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


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)

\[ a = 0.9 \]

\[ \omega = N/3.2 \]

\[ \text{Re} = 10^4 \]

\( C_g \)

\( C_p \)

Fritts et al. (2009)
GW amplitude growth with altitude yields strong induced mean motions, "self acceleration", and other effects.

Decreasing mean density

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

$\Rightarrow$ leading edge of GW packet accelerates
trailing edge decelerates

$\Rightarrow$ self-acceleration & phase distortion

$<u'w'>$ and $\Delta U > 0$
“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 $\zeta$ 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 \( \sim 4 \, T_b \)

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 $T_b$

\[ N^2 = 0 \]
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

$t = 4 \text{ hr}$

$t = 10 \text{ hr}$

$t = 22 \text{ hr}$
GW – fine structure interactions

a "simple" DNS of GW-FS superposition

- a GW with $a = u_0'/(c-U) = 0.5$, $\omega = N/10$, $m = 2\pi/\lambda_z = 1$, $Re = \lambda_z^2/T_{bn} = 100,000$
- 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 $a = 0.5$, $\omega = N/10$, $Re = 100,000$ and small-scale oscillatory shear with $dU/dz = N$ - thermal energy dissipation rate (log scale)

L0100k_00.00.001, Time=0.000, tdis (Logarithm)
Dominant turbulence sources shown in energy dissipation rate $\varepsilon$ (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 \( \sim 15-100 \) km
- new NGV MTM \( T(x,y,t) \) measurements at \( \sim 87 \) 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, \( z \sim 0-200 \) km
- Spectral DNS of multi-scale GW dynamics and instabilities in UTLS and MLT
Anticipated DEEPWAVE Science Collaborations
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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