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Dropsonde Data Report 14 June 2024

Cold Air Outbreak Experiment in the Sub-Arctic Region CAESAR (2024)

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Campaign Websites:
CAESAR home page:
https://www.eol.ucar.edu/field_projects/caesar
AVAPS dropsondes home page:
https://www.eol.ucar.edu/observing_facilities/avaps-dropsonde-system

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1.0	14 June 2024	H. Vömel	Initial Data Release

1 Table of Contents

2 Dataset overview

The Cold Air Outbreak Experiment in the Sub-Arctic Region (CAESAR) field campaign studies the structure of marine boundary layer clouds during cold air outbreaks (CAO). The surface heat fluxes during CAOs are among the highest observed on Earth, supporting highly convective clouds capable of producing heavy snowfall and occasionally spawning intense "polar lows." Little is known about their Lagrangian evolution, the relationship between up- and downstream conditions, and between the surface fluxes, boundary-layer structure, cloud and precipitation properties, and mesoscale circulations. These clouds provide a powerful modeling test bed for improving the representation of mixed-phase cloud processes in large eddy simulations, numerical weather prediction, and global climate models.

To address these questions, CAESAR conducted a 6 weeklong field campaign of NSF/NCAR Lockheed C-130 aircraft observations using a wide array of in situ and remote sensing instrumentation to characterize the thermodynamical, chemical, and microphysical state of the marine boundary layer. In this data report we describe observations obtained by the NCAR Airborne Vertical Atmospheric Profiling System (AVAPS) dropsondes.

10 research flights were conducted between 28 February and 3 April 2024; during eight of these we successfully released a total of 116 NRD41 dropsondes.

All dropsondes were released over the North Atlantic Ocean, in particular over the Norwegian Sea and Greenland Sea. Flight tracks were optimized to study CAOs. For operational reasons, only 8 research flights deployed dropsondes (Figure 1).

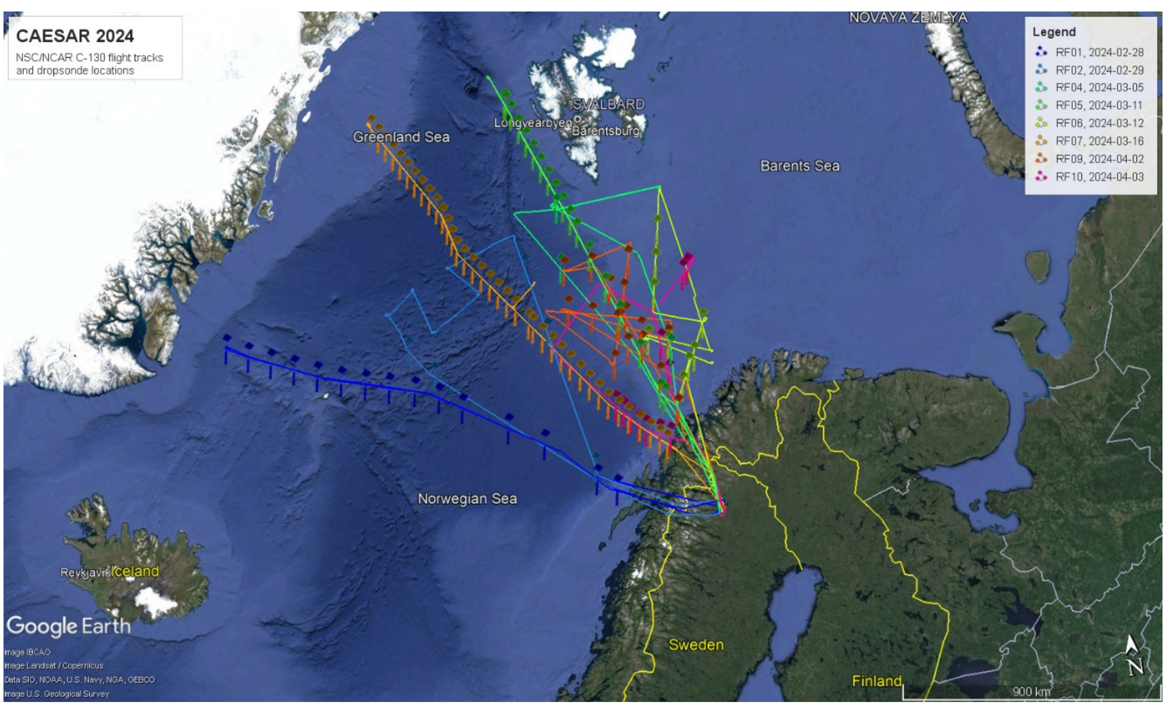


Figure 1: Flight tracks of the NSF/NCAR C-130 releasing dropsondes for in situ vertical profiling of the marine boundary layer.

Table 1 provides an overview over all dropsondes, which were released during CAESAR. We used two different versions of the NRD41 dropsonde during this campaign. The main type was the standard NRD41 dropsonde produced by Vaisala in license from UCAR. In addition, we used NRD41 engineering sondes, in which we installed sea surface temperature sensors, accelerometers, and new GPS receivers. These sondes were supplied in addition to those requested by the project and allowed testing new sensor technology. The pressure, temperature, and humidity measurements are of equal quality for all sondes. A small number of engineering sondes had degraded GPS reception and provided reduced or no wind measurements. Sea surface and accelerometer measurements are available only on engineering sondes.

Table 2 provides an overview over the performance of the dropsonde system as whole. In total, 117 sondes were released from the aircraft. Ninety two were standard NRD 41 dropsondes, 25 were engineering sondes carrying sea surface temperature sensors and different GPS configurations. All sondes transmitted data down to the ocean surface. In five sounding, the GPS unit failed and provided only partial or no winds. In one sonde, the parachute did not open, and the sonde fell significantly faster. This sonde was excluded from the final quality controlled data set.

The overall success rate of the dropsonde system for this campaign is at 95.7% using the NCAR NRD41 dropsonde, which is in parts due to our tests of new GPS configurations in engineering sondes, of which some did not work as expected.

Table 1: Overview over all successful sonde releases during CAESAR.

Flight	Date	# of Soundings
RF01	28 Feb	15
RF02	29 Feb	5
RF04	05 Mar	3
RF05	11 Mar	18
RF06	12 Mar	9
RF07	16 Mar	36
RF09	02 Apr	17
RF10	03 Apr	13

Table 2: Overview of the dropsonde system performance.

	# of Sondes	Percent
Total number of sondes released	117	100
Standard sondes	92	79
Engineering sondes	25	21
Complete thermodynamic profiles to the ground	116	99
Complete wind profiles to the ground	112	96

3 Dropsonde sounding system

The NCAR dropsonde system deployed in CAESAR used the manual dropsonde launcher installed in the cargo ramp in the back of the NSF/NCAR C-130 and the dropsonde model NRD41.

The NRD41 dropsonde uses the pressure, temperature, and humidity sensor of the Vaisala RS41 radiosonde and employs an improved version of the GPS, telemetry, and the electronically controlled parachute release system, which has been in use in the smaller dropsondes sondes since 2011. This sonde type has been successfully used during several previous field campaigns (e.g., Vömel et al., 2021 and Vömel et al., 2023) and since 2023 is used by NOAA and the Air Force in operational hurricane surveillance and monitoring of Atmospheric Rivers.

All but three dropsonde humidity sensors were reconditioned during the sonde preparation. This process, which is unique to the newer NRD41 and older RD41 dropsondes, reduces the potential of humidity contamination to a minimum and assures the best measurement performance throughout the entire altitude and temperature range of the profiles.

During CAESAR all AVAPS components were operated using the newly written AVAPS Control Suite (ACS), which also recorded all data, including those of a high quality reference pressure sensor, which was installed in the AVAPS rack.

Almost all data files generated by ACS are in ncdf format, which is incompatible with the older ASCII files generated by the Labview based AVAPS software. The Atmospheric Sounding Processing ENvironment (ASPEN) software package version 4.0 was adapted to ingest this new file format for real time processing as well post campaign data quality control.

It was planned that all dropsonde data would be transmitted to the operation center after the completion of each sounding, where CAESAR scientific staff controlled the quality of each sounding using the ASPEN. The quality controlled data of all soundings that did not raise any quality concerns were transmitted to the Global Telecommunications System (GTS) of the WMO, which allowed data centers assimilating these data for analysis and forecasting.

However, the limited satellite communication between the aircraft and the ground strongly reduced the number of profiles that could be processed in real time. Nevertheless, we decided that all profiles that could not be transmitted in real time, would still be processed after the return to the aircraft and transmitted to the GTS.

This was the first time that the smaller NRD41 dropsondes were launched from the NSF/NCAR C-130. The upper launch tube of the existing launcher in the cargo ramp was modified to accept the smaller dropsondes. This launch tube allowed GPS signal retransmission into the sonde inside the launch tube as well as data reception by the AVAPS rack. As a result, the sondes received GPS signals and the AVAPS receiver recorded data from the sonde continuously through the launch process.

4 Quality control procedures

4.1 Standard quality control

Standard quality control in near real time and as part of the final data QC is based on the algorithms implemented in the ASPEN software. The following quality checks, corrections, and calculations are performed:

- Removal of outliers and suspect data points in pressure, temperature, humidity, zonal and meridional wind, latitude, and longitude
- Removal of data between release from the aircraft and equilibration with atmospheric conditions
- Dynamic correction to account for the lag of the NRD41 temperature sensor using the appropriate coefficients for the NRD41 dropsondes
- Dynamic correction to account for the sonde inertia in the determination of the wind profile using the appropriate parameters for the NRD41 dropsondes
- Smoothing of pressure, temperature, humidity, zonal and meridional wind
- Recomputing of wind speed and wind direction after smoothing of the wind components
- Extrapolation of the last reported pressure reading to a surface pressure value (where possible), based on the fall rate of the sonde
- Recalculation of the geopotential height from the surface to the top of the profile
- Computing a vertical wind speed component

During each flight, scientific staff processed each sounding as they were transmitted from the aircraft and generated the appropriate FM 37 TEMP DROP and 3 09 053 BUFR messages using ASPEN. All soundings that were considered of high enough quality were sent to the WMO GTS for use in forecast and climate models.

In the final data quality control step ASPEN generates all product files. It has been configured for the smaller NRD41. The equilibration time for the temperature has been adjusted to 9 s and that for the RH sensor has been adjusted to 14 s. The smoothing wavelength for both parameters has been adjusted to 5 s.

4.2 Custom quality control

4.2.1 Pressure corrections

The pressure sensor of the NRD41 dropsonde is known to have a small bias. This sensor bias is measured during the production of the dropsondes, and a correction is stored in the sonde to minimize the bias during observation. In addition, during CAESAR we installed a high quality reference pressure sensor in the AVAPS rack, which measures the pressure inside the aircraft cabin during the dropsonde preparation. This reference pressure was used to further reduce any residual bias of the NRD41 pressure sensor.

The statistics of the residual pressure bias measured in the aircraft cabin is shown in Figure 2. During CAESAR, the median pressure difference between the sonde and the reference pressure in the cabin was -0.1 hPa, with a range between -1.0 hPa and +0.7 hPa. All sonde pressure measurements except for those during RF01 were corrected in the post campaign QC using the reference pressure measurements. The mean bias of all sondes during RF01 is expected to be less than -0.1 hPa; however, the sonde to sonde variability of the bias may be larger during that flight.

The surface pressures reported by the dropsondes are expected to have only minimal systematic biases.

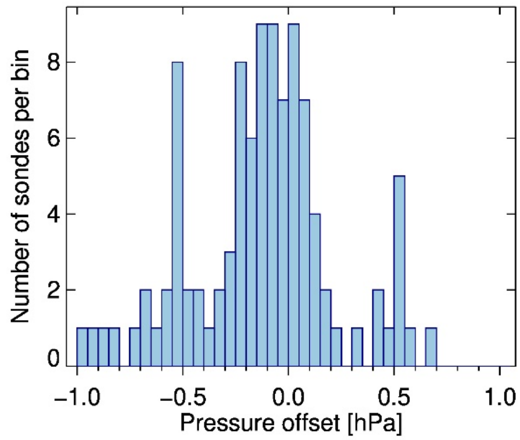


Figure 2: Pressure offset between the dropsonde and the reference sensor before launch.

In previous campaigns (e.g., Vömel et al., 2021), the dropsondes occasionally repeated a reported pressure measurement. This happened up to 20 times per sounding and in a few cases more frequently. In the dropsondes used during CAESAR, this issue has been much reduced and pressure repetitions occurred at most up to 3 times for almost all sondes. While this is barely noticeable in any vertical profile, it did lead to additional noise in the calculated vertical fall rate. In post processing, these repeated pressure readings were interpolated, and the fall rates were recalculated excluding these values. Only pressure readings had to be corrected. Temperature and relative humidity readings did not show any artificial repetition of measurements.

4.2.2 Relative humidity

The RH sensor on the xRD41 dropsondes should be reconditioned prior to launch. The sondes store the information, whether the reconditioning was successful. Therefore, we were able to verify that all sondes were properly reconditioned prior to take off before each flight. Any contamination in the sensor material was removed and the relative humidity sensors were expected to perform with negligible calibration drift.

Three sondes (Table 3) were not reconditioned and may have slightly degraded relative humidity measurements.

Table 3: Soundings without reconditioning of the relative humidity sensor

#	Research Flight	Sounding
1	RF01	20240228T122404
2	RF01	20240228T125201
3	RF04	20240305T080213

During CAESAR, the humidity sensors encountered temperatures as low as -47°C. The response time of the humidity sensors at the coldest temperature is expected to be up to 17 s. Therefore, all humidity measurements were corrected for this response time delay. The median raw and time response corrected humidity profiles are shown in Figure 3. Below 3.5 km, the time response correction is negligible. Above that, the time response correction changes the relative humidity profile of the coldest profiles.

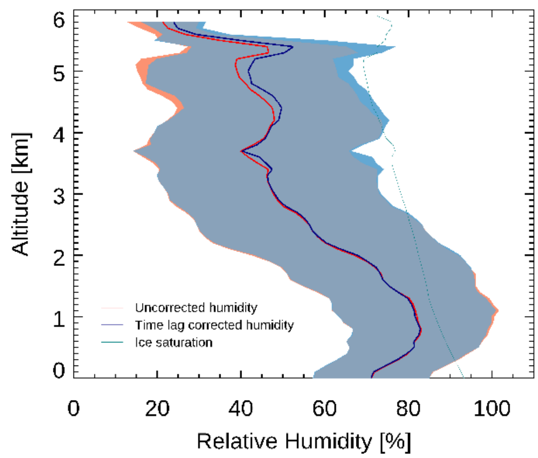


Figure 3: Mean (solid lines) and standard deviation (shaded areas) for all raw (red) and all time response corrected (blue) humidity profiles. Relative humidity is plotted relative to liquid water. Ice saturation is shown as thing green line. Liquid supersaturation shown here near 1 km altitude has been set to 100% by ASPEN, which slightly lowers the mean of the final data not related to the time response correction.

4.2.3 Parachute performance

The parachute performed as expected in all soundings but one. In sonde 20240316T113953 launched during RF07, the sonde failed to detect launch and did not release the parachute. This sonde fell approximately twice as fast as all other sondes, which strongly degraded the accuracy of all measured atmospheric parameters. As a result, this sonde was excluded from the final quality controlled data set.

4.2.4 GPS performance

The GPS unit in the dropsondes operated properly in 96% of all soundings, i.e., the reported uncertainty of the GPS was around 0.2 m/s for most of the profile.

In three soundings (Table 4), reception of GPS satellites was established late after launch leading to a loss of wind measurements for more than 1.5 km below the aircraft. During this time, the GPS had to re-initialize. Once GPS satellites were received, wind measurements were reported with nominal accuracy.

In four soundings (Table 5), the GPS module failed completely. Two of these failures occurred in engineering sondes, where we tested a new GPS configuration, which were launched in addition to the requested sondes and turned out not to be working in a field environment.

Table 4: Soundings with delayed GPS reception.

#	Research Flight	Sounding	Comment
1	RF06	20240312T111209	Complete winds below 1.1 km
2	RF09	20240402T091502	Complete winds below 2.3 km
3	RF09	20240402T095527	Complete winds below 1.3 km

Table 5: Soundings, in which the GPS module failed.

#	Research Flight	Sounding
1	RF01	20240228T122404
2	RF01	20240228T140942
3	RF07	20240316T112959
4	RF10	20240403T091420

4.2.5 Sea surface temperature

Twenty five soundings carried a low cost sensor for sea surface temperature, which measures the skin temperature of the surface below using an infrared thermometer. These measurements are highly experimental and have not yet been rigorously evaluated. Seven soundings are suspected to have landed on sea ice and reported infrared surface temperatures between -3°C and -26°C. These readings have been excluded from the final data set. Eighteen soundings (Table 6) reported surface skin temperatures between -2.2°C and 4.5°C. The uncertainty of these measurements is currently unknown. In addition to the calibration of the sensor, environmental factors contribute additional uncertainty, which is not well understood. Feedback on the quality and usefulness of these data is desired.

Table 6: Sea surface temperature estimates reported by 18 dropsondes.

#	RF	File	Longitude	Latitude	SST [°C]
1	RF01	20240228T132326	2.77946	71.164	1.0
2	RF02	20240229T160903	8.35237	74.5939	1.4
3	RF04	20240305T080213	12.0636	75.9889	3.0
4	RF04	20240305T104621	11.6987	74.5024	3.8
5	RF05	20240311T074924	18.0049	71.0055	4.1
6	RF05	20240311T090500	12.1502	76.3691	0.2
7	RF05	20240311T092500	9.53427	77.7782	-1.1
8	RF05	20240311T120450	18.2922	70.8791	4.5
9	RF06	20240312T082357	20.3653	74.1656	-2.2
10	RF06	20240312T111209	21.321	71.6729	0.9
11	RF07	20240316T111521	11.4514	72.0899	3.4
12	RF09	20240402T084525	19.0087	70.517	1.8
13	RF09	20240402T095527	14.536	74.4226	0.5
14	RF09	20240402T132543	19.6647	72.2611	3.1
15	RF09	20240402T140707	11.8837	73.4511	2.4
16	RF10	20240403T092220	15.4604	70.563	3.7
17	RF10	20240403T115049	22.8987	73.8008	0.7
18	RF10	20240403T150007	19.0079	71.4203	3.6

5 Data file format

The format for all quality controlled dropsonde data files follows that defined for the NCAR/EOL/ISF radiosonde NetCDF data files. It is based on the Climate and Forecasting (CF) convention version 1.6 and is compatible with any tool accepting this convention. The data file format is described in Vömel et al. (2019).

6 Sounding metrics

6.1 Release altitude

Dropsondes were released typically at the ceiling altitude of longer flight lights, prior to in situ sampling of the boundary layer by the aircraft. Common release altitudes were 4.0 km, 4.6 km, and 5.6 km (Figure 4).

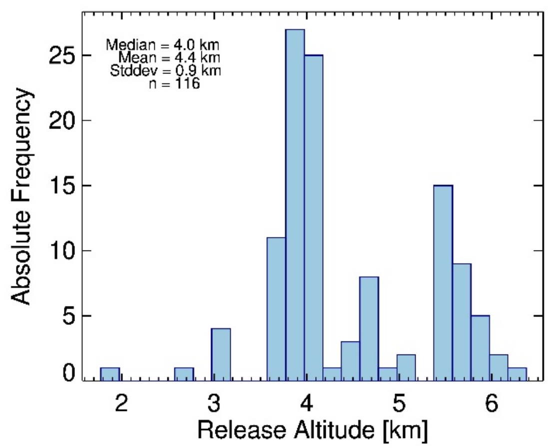


Figure 4: Distribution of the release altitudes of all dropsondes during CAESAR.

6.2 Fall rate

The fall rate above the surface varies from 8.3 m/s to 12.6 m/s with a mean of 10.9 m/s. This is a typical range of fall rates for this sonde and parachute type.

A histogram of the measurement time for all soundings is shown in Figure 5. The mean sounding duration for this data set is 6.0 min and the longest drop time is 8.0 min. The shortest drop time is only 2.7 min for the sounding dropped from only 1.8 km altitude.

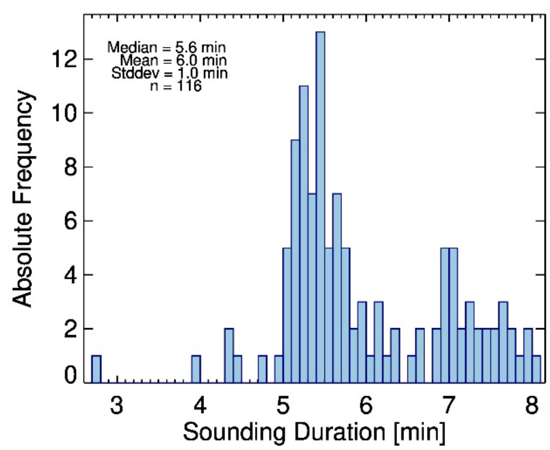


Figure 5: Measurement duration for all dropsonde with normal parachute behavior reaching the surface.

6.3 Horizontal drift

Wind speeds during CAESAR varied widely with peaks of up to 35 m/s. Combined with the variable release altitude, the horizontal drift of the dropsondes varied strongly as well (Figure 4). The mean horizontal distance the dropsondes traveled was 3.7 km and no sonde traveled more than 8 km horizontally.

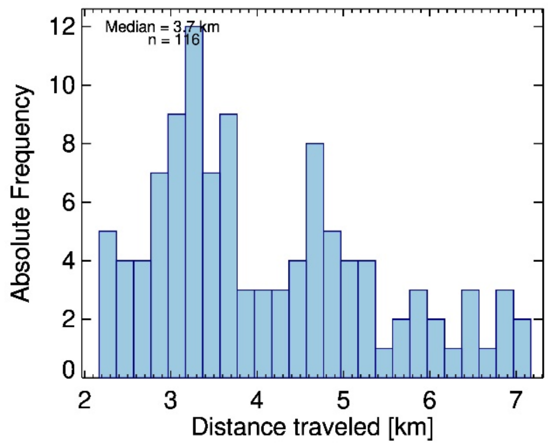


Figure 6: Distance between launch and landing for all dropsondes during CAESAR.

6.4 Surface pressure

The surface pressure reported by the sondes is an extrapolation of the last measured air pressure above the surface to sea level using the current fall rate. The surface pressure reported by all sondes, which transmitted to the surface is shown in Figure 7.

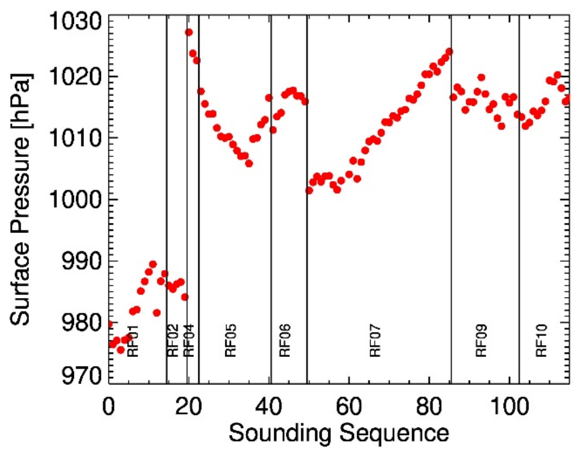


Figure 7: Surface pressure reported by all sondes

7 Atmospheric observations

7.1 Temperature

The temperature measured by all dropsondes is shown as contour plot in Figure 8. The individual research flights are separated by vertical lines. The temperature at flight level were in the range of -10°C to -48°C and near the surface in the range of 5°C to -25°C.

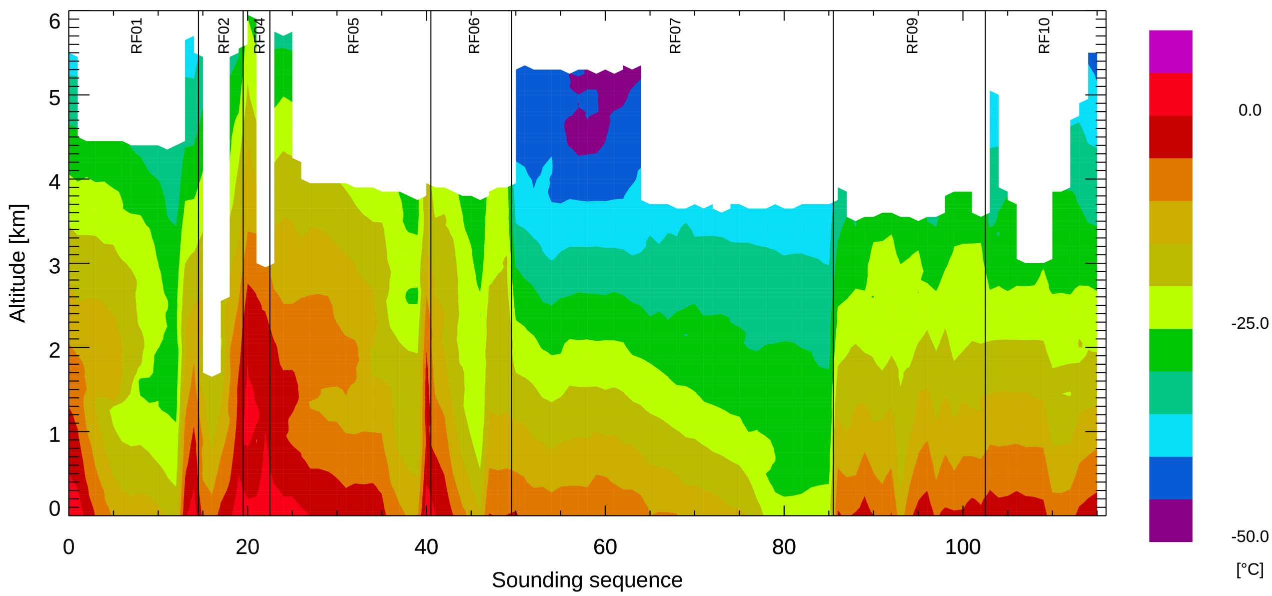


Figure 8: Color contours for all temperature measurements. Apparently missing data shown in white are due to drops from a lower altitude. All soundings are shown in the sequence in which they were released.

7.2 Relative humidity

Relative humidity measured by all dropsondes is shown in Figure 9. Almost all measurements were taken at temperatures below 0°C. To highlight the possibility for ice clouds, relative humidity is expressed as relative humidity over ice instead of the conventional relative humidity over liquid water. Purple colors indicate possible mixed phase or ice clouds.

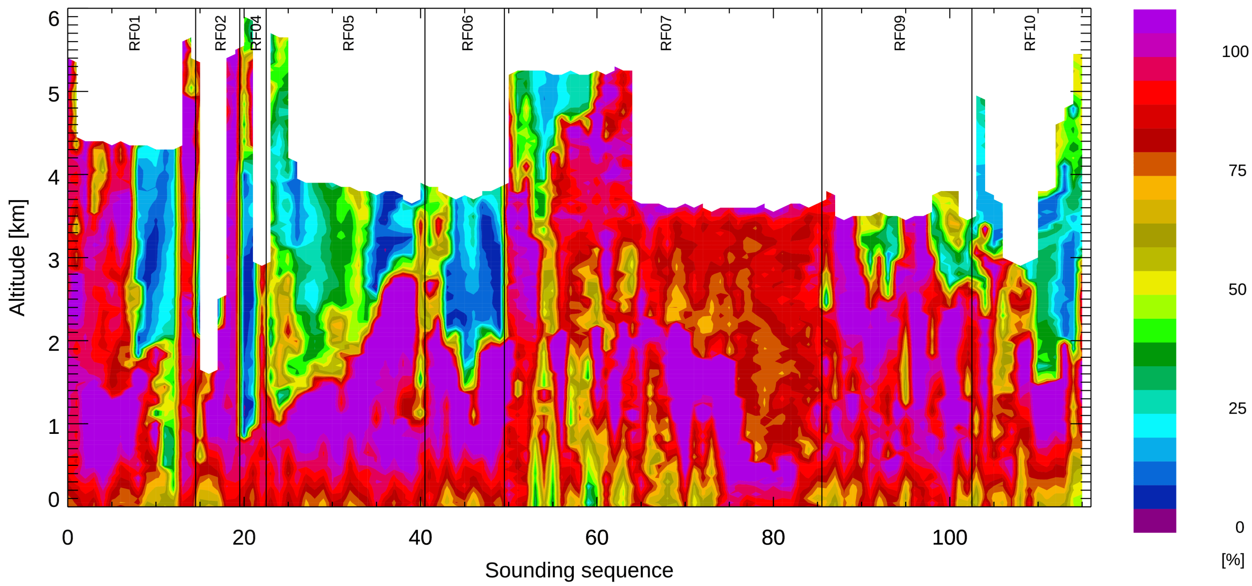


Figure 9: Color contours for all relative humidity measurements. Note that relative humidity is shown with respect to ice.

7.3 Zonal winds

Zonal wind speeds are shown in Figure 10. Red and brown colors indicate westerly winds, yellow and green colors indicate easterly winds.

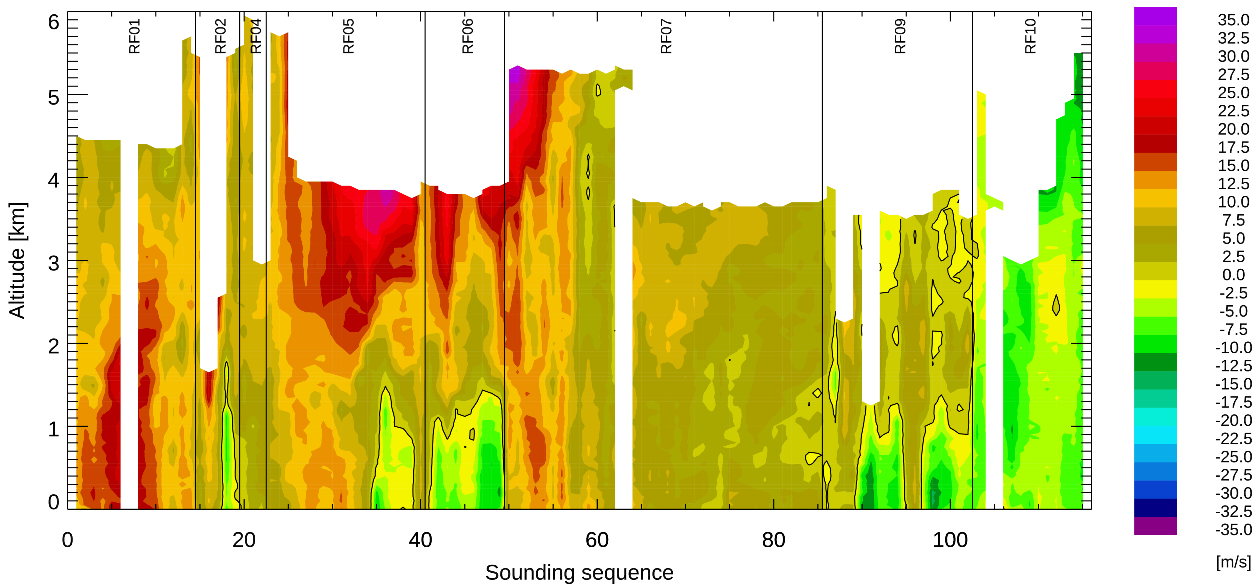


Figure 10: Color contours for all zonal wind speed measurements

7.4 Vertical winds

Vertical wind speeds were derived from the difference of the actual measured fall rate and a mean (theoretical) fall rate for this campaign. These are shown in Figure 12. Uncertainties are at least ±1 m/s. All profiles plotted on top of each (Figure 11) other highlights the magnitude of the up and downdrafts outside the uncertainty regime.

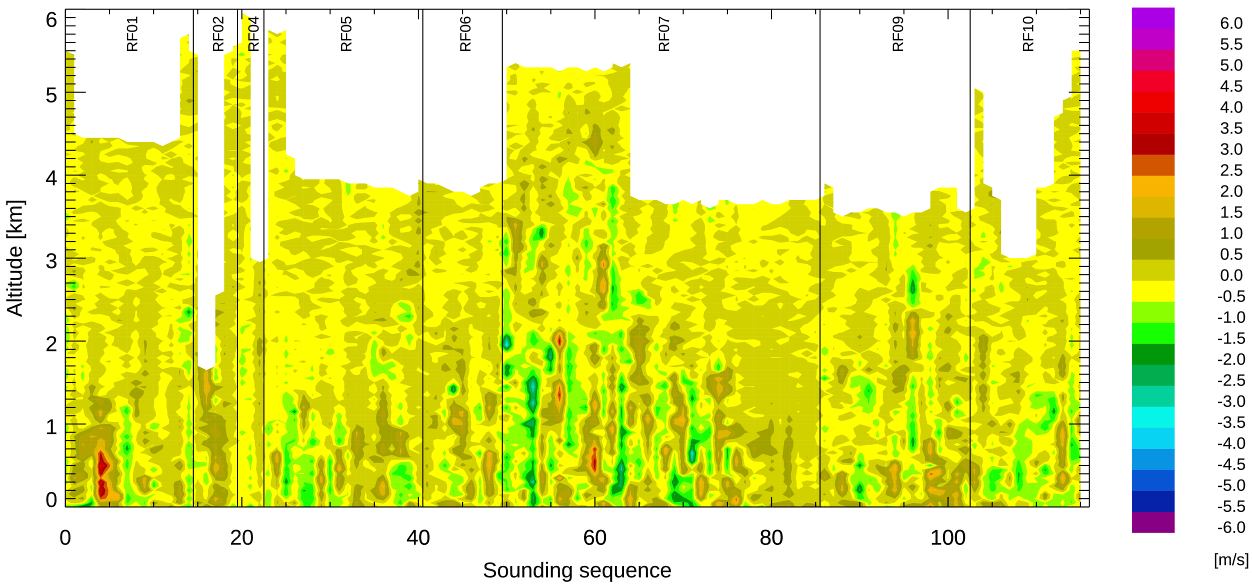


Figure 12: Color contours for all zonal wind speed measurements. Green and red colors indicate significant down- and updrafts.

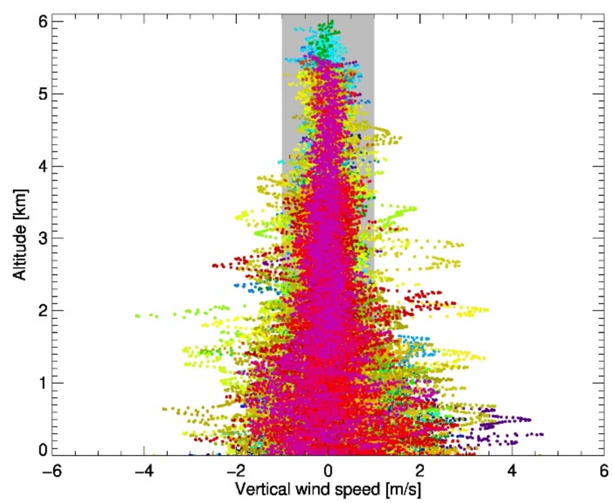
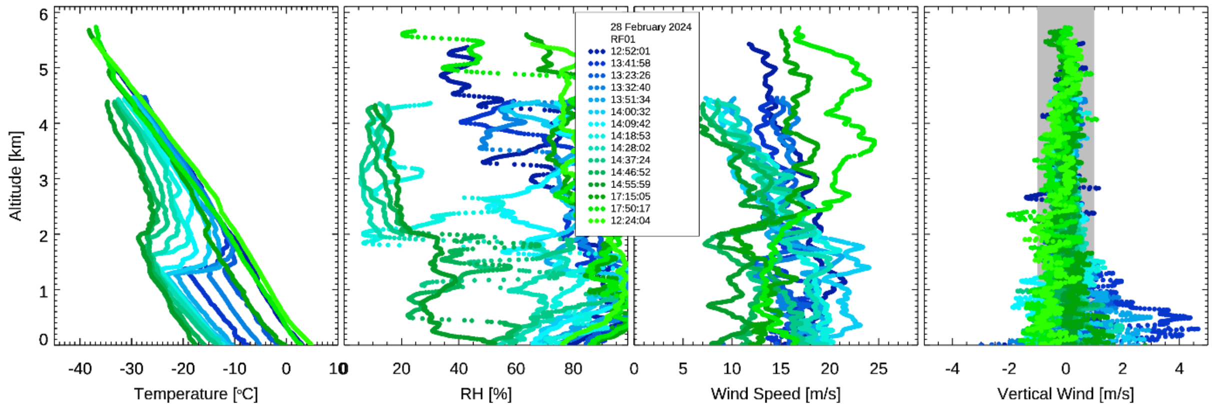
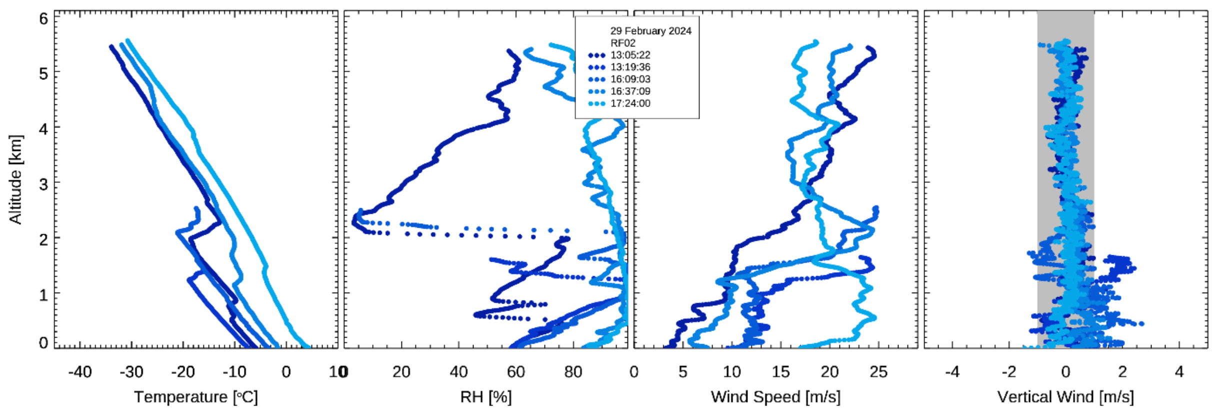


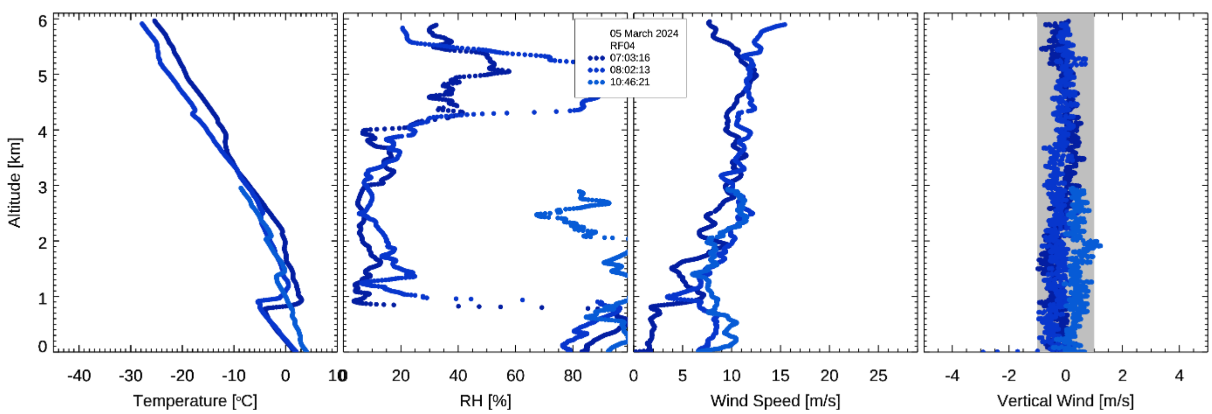
Figure 11: Vertical wind speeds encountered by all dropsondes. The color coding distinguishes all profiles.

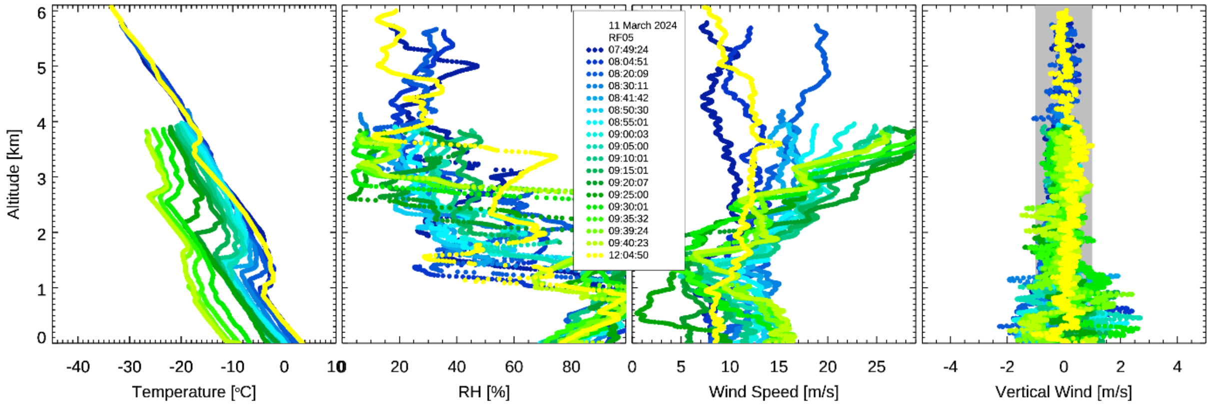
7.5 Summary plots

All individual profiles of pressure, temperature, relative humidity, horizontal and vertical winds from the 8 research flights during which dropsondes were released are shown in the Figures below.








11 March 2024
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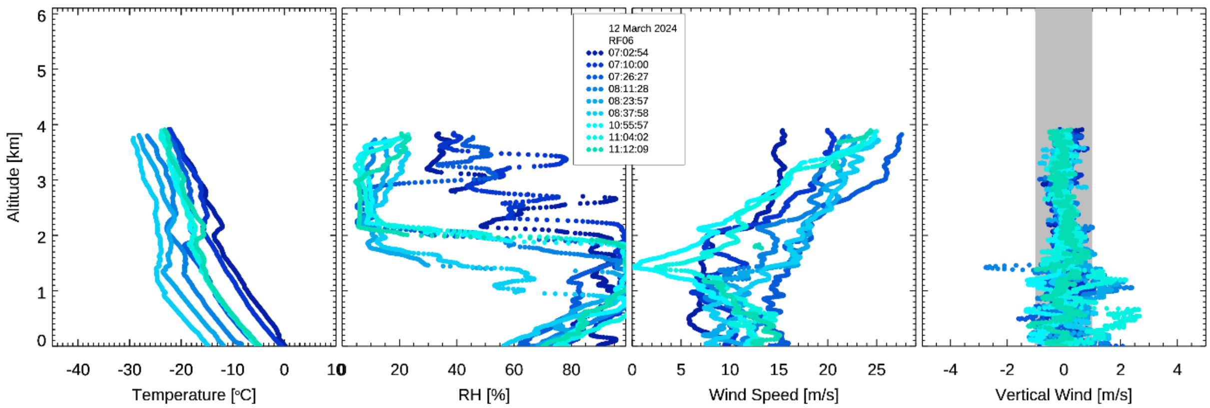
08:04:51
08:20:09
08:30:11
08:41:42
08:50:30
08:55:01
09:00:03
09:05:00
09:10:01
09:15:01
09:20:07
09:25:00
09:30:01
09:35:32
09:39:24
09:40:23
12:04:50
Altitude [km]
Temperature [°C]
RH [%]
Wind Speed [m/s]
Vertical Wind [m/s]


12 March 2024
RF06
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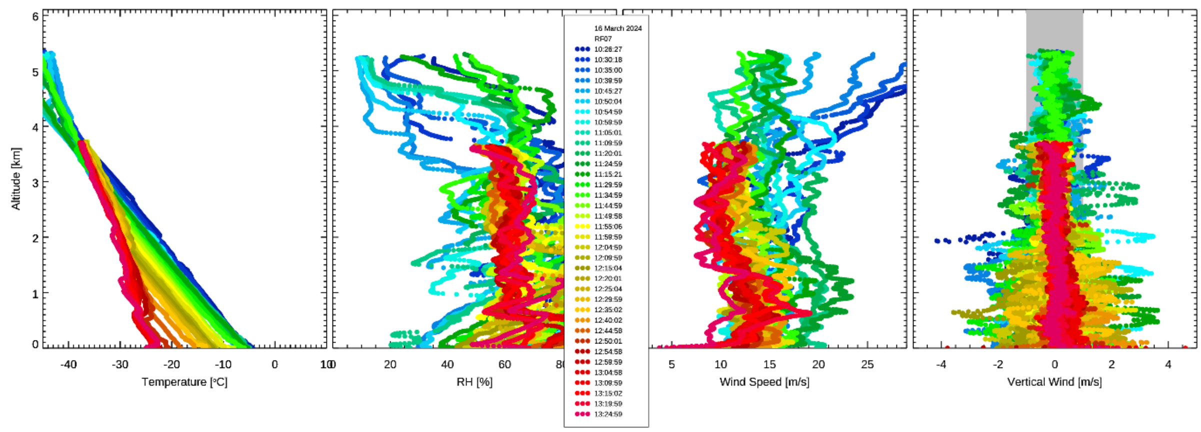
07:10:00
07:26:27
08:11:28
08:23:57
08:37:58
10:55:57
11:04:02
11:12:09
Altitude [km]
Temperature [°C]
RH [%]
Wind Speed [m/s]
Vertical Wind [m/s]


16 March 2024
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11:05:01
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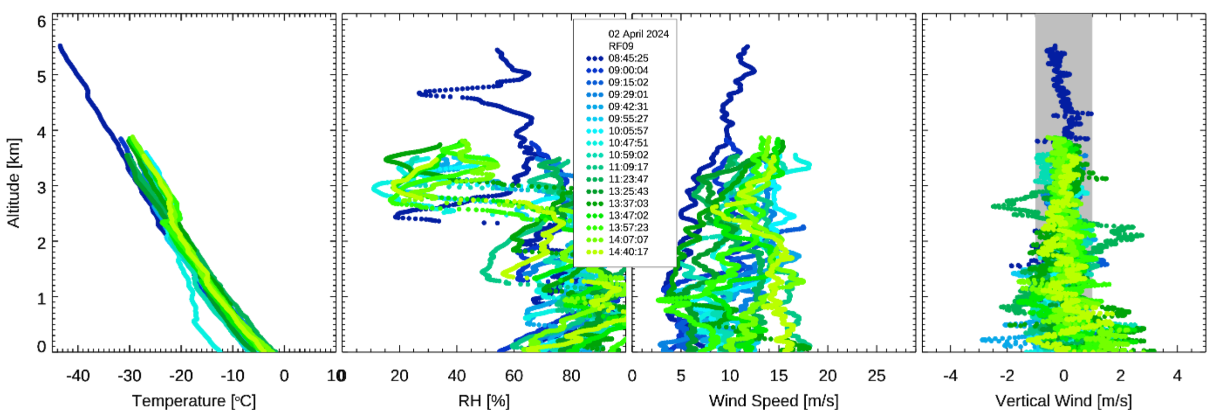
Vertical Wind [m/s]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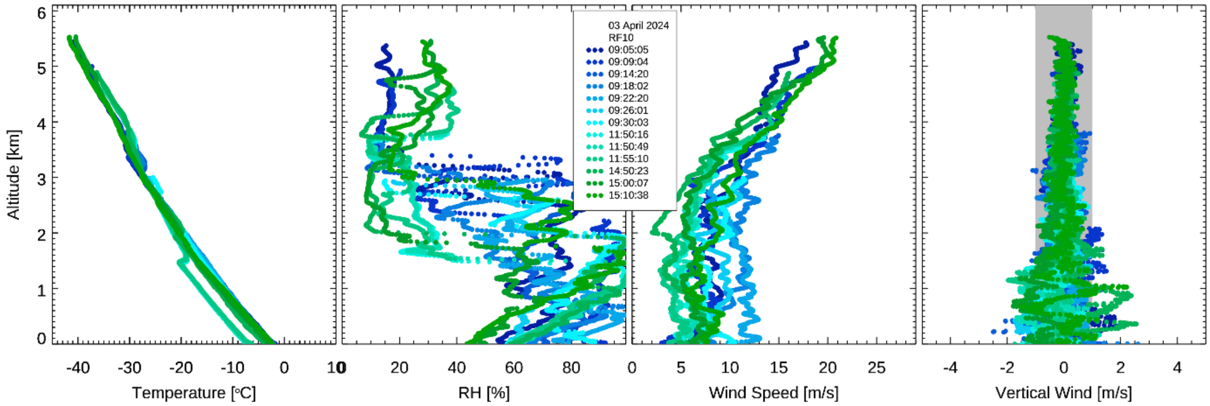
11:23:47
13:25:43
13:37:03
13:47:02
13:57:23
14:07:07
14:40:17
Altitude [km]
Temperature [°C]
RH [%]
Wind Speed [m/s]
Vertical Wind [m/s]


03 April 2024
RF10
09:05:05
09:09:04
09:14:20
09:18:02
09:22:20
09:26:01
09:30:03
11:50:16
11:50:49
11:55:10
14:50:23
15:00:07
15:10:38
Altitude [km]
Temperature [°C]
RH [%]
Wind Speed [m/s]
Vertical Wind [m/s]

8 References

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