POLAR EXCHANGE AT THE SEA SURFACE (POLES)

A report and proposal to the University of Washington
Dr. D.A. Rothrock, Applied Physics Laboratory

Summary of Recent Progress and Plans for the 1999-00 Project Year at the University of Wisconsin-Madison

(formerly subcontract 520186 to Boston University)

Report Period: June 1, 1998 - May 31, 1999
Proposed Funding Period: September 1, 1999 - May 31, 2000

Principal Investigator:

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Cheryl E. Gest 8-4-99
Cheryl E. Gest, Admin. Officer
Research & Sponsored Programs

July 24, 1999

1. PURPOSE

This document is a report of progress for the 1998-99 project year at Boston University and plans for the 1999-00 project year at the University of Wisconsin-Madison. It is provided to Dr. D.A. Rothrock, Principal Investigator of the POLES project, as part of the request to transfer the project from Boston University (subcontract 520186) to the University of Wisconsin. The progress report covers the period June 1, 1998 through May 31, 1999, with plans for the period September 1, 1999 through May 31, 2000, the final year of the grant. September 1 is the requested date of transfer.

The POLES-BU effort addresses the energy and moisture balance of the polar atmosphere, in particular the radiation budget, cloud properties, and, most recently, heat and moisture advection. These research areas encompass the first two POLES objectives listed in the January 1997 POLES report to NASA:

- Determine the heat and moisture balance of the polar atmosphere, including the surface heat balance, radiation to space, and the transport of heat and moisture into the polar atmosphere from mid-latitudes.

- Determine more accurately the amounts of polar clouds and their effect on the surface and top-of-atmosphere radiative balance.

2. SUMMARY

Progress has been made in the areas of algorithm development, validation, analysis of satellite-derived variables, regional climate modeling, and circulation studies. We believe that we have the most accurate set of cloud, surface, and radiative flux retrieval algorithms available for the polar regions, although we recognize that further improvements may be necessary after additional validation work is done. These algorithms have matured over the past few years and are now ready to be applied to large satellite data sets. Our analyses of the new ISCCP "D" products have shown that while it is an improvement over the "C" product, problems remain, further emphasizing the need for a similar set of POLES products based on POLES algorithms. *Therefore, our emphasis in the final year of POLES will be the generation and analysis of at least one year of cloud properties, surface temperature and albedo, and radiative fluxes derived from the AVHRR Polar Pathfinder radiance data set.*

3. PERSONNEL

POLES personnel at Boston University include J. Key and Chuanyu Xu, a PhD graduate student. Mr. Xu is supported for 12 months by POLES; J. Key's level of effort was 1.5 months in the current project year. An undergraduate student, Alan Chan, also contributed to POLES but was unfunded. His undergraduate thesis (called "Work for Distinction" at BU) dealt with the development of a new wave cyclone climatology. This work is described below. Mr. Xu will be supported for at least part of the final project year. However, it is uncertain at the time of this writing if he will transfer to the University of Wisconsin. If not, a new graduate student will be supported at that institution.

4. Algorithm Development, Data Set Production, and Validation

Accomplishments: The cloud optical depth/particle effective radius and particle phase retrieval procedures have been rewritten and are currently being validated with aircraft data from SHEBA. Cloud detection procedures have been further refined. Preliminary results are encouraging. By the end of the current project year, cloud and surface property retrieval algorithms will be ready for application to large data sets.

4.1 Algorithm and Tools Development

The cloud **optical depth** and particle **effective radius** algorithms have been revised, extending the range of ice particle sizes based on observations by personnel at the South Pole Observatory (S. Warren, personal communication, 1999). Computational efficiency has also been improved. Retrievals are being done for the SHEBA year with the 5 km APP data, and comparisons to C-130 aircraft observations are being made. Cloud detection procedures have also been improved. Preliminary results are encouraging.

Our AVHRR algorithm for determining cloud **particle phase** has been revised based on extensive model calculations over a variety of atmospheric conditions. The algorithm is no longer polar specific, and extends work by other investigators whose procedures were limited in scope.

The retrieval of **surface albedo** done for the AVHRR Polar Pathfinder continues to be problematic, particularly at low sun angles. Possible revisions are being considered.

Minor modifications to the *Streamer* radiative transfer model have been made and will continue to be made. This model is very popular in both research and teaching environments. A number of modifications are planned, including new surface albedo models, enhanced standard temperature and humidity profiles, and enhancements to the user interface.

The Cloud and Surface Parameter Retrieval (CASPR) system for polar AVHRR data continues to be updated as our algorithms change. Both *Streamer* and CASPR (and *FluxNet*) have been, and will continue to be, available via the Web (http://stratus.bu.edu).

Goals for the coming year:

- Further refine cloud and surface property retrieval algorithms. Only minor modifications are expected to be necessary.
- A journal publication detailing the cloud particle phase determination is in preparation and will be submitted soon.
- The problems in surface albedo retrieval will be investigated. If it is determined that errors in the retrieval translate into large errors in radiative fluxes, an alternate method will be implemented.
- Minor modifications to *Streamer* and CASPR will continue. They're just too popular to ignore, *Streamer* in particular.

4.2 Validation and Intercomparison

Our plans to assess errors in the estimates of TOVS and AVHRR Polar Pathfinder temperature and albedo data products by comparison with *in situ* data from LEADEX (1992), CEAREX (1988), and the Arctic cross-section (1996) have proceeded. A. Schweiger has taken the lead on this. Comparisons between cloud amounts from the North Pole (NP) drifting stations and the ISCCP D1 (3-hourly) data have been done.

The SHEBA remote sensing group, an informal group that includes satellite remote sensing, surface remote sensing, and aircraft investigators, have selected a number of case study dates for intercomparison of cloud properties and radiative fluxes (see the report at http://stratus.bu.edu/sheba). Additionally, we will estimate cloud optical depth from surface shortwave fluxes measured during SHEBA and from the NP drifting stations for comparison with our satellite retrievals.

Goals for the coming year:

- Validate our retrievals with SHEBA aircraft and surface data.
- Compute cloud optical depth from North Pole drifting station surface measurements and compare them to our satellite-derived optical depths and those of the ISCCP.

4.3 Data Products and Analysis

As described above, the primary focus of our last POLES year is to develop our own data set of cloud and surface properties from the APP data. The surface and top-of-atmosphere radiative fluxes calculated from the ISCCP D1 cloud data are available upon request (http://stratus.bu.edu), and will be made public after a few more years are processed. At present 1986 and 1989-93 are complete.

A special version of *FluxNet* was developed for the TOVS Path-P+ processing, though refinements are required. J. Key is working with A. Schweiger and J. Francis on this task.

Goals for the coming year:

- We will apply the cloud property, surface temperature and albedo, and radiative flux retrieval procedures to at least one full year of APP 5 km radiance data and perform a complete analysis of the results from a climatological perspective (e.g., summary of spatial and temporal patterns of variables, relationships between cloud properties and atmospheric circulation). As these are not standard APP products, we will perform the data processing at Boston University. The resulting data sets will be POLES products. *The generation of this product is the primarily goal of our final project year.*
- Complete the development of *FluxNet* for TOVS Path-P+ and apply it to the multiyear data set.

5. Polar Processes and Global Climate - Atmosphere and Surface Fluxes

5.1 Polar Cloud Climatology: Properties and Relationships to Circulation

Accomplishments: We have examined the new ISCCP D2 cloud data and found it to be an improvement over the older C2 product, although comparisons with the North Pole drifting station observations (A. Schweiger) indicate that cloud amounts still have a large uncertainty. Relationships between cloud temperature and cloud optical depth have been determined, and an initial analysis of the relationship between cloud types and atmospheric circulation has been undertaken.

Differences between the new ISCCP D2 and the old C2 monthly cloud products have been examined. Values were averaged for each month during 1988-1990, the only consecutive years common to both datasets. Cloud amount differences range from 10% to nearly 25%, where the largest differences are during the spring and fall in the Arctic and during the austral summer in the Antarctic. D2 cloud amounts are greater than C2 amounts in all months. Spatially, the largest differences in cloud amount are over the ice sheets of Greenland and Antarctica, up to 50% in some cases, but more typically 10-30%. Over the snow-free land and ice-free oceans differences are small.

Cloud temperatures are higher in the new data during the Arctic spring, but lower during the summer. In the Antarctic, cloud temperatures are higher in the D2 data during summer, with little difference at other times. Cloud optical depths are lower in the D2 data at all times in both polar regions, with the largest differences being in the Arctic spring and the Antarctic summer. Collectively, these differences imply that more low, thin clouds are being detected in the new dataset. While we believe this is a change in the right direction, summer cloud amounts are still too low and the annual cycle is nearly absent.

Cloud feedback is a source of large uncertainty in GCM simulations of climate. Because there are few observations of cloud properties and radiative effects, recent studies have focussed on cloud cover and cloud height and their effect on climate; changes in cloud optical properties have received less attention. This is unfortunate as changes in cloud optical properties are much more important than that in cloud cover and height. We have begun to examine the relationship between cloud temperature and cloud optical depth in an attempt to gain a better understanding of cloud processes in the polar regions. As shown in Figure 1, there is an inverse relationship between the two properties. Additionally, the rate of change of optical depth with temperature itself varies with temperature, and can be divided into distinct regimes (not shown).

The association between cloud types and atmospheric circulation systems has been noted by other investigators, but the examinations were done as qualitative interpretations of satellite images. In an attempt to quantify these relationships we use NCEP reanalysis data and ISCCP cloud amounts to examine basic spatial and temporal patterns. Figure 2 gives an example for January in the Arctic. There is one large area of low pressure in the middle troposphere over Baffin Bay and Baffin Island. Low cloud amounts are large in the area of the 500 mb low, and also west of a trough near Novaya Zemlya. The latter area of low clouds is likely a result of advective rather than convective processes. Interestingly, in those areas with low cloud amounts, middle cloud amounts are large. The largest high cloud amounts occur over Greenland. As atmospheric circulation becomes weaker from winter to spring, the low pressure center shifts poleward. Correspondingly, low cloud amount increases gradually, especially in the area of Siberia, where low cloud amount increases from 5% in winter to 20-30% in summer. In contrast, middle and high cloud amounts gradually decrease as the low pressure area weakens.

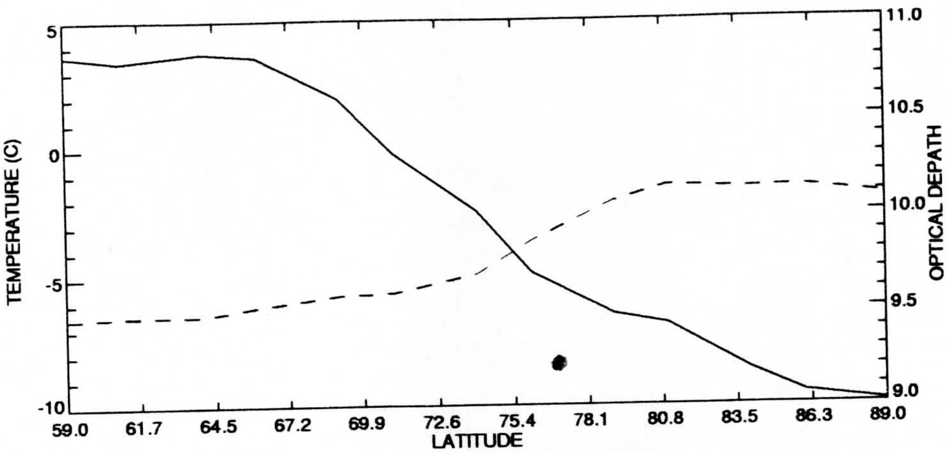


Fig. 1. Low cloud temperature and optical depth in the Arctic during June (three year average).

Goals for the coming year:

- The level of effort devoted to this project will decrease significantly as a result of the large uncertainty that remains in the ISCCP wintertime cloud amounts. Comparisons with our retrievals will, however, be performed.

5.2 Recomputation of Surface Radiative Fluxes with the ISCCP Cloud Product

Accomplishment: Surface and top-of-atmosphere (TOA) radiative fluxes have been computed for both polar regions, land and ocean, 1986 and 1989-93. It has been determined that Arctic clouds have a cooling effect for a brief period during the summer, but in the Antarctic clouds have a warming effect at all times (monthly mean).

The surface and top of the atmosphere radiative flux dataset that Schweiger and Key (1994) produced using the ISCCP C2 cloud product is being redone with the following changes:

1. The reprocessed "D" ISCCP product with the improved polar algorithm is being used.
2. Fluxes are computed from the 3-hourly (D1) rather than monthly (D2) data.
3. A special version of *FluxNet* is employed rather than *Streamer* for computational efficiency.
4. Fluxes are computed for all cloud types, defined by temperature, phase, and thickness, rather than for the mean cloud in a cell.
5. When and were available, the TOVS PathP+ temperature and humidity profiles are used.
6. The area covered includes both land and ocean poleward of 60 degrees latitude, Arctic and

Antarctic. The previous analysis was of the north polar oceans only.

At present only six full years of ISCCP D1 data are available: 1986 and 1989-1993. These have been processed. An example of the results is given in Figure 3. Additional years will be processed as they become available. A. Schweiger is also involved in this project. (NOTE: This work began under POLES but was continued under NSF funding. The NSF funding has ended so the work will continue under POLES.)

While cloud properties in the ISCCP D dataset are significantly different than those in the C product, basin-wide average radiative fluxes computed with the two dataset are not significantly different. However, regional differences can be large.

<u>Goals for the coming year:</u>

- Process additional years as they become available. **This is a small effort.**

5.3 Cloud simulations from ARCSyM model

Accomplishment: We have begun a comparison of model output with satellite data. Early results show large discrepancies in the model simulations of Arctic cloud amounts and the satellite-derived quantities.

In addition to the empirical approach to understanding cloud evolution presented in the previous section, we are also examining cloud processes in a regional climate model. Our goal is to examine the roles of convection, advection, and moisture fluxes in cloud dynamics. The model we are using is ARCSyM, which is basically MM5 with some modifications for Arctic processes, sea ice in particular.

To date, we have used ARCSyM to simulate the total cloud amount over the Arctic area poleward of 60N at a 100 km horizontal resolution. Figure 4 shows a comparison of January 1990 cloud amounts produced by the model and that given in the ISCCP D2 data. On the average, the cloud amount from model is significantly less than that of satellite, especially over the Arctic ocean. In contrast, cloud amount over north Greenland is overestimated. Obviously, there is a large discrepancy between the ARCSyM and ISCCP clouds. David Baily and Amanda Lynch at the University of Colorado are investigating changes to the cloud physics in the model. They are interested in our comparisons and are willing to collaborate.

<u>Goals for the coming year:</u>

- **This task is being eliminated.** Given the uncertainties in the ISCCP clouds, there will not be any way to assess the accuracy of the modeled clouds until after we generate our own cloud data product.

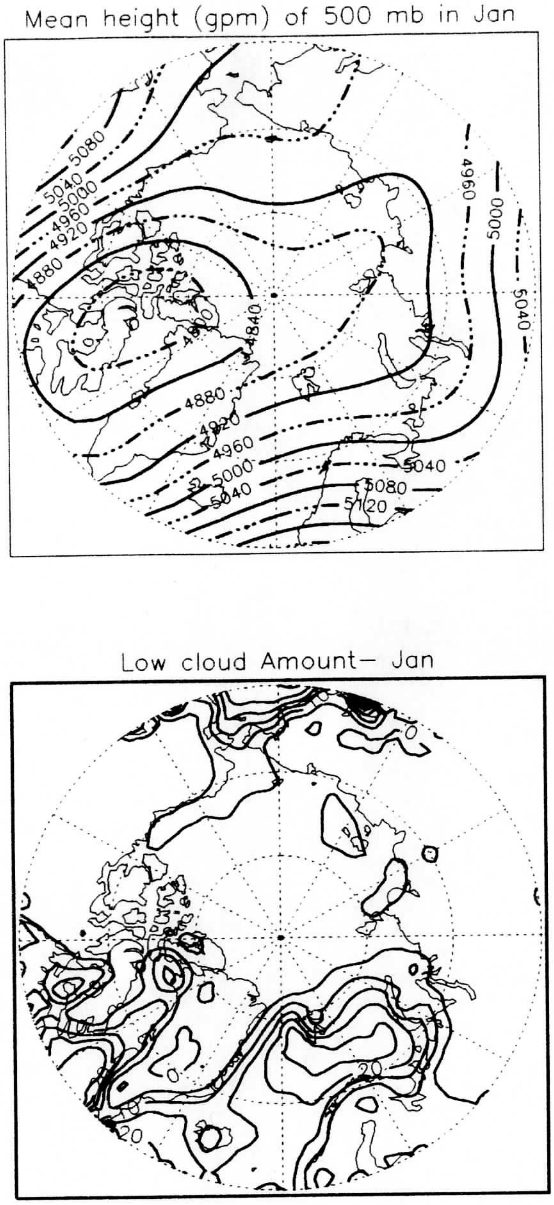


Fig. 2. Mean January geopotential height over the Arctic (top) and low cloud amounts from the ISCCP D2 cloud product (bottom).

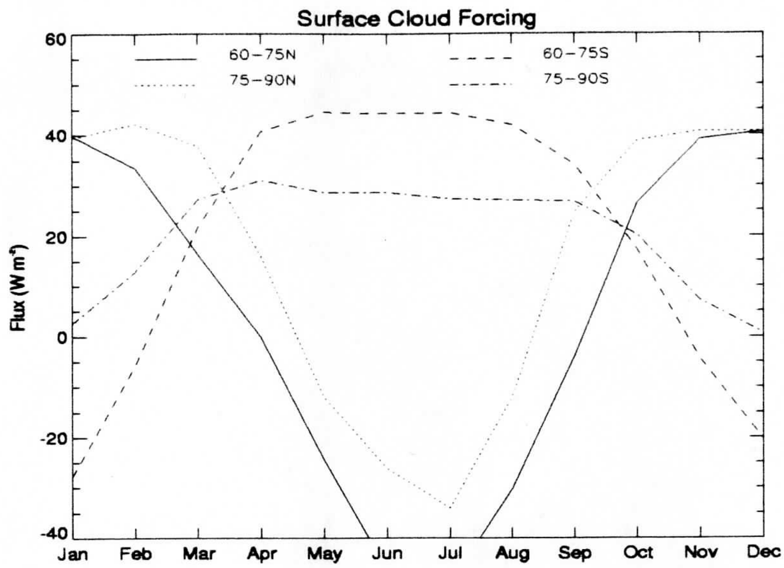
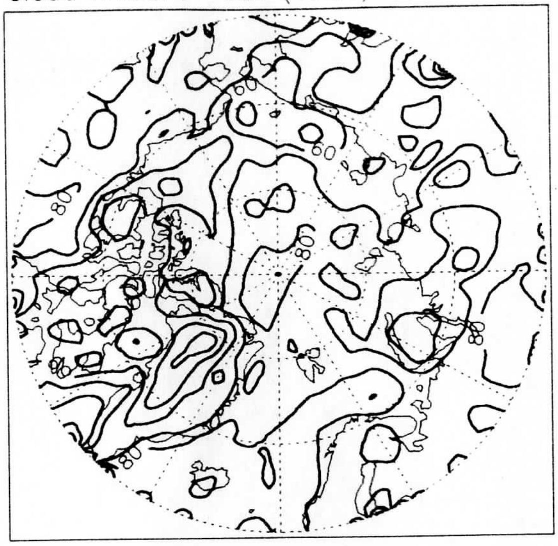


Fig. 3. Monthly mean cloud radiative effect ("forcing") at the surface for two latitudinal zones in the Arctic and two in the Antarctic. Values are derived from the ISCCP D1 cloud data and the TOVS Path-P temperature and humidity profiles.

Cloud Amount– Jan (1990) Source:ISCCP



Cloud amount–Jan (1990) Source: Model

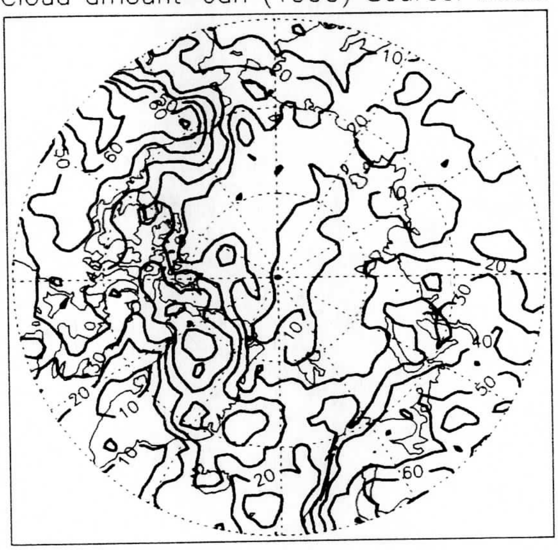


Fig. 4. ISCCP D2 and modeled (ARCSyM) cloud amounts in January 1990 over the Arctic.

5.4 Wave Cyclone Climatology

Accomplishment: Trends in frequencies of surface and mid-tropospheric closed lows (cyclones) have been determined for the Arctic and mid-latitudes. Opposite trends at the two levels have been observed in some regions and seasons implying changes in synoptic-scale circulation.

Changes in atmospheric circulation will have an important effect on ice movement and energy fluxes. But is the Arctic atmospheric circulation changing? One way to answer this question is to examine changes in closed lows. Surface and 500 mb level cyclones were identified and tracked over a 40 year period using the NCEP 12-hourly reanalysis data. Cyclone frequencies, deepening rates, and speeds and directions of movement are being summarized for various regions and time periods. Similar work has been done by M. Serreze (University of Colorado) using surface pressure for the Arctic. The main objective is to examine these cyclone characteristics over time and identify correlations with El Niño and the North Atlantic Oscillation. An example of trends in cyclone frequencies is given in Figure 5. While the figure gives results for the summer, other seasons are similar. Interestingly, trends in the midlatitudes are of opposite sign to those in the Arctic during certain seasons.

Goals for the coming year:

- Submit paper for publication. **This task is essentially complete.**

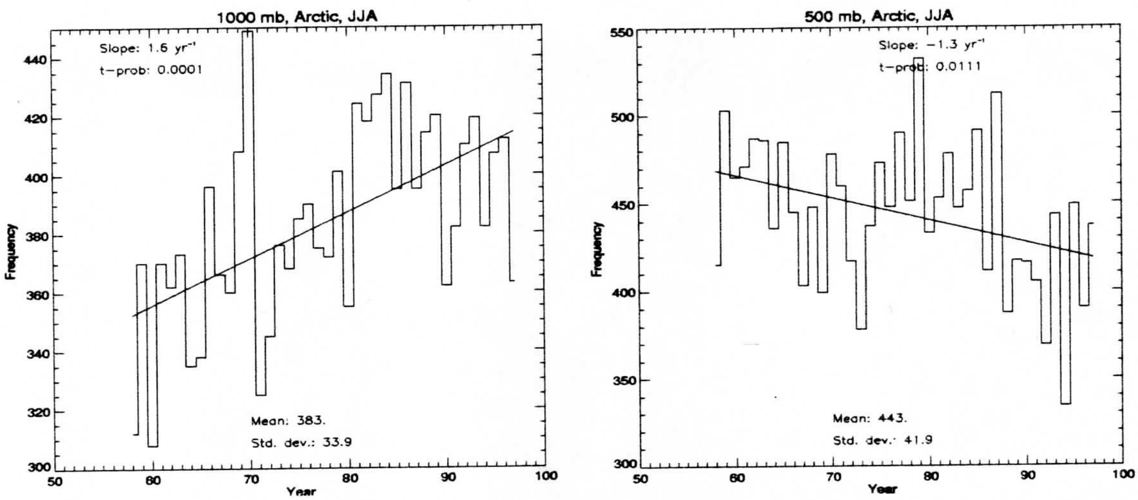


Fig. 5. Trends in cyclone frequencies in the Arctic summer at 1000 mb (left) and 500 mb (right). Both trends are statistically significant. The opposite sign of the trends implies a change in large scale circulation and tropospheric temperatures.

6. Interaction with NASA and Other Groups

Our AVHRR algorithms for the retrieval of cloud detection, surface temperature, and surface albedo are being applied by the AVHRR Polar Pathfinder (APP) group. J. Key was funded by Pathfinder, but only for implementation assistance. Algorithm issues are still in the POLES realm. Our interaction with the APP and TOVS Path-P activities was described in section 3.

The comparison of polar cloud detection algorithms, let by Eugene Clothiaux of Penn State, is entering a second phase. The participants include Todd Berendes of JPL, Jeff Key, Steve Ackerman, and Ron Welch. Cloud masking algorithms being compared are: CASPR (J. Key), MODIS (S. Ackerman), and ASTER (T. Berendes, R. Welch). The MISR cloud mask has also been included, but the algorithm does not operate over snow/ice. First results show many areas of disagreement, but similar total cloud amounts. Nighttime conditions have not yet been examined.

D. Hall created an ad hoc advisory group for MODIS snow and ice products, of which J. Key is a member. In response to comments from the scientific community, her group is planning a MODIS ice surface temperature product based on our algorithm. There has been no significant action during the past year.

7. Scientific Computing Facility (BU)

One of the originally Sun workstations acquired on this grant (at the University of Colorado) has been replaced with a Sun Ultra 10. Additional disks have been purchased for storage of satellite data. A new black and white printer will be acquired before the end of the project year. Funds for additional disk storage and a tape drive are requested, as detailed in "Budget Justification".

8. POLES-SUPPORTED PUBLICATIONS

The papers listed below were supported in whole or in part by POLES (NAGW-2407).

8.1 Reviewed Papers

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

Serreze, M.C., J. Box, and J. Key, 1998. A new monthly climatology of global radiation for the Arctic and comparisons with NCEP/NCAR reanalysis and ISCCP-C2 fields. *J. Climate,* 11(2), 121-136.

8.2 Proceedings Papers

Key, J.R. and A.C.K. Chan, 1999. Global and regional trends in 1000 mb and 500 mb wave cyclone frequencies, 1958-1997. *Proceedings of the Tenth Symposium on Global Change Studies,* American Meteorological Society, Dallas, TX, January 10-15, 388-391.

Key, J., D. Slayback, C. Xu, and A. Schweiger, 1999. New climatologies of polar clouds and radiation based on the ISCCP "D" products. *Proceedings of the Fourth Conference on Polar Meteorology and Oceanography,* American Meteorological Society, Dallas, TX, January 10-15, 227-232.

BUDGET JUSTIFICATION

The overall project period at the University of Wisconsin is nine months. A budget is provided for two periods as requested by the University of Washington. The budget total is $24,000 less (40% less) than the original BU budget. This is due primarily to the fact that POLES does not need to cover any of J. Key's salary. His involvement in the project will not change, however, as NOAA has agreed that this project fits well with the NOAA group's objectives. The project tasks and schedule have not changed.

Funds are requested to support one graduate student for nine months and another for four months during the first period. The short-term graduate student will function primarily as a scientific programmer to assist in data processing tasks required for the processing of the AVHRR Polar Pathfinder (APP) data set. The other graduate student will be more involved in basic climate research and in the analysis of the APP results.

Additional hard disks, memory, and a new tape drive are required for satellite data transfer and storage. While we upgraded our storage capacity last year, our recent decision to process the AVHRR Polar Pathfinder dataset for cloud properties and radiative fluxes brings with it the need for significantly more on-line storage space. Our current 8 mm tape drive is more than five years old and will not read all of the commonly used formats.

The software maintenance funds are for the annual maintenance fee for IDL (three network floating licenses, one PC license) and upgrades to other software such as FrameMaker. Hardware maintenance funds are for the support of our Scientific Computing Facility.

Other funds are requested for travel to Seattle and a national conference, page charges for journal papers, data tapes and other supplies, and computer hardware maintenance.

Polar Exchange at the Sea Surface (POLES), Univ. of Washington subcontract
Project year: 9/1/99 - 5/31/00
CIMSS, University of Wisconsin

	9/1/99-12/31/99		1/1/00-5/31/00	
Salaries				
J. Key, no cost to project				
Grad Student RA, 50% FTE, AY (9 mo., 4 & 5)	$	5,014	$	6,268
Grad Student RA, 50% FTE, AY (4 mo., 1st period)	$	5,014		
Total Salaries	**$**	**10,028**	**$**	**6,268**
Fringe Benefits, RA (16.5%)	**$**	**1,655**	**$**	**1,034**
Travel, 2 trips, 1 to Seattle, one to nat'l conf.	**$**	**1,200**	**$**	**1,200**
Other				
Publications	$	700	$	700
Supplies, postage, telecom.	$	150	$	159
Software purchase and maintenance			$	1,100
Computer hardware maintenance	$	300	$	300
Total "Other"	**$**	**1,150**	**$**	**2,259**
Equipment				
External hard disks	$	2,600		
Computer memory	$	350		
Color printer	$	2,600		
8 mm tape drive	$	1,600		
Total Equipment	**$**	**7,150**	**$**	**-**
Total Direct Costs	**$**	**21,183**	**$**	**10,761**
Indirect Costs (44%)		**9,321**		**4,735**
TOTAL PROJECT COST, EACH PERIOD:	**$**	**30,504**	**$**	**15,496**
TOTAL PROJECT COST:	**$**	**46,000**		