# Medium-scale thermospheric gravity waves simulated by high-resolution Whole Atmosphere Model

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## Introduction and Questions

- The signatures of gravity waves (GWs) are often observed at thermospheric and ionospheric (IT) heights, as traveling atmospheric and ionospheric disturbances (TADs and TIDs).
- GWs at IT heights can either be of the meteorological origin propagating up from the lower atmosphere, or generated from the auroral zone propagating quasi-horizontally, or excited in-situ.
- GWs couple different regions of the Earth’s atmosphere via heat and momentum transport and play an important role in the generation of equatorial plasma bubbles.
- Few satellite observations of GWs have been studied previously, however, as per our knowledge, there are not many studies that use global circulation models (GCMs) to understand the evolution, spectrum and climatology of medium-scale GWs at IT heights, during geomagnetically quiet and active times.

- **QUESTIONS** : a) What is the global distribution of medium-scale GWs during quiet and active times ? b) Can a GCM reproduce characteristics of medium-scale GWs as observed in the previous studies?

## Methodology/Model

- The Whole Atmosphere Model (WAM) *[Akmaev et al., 2008; Fuller-Rowell et al., 2008]* was developed based on the National Weather Service (NWS) operational Global Forecast System (GFS) model, and is a spectral model spanning the Earth’s atmosphere from the surface till about 600 km.
- We run the standalone high-resolution version of WAM, T254 with a resolution of 0.47° x 0.47° (ƛ> ~155 km), and compare its spectrum with the lower resolution model, T62 with a resolution of 1.9° x 1.9° (ƛ> ~640 km). Both have similar initial conditions and high-latitude forcing.
- For GW climatological distribution, we use WAMT254 (Kp=1, F10.7=70), and output results every 10 minutes, and thus GW with periods> 20 minutes can be resolved. We focus our analysis on medium-scale GWs with spatial scales between 155-620 km.

## Small Scale Variability- WAMT62 / WAMT254

**Figure 1**

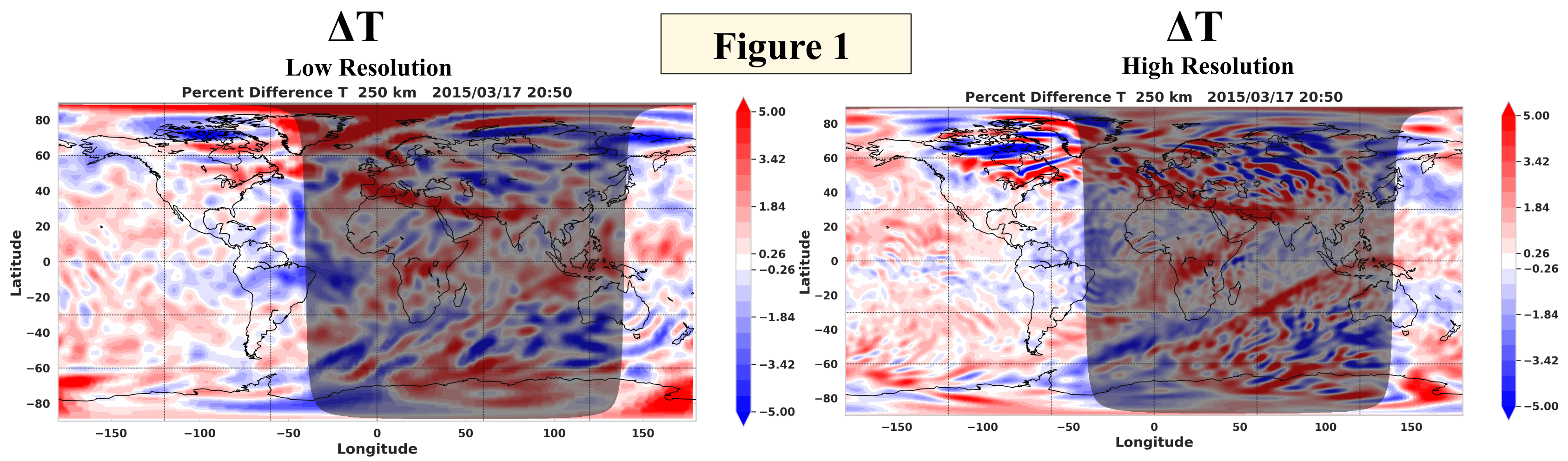


**Figure 2**

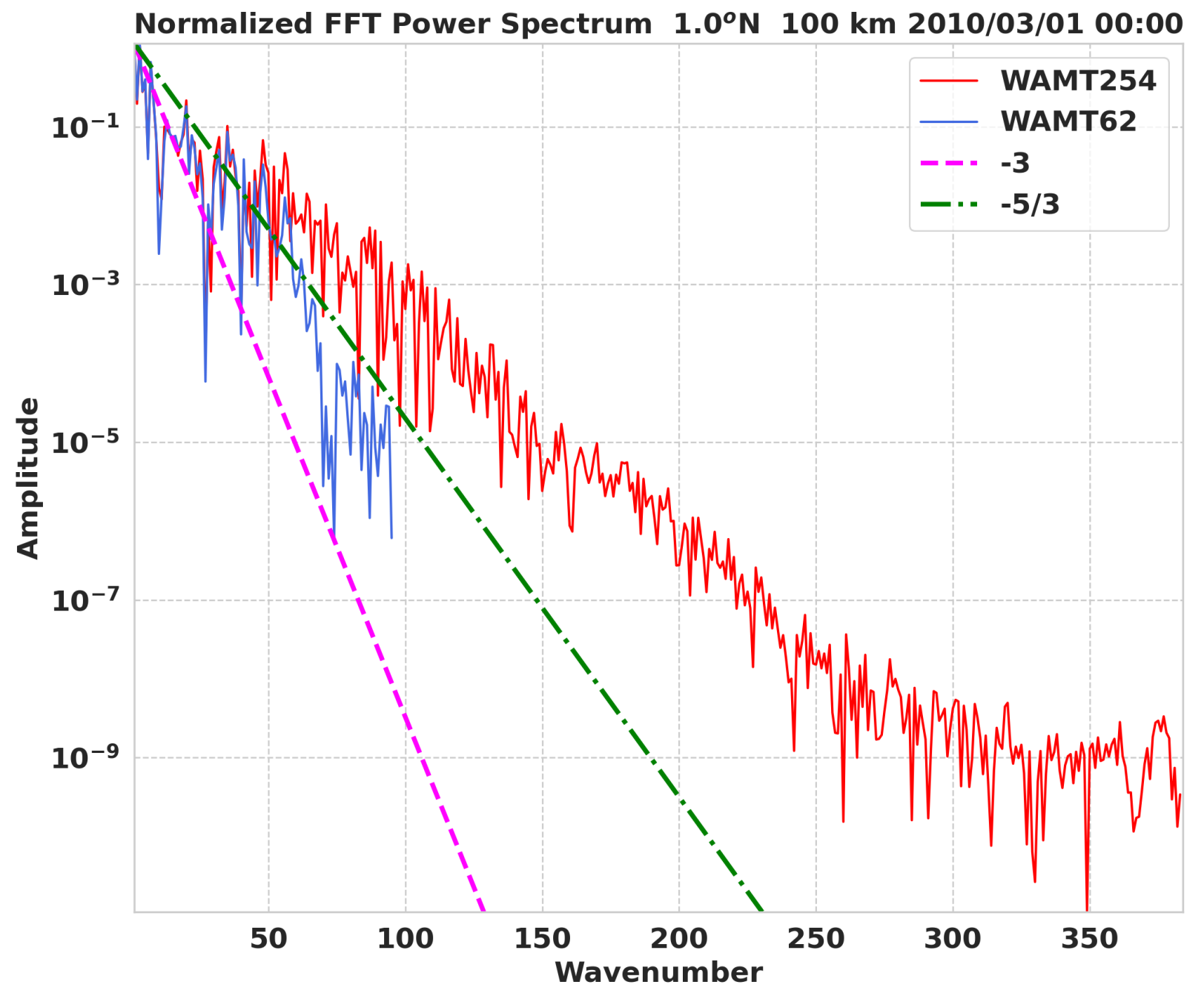


**Figure 3**

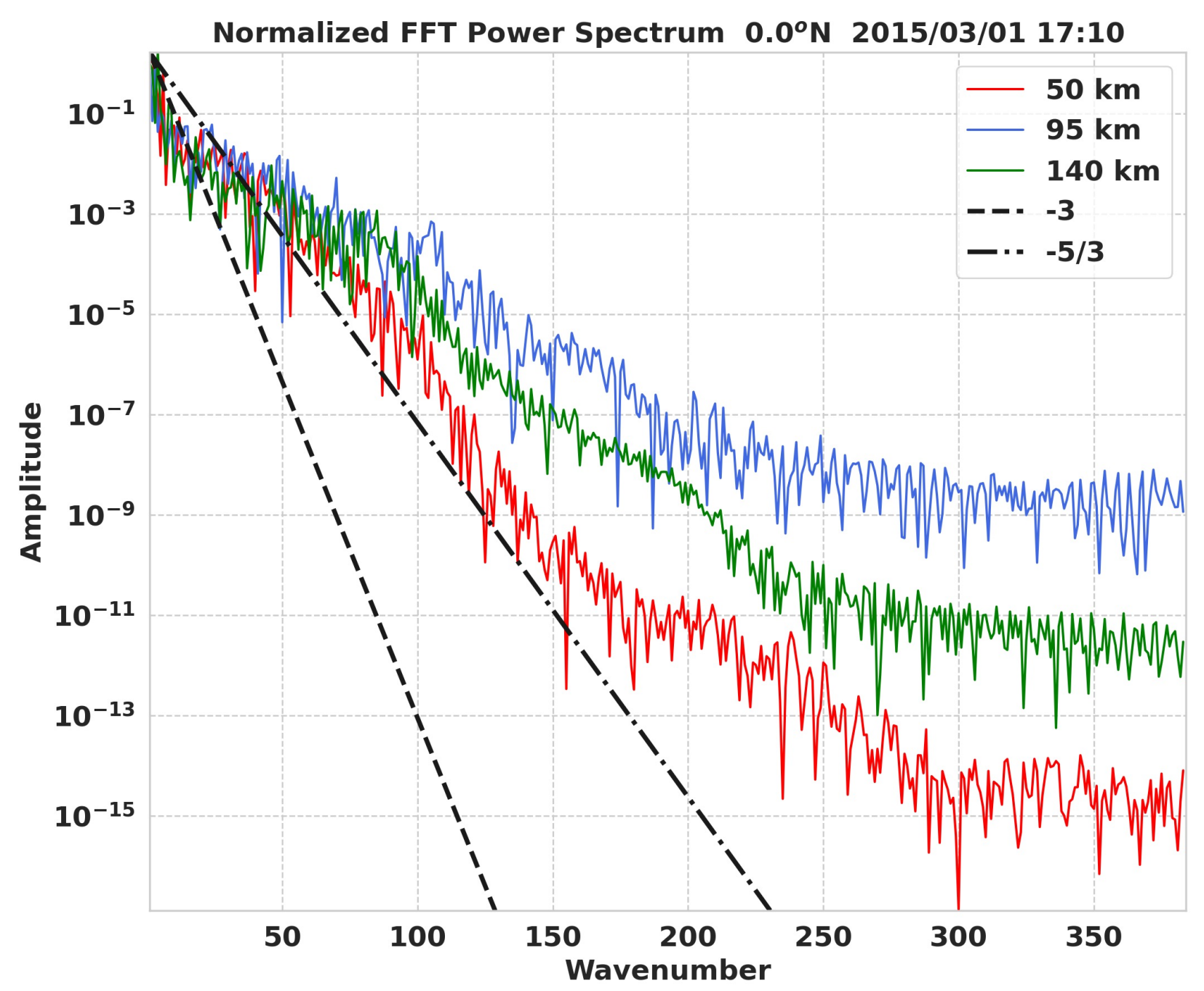


**Figure 1:** *Comparison of temporal change in temperature between WAMT62 and WAMT254.*
**Figure 2:** *Comparison of spatial power spectrum between WAMT62 and WAMT254.* WAMT254 has a richer spectrum of waves in the upper atmosphere. The shallower spectrum at high wave numbers corresponds to the wave and 3-D turbulence regime.
**Figure 3:** *Comparison of spatial power spectrum for WAMT254 between different altitudes.* Shallower slope at lower wavenumbers with altitude indicates the increasing dominance of GWs with altitude.

## Global Response - WAMT62 / WAMT254

**Figure 4**

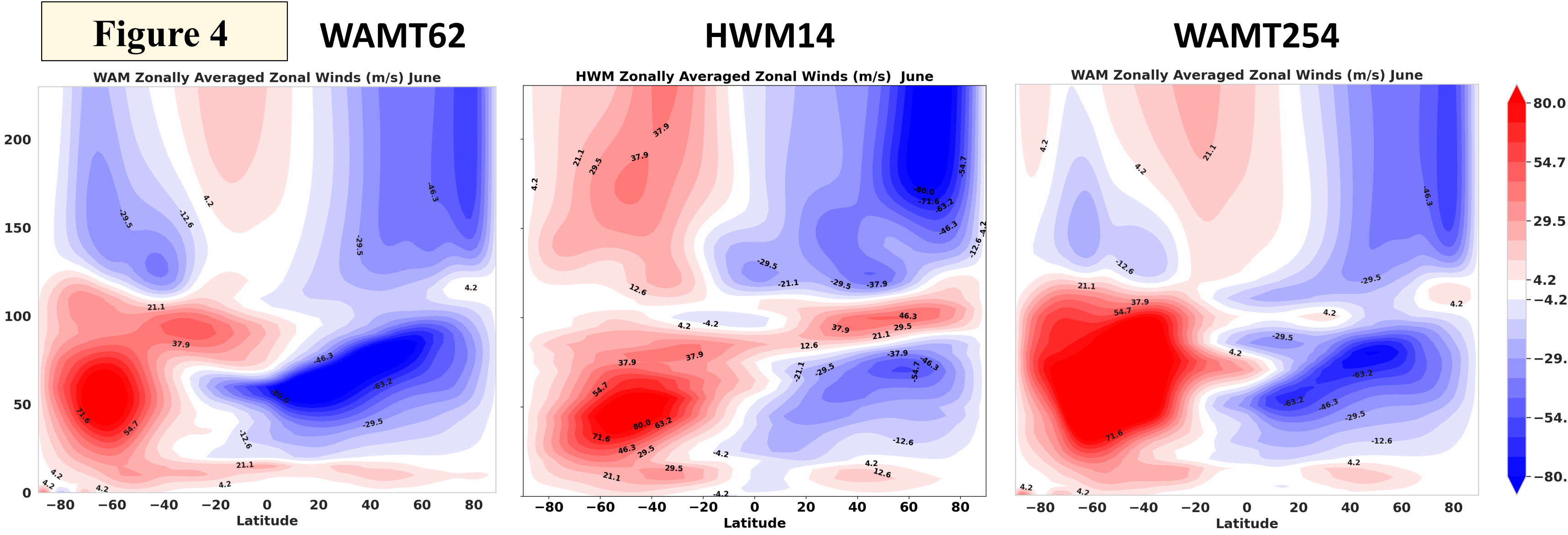


**Figure 4 :** *Comparison of zonal mean winds between WAMT62, HWM14 and WAMT254.* The major difference is in the Mesosphere and Lower Thermosphere (MLT) region where HWM winds in the summer hemisphere become eastward. These winds are largely attributed to the forcing provided by momentum deposition of upward propagating breaking GWs. WAMT254 also shows weak eastward winds and agrees better with HWM.

## Quiet Time Distribution of Gravity Waves – WAMT254 (Kp=1, F10.7=70)

**Figure 5 – 45 km**

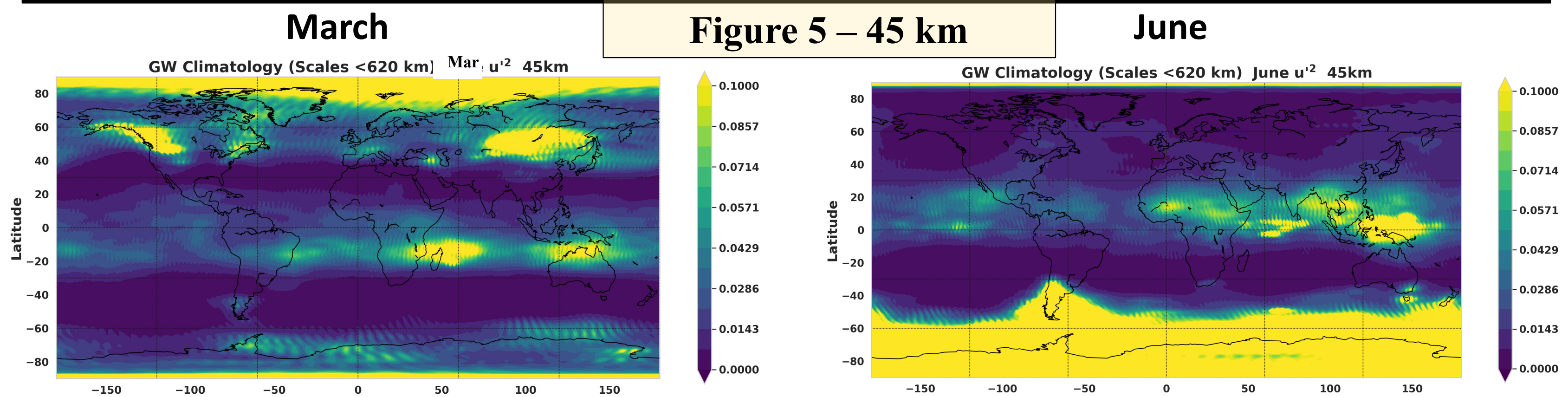


**Figure 6 – 105 km**

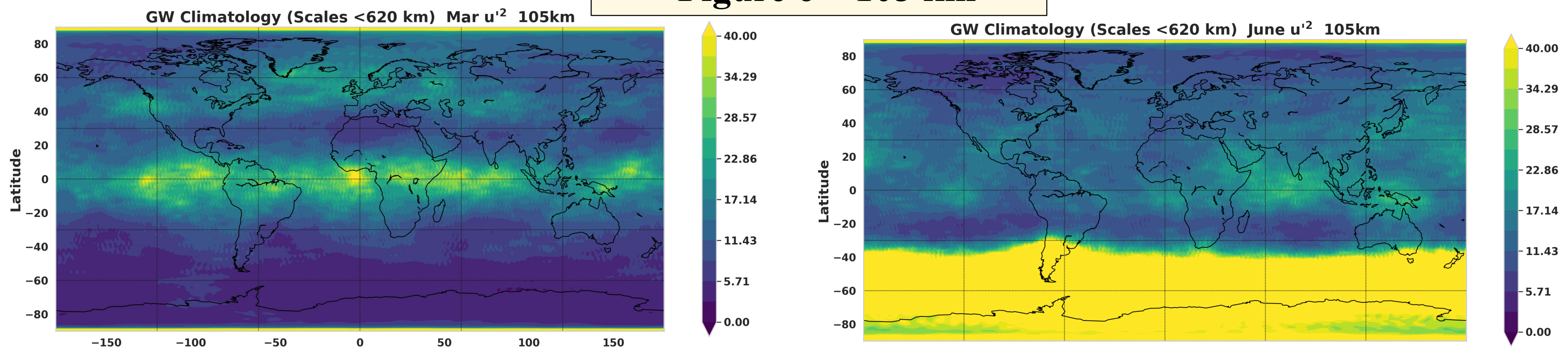


**Figure 7 - 255 km**

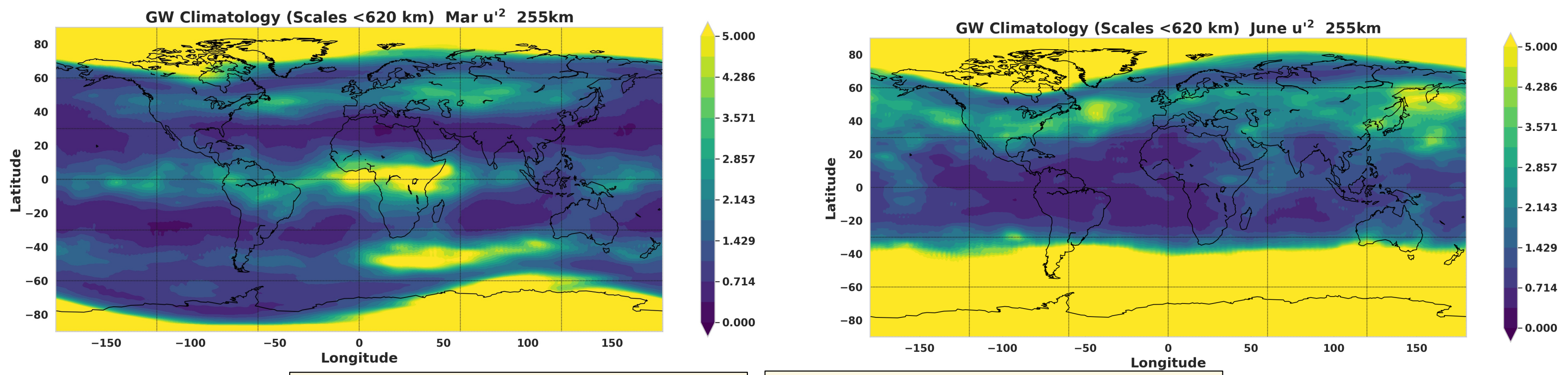
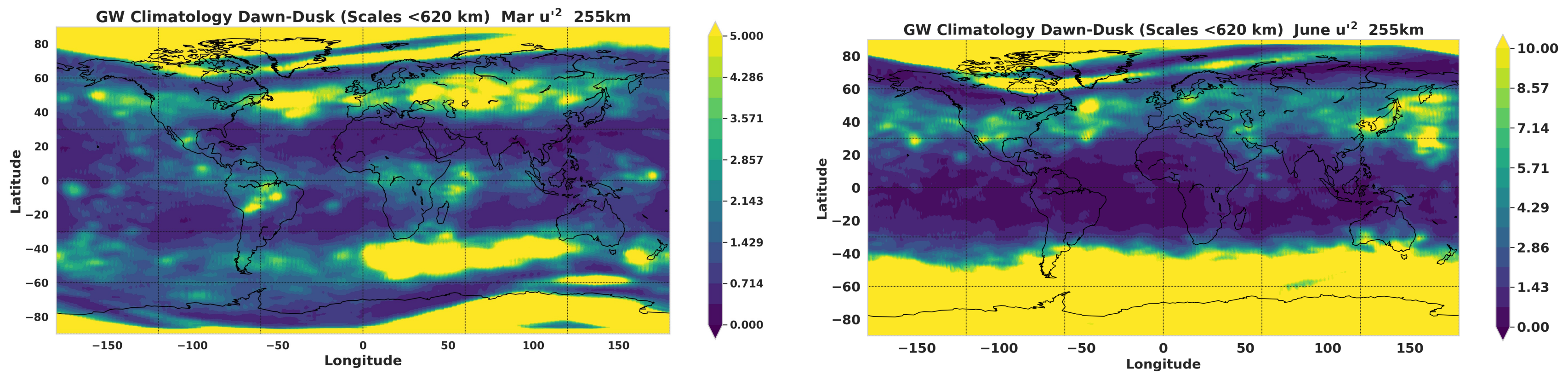


**Figure 8 – 255 km** **Along Dawn-Dusk Sector**



*Medium-scale GWs (~155-620 km) are extracted across zonal direction by using butterworth filter of order 5.*
**Figure 5**: *GW activity in zonal winds averaged across all local times at 45 km.* During March, GW hotspots in the stratosphere can be observed around the Rockies and Himalayan mountain ranges. In June, large activity is also observed around the Andes and Antarctic peninsula.
**Figure 6 and Figure 7**: *At 105 km and 255 km*. With altitude, GWs propagate away from their source regions and hence their features smear out. GWs due to auroral activity are also generated in the thermosphere. At low-latitudes, most of activity is from upward propagating waves from the lower atmosphere.
**Figure 8:** *GW activity in zonal winds across the dawn-dusk sector at 255 km.*

## GOCE Gravity Wave Distribution

**Figure 9 ~ 250 km**

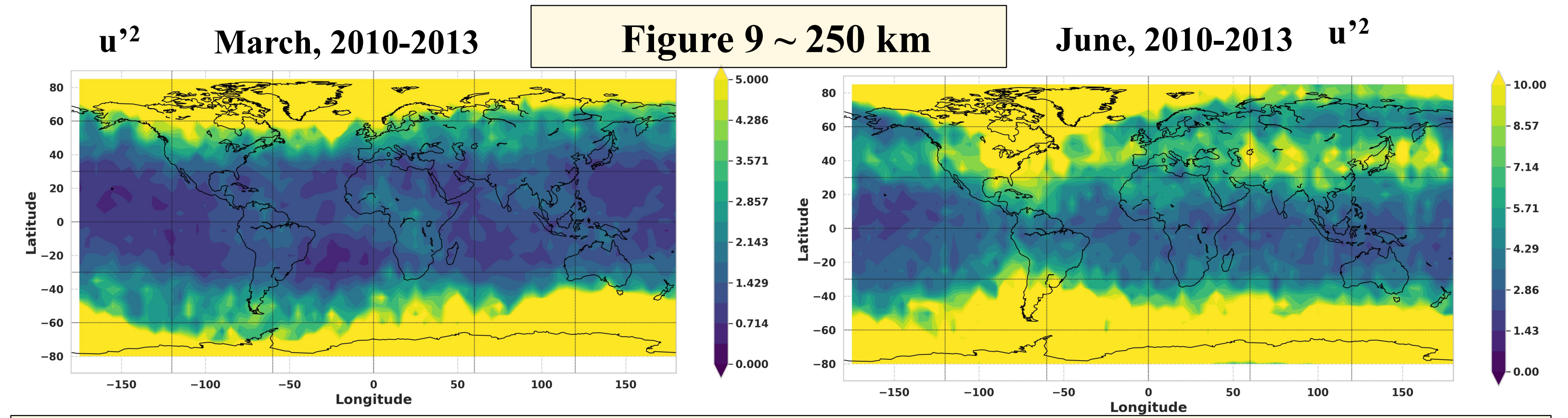


**Figure 9:** *Medium-scale GWs (derived from GOCE cross-track zonal winds*. Only days with Kp<3 are included (adopted from *Liu et al. 2017)*. GOCE has a dawn-dusk orbit and can be compared with WAMT254 results in Figure 8. During March, at low latitudes, larger GW activity is observed over the continents. This feature is however not prominent in WAM. The mid-high latitudes in both seasons agree better between WAM and GOCE.

## March 2015 Storm Time Response

**Figure 10**

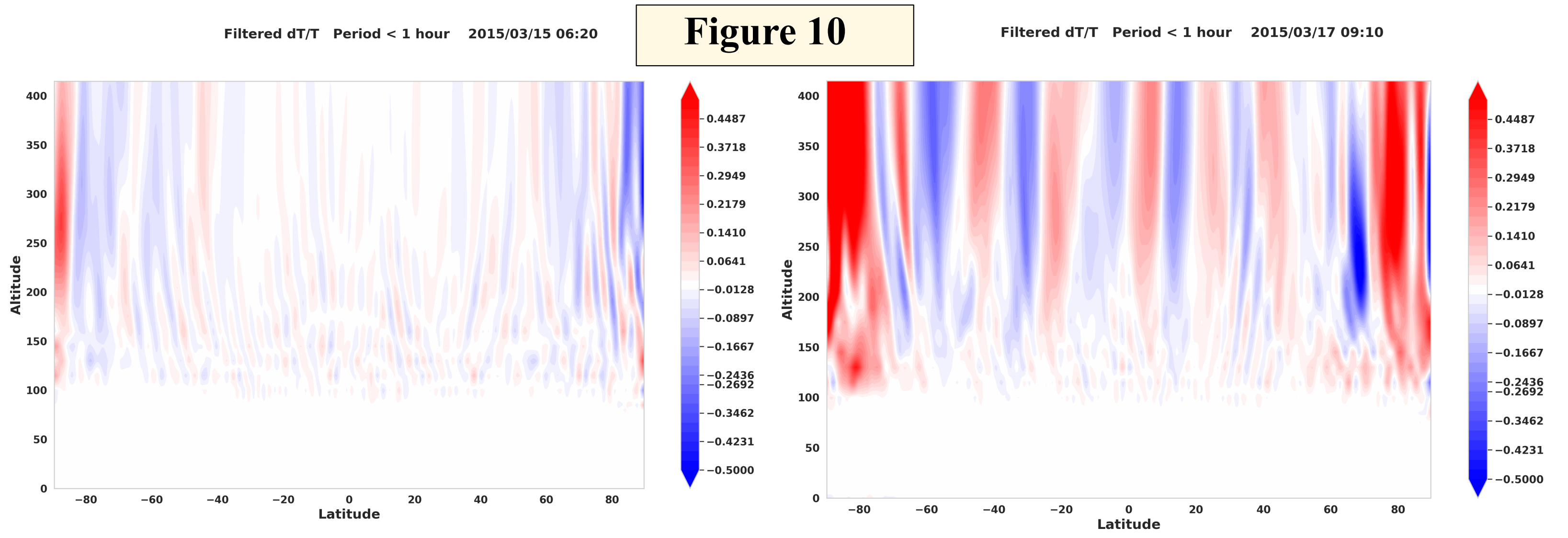


**Figure 10:** GWs filtered by time periods (Periods<1 hour) before and during the March 2015, St. Patrick’s Day Storm. Before the storm, GWs with smaller horizontal wavelengths dominate the lower latitudes. These waves are more likely to be the secondary GWs generated from upward propagating lower atmospheric GWs. However, during the storm, as large-scale TADs propagate from high to low latitudes, the smaller-scale GWs from the lower atmosphere get dissipated.

## Summary and Next Steps

- WAMT254 displays a rich spectrum of waves and reproduces medium-scale GWs (~155-620 km) that resemble GOCE observations of GWs at mid-high latitudes, especially in the Andes, Antarctic peninsula in the winter hemisphere, and auroral regions. This also agrees with the observations from Park et al. 2014, Liu et al. 2017. (*Figs 2, 8, 9)*
- The global GW activity is overall larger during June than March. (*Figs 5, 6, 7, 8, 9*)
- During March, when observed at a constant local time, GOCE GW activity at lower latitudes is slightly larger over the continents. This feature is however not very prominent in WAM. *(Figs 8, 9)*
- During storm-time, TADs cause dissipation of smaller-scale waves at low latitudes.*(Fig 10)*
- A high-resolution coupled WAM-IPE model is currently being developed and will be used to investigate smaller-scale structures in the ionosphere driven by the GWs in the E and F region.
- The dynamical core of WAM is fairly diffusive and a FV3 (Finite-Volume-Cubed-Sphere) is currently being developed. FV3 is non-hydrostatic and much less diffusive, thereby retaining a richer spectrum of waves penetrating in the upper atmosphere.
- The zonal wind climatology in WAMT254 shows an improvement (agrees better with HWM14) over the WAMT62 model, but still does not have the correct MLT winds. These winds are largely an outcome of the momentum deposition of upward propagating breaking GWs. This needs to be corrected by either using a GW parameterization scheme, or data assimilation/nudging in the MLT region.

## References

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