Seasonal and Interannual Temperature Variations in Nares Strait, North-West Greenland

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1. Introduction

Greenland's ice-sheet is a prominent feature of the global climate system. Its topographic relief influences global-scale atmospheric circulation [*Woollings*, 2010] while its discharge of freshwater in the form of meltwater [*Hanna et al.*, 2008], icebergs [*Broecker*, 1994], and ice islands [*Johnson et al.*, 2011] all potentially impact the global meridional overturning circulation in the ocean and sealevel rise. Upper bounds of global sealevel rise caused by a diminishing Greenland ice-sheet were initially estimated to be 1-2 m by 2100 [*Pfeffer et al.*, 2008], but more systematic and comprehensive recent analyses by *Moon et al.* [2012] suggest a more modest impact of less than 0.1 m global sealevel rise by 2010 due to Greenland's retreating tidewater glaciers.

Both ocean and atmosphere also impact the ice-sheet around its margins via melting of tidewater glaciers from the ocean below [*Rignot and Steffen*, 2008; *Holland et al.*, 2008] and the atmosphere above [*Mote*, 2007; *Mernild et al.*, 2011]. Satellite observations document change of retreating glaciers [*Moon et al.*, 2012] that is most profound in the southern part of Greenland [*Joughin et al.*, 2010], but these change appear to be spreading towards the north-west of Greenland [*Khan et al.*, 2010] which is the focus of the this study.

Northern Greenland separates two pathways of atmospheric and oceanic exchange between the Arctic and North-Atlantic Oceans. To the east lies Fram Strait, a 500 km wide and 3000 m deep opening between Greenland and Spitsbergen while to the west lies Nares Strait, a 40 km wide and 300 m deep opening between Greenland and the Canadian Archipelago. While these geographic scales may suggest that most exchange of water and ice takes place via the deeper and wider Fram Strait, dynamical constraints involving ocean stratification and the earth's rotation imply that either pathway is wide and deep enough to accommodate similar exchange via semi-geostrophic boundary currents such as the East Greenland [*Sutherland and Pickart*, 2008; *Sutherland et al.*, 2009] and Baffin Island [*LeBlond*, 1980; *Tang et al.*, 2004; *Smith*, 1931] Currents advecting cold and fresh water as well as ice and icebergs southward along the western margins of the Greenland Sea to the east and Baffin Bay to the west of Greenland, respectively. The generally cyclonic ocean circulation on both sides of Greenland suggests large spatial correlation scales along- but not necessarily across topographic features [*Chapman and Beardsley*, 1989; *Greene et al.*, 2008] such as shelves and continental slopes.

Within this context we ask if it is possible to detect and identify temperature changes within the the atmosphere-ice-ocean system within Nares Strait, a narrowly focused region that facilitates the generally southward exchange of air [*Samelson and Babour*, 2008], ice [*Kwok et al.*, 2010], and water [*Münchow and Melling*, 2008]. For this purpose we will use and analyze observational data from an incomplete network of surface air stations, thermal satellite remote sensing, and a limited ocean mooring array.

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2. Data

The National Climatic Data Center distributes daily surface air station data and Table-1 lists pertinent details of all records from northern Greenland longer than 10 years at elevations less than 100 meters. Records contain substantial gaps in time from days to decades. Addressing the gappy data, we construct an annual cycle by averaging all available data for a given year day without any corrections or data interpolation. Figure 1 shows this annual cycle along with the number of years that a record is available for a particular year day. We interpret each data year as an independent sample or degree of freedom from which to estimate upper and lower limits at 95% confidence. The record at Thule Air Force Base, Greenland is most complete with more than 55 different years available for the 1950-2010 period. In the absence of a better observational record, we define these annual cycles as climatological mean temperatures against which we will compare observations from the 21st century.

The Moderate Resolution Imaging Spectroradiometer (MODIS) flown aboard the Terra satellite provides almost continous measurements of radiation in 36 optical and infrared frequency bands starting in February of 2000 at spatial resolution of 1 km or better at its nadir. The polar orbiting, sun-synchronos satellite provides about 8-12 scenes each day of northern Greenland with a repeat orbit every 16 days. The National Aeronautical and Space Agency (NASA) distributes the raw Level-0 as well the altitude and ephemeris data in near realtime in segments of 5 minutes along the flight path. For each day within the 16-day orbit cycle we select one such 5 minute segment for processing to geolocated Level-1B data in engineering units using open-source, public domain software provided by NASA and the HDF Group.

A major challenge of optical and thermal MODIS data relates to clouds obstructing the view to the surface of the earth. Standard cloud products designed for mid-latitude applications are often of little use at polar latitudes in the presence of ice, snow, and temperature inversions during polar night. Verification and calibration data are often lacking for polar applications, especially polar night. Using prior work by *Ackerman et al.* [2010]; *Frey et al.* [2008]; *Liu et al.* [2004] we implement 5 cloud tests as well as 3 clear-sky tests that use MODIS bands at $3.9\mu, 6.7\mu, 7.2\mu, 11\mu, 12\mu, and 13\mu$ at each pixel. Figure 3 shows our 10-year-long record of daily brightness temperature at a single pixel location of the generally ice-coverd center of Nares Strait near 66.7 W longitude and 80.8 N latitude. Both seasonal and interannual variations are pronounced and will be discussed below.

3. Hydrography

4. Circulation

5. Discussion

5.1. Under-ice watermass structure

6. Conclusions

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Table 1. Surface air stations.

Name	ID	Lon., W	Lat., N	Height, m	Time	Data
Alert	710820	62 17	82 30	66	1950-2005	6514
Alert Climate	713550	62 19	82 30	65	2006-2010	1820
Grise Fjord Airport	719246	82 52	76 25	31	1978-2010	6551
Thule AFB	042020	68 30	76 32	59	1951-2010	20875
Carey Island	042030	73 00	76 38	11	1973-2010	8164
Cape Morris Jesup	043010	33 22	83 38	4	1981-2010	8370
Nord AWS	043120	16 41	81 36	34	1985-2010	7882

Table 2. MODIS Polar Cloud and Clear SkyTests Applied.

Test	Bands	Threshold, K	Temperature, K	Type
1.	6.7μ	-48.5		Day and Night Cloud
2.	$11\mu - 12\mu$	2		Day and Night Cloud
3.	$3.9\mu - 12\mu$	4.5/2.0	235/265	Night Cloud
4a.	$11\mu - 3.9\mu$	-0.6/+0.8	235/265	Night Cloud
4b	$11\mu - 3.9\mu$	-11.5/-4.0	230/245	Day Cloud
5.	$7.2\mu - 11\mu$	+2/-4.5/-17.5/-21.0	220/245/255/265	Night Cloud
6.	$6.7\mu - 11\mu$	10		Night Clear Sky
7.	$13\mu - 11\mu$	3		Night Clear Sky
8.	$7.2\mu - 11\mu$	5		Night Clear Sky

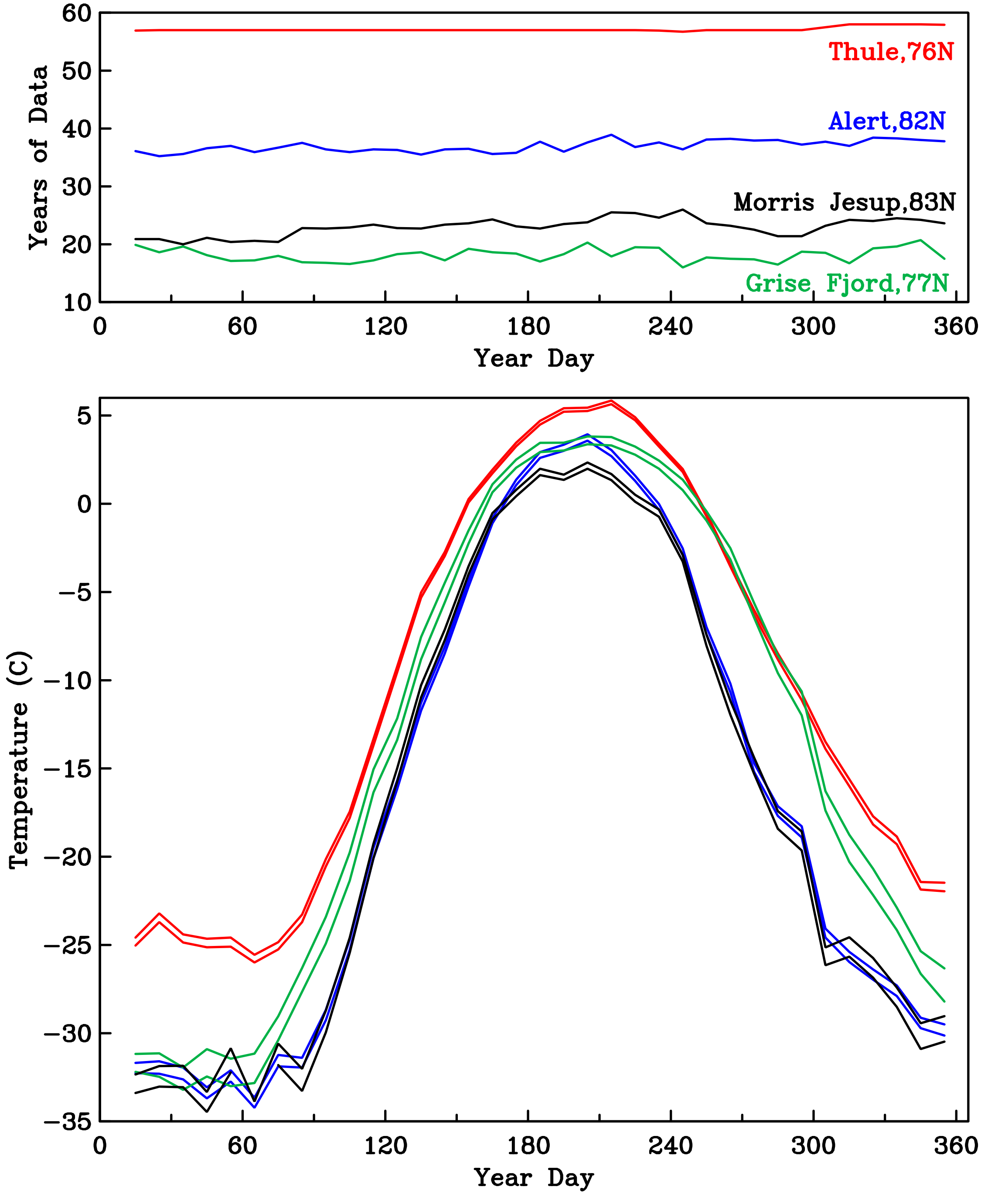

Figure 1. Annual cycle of air temperature (bottom panel) from south to north at Thule (red), Grise Fjord (green), Alert (blue), and Cap Morris Jesup. Data years (top panel) for each year day are degrees of freedom. For each location two temperature curves indicate upper and lower limits of the climatological mean temperature for that day at 95% confidence.

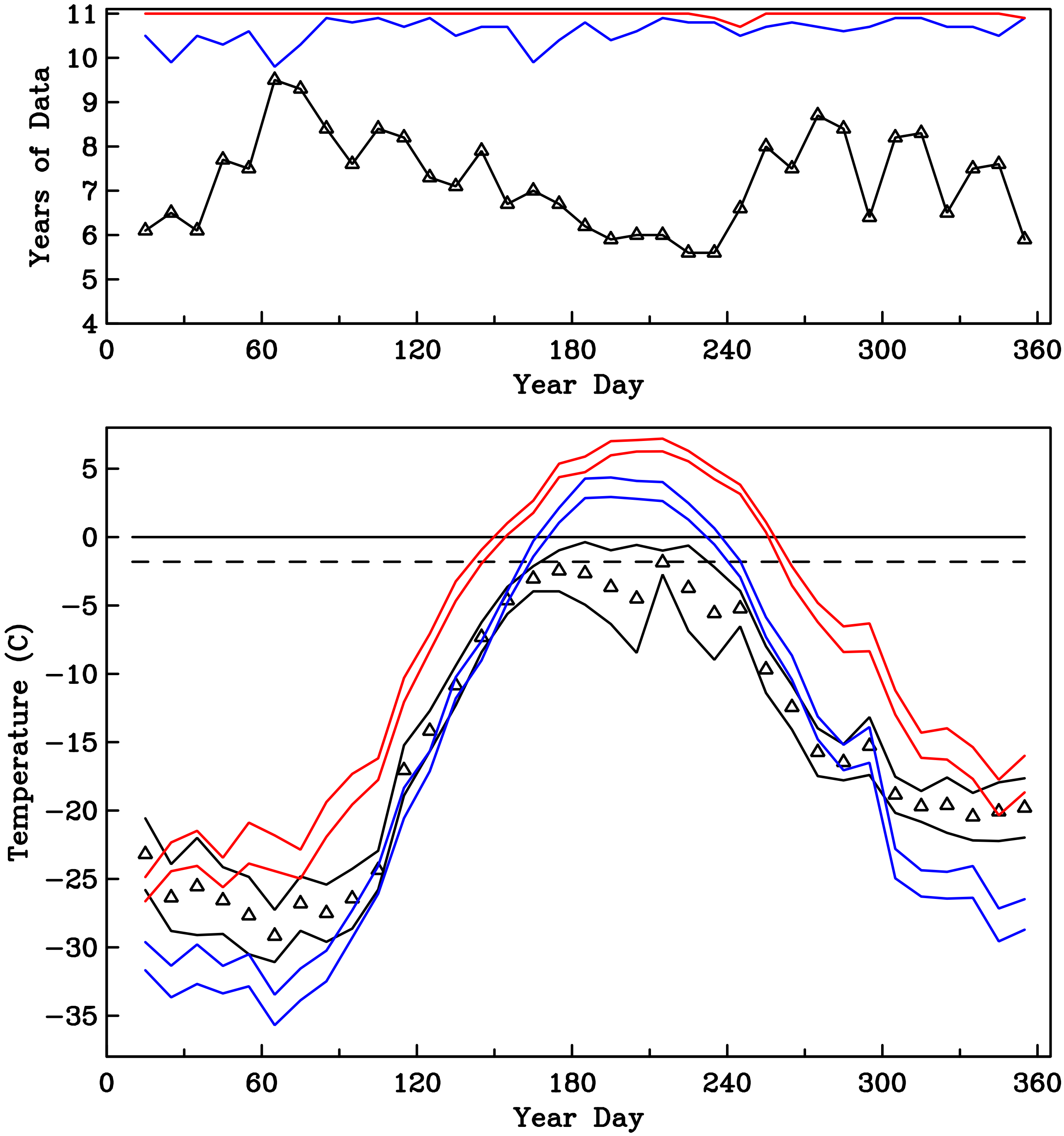

Figure 2. Annual cycle of surface temperature from a single MODIS pixel over generally ice-covered ocean in Nares Strait (black) compared with air temperature at Alert (blue) and Thule (red) for the 2000-10 period. Solid lines indicate upper and lower limits of the mean temperature for that day at 95% confidence. Each year of data is taken as a degree of freedom

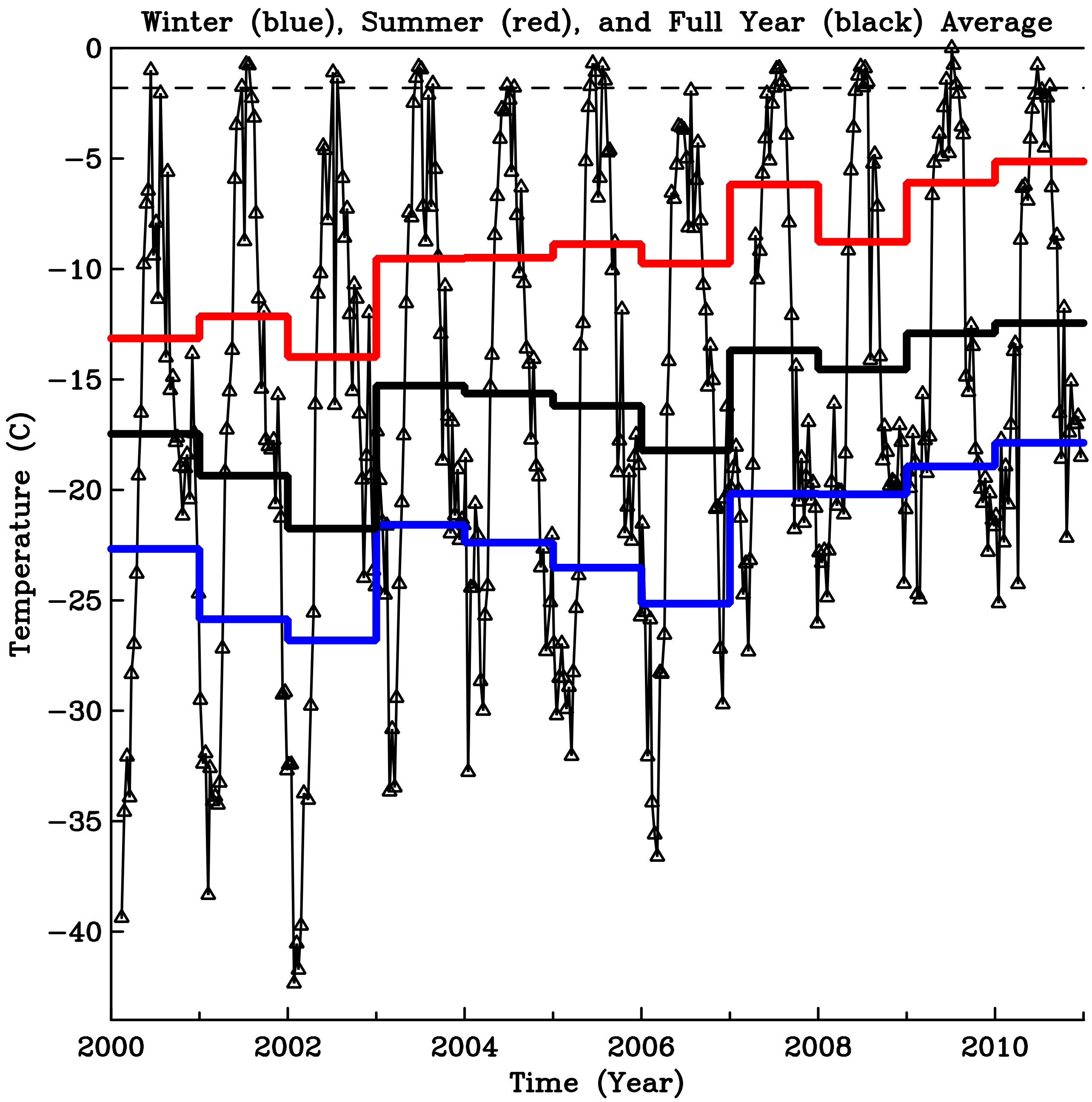

Figure 3. Time series of surface temperature from a single MODIS pixel over generally ice-covered ocean in Nares Strait. Seasonal cycles are indicated by symbols from 10-day averages while lines indicate annual averages for the calendar year (black), summer (red), and winter (blue) seasons..

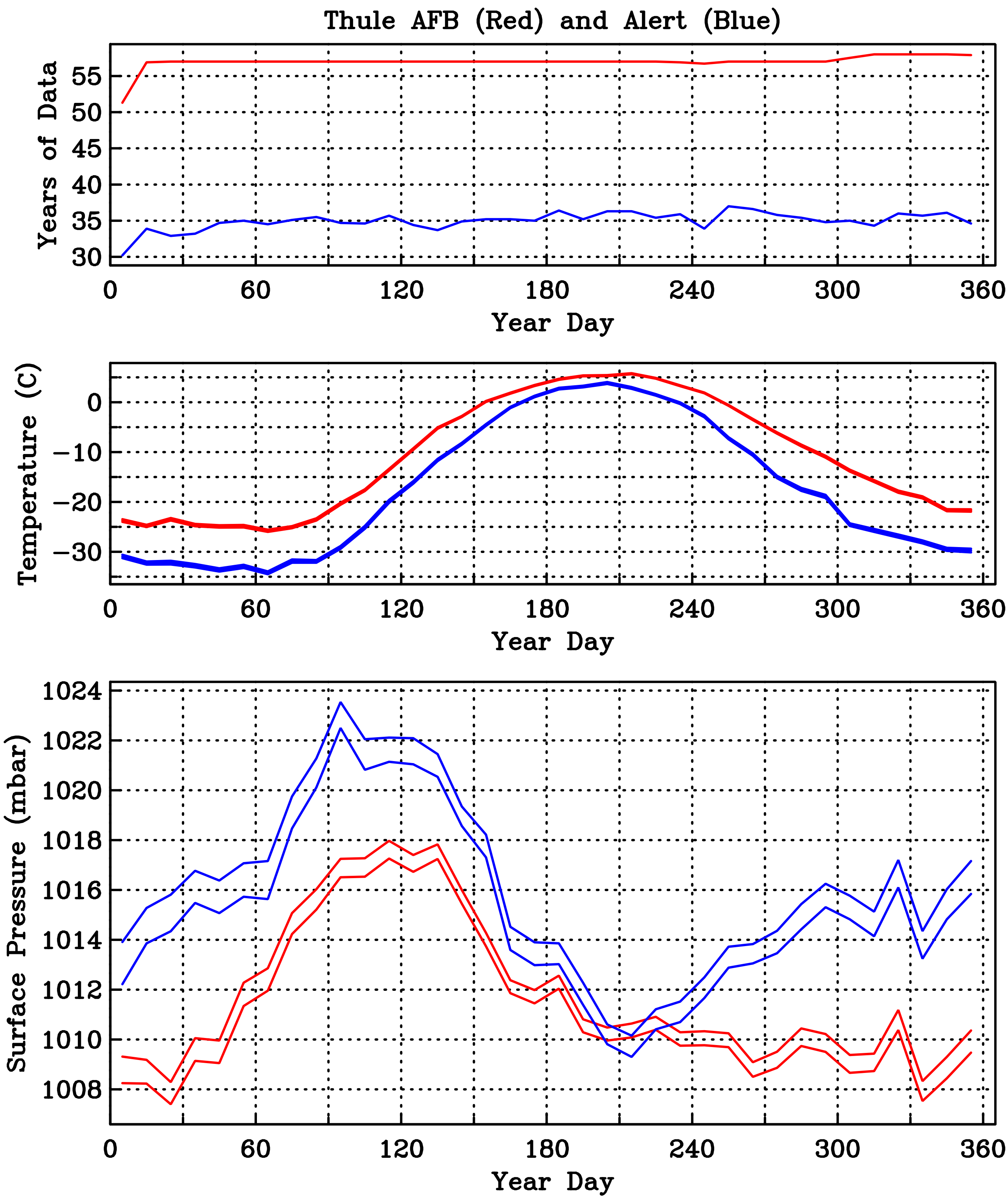

Figure 4. Annual cycle of atmospheric pressure and temperature at Alert (blue) and Thule (red).