The Space Weather Timeline Viewer

Interactive exploration of Swarm observations with other datasets and models

April 12, 2024 - Copenhagen

Eelco Doornbos, KNMI
Kasper van Dam, KNMI
Mark ter Linden, S&T
Timothy Kodikara, DLR

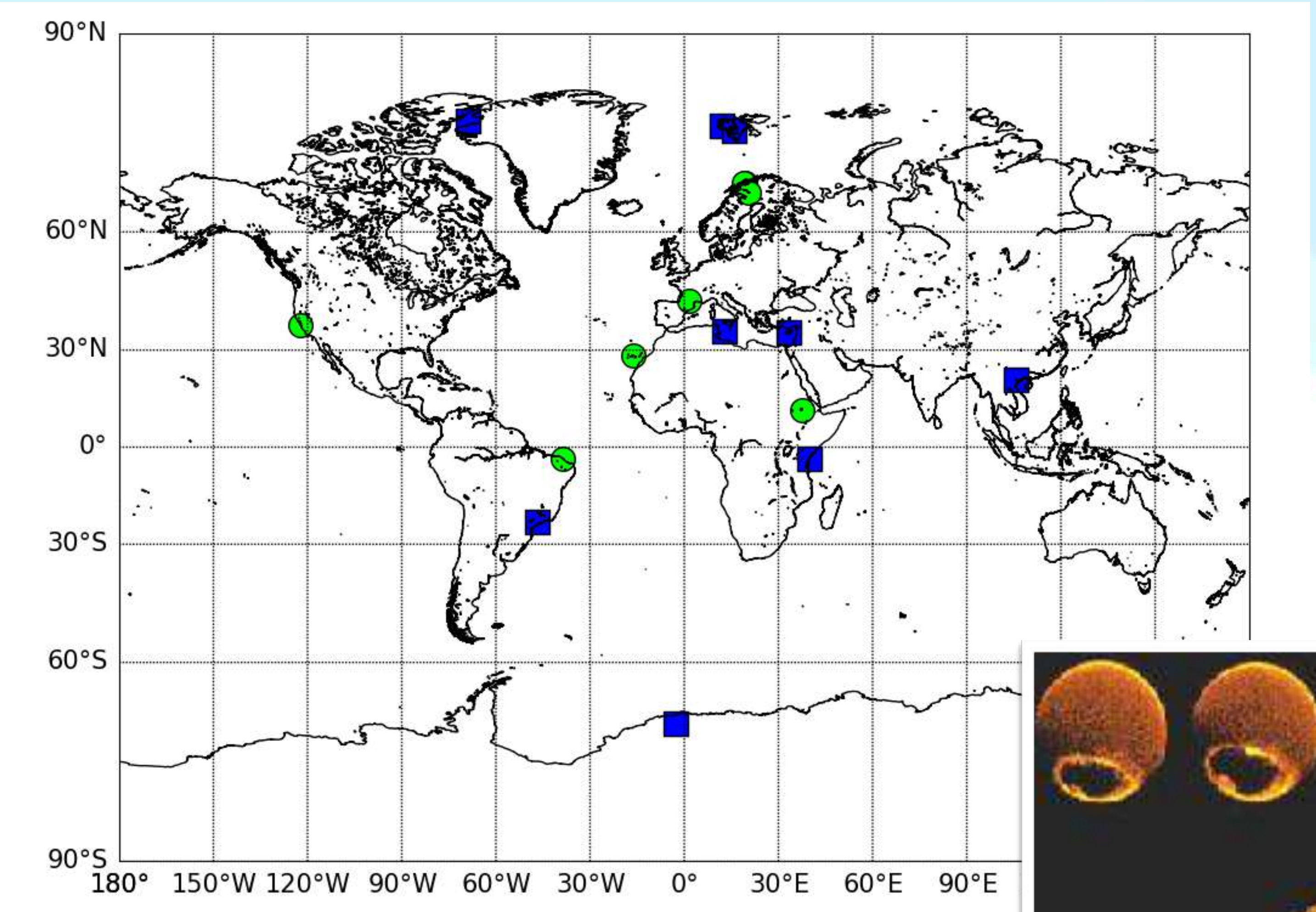
Introduction

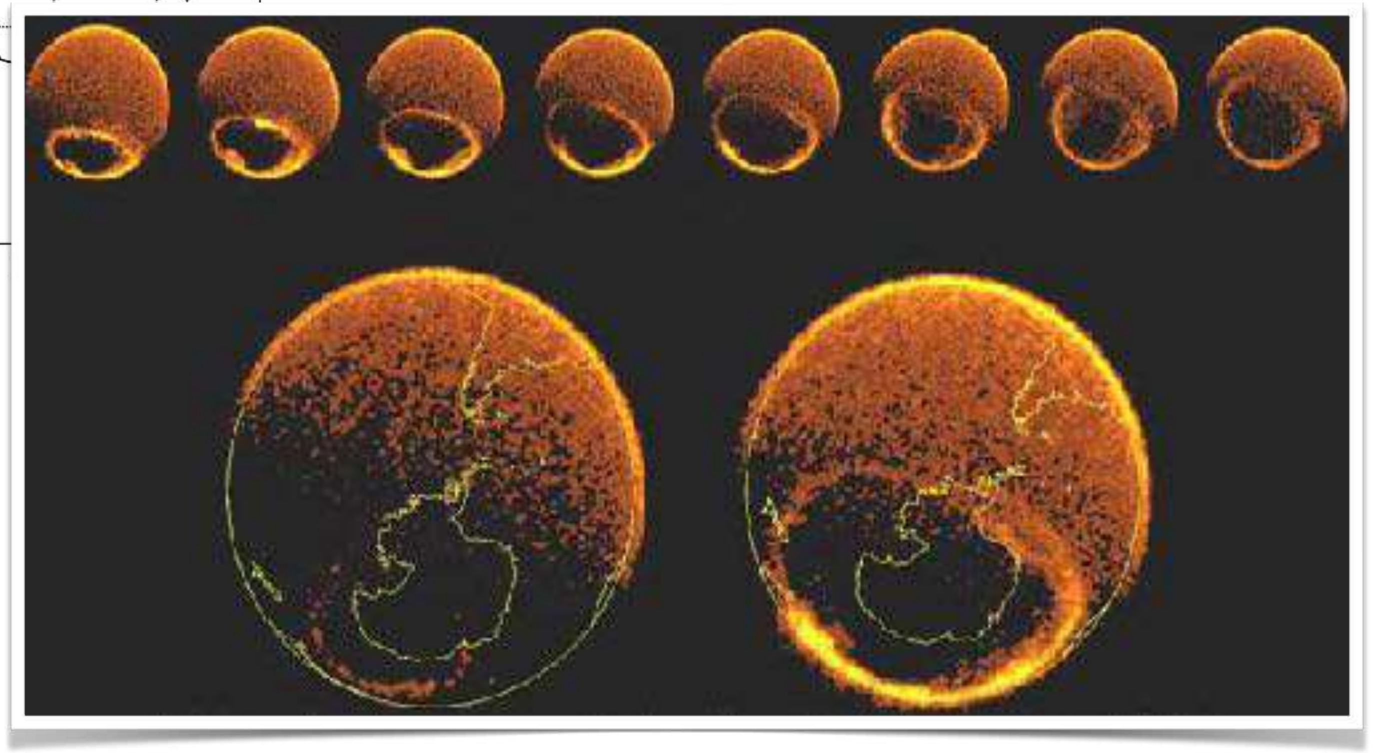
Open questions in our space weather work at KNMI

- Example 1: How can we best provide advisories to international civil aviation about GNSS scintillations?

- Example 2: What should be the criteria to safely operate a medical drone service?

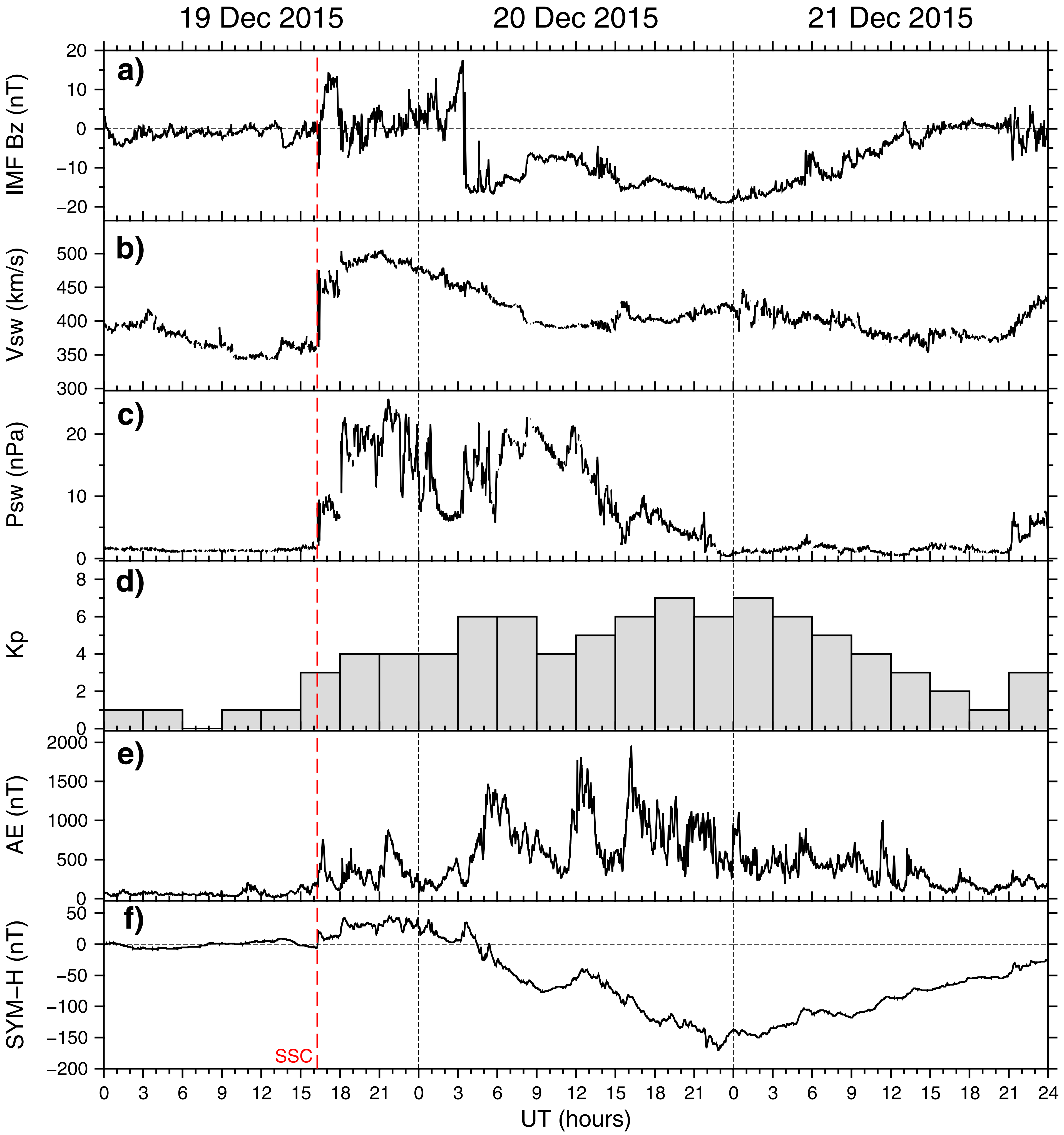
- Example 3: When and how will GICs be able to affect mid-latitude infrastructure?

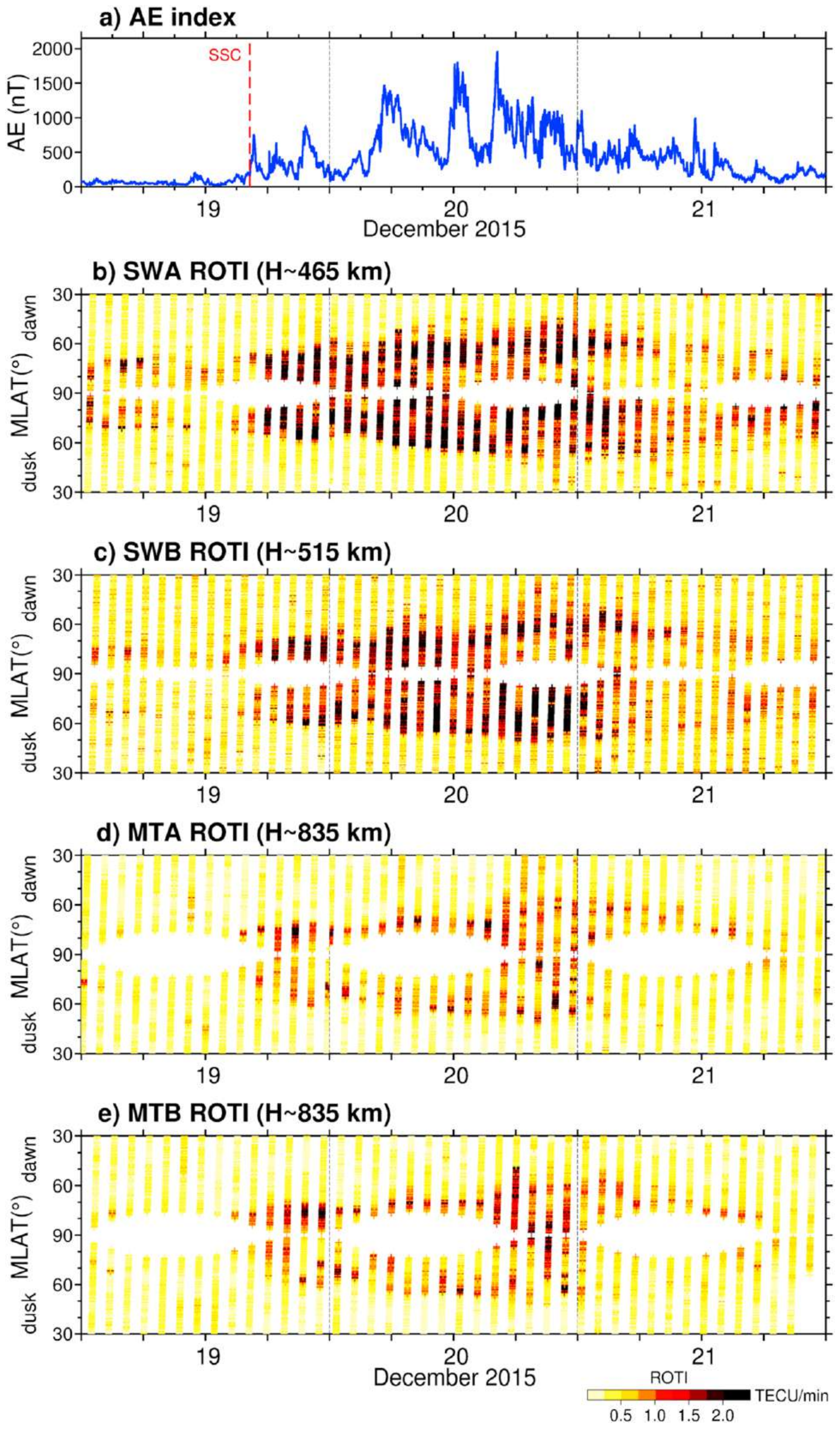




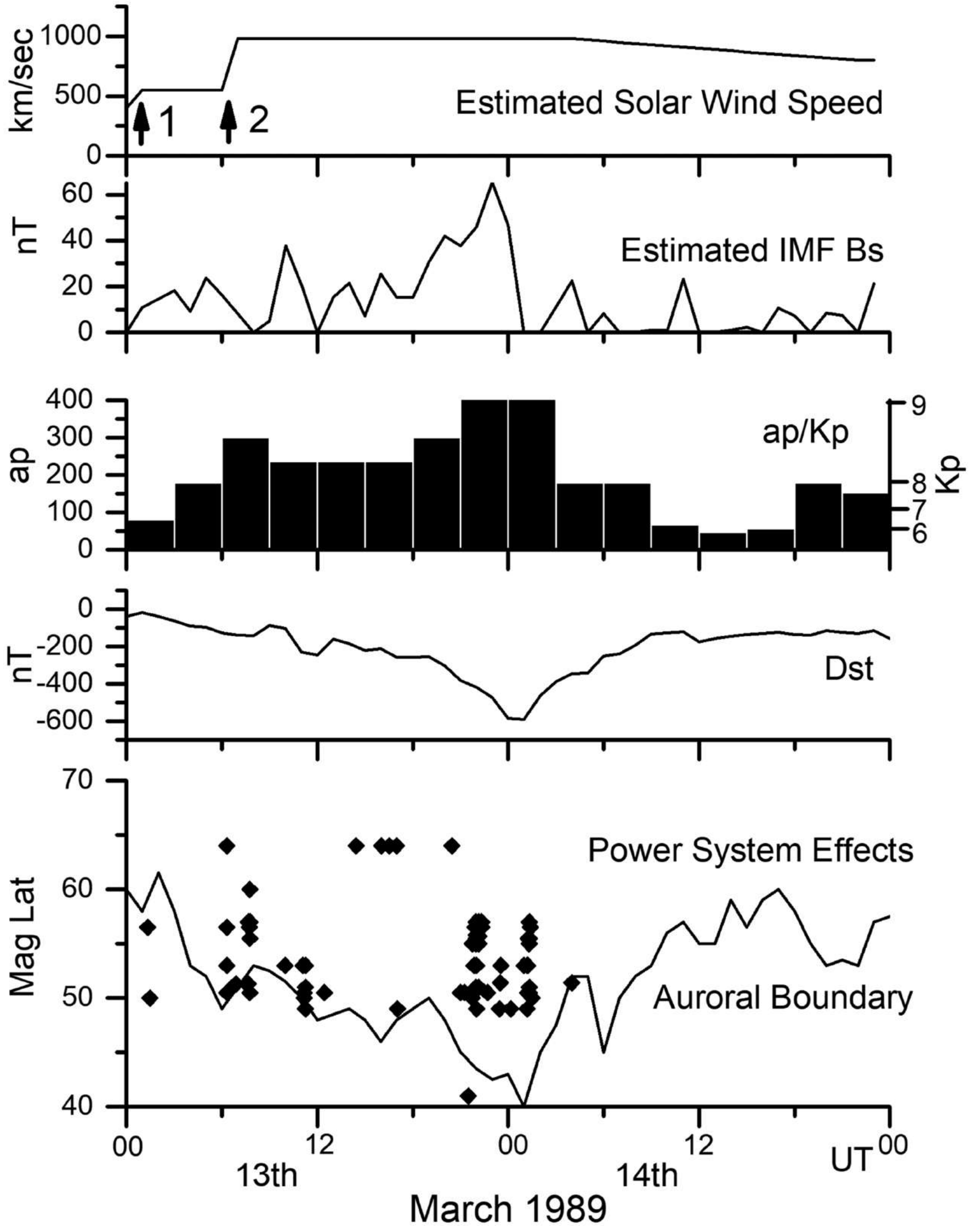
We need effective tools - making use of observations and models - that can be used to help to answer these questions, to illustrate our answers or the reasons for not being able to provide an answer yet.

Examples from case study papers



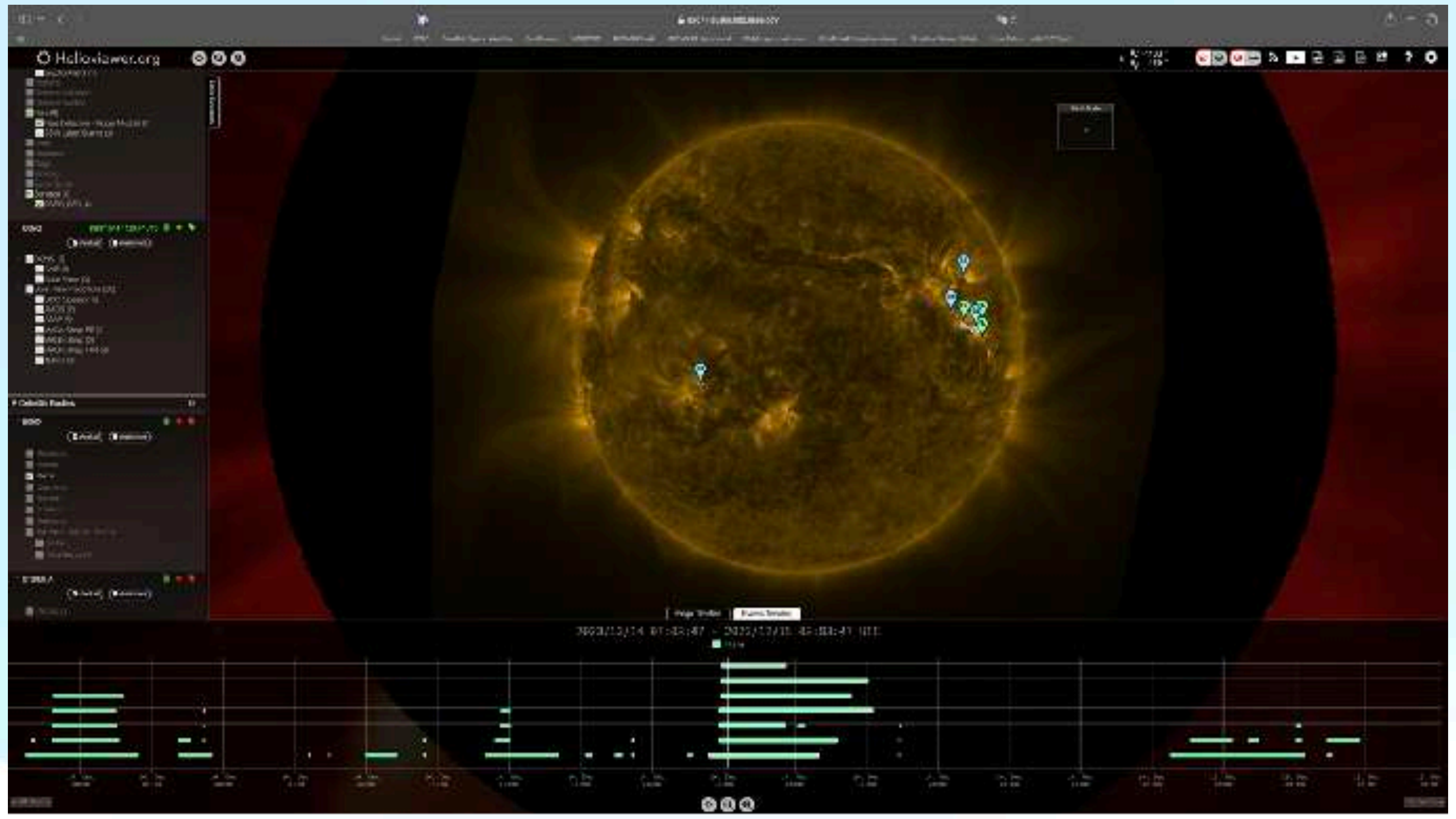


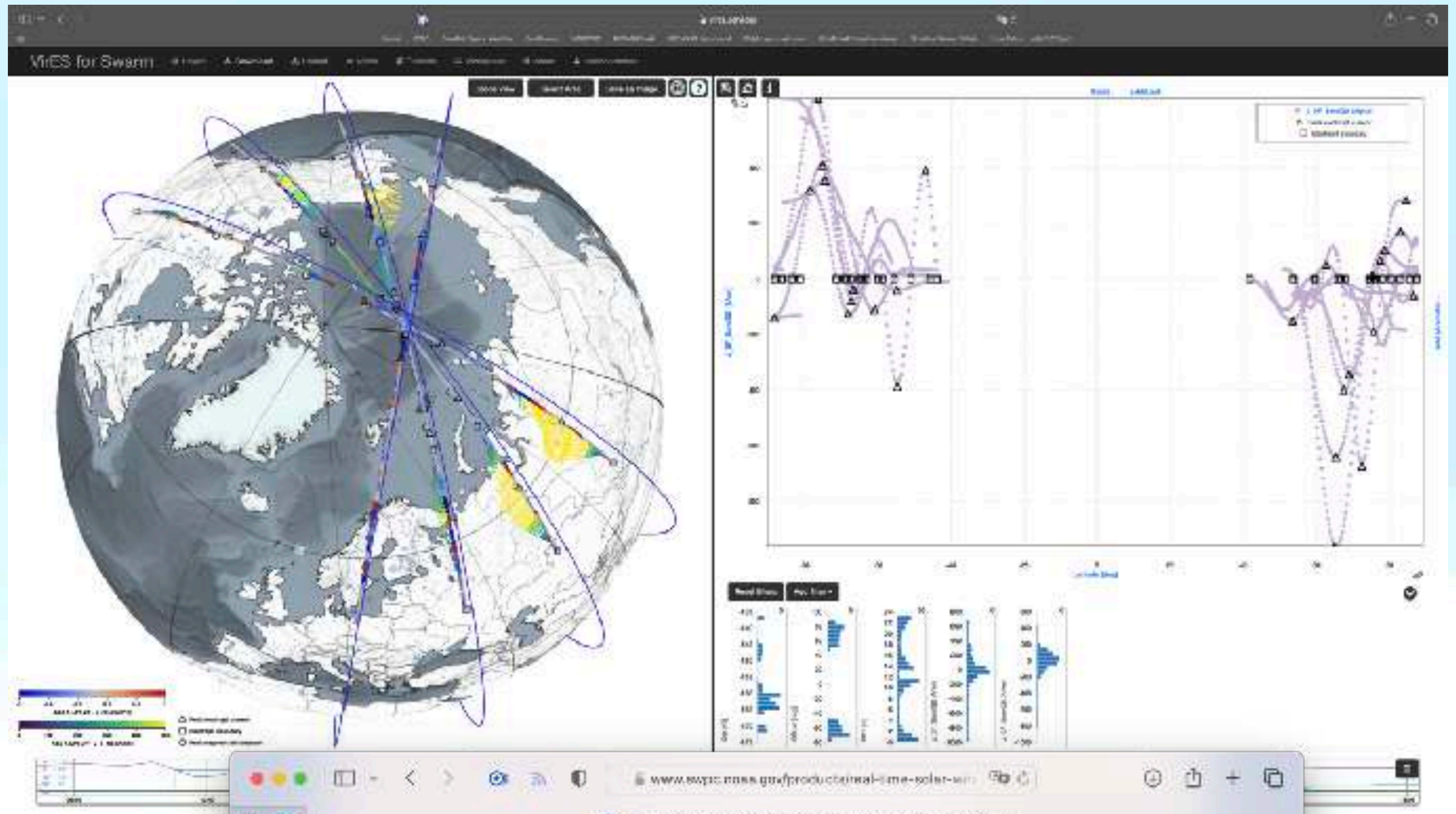
Zakharenkova and Cherniak, 2018

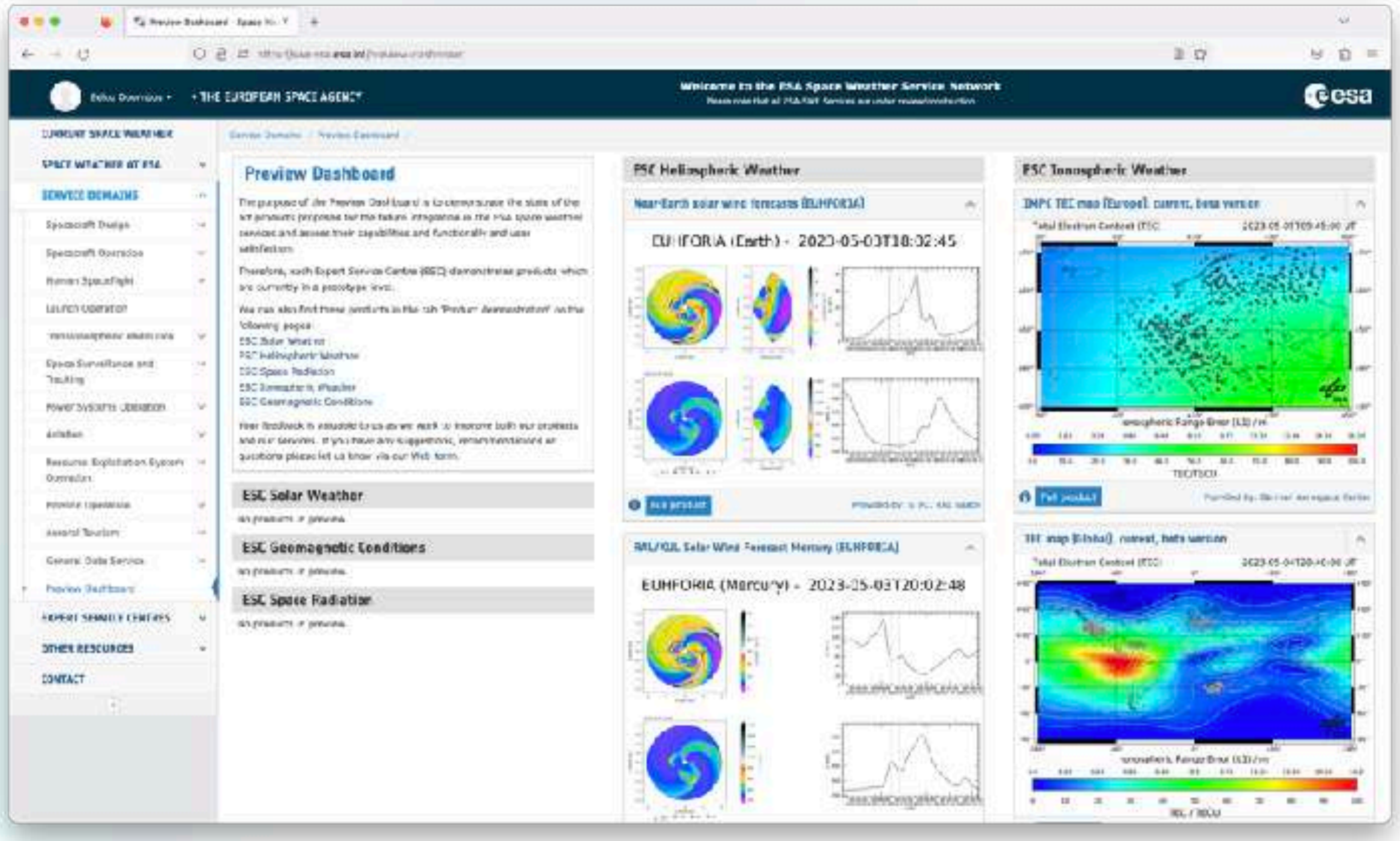


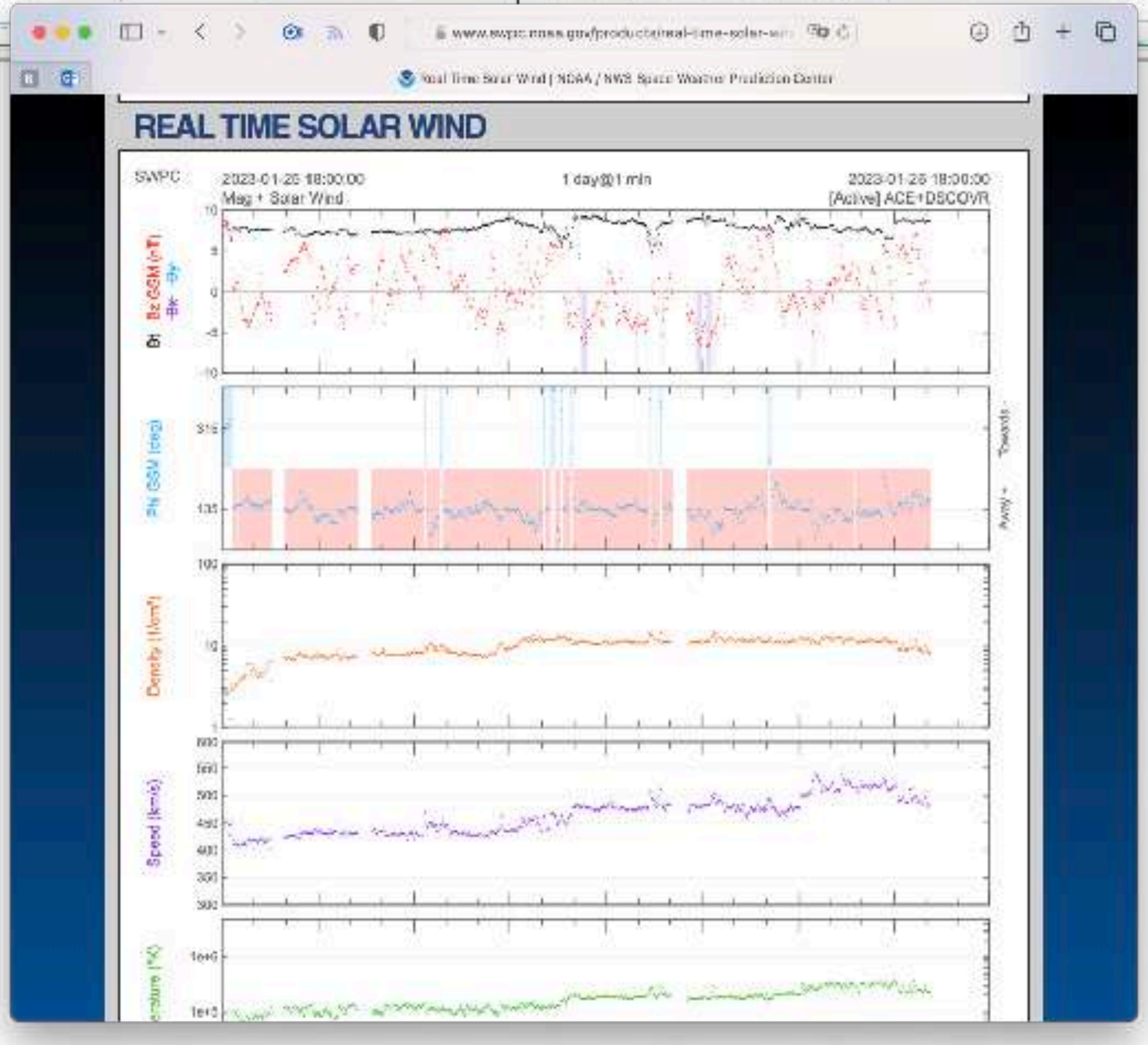
Boteler et al., 2019

Portals for accessing space weather data









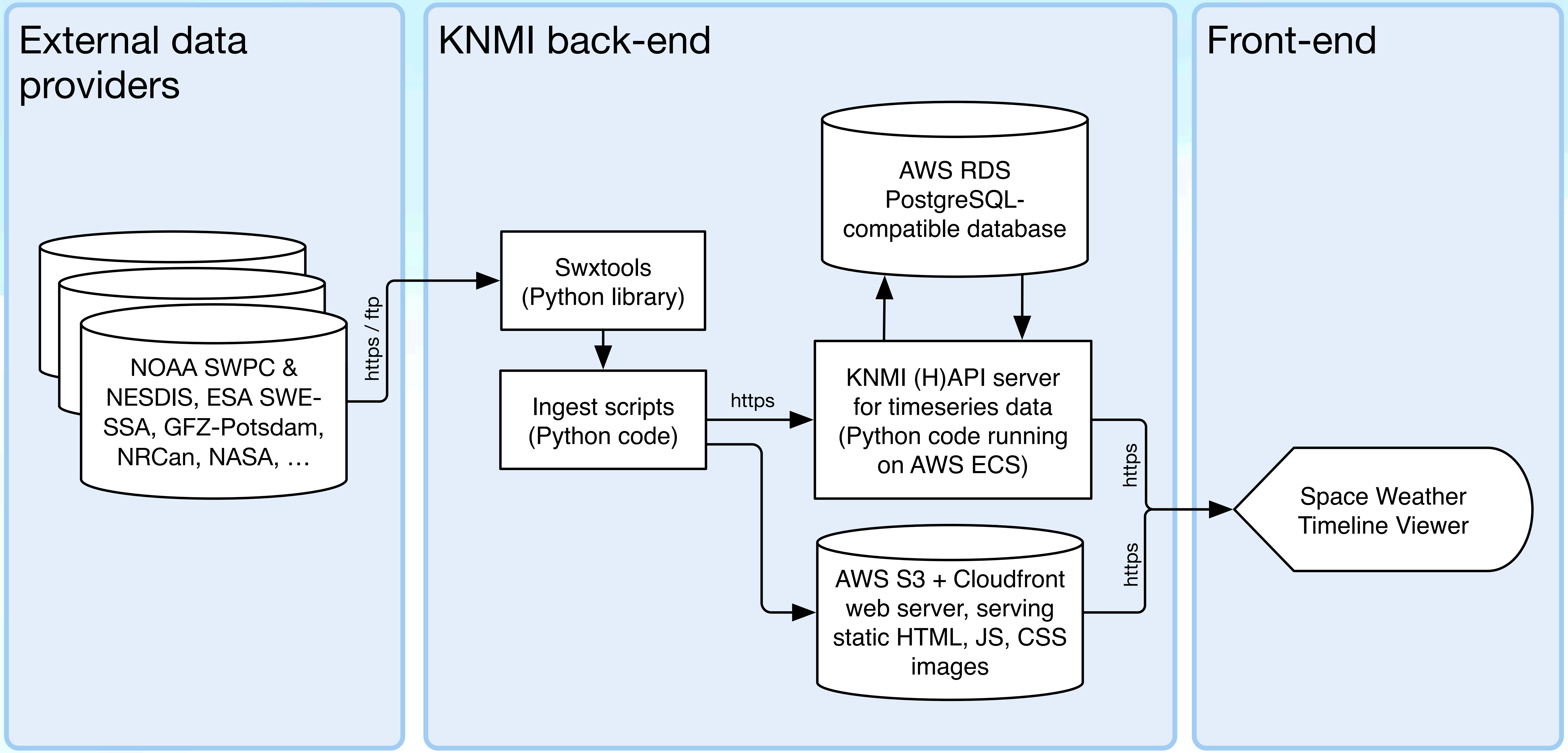
Literature survey for the timeline viewer tool

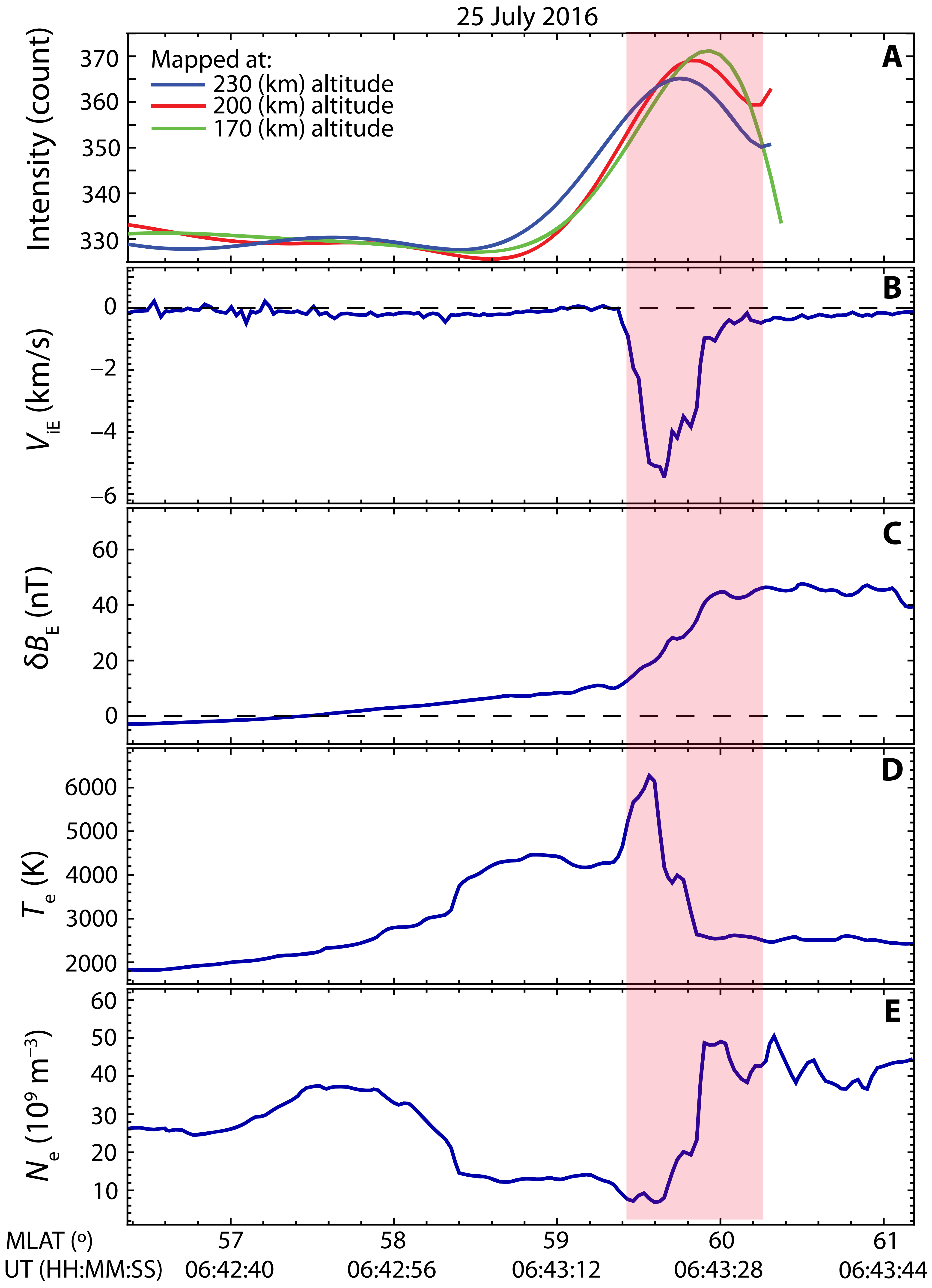
Conclusions

- Both details and wider context are important for understanding space weather, but these are often difficult to access in combination
- Data (observations and model output) of related phenomena need to be shown side-by-side. But each source has its own presentation.
- Need for a clear and simple user interaction model for time-based data:
    - Like Google Earth for geographical data
    - Like helioviewer for solar imagery

KNMI HAPI Server & Timeline Viewer

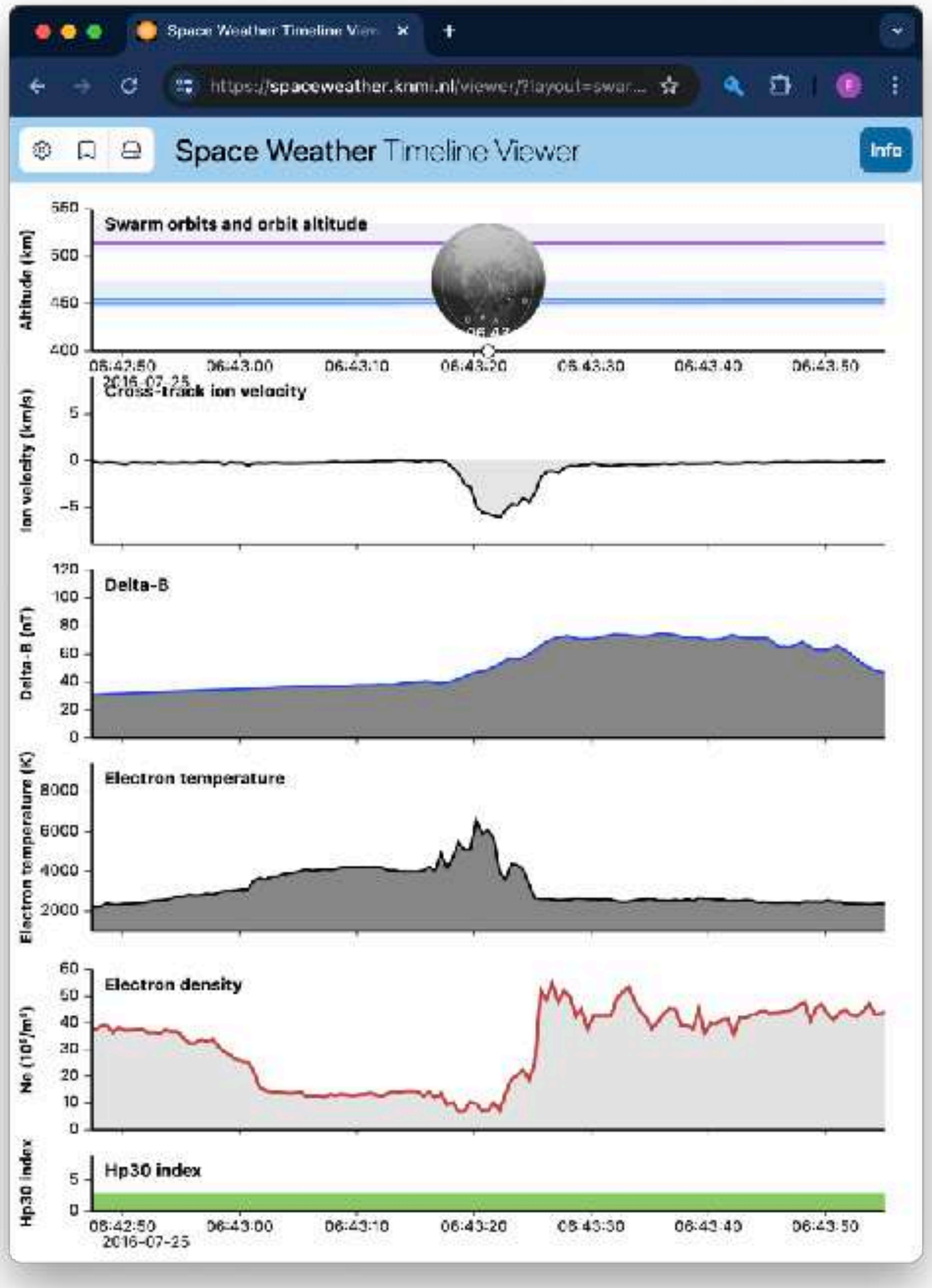
High-level architecture





New science in plain sight: Citizen scientists lead to the discovery of optical structure in the upper atmosphere

Elizabeth A. MacDonald,[1,2]* Eric Donovan,[3] Yukitoshi Nishimura,[4,5] Nathan A. Case,[6] D. Megan Gillies,[3] Bea Gallardo-Lacourt,[3,5] William E. Archer,[3†] Emma L. Spanswick,[3] Notanee Bourassa,[7] Martin Connors,[3,8,9] Matthew Heavner,[2,10] Brian Jackel,[3] Burcu Kosar,[1,2] David J. Knudsen,[3] Chris Ratzlaff,[7] Ian Schofield[8]



https://spaceweather.knmi.nl/viewer/?layout=swarm_switch_steve

Demo

- Real-time space weather

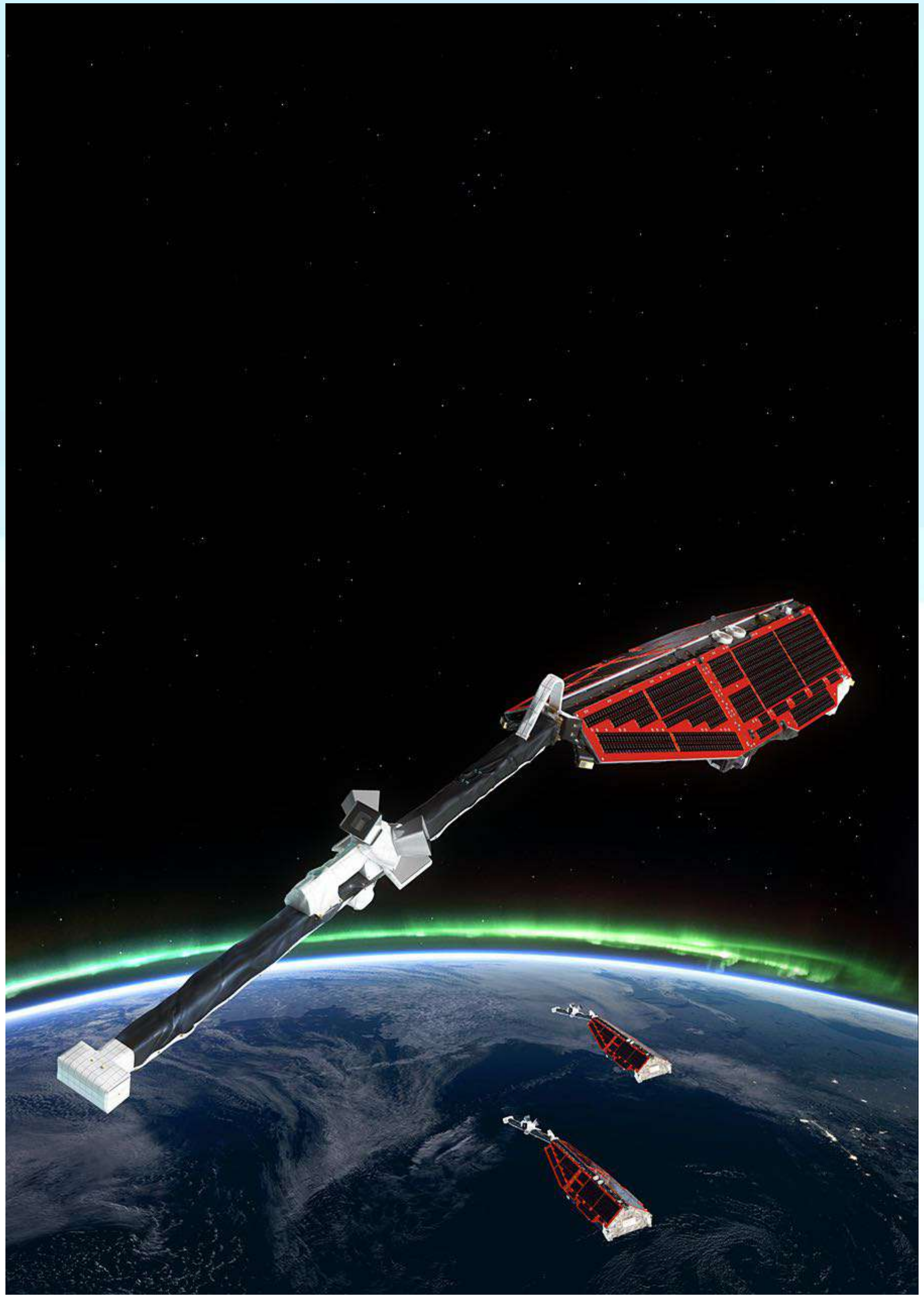
Conclusions & recommendations

Conclusions:

- Swarm observations and Swarm-based models help provide insight in space weather events such as storms, as well as day-to-day space weather such as plasma bubbles.

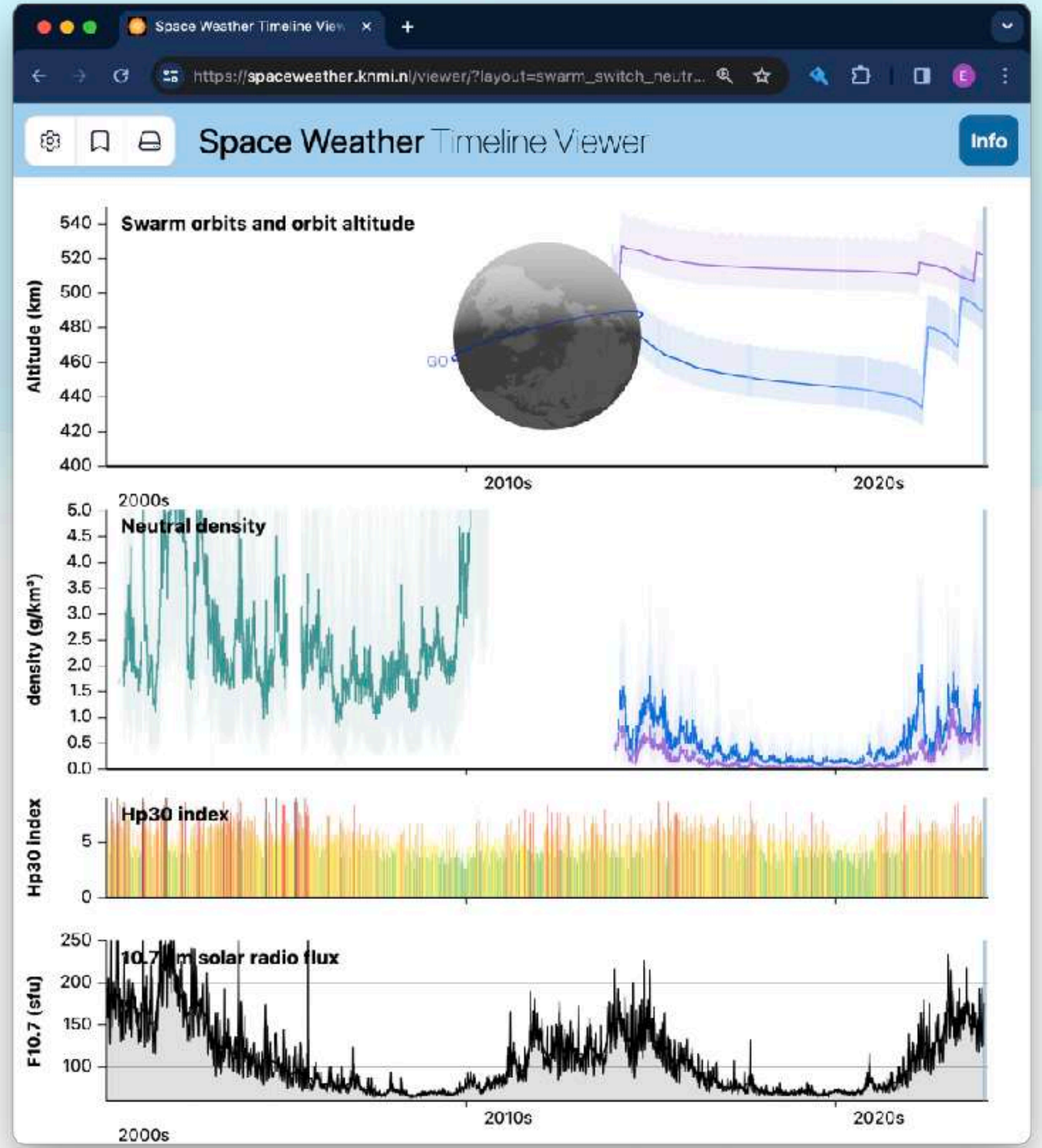
- The timeline viewer helps to make these observations much more easy to quickly inspect.

- Availability of FAST Swarm data means that the observations will be much more relevant during times when there is a strong interest, such as during and shortly after events (Starlink, Tonga, the next big geomagnetic storm…)



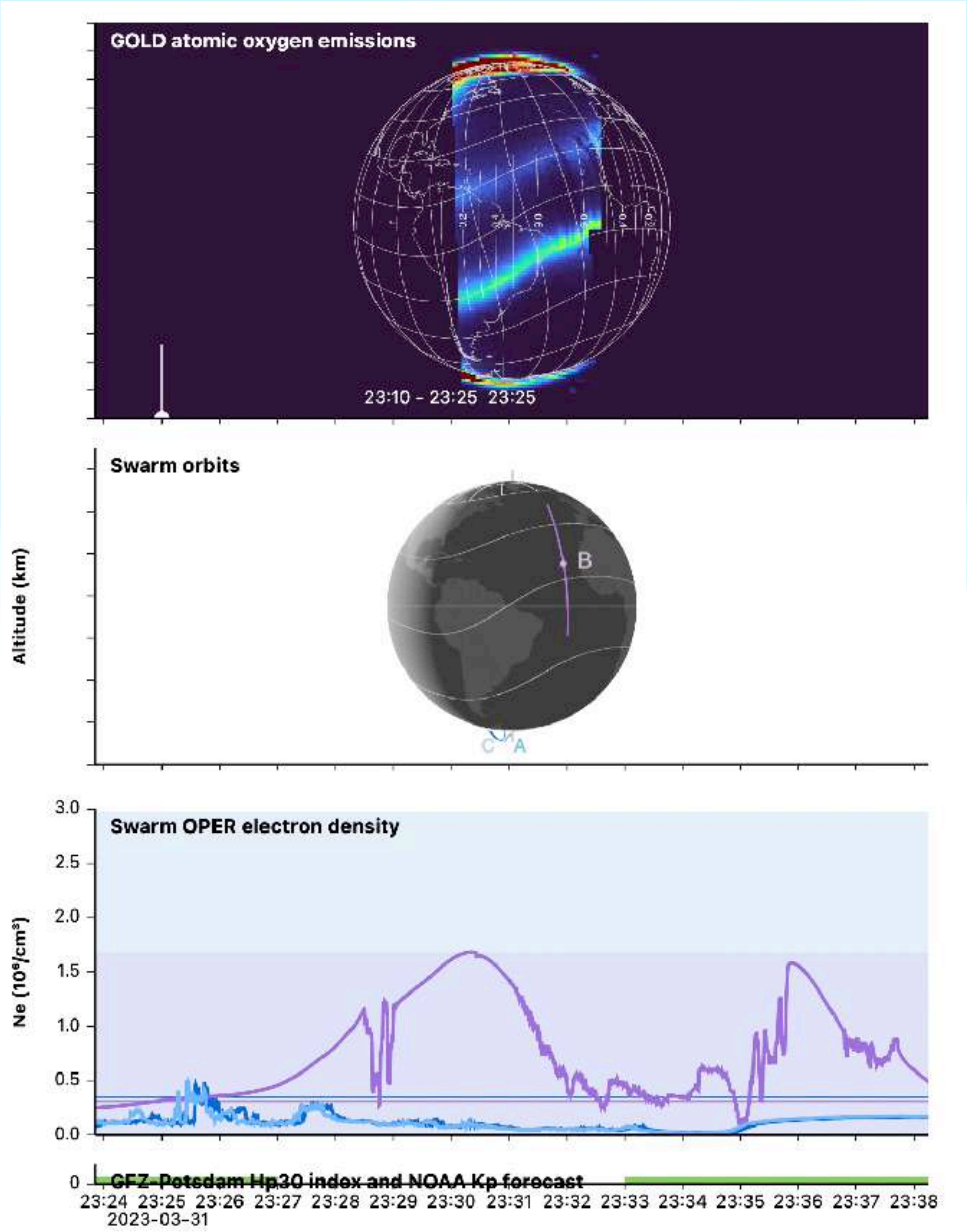
Recommendations 1

- The project has focused on Swarm L1B ionosphere data since 2021and L2 thermosphere data. There is the opportunity to do a lot more:
    - data from earlier in the mission,
    - magnetic data,
    - higher level data (FAC, EEJ, …),
    - Swarm-based climatological models (AMPS, IPB, …).
- The use of the compact data representation of interval images looks very useful for applying to additional data sets, especially spectrograms of high rate data, keograms, etc.
- Epoch-based image sequences of remote sensing (GOLD), and global models can provide global context to Swarm in-situ observations



Recommendations 2

- Because of its ease-of-use, the timeline viewer holds a lot of promise for the exploration of multi-mission datasets, such as Swarm in combination with:
    - Current and past missions providing data on space weather, space climate and comparative case studies:
        - E-POP, GOLD, ICON, COSMIC-2, CHAMP, GRACE, GRACE-FO, GOCE, Cryosat, …
    - Preparing for synergies with future space weather related missions (NanoMagSat, Aurora, Vigil, SMILE, GDC)
    - Reviving the accessibility and interoperability of older mission data, for example POLAR and IMAGE in combination with CHAMP data



Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

Thank you for your attention!

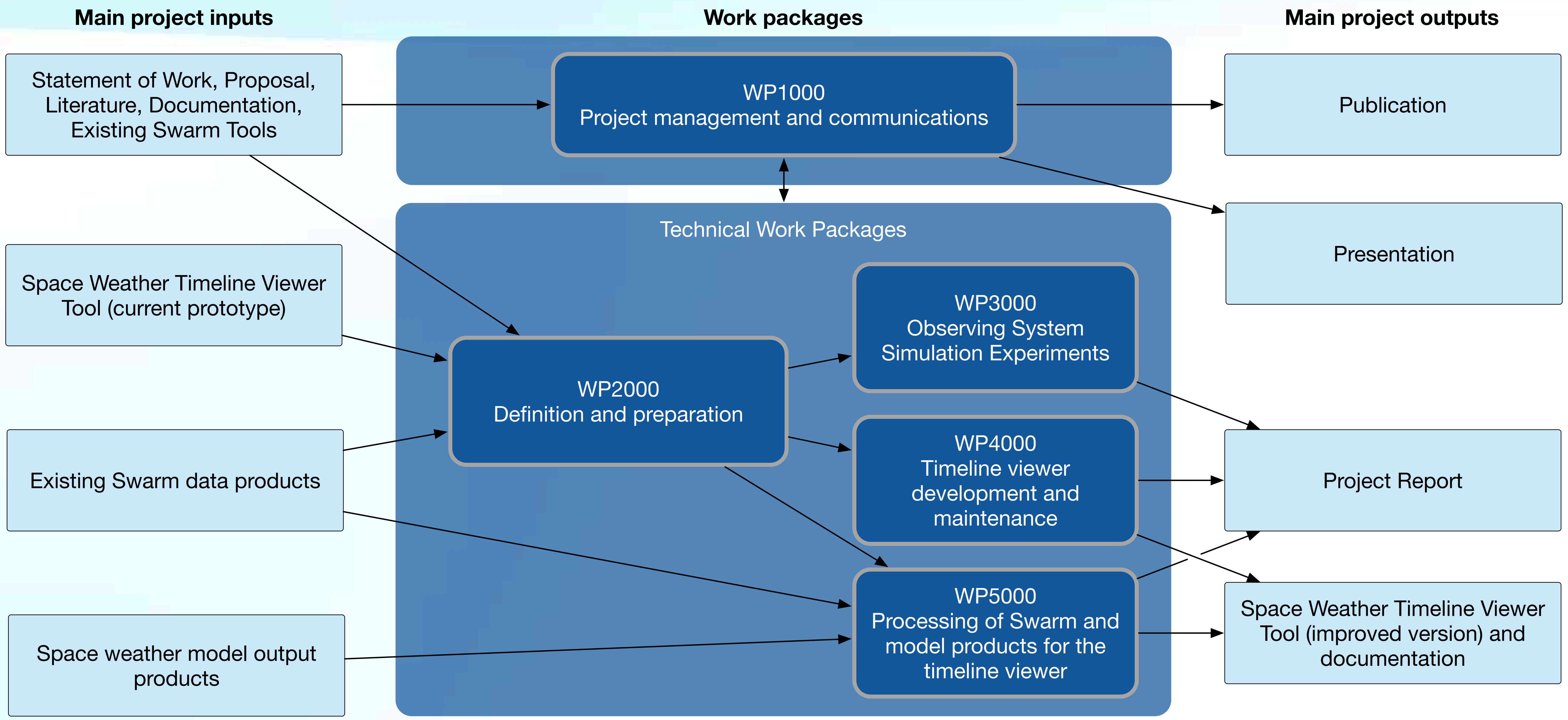
https://spaceweather.knmi.nl/viewer/

Feedback welcome: eelco.doornbos@knmi.nl

Extra slides

Project definition and work plan

- Main project outputs:
  - Space weather timeline viewer including Swarm and related model products
  - Observing System Simulation Experiments
  - Report, presentations and journal paper publication(s)

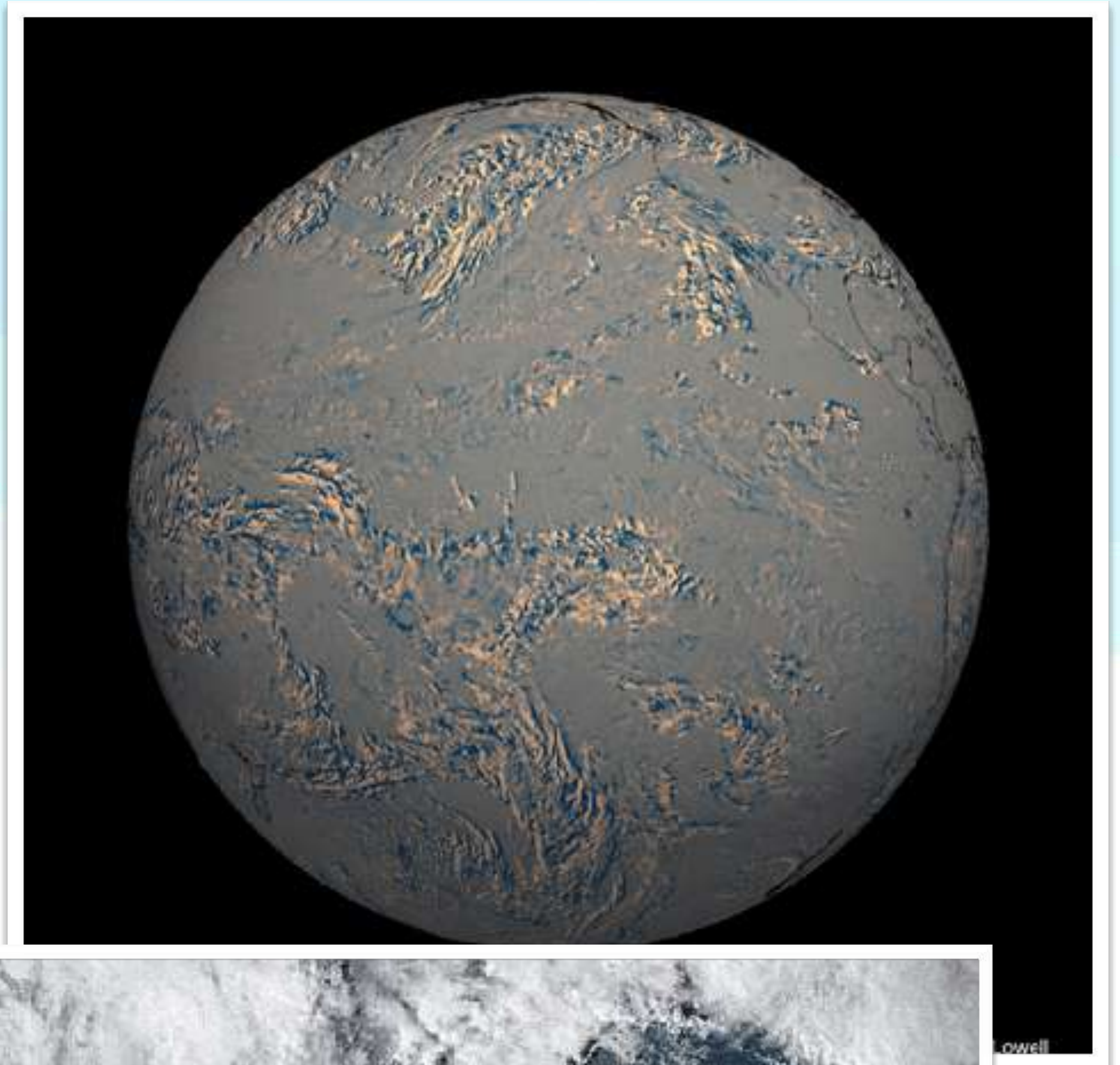


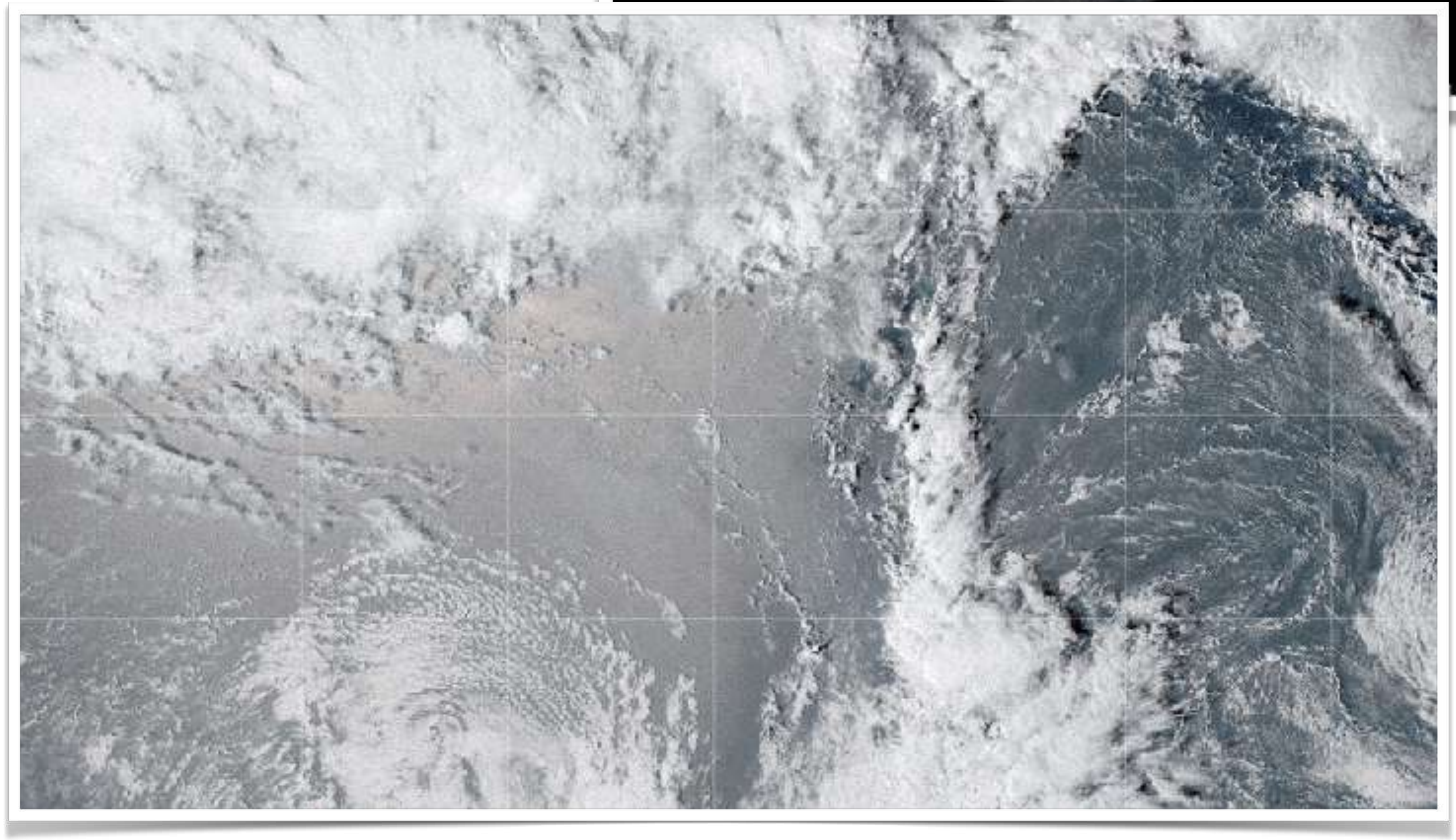
- Project started in September 2022
- Mid-term presentation on May 10 2023
- Final presentation, January 10, 2024Abstracts submitted for the Swarm Anniversary and Science meeting, 8-12 April 2024 in Copenhagen
- Many other presentations and demos during the course of the project (Swarm DQW, ESWW, NOAA/SWPC, BOM Australia, FMI, Met Norway, Met Office, Heliophysics in Europe, DASH, etc.)

Hunga Tonga–Hunga Ha‘apai eruption

Bonus case study

- Eruption of submarine volcano near Tonga in the southern Pacific Ocean on 15 January 2022.
- Atmospheric Lamb wave observed around the globe in the lower atmosphere.
- Investigate thermospheric and ionospheric effects with Swarm and GRACE, and compare with special model runs.





Hunga Tonga–Hunga Ha‘apai eruption

Bonus case study

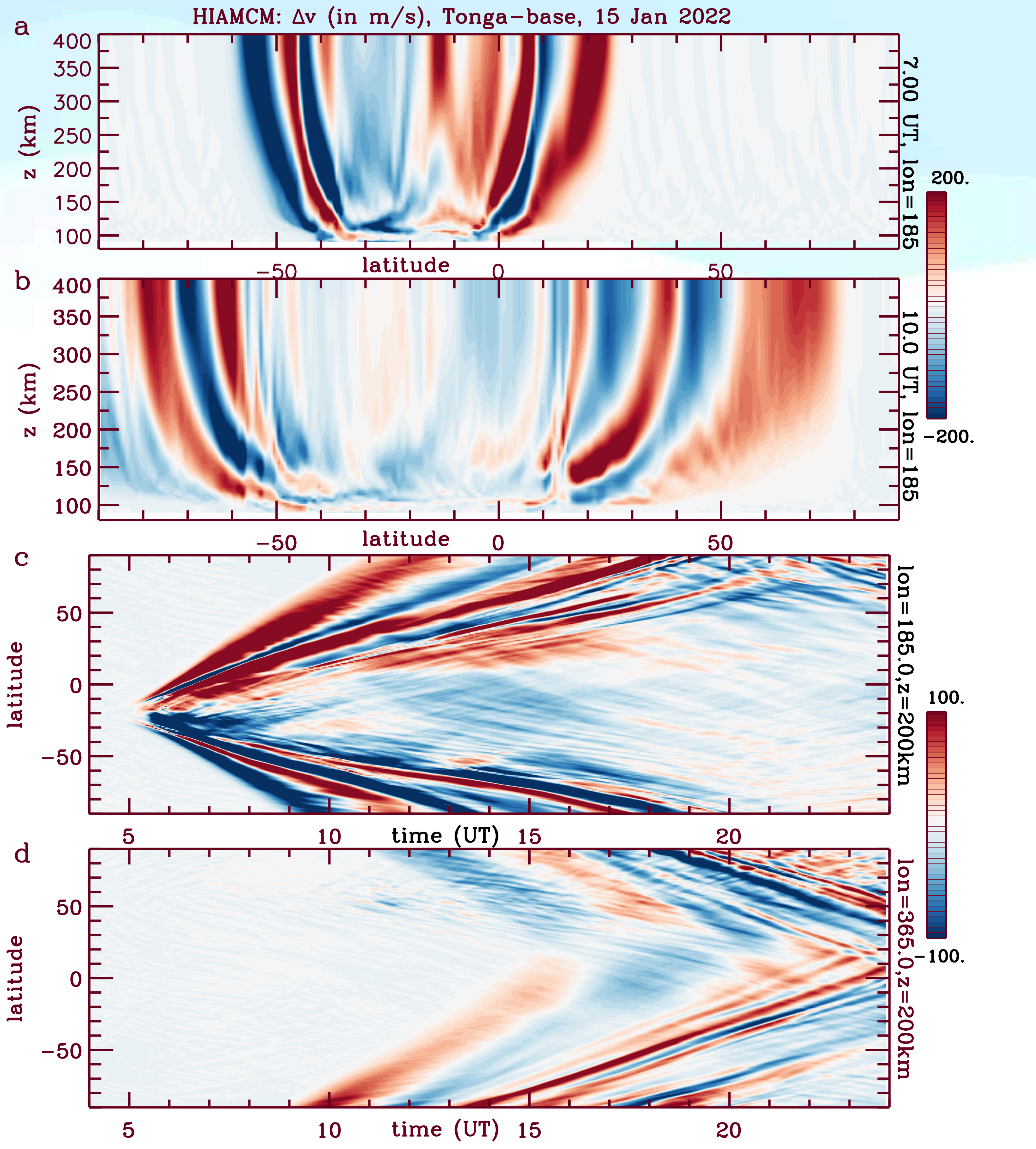
- Investigate thermospheric and ionospheric effects with Swarm and GRACE, and compare with special model runs:
  - Sami3 (Sami3 is Also a Model of the Ionosphere)
    - A seamless, global, three-dimensional, physics-based model of the ionosphere/plasmasphere system.
  - HIAMCM (High Altitude Mechanistic General Circulation Model)
    - HIAMCM extends from the surface to an altitude of about 450 km. The model is based on a standard spectral dynamical core and has a high spatial resolution.
  - WACCM-X (Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension)
    - A model of the entire atmosphere that extends into the thermosphere to ~500 km altitude, and includes the ionosphere.

Simulation Study of the 15 January 2022 Tonga Event: Development of Super Equatorial Plasma Bubbles

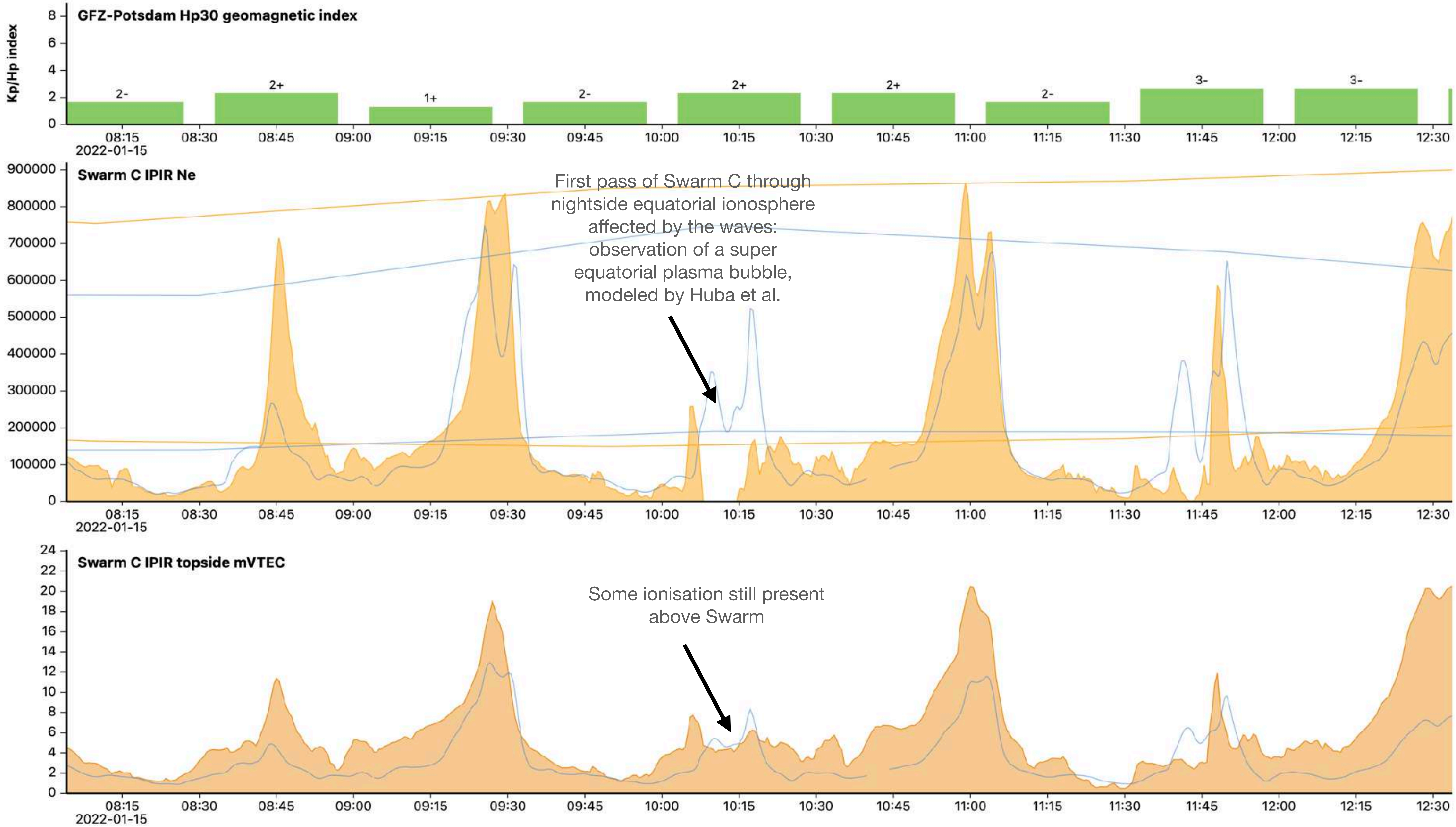
J. D. Huba[1], E. Becker[2], and S. L. Vadas[2]

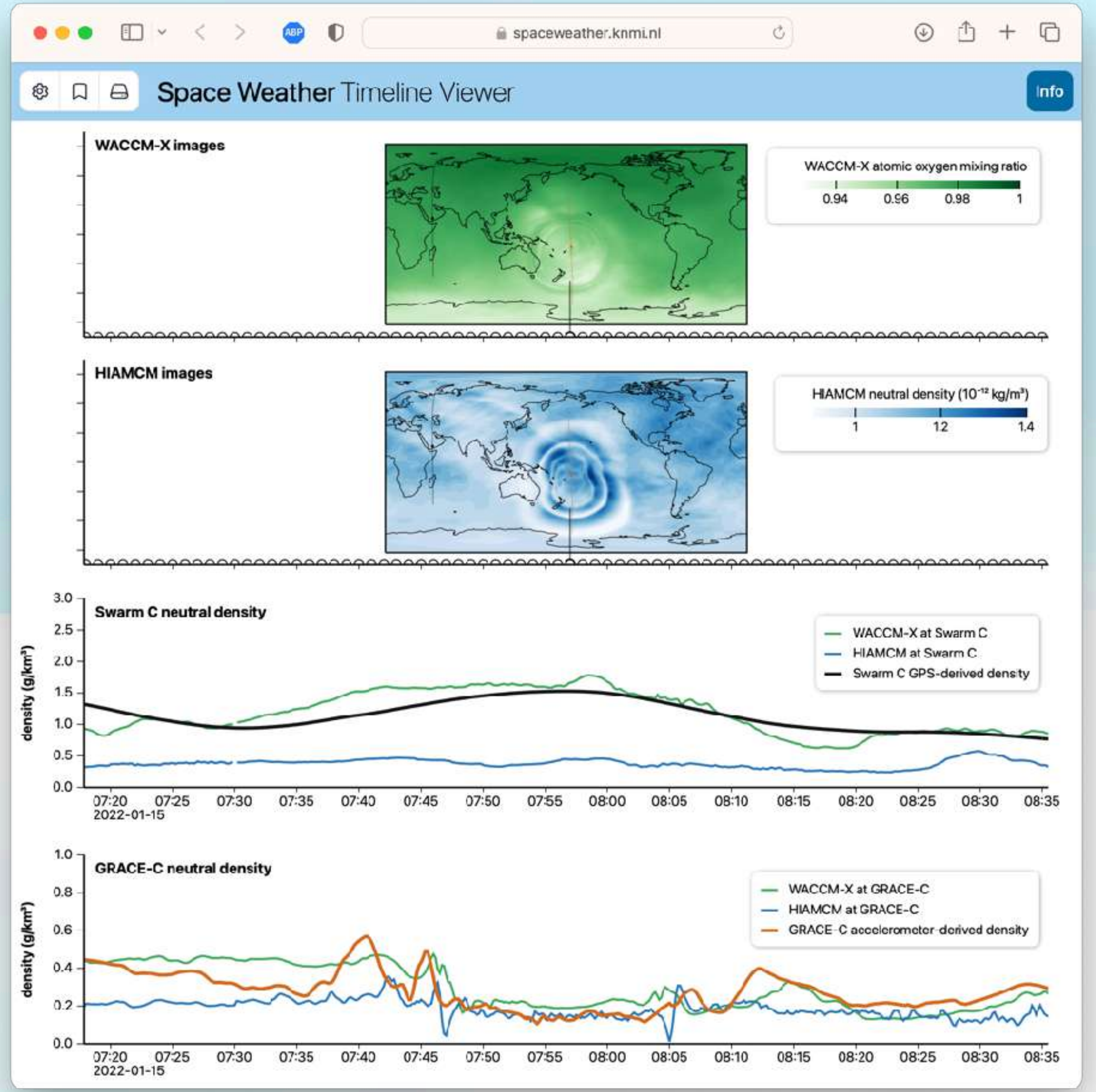
Primary and Secondary Gravity Waves and Large-Scale Wind Changes Generated by the Tonga Volcanic Eruption on 15 January 2022: Modeling and Comparison With ICON-MIGHTI Winds

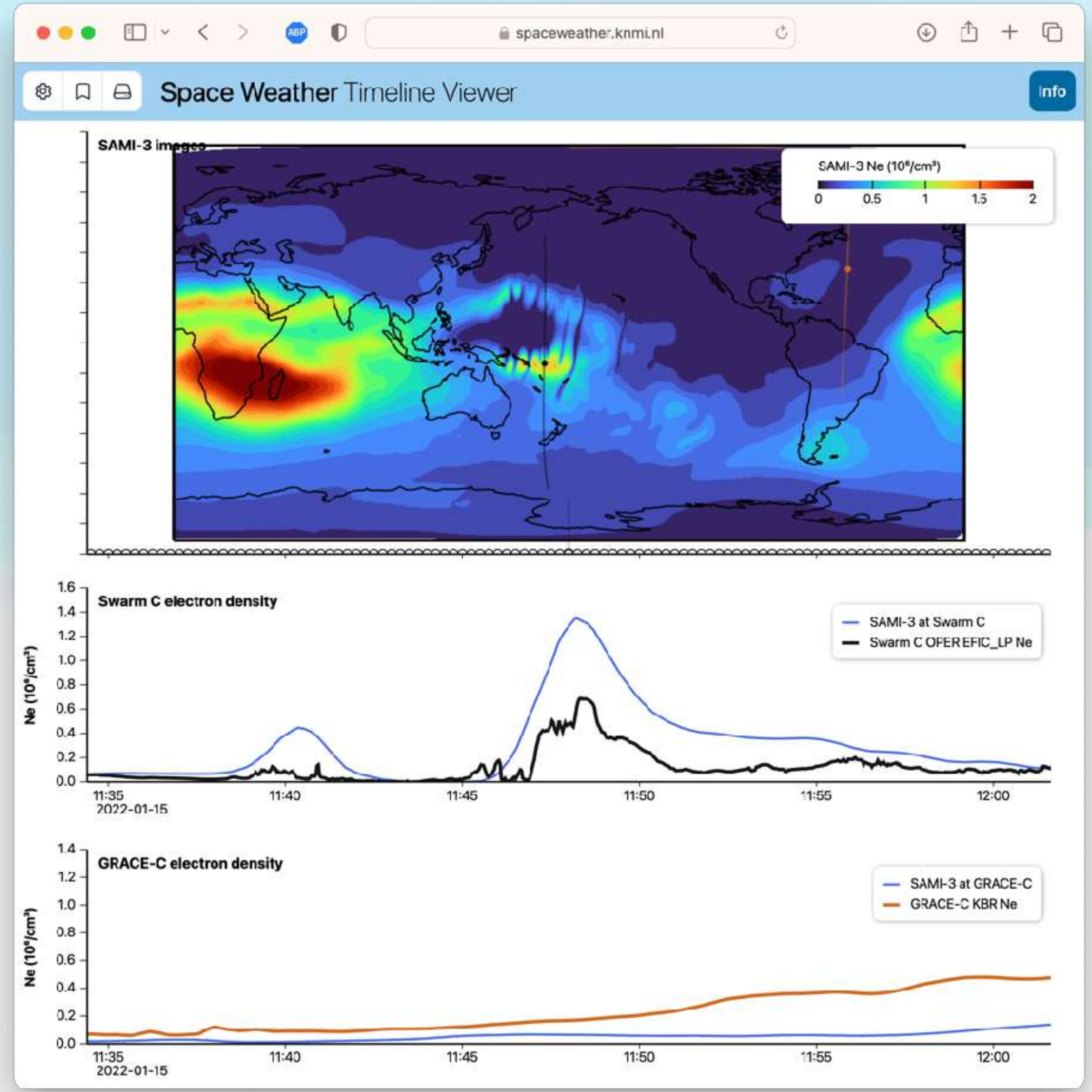
Sharon L. Vadas[1], Erich Becker[1], Cosme Figueiredo[2], Katrina Bossert[3], Brian J. Harding[4], and L. Claire Gasque[4]




GFZ-Potsdam Hp30 geomagnetic index
Kp/Hp index
Enhanced geomagnetic activity
before eruption
Time of eruption
2022-01-14
2022-01-15
2022-01-16
2022-01-17
Swarm C neutral density
Typical response to
geomagnetic activity:
enhancement and recovery
of global (min and max)
neutral density
Unusual behaviour: peaks coinciding with deeper minima
as a result of waves generated during the eruption.

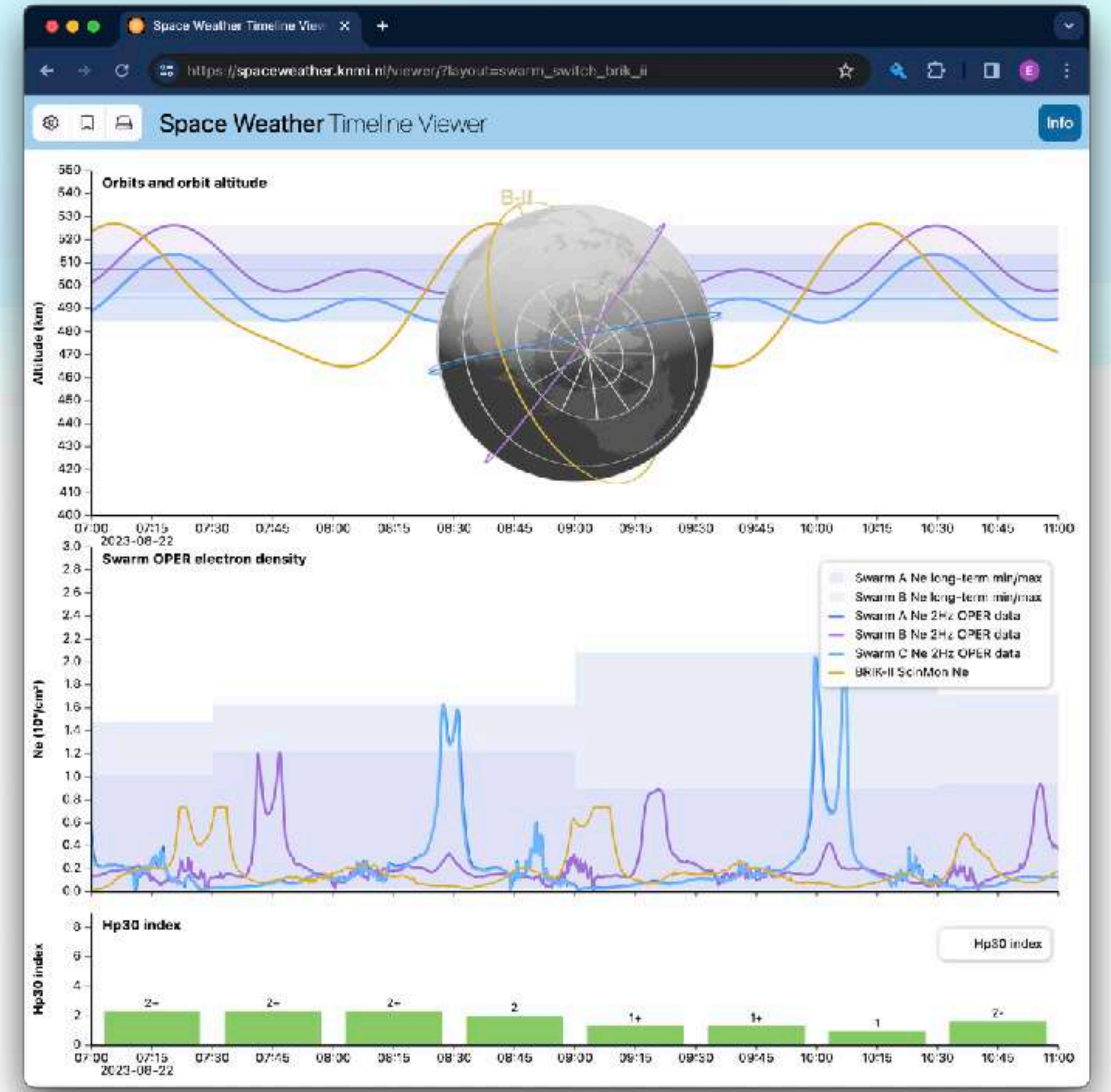

GFZ-Potsdam Hp30 geomagnetic index
Kp/Hp index
2-
2+
1+
2-
2+
2+
2-
3-
3-
2022-01-15
Swarm C IPIR Ne
First pass of Swarm C through nightside equatorial ionosphere affected by the waves: observation of a super equatorial plasma bubble, modeled by Huba et al.
Swarm C IPIR topside mVTEC
Some ionisation still present above Swarm


spaceweather.knmi.nl
Space Weather Timeline Viewer
Info
WACCM-X images
WACCM-X atomic oxygen mixing ratio
0.94 0.96 0.98 1
HIAMCM images
HIAMCM neutral density (10⁻¹² kg/m³)
1 1.2 1.4
Swarm C neutral density
WACCM-X at Swarm C
HIAMCM at Swarm C
Swarm C GPS-derived density
density (g/km³)
2022-01-15
GRACE-C neutral density
WACCM-X at GRACE-C
HIAMCM at GRACE-C
GRACE-C accelerometer-derived density


spaceweather.knmi.nl
Space Weather Timeline Viewer
Info
SAMI-3 images
SAMI-3 Ne (10⁶/cm³)
0 0.5 1 1.5 2
Swarm C electron density
SAMI-3 at Swarm C
Swarm C OPER EFIC_LP Ne
Ne (10⁶/cm³)
2022-01-15
GRACE-C electron density
SAMI-3 at GRACE-C
GRACE-C KBR Ne

New and improved features of the client (web application)

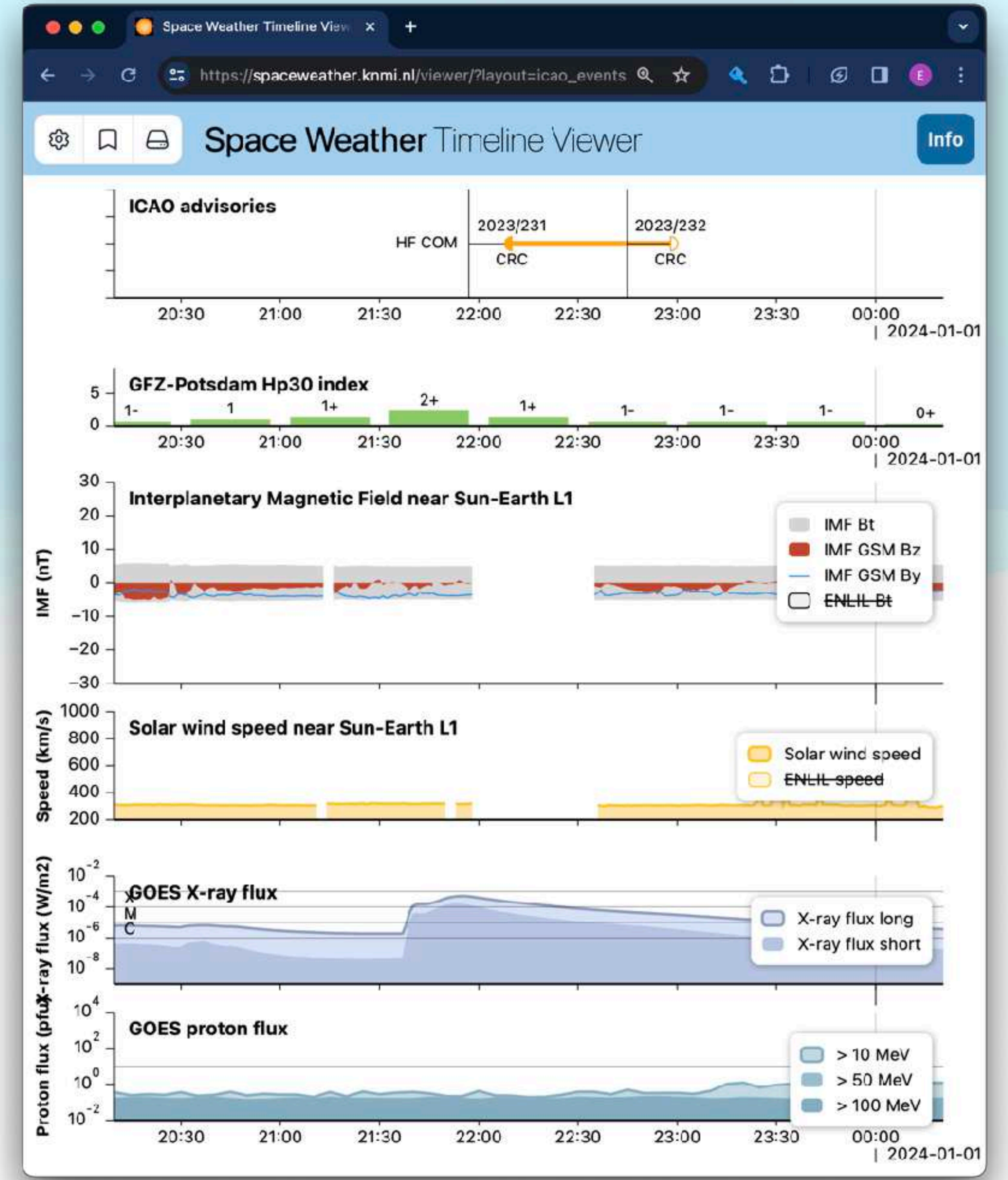
- Title bar with access buttons for improved editor sidebar, new bookmarks sidebar, new info panel, indicator for number of running HAPI queries
- New plot types (incl. 3D Earth, interval images, epoch images, symbols)
- Now works with any HAPI server (ViRES, NASA CDAWeb, ESA Cluster, …)
- Support for new Intermagnet HAPI server with 1 minute and 1 second cadence data
- Plot legends



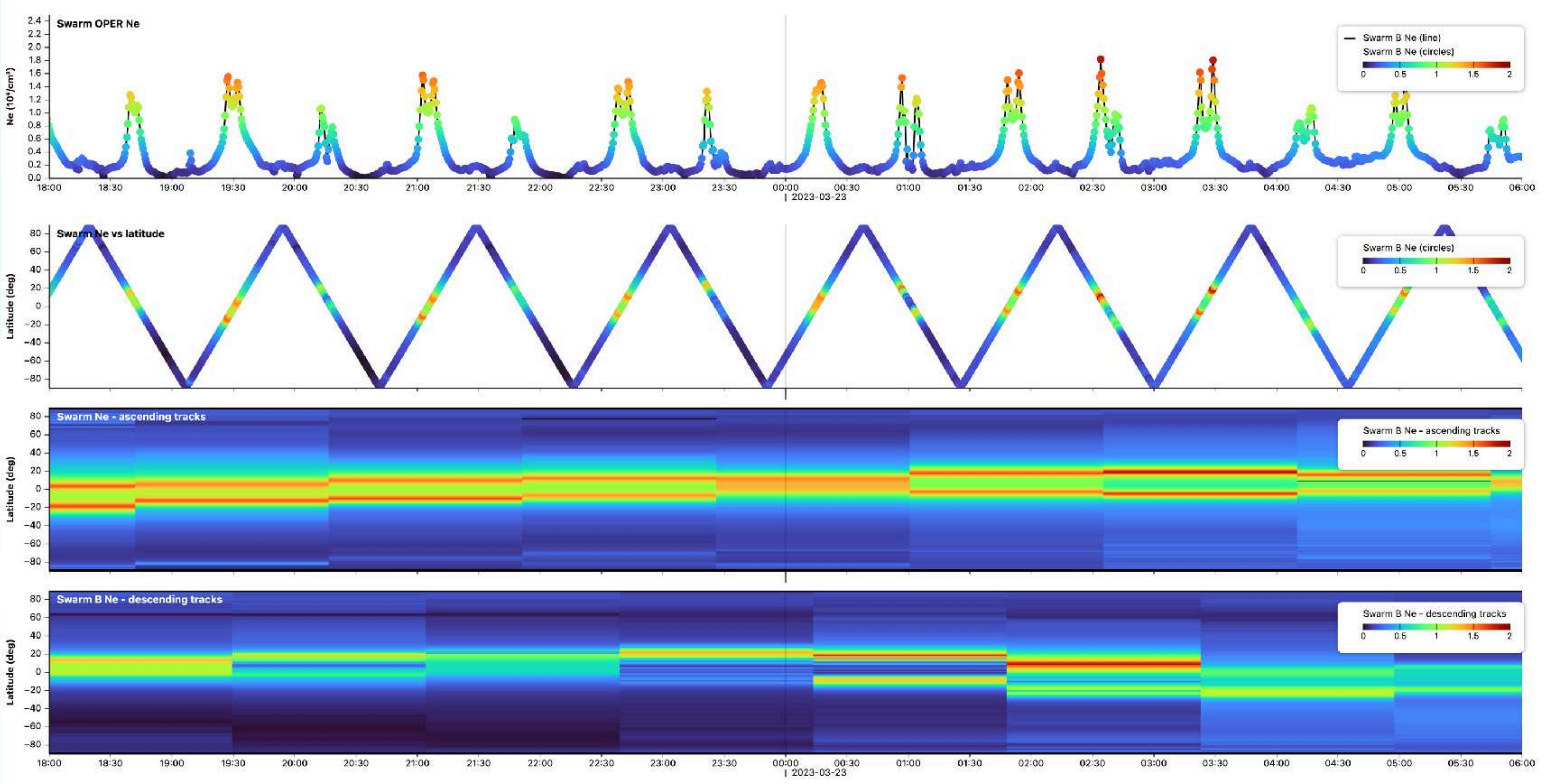
Interactive 3D Earth and orbit views

- 3D-rendered element
- Technologies used: Threlte, (three.js, WebGL)
- Elements:
  - Earth globe with solar illumination based on analytic equations for Sun position
  - Satellite orbit
  - Satellite location with radius vector and label
  - Magnetic latitude graticule
- Camera can be in inertial, Earth-fixed or fixed local time frame, and fixed, freely movable (“orbit controls” with north up), or fixed to a satellite’s location

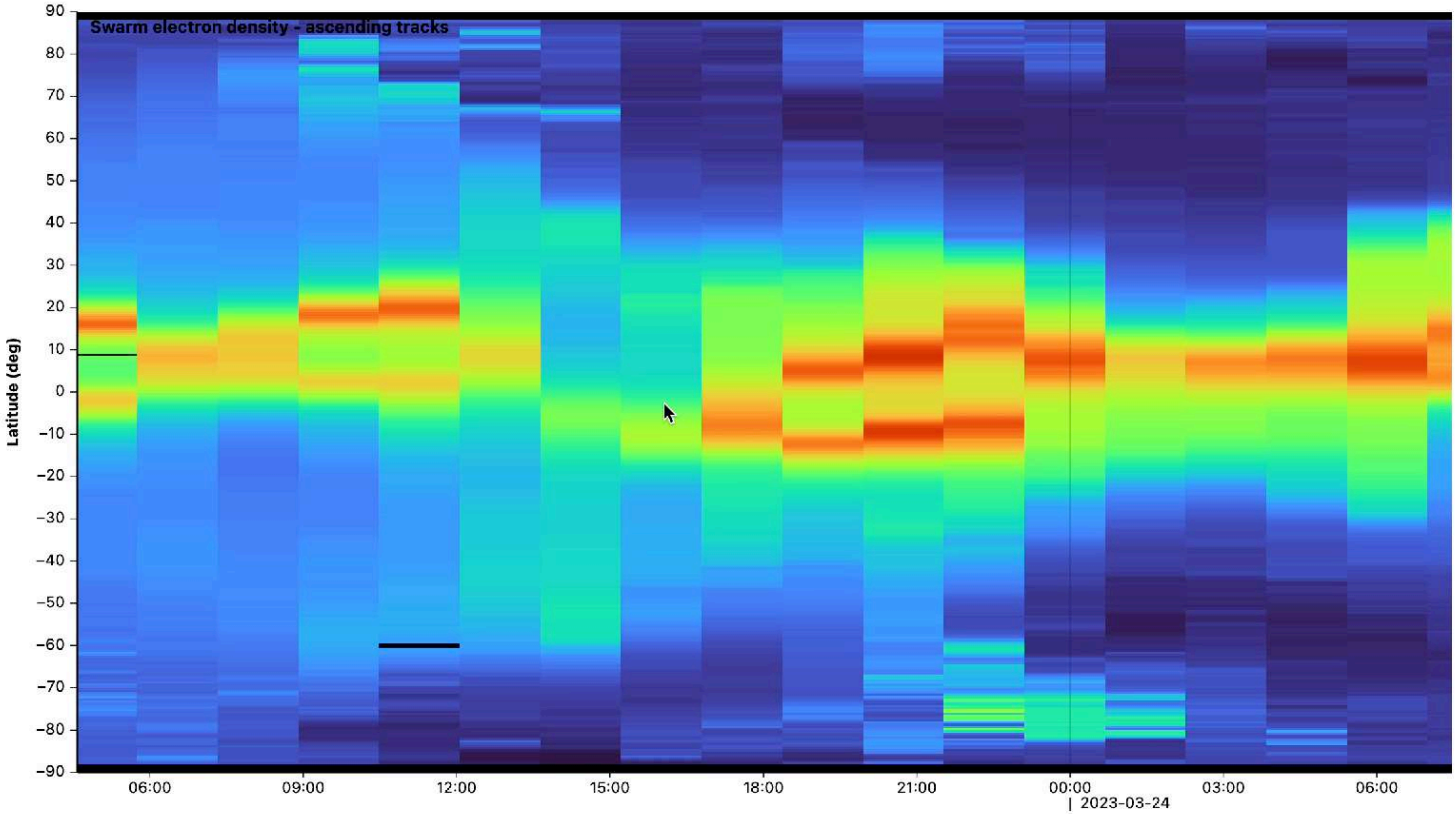
Annotated symbols (right) & color-mapped symbols (bottom)



Interval images



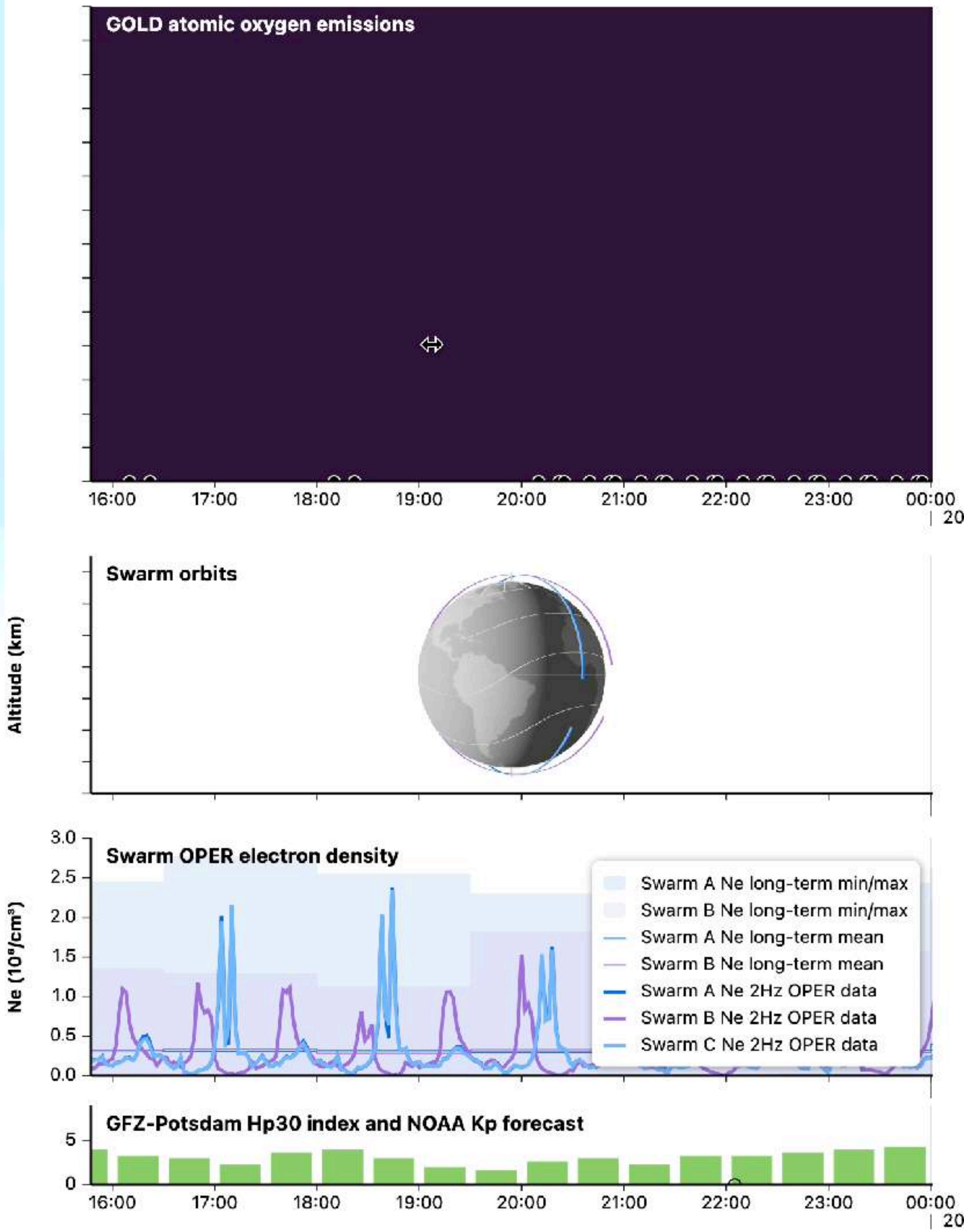
Interval images (Swarm B Ne, ascending tracks)



Epoch-based image sequences

GOLD+Swarm example

1. Individual GOLD images

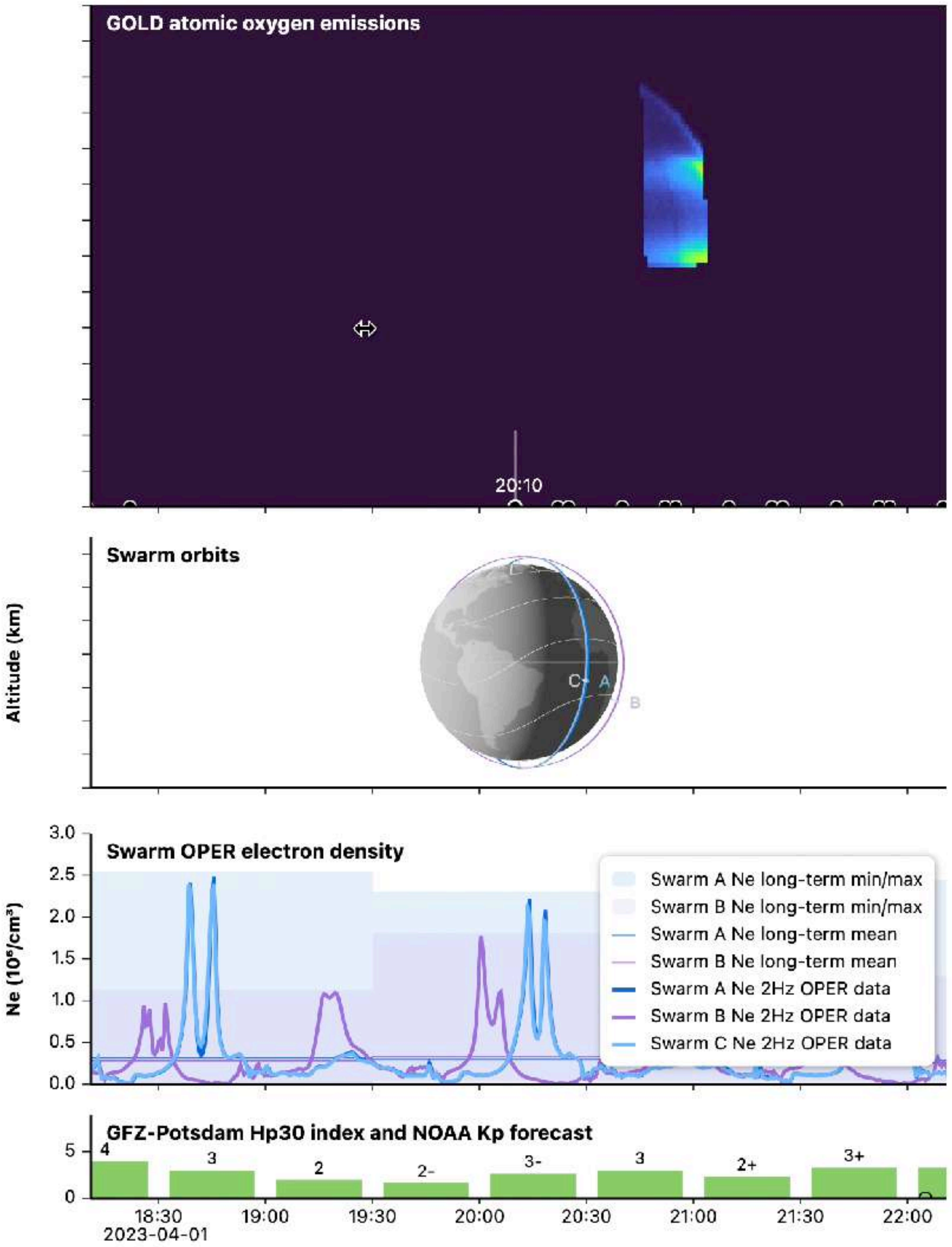


Epoch-based image sequences

GOLD and Swarm example

1. Individual GOLD images

2. Retaining a short history of GOLD images making use of transparency



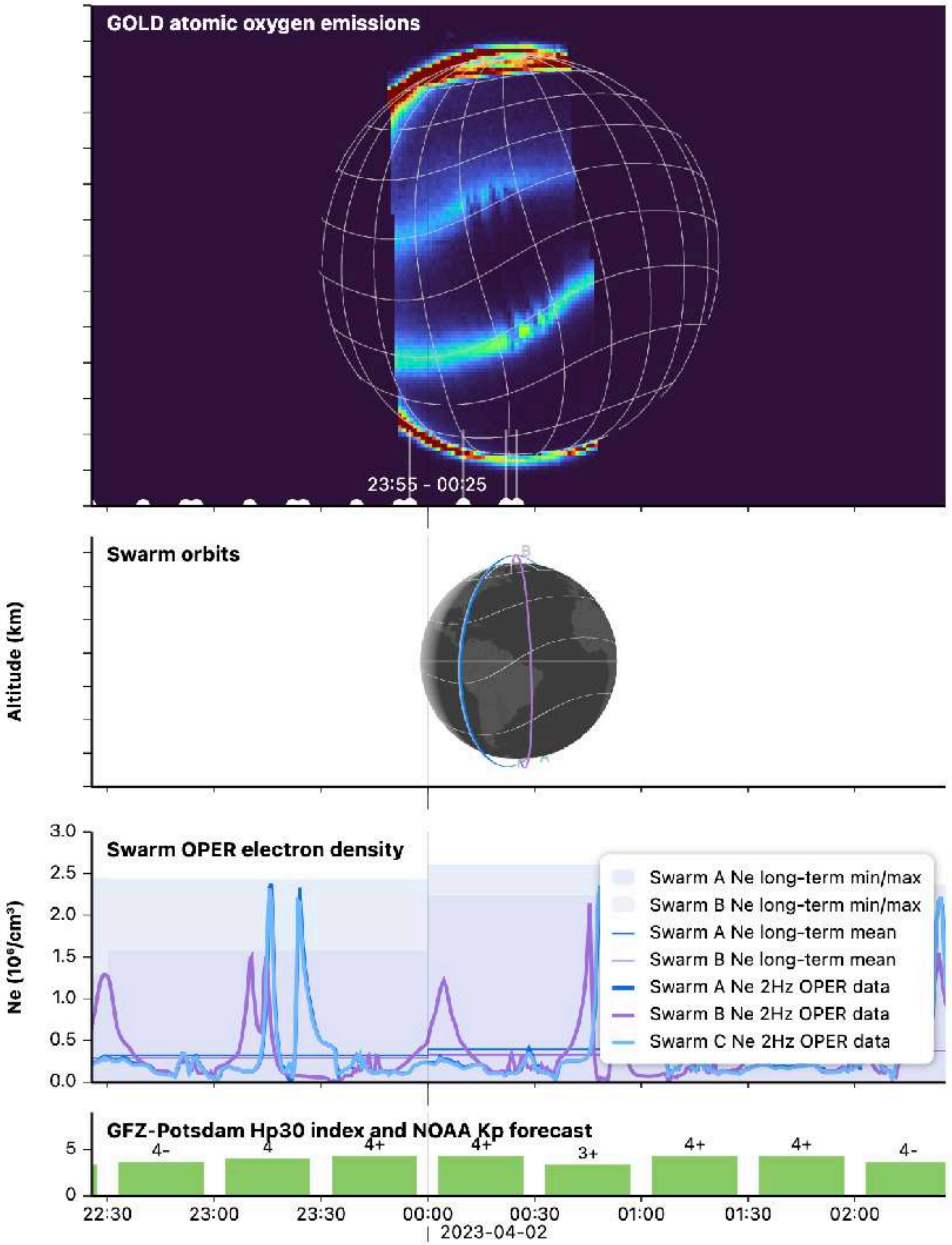
Epoch-based image sequences

GOLD and Swarm example

1. Individual GOLD images

2. Retaining a short history of GOLD images making use of transparency

3. Static overlays of coastlines and graticule



Epoch-based image sequences

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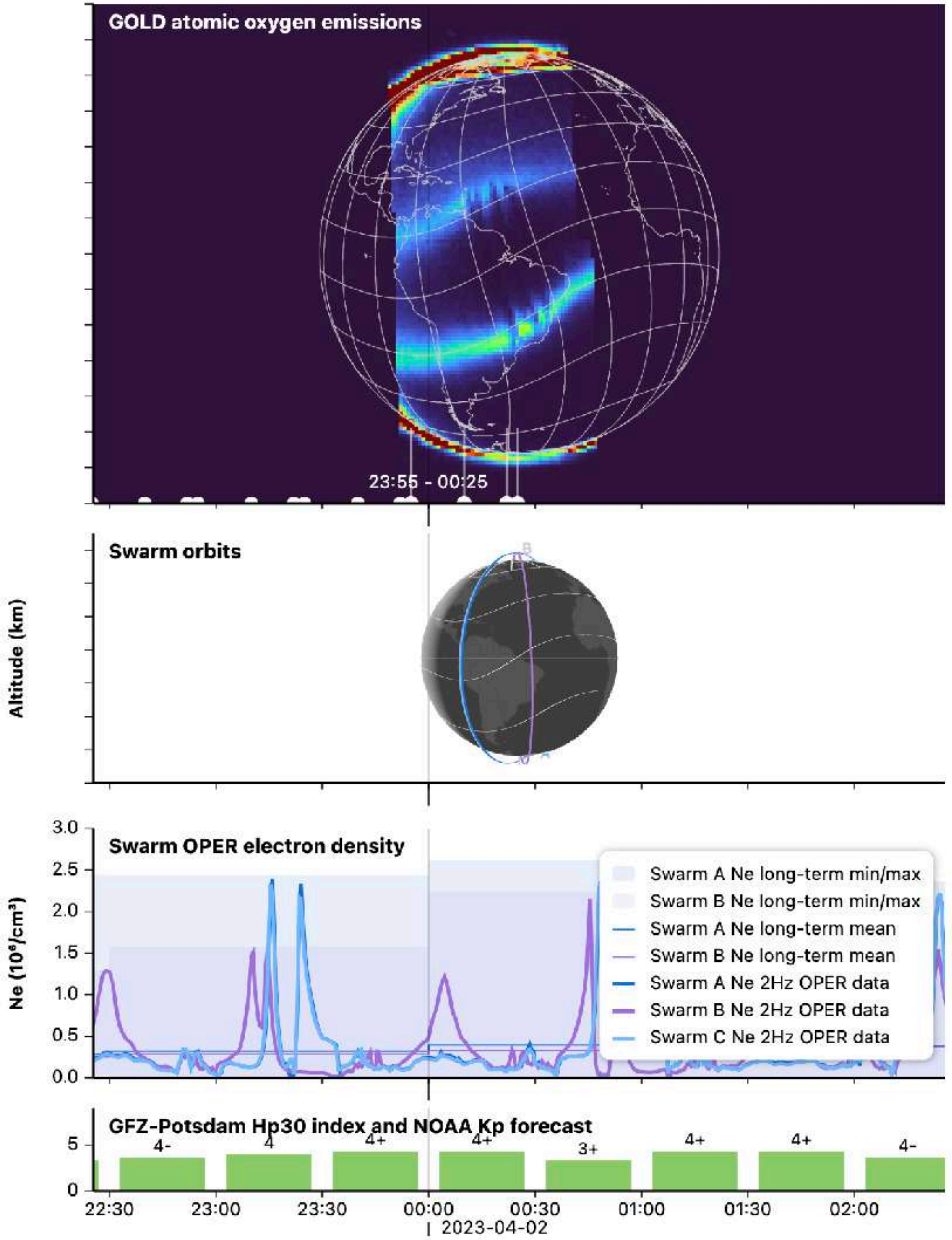


Epoch-based image sequences

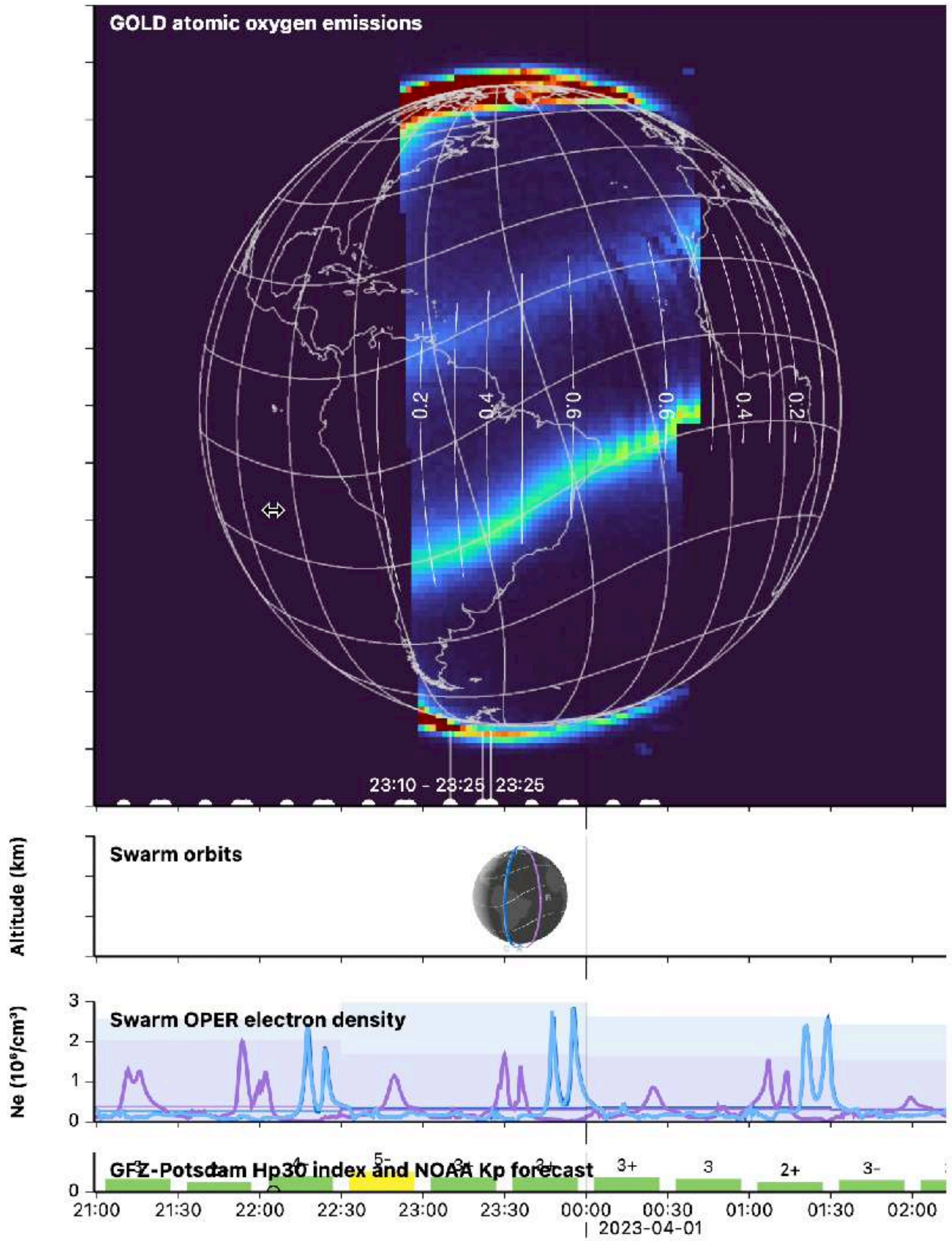
GOLD and Swarm example

1. Individual GOLD images

2. Retaining a short history of GOLD images making use of transparency

3. Static overlays of coastlines and graticule

4. Overlay of IBP model contour lines and comparison with in-situ Swarm B (purple) Ne data



Validation of 3D view using IMAGE observations