Optical and Radio Remote Sensing at Svalbard for Studying Vertical Coupling Processes in the Atmosphere from 80 to 1000 km

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Purpose of this study

Vertical coupling process in the arctic atmosphere

- The middle and upper atmosphere in polar regions are influenced by processes from both below and above
  - Solar forcing: X-ray and EUV, charged particle precipitations, and electric field
  - Lower atmosphere forcing: atmospheric waves, SSW, and global meridional circulation

- Vertical coupling processes are fundamentally important for atmospheric science.

- **The motivations of this study:**
  - To gain a comprehensive understanding of the magnetosphere–ionosphere–thermosphere coupling processes from 80 km to 1,000 km in the polar regions
  - To extend the coverage of space weather forecasting up to the exosphere

- Tracers for our optical remote sensing
  - OH: upper mesosphere (80 km - 90 km)
  - N_2^+: lower thermosphere (100 km -150 km) , only in aurora
  - He: upper thermosphere — exosphere (300 km - 1,000 km)

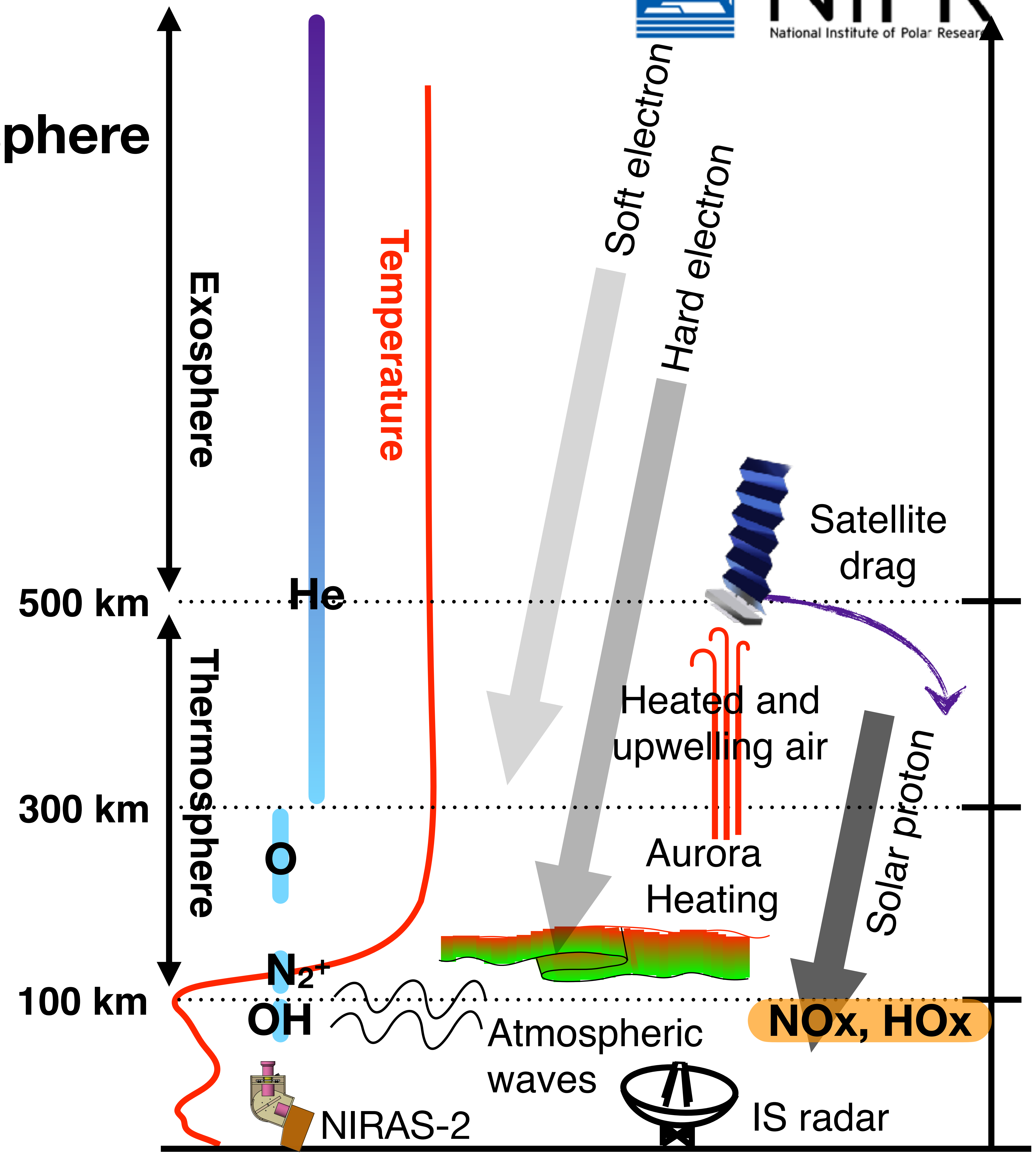


Fig. A schematic illustration showing MIT coupling

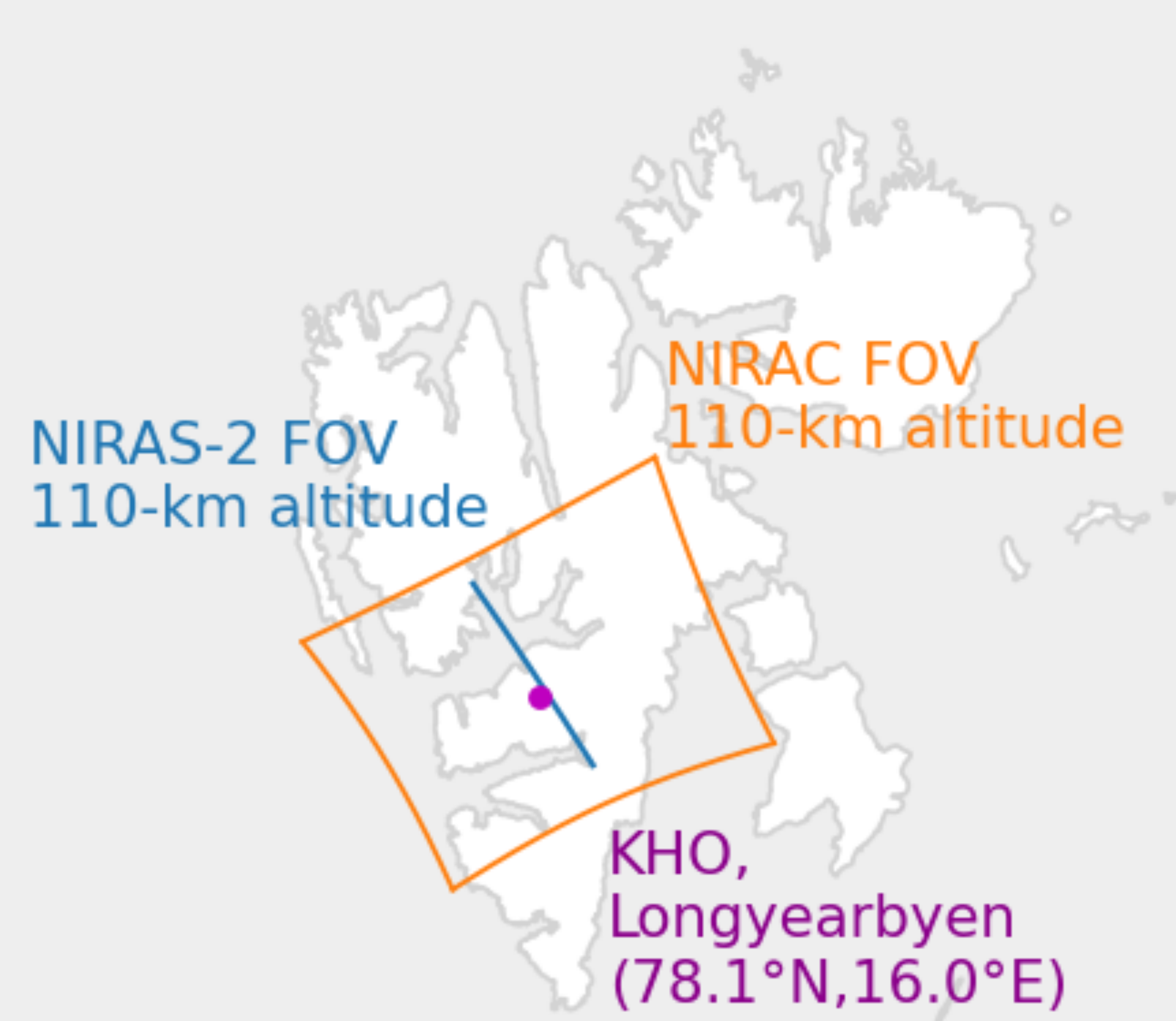
Observations

Longyearbyen, Svalbard

- We have installed new instruments at the KHO, Longyearbyen in November 2022 (Nishiyama et al., 2024).
  - **N**ear **I**nfra**R**ed **A**urora and airglow **S**pectrograph-2 (NIRAS-2)
    - Spectrum: N_2^+ aurora, OH and He(2^3S) airglow
  - **N**ear **I**nfra**R**ed **A**urora and airglow **C**amera (NIRAC)
    - 2-D imaging: N_2^+ aurora and OH airglow

- Radar measurements in VHF
  - EISCAT Svalbard radar (ESR)
    - Electron density, electron/ion temperature, ion velocity: 80 — 500 km
    - Meridional and zonal wind with some assumptions: 100 — 120 km
  - Nippon/Norway Svalbard Meteor Radar
    - Meridional and zonal wind: 80 km — 100 km
    - https://radars.uit.no/NSMR-index.html

- At Veksthuset, Ny-Ålesund
  - RiS ID 12514: LF radio wave measurement
  - RiS ID 12387: GNSS and next generation SBAS receivers
  - A new spectrometer for He(2^3S) and OH airglow is under consideration



KHO
Magnetic latitude: 75.4° (*L*-value: 15.8)
Magnetic longitude: 110.7° (MLT = LT + 1.5 = UT + 2.5)

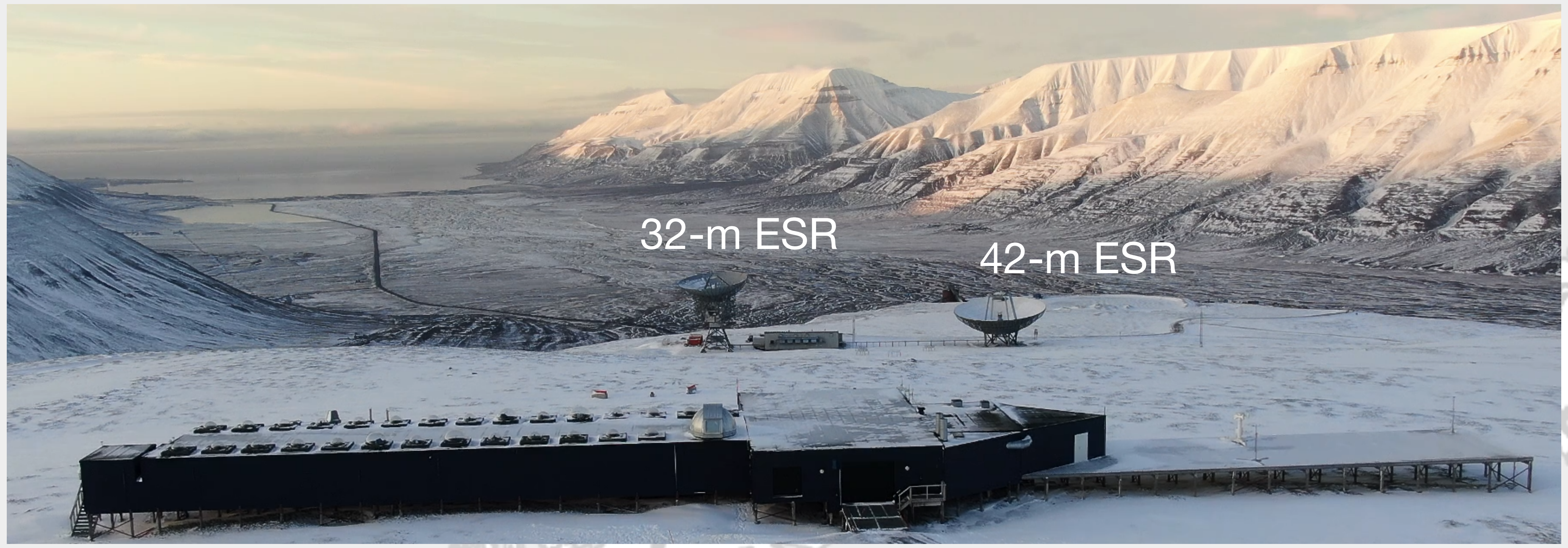


Fig. A bird's eye view of the Kjell Henriksen Observatory. (Herlingshaw et al., 2024)

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Instruments

Dataset in this study

- Dataset: NIRAS-2 aurora fine mode

Center/Range	FWHM (30/60-μm slit)	Target: Aurora and Airglow	
1105 nm/1060-1130	0.22/0.44 nm	N_2^+ M(0,0)	OH(5,2), He(2^3S)

- OH rotational temperature: errors less than 10 K, with 10 minutes integration
- N_2^+ rotational temperature can be also estimated
- “Pure” He(2^3S) spectra is obtained from subtraction of Q-lines in OH(5,2) described in Nishiyama et al., (2025)

He(2^3S) three lines ($2^3P_{0,1,2}$ → 2^3S_1) blended with OH(5,2) Q_2(1) and Q_1(1)

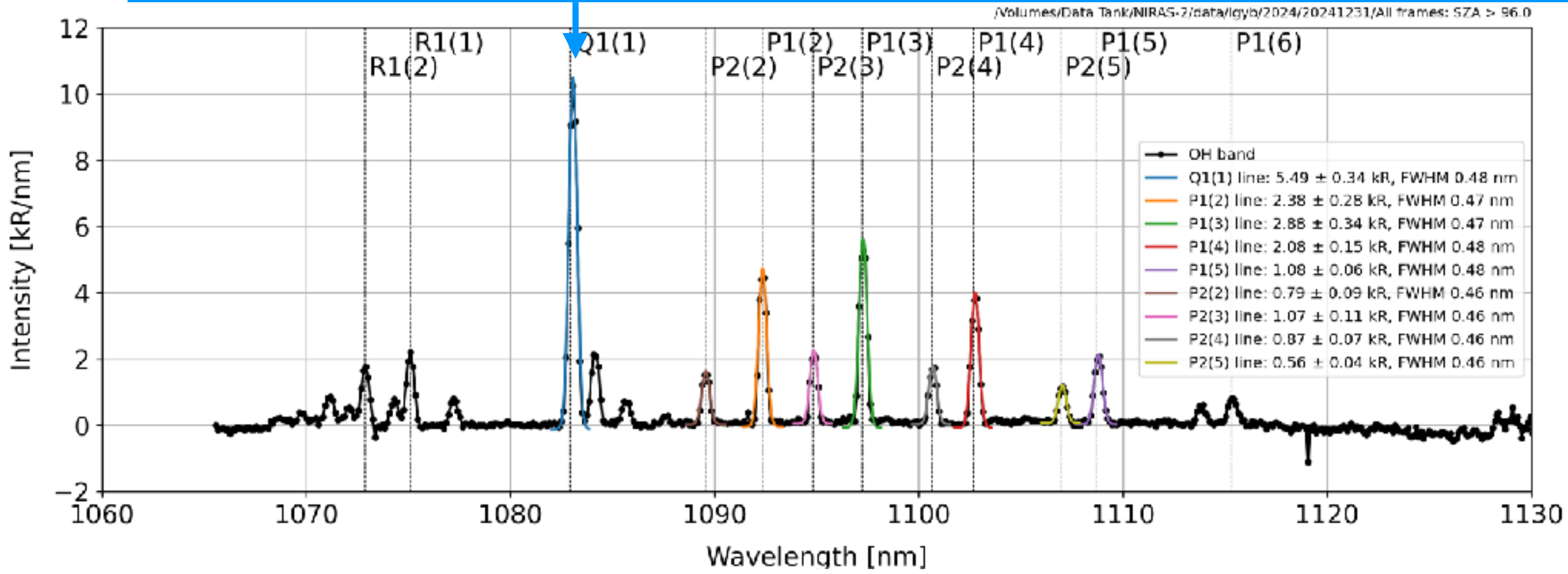
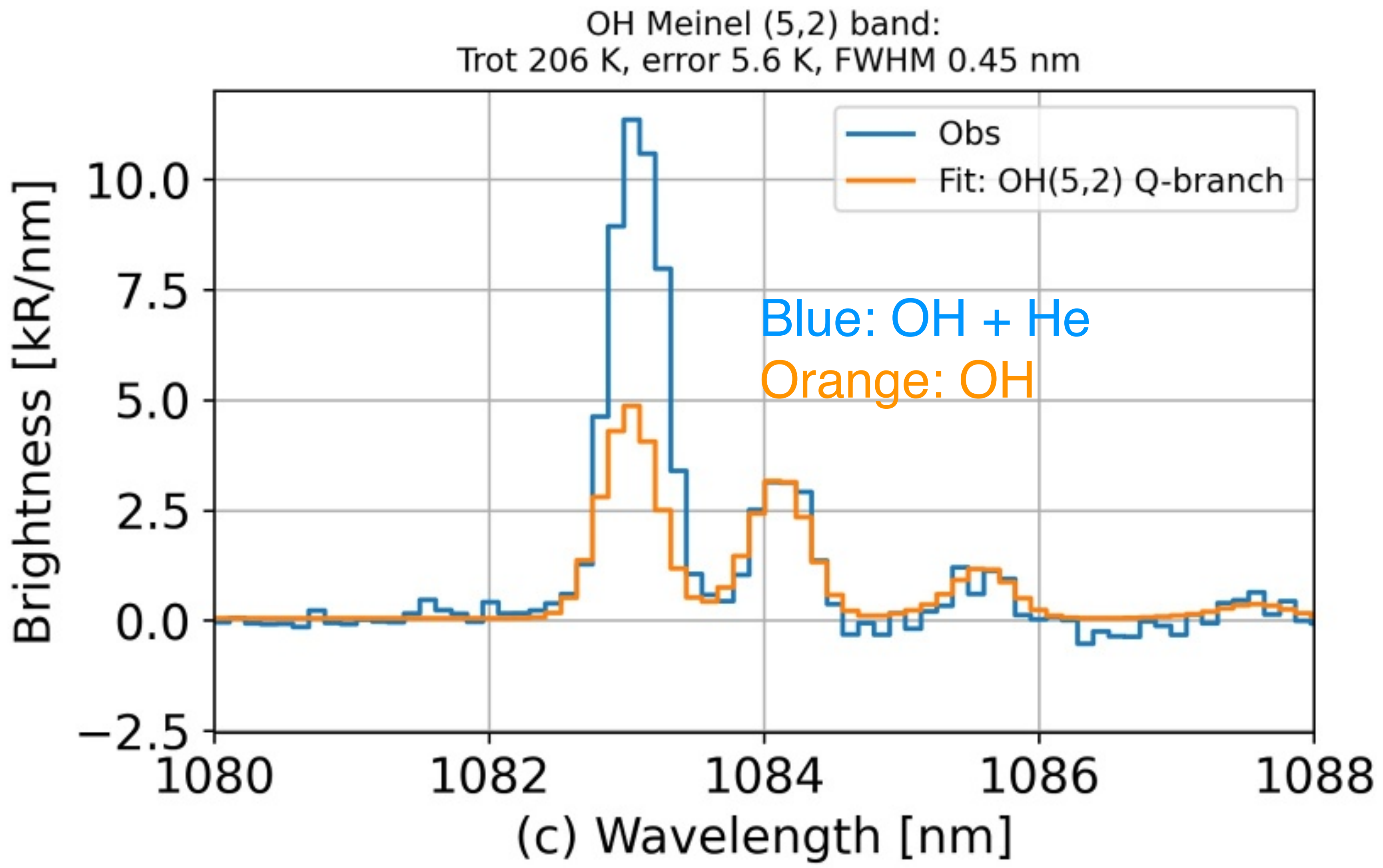


Fig. An example of spectrum by NIRAS-2 measurements in Mode-1



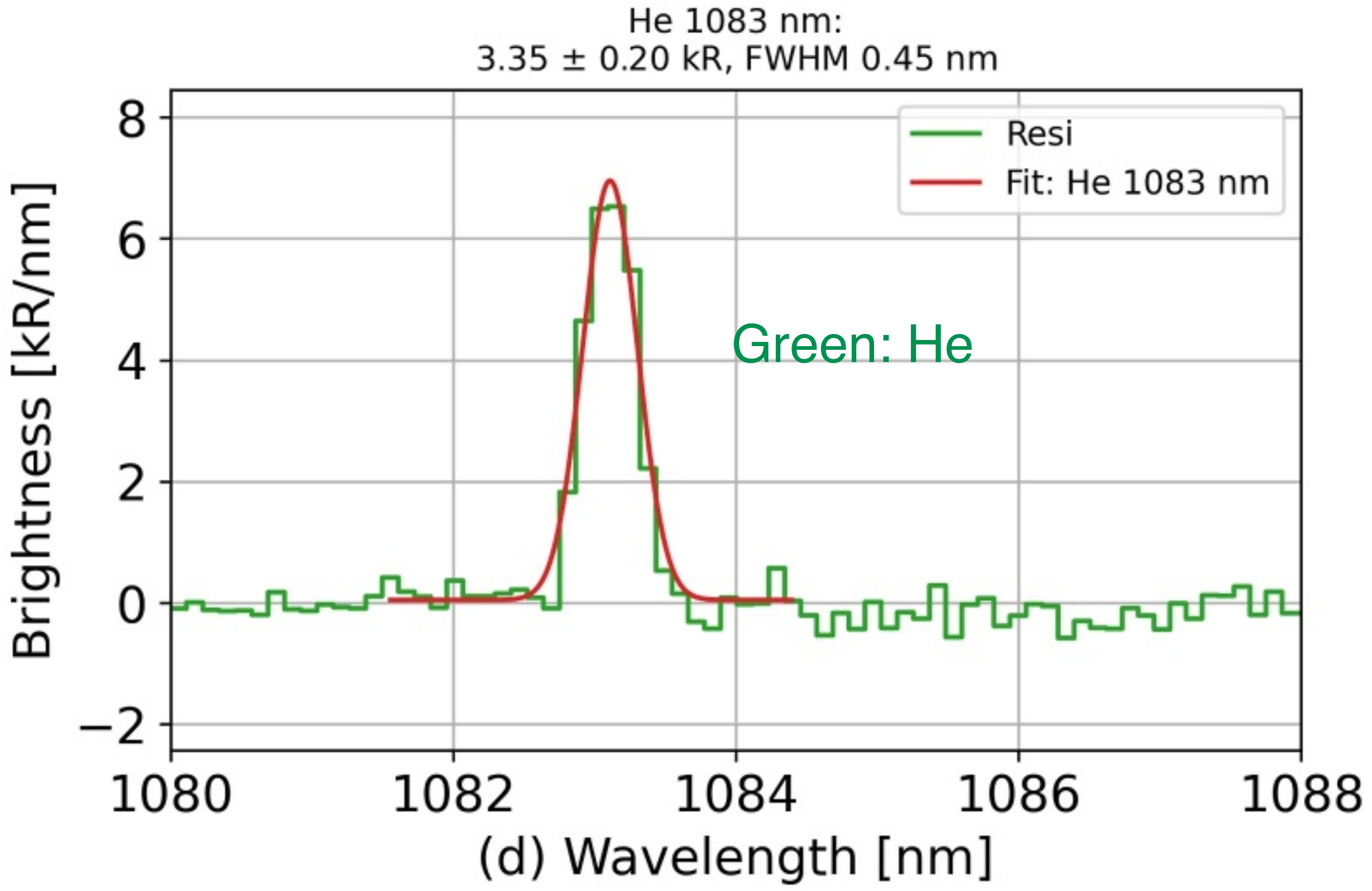


Fig. (Top) Synthetic spectrum of Q-branch lines in OH(5,2) band as a function of Trot (Bottom) Pure He(2^3S) spectrum obtained by subtracting the OH spectrum from the observed one.

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He(2^3S): tracer of upper thermosphere

Why Upper Thermosphere is important…?

- He behaves as a dynamical tracer in the uppermost region of the global atmospheric circulation.
  - Seasonal variations known as "He winter bulge"

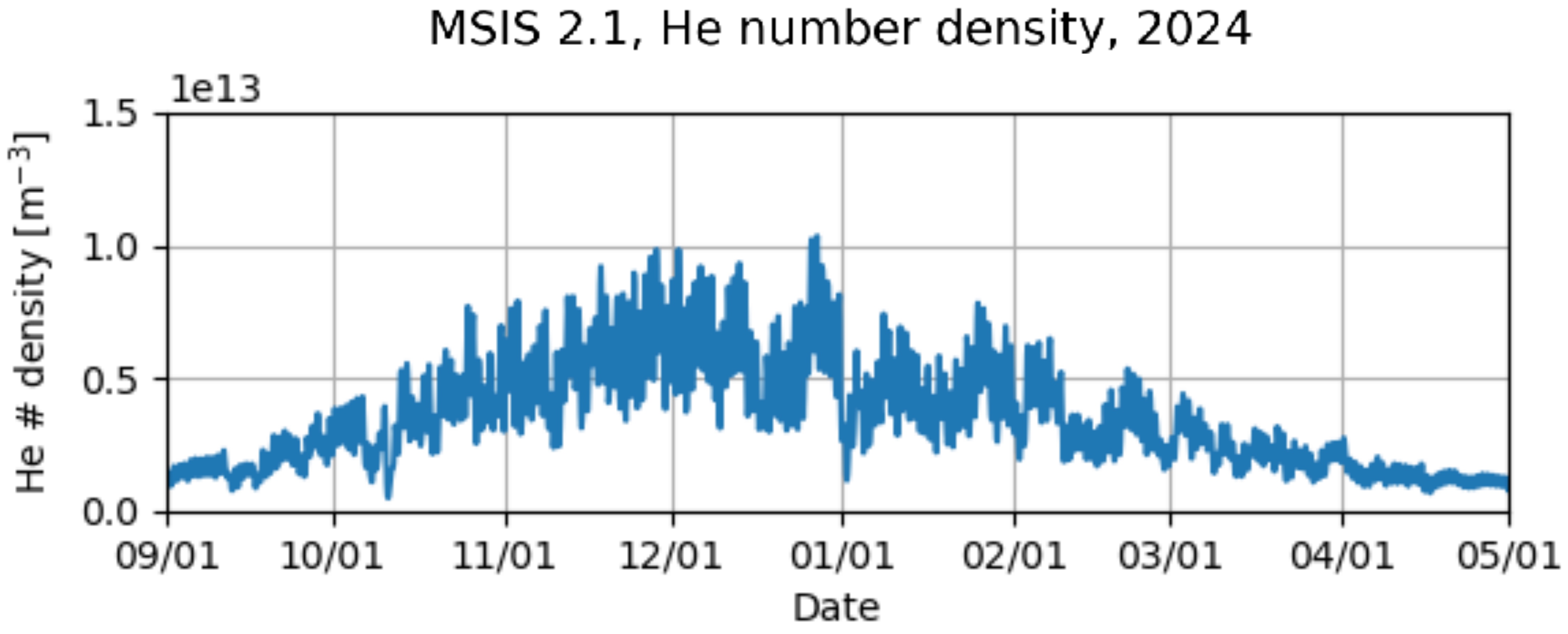


Fig. MSIS 2.1 calculation for time variations in He density at Longyearbyen from Sep 1 2024 to May 1 2025

  - Interhemispheric transport in the upper thermosphere, flowing from the summer hemisphere toward the winter hemisphere, plays a major role in producing the bulge (e.g., Liu et al., 2014; Sutton, 2016)

- Upper thermosphere is the critical region for low earth orbit satellites operations (*Hapgood et al*., 2022; *Zhang et al*., 2022).
  - 38 Starlink satellites failed to enter orbit shortly after launch in 2022, due to atmospheric heating associated with geomagnetic "storm"

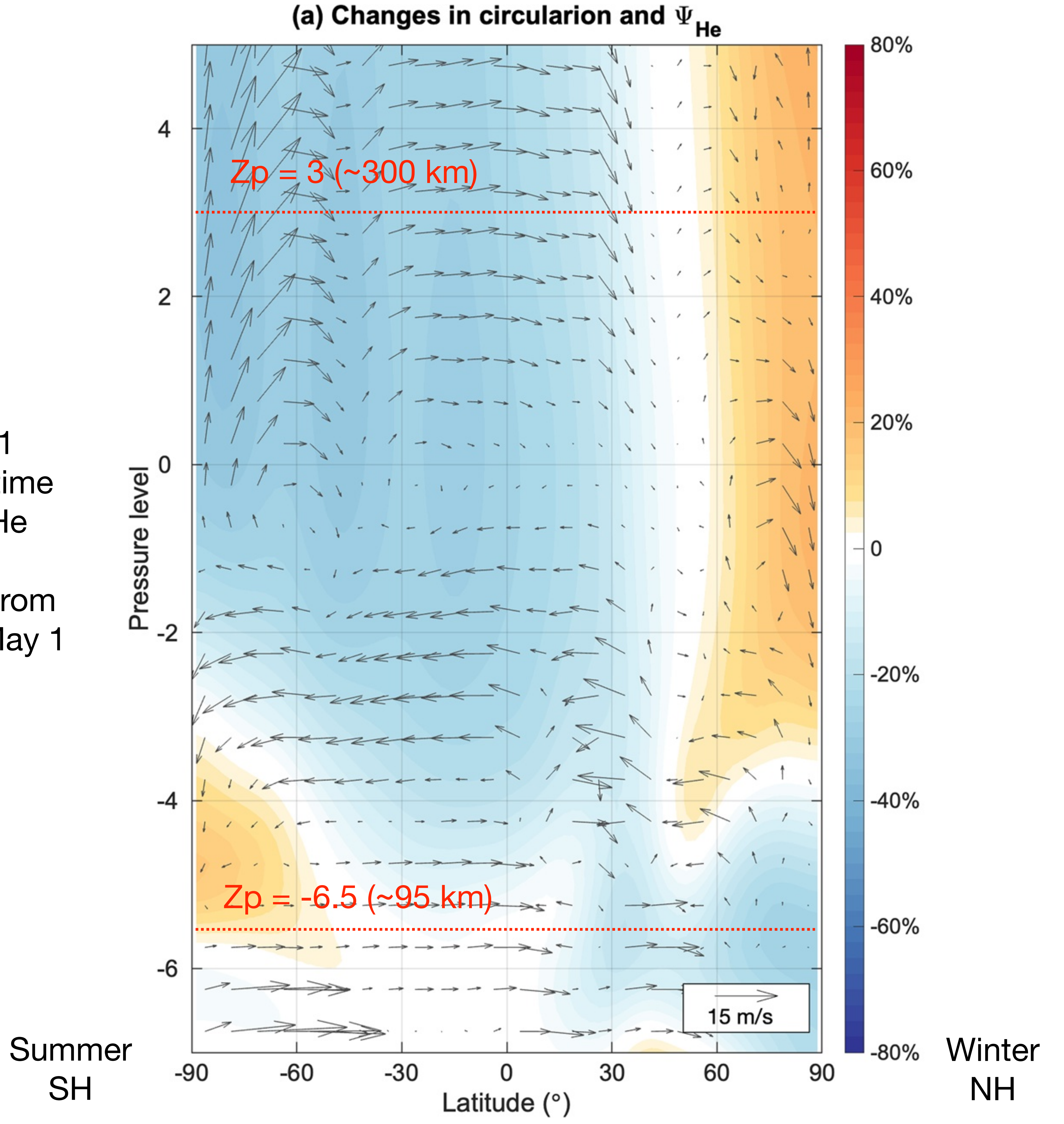
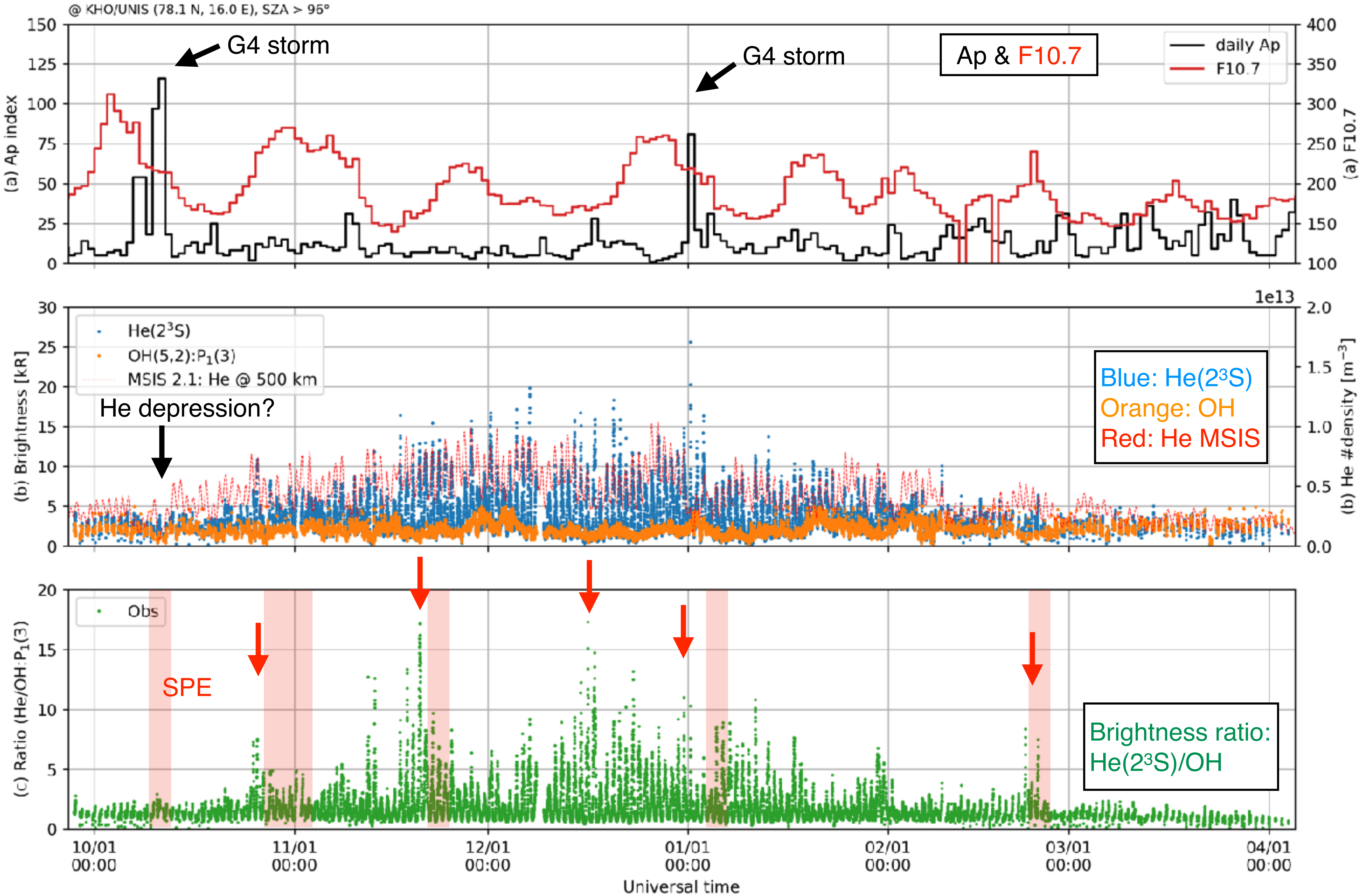


Fig. The latitude-pressure level distribution of the percentage change of mass mixing ratio of helium ΨHe (color shading) as well as the difference of thermospheric circulation (black arrows) (Ren et al., 2023)

Results

Winter bulge: Sep. 2024 - Apr. 2025

SPE list:
https://www.ngdc.noaa.gov/stp/space-weather/interplanetary-data/solar-proton-events/SEP%20page%20code.html

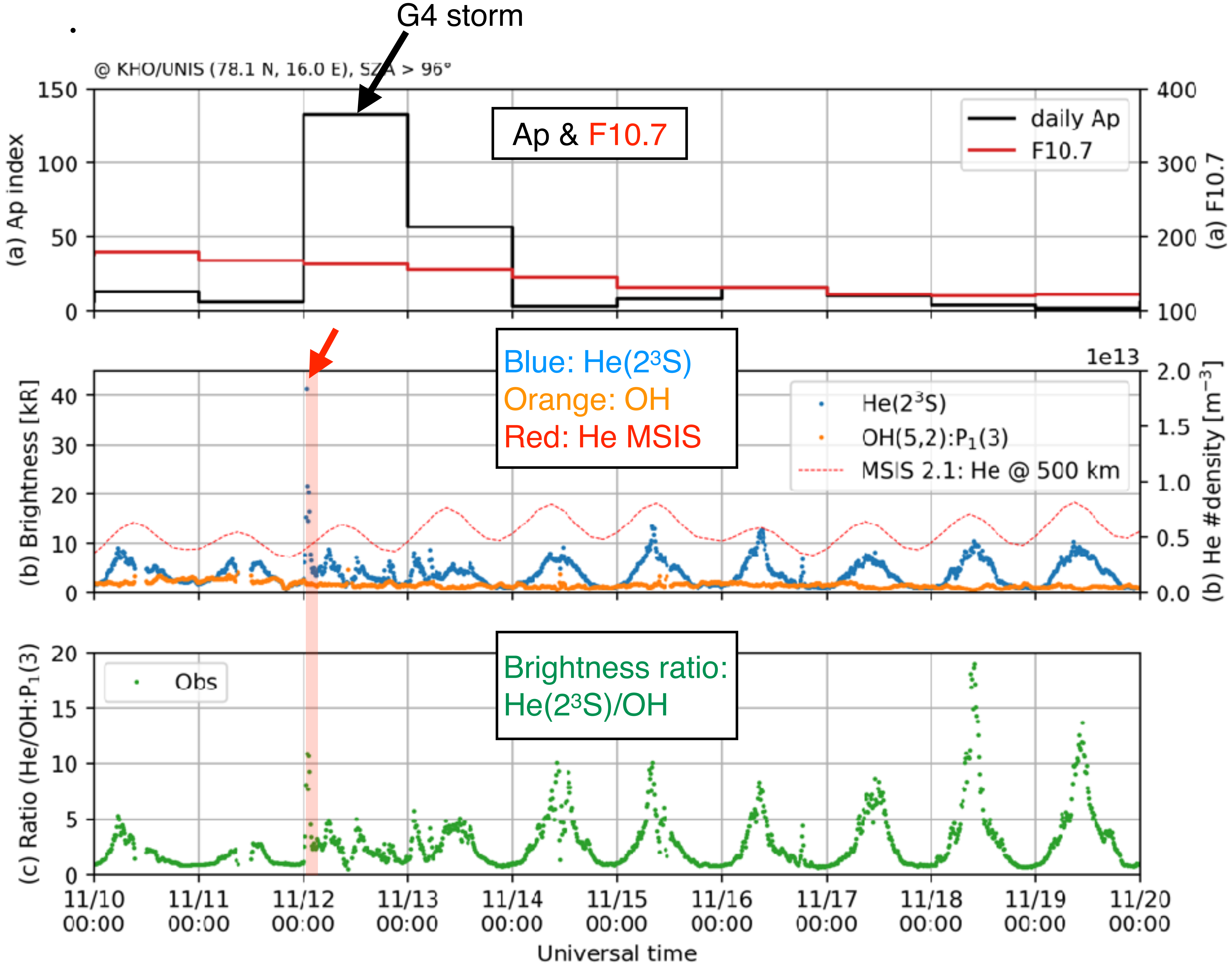


- He(2^3S) brightness clearly shows winter bulge (Geach & Kaifler, 2025)
- With large day-to-day variability related to geomagnetic activity
- Sudden increases in brightness ratio, He(2^3S)/OH, agrees well with some Solar Proton Events

Fig. (1st) Ap and F10.7 (2nd) Observed airglow brightness and helium density at 500 km calculated by MSIS 2.1 (3rd) Normalized orthohelium brightness to OH

Results

Storm in Nov. 2025



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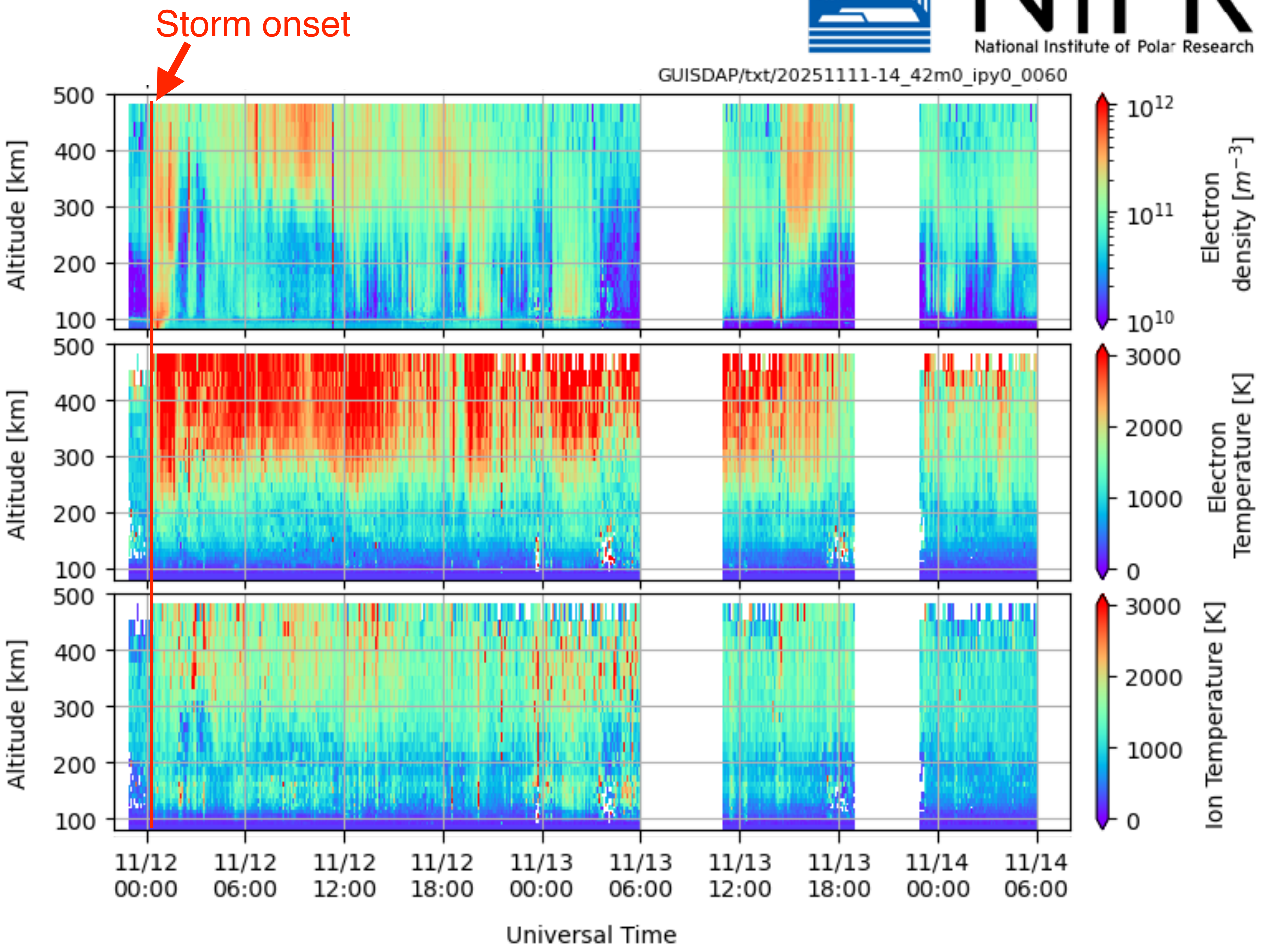

Fig. (1st) Electron denisty (2nd) electron temperature (3rd) ion temperature measured by EISCAT Svalbard Radar

- One severe storm: Nov. 2025
  - The highest Ap index during the period in this study
  - Rapid enhancement in brightness He(2^3S) exceeding 40 kR on Nov.12
    - Consistent with drastically changes in plasma parameter measured by ESR

Results

Upper mesospheric temperature

NIRAS-2: OH Rotational temp. (Synthetic spectrum fitting)
Aura/MLS: Kinetic temp. @ 82 km
Aura/MLS: Kinetic temp. @ 78 km

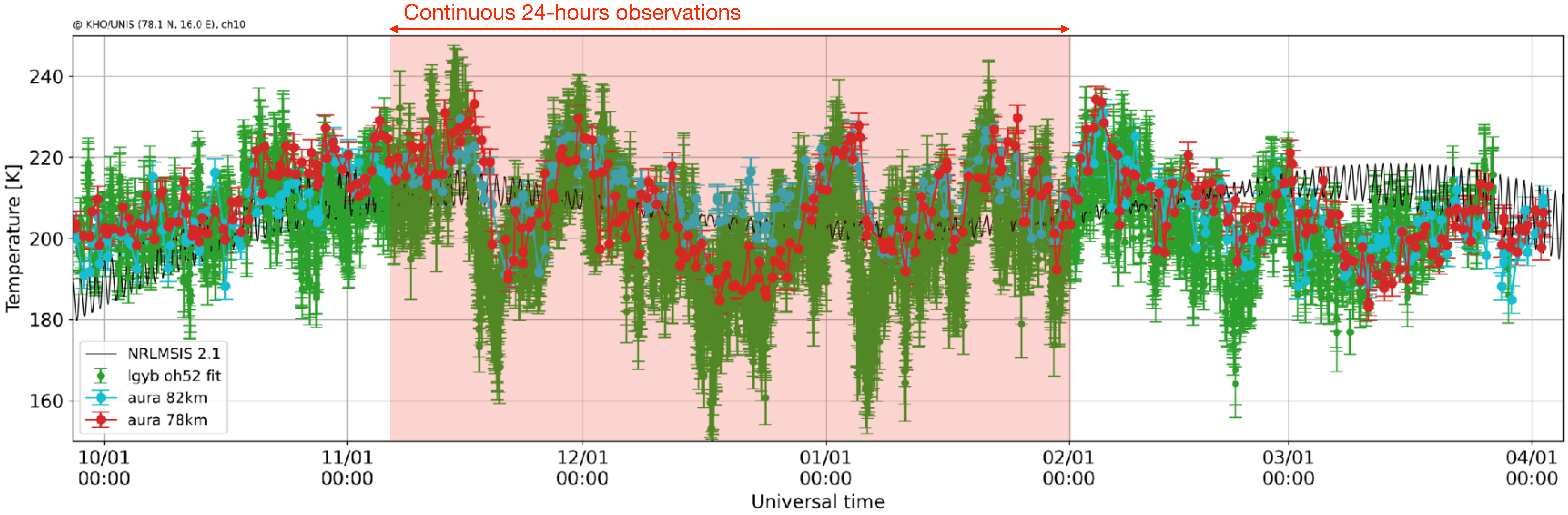

Fig. A time series of OH rotational temperature for 6-month, and Aura/MLS measurements at 78 and 82 km altitudes are also plotted for comparisons.

- Horizontal wind based on the meteor radar can be compared to temporal variations in the temperatures

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Conclusion

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  - With active and passive radio remote sensing

- Collaboration with other WGs can be proposed as follows.
  - Mesospheric and stratospheric ozone changes: increases in density of minor species such as NOx and HOx due to solar forcing, and vertical downward transport

  - Atmospheric wave connections between troposphere and middle/upper atmosphere: Tides and GWs up to 1,000 km altitudes

  - Corrections of atmospheric absorption using observed H_2O vertical profiles in the lower atmosphere

- Continuous measurements will improve our understanding of vertical coupling processes in the atmosphere.
  - Challenge to extend the lower boundary of atmospheric studies downward to the troposphere or the ground surface.