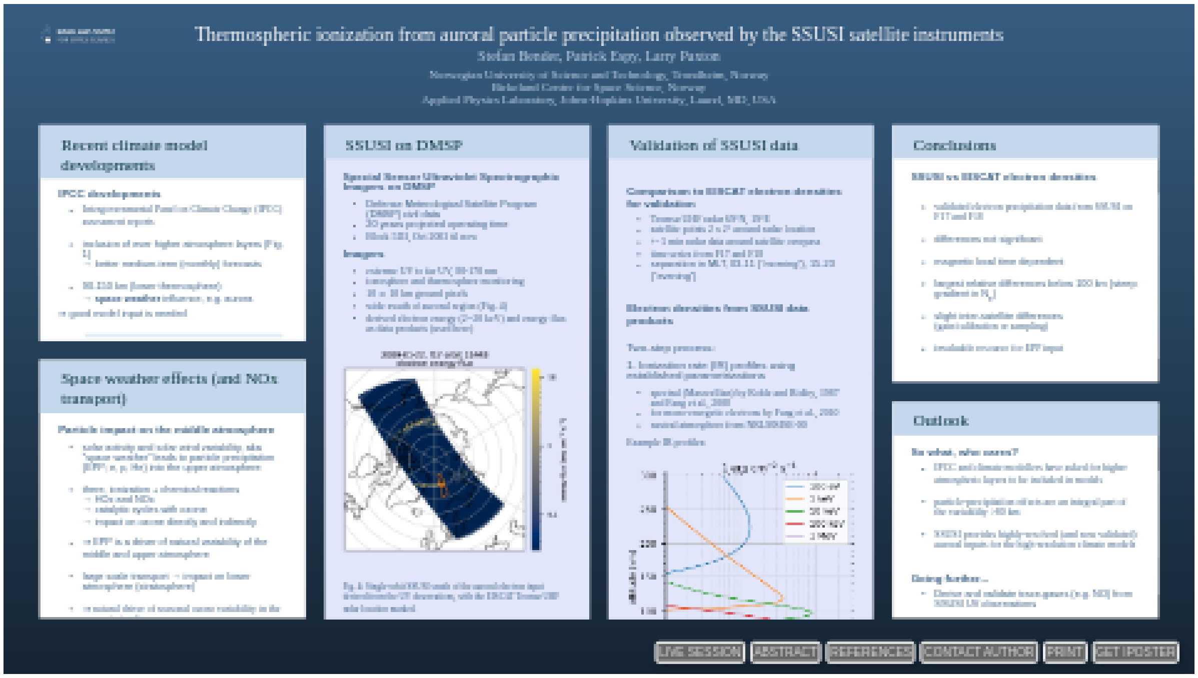
Thermospheric ionization from auroral particle precipitation observed by the SSUSI satellite instruments



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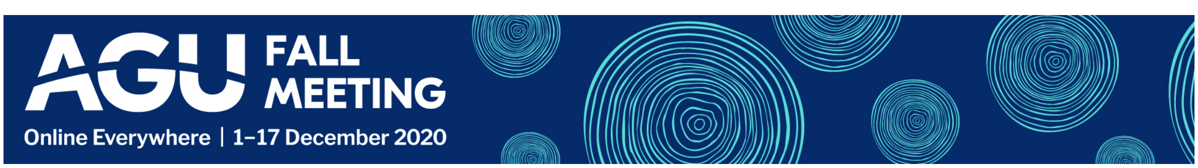

RECENT CLIMATE MODEL DEVELOPMENTS

IPCC developments

- Intergovernmental Panel on Climate Change (IPCC) assessment reports

- inclusion of ever higher atmosphere layers (Fig. 1)
  → better medium-term (monthly) forecasts

- 90-150 km (lower thermosphere)
  → **space weather** influence, e.g. aurora

⇒ good model input is needed

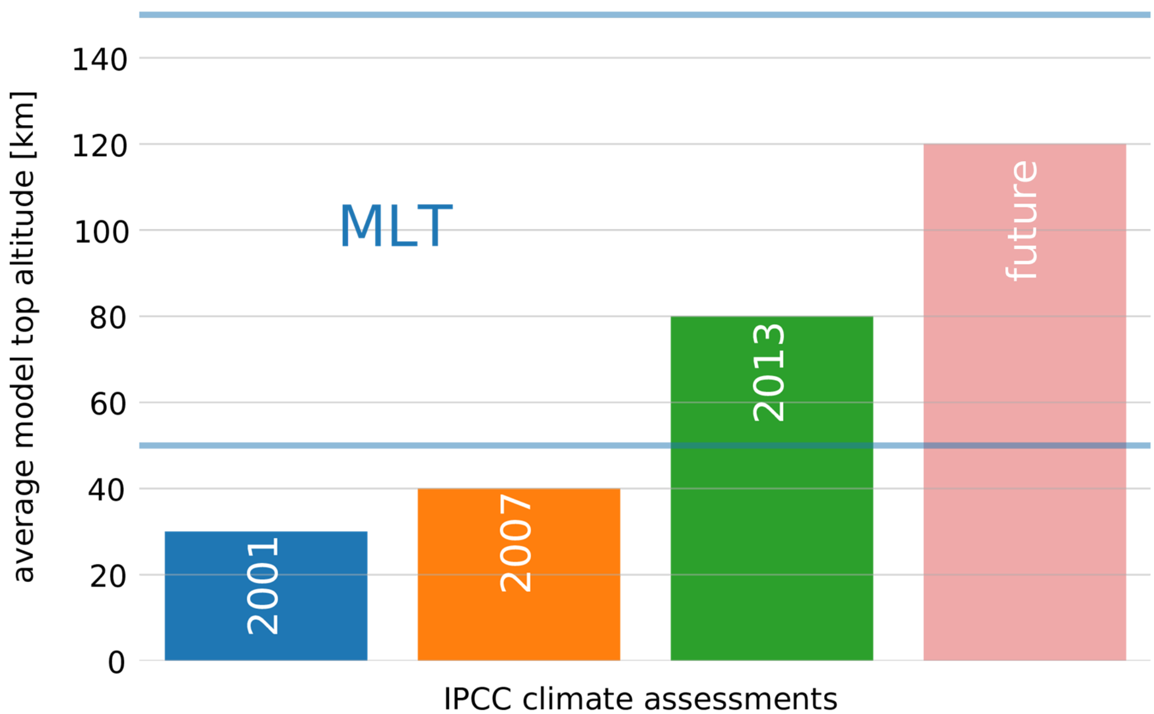

Fig. 1: Development of model top altitudes in the latest IPCC assessment reports.

SPACE WEATHER EFFECTS (AND NOX TRANSPORT)

Particle impact on the middle atmosphere

- solar activity and solar wind variability, aka "space weather" leads to particle precipitation (EPP; e, p, He) into the upper atmosphere

- there, ionization + chemical reactions
  → HOx and NOx
  → catalytic cycles with ozone
  → impact on ozone directly and indirectly

- ⇒ EPP is a driver of natural variability of the middle and upper atmosphere

- large scale transport → impact on lower atmosphere (stratosphere)

- ⇒ natural driver of seasonal ozone variability in the upper stratosphere

- influence on surface climate suspected

⇒ so far model input still lacking

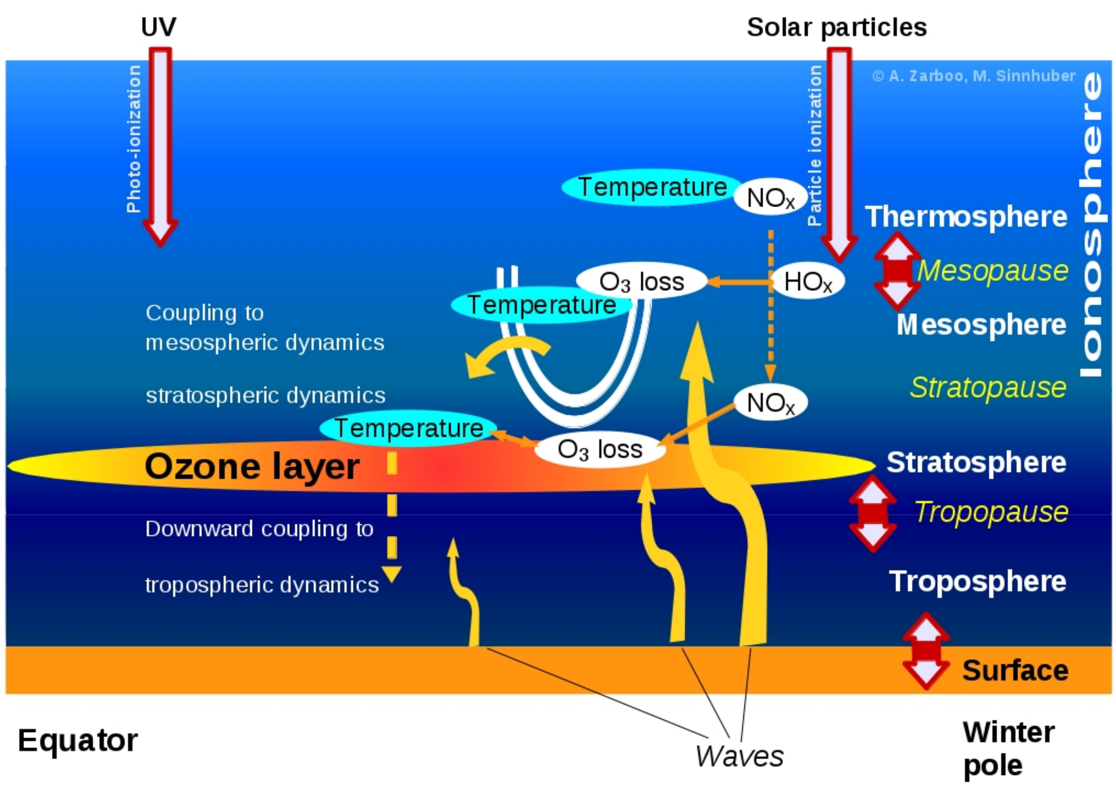

Fig. 2: Porcesses in the middle and upper atmosphere driven by solar particle input (right hand side).

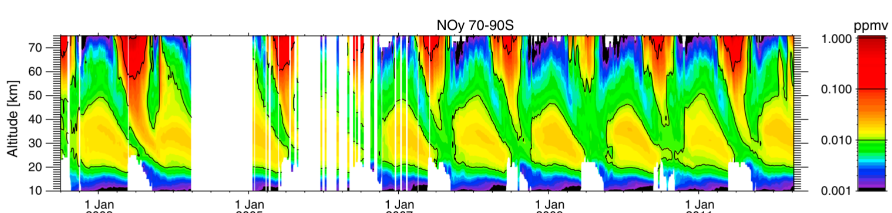

Fig. 3: Annual NOy descent in the SH polar region observed from satellite (MIPAS).

State of the art climate model input

(e.g. Matthes et al., 2017)

- POES/GOES-derived input data
  (AIMOS; Wissing et al., 2009, van de Kamp 2016, 2018)
  - in-situ at satellite altitude
  - needs heavy interpolation in latitude and longitude

- Satellite trace-gas data driven input at upper model boundaries (Funke et al., 2016)
  - only implicit connection to EPP

⇒ direct particle input on a fine spatial scale with dense observations so far lacking

SSUSI ON DMSP

Special Sensor Ultraviolet Spectrographic Imagers on DMSP

- Defense Meterological Satellite Program (DMSP) civil data
- 20 years projected operating time
- Block 5D3, Oct 2003 til now

Imagers

- exterme UV to far UV, 80-170 nm
- ionosphere and thermosphere monitoring
- 10 × 10 km ground pixels
- wide swath of auroral region (Fig. 4)
- derived electron energy (2--20 keV) and energy flux as data products (used here)

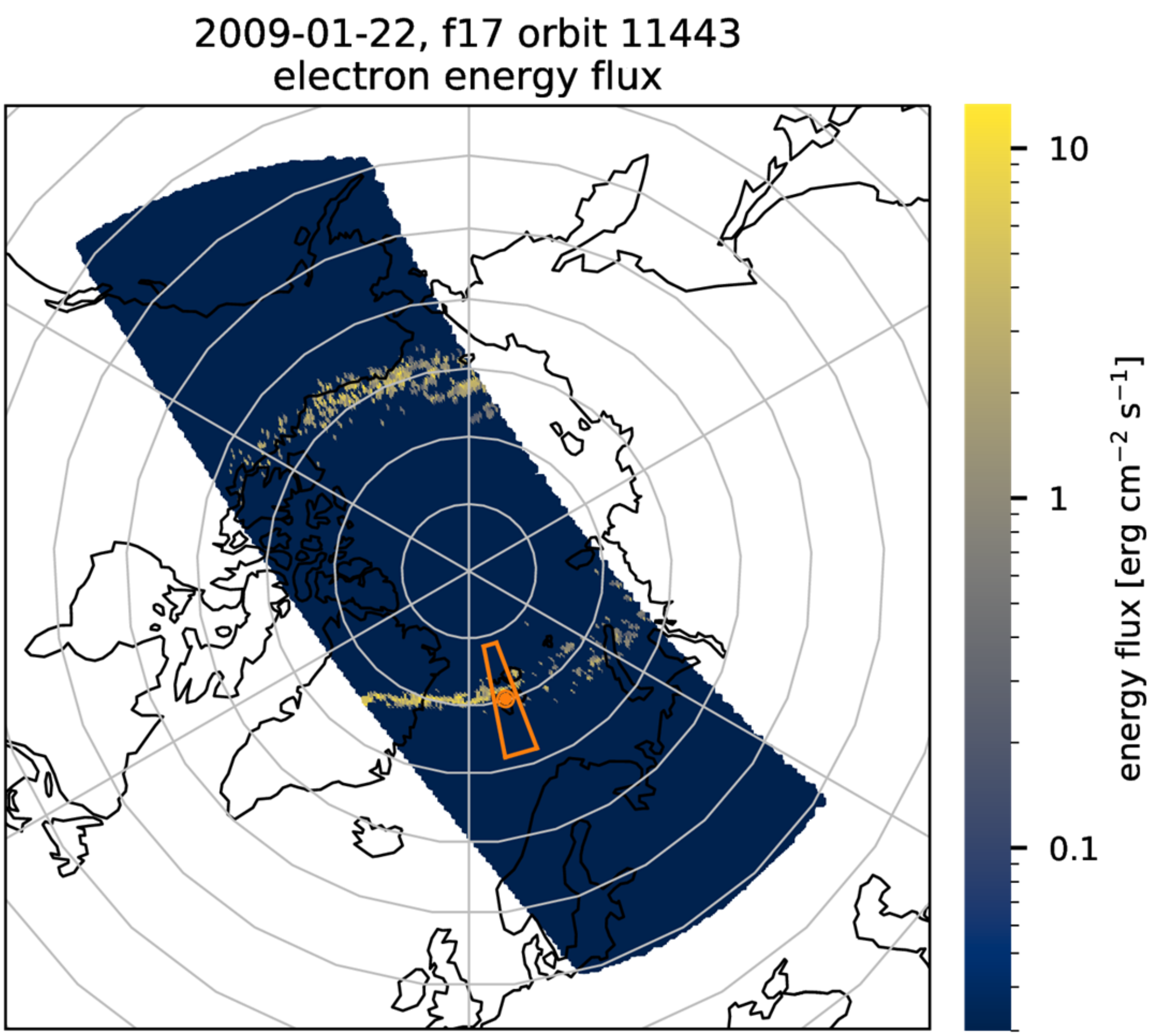

Fig. 4: Single-orbit SSUSI swath of the auroral electron input derived from the UV observations in the Northern polar region. The EISCAT Tromsø UHF radar location is indicated by the orange dot.

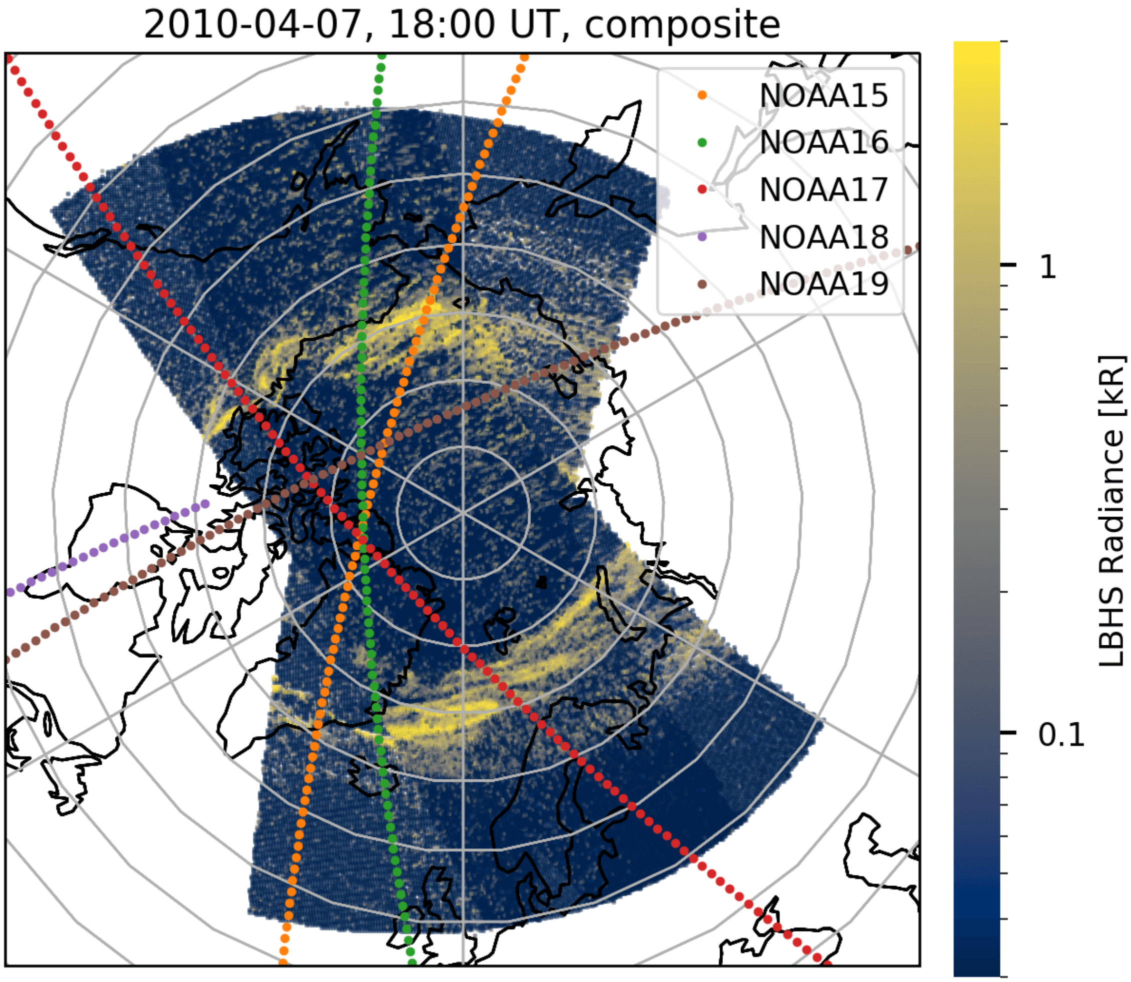

Fig. 5: Composite image from three satellites, within a 2h interval. showing the structure of the UV emissions. The POES satellite tracks (with in-situ particle observations at ~850 km) are indicated by the dotted lines.

SSUSI provides:

- High-resolution data in time [✓] and space [✓]
- of an extended area [✓] of auroral emissions [✓]
- direct observation of atmospheric effects [✓]

⇒ perfect for high-resolution models

...but how good is it?

⟶ Validate against other measurements, here ground-based by EISCAT

VALIDATION OF SSUSI DATA

Comparison to EISCAT electron densities for validation

- Tromsø UHF radar 69°N, 19°E
- satellite points 2 x 2° around radar location
- +- 5 min radar data around satellite overpass
- time series from F17 and F18
- separation in MLT, 03-11 ("morning"), 15-23 ("evening")

Electron densities from SSUSI data products

Two-step process:

1. Ionization rate (IR) profiles using established parametrizations

- spectral (Maxwellian) by Roble and Ridley, 1987 and Fang et al., 2008
- for mono-energetic electrons by Fang et al., 2010
- neutral atmosphere from NRLMSISE-00

Example IR profiles:

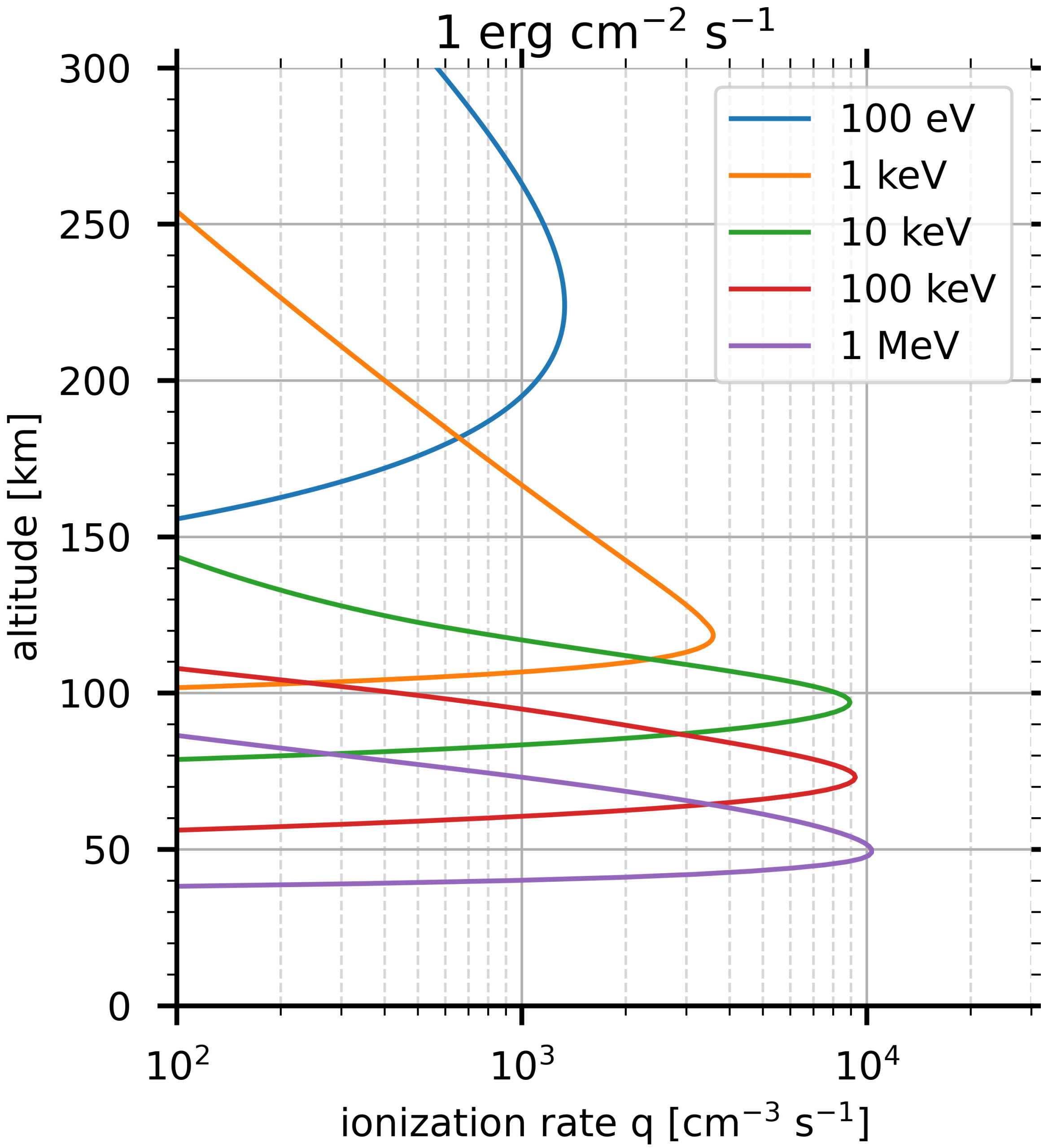

Fig. 6: Atmospheric ionization rate profiles from electrons with different energies, normalized to the same integrated energy flux

2. Conversion of IR to electron densities

- steady-state assumption, between IR q and electron density n_e (changes):

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

- recombination rates α from
  Vickrey et al., 1982 or Gledhill et al., 1986:

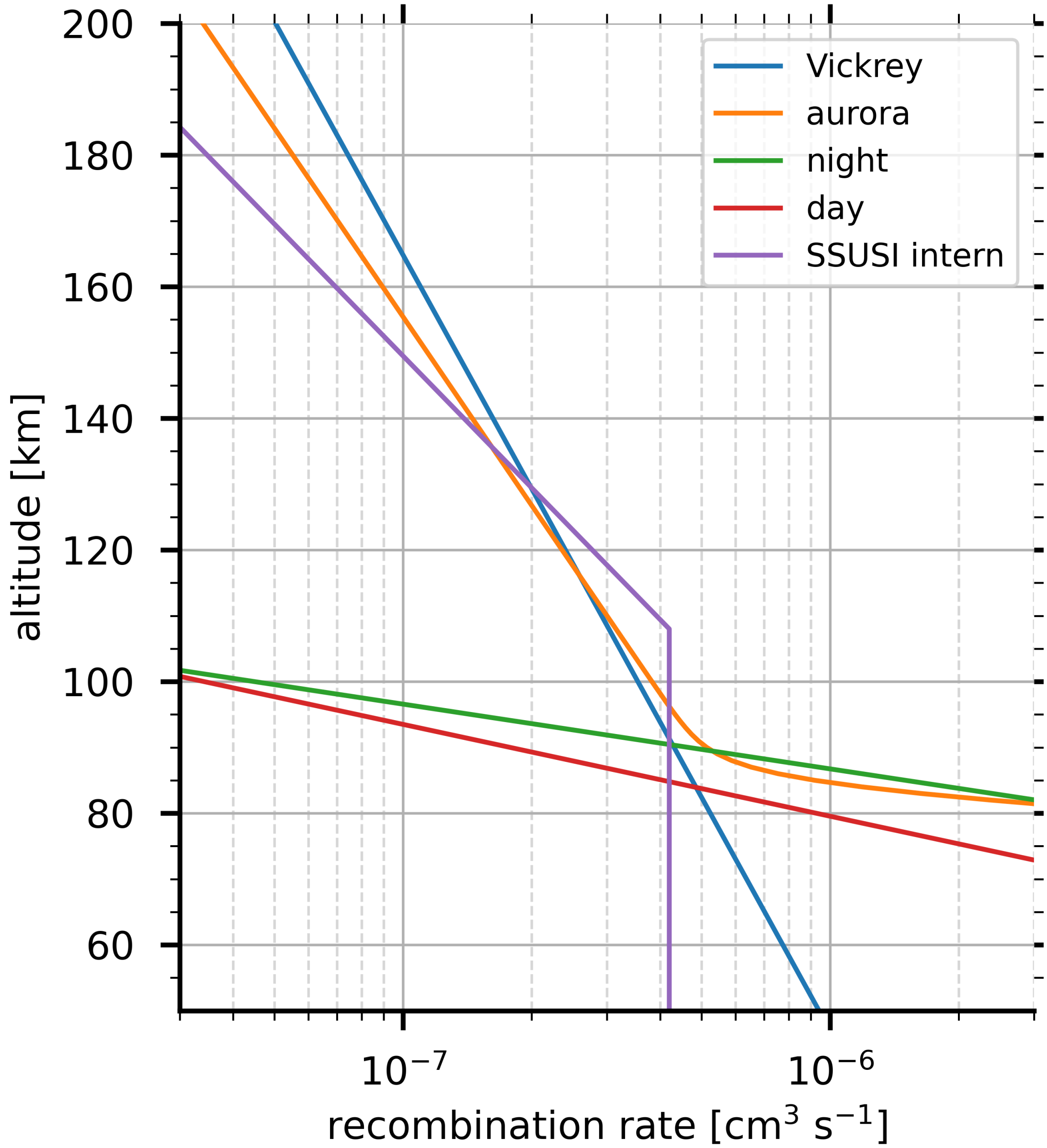

Fig. 7: Recombination rate profiles from different parametrizations, used to convert ionization rates to electron densities

Example comparison

- SSUSI on DMSP F17
- 2--20 keV electrons

Available data

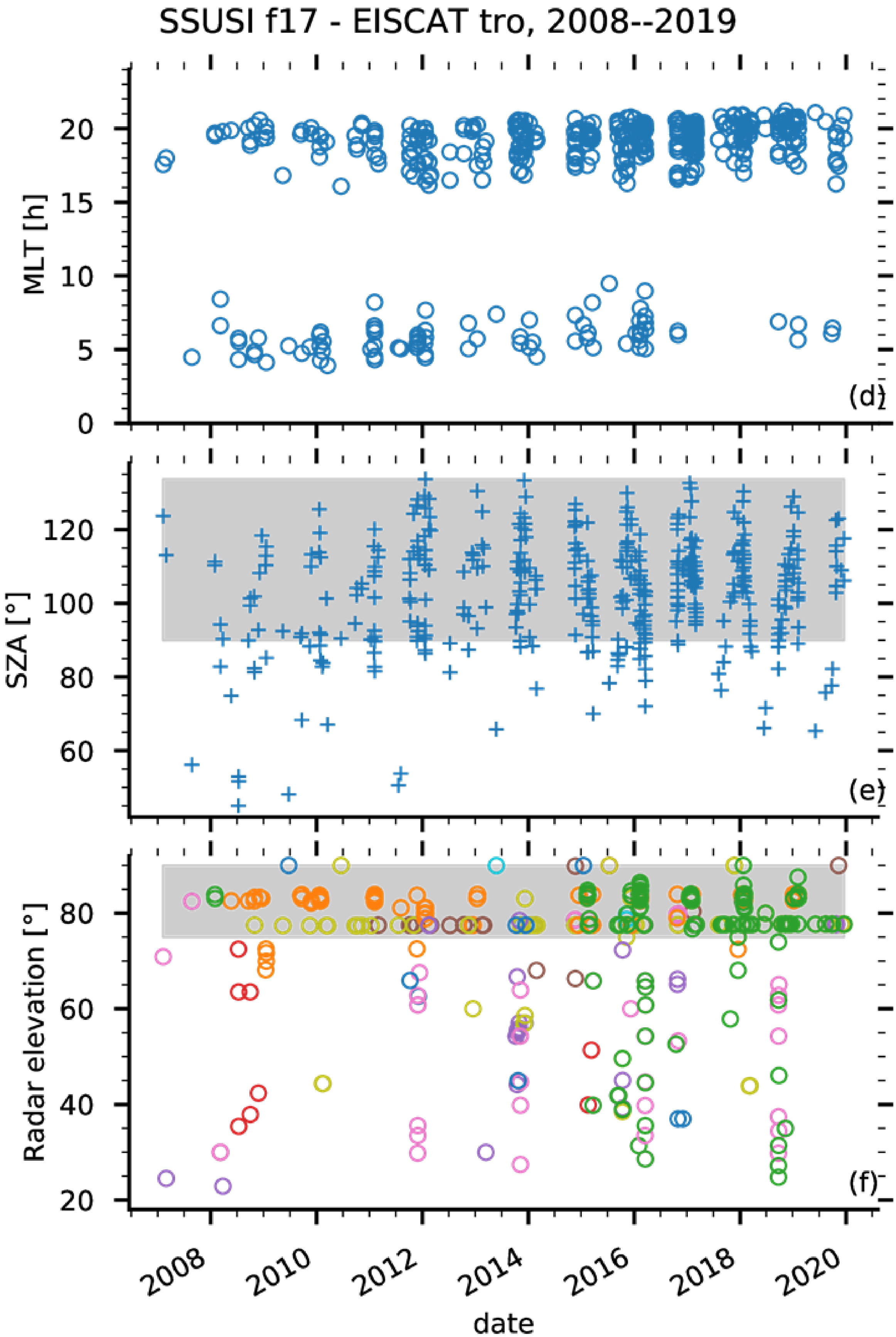

Fig. 8: Coincident data between SSUSI on F17 and the EISCAT Tromsø UHF radar.

Electron density profiles

- MLT 03 -- 11
- SZA > 90°
- radar elevation angle > 75°

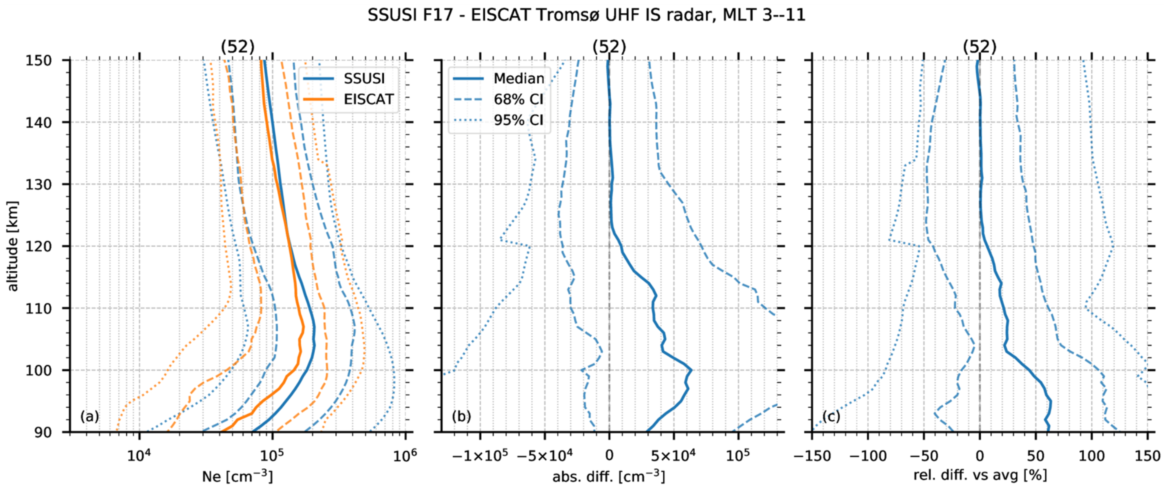

Fig. 9: Electron density profiles (a) of SSUSI (blue) and EISCAT (orange), absolute differences (b), and relative differences (c) vs altitude.

CONCLUSIONS

SSUSI vs EISCAT electron densities

- validated electron precipitation data from SSUSI on F17 and F18
- differences not significant
- magnetic local time dependent
- largest relative differences below 100 km (steep gradient in N_e)
- slight inter-satellite differences
  (gain/calibration or sampling)
- invaluable resource for EPP input

OUTLOOK

So what, who cares?

- IPCC and climate modellers have asked for higher atmospheric layers to be included in models
- particle-precipitation effects are an integral part of the variablilty >80 km
- SSUSI provides highly-resolved (and now validated) auroral inputs for the high-resolution climate models

Going further...

- Derive and validate trace-gases (e.g. NO) from SSUSI UV observations
- Statistical analysis (modelling)
- Particle input data for climate modelling
- Evaluate feedback on atmospheric chemistry and dynamics

ABSTRACT

Solar, auroral, and radiation belt electrons enter the atmosphere at polar regions leading to ionization and affecting its chemistry.
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 the electron energy and flux measurements from the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) instruments on board the Defense Meteorological Satellite Program (DMSP) satellites.
This formation of now three operating satellites observes the auroral zone in the UV from which electron energies and fluxes are inferred in the range from 2 keV to 20 keV.
We use these observed electron energies and fluxes to calculate ionization rates and electron densities in the upper mesosphere and lower thermosphere (≈ 80–200 km).
We present our validation study of the SSUSI-derived electron densities to those measured by the ground-based EISCAT radar stations.
We find that with the current standard parametrizations, the SSUSI-derived auroral electron densities (90–120 km) are 2-3 times larger than the ground-based measured ones.
It is still under investigation whether these differences are due to mis-matched collocations in space and time, EISCAT mode characteristics,
or if they are caused by inaccurately modelling the incoming energy and flux from the UV measurements as well as the ionization and recombination processes with the parametrizations used.

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