

# RESEARCH AIRCRAFT OBSERVATIONS AND THE NUMERICAL SIMULATION OF A BREAKING GRAVITY WAVE EVENT OVER GREENLAND OBSERVED DURING FASTEX

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Measurements from the NOAA G-4 research aircraft and high-resolution numerical simulations are used to study the evolution and dynamics of a large-amplitude gravity wave event over Greenland that took place on 29 January 1997 during the Fronts and Atlantic Storm-Track Experiment (FASTEX). Vertical cross section analyses of continuous flight-level and dropwindsonde data, with 50-km horizontal spacing, documented the presence of a large-amplitude breaking gravity wave extending from above the 180 hPa level to 500 hPa (Fig. 1). The dropwindsonde data measured deep layers with isentropic overturning and an upshear tilt to the gravity wave. Flight-level data (~180 hPa or 12 km) indicate a horizontal shear of over  $10^{-3} \text{ s}^{-1}$  across the breaking wave with 25 K potential temperature perturbations. The wind speed downstream of the breaking wave decreased by  $30 \text{ m s}^{-1}$  resulting in the reduction of the cross mountain flow to near zero with localized regions of flow reversal.

Naval Research Laboratory's nonhydrostatic model COAMPS (Hodur 1997) is used with three nested grids, which have horizontal resolutions of 45 km, 15 km and 5 km and 65 vertical levels, to simulate the gravity wave event. The model solves the finite difference approximation to the fully compressible set of equations, and contains complete physical parameterizations and a mesoscale data assimilation system. The model simulation captures the temporal evolution and 3-dimensional structure of the wave. The model results indicate that weak, low-level, westerly flow of approximately  $10 \text{ m s}^{-1}$  near the top of the Greenland ice sheet was enhanced by katabatic effects. Vertically propagating gravity waves emanate from near the surface along the steep glacial slopes as the cold-air mass accelerated down the western portion of Greenland. Near-surface wind speeds greater than  $40 \text{ m s}^{-1}$  were present in the simulation along the steep slopes and documented in the dropwindsonde data. Research aircraft scientists observed snow plumes driven by high surface winds along the glacial slopes.

Figure 2 shows the west-east oriented vertical cross section of potential temperature for the 12-h simulation time (1200 UTC 29 January) for the third grid mesh ( $\Delta x=5 \text{ km}$ ). A large amplitude gravity wave is apparent in the lower troposphere with wave breaking in the stratosphere established in a deep layer between 9 km and 16 km. The wave structure has obvious similarities to the vertical cross section based on dropwindsonde data (Fig. 1), however the model underestimates the vertical amplitude of the wave. Characteristics of the breaking wave include an upshear vertical tilt, significant superadiabatic layers, and well-mixed near-neutral conditions that extend downstream from the breaking region. Hydraulic jump-like features are present at the level of wave breaking and remain nearly stationary. As a consequence of adiabatic cooling associated with the gravity wave amplification (e.g., Dörnbrack et al. 1997), a region of enhanced cooling forms that is characterized by temperatures less than 198 K in the 18-22 km layer (hatched area in Fig. 2). These cold temperatures in the stratosphere are often associated with the formation of polar stratospheric clouds in which chlorine compounds may be converted into ozone-destroying chlorine radicals and may also result in denoxification.

A vertical cross of model simulated wind speed for the 12-h time (1200 UTC 29 January) is shown in Fig. 3. Lateral shear of  $\sim 10^{-3} \text{ s}^{-1}$  is maintained in the vicinity of the breaking wave in the layer between 10 km and 12 km. As the result of intense vertical shear ( $60 \text{ m s}^{-1}/500 \text{ m}$ ) and isentropic steepening associated with the wave amplification, turbulent kinetic energy is generated that leads to enhanced momentum dissipation (hatched area in Fig. 3). This is in agreement with analysis of the dropwindsonde data that indicate a large increase of high frequency structure to the vertical velocity near the center of the wave as opposed to less turbulent conditions upstream. Diagnostic computations of the simulated momentum flux indicate a large dissipation region of momentum that coincides spatial and temporally with the wave breaking in the lower stratosphere. Diagnosis of the vorticity tendency budget suggests that filamentation of the vertical vorticity component results from the tilting of horizontal vorticity generated by the large shear associated with the breaking gravity wave (Fig. 3). The scale of the vortex filaments may inherently depend upon the distribution of the vertical motion along the isentropic sheets associated with the turbulent breakdown of the gravity wave.

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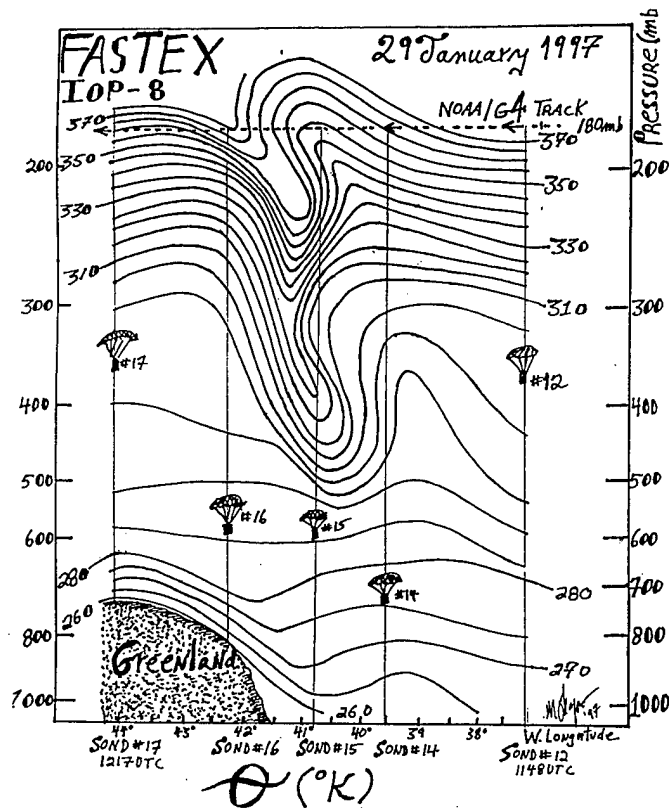


Fig. 1. Vertical cross section of potential temperature derived from dropwindsonde and NOAA G-4 flight-level (~12 km) data at 1200 UTC 29 January 1997. The isentropes interval is 5 K.

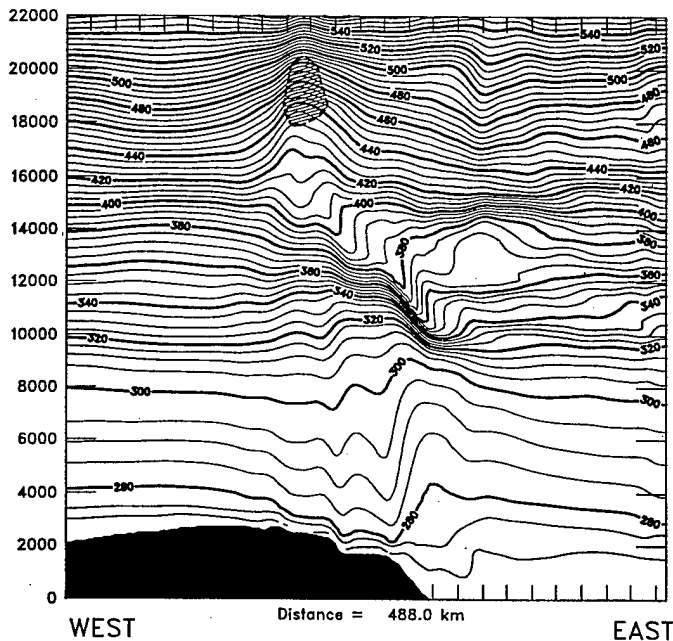


Fig. 2. Vertical cross section of model simulated potential temperature for 12-h (1200 UTC 29 January 1997). The isentropes interval is 5 K. The region with temperature less than 198 K corresponds to the hatched area.

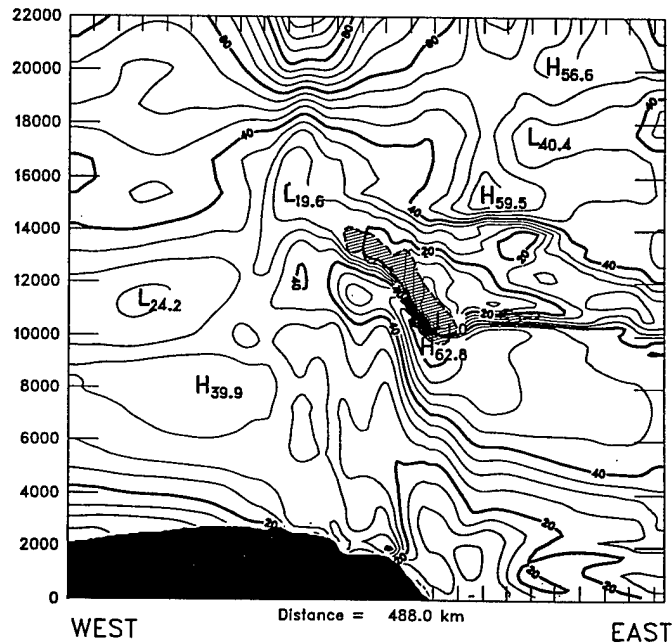


Fig. 3. Vertical cross section of model simulated horizontal wind speed ( $m s^{-1}$ ) for 12-h (1200 UTC 29 January 1997). The isobars interval is 5  $m s^{-1}$ . The region with turbulent kinetic energy greater than  $5 m^2 s^{-2}$  corresponds to the hatched area.

#### References

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- Hodur, R.M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere mesoscale prediction system (COAMPS). *Mon. Wea. Rev.*, 125, 1414-1430.