MODIS DATA STUDY
TEAM PRESENTATION

March 2, 1990

AGENDA

1. Some Thoughts on Planning and Scheduling Operations Concepts for MODIS-T (Ardanuy)
2. Simulation of Global Coverage by MODIS-T: Progress Report (Gregg, Riggs)
3. Status Report on MODIS Packetization Trade-Offs (McKay)
4. Sizing Estimates for Ocean Color Products (continued): Concentrations of Pigment, Case 1 Chlorophyll, Case 2 Chlorophyll, Dissolved Organic Matter, and Total Seston for MODIS (Gregg)

SOME THOUGHTS ON PLANNING AND SCHEDULING OPERATIONS CONCEPTS FOR MODIS-T

Here we consider some of the science and data system requirements and considerations that arise out of an operations concept that mandates commanded gain changes within orbits for MODIS-T. The conclusions reached for the treatment of these gain changes also apply in general for any MODIS mode change.

1. Parameters Regularly Subject to Scheduling

- Scan-on/Scan-off

MODIS-T may take Earth radiance measurements 40% of the time to observe primarily ocean data. If regular polar coverage for snow-ice observations is required, the duty cycle could increase to 50% or perhaps 60%.

- Ocean-gain/Land-gain

Gain settings are being defined that optimize the sensitivity, saturation level, and signal-to-noise ratios for the MODIS-T radiance measurements of: (1) ocean color and (2) terrestrial and cloud radiances. The gain will be switchable upon command. Present concepts indicate that the gains would be held constant for a complete scan.

- Tilt changes

The MODIS-T instrument will be capable of altering its scan plane either fore or aft of nadir upon command. The primary mode of operation will be sun-glint avoidance for ocean-color observations. Alternative modes could include a fixed tilt, a stare mode (for BRDF model determination and possibly lunar/terrestrial calibration verification), and perhaps a stereo mode. With the exception of the fixed tilt, all modes will be composites of a number of tilt changes over complete orbits or segments of orbits. For example, sun-glint avoidance may require five tilt changes over a half orbit (0°, -20°, -30°, 30°, 20°).

- Calibration mode

Operating modes dedicated to calibration may not permit the simultaneous collection of Earth radiances. Lunar calibration, for example, will be possible for one quarter of each lunar cycle (about one week per month) and might be accomplished in some form of stare mode for all 100 orbits with a suitable geometry (precluding collection of snow/ice data over the north pole.

2. Possible Control Techniques

To control these mode changes, the desired commands must be executed at precisely the correct point (time) in the orbit. This precise scheduling problem can either be handled in real time by the MODIS instrument, or predicted several days to a week in advance on the ground.

- Real Time Decision-Making On Orbit

For the MODIS-T instrument to be capable of determining the correct times to effect mode changes, it must have access to certain ancillary data, processing capability, and additional storage. For gain changes, ancillary data would include the platform position and attitude and a land-ocean map. On-board software would include a navigation package. The software would locate key anchor points for an upcoming scan, determine the mix of land and ocean, and then command the appropriate gain set at the start of the scan. This capability does not appear to be required.

- Predictive Decision-Making

Under this scenario, the orbit is predicted by integrating a week ahead. For gain changes, IFOVs are then navigated to the Earth's surface and a land/ocean determination made for key anchor points. Times for the gain changes are then specified, to be executed in the off-Earth portion of the indicated scan. The platform and instrument must be capable of storing the required number of commands.

3. Possible Concept Implications and Refinements

- Accuracy of Orbital Predictions

For well behaved spacecraft such as LAGEOS (high orbit, small cross-sectional area, large density), orbits may be predictable to the accuracy of centimeters a month in advance. For the polar platform (in a lower orbit, with a large and possibly variable area, and a relatively low density) the accuracy of a prediction will be lower. However, it may be possible to predict to an accuracy of 100m for a week, and 1 km over a month. This precision would be entirely adequate for most MODIS purposes. However, routine orbit maintenance (scheduled or unscheduled burns to correct velocity or dump momentum from the gyros) would degrade or invalidate the prediction. Therefore, there are operational considerations that impact the mission plan.

- Gain Changes Within Scan

Because about 75% of a scan for MODIS-T is off-Earth (about three seconds), this is the logical time to change gains. However, additional land data could be taken by changing modes within a scan (e.g., by quadrants). The predictive task is no more complicated, though the number of commands would be increased slightly. However, in the dual mode concept, a mode change has both analog and digital components. There will be about 1007 detector array positions. When detector readouts are considered, there may be only microseconds to make the change. (Though it might be acceptable to lose a few milliseconds over the land portions). If this capability is desired, it might be a legitimate design issue.

- Orbit Prediction Model/MODIS Scan Simulation

To support the dual mode of operation, it appears that the capability must exist to predict (perhaps through an EOS-provided model), or obtain predictions of, the NPOP orbit out to at least one week prior to real time. These could be updated perhaps two days before real time. Land/ocean matrices exist in resolutions from 1° to 1/8° of lat/lon. Substantial tracking data, or alternatively GPS or GGI data, will be required. An optimal sun-glint avoidance tilt operations concept must be developed, as the geometry depend upon the tilt. Determination of the

timing of gain changes, and other mode changes, will then be tractable problem, with the MODIS-T planning code possibly handled as a team-leader utility.

Simulation of Global Coverage by MODIS-T: Progress Report

In response to requests by Wayne Esaias, Daesoo Han, and Al Fleig, we have initiated a simulation of global coverage by MODIS-T, in an effort to examine the effects of conflicting land/ocean gain mode. According to the MODIS-T operational scenario, gain may be switched to be useful for land observations or ocean observations, but not both simultaneously. This gain-switching is required because of the different reflectance properties of land and ocean. Land reflectance is typically ≈50% while ocean reflectance may be < 10%. It is our understanding that these modes may be switched between scans, but not within scans.

The questions addressed here are: what will be the land coverage if for any scan containing ocean the sensor is ocean mode, and what will be the ocean coverage if for any scan containing land the sensor is in land mode? The answers to these questions will provide extrema in land/ocean coverage and help to assess the sometimes conflicting needs of the land and ocean sciences.

This report is intended to be a progress report of the activities underway. We have designed computer code to simulate the EOS orbit, and scan characteristics of MODIS-T, as given by T. Magner, Jan. 31, 1990 (MODIS-T Instrument Status Report). Important EOS orbital parameters and MODIS-T instrument characteristics used in the code are summarized in Table 1. Given these orbital parameters and sensor characteristics, we computed the sub-orbital track for an untilted sensor, at the nadir-viewing scan position.

The EOS orbits simulated for the ascending node over the Northern Hemisphere are projected over a north polar stereographic map in Figure 1. With the orbital parameters used in these simulations, MODIS-T ground swaths begin to overlap at approximately 55°N. Latitudes and longitudes of the first simulated orbit for the sub-satellite track, and right and left swath edges, are listed in Table 2, in approximately 5° latitude increments up to 81° N.

Applying the criteria that MODIS-T be placed in land mode <u>only</u> when there are <u>no ocean pixels</u> in the scan and using the orbits presented in Figure 1, the swaths over continental regions meeting this criteria of no ocean pixels were shaded in (heavy shading in Figure 2), to visualize how this "absolute ocean priority" would affect the switching of MODIS-T between land and ocean mode. What is apparent is that coverage of land by MODIS-T in land mode, is for the most part, restricted to interior continental regions, the coastal regions are covered in ocean mode (Figure 2). If the sub-satellite tracks are progressed or regressed then the ground swaths would cover different surface features.

Table 1. EOS orbital simulation parameters and MODIS-T instrument characteristics.

EOS Orbital Parameters	
Altitude	705 km
Orbital Repeat Time	16 days (233 orbits)
Period	98.9 minutes
Inclination	98.25 degrees
Equatorial Crossing Time	1:30 local time

MODIS-T Instrument Characteristics	
Scan Width	± 45°
IFOV	1.56 mrad (0.089°)
Ground IFOV at nadir	1.1 km
Scan time	4.75 secs
Pixels Along Scan	1007
Ground Coverage Along Scan	1500 km (at nadir; no tilt)
Tilt	± 50°
Pixels Along Track	30 pixels
Ground Coverage Along Track	32.6 km (at nadir; no tilt)
Successive Orbit Equatorial Crossing Longitude	-24.721°

Table 2. EOS, MODIS-T Ground swath parameters. Ascending node for Northern Hemisphere, in approximately 5° latitude intervals from the equator.

Orbit	Left most		Sub-satellite		Right most	
	long	lat	long	lat	long	lat
1	-6.660	-0.963	0.006	0.001	6.690	0.968
1	-7.779	4.132	-1.096	5.135	5.624	6.071
1	-8.894	8.936	-2.149	9.983	4.655	10.896
1	-10.152	14.012	-3.287	15.115	3.662	16.01
1	-11.508	19.074	-4.464	20.243	2.693	21.129
1	-12.900	23.840	-5.626	25.083	1.794	25.968
1	-14.427	28.587	-6.850	29.918	0.903	30.809
1	-16.228	33.589	-8.260	35.031	-0.039	35.937
1	-18.275	38.557	-9.804	40.133	-0.991	41.068
1	-20.503	43.208	-11.437	44.938	-1.910	45.915
1	-23.279	48.075	-13.427	50.008	-2.921	51.049
1	-26.642	52.860	-15.801	55.049	-3.997	56.183
1	-30.834	57.526	-18.756	60.047	-5.183	61.317
1	-36.232	62.014	-22.632	64.976	-6.558	66.449
1	-43.892	66.444	-28.448	70.047	-8.401	71.863
1	-55.275	70.533	-38.283	75.088	-11.354	77.548
1	-75.357	74.030	-61.661	80.071	-20.575	84.297
1	-95.880	75.021	-95.641	81.756	-93.262	88.508

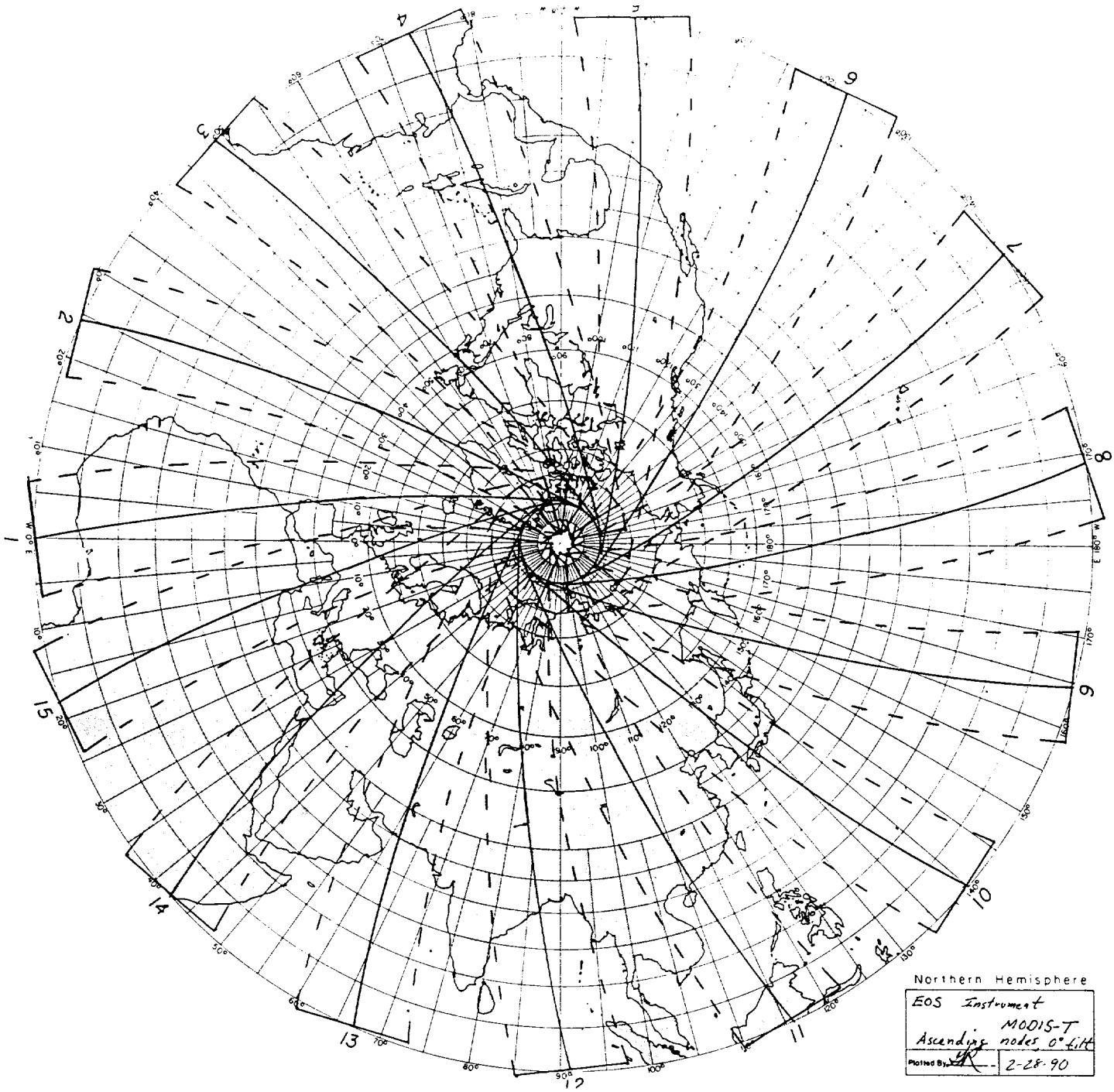


Figure 1. Ascending nodes, Northern Hemisphere, polar stereographic projection, calculated for EOS instrument MODIS-T at 0° tilt angle. Solid lines are sub-satellite track, dashed lines are edges of ground swath.

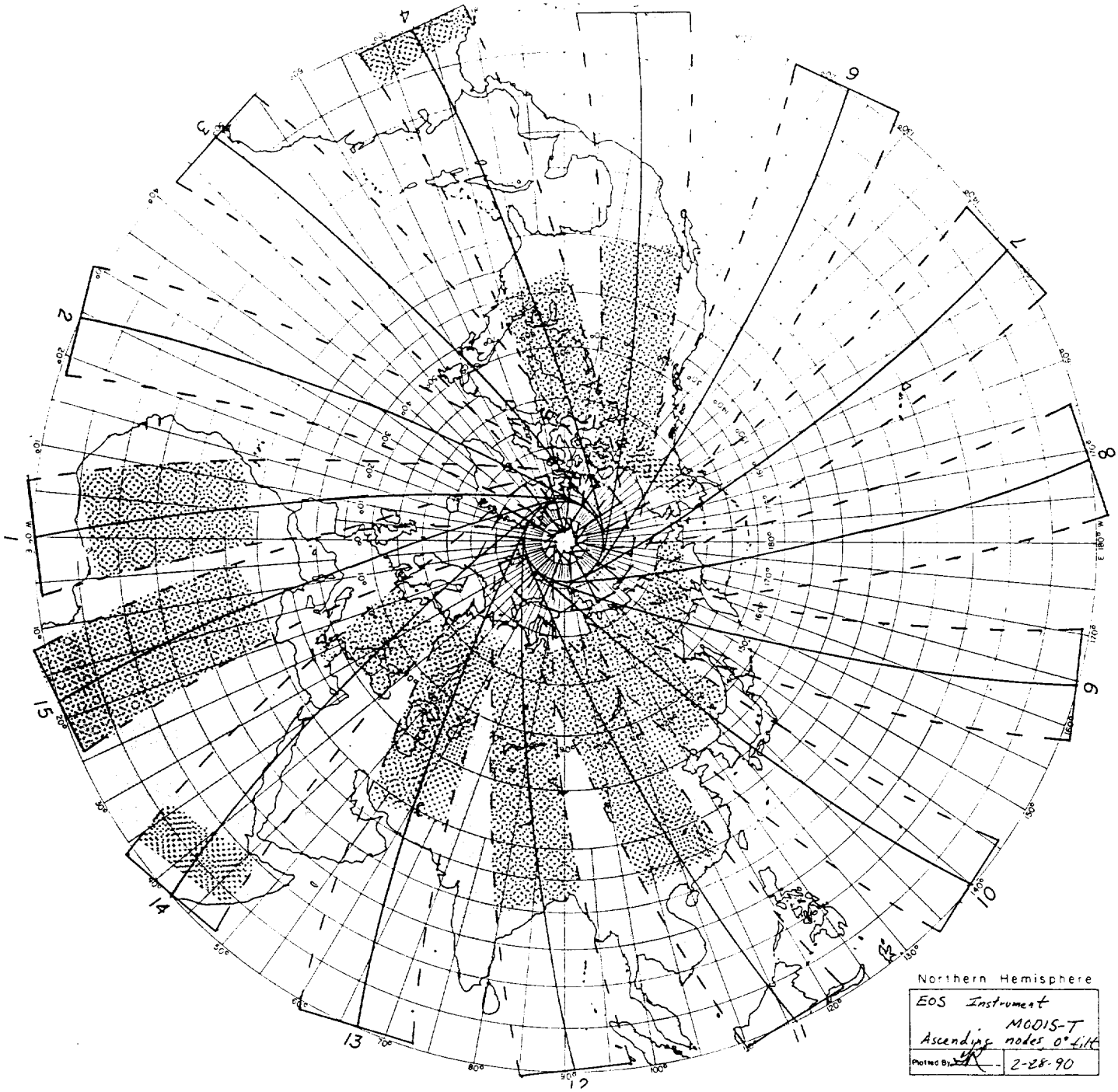


Figure 2. Predicted coverage of land, 100% of scan covering <u>land only</u>, for MODIS-T at 0° tilt, ascending node, Northern Hemisphere. Light shading continents, heavy shading portions of MODIS-T scans covering land only.

Sizing Estimates for Ocean Color Products, Continued.
Concentrations of Pigment, Case 1 Chlorophyll
Case 2 Chlorophyll, Dissolved Organic Matter,
and Total Seston for MODIS

Pigment, Case 1 chlorophyll and Case 2 chlorophyll concentrations, and dissolved organic matter and total seston concentrations are relatively minor products from a computational requirements perspective. Generally they involve ratios of water-leaving radiances, which are derived from atmospheric correction. Sizing estimates of water-leaving radiances were discussed in the MODIS Data Study Team Report of February 16, 1990.

Pigment Concentrations

The method for obtaining pigment concentrations derives directly from the CZCS methodology (Gordon et al., 1983), whereby a ratio of the water-leaving radiances at 443 nm and 550 nm were formed, and pigment concentration estimated by a power function. For high concentrations (> 1 or 1.5 mg m^{-3}), the ratio of 520 nm to 550 nm was formed. This method has been modified to utilize normalized water-leaving radiances (where the solar zenith angle is normalized to nadir and the atmosphere is removed), with different coefficients and exponents, as well as slightly different bands (Gordon, 1988). Although the bands may be different for MODIS, and the coefficients and exponents may change slightly, the method is expected to remain essentially the same and is, thus, a well-defined algorithm. The code for the algorithm (written in FORTRAN 77) is presented in Appendix I. It is assumed that all processing for water-leaving radiances has been performed previously, and that error flags (clouds and missing data) have been checked previously and passed, such that the pigment algorithm will be performed. the only error check in this algorithm is for negative radiances.

Assuming that a power function requires 10 times the number of operations as other arithmetic functions, we estimate the number of operations for the pigment concentration algorithm as shown below. Operations/scan include the assumption of 12,656 pixels per scan for MODIS-N (1582 x 8) and 30,210 pixels per scan for MODIS-T (1007 x 30).

	MODIS-N	MODIS-T
Operations/pixel	34	34
Operations/scan	0.43×10^6	1.03×10^6

Case 1 Chlorophyll Concentrations

The method for determining Case 1 chlorophyll concentrations is unknown at this time and is expected to be a subject of intensive study before MODIS is launched. It is, however, expected that an algorithm will be in place before launch. It is also expected that this algorithm will change substantially after launch. If Sea-WiFS is launched, it will enable testing and validation of this algorithm, thereby reducing the amount of post-launch modifications.

We assume that this algorithm will follow the procedure for determining Case 1 pigment concentrations; that is, taking ratios of water-leaving radiances and empirically fitting coefficients and exponents to in-situ data. However, to isolate chlorophyll from the effects of degradation pigments (primarily phaeophytin), at least another wavelength will be required. Thus we assume that the Case 1 chlorophyll algorithm will contain the ratio of at least one other water-leaving radiance wavelength (probably near 410 nm) to 440 or 560 nm. Computation of the ratio will involve a single additional operation, and we assume that relating this ratio to the pigment ratio will require four additional operations, bringing the total to 39 operations per pixel.

Since this value is, if anything, an underestimate, we do not assume that the algorithm will operate in conjunction with the pigment algorithm, and will be performed separately and independently. This means there are 39 additional operations per pixel to the pigment algorithm. Total operations for MODIS-N and MODIS-T are shown below.

	MODIS-N	MODIS-T
Operations/pixel	39	39
Operations/scan	0.49×10^6	1.18×10^6

Case 2 Chlorophyll Concentrations

A prototype algorithm for Case 2 chlorophyll concentrations has been proposed by K.L. Carder (1989). The algorithm uses ratios of water-leaving radiances at 412 nm, 440 nm, and 560 nm and interpolates through a look-up table of pre-calculated values to determine the amount of chlorophyll and gelbstoff. It thus also provides estimates of gelbstoff in addition to chlorophyll.

Computer code (written in FORTRAN 77) is presented for this algorithm in Appendix II. As with pigment concentrations, it is

assumed that water-leaving radiances are available, and that all cloud/other error flags have been passed. The algorithm operates on a bi-linear interpolation (8 operations) through a pre-calculated look-up table. The only error checks are to ensure that the water-leaving radiance ratios are within range of the look-up table.

If the radiances are out of range of the look-up table, the algorithm requires 22 operations per pixel. We assume this occurs 10% of the time. If radiances are within range, the algorithm requires 142 operations per pixel. A summary is provided below.

	MODIS-N	MODIS-T	
Operations/pixel	22	22	Radiance out of range (10%)
	142	142	Radiance within range (90%)
Operations/scan	1.65×10^6	3.93×10^6	

Dissolved Organic Matter Concentrations

The only optically active dissolved organic matter constituent, to our knowledge, is gelbstoff, or yellow substances. Since it is the only optically active constituent, it is the only one that MODIS is capable of detecting. We assume that estimations of dissolved organic matter will be related to this gelbstoff through an algorithm. But first an algorithm relating water-leaving radiances to gelbstoff must be developed. As one may infer from the preceding discussion, these algorithms were not used in the CZCS era and have not yet been defined, and any estimate of their sizing requirements therefore will have a considerable lack of confidence associated.

Dr. Carder's Case 2 chlorophyll algorithm, described above, explicitly solves for gelbstoff concentrations, for chlorophyll concentrations < 2 mg m^{-3}. Thus, by using this algorithm, gelbstoff concentrations may be obtained at no extra computational cost. However, since Dr. Carder is not listed as the responsible scientist for the dissolved organic matter product as of the most recent MODIS Science Team Meeting (Jan. 30 - Feb. 1, 1990), we assume that this algorithm will not be the primary dissolved organic matter algorithm. Dr. Parslow, who was not in attendance at the meeting, is designated as the responsible scientist.

Given the lack of heritage and information on this algorithm, our sizing estimates can only be a rough guess. However, a reasonable guess is that the algorithm will be some type of combination of the ratios of water-leaving radiances at several wavelengths. Thus we estimate the size as approximately the same as the Case 1 chlorophyll algorithm, i.e., 39 operations per pixel.

Total Seston Concentrations

Seston is suspended matter (organic or inorganic) in the oceans. It is important to know the contribution of seston to the total radiance signal at the satellite in order to more accurately estimate chlorophyll concentrations. This optical constituent will most likely be determined by its spectral scattering properties, rather than the absorption properties that will be used to characterize gelbstoff.

Unfortunately, this algorithm, too, is undefined at this time. Considerable effort on developing this algorithm is expected to result as a consequence of the launch of SeaWiFS and information obtained by Dennis Clark's in-situ buoy network. However, without further information we are again forced to estimate the size of this algorithm as similar to that for dissolved organic matter, i.e., 39 operations per pixel.

Summary

Only one of the 5 algorithms discussed here has previously been used in remote sensing -- the CZCS pigment concentration algorithm. For another, Case 2 chlorophyll concentrations, a prototype approach has been outlined in a proposal (Carder, 1989). Thus we may have good confidence in our estimates of the sizing requirements for MODIS for pigment concentrations, and a reasonable confidence in the Case 2 chlorophyll algorithm. For the remaining three algorithms -- Case 1 chlorophyll, dissolved organic matter, and total seston -- no such information exists. The importance of these potential products is considerable, so that substantial effort will likely go into defining such algorithms. However, at the present time our sizing estimates must be used with great caution, and major changes must be expected. However, based on previous remote sensing work in oceanography, a water-leaving radiance ratio technique has most often been employed, and one might expect its continued usage for these unexplored products. Such reasoning leads to the estimates given here, namely, that the size of these products will be only slightly larger than the pigment algorithm. But it cannot be emphasized too strongly that these estimates carry a poor level of confidence and are, at best, a rough approximation.

References

Carder, K.L. 1989. High spectral resolution MODIS-T algorithms for

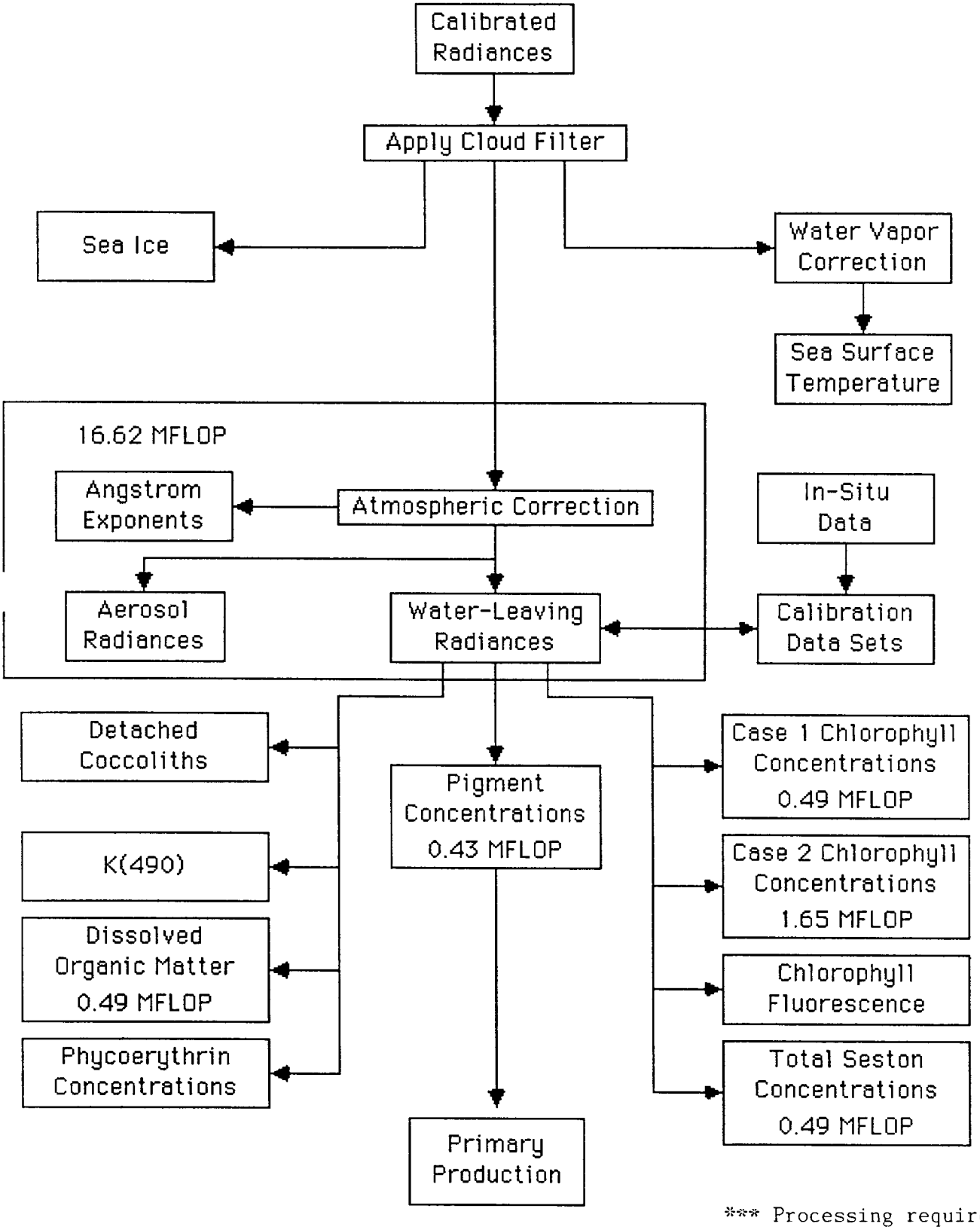
ocean chlorophyll in Case II waters. Eos Team Member Proposal.

Gordon, H.R., 1989. Algorithm development for ocean observation with EOS/MODIS. MODIS Science Team Member Report.

Gordon, H.R., 1988. Ocean color remote sensing systems: radiometric requirements. Recent advances in sensors, radiometry, and data processing for remote sensing, Proceeding of the SPIE, P.N. Slater, ed., pp. 151-165.

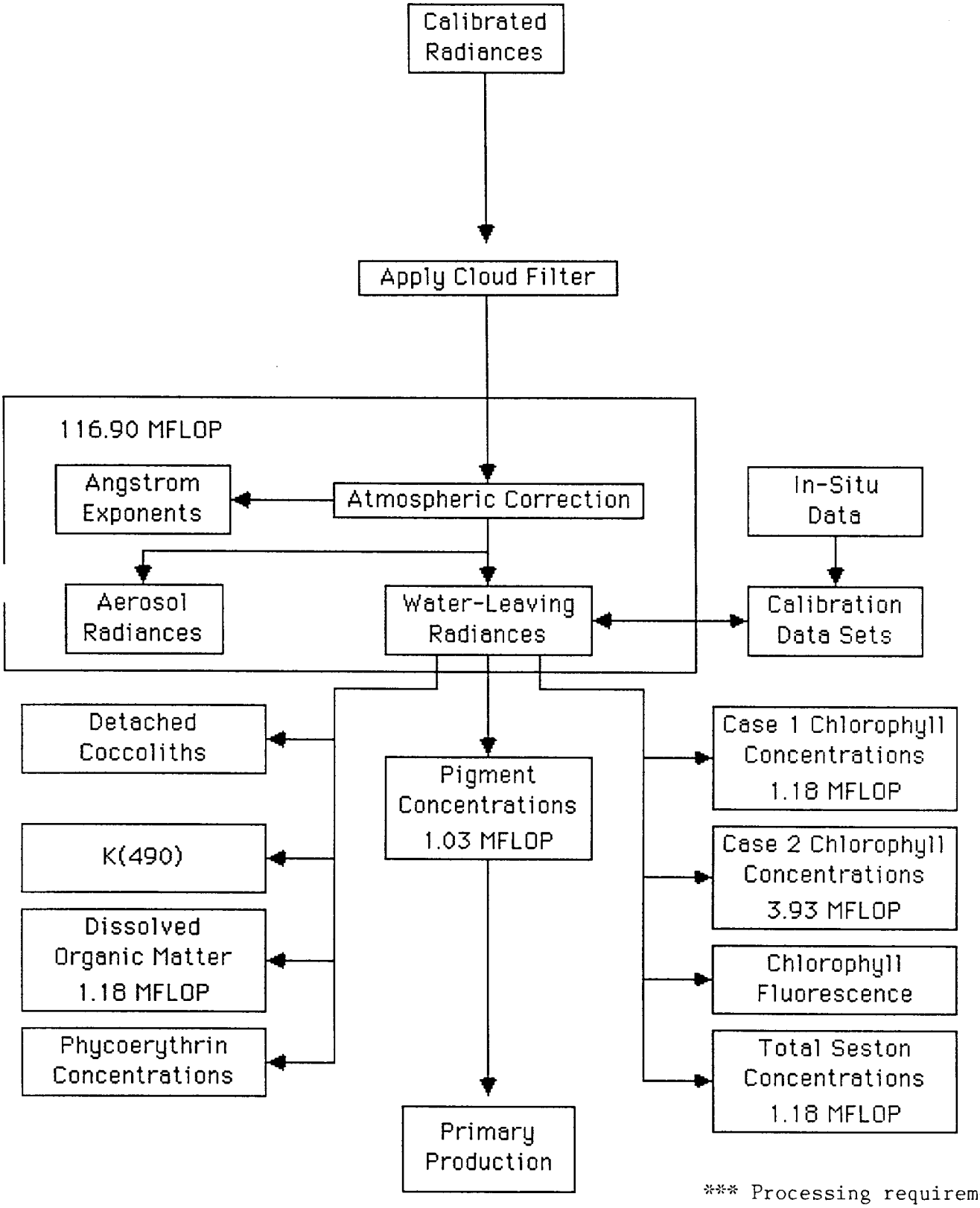
Gordon, H.R., D.K. Clark, J.W. Brown, O.B. Brown, R.H. Evans, and W.W. Broenkow, 1983. Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates. Applied Optics 22: 20-36.

MODIS-N Processing Scenario and Sizing Estimates



*** Processing requirements are per scan

MODIS-T Processing Scenario and Sizing Estimates



*** Processing requirements are per scan.

```
      subroutine pigment(r1,r2,r3,pig)
c
c  Case 1 pigment algorithm for MODIS.  Derived from CZCS
c  method.
c
      ex1 = -1.42
      ex2 = -2.62
      if (r3 .gt. 0.0 .and. r1 .ge. 0.0 .and. r2 .ge. 0.0)then
       rat1 = r1/r3
       rat2 = r2/r3
       c1 = 1.15*rat1**ex1
       c2 = 3.64*rat2**ex2
       if (c1 .le. 1.0)then
        pig = c1
       else
        pig = c2
       endif
      else
       pig = 0.0
      endif
c
      return
      end
```

```
      subroutine case2(chlt,gelt,r1,r2,r3,chl,gelb)
c
c  Carder's proposed Case 2 algorithm for chlorophyll a
c  concentrations and gelbstoff in Case 2 water.  Applies
c  only to concentrations < 2 mg/m3.  Method: bi-linear
c  interpolation through a look-up table.
c  r1 = Lw(410) (or nearest band)
c  r2 = Lw(440) (or nearest band)
c  r3 = Lw(560) (or nearest band)
c
      real chlt(13,15),gelt(13,15)
c
c  Form radiance ratios
      r412 = r1/r2
      r443 = alog10(r2/r3)
c
c  Interpolate within specific range of look-up table
      if (r412 .gt. 1.35 .or. r412 .lt. 0.9)go to 100
      if (r443 .gt. 1.2 .and. r443 .lt. 0.1)go to 100
      do j = 7,15
       r1412 = j/10.0
       if (r1412 .ge. r412)then
        do i = 1,13
         r1443 = (i-1)/10.0
         if (r1443 .ge. r443)then
          x0 = r1443
          x1 = i/10.0
          y0 = r1412
          y1 = (j+1)/10.0
          f00 = chlt(i,j)
          f10 = chlt(i+1,j)
          f01 = chlt(i,j+1)
          f11 = chlt(i+1,j+1)
          x = r443
          y = r412
          call bilin(x0,x1,y0,y1,f00,f10,f01,f11,x,y,chl)
          f00 = gelt(i,j)
          f10 = gelt(i+1,j)
          f01 = gelt(i,j+1)
          f11 = gelt(i+1,j+1)
          call bilin(x0,x1,y0,y1,f00,f10,f01,f11,x,y,gel)
         endif
        enddo
       endif
      enddo
      go to 200
c
100   chl = 0.0
      gelb = 0.0
c
200   continue
      return
      end
```