Ionospheric Tomography II:
Applications to space weather and the high-latitude ionosphere
Why tomography at high latitudes?

- Magnetic field
  - ‘railway tracks’ and ‘telephone wires’ of space

- Field converges in high-latitude ionosphere
  - different plasma populations in adjacent flux tubes
  - linked to widely separated regions of space
  - brought into close proximity in high-latitude ionosphere

- Tomographic image
  - spatial structure of plasma
  - information about space-weather processes far out in space
Space Weather

Sun and CMEs

Solar wind

Parker spiral

Interplanetary magnetic field (IMF)

$B_y$

$B_z$

+north

-south
Space Weather and the Earth

- distortion of geomagnetic field
- polar cusps
- ‘open’ and ‘closed’ flux tubes
- reconnection
Reconnection

Interplanetary magnetic field (IMF) southward
\(B_z\) negative

Neutral point
Flux transfer event
FTE
IMF southward, $B_z$ negative

Reconnection near equatorial plane
Reconnection and the high-latitude ionosphere

-Southward IMF
-B_z negative

• Open polar cap – entry of plasma from dayside
• Fast anti-sunwards flow of plasma across polar cap
• Return flow at lower latitude
• Two cell ExB plasma convection pattern
Southward IMF $B_z$ negative
Convection patterns and IMF $B_y$

- Cusp rotated from magnetic noon
- Twin-cell patterns distorted
Lobe reconnection

Interplanetary magnetic field (IMF) *northward*

$B_z$ *positive*
IMF northward, $B_z$ positive

Reconnection in magnetospheric lobe

- Initial flow sunwards
- Polar cap closed to dayside plasma
Convection patterns for different IMF orientations, $B_z$ and $B_y$

Open polar cap with $B_z$ negative

Shrunken closed polar cap with $B_z$ positive

Convection is the key process for understanding of structures in the high-latitude ionosphere
Structures in electron density at high latitudes

Enhancements

Depletions

Irregularities
Tomography at high latitudes

UWA station chain

Svalbard under dayside cusp
Can study structures linked to reconnection
Structures in dayside cusp

- Signatures of reconnection processes
Ionospheric Footprint of Equatorial Reconnection

- Open/closed field line boundary
- Slope in peak height – energy dispersion of FTE precipitation
- E-region structures – upwards FAC
- Upper F region – downwards FAC
Ionospheric Footprint of Lobe Reconnection

- Adiaroic boundary – no flux transfer
- Reverse dispersion signature
Tongue of ionisation

Ionisation from sunlit dayside is convected into polar cap and carried across to nightside in anti-sunward flow

$B_z$ negative IMF south
Modelling of tongue of ionisation (TOI)

Bowline et al. (1996)
Evidence for TOI from tomography chain

$B_y$ negative  $B_y$ positive

TEC plots

Dayside pre-noon sector
Evidence for TOI in midnight sector

EISCAT Svalbard Radar

TEC from tomography chain
Polar-cap patches

- TOI broken up into patches
- Many different mechanisms proposed
- 100 to 1000 km size
- Electron density may change by >5x
- Convect at high speed in anti-sunward flow
- Steep gradients
- Instability mechanisms generate irregularities
- Radio-wave scintillation
First IITC Campaign
Tongue of Ionisation in the Polar Cap

Svalbard (Kersley et al.)

GPS TEC (Jakowski)

Greenland (Bust et al.)

SUCTIP Model (Denton et al.)
Second ITC Campaign

Greenland

Svalbard
‘TOI’ under northward IMF

‘Tongue’ of enhanced ionisation convected round edge of closed polar cap
Polar hole in ionisation

- Flux tubes circulating in winter darkness in dawn cell
- No production
- Loss processes dominate
- Very low densities
Polar hole

- Very low densities in dawn cell
- Flux tubes circulating in winter darkness
Auroral ionisation

- Precipitation in auroral zone
- Localised and transient structures in electron density
- Small-scales cause scintillation
Auroral ionisation

Auroral forms

Precipitation types
Auroral ionisation

All-sky camera

Red 630.0nm  Green 557.7nm

Tomographic Image: 10/12/96 13:48 UT
Electron Density (x10^11 m^-3)

<table>
<thead>
<tr>
<th>Latitude</th>
<th>75.0°</th>
<th>76.0°</th>
<th>77.0°</th>
<th>78.0°</th>
<th>79.0°</th>
<th>80.0°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>11.7°</td>
<td>11.3°</td>
<td>10.7°</td>
<td>10.1°</td>
<td>9.3°</td>
<td>8.4°</td>
</tr>
<tr>
<td>CGM Lat.</td>
<td>72.4°</td>
<td>73.4°</td>
<td>74.4°</td>
<td>75.4°</td>
<td>76.3°</td>
<td>77.3°</td>
</tr>
<tr>
<td>MLT</td>
<td>16:31</td>
<td>16:38</td>
<td>16:43</td>
<td>16:49</td>
<td>16:57</td>
<td>17:04</td>
</tr>
</tbody>
</table>
Main trough

- Main or mid-latitude trough
- Auroral / mid-latitude ionosphere boundary
- Most significant feature of sub-auroral ionosphere at night
- Difficult to model
Formation of Troughs

- Corotation flow at lower latitudes
- Sunward return flow from nightside
- Anti-sunward flow across polar cap
Trough Images

Tomographic Image: 21/11/95 12:51 UT
Electron Density (x10^11 m^-3)

Tomographic Image: 21/11/95 14:02 UT
Electron Density (x10^11 m^-3)

EISCAT CP-3
Electron Density (x10^11 m^-3)
21/11/95 12:30 - 13:00 UT
Trough

EISCAT CP-3
Electron Density (x10^11 m^-3)
21/11/95 14:00 - 14:30 UT
Trough
Location of dayside trough from tomographic images

Quiet geomagnetic conditions  Quiet + disturbed
Tomography and Validation of Coupled Thermosphere Ionosphere Plasmasphere Model (SUCTIP)

Idenden et al. (1999)
Validation of SUCTIP Model

Latitude of trough minimum vs MLT for quiet geomagnetic conditions

Balthazor et al. (2002)
Stations for recent trough studies in UK
Characterising trough for application model validation

Vertical TEC from tomographic images
Define a set of parameters to characterise trough that can be estimated experimentally or calculated from a model.
Parameterised trough TECs obtained experimentally for use in model validation

1. Quiet geomagnetic conditions
Boundary blob

- Density enhancement on poleward wall of trough
- Not always present
- Origin not certain
- Reconfigured polar patch
- In-situ precipitation
Tomographic image of boundary blob

Field-aligned enhancement on poleward wall of trough
Origins of boundary blobs

Model

EISCAT $T_e$

Fig. 8. Distortion of a circular blob of ionization as it convects from the polar cap through the auroral zone. The first panel shows the initial conditions and the assumed correction model.

Reconfigured patch?

Produced in-situ by soft precipitation
Ionospheric storms – mid-latitude effects

- Space weather disturbance
- Expansion of polar cap
- Heating in auroral zone
- Equatorward winds
- Lighter oxygen atoms
- Positive phase with increased electron densities
- Electrodynamic effects
- Storm enhanced densities
- Collapse of ionisation in late afternoon
- Very steep spatial and temporal gradients
- Molecular rich atmosphere
- Depleted densities
- Last for several days
Contraction of plasmapause at storm onset
Storm enhanced densities (SEDs) at mid-latitudes

GPS TEC map over USA during large storm (Carpenter, 2004)

Tomographic image of SED event over Europe
Note steep gradients

Plasma tail from IMAGE satellite
Conclusions

- Space weather affects the high-latitude ionosphere
- Many processes cause structures in electron density and TEC
- Steep gradients on many different scales
- Spread to mid-latitudes during disturbed conditions
- Propagation effects on radio systems
- Difficult to model complexities
- Tomography ideal for studying high latitudes
- Images important for testing of models