Ionospheric variations during January 2009 stratospheric sudden warming

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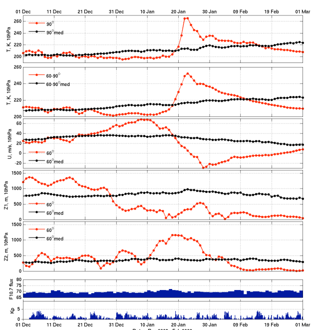
Abstract

The stratospheric sudden warming peaking in January 2009 was the strongest and most prolonged on record. We report significant ionospheric variations is association with this event, which are especially pronounced at low latitudes. Large increase in the vertical drifts is observed at Jicamarca, displaying 12-hour signature with upward drifts in the morning hours and downward drifts in the afternoon hours, with pattern persisting for several days. Analysis of GPS TEC data indicates that variations in electron density are observed in a large range of longitudes and latitudes. The entire daytime ionosphere is affected, with morning increase in low-latitude TEC exceeding 100% of the mean value, and afternoon decrease in TEC approaching ~50% of the mean value. These variations are consistent with ionospheric disturbances observed during other stratospheric warming events. We suggest the observed phenomena is related to planetary waves, which have a high amplitude level prior to the stratospheric warmings. Interaction of planetary waves with tides and modulation of tides can lead to changes in the low-latitude electric field through the wind dynamo process, which in turn is responsible for a large-scale redistribution of ionospheric electron density.

Summary and conclusions

- Evidence of dramatic changes in daytime Jicamarca electric field data and daytime electron density during January 2009 stratospheric sudden warming
- Strong 12-hour signature in both electric field and GPS TEC; the feature persists for several days after the peak warming
- Increase in TEC in the morning sector by 50-150%; suppression in the afternoon by ~50%;
- The features extend to middle latitudes and shift to later local times as SSW develops, indicating a phase shift in 12-h wave
- The suggested mechanism includes:
  - Strong planetary waves originating at high latitudes and propagating both horizontally and vertically;
  - Interaction of planetary wave with tidal modes in the low-latitude lower thermosphere and modulation of 12-h tide
  - Generation of electric field through the E-region dynamo process
  - Upward (in the morning) or downward (in the afternoon) plasma transport due to enhanced low-latitude electric field changes the structure of the entire daytime ionosphere.

1. Stratospheric and geophysical conditions



Stratospheric temperature over 90°N and 60-90°N

Stratospheric zonal wind at 60°N

Planetary wave 1 activity

Planetary wave 2 activity

F10.7 and Kp indexes

Figure 1. The stratospheric sudden warming of January 2009 was the strongest and most prolonged on record. The event occurred during very low solar flux conditions (F10.7 ~70) and very low geomagnetic activity, providing a "perfect-case" scenario for studies of coupling between the stratosphere and ionosphere. Black lines indicate 30-year means of stratospheric parameters at 10hPa (~32km), red lines indicate data for the winter of 2009.

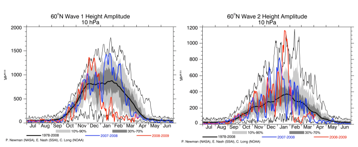


Figure 2. The SSW event was characterized by a low activity of planetary wave 1 and a high activity of planetary wave 2 prior to peak in temperature. The PW2 activity was factor of ~3 higher than 30-year mean.

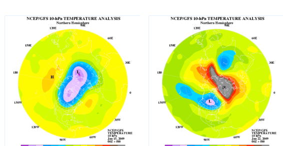


Figure 3. Stratospheric temperature at 10hPa (~32km) before (left) and during (right) stratospheric sudden warming. In this event the cold polar vortex split, with hot cell forming over the pole and two cold cells at lower latitudes.

2.Low latitude ionospheric observations

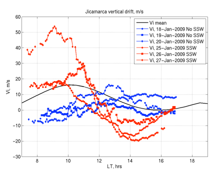


Figure 4. Observations at the magnetic equator (Jicamarca ISR,12°S) indicate large variations in the vertical plasma drift during the SSW. The drifts are upward in the morning and downward in the afternoon, with well-pronounced 12-hour signature. The observed variations reach maximum several days after the peak SSW temperatures, persist for several days and are consistent with vertical drifts observed during the January 2008 SSW event (Chau et al., 2008). Red lines indicate data during SSW, blue lines – data before SSW, black – climatological mean

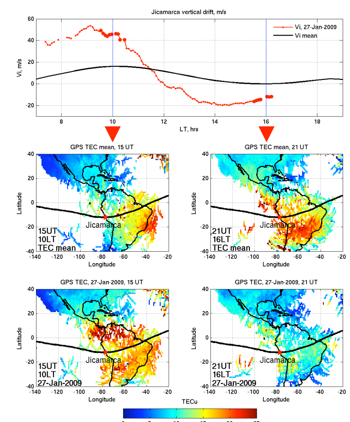


Figure 5. As low-latitude ionosphere is sensitive to the vertical transport, persistent upward drift during morning hours leads to increase in the low-latitude electron density and stronger equatorial anomaly, while downward drift in the afternoon leads to the suppression of equatorial anomaly.

Increase in the daytime electron density exceeds 100% of the mean value, decrease in the afternoon approaches 50%. The magnitude of variations is similar to the effects of major geomagnetic storms.

Top panel: Comparison of Jicamarca drift on Jan 27, 2009 (red) to the multi-year mean vertical drift for solar minimum conditions (black).

Middle panel: mean GPS TEC for Jan 3-12, 2009 at 15UT (left, 10LT at Jicamarca) and 21UT (right, 16LT at Jicamarca).

Bottom panel: GPS TEC for Jan 27, 2009 at 15UT (left) and 21UT (right).

3. Local time variation

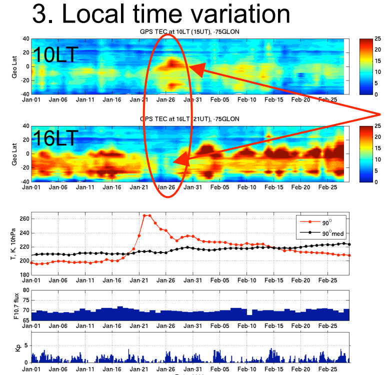


Figure 6. Analysis of GPS TEC data for the whole winter of 2009 indicates that increase in TEC at 10LT and 75W was observed only following SSW event and not during other times. The corresponding decrease in TEC 6 hours later, at 21UT (16LT) confirms that TEC variations are related to a 12-h wave.

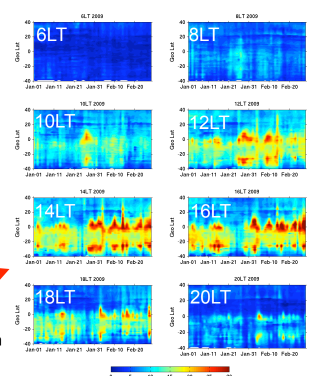


Figure 7. Variation in TEC demonstrates a complex pattern in local time

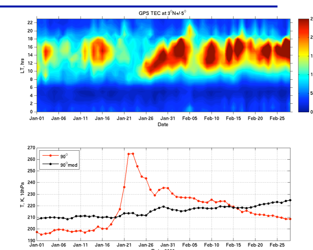


Figure 8. Local time variation of the northern crest of equatorial anomaly demonstrates that as SSW develops, increase in daytime TEC moves to later local times.