AUSTRALIAN ACADEMY OF SCIENCE

AUSTRALIAN SPACE RESEARCH

2000-2002

Report to the Committee for Space Research (COSPAR)

Australian National Committee for Space Science

Published by:
Australian Academy of Science, GPO Box 783, Canberra ACT 2601.
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This report is also available on the Internet:
http://www.science.org.au/academy/media/cospar.pdf

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PREFACE

This biennial report to the ICSU Committee on Space Research (COSPAR) has been assembled from contributions from the wide range of institutions undertaking space related research in Australia. It covers the period between COSPAR scientific assemblies, in this case from July 2000 to June 2002. The 34th COSPAR meeting will be held in Houston, USA from 10-19 October 2002. The report is available on the World Wide Web at http://www.science.org.au/academy/media/cospar.pdf

Australian institutions active in space research comprise the Commonwealth Scientific and Industrial Organisation (CSIRO), numerous University groups, and various government bodies such as the Australian Antarctic Division, and the IPS Radio and Space Services. The research areas encompass earth observation (remote sensing), solar terrestrial physics, upper atmospheric physics, climate and weather modelling, space astronomy, space communications research. Industry also makes contributions to space research in Australia. The contributions give an indication of the wide range of research activities taking place in Australia although inevitably, despite widespread solicitation for contributions to the report, not all organisations involved in space research in Australia provided information by the deadline set to compile the report. I thank those who have contributed, and I thank the National Relations Office in the Academy for collating the report.

Professor P L Dyson
Chair
Australian Academy of Science National Committee for Space Science

7 September 2002

AUSTRALIAN ANTARCTIC DIVISION

Space and Atmospheric Sciences (SAS)

The Australian Antarctic (Mawson, Davis and Casey) and sub-Antarctic (Macquarie Island) stations continue to provide a platform for the projects listed in Table 1. This work supports research programs of the Australian Antarctic Division (part of the Federal Department of Environment and Heritage), Australian Government agencies and Universities and the international community. The SAS program, formerly know as the Atmospheric and Space Physics (ASP) program, conducts research and monitoring studies in 'middle atmosphere' and 'space weather' in line with Australia's Antarctic Science Program Strategic Plan 2000-2005 (http://www.aad.gov.au/science/ResearchResources/green/gn_tocY2.asp) . The goals within that strategic plan of most relevance to the group are, *To Understand the Role of Antarctica in the Global Climate System* and *To Undertake Work of Practical, Economic and National Significance*.

Understanding the Role of the Antarctica in the Global Climate System

The role of the mesosphere in atmospheric energy transport is not well understood and the Antarctic polar vortex is of particular interest. Its break up in the southern spring and the role that this plays in global climate is of particular importance to the Australian Antarctic program. A suite of instruments have been developed and deployed at the Australian Antarctic base, Davis, to study mesospheric phenomena including temperature and wind profiles, polar stratospheric and noctilucent clouds, polar mesospheric summer echoes and atmospheric ozone depletion and aerosols. The instruments include a Rayleigh and Doppler Lidar, an MF radar, Czerny-Turner and Fourier transform I/R spectrometers for hydroxyl airglow measurements, a Fabry-Perot spectrometer and a VHF radar to be installed in the Austral summer of 2002-3.

Specific Results
A comparison between northern and southern polar gravity waves has shown significant differences in their strength and other properties. An investigation into the variations of the phase of the semidiurnal tide over Davis has led to a collaborative study using other Antarctic MF radars, which has identified signatures of non-migrating components of the semidiurnal tide. It was found that during the southern summer, the non-migrating component can be as large as the migrating one and so can have a significant effect on the observed tide. Using the Fabry-Perot spectrometer the properties and sources of observed atmospheric gravity waves in the thermosphere propagating into the polar cap rather than equatorward has also been investigated.

Analysis of 7 years of hydroxyl temperature data from Davis has provided the best determination of winter temperature variations in the upper mesosphere (~87 km) at high southern latitudes. Inter-year trends are correlated best with a solar-cycle variation of order ~7K. Within 5 years it should be possible to comment definitively on the extreme cooling that has been reported for this atmospheric region.

Polar Stratospheric Clouds were detected with the Lidar between July and September 2001 between altitudes of 12km and 25km. The clouds exhibited structure indicative of perturbations by gravity waves. The observations represent some of the highest resolution measurements of structures within this type of cloud. Analysis is ongoing, with the view to describing cloud microphysics under the influence of gravity waves. This is only the second such southern hemisphere observation reported.

The Lidar derived temperature structure of the stratosphere and lower mesosphere determined above Davis during 2001 is broadly consistent with predictions of the MSIS empirical model. However, the observations are generally 10-15K cooler than the model in the summer. A sudden cooling of this magnitude was also seen for a period of about 2 months following the end of the polar winter night. Work on understanding these differences is in progress.

Geoelectric field measurements have been made at Vostok, Antarctica, from Dec 1998 in association with Russian and American colleagues. Significant progress has been made in the development of an air-earth current meter. Independent confirmation that a global geoelectric field signal is present in ground-based geoelectric field data from Vostok was achieved. Similarly confirmed was a near instantaneous (coincident within an hour) influence of the By component of the Interplanetary Magnetic Field (IMF By) on the ground-based geoelectric field measured at Vostok, when Vostok is on the dayside of the magnetosphere. The results of an expanded analysis showing the details of the association between the Interplanetary Magnetic Field components, By and Bz, and the geoelectric field measured on the dayside at Vostok have been published.

Research of Practical, Economic and National Significance

The Australian Antarctic Program has a long and proud history of research in upper atmosphere and cosmic radiation physics. This research has continued with the thrust aimed at understanding space weather phenomena better and to contribute toward usable forecasting models. Much of the observational component of this program has been automated and the responsibility for the data and its archiving has been passed to the Ionospheric Prediction Service (IPS), both for predictive use and as a world data centre, and to Geoscience Australia.

Specific Results

The program of automation of data collection at all bases continued including a new logging system which logs data from the Standard Riometer, Fluxgate Magnetometer and Magnetic Pulsations experiments with daily data files being transferred back to IPS Radio and Space Services in Sydney who receive the data in their capacity as a World Data

Centre. These systems also send back smaller amounts of data every five minutes, which are used by IPS for ionospheric forecasting. A new data collection system recording digital all sky camera images was also installed at all stations. All of the new systems can be controlled and interrogated from the Australian Antarctic Division Head Office in Kingston with minimal interaction from station personnel. Instruments operated were: Fluxgate Magnetometers at Casey and Davis; Induction Magnetometers at all stations; Wide Angle Photometers at Casey (decommissioned at the end of 2001 because it requires skilled operators that would no longer be available) and Davis; 30 MHz Riometers at all stations; All Sky Imaging Systems operated at all stations except Mawson and the Mawson system was upgraded during the summer 2001/2 for subsequent automated operation. Casey magnetometer data is now collected remotely and processed by the Geomagnetism Section of Geoscience Australia.

Studies of cusp wave phenomena have been undertaken including field line resonances and ionospheric waveguide attenuation. Conjugate studies between Longyearbyen and Davis indicate systematic changes in the frequency response of the "Pc5 arch" with magnetic activity. These are predictable and may lead to the development of diagnostic techniques. The analysis of three years of ULF Pc3 hydromagnetic wave data has shown that some diurnal characteristics of these waves are controlled by the geomagnetic field geometry while others are controlled by the Sun Earth connection.

Eight years (1993-2001) of Casey ionospheric drift measurements form a unique data set that can be reliably used to test various convection models. A local Casey convection model has been constructed with these data. Comparison with the widely used Weimer 96 (W96) model shows good agreement with predicted velocities. The Casey observations have confirmed the existence of multiple convection cells for certain orientations of the interplanetary magnetic field. When compared with a previous study, Casey observations confirm the superiority of the Weimer model over the pioneering Heppner-Maynard model.

The influence of the IMF on the occurrence of sporadic E (Es)-layers in the southern polar cap ionosphere has been investigated. The main results are: the IMF By component mainly controls the occurrence of the midnight Es-layers through its influence on the corresponding southwest electric field; the IMF Bz component mainly controls the occurrence of the evening Es-layers; and the total occurrence of Es-layers depended more on By than on Bz.

In October 2001 the DPS-4 digital ionosonde, located at Casey since 1993, was relocated to Davis station. Of great concern however is the amount of RF interference generated. Mitigation strategies have been put in place to minimize the communications interference to acceptable levels but this is not a long-term solution and does not address the problems still encountered by the SHIRE experiment. AAD researchers involved in the digital ionosonde project are currently investigating filtering and other techniques to remove the interference

The Southern Hemisphere Imaging Riometer (SHIRE) was utilized to study riometer signatures associated with magnetic impulse events (MIEs) detected in co-located fluxgate magnetometer data. SHIRE allows two-dimensional imaging of localized regions of enhanced cosmic noise absorption (CNA) as they evolve over time, facilitating study of the morphology and dynamics of MIE-associated absorption events. Another type of impulsive event, which covers the complete 200 x 200 km square field of view of SHIRE, forms at the northern boundary of the instrument field of view and expand in 2 minutes over the entire field of view. It then convects west and south (poleward) out of the field of view. The total duration is about 4 minutes. The velocity is about 1-2 km/s westward and 4 km poleward. Davis is on closed field lines equatorward of the cusp during these events and the relationship to transient magnetic reconnection and impulsive penetration phenomena are being studied. Equipment for measuring the total electron content located at Casey was transferred to Davis over the 2001-2 summer in line with the focus of the SAS program at that base. Results from the Casey data collected around sunspot maximum indicate that the total electron content, as measured by GPS, is generally lower than predicted by the International Reference Ionosphere (IRI) Model. Patches and auroral activity have also been observed in the total electron content measurements. Scintillation activity is not always associated with the patches. This may result from the geometry of the ray path from GPS through the ionospheric patch. Diagnostic tools such as optical imaging should assist in determining the spatial and temporal motion of the patches now that the equipment is located at Davis. Comparisons of the scintillation activity with the model WBMOD show significant differences.

The Tasman International Geospace Environment Radar (TIGER) SuperDARN radar has been operating at Bruny Island, south of Hobart, since November 1999. Periodic visits to the radar site for data retrieval, maintenance and upgrading of equipment are undertaken. The radar scans south over Macquarie Island to coastal Antarctica and is operational for well over 90% of the available time. An evaluation of the International Reference Ionosphere (IRI) as a tool for predicting HF propagation at high latitudes by comparing predictions of sea-scatter with TIGER observations was made. It was found that the IRI predicted properties of propagation via the standard F2-layer mode quite well. However modes not predicted by the IRI become very important at night when the sea-echo occurrence is often 20% or higher. A new technique, based on the Fourier transform and cross-spectral analysis techniques, to determine propagation characteristics of medium-scale travelling ionospheric disturbances (MSTIDs) observed by TIGER was developed. Data obtained in winter were studied in detail and it was found the propagation direction changes of MSTIDs changes during the day from northeast to northwest at about 0500 UT (~1500 Magnetic Local Time).

Cosmic radiation bi-hemisphere studies have revealed possible evidence for precursor signatures to geomagnetic storms in the high-energy cosmic ray records. Further analyses are needed but the work is encouraging. The most advanced study of a GLE was undertaken. For the first time an analysis with fine time resolution was achieved and showed that the temporal development of the event, previously only guessed, has greater variability than expected. This indicates that understanding of the cosmic ray scattering in the dynamic heliomagnetic field is not as well developed as had been thought. The annual cosmic radiation latitude survey was conducted aboard the US Coast Guard icebreaker. A new container was commissioned with upgraded electronics and was transferred onto the icebreaker at Hobart. A second identical container has been fitted out for the other Coast Guard icebreaker to enhance the study and it will be operational next season. The Mawson Cosmic Ray Laboratory building was extended and heavy lead absorber delivered for the enlargement of the neutron monitor in 2002/3. Advanced electronics will also be added to bring the system on line as part of the Space Ship Earth international consortium.

Table 1: *Experiments in the Australian Antarctic Program showing location and collaborating agencies.*

Current Experiments

Experiment	*Casey*	*Davis*	*Mawson*	*Macquarie Island*	*Other*	*Research Agency*
Cosmic Ray Neutron Monitor			***X***		*Kingston Tasmania*	*AAD*
Cosmic Ray Surface Muon Telescope			***X***		*Kingston Tasmania*	*AAD, Shinshu U, Nagoya U*
Cosmic Ray Underground Muon Telescope			***X***		*Liapootah Tasmania*	*AAD, Shinshu U, Nagoya U*
30 MHz Riometer	**X**	**X**	**X**	**X**		*AAD, IPS*
Fluxgate Magnetometer	**X**	**X**				*AAD, GA, IPS*
Magnetic Absolutes	**X**	**X**	**X**	**X**		*GA*
Induction Magnetometer	**X**	**X**	**X**	**X**		*AAD, La Trobe U, Newcastle U*
Digital All-sky Imagers	**X**	**X**	**X**	**X** (2002)		*AAD*
Ionosonde	**X**	**X**	**X**	X		*IPS*

Digital Portable Sounder	***X*** *(2001)*	***X*** *(2002)*				*AAD, La Trobe U, IPS*
Satellite Scintillations	***X*** *(2001)*	***X*** *(2002)*		**X**		*AAD, La Trobe U*
Total Electron Content	**X**	**X**	**X**	**X**		*AAD, GA, La Trobe U*
VLF/ELF Radio Receiver	***X***					*BAS*
SHIRE Imaging Riometer		**X**				*AAD, Newcastle U, U Maryland*
MFSA 2MHz Radar		**X**				*Adelaide U, AAD*
Fabry-Perot Spectrometer		**X**	***X*** *(2001)*			*AAD, La Trobe U*
Czerny-Turner Spectrometer		**X**				*Adelaide U, AAD*
Scanning Radiometer		**X**				*U West. Ontario, AAD*
Fourier Transform I/R Spectrometer		**X**				*AAD, U West. Ontario*
3 Channel Photometer		**X**				*La Trobe U, AAD*
2 Channel Photometer	***X*** *(2001)*	**X**				*AAD*
Electric Field Mill		**X**			*Vostok*	*AAD*

UV-B	**X**		*AAD, ARL*
TIGER SuperDARN Radar	**X**	*Bruny Is Tasmania*	*La Trobe U, AAD, IPS, BAS, Newcastle U, Monash U, DSTO, RLM*
Lidar	**X**		*AAD, Adelaide U*

Commencing 2003

VHF Radar	**X**		*AAD, Adelaide U*
Ozone Sondes	**X**		*AAD, BoM*

AAD – Australian Antarctic Division, IPS – Ionospheric Prediction Service,
GA – Geoscience Australia,
BAS – British Antarctic Survey, ARL – Australian Radiation Laboratories,
RLM – RLM Systems Pty. Ltd.,
BoM – Bureau of Meteorology, U – University

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COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

INTRODUCTION

CSIRO, Australia's largest scientific and engineering research organisation, carries out R&D work under the terms of the Science and Industry Research Act 1949. The Act notes that CSIRO has a responsibility to carry out research that:

- assists Australian industry;
- furthers the interests of Australian community;
- contributes to the national objectives or international responsibilities of the Commonwealth; and
- responds to any other purpose determined by the responsible Minister.

Although not a space agency per se, CSIRO has a long recognised the relevance of space science and technology to its "core business", summarised above. Accordingly, CSIRO maintains an active space research program, particularly in the fields of earth observation; space-related engineering; and radioastronomy.

CSIRO also participates in major collaborative activities. Highlights of these appear elsewhere in this report.

EARTH OBSERVATION

CSIRO Earth Observation Centre

The Earth Observation Centre (EOC) was established in late 1995 to bring a level of collaborative underpinning development into the area of Earth Observation Research and Development in CSIRO. The EOC is collocated with the CSIRO Office of Space Science and Applications (COSSA), and the research program concentrates on generic research in four primary focus areas: applications support, measurement models, data systems, and sensor systems. Generic research tasks are being actively undertaken by a scientists from within a group of about 80 scientists spread through CSIRO and involved in one way or another in Earth Observation and associated space activities. Outcomes from this research become input into major divisional research programs, highlights of which are reported below.

The EOC has acted as coordination and Principal Investigator to a major international collaboration with NASA to evaluate and develop data from the EO1 experimental satellite system. EO1 is in a constellation orbit with Landsat 7 ETM, SAC-C and the EOS TERRA satellite and has advanced instruments on board including the first civilian Hyperspectral sensor to be deployed in space. A team from Australia has provided advanced validation research and is promoting the continuation of the deployment of the satellite to gather more earth information. Geoscience Australia was a participant and downloaded EO1 data at the Tasmanian TERSS ground station.

The Australian Ocean Colour Working Group (AOCWG) is a representative group of researchers from national marine research agencies and Universities. CSIRO and the AOCWG continue to collect in-situ atmospheric and underwater bio-optical data for calibration and validation of ocean colour satellite data and processing and archiving these data in order to support the development of long time series of surface parameters for high quality products derived from the processing of ocean colour instruments including ENVISAT, SeaWiFs and MODIS.

Further information on the EOC is available at: http://www.eoc.csiro.au

CALIBRATION AND VALIDATION

Progress with the CSIRO Continental Integrated Ground-Site Network - CIGSN.

CSIRO has been engaged in an international activity to provide calibration and validation data from carefully selected field sites for comparison with satellite measurements. Currently there are three main field site being used: Uardry, NSW (located at 34.4 S, 145.3 E), Amburla, NT (23.4S, 133.1 E), and Thangoo, WA (18.2 S, 122.4 E). Each site is homogeneous at scales ranging from a few metres up to a few kilometres. The Uardry site has been in operation since 1993, the Amburla site since 1995 and Thangoo began operations in 1998. The goal of the work is to establish a set of ground-truth radiation measurements that can be used to verify satellite measurements and be used for intercomparions with climate model simulations.

A unique feature of the Australian field site network has been the use of Radio Frequency communication that allows data to be collected at several locations across the site and hence estimate the spatial heterogeneity of the site - a very important factor for thermal studies at scales of 100 -1000 m. Measurements of surface temperature have been conducted using in situ ground sensors (temperature transducers) and methods have been developed to ensure correct placement of the sensors. Over time, the spatial average of these sensors (up to 25 across a 1 km x 1km area) has been shown to be a very good measure of the surface temperature of a 1 km x 1 km area. Because of the homogeneity of the Uardry site we have been able to develop algorithms which can be applied to larger scales for grassland surfaces and relatively low water vapor loadings (up to 3 cm). Recently CSIRO have been exploring the use of narrowband IR radiometers for use in the field. CSIRO have developed a self-calibrating radiometer and tested a version of this at the Uardry site for 1 year.

The Amburla site was established in 1995 and is running at present. Like Uardry the site uses remote data collection and RF communication. The climate is semi-arid and the surface is predominantly bare, covered by a quratz-rich, red-colored soil. Occasional rain causes rapid growth (Mitchell grass) and the character of the surface can change markedly in a matter of days to weeks. Surface temperature is measured using ground sensors (similar to Uardry) and these have proven to be very reliable. A satellite telephone and two network phones allow us to download data daily. Apart from surface temperature, a full suite of radiation and meteorological measurements are made. There is a daily radiosonde flight made from Alice Springs (about 100 km away) and these data are routinely acquired. A new set of spectral emissivity measurements was made at the site using a Fourier Transform Infrared (FT-IR) Interferometer. These measurements are being used in algorithms for determining surface temperatures of arid, sandy-soil environments.

The new site (started in 1998) at Thangoo was chosen because it is in a monsoonal climate zone with water vapour loadings ranging from as low as 1 cm of precipitable water to values in excess of 7 cm during the wet season. In a typical year the wet season lasts from December to April. The remaining seven months are dry with the highest percentage of clear skies anywhere in Australia. The site is located in tropical savanna woodland (Acacia) and suffers occasional bushfires. The cycle of burning in tropical Australia is currently under intensive research and the choice of this site has been influenced by the need to collect information on biomass burning aerosols. Instruments at the site consist of a suite of radiation devices (pyranometers and pyrgeometers), a Yankee MFRSR for aerosol optical depth and water vapor measurements, and four CSIRO scanning radiometers. Some ground sensors are used, but the nature of the biome make relating understory surface temperature measurements to satellite measurements impractical.

Strong involvement in the thermal infrared aspects of ESA's ENVISAT program, NASA's MODIS/ASTER program and NASDA's ADEOS-II GLI program has occurred. New international collaborations have been established with the University of Valencia (Prof. Jose Sobrino). Measurements of the angular behaviour of IR radiation within a canopy have been made and a detailed set of spectral emissivity measurements have been made at the Amburla field site. These data are being used to establish means for correcting satellite data for the effects of viewing angle and emissivity variations. Satellite data from ATSR-2, Landsat-7, AVHRR and GMS-5 have been analysed during the course of this work. Due to unfortunate delays in the launch of Terra, no MODIS or ASTER data have been analysed.

Common AVHRR Processing Systems (CAPS)

The Common AVHRR Processing System (CAPS) is a suite of platform-independent software that has been developed to provide uniform base processing (calibration and navigation) of AVHRR data at all Australian reception and distribution sites.

The CSIRO science working group CAPS continues to establish "best practice" approaches to process AVHRR, ATSR-2 and data from other sensors. The goal is to reduce redundant algorithm development; to increase scientific return on investment; to ensure that those who develop useful algorithms are appropriately acknowledged; to assure greater scientific integrity and consistency; and to make provision for easier re-processing in the event of improvements to algorithms. The use of this processing system at all Australian AVHRR stations will ensure that common formats, products, and archives will be applied to all data sets. Research programs and applications requiring data from more than one source, or data from non-local stations, are able to easily analyse, apply, and combine data from any Australian AVHRR station.

In a second stage of development the basic approach to processing AVHRR data has been recast in a modular form to allow easier configuration by users. Some additional functions have been added to support geolocation using ground control points. A new system for characterising surface and atmospheric transmission effects is also being added. It is expected that the user community will make more contributions to the development over time.
CAPS is now being used by a number of Government and University departments in Australian and also has a small but growing group of overseas users. .

The CAPS project has been funded by COSSA/.EOC, and the CSIRO Divisions of Atmospheric Research and Marine Research.

AVHRR Time Series

COSSA/EOC has assembled the largest and most comprehensive daily record of the state of the Australian region using the collection of AVHRR scenes collected from six different reception stations since 1992. The majority of these data have been acquired in the course of the Australian participation in the Global 1km Land Project for which COSSA/EOC was the regional coordinating node. The data have all been transformed to a common format, re-archived on DLT media, catalogued comprehensively and had browse imagery generated. In addition a new best-data set has been constructed by exploiting the redundancy due to multiple simultaneous acquisitions and stitching the individual scenes to create full continent spanning passes. The archive contains approximately 60000 scenes and includes afternoon and morning passes, and also evening and pre-dawn passes.

SeaWiFS Data Reception

The CSIRO Division of Marine Research continues to receive the ocean colour data from the SeaWiFS instrument on the SEASTAR satellite. The Division has a real-time license that allows the data to be used in NASA-approved marine research programs. The full data set within the range of the Hobart station will be archived for later use in climate, fisheries, and applications programs.

Topex/Poseidon and other Altimeter data

The CSIRO Division of Marine Research is a major user of satellite borne altimeter data from the JASON, Topex/Poseidon, ERS-1 and ERS-2 satellites. The altimeter data provide information on sea surface height which can be used for studies of variability, eddy statistics and surface currents and also for the study of larger scale phenomena. The Division contributes to international programs by operating an altimeter validation site in Bass Strait - one of the few such stations in the southern hemisphere.

TERSS

The Tasmanian Earth Resources Satellite Station (TERSS) in Hobart continues to receive satellite-data. The receiving station was wholly Australian designed and built. Dr David Jupp, Head of COSSA, chairs the TERSS Board which is responsible for the management of the facility.

ATSR-2 and AATSR

CSIRO continues to be a major user of ATSR data for both marine and land surface applications. Algorithms are continually improved and developed for the derivation of land and sea surface temperatures and for climate research applications. The AATSR Science Plan is well advanced and has involved significant input from CSIRO.

The Australian Government has supplied 30% of the cost of the AATSR program and is thus a joint partner with the UK Department of Environment in this project. Australia has full representation on several of the committees and groups managing the AATSR program.

Australian scientists from CSIRO and AIMS are involved in supplying ship-borne data for the geophysical validation of data products supplied by AATSR.

Remote Sensing in Forest Research

CSIRO Forestry and Forest Products undertakes a number of projects which utilize remote sensing data for forest inventory and biomass accumulation. Research is being undertaken on the relationships between remotely sensed data, acquired at a number of spatial scales and spectral resolutions, and the structure, growth and health of native eucalypt and plantation forests.

A number of new and innovate projects have been undertaken in the past year. These include:
Prediction of forest infestation and diseases from hyperspectral remote using imagery and the development of routine and generic methodologies that can be applied by forest plantation mangers.
Use of high spatial resolution imagery and digitized aerial photography to automatically predict stem numbers in plantation forests
Use of ground based and airborne LIDAR to predict a range of forest inventory attributes
Use of broad scale MIODIS and AVHRR imagery to predict biodiversity and forest production at a region level in the United State, Canada and South America

Prediction of leaf bio-chemistry from satellite EO-1 HYPERION and airborne HYMAP imagery;

Remote Sensing of Land Cover Processes and Water Quality

The remote sensing research group at the CSIRO Division of Land and Water, Environmental Processes and Resources Program, has close to 20 years experience in the use and interpretation of remotely sensed data for environmental applications and resource mapping.

The team, led by Drs Alex Held and Arnold Dekker, has its main areas of expertise in:

- Hyperspectral remote sensing, with emphasis on vegetation mapping, land use assessment, water quality and coastal zone mapping;
- Ground-based field verification and use of hand-held spectroradiometers, and related water quality, plant or forestry measurement methodologies;
- Imaging radar remote sensing for assessment of soil moisture, vegetation structure and biomass;
- Instrumentation development for ground-truthing and measurement during remote sensing projects; and
- Time-series analysis and data integration for regional/continental resource assessment.

Remote Sensing to Monitor Salinity and Vegetation Change

The CSIRO Mathematical and Information Sciences Remote Sensing group is pursuing the Land Monitor project which involves the production of maps of salinity and remnant vegetation over the South West of Western Australia. The work is being done in conjunction with several state government agencies. Sequences of Landsat TM images in conjunction with landform maps derived from digital terrai models will be used to produce the output map products.

Some of the technical aspects of the work include accurate registration of sequences of images, callibration and mosaicing of images and the integration oftime series of satellite images with landform maps using conditional probability networks. The work has resulted in the production of salinity change maps, predictions of salinity risk areas and vegetation change maps for the south west of Western Australia. These maps form part of a co-ordinated approach in managing the salinity problem in western Australia.

The development of these skills and methods has been put to test in the major land cover mapping being undertaken by the Australian Greenhouse Office for an Australian baseline cover map at the 1992 timeslice.

Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) System

The Japanese ASTER sensor (Advanced Spaceborne Thermal Emission and Reflectance Radiometer - http://asterweb.jpl.nasa.gov/ or http://www.gds.aster.ersdac.or.jp/) , onboard the US TERRA satellite, was successfully launched on 18th December 1999 and is now positioned in orbit 30 minutes behind Landsat Thematic Mapper (TM). In contrast with Landsat TM, ASTER provides calibrated multispectral imagery over three wavelength regions, namely: the visible and near infrared (VNIR); shortwave infrared (SWIR); and thermal infrared (TIR). The three VNIR bands between 0.5-1.0 μm have a spatial resolution of 15 metres, the six SWIR bands between 1.0-2.5 μm have a 30 metre spatial resolution and the five TIR bands between 8-12 μm have a 90 metre spatial resolution. ASTER has an along-track stereo imaging capability for producing digital elevation models (DEM). The swath width is 60 km with cross-track pointing laterally to 136 km, which will allow viewing of any one spot every sixteen days.

Another advantage of ASTER is that the data are preprocessed to surface units (e.g. reflectance, emissivity, temperature) and georeferenced to a standard map grid in Japan/US prior to their distribution to the scientific community. The high spatial resolution, multispectral VNIR-SWIR-TIR coverage of ASTER has the potential to provide a new generation of geological mapping products. For example, the five ASTER bands in the 2.1 to 2.4 μm region (Landsat TM has only one band) theoretically enables mapping of the abundance of Mg-OH and carbonate group mineralogy (e.g. chlorite, amphibole, calcite and dolomite) as well as one Al-OH group (kaolinite, dickite, muscovite, montmorillonite) from another Al-OH group (pyrophyllite and alunite). The five TIR bands should produce maps of SiO_2 abundance while the combination of VNIR and SWIR bands should provide information of ferrous- versus ferric-bearing mineralogy.

ASTER data processed to Level 1A (radiance at sensor and suitable for DEM generation), Level1B (radiance at sensor and georeferenced and corrected for various instrument effects not addressed in Level 1A) and most Level 2 products have now been validated and are available (currently free of charge, probably only to September 2002) from the EOS Data Gateway (http://asterweb.jpl.nasa.gov/gettingdata/default.htm). Cloud free, high sun angle ASTER coverage of the Earth's land surface collected as part the ASTER Science Teams (AST) Global Mapping Program is nearly complete. These data form the bulk of the available Level 1A and Level 1B scenes available to the public. Australia, together with the US, has been the largest downloader of ASTER data from the US EOS Data Gateway. ASTER data has now been acquired over most of the Australian continent by Australian government mapping agencies.

CSIRO is working with the mapping agencies on a number of fronts related to ASTER. The first involves an MOU between Japan-Australia, which provides continued priority access to ASTER data, processed data (e.g. ASTER derived digital elevation models), calibration and validation of the standard ASTER Level 1B and Level 2 products and the development of a methodologies that enable the seamless production of accurate geological information products. The objective being the development of publicly available, seamless ASTER geological maps of the Australian continent. To this end, CSIRO has been conducting ASTER workshops around the country to raise the profile of ASTER in the community as well as working on collaborative projects with the mapping agencies and ERSDAC (Japanese department that manages ASTER) to tackle critical research issues, like calibration and product validation.

CEOS Working Groups and Plenary

CSIRO strongly supports its continuing role as CEOS Member, and will continue to enthusiastically support scientists attending and actively developing CEOS Working Groups and Tasks

The Working Groups on Information Systems and Calibration and Validation have and will have meetings in Australia and are key international forums for Australian space earth observation science activities.

RADIOASTRONOMY

Earth-based Antennas

CSIRO Telecommunications & Industrial Physics (formerly the divisions of Radiophysics and Applied Physics) designed, built and supplied an X-band transmit/receive feed system for a Department of Defence earth station. A high degree of isolation was required between the transmit and receive frequency bands and this was achieved by a combination of special techniques including shaping the subreflector to simultaneously reduce reflections back to the feed and meet the CCIR antenna sidelobe requirements.

Considerable progress has been made at CSIRO in developing and supplying feed systems for earth station antennas where simultaneous operation over two frequency bands is required. In some cases the bands are well separated (~ 4:1 separation) and in other cases they can be almost contiguous (1.1:1). Work is continuing on multi-band feed systems.

CSIRO has recently developed extremely wideband hybrid mode horns using dielectrically-loaded waveguide as the basis of the design. Current applications have been in dual-band feed systems just mentioned and in supplying to the SETI (Search for Extra Terrestrial Intelligence) Institute, USA, a feed system with a very large conical feed horn, 3 m in length with an aperture of 1.3 m, for use on a 30 m diameter Cassegrain antenna for SETI observations. The design, which was fully analysed before construction, has sandwiched layers of Teflon and polystyrene foam inside the horn to form the required average dielectric. The feed system as supplied operates over 1-3 GHz but the horn itself is capable of high performance up to 7 GHz.

Radio-telescopes

A 13-element multibeam feed and associated receiver was completed and installed in the Parkes radio telescope. This multibeam system operates in the 21 cm band and has 26 signal channels (13 beams x 2 polarizations). It required the development of an array feed system that has minimal beam cross-coupling and also large-scale radio frequency and cryogenic components.

Following from the success of the Parkes multibeam receiver, CSIRO designed a 4-element multibeam feed for the Lovell radio telescope at Jodrell Bank, UK. This required developing a feed element that gives efficient illumination of a deep and is small in cross-section so the array elements can be closely packed to minimize scan gain loss and coma sidelobes. The design adopted uses a coaxial waveguide with iris matching at the aperture to give low return loss.

A joint project between CSIRO Telecommunications & Industrial Physics and the Paris Observatory to design a new feed system for the Nançay radio-telescope in France that will allow the telescope to operate over the entire 1 to 3.5 GHz band, has now been completed and supplied The new feed system is of considerable size (contained within a volume of 9.3m x 5m x 6m) and consists of two shaped reflectors in a Gregorian configuration and uses two compact corrugated horns. It permits a more symmetrical beam, decreases the system noise temperature by at least two at all critical frequencies, and improves the system sensitivity by a factor of 2 to 3.

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COOPERATIVE RESEARCH CENTRE FOR SATELLITE SYSTEMS (CRSS)

Introduction:

The Cooperative Research Centre for Satellite Systems was established on 1 January 1998, under the Commonwealth Government's Cooperative Research Centres Program which encourages Australian universities, government research agencies and private companies to collaborate on technological developments in the national interest.

The Centre carries out research and training in space technologies; its business orientation is to develop Australian capability in the development and exploitation of small satellites.

The rationale for this is based on the following:

- satellite technologies are used daily to provide key services to Australia in areas such as weather forecasting, communications, environmental management, navigation, and resource exploration;

- in recent years, a new "smaller, cheaper, faster" approach to satellite systems has begun to open space markets to a wider range of public and private sector players; and

- new small satellite technology is well within the capability of Australian industry to produce.

The Centre currently comprises twelve participants of two types: *Core,* or major participants with a seat on the Governing Board; and *Supporting* participants, which do not have a seat on the Board (**refer Table 1**). The inaugural independent Chair of the Governing Board is the Honourable Tony Staley, former Commonwealth Minister for Communications. The Executive Director of the Centre is Dr Brian J J Embleton, former Head of the CSIRO Office of Space Science and Applications and past chair (1995/96) of the Committee on Earth Observation Satellites.

The participants provide the bulk of the Centre's resources, contributing some $AUD 35 million over the initial 7-year lifetime, while the Commonwealth government will contribute $AUD 20.7 million, and the State Government of Queensland and South Australia a further $AUD2 million. The total resources available to the Centre over the financial year period 1997/2005 is about $AUS 61 million. The Commonwealth support comprises the Cooperative Research Centre Program ($18.7 m) and AusIndustry's Innovation Access program ($2 m). The Innovation Access Program grant was awarded in March 2002.

Table 1 Participants in Cooperative Research Centre for Satellite Systems

Organisation: core participant	**Organisation: supporting participant**
University of South Australia	Defence Science and Technology Organisation
CSIRO	La Trobe University
Queensland University of Technology	Codan Ltd
University of Technology, Sydney	DSpace Pty Ltd
University of Newcastle	Curtin University of Technology
Vipac Engineers & Scientists Limited	
Auspace Ltd	

In addition to the formal participants above, who have signed mutually binding contracts to participate in the Centre for the next seven years, the Cooperative Research Centre for Satellite Systems collaborates widely with the international space community and with kindred Australian research and development organisations.

In late 2001 the Centre established a private company, Satellite Systems Pty Ltd, intended to commercialise research outcomes of the Centre.

Research

The Cooperative Research Centre for Satellite Systems carries out research in the following primary areas: space science; satellite communications; remote sensing; satellite systems; and satellite engineering.

Space science

Professor Brian Fraser at the University of Newcastle coordinates this program. Professor Fraser also chairs the Centre's Research Panel. The program has these objectives:

- To conduct basic research on the structure and dynamics of the ionosphere and exosphere using magnetic field observations and propagation delays of Global Positioning System (GPS) signals.
- To apply the results of this research to space weather and communications prediction models.
- To study the dynamics of field aligned currents in the auroral zones and the equatorial current system.
- To study oscillating wave fields and their variability in the ionosphere and exosphere, including ELF ion cyclotron waves and ULF hydromagnetic waves in conjunction with ground station observations.
- To provide vector measurements for the mapping of the geomagnetic field over Australia and contribute to secular variation and solid Earth studies.
- To provide improved accuracy for GPS applications which will deliver benefits to the navigation and position service industries - including geomagnetic mapping; and

Satellite communications

This program is coordinated by Professor Bill Cowley of the Institute for Telecommunications Research at the University of South Australia. The objectives of the program are:

- To develop new communications techniques for the use in future small Low Earth Orbit (LEO) satellite communications and Earth observation constellations.
- To develop innovative solutions to network management, and to satellite tracking and control.
- To test applications in new services such as Two Way Paging, Mobile Computing and Internet Access for uses in remote areas; and
- To find new solutions to the design of LEO satellite communications systems and networks that are robust in the face of interference and fading.

Satellite systems

This research program is led by Professor Miles Moody at the Queensland University of Technology, and has the following objectives:

- to develop new techniques utilising GPS receivers on board LEO satellites for real time tracking, and for high precision determination of satellite orbit/attitude; the research will also develop techniques that would enable GPS corrections to be broadcast from LEO satellites to improve the accuracy of wide area global positioning systems.
- to study the design of adaptable, high performance computing systems for use on board LEO satellites; modular, reconfigurable structures will be developed, together with formal verification techniques for satellite software systems.

Satellite engineering

Mr Mirek Vesely Vipac Engineers & Scientists Limited leads this research program. Mr Vesely is also the Project Manager for the FedSat mission. The objective of the program is to develop and implement satellite flight and ground segments for Centre space projects.

FedSat experimental microsatellite

History

The Centre's first major project is the FedSat experimental microsatellite, announced by the Minister for Science, the Hon. Peter McGauran MP, in August 1996. The primary purpose of FedSat is to develop and demonstrate Australian space capability. The satellite is intended to function as a platform for scientific and engineering research, much of which is being carried out in the six universities that are Centre participants.

A Request for Proposal for the platform was issued in February 1998 and Space Innovations Limited (SIL) of England was the successful tenderer. SIL became insolvent and ceased trading in July 2000, after which the FedSat project material was repatriated to Australia. The Centre assumed full control of the project and the satellite was assembled by mid 2002, in our project office at Auspace Limited, Mitchell ACT. Launch is being arranged with the cooperation of the National Space Development Agency of Japan (NASDA) and is expected on the fourth flight of the H-IIA vehicle in November 2002. FedSat will be a "piggyback" payload, with the primary payload being the ADEOS-II Earth observation mission.

Overview

FedSat is a small or “micro” satellite mission, approximately 58 kg and 50 cm X 50 cm X 50 cm. Nevertheless it is a sophisticated science and engineering test satellite, the construction of which has enabled Centre staff including researchers, engineers, and graduate student to significantly increase their hands-on experience with spacecraft and space systems. Outreach to the public is expected to be a feature of the FedSat project, since the mission is intended to be one for all Australians.

The satellite is expected to have a sun-synchronous polar orbit with altitude about 800 km and period about 100 minutes. The lifetime of FedSat is expected to be 3 years. The ground station is located at the University of South Australia in Adelaide.

Payloads

FedSat carries four scientific payloads and a CD containing messages from the Australian public. The commemorative CD also carries a copy of the Paul Kelly/Kev Carmody song, “From Little Things, Big Things Grow”.

NewMag magnetometer

The scientific objectives are to study small naturally occurring magnetic variations and waves in the frequency range 0.1 to 1 Hz; observe field aligned currents in the auroral zones and equatorial region currents; obtain real-time field data for space weather forecasting and modelling; and to derive vector measurements for magnetic field mapping in the Australian and other regions.

This experiment is led by the University of Newcastle and is performed in conjunction with the University of California in Los Angeles; NASA; the Australian Geological Survey Organisation, and others. Since the current period corresponds to a solar activity peak, the scientific returns from this project are expected to be significant. The experiment has complementary objectives to ESA’s Cluster mission.

GPS Signal Propagation

FedSat carries a Turbo Rogue GPS receiver, both for satellite tracking and for scientific purposes. The scientific experiments anticipated rely on the phase delay of GPS signals as a function of the length and properties of the atmosphere and ionosphere segment traversed by the signals. From these data, electron content, refractivity, and related parameters can be deduced.

The upper atmosphere (ionosphere) component of this experiment is being planned by La Trobe University.

The US National Aeronautics and Space Administration (NASA) supplied the receiver, under a collaborative agreement with CSIRO, acting on behalf of the Centre.

Advanced Communications Payload

Small LEO satellites are the focus of increasing commercial interest in relation to global personal communications and data/multimedia networking. FedSat is expected to carry an advanced communications packages which will investigate:

- new communication techniques using Ka, S- and VHF bands for communications and data delivery
- Internet and ATM-like services
- Advanced Earth terminals for communications, tracking and control
- Advanced Radio Frequency sub-systems, including new Ka band antenna structures; GaAs-based Monolithic Microwave Integrated Circuits (MMIC) for Ka band; and measurements of the rate of degradation of GaAs devices in space.

The University of South Australia, with CSIRO Telecommunications and Industrial Physics, and the University of Technology, Sydney lead the advanced communications payload.

The VHF payload comprises the Advanced Data Acquisition and Messaging system (ADAM). Identical payloads are being developed by the Centre's participant, the Institute for Telecommunications Research at the University of South Australia, for flight on the Republic of Korea's KAISTSAT-4 satellite and on Singapore's X-Sat.

Codan, the Defence Science and Technology Organisation and DSpace Pty Ltd, in close consultation with prospective user organisations in the telecommunications industry, also participate in the Centre's ongoing research and development program.

Advanced satellite tracking

The Queensland University of Technology (QUT) aims to improve the efficiency with which small satellites can be tracked using GPS techniques; to improve the accuracy of terrestrial and marine positioning using on-board GPS; and to carry out experiments intended to improve on-board GPS processing.

High Performance Computing

QUT is also leading an experiment designed to space-qualify an advanced computing device equipped with reconfigurable logic. The objective is to develop future, possibly commercial applications for on-board computing systems featuring data filtering and compression. This work is carried out in collaboration with the Applied Physics Laboratory of Johns Hopkins University, USA.

Education

The Centre has approximately 60 PhD and Masters degree students enrolled at its six constituent campuses, in the following research areas:

- space science
- satellite systems
- satellite telecommunications
- Global Positioning
- High Performance Computing

Over twenty students have already graduated from the Centre's participating university courses.

International links

The Centre is also planning or negotiating collaborative experiments with:

- Canadian Space Agency
- Johns Hopkins University, USA
- Korean Advanced Institute for Science and Technology
- Nanyang Technological University, Singapore
- National Aeronautics and Space Administration, USA
- National Space Development Agency of Japan
- Stellenbosch University, Republic of South Africa
- University of California in Los Angeles
- United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Bangkok

Dr Brian Embleton, the Centre's Executive Director, served as the Regional Coordinator for ESCAP's Regional Working Group on Space Science and Technology Applications, 2000-2002. The Centre hosted the Regional Working Group Meeting, and held the Symposium on Microsatellite Applications for Asia and the Pacific, in Canberra in 2000. Senator The Honourable Kay Patterson opened the meeting.

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Appendices

Appendix 1: Acronyms

ATM	Asynchronous Transfer Mode
COSSA	CSIRO Office of Space Science and Applications
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CRCSS	Cooperative Research Centre for Satellite Systems
ELF	Extra Low Frequency
EO	Earth Observation
EOC	CSIRO Earth Observation Centre
ESA	European Space Agency
ESCAP	Economic and Social Commission for Asia and the Pacific
GPS	Global Positioning System
ITR	Institute for Telecommunications Research
LEO	Low Earth Orbit
NASDA	National Space Development Agency of Japan
NASA	National Aeronautics and Space Administration
QUT	Queensland University of Technology
ULF	Ultra Low Frequency
UHF	Ultra High Frequency
UniSA	University of South Australia
UTS	University of Technology, Sydney
VHF	Very High Frequency

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GEOSCIENCE AUSTRALIA

Geoscience Australia's[1] space-related activities encompass:

- operation of the national space geodesy observation stations (Figure 1) and permanent geomagnetic observatories and repeat stations (Figure 2)
- data processing and analysis carried out by the Space Geodesy Analysis Centre,
- activities of the Australian Centre for Remote Sensing

use of high-resolution earth observation data in geoscience and geohazards programs.

The geodetic techniques employed cover GPS base stations, GLONASS, DORIS, SLR, VLBI, and absolute gravity. Data are provided to the world community to be used for determining the geodetic properties of the Earth and its position in space, measuring precise orbits of satellites, and support for ground positioning systems. Processing and analysis of the geodetic data at the Space Geodesy Analysis Centre contribute to determination of the earth's orientation in space, densification and refinement of the International Terrestrial Reference Frame (ITRF) and scientific studies in geodynamics.

The Australian Centre for Remote Sensing (ACRES) operates satellite ground receiving stations at Alice Springs and Hobart. Data are downloaded from a range of low earth orbiting satellites, processed, and distributed in a timely manner as high quality images in support of earth observation activities and research in Australia. Recent developments that have assisted in this effort include:

- installation of a dedicated reception/processing system for AVHRR data
- development of online capability to provide processed MODIS and AVHRR data to researchers online within 24 hours of reception free of charge
- improvement of the geocoding process using GPS control to provide pixel-to-pixel registration of time based series of data over two thirds of Australia.
- installation of an additional antenna to avoid conflicts due to simultaneous satellite overpass times, and provide a back up to the existing antenna.
- initial development of test algorithms to enable automatic cloud cover assessment of images.

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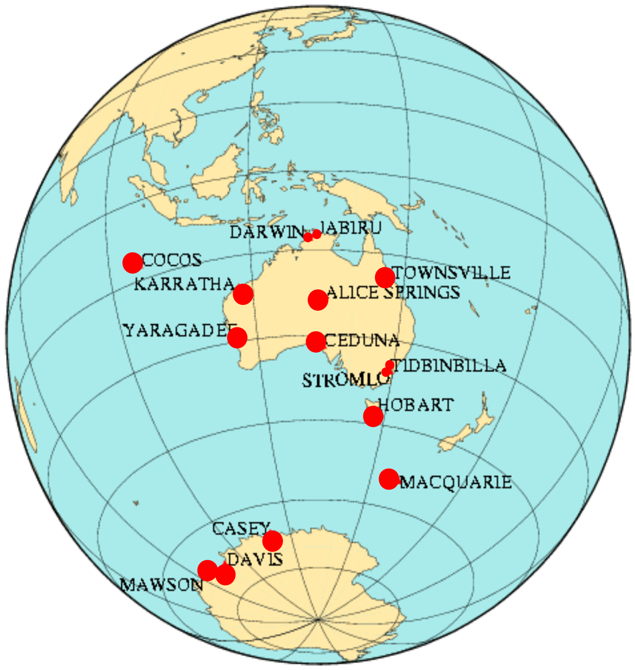
[1] Formerly the Australian Geological Survey Organisation (AGSO) and the Australian Land Information Group (AUSLIG) – the two organisations merged in October 2001.

Geoscience Australia has continued to use space-borne remote sensing data to support it's onshore and offshore operations. RADARSAT imagery is used for detecting natural oil seeps in established and emerging offshore petroleum exploration areas. Integration of GEOSAT gravity data with onshore Bouger anomaly data and ship-borne multi-beam swath mapping is crucial in determining Australia's territorial boundaries for the Law of the Sea program. Landsat TM data, in conjunction with aerial photography, was instrumental in rapid mapping and assessment of the condition of Australia's estuaries. Data from NASA's Earth Observation System's MODIS sensor is providing multi-temporal regional data for monitoring estuarine and coastal processes. The availability of EOS's moderate spectral and spatial ASTER data is being applied to coastal mapping as well as enhancing geological and regolith mapping programs. Finaly, high resolution satellite imagery have been used extensively the geohazards areas, particularly in developing risk-GIS methodologies for multi-hazard risk assessment for Australian communities.

Information about the variations of the geomagnetic field and magnetic disturbances is used in support of solar-terrestrial physics research and space-weather reporting – through collaboration with IPS, Radio and Space Services. One-second data, calibrated to rigorous absolute standards, are recorded at the observatories. Much of the data can be provided in near-real time. Four more Australian observatories (Alice Springs, Macquarie Island, Charters Towers, and Kakadu) were brought on-line as INTERMAGNET observatories, providing near-real time data globally. Geoscience Australia and IPS are collaborating to develop new indices of magnetic disturbance that align more closely with user requirements and the growing need for real-time space weather information.

New magnetic field survey microsatellites, notably OERSTED and CHAMP, are greatly improving our ability to map the geomagnetic field globally. Australian magnetic observatory data have been supplied monthly in support of these missions. Magnetometers and magneto-torquers for Australia's FEDSAT microsatellite were calibrated at GA's Magnetometer Calibration Facility at the Canberra Observatory.

Figure 1. Australian Regional GPS network. SLR and DORIS facilities are at Stromlo and Yaragadee; GLONASS at Stromlo, Yaragadee, Darwin and Davis; VLBI at Tidbinbilla and Hobart.



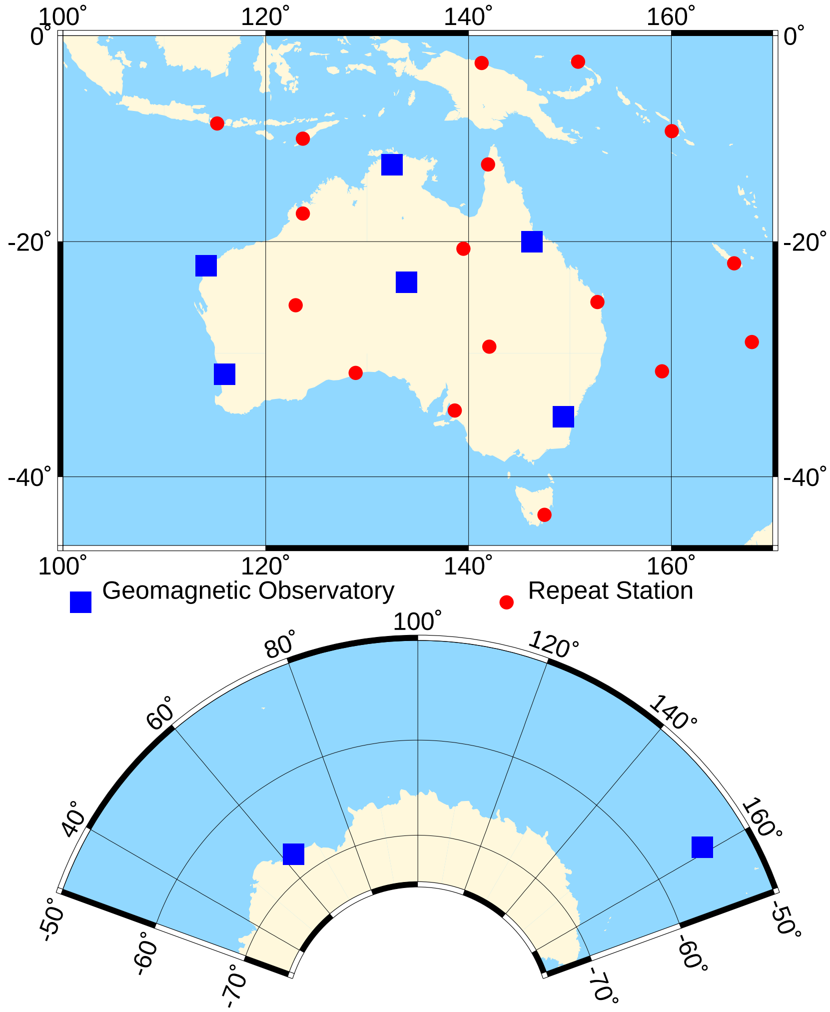


Figure 2. Locations of Australian magnetic observatories (squares), and repeat stations (dots). Annual observations are made at the repeat stations to obtain supplementary information about the geomagnetic secular variation.

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IPS RADIO AND SPACE SERVICES

Department Of Industry, Tourism and Resources

Ionospheric Monitoring

IPS has a widely dispersed ionospheric network complemented by the two solar observatories. All sites operate at least one vertical incidence ionosonde and some (Vanimo and Townsville) host oblique ionosondes. During the last year the vertical ionosondes have been upgraded at all sites, the aging IPS-4D ionosondes being replaced by either an IPS-5D ionosonde or a Canadian CADI ionosonde. Data are obtained in real time from Vanimo, Pt. Moresby, Darwin, Townsville, Learmonth, Brisbane, Norfolk Is., Mundaring, Canberra, Camden, Christchurch, Hobart, Macquarie Is., Scott Base, Casey, Davis and Mawson. At the Casey and Macquarie Island sites, drift observations are also made regularly. Wide beam riometer observations are collected at Macquarie Island, Casey, Davis and Mawson, in cooperation with Antarctic Division, to support space weather services. Currently, they are used to confirm the presence of polar cap absorption events.

All ionograms recorded are scaled automatically and the data are used to generate real time ionospheric maps that are placed on the IPS Web site (http://www.ips.gov.au) and also used as the basis of a variety of real time services. The real time ionograms are all made available on the IPS Website as they are obtained. The IPS autoscale software has been further improved and adapted to handle different ionogram formats. Data from the network is currently being used to support modernised HF installations in Australia.

The effects of scintillation on GPS have been investigated by making direct observations from Vanimo, equatorward of the equatorial anomaly. IPS also makes total electron content observations at Vanimo and, more recently, at Pt Moresby with the re-sited Culgoora receiver.

Geomagnetic pulsations

The IPS magnetometer network has been expanded to include Darwin, and will be upgraded with 24-bit A/D converters, low-pass noise filter systems and automated timing checks. The data are sampled at 1 second intervals and used to produce estimated K-indices and "pc3-indices" for the Australian region. Pc3-indices are the root-mean square values of the component data filtered over the Pc3 pulsation period range (10-45 seconds) and scaled by a factor of 10. Both types of indices are used to generate contour maps, which indicate the levels of geomagnetic activity for the associated period ranges. Magnetograms and time series index plots are also produced from the data, with the indices also used as the basis of several alert systems for space weather conditions. These may be extended to include early warnings for very large geomagnetic field rates of change.

Solar Observations at Culgoora

At the IPS Culgoora Solar Observatory, the principal radio equipment is a radio spectrograph that scans in frequency from 18 MHz to 1.8 GHz. The lower frequency band antennas have been rebuilt and will not be available for a few months but all the other frequency data are available, through the IPS Web site (www.ips.gov.au). Data from the spectrograph, together with observations from WIND, have been used to track a coronal mass ejection from the corona out into the solar wind.

The Learmonth Solar Observatory

The Learmonth Solar Observatory (22S, 114E) on North West Cape, Western Australia, is jointly managed with the US Air Force Weather Agency. Continuous automated H-alpha patrol is accomplished with on-site human analysis and digital archive. This is supplemented by photospheric magnetograms (longitudinal component), and daily manual white light sunspot analysis. All data products and a selection of H-alpha images are available from the IPS website (solar section, www.ips.gov.au). Continuous solar radio observations are made on eight discrete frequencies (245, 410, 610, 1415, 2695, 4994, 8800, and 15400 MHz) and from 25 to 180 MHz with a swept frequency solar radio spectrograph. These data are archived digitally at a cadence of one second for the fixed frequencies and every three seconds for the spectrograph scan. The spectrograph data is available on the website at the real-time cadence, and the fixed frequency data at reduced (1-minute) cadence. Radio burst analysis messages are also available in near-real time on the website.

Geomagnetic data are collected from total field (proton precession) and component (fluxgate) magnetometers run in cooperation with Geoscience Australia. These data are available within 5 minutes of collection. Ionospheric data are collected at half hourly intervals from a University of Lowell DGS-256 ionosonde.

Several international research experiments are hosted on-site. These include a station of the GONG helioseismic network (hosted for the US National Solar Observatory), that also provides real-time magnetograms and white-light images. Other monitors include a high time resolution magnetometer (STEL Magnetic Meridian 210 Network) from the Solar Terrestrial Environment Laboratory of Nagoya University, and an ELF (1-100 Hz) monitor from the Geophysics Institute at the University of Alaska. Experiments are underway with a GPS sensor (TEC), and a GLE indicator. In 2003 a small aperture telescope with megapixel CCD camera will commence operations to provide support to the global effort to track Near Earth Objects.

World Data Centre for Solar-Terrestrial Science

The IPS World Data Centre (WDC) has completed a successful installation of a mirror site for the space physics interactive data resource (SPIDR) from the WDC-A for Solar Terrestrial Physics, Boulder. Data are available for on-screen viewing (www.ips.gov.au).

Space Weather Plan

There has been continued consultation over the development of an Australian space weather plan with science and industry groups involved in space weather. The plan deals with the monitoring, research and outreach aspects of space weather information. The Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering are developing the draft plan further.

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LA TROBE UNIVERSITY - DEPARTMENT OF PHYSICS

The Space Physics Group at La Trobe [http://www.latrobe.edu.au/www/physics/space/space.htm] consists of staff from the Departments of Physics and Electronic Engineering. The Group conducts research in Solar-Terrestrial Physics in the areas of the behaviour and interactions of the ionosphere, magnetosphere, thermosphere and mesosphere. It also conducts an extensive program studying the properties of radio wave propagation in and through the ionosphere and plasmasphere and applying the results to practical communication and surveillance systems. Experimental work involves observations of the ionosphere, plasmasphere, thermosphere and mesosphere at mid and high latitudes using ionospheric radars, satellite transmissions and optical spectrometers. Radars and optical instruments are developed by the Group. Theoretical work involves the development of ray tracing and inversion techniques applicable to research sounders and radars and, to applications in surveillance techniques and communications.

Ionosonde Studies of the Ionosphere

The Group operates a digital ionosonde at its Bundoora campus to study ionospheric dynamics and ionospheric irregularities at mid-latitudes. A digital ionosonde installed at Casey, Antarctica by the Australian Antarctic Division is used to conduct a joint research program. F region drift measurements have been conducted since April 1993. Studies include the detailed morphology of drift as a function of local time, IMF, Kp and season; the height variation of drift velocity through the E and F regions, the formation of Es by electric fields and the development of a model describing ionospheric convection at Casey and its dependence on the interplanetary magnetic field.

TIGER Radar

The Group leads a consortium comprising Australian universities, government departments and industry that has built the Tasman International Geospace Environment Radar (TIGER) [http://www.tiger.latrobe.edu.au/tiger.html]. The radar is located at Bruny Island, Tasmania and operated remotely from La Trobe. It is a component of the Super Dual Auroral Radar Network (SuperDARN) [http://superdarn.jhuapl.edu/]. Operations began November 1999. TIGER is located more equatorward than other existing SuperDARN radars and is therefore able to routinely observe sub-auroral processes and open up new areas of research using this radar technique.

Airglow Studies

A Fabry-Perot Spectrometer is operated at Beveridge to measure thermospheric winds and temperatures. In conjunction with Australian Antarctic Division, a similar instrument is operated at Davis, Antarctica. These instruments measure both thermospheric and mesospheric winds and temperatures. Major areas of study are the propagation of atmospheric gravity waves and identification of their sources, upwellings in the thermosphere that occur quite regularly in the region immediately poleward of the auroral oval and, the unexpected temperature increase that occurs with increasing magnetic latitude. Measurements of the OH (6-2) airglow emission is used to study tides and planetary waves in the mesosphere. At mid-latitudes the emphasis is on the coupling between the ionosphere and thermosphere.

Ionospheric studies using GPS

Several projects are being undertaken to study the ionosphere in the Australian region extending from equatorial to high latitudes. At the Antarctic bases of Casey (now at Davis) and Macquarie Island, the GPS satellites signals are being used to map the total electron content variations and the occurrences of amplitude and phase scintillation activity. These data are being used to investigate the formation of patches and auroral blobs and the associated scintillation activity as well as gravity wave activity. This research is being undertaken in collaboration with the Australian Antarctic Division and the National Mapping Division. In the low latitude regions of Northern Australia, the detailed morphology of GPS scintillation activity is being investigated in collaboration with DSTO.

Occultation studies of the Ionosphere

La Trobe University is a partner in the Cooperative Research Centre for Satellite Systems. As part of its activities, Australia is developing a scientific satellite, called FedSat, in celebration of the centenary of Federation. One of the payloads on board is a Blackjack GPS receiver, which will be used to undertake occultation studies of the ionosphere. Particular emphasis will be directed toward the improvement of the current models of the ionosphere over the vast expanses of the Southern Hemisphere where existing data is sparse. This new, cost-effective technology based on the GPS constellation, offers a new data source for the upper atmosphere of this region.

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UNIVERSITY OF NEWCASTLE

Space Plasma Physics Group
Department of Physics

Research within the Space Plasma Physics Group is concerned with a number of aspects associated with plasma waves in the Earth's magnetosphere and ionosphere. These include the study of ultra-low frequency (ULF) hydromagnetic and ion-cyclotron waves in the magnetosphere, using observations from spacecraft and from ground magnetometer arrays at low and high latitudes; the transmission of these waves through the ionosphere; high latitude studies of magnetosphere-ionosphere coupling, including with HF radars; and the use of ULF waves as diagnostic probes of the magnetospheric plasma and its variation, and the energy flux coupled to the atmosphere.

The group is also a core partner in the Cooperative Research Centre for Satellite Systems, which is developing the first Australian satellite for 30 years, FedSat. This low-Earth orbit microsatellite will be launched in 2002 and will carry the NewMag magnetometer experiment to measure the Earth's main field and ULF waves.

Studies of Magnetospheric ULF Waves

Plasma waves are important in distributing energy of solar wind origin throughout the magnetosphere and down to ionospheric altitudes. General studies using the Group's Antarctic magnetometer array (Casey, Davis, Mawson and Macquarie Island) and from the IMAGE array in the Arctic have shown that Pc1-2 (0.1-100 mHz), Pc3-4 (7-100 mHz) and Pc5 (< 7 mHz) pulsations are generated in specific regions of the outer magnetosphere, boundary layer and dayside cusp. Pc5 waves generated by boundary layer instability processes such as the solar-wind driven Kelvin-Helmholtz instability, have been found to couple to field line resonances (FLRs) in the outer magnetosphere. The FLR signatures are detected by high latitude magnetometers and HF radars, and often exhibit a set of discrete frequencies. This leads to the notion that the waves excite cavity modes in the magnetosphere or in the waveguide formed around the boundary layer.

More detailed studies of wave propagation have been undertaken using a square array of solar-powered magnetometers near and inland from Davis, Antarctica. These have allowed direction of arrival determinations of daytime quasi-structured and unstructured Pc1-2 emissions, and Pc3-4 and Pc5 waves. The Pc1-2 are associated with sources at the boundary region, near the magnetopause, and may propagate over short distances (< 500 km) but not the ionospheric F2 region waveguide. Detailed studies using the Antarctic magnetometers and the Arctic IMAGE array have shown that monochromatic Pc3-4 pulsations exhibit high coherence over about 1000 km waves and propagate poleward across the ground. The wave energy spreads across the ionosphere at apparent speeds of a few tens of km/s. This speed can be interpreted as a time delay between two different paths by which compressional and Alfven wave energy may reach the ground from a sub-solar magnetopause source. These pulsations are therefore probably due to fast mode waves propagating through the magnetosphere, due to compressional mode hm waves generated in the upstream solar wind by the ion-cyclotron resonance with backstreaming ions.

It has been shown that the high latitude Pc5 FLRs can be used to provide information on the open-closed field line boundary. This is important for space weather diagnostic studies and the focus of current research using the remote magnetometer array.

We have also examined incoherent Pc3-4 signals that are characterised by a small scale size and are probably generated by fluctuations in the precipitating particles in the boundary layers. For this purpose we performed a statistical study of pulsation amplitude, frequency and polarization over the 1 – 100 mHz range over 3 years for Davis and Mawson, Antarctica.

The group has operated a low light all-sky optical imager at Scott Base, in the polar cusp/cap region for some years. This monitors the dayside cusp and nightside polar cap in conjunction with other stations of the US AGO program and is part of the US NSF PENGUIn program. Specific studies are focusing on the response of optical emissions in the F and E regions to variations in solar wind input in the polar cap, and to investigate joint optical and magnetic signatures of the cusp and cap regions. A new result is the observation of long, rotating polar cap auroral arcs.

The group also operates an imaging riometer at Davis in Antarctica, as a cooperative program with the University of Maryland and the Australian Antarctic Division. This is providing data on precipitation signatures and motions of impulsive events which are also recorded with nearby magnetometers. In particular, we are focusing on the evolution of transient magnetic impulse events (MIE), associated with flux transfer events or solar wind pressure pulses.

The group has a long history of ULF wave studies at low latitudes. The main emphasis of this work is on identifying the signature of FLRs. These are very difficult to study using spacecraft, due their rapid motion at these altitudes. An important aspect involves using the observed FLRs to monitor the magnetospheric plasma, discussed below. This resonance excitation energy is clearly present deep in the inner plasmasphere, and probably involves compressional mode MHD waves at least partially in the form of cavity oscillations. Common features of low latitude observations are both latitude independent and latitude dependent spectral peaks.

Wave spectral and polarisation properties recorded with an extensive Australian magnetometer array have revealed a rich spectrum that can be explained in terms of cavity mode resonances coupled to local FLRs. The FLR response in the frequency domain at low latitudes usually occupies a bandwidth around 20 mHz. The mean frequency varies in the expected manner with latitude. At very low latitudes, the influence of ionospheric O^+ means the FLR frequency begins to decrease with decreasing latitude. We have experimentally confirmed this effect with the maximum FLR frequency found around L = 1.6. We have also measured the scale size and damping of the resonances. Superposed on the FLR response is a fine structure with adjacent peaks in power ~ 4 mHz apart. These fine structure peaks are latitude dependent over the 2.0<L<1.4. A 1-D, linear MHD model of incoming fast mode wave energy, which resonates in the coupled plasmasphere-plasmatrough cavities and excites inner plasmasphere FLRs has been developed. This model can explain the major features of the observed fine structure seen in low latitude ULF data, providing experimental evidence for the excitation of low latitude FLRs by cavity mode resonances.

Using equatorial and very low latitude data from the 210° longitude magnetometer array operated by Nagoya University, we have examined for the first time the meridional and longitudinal phase structure of ULF field line oscillations near the equator. By developing models of hydromagnetic wave propagation through the ionosphere we have been able to demonstrate that the observed phase structure is consistent with ionospheric conductivity variations around the equatorial electrojet.

Magnetospheric Diagnostics Using ULF Waves

The plasmasphere (the inner portion of near-Earth space) is populated by relatively dense, co-rotating particles of atmospheric origin. Very recent measurements have shown that it is highly variable, even at magnetically quiet times, challenging present understanding of basic geophysical and space weather processes. Since the latter can severely disrupt radio and satellite operations, there is great interest in probing this region.

We have developed analytical techniques that allow ground-based magnetometers to be used to monitor the field line resonance eigenfrequency, based on the cross-phase and power difference and ratio between adjacent stations. This allows the determination of the temporal evolution of FLRs even when power in the spectrum is dominated by other wave modes. This has enabled the comparison of eigenfrequency calculations based on the IRI/DE and Bailey plasma models with low latitude magnetometer data, with the latter model proving more successful. The effects of heavy ions in the thermosphere and ionosphere on low latitude FLRs can now also be evaluated.

It is now possible to diagnostically monitor the magnetospheric plasma distribution from the ground using ULF waves. Several international groups are now establishing magnetometer arrays specifically for this purpose. This technique has been demonstrated in one particular study monitoring spatial and temporal variations in the vicinity of the plasmapause using magnetometer arrays in the UK and Scandinavia. Much of the present knowledge of the plasmasphere comes from the analysis of the propagation of naturally occurring and man-made whistler-mode VLF signals. Electron densities derived from whistler measurements can be compared with the ULF-derived mass calculations to obtain information on the plasma composition.

As part of a new collaborative project, VLF Doppler receivers and a 3-station array of solar-powered magnetometers has been established by the British Antarctic Survey near Rothera, Antarctica. This allows the VLF- and ULF-derived electron and mass densities to be compared for the same L=2.5 flux tube. This powerful new experiment is shedding new light on the formation and evolution of plasma density irregularities in the inner magnetosphere. These ground-based data may also be compared with in situ observations. The IMAGE satellite that was launched in 2000 includes an EUV experiment that is able to image the structure of the whole plasmasphere. The images provide two-dimensional line-of-sight information on He^+ concentration, and require significant interpretation to deconvolve the multi-layered information. Crucially, information on the ion composition of the inner-magnetosphere is necessary to accurately interpret the images during varying periods of geomagnetic activity levels. The IMAGE spacecraft also includes the RPI experiment that provides actual measurements of the electron density at that point. These are snapshot observations along the spacecraft's elliptical 14-hour orbit. Finally, the Polar spacecraft and 4-satellite constellation of Cluster spacecraft provide data on electron density along their orbit. This is obtained indirectly from a complex procedure involving deconvolution of effects responsible for spacecraft charging. This is an important but as yet unverified technique.

A focus of new work is to provide the first multi-technique and independent study of the inner magnetosphere using all of these techniques observing the same geomagnetic field-line. This is expected to provide important new information on plasma dynamics, such as refilling from the underlying ionosphere and convection processes, in the inner magnetosphere.

Hydromagnetic wave propagation in the ionosphere

One program at Newcastle is investigating both experimentally and theoretically the appearance of ULF oscillations monitored in the ionosphere using HF radio techniques. These are the ionospheric signature of down going hydromagnetic waves, and exhibit high correlations with ULF waves detected by ground based magnetometers.

Collaborations with University of Leicester (UK) DOPE array in Scandinavia and the over the horizon radar employed by the SuperDARN community and the Australian Defence Science Technology Organisation have arisen from these investigations.

In parallel with the experimental program, we have been developing the theoretical and computer modeling aspects of this work. Even though the wavelengths of the ULF waves are much larger than the vertical dimensions of the ionosphere, solving the equations that describe the interaction between the ionosphere and ULF waves is non-trivial. Past efforts have limited the description to either vertical or parallel background magnetic field. We have developed both analytic and numerical, 1-D models of these processes, allowing for the background magnetic to be at any dip angle. The complex wave reflection and mode conversion matrix has been obtained. This matrix contains 4 elements and describes how the combination of the ionosphere, atmosphere and ground influence the reflection, transmission and mode conversion of the two Alfven ULF waves modes. Results from the model indicate that the ionosphere affects the properties of ULF waves in a complicated way which depends on the spatial scale size of the ULF disturbance, the dip angle of the magnetic field (latitude), the ionosphere conductivities (Hall and Pedersen) and ULF wave frequency.

Using the results from the ULF wave model, the effect of ULF wave interaction with the ionosphere on HF propagation is being investigated. Initial comparisons between the model predictions and the Doppler shift data from the University of Leicester DOPE experiment show that the experimental Doppler frequency shifts are up to 10 times larger than those predicted by the model. Investigations of the cause for the discrepancy have begun. We are pursuing this work to be able to predict the effect on over-the-horizon radar data given the ground based magnetometer data.

Spacecraft Studies

It is now known that electromagnetic ion cyclotron waves in the 0.1-5 Hz frequency range are generated by wave-particle interactions involving ring current keV protons in the middle magnetosphere.

The USAF/NASA Combined Release and Radiation Effects satellite (CRRES) was launched on July 25, 1990 into an elliptical 6.3 Re x 350 km orbit of period ~10 hr and ceased operation in October 1991. It carried a full complement of wave and particle experiments including fluxgate and search coil magnetometers, plasma wave and electric field experiments, and low, medium and high energy particle detectors. Studies on ion cyclotron waves show that the plasmapause is not a preferential region for the wave generation as previously thought. Waves are equally likely to be generated in the plasmatrough or the outer plasmapause. From simple resonance energy modelling it is estimated that ring current protons of 5-70 Kev are involved.

At lower frequencies, field line resonance harmonic structure is seen in Pc3-5 (5-100 mHz) waves. Extrapolation of these L = 3.5 – 6 CRRES measurements to low latitudes show very good agreement with middle and low latitude simultaneous ground based Pc3 harmonic structure resonance measurements.

A major new development is the involvement of the Group as a core partner in the Cooperative Research Centre for Satellite Systems (CRCSS). This Centre brings together leading university groups, space industries, and the CSIRO (national government research agency) to work on projects that will stimulate space-related activities in Australia.

The first and main task of the CRCSS is the development and operation of a microsatellite, FedSat, to be launched into low-Earth orbit in late 2001. The orbit will be ~800 km altitude, 98° inclination and sun-synchronous in the 10:30 – 22:30 LT plane. The satellite will include a magnetometer payload, NewMag, to be developed and operated by the Space Physics Group at the University of Newcastle. This will form a major part of the science program managed and undertaken by the CRC.

The NewMag experiment will investigate improved modelling of the ionosphere and exosphere through satellite-based field observations. The magnetometer will measure ULF (~ 1 mHz – 10 mHz) and ELF (~10 – 50 Hz) waves in the ionosphere/exosphere, field aligned currents in the auroral zones, equatorial electrojet currents, the background geomagnetic field in the Australian region, and will provide parameters for space weather studies.

The NewMag payload comprises a fluxgate magnetometer that samples the three mutually perpendicular components of the geomagnetic field. In order to reduce background noise the triaxial sensor head is mounted on a 2.5 m long deployable boom. During NewMag operation, signals from the sensor will be filtered and decimated to achieve sample rates of 100 or 10 vectors/second for high resolution or synoptic study modes respectively. Frequency response of the magnetometer is around 250 Hz. The spacecraft data handling system (DHS) will provide command interface and data collection support and store the data for transmission to the ground. The magnetometer is based on a University of California, Los Angeles (UCLA) design, which has been built and successfully flown in space twice previously, on the POLAR and FAST missions.

One of the primary goals of NewMag will be to measure waves and currents at LEO while FedSat is flying over stations of ground magnetometer arrays. We plan to perform ground-satellite studies of ULF wave amplitude and phase characteristics, especially in the polar regions. This will complement the other projects presently underway.

Communications requirements have extended into Low Earth orbit spacecraft technology. Examples are the Iridium and Global Star ventures. While Iridium was on the verge of collapse in the year 2000, new business negotiations and US Defence contracts have kept the constellation in orbit. Iridium comprises over 70 LEO satellites located in 6 equally spaced longitude, polar orbit planes. The constellation was originally designed for 77 satellites, hence the name Iridium. However, a redesign reduced the requirements to 66 satellites, all at an altitude between 780 and 800 km.

The engineering magnetometer (attitude control system) data are provided to the Johns Hopkins University Applied Physics Laboratory (USA) under a special agreement negotiated by Dr Brian Anderson. Access to this data at Newcastle is through a collaboration with JHU/APL formed during 2000. While the Iridium magnetometers were designed for attitude control, it turns out they can detect the auroral (Birkeland) currents. Obtaining the perturbation magnetic field is a complicated process involving subtraction of the main field, correcting for orientation, cross-talk and so on. The perturbation signatures are then processed using a spherical harmonic fit to provide the vector magnetic field and field aligned current pattern over the north and south auroral zones. The over the horizon radars comprising SuperDARN provide data on the electric field in the F region of the ionosphere. Using similar spherical harmonic expansions, the electric field over the auroral zone is obtained. Combining these data sets gives, for the first time, direct estimates of the EM energy flux into the ionosphere.

Instrumentation

The group has established and operated arrays of induction and fluxgate magnetometers at up to 16 sites in Australia and New Zealand on a campaign basis. In addition, induction magnetometers are operated for the group at 6 sites in Antarctica (in cooperation with the Australian Antarctic Division) and 4 sites in the Scandinavian Arctic (in cooperation with the Swedish Institute of Space Physics, and the University of Tromso). The induction magnetometers, using magnetic feedback to optimise amplitude, spectral and phase characteristics, and the associated digital data loggers have been designed and constructed within the group. They are relatively inexpensive and have also been sold to research groups in India and South Africa. The Scandinavian systems operate in conjunction with the ALIS and related programs, but offer better resolution than other instruments.

The group has obtained 10 low power fluxgate magnetometers developed by Narod Geophysics, Canada. These contain palmtop data loggers and are powered by solar panel and battery. They are currently used for specific campaigns in central Australia and Antarctica and to provide routine magnetic field observations at Newcastle and Launceston.

All the research described is supported by grants from the University of Newcastle, the Cooperative Research Centre for Satellite Systems, the Australian Research Council, the Antarctic Science Advisory Committee and the Department of Industry, Science and Tourism.

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X-ray study of nearby star formation regions

Warrick Lawson and Eric Feigelson (Pennsylvania State University) have used the Chandra X-ray observatory to observe nearby star forming regions, including the Chamaeleon I molecular cloud and the surrounds of several Herbig AeBe stars. With ~ 50 times the flux sensitivity and ~ 10 times the spatial resolution of ROSAT satellite PSPC observations, Chandra can sample these regions to an extent comparable to ground-based studies. Subsequent optical/infrared studies will characterise the stellar and sub-stellar populations of these regions. Together with post-graduate students A-Ran Lyo and Eric Mamajek (formerly UNSW@ADFA, now at the University of Arizona) the group has continued to study the eta-Chamaeleontis star cluster, a spatially-compact 9 Myr-old pre-main sequence cluster at a distance of 97 pc discovered in a ROSAT HRI pointing at several ROSAT All-Sky Survey sources. Hipparcos satellite proper motions show the cluster has a kinematic link to the Lower Centaurus Crux subgroup of the Sco-Cen OB association, with clearing of the cluster's molecular material likely owing to Sco-Cen supernova remnants in the past few Myr. Ground-based photometric study of the cluster members shows an unexpected lack of correlation between the X-ray flux and rotational period, with the majority of stars having L_X/L_{bol} ratios near the 'saturation limit' of 10^{-3} despite a factor > 10 in rotation period. Ongoing optical/infrared searches for new cluster members have discovered a rare example of an 'old' classical T Tauri star with heightened chromospheric emission and strong IR excess emission. Near-IR studies show the majority of cluster members have retained a circumstellar disk in difference to studies of other star-forming regions that show disks dissipating on timescales of 5–10 Myr.

Star Formation, Radiative Transfer Modelling and Laboratory Astrophysics

In the field of Star Formation, a major work has been undertaken on the OH Zeeman measurements of magnetic field strengths in molecular clouds. This work constituted the PhD thesis topic of Tyler Bourke. On the infrared observational side, spectra from 2.2 to 2.5 μm of IRAS 09371+1212 (the Frosty Leo Nebula) have been obtained allowing the determination of the $^{12}CO/^{13}CO$ band strength ratio. These results support the proposal that the object is highly evolved.

Radiative transfer models are being used to explore the infrared spectra of Ultra-Compact HII regions, and to conduct a theoretical investigation of the conditions under which emission and absorption features may occur in the far infrared. The spectrum of crystalline water ice in the OH-IR source OH32.8-0.3 is also being investigated.

In Laboratory Astrophysics two topics are currently under study: i) Simulating the water ice formation process on dust grains in Young Stellar Objects by deposition of atomic oxygen and hydrogen onto a cold substrate, and ii) the study of crystalline silicates involving both their chemical composition and their athermal crystallisation. This work constitutes part of the PhD thesis work of Marco Maldoni.

Interstellar Dust Studies

Work continued on the study of dust in the discs and bipolar outflows of stars in both the early and late stages of their evolution, with the involvement of Ph D student Dale Quinn. This has been done through an observational programme comprising infrared spectroscopy and imaging combined with theoretical modeling of the absorption and scattering properties of dust in different environments. This work has culminated with the successful completion of Dale's Ph.D. thesis.

Ph.D. student Marco Maldoni has continued work on aspects of the formation and evolution of dust and ices in the circumstellar environments of AGB stars. This has initially been based on radiative transfer modeling of infrared spectra of AGB stars from ESA's Infrared Space Observatory (ISO) but will subsequently involve laboratory studies of the formation and evolution of analogues of the dust and ice in these objects.

Rob Smith has continued a laboratory programme studying the laboratory analogues of mixed and pure interstellar ices and dust grains, particularly ices predicted to be present in low concentration which are difficult to identify without high quality laboratory spectra.. In conjunction with this programme the theoretical aspects of the formation of ices on interstellar dust grains have also been studied.

A study of the distribution of ice coated grains in the globules that comprise the Coalsack dark cloud region has recently been completed. This region provides an ideal laboratory to study interstellar ices in their most primitive, unprocessed state.

High Energy Astrophysics

Paul O'Neill led a study of Scorpius X-2, which is one of the persistently bright neutron star low-mass X-ray binaries, and a Z sources. The X-ray fast-time variability of Z sources is a signature of the nature of the flow of matter very near the neutron star, the matter being gravitationally attracted from the companion star. It is related to the changes in the energy spectrum of the observed X-rays. Observations of such time variability, called quasi-periodic oscillations (QPOs), in the kilohertz range may provide a test of general relativity, and allow neutron star masses and radii to be measured. The low frequency variability is also important because certain features in it are related to the kilohertz QPOs. Archived data from the European Rossi X-ray Timing Explorer spacecraft was analysed to show that the energy dependence of the low frequency variability was different from that seen in other Z-sources. This highly successful programme built on an earlier analysis of archived data gathered by the Japanese Ginga spacecraft, relating to the same source Scorpius X-2.

A second area of activity related to ground based observations at millimetre wavelengths of selected X-ray binaries that show evidence of high-energy jets of material being ejected. Some binaries exhibit permanent jet structure while others show transient behaviour. Observations were carried out with the Mopra telescope at Siding Spring, NSW, and with the SEST telescope at La Silla in Chile. In addition to continuing investigations of the structure of the supernova remnants SS433 and G54.1+0.3, the millimetre observations were used to estimate the distances to a number of other sources by measuring the masses and distances of all intervening and associated molecular clouds. The presence of these clouds is revealed by the detection of carbon monoxide lines in the millimetre wavelength range.

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School of Physics

Ionospheric Physics

Research has been proceeding in the following areas:

- Simulation of the lunar geomagnetic tide using the equivalent circuit model
- Simulations of the equatorial electrojet
- Analysis of AWAGS data by spherical cap harmonic analysis to determine changes in the ionospheric current system over Australia
- Analysis of lunar variations in upper atmosphere winds
- Analysis of magnetic data from the Oersted and CHAMP satellites
- The variability of the Sq current system

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Plasma Waves & Radio Emissions in Space

1. Introduction

A large team performs research on Space Physics at the School of Physics, University of Sydney. Led by Dr Iver Cairns (an ARC Senior Research Fellow) and Professor Peter Robinson, as of July 2002 the team includes three postdoctoral scientists (Drs Bo Li, Zdenka Kuncic, and Andrew Willes), one doctoral student (Mr Stuart Knock), one Honours student (Mr Jeremy Mitchell), and a part-time computational officer (Dr Pritha Das). Professor Robinson is Director of the University of Sydney's Center for Wave Science, of which Dr Cairns is also a member. Several members of the team also work in theoretical plasma astrophysics; until recently, the School hosted the ARC's Special Research Center for Theoretical Astrophysics, led by Professor Donald Melrose, some of whose members are also interested in solar and space physics (Drs N.F. Cramer, M.S. Wheatland, and S. Vladimirov). This report summarizes the progress made during the period 2000 - 2002 by the space physics team, Professor Melrose, and Dr Wheatland, including the scientific papers published or accepted for publication.

2. Research Progress

Major progress was made in the applicability of stochastic growth theory (SGT) to plasma waves in many regions of space, type II and III solar radio bursts, plasma waves and radio emissions in planetary foreshocks, radiation from the outer heliosphere, and the nature and conditions for nonlinear Langmuir wave processes, linear mode conversion, and other wave-particle processes to occur in space. This research involved analytic plasma theory, analysis and interpretation of spacecraft data, and comparisons between theory and observation. A foreshock is the region upstream of and magnetically connected to a shock waves, thereby containing energised particles reflected and accelerated at the shock, as well as the plasma waves and radio emissions generated by these particle. Foreshocks are a common theme in our current research program since type II solar radio bursts and the 2-3 kHz radio emissions observed by the Voyager spacecraft in the outer heliosphere are most likely generated in foreshock regions upstream of travelling shock waves, and so are qualitatively similar to radio emissions generated in Earth's foreshock for which abundant spacecraft data exist.

2.1 Stochastic Growth Theory (SGT)

2.1.1 Foreshock Langmuir waves

- We showed [Cairns et al., 2000a] that thermal Langmuir waves in the solar wind and
  Langmuir waves at the upstream edge of Earth's foreshock are well described by thermal SGT and by the SGT prediction for driven thermal waves, respectively.

- We showed that SGT can explain the power-law field distributions obtained when foreshock data are averaged over observing location in the foreshock [Boshuizen et al., 2001].

2.1.2 Widespread applicability of SGT

- We developed a theory based on SGT for low frequency waves near the ion cyclotron frequency that should be driven by interstellar pickup ions beyond about 1 AU [Zank and Cairns, 2000, 2001]. The theory predicts that the waves should be bursty, irregular, and very hard to detect, not inconsistent with observational failures to date.
- We demonstrated that bursty waves near the plasma frequency over Earth's polar cap (so-called PF waves) have field statistics consistent with SGT [Cairns and Menietti, 2001]. We also developed a theoretical model for why SGT applies that appears consistent with the observations to date and inferred the presence of slow electron beams in this region.
- We demonstrated that electromagnetic ion cyclotron (EMIC) and mirror mode waves in Earth's magnetosheath have field statistics consistent with SGT [Cairns and Grubits, 2001]. This represents a major test of SGT, since the waves were known independently to be near marginal stability (as expected for SGT states), and a major generalisation in applicability since these waves are electromagnetic, are driven by an ion temperature anisotropy instability, and are in ``ion'' rather than ``electron'' modes.
- We showed that the well-known variability of the Vela pulsar, both from pulse to pulse at a given phase and also from phase to phase in a given pulse, corresponds to lognormal statistics, and so to consistency with pure SGT [Cairns et al., 2001; Cairns and Robinson, 2002]. The field statistics show no evidence for nonlinear processes, thereby ruling out nonlinear processes for the Vela pulsar. This extends SGT's applicability to pulsars, the archetypal astrophysical example of coherent emissions, and also to freely propagating electromagnetic radiation.
- This research shows that SGT is widely applicable in space plasmas and some astrophysical plasmas, applying in all 9 cases yet considered

[Cairns et al., 2000a; Robinson and Cairns, 2001].

2.2. Theories for Radio Emissions

2.2.1 Type III solar radio bursts

- We extended the metric type III theory to decimetric frequencies and to both downgoing and upgoing type III bursts, showing that fundamental-harmonic structure should be common only in the metric frequency range, as observed [Robinson and Benz, 2000]. The predicted dynamic spectra appear consistent with available data.
- We reviewed our earlier SGT theory of metric type III solar radio bursts [Cairns et al., 2000b; Robinson and Cairns, 2001]. This detailed theory for type III bursts predicts dynamic spectra with the observed timescales, frequency ranges, and spectral densities. It can also explain the fundamental-harmonic structure and the exponential decay of the radiation at a given frequency. No quantitative or even semi-quantitative competitor exists for the theory, which appears consistent with the available observational data and can, moreover, be used to constrain the properties of density irregularities and the electron beam as a function of heliocentric distance.

2.2.2 Type II solar radio bursts and radiation from Earth's foreshock

- We analysed and interpreted observations of an unusual continuum radiation associated with a metric type II burst [Leblanc et al., 2000], both believed to be radio emissions associated with a shock wave.
- An analytic model for the electrostatic potential jump across collisionless shocks was developed and applied to Earth's bow shock [Kuncic et al., 2002a]. The theory appears consistent with existing data.
- A detailed, semiquantitative analytic theory was developed for interplanetary type II solar radio bursts [Knock et al., 2001]. It involves the reflection and acceleration of electrons at shocks (incorporating the theory for the cross-shock potential [Kuncic et al., 2002]), the development of electron beams in the foreshock by time-of-flight effects, the generation of Langmuir waves with energy flows described by SGT, and the generation of fundamental and harmonic radiation by nonlinear processes. The theory appears consistent with available data for one well-observed interplanetary type II solar burst.
- We generalised the type II theory to Earth's foreshock radiation, showing that the theory appears consistent with available data, typically predicting fluxes within a factor of about 2 of those observed [Kuncic et al., 2002b].
- We reviewed the observations and theory of radiation for Earth's foreshock, the foreshocks of interplanetary type II bursts, type III solar radio sources, and the outer heliospheric radiation observed at 2-3 kHz

by the Voyager spacecraft [Cairns et al., 2000; Robinson and Cairns, 2000; Cairns and Kaiser, 2001]. Except for type III bursts, these applications all potentially involve the foreshock theory of Knock et al. [2001].

- More recently we extended the type II theory to predict the radiation flux as a function of the shock and solar wind parameters [Knock et al., 2002], as well as relating the theory to space weather events.

2.2.3 2-3 kHz radiation from the outer heliosphere

- We developed a new theory for why the 2-3 kHz radio emissions turn on when a shock driven by a GMIR passes beyond the heliopause [Cairns and Zank, 2001a,b]. The theory provides a detailed theoretical basis for Gurnett et al.'s [Science, 1993] model for the radiation. The theory is based on ``lower-hybrid drive'' producing a fast electron tail in the outer heliosheath that is then accelerated by the GMIR shock, the lower hybrid waves being driven by pickup ions. Scattering and propagation effects are argued to permit primarily fundamental radiation to move into the inner heliosphere, not inconsistent with the available data.
- Simulations of shock propagation through the inhomogeneous solar wind were combined with spacecraft data to predict a new 2-3 kHz radiation event in September 2001 [Zank et al., 2001]. However, examination of the Voyager wave data shows that any radiation produced then remained below background.

2.3 Plasma Theory

2.3.1 Simulations

- We developed a 1-D, electrostatic, quasilinear simulation code for the injection and propagation of multiple electron beams, as well as the generation of Langmuir waves. Simulations show that multiple beams can enhance or suppress the waves [Li et al., 2002].
- Extensions of the code to include electrostatic and electromagnetic nonlinear processes, and the effects of background density turbulence, are proceeding.

2.3.2 Nonlinear processes

- We elucidated the theoretical conditions for which electrostatic three-wave decay should dominate scattering off thermal ions and showed that these constraints are consistent with existing simulations and with observations in type III sources [Cairns, 2000]. This analysis also showed that the simulations are in the wrong domain to properly model type III and foreshock waves, predicting wave levels that are far too high and domination of scattering off thermal ions, whereas the observed type III and foreshock waves are typically in the domain predicted for ES decay.

- The roles played by electrostatic waves in producing radio emissions were reviewed, treating nonlinear processes, linear mode conversion, and mechanisms involving localized wave packets [Cairns and Robinson, 2000].
- We generalised the nonlinear dispersion equation for decay and modulational instabilities to include finite bandwidth effects [Robinson et al., 2002]. The results elucidate how finite bandwidth effects reduce the growth rate of the decay and modulational instabilities, typically requiring the electrostatic decay to proceed as a random-phase process and stabilising most modulational instabilities. However, a broadband modulational instability is confirmed to exist in a specified region of energy density -- wavenumber space.

2.3.3 Wave modes, waveforms, linear mode conversion, \& propagation in density turbulence

- We investigated the characteristics of Langmuir/z mode waves in the solar wind and other magnetised plasmas, relevant to interplanetary radio sources and to more strongly magnetised plasmas [Willes and Cairns, 2000].
- We investigated theoretically the waveforms of Langmuir waves propagating in density turbulence and subject to reflection, linear mode conversion, tunnelling and trapping in density irregularities [Willes and Cairns, 2001]. This involved directly calculating the waveforms using Maxwell's equations and fluid theory. The predictions are directly relevant to Wind spacecraft observations.
- A preliminary analysis of waves subject to propagation in and reflection by density irregularities [Willes et al., 2002] shows the theoretical predictions to be very similar to available waveform data. However, the theory shows that the signatures of linear mode conversion should be very difficult to detect observationally.

2.4 Other Progress

2.4.1 Statistics of solar flares

- Mike Wheatland worked on topics as diverse as methods for modeling solar coronal magnetic fields, interpretation of solar photospheric vector magnetic field measurements, analysis of the solar neutrino flux, and solar flare statistics [Litvinenko et al., 2001; Uchida et al., 2001; Wheatland, 2000a,b,c,d, 2001a,b; Wheatland et al., 2001].

- Recent work has focused on flare statistics, and a particular highlight is the construction of a new model for the observed power-law spectrum of flare energies (Wheatland, 2002; Craig and Wheatland 2002). Part of this work was done in collaboration with Assoc. Prof. Ian Craig from the University of Waikato.

2.4.2 Type III burst electrons and solar heating

- We addressed the origin of fast electrons in type III bursts and heating of the lower solar atmosphere by analysing the effects of neutral-proton charge-exchange collisions in reconnection regions [Cairns, 2001]. The physics involves the driving of lower hybrid waves by pickup ions, generation of an enhanced tail of fast electrons, and significant electron and proton heating. The idea seems most attractive as a heating mechanism for the chromosphere and transition region, and for electron acceleration there, but seems less attractive for type III electrons accelerated in the corona itself.

2.4.3 Shock models and location in Earth's foreshock

- Models for the 3-D shape and location of Earth's bow shock are important for determining a spacecraft's location in the foreshock and so the properties of electron beams, Langmuir waves, and radio emissions as a function of foreshock location and solar wind conditions. Accordingly we analyzed crossings of Earth's bow shock observed by the Wind, Geotail, IMP-8, and Interball spacecraft under conditions of low solar wind Alfven Mach number, finding relatively poor agreement with existing models and placing strong constraints on future models [Fairfield et al., 2001].
- We analyzed and interpreted 3-D global MHD simulations of the magnetopause's interaction with the solar wind, resulting in new 3-D models for the location of Earth's bow shock as functions of the solar wind parameters [Chapman and Cairns, 2002].

2.4.4 Density turbulence in the outer heliosphere

- Density turbulence in the outer heliosphere was investigated using standard Fourier analyses of data from the Voyager-2 spacecraft, resulting in a new model for the level and spectral index of density turbulence as a function of heliocentric distance and direct evidence for interstellar pickup ions driving enhanced turbulence in the outer heliosphere [Cairns et al., 2001].

2.4.5 Shock acceleration

- Shock-drift acceleration of electrons was reviewed and the analytic theory extended, resulting in predictions for the effectiveness of acceleration for incoming power-law and Maxwellian electrons [Ball and Melrose, 2001]. The theory also includes a constraint for when the accelerated electrons should be unstable to growth of Langmuir waves.
- Analytic theory and simulations were used to address the ``injection problem'' of how shocks accelerate ions from mildly superthermal energies to the high energies required for diffusive shock acceleration to operate [Zank et al., 2001].

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(1 July 2000 – 30 June 2002)

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