Dear Editor and Reviewers 1, 2 and 3,

Thank you for your comments on our manuscript. We have found them to be quite helpful. Below, we have addressed our responses to each of the reviewers' comments in red.

Thanks,

Shelley Knuth

Anonymous Referee #1
Received and published: 14 December 2012

This paper describes data obtained during 8 flights with an unmanned aircraft over the Terra Nova Bay polynya between 14th and 26th September 2009 which have been submitted to the United States Antarctic Program Data Coordination Center.

Our present knowledge of atmospheric processes over polynyas and their interaction with ice formation is mainly based on modeling. Thus observations as those presented in this paper are unique and helpful to obtain a more solid basis for the validation and to improve our understanding. The paper shows furthermore that the use of UAV technique has reached already a high level.

The focus in the present version of the paper is - as it should be for this journal - on the technical description of the experiments and instrumentation. My impression (as a non-expert for technical questions related to the instrumentation) is that the description is well done. However, I think that the number of possible readers or data users could be larger when the meteorological background would be described in some more detail.

Revisions
1) The description of the experiment given in Section 2 could be improved. I guess that those who are most interested in the data are (mesoscale) modelers. A modeler would like to have some background information about the synoptic conditions. Was the main wind direction always as in Figure 3? A rough estimate of air temperature would be helpful to understand the conditions.

This is an excellent suggestion. We have included Figure 8 and Table 3 to address this reviewer's comments. Figure 8 shows the mean sea level pressure for the six flight days to TNB. This figure gives the reader a background in the meteorological conditions during those flights, which are likely to be the ones of most scientific interest. The synoptic conditions were not included for all 16 flight days due to space concerns. Table 3 gives maximum, minimum, and mean values of temperature, maximum and mean values of wind speed, mean values of wind direction, and the maximum altitude flown during the flights.

2) What was the usual height of horizontal flight sections? The present information (between 150 and 3000 m) is not helpful. The user of data would like to know in advance if the main part of the data (horizontal flights) is above the internal boundary layer (ABL) forming over the polynya or within the ABL. Another reason is that the observations of the surface temperature and of the freeboard measurements are less accurate when the aircraft is flying at larger heights. Is the height in horizontal sections approximately constant along the path?

The horizontal transects were flown at approximately constant altitudes between about 150 and 250 meters. We have added text to Section 2, paragraph 4 to specify this. Specifically, the text added is, "Typically, the downwind flight transects were flown at an approximately constant altitude between 150 and 250 m. Figures 3 to 5 also now indicate the flight altitude along the entire flight path for each UAS flight."

3) An information about the typical ice situation in the polynya would be helpful (concentration, ice type). Not all readers are familiar with the conditions around TNB. A satellite image showing the typical ice situation in the whole flight region would be helpful.

Text about general information on typical ice conditions in TNB as well as a satellite figure from one of the flight days has been added. The text, added in Section 1, paragraph 1, is, "Typical ice conditions in the region consist of open water immediately offshore, with areas of pancake and pack ice further away from the coast (Figure 1). However, ice conditions within TNB can vary greatly depending the strength of the prevailing winds, where calm winds can result in pack ice being present up to the coastal edge."

4) Is there always a flight section with the flight oriented along the mean wind as in Figure 3? It remains unclear if vertical profiles are taken along along this line or somewhere else. I propose to show each panel of Figure 2 in the same size as in Figure 6 and to mark each position where a vertical profile is available.

In most of the Terra Nova Bay flights, the mission was to sample the evolution of the boundary layer within the layer of strongest offshore winds, so yes, most flights included a section with the aircraft moving along-wind. To clarify where the profile locations are, they have been marked with a black dot on figures 3, 4, and 5, and this has been noted in the figure captions.

5) Page 1037, Lines 17 to 28: There is a mixture of tenses. I propose to replace sentences with 'would' by past tense as in line 25.

We changed the tense of the text to be past tense, as suggested.

6) Page 1037, line 20: skip “of TNB near the coast”?

We think that keeping this text in the manuscript is pertinent for the reader to understand exactly how the location of the downwind UAS flight transect was selected. Therefore, we opted not to remove this text since it describes where the UAS was directed to make these measurements.

7) Page 1037, line 21: I understand that the position and altitude of strongest wind is given to the mission scientist. For which scientific goal is this information used?

This is an excellent point. We needed the data to calculate sensible heat, latent heat, and momentum fluxes later. We have made this point clearer in the manuscript (Section 2, paragraph 2). The text from the manuscript is included below, with the added text in bold.

“Once the aircraft did a complete south to north transect of TNB near the coast, the mission scientist used the telemetered meteorological data to locate the position and altitude of strongest winds across TNB. Based on this, a revised set of waypoints and altitudes were then uploaded in real time to the Aerosonde's autopilot, and the UAS then flew parallel to the strongest winds (as determined from the telemetered data stream) across TNB (Figure 6). **Finding the area of strongest winds was important for meeting the scientific goals of the project, which included estimating the largest air-sea fluxes over the polynya. As air-sea fluxes are (in part) controlled by wind strength, flights within the area of strongest winds provided the data to calculate the largest fluxes within TNB. This flight strategy also documented the downstream evolution of the fluxes when moving from stronger to weaker winds within the jet.”**

8) The quality of some figures should be improved. Figure 2: Enlarging of the figure could help. Labels and text in its present form are nearly unreadable. Also Figure 5 has poor quality. I suggest also to label the topography lines.

Figure 2 (now Figure 3) and Figure 5 (now 4) have been enlarged. The topography lines have been labeled.

9) Page 1038, Line 27: I did not understand how wind is measured '...during aircraft maneuvers...'

We have added the following text to paragraph 5, Section 2 to clarify this: “The autopilot navigation system contains a Kalman filter, which estimates the wind vector continuously during the flight. Periodic ‘wind finding’ maneuvers are performed during the flight to improve the wind estimates which otherwise degrade in accuracy over time whilst flying a constant heading, as the aircraft

heading is not directly observable without magnetometer input."

10) Page 1039, line 14: ' monitor the weather ', what is 'weather' in this connection?

Specifically, we were looking at the wind speed and direction, air temperature, and relative humidity values during flights. This data was used both to ensure the safety of the aircraft as well as determine the most scientifically optimal conditions for which to fly the plane. We have clarified the text in the second sentence in Section 3 to read, "The telemetered data stream was sent back to the field team in real-time to monitor the aircraft and the weather (specifically temperature, wind speed and direction, and relative humidity) in which it was flying."

11) Section 4: Information on the accuracy of the different measured variables (wind, temperature etc.) would be helpful.

We have added information on accuracy, response time, and operating range in Table 2.

Anonymous Referee #2
Received and published: 2 January 2013

The manuscript presents an interesting data set: unmanned aircraft system measurements in the Antarctic in winter. According to my knowledge, there are very few such data available, if any. Hence, a publication on the data would be welcome. The manuscript includes, however, weaknesses, and a major revision is necessary. Below are my detailed comments.

1. The presentation is very technical, but it would be important to provide better evaluation on how suitable the data are to study the issues described in the first paragraph of the Introduction. In the journal homepage it is stated that "Any interpretation of data is outside the scope of regular articles.", but I guess that the authors should evaluate if the data are useful and adequate. The main question include:

This is an excellent point. The scientific analysis from the data collected during these flights is currently underway, and intended to be a part of several papers currently being prepared. However, a brief examination of why this data is important for our use can be included in the manuscript. In the third paragraph of Section 1, the following text was added: "The purpose of these flights was to document the downstream evolution of the boundary layer over Terra Nova Bay and to study air-sea interactions in the winter months over the Terra Nova Bay polynya (Figures 1 and 2). The meteorological data collected by the UAS are sufficient to allow us to document the downstream evolution of the temperature,

humidity, winds, and the boundary layer over the polynya. The data collected are also sufficient to allow us to estimate the turbulent sensible heat, latent heat, and momentum fluxes as well as to estimate all of the terms in the horizontal momentum equation. The method for estimating these terms from the UAS data will be described in separate papers that are currently in preparation. Turbulent flux instrumentation was not carried during the flights due to weight restrictions and to keep the instrumentation simple and robust."

a) Are all the essential variables measured by the UAS system? It seems that at least the observations on turbulent fluxes of heat, moisture and momentum are not obtained by the UAS.

Yes, all essential variables needed for our scientific purposes have been measured by the UAS system. As noted above, we did not carry turbulent flux instrumentation on board due to weight restrictions. However, we have developed a methodology to calculate these fluxes based on the data collected. The results of this analysis are currently being prepared in a separate manuscript.

b) Are there any means to distinguish between spatial and temporal variations in the data?

Unfortunately, with this data set, there is not. In flights conducted in September 2012, we attempted to distinguish between spatial and temporal variations by sampling the downwind flight legs a second time. This allowed us to examine how the atmosphere changed between the time when the first downwind leg and the second downwind leg was flown. However, as this was not done during the 2009 flights, the only way to determine atmospheric changes due to time vs. spatial changes is to examine data from an automatic weather station on the Terra Nova Bay coast.

c) Under stable background stratification, heat and moisture fluxes from a polynya do not necessarily reach high altitudes. Are the data useful, if the lowermost measurement height is 150 m? This naturally depends on the width of the polynya, but it is not mentioned in the manuscript.

This also brings up an excellent point, and one that we have considered in our scientific analysis. Vertical profiles of temperature, humidity, and winds obtained by the UAS over the polynya indicate that our lowest flight level is within the boundary layer on all flight days. Given the strongly convective nature of the polynya boundary layer we believe that the flight level data is sufficient to represent the near surface conditions. Given that potential users of this data may have varied interests in analyzing this data we did not feel it was necessary to discuss this aspect of the data in the current manuscript.

2. The measurement accuracies of meteorological variables are not at all addressed. This is a major deficiency. I am particularly concerned about the accuracy of air humidity measurements in temperatures as low as -35 deg C. Further, it is not just the absolute accuracy, but also the response time of the sensor is important. In low temperatures, most humidity sensors are slow. When the aircraft is flying fast, are the vertical profiles of humidity reliable (Figure 4)? In Table 4 the 0.01% resolution given for the relative humidity is certainly not any true measurement accuracy, and the same is probably true for the air temperature.

The reviewer has brought up a good point in this comment. We have noticed, particularly in the humidity profile data, that the data in the profiles is lagged a bit. This is likely, as the reviewer points out, due to the response time of the instrument in the cold temperatures. While the instruments are technically accurate to below -35°C, there are issues with the sensor in some of the profile collections. We have added text to the manuscript to inform users of this issue. In the fifth paragraph of Section 2, we have added, "It is important to note that the response time of the relative humidity sensor is likely slower than stated due to the cold temperatures in the region and this may present some issues when interpreting the data collected during the quick ascent/descent of the profiles (Table 2). The use of this data in the soundings should, as such, be used with caution."

3. Is 0.01 degrees in latitude a sufficient accuracy in the data archive (Table 4)? There may be smaller-scale horizontal variations especially close to the polynya edge. Figure 4 suggests this for the wind.

The data within Table 6 (previously Table 4) has actually been truncated to fit it all on one page. The actual latitude and longitude data in the repository has a much higher degree of accuracy. We have adjusted Table 6's caption to read, "Table 6. A sample of the data available in the USAP-DCC repository. Data has been truncated in this table to save space."

Anonymous Referee #3
Received and published: 2 January 2013

Review of the manuscript 'Unmanned aircraft system measurements of the atmospheric boundary layer over Terra Nova Bay, Antarctica' by S. L. Knuth et al.

Boundary layer observations in Arctic regions are extremely sparse so any data set as the one presented here is highly valuable for atmospheric science. In my opinion the presented measurements are without doubt worth publication, although I mean a careful revision is necessary, taking in particular in account

the following aspects:

1) I feel the local flights (at least 6 of them will not be of great value for scientific investigations, I therefore suggest to remove figure 5. For the same reason I would erase the right column in Table 1 and use the gained space there for a more detailed description of the scientific flights (e.g. synoptic condition, mean/max wind speed, mean wind direction, mean temperature and number of profiles flown during each mission). That would highly ease the estimation of the different flights for future investigations by potential users.

We believe that Figure 5 (now Figure 4) is critical to this paper, as showing the flight paths of all 16 flights is important since we cannot know what potential use the data collected during either the Terra Nova Bay or local flights may have. The reviewer's comments regarding including information on the background conditions on each flight is an excellent suggestion. We have included Figure 8 and Table 3 to address this reviewer's comments. Figure 8 shows the mean sea level pressure for the six flight days to TNB. This figure gives the reader a background in the meteorological conditions during those flights. The synoptic conditions were not included for all 16 flight days due to space concerns. Table 3 includes information on the maximum, minimum, and mean values of temperature, maximum and mean values of wind speed, mean values of wind direction, and the maximum altitude flown during each flight.

2) Table 4 can be cut out without any loss of information for the manuscript

We think it is important to provide potential users of the data with a sample of the data as archived in the repository and as such we chose to leave Table 4 (now Table 6) in the manuscript. If the editor feels that this table should be removed we will be happy to comply with this decision.

3) Fig 2 is too small in its current version, it should be a full page plot. I also suggest to label the flight altitude by a color code in this figure, giving a better overview of the different flights. A marker for the positioning of profiles performed would also be highly appreciated.

Figure 2 (now Figure 3) has been adjusted to be more readable, with two panels per page. The flight altitudes have now also been labeled by color, and a marker for the position of the spiral ascents and descent profiles has been added.

4) Fig. 4: the profiles should be labeled with time and position instead of "Profile 1,2 3"

This is a good idea, but not logistically feasible. To add the locations of all the profiles (sometimes 4) to each figure, would add a lot of text to the figure. We thought about adding these values to the figure captions, but it would also add a lot of text to the figure caption, thus causing a significant reduction in the size of

the image to fit it all on one page. With the profile markers added to each map, this gives the reader a location for each profile. The times of the profiles can be found by looking at the data.

5) Page 1038, line1: do I understand right that some of the profiles are measured in upward flight and others in downward? If so, is there a constant climb/descent velocity. If not this would lead to inconsistencies due to the sensor time lag. Could you comment on this.

The reviewer has brought up a good point in this comment. The climb and ascent rates are not the same, and as such, we have noticed, particularly in the humidity profile data, that the data in the profiles is lagged a bit. We have added text to the manuscript to inform users of this issue. In the fifth paragraph of Section 2, we have added, "It is important to note that the response time of the relative humidity sensor is likely slower than stated due to the cold temperatures in the region and this may present some issues when interpreting the data collected during the quick ascent/descent of the profiles (Table 2). The use of this data in the soundings should, as such, be used with caution. "

6) Page 1038, line 27: I would like to have more information on this procedure with the help of flight maneuvers, at least a reference describing it is required here.

We have added the following text to paragraph 5, Section 2 to clarify this: "The autopilot navigation system contains a Kalman filter, which estimates the wind vector continuously during the flight. Periodic 'wind finding' maneuvers are performed during the flight to improve the wind estimates which otherwise degrade in accuracy over time whilst flying a constant heading, as the aircraft heading is not directly observable without magnetometer input."

7) Page 1039, line 23: is there a good reason not to log the u and v-components?

Unfortunately the data logging system used for these flights was one that had already been developed prior to our project. As such we did not have control over the data that was logged. For flights made in 2012 the data logging system was revised and all meteorological data, including wind, were logged.

8) I am a bit confused about the time stamp discussion in section 4.2 (page 1041/1042):
"However, there were no common data values between the telemetered and ADC logger data…." Is this correct? Could not the skin surface temperature logged by both systems be used to identify e.g. changes at overflight of land-sea/ice-sea boundaries? Or could a correlation analysis of the time series of e.g. shortwave radiation help to synchronize the data sets?

We explored the approach of using the skin temperature to tie in ice/water boundaries to merge the two files. This process was somewhat subjective and quite involved. Because the field team had written down the start time for when the logger was turned on, this provided a much more feasible method of merging the two datasets.