Synoptic controls of moisture transport and accumulation during 2009-2010 at the Belgian Antarctic Station Princess Elisabeth, Dronning Maud Land

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Introduction

A new Antarctic research station Princess Elisabeth (PE) has been inaugurated during the IPY2007-2008 - located near Utsteinen nunatak, north of Sør Rondane mountains, in Dronning Maud Land (72^0S, 23^0E, 180 km inland, 1.4 km asl). The site is situated at the ascent to the Antarctic Plateau, in escarpment area, where the topographic slope is relatively large (9 m km^{-1}) and thus the katabatic force is large. At the same time, the site is close to one of the high density cyclone zones situated around Antarctica (Simmonds and Keay 2000). While the mountain range shelters the site from the south/south-easterly shallow cold katabatic flow, synoptic events associated with large-scale pressure gradients and deep tropospheric advection of heat and moisture are frequent at Utsteinen. A number of publications have been dedicated to understanding the moisture origins and transport pathways and precipitation mechanisms over Antarctica, with one of the primary goals being able to interpret the paleo-record from deep ice cores (e.g., Noone 2008, Sodemann and Stohl 2009). The meteorological observatory established at Utsteinen contributes to understanding precipitation mechanisms in Dronning Maud Land, where climate models disagree about the magnitude and variability of the surface mass balance.

Figure 1. Automatic Weather Station installed as part of the HYDRANT project near the Belgian Antarctic station Princess Elisabeth (photo - February 2010). The AWS is designed by the IMAU group (www.projects.science.uu.nl/iceclimate/aws/).

Data and Methods

An automatic weather station (AWS) has been installed at Utsteinen in February 2009 (Fig. 1), providing hourly mean data of near-surface air temperature, relative humidity, pressure, wind speed and direction, up and downward directed broadband short-wave and long-wave radiative fluxes, snow height changes, and a 1-m snow temperature profile. In addition, ground-based cloud and precipitation remote-sensing instruments have been operating during several months (Feb-March 2010 and Jan-March 2011), from which characteristics of cloud properties and individual storms have been derived. The instruments include ceilometer (vertical backscatter profile, cloud base height and vertical visibility), infrared pyrometer (cloud base temperature), and vertically pointing 24GHz precipitation radar (snowfall layer depth and intensity). Information about the instruments and measurement campaigns can be found on the project website (http://ees.kuleuven.be/hydrant).

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A multivariate hierarchical cluster analysis was applied to the daily means of the five parameters derived from AWS measurements: near-surface temperature inversion, specific humidity, barometric pressure, wind speed and incoming longwave flux (indication of cloud presence). The large-scale synoptic analysis for particular events and composites was done using the mean sea level pressure from ECMWF ERA-Interim Analysis. The cloud and moisture transport from the ocean across Dronning Maud Land coast was analyzed using the infra-red and water vapor satellite composite maps provided by the AMRC group of the University Wisconsin-Madison (Lazzara et al. 2003; Lazzara and Willmot 2010, personal communication).

Results

The two years of measurements (2009 and 2010) at the Utsteinen site have been characterized by very different total accumulation amounts (Table 1). Though the measurement record is rather short, these two years and the comparison with the measurements during 2005 (Pattyn et al. 2010) point to the very high inter-annual variability at the site.

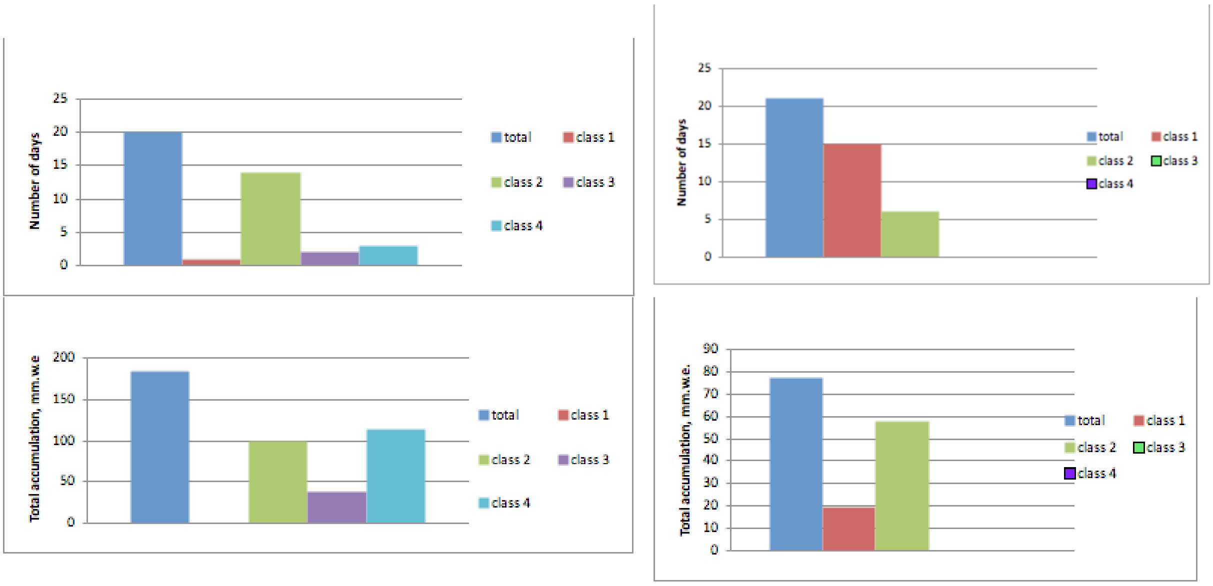
Three major meteorological states were identified using cluster analysis: cold, warm and transitional. Cold events are characterized by a strong near-surface temperature inversion, low specific humidity, relatively high pressure, close to zero wind speeds, and a low downwelling longwave radiation flux. Warm synoptic events have all the opposite characteristics (isothermal near-surface temperature, relatively high specific humidity, low pressure, high wind speeds, and high downwelling longwave flux) and indicate advection of heat and moisture from the ocean associated with the nearby low pressure system. The transitional states combine the transitions between the warm and the cold regimes.

Year	2009	2010
Observation period	Feb 2 - Nov 21	Jan 12 - Dec 31*
Air temperature, K	254.0± 5.4	253.7± 7.1*
Specific humidity, g/kg	0.58± 0.37	0.52± 0.51*
Relative humidity wrt ice, %	61± 22	48± 19*
Wind speed, m/s	5.3± 3.4	4.6± 2.5
Pressure, hPa	827± 8.7	824± 10.3
Total accumulation, mm.w.e. **	235	10

Table 1. Yearly means ± standard deviations based on daily values for major meteorological parameters measured by HYDRANT AWS at Utsteinen during 2009 and 2010. (*a gap in air temperature, relative and specific humidity data from October 17 to December 22, 2010; **calculated using the snow density = 335.7 kg/m^3 measured Feb 2009 near the AWS.)

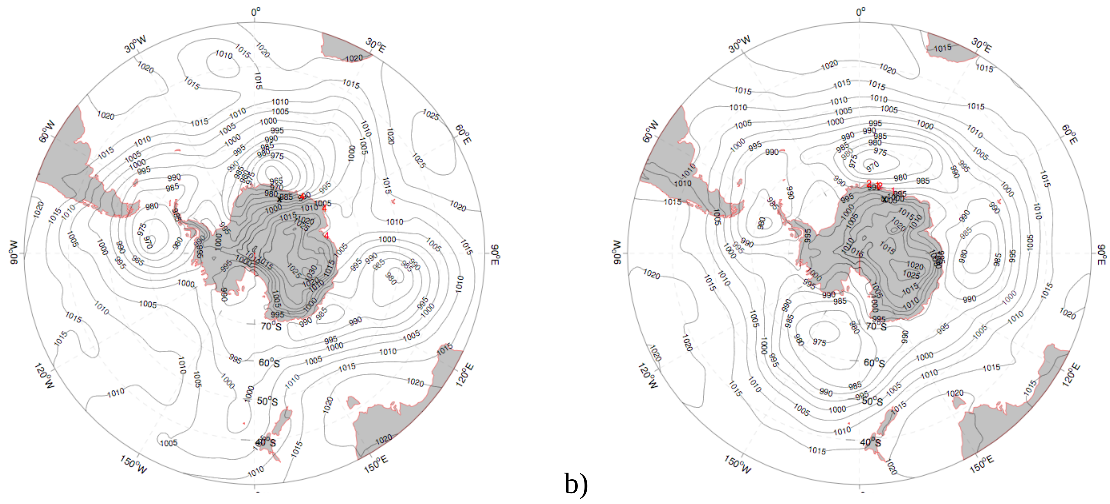
Warm synoptic events were observed at Utsteinen in total during 20 days during each of the two years (Fig. 2). These events are responsible for the majority of accumulation in 2009, while in 2010 warm events have very low accumulation (comparable to transitional and cold events). More than half of the total warm event accumulation during 2009 happened during only three events. In 2010, only warm events with small accumulation were observed. Figure 2 shows the number of days and accumulation during the warm events classified by the daily accumulation amounts from small (0-3 mm w.e./day) to high (>33 mm w.e./day) for the two years.

The warm events with highest accumulation during 2009 were all associated with a deep cyclone (with the average position of the systems around 68^{0}S,15^{0}E) blocked by a high-pressure ridge to the east (Fig. 3a). A water vapor inflow corridor was observed between 30-60^{0}E and further east on one occasion. The warm events with low accumulation observed during 2010 were associated with a weaker cyclone that was on average located further west and north (around 65^{0}S, 5^{0}E) with the water vapor inflow centered within 0-30^{0}E sector (Fig. 3b).



a) b)

Figure 2. The number of days and total positive accumulation during warm events classified by the amount of positive daily accumulation: 0-4 mm w.e. (class 1), 4-17 mm w.e. (class 2), 17-33 mm w.e. (class 3), and >33 mm w.e. (class 4) for (a) 2009 and (b) 2010.



a) b)

Figure 3. Maps of mean sea level pressure (contours, hPa) composites for warm (synoptic) events for (a) 3 days with high daily accumulation during 2009 (class 4) and (b) 4 days with low daily accumulation during 2010 (classes 1-2). The numbers in red indicate the accumulation class showing the center of the water vapor tongue associated with the cyclone. Note that the MSLP values over land represent hydrostatic interpolation from the surface values down to the sea level using isothermal temperature profile and are unphysical.

Discussion

The radically different amount of accumulation during the two years of observations at Utsteinen can be attributed to the atmospheric circulation patterns controlling the path and the amount of moisture transported into Dronning Maud Land. The selected warm events with small amounts of accumulation observed during both years are associated with relatively weak cyclones with a marginal inflow of water vapor resulting in relatively small specific humidity increase at

Utsteinen and small amounts of accumulation. The high accumulation during 2009 is a consequence of the few deep cyclones blocked by a high pressure ridge to the east bringing large amounts of water vapor in a wide corridor across the Atlantic part of the east Antarctic ice sheet. Further investigation is ongoing regarding the moisture transport along isentropic surfaces, which will show the moisture origins associated with each accumulation event. The present analysis demonstrates significant differences in accumulation controls from year to year at one of the Dronning Maud Land sites.

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