The TIGER Radar - An Extension of SuperDARN to sub-auroral latitudes

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ABSTRACT

This invited paper describes the Tasman International Geospace Environment Radar (TIGER). The TIGER concept is to have two HF ionospheric radars operating at oblique incidence, with intersecting footprints covering the auroral and sub-auroral ionospheres south of Australia and New Zealand. TIGER will be part of the expanding Super Dual Auroral Radar Network (SuperDARN) developed by scientists from several different countries to study the high latitude ionosphere in each hemisphere. One of the main features of SuperDARN is the ability to map ionospheric convection, an important space weather system that plays a dominating role in the high latitude ionosphere. TIGER is at lower geomagnetic latitude than other SuperDARN radars and as a consequence will, for the first time, extend the SuperDARN technique routinely to the sub-auroral region of the plasmapause and ionospheric trough. TIGER is being developed by a consortium of Australian universities, government departments and industry. The first radar has been established on Bruny Island, Tasmania and is now operational. This paper presents an overview of the TIGER project by briefly describing: the solar wind interaction with the Earth's magnetosphere and ionosphere; ionospheric propagation and the features that make HF radar an excellent technique for studying the high-latitude ionosphere; characteristics of the TIGER radar and some initial observations; and features of the TIGER research program.
1. INTRODUCTION

The Tasman International Geospace Environment Radar (TIGER) concept is to have two HF ionospheric radars operating at oblique incidence, with intersecting footprints covering the auroral and sub-auroral ionospheres south of Australia and New Zealand (Figure 1). Each radar will detect ionospheric scatter and determine the echo power, apparent range (group path), doppler spectrum, and the azimuth and elevation angles of arrival. The basic purpose of the radars is to utilise the detected ionospheric echoes for the study of the magnetosphere-ionosphere plasma system.

![Figure 1: Footprints of the TIGER Radar beams. The lines represent the 16 azimuthal directions scanned by the narrow azimuthal beam of each radar.](image)

The same echo information will also be obtained from meteor echoes and echoes backscattered from the sea or land. The detection of meteor echoes provides a means of studying the mesosphere region of the atmosphere. Sea and land surface echoes can also be used to study certain ionospheric features. Of course there is very little land immediately south of Australia and New Zealand, so most of these echoes will be sea-surface echoes, which can potentially provide monitoring of the
sea-state in the southern ocean. However, this is a long-term aim, as obtaining useful data for meteorological purposes requires further development to increase the sensitivity of the TIGER system.

The TIGER radar components will be capable of operating as stand-alone radars, as a combined pair, and/or as part of the Super Dual Auroral Radar Network (SuperDARN). SuperDARN (Greenwald et al., 1995) is an expanding international network of HF ionospheric radars established in both the northern and southern hemispheres (URL: http://superdarn.jhuapl.edu/). Its purpose is to provide extensive coverage of the high-latitude ionosphere in both hemispheres in order to study the response of the magnetosphere-ionosphere system to the changing solar wind environment. To date SuperDARN has been very successful, particularly in studying the complexities of ionospheric convection in the auroral region. TIGER is at lower geomagnetic latitude than other SuperDARN radars and hence will, for the first time, extend the SuperDARN technique routinely to the sub-auroral region of the plasmapause and ionospheric trough.

The TIGER project is being developed by a consortium of universities, government departments and industry. The organisations involved and their representatives on the TIGER Management Team are listed in Table 1.

| Principal Investigator: | Prof Peter Dyson (La Trobe University) |
| Co-Investigators: | Dr J. Bennett (Monash University) |
| | Prof B. Fraser (University of Newcastle) |
| | Dr R. Morris (Australian Antarctic Division) |
| | Dr B. Ward (DSTO) |
| | Dr P. Wilkinson (IPS Radio & Space Services) |
| | Dr A. Rodger (British Antarctic Survey) |
| | Mr M. Keith (RLM Systems Pty Ltd) |
| Project Engineer: | Dr J. Devlin (La Trobe University) |
| Data Management: | Dr C. Waters (Newcastle University) |

The project's operational, scientific and engineering aims are listed in Table 2.

| Operational: | - Deploy two radars that can be operated remotely via the internet. |
| | - Each radar to be capable of: |
| | • imaging ionospheric spatial features in latitude and longitude, |
| | • detecting meteor echoes, |
| | • detecting sea-surface echoes. |
| | - Real-time links with universities, schools and Antarctic Research Centre. |

| Scientific: | - Develop an understanding of the phenomena observed. |
| | - Develop an understanding of the impact at other latitudes of features that develop in the high latitude ionosphere, particularly those that propagate to lower latitudes. |
- Develop capability to better predict ionospheric changes and their impact on technologies.

**Engineering:** - Develop new techniques of signal transmission, reception and analysis to upgrade performance of mini-HF radar systems.

The first component of TIGER has been installed on Bruny Island, Tasmania and operations began in December 1999. This paper will present an overview of the TIGER project by briefly describing:

- the solar wind interaction with the Earth's magnetosphere and ionosphere,
- ionospheric propagation and the features that make HF radar an excellent technique for studying the high-latitude ionosphere,
- characteristics of the TIGER radar and some initial observations,
- features of the TIGER research program.

2. GEOSPACE

Geospace is the region of space immediately surrounding the Earth that is bounded by the solar wind's interaction with the Earth's magnetosphere. It consists of the ionosphere, magnetosphere, and nearby solar wind and is consequently a vast region, extending from about 50 km altitude to geocentric distances in excess of a million kilometres. The main features of geospace are shown in Figure 2. Energy is transferred from the solar wind to the magnetosphere-ionosphere system through a variety of processes, many quite complex and still poorly understood. Information on these processes can be obtained by studying the time-varying spatial structures that are the end result.

![Figure 2. The key regions of Geospace.](http://iacg.gsfc.nasa.gov/iacg/geospace.html)
Geospace is a very dynamic region, undergoing almost continual change as the solar wind responds to highly variable processes occurring in the Sun, including coronal mass ejections (CMEs), which inject billions of tons of matter into the solar wind stream.

When CMEs are directed towards the Earth, they cause large magnetic storms that greatly affect the magnetosphere, ionosphere and thermosphere, producing spectacular auroral displays at locations where the aurora is rarely seen. The varying conditions of geospace, including these dramatic storm effects, are referred to as *space weather*, which has significant impacts on our technological lifestyle, including:

- Disruption of communications and navigation systems dependent on radio frequencies from Low Frequencies to Ultra High Frequencies;
- Inaccuracies in geomagnetic surveys for minerals;
- Corrosive currents in pipelines;
- Induced currents in power lines that occasionally cause dramatic power failures;
- Large changes in satellite orbits and orientation due to increased atmospheric drag;
- Failure of satellite systems due to energetic particle impact.

High energy charged particles emitted during major bursts of solar activity are also potentially lethal to space travellers, either in earth orbit or on future interplanetary missions.

![Figure 3. Depiction of a CME event and its study using coordinated satellite and ground-based instruments (modified NASA image, http://www-istp.gsfc.nasa.gov/istp/cloud_jan97/event.html).](image-url)
To understand the complexities of space weather it is necessary to study the solar-terrestrial system as a whole and this requires combined observations using both spacecraft and ground-based instruments. Figure 3 describes such a combination for a CME event. SuperDARN is now a major ground-based facility that provides essential observations for such detailed studies.

The solar wind consists of a fully ionised, hydrogen/helium plasma, streaming outwards from the Sun at ~300-800 km/s and carrying with it the Interplanetary Magnetic Field (IMF). The Earth's magnetic field acts as a barrier to the IMF and solar wind particles. As the solar wind streams past the Earth, the terrestrial magnetic field is compressed on the dayside and extended on the nightside, giving the magnetosphere a comet-like shape as shown in Figure 2. The interaction between the IMF and terrestrial magnetic field is extremely complex. Some IMF field lines connect to the terrestrial field in a process known as reconnection (Cowley, 1998). The geometry of the reconnection depends on the IMF direction, which is rarely steady. A sketch of the structure when the IMF is southward, is shown in Figure 4.

![Figure 4: Schematic of IMF-magnetosphere reconnection when IMF has a southward component (after Cowley, 1998).](image)

The complex interaction of the solar wind and IMF with the magnetosphere initiates a wide variety of phenomena from plasma waves, to ionospheric convection and the aurora. As the solar wind blows across the connected field lines a current is generated and the magnetic field lines provide excellent conduction paths down into the ionosphere, allowing the magnetospheric generator to discharge through the high-latitude lower ionosphere at ~100 km altitude (Figure 5). A consequence is the production of the aurora by energetic electrons (tens of keV) that travel down the magnetic field lines, exciting and ionising atoms and molecules in the Earth's atmosphere. The excited atoms and ions emit the auroral light and pronounced irregularity structures are produced in the ionosphere.

The electric field across the magnetosphere is directed from dawn to dusk (Cowley, 1998) and, as shown in Figures 5 and 6, causes an $E \times B$ convection flow in the ionosphere that is anti-sunward, i.e. from the noon side of the Earth, across the pole to the midnight side. Return currents flow at lower latitudes resulting in cells of convective flow that are a dominant feature of the high latitude ionosphere.
Figure 5. Ionospheric current systems. Dawn-Dusk electric field causes anti-sunward $E \times B$ convection.

Figure 6. Simple two-cell ionospheric convection pattern over the polar cap (Cowling, 1998).
Two or more convection cells develop, with the simplest pattern of two cells, shown in Figure 6, occurring when the IMF has a southward component, as in Figure 4. The pattern is dependent on the IMF direction and is much more complicated when the IMF points northward because then the IMF and terrestrial magnetic fields are co-directional on the dayside. This is opposite to that depicted in Figure 4 and the magnetic field configuration in the region of the magnetopause is then vastly different to that shown. The solar wind and IMF are rarely steady for very long periods of time and when the IMF changes from northward to southward, the changes in the ionosphere, more than 30,000 km away from the magnetopause, are dramatic and rapid, starting within a few minutes of the IMF change at the magnetopause.

The aurora and ionospheric convection are just two of the many phenomena occurring at high-latitudes that have their origin in solar wind-magnetosphere interactions and which produce distinct features in the ionosphere. They extend over large areas and are highly variable in both time and space. Consequently to extend our understanding it is essential to develop and deploy observational techniques that can observe large areas with relatively high time resolution. HF ionospheric radar, operating at oblique incidence, is one such technique.

3. THE IONOSPHERE AND HF PROPAGATION

The vertical structure of the ionosphere is described in terms of three regions, or layers, known as the D, E and F regions. During the day in summer the F region bifurcates into the F1 and F2 regions (e.g. Davies, 1996). The behaviour of the layers is quite complex, varying with time of day, latitude, season and sunspot activity. Figure 7a depicts typical diurnal and seasonal variations. The ionosphere supports MF and HF propagation and typical ray paths are presented in Figure 7b. For a single frequency of transmission, the range varies with elevation angle and often a single layer supports propagation to a single location via two different ray paths, described as high and low angle rays.

![Figure 7](image)

**Figure 7.** (a) Top panel shows typical vertical ionospheric profiles. (b) Bottom panel shows schematic ray paths for an ionospheric layer. (McNamara, 1991)
Other ionospheric layers present may also support propagation to the same location. Furthermore the ionosphere is birefringent, supporting ordinary and extraordinary propagation modes that add to the number of rays which can propagate to a single location (e.g. Davies, 1996). Consequently description of HF ionospheric propagation can become complex, but for our purposes here it is sufficient to note that at a single frequency, transmission over a range of elevation angles provides propagation over a large range window. Figure 8 shows the plot of apparent range versus frequency for single hop propagation in a model ionosphere containing E, F1 and F2 layers. The simulation was carried out using the method described by Dyson et al. (1988). It is apparent that depending on frequency, the apparent range of propagation for a single ionospheric hop can be 3000 km or even greater and this is also true of the true range, which is less than the apparent range. Usually significant amounts of energy are reflected at the Earth's surface at the end of a hop so that two and three-hop propagation can provide coverage to 3000 km or more when the first hop range is, say, 1500 km or less. Thus there is a wide choice of frequencies that can be used to explore the ionosphere out to a range of 3000 km using an HF radar.

![Figure 8](image.png)

**Figure 8.** Synthesized backscatter ionogram showing propagation characteristics of ground or sea scatter for an ionosphere containing E, F1 and F2 layers. Ionospheric absorption and antenna patterns have been ignored.

Small-scale (100m) ionospheric irregularities are formed as a by-product of many processes occurring in the high-latitude ionosphere (e.g. Kelley, 1989). These irregularities are aligned along the terrestrial magnetic field direction and they Bragg-scatter radio waves as shown in Figure 9a. Since at high latitudes the Earth's magnetic field lines are almost vertical, ionospheric scatter echoes are detected by HF radars at ranges approximately equal to 0.5 and 1.5 times the range of backscattered ground or sea single hop echoes (Figure 9b). Referring again to Figure 8, it is apparent that through suitable choice of operating frequency, HF radar can map the location of ionospheric scatter enabling SuperDARN to achieve the aim of providing continuous mapping over very significant portions of the high-latitude ionosphere in each hemisphere.
Figure 9. (a) Top panel illustrating Bragg scatter from ionospheric irregularities aligned along the Earth's magnetic field direction (After Hargreaves, 1992). (b) Bottom panel showing ray paths for single hop ground or sea scatter and 0.5 and 1.5 hop ionospheric scatter.
4. TIGER RADAR

As explained in the Introduction, the TIGER concept is to have two component radars that can operate successfully as individual radars, as a radar pair, and as part of SuperDARN. SuperDARN has been developing now over approximately 10 years and many improvements have been made to the basic radar system. We envisage new developments that will include a new antenna, digital receivers, and phasing networks to provide greater flexibility, particularly in antenna beam steering. On the scientific side, establishing a SuperDARN radar at sub-auroral latitudes immediately, provides opportunities to study phenomena not studied previously by HF radar techniques so this was made the initial aim to be pursued as quickly as possible. Consequently the first TIGER radar has been constructed using the most recent SuperDARN radar design, that of the University of Leicester CUTLASS radar (Lester et al., 1997). At the same time we have started developing new engineering approaches to be incorporated in the second component radar.

Basic properties of the first TIGER radar are that it is a monostatic, pulse radar that can transmit over the frequency range, 8 - 20 MHz. The transmitting antenna consists of an array of 16 log-periodic antennas (Figure 10) that form a narrow azimuthal beam (4° at 12 MHz) that is swept across the radar footprint in 16 steps (Figure 1). In the vertical direction the beam is rather broad (~30°) with a maximum in the range of 15° (at 20 MHz) to 35° (at 8 MHz). An additional four antennas placed behind the transmitting array are used to form an interferometer receiving array that measures the elevation angle of echoes. In the standard mode of operation the radar operates in a fixed frequency mode, changing frequency only to accommodate changing ionospheric conditions. This is achieved by regularly scanning the frequency band to determine automatically which channels, free of interference, provide the best coverage of ionospheric scatter.

TIGER operates with a peak pulse power of 9.6 kW and a mean power of 200 W. Each element of the transmitting antenna is fed by a separate power transmitter module. Figure 11 shows the radar hardware consisting the 16 power modules plus four spares, receiver, phasing array and power supplies. Top and bottom views of the electronics in one of the transmitter modules are also shown.

In the standard pulse radar approach, the time between the transmitted pulses defines the range window so echoes from a greater range appear falsely at a lower range because they return after a new pulse has been transmitted (Figure 12). Thus the lower the transmitter pulse repetition frequency, the larger the range window for unambiguous detection of echoes. On the other hand, if the pulse repetition frequency is too low, measurements of echo Doppler shift will be aliased and
Figure 11. TIGER Hardware. Top panel is a view of the front of the radar racks showing, on the right, the 20 transmitter modules above 4 power supplies. The receiver and phasing matrix are on the left. The bottom panels show views of a transmitter module chassis from the top (left) and bottom (right).

Figure 12. Range ambiguity caused by a second echo of the first transmitter pulse arriving after the transmission of a another pulse.
the velocity of the ionospheric structures will be underestimated. Transmitting a regular pulse train is unsuitable for TIGER because ionospheric velocities often impose doppler shifts on echoes in excess of 100 Hz, requiring the radar to sample at least at 200 Hz. The corresponding range window of 750 km is much too short since many echoes are returned from distances in excess of 2000 km.

The problem is overcome by transmitting the pulse sequence shown in Figure 13 in which the pulse spacing is varied from pulse to pulse [Greenwald et al., 1985]. The Doppler spectrum is then derived by first calculating the backscatter autocorrelation function which is then Fourier transformed to obtain the spectrum.

![Figure 13. SuperDARN Pulse sequence. Pulse width = 300 μs; Pulse Pattern Repetition Rate = 100 ms; Bandwidth = 10 kHz at -20 dB; Duty cycle = 2.1% (Greenwald et al., 1995).](image)

Operation of the radar is computer controlled and flexible, allowing many possible modes of operation for special campaigns. For example, the radar can be operated on, say just 2 or 3 beam directions, or a single direction can be interleaved with a complete azimuthal scan, giving high time resolution (7 sec) in a single direction.

This Tasmanian component of TIGER began operations on 1 December 1999. The fundamental element of any mode of operation consists of selecting an operating frequency and one of the antenna beam directions. The radar then transmits for a set period of time (commonly 7s), recording autocorrelation functions for echoes received on the 16 element transmit/receive antenna and cross-correlation functions for the echoes detected with the 4 element receive-only antenna. The power, angle of arrival, velocity and width of the velocity spectrum are then calculated and are available for routine display, providing a very useful summary of the characteristics of phenomena detected by the radar. Figure 14 shows a daily summary plot of echo power, velocity and spectral width for the single antenna beam direction that looks south from the radar site. The data were obtained
Figure 14. TIGER summary plot for Beam 5 on 20 November 1999.
during TIGER's test phase when operation was restricted to just two HF frequencies, selected according to typical daytime and nighttime propagation conditions. The figure gives the range in range bins, where one range bin equals 45 km. The Universal Time (UT) scale provides an unambiguous time scale when combining data from other radars or satellite data, although Local Magnetic Time (MLT) is the appropriate local time reference for many space weather phenomena. For TIGER, MLT along the boresight is 10 hours ahead of UT.

Throughout the day single-hop sea-echoes were detected and are identified by their almost zero velocity and narrow spectral width. At times second-hop sea-echoes are also evident. Echoes from aurora and other ionospheric features have significant velocities and spectral widths. Just before the change in transmission frequency at 1000 UT there is a sharp onset of ionospheric echoes beyond the first hop sea-echoes. These echoes continue until 1900 UT. A patch of ionospheric echoes at long range is also evident from 00-03 UT. This record gives an indication of just some of the variety of conditions that can exist.

As part of test operations, TIGER has also been operated in a swept frequency mode to provide an overview of propagation conditions. An example when the ionosphere is relatively undisturbed is shown in Fig 15. At most frequencies there is strong first-hop sea-scatter from a narrow range window defined by ionospheric conditions and the antenna system. The plots of echo velocity and spectral width show no significant velocity features so the echoes are all due to sea-catter. As expected for HF propagation, the region of sea-scatter moves steadily out to longer ranges as the transmitting frequency is increased. Second hop sea-scatter is also evident at the lower frequencies. No ionospheric scatter is evident and since the entire range out to 3000 km is covered during the frequency sweep, there were clearly no ionospheric irregularities present in the region at this time.

Figure 15.  TIGER Backscatter ionogram recorded 0012 UT 19 February 2000.
Top Left:  Echo Power Contours
Bottom Left:  Echo Velocity Contours
Top Right:  Elevation Angle Contours
Bottom Right:  Spectral Width Contours
Figure 16. Ionospheric profile from IRI (top left), TIGER backscatter ionogram (top right), Simulated backscatter ionogram (bottom). Lines have been added at three frequencies to aid comparison of the predicted and observed leading edges of E and F layer echo traces.

The propagation has been modelled using the International Reference Ionosphere (Bilitza, 1996) prediction for the ionosphere located 1500 km south of the radar and the results are shown in Figure 16. The comparison on the leading edge echoes clearly indicate a weaker E layer echo trace at slightly closer apparent range than the stronger F2 layer trace. When the antenna patterns and dynamic range of the system is considered the basic shape of the echo traces in reproduced quite well (Figure 17).

The elevation angle behaves as expected:
- the E layer echoes are at a higher elevation than the F2 echoes;
- within the F2 echo trace the elevation angle decreases with increasing range;
- at a fixed apparent range, the elevation increases with frequency.
Figure 17. Simulation of backscatter ionogram using IRI model ionosphere and taking account of TIGER antenna patterns and dynamic range.

While the elevation angle variations are as expected, the actual values are up to 5 degrees higher than the model predicts. This may be due to the fact that latitudinal gradients were ignored in the modelling, or it could be due to phase errors not yet accounted for in the interferometer. Further tests are underway to resolve this apparent discrepancy.

A second backscatter ionogram example, (Figure 18) shows a patch of ionospheric backscatter at 2.5 hops over the frequency range 8 - 10 MHz and at 1.5 hops over the frequency range 10 - 13 MHz. These echoes also have non-zero velocity, further confirming that they are ionospheric backscatter rather than sea-scatter which has either zero or relatively low velocity. Clearly on this
occasion ionospheric convection could be studied using any frequency up to 13 MHz but the propagation mode would need to be identified to correctly map the location of the scatter region.

A third example is shown in Figure 19 in which only the spectral width is shown. It is evident that in this night-time case, ionospheric irregularities are widespread as the frequency-range signature of the ionospheric scatter at 1.5 hops is essentially identical to the signature of the one-hop sea scatter.

These illustrative observations demonstrate the capabilities of the TIGER system which is now operating continuously conducting scientific campaigns on a monthly basis.

Figure 18. Backscatter ionogram showing one and two hop sea scatter and 1.5 and 2.5 hop ionospheric scatter. Ionogram on left displays echo power, one on right displays echo velocity.

Figure 19. Backscatter ionograms displaying spectral width. Echoes with low spectral width (dark colours) indicate 1 hop sea scatter and echoes with high doppler shift (red) indicate 1.5 hop ionospheric scatter.
5. TIGER RESEARCH PROGRAM

While TIGER provides an important extension of the southern hemisphere SuperDARN to a new longitude sector, it provides other very significant new features as well. Firstly, as already pointed out, TIGER is located more equatorward than previous SuperDARN radars, enabling it to study the plasmapause region, that is the boundary of the plasma co-rotating with the Earth. Secondly, TIGER is in a better location to study the expansion of the auroral phenomenon to lower latitudes that takes place during large magnetic storms. Sunspot maximum is expected to occur in April 2000 and large magnetic storms can be expected during the next 2 years.

Thirdly, it is the impact of these space weather features on the mid- and low-latitude ionosphere that is of most relevance to Australia. The combination of TIGER and the extensive ionosonde networks operated by IPS Radio & Space Services and JORN provide an outstanding opportunity to study, for example, the evolution of large scale atmospheric gravity waves generated in the auroral region, their propagation to lower latitudes, and final decay as they propagate across Australia.

Several specific studies listed in Table 3 will form the first group of scientific projects to be undertaken using Stage 1 of TIGER, the radar located in southern Tasmania. They are all collaborative projects to be conducted by various sub-sets of the TIGER Investigators listed in Table 1 together with colleagues at their institutions. Three of the projects are discussed briefly here.

Table 3
Initial TIGER Research Projects

<table>
<thead>
<tr>
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<th>Project Description</th>
<th>Collaborators</th>
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<tbody>
<tr>
<td>1</td>
<td>Noon - Midnight response to magnetic storms</td>
<td>(La Trobe - BAS)</td>
</tr>
<tr>
<td>2</td>
<td>ULF Waves</td>
<td>(Newcastle)</td>
</tr>
<tr>
<td>3</td>
<td>HF Propagation</td>
<td>(IPS, La Trobe - Monash, DSTO)</td>
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<tr>
<td>4</td>
<td>Neutral Wind-Ionospheric Convection Coupling</td>
<td>(Antarctic Division-La Trobe)</td>
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<tr>
<td>5</td>
<td>Travelling Ionospheric Disturbances</td>
<td>(IPS - La Trobe)</td>
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<tr>
<td>6</td>
<td>Digital Receivers, Digital Phasing Array</td>
<td>(La Trobe - RLM)</td>
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5.1. Coupling between the Dayside and Nightside of the Magnetosphere

As already pointed out, the responses to changes in the IMF of the Earth's magnetosphere and ionosphere are extremely complex. Siscoe and Huang [1985] introduced the idea of a polar cap boundary that expands and contracts. At any instant the polar cap area depends on the time history of IMF-magnetosphere reconnection on the dayside and nightside, and it is the noon and midnight sectors that drive ionospheric convection. As changes in the IMF embedded in the solar wind flow reach the Earth, they first impact on the noon sector and until now it has been thought that the nightside took relatively long to respond. Consequently ionospheric convection in the noon sector was thought to respond in about 2 minutes whereas in the midnight sector the response time was ~40 minutes. However recent observations have brought this into question and new ways in which the information about changes in the IMF may propagate through the system have been proposed. TIGER and the British Antarctic SuperDARN radar at Halley, Antarctica, are almost diametrically across the magnetic pole from each other and so are separated by ~12 h in MLT. Thus as a combined radar pair they are well placed to test these new ideas.
5.2. Travelling Ionospheric Disturbances (TIDs)
TIDs are coherent, frontal disturbances that travel large distances through the ionosphere. They are manifestations of Atmospheric Gravity Waves (AGWs) and auroral events can be the source of relatively large and medium-scale AGWs.

Medium-scale waves are prevalent throughout the thermosphere making it difficult to identify sources but in some instances sources can be identified using SuperDARN radars [Samson et al., 1990; Bristow et al., 1994]. As discussed earlier, radar echoes are not observed directly from the ionospheric distortions produced by the AGWs. Instead, the distortions focus and defocus rays reflected by the ionosphere, causing variations of the signal strength of ground and sea echoes with range and time. This effect was also predicted to occur with the Jindalee OTHR system by Dyson and Bennett [1989].

TIGER will be used to systematically study the generation of AGWs, identifying the auroral source regions and, with the aid of the Australian ionosonde networks, study the AGW propagation characteristics as they move to low latitudes, affecting HF communications and surveillance systems.

5.3. Plasmapause Phenomena
The plasmapause is a relatively high-concentration, torus-like, inner magnetospheric region whose dynamics are very sensitive to activity in the solar-terrestrial environment. Its outer boundary, the plasmapause, was extensively studied in the 1970s, but it is a region of substantial new interest because it is recognised as a key area of wave generation, particle precipitation and a major source of plasma for the geomagnetic tail that extends away from the Earth on the night side.

The dynamic interactions of the plasmapause with the ionosphere are unexplored using the HF radar technique and TIGER's relatively low-latitude location means it can comprehensively explore this region. Of specific interest is the role of the plasmapause in the propagation and generation of ULF wave energy detected at low latitudes. ULF wave energy in the cold plasma of the magnetosphere is manifested as the fast and the shear Alfvén modes. Fast-mode waves are generated in the bow shock and magnetosheath regions and pass into the magnetosphere with little change in their spectrum. The fast mode can propagate across the ambient magnetic field to low latitudes, stimulating shear Alfvén field line resonances (FLRs). Theoretical studies predict fast-mode wave reflection surfaces so the fast-mode energy may form cavity or waveguide modes [eg. Kivelson and Southwood, 1985; Allan et al., 1986]. However, experimental verification for these models is scarce. Recently, the discovery of fine structure in the power spectrum of low latitude ULF data was interpreted as the signature of cavity modes [Samson et al., 1995; Waters et al., 1999]. These studies emphasised the importance of plasmapause dynamics in determining the detection and properties of cavity modes.

TIGER will be used to search for evidence of cavity and waveguide modes and to differentiate between modes (i.e. surface, cavity, and field-line resonance). The University of Newcastle's low latitude magnetometer array [Waters et al., 1995] will be used to identify the fine structure signature which will be compared with the radar data.
6. SUMMARY

The TIGER radar project has been described with emphasis on Stage 1, the Tasmanian segment that is now operating. The data being obtained shows that the radar is operating excellently and an exciting time is ahead as the various science and engineering projects already started are completed.

7. ACKNOWLEDGEMENTS

We acknowledge contributions from members of the TIGER Management Team listed in Table 1 and Drs R. Norman and M. L. Parkinson. TIGER has been funded by contributions from the organisations represented by members of the Management Team, the Australian Research Council and the Antarctic Foundation. Members of the SuperDARN international community, particularly at British Antarctic Survey and University of Leicester, have contributed significantly to TIGER's development through the provision of essential software, circuitry and much advice.

8. REFERENCES


