EISCAT observations of field-aligned ion flow in the topside ionosphere

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Some recent results of ion upflow using EISCAT (How, When, and Where do ion upflows occur in the polar ionosphere?
Which ion species do flow up?)

What are needed for EISCAT_3D?

Summary

Introduction

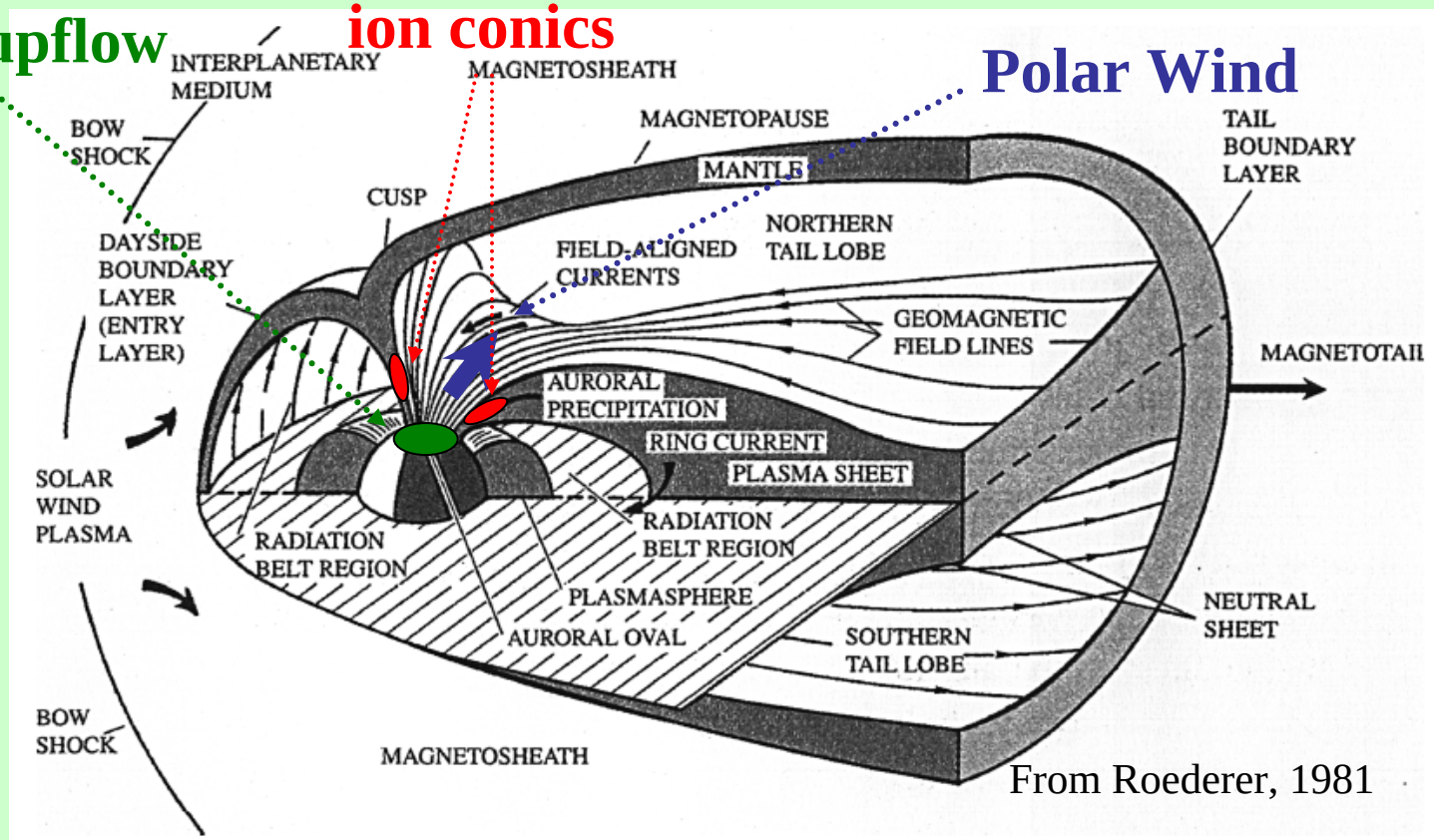
Ion flows from the polar ionosphere to the magnetosphere

Transversely accelerated ions (TAIs),

ion conics

Bulk ion upflow

Polar Wind



From Roederer, 1981

An important phenomenon of the magnetosphere-ionosphere (M-I) coupling is the formation of upward ion flows from the ionosphere since they can be a significant source of magnetospheric plasma and also affect dynamics of the magnetosphere.

Bulk ion upflow in the polar ionosphere transiently occurs with upward velocities of a few 100 to 1000 m s^{-1}, and must play an important role as plasma source for ion outflow.

Introduction

Field-aligned ion flow is affected by

- Chemical reaction (ionization, charge exchange,…)
- Ion pressure gradient (Joule heating)
- Ambipolar effect (pulls ions down electron pressure gradient), which is normally upward in height
- Mirror force and centrifugal force (both important only in collisionless plasma > 1000 km)
- Plasma waves (NEIALs?, Ion cyclotron waves, broad band ELF)

Upflow is expected to become supersonic flow.

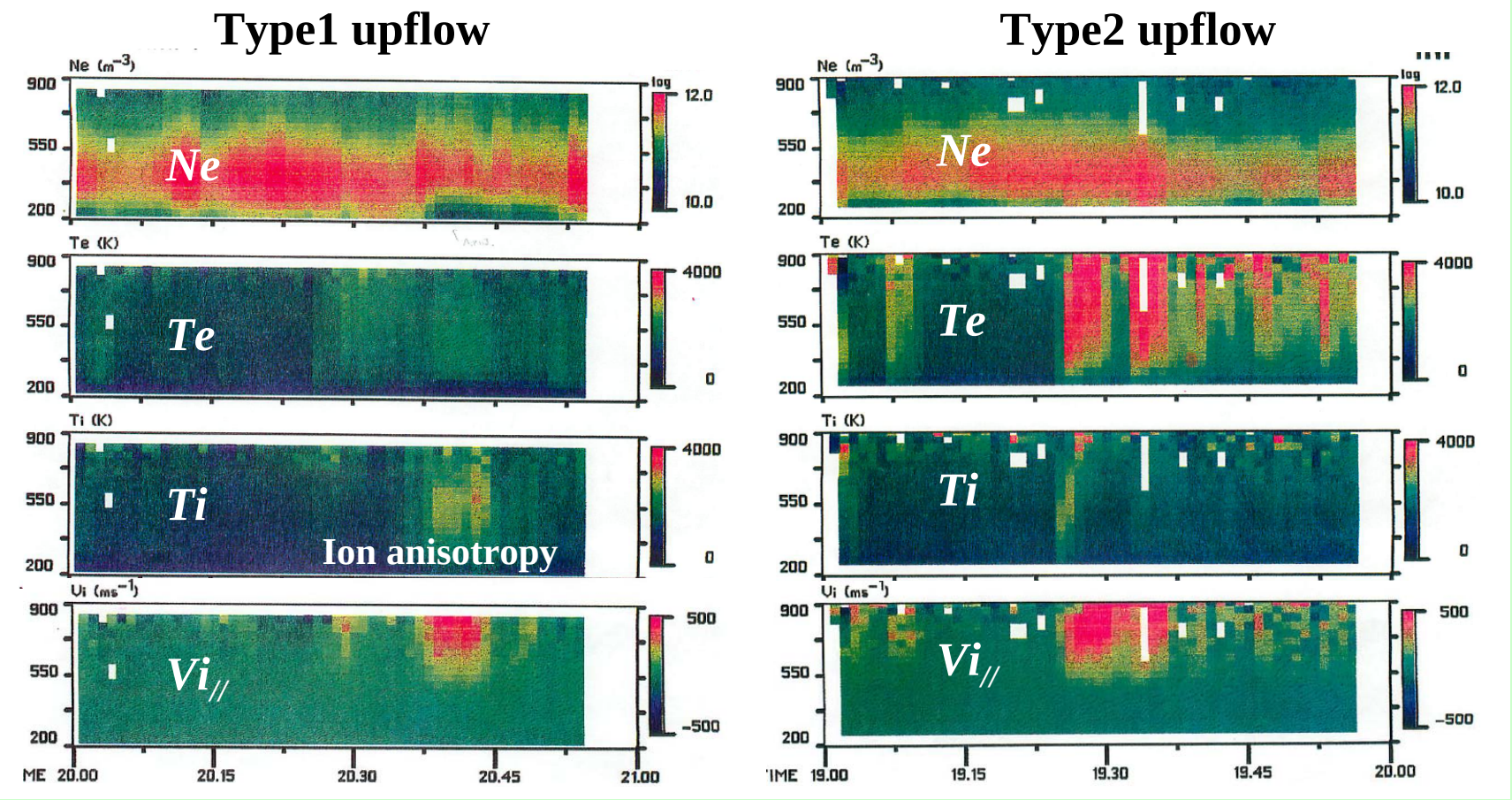
EISCAT gives information of accurate thermal ion velocity and upward flux along the field line, whereas thermal ion detector on satellite suffers from the effect of positive spacecraft charging.

How do ion upflows occur in the polar ionosphere?

Two main processes associated ion upflow (Wahlund et al., *JGR*,1992)

(Type1 upflow) Thermal ion heating by DC electric field

(Type2 upflow) Electron heating and NEIALs



Statistical relation between upflows and NEIALs

Results from ESR (2007-2008)

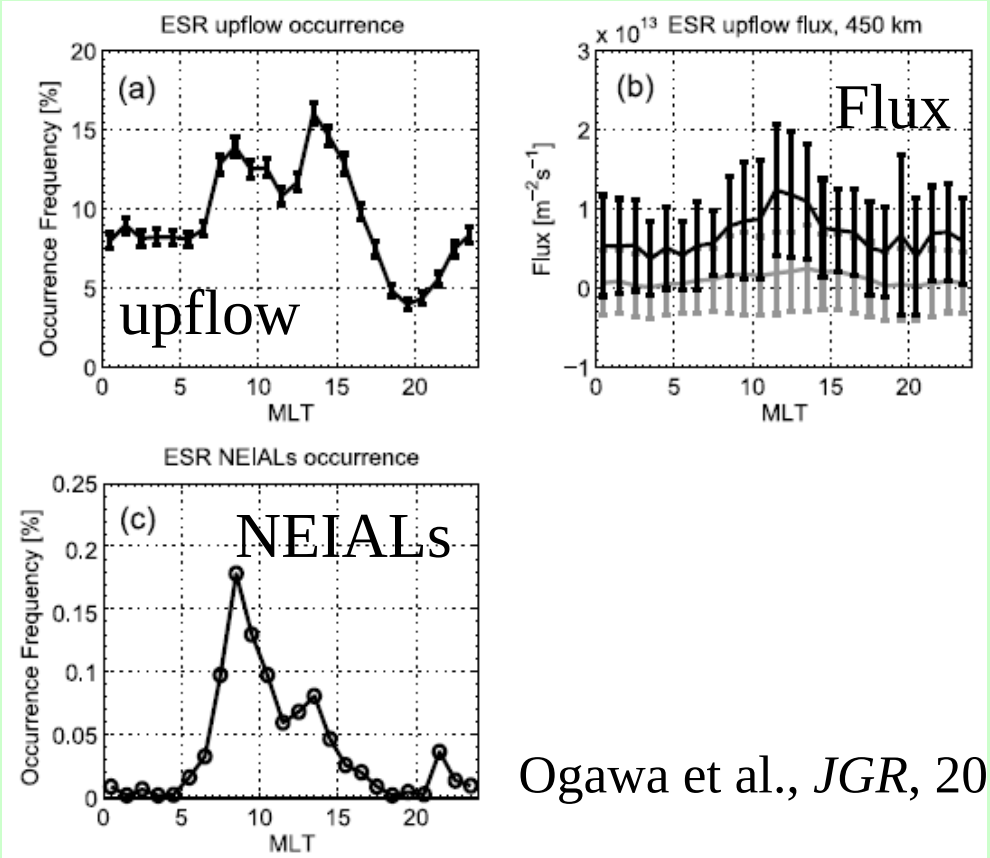
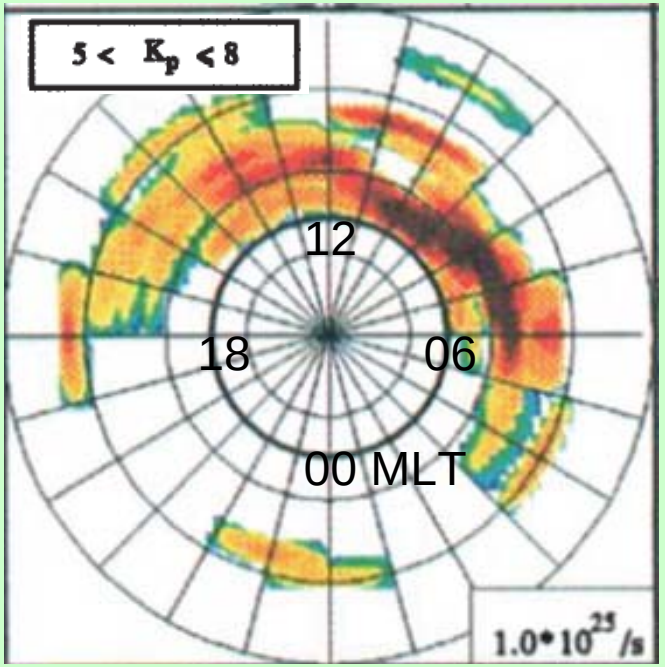


Figure 3. MLT distribution of (a) the occurrence frequency of ion upflow, (b) the upward ion flux at 450 km altitude, (c) the occurrence frequency of NEIALs in the *F* region ionosphere. The black line in Figure 3b indicates the average flux in upflow events, while the gray line indicates the average flux of all data (upflow, downflow, and no flow events).

Ogawa et al., *JGR*, 2011

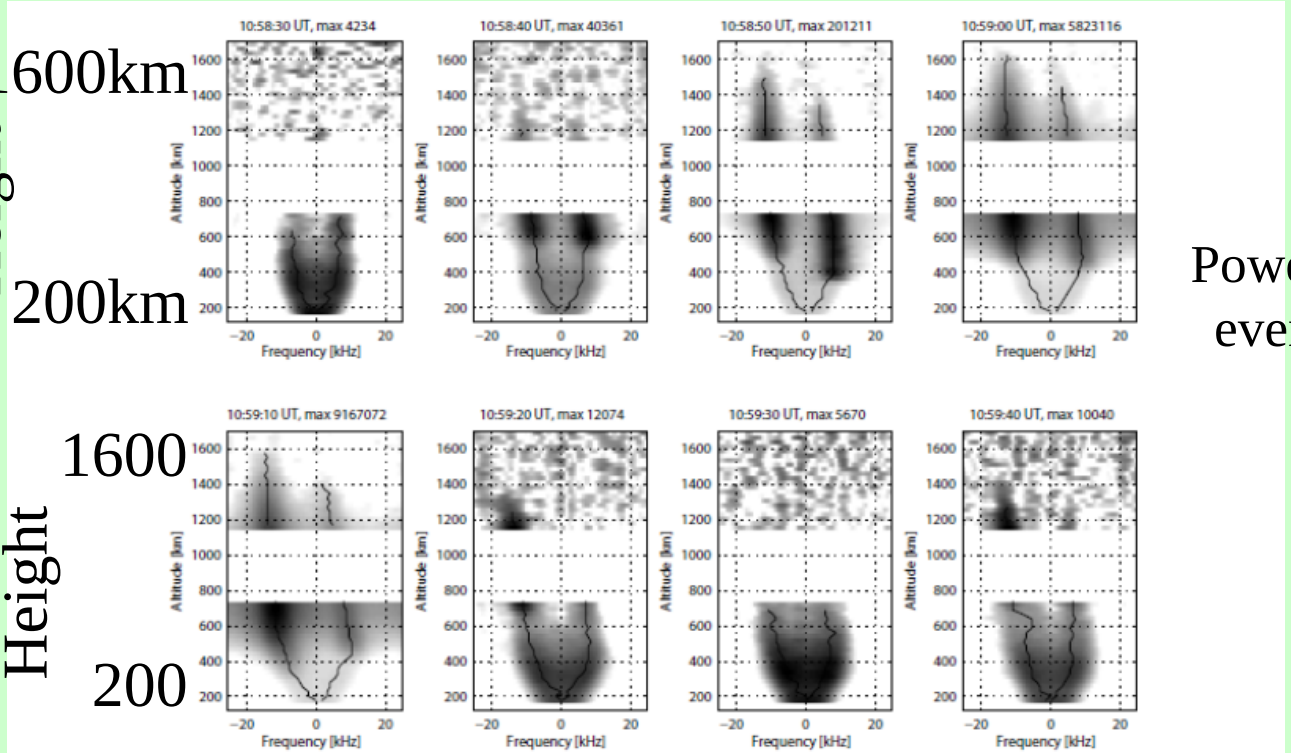
O^+ heating (associated with precipitating H^+ and electrons, and BBELF waves) measured with Freja satellite



Norqvist et al., JGR, 1998

The high occurrence frequency of NEIALs in the prenoon region (08–10 MLT) might be associated with acceleration of thermal ions to suprathermal ones.

Naturally enhanced ion-acoustic lines at high altitudes



Power spectra every 10 sec

Fig. 3. NEIALs observed with the ESR 32 m antenna between 10:58:30 and 10:59:30 UT on 28 July 2000. Power spectra from channel 3, altitude 200–850 km and 1200–1650 km (background) are plotted with a gray scale. A format of the plots is same as Fig. 2. The spectra are multiplied by the range squared and normalized to the value given at the top.

Ogawa et al., *Ann. Geophys.*, 2006

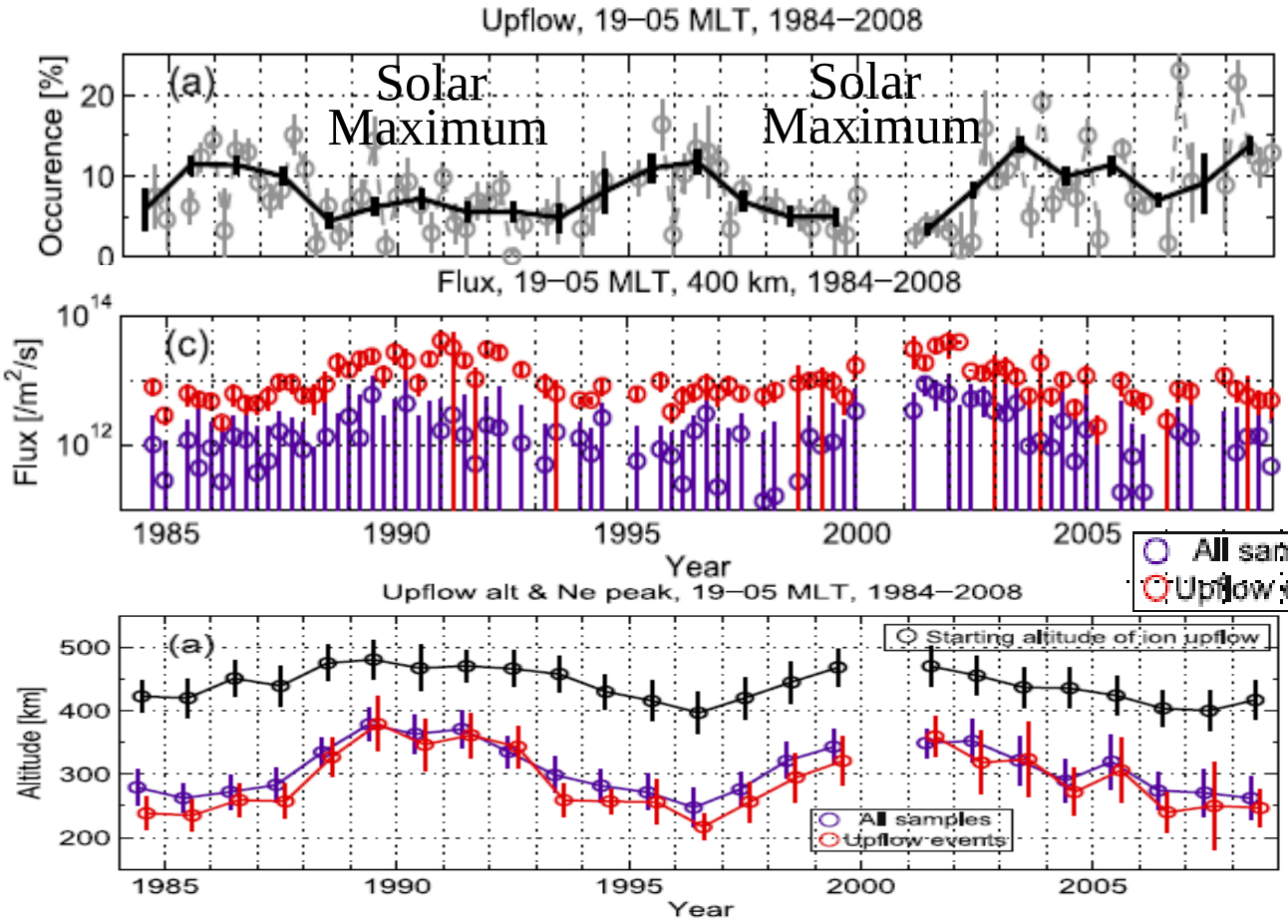
- NEIALs have been seen at heights up to 1600 km (near solar maximum).
- The NEIALs seem to indicate that a transition subsonic to supersonic upflow is somewhere near 2000 km altitude.

→ EISCAT_3D could possibly help answering the following question:

What kind of physics is behind the transition subsonic to supersonic upflow in the topside ionosphere?

When do ion upflows occur in the polar ionosphere?

Solar activity dependence of ion upflow
(Foster et al., *Ann. Geophys.*, 1998; Ogawa et al., *JGR*, 2010)



High upflow occurrence around solar minimum

High upward ion flux around solar maximum

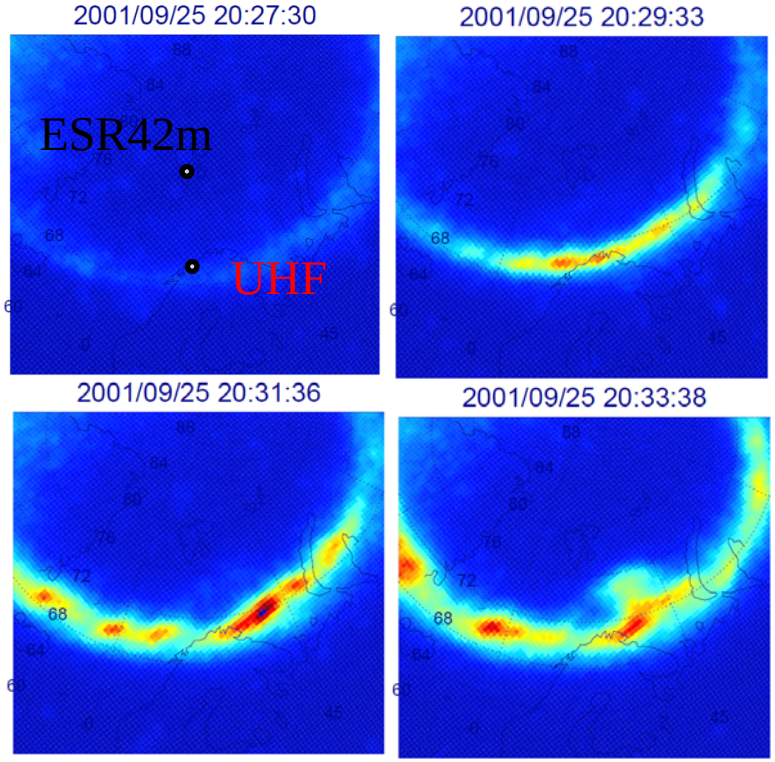
Starting altitude of ion upflow also changes as altitude of electron density peak changes

These investigations will give important implications for the long term evolution and future climatology of planetary atmospheres.

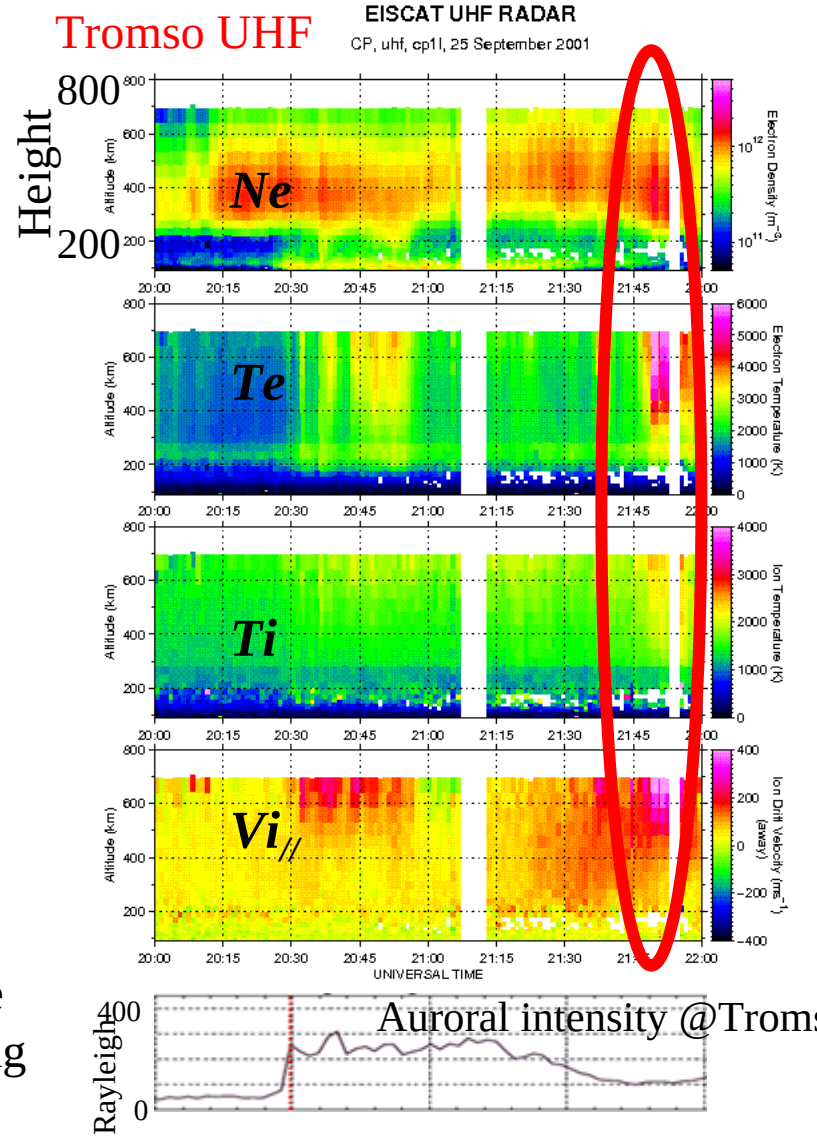
When do ion upflows occur in the polar ionosphere?

Relation between ion upflow and phase of auroral substorm

IMAGE WIC results



Tromso UHF



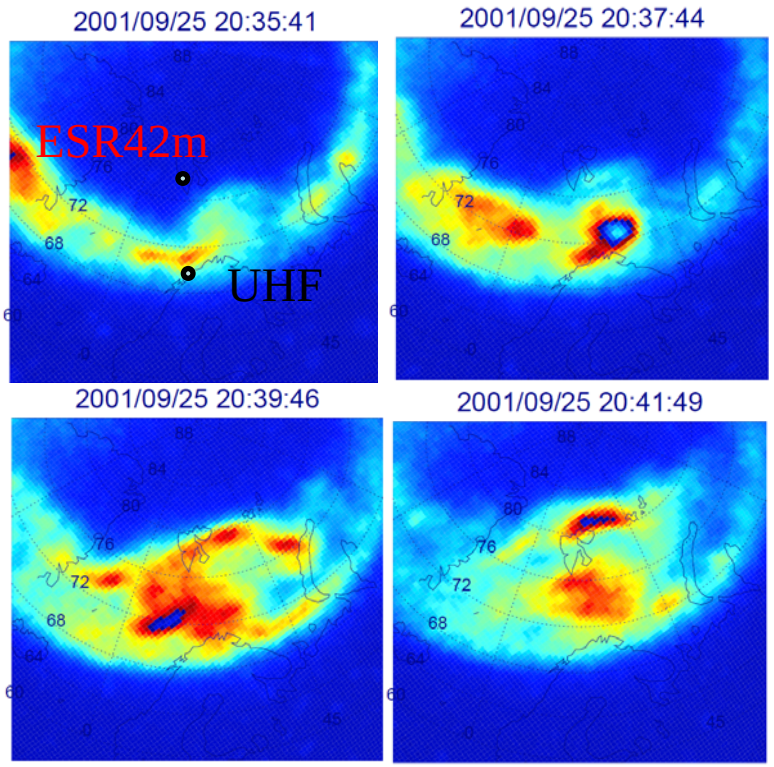
- Substorm initial brightening: ~2029 UT
- Ion upflow started at ~2034 UT

This indicates that soft precipitation follows the hard precipitation carrying the initial brightening after about 5 minutes.

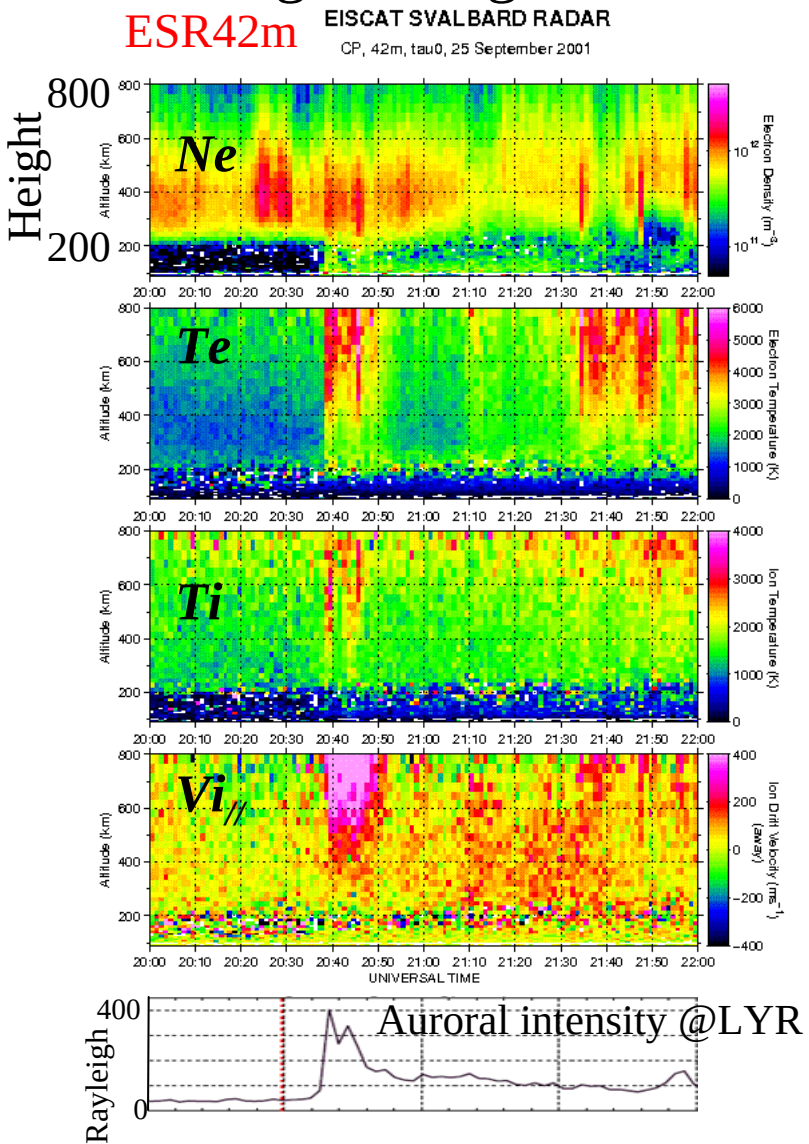
Where do ion upflows occur in the polar ionosphere?

Relation between ion upflow and an auroral bulge during a substorm

IMAGE WIC results



ESR42m

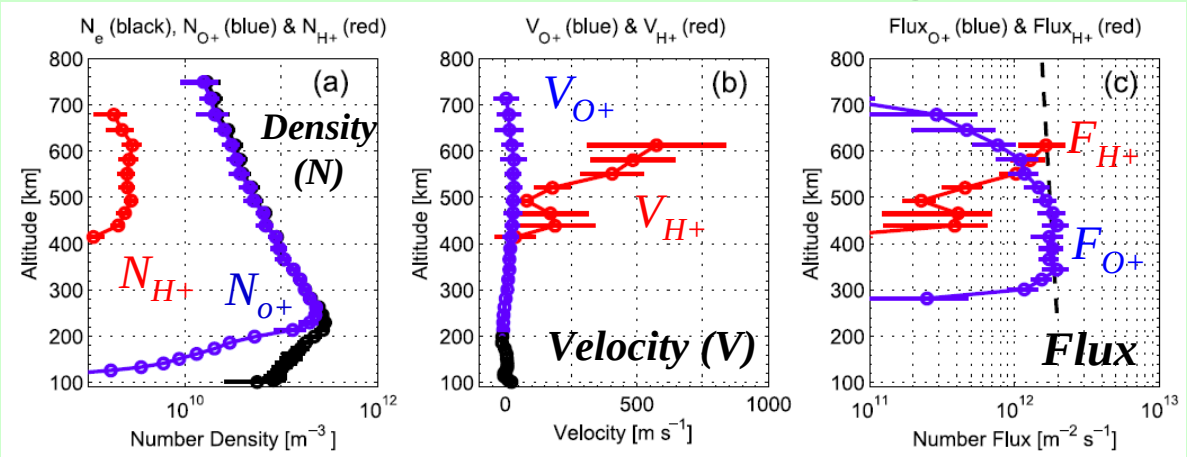


- Maximum upward velocity and flux are seen around the poleward edge of the expanded auroral oval at 2040-2050 UT

Which ion species do flow up?

Hydrogen ion upflows (polar wind) in the topside ionosphere (Løvhaug et al., *Radio Science*, 2001; Ogawa et al., *GRL*, 2009)

Equatorward of the cusp region



Ogawa, Häggström, Buchert et al., *GRL*, 2009

On closed field lines the H^+ becomes the larger contributor to the upward flux above about 550 km. The total upward flux seems to be conserved.

However, radar cannot well distinguish between different ion species in upflow. It takes integration time of a few hours to derive the profiles

What are needed for EISCAT_3D

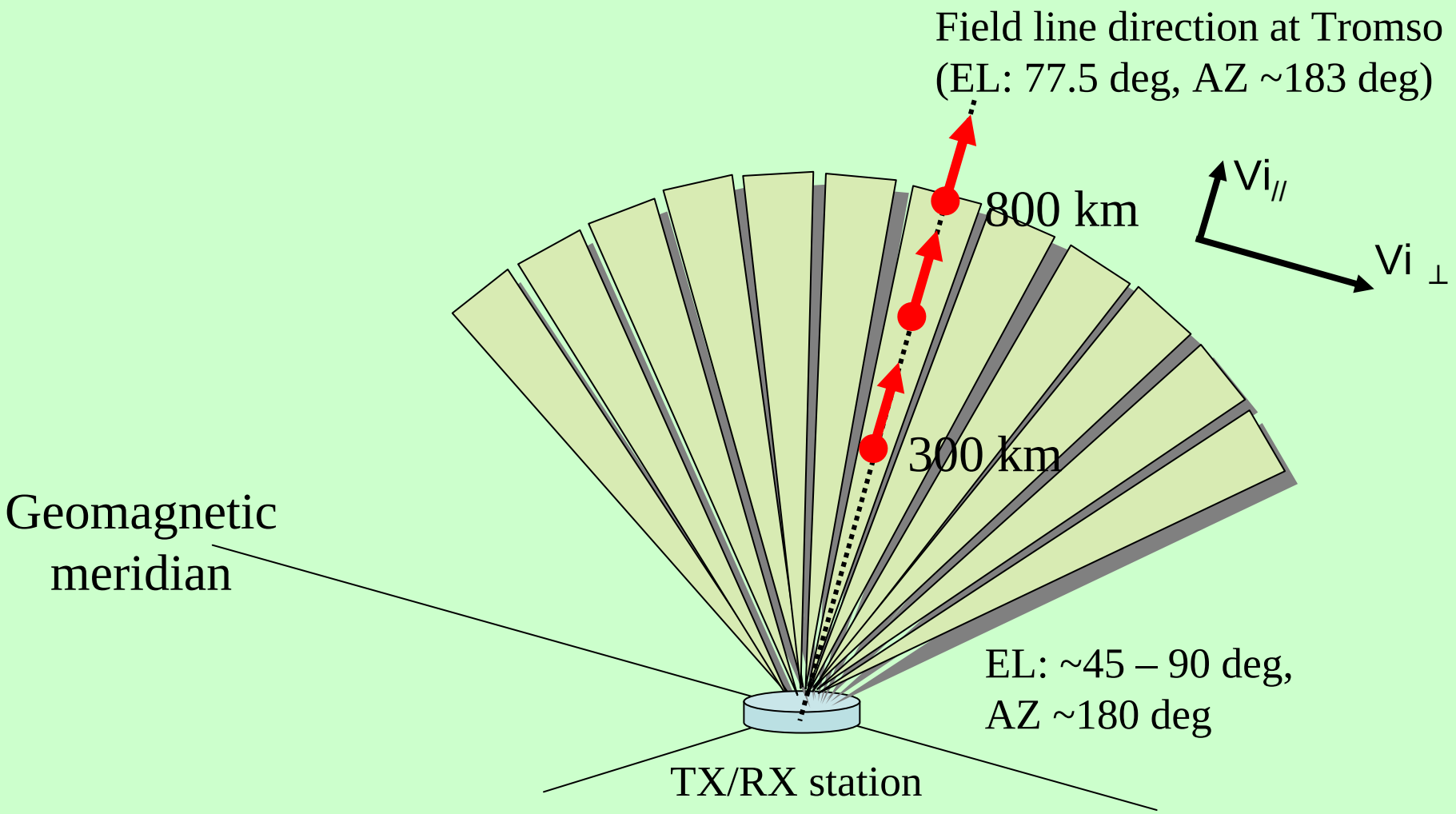
- High altitude observation (above 800 km)
- Ion composition (O^+, H^+, and hopefully NO^+)
- Ion velocity with higher time resolution (< 1 min)

→More transmitter power density and higher sensitivity are desirable.

- If raw data is recorded, we can choose a filter suitable for H^+ analysis after the observation.
- For the highest altitudes one transmitted and received beam along the field line is desirable → One receiver must use transmitter antenna field.)

What are needed for EISCAT_3D

In order to investigate relation between aurora and ion upflow, two TX/RX stations along the geomagnetic meridian* are desirable. (* AZ ~180 deg, not ~165 deg)



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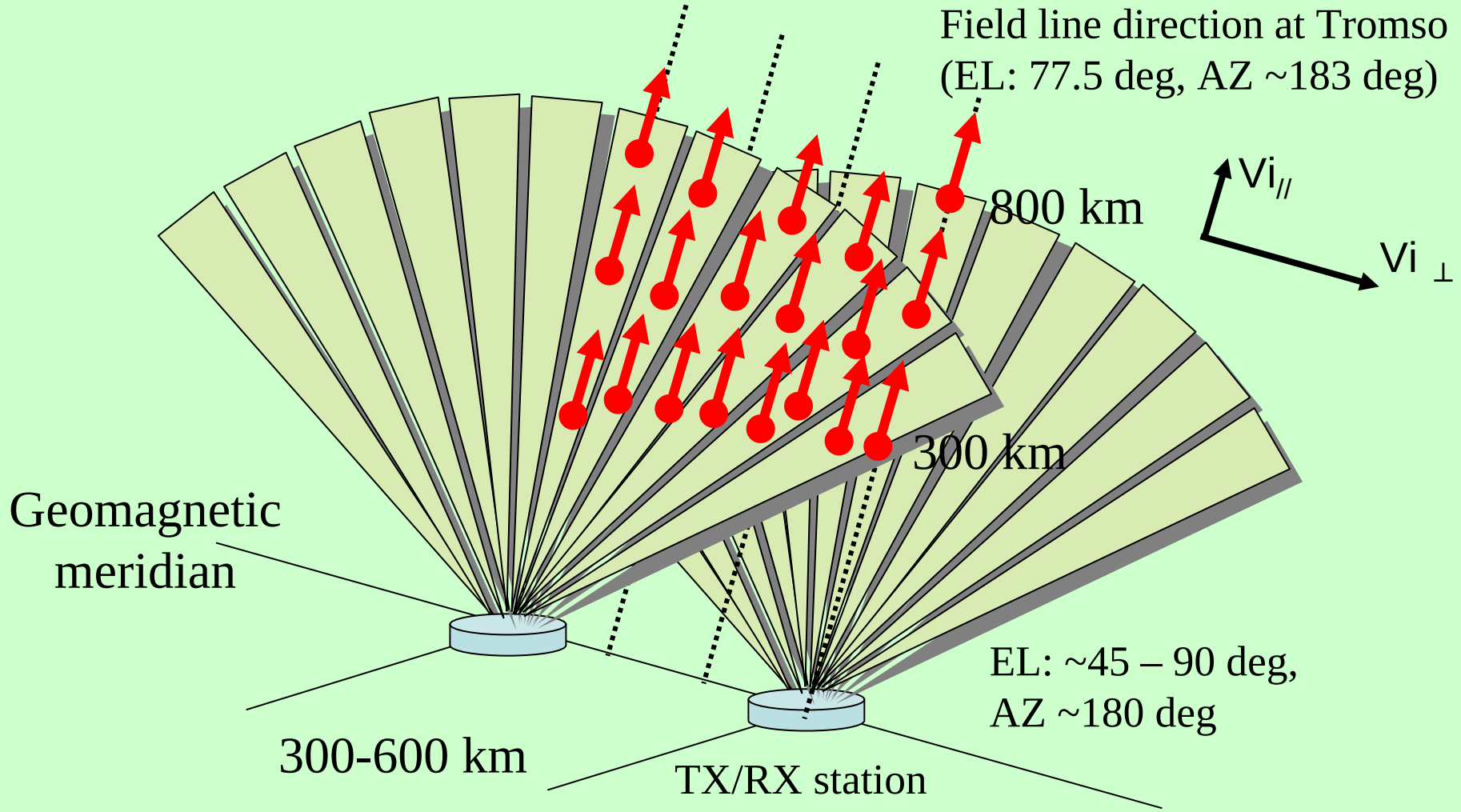

Summary

Bulk ion upflow in the polar ionosphere transiently occurs with upward velocities of a few 100 to 1000 m s^{-1}, and must play an important role as plasma source for ion outflow.

The ionospheric ion upflow and its related phenomena have been intensively investigated with the EISCAT radar systems.

For high altitude observation (above 800 km), ion composition (O^+, H^+, and hopefully NO^+), and ion velocity with higher time resolution (< 1min), more transmitter power density and higher sensitivity are desirable.