Middle Atmosphere Ionization from Particle Precipitation as Observed by the SSUSI Satellite Instruments

Stefan Bender[1] and Patrick Espy[2]

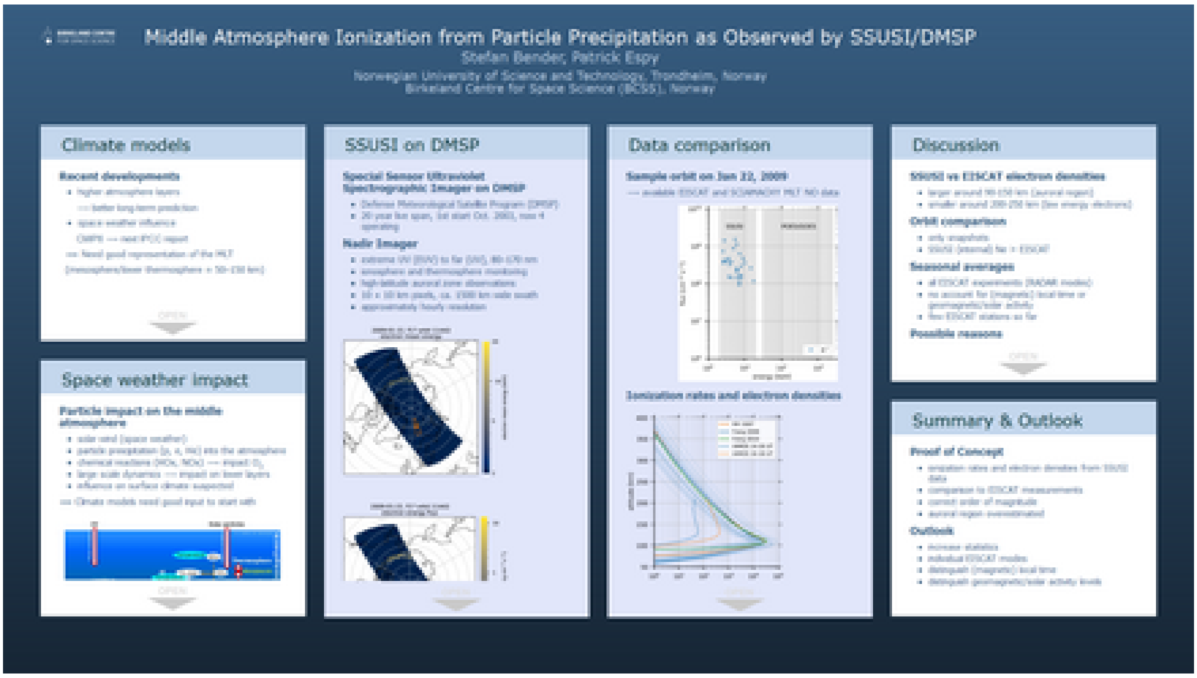
[1]Norwegian University of Science and Technology
[2]NTNU

November 22, 2022

Abstract

Solar, auroral, and radiation belt electrons enter the atmosphere at polar regions leading to ionization and affecting its chemistry. For example particle-produced OH and NO molecules affect the ozone content in the middle atmosphere. Climate models usually parametrize this ionization and the related changes in chemistry based on satellite particle measurements. Precise measurements of the particle and energy influx into the upper atmosphere are difficult because they vary substantially in location and time. Widely used particle data are derived from the POES and GOES satellite measurements which provide electron and proton spectra. We present electron energy and flux measurements from the Special Sensor Ultraviolet Spectrographic Imagers (SSUSI) satellite instruments. This formation of satellites observes the auroral zone in the UV from which electron energies and fluxes are inferred. We use these observed electron energies and fluxes to calculate ionization rates and electron densities in the mesosphere and lower thermosphere ([?] 40–200 km). We also present an initial comparison of these rates to other models and compare the electron densities to those measured by the EISCAT radar. Together with photochemical models, trace gas concentrations, for example of NO, can be calculated from these electron densities. These concentrations then provide an independent source for comparing and validating satellite trace gas measurements.

Middle Atmosphere Ionization from Particle Precipitation as Observed by SSUSI/DMSP



Stefan Bender, Patrick Espy

Norwegian University of Science and Technology, Trondheim, Norway
Birkeland Centre for Space Science (BCSS), Norway

PRESENTED AT:

CLIMATE MODELS

Recent developments

- higher atmosphere layers

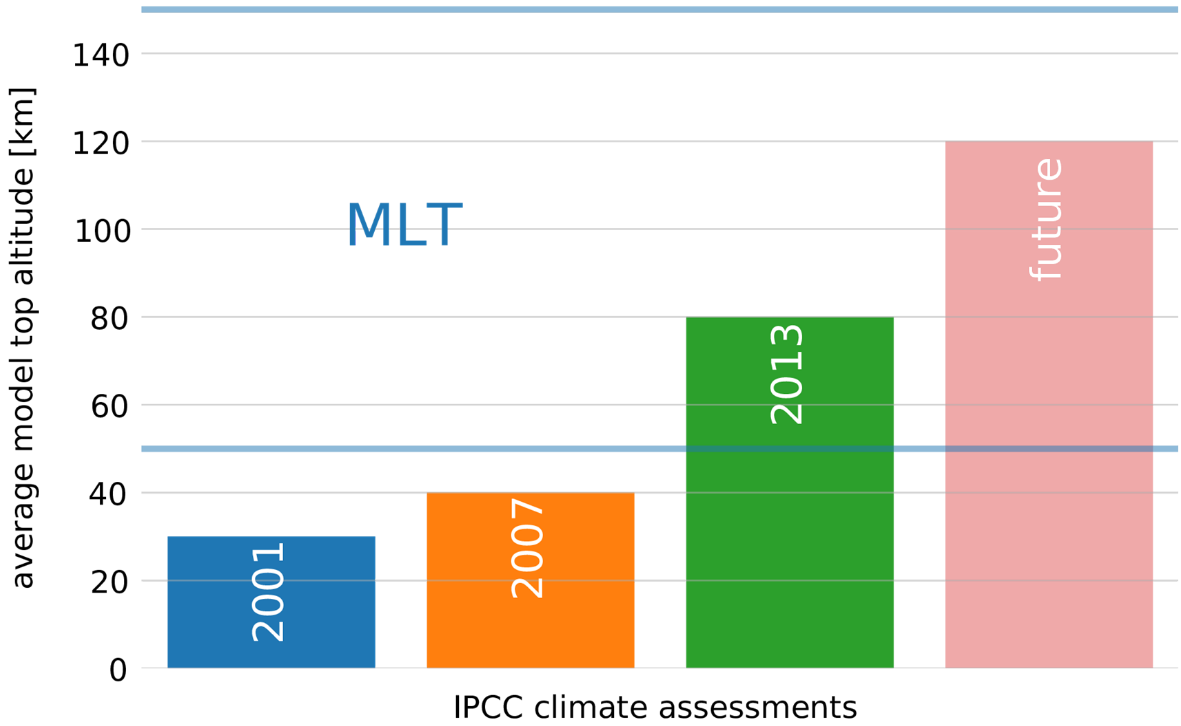
  ⟶ better long-term prediction

- space weather influence

CMIP6 ⟶ next IPCC report

⟹ Need good representation of the MLT

(mesosphere/lower thermosphere ≈ 50–150 km)

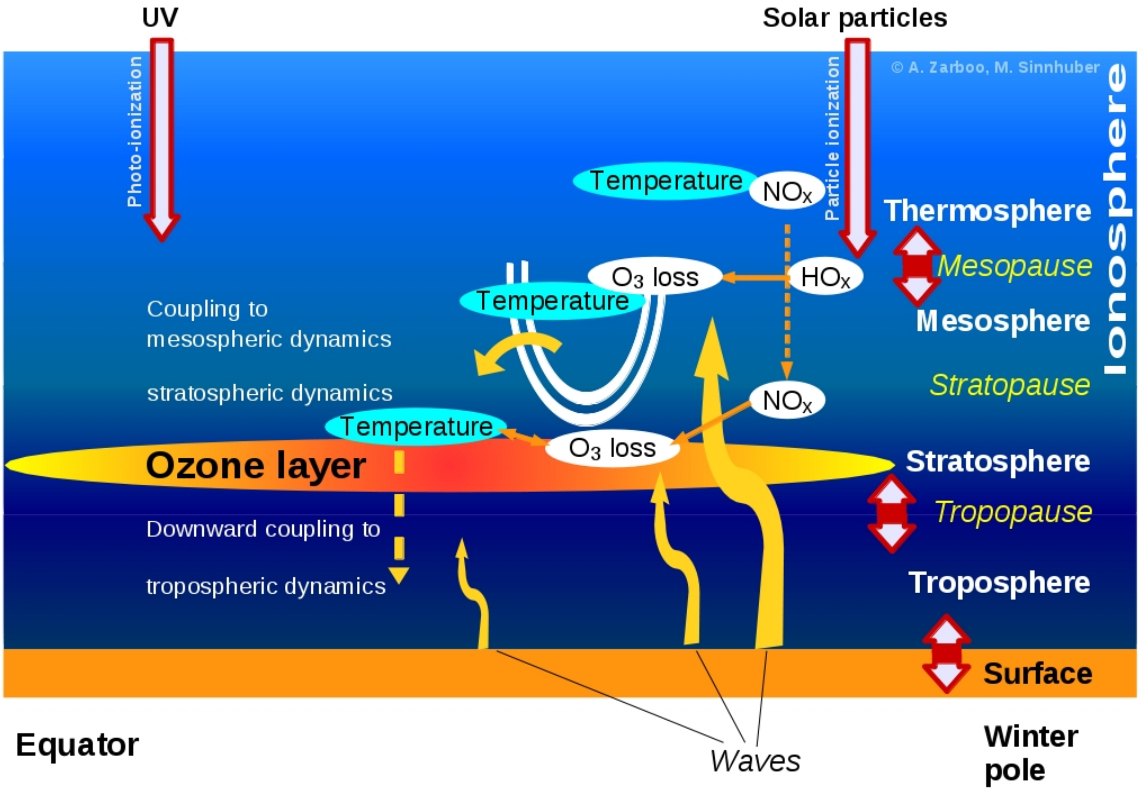


SPACE WEATHER IMPACT

Particle impact on the middle atmosphere

- solar wind (space weather)
- particle preicipitation (p, e, He) into the atmosphere
- chemical reactions (HOx, NOx) ⟶ impact O_3
- large scale dynamics ⟶ impact on lower layers
- influence on surface climate suspected

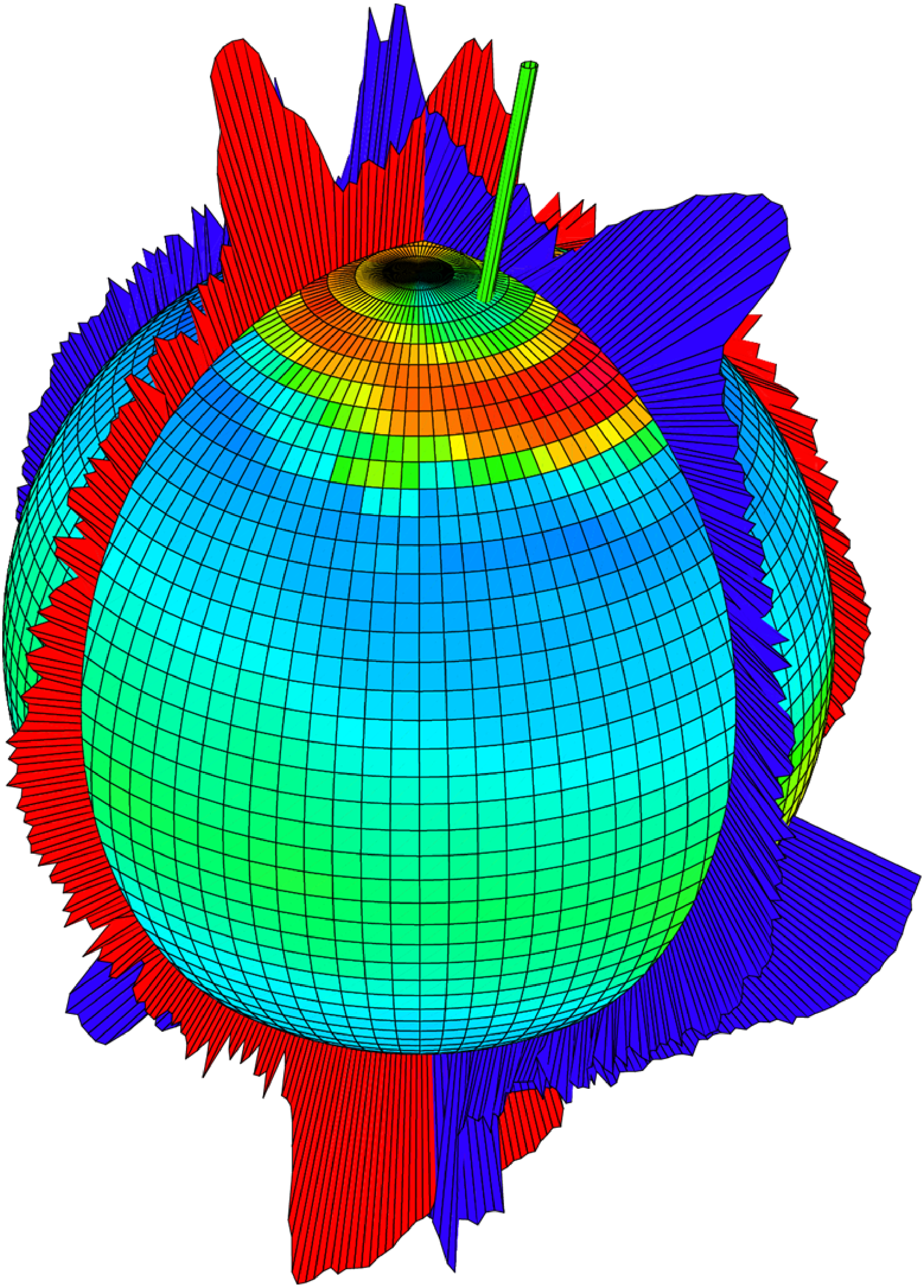
⟹ Climate models need good input to start with



State of the art

- POES/GOES derived data (AIMOS; Wissing et al., 2009; van de Kamp 2016, 2018)
- MIPAS derived parametrization for NO at the upper boundary (Funke et al., 2016)

⟶ CMIP6 (Matthes et al., 2017)



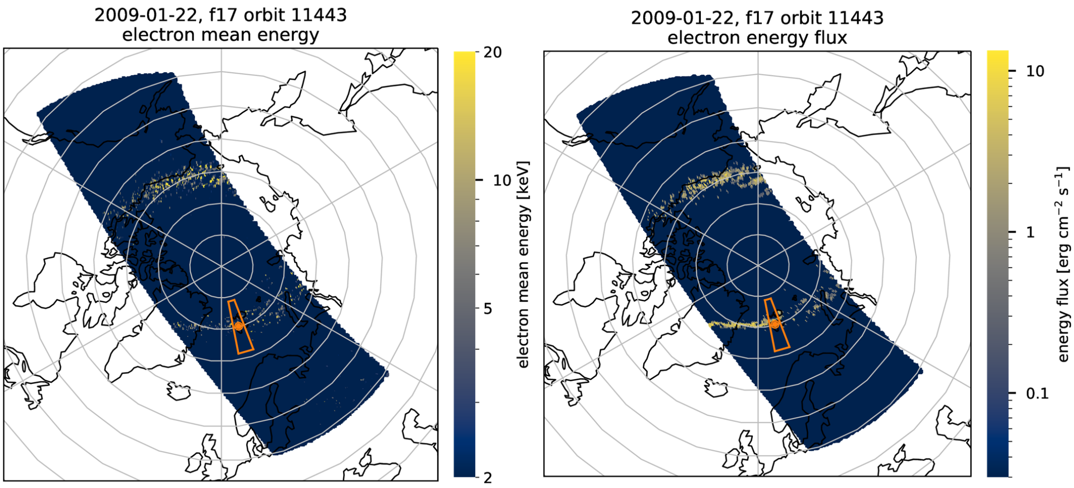
SSUSI ON DMSP

Special Sensor Ultraviolet Spectrographic Imager on DMSP

- Defense Meteorological Satellite Program (DMSP)
- 20 year live span, 1st start Oct. 2003, now 4 operating

Nadir Imager

- extreme UV (EUV) to far (UV), 80–170 nm
- ionosphere and thermosphere monitoring
- high-latitude auroral zone observations
- 10 × 10 km pixels, ca. 1500 km wide swath
- approximately hourly resolution



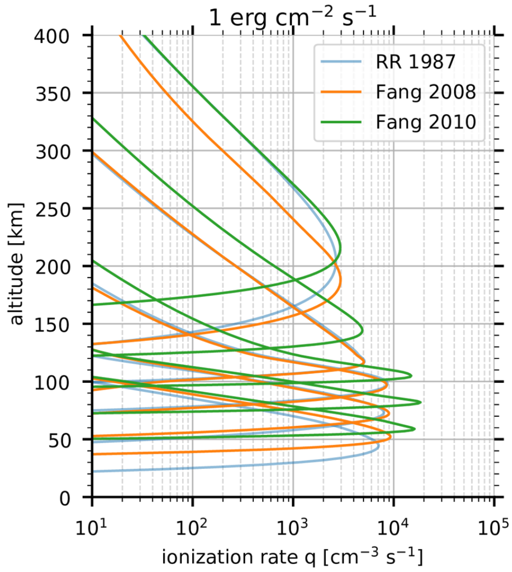
Ionization rate parametrizations

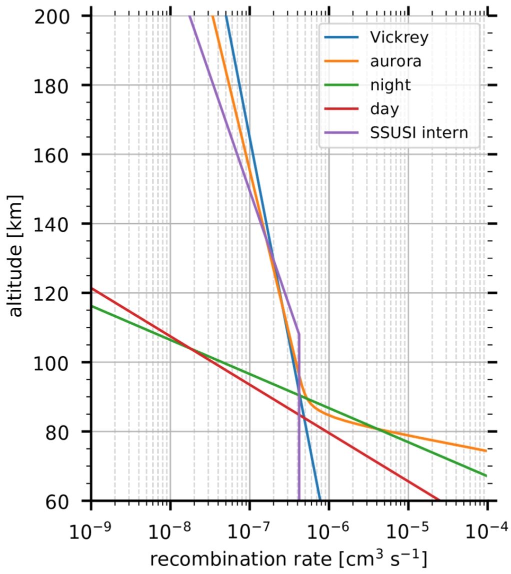
- spectral: Roble et al., 1987, Fang et al., 2008
- mono-energetic: Fang et al., 2010
- NRLMSISE-00 atmosphere

Recombination rate α

- Steady state model

$$\frac{\partial n_e}{\partial t} = q - \alpha n_e^2 = 0$$

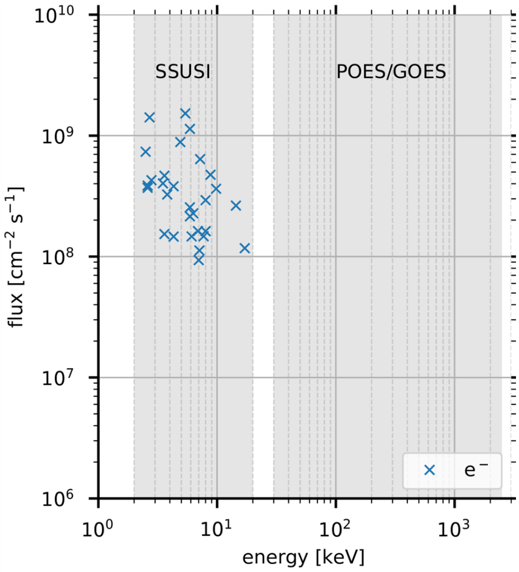

1 erg cm^{-2} s^{-1}
RR 1987
Fang 2008
Fang 2010
altitude [km]
ionization rate q [cm^{-3} s^{-1}]


Vickrey
aurora
night
day
SSUSI intern
altitude [km]
recombination rate [cm^{3} s^{-1}]

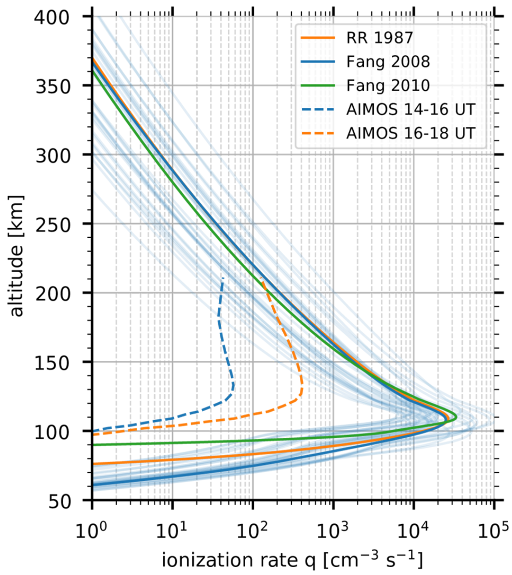
DATA COMPARISON

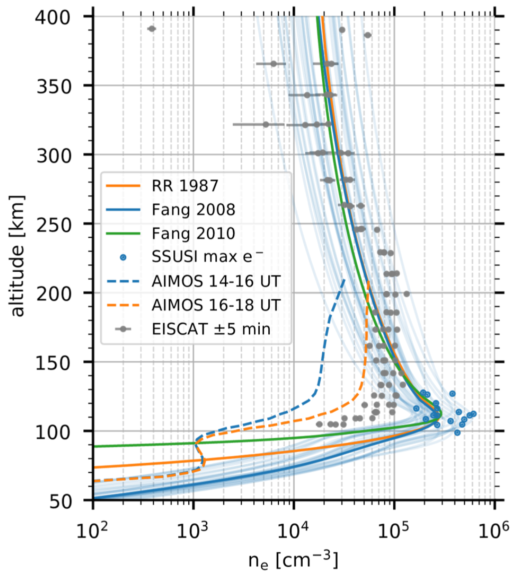
Sample orbit on Jan 22, 2009

⟶ available EISCAT and SCIAMACHY MLT NO data



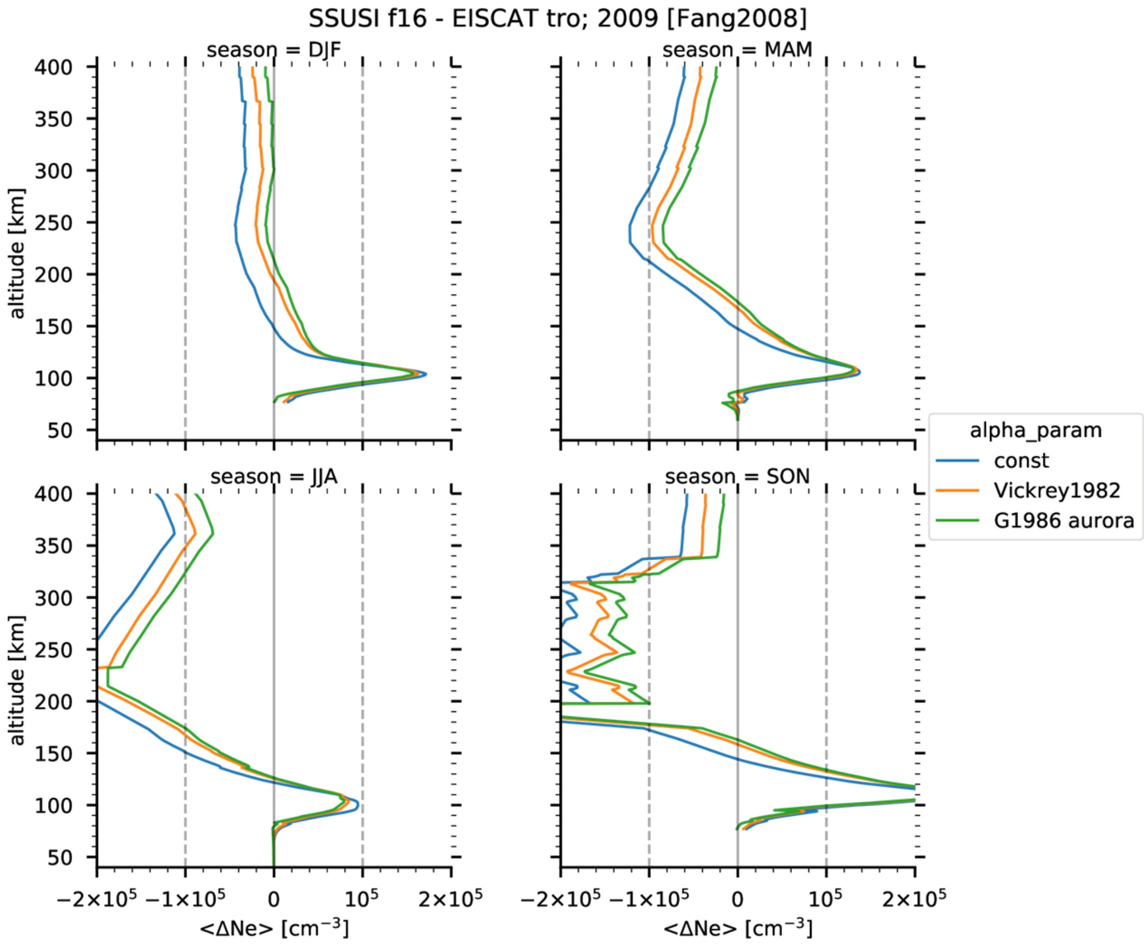
Ionization rates and electron densities





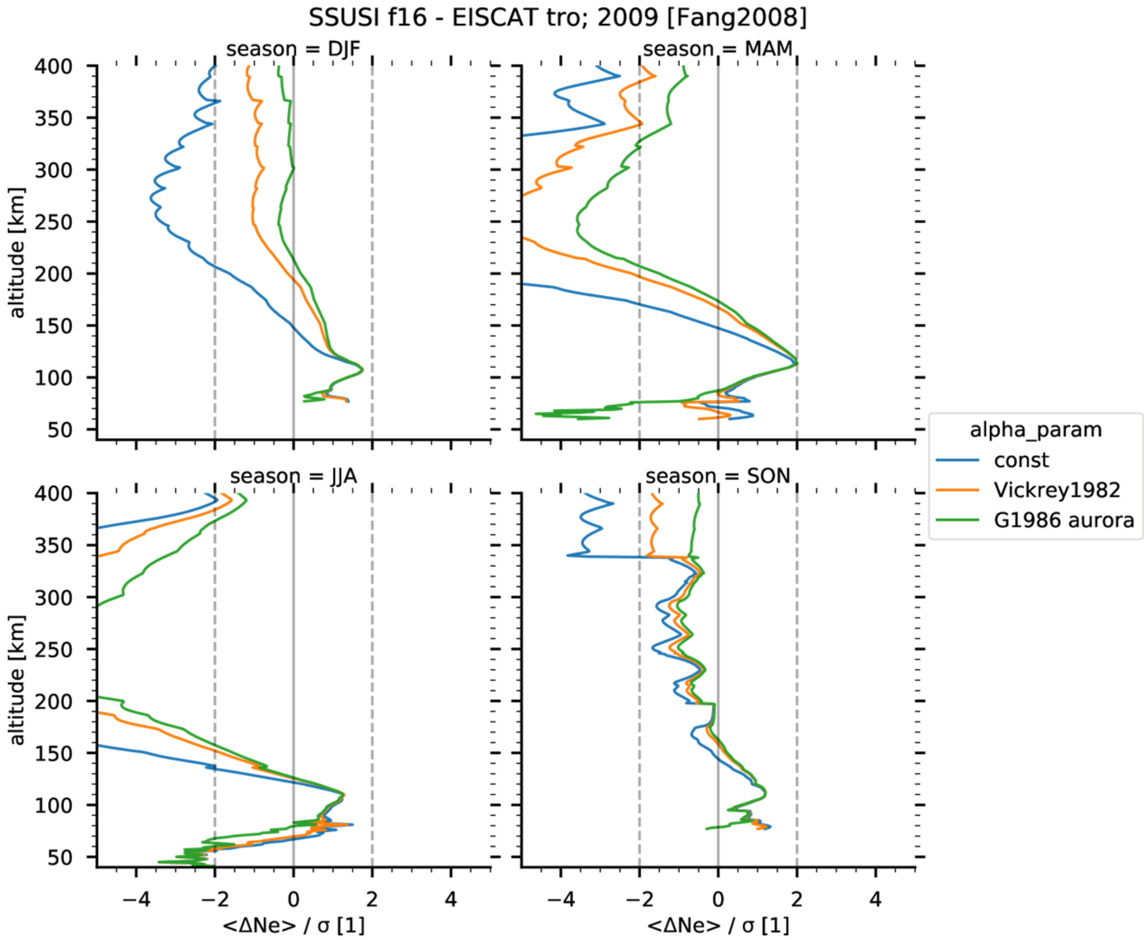
Statistical comparison to EISCAT data

seasonal average, all EISCAT experiments



Significance

mean difference / standard deviation of differences



DISCUSSION

SSUSI vs EISCAT electron densities

- larger around 90-150 km (auroral region)
- smaller around 200-250 km (low energy electrons)

Orbit comparison

- only snapshots
- SSUSI (internal) Ne > EISCAT

Seasonal averages

- all EISCAT experiments (RADAR modes)
- no account for (magnetic) local time or geomagnetic/solar activity
- few EISCAT stations so far

Possible reasons

- large area (5° × 5°) compared to EISCAT beam size (≈1°)
- mismatch in time ∓5 min
- many (>20) different EISCAT modes, not all may be equally suitable

SUMMARY & OUTLOOK

Proof of Concept

- ionization rates and electron densities from SSUSI data
- comparison to EISCAT measurements
- correct order of magnitude
- auroral region overestimated

Outlook

- increase statistics
- individual EISCAT modes
- distinguish (magnetic) local time
- distinguish geomagnetic/solar activity levels

ABSTRACT

Solar, auroral, and radiation belt electrons enter the atmosphere at polar regions leading to ionization and affecting its chemistry. For example particle-produced OH and NO molecules affect the ozone content in the middle atmosphere. Climate models usually parametrize this ionization and the related changes in chemistry based on satellite particle measurements. Precise measurements of the particle and energy influx into the upper atmosphere are difficult because they vary substantially in location and time. Widely used particle data are derived from the POES and GOES satellite measurements which provide electron and proton spectra.
We present electron energy and flux measurements from the Special Sensor Ultraviolet Spectrographic Imagers (SSUSI) satellite instruments. This formation of satellites observes the auroral zone in the UV from which electron energies and fluxes are inferred. We use these observed electron energies and fluxes to calculate ionization rates and electron densities in the mesosphere and lower thermosphere (≈ 40--200 km). We also present an initial comparison of these rates to other models and compare the electron densities to those measured by the EISCAT radar. Together with photochemical models, trace gas concentrations, for example of NO, can be calculated from these electron densities. These concentrations then provide an independent source for comparing and validating satellite trace gas measurements.

REFERENCES

Gledhill, J. A., Radio Sci. 21(3), 1986

Fang, X. et al., J. Geophys. Res. Space Phys. 113(A9), 2008

Fang, X. et al., Geophys. Res. Lett. 37(22), 2010

Funke, B. et al., Atmos. Chem. Phys. 16, 2016

Matthes, K. et al., Geosci. Model Dev. 10, 2017

Paxton et al., Johns Hopk. APL Techn. Dig., 34(3), 2018

Roble, R. G. and Ridley, E. C., Ann. Geophys. 5, 1987

van de Kamp et al., J. Geophys. Res. Atmos., 121(20), 2016

van de Kamp et al., J Geophys. Res. Atmos., 123(17), 2018

Vickrey et al., J. Geophys. Res. Space Phys. 87(A7), 1982

Wissing, J. M. et al., J. Geophys. Res. Space Phys. 114(A6), 2009