AUSTRALIAN ACADEMY OF SCIENCE

AUSTRALIAN SPACE RESEARCH

1998-2000

Report to the Committee for Space Research (COSPAR)

Australian National Committee for Space Science

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

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PREFACE

This biennial report to the ICSU Committee on Space Research (COSPAR) has been assembled from contributions from the wide range of institutions undertaking space related research in Australia. It covers the period between COSPAR scientific assemblies, in this case from July 1998 to June 2000. The 33rd COSPAR meeting will be held in Warsaw, Poland from 16 July – 23 July 2000. The report is available on the World Wide Web at http://www.science.org.au/academy/media/cospar.pdf

Australian institutions active in space research comprise the Commonwealth Scientific and Industrial Organisation (CSIRO), numerous University groups, and various government bodies such as the Australian Antarctic Division, and the Ionsopheric Prediction Service. 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 and this is represented through contributions from British Aerospace and DSpace. A look at the contributions indicates the wide range of research activities underway. The reviews that follow have been gathered, collated and edited at short notice. It is worth noting that there are, unfortunately but inevitably, some omissions. The request was circulated as widely as possible but there are some people who did not contribute. If further information is required, I will be happy to provide it.

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 2000

Atmospheric and Space Physics (ASP)

The Australian Antarctic (Mawson, Davis and Casey) and sub-Antarctic (Macquarie Island) stations, continue to provide a platform for the research projects as listed in Table 1. This work supports research programs of the Australian Antarctic Division, Australian Government agencies and Universities, and those of the international community. The ASP program conducts research and monitoring studies on 'middle atmosphere climate change', and practical value 'space weather' research in line with the
Antarctic Science Advisory Committee (ASAC), Australia's Antarctic Science Program Strategic Plan 2000-2005.

Climate change research

The measurement of middle atmospheric parameters has only recently become achievable so that the investigation cycle of measurement, characterisation and interpretation is at an early stage. Our measurements are guided by what is already known but much remains to be learned from these measurements. The MFSA radar, the OH spectrometer and the Fabry-Perot spectrometers that are operated in the Australian Antarctic Territory allow the measurement of winds through the height range 60 to 100km and temperatures near 86km. The LIDAR system, to be commissioned at Davis during 2000/2001, will allow the measurements of winds and temperatures through the stratosphere and lower mesosphere. The geoelectric field is postulated as providing a mechanism via which solar variability can influence weather and climate. The measurement of middle atmosphere parameters has only recently been achieved and a major focus of the program during the coming period will be to measure winds and temperatures through the stratosphere and lower mesosphere.

- A paper refining the accuracy to which temperatures of the Antarctic mesopause region can be determined from OH(6-2) airglow measurements has been accepted for publication by 'Annales Geophysicae' (after correction to account for an initial mis-calibration of a Low Brightness Source by the National Measurement laboratory). An observation program for noctilucent clouds at ANARE stations and aboard Australian Antarctic resupply vessels was instigated and a general science paper on the 'climate change' importance of Southern Hemisphere noctilucent cloud observations has been accepted for publication by 'The Physicist'. Measurements of the temperature independent line ratios of the OH(8-3) band were collected at Davis during 1999. When analysis of these data are completed, we will be able to accurately extend our hydroxyl airglow temperature sequence to include data collected prior to 1990. Measurements of hydroxyl airglow intensities to enable determination of the temperature of the climate sensitive Antarctic mesopause region above Davis station, Antarctica, have continued during the 1999 and 2000 winters. (Australian Antarctic Division and University of Western Ontario, Canada)

- A paper demonstrating that solar variability can influence the ground-measured vertical geoelectric fields measured at an Antarctic plateau site (Vostok) has been published in the Journal of Atmospheric and Solar-Terrestrial Physics in collaboration with Russian and American colleagues. This is a necessary but not sufficient condition for a viable solar variability - climate influence via the geoelectric field. A paper on a set of modern geoelectric field data collected at Vostok in 1998 has been accepted for publication by the Journal of Geophysical Research. This work is conducted in association with Russian and American colleagues. A research program to determine the thunderstorm and solar wind influences on the 1998 Vostok geoelectric field data set has been

initiated in association with the Institute of Southern Ocean Studies, University of Tasmania. (Australian Antarctic Division and the Arctic and Antarctic Research Institute, Russia)

- Analysis of the data produced by the MF radar system operating at Davis has yielded results on the dynamics of the mesosphere/lower thermosphere region and the nature of the radar echoes. Cross-spectral analysis of wind data obtained at Davis and Adelaide has led to the discovery that large scale polar waves, thought to be confined to the polar mesosphere, can extend to mid-latitudes. A study of the characteristics of wind motions due to the 12-hour atmospheric tide has yielded a model that can explain the unusual variations in the time of its maximum strength. Radar observations of this tide have also been compared to those derived from observations of the OH layer with a Fabry-Perot spectrometer. Comparisons of gravity wave activity in the mesosphere and lower thermosphere above Davis, with that at Poker Flat, Alaska (65 N), are identifying hemispheric differences in wave activity and, potentially, the impact of waves on the atmospheric circulation in the two hemispheres. Polar Mesospheric Summer Echoes (PMSE) and Noctilucent clouds (NLCs) are both thought to be related to the cold summer polar mesosphere. A paper describing the characteristics of enhancements in radar signal amplitude and their potential as a proxy measure of PMSE is currently being reviewed. The MF radar at Davis is due to be upgraded in the summer of 2000/2001 to allow the collection of electron density profiles through differential absorption profiles.
  (Adelaide University and Australian Antarctic Division)

- Fabry-Perot Spectrometers have operated at both Davis and Mawson since 1997. Observing campaigns have concentrated on the oxygen ?630 nm thermospheric emission and mesospheric OH (6–2) ?834 nm emission. Analysis of simultaneous thermospheric observations has enabled description of mean winds and gradients in the thermospheric wind-field. It is important to include gradients as the thermospheric wind has significant small-scale features at polar latitudes. This has been used to characterise overall features of the thermospheric wind and also to compare thermosphere neutral winds with SuperDARN plasma velocities. As well as studies of the overall wind field studies of particular events, specifically vertical winds events have continued. Simultaneous observations of vertical winds from both Mawson and Davis have provided spatial information not previously available permitting modeling of such events. Studies on the long thermospheric data base are continuing. A comparison of mesospheric mean winds and tides with those determined from MF radar data has shown that the two techniques are in good agreement. (La Trobe University and Australian Antarctic Division)

Practical value research

The geographic and magnetic locations of Australia's Antarctic stations provide a significant opportunity to contribute to monitoring and knowledge of space weather - a matter of importance for correct functioning of space-based technological systems. The energy that a single solar disturbance puts into the geospace environment can destroy orbiting satellites, disrupt continental power grid systems, radio communications (including satellite TV and mobile telephones) and GPS navigation. Space weather
research involves the development of an operational global circulation model linking the magnetosphere-ionosphere-atmosphere systems. These models, using real time data inputs, are used to minimise the impact of potentially damaging space weather events. We continue to provide the national and international community with access to routine geophysical data of value to 'space weather' research projects and of practical value to HF communication circuit prediction.

- The automated operation of the Mawson Cosmic Ray Observatory continued with only 0.2% down time in 1999. Bi-hemisphere comparative analyses with data from Japanese muon telescopes has shown some evidence of precursor signatures to Forbush Decreases at high energies. Other high energy muon studies have confirmed the existence of the sidereal Tail-in and Loss-cone

anisotropies. Rationalisation of the Australian neutron monitor network has commenced with the closure of the Brisbane monitor and with Darwin to close late in 2000. A new monitor has begun operation in Hobart and the Mawson monitor will be enlarged over the next few years. The Mawson neutron monitor has also formally become part of the Space Ship Earth consortium (with South African, Russian and USA partners) to provide data for the near real time 3-d study of the cosmic ray radiation environment in near earth space. Establishment of the international Ground Level Enhancement database, with web access to the data, is well advanced with the first on-line trials expected this year. Once complete mirror sites in Europe and USA will be established. (Australian Antarctic Division and University of Tasmania)

- The Lowell Digital Ionosonde (DPS-4) has been used at the Australian Antarctic polar cap station Casey (-80.6^{o} CGM latitude) in a study of ionospheric polar cap patches. The instrument ran a series of campaigns consisting of 3 minute cycles of ionograms and drift velocity measurements during 1997-1999. Patches were identified from U-shaped traces in group range and enhanced critical frequencies on the ionogram records. These were compared with drift measurements and other geophysical data sets. The influence of the Interplanetary Magnetic Field has been investigated. Correlations were observed with Total Electron Content derived from GPS satellite observations with a receiver also located at Casey. The field-of-view for GPS observations allowed patches to be observed over large distances, providing some insight into their origin. Comparisons with plasma drift velocities, (derived from DPS drift measurements), indicate that patches are often associated with fluctuations in horizontal drift velocity. Peaks in the horizontal velocity appear to correlate with the patch edges. Further investigations of polar patches will involve comparison with GPS scintillation measurements and SuperDARN radar observations. (Australian Antarctic Division, La Trobe University and IPS Radio and Space Services)

- At Davis an imaging riometer, SHIRE (Southern Hemisphere Imaging Riometer Experiment) continues to provide a two-dimensional image of regions of enhanced cosmic noise absorption at 38.2 MHz (with a spatial resolution of 20km and a time resolution of 1 s). In conjunction with an Antarctic ULF induction magnetometer array and optical observations it is be possible to identify temporal and spatial characteristics of ionospheric sources and signatures of cusp and substorm phenomena. This instrument compliments the suite of instruments at Davis and the science goals of both climate change and practical value research. (Newcastle University, University of Maryland (USA) and Australian Antarctic Division)

- Several ionospheric studies using beacon satellite transmissions are being undertaken to study the ionosphere in the Australian region extending from equatorial to high latitudes. These include computerised ionospheric tomography for mapping the ionosphere in the Australian and Antarctic region using a GPS Network. (La Trobe University, AUSLIG and Australian Antarctic Division)

- The Tasman International Geospace Environment Radar (TIGER) was commissioned on Bruny Island, Tasmania, during 2000 to look south to Antarctica. TIGER will image ionospheric features associated with the aurora and other phenomena arising from solar wind-magnetospheric coupling. It will study basic space plasma processes and space weather effects and will be part of the international Super Dual Auroral Radar Network (SuperDARN). (La Trobe University, Australian Antarctic Division, DSTO, IPS Radio and Space Physics, Monash and Newcastle Universities, BAS and RLM Systems Pty Ltd)

TABLE 1

Tabulation of current and proposed experiments conducted at the Australian Antarctic and sub-Antarctic stations, together with a listing of collaborative agencies.

Experiment	Casey	Davis	Mawson	MQ Is.	Research Agency
Cosmic Ray Observatory			X		AAD & U Tasmania
30 MHz Riometer	X	X	X	X	AAD
Magnetometer	X	X	X	X	AAD & AGSO
Magnetic Absolutes	X	X	X	X	AGSO
Auroral Video Imager	X	X	X	X	AAD
Induction Magnetometer	X	X	X	X	AAD, La Trobe U & U N'Castle
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	AUSLIG, AAD & La Trobe U
SHIRE Imaging Riometer		X			AAD, U Newcastle & Maryland
MFSA 2 MHz Radar		X			U Adelaide & AAD
Fabry-Perot Spectrometer		X	X		AAD & La Trobe U
Czerny-Turner Spectrometer		X			AAD & U Adelaide
Scanning Radiometer		X			UWO & AAD
3 Channel Photometer		X			La Trobe U & AAD
2 Channel WA Photometer	X	X			AAD

Electric Field Mill - Vostok					AAD &
UV-B Super DARN radar - Bruny Island, Tasmania		X			AAD & ARL La Trobe U, AAD, IPS, BAS, Newcastle U, Monash U, DSTO, RLM

PROPOSED EXPERIMENTS					
Lidar - 2001		X			AAD & U Adelaide
VHF radar - 2002		X			AAD & Adelaide U
Ozone - 2003		X			AAD & BoM

AAD – Australian Antarctic Division, AGSO – Australian Geophysical Survey Organisation, IPS – IPS Radio and Space Services, ARL – Australian Radiation Laboratory, BoM – Bureau of Meteorology, DSTO – Defence Science and Technology Organisation, BAS – British Antarctic Survey, UWO - U Western Ontario, RLM Systems Pty Ltd, U – University.

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Australian Geological Survey Organisation

The Australian Geological Survey Organisation (AGSO) operates the national network of permanent magnetic observatories and repeat stations (Figure 1). Information is obtained about the variations of the field and magnetic disturbances in support of solar-terrestrial physics research, solid-Earth applications of geomagnetism, and space-weather reporting. The latter is in support of the work of the Ionospheric Prediction Service, Radio and Space Services. One-second data, calibrated to rigorous absolute standards, are recorded at the observatories. Much of the data can be provided in near real time. New initiatives are being taken to produce and disseminate indices of magnetic disturbance that are more closely aligned to user requirements and the growing need for real-time information.

An updated version of the Australian Geomagnetic Reference Field model (AGRF00) was released by AGSO at the beginning of the year, and a substantial contribution was made to the year 2000 revision of the International Geomagnetic Reference Field. Further AusAID funding has been provided to support geomagnetism observatory activities in Indonesia, which will lead to improved magnetic reference field models.

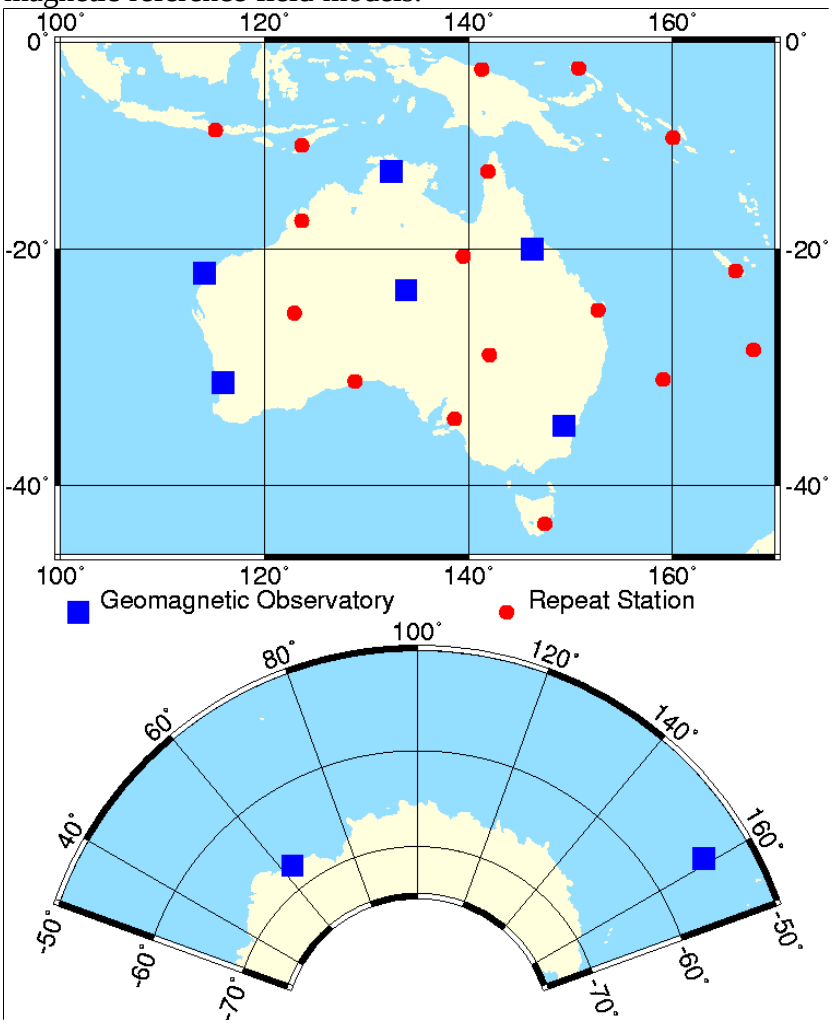

Figure 1. Locations of Australian magnetic observatories (squares), and repeat stations (dots). One-second vector data are recorded at the observatories. Annual observations are made at the repeat stations to obtain supplementary information about the geomagnetic secular variation.

Several new magnetic field survey microsatellites have been launched, or are at the development stage. The most important one is the successful Danish OERSTED satellite launched in February 1999. AGSO, in collaboration with the University of Sydney, is involved in processing new satellite data for mapping the main field and the long-wavelength crustal anomaly field. In addition, AGSO is participating in Australia's FEDSAT mission, coordinated by the Cooperative Centre for Satellite Systems and scheduled for launch in late 2001, with the intent of obtaining three-component main field data.

AGSO uses Earth-observation satellite data in support of its geoscience operations onshore, offshore, and in Antarctica. Satellite data are particularly important for the minerals- and petroleum-oriented mapping functions. The primary data used are from the Landsat Thematic Mapper because of its spectral discrimination capability and regional coverage. Other satellite data used include NOAA-AVHRR, SPOT, and ERS-1 radar data. Specially-processed Landsat imagery has proved to be a valuable tool for mapping regolith materials and lithologies in layered igneous and meta-igneous sequences of moderately well-exposed Precambrian geological provinces. Remotely sensed data are combined with airborne magnetics and gamma ray spectrometer data in GIS to aid in geological modelling and interpretation.

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The Bureau of Meteorology, as Australia's National Meteorological and Hydrological Service, provides weather and climate services for the Australian public. Satellite information on the state of the atmosphere, the land surface and the oceans form an essential input to the provision of such services. The contribution of satellite-based, remotely-sensed data to Australian meteorology is very substantial. Satellite data, for example, form the largest component of the meteorological data base.

The Bureau now has MDUS (Medium Data Utilisation Station) receiving stations in Melbourne, Crib Point, Perth, Darwin and Sydney. It is intended that Perth, and probably Darwin, will be re-oriented to receive data from the recently-launched Chinese Fengyun-2 satellite which will provide valuable data from west of the Australian land mass.

Bureau of Meteorology Research Centre (BMRC) scientists have developed two key systems for receiving satellite observations directly from spacecraft and for using the data in analysis and forecasting. The first takes measurements every 30 km horizontally at several wavelengths in the infrared and microwave spectrum from the sounding instruments on American polar-orbiting satellites and derives estimates of temperature, moisture and total ozone amount in the atmosphere; without these data, Australian forecasts would be significantly degraded. The second compares sequential observations of selected cloud or water vapour targets from Japanese Geostationary Satellite (GMS) images and calculates wind speed and direction at many levels throughout the atmosphere. Other satellite-based systems provide winds at the sea surface, relay surface pressure data from floating buoys, and measure rainfall.

A great deal of research and development effort is expended within the BMRC into the optimal assimilation of data – including satellite data - into numerical models of the atmosphere and ocean. Development work associated with a December 1998 upgrade of the operational global Numerical Weather Prediction (NWP) and analysis systems to higher horizontal and vertical resolution, for example, enabled the direct assimilation of satellite radiances into the model.

Following the launch of the GMS-5 satellite, the capability to generate and assimilate winds estimated from sequential observations using the 6.7 μm water vapour absorption channel became available to the Bureau. Data from the GMS satellites are now used routinely to estimate cloud drift and water vapour drift winds. Several case studies have been conducted on the impacts of using these wind estimates in the nationally important area of tropical cyclone track forecasting.

A study on the assimilation of altimeter data into the ocean wave model also showed a positive impact; it indicated a reduction in bias in the analysed significant wave height and peak period, when compared to independent wave-rider buoy data, of around 40% and in the root-mean-square error of about 10%. Operational trials indicate that this improvement is maintained through a 36-hour forecast. The system, as well as being implemented in Bureau operations, has also been provided to the US Fleet Numerical Meteorology and Oceanography Center (FNMOC) for possible implementation in their operational system.

The Tropical Rainfall Measuring Mission (TRMM) satellite, operated by the US National Aeronautics and Space Administration and the Japan National Space Development Agency, uses the first rainfall-measuring radar instrumentation flown on satellites. The primary aim of TRMM is to estimate the amount of rain falling annually around the tropical belt and the associated release of latent heat. This energy release associated with rainfall accounts for about three-quarters of that which drives the global atmospheric circulation, and some two-thirds of all rain falls in the tropics, an area of the globe where conventional observing networks are sparse. Knowledge of tropical

rainfall is therefore crucial to the further development of numerical models of the global atmosphere.

The BMRC Darwin Climate Monitoring and Research Station, located in Darwin, NT, continues to play a major role in the ground validation of satellite-borne radar estimates of rainfall, and is one of only four such stations around globe. In addition to a dense network of raingauges and disdrometers for primary ground validation, use is being made of polarimetric radar technology. The polarimetric radar's ability to differentiate between rain, hail and snow and other precipitation forms can be used to refine the satellite's rainfall estimates, based upon computerised calculations of the radiative properties of the clouds.

The prediction of infrared brightness temperatures from all geostationary satellites is now part of the operational suite from the Global ASsimilation and Prediction System (GASP), and it is used to forecast cloud and to validate cloud and water vapour fields from all the operational models.

Geostationary satellite infrared imagery is also being used to provide rainfall estimates at high temporal and spatial resolution, but research to 'tune' the relationship between surface rainfall and cloud top temperatures has been necessary. Another aspect of this same problem has been the incorporation of satellite estimates of 'no rain' into the routine objective rainfall analysis scheme; using a critical value of the difference between the daily minimum infrared brightness temperature and the climatological minimum surface temperature to delineate areas of no rain. The mean bias of the satellite augmented analysis was roughly half that for gauge-only analyses.

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COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

INTRODUCTION

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

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

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

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

EARTH OBSERVATION

CSIRO Earth Observation Centre

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

Together with the University of New South Wales and the CRC for Landscape Evolution and Mineral Exploration, CSIRO is collaborating with NASA/JPL in the 2000 Pacific Rim (PACRIM) AirSAR/MASTER campaign.

The Australian Ocean Colour Working Group (AOCWG) is a representative group of researchers from national marine research agencies and Universities. Formed 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

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

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

Some ground sensors are used, but the nature of the biome make relating understory surface temperature measurements to satellite measurements impractical.

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

Common AVHRR Processing Systems (CAPS)

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

The CSIRO science working group CAPS continues to establish “best practice” approaches to process AVHRR 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 future, research programs and applications requiring data from more than one source, or data from non-local stations, will be able to easily analyse, apply, and combine data from any Australian AVHRR station.

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 Data Reception

The CSIRO Division of Marine Research has commenced the regular reception of ocean colour data from the SeaWiFS instrument on the SEASTAR satellite. The Division has a real-time license that allows the data to be used in NASA-approved marine research programs. The full data set within the range of the Hobart station will be archived for later use in climate, fisheries, and applications programs. A full re-analysis of the OCTS data set in the Australian region is now under way.

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 Jupp, Head of COSSA, chairs the TERSS Board which is responsible for the management of the facility.

ATSR-2 and AATSR

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

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, led by Dr Nicholas Coops, 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 Land Cover Processes and Water Quality

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

The team, led by Dr Alex Held, main areas of expertise are:
Hyperspectral remote sensing, with emphasis on vegetation mapping, land use assessment, water quality and coastal zone mapping;
Ground-based field verification and use of hand-held spectroradiometers, and related water quality, plant or foresrty measurement methodologies;
Imaging radar remote sensing for assessment of soil moisture, vegetation structure and biomass;
Instrumentation development for ground-truthing and measurement during remote sensing projects; and
Time-series analysis and data integration for regional/continental resource assessment.

Remote Sensing to Monitor Salinity and Vegetation Change

The CSIRO Mathematical and Information Sciences Remote Sensing group 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 terrai models will be used to produce the output map products.

Some of the technical aspects of the work include accurate registration of sequences of images, callibration and mosaicing of images and the integration oftime series of satellite images with landform maps using conditional probabilitynetworks. 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.

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 SiO_2 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.

The results will be presented at an international conference in the US later in 2000.

Dr Graham Harris, Chief of CSIRO Land & Water is the Australian CEOS (Committee on Earth Observation Satellites) Plenary representative. 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

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-sidelobes to minimize interference with other satellite services and to be compact to 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

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:

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 thirteen 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 (**Table 1**). The independent Chair of the Governing Board is the Honourable Tony Staley, former Commonwealth Minister for Communications. The Executive Director of the Centre is Dr Brian J J Embleton, former Head of the CSIRO Office of Space Science and Applications and past chair (1995/96) of the Committee on Earth Observation Satellites.

The participants provide the bulk of the Centre's resources, contributing some $AUD 38 million over the initial 7-year lifetime, while the Commonwealth government will contribute $AUD 18.6 million and the State Government of Queensland and South Australia a further $AUD2 million. The total resources available to the Centre over the financial year period 1997/2005 is about $AUS 58 million.

Table 1 Participants in Cooperative Research Centre for Satellite Systems

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

In addition to the formal participants above, who have signed mutually binding contracts to participate in the Centre for the seven years, the Cooperative Research Centre for Satellite Systems collaborates with the Australian Space Research Institute.

Research

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

Space science

This program is coordinated by Professor Brian Fraser at the University of Newcastle. 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;
To utilise GPS data to image ionospheric total electron content and the ionospheric elecron density distribution in the Australian region.

Satellite communications

This program is coordinated by Professor Mike Miller of the Institute for Telecommunications Research, University of South Australia. Professor Miller is also the Centre's Deputy Executive Director. The objectives of the program are:
To develop new communications techniques for the use in future small Low Earth Orbit (LEO) satellite communications and Earth observation constellations.
To develop innovative solutions to network management, and to satellite tracking and control.
To test applications in new services such as Two Way Paging, Mobile Computing and Internet Access for uses in remote areas; and
To find new solutions to the design of LEO satellite communications systems and networks that are robust in the face of interference and fading.

Satellite systems

This research program is led by Professor Miles Moody at the Queensland University of Technology, and has the following objectives:
to develop new techniques utilising GPS receivers on board LEO satellites for real time tracking, and for high precision determination of satellite orbit/attitude; the research will also develop techniques that would enable GPS corrections to be broadcast from LEO satellites to improve the accuracy of wide area global positioning systems.
to study the design of adaptable, high performance computing systems for use on board LEO satellites; modular, reconfigurable structures will be developed, together with formal verification techniques for satellite software systems.

Satellite engineering

This research program is led by Mr Chris Graham of CSIRO Telecommunications and Industrial Physics. Mr Graham 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.

The FedSat microsatellite

History

The Centre's first major project is the FedSat experimental microsatellite, announced by the Minister for Science, the Hon. Peter McGauran, in August 1996. The primary purpose of FedSat is

to celebrate Australia's technological capability, during 2001, the Centenary of the establishment of the nation of Australia.
A Request for Proposal for the platform was issued in February 1998. Space Innovations in England was the sucessful tenderer, and may become a supporting partner in the CRC subject to government approval. FedSat will undergo final construction in England during 2001, then payload integration and testing in Canberra during 2001.

Overview

FedSat is a small mission, approximately 58 kg and 50 cm cubed. Nevertheless it is a sophisticated science and engineering test satellite, the construction of which will afford learning experiences for the participants in the Centre, including the researchers, engineers, and students.
The satellite will have a sun-synchronous polar orbit with altitude about 800 km and period about 100 minutes. NASDA, the Japanese space agency, will launch the satellite gratis, probably in late 2001. The lifetime of FedSat should be at least 3 years.

Payloads

FedSat will carry 4 scientific payloads, plus a CD carrying messages from the Australian public.

NewMag magnetometer

The scientific objectives are to study small naturally occurring magnetic variations and waves in the frequency range 0.1 to 1 Hz; observe field aligned currents in the auroral zones and equatorial region currents; obtain real-time field data for space weather forecasting and modelling; and to derive vector measurements for magnetic field mapping in the Australian and other regions.
This experiment is led by the University of Newcastle and is expected to be performed in conjunction with the University of California in Los Angeles; NASA; the Australian Geological Survey Organisation, and others. Since the period around 2001 corresponds to a Solar activity peak, the scientific returns from this project are expected to be significant. The experiment has complementary objectives to ESA's Cluster mission.

GPS antenna

FedSat will carry a GPS receiver, both for satellite-tracking and for scientific purposes. The scientific experiments anticipated rely on the phase delay of GPS signals as a function of the length and properties of the atmosphere and ionosphere segment traversed by the signals. From these data, electron content, refractivity, and related parameters can be deduced.
The upper atmosphere (ionosphere) component of this experiment is being planned by La Trobe University, while the lower atmosphere (meteorological modelling and forecasting) experiment is being planned by CSIRO Atmospheric Research.
The Queensland University of Technology (QUT) aims to: improve the efficiency of tracking small satellites using GPS techniques; to improve the accuracy of terrestrial and marine positioning using on-board GPS; and to carry out experiments intended to improve on-board GPS processing.

Advanced Communications Payload

Small LEO satellites are the focus of increasing commercial interest in relation to global personal communications and data/multimedia networking. FedSat is expected to carry an advanced communications packages which will investigate:
new communication techniques using Ka-, S- and UHF-bands for communications and data delivery
Internet and ATM-like services
Advanced Earth terminals for communications, tracking and control
Advanced Radio Frequency sub-systems, including new Ka band antenna structures; GaAs-based Monolithic Microwave Integrated Circuits (MMIC) for Ka band; and measurements of the rate of degradation of GaAs devices in space.

The advanced communications payload is being led by the University of South Australia, with CSIRO Telecommunications and Industrial Physics, University of Technology, Sydney, Codan Qld. Ltd, the Defence Science and Technology Organisation and DSpace Pty Ltd, in close consultation with prospective user organisations in the telecommunications industry.

High Performance Computing

QUT is also leading an experiment designed to space-qualify an advanced computing device equipped with reconfigurable logic. The objective is to develop future, possibly commercial applications for on-board computing systems featuring data filtering and compression.

Public outreach payload

FedSat will carry a Compact Disc containing audio messages from the Australian public. A copy of the CD will be placed in the national museum of Australia.

Education

The Centre partner universities have 45 PhD and 12 Masters students enrolled in the following research areas:

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

The first enrolments commenced March 1998.

International links

The Centre has established links with several international organisations:

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

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Appendix 1: Acronyms

ATM	Asynchronous Transfer Mode
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ELF	Extra Low Frequency
EO	Earth Observation
EOC	CSIRO Earth Observation Centre
ESA	European Space Agency
GaAs	Gallium Arsenide
GPS	Global Positioning System
ITR	Institute for Telecommunications Research
LEO	Low Earth Orbit
MMIC	Monlithic Microwave Integrated Circuits
NASDA	National Space Development Agency of Japan
NASA	National Aeronautics and Space Administration
QUT	Queensland University of Technology
ULF	Ultra Low Frequency
UHF	Ultra High Frequency
UniSA	University of South Australia
UTS	University of Technology, Sydney
VHF	Very High Frequency

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Defence Science and Technology Organisation (DSTO)

Introduction

DSTO conducts an innovative R&D program in applied science. This program provides support and advice on the application of science and technology that is best suited to Australia's defence and security needs. Space research is a small but far-reaching component of this broad and intense defence program. Areas of research include surveillance and reconnaissance, command and control, communications, intelligence, military information systems and electronic warfare. Current research activities include the implementation of defence policy through the innovative use of space systems.

DSTO is organised into a number of divisions which address broad components of its R&D program. Space-related activities are addressed individually by these divisions rather than being collected under a single space-focused section. Surveillance Systems Division(SSD) has the principal responsibility for understanding the capability of space-based systems, for exploiting the recorded images and for integrating the intelligence achieved from these systems into more general network architectures. What follows is a selection of the major space research activities undertaken by DSTO in 1999/2000.

Ionospheric Research

SSD conducts research into the structure of the environment and its effect on radiowave propagation. In particular, the Electromagnetics and Propagation (EP) group studies those phenomena that can affect the operation of radars, communication links and GPS navigational systems. EP group monitors the ionosphere by means of ionosondes and TEC/scintillation receivers that are located across South East Asia. Additionally, it observes the ionosphere at long ranges by means of backscatter soundings from Alice Springs in central Australia. EP group is developing the capability to produce real time ionospheric maps from the output of these sensors and, in support of this, conducts research into real time mapping, ionospheric modelling, sensor data inversion and ionospheric radiowave propagation. In conjunction with these active measurements, the signal environment and background noise is continually monitored between 5 and 45 MHz.

Another major area of research in the group concerns ionospheric disturbances and their impact on radiowave systems. EP group monitors such disturbances through their effect on its system of ionosondes, HF channel probes and GPS scintillation receivers. The group carries out research into the modelling and prediction of scintillation and other disturbance related phenomena. A significant part of this research supports navigational warfare studies for GPS systems and for SATCOM.

Multispectral-Hyperspectral Surveillance Technology

The Spectral Sensor Assessment Lab within SSD is conducting research on the operational effectiveness multi and hyperspectral sensors for surveillance. Under this study a simulation software package - HISAS (Hyperspectral Imaging Surveillance Assessment System) has been developed. The software is used to simulate scenarios and synthesise hyperspectral images to test target detection performances.

A hyperspectral signature database has been created, which acts as the basis for investigating the usefulness of different spectral regions and in designing sensors. New target detection algorithms have been developed and tested. The theoretical work on target detection is backed up by significant data processing effort. Data have been collected through three trials, including a major trial (MUST2000) involving the TTCP countries.

The hyperspectral research has produced very encouraging results. The major attractions of the hyperspectral technology are: 1. high efficiency in target detection, 2. Target surface-material identification, 3. detection of small and partially hidden targets and 4. detection of soft targets such as camouflages and gas emissions. All these advantages have been demonstrated through trial results. It has been reported that a target detection rate and material identification rate of better than 90% is achievable under good lighting conditions.

SSD also represents DSTO on the Australian GNSS (Global Navigation Satellite Systems) Coordination Committee where it is responsible for the security implications of GNSS within Australia

SmallSat Study

A study on satellite surveillance capabilities was performed for DSTO by Auspace Ltd in conjunction with its parent company Matra Marconi Space UK. The study addressed small to medium sized (15000-3000kg, 2.5-6kW DC power) commercially available satellite options that could be procured to contribute to surveillance and reconnaissance of Australia's maritime approaches. A five year technology horizon was applied. The study was performed in a number of phases permitting an initial assessment of sensor options (electro-optic and radar sensors), development of single satellite options (satellite bus, payload, launcher, orbit altitude and inclination), and finally, assessment of three constellation options against a set of surveillance requirements developed for the study.

The study considered tasking of the satellites, collection of surveillance data by the sensors, and reception of the down-linked data at suitable ground sites on and off-shore from Australia. The study did not address the additional requirements associated with data analysis, exploitation and dissemination in detail.

A range of measures were developed to enable the effectiveness of the various options to be examined. These included spatial resolution of collected data, time to provide complete coverage of the region of interest, time to revisit to specific locations, and access opportunities for down-linking of data. Twenty-year life cycle costs were developed for the constellation options assuming a seven year individual satellite lifetime.

Global Positioning System (GPS) research:

DSTO’s Surveillance Systems Division (SSD) is Australia’s Centre of Expertise for Navigation Warfare (NAVWAR) and GPS. The Division has also recently installed a navigation satellite simulation (SATSIM) facility that is unique within Australia. It allows accurate replication of signals from the entire GPS satellite constellation, as they would be seen by a range of GPS technologies subjected to a variety of dynamic, environmental, and NAVWAR conditions. The SATSIM also allows replication of the signals received from the GLONASS satellites (GLONASS is the Russian equivalent of GPS) as well as many of the augmentation systems proposed for GPS.

SSD also operates one of the seven GPS monitoring stations that form part of the worldwide GPS control network. Data is relayed from this station to the United States in real time and then used to compute the navigation message ultimately broadcast by the GPS satellites.

SSD conducts operational analysis to quantify the military effectiveness of GPS. It also develops strategies and techniques for mitigating the effects of accidental and intentional GPS interference, as well as for preventing potentially hostile forces from exploiting the inherent operational capabilities of GPS.

DSTO Space Communications Activities

Broadcast Technologies

DSTO continues to refine the broadcast capability known as the Theatre Broadcast system. This system uses satellite communications to deliver large volumes of data to users via small, transportable satellite receive equipment. A large part of the research program has focussed on information management and a broadcast control suite allows the user to optimise information delivery based on available bandwidth. A low capacity satellite return link also allows the remote user to interact and browse for wanted data. This integrated return link also allows for e-mail connectivity to and from the remote site.

Mobile Communications

DSTO has been conducting an ongoing evaluation of commercial L band mobile satellite services in remote locations. This activity focused on the performance of these systems in the types of environment often encountered by users in the northern parts of Australia. The impact of foliage and terrain on the communications performance (voice quality, availability, messaging, data transfer, call dropout to name a few) has been the key aspect of this work.

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IPS RADIO AND SPACE SERVICES

Department Of Industry, Science And Tourism

In May, 2000, IPS was invited to become a World Data Centre (WDC) for Solar Terrestrial Science.

At the IPS Culgoora Solar Observatory, the principal radio equipment is a radio spectrograph that scans in frequency from 18 MHz to 1.8 GHz. These data are available, through the Web, during the forthcoming solar maximum. Data from the spectrograph, together with observations from WIND, have been used to track a coronal mass ejection from the corona into the solar wind.

The Learmonth Solar Observatory is a joint operation with the USAF Space Forecast Center. Continuous hydrogen alpha patrols and computer-automated patrols are supported by image processing methods. Solar images are archived digitally and are also available on the IPS Website. Radio observations are made on discrete frequencies (245, 410, 610, 1415, 2695, 4995, 8800 and 15400 MHz) as well as across the lower VHF band (30 to 80 MHz) with a swept frequency radiometer. A new Solar Radio Spectrograph based on the Culgoora design will be installed at Learmonth, in cooperation with the US Airforce during 2000. In addition to solar observations, a proton precession magnetometer and a three component fluxgate magnetometer are operated for AGSO, the data being sampled and recorded digitally every 5 seconds and used both for short-term and long-term monitoring. A high time resolution fluxgate magnetometer is managed for the solar Terrestrial Environment Laboratory (STEL) of Nagoya University and forms part of the STEL 210° magnetic meridian network. Finally, the US National Solar Observatory helioseismic observatory, part of the GONG network, is also operated at Learmonth.

IPS has a widely dispersed ionospheric network complemented by the two solar observatories. All sites operate at leastone vertical incidence ionosonde and some (Vanimo and Townsville) host oblique ionosondes. During the last year the vertical ionosondes have been upgraded at all sites, the aging IPS-4D ionosondes being replaced by either an IPS-5D ionosonde or a Canadian CADI ionosonde. Data are obtained in real time from Vanimo, Pt. Moresby, Darwin, Townsville, Learmonth, Brisbane, Norfolk Is., Mundaring, Canberra, Camden, Christchurch, Hobart, Macquarie Is., Scott Base, Casey, Davis and Mawson. The ionograms are scaled automatically and the data are used to generate real time ionospheric maps that are placed on the IPS Web site (http://www.ips.gov.au) and also used as the basis of a variety of real time services. The real time ionograms are all available from the IPS Website as they are obtained. The IPS autoscale software has been further improved and adapted to handle different ionogram formats. Data from the network has been used in a number of studies comparing model outputs with observations of the ionosphere.

To refine the IPS ionospheric predictions and achieve a more realistic description of ionospheric high-frequency propagation, a new computer code based on ray tracing has been developed. In contrast to the IPS Advanced Stand Alone Prediction System (ASAPS) kernel, which assumes mirror reflections from regular E and F regions and where ionospheric refraction is indirectly implemented via a reflection height model derived empirically, refraction effects and anisotropy caused by the spatially varying ionospheric electron density and Earth's geomagnetic field are taken into account. The code integrates the Haselgrove ordinary differential equations for both two-dimensional great-circle and three-dimensional general propagation in a spherical coordinate system. The Haselgrove equations are derived from Hamiltonians built on the Appleton-Hartree-

Lassen dispersion relation for a weakly collisional, cold and magnetised plasma. The code implements a wide range of one-dimensional, analytical and spherically stratified models for the electron density and electron collision profiles. The IRI 1995 and IGRF 2000 models have been implemented for three-dimensional propagation. A simple homing option using the `shooting method' based on the Newton-Raphson algorithm has been added. The spatial attenuation at the receiving end for any given ray is computed by calculating the divergence of a small triangular ray tube bounded by the ray itself and two neighbouring rays.

A new version of the IPS Ground Wave Propagation Prediction Software (GWPS 2.0) was created that features Electric Field vs Range graph and provision for the batch mode.

IPS makes total electron content observations at Vanimo and Culgoora. More recently, the effects of scintillation on GPS have been investigated by making observations from Vanimo, equatorward of the equatorial anomaly.

Geomagnetic pulsation indices have been derived from Pc3 pulsation data. A pulsation index has been defined as the rms value generated from 20 minutes of geomagnetic field data filtered over the Pc3 pulsation bandwidth. A network of stations may be used to produce contour maps of pulsation activity. Much of the work over the past 2 years has been involved with establishing a variometer network over the Australian region with an aim to producing near real-time pulsation activity maps for this region. Further, forecasting pulsation activity from recurrent pulsation index patterns and the relationship between daily pulsation indices and other geomagnetic indices such as Ap have been investigated.

Over the past 2 years the IPS magnetometer network has been expanded to include near real-time, high resolution, variometer data from Canberra, Townsville and Hobart. 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 rms value of the component data filtered over the Pc3 pulsation period range (10-45 seconds) and scaled by a factor of 10. Both types of indices are used to generate contour maps, which indicate the levels of geomagnetic activity for the associated period ranges. Magnetograms and time series index plots are also produced from the data, with the indices also used as the basis of several alert systems for space weather conditions.

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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 to applications in surveillance techniques and communications.

Ionosonde Studies of the Ionosphere

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

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.

Airglow Studies

A Fabry-Perot Spectrometer is operated at Beveridge to measure thermospheric winds and temperatures. In conjunction with Australian Antarctic Division, a similar instrument is operated at Mawson, Antarctica, and another at Davis, Antarctica. These instruments measure both thermospheric and mesospheric winds and temperatures. Major areas of study are 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. Simultaneous observations from Mawson and Davis are providing new important measurements of spatial structures in thermospheric winds and temperatures. Measurements from both stations of OH (6-2) airglow emission are being 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 Beacon Satellite Transmissions

Several projects are being undertaken to study the ionosphere in the Australian region extending from equatorial to high latitudes. These include computerised ionospheric tomography, mapping the ionosphere in the Australian and Antarctic region using the AUSLIG Australian Regional GPS Network (ARGN) and the Topex Oceanographic Satellite and the development of a dynamic ionosphere/plasmasphere model for GPS error corrections.

Collaborative Research Centre for Satellite Systems (CRCSS)

The mission of the CRCSS is to deliver a new, sustainable advantage for Australian industries and government agencies involved in services based on the application of future generations of small satellites. The University is a partner in the program to explore the properties of the ionosphere and exosphere in order to provide real time data for regional space weather forecasting. The Major project currently in progress is the microsatellite FedSat which is to launched to celebrate the centenary of Australia's Federation. Included in the payload is a GPS receiver which will be used to undertake limb sounding studies of the Earth's ionosphere.

National and International Meetings

The Space Physics Group hosted three conferences which were forums for space science research. These were:
South Pacific S-RAMP Meeting, held 27-28 September 1999 at the Bundoora Campus;
WARS'00, the biennial Workshop on Applications in Radio Science, held 27-29 April 2000 at the Beechworth Campus;
SuperDARN2000 Workshop, the annual meeting of the Super Dual Auroral Radar Network Group, held 22-26 May 2000 at the Beechworth Campus.

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The Hubble Constant

Seventy five years ago, when the Observatory was established at Mount Stromlo, the standard model of the Universe, the expanding Universe, was in its infancy. Hubble's evidence for the expanding Universe was a basic graph of the recession velocity of galaxies (how fast they are travelling away from us) versus his estimates of their distances. The velocities on Hubble's graph presented no great measurement difficulty, and they present even less difficulty to us today. Distances, however, were, and are, difficult to measure in the Universe. The closest stars to the Sun can actually be triangulated using the baseline of the earth-sun distance. But typical distances of stars within our own Galaxy, the Milky Way, are at the limit of what we can measure by this technique. More resolution was needed, and that was provided by the Hubble Space Telescope. Measuring galaxy distances with HST was designated a Key Project for the telescope in 1984. Specifically, the goal was an accuracy in the slope of Hubble's Law, which is known as the Hubble Constant, of 10%.

To measure distances of galaxies, Hubble and others before him and since used the method of standard candles. Cepheid variable stars are good standard candles. A Cepheid which varies in brightness with a certain period, say 20 days, has a fixed power output, like a 100 watt light globe. If we measure how bright such a star appears in a distant galaxy, we are able to measure the distance of that galaxy. If a 20 day Cepheid appears 100,000 times (10^5) fainter in the Virgo galaxy M100 than it is in the Large Magellanic Cloud, our nearest galaxy, then M100 is $10^{2.5}$ times further away than the LMC.

That is how the Hubble Space Telescope Key Project team has measured the value of the Hubble Constant, the ratio of galaxies' recession velocities to their distances. The velocities were known; the distances have been measured by finding Cepheids in galaxies to the limit of HST's resolution, which is ten times what can be achieved from the ground. Perhaps one should say *could* be achieved, because the Gemini telescope opened this year has started to out-resolve Hubble in the infrared.

Measuring Cepheid distances is not the end of the story in the Key Project, however. They only take us to roughly 25 megaparsecs (75 million light years), before one strikes the limit of what HST can do. So Cepheid distances have been used to calibrate four other standard candles which are measureable to much larger distances.

The first of these more powerful standard candles is a dynamical relation for spiral galaxies, called the Tully-Fisher relation. Spiral galaxies, like our own, support themselves against their own gravitational forces by rotation. Larger galaxies rotate faster. A galaxy with a rotation speed of, say, 200 km/sec (similar to the rate the sun is moving around the centre of the Milky Way) is

a standard candle. The HST project has told us the total power of this standard candle by measuring the distances of some of them. Henceforward, wherever we see such galaxies, we know their distances. The way the rotation speed of galaxies is measured is from the 21 cm emission line of hydrogen gas, which is abundant in galaxies. The Tully Fisher relation, calibrated by Cepheid distances measured with HST, allows one to measure the distance of galaxies up to 150 megaparsecs away, the limit of the Arecibo radio telescope.

Supernovae are another standard candle calibrated by Cepheid distances. These stellar explosions are visible to immense distances across the Universe, as Brian Schmidt of the ANU showed last year. Combining the constraints on the Hubble Constant from a total of four distance indicators, one obtains a slope for the velocity/distance relation of 71 +/- 6 km/sec/megaparsec.

The Hubble Space Telescope Key Project on the Extragalactic Distance Scale has been a 10 year team project supported by NASA's Space Telescope Science Institute. Partial support for Jeremy Mould's participation at the ANU as one of the co-Principal Investigators was provided by the International Science & Technology program of DISR.

MACHO

The Massive Astronomical Compact Halo Objects (MACHO) Project is searching for galactic dark matter by looking for its gravitational lensing effects on the light of background stars. The changing geometry of the lensing system as the lens moves relative to the background star causes the brightness of the background star to change with time. These 'microlensing' events can be detected by monitoring the brightnesses of large numbers of stars. MACHO began gathering data in 1992 using the 50 inch telescope at Mt. Stromlo, and now monitors roughly forty million stars in the Large and Small Magellanic Clouds, and in the Galactic Bulge. A large number of microlensing events have now been detected, with well over 200 along lines of sight to the Bulge, over 16 toward the LMC, and 2 toward the SMC.

During 1999 analysis was completed of the first 5.7 years of LMC data, including a careful determination of the experiment's detection efficiency. The results have been submitted for publication. In brief, the population of lensing objects detected in our first two years of data is confirmed by our new results, with smaller statistical errors. The fraction of dark matter represented by this population is still uncertain, but is roughly 20%. The mass of the individual lenses is around 0.5 solar masses. The controversy continues over whether these objects are a galactic halo population, or are somehow associated with the LMC itself. It now appears that this controversy may soon be settled by analysis of images from the HST. Ibata et al reported this year that they detected several moving objects in the Hubble Deep Field that have velocities, colors, and brightnesses consistent with very old halo white dwarfs, the most likely candidate for the MACHO objects. If confirmed, this result will be a conclusive confirmation of the halo nature of the MACHOs.

The MACHO project ended its observations at the end of 1999. Subsequent work will be exclusively data analysis on the very large database that has been accumulated. In addition to analyzing the entire LMC and SMC dataset, the team will fully analyze the data from the Galactic Bulge, an effort which is sure to lead to some exciting insights into galactic structure.

Probing the Universe in the Time Domain

Dr. Brian Schmidt leads a team of more than 20 astronomers on four continents who discover supernovae - stars which explode at the end of their lives with the energy of an entire galaxy. This team, known as the High-Z SN Search, mounted two search programs in 1999, using telescopes in Chile and Hawaii. The first program uncovered more than 20 objects, four of which were followed by the Hubble Space Telescope. These data will help pin down the expansion of the Universe to 8 billion light years, and help to confirm or refute the major result that the Universe appears to be accelerating in its expansion. In November an additional 25 objects were found, including the most distant supernova yet discovered, located some 9 billion light years away. While the simplest solution to these observations is still Einstein's Cosmological Constant - a form of energy that pervades every piece of space in the Universe, Schmidt is continuing to use these distant supernovae to see if a simpler solution might exist to these startling observations.

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Hydrogen-Deficient Stars and Related Objects (W. Lawson)

Warrick Lawson and Peter Cottrell (University of Canterbury, New Zealand) analysed Hipparcos satellite parallaxes and proper motions for 21 galactic hydrogen-deficient carbon stars. These stars had either negative or statistically insignificant parallaxes, indicating they lie beyond the detection capability of the satellite. Although the distances remain unknown, at least the observations did confirm that the galactic hydrogen-deficient carbon stars have high luminosity like the LMC stars, with $M_{bol} = -4$ to -5. Hipparcos proper motions allowed us to estimate the *UVW* space velocities, assuming $M_{bol} = -3$ to -5. The *UW*-velocity dispersion supports existing evidence that these types of stars have a predominantly bulge distribution.

Warrick Lawson, Marco Maldoni (PhD student, ADFA) Geoff Clayton (Louisiana State University), Albert Jones (Carter Observatory, New Zealand), Dave Kilkenny (South African Astronomical Observatory), and others, completely a study of archival low-dispersion International Ultraviolet Explorer spectroscopy of the R Coronae Borealis (RCB) star V854 Cen, obtained across several deep declines in the early-1990s. Analysis of the UV emission line spectra shows most features decayed on timescales comparable to that reported for optical features. Fe, Mg and neutral C lines decayed on timescales of 50–100 days and are believed to originate close to the star; ionised carbon lines decayed of timescales of > 200 days and are believed associated with an extended emission line region. We also reported the first detection of the C IV] 1550 transition region line, supporting the existence of a chromospheric region in these stars.

Warrick Lawson, Geoff Clayton, and others made the first observations of an RCB star with the Hubble Space Telescope Imaging Spectrograph. Evidence was found for CO bandheads and weak CO fluorescent emission in RY Sgr. The probable detection of CO is significant since the molecule is thought to play a significant cooling role during dust ejection episodes in these types of stars.

The *h* Chamaeleontis cluster – a nearby young open star cluster (W. Lawson and E. Mamajek)

Warrick Lawson, Eric Mamajek (MSc student, ADFA) and Eric Feigelson (Pennsylvania State University) announced discovery of the ? Chamaeleontis star cluster as the fourth known compact open cluster to the Sun. The cluster consists of 13 known systems, of which 12 were detected in a 42 ks ROSAT High-Resolution Imager pointing at a tight group of 4 ROSAT All-Sky Survey sources. The 12 X-ray sources were found to have stellar counterparts consisting of the B8 star *h* Cha, the A8 binary RS Cha, and 10 late-type weak-lined T Tauri stars (spectral types K3–M5). The thirteenth member is the A5 star HD 75505, which linked to the other stars via parallax and proper motion studies. The cluster lies at a distance of only 97 pc, determined to ± 3 pc from Hipparcos parallaxes. HR diagram placement indicates an age of 8–10 Myr, and that the cluster is pre-main sequence. The RS Cha binary is therefore one of few known pre-main sequence binaries with accurate dynamical masses. It promises to be a significant test for stellar evolutionary models.

Laboratory Astrophysics (G. Robinson)

Recent work in laboratory astrophysics has involved measurements, over the temperature range 10 to 140 K, of the 44 and 62 micron bands of H_2O ice deposited on amorphous carbon and amorphous silicate substrates, the substrates being in the form of thin films. The object of this study was to simulate the so-called core-mantle interstellar and circumstellar grains, with the specific aim of determining whether the core material has an effect on the temperature at which the H_2O ice mantle changes phase, from amorphous to crystalline. We found that the 62 micron emission peak, characteristic of the H_2O ice turning crystalline, first appears at a temperature of about 130 K, irrespective of the substrate material (Maldoni *et al*. 1999). The work constituted part of the MSc thesis of Marco Maldoni.

Studies of Star Formation Regions and Radiative Transfer Modelling

High mass star formation is often traced by the presence of Ultracompact (UC) HII regions, and such regions are often strong emitters in the 6.669 GHz methanol maser line. Our earlier survey of some 483 candidate regions with the Parkes Radio Telescope in the 6.669 GHz methanol line, resulted in 57 newly discovered masers. High spatial resolution (1.5 arcsec) observations using the Compact Array of the Australia Telescope (AT) at Narrabri have now been obtained and the resulting methanol and continuum maps of the sample published (Walsh *et al*. 1998). Near-Infrared images have also been obtained of many of the objects. Radiative transfer modelling has been used to represent the spectral energy distribution of eight of these UC HII regions. The models predicts the silicate feature at about 10 microns to be deeply in absorption for all eight objects modelled (Walsh *et al*. 1999).

Other recent work in radiative transfer modelling includes an investigation of the dust temperature in the vicinity of the source IRS2 within the southern HII region RCW 38 (Smith *et al*. 1999).

Interstellar Dust Studies (R. Smith)

With Ph.D. student Dale Quinn I am studying dust in the discs and bipolar outflows of stars in both the early and late stages of their evolution through an observational programme comprising infrared spectroscopy and imaging combined with theoretical modelling of the absorption and scattering properties of dust in different environments. Several evolved AGB stars and massive protostars have been studied in the far-infrared using observing time awarded on ESA's Infrared Space Observatory (ISO). Recently Ph.D. student Marco Maldoni has joined the group to work on aspects of the formation and evolution of ices on the dust grains in the circumstellar envelopes of AGB stars and protostars. We are continuing development of a theoretical model for ice formation in circumstellar envelopes.

We have continued our laboratory programme with Walt Duley to study laboratory analogues of mixed and pure interstellar ices and dust grains. In conjunction with this programme we have also been looking into the theoretical aspects of the formation of ices on interstellar dust grains.

High Energy Astrophysics (R. Sood, S. James, P. O'Neill)

The High Energy Astrophysics Group continued its activities in the investigations of X-ray binaries over a range of wavelengths. GX 339-4 was studied at radio wavelengths (MOST and ATCA) over a period of four years. Comparison with X-ray data showed a clear correlation between emission at the two energy regimes. However, no changes in emission at these energies or at gamma-ray energies were seen during the time of a possible jet ejection.

Radio and X-ray measurements of 4U1630-47 made during the 1998 outburst suggested that the emission came from an elongated, optically thin jet along the axis of the accretion disc. The ATCA radio observations detected linear polarisation up to 28%, unusually high compared to the norm for radio sources of less than 10%.

A programme of millimeter wavelength observations of galactic jet sources using the MOPRA telescope was continued in collaboration with Dr. Ph. Durouchoux (CE Saclay). Strong evidence was obtained for the interaction of the jet in SS433 with the W50 shell that would have resulted from the supernova explosion in this system. Observations of the soft gamma-ray repeater SGR 1814-13 enabled us to establish the galactic distance to this very rare class of objects.

A programme has been started into the investigation of the timing properties of Z- and Atoll-sources, using archived data from several X-ray satellites. This programme will form the basis of the PhD thesis of P. O'Neill.

Investigations continued into the properties of X-ray astronomy proportional counters filled with gases at pressures up to 30 atmospheres. Argon-ethylene mixtures show very high gas gains compared to conventional argon-methane mixtures, with a dramatic reduction in operating voltage without sacrifice of energy resolution.

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School of Physics

Ionospheric Physics

Research has been proceeding in the following areas:

- Simulation of the lunar geomagnetic tide using the equivalent circuit model
- Analysis of lunar variations in upper atmosphere winds over Collm and Djakarta
- Analysis of lunar variations in the ion drifts at Jicamarca
- 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 satellite

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THE UNIVERSITY OF QUEENSLAND
The Centre for Hypersonics

Introduction

Technology developed in Australia over the last 30 years has lead to the establishment of several free piston driven shock tunnels with Earth orbital simulation capability in the USA, Europe, Japan and in Australia itself. Such facilities have proven to be extremely useful for the study of hypersonic aerodynamics with real gas effects, for scramjet combustion, and for fundamental high speed shock wave studies. Australian expertise in this field has enabled researchers to be involved in projects of international significance, and be core contributors to a multinational collaborative research network. The Australian hypervelocity facilities are located at the University of Queensland Centre for Hypersonics and the Australian National University.

The Centre for Hypersonics at The University of Queensland (UQ) had its foundations in the development and use of free piston shock tunnels for the study of scramjet combustion. This was pioneered in the 1980's by research groups at UQ and the Australian National University (ANU), and has lead to substantial advances in this technology, including the development of the first scramjet engine to produce more thrust than drag. This work has been well supported by the ARC and the NASA Langley Research Center. The scramjet technology and development has matured to such an extent that plans are in progress to launch a scramjet engine, designed at UQ and tested in their shock tunnel, on a rocket supplied by the US company Astrotech.

Recent work by the Centre for Hypersonics at UQ has transferred this tunnel technology to the expansion tube concept, leading to the development of a new class of test facility capable of simulating flows in excess of Earth orbital speed. This creates the possibility of simulating in the laboratory aerodynamic flows around potential spacecraft body shapes for a range of space missions which are of great interest to mankind, and which cannot be experimentally tested on Earth in any other way.

The Centre for Hypersonics also has major strengths in instrumentation development. In the past eight years instruments have been developed to measure forces, skin friction, species concentrations, radiation and driver-gas contamination. In addition non-intrusive diagnostic techniques have also been developed for both the expansion tubes and shock tunnels at UQ and the ANU, respectively. These devices, techniques and associated expertise are unique, and their continued development and use has allowed the Centre to lead many areas of research. It has lead to collaborative agreements with NAL (Japan) and the DLR (Germany) and forms a significant portion of all our international collaboration programs.

UQ facilities at the Centre for Hypersonics include;

- **T4 reflected shock tunnel.** Commissioned in 1987 is capable of simulating flight speeds up to 8 km/s. This was the first shock tunnel designed specifically for scramjet testing, and has performed more scramjet tests than any other facility in the world. It has also been widely used for aerothermodynamic testing and instrumentation development.
- **X3 super-orbital expansion tube. (under construction).** This facility with a length of 65m and a bore of 182 mm will be the biggest expansion tube in the world, with estimated speed

capability in the range 15 to 20 km/second. Designed for testing aerodynamic phenomena associated with very high speed atmospheric entries. Expected to be commissioned in July 2000.

- **X2 super-orbital expansion tube.** This facility has a bore of 85 mm, and uses a twin piston compression process also used on X3. Commissioned in 1995, it simulates flows up to 11 km/second. Primarily for the study of reentry bodies at very high speeds.
- **X1 super-orbital expansion tube.** Commissioned in 1990 as a double diaphragm expansion tube converted from a reflected shock tunnel, this facility has a bore of 38 mm, and was the proof of concept study for the super-orbital operating mode. Flows up to 14 km/second created, it is the most frequently used expansion tube in the laboratory due to its ease and cheapness of operation.
- **D1 Detonation tube.** Commissioned in 1992, this facility has a bore of 60 mm, and is used for investigating the viability of detonation processes in scramjet combustors.
- **Drummond tunnel**. Small clean shock tunnel for diagnostics testing.
- **UQ Blow down tunnel**. Small supersonic blow down tunnel for low enthalpy intake testing.
- **Loepard light gas gun/reflected shock tunnel.** This test facility built for fundamental studies of driver operation is to be configured for use as a light gas gun or a shock tunnel. To be used for small scale testing of concepts before application in the larger facilities, and to initiate light gas gun testing in Australia.

Hypervelocity Propulsion Development

If humans are to become a genuine space-faring race then a less expensive and more reliable means of access to space than present day rockets must be found. Hypersonic airbreathing propulsion theoretically promises such a means, but a great deal of research must be done before this promise can be brought to reality. This research is being pursued in laboratories around the world. The contributions of The University of Queensland (UQ) to this world effort is two-fold: First, UQ is playing a leading role in developing the use of shock tunnels for this type of research. This is an important role as shock tunnels offer the only practical means of covering the range of velocities over which it may be expected that hypersonic airbreathing propulsion will be used. Second, UQ is the leader of the HyShot Flight Program, which is an international consortium (Australia, UK, USA, South Korea and Germany) that will conduct scramjet flight experiments, by extending sounding rocket technology. The first experiments undertaken by the consortium will be the correlation of flight data on supersonic combustion with shock tunnel data.

The broad objective of the Hypersonic airbreathing propulsion research is to develop the supersonic combustion ramjet (scramjet) as an efficient means of airbreathing flight propulsion, at speeds that allow economical launch into Earth orbit. To further this objective, this program is directed towards:
Testing the utility of new or mostly untried concepts (ie. intake fuel injection, combustion induced boundary layer skin friction reduction and shock-induced combustion) to improve the performance of simple shock tunnel engine models.
Developing, through ground testing, an engine capable of efficient atmospheric flight, and
Resolving the uncertainty concerning the application to flight of wind tunnel performance measurements, by flight testing the engine arising from (a) and (b) above.

Performance enhancing techniques have been identified and if they prove to be as successful as preliminary experiments suggest, then this project will play a major role in opening the way for hypervelocity airbreathing propulsion. Because, Australia will be at the forefront of this development, it would be expected that it would reap the rewards for having the initiative to invest in this research.

In addition, this project will also attempt to further develop sounding rocket techniques for hypersonic flight experiments. This approach will be tested in the HyShot Program. It is much cheaper than previous flight programs because it avoids the engineering exercise to develop a new comprehensive flight-worthy vehicle. Hence, although the engineering requirements still drive the science, there is a major reduction in the engineering overheads. This new approach to this research allows the scientific objectives to take greater precedents than previously possible. Again, being the first to develop this approach will have a major impact on Australia's position in any future international collaboration and participation in these and related activities.
This type of project has immediate impact on the wider community. It generates tremendous excitement and is used as an example of engineering prowess. It is also used to promote public awareness and attract students towards engineering and science.
In general, it is expected that further international respect for Australia's capabilities to undertake hypersonic and hypervelocity activities would result from this project. It would be expected that this would lead to closer ties with international organisations, reducing the dependence on national funding.
In particular, the outcome from the planned testing to be undertaken in T4, will be a better understanding of the interaction between different aerophysical phenomena which influence the performance of an operational scramjet. This will include the interaction between the intake, the fuel injection system, skin friction and heat loads and the effect they have on the overall thrust production. It will provide another stepping stone towards the realisation of inexpensive space access through the use of airbreathing engines.
Finally, the main scientific outcome expected from the flight trials is a correlation of the thrust measured in a shock tunnel with that measured in flight.

Preliminary Studies

In this section an overview is given of the scramjet investigations which have been undertaken in the Centre. An overview is also provided of the HyShot Flight Program.

Hypervelocity Propulsion Overview

The hypervelocity propulsion program was designed to increase the efficiency of scramjets by developing greater understandings of the engine's aerophysics. In general, aerophysics covers a broad range of topics, but the applicant's studies have considered.

- Skin friction
- Intake geometries
- Intake fuel injection
- Boundary layer separation
- Thrust nozzle geometries
- Shock induced combustion and
- Component interaction

This research followed the development in T4 of a silane/hydrogen fuelled model scramjet that produced positive thrust (at elevated freestream temperatures) (Paull *et al* (1995)) and also the development at UQ of a force balance that could measure this thrust in a shock tunnel.
Throughout the project the scramjet efficiency has increased. A cruising hydrogen fuelled engine model was developed midway through the project (Stalker and Paull (1998)) and just recently a

hydrogen fuelled accelerating model has been developed. Although these milestone achievements are important, they are not as significant as the understanding of the aerophysics that lead to them. To develop this understanding, experiments have been made on either one component of the engine in isolation, or on simple engine configurations that are aerodynamically complete. Early in the project, the overall performance levels of these engines were much lower than expected, and to develop an understanding of this shortfall, the following investigations were made.

Skin friction measurements

Point measurements of skin friction in a combustion chamber have been made by Goyne *et al* (1999). Measurements were also made using the force balance of the integral internal skin friction loads of a combustor (Tanno and Paull (1997)). These measurements confirm that the viscous drag of a combustor is the dominant aerophysical parameter that will limit the upper flight speed of a scramjet, unless ways to reduce it are obtained.
In response, investigations of the reduction of the viscous loads produced by film cooling a duct with hydrogen were made. These measurements showed that skin friction could be at least halved. Furthermore, this reduction in drag is sustained well after the thermal protection afforded by this technique is of any significance. It was also observed that it requires some burning of the fuel to produce this reduction. This was an unexpected observation, the physics of which is not yet fully understood. Experiments are currently being undertaken to determine if the reduction in skin friction load is still realised in an operational combustion chamber, where there are major pressure disturbances present (Paull ARC Small 1998).

Intake geometry

The cowl of the combustion chamber is an important part of the intake. It was shown, that provided the shock from the cowl which turned the flow into the combustor, impinged downstream of the corner between the combustor and intake, the combustion chamber would support supersonic flow with combustion (Paull (1999)). But, if it impinged upstream of this corner, it would separate the boundary layer on the intake and subsequently choke it. This was consistent with results obtained in continuous facilities and was the first evidence that shock tunnels could reproduce results associated with these recirculation zones.

Intake fuel injection

In response to reduce the combustion chamber length, preliminary investigations into mixing fuel on the intake were made. Once the aerophysics of the intakes without fuel injection was established, intake injection that did not burn the fuel on the intake was relatively straight-forward to develop (Paull (1999)). It was demonstrated that the combustor length (and its viscous drag) could be halved using this approach. This research is being extended by McIntyre *et al* (ARC Large 1999) to investigate with optical techniques if combustion occurs in the intake's boundary layer when the intake is hot, as it would be in a flight vehicle. Although this technique looks promising, because our experiments were made with a simple wedge intake, it is unknown if it can be applied to more complex intakes. Hence, further research is needed in this direction.

Boundary layer separation

Boundary layer separation in the combustion chamber is of primary concern as it limits the amount of fuel that can be burnt and therefore limits the thrust that can be developed. It has been shown (Paull (1999)) that the correlations developed by Korkegi (1975) predict the pressure rise that will induce separation in the combustor. This highlighted the importance of divergent combustion chambers, which effectively relieves the pressure rise produced by combustion. However, finesse is need in choosing the divergence, as too much divergence quickly quenches the burning process.

Shock-induced combustion

The flow entering the combustion chamber can have an average temperature and pressure of approximately 800K and 130kPa, respectively, and without a flame holder or plasma jet, this average temperature is too low to sustain combustion. However, the cowl can be designed to produce a large shock that passes through the combustor. The shock produces temperatures and pressures in regions of the combustor that are of the order of 1200K and 200kPa, respectively (not unlike the diamond region produced by the Busemann inlet proposed by Ferri (1973)). These conditions are ample to sustain combustion and good combustion is observed despite the low mean temperatures in the combustor. When used in conjunction with upstream injection, the advantages of this shock-induced combustion are reduced skin friction loads on the combustor and better heat release from the fuel. The combustor can be shortened as the combustion is effected locally at higher temperatures, and the average skin friction load on the combustor is reduced, because the average freestream dynamic pressure is lower. It is well known that better heat release occurs at lower temperatures and it has been observed that the average pressure rise produced by combustion is close to that expected from the mean combustor intake temperature, and thus, greater efficiency is also obtained for this reason. Although this technique is promising, research is needed to determine its limitations.

Component interaction and final remark

Although these results have been presented in some isolation from one another, scramjet development is interesting because these different aerophysical phenomena interact with one another. For example, simply changing the intake compression angle will, alter the intake efficiency (due to changes in the boundary layer and entropy generation), effect the upstream injection, change the cowl position and maximum pressure rise which can be sustained in the combustion chamber. Hence, a complex change in the performance can result from a simple parameter change, and unless the aerophysics is understood, there is little hope of predicting such a change. One of the goals of this research is to continue to develop this understanding.

The HyShot Flight Program – Overview

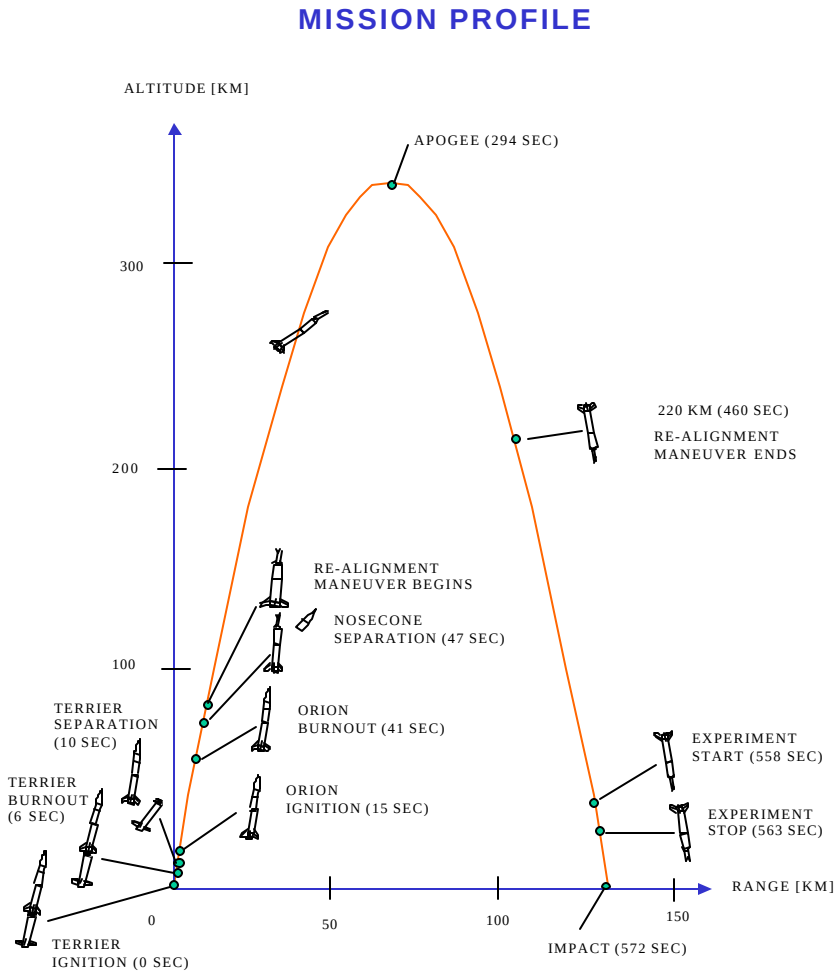
There is little doubt that the most ambitious part of this proposal is undertaking the flight program. However, the applicant leads the HyShot Flight Program and has gained extensive experience in doing so. HyShot is designed to develop a correlation between the pressures measured in a

supersonic combustor operated in T4 and that measured in flight. Two flight trials are expected to be completed by mid 2000.

At present, formal publications on the procedures and difficulties encountered in the development of a suitable trajectory and payload for the HyShot Program are not available. However, the program has gone through three critical design reviews. The most recent (Jan. 2000) was with personal from NASA Langley and Goddard Research Centers. As a result of this latest review, the program has been advised to continue with integration of the payload in readiness for the trials.

The HyShot Program uses a two stage Terrier-Orion Mk70 rocket to boast the payload and the empty Orion motor (the Orion motor remains attached to the payload) to an apogee of approximately 330km, as shown in Fig. 1. As the spent motor and its attached payload falls back to Earth, they gather speed, and the trajectory is designed so that between 35km and 23km, they are travelling at Mach 7.6. It is during this part of the trajectory that the measurements of supersonic combustion are made.

Figure 1. HyShot Mission Profile



As the combustion process in the scramjet are dependant on the ambient pressure, a highly parabolic trajectory with a near vertical decent during the test time was chosen, so that a correlation could be developed over an envelop of ambient pressures. In addition to the scientific merits, a vertical trajectory is also more cost efficient and there are less structural difficulties resulting from the lower heat and dynamic loads.
However, one difficulty with this trajectory is that small aerodynamic forces act on the motor and its payload during re-entry to the atmosphere. This makes it difficult to turn the payload into a downwards direction, which is necessary for the experiment to function. To alleviate this problem, the payload is rotated so that it is correctly oriented before it re-enters the atmosphere. Developing this procedure has required extensive research at UQ, however the algorithms and thruster design to perform the maneuver have been approved by the consortium and are due for ground testing in early 2000.

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UNIVERSITY OF SOUTH AUSTRALIA

Satellite Communications R & D in the Institute for Telecommunications Research

A partner in the CRC for Satellite Systems

Institute for Telecommunications Research

The Institute for Telecommunications Research (ITR) is one of Australia's largest research organizations in the field of satellite communications and terrestrial wireless communications. The work of ITR's 80 research staff and postgraduate students aims to develop new techniques in the field of terminals, network infrastructure and services for wireless and satellite information networks. Particular emphasis is on the use of coding and digital signal processing techniques for mobile communications systems.

ITR is a core partner in the Cooperative Research Centre for Satellite Systems (CRCSS) established by the Australian Government. ITR's role is to lead the satellite communications research program in CRCSS, which is focussed on the applications of future generations of small satellites.

The following summarises key ITR space related activities in the period 1998-9

Coding and modem techniques for bandwidth-efficient satellite communications

Under the leadership of Associate Prof Bill Cowley, good progress was made in the development of techniques for applying turbo codes to improve the efficiency of satellite communications links. Turbo codes represent a relatively new error control coding technique which can be used to dramatically improve satellite transmission efficiency. By combining turbo codes with new modems using higher order modulation schemes, the bandwidth efficiency of satellite transmission can be significantly increased. These techniques are expected to replace many of the traditional coding and modem methods which have been used in satellite communications over the past decade.

The CRCSS team of UniSA and DSpace researchers has now achieved an international reputation for turbo coding techniques. This has been demonstrated by their success in winning an impressive number of commercial contracts with overseas companies, including Intelsat (USA), Inmarsat (UK) and ICO (UK).

Considerable progress has also been made in the further development of demodulators for ground stations receiving high speed image information from remote sensing satellites. This has led to commercial contracts for the supply of these demodulators to organisations in Australia and overseas.

Architectures and protocols for satellite-based Internet services

Over the past two years, the explosive growth in demand for Internet services has had a dramatic effect on the approach to telecommunications system design. It has become clear that new satellite and terrestrial communications network techniques to accommodate Internet services have now become essential. The research of the CRCSS team over the past year has led to the development of new architectures and protocols for satellite-based Internet services. A commercial contract was won with Inmarsat for satellite resource management studies. This study was led by Dr. Nirmala Shenoy (UniSA) and Dr Mark Rice (DSpace).

Earth terminals for communications and control of satellites in low earth orbits

Under the leadership of Associate Prof Sam Reisenfeld of UTS, considerable activity was focussed on the development of new types of Ka-band earth terminals for communications to satellites in low earth orbits (B3 Subprogram). Good progress was made in the development of two Ka-band small earth terminals for experimentation with FedSat. This has included the development of innovative techniques for tracking LEO satellites.

Prof Steve Seumahu of UniSA has also led a team designing and installing satellite ground station facilities at UniSA for telemetry, tracking and control (TT&C) of FedSat and other LEO satellites. This is likely to lead to opportunities for international collaboration. Cooperative arrangements are being negotiated with research groups in other countries including Korea, Singapore and Malaysia for utilising the CRCSS TT&C station to carry out joint experiments with experimental satellites being launched by each of these countries.

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Space Plasma Physics Group

Department of Physics

Research within the Space Plasma Physics Group is concerned with a number of aspects associated with waves, the ionosphere and the magnetosphere. These include the study of ultra-low frequency (ULF) hydromagnetic waves in the Pc3 (10-100 mHz) band at low latitudes; the transmission of Pc3 hydromagnetic waves through the ionosphere; the propagation of long period ULF waves in the Pc5 (1-10mHz) band at high latitudes in Antarctica; high latitude studies of magnetosphere-ionosphere coupling; and spacecraft studies of hydromagnetic and ion cyclotron waves in the middle magnetosphere.

The group is also a core partner in the Cooperative Research Centre for Satellite Systems, which will build the first Australian satellite in thirty years, FedSat-1. To be launched in 2001 this LEO microsatellite will carry the NEWMAG magnetometer experiment to measure the Earth's main field and ULF waves.

High Latitude ULF Waves

Plasma waves are important in distributing energy of solar wind origin throughout the magnetosphere and down to ionospheric altitudes. General studies using the Group's Antarctic magnetometer array (Casey, Davis, Mawson and Macquarie Island) and from the IMAGE array in the Arctic have shown that Pc1-2, Pc3 and Pc5 pulsations are generated specifically in the outer magnetosphere, and the boundary layer and cusp regions. Long period (1-10 mHz) waves generated by boundary layer instability processes such as the Kelvin-Helmholtz instability, have been found to couple to field line resonances at plasmatrough latitudes.

Studies of Pc1-5 waves undertaken near Davis Antarctica, using a small network of induction magnetometers located in a triangle of side 120- 150 km allowed direction of arrival determinations of daytime quasi-structured and unstructured Pc1-2 emissions. These were found to be associated with sources on closed field lines in the outer magnetosphere. This region or the boundary region just inside the magnetopause may also be the origin of a prenoon Pc1-2 band, possibly a consequence of electromagnetic ion cyclotron wave (EMIC) generation resulting from ion injection into the magnetosphere from the dayside cleft. It has also been shown that these waves may propagate over short distances (< 500 km) but are not propagated in the ionospheric F2 region waveguide.

Detailed studies of Pc5 field line resonances using the small network revealed a pattern of longitudinal phase characteristics that can be related to resonance structures for Kp<3, when the Davis region is under closed field lines. At times of higher geomagnetic activity this phase pattern

collapses, indicating that the network is under open field lines. These studies have provided a valuable introduction in the use of ULF waves as boundary region locators and may be employed in space weather diagnostic studies in the future. To examine these aspects in more detail, we deployed two portable fluxgate magnetometers approximately 120 km inland from Davis over summer 1999 – 2000. These are new solar-power instruments (see "Instrumentation") and this study was partly a pilot project for a more extensive campaign involving operation over a full year.

Conjugate studies of low azimuthal wave number Pc5 waves between Longyearbyen on Svalbard, and Davis and Mawson at times of low Kp show a phase relationship that places the Longyearbyen conjugate point midway between Davis and Mawson. This agrees with the T87 model and the technique is being used to compare measured conjugate locations with geomagnetic field models.

In the Pc3 band, it has been found that both coherent and incoherent waves are resident in the cusp and boundary layers. The coherent portion has been identified by wave propagation characteristics between spaced stations in Antarctica and the Arctic, including interstation phase, coherence and polarisation. Comparison of conjugate Pc3 and Pc5 data indicate common wave packet structure in the 30 mHz and 5 mHz bands, again supporting the concept of closed field line oscillations. However, while the 5 mHz pulsations are most likely field line resonances, it seems unlikely the 30 mHz signals are higher harmonics of this.

We have found that the high latitude signals may represent the signature of external sources in the upstream solar wind, or cavity or waveguide mode oscillations in the outer magnetosphere. In particular, we have found that there exists a sub-class of monochromatic Pc3-4 pulsations that exhibit high coherence over about 1000 km and propagate poleward. 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.

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.

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

A related new development is the installation and operation of an imaging riometer at Davis in Antarctica. The instrument is operated as a cooperative program between the Newcastle Group, the University of Maryland and the Australian Antarctic Division. It 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.

Hydromagnetic Waves at Low Latitudes

Studies here have focused on identifying the signature of field line resonances (FLRs) of standing, shear Alfven mode oscillations of magnetospheric field lines. Previously these have been recorded by satellites, but their rapid motion means that at low latitudes ground measurements are important. An important aspect involves using the observed FLRs to monitor the magnetospheric plasma. The satellite observations of FLRs agree with model calculations using realistic plasma density profiles. These resonances are also seen at low latitudes suggesting that the excitation energy must be present deep in the inner plasmasphere. The favoured excitation mechanism for low latitude shear Alfven mode ULF resonances involves incoming compressional mode MHD waves at least partially in the form of cavity oscillations. Common features of low latitude observations are both latitude independent and latitude dependent spectral peaks.

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

A conjugate study of substorm-associated transient Pi2 pulsations at very low latitudes, using Newcastle and Nagoya University STELab 210° meridian chain conjugate data has carefully defined the latitudinal and longitudinal spatial phase properties with respect to the location of the substorm current wedge. The conjugate signals exhibit similar spectral properties across L = 1.03 to L = 2.1 with frequencies above 20mHz dominating. At higher latitudes, up to L = 5.5 frequencies below 20 mHz are stronger. These results and conjugate and intra-hemisphere phase information along with 1-D MHD modelling suggests that Pi2 waves at high latitudes are due to transient standing field line oscillations driven by compressional mode waves propagating away from a substorm current system. The equatorial and low latitude signature is considered to be driven by a magnetospheric cavity mode wave.

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

The development of the cross phase technique allows the determination of the temporal evolution of field line resonances even when power in the spectrum is dominated by other wave modes. This enabled the comparison of eigenfrequency calculations based on the IRI/DE and Bailey plasma

models with low latitude magnetometer data, with the latter model proving more successful. While the effects of heavy ions (He^+, O^+) on ion cyclotron wave propagation in the magnetosphere are well known, the effects of heavy ions in the thermosphere and ionosphere on low latitude field line resonances can now also be evaluated. Using consecutive harmonics of ULF field line resonances, a technique has been developed to determine the cold plasma mass density at discrete sites along the field line without imposing a plasma density model. This brings the remote sensing, in near real time, of inner plasmasphere cold plasma dynamics a step closer to reality. Other important properties which can be determined are the Q of the field line resonance, the scale size of the flux tube, and the ionospheric damping rate. It is therefore becoming possible to diagnostically monitor the plasmasphere from the ground. Our increasing knowledge of the properties of low latitude ULF pulsations is important to applied aspects of geophysics.

This work has been applied in one particular study to monitoring spatial and temporal variations in plasmaspheric plasma density. This was done with the cross-phase technique by measuring FLRs across L=2.8 - 3.9 using ground magnetometers in Tasmania, the UK and Scandinavia (stations of the SAMNET and IMAGE arrays), and thus calculating the associated plasma density and resonance properties, and their variation with time and location. The plasma density calculations were also compared with ducted VLF whistler mode electron density determinations for the same paths. These produced good agreement, suggesting that over this range of latitudes the plasmasphere may be represented by a two component (protons and electrons) medium. This has also demonstrated a longitudinal asymmetry in plasma mass density and has allowed the plasma mass loading to be estimated. The ability to monitor plasma densities with good time resolution for extended periods has been demonstrated.

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 downgoing hydromagnetic waves, and exhibit high correlations with ULF pulsations on the ground. We have developed the ability to routinely monitor these signals in the ionosphere, and spatial and temporal variations in their properties.

A surprising finding is a clear linear phase relationship between the ionospheric and magnetic signals, which argues against present models involving field line resonances. Studies using a large network of stations across Australia have shown spatial phase differences in the ionospheric oscillations consistent with ground observations of propagating ULF wave features. We have taken previous models and extended them to include ULF fast mode waves in the ionosphere. The models include a realistic ionosphere, observed wave numbers, and any magnetic dip angle. They can thus be applied to real situations. The modelled phase and amplitude relationships between the ionosphere and ground magnetic signals at low latitudes agree with the experimental data over the ULF range of 10-100 mHz. This more complete model explains why agreement in the past between theory based on the shear Alfven wave mode only and experiment have not been good. We are pursuing this work to be able to predict the effect on over-the-horizon radar data based given the ground based magnetometer data.

Spacecraft Studies

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

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

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

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

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

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

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

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

Instrumentation

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

The group has recently obtained 10 low power fluxgate magnetometers developed by Narod Geophysics, Canada. These are palmtop data loggers and are powered by solar panels. They will be used for array studies at remote locations in Australia and Antarctica in future campaigns.

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

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