National Snow and Ice Data Center
Cooperative Institute for Research in Environmental Sciences

Validation Studies and Sensitivity Analyses for Retrievals of Snow Albedo from EOS AM-1 Instruments

Progress Report for 1997-1999 Work

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Home Page: http://www-nsidc.colorado.edu/PROJECTS/ALBEDO

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1. Background

1.1 Project Summary

As part of NASA's effort to map and characterize the Earth system from space, this investigation is engaged in validating snow albedo retrievals from instruments on board Terra, the Earth Observing System satellite. Surface albedo, the surface hemispheric reflectivity integrated over the solar spectrum, is a fundamental component needed for determining the radiation balance of the Earth-atmosphere system. It also appears to control not only the amount, but also the sign of cloud radiative forcing in the polar regions. Because snow is strongly forward scattering and has a variable albedo across the solar spectrum, spaceborne measurements in a few channels and one or few viewing angles are not representative of the spectrally-integrated albedo. In addition to validation activities, we are also undertaking sensitivity studies to investigate how atmospheric properties, topographic complexity and spatial resolution affect albedo retrievals.

Surface albedo will be one of the standard data products to be generated from data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The Multiangle Imaging SpectroRadiometer (MISR) requires characterization of the angular reflectance characteristics over snow. A critical concern is the current lack of an aerosol retrieval method that provides accurate estimates over snow-covered surfaces. This prevents accurate atmospheric correction of MODIS and MISR data over snow. Through a combination of model simulations and field validation experiments (both pre-launch and post-launch) this research will validate an existing scheme for converting measurements of snow bidirectional reflectance to snow albedo for both MODIS and MISR. A narrowband-to-broadband conversion will be developed and tested for both instruments allowing intercomparison of broadband albedo retrievals between MODIS and MISR. In sensitivity analyses, we will evaluate how atmospheric characterizations and digital elevation model errors affect the accuracy of the albedo estimates.

We are working in close collaboration with both MISR and MODIS team members. Our 1998 pre-launch field validation campaign at Mono Lake area was conducted with the support of MISR scientists who contributed ground instruments and technical expertise. A planned post-launch campaign (Wisconsin 2000) is being coordinated with Dr. Dorothy Hall and will again involve ER-2 overflights and ground based instruments with the addition of Terra satellite overpasses. We are working with Dr. Jiancheng Shi, of the University of California, Santa Barbara who will be performing validation of the snow covered area retrievals over alpine regions for the MODIS instrument.

1.2 List of Objectives

1. Validate snow albedo retrievals from MODIS and MISR
   - Validate snow BRDF model
   - Quantify sensitivity of snow albedo estimates to atmospheric variables
   - Quantify effects of DEM inaccuracies on snow albedo estimates
2. Develop and test a narrowband-to-broadband snow albedo conversion scheme for MODIS and MISR
3. Perform intercomparisons of broadband snow albedo estimates from MODIS and MISR

2. Scientific Accomplishments

2.1 Mono Lake Field Experiment, March 1998

In the spring of 1998, we participated in a multi-instrument 2-week field campaign near Mono Lake, California March 9 -20, 1998. The study site, located south of Mono Lake in the Eastern Sierra Nevada (see Figure 2), was the focal point for calibration and validation of the snow surface albedo, atmospheric characterization and snow surface temperature from AirMISR and the MODIS Airborne Simulator (MAS), both flown on the ER-2. The two week field campaign (3/9/98 - 3/20/98) represents the first time that MODIS and MISR scientists have come together to study snow cover. With extensive support from JPL scientists Dr. James Conel and Mark Helmlinger of the MISR validation team, Drs. Nolin and Stroeve were able to collect a unique data set of snow bidirectional reflectance using a continually rotating radiometer known as PARABOLA. Data from this instrument have now been calibrated and compared with model results from DISORT. These results are described in greater detail in Section 2.2.

Additional measurements included atmospheric optical depth, diffuse and total irradiance and snow physical properties. Ground-based snow spectral reflectance measurements were made using an Analytical Spectral Devices FieldSpec FR field spectrometer. Examples of these data are shown in Figure 1.

Airborne data were successfully acquired on March 10. MAS data were collected over the study site, concurrent with the ground-based measurements of atmospheric and snow properties. The MAS data have now been calibrated (see Figure 2) and are in close agreement with ground-based snow reflectance measurements. Unfortunately, technical problems with AirMISR prevented data collection with that instrument. Both technical problems and cloud cover interfered with airborne data collection later in the week but additional ground measurements were made. MODIS scientist Dr. Zhengming Wan was also involved in this campaign in which members of his group measured snowpack and ground temperatures for validation of their MODIS land surface temperature product.

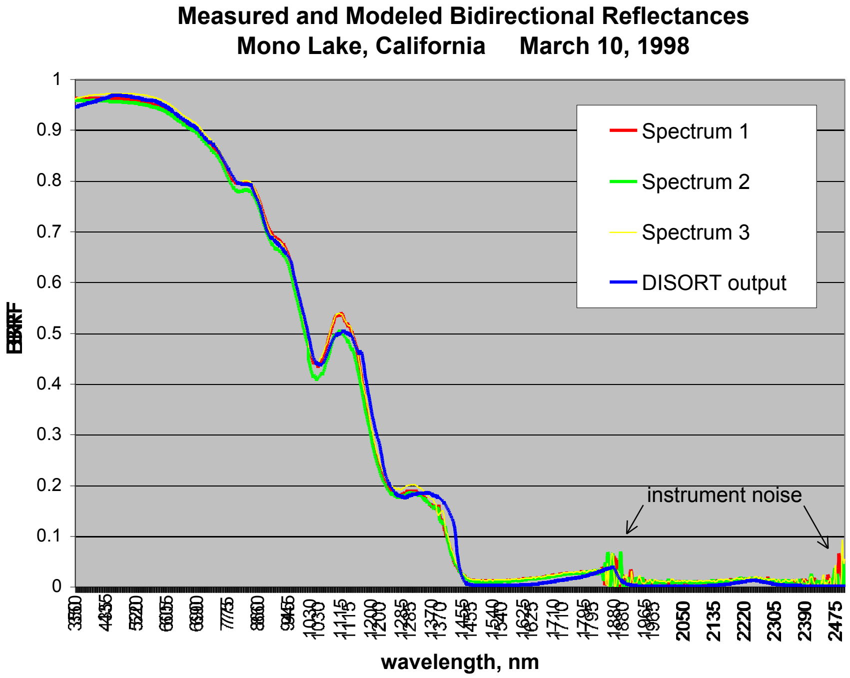


Figure 1. Measured reflectances from the study site south of Mono Lake. Measurements were made using an ASD FieldSpec FR portable field spectrometer. These data snow excellent agreement with model output the DISORT radiative transfer model.

Figure 2. Calibrated reflectance image from the MODIS Airborne Simulator (MAS), Band 1 (0.47 μm) showing the study site for the March 1998 experiment. Mono Lake is to the north of the site.

2.2 Snow BRDF Modeling Results

The DIScrete Ordinates Radiative Transfer (DISORT) model (Stamnes et al., 1988) has been used to model the directional-hemispherical and angular spectral reflectances from snow for user defined snow properties(grain size, density, layering, depth), illumination and viewing geometries, and atmospheric conditions. Mie theory is used to calculate single particle scattering and absorption. The model is used to convert remotely sensed measurements of bidirectional reflectance to surface albedo. Conversion factors are determined from the model runs and stored in a lookup table. Part of the effort of this investigation is to provide further validation for this conversion approach. To date, numerous runs of the model have been tested to examine the effects of different snow properties on the BRDF of snow. These include snow grain size, concentrations of light absorbing impurities, snow depth and the proportion of diffuse and direct irradiance. While these model runs are still undergoing analysis, a number of patterns are clear.

Validation of the model is being done through comparison to calibrated ground-based measurements from PARABOLA and the ASD FieldSpec FR spectrometer. PARABOLA measures the spectral reflectance in both the upward and downward hemispheres, in angular increments of 5 degrees. It has eight channels (0.44, 0.55, 0.65, 0.86, 0.94, 1.03, 1.665, and a PAR band). A calibrated spectralon target is viewed at the end of each sequence of angular measurements (approximately every 3 minutes) for use in determining reflectance. Results of the PARABOLA data show very good agreement with the DISORT model output. Forward scattering is stronger in the near infrared channels than in the visible channels. Spectral albedos were calculated by integrating over the downward-looking hemisphere. Instrument self-shadowing was problematic and was removed from the albedo computation by interpolating values over the narrow shadow region. The range in bidirectional reflectance values and the albedo estimates both agree very closely with those calculated by the DISORT model. Figures 3 and 4 show the angular distribution of bidirectional reflectance (at 1.03 µm) as measured from PARABOLA and modeled using DISORT.

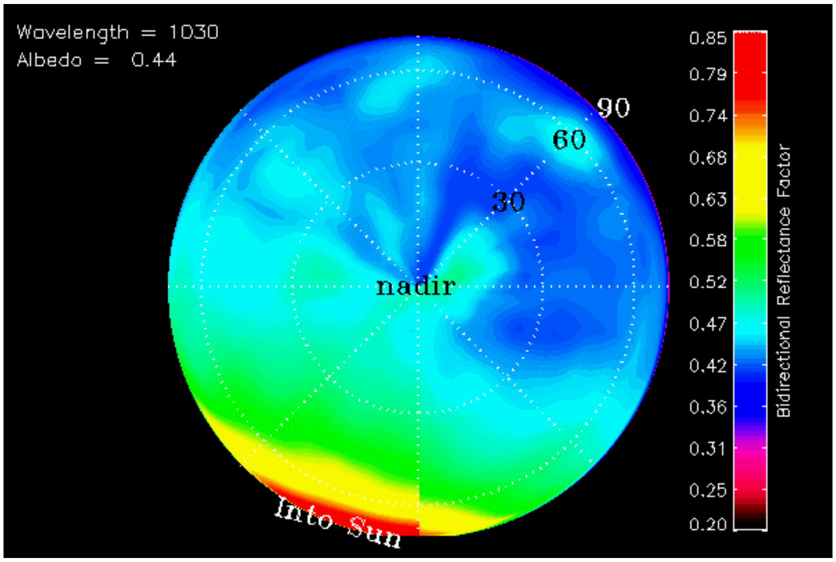


Figure 3. Measured snow BRDF from PARABOLA at a wavelength of 1.03 µm. Bidirectional reflectance in the forward directions is much greater than in the backscatterered direction.

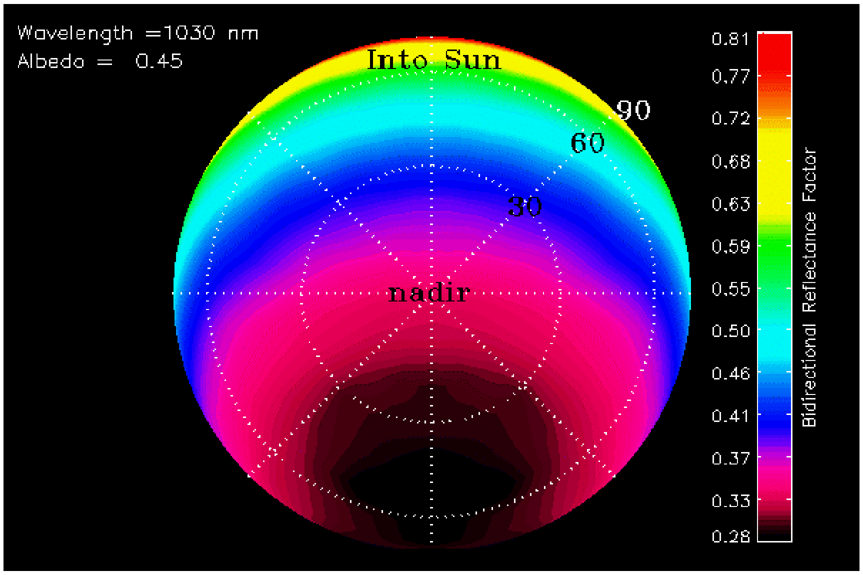


Figure 4. Modeled snow BRDF using the DISORT model. The albedo estimate and the overall range of values for bidirectional reflectance agree very well with PARABOLA measured values.

2.3 Atmospheric Sensitivity Model Experiments

The atmospheric sensitivity runs have been completed. These runs were made using the atmospheric model 6S. The model was modified by adding a snow spectrum for surface reflectance. Currently, the snow surface is considered lambertian but we will soon be adding a snow bidirectional reflectance distribution function to characterize the anisotropic reflectance of snow. Sensitivity tests included simulated impacts on satellite-derived reflectances corresponding to the MISR and MODIS spectral bands related to changes in aerosol optical depth, column ozone, and water vapor amounts. Out of these three atmospheric parameters, changes in aerosol optical depth have the largest impact on satellite-derived radiances over snow. These sensitivity experiments have demonstrated that aerosols significantly diminish the accuracy of snow surface albedo estimates over which aerosols have a darkening effect. These effects are described in greater detail below.

Reflectance for all channels tends to decrease as aerosol optical depth increases. Figure 5 shows the results for a channel centered at 0.55 μm for four different aerosol models: continental, maritime, urban and dust-like. Since snow is brighter than the path radiance, the aerosols have a net darkening effect. For the continental and maritime aerosol models, the decrease in reflectance with optical depth tends to be mostly linear at small viewing and solar zenith angles (Figure 5) but the dependence becomes less linear as the solar and viewing zenith angles become more oblique (Figure 6). For the urban and dust-like aerosol models, the reflectance decreases faster with optical depth at low optical depths, and slower at high optical depths.

The maritime aerosol model has the least impact on simulated snow reflectances. The reason for this is that the extinction coefficient for the maritime model is nearly 1 at these wavelengths. The urban model, with its higher content of carbonaceous soot, has its largest effect at shorter wavelengths whereas the desert model, with high dust content, has a greater impact in the longer wavelengths. The desert model is highly scattering in contrast to the urban aerosol model in which absorption dominates. Over bright snow-covered surfaces, the increase in path radiance from the highly scattering dust-like model causes a strong darkening affect for the TOA albedo.

TOA spectral reflectance changes linearly as a function of aerosol optical depth for the continental aerosol model. Note however, that this assumption breaks down at oblique viewing and solar zenith angles. At a solar zenith angle of 40^o, the reflectance in the green is most sensitive to changes in aerosol optical depth, with decreases of nearly .03 (in absolute albedo) for nadir viewing angles. At $\theta_o = 40^o$, reflectance in the near infrared is least sensitive to an increase in the aerosol optical depth. Near infrared reflectance is less sensitive to changes in aerosol optical depth because aerosol absorption is not significant in those wavelengths, rather, it is the absorption by water vapor that dominates.

The magnitude of the aerosol affect is highly sensitive to solar zenith angle. In general, there is a decrease in reflectance with increasing solar zenith angle. This is because the single scattering component and multiple scattering components of the path radiance both tend to decrease with increasing solar zenith angle. This decrease may become more pronounced with increasing aerosol optical depth depending on the illumination/viewing geometries. Radiance decreases for the single scattering component for both Rayleigh and aerosol scattering are nearly independent of their respective optical depths and there is only a slight dependence on optical depth for the multiple scattering components (greater decrease with increasing optical depth). As aerosol optical depth increases, the aerosol phase function begins to dominate over the Rayleigh phase function. Since aerosol phase functions have a steeper decrease with phase angle at certain illumination/viewing geometries, increasing the aerosol optical depth will lead to a steeper decline. For different wavelengths (implying different Rayleigh optical depths) and different viewing geometries, the rate of decrease with increasing aerosol optical depth is not as large.

The general tendency of a decrease in reflectance with aerosol optical depth breaks down at very oblique viewing and solar angles for the continental aerosol model when looking in the forward direction. Analysis of aerosol affects for each MISR channel in the principal plane show that at high solar zenith angles (e.g. $\theta_o = 70^o$) and at very oblique viewing angles in the forward direction, increasing the aerosol optical causes a decrease in the reflectance for all the MISR channels. It is only at very oblique viewing angles in the forward directions and at high solar zenith angles that the reflectance actually increases with increasing aerosol optical depth. The change in reflectance with increasing aerosol optical depth is positive at oblique viewing and solar angles and $\phi=180^o$ (forward scattering direction). At these angles, reflectance initially increases with aerosol optical depth and then begins to taper off and may even decrease as the aerosol load increases. In the forward scattering direction, reflectances may exceed unity indicating preferential scattering in that direction.

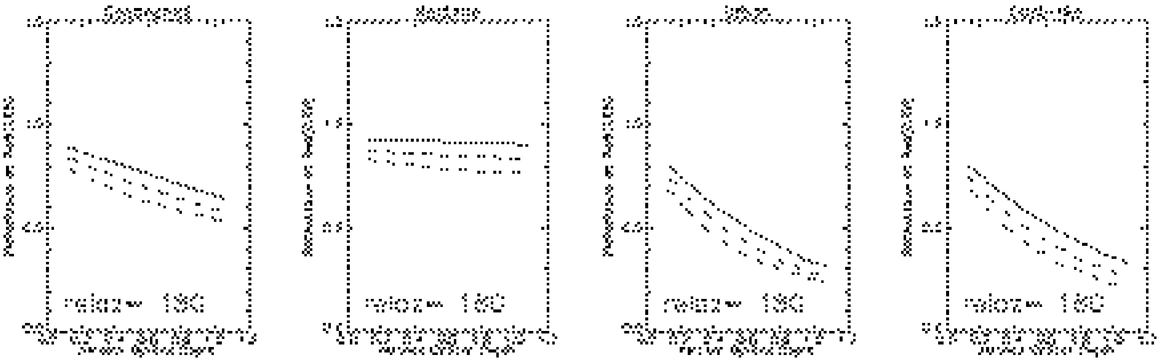


Figure 5. Reflectance at 0.55 microns as a function of aerosol optical depth at a viewing zenith angle of 26.1 degrees. Results are shown for 4 aerosol models: continental, maritime, urban and dustlike and at 4 different solar zenith angles: sza=40 (solid), sza=50 (dotted), sza=60 (dashed), sza=70 (dot-dash). Model inputs include a lambertian dry snow surface and arctic winter atmospheric profile.

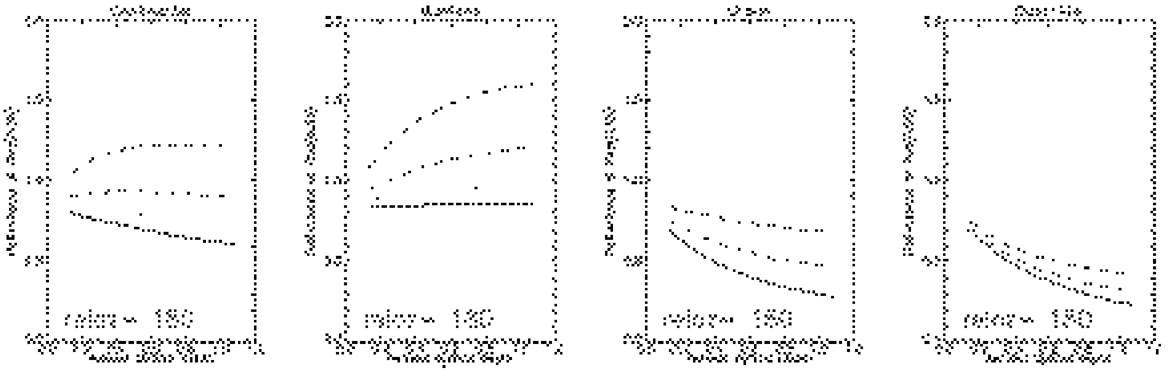


Figure 6. Reflectance at 0.55 microns as a function of aerosol optical at a viewing zenith angle of 70.5 degrees. Results are shown for 4 aerosol models: continental, maritime, urban and dustlike and at 4 different solar zenith angles: sza=40 (solid), sza=50 (dotted), sza=60 (dashed), sza=70 (dot-dash). Model inputs include a lambertian dry snow surface and arctic winter atmospheric profile.

3. Programmatic Efforts

3.1 Collaborations with MODIS and MISR Science Teams

We continue to work closely with members of both the MISR and MODIS Science Teams. On the MODIS side, we are working with Dr. Dorothy Hall's group to coordinate validation objectives, priorities and activities. We are planning a joint field campaign in Wisconsin for February 2000 with Dr. Hall and her team. This past year we have also worked very closely with the MISR validation team. Dr. Jim Conel and his group provided essential support at our Mono Lake Validation Campaign in March 1998. The MISR team contributed instrumentation and technical support personnel as well as data processing and calibration expertise. Drs. Nolin and Stroeve were co-authors in a paper on multi-angle imaging, contributing the snow section for that group effort. MISR-Local Mode data will be collected over our validation sites (see Appendix A). ASTER data have also been scheduled for acquisition over the sites.

Dr. Nolin has attended all recent MODIS and MISR Science Team meetings and will continue to do so. Unofficially, Dr. Nolin is considered a "Friend of MISR" (Dave Diner's term) -- sort associate team member status for this small science team. She has access to the MISR science team restricted website, is included on email lists and invited to all MISR science meetings. While there has perhaps been less access to MODIS information, Dorothy Hall has been very helpful in providing MODLAND and snow validation information to us. One concern has been that the focus of the MODLAND group and related validation activities is on vegetation parameters. It seems that in discussions, the snow and ice activities are left to the last, often meaning that MODLAND members have left the meeting and leaving little time for presentations and discussion. MODIS data processing for key validation sites for first-year was previously a problem (no grid cells were chosen that cover Greenland) but since have been resolved. Currently, the plan includes a MODIS data grid cell over central-western Greenland allowing some (but not all) of our Arctic validation sites to be covered. Through improved coordination and communication, we anticipate that other minor MODLAND issues will be resolved. Towards that end, we are supplying Jeff Morisette with information on our upcoming Wisconsin 2000 campaign and we will join with Dorothy Hall to author an article about our validation efforts to be published in The Earth Observer.

3.2 Data archive and distribution

Currently, the primary archive site for our validation data is on the P.I.'s and Co-I's computers. Data distribution is via the project home page or via contact with the P.I. We will be transitioning the data to a permanent archive and distribution site at the National Snow and Ice Data Center (NSIDC) in the final year of the project. NSIDC will advertise the data via it's web-based Data Catalog and data will be distributed via ftp. For an example of web-based access through the NSIDC Data Catalog, see the following website: http://www-nsidc.colorado.edu.

4. Tasks for 1999-2000

4.1 Modeling Activities

Atmospheric model runs using 6S have recently been completed. The MODIS runs still require analysis. Dr. Stroeve is preparing a report and journal article that provides a detailed overview of these atmospheric sensitivity model analyses.

Additional snow BRDF model runs are being performed using the MAS, MODIS and MISR spectral response functions. These include runs for a wide range of snow properties and atmospheric conditions. Output from these will appear in a journal article currently in preparation. Results from selected runs will also be incorporated into the 6S atmospheric model and provided to the BRDF/albedo group headed up by Dr. Alan Strahler. This latter task will be completed in summer 1999.

Topographic sensitivity tests are scheduled to begin in fall, 1999. DEM data are being acquired for selected regions (alpine and polar) and we will analyze the sensitivity of DEM accuracy on albedo retrievals for these regions.

4. 2 Narrowband-to-Broadband Albedo Conversion

Our present investigation of converting narrowband reflectances in the visible and near infrared spectra to the broadband surface albedo addresses a ground-level conversion. Ideally, multispectral reflectance and broadband albedo need to be measured simultaneously over various snow surfaces, for various atmospheric conditions, and at different solar zenith angles. During the 1998 field campaign we were unable to collect these measurements, but these measurements will be collected during a small experiment in Colorado during winter 1999-2000 and during the Wisconsin 2000 field campaign. A limited data set collected over the Greenland ice sheet is also available. In preparation for the field measurements, modeling results will be used to determine the appropriate conversion factors as a function of solar zenith angle, changing atmospheric optical depths due to aerosols and water vapor, and surface conditions (grain size). Relationships between modeled narrowband and broadband albedo will be determined using a regression approach applied to the MODIS and MISR channels.

4.3 Wisconsin 2000 Field Campaign

We are planning a post-launch field campaign to take place in the Madison, Wisconsin area during the period of February 10 - 20, 2000. This is a joint campaign with Dr. Dorothy Hall. Members of the MODIS atmospheres group (Ackerman and Moeller) have also expressed a strong interest in joining our efforts. The MISR validation team may also participate but as yet this is not confirmed. We have requested flight hours for the ER-2 and plan to have MAS, AirMISR, VNIR camera, MIR and possibly SHIS instruments on board. See Appendix B for flight request details. Ground-based measurements will include atmospheric characterization, measurement of snow properties, snow spectral reflectance and snow albedo.

4.3 Collaborations

We will continue and strengthen our collaborations with MODIS and MISR Science team members. Two joint publications are currently in preparation and others are planned. Snow BRDF data will be provided to Strahler (for their BRDF/albedo product) and Vermote (for 6S). The Wisconsin 2000 campaign is seen as a significant collaborative effort with members of both MODLAND and MODIS Atmospheres Group.

List of Publications

Diner, D. J., G. P. Asner, R. Davies, Y. Knyazikhin, J.-P. Muller, A.W. Nolin, B. Pinty, C. B. Schaaf, and J. Stroeve, New directions in Earth observing: Scientific applications of multi-angle remote sensing. Bull. Am. Meteor. Soc., in press.

Nolin, A. W., Mapping the Martian polar ice caps: Applications of terrestrial optical remote sensing methods, J. Geophys. Res., 103, 25851-25864, 1998

Nolin, A. W. and J. C. Stroeve, Validation of the MODIS snow albedo product: An update, Proc. Assoc. Amer. Geogr., issued on CD-ROM, 1999.

Appendix A: Table of validation sites for snow albedo

Investigator(s)	Nolin, Shi	Nolin, Wan, Conel	Hall, Nolin, Shi Ackerman/Moeller	Nolin
Time Frame	Ongoing, continuous	3/9/98 – 3/20/98	2/10/00 – 2/20/00	Ongoing, continuous
Other Spaceborne Data	ASTER, MISR-LM	None	ASTER, MISR-LM	ASTER, MISR-LM
Ground Measurements	Albedo	PARABOLA, MFRSR, sunphotometer, ASD spectrometer, albedometer, temperature, snow properties	PARABOLA, MFRSR, Sunphotometer, ASD spectrometer, albedometer, temperature, snow properties	Albedo, snow properties
Airborne Measurements	AVIRIS	MAS, AirMISR, VNIR camera	MAS, AirMISR, MIR, SHIS, VNIR camera	None
Validation Parameter	Snow albedo Snow covered area	Snow albedo	Snow albedo Lake ice cover Snow covered area	Snow albedo
Latitude, Longitude	37.62 N, 119.00 W	37.89 N, 119.08 W	43.10 N, 89.42 W	40.05 N. 105.60 W
Site/Location	Mammoth Mtn., CA	Mono Lake, CA	Lake Mendota, WI	Niwot Ridge LTER, CO

Nolin
Ongoing, continuous
ASTER, MISR-LM AVHRR
Albedo
None
Snow albedo
69.57 N, 49.30 W (ETH/CU) , 69.88 N, 46.98 W (Craw1) 73.84 N, 49.50 W (NASA-W) , 77.18 N, 61.10 W (GITS) 78.53 N, 56.83 W (Humboldt) , 72.50 N, 38.50 W (Summit) 78.03 N, 33.99 W (Tunu-N) , 66.48 N, 46.28 W (DYE-2) 69.30 N, 49.50 W (JAR) , 66.00 N, 44.50 W (Saddle) 63.15 N, 44.82 W (S. Dome) , 75.00 N, 30.00 W (NASA-E) 69.91 N, 46.85 W (Craw-2) , 75.10 N, 42.33 W (N. GRIP)
Greenland Climate Network (GC-Net)

Appendix B: Flight Request for Wisconsin 2000 campaign

AIRBORNE SCIENCE FLIGHT REQUEST

National Aeronautics and Space Administration

LOG NUMBER

Investigation Title: Snow Albedo Validation for MODIS and MISR

Rationale for use of NASA Facilities: Post-launch validation for snow albedo from MODIS, MISR

☒ NASA RTOP If checked, RTOP Number/Grant or Contract # NAG5-6462

☐ Proposal submitted to NASA If checked, Proposal # ________ ☐ Non-NASA

Principal Investigator:

Name: Dr. Anne W. Nolin
Organization: University of Colorado
Address: CIRES/NSIDC
Campus Box 449
University of Colorado

City, State & Zip: Boulder, CO 80309-0449
Phone: (303) 492-6508

FAX: (303) 492-2468

E-Mail address: nolin@spectra.colorado.edu

Funding Agency Sponsor:
(For NASA Programs List NASA HQ Sponsor)

Name: David O'C Starr
Organization: NASA/GSFC
Agency/Code: Code 913
Address: NASA GSFC, Code 913

City, State & Zip: Greenbelt, MD 20771
Phone: (301) 614-6191

FAX: (301) 614-6307

E-Mail address: starr@climate.gsfc.nasa.gov

Aircraft Required:

	☒ ER-2	☐ DC-8	☐ P-3B
	☐ DOE B-200	☐ UND CITATION	☐ WB-57
	☐ Other (please specify)	________	

General Flight Window (Month):
A) February, 2000
B)
C)
D)
E)

General Site Location (State or Country):
A) Madison, Wisconsin
B)
C)
D)
E)

This Form must be completed and returned to NASA/DFRC by:

JUNE 4, 1999

(Do not mark in this space/For office use only)

Mail completed forms to:

Dryden Flight Research Center
National Aeronautics and Space Administration
Attn.: Airborne Science Directorate, Flight Requests
MS D1623H P.O. Box 273
Edwards, CA 93523-0273

Phone (661) 258-7540 FAX (661) 258-3719
E-Mail: randy.albertson@mail.dfrc.nasa.gov

Background and Primary Science Objectives

(Attach RTOP, grant, or contract proposal abstract) Please list your primary science objectives.
Primary objective: Clear-sky snow albedo retrievals over open, flat, snow-covered area.
Project Summary for NASA grant #NAG5-6462:
This research focuses on validation of snow albedo estimates from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multiangle Imaging SpectroRadiometer (MISR). Sensitivity studies will also be undertaken to investigate how atmospheric properties, topography, and spatial resolution affect albedo estimates.
Anticipated results include:

1. Reflectance-to-albedo conversion scheme for MAS, MODIS, AirMISR and MISR
2. Sensitivity analysis of snow albedo retrievals to atmospheric correction algorithm input data, DEM accuracy, and determinations of diffuse/direct irradiance proportions
3. Validation of snow BRDF model and conversion scheme
4. Narrowband-to-broadband albedo conversions for MAS, MODIS, AirMISR and MISR

Aircraft sensor and data requirements:

PLEASE NOTE: Investigator(s) responsible for cost associated with instrument and Starlink operation.
For more information see Airborne Sensor Facility webpage at *http://asapdata.arc.nasa.gov*

SENSORS: ☐ SAR ☐ AVIRIS ☒ P.I. Instrument MAS, AirMISR

CAMERA: ☒ RC10, 12” Color IR ☐ Other

OTHER: ☐ STARLINK

Data Requirements:

SPECIAL DATA REQUIREMENTS:

GROUND RESOLUTION:

OTHER:

Advance Notification of Flight Attempt (Please Check One)

☐ Does Not Require Notification Prior to Flight

☒ Requires Notification Prior to Flight (see below)

Name and Phone # of Person to Contact: Anne Nolin (303) 492-6508; (303) 554-7863

Alternate Person to Contact: Dorothy Hall (301) 614-5771

Notify above individual on: ☒ day of flight ☒ days in advance of flight (7 days)

Supplemental Information or Comments: Coordinate flights with overpass of Terra

Coordinate flights with flight request by Dorothy Hall

TEST SITE REQUIREMENTS

(Photocopy this sheet and complete a separate page for each site)
NOTE: For AIRSAR, please fill out JPL flight line request form, page 4.

Test Site Location/Descriptions: Lake Mendota, Wisconsin

Test Site Mean Altitude (Above sea level): 500 ft.

(Attach map(s) showing region of interest or desired flight lines) See attached map

OVERFLIGHT TIME PERIOD(S) REQUIRED
(Show date or dates if temporal coverage required)

Date:	Tolerance:
Date:	Tolerance:
Date:	Tolerance:

SPECIAL OBSERVATION REQUIREMENTS AND CONSTRAINTS

Weather Conditions: Mostly clear sky, low winds	Satellite Overpass: Terra
Cloud Cover % (Maximum): 10%	Flight Line Orientation: See attached diagram
Sun Angle Limits: min = 25^{o} above the horizon	Sea State:
Ground Condition: Snow-covered	Tidal Cycle:

Other:

FLIGHT LINE REQUIREMENTS (Check one)

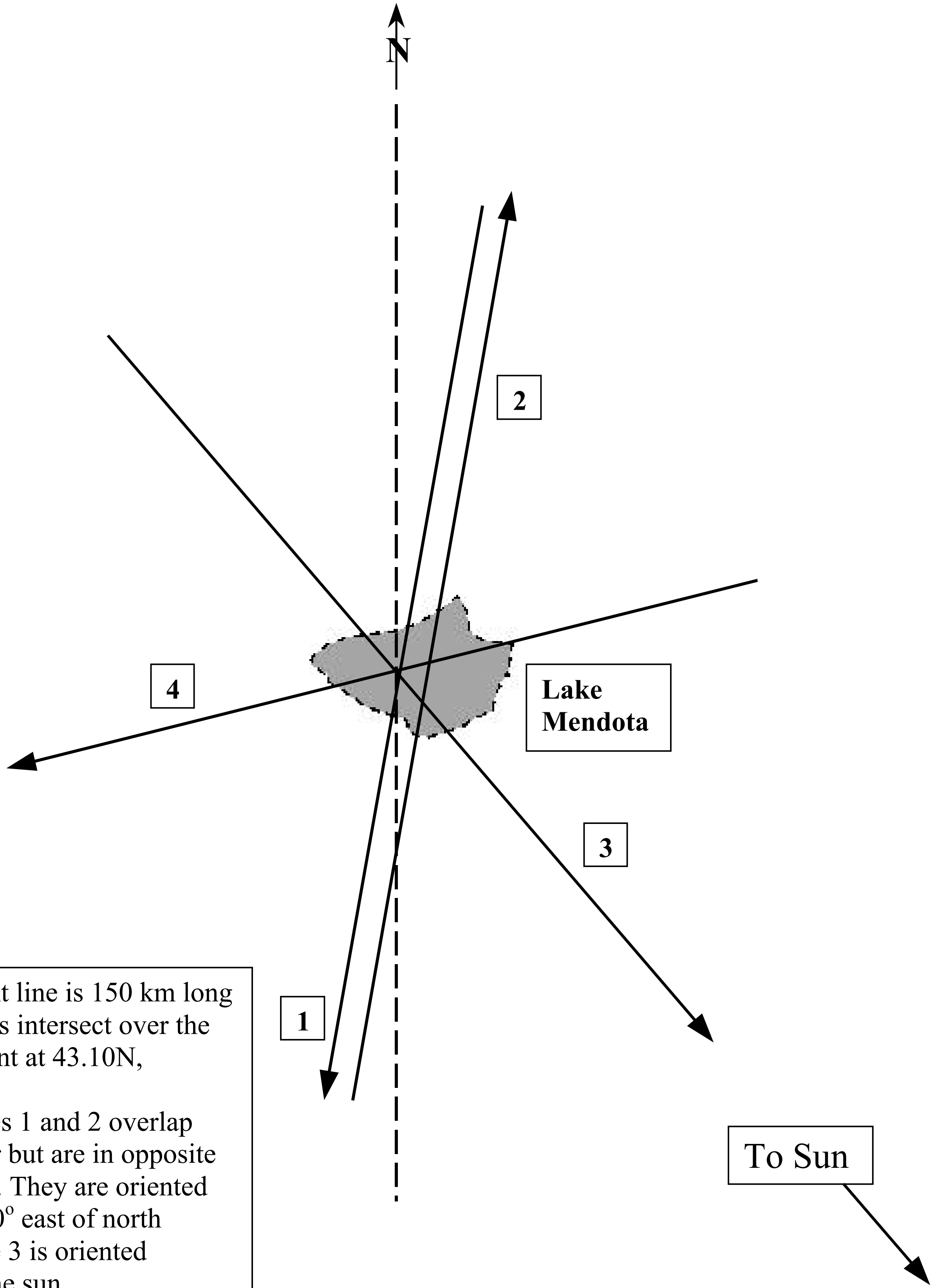
☐ Actual Flight Coordinates ☐ Coordinate Box (List 4 Corners) ☒ Center Point (See Below)

Flight Line Number	Flight Altitude (MSL in 1000 ft.)	Line Length (Nautical Miles)	Overflight Time of Day (local)	Flight Lines (Latitude & Longitude) *(degrees, minutes & tenths)*	
				Start	End
1	60,000	80.95	10:30-noon	See attached diagram	
2	60,000	80.95	10:30-noon		
3	60,000	80.95	10:30-noon		
4	60,000	80.95	10:30-noon		

CENTER POINT COORDINATES

Lat.: 43.10N Long.:89.42W Coverage Length/Heading: see diagram

Scene Overlap Front: Side:



- Each flight line is 150 km long
- The 4 lines intersect over the center point at 43.10N, 89.42W
- Flight lines 1 and 2 overlap each other but are in opposite directions. They are oriented approx. 10^{o} east of north
- Flight line 3 is oriented towards the sun
- Flight line 4 bisects the angle made by lines 1 and 3