

# **Chapter 1 SEDNA Meteorological Data**

## ***Summary of meteorological observations***

There were three separate groups of meteorological data collected during the SEDNA field campaign. Firstly, a weather station was erected at commencement of the SEDNA fieldwork and removed at the end of the campaign. This forms the most reliable and continuous set of atmospheric observations from the campaign. Secondly, observers recorded a rough set of cloud and precipitation observations to assist in the interpretation of satellite images and data from the SEDNA weather station. Finally, the Applied Physics Laboratory ice camp logged observations using an anemometer, wind vane, barometer and temperature sensors mounted approximately 6m above the command and control hut. Information on each of these data sources follows.

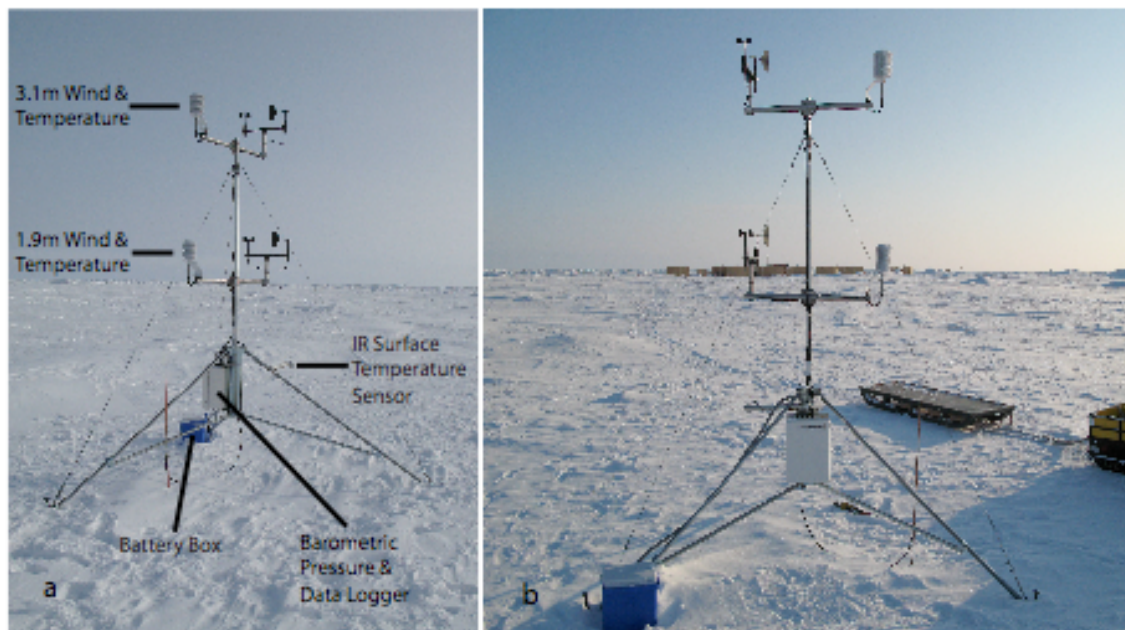
## ***The SEDNA weather station***

### **Introduction**

A SEDNA weather station was operated during the April 2007 field campaign to measure surface atmospheric variables necessary to estimate atmosphere-ice momentum fluxes. An annotated image of the station configuration appears in Figure 1. Wind speed and direction were measured with temperature and humidity 3.1 and 1.9 m above ground, in addition to barometric pressure and surface temperature. These were logged every ten minutes between April 2 2007, 05:50 and April 15 2007, 02:50 UTC. The weather station's short 3m mast provided a robust instrument platform in strong winds, but the maximum measurement height of 3.1m precluded its use for estimating buoyant turbulent fluxes in the vicinity of leads, based on model results of Dare and Atkinson (1999) and Esau (2007). However the station was never within 400 meters of a lead and was of sufficient height to detect stably stratified surface conditions. Downward shortwave and longwave radiation fluxes were not measured because they are not of direct relevance to the sea ice momentum budget which was the focus of SEDNA campaign.

### **Weather Station Site**

The station was located on flat, multi year sea ice more than 100m from recent ridge formations. No ridges formed within the vicinity during the field camp (Figure 1). Ice camp structures up to 4 meters high were more than 170 meters from the weather station, easily surpassing minimum WMO (2006) guidelines for structure and obstacle distances from a weather tower. The surface surrounding the weather station was covered with a mean snow depth of about 10cm during the recording period, varying spatially between bare ice and drifts approximately 30cm deep. Instrument heights quoted here were measured from the mean snow surface height above sea ice.



**Figure 1 Weather station site on level multi year sea ice indicating a) instrument heights including an infrared (IR) surface radiometer mounted 1m above ground level to measure surface temperature and b) proximity of the station to the Applied Physics Laboratory ice camp more than 170 meters behind the weather station.**

## **Weather Station Instrumentation**

Instruments deployed on the station structure are listed in Table 1. The Young Wind Sentries comprised a lightweight cup anemometer and a wind vane separated by a spar. Temperature and humidity were measured inside a radiation shield using Vaisala HMP45C-L probes. Each of these sensors was mounted at 3.1m and 1.9m above the mean snow surface on cross-arms of a Campbell Scientific CM10 tripod 3m high (Figure 1). The 1-meter cross-arms reduced fowling of the Wind Sentries when downwind of the tripod mast or radiation shields, extending instruments at least 45cm away from the 5cm-diameter mast surpassing WMO (2006) guidelines. Surface temperature was measured with an Apogee infrared radiometer mounted on a 50cm horizontal arm extending from one leg of the tripod (Figure 1). The data logger box was positioned low on the tripod to negate fowling of the 1.9m Wind Sentry. This box was also inverted to prevent Arctic Foxes chewing instrument cables, and the power cable from the instrument box to the 12V battery were encased in fox-proof conduit. The battery was insulated in a small cooler located at one foot of the weather station, and a copper steak frozen into sea ice provided data logger grounding. The weather station was rigid in all wind conditions experienced. Each foot of the tripod was anchored by metal steaks frozen into sea ice with cables extending to the upper mast in counter tension.

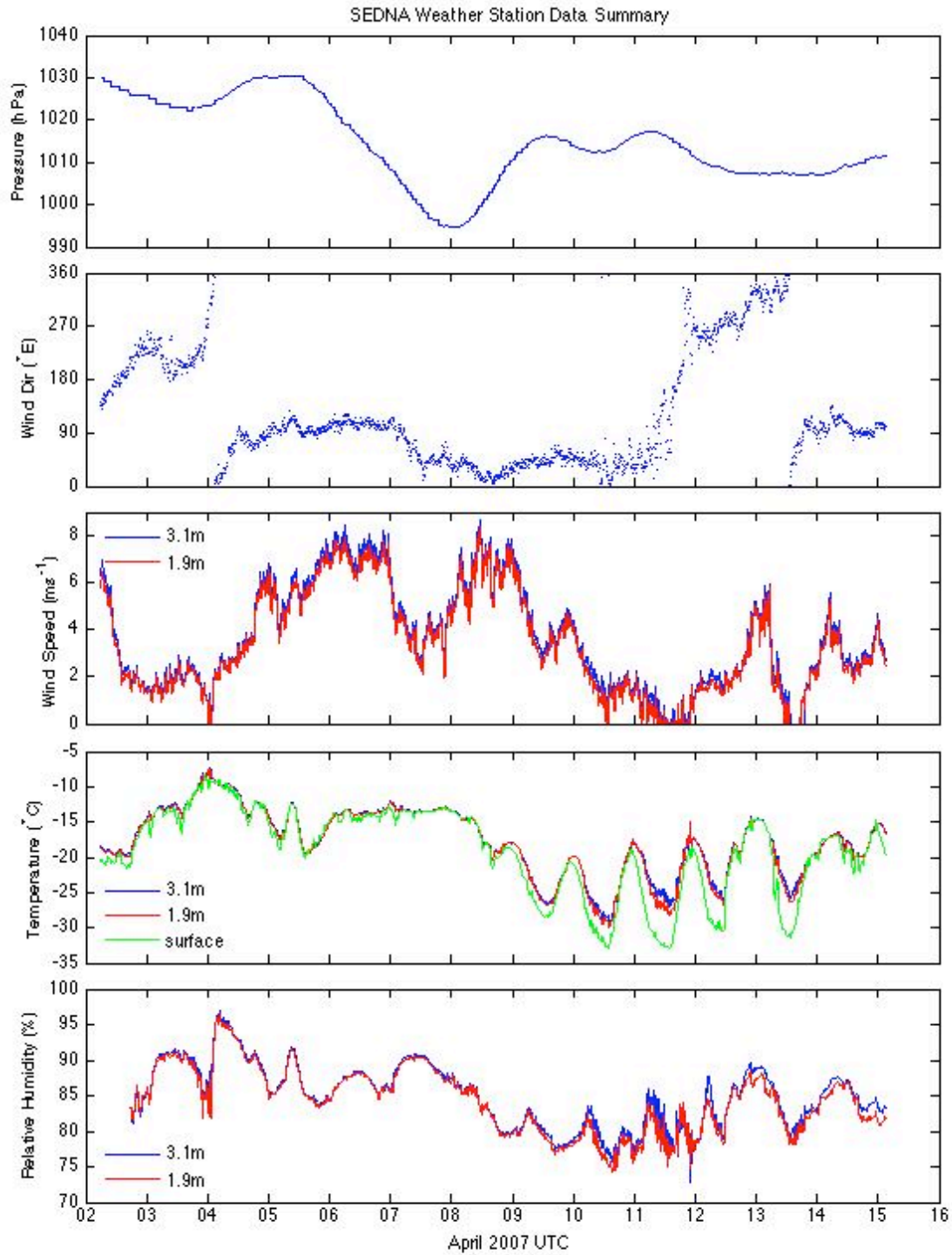
**Table 1 Weather station instrumentation and accuracy quoted from Campbell Scientific Inc. manuals for relevant environmental conditions. Accuracy statistics for the humidity sensor are not available for freezing temperatures (RH is Relative Humidity, AGL abbreviates Above Ground Level).**

Measurement	Height AGL	Instrument	Instrument accuracy
Wind speed	3.1, 1.9m	Young 03101 R.M. Wind Sentry Anemometer	$\pm 0.5 \text{ m s}^{-1}$ , 0-50 $\text{ms}^{-1}$
Wind direction	3.1, 1.9m	Young 03301 R.M. Wind Sentry Vane	$\pm 5^\circ$
Air temperature and humidity	3.1, 1.9m	Vaisala HMP45C-L Temperature and Humidity Probe housed in Campbell Scientific 41003-5 10-Plate Gill Radiation Shield	$\pm 0.5^\circ\text{C}$ at $-40^\circ\text{C}$ linearly increasing to $\pm 0.2^\circ\text{C}$ at $20^\circ\text{C}$ $\pm 2\%$ RH, 0-90% at $20^\circ\text{C}$ $\pm 3\%$ RH, 90-100% at $20^\circ\text{C}$ 0.15 second settling time Operating range $-40^\circ$ to $60^\circ\text{C}$ $\pm 0.5^\circ\text{C}$ at $-40^\circ\text{C}$ to $70^\circ\text{C}$
Surface temperature	0m	Apogee IRR-P Precision Infrared Temperature Sensor mounted 1 meter AGL with $\sim 0.8$ meter ( $22^\circ$ half angle) footprint diameter.	
Barometric Pressure	1m	Campbell Scientific CS1000 Barometric Pressure Sensor located in data logger housing.	$\pm 1.5 \text{ hPa}$ at $-40^\circ\text{C}$ to $60^\circ\text{C}$ 800-1100 hPa
Sampling		Campbell Scientific CR1000 Data Logger with LLAC4 module.	Clock: $\pm 3$ minutes $\text{year}^{-1}$

## Weather Station data

A summary of the weather station data is presented in Table 2 and Figure 2. Sampling and logging procedure for each recorded variable are summarized in Table 3. Wind speed, temperature and humidity were sampled every 5 seconds, with the mean, maximum, minimum and standard deviation of these samples logged for each consecutive ten minute period. Ten-minute samples were logged for wind direction and barometric pressure. In addition to meteorological data, battery voltage and data logger temperature were also recorded and indicated normal operation of the weather station throughout the recording period.

A complete list of logged data is provided in Table 4. The data are available as a CF-1.0 NetCDF file named SEDNA\_WX.nc and a subset of this data is available in the file SEDNA\_WX\_SUMMARY.nc that only includes variables marked with an asterisk in Table 4. Both NetCDF data files include re-sampled GPS positions recorded at the “Walrus” GPS antenna every 10 seconds on the same ice floe as the weather station (Figure 3). Table 4 indicates maximum error bounds on the 10-minute means and samples derived by applying the instrument accuracies in Table 1 to ambient conditions, then incorporating error bounds introduced in post-processing. Further explanation follows.



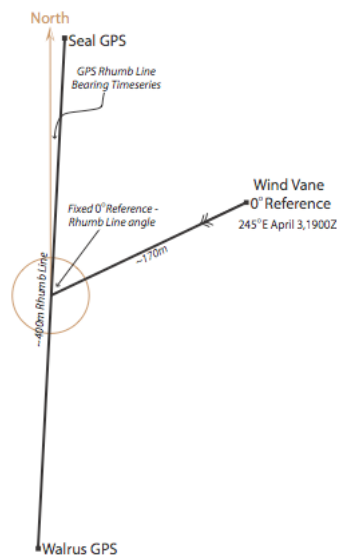
**Figure 2 Summary surface atmospheric conditions at the SEDNA weather station. Legends indicate the height above ground level of measured quantities. Wind direction is shown for 3.1m above ground level only.**

**Table 2 Summary surface SEDNA field campaign atmospheric statistics for April 2 2007, 05:50 to April 15 2007, 02:50 UTC.**

Variable	Median	Minimum	Maximum	
Wind Speed at 3.1m	3.3	0	8.6	$\text{m s}^{-1}$
Wind Direction at 3.1m	95			$^{\circ}\text{East}$
Air Temperature at 1.9m	-17.5	-29.2	-7.6	$^{\circ}\text{C}$
Relative Humidity at 1.9m	84.8	74.3	96.5	%
Barometric Pressure	1013.2	994.6	1030.4	hPa

**Table 3 Weather station sampling procedure**

Sampling procedure	Variable
10 minute mean and statistics (Sampled every 5 seconds, logged means, maximums, minimums and standard deviations every 10 minutes)	Wind speed Temperature Humidity
10 minute mean (Sampled every 5 seconds, logged means every 10 minutes)	Battery voltage Data logger temperature
10 minute sample (Sampled and logged every 10 minutes)	Barometric pressure Wind direction



**Figure 3 Schematic of simple planar geometry used to correct wind direction against a rhumb line between two Global Positioning System (GPS) receivers 'Walrus' and 'Seal' located on the same sea ice floe as the weather station. There was no sea ice deformation between Walrus, Seal and the weather station throughout the field campaign.**

The weather station was neither equipped with a Global Positioning System (GPS) receiver nor with a compass for determining absolute wind direction. Instead, the wind vane  $0^\circ$  reference direction was corrected against two fixed GPS receivers as illustrated in Figure 3. These two receivers, named ‘Walrus’ and ‘Seal’, sampled geographic position every 10 seconds throughout weather station operation. A 170m reference line was used to calculate a bearing of  $\sim 245^\circ\text{E}$  for the  $0^\circ$  wind vane direction at 1900Z on April 3 2007. This was then used to correct the entire wind direction time series. There was a 4.6m error in handheld GPS position when establishing the 170m-reference line, resulting in directional error of  $\pm 3^\circ$ . The positional error to the Walrus-Seal rhumb line introduces an additional error of  $\pm 2^\circ$  (see introductory chapter of this report). The wind vane instrument error is  $\pm 5^\circ$  (Table 1) giving a total wind direction error of  $\pm 10^\circ$ . A more complicated wind direction correction is unlikely to yield significantly different results.

Riming occurred on April 4 UTC and is evident in the sharp increase in relative humidity in Figure 2. Thin rime ice was deposited on all weather station instruments during this event. The affect of this was closely monitored by visual inspection, but did not appear to adversely affect any instrument’s operation. Both the wind vane and anemometer continued to rotate at the time of the riming event, even in light wind conditions (Figure 2). Rime ice gradually sublimed from instruments during the course of the day via solar heating. It is difficult to gauge the extent to which the weight of rime ice affected recorded wind speed, but it is suggested instrument error bounds of  $\pm 0.5 \text{ m s}^{-1}$  still apply for this segment of the data.

Temperature retrievals from the Apogee radiometer could be adversely affected by blowing snow. However a brief analysis suggests there is no discernable correlation between 10-minute standard deviation of surface-temperature and 10-minute mean wind speed. Moreover, in windy conditions, surface temperature closely tracked air temperature (Figure 2), and blowing snow was infrequently observed more than 50cm above the surface. For this reason it is suggested the error bounds for surface temperature are within the instrument limits of  $\pm 0.5^\circ\text{C}$  for the given environmental conditions.

Due to a coding error, barometric pressure was logged to integer precision in hPa between 02-Apr-2007 05:50 and 03-Apr-2007 19:00 UTC, but was reset to log to three decimal places after this time. This affects the accuracy of relative humidity calculated from dew point; Relative humidity was not calculated and logged onboard until 02-Apr-2007 17:30, although dew point records extend throughout the time series. For this reason post-processed relative humidity values prior to 02-April 17:30 UTC have not been included in the station dataset to avoid publishing time series with variable quotable accuracy. Published relative humidity values have the same level of accuracy as quoted in Table 1.

**Table 4 Data logged between 02-Apr-2007 05:50 and 15-Apr-2007 02:50 UTC. All data listed is included in the NetCDF archive SEDNA\_WX.nc, while data with an asterisk is provided in the summary dataset SEDNA\_WX\_SUMMARY.nc.**

Data	Description	Error
Time*	UTC for each data 10 minute sample	negligible
battery	10 minute average of battery voltage	
panel	10 minute average electronics panel temperature	
Bar*	10 minute sampled barometric pressure	$\pm 1.5$ hPa
w3dir*	10 minute sample of wind direction 3.1m above the surface	$\pm 10^\circ$
w3mean*	10 minute mean wind speed 3.1m above the surface	$\pm 0.5$ m s <sup>-1</sup>
w3max	10 minute maximum wind speed 3.1m above the surface	
w3min	10 minute minimum wind speed 3.1m above the surface	
w3std	10 minute standard deviation of wind speed 3.1m above the surface	
t3mean	10 minute mean air temperature 3.1m above the surface	$\pm 0.45^\circ\text{C}$
t3max	10 minute maximum air temperature 3.1m above the surface	
t3min	10 minute minimum air temperature 3.1m above the surface	
t3std	10 minute standard deviation air temperature 3.1m above the surface	
rh3mean	10 minute mean relative humidity 3.1m above the surface	$\pm 3\%$
rh3max	10 minute maximum relative humidity 3.1m above the surface	
rh3min	10 minute minimum relative humidity 3.1m above the surface	
rh3std	10 minute standard deviation relative humidity 3.1m above the surface	
dew3mean	10 minute mean dew point temperature 3.1m above the surface	$\pm 0.45^\circ\text{C}$
dew3max	10 minute mean dew point temperature 3.1m above the surface	
dew3min	10 minute minimum dew point temperature 3.1m above the surface	
dew3std	10 minute standard deviation dew point temperature 3.1m above surface	
w2dir	10 minute sample of wind direction 1.9m above the surface	$\pm 10^\circ$
w2mean	10 minute mean wind speed 1.9m above the surface over averaging period	$\pm 0.5$ m s <sup>-1</sup>
w2max	10 minute maximum wind speed 1.9m above the surface	
w2min	10 minute minimum wind speed 1.9m above the surface	
w2std	10 minute standard deviation of wind speed 1.9m above the surface	
t2mean*	10 minute mean air temperature 1.9m above the surface	$\pm 0.45^\circ\text{C}$
t2max	10 minute maximum air temperature 1.9m above the surface	
t2min	10 minute minimum air temperature 1.9m above the surface	
t2std	10 minute standard deviation of air temperature 1.9m above the surface	
rh2mean*	10 minute mean relative humidity 1.9m above the surface	$\pm 3\%$
rh2max	10 minute maximum relative humidity 1.9m above the surface	
rh2min	10 minute minimum relative humidity 1.9m above the surface	
rh2std	10 minute standard deviation of relative humidity 1.9m above the surface	
dew2mean*	10 minute mean dew point temperature 1.9m above the surface	$\pm 0.45^\circ\text{C}$
dew2max	10 minute maximum dew point temperature 1.9m above the surface	
dew2min	10 minute minimum dew point temperature 1.9m above the surface	
dew2std	10 minute standard deviation of dew point temperature 1.9m above surface	
surftmean	10 minute mean surface temperature	$\pm 0.5^\circ\text{C}$
surftmax	10 minute maximum surface temperature	
surftmin	10 minute minimum surface temperature	
surftstd	10 minute standard deviation of surface temperature	

## Cloud and precipitation observations

A brief set of cloud and precipitation observations were collected at 8am, 2pm and 8pm, Alaska Daylight Saving Time (1600, 2200 and 0400 UTC respectively) between April 2 and 12, 2007 by technical staff involved with the SEDNA campaign. The observers were without specific training for the task, however they used the National Weather Service Observing Handbook (NOAA 2004) to guide their observations. For that reason the observations should only be considered a broad guide to cloud cover and precipitation rather than a rigorous guide to meteorological conditions matching World Meteorological Organization standards. A summary of this dataset appears in Table 5.

**Table 5 12-hourly weather observations at the Applied Physics Laboratory ice camp during the SEDNA field campaign using terminology defined either in (NOAA 2004) or (AMS 2000).**

2007 April	UTC	Significant Weather	Cloud			Visibility NM
			Low	Middle	High	
3	0400	-	-	Ac 4/8	Cs 4/8	10
	1600	Isolated star-like snow crystals	St 1/8	Ac 1/8	-	8
4	0400	Snow grains, fog depositing rime	St 8/8	-	-	1
	1600	-	St 1/8	Ac 2/8	Ci 2/8	8
5	0400	-	-	Ac 2/8	Cs 2/8	8
	1600	-	St 2/8	Ac 6/8	-	8
6	0400	-	St 4/8	Ac 4/8	-	8
	1600	Low drifting snow	St 4/8	Ac 4/8	-	6
7	0400	Continuous slight snow in flakes	-	-	-	5
	1600	Intermittent slight snow in flakes Watersky south of camp	St 8/8	-	-	2
8	0400	Intermittent slight snow in flakes	-	As 8/8	-	2
	1600	-	-	Ac 1/8	-	10
9	0400	-	-	-	-	10
	1600	-	-	-	-	10
10	0400	-	-	As 8/8	-	10
	1600	Watersky on East horizon	-	-	Ci 1/8	10
11	0400	Watersky on Southeast horizon	-	-	-	10
	1600	Shallow fog in patches	St 2/8	-	-	1
12	0400	Watersky on South horizon Arctic sea smoke over runway lead	-	-	-	10
	1600	Intermittent slight snow in flakes	St 8/8	-	-	5

## APLIS weather data

In addition to atmospheric data collected by scientists involved with the SEDNA field campaign, the Applied Physics Laboratory Ice Station (APLIS) also recorded an independent meteorological dataset summarized by Karig and Wen (2007). This set of



observations provides a time series of wind speed and direction, air temperature and barometric pressure 8m above ground level. The instrument mast was mounted on the APLIS command and control hut. Caution should be employed if using the data for momentum flux calculations: The instrument mast flexed, the anemometer seized with rime ice when the SEDNA Young Wind Sentries did not, and the station location was outside WMO (2006) site criteria. Notwithstanding, the measurements provide a good first-look at meteorological conditions during the ice camp.

## **Summary**

A set of high quality surface atmospheric measurements is available in NetCDF format from the SEDNA weather station. The data may be obtained from the International Arctic Research Center SEDNA data repository. They include all variables of use in estimating the atmosphere-ice momentum flux in the vicinity of the Applied Physics Laboratory ice camp. Ambient weather conditions were also noted, while single-height wind, pressure and temperature time series are available from the University of Washington Applied Physics Laboratory for the same time period.

## **References**

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