CIMSS - 25 Years Improving Meteorology in the Northern and Southern Hemispheres
An ABM and JCSDA Perspective
Global RAOB Coverage
Hemispheric Analysis 9 June 1963
Conventional Data Coverage
The Australian UW/CIMSS Link

<table>
<thead>
<tr>
<th>Year</th>
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<tr>
<td>1969 - 71</td>
<td>Bill Downey</td>
<td>Dynamics of Extra-Tropical Cyclones</td>
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<tr>
<td>1970 - 71</td>
<td>John Zillman</td>
<td>A study of some aspects of the radiation and heat budget of the SH oceans</td>
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<td>1976 – 77</td>
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<td>1978 - 79</td>
<td>Graeme Kelly</td>
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<td>ARPE, METANAL, initialisation</td>
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<td>John Le Marshall</td>
<td>ARPE/Impact Expts, Normal Modes</td>
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<td>1984</td>
<td>John McGregor</td>
<td>Normal Modes</td>
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<td>1986 – 87</td>
<td>Lance Leslie</td>
<td>ARPE</td>
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<td>1988 (March - Oct.)</td>
<td>Bob Seaman</td>
<td>univariate SI, 3DVARBL</td>
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Surface pressure analysis including satellite data
a) 23 Aug 1975 b) 24 Aug 1975

24 hour prognoses valid 24 Aug. 1975
a) using no satellite data and b) including satellite data
OPERATIONAL SYSTEMS AT THE AUSTRALIAN OF METEOROLOGY (ABM) DEVELOPED THROUGH COLLABORATION WITH CIMSS

- Polar Orbiting Direct Readout System
- Direct Readout RT TOVS Processing System (1980)
- Physically Based RT TOVS Data Processing System (1985)
- Australian Region McIDAS (SSEC/CIMSS) (1986)
- GMS S-VISSR Processing System (1990)
- Atmospheric Motion Vector System (1991)
- Solar Radiation System
DIRECT READOUT TOVS SYSTEMS

- Statistical (Discriminant Analysis) system (1982). Output used in NMC for 1000/500 THK bogus of regional model.


- Physical Perturbation Solution of RTE. Using single level Cloudy Radiances (Expt. 4.5) Assimilation of Thick Layers in Operational Regional Model (1994).

- ARM (Australian Region McIDAS) based 1D VAR Solution of RTE for ATOVS and Assimilation of Thick Layers (1999).
A Satellite-Based Operational System for Upper Air Analysis in the Australian Region

G. A. KELLY, B. W. FORGAN, and P. F. POWER

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Head Office, Bureau of Meteorology, Melbourne, Victoria, Australia

The Australian Bureau of Meteorology has had the capacity since May 1980 to receive, process, and utilize routinely sensed meteorological data from the TIROS-N/NOAA A series of satellites. This paper describes the hardware established for data reception, the methods used in the extraction of meteorological data, initial assessment of these data, and the final configuration of the operational system.

1. Introduction

Launching of the TIROS-N series of satellites began in October 1978. These satellites are operational observation platforms supplying large amounts of data dealing with the Earth’s surface and enveloping atmosphere. The TIROS-N Operational Vertical Sounder (TOVS) instrument packages on board these satellites allow vertical temperature and moisture structures (soundings) to be calculated between the surface and the stratopause. Ideally two satellites are operational and are in sun-synchronous polar orbit at any one time. With two satellites this implies a full global coverage every 6 h.

The TOVS package consists of three radiance measuring instruments: the High resolution Infrared Radiation Sounder (HIRS), sampling at 20 infrared frequencies; the Microwave Sounding Unit (MSU), sampling at four microwave frequencies; the Stratospheric Sounding Unit (SSU), sampling at three infrared frequencies. Typical scan patterns of the HIRS and MSU instruments across the suborbital track are shown in Fig. 1. The SSU instrument resolves a circular area 17 km in diameter at the subsatellite point whereas the MSU resolves a circular area of 110 km in diameter. With 56 fields of view (fovs) within each scan line width of 2250 km, the HIRS instrument has greater horizontal resolution than the MSU instrument. Only 11 fovs are completed in every MSU scan line in the time the LIIRS instrument takes for five scan lines or 280 fovs. For both instruments, the fov “footprints” become elliptical and calculate as the fov location is removed farther from the subsatellite point.

The reasons behind the decision to receive and process these data locally are based on present and future operational
timely, as well below that required for optimum specification of temperature and moisture on both the present resolution and proposed double resolution analysis grid. Local readout and processing are able to overcome these problems by providing data up to 60 km resolution within 1 h of a satellite pass. The establishment of a Perth (21° 55' S, 115° 58' E) receiving station in addition to the present Melbourne (37° 53' S, 144° 57' E) station will provide full coverage of the Australian region. Interactive processing of the local readout and processing via a graphics terminal (see, for example, Smith et al. 1978) gives the ability to delete or correct erroneous data and display a variety of analyzed data fields. These advantages, combined with the ability to display derived fields (e.g., Snowfall Index) on request at high spatial resolution, also make the local retrieval system a powerful tool in the hands of the weather forecaster.

2. Reception and Processing Hardware

Raw TOVS data in their TIROS-N Infrared Sounder Receiver Output (TIFO) form are acquired directly by reception and processing of the VHF Beacon Direct Sounder Broadcast from the TIROS-N satellites. These TIFO data of coded bit streams contain information from the TOVS package as well as ARGOS, Solar Environmental Monitor (SEM), and other environmental packages. The data are transmitted as a Manchester code (bi-phase change), phase-shift-keyed (PSK) transmission at 5120 bits per second (bps). The PSK receiving equipment is located at an unattended, remotely controlled tracking station, 30 km west of Melbourne, Victoria. TOVS data are relayed to the Melbourne processing centre by means of a 8000-bps data service line through two modems. This receiving system is illustrated in Fig. 2.

![Diagram of TOVS reception system](image)

**FIGURE 2** A schematic diagram of the present monoparameter receiving system and associated hardware components.
FIGURE 11. The analysis 500 mb (potential) dashed (d) and thermal shown (solid). (b) from satellite-derived temperature data. The thickness and shown derived from redrawn areas at 90% are also shown.
DIRECT READOUT TOVS SYSTEMS

- Statistical (Discriminant Analysis) system (1982). Output used in NMC for 1000/500 THK bogus of regional model

- Physical Perturbation Solution of RTE with bias tuning. Assimilation of Thick Layers in Operational Regional Model. (1987)

- Physical Perturbation Solution of RTE. Using (single level) Cloudy Radiances (Expt. 4.5) Assimilation of Thick Layers in Operational Regional Model. (1994)

- ARM (Australian Region McIDAS) based 1D VAR Solution of RTE for ATOVS and Assimilation of Thick Layers (1999).
A physically based operational atmospheric sounding system for TOVS data in the Australian region

Head Office, Bureau of Meteorology, Melbourne, Australia

The Australian Bureau of Meteorology implemented a physically based real-time TOVS processing system in November 1987. This system provides atmospheric temperature and moisture soundings, total ozone concentration, and cloud brightness and amount information for the Australian region. The scheme uses either a statistical retrieval based, or an operational numerical weather prediction (NWP) model derived, first guess for temperature and moisture fields. Numerically forecast or current analysis-based first guess surface temperature and surface moisture fields are also used. In addition, in the retrieval process, the scheme uses operational numerical analysis and prognostic fields to control the quality of the processing of radiance data to soundings. By calibrating and atmospheric transmissibilities are also used operationally, based on historical symposia, solar, astronomical and radiative data. This system has been run continuously in real-time from late 1987 and provides real-time data to the National Meteorological Centre, Regional Forecast Centres, and research workers.

Introduction

Since Christmas Day 1963, when the Australian Bureau of Meteorology (BOM) first received satellite imagery, analysis and forecasting in the Australian region have depended heavily on satellite data. These data have been used continuously by forecasters for a variety of operational purposes (BOM, 1986) and they have also been used for several tasks within the National Meteorological Centre (NMC). From the late 1960s, use of the data at NMC was via subjective cloud picture interpretation (Gerritsen, 1966; Solomon, 1968, Radford, 1968); providing qualitative estimates of more than 200 parameters (ISPS, 1974) and the second generation of sounding on the TIROS N series of satellites was completed (Kelly et al., 1978; Roux et al., 1983). These data have become an ever-increasing role in the numerical analysis and prognosis system of the NMC. This data has been enhanced since May 1980 by the ability to receive and process these data hourly in real-time (Kelly et al., 1983). Initially, the retrieval system was a simple numerical procedure closely coupled to the operational analysis and prognosis system. However, the atmospheric transmissibilities used in the retrieval process were determined empirically by the state of the sounding being produced. This system was later operated on a computer which used the same automatic retrieval and post-process analysis to select weighting coefficients for each retrieval product (Kelly et al., 1983). This system also benefits from the International Satellite Cloud Imager (ISCI), which selects weighting coefficients based on a synoptic type rather than purely categorical values.

In late 1982, partly as a result of a long standing collaborative research program with the University of Wisconsin, the BOM implemented the
Real-time assimilation and synoptic application of local TOVS raw radiance observations

Bureau of Meteorology Research Centre, Australia

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National Meteorological Centre, Bureau of Meteorology, Australia

and

W.L. Smith
Co-operative Institute for Meteorological Satellite Studies,
University of Wisconsin, Madison, USA

(Manuscript received December 1993; revised April 1994)

This paper describes the physically based, real-time TOVS (TIROS Operational Vertical Sounder) retrieval system currently employed in the Australian Bureau of Meteorology to generate meteorological fields from locally received TOVS raw radiances. It summarizes the cloud height and ozone determination methods and the radiance and transmittance testing techniques employed in the system. It discusses the synoptic application of the data and recent numerical experiments designed to investigate the impact of locally processed TOVS data from the system on operational Australian region numerical weather prediction. These experiments, performed in a data environment which already included National Environmental Satellite Data Information Service (NESSDIS) low resolution TOVS data and locally generated cloud-drift winds, indicated the potential of these data to improve numerical forecasts in the Australian region. The system is now used to provide data for direct use in the operational regional analysis prognostic system (RASP).

Introduction

The Australian Bureau of Meteorology (BoM) has been receiving and utilizing NDOA second assimilation sounding data from the TIROS-N NDOA/A series of satellites and Geostationary Meteorological Satellite (GMS) visible and infrared (IR) data for over a decade (Kelly et al. 1983). The real-time use of these data in the BoM's RM is vital for numerical weather analysis and prediction both in the Australian region and over the southern hemisphere.

The benefits of temperature and moisture profiles from NIMBUS 6 (NASA 1979), TIROS-N (Smith et al. 1979) and subsequent satellites with second generation sounders are now fully exploited (Kelly et al., 1978; Houze et al., 1982). These sounding data, along with the ability to receive and process the data from regional polar orbiting satellite sounders (Melbourne, Perth, Darwin and Lae) (Fig. 1) in real time (Le Marshall et al. 1985), have assumed increasing importance in the BoM's meteorological model. More recently, sequential geostationary satellite imagery, received locally from GMS in Standard VSSR (S-VSSR) format, has been used to generate cloud-drift winds across the Australian
S1 Skill Score for local physical TOVS data assimilation forecasts (TOVS/RASP) and the matching control (NMC) forecasts during the period 23UTC 17-12-92 to 11UTC 30-1-93.

<table>
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<td>MSLP</td>
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<td>MSLP</td>
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<td>37.8</td>
<td>45.1</td>
</tr>
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<td>500Hpa</td>
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<td>21.2</td>
<td>28.7</td>
</tr>
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<td>500Hpa</td>
<td>14.1</td>
<td>19.3</td>
<td>25.5</td>
</tr>
<tr>
<td>RASP</td>
<td>300Hpa</td>
<td>12.9</td>
<td>17.9</td>
<td>24.9</td>
</tr>
<tr>
<td>TOVS/RASP</td>
<td>300HPa</td>
<td>12.2</td>
<td>16.9</td>
<td>23.0</td>
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</table>
Tropical Cyclone Bobby - a notable example of the impact of local TOVS data
Tropical Cyclone Bobby - a notable example of the impact of local TOVS data

The MSLP analysis from LAPS (with TOVS) for 1100UTC on 25 February 1995
Tropical Cyclone Bobby -
-- The analyses --

The MSLP analysis from LAPS for 1100UTC on 26 February 1995

The MSLP analysis from LAPS for 1100UTC on 27 February 1995
Tropical Cyclone Bobby - -- The Forecasts --

The 24 hour operational forecast from the RASP for 11UTC on 26 March 1995

The 24 hour LAPS MSLP forecast for 11UTC on 27 March 1995
Tropical Cyclone Bobby -
Real time direct readout local TOVS data
Tropical Cyclone Bobby -
-- With Local TOVS Data --

The 24 hour LAPS MSLP forecast with direct readout TOVS data for 11UTC on 26 March 1995
Tropical Cyclone Bobby -
-- With/Without Local TOVS Data --

Fig. 2 (a) The 24 hour MSLP RASP forecast valid at 1100 UTC on 26 February, 1995

Fig. 2 (b) The 24 hour MSLP LAPS forecast valid at 1100 UTC on 26 February, 1995

Fig. 2 (c) The 24 hour MSLP LAPS + local TOVS forecast valid at 1100 UTC on 26 February, 1995

Fig. 2 (d) The verifying analysis at 1100 UTC on 26 February, 1995
The Australian Region McIDAS

John F. Le Marshall, Lioned J. Stirling, Rodney F. Davidson and Michael J. Hassett
Head Office, Bureau of Meteorology, Melbourne, Australia.

(Manuscript received December 1986, revised June 1987)

This paper describes a locally-implemented McIDAS-type system, namely the
Australian Region McIDAS (ARM). The ARM system was commissioned in the
Bureau of Meteorology Research Centre in September 1985 and installed in the
National Meteorological Centre in July 1986. It provides real-time access to a very
extensive historical and real-time meteorological data base. The system also provides
an extensive number of application programs to enable use to be made of the data base
for research and forecasting tasks.

The paper includes details of the hardware, software, data base and key applications
software which form the system. It illustrates the utility of the system for performing
research and operational tasks in the Australian region. It notes the planned future
developments and concludes that improved efficiency in both operational and
research meteorology can be expected from implementation of the system.

Introduction

There is a burgeoning amount of meteorological data available to people working in geophysics and in
particular meteorology. This has led to the need to develop specialized systems for data access and
analysis. In meteorology much of the increase in the data base is comprised of remotely sensed observations
from satellites. Several systems have been developed to store, access and analyse such data. These include the
FRONTIES system (Carpenter and Browning 1984), the PROFS system (MacDonald 1984) and the PRO/MIS
system (Shoden et al. 1984). The first and assembled the most complete system, which contains the most
extensive and flexible suite of applications programs, is the Man Computer Interactive Data Access System
(McIDAS) (Suomi et al. 1983).

The McIDAS system was originally designed at the
Space Science and Engineering Center of the University of Wisconsin in the early 1970s for deriving cloud-drift
winds from geostationary satellite images. It has since undergone two redesigns. It was initially microcomputer
based (Smith 1972; Chatterly and Suomi 1977), then based on networked minicomputers and finally took its
present form in the early 1980s (Suomi et al. 1983).

There are two important characteristics of a McIDAS-type system that make it an apt tool for
research and operational meteorology in the Australian region. Firstly, it has an extensive amount of diverse
applications software, which is pertinent to Australian needs. For instance, this software allows the calculation
of cloud-drift winds and the calculation of temperature and moisture profiles from radiation data measured by
satellite. Secondly, as a result of eleven years of collaborative research effort and staff exchange between
the Bureau of Meteorology (BoM) and the
University of Wisconsin, the applications software is the same as the local (BoM) software in several
important senses. For example, the Numerical Weather Prediction (NWP) capability of the McIDAS at the
University of Wisconsin is based on the local Australian Region limited area Primitive Equations (LAPPE) model
and analysis scheme (Smith et al. 1984). In addition several key data processing tools in the BoM for
conventional and satellite data have been integrated into the McIDAS at University of Wisconsin.

The ARM system was commissioned in the BoM in September 1985. There are now large
workstations and personal computer based workstations at several local
and remote sites. This paper describes the hardware, software, database and key applications programs
which make up the system. It describes the system's utility in an Australian context and its planned development.

The system hardware

The ARM system has three principal hardware components: a host computer, data acquisition
hardware, and local and remote user terminals. A schematic diagram showing the hardware configuration
of the ARM system may be seen in Fig. 1. The host computer for the ARM system is the BoM
VAXstation 1110 mainframe, whose initial function was
principally for communications.
Fig. 1 A schematic diagram showing the present ARM system configuration.
Data Base:

- Real Time Imagery From Polar Orbiting and Geostationary Satellites eg NOAA 9, 10, 11, 12,..) GM5-4,5 FY-2, RADAR etc.
- Real Time Conventional and Satellite Observations: Synoptic Observations, RAOBS, CODARS,… AMVs, TOVS ATOVS, Low Cloud, Solar Exposure, etc.

Applications:

- Wide Range of Image Analysis, Image Processing Grid Display and Manipulation, and Observation analysis applications.
- Wide Range of Programs Used Operationally Including:
  - Image Navigation and Calibration
  - Solar Radiation Estimation
  - Low Cloud Detection, sea ice detection, volcanic ash detection…
  - AMV Generation……
GMS S-VISSR PROCESSING SYSTEM

- Direct Reception of GMS S-VISSR.
- Direct Channel Ingest Into Mainframe Computers Via SSEC Ingestion.
  - Calibration and Navigation Using McIDAS.
  - Product Generation Using Australian Region McIDAS.
  - Image/Data Access/Distribution Through McIDAS.
The real-time generation and application of cloud-drift winds in the Australian region

John Le Marshall, Neil Pescod, Andrew Khaw and Gordon Allen
Bureau of Meteorology Research Centre, Australia
(Manuscript received June 1992, revised March 1993)

This paper is the first detailed report of the generation in the Australian region of cloud-drift wind vectors using hourly high resolution facsimile (HRS-FAX) and half hourly stretched-frame and infrared spin-scan radiometer (S-VISIR) images from the Japanese Geostationary Meteorological Satellites, GMS-5 and GMS-6. It describes the techniques used in the wind calculation, in particular for brightness assignment and quality control. It also records the accuracy of the vectors, with appropriate qualification, and illustrates the impact of these data on regional numerical analysis and prediction by use of examples. These locally generated high resolution wind data are now being assimilated in real time into a test version of the operational regional forecast system. Evidence is presented from this assimilation experiment to indicate that they have the potential to modify the operational analysis in a manner which benefits numerical weather prediction.

Introduction

For two decades, meteorologists have been using cloud motion, computed from animated sequences of images taken from geostationary satellites, to estimate wind vectors. Early work included that of Fujita et al. (1968) and Yoss et al. (1972), and an automated computer technique for estimating low-level wind vectors using cross-correlation of small arrays of brightness values from consecutive geostationary images (Leese et al. 1971). Hubert and Whitney (1971) reported that low-level cloud-drift winds represented flow at those levels with accuracies close to those of the radiosonde. This result has been vindicated by other studies such as Haltiner et al. (1976, 1977), Mibor and Timchalk (1977), Hubert and Whitney (1971), and Madden and Vonder Haar (1979).

The early estimates of Hubert and Whitney (1971) of the errors in cloud-drift winds were re-examined by Haltiner et al. in 1977. They conducted an aircraft verification program to examine the accuracy of lower and upper-level cloud-drift winds. Their results generally indicated errors smaller than those of Hubert and Whitney (1971), with errors in low-level winds associated with the cloud base, of the order of 1.5 metres per second and upper-level winds errors of approximately two metres per second, although, in the latter case, the slopes examined had only small velocities (near 1.1 m s^{-1}).

The usefulness of these errors indicates a utility for cloud motion winds in numerical weather prediction (NWP), and for more than a decade now cloud-drift winds have become part of the operational observational data base. They are routinely used in meteorological centres around the world in input to NWP although there is only a limited amount of published work addressing their utility (e.g. Kalnay et al. 1987). It is important to note that the accuracy of these winds is generally limited to the extent that cloud motion represents the wind, and to the extent that a representative cloud field can be determined from the brightness temperature field associated with the clouds. In addition, it can be shown that the accuracy of the winds is also dependent upon the time difference and, to a limited extent, the correlation between image images used in their calculation, the spatial resolution of these images, the error in the first guess field, the degree to which the first guess field limits the system for correlated patterns in sequential images and the
The estimation of high density atmospheric motion vectors and their application to operational numerical weather prediction

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and

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(Manuscript received November 2001; revised July 2002)

As the spatial, temporal and spectral resolution of observations from space has improved, their benefit to numerical weather prediction (NWP) has increased. The utility of these data has also been aided by increased computer power, improved NWP models and the use of improving data assimilation techniques.

This paper provides a summary of high spatial and temporal resolution atmospheric motion vector (AMV) estimation at the Bureau of Meteorology and new data impact results for the Australian region. In particular, it summarises recent experiments examining the use of each type of these vectors in NWP and also details an operational trial in which all types of AMVs were used simultaneously. As a result of this trial, these AMVs are now used for operational regional NWP.

Introduction

Wind is a primary variable for describing atmospheric state. Accurate depiction of the wind field in areas with no conventional data is essential for operational weather forecasting and initialisation of NWP models. Measurement of wind from geostationary platforms is important as it provides near continuous data where conventional observations are lacking, particularly over the data-sparse oceans. Studies as early as Liu (1978) showed that AMVs have a capacity similar to that of radars for representing atmospheric flow.

Use of cloud drift wind vectors is now widespread. Applications include monitoring, global and regional NWP and tropical cyclone forecasting. The characteristics of the winds and their impact on medium-range global NWP were examined in Krüger et al. (1982)
<table>
<thead>
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<th>Channel ID</th>
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<th>Resolution</th>
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<td>VIS</td>
<td>0.5 - 1.0 µm</td>
<td>1.25 km</td>
</tr>
<tr>
<td>IR1</td>
<td>10.2 - 11.4 µm</td>
<td>5 km</td>
</tr>
<tr>
<td>IR2</td>
<td>10.9 - 12.2 µm</td>
<td>5 km</td>
</tr>
<tr>
<td>IR3</td>
<td>6.7 - 7.2 µm</td>
<td>5 km</td>
</tr>
</tbody>
</table>
Table 7.3  Cloud drift wind types generated operationally in the BoM. The table indicates type, image resolution, frequency of wind extraction, time of wind extraction and the separation of the image triplets used for wind generation (ΔT).

<table>
<thead>
<tr>
<th>Wind Type</th>
<th>Image Resolution</th>
<th>Frequency</th>
<th>Time (UTC)</th>
<th>Wind image triplet (ΔT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>5 km sub-satellite</td>
<td>6 hourly</td>
<td>05, 11, 17, 23</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Low-res. VIS.</td>
<td>5 km sub-satellite</td>
<td>6 hourly</td>
<td>05, 23</td>
<td>30 minutes</td>
</tr>
<tr>
<td>High-resolution visible</td>
<td>1.25 km sub-satellite</td>
<td>6 hourly</td>
<td>05, 23</td>
<td>30 minutes</td>
</tr>
<tr>
<td>WV winds</td>
<td>5 km sub-satellite</td>
<td>6 hourly</td>
<td>05, 11, 17, 23</td>
<td>30 minutes</td>
</tr>
<tr>
<td>IR (hourly)</td>
<td>5 km sub-satellite</td>
<td>hourly</td>
<td>01, 02, … 23</td>
<td>1 hour</td>
</tr>
<tr>
<td>Low-res. vis. (hourly)</td>
<td>5 km sub-satellite</td>
<td>hourly</td>
<td>23, 00, 01 …, 05, …</td>
<td>1 hour</td>
</tr>
<tr>
<td>High-res. vis. (hourly)</td>
<td>1.25 km sub-satellite</td>
<td>hourly</td>
<td>23, 00, 01 …, 05, …</td>
<td>1 hour</td>
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<tr>
<td>WV winds</td>
<td>5 km sub-satellite</td>
<td>hourly</td>
<td>00, 01, …, 23</td>
<td>1 hour</td>
</tr>
</tbody>
</table>
Shorter contribution

The contribution of GOES-9 to operational NWP forecast skill in the Australian region

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Bureau of Meteorology, Australia and Joint Center for Satellite Data Assimilation, Maryland, USA

R. Seccombe
Bureau of Meteorology, Australia

J. Daniels
NOAA NESDIS, Maryland, USA

C. Velden
CIMSS, University of Wisconsin, USA

K. Puri, R. Bowen and A. Ros
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and

M. Dunn
Physics Department, Latrobe University, Australia

The GOES-9 satellite was moved along the Equator to 155°E, 6°S in 2000 and has operated over the Western Pacific, Asia and the Australian region as the primary geostationary meteorological satellite by the joint effort of the Japan Meteorological Agency (JMA) and the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS). Since 22 May 2000, GOES-9 C-Var data have been received via direct readout by the Bureau of Meteorology (hereafter referred to as the Bureau), Victoria, and the calibrated and navigated radiances data (imagery) has subsequently been used to calculate atmospheric motion vectors (AMV). These operational AMVs are important to Australian region numerical weather prediction (NWP) as no other AMV data are available within operational cut-off times. The method used to determine atmospheric motion differs from that usually employed for GOES east satellite data, particularly in height assignment, error characterization and quality control. The method resulted from a detailed study of errors in height assignment in the initial experimental system. The AMV data have been used in a real-time trial to gauge their impact on operational regional NWP. Their clear benefit is described below. As a result of this trial these vectors are now being used in the National Meteorological and Oceanographic Centre (NMOC) for operational regional NWP.

Background

Australia’s position in the data-space southern ocean has resulted in dependence on satellite remote sensing for maintaining high quality analysis and numerical weather prediction. For a long time, satellite imagery has contributed to analysis and forecast preparation in the Australian region (Gohmert 1978) and normally prepared pseudo-observations are still expected to contribute a small positive impact to southern hemisphere forecasts (Searman et al. 1995). Atmospheric motion vectors also make an important contribution to the database (Le Marshall et al. 1994). To provide high-quality winds in a timely fashion for operational NWP in the Australian region, AMVs have been calculated locally, initially from sequential GMS image data and, recently, from GOES-9 images. The methods used at the Bureau, to estimate AMVs, from C-Var data, as accumulated in Le Marshall et al. (1999, 2000). Sequential infrared (IR), visible (VIS) or water vapor (WV) bands image (a triplet), separated by an hour or half an hour were used for velocity estimation. As a result, high density winds were generated continuously at hourly or half-hourly intervals. Selected targets in the imagery were tracked automatically using feature winds, then a lagged correlation technique, which minimized most mean squares (RMS) differences in brightness from successive pic-
GOES_9 was moved along the Equator to 155° E, 0° S in 2003 and has been operated over the Western Pacific, Asia and the Australian Region as the primary geostationary meteorological satellite by the joint effort of JMA and NOAA/NESDIS. Since 22 May 2003, GOES_9 GVAR data have been received via direct readout by the Bureau of Meteorology (hereafter referred to as ‘the Bureau’) groundstation at Crib Point, Victoria, and the calibrated and navigated radiance data (imagery) has subsequently been used to calculate Atmospheric Motion Vectors (AMVs). These data have been used in a real time trial to gauge their impact on operational regional Numerical Weather Prediction (NWP). Their clear benefit is described below. The vectors are now being used in NMOC for operational regional NWP.

Background

Australia’s position in the data sparse southern oceans has resulted in dependence on satellite remote sensing for maintaining high quality analysis and numerical weather prediction in our region. For a long time, satellite imagery has contributed to analysis and forecast preparation in the Australian Region (Guymer, 1978) and manually prepared pseudo observations are still expected to contribute a small positive impact to Southern Hemisphere forecasts (Seaman et al. 1993). Atmospheric motion vectors also make an important contribution to the data base. To provide high quality winds in a timely fashion for operational NWP in the Australian Region, AMVs have been calculated locally, initially from sequential GMS image data and, recently, from GOES_9 images.
ATMOSPHERIC MOTION VECTOR SYSTEM

Table 1  Real time schedule for GOES_9 Atmospheric Motion Vectors at the Bureau of Meteorology Sub_satellite image resolution, frequency and time of wind extraction and separations of the image triplets used for wind generation (ΔT) are indicated.

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<th>Wind Type</th>
<th>Resolution</th>
<th>Frequency-Times (UTC)</th>
<th>Triplet (ΔT)</th>
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Fig. 2  GOES_9 AMVs generated around 22 UTC on 2 July 2003. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors
Fig. 3. The S1 Skill Score from Operations versus the S1 Skill Score from the Operational system, including GOES_9 winds, 9 June to 30 June 2003
Fig. 6   S1 Skill Score versus Pressure for real time 48_hour forecasts (right hand pair) and 24_hour forecasts during the period 9 June to 30 June 2003
An operational system to estimate global solar exposure over the Australian region from satellite observations

I. Method and the initial climatology

G. Weymouth and J. Le Marshall
Bureau of Meteorology Research Centre, Australia
(Manuscript received January 1998; revised August 1998)

The Australian Bureau of Meteorology has produced, in near real-time for more than three years, high resolution daily surface global solar exposure estimates over the Australian continent. Physical modelling of radiative transfer within the atmosphere has been used to provide these estimates from full resolution hourly visible Geostationary Meteorological Satellite (GMS) Stretched-Visible and Infrared Spin Scan Radiometer (S-VISSR) data.

This paper describes the models and their calibration for estimating exposure from satellite observations. The accuracy of the exposure data is presented, along with the first high resolution initial climatology of exposure across Australia. The models provide high quality data. They perform best in clear and near clear-sky conditions, with the average deviation of model areal means from surface-based point pyranometer measurements being less than five per cent. In cloudy conditions, the average percentage deviation is larger, but absolute deviations remain small as the exposure is lower. Over most of the continent, the cloud conditions that actually occur lead to estimates being within eight per cent (mean modulus of daily percentage difference) of collocated point pyranometer measurements, an accuracy similar to or exceeding that of the older pyranometers which still comprised half of the Australian pyranometer network during this study.

Introduction

The Australian Bureau of Meteorology (BoM) is currently upgrading its radiation monitoring system. This upgrade includes improvement of the space-based measurement capability and significant improvements to its surface solar and terrestrial radiation monitoring network. This paper describes the space-based system which uses satellite observations and a physical model developed from those of Gautier et al. (1980) and Diak and Gautier (1983).

The model has been implemented to estimate surface global solar exposure (sometimes called insolation but here abbreviated to ‘exposure’) over the Australian continent, at fine spatial scales which cannot be practically or economically provided through the conven-
GLOBAL SOLAR EXPOSURE SYSTEM

- Uses GMS S-VISSR Data
  - Hourly Computation of Surface Albedo and Surface Global Exposure
  - Available Operationally in Near Real Time.
  - Comprehensive Timing, Quality Control and Verification.
  - High Quality High Resolution Gridded Regional Climatology Available.
Estimation of Solar Radiation in the Bureau of Meteorology

Basic Theory

Gautier, Diak and Masse (JAM) 1980
Diak and Gautier (JAM) 1983
Weymouth and Le Marshall (PORSEC) 1994
* * * (AMM) 1998

Clear/Cloudy Model

- Raleigh scattering
- Water vapour/ozone absorption
- Albedo and absorption derived from brightness
- Daily insolation accurate to 5% (clear).

Clear Air Model

\[ SW' = F_0 a + F_0 (1 - a)(1 - a(u_i))(1 - a(u_j))(1 - \alpha_i) \]

Solving for surface albedo yields

\[ A = \frac{SW' - F_0 a}{F_0 (1 - \alpha)(1 - a(u_i))(1 - a(u_j))(1 - \alpha_i)} \]

Then incident shortwave at surface is

\[ SW = F_0 (1 - a)(1 - a(u_i))(1 + A\alpha_i) \]

And net SW energy budget at surface is

\[ SW_{net} = F_0 (1 - a)(1 + a(u_i))(1 - A(1 - \alpha_i) - A^2\alpha_i) \]

Where:

- \( SW' \) upward SW radiant flux Wm\(^{-2}\)
- \( F_0 \) instantaneous SW radiant flux
- \( a \) reflection coefficient for beam radiation
- \( \alpha_i \) reflection coefficient for diffuse radiation
- \( a(u_i) \) absorption coefficients for slant water vapour path (\( u_i \) sun angle, \( u_i \) satellite angle)
- \( \Theta \) zenith angle of sun
- \( A \) surface albedo.
SOLAR RADIATION
SOLAR RADIATION

![Graph showing relationship between satellite daily exposure (MJ per square metre) and station daily exposure (MJ per square metre).]
MODELING

The ABM installed in CIMSS/U of W the ARPE analysis and forecast system (1978 – 1986).

Initially ARPE/METANAL
Later ARPE/SI 3DVARBLEND

The system has been developed and supported by several visiting scientists and has evolved into the current CRASS system which has been used to demonstrate the utility of many new satellite data types and assimilation methodologies.
CONCLUSION

The ABM has enjoyed a quarter of a century of extremely productive collaboration with CIMSS and the University of Wisconsin.

The present rapid expansion of current meteorological satellite systems and the great potential benefits for all make it vital for both partners this collaboration continues well into the future.
CIMSS – Continuing Collaboration
Joint Center for Satellite Data Assimilation

PARTNERS

NASA/Goddard
Global Modeling & Assimilation Office

NOAA/NCEP
Environmental Modeling Center

NOAA/OAR
Office of Weather and Air Quality

US Navy
Oceanographer of the Navy, Office of Naval Research (NRL)

NOAA/NESDIS
Office of Research & Applications

US Air Force
AF Director of Weather, AF Weather Agency
JCSDA Structure

Associate Administrators
NASA: Science
NOAA: NESDIS, NWS, OAR
DoD: Navy, Air Force

Management Oversight Board of Directors:
NOAA NWS: L. Uccellini (Chair)
NASA GSFC: F. Einaudi
NOAA NESDIS: M. Colton
NOAA OAR: M. Uhart
Navy: S. Chang
USAF: J. Lanici/M. Farrar

Advisory Panel

Joint Center for Satellite Data Assimilation Staff
Director: J. Le Marshall
Deputy Directors:
Stephen Lord – NWS/NCEP
James Yoe - NESDIS
Lars Peter Riishojaard – GSFC, GMAO
Pat Phoebus – DoD,NRL
Secretary: Ada Armstrong
Consultant: George Ohring

Technical Liaisons:
NASA/GMAO – D. Dee
NOAA/NWS/NCEP – J. Derber
NASA/GMAO – M. Rienecker
NOAA/OAR – A. Gasiewski
NOAA/NESDIS – D. Tarpley
Navy – N. Baker
USAF – M. McATee
Army – G. McWilliams
JCSDA Mission and Vision

• Mission: Accelerate and improve the quantitative use of research and operational satellite data in weather and climate analysis and prediction models

• Near-term Vision: A weather and climate analysis and prediction community empowered to effectively assimilate increasing amounts of advanced satellite observations

• Long-term Vision: An environmental analysis and prediction community empowered to effectively use the integrated observations of the GEOSS
Goals – Short/Medium Term

- Increase uses of current and future satellite data in Numerical Weather and Climate Analysis and Prediction models
- Develop the hardware/software systems needed to assimilate data from the advanced satellite sensors
- Advance common NWP models and data assimilation infrastructure
- Develop a common fast radiative transfer system (CRTM)
- Assess impacts of data from advanced satellite sensors on weather and climate analysis and forecasts (OSEs, OSSEs)
- Reduce the average time for operational implementations of new satellite technology from two years to one
Required Capabilities to Achieve Goals

• A satellite data assimilation infrastructure
• A directed research and development program
• A grants program for long-term research
• An education and outreach program
The Challenge
Satellite Systems/Global Measurements

GRACE
Cloudsat
CALIPSO
Aqua

SSMIS
TRMM
TOPEX
Meteor/SAGE
COSMIC/GPS

SeaWiFS
Terra
WindSAT

SeaWiFS
Jason
ICESat
SORCE

GIFTS
Landsat
NPP

GOES-R
NOAA/POES
NPOESS

Aura
## Satellite Instruments and Their Characteristics (* = currently assimilated in NWP)

### Primary Information Content

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The NPOESS spacecraft has the requirement to operate in three different sun synchronous orbits, 1330, 2130 and 1730 with different configurations of fourteen different environmental sensors that provide environmental data records (EDRs) for space, ocean/water, land, radiation clouds and atmospheric parameters. In order to meet this requirement, the prime NPOESS contractor, Northrop Grumman Space Technology, is using their flight-qualified NPOESS T430 spacecraft. This spacecraft leverages extensive experience on NASA’s EOS Aqua and Aura programs that integrated similar sensors as NPOESS.

As was required for EOS, the NPOESS T430 structure is an optically and dynamically stable platform specifically designed for earth observation missions with complex sensor suites.

In order to manage engineering, design, and integration risks, a single spacecraft bus for all three orbits provides cost-effective support for accelerated launch call-up and operation requirement changes. In most cases, a sensor can be easily deployed in a different orbit because it will be placed in the same position on the any spacecraft. There are ample resource margins for the sensors, allowing for compensation due to changes in sensor requirements and future planned improvements.

The spacecraft still has reserve mass and power margin for the most stressing 1330 orbit, which has eleven sensors. The five panel solar array, expandable to six, is one design, providing power in the different orbits and configurations.
5-Order Magnitude Increase in Satellite Data Over 10 Years

Daily Upper Air Observation Count

Satellite Instruments by Platform

- NPOESS
- METOP
- NOAA
- Windsat
- GOES
- DMSP

<table>
<thead>
<tr>
<th>Year</th>
<th>Count (Millions)</th>
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<tr>
<td>2000</td>
<td>1</td>
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<tr>
<td>2010</td>
<td>100,000</td>
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</table>
ABI – Advanced Baseline Imager

HES – Hyperspectral Environmental Suite

SEISS – Space Environment In-Situ Suite including the Magnetospheric Particle Sensor (MPS); Energetic Heavy Ion Sensor (EHIS); Solar & Galactic Proton Sensor (SGPS)

SIS – Solar Imaging Suite including the Solar X-Ray Imager (SXI); Solar X-Ray Sensor (SXS); Extreme Ultraviolet Sensor (EUVS)

GLM – GEO Lightning Mapper
Short Term Priorities 04/05

• **MODIS**: MODIS AMV assessment and enhancement. Accelerate assimilation into operational models.

• **AIRS**: Improved utilization of AIRS
  • Improve data coverage of assimilated data. Improve spectral content in assimilated data.
  • Improve QC using other satellite data (e.g. MODIS, AMSU)
  • Investigate using cloudy scene radiances and cloud clearing options
  • Improve RT Ozone estimates
  • Reduce operational assimilation time penalty (Transmittance Upgrade)

• **SSMIS**: Collaborate with the SSMIS CALVAL Team to jointly help assess SSMIS data. Accelerate assimilation into operational model as appropriate
Some Major Accomplishments

- Common assimilation infrastructure at NOAA and NASA
- Common NOAA/NASA land data assimilation system
- Interfaces between JCSDA models and external researchers
- Community radiative transfer model—Significant new developments, New release June
- Snow/sea ice emissivity model – permits 300% increase in sounding data usage over high latitudes – improved polar forecasts
- Advanced satellite data systems such as EOS (MODIS Winds, Aqua AIRS, AMSR-E) tested for implementation
  - MODIS winds, polar regions - improved forecasts. Current Implementation
  - Aqua AIRS - improved forecasts. Implemented
- Improved physically based SST analysis
- Advanced satellite data systems such as
  - DMSP (SSMIS),
  - CHAMP GPS
  being tested for implementation
- Impact studies of POES AMSU, Quikscat, GOES and EOS AIRS/MODIS with JCSDA data assimilation systems completed.
CIMSS contributions to JCSDA

Directed Research

MODIS polar winds data assimilation experiments (ORA: J. Key, DAO: LP. Riishojgaard, CIMSS: C. Veldon, J. Jung, T. Zapotocny, JCSDA JLM)

Data denial studies using NCEP global and regional models (CIMSS: J. Jung, T. Zapotocny)

Global denials: HIRS, AMSU, RAOB, Quickscat, Conventional data, Geo. AMVS, NoSAT.
Regional denials: Geo. AMVS, SSM/I, GOES Precip. Water, ACARS, RAOB (T(p), r(p), V(p)), TOVS, Surface Data

GOES wind products assimilation into the ETA data assimilation suite (ORA: J. Daniels, CIMSS: J. Jung, EMC: D. Parrish)

Direct assimilation of multi-channel satellite observations (ORA: J. Key, CIMSS: W. Raymond)


AO Contributions

U. Wisconsin – Passive microwave assimilation of cloud and precipitation (R. Bennartz)
JCSDA

RECENT ADVANCES
MODIS Wind Assimilation into the GMAO/NCEP Global Forecast System
11_m and 6.7_m gradient features tracked

Tracers selected in middle image

Histogram, H_2O intercept method, forecast model and auto editor used for height assignment
Global Forecast System

Background

• Operational SSI (3DVAR) version used

• Operational GFS T254L64 with reductions in resolution at 84 (T170L42) and 180 (T126L28) hours. 2.5hr cut off
<table>
<thead>
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<th>Satellite Data Used</th>
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<tr>
<td>HIRS sounder radiances</td>
<td>TRMM precipitation rates</td>
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<tr>
<td>AMSU-A sounder radiances</td>
<td>ERS-2 ocean surface wind vectors</td>
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<tr>
<td>AMSU-B sounder radiances</td>
<td>Quikscat ocean surface wind vectors</td>
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<td>GOES sounder radiances</td>
<td>AVHRR SST</td>
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<td>GOES 9,10,12, Meteosat atmospheric motion vectors</td>
<td>AVHRR vegetation fraction</td>
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<td>GOES precipitation rate</td>
<td>AVHRR surface type</td>
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<td>Multi-satellite snow cover</td>
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<td>SSM/I precipitation rates</td>
<td>Multi-satellite sea ice</td>
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<td>SBUV/2 ozone profile and total ozone</td>
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NH 500 mb Z AC  3 day fcst
60N - 90N Waves 1-20
2 Jan - 12 Feb '04

Anomaly Correlation

Day

Ops
Ops + MODIS
## 2004 ATLANTIC BASIN
### AVERAGE HURRICANE TRACK ERRORS (NM)

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Results compiled by Qing Fu Liu.
N. Hemisphere 500 mb AC Z
60N - 90N Waves 1-20
15 Jan - 15 Feb '04

Anomaly Correlation

Forecast [days]

- Control
- AMSU emissivity+MODIS
Hyperspectral Data Assimilation
AIRS Data Assimilation

J. Le Marshall, J. Jung, J. Derber, R. Treadon, S.J. Lord,
M. Goldberg, W. Wolf and H-S Liu, J. Joiner and J Woollen

January 2004

Used operational GFS system as Control

Used Operational GFS system Plus Enhanced AIRS

Processing as Experimental System
The Trial

• Used `full AIRS data stream used (JPL)
  – NESDIS (ORA) generated BUFR files
  – All FOVs, 324(281) channels
  – 1 Jan – 27 Jan ’04

• Similar assimilation methodology to that used for operations
• Operational data cut-offs used
• Additional cloud handling added to 3D Var.
• Data thinning to ensure satisfying operational time constraints
The Trial

- AIRS related weights/noise modified
- Used NCEP Operational verification scheme.
Figure 1(a). 1000hPa Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004.
Figure 1(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004
Figure 2. 500hPa Z Anomaly Correlations 5 Day Forecast for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, (1-27) January 2004
Figure 3(a). 1000hPa Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004.
Figure 3(b). 500hPa Z Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004
AIRS Data Assimilation


January 2004

Used operational GFS system as Control

Used Operational GFS system Plus Enhanced AIRS

Processing as Experimental System
Landslide Surveillance: New Tools for an Old Problem

Landslides are one of the most widespread and destructive natural hazards on Earth, responsible for significant economic and human losses. However, accurate and timely information on landslide activity is crucial for effective risk management and disaster preparedness. Traditionally, monitoring landslides has relied heavily on manual surveys and satellite imagery, which can be time-consuming and costly.

In recent years, advancements in remote sensing, particularly from air and space-borne platforms, have offered new tools for landslide monitoring. These technologies can provide near-real-time data on landslide activity, allowing for more effective and timely decision-making. This paper discusses the integration of these advanced technologies and their potential applications in landslide surveillance.

Impact of Atmospheric Infrared Sounder Observations on Weather Forecasts

Experimental meteorological forecasts at the Joint Center for Satellite Data Assimilation (JCDAS) have shown that incorporating observations from the Atmospheric Infrared Sounder (IRS) can improve the accuracy of weather predictions. The IRS measures temperature and emissivity at the Earth's surface and in the lower atmosphere, providing valuable information for atmospheric modeling.

The results indicate that the use of IRS observations can significantly enhance the accuracy of atmospheric models, particularly in areas with limited surface observations. This improvement could lead to more accurate and timely weather forecasts, potentially saving lives and reducing economic losses.
AIRS Data Assimilation
-The Next Steps

Fast Radiative Transfer Modelling (OSS, Superfast RTM)

GFS Assimilation studies using:

- full spatial resolution AIRS data (___ & MODIS)
- full spatial resolution AIRS data with recon. radiances
- full spatial res. AIRS with cld. cleared radiances
  (___ AMSU/MODIS/MFG use)
- full spatial and spectral res. AIRS data
- full spatial and spectral res. raw cloudy AIRS
  (___ MODIS/AMSU) data
  (full cloudy inversion with cloud parameters etc.)
CONCLUSION

The JCSDA has enjoyed extremely productive collaboration with CIMSS and the University of Wisconsin since its inception.

The present rapid expansion of current meteorological satellite systems and the great potential benefits for all, make it vital for both partners this collaboration continues well into the future. This will ensure the development of the state of the art data assimilation system for the community with attendant benefits.
CIMSS – A REFLECTION

Great and Fertile Environment to work in. – ‘a great working environment, with friendly and supportive colleagues’

Been important in developing many of the world's top satellite meteorologists. Its training role is now more important than ever.

Supported the international community during the past quarter century in the application of satellite data.

Its work is now as vital as ever.
In conclusion, CIMSS significant interaction with the ABM and JCSDA has been an example of their significant contribution to international meteorology. Their facilitation of access to satellite data, education in satellite meteorology, provision of software to the global community to allow exploitation of satellite data and their contribution to the international satellite program has given CIMSS a unique place in satellite meteorology. Their work has been of considerable benefit to humankind and will remain so into the future.