Influence of Sudden Stratosphere Warmings on the Ionosphere and Thermosphere

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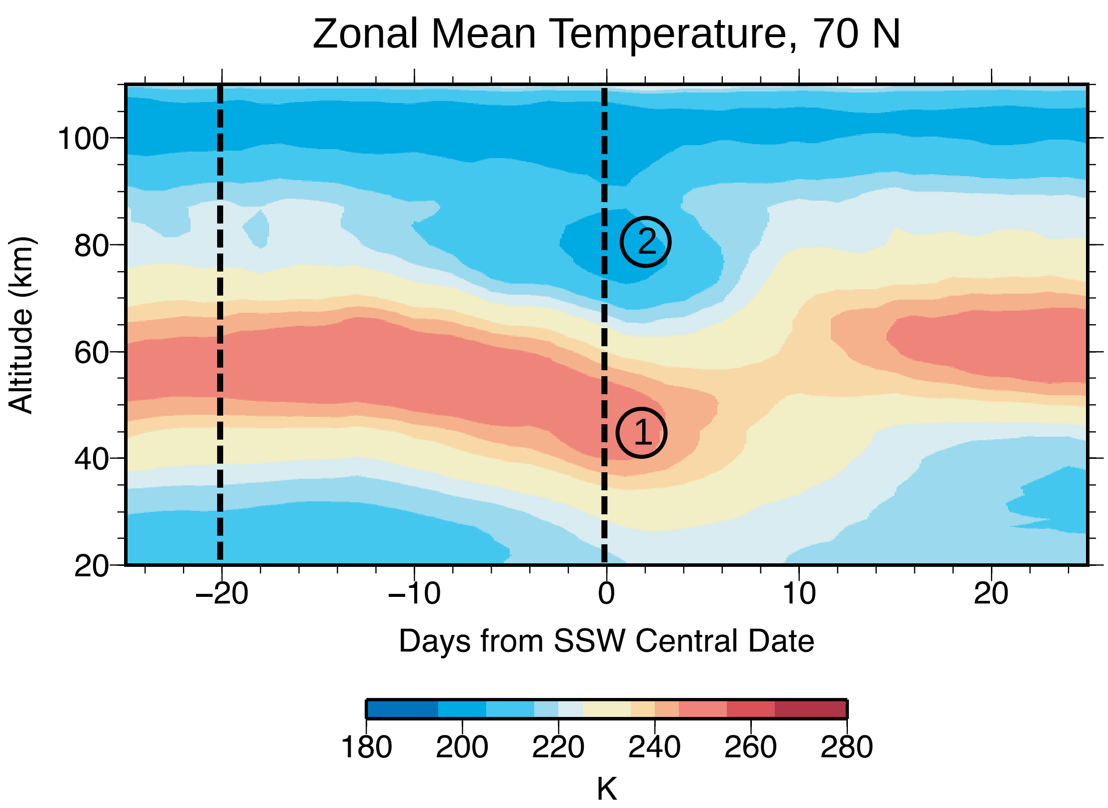
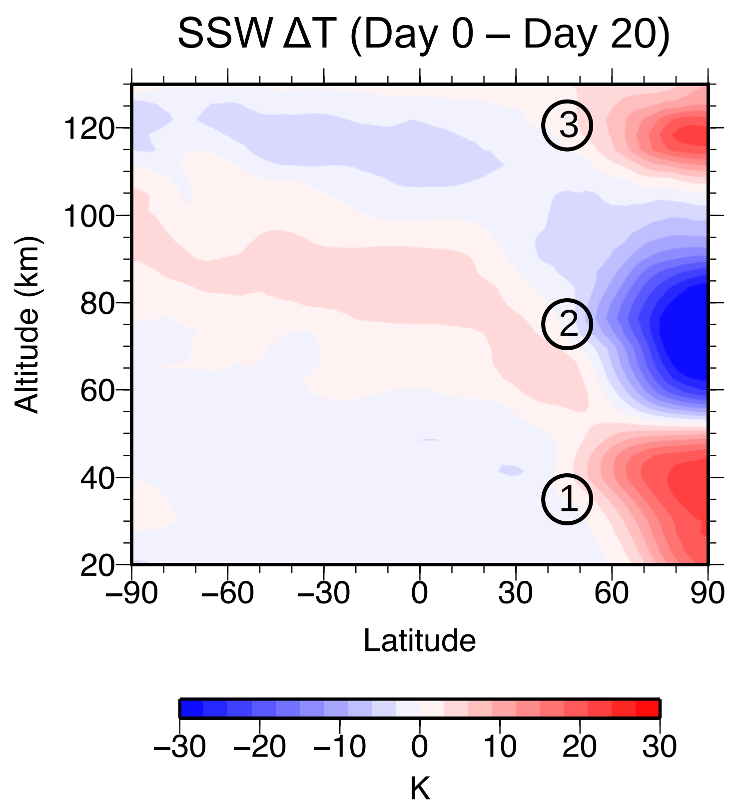
Sudden stratosphere warmings are dynamical disturbances in the high latitude wintertime stratosphere, mesosphere, and lower thermosphere.

Characteristic features of SSWs:

1. Warming of the high latitude stratosphere
2. Cooling of the mesosphere
3. Warming of the lower thermosphere
4. Deceleration and/or reversal of stratospheric winds





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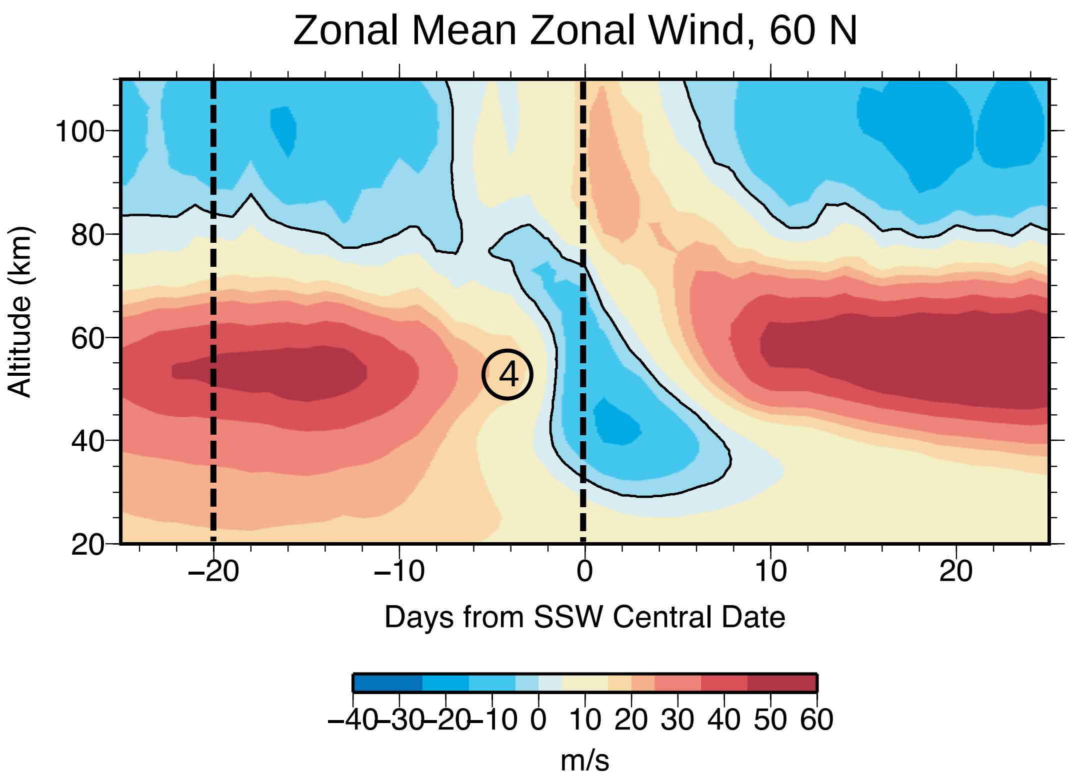
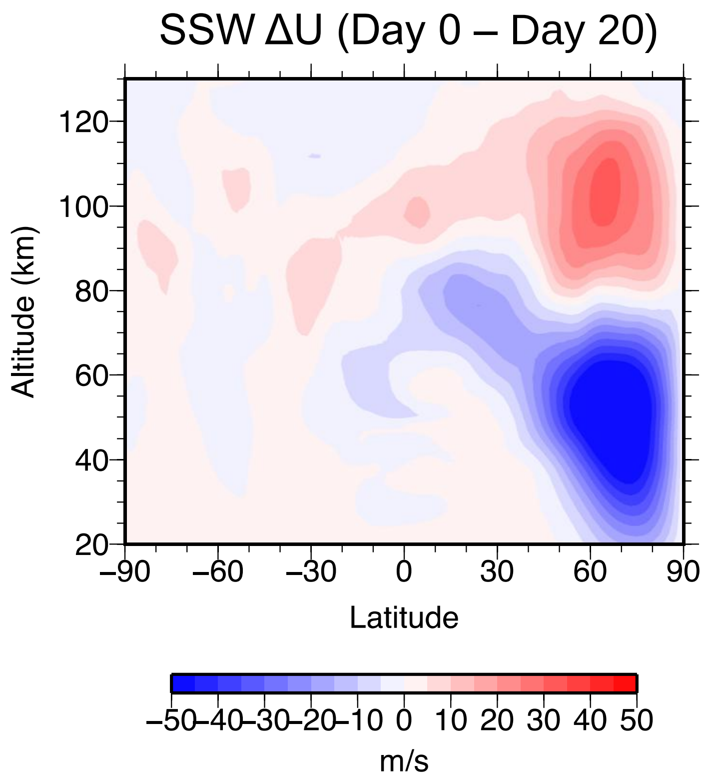
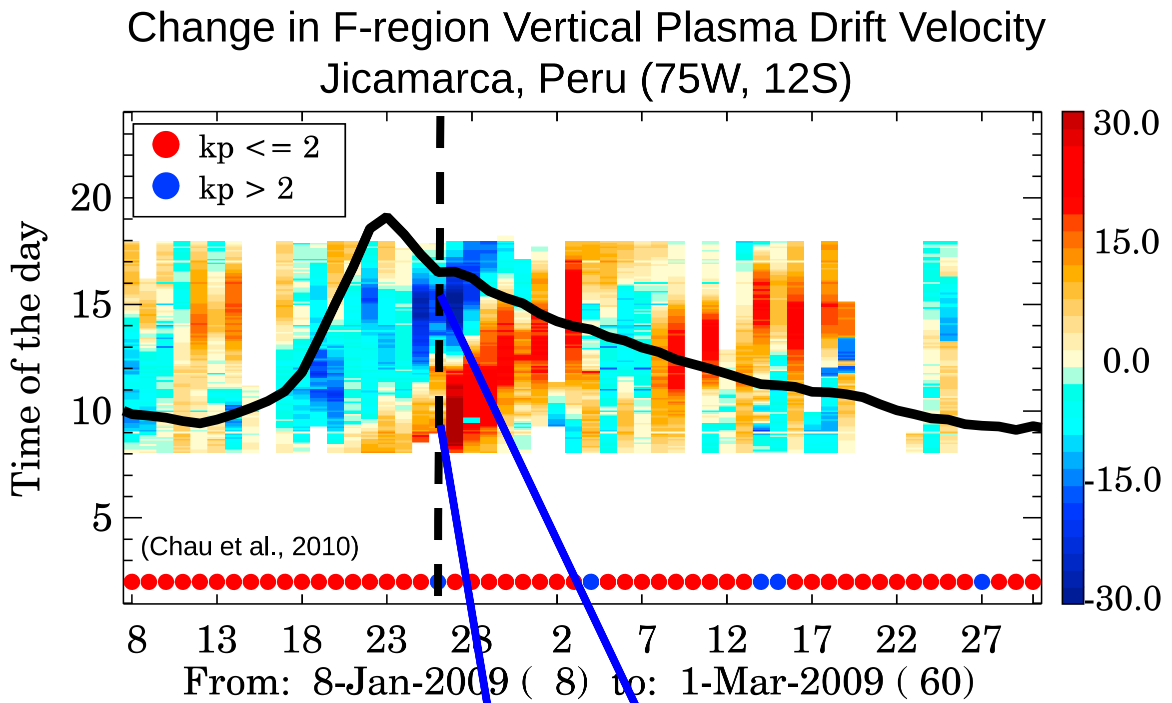
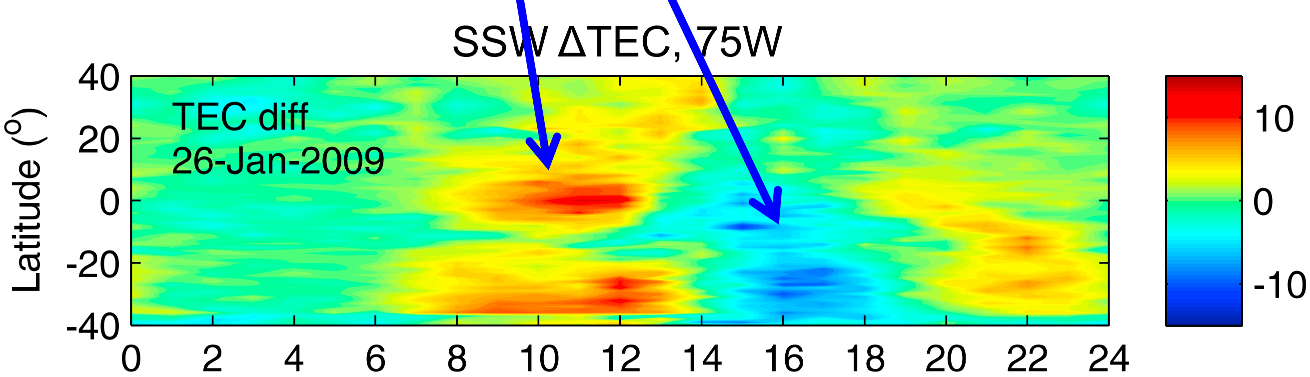




Although the dynamical changes associated with SSW occur in the high latitude stratosphere and mesosphere, observations reveal large changes in the equatorial ionosphere occur during SSWs.

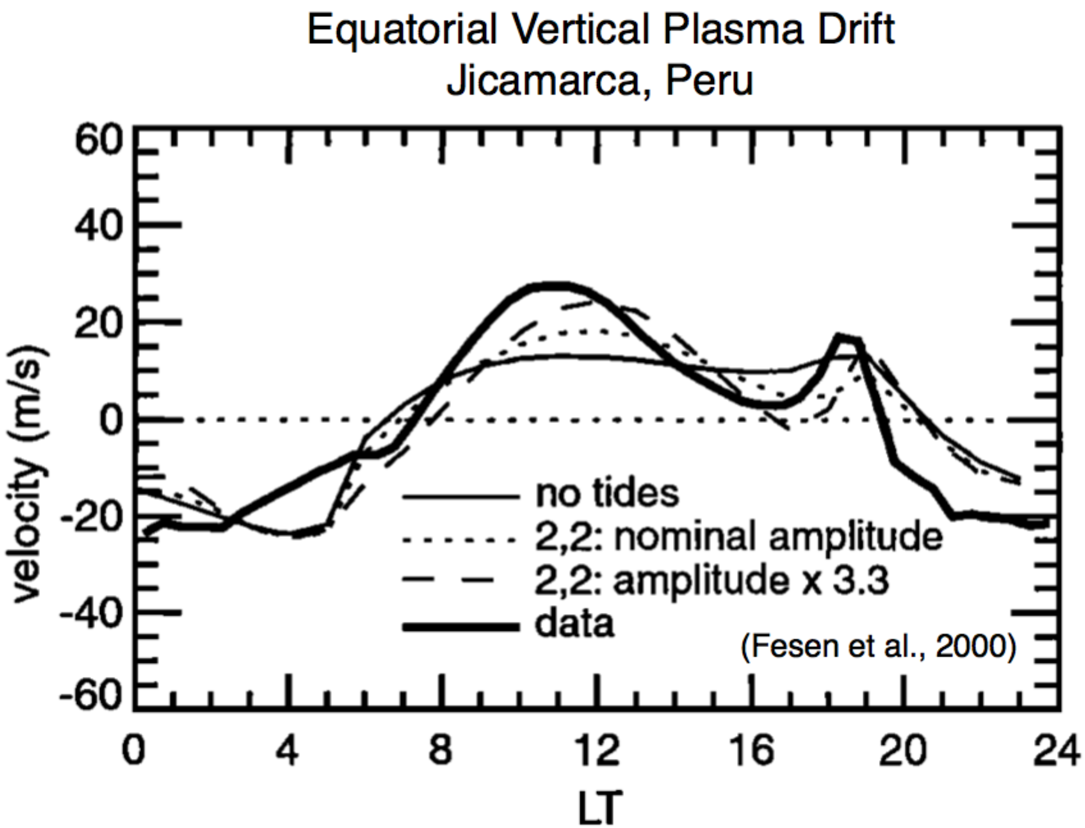




(Goncharenko et al., 2010)

Objective: Use numerical simulations to elucidate the mechanisms that couple SSWs to upper atmosphere variability

The primary hypothesis is that changes in ***atmospheric tides*** during SSWs are the source of the ionosphere variability at equatorial latitudes.



Solar and Lunar Atmospheric Tides

- Atmospheric tides are global-scale periodic oscillations of the atmosphere that are generated by **periodic solar heating**, the **gravitational pull of the Moon**, and **latent heat release** due to tropical convection.

- Tides are termed **migrating** if they propagate westward with the apparent motion of the Sun, and **nonmigrating** if they propagate faster or slower than the apparent solar motion

- Tides generated in the troposphere and stratosphere can propagate vertically, growing exponentially with height, until ~90-120 km where they dissipate due to increasing diffusion

- Tides can interact with each other, as well as with other waves, generating secondary waves:

$$\cos(\omega_1 t - s_1\lambda + \phi_1)\cos(\omega_2 t - s_2\lambda + \phi_2) = \alpha\cos[(\omega_1+\omega_2)t - (s_1 + s_2)\lambda + \phi_1 + \phi_2] + \beta\cos[(\omega_1 - \omega_2)t - (s_1 - s_2)\lambda + \phi_1 - \phi_2]$$

- The primary interest during SSWs is on the migrating semidiurnal solar (**SW2**) and lunar (**M2**) tides, as well as the westward propagating nonmigrating semidiurnal tide with zonal wavenumber 1 (**SW1**)
  - SW2 is primarily generated in the stratosphere due to ozone absorption of solar UV radiation
  - M2 is the dominant lunar tide in the atmosphere
  - SW1 can be generated by interaction between SW2 and a wavenumber 1 planetary wave (PW1). Enhanced planetary waves are a source of SSWs

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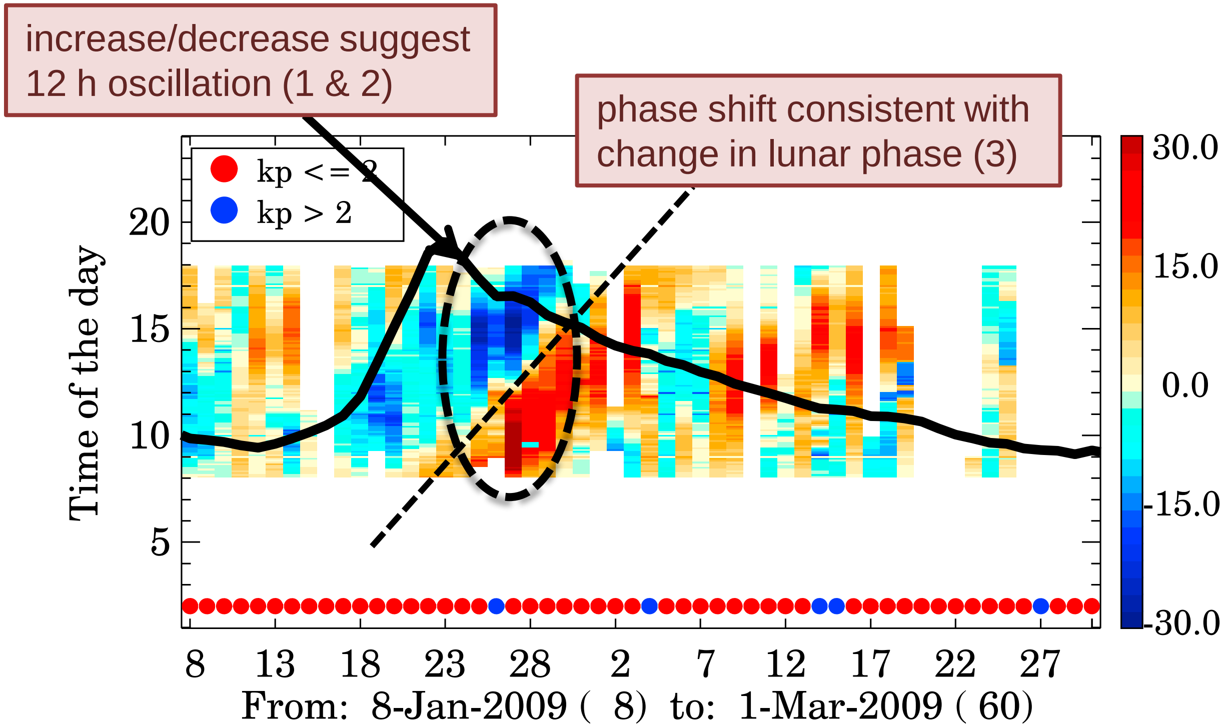
Potential tidal changes during SSWs:

1. Enhanced solar semidiurnal migrating tide
2. Enhanced solar semidiurnal nonmigrating tide
3. Enhanced lunar semidiurnal migrating tide



Model simulations are used to determine the tidal variability during SSWs and its influence on the ionosphere and thermosphere.

The impact of SSWs on tidal variability and the upper atmosphere is investigated using a combination of WACCM and TIME-GCM

- WACCM simulates the chemical and dynamical variability from the surface to ~140 km

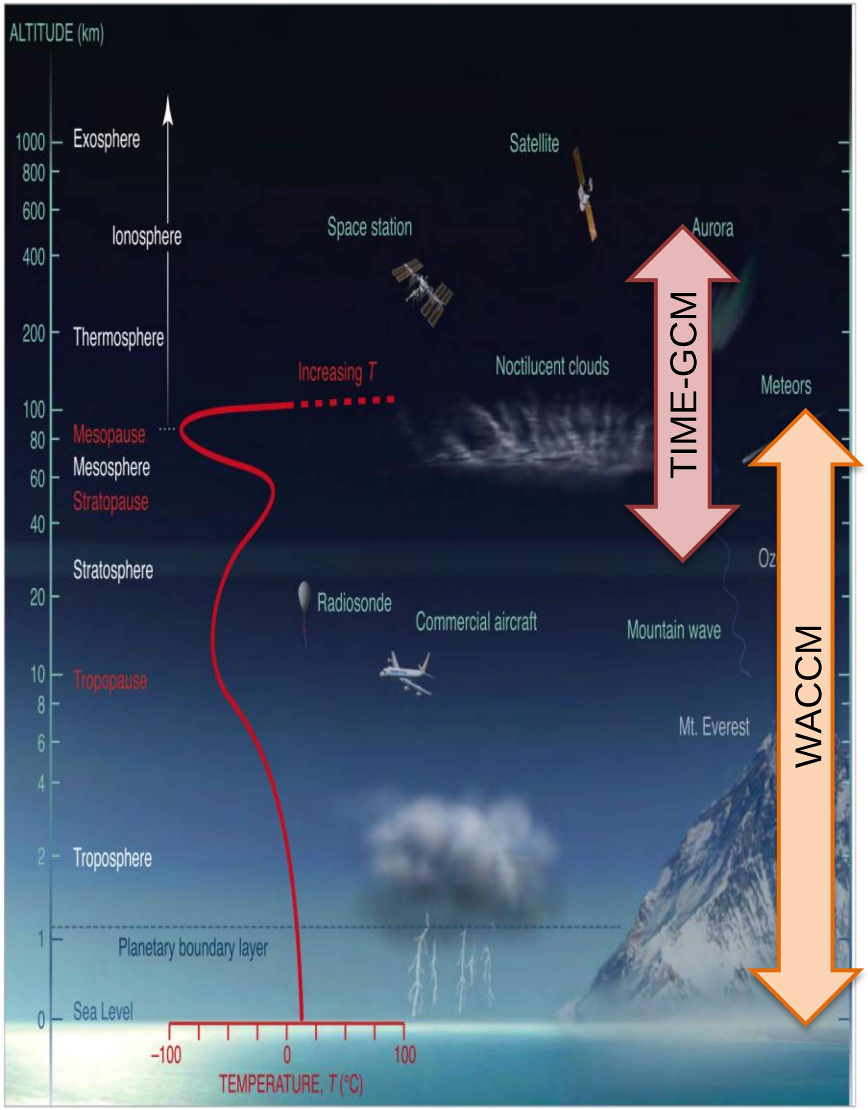
- TIME-GCM covers altitudes of ~30-500 km, and simulates the mesosphere, ionosphere, and thermosphere, with self-consistent electrodynamics

- To capture lower atmosphere variability, forcing must be added to the TIME-GCM lower boundary.

- SSWs are introduced in TIME-GCM by nudging TIME-GCM zonal mean fields up to ~95 km

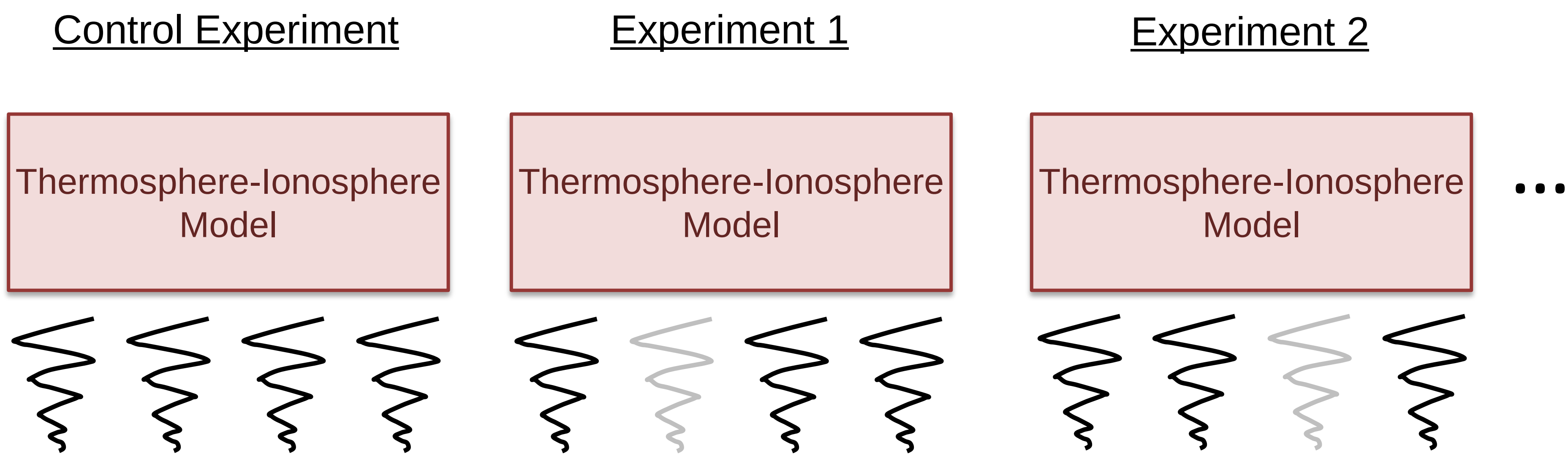
- WACCM planetary waves and tides are also added at the TIME-GCM lower boundary

- WACCM fields are based on either the composite of 13 major SSWs, or WACCM constrained to reanalysis fields for realistic simulations



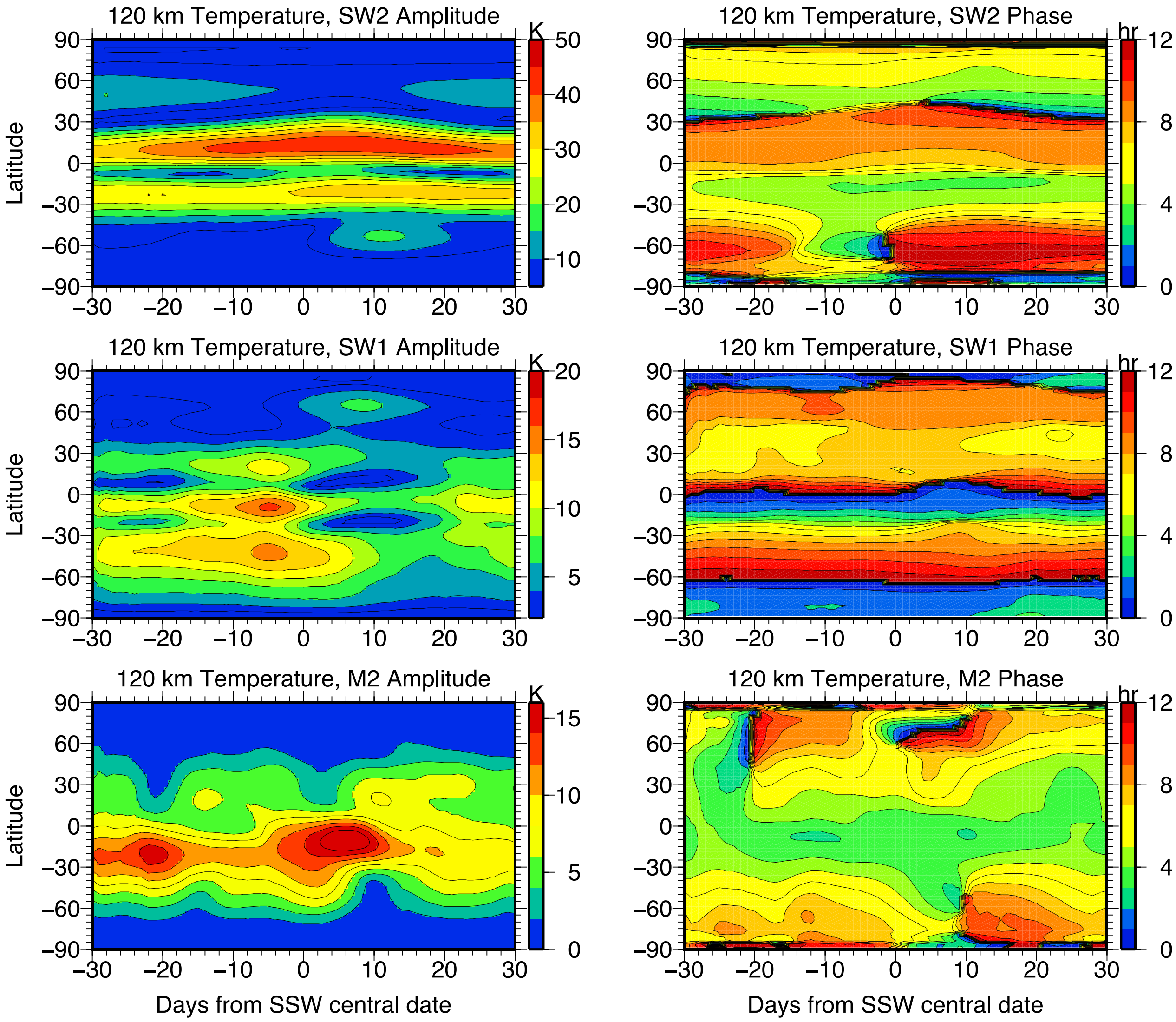
WACCM – Whole Atmosphere Community Climate Model
TIME-GCM – Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model

To identify the main mechanisms that generate the equatorial ionosphere variability, numerical experiments are performed with different lower boundary forcing conditions, but an identical zonal mean SSW



By performing *controlled* experiments the impact of different waves on the ionosphere variability can be determined

Simulations reveal variability in SW1, SW2, and M2 during SSWs

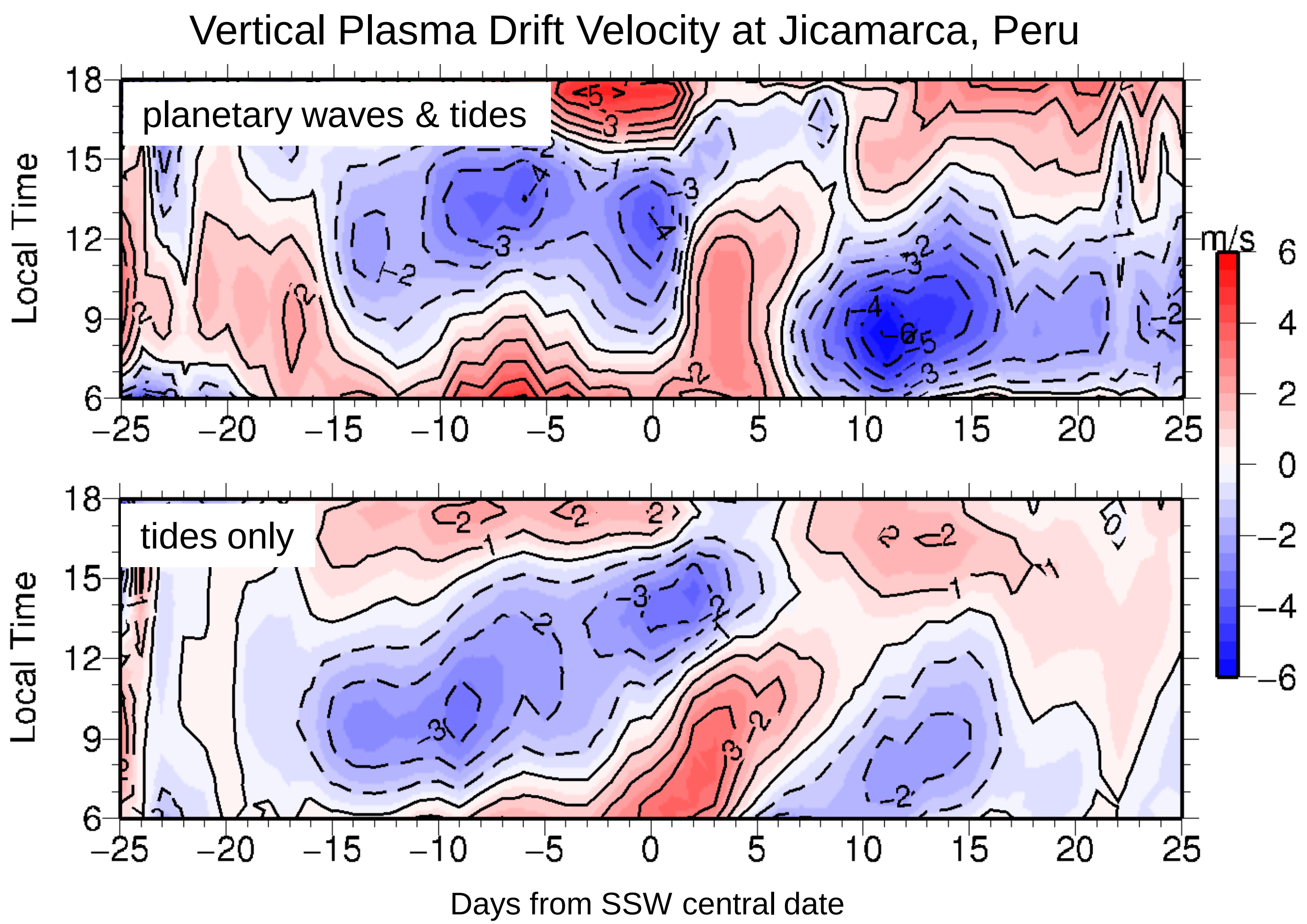


Changes in the mean winds during SSWs generate the SW2 and M2 variability. The SW1 variability is due to nonlinear interaction between PW1 and SW2.

Change in SW2 amplitude and phase can generate temporal plasma drift variability similar to what is seen in the observations

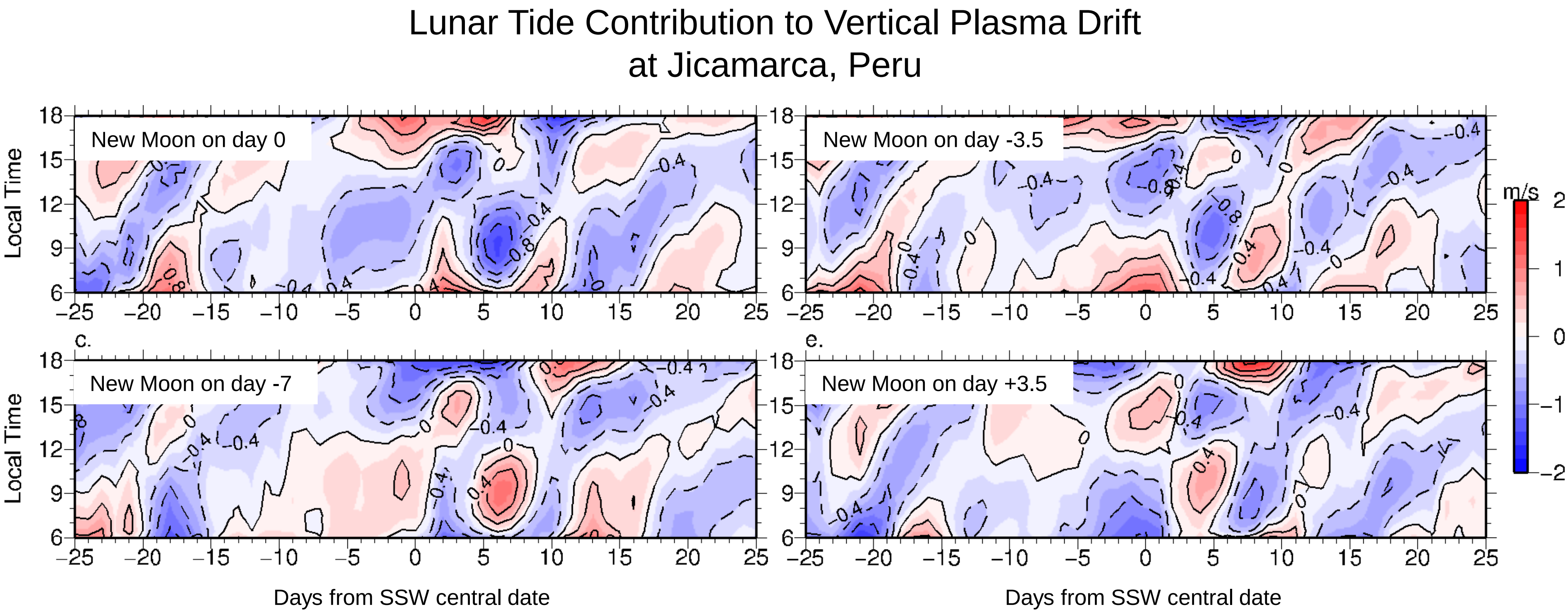
variability due to SW1+SW2

variability due to SW2



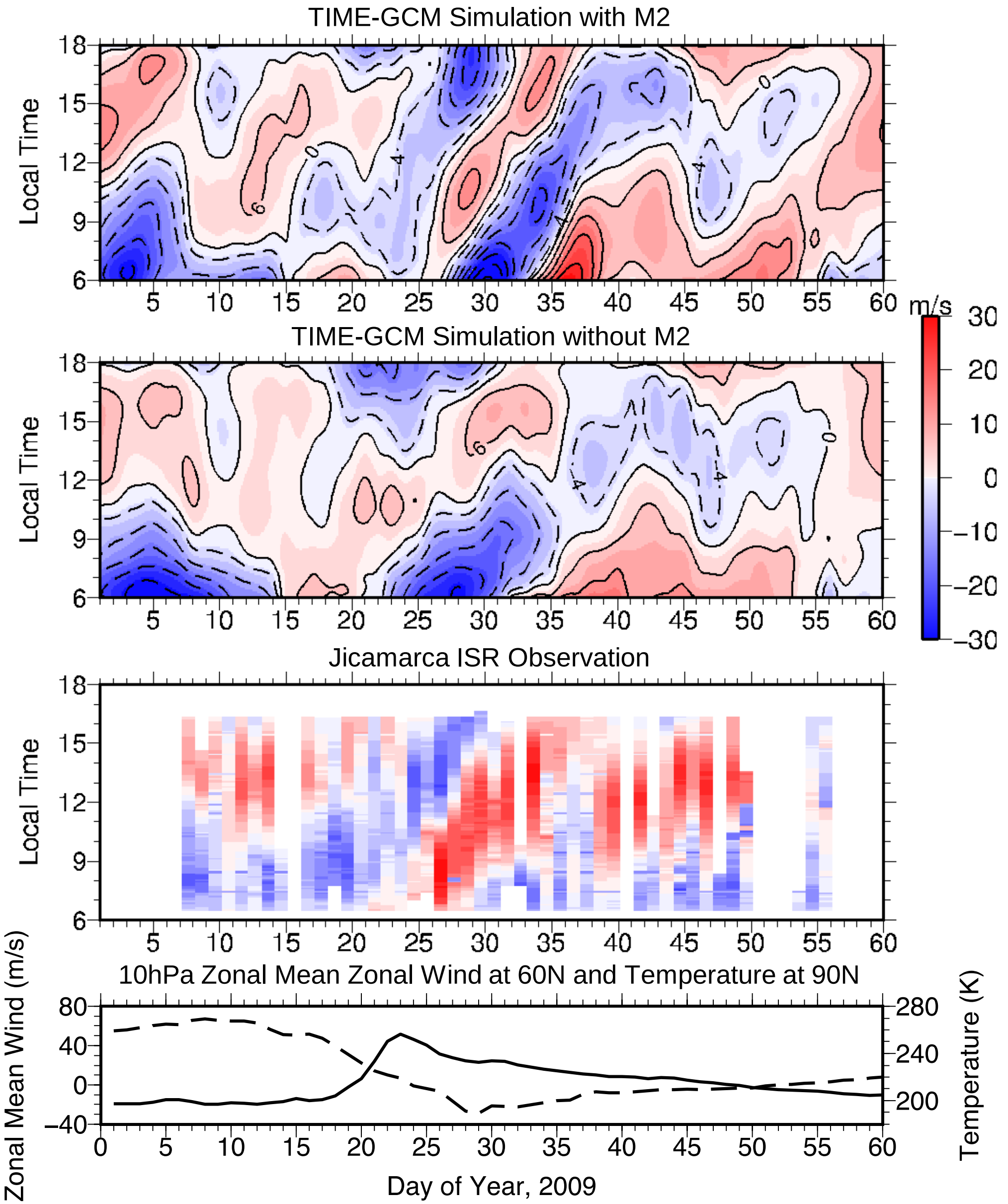
Results for simulation without lunar tide

The lunar tide contributes to ~30% of the ionosphere variability during SSWs

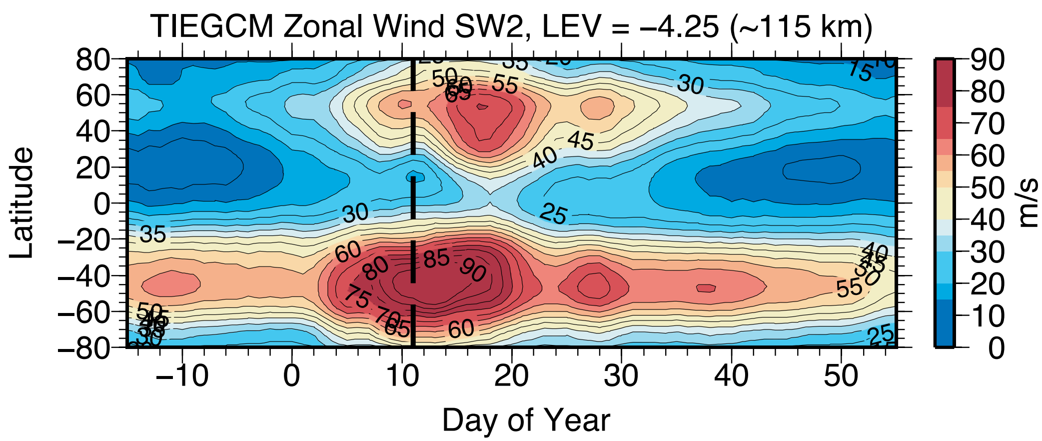


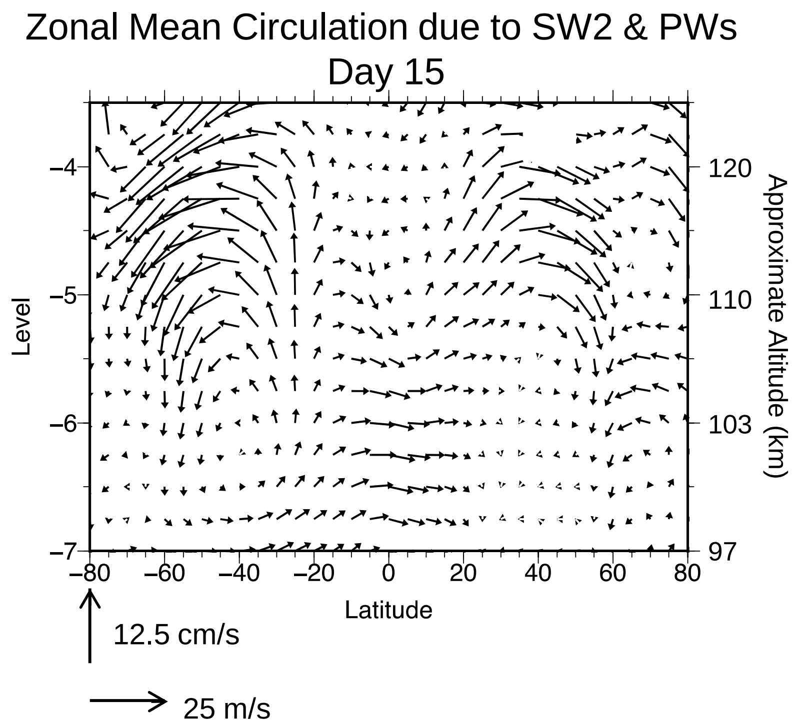
Impact of lunar tide depends on the phase of the moon relative to the SSW

The lunar tide is not only important in the idealized simulations, but also is critical for simulating the variability during realistic SSW events.



The tidal variability during SSWs also influences the mean circulation in the lower thermosphere, impacting the thermosphere composition





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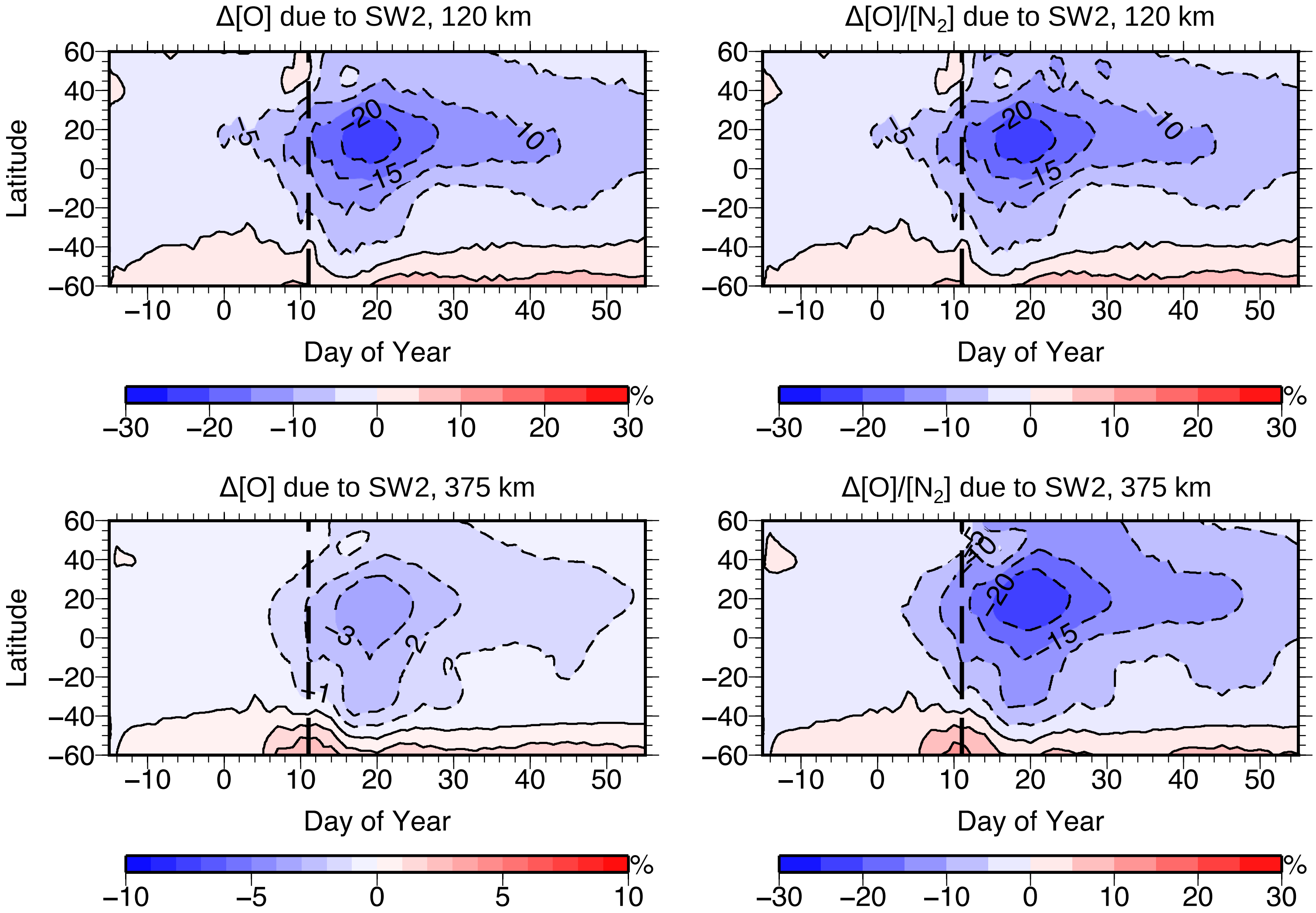
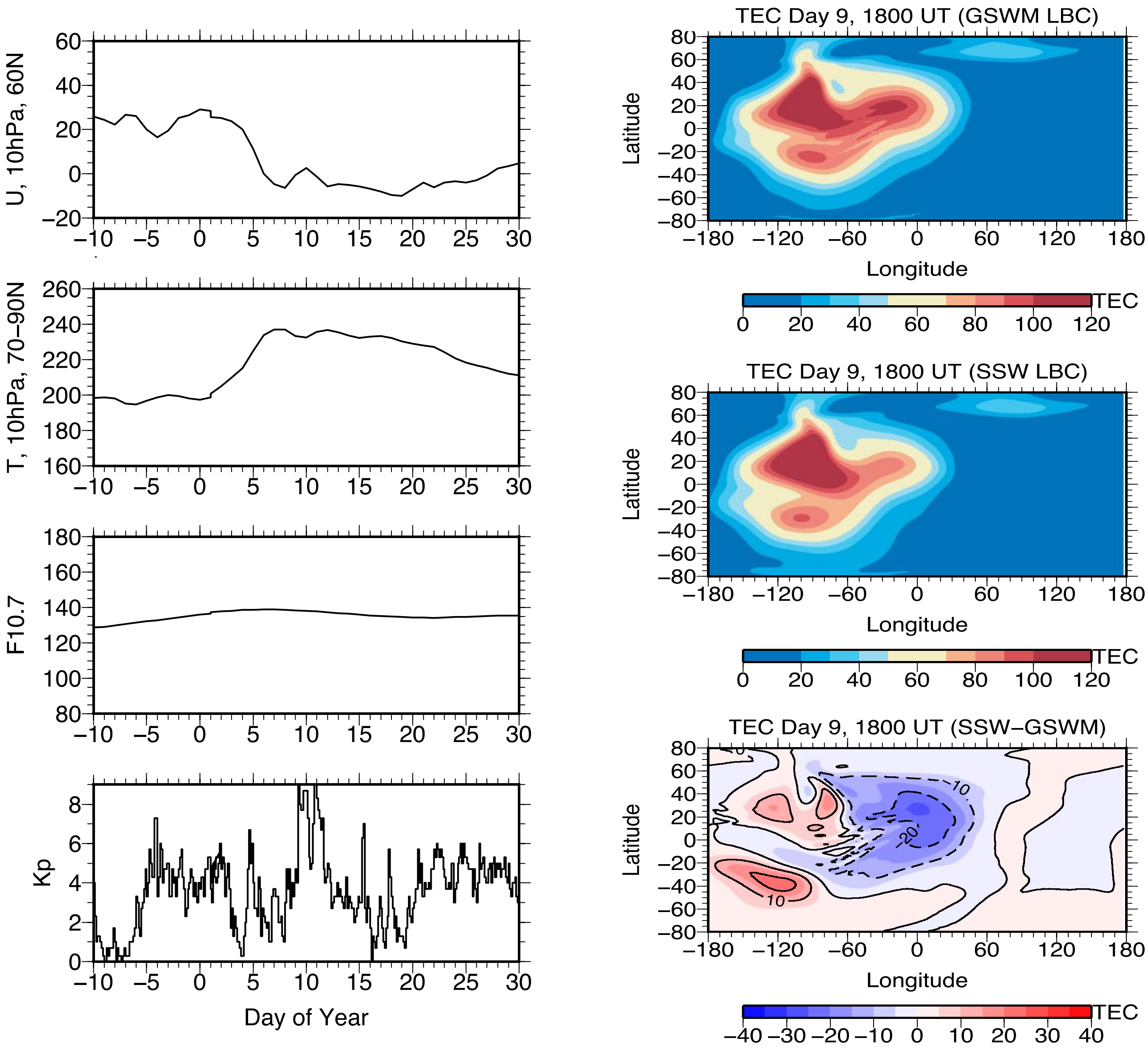


Idealized simulations of a large geomagnetic storm during a SSW indicate that the occurrence of a SSW can impact the ionosphere response to geomagnetic disturbances



~20% difference in TEC response to geomagnetic storm due to SSW

Summary and Conclusions

- Sudden stratosphere warmings provide an ideal scenario for studying the coupling processes between the lower and upper atmospheres

- By performing controlled numerical simulations, changes in the SW2 and M2 tides are found to be the primary source of the equatorial ionosphere variability during SSWs. The SW1 is of secondary importance.

- Enhancements in SW2 and M2 occur due to changes in the zonal mean atmosphere, while the SW1 is generated by nonlinear interaction with PW1

- The dissipation of the SW2 modifies the lower thermosphere circulation, leading to changes in thermosphere composition, and also electron density at low-mid latitudes

- Despite the recent progress many questions remain:

    Are SSWs representative of other periods of enhanced PW activity?

    What is the role of the lower atmosphere on dictating the upper atmosphere response to geomagnetic storms?

- Thanks to Astrid Maute, Art Richmond, and Hanli Liu for their collaboration on modeling upper atmosphere variability during SSWs