# INTERANNUAL VARIABILITY OF ARCTIC RADIATION BALANCE IN JULY

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## 1. INTRODUCTION

As the Earth warms due to $CO_2$ increase and natural variations, the Arctic is the region which is most sensitive to change, as the melting of snow and ice creates a powerful feedback mechanism (Budyko, 1966; Hansen et al., 1981; Manabe et al., 1992). Comiso et al. (2003) used surface temperature data from the Advanced Very High Resolution Radio meter between 1981 and 2001 and found that the rate of warming in the Arctic for the 20-year satellite record was about eight times larger than the 100-year trend of the ground-based surface temperature data, indicating a rapidly increasing warming rate. The trends are predominately positive in spring, summer, and autumn and cause the lengthening in the melt season by 10 to 17 days per decade. The extent of Arctic sea ice and Northern Hemispheric snow has decreased dramatically in the last few decades (Parkinson et al., 1999). Consequently, it is expected that the albedo has decreased and the absorbed solar radiation has increased. This effect will be the greatest in July, when the solar declination is still high and the snow and ice have had sufficient time to melt.

In this paper we examine radiation balance data from the Earth Radiation Budget Experiment (ERBE) for Julys from 1985 to 1988 and from the CERES (Clouds and Earth's Radiant Energy System) from 2000 through 2004. These data provide information about interannual variations of radiation for the four years at the beginning and five years at the end of the two-decade period from 1985 to 2004 as well as the trends. We use the monthly-mean values of absorbed solar radiation, outgoing longwave radiation and net radiation fluxes for the region north of $60^{o}$.

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## 2. DATA SETS

For this study data from the ERBE scanning radiometers aboard the NOAA-9 and –10 operational meteorological spacecraft and the CERES scanning radiometers aboard the Terra and Aqua Earth Observation System satellites were used. The ERBE scanning radiometer aboard the NOAA-9 spacecraft began operating in February 1985 and provided two years of radiation budget data. This spacecraft was in a near-polar orbit with an equatorial crossing time of 1420 hours at ascending node, so that it reached its most northern point at 0820 local time. The ERBE scanning radiometer aboard the NOAA-10 spacecraft began operating in November 1986 and also provided data for two years. This spacecraft was also in near-polar orbit, with an equatorial crossing time of 1930 hours local time and a most northern position at 1330 hours. The measurements were used to compute reflected solar and Earth-emitted longwave fluxes at the "top of the atmosphere" (Smith et al., 1986) and are then spatially averaged on a $2.5^{o}$ equal–angle grid. Monthly-mean fluxes were then computed (Brooks et al., 1986). These monthly-mean fluxes are archived on files denoted S-4 and are available at the Atmospheric Science Data Center (ASDC) at NASA's Langley Research Center.

The Terra satellite was placed into a near-polar orbit in December 1999 and the CERES radiometers began operating in mid-February 2000. The Equator crossing local time of Terra is 2230 hours, so that it passes its northern-most point at 1630 hours. The Aqua satellite was placed into orbit in May 2002 and the CERES radiometers began operating in June 2002. Its equatorial crossing time is 1330 hours, so that its northern-most passage is at 0730 hours local time. Data products from the CERES radiometers are generated using the same methods as for the ERBE data, so as to be compatible. These data products are denoted as ES-8 and are likewise available at the ASDC.

## 3. RESULTS

The net radiation is shown in figure 1 for the region poleward of $60^oN$ for each of the eight Julys. Typically land areas have a net radiation flux of 40 $W\text{-}m^{-2}$ and greater, the Arctic Ocean has a net flux of +/-20 $W\text{-}m^{-2}$ and the plateau of Greenland has a net loss of flux of 80 to 100 $W\text{-}m^{-2}$. Interannual variations are noted for European Russia, far-east Siberia and the Norwegian Sea. Over the total period, there is an increase of net radiation at the North Pole and around the coast of Greenland.

Figure 2 shows the corresponding outgoing longwave radiation (OLR) difference maps. There are variations of +/-20 $W\text{-}m^{-2}$ over the region north of $60^oN$. In 1985 and 1986 there are regions of low OLR over Siberia and eastern Canada. In 1987 and 1988 there is a region of high OLR over European Russia. In 2001 and 2003 there are high OLR values over Siberia.

In order to reduce the interannual variations and clarify the trend, the absorbed solar radiation of the four Julys of ERBE/NOAA-9 and -10 have been averaged and likewise with the four years of CERES/Terra measurements. The map of differences is shown by figure 3.

The plateau of Greenland is of particular interest because the differences there are very nearly zero, as one would expect for this expanse of snow. This is a strong indication that the differences in this map are not due to artifacts of the measurements from the different spacecraft, instruments or any of the other factors which can affect measurements. Around the coast of Greenland there is an increase of absorbed solar radiation of 20 $W\text{-}m^{-2}$ and greater due to the disappearance of sea ice. This increase also occurs around the North Pole and along the northern coasts of Siberia and Alaska.

Over the land areas of northern Canada and western Russia the absorbed radiation is reduced by 20 $W\text{-}m^{-2}$ and more. Additional study is needed to determine whether this decrease is due to increased cloudiness. Such changes must be related to significant changes in large scale circulation. Also, study is needed to understand the interannual variations in these maps. Features which should be examined include the Arctic Oscillation, the North Atlantic Oscillation (for changes over Russia) and the Pacific North American Oscillation (for changes over Canada)

Figure 4 shows the zonal average net radiation during these years. The interannual variations over the southernmost part (land) are seemingly random, but the northernmost part shows a strong increase in net radiation over the period from -30 $W\text{-}m^{-2}$ to greater than -10 $W\text{-}m^{-2}$. The figure also shows the gap of data in the period between ERBE and CERES.

Figure 5a shows the zonal averages of net radiation flux for $73^oN$ to the North Pole for the ERBE data period of 1985 through 1988, together with an eight-year zonal average of combined ERBE and CERES data. Northward of $78^oN$ the net radiation is below the eight-year mean for every year but 1985. Figure 5b shows the zonal averages for the CERES/Terra data period of 2000 through 2003. The net radiation for all four years from 2000 to 2003 are above the eight-year average and well above the 1985 through 1988 values. Furthermore, for 2003 the zonal mean is positive, i.e., radiatively warming rather than cooling, over the entire latitude range.

The zonal averages are combined to give the average net radiative flux for the region poleward of $72.5^0N$ and fig. 6 shows the history of the net radiation for this region. For 1985 through 1988, the average net radiative flux is 2 +/-3 $W\text{-}m^{-2}$. During the 2000 to 2004 period the net radiation flux increases to to 9 +/-3 $W\text{-}m^{-2}$. The net radiation from the CERES aboard the Terra and Aqua agree to 0.5 $W\text{-}m^{-2}$, with the Aqua high in each of the three years for which data are available from both instruments.

The results presented here are for radiation at the “top of the atmosphere” and thus include the effects of clouds, which are presumed to be modified by the changes of the surface from ice to sea water. It remains to investigate the changes of cloud cover due to the interactions of the Arctic Ocean and the overlying atmosphere.

During the time between the ERBE scanning radiometer records from the NOAA-9 and –10 spacecraft and the CERES instrument aboard the Terra spacecraft, the ScaRaB-1 provided Earth radiation budget measurements from March 1994 through February 1995 (Kandel et al., 1998), so that these data for July 1994 can be included in further study of the Arctic region. Although measurements are available from the ERBE nonscanning radiometers aboard the NOAA-9 and –10 spacecraft provided measurements after the scanners stopped, it is problematic whether these measurements can be used to augment this study.

## 4. CONCLUSIONS

The satellite record of Earth radiation budget demonstrates that the effect of melting ice on the Arctic Ocean has increased the net radiation for the region from 72.5$^{o}$N to the North Pole from 2 +/-3 W-m$^{-2}$ to 9 +/-3 W-m$^{-2}$ during the two decade period between 1985 to 2004. Most of this increase is due to the decrease of albedo as the ice cover is replaced by dark ocean, resulting in increased absorbed solar radiation. Only a small part is due to changes of outgoing longwave radiation. The maps quantify the ice-feedback effect on radiation, which includes the effects of the changing surface conditions on the clouds and subsequently the effects of these clouds on the top of atmosphere albedo. Over northern Canada and western Russia, the absorbed solar radiation decreased significantly.

Although the trend over this period is quite clear, the interannual variations require additional study to determine the causes and effects of these variations.

## 5. ACKNOWLEDGEMENTS

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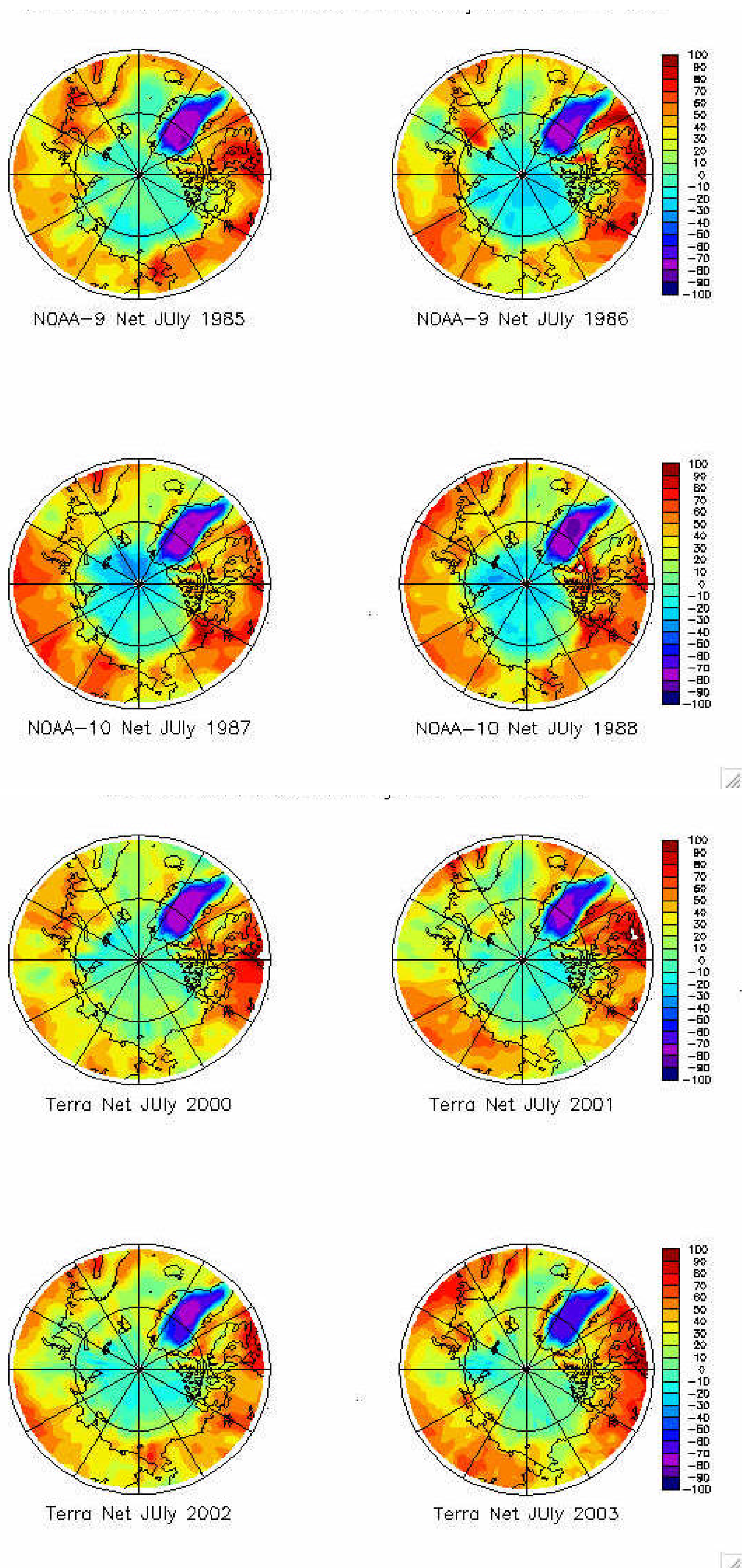


Figure 1: Net radiation for the region poleward of 60$^{o}$N for each of the eight Julys of 1985-1988 and 2000-2003, W-m$^{-2}$.

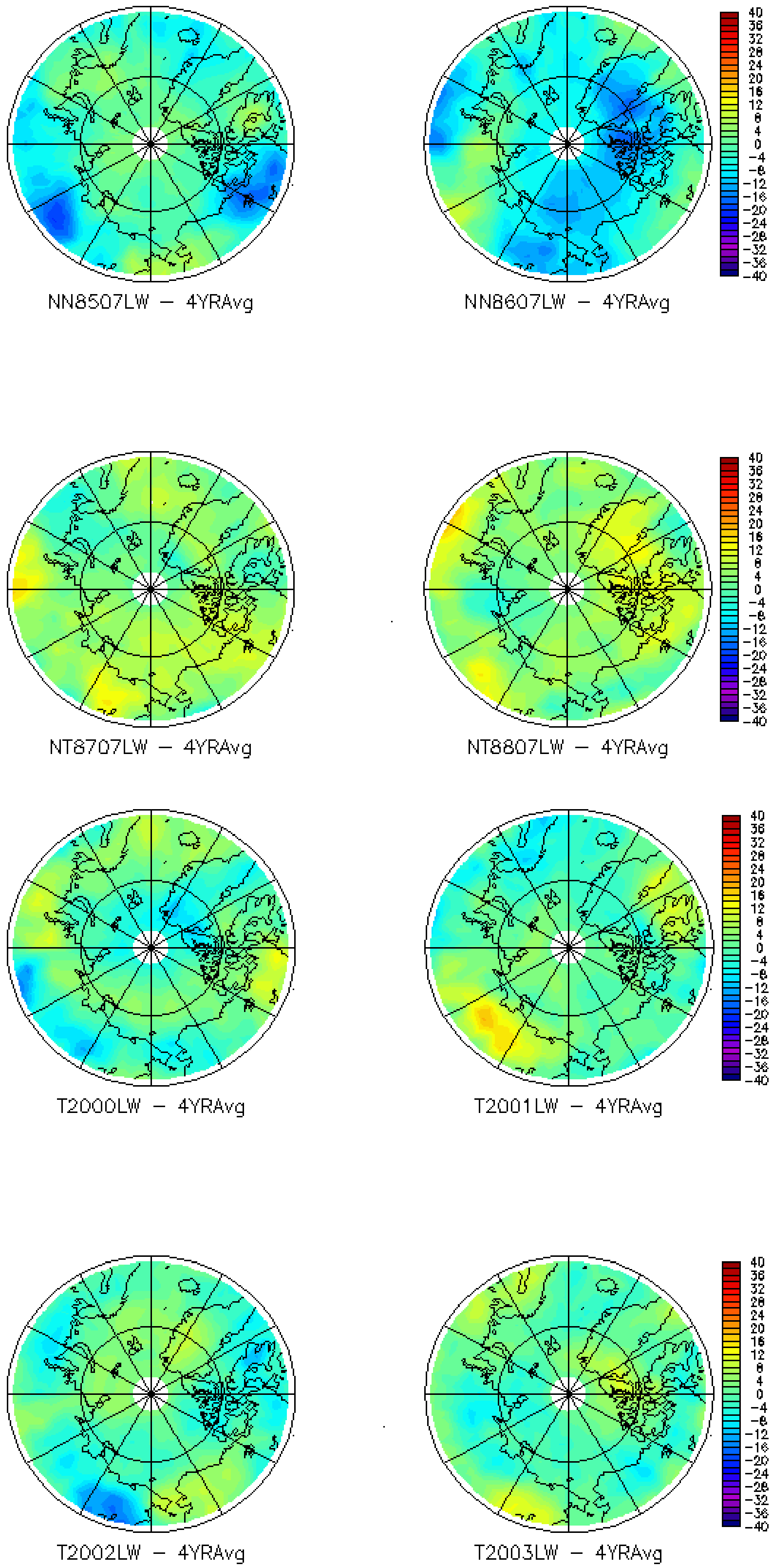


Figure 2: Maps of differences of OLR for the region poleward of $60^{o}$N from four-year mean for ERBE and for Terra periods.

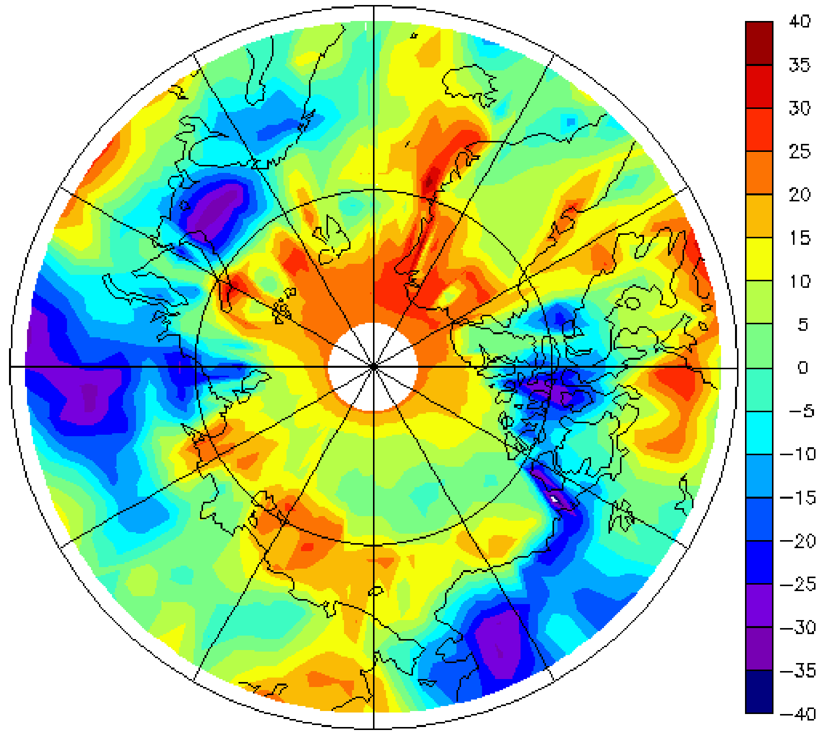


Figure 3: Map of change of absorbed solar radiation for the region poleward of 60°N in July from the average July of ERBE (1985-1988) to the average July of CERES (2000-2003).

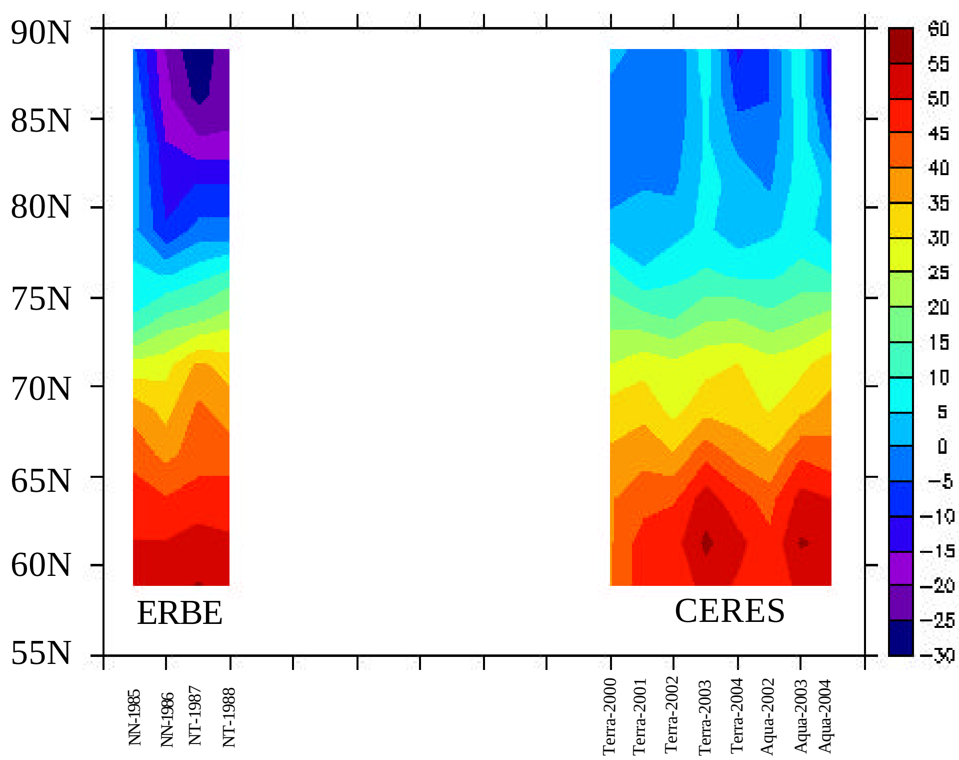


Figure 4: Hovmueller diagram of zonal average net radiation for July of 1985 through 2003.

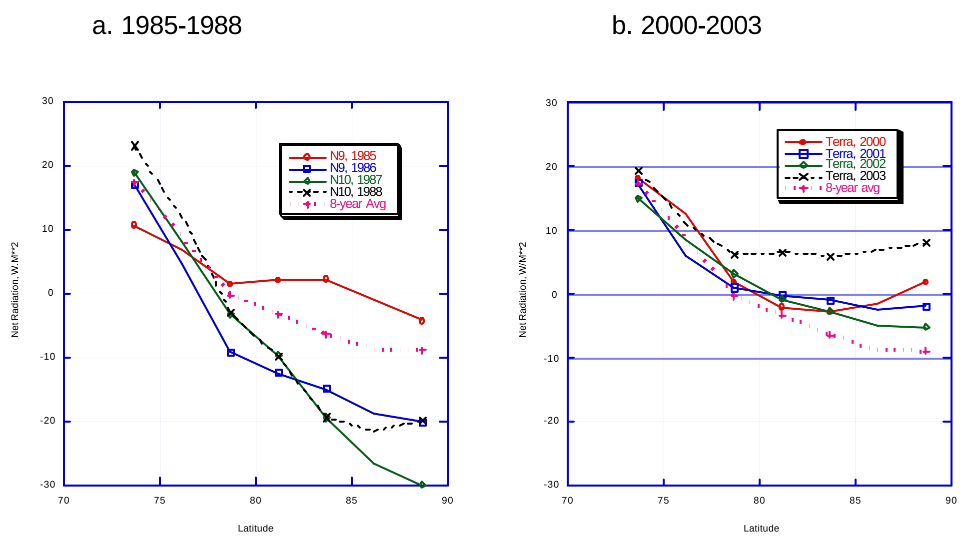


Figure 5: Zonal averages of net radiation $W\text{-}m^{-2}$ in July for $73^{o}N$ to North Pole. Left panel is for ERBE period 1985-1988, right panel is for Terra period 2000-2003.

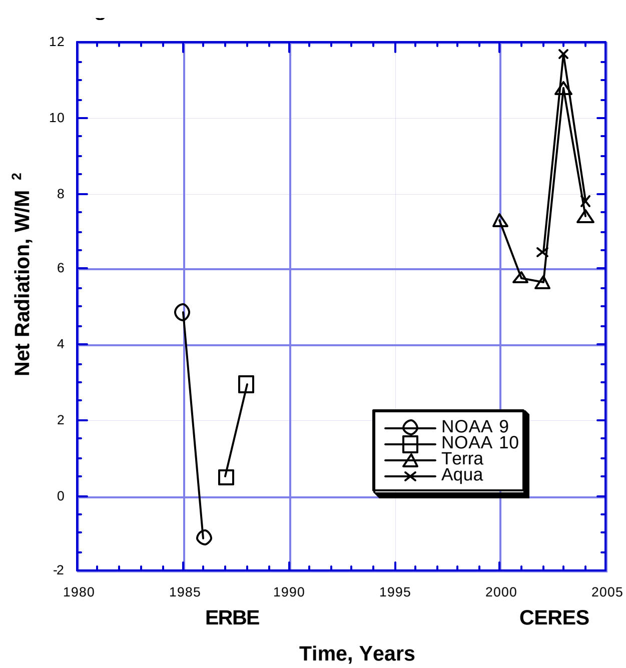


Figure 6: Variation of average net radiation for region $72.5^{0}N$ to North Pole for 1985 through 2003.