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COMMENT
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This article is a comment on Yi et al. (2017), http://doi:10.1002/2017JA024446.

Key Points:

- During HSS substorm events, fresh ~10- to 100-keV electrons are injected and scattered by waves creating the diffuse aurora
- The ~20- to 50-keV portion of the precipitating electrons deposit most of their energy at heights of ~95 km down to ~85 km
- The energy deposition creates NOx and$_3$ O_3 loss. This leads to atmospheric cooling and modulation of zonal wind speeds and neutral densities

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Comment on "First Observation of Mesosphere Response to the Solar Wind High-Speed Streams" by W. Yi et al.

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Abstract While Yi, Reid, Xue, Younger, Spargo, et al. (2017, http://doi:10.1002/2017JA024446) described the observational results showing solar wind high-speed stream (HSS) impacts on the mesosphere over Antarctica, the specific physical mechanism behind them was not discussed. We discussed here how magnetospheric wave-particle interactions and energetic ~20- to 50-keV electron precipitation into the auroral zone atmosphere (diffuse auroras) during HSS intervals can cause the observed effects in the mesosphere.

Comments

We would like to commend Yi and coauthors for their interesting scholarly work (Yi, Reid, Xue, Younger, Spargo, et al., 2017) on solar wind high-speed stream (HSS) impact on the mesosphere (~90 km) over Antarctica (68.5°S, 77.9°E; magnetic latitude: 74.6°S). However, the authors did not comment on the specific physical mechanism causing their observed mesospheric response to HSSs, the main topic of their paper.

Magnetic reconnection between southward component of the embedded nonlinear Alfvén wave magnetic field within solar wind HSSs and the Earth's northward magnetic field at the dayside magnetopause (Dungey, 1961) causes high-intensity long-duration continuous AE activities (HILDCAAs: Tsurutani & Gonzalez, 1987). These are substorms and convection events (Hajra et al., 2013, 2014a, 2014b; Tsurutani et al., 2004) which are characterized by two types of electron auroras. There is energetic ~1- to 10-keV electron acceleration associated with discrete auroras (e.g., Carlson et al., 1998; Swift, 1978) and ~10- to 100-keV electron precipitation associated with diffuse auroras (e.g., Meng et al., 1979; Thorne et al., 2010). Numerous studies based on numerical computations (Rees, 1963, 1964, 1989), parameterized modeling (Artamonov et al., 2016; Fang et al., 2010), and observations (Jones et al., 2009; Semeter & Kamalabadi, 2005) have shown that the ~1- to 10-keV electrons deposit their energy in the ~160- to ~100-km altitude range, while the ~10- to 100-keV electrons deposit their energy deeper in the atmosphere in the ~100- to ~75-km altitude range. For the altitude range of interest, ~85 to ~95 km, it is ~20-to ~50-keV electrons within the ~10- to 100-keV energies that are most important.

The diffuse auroral precipitation is reported to be the main source of auroral energy deposition, accounting for ~75% of the total energy into the mesosphere (Newell et al., 2009; Sandford, 1968; Thorne et al., 2010). This precipitation leads to enhanced ionization and chemical changes in the mesosphere (Frahm et al., 1997).

What is the physical process that causes the ~10- to 100-keV magnetospheric electrons to precipitate? During HILDCAAs (substorms and convection events: Tsurutani et al., 2004), electromagnetic plasma waves called chorus (Inan et al., 1978; Hajra, Tsurutani, Echer, Gonzalez, Brum, et al., 2015, Hajra, Tsurutani, Echer, Gonzalez, & Santolik, 2015; Hajra & Tsurutani, 2018; Meredith et al., 2001; Tsurutani & Smith, 1977; Tsurutani et al., 2013) are generated by the loss cone/temperature anisotropy instability (Brice, 1964; Kennel & Petschek, 1966; Lakhina et al., 2010) associated with the anisotropic, energetic electrons. The chorus waves cyclotron resonate with the energetic electrons leading to pitch angle scattering and loss to the ionosphere (Tsurutani et al., 2013; Tsurutani & Lakhina, 1997).

It has been suggested that energetic auroral particle precipitation can modulate the chemical composition of the mesosphere, which in turn can affect the temperature and dynamics of the region through changes in the atmospheric heating and cooling rates. See Frahm et al. (1997) and Sinnhuber et al. (2012) and references therein for detail reviews on related atmospheric processes. In particular, we refer the reader to the seminal work by Thorne (1980). Thorne has shown that the precipitation of ~10- to 100-keV substorm electrons lead to the ionization and dissociation of nitrogen (N_2) molecules with the ultimate formation of nitric oxide (NO). The formation of NO will do two things. It will radiate infrared at 5.3 microns, leading to local cooling. The formation of NO will also catalytically lead to the destruction of ozone (O_3) and therefore will cause a lack of solar ultraviolet absorption in the region. With a sudden cooling of localized regions of the mesosphere, strong winds might be generated. Tsurutani et al. (2016) have proposed a similar mechanism associated with relativistic electron precipitation (the effects occurring at much lower altitudes) causing the Wilcox et al. (1973) atmospheric effect.

To summarize, chorus waves generated from substorm/convection event-injected, temperature-anisotropic ~10- to 100-keV electrons during HSS events can efficiently pitch angle scatter these electrons, with the ~20- to 50-keV portion depositing most of their energy in the ~85- to ~95-km altitude range. This will lead to effective mesospheric cooling and modulation of local winds and neutral densities.

In response, Yi et al. (2019) have mentioned a Yi, Reid, Xue, Younger, Murphy, et al. (2017) paper which discussed a mechanism for the Yi, Reid, Xue, Younger, Spargo, et al. (2017) mesospheric effects. We agree with much of what Yi, Reid, Xue, Younger, Murphy, et al. (2017) have stated, but what is missing is that these are freshly injected ~10- to 100-keV electrons into the magnetosphere (not trapped particles) and specifically ~20- to 50-keV electron energies (not a "few kiloelectron volt to several megaelectron volt energies"). These ~20- to 50-keV particles are lost to the ionosphere due to pitch angle scattering near the equatorial plane of the magnetosphere by electromagnetic chorus, generated by the temperature anisotropy/loss cone instability (Kennel & Petschek, 1966).

As mentioned previously, ~1- to 10-keV electrons will deposit their energies too high in the atmosphere to affect the ~85- to 95-km region. The mechanism for their precipitation is different than the chorus-particle pitch angle scattering of ~10- to 100-keV electrons. It is acceleration by low-altitude double layers (Carlson et al., 1998). Several megaelectron volt electrons will deposit their energy much below the region of interest. Again, their mechanism for precipitation is different still, which is electromagnetic ion cyclotron wave-particle pitch angle scattering (Tsurutani et al., 2016). On the other hand, the ~20- to 50-keV portion will deposit most of their energy in the ~85- to ~95-km altitude range. This is hypothesized to lead to effective mesospheric cooling and modulation of local winds and neutral densities. This general mechanism provides a plausible explanation for the observations of Yi, Reid, Xue, Younger, Spargo, et al. (2017).

However, the above scenario needs testing. For the proposed atmospheric cooling effect to be operable, the hypothesis implies that the atmosphere where the precipitation is taking place be exposed to sunlight. With the lack of O_3, this region will be cooled. For winds to take place, neighboring regions (on the sides or top or bottom) should not be cooled or cooled as much, creating a spatial temperature gradient which could be the source of the winds. If this is not the case, then another chemical reaction must be important in association with the ~20- to 50-keV electron precipitation.

We think this hypothesis can explain the Yi, Reid, Xue, Younger, Spargo, et al. (2017) observations. We hope that Yi et al. will do further research to verify whether the proposed sunlight effect is the correct answer or not.

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