Modeling Gravity Wave Dynamics in the Middle Atmosphere

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Outline

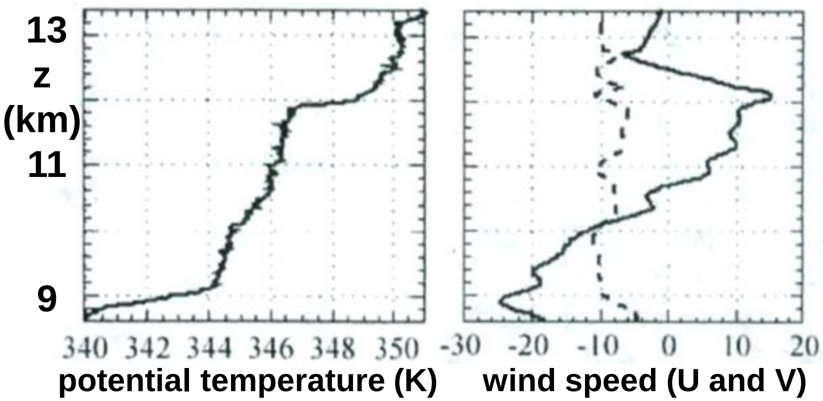
1. evidence of diverse GW dynamics and instabilities

2. modeling deep GW dynamics
   - large-amplitude GW breaking
   - localized GW packets
   - variable stratification
   - filtering by tidal shears

3. modeling gravity wave – fine structure interactions

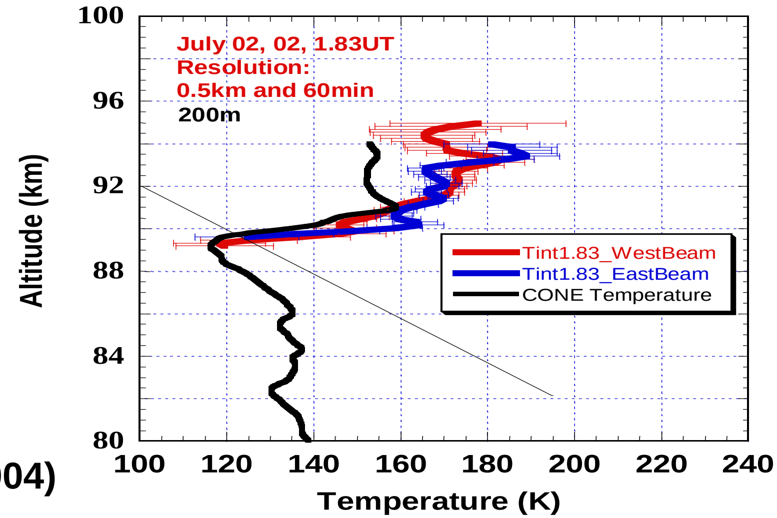
Large-amplitude GWs and multi-scale structures are ubiquitous

GWs occur at many scales ~all the time

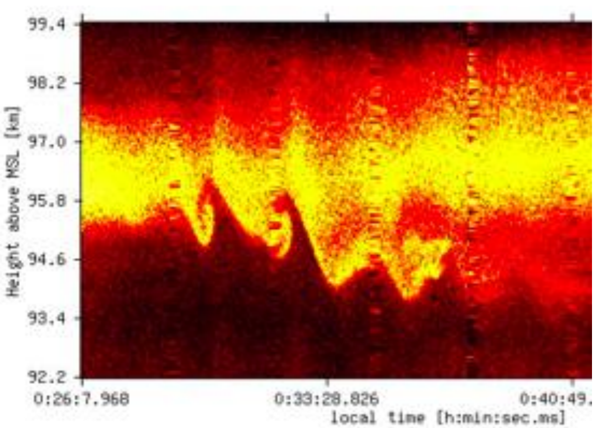


Kelley et al. (2005)

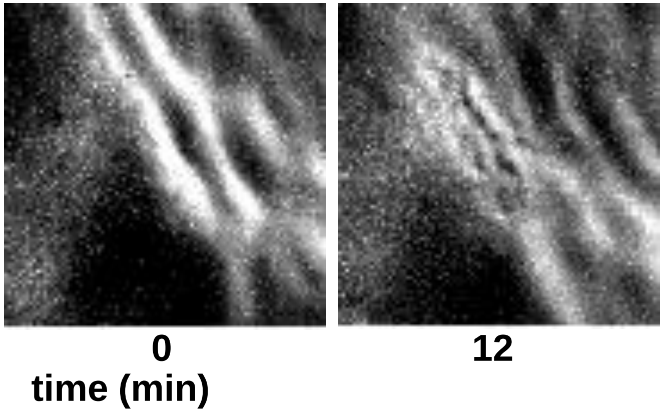
Fritts et al. (2004)



GW "breaking", shear instabilities, often seen in NLC, airglow, radar, lidar



Pfrommer et al. (2009)



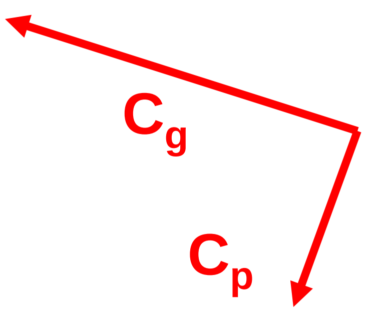
(Yamada et al., 2001)

large-amplitude GW breaking – 3D views (side & top views)

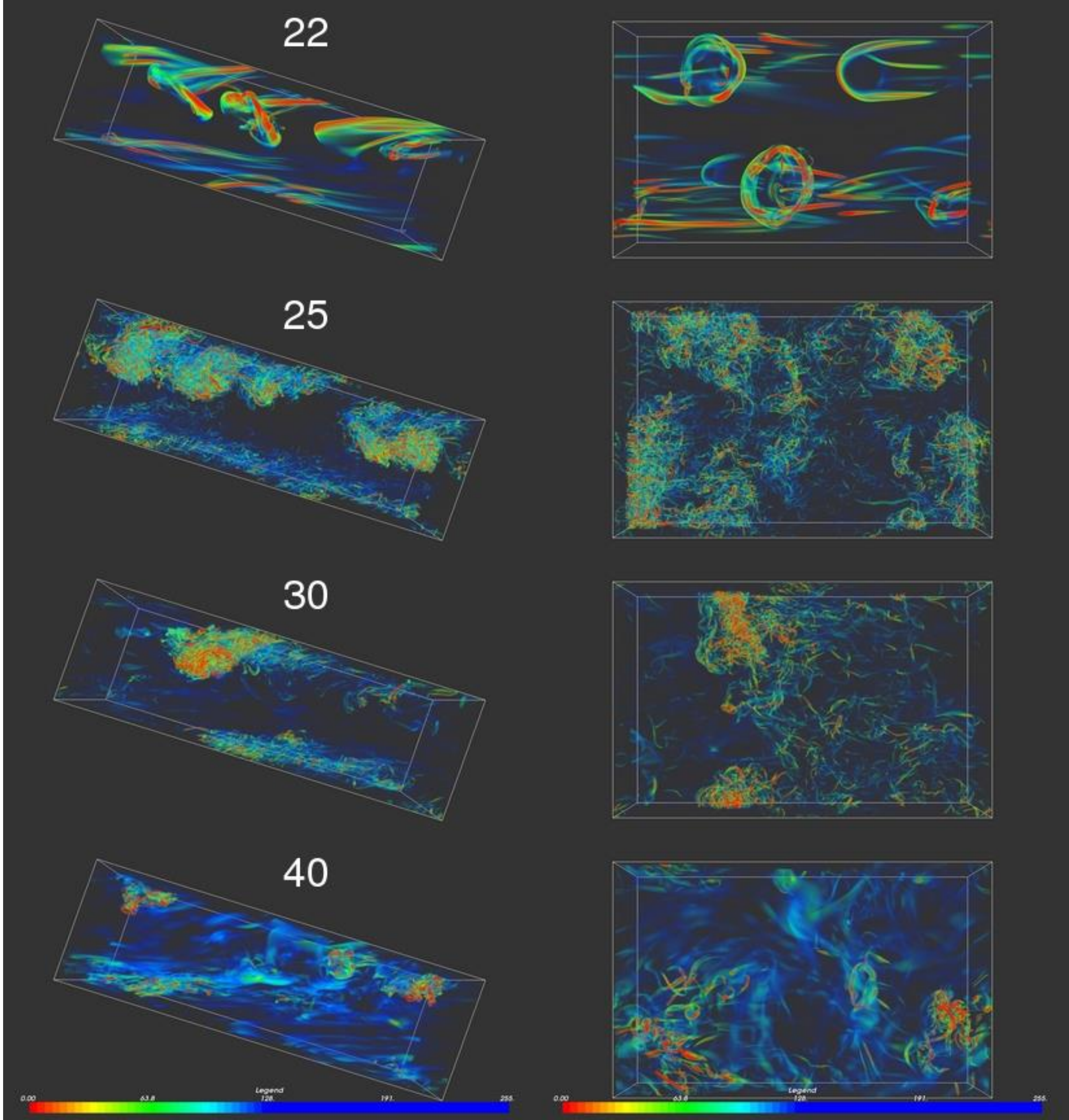
a = 0.9

ω = N/3.2

Re = 10^4



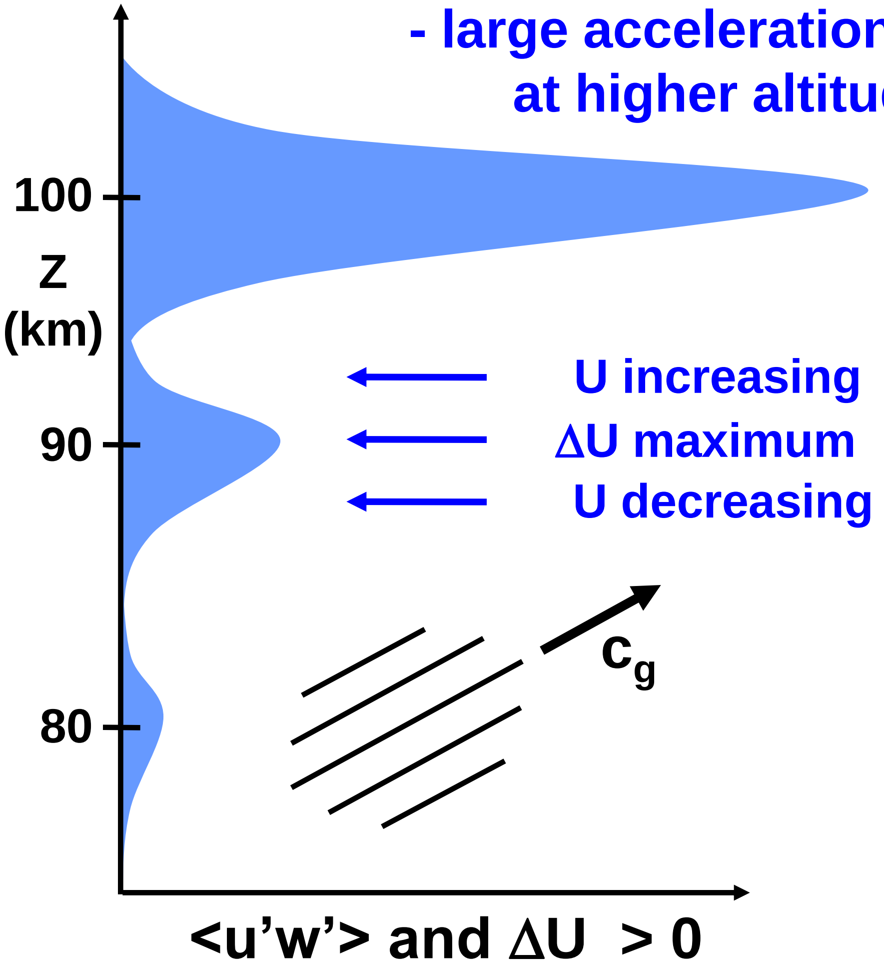
Fritts et al. (2009)



GW amplitude growth with altitude yields strong induced mean motions, "self acceleration", and other effects

Decreasing mean density

=> - GW amplitudes increase as ~ $1/\rho^{1/2}(z)$
- $\Delta U \sim 1/\rho(z)$
- large accelerations, altered GW phase structures at higher altitudes



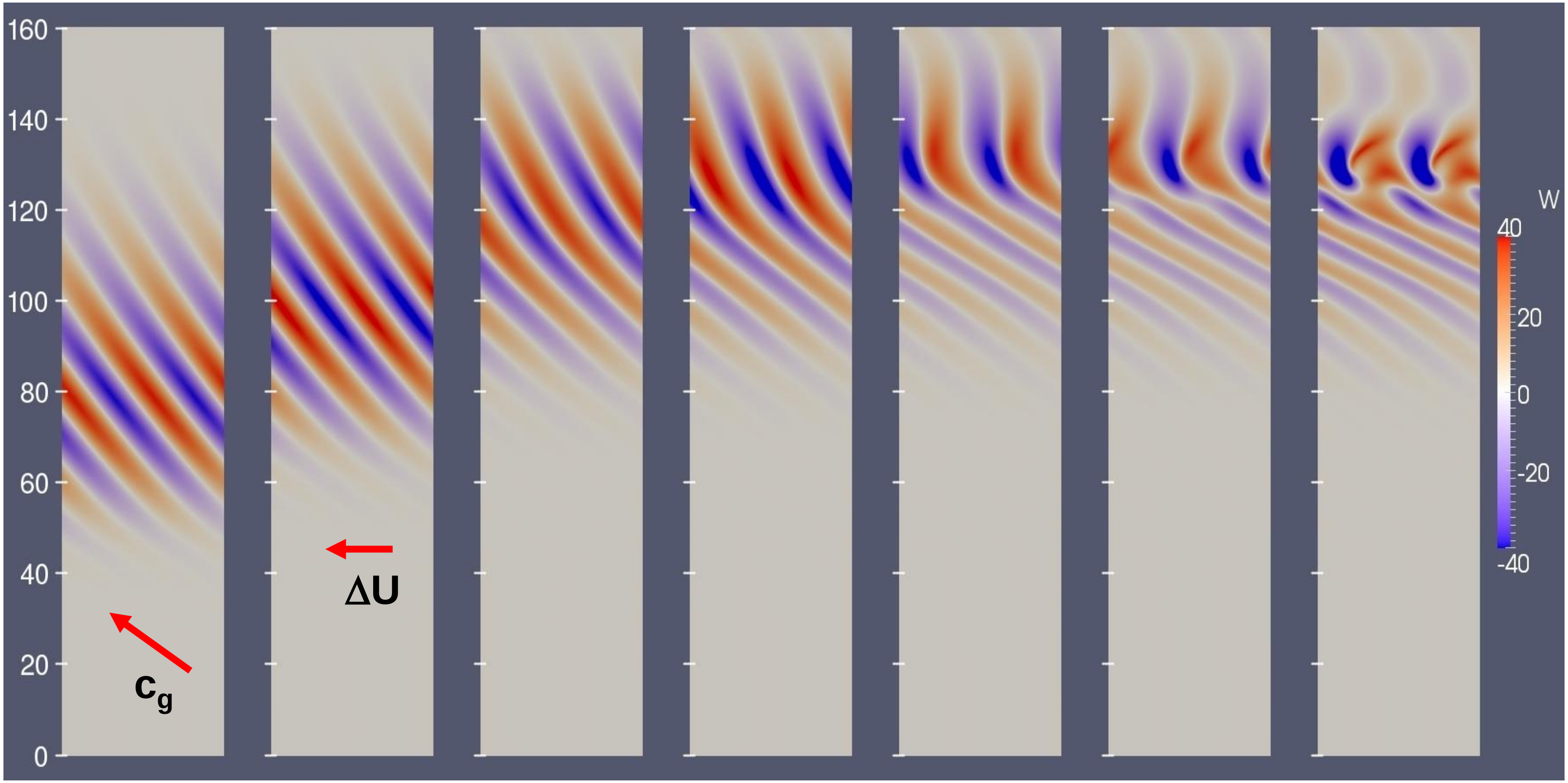
=> leading edge of GW packet accelerates

trailing edge decelerates

=> self-acceleration & phase distortion

"Self-acceleration" of a localized GW packet vert. velocity)

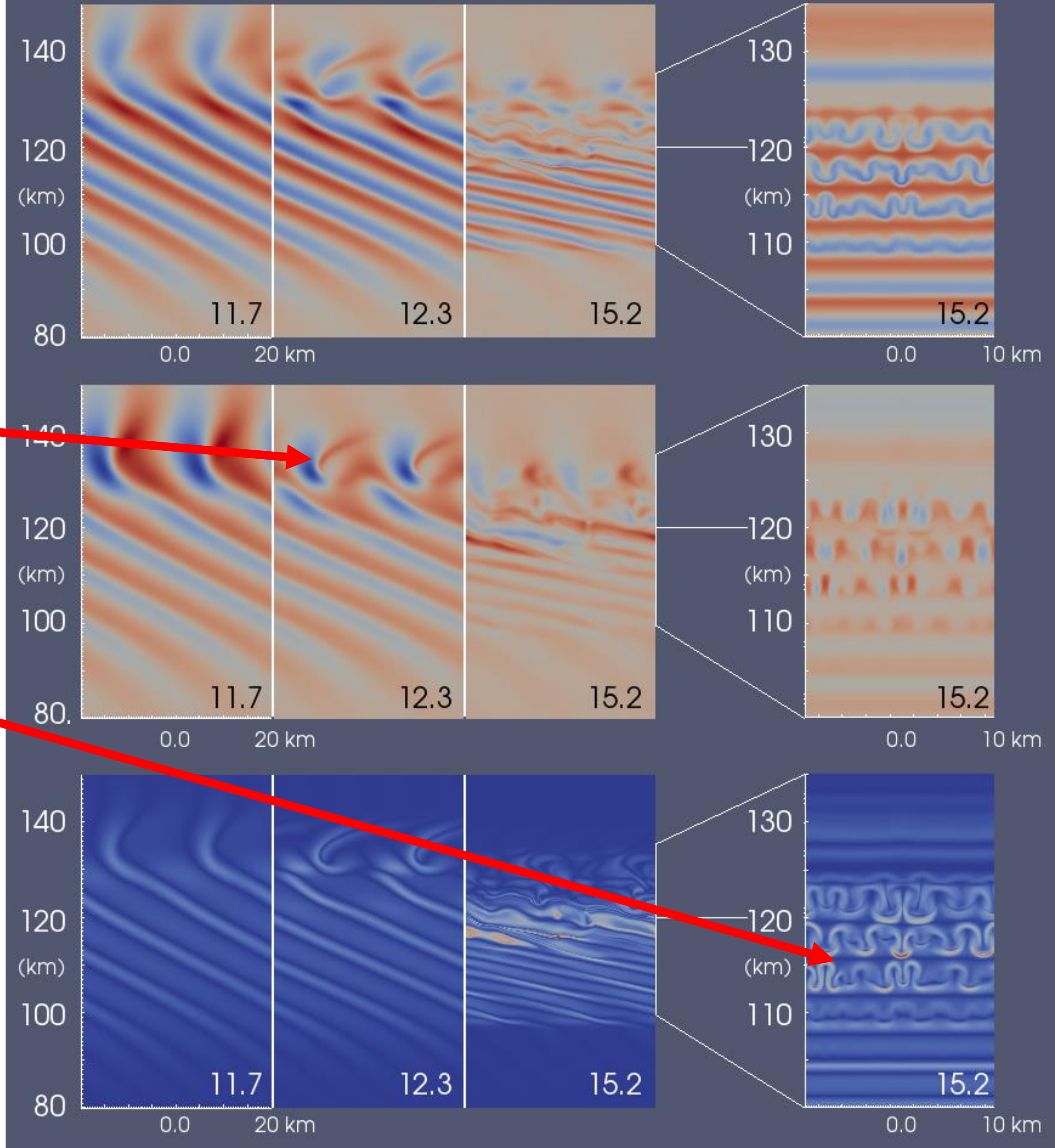
=> - steepening phase structures at leading edge
- altered GW group velocities and GW instability



"Self-acceleration" and instability dynamics in u', w', and ζ fields

=> - primary SA instability **is 2D,**
- excites additional small-scale GWs

- secondary SA instability **is 3D,**
- occurs in highly sheared trailing GW packet,
- yields turbulence and mixing



SA dynamics of a 2D localized GW packet

(U + u', positive to the right, red)

- duration ~4 T_b

effects include:

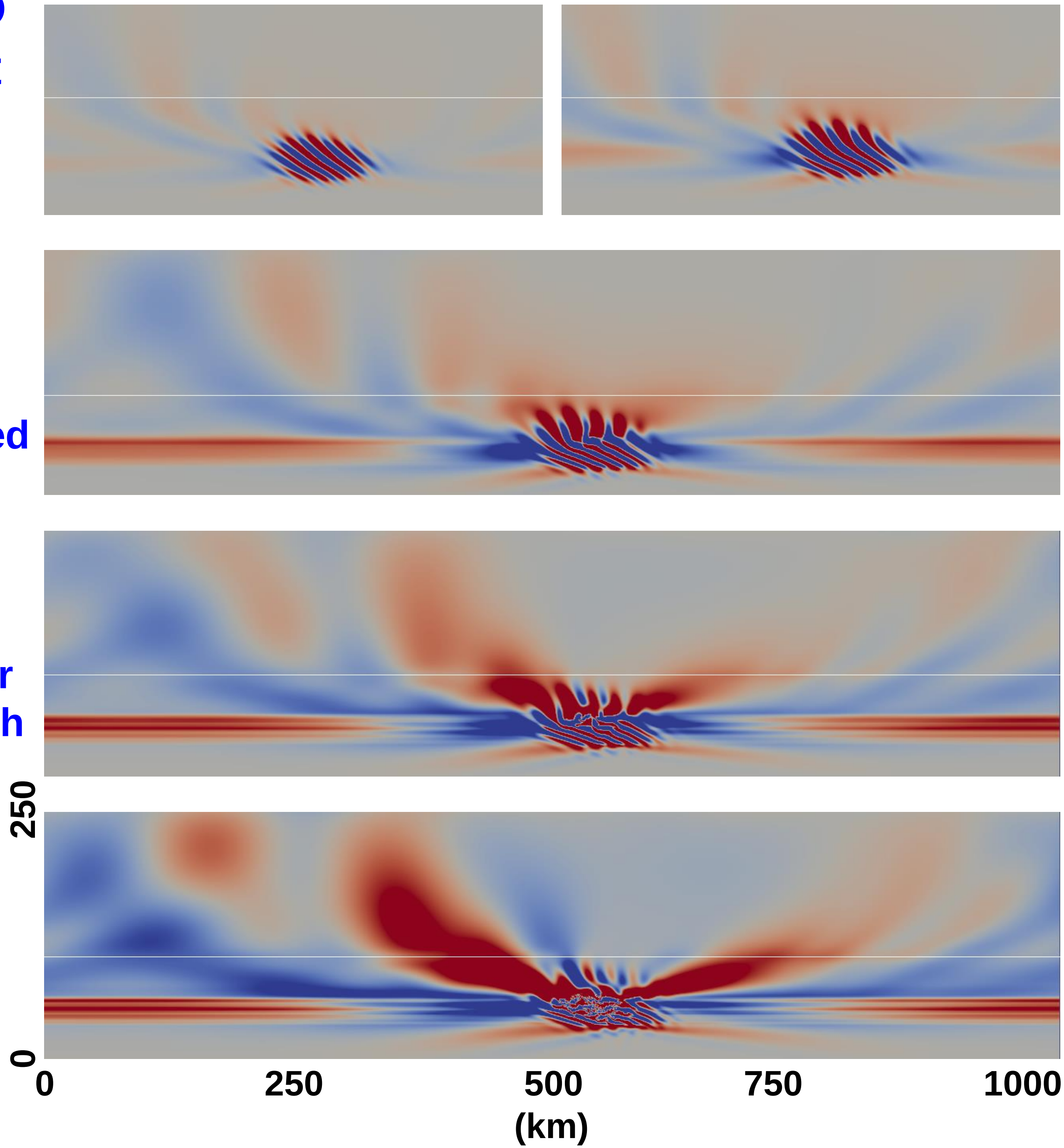
- local body forces, induced horiz. & vertical motions

- local mean flow

- secondary GWs at larger scales penetrating to much higher altitudes

=> two potential sources of plasma seeding:

- 3D instabilities (below)
- 2D GWs in F layer

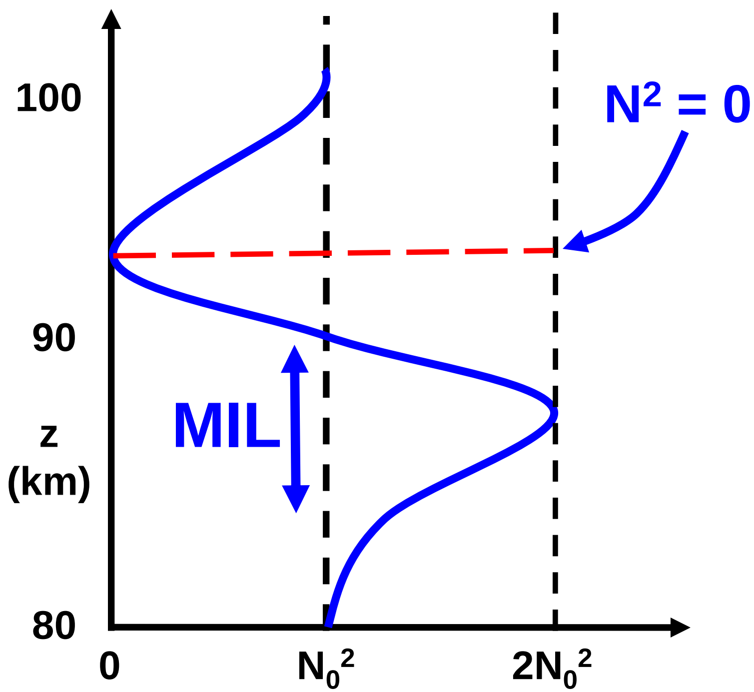


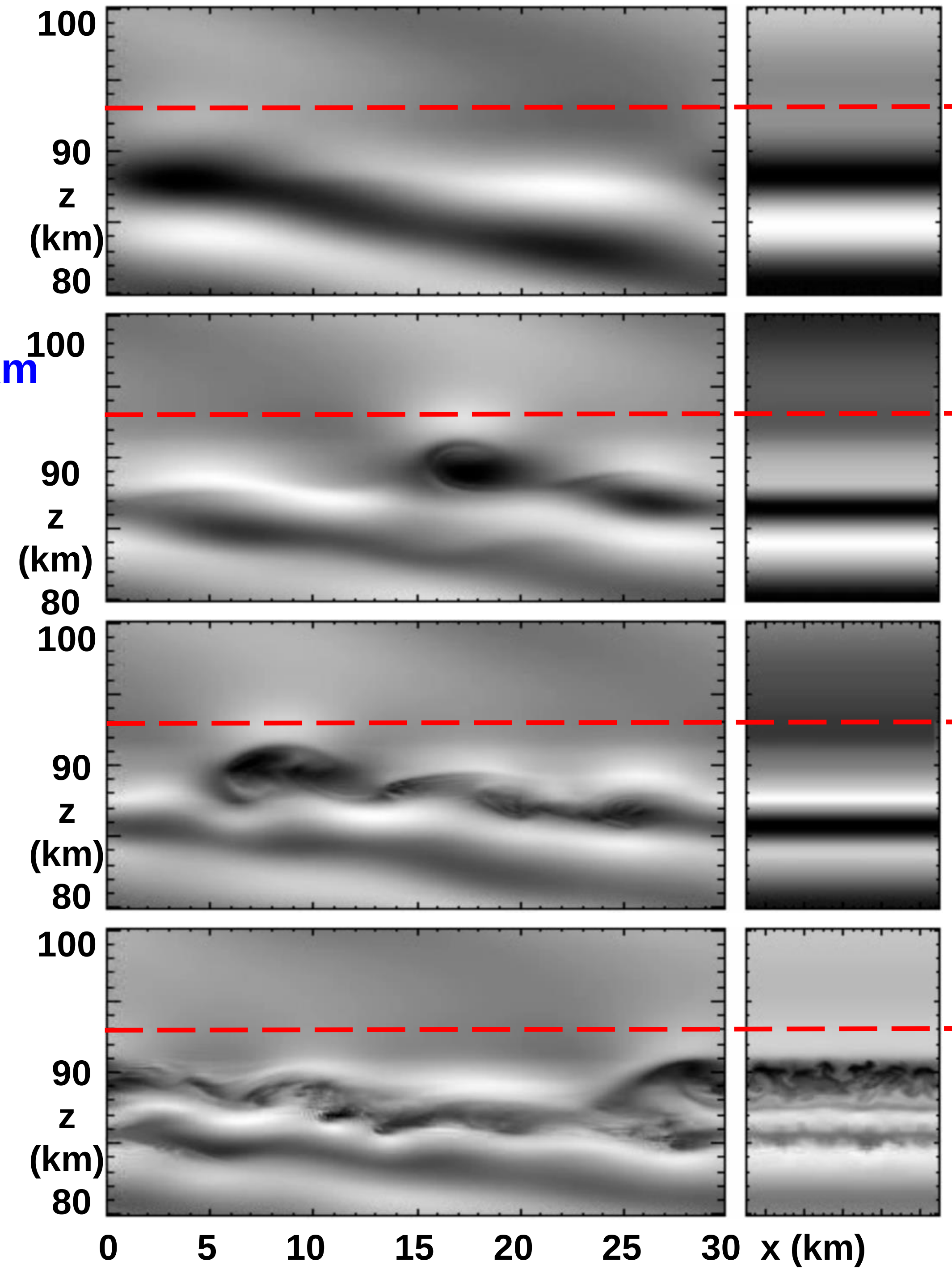
GW propagating into a mesospheric inversion layer

- other large-scale waves may yield similar responses

- the important GW responses will be nonlinear below ~200 km

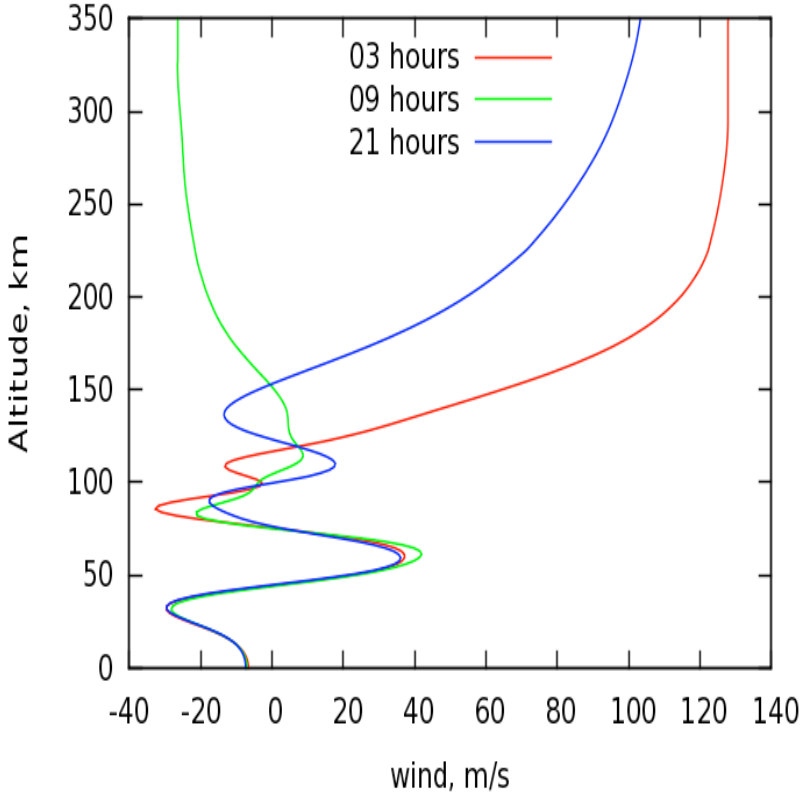
evolution spans ~4 T_b

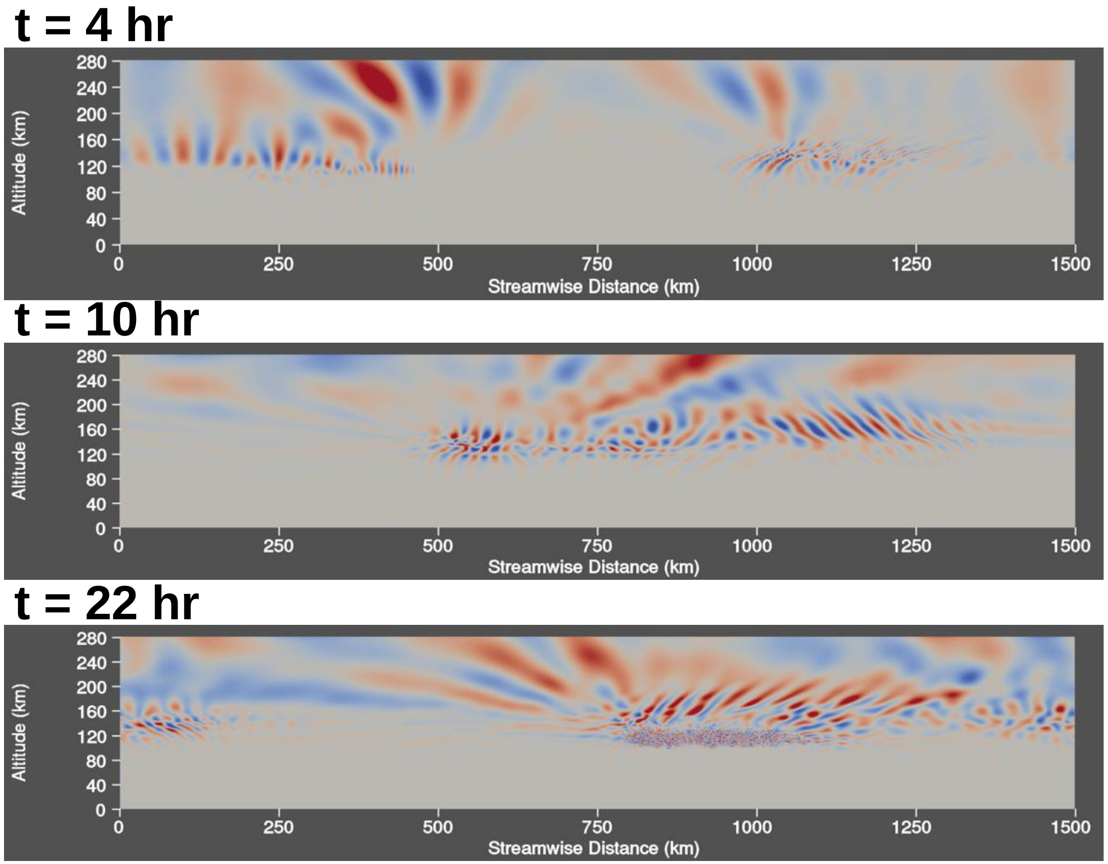




Convective GWs propagating in tidal wind shears

- stochastic convective GWs propagating into a diurnal tide wind field (8°S) provided by WACCM-X
- convective GWs interact strongly with tidal shears, exhibit local dissipation below ~200 km, yield secondary GW generation
- secondary GWs penetrate easily to higher altitudes, exhibit preferential propagation against the tidal winds at high altitudes



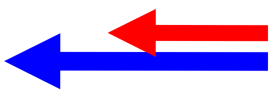


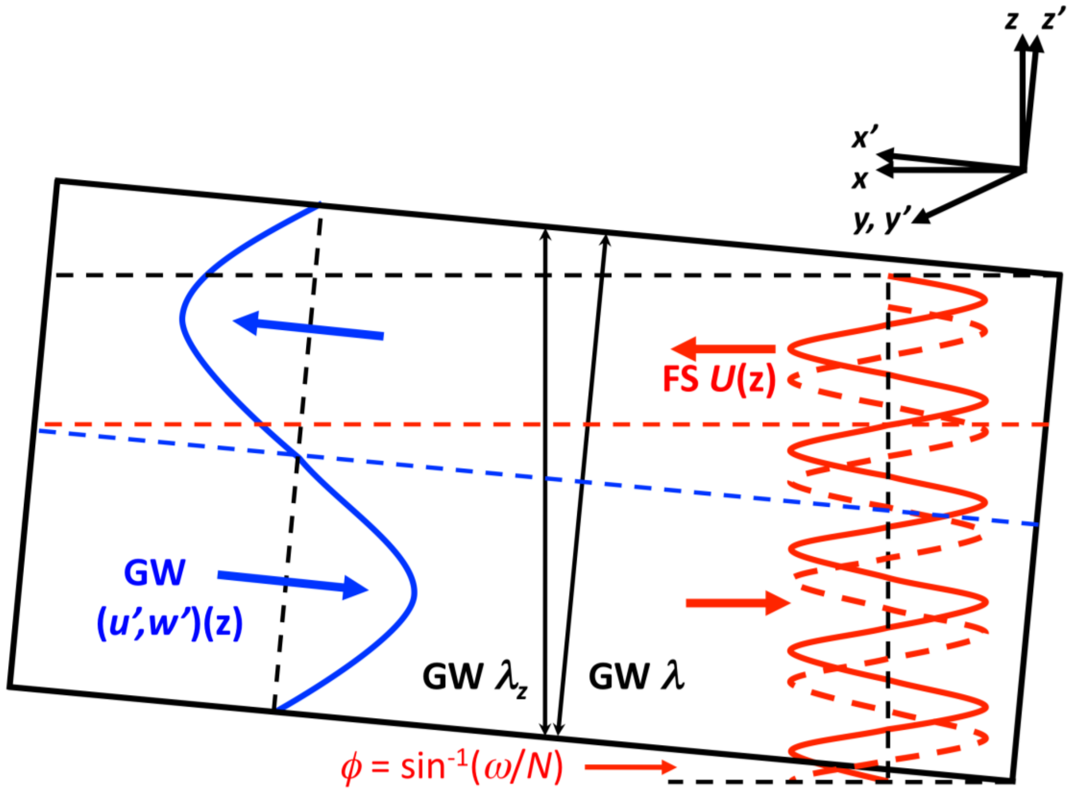
GW – fine structure interactions

a "simple" DNS of GW-FS superposition

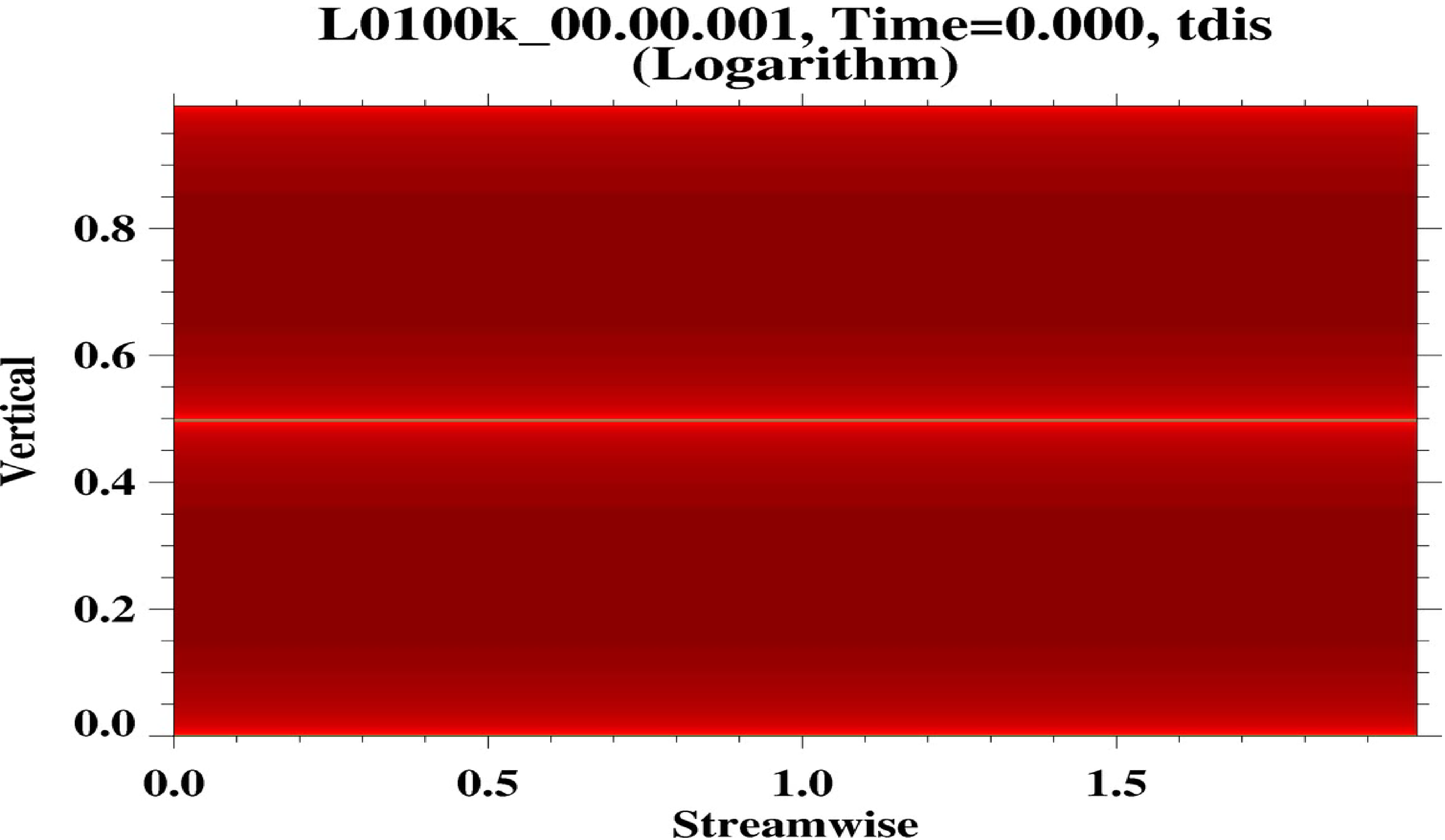
- a GW with $a = u_0'/(c\text{-}U) = 0.5$, $\omega = N/10$, m $(= 2\pi/\lambda_z) = 1$, $Re = \lambda_z^2/T_b\nu = 100{,}000$
- and oscillatory fine-structure shears with $dU_{FS}/dz = 2N$, $m \sim 5$

1. GW (U) & linear (aligned u) fine structure



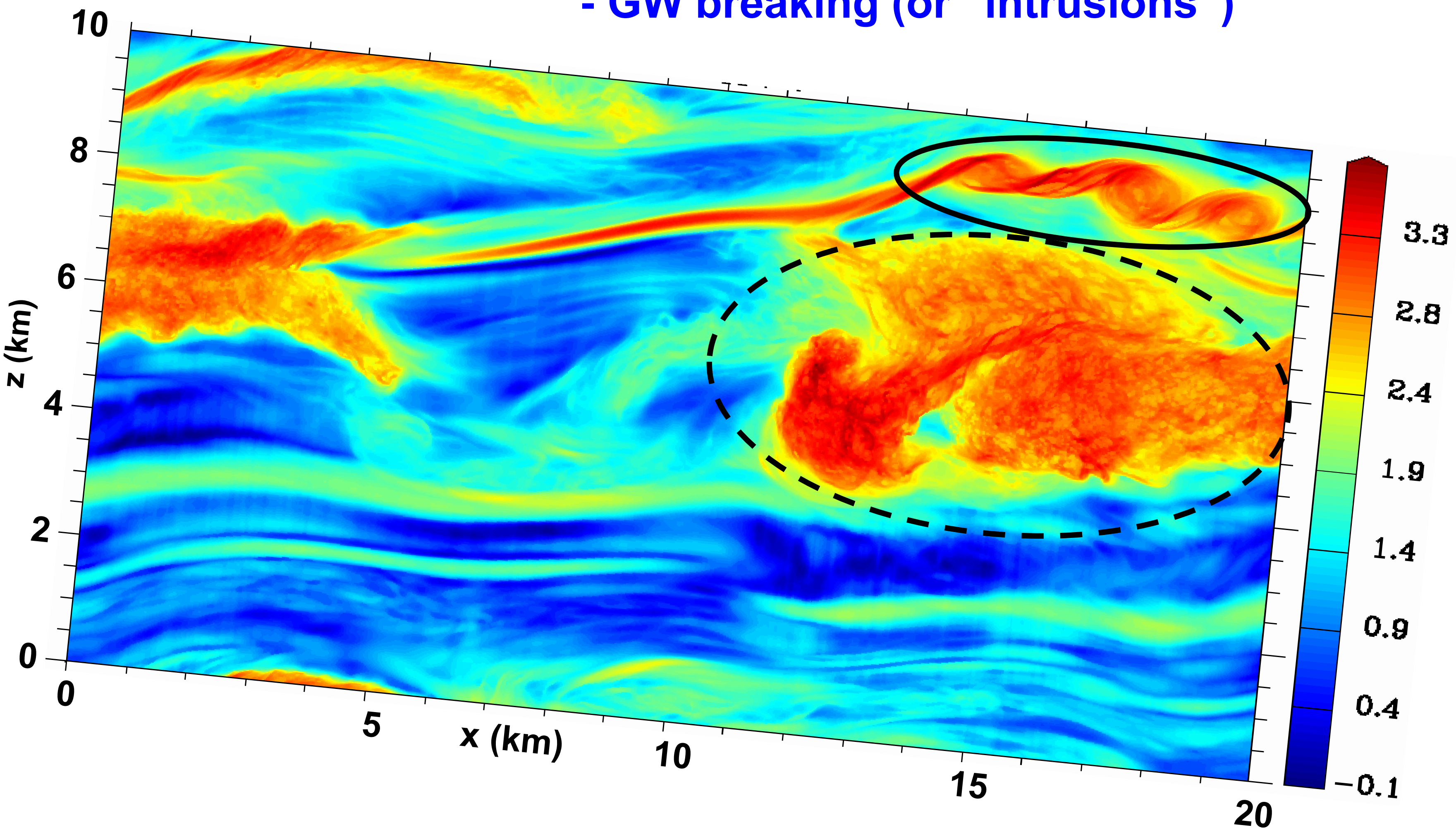


Superposition of GW with *a* = 0.5, ω = N/10, Re = 100,000 and small-scale oscillatory shear with dU/dz = N - thermal energy dissipation rate (log scale)



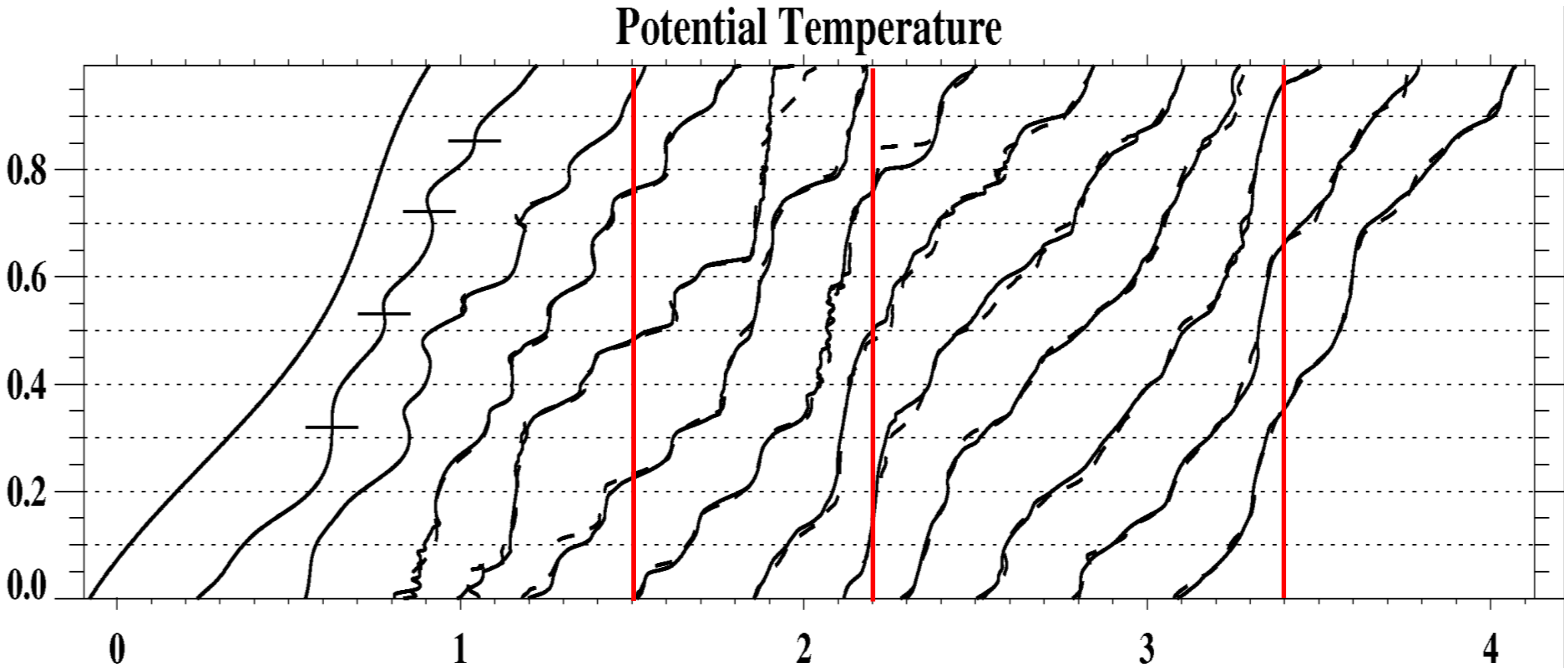
Dominant turbulence sources shown in energy dissipation rate ε
(aligned shears, x-z plane, spanwise mean, t = 11.5 T_b)

- KH instability (large and small scales)
- GW breaking (or "intrusions")



GW – FS interactions =>
complex, highly-structured flows due to sporadic turbulence & mixing

θ FS exhibits "sheet and layer" structure during active turbulence



increasing time $\Delta t = T_b$

Conclusions

- GWs exhibit diverse dynamics throughout the atmosphere

- GW amplitude growth with altitude enables strong interactions and instabilities

- mean and tidal wind shears and variable stratification have strong influences on GW anisotropy and dissipation

- multi-scale GW interactions impose significant intermittency in turbulence events, momentum deposition

- we should anticipate these dynamics to occur at many scales in DEEPWAVE measurements

- DEEPWAVE measurements should provide opportunities for assessing these dynamics, their statistics, and effects

    - especially near the tropopause and in the MLT

Anticipated DEEPWAVE Science Collaborations
(D. Fritts, M. Taylor, and DEEPWAVE colleagues)

Efforts will employ various data and models:

- DEEPWAVE airborne data from NGV and Falcon (dropsondes, in-situ, MTP, DLR Doppler lidar)
- new NGV Rayleigh/Na lidar measurements ~15-100 km
- new NGV MTM T(x,y,t) measurements at ~87 km
- GB meteor radar and lidar measurements in NZ, other
- AIRS/MLS data (S. Eckermann)
- COAMPS/ECMWF models/reanalysis (J. Doyle, A. Dörnbrack)
- Finite-Volume DNS of deep GW dynamics, z ~0-200 km
- Spectral DNS of multi-scale GW dynamics and instabilities in UTLS and MLT

Anticipated DEEPWAVE Science Collaborations
(D. Fritts, M. Taylor, and DEEPWAVE colleagues)

Science foci:

- quantification of GWs from orographic and other sources, their vertical propagation, interactions, and momentum deposition at higher altitudes

- multi-scale GW dynamics and instabilities in the UTLS

- GW propagation, filtering, and refraction in the stratosphere

- deep GW dynamics, instabilities, and MF interactions in the MLT

- GW-tidal interactions and MF modulation in the MLT

- evaluation/quantification of satellite GW measurements