Modeling ionosphere response to Solar Proton Events in the whole atmosphere model EAGLE

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Altitude of maximum energy deposition

(Wissing and Kallenrode 2009)

(Quack, 2005)
Whole Atmosphere Global Model

EAGLE

HAMMONIA

- ERA-Interim nudging
- Stratospheric aerosols
- Solar irradiance
- GHG/ODS

Physics & Dynamics
- 0-180(280) km, L119
- 1.9°-1.9°, T63
- Column physics
- Tracer transport

Chemistry
- 48 species
- 107 neutral reactions
- 46 photolysis reactions
- 18 ion-involved reactions

- Sea ice
- Sea temperature
- Land use
- Ionization rates (MA)
- Ionization rates (UA)

GSMTIP

D, E, F1 Ionosphere
- 80-175 km
- Mostly molecular ions, electrons
- Ion-involved reactions
- Ion, electron/neutral interactions

- Solar EUV
- Auroral precipitation/Field-aligned current

Electric field

- F2 Ionosphere, Protonosphere
- 175-100000 km
- Mostly atomic ions, electrons
- Quasihydrodynamics
AIMOS models of ion pair production due to precipitating particles solar and magnetospheric origin.

AIMOS is designed to convert observations of energetic solar and magnetospheric particles from satellites (POES and GOES) into a 3-D ionization pattern in the atmosphere.

AIMOS consists of two parts: a GEANT4-based Monte Carlo simulation and a sorting algorithm to assign observations from two polar-orbiting satellites to horizontal precipitation cells, depending on geomagnetic activity.

The POES satellites (POES: Polar Orbiting Environmental Satellite) are polar-orbiting satellites in a Sun synchronous orbit with a height of 850 km and an inclination of 98 degrees.

The GOES satellites (GOES: Geostationary Operational Environmental Satellite) are in geostationary orbit located at W135 and W104.
AIMOS

Higher energetic particles (0.8–2.5 MeV protons) flux.

Low energetic particles (30–80 keV protons) flux

A view on the south pole is shown.
Solar Proton Events, January of 2005

Proton Flux Measurements by GOES 11 (cm$^{-2}$ s$^{-1}$ sr$^{-1}$)

- >10 MeV
- >50 MeV
- >100 MeV

(Edgar A. Bering et al., 2015)

Ion rates by protons in the northern polar region (cm$^{-3}$ s$^{-1}$)

WACCM (Jackman et al., 2011)
EAGLE simulations

Data comparisons for two model runs:
- reference model simulation (quiet condition)
- SPE simulation.

It was changed ONLY proton flux in AIMOS
Proton Flux Measurements by GOES 11 (cm⁻² s⁻¹ sr⁻¹)

EAGLE log-ionization rates by protons (AIMOS)
on 80 N (ion pairs cm⁻³ s⁻¹)
SOLAR PROTON EVENT, EAGLE model simulation

Zonally averaged $Ne, cm^{-3}$ at 83 km, January, 17

$Ne, cm^{-3}$ at 83 km, 17 of January, 19 UT
Zonally averaged $\Delta T_{e,K}$ (electron temperature) on 80 N and ratio $\Delta N_{e}/N_{e}$ on 80 N latitude.
ratio $\Delta f_{o\text{F2}}/f_{o\text{F2}}$ (top) and $\Delta f_{o\text{F2}}$, MHz (bottom)

Dashed vertical lines indicate SPE.

Direct effect at higher latitudes

Indirect effect at low latitudes
Day to day variation zonally averaged O/N2 ratio at 300 km

Zonally averaged $\Delta T_n$ at 300 km
The whole atmosphere model (EAGLE) allows to investigate large-scale phenomena covering all layers of the atmosphere.

The response of the ionosphere to the proton event of January 2005 is considered.

Despite the relative transparency of the thermosphere to the high-energy particles, ionospheric response on SPE was obtained.

The direct and indirect effects of the proton event due to ionization and variations of the atmosphere parameters, respectively, should be noted.

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