

Chapter II.5

An Integrated Observing System for Boundary Layer Monitoring at Concordia Station, Antarctica

S. Argentini and I. Pietroni

1 Introduction

Antarctica has a fundamental role in the global climate system; its ice sheet acts as a heat sink by extracting sensible heat flux from the atmosphere. Due to its remoteness and inaccessibility, yet relatively little is known about processes in the interior of the ice sheet. In the long Antarctic winter, when the shortwave radiation is not present, the surface is cooled continuously through negative net longwave radiation which is enabled by clear sky conditions and the very cold and dry overlying atmosphere. This energy loss is partially compensated by the turbulent and sub-surface heat fluxes which extract heat from both atmosphere and ice sheet, cooling the near surface air and snow. When a surface slope is present, the denser and colder mass of air adjacent to the surface is forced down-slope by a horizontal pressure gradient and deflected to the left by the Coriolis force. As a result the well-known katabatic winds take place. This situation can be occasionally interrupted by the horizontal advection of warm air masses or the presence of strong large-scale winds. On the other hand, during the Antarctic summer, the absorption of shortwave radiation introduces a diurnal cycle. The amount of solar radiation available to heat the surface is limited by the high surface albedo. However, the surface warming may cause a weak convection and the formation of a mixed layer can be observed on the plateau during daytime (Mastrantonio et al., 1999, Argentini et al., 2005).

A large atmospheric field experiment STABLEDC (study of the STABLE boundary layer at Dome C) was held at the Franch-Italian station of Concordia located on the Antarctic plateau at Dome C during 2004–2005. This was the first over wintering at Concordia. The aim of the field experiment was to test an observing system to study the processes occurring in the long-lived stable and the weak convective atmospheric boundary layers observed during winter and summer respectively, and to collect the parameters relevant for the atmospheric models.

S. Argentini (✉)

ISAC/CNR, via del Fosso del Cavaliere, 100, 00133 Roma, Italy

e-mail: s.argentini@isac.cnr.it

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2 Site and Instrumentation

Dome C (75° 06' S, 123° 23' E) lies at 3,250 m a.s.l. on the East Antarctic plateau, approximately 1,000 km from the nearest coast on the top of a large dome, with no discernible slope, therefore it is not subjected to the typical katabatic winds observed in Antarctica (King and Turner, 1997). The annual mean wind speed is 3.4 m s^{-1} with extreme values up to 16 m s^{-1} . Monthly mean temperatures were -39°C in summer and -61°C in winter. Most of the time, strong surface inversions occur at Dome C, creating a large cold air source feeding the katabatic winds observed in some zones of confluence along the East Antarctic coast. In situ and ground-based remote sensing sensors were used to monitor the behaviour of the meteorological parameters. The instrumentation and the measurements done during the field experiment are listed in Table II.5.1.

Turbulence and radiation measurements were made in the period November 2004–February 2006. Turbulent fluxes of heat and momentum were measured using a Metek USA-1 thermo-anemometer (Sozzi and Favaron, 1996) installed on a 3.6 m mast above the snow surface; long- and shortwave radiation components were measured using Kipp & Zonen pyrgeometers and pyranometers installed 1 m above the snow surface. The heat flux within the snowpack was measured at a depth of 50 mm using a Campbell Scientific HFP01 heat flux plate. A mini-SODAR (SOUND

Table II.5.1 Sensor and measured micrometeorological variable

Sensor	Measure
Radiometer mod. <i>CNR-1</i> (Kipp & Zonen) with two pyranometers (<i>CM3</i>) up and down and two pyrgeometers (<i>CG3</i>) up and down	<i>Radiative budget.</i> Incoming and outgoing shortwave and longwave radiation. – Net Radiation – Albedo
Conventional <i>HFP01</i> heat flux plates – 0, 5, 15, 30 and 50 cm	<i>Sub-surface energy fluxes, snow temperature profiles</i> – Snow heat fluxes
A sonic anemo-thermometer mod. <i>USA-1</i> (Metek) and a fast response <i>LICOR Lyman-alpha-hygrometer</i> (only summer)	<i>Energy budget.</i> – Turbulent fluxes (heat, water vapour, momentum)
<i>13-m tower</i> : thermometers, hygrometers and wind probes at 1.25, 2.5, 5, 10 and 13 m	<i>Surface layer profiles of mean variables</i>
A <i>triaxial Doppler mini-sodar</i> – range: 12–400 m, resolution: 13 m	<i>PBL measures.</i> Thermal structure of the ABL, boundary layer depth, and wind speed
<i>Micro-lidar</i> : 532-nm wavelength, range: 300 m	<i>PBL measures.</i> Aerosols content, aerosol phase (liquid water or ice cristal), particles size
<i>Passive microwave radiometer MTP- 5P</i> by Kipp & Zonen. Range: 0–600 m	<i>PBL measures.</i> Temperature, development and break down of atmospheric inversions
<i>Radiosoundings</i>	<i>Atmosphere.</i> Temperature, pressure, wind speed

Detection And Ranging) Doppler system (Mastrantonio et al., 1999) provided a continuous record of the structure of the atmospheric boundary layer along the year. A passive Meteorological Temperature Profiler (MTP-5P) (Kadygrov and Pick, 1998) was used for the remote measurement of the air temperature profile.

The instrumentation was placed approximately 500 m south of the main base buildings. Since the dominant wind direction is from the sector 150°–210° this ensured an unobstructed fetch over the measurement site.

In addition to the measurements described above, standard meteorological parameters – provided by the AWS (Automatic Weather Stations), and daily radiosonde profiles – were available from other projects.

For convenience, all subsequent results are presented with reference to local time. All time we use the term “night-time” or “nocturnal” we refer to the periods when the surface radiation balance is negative.

3 The Climatological Setting

Table II.5.2 shows the average values of the mean wind, temperature, and sensible heat flux for the period 14 December 2004–13 January 2006 and for the different seasons. The “seasons” have been defined as follows:

- 1° Summer: 14 December 2004 – 1 February 2005
- Autumn: 1 February 2005 – 1 April 2005
- Winter: 1 April 2005 – 15 September 2005
- Spring: 15 September 2005 – 15 November 2005
- 2° Summer: 15 November 2005 – 13 January 2006

The annual mean wind speed is 4.4 m s⁻¹ with extreme values (not shown in the table) up to 12 m s⁻¹. The annual mean temperature is -44°C. The lowest temperatures (-72°C) are observed during the winter while the highest temperatures (-29°C) are observed during the summer. Strong long-lived ground-based inversions occur most of the time at Dome C with the exception of the summer days during the hours of maximum insolation (and positive values of net radiation). These inversions

Table II.5.2 Mean values of the wind speed, temperature and sensible heat flux for the all measurement period

Period	All data	1° Summer	Autumn	Winter	Spring	2° Summer
<i>Parameter</i>						
Mean wind speed (ms ⁻¹)	4.4±2.0	3.5±1.6	4.2±1.7	4.9±2.0	4.8±2.2	4.0±2.0
Mean temperature (°C)	-44.8±12.2	-29.3±4.7	-47.2±7.8	-54.8±6.9	-46.8±7.6	-30.2±5.7
Mean sensible heat flux (Wm ⁻²)	-4.5±10.4	3.2±8.9	-4.8±8.1	-10.6±8.8	-6.1±9.5	2.4±9.0

contribute to create a large cold air source producing and feeding the katabatic winds observed in most of the glaciers confluence zone along the East Antarctic coast. Few clouds are generally present in the sky above Dome C since cloud cover and precipitation decrease as one moves inland from the coast, and the frequency of occurrence of active weather systems is low (King and Turner, 1997). However Argentini et al. (2001) have shown that warming events are periodically observed at Dome C during the winter, during these periods the surface temperatures sometimes may reach the summer values. In correspondence of these warming events the wind direction changes from 180° (the most frequent wind direction) to 0° (which is from the coast), indicating that the warming events are correlated to phenomena originating along the coast (i.e. advection of warm air).

4 Measurements

4.1 Wind and Temperature Distributions, Time Behaviour of Some Meteorological Parameters

4.1.1 Wind Distribution

The frequency distribution of the wind for three velocity ranges ($1 \text{ m s}^{-1} \leq v \leq 2 \text{ m s}^{-1}$, $2 \text{ m s}^{-1} \leq v \leq 4 \text{ m s}^{-1}$, $v \leq 4 \text{ m s}^{-1}$) is shown in the polar graph of Fig. II.5.1. Most of the data fall in the angular sector 180° – 210° that is from the continent. In this sector the strongest winds (greater than 4 m s^{-1}) are also observed.

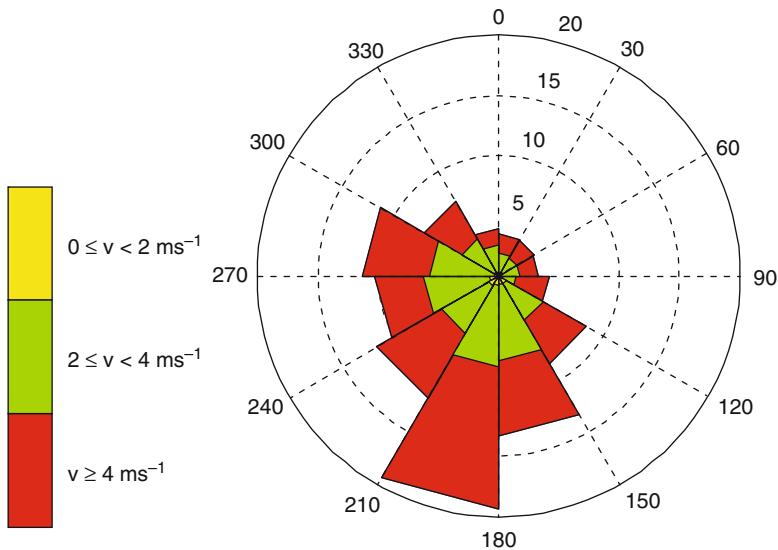


Fig. II.5.1 Wind rose for three different velocity ranges

4.1.2 Temperature

Figure II.5.2 shows the daily averages of the 3-m sonic temperature. The sonic temperature has a strong seasonal cycle with values varying between -25°C during the short summer and -70°C in the long and coreless winter. If warming events would not occur periodically between April and the end of October the average temperature variations during the winter would be contained within 10°C . These warming events are due to synoptic perturbations periodically penetrating the continent and reaching the Antarctic plateau (Argentini et al., 2001). As shown by Van As et al. (2005a, b) a similar phenomenon was also observed at the high Antarctic plateau station of Kohonen.

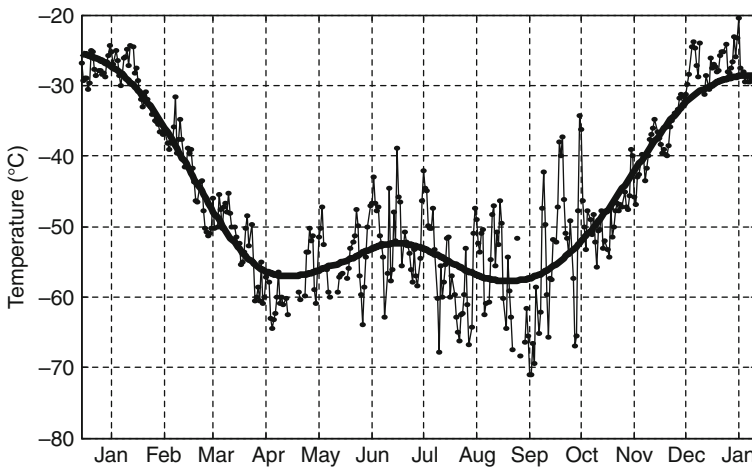


Fig. II.5.2 Temperature behaviour during the year

4.1.3 Sensible Heat Flux

The sensible heat flux on average is negative (Fig. II.5.3). Positive (approximately 5 Wm^{-2}) values occur in full summer (months of December and January) and in a few cases in correspondence of the winter warming events. The minimum of the sensible heat flux is observed at the end of June–beginning of July. Carefully analysing the high frequency data we realized that when the temperature drops below -50°C the sonic anemometer does not work properly and the fluxes could not be estimated.

4.1.4 Wind Speed

The wind (Fig. II.5.4) reaches the highest velocities that is around 11 m s^{-1} (average value over 1 h) during the winter warming events. For the rest of the time it periodically varies between 2 m s^{-1} and 7 m s^{-1} . The friction velocity, as expected, follows the behaviour of the wind speed although it varies between 0.075 m s^{-1} and

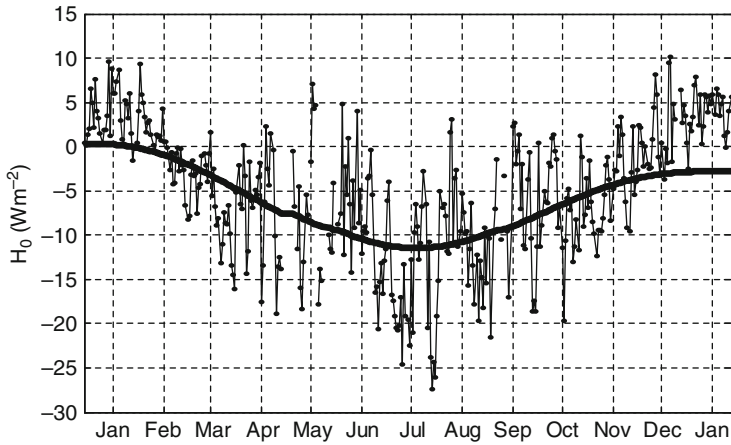


Fig. II.5.3 Sensible heat flux behaviour during the year

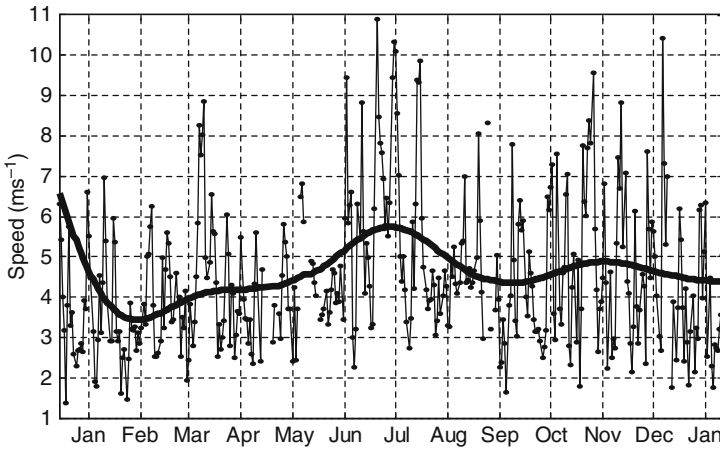


Fig. II.5.4 Wind velocity behaviour during the year

0.4 m s^{-1} , values which are 20 times smaller than the wind speed (at mid-latitudes a ratio of 10 is generally observed).

4.2 Thermal Structure of the Atmosphere and Temperature Profiles

As an example of the atmospheric thermal structure during the winter we show the sodar echogram for day 21 July 2005 (Fig. II.5.5a). Although the temperature decreases of about 25° in 200 m (Fig. II.5.5b) no echoes are shown in the echogram because the strongest fluctuations occur in a narrow layer close to the ground which is not resolved by the mini-SODAR.

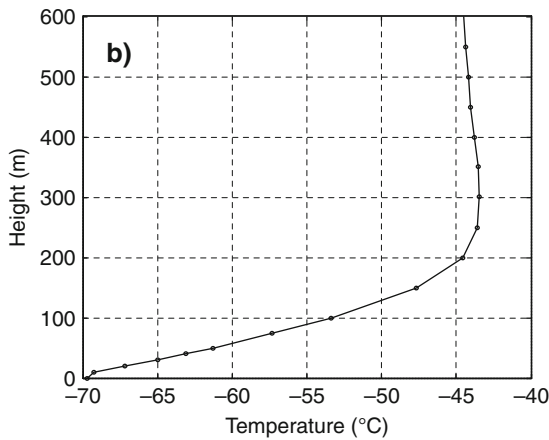
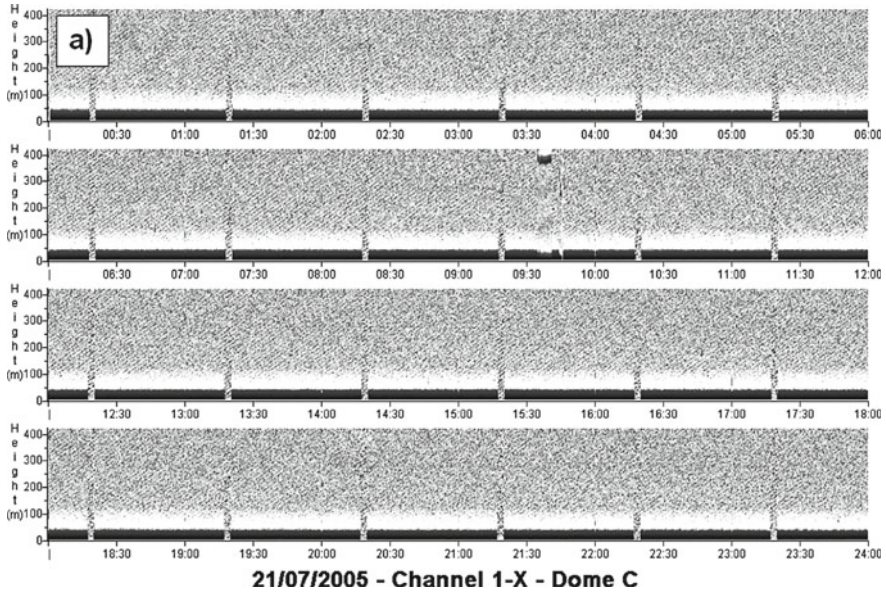


Fig. II.5.5 **a** Thermal structure of the atmosphere during winter as seen by a sodar for day 21 July 2005 and **b** temperature profile by MTP5 for the same day at 1400 LT

Figure II.5.6a gives instead the thermal structure during the summer for 7 January 2005. Figure II.5.6b shows for the same day, the temperature profile at 1400 LT (Fig. II.5.6b). In spite the small amount of sensible heat flux at the ground, a convective boundary layer develops during the warmest hours of the day. The height of the inversion capping the well-mixed layer reaches a maximum (about 200 m) at 1400 LT.

Figure II.5.7a–d shows the seasonally averaged temperature profiles for summer (a), autumn (b), winter (c) and spring (d) in the height range of 0–600 m. Each

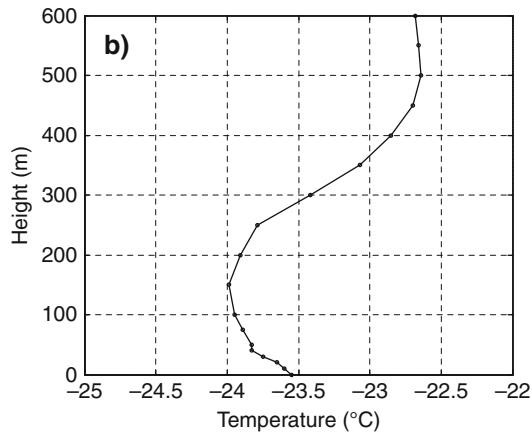
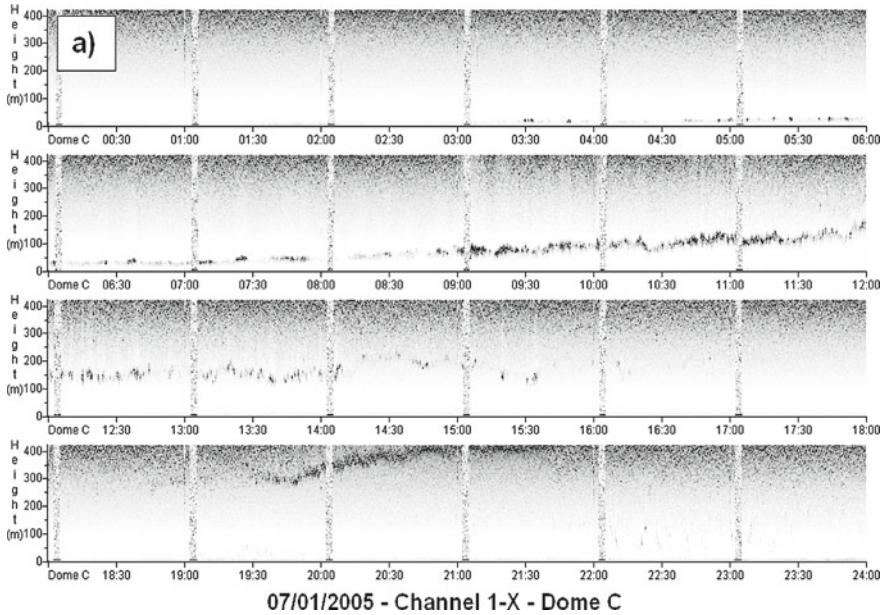


Fig. 11.5.6 a Thermal structure of the atmosphere during summer as seen by sodar for day 7 January 2005 and **b** temperature profile by MTP5 for the same day at 1400 LT

figure contains three profiles corresponding at averages over different hours of the day. A “diurnal” profile (averages between 1000 and 1400 LT), an “all day” profile (averages over the 24 hours), and a “nocturnal” profile (averages between 2200 and 0200 LT). An unstable profile is observed only during the summer when the sun elevation reaches a peak. For all the other hours/seasons a stable boundary layer develops. The temperature increases of about 5°C in the first 100 meters during the summer and 20°C during the winter (if we do not include the days with the warming events).

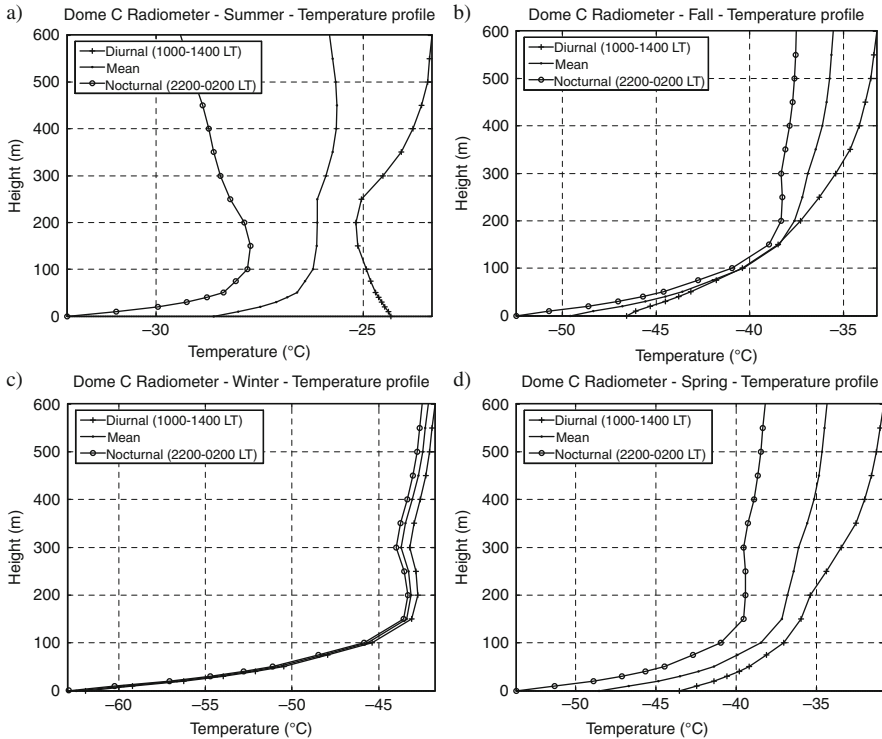


Fig. II.5.7 Temperature profiles diurnal (*crossed line*), averaged (*black dotted line*), nocturnal (*black dotted line*) during **a** summer, **b** autumn, **c** winter, and **d** spring

5 Summary and Future Work

A large PBL field experiment STABLEDC (study of the STABLE Boundary Layer Environmental at Dome C) was held at the French-Italian station of Concordia located on the Antarctic plateau at Dome C during 2004–2005. The aim of the field experiment was to test an automatic observing system to study the processes occurring during the year in this remote region of the world.

The measurements provided are fundamental to study the physical processes, to be used into numerical models and to support the activities related to the atmospheric site testing for astronomic purposes. This paper presents the experimental setup and the instrumentation and a few preliminary results related to the performances of the sensors and to the structure of the atmospheric boundary layer during the summer and winter. A long-lived stable and a weak convective atmospheric boundary layer were observed during winter and summer, respectively. The behaviour of the physical parameters and typical temperature profiles are shown. The thermal structure of the PBL has been investigated using a mini-SODAR.

In the future we want to study the shallow turbulent layer of about 30–40 m depth observed during the winter that up to now could not be studied with a certain detail

because it was below the first range gate of the sodar system. We plan to develop a new mini-sodar with higher frequencies and a larger antenna to investigate the turbulent structure of this very-stable PBL. In order to monitor the winter as well as the summer boundary layer structure we want to develop a system which can work in two modes:

- very high resolution (resolution 2.5 m, first range gate 5 m, maximum range 150 m) during the winter.
- high resolution (resolution 5m, first range gate 10 m, maximum range 300 m) during the summer.

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