The Use of Sodars with Supporting Instrumentation to Study Chemically Active Stable Boundary Layers over the Polar Ice Sheets

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Abstract

Over the last ten years, considerable attention has been devoted to the study of chemically active boundary layers in the polar regions [1, 2]. However, major challenges to boundary layer studies in these areas include the harshness of the environment and the sparseness of observations (both primary and supporting). There is also a need to integrate in conceptual models a diverse range of information so as to overcome the paucity of data over the polar ice sheets. In this paper we describe recent results that have emerged from site-specific and aircraft measurements over the Antarctic Plateau [3, 4] as well as preliminary results from Summit Station, Greenland. Our premise is that carefully posed intensive studies using remote and in situ sensors can help inform the analysis of more limited measurements in data sparse regions.

1. BACKGROUND

In recent years sodars have been deployed to the Antarctic to aid in the interpretation of the chemical exchanges between the ice/snow surface and the overlying atmosphere [3]. These boundary layers are often quite shallow, obtaining depths of a few tens of meters or less, trapping NO_X released at the surface through photolysis of nitrate in the snow [5]. Interpretation of boundary layer processes controlling this exchange has come about through the use of sodars, sonic anemometer turbulence data, short (22m) towers with wind and temperature profiles, balloon profiling of meteorology and chemistry, and boundary-layer aircraft profiling [3, 4, 6, 7].

Designing sodars to work in a polar environment with high resolution, minimum range, and reliability has been a challenge. For example, we have used a bistatic arrangement with nearly collocated transmitters and receivers to avoid contamination of the return signal from ringing of the transducer. However, the greatest value of the sodars has been in their integration with chemical time series and profiling in addition to measurements of turbulence, wind and temperature on short towers. In this presentation we will describe these integrated observing approaches and the insights into polar chemistry gained from them. For example, with surface emissions of nitric oxide (NO) from snow, its vertical profile measured with a tethered balloon system provides significant interpretive value for sodar echo returns viewed either in facsimile mode or as averaged amplitude profiles.

More recently, analysis of integrated observations from a few isolated locations on the Antarctic Plateau have been used to develop conceptual models of the boundary layer that can be extended over vast areas of the plateau and tested against much more limited data from aircraft probing of the boundary layer.

2. COLLOCATED PROFILING

A major field program (the Antarctic Tropospheric Chemistry Investigation: ANTCI) was carried out in November and December 2003 at the South Pole that utilized a sodar to document boundary layer depth and evolution concurrent with near-surface turbulence measurements and tethered balloon m, measurements of wind, temperature, nitric oxide (NO) and ozone [5]. A nearby 22-m-tower provided wind and temperature at two levels. Figure 1 shows these instruments while Figure 2 provides an interpretation of the stable boundary layer during conditions of high concentrations of nitric acid.

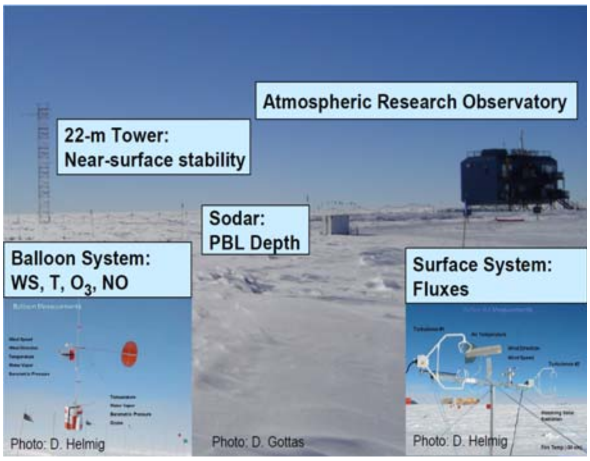

Figure 1. Tethered balloon system, sodar, flux system, and meteorological tower at the South Pole in December 2003.

As described in more detail in Neff et al. (2008), an automated method was applied to half-hour averaged amplitude profiles of sodar backscatter to determine mixing layer depth. From these data, comparisons of sodar-derived boundary layer depth were made with NO concentrations and with a simple stable boundary scaling argument with considerable success for very shallow, stable boundary layers. This method worked for the boundary layer at the South Pole because of its slowly evolving character (no diurnal cycle and relatively weak synoptic forcing).

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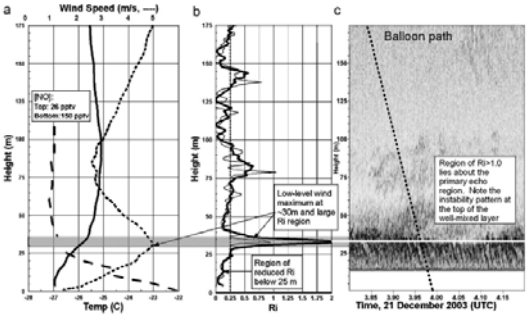

Figure 2. Example of NO, wind, temperature (left), and Richardson number (middle) for the sodar example on the left. (from Neff at al., 2008)

Typical 0.5 hr profiles used for the analysis of mixing layer depth are shown in Figure 3, while Figure 4 shows the resulting comparison of NO with the sodar derived depth. The difference in slope for the two periods in this comparison is thought to reflect seasonal changes in snow nitrate loading which produces the flux of NO into the boundary layer.

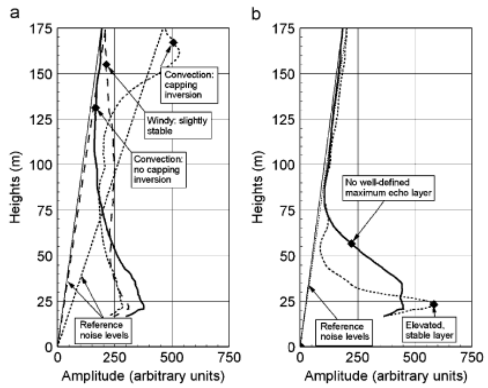

Figure 3. Typical sodar amplitude profiles under (a) windy/convective condtions and (b) stable conditions. Solid circles indicate the depth deduced from our automatic algorithm. (from Neff at al., 2008)

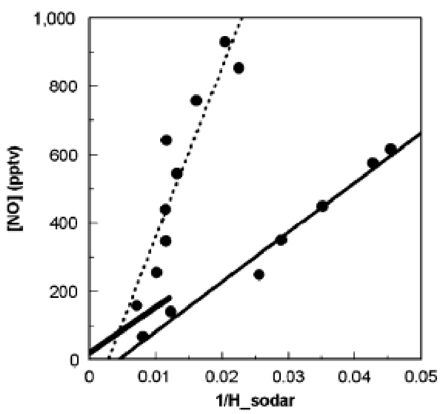

Figure 4. Comparing binned [NO] and sodar mixing height data for early (Days 326–335: dashed line) and late (Days 355–359: solid line) experimental periods. Results reported by [8] are shown by the short solid line. Note that these latter data, based on indirect estimates, have a more limited height range than those observed with the sodar. (from Neff at al., 2008)

3. DEVELOPMENT OF CONCEPTUAL MODELS IN DATA SPARSE ENVIRONMENTS

One of the dominant features of elevated ice sheets is the prevalence of katabatic or gravity-driven wind fields in the absence of strong weather systems. These winds have been implicated in the trapping of surface emissions of NO in the boundary layer below the wind speed maximum as shown in Figure 2. However, results from the South Pole, which has no diurnal heating cycle, while useful to the study of idealized stable boundary layers, may not be applicable further north where the diurnal cycle in the summer has been implicated in the development of daytime convective boundary layers. For example, at Concordia Station a well-defined summer convective boundary layer is often found extending to 200-300 m [9]. Contrasting with this is the convective boundary layer at Kohnen Station, which is at the same latitude, but has a delayed and shallower convective boundary layer growth because of a persisting katabatic wind [10]. As surmised by [4] differences in boundary layer evolution over Antarctica may thus be due to not only large scale meteorological variability but also to latitude and terrain slope. In this respect future sodar measurements of boundary layer depths over Antarctica might well be useful over a number of characteristic topographic and latitudinally distinct regions.

4. EXAMPLE: AIRCRAFT PROBING OF THE ANTARCTIC PLATEAU

Site specific insights into the behaviour of the chemical boundary layer have come primarily from the South Pole where it was found that shallow, light wind, stable boundary layers were conducive to high concentrations on NO. Questions remained however, as to whether such boundary layer chemistry was active over the entire Antarctic plateau. To this end a series of airborne sampling flights were carried out in December of 2005 as described in detail by [4]. The flight probed the area over the Plateau between 90°E and 180° with aircraft measurements of NO and temperature at heights ranging from 15 m to 200 m above the surface. One flight in particular provided a detailed view of NO in the boundary layer as shown in Figure 5 where the flight path is displayed over the surface wind speed derived from Reanalysis data.

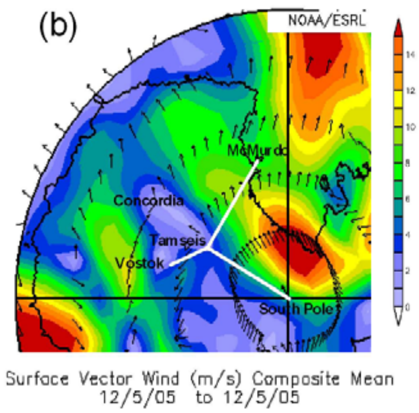

Figure 5. Surface vector wind for Flight 7 on the ANTCI 2005 experiment [4].

As shown in Figure 5, the segment of Flight 7 from Tamseis to Vostok was in a region with light surface winds similar to those found during high NO at the South Pole in past experiments. NO and boundary layer depths were also comparable as described in more detail in [4]. Thus, even though there were no meteorological observations along the flight paths and the resolution of the aircraft profiles was coarse (due to 1-min averaging), the conceptual model developed from data at the South Pole appears to apply to other portions of the plateau.

5. THE GREENLAND SODAR

In 2008 we deployed a sodar to Summit Station Greenland following an earlier study that sought to infer boundary layer depth from surface turbulence measurements [11] using the method proposed by [3].

In the earlier effort the only comparisons were with occasional rawinsondes. This new application of sodar came about as a collaborative study with a research project involving the Institute for Arctic and Alpine Research at the University of Colorado: *A synthesis of existing and new observations of air-snow gas exchanges to assess the Arctic Tropospheric Ozone Budget* (Honrath, Helmig, Ganzeveld). However, expert sodar technician support was not available. As a result, a number of problems were encountered leading to a fairly intermittent record. In July of this year we sent a new sodar to Summit and it is now working routinely. In Figure 6 we show some initial results from 2008 after enhancing the images with some additional signal processing.

The sodar as deployed is shown in Figure 7 which is a bistatic arrangement similar to that used at the South Pole in 2003.

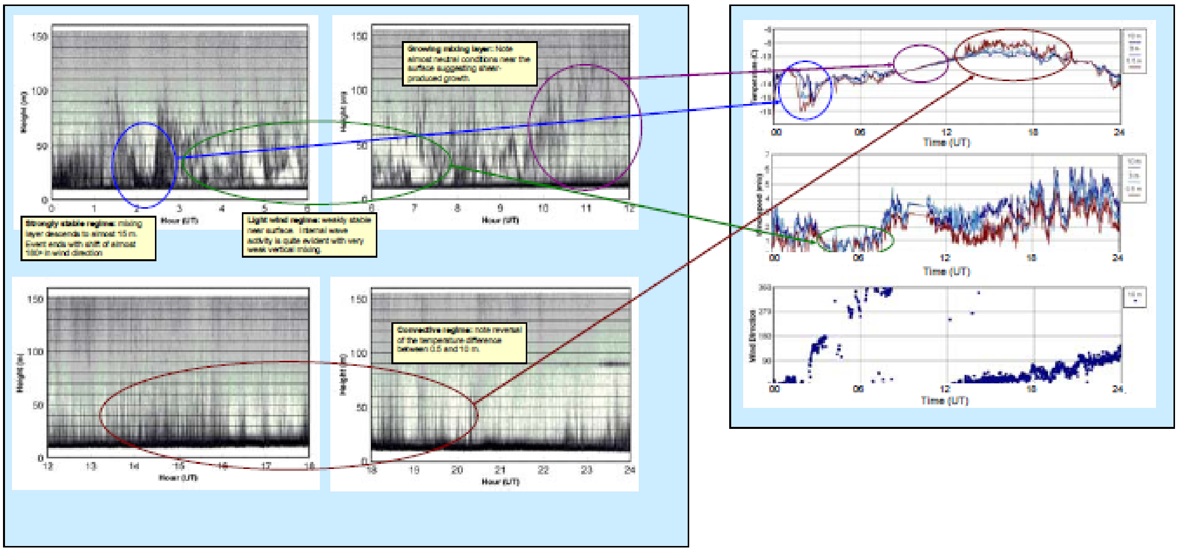

Figure 6. Comparison of sodar data under stable (upper image) and convective (lower image) conditions with concurrent tower data showing reversals of the vertical temperature gradient

Figure 7. The bistatic sodar is shown with its separate transmit and receive systems (used to reduce the contamination produced by the ringing of the transducer).

6. FUTURE PLANS

The new sodar is now operating at Summit Station and will continue to support the current air-snow gas exchange experiment through the summer of 2010. We now expect to remain at the site for four more years with the funding of a new experiment examining cloud processes over Greenland.

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