

**Documenting, Understanding, and Predicting the Aggregate
Surface Radiation Fluxes for SHEBA**

NASA Grant NAG5-4903

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**Annual Report, Year 2
Plans for Year 3 at the University of Wisconsin
Transfer Request**

Report Period: June 15, 1998 - April 19, 1999
Project Duration: June 15, 1997 - June 14, 2000 (3 years)

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July 25, 1999

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

PURPOSE

This document contains a summary of progress to date for the second project year, a description of plans for the final project year at the University of Wisconsin, and a revised (reduced) budget. It is provided as part of the request to transfer NASA award number NAG5-4903 from Boston University to the University of Wisconsin-Madison.

This is a group project with the University of Colorado (CU) as the lead institution, where Judith Curry is the Principal Investigator. The overall project is jointly funded by NASA and NSF. The progress reported herein is that specific to Boston University, but no attempt has been made to separate NASA and NSF activities.

OBJECTIVES

The overall project addresses issues related to the cloud-radiation feedback and the ice-albedo feedback through a coordinated effort that utilizes aircraft and satellite observations in conjunction with surface-based observations from SHEBA. The field measurements will be used to developing an empirical and theoretical understanding of radiative transfer in the Arctic, which can be used to develop improved models for surface radiation properties and surface radiation fluxes.

Our specific objectives are to:

1. document the variations of surface characteristics, surface radiation fluxes and cloud characteristics on a horizontal scale of approximately $(60 \text{ km})^2$ using research aircraft
2. use aircraft observations in concert with surface observations and models to develop an understanding of how the surface radiation flux components vary with surface and cloud characteristics
3. develop an empirical and theoretical understanding of 3-D radiative transfer in the Arctic and use this understanding to develop an improved parameterization of surface radiative characteristics and a 1-D radiative transfer model for the Arctic that can be used to determine surface radiative fluxes and the radiation feedbacks in climate models.
4. devise and test strategies to determine the aggregate-scale surface radiative flux components for each surface type during periods when aircraft is unavailable, using only surface and satellite observations in conjunction with models
5. create an integrated dataset of the aggregate-scale surface characteristics, surface flux components, and cloud characteristics for use by the SHEBA community in Phase III investigations

At Boston University, J. Key and two graduate students (one funded by NASA and one by NSF) are addressing all of these to some degree, but are focussing on #2 and #3 at present. Results to date are described in the next section.

SUMMARY OF PROGRESS

Progress has been made in three areas: (1) modeling and empirical studies of the effects of clouds on the surface temperature, (2) modeling the effects of cloud horizontal and vertical inhomogeneity on surface fluxes, and (3) satellite-retrievals of cloud and surface properties for the SHEBA period.

The Influence of Clouds on Surface Temperature

In the Arctic cloud cover is extensive at all times of the year, with monthly means ranging from 50-80%. Retrievals of the clear sky surface temperature are therefore of limited utility for climate studies. Is it possible to estimate the surface temperature under cloud cover from thermal satellite data? Previous studies have used nighttime data to examine the relationship between clouds and surface temperature. Here a thermodynamic model is used to extend the analyses to daytime conditions. The thermodynamic model includes radiative transfer, sea ice/snow energy balance, and atmospheric turbulence components.

Figure 1 illustrates the effect of clouds on the surface temperature of sea ice. The results shown were determined with SCCM, a single column version of NCAR's CCM3 climate model. All other surface and atmospheric properties were held constant while cloud optical depth was varied.

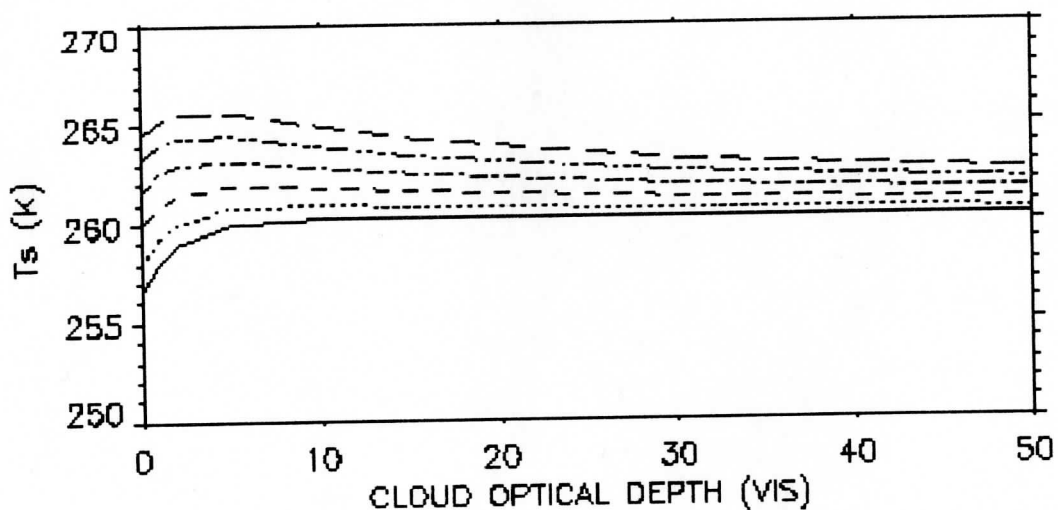


Fig. 1. Modeled (SCCM) change in the surface temperature of sea ice with a change in visible cloud optical depth. Lines correspond to different solar zenith angles from 90 degrees (bottom, solid line) to 40 degrees (top) in increments of 10 degrees. For this simulation the ice thickness is 2 m, snow depth is 20 cm, and the wind speed is 3 m/s.

Figure 2 shows the modeled surface temperature of sea ice over time, for transitions from cloudy to clear and back to cloudy with a fixed cloud optical depth. Results are given for a variety of wind speeds and for fixed cloud and surface properties. The figure illustrates the effect of clouds on the surface temperature during a transition from cloudy to clear conditions during the day and

at night (no solar radiation). The warming effect of clouds at night is readily apparent, as is the cooling effect during the day. The rate of cooling or warming depends on the near-surface winds, ice and snow thickness, and cloud properties. An equilibrium surface temperature model with atmospheric turbulence was used to generate the data in Figure 2. Unlike SCCM, the surface temperature adjusts to changes in cloud cover almost immediately.

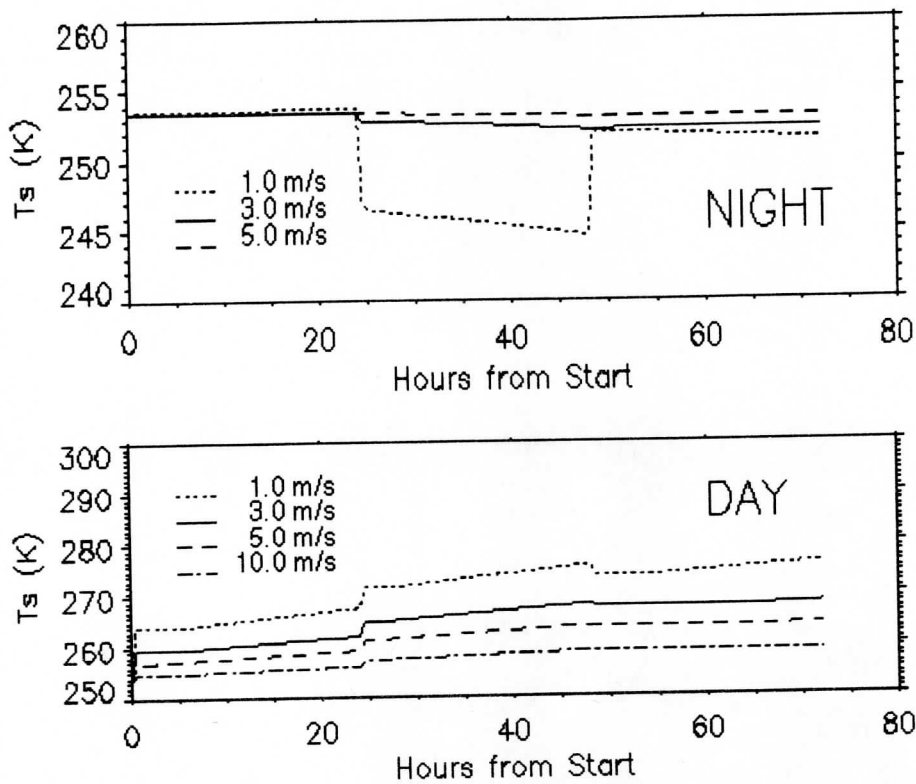


Fig. 2. Modeled (not SCCM) surface temperature over time for nighttime (top) and daytime (bottom) cases, and for various wind speeds. The time series incorporates transitions from cloudy to clear after 24 hours, then to cloudy again at hour 48.

If we could accurately simulate changes in surface temperature with a model, we could conceivably develop a parameterization of the cloudy sky temperature as a function of the previous (or nearby) clear sky temperature, cloud optical depth, and near-surface wind speed. Such a parameterization could be used to provide a spatially complete satellite-derived surface temperature product. However, SCCM does not appear to be adjusting the surface temperature under clear-cloudy transitions quickly enough. SHEBA surface observations show wintertime changes of 5-15 degrees within 6-12 hours, but SCCM takes more than 24 hours for a change of that magnitude. This problem is under investigation.

The Effects of Horizontal Variability of Cloud on the Surface Radiation Budget

One of the primary goals of our project is to assess the effect of 3-dimensional (3D) surface and

cloud structure on large-area aggregate fluxes and satellite retrievals of cloud and surface properties. We have begun the investigation using the 3D radiative transfer model SHDOM, written by F. Evans (Univ. of Colorado), a Co-PI on the project. Figure 3 illustrates the effect of horizontal variability of cloud optical depth on downwelling visible fluxes as a function of solar zenith angle and surface albedo. The plot gives average optical depths over a hypothetical cell (e.g., a GCM grid cell), with varying optical depths but identical geometrical thickness at every point in the cell. Clearly, the assumption of a horizontal, uniform cloud layer, as often used in GCMs, can result in significant errors in fluxes. Errors in top-of-atmosphere radiances are expected to be much larger. Experiments such as this will be used to assess the uncertainty in aggregate fluxes due to 3D variability, and will (hopefully) lead to a method of parameterizing 3D effects in a 1D radiative transfer model. Additionally, we hope that this work can lead to a method of correcting what we believe are large errors in satellite retrievals of cloud optical depth at low sun angles.

Estimating Cloud and Surface Properties from AVHRR Data

Cloud and surface properties have been estimated from AVHRR data for the SHEBA year. The results presented here are preliminary (i.e., version 0) and may change in future retrievals. Five kilometer data from the AVHRR Polar Pathfinder project were used in the analyses. The retrieval algorithms of the Cloud and Surface Parameter Retrieval system were applied (CASPR; <http://stratus.bu.edu/caspr/caspr.html>).

Time series of area averaged results are shown in Figure 4. The area covered by the AVHRR subsets extends from central Alaska to the North Pole, and from Banks Island to the Laptev Sea. The plots give the mean values over the entire image area. Time is shown as decimal year, where 98.0 is January 1, 1998. Results for cloud pressure and surface radiative fluxes are not given for periods with no radiosonde data. Additional results are provided on the SHEBA remote sensing group web site here at BU (<http://stratus.bu.edu/sheba>).

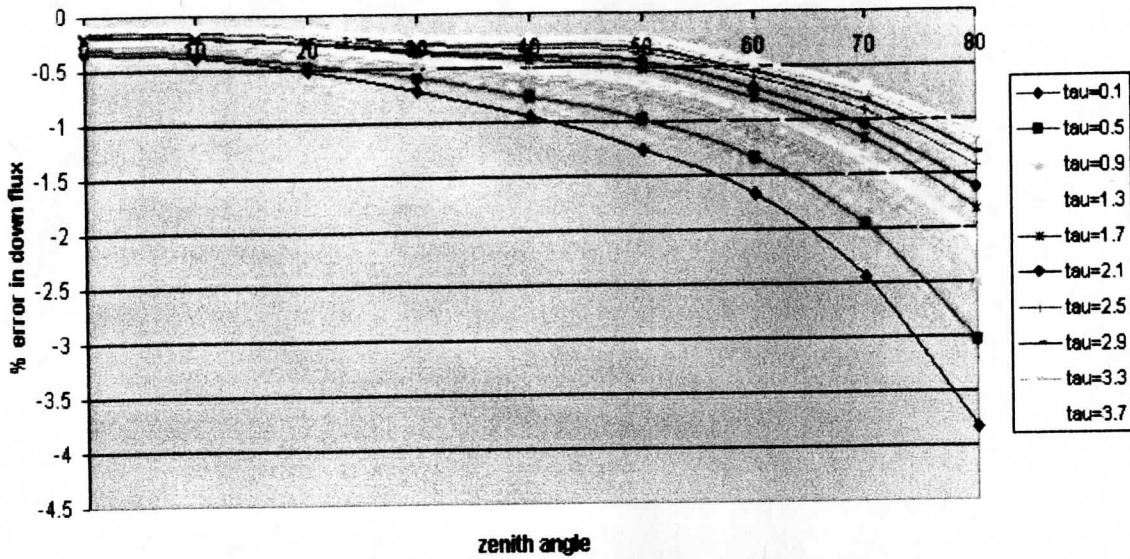
While there are some obvious outliers in the results, of greater concern are the large cloud optical depths during the spring. These may be the result of unmodeled three-dimensional radiative transfer effects at low sun angles. However, the fact that such large optical depths are not observed during the fall implies that either the vertical and horizontal cloud structure is not important or that springtime clouds have a different morphology than clouds in the fall.

Comparisons of these satellite-derived cloud and surface properties with surface observations are in progress, using dates identified by the remote sensing group at the recent SHEBA investigators (Tucson, January 1999).

PLANS FOR THE FINAL PROJECT YEAR

During the final project year we will continue work on the surface temperature under cloud cover and on the effect of horizontal variability on aggregate area surface fluxes, including three-dimensional effect. Satellite retrievals will be refined and results will be made available to other SHEBA investigators. Validation studies will be done using surface and aircraft observations collected during the experiment. Much of this work is already underway.

Downwelling Flux as a Function of Zenith Angle



Downwelling Flux as a Function of Ground Albedo

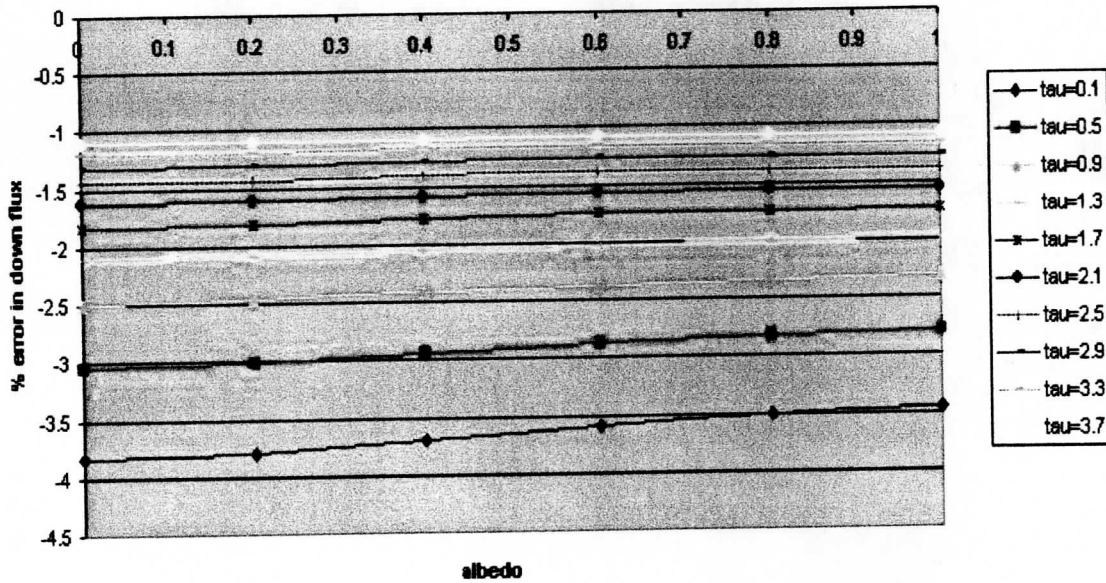


Fig. 3. Differences ("error") in downwelling visible (narrow band) flux at the surface computed using one-dimensional and three-dimensional radiative transfer models over a range of cloud optical depths. The top plot shows the error as a function of solar zenith angle; the bottom plot gives the error as a function of surface albedo.

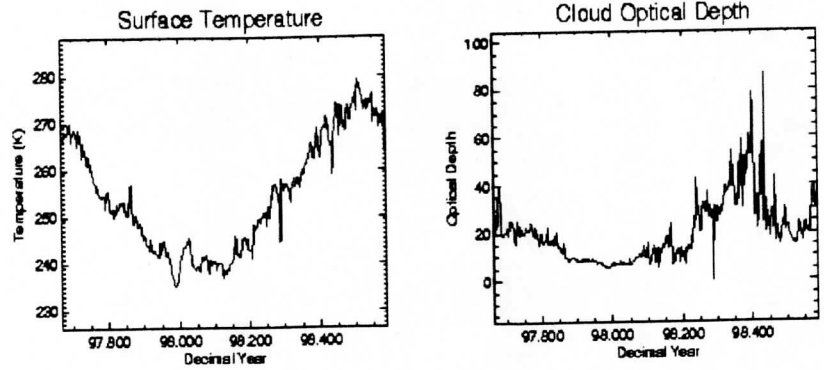
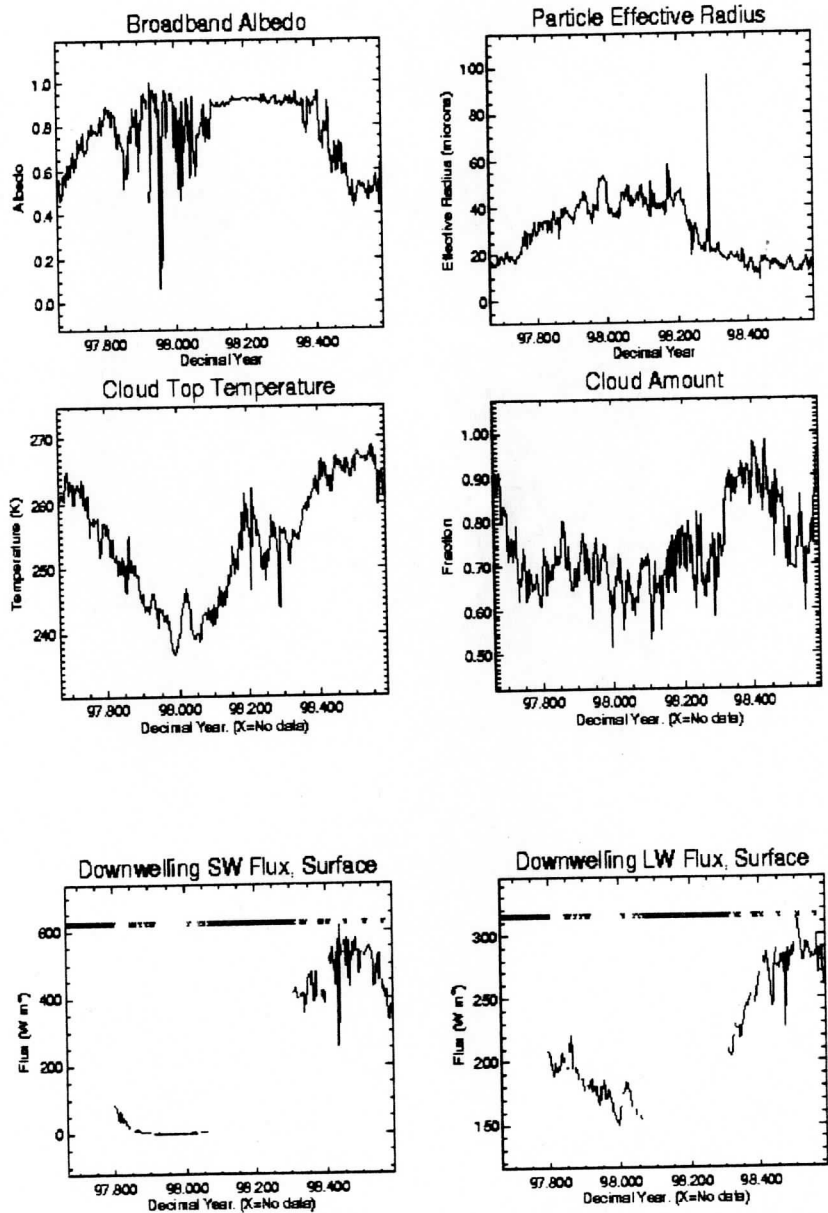


Fig. 4. Satellite retrievals of cloud and surface properties for the SHEBA region using AVHRR data. The area covered is from central Alaska to the North Pole, and from Banks Island to the Laptev Sea. Shown are area averages for the SHEBA year, where decimal year 98.0 is January 1, 1998.



PUBLICATIONS SUPPORTED BY NAG5-4903 AND OPP-9701757

- Key, J., 1999. Cloud particle phase determination with the AVHRR. *J. Appl. Meteorol.*, submitted (April).
- Schweiger, A.J., R. Lindsay, J. Key, and J. Francis, 1999. On the status of arctic clouds in multi-year satellite data sets, *Geophys. Res. Lett.*, 26(13), 1845-1848.
- 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.
- Wong, A.M., J.R. Key, and R.S. Stone, 1999. The effect of clouds on surface temperature and implications for remote sensing at high latitudes. *Proceedings of the Fourth Conference on Polar Meteorology and Oceanography*, American Meteorological Society, Dallas, TX, January 10-15, 294-299.
- Curry, J.A., J. Pinto, J. Maslanik, and J. Key, 1999, Overview of C-130 research aircraft observations obtained during SHEBA/FIRE. *Proceedings of the Fourth Conference on Polar Meteorology and Oceanography*, American Meteorological Society, Dallas, TX, January 10-15.

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). It deals with the remote sensing of the cloudy-sky surface temperature.

BUDGET JUSTIFICATION

As we are already three months into the final project year (though no funds allocated for that year have been spent), the overall project period at the University of Wisconsin will be nine months. The budget total is approximately \$11,000 less (21% 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 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 five months during the Spring semester. The latter 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 for the SHEBA year. The other graduate student is the same person funded at Boston University (Xuanji Wang), who is transferring to Wisconsin. He will be more involved in algorithm development and in the analysis of the APP results.

Travel funds are requested for participation in project meetings with the other investigators (Boulder), and for presentation of results at national conferences (e.g., AGU or AMS). Other direct costs include page charges for the publication of scientific results in national and international journals, research related supplies (e.g., data tapes), computer hardware and software maintenance charges for the use of existing computing equipment, and costs of long-distance phone calls and express mail needed for communication with project personnel at the lead institution (University of Colorado) and with the scientific community. Additional hard disks and memory are required for satellite data transfer and storage.

**Documenting, understanding, and predicting the aggregate
surface radiation fluxes for SHEBA (NASA)**

Project year: 9/1/99 - 6/14/00
CIMSS, University of Wisconsin

Salaries

J. Key, no cost to project	
Grad Student RA, 50% FTE, 9 mo.	\$ 11,282
Grad Student RA, 50% FTE, 5 mo. (1/1/00-5/31/00)	\$ 6,268
<i>Total Salaries</i>	\$ 17,550

Fringe Benefits, RA (16.5%)	\$ 2,896
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Travel, 3 trips, 2 to Boulder, one to nat'l conf.	\$ 2,700
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Other

Publications	\$ 1,200
Supplies, postage, telecom.	\$ 200
Software purchase and maintenance	\$ 300
Computer hardware maintenance	\$ 200
<i>Total "Other"</i>	\$ 1,900

Equipment

External hard disks	\$ 2,600
Computer memory	\$ 350
<i>Total Equipment</i>	\$ 2,950

Total Direct Costs	\$ 27,996
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Indirect Costs (44%)	12,318
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TOTAL PROJECT COST:	\$ 40,314
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