



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

Visualizing models and observations of the thermosphere-ionosphere

in support of the ESA EE10 candidate mission Daedalus

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Presentation contents

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 - WACCM-X model slices
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The Daedalus mission

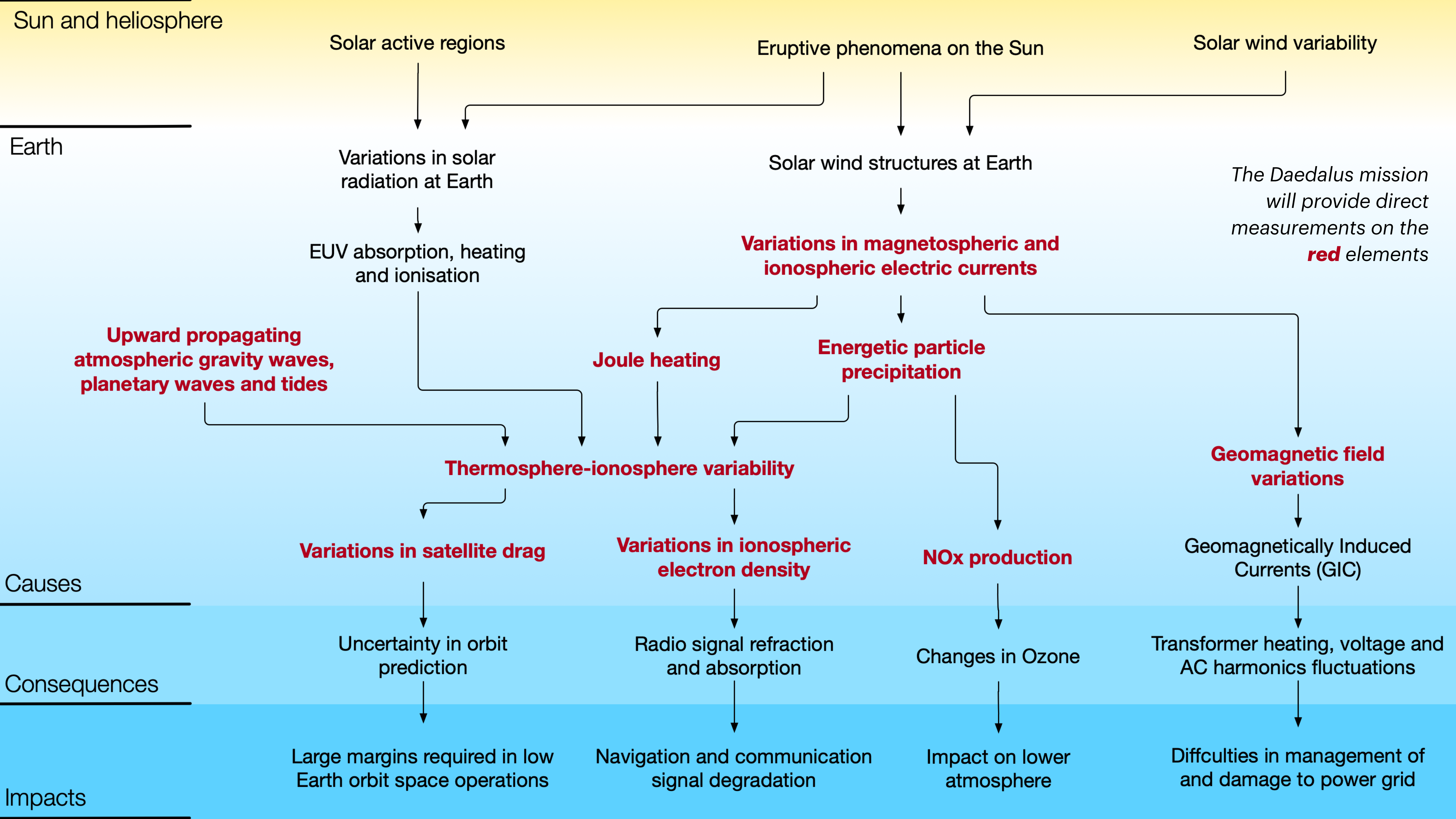
An Earth Explorer 10 candidate mission

- The ESA Earth Explorers are **cutting-edge** satellite missions to advance **scientific understanding of our planet** and to show how new technologies can be used in space. Previously realised missions in this programme include GOCE, Swarm, Aeolus, Cryosat and SMOS.
- Currently three missions (Daedalus, HydroTerra and Harmony) are undergoing **definition and feasibility studies** (phase 0). At the end of 2020, two out of three can be selected to go into more detailed studies (phase A), after which a decision on which mission will be selected for implementation as **Earth Explorer 10** will be made in 2022.

Daedalus

low flying spacecraft for the exploration
of the thermosphere-ionosphere

- The lower thermosphere-ionosphere is an **under-explored region** of the Earth's **atmosphere**, important for **space weather** effects on technological systems on Earth as well as for space operations.
- This region of the Earth's atmosphere is of high **scientific** interest, because it is strongly affected by, and interacts with the lower atmosphere, as well as with solar EUV irradiation, and coupling with the solar wind via the Earth's magnetosphere.
- Daedalus will make **in-situ measurements** of the neutral and charged particles, as well as electric and magnetic fields in this environment, from an elliptical orbit with a very low perigee (140 km and lower).
- The Daedalus measurements will put important constraints on **physics-based models**, provide much needed data for **empirical models**, and support new types of detailed investigations into the **energetics, dynamics** and **chemistry** of the lower thermosphere-ionosphere.



More information on Daedalus

For more detailed information on the mission definition and science, visit:

- The Daedalus website at <https://daedalus.earth/>
- [Our presentation in EGU2020 Session 3.1](#), scheduled for chat on Thursday, May 7, 08:30–12:30
- Our virtual conference (originally planned as a splinter during EGU2020) with several presentations and discussions by scientists ([agenda here](#)). Registration is possible via: <https://tinyurl.com/vkvumuq>.

The role of visualisations

The scientific domain covered by Daedalus is **not as well known** as many other Earth science disciplines.

It is characterised by very **dynamic processes**, for example during geomagnetic storms, densities and winds can exhibit order of magnitude variations that take place on time scales of just minutes (local) to hours (global).

High quality visualisations, in particular making use of **3D graphics** to convey spatial variability, as well as **animation** to convey time variation, are extremely helpful tools to communicate our understanding of this region obtained through modeling, and the role that the mission will play in improving this understanding.

In this work, the output of **current state-of-the-art models** of the thermosphere-ionosphere are coupled with **3D animation software**.


The **WACCM-X model** is especially useful for this purpose, since it can be used to show the **connection** with lower atmospheric layers, with which many people are more familiar.

How to view the animations

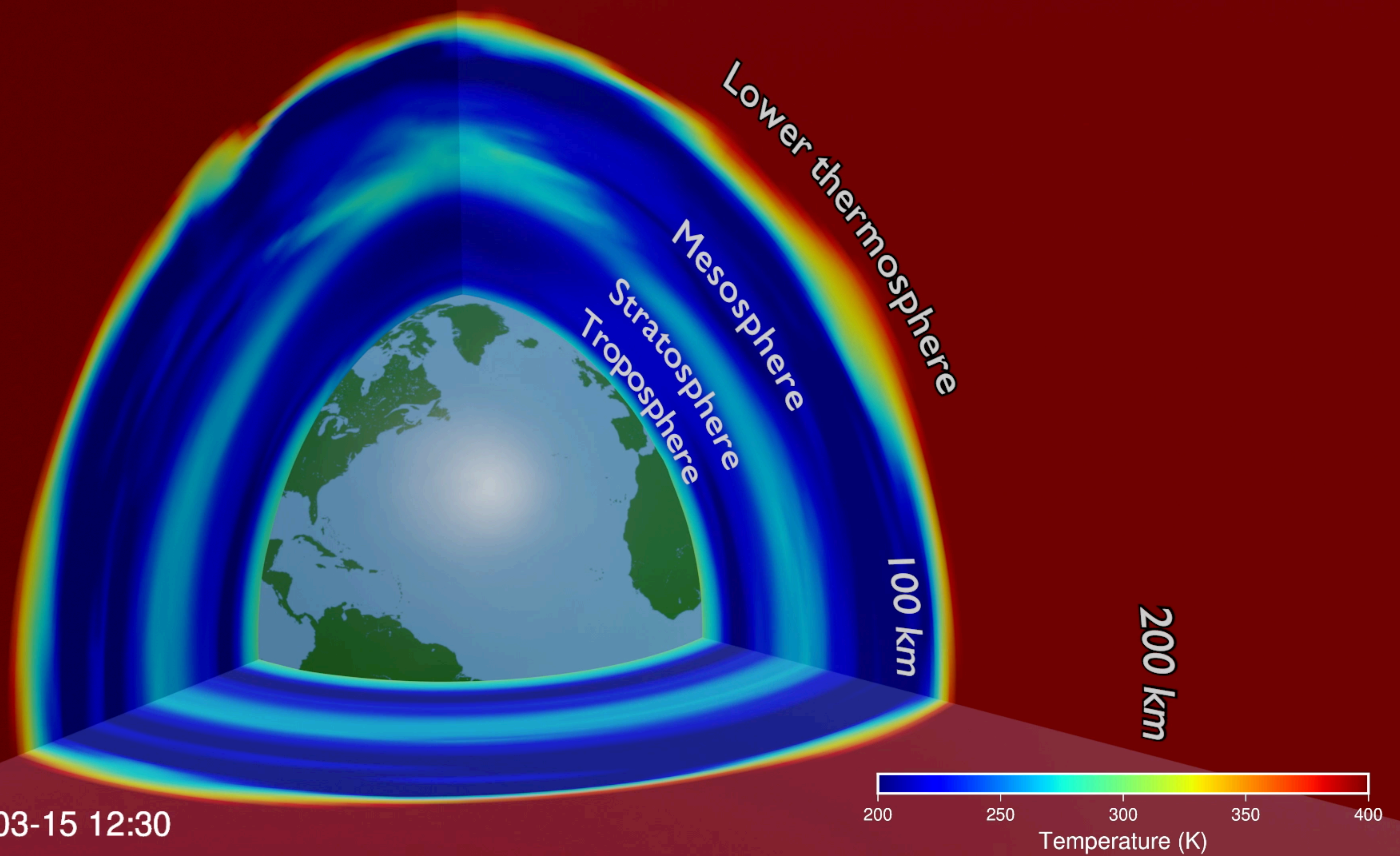
The format restrictions of this EGU 2020 presentation do not allow the embedding of many large video files.

The next slides will therefore only show still frames from some of the videos in the PDF version of this presentation.

The full animations will be uploaded to the Daedalus YouTube channel:
<https://www.youtube.com/channel/UCDJNwxvy736RR4pkbVV7u5g>.

Several videos are already available there, and others will be uploaded and updated once they approach a finished state. Direct links will be provided in the PDF, where available, making use of this symbol: 

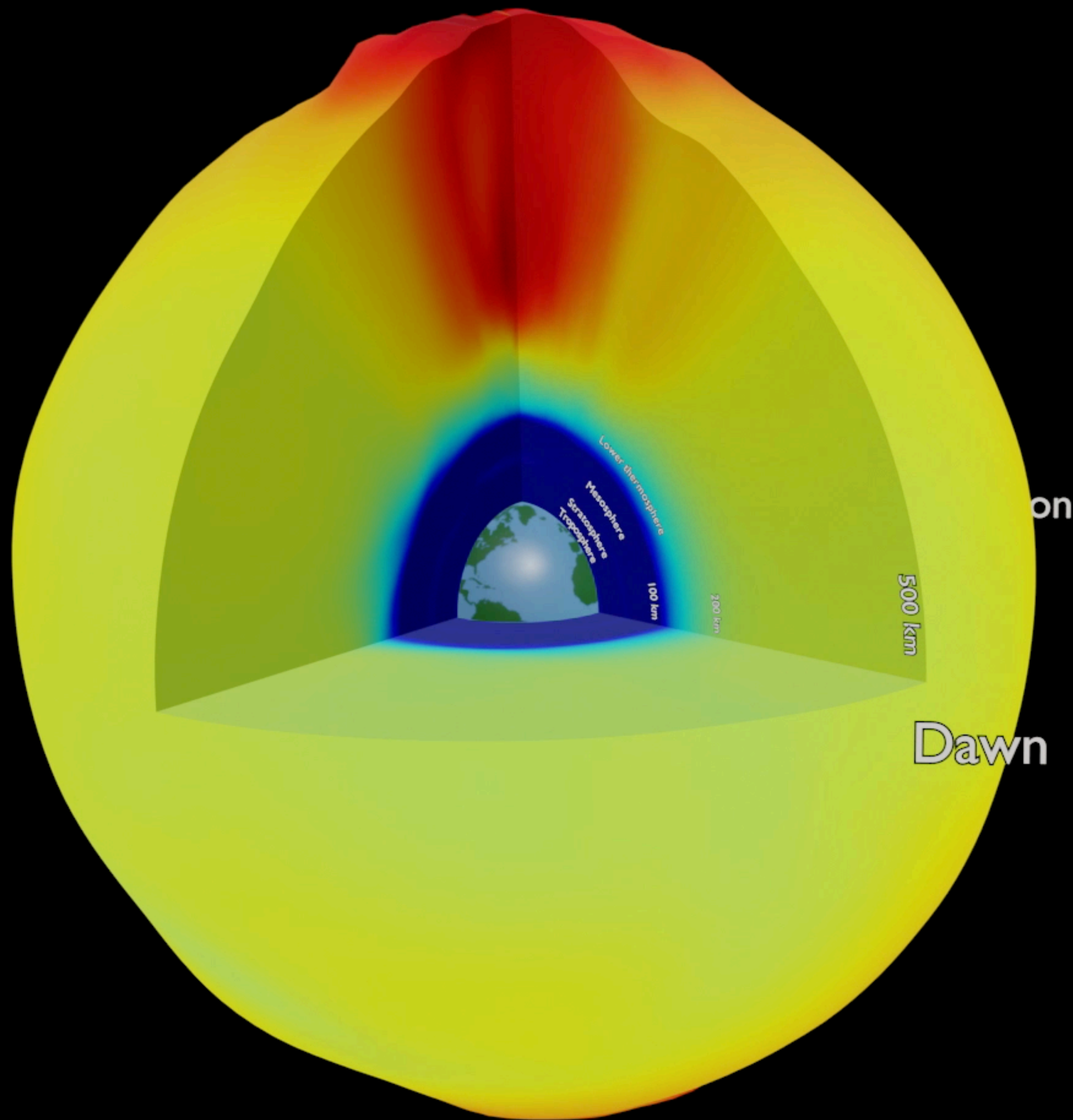
Examples part 1: **WACCM-X model slices**





Midnight

Dawn

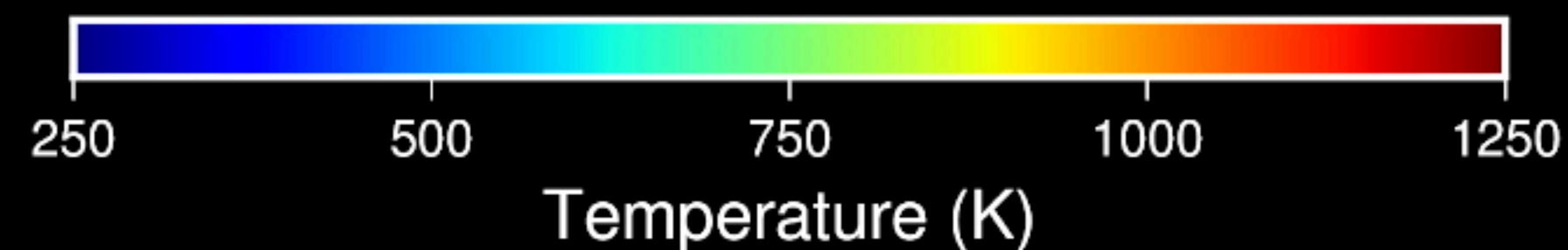


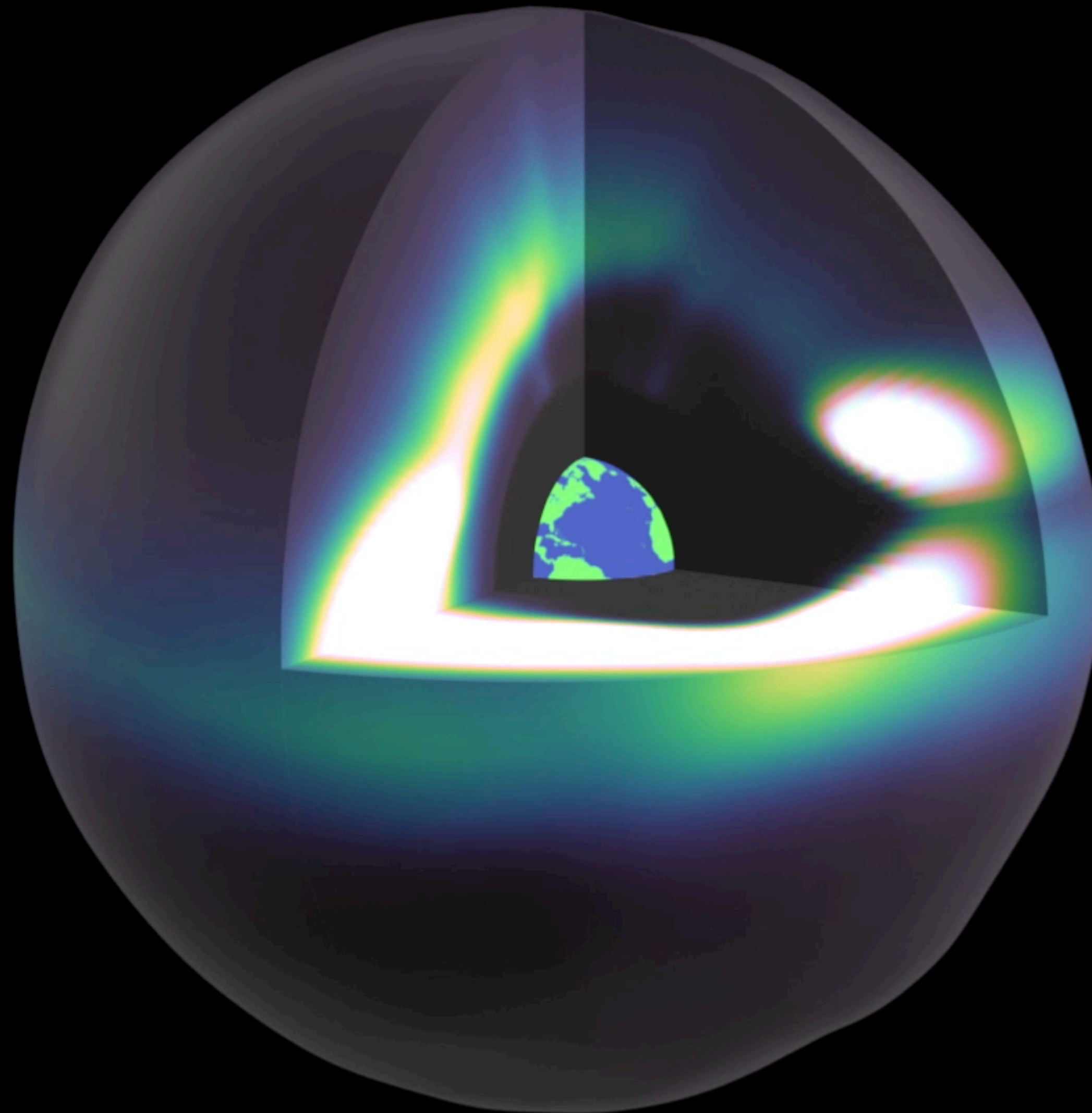
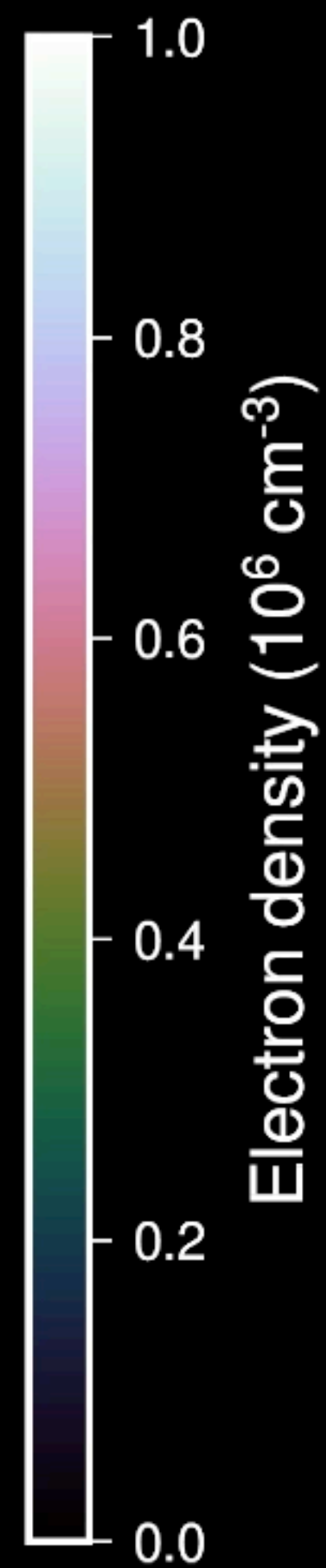
These animations show four slices through the output of the WACCM-X model. Heights above the surface are exaggerated up to 50 times.

The outer shell is the topmost pressure level of the model, at >500 km altitude. Two vertical slices at 0 and 90 deg longitude, and a vertical slice close to the equator, offer a look at the vertical variations in the model.

The varying heights of the pressure levels are converted into a so-called mesh-cache or point cache file for animation. The temperature data slices can then be provided in the form of a series of rectangular image maps (PNG files) that are projected onto this constantly changing geometry by the 3D software.

2015-03-17 06:55



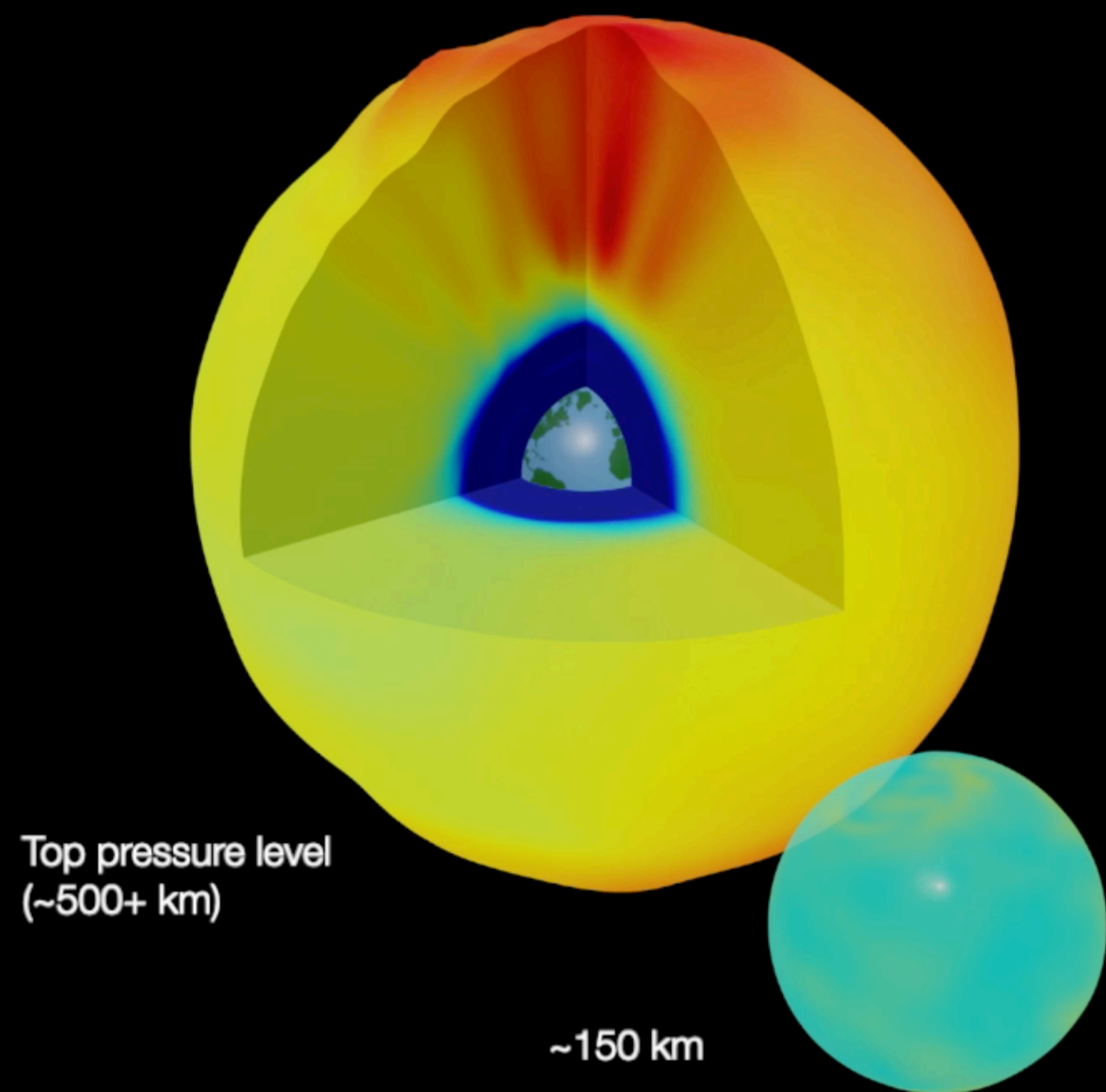


The large range of values of some parameters can be a problem in visualisation.

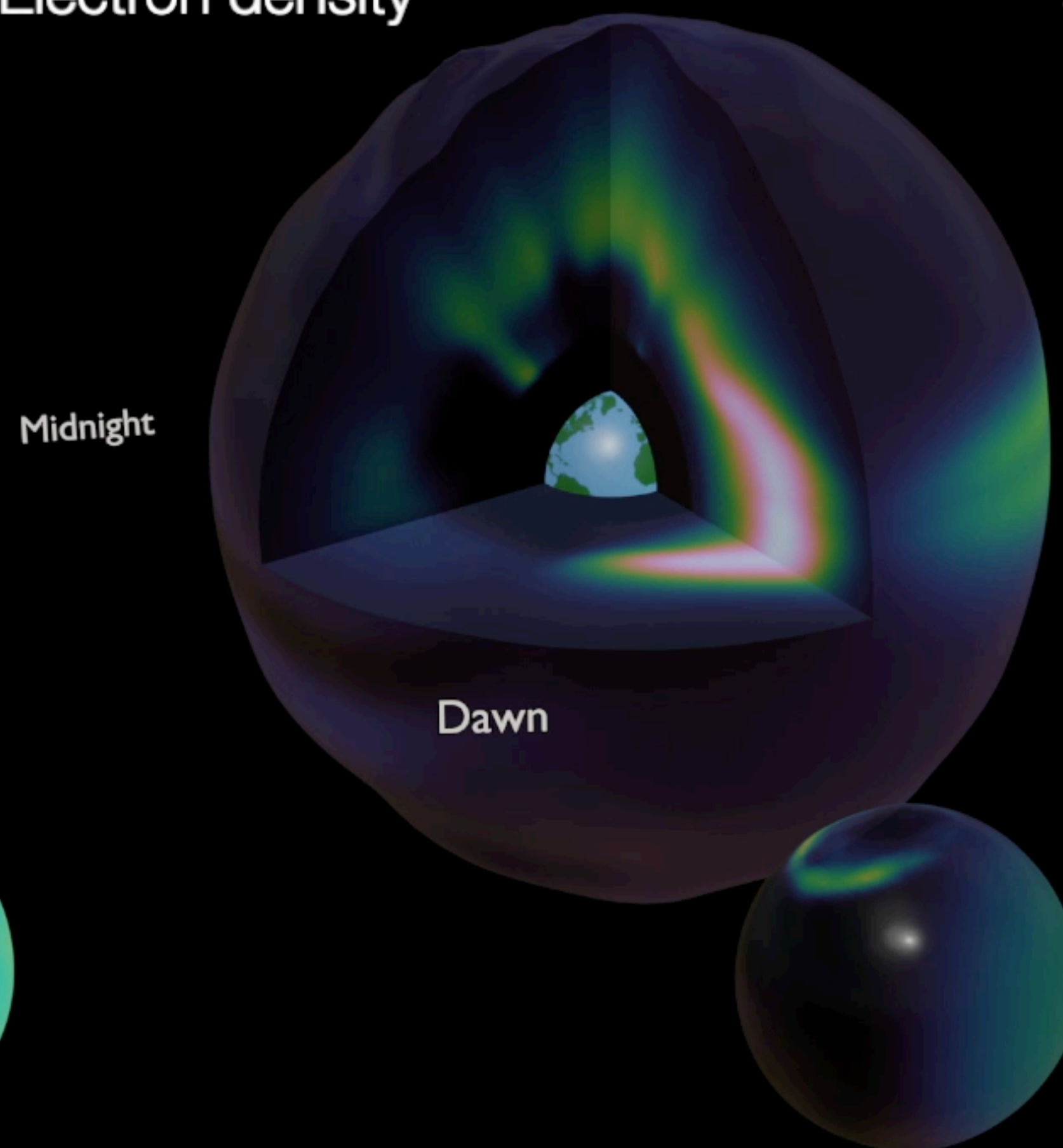
The maximum electron density during this simulation reaches twice the maximum in the colour scale used here.

Because of this, the F-region peaks are saturated in white. But this choice enables us to still see some detail in the E-region, below 200 km.

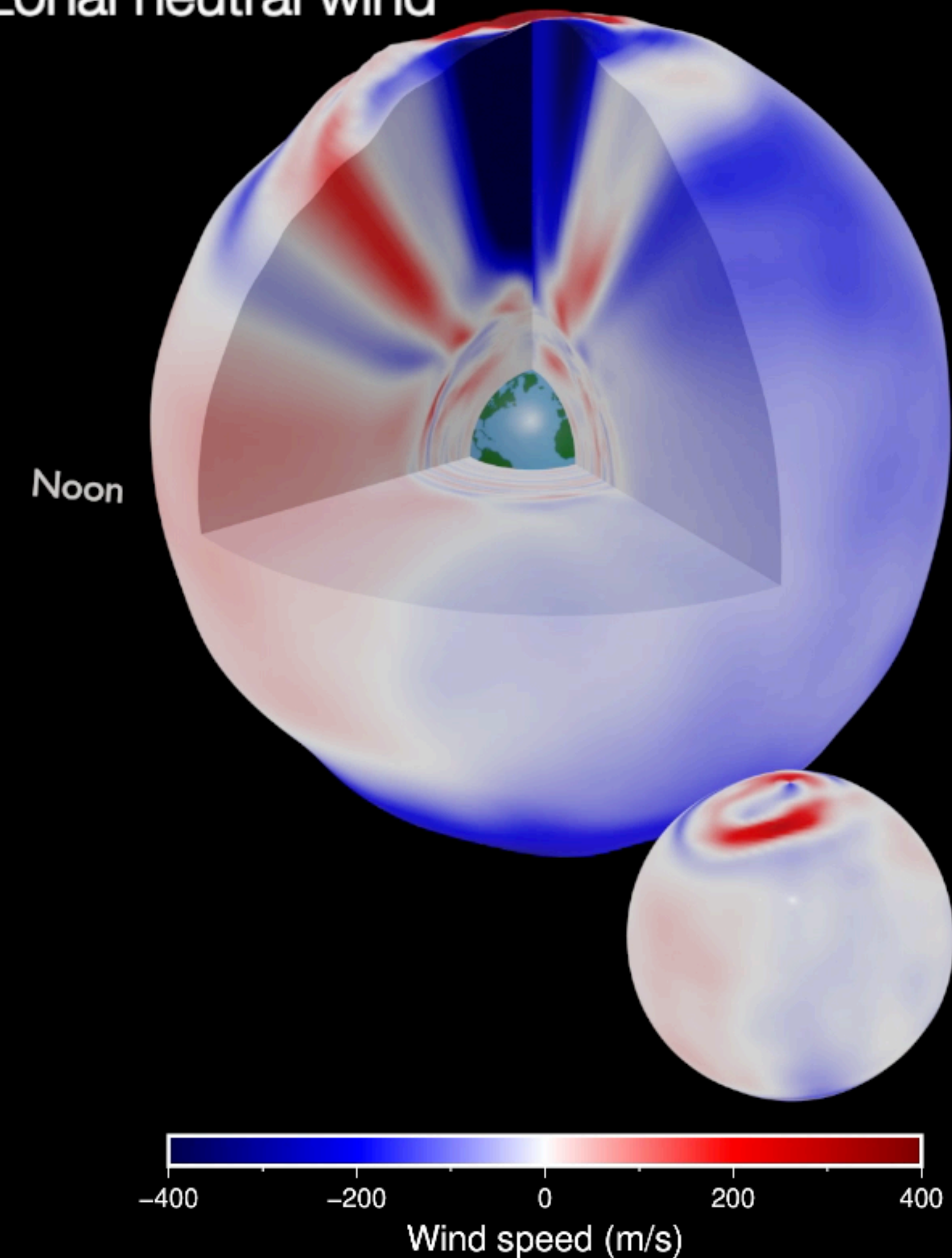
Temperature



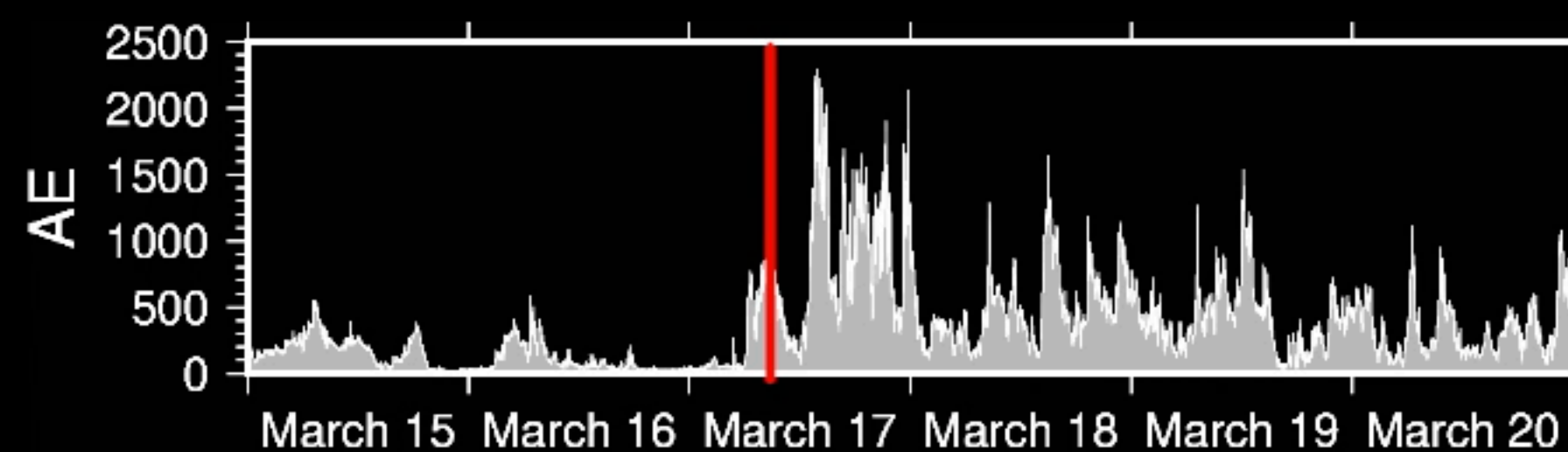
Electron density



Zonal neutral wind

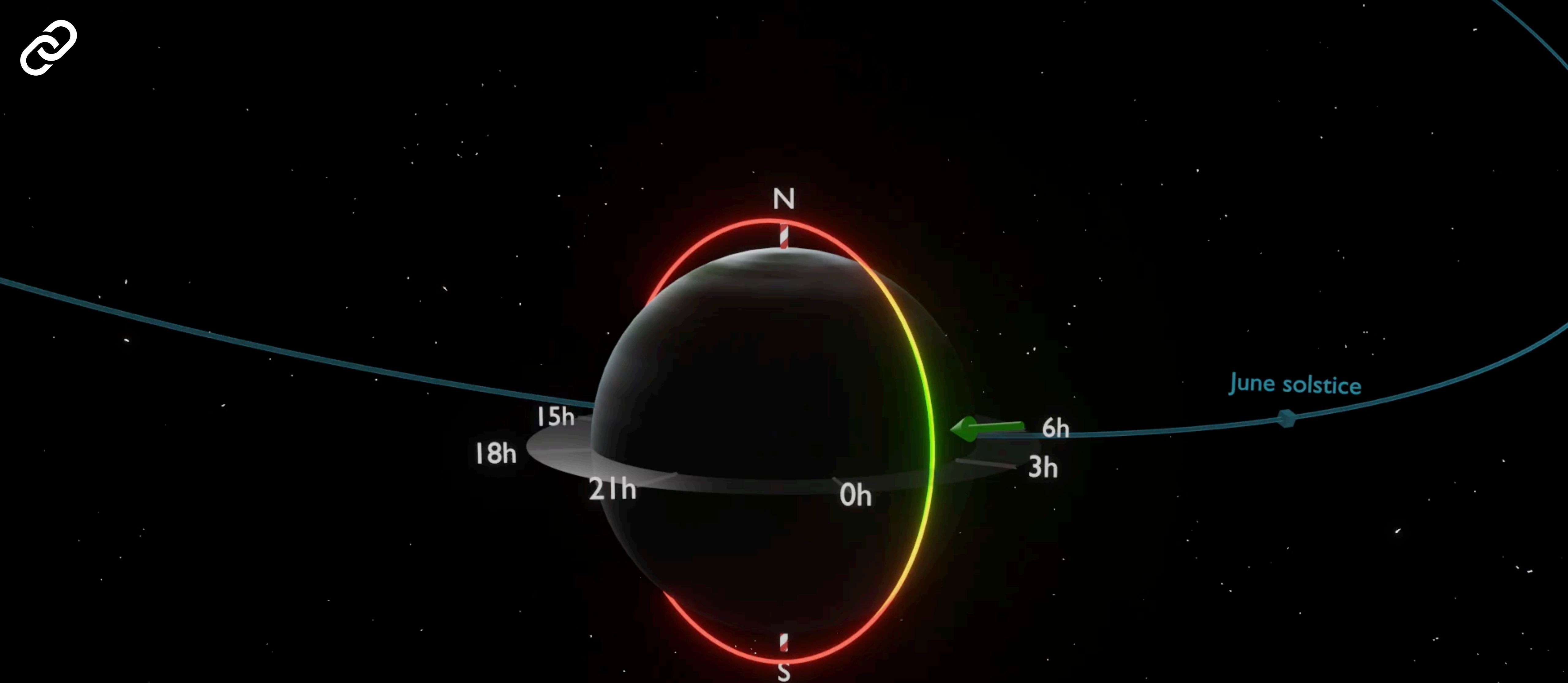


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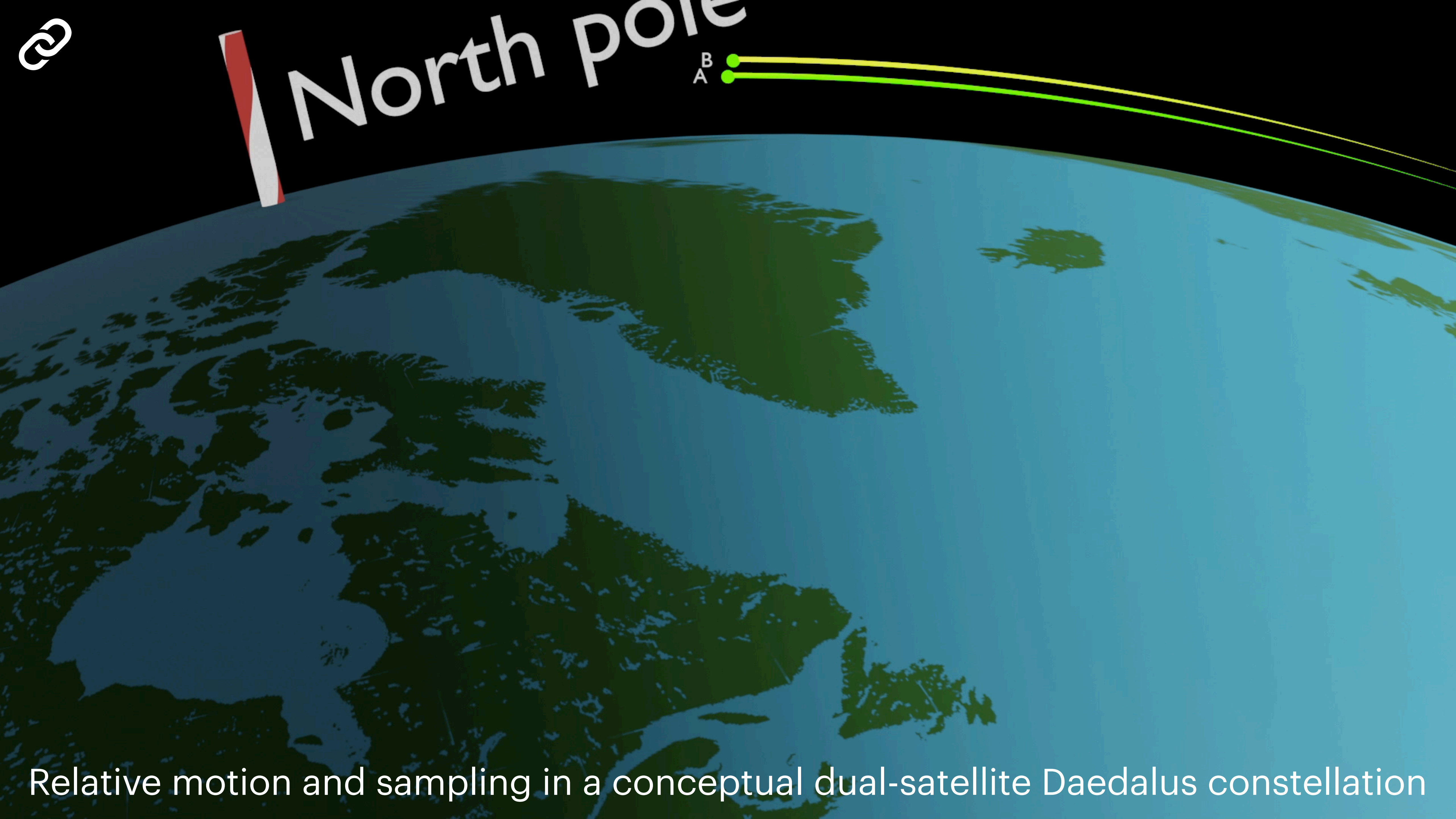


Examples part 2:

Sampling of the thermosphere-ionosphere along the Daedalus orbit



The orientation of the orbit of Daedalus will precess under the influence of Earth's gravity. This will bring the perigee, where the most important measurements will take place, to a large range of different latitudes and local times, over the duration of the mission.



Relative motion and sampling in a conceptual dual-satellite Daedalus constellation

2015-03-16 03:40:00

Vertical profiles at satellite latitude and longitude

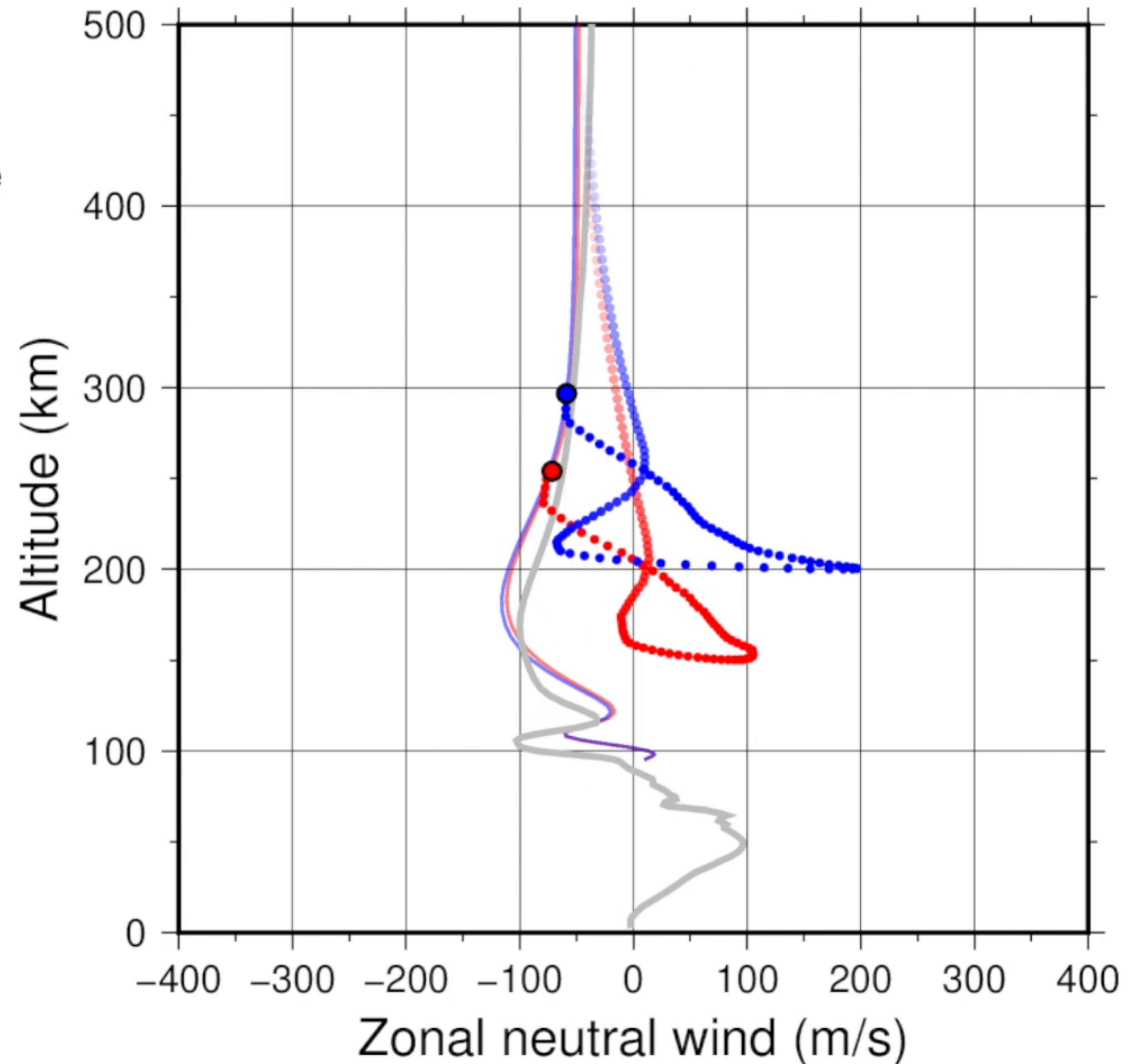
Thin red/blue lines: TIE-GCM 2.0

Grey line: WACCM-X 2.1

Res/blue dots: TIE-GCM sampled at satellite altitude

Red: Satellite A (perigee 150 km)

Blue: Satellite B (perigee 200 km)

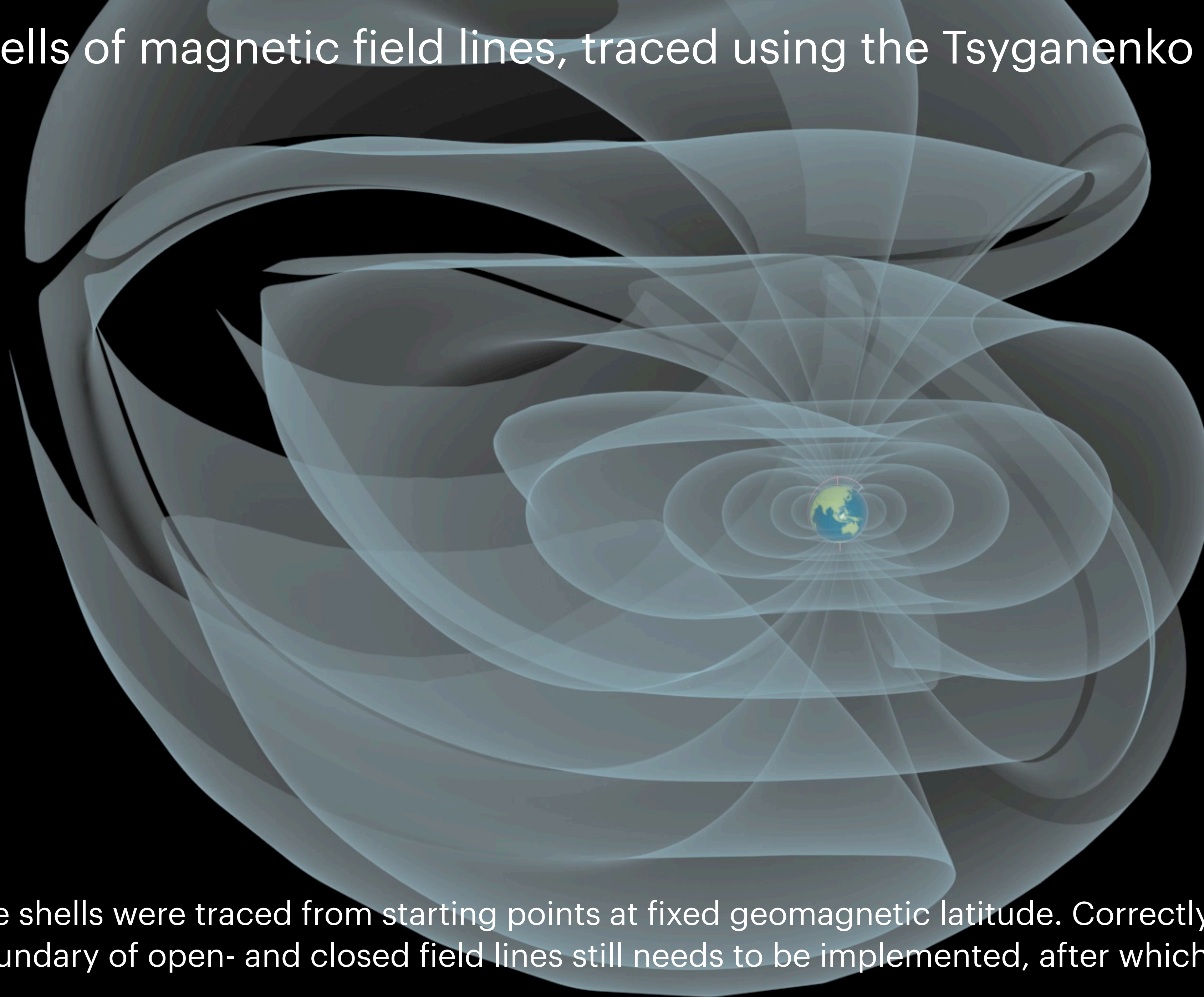


This video will need to be finalised before it will be published on [our YouTube channel](#). Please check back later.

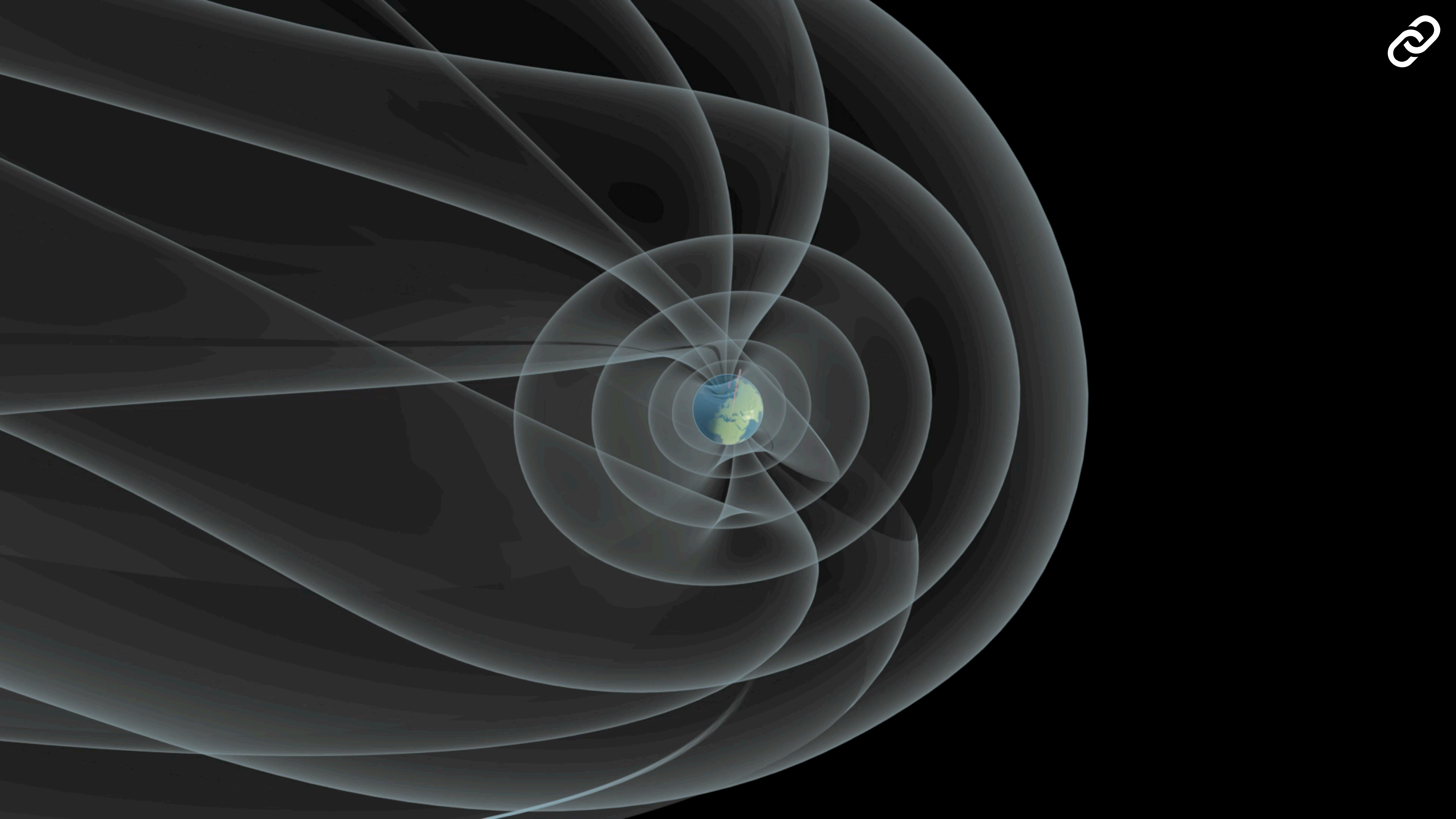
Examples part 3:

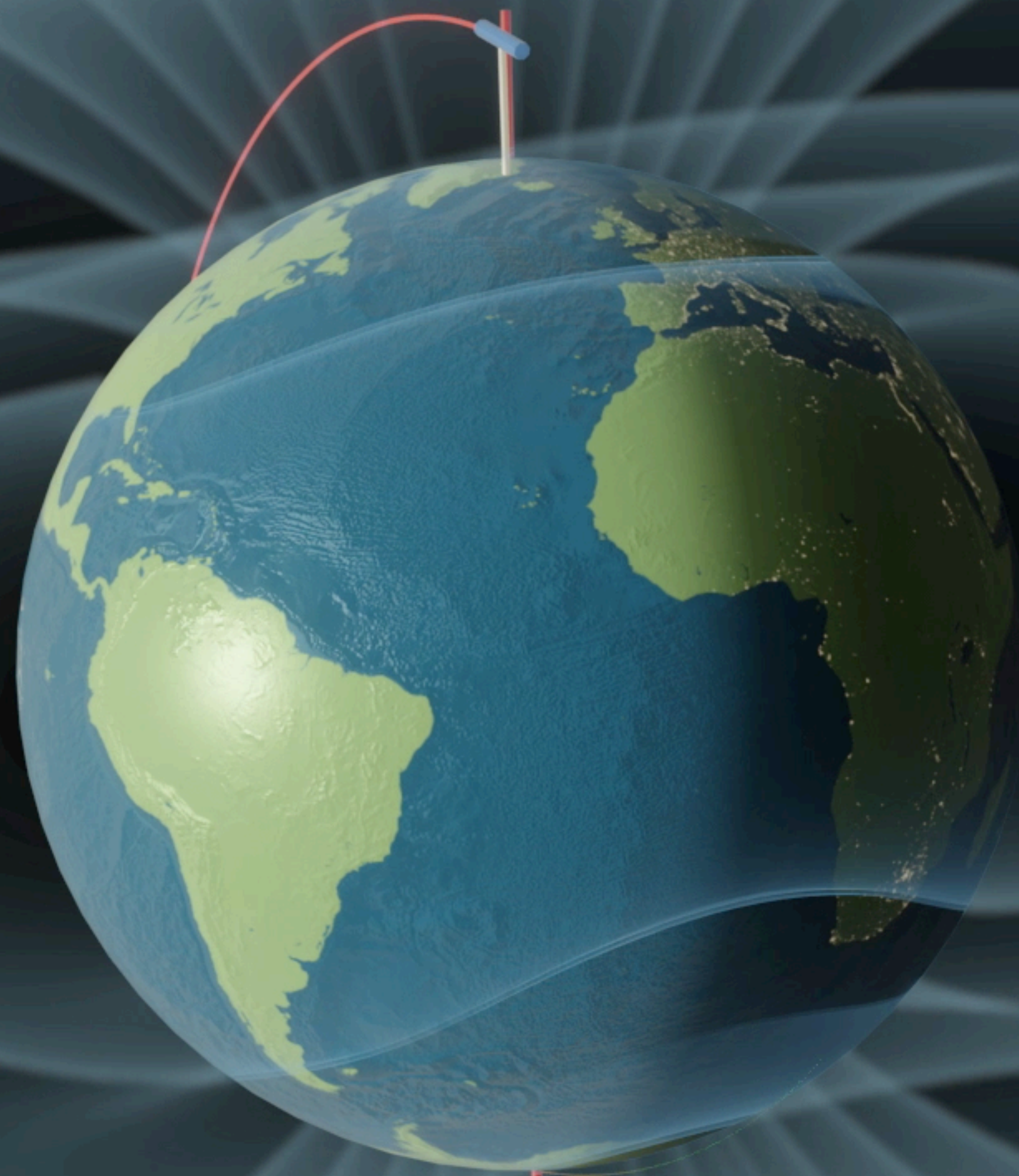
Visualising the Magnetosphere

Shells of magnetic field lines, traced using the Tsyganenko geopack08 code



The shells were traced from starting points at fixed geomagnetic latitude. Correctly connecting the geometry at the boundary of open- and closed field lines still needs to be implemented, after which the video will be updated.





The Earth material is kept simple, with just two colours for continents and oceans, since the focus should not be on the Earth's surface here. Still, adding a bit of bathymetry and topography information, as well as night lights, adds to the feeling of looking at a physical object and a sense of orientation.

Overview of tools and code repositories used

Software tools used

- 3D animations were made using the free and open source Blender software (www.blender.org). Blender has excellent possibilities for integration with Python scripts.
- Unless otherwise noted, 2D animations and static graphics were made using the free and open source Generic Mapping Tools (<https://www.generic-mapping-tools.org>).
- Apple Motion software was used to combine animation elements with static elements and transitions. It is also possible to do this using free software, including in Blender.
- Conversion of model output files to graphics software input was done using Python, the NetCDF4, numpy and pandas packages, and the Jupyter Notebook development environment.
- The astropy and apexpy packages were used for coordinate transformations.

Code repositories

- We are working on making the code that was developed to create the animations available as open source. It would be great if this would be helpful for others to also start using these powerful tools for creating visuals and animations.
- A simple set of Python functions for the creation of satellite orbits is available here: https://gitlab.com/eelcodoornbos/kepler_orbit
- A first version of the Python package that is used to interpolate within TIE-GCM and WACCM-X NetCDF output is available here: https://gitlab.com/eelcodoornbos/gcm_interpolation
- Jupyter Notebooks, further Python scripts and .blend files will be put on gitlab at a later stage. In the meantime, they are available on request.
- The TIE-GCM and WACCM-X models and GEOPACK-2008 are also open source projects.

Lessons learned and outlook

Lessons learned

- While the goal of this ongoing work is to help explain Daedalus and its science domain to those new to it, the graphics and animations have also already been great teaching, learning and discussion tools for the experts working on the mission, including the authors.
- There are excellent professional-level software tools available for creating high quality visuals, that are either low cost or free.
- Powerful tools, such as Blender and Generic Mapping Tools, historically have had steep learning curves, but their developers are making great progress in making their software more user friendly. Especially for Blender, there are excellent free video tutorials online.
- The most difficult and time consuming aspect of the work has been to glue together model outputs with these graphics and animations tools. The Python and Jupyter Notebooks ecosystem has been invaluable for that.

Outlook

- Work on the visuals will continue throughout most of 2020, at least until the presentation to ESA's Advisory Committee on Earth Observation in late fall 2020 for EE-10 mission down selection.
- Steps in the next months will be:
 - To further integrate various existing graphical elements, such as the satellite orbits, WACCM-X model interpolation, and magnetosphere morphology into single animations.
 - To further integrate with the work on the Daedalus end-to-end simulator and performance demonstration development, including visualisation of derived data types such as Joule heating rates, visualisation of the defined areas of interest, investigation of data usage scenarios, etc.

More information on Daedalus (reprise)

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