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The considerable impact of earth observations from space on numerical weather prediction

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Experiments were conducted to quantify the impact of satellite data (Earth Observations from Space—EOS) on the determination of current and future atmospheric state. These experiments have examined two different time periods using two different operational forecast models. The results show that, in the southern hemisphere, the accuracy of a no-satellite data 24-hour (one day) forecast is of the same accuracy, on average, as a 96 hour (four day) with-satellite data forecast when forecasts were verified against the control (all data used) analysis. Satellite data increases the forecast duration by a factor of four for the same accuracy forecast. In the northern hemisphere, the addition of satellite data results in the forecast duration increasing typically by a factor of around 1.6. This gain in forecast skill has resulted in significant societal benefits from improved forecasts, improved warnings and more apropriate time being available to prepare for extreme weather.

Determining the impact

One Observing System Experiment (OSE) was conducted between 28 October and 30 November 2011 to gauge the impact of satellite data on operational numerical weather prediction (NWP). The OSE used the Australian Bureau of Meteorology's operational global ACCESS-G system (Puri at al. 2013) Version APS1, with a horizontal resolution of 47 km and 70 levels in the vertical. The second OSE was conducted between 15 August and 30 September 2010 and used the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) with a resolution of better than 30 km in the horizontal and 64 levels in the vertical (www.emc.ncep.noaa.gov/GFS/doc.php).

The results are summarised in Fig. 1, which shows the 500 hPa geopotential height anomaly correlation die off curves for the ACCESS and GFS operational forecast systems. The 500 hPa geopotential height anomaly correlation is often taken as a robust measure of large scale forecast skill. Figure 1 shows curves which represent the satellite (blue) and no satellite data (red) cases. Each set of forecasts have been verified against the satellite data analyses (or control) as these analyses have been run using the complete operational database. For the ACCESS study, Fig. 1(a) shows, for the southern hemisphere case, the accuracy of a no-satellite data 24-hour (one day) forecast is of the same accuracy on average as a 96-hour (four day) with-satellite data forecast where forecasts are verified against the control (all data used) analysis, increasing the forecast duration by a factor of four for the same accuracy forecast. For the ACCESS study, Fig. 1(c) shows for the northern hemisphere the accuracy of a no-satellite data forecast at 24 hours is equivalent on average to a control (with-satellite data) forecast at 39 hours—an improvement in forecast duration (for the same accuracy) of around 60 per cent when forecasts are verified against the control (all data used) analyses.

In the second OSE using the NCEP GFS the same verification metrics for another period, 15 August to 30 September 2010, are shown in Figs 1(b) and 1(d). The impacts measured are quite similar to those cited above for the ACCESS model, both indicating a similar extension of forecast duration for the with-satellite data prognosis to reach the accuracy of a 24-hour no-satellite data forecast. In the case of the southern hemisphere the forecast extension is around 300 per cent before the accuracy declines to that found in the no-satellite data case at 24 hours. In the northern hemisphere, the forecast extension for the same accuracy is again around 60 per cent to achieve the accuracy found in the no-satellite data case at 24 hours.

It should also be noted that for the ACCESS case, the gain in anomaly correlation in the southern hemisphere at a particular forecast duration (the difference between the SAT and NOSAT curves at that time), with the addition of satellite data, for forecasts of duration between 24 and 144 hours is about six to ten times of that found in the northern hemisphere with the addition of satellite data. Results for the NCEP GFS system are consistent with these results.

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Fig. 1(a) Southern hemisphere 500 hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS-G and verifying against the control analysis.

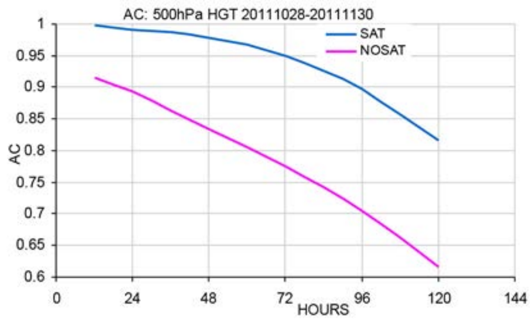


Fig. 1(b) Southern hemisphere 500 hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using GFS and verifying against the control analysis.

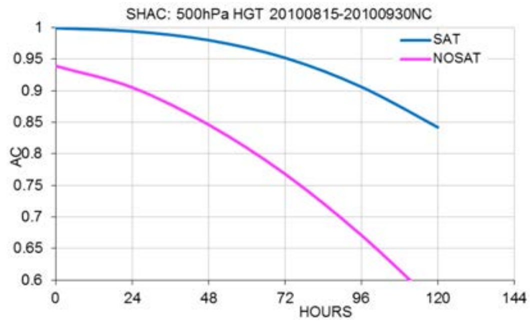


Fig. 1(c) Northern hemisphere 500 hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS-G and verifying against the control analysis.

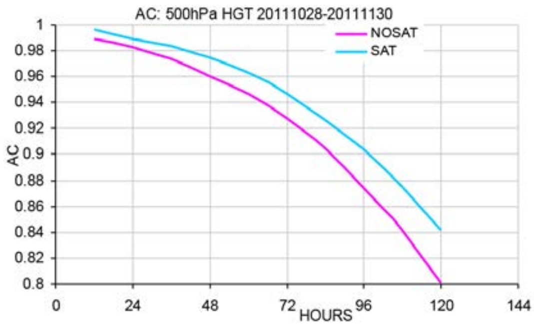
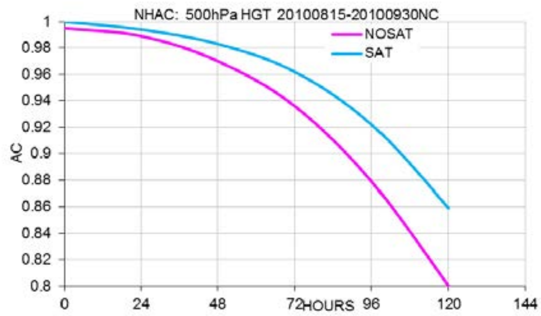


Fig. 1(d) Northern hemisphere 500 hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using GFS and verifying against the control analysis.



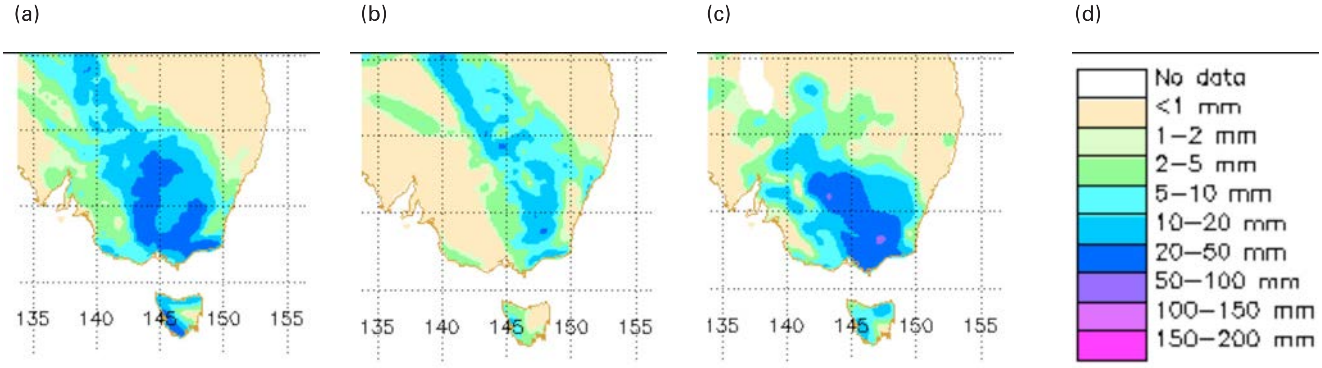
Extreme weather

These improvements in NWP capability shown by large-scale average verification statistics are also reflected in forecasting of individual extreme weather events. An example of this is seen in the 48 to 72 hour ACCESS-G rainfall forecast for 9 November 2011. On this day, over the full Australian region, using the operational RAINVAL rainfall verification scheme (Ebert and McBride 2000), the correlation between observed and forecast rainfall for a 48 to 72 hour forecast was 0.699 and 0.282 for the with-satellite data and no-satellite data forecast cases respectively. This represents a remarkable gain in skill for the with-satellite data case. The associated Hanssen and Kuipers Scores (Hanssen and Kuipers 1965, McBride and Ebert 2000), a common operational measure of skill in precipitation forecasting, which ranges from -1 to +1, were calculated. They were 0.596 and 0.360 respectively, again a clear improvement for the with-satellite data case. The difference in 72 hour rainfall forecasts for the very heavy rainfall event over southeastern Australia on that day is shown in Fig. 2. Figures 2(a) and 2(c) show the extensive heavy rain predicted with the use of satellite data and the observed rainfall respectively, while Fig. 2(b) shows a considerably reduced rainfall event for the no-satellite data case. In this case satellite data have clearly provided more information, several days ahead of time, to allow for example more effective warning and preparation by emergency services managers for this heavy rainfall event.

The 72–96 hour (four day) rainfall forecast verification statistics for the operational ACCESS-G model for all of Australia for the full month, 1–30 November 2011 for forecasts produced with and without satellite data are shown in Table 1. It is clear from this table that satellite data (i.e. EOS) have greatly improved the accuracy of rainfall prediction and as such are already playing a significant role in providing effective warning to the community, particularly in relation to emergency management preparation for potential heavy rain events. Note the rainfall forecast verification statistics reported here are based on rainfall observations which are completely independent of the numerical forecast system. The forecast verifications shown in Fig. 1 for example are not independent of the forecast system as they use analyses generated from observations by the numerical forecast system.

Another important benefit from the use of EOS is great improvement in tropical cyclone detection and track

Fig. 2. (a) ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using satellite data. (b) ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data. (c) Daily rain gauge analysis for 9 November 2011. (d) Legend for (a) to (c).



forecasting. Without EOS many cyclones would spend part of their lives undetected, untracked and unforecast. In addition there are cases where cyclones are forecast to move in entirely the wrong direction without components of the satellite database being included (e.g. Le Marshall et al. 1995). The impact of the full removal of the satellite data base on tropical cyclone track forecasting has been documented for example in Zapotocny et al. (2007). Significant increases in forecast track errors were a result of the removal of satellite data from the database and these would have resulted in poorer forecasts, poorer preparation for example by emergency managers attempting to mitigate impacts of tropical cyclones and poorer forecasts from those estimating storm surge. Similar results have been found in this study (Fig. 3) where removal of satellite data has resulted in significant degradation of tropical cyclone (hurricane) forecast skill with, for example, an average doubling of 36-hour forecast track error in the Atlantic basin. An example of the impact of satellite data on the forecast track of hurricane *Earl* is shown in Fig. 3(b), where the withholding of satellite data has generated large errors in the forecast track from 0000 UTC on 27 August 2010. It should be noted that the Atlantic Ocean is a comparatively well-observed ocean basin in relation to conventional data with aircraft and shipping providing significant observations.

The future

The already great benefits of EOS to forecast accuracy will continue to increase as space based observations expand and improve and as we continue to address the challenges of satellite data assimilation. These include, using more effectively, the large number of diverse instruments providing data to be assimilated, refining the radiative transfer calculations associated with the use of many of the instrument observations and the complexity of modern data assimilation systems. To date, these challenges have required both intra-national and international collaboration, to allow the international NWP centres to successfully exploit the observations from the current space based systems, and considerable societal benefit from the investment in these systems. This collaboration has been aided by groups such as The International TOVS Working Group, a working group of the International Radiation Commission (Le Marshall and Rochard 2003) and the International Winds Working Group, a formal working group of the Coordination Group for Meteorological Satellites, which have provided advice, recommendations and software to the international community. In future, effective collaboration and cooperation amongst the international community will remain an important component for the effective exploitation of EOS, as, for example, operational NWP will require assimilation of data from over 40 space based instruments into global assimilation systems.

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.

1–30 November 2011 (72–96 hrs)	*NOSAT*	*SAT*
Correlation between observed and forecast rainfall (full Aust. region)	0.25	0.41
Hanssen and Kuipers (full Aust. region)	0.36	0.51

Conclusion

The considerable benefits from using earth observations from space in numerical weather prediction have been described.

Improved observational capacity has been and will continue to be further expanded, with the launch of instruments such as those in the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC; Anthes et al. 2008) and advanced infrared sounders (Chahine et al. 2006). These third generation instruments will continue to have significant impact on global NWP and high impact weather forecasting. The benefits of this improved observational capacity, enhanced by improving data assimilation methods such as 4D variational assimilation and the availability of burgeoning computer power, have already led to significantly improved forecast accuracy and, overall, it would appear that the near future prospects of improved specification of atmospheric state, i.e. improved analyses, and the related improvement in forecast capability as well as improved climate monitoring are very great. Generally it points to the next decade being one of potentially significant improvement in observational capacity and the potential gaining of significant societal benefits from its exploitation.

Fig. 3(a) 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.

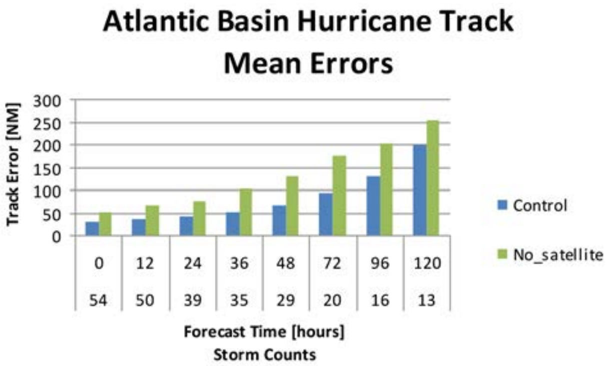
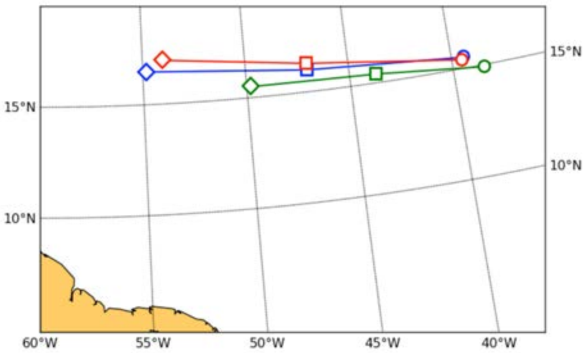


Fig. 3(b) Atlantic basin tracks for hurricane *Earl* commencing 0000 UTC 27 August 2010. The control (all data) forecast is red and the no satellite data forecast case is green. The blue line is the best track. Circles represent 0000 UTC on 27 August, squares 0000 UTC on 28 August and diamonds 0000 UTC on 29 August 2010.



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