Zero-Degree Height in the Arctic Derived From Radiosonde and Numerical Weather Data

Terje Tjelta and Jostein Mamen

Abstract – The zero-degree height (0°C isotherm) is an indicator for separation of liquid and frozen hydrometeors. With respect to radio systems, the zero-degree height is particularly important for estimating satellite-link rain attenuation. Analyses of measurement data from three Norwegian radiosonde launch sites and numerical weather data covering the polar region at latitudes above 70°N indicate significantly lower zero-degree heights than the current guidance given by the International Telecommunication Union Radiocommunication Sector. In practice for link design, this means significantly less predicted satellite-link rain attenuation. However, data analysis covering a period from 1980 to 2020 also shows a clear trend of increasing zero-degree height. The increase is in line with global surface temperature increase for the same period, but clearly less than the increase of the temperature at the surface.

1. Introduction

Radio waves for systems operating at frequencies above ~10 GHz may be heavily attenuated under rainfall or hydrometeor precipitation, but with small attenuation due to dry snow and ice particles. Attenuation calculation methods use the path length through rainfall, and for satellite links the upper end is given by the rain height. It is common practice to set the rain height at 360 m above the zero-degree height h_0. Hence, establishing h_0 is very important for correct estimation of rain attenuation on satellite links.

The International Telecommunication Union Radiocommunication Sector (ITU-R) provides guidance that is widely used for the design and dimensioning of radio systems. For satellite links this is provided in Recommendation P.618 [1]. Frequencies above ~10 GHz are heavily influenced by rainfall. Also, gaseous attenuation, cloud attenuation, and scintillation and ducting caused by variations in the air refractivity must be considered, but often the rainfall attenuation will dominate and dictate the system performance. The key climate parameters in this case are the rainfall intensity and the rain height. Recommendation P.618 suggests that local data be used in calculations. However, when such data are not available, it points to other ITU-R recommendations with appropriate data for rain rate (P.837 [2]) and rain height (P.839 [3]).

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For the arctic sector 40°W to 70°E, north of Norway, Figure 1 indicates P.839 h_0 heights in the range of 1 km to more than 2 km for regions over sea level. These heights are indeed significant in the Arctic and have been a motivator to analyze radiosonde data from the region as well as more recent numerical weather data that have been used for the P.839 maps, for either confirmation or revision of these values.

The study reported here used radiosonde data from the locations of Bjørnøya, Jan Mayen, and Ny-Ålesund and the ERA5 numerical weather data issued by the European Centre for Medium-Range Weather Forecasts. Trend analysis of temperatures at the surface for the radiosonde launch sites and period 1980 to 2020 have been included for comparison.

2. Analysis of Radiosonde Data

The two Norwegian meteorological stations at Bjørnøya and Jan Mayen are north of 70°N and have long time series of radiosonde data. The data are available from the 1950s or 1960s, but after 1980 the records include data that allow precise calculation of the zero-degree height. These stations are operated regularly, with observations conducted three or four times daily at synoptic times. The radiosonde data from the station at Ny-Ålesund are available from 2015. However, this station has not been operated regularly at synoptic time, and there are no radiosonde accents from the nighttime—that is, 0:00 UTC.

Figure 2 shows observations from Bjørnøya for November 2015. The radiosonde can ascend to altitudes of about 30 km, and by this height it has drifted somewhat eastwards.

Figure 3 depicts the temperature as a function of height in August 2015 for the station at Bjørnøya. Close to the surface the observations show large variability, but then they align well with the average atmospheric lapse rate of 0.6°C/km, which is close to the largest values of the moist adiabatic lapse rate.

There are two different sets of data, one low-resolution covering 1980 until late 1994 and then another high-resolution covering late 1994 until present. The first has data at mandatory and significant layers, whereas the second is a high-resolution set with a reading every ~10 m. Only data below about 6000 m were used here, and checked before being accepted for further calculations, because the zero-degree height in the Arctic is usually well below this height. Values for height, temperature, and pressure must be within reasonable ranges, and for the low-resolution data set

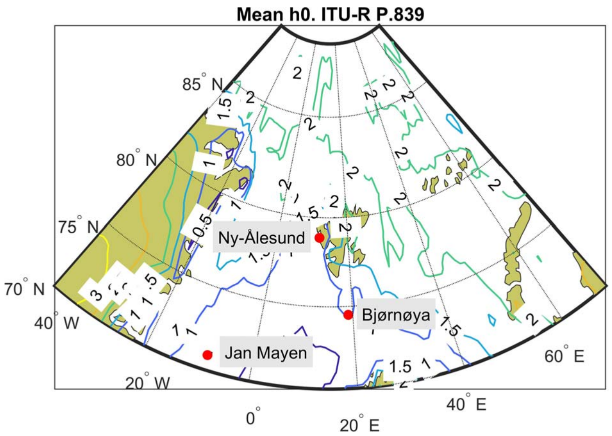

Figure 1. Mean zero-degree height (km) in the Arctic sector 40°W to 70°E [3].

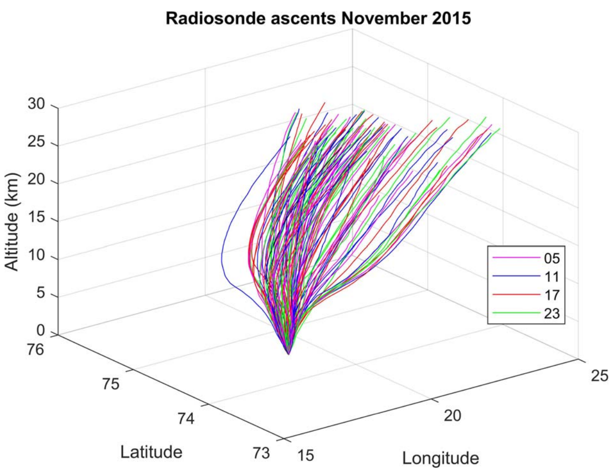

Figure 2. Example radiosonde ascents from Bjørnøya, November 2015.

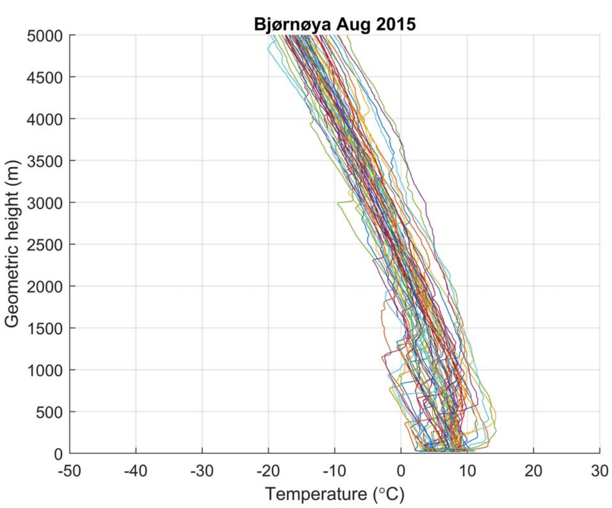

Figure 3. One-month ascent at Bjørnøya showing temperature versus altitude.

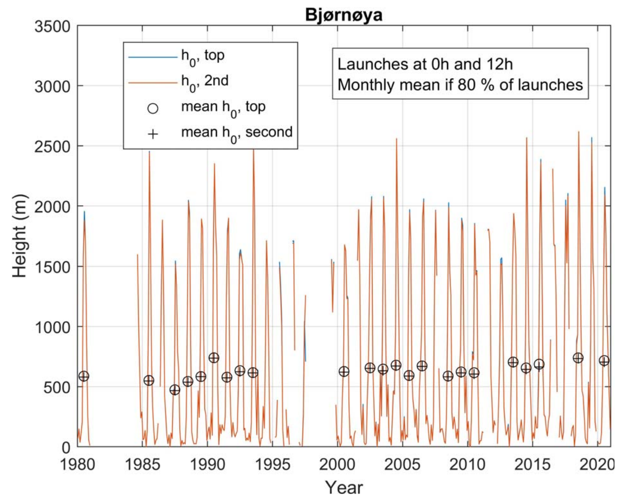

Figure 4. Mean monthly and yearly zero-degree heights at Bjørnøya.

a hydrostatic check was performed to accept reported geopotential heights, but the limits set were relaxed. Furthermore, plots of temperature versus height were screened to look for outlier ascents.

The temperature changing from positive to negative values defines a zero-degree height. If this happens more than once, the top values are noted as well as the value derived from the second-highest temperature layer. A monthly mean value is calculated, followed by computation of the yearly mean. Figures 4 and 5 show monthly and yearly mean values for the ascent at synoptic times 0:00 and 12:00 UTC. The monthly mean is calculated if there are 80% or more of the possible number of ascents (which is twice the number of days in the month). A value for all months was required in order to find the yearly mean.

Both Bjørnøya and Jan Mayen show yearly zero-degree heights between 500 and 900 m, with the lowest heights at Bjørnøya, being north of Jan Mayen.

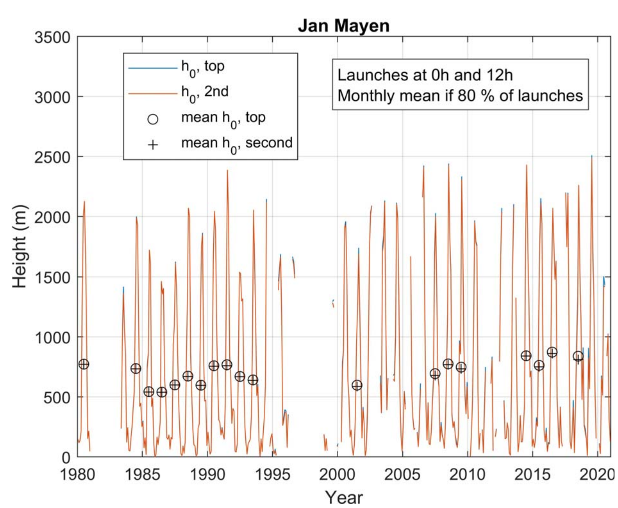

Figure 5. Mean monthly and yearly zero-degree heights at Jan Mayen.

Table 1. Radiosonde launch sites and locations in the ERA5 grid

	Bjørnøya		Jan Mayen		Ny-Ålesund	
Coordinate	Site	ERA5	Site	ERA5	Site	ERA5
Latitude (°)	74.5	74.5	70.93	70.75	78.92	78.25
Longitude (°)	19	19	−8.66	−8.5	11.92	12
Altitude (m)	20	5.2	9	22.3	16	13.4

3. Analysis of Numerical Weather Data

The numerical data used are the ERA5 data [4]. These data have a regular grid in longitude and latitude with a 0.25° resolution. The geopotential parameter z (m^2/s^2) is used to establish the surface altitude for the grid, and the parameter deg0l (m) gives the zero-degree height above the surface. ERA5 data are available from 1950, but in this work data from 1980 to 2020 are used.

Table 1 lists the location of the radiosonde launch sites and selected ERA5 grid points. The selection of a representative grid point for the radiosonde launch sites was done from geographical proximity and closest grid altitude compared with actual location and height.

Figure 6 shows the mean monthly and yearly average zero-degree heights using the ERA5 data for Ny-Ålesund. It is noted that the mean yearly zero-degree heights are generally below about 500 m.

Figures 7 and 8 show the average zero-degree heights from the decades of 1980 to 1989 and 2010 to 2019 for the polar region. Clearly, the area of 200 m has become much smaller in the latter decade, 30 years after the former decade, indicating a higher zero-degree height.

4. Discussion and Conclusion

The zero-degree height derived from the radiosonde data are comparable with the numerical weather data. At the site locations, the zero-degree height is somewhat lower than that given by ITU-R Recommendation P.839, as noted from Figure 1. In particular, the more recent ERA5 data show significantly lower heights for regions closer to the north pole.

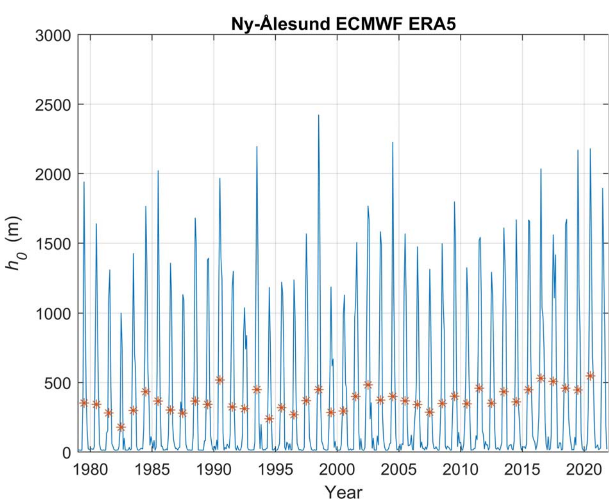

Figure 6. Mean monthly and yearly zero-degree heights at Ny-Ålesund.

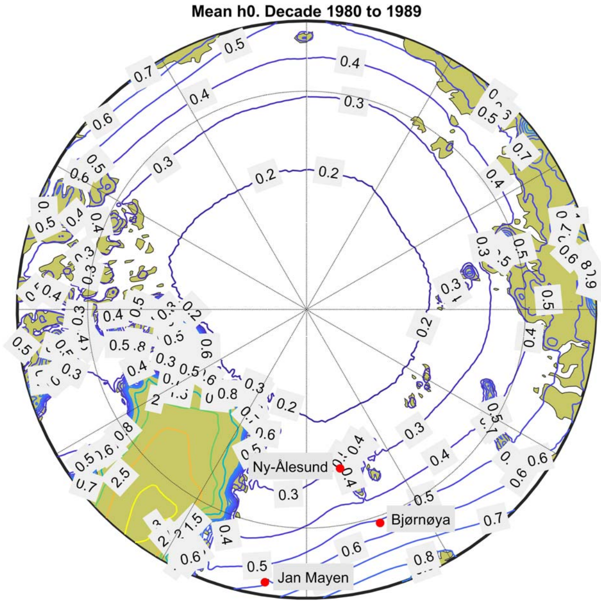

Figure 7. Average zero-degree height (km), 1980–1989.

The trend is clearly increasing from all radiosonde launch sites, and apparently largely in the whole polar region. All sites, as indicated in Figures 9, 10, and 11, show a general increase. Both Bjørnøya and Jan Mayen indicate an increase in line with the increase of average global temperature, according to, for example, HadCRUT5 data [5], suggesting an increase from 160 to 170 m for a temperature increase of 1°. There is good correspondence with radiosonde and numerical weather data.

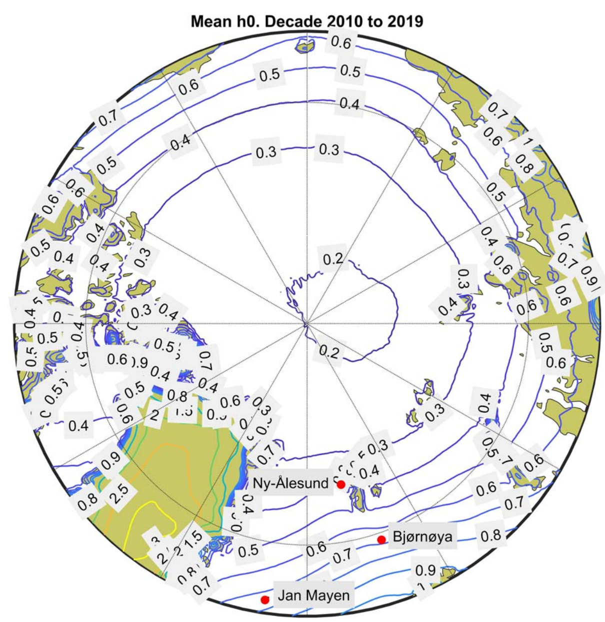

Figure 8. Average zero-degree height (km), 2010–2019.

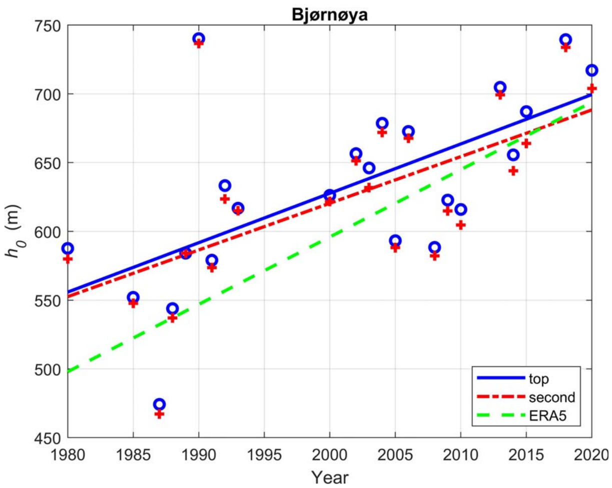

Figure 9. Zero-degree height trend at Bjørnøya.

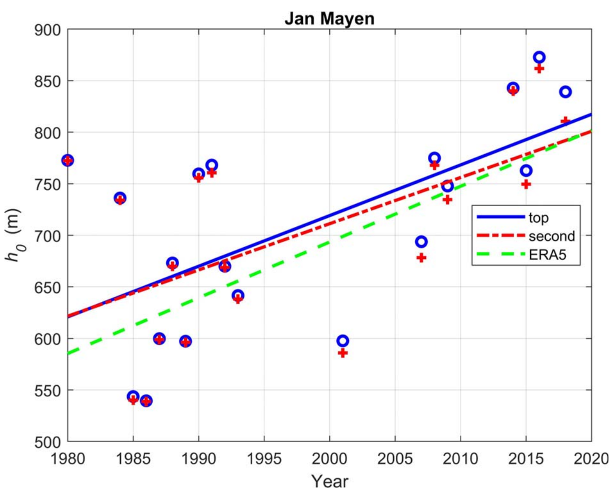

Figure 10. Zero-degree height trend at Jan Mayen.

At Ny-Ålesund the time series is much shorter, and daytime launches may explain the deviation of radio observations from the numerical weather data.

It is of interest to note that the yearly average temperature measured at the surface of the radiosonde launch sites has a remarkable higher increase rate over the 40 years. Figure 12 suggests an increase of 2°C to 3°C for the three sites, which is very much higher than the global mean temperature increase of less than 1°C.

The gradient between the surface temperature and the zero-degree height has increased. This is consistent with earlier findings that lapse-rate feedback leads to polar temperature amplification [6]. Generally, global warming increases the lapse rate at high latitudes and decreases it in the tropics.

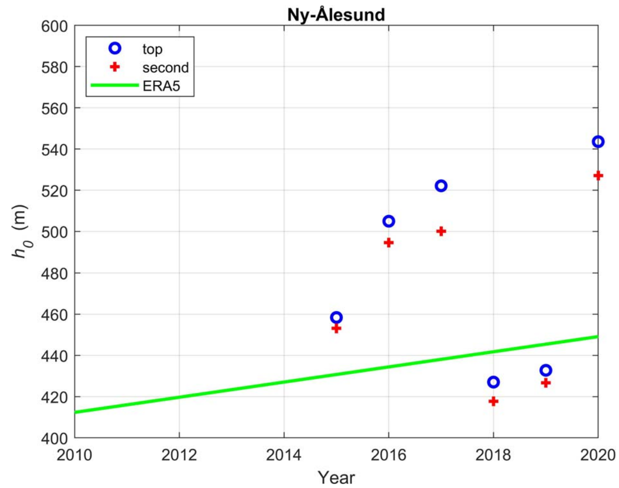

Figure 11. Zero-degree height trend at Ny-Ålesund.

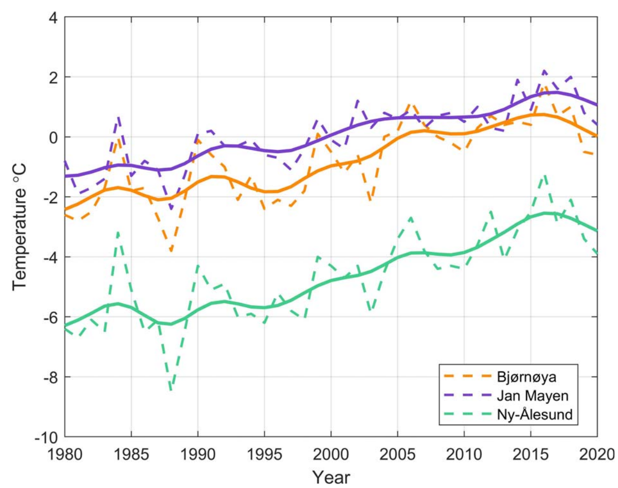

Figure 12. Yearly mean temperature and smoothed trend at the radiosonde launch sites at Bjørnøya, Jan Mayen, and Ny-Ålesund.

6. References

1. International Telecommunication Union, Radiocommunication Sector, *Recommendation ITU-R P.618-13: Propagation Data and Prediction Methods Required for the Design of Earth-Space Telecommunication Systems*, International Telecommunication Union, Geneva, December 2017.
2. International Telecommunication Union, Radiocommunication Sector, *Recommendation P.837-7: Characteristics of Precipitation for Propagation Modelling*, International Telecommunication Union, Geneva, June 2017.
3. International Telecommunication Union, Radiocommunication Sector, *Recommendation ITU-R P.839-4: Rain Height Model for Prediction Methods*, International Telecommunication Union, Geneva, September 2013.
4. H. Hersbach, B. Bell, P. Berrisford, G. Biavati, A. Horányi, et al., "ERA5 Monthly Averaged Data on Single Levels From 1979 to present," Copernicus Climate Change Service Climate Data Store, doi: 10.24381/cds.f17050d7 (Accessed 8 January 2022).
5. C. P. Morice, J. J. Kennedy, N. A. Rayner, J. P. Winn, E. Hogan, et al., "An Updated Assessment of Near-Surface Temperature Change From 1850: The HadCRUT5 Data Set," *Journal of Geophysical Research: Atmospheres*, **126**, 3, February 2021, p. e2019JD032361.
6. R. G. Graversen, P. L. Langen, and T. Mauritsen, "Polar Amplification in CCSM4: Contributions From the Lapse Rate and Surface Albedo Feedbacks," *Journal of Climate*, **27**, 12, June 2014, pp. 4433-4450.