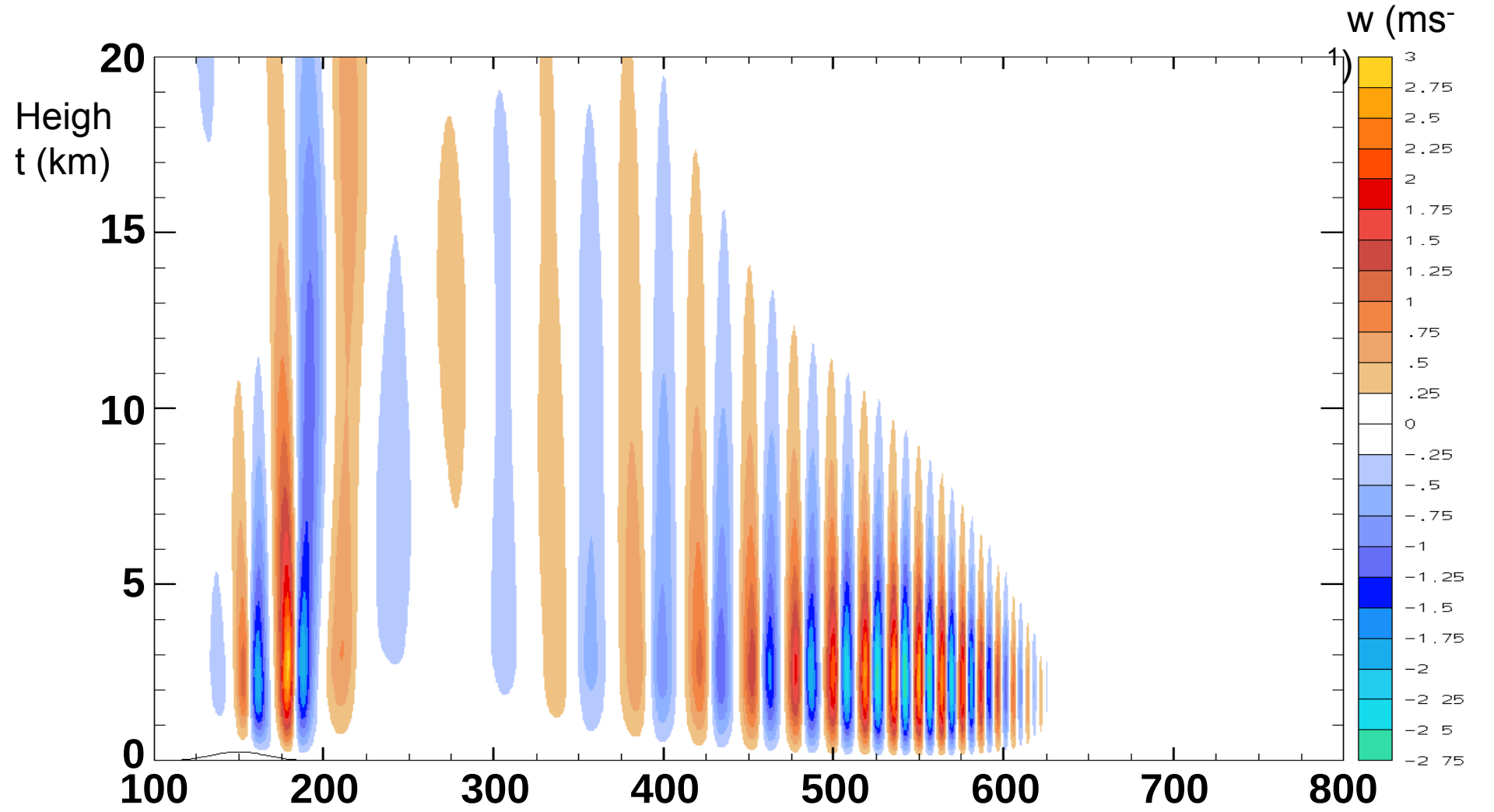
Model setup

- 1200km x 1200km horizontal domain.
- 20km vertical depth.
- Translating square-wave slowly crosses the mountain
  - τ = 33.3 hours.
- Stability interface at 3km
  - $N_L = 0.0118s^{-1}$, $N_U = 0.003s^{-1}$.





Vertical velocity animation



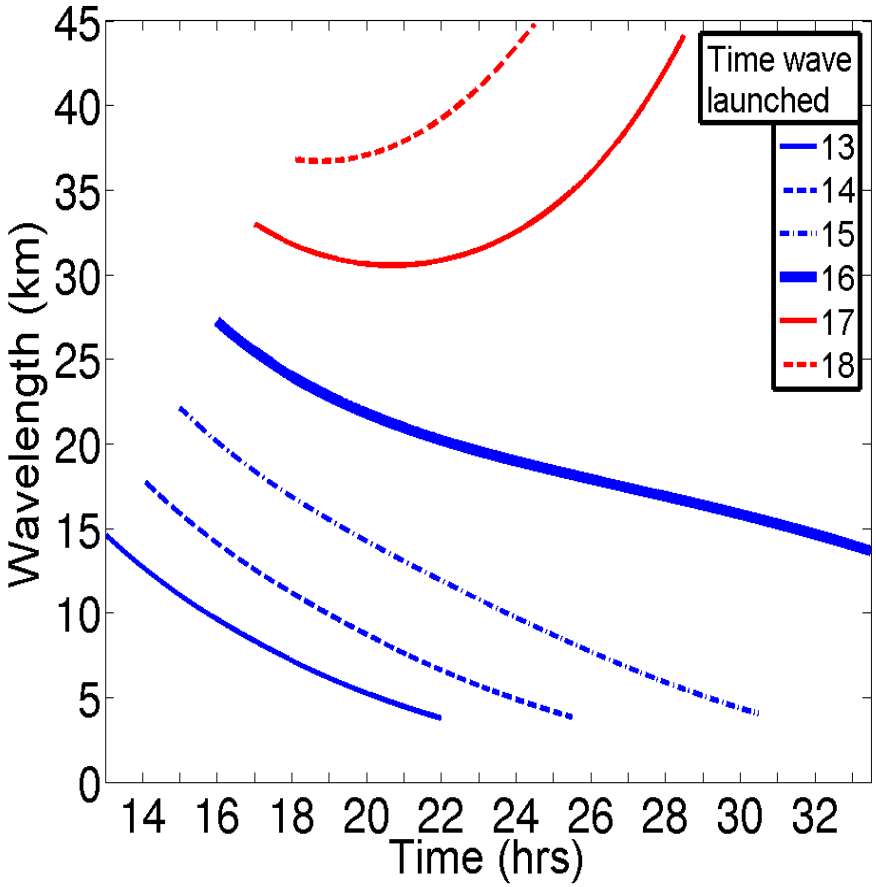
Ray tracing

- Wave packets have been followed through the simulation using ray tracing.
  - Packet motion assumed 2D(x,t).
- Dispersion relation: $cot(S_L d) = -\frac{S_U}{S_L}$, where $S_U = \left(k^2 - \frac{N_U^2}{(c-\bar{u})^2}\right)^{\frac{1}{2}}$ and $S_L = \left(\frac{N_L^2}{(c-\bar{u})^2} - k^2\right)^{\frac{1}{2}}$
- Group velocity: $c_{g_x} = \bar{u} + \frac{S_L^4 S_U d(c-\bar{u})^3}{N_L^2 S_L^2 S_U d + k^2(N_L^2 - N_U^2) sin^2(S_L d)}$
- Parameters of interest: wavelength, position, and intrinsic frequency ($\tilde{\omega}$).
  - Waves are trapped provided: $N_U < |\tilde{\omega}| < N_L$, where $\tilde{\omega} = (c - \bar{u})k$.

Ray tracing

- Decaying waves are untrapped by the background flow slowly varying with time.
  - Untrapping can be described by: $\frac{D\tilde{\omega}}{Dt} = k\frac{D\bar{u}}{Dt}$, where $\frac{D}{Dt} = \frac{d}{dt} + \bar{u}\frac{d}{dx}$
    - Before peak flow at mountain top, this says $\frac{D\tilde{\omega}}{Dt} < 0$, and $\tilde{\omega}$ remains bounded throughout the simulation.
    - After peak flow at mountain top, this says $\frac{D\tilde{\omega}}{Dt} > 0$, meaning $\tilde{\omega}$ eventually leaves the bounds, and waves become untrapped.
- Behavior is seen to be highly dependent on the structure of the background flow.

Ray tracing


Wavelength (km)
Time (hrs)
Time wave launched
13
14
15
16
17
18

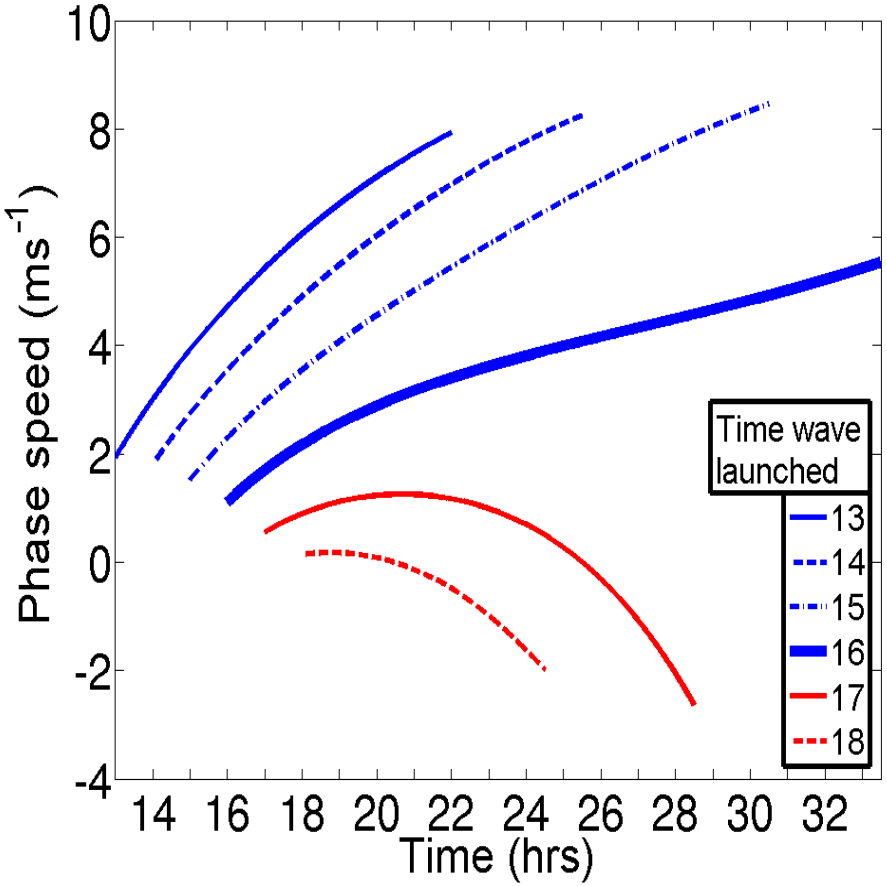

Phase speed (ms^{-1})
Time (hrs)
Time wave launched
13
14
15
16
17
18

Illustration of wave untrapping

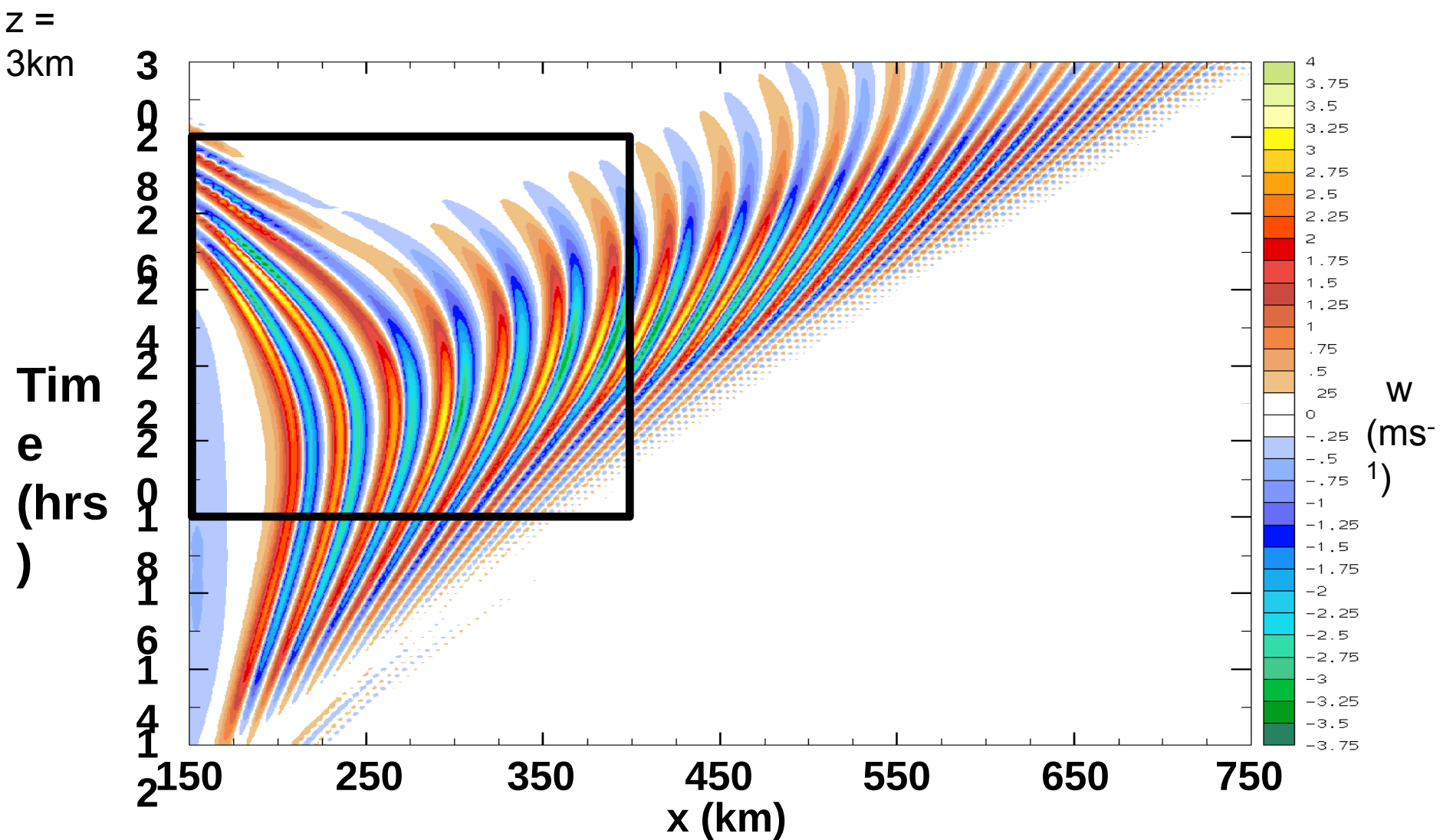
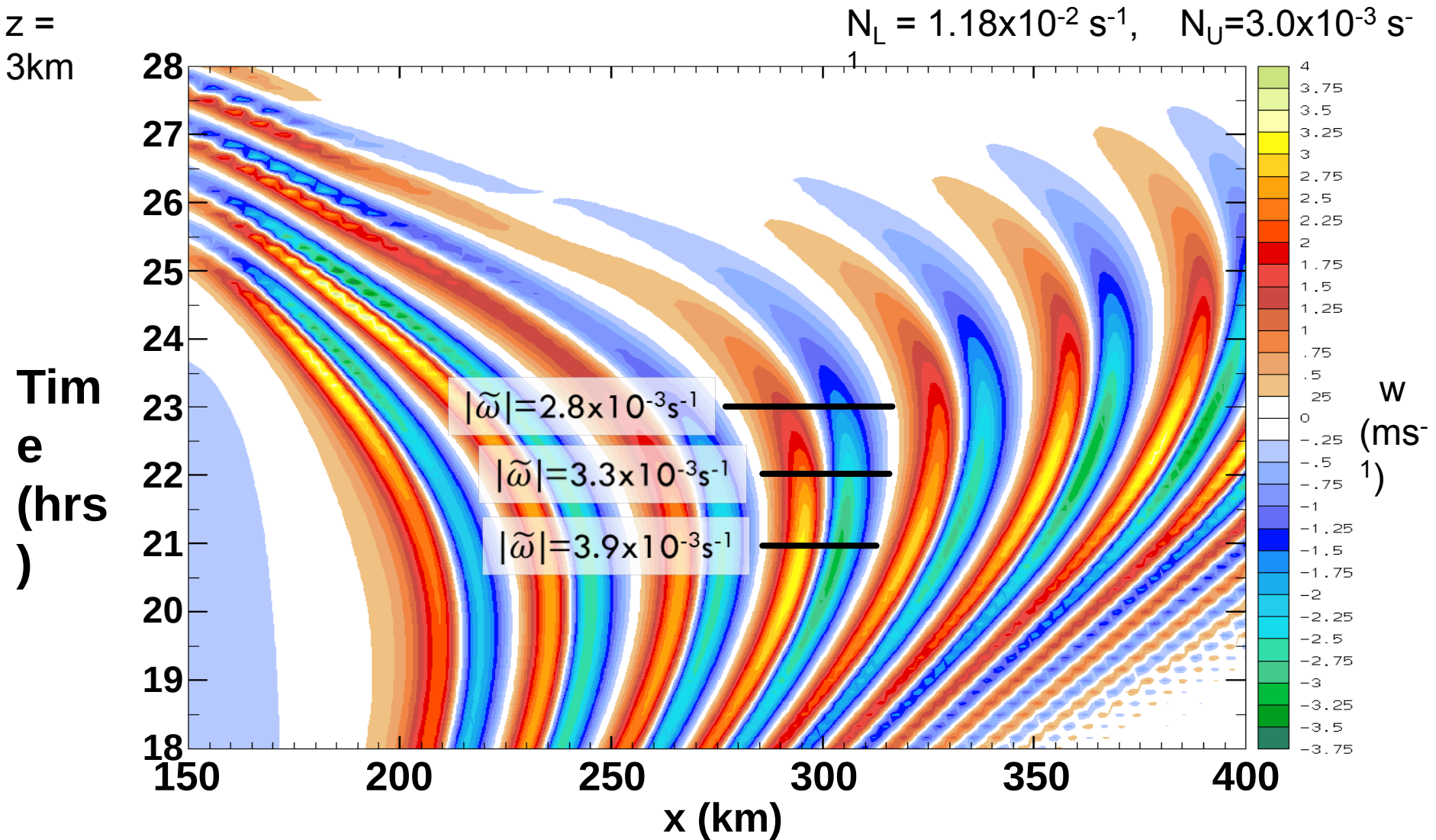


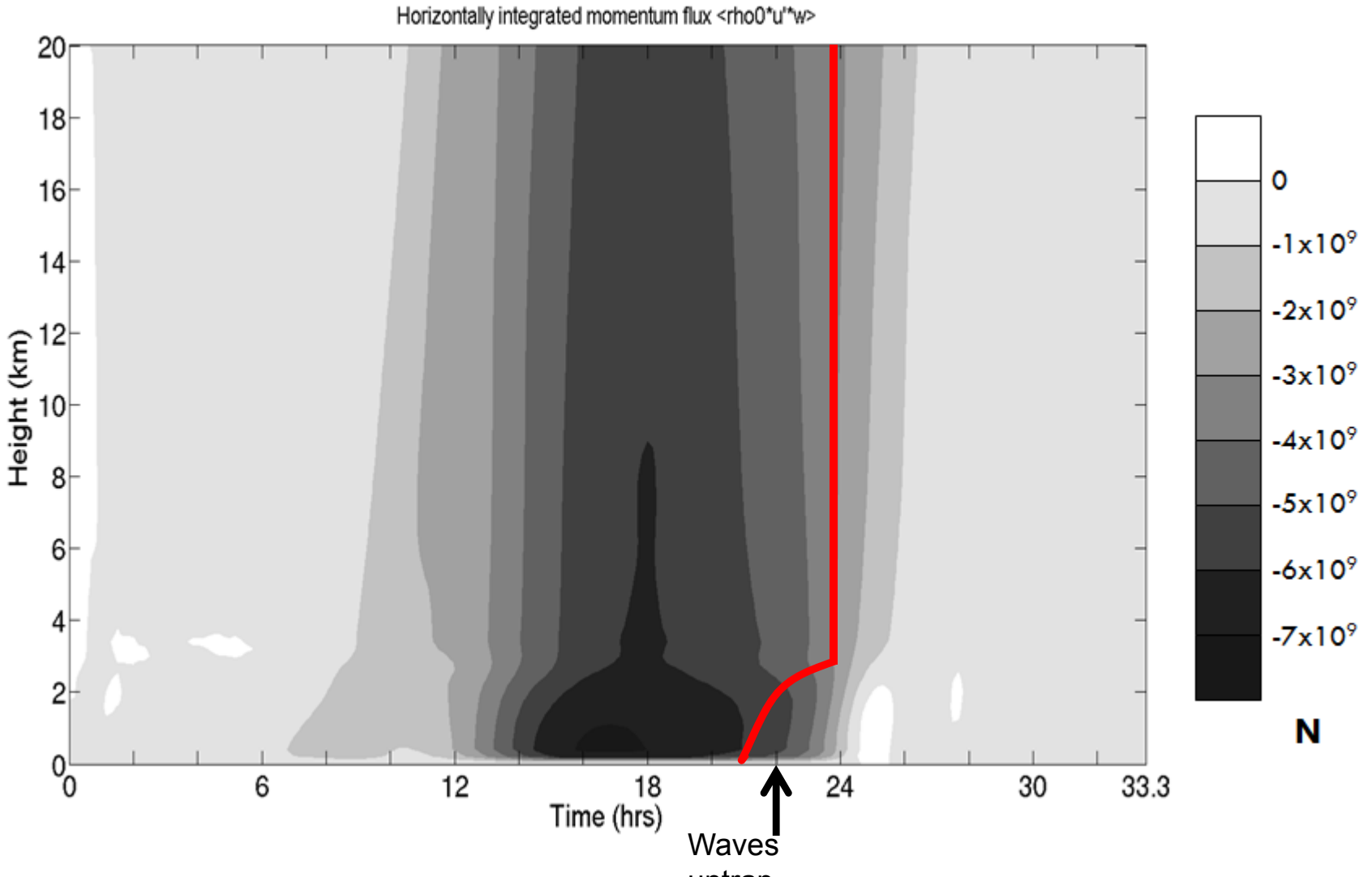
Illustration of wave untrapping



Vertical momentum flux

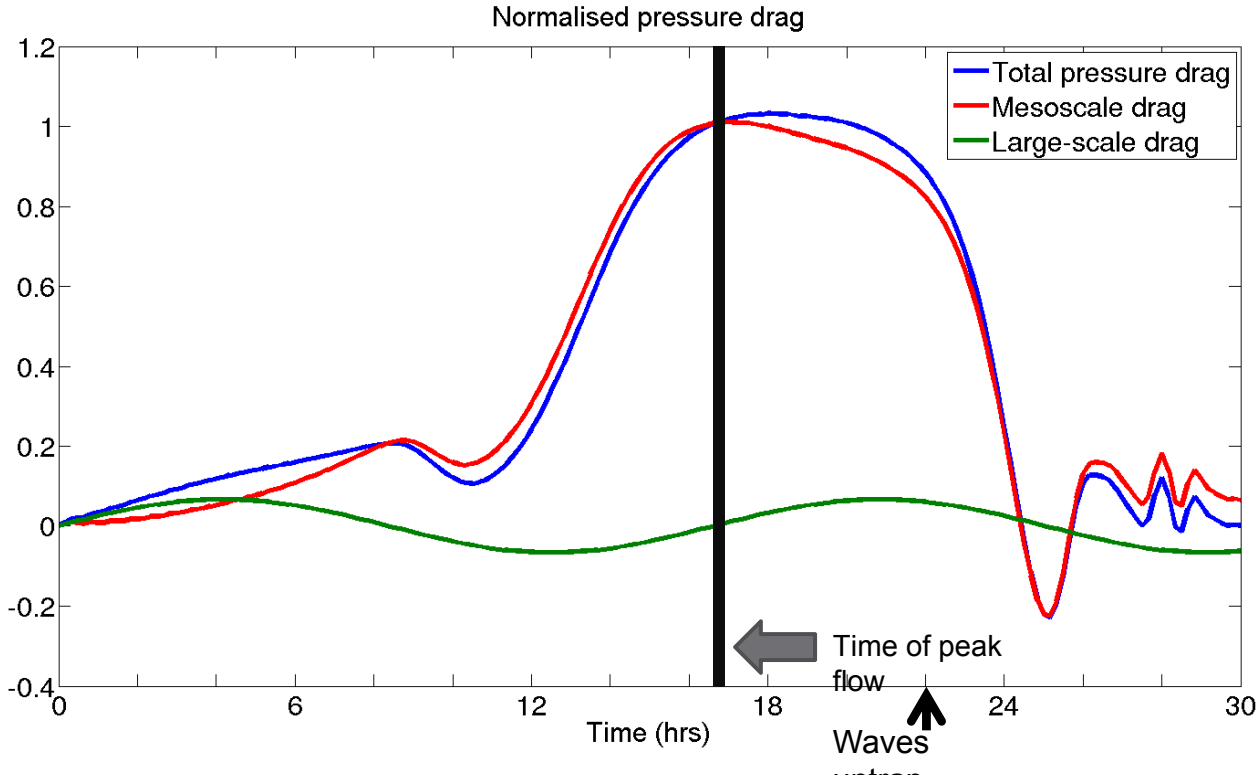
- Vertical gradient of momentum flux can tell us about changes to the large-scale flow.
  - $\frac{d\langle \rho_0 \bar{u} \rangle}{dt} = -\frac{d\langle \rho_0 u'w' \rangle}{dz}$
- If the flux becomes more negative with height:
  - Background flow is accelerated.
- If the flux becomes less negative with height:
  - Background flow is decelerated.

Vertical momentum flux



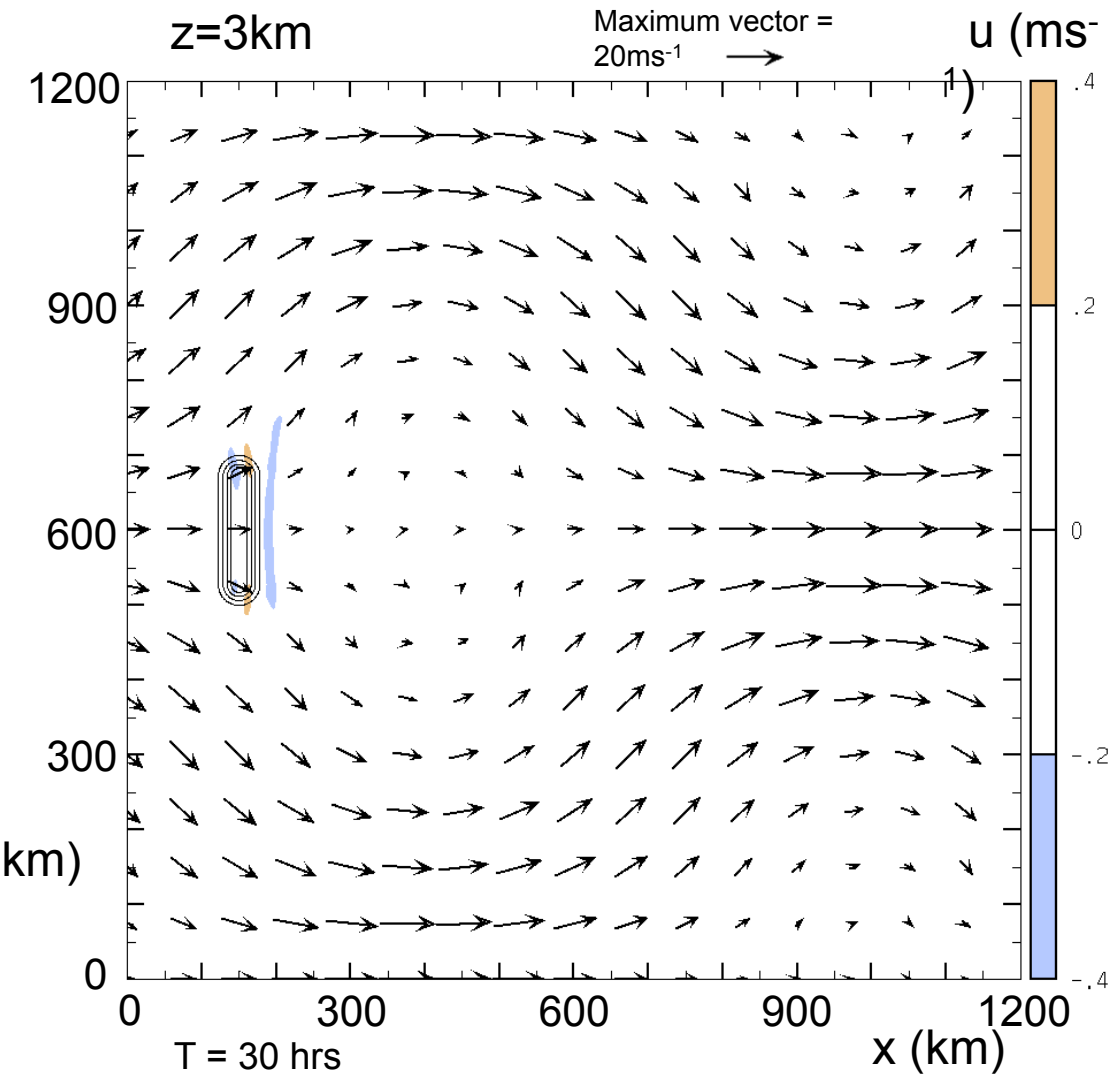
Pressure drag

- Trapped wave train requires a drag on the flow (Broad 2002).
  - Pressure drag balances the vertical momentum flux forced by the waves seen on the previous slide.
- Features of interest:
  - Note that the drag profile is non-symmetric about the time of peak wind.
  - Dominant component of the total drag comes from the mesoscale part of the flow
- **Considering flux magnitude from previous slide**
  - **~5/7 of mesoscale drag comes from vertically propagating waves.**
  - **~2/7 comes from the trapped waves.**



Perturbations to the large-scale

- Background zonal flow is modified at all levels by trapped wave train
  - Changes are both local and far reaching.
- u changed by ≈10% in some parts of the domain.
  - Perturbations away from the waves may be ≈0.5ms^{-1}, forced by our 250m mountain.

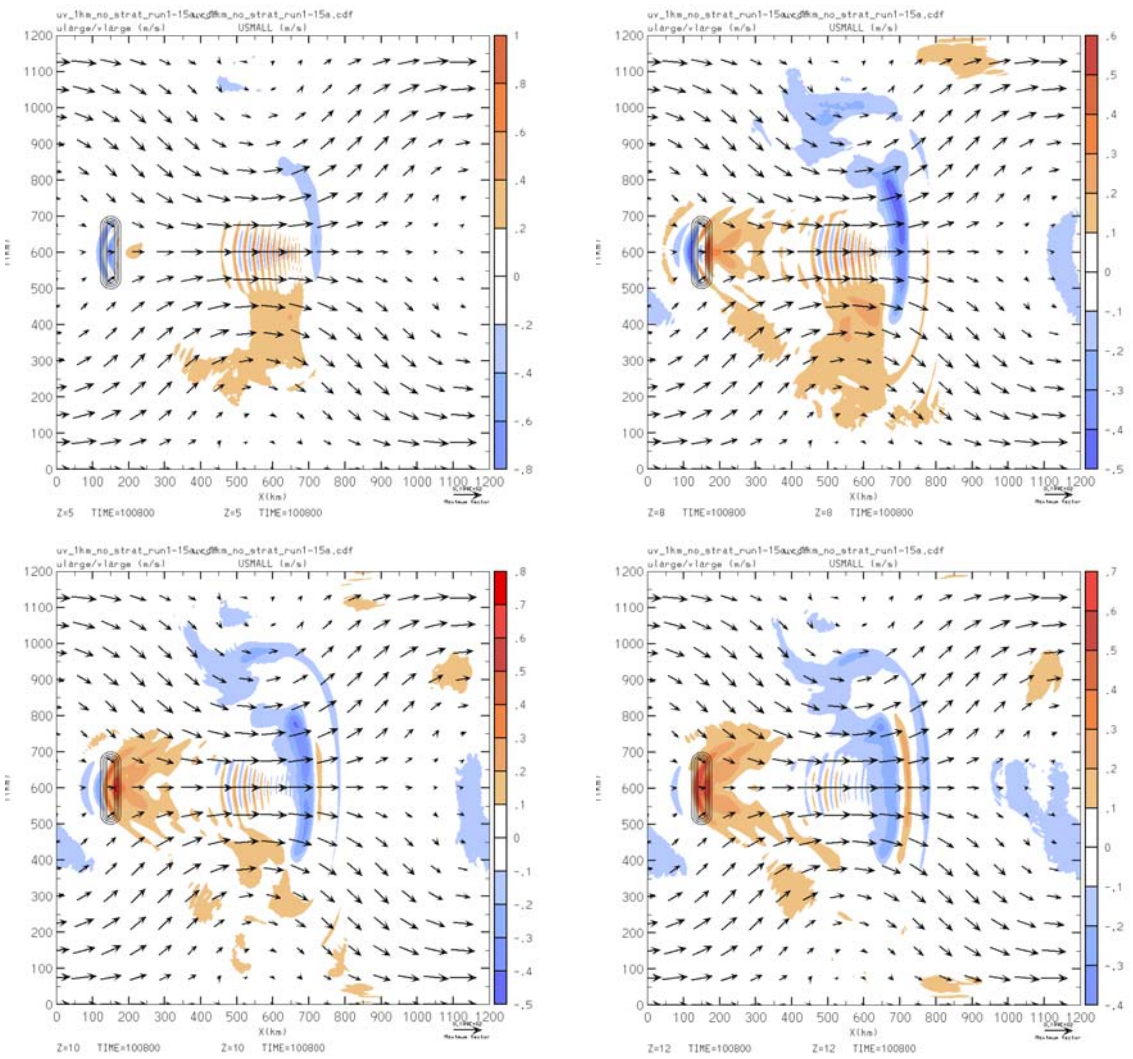


Conclusions

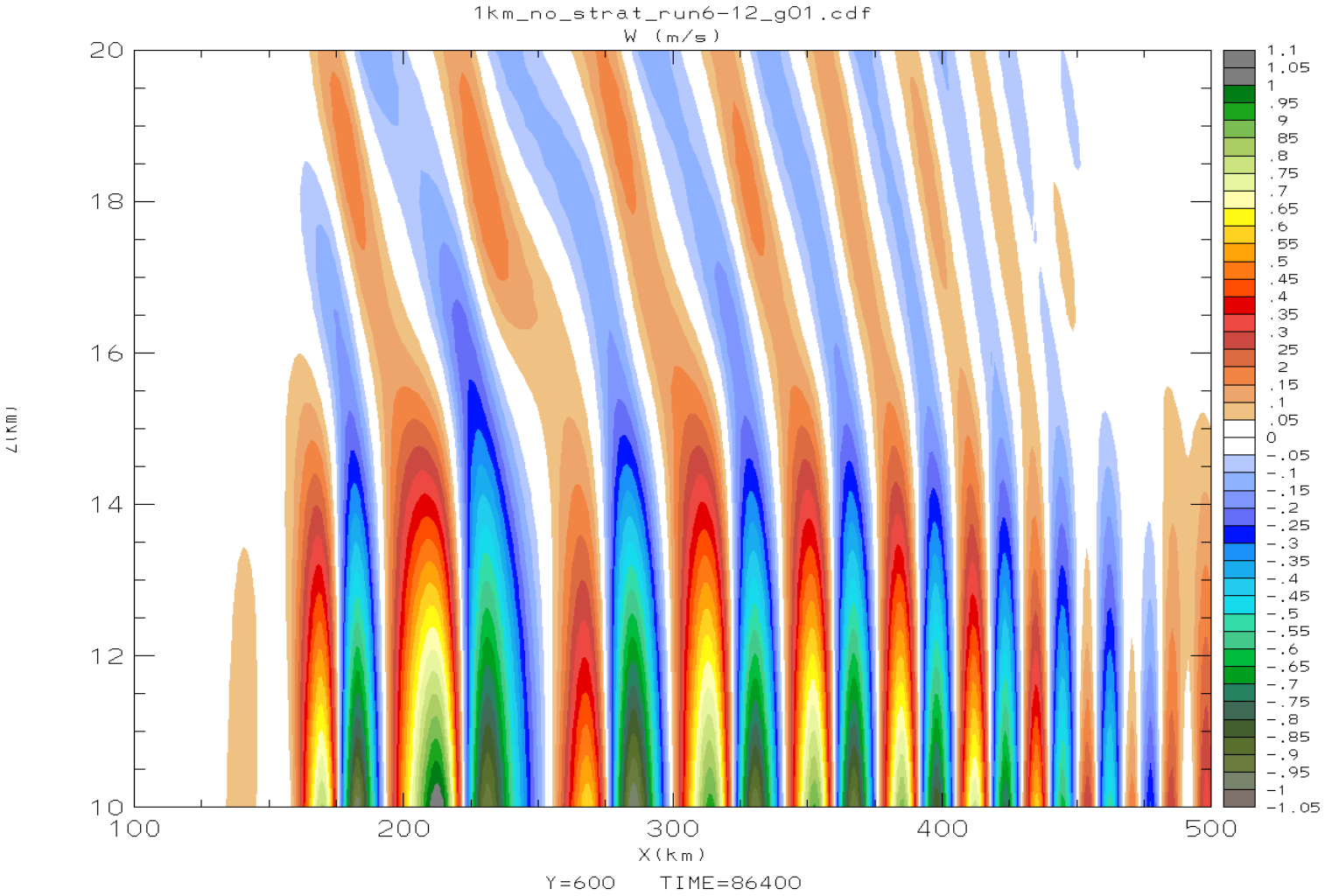
- Trapped waves can become untrapped through changes in the background wind field.
  - Waves forced when the background flow at the mountain is accelerating remain trapped.
  - Waves forced when the flow at the mountain is decelerating become untrapped, and decay.
- Changes in the mean flow occur due to the trapped waves.
  - Flow is decelerated while the trapped wave train is present.
  - Background flow is accelerated following wave untrapping.
- Non-negligible changes are made to the background wind field.

Perturbations to the large-scale

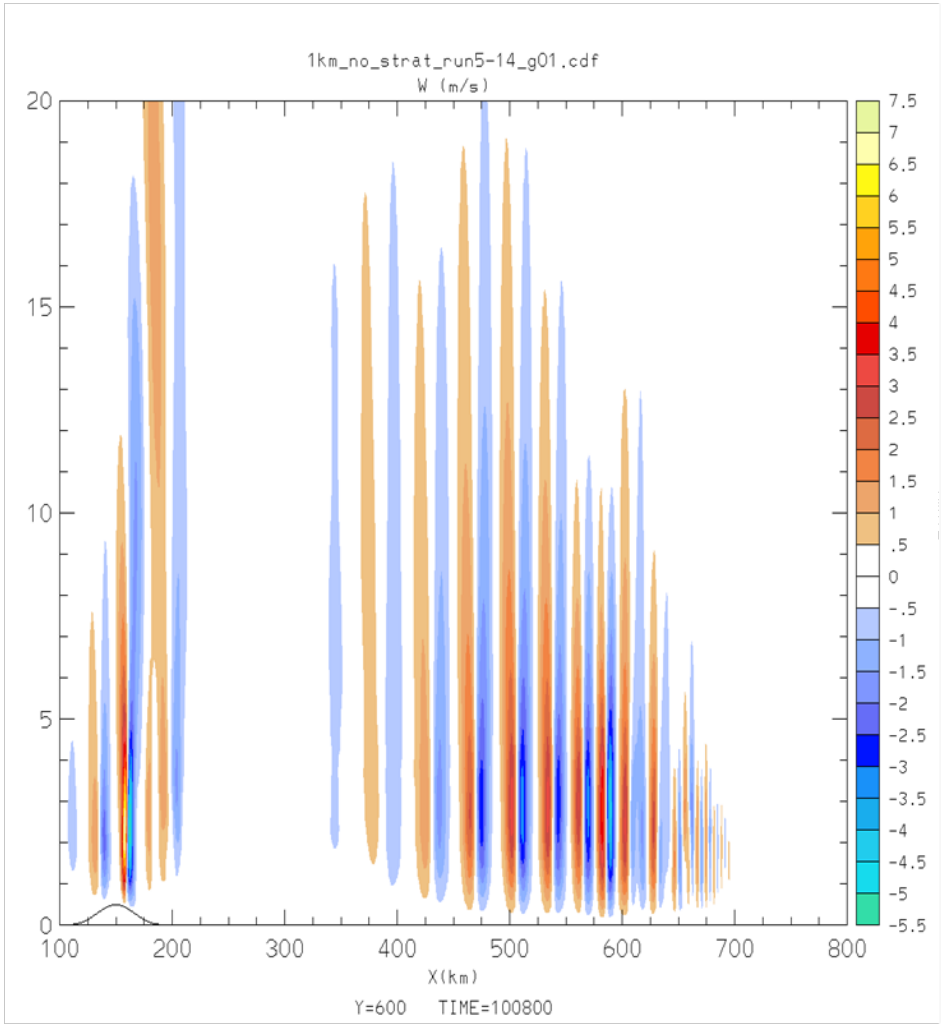
- Significant changes are seen at all levels.
  - Most notable modification is observed in slower regions of the background flow, at the edges of the localized jet.
- Broad pattern away of the wave train:
  - Flow to the south of the ridge is accelerated.
  - Flow to the north of the ridge is decelerated.

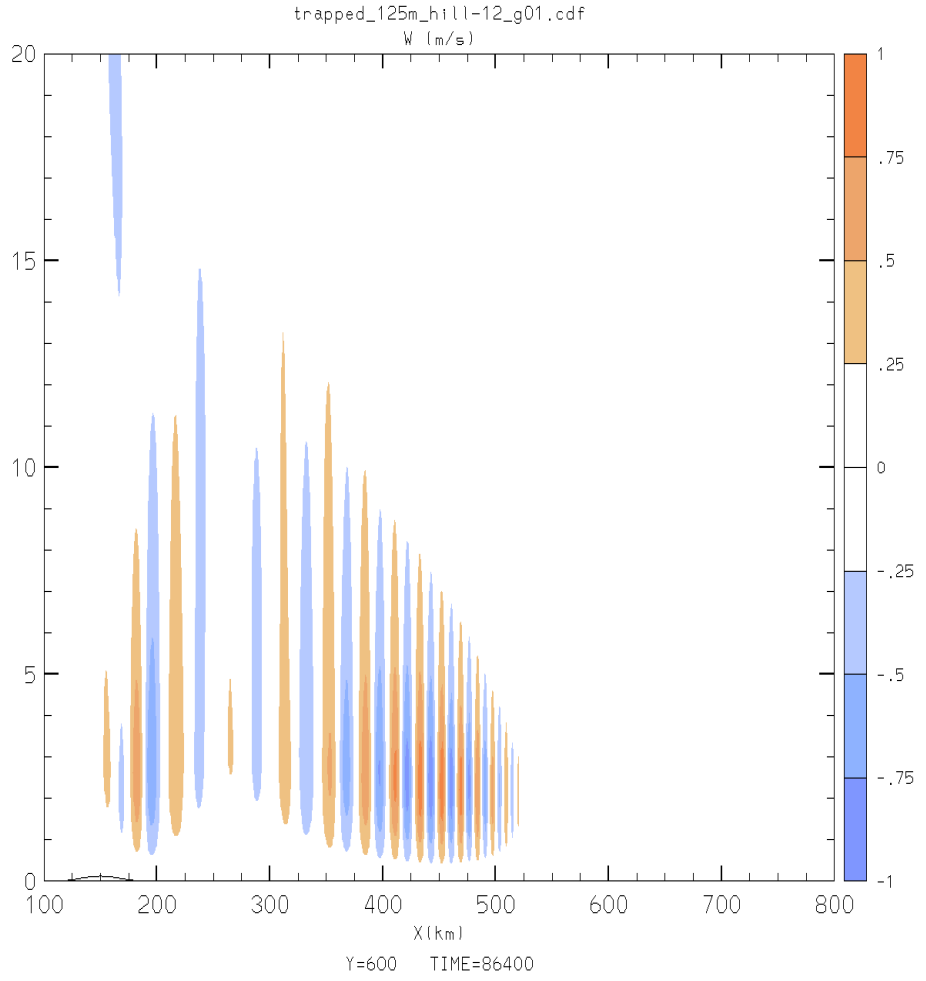


Stratosphere run



Different mountain heights





Satellite imagery

