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Snow on the Ross Ice Shelf: comparison of reanalyses and observations from automatic weather stations

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Abstract

An analysis of precipitation from the ECMWF ERA-Interim and NCEP/NCAR Reanalysis-2 datasets is developed using snow accumulation measurements from Automatic Weather Stations (AWS) around the Ross Ice Shelf (RIS), Antarctica. The high temporal resolution of the AWS snow accumulation measurements allow for a new, event-based comparison of reanalyses precipitation to in-situ observations. Snow accumulation records from nine AWS provide multiple years of accumulation data between 2008–2012 over a relatively large, homogeneous region of Antarctica and provide the basis for a statistical evaluation of accumulation events. The analysis shows that ERA-Interim reproduces significantly more precipitation events than NCEP-2 and these events correspond to an average 8.2 % more precipitation. Correlations between reanalyses and AWS event sizes are seen at several stations (at > 90 % significance levels) and show that ERA-Interim consistently produces larger precipitation events than NCEP-2. The significant and complex effects of wind on snow accumulation (which can both limit and enhance accumulation) make determining biases in the reanalyses data not possible with the AWS data, however the analysis does illustrate significant and important differences between ERA-Interim and NCEP-2 precipitation.

1 Introduction

Knowledge of the spatial and temporal variability of precipitation and snow accumulation in Antarctica is essential for further understanding of Antarctic mass balance, ice core interpretation, and atmospheric circulation changes. Because of the sparseness of in-situ and satellite measurements in Antarctica, reanalyses products are a key tool for studying precipitation in Antarctica (e.g. Monaghan et al., 2006; Krinner et al., 2007; Marshall et al., 2009; Bromwich et al., 2012). However, understanding how well precipitation is represented by various reanalyses products is difficult to ascertain because of the lack of precipitation measurements. Previous studies have focused on

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annual and longer timescales and primarily use glaciological observations (e.g. Cullather et al., 1998; Bromwich et al., 2004, 2007, 2011). These studies provide valuable information on trends and large-scale variability of precipitation and show that there are significant differences in precipitation representation between various reanalyses datasets. Most recently, Bromwich et al. (2011) showed that the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim dataset represents the spatial variability and recent trends in precipitation over most of Antarctica better than the National Centers for Environmental Predication/National Center for Atmospheric Research (NCEP/NCAR) Reanalyses 2 dataset. However, this assessment is based on annually-averaged precipitation from satellite and glaciological observations and doesn't give insight into how well reanalyses represent precipitation on much shorter timescales.

Understanding how well reanalyses precipitation is represented on synoptic scales is of interest primarily for ice core interpretation and atmospheric circulation change studies (e.g. Simmonds et al., 2003; Helsen et al., 2007; Thomas and Bracegirdle 2009; Sinclair et al., 2010; Fogt et al., 2012). Synoptic-scale systems drive much of the temporal and spatial variability of precipitation in Antarctica and understanding how that variability affects climate proxies in ice cores is very important (Noone and Simmonds, 2002). The Ross and Amundsen Seas in particular are regions of significant synoptic-scale cyclone activity in the Southern Ocean which are the source of most of the precipitation on the Ross Ice Shelf and West Antarctic Ice Sheet (King and Turner, 1997; Simmonds et al., 2003). The synoptic variability of these regions are of interest and the source of ongoing research as they are known to be influenced by large-scale atmospheric circulation changes such as the Southern Annular Mode and El Niño–Southern Oscillation (Cullather et al., 1996; Fogt and Bromwich, 2006; Fogt et al., 2012; Cohen et al., 2013).

In order to assess reanalyses precipitation on synoptic scales, we use high temporal resolution snow accumulation measurements to compare individual precipitation events from the ECMWF ERA-Interim (ERA) and NCEP/NCAR Reanalyses 2 (NCEP) datasets. This event-based assessment uses snow accumulation measurements from the University of Wisconsin Antarctic Meteorological Research Center (UW-AMRC) network of un-manned Automatic Weather Stations (AWS) on the Ross Ice Shelf, Antarctica. The stations provide measurements of snow accumulation via changes in snow height as well as the standard suite of meteorological parameters (temperature, pressure, relative humidity, and wind speed and direction) (Lazzara et al., 2012). Snow height changes are measured with acoustic depth gauge (ADG) instruments which measure amount of snow accumulation and exact timing of accumulation events. These instruments have been widely used in Antarctic studies to characterize precipitation and surface mass balance on sub-annual timescales (e.g. Braaten, 1997, 2000; Qin et al., 2004; Eisen et al., 2008; Reijmer and van den Broeke, 2003; Thiery et al., 2012) and in climate proxy studies to investigate the synoptic origins of individual accumulation events (e.g. Noone et al., 1999; Reijmer et al., 2002; Helsen et al., 2007).

The ADG measurements on the Ross Ice Shelf provide a relatively dense network of multi-year accumulation records for a relatively homogeneous region of Antarctica. This study uses these records to compare for the first time the timing and sizes of individual accumulation events in the NCEP-2 and ERA-Interim reanalyses datasets, which provides some insight into how well reanalyses represents precipitation on synoptic time-scales for this region.

2 Site description and snow accumulation data

Figure 1 shows the locations of the nine UW-AMRC AWS snow height measurements used in this study. The eight stations on the Ross Ice Shelf (RIS) provide a relatively dense network of stations in a geographically constrained area. We also use data from a station located on the West Antarctic Ice Sheet (WAIS) because of its proximity to the RIS and the significance of the WAIS for mass balance and ice core interpretation. The snow height change measurements are available for varying time periods between January 2008–August 2012. All of the stations except for Linda and Byrd have over

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two years of continuous accumulation measurements, with Windless Bight having the longest record of four and a half years. Each station's length of record and location are summarized in Table 1.

Knowledge of the surface wind regime of the RIS is important to help interpret the ADG accumulation measurements, because wind redistribution can be a significant component of snow accumulation (Bromwich, 1988). The RIS is a topographically flat ice shelf bordered to the south and west by the Transantarctic Mountains (TAM), which rise to over 4000 m, and to the east by the Siple Coast which rises gradually to the WAIS at ~2000 m elevation. Katabatic winds, which flow from the ice sheets through the outlet valleys in the TAM and Siple Coast, and barrier winds, which are the result of cold, stable air forced along the TAM, are common features of the surface wind field of the RIS (King and Turner, 1997; Parish et al., 2006). The surface wind regime is also influenced by synoptic scale and mesoscale cyclones, which enhance and provide forcing for katabatic and barrier wind regimes (King and Turner, 1997).

Most of the AWS are located in katabatic outflow paths (Mary, Linda, Elaine, Ferrell, Nascent, and Byrd) and barrier wind regimes (Sabrina), and as a result these sites experience strong winds more often than the other sites (Braaten, 1997; Parish et al., 2006; Knuth et al., 2010; Nigro et al., 2011). We expect the snow accumulation at these sites may be more affected by wind redistribution than other sites such as Margaret, which is located on the eastern side of the RIS near Roosevelt Island. The Windless Bight site, located near Ross Island on the northwestern edge of the RIS, is also less affected by strong wind regimes, but is known to experience high accumulation compared to other sites due to its location on the windward side of Ross Island (Monaghan et al., 2005).

Wind redistribution of snow is a significant and on-going challenge for studying precipitation events in Antarctica because the process is complex and dependent on many additional factors such as snow age, air temperature, snow moisture, local topography (down to meter-scale sastrugi), and snow grain size (Li and Pomeroy, 1997). Increases in measured snow accumulation at a site can occur due to either precipitation,

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or blowing snow, or both, as precipitation often occurs in conjunction with high wind speeds. Increases in accumulation due to clear-sky precipitation and hoar frost are not considered significant for this region (Bromwich, 1988). Decreases in accumulation due to ablation, compaction, and sublimation are significant contributers to net accumulation but can be largely ignored in this study as the event-based analysis only considers positive changes in accumulation. The densification of the snowpack that occurs on the timescale of an event (< 100 h) is less than 1 mm (Arthern et al., 2010) and can thus be ignored for this study. However, the densification of snow deposited during an event due to wind can significantly increase surface snow densities (Pomeroy and Brun, 2001) and this is considered further in the analysis.

As wind is the primary factor affecting the magnitude of measured accumulation (both positively and negatively), previous studies can help provide some estimate of the frequency of high winds occuring during accumulation events on the RIS and their effects on measured accumulation (Braaten 1997, 2000; Knuth et al., 2010). Based on wind speed measurements for several stations on the RIS, Knuth et al. (2010) showed that most (72 %) measured large accumulation events (> 1 cm per 30 min) were associated with blowing or drifting snow which may or may not have been concurrent with precipitation. In another study on the RIS, Braaten (1997) showed that while most ADG measured accumulation events were associated with human-observed precipitation events (using a much smaller event size threshold of 1.3 mm), less than half of the observed events (38 %) resulted in measurable accumulation by the instrument.

Here we describe a methodology for identifying plausible accumulations events within the ADG records that allows for an event-based comparison with reanalyses. By utilizing long records from a large number of stations we can construct a statistical comparison, which still acknowledges the imperfections in the observations. This approach allows for a straightforward validation of the timing and duration of individual events in the reanalyses datasets. Comparison of the sizes of these events requires conversion of a snow height change to a mass (water equivalency) and ideally requires a measurement of snow density at each site and event. Since this information is not

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available we consider a range of snow densities that include the full range of freshly deposited snow (70–120 $\mathrm{kg\,m^{-3}}$ for temperatures < +1 °C) and wind-redistributed snow (from 250 $\mathrm{kg\,m^{-3}}$ and up) (Pomeroy and Brun, 2001). We use an average surface (the top 1–4 m) snowpack density of 350 $\mathrm{kg\,m^{-3}}$ to compare the multi-year accumulation records (Kojima, 1964).

3 Data processing

3.1 ADG data

Snow accumulation is measured with a Campbell Scientific SR50 acoustic depth gauge (ADG) which determines the distance to the snow surface using reflected sonic pulses. The SR50 has a resolution of 0.0001 m and accuracy of 0.01 m or 0.04 % of sensor height (whichever is larger). The instrument measures the distance to snow surface from the speed of reflected sonic pulses and spurious measurements can occur due to drifting and blowing snow reflecting the acoustic signal, high winds (> 18 $\mathrm{m\,s^{-1}}$) (Brazenec and Doesken, 2005), low temperatures (< –35 to –40 °C) (Fountain et al., 2010), and rime or ice on the sensor. The ADG raw data were retrieved from the University of Wisconsin, AMRC ftp site (ftp://amrc.ssec.wisc.edu). Further information and specifications on the AWS instrumentation and network is described in Lazzara et al. (2012) and on the University of Wisconsin, AMRC site (http://amrc.ssec.wisc.edu).

Snow accumulation records for each station were produced by removing null measurements and measurements that don't represent physical accumulation (i.e. spurious data points outside of the initial and final accumulation values). The ADG data were recorded at a 10 min sampling rate except for Nascent which is at 20 min resolution. The ADG sensor heights are periodically adjusted to keep the sensors ∼ 1 to 2 m above the snow surface and these height adjustments were applied based on the maintenance logs.

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The datasets all contain some high frequency noise which was minimized using the same methodology as Fountain et al. (2010), which removes data outside of one standard deviation of a running daily value. Since snow accumulation due to precipitation is stepped and episodic, the removal of data points outside of the daily standard deviation removes some of the high-frequency noise while retaining the amplitude of an accumulation event, though the timing of can be shifted by up to one day. The ADG data were then averaged to a three-hourly resolution in order to compare with the reanalyses datasets.

The ADG records are continuous with no significant gaps except for Mary and Windless Bight which have large gaps during the winter months of 2011 (June–October). Removal of spurious data, high frequency noise, and gaps in the raw data account for between 1.5 to 6.8 % of the data in all stations except for Mary and Windless Bight which are missing 17.1 % and 22.5 % of their data respectively.

3.2 Reanalyses data

Reanalyses assimilate in-situ meteorological data and satellite data into a global circulation model to produce comprehensive global datasets of meteorological parameters at regular vertical and horizontal resolutions throughout the atmosphere. This study investigates the precipitation products from the NCEP-2 (NCEP) and the ERA-Interim (ERA) reanalyses datasets (Kalnay et al., 1996; Dee et al., 2011). The NCEP reanalysis provides parameters at 2.5° latitude/longitude resolution through 30 June 2012; ERA provides parameters at 1.5° latitude/longitude resolution through 31 August 2012 (though the underlying models for both are run at higher resolution). Though both reanalyses datasets assimilate meteorological observations from the AWS network, the snow accumulation data is not used. Precipitation products from both reanalyses rely entirely on the model's representation of the hydrological processes as they are not directly constrained by observational data (Dee et al., 2011).

The NCEP precipitation is given as an instantaneous precipitation rate, $\mathrm{kg\,m^{-2}\,s^{-1}}$ water equivalent (w.e.), averaged over each six hour forecast period which we convert

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to m w.e. For ERA, total precipitation is derived from the three-hourly forecast fields and given in m w.e. Precipitation data from the reanalyses grid points nearest to each AWS location are used for the analysis. Distances from the stations are listed in Table 1; all are less than ~100 km from their respective AWS location.

3.3 Determination of coincident events

Individual accumulation events are identified from the daily accumulation values for each dataset. As with Fountain et al. (2010), we found that the ADG measurements were able to resolve relative changes in snow height as small as 5 mm snow day^{-1}, and set that as the event size cutoff for the ADG datasets. For the reanalyses data cutoff value, we use 0.5 mm w.e. day^{-1}, which is equivalent to the ADG cutoff using a mid-range fresh snow density of 100 kg m^{-3}. For each dataset, a daily accumulation/precipitation rate is calculated at each time point (3-hourly for ADG and ERA; 6-hourly for NCEP) with the day defined as the 12 h before and 12 h after the time point. Events are defined separately for each dataset as the period of time that the accumulation/precipitation rate remains above the cutoff value (only events lasting longer than 6 h are considered). Coincident events are then determined by identifying the reanalyses events which overlap in time with or are within one day of an ADG event.

4 Results

Figure 2 shows each station's ADG accumulation record along with the ERA and NCEP precipitation. Accumulation events can be seen as stepped increases in height while decreases in height (in the ADG records only) indicate the effects of ablation, compaction, or sublimation which are important for surface mass balance, but are not accounted for in this study. For an approximate comparison of the magnitudes between the datasets (snow accumulation and precipitation), a snow density of 350 kg m^{-3} is used to equate each station's y-axes in Fig. 2. The reanalyses precipitation shows that

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the ERA produces significantly more accumulation than NCEP (~2–4 times as much over the varying time periods) with the exception of Ferrell, Margaret, and Nascent which have similar total precipitation amounts for ERA and NCEP over these time periods.

Figure 3 shows a close-up of the ADG, ERA, and NCEP records for Margaret station (corresponding to the grey box in Fig. 2) and illustrates one of the larger coincident events in the datasets. The highly stepped nature of ADG accumulation events is seen clearly as is the more broad nature of reanalyses events. The duration of an event can be different for each dataset as illustrated in Fig. 3. The greater duration of reanalyses events as compared to the ADG events is seen throughout the datasets. The mean duration of coincident events for all ADG events is 27 h, while the mean durations for ERA and NCEP are 65 and 61 h respectively. While this may indicate that the cutoff value for the reanalyses data is too low, increasing the cutoff value to a much higher value (2 mm w.e. day^{-1}) only decreases the average duration of events to 48 and 46 h for ERA and NCEP respectively.

Table 2 shows the number of accumulation events (> 5 mm day^{-1} for ADG and > 0.5 mm day^{-1} for reanalyses) identified for each of the ADG, ERA, and NCEP datasets as well as the number of coincident events for each pairing (ADG–ERA and ADG–NCEP). The probability that the number of coincident events in each timeseries is random is determined from the hypergeometric probability density distribution and is much less than 0.01 for all pairings. For all stations except Nascent, ERA produces a significantly higher number of precipitation events, and except for Sabrina, a higher percentage of these events are coincident with ADG events.

Table 3 shows the percentage of coincident events captured by reanalyses datasets and the percentage of precipitation derived from these coincident events. ERA events coincide with between 22–51 % of ADG events and NCEP events coincide with 14–40 % of ADG events. ERA captures significantly more ADG events than NCEP (average 37 % versus 23 %). Because of the known significant influence of wind-redistributed snow on snow accumulation discussed in Sect. 2, many of the events

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identified in the ADG data may actually be due to blowing/drifting snow, where no precipitation occurred, and as such we would not necessarily expect these percentages to be very high. Identifying and quantifying these events is very difficult and is a persistent problem in snow accumulation studies. The coincident events do correspond to significant amounts of the total reanalysis precipitation (between 63–86 % and 48–79 % for ERA and NCEP respectively) with ERA producing an average of 8.2 % (significant at the 93 % confidence level) more precipitation than NCEP. That ERA captures on average 14 % more events, but only 8.2 % more precipitation indicates that the "extra" events ERA is capturing are smaller precipitation events.

Table 3 also shows the percentage of reanalyses events that aren't seen in the ADG data ("false" events). The NCEP reanalyses dataset has more false events than ERA (average 50 % and 44 % respectively). These events would include cases where snow accumulation is less than the ADG threshold of 5 mm day^{-1} (either due to small amounts of precipitation or wind limiting accumulation) or the event does not fall within the two-day window we used to define a coincident event. Distinguishing between these circumstances are difficult, but in a study of one ADG record on the RIS, Braaten (1997) found that 38 % of meteorologist-observed precipitation events resulted in no measured accumulation in the ADG record suggesting that identifying whether the additional reanalyses events are in fact real is beyond the capability of the ADG dataset.

To assess the effect of changing the reanalysis event size cutoff on the analysis, we compare the number of coincident events and percentage of precipitation captured by coincident events using different reanalyses cutoff values of 0.35 mm day^{-1}, 0.5 mm day^{-1}, 1 mm day^{-1} and 2 mm day^{-1} (the values in Tables 2 and 3 are calculated using 0.5 mm day^{-1}). The lowest two values are equivalent to the ADG threshold value using freshly precipitated snow densities (7 % and 10 %). Not surprisingly, increasing the reanalyses cutoff value decreases the number of coincident events and amount of precipitation accounted for. Over the range of cutoff values the average percentage of coincident events captured for all stations decreases from 40 % to 24 % for ERA and from 27 % to 13 % for NCEP. The average percentage of precipitation accounted

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for decreases from 77 % to 61 % for ERA and from 70 % to 49 % for NCEP. For the NCEP dataset, though the decrease in number of coincident events is similar to ERA (16 % versus 14 %), a larger change in the amount of precipitation (16 % vs 21 %) is seen. This suggests that the NCEP dataset produces more of its precipitation at lower amounts making it more sensitive to the lower threshold values. The percentage of "false" events also changes much more in the NCEP dataset, decreasing from 51 % to 39 % as the threshold decreases (from 0.35 to 2 mm day^{-1}), while ERA "false" events change only slightly from 44 % to 40 %.

Further comparison of the coincident events identified between ADG and reanalyses data, Fig. 4 plots the sizes of coincident events for each station to show the relationships between the ADG and reanalyses events. The sizes are calculated as the total amount of precipitation/accumulation during each coincident event. Although we can not directly compare the sizes (snow versus water equivalent), a range of snow densities for freshly fallen snow (70 kg m^{-3} to 120 kg m^{-3}) and wind-redistributed snow (250 kg m^{-3}) is shown as dashed lines in Fig. 4. Least-squares linear regressions and correlations (r values) are shown for the relationships between ADG and reanalyses event sizes that are significant at 90 % level. Regression lines which lie near the range of fresh snow densities, with zero-intercept and higher correlation coefficients indicate better relationships between reanalyses precipitation and ADG data.

Five of the nine stations have significant relationships with both ERA and NCEP (Elaine, Margaret, Mary, Ferrell, and Windless Bight) and one has a significant relationship with NCEP (Byrd), indicating that many precipitation events are being accurately represented by both reanalyses datasets. The r values vary between 0.26 to 0.69 with neither reanalyses product showing higher correlations over all stations. The regressions show that ERA events are generally larger than NCEP events. The smaller values seen in NCEP would be consistent with previous studies showing that NCEP underestimates precipitation in Antarctica (Cullather et al., 1996; Zou et al., 2004). However the NCEP regressions are not consistent enough to draw any conclusions about biases and none are significantly lower than expected values. The one regression that is significantly higher than expected values (Ferrell) is dominated by several events.

The complex effects of wind on ADG snow accumulation means that we cannot determine biases in reanalyses precipitation amounts. In Fig. 4, events that are in the region above the freshly-fallen snow densities could have several causes: snow accumulation being limited by wind, higher snow densities due to wind-blown snow, or reanalysis overestimating event sizes; events that fall below the range could be either due to excess accumulation due to wind or reanalysis underestimating event sizes. At sites known to exhibit significant ablation such as Ferrell, Mary, Nascent, and Sabrina (Braaten, 1997; Knuth et al., 2010; Nigro et al., 2011), where we would expect a low-bias in the ADG data (i.e. ADG snow accumulation is often limited due to wind), these sites do show a significant number of events where reanalyses are much larger than ADG events (except for the NCEP events with Mary). At Windless Bight, which is a low-wind, high-accumulation site (Knuth et al., 2010) where we would expect a high-bias in the ADG (i.e. ADG snow accumulation is often enhanced by wind conditions), the ERA and NCEP regressions do reflect this (via regression slopes closer to fresh-snow values). However, the ERA data for this site still shows a significant number of events where ERA events are much larger than ADG events. Finally, Margaret, which is located in the least wind-affected region of the RIS (Parish et al., 2006), has the highest correlation and near-zero intercept for the ERA data, but interestingly has the lowest correlation for NCEP.

5 Conclusions

This study provides a new assessment of precipitation from ERA-Interim and NCEP-2 reanalyses on sub-annual timescales using an event-based analysis of ADG snow accumulation records from nine AWS located around the Ross Ice Shelf. The high temporal resolution ADG measurements provide a dense network of multi-year accumulation records in a relatively homogeneous region of Antarctica and allow us

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to assess reanalyses precipitation on sub-annual timescales for recent time periods (2008–2012). Analysis of the number of events in each dataset shows that for all locations, ERA has more matching events with the ADG measurements than NCEP, capturing an average 37 % of ADG accumulation events versus 23 % for NCEP. These coincident events correspond to an average 75 % and 66 % of the total reanalyses precipitation for ERA and NCEP respectively. Quantifying how many of the ADG events are precipitation versus blowing/drifting snow (and thus how many events the reanalyses are missing) is a difficult and on-going issue in measuring precipitation. Previous estimates of the number of wind-affected accumulation events from ADG data (which may or may not be coincident with precipitation events) on the RIS are on the order of 70 % (Knuth et al., 2010) suggesting that the reanalyses may be capturing a significant number of precipitation events. Overall this analysis suggests that the ERA data performs significantly better than NCEP, capturing 14 % more events and 8.2 % more precipitation.

Comparisons of the sizes of coincident events between ADG and reanalyses data show that there are significant correlations for several of the stations and these correlations are near the range of expected values providing further evidence that the reanalyses are reproducing actual precipitation events. The ERA data consistently produces more precipitation per event than the NCEP which is consistent with capturing more precipitation overall. Neither reanalyses dataset shows consistently higher correlations with the ADG event sizes, but using known biases of wind-limiting snow (Ferrell, Nascent, Mary, Sabrina) or wind-enhancing snow (Windless Bight) helps interpret some of the overall patterns of the event size correlations. ERA consistently shows correlations in the upper range of expected snow densities while NCEP less consistently shows correlations in the lower range of expected snow densities.

Determination of the biases in the reanalyses datasets (i.e. ERA overestimating or NCEP underestimating precipitation) is not possible due to the limitation of the ADG dataset. Further work to identify biases and make quantitative estimates would require extensive further analysis of site-specific wind conditions and snow density. Despite

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this, the analysis does show important differences between the two datasets. For synoptic-scale representation of precipitation on the RIS, ERA reproduces more precipitation events, and produces more precipitation per event than NCEP.

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Table 1. AWS locations, elevations, dates and lengths of ADG records, and distances to nearest ERA-Interim and NCEP-2 gridpoints.

Station	Location	Elev. (m)	Dates of ADG data and Length of Record (yr)		Distance to ERA/NCEP (km)
Byrd	80.007° S, 119.404° W	1530	Nov 2011–Aug 2012	0.8	58/105
Sabrina	84.247° S, 170.068° W	88	Jan 2010–Aug 2012	3.5	29/57
Elaine	83.094° S, 174.285° E	58	Jan 2010–Aug 2012	2.6	66/27
Margaret	80.000° S, 165.000° W	67	Nov 2008–Aug 2012	3.8	56/105
Nascent	78.129° S, 178.498° W	30	Jan 2009–Apr 2011	2.3	44/10
Mary	79.305° S, 162.985° E	58	Jan 2008–Dec 2011	3.8	24/29
Linda	78.426° S, 168.418° E	42	Nov 2011–Aug 2012	0.8	50/68
Ferrell	77.833° S, 170.819° E	45	Jan 2009–Dec 2010	2.0	19/77
Windless Bight	77.725° S, 167.687° E	40	Jan 2008–Aug 2012	4.6	31/68

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Table 2. The number of events for ADG, ERA-Interim, and NCEP-2 datasets and number of coincident events.

	Number of Events					
	ADG[a]	ERA	ADG-ERA	ADG[b]	NCEP	ADG-NCEP
Byrd	51	50	26	42	22	11
Sabrina	182	173	73	170	127	68
Elaine	146	98	59	137	84	37
Margaret	237	143	72	235	118	58
Nascent	200	65	44	200	80	40
Mary	305	154	97	305	82	42
Linda	59	42	27	49	16	8
Ferrell	94	81	33	94	55	23
Windless Bight	369	209	142	353	112	66

[a] To 31 August 2012.
[b] To 30 June 2012.

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Table 3. Percentages of ADG events captured by reanalysis datasets, the amount of precipitation captured by those events (as a percentage of the total reanalysis precipitation), and percentage of reanalysis events that are not seen in ADG data ("false" events) for each reanalysis dataset.

	ERA			NCEP		
	ADG captured (%)	Precipitation (%)	"False" events (%)	ADG captured (%)	Precipitation (%)	"False" events (%)
Byrd	51.0	70.8	48.0	26.2	67.7	50.0
Sabrina	40.1	63.0	57.8	40.0	74.5	46.5
Elaine	40.4	81.5	39.8	27.0	72.0	56.0
Margaret	30.4	67.3	49.7	24.7	59.7	50.8
Nascent	22.0	81.9	32.3	20.0	74.6	50.0
Mary	31.8	78.4	37.0	13.8	62.4	48.8
Linda	45.8	71.0	35.7	16.3	47.7	50.0
Ferrell	35.1	71.6	59.3	24.5	59.9	58.2
Windless Bight	38.5	85.8	32.1	18.7	79.0	41.1

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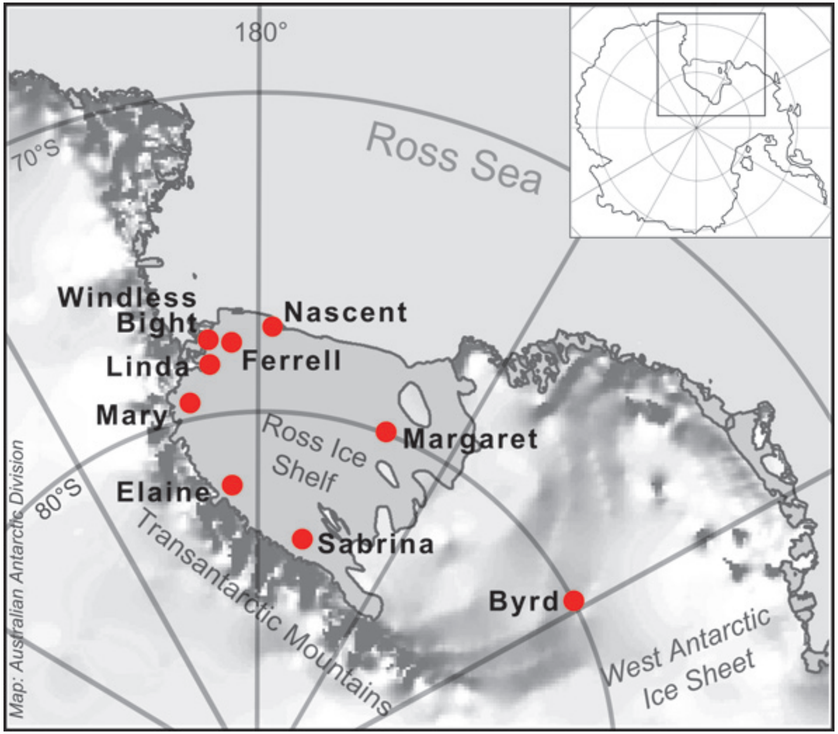

Fig. 1. Locations of the automatic weather stations (AWS) used in this study.

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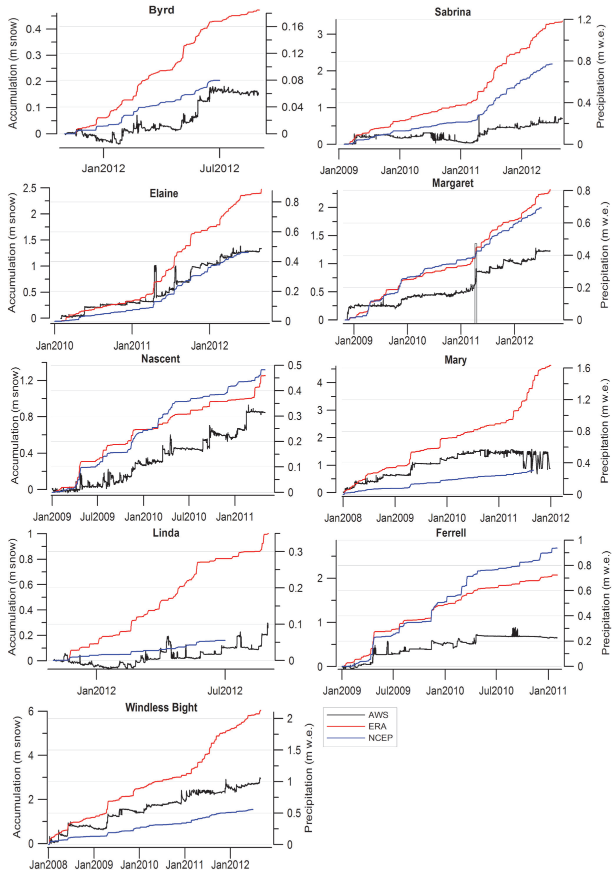

Fig. 2. Total accumulation and precipitation over time for each station (note different time periods). ADG accumulation is in m snow (left axes) and ERA and NCEP reanalyses is in m w.e. (right axes), with axes offset by 35 % (approximate density of surface snow on RIS). A close up of the time period outlined by the grey box in the Margaret plot is shown in Fig. 3.

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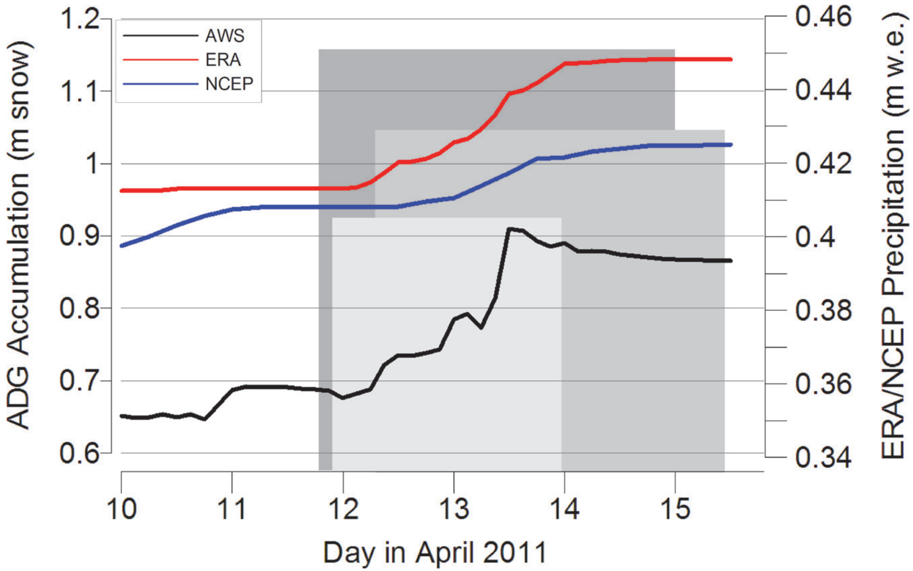

Fig. 3. Six days of data from the Margaret station (corresponding to the grey box in Margaret in Fig. 2). ADG accumulation is on the left y-axis and ERA/NCEP precipitation is on the right y-axis as in Fig. 2 but axes are different scales for clarity. The shaded grey boxes highlight one coincident event during this time period and illustrate the different durations of the event for each dataset.

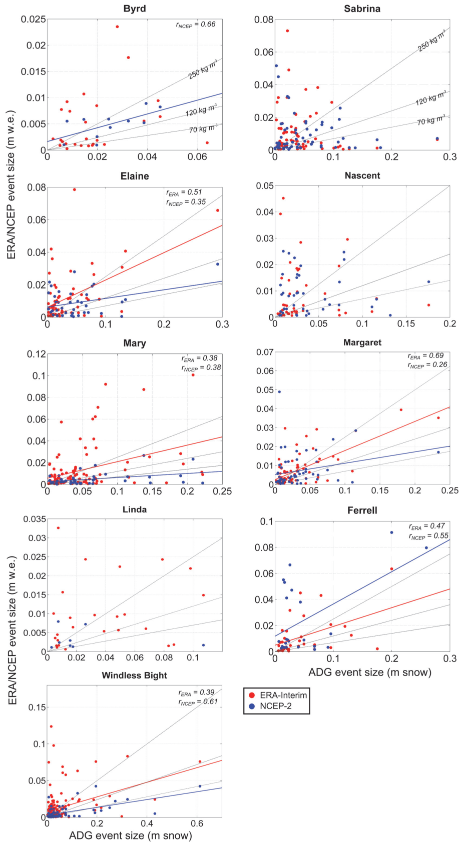

Fig. 4. Comparison of event sizes for all coincident events. ADG event sizes are m snow, reanalyses event sizes are m w.e. Regression lines and r-values are shown for correlations at 90 % significance level. Black lines indicate the slope of the regression that would be expected for snow densities at various ranges (freshly fallen snow, ρ = 70–120 kg m^{-3}; wind-redistributed snow, ρ = 250 kg m^{-3}).