Antarctic Cloud Properties and Their Effect on the Surface Energy Budget

NSF Award OPP-9818595

First-half Year 1 Report
Plans for Years 2 and 3 at the University of Wisconsin
Transfer Request

Report Period: January 1, 1999 - July 20, 1999
Project Duration: January 1, 1999 - December 31, 2001 (3 years)

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PURPOSE

This document contains a summary of progress to date for the first half of the first project year at Boston University, a description of plans for the remaining two and a half years at the University of Wisconsin, and a revised (reduced) budget. It is provided as part of the request to transfer NSF award number OPP-9818595 from Boston University to the University of Wisconsin-Madison.

OBJECTIVES

The purpose of the proposed research is to characterize clouds over Antarctica using satellite data, and to assess their influence on the surface energy budget relative to other meteorological variables using data and models. Specifically, our objectives are to:

- Construct a cloud climatology (amount, height, temperature, and microphysical properties) for the Antarctic continent and surrounding ocean from satellite data.
- Assess the relative importance of various cloud, atmospheric, and surface properties on the surface energy budget using models forced with in situ and satellite-derived data.
- Generate a surface energy budget product using a combination of satellite-derived quantities and model analyses (ECMWF or NCEP) with a regional climate model. While the uncertainty in some variables may be large, the energy budget components resulting from this high degree of data assimilation will undoubtedly be more accurate than anything else currently available on the large scale.

The proposed research extends recent work by the PI and colleagues on high-latitude cloud characteristics, Arctic surface radiation budget from satellite data, and methods of satellite data assimilation for surface energy balance estimation. It complements work by other investigators on cloud property retrieval over Antarctica and GCM simulations of Antarctic cloud effects.

SUMMARY OF PROGRESS

Research performed to date has focussed on the acquisition of surface meteorological and radiation data for Antarctic stations, comparison of surface radiation to satellite-derived quantities, and the role of heat advection in explaining the differences between the clear and cloudy sky surface temperature. All tasks described below are incomplete and will continue for at least the next 12-15 months.

In-situ Data Collection

Surface observations of the energy balance components are essential for validating models and satellite retrievals. We have contacted scientists from a number of different countries that operate meteorological stations around Antarctica, and have been provided with a variety of data sets. Most of the meteorological stations are located along the coast, except for South Pole Station and the Automatic Weather Stations.

For example, hourly meteorological data (wind direction, wind speed, wind steadiness factor, pressure, air temperature, dew point temperature and precipitation amount) and hourly radiation data (total downwelling shortwave radiation) have been obtained for the South Pole Observatory from 1976 to 1998. The Meteorology Observatory of Neumayer Station made available 3-hourly synoptic data (2-m air temperature, 10-m wind speed and direction, relative humidity, cloud amount, cloud height) and daily radiation data (upwelling and downwelling shortwave, upwelling and downwelling longwave) during the years 1986-89. We have also obtained hardcopies of data from the National Institute of Polar Research (Japan Meteorological Agency) for Syowa Station.

Cloud-Radiation-Temperature Relationships at Neumayer Station

Our hypothesis is that the primary effect of clouds on the surface energy budget is a result of their radiative effect, often called "cloud forcing", rather than associated changes in heat and moisture advection. Daily synoptic and radiation data from Neumayer Station are being investigated to better understand the relationship between surface air temperature, cloud fraction, and wind speed. A daytime example is shown in Figure 1. The following observations can be made:

- Generally, the surface air temperature increases with an increase in cloud amount during the winter, illustrating the warming effect of clouds in the absence of solar radiation.
- The temperature-cloud relationship is more complicated in summer with competing cooling and warming effects of clouds. Both positive and negative correlations can occur. The surface temperature is also affected by cloud optical depth, cloud height, heat and moisture advection.
- A strong positive correlation exists between the surface air temperature and wind speed, especially in winter. It is also obvious that cloud fraction increases with increasing wind speed, which explains (in part) the strong temperature-wind relationship.
- The pattern of changes in net radiation does not agree with that of surface temperature, though it was observed that the surface temperature responds to changes in surface net radiation after approximately one day.

In order to investigate the importance of heat advection to changes in surface temperature, we are using daily NCEP reanalysis data. ECMWF reanalysis data was not employed because a recent study (Walsh and Chapman, 1998) showed that the differences between cloudy and clear surface temperature are underestimated. Heat advection is calculated from the NCEP winds and temperatures for grid boxes surrounding Neumayer Station. Results for one month are shown in Figure 2, where temperature, cloud cover, and heat/moisture advection are compared during April 1987. Heat and moisture advection are represented in the figure by $[(U_1T_1 - U_0T_0) + (V_2T_2 - V_0T_0)]$ and $[(U_1q_1 - U_0q_0) + (V_2q_2 - V_0q_0)]$ where U and V are the east-west and north-south wind components, T is temperature, and q is specific humidity, and the subscripts are for different grid cells, with zero representing Neumayer Station.

Both heat and moisture advection exhibit a positive correlation with cloud fraction, which is evidence of the fact that at high latitudes cloud formation is controlled primarily by the large-scale horizontal transport of heat and moisture. So while the cloud radiative effect may be the dominant process in controlling surface temperature and the energy budget overall, the relative contribution of advection must also be considered.

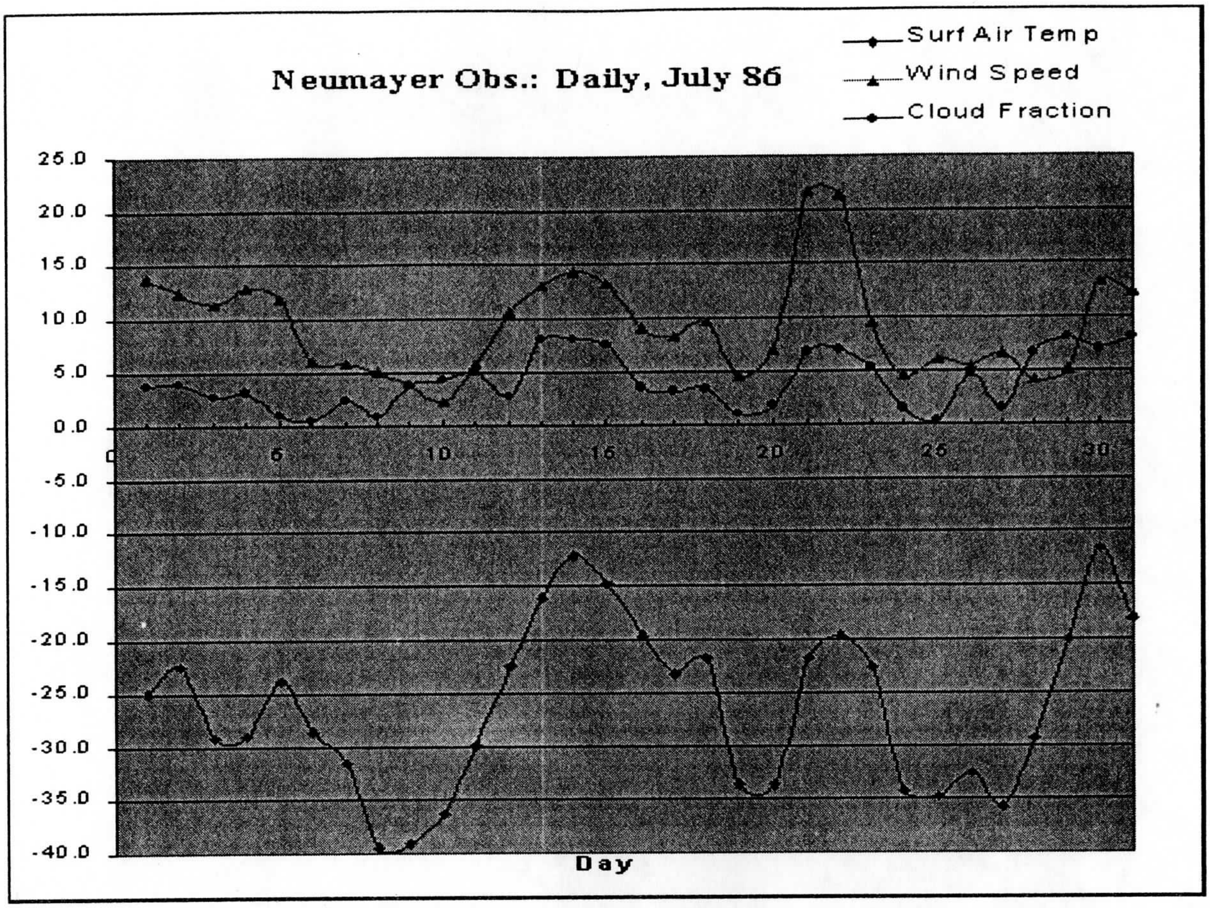

Figure 1. Surface air temperature, wind speed, and observed cloud fraction for Neumayer Station, Antarctica, during July 1986.

Model Evaluation

Modeling studies have been undertaken with both single-column and regional models. The new SCCM, which is a single-column version of NCAR's CCM3, has been run for a variety of daytime and nighttime cases in an attempt to evaluate theoretically the effects of clouds on the surface temperature of sea ice. The results have been compared to observations from SHEBA and Neumayer Station and to other single column models. Unfortunately, SCCM underestimates the effects of clouds when the surface temperature is low. The reason for this is unclear, but we hypothesize that the diffusion coefficients are too large and the model is trying to heat too much of the lower troposphere.

Comparisons of cloud amount generated by the ARCSyM regional climate model with the ISCCP D1 product during the polar summer indicate that the model grossly underestimates the cloud cover. Tests are underway for other times of the year.

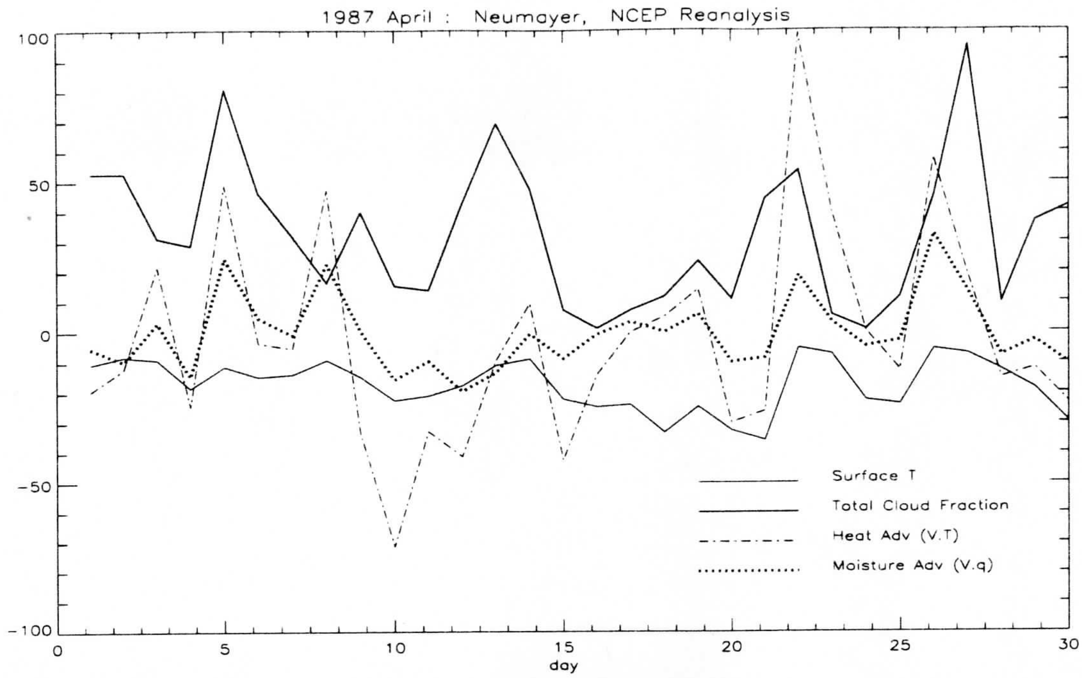

Figure 2. Surface temperature (lower solid line), cloud fraction (%, upper solid line), and proxies for heat and moisture advection for April 1987 at Neumayer Station, Antarctica, based on daily NCEP data.

ISCCP D1 Data Extraction and Rough Assessment

One goal of the project is to derive cloud properties such as cloud amount, height, phase, and optical depth from satellite data (AVHRR). Our intention is to evaluate the polar portion of the International Satellite Cloud Climatology Project (ISCCP) cloud product by comparisons to surface observations and to our own satellite retrievals of cloud and surface properties. We previously identified a number of deficiencies in the ISCCP product at high latitudes, but have also found that the new "D" data set is a significant improvement over the original "C" product. Comparisons of surface observations of the downwelling shortwave flux at South Pole Observatory to modeled fluxes using the ISCCP D1 cloud data as input reveal errors of 5-20% for instantaneous observations. Errors on the order of 0-10% for monthly averages are typical.

Tasks to be Completed

As only seven months have elapsed since the project began, all major tasks remain to be completed. The major tasks are to construct a cloud climatology from satellite data (ISCCP and AVHRR Polar Pathfinder), perform modeling studies to assess the relative importance of various cloud, atmospheric, and surface properties on the surface energy budget, and generate a surface energy budget product using a combination of satellite-derived quantities and model analyses.

The schedule of activities as originally proposed has not changed (Table 1). The proposed start date was 9/1/98, but was changed by mutual agreement to 1/1/99. Table 1 reflects this change.

TABLE 1. Schedule of activities for the three project years.

Project Year	Tasks
Year 1: 1/1/99 - 12/31/99	• Extract and summarize the ISCCP D1 cloud product for available years; begin climatological analyses of cloud properties. • Compute cloud properties and surface radiative fluxes from AVHRR Polar Pathfinder data. • Collect and preprocess in situ data (e.g., South Pole radiation and meteorology; GEBA data for other stations). • Begin model modifications for data assimilation. • Begin surface energy budget sensitivity studies with single-column model.
Year 2: 1/1/00 - 12/31/00	• Continue compilation of ISCCP D1 cloud product for additional years; continue climatological analyses of cloud properties. • Continue surface energy budget sensitivity studies with single-column model and begin analyses with regional model. • Complete the analyses of the cloud properties data: sensitivities, climatology, implications.
Year 3: 1/1/01 - 12/31/01	• Document cloud dataset and compile into standard format; make available via the Web. • Compile, document, and make available the surface energy budget product. • Complete the analyses of the surface energy budget data: sensitivities, climatology, implications.

PUBLICATIONS SUPPORTED BY OPP-9818595

Key, J. and A.M. Wong, 1999. Estimating the cloudy sky surface temperature of sea ice with optical satellite data. *IGARSS'99 Proceedings*, Hamburg, Germany, 28 June - 2 July.

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.

In preparation:

Wong, A.M., J.R. Key, 1999. The effect of clouds on surface temperature of sea ice and implications for remote sensing, *J. Geophys. Res.*, in preparation.

Additionally, A.M. Wong's Master's thesis is in preparation (expected completion in August 1999). The thesis deals with the effects of clouds on the surface temperature of sea ice.

BUDGET JUSTIFICATION

As we are only seven months into the fist project year, the overall project period at the University of Wisconsin will be two years and five months. The budget total is more than $30,000 less (20% less) than the original BU budget. This is due primarily to the fact that the project does not need to cover any of J. Key's salary. His involvement in the project and level of effort 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.

Apart from J. Key's salary and different (lower) benefits, indirect costs, and graduate student stipends, the budget is comprised of the same items as the original. Funds are requested to support two graduate students at the University of Wisconsin. Graduate student stipends are for the academic year and summer. Because the graduate research assistants currently funded on the project at BU will not be transferring to UW, graduate students will be selected from the UW applicant pool.

Two trips per year are anticipated for the purpose of attending national conferences and presenting scientific results. Costs of page charges, software and hardware maintenance, and supplies are included in the budget.

Equipment funds are requested for the purchase of a high-end PC to be used by one of the graduate students for data processing. The other graduate student will use computing resources available through the Cooperative Institute for Meteorological Satellite Studies (CIMMS) and the Department of Atmospheric and Oceanic Sciences.

Antarctic Cloud Properties and Their Effect on the Surface Energy Budget (NSF)
Project period: 9/1/99 - 12/31/01
CIMSS, University of Wisconsin

	Year 1 9/1/99- 12/31/99	Year 2 1/1/00- 12/31/00	Year 3 1/1/01- 12/31/01
Salaries			
J. Key, no cost to project			
Grad Student RA, 50% FTE, 4, 12, & 12 mo.	$ 5,014	$ 15,042	$ 15,644
Grad Student RA, 50% FTE, 4, 12, & 12 mo.	$ 5,014	$ 15,042	$ 15,644
Total Salaries	**$ 10,028**	**$ 30,084**	**$ 31,288**
Fringe Benefits, RA (16.5%)	**$ 1,655**	**$ 4,964**	**$ 5,163**
Travel, 2 trips per year	**$ 2,200**	**$ 2,200**	**$ 2,200**
Other			
Publications	$ 800	$ 1,200	$ 1,400
Supplies, postage, telecom.	$ 150	$ 165	$ 180
Software purchase and maintenance	$ 300	$ 500	$ 700
Computer hardware maintenance	$ 200	$ 225	$ 250
Total "Other"	**$ 1,450**	**$ 2,090**	**$ 2,530**
Equipment			
PC workstation	$ 3,500		
Data storage		$ 700	$ 700
Total Equipment	**$ 3,500**	**$ 700**	**$ 700**
Total Direct Costs	**$ 18,833**	**$ 40,038**	**$ 41,881**
Indirect Costs (44%)	**$ 8,287**	**$ 17,617**	**$ 18,428**
ANNUAL PROJECT COST:	**$ 27,120**	**$ 57,655**	**$ 60,309**
TOTAL PROJECT COST:			**$ 145,084**