Annual Report on

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

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PROGRESS REPORT

Validation of MODIS and Sea Ice Products in the Southern Ocean. NAG5-6338, Award amount $ 447,696; Duration, 1 October 1997 to 30 September 2001; 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 three cruises in the Ross and Amundsen Seas. Two were pre-launch cruises in 1998 and 1999 and one was an after-launch cruise between 15 February and 31 March 2000. During the cruises, we made surface spectral bidirectional reflectance and albedo, total albedo, and surface temperature measurements on a total of 76 individual ice stations, including 24 stations during the austral winter cruise in 1998, 30 floes during the austral summer cruise in 1999, and 22 stations during the austral summer cruise in 2000.

This report will focus on the progress made since late 2000, i.e., the progress made after our latest cruise in February and March 2000. During the past year, we made the following main accomplishment:

(1) Analyzed images from various remote sensors for comparison with MODIS images.
(2) Made a quantitative analysis of cruise-related MODIS images.
(3) Further investigated sea ice albedo.
(4) Presented results at various conferences, symposia and prepared science papers for publication.

1. Analysis of Various Remote Sensing Images

After the 2000 cruise, we investigate the sea ice extent, ice concentration and ice zonation in the Southern Ocean using three new satellite sensors. One is the MODIS. The other is the synthetic aperture radar (SAR) on the first Canadian Space Agency RADARSAT satellite. The third is NASA's Quick Scatterometer (QuikScat).

On MODIS images (e.g., Figure 1 and 2), heavy ice areas are characterized by their high spectral reflectance in solar reflective bands, whereas open water can be identified by the low albedo and warm temperature (Figure 2). On SAR images (e.g., Figure 3), ice edge can be delineated accurately. Four heavy ice areas appear bright. Large areas of open water look either dark or bright, depending on wind conditions. Areas of low ice concentration usually look moderately dark because the small areas of open water between ice floes are calm due to the wave-damping effects of ice.

Pancake ice and cake ice zones have relatively strong backscatter due to the wet rim effects of the pancakes and ice cakes. Those zones, however, still differ from heavy ice areas in the SAR images where many large ice floes can be identified easily. QuikScat and RADARSAT SAR images resemble each other, except that the latter has much finer spatial resolution. A time series of QuikScat images (Figure 4) is used to study the evolution of different ice zones in February and March 2000. The ice edge had dramatically irregular shape in February when the ice cover was at minimum. Gradually, the shape of the ice edge became less irregular as the ice extent expanded. Both RADARSAT SAR and QuikScat images are useful for validation MODIS ice extent.

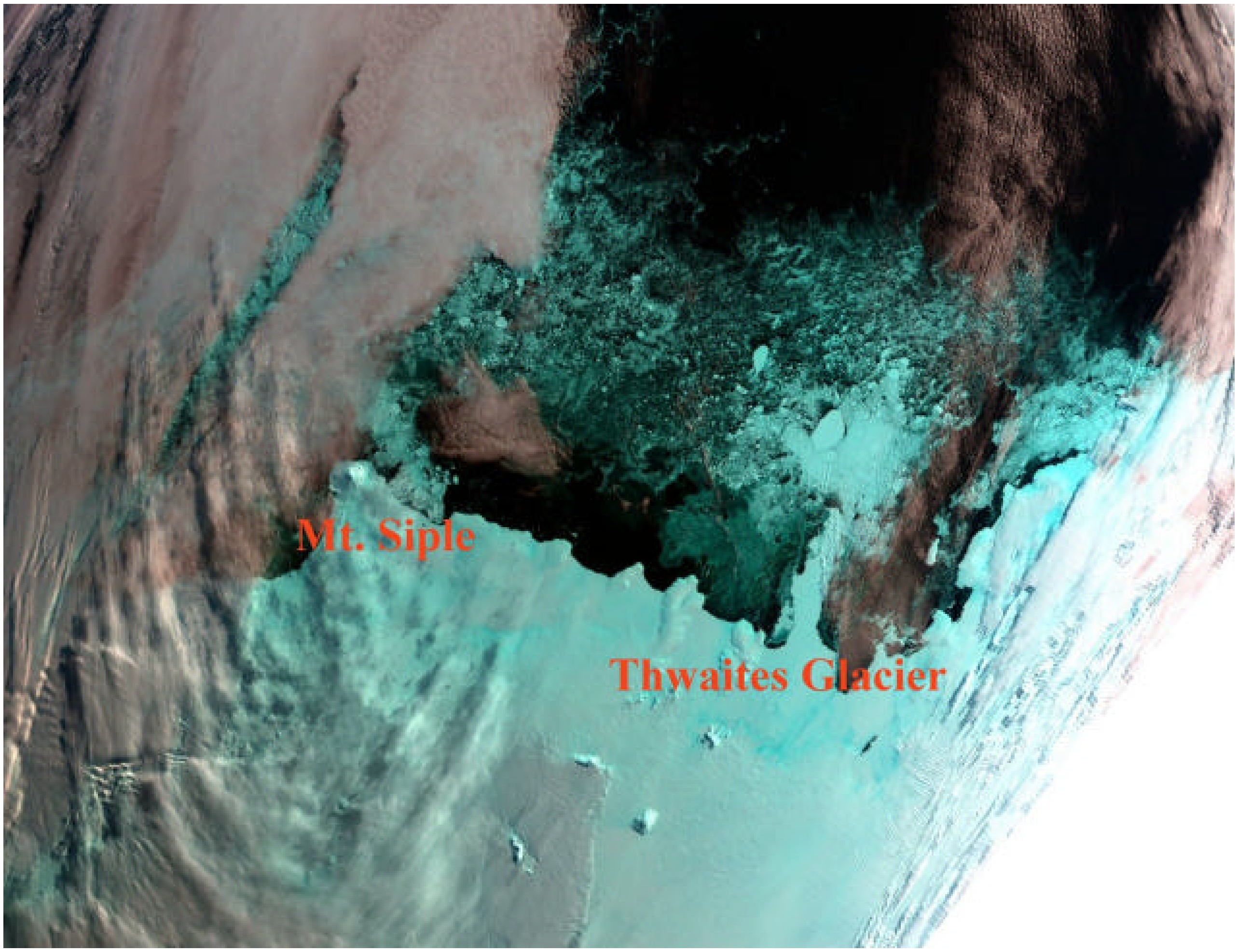

Figure 1. Color image composed of MODIS bands 3, 4, and 5. Blue is assigned to Band 3 (459-479 nm). Green is assigned to Band 4 (545-565 nm) and red is assigned to Band 5 (1230-1250 nm). The image was acquired at GMT 17:00 on March 6, 2000.

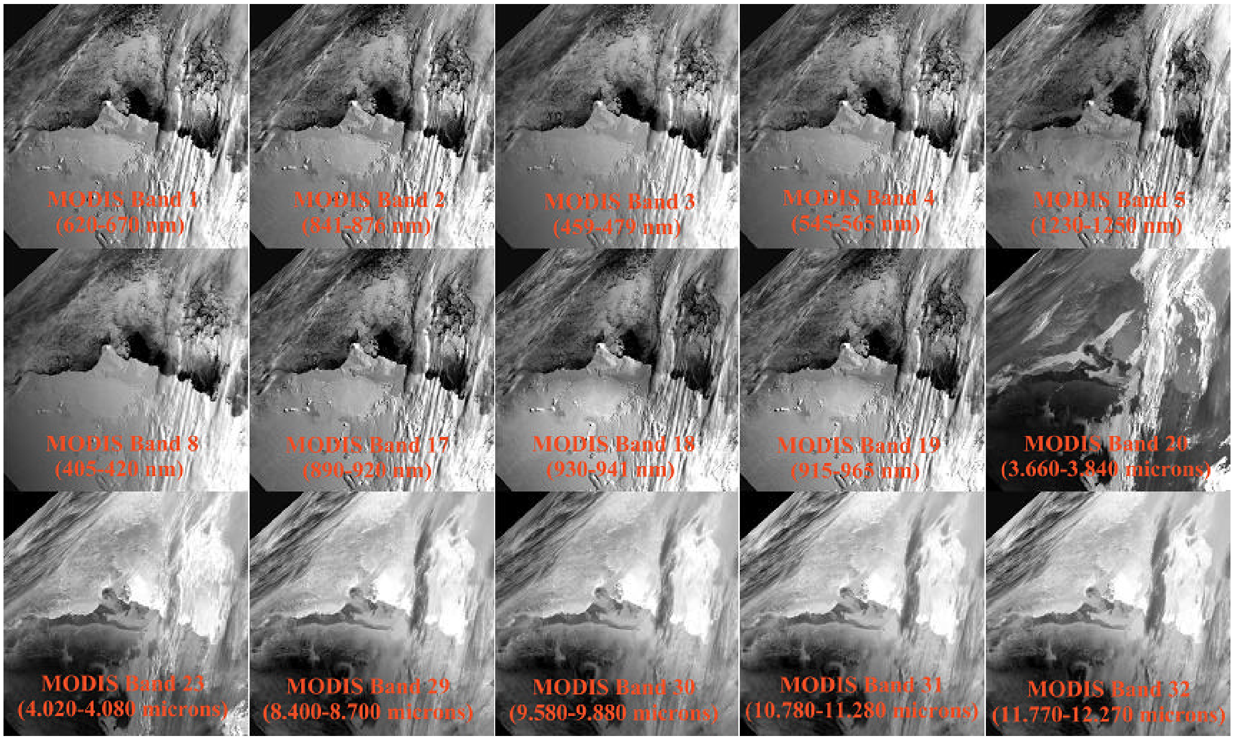

Figure 2. Representative MODIS bands for the area near Siple Island, Antarctica, acquired at 16:35 GMT on March 10, 2000.

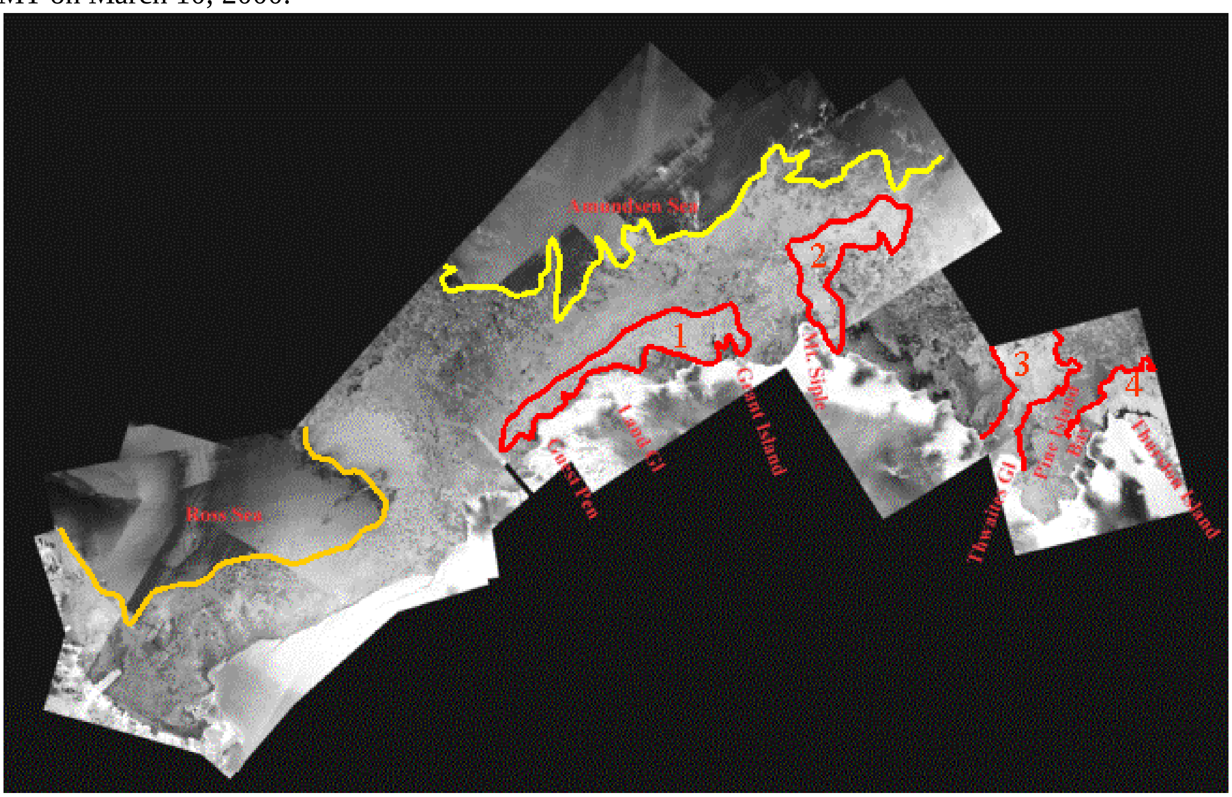

Figure 3. Mosaic of RADARSAT SAR images acquired between March 6 and 8, 2000. The yellow lines represent the ice edge and the red lines delineate four heavy ice zones.

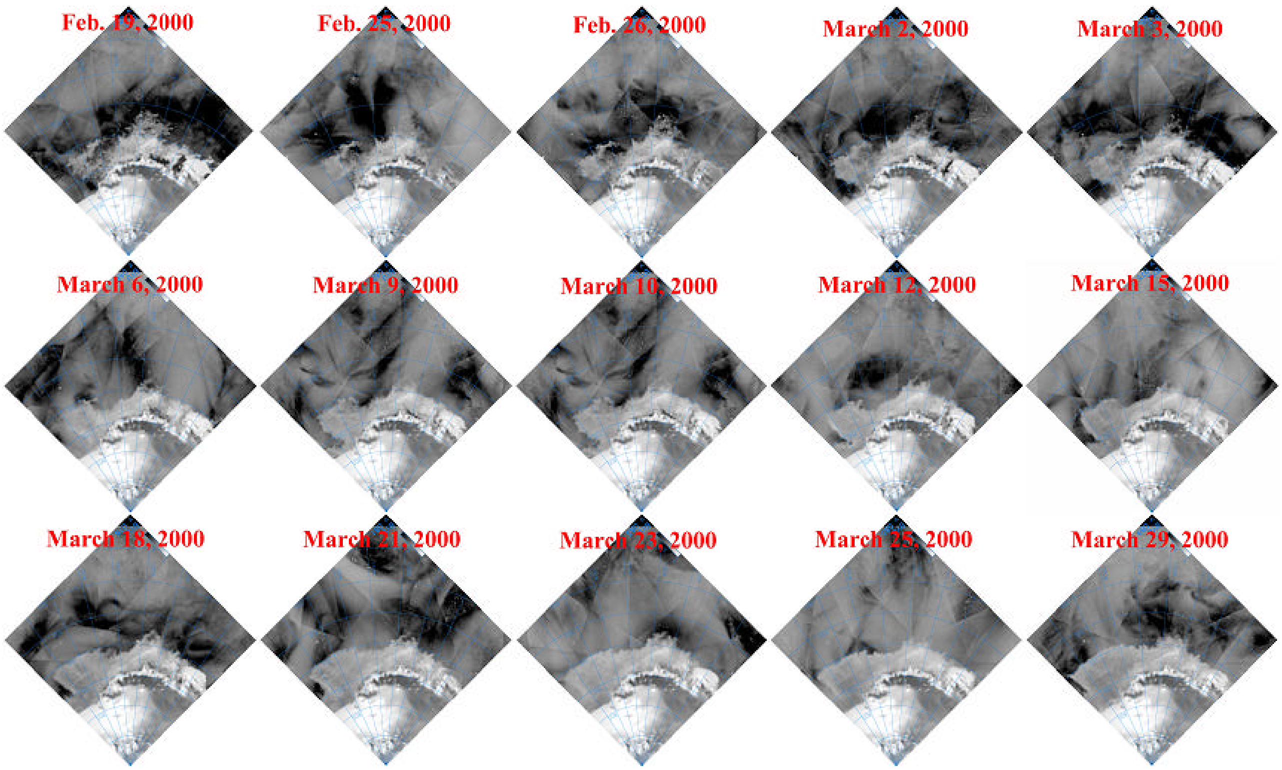

Figure 4 QuikScat Images Acquired during the cruise.

2. Quantitative Analysis of Cruise-Related MODIS Images

Spectral albedo and directional reflectance of snow and sea ice were measured in the Ross, Amundsen and Bellingshausen seas during the summer cruise in February through March 2000 aboard the U.S research vessel *Nathaniel B. Palmer*. Measurements were made on sea ice of various types, including nilas, grey ice, pancake ice, multi-year pack ice, and landfast ice using a spectroradiometer that has 512 channels in the visible and near-infrared (NVIR) region in which 16 of the 36 bands of the Moderate Resolution Imaging Spectroradiometer (MODIS) are covered. Comparison of spectral albedo and directional reflectance among various ice types is made.

Directional reflectance under clear skies is also retrieved from the MODIS radiometrically calibrated data (L1B) concurrently acquired from the first NASA Earth Observing System (EOS) satellite, Terra. For comparison with ground measurements, the locations of the concurrent ice stations are identified accurately on the MODIS images, and the spectral albedo and directional reflectance values at the 16 visible and near-infrared MODIS bands are extracted for those pixel locations. The MODIS-derived reflectance is then corrected for the intervening atmosphere whose parameters are retrieved from the MODIS atmospheric profiles product (MOD07_L2) for the same granule as MODIS L1B products from which the apparent reflectance is retrieved. Meanwhile, the corresponding spectral albedo and directional reflectance at the same viewing geometry as MODIS are derived from ground-based spectroradiometer measurements. As the footprint of the ground spectroradiometer is much smaller than the pixel sizes of MODIS images, the averaged spectral reflectance in the vicinity of each ice station is simulated for the corresponding MODIS pixel from ground spectral measurements by weighing over different surface types (various ice types and open water). The averaging is based on ground-based ice observation and digital images taken concurrently with the *in situ* reflectance measurements. Values of ground-based MODIS spectral simulation are compared with satellite-derived values (Figure 5).

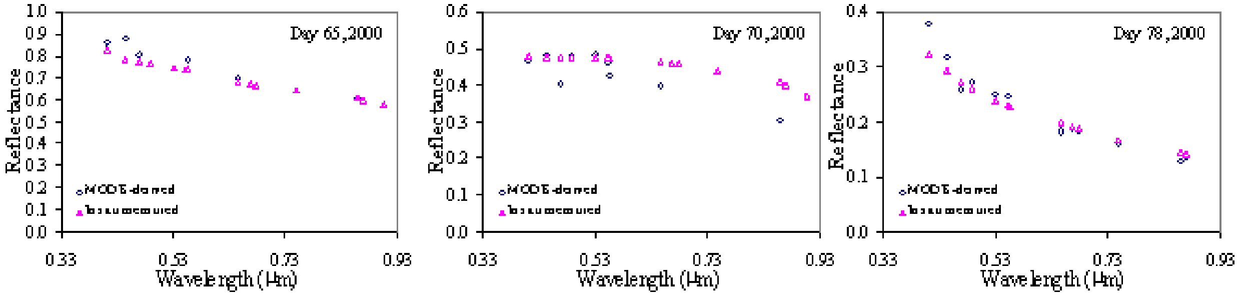

Figure 5. Comparison of bidirectional reflectance of *in situ* measurements and MODIS-derived data. for day 65, 70 and 78, 2000.

Comparison between MODIS-derived and *in situ* reflectance shows that, agreement is good (with discrepancy being 0.8-16.9%, average difference within 6.2%) when the pixel is one ice type dominated and the measurement is taken on the dominated ice floe (as on Day 78) or when the ice concentration is 10/10 with the most coverage similar in reflectivity (as on day 65, with discrepancy range being 0.2-11.6%, and the average agreement within 4.8%). On day 70, two types of ice with significant difference in reflectance and a large amount of open water (3/10) existed in the vicinity of the ice station. MY ice was the dominant (4/10) over the new ice (nilas and pancake ice) (5-10 cm thick). Measurement was made on the MY ice. Good agreement occurs for bands in visible regions but the agreement deteriorates at near-infrared bands. The average difference between the ground- and space-based measurements is about 8.2%. The best agreement is within 1.2% at band 10 (0.488 ?m) and the worst is as mush as 25.1%, occurring at band 2 (0.858 ?m). In the visible regions, MODIS-derived reflectance values are larger than the *in situ* measurements, although the differences are small. Considering the difference in point measurement and remote sensing with 1-km pixel resolution in our case, the somewhat uncertainty of the MODIS performance during the early stage of the Terra mission, and some ground measurement error, this level of discrepancy between the ground measurements and satellite derivation is regarded as moderate.

3. Further Investigation of Sea Ice Albedo

As a result of surface reflectance measurements made during two austral summer cruises aboard the R.V. *Nathaniel B. Palmer*, we have developed a method to derive surface direct beam spectral albedo for clear skies from spectral reflectance measurements made under overcast conditions [Li and Zhou, 2001]. This method, which can be used to derive surface direct beam spectral albedo for a wide range of solar incidence angles (e.g., Figure 6 and 7), is based on the reciprocity between the hemispherical-directional spectral reflectivity under overcast conditions and the direct beam spectral albedo under clear sky conditions. The reciprocity requires uniform incident intensity, and this condition can be met under overcast conditions. The reciprocity can be derived from a more fundamental and none-restrictive reciprocity of bi-directional reflectance distribution function (BRDF) when the incident and viewing directions are interchanged.

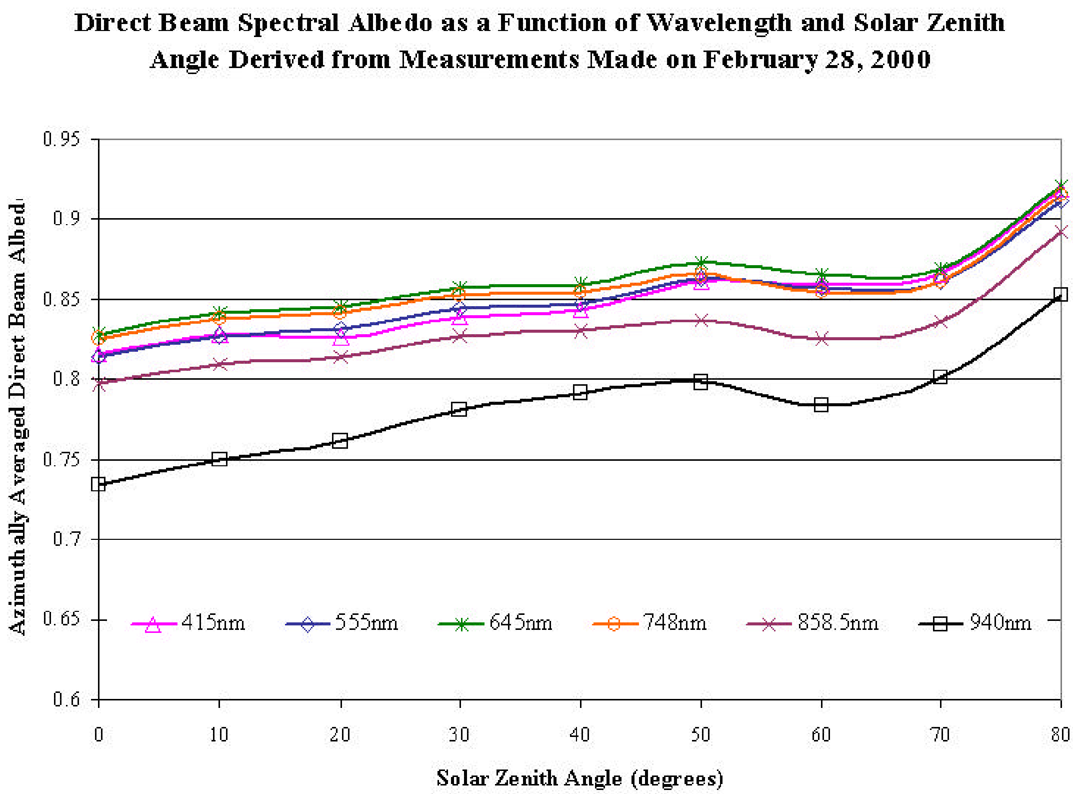

Figure 6. Direct beam spectral albedo as a function of wavelength and solar zenith angle derived from hemispherical-directional spectral reflectance measurements on a multiyear ice floe in the Amundsen Sea, 28 February 2000. The air temperature was –2.7°C, the snow was 0.85 m deep, and the topmost 0.06 m of snow had a mean grain size of 1.5 mm.

The derived product is the spectral albedo from direct beam in the truest sense because the impact of diffuse sky radiation has been eliminated. This method overcomes two problems of traditional field measurements of surface direct beam albedo: the narrow range of solar zenith angles for the polar ice cover and contamination of diffuse sky light to the measurement. Under clear skies, the impact of diffuse sky light is strong in ultra-violet, violet and blue wavelength regions because of Rayleigh scattering. Furthermore, since clear skies are uncommon in the polar regions and the range of solar zenith angles for which previous measurements have been made is small, this method promises to allow a considerable increase in the knowledge of direct beam spectral albedo of polar snow and ice surfaces, and thus improve the parameterization of albedo in numerical models of snow and ice processes, and climate.

Based on the spectral reflectance data during the cruise, we derived direct beam spectral albedo from multi-year ice (e.g., Figure 5) and landfast ice (e.g., Figure 6) Because the derivation of the method is made without specification of the surface types, it is very likely that the same procedure can be used for other surface types, too.

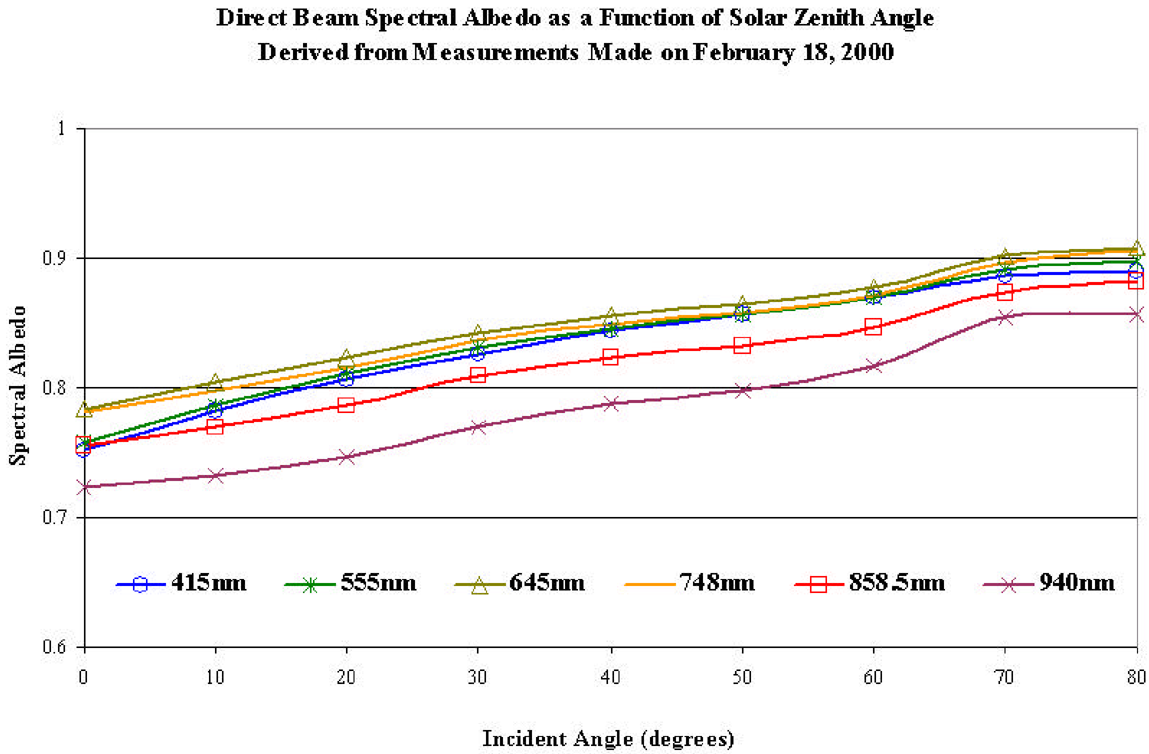

Figure 7 Direct beam spectral albedo of landfast ice surface derived from calibration of the measured hemispherical-directional spectral reflectance measurements of the sea ice surface. Measurements were made in the Ross Sea on February 18, 2000.

4. Publications and Conference and Symposium Presentations

We have made various presentations at conferences and submitted papers to symposia or peer-reviewed journals.

1. S. Li and X. Zhou, Derivation of Austral Summer Sea Ice Surface Direct Beam Spectral Albedo for a Wide Range of Incident Angles from Spectral Reflectance Measurements under Overcast Skies, submitted to Journal of Glaciology.
2. S. Li, Polar Environments Assessment by Remote Sensing, in Encyclopedia of Analytical Chemistry, R.A.Meyers(Ed.), John Wiley & Sons Ltd, Chichester, pp.8660–8679, 2000.
3. X. Zhou and S. Li, Comparison between *in situ* and MODIS-derived Spectral Reflectances of Snow and Sea Ice in the Amundsen Sea, Antarctica, to be submitted to International Journal of Remote Sensing.

4. X. Zhou, S. Li, and K. Morris, Measurements and Modeling of Solar Radiation and Albedo on the Summer Melting Snow and Sea Ice in the Ross Sea, in press, Annals of Glaciology (Vol. 33).
5. S. Li, X. Zhou, K. Morris and M. Jeffries, The Spatial Variability of Summer Sea Ice in the Amundsen Sea Seen from MODIS, RADARSAT SCANSAR and LANDSAT 7 ETM+ Images, *Proceedings of IEEE 2001 International Geoscience and Remote sensing Symposium (IGARSS 2001)*, Sydney, Australia, 9-13 July, 2001.
6. S. Li and X. Zhou, Derivation of Surface Direct Beam Spectral Albedo for a Wide Range of Incident Angles from Spectral Reflectance Measurements under Overcast Conditions, *Proceedings of IEEE 2001 International Geoscience and Remote sensing Symposium (IGARSS 2001),* Sydney, Australia, 9-13 July, 2001.
7. X. Zhou and S. Li, Measurement of BRDF of Snow and Sea Ice in the Ross and Amundsen Seas by Visible and Near-Infrared Channels of MODIS, IEEE 2000 International Geoscience and Remote sensing Symposium, Honolulu, Hawaii, 24-28 July, 2000.
8. X. Zhou and S. Li, Concentration Determination of Sea Ice Pressure Ridge in the Ross Sea Based on Radar Backscatter and Object Delineation Methods, IEEE 2000 International Geoscience and Remote sensing Symposium, Honolulu, Hawaii, 24-28 July, 2000.
9. S. Li, X. Zhou, K. Morris, M. Jeffries, D. Hall and G. Riggs, Validation of MODIS Derived Sea Ice Cover and Ice-Surface Temperature in the Southern Ocean, to be presented at symposium on Sea Ice and Its Interactions with the Ocean, Atmosphere and Biosphere, Fairbanks, Alaska, June 19-23, 2000.
10. S. Li, X. Zhou and K. Morris, Measurement of Snow and Sea Ice Surface Temperature and Emissivity in the Ross Sea, *Proceedings of IEEE 1999 International Geoscience and Remote Sensing Symposium 1999* (IGARSS'99), 28 June – 2 July, 1999, Hamburg, Germany, 1034-1036, 1999.
11. X. Zhou and S. Li Summer and Winter Snow and Sea Ice Surface Spectral Directional Reflectance and Albedo Measured in the Ross Sea, *Proceedings of IEEE 1999 International Geoscience and Remote Sensing Symposium 1999* (IGARSS'99), 28 June – 2 July, 1999, Hamburg, Germany, 104-106, 1999.
12. X. Zhou and S. Li, Measurement and Modeling of the Spectral Albedo of Snow and Sea Ice in Ross Sea in Austral Summer 1999, 50th Arctic Science Conference, Denali National Park, 19-22 September 1999, 250, 1999.
13. X. Zhou, and S. Li, Measurement of the Albedo of Melting Snow and Sea Ice in Ross Sea in 1999 and Its Comparison with Modeling Results, AGU, 1999 Fall Meeting, EOS, Transactions, AGU, 80(46), F552, 1999.
14. D. K. Hall, S. Li, A.W. Nolin, J. Shi, Pre-Launch Validation Activities for the MODIS Snow and Sea Ice Algorithms, Earth Observer Article, 2000.