Report on

Validation of MODIS Snow and Sea Ice Products in the Southern Ocean

by

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PROGRESS REPORT

Validation of MODIS and Sea Ice Products in the Southern Ocean. NAG5-6338, Award amount $227,556; Duration, 1 October 1997 to 30 September 1999; Shusun Li and Martin Jeffries.

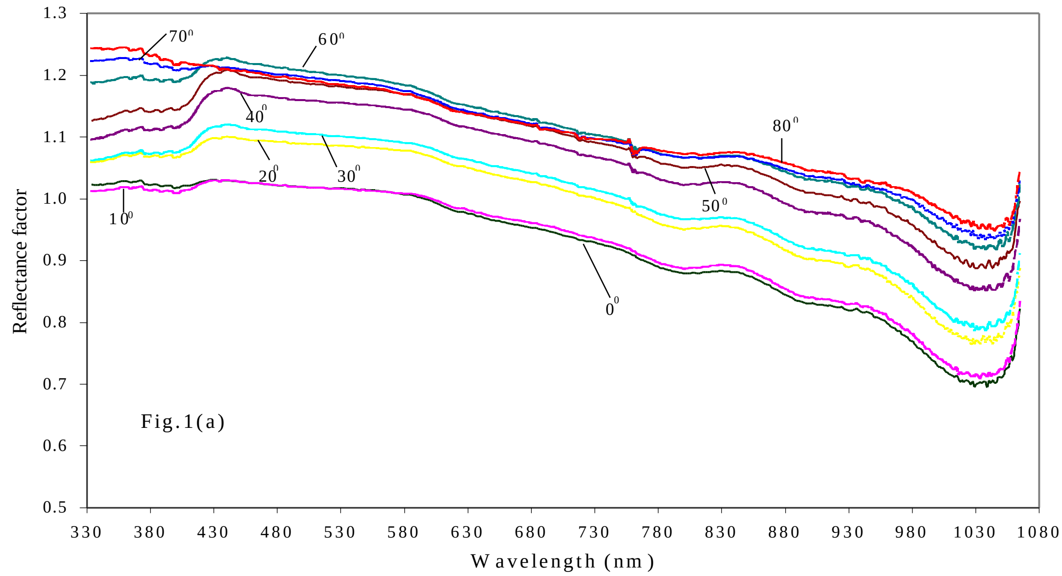
The purpose of this study is to validate and promote the utilization of the MODIS snow cover, sea ice cover, and sea ice temperature products in the Southern Ocean.

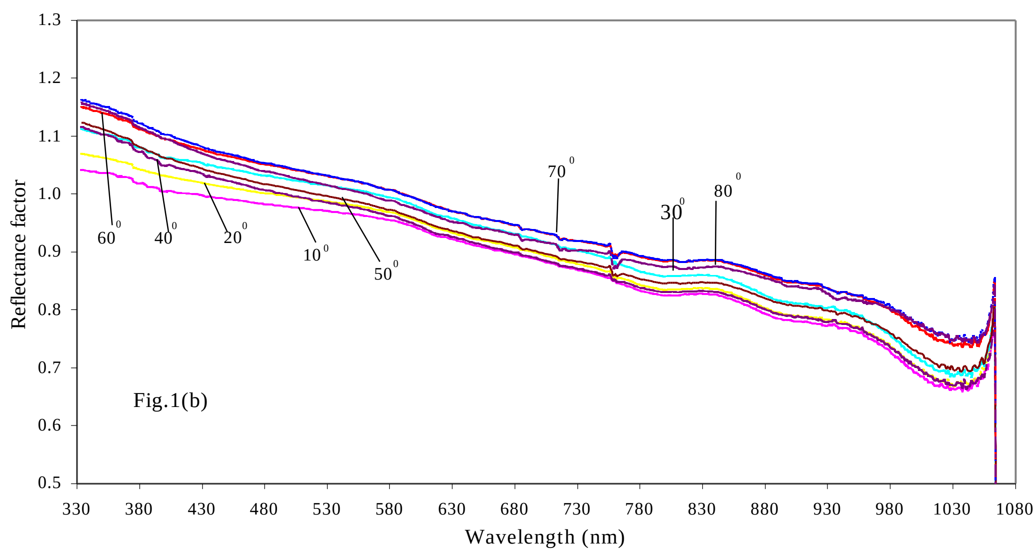
Since the beginning of the project, we have conducted two cruises in the Ross Sea. One was an austral winter cruise in May and June 1998, and the other was a summer cruise in January and February 1999. During the cruises we made surface spectral bidirectional reflectance and albedo, total albedo, and surface temperature measurements on 54 individual ice floes; 24 floes during the winter cruise and 30 floes during the summer cruise.

The snow surface spectral albedo and BRDF measurements were made using a field visible and near infrared spectroradiometer (model 10400) manufactured by Analytic Spectral Device, Inc. (ASD). Its 256 spectral channels cover a spectral range between 350 -10500 nm at a spectral resolution 2.5 nm. Spectral upwelling and downwelling irradiance were directly measured using an additional fore-optic flux sensor for derivation of spectral albedo. The spectral downwelling diffuse irradiance values were measured using a circular shade to block the direct beam. This makes it possible to derive direct beam spectral irradiance from total spectral downwelling irradiance. Spectral

BRDF with the same spectral resolution and coverage were measured using a different fore-optics, a radiance sensor, with a lens of 3-degree instantaneous field of view (IFOV). For each BRDF measurement sequence, scans were made at nine individual viewing zenith angles (θ=0°, 10°, ……, 80°). For each scan, the sensor started from the forward direction of the principal plane (azimuth angle φ=0°), and then sampled at other azimuth directions with a 10° increment until the backward direction of the principal plane (azimuth angle φ=180°) was reached. The forward direction of the principal plane is defined as the azimuth from which the solar illumination comes. The measurements in a full BRDF set thus form a hemisphere that contains both forward and backward reflectance. In this report, measurements along the principal plane and the supplement plane are presented. The latter is defined as the azimuth plane perpendicular to the principal plane (φ=π/2).

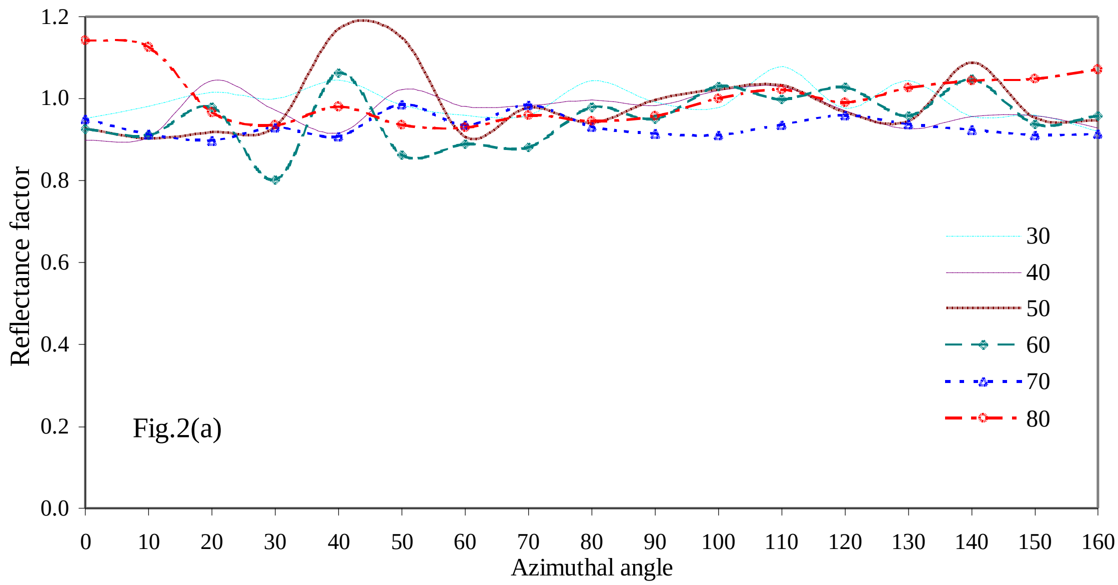
Figs.1(a)-(b) are spectral reflectance curves measured at 71°59.9'S, 165°07'W on January 8, 1999 during the austral summer cruise. At this site, the ice floe was relatively flat. Snow depth was 39cm and the ice thickness was 1.2m. The air temperature and snow surface temperature were –0.7°C and -0.3°C, respectively. The snow grain size was 0.2-0.4mm. The optical sensor was installed 60cm above surface. The diameter of the FOV of the 3° sensor on the ground is about 3.1cm at θ=0°, and becomes larger as the viewing zenith angle increases. It is obvious that the spectral reflectance decreases with wavelength in the spectral region between 300 and 1000 nm. While the spectral reflectance essentially increases with viewing zenith angle in the forward direction (Fig.1(a)), it does not show substantial variation with zenith angles in the supplement plane (Fig.1(b)). This obvious forward scattering pattern of the surface indicates that volume scattering is a dominant process in the propagation of radiation in this type of snow cover. Likewise, the fact that no obvious high reflectance values were observed for the 50° viewing zenith angle under a solar zenith angle 50° indicates that the specular reflectance is negligible. Because the ice surface was flat, there were few local variations of surface reflectance in relation to the zenith and azimuth angles.

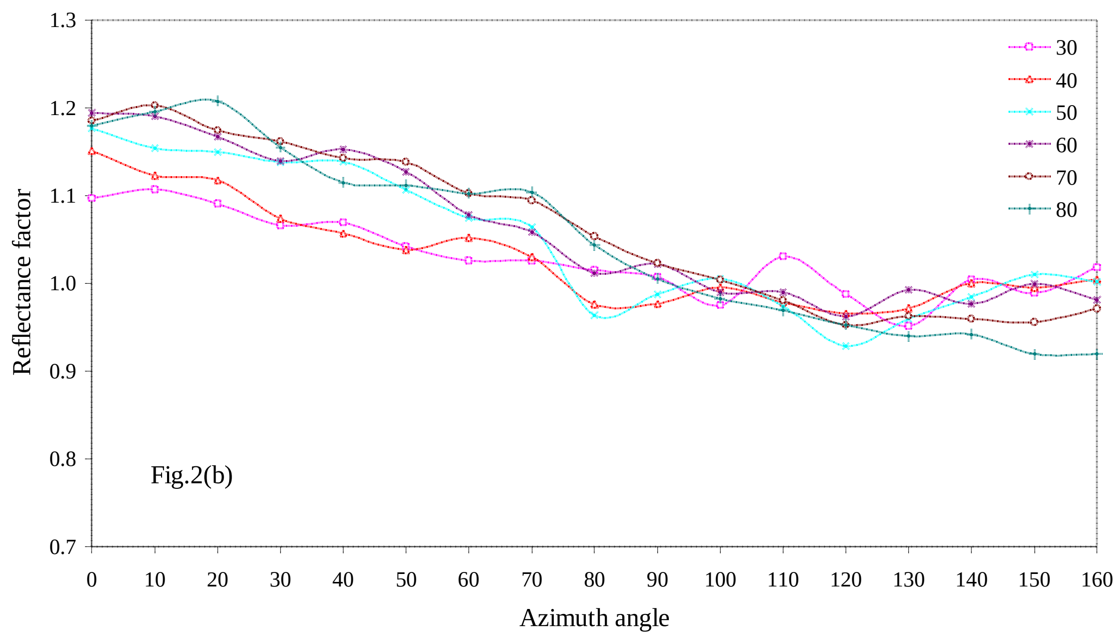




Figs.1(a)-(b). Spectral reflectance of snow and sea ice surface acquired on January 8, 1999 in the Ross Sea at 71°59.9'S, 165°07'W. a) measured in the principal plane; b) measured in the supplemental plane.

The spectral reflectance pattern of winter snow was measured at 66°55.6'S, 174°57'W on June 10, 1998. The sea ice surface was covered by a wind packed snow layer of 10cm thickness. The air temperature and surface temperature were both below -10°C. The





Figs.2(a)-(b). Angular BRDF patterns for (a)551.57nm band measured on June 10, 1998 in the Ross Sea at 66°55.6'S, 174°57'W; (b)552.59nm measured on January 8, 1999 in the Ross Sea at 71°59.9'S, 165°07'W.

average wavelength of surface roughness caused by sastrugi (> 20cm) was much larger than the IFOV of the 3° fore-optical sensor when the viewing zenith angles were small. In addition, there were ridges on the floe. The spectral patterns of this site are similar to the summer snow case shown in Figs.1(a)-(b) except that variations with viewing zenith angles are larger. This is because the solar zenith angle was larger (89°) and the surface was rougher. The large variation of spectral pattern of the surface at this winter site is clearly shown in Fig.2(a), which depicts the surface reflectance patterns at 551.57 nm wavelength band as a function of both zenith and azimuth angles. Fig.2(b) is for the results of 552.59nm band taken at the same summer site as in Fig.1. As the azimuth patterns for small viewing zenith angles are more sensitive to the surface roughness, for clearness they are not shown here. Fluctuations seen in Fig.2(a) were due to ridges and their shadows. Fluctuations in the curves in Fig.2(b) are much less than Fig.2(a) and thus the curves are smoother. This is because the topography of the sea ice floe was much flatter.

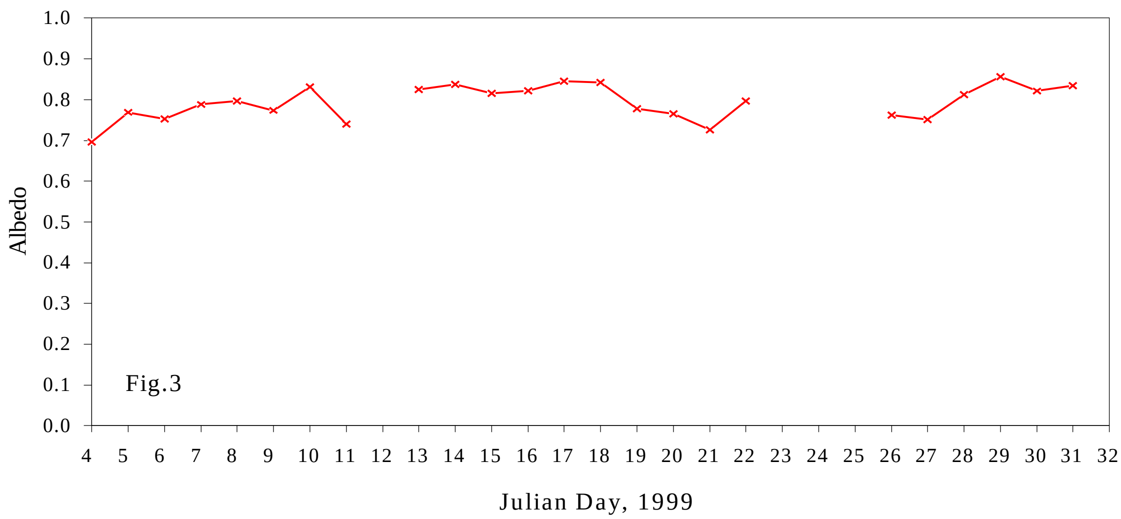


Fig.3. The daily averaged total albedo measured during the summer cruise on pack ice in Ross Sea.

The snow surface total albedo measurements included measurements of the total downwelling and upwelling snow surface irradiance, in solar spectra (0.3 - 2.8 microns), on medium to large floes, using a pair of Eppley Precision Spectral Pyranometers (Model PSP). The two well-calibrated instruments were mounted on a horizontal bar of 2.2 m with one pointing up and one pointing down. Each data set consists of a time series of 2- to 6-hours duration with a one-minute recording interval. Fig.3 shows the daily averaged total albedo for the summer cruise. The summer cruise consisted of three legs, including a southbound leg along the 165°W meridian, a northbound leg along 150°W and another southbound leg along 135°W. Each leg spanned the pack ice between northern and southern ice edges in the eastern Ross Sea. The three lines segments in Fig.3 correspond to the three legs. Obviously, the albedo of snow and pack ice in the Ross Sea generally increased from the northern ice edge southward, then decreased as the southern ice edge was reached. However, there was no decrease when land fast ice instead of the ice edge was reached. The variation was mainly caused by the increase in snow thickness, decrease in surface temperature, difference in liquid water content in snow and snow grain size, etc.

Thermal measurements were made using three sets of instruments. They are StowAway thermisters, Heinmann Infrared Radiometer, and Exergen Infrared Microscanner. Thermisters were used daily during the winter cruise. During the summer cruise, attempts were also made to measure surface temperature using the thermisters. However, we found their readings were about 2 degrees higher than true surface temperature due to absorption of solar radiation. During the winter cruise, this problem did not exist because the sun was always below the horizon during the measurement. The winter data sets collected by the thermisters are reliable.

At each of the 24 winter ice stations (or floes), 18-20 synchronized thermisters were deployed in grids or lines with a typical spacing of 10 meters. Surface temperature was recorded every 15 seconds with duration of 2 hours to one day depending on the overall needs of various research groups aboard the ship. When there was a snow cover on top of the sea ice layer, the thermisters were half buried into the snow cover.

Fig. 4 is a 17-hour time series of surface temperature acquired on May 20, 1998. The surface temperatures in the time series were obtained by averaging synchronized measurements made by 19 thermisters. The series matches well with the ship-measured air temperature except for occasional discrepancies.

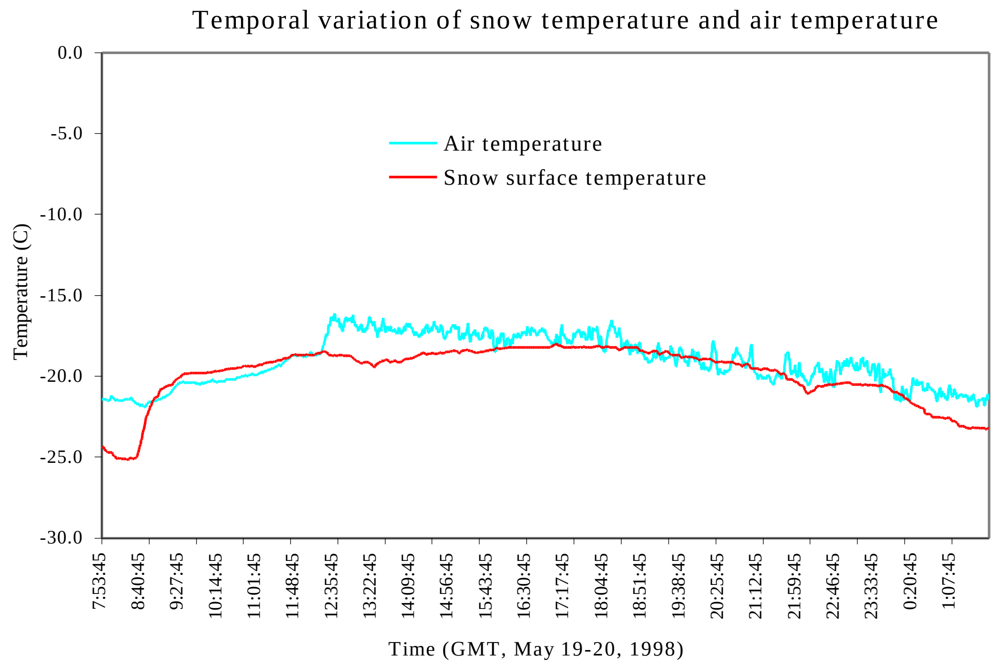


Fig. 4. Snow surface temperature measured by thermisters vs. air temperature measured by the ship on May 20, 1998.

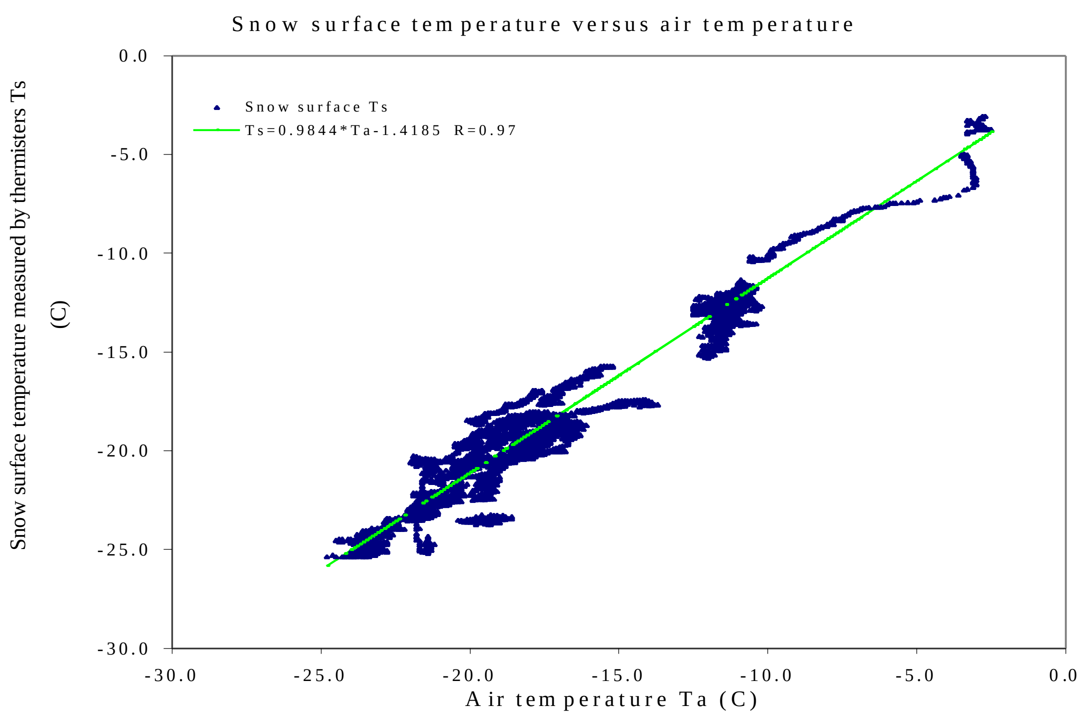


Fig. 5. Regression of air temperature against snow surface temperature for all winter cruise ice stations.

The same averaging method was used for all 24 stations. Results are compared with the ship-measured air temperatures (Fig. 5). While there is a considerable scattering in the relation between the two data sets, a strong correlation is found between them. For 12681 pairs of temperature data, a linear regression indicates

$T_{surface} = -1.4185°C + 0.9844\ T_{air}$

The correlation coefficient r is 0.9707.

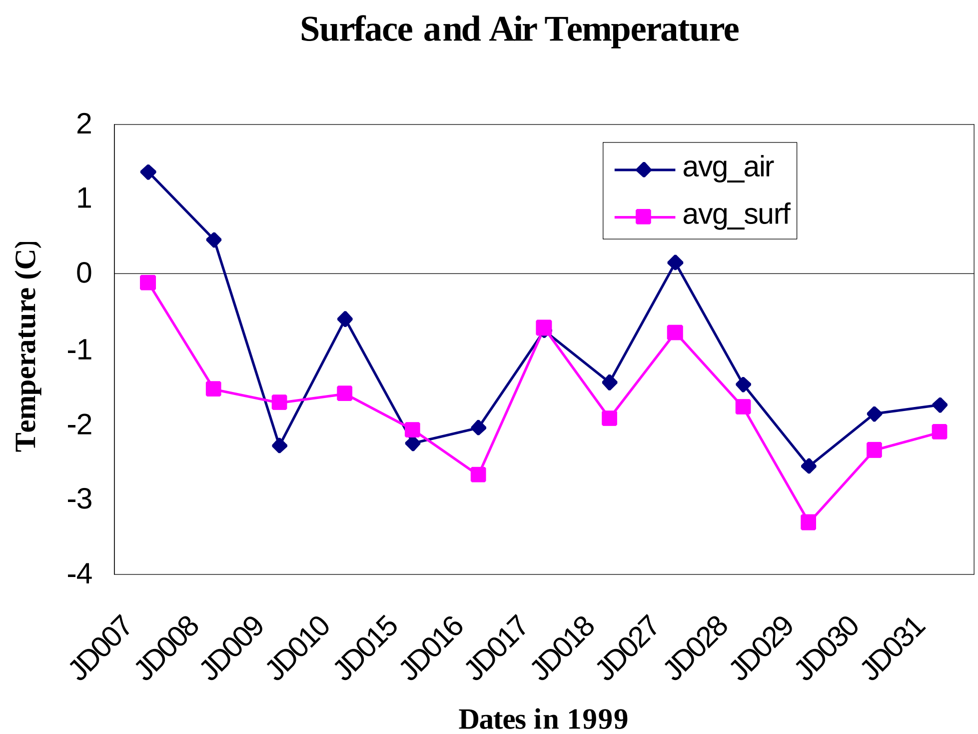


Fig.6. Station averaged air temperatures vs. surface temperatures measured during the summer cruise.

During the summer cruise in January and February 1999, we used the Exergen microscanner to measure the surface brightness temperatures on 13 ice floes. Measurements were made along lines 200-350 meters long, with a spacing of 10 meters. The readings on each individual ice floe were consistent, with a standard deviation less than 0.5°C. The floe-averaged temperatures also match well with the air temperature measured during the same time period (Fig. 6). The main discrepancies occurred when the air temperature was above freezing. This is reasonable because the snow surface should be at freezing when the air temperature is higher. The low variation with space and time indicates a quasi-isothermal condition of the pack ice in the Ross Sea during the austral summer.

The results of the winter cruise provide patterns of snow surface reflectance under low solar elevation angles, while those of the summer cruise provide patterns of reflectance at intermediate solar zenith angles. Because very few BRDF data sets are available in the literature for the Southern Ocean, concurrent measurements of the snow and ice surface spectral BRDF, spectral albedo and total albedo under clear sky conditions obtained during the cruises will help improve estimation of albedo from satellite remote sensing data sets in the region. The experience gained for snow and sea ice surface temperature measurement is also invaluable to the proposed future campaign. The two previous cruise laid a solid foundation for success in validation of the MODIS snow and ice products in the Southern Ocean to be conducted during the new cruise in February and March 2000.

Four poster papers were written based on results of these cruises, and were presented to national and international conferences. Two additional papers were accepted by IEEE 1999 International Geoscience and Remote Sensing Symposium, and will be presented at the conference in Hamburg between 28 June and 2 July this summer. They are:

[1] X. Zhou and S. Li, Summer and Winter Snow and Sea Ice Surface Spectral Directional Reflectance and Albedo Measured in the Ross Sea, IEEE 1999 International Geoscience and Remote sensing Symposium, Hamburg Germany, 28 June - 02 July, 1999.

[2] S. Li, X. Zhou, and K. Morris, Measurement of Snow and Sea Ice Surface Temperature and Emissivity in the Ross Sea, IEEE 1999 International Geoscience and Remote sensing Symposium, Hamburg Germany, 28 June - 02 July, 1999.

[3] X. Zhou, and S. Li, High Resolution Sea Ice Surface BRDF Measurements in the Ross Sea in Austral Winter, 49th Arctic Science Conference, International Arctic Research Center Inauguration, 25-28 October 1998, University of Alaska Fairbanks, Fairbanks, Alaska, Program and Abstracts, (AAAS Arctic Division), Program and Abstracts, p. 75, 1998.

[4] S. Li, X. Zhou, and K. Morris, Multi-Sensor Measurements and Comparison of Winter Sea Ice and Snow Temperatures in the Ross Sea in 1998, 49th Arctic Science Conference, International Arctic Research Center Inauguration, 25-28 October 1998, University of Alaska Fairbanks, Fairbanks, Alaska, Program and Abstracts, (AAAS Arctic Division), Program and Abstracts, p. 54, 1998.

[5] X. Zhou, and S. Li, A Comparison Study of Snow Surface BRDF Measured in the Ross Sea and Alaska Regions, *EOS, Transactions*, AGU, 1998 Fall Meeting, Vol. 79, No. 45, H11A-15, F270, 1998.

[6] S. Li, X. Zhou, and K. Morris, Snow and Sea Ice Surface Temperature and Its Variability in the Ross Sea Measured during a 1998 Winter Cruise, *EOS, Transactions*, AGU, 1998 Fall Meeting, Vol. 79, No. 45, H11A-16, F270, 1998.

Report to Dr. David Starr

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Objectives

The purpose of this study is to validate and promote the utilization of the MODIS snow cover, sea ice cover, and sea ice temperature products in the Southern Ocean.

Accomplishments and Progress

See attached report.

Planned Activities and Schedule.

We will conduct further field investigations during a cruise in the Southern Ocean in February and March 2000. We expect there will definitely be AM-1 (Terra) overflights. Therefore, the cruise will be ideal for validation of MODIS data. The preliminary validation result will be reported in late 2000. The project will be completed in 2001.

Collaborations with the EOS Instrument Teams

Connection with the EOS instrument team is made through two EOS scientists. One is Dr. Dorothy Hall at Goddard Space Flight Center, who is the EOS representative for coordinating the efforts in validating MODIS snow and ice products. We constantly report to Dr. Hall our progress in field campaigns. The other is Dr. Zhengming Wan at the University of California, Santa Barbara. Dr. Wan is a member for the MODIS sensor. We constantly consult with him on the selection of field instruments and measurement methods, the accuracy of our results, and possible approaches for further improvement.

Problems and Concerns

(1) One of our main concerns is the cost for the extra cruise in February and March 2000. The cruise is crucial to the success of the project because there will be satellite over-flights then. However, the cruise was not included in our original budget submitted to NASA due to the delay in the launch of the satellite. Dr. Lettau, the NSF project manager of the Antarctic Ocean and Climate program (703 306-1033, blettau@nsf.gov), has agreed to allow 2-4 of investigators in our group to participate in the cruise. Although NSF will provide free berths to the participating scientists, the other cost required for the cruise is an issue that needs to be settled soon.

(2) The detailed information about where and when the New Terra satellite will fly over is critical to collecting concurrent field data. We hope that we can be provided with accurate information or software tools to predict Terra flights over the Southern Ocean during the cruise.