MODIS DATA STUDY
TEAM PRESENTATION

November 3, 1989

AGENDA

1. Determination of Snow Cover from MODIS Observations
2. Potential Value of Band 7 (2060 nm) for Terrestrial Research
3. Potential Value of Atmospheric Corrections for Terrestrial Research
4. Land-Leaving Radiances and Normalized Difference Vegetation Index
5. Ocean Product Required External Data Sets, External Look-Up Table, and Internal Data Sets: Data Volumes and Timeliness Requirements
6. Data Resource Requirements for Core MODIS Land Products
7. The Moderate Resolution Imaging Spectrometer (MODIS) Data System and Its Science Requirements (submitted to IEEE Transactions on Geosciences and Remote Sensing; distributed under separate cover)
8. MODIS Core Data Product and Algorithm Report (revised version for MODIS science team members; distributed under separate cover)

DETERMINATION OF SNOW COVER FROM MODIS OBSERVATIONS

This snow cover algorithm uses MODIS-N because MODIS-T does not have any infrared channels (in the 11 to 12 μm region). Here we consider two present day algorithms using AVHRR data as analogs for the capabilities of MODIS-N. However, in addition to extending the measuring capabilities of the AVHRR, MODIS will also observe in the near-IR 1.6 μm spectral region, which permits the discrimination between clouds and snow (Wiscombe and Warren, 1980; Dozier, 1984).

1. AVHRR Algorithm of Gesell (1989)

Gesell (1989) presents an algorithm using the five channels (0.58 to 0.68 μm, 0.725 to 1.1 μm, 3.55 to 3.93 μm, 10.3 to 11.3 μm, and 11.5 to 12.5 μm) available on the Advanced Very High Resolution Radiometer (AVHRR) to determine surface and cloud parameters (Figure 1).

Sea ice or snow-covered pixels are flagged as cloudy by the AVHRR Processing scheme Over Land, cLoud and Ocean (APOLLO) software. APOLLO is a software package developed at the United Kingdom's Meteorological Office. The algorithms use all five AVHRR channels and the differing spectral properties of clouds at those wavelengths. However, in the presence of snow and ice containing pixels the classification tests fail.

This procedure considers snow or sea ice covered pixels as contaminates of the cloud algorithm. The snow and ice detection algorithms uses an empirical threshold testing scheme based upon the wavelength and spectral properties of sea ice and snow. The snow free test results at the figure's top right hand side verify the original cloudy classification. The cloud-free snow results change the original mis-identified cloudy pixel identification. The snow under clouds change cloudy to partially cloudy over snow.

Reflectances at 3.7 μm are used to distinguish between snow or sea-ice covered pixels and cloudy pixels. Reflectances less than a threshold value can be tagged as snow or ice covered and cloud free. At 3.7 μm, clouds have much higher reflectivity. Additional testing is done to the pixel using the difference in reflectance between channel 1 and 2, (D_{12}).

The first two tests (R_{T3} and D_{12}) identify pixels for further testing to determine if they are snow free. These tests use the channel 4 temperature, channel 1 and 2 reflectances, and temperature difference between channel 4 and 5. Both the dynamic visible threshold test (DVT) and the channel 2/channel 1 ratio tests (R21T) detect snow or ice and clouds.

The R_{21} test (in the sixth box down) determines if the ratio of the reflectances indicates the presence of snow cover. The remaining tests determine the presence of cloud-free snow pixels or snow pixels under clouds. These threshold values used are shown in the appropriate boxes.

The snow cover algorithm has one test which applies to sea ice. A category snow-on-ice is chosen for an ocean pixel if the R_{31} test indicates it is snow contaminated.

This algorithm was tested during the 1987 Baltic Sea ice season. Only when thin ice clouds over snow, ice, or ice free water caused the classification of a few pixels to be uncertain. When it failed, it caused sea-ice free pixels with thin ice clouds over water to be classified as sea-ice covered. The algorithm also fails to distinguish between thick, bright ice with a rough surface and when the snow is melting or frozen

Figure 1 symbols and their meanings are explained below.

- o $R_{T1,2,3}$ - Top of the atmosphere reflectances of channels 1, 2, and 3 respectively.
- o $T_{4,5}$ - Channel 4 and 5 temperatures °K
- o R_{21} - Ratio of reflectances of channel 2/ channel 1 ;i.e., R_{T2}/R_{T1}
- o D_{45} - Temperature difference between channel 4 and channel 5 in °K ;i.e., $T_4 - T_5$
- o R_{31} - Ratio of reflectances of channel 3/ channel 1 ;i.e., R_{T3}/R_{T1}
- o D_{12} - Difference of reflectances of channel 1 and channel 2 ;i.e., $R_{T1} - R_{T2}$
- o T45T - Temperature difference test between channels 4 and 5 This test detects sea ice as thin clouds.

Above 40°N latitude the annual mean cloudiness exceeds 55%. From 50° to 70°N latitude the annual mean cloudiness is 64% (London, 1957). Sasamori et al (1972) indicate that the cloud coverage in the southern hemisphere is at least 10% higher than for an equivalent latitude in the northern hemisphere reaching a maximum at 60°S latitude. Consequently, at least 50% of the time in the Northern Hemisphere, and about 55% of the time in the Southern Hemisphere no information is available when using this algorithm.

2. NOAA Satellite Operational Algorithms

Dave McGinnis Jr. (763-8024) in the Land Sciences Branch of the National Environmental Satellite, Data, and Information Service used AVHRR satellite data to look at clouds and snow at three locations. They were the midwest, the Sierra Nevada Mountains, and Canada. Similar algorithms were originally published by Bunting and D'Entremont (1982). The algorithm uses AVHRR normalized channel (1-2)/(1+2) [channel 1 is visible, channel 2 is near infrared]. The algorithms worked in the midwest and the Sierra Nevada mountains but failed in Canada -- particularly north of 50°N latitude. The algorithm failure was attributed to low sun angles. He has not tested the case where ice clouds are present, but he intends to when he can.

McGinnis stated that they need to fine-tune the threshold values before the algorithm is operational although software has been written. He hopes to do this within a year. World-wide coverage is planned to be at 4 kilometers.

The cloud/snow detection algorithm will be used with the NOAA polar orbiting K,L. and M satellites. Launch is presently scheduled for 1991, but the date may slip. McGinnis also stated that the channel may be 1.6 μm (3A) during the day and 3.55 μm (3B) at night.

NOAA/NESDIS presently are arbitrarily stating if the pixel is north of 50°N latitude, it is snow covered in the wintertime. Work on this algorithm has stopped. Sounding algorithms are presently receiving higher priority.

3. References

Bunting, J. T. and R. P. D'Entremont, 1982: Improved Cloud Detection Utilizing Near Infrared. Defense Meteorological Satellite Program, Environmental Research papers No. 765
AFGL-TR-82-0027, Hanscomb Air Force Base.

Dozier, J., 1984: Snow Reflectance from LANDSAT-4 Thematic Mapper. IEEE Transactions, GE-22 (Special Issue on LANDSAT-4), 323-328.

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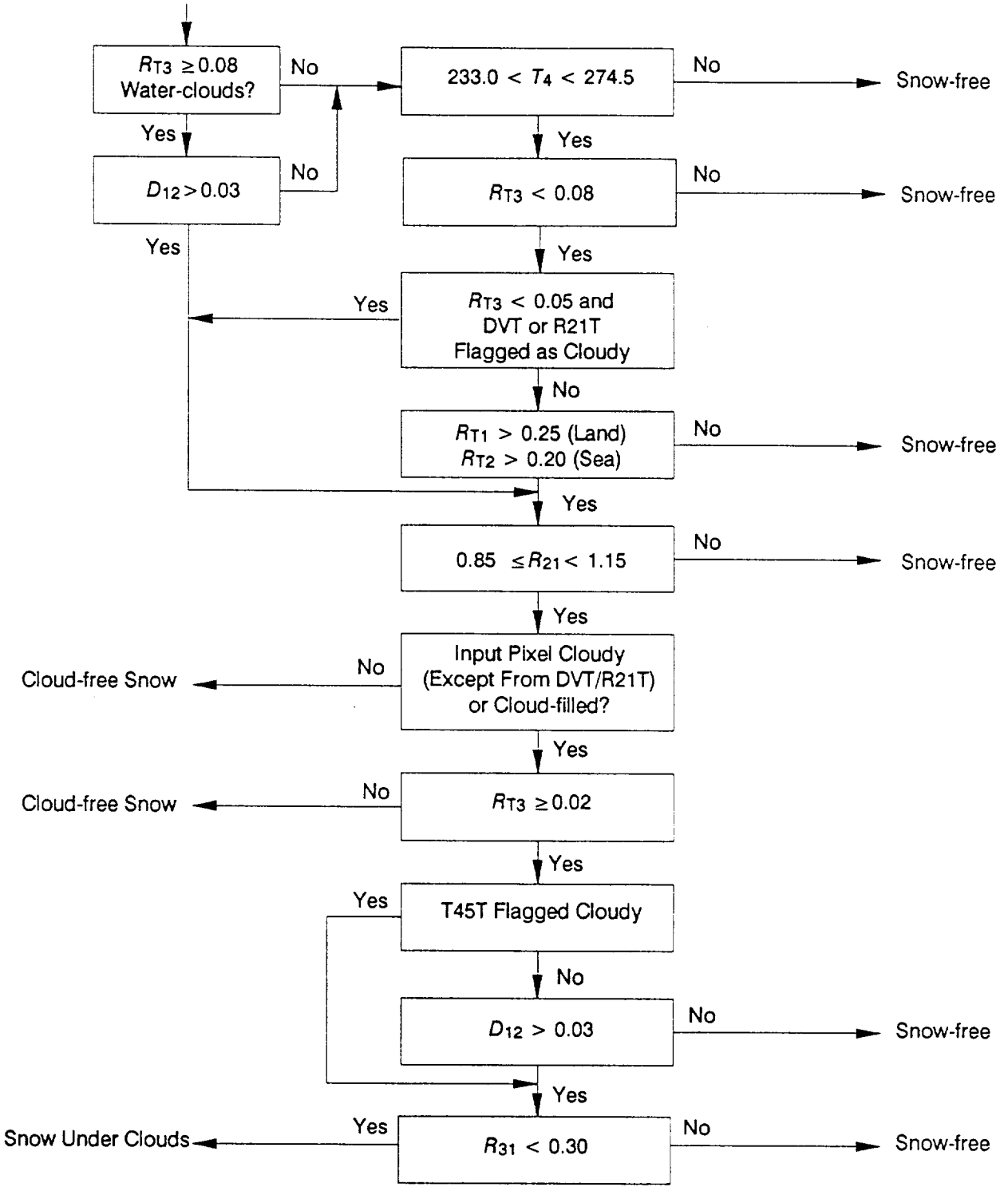
Sasamori,T., J. London, and D. Hoyt, 1972: Radiation Budget of the Southern Hemisphere. Meteorology Monographs, Meteorology of Southern Hemisphere, American Meteorology Society.

Snow Cover

An Algorithm for Snow and Ice Detection Using AVHRR Data: An Extension to the APOLLO Software Package, Gesell, G., *International Journal of Remote Sensing*, Vol. 10, No. 4 and 5, 1989, pp.897-905.



POTENTIAL VALUE OF BAND 7 (2060nm) FOR TERRESTRIAL RESEARCH

In the 2060 nm region there has been found a spectral feature related to lignin and cellulose in plants. This cellulose/lignin feature has been noted in dry plant materials (Elvidge, 1987,1988; Peterson et al., 1988) and current research indicates that cellulose in green plant material may influence the shape of the spectral reflectance curve in the 2060 nm region (C. Wessman, personal communication). As research advances it may be expected that the significance of this cellulose spectral feature will be further elucidated. Thus, this band has potential value for terrestrial vegetation studies and should be retained as a MODIS-N band.

POTENTIAL VALUE OF ATMOSPHERIC CORRECTIONS FOR TERRESTRIAL RESEARCH

In remote sensing of terrestrial vegetation, nearly all research results have/are presented in a <u>qualitative</u> way, e.g. ratios of reflectance, correlation of ratios with ground data, or simple digital number reflectance. Research has been limited to qualitative analysis because atmospheric corrections have not generally been performed. But, the availability of atmospherically corrected data would allow for <u>quantitative</u> analysis of remotely sensed data. Atmospheric correction of MODIS-N data would produce Land Leaving Radiance as a core Level 2 data product.

Land leaving radiances are desirable for several reasons; for comparison of in situ ground based data with MODIS data; in ecological modelling studies radiances will be required for calculating physiological processes and energy balances, and radiances will be needed by studies employing multitemporal data sets. Also, some literature suggests that atmospherically corrected data may enhance the ability to discern among surface features; by accounting for atmospheric attenuation and radiance, it may be possible to discriminate and or detect smaller differences among surface spectral features.

Atmospheric correction of MODIS-N data would give Land Leaving Radiances as a core Level 2 data product. The two basic atmospheric effects that should be accounted for in calculating land leaving radiances are attenuation and radiance. Because of the nature of scattering of light in the atmosphere, atmospheric effects are greatest in the visible region, so atmospheric corrections would be most valuable for MODIS-N bands 1-4, and 9-17.

Elvidge, C.D. 1987. Reflectance characteristics of dry plant materials. Twenty-First International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 26-30.

Elvidge, C.D. 1988. Vegetation reflectance features in AVIRIS data. Sixth Thematic Conference:"Remote Sensing for Exploration Geology", Houston, Texas, May 16-19.

Peterson, D.L, J.D. Aber, P.A. Matson, D.H. Card, N. Swanberg, C. Wessman, and M. Spanner. 1988. Remote Sensing of Environment, 24:85-106.

LAND LEAVING RADIANCES AND NORMALIZED DIFFERENCE VEGETATION INDEX

Does the MODIS data system require atmospheric corrections to derive land leaving radiances which are used to calculate the Normalized Difference Vegetation Index (NDVI)? Or alternatively, can the top of the atmosphere radiances be used to calculate NDVI? Historically, the NDVI calculated using AVHRR measurements have used top of the atmosphere radiances. It appears that it is the intent of the MODIS science team to use the top of the atmosphere radiances to calculate MODIS NDVI's. However, land leaving radiances may also be available for some regions allowing an improved NDVI to be derived. Is the additional computational effort required or are the top of the atmosphere and bottom of the atmosphere NDVI's virtually equivalent?

To answer this question, the radiative transfer model of Bird and Riordan (1986) was modified in the same manner as Justus and Paris (1985) to allow the spectral radiances at the top of the atmosphere to be modelled for 122 wavelengths. The model was put on a Lotus 123 spreadsheet for ease of computations and to allow plotting. A standard atmospheric model is chosen and then the NDVI's using top of the atmosphere radiances will be compared to the true NDVI which would be calculated if land leaving radiances were available. For MODIS the NDVI is the difference in radiance at 880 nm minus 665 nm divided by their sum. The standard atmosphere, geometry, and surface albedos are as follows: 1) solar zenith angle of 0 degrees, 2) satellite zenith angle of 0 degrees, 3) Total precipitable water of 1.42 cm., 4) total column ozone of 0.344 cm., 5) Angstrom beta coefficient of 0.1, 6) Angstrom alpha coefficient of 1.3, 7) Surface pressure of 1013.25 mb, 8) aerosol single scattering albedo of 0.945, 9) surface albedo of 0.1 at 665 nm, and 10) surface albedo of 0.5 at 880 nm. The true NDVI will be 0.530 for this situation whereas the top of the atmosphere NDVI will be 0.487 or 8.15% lower.

In the model results, the NDVI's are always smaller than the true NDVI since atmospheric and aerosol scattering is always greater for the shorter wavelengths, so the difference between the 880 nm and 665 nm becomes smaller the more atmosphere the radiation traverses. The errors in NDVI as a function of solar and satellite zenith angles are given in Table 1.

Table 1. Top of atmosphere NDVI errors in percent as a function of solar zenith angle and satellite zenith angle.

Z(sat.)=	0	15	30	45	60
Z(sun)					
0	-8.15	-8.09	-7.88	-7.45	-6.64
20	-9.37	-9.31	-9.12	-8.72	-7.97
40	-14.07	-14.03	-13.88	-13.58	-13.04
60	-27.75	-27.24	-27.20	-27.16	-27.16
70	-41.92	-41.94	-42.02	-42.20	-42.69
80	-68.14	-68.20	-68.40	-68.85	-69.88

From the table it is evident that the top of the atmosphere NDVI as measured is strongly dependent upon the solar zenith angle and only weakly dependent upon the satellite zenith angle. The weak dependence on satellite zenith angle arises from the assumption that the surface is a Lambertian reflector. For a solar zenith angles greater than 60 degrees, no reliable NDVI values can be expected. In contrast the NDVI using land leaving radiances is nearly independent of both zenith angles.

Holben (1986) and others indicate that the AVHRR NDVI is a strong function of not only viewing angle but also of aerosol loading. In Table 2, percent errors in the top of the atmosphere NDVI are plotted as functions of the Angstrom coefficients alpha and beta.

Table 2. Top of atmosphere NDVI errors in percent as a function of Angstrom coefficients alpha and beta.

alpha =	0	1.0	2.0
beta			
0.0	-4.40	-4.40	-4.40
0.1	-7.95	-8.11	-8.20
0.2	-11.53	-11.96	-12.38
0.3	-15.13	-15.88	-16.71

As Table 2 shows, the amount of aerosols, expressed through the value of beta, strongly affects the NDVI values, but the size distribution does not have much effect unless there is a great deal of aerosols. In contrast, using land leaving radiances, the NDVI would be independent of aerosol loading.

The only other variable with a notable effect on the NDVI is surface pressure. As surface pressure decreases, the measured NDVI becomes closer to the true NDVI since atmospheric influences are decreasing. The error decreases from -9.3% to -6.1% as the surface pressure decreases from 1000 mb to 700 mb.

Water vapor, ozone, and the aerosol single scattering albedo all have little effect on the measured NDVI, the range of errors being within 0.5% of the -9.34% error of the standard atmosphere for all reasonable values of water, ozone, and dust absorption.

Let's return to the original question asked at the beginning of this note: Does MODIS need to make atmospheric corrections to derive land leaving radiances which are then used to calculate the Normalized Difference Vegetation Index (NDVI)? If one confines the derivation of the top of the atmosphere NDVI to regions with a solar zenith angle of less than 40 degrees and avoids hazy regions, the NDVI calculated at the top of the atmosphere will give a good representation of the true state of the vegetation, although it will be systematically offset by the order of 10%. Random errors in this approach will be about 5%. If there is an annual cycle in the dust amount, the annual cycle in NDVI may be

modified as well.

If land leaving radiances are calculated, they can probably only be found in a fraction of the available area primarily because of the difficulties in finding the amount of aerosols over land. To their benefit however, the NDVI calculated using land leaving radiances will be independent of atmospheric influences. The scatter in the measurements will be reduced and comparisons from one satellite to another will be better. The land leaving radiances will also be useful in surface radiation budgets. In conclusion, it is felt that the MODIS data system should calculate land leaving radiances since the potential improvement in the NDVI could be significant.

References:

Bird, R. E. and C. Riordan, 1986. Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the Earth's surface for cloudless atmospheres. J. Climate Appl. Met., 25, 87-97.

Holben, B. N., 1986. Characteristics of maximum value composite images from temporal AVHRR data. Int. J. Remote Sensing, 7, 1417-1434.

Justus, C. G. and M. V. Paris, 1985. A model for solar spectral irradiance and radiance at the bottom and top of a cloudless atmosphere. J. Climate Appl. Met., 24, 193-205.

External Data Sets, External Look-Up Tables,
and Internal Data Sets.
Data Volumes, Timeliness Requirements
Preliminary

Listed below are the external data sets, external look-up tables, and internal data sets required for the data processing scenario for ocean products, and the corresponding data volumes and timeliness requirements for each.

An external data set is a set of variables obtained outside the MODIS processing environment that vary as a function of time and space. They are thus required for each MODIS position and time. An external look-up table is a fixed data set comprised of constants that do not change for location and space. The look-up table may either be a set of constants that are used directly in the processing scenario, or may require input variables which are then used to produce other variables necessary for data processing. The inputs may be internal or external variables, but are used in the tables to interpolate in pre-specified variable dependencies. Internal data sets are those variables produced within the MODIS processing scenario that are used more than once in the processing. This list applies both to the MODIS-N as well as the MODIS-T processing scenarios.

This list does not include data sets associated with clear sky PAR, nor those associated with empirical K_{PAR} relationships, and must be considered both preliminary and as a lower bound.

External Data Sets

1. Atmospheric Surface Pressure
   Data Volume: Data or predictions from NMC will probably be sufficient. These may be acquired as gridded pressure fields (possibly 2.5 by 2.5 degree grids) or as spectral harmonics. In either case, this data set will be of low resolution, not necessitating pixel-by-pixel corrections.
   Timeliness Requirement: Within 24 hours[1]

2. Surface Wind Speeds
   Data Volume: These will be acquired along with NMC surface pressure fields, and will be at the same resolution.
   Timeliness Requirement: Within 24 hours[1]

3. Spectral Ozone Optical Thickness
   Data Volume: A maximum size will occur if MODIS-N band 30 (9.7 μm) is used to estimate ozone optical thickness. In such case, data will be available for each MODIS-N pixel. These data

may also be used for MODIS-T, probably at lower resolution. Otherwise, low resolution data from other sources will be used.

Timeliness Requirement: None if MODIS-N is used; within 24 hours otherwise.

External Look-Up Tables

1. Mean Extraterrestrial Solar Spectral Irradiance
   Data Volume: Maximum 32 values for MODIS-T
   Most likely 23 values (includes only those bands requiring atmospheric correction; see Table 2)
   Maximum 36 values for MODIS-N
   Most likely 9 values (includes only those bands requiring atmospheric correction; see Table 1)
   Timeliness Requirement: None

2. Spectral Rayleigh Optical Thickness at Standard Temperature, Pressure
   Data Volume: Maximum 32 values for MODIS-T
   Most likely 23 values (includes only those bands requiring atmospheric correction; see Table 2)
   Maximum 36 values for MODIS-N
   Most likely 9 values (includes only those bands requiring atmospheric correction; see Table 1)
   Timeliness Requirement: None

3. Fourier Coefficients of Rayleigh Scattering (function of solar zenith angle, spacecraft zenith angle)
   Data Volume: 2070 values (45 solar zenith angles, 45 spacecraft angles, at 23 bands)
   Timeliness Requirement: None

4. Fresnel Reflectance for Downwelling Irradiance, Upwelling Irradiance
   Data Volume: Single value for each
   Timeliness Requirement: None

5. Seawater Index of Refraction
   Data Volume: Single value
   Timeliness Requirement: None

6. Empirical Constants for
   - chlorophyll
     Data Volume: Two values (coefficient and exponent)
     Timeliness Requirement: None
   - K_{490}
     Data Volume: Two values (coefficient and exponent)
     Timeliness Requirement: None
   - possibly coccoliths

Data Volume: TBD
Timeliness Requirement: None

- primary production
  Data Volume: Two values (coefficient and exponent)
  Timeliness Requirement: None

7. Backscattering Coefficients
   - chlorophyll for Case 1 waters
     Data Volume: Maximum 20 values for MODIS-T (uses bands within the spectral range 400-700 nm)
     Maximum 7 values for MODIS-N
     Timeliness Requirement: None
   - chlorophyll and other substances for Case 2 waters
     Data Volume: Maximum 20 values for MODIS-T (uses bands within the spectral range 400-700 nm)
     Maximum 7 values for MODIS-N
     Timeliness Requirement: None

8. Case 2 Gelbstoff-Chlorophyll Table (function of ratio $L_w(410)/L_w(443)$ and ratio $L_w(443)/L_w(565)$)
   Data Volume: 11 chlorophyll values and 9 gelbstoff values = 20 values
   Timeliness Requirement: None

<u>Internal Data Sets Used More Than Once</u>

1. Pixel Latitude and Longitude
   Data Volume: TBD
   Timeliness Requirement: Immediate

2. Spacecraft Pitch, Roll, Yaw
   Data Volume: TBD
   Timeliness Requirement: Immediate

3. Solar Zenith Angle
   Data Volume: TBD
   Timeliness Requirement: Immediate

4. Solar Azimuth Angle
   Data Volume: TBD
   Timeliness Requirement: Immediate

5. Spacecraft Zenith Angle
   Data Volume: TBD
   Timeliness Requirement: Immediate

6. Spacecraft Azimuth Angle
   Data Volume: TBD
   Timeliness Requirement: Immediate

7. Instantaneous Extraterrestrial Solar Spectral Irradiance
   Data Volume: Maximum 32 values for MODIS-T
   Most likely 23 values (includes only those bands requiring atmospheric correction; see Table 2)
   Maximum 36 values for MODIS-N
   Most likely 9 values (includes only those bands requiring atmospheric correction; see Table 1)
   Timeliness Requirement: Immediate

8. Instantaneous Extraterrestrial Solar Spectral Irradiance Corrected for Ozone Absorption
   Data Volume: Maximum 32 values for MODIS-T per pixel
   Most likely 23 values; total = 25,461 per scan (23 * 1107 pixels/scan)
   Maximum 36 values for MODIS-N per pixel
   Most likely 9 values; total = 14,382 per scan (9 * 1582 pixels/scan)
   Timeliness Requirement: Immediate

9. Rayleigh Optical Thickness
   Data Volume: Same as Atmospheric pressure
   Timeliness Requirement: Immediate

10. Water-Leaving Radiances
   Data Volume: 21 values for MODIS-T per pixel[2]; total = 23,247 per scan (21 * 1107 pixels/scan)
   7 values for MODIS-N per pixel[2]; total = 11,074 per scan (7 * 1582 pixels/scan)
   Timeliness: Immediate

11. Chlorophyll
   Data Volume: One value per pixel
   Timeliness Requirement: Immediate

Footnotes

1. We do not expect Level 0 data to be ready before 24 hours. If these data sets are available at 24 hours, Levels 1 and 2 processing may proceed uninterrupted in memory (RAM).

2. This assumes that water-leaving radiances will be computed and stored for all visible channels, i.e., between 400 and 700 nm. Even if all of these bands are not directly required for core data products, they are desired for research purposes, and so it is advantageous to recommend storing these radiances in advance.

Table 1. MODIS-N bands requiring atmospheric correction for water-leaving radiance.

Band	Product
1. Band 9 (415 nm)	Gelbstoff/Case 2 Chlorophyll/K_{PAR}
2. Band 10 (443 nm)	Chlorophyll/K_{490}/K_{PAR}
3. Band 11 (490 nm)	Chlorophyll/K_{PAR}
4. Band 12 (531 nm)	Chlorophyll/Aerosol Radiances/K_{PAR}
5. Band 13 (565 nm)	Chlorophyll/Aerosol Radiances/K_{490}/K_{PAR}
6. Band 14 (653 nm)	Atmospheric Correction/Aerosol Radiances/ Fluorescence/K_{PAR}/Angstrom Exponents
7. Band 15 (681 nm)	Aerosol Radiances/Fluorescence/K_{PAR}
8. Band 16 (745 nm)	Atmospheric Correction/Aerosol Radiances/ Angstrom Exponents
9. Band 17 (865 nm)	Atmospheric Correction/Aerosol Radiances

Total MODIS-N Bands = 9

Table 2. MODIS-T bands requiring atmospheric correction for water-leaving radiance.

Band	Product
1. Band 1 (410 nm)	Gelbstoff/Case 2 Chlorophyll/K_{PAR}
2. Band 2 (425 nm)	Research/K_{PAR}
3. Band 3 (440 nm)	Chlorophyll/K490/K_{PAR}
4. Band 4 (455 nm)	Research/K_{PAR}
5. Band 5 (470 nm)	Research/K_{PAR}
6. Band 6 (485 nm)	Chlorophyll/K_{PAR}
7. Band 7 (500 nm)	Research/Aerosol Radiances/K_{PAR}
8. Band 8 (515 nm)	Chlorophyll/Aerosol Radiances/K_{PAR}/K_{490}
9. Band 9 (530 nm)	Research/Aerosol Radiances/K_{PAR}
10. Band 10 (545 nm)	Chlorophyll/Aerosol Radiances/K_{PAR}
11. Band 11 (560 nm)	Chlorophyll/Aerosol Radiances/K_{PAR}
12. Band 12 (575 nm)	Research/Aerosol Radiances/K_{PAR}
13. band 13 (590 nm)	Research/Aerosol Radiances/K_{PAR}
14. Band 14 (605 nm)	Research/Aerosol Radiances/K_{PAR}
15. Band 15 (620 nm)	Research/Aerosol Radiances/K_{PAR}
16. Band 16 (635 nm)	Research/Aerosol Radiances/K_{PAR}
17. Band 17 (650 nm)	Fluorescence/Aerosol Radiances/K_{PAR}
18. Band 18 (665 nm)	Atmospheric Correction/Fluorescence/ Aerosol Radiances/Angstrom Exponents/ K_{PAR}
19. Band 19 (680 nm)	Fluorescence/Aerosol Radiances/K_{PAR}
20. Band 20 (695 nm)	Fluorescence/Aerosol Radiances/K_{PAR}
21. Band 21 (710 nm)	Fluorescence/Aerosol Radiances

22.	Band 24 (755 nm)	Atmospheric Correction/Aerosol Radiances/ Angstrom Exponents
23.	Band 31 (860 nm)	Atmospheric Correction/Aerosol Radiances/ Angstrom Exponents
	or	
23.	Band 32 (875 nm)	Atmospheric Correction/Aerosol Radiances/ Angstrom Exponents

Total MODIS-T Bands = 23

DATA RESOURCE REQUIREMENTS FOR CORE MODIS LAND PRODUCTS

In addition to the basic computer software and hardware that will generate all MODIS data products, several special data sets will be required to complete the land processing of MODIS observations. The types of data required include external data sets that will be obtained from the National Meteorological Center (NMC) or other scientific investigations, numerical maps and lookup tables that are fixed but may be difficult to obtain or generate initially, and Eos internal data products that will be available within the Eos Data System.

The external data items that have thus far been identified as necessary to produce core MODIS land products are identified in Table 1. Atmospheric Surface Pressure is approximately correlated with the mass of the air column associated with an observation, and serves as an correction input for the computation of Rayleigh scattering effects. As defined from team member proposals, Rayleigh scattering coefficients may be important to two land products: Spectral Surface Albedo and Land-Leaving Radiances.

Spectral Ozone Optical Thickness is important to the same two products. At present, the source of this data is not defined. The Eos platform may carry other sensors that will provide ozone products; otherwise, MODIS-N Band 30 (9.7 μm) may be used to obtain an estimate of ozone optical thickness.

Some of the fixed data sets required to generate core MODIS land products are listed in Table 2. The land/ocean/political-boundary map serves initially in Level-1 processing to distinguish regions requiring terrain elevation correction for earth location of selected "anchor points" (earth-located pixels serving as references for pixel-by-pixel earth-position interpolation). The political feature map (perhaps also including important cities or other distinguishing features) will be important in creating data overlay maps for use with higher-level MODIS products. The terrain elevation map will, of course, also support the generation of earth-referenced anchor points as described above. Both of these items are relatively extensive data sets.

The table of expected radiances as a function of Surface Albedo and Aerosol Optical Depth is required to obtain the Spectral Surface Albedo. Because of the large dimensionality of the table (six visible radiances and one thermal radiance) and the resolution desired in Spectral Surface Albedo and Aerosol Optical Depth, this is also expected to be a large data set.

A number of researchers have concluded that Land Surface Temperatures cannot be adequately determined unless surface thermal emissivities are known. A map of expected surface emissivity may be required for all land surfaces of the earth. Since this is a research topic, it is not clear what sort of updates might be

required or what sort of terrain classification maps might be required to support the generation of updated surface emissivities.

Table 2 also includes several constants that will profoundly affect their associated land products. The data storage requirements associated with these numbers will, of course, be small.

Table 3 shows the internally-generated Eos products that have been identified as essential inputs for the generation of core MODIS land products. The required inputs are basically either calibration-corrected Level-1 radiances or atmospheric parameters.

TABLE 1

External Data Sets Required to Generate
MODIS Land Data Products

Item	Product	Data Volume	Timeliness
Atmospheric Surface Pressure	Spectral Surface Albedo	Low Resolution Data Sufficient	Within 24 hours
Atmospheric Surface Pressure	Level-2 Land Leaving Radiances	Low Resolution Data Sufficient	Within 24 hours
Spectral Ozone Optical Thickness	Spectral Surface Albedo	Low Resolution Data Sufficient	Within 24 hours
Spectral Ozone Optical Thickness	Level-2 Land Leaving Radiances	Low Resolution Data Sufficient	Within 24 hours

TABLE 2

Numerical Maps, Lookup Tables, and Constants
Required to Generate MODIS Land Data Products

Item	Product	Data Volume
Land/Ocean/Political-Boundary Map	Level-1 Radiances; Product Overlays	Large
Terrain Elevation Map	Level-1 Radiances	Large
Expected Radiances as Function of Surface Albedo and Aerosol Optical Depth	Spectral Surface Albedo	Large
Map of Expected Surface Emissivities	Land Surface Temperature	Large
Thermal Anomaly Identification Thresholds	Thermal Anomalies	Small
SAVI Adjusting Parameter	SAVI	Small

TABLE 3

Eos Internal Data Required to Generate
MODIS Land Data Products

Item	Product
NDVI (top of atmosphere) (6) MODIS-N Visible Radiances (1) MODIS-N Thermal Radiance Total Column Ozone Total Precipitable Water Aerosol Single Scattering Albedo Aerosol Phase Function Aerosol Scale Height	Spectral Surface Albedo
Level-1 Radiances Total Column Ozone Total Precipitable Water Aerosol Optical Depth Aerosol Single Scattering Albedo	Level-2 Land Leaving Radiances
Level-1 Visible and Thermal Radiances	Land Surface Temperatures
Level-2 Land Leaving Radiances[1]	Thermal Anomalies
Land Surface Temperatures Level-2 Land Leaving Radiances[2]	Snow Cover
Level-2 Land Leaving Radiances[3]	NDVI & SAVI

[1] Level-2 radiances may be used.

[2] Spectral Surface Albedos or Level-1 Radiances may be used.

[3] Level-1 radiances may be used.