## Earth Observing System (EOS) Snow and Ice Products for Observation and Modeling

Snow and ice are the key components of the Earth's cryosphere, and their influence on the Earth's energy balance is very significant due at least in part to the large areal extent and high albedo characterizing these features. Large changes in the cryosphere have been measured over the last century and especially over the past decade, and remote sensing plays a pivotal role in documenting these changes. Many of NASA's Earth Observing System (EOS) products derived from instruments on the Terra, Aqua, and Ice, Cloud and land Elevation Satellite (ICESat) satellites are useful for measuring changes in features that are associated with climate change. The utility of the products is continually enhanced as the length of the time series increases.

To gain a more coherent view of the cryosphere and its historical and recent changes, the EOS products may be employed together, in conjunction with other sources of data, and in models. To further this goal, the first EOS Snow and Ice Products Workshop was convened. The specific goals of the workshop were to provide current and prospective users of EOS snow and ice products up-to-date information on the products, their validation status and future enhancements, to help users utilize the data products through hands-on demonstrations, and to facilitate the integration of EOS products into models.

Oral and poster sessions representing a wide variety of snow and ice topics were held; three panels were also convened to discuss workshop themes. Panel discussions focused on data fusion and assimilation of the products into models. Approximately 110 people attended, representing a wide array of interests and organizations in the cryospheric community.

EOS Data Products

Data products from the Moderate-Resolution Imaging Spectroradiometer (MODIS), Advanced Space-borne Thermal Emission and Reflection radiometer (ASTER), Multi-angle Imaging Spectro-Radiometer (MISR), Advanced Microwave Scanning Radiometer – EOS (AMSR-E), Clouds and the Earth's Radiant Energy System (CERES), Enhanced Thematic Mapper Plus (ETM+) and the Geoscience Laser Altimeter System (GLAS) were highlighted in the workshop.

Together, the spatial (up to 500-m) and temporal (daily) resolution of the MODIS snow products (http://modis-snow-ice.gsfc.nasa.gov) and the ability of AMSR-E to produce snow-water equivalent (SWE) estimates through cloud cover and darkness (http://amsre-snow.gsfc.nasa.gov/) allow EOS-derived snow products to provide useful input to hydrologic and general-circulation models (GCMs). The MODIS snow albedo product, though not yet validated, provides daily snow albedo, while the bidirectional reflectance distribution function and albedo

products (http://geography.bu.edu/brdf/index.html) have been validated, and are useful for measuring snow albedo.

EOS-derived sea ice products provide advancements relative to earlier products. The MODIS ice-surface temperature (IST) products (http://modis-snow-ice.gsfc.nasa.gov) are validated for the "cold period" (no meltwater present) with an RMS error of 1.6K; ice concentration, ice temperature and snow depth on sea ice are products from AMSR-E on Aqua. Results from field programs are currently being studied for determination of the accuracy of the AMSR-E sea ice products (http://aqua.nasa.gov/AMSRE3.html and http://nsidc.org/daac/amsre/). MODIS sea ice extent and IST are being studied in conjunction with AMSR-E ice-concentration products, and Landsat-7 ETM+ data, which provide fine resolution images albeit only once every 16 days, are used for "ground truth."

Though most of the Earth's fresh water (>70%) is locked up in the Antarctic and Greenland ice sheets, it has been difficult to extract the information on ice-sheet mass balance because of the large areal extent and great thickness of the ice sheets. A keynote address by Waleed Abdalati highlighted the important tools such as aircraft- and satellite-borne lasers that NASA now has available to study ice-sheet elevation changes in Greenland and Antarctica. The main objective of the ICESat mission is to measure, using the GLAS sensor, ice sheet elevations and changes in elevation through time, which translate to changes in ice-sheet mass balance, a difficult parameter to measure.

The Satellite Image Atlas of Glaciers of the World is a multi-decade project, culminating in a series of major reports written by an international team of experts. This project, started in the late 1970s, by the USGS (Richard S. Williams, Jr.), uses Landsat data to map the Earth's glaciers. And while the final chapters are now being completed and published (http://pubs.usgs.gov/fs/fs133-99/), the ASTER-based Global Land Ice Monitoring from Space (GLIMS) project is getting started providing an excellent follow-on to the The Satellite Image Atlas series. GLIMS objectives are to measure the changes in extent of the Earth's glaciers. The international GLIMS team uses high-resolution satellite images from ASTER and the Landsat-7 ETM+ to track the size and movement of glaciers. The Landsat-7 (http://landsat.gsfc.nasa.gov/) data acquisition plan for Greenland and Antarctica is key to the GLIMS project and other glacier work. Landsat-7 data is not only useful for studying small glaciers, but has proven very useful for studying flow patterns and other parameters over ice sheets as well.

Product Availability

Most EOS products relevant to snow and ice research are available free of charge from the National Snow and Ice Data Center (NSIDC) (http://nsidc.org). These products include the MODIS snow and sea ice products from both the Terra and Aqua platforms, all AMSR-E products from Aqua, and GLAS products from ICESat. The products are available through various approaches such as

the EOS Data Gateway (EDG), data pool Search 'n' Order Web Interface (SNOWI), user subscriptions, and Machine-to-Machine Gateway (MTMGW). The data pool is a short-term data cache that provides FTP access to MODIS, AMSR-E and GLAS products (http://nsidc.org/data/data_pool/). Many other EOS precursor and ancillary products can also be obtained from NSIDC.

At the workshop, representatives from the NSIDC and Goddard Distributed Active Archive Centers (DAACs) provided hands-on demos to answer users' questions and to instruct prospective users about the product details and ordering. Demos of new data analysis tools were also conducted, showing users the broad utility of the products.

Panel Discussions

Discussions resulted from the three panels and from oral presentations. A modeling panel was chaired by Robert Dickinson, Georgia Institute of Technology; a data-fusion panel was chaired by David Robinson, Rutgers University; and a sea ice panel was chaired by Michael Van Woert, NOAA/National Ice Center. Discussions highlighted concerns about differing requirements of operational monitoring and modeling organizations, as compared to those of the scientific research community. Common among those concerns was the need for timely, quality data products that could be used alone or blended with other products to help achieve the operational or research goals of the user.

One of the biggest issues in GCM modeling is the fact that many subgrid scale processes must still be averaged in GCM grid cells. Also, models need to improve their parameterization of snow albedo, including analysis of the effect of desert dust and other contaminants on the albedo of snow. EOS products have enabled improvements in data-assimilation models since early 2000.

The future availability of passive-microwave (Cross-Track Microwave Imaging Sensor (CMIS)) and visible (Visible Infrared Imaging Radiometer Suite (VIIRS)) data for blending of data sets, provided in part by the launch of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) in 2010, was also discussed.

Workshop Recommendations

Significant recommendations emerged from the workshop concerning validation, the importance of estimating errors, and creation of Climate Data Records (CDRs). Optimally, validation should be undertaken (and funding provided) when data-product funding is awarded by NASA. While it is recognized that there is a tradeoff between science and validation in terms of funding, the discussions concluded that validation should be an integral part of algorithm and product development, and validation activities should be a component of product

monitoring. Including error estimates associated with a derived geophysical parameter (with the product) is necessary to evaluating the product, especially those products that are used to construct CDRs. Scientific stewardship should be applied in constructing and maintaining CDRs so that they possess the consistent quality necessary for study of decade-scale change in a geophysical parameter. EOS products will be useful in the creation of CDRs.

The EOS Snow and Ice Products Workshop was held on November 16 - 17, 2004, in Upper Marlboro, Maryland; the agenda and presentations from the workshop are available at: http://nsidc.org/events/eos_workshop04/ .

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