Benefits from Advances in the Data Assimilation of Earth Observations from Space

John Le Marshall¹, Robert Norman², Yi Xiao¹, Chris Tingwell¹, Kefei Zhang², Paul Lehmann¹, David Howard¹, Tim Morrow¹, Jim Jung³, Jaime Daniels⁴ and Steve Wanzon⁵ ……..

¹ Bureau of Meteorology, Melbourne, Australia
² RMIT University, Melbourne, Australia
³ UW/CIMSS, Madison, USA
⁴ NOAA/NESDIS/STAR, College Park, USA
Overview

• The Importance of EOS (in the SH)
• Recent and Impending Benefits
• The Advanced Sounders
• Atmospheric Motion Vectors - Himawari – 6,7,8
• Radio Occultation
• Future Prospects
• Summary
The Importance of EOS (in the SH)

Observing System Experiments (OSEs)

With and Without Satellite Data

- **Systems Examined**
  - ACCESS (APS1) – Operational data base (Australian Op. Sys)
  - 28 October to 30 November 2011
  - 15 August to 30 September 2010
There are currently 31 data-stream/distinct instrument-type products:

**Radiances**
- HIRS (multi-platform)
- AMSUA (multi-platform)
- AMSUB/MHS (multi-platform)
- IASI (multi-platform)
- AIRS
- CrIS
- ATMS
- GPS-RO (multi-platform)
- AVHRR (via SST analysis)
- AATSR (via SST analysis)
- AMSR-E (via SST analysis)

**Wind products (sfc or AMV)**
- ASCAT (multi-platform)
- Himawari-8 IR
- Himawari-8 VIS
- Himawari-8 cloudy WV 6.7
- Meteosat-10 IR
- Meteosat-10 cloudy WV 7.3
- Meteosat-10 VIS
- Meteosat-10 HRVIS
- Meteosat-7 IR
- Meteosat-7 VIS
- Meteosat-7 cloudy WV
- GOES-15 IR
- GOES-15 cloudy WV
- GOES-13 IR
- GOES-13 cloudy WV
- Terra/Aqua IR
- Aqua cloudy WV
- Aqua clear sky WV
- NOAA-15/NOAA-18/NOAA-19 IR
- MetOp-A/MetOp-B IR

Within 3 years there will be 11 more:

**Radiances**
- Himawari-8 Clear sky radiances
- SEVERI Clear sky radiances
- SEVERI All sky radiances
- SAPHIR
- MWTS-2
- MWHS-2
- SSMIS (multi-platform)

**Winds**
- RapidScat
- ADM-Aeolus/ALADIN
- LeoGeo IR AMVs (multi-platform)
- VIIRS
- Windsat
The Importance of EOS in the Southern hemisphere

In the SH EOS extend the length of a high quality numerical forecast by a factor of four
In the northern hemisphere EOS extend the length of a high quality forecast by a factor of 1.6

ACCESS FORECAST SKILL (AC) VERSUS TIME
SH 500hPa HGT 26 October - 31 November 2011

A high quality (AC=0.9) 24 hour (1 day) forecast without using satellite data is of the same quality as a 96 hour (4 days) forecast using satellite data.

From Le Marshall et al. 2013. The considerable impact of earth observations from space on numerical weather prediction. JSHESS
Fig. 8(c). SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS and verifying against the control analysis.

Fig. 8(f). NH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS and verifying against the control analysis.
Earth observations From Space

Fig. 8(g). SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using GFS and verifying against the control analysis.

Fig. 8(hNH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using the GFS and verifying against the control analysis.
ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using satellite data.

ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data.

Daily rain gauge analysis for 9 November 2011.

<table>
<thead>
<tr>
<th>9 November 2011</th>
<th>NOSAT</th>
<th>SAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation between observed and forecast rainfall (Aust. Region)</td>
<td>0.282</td>
<td>0.699</td>
</tr>
<tr>
<td>Hanssen and Kuipers (Aust. Region)</td>
<td>0.360</td>
<td>0.596</td>
</tr>
</tbody>
</table>

Daily rainfall values.
Table 1. ACCESS-G verification statistics for all of Australia for the month of November 2011 for forecasts produced with (SAT) and without (NOSAT) satellite data

<table>
<thead>
<tr>
<th>1 – 30 November 2011 (72-96 hrs)</th>
<th>NOSAT</th>
<th>SAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation between observed and forecast rainfall (Full Aust. Region)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanssen and Kuipers (Full Aust. Region)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Atlantic basin mean hurricane track errors for the control (all data) and no satellite data case, 15 August to 30 September 2010 using GFS and verifying against the control (all data) analysis.
# Current NWP Usage

<table>
<thead>
<tr>
<th><strong>Conventional Data</strong></th>
<th>Surface: synops, ships, buoys Sondes, extra wind profilers Aircraft: AIREPS, AMDARS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EOS</strong></td>
<td><strong>Satellite observations (26 inst.)</strong> Wind: Scatterometer surface winds (ASCAT (2)), AMVs from GEOS(H, GE, GW, MS, M8, IN) &amp; POES(MA, MB, A, T, N(3)) GNSS-RO: (C(6), G, M) bending angle observations SST: AVHRR, AATSR, AMSR-E</td>
</tr>
<tr>
<td><strong>Satellite observations (14 inst.): IR and MW radiances</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Platform</strong></th>
<th><strong>Instrument</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA-18</td>
<td>AMSU-A/B</td>
</tr>
<tr>
<td>NOAA-19</td>
<td>AMSU-A/B</td>
</tr>
<tr>
<td>MetOp-A</td>
<td>AMSU-A/B</td>
</tr>
<tr>
<td>MetOp-B</td>
<td>AMSU-A/B + HIRS</td>
</tr>
<tr>
<td>EOS: Aqua</td>
<td>IASI (138 channels)</td>
</tr>
<tr>
<td>Suomi-NPP</td>
<td>AIRS (139 channels)</td>
</tr>
<tr>
<td></td>
<td>CrIS (134 channels)</td>
</tr>
<tr>
<td></td>
<td>ATMS</td>
</tr>
</tbody>
</table>
## Future Usage

<table>
<thead>
<tr>
<th>Instrument/observation</th>
<th>Platform</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHI clear sky radiances</td>
<td>Himawari-8</td>
<td>Improved DA in AUS region</td>
</tr>
<tr>
<td>COSMIC-2 Receivers Bending Angle</td>
<td>COSMIC-2 Constellation</td>
<td>Improved Global Analysis</td>
</tr>
<tr>
<td>GPS Sat2Ground ZTD</td>
<td>GPS</td>
<td>Improved moisture analysis</td>
</tr>
<tr>
<td>SEVERI clear and SEVERI all-sky IR radiances</td>
<td>Meteosat-8</td>
<td>Indian Ocean coverage, potential to improve TC forecasts</td>
</tr>
<tr>
<td>SAPHIR water vapour sensitive microwave radiances</td>
<td>Megha-Tropiques</td>
<td>Potential to improve tropical, TC analyses and forecasts</td>
</tr>
<tr>
<td>MWTS-2 and MWHS-2 microwave radiances</td>
<td>Fengyun-3C</td>
<td>General improvement to analysis</td>
</tr>
<tr>
<td>RapidScat Scatterometer surface winds</td>
<td>International Space Station</td>
<td>Significant improvement to TC track forecasts</td>
</tr>
<tr>
<td>SSMIS microwave radiances</td>
<td>DMSP F17,18,19</td>
<td>General improvement to analysis</td>
</tr>
<tr>
<td>ADM Aeolus</td>
<td>ADM</td>
<td>General improvement to (wind) analysis</td>
</tr>
<tr>
<td>LeoGeo AMVs</td>
<td>multiplatform</td>
<td>General improvement to (wind) analysis – high latitude</td>
</tr>
</tbody>
</table>
Recent and Impending Advances - Examples

AMVs

GPS RO

Ultraspectral Advanced Sounders

AIRS IASI CrIS
Operational ECMWF system September to December 2008. Averaged over all model layers and entire global atmosphere. % contribution of different observations to reduction in forecast error.

Advanced Sounders have largest single instrument impact in reducing forecast errors.

Courtesy: Carla Cardinali and Sean Healy, ECMWF 22 Oct. 2009
Global 24-hour forecast error reduction from each of the observation types assimilated in ACCESS

- Three months: April, May and June 2016. Himawari-8 AMVs included in full period.
- All types of observations are beneficial, i.e. reduce the forecast error.
- Total impact (LH panel) is dominated by satellite instruments (e.g. the IASI, AMSU and CrIS sounding instruments carried on polar orbiters and AMVs) - due to large numbers & global coverage.
- Greater impact per observation (RH panel) comes from balloon upper air measurements plus surface measurements from drifting and fixed buoys.
Ultraspectral Advanced Sounders

AIRS
IASI
CrIS
Spectral Coverage and Example Observations of AIRS, IASI, and CrIS

MODIS & AIRS (Δν=2400/ν) Channels

AVHRR, HIRS & IASI Channels (Δν = 0.25 cm⁻¹)

Sampling of VIIRS & CrIS (Δν = 0.6 cm⁻¹)

CIMISS
The vertical resolution and accuracy increases greatly going from multi-spectral to ultra-spectral resolution. The improvement in ultra-spectral performance is proportional to the square root of the number of channels (i.e., S/N).
AIRS Data Assimilation

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

1 January 2004 – 31 January 2004

Used operational GFS system as Control

Used Operational GFS system Plus AIRS as Experimental System
Figure 1(a). 1000hPa Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004.
N. Hemisphere 500 mb AC Z
20N - 80N Waves 1-20
10 Aug - 20 Sep '04

Anomaly Correlation

Forecast [days]

1/18fovs AIRS
alloffvs AIRS
Day 5 Average Anomaly Correlation
Waves 1-20
2 Jan - 15 Feb 2004

control  short airs  airs-152ch  airs-251ch
AIRS Data Assimilation

Using Cloudy Fields of View

1 January – 24 February 2007
**AIRS Data Assimilation**

**Using Cloudy Fields of View**

Initial Experiments: 1 January – 24 February 2007

Assume:

\[ R_j = (1 - \alpha_j) R_{clr} + \alpha_j R_{cld} \]

Only variability in AIRS fov is cloud amount \( \alpha_j \)

9 AIRS fovs on each AMSU-A footprint used to estimate \( R_{clr} \)
N. Hemisphere 500 hPa AC Z  20N - 80N  Waves 1-20
1 Jan - 24 Feb '04

Anomaly Correlation

Forecast [days]

Control  AIRS (cloudy fovs)
S. Hemisphere 500 hPa AC Z  20S - 80S   Waves 1-20
1 Jan - 24 Feb '07

Anomaly Correlation

Forecast [day]

Control  AIRS(cloudy fovs)
Figure 6: The impact of AIRS data on GFS forecasts at 500hPa (20°N - 80°N), 1 Jan. – 24 Feb. 2007; The pink curve denotes use of clear radiances from clear and cloudy AIRS fovs (see text) and the blue curve denotes use of non cloud effected radiances (Control).

Figure 7: The impact of AIRS data on GFS forecasts at 500hPa (20°S - 80°S), 1 Jan. – 24 Feb. 2007; The pink curve denotes use of clear radiances from clear and cloudy AIRS fovs (see text) and the blue curve denotes use of non cloud effected radiances (Control).
**AIRS Data Assimilation**

**MOISTURE**

*Forecast Impact* evaluates which forecast (with or without AIRS) is closer to the analysis valid at the same time.

\[
\text{Forecast Impact} = 100 \times \frac{[\text{Err(Cntl)} - \text{Err(AIRS)}]}{\text{Err(Cntl)}}
\]

Where the first term on the right is the error in the Cntl forecast. The second term is the error in the AIRS forecast. Dividing by the error in the control forecast and multiplying by 100 normalizes the results and provides a percent improvement/degradation. A positive Forecast Impact means the forecast is better with AIRS included.
AIRS / IASI Data Assimilation

Using Moisture Channels

Adding 80 AIRS and IASI Tropospheric Water Vapour channels

Adding 40 AIRS and IASI Stratospheric Water Vapour channels
The AIRS and IASI water vapour channels added to the operational data base for the water vapour experimental runs.

<table>
<thead>
<tr>
<th>Tropospheric Channels</th>
<th>AIRS tropospheric channels (2378 channel set): 1301, 1304, 1449, 1455, 1477, 1500, 1519, …27 AIRS Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IASI tropospheric channels (8461 channel set): 2701, 2741, 2819, 2889, 2907, 2910, 2939, …53 IASI Channels</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stratospheric Channels</th>
<th>AIRS Channels: AIRS stratospheric channels (2378 channel set): 1466, 1614, …..9 AIRS Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IASI Channels: IASI stratospheric channels (8461 channel set): 3168, 3248, …31 IASI Channels</td>
</tr>
</tbody>
</table>
Figure 2: Water Vapor Jacobians for IASI channel 3168 (black), which is sensitive to moisture in the Stratosphere, similar CrIS channels half (red) and full (dark blue) spectral resolution and the HIRS channel 12 (light blue).
Analysing Tropospheric Moisture by Assimilating Hyperspectral Infrared Water Vapor Channels

Figure 3: Specific humidity fits to rawinsondes humidity data during the time period March to May 2010 for the analysis, 6(Ges)-, 12-, 24-, 36- and 48-hour forecasts. Note the considerable improvement in the 6-hour and 12-hour forecasts.
Figure 11: Emissivity near 10.85 or µm computed from IASI observations over South Central Australia on the 17th of June 2008. The image is from MTSaT-1R. (Emissivity greater than 0.984 yellow, emissivity between 0.92 and 0.984 magenta).
Himawari-6, 7 and 8

THE GENERATION AND ASSIMILATION OF CONTINUOUS ATMOSPHERIC MOTION VECTORS WITH 4DVAR
<table>
<thead>
<tr>
<th>Band</th>
<th>Central Wavelength $[\mu m]$</th>
<th>Spatial Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.43 -0.48</td>
<td>1Km</td>
</tr>
<tr>
<td>2</td>
<td>0.50 -0.52</td>
<td>1Km</td>
</tr>
<tr>
<td>3</td>
<td>0.63 -0.66</td>
<td>0.5Km</td>
</tr>
<tr>
<td>4</td>
<td>0.85 -0.87</td>
<td>1Km</td>
</tr>
<tr>
<td>5</td>
<td>1.60 -1.62</td>
<td>2Km</td>
</tr>
<tr>
<td>6</td>
<td>2.25 -2.27</td>
<td>2Km</td>
</tr>
<tr>
<td>7</td>
<td>3.74 -3.96</td>
<td>2Km</td>
</tr>
<tr>
<td>8</td>
<td>6.06 -6.43</td>
<td>2Km</td>
</tr>
<tr>
<td>9</td>
<td>6.89 -7.01</td>
<td>2Km</td>
</tr>
<tr>
<td>10</td>
<td>7.26 -7.43</td>
<td>2Km</td>
</tr>
<tr>
<td>11</td>
<td>8.44 -8.76</td>
<td>2Km</td>
</tr>
<tr>
<td>12</td>
<td>9.54 -9.72</td>
<td>2Km</td>
</tr>
<tr>
<td>13</td>
<td>10.3 -10.6</td>
<td>2Km</td>
</tr>
<tr>
<td>14</td>
<td>11.1-11.3</td>
<td>2Km</td>
</tr>
<tr>
<td>15</td>
<td>12.2 -12.5</td>
<td>2Km</td>
</tr>
<tr>
<td>16</td>
<td>13.2 -13.4</td>
<td>2Km</td>
</tr>
</tbody>
</table>

RGB Composited True Color Image

Water Vapour

SO2

O3

Atmospheric Windows

CO2

Full Disk Image every 10 minutes

as of MTSAT-1R/2
NEAR RT TRIAL
OPERATIONAL SYSTEM

27 January – 23 February 2011

Used

- Real Time Local Satellite Winds MTSAT-2 (EE, hourly since 96, TB)
  - 2 sets of quarter hourly motion vectors every six hours.
  - Hourly motion Vectors

- Operational Regional Forecast Model (ACCESS-R) and Data Base (Inc JMA AMVs)
**HIMAWARI-7 NEAR RT TRIAL**

**Fig. 6(a).** The RMS difference between forecast and verifying analysis geopotential height (m) at 24 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.

**Fig. 6(b).** The RMS difference between forecast and verifying analysis geopotential height (m) at 48 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.
GENERATION AND ASSIMILATION OF CONTINUOUS (10 Minute) ATMOSPHERIC MOTION VECTORS FROM MTSAT-1R USING 4DVAR
First Results - MTSAT-1R

Fig. 13 Bureau of Meteorology Analysis for 12 UTC on 27 January 2014.

Fig. 14 Bureau of Meteorology Analysis for 12 UTC on 30 January 2014

Fig. 15 The Bureau of Meteorology operational three-day MSLP (hPa) forecast valid 1200 UTC 30 January 2014, shown remapped over an MTSat infrared image, valid at the same time.

Fig. 16 The Bureau of Meteorology three-day MSLP (hPa) forecast valid, 1200 UTC 30 January 2014 using the next generation operational regional forecasting system with ten, fifteen and sixty minute AMV data from MTSat-1R and MTSat-2. The forecast remapped over the 1200 UTC MTSat image.
RECENT GENERATION AND ASSIMILATION OF CONTINUOUS (10 Minute) H-8 ATMOSPHERIC MOTION VECTORS, GEOCAT AND 4DVAR
Himawari-8 Operational AMV Generation

Uses 3 images separated by 10 min in HSF format.

Employs modified GEOCAT (Geostationary Cloud Algorithm Testbed) software in initial processing.

Height assignment methods similar to GOES-R ABI ATBD For Cloud Height (Heidinger, A. 2010)

AMV estimation is similar to GOES-R ABI ATBD for Derived Motion Winds (Daniels, 2010) / BoM system

Error characterization, data selection, QC via EE, QI, ERR etc. (Le Marshall et al., 2004, 2015)

Height assignment verification Cloudsat/Calipso, RAOBS
Fig. 3 Himawari-8 AMVs tracked using IR (11 µm) channel 14 tracers at 00 UTC 16 January 2016 using the next generation operational system.

Fig. 4. Measured error (m/s) vs Expected Error (m/s) for low-level Himawari-8 IR winds (13 – 29 August 2016).

Fig. 5 Coverage of AMVs from Himawari-8 in the tropics to the north of Australia 0600 UTC 6 September 2015.

Fig. 6 Himawari-8 level of best fit height assignment statistics for CH.14 AMVs for September 2015 (see text).
Fig. 7 Himawari-7 AMVs tracked using the IR and VIS channels at 00 UTC on 20 August 2015 from the operational system

Fig. 8 Himawari-8 AMVs tracked using the IR (11 μm) channel at 00 UTC on 20 August 2015 using the next generation operational AMV system
Fig. 7: AMVs generated around Australia 0000 UTC 29 April 2015 – Note box around Australia.

Fig. 8: AMVs generated around Australia 0000 UTC 29 April 2015 – View from the south.

Fig. 9: AMVs generated around Australia 0000 UTC 29 April 2015 – View from the west.

Fig. 10: AMVs generated around Australia 0000 UTC 29 April 2015 – Slant view from southwest.
Verification for real time vectors from Himawari-7 and Himawari-8

**Table 2 Verification Table for Himawari-8 IR (channel 14) AMVs compared to radiosondes 1 March – 31 March 2016**

<table>
<thead>
<tr>
<th>AMV Type</th>
<th>Category</th>
<th>m/s</th>
<th>NOBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sep.</td>
<td>MMVD</td>
<td>2.4</td>
<td>358</td>
</tr>
<tr>
<td>&lt;50 km</td>
<td>RMSVD</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIAS</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>High Sep.</td>
<td>MMVD</td>
<td>3.3</td>
<td>1460</td>
</tr>
<tr>
<td>&lt;50 km</td>
<td>RMSVD</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIAS</td>
<td>-0.6</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3 Verification Table for Himawari-7 IR (channel 14) AMVs compared to radiosondes 1 March – 20 March 2016**

<table>
<thead>
<tr>
<th>AMV Type</th>
<th>Category</th>
<th>m/s</th>
<th>NOBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sep.</td>
<td>MMVD</td>
<td>2.5</td>
<td>57</td>
</tr>
<tr>
<td>&lt;50 km</td>
<td>RMSVD</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIAS</td>
<td>-0.6</td>
<td></td>
</tr>
<tr>
<td>High Sep.</td>
<td>MMVD</td>
<td>3.5</td>
<td>291</td>
</tr>
<tr>
<td>&lt;50 km</td>
<td>RMSVD</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIAS</td>
<td>-1.4</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 13 MSLP anomaly correlation coefficients for the Northern Hemisphere Annulus for the operational system (blue) and for the operational test system for 4 – 26 March 2016.
Summary and Conclusions

10-minute winds are being continuously generated and assimilated operationally in the Australian region with 4D Var – First country to do so.

H-8 10 minute DMVs provide an improved spatial and temporal resolution database for analysis and forecasting.

The quality of these higher spatial, temporal and spectral density data is of a level which renders them beneficial for NWP.

If the data is thinned to equal spatial density, the quality of the H-8 data exceeds that of the operational H7 data.

Data assimilation tests showed successful transfer of data into operations and successful use of the data by the NWP system.

Further quantification of the impact of these data in our current operational prediction system is underway. This involves use of all 10 minute data in the prediction of TC activity and severe weather.
GPS/COSMIC RADIO OCCULTATION

- 24 transmitters
- 6 receivers
- 3000 occultations/day
Used

- Bending Angle data from
  - the COSMIC Constellation
  - GRACE and METOP

- Operational Global
  Forecast Model (ACCESS-G) and
  Operational Data Base
Figure 10(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region. Shown are results for Control (black), and with GPS RO data (red) for the period 1 November to 30 November 2010.

Figure 10(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

Figure 10(c). RMS errors and anomaly correlations for ACCESS-G 200hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.
Recently
Anomalous GNSS Radio Occultation COSMIC 2 Ground Station

Command and acquisition groundstation for the new COSMIC-2 Constellation
The Future

Distribution of simulated daily COSMIC II RO events in the Australasian region with GPS, Galileo, Glonass and QZS-1

Legend
- COSMIC II (QZS-1)
- COSMIC II (GPS+Galileo+GLONASS)
Summary

- The great benefit of current RO data in the Australian Region and Southern Hemisphere have been recorded using data impact studies.

- COSMIC, GRACE and METOP data have been successfully assimilated into the current ACCESS system and the data are now being used in the BoMs operational forecast system.

- The data are important for climate quality analyses.

- The data are important for climate monitoring.

- The BoM is providing a command and acquisition Ground-station for the new COSMIC-2 Constellation.
ADM (Atmospheric Dynamics Mission) - Aeolus

Satellite built by the European Space Agency that is due for launch in 2017.

ADM-Aeolus Doppler wind lidar Observing System Simulation Experiment
By A. STOFFELEN1*, G. J. MARSEILLE1, F. BOUTTIER2,
D. VASILJEVIC3, S. de HAAN1 and C. CARDINALI3

Forecast skill, as represented by the wind vector RMSE (m s\(^{-1}\)) at 500 hPa of the forecast fields for the NoDWL (dashed) and DWL (solid) experiments (both with respect to the nature run), as a function of forecast range and for six regions: (a) the northern hemisphere, (b) the southern hemisphere, (c) the tropics, (d) Europe, (e) the North Atlantic and (f) North America. Forecasts are initialized with analyses at 12 UTC each day in the period 6 to 20 February 1993. The mean is taken over all 15 cases.
Future Prospects

Environmental analysis /prediction using current and future satellite systems have been examined.

The great benefits from recent advances using current Earth Observations from Space have been noted.

The potential for greatly increased benefit from current and future satellite and assimilation systems has been noted and some of the planning related to gaining these benefits summarised.

Increasing benefits will continue to accrue from current and next generation advanced instruments, which represent an investment of billions of dollars by the international community. (eg.CrIS, ATMS, VIIRS,ABI,AHI, ADM, …ASCENDS….). This will need some local co-investment in infrastructure, research and trained staff.
Looking Down

Is

Looking Up