Gravity Waves and the High-Resolution Modeling
(Using ECMWF-T799)

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Gravity wave parameterization is one of the leading model uncertainties (e.g., QBO, cold-pole problem).

The high-resolution modeling that resolves gravity waves can improve the models.

This presentation introduces

- Validations of gravity waves resolved in ECWMF-T799 with observations
- Capability of ECMWF-T799:
  - Gravity wave variations during the 2009 stratospheric sudden warming

The high-resolution WACCM simulations
The European Centre for Medium-Range Weather Forecasts (ECMWF) T799 version

- The global 4D data assimilation

- Horizontal resolution ~25 km and 91 vertical levels up to 0.01 hPa (~80 km). Vertical resolution is ~400 m in the troposphere and ~1-2 km in the stratosphere

- Gravity wave with horizontal wavelength longer than ~100 km and vertical wavelength longer than ~4-6 km can be resolved in ECMWF-T799 [Wu and Eckermann, 2008]

- Gravity waves (u’, v’, w’, p’, T’) are extracted using wavelet analysis, and separated into different spectral bands (100-200, 200-400, 400-800, 800-1600, 1600-2400 km).
1. Comparing the versions of ECMWF T799 and T1279
2. Ground-based lidar observations (Seasonal variations)
3. COSMIC/GPS observations (Seasonal variations)
4. COSMIC/GPS observations (Short-term variations)
Comparison between T799 and T1279

T799
Δh = ~25 km

T1279
Δh = ~16 km

These versions of ECMWF data are provided by Peter Bechtold (ECMWF)

Gravity waves in T799 and T1279 are similar
Validations of Seasonal Variations
ECMWF-T799 vs. Lidar Observations
Validations of Seasonal Variations
ECMWF-T799 vs. Lidar Observations

GW-Ep at RO [Rothera (67.5°S, 68°W)] SP [the South Pole (90°S)]

- Lidar GW-Ep at RO exhibits the clear seasonal variations with a maximum in winter and a minimum in summer, which is consistent with ECMWF.
- GW-Ep at SP from both lidar and ECMWF shows flat seasonal variations.

[Yamashita et al., 2010]
Validations of Seasonal Variations
ECMWF-T799 vs. Satellite Observation

- Climatology of GW-Ep in NH and SH is well compared with CHAMP/GPS observations.
- These results indicate that ECMWF-T799 contains the important gravity wave sources in the polar region.
Daily variations of GW-Ep in ECMWF-T799 are comparable with COSMIC/GPS GW-Ep during the 2009 SSW.

These comparisons demonstrate the capability of ECMWF-T799 resolving gravity waves.
Case Study: The 2009 SSW
Stratospheric Sudden Warming in 2009

Peak SSW at 10 hPa = Jan 23-24

Wind Reversal at 1 hPa = Jan 21

Spatial, Temporal, Spectral dependence of gravity waves
Spatial Variations of Gravity Waves

(a) Dec 20
(b) Jan 5
(c) Jan 16
(d) Jan 21
(e) Feb 5
(f) Feb 20

W (cm/s)
Temporal Variations of Gravity Waves

- Enhancements of GW-Ep correspond with the growth of planetary wave 1 and wave 2.
- Downward progressions of gravity wave enhancements are captured.
Spectral Dependence of Gravity Wave Variations

- Two enhancements of GW-Ep are seen in all wavelength bands.
- GW-Ep in 400-800 km band is dominated.
Gravity waves resolved in ECMWF-T799 are validated with satellite and ground-based lidar observations.

During the 2009 SSW, significant gravity wave variations are simulated by ECMWF, indicating the importance of the high-resolution modeling.
Example of Gravity Wave Analysis Method

Total Perturbation Energy Flux ($F_E$) is conserved without wave dissipation:

$$F_E = p'w' + U\rho u'w' + V\rho v'w'$$

[Hines and Reddy, 1967; Lidzen, 1990]
ECWMF-T799 analysis and forecast versions (12, 24, 48, 240 hours) are comparable, indicating no significant influences on gravity waves by assimilation process.
Gravity wave parameterization is one of the leading model uncertainty (QBO, cold-pole problem).

The high-resolution that can resolve gravity waves will solve this problem.