Gravity Waves and the High-Resolution Modeling

(Using ECMWF-T799)

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Motivations

- ✓ 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

ECMWF-T799 and Analysis Method

The European Centre for Medium-Range Weather Forecasts (ECMWF) T799 version

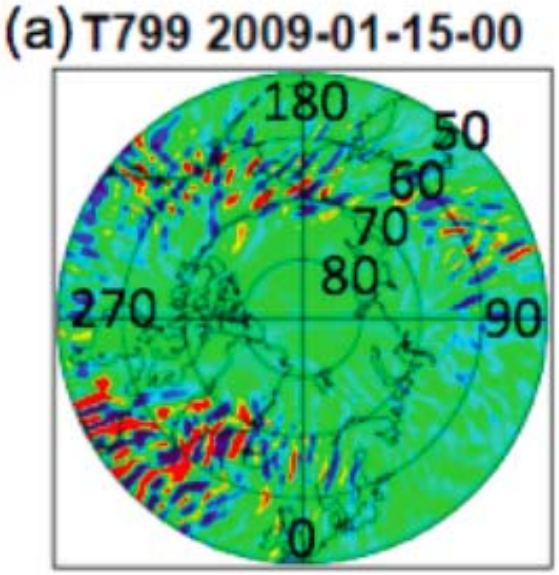
- ✓ The global 4D data assimilation
- ✓ Horizontal resolution ~25 km and 91 vertical levels up to 0.01 hPa (~80 km). Vertical resolution is ~400 m in the troposphere and ~1-2 km in the stratosphere
- ✓ Gravity wave with horizontal wavelength longer than ~100 km and vertical wavelength longer than ~4-6 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).

Validations

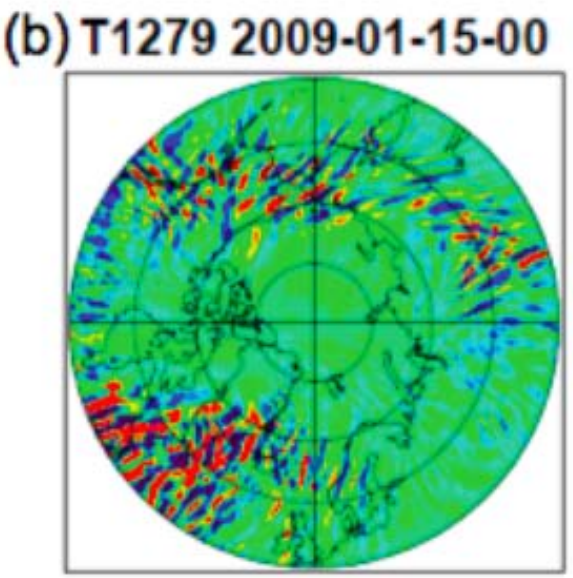
1. Comparing the versions of ECMWF T799 and T1279
2. Ground-based lidar observations (Seasonal variations)
3. COSMIC/GPS observations (Seasonal variations)
4. COSMIC/GPS observations (Short-term variations)

Comparison between T799 and T1279

T799
Δh = ~25 km



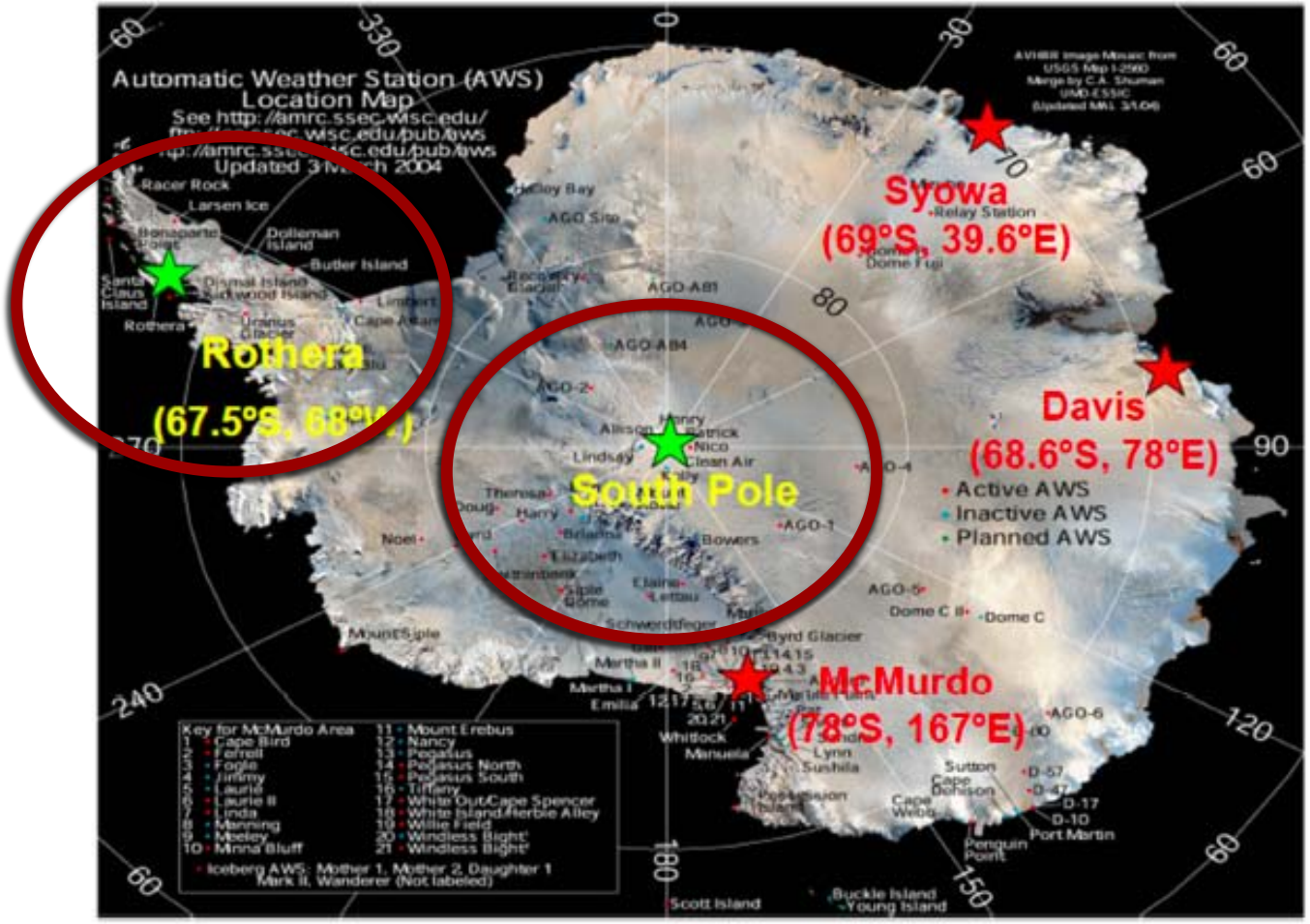
T1279
Δh = ~16 km



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

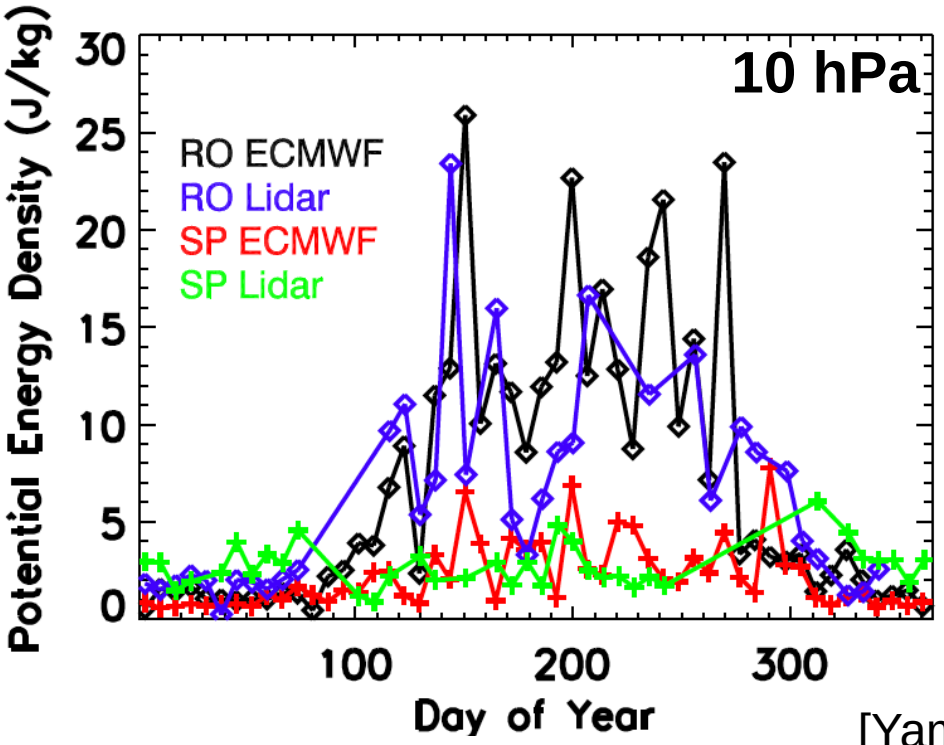
Gravity waves in T799 and T1279 are similar

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)]

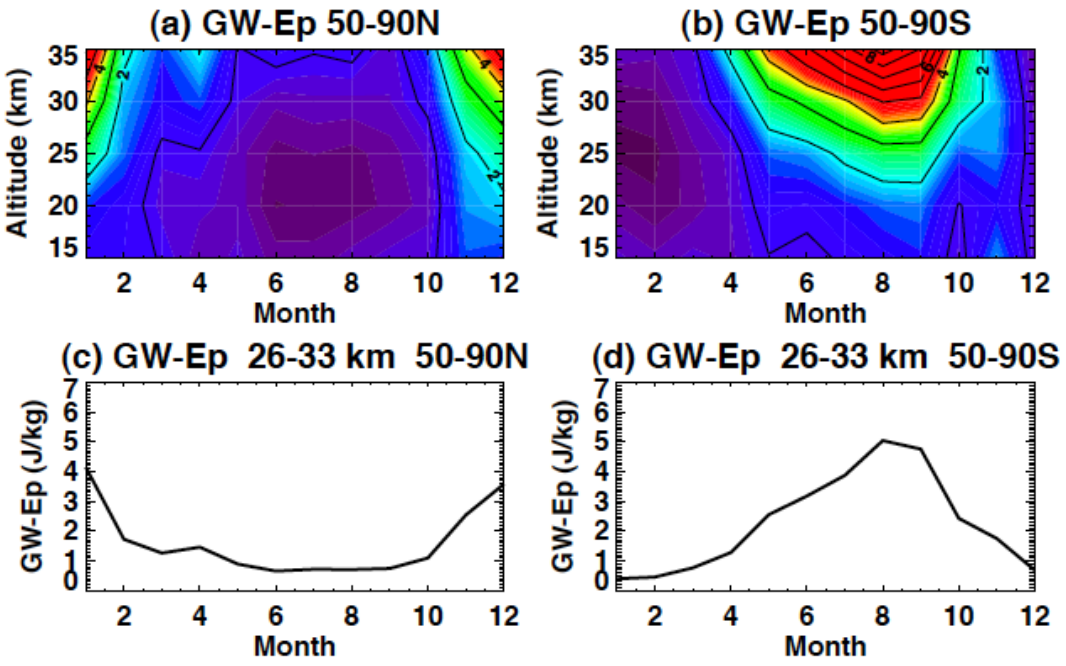


[Yamashita et al., 2010]

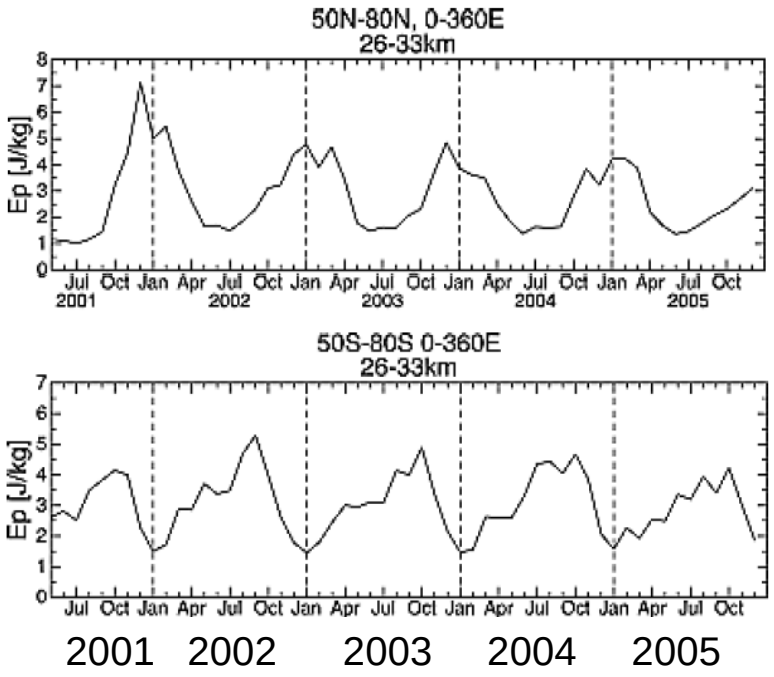
- ✓ Lidar GW-Ep at RO exhibits the clear seasonal variations with a maximum in winter and a minimum in summer, which is consistent with ECWMF
- ✓ GW-Ep at SP from both lidar and ECMWF shows flat seasonal variations.

Validations of Seasonal Variations ECMWF-T799 vs. Satellite Observation

ECMWF-T799

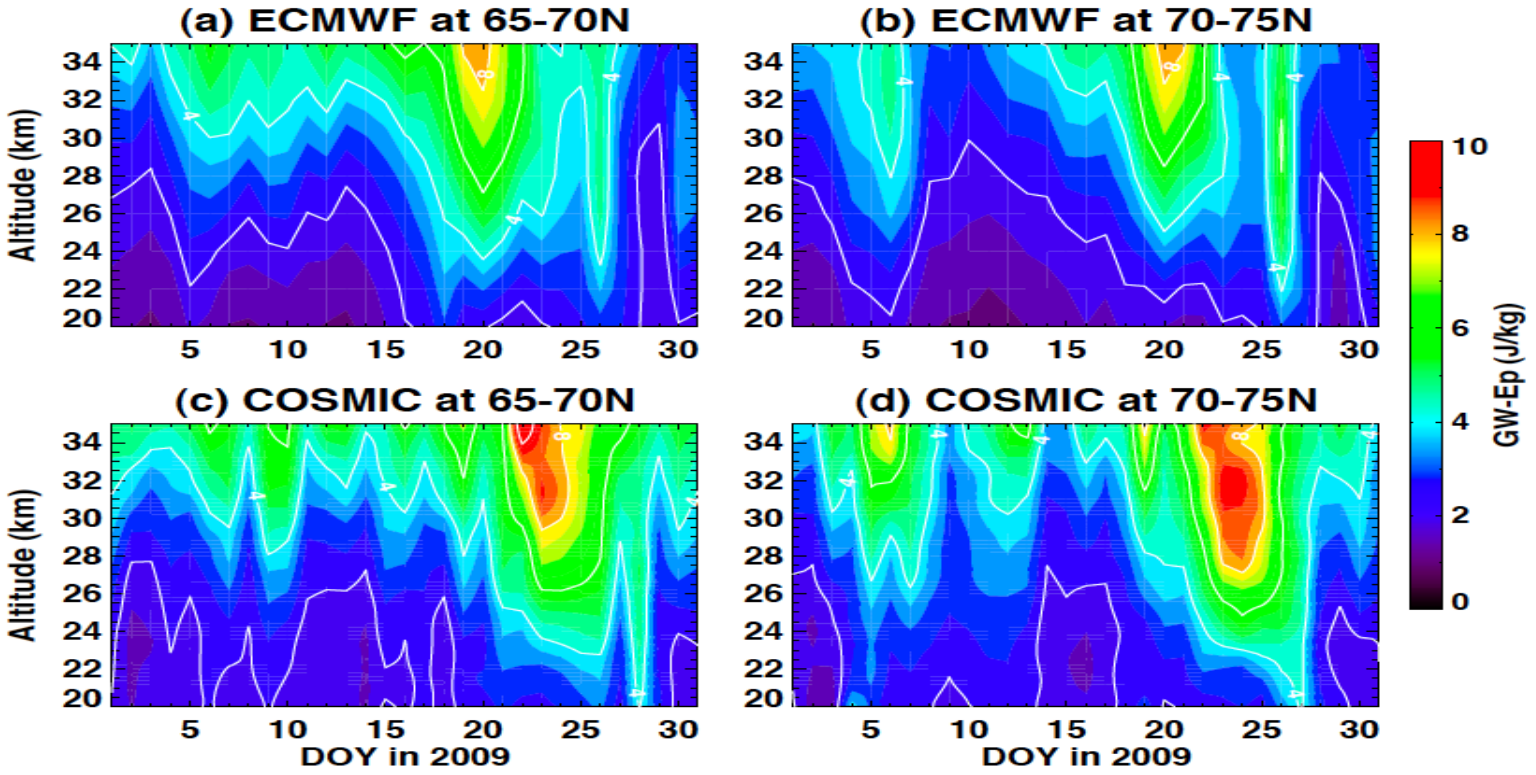


CHAMP/GPS observations [Hei et al., 2008]



- ✓ 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.

Short-term Variations
ECMWF-T799 vs. COSMIC/GPS observations

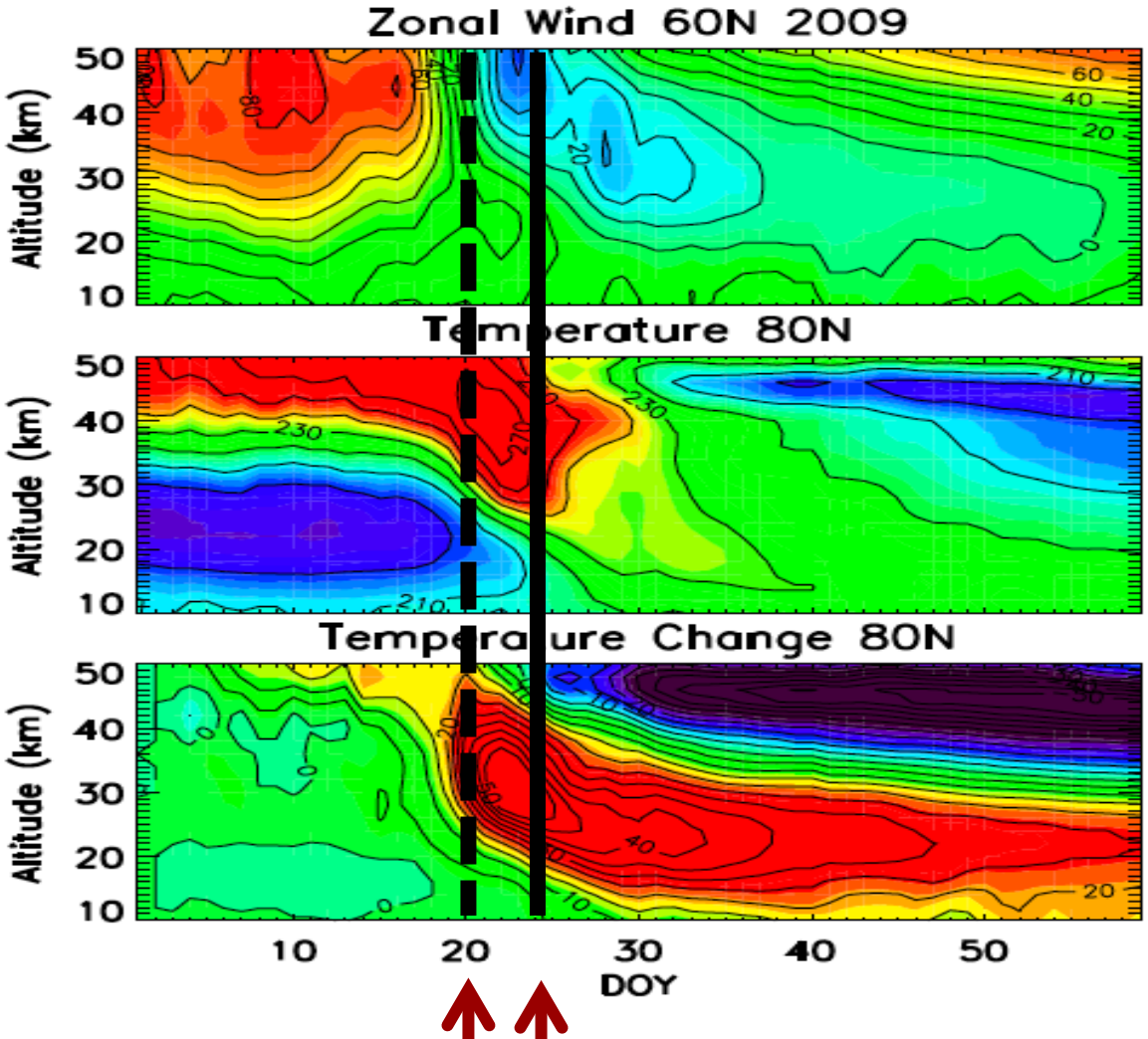


- ✓ Daily variations of GW-Ep in ECMWF-T799 are comparable with COSMIC/GPS GW-Ep during the 2009 SSW.

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

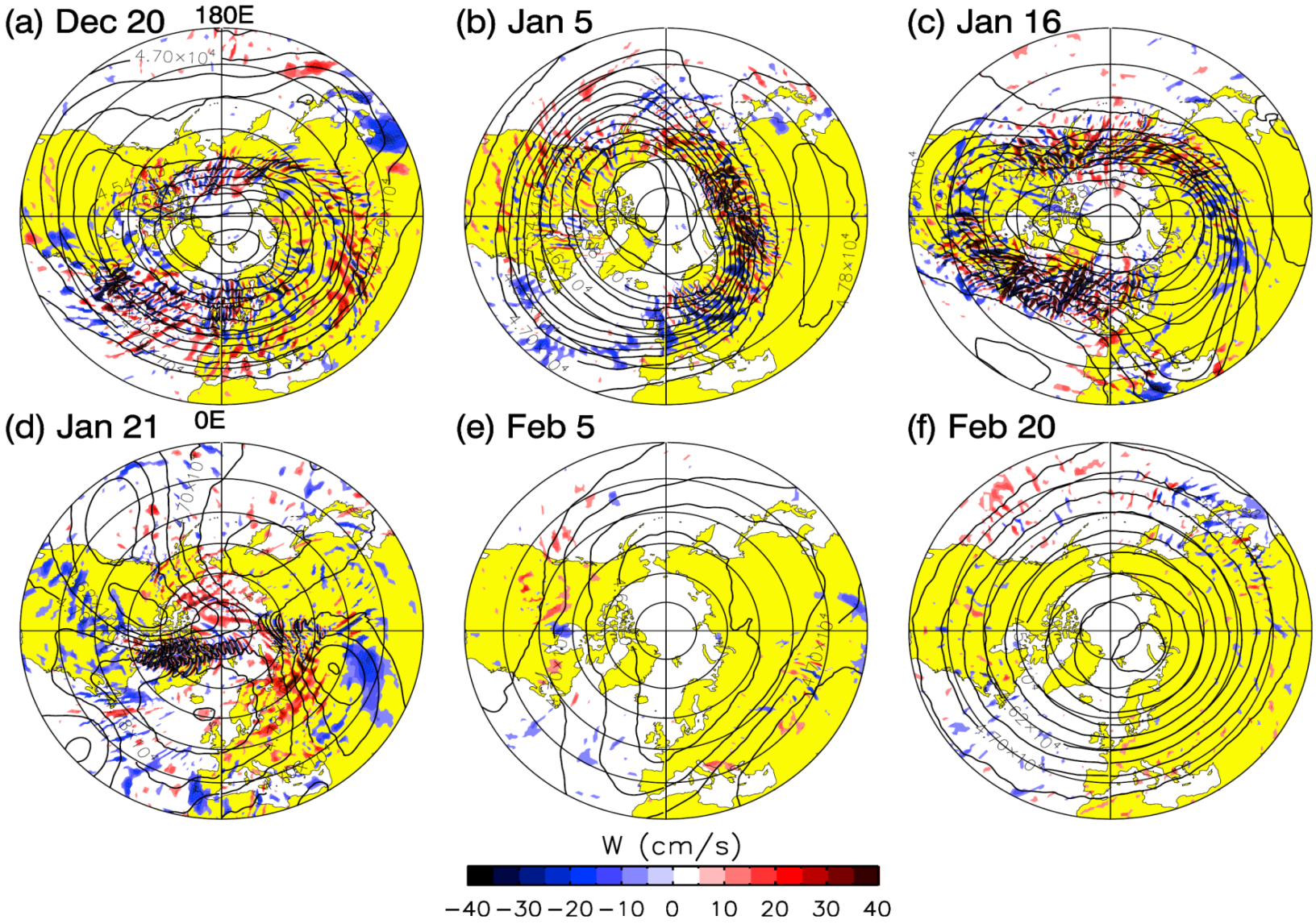
Wind Reversal at 1 hPa
= Jan 21

Spatial, Temporal ,
Spectral dependence
of gravity waves

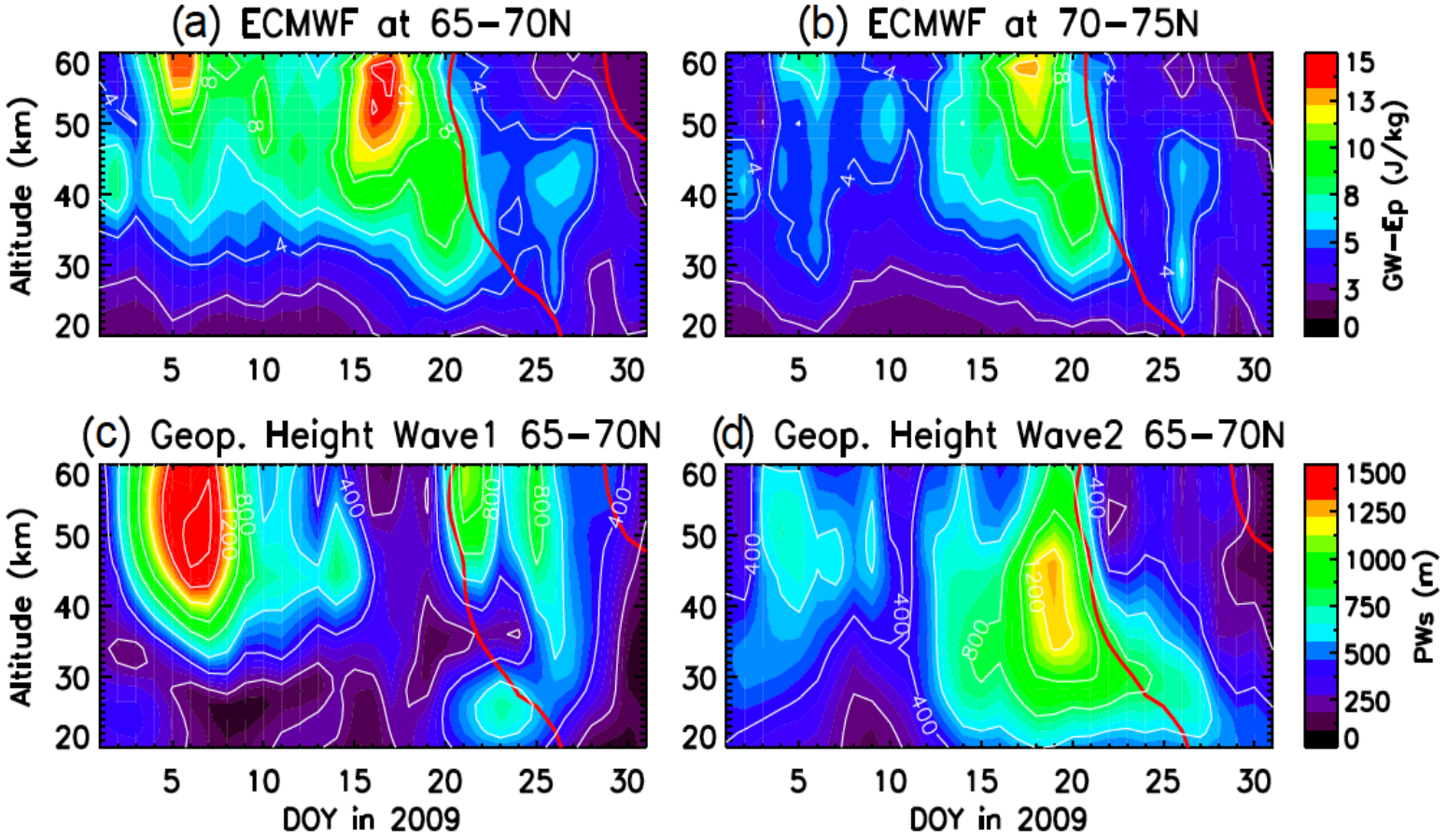
Wind Reversal @1 hPa

Wind Reversal @10 hPa (Peak SSW)

Spatial Variations of Gravity Waves



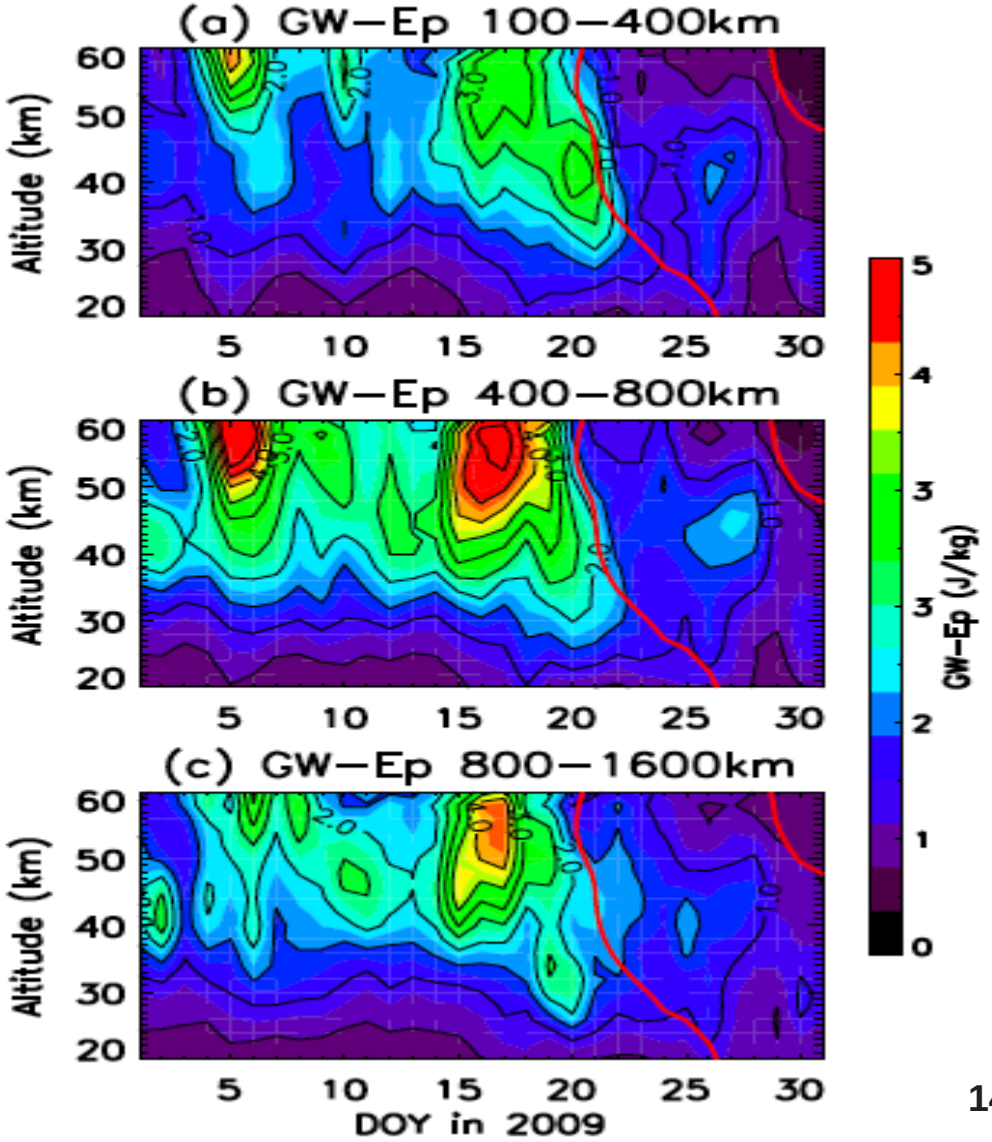
Temporal Variations of Gravity Waves



- ✓ Enhancements of GW-Ep correspond with the growth of planetary wave 1 and wave 2.
- ✓ Downward progressions of gravity wave enhancements are captured.

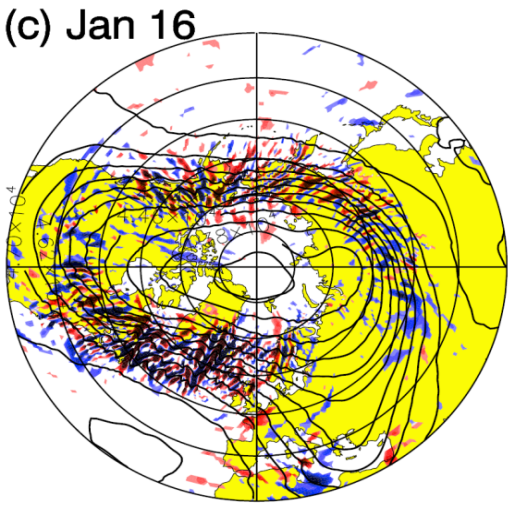
Spectral Dependence of Gravity Wave Variations

- ✓ Two enhancements of GW-Ep are seen in all wavelength bands.
- ✓ GW-Ep in 400-800 km band is dominated.



Conclusions

- ✓ 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.

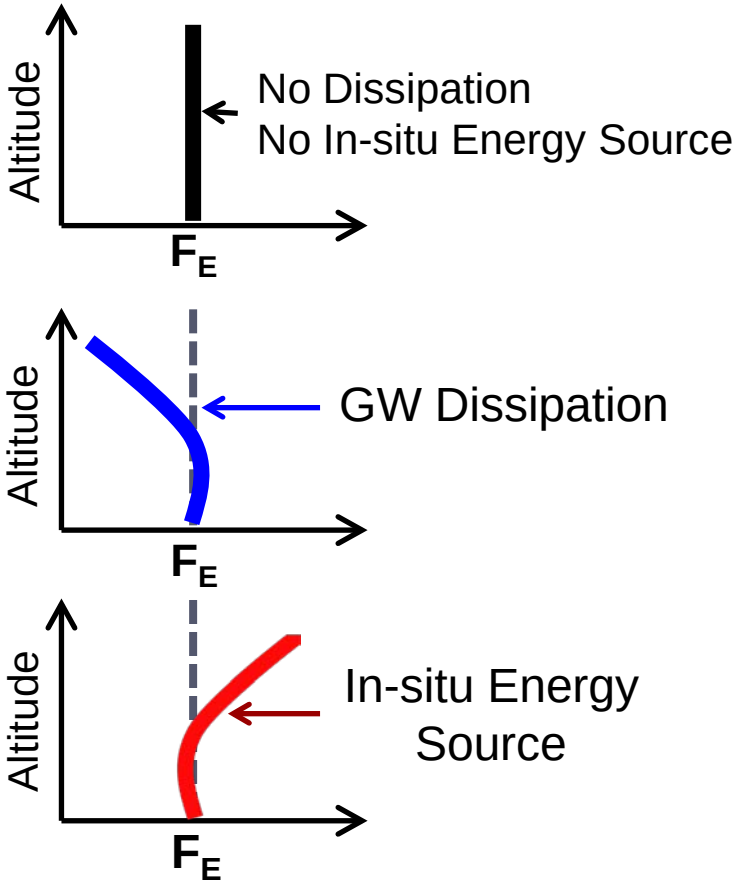


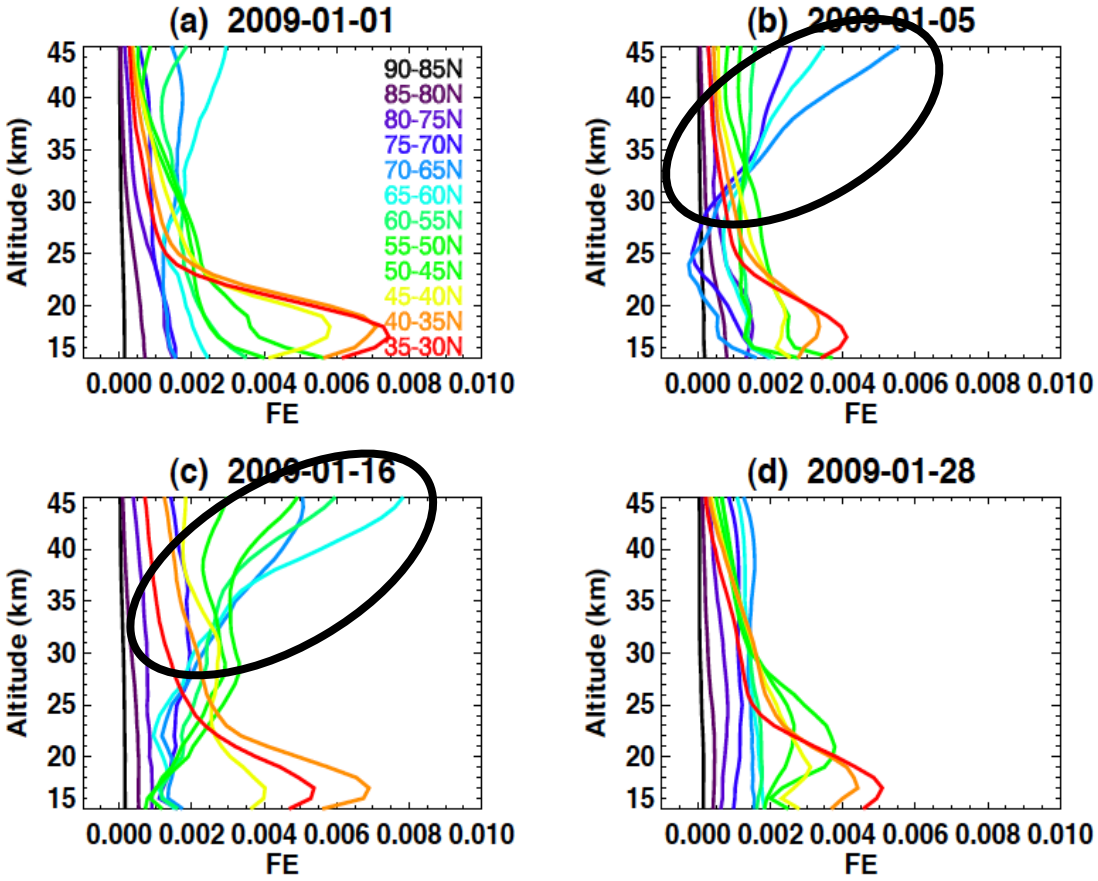
Example of Gravity Wave Analysis Method

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

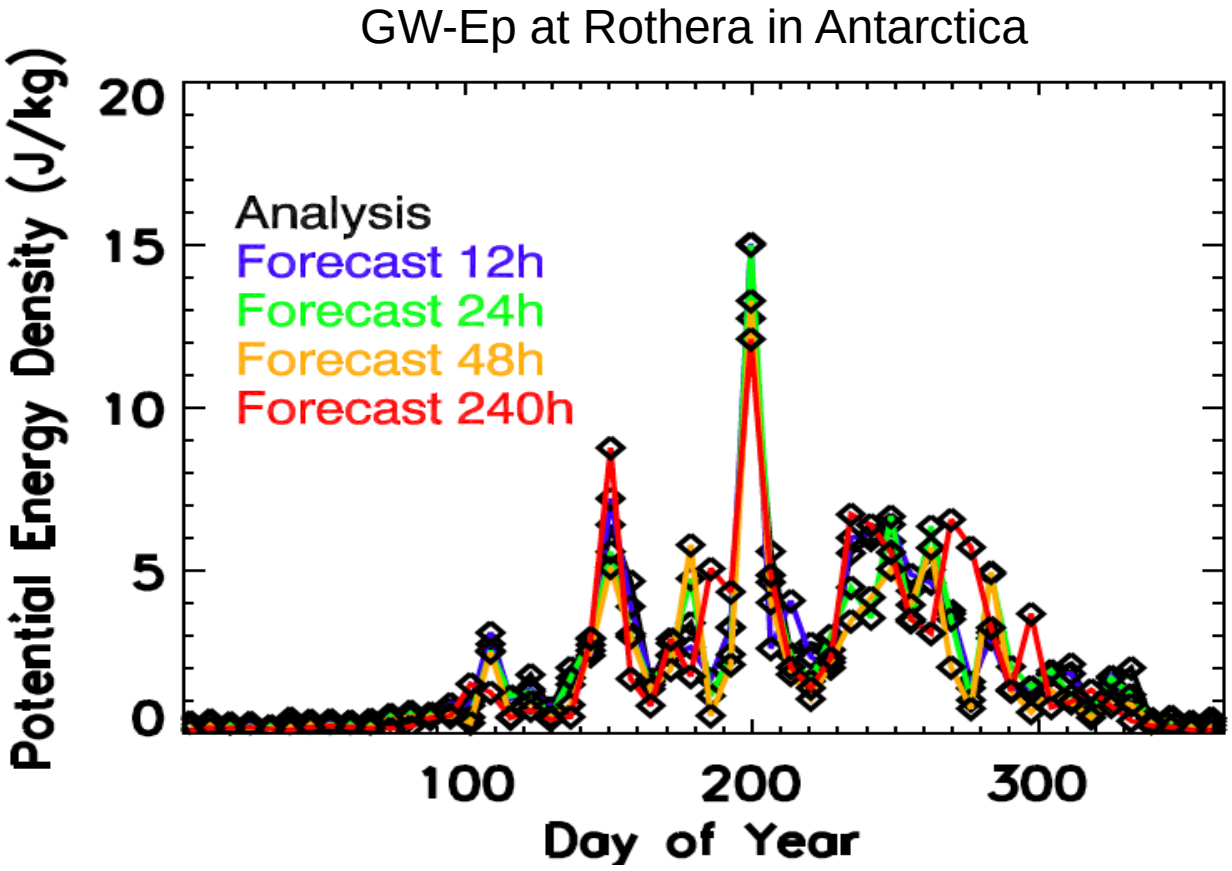
$$F_E = \overline{p'w'} + U\rho\overline{u'w'} + V\rho\overline{v'w'}$$

[Hines and Reddy, 1967; Lidzen, 1990]



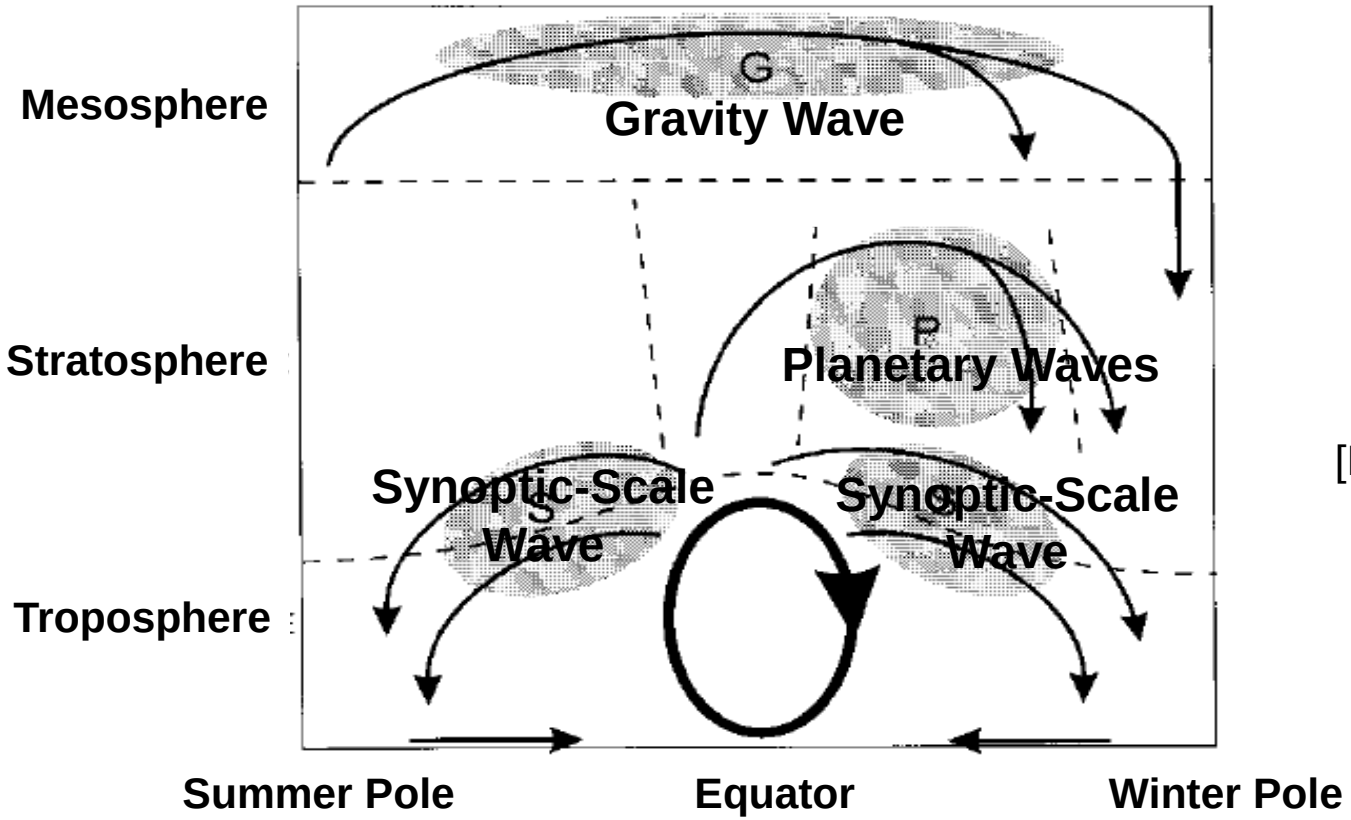


Validations of ECMWF-T799 Analysis vs. Forecast Versions



- ECWMF-T799 analysis and forecast versions (12, 24,48, 240 hours) are comparable, **indicating no significant influences on gravity waves by assimilation process.**

Motivations



[Plumb, 2002]

- ✓ 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.