DNS Studies on Mixing and Instability Characteristics in the Middle Atmosphere

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Outline of Talk

- Motivation
- Model and simulation set-ups
- Results of two 3-D direct numerical simulations
- Conclusions and future work

Motivation

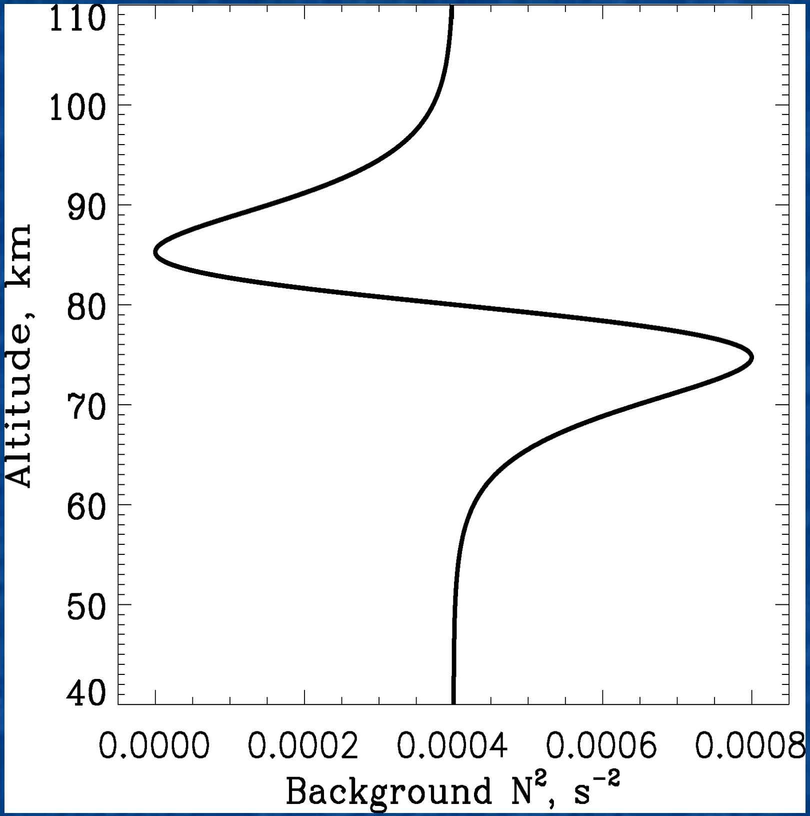
- Transport & mixing processes <u>are not well understood</u> at present.
- With the availability of ever increasing computational power, we are starting to be able to study these processes in detail.
- In this study, we will explore transport & mixing by studying the propagation of a gravity wave packet through two representative environments using idealized direct numerical simulations. By doing so, we hope to provide some guidance on improved representations of these processes in global models.

Numerical Model

- Anelastic Navier-Stokes equation solver (by Tom Lund)
- Second-order finite-volume scheme by Felton and Lund (2006) -> conservation of momentum, mass, and no numerical dissipation
- Periodic boundary condition in the horizontal, radiation boundary condition at the top
- A gravity wave packet (localized in altitude and time) is launched from the lower model domain.

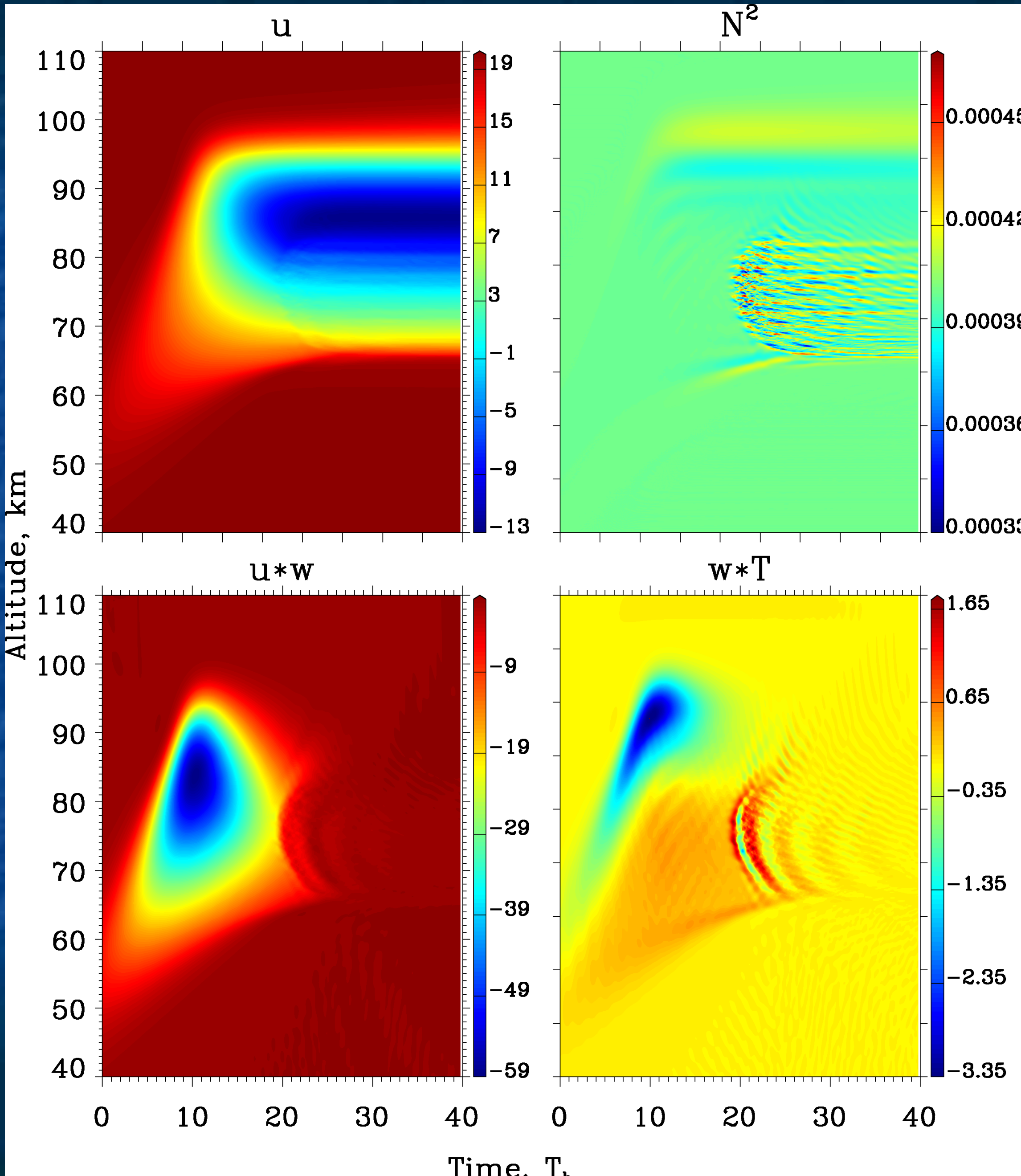
3-D DNS Setups

- Case 1: A GW packet propagates through isothermal atmosphere with constant wind & constant stratification
- Case 2: same as Case 1 but with a mesopause inversion layer (MIL) added at the upper part of model domain



$$N^2(z) = N_0^2\{1 - \beta\ 3^{3/2} \tanh[(z - z_M)/h]\ \mathrm{sech}^2[(z - z_M)/h]\}$$

(N_0=2e-2 --> T_b=314 s, beta=1, z_M=80 km, h=5 km, H=7 km)



Momentum transport yields an increasing U(z) deficit with increasing altitude as GW packet propagates upward.

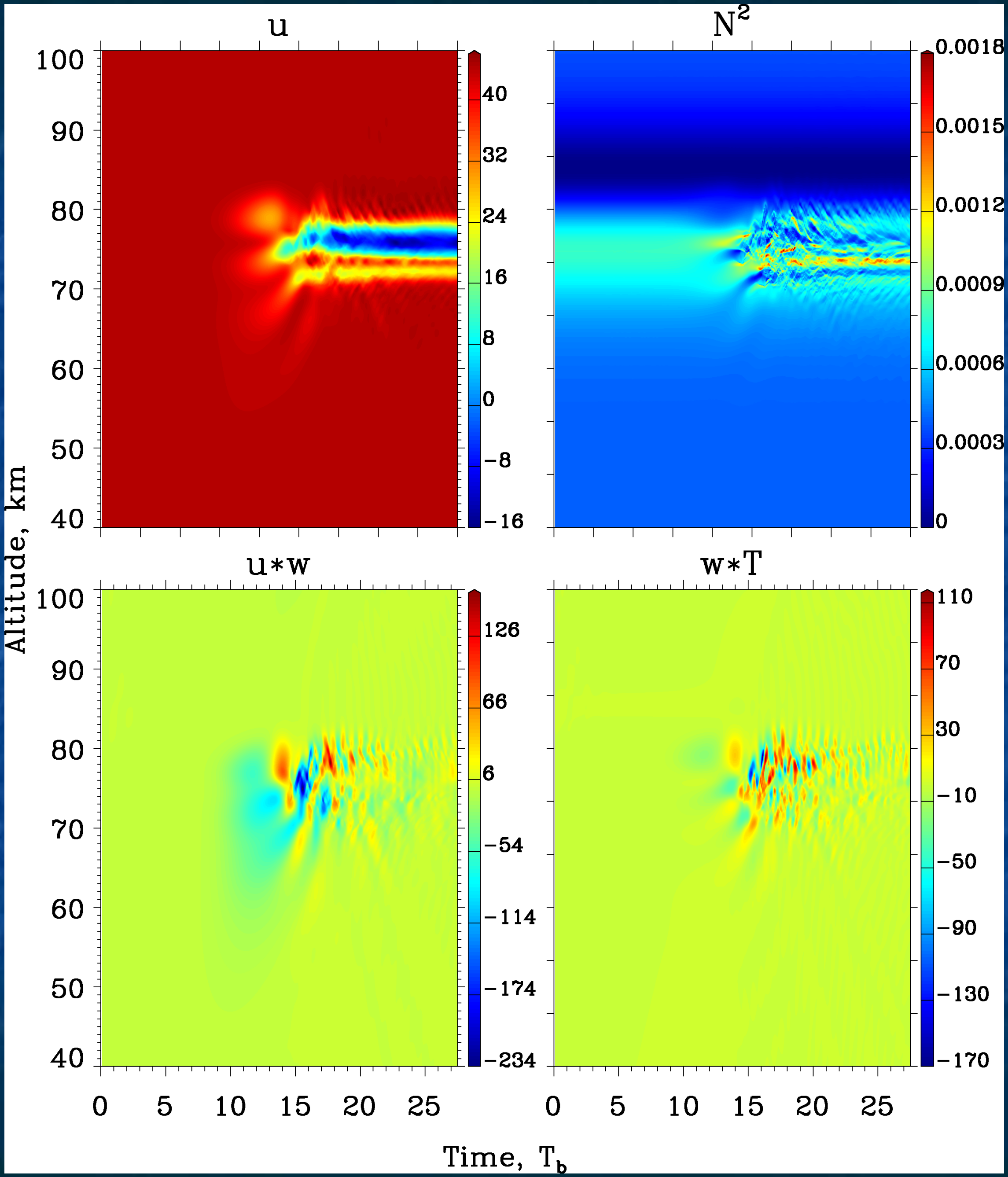
Momentum deposition is due to instability and turbulence at z<83km and to viscous dissipation at z>83 km

2D instability occurs before 3D instability.

Instabilities cause the very small scale features after ~ 19 T_b.

Layered structures in N^2

<u>Time-altitude contours of horizontal averaged u, N^2, uw, and wT for Case 1</u>



Some similarities, e.g, 2D instability occurs before 3D (after ~15 T_b); reduced mean flow due to momentum deposition

Very different dynamics: zero N^2 at 85 km acts as a barrier

Wave packet is trapped by MIL →
momentum & heat fluxes are much larger than Case 1

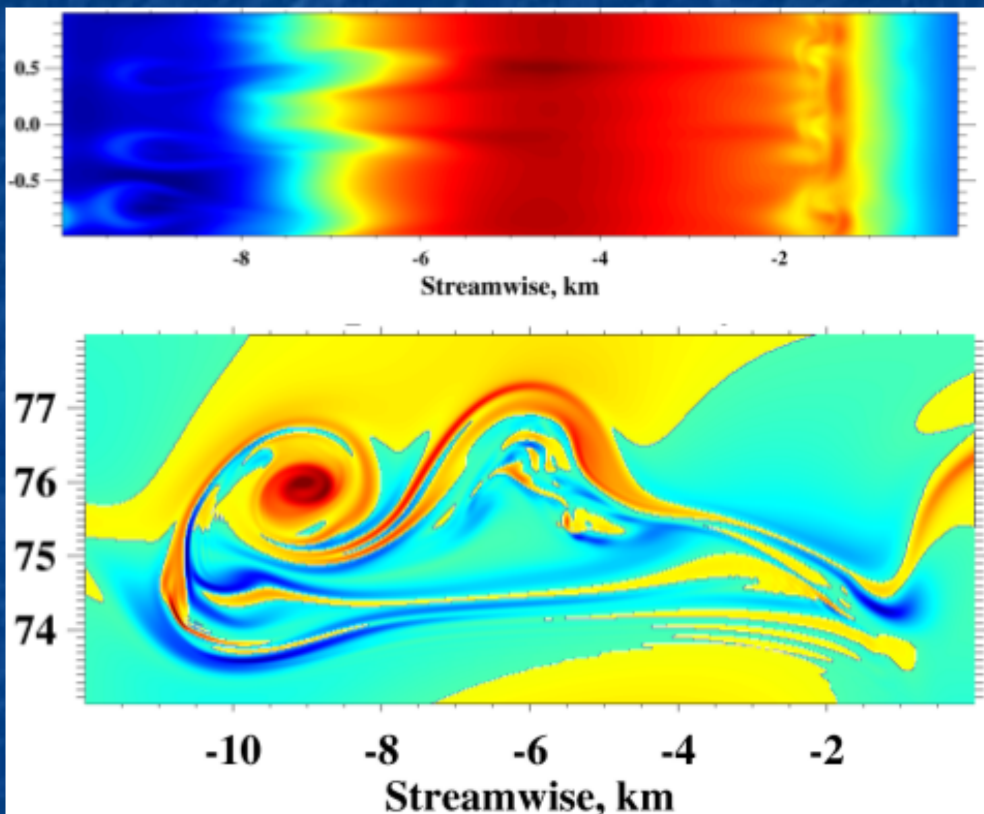
Time-altitude contours of horizontal averaged u, N^2, uw, and wT for Case 2

Examples of Instability Structure for Case 2

Time=15 T_b

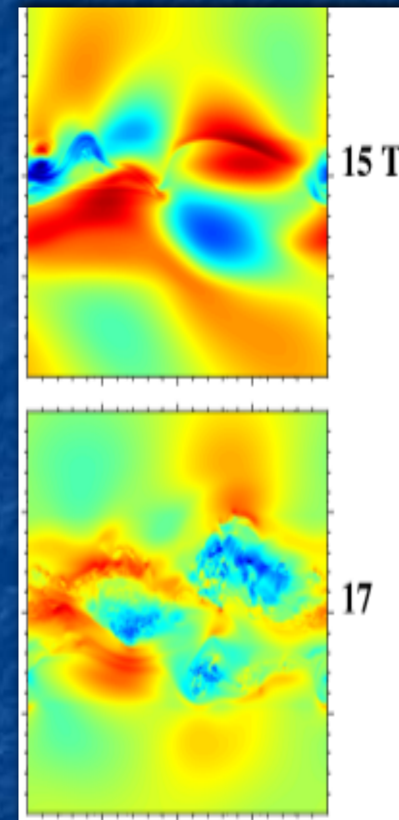
Y

Z



X

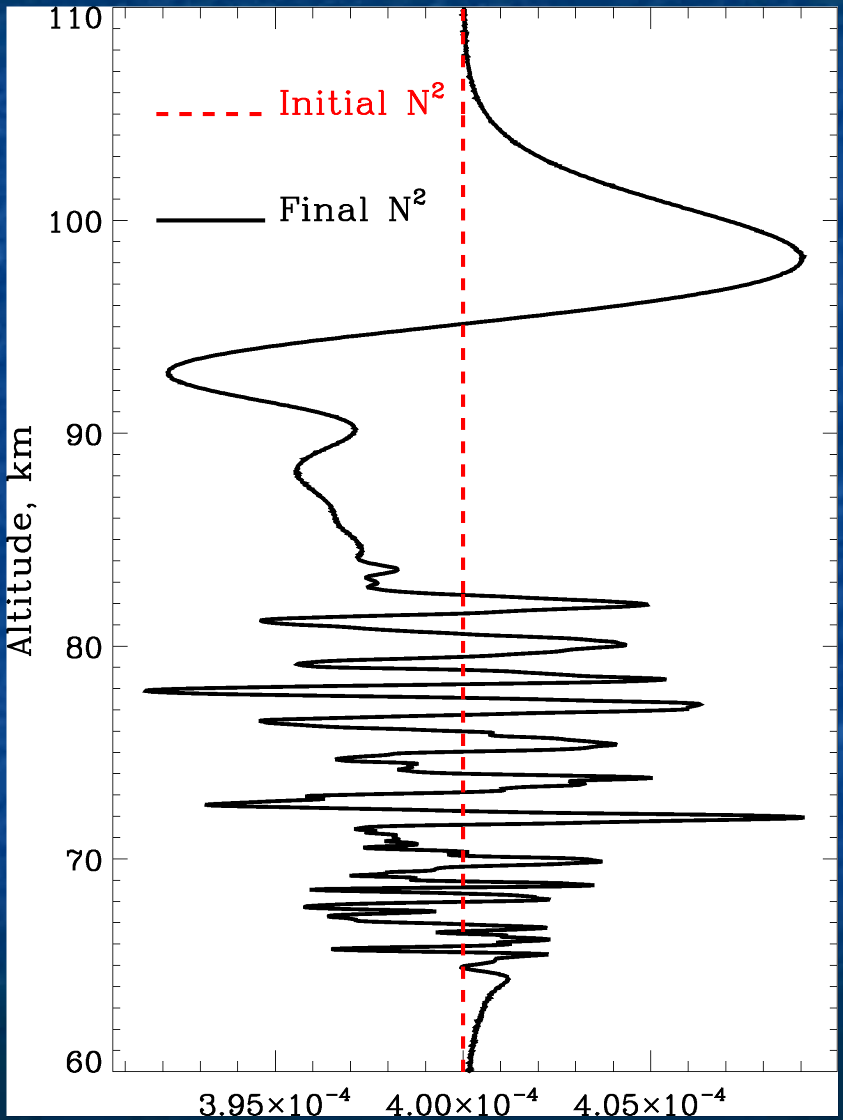
Z



X

The simulation is resolving the instability structures and turbulent motions sufficiently well.

Initial vs. Final Horizontal Averaged N^2 for Case 1



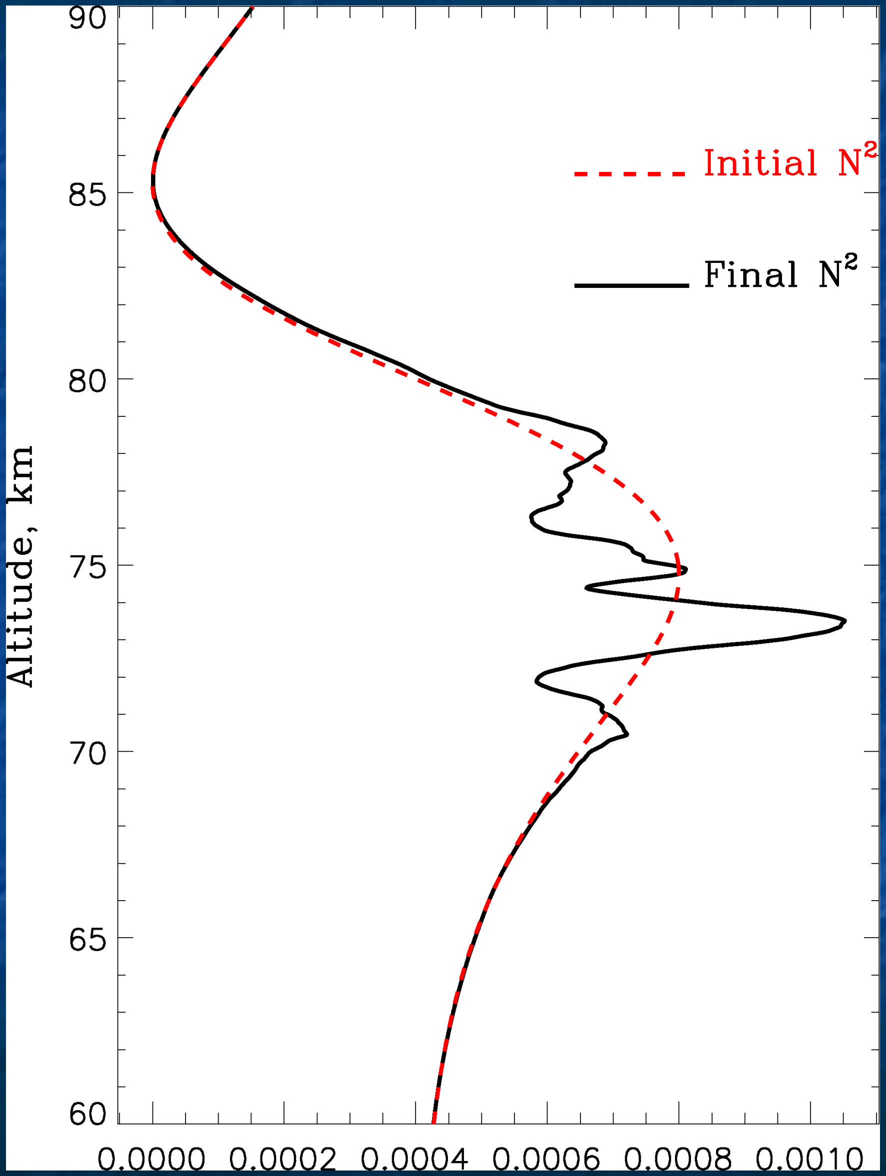
Final N^2 is calculated by averaging over the last 3 buoyancy periods.

Model prediction of the formation of layered structures

Layering is often observed (e.g., on the lee side of a mountain wave breaking event from the DEEPWAVE campaign, cf. Dave Fritts' talk on Wednesday)

The variation of N^2 is tiny in this case, very far from achieving an adiabatic lapse rate → mixing is very weak here

Initial vs. Final Horizontal Averaged N^2 for Case 2



Again, layered structures are evident.

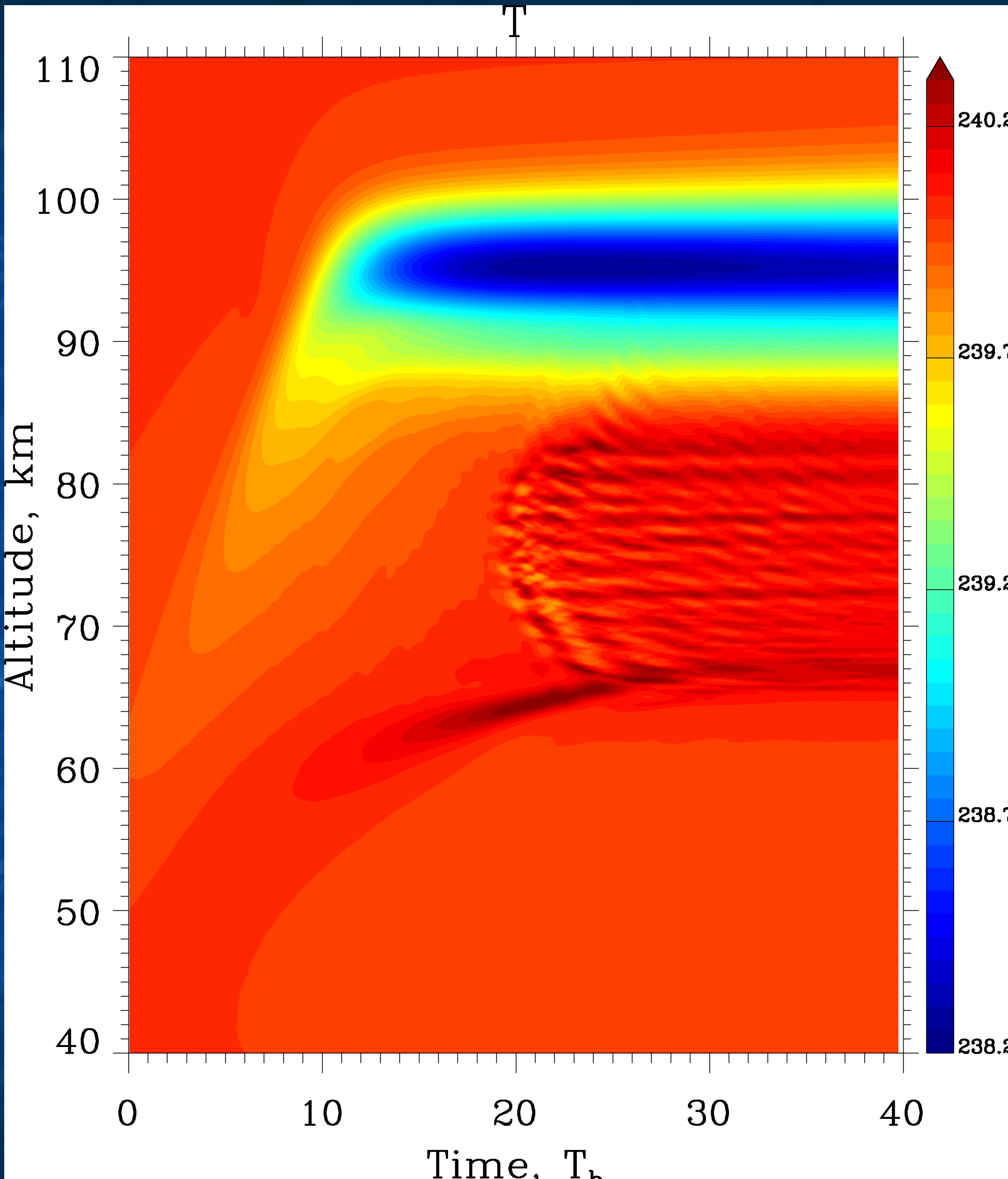
Mixing is much stronger in the presence of MIL as compared to Case 1.

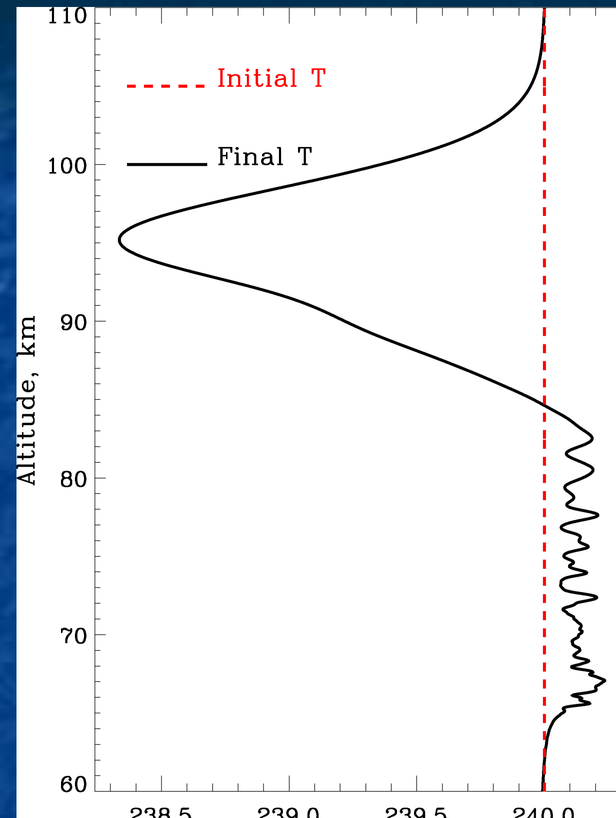
Nevertheless, strong instability and turbulent mixing does NOT cause a region with an adiabatic lapse rate, very different from what has been assumed in the past.

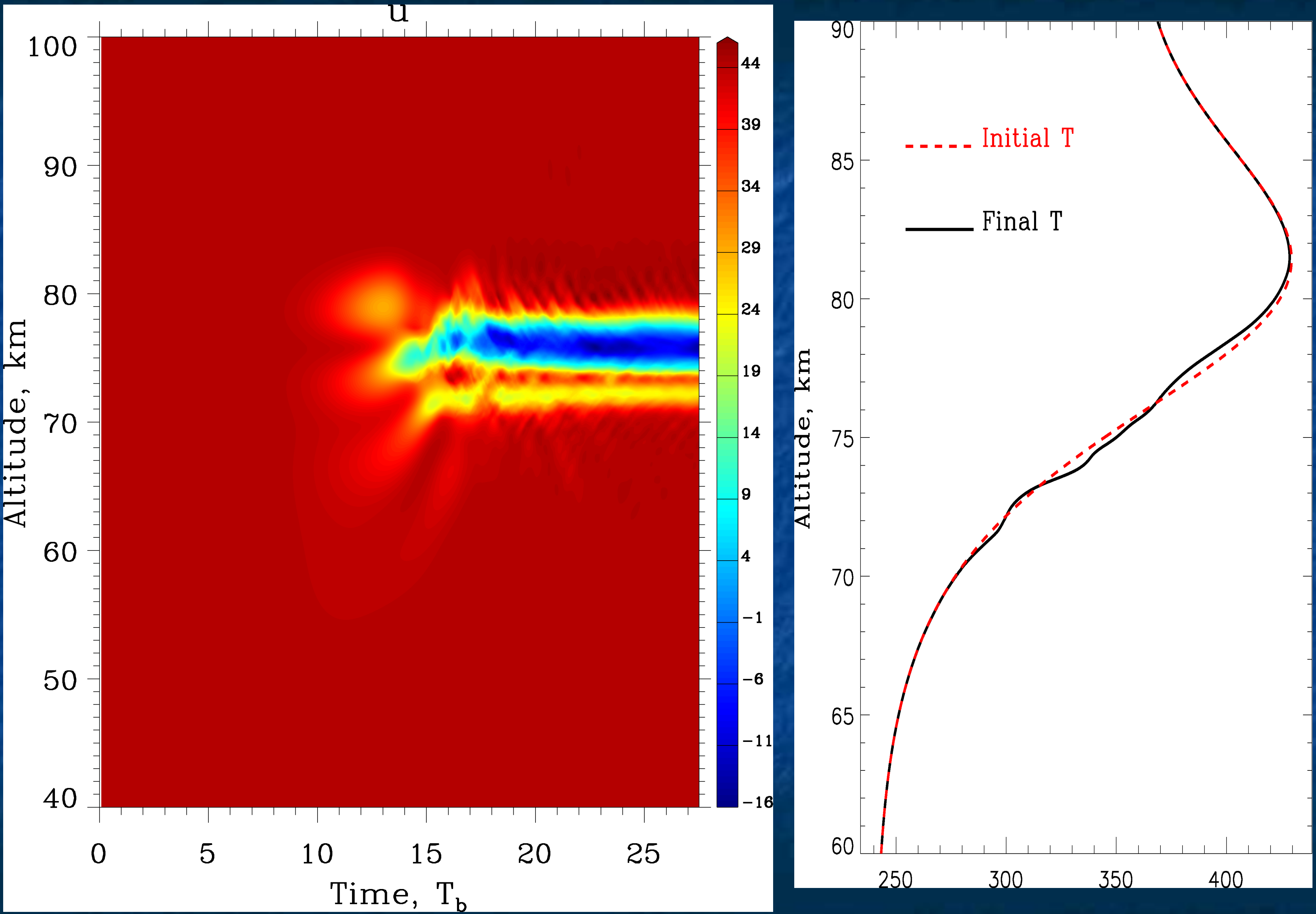
Conclusions and Future Work

- Turbulent mixing efficiency due to wave breaking is much weaker than has often been assumed before.
- Instability and turbulent mixing often causes the formation of layered structures.
- The presence of MIL enhances significantly local turbulent mixing.
- We will perform more detailed diagnostics of the existing simulation results to quantify turbulent mixing efficiency which may provide some quantitative guidance to global modelers and will explore the dependence of instability, turbulence and mixing on wave packet properties and additional representative background states.

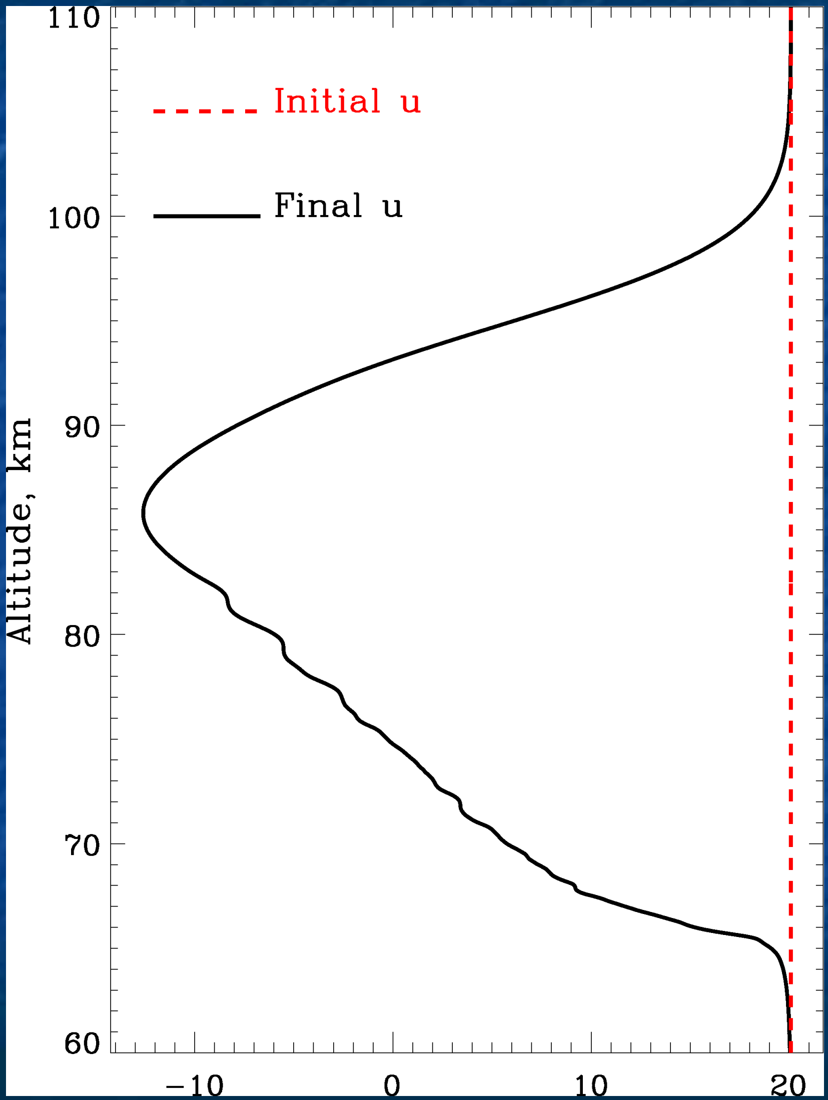
Thank you!


T
Altitude, km
110
100
90
80
70
60
50
40
0
10
20
30
40
Time, T_b
240.2
239.7
239.2
238.7
238.2


Initial T
Final T
Altitude, km
110
100
90
80
70
60
238.5
239.0
239.5
240.0

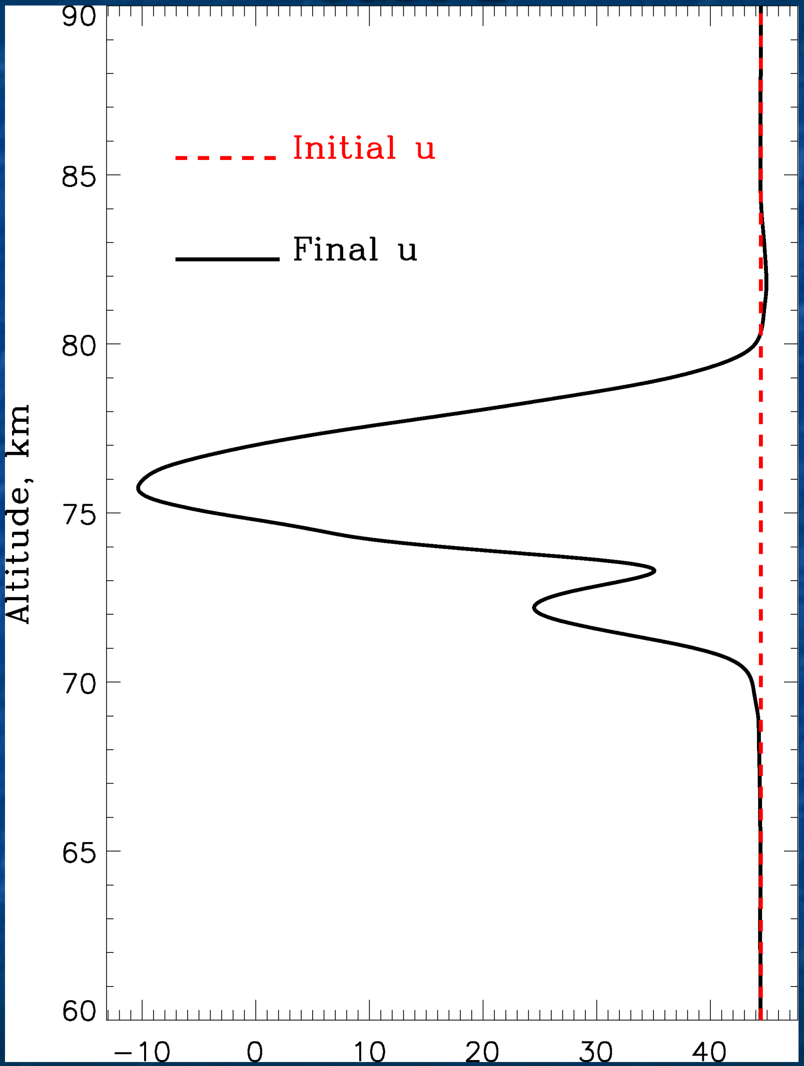

u
Altitude, km
Time, T_b
Initial T
Final T
Altitude, km

Case 1



110
100
90
80
70
60
Altitude, km
Initial u
Final u
−10
0
10
20

Case 2



90
85
80
75
70
65
60
Altitude, km
Initial u
Final u
−10
0
10
20
30
40