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ARCTIC SURFACE TEMPERATURE: A COMPARISON AMONG SATELLITE RETRIEVALS AND CONVENTIONAL OBSERVATIONS

Yonghua Chen*, James Miller, Jennifer Francis
Institute of Marine and Coastal Sciences, Rutgers University, New Jersey

1. INTRODUCTION

The study of the Arctic region has been at the forefront of climate research. Global circulation model (GCM) simulations suggest that global warming may be detected in the Arctic region because any change in the climate would be the enhanced owing to powerful feedback mechanism, operating in snow- and sea-ice-covered areas. The snow/ice-albedo feedback (Curry, et al. 1996) is an important positive feedback mechanism which responds to and enhances the effects of increased greenhouse gas concentrations. Surface temperature is one of the most important variables participating in these feedbacks, as it affects the surface energy balance through longwave radiation and turbulent fluxes between the ocean and the atmosphere (Maykut, 1982). Thus we need accurate surface temperature observations in the Arctic to validate numerical models and to improve our understanding and prediction of the effects of any climate change in the Arctic.

Existing global surface temperature data sets have poor spatial representation over polar regions (Peterson et al., 2000). However, several long-term surface temperature data sets have been generated for the Arctic region (Martin et al., 1997; Scott et al., 1999; Rigor et al., 2000), which include both satellite and conventional observations. Because it is difficult and expensive to obtain in situ observations in the Arctic, satellites provide the only practical source of basin-wide information. However, it is difficult to obtain surface temperature from satellites under polar conditions owing to problems such as cloud detection, view angle effects, atmospheric temperature inversions, and large surface inhomogeneities such as leads mixed with snow and ice. Thus, it is important to assess how well the satellite-derived temperatures agree with conventional observations. Earlier attempts to retrieve surface temperature over the Arctic used the infrared channel of the Advanced Very High Resolution Radiometer (AVHRR), but it was limited to the clear-sky condition (Key et al., 1992; Lindsay et al., 1994; Yu et al., 1995). Recently another set of satellite retrievals and surface observations based on the measurements from the NASA/NOAA TIROS Operational Vertical Sounder (TOVS) Polar Pathfinder (Path-P) data set (Scott et al., 1999, Schweiger et al., 2000) was created. The International Arctic Buoy Programme/Polar Exchange at the Sea Surface (IABP/POLES) data set (Rigor et al., 2000) contains surface temperatures assembled from a variety of surface-based measurements. The purpose of this study is to compare TOVS/Path-p satellite retrievals with the IABP/POLES surface temperatures. Additional data sets are used to help understand the details of the comparisons between these two data sets.

2. SURFACE TEMPERATURE DATA SET

In this study, we use four data sets of surface temperature in the Arctic (Table 1). TOVS/Path-P is a satellite-derived data set using 3I method (Chédin et al. 1985; Francis, 1994; Scott et al., 1999). IABP/POLES is a collection of surface observations combining data from drifting stations, buoys and meteorological stations using optimal interpolation. Those two data sets are the primary data sources used to reveal discrepancies between satellite retrievals and in-situ observations. The North Pole Drifting Station Data Set (NPDS) over the Arctic Ocean and Comprehensive Ocean-Atmosphere Data Set (COADS) over GIN Sea provide additional information for interpreting the differences. Surface temperatures used in this study include surface skin temperatures retrieved from satellite measurements, surface 2-m air temperatures observed at stations drifting on the pack ice, surface temperatures measured by buoys, and surface temperatures of the lowest level of radiosonde temperature profiles at a height of approximately 9 meters. Thus, comparisons among these data will introduce errors caused by inherent differences in the measurements themselves.

Table 1: **Observations of Surface Temperature in the Arctic**

Names	**TOVS/ PATH-P**	**IABP/ POLES**	**NPDS**	**COADS**
Source	Rutgers Univ. & Univ. of Washington	Univ. of Washington	NSIDC Data Center	NSIDC Data Center
Temporal Coverage	1979.7 - 1996	1979 - 1997	1983.7 - 1990.7	1978 - 1995
Spatial Coverage	60N-90N	Using 60N-90N	along drifting station track	along ship track over GIN Sea
Resolution	(100 km)^2	(100km)^2	points	points
Format	HDF	ASCII	ASCII	ASCII

TOVS/Path-P and IABP/POLES contain gridded surface temperature given at the center of each grid box. The other data sets are point measurements at different locations. Thus the central points of grid boxes

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**Corresponding author address*: Yonghua Chen, Institute of Marine and Coastal Sciences, 71 Dudley Rd., Rutgers University, New Brunswick, NJ 08901-8521; email: chen@imcs.rutgers.edu.

and the points where the observations are made are not the same among the different data sets. The spatial resolution of TOVS Path-P and IABP/POLES is about (100 km)^2 for both. However, the TOVS/Path-P retrieval algorithm averages HIRS and MSU measurements contained in a (100 km)^2 equal area grid box, while the IABP/POLES values, which are averaged over the (100 km)^2 rectangular grid, are computed by using optimal interpolation. To compare these two data sets, the central grid points are matched by finding the closest IABP/POLES point to each TOVS/Path-P point. Comparisons between TOVS/Path-P or IABP/POLES grid-box averages to point observations from NPDS and COADS are done by finding the nearest central grid box location from TOVS/Path-P or IABP/POLES to the point where in-situ observations are made. Owing to missing data at some TOVS grid points, if there are too few collocated points during one specific month, the distance-weighted average value is used at those points. This means to find all the points within certain range, such as 100 km, and we take the average among valid points using a weighting coefficient according to the distance away from the reference points. In this study, we focus our analyses over the ocean area in the Arctic region. We use a land/ocean mask to exclude land areas.

3. RESULTS

3.1. Comparison: TOVS Path-P to IABP/POLES:

In this section, we compare the satellite-derived surface skin temperature from TOVS/Path-P with the IABP/POLES 2-m air temperatures over ocean. We will use the other data sets described in section 2 to provide additional information.

Figure 1 shows the January and July differences between TOVS/Path-P and IABP/POLES surface temperatures, averaged over the decade of the 1980s. It shows that TOVS/Path-P is colder than IABP/POLES throughout the Arctic Ocean in January. There are two regions where TOVS/Path-P is much colder (4 to 6 K lower) than IABP/POLES. One is between the North Pole and Greenland, and the other is over the Canadian Basin. These cold regions appear in the 1990s (not shown) too, but they are displaced somewhat from their location in the 1980s. TOVS/Path-P is much warmer (> 4 K) over the GIN Sea in the 1980s and 1990s. In July, TOVS/Path-P is colder than IABP/POLES over the Arctic Ocean both in the 1980s and 1990s (not shown). North of 85°N TOVS Path-P is 4 to 6 K colder than IABP/POLES and with extremes more than 6 K colder. TOVS Path-P is warmer over the GIN Sea, but the difference is smaller than that in winter.

Comparison of the decadal differences and of specific years indicates that there is an apparent systematic discrepancy between TOVS Path-P and IABP/POLES. Additional analyses will focus on two areas where large differences occur in January and July: the GIN Sea where TOVS Path-P is always warmer than IABP/POLES; the Central Arctic Ocean where TOVS Path-P is always colder than IABP/POLES. To further investigate causes for these differences, we use additional sources of surface observations (NPDS and COADS).

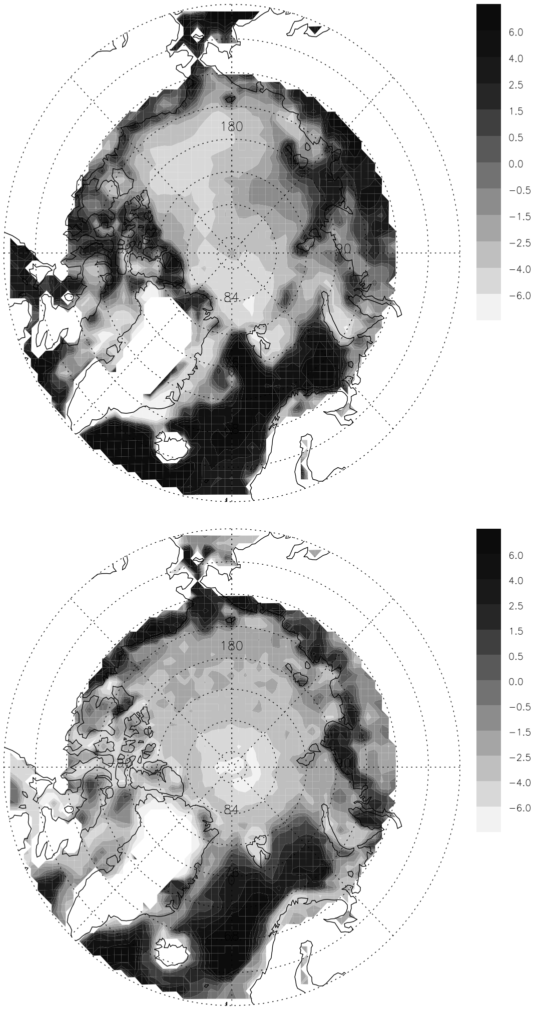

Figure 1 Temperature Difference Distribution of TOVS/Path-P - IABP/POLES in Jan. and Jul. during 1980s

3.2 Comparison using additional data sets

3.2.1 Central Arctic: NPDS

Point measurements from drifting stations 26,28 and 31 between 1981-1990 are used in this study. The trajectories of these three stations crossed through the North Pole in January and July from 1983 to 1990. In January, the three sets of observations show similar variability. The biases between each two sets are pretty small, but the RMSD is large (Table 2). The TOVS Path-P temperatures are generally colder than the surface-based data except in 1987 when TOVS Path-P is much warmer (> 10 K) on several days. In July, TOVS Path-P values are much lower (-3 K on average) than the others. On some days the difference between TOVS Path-P and NPDS is as large as 15 K. In summary, the comparison between TOVS Path-P and NPDS in the central Arctic Ocean is much better in January than that in July. In summer the surface temperature is constrained by the melting point of sea ice and variability is very small, while TOVS Path-P temperatures vary dramatically day-to-day and some values are below -10 ˚C, which indicates that there are apparent problems in retrieving surface skin temperature from satellite in July.

Table 2: Bias and RMSD for Comparison over Central Arctic

ΔT	Bias (Jan.)	RMSD (Jan.)	Bias (Jul.)	RMSD (Jul.)
TOVS/Path-P - IABP/POLE	0.263	7.184	-3.024	3.465
TOVS/Path-p - NPDS	-0.407	6.604	-2.832	3.500
IABP/POLES - NPDS	0.699	3.080	-0.250	0.736

3.2.2 GIN Sea: COADS

The comparison between TOVS Path-P and COADS, IABP/POLES and COADS, TOVS Path-P and IABP/POLES in Jan. 1988 (Fig. 2) over the GIN Sea show that TOVS Path-P is generally warmer than ship observations, and that IABP/POLES temperatures are lower than ship observations. Thus the differences between TOVS Path-P and IABP/POLES (T-P) are large and positive over this area, which explains the pattern seen in Figure 1. In July, the situation is similar. The temperature distribution of IABP/POLES points falls into two belts: most points are near 2 ˚C which is about 5 to 10 K colder than collocated ship reports, and there is a group of points near to or warmer than both TOVS Path-P and COADS. In general, most of the IABP/POLES points are much colder than COADS and TOVS Path-P points.

4. DISCUSSION

Probable reasons for the differences between data sets

1. As mentioned in section 2, different quantities are measured in different data sets, which introduces inherent errors when comparing those variables. From TOVS Path-P we get a surface skin temperature based on long-wave surface emission, while IABP/POLES contains the in-situ 2-meter air temperature. The near-surface temperature inversion existing in the Arctic Ocean may also cause difference between skin temperature and that at 2 or 10 meters. However, previous studies showed that differences due to the inversion is generally less than 2 K (Yu, et al., 1995) in January. AVHRR retrievals for clear sky are more accurate (Key, et al. 1992, 1994; Linday, et al., 1994; Yu, et al, 1995). Because drifting stations are on the thick ice, the station observations may be biased toward the coldest temperatures. Buoys sensors may have problems with solar contamination during the warm season and insulation by snow cover during the cold season.
2. Observations are not made at exactly the same time and location. Spatial and temporal variability of surface temperature fields would introduce errors into the comparison. The comparison of surface point observations with (100 km)2 averages also may cause errors especially when ice and open water exist in the same grid box or during period of rapid meteorological changes (e.g., fronts, clear to cloudy etc.). The different locations of the TOVS Path-P and IABP/POLES center grid points along coastal area may be a reason for the observed differences there. IABP/POLES uses data from fixed land stations in their interpolation scheme.
3. Clouds may cause significant errors in the TOVS Path-P temperature. Negative differences between TOVS Path-P and other surface temperatures are much larger in July when cloud fraction are higher than in January, when there is less water vapor in the atmosphere. From the scatter plot of TOVS Path-P cloud vs. temperature difference, however, the relationship is weak in January. The daily scatter plots of ΔT vs. cloudy fraction in July from drifting station used in this study show a decreasing trend when cloud cover increases (Fig. 3).

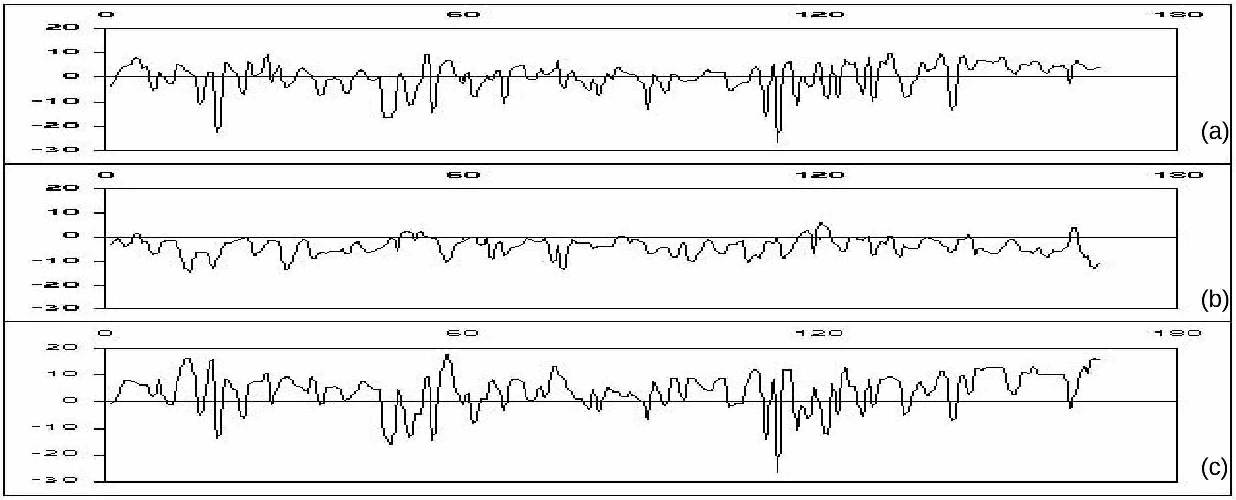

Figure 2. Temperature Difference over GIN Sea in Jan. 1988 (a) TOVS/Path-P - COADS (b) IABP/POLES - COADS (c) TOVS/Path-P - IABP/POLES X-axis is the number of point measurment, Y-axis is ΔT

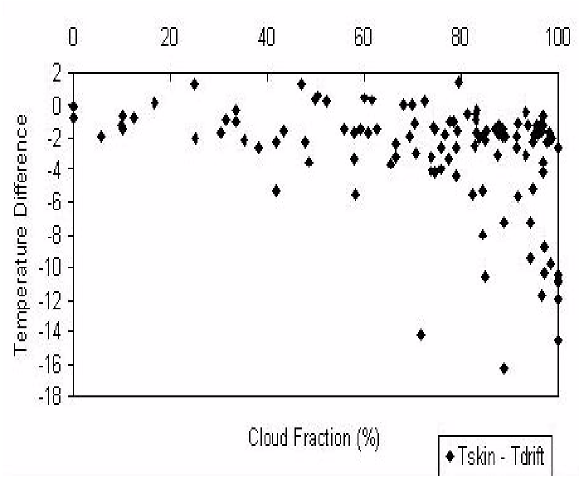

Fig. 3 Temperature Difference Tskin - Tdrift vs. Cloud Fraction (%) in Jul. It shows the difference increases with the increase of cloud coverage.

4. Satellite view angle affects the path length through the atmosphere from sensors to the surface. This may cause the satellite-derived skin temperature to decrease as the view angle increases (Dozier et al., 1982). Effects will be examined by scatter plot (TOVS Path-P Skin T vs. View Angle under different cloud coverage). Near north pole the average view angle in the TOVS Path-P data set approaches the maximum value of 58 degrees. The daily scatter plots and linear fit in July, 1986 show a decreasing trend when view angle increases (not shown). Study by Warren (1998) indicates that emissivity of snow decreases with increasing view angle too.

5. The limitations of each data set also cause some of the differences among them. Comparisons between IABP/POLES and COADS over the GIN Sea show a two-belt distribution of IABP/POLES data, which indicates the possible limitation of interpolation. Also, the interpolation scheme in IABP/POLES appears to reduce its variability compared with ship measurements. TOVS Path-P is a satellite-derived data set, thus retrievals using longwave radiations will be affected if factors such as clouds, water vapor, and surface emissivity have not been accounted for properly.

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