MODIS Science Team Meeting Summary
December 15–17, 1998
Plenary Meeting
December 15–16

Introduction

The Moderate Resolution Imaging Spectroradiometer (MODIS) Science Team meeting was held on December 15–17, 1998 at the University of Maryland Inn and Conference Center. Vince Salomonson, MODIS Science Team Leader, convened the meeting. The major focus was to share scientific results from Science Team members and guests. Salomonson reported that approximately 500 articles from refereed journals are currently in the MODIS Document Archive (MODARCH), at http://modarch.gsfc.nasa.gov/cgi-bin/texis/EOS/eos. The meeting began with updates on the progress of the Protoflight Model (PFM) scheduled to fly on the EOS AM1 spacecraft, and progress of FM1 scheduled to fly on the EOS PM1 spacecraft. The launch of AM1 is scheduled on or near July 15, 1999 from Vandenberg Air Force Base in Santa Barbara, CA. (Refer to Attachment 1 for the meeting agenda.)

Instrument Reports

Bruce Guenther provided an update on the MODIS Protoflight Model (PFM), slated to fly on the EOS-AM1 spacecraft and Flight Model 1 (FM1) which will fly on EOS-PM1. There are Response versus Scan Angle (RVS) issues on the PFM scan mirror (see Attachment 4). It will not be possible to perform all the testing needed to characterize PFM scan mirror, so strategies for determining the calibration coefficients for the PFM are being revised. A workshop on how the calibrations will be done for the thermal emissive and solar reflective bands is being planned. The FM1 showed improvements in mixed scene tests after replacing resistors on the instrument, with peak errors decreasing from tens of percents to a peak of about 25 percent. Electronic crosstalk has improved significantly since the errors reported at the June 1998 Science Team Meeting. However, the data set will still have problems that need to be flagged.

Because of crosstalk between bands 5, 6, 7 and 26, some extrapolations will be necessary in calibrating band 7. The project and SBRS have made significant improvements in FM1. Electronic crosstalk has been fixed in both instruments, and replacing a lens has resulted in better scatter performance in the thermal IR bands. SWIR light leaks have been reduced by adding blocking filters; other light leak reductions have also been made.

Neil Thierren reviewed the FM1 instrument status (see Attachment 5, "FM1 Status"). He said the FM1 thermal vacuum tests have been completed and that FM1 SWIR crosstalk has been significantly reduced for band 6. Similarly, there have been band 20 MWIR improvements, and LWIR improvements. Thierren reported excellent radiometric performance. SNRs are better in FM1 than in PFM, bands 35-36 are now within specifications on FM1, but still out of specifications on band 21 (fire band). This may be due to low signal level and an inability to get the blackbody hot enough to test noise.

Thierren noted that most bands meet the bandwidth requirements. SBRS still is analyzing Out Of Band (OOB) data, with limited results currently available. A 5.3-micron leak on PFM was reduced but not eliminated, and an 11micron leak was significantly reduced. FM1 MWIR/LWIR RVS is much better than for PFM; it does not meet the 0.1 specification, but the PFM's RVS characterization is getting better.

Issues in work include power supply resets, a PC detector drift anomaly which has been traced to a temperature control card, and the Nadir Aperture Door / Solar Diffuser Door (NAD/SDD), fail-safe operation strategy.

Ocean Science Reports

Wayne Esaias introduced the Ocean Science Reports. He said the presenters would review most Ocean products except Howard Gordon, who presented products based on SeaWiFS data at the previous science team meeting in June 1998. The Ocean Science Reports were reordered from the original agenda, with the order of the second and third reports reversed.

Peter Minnett presented for Otis Brown on Sea Surface Temperature (SST) (see Attachment 6, “MODIS Sea Surface Temperature Progress”).

The strategy for the MODIS SST algorithm involves using a Radiative Transfer Equation (RTE) model to simulate SST measurements pre-launch. This requires an excellent RTE model, good instrument characterization, and a good representative set of environmental conditions. The model used was a line-by-line RT model developed by RAL in the U.K. for ASTER pre-launch algorithm, which includes the latest water vapor continuum model and permits specification of realistic aerosol distributions. A database of over 30,000 brightness temperatures each in MODIS bands 31, 32, 20, 22, and 23 was developed using 1200 radiosondes taking measurements at 5 zenith angles at 5 atmosphere/sea surface temperature differences for use in the MODIS simulation. The resulting algorithm is based on the Miami Pathfinder AVHRR algorithm, using 11-12 micron (band 31-32) measurements

The ATBD algorithm has an uncertainty of 0.337K at nadir due to clear-sky atmospheric variability, primarily water vapor. The MWIR has an uncertainty of about 0.25K, but there is a potential for reduction in this uncertainty. The instrument error budget adds to the uncertainty; scan mirror emissivity by scan angle, blackbody temperature, and NE T uncertainties all affect SST retrieval. Sea surface uncertainty due to wind can add another 0.05K uncertainty.

The uncertainty in SST retrieval depends in part on whether response versus scan angle (RVS) errors for bands 31 and 32 are correlated or not. The SST uncertainty is much lower if they are correlated. A correlated uncertainty of about 10% in RVS for bands 31 and 32 is required to retrieve SST with an uncertainty of less than 0.5K at 45 degrees off-nadir.

Minnett next discussed SST validation. He stresses that the SST validation plan is not a vicarious calibration of the MODIS infrared channels. The purpose is to provide confidence in the MODIS SST product, and to both confirm proper functioning of the atmospheric correction algorithm and to learn how to improve the algorithm.

One important consideration in validation is comparing "like with like". A "skin effect" plus the diurnal thermocline can affect SST measurements; remote-sensing instruments measure the "skin temperature", while in-water instruments will measure "bulk temperature". The skin effect is on the order of 0.2 - 0.3K; the thermocline can contribute up to a 2.5K difference during the day with the maximum occurring at about 2:30 pm. At 10:30 am, the effect is still several tenths of a degree; this can be larger than the uncertainty in the SST measurements.

The Marine-Atmosphere Emitted Radiance Interferometer (M-AERI) is being used to collect skin temperature SST measurements, and will be used for MODIS SST validation. Minnett reviewed cruise histories and data from completed campaigns, noting that uncertainty in skin temperature measurements was very low; on the order of 5 millikelvins. In calibrations to NIST reference black-body targets, M-AERI showed a maximum error of 20 millikelvins at 20C and less than 50 millikelvins at 60C, providing good confidence in the accuracy of the instrument.

In summary, Minnett noted that the at-launch SST algorithm has an uncertainty of 0.33K due to atmospheric uncertainties, and that unless the uncertainty in RVS is significantly reduced, MODIS will not do better than AVHRR in SST retrieval. The contamination of SST fields by aerosol is likely to be a concern as well, but MODIS has a better potential for diagnosing and recovering from aerosol effects than AVHRR or ASTER.

Dennis Clark presented an overview of the MOBY program and plans for MODIS initialization and vicarious calibration campaigns using MOBY. See Attachment 7, "Use of MOBY Observations for Initialization and Vicarious Calibration of OCTS, SeaWiFS, and MODIS."

Clark began with a description of the MOBY program to date, noting that the system has been providing data in test mode since December 1996 and went into production in June 1997. He described the physical configuration of the MOBY buoys and of the optics and spectral characteristics of the on-board detectors. He described the MOBY site and discussed the data transmission and posting strategy, which utilizes an on-board cellular phone and allows data to be processed and posted within 24 hours of collection, and reviewed planned enhancements to MOBY for the coming year.

Clark continued with a review of SeaWiFS initialization and vicarious calibration, presenting water-leaving radiance results and comparisons between MOBY and SeaWiFS. He noted that there were out-of-band atmospheric problems with SeaWiFS, where energy from blue bands is being picked up on infrared detectors. He concluded that MOBY provides a stable database for instrument initialization use, and stated that MOBY did a pretty good job initializing SeaWiFS.

MOBY Calibration was discussed next. Pre-deploy, MOBY buoys were calibrated to NIST-traceable standards. During deployment, internal reference lamps, diver reference lamps, and coincident ship observations are used to calibrate MOBY, with before and after cleaning measurements taken by divers during maintenance visits. Post-deploy, the MOBY instruments are re-calibrated to NIST-traceable standards. The result is high-quality MOBY data, with a difference between MOBY and other instruments of less than 1% in most bands. IR bands are the exception to this, where crosstalk is a problem. The overall error for MOBY data is on the order of 2-3 %.

Bob Evans reported on using the NOAA-14 AVHRR instrument as a pathfinder for validating Sea Surface Temperature (SST) and Ocean Color on SeaWiFS. He reviewed the factors to be considered in comparing SST products between instruments, noting the difference between skin temperatures measured from satellites and bulk temperatures measured in-situ.

Evans noted that cloud and aerosol effects were sources of difficulty in retrieving SST. Boresighting and internal scattering on AVHRR result in cloud effects impacting SST retrieval within 5 pixels (about 20 km) of the clouds. Beyond the 5 pixel distance, SST retrievals match up as expected with M-AERI data. On aerosols, AVHRR incept data appears to match the TOMS aerosol index fairly well. With SeaWiFS, the aerosol can be backed out in regions where there is low chlorophyll (and thus low-scattering water) from the initialization algorithm and the standard atmospheric correction. Comparing MOBY to SeaWiFS scattering data gives confidence that the SeaWiFS product is well-calibrated.

It is possible to take SeaWiFS data, convert it into a MODIS product, and run it through the MODIS algorithms for pre-launch algorithm testing and development. There are only very small differences between the MODIS and SeaWiFS products.

In summary, Evans noted that M-AERI data suggests that satellite SST retrievals have lower errors than expected. The SeaWiFS initialization has resulted in good water-leaving radiance, and the MODIS PGEs reproduce the SeaWiFS results.

Kendall Carder presented “Observations of Dissolved Organic Material and Case 2 Algorithms.” He began with a description of the Case 2 algorithm and the differences between case 1 and case 2 waters. He noted that variations in phytoplankton absorption can be fivefold; which impacts the algorithm's performance.

Carder described a process whereby dissolved organic materials affects circulation patterns in the upper ocean. In case 1 waters, absorption due to Chromophoric Dissolved Organic Matter (CDOM, or gelpstoff) ranges from 30%-70% of the absorption due to phytoplankton. In case 2 waters, CDOM absorption can be 20 times the phytoplankton absorption or more. A number of factors, including land runoff and primary productivity, can result in areas of higher CDOM concentration. CDOM absorption in these areas will cause the water to warm and expand; this water will flow “downhill” and turn due to coriollis forces, the result being a “forbidden zone” at the center of the circulation.

Carder noted that there is a correlation between low salinity and high gelpstoff concentrations. He hopes to add primary productivity and heat budget to models for the Western Florida Shelf.

Frank Hoge discussed Accessory Pigment Algorithms (see Attachment 8), and described capabilities of a ship-based laser system (LIDAR) which will provide similar capabilities to airborne instruments.

Hoge noted that data collection includes both upwelling radiance from the ocean and sky radiance. On aircraft, you can repeat measurements from different altitudes, and obtain an atmospheric correction directly from the data. With shipboard instruments, this is not possible, and uncertainties in the atmospheric correction can make producing a usable product from the data untenable.

Other pigments interfere with chlorophyll absorption, as they contribute to the absorption spectra. The pigment absorption line shapes can be modeled with a Gaussian line shape. Hoge noted that the analytical Radiative Transfer Equation was difficult to impossible to invert, and discussed a matrix-based model of the radiative transfer process that is invertable. Refer to Attachment 8 for details.

Hoge then discussed retrieving Phycoerytherin pigment concentration. This is complicated by the existence of two different chromophores—PEB and PUB. There are different characteristic spectra for different PEB/PUB ratios. Another concern in retrieval is that phytoplankton and phycoerytherin concentrations seem to correlate, resulting in combined chlorophyll/PEB/PUB signatures, which can be difficult to separate.

In closing, Hoge noted that PEBs are very good nitrogen fixers, which has climatological significance. Photosynthesis by cyanobacteria may account for 25% of net primary productivity (NPP), but this is not well characterized at this time.

Wayne Esaias next discussed weekly and annual ocean primary productivity (OPP), noting trends in OPP and comparing products from different instruments. He discussed the OPP software in the SCF, and compared the performance of models for predicting OPP. Reviewing data from the SeaWiFS and CZCS instruments, he noted that there were differences in the statistical distributions for annual chlorophyll. Esaias concluded that the product derived from the 490:555 micron ratio represents different information than that provided by the algorithm using a combination of 443:555 and 520:555 micron ratios.

Mark Abbott followed with a presentation on "Chlorophyll Fluorescence and Primary Productivity" (see Attachment 9). He began with an examination of the decorrelation scales between SST, chlorophyll concentration, chlorophyll fluorescence, and ocean current speeds in three regions—near-shore, off-shore, and an intermediate transition region off the California coast. The data suggests that there is an imbalance between light harvesting utilization near-shore, while these processes are in equilibrium off-shore due to different physical processes driving sea-surface temperature and chlorophyll concentrations.

Abbot them moved on to results from data collected from the Antarctic Polar Front Zone. The region is defined by the location of the circumpolar current, and is subject to significant changes in the light environment throughout the year. Data was collected by a series of buoys moored near 60S latitude, 170W longitude, along with a series of free-drifting buoys. SeaWiFS data was used as "ground truth" for data from the buoys.

Sun-stimulated fluorescence data combined with chlorophyll levels were used to develop a scenario to describe the spring phytoplankton bloom. Starting from a light-limited state, the spring bloom begins as the phytoplankton light-adapt to the increasing length days. After about 20 days, the bloom begins to decrease, possibly due to silicate supply limitations. The final equilibrium level may be iron limited.

Referring to the climatological significance Antarctic primary productivity, Abbott suggested that the Southern Ocean was likely an atmospheric carbon sink during last glacial period.

Abbott moved on to a discussion of a series of Chemostat experiments, working with Dunaliella tertiolecta, and examining the daily cycle of fluorescence yield and primary productivity. Results from these experiments are included in Attachment 9.

Abbott concluded by noting that improved models of primary productivity are essential to understanding the linkages between atmospheric CO2 and ocean uptake, and noted that simple chlorophyll-based models will not be adequate for this task. He described MODIS as a significant step forward in ocean remote sensing, and expressed concern that proposed future instruments would be a step backwards from MODIS.

Atmosphere Science Reports

Michael King opened the session on Atmosphere Science Reports with an overview of the MODIS Atmosphere Data Products and their status (see Attachment 10). He noted that Atmospheres will produce a single Level 3 product incorporating all atmosphere parameters in a 1 degree by 1 degree grid, producing 1, 8, and 30 day products. He reviewed the Cloud Mask algorithm, noting that the Cloud Mask will use 17 spectral bands and will be an input to the rest of the land, atmosphere, and oceans algorithms. He discussed the Cloud Properties algorithm and its use of 12 bands for retrieving cloud properties. A scattering phase function can be used to determine ice crystal shape, and CO2 slicing will be used to determine cloud top altitude.

King next discussed Aerosol Properties retrieval over land and ocean, using 8 MODIS bands. He compared the capabilities of 11 instruments, examining the channels used for cloud mask and aerosol retrieval. Results for aerosol retrieval over oceans from Polder and OCTS for April 1997 were compared. Algorithms for retrieving column water vapor were discussed next, and the AERONET sun/sky photometer network for ground truth was described.

A status report on the Atmosphere software and documentation was presented. King noted that all PGEs had been accepted with the exception of a new Level-3 "weekly" product. This new product is virtually identical to the Level-3, 30-day product, and should be in place in January 1999. All 6 ATBDs from the MODIS Atmosphere group have been updated and delivered to the MODIS Project Science Office, and validation plans are being updated to include new features.

King closed with a report on the use of a Cloud Absorption Radiometer, which he had developed in 1982, for measuring surface BRDF.

Lorraine Remer followed with a discussion of the Retrieval and Validation of Aerosol Optical Thickness and Total Precipitable Water using AVIRIS and MAS Measurements during SCAR-B (see Attachment 16). Remer focused on the validation of aerosol products, noting that King had covered most of the issues relating to aerosol retrieval.

The Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) campaign utilized an ER-2 aircraft flying at high-altitude, looking down over the ocean with the MODIS Airborne Simulator (MAS) instrument and the University of Wisconsin’s C131A flying low and low looking up with a sun photometer. The results of this campaign suggest that the algorithms for aerosol retrieval over oceans are in good shape.

The SCAR-B campaign flew the ER-2 over AERONET sites in Brazil, using MAS to observe in the red bands and AVHRR to take measurements in the blue bands. It was discovered that the blue bands are very sensitive to single-scatter albedo.

Remer noted that clouds pose a difficulty in aerosol and water vapor retrieval. In the visible channels, you can only see down to the cloud tops, hiding water vapor deeper in the atmosphere. She then discussed the use of the Sounding Microwave Radiometer (SMiR) for column water vapor retrieval, and using AERONET, radiosondes, and possibly GOES-8 IR data for validation.

Remer next discussed a rapid-response campaign to collect aerosol data during the 1998 Mexico fires to provide ground truth for satellite measurements. The fires occurred in areas where there are no AERONET stations; portable instruments were used to take in-situ measurements.

In conclusion, Remer stated that the validation of aerosol and water vapor algorithms appeared to be successful, and the plans are now to validate aerosol and water vapor products. She noted that there are a number of methods that are available for water vapor product validation. Steve Ackerman suggested that FluxNet is interested in hosting sun photometers, which could expand the validation network.

Steve Ackerman discussed “Cloud Mask and Water Vapor: Results and Validation” (see Attachment 12). There are a number of tests that are used to determine the cloud mask; in putting the mix of tests together, it is important to ensure that no one band of the 17 used is dominating the results. It is equally important to make sure that there are no bands that are never used. Additionally, no band or test should be routinely at odds with other tests. The results from tests run using data from MAS seem to indicate that there is a good balance in the tests being used to determine the cloud mask, which provides good confidence in the cloud mask algorithm. Ackerman reported that the MAS Cloud Mask Release 2.0 is now available.

A comparison was made between 6 different cloud mask algorithms. MODIS, which is “clear-conservative,” surprisingly calls pixels “clear” more frequently than other algorithms, but it seems to be accurate. One explanation is that MODIS successfully retrieves more pixels than other instruments, and most of these seem to be clear.

Ackerman next reported on WILT (Week In The Life Testing). Concerns arose when the cloud mask, run against simulated data, reported clouds when it should be reporting clear. The problem was identified as the split-window algorithm kicking in and reporting cloud because clear pixels are showing a negative brightness temperature difference in the simulation. Given this, the cloud mask algorithm is actually behaving as expected. There are also concerns about “cigar shaped” areas of uncertainty in cloud mask. The cloud mask team is worried that the cigar-shaped patterns are artifacts of the aggregation routines. Ackerman noted that simulating MODIS scenes has turned out to be a difficult proposition, and is confident that most of the problems encountered were artifacts of the WILT data set. A 10-page (maximum) Cloud Mask Users Guide is being prepared for the MODIS community.

Ackerman then provided a brief overview of total column precipitable water vapor (TPW) retrieval product. He stated that the determination of TPW is most directly done by integrating the moisture profile through the atmospheric column. In validating TPW, different instruments look at different size ground footprints. In areas with large TPW gradients, one would expect to find differences between instruments like GOES, with a 30 kilometer footprint, and M-AERI, with a 10 to 100 meter footprint.

Paul Menzel followed with a discussion of Cloud Top Properties (see Attachment 13). He reported on results of the SUCCESS campaign, where MAS cloud-top determination using CO2 slicing correlated well with co-located LIDAR cloud-top measurements. The use of an IR band near 1.38 microns enhances the ability to spot high thin cloud. CO2 slicing can be used to knock emissivity out of the equation, provided that you to know whether you have water or ice clouds. The 11 and 13 micron CO2 channels can be used to determine this. Optically thin clouds are more difficult to retrieve than optically thick clouds are.

Data from SAGE was compared to HIRS data from the 1989–91 timeframe. In general, SAGE does better at high cloud retrieval. Over an 8-year period, HIRS found clouds in about 75% of the observations; corresponding to about 69% of globe being cloud-covered.

A tri-spectral approach to cloud phase determination, using 8.6, 11, and 12 micron channels, is showing good sensitivity to high cirrus clouds. Using multiple IR channels is proving effective in determining cloud particle size and optical path; having additional IR channels on the AGI instrument would prove beneficial.

Steve Platnick reported on Cloud Retrievals in the Arctic, presenting preliminary results from the FIRE/ACE (First ISCCP Regional Experiment/ Arctic Cloud Experiment) campaign (see Attachment 14). The experiment utilized the ER-2 aircraft for high-altitude observations, the UW CV-580 and NCAR C-130Q aircraft for low-altitude observations, and a number of ground stations to study the radiative effects of clouds in several locations, including Barrow, Alaska, several ocean sites, and the SHEBA station, adrift on pack ice.

The usual strategy for cloud retrieval is to use one nonabsorbing (water) VIS/NIR band and one absorbing SWIR band to simultaneously retrieve cloud optical thickness and effective radius. This algorithm is set up for surface albedo of about 5%, which represents dark ocean water. Over sea ice, the surface reflectance is much higher, with albedos in the 50% range. In addition, the uncertainties in surface reflection can render cloud retrieval meaningless. In order to accurately retrieve clouds over sea ice, it is necessary to minimize both the uncertainty and variability of surface reflection measurements. A complicating factor is that there can be a high temporal variability in albedo—a 5-day difference can show significant melting and hence a change in scene properties.

In the SWIR bands, however, reflectance is almost the same for ice and open water, this suggests that using these bands can reduce the variability of surface reflectance measurements. A modified cloud retrieval algorithm was developed using only SWIR bands—in particular, the 1.6 micron band eliminates surface features that contribute to surface reflectance variability. Preliminary cloud retrievals with MAS using the modified algorithm are in good agreement with in-situ measurements and may be appropriate for use in producing MODIS data products.

Bo-Cai Gao followed with a discussion of the MODIS Thin Cirrus Reflectance Algorithm Using the 1.375 micron Channel (Attachment 15). He began with a series of images showing surface features in the visible band while showing high-cirrus clouds in the infrared to show the effects of band selection on cirrus visibility. An empirical technique for correcting for the effects of thin cirrus clouds was described, and results from that correction were shown.

Gao then demonstrated how removing cirrus effects can significantly improve the NDVI product, with examples of NDVI retrievals using AVIRIS over Gainesville, FL provided. Two images were taken 15 minutes apart with different levels of cirrus coverage; the uncorrected NDVI products were significantly different, while the products with the cirrus correction correlate well to each other. Similar results were shown for measurements taken over Palmdale, CA.

Gao closed with an example of hyperspectral remote sensing over coastal waters, taking reflectance spectra over variously turbid waters—the Florida Keys were used as an example. By using the assumption that water reflectance beyond 1.0 microns is zero, the measured reflectance over 1.0 microns can be used to characterize and correct out aerosol effects. He concluded that using the 1.375-micron channel will have important applications in correcting out thin cirrus cloud effects and in improving remote sensing capabilities for land surfaces and ocean color.

The atmospheres session concluded with a presentation by Yoram Kaufman on MODIS Aerosol Products and Aerosol Radiative Forcing of Climate (see Attachment 11). Kaufman began by asserting that aerosols are the biggest uncertainty in the radiative forcing of climate, that they pose impacts to public health when produced by forest fires, and are a significant source of uncertainty in atmospheric corrections. The MODIS aerosol products offer the first global measurements of aerosol optical thickness and mass loading over land, and the first aerosol size estimations over oceans. Kaufman noted that this is not sufficient, as it offers no clear pathway to radiative forcing; and no measure of aerosol absorption. MODIS can detect about 70% of the total global direct radiative forcing, but only 50% of indirect forcing. There is a need to come up with clever ideas to improve the detection of indirect forcing.

An evaluation of the models used to estimate global direct and indirect radiative forcing was performed. Using dust absorption models, absorption was over-estimated. A single-scattering model showed promise over the ocean in the 0.4 to 1.0 micron range. Kaufman suggests that a combination of MODIS remote sensing observations with AERONET sun/sky radiation measurements can be a powerful tool to narrow the uncertainty in climate forcing.

For the future, Kaufman would like to consider the possibility of adding a direct radiative forcing product, along with a Level-3 single-scattering albedo product. He would like to determine if there are any other Level-3 procedures that can help more accurately derive changes in optical thickness, and hopes to use MODIS and LANDSAT-7 remote sensing data in combination with AERONET data to derive the effects of particle non-sphericity on remote sensing, atmospheric corrections, and climate forcing.

Land Science Reports

Chris Justice opened the Land Science Reports Session with a discussion of the context for MODIS Land Science Products (see Attachment 17). He traced the heritage of MODIS, and noted the anticipated improvements in land remote sensing capabilities that MODIS will offer.

Justice then outlined the MODLAND approach to land science. There is a small number of critical products that will be produced, with a number of enhanced products that will build on existing capabilities. Community algorithms which are responsive to the ATBD reviews are being used, and explicit product QA, accuracy, and validation plans are an integral part of each product.

Justice reviewed the planned land data products, and noted that the context of the science being done is to provide input to the U.S. Global Change Science Program (USGCRP), the NASA remote sensing R&D program, and other programs in the global remote sensing community.

The primary focus areas of the USGCRP in 1998 are the heating and cooling of the Earth, changes in the Earth's ecosystem, interactions between terrestrial surfaces and the atmosphere (including energy transfer, water vapor, carbon cycling), mapping global land cover, and observation, analysis, and modeling of El Nino Southern Oscillation (ENSO). Justice outlined the mapping of MODLAND product suites to USGCRP goals.

Alan Strahler continued with a discussion of the MODIS Energy Balance Produce Suite (see Attachment 18), indicating that he would be focusing on prototyping rather than algorithm development. He noted that monitoring global change requires a global viewpoint, and highlighted the need to monitor spatial and temporal variation in Earth's energy budget in order to adequately understand and model global change.

The Earth has an albedo of 31% in the short-wave bands, absorbing 69% of the incoming energy. Of this, 48% is absorbed by the ground and about 20% by the atmosphere. The long-wave fluxes include atmospheric up- and down-welling emittance and net long-wave radiation from the surface to the sky. The land surface energy balance is highly dynamic and spatially variable, and there is a significant day/night cycle; the global energy balance is the integral of these spatially and temporally variable factors. The role of the MODIS land products is to provide a daily and nightly mapping of surface parameters that drive the instantaneous land surface energy balance.

The Land Surface Reflectance Product (MOD09R), being developed by Eric Vermote, is intended to provide surface reflectance values independent of atmospheric conditions. SeaWiFS data has been used for prototyping, including the generation a land cover product and aerosol retrievals over the ocean.

The Bi-Directional Reflectance/Albedo Product (MOD43), being developed by Strahler, is intended to quantify angular variation in reflectance of land surface covers and estimate albedo for energy balance and climatic studies. Prototype BRDF/Albedo algorithms and databases have been developed and tested using AVHRR, GOES-8, POLDER, and field data; the purpose of the prototypes is to provide a global, at-launch broadband albedo database to initialize the BRDF/Albedo algorithm.

The Land Surface Temperature Product (LST - MOD11) is being developed by Zhengming Wan. It is intended to provide surface temperature and emissivity information for input into surface energy balance and global climate models, and features two alternative approaches to retrieving LST. One approach uses a generalized split-window LST method, utilizing a knowledge bade of regional and seasonal land characteristics keyed to the Land Cover product; the other uses a day/night LST method for land covers with variable emissivities, such as desert or bare rock.

Results from prototyping LST retrieval using data from the MAS-Snow campaign were detailed. Field measurements and radiosonde data was used to calibrate the MAS channels; a thin cirrus correction was applied to the MODIS LST algorithm, and surface temperature, air temperature, water vapor depth, and cirrus optical thickness were retrieved for each pixel. Pixels were averaged in order to collapse the resolution to examine scaling effects; the retrieved values show little variance due to scaling. The enhanced MODIS LST algorithm appears to be capable of retrieving and removing thin cirrus clouds, even over cold targets.

The Snow Cover Product (MOD10), being developed by Dorothy Hall and Vince Salomonson, is intended to map the extent and variability of snow cover for input into regional-scale hydrologic models and global change models. The product uses a modified SNOMAP algorithm with inputs from MODIS VNIR and SWIR bands.

The algorithm was tested using MAS data over Harding Lake, Alaska collected in April 1995. While the algorithm in general performed quite well, it proved to be difficult to identify snow through dense vegetation. Hall enhanced the algorithm to allow the detection of snow in 50%+ dense vegetation areas; the enhanced algorithm has an estimated error of 15% in forested areas, and 5% in most other land cover type areas. Snow cover errors are expected t average 8-10% during the winter months, less in the summer.

In addition, the Snow Cover Product will categorize and map sea ice using MODIS bands. Sea ice can be identified by reflectance, by Ice Surface Temperature, and by cloud identification using a brightness temperature test. Examples of Sea Ice retrievals of different ice types—new, young, first-year, multiyear, and old ice—were provided.

Steve Running next reported on the MODIS Land Ecosystem Product Suite (see Attachment 19), beginning with an overview of the data products that comprise this suite. Vegetation Index (VI) is a radiometric measurement of the amount, type, and condition of plant matter. Leaf Area Index (LAI) quantifies the vegetation canopy structure, and is used in global climate modeling, hydrologic models, and carbon cycle models. Fraction Photosynthetically Active Radiation (FPAR) quantifies absorbed canopy radiation, and changes daily. It is used as an input to Net Primary Productivity (NPP) algorithms, and bears a non-linear relation to LAI. NPP quantifies vegetation growth. It has two primary uses—as a component of NEP for global terrestrial carbon sink/source analyses, and as a practical measure of crop, range, or forest growth for local applications.

In order to deal with temporal and spatial variability in the NPP, LAI, and FPAR products, a look-up table is built behind the scenes to model biome types. The MOD-17 product was offered as an example. In computing NPP, respiration losses, which are invisible to satellites, must be accounted for. The computation of NPP is accomplished by subtracting from the measured gross primary productivity (GPP) respiration losses derived from a biome model appropriate to the area being observed. Results from exercises to calibrate the MOD-17 product and test the biome model look-up table were presented.

Running continued with a discussion of MODLAND calibration and validation activity. A set of EOS Land Validation Core sites is being defined, for which scientists can readily access in-situ and EOS instrument data. A series of product-specific sites will supplement the core sites as needed on a product-by-product basis.

Specific developmental activities for MODLAND calibration/validation include the MODIS Quick Airborne Looks (MQUALs) airborne radiometric system being developed by Huete for rapid, low-cost product validation, and modified CIMEL sun photometers that are being reconfigured to collect directional surface radiances to assist in validating atmospheric corrections, vegetation indices, and BRDF.

In addition, EOS Land validation will take advantage of collaborations with existing science networks, including the AERONET CIMEL sun photometer network, the global FluxNet array of flux towers, the Bigfoot project, and a series of intensive NPP and LAI data sites.

John Townsend followed with an overview of the MODIS Land Cover Product Suite (see Attachment 20). Two broad classes of land cover products will be produced—Global Land Cover products, which will describe and categorize land covers, and Land Cover Change products, which will track and describe land cover changes on a variety of scales and due to a number of factors, including anthropogenic effects, interannual climate changes, and fires .

The requirements for Land Cover Products are to provide parameters for GCM, carbon, and hydrologic modeling, monitor changes in these parameters, and provide improvements in land remote sensing products.

The At-Launch Land Cover Categorical Product will be essential for the creation of some MODIS Land Products. There will be two alternate products available. One will be based on 1 km AVHRR data from the Eros Data Center (EDC), using 17 categories of land cover classification proposed by the IGBP. The second is the University of Maryland/College Park (UMCP) product, which uses a decision-tree approach to process a set of 154 metrics into a simplified IGBP scheme of 13 land cover classes.

A Post-Launch Land-Cover product which relies on advanced classifier technologies is being developed at Boston University. The inputs to this product include surface reflectance, spatial texture, vegetation index, snow cover, land surface temperature, and BRDF, as well as ancillary data. A set of algorithm training and test sites will be used to develop the product and to provide ongoing calibration and validation for the product.

The MODIS 250-meter Land Cover Change Product is designed to detect changes caused by human activity or extreme natural events. These changes will include deforestation, agricultural expansion or contraction, flood events, and burn scars due to fire events. Changes will be tracked over 3 month and one year time scales. In addition, these products can serve as an alarm system for change events; the response to an alarm could include monitoring the area with at high resolution to track what changes are occurring on a local scale after the alarm is triggered.

The MODIS Vegetation Continuous Fields Product is an alternative to the traditional classification scheme. It will depict gradients in and mosaics in the landscape, capture spatial heterogeneity in vegetation cover, and estimate the proportions of various vegetation types in a given area. It will be produced annually at 500-meter resolution. A mixture modeling simulation test using LANDSAT pixels degraded to MODIS resolutions was described, including the difficulties encountered and strategies for improving the mixture model based on lessons learned.

The MODIS 1-kilometer land change product will initially focus on NDVI and surface temperature, and the ratio between the two. Post-launch, as MODIS data becomes available, surface texture and BRDF data will be added to the product. Reference values, in the form of a 12-element vector, will be used to identify deviations from the baseline conditions. The change vectors will be generated every 3 months for the preceding 12-month period - the use of a quarterly rather than an annual product will allow earlier detection of any inter-annual variability.

Townshend next discussed the MODIS Fire products. Fire is significant because it is a source of trace gas and particulate emissions. It can be either the cause or an indicator of land cover change. Fire is both a driver of ecological change and a land management tool, and can be a hazard with significant societal costs and impacts. MODIS Fire Products include the Active Fires, Fire Characteristics, Burned Areas, and a Fire/Volcano alarm. A multi-temporal active fire-based burn scar index was described, and active fire and burn scar example images were provided. Ongoing research issues in fire algorithm development, including the effects of registration uncertainties and the algorithm's sensitivity to the presence of liquid water were discussed.

Chris Justice closed with an overview of the steps needed to prepare for a July 15, 1999 launch and subsequent data product production, which include testing the MODAPS system and completing algorithm and QA procedures prototyping and development. Outstanding issues include data continuity, cross-instrument linkages, incorporating EOS-PM algorithms and data into the MODLAND product suite, providing early science results, and MODIS data production, reprocessing, and distribution.

Break-Out Sessions

Presentations from the MODIS Programmers Forum, which met Tuesday morning, Dec 15, 1998, are available as Attachments 2 and 3.

The Oceans Discipline Group held a break-out session on Thursday, Dec. 17, 1998. The session focused on requirements for completing Oceans ATBDs, oceans validation plans for the immediate post-launch period, and PI processing issues. In addition, Motoaki Kishino of Japan's NASDA provided an update on the GLI instrument which will fly on the ADEOS-II spacecraft. His presentations are included as Attachments 21 and 22. The GLI web site is at http://www.eorc.nasda.go.jp/ADEOS-II/GLI/gli.html.

Adjournment

Bob Murphy adjourned the meeting after a few closing remarks and a brief discussion of scheduling for the next MODIS Science Team Meeting, tentatively to be held in April or May 1999.