EISCAT Science: Multi-scale structure

- Micro-scale structures
  - Distribution functions (non-Maxwellians, F region and E-region)
  - Natural plasma instabilities (NEIALs,)
  - Small-scale plasma waves (coherent structures)

- Meso-scale structures
  - Gradients and scintillation (space weather applications)
  - Auroral arcs and electrodynamics (what happens near an arc?)
  - Large-scale waves (Gravity waves and TIDs)

- Large-scale structures
  - Large-scale convection (effect of solar wind coupling)
  - Flow channels (heating and composition effects)
  - Blobs and patches (formation and development)
  - Holes and troughs (high-latitude and middle latitude)

- Temporal structure
  - Event statistics (ion heating, ion upflows)
  - Long-term trend (upper atmosphere cooling)

Microscale Structure
I: Effects on the ion distribution function

All our standard parameter fitting is based on assumption of equilibrium plasmas (isotropic Maxwellian distributions)

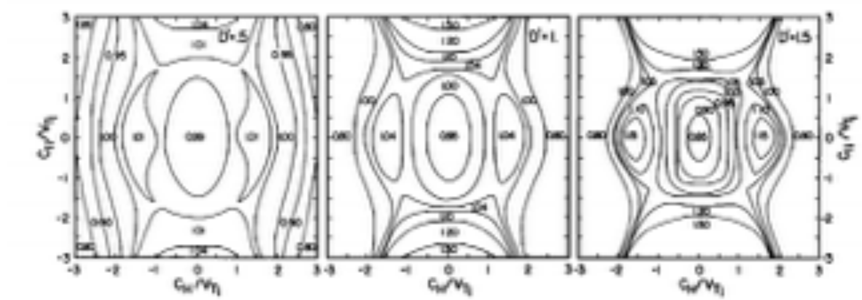
We know this assumption breaks down when plasma convection is strongly driven by electric fields

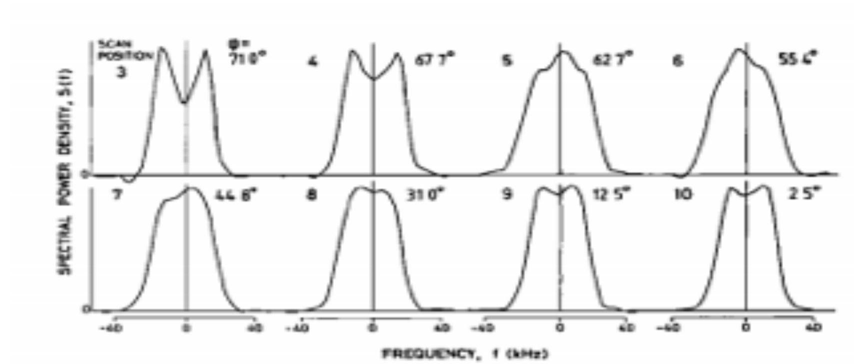
This is particularly true in the F-region, because O+O collisions are strongly backscattering

Molecular species have more isotropic collisions

Limiting case is a toroidial distribution

Partition coefficient tells how anisotropic the plasma is.





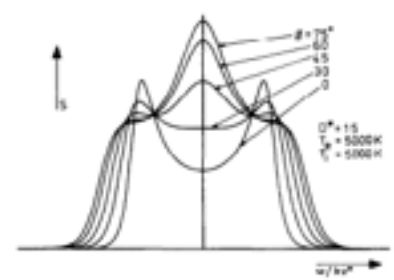
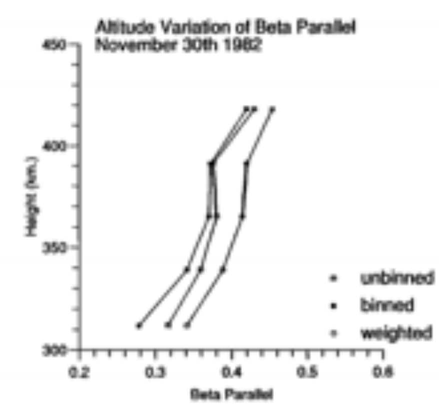


Fig. 7. Incoherent scatter spectra for the generalised relaxation model with $D^* = 1.5$ and equal electron and 3-D ion temperatures of 3000 K, for aspect angles, Φ, of 0°, 30°, 45°, 60° and 75°. The corresponding line-of-sight ion velocity distributions are given in Fig. 1. The phase speeds are normalised to v^*.



Microscale Structure
II: Natural plasma-irregularities

- EISCAT occasionally sees powerful, strongly asymmetric spectra

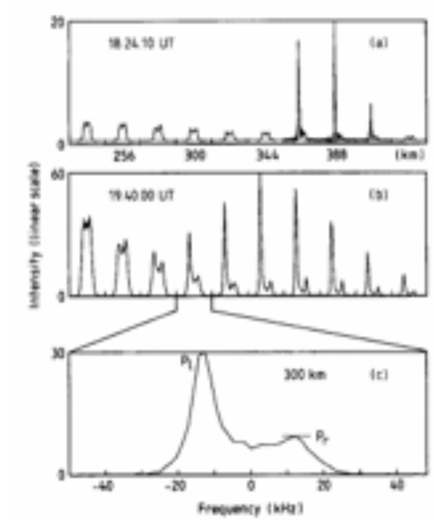
- They occur infrequently, and are typically very short-lived, being typically seen for ~<10s.

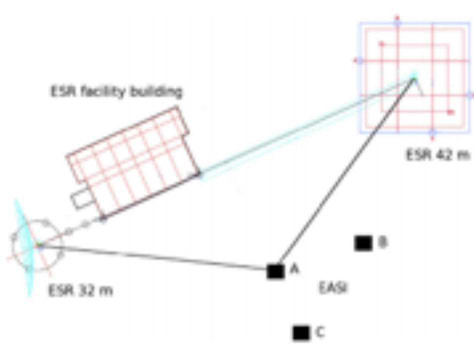
- They have been seen to be linked to auroral phenomena such as rayed arcs

- Theories of generation include ion-acoustic instability, ion-ion two-stream instability or Langmuir wave decay from electron beams

- Likely they come from very small regions (sub-beamwidth)

- This has led to the construction of a small interferometer to





Microscale Structure:
III: Coherent ionospheric structure

The EISCAT mainland radars cannot look at very low elevation

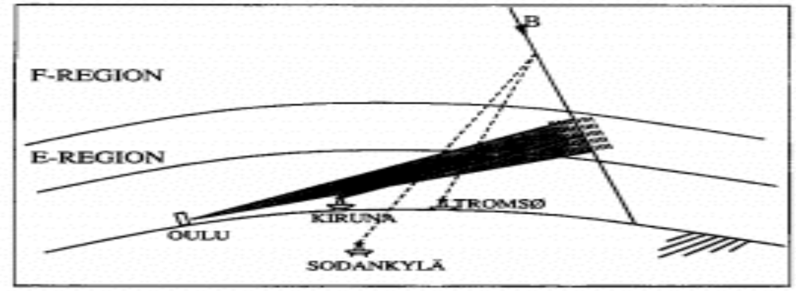
Hence the EISCAT cannot satisfy orthogonality condition for backscatter from FAIs

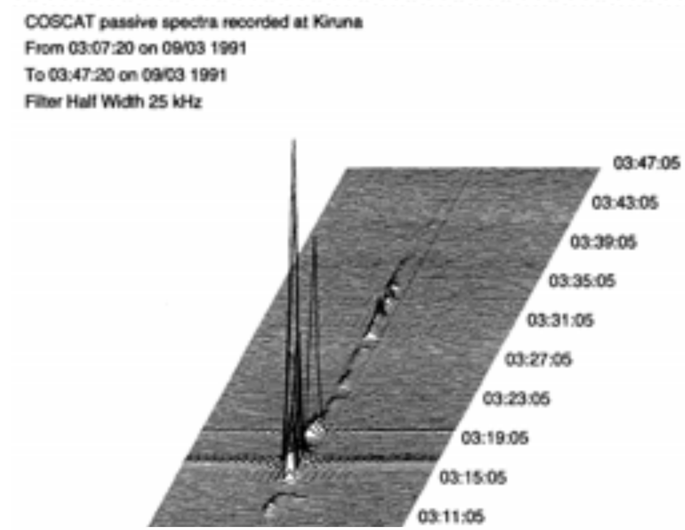
However this can be done by putting a transmitter further south (bisector vector perp. to field)

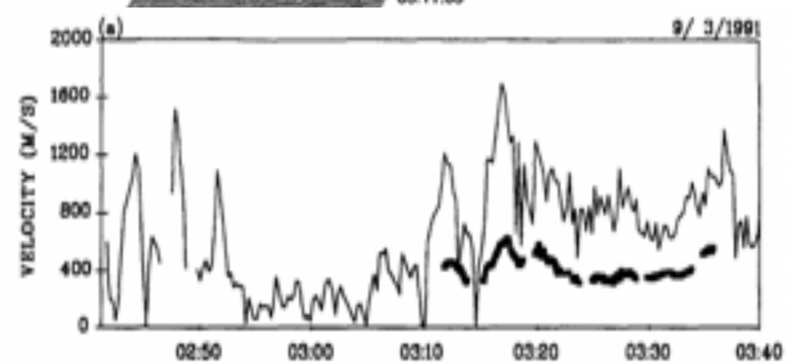
In this case, Kiruna has been used as a receiver for coherent scatter @ 930 MHz.

Narrow spectra with phase speeds limited to around 420 m/s (ion-acoustic speed)

Likely to indicate scatter from a narrow region around 100km







Meso-scale structure
I: Gradients, TEC and scintillation

EISCAT frequently sees highly structured density and strong gradients in the high-latitude ionosphere

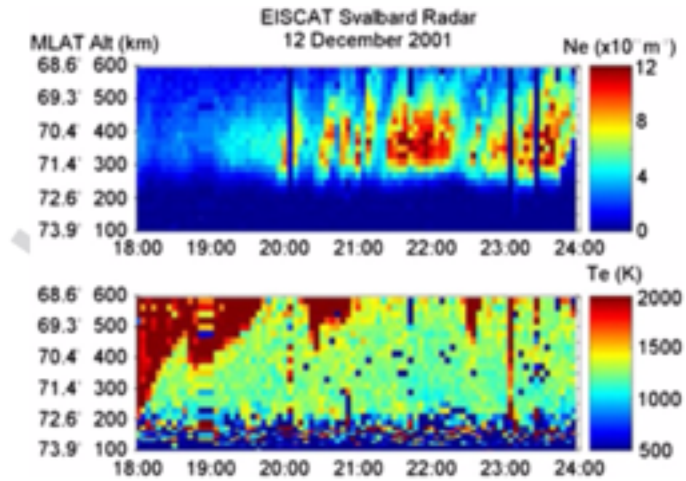
Structure is interesting in itself, but also has practical implications because these irregularities cause phase and amplitude fluctuations (scintillation) in radio signals

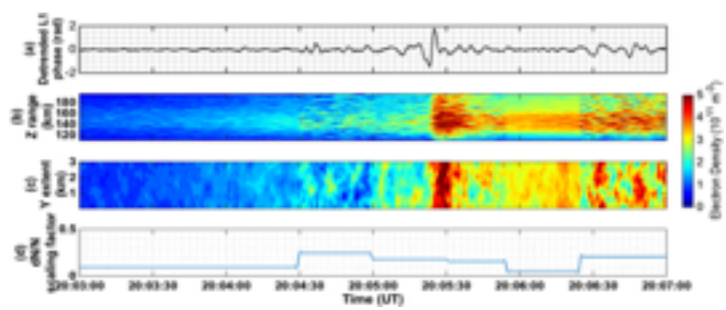
Phase and amplitude scintillation do not necessarily occur together (different irreg scales)

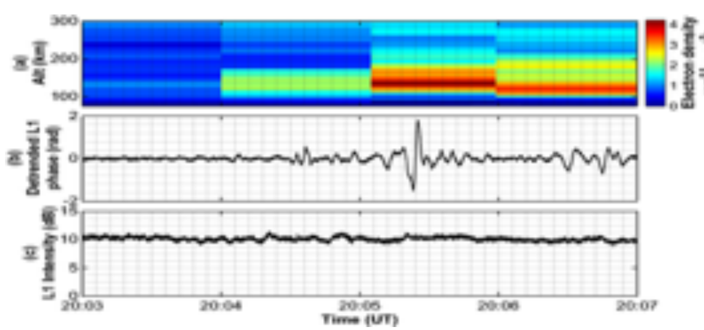
Example by Chartier et al (2016) shows (predominantly) phase scintillation during density enhancements at Tromso

These enhancements are predominantly in the E-region density

Magnitude of phase scintillation is not







Meso-scale structure
II: Auroral arcs and electrodynamics

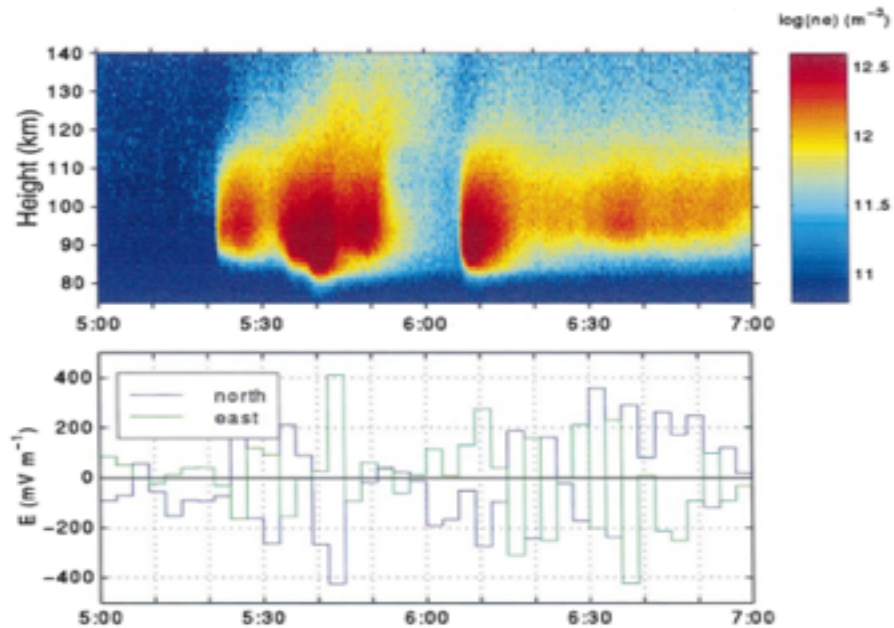
Radars can make unique observations of aurora, in a way not possible for rockets and satellites

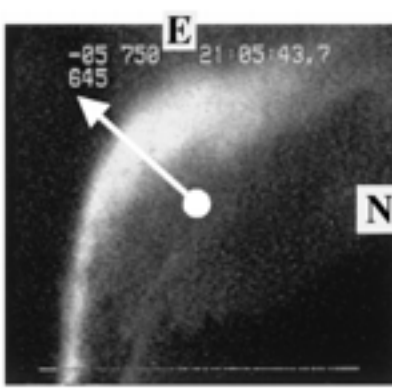
In particular, the tristatic capability of EISCAT has helped us understand the electrodynamics at high time resolution

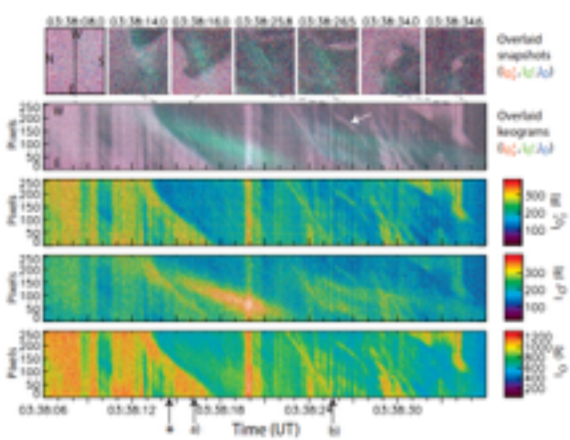
EISCAT needs complementary data from auroral imagers to do this kind of science

What seems to be continuous density structure in radar data is revealed to be made of made of multiple arc elements

Optical measurements make clear that the largest fields are adjacent to the







Meso-scale structure:
III: Large and medium-scale TIDs

EISCAT cannot sense AGWs directly, but does so through their effect on the ionosphere (TIDs)

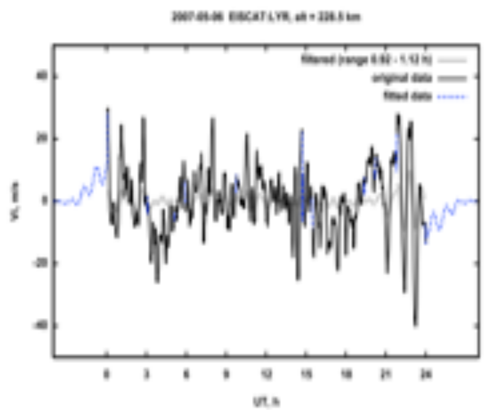
These signatures are common, best seen under quiet conditions

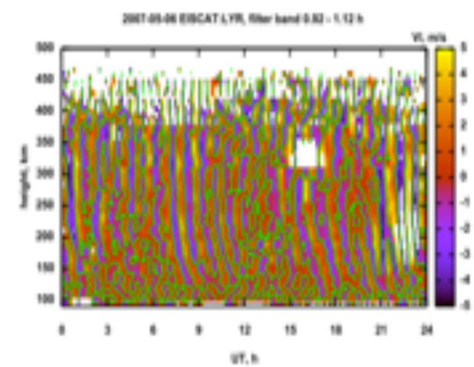
Seasonal distribution is biased by Ne variation

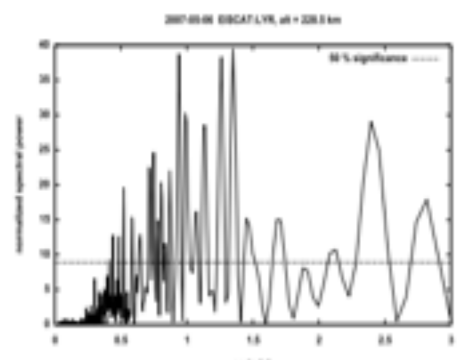
TID characteristics can be explored most directly through effects on field-aligned velocity

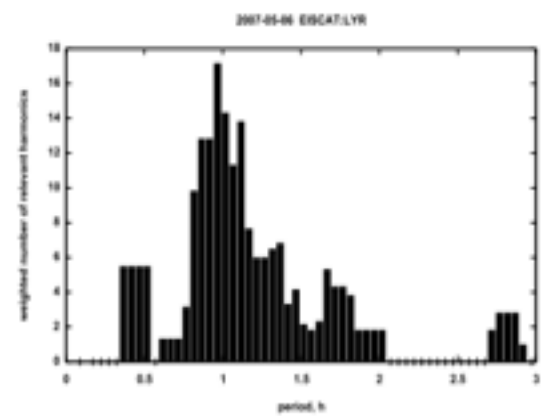
LS and MSTID: periods > 15 min, Most commonly 0.5-07h, 1.1-1.3h.

Can also use EISCAT to investigate auroral source mechanisms.









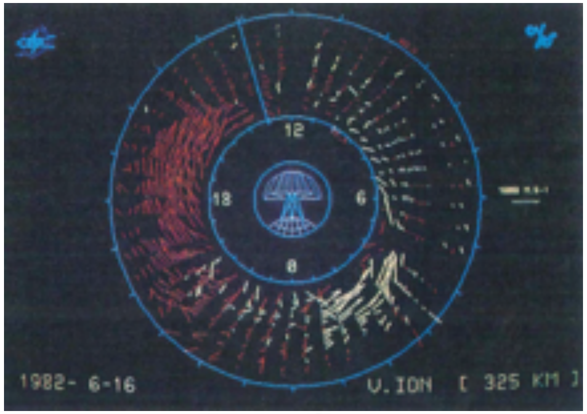
Large-scale structure
I: Large-scale convection

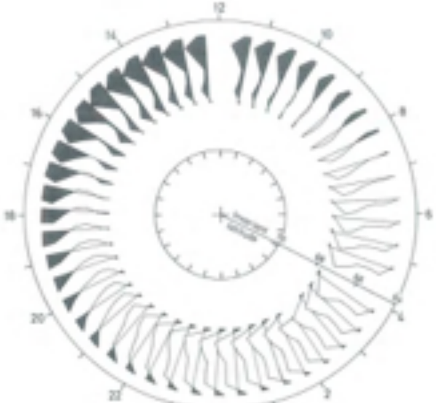
EISCAT's scanning mode (CP3) enables large-scale monitoring of the plasma convection pattern, especially in the days when remote sites operated at UHF.

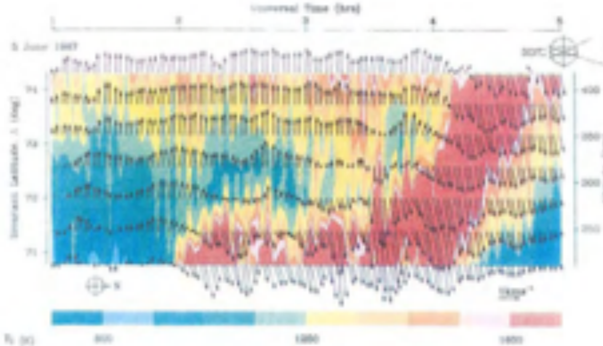
Tristatic and beam-swinging approaches are both possible

Key issues include response to large and small scale responses to IMF variation, implications for electrodynamics and coupling, relationships to other parameters.

EISCAT has been one of the key systems in demonstrating the very dynamics coupling of the ionosphere to the magnetosphere and solar wind, especially in FTEs, and determining location and time constants of responses.







Large-scale structure II: Flow channels

These are examples of smaller-scale responses to specific events, such as FTEs, most often seen on the dayside

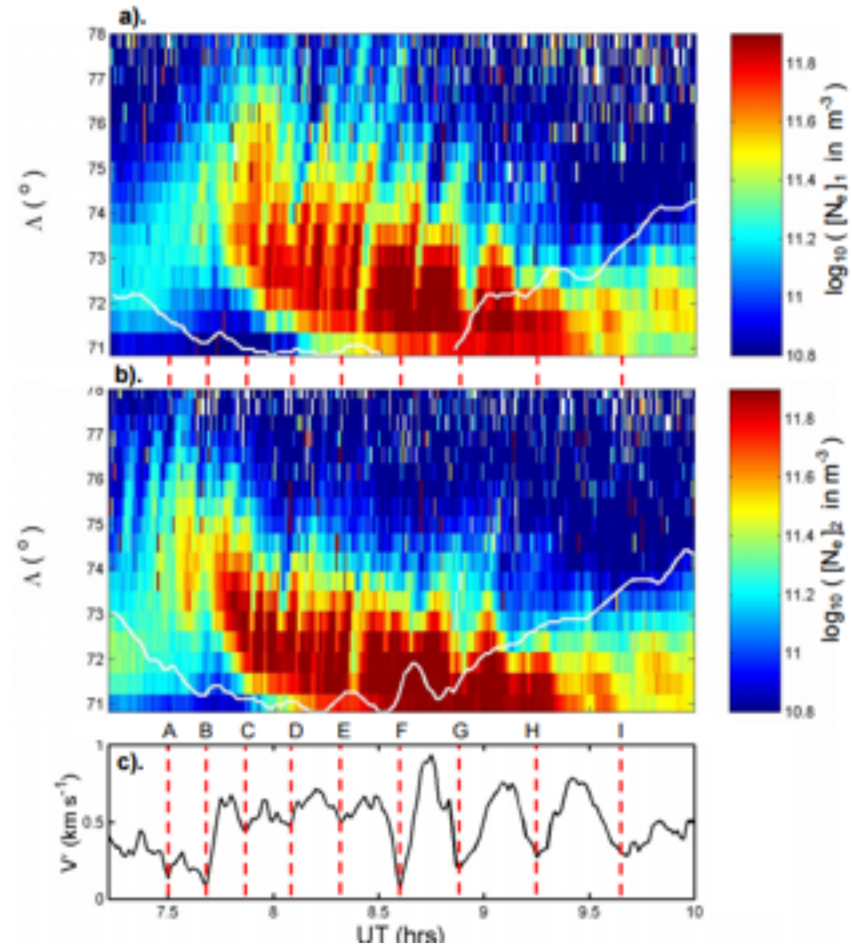
Transient flow channels seem to be a regular feature of the dayside cusp

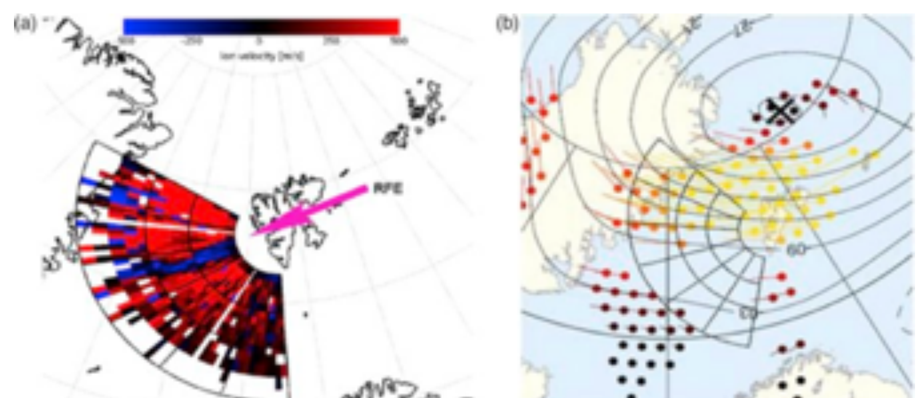
Illustrates response of flux tubes to solar wind-magnetosphere coupling processes, occur over a range of By and Bz conditions

Convecting flux tubes can display dispersed precipitation into ionosphere

High-speed flow drives ion frictional heating, changes chemistry, density structure

Shows how IMF and MI coupling can





Large-scale structure III: Blobs and patches

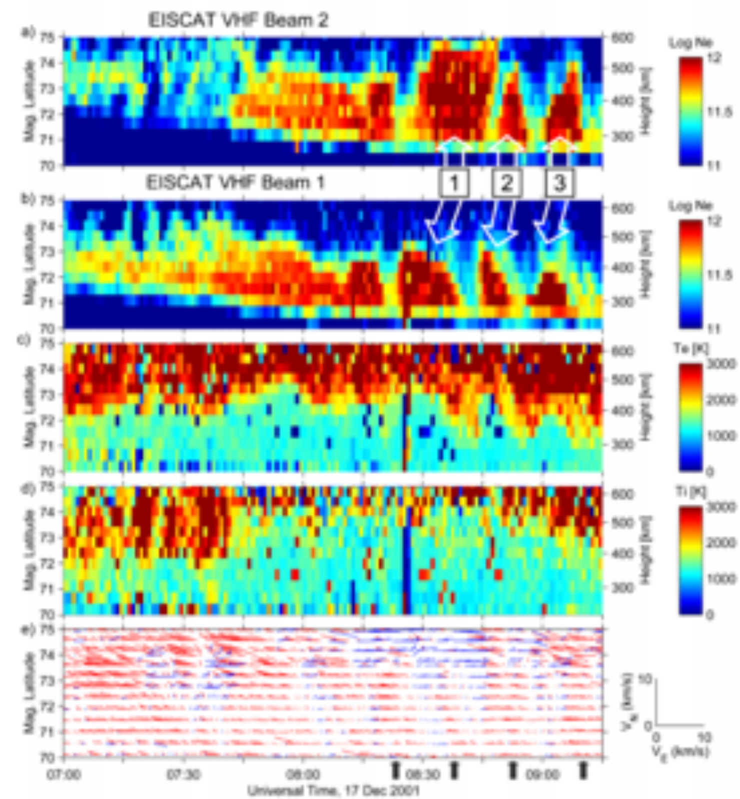
The product of the processes we just discussed: small-scale structuring and large-scale convection.

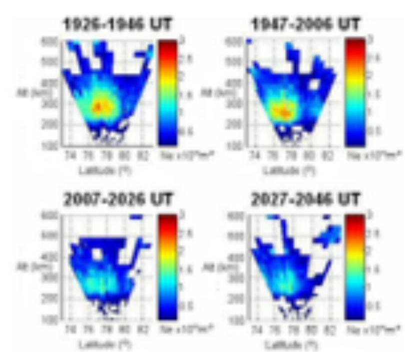
Global-scale propagation with local production

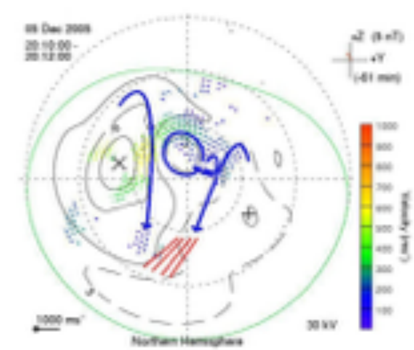
Lots of small-scale structure embedded in large-scale structure, implications for radio communications, positioning, timing etc.

Patches (polar cap) and blobs (lower latitudes) can have a variety of formation mechanisms (direct deposition, segmentation, convection effects), scale sizes, positions and time histories as conditions change.

Full time history not observable from a single ISR, need other data to put ISR data in context.







Large-scale structure IV: Troughs and holes

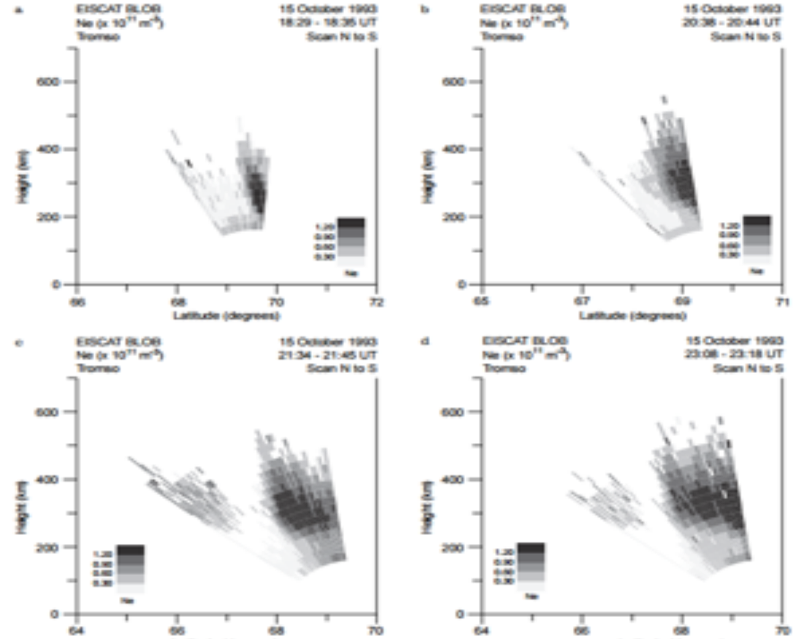
The flip side of high density structures

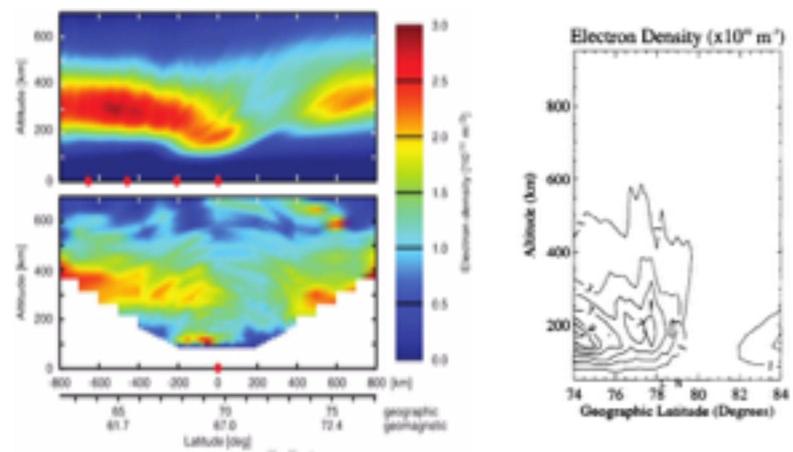
Some regions of the ionosphere, e.g . equatorward of auroral zone, connect to regions of magnetosphere which are not a good plasma source.

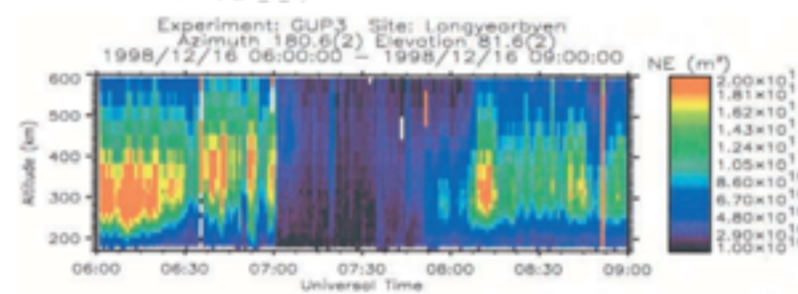
These regions can be subjected to mechanisms that deplete the plasma e.g. enhanced plasma velocity, ion temperature, reaction rate.

Troughs and holes can form anywhere that depletion happens faster than production.

For that to happen, production can decrease, or recombination/transport can increase.







Temporal structure I: Statistical studies

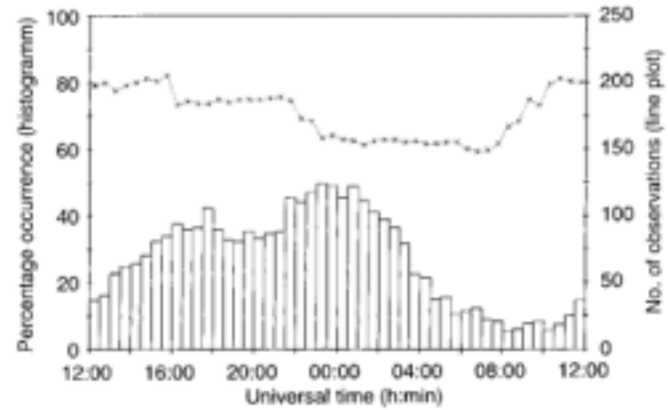
Once EISCAT had been in business a few years, lots of people started doing statistical studies

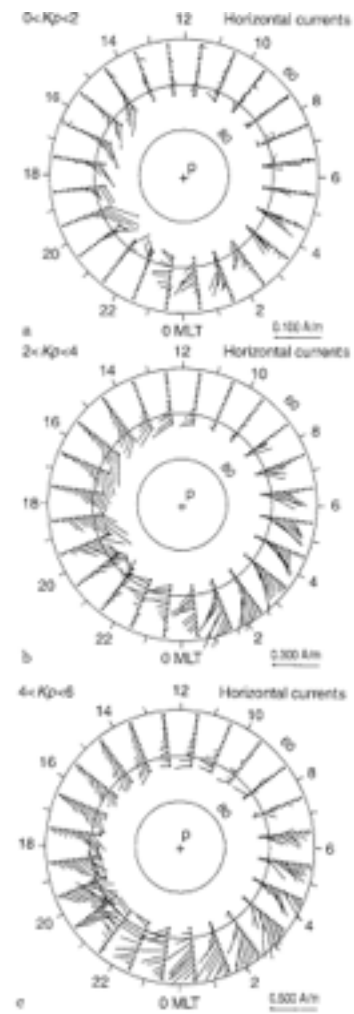
A good way of learning about the physics, because any day of data exhibits so many different dependences

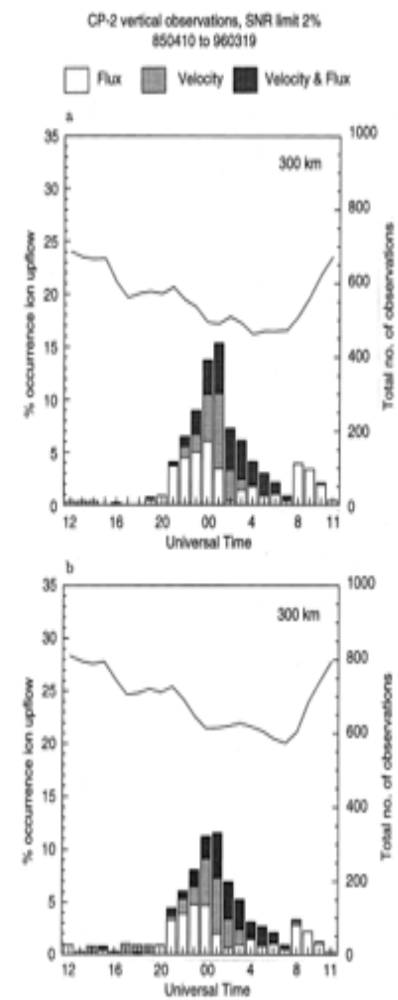
Using statistics, these factors become controllable: time, season, IMF, solar zenith angle, Kp, values of other parameters etc etc.

Statistical data sets can also be put together, e.g convection pattern statistics can be used to derive field-aligned currents and horizontal currents

These had previously been measured by other techniques e.g. satellites, but EISCAT data had some distinct properties (e.g. resolution).

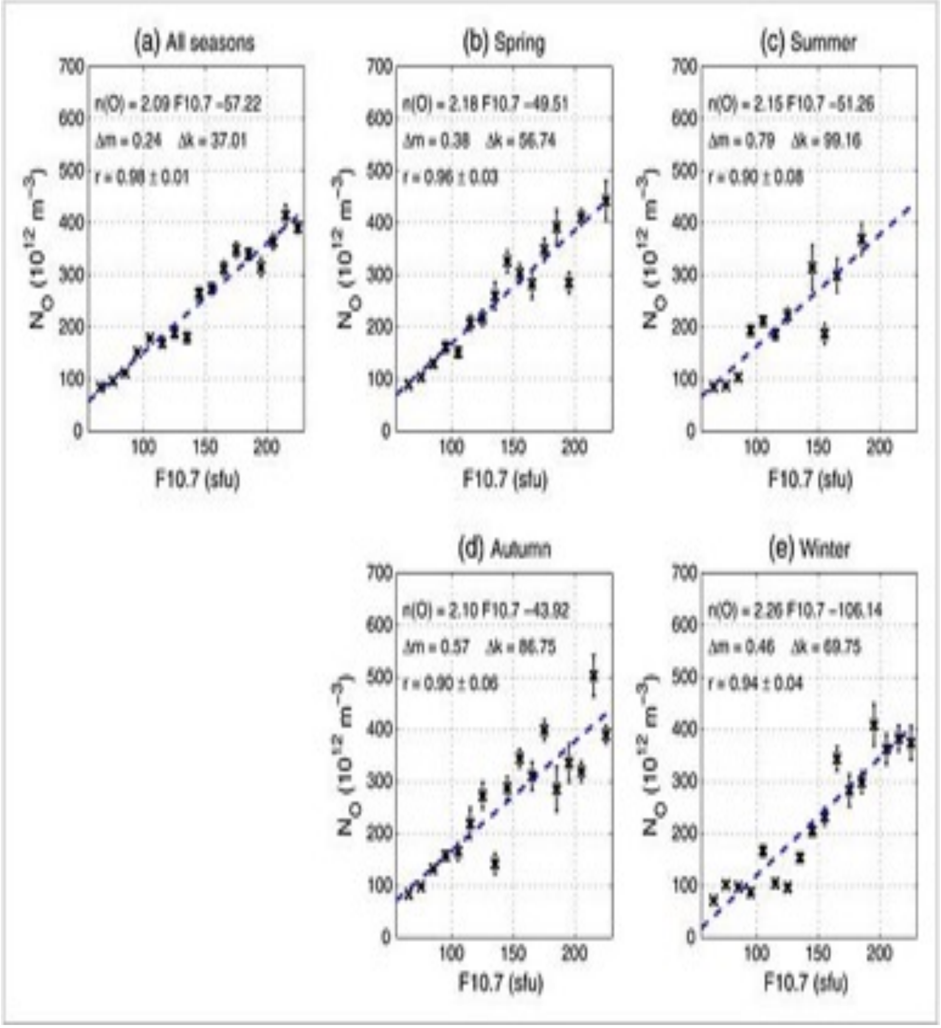






Temporal structure
II: Long-term trends

- Now EISCAT has been running for multiple solar cycles, people are doing longer-term trends.
- Vickers et al (2013) used ion momentum equation, simplified for field-aligned velocity, on a 13 year data set to derive variation of [O] at 350km with solar activity.
- Find factor 5-6 variation in [O] between solar min and solar max
- Also suggested a small overall decline in [O} at 350km from one solar maximum to the next
- Would suggest long-term thermospheric cooling, but effect was hardly significant



Ogawa et al (2014): 32 years of thermosphere cooling

Upper atmosphere has cooled steadily for three decades

Increasing amounts of greenhouse gases released by human activities do not just affect only the lower atmosphere: Scientists project that anthropogenic carbon emissions have caused a cooling trend in the upper atmosphere, between 200 and 400 kilometers, over the past few decades. Cooling in this atmospheric region can affect the operations of satellites and the orbits of space junk. However, data about cooling trends in the upper atmosphere are still incomplete, and better data are needed to confirm this projection.

Ogawa et al. present the first quantitative measurements that match projected upper atmospheric cooling. The authors analyzed data from the European Incoherent Scatter radar, which studies the interactions between the Sun and Earth on the basis of disturbances in Earth's ionosphere and magnetosphere.

From the radar's raw data spanning from 1981 to 2013, the authors teased out information about changes in upper atmospheric temperature. They calculated a cooling trend of 10–15 kelvins per decade near altitudes of 220–380 kilometers and little to no cooling at 400 kilometers.

The authors note that this height profile of their observed trend is in accord with those projected by previous models, but their estimated levels of cooling actually exceed the modeled ones. They speculate that this excess could be related to increases in anthropogenic carbon emissions. Further, their findings may have an impact on future modeling of the upper atmosphere, which will be important for planning future satellite missions. (*Geophysical Research Letters*, doi:10.1002/2014GL060591, 2014) —JW

Yasunobu Ogawa

The European Incoherent Scatter radar near Tromsø, Norway, was used to study climate change in the upper atmosphere.

EISCAT_3D Science Case

- EISCAT_3D Preparatory Phase project included a dedicated work package on building the science case
- Succession of working groups drawn from the EISCAT user community
- Different “focus area” in each of the first three years (atmospheric science, plasma physics, space weather – also solar system science and new techniques as background tasks)
- Annual updates of the science case and table of capabilities
- Appendices covering observing modes and supporting instruments. Feed into data requirements.
- McCrea, I., A. Aikio, L. Alfonsi, E. Belova, S. Buchert, M. Clilverd, N. Engler, B. Gustavsson, C. Heinselman, Johan Kero, M. Kosch, H. Lamy, T. Leyser, Y. Ogawa, K. Oksavik, A. Pellinen-Wannberg, F. Pitout, M. Rapp, I. Stanislawska and J. Vierinen, The science case for the EISCAT_3D radar, Progress in Earth and Planetary Science, 2:21, DOI 10.1186/s40645-015-0051-8, 2015.