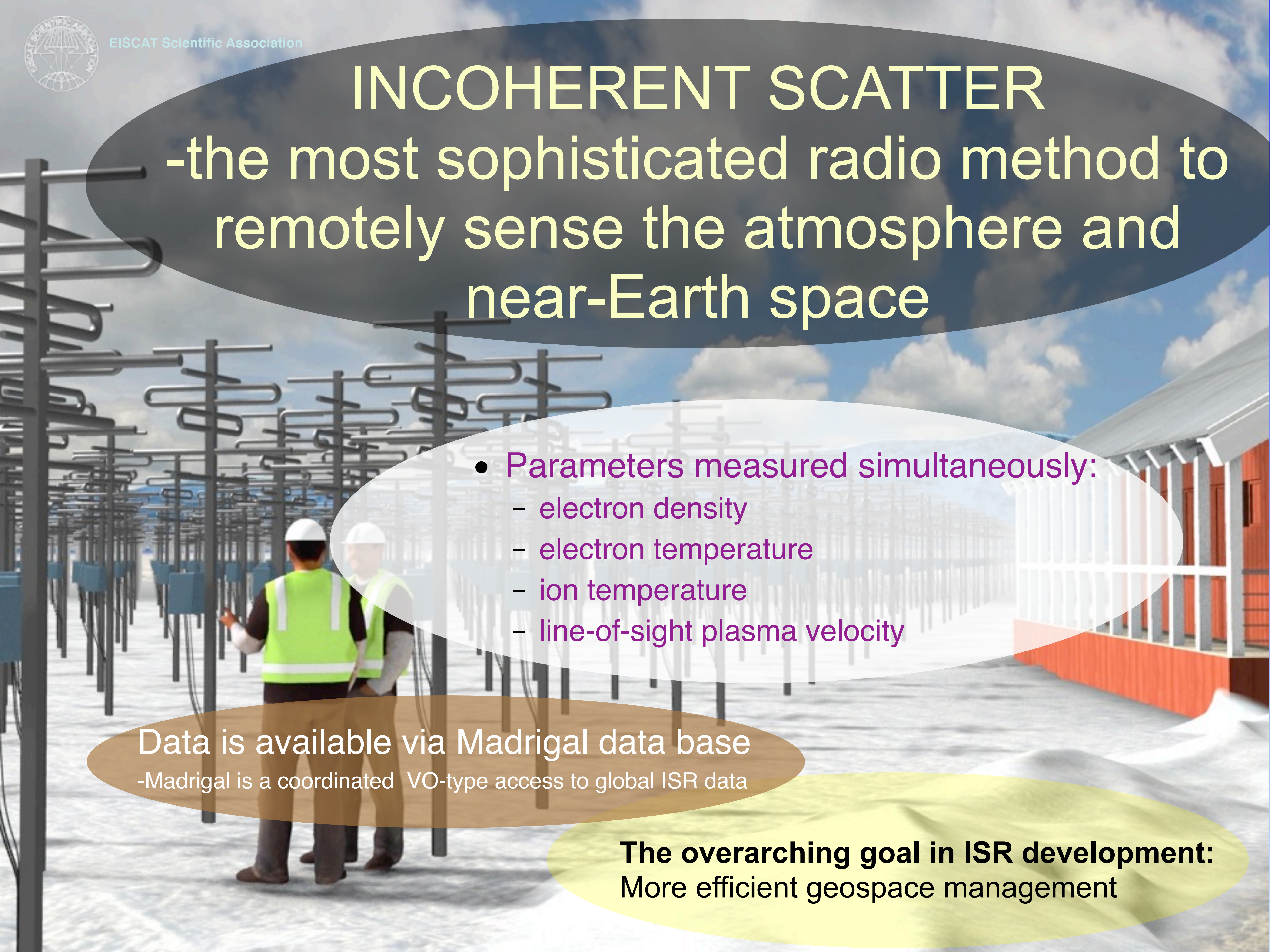
EISCAT_3D – European 3D imaging radar for atmospheric and geospace research

EISCAT Scientific Association

Esa Turunen

EISCAT Scientific Association, Kiruna, Sweden

EISCAT Svalbard Radar



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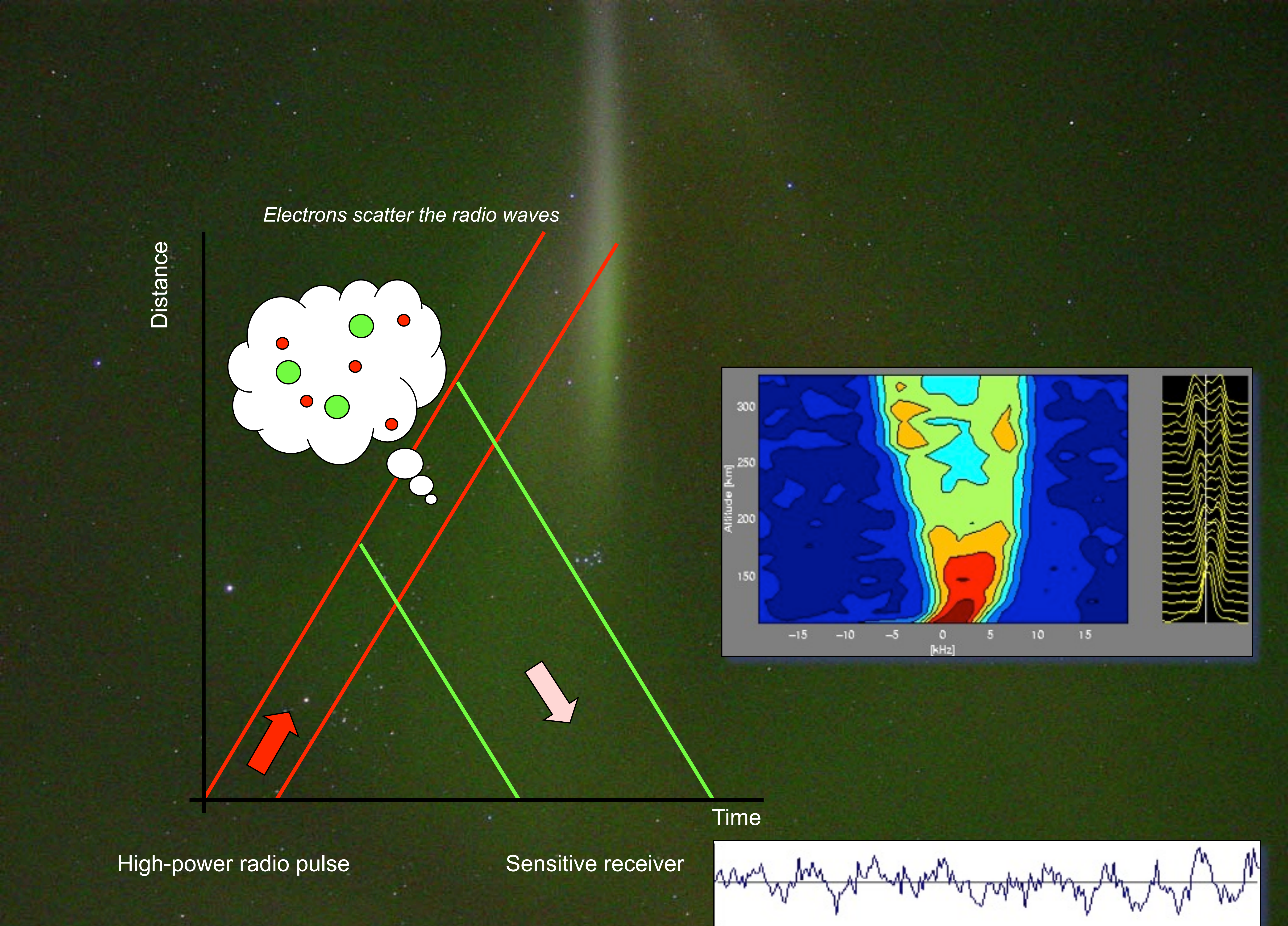
INCOHERENT SCATTER -the most sophisticated radio method to remotely sense the atmosphere and near-Earth space

- Parameters measured simultaneously:
  - electron density
  - electron temperature
  - ion temperature
  - line-of-sight plasma velocity

Data is available via Madrigal data base

-Madrigal is a coordinated VO-type access to global ISR data

The overarching goal in ISR development:
More efficient geospace management



E. Turunen, Transatlantic EU-U.S. Cooperation in the Field of Research Infrastructures, 01.10.2010, Rome

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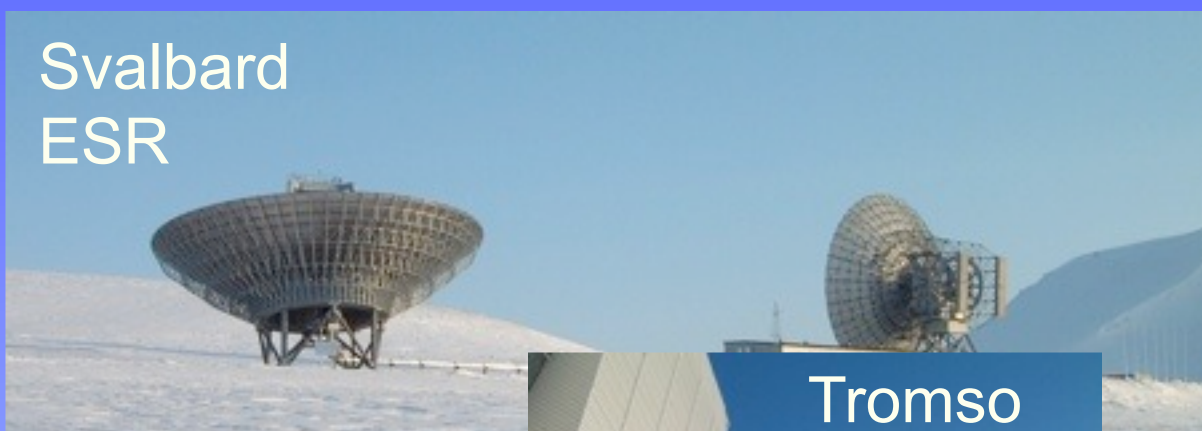
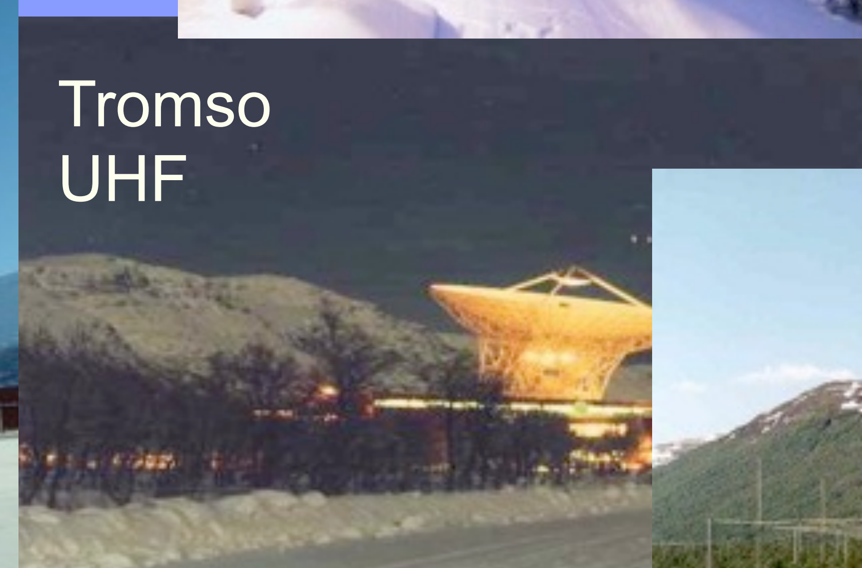
Associate countries and institutes

Contributing:

EISCAT Incoherent Scatter Radars





EISCAT Svalbard Radar

EISCAT - European Incoherent Scatter Scientific Association

We want to understand the various forms of

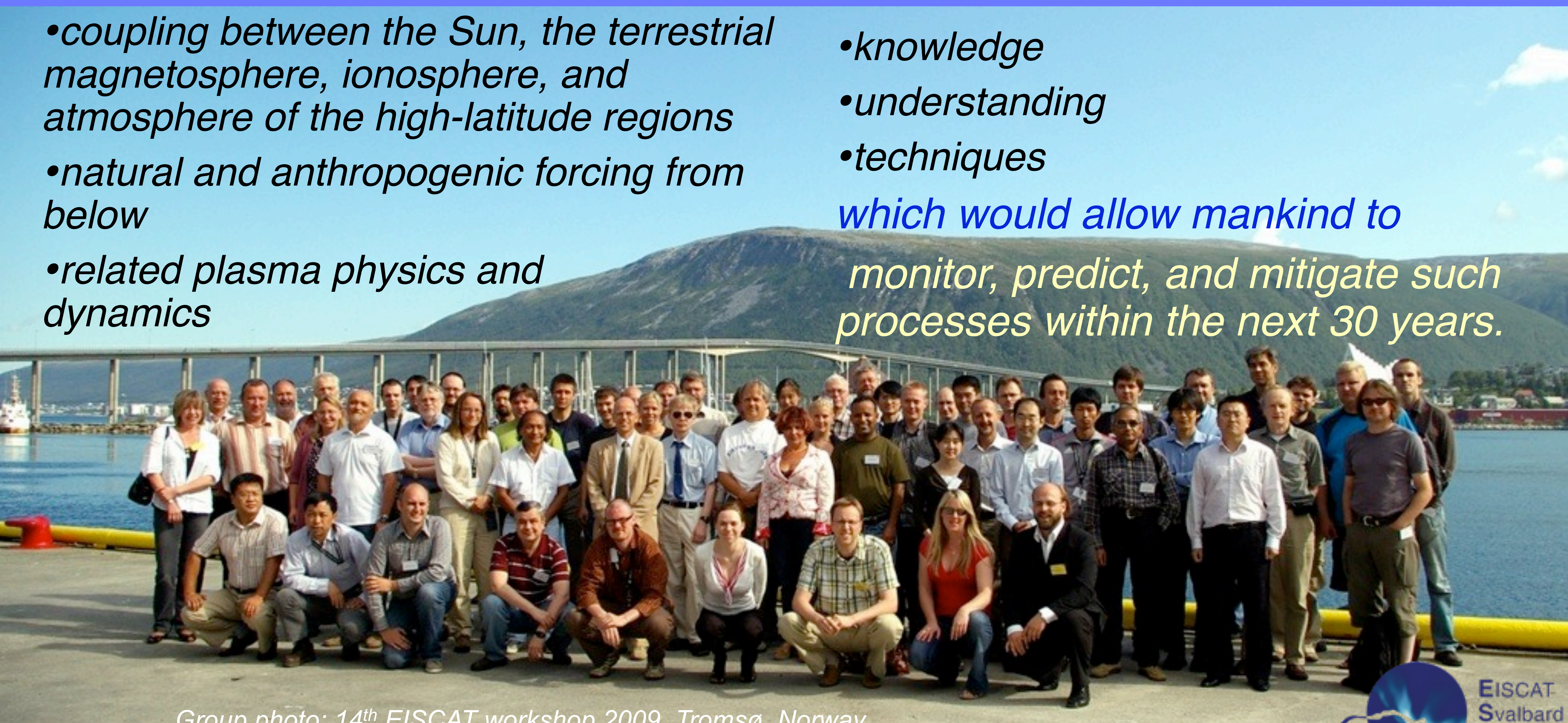
- *coupling between the Sun, the terrestrial magnetosphere, ionosphere, and atmosphere of the high-latitude regions*
- *natural and anthropogenic forcing from below*
- *related plasma physics and dynamics*

We aim to achieve the necessary

- *knowledge*
- *understanding*
- *techniques*

which would allow mankind to

monitor, predict, and mitigate such processes within the next 30 years.



Group photo: 14th EISCAT workshop 2009, Tromsø, Norway

EISCAT Svalbard Radar

EISCAT VHF 224 MHz, Tromsø

- Worlds largest klystrons in transmitter
- Antenna cylindrical paraboloid 40 m x 120 m

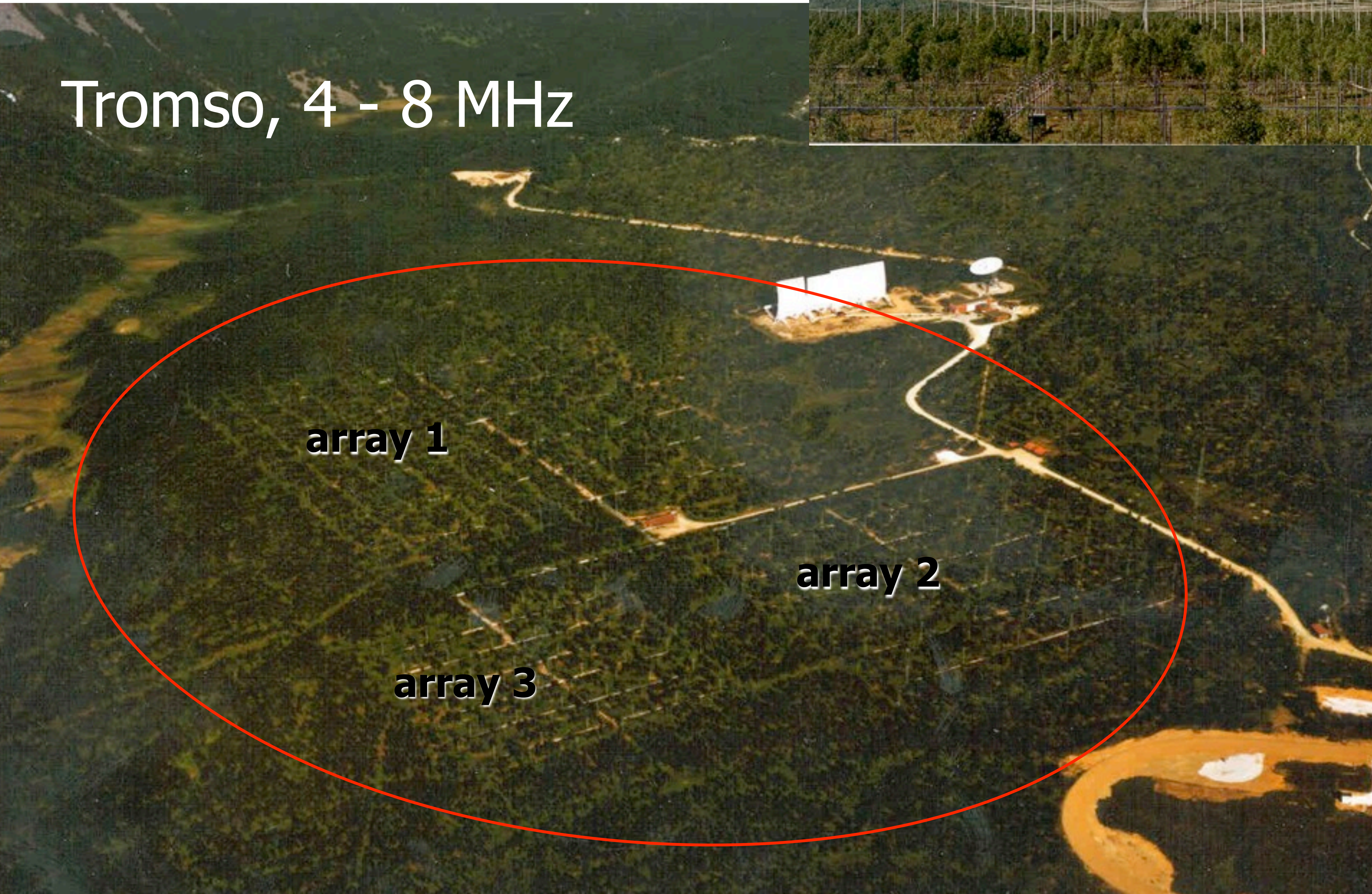
UHF radar, 933 MHz

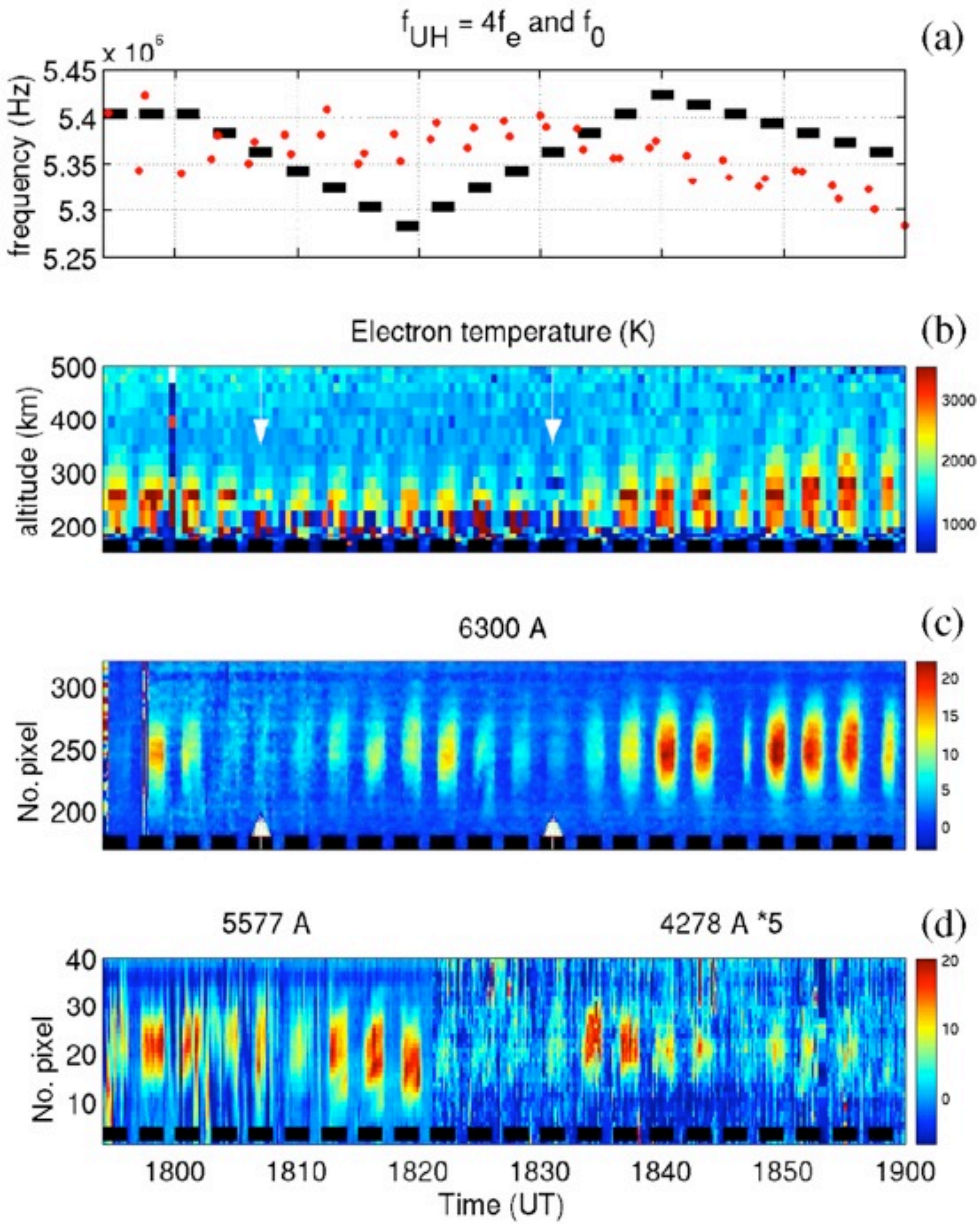
- 3 identical fully steerable 32 m paraboloids
- Passive reception also at 1.420 GHz
- Mobile phones occupy the current frequency in 2010 in Sweden and in Finland
- In Norway the Tromso UHF monostatic radar continued at least to end of 2013

EISCAT Svalbard Radar

HF Heating Facility

Tromso, 4 - 8 MHz





- Heating can produce high electron temperatures and artificial light emission.

Electron temperature

Intensity of red line

Intensity of green line

Gustavsson et al, PRL, 2006

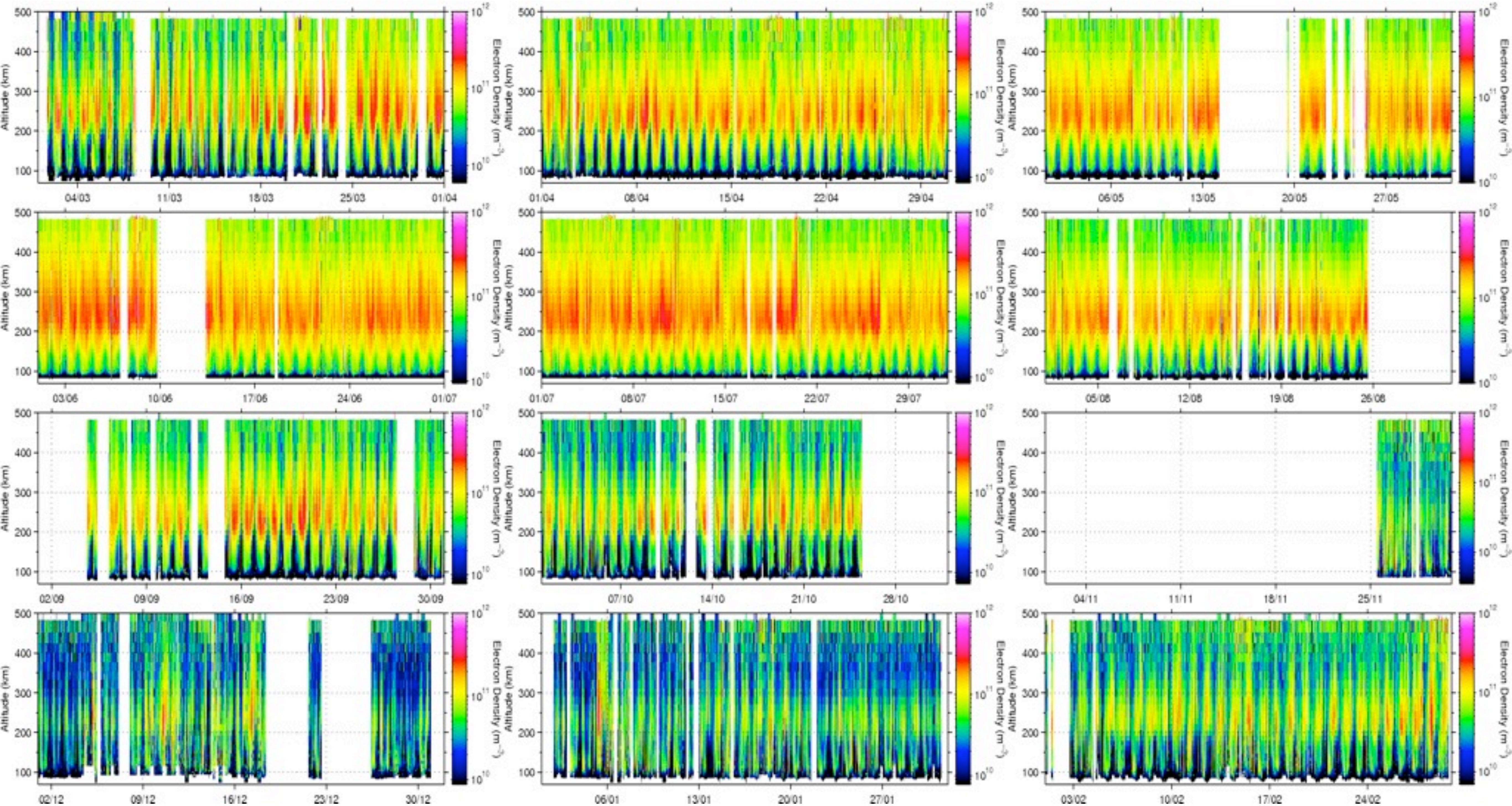
EISCAT Svalbard Radar

Fully operational now and in future - One of world’s most advanced radars:

The EISCAT Svalbard Radar

- Excellent example: the IPY one year run data!
  - Support and gain from infrastructure development in Svalbard in the ESFRI SIOS project
  - Investigate possibility for continuous long-term runs in future 2012-2014
    - NEXT SOLAR MAXIMUM 2013?
    - needs extra funding, scale 1 MEUR/ year

EISCAT Svalbard Radar data: Spring, Summer, Autumn, Winter



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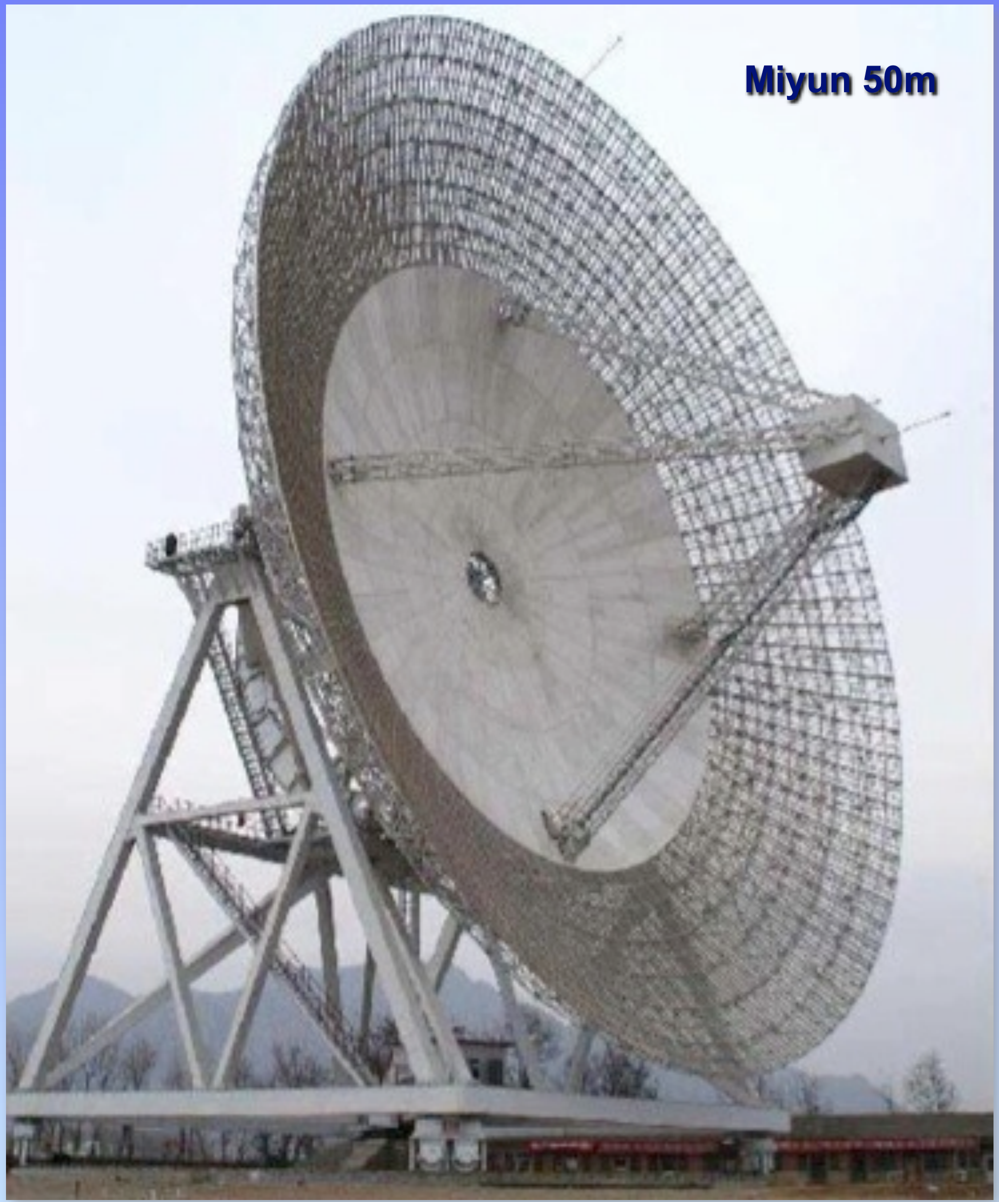
Proposal by China: ESR Third Antenna

- Feasibility study of construction ongoing
- 50 m steerable dish in a 70 m radome

- Combined ISR and Moon Project communication proposed by China



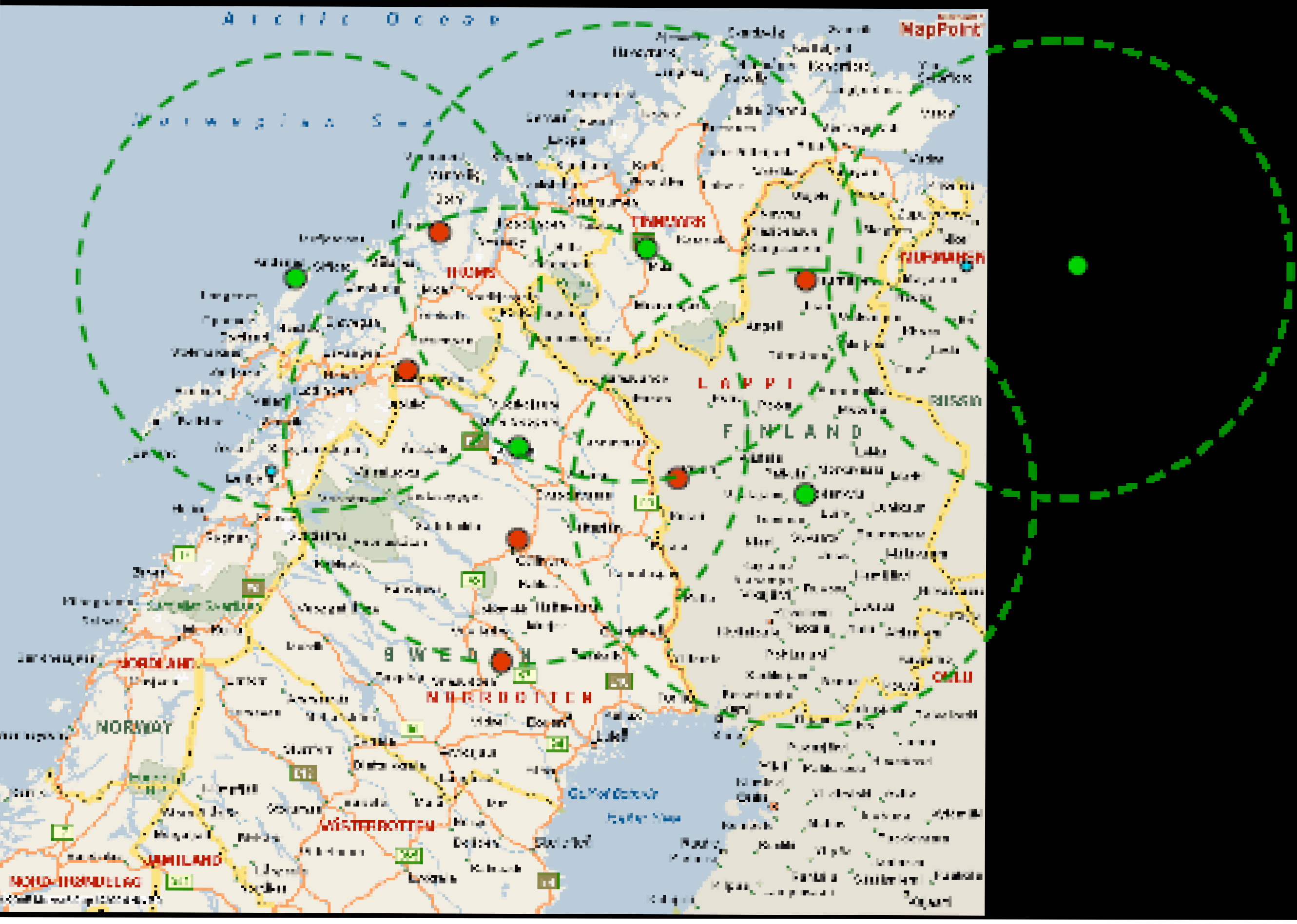
Svalbard authorities: *“The area between KHO and ESR is now allocated for science use”*

Plan for future: EISCAT_3D

SCALE: several 10's of thousands of antennas

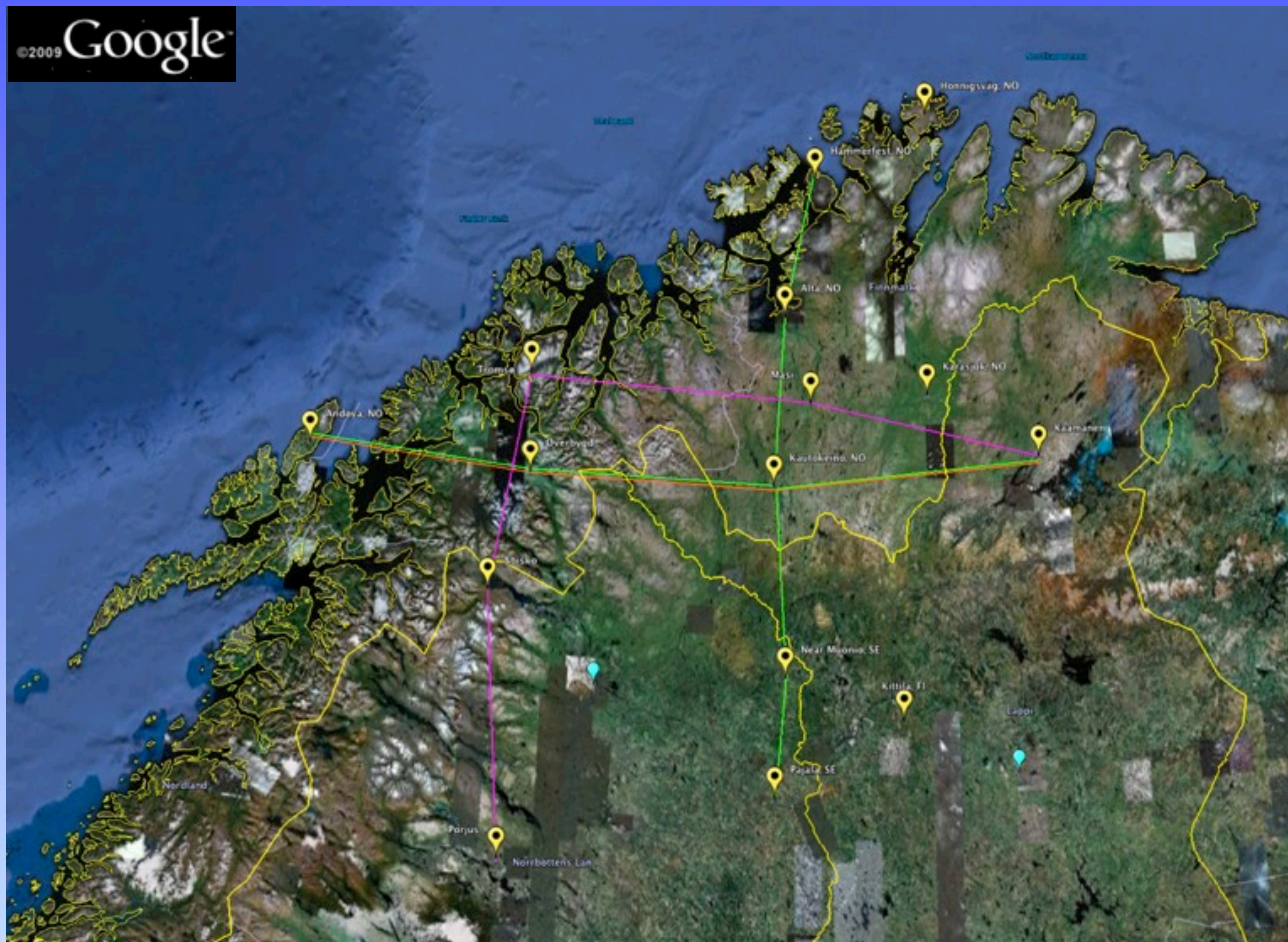
Current schedule of EISCAT 3 D

- Design Study 2005-2009
- Preparatory phase studies 2010-2014, EU FP7
  - -includes prototyping
- Construction 2014-2015
- Operation 2015-2045



- Modular construction
- Site locations need to be considered carefully
- Sites may be very different in size and purpose
- In long-term future, one could also think of a Mid-Latitude Site

Science goals should dictate the geometry of the multistatic facility



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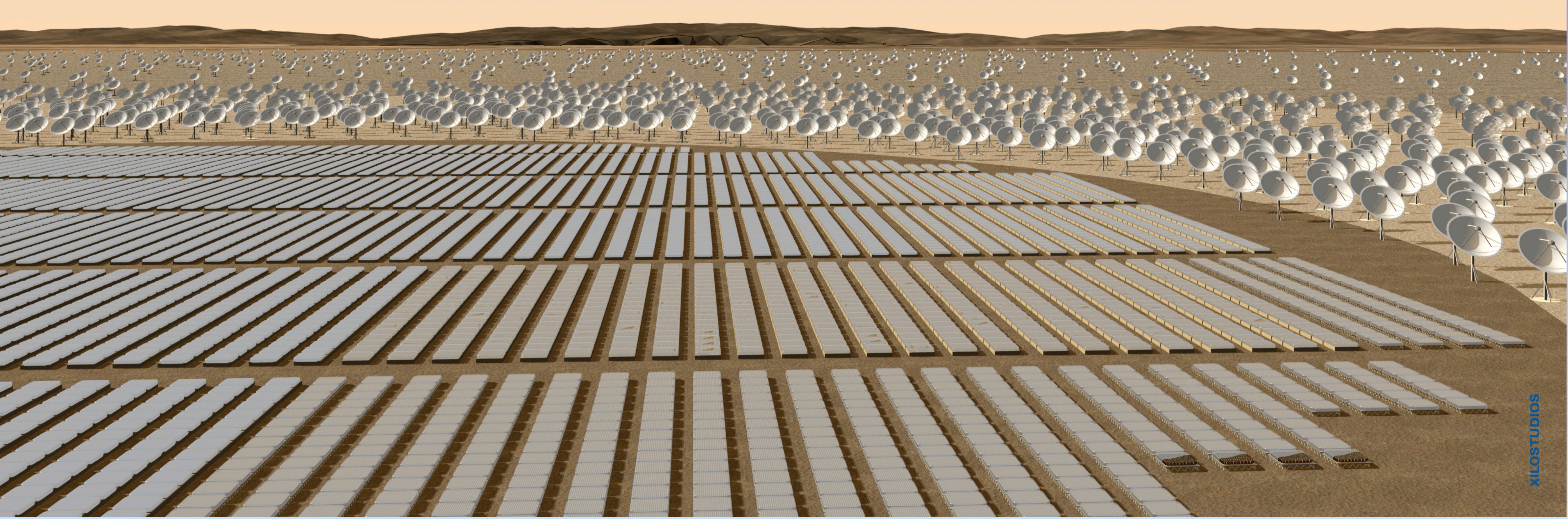
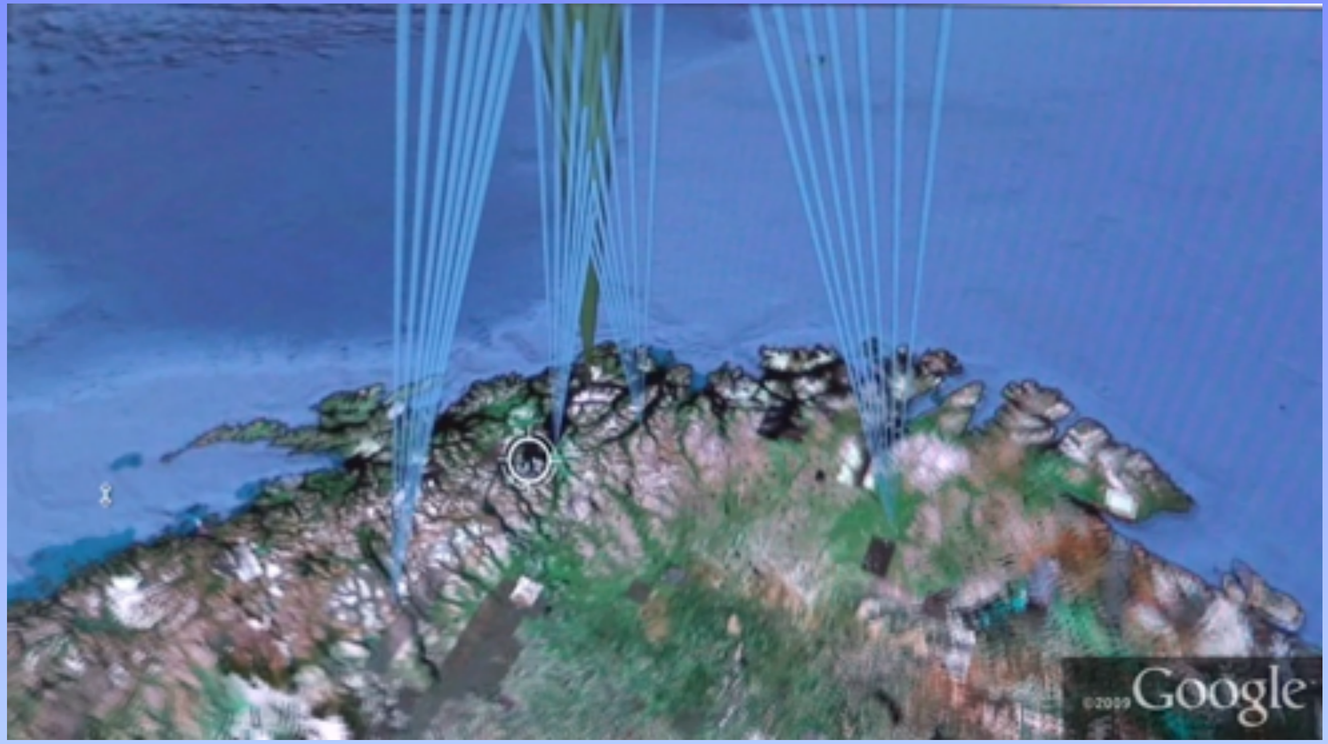
Similarity to modern radio astronomy

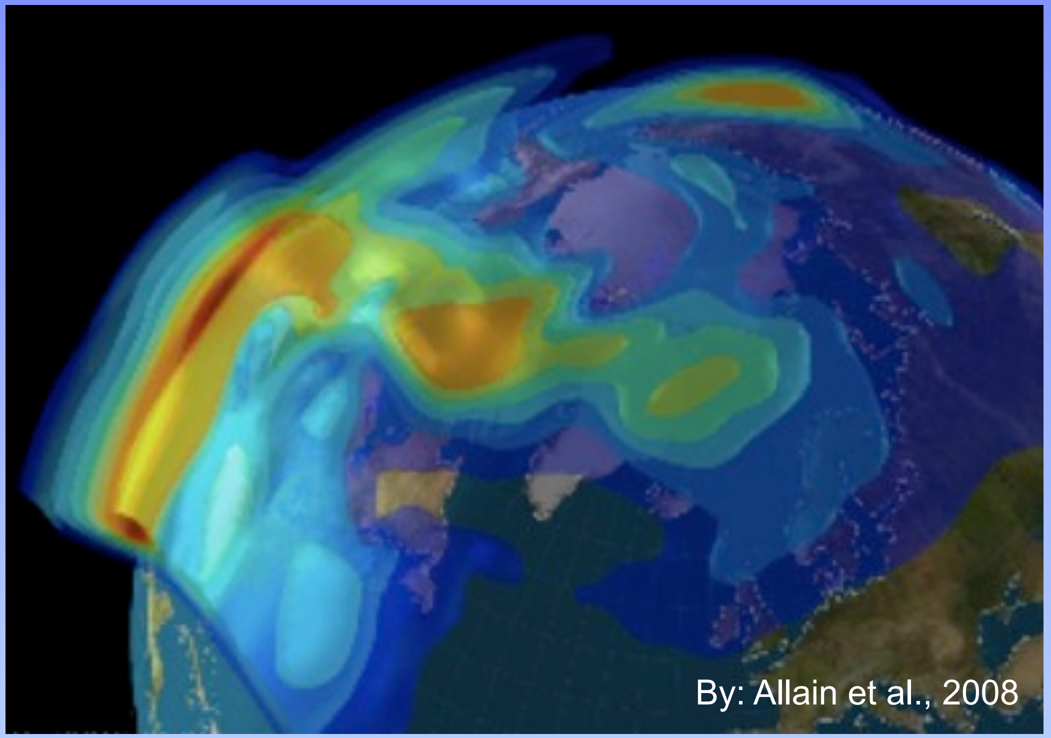
- SKA project
  - artist image below
- LOFAR (Low Frequency Array)
  - in fact one LOFAR international site was ordered to Finland, to be installed as a test and technology prototyping receiver site for EISCAT_3D in Northern Finland.



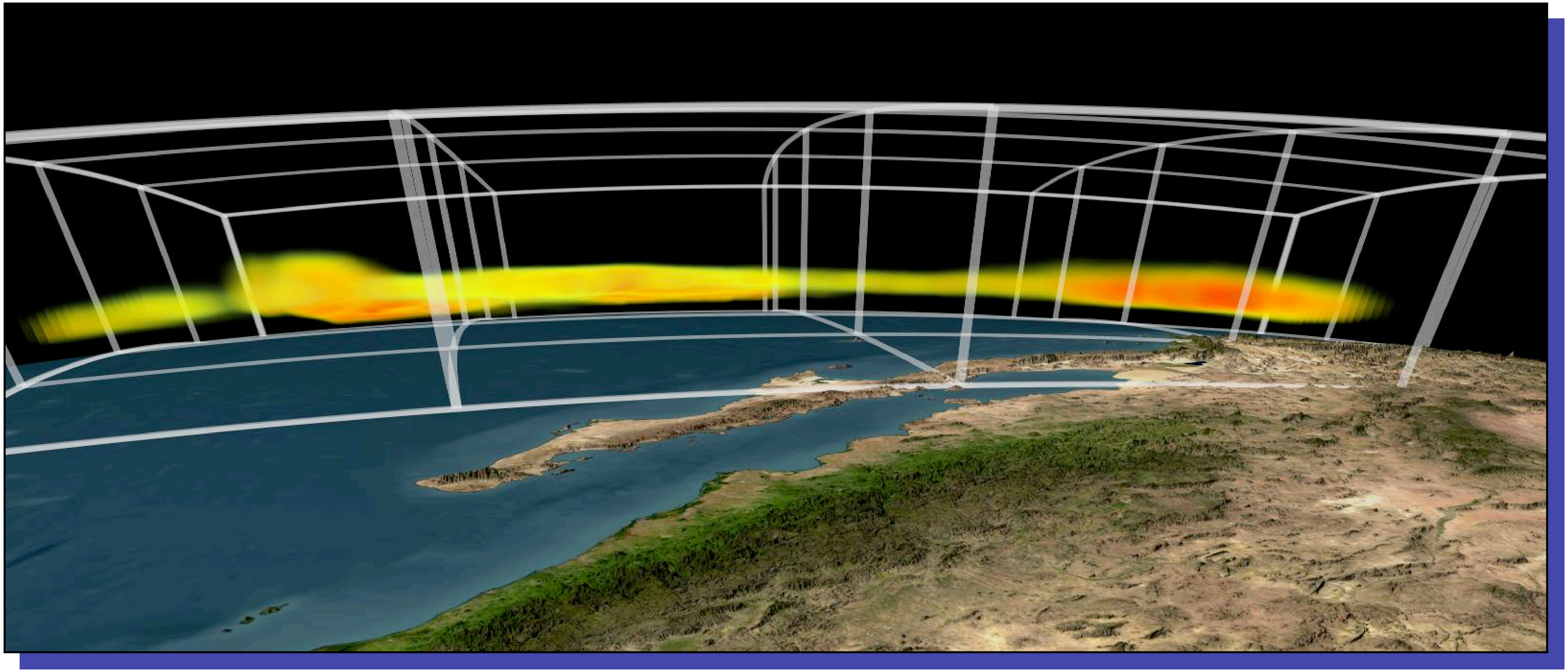
EISCAT_3D

- EISCAT_3D is a 3-dimensionally imaging radar
- *Continuous measurements of the space environment - atmosphere coupling at the statistical southern edges of the polar vortex and the auroral oval.*





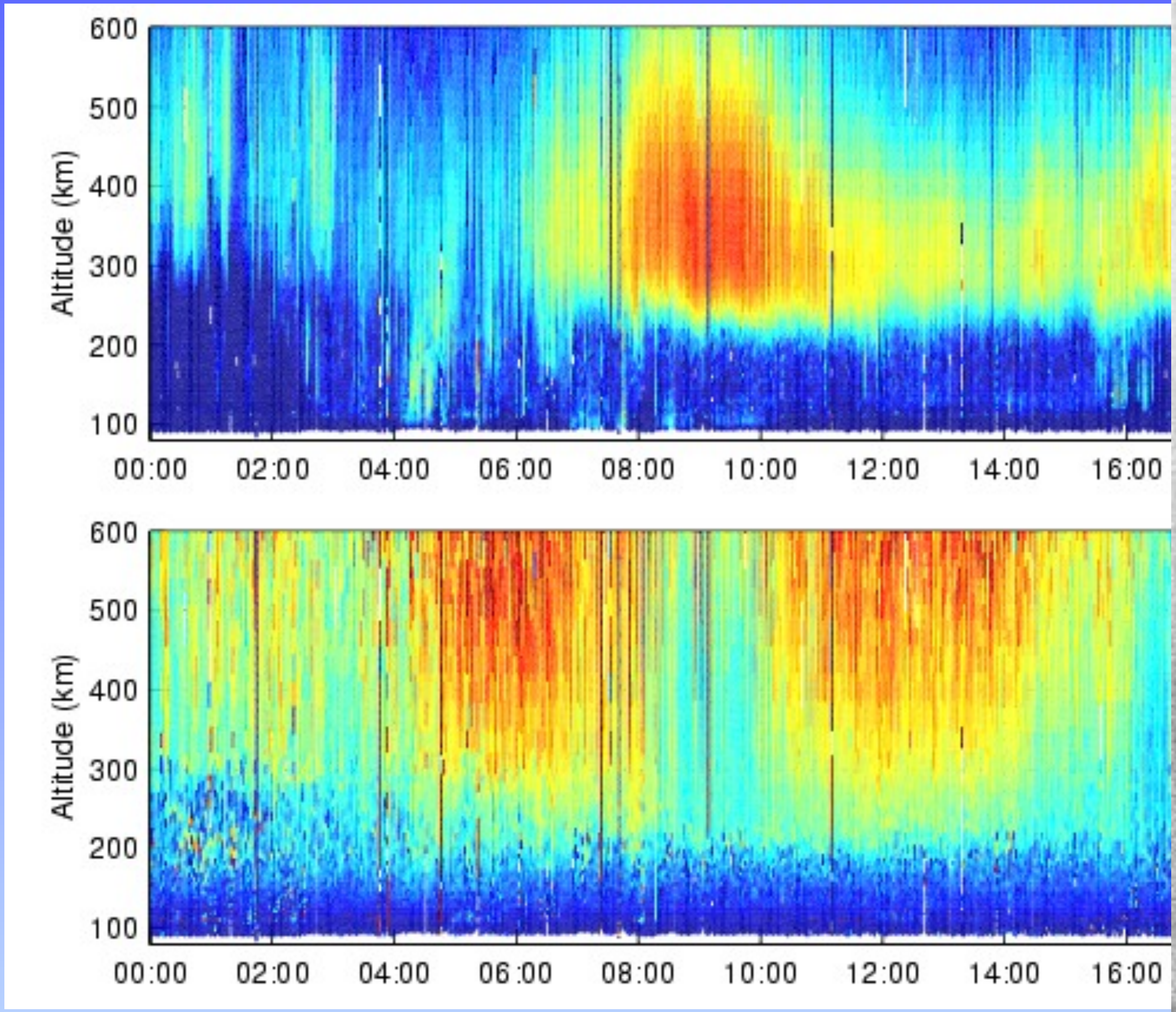
EISCAT 3D provides volumetric imaging



EISCAT_3D will give accurate, large-scale, three dimensional measurements of the ionosphere and atmosphere for the first time – and much else besides

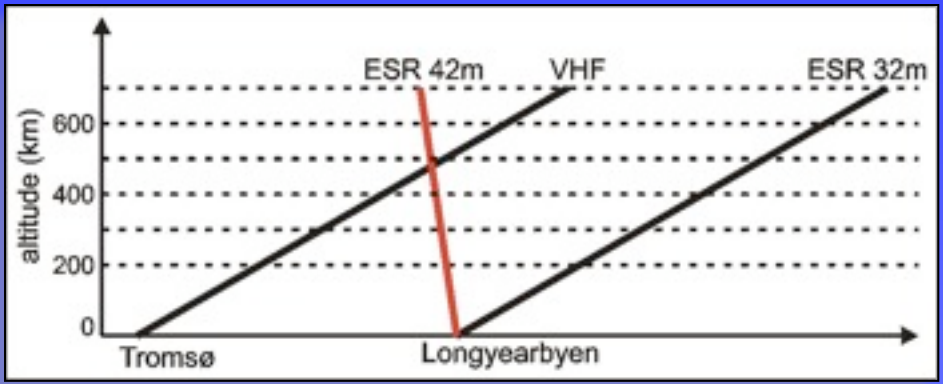
EISCAT_3D will give us unprecedented temporal and spatial information about the plasma environment and neutral atmosphere – essential to understanding crucial and societally relevant problems in the geospace environment, in space weather, and in the global energy budget and related atmospheric effects

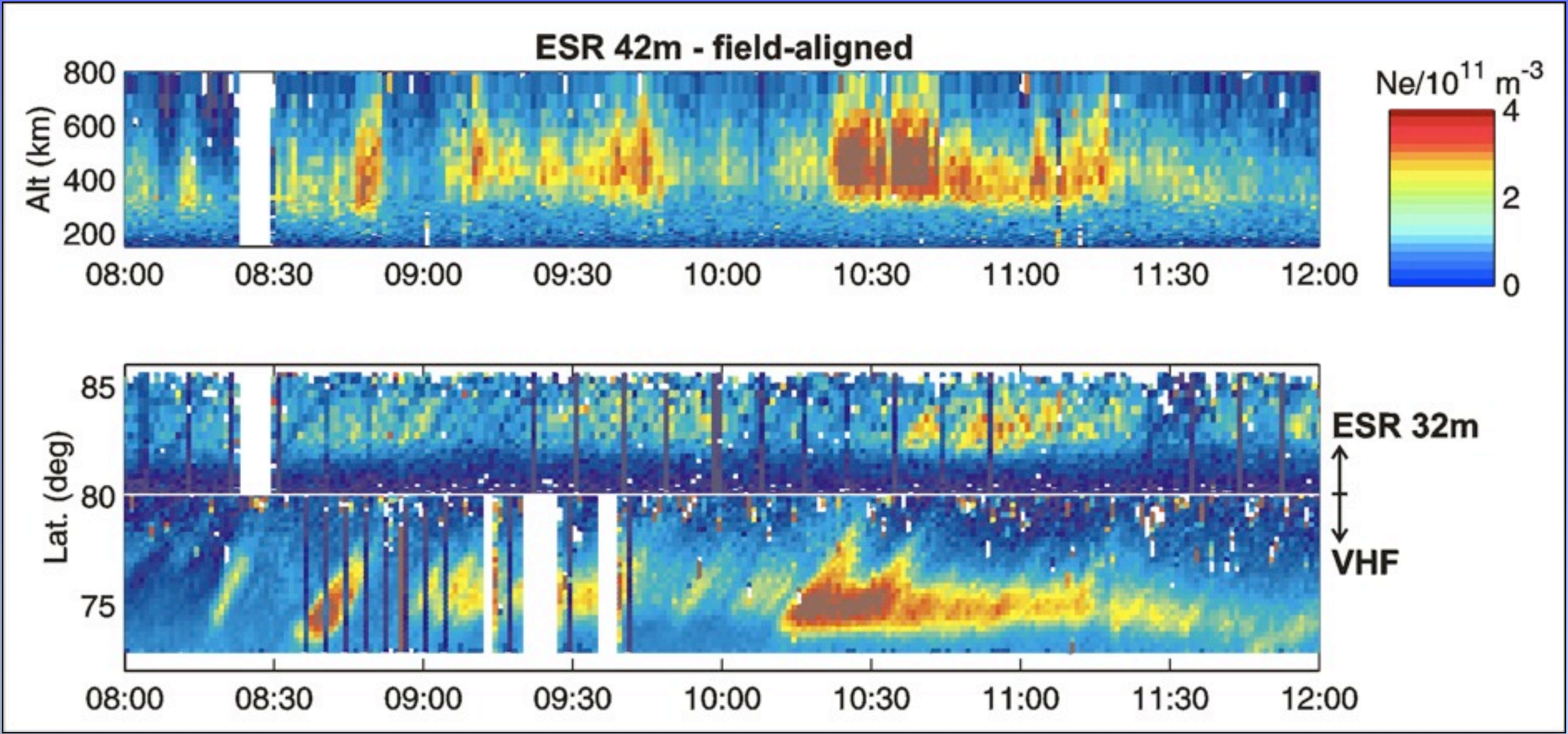
Space-time ambiguities can make the interpretation of radar data quite challenging



Multi-radar data

Poleward Moving Forms
4 October 2002





K.A. McWilliams, University of Saskatchewan

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Poker Flat Incoherent Scatter data by J. Semeter et al.

Example on volumetric data: PFISR

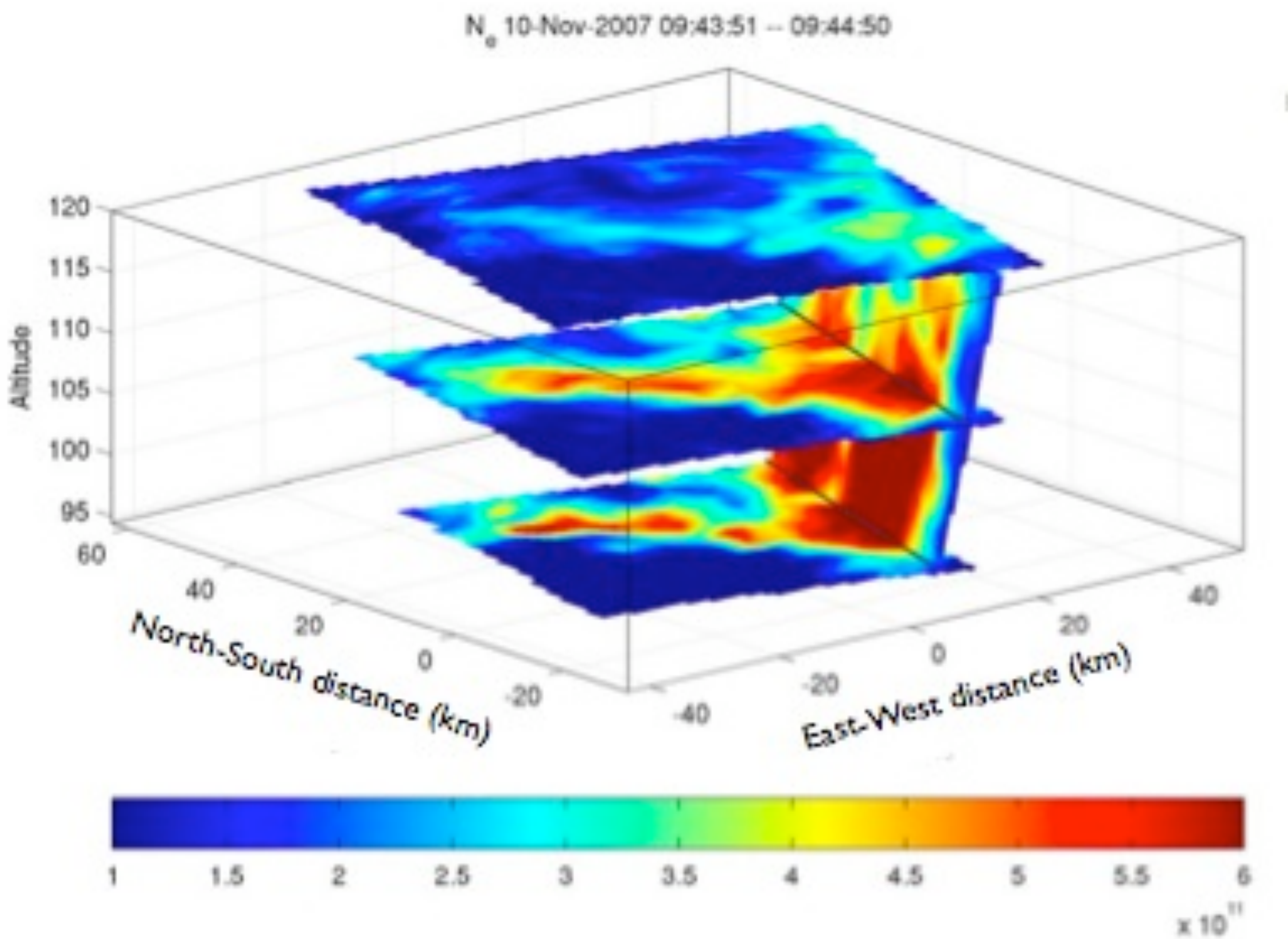

Fig. 2. Volumetric image of *E*-region on 10 November 2007, 09:43:51–09:44:50 UT. The image was produced by averaging 192 pulses-per-position. The horizontal cuts are at 100, 107, and 120 km. The structured density enhancement seen in the image was produced by auroral electron precipitation in the 20 keV range.

Semeter et al., JASTP., 2008

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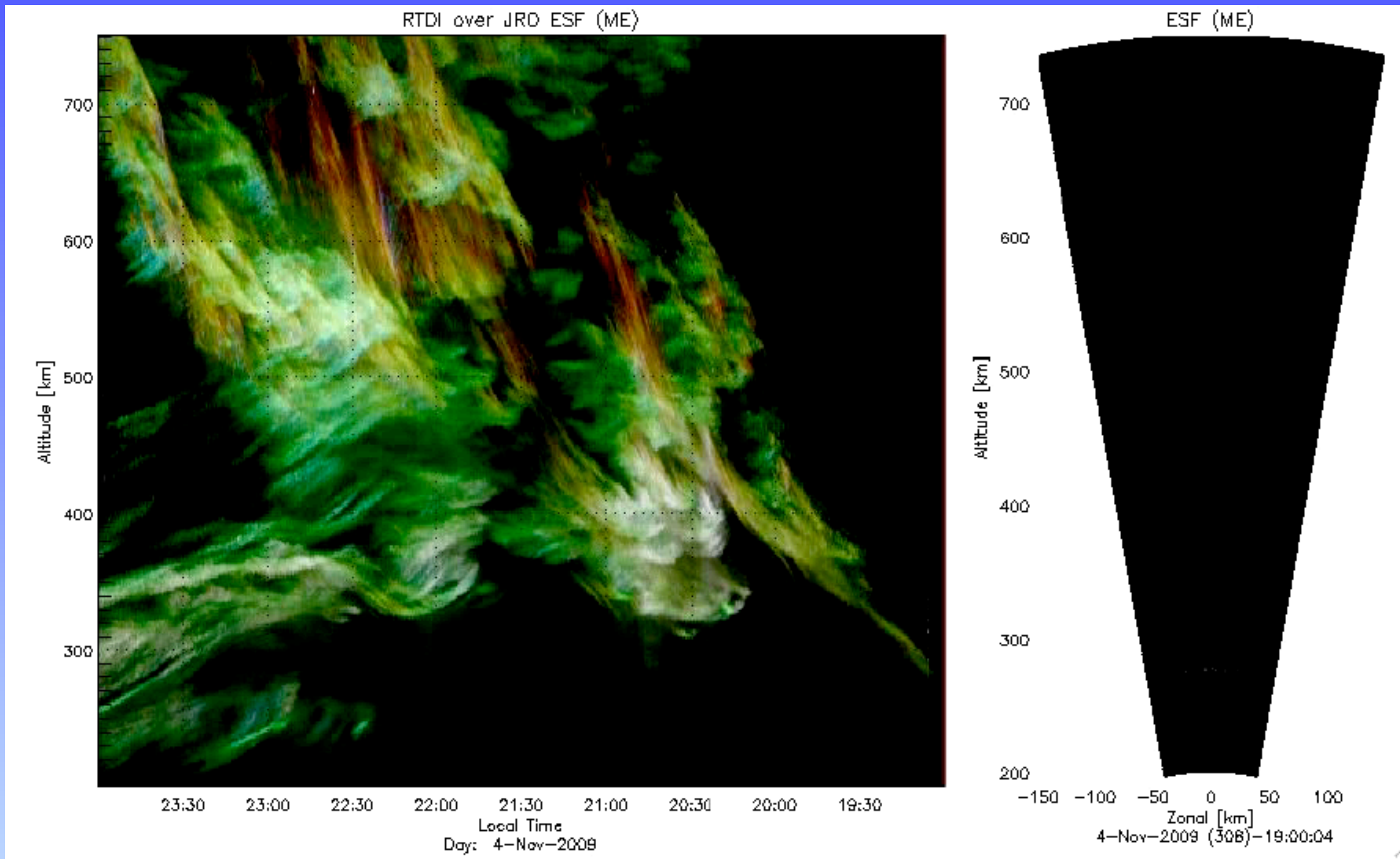
Imaging radar: Jicamarca 50 MHz



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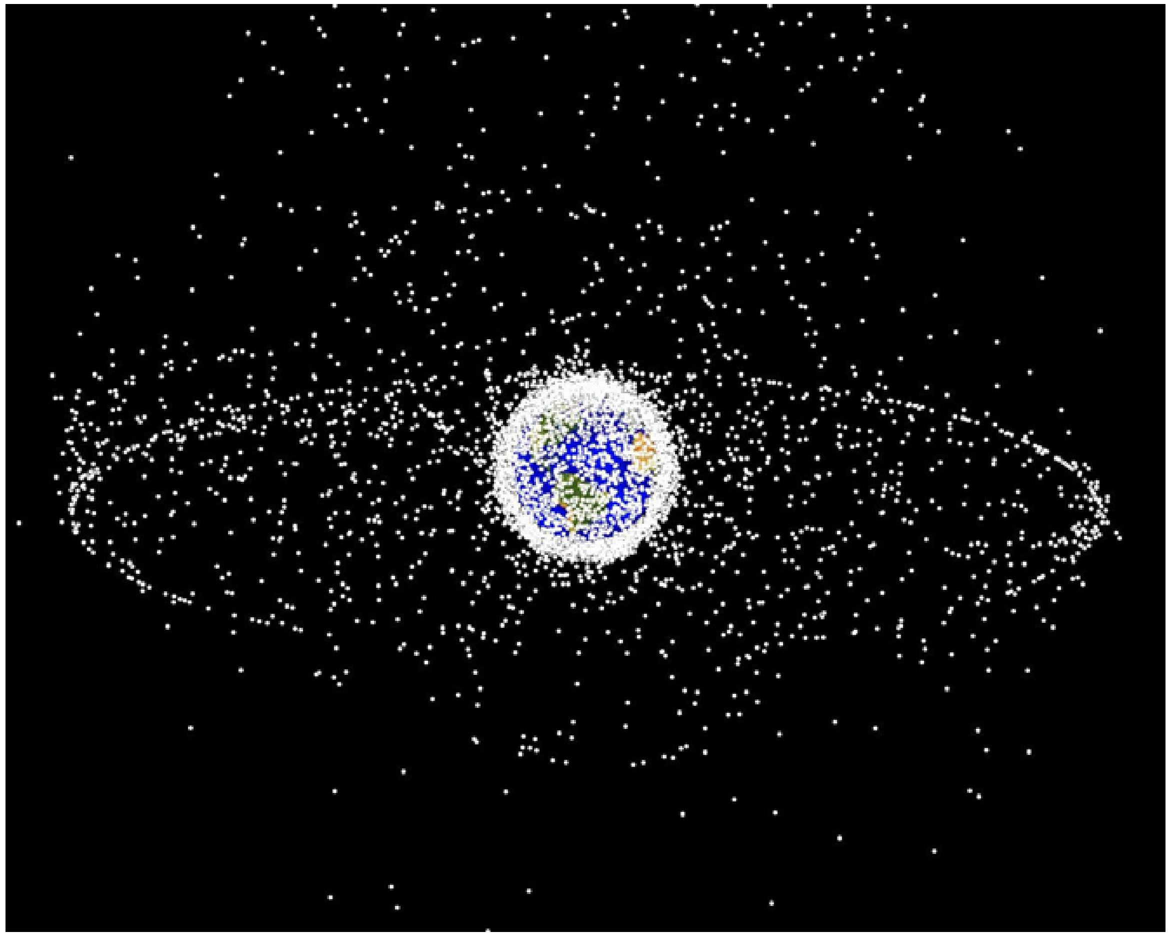
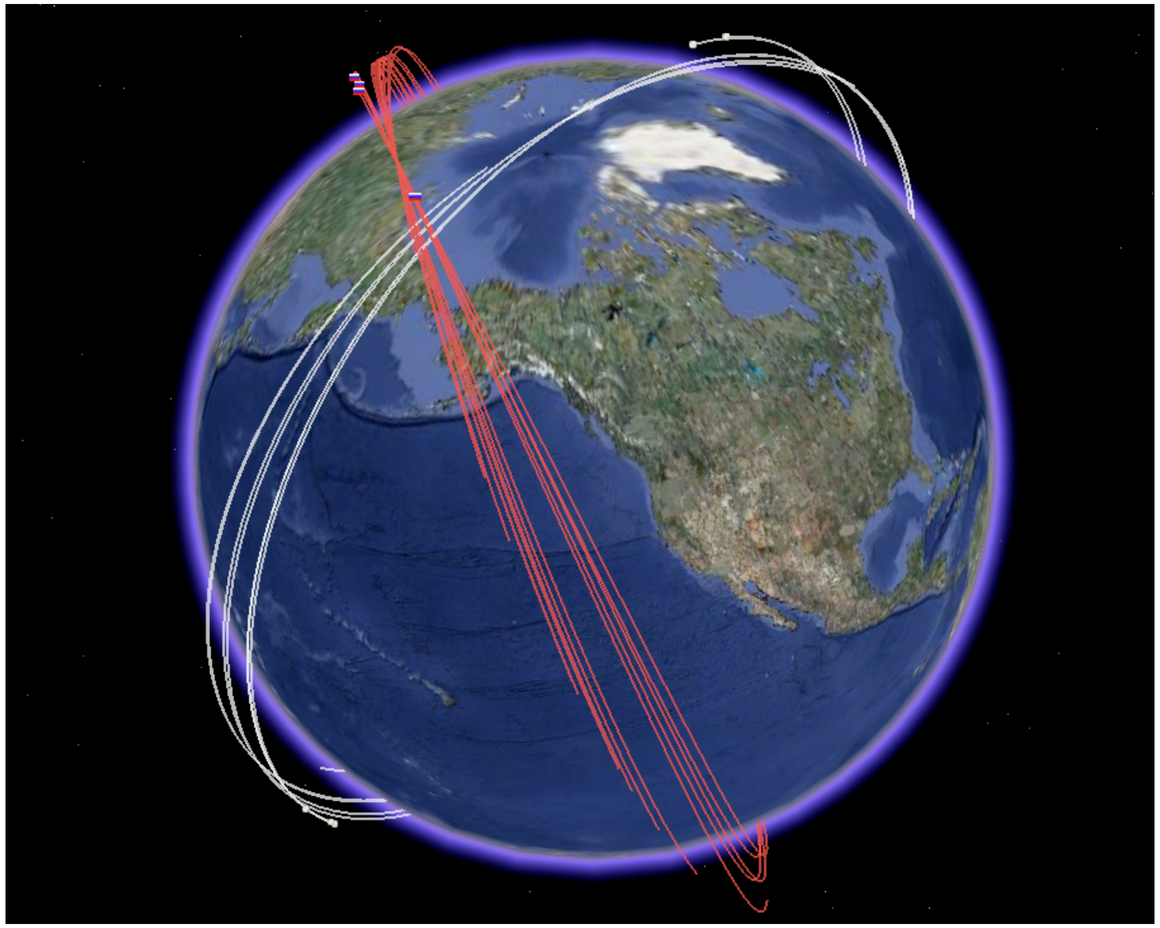
Track space debris





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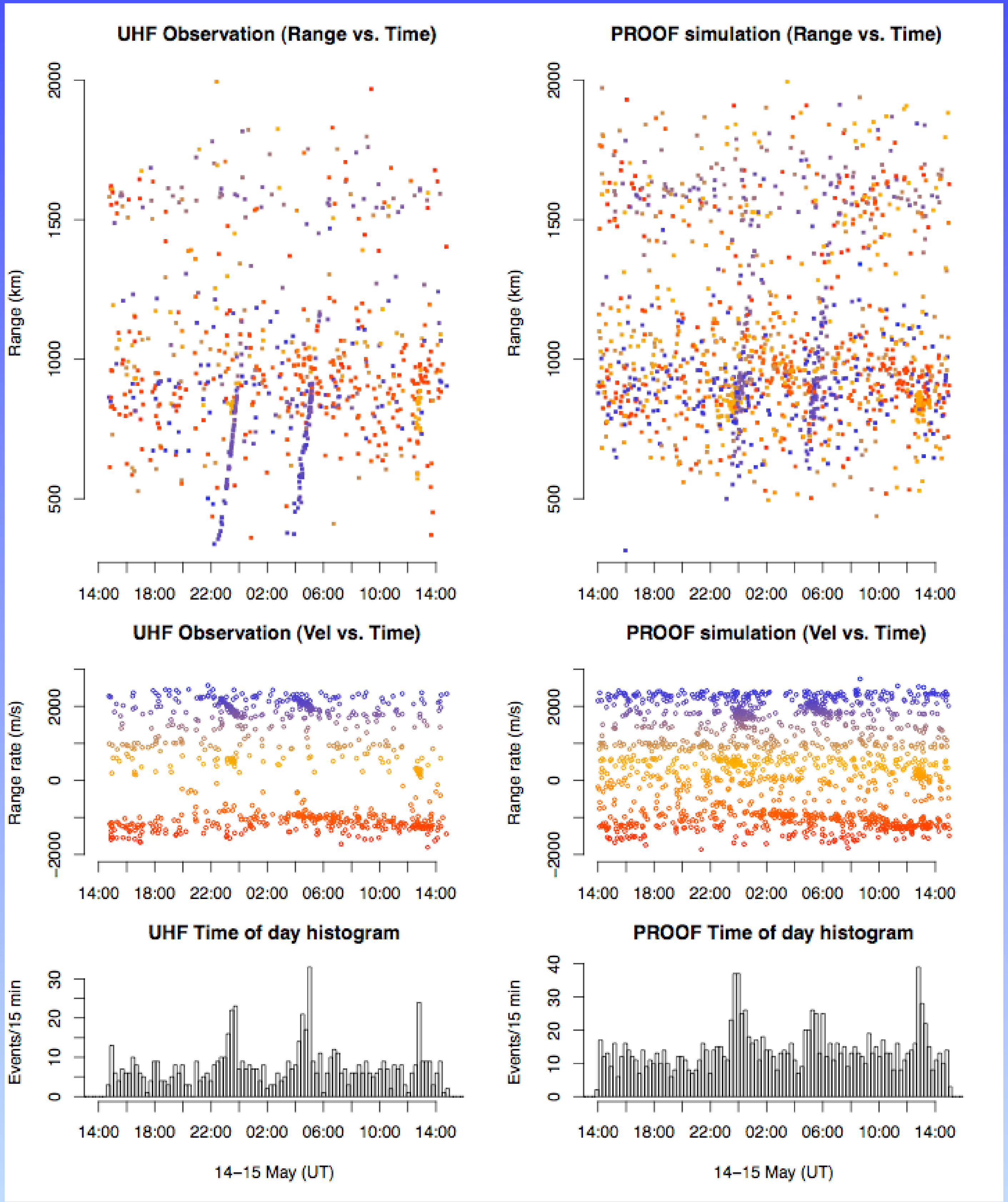
Recent highlights



Space debris detected using the EISCAT UHF system on May 14-15th 2009, a few months after the Iridium-Cosmos satellite collision.

The Iridium cloud orbital plane passes are visible at about 00:00 and 13:00 UT; and the Cosmos cloud pass at about 00:00 and 06:00 UT. The figure also compares the measurement with a statistical debris model called PROOF.

Differences show that the model could be improved by using the EISCAT measurements.

(from J. Vierinen et al., 2009)

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EISCAT Reaching for The Moon

Credits: Juha Vierinen and Markku Lehtinen, Sodankyla Geophysical Observatory, Finland

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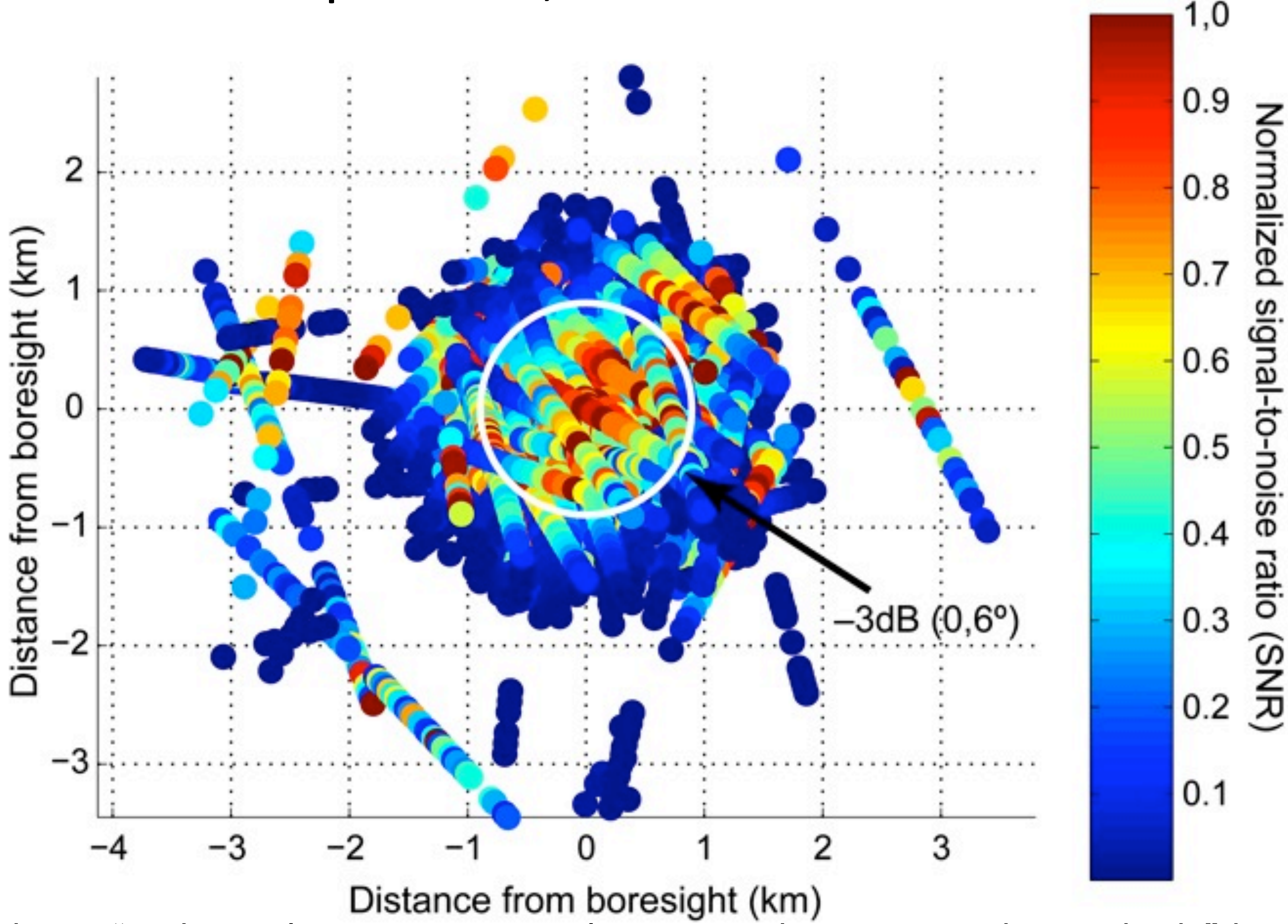
Radar reflectivity map of Moon, made
by using EISCAT
Reach down to 600 m resolution!

Uniquely determine the velocity vector of meteorites and smoke particles, obtain meteoroid mass flux



Meteor studies, recent example

The Ph.D. thesis “High-resolution meteor exploration with tristatic radar methods” by Kero (2008) describes a method to determine the position of a compact meteor target with the EISCAT UHF system. This figure displays 194 meteoroid trajectories projected onto a plane perpendicular to the Tromsø radar beam. The maximum SNR of each meteor head echo streak is normalized to one. The white circle marks the -3 dB beamwidth (0.6°).

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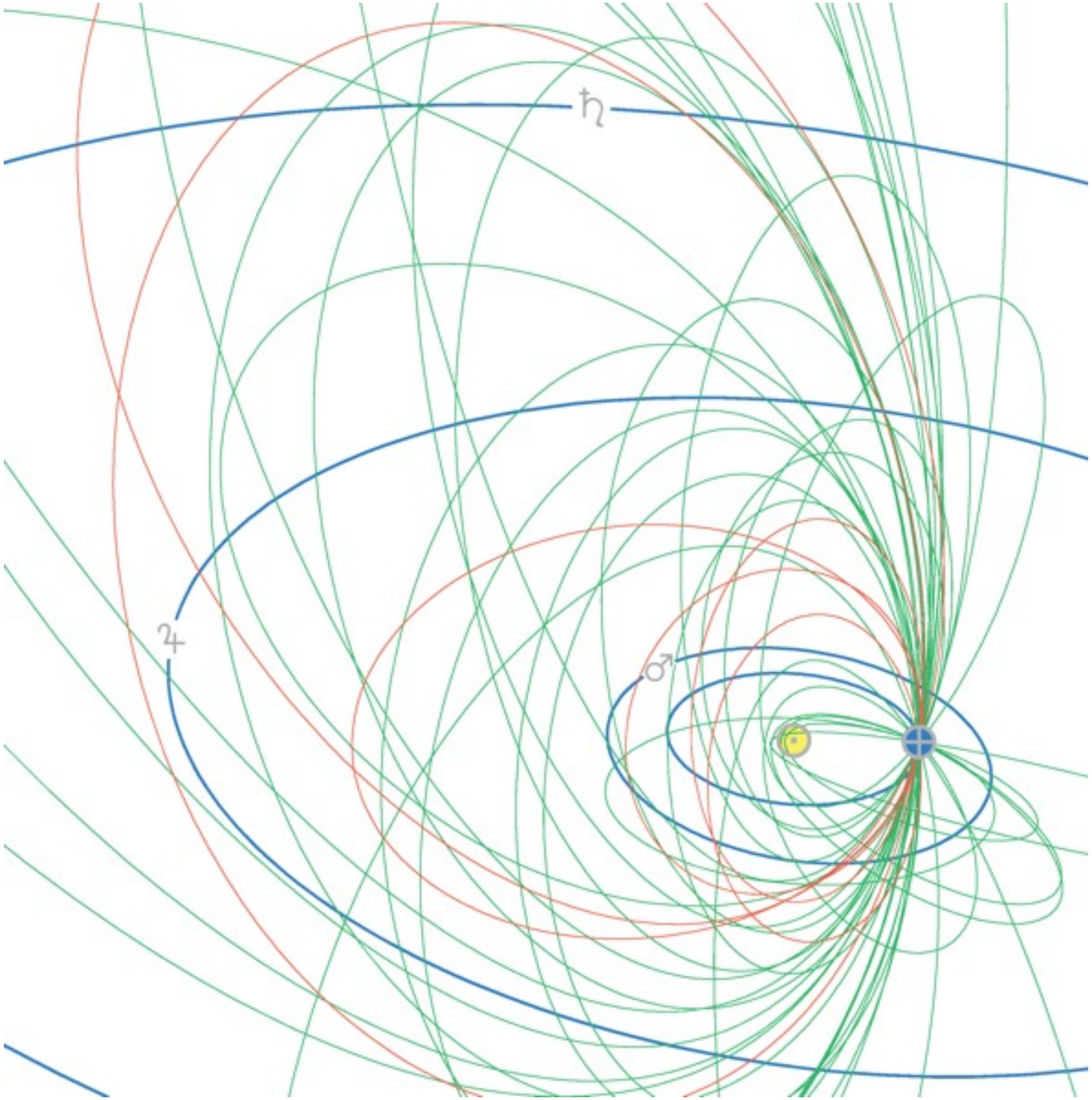
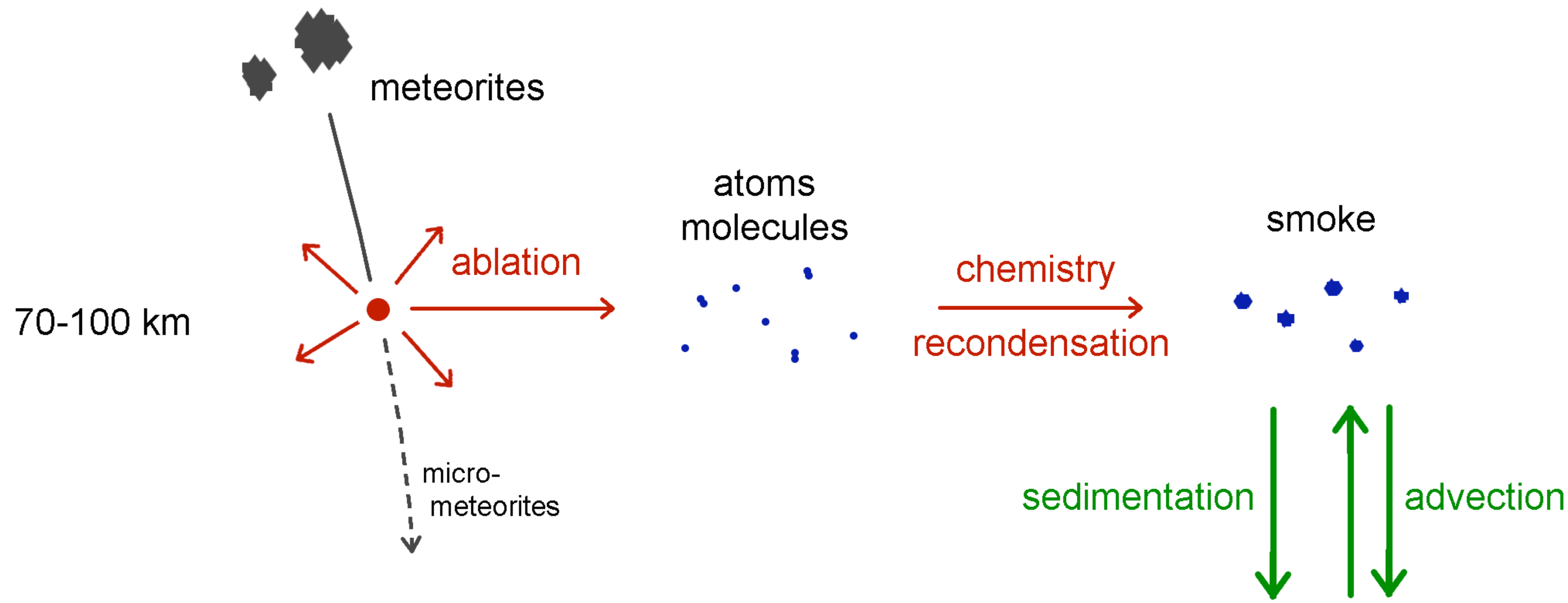
Meteor studies



The Ph.D. thesis ”Radio meteors above the Arctic Circle - radiants, orbits and estimated magnitudes” by Szasz (2008) describes meteoroid orbit calculations from EISCAT UHF measurements. This figure displays the sun (yellow), the Earth (blue) and 39 prograde (green) and retrograde (red) meteoroid orbits.

With EISCAT 3D we could map the whole dust cloud of the solar system!

The role of smoke particles



Nanometre-sized meteoric smoke particles (MSP) formed from the recondensation of ablated meteoroids in the atmosphere at altitudes >70 kilometres, are transported into the winter polar vortices by the mesospheric meridional circulation and are preferentially deposited in the polar ice caps. Further smoke particles resulting from recondensation of the meteoric vapor, are believed to be an important ingredient in a number of mesospheric processes.

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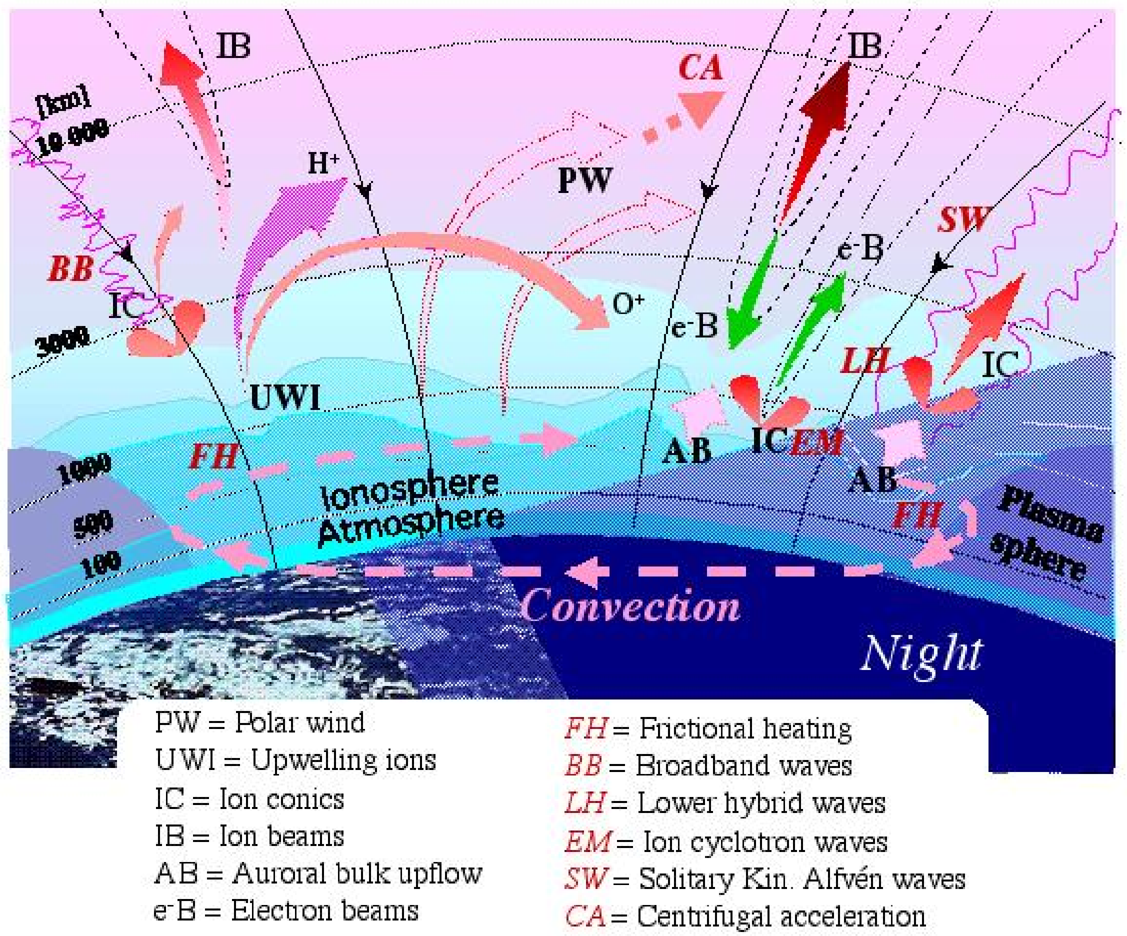
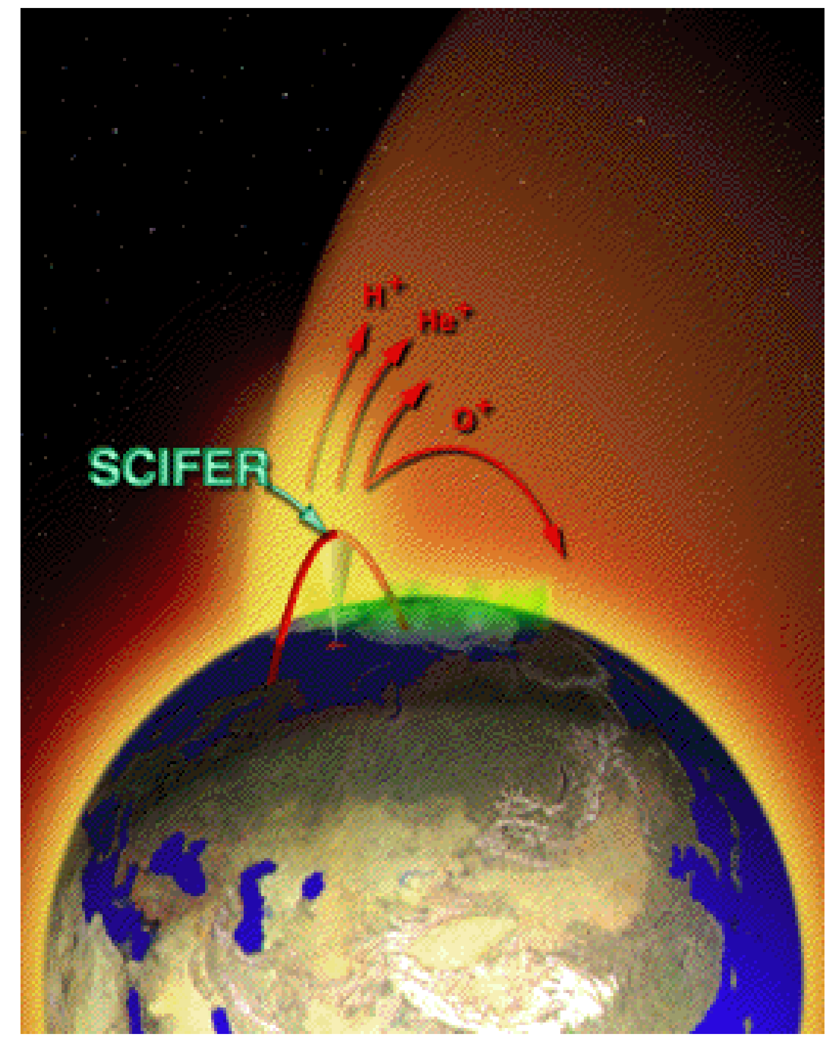
Radar image ionospheric plasma vertical flow

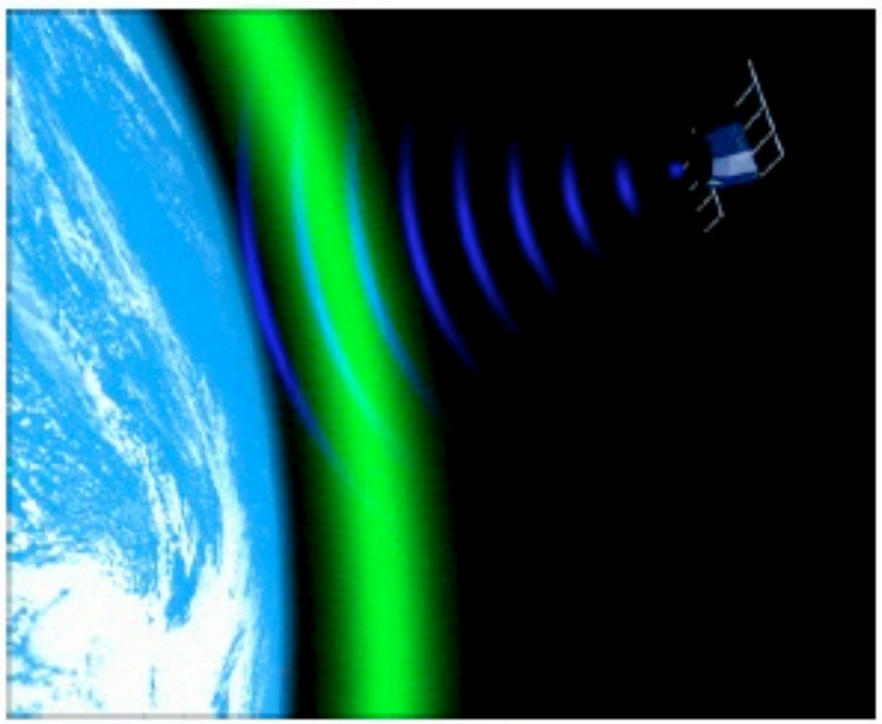
Application: Ion outflow events
Observe O+, He+, H+ ions
Search for signatures of field-aligned potential drops



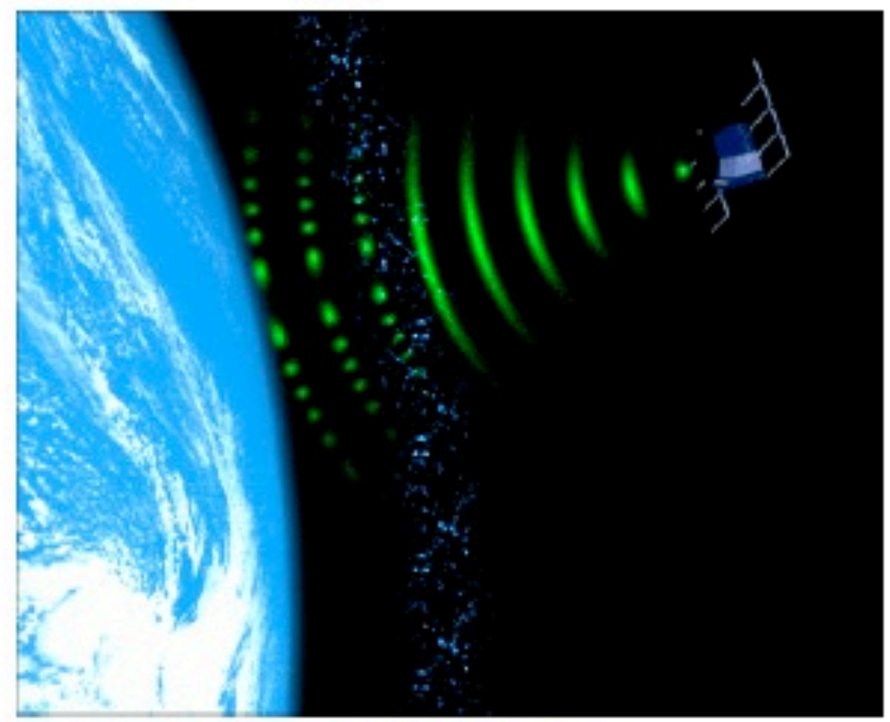


Ionospheric impact on navigation

Ionosphere and GPS



Delay



Scintillation

Perturbs the signal propagation speed proportional to total electron content tens of metres error at solar maximum

Causes rapid changes in signal phase and signal strength – most severe in auroral/equatorial regions and storms

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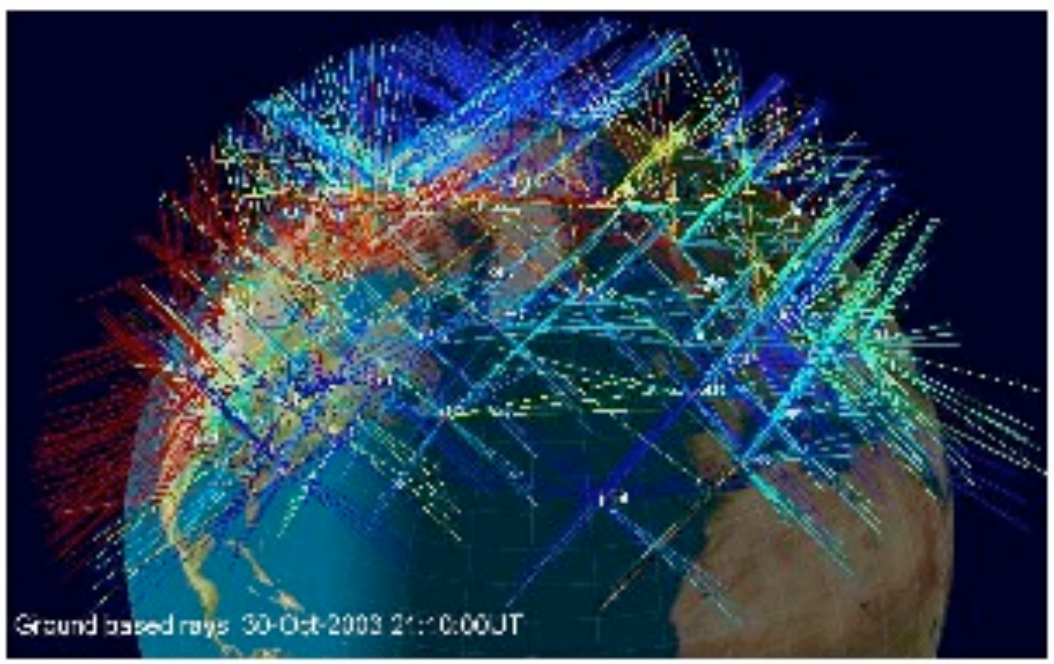
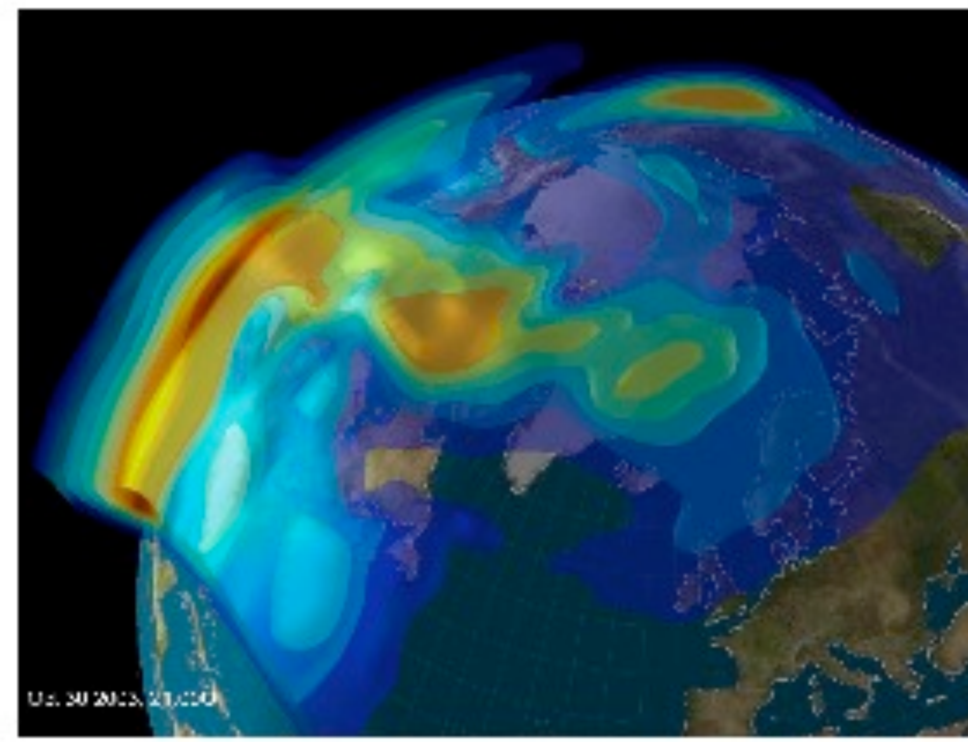
3D Electron density retrieval from TEC (Total Electron Content) measurements by GPS



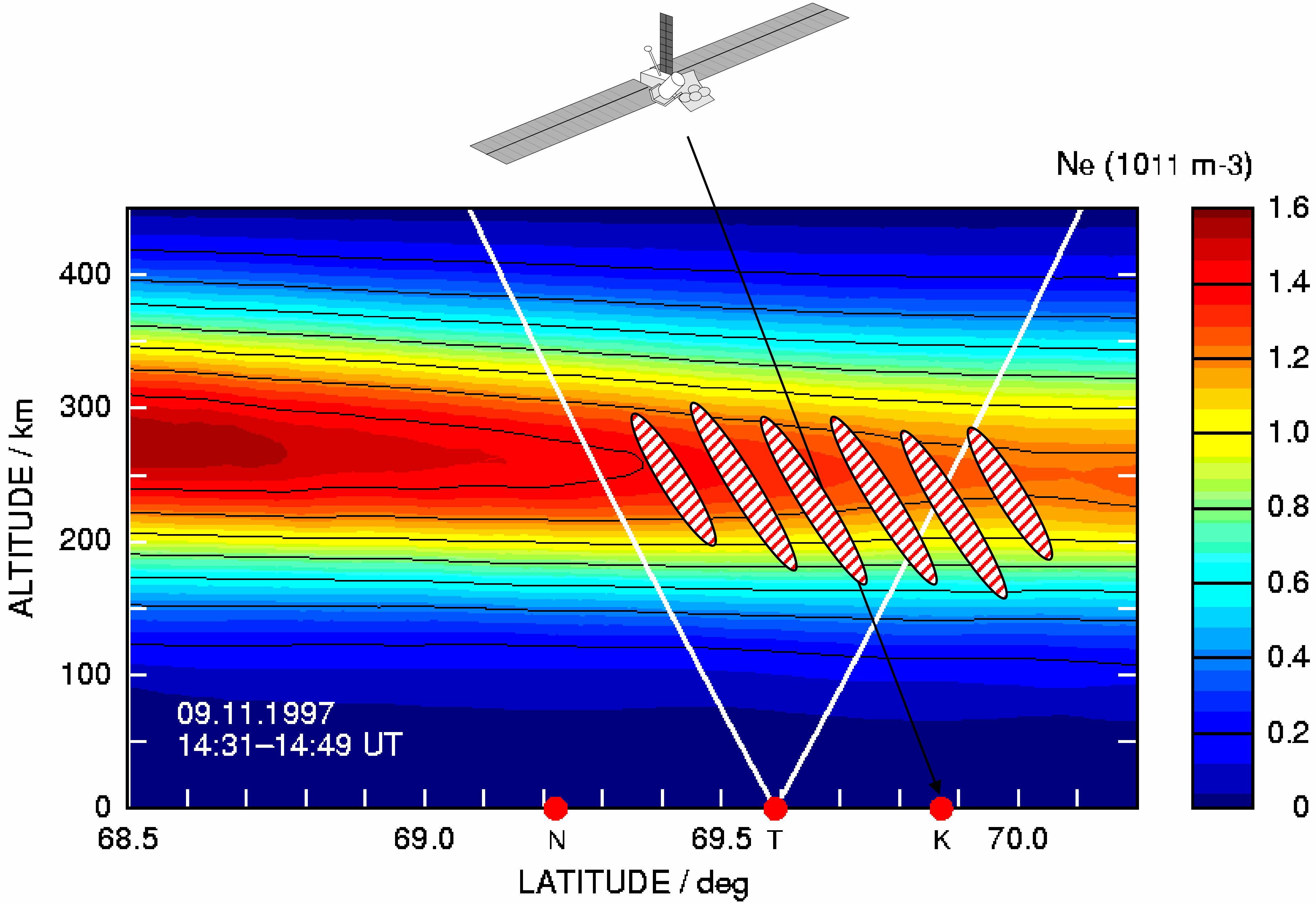


The images above are based on mathematical inversion from phase measurements of satellite signals. Results dramatically improve when measured profiles are added to the calculation

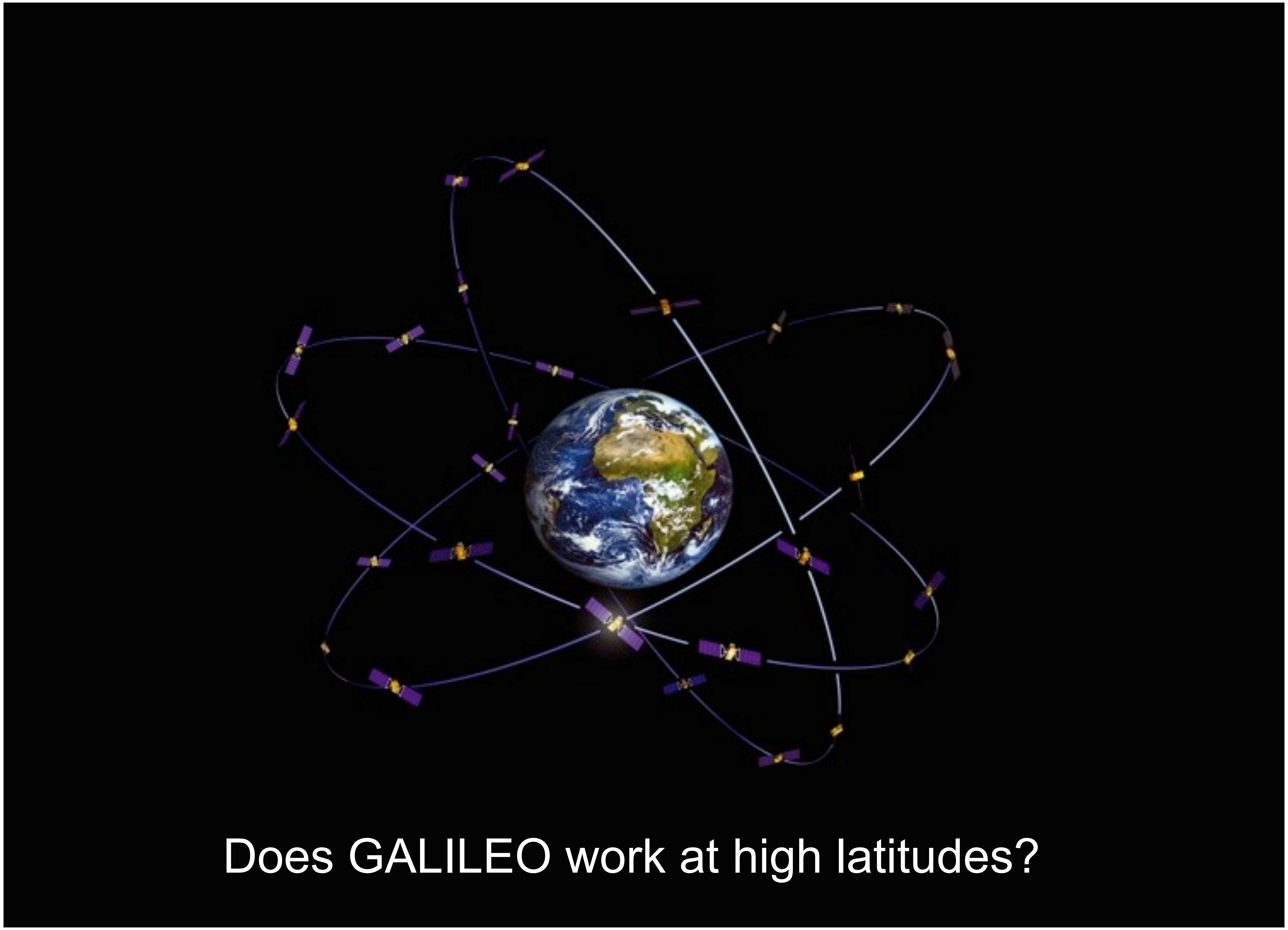
By: Allain et al., 2008

Mapping field-aligned density irregularities

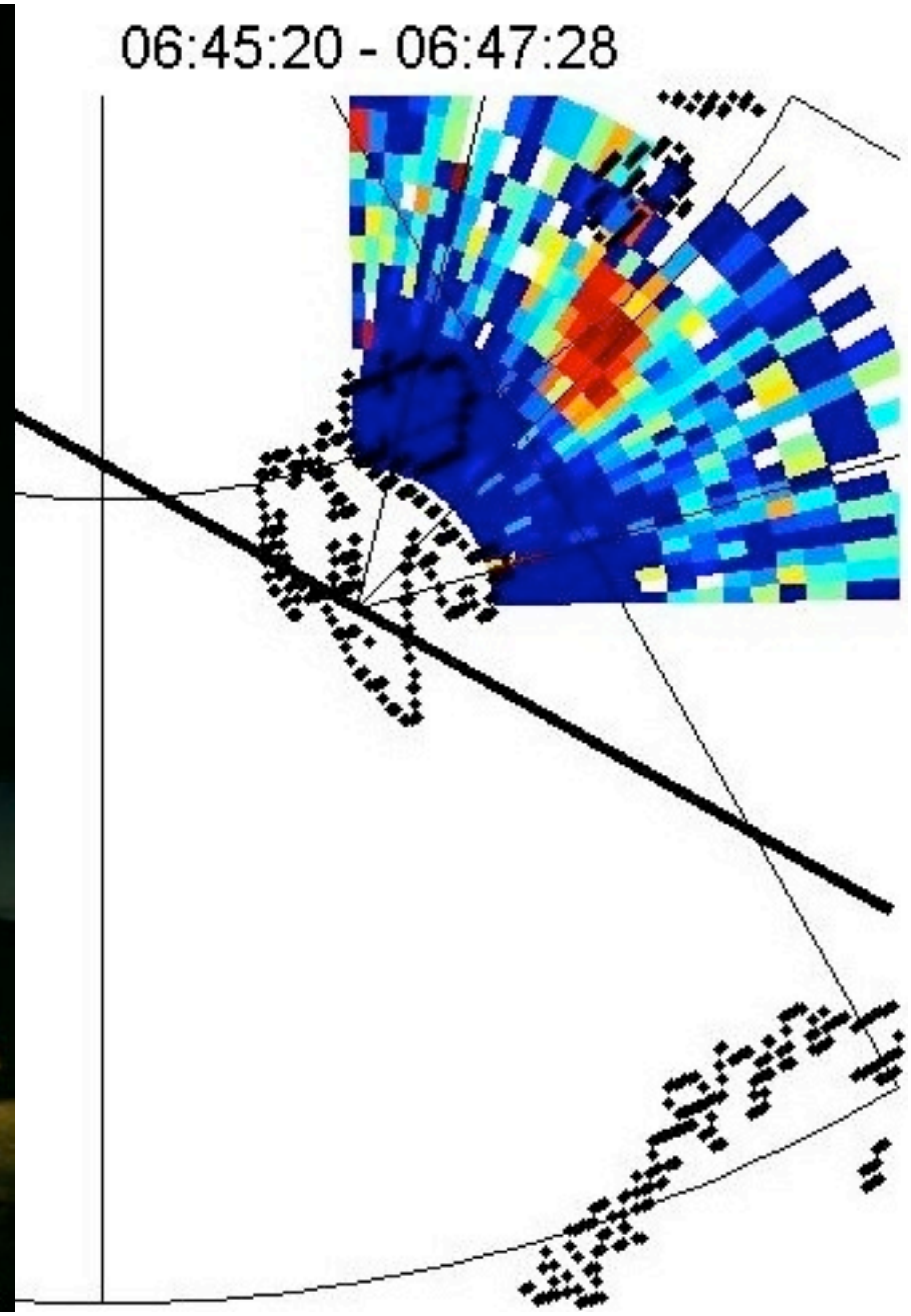
Application: Navigation signals and polar aircraft communications

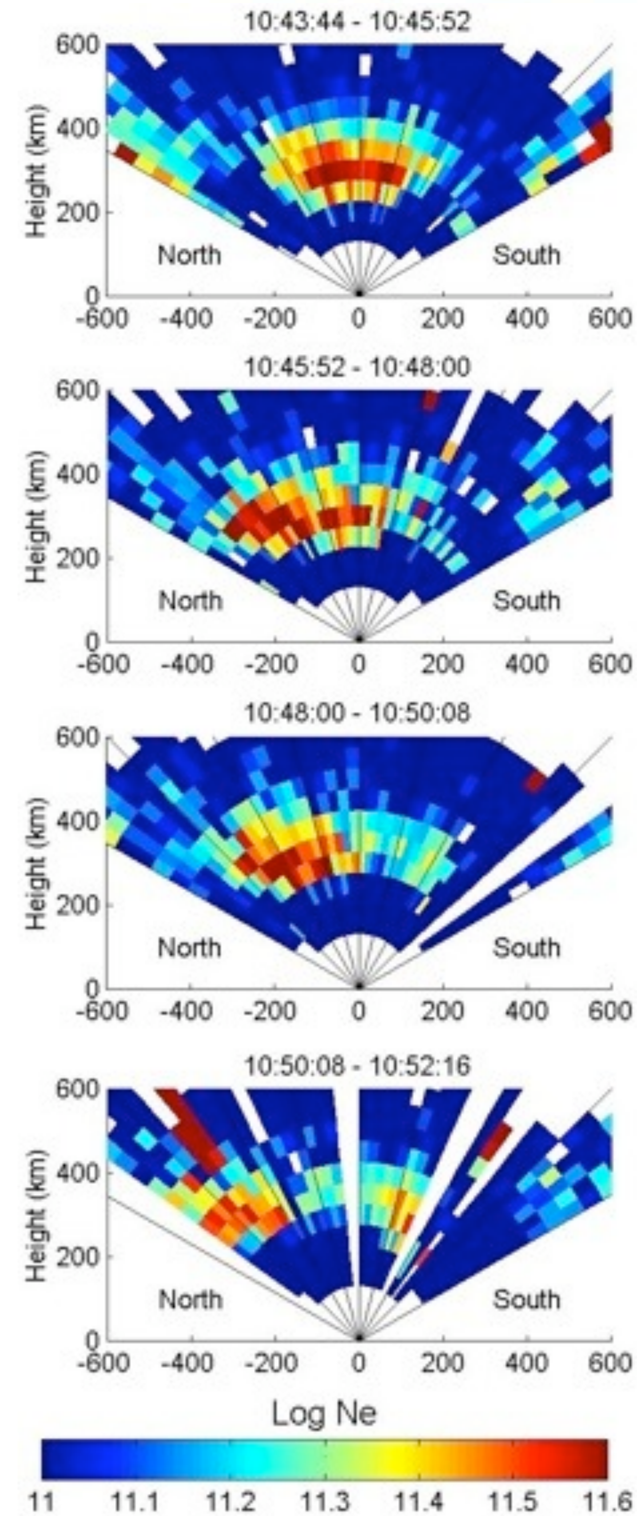


Effects on navigation and space-based radars



Plasma patches in the ionosphere





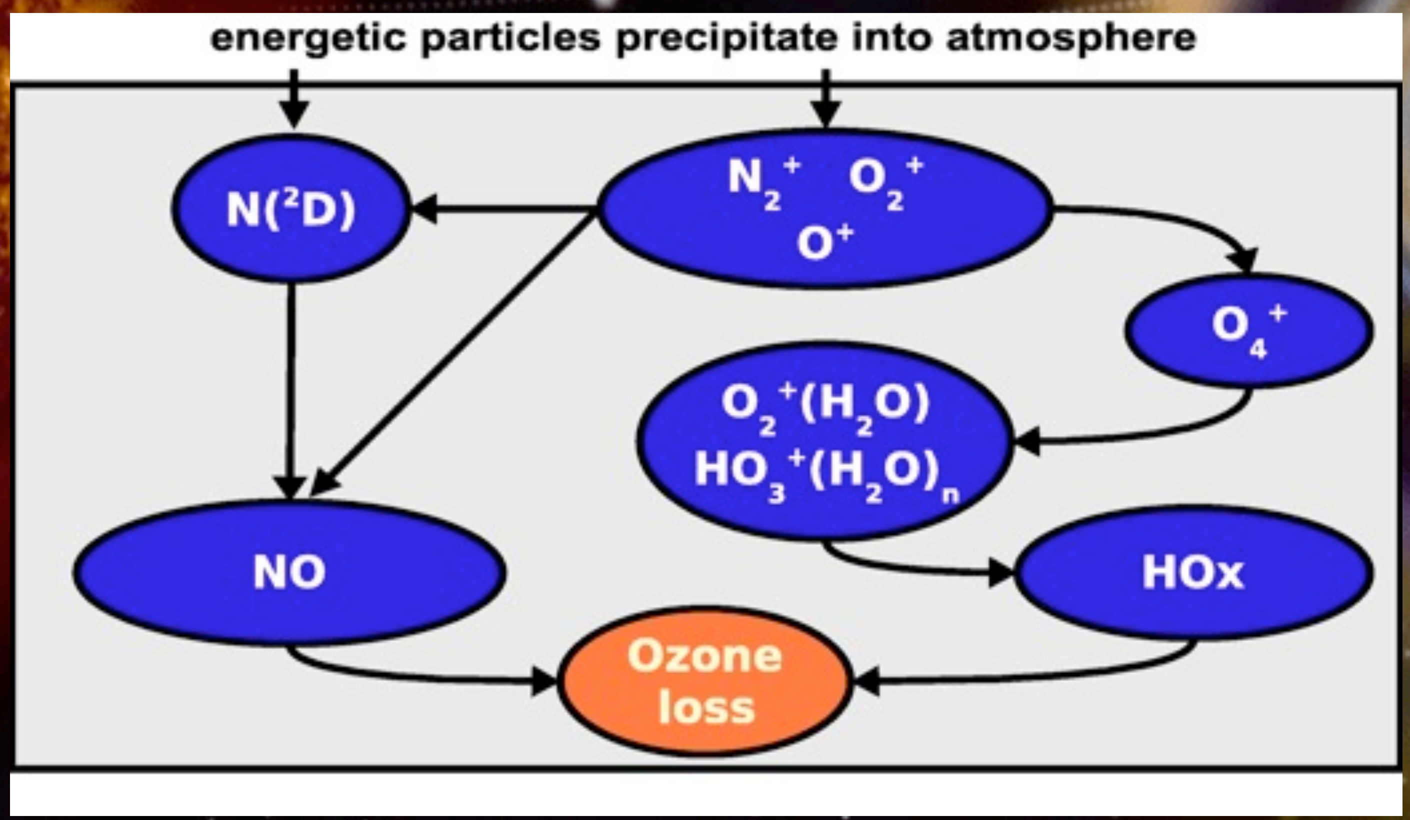
[Carlson & Oksavik et al., 2002, 2004, 2006, 2008; Oksavik et al., 2006]

Role of the arctic upper and middle atmosphere

We live in the neighborhood of a star

- Some key questions:
  - How does the space weather affect the climate?
  - How do the atmospheric layers couple to each other?

Energetic particle precipitation creates NO_x and HO_x



O_3 is affected !

NO_x is long-lived in the absence of sunlight

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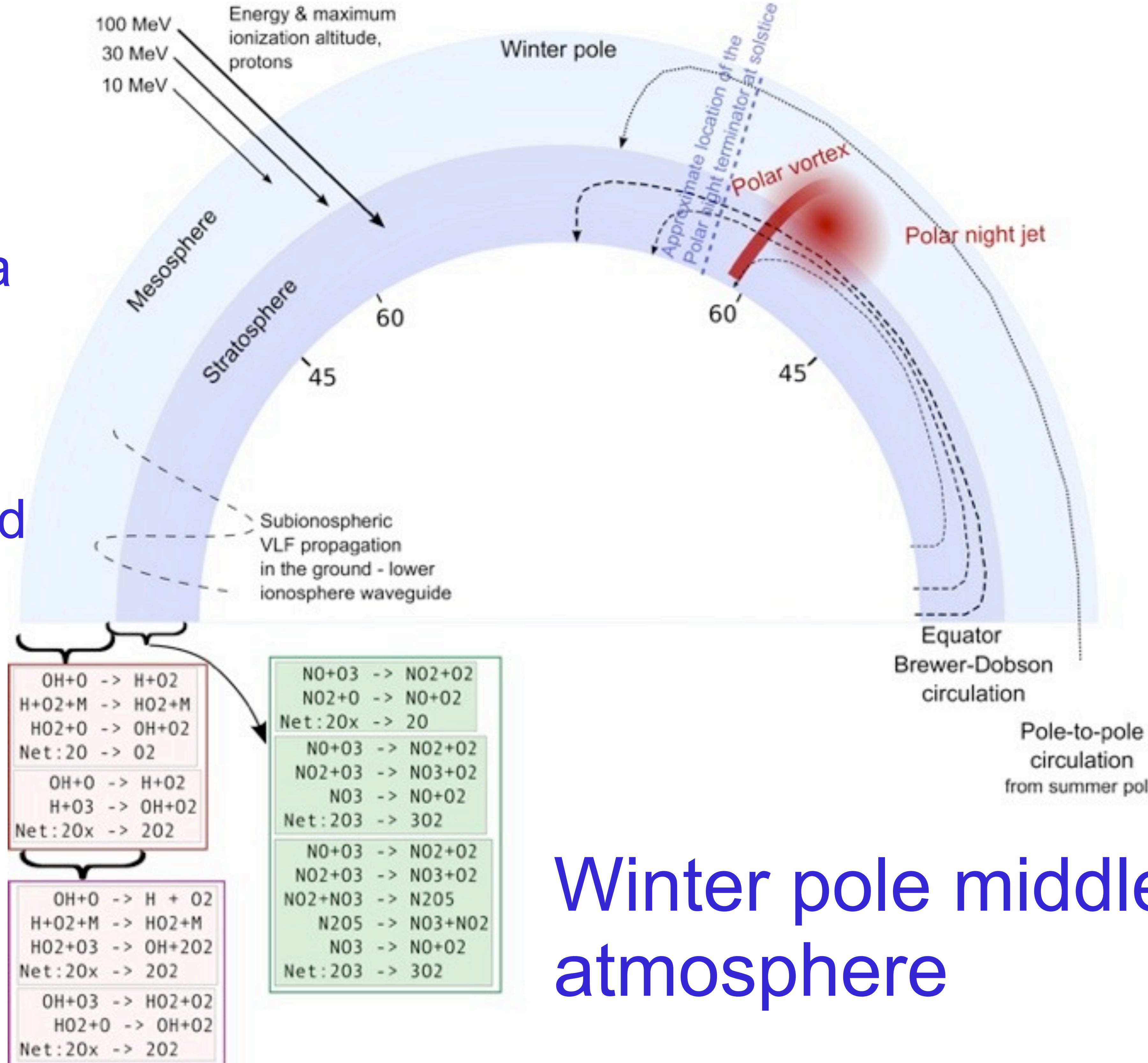
Descent of air from higher atitudes to the stratosphere is a highly variable process, controlled by stratospheric and mesospheric dynamics



Winter pole middle atmosphere

Figure from A.Seppälä , 2007

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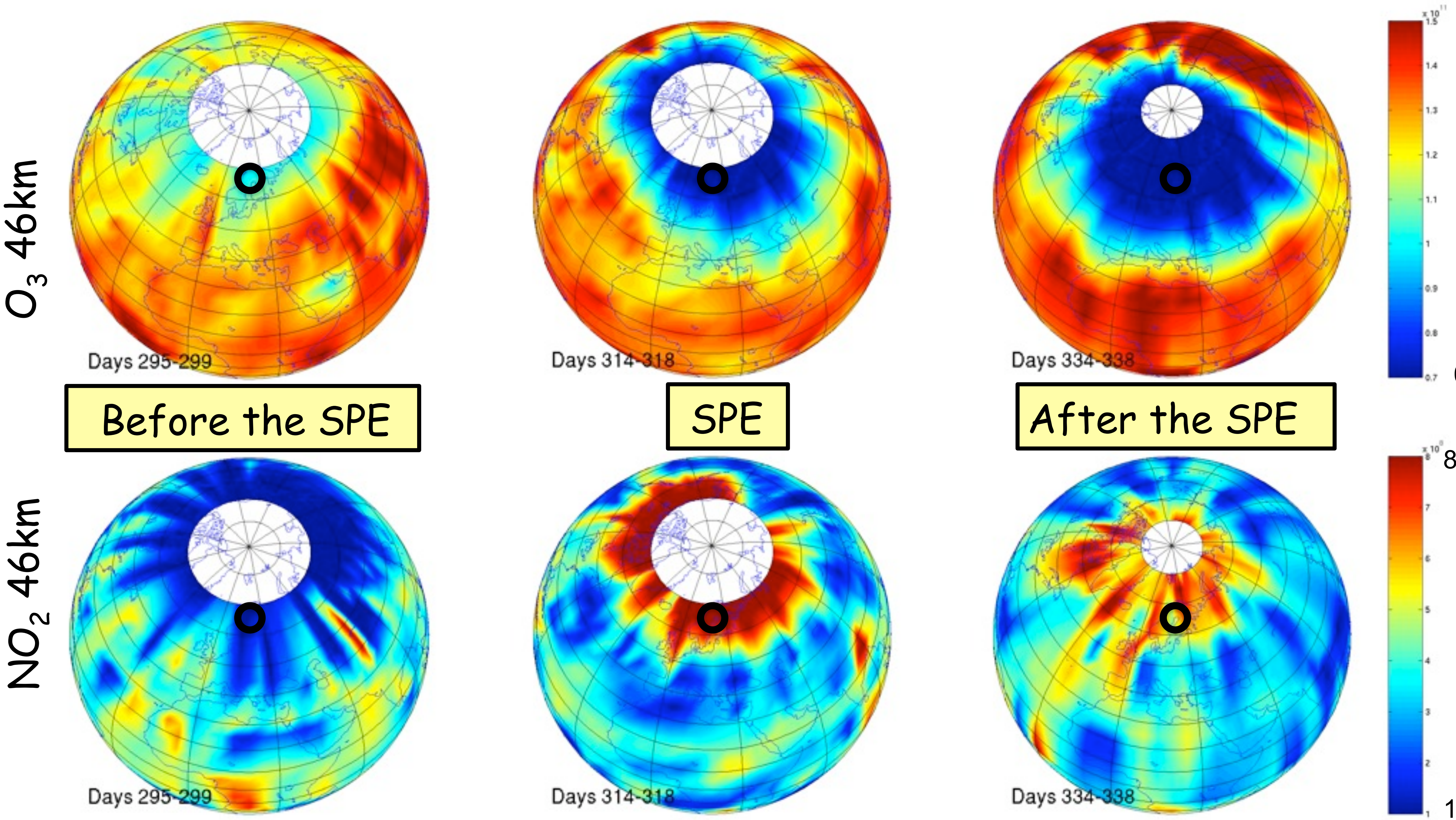
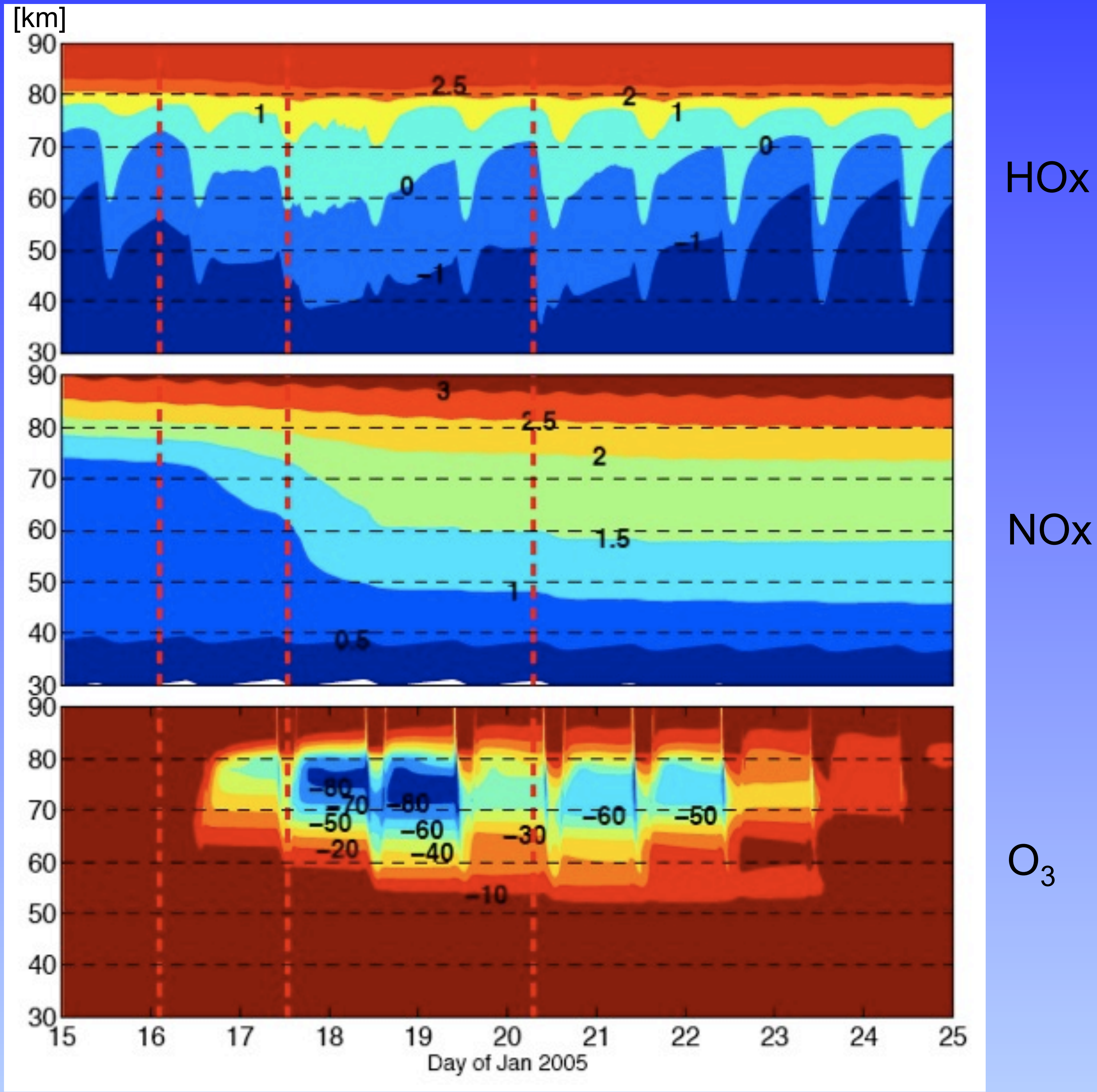
SPE 2003: GOMOS NO_2 and O_3 (46 km)



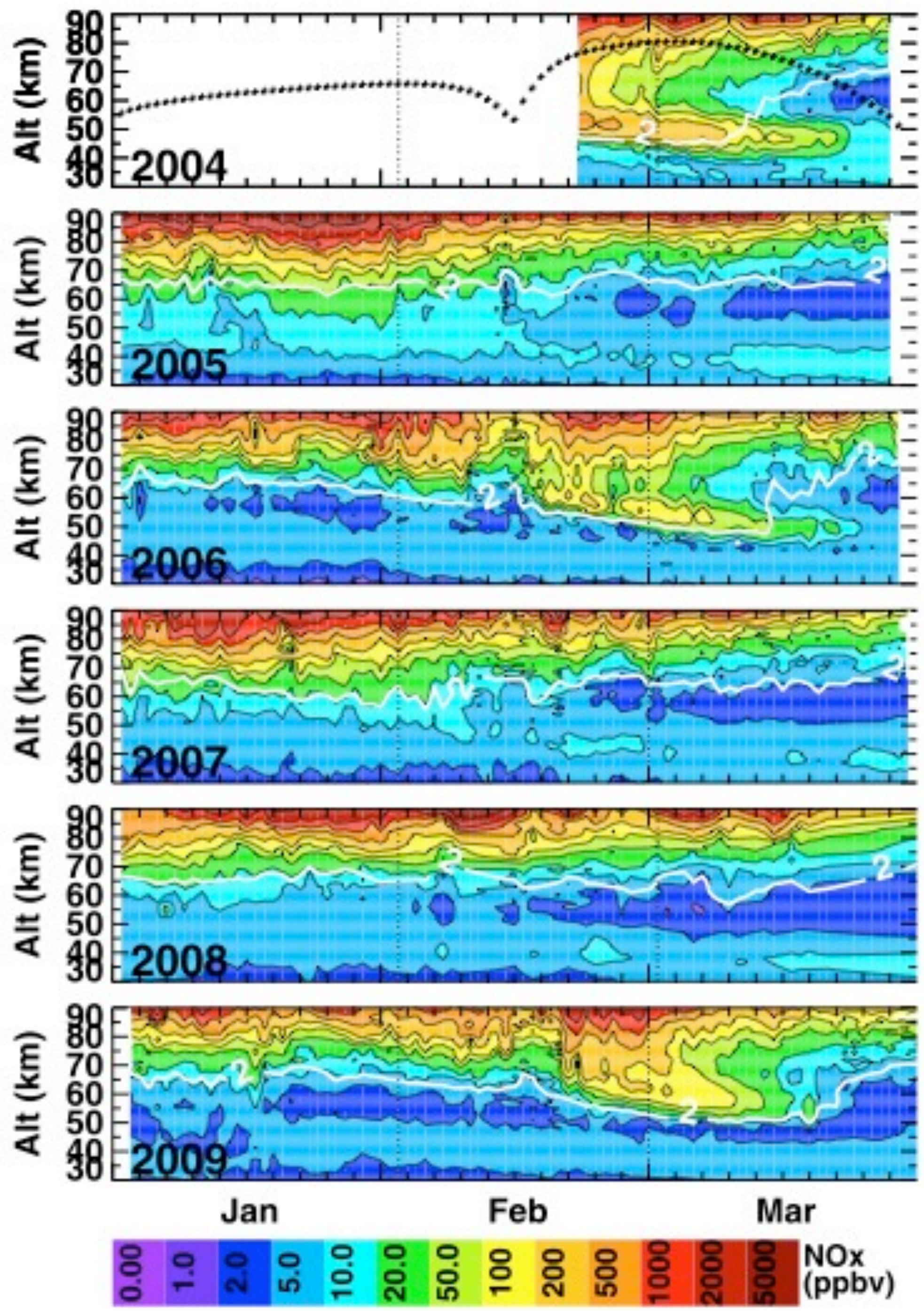
January 2005 SPE:

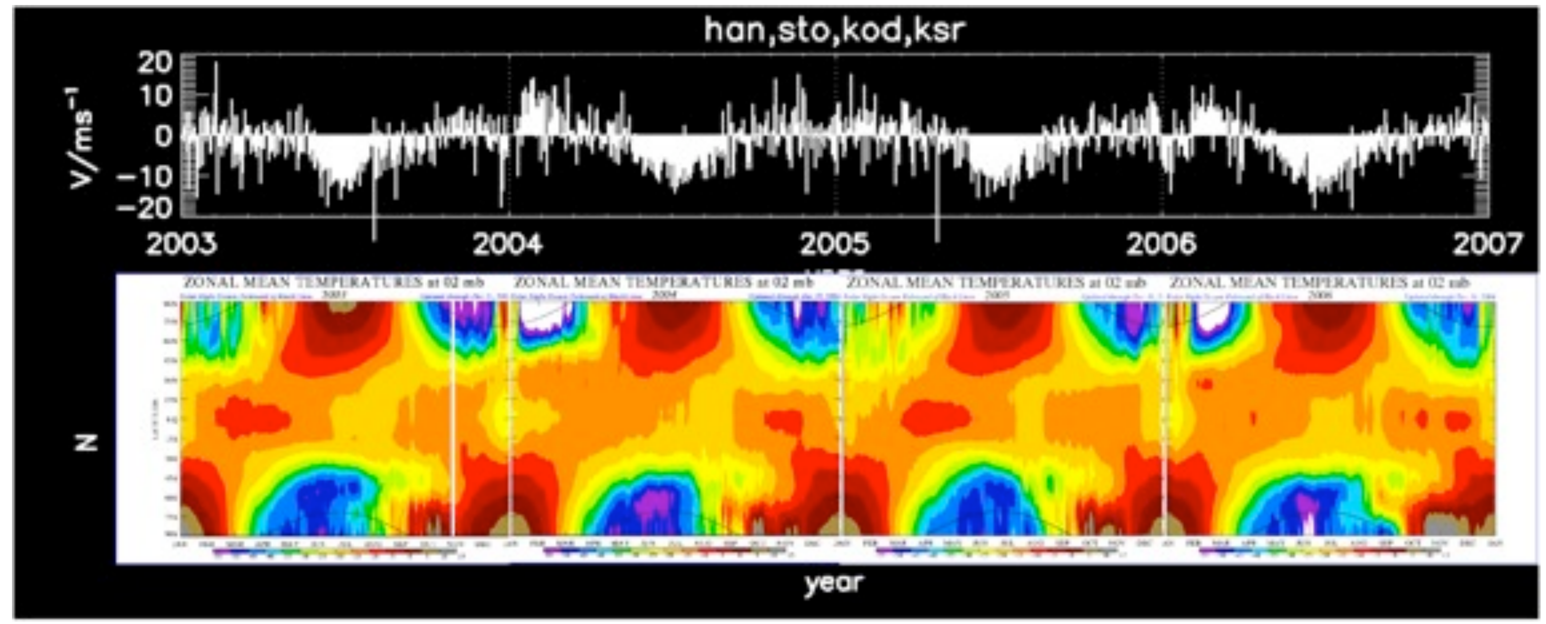
O_3 -loss at 70-80 km as high as 80%!



Calculated HOx and NOx (log10ppbv) and O3 change (%) for the JAN 2005 SPE's (from A. Seppälä, 2005)

Growing experimental evidence for significant mesosphere-stratosphere interactions





Above: Meridional lower thermospheric winds by 4 SuperDARN radars and Stratospheric temperature at 2mb 2004-2007.

Unpublished data, shown with permission of the author Rob Hibbins, BAS.

Left: Zonal average ACE-FTS NOx in the Northern Hemisphere from 1 Jan through 31 Mar of 2004 – 2009

Randall et al., GRL, vol 36, L18811, doi:10.1029/2009GL039706, 2009

EISCAT Svalbard Radar

Thermosphere is affected by stratosphere!

- stratospheric warming is recently seen to be connected with large temperature variations in thermosphere by the Millstone Hill radar.

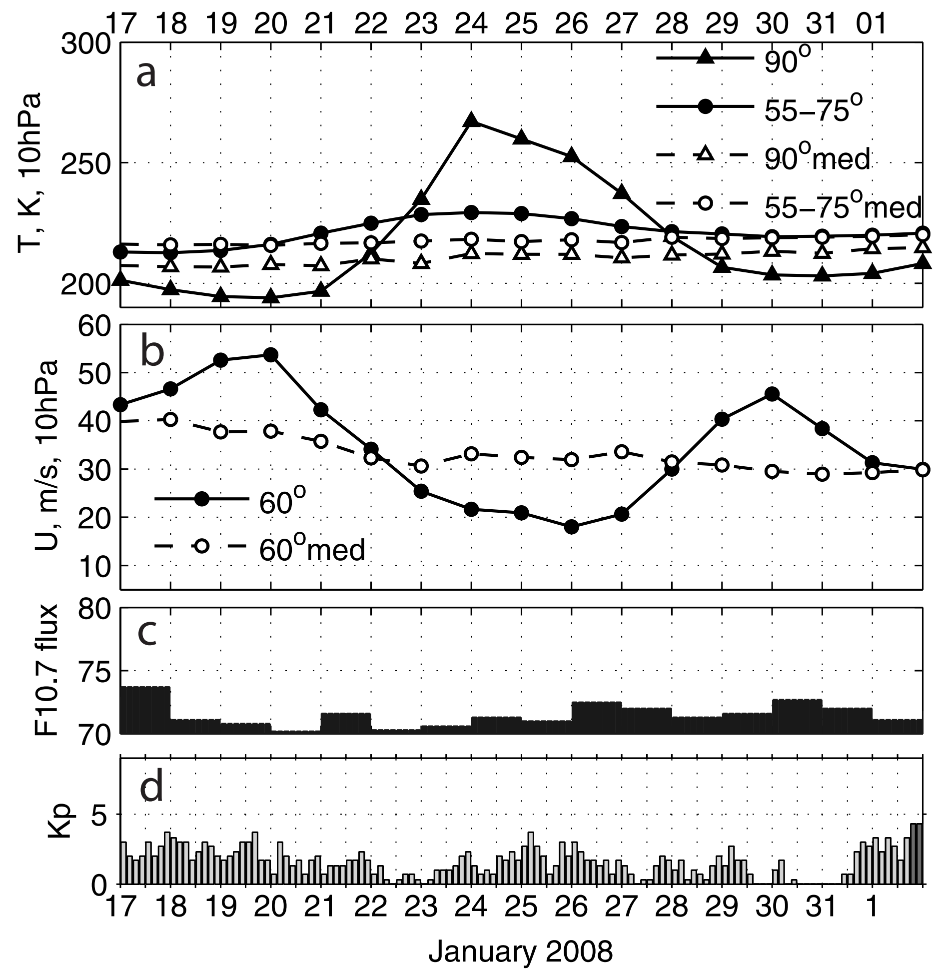


Figure 1. Stratospheric winter of January 2008 (solid lines) in comparison with 30-year mean January conditions (dashed lines). (a) NCEP zonally averaged stratospheric temperatures at 10hPa (~30 km) in different latitude bands. A SSW event occurred in late January 2008, with peak warming at 10hPa level on January 24–25, 2008. (b) Abatement in the zonal mean zonal flow at 60°N. The stratospheric warming occurred during (c) low solar flux and (d) quiet geomagnetic conditions.

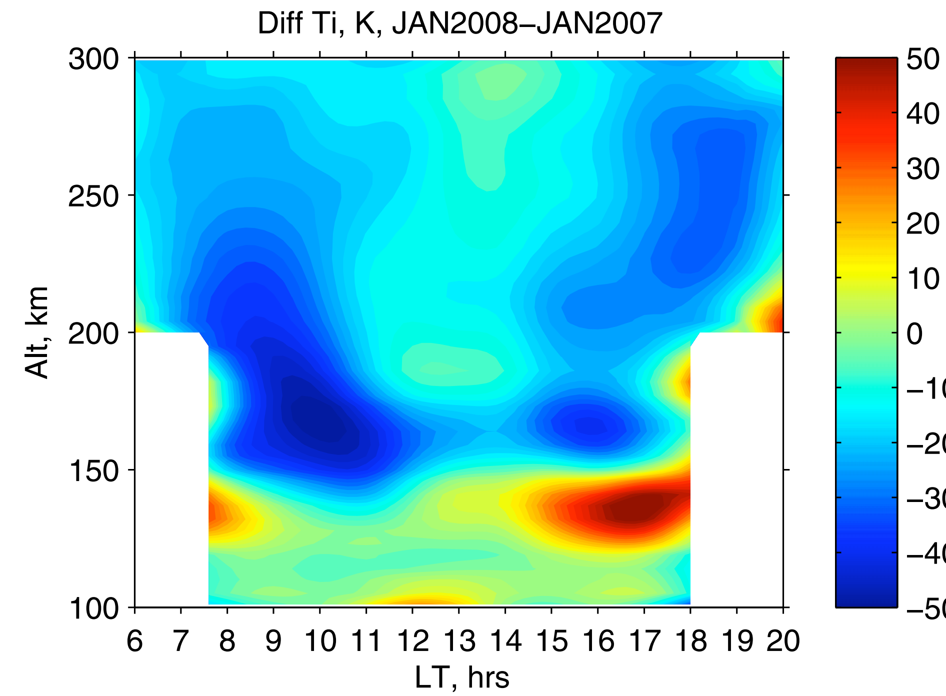


Figure 2. Difference field of ion temperature between mean January 2008 data and mean January 2007 data. A 20–50K decrease in temperature is observed above ~140 km in the morning hours (7–11LT) and afternoon hours (15–19LT). A narrow area of warming is observed in the lower thermosphere at ~120–140 km.

from: Goncharenko et al., GRL, VOL. 35, L21103, doi:10.1029/2008GL035684, 2008, "Ionospheric signatures of sudden stratospheric warming: Ion temperature at middle latitude"

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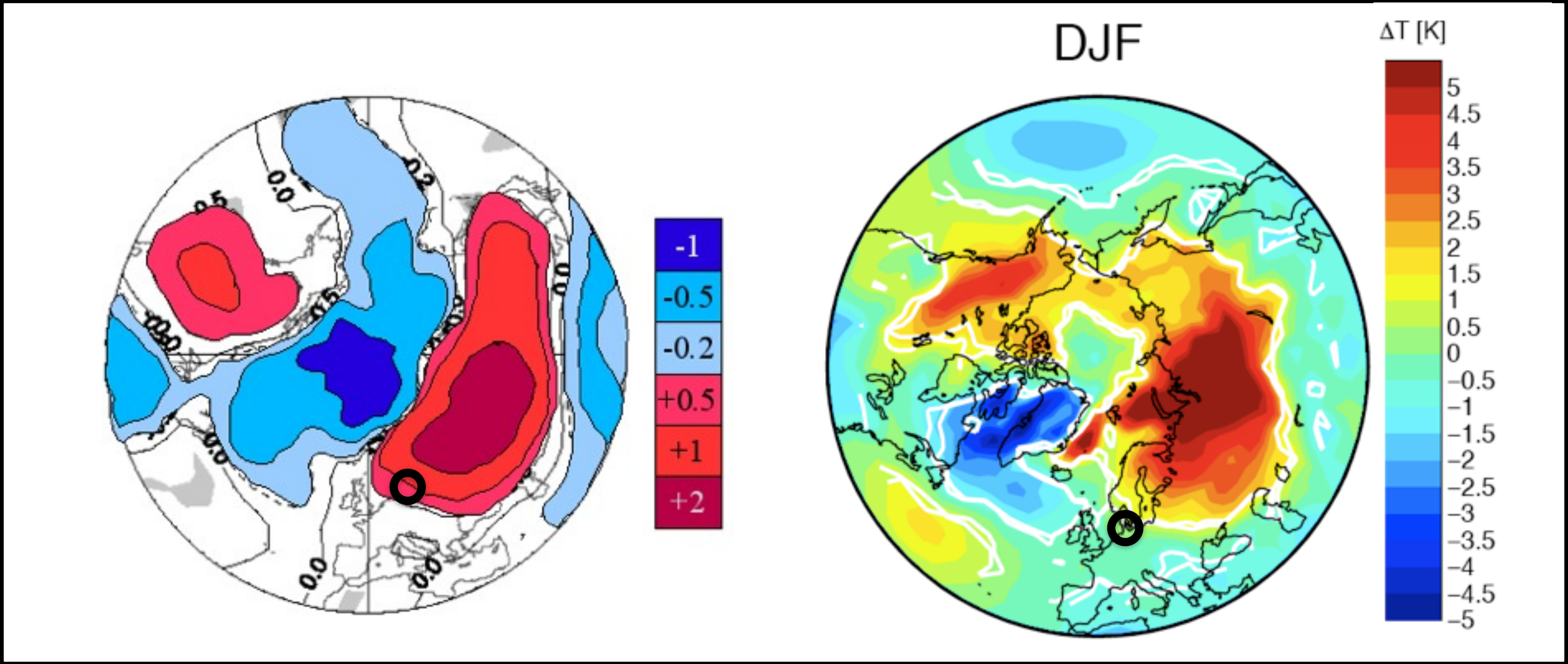
Could these couplings change the surface temperatures?



Rozanov et al., 2005

Seppälä et al., 2009

40 years of surface T data show consistent areas with +4 C warmer during magnetically active winter months (right).

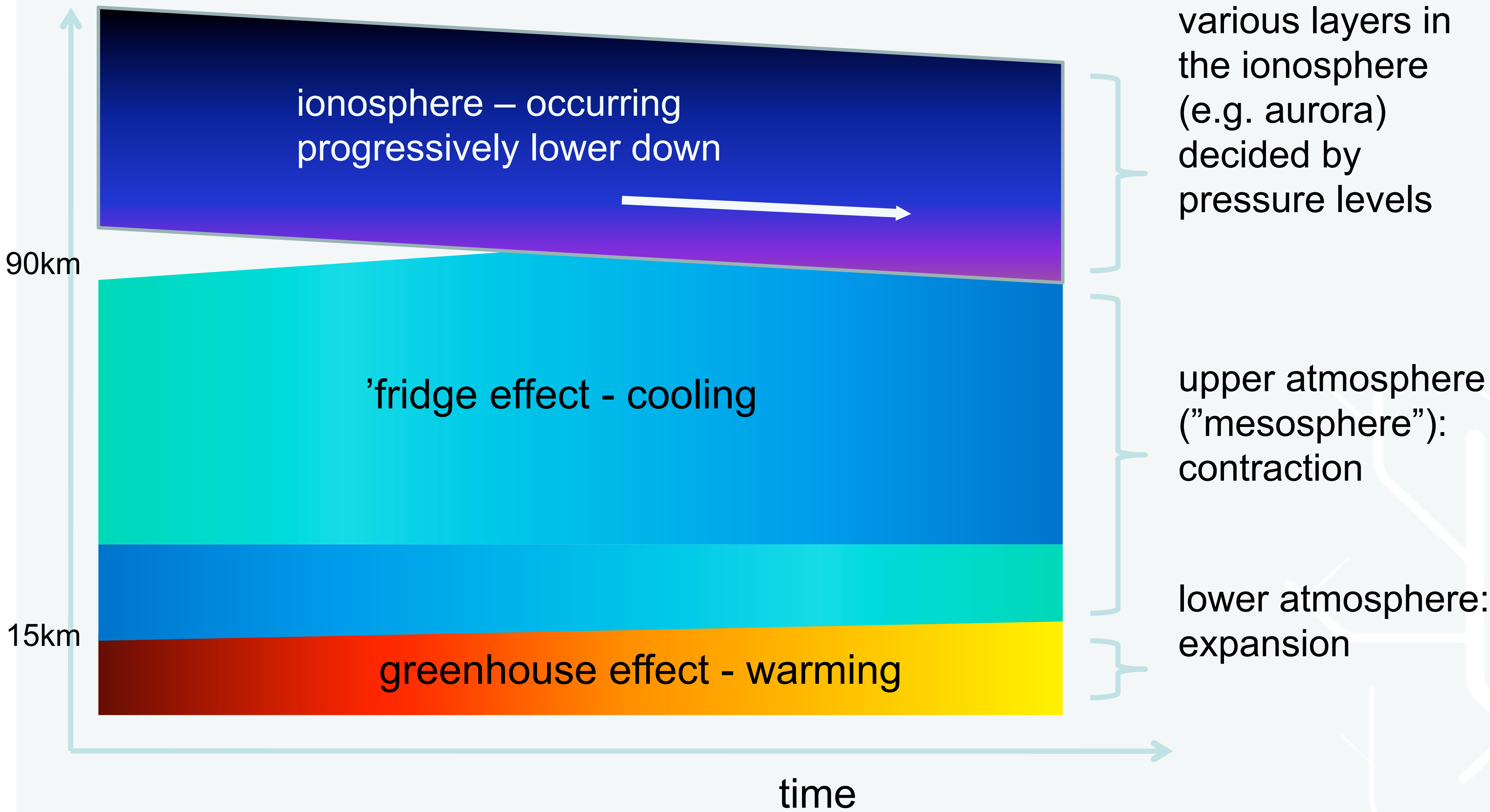
General Circulation Model study with Energetic Particle Precipitation shows similar consistent structures as experimental data on Earth surface temperatures during high solar activity, in winter months (left)

Seppälä, A., C. E. Randall, M. A. Clilverd, E. Rozanov, and C. J. Rodger (2009), Geomagnetic activity and polar surface air temperature variability. J. Geophys. Res., 114, A10312, doi:10.1029/2008JA014029

Another side of the coin:

Effects of greenhouse gases

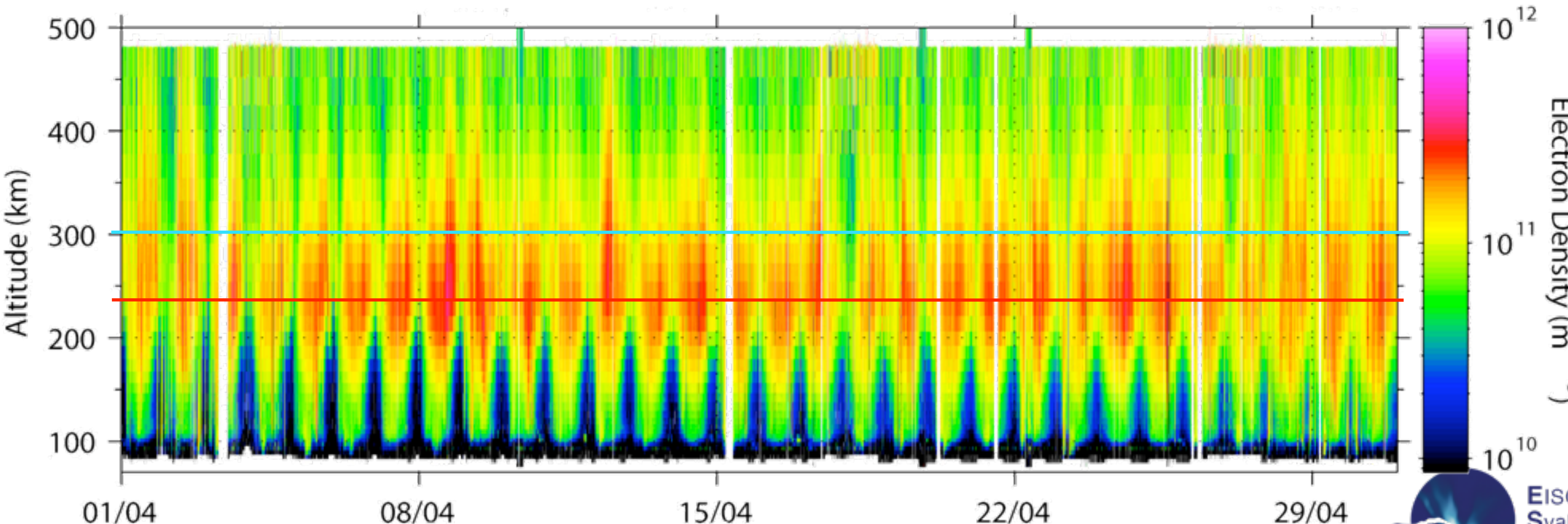
- global warming in the troposphere
- cooling in the middle atmosphere



Courtesy of Chris Hall, UiT

Climate Change: Greenhouse cooling in the upper atmosphere?

- ESR April 2007 data showing the daily variation of the ionosphere with altitude and time
- The red line is the approximate mean height of the observed ionization peak (~240km)
- Blue line is the best modellers' estimate of where it should be (~300km)



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Unique science opportunity in order to answer important fundamental questions:

- Energy input from solar wind -> magnetosphere ->ionosphere
- Solar variability effects in the atmosphere in the Arctic
- Coupling of atmospheric regions
- Turbulence in the neutral atmosphere and space plasmas
- Dust and aerosols, meteoric input
- Ion outflow at high latitudes

Note: The wind field can be measured continuously in the whole atmosphere, in a large geographical area, with high resolution, as a 3D image!

EISCAT_3D + EISCAT Svalbard Radar
+existing infrastructure (Andoya, Esrange,SIOS, Heating, Radar, Lidar, Riometer, Magnetometer, GPS, Tomography receivers, etc.)

European
Window to Geospace in Northern Scandinavian Arctic

EISCAT/US(NSF) Collaborations:

- US external members in EISCAT committees
  - EISCAT Science Oversight Committee
- EISCAT community users in NSF evaluation panels
  - e.g. for AMISR
- EISCAT attendance at NSF UAF meetings
- EISCAT has had a US director, several ex-EISCAT staff employed in US radar community
- Previous NSF/EISCAT joint postdoc position
- Engineer exchanges
- EISCAT_3D related development work done at US radars
  - currently at Jicamarca

EISCAT/US(NSF) Collaborations:

- EISCAT support for, and interest in, NSF Antarctic Radar proposal
  - Antarctic Radar Workshops 2008, 2011
- Plans for NSF in-kind support for EISCAT_3D
  - Technical advisor?
- US teachers at EISCAT training schools, EISCAT teacher at this year's (2010) US school
- Planned joint US/EISCAT radar school in Greenland, July 2011
- Many US attendees at EISCAT scientific workshops, one EISCAT workshop held in US (2003)

EISCAT/US(NSF) Collaborations:

- Co-ordinated regular radar operations
  - World Days and multi-radar Special Programmes
- Northward face of US/Canada Resolute Bay AMISR radar oriented to point toward the ESR
- Major US/EISCAT collaboration for IPY
  - PFISR and ESR
- Common radar database
  - Madrigal
- EISCAT-developed codings used at some US radars
  - Alternating codes
- US users of EISCAT (e.g. in rocket campaigns), EISCAT community users of US radars
  - EISCAT Council will announce 200h peer-reviewed experiment time for 2011, anyone can apply.

EISCAT/US(NSF) Collaborations:

- First NSF-funded cubesat (RAX) will be used in conjunction with ESR
- EISCAT uses Dynasonde instruments developed in US, and undertakes joint software development for these

EISCAT Workshop 2003 in California

Discussion of common infrastructure needs

- Better global
  - Monitoring of Geospace
  - Management of Geospace
- Advancing Earth System Science
  - Understand the coupled Earth-Space system in such detail that data assimilation allows efficient forecasting using models
  - Have such data available
- Space Situational Awareness (SSA)
  - Space Weather services
  - Space Surveillance development

Discussion of common infrastructure needs

- Support operation of current facilities to the future
  - Joint user community
  - Efficient upgrades
- Collaborative education
  - Mobility schemes
  - Regular radar schools
- Build up-to-date new facilities
  - Fill global coverage gaps
    - Southern hemisphere
    - Eastern Europe, Asia?
  - Build new dimensions in resolution, applications and functionality
    - Joint efforts for new phased-array facilities, technology transfer
    - Continuous operation
- Build new dimensions to data access and availability