Relationship Between Arctic Clouds and Synoptic-Scale Variability

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Introduction

Arctic clouds play an important role in the Arctic climate system. During summer, fall and spring, cloud fractions are typically in excess of 70% over the pack ice and near the Alaskan coast (Curry et al. 1996; Intrieri et al. 1999). Cloud cover over the sea-ice typically maximizes in summer, whereas coastal Alaskan cloudiness typically maximizes in October (Dissing and Wendler 1998). This large spatial and temporal cloud coverage has a huge impact on the radiative budget of the Arctic system (Curry et al. 1996; Harrington and Olson 2001) with clouds having a cooling effect in the summer and a warming effect in winter. Because of this strong cloud dependence, surface radiative fluxes are quite sensitive to changes in cloud cover. Alterations in cloud properties could affect the state of the sea-ice due to the underlying sea-ice sensitiveness to changes in surface fluxes.

Although cloudiness is an important issue with regard to Arctic climate, and though much good work has been accomplished in this area, we still lack knowledge regarding the physical processes responsible for the large cloud fractions over the Arctic terrestrial and oceanic regions. Curry and Herman (1985) found that during the summer synoptic-scale activity, while affecting low cloud cover over the Arctic ocean, appears to act in a secondary role with its effects superimposed on the first-order effects of air mass modification. Later, Olsson et al. (2001) have concluded that the processes over coastal Alaska are substantially different than those over oceanic regions. However, it still remains as an open question what is the principal driver of the cloudiness over coastal and terrestrial arctic regions during transitional and cold seasons. We are also interested to find out for what region the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) North Slope of Alaska (NSA) site at Barrow, Alaska is representative. As an attempt to address these questions we compare the synoptic-scale variability over oceanic, coastal and terrestrial arctic regions and try to relate it to the observed cloud characteristics.

Data and Methods

National Centers for Environmental Prediction (NCEP) reanalysis data for the period of 1992 to 2001 and cloud cover fractions at ARM NSA site at Barrow, Alaska derived from active remote sensing cloud (ARSCL) data collected in 2001 are used in this study. The reanalysis data were provided by the National Oceanic and Atmospheric Administration (NOAA) Cooperative Institute for Research in Environmental Sciences (CIRES) Climate Diagnostics Center, Boulder, Colorado, from their Web site at http://www.cdc.noaa.gov. The data are additionally divided into three datasets representing each of the seasons:

1. winter - November, 16th to April, 15th
2. summer - June, 16th to September, 15th
3. transitional - April, 16th to June, 15th; September, 16th to November, 15th .

The cloud fractions derived from ARSCL data were divided into three types:

1. low level (0-2000m)
2. middle level (2000-5000m)
3. high level (5000-10000m)

The region selected for the analysis includes the whole area north of 60°N and is shown in Figure 1.

The weather conditions at each of the grid points of the NCEP grid are characterized by four meteorological parameters (geopotential height Φ or surface pressure p_s, air temperature T, dew point temperature T_d and wind speed |V|) at 12 levels between surface level and isobaric surface p = 100 mb, thus forming a set of 44 variables. Dew point temperature data were available at the first 8 levels only (up to 300 mb); however, this is not a limitation as the Arctic tropopause is typically low.

Before comparing the weather conditions at the different grid points, however, it is important to eliminate the mutual collinearity between the original variables. This is achieved by implementation of principal component analysis (PCA), which also reduces the initial set of 44 inter-correlated variables to a smaller set of orthogonal principal components (PCs). The PCs are the eigenvectors extracted from either a covariance, correlation or cross-products input matrix of the size $\mathbf{n} \times \mathbf{n}$, where n is the number of variables (Yarnal 1993). Because the data used in this study are measured in different units - mb, meters, degrees Celsius, etc., we use the correlation matrix approach. Each of the resulting PCs defines a new variable that is a linear combination of the original variables. The first PC explains the largest amount of variance of the original variables and each of the subsequent PCs accounts for lesser amount. Because of the orthogonality of the PCs, one can extract only a number of components $\mathbf{m}$ ($\mathbf{m} < \mathbf{n}$) explaining predetermined part of the original variance. Thus, in addition to eliminating the inter-variable collineraity, PCA also reduces the size of the original dataset.

Further, the PC scores at each grid point are produced by projecting the time series of the original 44 variables into an m-th dimensional space defined by the retained PCs. As a result of this procedure, the weather conditions at each grid point are described by smaller number of variables, which are orthogonal to each other.

Next, to group together grid points with similar weather variability, a two-stage clustering procedure consisting of average linkage and K-means clustering algorithms (Davis and Kalkstein 1990) is applied to the data. The average linkage algorithm was used to determine the number of clusters and their initial centers, while the final solution is obtained through application of the K-means clustering procedure. The resulting clusters represent regions that experience similar weather variability.

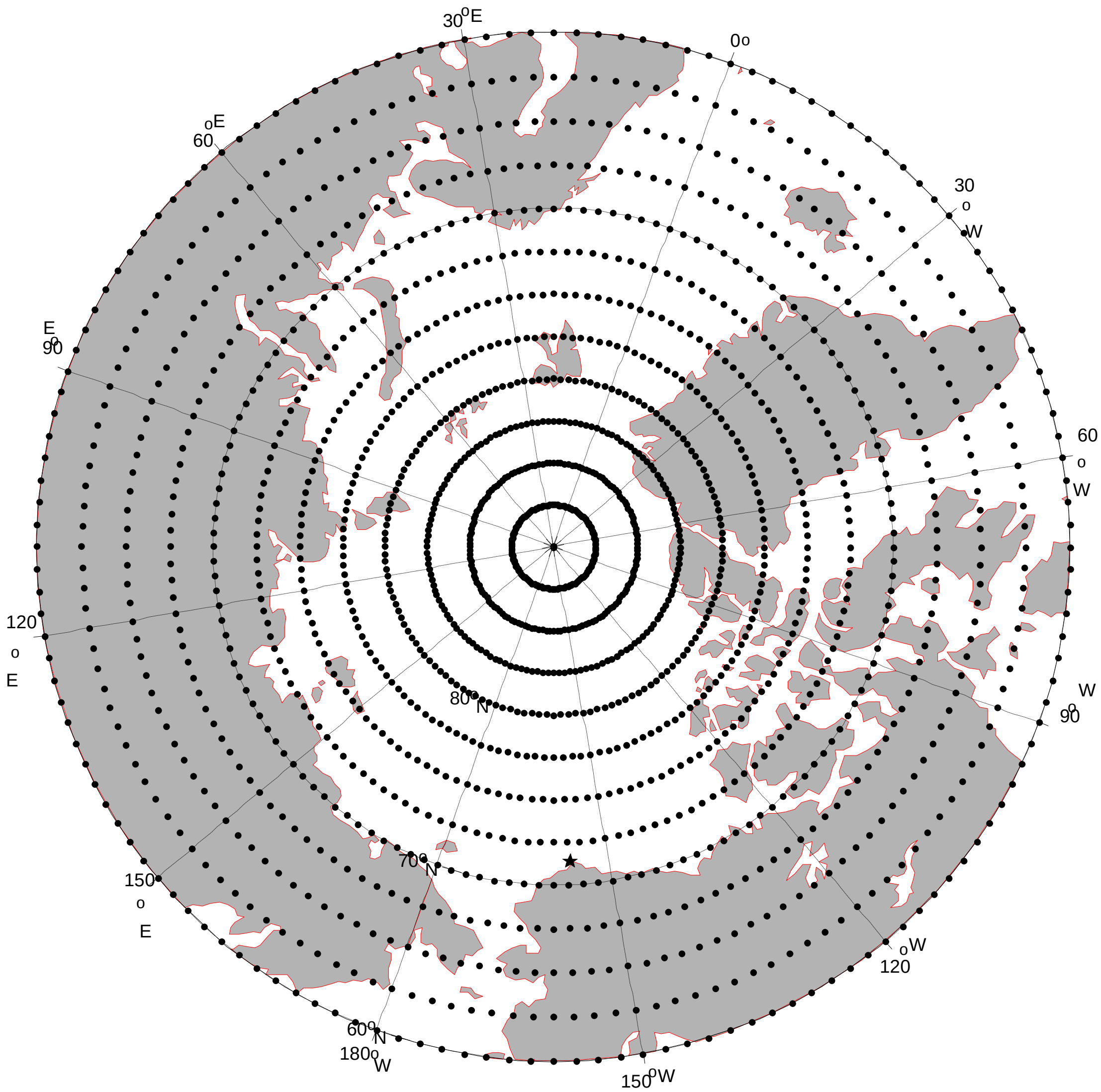

Figure 1.

Results

The input data matrix is arranged so that each column is one of the original variables and each row represents one day at one of the grid points.

$$\begin{pmatrix} p_s, \Phi_{850} & \cdots & |V|_{100} \\ \vdots & \ddots & \vdots \\ p_s, \Phi_{850} & \cdots & |V|_{100} \end{pmatrix}$$

The data matrices for the different grid points are then appended to each other, forming the input matrix of size Ngrids × Ndays rows by Nvars columns, where Ngrids is the number of the grid points; Ndays – the number of days; and Nvars – the number of the original variables.

Then 44 eigenvalue-eigenvector pairs are extracted from the correlation matrix, calculated from the input data matrix. The number of PCs that should be retained is determined using the Scree test (Cattel 1966) and N rule (Preisendorfer 1988), both suggesting a five or six component solution. The choice of six PCs is also in accordance with the other often used criteria—a component is retained if its associated eigenvalue is greater than 1. Retained six PCs explain 91% of the variance of the original dataset. The PC scores for each grid point are calculated and then clustered using the two-stage clustering procedure.

The final results for the three seasons are shown in Figures 2 to 4, where the different clusters are represented by different color symbols. Looking at the figures it becomes apparent that answering the question for what region the NSA site is representative is not a trivial task. While during the "summer" season the weather variability at Barrow can be considered as "continental" type, during the "winter" and particularly during the "transitional" season it exhibits completely different behavior.

In the second part of our study we try to relate the cloud fractions over DOE-ARM NSA site at Barrow, Alaska to the different weather regimes that influence this region. In order to define these weather regimes, the same procedure described above is used. The only differences are that u- and v-wind components are used instead of wind speed, one year long period of data was used and the procedure is applied to a single grid point—72.5°N 157.5°W, that is the closest to Barrow grid point. The procedure identified 7 clusters, which in this case group the days with similar weather into the same clusters. Then each of the cloud observation data is assigned to the appropriate cluster. As an illustration of the method, the histograms showing the cloud fraction distributions for the two most clearly expressed cases—"clear-sky" and "cloudy" clusters are shown in Figures 5 and 6.

Conclusions

We need to point out that this study is still not a finished project; instead it is an ongoing process that we hope to finish soon. At this stage however, the following conclusions could be made:

- Weather at Barrow is influenced by a variety of different regimes and we have a procedure to classify each day into a particular weather regime.
- Initial results suggest that cloudiness at Barrow is correlated with weather regimes.
- These results are promising as they suggest that a parameterization scheme that relates large-scale features to cloudiness can be developed.

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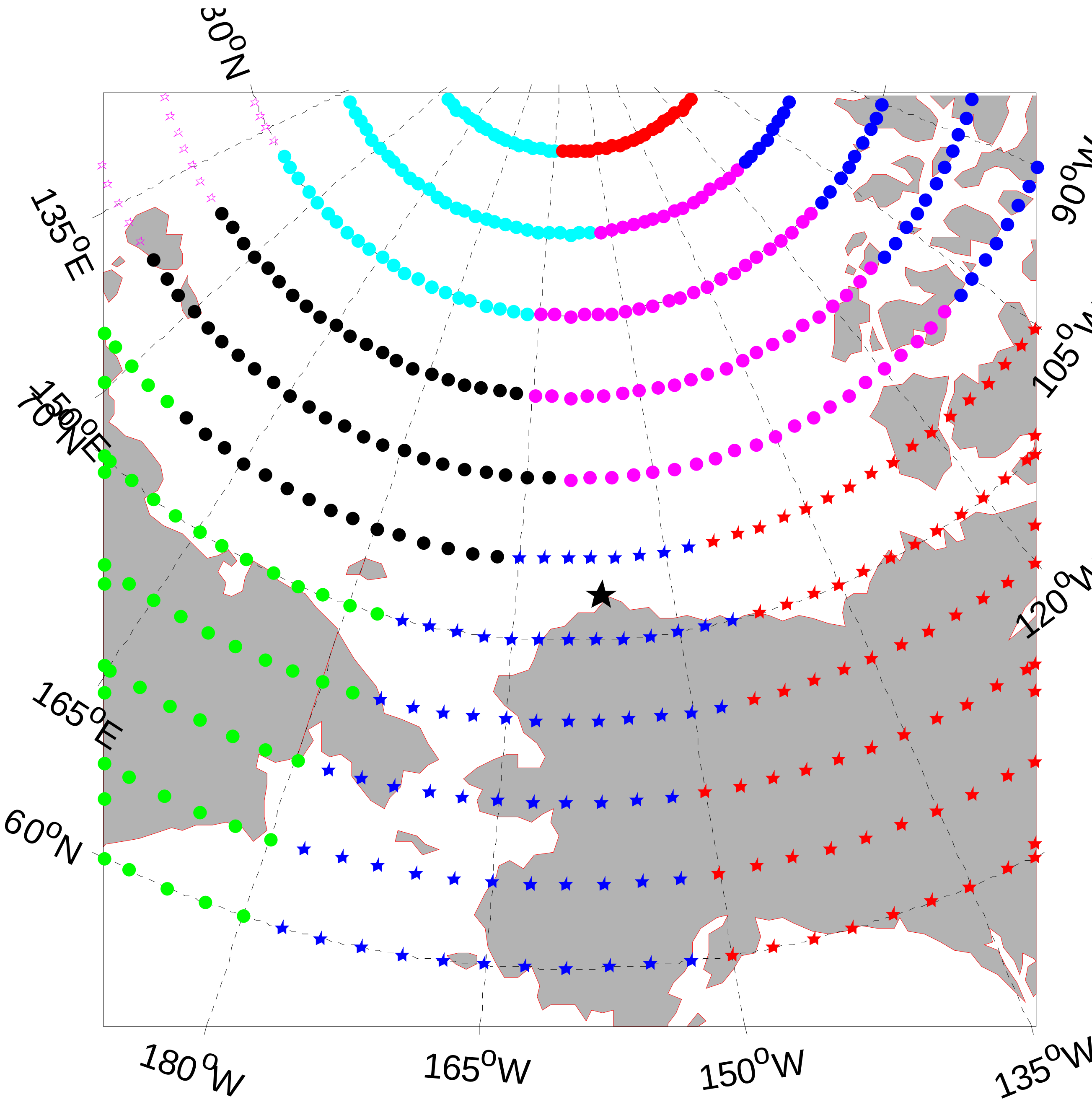
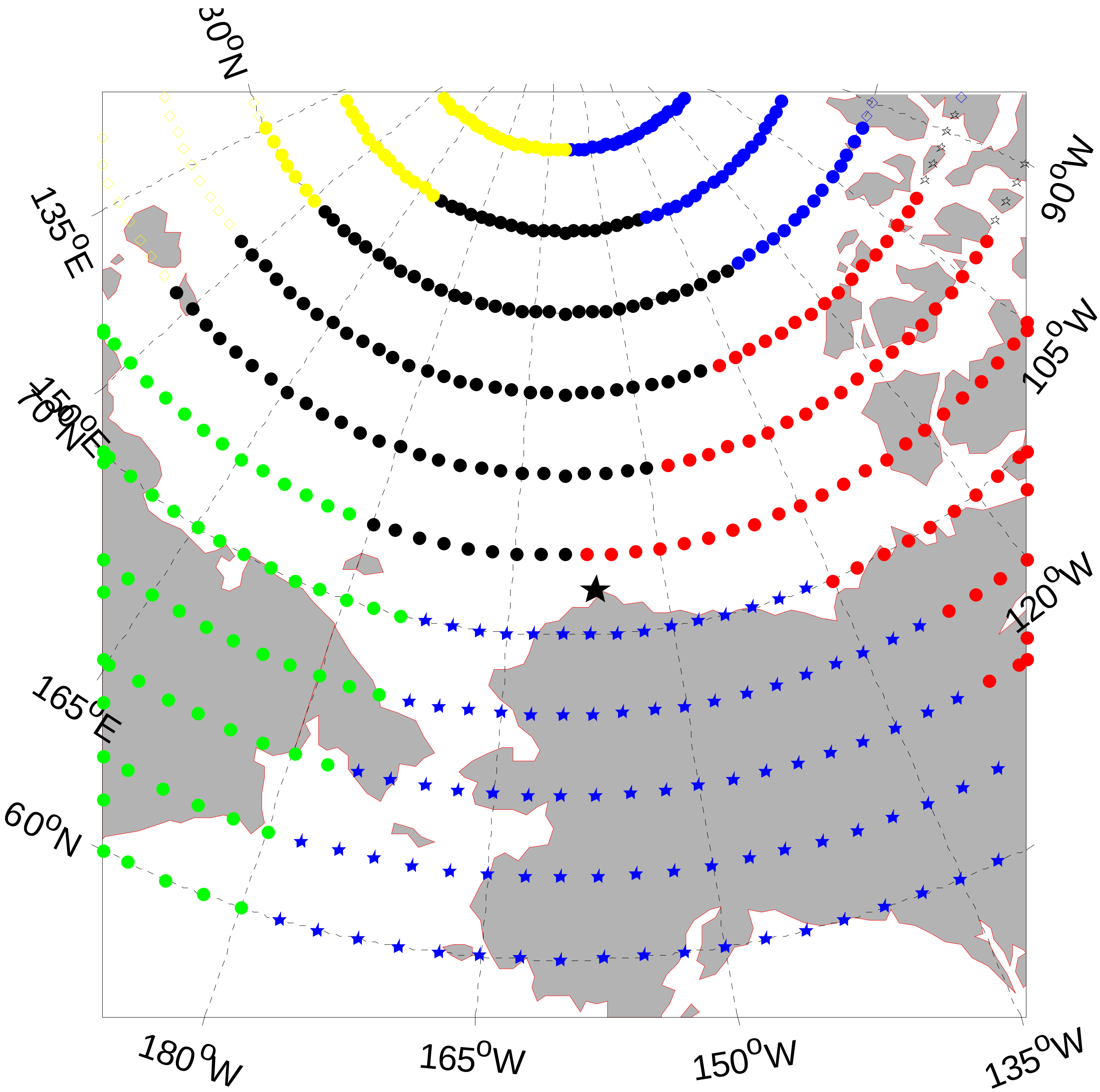


Figure 2.



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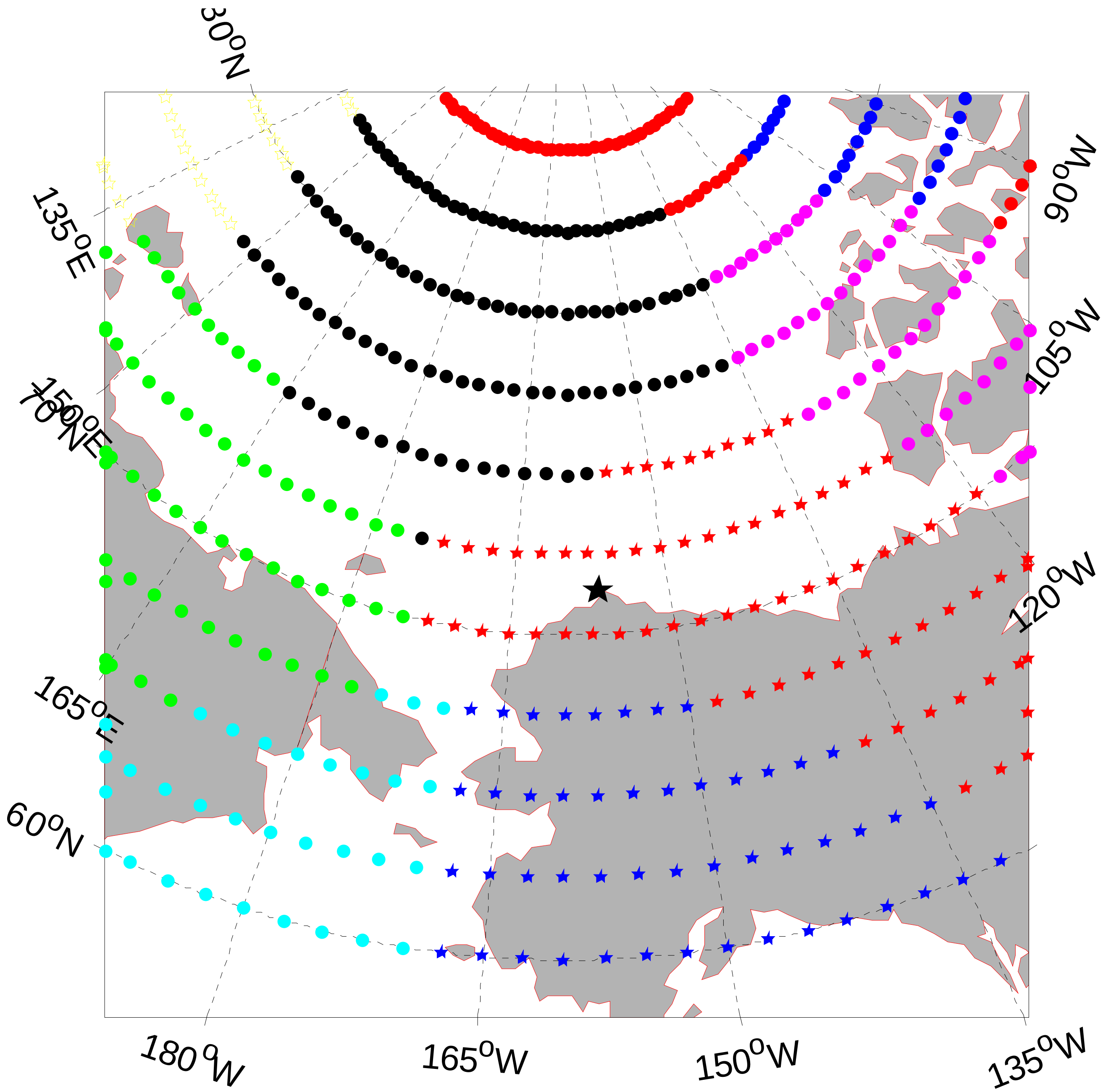

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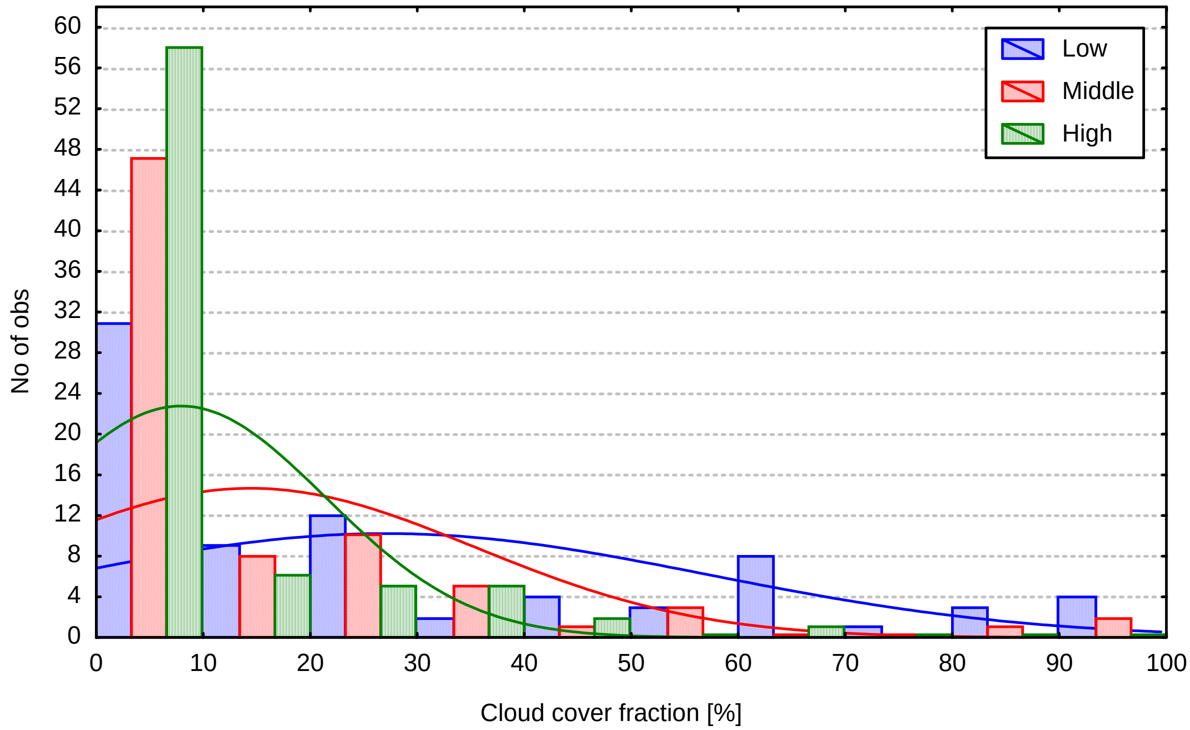

Figure 5.

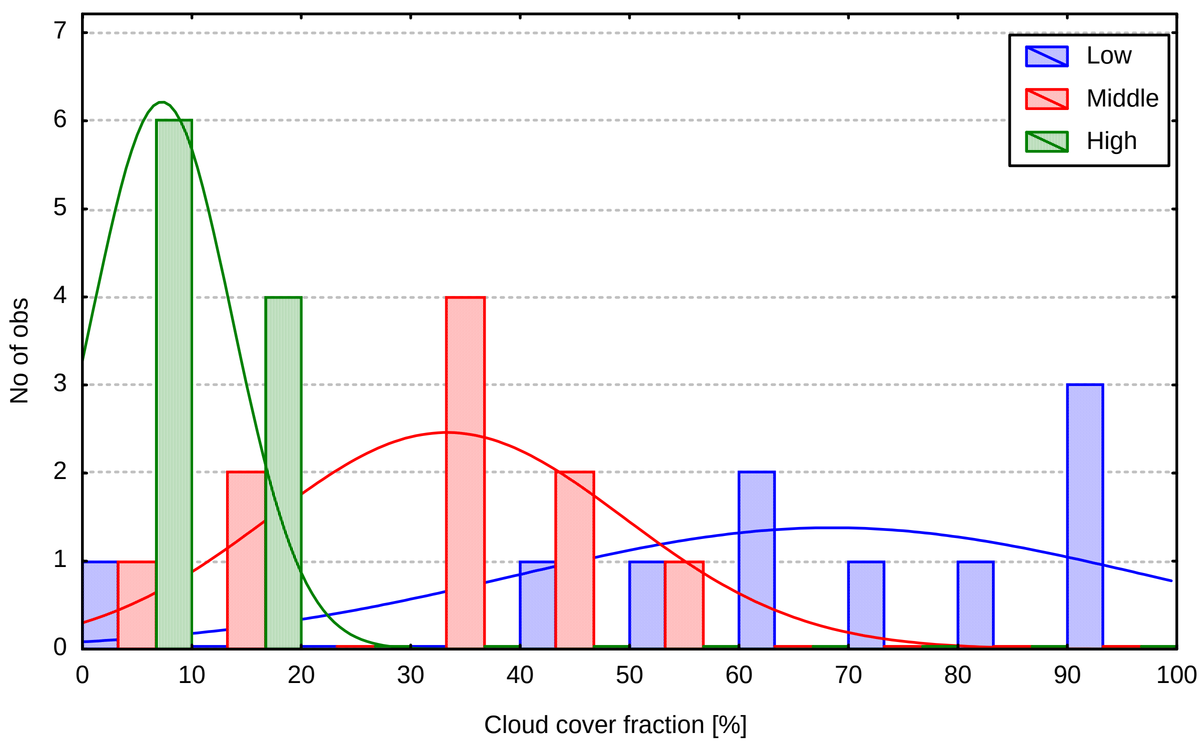

Figure 6.