Exploring Wave-Wave Interactions in a General Circulation Model

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Overview

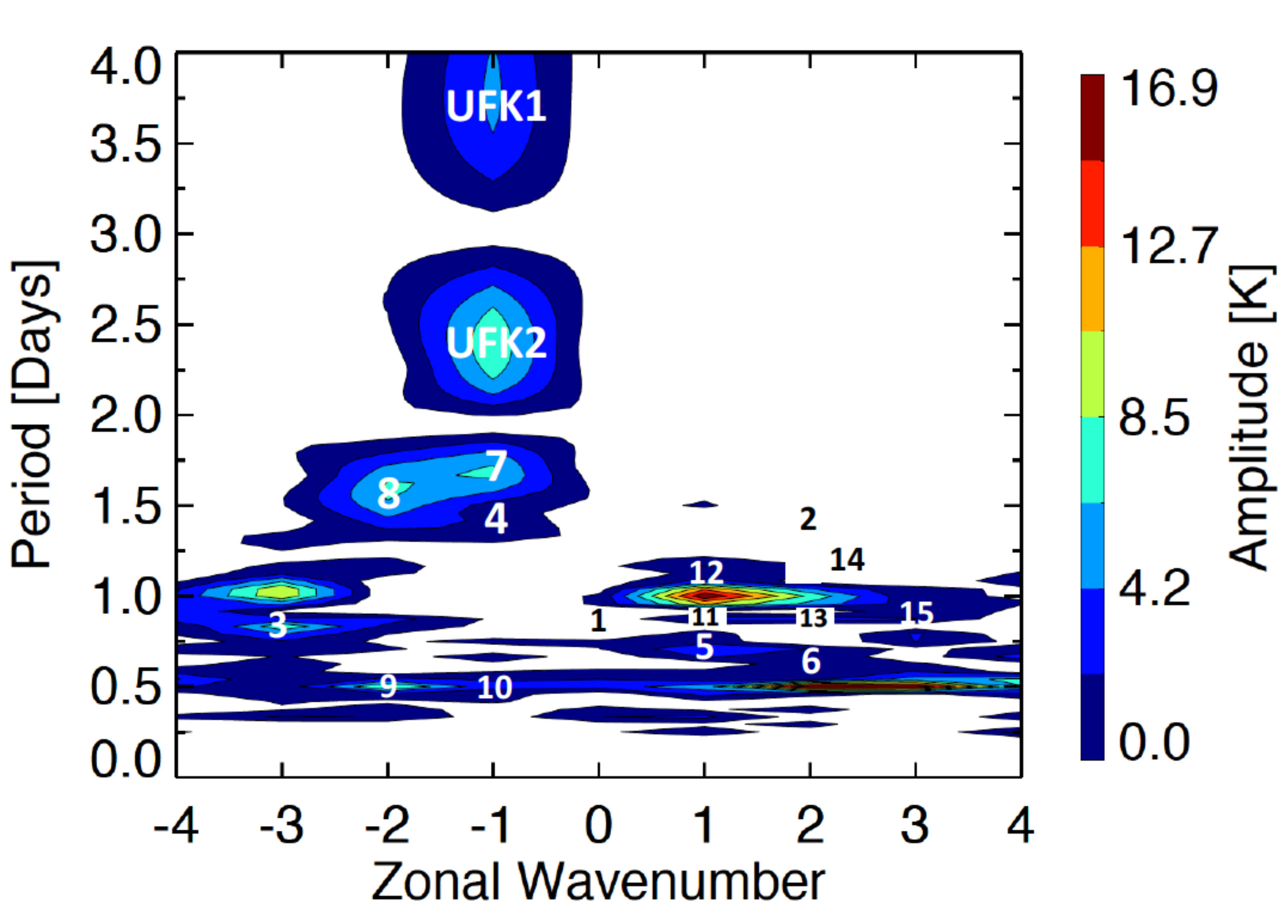
The NCAR Thermosphere – Ionosphere – Mesosphere – Electrodynamics General Circulation Model (TIME-GCM) is used as a framework to explore nonlinear wave-wave interactions in Earth's upper atmosphere, a mechanism thought to account for much of the observed variability in solar thermal tides.

The model simulation employed here [Häusler, et al., 2014] is forced at its ~30 km lower boundary by output from the NASA MERRA (Modern Era Retrospective-Analysis for Research and Applications) for all of 2009, which provides tidal components and waves similar to those known to exist in the mesosphere-lower thermosphere (80-150 km) region. Only results covering April 10-20, 2009, are shown here.

Each wave-wave interaction produces two secondary waves. The importance of nonlinear interactions is measured by the scope and magnitudes of secondary waves that are produced, and their aggregate influence on the spatial and temporal variability of dynamical fields.

The interactions that give rise to important secondary waves in this simulation are the westward-propagating diurnal tides with zonal wavenumbers s = 1, 2 and 3 (DW!, DW2, DW3); the eastward propagating diurnal tides with s = -2 and -3 (DE2, DE3); two ultra-fast Kelvin waves, UFKW1 and UFKW2, with s = -1 and respective periods of 3.7d and 2.4d; and quasi-9-day oscillations with s = 0 and s = 1 (see Table 1 and accompanying Figures).

Equatorial Wave Spectrum, Temperature Amplitude, 120 km, DE2 & TW3 Removed



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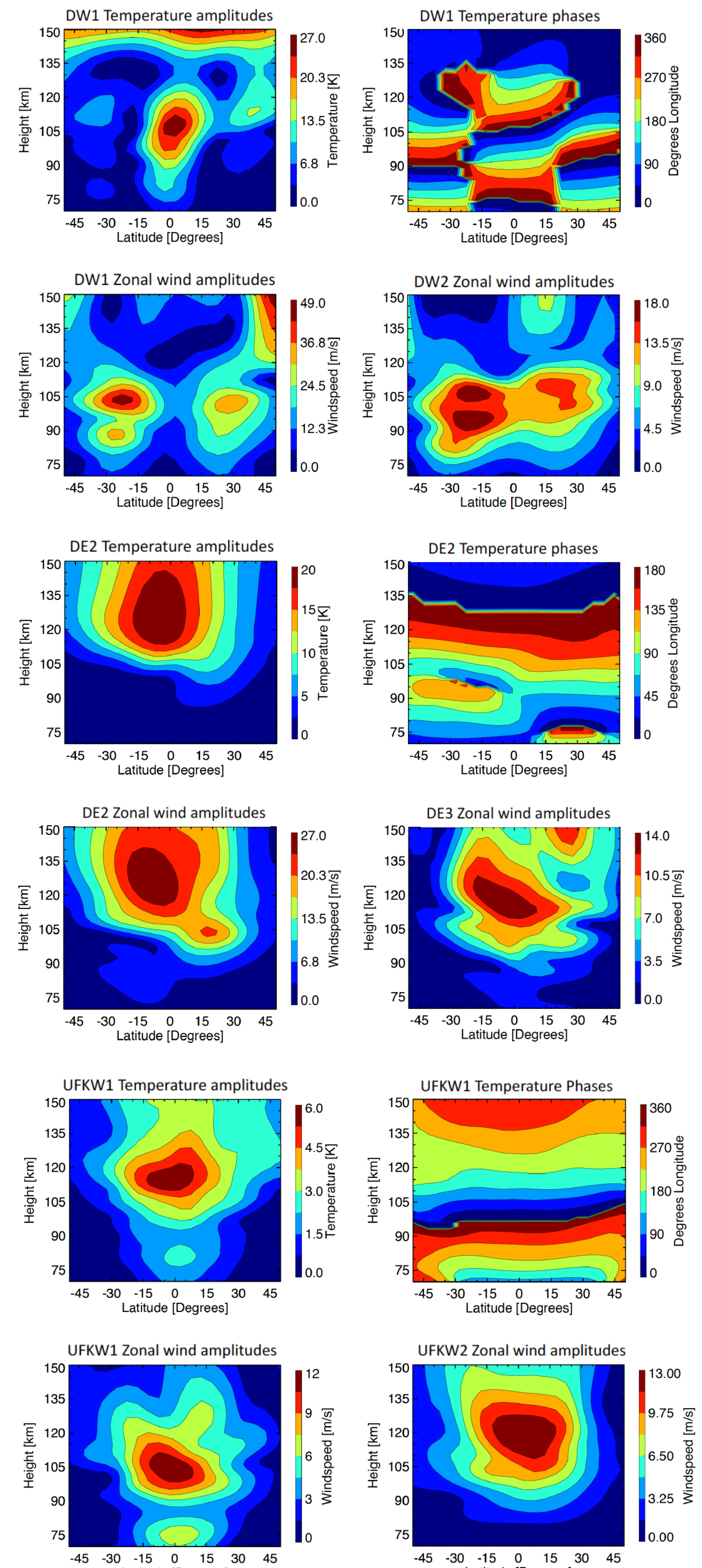
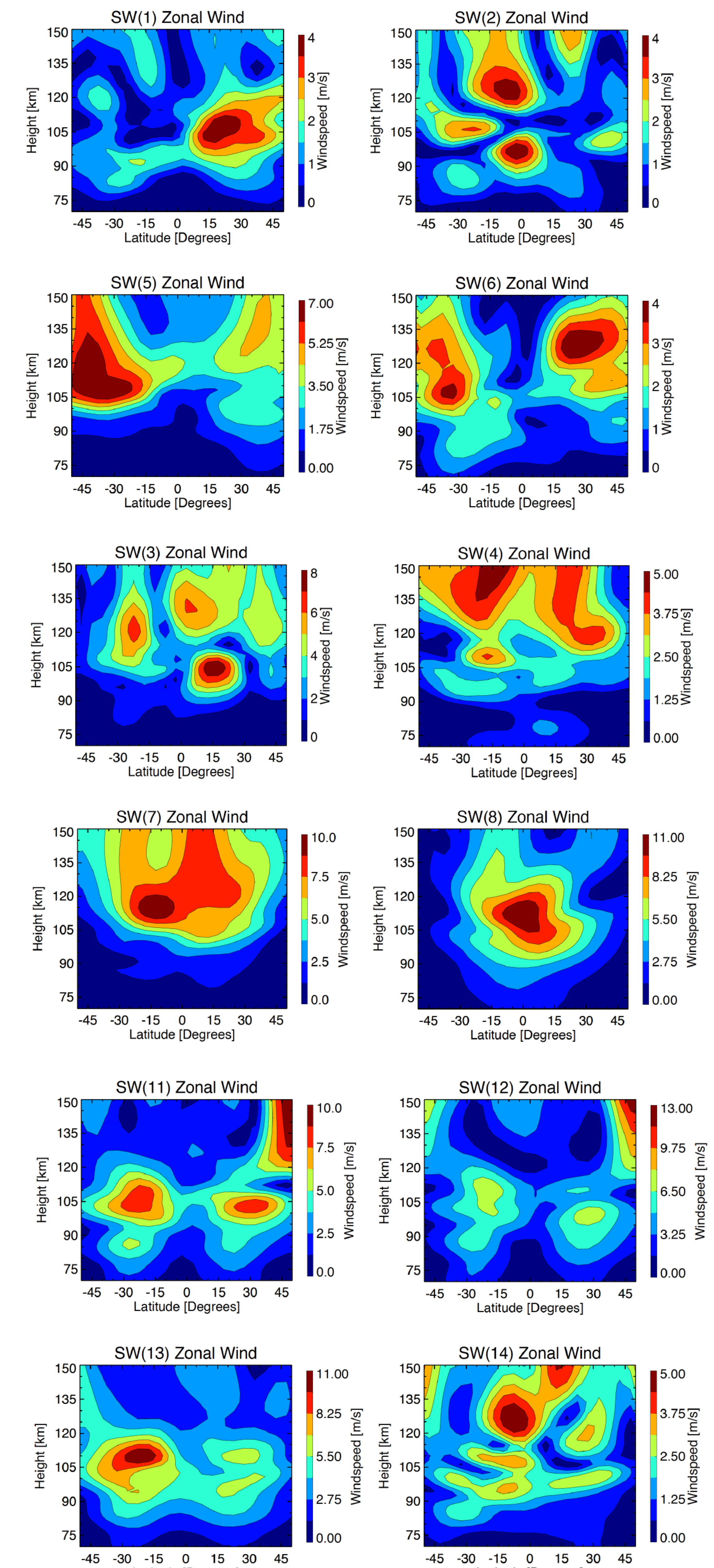
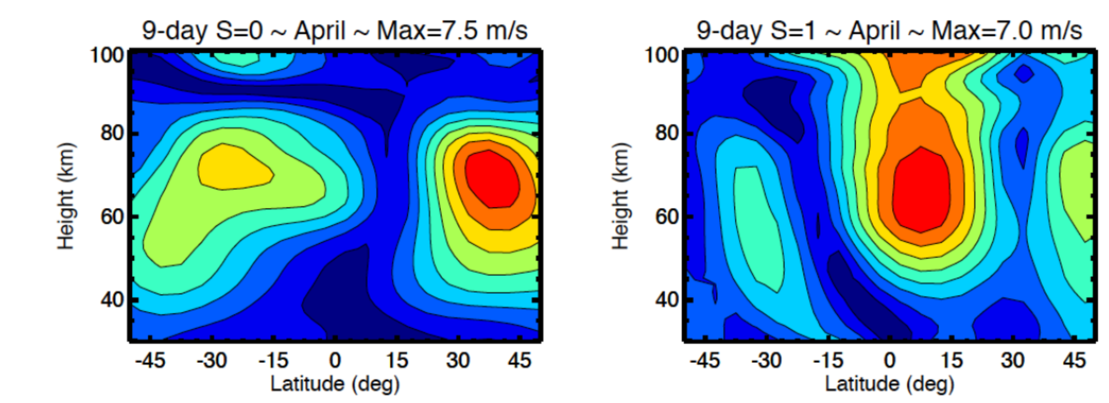
Primary Waves – Tides and Kelvin Waves



Secondary Waves



Primary Waves – 9-day Planetary



Primary Waves s > 0 (s < 0) westward-(eastward)-propagating		
Wave	**Period (days)**	**Zonal wavenumber (s)**
DW1	1.0	1
DW2	1.0	2
DW3	1.0	3
DE2	1.0	-2
DE3	1.0	-3
UFKW1	≈3.7	-1
UFKW2	≈2.4	-1
Q9DW0	~9	0
Q9DW1	~9	1

Secondary Waves s > 0 (s < 0) westward-(eastward)-propagating		
Secondary Wave (SW) Identifier	**Observed (Calculated) Period, s**	**Wave Interaction Sum (+) or Difference (-)**
SW(1)	0.79d (0.79d), s = 0	[UFKW1 x DW1 (+)]
SW(2)	1.37d (1.37d), s = 2	[UFKW1 x DW1 (-)]
SW(3)	0.83d (0.79d), s = -3	[UFKW1 x DE2 (+)]
SW(4)	1.40d (1.40d), s = -1	[UFKW1 x DE2 (-)]
SW(5)	0.71d (0.70d), s = 1	[UFKW2 x DW2 (+)]
SW(6)	0.69d (0.70d), s = 2	[UFKW2 X DW3 (+)]
SW(7)	1.67d (1.72d), s = -1	[UFKW2 x DE2 (+)]
SW(8)	1.49d (1.45d), s = -2	[UFKW1 x UFKW2 (+)]
SW(9)	0.50d (0.50d), s = -2	[DE3 x DW1 (+)]
SW(10)	0.50d (0.50d), s = -1	[DE3 x DW2 (+)], [DE2 x DW1 (+)]
SW(11)	0.88d (0.90), s = 1	[Q9DW0 X DW1 (+)]
SW(12)	1.17d (1.12d), s = 1	[Q9DW0 X DW1 (-)], [Q9DW1 X DW2 (-)]
SW(13)	0.88d (0.90d), s = 2	[Q9DW0 X DW2 (+)], [Q9DW1 X DW1 (+)]
SW(14)	1.17d (1.12d), s = 2	[Q9DW0 X DW2 (-)]
SW(15)	0.90d (0.90d), s = 3	[Q9DW1 X DW2 (+)]

Secondary Waves Produced by Wave-Wave Interactions

The interaction between any non-tidal wave (frequency = $\delta\Omega$, zonal wavenumber = m) and any tide (frequency = $n\Omega$, zonal wavenumber = s) gives rise to "sum (+)" and "difference (-)" secondary waves (SW) as follows [Teitelbaum and Vial, 1991]:

$$\cos(\delta\Omega t + m\lambda) \times \cos(n\Omega t + s\lambda) \rightarrow \cos\left[(n \pm \delta)\Omega t + (s \pm m)\lambda\right]$$

where $\Omega = 2\pi$/day-1, t = UT (days), λ = longitude, δ = 1/T, and T is wave period in days.

CONCLUSIONS

- Sum and difference secondary waves (SW) arise in the MLT due to nonlinear wave-wave interactions.
- SW amplitudes are significant fractions of primary wave amplitudes. Their aggregate effect is to measurably add to the spatial-temporal complexity of the dynamics.
- This complexity is expected to translate to ionospheric fields.

References

Häusler, K., M.E. Hagan, A.J.G. Baumgaertner, A. Maute, G. Lu, E. Doornbos, S. Bruinsma, J.M. Forbes, and F. Gasperini (2014), Improved short-term variability in the thermosphere-ionosphere-mesosphere-electrodynamics general circulation model, J. Geophys. Res., 119, 6623–6630, doi:10.1002/2014JA020006.

Teitelbaum, H., and F. Vial (1991), On tidal variability induced by nonlinear interaction with planetary waves, J. Geophys. Res., 96, 14169–14178.