MODIS Science Team Meeting
Wednesday January 24-25, 2001

Dr. Vincent Salomonson welcomed the group, reviewed the meeting agenda, and announced that the major focus of the meeting was to present preliminary science results. He expressed his hope that the presentations would demonstrate how MODIS ties into the Earth Science Enterprise's research strategy. Salomonson emphasized the MODIS team's commitment to aligning its efforts with those plans and strategies.

Salomonson gave a presentation on the state of MODIS (see Attachment 1), noting that the major instrument systems work, that spectral bands are properly located, that signal to noise ratios are good, and that the gains appear to be stable. Although data processing has been a concern, the system is stabilizing and products are being produced and archived. In addition, the MODIS direct broadcast feature is quite popular, with over a dozen receiving stations already, and more being planned.

The calibration and characterization efforts overcame several challenges this first year after launch. Electronic noise problems have stabilized this past fall, and the instrument recovered from a brief loss of focal plane temperature control this summer. In October, a switch to B-side electronics reduced the effect of many problems. With the instrument more stabilized, the team is working toward getting beta and provisional products out to the community.

Salomonson summarized the areas of improvement that have been or are being studied for the Level 1 B, including non-functioning detectors, response versus scan angle differences, optical and electronic cross talk, non-uniform channel to channel response within a band, and scan-dependent noise. Several of these problems are corrected on Aqua MODIS, such as the gain changes on bands 31 and 32.

Salomonson showed charts summarizing the sources and magnitude of uncertainty in bands. Both the number of sources and the magnitude of uncertainty have been decreasing over time. For example, one substantial component of Band 4 uncertainty—the misregistration of some 1000m bands—was recently eliminated. In Band 5, minimization of electronic cross talk greatly reduced uncertainty. Salomonson talked about expected and unexpected adjustments that had to be made on orbit.

Many of the MODIS products have been released, including some L3 products from every discipline group. He acknowledged the Project's interest in when the team will be releasing validated products, and he expressed his hope that the briefing on Terra data products given at NASA Headquarters combined with the presentations being given over the next two days would help address those questions.

Salomonson concluded the talk with a summary of challenges that the team would be addressing in the future: reaching a stable instrument characterization state, ensuring data processing systems are efficient and that they are able to supply sufficient power to process and reprocess data, determining how to support MODIS Direct Broadcast users, and preparing for Aqua and recompete transitions.

Terra Status Since Launch

Paul Ondrus gave a history of Terra since launch (see Attachment 2). The high points are that all major systems are working within specs, the craft is producing enough power, it is collecting all science data, and it is satisfying pointing requirements. The biggest challenge is managing the solid state recorder, which has given them some trouble. They have instituted small monthly burns to stay within a ±20 km ground-track tolerance. One notable problem is that solar array circuit 10 failed, which could be a cause for concern toward the end of the mission's life. Ondrus reported that Terra makes 4.8 TB of data each month, and that the spacecraft has acquired 99.7% of the data that they planned to collect. This means that in one year, Terra has doubled the amount earth science data available to the community.

Ondrus summarized Terra's calibration maneuvers, and announced that the deep space maneuver is still being negotiated with the Project and the other instrument teams. They have conducted a series of simulations, and it seems that the primary concern is that a gyro might fail during the roll. Ondrus felt that the issue would come down to other instrument teams coming to terms with the risk. Bruce Guenther commented that the risk was limited to a one-hour time slot, and that the earlier in the mission you perform the maneuver, the lower the risk should be. Ondrus agreed that the older the parts, the greater the risk. Ondrus indicated that if they got the approval from the Project to do the maneuver, they could be ready to perform it in about 6 weeks.

One point for concern was a close call that Terra had with another spacecraft; they came within approximately 4 km of each other. This will be an increasingly likely event as spacecrafts begin to fly in formation with one another, and they will have to continue to watch it carefully. Ondrus reported that the equator crossing time is about 10:42 a.m. and coming down. One issue for the SWAMP meeting is whether to do all Aqua inclination maneuvers in one burn, or to space them out. He felt that would have to be a science decision. Among the challenges they have encountered are MDA byte failures, which coincide with solar storms, and average about three a week. Another is depriming of the CPHTS during burns. Terra also experienced a formatter failure on the A-side, and one science formatting equipment error.

MODIS Instrument Status

Bruce Guenther gave a brief summary of instrument status, starting with the year's highlights (see Attachment 3). First, MODIS was successfully turned on and activated, and command operation continues without event. Another high point was that MODIS L1B data was the first Terra data to be publicly released, and the solid state recorder delivered 22.9 TB of data in 2000. The past three months have been in a stable operation in the best configuration, particularly with respect to minimization of electronic cross talk, and signal-to-noise ratios are exceeding the team's best expectations. The switch to B-side electronics has been especially helpful to the Sea Surface Temperature product.

Guenther revisited charts initially presented by Salomonson that summarize the progress being made toward calculating radiometric uncertainty. Guenther summarized what corrections and adjustments the team knew before launch it would have to make, including calibration of the reflected solar bands, testing of the solar diffuser stability monitor (SDSM), channel-to-channel and band-to-band co-registration, and testing of pre-launch improvements that were made to minimize electronic cross-talk. As introduced by Salomonson in his talk, the known issues were accompanied by some surprises that began with the longer-than-expected turn on time, due to Y2K and

Christmas shutdowns. In addition, the pre-launch changes to minimize cross talk worked on some but not all bands, and affected the performance regime of those that it did not fix. Also, ripples in the SD screen interfere with channel-to-channel equalization, which complicates the calibration of the ocean color bands.

Among the corrections still being worked on are the response versus scan angle differences and mirror-side uncertainty, which the team really needs the deep space maneuver to understand. Also, the SDSM is yet to be integrated, and polarization studies have not yet begun.

MODIS Data Acquisition and Production

Ed Masuoka presented a status report on the data production system (see Attachment 4). There are three basic elements in the MODIS data acquisition and processing chain: EDOS to the GES DAAC to MODAPS. The overall flow is from TDRSS in White Sands, NM, to EDOS for Level 0 (L0) processing. The L0 data are sent both to the GES DAAC and to NOAA, where expedited products are made (see NOAA Bent-Pipe Summary on page 29). The GES DAAC processes data to Level 1B, and then sends them on to MODAPS for Level 2 and higher processing. MODAPS distributes products to the Japanese Space Agency, NASDA, for use in the GLI project (see MODIS Use in the GLI project, p. 29), and also to the MODIS team for QA and validation purposes. Data are sent from MODAPS to the three "MODIS" DAACs for archive and distribution to the user community: the NSIDC DAAC, for snow and ice data sets; the EDC DAAC, for land data sets; and back to the GES DAAC, for atmosphere and ocean data sets.

Despite some early delivery problems, EDOS is currently working well, and the GES DAAC reports that 1 % or less of L0 data need to be reordered. Current GES DAAC production is about 2X, and will be increasing to about 3X with the installation of remaining Aqua hardware, which will increase processor throughput as well as I/O efficiency. Over 150 TB of MODIS data have been produced and stored at the three DAACs.

MODAPS ships about 300 GB to the DAACs, and up to 400 GB/day to the SCFs. Masuoka commented that they need a better average metric for how much is distributed. Production of Level 2-Level 4 science products is above the 2/96 baseline of 229GB/day but less than the 460GB/day that the Science Team has requested for MODIS in the SWAMP Working Group on Data (SWGD) report. The MODIS goal is 950 GB/day, but they will need the new Version 2 software and new hardware to achieve that. Masuoka summarized the volumes of data ingested at the three DAACs, and pointed out that only the EDC DAAC has a potential problem, with the amount of data being ingested exceeding previously set baselines. When asked if data were being compressed, Masuoka replied that compression was being looked into, and it was uncertain whether the processing system would get "credit" for getting better compression at the GES DAAC than was required. The product volumes summarized in the chart do not reflect Aqua volumes.

Masuoka described upcoming changes to the MODAPS system that should increase throughput to about 2X, including a new 7TB disk, new Linux servers, and a second tape drive. In addition to the hardware upgrades, the V2 software should speed up production and tape retrievals. Masuoka indicated that many steps still needed to be taken to implement V2. They plan to start shadow processing March 1, 2001, and hope to be switched to full production by the end of March. MODAPS is currently about 2 months behind real time. Yoram Kaufman suggested that because that the processing system seems to be reaching a stable state with respect to the instrument and algorithms perhaps we really need to work at progressing toward real time production. To that end the team should consider, for example skipping days, if we can't seem to catch up in the next few months. Murphy answered that the issue would be discussed in the PIP processing meetings.

Finally, Masuoka discussed things the science team could do to help with the transition to V2. Also MODAPS needs any merged Terra/Aqua PGEs that the team has available. He also wanted the team to be aware that they expect a period of intense bug-fixing during the transition, and that it would be good for the science team to check for problems in V2 through QA.

Data Distribution and User Services

Steve Kempler began by introducing Greg Sharfen and John Dwyer from the NSIDC and EDC DAACs and thanking them for their contribution to the presentation (see Attachment 5). The first part of the presentation summarized archive metrics for each of the three "MODIS DAACs." So far, 167 TB of MODIS data have been archived; the average per month, based on the last three months of steady production, is about 21.2 TB. Taken together, the total capacity for the three DAACs is about 1060 TB, figuring a compression level of 1.5 to 1. The DAACs are continuing to refine the estimate based on true compression factors, and as production becomes more stable, they will need to begin cleaning up the archive. Currently, however, the archive is in fine shape.

With respect to distribution volumes, the situation is slightly more complicated. The DAACs are distributing far less data than they are capable of distributing; so far, just over 60 TB have been distributed to users. One reason is that the DAACs have a hard time filling large orders (they have received individual orders for all MODIS data). These requests typically go unfilled, or are broken into smaller orders, which take time to fill. At the same time, they are not receiving enough small orders to distribute at their capacity. So, large orders are exceeding their capacity to distribute, but small orders are below their capacity to distribute.

The GES DAAC conducted an informal survey at the most recent AGU meeting, in which they asked a variety of questions to find out why the small orders weren't coming in. Their poll of over 350 people indicated that people were aware of MODIS data, but were not ordering it for a variety of reasons. One was simply data maturity; users felt they would wait for a more mature product. This is normal for a new data product, and is expected. Another reason was that people had difficulty with the data ordering system, an issue that is being addressed and improved. Users also commented that data files were too big to download efficiently. The DAACs are currently working on tools to subset data so that users could get only certain parameters for certain geographic regions. Finally, people expressed unfamiliarity with HDF format and a desire for translation tools.

Kempler indicated that the EDC DAAC is developing a Product Distribution System to increase hard media distribution capacity. He also discussed the Earth System Information Partnership's intention to set up a MODIS "cluster". The cluster will include current data providers and other ESIPs who are committed to facilitating access to MODIS data for current and future distribution requirements. They intend to provide some value-added services such as granularity and alternative formats.

Kempler also discussed how the GES DAAC is preparing for MODIS reprocessing. Their current hardware capacity will allow 1X forward processing and 1X reprocessing. In April they will have 2X reprocessing from the installation of Aqua hardware, and they are pulling together all the necessary L0 and ancillary data they need. One outstanding issue is the insertion of new ESDTs, which is a time-consuming, manual task at present. The MODIS team and the DAAC are investigating solutions. Someone asked about the mechanism for making decisions about reprocessing, and Bob Murphy indicated that the science team makes those decisions at the PI Processing and Technical Team Meetings. Finally Kempler summarized the ways of getting MODIS data: the EOS Data Gateway, or EDG; the GES DAAC's interface, TerraWHOM; anonymous ftp sites at the DAACs; and subscriptions.

At the end of the presentation, Jim Dodge (NASA Headquarters) asked whether, given the backlog, low user demands, and unvalidated product status, it might be more useful to stop with the forward processing, work off the back log, and do on-demand processing. Masuoka replied that there is a need to stay current with EDOS to eliminate time-consuming tape retrievals. Salomonson added that the science team, which at times has received as much as 300GB/day, needs to look at the data all the time to make sure the instrument is functioning and to develop and refine the L3 products. He also indicated that the team's efforts were focused on providing as assessment of the current accuracy, and showing the decrease in uncertainty over time. The team can't continue to improve the products' accuracy by processing in pieces.

Dodge then expressed concern that the instrument isn't even calibrated, but Salomonson and other team members disagreed, pointing out that sources and magnitude of uncertainty have been decreasing over time, and that much calibration has been accomplished. Many people are excited about the data and the team's progress toward climate-quality data products. He expressed regret that the briefing the team had provided to Headquarters' in December did not seem to have provided a clearer picture on what MODIS has accomplished and what still needed to be worked on.

Diane Wickland (Terra Program Scientist, NASA Headquarters) indicated that the briefing had conveyed a more positive message to her, but that she is still hoping for a clearer understanding of what is planned and when it is planned as far as providing the community with seamless data products of good quality, and what is planned and when for reprocessing. She indicated that she really needs those details to determine where the processing system may fall short.

Oceans Summary

Wayne Esaias began his ocean discipline group summary by saying how pleased he was to be the head of such a fantastic ocean team, and how proud he was of the way the team had overcome many challenges. His theme for the presentation was that the seas are calming, and the ship is answering at the helm (see Attachment 6). Progress this year has been substantial. There was a crossing-time adjustment that reduced sun glint, and the on-orbit characterization of the ocean bands has identified key calibration issues, most of which are being addressed. In addition, he expressed the team's excitement over MODIS' florescence capability, and the clean observations being made with it. Esaias also expressed appreciation for Headquarters' help in getting the gain changes in the SST bands on Aqua. As far as data products, all ocean parameters are in production through L4, and are approaching science quality, with near-daily, global, 1km coverage. Complementing this is three years of MOBY data, which has a NIST accuracy of about 3%. The teams and the DAACs have worked together to address each bottleneck that was anticipated for the archive and ingest of the large volumes of Oceans data. Provisional products will be released over the next few months, and the team believes that the community is going to be really excited. Many of the ESE research questions are addressed with the Ocean NPP product, including global ecosystem changes, the carbon cycle, and the impacts of human activities in coastal regions.

The Oceans team has accommodated several unanticipated instrument changes, and they are now moving on to L2 and L3 software problems, such as binning and thresholding issues. Esaias reported that the Oceans team is pleased with the switch to B-side electronics, and concomitantly, sensor digitization noise has been reduced by a factor of 2. The single outstanding issue for the team is to understand the effect of mirror side uncertainty, a process that may take months of analysis before corrections can be introduced.

Oceans team members have presented numerous posters at several conferences, and already some exciting applications of MODIS data are being reported. For example, the 250m-resolution bands can detect red tides, and have been used to confirm the proposed relationship between nitrogen-fixing cyanobacteria and harmful algal blooms (HAB). The mechanism proposes that iron-rich Saharan dust makes its way to the Gulf of Mexico, where it causes a bloom, or rapid proliferation, of Trichodesmium. The increasing nitrogen fixation by Trichodesmium acts as fertilizer for other organisms that can produce HABs, which kill fish and other marine life. These observations from MODIS represent the first time such a connection has been shown with satellite imagery.

Esaias presented several examples of the Oceans products, including examples of how the A-side/B-side transition and detector striping corrections are greatly improving them. The fine structure seen in products such as the 443 nm water-leaving radiance and chlorophyll are quite impressive, and surpass the capabilities of SeaWiFS.

Finally, Esaias mentioned validation activities for ocean color products, water-leaving radiance, coccolith and SST. Products are validated using a variety of techniques, including MOBY data comparison, AVHRR comparison (SST), field experiments, such as chalk deposition for coccolith study, and other cruises. He expects that in June the product quality will transition from beta to provisional.

Perhaps the most significant issue for the Oceans team is the necessity of the deep space maneuver to improve the SST product. The team feels that the maneuver is mandatory. Wickland wondered whether they were confident that the deep space maneuver would conclusively fix the problem. He said they were not positive it would fix the problem, but they were positive that there is little chance without it.

Atmosphere Summary

Michael King began his talk by showing an RGB image of April 19, 2000, which the atmosphere group is considering a golden day (see Attachment 7). They have archived all the data from that day in the MODIS atmosphere system, and are using it to test algorithm developments. Next King discussed each of the atmosphere products, beginning with the cloud mask. The cloud mask--which has four categories: confident clear, probably clear, probably cloudy, and cloudy--uses more spectral bands than any heritage instrument. Different tests are conducted over five different domains: land, ocean, coast, snow, and desert. The cloud mask is available at 250m and 1 km resolution.

The cloud product uses the results of the cloud mask combined with cloud top properties, dynamic ecosystem maps, and surface reflectances as inputs to a decision tree that determines first, whether to proceed with a retrieval (eliminating retrievals in sun glint, for example), and then estimates cloud phase—liquid, ice or mixed. Twelve bands, including some from the visible, near-infrared, and thermal, are used to determine cloud properties such as temperature, altitude, optical depth, and effective radii. King commented that MODIS would be the first sensor to have CO_2 slicing at high spatial resolution.

King also showed how MODIS is accomplishing thin cirrus detection and corrections, and also the detection of cirrus clouds over snow and ice, which is a new capability. He showed results from the total precipitable water product, which may be overestimating a bit, but provides terrific spatial resolution. Next King discussed the aerosol product, which includes optical thickness and effective radius parameters. The aerosol retrievals use seven bands, and can be produced not only over ocean but over land as well, which is a new capability of MODIS. The team has seamlessly worked together a variety of wavelengths and algorithms for land and ocean that are producing excellent results.

All MODIS atmosphere products have been released at this point, including L3 daily, eight-day, and monthly products, and they believe their product maturity will move from beta to provisional in April or May. King concluded by pointing out that the atmosphere discipline group web site (http://atmos-modis.gsfc.nasa.gov) has many data tools available that were developed in house, including subsetting and visualization tools.

At the conclusion, Salomonson pointed out that the detection of aerosol over land, and the cirrus detection are exciting capabilities of MODIS that may provide information on the radiation budget that we haven't had in the past.

Land Summary

Chris Justice began his presentation (see Attachment 8) by pointing out the relationship between the Land Discipline's products and the questions of the Earth Science Enterprise's Research Strategy, including the global water cycle, the carbon cycle, and the biogeochemistry of Earth's ecosystems. MODIS Land products fit within the ESE strategy, and also into the broader context of the U.S. Global Change Research Program (USGCRP). Justice summarized several instrument issues that Land is working on now. Among them are refining the geolocation, understanding SWIR, sub-frame differences, evaluating electronic cross talk, and minimizing detector destriping.

Production of land products has been steady since August 2000, and includes everything up to the monthly products, except the CMG products. Data subsets for validation sites are being generated for all publicly released products, and although MODAPS production is about 45 days behind real time, there has been the capacity for expedited L2 processing to cover validation campaigns. Justice provided the URLs for MODLAND's, MODAPS's, and the GES DAAC's production status pages. Most products are currently available to the public, with the exception of the NPP and VCC products, which will soon be released as well.

The Land Data Operational Product Evaluation (LDOPE) facility is working on Quality assurance activities. In addition to documenting product quality they are also addressing product dependencies and establishing time series of quality assurance records. They have an internal known problems page that they are considering making public. There is a separate page for every product, which describes known problems and the current status.

The MODLAND team is providing several features for users via its web site, including history of changes in PGEs since launch and MODLAND-generated browse for L1B and most of the land products. The images are updated every 6 hours and come in 40-km and 20-km resolution; 5-km resolution browse products are being added.

The 250-m production system began 10% production of the L3 surface reflectance and the L3 Vegetative Index in October. Currently the data are distributed by the production system, but in the next year the data will be shipped to the EDC DAAC for distribution. Production began to be transitioned to MODAPS in early November. Data are shipped from MODAPS to ESIPs like University of Maryland, where value-added services are offered, such as regional subsets and different formats.

The Land team is developing a fire rapid response system, which will draw on experience they gained during their support of the Montana fires in the summer of 2000. For the system to be useful, of course, they will need near-real-time data, which they will take from the NOAA "bent pipe" system, which is under development. Streamlined processing at SCFs would produce stand-alone code, and the products would be made available via the web.

Among the most outstanding issues for the land team are cloud mask refinements, data processing and reprocessing resources, validation of global products, availability of data subsetting and projection tools at the DAACs, and developing those data analysis tools for the user community. In addition, he indicated that the development of shareware code for land data is really needed, as requests from direct broadcast users are increasing.

Justice concluded by highlighting some of the team's achievements, among them the evolution of new products (LST, BRDF, EVI, VCC), getting data out to the community in the year post launch, and developing new paradigms for quality assurance with the LDOPE facility and Land Product Validation. He expressed confidence that the lessons learned from MODIS would be valuable to future instrument teams, including VIIRS, and said that the team was looking forward to developing an international community of scientists for validation and answering science questions.

Energy Balance and Radiation Budgets

Eric Vermote gave a presentation that represented several products (see Attachment 9). He began by discussing how the surface radiation product suite addresses key ESE research questions. Understanding albedo and temperature are essential for studying climate and climate change. With its surface reflectance, BRDF, snow/ice albedo, and emissivity products MODIS will help answer those key questions by allowing scientists to decouple the land and atmosphere and study the effect of each individually.

The first uncorrected surface reflectance product was released August 2000, and the current product has correction for aerosol. MODIS surface reflectance is much improved over heritage instruments, but is still not validated globally. However, areas for improvement have been prioritized and validation is underway. Among the areas needing improvement are better aerosol retrievals, with finer resolution inputs and less snow contamination; cloud shadow filtering, extensions to thermal infrared, and improvements to the cloud mask.

The team is applying their own aerosol corrections, and Vermote showed several examples of how the algorithm improves the surface reflectance product, allowing finer detail to be seen. Preliminary validation with AERONET shows that MODIS channel 3 aerosol retrieval that they are using is working OK. Currently they are testing it on coarse resolution global data.

Vermote went on to talk about the surface reflectance at 3.79 μm, which is of good quality and is being used for fire detection. Vermote presented charts showing a lot of variation in spectral emissivity among Bands 20, 29, and 31, but that land surface temperature appears to be identical across bands.

Vermote talked about the evolution of the surface reflectance algorithm, which initially was based on minimum blue. Now the algorithm includes a "minimum blue" atmospheric correction, plus a shadow filter, plus minimum view angle and maximum NDVI. He presented several examples of the improved algorithm. Future investigation will focus on instrument performance (with respect to product quality and calibration, adjacency and BRDF coupling, cirrus correction, aerosol refinement, and overall product accuracy.

Vermote then spoke about the BRDF/albedo product, which is a 16-day, 1 km gridded product that provides the albedo, surface reflectance, and surface anisotropy. This data is useful to climate modelers because it allows them to compute albedo and surface reflectance at any view angle or geometry. The product can provide both bihemispherical (white-sky) albedo and directional hemispherical (black-sky) albedos, and nadir, BRDF-adjusted reflectances (NBAR) are available to all users who need surface reflectances that are not only corrected for cloud and atmosphere, but also corrected to a common viewing geometry. He concluded by showing examples of how the corrections improved the NDVI maps.

The next products in the surface energy product suite were the snow products. The cryosphere team released snow products beginning in September, and they are providing special versions of these on a climate-modeling grid as well. The presentation included maps of maximum extent of snow cover for two eight-day periods in November. The maximum extent of snow cover maps were used to produce maps of the fractional snow cover for the composite periods, and showed that there was above-average snow cover during the first weeks of November. The team is validating their products through fieldwork and ER-2 aircraft measurements, as well as through comparison with other snow maps, such as NOAA operational maps.

The cloud mask is performing pretty well over snow, but there is some snow/cloud confusion, and false detections of snow. They will continue to work on these issues in the future. Also upcoming for the team is the delivery of the snow albedo algorithms this spring, more fieldwork, and the testing of two potential algorithms for the 500-m resolution snow cover maps.

The final product in the suite that Vermote discussed was the Land Surface Temperature and Emissivity product, the daily version of which has been released in beta version since late July 2000. The 8-day composite was released in August 2000. The product has had quite a bit of validation, including comparison with ground-based measurements at grassland and rice field sites in California in conjunction with outreach activities centered on the use of remotely sensed LST measurements for agricultural purposes. Validation will move to semi-arid and arid areas in 2001, and a 5-km daily LST product will be evaluated and released in 2001. Both daytime and nighttime LST maps were shown using data from B-side. It is expected that the LST product will be greatly improved with Aqua MODIS data, especially that produced by the day/night algorithm.

Aerosol Optical Properties

In his overview of the presentation on aerosol optical properties (see Attachment 10), Yoram Kaufman indicated that the presentation team would address first the physical basis of the algorithm, how the cloud mask was being altered for aerosol correction, the scope and progress of validation over land and oceans, and finally, the implications for climate change research.

Didier Tanré discussed the physical basis of the algorithms that retrieve aerosol over land and over ocean (see Attachment 11). The total spectral reflectance is equal to the reflectance of the surface plus the reflectance of the atmosphere, and over the ocean, the reflectance at the surface is known. So the reflectance of the atmosphere can be calculated, and from that the optical thickness and size distributions. Over the ocean, radiances at six bands are used to make LUTs for size distribution, and the radiance at 865μm is used to derive the optical thickness. Both a fine and a coarse mode optical thickness can be retrieved. The ocean product is produced at 10-km by 10-km resolution.

Over land aerosol retrieval is slightly more complicated, as the reflectance at the surface is unknown. However, over dark pixels, atmospheric reflectance at 2.13 μm is approximately equal to zero. So the surface reflectance can be calculated. The reflectance at this wavelength is used to estimate the surface reflectances at other wavelengths (.47 and .66 μm) using known relationships. The algorithm uses 250-m and 500-m data at these three wavelengths. Fine mode aerosols are determined by location and season, and coarse mode aerosols are fixed using a dynamical model. The land aerosol product is also at 10-km by 10-km resolution.

Next, Vanderlei Martins described how the team was altering the Cloud Mask algorithm in order to better separate between aerosols and clouds (see Attachment 12). They begin by taking the standard deviation of every 3 x 3 pixel area, which creates a picture of the scene's standard deviation. When lots of clouds are present, there is high spatial variability, which produces high standard deviations. Low cloud areas show low standard deviations. They have profiled several types of clouds and aerosols, and assigned a standard deviation to each. These standard deviation thresholds successfully remove 95-99% of the clouds. Then they apply the IR tests from the Cloud Mask to identify high cirrus clouds. The spatial variability test is simple, uses few wavelengths and is not particularly sensitive to instrument calibration changes. Martins showed examples of how the test successfully separates dust from aerosol, and cloud from aerosol.

After Martins, Charles Ichoku discussed the technique that the team uses to compare AERONET data to MODIS aerosol retrievals (see Attachment 13). He explained that the challenge is that MODIS retrievals are provided globally at 10km by 10km resolution, but that validation sets are typically from ground-based point sources many times a day. So they have to find a way to accommodate the spatial and temporal variability between MODIS measurements and those ground-based point measurements.

To do this, an algorithm selects a 50 x 50-km box of MODIS data around the validation site, and statistics are calculated for the box. The automatic procedure then pulls data from any site that has a sun photometer, and pulls all temporal points for the hour that corresponds to the MODIS overpass. Statistics are compared to the MODIS data to validate the optical depth. Ichoku presented a graph of MODIS vs. AERONET data that shows good agreement between the two. He also presented a graph that showed that AOT measurements were improving over time, due to improved calibration of MODIS.

Lorraine Remer then talked about validation results for aerosol optical thickness and effective radii retrievals over oceans (see Attachment 14). She began by presenting maps of each type of retrieval as well as a map showing small mode weighting. Remer indicated that the team is extremely excited about the close correlation between ground truth measurements and MODIS retrievals. Over ocean, the retrieved optical thickness of MODIS vs. AERONET shows only 2% deviation, which is an amazing validation.

The effective radius measurements are also quite good--within ± 0.1μm. Maritime aerosols show up as large, smoke shows up as small. She emphasized that no one has ever measured effective radius from space before—actual radii, not estimates. Finally, she showed that correlation between fine mode comparisons for MODIS and AERONET are good, despite the fact that one comes from the optical thickness and one comes from volumes. She concluded by saying that the look up tables are good, but the surface assumptions may still need some work.

Following Remer, Alan Chu summarized validation results for retrievals over land (see Attachment 15). As with ocean retrievals, there is good correlation between MODIS and AERONET AOT measurements. His map of retrieval frequencies showed large numbers of retrievals in the mid-latitudes between July and September. Successful retrievals have been performed over several areas including the fires in the western US in the summer of 2000 as well as pollution over Asia.

They have made validation comparisons with AERONET data for the US, Europe, South America and Africa, and found good agreement for all. In the course of these validation comparisons they discovered that the characteristics of soot from Africa are different than soot from South America.

Kaufman finished off the presentation by discussing where these high-quality aerosol measurements can take them next. He indicated that their team's optical thickness and effective radius retrievals are performing as well or better as they predicted in 1997 except for the issue of non-sphericity of dust. The next generation of products will include models for handling the issue. The team also looks forward to using the products for regional applications, such as monitoring pollution.

The real point, Kaufman said, was how do researchers move from these aerosol products to climate forcing. Aerosol optical thickness, effective radius, and the ratio of fine to coarse aerosol particles all factor into climate forcing. For example, combining MODIS top-of-the-atmosphere data with AERONET surface measurements allowed them to calculate the effect of smoke on heating in the atmosphere in Brazil at 55 W/m^2.

To integrate the aerosol measurements into climate studies, they need to find aerosols' effects on solar flux, irradiation at the surface, solar heating in the atmosphere, cloud properties and reflectance. But there are still challenges: trying to integrate the data on a daily cycle, deciding how to subtract the background, and differentiating between human-induced and natural changes.

The team has made steps toward addressing those challenges. AERONET data provides answers on how to integrate on a daily cycle, and the ability of MODIS to differentiate between fine and coarse particle will be key to distinguishing between human and non-human induced changes. They hope that AERONET will be able to provide information on background as well.

Ocean Color and Biogeochemistry

Mark Abbott began his presentation (see Attachment 16) on ocean color and biogeochemistry by pointing out that the science community is finally in a position where it has high-quality physical data sets of the ocean. He presented global maps from TOPEX/POSEIDEN and AVHRR Pathfinder that showed the sea level and surface temperature anomalies associated with El Niño events. The community also has wind stress measurements, which are important because they drive ocean circulation. This better physical data allows us to examine carbon cycling more thoroughly than before.

Abbott then gave an overview of the carbon cycle in the ocean. He explained that the presence of a vertical chemical gradient, which is maintained by the sinking of organic particles and the upwelling of nutrient rich waters, slows down mixing of the layers, and keeps the rate of carbon dioxide removal from the atmosphere three to four times higher than it would be if the layers of the ocean were mixed.

Estimates of annual flux of CO_2 have been largely based on ship-based models that leave large areas of the ocean unmeasured. This is why remote sensing measurements such as those taken by MODIS are so important to studying the ocean carbon cycle.

Abbott went on to discuss how the model of ocean biogeochemistry has changed over time. The first models were based on assumptions that no longer seem valid. All the factors that went into the model were placed in isolated boxes: nutrients, physical processes, etc. The model assumed that ratios between uptake of nutrients and sinking were fixed and steady; the model did not take into account episodic changes or changes in external fluxes. The model assumed that all parameters were in equilibrium.

However, we now know that the ratio between uptake and sinking isn't fixed. The ocean is not in a steady state—deep water, sea ice, and organism concentrations can all change. And the interaction between ecology and physics is more complex than we expected. Ocean biota play a pivotal role in the oceanic carbon cycle, although they do not react directly to increases in atmospheric CO_2. Assumptions that ocean biota would respond directly to increasing CO_2 by increasing their uptake of it, thereby scrubbing the atmosphere clean of greenhouse emissions, are overly optimistic. However, complex indirect responses of phytoplankton play a large role in the removal of carbon from the atmosphere and its ultimate deposition on the sea floor. Among the factors regulating this biological pump, which Abbott presented in a schematic, is the availability of nutrients such as nitrogen and iron. Abbott then showed a global map of carbon flux generated using SeaWiFS data.

One area of research that may help scientists better understand carbon flux is measuring changes in the position of the polar front over 9 years. These changes are interesting because the amount of chlorophyll changes in response to changes in the polar front. These episodic events may dominate carbon flux dramatically, and we need multiple data sets to get the whole picture.

Abbot then discussed estimates of Ocean Primary Productivity. Satellite-based estimates of Primary Productivity vary widely depending on which satellite collected the data. In assessing primary productivity, researchers are interested in identifying iron-rich and iron poor regions of the ocean because one hypothesis about productivity is that iron is the limiting factor. If you add iron to an area, a marine bloom results.

One way to investigate primary productivity is through florescence measurements, which is a new capability on MODIS. The amount of fluorescence given off by phytoplankton is related to the nutrient level in the surrounding ocean. Phytoplankton in nutrient-poor waters can't make food, so when light falls on them, they reradiate that light as florescence. Phytoplankton in nutrient-rich waters fluoresce less and instead use the light energy to produce food. The ability of MODIS to measure this florescence means that we can measure these organisms physiology from space, which is an astounding capability.

Not only can high or low florescence measurements be used to identify areas of high or low productivity, but they also can be used to differentiate between classes of phytoplankton because different classes have different florescence profiles. Because each group of organisms uses carbon differently, being able to differentiate among these classes can further refine estimates of primary productivity. Abbott showed examples from organisms near the polar fronts, as well as the simultaneous identification of a bloom of the organism Trichodesmium and a related "Red Tide" in the Gulf Coast.

Abbott concluded by saying that MODIS data will be integrated with physical measurements to provide the long-term data sets necessary to understand Ocean Primary Productivity's role in the global carbon cycle, and so MODIS will be making a substantial contribution to US Carbon Cycle Science Plan.

Biophysical Parameters

Steve Running introduced the next group of land presentations (see Attachment 17 for the group's presentation), which focused on Land Biophysical Parameters. The first presenter in the group was Alfredo Huete, who talked about the Vegetation Index products. MODIS produces two indices at 16-day and monthly intervals: Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). The indices come in four resolutions: 250m, 500m, 1 km, 25 km. Using a combination of bands 1 and 2 maximizes chlorophyll sensitivity and minimizes water vapor and aerosol contamination.

In his introduction Huete indicated that processing, product development, and QA have become more sophisticated and have resulted in greatly improved products. He expressed his gratitude to the data system staff, and in particular Jacques Descloitres, for helping their product along. Huete showed several examples of the EVI from May, June and October and their corresponding QA products.

Evaluation of MODIS data from several field campaigns both in the US and abroad shows that agreement is quite good in many environments, especially those without aerosol. The overall dynamic range is good and has normal distribution. For example, EVI is a structural indicator, and therefore the team expected to see a canopy-dependent difference. That difference was observed.

Huete discussed how these indices could be used to investigate ESE research questions, such as the consequences of land use change for ecosystem and economic sustainability, and he showed examples of their application to regions in the Amazon. The two products complement each other: when the NDVI is saturated, the EVI picks up secondary growth and grassland that the other misses. QA analysis indicated that the products are within their tolerance for uncertainty.

One significant issue for the team is determining the relationship between MODIS and the AVHRR time-series. MODIS is far more sensitive, and is not as subject to water vapor contamination in humid sites. So MODIS signals are much higher than AVHRR in those regions. In semi-arid regions the problem is present during the growing season (which is more humid), but less conspicuous during the dry season. This will continue to be an issue for the team.

After Huete, Ranga Myneni discussed the Leaf Area Index (LAI) and the Fraction of Photosynthetically Active Radiation (FPAR). He began by showing images of LAI/FPAR for March, which included the location of SAFARI sites. The products were first released in August 2000, and they look quite good. Increasingly more complete coverage is available from the EDC DAAC.

An important consideration for the LAI product is the presence of cloud contamination. Currently when the main algorithm fails, a back up algorithm generates a LAI value using simple NDVI-LAI and NDVI-FPAR relationships. The main algorithm fails in the presence of cloud or atmospheric contamination, and originally they intended to use the cloud mask to suppress production of the LAI in those cases. However, they are not currently using the cloud mask because it so rigorously identifies cloud that too many pixels would be excluded. So when the main algorithm fails due to cloud contamination, the back up algorithm generates a value anyway. The resulting LAI value is low since NDVI of clouds is also very low. Similarly, if the cloud mask mistakes a cloudy pixel for a cloud-free pixel, the resulting LAI produced by the algorithm would be very low. Consequently both of these situations could result in non-biologically driven variations in LAI values. The team encourages users to investigate QC bits two and four: two tells whether the main or back up algorithm was used, and four tells whether clouds were detected or not.

Myneni discussed the team's involvement in the SAFARI 2000 Wet Season Field Campaign. It was a useful validation activity because of the wide range of vegetation types. Myneni discussed the team's sampling protocol, and showed a matrix of measurements taken during SAFARI.

MODIS appears to be doing well as compared to Ikonos and ETM at most, but not all, sites. At Harvard Forest, the results from MODIS and Ikonos differed substantially. This may be due to calibration errors on Ikonos. Myneni then discussed how scaling techniques based on the Law of Conservation of Energy were used to compare the results from various sensors and ground-based measurements. He concluded by saying that validation activities indicate that the algorithms are performing as expected.

Steve Running wrapped up the presentation by discussing the status of the Level 4, eight-day Photosynthesis product and the Annual Primary Productivity product. He prefaced his discussion by saying that he was sorry to have to report that he wouldn't have any results to show because numerous setbacks had hampered product development. Problems with the data production system meant that they got a late start, but in June they attempted to make their first global map. Unfortunately, a parameter was calculated for 0º latitude and longitude and applied to the entire globe. Their next attempt was a regional map of Montana, and their main concern was how to interface the 2° X 2° DAO meteorology with the MODIS Data set.

It turns out the concern was justified. They found two types of errors: a simple error in unit definition, and a more disturbing problem that became evident when a map of Amazonia showed no photosynthetic activity. It turned out that when the DAO had moved from a 1°x1° to 2°x2°, they missed some implicit scaling, and the result was that it appeared as though no rain fell in the region. The DAO was aware of the problem, but the fix didn't go in until November. So, the team is now waiting for MODAPS to reach that date, and then they will make their next attempt.

As far as validation for Gross/Net Primary Productivity, Running discussed how they swap out different data streams from DAO or tower measurements, and explained that they have been working on a weekly, real-time calculation of carbon balance that they have compared to several broadleaf sites. They are currently just waiting for the data stream.

Land Cover, Land Use Change

The final land discipline presentation, by John Townshend, summarized the Land Cover/Land Use Change Products (see Attachment 18). The Land Cover product suite is relevant to several of the ESE science questions, including the nature of global ecosystem change and its causes, the effect of regional pollution on the global climate, the consequences of land cover and land use change for ecosystem sustainability, and the modeling of the global carbon cycle.

Townshend first discussed the quarterly 1-km Land Cover product, which seeks to provide a simple land-cover categorization for climate and carbon cycle models. It uses the IGBP-DIS scheme and relies on spectral, spatial, temporal and directional information. The product relies on more inputs than previous versions, including nadir-corrected surface reflectance, VI, Snow cover, and LST.

The classification uses both supervised and non-parametric approaches. The non-parametric approach is based on neural networks, and draws from databases from all over the globe. The System for Terrestrial Ecosystem Parameterization (STEP) database assigns parameters to manual classifications from over 900 sites around the globe. Parameters include leaf type, phenology, elevation, moisture, cover fraction and perturbation.

The team is trying to improve on previous classifications, without being so totally different that time series comparisons can't be made. Townshend showed several global and regional examples, including the ability to pick out urban areas by using MODIS data and city light data. One way they are improving classification is through the inclusion of prior probabilities. Ancillary information is integrated according to Baye's rule, and can help pick out transition areas such as the change in land cover type from natural vegetation to agriculture, and vice versa.

Townshend then discussed his own work on Vegetation Continuous Fields (VCF) and Vegetative Cover Conversion (VCC). The VCF product seeks to overcome fixed boundaries between classification types, and thus to provide data on areas of vegetation transition. These products are independent of strict class definitions, and can be applied temporally to monitor changes in percent cover.

The approach used for the VCF product employs continuous training data taken from high-resolution datasets that are scaled to MODIS resolutions. Vegetation phenology metrics are created and used as independent variables in a regression tree, which has percent cover as a dependent variable. Among the metrics being used are maximum annual NDVI and mean surface temperature for the four warmest months. Townshend showed examples of 250m training data for tree cover, and how they were used to generate a percent tree cover map of the US for the summer of 2000. Compared to Landsat and AVHRR, MODIS maps are much richer. Validation will be conducted with high and very high-resolution data (from Ikonos) at locations in the US and Zambia.

The VCC product identifies areas of particular concern for land use change, many of which are anthropogenic. The product characterizes five types of Land cover: forest, non-forest, bare ground, water, and burn scar. Transitions between one type and another often signal anthropogenic changes such as deforestation or urbanization, but can also signal flooding or naturally occurring fires.

Five different change-detection algorithms, which are dependent on region- and month-specific LUTs, are integrated and the results are labeled. Refinements of the algorithm will replace at launch LUTs, which came from AVHRR data, with MODIS-derived LUTs. In addition, the algorithm is challenged by calibration and instrument changes because it depends on a time series.

Townshend showed an example of the product's ability to detect floods in Cambodia and burn scars in the western U.S. this past summer. A case study of fires along the Montana/Idaho border addressed the question of whether roadless areas tend to burn faster than areas with roads, the idea being that roads in wilderness acts as fire breaks. Using the VCC product, they were able to show that the presence or absence of roads had no impact on whether an area burned.

One area of concern is the day-to-day registration of the Level 2G data, which appears to be shifting. Another area of concern is the degradation of composited data such as the NDVI. The initial VCC results will be released in March 2001.

The last products that Townshend discussed were the fire and burned area products. He first summarized why it is important to study fire. There are scientific reasons having to do with the release of trace gasses and particulates, its role in carbon and nitrogen cycles, and its role in natural ecological change. In addition, there are practical reasons such as fire management.

Reporting on the status of the fire bands, Townshend indicated that before the switch to B-side in November, the bands were a bit disappointing as far as noisy and dead detectors, and mid-IR artifacts, which rarely, but occasionally produced false alarms. However, since the switch, performance in those bands has improved although artifacts are still sometimes significant in high contrast scenes. Calibration in these bands is still ongoing.

The active fire algorithm uses absolute and difference thresholds from Bands 2, 21, 22, and 31. It compares standard deviations of surrounding pixels, and uses the cloud mask and geolocation. Townshend summarized the six sets of fire products, three of which are released: the active fire detection product (L2 swath); the Level 3, 1-km gridded product; and the Level 3, 5-km, daily global browse.

He then showed some examples of fire detection on a global scale. He talked about how successfully MODIS was able to detect Australian fires in October, and how that data could be correlated with the aerosol products to give an interdisciplinary view. To make sure they are looking at the right time of day, they check TRMM data. Although Terra seems to miss many African fires due to the early overpass time, Aqua will be able to pick them up.

Despite problems with instrument, the team is reasonable happy with the algorithm's performance. Data are available from the EDC DAAC via ftp or the EOS Data Gateway.

Townshend then briefly discussed an experimental product called the burned-area product, which identifies pixels exhibiting consistent change over a certain number of days. The product uses the BRDF 16-day composite to predict what the spectral reflectance in a given area should be, and then compares that to what is actually observed.

Product QA has included numerous field campaigns, including SAFARI 2000 and sites in the western U.S., and comparisons with other sensors, including AVHRR, ASTER, MAS, Landsat-7, and Ikonos.

In summary, Townshend indicated that several fire products are being distributed, but most of the other Land Cover products depend on several months of consistent data, which is just on the verge of being available. Although validation plans are in place, validation activities may take months to years to fully complete.

Cloud Top Properties and Atmospheric Profiles

Paul Menzel began his presentation (see Attachment 19) by discussing calibration/validation activities for the L1B product. Data taken by the MAS flown on ER-2 during September was compared to MODIS data for all wavelengths. Results show that IR calibration is quite good in the windows. They are also comparing MODIS to GOES IR and water vapor. While the IR window is in excellent agreement with GOES, the water vapor shows a bias. They are unsure what the problem is at this point, but to bring MODIS in line with GOES, the MODIS spectral response would have to move by 5 wave numbers.

Menzel then summarized all the tests that go into the cloud mask detection algorithm, which makes use of 17 spectral bands, including some from the VIS and some from IR. The tests include first testing for snow, then VIS tests, then low clouds, and then high clouds. In addition they have added an inversion test based on brightness temperature differences seen when water vapor is present. He also pointed out that the 1.38-μm test is finding high, thin clouds not previously found in IR tests. This is important because of the need to delineate between actual SST differences and cloud cover contamination. While the test does not seem to change the total percent of clear sky detection over the globe, there are large differences in localized regions.

Menzel then provided a summary of changes to the cloud mask made in late September, and announced pending changes. Upcoming changes include an elevation check, adjusting Antarctic thresholds, and mitigation of striping problems.

MODIS sees more layers and structure of clouds than HIRS, and the 8.6, 11 and 12-μm channels are being used for an ice vs. water classification. As a check on classification success, it's import to determine how much of the time the algorithm is able to make a definitive decision. For much of the globe, in fact, we can tell with 100% certainty whether a cloud is ice or water. The algorithm is less successful at polar latitudes. As another check they have correlated phase with temperature, and found that there are more ice clouds during the night than the day, which is as expected. The tri spectral technique is a new capability of MODIS that is very exciting.

Menzel came back to the apparent wet bias of MODIS. As compared with GOES, MODIS has a bias of about 1.5 mm in derived precipitable water. The bias might be due to surface pressure, which comes from different inputs, or it may be a radiometric difference. The bias will be eliminated after further validation. Nevertheless, the 1-km resolution water vapor is fabulous, and can be successfully used to estimate total precipitable water.

Other interesting MODIS applications include ozone and polar winds. Menzel reported that MODIS ozone measurements are very near to GOES ozone, with the exception of the polar regions. This is simply due to lack of training data. Models in polar regions are badly in need of inputs such as polar winds, which MODIS can be used to track from cloud motion.

Product quality is about as expected, with MODIS IR radiances, cloud top pressures, phase determination, temperatures, and ozone correlating well with other sensors. The water vapor has an upward bias, but that will be corrected with more validation. Before concluding, Menzel expressed his excitement about the MODIS Direct Broadcast Receiving Station established at the University of Wisconsin-Madison's Cooperative Institute for Meteorological Satellite Studies. They have been capturing data since August, and have collected data from 500 Terra overpasses. They have automated processing to Level 1B, and they should be making available the most recent week of data via ftp by the end of January. The hope that their release of a Direct Broadcast Processing Package that includes the necessary NCSA HDF toolkit and supports multiple platforms will help the team achieve their goal of engaging international partners.

Bo-Cai Gao (see Attachment 20) gave the next presentation in the Cloud Properties slot. He focused his presentation on providing examples of preliminary results of the MODIS near-IR water vapor and thin cirrus products. Comparisons of RGB images to the water vapor product over Tibet and India show that these early results are good results. The product shows the water vapor boundaries that exist between the Himalayan Plateau and the remainder of the Indian continent. They have been successfully tracking changes in water vapor as the wind moves it around the continent.

Images over Spain indicated that water vapor retrievals are paralleling NDVI, which is expected, and that coastal margins have more water vapor than the interior of the continent. The same pattern is seen in images over South Africa, where coastal tips have high water vapor levels, and things begin to dry up toward the interior. Images from the U.S. show the dry arctic air down the center of the country.

The 20% bias in water vapor measurements seen by MODIS may be due to line parameters compiled on HITRAN96. Recent work indicated that the 0.94 μm band intensity may need to be adjusted by as much as 21.3%; however the line parameters aren't yet publicly available.

Moving on to cirrus detection, Gao showed examples of the 1.38 μm channel correction applied to data over South America, Canada, and several examples over the arctic. Quick-look images show that the detection of clouds that are barely visible in the arctic images is quite good. Gao indicated that current knowledge of climatology over the poles shows that AVHRR often differs greatly from surface observations. MODIS should be able to improve scientists understanding of cloud cover in those regions.

In summary, Gao concluded that preliminary results from both water vapor and cirrus detection are quite encouraging, especially the cirrus detection, which is excellent. Cross talk present in the 1.38 μm channel on Terra MODIS should be absent on Aqua. The water vapor and cirrus products should prove to be quite useful to the hydrology and meteorology research.

Open Plenary Session: Day 2

MODIS Sea Surface Temperature (SST)

Peter Minnett began his presentation (see Attachment 21) by rhetorically asking, why measure SST? Because a time-series of calibrated SST data is a critical indicator of climate change. The exchanges of heat, moisture, and gases between the ocean and atmosphere are to some extent driven by SST. Satellites offer the only way to obtain consistent basin-scale data with the required spatial and temporal and spectral resolution needed. MODIS makes SST measurements in conventional thermal bands as well as mid-infrared bands for the first time.

The Ocean Group has derived SST using state-of-the-art radiative transfer code based on the same used for ATSR, and that builds upon AVHRR pathfinder experience. Minnett showed plots of predicted brightness temperature, noting that Band 22 is independent of atmospheric variability. The goal for MODIS is to measure SST accurately to within 0.2K. This requires excellent instrument calibration and characterization. Also, his team needs validation data to verify MODIS measurements with radiometer data collected at the sea surface. Minnett noted that the skin temperature is different from temperatures at depths, and that the skin responds quickly to atmospheric changes. For validation, he uses SkinDeEP—an autonomous upper-ocean profiler that measures temperature at depths of up to 6 meters. He also makes surface-based measurements using the M-AERI instrument aboard ship that measures reflectance near the surface. He showed a map of his recent M-AERI cruise paths.

Comparing M-AERI measurements to AVHRR measurements, Minnett found that there is a diurnal effect on skin temp. This is to some extent also dependent upon wind speed. He uses four methods for measuring air-sea fluxes of heat, carbon dioxide, wind speeds and vectors, precipitable water, and precipitation. He said there is a relationship between precipitable water and surface humidity that helps us understand latent heat fluxes relatively accurately. The uncertainties in latent heat flux are quite large and need to be better understood.

Minnett noted that there are interesting synergies with Terra and Aqua that will help scientists better understand these air-sea fluxes. In conclusion, he said the MODIS mid-IR bands offer new accuracy for measuring SST. Instruments exist for validation of SST at this accuracy. These new levels of accuracy are needed for new research applications like studying air-sea fluxes. But this requires synergistic melding of data from multiple satellites and surface-based instruments.

Bob Evans then discussed examples of SST work. He reported that the MODIS sensor characteristics provided initial corrections for detector-to-detector discrepancies within wavebands, variations in mirror sides, spatial and spectral cross talk, and problems with polarization and sun glint. He showed a map of the eastern Mediterranean Sea, noting that there are typical circulation patterns for that region. The MODIS data revealed sub-structures of eddies that couldn't be discerned in the AVHRR data.

Evans found that when comparing MODIS data with SeaWiFS the former is more sensitive to the presence of absorbing aerosols. He showed an image where aerosol affects SST; in that same region he could also see changes in thermal and mid-wave IR data. He noted that mid-wave channels, for instance, better reveal the mid-latitude waves in the eastern Pacific.

Evans showed MODIS SST data with QuikScat wind data overlaid. On August 27, there was an anomalous wind event in the Gulf of Oman that pushed water toward the southeast and allowed colder water to upwell. The combination of colder water temperature and lower oxygen content stressed the fish in the area. Early on, the event enhanced the local fishermen's catch as fish moved to try to escape. But as of Sept. 2, the area of cold water spread, and there was a large fish kill. In short, Evans demonstrated that the fish kill was due to natural causes and not the release of ballast water from a U.S. ship.

In summary, Evans said the Ocean Group was able to quantify geophysical retrievals that surpass previous satellite sensor capabilities. With MODIS data we can see small-scale features never seen before. He found that eddy populations are more extensive than previously seen. The combination of overpass time with 12-bit data enhances the team's ability to do science.

Review of Material and Conclusions from MCST Workshop

Bruce Guenther said MCST must find time for weekly phone conferences with key members of the Science Team to address critical issues (see Attachment 22 for the presentation). Regarding operations and computer infrastructure, all onboard consumables look like they are able to work well within the mission lifetime. MCST is connected to the GDAAC with a T-3 line and so it can smoothly handle as much as 88

GB per day. Regarding the MODIS L1b data, he reported that code and Look-Up Table (LUT) histories are on the MCST web site—there are 6 code versions and 6 LUT updates. Guenther's team reviewed MODIS' Reflected Solar Band (RSB) and Thermal Emissive Band (TEB) algorithms and will post the results on their Web site.

Regarding the RSB, MCST demonstrated that Band 14 High could be recalibrated to an uncertainty of about 1 percent, in addition to the uncertainty on Band 14 Low. Further study is needed for response versus scan angle (RVS) for channel-to-channel image smoothness. The team may need to rethink the calibration strategy using instrument polarization characteristics. He announced that the electronic cross talk problem would be mitigated in the data collected after October 2000.

Guenther said the deep-space calibration maneuver is still needed for the TEB RVS adjustments. MCST can calibrate within 10° mK for measurements within the Onboard Calibrators' temperature range. They still need to review the blackbody emissivity calculations. Further study is needed for RVS, mirror side, and channel-to-channel image smoothness.

Guenther reported that the thermal cooler intermediate window temperature drift introduced a small gain drift in Band 27 that needs to be corrected at some point. There were mirror rotation-correlated noise variations found in the pre-launch calibration data sets as well as on-orbit data. This induces errors in the scene-smoothing coefficients. Guenther expects this problem to be present in the Aqua MODIS too. He said that MCST made improvements in MODIS optical leak problem.

Regarding SRCA, the SRCA shows that MODIS' spectral bands have not shifted although Band 8 shows some anomalous characteristics. Guenther noted that the spatial patterns in the data agree with those determined in earth-location studies. MCST found small ripples in the onboard Solar Diffuser, which is needed for the ocean bands. He said these ripples might be contributing in MODIS' channel-to-channel problems. There are modest ripples in the SDSM too.

MCST plans to respond to Science Team member comments: e.g., Band 2 saturation over high clouds and the SWIR sub-frame differences in Band 5. Band 26 has a residual thermal leak that may need added tuning with Band 25. There has been significant improvement in the PC cross talk problem, but it may need more tuning in Band 36.

Guenther said the mirror rotation-correlated noise is an issue. The Analog-to-Digital Converter (ADC) is now as good as it gets on Terra. Residual cross talk is still present, and surface smoothing studies are needed. Confirmation of stability within an orbit needs more attention, and there is some temperature instability. There is general agreement in the degradation from SRCA and lunar observation data.

Guenther reported that there would still be ADC effects and mirror rotation-correlated noise on the Aqua MODIS. However, MCST and SBRS will remove all cross talk effects (optical and electronic).

MODIS Geolocation Status

Robert Wolfe reported that they have met the geolocation accuracy specification of 150 m (1 sigma) and are making progress toward the accuracy goal of 50 m (1 sigma). (see Attachment 23 The Land Group's 250-m resolution products drive the goal. SDST reduced MODIS' geolocation error in March from 1.7 km to 500 m RMS, and then further reduced the error to within 100 m RMS in June 2000. Further correction is expected in February 2001. Wolfe presented the bias numbers for roll, pitch, and yaw, as well as mirror scan angles. He showed a chart of scan control point residuals versus time.

SDST's next steps include examining a possible confusion between time and pitch biases. Longer-term analysis of trends and cyclical variations is also needed. SDST will examine MODIS' performance during periods near orbit and attitude maneuvers and other events to determine when the instrument is outside accuracy specs/goals. They will look for dependence on temperature, time on orbit, etc. They will also evaluate terrain model, correction algorithm, and examine cross-instrument issues (comparing results with the MISR and ASTER teams). Wolfe expects MODIS to reach its goal by the end of February 2001

Regarding Terra Aqua software plans, there will be a new Terra code delivery in March. Aqua code will soon be delivered to the DAAC. SDST will use the same error analysis approach for Aqua.

Ocean Validation Update

Bob Evans reviewed the iterative steps used by the Ocean Group in the on-orbit characterization and initialization of MODIS (see Attachment 24). They began by removing the RVS problem. Then they removed the polarization effects and adjusted detector gains by evaluating $L_{typical}$. Next, the Ocean Group removed the sun glint problem. They tweaked the filter for aerosol radiance at 750 nm and 865 nm wavelengths prior to making their epsilon calculations. Then, they evaluated the resulting saturation water-leaving radiance L_w fields propagated to the sea surface. Evans showed plots of noise in the Analog-to-Digital Converter. Regarding sun glint correction, several approaches were investigated. The Ocean Group can now derive water-leaving radiance near the point of detector saturation at the maximum of the glint field.

Regarding polarization, the MODIS sensor has a rotating mirror so that the angle of incidence on the mirror changes substantially from West to East across each scan line. The Ocean Group developed a polarization correction per band with consistency across spectral bands. They then applied a filter to decouple noise from model selection. They can now see an unprecedented level of detail of sediment in water, so they expect MODIS will advance the frontier in space-based oceanography.

Evans said the Group is using the western half of a given swath mainly for their validated data products. He noted there is a mirror side striping and banding issue that requires correction in data processing. The Group now plans to produce new water-leaving radiance and chlorophyll fields separately for mirror sides 1 and 2. They can then get insights into the total RVS and polarization effects within MODIS data.

Evans flagged the following as outstanding issues: The Group needs to make sure its data quality flags are producing good quality data. They must take advantage of *in situ* data to make sure they understand where errors are in the data. They plan to continue tests of time-dependent variable correction tables. They will test to ensure their methods to determine correction coefficients provide absolute calibration of spectral radiances. They will develop a correction model for time-dependence of corrections (RVS, mirror side, detectors, etc.).

Evans noted that the imagery he showed in his presentation is producible now. Those data were produced in Miami, but all the corrections have not yet been implemented to the point where that quality of data is coming out of MODAPS. When they start B-side processing, most tweaks will be in the processing software. They now have a better understanding of MODIS' error sources and how to best minimize them. Also, they are averaging space view black body data to reduce noise.

The Ocean Group will use MOBY/MOCE & SeaWiFS data for validation of MODIS optical data, and they will use drifting buoys and M-AERI for validation of thermal data. For Aqua, the Group can use Terra data to help in validation.

Atmosphere Group Validation Effort

Steve Platnick reported that the Atmosphere Group's validation efforts include their cloud mask, cloudy skies, and clear skies data products (see Attachment 25). The scale of their validation plan ranges from molecules to ice particles, vertical and horizontal distributions, so no single approach is suitable for all products. The Group's approach is to compare MODIS data with existing satellites and algorithms, or other MODIS products. Also, they are using data from fixed sites (e.g., AERONET) as well as field campaigns (e.g., PRIDE and SAFARI 2000).

In PRIDE, the Group deployed an array of ground-based, ship-based, and airborne sun photometers in order to increase its opportunity to validate measurements of aerosol retrievals. Platnick noted that AERONET retrievals agreed well with MODIS measurements. In SAFARI, the Group integrated remote sensing data, computer models, airborne sampling, and ground-based measurements to study biological, physical, and chemical components of the regional ecosystems of Southern Africa. They used the University of Washington's CV-580 aircraft to carry a suite of sensors.

Platnick showed MAS data of a fire, in both RGB and mid-IR channels. He also showed samples of other MODIS products, including cloud mask, aerosol optical depth, cloud particle radius and phase, and cloud top temperature.

Chris Moeller reported on his activities focused on radiometric comparisons (see Attachment 26). He listed the Group's multiple Level 1b data validation sources of data. He participated in various field campaigns, including WISC-T2000, SAFARI 2000, and CLAP-T2000. He showed MAS versus MODIS scatter plots and found very good agreements for bands 20, 31, 32, and 35. He showed comparison charts of different versions of code, noting that the current Version 2.5.4 is significantly better than Version 2.3.2. In summary, the Group is doing small corrections for atmospheric window bands with high confidence, and is validating their data to within 0.5°C. Atmospheric correction is still challenging for upper tropospheric ozone and carbon dioxide bands. The 11- and 12-µm band residual is less than 0.5°C. He feels they can further decrease the residuals as the L1b algorithm matures. So the results he presented must be considered "snapshots" of MODIS' performance.

MODLAND Validation Summary

Dorothy Hall said the science community requires a global daily product of snow and ice cover to build data sets of climate quality (see Attachment 27). The Data Assimilation Office and the modeling community are ready to use MODIS' test data set for the month of November. She showed an 8-day composite snow map on the climate-modeling grid for November 2000. Hall believes the metrics will show significant improvement in the models' output; e.g., surface fluxes, air temperature, and precipitation. General Circulation Model (GCM) modelers are increasingly requiring fractional snow cover, which she said MODIS can provide but is still a work in progress. The bottom line is the community really needs global snow cover and sea ice products, but we currently only have regional products at 500-m resolution, so we need to get out the global product.

Jeff Morisette gave the URL for the Land Group's validation Web site. He showed a map of their validation core sites. He said these data are registered for access via the ORNL Mercury System. Also, there is a MELite interface for working with these data at remote locations in the field.

Regarding current results, Morisette said there are field data being collected at a number of sites. The strategy includes collecting several layers of remote sensing data ranging from MODIS down to Ikonos resolution, and then complementing these with field data. The Group is finding good agreement between surface-based land surface temperature measurements and MODIS'. Regarding snow and sea ice cover, the Group is again finding good agreement. He showed the validation measurement strategy for BRDF/Albedo, which involves using Dr. Honda's (from Japan) remote-controlled helicopter. Alfredo Huete is using light aircraft to help validate his LAI and NDVI measurements.

Daily photosynthesis and annual NPP data are being collected from Steve Running's fluxnet towers. The Bigfoot Campaign is using Landsat 7 ETM+ data and models, and then scaling up to MODIS' resolution. Also, the Group is collaborating with the USDA's Forest Service (Wei Min Hao).

Morisette listed concerns from the Land Group's Validation workshop: first among them was the availability of stable MODIS products. There is an urgent need to reprocess MODIS data over validation sites. Also, the availability of coincident Terra data (MODIS, MISR, and ASTER) is a concern. The Group is taking various approaches to the scaling issue, although there is no convergence yet. There is still the need for an effective interpretation of the QA/cloud mask for understanding Land products. The Group said it needs faster response time in getting data products out in support of field campaigns. He stated the EOS Data Gateway (EDG) lacks the level of support needed by scientists, including subscriptions, etc. There are reprocessing issues for validating data products to be used operationally. The Group needs to reprocess now, but the earliest opportunity appears to be around April 2001. In their reprocessing, the Land Group will request the "best" L1b data from the GDAAC. Reprocessing targets include four Bigfoot sites, LAI campaigns in Finland and Canada, SAFARI 2000 wet and dry seasons, etc.

Morisette noted there is no definition for what it means for a product to be "validated"; he feels the driver should be the utility of products to address science and applications questions.

EOS Direct Broadcast Report

Dodge reported that there is now complete coverage of the United States in real time with five operational direct broadcast receiving stations (see Attachment 28). The cost to build a MODIS DB station is currently around $300,000. He showed sample MODIS imagery made from DB data, and gave the URL for the Web page devoted to this topic. A full swath of MODIS DB data is about 1 GB in size. The U.S. receiving stations keep full swaths available online for up to one month after acquisition. Each DB site is equipped with the software to acquire and decode raw data for a full swath as well as calibrate and navigate the data and generate selected data products. The network of receiving stations is providing reasonable amounts of raw data to requesting scientists and other users.

Dodge noted that most of the sensors on Aqua would have direct broadcast capabilities. The AIRS sensor on Aqua will provide weather forecasting capability. Also, AMSR-E gives measurements of temperature, ocean wind speed, water vapor over ocean, cloud liquid water content, SST, surface soil moisture, global rainfall, and global rain type (convection fraction).

Justice advocated establishing standardized shareware for certain land products. He is in process of developing that kind of shareware and is interested in participating in further discussion on that topic.

ESE Science Implementation Plan

How is Earth's climate changing and what are consequences for life on Earth? Diane Wickland said answering that question is the overarching Earth Science Enterprise (ESE) objective. The criteria for determining priority are (in order): Science return, benefit to society, mandated program, appropriate for NASA, partnership opportunities, technological readiness, program balance, and cost/budget context. Wickland listed priorities on research and field campaigns.

NOAA MODIS Bent Pipe Status Report

Why use MODIS imagery in NOAA? Bruce Ramsay reported that it was decided years ago to leverage MODIS data for operational and evaluation use in NOAA (see Attachment 29 for presentation). NOAA will also use MODIS data to help reduce the risk in the transition from POES AVHRR to the NPOESS VIIRS era.

Ramsay said NOAA has the capacity to produce MODIS data products. In particular, they are focused on MODIS' cloud products, atmospheric profiles and stability data, snow/ice maps, fires and other hazards, and coastal environmental monitoring. Also, NOAA is using MODIS data for experimental use in its computer networks and communications systems for testing data streams. There is a NOAA-NESDIS server at NASA GSFC Building 32. With this system NOAA is processing a subset of MODIS data within a 3-hour window. In the summer of 2001, they expect to be able to distribute MODIS subsets of products to the NOAA community. NOAA has now laid the groundwork for processing and distributing data in this experimental mode for use in NOAA operational endeavors.

ADEOS II/GLI Update

Teruyuki Nakajima reported that the Global Land Imager (GLI) L2 algorithms were shipped to the EOC in Oct 2000 (see Attachment 30). The validation system for that mission is currently under development. He reported there was a large budget cut in FY2000. He listed the specs for GLI.

Takashi Nakajima said his team has been working on reformatting MODIS data into GLI format (see Attachment 31). He is working with MODIS data to produce data products, like water clouds. Also, his team did rapid MODIS data analysis for campaign support with products like aerosol and cloud properties. He noted that data visualizations were made within 18 hours after acquisition. In summary, NASDA has developed a command and control script for converting MODIS L1b data to GLI format. They also developed a GLI signal simulator.

MODIS Aqua Processing Readiness & Terra Reprocessing

Mike Moore showed a high-level science data flow diagram for Aqua (see Attachment 32). He reported that ESDIS completed its first Aqua end-to-end test. They were able to get Level 0 data from EDOS into the GDAAC and then produce Level 1a data. Level 1b and Level 2 processing was done at MODAPS. Additionally, they successfully produced orbit and attitude data. Moore said all ECS Aqua elements are in place at the DAACs, except for some new items (which he listed).

Moore also listed potential impacts for DAAC activities in support of Aqua. These include the archive migration in late February, a new firewall installation (there will be no impact on Terra) and the forthcoming release of the 5B.07 software.

Esaias asked if Aqua does not launch until November 2001, does that affect the resources that ESDIS will devote to Aqua testing between now and then? Moore responded that ESDIS would continue with its planned testing schedule and then add or subtract tests as needed between now and then. He feels we can't do enough tests, as Terra experience shows. Esaias said the MODIS Team was considering using some of the Aqua system to help expedite reprocessing of Terra data. Moore said there is some room for exploiting that extra computing capacity before Aqua launches. He said ESDIS is open to discussing that idea further.

Moore listed the calendar year 2001 driving capacity requirements for Terra Level 1 production is 2x and Aqua is 1x. He showed a flow cartoon of 2001 throughput capacity requirements for DAACs. For MODIS data archive capacity, they will have a half petabyte of data by the end of 2001. Moore noted that the archive compression factor for Terra data is currently 1.5 to 1. Level 0 data are retained indefinitely. Level 1a data are deleted 6 months after being processed to Level 1b, and Level 1b data are deleted 6 months after they are reprocessed. Level 2 data are deleted after being reprocessed to Level 3. In short, Levels 0, L1B, and L3 are stored forever in the archive.

Aqua Launch Readiness Report

Claire Parkinson began her presentation (see Attachment 33) by showing a photo of Aqua at the TRW facility clean room. Electrical integration of the instruments onto the spacecraft was completed in mid-2000. The first comprehensive performance test was completed on August 23. The solar array was put on the spacecraft for testing in October. The Aqua launch date is currently July 12, 2001, but the mission will probably launch much later in the year. Parkinson listed the major steps remaining to final launch readiness. The full system CPT test still remains, as does the thermal vacuum test. They will also need to reinstall the solar array prior to shipment to Vandenberg Air Force Base.

In recent activities the CERES and MODIS teams have been receiving and analyzing data, and conducting field campaigns. The other teams updated their ATBDs in November and December. At-launch algorithms have been delivered, but validation plans are being adjusted due to the slip in launch. The AIRS team is working with U.S.

and European weather prediction agencies for incorporating those data into their models. A pre-launch aircraft campaign for validation of the AMSR-E sea ice algorithm took place in June-July 2000 out of Thule, Greenland.

The Aqua Project is now exploring constellation flying of NASA's afternoon satellites; i.e., Aqua, PICASSO-CENA, CloudSat, PARASOL, and Aura. Parkinson announced that the *EOS Data Products Handbook, Vol. 2,* is out now in hardcopy. She reported that George Morrow, project manager, is leaving the Aqua Project and Phil Sabelhaus will succeed him. Esaias asked how Aqua's flight track lines up with Terra's each day. He said there might be some benefits for looking at track relationships for MODIS science.

Introduction to VIIRS

Bob Murphy presented an overview of the planned specs for the Visible Infrared Imaging Radiometer Suite (VIIRS) (see Attachment 34). Raytheon SBRS was selected by NASA to build VIIRS. It will be a single sensor covering the spectral region from 0.4 to 12 µm. It will have 22 spectral bands, including one broadband "day-night" band. VIIRS will have a rotating telescope design, an onboard solar diffuser, and an SDSM.

There will either be 16 or 32 detectors onboard, with 12-bit quantization, and some bands will have dual gains (like SeaWiFS). VIIRS' resolution at nadir will range from 742 m to 371 m. Its first flight will be on NPP in 2005, at an altitude of 805 km and with an equatorial crossing time of 10:30 a.m. All subsequent NPOESS missions will carry a copy of VIIRS, starting in 2008. In summary, Murphy said VIIRS is an exciting instrument for Earth system science. In its design, NASA incorporated many lessons that were learned from MODIS. The sensor will be similar to MODIS, but there are some differences too (i.e., no fluorescence bands).

Adjourn

Salomonson told the Team that his next milestone is a presentation on MODIS at the EOS-IWG Meeting. He said he got a good feeling from this meeting. His intent is to paint a positive picture revolving around the idea that the sensor is working well and that its characteristics that needed improvement were corralled and are stabilizing. The MODIS Team will have most products out in steady production fashion soon for folks to look at. There are complete data months, like December 2000. He now would like the Team to work toward producing a consistent data year. Because of the limitations of the data processing system, the Team may have to choose some products to really focus on for that year. Plans will be developed to have a symposium of conference toward the end of 2001 or the beginning of 2002, at which results of MODIS investigations will be presented and published. Details are still to be decided.