23 YEARS OF SURFACE LONGWAVE FLUXES IN THE ARCTIC FROM TOVS SATELLITE RETRIEVALS

Jennifer Francis[1], Axel Schweiger[2], Jeff Key[3], Jaclyn Secora[1]

Abstract

A reliable estimate of the surface downwelling longwave radiation flux (DLF) is a glaring void in available forcing data sets for models of Arctic sea ice and ocean circulation. A new data set of DLFs is derived from a combination of satellite sounder retrievals and brightness temperatures from the TIROS Operational Vertical Sounder (TOVS), which has flown on NOAA polar-orbiting satellites continuously since late 1979. The fundamental concepts behind our methodology were published in Francis, 1997. Further validation and improvement of the method have been done using nearly 5 years of surface radiation measurements and surface-based cloud remote sensing retrievals from the ARM (Atmospheric Radiation Measurement) site in Barrow, AK, as well as from the SHEBA field experiment. We have transitioned calculations to a neural-network version of a forward radiative transfer model to achieve a substantial increase in computing speed. We produce daily fields between late 1979 and 2001 on a grid with a spatial resolution of 100 km x 100 km north of 60°N. Comparisons with SHEBA and ARM radiation measurements reveal biases of approximately 6.5 W m^{-2} and RMSEs of about 30 W m^{-2}.

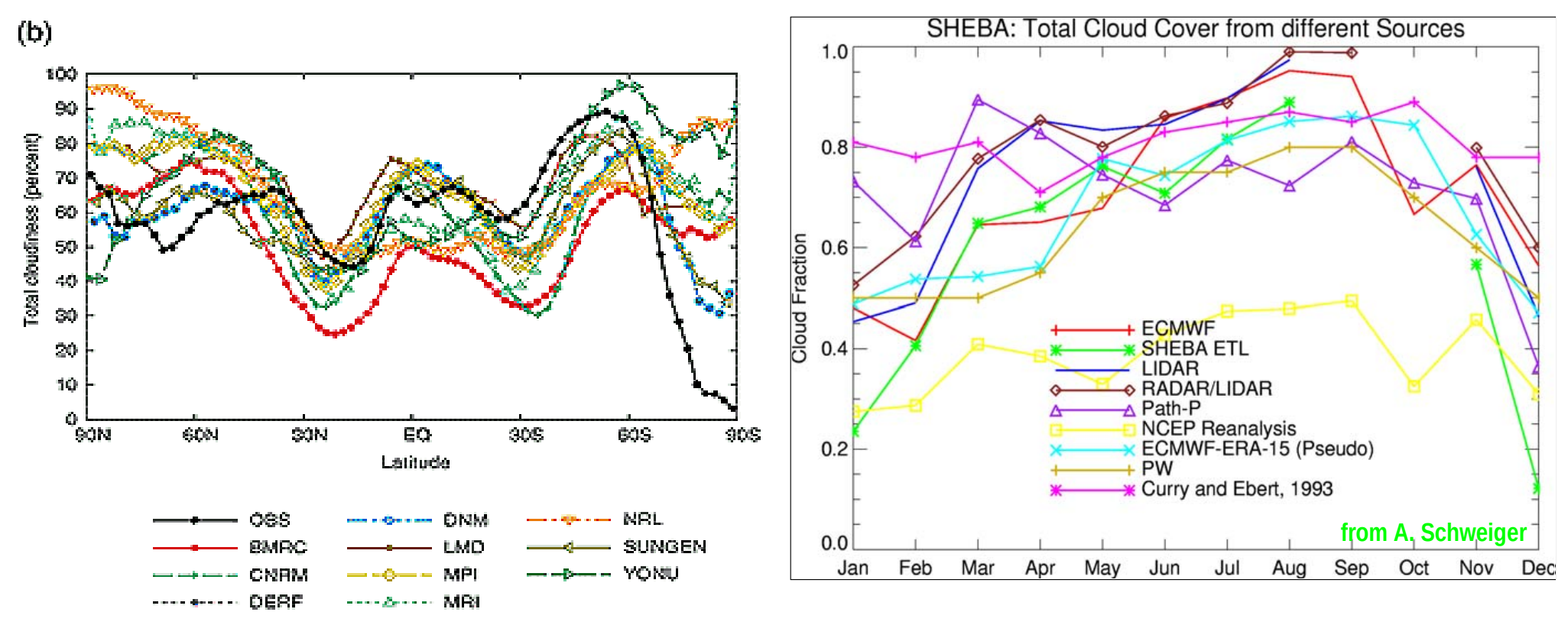


Figure 1: LEFT: Comparison of simulations of present-day winter cloud fraction by numerous climate models and the ISCCP satellite retrievals (from Gates et al, 1999). Disagreement among models is largest in high latitudes. RIGHT: Comparisons of cloud fraction at the SHEBA camp. SHEBA ETL, LIDAR, RADAR/LIDAR, PW and Curry and Ebert are based on surface measurements; Path-P is the TOVS satellite retrieval, and the others are based on NWP models. From Axel Schweiger, Polar Science Center, U. of Washington.

DLF Retrievals: A Challenge in the Arctic

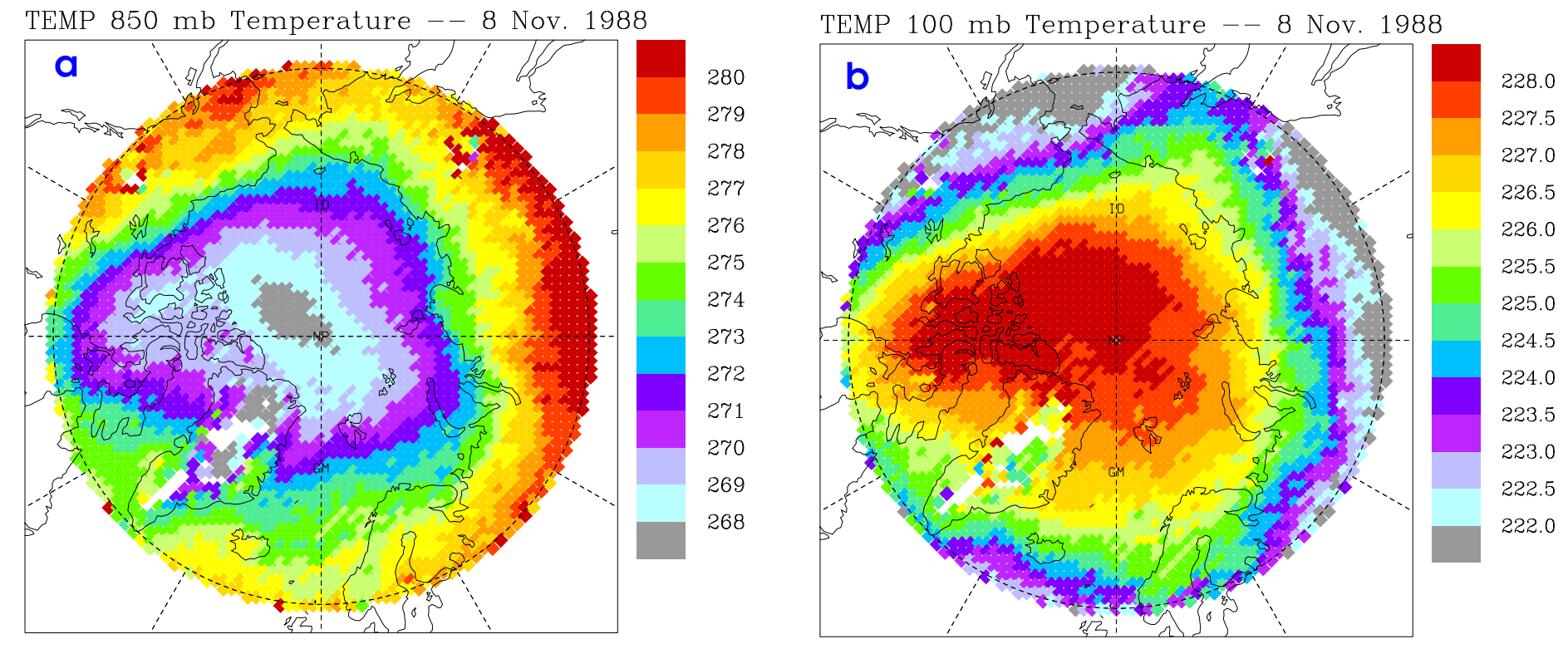
In cold, dry polar conditions, the primary factors affecting DLF are cloud fraction, cloud-base height, cloud LWP/IWP, and surface temperature. This is in distinct contrast to lower latitudes where low-level humidity often plays a dominant role. The disagreement among models, particularly in high latitudes) shown in **Fig. 1** left is largely caused by our poor knowledge of cloud properties in the Arctic (**Fig. 1** right). Our new method to estimate DLF in the Arctic relies on profiles and cloud properties retrieved from TOVS radiances. The so-called "Path-P" data set comprises daily fields of gridded atmospheric and surface parameters for the Arctic region north of 60°N. Processing is achieved with the Improved Initialization Inversion ("3I") algorithm (Chédin et al, 1985; Scott et al, 1999), improved for polar conditions by Francis (1994). Products have been extensively validated with data from SHEBA, Russian Arctic ice stations, and field programs (Schweiger et al, 2002). Documentation, validation information, and data are available from NSIDC (http://nsidc.org).

Path-P Products

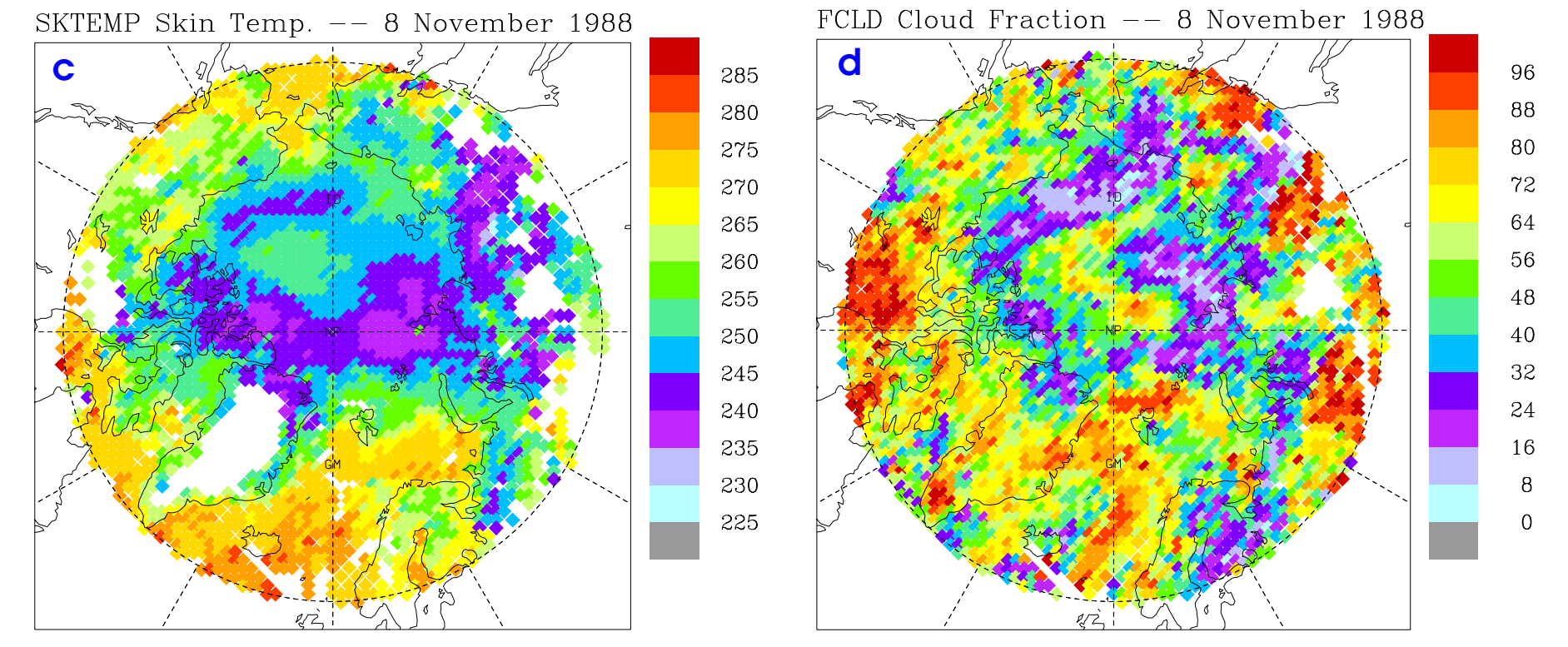
Parameter Name	Description	Units	~RMS error
TEMP	temperature at 9 standard levels	K	3
SKTEMP	surface skin temp	K	3
WVAPOR	precipitable water in 5 layers	mm	30%
FCLD	effective cloud fraction (εN)	%	30
HIRS_CLDY	% cloudy HIRS pixels	%	20
CLTEMP	cloud-top temperature	K	TBD
CLPRESS	cloud-top pressure	mbar	TBD
EMISS	surface emissivity @50 GHz		5%
PBLSTRAT	bulk PBL stratification	K	5
Cg	geostrophic drag coefficient		10%
ALPHA	turning angle of wind stress	deg	20
ZANGLE	average satellite view angle	deg	
ISICE	surface type		
PRESS	surface pressure (from NCEP Reanal.)	mbar	

Examples from PathP

850 kPa Temp **100 kPa Temp**



Surface Skin Temperature **Effective Cloud Fraction**



PW 1000 to 700 kPa **Total Precipitable Water**

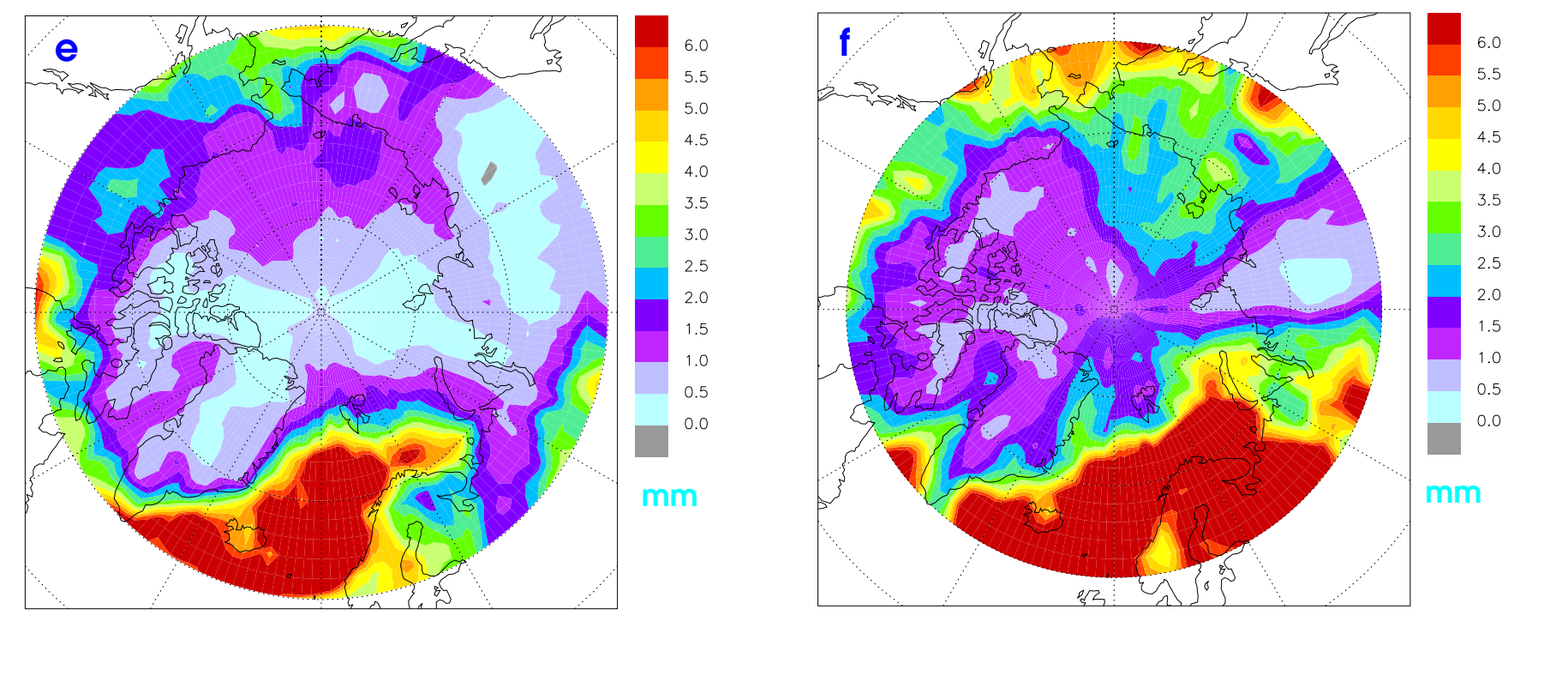


Figure 2: Selected Path-P fields for 8 November 1988. (a) is the temperature at the 850 kPa level, (b) is the temperature at 100 kPa, (c) is the surface skin temperature, (d) is the effective cloud fraction, (e) is precipitable water in the 1000-to-700 hPa layer, and (f) is the total precipitable water. Skin temperatures on sea ice (c) tend to be higher in cloudy areas.

Method to Retrieve Longwave Fluxes

Acquire retrieved variables from TOVS:
- Temperature profile
- Water vapor distribution
- Effective cloud fraction
- Cloud-top pressure

⇓

Cloud "type" and phase

⇓

Cloud thickness ⇒ cloud base height

⇓

Mean cloud temp in 1 layer

⇓

LWC/IWC ∝ cloud mean temp.

⇓

Assume typical size of effective particle radii

⇓

Neural Network (FluxNet) RT Model

The cloud "type" refers to whether the cloud is above or below a surface-based temperature inversion, and is determined by the sign of the 3.7–11μm TB difference. The phase identification exploits the large difference in absorption coefficient between ice and water in channels near 8.3 and 11 μm shown in **Fig. 3**. An estimate of cloud thickness is empirically derived from two pairs of sounding channels. In each pair the weighting functions peak at slightly different levels, resulting in differing TBs in clear-sky conditions. The reduction in this difference is related to cloud optical depth, and from this a geometric thickness is estimated. Using the temperature profile, a cloud-mean temperature is determined, which is related empirically to a LWC/IWC. Typical effective droplet sizes for Arctic clouds are assigned according to phase, and the entire suite of information is input to a neural network RT model (FluxNet: Key and Schweiger, 1998) to increase processing speed.

ABSORPTION COEFFICIENT VS. WAVELENGTH

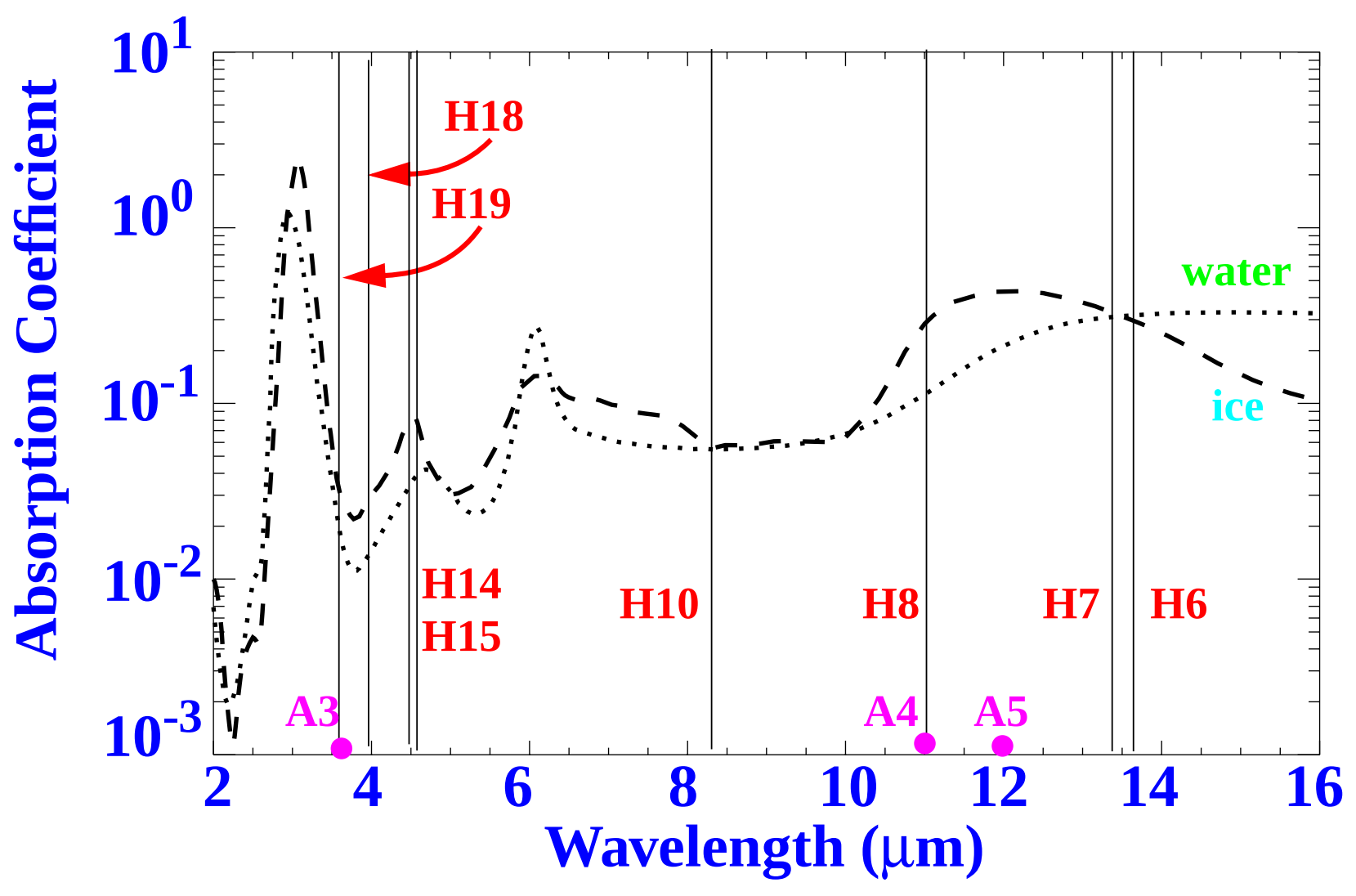


Figure 3: Variations in ice and water absorption coefficients with wavelength. Central wavelengths of HIRS channels are superimposed.

Results -- 23 Years of Surface Longwave Flux

Figures 4 and 5 present comparisons of daily mean TOVS-derived longwave flux to data from the year-long Surface Heat Budget of the Arctic (SHEBA) experiment and to nearly 4 years of measurements from the ARM North Slope of Alaska site. In the SHEBA comparison, biases are near zero and monthly means agree well. In general one would expect TOVS values (retrievals within 100 km of SHEBA site) to exhibit less variability than measurements from a point in space, which is apparent in the scatter plot. Comparisons to ARM data (**Fig. 5**) also suggest that TOVS retrievals capture observed fluctuations, and thus will be valuable for a variety of applications. One of these is to investigate causes for observed recent change in the Arctic, such as increased surface temperatures, decreased sea ice extent and thickness, increased duration of melt season, loss of permafrost. One likely factor contributing to these changes is a trend in surface longwave forcing. Our preliminary calculations shown in **Fig. 6** suggest large, basin-wide changes that vary greatly by season and region.

TOVS-Derived DLF versus Measurements from SHEBA

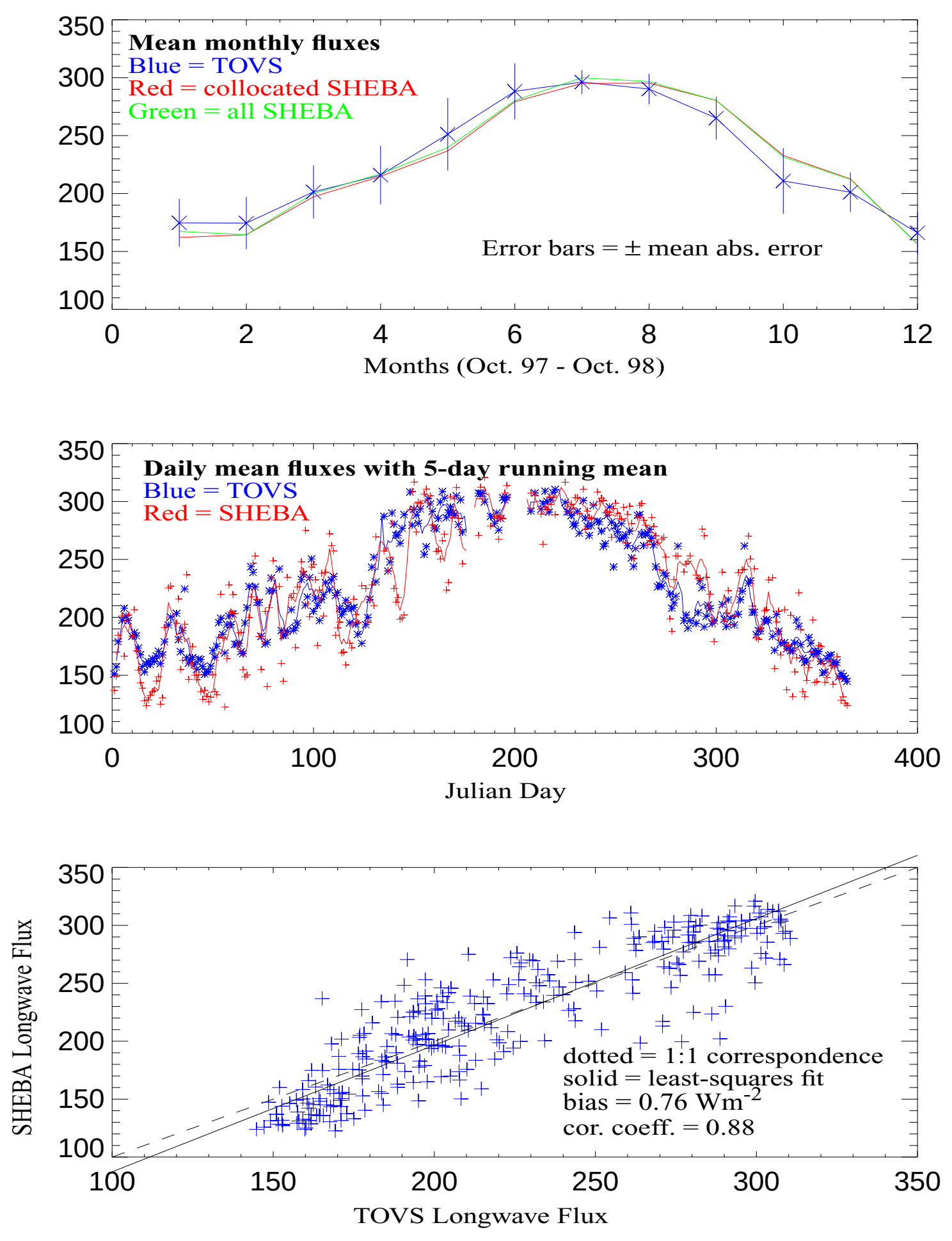


Figure 4: Comparison of TOVS-derived surface downwelling longwave fluxes with measurements during Oct. '97 to Oct. '98 from the SHEBA field program. Top: comparison of monthly averages. Middle: daily averages and 5-day running means. Bottom: scatterplot of daily values.

TOVS-Derived DLF versus ARM/NSA Measurements

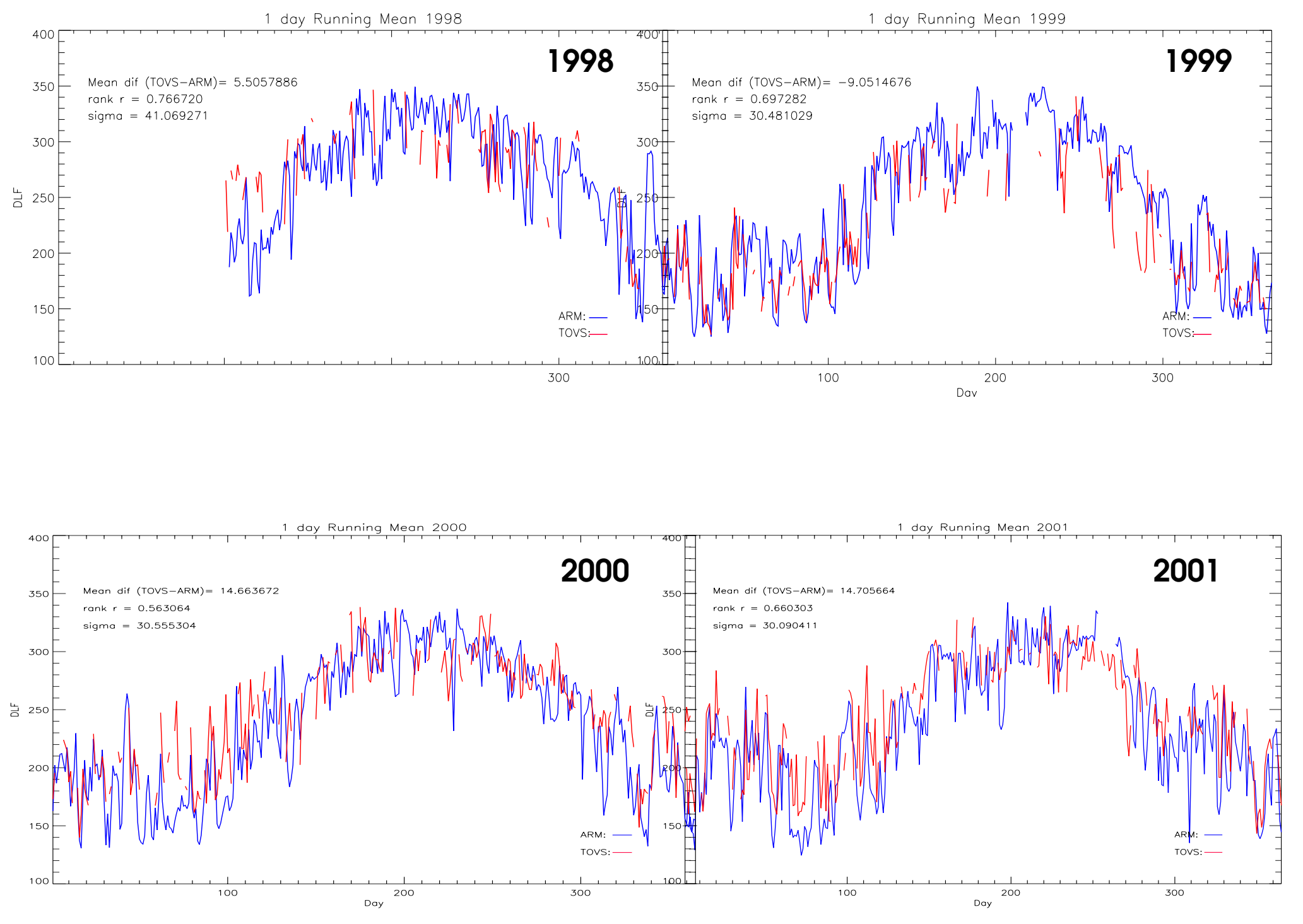


Figure 5: Comparison of daily-mean TOVS-derived DLF (red) with measurements from the ARM Barrow site (blue) during 1998 to 2001.

Decadal Trends in DLF -- 1980 to 2001

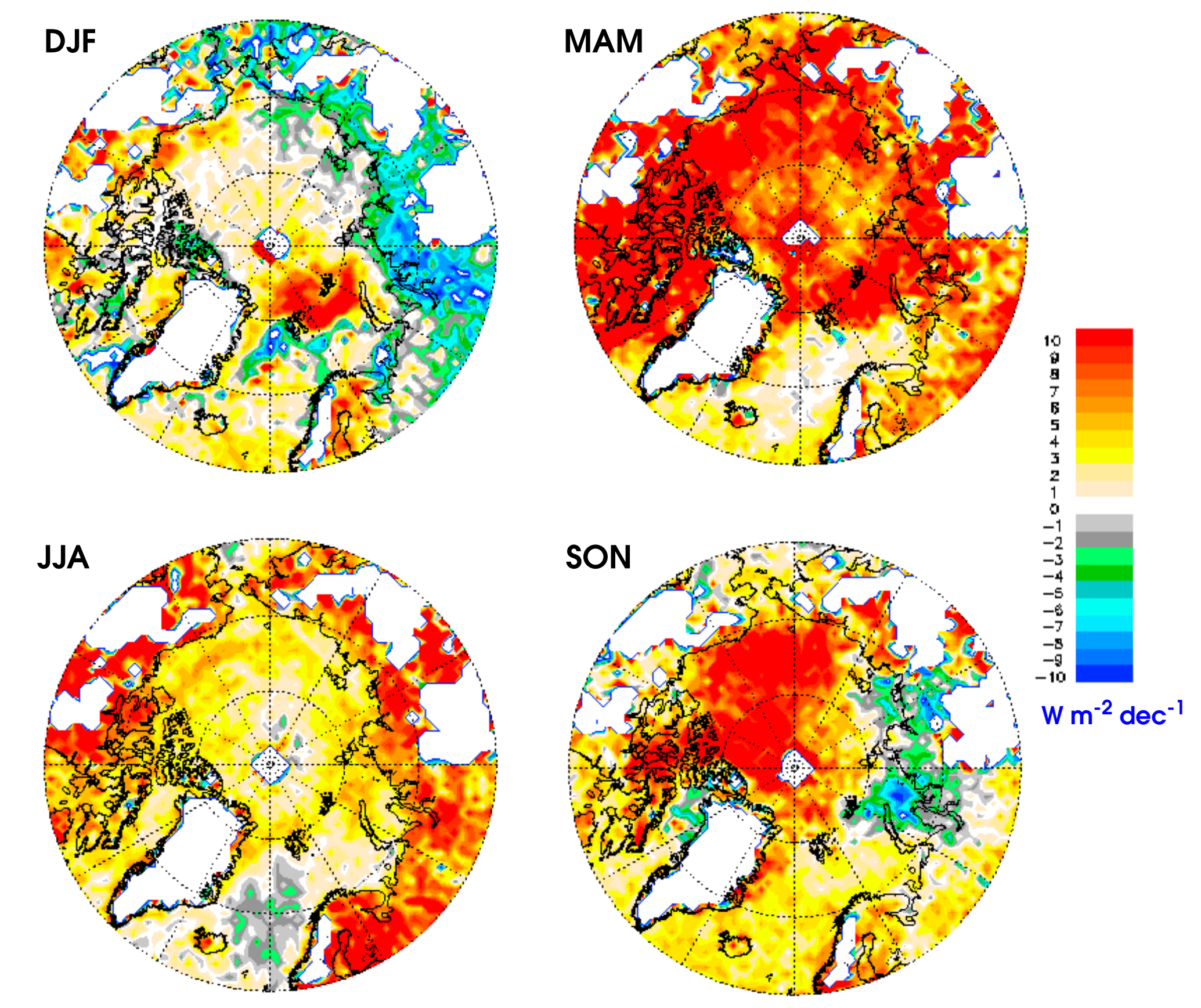


Figure 6: Decadal trends in DLF calculated from TOVS retrievals for 1980 to 2001 in each season

Conclusions

Our 23-year product of downwelling longwave fluxes over the Arctic show great potential for investigating causes for observed dramatic change in recent decades and for driving sea ice models. The Arctic DLF has apparently changed substantially, but why? Have clouds increased? Are clouds lower, thicker, or has their phase changed? Has water vapor or temperature changed? Are changes related to variability in large-scale circulation patterns? Future work will focus on answering these questions and what these changes mean for the Arctic and global climate.

References

Chedin, A., N.A. Scott, C. Wahiche, and P. Moulinier, 1985: The Improved Initialization Inversion method: A high resolution physical method for temperature retrievals from satellites of the TIROS-N series, *J. Clim. Appl. Meteorol.*, 24, 128-143.

Francis, J.A. and A.J. Schweiger, 2000: A new window opens on the Arctic. *AGU Eos Trans., 81,* 77-83.

Francis, J.A. 1994: Improvements to TOVS retrievals over sea ice and applications to estimating Arctic energy fluxes, *J. Geophys. Res., 99*, 10,395-10,408.

Francis, J.A., 1997: A method to derive downwelling longwave fluxes at the Arctic surface from TIROS operational vertical sounder data, *J. Geophys. Res., 102,* 1795-1806.

Gates, W.L. and 15 co-authors, 1999: An overview of the results of the atmospheric model intercomparison project (AMIP I). Bull. Am. Meteor. Soc., 80, 29-55.

Key, J. and A.J. Schweiger, 1998: Tools for atmospheric radiative transfer: Streamer and FluxNet, Computers and Geosciences, 24(5), 443-451.

Schweiger, A.J., R. Lindsay, J.A. Francis, J. Key, J. Intrieri, and M. Shupe, 2002: Validation of TOVS PathP data during SHEBA, *J. Geophys. Res*.,.107(C10), 8041, 10.1029/2000JC000453.

Scott, N.A., A. Chedin, R. Armante, J. Francis, C. Stubenrauch, J.-P. Chaboureau, F. Chevallier, C. Claud, and F. Cheruy, 1999: Characteristics of the TOVS Pathfinder Path-B dataset. Bulletin of the Am. Meteor. Soc., 80, 2679-2701.

I thank ARM and NASA for providing funding to Rutgers University and the University of Washington to support this and related work.

[1] Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey -- *francis@imcs.rutgers.edu, secora@imcs.rutgers.edu*

[2] Polar Science Center, University of Washington, Seattle, Washington *axel@apl.washington.edu*

[3] NOAA/NESDIS, Madison, Wisconsin -- *jkey@ssec.wisc.edu*