MODIS DATA STUDY
TEAM PRESENTATION

August 18, 1989

AGENDA

1. Role of MODIS Core Data Product Requirements
2. Hypothetical Template for the Qualitative Assessment of Algorithm Status
3. Notes from 9 August Meeting with Dr. King
4. Notes from 9 August Meeting with Dr. Justice
5. Notes from 15 August Meeting with Dr. Esaias
6. AVHRR-Based Multichannel Sea Surface Temperature Estimation
7. MODIS Data Rates Under Various Assumptions of Channel Selections

Role of the MODIS Core Data Product Requirements

1. Identify the candidate core MODIS data products for the terrestrial, meteorological, and oceanographic disciplines.

2. Identify the algorithm to be employed in the generation of each core product.

3. Perform an in-depth analysis of the algorithm to quantify its role and impact on the MODIS science requirements.

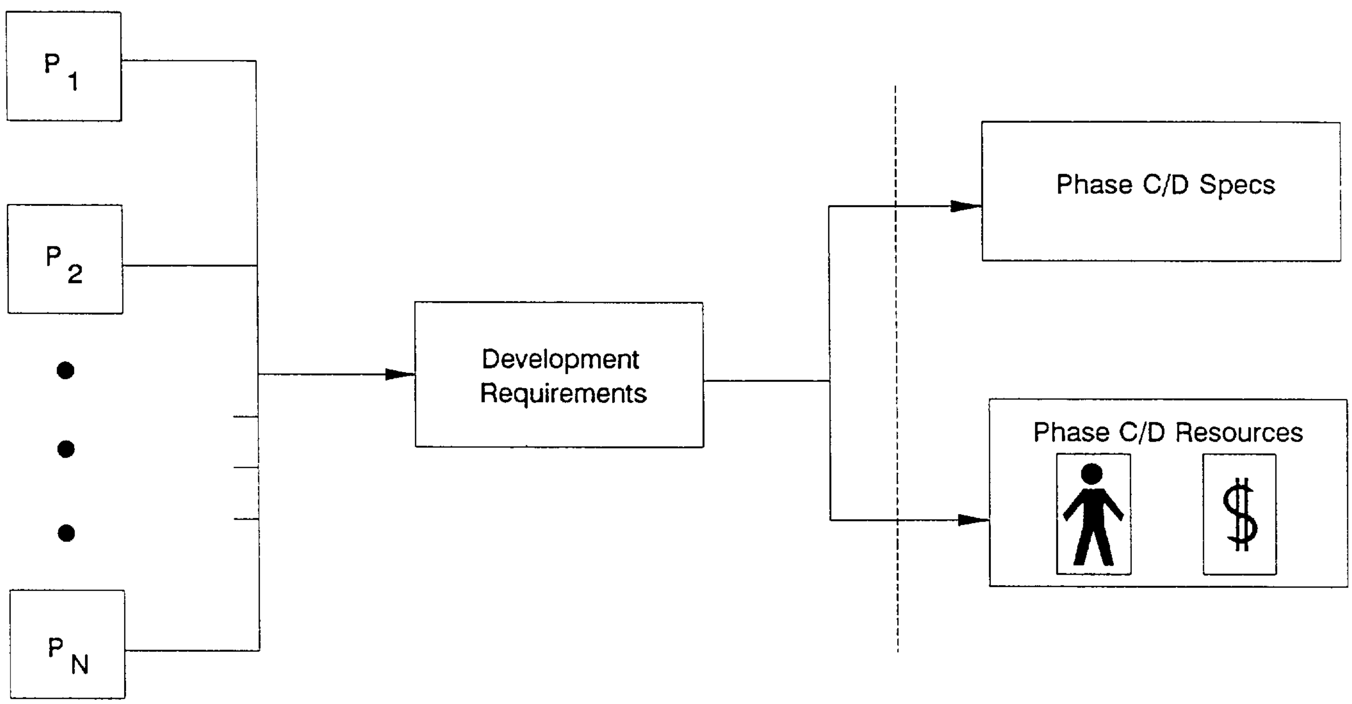
4. Identify the requirements implicit in the generation of each of the core products:

   - input MODIS data
   - input non-MODIS data
   - preprocessing (e.g., atmospheric corrections, cloud identification)
   - developmental status and resources required
   - lines of code (LOC)
   - RAM storage
   - magnetic/optical storage
   - data volume
   - processing frequency
   - processing capacity (MIPS/MFLOPS)

5. Sum the requirements over all the core products to obtain an integrated MODIS core product developmental and processing requirement. This will be performed on a spreadsheet to facilitate periodic revisions as new products are added, algorithms are revised, and more detailed information becomes available.

6. The algorithms may be dissected in terms of their fundamental instructions (number of trig functions, additions, multiplications, divisions, exponentials, IF statements, etc) and other properties (e.g., vector length, domain, spatial resolution) to facilitate the evaluation of candidate architectures and processing scenarios.

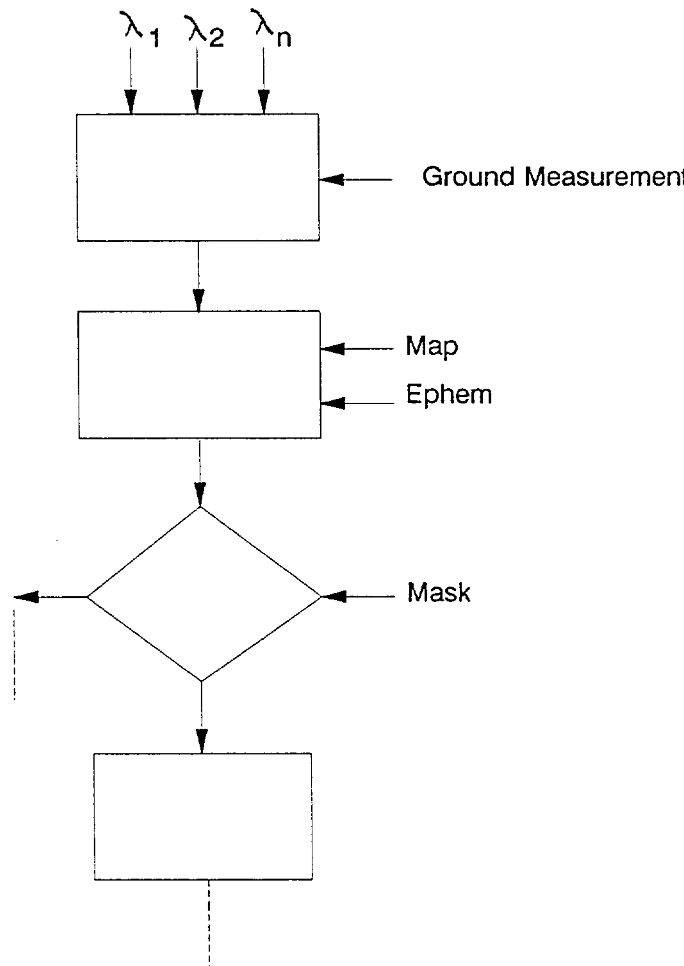
7. With the more complete knowledge of the entire chain of the core product algorithms, including the so-called "utility algorithms (such as cloud identification, atmospheric correction, calibration, Earth location, quality control, etc.), the products and their algorithms can be related in a definitive manner in terms of a processing tree (as was previously done for the core data products in a qualitative manner).



MODIS CORE Data Product Requirements

Sta	LOC	HI
C	–	A
O	200	A
C	–	H
D	–	M

XYZ Alogrithm (P_2)



Alogrithm Status

O – Operational

D – Development

C – Conceptual

LOC

Lines of Code

Current Human Intervention

A – Autonomous

H – Some Human

M – All Manual

Data			
Vol.	Memory	Storage	Speed
MB	MB	GB	MIPS/FLOPS

Qualitative Assessment of Algorithm Status

NOTES FROM 9 AUGUST 1989 MEETING WITH DR. MICHAEL KING

On the afternoon of August 9, several members of the MODIS Data Team visited Dr. Michael King to obtain preliminary information on MODIS atmospheric products and, working with Mike as an intermediary, to begin communications with other Science Team Members who will produce atmospheric products. The goal of the communications process is to obtain information on atmospheric products that is needed to adequately and accurately specify requirements for MODIS data processing. This is a report on the meeting with Dr. King.

1. Generally, it appears that representative computer code for producing many MODIS atmospheric products does exist. Although most of the code has not been optimized for quick execution, Mike believes that future enhancements and additions to the code might more or less directly offset time savings from optimization, so that the overall processing requirement may stay about constant.

2. For his own products, Mike is able to supply all three types of information that the data team is attempting to examine. The types of information desired include literature references and technical discussions, listings of actual computer code that can be examined by team members to determine input data requirements and establish estimates of execution times and code complexity, and results from direct timing runs of the subject code to directly measure required resources (referenced to the data system on which the code is executing). The products that Mike will supply include cloud optical thickness, cloud droplet effective radius and thermodynamic phase, aerosol optical depth, and aerosol size distributions.

Since Mike is able to provide redundant information to the data team, (i.e. literature references, actual code, and measured execution times) his products can serve as a standard for the validation of resource estimates on those products for which only incomplete information is available (suppose, for example, that technical descriptions are available for a specific product, but no code is available for data team examination and no actual measurement of code execution time has been made). Redundant information will also be useful in establishing error limits for the overall resource estimates made by the data team.

3. Mike believes that a substantial amount of representative code for atmospheric products exists among the Science Team Members and Mike will serve, as time permits, as an intermediary for data team access to the required information. However, Mike has responsibilities with several other programs and it appears that he may need to limit the time he devotes to data team support.

NOTES FROM 9 AUGUST 1989 MEETING WITH DR. CHRIS JUSTICE

As a part of the effort to obtain additional information on MODIS Core Data Products, the algorithms that will produce them, and the hardware capabilities needed to support their routine production, several members of the MODIS Data Team interviewed Dr. Chris Justice to obtain information on land-based Core Products. Since the topics involved are complex and support from several land-science team members is needed, it is envisioned that a number of meetings with Dr. Justice will be required to obtain the needed information. This is a report on the first meeting, held on the morning of August 9.

1. Generally, representative computer code for MODIS land products does not exist; even at the time of platform launch, it is expected that perhaps only one-fourth of the products and product features that will ultimately be implemented will be available. This statement is to be construed to mean that the hardware support required at launch will be perhaps only one-fourth of that ultimately required. For the first several years following launch, support requirements are expected to grow by 40 or 50 percent each year. Many of the land products are experimental and can be fully developed only after appropriate observation data is available.

2. When suitable atmospheric correction algorithms are developed by other Science Team Members (perhaps from the atmospheric group), members of the land team would be generally quite content to begin their processing assuming that land-leaving radiances are known, and further correction for atmospheric effects is not required as a part of land data processing. Dr. Kaufman and perhaps Dr. Tanre do have an interest in atmospheric corrections.

3. Land data will require topographic correction for earth features that is not required for atmospheric or ocean data. Two types of correction may be involved. One type of required correction accounts for the effect of terrain elevation on apparent pixel location. A second type of correction would account for the effect of local terrain slope on space-based observations.

4. Computer code that generates Normalized Difference Vegatative Index (NDVI) and Soil Adjusted Vegetative Index (SAVI) does exist and can be provided to the MODIS Data Team. Dr. Wan does have at least a preliminary algorithm to determine land surface temperature; as proposed, however, he would produce only a regional product valid for specified regions of the earth. He needs support for his work and may not be able to supply the desired code for MODIS Data Team use. Dr. Justice will investigate further. As a subset of the land surface temperature effort, Dr. Kaufman is interested in detecting fires and determining their temperature and size. He may be able to provide us with basic information on the scheme to be used.

5. Dr. Dorothy Hall and Dr. Vince Salomonson will be responsible for the snowcover product. As a local Goddard employee, Dr. Hall is easy to contact and would perhaps be the best person to contact for initial product information. Drs. Kaufman and Huete will produce the surface spectral albedo product and may be able to come up with some information to support data team efforts. Dr. Justice will follow up on this topic. The investigators who will be responsible for the MODIS surface water cover product have not yet been determined.

6. With two exceptions, Dr. Justice will initiate all contacts with Science Team Members required to obtain needed information. The exceptions are Drs. Hall and Salomonson, who are Goddard employees and will be contacted directly for needed information by representatives of the MODIS Data Team. Dr. Justice himself can supply the algorithms for NDVI and SAVI.

Notes from 15 August 1989 meeting with Dr. Wayne Esaias

On the morning of August 15, several members of the MODIS Data Team visited Dr. Wayne Esaias to obtain preliminary information on MODIS oceanographic products and, working with Wayne as an intermediary, to begin communications with other Science Team Members who will produce oceanographic products. The goal of the communications process is to obtain information on oceanographic products that is needed to adequately and accurately specify requirements for MODIS data processing. The specific purpose of the meeting was to get information concerning algorithms used in the Ocean Core Data Products and the Ocean R & D Products. These product lists were developed at the July 5-7, 1989 MODIS Science Team Meeting. This is a report on the meeting with Dr. Esaias.

1. At present, we have identified fourteen Ocean Core Data Products and at least 10 Ocean R & D Products. Our discussion centered around five of the core data products. No Ocean R & D Products were discussed. Further meetings are planned, but no dates were set.

2. The Ocean Core Data Product algorithms discussed were:

- Sea Surface Temperature
- Water Leaving Radiance
- Chlorophyll Fluorescence
- Chlorophyll-A Pigment Concentration
- Detached Coccoliths Concentrations

3. In addition, the atmospheric correction procedures were discussed in depth. The number of channels requiring atmospheric corrections to determine the water-leaving radiances as standard products are a function of whether there is a SeaWIFS experiment. Experience with SeaWIFS will help develop algorithms which will be available at launch for MODIS. Based on Coastal Zone Color Scanner experience, six MODIS-N (reflected bands) and six MODIS-T channels can be used to generate higher-level products at launch. These are essential (visible) channels which are used in higher-level product generation. The number of channels which require atmospheric correction clearly depends on the number of channels on MODIS. Dr. Esaias estimated, if MODIS-T has 64 channels, on the order of 30 bands will require correction for the generation of standard water-leaving radiance Level-2 products. Dr. Esaias also estimated, if MODIS-T has 32 channels, 20 bands will require corrections.

If SeaWIFS flies, the aerosol correction will be a multiple scattering, absorption model. If SeaWIFS does not fly, the aerosol corrections will be multiple scattering, with no absorption. Each pixel will require an aerosol correction. Other atmospheric correction parameters are:

- Foam: the correction is a function of wavelength and solar/viewing geometry.

- Rayleigh scattering: due to gas molecules in the atmosphere; the correction is a function of the surface atmospheric pressure, wavelength, and viewing geometry.

- Ozone: the results of the six major ozone products differ significantly. Therefore, it is unclear what the optimal data source for MODIS product corrections will be. TOMS ozone data has been used for the ozone correction for the last 1.5 years.

- Sun glint/Fresnel reflection: the correction is a function of the wavelength, solar/viewing geometry, and near-surface winds (vector winds are preferred; a correction can be generated using wind speed alone).

- Water vapor: the correction is important in the thermal infrared, and may be useful in the reflected bands as well.

For the case of these corrections, once basic information is obtained (wavelength, geometry, surface windspeed, surface pressure, ozone optical depth, solar constant, aerosol optical depth, etc.), the corrections may be most efficiently implemented as table look-ups. Furthermore, with the exception of the aerosol correction, the other atmospheric corrections may be made at a reduced resolution and interpolated to each pixel.

4. There are competing aerosol models. Drs. Gordon and Brown have algorithms already in use for the CZCS processing. Drs. D. Tanre and K. Kaufman have aerosol models which are implemented over land. The present CZCS aerosol correction is implemented by measuring MODIS outputs at 653nm, 750nm, and 865nm. Using the Angstrom coefficients, a log-linear relationship between aerosol optical depth and wavelength is then fitted to these three values and extrapolated down to the blue wavelengths. Of sourse, extrapolation is always dangerous. Under conditions of excessive scattering, a two-wavelength model may be applied (dropping the shortest wavelength).

5. Sea surface temperatures will be computed using three channels (350 nm, 1050 nm, and 1150 nm) with existing algorithms. These algorithms are presently implemented in the University of Miami ESP package. (This program consisting of about 6,000,000 lines of code runs under an active data base management system. The ESP package is currently installed and running at the Goddard Space Flight Center.)

6. The algorithm for chlorophyll fluorescence is relatively straightforward (Gower and Borsted, Oceanography from Space, p329). MODIS outputs at 650nm and 750nm are interpolated to

681nm. Then, the interpolated value is compared to the measured radiance at 681 nm to determine the fluorescent line height value (peak at 681nm). This product does require an atmospheric correction for each channel; i.e., a water leaving radiance computation for that pixel. Chlorophyll fluorescence measurements depend critically on the signal to noise ratio. A 1000:1 S/N ratio implies that chlorophyll fluorescent values may be measured in a 1 kilometer by 1 kilometer area globally. In many regions, low plankton concentrations may require the area be increased to 10 kilometers by 10 kilometers to detect those concentrations if a 750:1 S/N ratio is retained in the key channels.

7. Chlorophyll-A pigment concentrations is another algorithm which will be improved if SeaWIFS flies. Presently the chlorophyll-A algorithm is simple. The algorithm measures the MODIS outputs at 443nm, 520nm, and 550nm. Then it computes the ratios 443/550 and 520/550 using the measured values. An expression of the form $a(\text{channel } n/\text{channel } m)^b$. Low chlorophyll concentrations are determined using the 443/550 ratio while high chlorophyll concentrations are determined from the 520/550 ratio. The basic reference for this work is by Drs. Gordon and Brown.

8. The detached coccolith algorithm is a correction for excess scattering. A coccolithophora is a small animal (about 6 microns in diameter) which grows small circular plates of calcium carbonate to protect itself from predators. As it lives, it sheds these plates into the water. These small, white circular plates (about 2 microns in diameter) scatter the light. If the computed water-leaving radiance value is high, the excess is due to coccolith scattering. The primary reference for this algorithm is authored by P. Holligan, M. Viollier, D. Harbour, P. Camus, and M. Champagne-Philippe in Nature (1983).

AVHRR-BASED MULTICHANNEL SEA SURFACE TEMPERATURE ESTIMATION

1. Domain

Processing is performed for global oceans.

No attempt is made to process SST's in regions of direct specular reflection (glitter), as cloud identification in the reflected bands is difficult.

2. Cloud Screening

First, thresholds are applied which relate the expected reflectance of the cloud-free ocean as a function of satellite and solar zenith angles and relative azimuth angle to the observed reflectance.

Second, uniformity tests are applied which examine the variability of the signal from adjacent cloud-free fields of view. The threshold is set slightly in excess of the instrument noise. This test is particularly useful at night, when the visible channels cannot be employed.

Finally, a channel intercomparison test is applied. This is particularly useful for detecting low-level stratus at night. SST's are formed from the relationship SST = A + B (Ti - Tj) + Ti. The ratio to two of these expressions (T3.7 - T11)/(T11 - T12) is invariant to changes in atmospheric conditions, but not under cloudy conditions.

3. Correcting for Atmospheric Attenuation

The atmospheric attenuation due to water vapor is removed by applying expressions of the form Ts = Ti + C1 (Ti - Tj) + C2. For large satellite zenith angles (greater than 40°, an extra term of the form (sec Z -1) is required for all expressions except for the split-window daytime equation. A residual systematic bias is removed through regressions between matched buoy and satellite data.

4. Operational Preprocessing Procedures

GAC data[1] are organized into targets with a nominal spacing of 25 km. The target consists of five 11X11 arrays, one for each of five spectral channels. Failure of any quality flag or check results in the rejection of the target. Land data is rejected at this

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[1]Global Area Coverage (GAC) data are created on board by combining four of every five samples along a scan line to create one average value, and then processing every third scan line. This processing yields data with a nominal spatial resolution of about 4 km at nadir.

time. The SST algorithm is then selected. The daytime algorithm is used for solar zenith angles less than 75°, and the nighttime algorithm for angles greater than 90°. Between 75° and 90°, the nighttime algorithm is used if the near-IR reflectance channel indicates a reflectance of less than 1%; otherwise the target is rejected.

5. Nighttime Algorithm

a. The satellite zenith angle must be less than 45°.

b. At least 30 of the 121 11-micron target elements must have brightness temperatures greater than -5°C.

c. Any targets with elements within 50 km of land are rejected.

d. The warmest element of the 11 micron array is identified. The element is used to produce four 2x2, 3x3, or 4x4 element subarrays depending on the noise characteristics of the data. The following four steps are applied to each of the subarrays until one passes all the tests:

e. All elements must agree within 0.2°K at 11 microns.

f. A sub-array average for each channel is calculated for the cloud tests.

g. Thermal IR cloud tests are performed by checking the consistency between the different temperatures as follows:

$T^*3.7 = a + b\ T11$

$|T^*3.7 - T3.7| < 3°K$?

$T^*11 = c + d\ T12$

$|T^*11 - T11| < 1°K$?

(a,b,c, and d were all previously determined by regression using cloud-free data.)

h. A uniform low stratus test is employed for either the subarray or the full target if the 3.7 micron channel is excessively noisy as follows:

$|T11 - T3.7| < 0.7°K$ (for subarray)

$|T11 - T3.7| < 0.4°K$ (for target)

i. Three separate estimates of the SST are calculated:

$SST1 = a\ T3.7 - b\ T11 - c$

SST2 = d T11 - e T12 - f

SST3 = g T11 + h (T3.7 - T12) - i,

where T3.7, T11, and T12 are the brightness temperatures and SST1, SST2, and SST3 are the dual-window, split window, and triple-window SST's, respectively.

j. SST1, SST2, and SST3 must agree to within 1°C.

k. SST3 is selected for the operational SST (SST2 is selected if the 3.7 micron channel is too noisy). The SST must fall between -2°C and 35°C.

l. The SST must not differ from monthly climatology by more than 7°C.

m. The SST is stored along with earth location, time, algorithm ID, solar and satellite zenith angles, brightness temperatures/reflectances for all five AVHRR channels, and space-view noise level.

l. A table of failure statistics are as follows:

TEST	PERCENTAGE OF REMAINDER FAILING THIS TEST
Gross Cloud	39.7%
IR Uniformity	74.1%
IR Cloud	17.3%
Uniform low stratus	10.8%
SST intercomparison	15.8%
Climatology	0.4%

185,401 target arrays are available after application of the low-resolution land/sea screening. 17,944 target arrays survive the application of the tests (9.7%).

6. Daytime Algorithm

a. The satellite zenith angle must be less than 53°.

b. At least 10 of the 121 11-micron target elements must have a 0.9 micron reflectance of less than 10%.

c. All elements of the target within 10 km of land are rejected.

d. Subarrays are chosen to give the highest resolution near the coastal US and other selected regions (8km). The resolution is degraded to 15 km in open ocean near the US and 25 km elsewhere.

e. All four elements of the 2x2 array must agree to 0.32% reflectance for the 0.9 micron channel.

f. The element with the greatest reflectance within the array must have a value below a threshold which depends on empirical tables of bidirectional reflectance (5° solar zenith angle, 5° satellite zenith angle, and 10° in relative azimuth).

g. A 2x2 sub-array average for each channel is calculated for the following steps:

h. SST4 = g T11 + h (T3.7 - T12) - i,

i. The SST must fall between -2°C and 35°C.

j. The SST must not differ from monthly climatology by more than 7°C.

k. If more than one SST is to be computed for the target (at the higher resolutions, then this is done). If no SST's are obtained using the normal daytime algorithm, then a "relaxed" algorithm is employed. (The thresholds are increased by a factor of 1.5.) In the relaxed case, certain steps from the nighttime algorithm are employed: subarray selection, thermal-IR uniformity test, and the climatology test.

l. The SST is stored along with earth location, time, algorithm ID, solar and satellite zenith angles, brightness temperatures/reflectances for all five AVHRR channels, and space-view noise level.

m. A table of failure statistics are as follows:

TEST	PERCENTAGE OF REMAINDER FAILING THIS TEST
Gross Cloud	23.7%
Refl-IR Uniformity	78.5%
Refl-IR Cloud	89.4%
Unreasonable SST	12.5%

1,464,715 target arrays are available after application of the low-resolution land/sea screening. 22,179 target arrays survive the application of the tests (1.5%).

7. Analysis

Sea surface temperature computations using MODIS radiance data to generate a core product is feasable using existing operational algorithms developed for the AVHRR instrument. The essential expressions are simple (as are many of the core product algorithms) and depend on an algebraic combination of radiances from several different channels. Different expressions are used for day and night. Much of the complexity arises from the cloud screening procedure, which may be common for many MODIS products. Simultaneous QC procedures have been developed to validate the SST's based on climatology and other reasonableness criteria.

Recent revisions to the QC algorithms now permit on the order of 30,000 and 100,000 targets to be passed during nighttime and daytime, respectively.

8. <u>SST Fields</u>

Objective analyses are performed to generate latitude/longitude gridded fields of the SST from the irregularly spaced observations (targets) which pass the QC steps outlined above. The same basic technique is used for fields at 1/8°, 1/2°, and 1° resolutions. Two compositing intervals are defined: 24 hours and one week, although the weeekly product is apparently the only one operationally generated by NOAA. The observations are weighted by their timeliness and distance from the grid point, and are selected for participation in the grid-point average if they fall within a defined search area and compositing interval. Grid-point updating follows this basic procedure:

a. The search area is defined. The distance between the grid point and the boundary of the search area in any direction varies as a function of the SST gradient in that direction (tighter gradient yields a smaller search area dimension).

b. The observations are selected.

c. The observations' weights are assigned based on the inverse square of the distance.

d. The weighted average of all the observations in the search area is computed for each grid point.

e. The previous grid-point analysis is replaced with a weighted average of its old value and the new estimate based on the step d. If the new weighted set of observations has a higher weight than the previous field element, then the previous temperature is given a weight of zero. If no new observation is obtained, the previous field temperature is retained and its weight is halved.

f. Contoured fields are generated with a 1°C contour inverval. Dashed isotherms indicate regions where no new observations were obtained during the most recent analysis period.

9. <u>Products</u>

2.5° analyses are sent out daily on the GTS network. Global SST analyses (70°S to 70°N) are generated on a 1° grid, regional analyses are produced at a 1/2° resolution for the western North Atlantic, the eastern North Pacific, Hawaii to Alaska, the eastern Equatorial Pacific, and the central Equatorial Pacific. Local analyses are produced weekly at 1/8° resolution along the conterminous US coasts.

10. Reference

The information presented above was obtained primarily from the below reference. It was Wayne Esaias' feeling that the core MODIS SST algorithms to be applied by Otis Brown and Ian Barton will largely follow those currently being used operationally by NOAA for the AVHRR. Dr. McClain indicated that the expressions and algorithms presented in the reference are being used operationally at this time, with the exception of some coefficient changes.

For further information, Dr. McClain can be reached at 763-8078. However, he suggests that we contact John Sapper at 763-7255 for specific information.

McClain, E. P. W. G. Pichel, and C. C. Walton, 1985: Comparative Performance of AVHRR-Based Multichannel Sea Surface Temperatures. J. Geoph. Res., 90, 11,587-11,601.

		Contingency 10%	Total
Earth Radius (km)	6371		
Satellite Altitude (km)	705		
Orbital Period (min)	98.9		
MODIS-N # 856 m REF channels	15		
MODIS-N # 428 m REF channels	8		
MODIS-N # 214 m REF channels	2		
MODIS-N # 856 m TIR channels	15		
MODIS-T # 1 km REF channels	64		
MODIS-N # bits/REF channel	12		
MODIS-N # bits/TIR channel	12		
MODIS-T # bits/REF channel	12		
MODIS-N REF Duty Cycle	50%		
MODIS-N TIR Duty Cycle	100%		
MODIS-T REF Duty Cycle	50%		
MODIS-N # Along-track IFOVs	8		
MODIS-T # Along-track IFOVs	64		
MODIS-N # Along-track detectors	752		
MODIS-T # Along-track detectors	64		
MODIS-N Maximum scan angle (deg)	55		
MODIS-T Maximum scan angle (deg)	45		
MODIS-N IFOV FWHM (deg)	6.95E-02		
MODIS-T IFOV FWHM (deg)	8.13E-02		
MODIS-N # pixels along-scan/on-Earth	1582		
MODIS-T # pixels along-scan/on-Earth	1107		
MODIS-N Scan Period (sec)	1.02		
MODIS-T Scan Period (sec)	9.50		
MODIS-N VIS Data (megabits/scan)	12.0		
MODIS-N TIR Data (megabits/scan)	2.3		
MODIS-N Daytime Data (megabits/scan)	14.3		
MODIS-T Daytime Data (megabits/scan)	54.4		
MODIS-N # Scans/Orbit	5841		
MODIS-T # Scans/Orbit	312		
MODIS-N Daytime Data Rate (mbps)	14.1	1.4	15.5
MODIS-N Nighttime Data Rate (mbps)	2.2	0.2	2.5
MODIS-T Daytime Data Rate (mbps)	5.7	0.6	6.3
MODIS-N Orbital Ave Data Rate (mbps)	8.1	0.8	9.0
MODIS-T Orbital Ave Data Rate (mbps)	2.9	0.3	3.2
MODIS-N Daily Data Volume (gigabits)	703.9	70.4	774.2
MODIS-T Daily Data Volume (gigabits)	247.6	24.8	272.4
Total MODIS Data Volume (gigabits)	951.5	95.1	1046.6

Table 1. Control case: all channels retained.

		Contingency 10%	Total
Earth Radius (km)	6371		
Satellite Altitude (km)	705		
Orbital Period (min)	98.9		
MODIS-N # 856 m REF channels	15		
MODIS-N # 428 m REF channels	8		
MODIS-N # 214 m REF channels	0	<---Note	
MODIS-N # 856 m TIR channels	15		
MODIS-T # 1 km REF channels	64		
MODIS-N # bits/REF channel	12		
MODIS-N # bits/TIR channel	12		
MODIS-T # bits/REF channel	12		
MODIS-N REF Duty Cycle	50%		
MODIS-N TIR Duty Cycle	100%		
MODIS-T REF Duty Cycle	50%		
MODIS-N # Along-track IFOVs	8		
MODIS-T # Along-track IFOVs	64		
MODIS-N # Along-track detectors	496		
MODIS-T # Along-track detectors	64		
MODIS-N Maximum scan angle (deg)	55		
MODIS-T Maximum scan angle (deg)	45		
MODIS-N IFOV FWHM (deg)	6.95E-02		
MODIS-T IFOV FWHM (deg)	8.13E-02		
MODIS-N # pixels along-scan/on-Earth	1582		
MODIS-T # pixels along-scan/on-Earth	1107		
MODIS-N Scan Period (sec)	1.02		
MODIS-T Scan Period (sec)	9.50		
MODIS-N VIS Data (megabits/scan)	7.1		
MODIS-N TIR Data (megabits/scan)	2.3		
MODIS-N Daytime Data (megabits/scan)	9.4		
MODIS-T Daytime Data (megabits/scan)	54.4		
MODIS-N # Scans/Orbit	5841		
MODIS-T # Scans/Orbit	312		
MODIS-N Daytime Data Rate (mbps)	9.3	0.9	10.2
MODIS-N Nighttime Data Rate (mbps)	2.2	0.2	2.5
MODIS-T Daytime Data Rate (mbps)	5.7	0.6	6.3
MODIS-N Orbital Ave Data Rate (mbps)	5.8	0.6	6.3
MODIS-T Orbital Ave Data Rate (mbps)	2.9	0.3	3.2
MODIS-N Daily Data Volume (gigabits)	497.2	49.7	546.9
MODIS-T Daily Data Volume (gigabits)	247.6	24.8	272.4
Total MODIS Data Volume (gigabits)	744.9	74.5	819.3

Table 2. Hypothetical test case: both 250 m channels deleted.

Earth Radius (km)	6371		
Satellite Altitude (km)	705		
Orbital Period (min)	98.9		
MODIS-N # 856 m REF channels	13	<---Note	
MODIS-N # 428 m REF channels	8		
MODIS-N # 214 m REF channels	0	<---Note	
MODIS-N # 856 m TIR channels	15		
MODIS-T # 1 km REF channels	64		
MODIS-N # bits/REF channel	12		
MODIS-N # bits/TIR channel	12		
MODIS-T # bits/REF channel	12		
MODIS-N REF Duty Cycle	50%		
MODIS-N TIR Duty Cycle	100%		
MODIS-T REF Duty Cycle	50%		
MODIS-N # Along-track IFOVs	8		
MODIS-T # Along-track IFOVs	64		
MODIS-N # Along-track detectors	480		
MODIS-T # Along-track detectors	64		
MODIS-N Maximum scan angle (deg)	55		
MODIS-T Maximum scan angle (deg)	45		
MODIS-N IFOV FWHM (deg)	6.95E-02		
MODIS-T IFOV FWHM (deg)	8.13E-02		
MODIS-N # pixels along-scan/on-Earth	1582		
MODIS-T # pixels along-scan/on-Earth	1107		
MODIS-N Scan Period (sec)	1.02		
MODIS-T Scan Period (sec)	9.50		
MODIS-N VIS Data (megabits/scan)	6.8		
MODIS-N TIR Data (megabits/scan)	2.3		
MODIS-N Daytime Data (megabits/scan)	9.1		
MODIS-T Daytime Data (megabits/scan)	54.4		
MODIS-N # Scans/Orbit	5841	Contingency	
MODIS-T # Scans/Orbit	312	10%	Total
MODIS-N Daytime Data Rate (mbps)	9.0	0.9	9.9
MODIS-N Nighttime Data Rate (mbps)	2.2	0.2	2.5
MODIS-T Daytime Data Rate (mbps)	5.7	0.6	6.3
MODIS-N Orbital Ave Data Rate (mbps)	5.6	0.6	6.2
MODIS-T Orbital Ave Data Rate (mbps)	2.9	0.3	3.2
MODIS-N Daily Data Volume (gigabits)	484.3	48.4	532.7
MODIS-T Daily Data Volume (gigabits)	247.6	24.8	272.4
Total MODIS Data Volume (gigabits)	731.9	73.2	805.1

Table 3. Hypothetical test case: both 250 m channels and both one km polarization channels deleted.