6.26 SPATIAL AND TEMPORAL CHARACTERISTICS OF SATELLITE-DERIVED CLEAR-SKY ATMOSPHERIC TEMPERATURE INVERSIONS IN THE POLAR REGIONS

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1. INTRODUCTION

Low-level atmospheric temperature inversions are ubiquitous at high latitudes during the polar winter. Temperature inversions in the polar regions may result from radiative cooling, warm air advection over a cooler surface layer, or subsidence. Temperature inversions influence the magnitude of heat and moisture fluxes through openings in the sea ice, the depth of vertical mixing in the boundary layer, cloud formation, aerosol transport, surface wind velocity, and lead formation. A number of recent studies have investigated the characteristics of polar temperature inversions based on radiosonde data (Bradley et al. 1992, 1993, Kahl 1990, Serreze et al. 1992).

In order to gain a more complete understanding of the spatial and temporal characteristics of low-level temperature inversions in the Arctic and Antarctic, an algorithm for detecting and estimating clear-sky inversions using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data was developed (Liu and Key, 2003). However, MODIS does not provide a long enough time series for climatological analyses, so here we investigate the use of the TIROS-N Operational Vertical Sounder (TOVS), which provides continuous measurements of the earth's surface and atmosphere since 1978. The application of the empirical method developed for MODIS to TOVS data for the period 1980-1996 provides an opportunity to study trends in low-level temperature inversion characteristics.

2. DATA

The radiosonde data in this study are from Historical Arctic Rawinsonde Archive (HARA), which comprises over 1.5 million vertical soundings of temperature, pressure, humidity and wind, representing all available rawinsonde ascents from Arctic land stations north of 65°N from the beginning of record through mid 1996. Soundings from the Russian North Pole series of drifting stations are also included. All the soundings are processed with quality control using the method described by Serreze et al (1992). In this study, the inversion base is assumed to be at surface, and the inversion top is the height with the maximum temperature lower than 700 hPa. The inversion strength is defined as the difference between the surface temperature and the temperature at the inversion top.

TOVS brightness temperatures (BT) at 7.3 μm, 11 μm and 13.3 μm are used in the temperature inversion retrieval. NOAA-6 (1979-1982), NOAA-7 (1983-1984), NOAA-9 (1985-1986), NOAA-10 (1987-1991), and NOAA-12 (1992-1996) data are used. The spatial resolution of the TOVS data is 100 x 100 km over the Arctic region. Cloud detection tests described by Chedin et al. (1985) and Francis (1994) are applied to distinguish clear from cloudy scenes.

The inversion strength algorithm is based on radiosone-satellite data matched pairs. TOVS pixels closest in time to clear sky radiosonde observations are used.

3. THEORETICAL BASIS AND METHOD

The peaks of the weighting functions for the 7.2, 11, 13.3 μm channels are approximately 800 hPa, the surface, and 950 hPa, respectively, as shown in Figure 1. The brightness temperature of the window channel at 11 μm, BT_{11}, will be most sensitive to the temperature of the surface. The 7.2 μm water vapor channel brightness temperature, $BT_{7.2}$, is most sensitive to temperatures near 800 hPa. The magnitude of the brightness temperature difference (BTD) between the 7.2 μm and 11 μm channels, $BT_{7.2}$-BT_{11}, will therefore be proportional to the strength of temperature difference between the 800 hPa layer and the surface, which is related to the inversion strength. This is also true for the 13.3 μm carbon dioxide channel. The inversion strength can be estimated by the linear combination of $BT_{7.2}$, BT_{11} and $BT_{13.3}$, with the coefficients determined by linear regression.

Inter-satellite biases result from orbital drift and differences in spectral response functions for each satellite. TOVS inter-satellite calibration is essential for climate change studies. In this paper, in situ sounding data are used to improve the calibration of the different TOVS sensors staring with NOAA-6 through NOAA-12, where one or more sets of regression coefficients in the temperature inversion retrieval algorithm are determined for each satellite. The linear relationships between inversion strength and $BT_{7.2}$-BT_{11} for each NOAA satellite are shown in Figure 2.

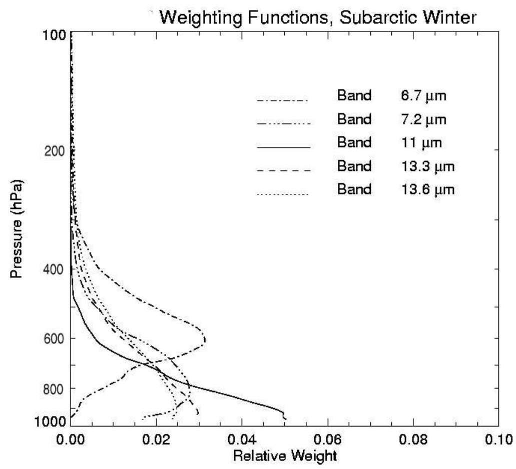

Fig. 1. Weighting function for 6.7 µm, 7.2 µm, 11 µm, 13.3 µm, and 13.6 µm channels using a subarctic winter standard atmosphere profile.

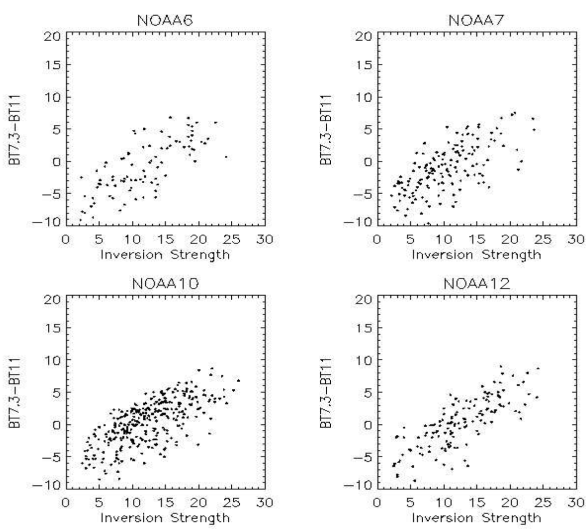

Fig. 2. Relationship between inversion strength and $BT_{7.2}$-BT_{11} for NOAA-6, -7, -10, and -12.

The initial TOVS clear-sky BTs, determined by TOVS cloud detection tests, are converted to inversion strength using the retrieval equations, then the inversion strength is mapped to the 100 km Equal-Area Scalable Earth Grid (EASE-Grid) based on longitude and latitude of the original data. For every ten days, a map of clear-sky temperature inversion is created.

4. RESULTS

Figure 3 gives the spatial distribution of seasonal mean temperature inversion strength averaged over the period 1980-1996 for winter (DJF), spring (MMA), summer (JJA) and autumn (SON). The mean seasonal value is the average of the available ten-day composite for that season. Temperature inversion strength has the largest mean value in winter, with greater inversion strength over the pack ice and near several river valleys in the Euroasian Arctic region. The inversion strength in the coastal areas is relatively small in winter. In the summer, the mean inversion strength is 0 except over Greenland. The inversion strength over land is greater in autumn than in spring. The two seasons have similar values over pack ice. Coastal areas have stronger inversions in spring than in autumn.

The annual cycle of inversion strength is shown in Figure 4 based on the monthly data. The inversion strength is

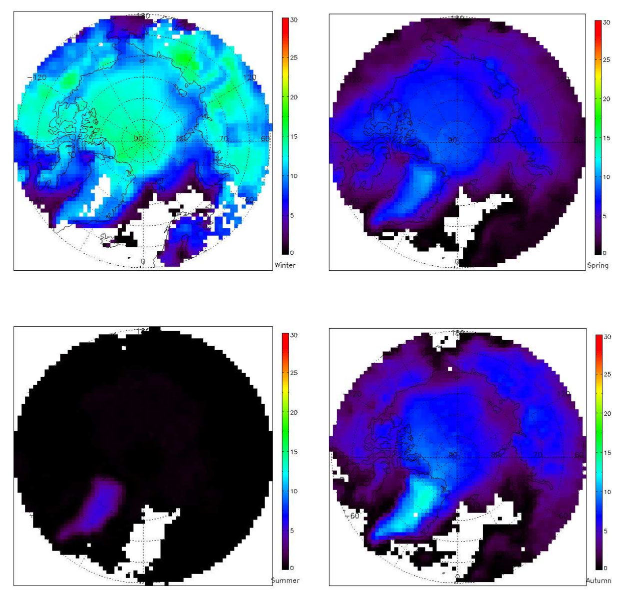

Fig. 3. Spatial distribution of mean clear-sky inversion strength (degrees C) in winter, spring, summer and autumn (clockwise from upper left) averaged over 1980-1996. The white areas are persistently cloudy.

greatest in winter with the mean around 12^{o}C, with the maximum in February. Inversion strength has a similar value in spring and autumn, and is weakest in the summer time. The inversion strength over Arctic Ocean has larger value than over Arctic land.

The 16-year times series of temperature inversion strength in winter and spring over the period 1980 to 1996 are shown in Figure 5. In spring, the inversion strength decreased from 1980 through 1990, but began to increase around 1990. The trend over the ocean is more apparent than over the land. In winter, the inversion strength decreased since 1980, and there is no apparent change over land.

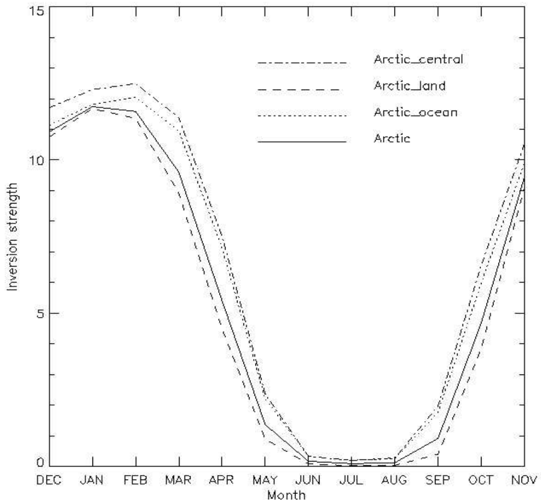

Fig. 4. Annual cycle of clear-sky inversion strength for four Arctic regions averaged over the period 1980-1996.

5. SUMMARY

The 16-year time series of clear-sky temperature inversion strength in Arctic is derived from TOVS data. Using at least one retrieval equation for each NOAA satellite alleviates the inter-satellite calibration problem. The annual cycle of the inversion strength shows the largest inversion strength in winter and similar inversion strength magnitudes in spring and autumn. The inversion strength over ocean decreased from 1980 to 1990, and increased since 1990 in springtime. In winter, the inversion strength over ocean decreased from 1980 to 1996.

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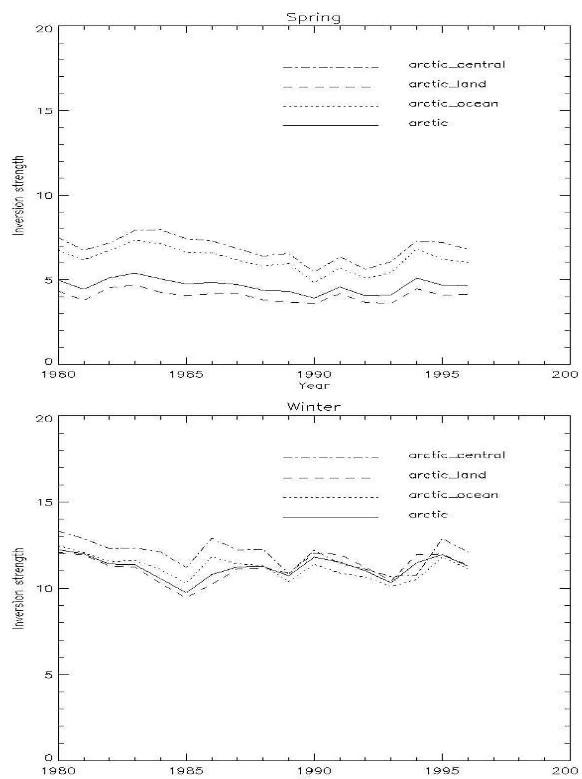

Fig. 5. 16-year time series of inversion strength in winter and spring over the period 1980 to 1996.