Lunar Tide Effects on the Atmosphere during the 2013 Sudden Stratospheric Warming (SSW) as Simulated by TIME-GCM

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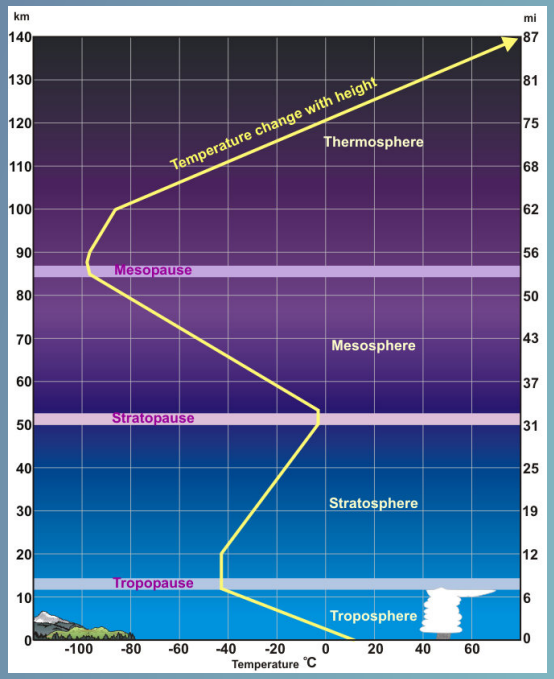
Outline

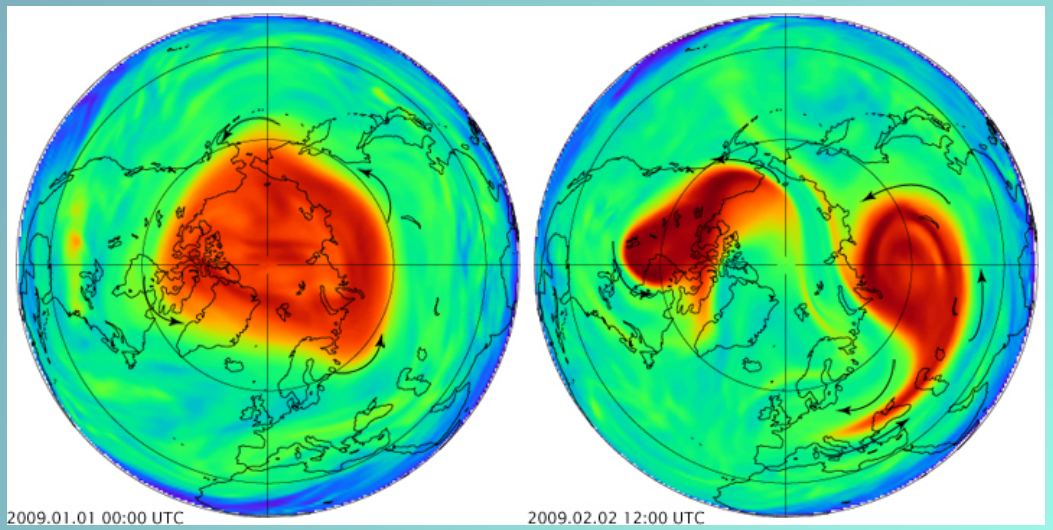
- Background
- General effects of the lunar tide during SSW
- Comparison with past SSW events and other models
- Conclusion

Sudden Stratospheric Warming

- Eastward winds of the polar vortex are slowed and sometimes even reversed in the wintertime, leading to an increase in stratospheric temperature in the winter polar region.
- Main Mechanism:

  Shift/split of the polar vortex with respect to the geographic pole and planetary waves propagating upwards.

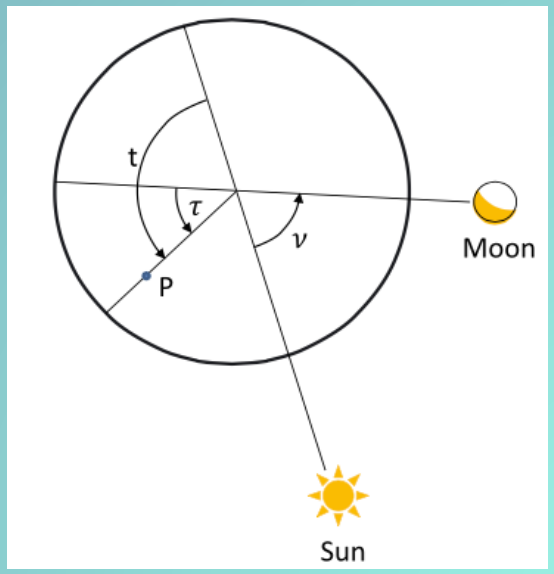




M2, N2, SW2 Tides

- M2: Principle lunar semidiurnal tide
  - Period: 12.42 hours
- N2: Larger lunar elliptic semidiurnal tide
  - Period: 12.66 hours
- SW2: Migrating solar semidiurnal tide
  - Period: 12 hours

- Lunar time is slower than solar time.
  - $\tau = 0.966\ t_s$

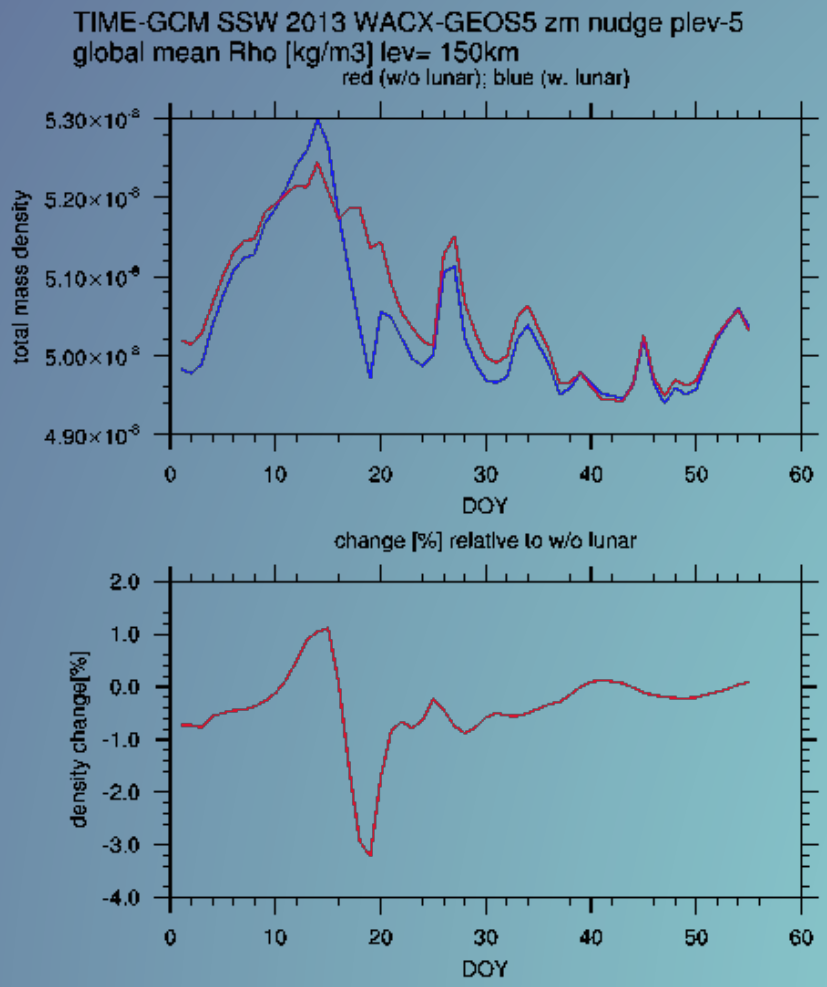


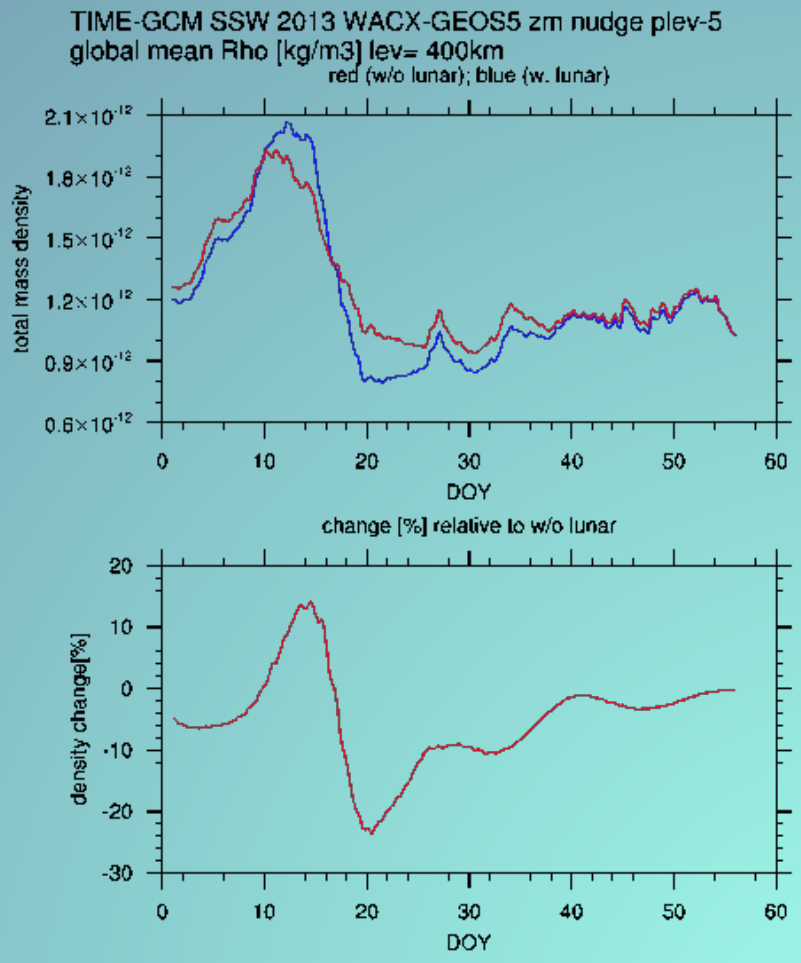
TIME-GCM Model

- Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model
- Numerical model for Earth's middle and upper atmosphere
- Uses a finite differencing technique to obtain the solution to the non-linear equations defining atmospheric dynamics.
- Lower boundary and background are specified using WACCMX

- Ran 2 simulations with TIME-GCM: one that includes lunar tide and one that doesn't.
- Difference?!

Our Focus: Air Density in the Upper Atmosphere



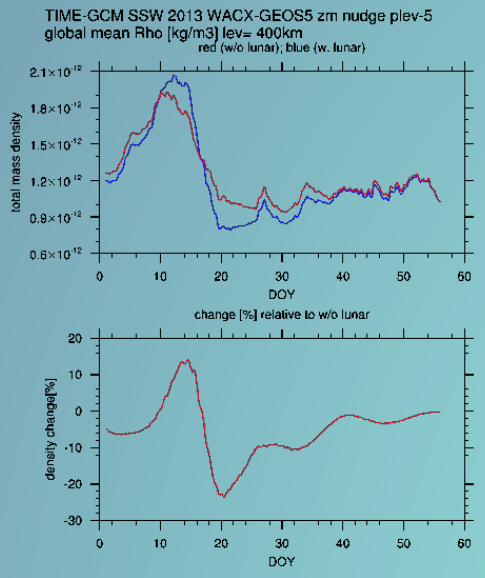


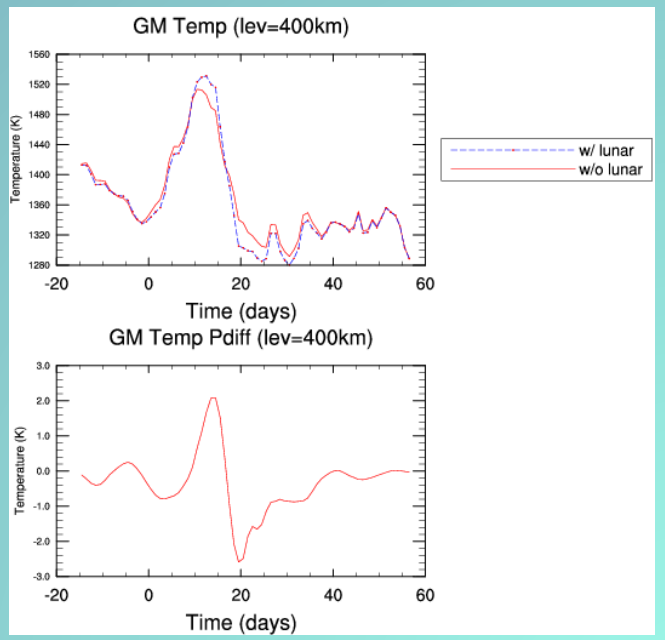
Explain why the temperature increase. Future work?

Connection between density and temperature

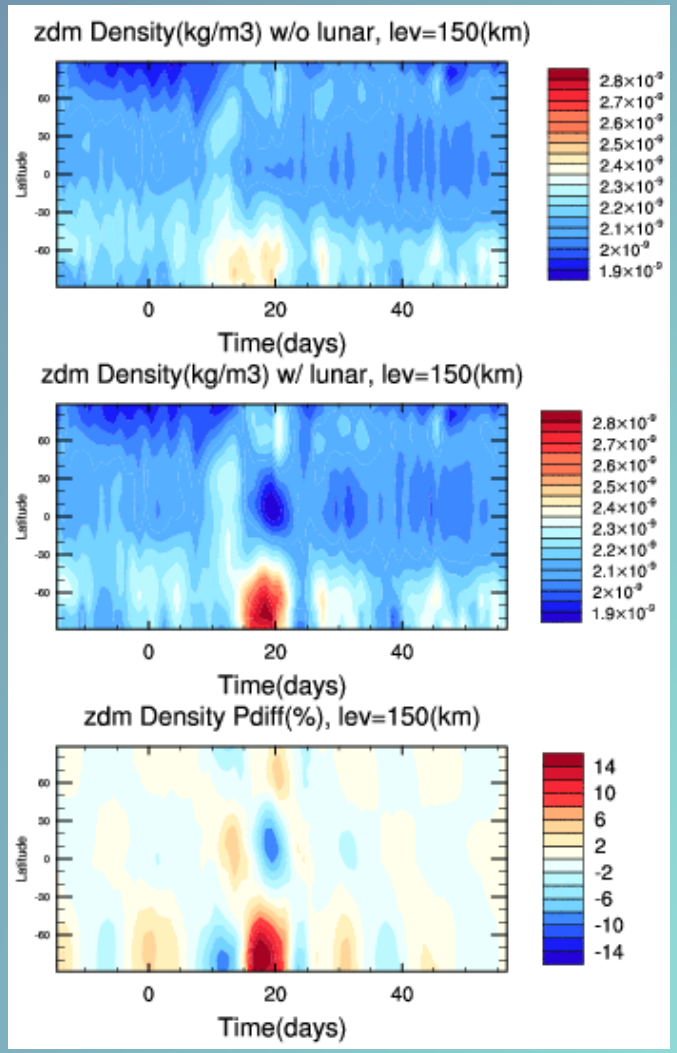
- Low alt: both temp and density are increased/decreased by about 2% due to the lunar tide
- High alt: Density is affected 22% at max, temp only affected about 5-6%

Perturbations in density and temperature are similar.
-Correlation coefficient: 0.67





Latitude vs. Time



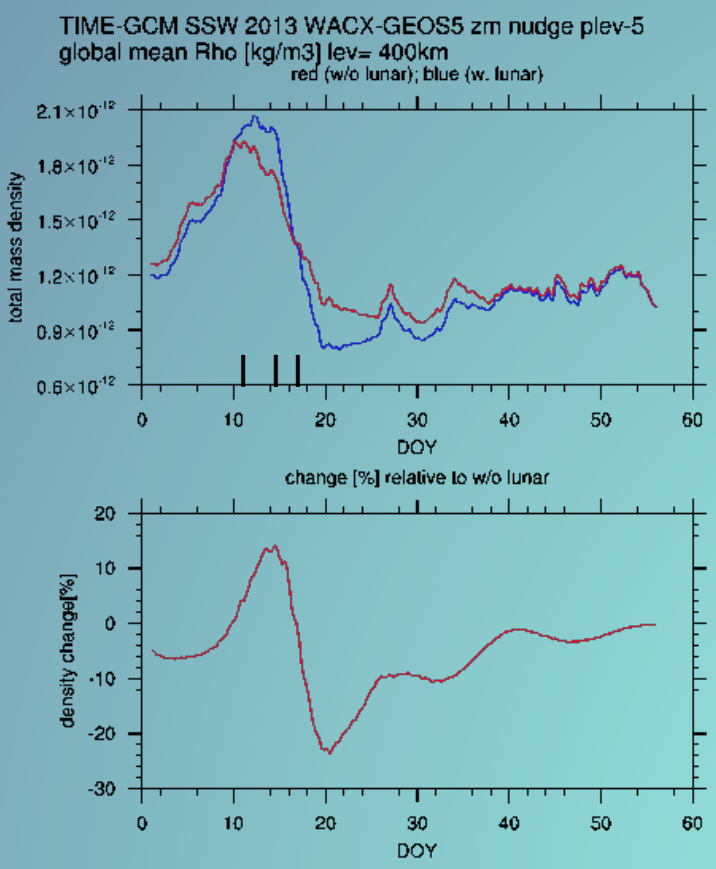
Other stuff must be going on…

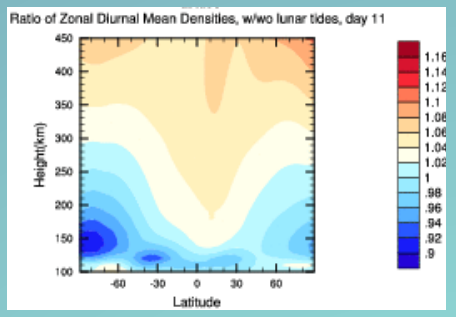
Possible causes of anomalies:

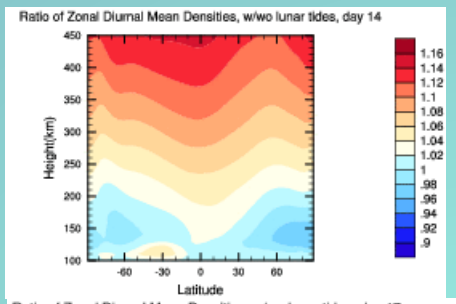
-Could be due to tides dissipate, change composition

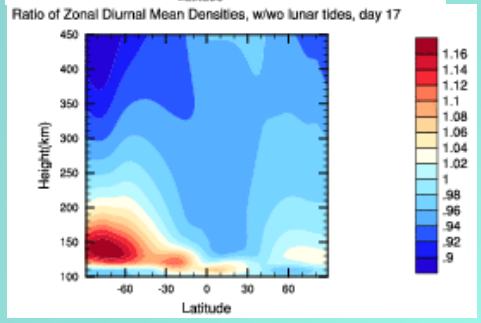
-Adiabatic heating/cooling (look at temp and vertical wind background)

-Tidal mixing can change densities





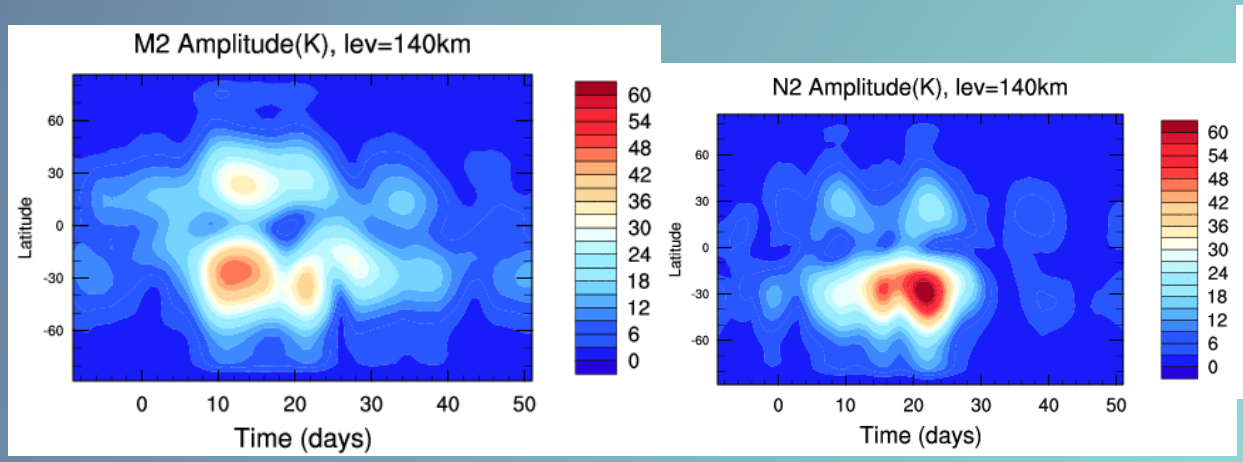


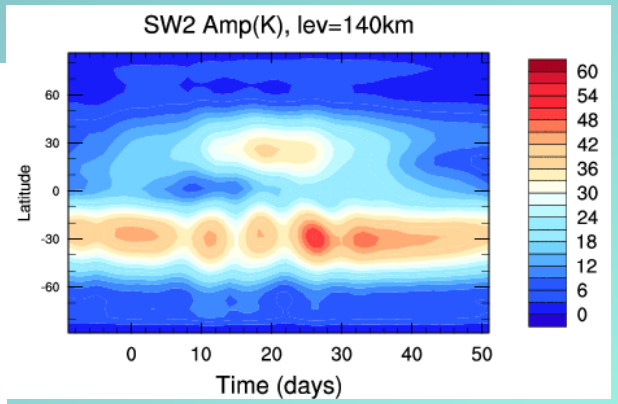


Move point with Forbes? Add global mean density plot and connect times.

M2, N2, SW2 Amplitudes

- All three tides peak during SSW, and all show periodicity.
- However, M2 and N2 peak sharply due to the amplification of lunar tides during SSW (due to resonance. Forbes 2013).
- N2 peaks about 10 days after M2. This delay is noted by Forbes et al. during the 2009 SSW event. Thus this is possibly a consistent feature in SSW events. The cause would need further research.

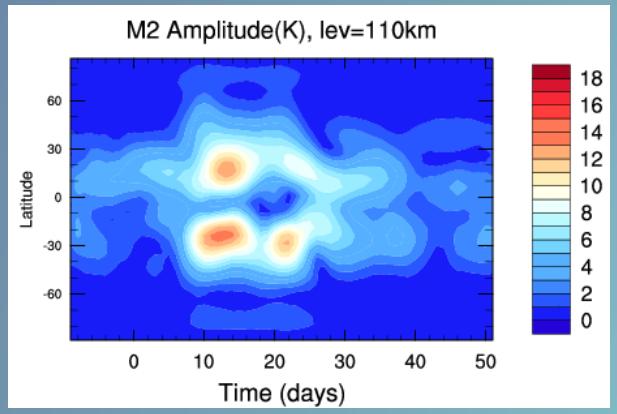


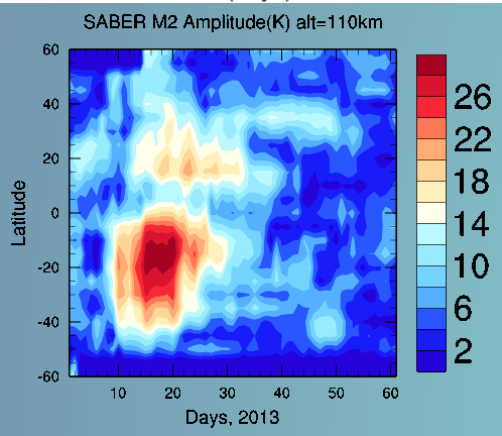


Make scales the same? Yes

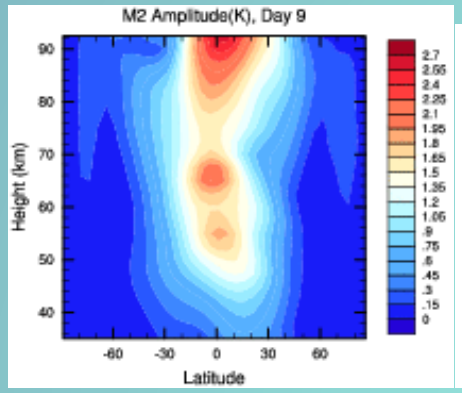
Comparison with observed data

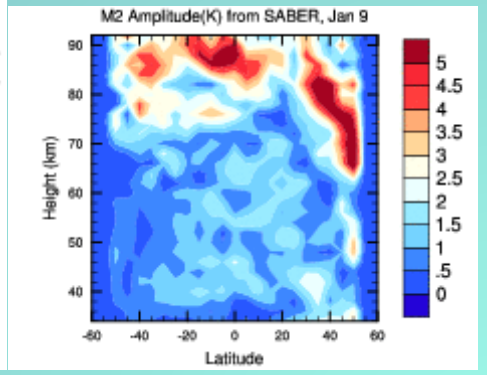
- SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) is an Instrument on NASA's TIMED satellite.
- Good agreement is seen in the temporal change of M2 amplitudes for different latitudes.





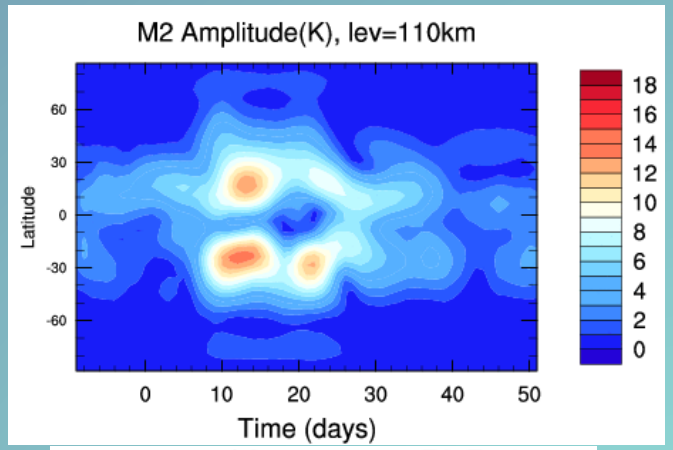
However! Discrepancies are definitely seen.

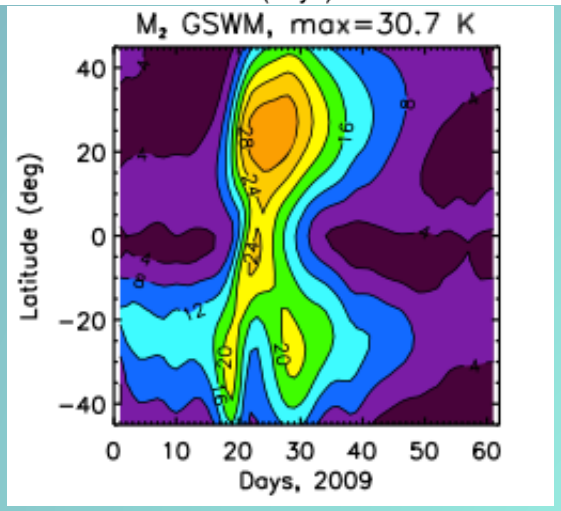




Comparison with GSWM from 2009

- M2 peaks near 30°N and 30°S.
- Similar amplitude ranges.
- 2009 GSWM had largest peak in northern hemisphere while 2013 TIME-GCM was southern.
  - Could be due to different SSW events or different models

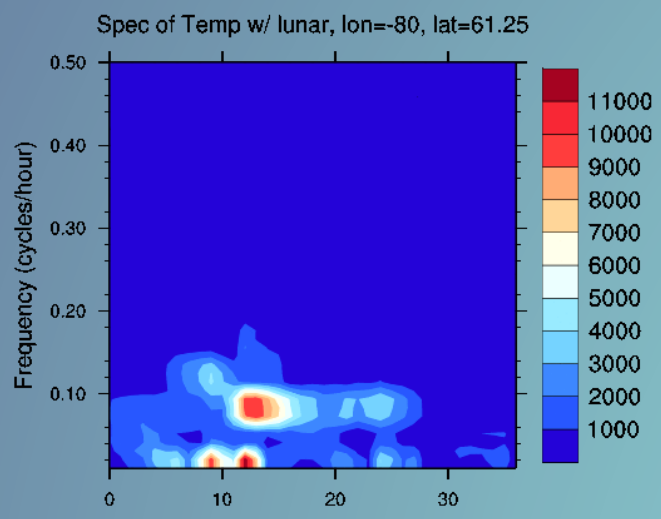


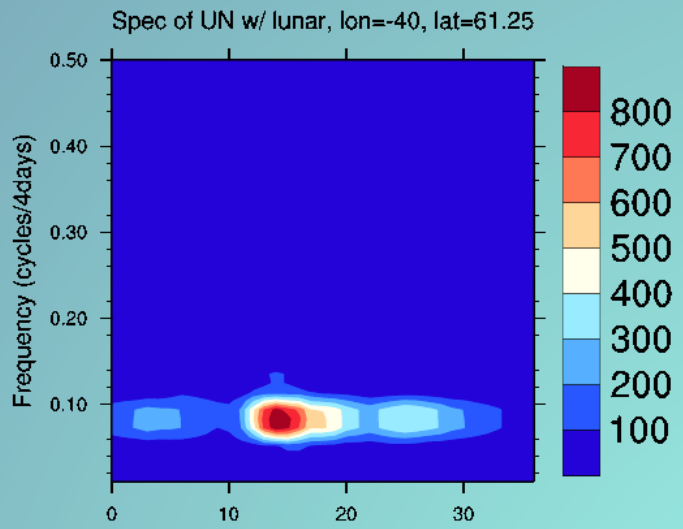


Reference: Forbes, J. M., and Zhang, X. (2012), Lunar tide amplification during the January 2009 stratosphere warming event: Observations and theory, *Journal of Geophysical Research, 117,* A12312.

Effects of other tides

- Large influence from waves with zonal wavenumber = 2 (M2, N2, SW2)
- Slight effect from waves with zonal wavenumber = 0 and 3.



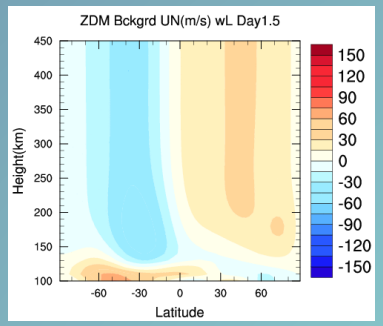


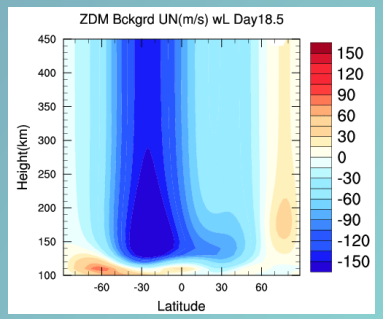
Change to Liu paper and make new days for UN

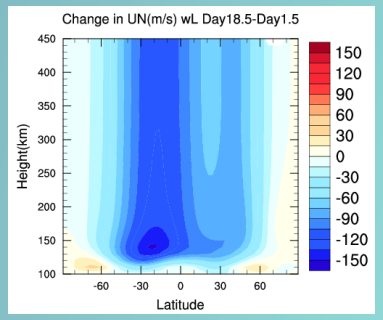
Background wind

- TIME-GCM simulated zonal winds before and during the 2013 SSW compared to GAIA zonal winds before and during the 2009 SSW.

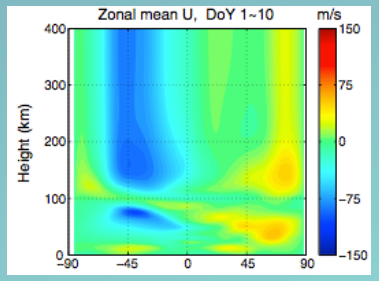
2013 background UN

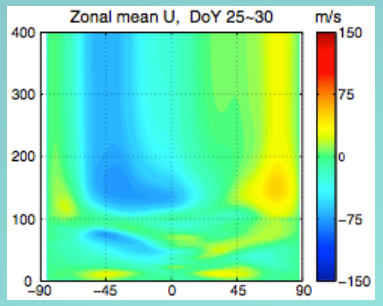


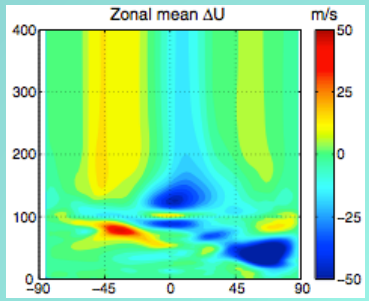


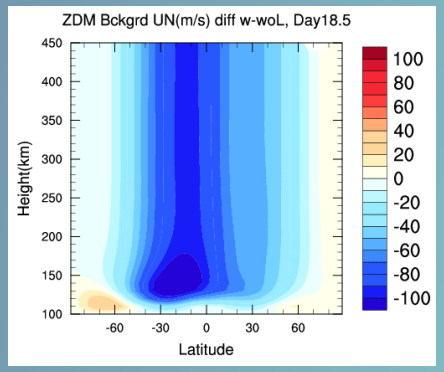


2009 M2 UN amp



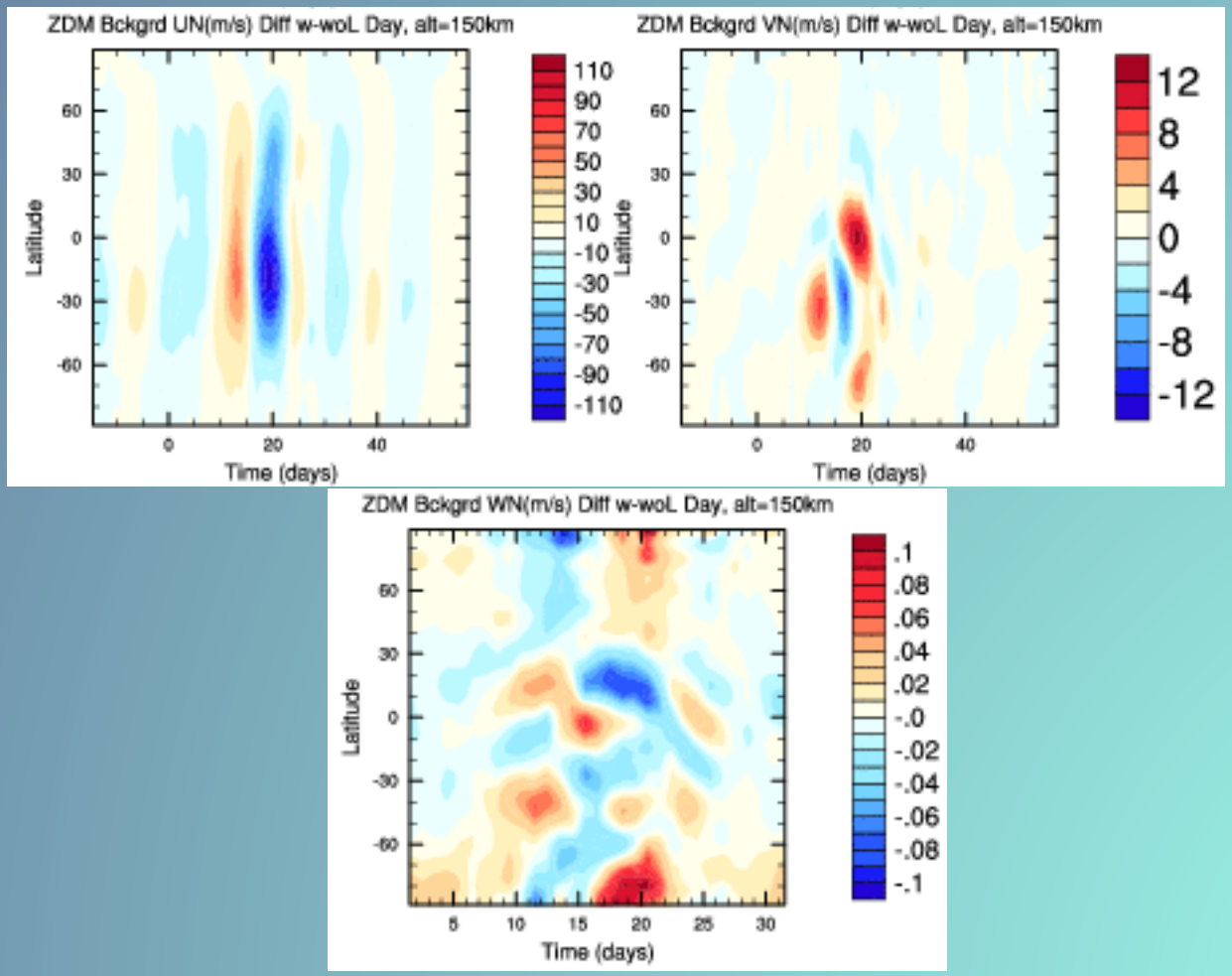






Liu, H. et al. (2014), Thermal and dynamical changes of the zonal mean state of the thermosphere during the 2009 SSW: GAIA simulations, *Journal of Geophysical Research: Space Physics,* JA020222.

Background wind through time



Conclusions

- Can use the model because with lunar tides it compares favorably with observation (and other models). Thus one can use it to look isolate lunar tide effects by differencing a simulation with lunar tides and one without lunar tides.
- Density was affected by upwards of 20% due to lunar tides at an altitude of 400km, and up to 14% at 150km near the poles (surprisingly large effects).

– Further Research:

- The mechanisms for the enhancements observed during SSW are still unknown. Density variation could be due to background wind circulation, tide dissipation, composition mixing, etc.
- How the lunar tides propagate and why a stronger response is seen in the southern hemisphere. Forcing at the lower boundary is symmetric over the equator, so probably some background is causing change as waves propagate upwards.

Thanks to….

My Mentor, Astrid Maute!

Maura Hagan and Art Richmond for helping us along the way

(They were all patient bears)