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SATELLITE-DERIVED WIND, CLOUD, AND SURFACE PRODUCTS AT DIRECT BROADCAST SITES IN THE ANTARCTIC AND ARCTIC

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1. INTRODUCTION

World Meteorological Organization (WMO) stations are sparsely distributed along the interior and costal regions of countries in the Arctic as well as the Antarctic continent. There are currently around 20 WMO stations covering the entire Antarctic continent. The Arctic region has more stations, mainly along the coasts of the Scandinavian countries, Russia, United States and Canada. While the Antarctic has South Pole Station providing a robust set of meteorological observations, and automated weather stations providing basic temperature, pressure, and wind measurements, the interior of both of these regions remains relatively void of stations. Given the large gaps in coverage, satellite observations can be used to provide a more complete picture of atmospheric and surface conditions in both polar regions.

A number of numerical weather prediction (NWP) centers worldwide have previously demonstrated that incorporating winds from polar regions in NWP models improves forecasts not just in the high latitudes, but globally (Key et al., 2003). Currently, six international NWP centers are assimilating our Moderate Resolution Imaging Spectroradiometer (MODIS) polar winds in their operational forecast systems, with at least two others planning operational use in the near future. In addition to polar winds, other satellite-derived data are being incorporated into NWP models. In fact, in the near future it is expected that the majority (~90%) of the data assimilated in forecast systems will be from satellites. Ideally, all parts of the globe should be covered, so data from polar-orbiting satellites will be needed to complement the lower-latitude geostationary satellites coverage.

As important as the MODIS polar wind data are for operational weather forecasts, much of the wind information is not generated fast enough for use in regional forecast models. This is primarily because of the delay in obtaining the MODIS data from ground stations. Direct broadcast (DB) sites, which receive real-time imagery from polar orbiting satellites, provide a means for improving the timeliness of the wind data. In addition, DB sites can provide local forecasters with near real-time products to help facilitate planning for research missions in remote regions.

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In order to facilitate this, the NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) Advanced Satellite Products Team and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, USA, have developed and implemented software to derive polar winds and other satellite-derived products at the McMurdo, Antarctica direct broadcast site. The primary reasons for this system are:

1) To generate polar wind and other information more quickly than is done with our current system, so that numerical weather prediction centers can assimilate more polar data in their model runs.
2) To provide an additional source of information, primarily winds, for weather forecasters in Antarctica.

The generation of polar wind data covering much of Antarctica began in March 2005, using MODIS data received by the U.S. National Science Foundation's direct broadcast system located in McMurdo. All of the processing is done in McMurdo, with only the derived wind data and plots being transferred back to the Cooperative Institute for Meteorological Satellite Studies (CIMSS) in the United States. Real-time products generated at McMurdo are available online at http://stratus.ssec.wisc.edu/products/db/mcmurdo. This paper gives an overview of the various products available from the McMurdo MODIS DB station, and discusses other potential DB sites for the Antarctic and Arctic regions.

2. DATA AND METHODOLOGY

The products that are generated at McMurdo use MODIS level 1b (L1b; calibrated radiances and geolocated) and level 2 products (e.g., the cloud mask) that are produced from level 0 data with the International MODIS/AIRS Processing Package (IMAPP, Strabala et al. 2002). IMAPP was developed to be portable and efficient in the generation of some of the same products generated at the Goddard Space Flight Center (GFSC) Distributed Active Archive Center (DAAC). The L1b products are then used to calculate the snow/ice surface temperature, snow/ice albedo, low-level temperature inversion strength and depth, and several IMAPP level 2 products. All of these products are displayed using the Man computer Interactive Data Access System (McIDAS; Lazzara et al., 1999) and then saved to the real time web page. Each product is briefly described below.

2.1 Cloud Mask

The IMAPP MODIS Cloud Mask is the direct broadcast version of the GFSC DAAC MOD35 product (Ackerman et al., 1998). Radiances from 19 spectral bands are used in the MODIS cloud mask algorithm to determine the confidence that a given scene is unobstructed (by clouds, aerosols, etc.). A full description of the MOD35 algorithm is provided in Ackerman *et al*. (1998). A further description of the IMAPP MODIS cloud mask is described in detail in Strabala et al. (2002). The cloud mask includes 4 levels of confidence of clear sky along with ancillary data information for each pixel. An example of the cloud mask product is shown in Figure 1.

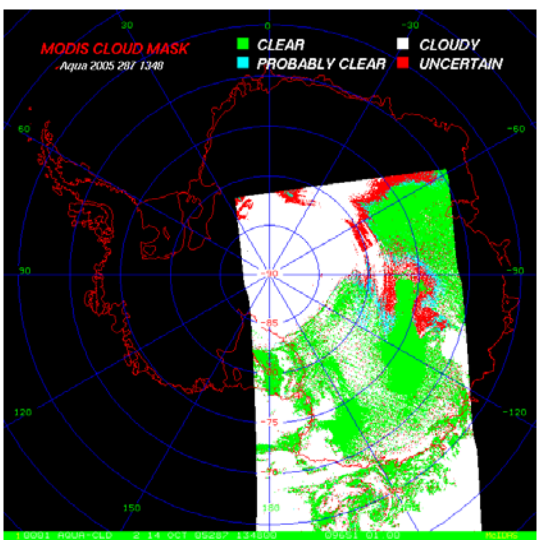

Figure 1. MODIS Cloud Mask IMAPP product from data obtained at McMurdo Station, Antarctica for 14 October 2005 13:48 UTC.

2.2 Cloud Pressure, Phase, and Precipitable Water

Cloud top pressure and cloud particle thermodynamic phase are the key parameters included in the MODIS cloud top properties product (Menzel et al., 2002; MOD06CT). These products require the cloud mask as well as forecast model fields of pressure, temperature and humidity as inputs. In addition to these MOD06CT cloud properties, atmospheric profiles (T, q) as well as total precipitable water vapor (MOD07) is now included in the list of products. An example of the cloud top pressure product is shown in Figure 2.

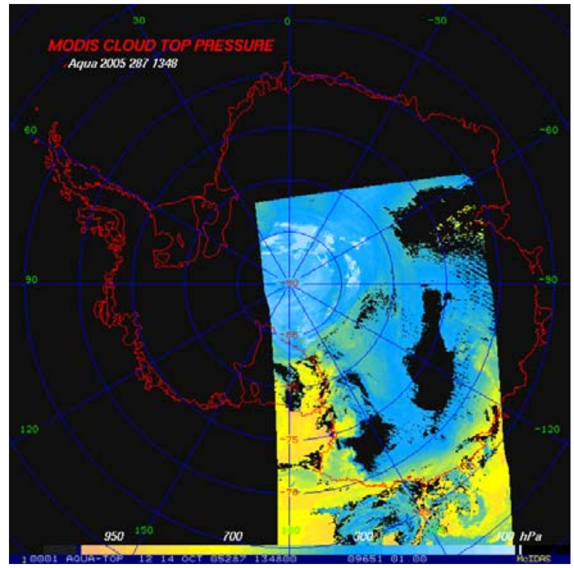

Figure 2. MODIS Cloud Mask IMAPP product from data acquired at McMurdo Station, Antarctica for 14 October 2005 13:48 UTC.

2.3 MODIS Polar Winds

The derivation of the polar winds from MODIS data is based on the established procedure used for the Geostationary Operational Environmental Satellite (GOES). Features from both the infrared window band at 11 μm and the water vapor band at 6.7 μm band are tracked over three consecutive obits. The infrared window band is used to track cloud, while the water vapor band is used for tracking clear sky water vapor and mid- to upper-level clouds. The majority of the wind vectors are derived from the water vapor channel because winds can be estimated in both clear and cloudy conditions.

After the orbital data are remapped, potential features that will be tracked are identified. They are tracked using a simple search for the minimum of the sum of squared radiance differences between the target and the search boxes in two subsequent images. However, unlike geostationary satellites at lower latitudes, it is not possible to obtain complete polar coverage in a single snapshot in time with one or two polar-orbiters. Because of this, winds must be derived for areas that are covered by two or three successive orbits. A model forecast of upper level wind is used to help choose the appropriate search areas. Displacement vectors are derived for each of the two subsequent images, which are then subject to consistency checks. Height assignments can be made with the infrared window, CO2-slicing, or the H2O-intercept methods.

MODIS winds are generated in near real-time at McMurdo Station and are made available for each 200-minute orbit triplet. They are available as they are produced at http://stratus.ssec.wisc.edu/db/mcmurdo. An example of the MODIS polar winds product is shown in Figure 3.

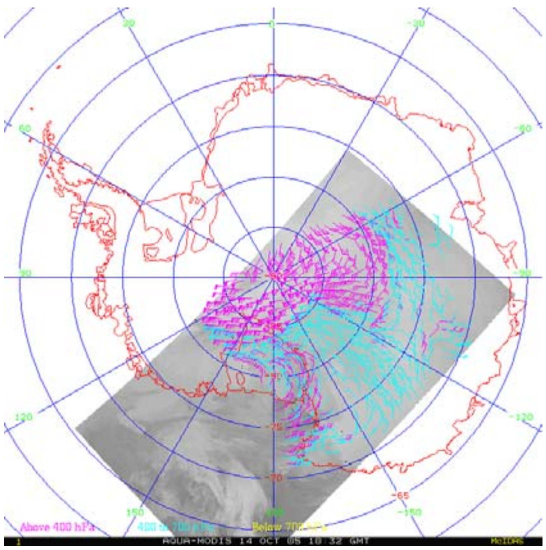

Figure 3. MODIS Polar Winds product from data acquired at McMurdo Station, Antarctica for 14 October 2005 10:32 UTC.

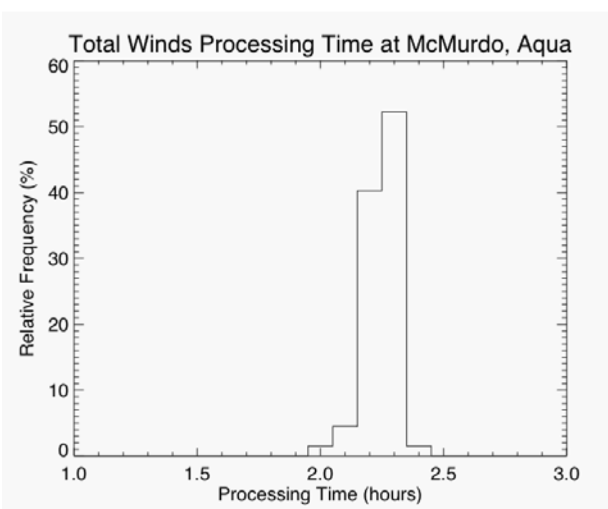

Figure 4. Relative frequency of the time it takes to generate polar winds with Aqua MODIS data at McMurdo.

Using our conventional MODIS data source, the NOAA real-time system (or "bent pipe"), the polar winds product is typically available 3-5 hours after MODIS views the earth. This processing time is for the middle image in a 3-orbit triplet. Actual processing time from image acquisition to the availability of wind vectors is 100 minutes less. With the DB system, the winds product is generated in 2.0-2.5 hours (Figure 4). MODIS images are available (image acquisition to level 1b) in 20-30 minutes. Winds processing takes an addition 10-15 minutes. This is a savings of more than one hour overall, and winds are now available soon enough to meet the 3-hour cutoff time typical of regional weather forecast models.

2.4 Surface temperature and albedo

The surface temperature and broadband albedo algorithms were originally developed for use with Advanced Very High Resolution Radiometer (AVHRR) data (Key et al., 1997; Key et al., 2001) but have been adapted for use with MODIS. Both variables are calculated for each non-cloudy pixel, as determined from the MODIS cloud mask, using the 11 and 12 μm channels for temperature, and 0.6 and 0.9 μm channels for albedo.

The surface temperature algorithm is empirical, with different sets of regression coefficients for different surface types. Surface type is available in the cloud mask product. Figure 5 gives an example of the surface temperature product from McMurdo.

The surface albedo is experimental at the time of this writing. This product should be fully operational in the near future. It is available online, but it should be considered a beta product.

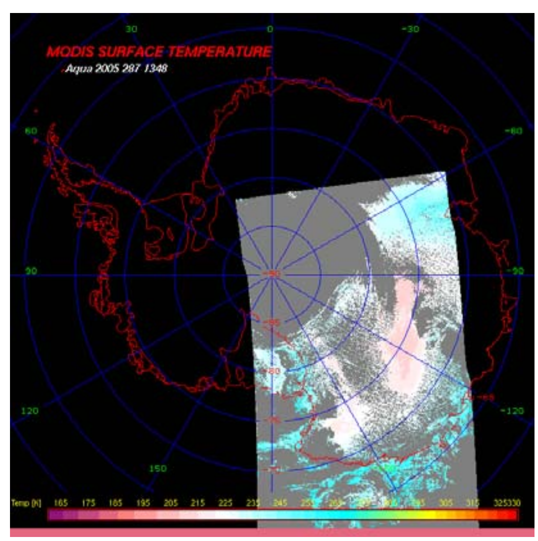

Figure 5. MODIS surface temperature product from data acquired at McMurdo Station, Antarctica for 14 October 2005 13:48 UTC.

2.5 Inversion Strength and Depth

Low-level atmospheric temperature inversions are ubiquitous in the polar regions for most of the year. They affect heat and moisture fluxes, the stability of the boundary layer, surface wind velocity, and ice lead formation. Inversion strength and depth are based on the algorithms described in Liu and Key (2003). The 7.2, 11 and 12 μm MODIS channels are used to calculate the temperature difference between the surface and the maximum inversion temperature, termed the inversion strength, and the height of the maximum inversion temperature above the surface, termed the inversion depth. An example of inversion strength calculated with MODIS data from McMurdo is given in Figure 6.

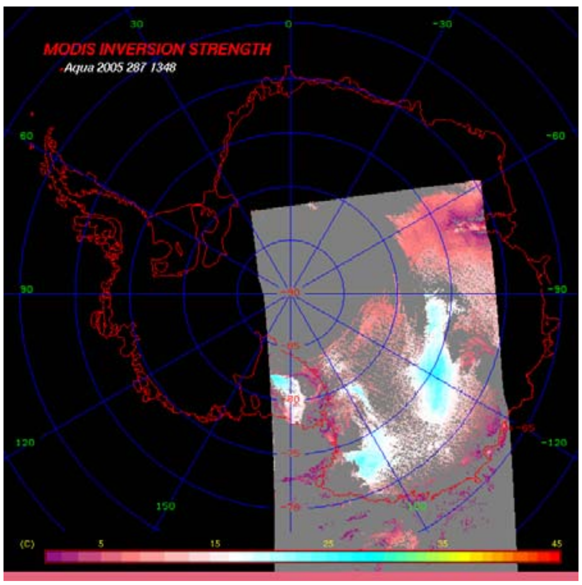

Figure 6. MODIS surface inversion strength product data acquired at the McMurdo Station, Antarctica for 14 October 2005 13:48 UTC.

3. OTHER POTENTIAL SITES

MODIS data acquired at the McMurdo DB site provides extensive, but not complete coverage of the Antarctic (Figure 7). At least two DB sites on opposite sides of each polar region are needed. In the Arctic, potential sites for implementation of a McMurdo-type system currently include Fairbanks, Alaska, Tromsø and Svalbard, Norway, and Sodankylä, Finland (Figure 8). Discussions are ongoing with the operators of those facilities (NOAA, Kongsberg Satellite Services, and the Finnish Meteorological Institute, respectively). In the Antarctica, the Troll, Norway site is being considered as a potential future site. In addition, the National Science Foundation's US Antarctic Program is considering installing a X-band DB system at Palmer Station.

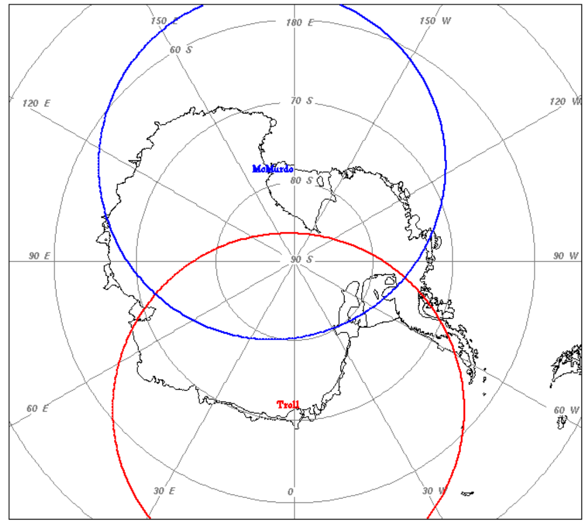

Figure 7. MODIS DB Site coverage for McMurdo (blue) and the potential DB site at Troll (red).

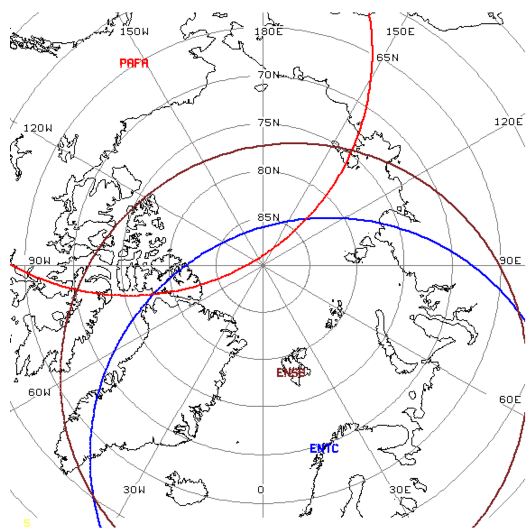

Figure 8. MODIS DB Site coverage for potential Arctic sites in Fairbanks, Alaska (red), Tromsø, Norway (blue) and Svalbard, Norway (brown).

4. CONCLUSIONS

The MODIS product suite currently generated at the McMurdo, Antarctica direct broadcast site was motivated by the requirement that numerical weather prediction centers need the MODIS polar winds product more quickly than it can typically be generated with our original data source. At McMurdo, the polar winds can be generated at least one hour faster, with data available in 2.0-2.5 hours.

While the MODIS polar winds were the primary product to be generated at the DB site, other products have since been added: a cloud mask, cloud top pressure, cloud particle phase, snow/ice surface temperature and albedo, and temperature inversion strength and depth. Several other products will be added in the near future, including cloud optical depth and particle size, surface radiative fluxes, and sea ice motion. It is hoped that local forecasters and field scientists will find these real-time products useful for weather prediction, flight planning, and field experiments. Furthermore, McMurdo and other high-latitude DB sites can provide a test bed for snow and ice products planned for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) as well as NPOESS itself.

Acknowledgements: The authors would like the thank Michael Pavolonis for the use of his programs to read in the MODIS Level 1b and MOD35 data. This research was supported by the NASA Earth Observing System, the National Science Foundation (NSF grant # OPP-0126262), and the National Oceanic and Atmospheric Administration.

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