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FedSat satellite, launch and deployment, 14 December 2002

Report to the Committee for Space Research (COSPAR)

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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 from July 2002 to June 2004. The 35th COSPAR meeting will be held in Paris, France from 18-25 July 2004. The report is available on the World Wide Web at http://www.science.org.au/natcoms/cospar2004.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, Geospace Australia and IPS Radio and Space Systems. The research areas encompass earth observation (remote sensing), solar terrestrial physics, upper atmospheric physics, climate and weather modelling, space astronomy, space communications research. Industry is also making a contribution to space research in Australia through companies such as British Aerospace and DSpace. This report presents the aspects of Australian space activity which the contributors regard as relevant to COSPAR. Submissions were widely sought in an attempt to ensure that all organisations involved in space research had opportunity to contribute to the report.

By the far the most significant event in Australian space science in the last two years was the CRC for Satellite System's satellite program which resulted in the launch of FedSat, the first satellite built in Australia since the 1960s. To quote from the CRCSS contribution, FedSat "is carrying out a research mission in space science and communications, and is also testing new concepts in space computing, satellite navigation and orbit determination. It is the first microsatellite operating in the Ka-band and the first to demonstrate self-healing computers in orbit".

However, in spite of FedSat's success, the CRC for Satellite Systems will not be renewed when its current funding ends in 2005 so, as in the 1960's, Australia will again fail to take advantage of the development of a significant capability in space-based instrumentation.

Of course the other areas of Australian space science will continue and hopefully receive sufficient support to develop new initiatives.

I thank contributors, both individuals and organisations, that have responded to requests for input to the report and the National Relations Office in the Academy for collating the report.

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

3 July 2004

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 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/default.asp?casid=920). 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 installed in the Austral summer of 2002-3. Results reported here relate only to projects where the Australian Antarctic Division staff are lead authors.

Specific Results

The MF radar at Davis continues to gather high quality wind data from the height range 70-100 km. In combination with similar systems spaced around the Antarctic continent, but at similar latitudes, it has been possible to investigate longitudinal variations in the semidiurnal tide. It has been found that modes whose propagation is not synchronous with the apparent motion of the sun can dominate the tide during the summer months. This helps to explain the variation in observed tidal amplitudes at high latitudes. Further work is expected to identify which modes are present with greater accuracy.

The new 55 MHz atmospheric radar commenced 'spaced antenna' mode observation with 20 kW of transmitted power from mid February 2003, and is scheduled to be upgraded to 120 kW of transmitted power and a beam steering capability from December 2004. Observations of meteor trails and lower atmosphere winds are also being made. Polar Mesosphere Summer Echoes (PMSE) were detected above the high-latitude station Davis, Antarctica (78.0°E, 68.6°S geographic; 74.6°S magnetic) during the 2003-04 austral summer. PMSE were recorded from 19 November to 3 December 2003 and from 27 January to 16 February 2004. These most southerly observations of PMSE reveal similar morphology and characteristics to northern hemisphere results.

Comparison of 2-years of mesopause region temperatures between Davis (hydroxyl rotational temperatures) and Syowa (Sodium lidar, Shinshu University) found a strong correlation of long-period (~20 K; 10 to 30 day period) temperature variations over a site separation distance of ~1500 km. The similarity of the temperatures in absolute value and variation provided evidence for the equivalence of rotational hydroxyl temperatures and kinetic temperatures.

Large-scale, quasi-periodic (50 to 60 day) oscillations have been found to dominate in March-April and July-October in an analysis of 7 years of Davis hydroxyl rotational temperatures The activity generally decreases over winter when shorter-period, smaller magnitude oscillations are more characteristic. A sliding-window multivariate fit yields an ~8 K solar-cycle and -0.5 to -1.5 K per annum trend in the Davis mesopause region for the 70-day windows centred between day-of-year 160 and 220, when the large-scale oscillations are minimal.

Vertical geoelectric field measurements at Vostok, Antarctica have been compared with model calculations of the solar-wind-induced polar-cap-potential above the station. Significant correlations were found, demonstrating that Antarctic polar plateau geoelectric field measurements can be used to investigate polar convection. After allowing for the local influence of the polar cap potential, good correlation is found between the seasonal variation of the electric field measured at Vostok and the seasonal variation of the global electric circuit.

Mesospheric clouds continued to be studied using a Rayleigh lidar at Davis. Statistical properties of the clouds have been derived from observations during the 2001/02 and 2002/03 austral summers. The mean centroid altitude of the clouds over this period was 85.35 ±0.21 km, which is similar to measurements reported for South Pole, but about 2km higher than for sites on the Arctic Circle.

Lidar measurements at Davis have also been used to investigate the planetary wave propagation in the stratosphere and lower mesosphere during the 2002 Southern Hemisphere stratospheric warming. Temperature inversions were observed in the lower mesosphere during the winter and spring of 2002, and the relationship between these events and wave processes is being investigated.

A program of ozonesonde measurements was initiated at Davis during 2003 in collaboration with the Australian Bureau of Meteorology. These measurements are being used to investigate the role of gravity waves in the microphysics of Polar Stratospheric Clouds and chemical ozone depletion, and have also contributed to the QUOBI (Qualitative Understanding of Ozone loss by Bipolar Investigations) international program. Analysis of Southern Hemisphere stratospheric data and lidar and balloon measurements from Davis correctly predicted that the Antarctic Ozone 'Hole' during 2003 would be near record size due mainly to below average temperatures in the polar vortex.

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. Similarly, much of the research is conducted by Australian universities and the Antarctic Division operates the equipment on their behalf. Results reported here relate only to projects where the Australian Antarctic Division staff are lead authors.

Specific Results

The program of automation of data collection at all bases continued. Standard Riometer, Fluxgate Magnetometer and Magnetic Pulsations experiment logging produces daily data files that are 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 data collection system records digital all sky camera images from all stations. These automated 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 Photometer at Davis; 30 MHz Riometers at all stations; All Sky Imaging Systems at all stations. Casey magnetometer data is now collected remotely and processed by the Geomagnetism Section of Geoscience Australia.

The previously reported communications and other interference caused by the digital ionosonde (DPS-4) following its move to Davis were resolved by the incorporation of a limited number of notch filters. The DPS-4 now operates satisfactorily but can be switched off if necessary for emergency radio communications or when aircraft are operating in the area. Before relocation the DPS-4 and a CADI digital ionosondes were operated concurrently at the polar cap station Casey (110.5°E, 66.3°S geographic, 81°S magnetic), Antarctica. An interleaved schedule allowed a comparison of ionograms and F-region drift velocities under a range of ionospheric conditions. F-region convection velocities derived from Casey DPS-4 were also compared with convection velocities derived from the application of $\mathbf{E}\times\mathbf{B}/B^2$ at the geomagnetic latitude of Casey to the relatively new DICM and IZMEM/DMSP fully parameterized electric potential convection models. Also unique E-region spectral features revealed as intervals of Bragg scatter superimposed on typical background E-region reflection were observed in digisonde Doppler spectra during intense lacuna conditions.

The cosmic ray laboratory at Mawson was extended and the neutron monitor subsequently increased from 6 to 18 NM-64 counters. Further development of GLE analysis has continued with an improved study of the Bastille Day 2000 event. The major finding of this study has been the unexpected discovery that the cosmic ray arrival was less influenced by an interplanetary geomagnetic storm than conventional wisdom predicted. The most definitive assessment to date of the cosmic ray spectrum variation during the solar cycle, derived from annual latitude surveys, has been published. New results on Space Weather forecasting capabilities from Muon telescope observations were presented at the Japan International Cosmic Ray Conference and this work is continuing.

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

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**		*AAD*
Ionosonde	**X**	**X**	**X**	X		*IPS*
Digital Portable Sounder		***X***				*AAD, La Trobe U, IPS*
Satellite Scintillations		***X***		**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*
VHF Radar		**X**				*AAD, Adelaide U*
VHF Meteor Radar		**X**				*Adelaide U, AAD*
Fabry-Perot Spectrometer		**X**				*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**				*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*
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

Publications

This publication list comprises all papers from 2002 to early 2004 having an Australian Antarctic Division author or using Australian Antarctic Division data from the Space and Atmospheric Sciences program.

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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 – www.eoc.csiro.au) was established in late 1995, and aims to bring a level of collaborative underpinning development into the area of Earth Observation Research and Development in CSIRO. The EOC headed by Dr. Michael Raupach, is co-located with the CSIRO Office of Space Science and Applications (COSSA) headed by Dr. Alex Held. COSSA in turn, undertakes national and international representation, as well as supporting technology transfer and business development for close to 20 remote sensing teams across the organisation.

The EOC's science is delivered through application projects with participating Divisions, through CSIRO 'Flagship Programs' and through partnerships with external agencies, universities and private industry. The work of the EOC is organised around four threads or themes:

Enabling Technologies: This thread is the mechanism by which the EOC promotes and advances remote sensing science and the use of new earth-observing technologies.

1. *Service Delivery:* The EOC provides a number of services to support earth observation projects throughout CSIRO. These include the development, quality-control and distribution of core image-data resources such as the rapidly-expanding 30+ year archive of various types of satellite imagery (e.g. AVHRR – MODIS) across Australia and surrounding oceans, warehousing of other community-based remote sensing products; and radiometric calibration facilities.
2. *Applications Development:* This theme is the engine by which remote sensing and earth observation serve the various applications in Australia (sustainable natural resource management in land, water and air; managing production systems; management of emergencies; mapping and exploring georesources; and understanding the earth system). Most project activity in this thread takes place in Divisions, with support from a central unit.
3. *Collaboration, Partnerships and Support:* This thread includes the management and business development functions of the EOC and COSSA.

The Australian Ocean Colour Working Group (AOCWG) is a representative group of researchers from national marine research agencies and Universities. Formed under EOC auspices to promote and advance the development and application of ocean colour information in the Australian region, it has been established as a National Working Group in COSSA's EOC program. CSIRO and the AOCWG have been collecting 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. CSIRO and the AOCWG plan to further develop these archives with high quality products derived from the processing of recently launched ocean colour instruments including OCTS.

Calibration and Validation Activities

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 compariosn 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 quartz-rich, red-coloured 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, MODIS and GMS-5 have been analysed during the course of this work.

In 2002, the EOC acting on behalf of several Divisions, took part in NASA's EO-1 Science Validation activities, in particular for the 'Hyperion' hyperspectral sensor on-board this technology-demonstration satellite. A number of filed calibration campaigns with a range of field spectroradiometers were undertaken, in particular to Lake Frome, and an agricultural site called Colleambally. The project was coordinated by Dr. David Jupp at the EOC, and is preparing a full report on this activity to be published shortly through the EOC website [www.eoc.csiro.au].

Ageless Aerospace Vehicles

CSIRO is working with NASA (Langley Research Center) to develop and test concepts for the development of structural health management systems for future generations of spacecraft. The purpose of structural health management systems is to detect the onset of damage (or, ideally, the threat of damage), using networks of sensors embedded in the vehicle structure, to determine the nature, extent and severity of the damage, to develop a prognosis for the damage, and ultimately to make a decision on remedial action. Essential characteristics of structural health management systems are robustness (the system must continue to operate effectively in the presence of damage), reliability (must detect damage reliably, and make appropriate decisions) and scalability (increasing the size or density of the network should not affect operational reliability or response times). Our approach is to develop the system as a complex multi-agent system, in which intelligent "agents" distributed through the structure control a group of sensors and active elements, but have information and knowledge only about their local environment. One of the principal research objectives of the work is to learn how to design the agents and their interactions in order to produce intelligent emergent behaviours that satisfy the desired goals. This is clearly difficult but not impossible: there are numerous examples in nature of multi-agent systems that display a collective intelligence and sophistication far beyond the capabilities of any of the individuals (e.g. a nest of ants, or a swarm of bees). To augment our theoretical work on multi-agent intelligence we have recently completed the first phase of construction of a hardware test-bed/demonstrator, which contains 192 autonomous sensing agents on the outer skin of a structure that is subject to damage from high-velocity particles that could be micro-meteoroids or space debris. Algorithms that enable the system to form self-organized continuous boundaries around critically damaged regions of the skin, and that self-assemble clusters and networks of non-critically damaged points, have been demonstrated.

NASA Deep Space Network

CSIRO is responsible to NASA under a cooperating agencies agreement for the operation of the Canberra Deep Space Communications Complex located at Tidbinbilla. This complex, as one of the three in the global network, featured in supporting the successful Mars missions in late 2003 and early 2004. The Parkes radio telescope was added to the network for this period to support the tracking of the large number of spacecraft.

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 data. The approach 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 to make provision for easier re-processing in the event of improvements to algorithms.

The CAPS project has been funded by COSSA/EOC, and the CSIRO Divisions of Atmospheric Research and Marine Research. 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. In the near future, research programs and applications across CSIRO requiring data will be able to easily analyse, apply, and combine data from any Australian AVHRR station via a new distribution system called Web_CATS.

CSIRO is planning to participate in the geophysical validation of sea surface temperature as derived from future infrared satellite sensors. These sensors include the MODIS, AATSR and GLI instruments to be launched on NASA, European, and Japanese satellites respectively over the next 3 years. Radiometric instruments have been developed and deployed on vessels in three coordinated programs. One is a joint project with AIMS that uses a tourist ferry which makes daily trips to the Outer Barrier Reef, the second uses a passenger ferry between Fremantle and Rottnest Island, and the third, based in Hobart, is a joint program with the Antarctic CRC, and uses the 3 Hobart-based research vessels (Franklin, Southern Surveyor, and Aurora Australis). Both radiometric and bulk SST data will be collected on a regular basis for comparison with the satellite-derived products. The extensive data sets collected will also aid in air-sea interaction and climate-related studies. Data comparisons with the NASA MODIS instrument are now starting.

SeaWiFS and MODIS Data Reception

The CSIRO Division of Marine Research has maintained a reception capability of ocean colour data from the SeaWiFS instrument on the SEASTAR satellite, as well as MODIS data from Terra and Aqua satellites, via the Hobart, Tasmania X-Band receiving station. 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. A full re-analysis of the OCTS data set in the Australian region is now under way.

Near Real-Time Satellite Data Delivery

In 2002, members of the CSIRO Division of Land and Water, implemented a system called Sentinel Hotspots [www.sentinel.csiro.au] intend to showcase the utility of satellite image products deliver in a time-critical manner to emergency managers. The system was officially launched to the Australian public by Australia's science minister just days before the devastating January 2003 fires in South Eastern Australia. The system proved extremely popular, and is currently being expanded to provide additional information of other emergencies such as flooding, toxic algae and oil spills.

Topex/Poseidon and other Altimeter data

The CSIRO Division of Marine Research is a major user of satellite borne altimeter data from the 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. Future data from the planned JASON satellite will also be used when available. The Division contributes to the international program by operating an altimeter validation site in Bass Strait - one of the few such stations in the southern hemisphere. This work is being extended to other Southern Hemisphere sites.

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 Griersmith from the Australian Bureau of Meteorology now heads the operating board responsible for the management of the facility. Dr. Alex Held, Head of COSSA is a member of the TERSS board, as well as the Western Australian Satellite Technology and Applications Consortium (WASTAC) board.

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 involved significant input from CSIRO.

NASA 8GHz receiver

The agreement with NASA to provide tracking support at Parkes during the 2003/2004 "Asset Contention Period" concluded in February 2004. (NASA's Deep Space Network was heavily subscribed during this period with many simultaneous missions, most notably to Mars).

All three of the main deliverables in the contract; the upgrade to the 64m surface, construction of a new 8.4GHz receiver, and the tracking operations themselves, were delivered on time, on budget and within specifications, with complete satisfaction on both sides. The total value of the contract to CSIRO was approximately $AU3M, leaving the Observatory with a substantially enlarged aperture at frequencies above 8GHz (55m vs 45m) , and a state-of-the-art receiver at 8.4GHz (rendering an overall 4dB improvement in sensitivity at this frequency). The contract also drew much favourable press attention, particularly the coverage of the official opening of the tracking operations by the US Ambassador to Australia.

NASA DSN Array Study

ATNF and ICTC are undertaking a collaborative design review of the proposed next-generation Deep Space Network (DSN) in partnership with JPL. The project runs from 1 September 2003 to 30 September 2004. A payment of USD 300k has already been made to the CTIP NASA disbursement account and an MOU drawn up between CTIP, ATNF and ICTC to set out the scope of the study and terms of payments. The MOU is now at sign-off stage. The split of the project studies is about 50-50 between ATNF and ICTC. Strategically, this project may be as the first stage of potential Australian engagement in the multi-billion dollar next-generation DSN.

Whilst the study SOW has been scaled-back in the area of the Antenna design, there is a option for the ICTC to prepare a study on their "flat-pack" antenna concept as an alternative solution to the JPL-proposed 12-m hydro-formed dishes. If undertaken, this study should be completed by June 2004, in time for the mid-term review meeting.

ATNF are currently exploring with NASA a program to install Ka-band receivers (7mm) at the Compact Array. Equipped with these receivers, ATCA could act as a ‘hot backup’ for future Mars missions, further exploring radio telescope arrays as next-generation DSN concept. A decision on this is expected with the next few months.

It is now over seven years since the HALCA Space VLBI satellite was successfully launched from Kagoshima. During that time Australian radio telescopes have been at the forefront of the co-observing program, both in terms of the general science proposals and of the mission-led VSOP Survey Program. However, for most of the last year HALCA has spent much of the time in "safe-hold-like" mode, and little astronomy observing has taken place. The spacecraft remains in reasonable health and plans are in place to attempt its recovery. Importantly, several important publications from the VSOP Survey program have been completed and submitted to the journals. In the mean time ATNF antennas remain available for co-observing should a recovery be successful.

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 (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 of the ASTER bands in the 2.1 to 2.4

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 um 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 SiO2 abundance while the combination of VNIR and SWIR bands should provide information of ferrous- versus ferric-bearing mineralogy.

CSIRO Exploration and Mining has been a member of the Japan-US ASTER Science Team (AST) from its inception because of ASTER's potential benefits to the minerals community in Australia. This close relationship has culminated in an international agreement (MOU) between CSIRO and ERSDAC (Japanese government agency managing ASTER) where large volumes of ASTER data are now available to CSIRO and their collaborators for research and application, primarily in the field of geological mapping and resource evaluation. This agreement allows for the prioritisation and scheduling of ASTER data collection according to the needs of CSIRO-ERSDAC and their collaborators. This is important as ASTER has a very short duty cycle for each orbit (8 minutes) because of TERRA's limited power resources are shared with 4 other sensors.

ASTER is currently in the Initial Check-Out (ICO) period where instrument performance, data reduction methodologies and data quality are being examined and signed off prior to routine data collection and distribution to selected science principal investigators, which is expected to begin in September 2000.

The May 2000 AST in Tokyo showed that ASTER appears to be performing to within preflight specifications (great news!) though too few data have yet been assessed. At this Tokyo AST meeting, ASTER data from the Mount Fitton test site in the Northern Flinders Ranges of South Australia was delivered to CSIRO for analysis as part of the ICO.

A collaborative project, called "The Australian ASTER Validation and Geological Mapping Product Development Project", has been established under the umbrella of the CSIRO-ERSDAC MOU and involves a number of Australian, State and Federal Government Geological Mapping agencies. The objective of this project is take advantage of CSIRO's strategic ASTER relationship to secure access and deliver a new generation of geological information products for all the government mapping agencies for much of the Australian continent. This is a vital opportunity to assist/improve on regional mapping programs and resource evaluation for Australia. This first stage of the project (2 month project beginning 1st July 2000) will focus on the ICO ASTER data collected from the Mount Fitton test site. The specific objectives of this stage are to determine:

1. The degree of instrument effects;
2. The validity of the ASTER spectral signatures;
3. The types of "accurate" geological information products that can be generated; and
4. What operational methods are necessary to deliver these products.

Remote Sensing in Forest Research

Within CSIRO Forestry and Forest Products remote sensing is a major data source providing information on the extent and the growth of Australia's forest resource. 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.

Studies relate to forest condition and its temporal change using variables such as leaf area index (LAI), above ground productivity (biomass), diameter at breast height (DBH) and structural complexity, which is important as habitat for native fauna. Additionally, studies also relate to carbon gain and storage (as both above and below ground biomass). This research involves modelling using remotely sensed data (from satellites and other airborne instruments) as well as climatic, terrain and soil spatial information. Image processing, Geographic Information Systems (GIS) and statistical modelling are important tools utilised.

This research is being undertaken at a number of sites in Australia, such as Tasmania, NSW and Queensland as well as internationally, in the USA and Canada.

Specific research projects, coordinated by Dr Darius Culvenor, include:
- development of techniques which utilises airborne videographic remote sensing data to predict the suitability of forest vegetation for habitat for a number of arboreal mammals;
- the development of physiologically-based models which incorporate remotely sensed, climate and terrain data to predict above ground Net Primary Productivity (NPP) for forested sites in Australia, New Zealand, USA and Canada;
- use of hyperspectral high spatial resolution imagery to assess forest health attributes
- use of CD-ROM's and the Internet to store, present and analyse forestry remotely sensed data.

Remote Sensing of Grassland and Pasture Quality

The remote sensing group at the Division of Livestock Industries, led by Dr. David Henry in Perth has been developing a methodology for timely delivery of pasture growth rate and 'food-on-offer (FOO), using a combination of Landsat/SPOT and AVHRR/MODIS data. The frequently updated information on PGR and FOO is delivered to various pastoralists and graziers in Western Australia, and soon in Victoria, through the internet portal "Pastures from Space'.

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 is led by Dr Arnold Dekker. It's main areas of expertise are:
- Hyperspectral remote sensing, with emphasis on vegetation mapping, land use assessment, water quality and coastal zone mapping;
- Near Real-time delivery of MODIS products such as bushfire hotspots [via www.sentinel.csiro.au].
- 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, including crop production forecasting.

Remote Sensing to Monitor Salinity and Vegetation Change

The CSIRO Mathematical and Information Sciences Remote Sensing group has developed 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 terrain 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, calibration and mosaicing of images and the integration of time 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.

International Representation

CEOS Working Groups and Plenary

Dr Alex Held, Head of COSSA is expected to be the Australian CEOS (Committee on Earth Observation Satellites) Plenary representative in November 2004. Australia hosted the November 1996 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.

GEO and Earth Observation Summits

Drs Held and Raupach have attended the Earth Observation Summit I (July 2003) and GEO-3 (February 2004) in Washington and Cape Town, respectively. Together with the Australian Bureau of Meteorology, COSSA–EOC will continue to represent Australian government's interests in this international coordination activity.

SPACE-RELATED ENGINEERING

On-board Satellite Antennas

CSIRO Telecommunications & Industrial Physics has produced a comprehensive computer software package for the design of antennas on satellites. The package was developed jointly for CSIRO research and for an overseas client. It uses the most accurate methods available for analysing reflectors, feed antennas and directly radiating arrays. Gridded or non-metallic surfaces can be included as well as combinations of reflectors allowing prediction for the first time the radiation patterns of complex antenna farms.

A new horn antenna has been developed for global coverage from a geostationary satellite. It has a multi-mode corrugated structure and is designed expressly with low-minimize weight. A 'brass-board' engineering model was fabricated and tested and excellent results were achieved. Production of a lightweight version is planned in the near future.

A CRC (Cooperative Research Centre) in Satellite Systems has been established to develop a Ka-band transponder and associated equipment for application to on-board satellite applications. A separate report has been provided by the CRC.

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 (CRCSS)

Significant events

For our Centre, and indeed for Australian space science and technology in general, the highlight for the period was the successful launch of the research microsatellite, *FedSat*, from Tanegashima Space Center on 14 December 2002. *FedSat* is the first satellite built in Australia since WRESAT and Oscar V in the late 1960s. It is carrying out a research mission in space science and communications, and is also testing new concepts in space computing, satellite navigation and orbit determination. *FedSat*, at around 58 kg, is one of the most complex spacecraft of its size, and the project received a 2003 National Engineering Excellence Award from the professional organisation Engineers Australia. The spacecraft is the first microsatellite operating in the Ka-band and the first to demonstrate self-healing computers in orbit.

Australian space activity has been characterised by brief periods of government support separated by lengthy periods of inactivity. This pattern is quite unusual in that the almost universal experience in other space-capable countries is one of long-term and extensive government support. The early success of WRESAT in 1967 was not followed by any coherent national space plan until the National Space Program of 1986-1996. Civilian space projects after that time were effectively spearheaded by the Cooperative Research Centre for Satellite Systems and University-based researchers, funded by generic industry or research fund programs. In 2003 the selection criteria for the Cooperative Research Centres Program – the only Australian space funding source of significant size and duration – was changed to emphasise commercial outcomes. The number of applications to the competitive, broad-based program far exceeded the funds available and in April 2004 the assessment panel advising the government rejected the Centre's funding application for the period 2005-2012. The Centre is currently expected to terminate on 31 December 2005, although we are exploring such other funding options and alternative approaches as may exist. However on present indications it would appear that Australia is likely to become the only country in the world to have twice achieved but then surrendered a space-faring capability.

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 Chair of the Governing Board is the Honourable Tony Staley, former Commonwealth Minister for Communications. The Centre's Chief Executive Officer (since March 2003) is Dr Andrew Parfitt, who replaced the inaugural CEO, Dr Brian J J Embleton.

The participants provide the bulk of the Centre's resources, contributing some $AUD 38 million over the Centre's 9-year lifetime, while the Commonwealth government will contribute $AUD 23.3 million; the Governments of Queensland, South Australia, and the Australian Capital Territory contributed a further $AUD2.1 million. The Commonwealth support comprises the Cooperative Research Centre Program ($21.3 m) and AusIndustry's Innovation Access program ($2 m). The Innovation Access Program grant concluded in March 2003. In December 2003 the Government announced new support under the Cooperative Research Centres Program, to provide the means of carrying out new research projects utilising the *FedSat* platform; to operate *FedSat* until its planned end-of life, December 2005, and to study space missions and technologies. Unfortunately in May 2004 the Government rejected our proposal for funding for the period 2005-2012, and currently the Centre is expected to terminate its activities on 31 December 2005.

Table 1 Participants in Cooperative Research Centre for Satellite Systems

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

In addition to the participants above, the Cooperative Research Centre for Satellite Systems collaborates widely with the international space community and with kindred Australian research and development organisations. In particular, we collaborate with the National Space Development Agency of Japan (NASDA) – renamed Japan Aerospace Exploration Agency, JAXA, in 2003 – as well as with the National Aeronautics and Space Administration (NASA) of the USA, the Korea Advanced Institute of Science and Technology and the Korea Aerospace Research Institute, the Canadian Space Agency, and the Asia-Pacific Regional Space Agency Forum.

Research

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

In 2003 we commenced three new projects:

- Improving estimates of energy input to the ionosphere
- Killer electron effects at Low Earth Orbit
- Dynamics and structure of high latitude currents.

These are based largely on fluxgate magnetometer and GPS data collected from *FedSat.* Significant partners in this work include the Australian Antarctic Division; the Ionospheric Prediction Service; JAXA; the Ørsted mission; and the University of California, Los Angeles.

In October 2003 *FedSat* detected extremely fast-moving electrons, particularly over the north magnetic pole. These are believed to have been connected with intense solar storms that affected several other satellites.

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.

Apart from the successful launch of *FedSat* in December 2002, and the subsequent verification of the performance of both the Ka-band and the UHF/VHF messaging payloads, major achievements in 2002-2004 include:

- Successful testing of the Centre's fast-tracking Ka-band antenna, located at the University of Technology, Sydney
- Successful operations of the *FedSat* primary ground station, located at the University of South Australia, Adelaide
- The delivery of a second data acquisition and messaging system to South Korea, where it was incorporated unto KAISTSat-4 (also known as Uribyol 4

and STSAT-1), launched successfully from Plesetsk Space Center in September 2003.

In 2003 we commenced four new projects:

- Advanced data acquisition from remote platforms
- Protocol enhancements for satellite communication links
- Ka-band system design evaluation
- Ka-band transponder performance monitoring.

The first of these is aimed at developing Mobile Terminals for use with the Centre's Advanced Data Acquisition and Messaging payload (ADAM) carried both on *FedSat* and on Korea's KAISTSAT-4. The second project is to study TCP/IP and other advanced network protocols designed specifically for satellites, utilising the Ka-band bent-pipe mode on *FedSat* as well as commercial transponders in GEO. The third project will study the performance of the pioneering *FedSat* Ka-band system, in its beacon tracking and in its bent-pipe repeater modes. The downlink attenuation and spacecraft antenna pointing losses will be calculated from observations of the downlink power and from attitude data derived from the on-board star camera. The fourth project is intended to characterise the in-orbit performance of *FedSat's* Monolithic Microwave Integrated Circuits (MMICs).

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.

In 2003 we commenced six new projects:

- Using GPS data for atmospheric radio occultation
- Enhanced spacecraft attitude control using modelling
- Processing strategies for precise orbit determination
- Evaluation of *FedSat* attitude control
- Performance evaluation of the *FedSat* high-performance computer
- High performance computing applications.

Major achievements of the period include a world first demonstration of "self-healing" computers in orbit. The High Performance computing experiment on *FedSat* employed Field Programmable Gate Arrays to demonstrate robust performance of on-board space computers that have been affected by Single-Event Upsets and other forms of damage due to radiation. In 2003 *FedSat* became the first satellite to demonstrate that a spacecraft computer could be repaired through software commands that re-routed the computer logic circuits.

Satellite engineering

Mr Mirek Vesely of 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.

Principal achievements for the period include:

- Completion of FedSat structure
- Integration of the payloads
- Vibration and vacuum testing
- Preparation for launch including meeting the specified launch environment conditions for the H-IIA vehicle
- Pre-launch testing on site at Tanegashima Space Center
- Successful initial acquisition of FedSat, approximately 6 orbits or ten hours after launch; and
- Early operations of FedSat until handover for routine /semi-routine operations.

FedSat mission summary

FedSat is a cuboid, about 60 cm on edge, with a deployable magnetometer boom of 2.4 m length. The launch mass was 58 kg and the expected operational lifetime is three years, at orbital altitude of 800 km and period of about 100 minutes. The primary purposes of FedSat are: to develop and demonstrate Australian space capability, and 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.

FedSat is three-axis stabilised, with its base (bearing the fixture for attachment to the launch vehicle) facing Earthward. The Attitude Control System uses three reaction wheels, three magnetorquers and three digital sun sensors. Precise pointing knowledge is accentuated through using a star camera, and the timing signal from the GPS receiver.

The satellite was assembled at our project office at Auspace Limited, Mitchell ACT, with vibration testing being performed in VIPAC Engineers and Scientists Limited premises in Port Melbourne. The satellite and approximately 1.5 tonnes of test equipment, tools, spares and documentation were road-freighted by air-ride truck to Sydney in October 2002, then flown to Narita Airport Japan via Subic Bay in the Philippines. The spacecraft and ground support equipment were then transported by truck and ship (ferry) some 1100 km to Tanegashima Space Center. The launch was arranged through a Memorandum of Understanding between the National Space Development Agency of Japan (NASDA) and the Commonwealth Scientific and Industrial research Organisation (CSIRO) of Australia, on behalf of its fellow-participants in the CRCSS.

Under the agreement, CRCSS exchanged scientific data from the triaxial fluxgate magnetometer and the GPS payload, for NASDA’s launch support, which included making available part of the Satellite Test and Assembly (STA)-1 building at Tanegashima for launch preparation and final testing.

Lift off on the H-IIA Flight No. 4 commenced exactly on time at 10:32 JST, 14 December 2002 and separation was successfully concluded some 15 minutes later. Of FedSat’s companions on the flight, the Advanced Earth Observing Satellite (ADEOS) –II was deployed before FedSat, and the microsatellites MicroLabSat and the Whale Ecology Satellite (WEOS) were deployed after. All four satellites were placed in the required orbits and their launch was a strong indication of the utility, flexibility and power of the H-IIA heavy lift vehicle.

Payload overview

FedSat carries five scientific payloads and a CD containing messages from the Australian public. The commemorative CD also carries a copy of a song by Australian songwriters and performers Paul Kelly and Kev Carmody, “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 5 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.

The instrument was built by UCLA and the CRCSS. The research team is also collecting and comparing data from the MDS-1, CHAMP, SAC-C, Iridium and Ørsted missions of Japan, Germany, Argentina, USA and Denmark, respectively. Comparative data are also acquired from the SuperDARN international over-the-horizon HF radar network.

Star camera

The digital star camera is an improved version of that flown on the Sunsat mission from the Republic of South Africa. It was supplied by Stellenbosch University and data are employed to yield precise attitude knowledge.

GPS dual-frequency receiver

FedSat carries a Turbo Rogue GPS receiver, used for satellite tracking, orbital prediction, and for ionospheric sounding purposes. The space science experiments 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, total electron content (TEC), refractivity, and related parameters can be deduced.

The receiver was developed by the Jet Propulsion Laboratory and was supplied to the CRCSS by the US National Aeronautics and Space Administration (NASA), under a collaborative agreement with CSIRO, acting on behalf of the Centre.

Communications Payload

The satellite’s communications payload comprises two modules:

- A VHF-based Advanced Data Acquisition and Messaging system (ADAM)
- A Ka-band transponder comprising antenna structures and GaAs-based Monolithic Microwave Integrated Circuits (MMIC).

Telemetry is in S-band.

Copies of FedSat’s ADAM payload have been developed by the Centre for flight on Korea’s STSAT-1 (formerly known as Kitsat-4, KAISTSAT-4 or Uribyol 4), launched in September 2003, and for Singapore’s X-Sat mission.

High Performance Computing

FedSat carries a High Performance Computing Experiment, based on Field Programmable Gate Arrays (FPGAs) and designed to demonstrate applications of space computers that are robust in the face of environmental stresses including single event upsets. The successful testing of this device is believed to be a world first. This work is carried out in collaboration with the Applied Physics Laboratory of Johns Hopkins University, USA.

Education program

The Centre conducts an extensive and highly successful education and training program. About twenty PhD and Master's theses have been completed and degrees awarded in the last two years, with the cumulative total likely to reach 60 in the Centre's lifetime from 1998 to 2005.

Appendices

Appendix 1: Acronyms

ADAM	Advanced Data Acquisition and Messaging system
ATM	Asynchronous Transfer Mode
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CRCSS	Cooperative Research Centre for Satellite Systems
ELF	Extra Low Frequency
GPS	Global Positioning System
ITR	Institute for Telecommunications Research
JAXA	Japan Aerospace Exploration Agency
KAIST	Korea Advanced Institute of Science and Technology
LEO	Low Earth Orbit
MMIC	Monolithic Microwave Integrated Circuits
NASDA	National Space Development Agency of Japan
NASA	National Aeronautics and Space Administration, USA
QUT	Queensland University of Technology
ULF	Ultra Low Frequency
UHF	Ultra High Frequency
VHF	Very High Frequency

Appendix 2:Publications 2002-2004

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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), scientific studies in geodynamics, gravity field, sea level change and climate change.

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.

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. Finally, 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.

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[1] Formerly the Australian Geological Survey Organisation (AGSO) and the Australian Land Information Group (AUSLIG)

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.

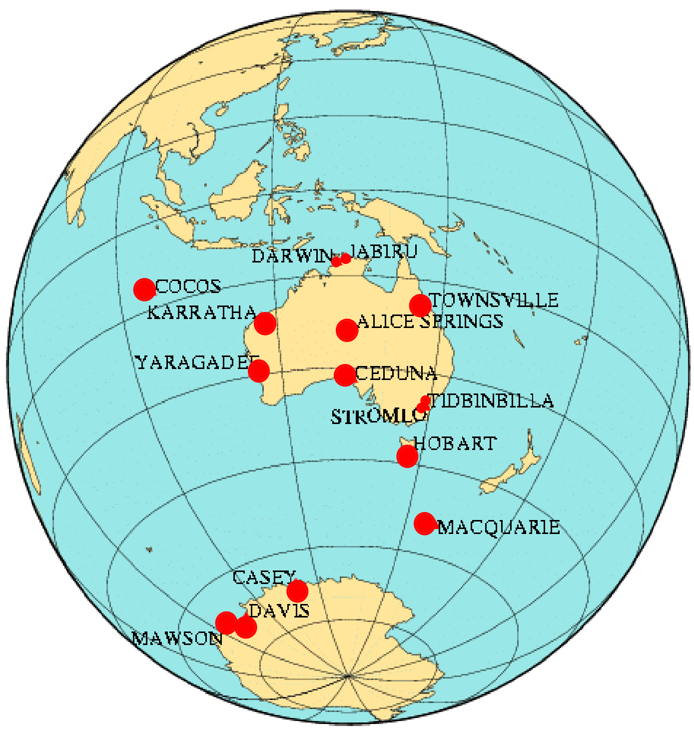
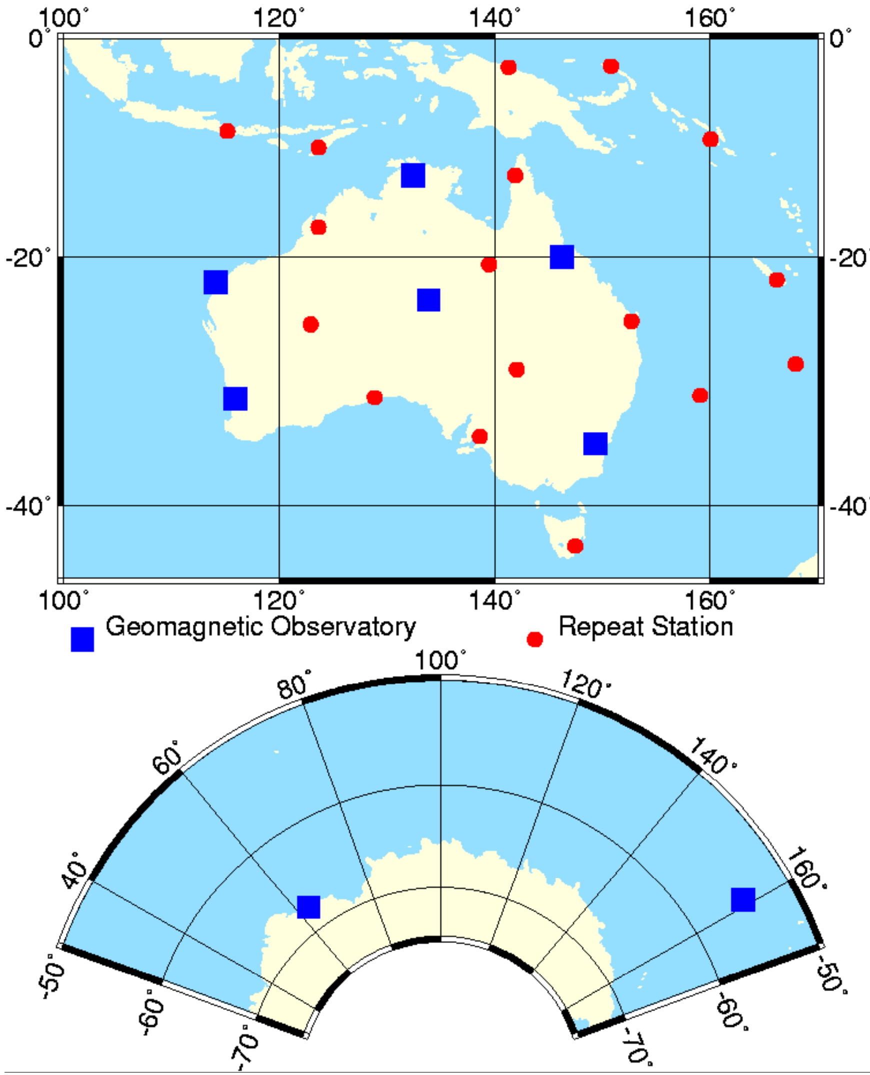


Figure 2. Locations of Australian magnetic observatories (squares), and repeat stations (dots). Annual observations are made at the repeat stations to obtain supplementary information about the geomagnetic secular variation.



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IPS RADIO AND SPACE SERVICES

Department Of Industry, Tourism and Resources

Ionospheric monitoring

IPS operates and analyses the data from a ground-based network of ionospheric monitoring sites. All sites operate ionosondes that provide data available in near-real-time (hourly intervals) and archive data at five-minute intervals. 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 high-latitude 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 the Australian Antarctic Division, to support space weather services confirming the presence of polar cap absorption events.

All ionograms recorded are analysed automatically and the data are used to generate real time ionospheric regional maps that are available on the IPS Web site (http://www.ips.gov.au). The data are used as the basis of a variety of real time services also delivered via the web site.

Geomagnetic pulsations

The IPS magnetometer network (Darwin, Townsville, Narrabri, Canberra, Hobart) has been 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 produced from the data, with the indices being used as alerts for adverse space weather conditions. Alerts include early warnings of very large geomagnetic field rates of change.

Solar observations at Culgoora, NSW

The radio spectrograph at the IPS Culgoora Solar Observatory, near Narrabri, records solar emission from 18 MHz to 1.8 GHz. The data are available from the IPS Web site (www.ips.gov.au). Data from the spectrograph, together with observations from WIND, have been used to track coronal mass ejections from the corona out into the solar wind. Data were used to assess the geo-effectiveness of major disturbances to the space environment in October-November 2003.

The Learmonth Solar Observatory, WA

The Learmonth Solar Observatory (22S, 114E) on North West Cape, Western Australia, is jointly managed by IPS and the US Air Force Weather Agency. Continuous automated H-alpha patrol is accomplished with on-site human analysis and digital archive. A prototype PC image processing system has been developed that assists analysis and archival. The H-alpha data are 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 are 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. In 2003 a small aperture telescope with megapixel CCD camera commenced observations of Near Earth Objects. This installation was made with the assistance of the Space Watch Program of the University of Arizona.

World Data Centre for Solar-Terrestrial Science

The IPS World Data Centre (WDC) continues to provide long sets of ionogram and solar radio spectrograph and magnetic variometer data. A mirror site is available to WDC-A for Solar Terrestrial Physics, Boulder. Data are available for on-screen viewing (www.ips.gov.au).

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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. Digital ionosondes installed by the Australian Antarctic
Division at Casey and Davis, Antarctica is used to conduct a joint research programs. 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. Currently at Davis simultaneous ionosonde and Fabry-Perot Spectrometer observations are being made to study the effect on the ionosphere of large neutral upwellings in the thermosphere.

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. A second radar, Unwin is being installed near Invercargill, NZ to complete the TIGER SuperDARN pair of radars.

Airglow Studies
A Fabry-Perot Spectrometer is operated at Beveridge to measure thermospheric winds and temperatures. A new FPS has been installed at Davis These instruments measure both thermospheric and mesospheric winds and temperatures. The new Davis instrument has greater sensitivity and time resolution for measuring changes in thermospheric 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.

A tomographic technique for determining ionospheric structure has been applied to a chain of GPS ground stations across Australia. The technique has been validated by comparison with ionosonde and CHAMP satellite observations. It has been used to study latitudinal changes in the ionosphere particularly during magnetic storms.

Studies using FedSat

Since the successful launch of FedSat in December 2002, La Trobe University, as a partner in the Cooperative Research Centre for
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UNIVERSITY OF ADELAIDE – DEPARTMENT OF PHYSICS

The Atmospheric Physics group (http://www.physics.adelaide.edu.au/atmospheric/) conducts research into atmospheric processes and dynamics and the physics of the lower ionosphere. It develops and operates an extensive network of medium frequency (MF) radars to measure winds in the mesosphere and lower thermosphere (MLT), as well as meteor radars and optical instruments to measure airglow emissions.

MF Radar studies of Atmospheric Dynamics and the Lower Ionosphere

The group operates MF (~2 MHz) radars at Christmas Island (2N) in the central Pacific, Pontianak (0N) in Indonesia, Katherine (14S) and Adelaide (35S) in the northern and southern Australia and at Davis Base (69S) in the Antarctic. This network gives a unique view of the dynamics of the southern hemisphere MLT (~60-100 km) from the equator to the pole. It is used to study the spatial and temporal variability of large-scale planetary waves and tides as well as small-scale atmospheric gravity waves. The Pontianak radar, operated in conjunction with the groups at Kyoto University and the Indonesian Aeronautics and Space Agency (LAPAN), consists of 800x800 m cross armed dipole antennas. This allows narrow beams to be generated and can be used as a Doppler radar for gravity wave momentum flux studies.

Observations of the Antarctic MLT have concentrated on investigations of the non-migrating semidiurnal tide and gravity wave coupling from the lower atmosphere. These studies have been conducted as part of collaborations with groups using MF radars at Syowa and Rothera. There has been a special emphasis on understanding the response of the MLT to the unprecedented major stratospheric warming of 2002.

Electron densities in the lower ionosphere were studied using the large (1-km diameter) MF radar at University's Buckland Park field site near Adelaide. The differential absorption/differential phase (DAE/DPE) techniques were used with very high quality data. Variations in electron concentrations between 65 and 75 km were investigated on both a diurnal and seasonal time scales during both low and high solar activity conditions. Night time electron densities in the 80-100 km height range were also measured and the possible ionizing sources investigated. The results obtained over a solar cycle indicate that scattered Lyman-alpha is the predominate source. A notable finding was that collision frequencies derived from the DAE/DPE measurements were larger than predicted by previously used models that relate collision frequency to pressure. The experimental estimates were compared with values calculated using new collision frequency momentum cross-sections for N2 measured in the laboratory. There was good agreement and a new collision-frequency pressure relation was derived.

Airglow Studies

A suite of optical instruments operated at Buckland Park is used to investigate airglow emissions and the modulation of intensity by atmospheric gravity waves. The instruments involved include 3-field photometers that monitor the 558 and O2 atmospheric emissions, a imager provided by Aerospace Corporation monitoring the OH and O2 atmospheric emissions and temperatures and a spectrometer provided by Embry Riddle University the measures temperatures at wavelengths in the OH and O2 atmospheric bands. Another imager operated in conjunction with Aerospace Corporation is located at Alice Springs.

Meteor Radar Studies of the Atmosphere

Meteor radar measurements of winds and waves in the 80-105 km height region continued at Buckland Park. The observations, made at a frequency of 31 MHz, were also used to investigate temperatures derived from the rate of diffusion of the meteor trails. There was very good agreement between the meteor and optical determinations of temperature.

A meteor system was also installed at Davis Base in the Antarctic during 2003 as part of a large 55-MHz coherent scatter radar used to study PMSE and other irregularities in the lower ionosphere. The meteor radar is being used to study the dynamics and temperature structure of the lower thermosphere.

As part of an international campaign, a 54-MHz VHF radar was located on the Tiwi Islands (10S) north of Darwin in March 2004. This system was configured so that it could be used as both a meteor radar and boundary layer wind profiler, so that gravity wave coupling between the lower and upper atmospheres could be investigated.

Radar Studies of Meteoroids

Radar investigations are also being used to investigate the speed that meteoroids enter the atmosphere from space. A Fresnel Transform technique has been developed to analyse radar meteor echoes detected in the transverse mode. The technique has been remarkably successful in not only giving insight into the fragmentation of meteoroids, but also revealing other significant features of the trails including diffusion, lateral motion of the trail during formation due to wind drift, and phase of the scattered signal in the vicinity of the head of the trail. An important outcome from these studies is the measurement of the speed and deceleration of meteoroids with unprecedented accuracy.

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University of Newcastle- Space Physics Group- Department of Physics

Research within the Space Physics Group is primarily concerned with plasma waves and current systems 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 spatial and temporal variability of the high latitude current systems and convection are studied using satellite and ground observations.

The Group is a core partner in the Cooperative Research Centre for Satellite Systems (CRCSS), which built the first Australian satellite to be launched in 30 years, FedSat. This low-Earth orbit microsatellite was launched in December 2002, carrying the NewMag magnetometer experiment to measure the Earth's main field, current systems and ULF waves.

High Latitude Studies of Magnetospheric ULF Waves and Absorption

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 (0.1-5 Hz), 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 close-spaced square array of solar-powered magnetometers near and inland from Davis, Antarctica. These have allowed direction of arrival determinations of daytime Pc3-5 waves, and field line tracing using Pc5 waves. 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, excited by compressional mode hm waves generated in the upstream solar wind by 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 and Davis-Mawson data. The precise time of the near-noon Pc5 polarisation reversal has been shown to be a proxy for the polarity of IMF By, while the latitude of the open-closed boundary varies with IMF Bz.

The Alfven wave toroidal mode field line resonance observed at conjugate points on the ground characteristically shows the H component in phase and the D component out of phase, between hemispheres. Commencing with a given field line from an observatory in one hemisphere it is possible to trace this field line and determine its footprint location in the opposite hemisphere. If a resonance is seen on this field line its phase projected into the opposite hemisphere will locate the conjugate point within a network of magnetometers in that hemisphere. This has shown field line distortion and may be used to refine magnetospheric field models.

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. It has been shown that some wave characteristics are geomagnetically controlled while others are geographically controlled.

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, and mapped these with respect to associated ionospheric current systems.

The location of a similar imaging riometer at Zhong Shan, 120km west, has provided an opportunity to apply parallax methods to measure for the first time the true height of absorption. Absorption mainly occurs between 85-95km, with a peak at ~92km. F2 region absorption is seen at 200km altitude.

Magnetospheric Diagnostics Using ULF Waves

The inner magnetosphere supports two types of particle distributions. One of these is a relatively dense population of low energy (few eV), co-rotating particles of atmospheric origin that defines the plasmasphere. Recent observations from the EUV imager experiment on the IMAGE spacecraft have shown that this particle population exhibits high spatial and temporal variability, even at magnetically quiet times. This challenges present understanding of basic geophysical and space weather processes.

The other important population is of energetic radiation belt particles. The radiation belts extend from low altitude roughly through to geostationary altitude and comprise particles with sufficient energy to damage spacecraft. The mechanisms for accelerating these particles to their high energies, or for their loss via precipitation into the atmosphere, are not yet clear, although ULF waves are likely to be involved in both situations.

One important technique for probing these regions is that developed at Newcastle with ground-based magnetometers. This uses the cross-phase and power difference and ratio between adjacent stations and to measure the field line eigenfrequency, from which the equatorial mass density is calculated. This in turn can be compared with model calculations and in situ observations. Importantly, the effects of heavy ions in the thermosphere and ionosphere on low latitude FLRs can also be evaluated.

In support of such studies we are undertaking a collaborative project with the British Antarctic Survey, who established VLF Doppler receivers and a 3station array of solar-powered magnetometers near Rothera, Antarctica. These instruments allows the VLFand ULF-derived electron and mass densities to be compared for the same L=2.5 flux tube. This experiment is shedding new light on the formation and evolution of plasma density irregularities in the inner magnetosphere. These ground-based data are also being compared with observations from the IMAGE EUV (imager) and RPI (electron density) experiments. The EUV images provide two-dimensional line-of-sight data on He^+ concentration that require information on the ion composition of the inner-magnetosphere for detailed interpretation. The RPI experiment furnishes snapshot observations of electron density along the spacecraft's orbit.

Work presently under way is using all these independent techniques to observe 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 Defense Science Technology Organisation have arisen from these investigations.

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, particularly when one requires detailed information of ULF energy interactions throughout the ionosphere. 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 field to be orientated at any dip angle. The complex wave reflection and mode conversion matrix has been obtained, providing insight into the reflection, transmission and mode conversion of the two Alfven ULF waves modes. Results from the 1-D 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. A 2-D computer model of these processes is under development.

Using predictions from the 1-D ionosphere/ULF wave computer 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. The cause for this discrepancy appears to be related to the way the evanescent wave mode fields attenuate through the neutral atmosphere. We are pursuing the merging of the ionosphere ULF wave computer simulation code with computer simulations of ULF wave propagation throughout the magnetosphere.

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 Combined Release and Radiation Effects satellite (CRRES) in an elliptical 6.3 Re x 350 km orbit of period -10 hr 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 are continuing using new analysis techniques which display wave Poynting flux in a dynamic spectral display. This allows the energy flow in multiple harmonics and individual wave packets to be studied. Results show that ion cyclotron waves are generated preferentially within +/-11^{o} geomagnetic latitude in the middle propagation is very rarely observed. The plasmapause is not the favoured region for wave sources as previously thought with waves equally likely to be generated in the outer plasmasphere or the plasmatrough.

At lower frequencies, Pc5 field line resonance and Pc3-4harmonic structure are being studied using up to five NOAA GOES geosynchronous spacecraft. Pc5 waves are seen to propagate simultaneously from the noon sector towards the dawn and dusk flanks, while Pc3-4 waves propagate westward all day.

The Group is 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 Group is responsible for the operation and the science undertaken by the NewMag fluxgate magnetometer experiment onboard FedSat. FedSat was launched into low-Earth orbit (LEO) at an 800km altitude, with 98.7 degrees inclination and Sun-synchronous in the 10:30 - 22:30 LT plane, in December 2002. The NewMag fluxgate magnetometer payload samples 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 boom. NewMag samples at rates of 100 or 10 vectors/second for high resolution or synoptic study modes respectively.

One of the primary goals of NewMag is to measure currents and waves at LEO while FedSat is flying over the auroral regions and ground magnetometer arrays. NewMag has been operational for 16 months with a 70% duty cycle on average. Research has concentrated on studying the high latitude auroral zone field-aligned current (FAC) systems. Of particular interest is the fine structure in FAC sheets and collaboration has commenced with the Danish satellite Oersted. Initial results show filamentary current sheets may be tilted with respect to the longitudinal east-west orientation.

Global Field Aligned Currents and Electromagnetic Energy Input

The ionosphere represents the inner boundary of the magnetosphere, the near-Earth space environment. Large electric currents (Birkeland currents) link stresses in the outer magnetosphere with the ionosphere. These field aligned currents (FAC) cannot be remote sensed using ground based magnetometer networks. Localised or long time averaged (~months) measurements of these currents and associated energy (Poynting flux) have provided limited understanding of the dynamics of magnetosphere-ionosphere interactions, the difficulty being the limited number of spacecraft for in-situ measurements.

A new project, in close collaboration with the Johns Hopkins University Applied Physics Laboratory (JHU/APL), has begun to provide global estimates of FACs and high latitude Poynting flux using Low Earth orbit (LEO) spacecraft technology. The Iridium LEO constellation comprises over 90 satellites located in 6 equally spaced longitude, polar orbit planes, 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 an agreement negotiated by Dr Brian Anderson. Access to these data at Newcastle is through collaboration with JHU/APL commencing in 2000. The Iridium magnetometers can detect the auroral (Birkeland) FACs. 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 global estimates of the Poynting flux into the ionosphere on time scales of ~1 hour.

In addition to SuperDARN data, the Iridium work is being extended by including ground magnetometer network data. Measurements above the ionosphere (Iridium) at the topside ionosphere (SuperDARN at ~300 km), and beneath the ionosphere (ground magnetometers) are being combined to produce global estimates of the ionosphere Hall and Pedersen conductivities. This represents the first global, direct estimates of these fundamental electric parameters of 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). 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 group has obtained 10 low power fluxgate magnetometers developed by Narod Geophysics, Canada. These contain palmtop data loggers and are powered by solar panels 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. An update of the digital data logger is currently underway.

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UNIVERSITY OF NEW SOUTH WALES

School of Physics

Ionospheric Physics

Research has been proceeding in the following areas:

- Simulation of geomagnetic daily variations and associated electric fields
- 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 magnetic data from the Oersted and CHAMP satellites
- Detailed examination of changes in the Sq current system using AWAGS and other data

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Space and Solar Physics at the School of Physics, The University of Sydney

1. Introduction

Space and Solar Physics is a major research focus at the School of Physics, University of Sydney. The primary research team is led by Associate Professor Iver Cairns (an ARC Australian Professorial Fellow) and Professor Peter Robinson (an ARC Federation Fellow). As of May 2004 this team includes five postdoctoral scientists (Drs Matthew Hole. Alexey Ivanov, Zdenka Kuncic, Bo Li, and Andrew Willes), and three PhD students (Reza Foroutan, Stuart Knock, and Jeremy Mitchell). Another two PhD students (Jacqueline Chapman and Christopher Boshuizen) are performing some of their thesis research with this team. Professor Robinson is Director of the University of Sydney's Center for Wave Science, of which A./Prof. Cairns is also a member. The team works on multiple facets of solar and space physics, focusing on the detailed plasma physics of the growth of plasma waves and radiation, on particle acceleration, and on solar system radio emissions associated with shocks. Several members of the team also work in theoretical plasma astrophysics, specifically pulsar physics and the statistics of astrophysical emissions.

Dr Michael Wheatland (an ARC Queen Elizabeth II Fellow) is active in solar physics, specifically the statistics of solar X-ray bursts, while Dr Neil Cramer (Emeritus) and Dr Sergey Vladimirov (an ARC Australian Professorial Fellow) are active in aspects of space physics related to dusty and complex plasmas. The final group involves Professor Donald Melrose, with widespread interests in plasma astrophysics, and members of the expired ARC Special Research Center for Theoretical Astrophysics. This report summarizes the progress made during the period 2002 - 2004 by these people, including the scientific papers published or submitted for publication, and professional service and awards.

2. Research Progress

Major progress was made in developing and understanding theories for bursty wave growth, 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, the nature and conditions for nonlinear processes involving Langmuir and low frequency MHD-like waves, linear mode conversion, critical phenomena involving the growth and damping of plasma waves, and new theories for particle acceleration and heating. This research involves analytic and numerical plasma theory, numerical simulations, analysis and interpretation of spacecraft data, and comparisons between theory and observation. In addition, significant time was devoted to identifying important research questions that could be answered using data from NASA’s upcoming STEREO spacecraft (for which Dr Cairns is a Co-Investigator on the radio and plasma wave instrument SWAVES) and the proposed LOFAR (Low Frequency Array Radio) telescope.

2.1 Theories for Wave Statistics

2.1.1 Basic Theory

- We developed a new theoretical analysis which extends and combines previously separate theories for wave growth, Stochastic Wave Growth (SGT) and Elementary Burst Theory (EBT). The new theory predicts new constraints for when the growth should be bursty and stochastic, as well as new predictions for the lognormal properties of the wave statistics. This research has been submitted for publication in Physical Review Letters [Robinson et al., 2004].
- We have developed a new quasilinear simulation code for the self-consistent interaction of electrons and Langmuir waves in an inhomogeneous background plasma. These inhomogeneities are evolved using standard wave equations. The new results show that bursty Langmuir waves are produced, with the lognormal statistics produced by SGT and the new generalized theory. These results are being written up for publication by B. Li et al.
- New analytic and numerical predictions for the probability distributions of the standard Stokes parameters, and the degrees of linear and circular polarization, have been developed. They are being written up for publication by M. Hole et al. Intended applications include solar radio bursts and pulsar radio emissions.

2.1.2 Widespread applicability of SGT

- We showed in detail 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., 2003a,b]. The field statistics show no evidence for nonlinear processes, thereby placing stringent conditions on nonlinear processes for the Vela pulsar. Subsequently we analyzed two other pulsars and found similar results [Cairns et al., 2004a]. While the role of Lorentz boosting still requires detailed analysis, these analyses extend SGT's applicability to the normal pulsed emission from pulsars, the archetypal astrophysical example of coherent emissions, and also to freely propagating electromagnetic radiation.
- Analyses of giant pulses and giant micropulses from pulsars were found to have power-law statistics [Johnston et al., 2003; Cairns et al., 2003c; Cairns, 2004d, so that not all emissions are directly consistent with SGT. The most probable interpretation is that wave collapse produces the giant pulse phenomena.
- Recently we analyzed the statistics of Langmuir waves driven by electron beams in the foreshocks of Earth, Saturn, Uranus and Neptune [Boshuizen et al., 2004]. Averaged over foreshock location, the statistics are power-laws with low index close to -1.0 that are inconsistent with wave collapse. Crucially, scaled by the thermal plasma energy density, it is found that the results from all the planets overlie each other and, moreover, that the data are consistent with convolution over foreshock depth of the lognormal statistics predicted by SGT based on Earth data. These results support SGT and argue that the same physics is relevant in all planetary foreshocks.
- This research shows that SGT is widely applicable in space plasmas and some astrophysical plasmas, applying in all but one context considered to date.

2.2. Theories for Radio Emissions

Radio emissions associated with shock waves are common in our solar system. A foreshock is the region upstream of and magnetically connected to a shock waves, thereby containing energized 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 traveling shock waves, and so are qualitatively similar to the radio emissions generated in Earth's upstream of Earth’s bow shock, for which abundant spacecraft data exist.
We also worked on radio emissions associated with electron beams released during solar flares,
the so-called type III solar radio bursts, and on other solar radio bursts.

2.2.1 Type II Radio bursts in the Corona and Solar Wind

- A detailed, semiquantitative analytic theory was developed for interplanetary type II solar radio bursts by Knock et al. [J. Geophys. Res., 2001]. It involves the reflection and acceleration of electrons at shocks (by the shock’s magnetic mirror in a process sometimes called shock-drift acceleration), 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. Subsequently Knock et al. [2003b] performed a detailed analysis of the radiation flux on the properties of the shock (e.g., shock speed relative to the medium, radius of curvature) and plasma (e.g., the electron temperature, density, and kappa parameter, the magnetic field orientation, the Alfven speed, and the relative fraction of nonthermal electrons). This theory was developed for a single ripple on a macroscopic shock.

- We generalized the type II theory to consider the effects of multiple simultaneously present ripples on the macroscopic shock and to predict dynamic spectra for type II bursts in the solar wind [Knock et al., 2003a]. Although the presence of multiple ripples can lead to multiple electron beams being present at different speeds at a given upstream location, the total radiation flux turns out to be approximately equal (within ~10%) of the flux predicted by treating each ripple independently. The dynamic spectra predicted for a relatively smooth solar wind agree well qualitatively with the broad emissions sometimes observed by the Wind spacecraft, while discrete, time-varying spectra require the shock to interact with localized solar wind structures.

- The type II theory was considered in the context of space weather [Cairns et al., 2003d]. Its prediction that more intense type IIs should be associated with faster, larger shocks/CMEs is consistent with existing data. Moreover, emission is favoured when the shock encounters regions with unusually high levels of nonthermal electrons, not inconsistent with discrete type II features being associated with shock-CIR interactions and a second, faster CME shock passing through a slower CME (e.g., by Reiner, Gopalswamy and colleagues).

- Predictions of the theory for a type II shock interacting with coronal structures like loops and interplanetary structures like CIRs and CME material have been developed and submitted for publication by Knock et al. The theory appears able to account for some fine structures observed on type II bursts, including multiple lane events, both broad- and narrowband events, and different behaviours for shock fronts moving along or transverse to the local magnetic field.

- An analytic model for the electrostatic potential jump across collisionless shocks was developed and applied to Earth's bow shock [Kuncic et al., 2002a], as well as being used in the type II theory. The theory appears consistent with existing data.

- Analytic conditions for particular nonlinear Langmuir wave processes (the electrostatic decay and scattering off thermal ions) were implemented in the type II code and its generalizations to related situations (see sections 2.2.3 and 2.2.4). A paper has been submitted for publication by Mitchell et al., which shows that the electrostatic decay process dominates under most conditions and that including both processes leads to radiation fluxes larger by less than a factor of 2 for electrostatic decay only.

2.2.2 Solar radio bursts: Types I, III, IV, V and metric spike bursts

- Our existing, detailed theory for type III bursts, based on SGT and specific nonlinear Langmuir processes, predicts dynamic spectra with the observed timescales, frequency ranges, and spectral densities [Robinson and Cairns, Sol. Phys., 1998a, b, c]. 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.

- A number of important theoretical issues remain for the acceleration of the type III electrons and the generation of Type I, IV, V, and metric spike bursts. Reviews of these issues and theories were published [Cairns and Kaiser, 2002; Cairns, 2004b], including discussion of how the proposed LOFAR telescope might allow these issues to be resolved.

2.2.3 Radiation from Earth's foreshock and magnetic anomalies on moons

- We generalized 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 5-10 of those observed [Kuncic et al., 2002b, 2004]. The theory also predicts the average level of Langmuir waves in the foreshock [Kuncic et al., 2004]. Detailed comparisons with Geotail and other spacecraft data are ongoing with Dr Y. Kasaba (ISAS, Japan).

- Magnetic anomalies on the Moon, as well as on moons for the other planets, can potentially standoff the solar wind at a bow shock and thereby give rise to foreshock radio emission. Such radio emissions could be a remote diagnostic for the presence of magnetic anomalies on moons, and associated magnetic shielding from cosmic rays (cf. life on Europa, for example). We extended our foreshock model to magnetic anomalies on the Moon and predicted that detectable levels of emission should be produced [Kuncic and Cairns, 2004].

- Kuncic et al. are currently extending the theory to predict the levels of foreshock radiation at all the planets in our solar system, for future comparisons with data from missions like Cassini, Bepi-Colombo, and Galileo.

2.2.4 2-3 kHz radiation from the outer heliosphere

- Cairns and Zank [2002] developed a new ``Priming/GMIR'' theory for why the 2-3 kHz radio emissions turn on when a shock driven by a GMIR passes beyond the heliopause. The theory provides a detailed theoretical basis for Gurnett et al.'s [Science, 1993] model for the radiation. The theory is based on priming of the outer heliosheath with a fast electron tail, due to operation of the ``lower-hybrid drive'' process, that is then accelerated by the GMIR shock. Here the lower hybrid waves are driven by pickup ions and the priming process occurs in the magnetic field draping region near the nose of the heliopause. The authors argued, on qualitative grounds, that fundamental radiation should be produced primarily, not inconsistent with the available data.

- Mitchell et al. [2004] and Cairns et al. [2004b] combined the Cairns and Zank priming theory with Knock et al.'s [2001, 2003a,b] theory for type II bursts in order to predict the level and dynamic spectrum of radiation produced by a GMIR shock moving from the 10 AU to beyond the heliopause. The radiation is found to be primarily fundamental radiation with levels of order those observed and a dynamic spectrum that closely resembles one of the observed classes of radiation event.

- Recent Voyager data from Kurth & Gurnett show that the radio source region appears along an approximately linear band on the sky, roughly parallel to the galactic plane. Cairns [2004c] argued that magnetic draping is expected to lead to the magnetic field being enhanced in an approximately linear band aligned with the local magnetic field direction, based on intuition and simple convected-field arguments. He then argued that the Priming/GMIR theory appears consistent with the Voyager data and that the magnetic field in the local interstellar medium is parallel to the galactic plane.

- Cairns [2004a] reviewed the observations and theories for the 2-3 kHz radiation, summarizing a number of unresolved issues and directions for further research.

2.2.5 Exo-planetary radio emission

- The discovery of exo-planets (planets in extrasolar systems) is a major area of activity, using both visible light and radio waves. Recently Willes and Wu (2004) developed a model predicting radio fluxes from white dwarf systems based on electron cyclotron maser emission in an analogue of the Jupiter-Io flux tube system.

- Predictions for observable radio emission from ultra-short-period white dwarf pairs have been developed (Willes et al., 2004]. Moreover, a paper by Willes and Wu has been submitted for publication: it predicts the levels of emission from terrestrial planets orbiting white dwarfs.

2.3 Particle Acceleration and Plasma Waves

2.3.1 Particle Acceleration

- How electrons are accelerated and both ions and electrons are heated in magnetic reconnection regions remains one of the fundamental unsolved issues in space physics, plasma physics, and astrophysics. In a submitted paper, Cairns [2004e] proposed a new and natural model based on lower hybrid (LH) waves generated by spatial inhomogeneities in reconnection regions: electrons are resonantly accelerated parallel to the magnetic field by the electric fields of LH waves (the so-called LH drive process) generated by the lower hybrid drift instability (LHDI). Analytic theory shows that the LHD/LHDI model should accelerate electrons from the thermal energy to greatly superthermal (even relativistic) parallel energies, while ions are heated perpendicular to the magnetic field. The model appears qualitatively consistent with Wind spacecraft data for magnetotail reconnection. Simulations and further research on the consequences of the model is required.

2.3.2 Linear damping as a critical phenomenon

- Textbooks discuss the Landau damping of waves by a thermal particle distribution in terms of linear (exponential) damping from an arbitrary initial amplitude to the noise background. From time to time other workers have predicted that trapping or other nonlinear effects might alter this picture of damping, with linear damping below some threshold and another behaviour above it. We have used numerical simulations of the Vlasov equation for an electron – Langmuir wave system to confirm the existence of a threshold phenomenon, show that this system obeys the power-law scalings expected of a critical phenomenon, and that the scalings and spectral behaviour are not consistent with trapping causing the critical threshold – although trapping clearly occurs and modifies the scalings well above the threshold. A paper presenting these results has been submitted for publication by Ivanov et al.

- The paper by Ivanov et al. also shows that the location of the threshold can be predicted (it is where the linear Landau damping rate equals the trapping frequency) and that this threshold is above the level of thermal noise for solar wind plasmas near 1 AU (e.g., in Earth's foreshock and the source region of interplanetary type III bursts). Further simulations on the importance of nonlinear electrostatic waves at harmonics of the plasma frequency, which grow above the threshold, are being pursued.

2.3.3 Linear mode conversion

- We investigated theoretically the waveforms of Langmuir waves subject to propagation in and reflection by density irregularities [Willes et al., 2002] , including reflection, linear mode conversion, tunneling and trapping in density irregularities. This involved directly calculating the waveforms using Maxwell's equations and fluid theory. The predictions for reflected waves were shown to be very similar to Wind spacecraft observations. However, the theory shows that the signatures of linear mode conversion should be very difficult to detect observationally.

- Subsequently we considered the efficiency of linear mode conversion in non-monotonic density gradients when density cavities are available to act as resonators. It was found [Willes and Cairns, 2003] that the conversion efficiency is a strong function of the Langmuir wave frequency, with narrow peaks occurring where an integer number of Langmuir wavelengths fit inside the density cavity. This effect is a way of producing narrowband electromagnetic radiation from relatively broadband Langmuir waves, one of the characteristic signatures of planetary continuum radiation and other emissions widely thought to be produced by mode conversion.

- Since the mode conversion efficiency depends on the incident Langmuir wavevector it is important to average the conversion efficiency over the range of incident angles and wavelengths and density scalelengths in the plasma. A paper submitted for publication by Cairns and Willes shows that averaging reduces the conversion efficiency by a factor of order c/V, where V is the electron thermal speed, in 2-D and by this factor squared in 3-D. For the solar wind at 1 AU the efficiency is then of order 5 orders of magnitude than the peak unaveraged efficiency of order 50%.

2.3.4 Nonlinear processes in multi-component and/or dusty plasmas

- We generalized 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.

- Refined conditions were developed for the electrostatic decay and scattering off thermal ions to proceed effectively (e.g., with nonlinear growth rates exceeding Landau damping rates) and/or to dominate one another [Mitchell et al., 2003].

- The parallel propagating transverse modes in a plasma are known to be exact solutions of the MHD and multifluid equations. We investigated these waves in a multi-component plasma consisting of two ion-like (or ion and dust) species [Hertzberg et al., 2003]. We perturbed these exact solutions and investigated modulational, parametric or decay instabilities where the pump wave is modified by the daughter waves in regions of instability. All of these instabilities involve the additional modes associated with the introduction of a second heavy species.

- In a warm plasma, the parallel modes can interact with transverse and acoustic modes. A tenth-degree polynomial dispersion equation was obtained, describing the interaction of the pump with two acoustic modes and sideband-beatwaves [Hertzberg et al., 2004a]. In the low temperature regime the effect of a second ion (dust) species is to reduce the usual modulational instability, and a new decay instability arises. In the high temperature regime two new decay instabilities, narrow in wavenumber, were found.

- When considering parametric instabilities, it was found that pairs of slow and fast parallel propagating modes are parametrically excited [Hertzberg et al., 2004b]. The growth rates of the various interactions were calculated and it was shown that the growth rates of slow–fast and fast–fast mode interactions can be maximized by varying the proportion of negative charge on the dust. Furthermore, both the ion-like species (including dust) were allowed to be fully mobile. The collection of charge by the dust from the background neutral plasma modifies the dispersion properties of the pump and excited waves. The introduction of an extra mobile species adds extra modes to both these types of waves. We investigated the pump wave in detail, in the case where the background magnetic field is perpendicular to the direction of propagation of the pump wave. Then we derived the dispersion equation relating the pump to the excited wave for modes propagating parallel to the background magnetic field. It was found that there are a total of twelve resonant interactions allowed, whose various growth rates are calculated and discussed.

2.3.5 Numerical 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, in a homogeneous plasma. Simulations by Li et al. [2002] show that multiple beams can enhance or suppress the waves and, moreover, that successive beams can be cannibalized by the first large event.
- The code has been extended to include the effects of the electrostatic decay of Langmuir waves into backscattered Langmuir waves and ion acoustic waves. Interestingly, multiple decays can proceed, the system becomes strongly inhomogeneous, and the decay proceeds faster for higher values of the ion to electron temperature ratio (provided this is less than about 1), an unexpected result based on linear theory [Li et al., 2003].
- Extensions of the code to nonlinear processes generating electromagnetic radiation at harmonics of the plasma frequency are underway, with a paper on harmonic radiation almost ready for submission. The effects of background density turbulence, and the evolution to stochastic growth states, are also being studied (see 2.1. 1).

2.4 Solar magnetic fields, CMEs, and flares

2.4.1 Solar magnetic fields

- The energy release in solar flares has been investigated, emphasizing the role of currents inferred from vector magnetograms, and the constraints of current and helicity conservation [Melrose, 2004a,b].
- The global energy balance in the solar corona is addressed in a paper [Litvinenko and Wheatland, 2004] produced as result of a collaboration with Dr Y. Litvinenko (University of New Hampshire).
- A paper demonstrating the relative accuracy of simple circuit estimates of coronal magnetic fields (Wheatland & Farvis 2004) has been accepted for publication in Solar Physics. It presents the surprising result that circuit estimates are inaccurate for large values of current, because of the influence of the magnetic field due to the current on the path taken by the current. However, circuit estimates are accurate for smaller values of current. These findings will be useful for future determination of the energies of solar active regions.

- A new parallel method of computation of nonlinear force-free fields has been developed, implemented in code, and tested on a variety or parallel computers including the ac3 cluster at the Australian Technology Park [Wheatland, 2004]. It uses a mathematically well-founded current-field iteration technique. The method will soon be applied to vector magnetic field data for active regions on the Sun, which should lead to accurate estimates of magnetic free energy.

2.4.2 Statistics of CMEs and solar flares

- 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.

- The waiting-time distribution of coronal mass ejections (CMEs) was investigated [Wheatland, 2003].

- A new method for solar flare prediction has been developed by Wheatland, based on the application of Bayesian inference to observed solar flare statistics in active regions. The method "refines" an initial prediction for the probability of occurrence of a large flare during a period of time by consideration of the number and size of flares already observed in an active region. The initial prediction may come from any of a number of conventional flare prediction schemes. A paper has been submitted for publication and discussions are proceeding with the Ionospheric Prediction Service in Sydney concerning their needs for flare prediction.

- Work with Professor Peter Sturrock (Stanford University) on solar neutrino time series has lead to the recent submission of two papers, one on methods of combining power spectra and the other on the analysis of Super-Kamiokande solar neutrino data.

2.5 Other Space Physics Topics

2.5.1 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 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 Alfven Mach number M_A [Chapman and Cairns, 2003]. This model predicts changes in shape and cross-section as a function of M _A for two magnetic field orientations, as well as the shock's symmetry axis no longer remaining the solar wind direction for non-aligned or perpendicular IMF orientations.

- The IMF direction was shown to have dramatic effects on the bow shock's shape and symmetry axis for low M_A [Chapman et al., 2004]. Specifically, due to the fast mode speed (and so the Mach cone) varying with these parameters in an asymmetric fashion, the shock was shown to become asymmetric for low M_A < 5. These effects are predicted to be observable.

- The new shock models have been compared with spacecraft observations, using both case studies and statistical analyses: the new models agree very well statistically in their expected domains of applicability, although finite propagation times and the relative paucity of stationary observations of the shock (typically it moves across the spacecraft) make the quantitative agreement relatively poor in case studies. A Chapman and Cairns paper has been submitted for publication.

2.5.2 LOFAR Telescope

- The Low Frequency ARray (LOFAR) telescope is intended to cover the frequency range 10 – 240 MHz with excellent angular, temporal, and frequency resolution. It should be very useful for solar, planetary, stellar, and exoplanetary studies related to solar system physics, as well as for studies of the Epoch of Reionization, pulsars, radio galaxies etc.

- A review of scientific questions that LOFAR observations could help answer, together with associated requirements for the telescope and observing modes, was prepared [Cairns, 2004b].

3. Service to the Australian Space Community, Awards and Fellowships

3.1 Service to the Community

- In 2003 Melrose was elected Vice-President of Division II (Sun and Heliosphere) of the International Astronomical Union, as well as President of Commission 10 (Solar Activity) of Division II.
- In 2003 Cairns was elected Chair of Division IV (Interplanetary Magnetic Field and Solar Wind) of the International Association for Geophysics and Aeronomy (IAGA).
- In 2003 Cairns accepted an invitation to Chair the Solar Terrestrial and Space Physics Subcommittee for the 2005 Australian Institute of Physics Congress. In 2004 he accepted an invitation to join the Australian National Committee for Space Science.
- In 2003 Cairns was invited to be a member in the ``Options of Australian Involvement in LOFAR'' Working Group, contributing strongly to its Report. Cairns and Melrose (and Dr S. Johnston from the School) were also members of the Australian LOFAR Science Working Group.
- In late 2003 Cairns organized a workshop on solar system science for LOFAR that complemented similar workshops for galactic and extragalactic science.
- Cairns, Cramer, Melrose, Robinson, and Vladimirov organized multiple sessions at international scientific conferences during the period 2002-2004, as well as playing large roles in organizing the 2002 International Congress on Plasma Physics.

3.2 Awards and Fellowships

- In 2002 Robinson was awarded the Walter Boas Medal by the Australian Institute of

Physics, in part for his research on space physics. Subsequently he was awarded the 2003 Eureka Prize for interdisciplinary work on brain physics, in part based on techniques developed for space physics.

- In 2002 Vladimirov was awarded the Pawley Medal of the Australian Academy of Science for his research on complex dusty plasmas.
- In 2003 Robinson was awarded a Federation Fellowship by the Australian Research Council (ARC).
- Cairns, Melrose, and Vladimirov all hold Australian Professorial Fellowships from the ARC, awarded in 2003, 2002, and 2000, respectively.
- Wheatland holds a Queen Elizabeth II Fellowship from the ARC.

4. Publications

1. Boshuizen, C.R., I.H. Cairns, and P.A. Robinson, Electric field distributions for Langmuir waves in planetary foreshocks, J. Geophys. Res., in press, 2004.
2. Cairns, I.H., Radiation from the Outer Heliosphere and Beyond, in ``The Sun and the Heliosphere as an Integrated System'', Eds. S. Suess and G. Poletto, Kluwer (Dordrecht), in press, 2004a.
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4. Partial List of Submitted Papers

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