MODIS Science Team Meeting
December 17-19, 2001
Baltimore-Washington Marriott Hotel

December 18, 2001

The MODIS Science Team was held December 17-19, 2001, in Baltimore, MD. The meeting began with a welcome from Dr. Vincent Salomonson, the MODIS Team Leader, who indicated that he felt a lot of good progress is being made thanks for the aggregated, dedicated efforts of the MODIS Science Team, Technical Team and all others associated with the MODIS effort. The MODIS efforts must continue to develop the data products for use by the science and applications community. From that perspective the primary goal focus of the meeting was to address MODIS product quality status with respect to the Terra data maturity definitions, *beta, provisional*, and *validated.*

Some really intense efforts have been put forth in recent months to process MODIS data, but there remains a need to evaluate and respond to the needs and perceptions of the user community. Toward that end Salomonson reported that he had initiated an end-to-end review of the MODIS data processing system by an external panel. The panel was chaired by Moshe Pniel from JPL and met December 11-13, 2001. This MODIS Data Processing Review Team (MDPRT) provided 5 essential recommendations on how MODIS processing could make the best use of its resources to get validated products out to the user community. Because MODIS is truly an instrument that can support global, interdisciplinary studies, one of the MDPRT recommendations included developing a reduced-resolution set of global data products that would be both useful to the scientific community and perhaps would allow for rapid reprocessing. The full report is available on the MODIS web site.

Salomonson reminded the group that in early 2002 there would be changes to how the team maintains algorithms. It appears that the March 2002 Aqua launch date will be met, and the team is excited about the new opportunities that will be available with Aqua.

The first day's presentations began with a status report on the Terra spacecraft by Jon Ranson, Terra Project Scientist. He reminded everyone that December 18th was Terra's second birthday after launch. Terra reached its $10{,}000^{th}$ orbit early in November, and everything is operating nominally. Despite a few serious anomalies in early spring, including two MOPPIT anomalies, a MODIS B-side power supply failure, and a temporary loss of the solid state recorder, things are back on track and all science data are being collected. Inclination maneuvers to adjust the equator crossing time will begin on December 13, 2001, and will entail a series of 6 burns, roughly a month apart, to put Terra at 10:30 a.m., $\pm$ 5 minutes.

The key Terra issue is data availability. Ranson announced that product maturity definitions had been refined to clearly indicate data usefulness, particularly with respect to provisional data. The data system has done better this year, new software integration is frequently problematic because there is no real test system, and they are looking for solutions for that issue. The Science Working Group on Data requested additional resources for reprocessing, which were declined, but there was an earmark to ESDIS, and there could perhaps be more in FY 02. With respect to budget no specific cuts materialized; however, later in the year, HQ might still need to call on us for help. Ranson concluded by saying that the deep space maneuver is still being coordinated, and the absolute earliest time it could be undertaken would be end of February.

Ocean Session

The meeting was organized into sessions by discipline, with the first session devoted to Ocean Group products. Wayne Esaias, Ocean Group Leader, expressed enthusiasm for the good results coming out of the team. They have found some calibration biases in the ocean color data processed to this point, but once those corrections are introduced this spring and the data are reprocessed, nearly all ocean products should be able to be considered validated. Despite the calibration biases, the MODIS ocean color products look quite good for unaffected time

periods, and a few products can already be considered validated for those specific periods (i.e., December 2000). The full time series will likely be validated after the next ocean reprocessing, expected in the summer of 2002.

Calibration of MODIS Ocean Products

Bob Evans, University of Miami, gave the first presentation, on using MOBY data to calibrate MODIS Ocean products. Although a variety of instrument and sensor issues needed to be addressed post launch, he believes that MODIS Oceans is ready to provide good data to the community. For example, analysis of imagery from the Arabian Sea from December 2000 shows mesoscale features in chlorophyll that are unprecedented by current sensors. Among the issues already tackled by the Oceans team are detector differences, sun glint correction, detector normalizations, and response versus scan angle (RVS) differences.

Coverage for SST is outstanding is detecting subtle features. Comparisons to buoys and interferometers show RVS corrections are working. The bottom line on thermal bands—based on validation from a variety of sources, many in real time from Caribbean and Pacific regions—They can show that our standard deviation is better than a quarter of a degree. So the answer to the question *Can MODIS do better than AVHRR?* is yes.

Evans summarized the challenges of calibrating the Oceans products. For cross-scan biases, there are two parts: polarization and RVS differences. Polarization is hard to correct because the degree of polarization changes both across the scan and seasonally, which produces discontinuity in the data set. Initially they were just cutting off large portions of the scan, but current corrections are working well, and they can now use almost the whole swath. There are 3 obvious epochs in the data: A-side to B-side and back to A-side. However, they have discovered other trends, and there appears to be a total of six that need to be addressed.

Evans felt that MODIS' calibration efforts and success are in line with what SeaWiFS experienced with MOBY. Band ratios that are indicative of chlorophyll are tracking very well with MOBY, but they still have corrections to make as far as their choice of models for calculating angstrom exponents. Comparing MODIS to in situ measurements, rms differences are on the order of 7-9%, which means MODIS is doing nearly as well from space as in situ measurements.

Normalized Water-Leaving Radiance

Howard Gordon, also from Miami-RSMAS, gave the next presentation, providing more detail on the calibration / validation of the Oceans atmospheric correction algorithm, also called normalized water leaving radiance (nLw). Normalized water leaving radiance represents what the reflectance would be at the ocean surface. Because the values of radiance are such a small part of the total signal, calibration is especially crucial. Three indicators of algorithm performance suggest MODIS nLws are looking good. First, the actual values are following the across-scan trends predicted by the models, although the absolute values may be a little high.

A second indication of good overall performance is comparison to SeaWiFS. Compared to SeaWiFS, the MODIS nLw values are in excellent agreement when optical depth less than 0 .2. Striping on MODIS affects the shape of histograms and makes them different, but the means are very close both at 551 and 443 nm. Scatter plots shows almost 1 to 1 comparison. Epsilon and aerosol optical depth also agree very well. He pointed out that the Epsilon values do show water structure and need to be corrected; those corrections, however, will increase computing time.

The third indicator of algorithm performance is that globally, the nLws at 412 nm behave as expected, showing expected global trends and good orbit-to-orbit continuity. The nLws at 551 need more work, as there are some apparent discontinuities from orbit to orbit. In the near-term they plan the following: refine calibration in the NIR and visible bands, add a routine to estimate the residual reflectance in the NIR, adjust calibration of fluorescence bands, and add BRDF correction to better compare with SeaWiFS. The first three will likely be ready for the reprocessing software delivery. In the far term, they must deal with retrievals through dust and in case 2 waters. These will require coupled ocean and atmosphere retrievals, which will take more computing resources.

In summary, Gordon said that after the adjustments are made and the team has a chance to review two months or so of MODAPS' results, he thought that the Ocean Color products could be considered validated. He indicated that more processing resources would certainly allow them to improve faster, for example, Case 2 waters can't be processed at all because it requires two passes through algorithm, which is a significant load on the system. Yoram Kaufman asked how they correct the edge of glint areas. Gordon said they use a Cox-Munck model on a 1° grid and adjust for wind speed. Esaias added that the correction could be improved with better resolution wind data.

Empirical Ocean Color Algorithms

Dennis Clark presented on the status of MODIS Ocean Color Products 19, 23, and 26. Product 19 includes CZCS pigments, chlorophyll-*a* from MODIS, and total pigments. Product 23 is total suspended matter, and Product 26 is a SeaWiFS downwelled irradiance attenuation coefficient algorithm. All these are empirical algorithms. A map of station locations shows that they have a lot of coverage from the United States East Coast, West Coast, Gulf of California, and Hawaii.

Comparisons of MODIS to fluoremetrically-derived values show that the curves fall very close to each other, with better agreement for case 1intiailly than case 2 waters. At high chlorophyll concentrations, agreement was not as good, but substituting fiber optic measurements for comparison brings the curves much closer, and they are now using one form for case 1 and 2 waters. Sample imagery shows large eddies and fine structure that is remarkable. For product 23, total suspended matter, the calibration data sets consist of two data sets, one from the 70s and one more current. Clark indicated that there is an offset between the two that has yet to be removed. He expects that the MODIS product, however, will make for good comparison to SeaWiFS.

Clark presented imagery from December 2000 with B-side electronics as a case study, with measurements from ship track compared to MODIS retrievals for the period. MODIS chlorophyll is lower than shipboard near Hawaii, with the percent difference being about 5-10 % on average, which is very good. CZCS pigment retrievals overestimate in situ. The percent difference is about 15 to 20%. An analysis of calibration differences between MODIS and MOBY shows that while there are still cross-track problems, calibration itself is within 20%. In summary, Clark felt that the recent Miami corrections will solve most problems with the Lws, and once they validate, his Ocean Color products could be validated within about 30 days.

Semi-analytic Ocean Color Algorithms

Ken Carder began by saying that light absorption is the key variable being derived by the semi-analytic ocean algorithms, and from that backscattering is derived. Total absorption is a combination of light absorbed by water, phytoplankton and dissolved organic matter. They separate the last two characteristics semi-analytically. The semi-analytic model provides inherent optical properties as intermediate products. Phytoplankton absorption coefficient is used to determine chlorophyll. Gelbstof infers dissolved organic carbon. Backscattering infers particulate matter. All these variables feed into carbon cycles and heat and water budgets.

To quantify these things, they must know how much light is available [Instantaneous Photosynthetically Available Radiation (IPAR)], and how much is being absorbed by phytoplankton [Absorbed Radiation by Phytoplankton (ARP)]. Another variable they are interested in is fluorescence efficiency, since fluorescence is a competitive path for photosynthesis. These products feed our knowledge of biology and the carbon cycle, and allow us to provide taxonomy from space, including identifying those organisms that are significant for food and fishery industries, such as those that cause red tides.

Carder provided imagery showing the relationship between Trichodesmium and red tides in the Gulf of Mexico. It appears that Saharan dust transport across the Atlantic feeds the Trichodesmium blooms, which in turn feed the red tide.

Carder reported that all products are being produced globally and since November 2000 compare well to similar SeaWiFS products. The field uniformity has been improving, and clear water angstrom exponents for aerosols are consistent with AERONET values in several case studies. IPAR values are consistent with model values (within 5%), and chlorophylls are consistent with SeaWiFS except at high latitudes, where SeaWiFS may underestimate. Carder considers the products provisional now and expects them to be validated within about three months once the new Miami calibration is in place.

One thing that is apparent is that they need to adjust for the nitrate-depletion temperature and what they call the "packaging effect" that results. Chlorophyll values vary widely based on those factors. In addition, they need to use a higher-resolution SST. In the next month they will begin using actual MODIS SST, which will really improve retrievals in high-gradient regions like Gulf Stream.

MODIS/SeaWiFS Chlorophyll Comparisons

Next, Janet Campbell summarized her work on making MODIS/SeaWiFS comparisons. She explained that there are three MODIS chlorophyll products: chlor_MODIS, for Case 1 waters; Chlor_a3, for Case 2 waters, and Campbell's product, chlor_a2, which is designed to be as close to SeaWiFS as possible. Initial comparisons of all show obvious differences for chlor_a3, which is much higher in the Southern Ocean than the others. Their validation approach was to compare algorithms with their own SeaBAM in situ data, COASTLOOC data form European waters (Case 2) and AMT cruise data (case 1) for a total of 1,229 observations. Comparisons of MODIS Chlor_a2 and SeaWiFS to in situ produced an rms error of about .3 log units, which is larger than SeaWiFS-MODIS comparison, which was about .2. In low chlorophyll, chlor_a2 is expected to be lower than SeaWiFS, and it is. In case 2 waters, there are greater differences, however this can be explained in terms of pigment-packaging effects.

Campbell showed an example of the advantages of having different ocean color satellites in orbit. On May 8, 2000, data were collected by MODIS and then SeaWiFS over the same area of the U.S. East Coast, and the chlorophyll can be seen to drift with the ocean surface layer. This may be the first time this has been revealed by satellite. When asked which chlorophyll she would pick for a study at this time, she said that if she were looking at transitions or comparing time series, she would use chlor_a2, which she has demonstrated is consistent with SeaWiFS. But Ken Carder believes that the pigment packaging effect that goes on at temperatures below the nitrate-depletion temperature is causing SeaWiFS to underestimate in the Southern Ocean, and so Chlor_a3 is where things will likely be going in the future.

Calcite

Barney Balch presented on the status of the calcite concentration algorithm. He explained that calcite ($CaCO_3$) is ubiquitous in the ocean and comes form coccolithophores. Also called particulate inorganic carbon, or PIC, calcite is responsible for backscattering from the ocean in a manner disproportionate to its low concentration because of its high refractive index. It plays a first order role in Lw, often accounting for as much as 30-40% of the signal. In many cases, reflectance from PIC exceeds organic carbon. Their goals for MODIS included validation of Gulf of Maine PIC concentrations, conducting the Chalk-Ex experiments to test calcite algorithm under simulated bloom, and using the algorithm globally to make the first estimates of global $CaCO_3$ standing stock.

In the Gulf of Maine, a plot of PIC vs. Lw shows that while regressions are not high, about 30-40% of Lw could still be attributed to calcite, which is a significant portion. In their case study, the algorithm was in good agreement with ship measurements to values of about 2µg/L. This is a factor of five better than expected. The caveat to this is that the analysis uses data only from the east side of the swath. If they were to add in west side, the analysis would not be as good. They expect full validation after reprocessing with the new Miami code, which should remove the east-west bias.

With respect to the field experiment to simulate a bloom, these simulations are necessary because real blooms are impossible to predict. For the experiment they spread two separate 13T chalk patches: one in Gulf of Maine, the

other off Cape Cod, using chalk that is identical to the natural chalk. The second patch was observed by MODIS, but analysis is not complete.

They have made the first maps of global calcite concentration in the euphotic zone. PIC ranges from 15 to 51 megatons with seasonal variations, while POC varies little, running about 100 Megatons. They reveal high concentrations of PIC in the Southern Ocean in April and near the Arctic in August. These estimates are within an order of magnitude of at least one set of numbers, but there are not many numbers to compare with in the literature. The global estimates show strong seasonal variability in the Southern Ocean and in the central gyres, a finding which suggests that in some cases there can be enough calcite present that it could be dominating chlorophyll retrievals, and certainly could influence the definition of Case 1 and 2 waters, since scientists are used to thinking of case 1 as being dominated by chlorophyll absorption. He considered the calcite product validated with the caveats about eastern and western swath sides.

Phycoerythrin and Other Ocean Color Validation

Frank Hoge prefaced his presentation by saying that validation is a continuing processing, and that this first step is the minimal to make the products scientifically useful. However, more improvements will be forthcoming. For their analysis they did inter-comparisons of lab measurements, airborne sensors (both active and passive), airborne plus SeaWiFS, and airborne plus MODIS. The MOD 31 algorithm (phycoerythrin concentration) itself was validated in 1998, and they think they can validate the data product as soon as the reprocessing begins.

Hoge's team is validating a variety of MODIS ocean color products in addition to their phycoerythrin product. Analysis of MODIS Florescence Line Height using data from an aircraft overpass on April 5, 2001, shows that the comparison is very good, with a correlation of r^2=0.680. Hoge said he would deem that product validated, because something scientifically useful could be done with it. As far as chlorophyll, he also thought the product would be useful for science at this point; the curves look very good. With respect to Phytoplankton Absorption Coefficient, he indicated that while the other algorithms are empirical, an inherent optical property inversion like Phytoplankton Absorption Coefficient is more difficult. In particular, it requires accurate Lw. Improvements over the last month are great, but this product is a little off. MODIS is a bit high, and they need better Lw to validate this one. For dissolved organic matter, a radiative transfer model approach was used, and showed MODIS is very low compared to passive and active airborne retrievals. Their plans are to continue these comparisons, and to better validate phycoerythrin using the improved Lws expected from reprocessing.

SST

Peter Minnett presented on the MODIS SST product status. He indicated validating the SST means adjusting for attenuation by the atmosphere, since MODIS has self-calibrating bands in the IR. In terms of the ESE research strategy, the goal is to characterize the variability of the ocean system and how it responds to forcing. A recent paper shows similarity and differences in two major decadal datasets of SST, and so more data are needed.

Minnett presented global SST images showing tropical instability waves, the Gulf Stream, and monsoon cooling in the Arabian Sea. These images indicate MODIS is producing reasonable SST with good continuity. The source of MODIS signal is skin layers, but the conventional idea of SST is bulk. And the accuracy levels for each are not the same. The skin effect responds quickly, and is opposite to the diurnal effect. Using depth measurements from buoys to validate satellite data is problematic. For example, skin temperature is influenced by wind speed, which can affect temperature as much as 4°. To validate MODIS, they need skin temperature, which they get from M-AERI, mounted on a cruise line taking weekly trips around the Caribbean. They now have a year of uninterrupted skin temperature measurements. Comparing these to MODIS produces standard deviation of around 0.2 K, which is great. Compared to AVHRR, MODIS is doing comparably. Their standard deviation is 0.29. If they restrict this analysis to their best pixels, MODIS compares to MOBY with about .5 W/m^2 standard deviation, which, again, is comparable to AVHRR. There may be a warm bias regionally. He stated that the community should be more careful about using MOBY data for satellite validation, because wind effects are significant. Buoy data should only be used with wind speeds of less than 6 m/s.

Using the definitions now available, he believes that SST is validated, within the limits of current analyses. He recognizes, however, that their sample size is rather small, and some regions are underrepresented. In addition, time series are not yet established. Their future efforts will be aligned toward developing reasons for regional and seasonal trends, preparing for 2002 validation cruises, and preparing their Aqua retrieval algorithm.

Chlorophyll Fluorescence

The next presenter was Ricardo Letelier, who began by saying that Earth's biology stores energy and elements and mobilizes them through the Earth system. Ecosystem structure plays a critical role. Scientists are trying to determine how ocean changes in response to climate change, both physical and biological. The surface waters of the ocean bridge the fast exchange of matter and energy between earth and atmosphere that goes on with vegetation, and the slower exchange of deep ocean. The role of MODIS fluorescence is to improve mesoscale estimates of primary production, to detect changes in phytoplankton's light/chlorophyll response, and to determine impacts of changes in physical environment versus changes in ecosystem structure in the ocean.

Validation can be accomplished through theoretical and empirical means. Empirically, they could compare MODIS observations to different platforms or to concomitant physiological observations; however, there are not many natural fluorescence measurements in existence and even fewer quantum yield (i.e. fluorescence efficiency) measurements from different platforms. So they must use theoretical approaches combined with field experiments. Ultimately, he continued, they cannot validate fluorescence line height until Lw is validated; they can validate chlorophyll fluorescence efficiency after PAR is validated.

However, a preliminary approach is to look at images and see if they are reasonable. Letelier showed an image from the Arabian Sea that displayed two cyclonic circulations spinning counter to each other. Depending on which way the vortices are spinning, the amount of nutrients available to the organisms would be different. Different nutrient availability would result in more or less fluorescence, and the images demonstrate that variability very well.

Comparing chlorophyll, FLH and CFE offshore of the East Coast show off shore value of CFE are higher than near shore, which is what one would predict. There is no relationship seen between CFE and chlorophyll, which is a sign that the CFE values are good. There are ongoing field observations planned using MOBY, HOT cruises, and some in situ Coastal campaigns. In conclusion Letelier stated that he thought that what the team was really talking about is characterization not validation. He felt that validity is dependent on the scientific question being asked and would be determined by the user.

Primary Production

Wayne Esaias presented on the status of what he called the tail end of the ocean food chain—Primary Productivity (PP). This product answer questions about global ecosystem change, water cycling, the consequences of carbon cycle changes as well as changes in coastal environments. It will also help understand the present uncertainty in ocean Net PP. Esaias described the two types of PP. P1 is integrated over the euphotic zone, and P2 is integrated over the upper mixed layer, the layer in contact with the atmosphere. Among the issues affecting quality of the Ocean PP are spatial and temporal resolution issues of the input products, including DAO PAR. As a sensor, MODIS has much greater coverage than heritage instruments due to greater swath width and the morning orbit that minimizes cloudiness.

Analysis of December 2001 (chosen because the incorrect sun-earth factor would have negligible effect at this time) shows that both P1 and P2 look very good. There is a very deep mixing layer at high and low latitudes, which increases productivity when that is factored in to the P2 model. Comparing the NPP output when different chlorophylls are used, they see very little difference between using SeaWiFS chlorophyll, chlor_a2 from MODIS, or chlor_MODIS; however, using chlor_a3 produced substantially higher values of PP than the others. They think this reflects the packaging effect at high and low latitudes.

To validate PP, they need validated SST and Lw, as well as acceptance of the higher global means of chlorophyll. Our initial uncertainties will be based on heritage, consistency, and comparison with ocean time series. They

expect that they can achieve validated status about one month after chlorophyll validates. They would really like to go to daily runs of the product, but that would be a major processing load so they are deferring that change, as well as the integration of a new and improved P1 model.

Land Session

Surface reflectance

The second discipline session was devoted to MODIS Land Products. It began with Eric Vermote's presentation on the status of the Land Surface Reflectance product, which is input to many downstream land products. Surface reflectance has used 1-km optical depth since Collection 3 began. A series of RGB images illustrated the effect of the aerosol correction that was introduced for Collection 3. The 4-µm reflectance and the 1-km aerosol are very useful for QA purposes and may also prove useful for future science studies. Fires, burn scars, and smoke can be accurately sensed using this combination of aerosol optical thickness, 4µm reflectance, and RGB assigned to 3.7, 1.6 and 2.1µm, respectively.

Vermote also discussed their development of an internal processing mask specifically for aerosol inversion and correction, and a cloud and sunglint mask, based on the mask from University of Wisconsin, but adapted for the surface reflectance product's needs. They realized that that fire can cause increase the reflectance at 2.1 µm, which they use for aerosol correction. So they developed an internal mask for fire as well as snow, which increase reflectance in the visible and elevates estimates of optical depth. Initial comparison of their aerosol optical depth to AERONET is good.

For validation of surface reflectance itself, they compared MODIS reflectance to high-resolution surface reflectance data aggregated to MODIS resolution. Compared to Landsat ETM, they got very good agreement—well within error bars. Overall, MODIS surface reflectance is working well, and evaluation of their internal masks is ongoing. They are working on atmosphere-BRDF coupling. Vermote would like to introduce a more dynamic aerosol correction. In addition, issues remain with the L1B in the mid-IR, and they are working with MCST to address these. In the long term, they would like to move into fine calibration (below error bars), and would like to correct for mirror side differences and polarization. Vermote concluded by saying that ordering data for validation is still challenging, and limited processing capability makes it impossible to run large volumes repeatedly. The core data set recommended by review panel could solve this. Finally, he stated that the Aqua surface reflectance code would require modification to accommodate non-functioning detectors.

Vegetation Indices

Alfredo Huete presented on the MODIS Vegetation Index Algorithms: the EVI and the NDVI. The MODIS VIs are considered to be provisionally validated, and uncertainties continue to be reduced. In contrast to heritage products, they have an improved red band for chlorophyll absorption, a very narrow near-IR for water vapor correction, and a blue band for aerosol variability, such as smoke from biomass burning. Among the most interesting examples of the applications of the MODIS EVI were images of the Colorado River delta showing temporal variations in VI that are due to water management issues not climate (i.e. greening that is not seasonally dependent, but coincident with water releases from the major dams on the Colorado). Water resources along the Colorado are an international issue, and various agencies are interested in these data for land use and management purposes.

For validation, they used core sites throughout the U.S. representing various ecosystems. Seasonal trends are evident in both the EVI and NDVI, for example, there is much less variation for coniferous forest than deciduous over time. The prairies exhibit greater seasonality than either forest type. Both VIs are performing well in assessing growing season in areas with scarce rainfall. Looking at the Harvard Forest test site, the VIs agree well with radiative transfer models. The peaks in EVI correlate well with temperature curves. Multi-temporal comparison with ETM and MQUALS and ground measurements look good. While they are getting good matches with ground measurements, he indicated that they are only trying to validate under clear sky

conditions. Similar analyses for many major biomes in South America show that both VIs track expected seasonal trends quite well.

They are particularly interested in looking at hyper-arid desert regions because they would like to zero their algorithm to these values. They are not seeing much sun-angle dependence, but they need to work on BRDF effects as well as cloud and snow contamination problems.

Albedo Products

Crystal Schaaf, Boston University, presented on the status of BRDF products. Their current products are 16-day, 1 km, and they are building 5 km and CMG products as well. Production of the CMG product will begin in July 2001. The BRDF product uses all 7 Land bands, which are cloud cleared, then applies a model to determine anisotropy at the surface. From this is derived nadir-adjusted BRDF. The products provide white sky (diffuse) and black sky albedo at local solar noon. The full model inversion is used when sufficient high quality MODIS observations are available to sample the BRDF. The lower-quality inversion couples *a priori* knowledge of the surface anisotropy with any available MODIS observations. This back up algorithm has been very robust.

She showed a year's worth of global albedo, showing interesting albedo features in Sahara over time. Provisional products began November 2000, and they have been waiting for the reprocessed data to do characterization. They expect to be able to release these consistent year products as validated. They have delivered their Aqua code, which will take all surface reflectance and combine them to improve the BRDF estimates.

In their evaluation of the product, the team is focused on assessing the QA flag, investigating some variability of products by cover type, and evaluating stability over surface type and time. Their yearly cycle shows expected phenology using data from various land cover training sites. Right now, the algorithm tends toward no-snow, but they are working on that as well. Data from last winter shows that BRDFs are quite stable over the period. They use past BRDF to predict future when conditions aren't good for retrievals, and they find that the predictions work very well, as an example from off the U.S East Coast showed. A number of field campaigns have been undertaken that have helped them with validation, including the U.S., Africa, and China. Results from the Beltsville Agricultural Research Center show error of less than 5% using scaled up ground and tower imagery. Comparisons are underway from South Africa validation sites. Initial evaluation of the BRDF products indicates good performance, well below 10%, sometimes as low as 3%. They expect validated products by the first half of 2002.

LAI/FPAR Products

Yuri Knyazikhin presented on the status of LAI/FPAR products, beginning with examples of temporal variation of LAI in Africa. As an example of expected contribution to global scale climate studies and modeling efforts that the MODI LAI/FPAR product can make, he showed results on the use of satellite-derived LAI in the NCAR LSM land model. Information on realistic satellite-derived global LAI can improve the simulation of near-surface climate. The dominant impact of interannual LAI variations is modification of the partitioning of net energy between latent and sensible heat fluxes through changes in the proportion of solar energy absorbed by the vegetation canopy and the underlying ground. Every 8 days, the MOD15A2 provides global distribution of a very important component of the distribution of the top-of-canopy radiation between its canopy and ground absorbed portions, namely, fraction of photosynthetically active radiation absorbed by vegetation (FPAR).

Given surface reflectance, land cover, and cloud state, they produce LAI, FPAR, and QA flags. A series of tests has been developed to ascertain that (a) the algorithm does not retrieve LAI/FPAR if uncertainties in input data exceed 15%; (b) retrievals obey known relationships, such as the relationship of LAI and NDVI; (c) the algorithm identifies situations when single-angle data convey little information about canopy structure and reports their occurrences by assigning a special value to the QA; (d) the MODIS LAI/FPAR fields are comparable with those derived from other instruments, e.g., MISR, AVHHR, SeaWiFS. These properties underlie the definition of the provisional status of the MODIS LAI/FPAR product.

To move to validated status, they will be testing the LAI/FPAR retrievals using field data collected at various sites representative of major biome types. They are working in collaboration with the BigFoot program, VALERI (VAlidation of Land European Remote Sensing Instruments) project, University of Goettingen (Germany) and conducting their own field campaigns in order to accomplish the validation of the LAI/FPAR product. They expect validated product by July 2002. Initial validation results at a highly heterogeneous site indicate that the presence of water in the 1 km MODIS land pixel may result in an increased uncertainty in LAI/FPAR retrievals. Comparison of the MODIS LAI retrievals (collection 2) with SAFARI 2000 (wet season) field data indicates that the MODIS LAI product is within the expected uncertainties. Because the surface reflectance product is input to the LAI/FPAR algorithm, information on its uncertainty is required to produce LAI and FPAR fields of the highest quality possible. It was also emphasized that users should always pay careful attention to the QA fields associated with the LAI/FPAR product.

Cryosphere Products

Dorothy Hall summarized the available cryosphere products, including the 500m and the CMG-scale products. Snow albedo will become available as a beta product in spring. The CMG products are available via their own web page as flat binary and hdf, but not from the DAAC yet. They have recently included a thermal mask and are improving cloud masking. As an example of the improvements of the thermal masking, she showed before and after imagery from Australia in the summer illustrating the lessening of false snow detection there. Errors of commission are now very low.

Cloud mask, though improved, remains an issue. As an example, she showed a Lesotho, Africa snowstorm that mapped as cloud. Their algorithm had been using the "certain" cloud test, and they have found that it overestimates cloud in snow maps. Currently, they are looking at combining bits 19 and 21 from the cloud mask. In test cases, it gets close to 45 % more snow, and 35% less cloud obscuration. They have been getting good results from SSEC Direct Broadcast station at Wisconsin, which is running the snow cover products. Even without cloud mask, which doesn't yet run in SSEC, the maps look good. Bruce Ramsay is working with Rapid Response to develop a similar system through NOAA.

Hall reported that they had received some recommendations of the Ad-Hoc Advisory Committee on the MODIS Snow and Ice Products:

- improve cloud masking,
- provide CMG
- complete evaluation of snow products so they could be considered validated
- release the snow albedo product for testing
- integrate passive MW and MODIS algorithms in the Aqua era to improve snow maps in clouds areas

MODIS maps are comparing well with operational NOAA maps, although they show more snow than do the operational maps since the MODIS product is maximum snow extent. The more frequent coverage of MODIS allows it to map more snow than do the other maps like those developed from the ETM+, which doesn't have as frequent coverage. Sea ice surface temperature (IST) results appear reasonable, however, the existence of thin clouds over sea ice can preclude accurate IST determination, which remains a problem. Hall felt that once they are able to compare the MODIS snow maps with operational maps and ground measurements from this winter, they would be able to declare that the snow maps are validated. Finally, she announced that they produced a snow video on MODIS global snow cover that is being used for educational purposes. They have a new website based on that video, and ten web-based activities that are being used in classrooms.

Land Cover

Crystal Schaaf presented on the status of the Land Cover Product. The beta version was released in April 2001, and it used only IGBP classification. In June, they released the provisional product, which added a few more time periods. So far they have been pleased with the quality, especially considering that the product is only based on a half year of data. The product includes IGBP classification, secondary classes, confidence measures;

University of Maryland classification; and LAI/FPAR classification. It draws from the at launch product when fewer than four periods of NBARs are available or when classification confidence is less than 40 %.

For evaluating the product, they are doing in-house accuracy assessments, cross validation of training site, where 20% of the training data are hidden and then the algorithm is asked to classify with the remaining 80%. The product provides a confusion matrix and a per-pixel confidence. Underpinning of the product is the STEP database, which is based on 1200 training sites. Initial evaluation of the first and second most likely classes show that they are very accurate. Discrepancies are usually between, e.g., *cropland* and *cropland mosaic*. Comparison to EDC DISCover shows that MODIS has a lot more structure. BIGFOOT comparisons look very good in most situations, but may overestimate needle leaf forest. When they get the Consistent Year data, they will have full year of data representing the phenological cycle, and at that point, they should be able to validate the products, likely by the first quarter of 2002.

Schaaf reported that they just delivered the CMG code. They are now looking ahead to land cover dynamics, investigating phenological attributes, such as when greenness and senescence begin. They are using changes in the NBAR-EVI curvature to pinpoint phenology transition dates. She concluded by showing examples of this approach applied to data from the northeastern Unites States.

Land Surface Temperature and Emissivity

Dr. Wan presented on the MODIS Land Surface Temperature (LST) and Emissivity products. The daytime and nighttime 1km LSTs are retrieved by the split window method using bands 31 and 32. There is an 8-day composite of the 1kmLST product. The daily 5km LST/emissivity product is generated by the day/night method using bands 20, 22-23, 29, and 31-33. Only clear sky pixels at 99% confidence, as defined by the MODIS cloud mask product, are used. But even then there are some cloud-contaminated pixels, so they use a double screen scheme to remove the cloud-contaminated LST values. To do this, they screen off 1% of lower and upper ends of the difference distribution of LSTs from the two LST methods, and also screen off 0.5% from lower and upper ends of the distribution of the day-night LST difference.

After screening off cloud-contaminated LSTs, the images look very good. Spatial distributions of temperature and emissivity are reasonable both regionally and globally. They did four field campaigns last year and four this year. They used lake sites because they know the emissivity of the surface and because they wanted to use the best possible sites to make accurate in situ measurements of the surface temperature for the validation. In addition, they used rice fields, grassland, snow cover over grassland, and a playa site. Wan felt that calibration of new A-side data is much better than older data especially in bands 22 and 23. The relative calibration accuracy between bands 31 and 32 is also improved.

For five cases over various lake sites, the differences in MODIS versus in situ LSTs ranged from 0.9K to 0.2 K. Over grassland and rice fields, differences were less than 1 K. Over a playa in Railroad Valley, Nevada, after a correction with 5km LSTs from the day/night method, the MODIS LSTs also agreed with in situ LSTs within 1° K. In general, MODIS LSTs agree very well with in situ LSTs in a wide range from -10 to almost 50 degree C, in the atmospheric column water vapor range of 0.4 to 3.0cm. Validated LST products will be available with the next reprocessing, probably in July 2002. The LST can be used to validate or improve meteorological model prediction, diurnal cycles, surface fluxes, and studies of land cover change, water requirements of crops, and soil moisture.

Their plan for 2002 is to validate the MODIS LST product using sites in Australia, CA central valley, and a few sites in the heart land of the U.S. during wet seasons. Wan expects that the use of MODIS BRDF product and the combined use of Terra and Aqua MODIS data will further improve the LST product.

250-m Land Cover Products

John Townshend presented on the MODIS Vegetation Cover Conversion (VCC) product and the Vegetation Continuous Fields (VCF). VCC runs in MODAPS and is a standard land product; VCF will be generated once a

year in their Science Computing Facility and will be made available via the EDC DAAC. First off, Townshend said that they are pleased with the geolocation is very good, but that the 250-m resolution cloud mask still needs work. The VCF provides per pixel estimates of vegetation cover. They have begun using IKONOS data to train the Landsat ETM data, and then using ETM to train MODIS data. A prototype tree cover map of the U.S. was shown, and Townshend indicated they are very pleased with it. It will improve based on the full year of data, but even with the available data, it is good. Their validation approach is to do some fundamental validation in Africa and U.S. At smaller grids, the results are good, though there is some scatter. He feels that the product is better than what is out there. Tree cover compared between Ikonos, ETM, and MODIS is quite reasonable. They are comparing their VCF estimates to US Forest Service data, and while MODIS seems to be underestimating for a few western states, they think that may be because the thresholds for definition of forest cover are different. They expect to have their first full version of the product (i.e. an annual cycle) by February 2002.

For VCC, they are working on compositing issues caused by clouds and aerosols, delivering new code. This product requires annual data for each of 4 zones in each of 12 months, so this product won't be filled in completely until after the consistent year is done. Even a dramatic change, like forest to a burned area, is not very big seen from MODIS, and can account for something as subtle as a 5% reduction in the signal from Band 2. VCC might seem to be underestimating, but that is likely because it is able to detect unburned areas within the fire perimeter. They used the VCC product to analyze the impact of roads on burn severity in the Montana/Idaho border region in 2000, and their results show that burned area density increased in managed areas. Contrary to the position held by some that roads are needed in wilderness areas to allow better fire management, they found that roadless areas suffered less burned area per total area than managed areas. The area burned by lightning-caused fires was roughly equal, but managed areas suffered more losses due to human-caused fires. Townshend showed other examples of application to deforestation detection in Brazil.

Continental scale results for U.S. are promising, but still have issues such as false detection from snow melt or cloud over water. The initial release will be limited to available 250 m data. They plan to develop a simplified version of the product that will run in the Rapid Response System in 2002, and they will continue to update the product with each reprocessing, which will be important for filling in the global land surface.

Fire Products

Chris Justice summarized the status of the Fire products from MODIS, emphasizing the importance of fire in the Earth system and global change research. The fire products from MODIS will make an important contribution to global change research by providing fire location, timing, and burned area estimation. Justice described how fire validation activities are engaging the broad user community under the Global Observation of Forest Cover/Global Observation of Landcover Dynamics (GOFC/GOLD) project, undertaking satellite product inter-comparisons, using controlled burns and wildfires. All the validation efforts from this will be documented for the community. In addition they may begin using field-based product validation by fire management agencies evaluating the products in the context of their use.

ASTER is the obvious choice for MODIS inter-comparisons being at a higher resolution. Preliminary results from active fire validation efforts in Africa based on seven concomitant ASTER/MODIS scenes show that errors of commission are rare and that agreement is good for the larger ASTER fires. MODIS-GOES comparisons show some differences that they have not investigated yet. Burned area comparisons using Landsat data show a good match between the prototype MODIS burned area product and Landsat over several sites in Africa. Preliminary results were presented using burned area information to model regional emissions for southern Africa, associated with the SAFARI 2000 experiment. Justice showed examples from the MODIS Fire Rapid Response System, and indicated the John Owens from his group is developing a web-based mapping tool that shows active fires locations from the rapid response system. Justice said that the global active fire detection product is planned to be validated in the middle of 2003.

Justice also discussed the fire detection capabilities of Aqua, including the benefits of multiple observations when combined with Terra, but also the potential issues with uncalibrated detectors. He added that although fire has been a low priority for the NPP mission previously, there has been a lot of interest in MODIS, which may

rekindle their interest and spur them to resolve issues with the sub-optimal 11µm channel. Justice concluded by saying that he felt that data distribution and ease of MODIS data access are the next “Tall Poles.”

Land Primary Production and Photosynthesis

Steve Running began his presentation on the Photosynthesis (PNN) product by saying that it is a time series measurements, and until they have a continuous first year of data, they can't start serious science. The biggest issue with respect to global validation is that PNN and annual NPP change across the biosphere based on temperature and moisture. So it can be regionally validated, but it can’t really be validated globally.

Running explained that their algorithm uses MODIS FPAR and incident PAR from DAO meteorology, which means inputs are dependent on those products’ quality. To get NPP they multiply epsilon, which is the radiation use efficiency of biota, by absorbed photosynthetically active radiation. They model the maximum epsilon, and then use two modifying coefficients: vapor pressure and temperature. Each biome has a different coefficient.

They have built a tool that allows them to look rapidly at the product in a targeted way to facilitate fast, local validation. Running showed examples of the product from Australia, India, and South America. The Amazon clearly has problems because of cloud cover, which makes estimates too low. The difficult thing about cloud cover is that it does decrease PNN, so they have to decide when what they are seeing is the effect of cloud cover on PNN, or an artifact.

They use the flux tower network as the corner stone of their validation activities. LAI and FPAR from last year tracked very well seasonally with flux net tower measurements. As yet, they haven't been able to put MODIS directly over fluxnet sites because those data aren't available, but they are ready to put MODIS data over top known curves and trends for grasslands and forest.

Running showed a time series of measurements from both the Pacific Northwest and Asia, and he talked about the encouraging finding that as the spring progresses into summer, NDVI (or LAI) perk up before PNN, which one would expect. In the transition to fall, PNN fades more quickly than NDVI or LAI, which is also expected. So the MODIS products are behaving seasonally as expected.

In summary, there are three sources of variability in the PNN products: radiometric, MODIS LAI and FPAR; meteorological, DAO IPAR and temperature; ecological, MODIS 17 itself and its representation of plant physiology. Each will require different validation techniques.

Vicarious Calibration of the L1B Over Land

The final presentation on the first day of the Plenary Session was given by Kurt Thome, a validation scientist looking at the vicarious calibration of the L1B product. He described their set-up at the ground reference calibration site in Nevada. Their approach is to take reflectance measurements and atmospheric transmittance and turn that back into MODIS reflectance. They have a both a 1-km and a high-resolution test site. They characterize the ground based on a calibrated standard, combine that with atmospheric information for the MODIS overpass, and then plug that into a model to predict what MODIS should see. The comparisons to ground measurements are within ± 5 %. They are seeing a problem with the 905 nm band, but nothing serious. As far as comparisons with ETM+, even with different resolutions, there is opportunity for registration. Cross comparisons for thermal show a little more scatter than for reflectance, but again both look pretty good. In most cases agreement is better than 2% on average, except for the 905nm Band and one anomalous point in the 1240nm band from a single day.

They need more data points, and so they are thinking of setting up a meteorological station. Among the challenges of trying to set up an automated site is that reflectance changes with rainfall. They would like to model a wet reflectance and a dry reflectance and then use meteorological data to decide which to apply. Initial tests of this approach seem good.

In the future, they plan to do cross-calibration with ASTER and Landsat-5 TM, and also plan to look at BRDF effects. They believe that the approach they have developed for calibration will be effective for Aqua. In summary he stated that MCST has successfully tracked the changes in sensor response for reflective bands, and he thinks L1B could be considered validated.

December 19, 2001

MODIS Land Rapid Response

The final day of the meeting began with a presentation by Jacques Descloitres on the MODIS Land Rapid Response System. The system evolved because the complexity of the ECS production system doesn't allow rapid access to MODIS data. Even the most optimistic delivery has L1B available within 24-48 hours, the L2 is available one week later, and L3 is only available 16 or 18 days later.

Two areas with a great need for rapid data are fire detection and PR imagery. The Rapid Response provides active fire information to the US Forest Service (USFS) and also for imagery for the earth Observatory, and the Goddard and MODIS web sites for PR purposes. This system was to be user-driven and would provide global coverage that highlights the unique capabilities of MODIS.

The products produced by the system are an in-house surface reflectance combined with fire detection. They tried to use existing hardware, software and etc, and so it was natural to turn to the 250-m production system and the global browse product previously created for MODLAND. They get their input feed from NOAA , and reuse IMAPP software from University of Wisconsin-Madison. They do not use real-time ancillary data, which allows them to process as soon as they receive data from NOAA. The system is 100% automated, producing products within 2-5 hours of acquisition. The standard product is an RGB image with active fire overlay. They are not keeping a long-term archive of data, but they do keep the imagery. Everything is online, so there is no ordering interface, just a simple point and click to download the image.

The RSAC in Salt Lake uses MODIS data to provide a synoptic view to help planners to decide where to allocate their resources. Compared to aircraft, MODIS isn't affected by smoke, and also has more frequent coverage. They get data five hours after acquisition from which they generate a map every day at 6 am local time in Salt Lake. MODIS has a link on the NIFC web page where MODIS maps are posted. The data are also sent to University of Maryland, which does some custom products that are available via the web. Rob Sohlberg is working to map burned areas after fires as a value added product.

Descloitres showed the wide range of events that can be captured with the rapid response system, including sample imagery of fire detection from the U.S. and Siberia, Hurricane Erin, dust plumes off the coast of Africa, and deforestation in Brazil. They plan to transition this system into NOAA's operational service and provide algorithms to the Direct Broadcast arena, using a code-sharing approach. The Forest Service installed their own Direct Broadcast receiving station and is now able to generate images and maps within a few minutes of acquisition. A partnership has been developed between NASA and the USFS to enhance the utility of the rapid response system. Data are being provided to a number of fire management agencies around the World through the GOFC/GOLD program. Data are also being provided to the Air Force Weather Agency. New developments are underway in the area of agricultural monitoring, food security and flooding with USDA Foreign Agricultural Service

This Rapid Response system filled a large gap in existing data system capabilities. They are considering adding new products and expanding geographic coverage (oceans). Descloitres concluded by summarizing the news coverage the project has garnered.

MODIS Cloud-top Pressure Validation

Peter Muller presented on validation work for first cloud-top pressure using MODIS-MISR comparisons and comparisons with ground-based radar. Using data from ARM sites alone to validate a product would take a really long time, so when inter-comparisons of two instruments are possible is speeds things up.

To do this they have been looking at MISR and MODIS Cloud Top Height versus radar measurements, scaling MISR 1.1km up to MODIS 5 km. They can make that code available to anyone who is interested. They find it hard to find coincident MODIS / MISR products due to different naming conventions, and no EDG tool exists to find overlapping orbits. This analysis consisted of 23 cases over the British Isles. Their results indicate that in some cases MISR is biased high compared to MODIS data, which may be due to MISR seeing more high thin cirrus. However, the summary of all 23 cases, there are no significant differences. Comparisons with ground radar show good agreement for MODIS, but MISR is missing some mid- to high-level clouds.

At the Southern Great Plains site, MISR has missed entirely high-level cloud in 3 of 8 cases. In general though, agreement among all three is very good. MISR cloud top heights appear to be lower at this site than MODIS, but it is difficult to say at this point due to the small N of the sample. MODIS and MISR both slightly underestimate cloud top height compared to radar. Muller indicated they would be expanding their validation work to more ARM sites in the future.

Atmosphere Session

Cloud Mask

Steve Ackerman presented on the cloud mask. He began by addressing issues raised at the previous day's presentations about various granule examples in which the cloud mask performed well or where it didn't. He emphasized that global cloud detection is difficult, and some tests work in some places and not others. He is proud of the work the team has done. He also said that he thought that the cloud mask could be considered validated at this point. He cautioned the "granule" correction approach because correcting single granules can produce undesirable effects elsewhere. Ackerman indicated that the cloud mask has 48 bits for a reason--users can see which bits work best for them. He understands that people will do their own corrections, but simple tests get about 80% of clouds, and getting the remaining 10-20% is really hard. They are the experts, and users should come back to them to see what they are doing to solve those harder issues.

He summarized the issues from the cloud mask meeting, including the 250m mask correction, high elevations, cloud above arid and semi-dry regions, false detection among water bodies, and detection in dust and aerosol. Many of those issues have been resolved or are being worked on. There are still issues with cloud shadows and the cloudy sky mask.

Among the most significant improvements to the cloud mask is elimination of much striping in Band 26, which allows them to lower the threshold for cirrus detection from .035 to .01 reflectance. The striping correction won't be in production for several months, probably, since they need to figure out how to implement it globally.

They have been using the cloud mask to study the "spectral greenhouse effect." They are using the ratio of SST and clear sky radiance from MODIS for different bands to study how water vapor varies with SST. Models predict that above a certain temperature, water vapor no longer increases with increasing temperature, but in fact begins to drop. This was predicted by models, but not measured because cloud detection was not possible outside a certain range. However, they used the MODIS data to show that as predicted, water vapor actually begins to drop above a certain temperature. They are also beginning to use MODIS data to assess the effect on forcing of thin cirrus clouds. Lastly, Ackerman said that they would be offering code for the cloud mask to Direct Broadcast users.

Cloud Optical and Microphysical Properties Products

Michael King summarized the status of the Cloud Optical and Microphysical Properties products. The product includes optical thickness, particle radius, and water path in the daytime. MODIS is the first satellite sensor with all useful SWIR, MWIR bands, and so they can compare retrievals from each. They can also use different wavelengths over different ecosystems. In simple terms, the algorithm works by comparing visible, non-absorbing reflectance band to an absorbing band to determine optical thickness of clouds. For a non-absorbing band the reflectance is largely a function of optical thickness, and for near-IR absorbing band it is a function of effective radius.

Among the significant improvements to the product are their revisions to their ecosystem model. They have added a “tundra” class to the MOD 12 “open shrubland” land cover classification. They use geographic locations to identify the ecosystem, and then they map ecosystem to MODIS white sky albedo. This is an improvement from using the broadband CERES albedos, which was the previous approach. Other refinements include fixing a single line of code that greatly reduces failed retrievals in the Arctic.

King showed example of a new feature of the MODIS Atmosphere web site, where they added to the web page a "golden day" and have put on the site all 144 unremapped, daytime granules separated into orbit. They have a series of seven images: true color, cloud mask, ecosystem classification, optical thickness, effective radius, cloud top temperature, and bispectral phase. This allows the algorithm developer to quickly identify regions where there are algorithm deficiencies, or inaccurate retrievals, and allows intercomparisons of two different techniques for identifying cloud thermodynamic phase (ice vs water).

King stated that validation in the cloud world is far different than aerosol in that there is no global network of flux towers or AERONET validation sites. He presented preliminary results from SAFARI 2000 activities in which MODIS was compared to aircraft measurements. Compared to the in situ aircraft measurements, MODIS retrievals are slightly larger for particle radius than in situ measurements suggest. Optical thickness is good compared to an integration of cloud liquid water content obtained during in situ profiles through the cloud, which yielded values of about 5 for in situ observations and $\pm 3 \pm 1$ for MODIS. An interesting question that is coming out of their work is why Namibian stratocumulus often have significantly smaller droplet sizes than other regimes, which might be due to cloud condensation nuclei concentrations.

Other validation work from ARM sites indicate that results for thin clouds are pretty good as well. Two things they are planning to fix are retrievals in sun glint and low clouds, but otherwise he is pleased with the product. He wouldn't feel comfortable saying globally validated, but definitely it is scientifically useful at the granule or even regional basis.

With respect to the L3 product, which has all Atmosphere products in one file at 1-degree resolution, it has the built-in feature of having the statistical joint histograms included. He showed several examples of the global products, including cloud top pressure, aerosol, and precipitable water. King thinks the L3 codes are powerful because they are easy to work with, but the validation level is really based on the quality of the Level 2 inputs.

Atmospheric Profiles

Paul Menzel gave the status of the atmospheric profiles: moisture, ozone, and cloud temperature and motion. As background information, he explained that for radiation emitted from Earth from 4 to 18μm, part of the curves adhere to plank envelopes, but some do not, like those for CO_2, water vapor, and ozone. The algorithm is based on the assumption that MODIS sees only thermal emission, not visible reflectance. It uses Bands 20-29 and Bands 30-36 to give vertical distribution of temperature. It appears that the bands are behaving as expected.

Since he is using radiances, he must know how good the radiances are, and validation using GOES and ER-s aircraft measurements shows radiances are within about 1.5 C except when he has to do a lot of atmospheric correction. They are seeing some noisy detectors in Band 34, and they were seeing the surface in the 14.3 μm channel, which was successfully corrected.

Menzel showed examples of MODIS versus GOES data for cloud top pressures over the eastern U.S. for a day in June, emphasizing MODIS' greater coverage. Comparing AMSU-A against MODIS at 850mb shows pretty good agreement, but not quite as good at 500mb. Africa is the biggest area of disagreement. This is probably due to surface reflectance contamination. They modified the algorithm to use the brightness Temperature differences rather than brightness temperature alone, which mitigated much of the African anomaly. Ozone agrees almost 1 to 1 as compared to GOES, which is excellent MODIS ozone agrees well with TOMS except at low ozone in Antarctic, but they just need more training data there. Global gradients are quite good.

MODIS IR total precipitable water vapor is capturing gradients very well over oceans, and has been greatly improved over land, however it is very sensitive to multi-spectral striping. MODIS shows a wet bias with respect to microwave for values less than 15mm and a dry bias for values greater than 15mm, but this should be removed with further validation. MODIS and GOES TPW agree well with rms difference of 3 mm. He thinks it could be considered validated with known characteristics. Menzel showed examples of the benefit of higher resolution water vapor data, including detection of gravity waves. Water vapor product can also be used to track motion at polar latitudes, which will provide much needed detail for weather models. They have also used the data to track polar winds.

In summary, Menzel reported that most products could be considered validated.

- IR radiances agree to within 1.5 C with GOES and ER-2 MAS/SHIS.
- Tropospheric temperatures compared to AMSU with rms better than 1 C, and to within 2 C of radiosonde observations,
- Dewpoint temperatures depict gradients very well and are within 2-3 C rms of radiosonde observations.
- IR total precipitable water vapor within 3 mm rms of GOES
- Ozone is very close to the GOES ozone (over North America), with rms of about 10 Dobson units
- Polar winds represent coherent atmospheric motion, geo-like quality observed within 7 – 10 m/s of the few observations available for validation
- Cloud top pressures compare well with GOES, with aircraft validation better than 50 hPa
- Cloud phase determinations are revealing interesting patterns, including the first global day/night, ice/water cloud determinations.

When asked if they would be going to 1km, Menzel said they would have to see how Aqua performs.

Water Vapor and Cirrus Detection

Bo-Cai Gao reported on the status of the Near IR water vapor and thin cirrus detection algorithms. Last year, they had reported a 20% bias in the water vapor product that was due to line parameters being compiled on HITRAN 96. In early spring of 2001, the new HIRTRAN2000 line parameters were released. The 0.94-micron water vapor line parameters were increased about 20%. So they made new LUTs using the HITRAN2000 line parameters. Comparisons to data from ARMS sites still show a little wet bias with respect to the microwave radiometer, about 10% now. Gao showed examples of regional trends in water vapor across North America, Asia, and Australia, and all show expected seasonal variation for the region. Globally, trends track well, with Southern Hemisphere being wet in December and Northern Hemisphere wetter in June-July.

With respect to cirrus, the product is picking up great detail, including many contrails. They have begun trying to estimate water vapor above the thin cirrus cloud. Over North America, cirrus cloud imagery from December 2000 shows moisture coming in from the Pacific Northwest, and then in July 2001, water vapor begins showing up predominantly along the East Coast. Trends in Asia show cirrus building up from December to March, but disappearing in July. Globally, cirrus is high in December over Alaska and over Asia, it begins to disappear in March –July, and by October it is beginning to form again. MODIS is capturing these global and regional seasonal trends very well.

Preliminary comparison between cirrus from MODIS and CERES albedo indicate that even with the optical leak, they are not getting too much water vapor over Africa. When asked how they correct for problems at high

elevation, Gao said that if the pixel is clear they using a “pressure scaling” scheme from LOWTRAN7 to correct surface elevation effects. If the pixel is cloudy, they make retrievals of “water vapor above clouds” assuming clouds are located at sea level. Although the absolute values of "water vapor above clouds" are not the true water vapor amount above clouds, their retrieved values of "water vapor above clouds" can be used for correcting water vapor absorption effects in other MODIS channels, with the same assumption that the clouds are located at the sea level.

Validation activities involving water vapor comparison between the MODIS near-IR vapor and microwave radiometer (MWR) vapor during the time period of 03/2001 - 06/2001 showed the near-IR vapor values to be about 10% higher than the MWR vapor values. However for the few months prior to March 2001 (i.e., for the time period between December 2000 to February 2001), the water vapor differences were much smaller. There is the possibility of a drift in the radiometric calibration of the MWR, and they plan to conduct additional validation of MODIS near-IR water vapor products based on MWR measurements and radiosonde measurements from a few DOE ARM sites.

Aerosol

Lorraine Remer gave the final Atmosphere presentation on behalf of Yoram Kaufman and the rest of the aerosol product group. The MODIS aerosol products are aerosol optical thickness (AOT) and size information (which is effective radius and fine and coarse mode aerosol fraction.) the optical thickness makes use of 7 wavelengths over ocean and 3 over land. The parameters in the products include aerosol spectral flux at the top of the atmosphere, which interest modelers, and cloud condensation nuclei (CCNs).

As a first example of the products, Remer showed a case study of a dust/pollution event over Asia, including the Korean Peninsula and the Yellow Sea and the Sea of Japan. She pointed out that even though they use two different algorithms for land and ocean, they have good continuity across the water and land portions of the image. A false color image in which red is assigned to coarse mode (dust, marine, natural aerosol) and fine mode is green (pollution and biomass burning) showed the product’s ability to separate the two different types of aerosols involved in this event. Remer showed calculations of top of the atmosphere and surface forcing caused by aerosols, and their results showed that while the two are about the same in the U.S., they are not for Asia, which has high amounts of black carbon, which increases surface forcing.

As far as validation, they compared MODIS ocean retrievals to AERONET for 64 measurements during a 2-month period at 11 stations. Their results show correlations of 0.94 for 660nm and 0.95 for 870 nm. They think that effective radius is validated to within 0.1µm in the 0.2 to 0.8 µm size range. Most AOT is also falling within the error bars advertised pre launch. There is larger error over land than ocean, which is expected. Keeping this in perspective, MODIS is much improved over AVHRR, with less displacement from the 1 to 1 line and much better correlation.

The issues that still need attention are some residual cloud contamination, problems over swamps and marshes, and the non-sphericity of dust. They are also getting a bit of cirrus contamination, but it is rare. They can correct that using the ratio of 1.38µm to 1.24µm, which separates cloud and aerosol well. Despite the fact that that they are using a spherical model for dust (when it is not spherical), they get great AOT values at 660 nm and 870 nm. Although it is not as good a fit for effective radius or at other wavelengths, it is not a major problem.

Using the definition of validated, the group is confident what uncertainties exists, i.e. 1 sigma (66%) of individual retrievals are accurate to within $\pm 0.03 \pm 0.05\tau$ over ocean, to within $\pm 0.05 \pm 0.20\tau$ over land, or to within 0.10 µm for effective radius. In addition, there is no systematic bias so that ensemble means and climatic averages will fall within the above stated uncertainties. Specifically, most of the AOT products could be considered validated from September 2000 onward. They hope that all AOT and size parameters will be validated by Spring 2002.

L1B Status

Jack Xiong, MCST, gave the status of the MODIS L1B. He talked first about Terra and then about Aqua. There were three major issues with Terra MODIS in 2000: a radiative cooler anomaly, a formatter anomaly, and the B-side electronics transition. In 2001, MODIS experienced two anomalies: a solid state recorder temporary failure, and the PS2 shutdown anomaly in late June. Other changes included gain changes in band five to improve dynamic range. MODIS is currently using A-side electronics, and door opening and SRCA are both below their lifetime use limits.

After the July 2 turn-on, things have been operating smoothly, with no changes in electronic configuration. Their work to prepare for the consistent year included modeling the solar diffuser stability monitor ripple effect, correcting solar diffuser (SD) degradation in the reflective solar bands, and developing alternative calibration for Band 14 H.

Xiong said that signal to noise (SNR) in the reflective solar bands is consistent, with no major anomalies, and the values are within specification. In the thermal emissive bands (TEB), the spec is based on Noise Equivalent temperature Difference (NEdT) as opposed to SNR. Most channels have NEdT below spec, except for Band 36, which has been out of spec since pre-launch. Band 34 does have some out of family response and calibration continues to be tough because the typical radiance is below the range of black body. They have not implemented changes for striping because of consistent year.

In the future, they will continue monitoring SD degradation, and will try to understand response versus scan angle (RVS) variation versus angle of incidence. They will also work on striping, out of family detectors, correcting SWIR cross talk, and refining TEB calibration.

With respect to changes in the L1B this year, there has been one change for misregistration during aggregation in the high resolution bands, a delivery for consistent year that used piecewise linear LUTs, and finally, a change to turn off 250 and 500m band while in night mode. Xiong said that the complete history of L1B and LUTs is available on the MCST web site. Xiong concluded by saying that they feel the L1B is validated. Esaias asked about RVS and mirror side differences, and Salomonson said that those were not in the specifications, and the team would have to discuss that issue further.

As far as Aqua MODIS, some improvements as afar as calibration goes are that the TEB relative spectral response was measured in thermal vacuum testing, and there was a system-level RVS TEB measurement, optical leak is much less on Aqua than Terra, as is the SWIR thermal leak. In addition, electronic cross talk and sub frame difference are reduced. Lastly, the Band 31/32 gain was increased to provide higher resolution for SST. Concerns for Aqua include the fact that Bands 33, 35, and 36 saturation temperature points are below the black body limit of 310K. In Band 5 and 6, there are some non-functioning detectors. Band-to-band registration may not be stable and will require modifications to L1B algorithms. When asked if MCST could take care of the band-to-band registration in the L1B code, Xiong said that they didn't think that would be best.

Geolocation Status

Robert Wolfe presented on the geolocation product. Since the collection 3 data set production began, the along scan error decreased from 58 to 56m; however, in the along-track direction, the error increased from 57 m to 74 m. This is based on about 82 matchups per day. Specification is 150 m, but they are shooting for 50. They have discovered that if they plot individual 16-day mean residuals for mid 2000-thorugh early 2001, there is a drift in both the scan and track direction. They think for the scan direction, they are seeing an annual cycle that is based on sun angle that changes with the pointing of the spacecraft. They don't know the cause of the track direction trend; it may be a step function. They are discussing the issue with the Flight Operations Team to see if they have tweaked anything that might cause this, but there could just be some flexing going on.

They are also talking to the Flight Dynamics team about attitude data process. Analysis shows that plots of track-adjusted control point residuals versus pitch angle have a lot of spread, which they think is because they are using predicted orbits and not definitive data from the spacecraft. They plan an update in January after consistent year is done that introduces correction for tilt versus pitch bias (40 m in track direction at large scan angles). They can also remove ±10 m, mirror-side difference in scan direction. They also plan to review the use of FDF-processed attitude data since the along-track errors seem to be correlated with the spacecraft pitch. They also plan to deliver time dependent LUTs. They are ready for Aqua, but will have to deal with band-to-band registration.

He is comfortable that geolocation and scan angles are within specifications. In some regions, the inland water bodies in the land-sea mask may not be as good as the team would like. The geolocation group uses the EOS Digital Elevation Model SWG, which is the best available. He cautioned people about using this for fine resolution work, and showed an example of rivers being displaced 2-3 km in South America. With the land team, they are investigating the possibility of using MODIS data to update the land-water mask. Wolfe concluded by saying that they will be looking at whether they can do geolocation for 250, and 500m as well.

Conclusions

Salomonson thanked everyone for attending and observed that MODIS is making very considerable progress in getting results that are useful to the science and applications community. He observed the "MODIS success" will continue to be the sum of: (a) science quality products being developed and validated; (b) the MODIS data products being produced, reprocessed as necessary, and delivered to the archives; (c) the access to the MODIS products is such that the users can get what they want without undue difficulty or burden. It was Salomonson's opinion that (a) is going fine, but considerable challenges lie ahead for (b) and (c). Of the two, (c) is probably the largest, near-term challenge and he and the Science Team need to work with the ESDIS, et al, to do whatever can be done to make the data access "user-friendly" as quickly as possible. It does no good to have available MODIS products if the broader community cannot get them. The data processing (b) will continue to be a challenge involving the utilization of known or expected resources for processing and reprocessing in as efficient and strategic manner as possible. The Team also needs to do whatever can be done in terms of outreach and interaction with the community to inform and assist regarding the status and use of MODIS data and products. This means planning workshops, attending and presenting at scientific meetings, etc.

The next Science Team meeting should occur 6-7 months from this one. In the meantime everyone will be kept informed via Technical Team minutes and, possibly, telecons as issues requiring such occur.