the microphysical processes of snow particle growth and sublimation (solid to vapour). This led to the discovery that the process of sublimation of snow falling through the lowest layers of the atmosphere has an important effect on the accumulation of Antarctic precipitation at the surface. This process had previously been neglected in the Antarctic ice sheet mass balance.

Katabatic winds

The DDU research station is at a location that is frequently affected by strong downslope winds flowing from the high Antarctic plateau, called katabatic winds. These winds are channelled by the topography and are particularly persistent in specific regions around the coast. The katabatic winds are dry and the air warms adiabatically as it descends, leading to low relative humidity in a layer above the surface. Very close to the surface, air is moistened by sublimation of surface snow, but aloft the low relative humidity layer leads to significant sublimation of falling snow particles as observed by the radar at the DDU station.

Modelling the sublimation of snowfall

The profiles of falling snow at the station location were compared with results from three numerical models including the IFS. All three confirmed the important role of snow sublimation caused by katabatic winds. The IFS operational global analysis and 24-hour forecasts for the whole year were then used to quantify the impact of sublimation on falling snow over the entire Antarctic continent. The IFS results show that the total Antarctic continent cumulative precipitation near the ground was 17% lower than its maximum level higher in altitude, due to snowfall sublimation. The largest reductions were around the coast in the regions of persistent katabatic winds, particularly in East Antarctica, where the data suggest precipitation is as much as 35% lower than it would be without sublimation.

The new radar observations and modelling results from this scientific collaboration have, for the first time, identified and quantified the impact of snowfall sublimation in Antarctic katabatic winds. This will help to inform our understanding of the Antarctic ice sheet mass balance, which is essential for predicting how sea levels will evolve.

Further information can be found in an article published by Grazioli et al. in the *Proceedings of the National Academy of Sciences* (doi:10.1073/pnas.1707633114).

Rapidly developing cyclones in ECMWF reanalyses

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The last few years have seen major developments in climate reanalysis at ECMWF. The production of ECMWF's fifth-generation global climate reanalysis ERA5 is under way, and the production of CERA-20C, a coupled reanalysis which covers the entire 20th century, is complete. In 2016 and 2017, in the framework of a master's thesis, rapidly developing cyclones in the North Atlantic–European region were studied at the Hungarian Meteorological Service (OMSZ), based on different reanalysis datasets. As part of this work, we investigated whether there are systematic differences in the monthly or seasonal number of such cyclones identified by the coarse-resolution but state-of-the-art CERA-20C on the one hand and the older satellite-era ERA-Interim reanalysis on the other. We also looked for long-term trends in the number of rapidly developing cyclones in CERA-20C. We found that fewer rapidly developing cyclones are identified by CERA-20C than by ERA-Interim. We also found that the number of such cyclones per 30-year period changes little in CERA-20C after 1920.

	Winter	Spring	Summer	Autumn	Total
ERA-Interim	1117	259	32	454	1865
CERA-20C	877	177	37	328	1419

Number of rapidly developing cyclones 1981–2010. The table shows the number of rapidly developing cyclones identified by ERA-Interim and CERA-20C in the North Atlantic–European region in the period 1981 to 2010.

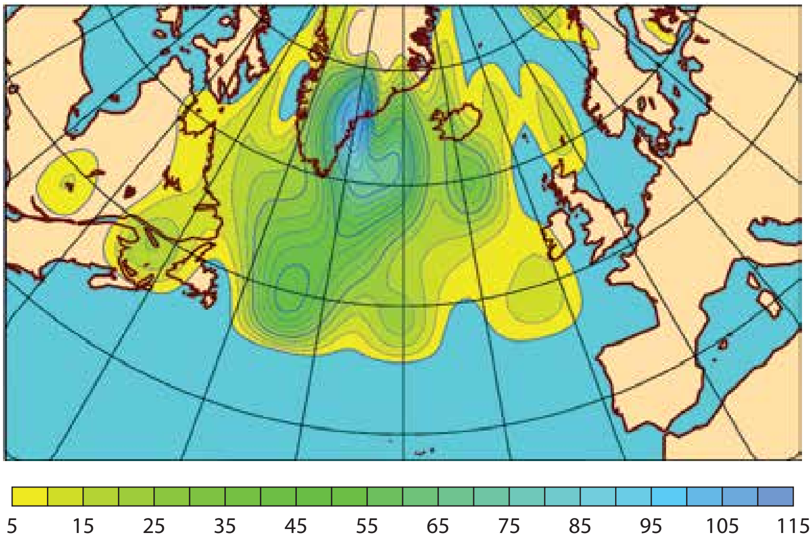
Rapidly developing cyclones

The dynamic conditions which give rise to rapidly developing extratropical cyclones have been intensively studied over the last few decades. The defining characteristic of these cyclones is their very fast development, with a rapid change in mean sea level pressure at the core. Typically such cyclones move fast and have a relatively small diameter (about 1,500 km). When they are generated in the North Atlantic, in a later stage of their life they may cause severe storms in Europe, especially from October to April. In summer such cyclones are quite rare. The criterion used in our study for the identification of rapidly developing cyclones in the CERA-20C and ERA-Interim reanalyses is a change in mean sea level pressure of at least 24 hPa in 24 hours at the core of the cyclone.

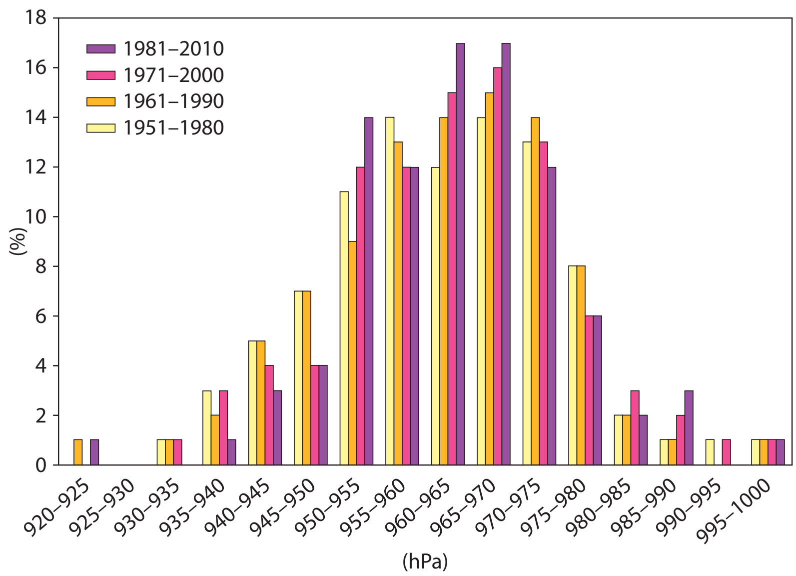
CERA-20C and ERA-Interim compared

There are several significant differences between the ERA-Interim and CERA-20C reanalyses. ERA-Interim is a global atmospheric reanalysis from 1979. The data assimilation system used to produce ERA-Interim is based on a 2006 version of ECMWF's Integrated Forecasting System (IFS Cycle 31r2). The system uses the 4D-Var technique with a 12-hour analysis window. The horizontal resolution of the dataset is approximately 80 km with 60 vertical levels going up to 0.1 hPa. CERA-20C reconstructs the weather and climate of the Earth system including the atmosphere, ocean, land, waves and sea ice for the period 1901–2010. Unlike ERA-Interim, CERA-20C does not use satellite data. To account for errors in the observational record as well as model error, CERA-20C provides a 10-member ensemble of reanalyses. CERA-20C was produced with IFS Cycle 41r2 (implemented in 2016) and has a horizontal resolution of about 125 km with 91 vertical levels going up to 0.1 hPa.

One of our findings is that there are considerable differences between the numbers of rapidly developing cyclones identified by the two reanalyses in the North Atlantic–European region. Between 1981 and 2010 CERA-20C identifies 24% fewer such cyclones than ERA-Interim. Broken down by season, in winter, spring and autumn CERA-20C identifies 20–30% fewer, while in summer it identifies 15% more. It should be noted that the latter percentage is based on very small absolute numbers (see the table for details). The identification of such cyclones thus appears to be sensitive to the type of reanalysis. At the same time, the distribution of rapidly developing cyclones across the seasons (spring, summer, autumn, winter) is very similar in ERA-Interim (13, 2, 25, 60%) and CERA-20C (12, 3, 24, 61%). There are no significant differences in these patterns for any selected subdomains.



Geographic distribution of rapidly developing cyclones 1981–2010. The map shows the number of rapidly developing cyclones broken down by 5°x5° grid box in the North Atlantic–European region based on CERA-20C for the period 1981 to 2010.



Breakdown according to minimum mean sea level pressure. The chart shows the percentage of rapidly developing cyclones in the North Atlantic–European region from October to March identified by CERA-20C that fall into different minimum mean sea level pressure bins, for four 30-year periods: 1951–1980, 1961–1990, 1971–2000 and 1981–2010.

In selected cases, such as cyclone Kyrill (January 2007), some relatively large differences between the two reanalyses in mean sea level pressure (4–6 hPa) can be seen in some areas, especially above the ocean and in the Arctic region. These differences do not show any systematic patterns around the core of the cyclone, and they can change quite quickly during a cyclone's lifetime. In continental Europe differences in mean sea level pressure are always smaller than 2 hPa. A frequency map of rapidly developing cyclones shows that many of them form in the area of southeast Greenland.

Long-term trends

To study long-term trends, we defined overlapping thirty-year intervals, shifted by ten years from one interval to the next and starting from 1921. In the first two decades of the 20th century, significantly fewer rapidly developing cyclones are identified in CERA-20C than in later decades. This is probably a result of less dense observation networks. For this reason we did not include the first two decades of the century in our investigation. For any particular season or month, some relatively small fluctuations in the number and intensity of rapidly developing cyclones can be seen, but there is no significant overall trend (increasing or decreasing) in the number of such cyclones over the North Atlantic–European area or any subdomains.

Outlook

Reanalysis datasets provide useful information for studying rapidly changing weather systems, such as rapidly developing cyclones in the North Atlantic–European region. We have started to study data from the latest ECMWF reanalysis, ERA5, which provides a 10-member ensemble at a horizontal resolution of 31 km. As we have found that there may be considerable differences in the representation of rapidly changing weather systems between two reanalyses, especially above the ocean and in the Arctic region, a high-resolution ensemble reanalysis is likely to provide valuable information about the uncertainty associated with cases where such differences are found.

For more information on reanalysis, visit: https://www.ecmwf.int/en/research/climate-reanalysis