MODIS DATA STUDY
TEAM PRESENTATION

February 9, 1990

AGENDA

1. Status of the MODIS Data Study Task (Ardanuy)
2. MODIS Ocean Science Team Meeting Summary (Gregg, Wolford)
3. MODIS Land Science Team Meeting Summary (Riggs, Schols)
4. MODIS Atmosphere Science Team Meeting Summary (Ardanuy, Andrews)
5. MODIS Calibration Science Team Meeting Summary (McKay, Hoyt)
6. Accuracy Requirements for Wind Speeds for Ocean Color Data Processing (Gregg)
7. Two Aerosol Size Distribution Estimates: Reasons for Differences (Hoyt, Andrews)
8. Timing Tests on the IBM 3081 (Hoyt)
9. Processing Estimates of Optical Depth Effective Radius (Andrews, Hoyt)

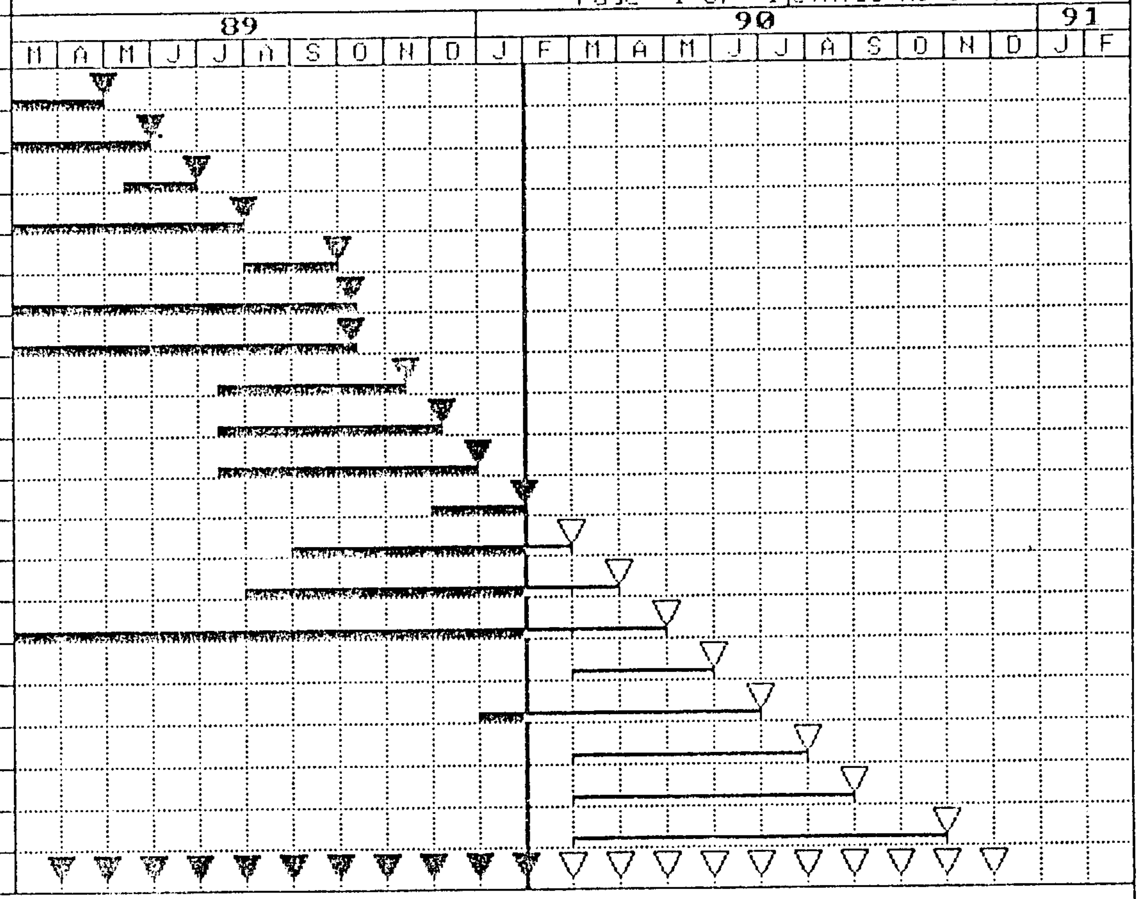
MODIS DATA SYSTEM STUDY
APPROVAL
ACCOMP.

Summary of Deliverables

Page 1 of 1

ORIG. APPVL. 06/24/88
LAST CHANGE 12/15/89
STATUS AS OF 02/01/90

	MILESTONES
01	Scenarios for Science Team
02	Prel TM Sci Prod Summary
03	Support MODIS Science Team Mtg
04	Input Data Attributes Report
05	MODIS Data Pkt Recommendation
06	Prel Core Prod Algorithm Rep
07	Prel TM Core Prod Analysis Rep
08	Core Data Proc Scenario Doc
09	Post-L'nch Da Proc Sc'rio Doc
10	Utility/Sup't Algo Req'ts Doc
11	Pres'n to MODIS Sci Team
12	MODIS SDST/~~ICT~~ Req'ts Document
13	Proc/Stor&Comm Req'ts Doc
14	Core Product Requirements Doc
15	MODIS Science Team Mtg Support
16	Earth-Loc'n Comp'n Req'ts Doc
17	Prel L-1 Data Format Document
18	~~Cal'n Algo Implement'n Report~~
19	Prel L-1 Proc Sys Design
20	Monthly Reports



Note:

Scenario / Ops concept ... new proposals.

MODIS Ocean Science Team Meeting Minutes

Attendees

MODIS Science Team: W. Esaias (Group Leader), M. Abbott (OSU), I. Barton (CSIRO), W. Barnes (GSFC), O. Brown (U.Miami), K. Carder (USF), D. Clark (NOAA), R. Evans (U.Miami), H. Gordon (U.Miami), F. Hoge (GSFC)
Others: D. Case (ARC), A. Fleig (GSFC), W. Gregg (RDC), M. Lewis (NASA HQ), T. Wolford (GSC).

Recommendations

1. Instrument
-- Require Dual Mode. Composite Mode fails to meet SNR requirements in the near infrared.
-- Recommend series of clear apertures to minimize exposure of integrating sphere.

2. EosDIS Role Pre-Launch
-- Request better definition.

3. Algorithm Development/Software
-- Provide integrated, optimized code for algorithms to EosDIS through University of Miami. All algorithms developed by the Ocean Science Data Team will be sent to Miami for integration and optimization, including required ancillary data, which will then provide for interaction with EosDIS. This approach was selected because of the strong historical record of Miami in developing algorithms and processing previous ocean data (CZCS and AVHRR), and prospective future sensors (SeaWiFS, OCTS, ATSR). Another consideration was the "amorphous nature" of EosDIS, making it difficult for the investigators to know how to structure their code and algorithms.

4. Utility Algorithms
-- Add navigation. Note: Earth-location is already included as a utility algorithm.

5. Real Time/Quick Look Data
-- Require Level 0 data within 3 hours.

6. Calibration/Validation Program
-- Require dedicated cruises pre- and post-launch, regionally

and globally. Ships, buoys, drifters and aircraft all required.
Visible: 3 moorings, 3-6 month turnaround
10 drifters per ocean basin, with a 6 month lifetime, including water-leaving radiances at 4-6 wavelengths
2 Case 2 cruises per year pre-launch, 1 blue water cruise
3-4 cruises the first year post-launch
Series of dedicated cruises (every 2 years) for 15 years including Case 1 and Case 2 waters
Areas needed to sample:
High latitudes
Southern Ocean
Dust areas (NW Africa, Japan, NY Bight)
Tropics
Central Gyres
Need also primary production data from these areas.
In-Situ Sensors/Instrumentation Needed:
Shipboard 5-channel radiometer for IR, with 10 copies
Drifters (≈50/year)
Shipboard laser system
Compact aircraft lidars
Aircraft bathyphotometers
Protocol
Costs for validation: 10-20 million/year for 4 cruises

7. Accuracies of Products

-- Generally agreed that they were not representative, but did not resolve issues at this meeting. Decided that each accuracy statement required a number of caveats. For Product A (Chlorophyll a Concentrations), caveats were:

- 50% RMS error compared to ships
- In the Sargasso Sea
- 6 months after launch
- Validation required
- Chlorophyll concentrations < 1 mg m^{-3}
- Sensor calibration within ± 5%
- Assume L_w known to ± 10%
- Given ancillary data wind speeds, ozone, pressure

Team did not assess accuracies of other products. Issue was delayed.

8. Level 3 Products

-- Define 3 types of products
1) Local: 1 km, daily
2) Regional: 4 km, weekly
3) Global: 20 km, monthly
for all products

9. Data Packetization

-- Request band-interleaved. Since algorithms require multiple bands, this is the easiest and best approach. If lose a packet, only lose a pixel, not all pixels as would happen otherwise.

MODIS Ocean Data Products

I. Standard Products

Product	Responsible Scientist	MODIS Sensor
A. Chlorophyll a Concentrations (Case 1)	Clark	N,T
B. Chlorophyll a Concentrations (Case 2)	Carder	N,T
C. Chlorophyll a Fluorescence	Abbott	N
D. CZCS Pigment Concentrations	Gordon	N,T
E. Sea Surface Temperature	Global[1] Barton	N
	Regional[1] Brown	N
F. Water-Leaving Radiances	Gordon	N,T
G. Attenuation at 490 nm (K_{490})	Gordon	N,T
H. Detached Coccolith Conc.	Gordon	N,T
I. Dissolved Organic Matter	Parslow	N,T
J. Sea Ice	Salomonson	?
K. Phycoerythrin Concentrations	Hoge	T
L. Single Scattering Aerosol Radiances (τ_a<0.6)	Gordon	N,T
M. Angstrom Exponents (τ_a<0.6)	Gordon	N,T
N. Total Seston Concentrations	Clark	N,T
O. Calibration Data Sets	Evans	N/A
P. Primary Production[2]	Esaias	N,T

MODIS Ocean Data Products

II. Special Products

Product	Responsible Scientist	MODIS Sensor
A. Primary Production[2]	Esaias/Abbott	N,T
B. High Chlorophyll Conc. from Fluorescence	Abbott	N
Fluorescence Efficiency	Abbott	N
Primary Production from Fluorescence	Abbott	N
C. Surface Incident PAR	Gordon	N
D. Attenuation of PAR	Gordon	
E. Daily Par	Ancillary	N/A
F. Beam Attenuation at 520 nm	Clark	N,T
G. Particulate Scattering	Parslow	N,T

III. Other Products

Product	Responsible Scientist	MODIS Sensor
A. Cloud Flag		
B. Scattering Coefficient	Gordon (Case 1) Carder (Case 2)	
C. Phytoplankton Scattering Coefficient	Gordon (Case 1) Carder (Case 2)	
D. Non-Phytoplankton Scattering Coefficient	Gordon (Case 1) Carder (Case 2)	
E. Total Absorption Coefficient	Carder	
F. Phytoplankton Absorption Coefficient	Carder	
G. Non-Phytoplankton Absorption Coefficient	Carder	
H. Glint Field	Evans	N,T
I. Error Flags	Evans	N,T

1. Global -- 20, 50 km, weekly and monthly
   Regional -- 1, 4, 20 km, daily and weekly

2. monthly by region; annually by global

MODIS Science Team Meeting
31 January - 2 February, 1990

Land Discipline Working Group Summary

Discussion in the working group sessions focused on identifying and defining at launch and post launch data products, which scientist(s) would be responsible for them, utility/support algorithms needed, ancillary data sets needed, and simulated data needed for algorithm development. The emphasis common through the working group sessions was the integration of execution phase proposals so that there would be a cohesive group of proposals among team members in regards to allocation of research resources, prioritization of research, and the dependency upon one another for data products or algorithms. Specifics of algorithms, data products, or ancillary data were not emphasized in those discussions. As a group they were not concerned with the information requested in the Data Product Tables (i.e. II Land At-Launch Data Product) except for the product itself and the scientist(s) responsible, and how the product could be used among them to produce other data products. Also, a concern was raised that there should be a means for infusion of new research "blood" in to the group should a team member depart, for whatever reasons.

Discussions in the land working group sessions indicate that the team members will be expecting the CDHF to routinely supply calibrated at satellite radiance, with a suite of utility/support algorithms applied, or available for selection and application in the production of data products. There is also the expectation that the MODIS imagery will be earth located and that a Digital Terrain Model (DTM), for topographical correction of data, be in place at time of launch. Team members will also be expecting EosDIS to have a Geographic Information System (GIS) component, containing e.g. geophysical information, soils maps, biophysical data, and surface meteorological data at regional and global scales available for their use.

Land products discussed in the land working group are given below with comments on development and production of the product discussed during working group sessions. Changes from previously identified land products are noted, and data inputs are mentioned. (Some data products require both ancillary data and MODIS data products for production, so are simply identified as data inputs here.) The algorithms for these land products are in an evolving state and expected to change during the next four years.

Discussions did not resolve the priority and integration of data products production in the CDHF environment, nor explicitly define sources and integration of required input data. These tasks apparently fall to the team leader.

AT LAUNCH DATA PRODUCTS

Team members will accept the at satellite radiance but, want data from the calibration and/or characterization team(s) assuring that the radiance values are good.

Land Leaving Radiances (Kaufman/Tanre)

Surface Directional Reflectance is the revised name for this product. (Discussed for only the reflective bands.) And, in some respects is considered as a Utility product from which other products are derived.

Lots of discussion and concern as to how atmospheric corrections are to be done, and how accurate would the resulting surface reflectance be. The atmospheric corrections algorithm proposed by Kaufman & Tanre corrects for ozone absorption, water absorption, Rayleigh (molecular) scattering, and aerosol scattering. Correction for aerosols derives aerosol optical thickness from the image itself, this requires a priori knowledge of the location and nature of invariant targets, e.g. dense, dark green vegetation in the image. It may be possible that this a priori reflectance knowledge could be supplied by surface location map(s) of known surface reflectance targets. (Such maps could also serve the atmospheric group; Kaufman is likely to develop this algorithm for use in both disciplines.) This may require that surface cover maps be developed that could be referenced by the aerosol correction algorithm during processing at the CDHF. Of immediate concern is to compile/develop simulated data to be used in developing/testing the atmospheric correction algorithms. Kaufman & Tanre suggest that the aerosol correction should be a specialized product at this time. Corrections for ozone absorption, water, and Rayleigh scattering could be done routinely, and require data inputs of ozone amount, water amount, and surface pressure.

Vegetation Index (Justice/Huete)

NDVI was the vegetation index identified for at launch production, with an improved NDVI in post launch. Spatial resolution, 214 m; Temporal resolution, daily; Space scale, global; Accuracy, absolute, 0.03-0.04, relative, 0.02. Utilities; atmospheric correction, topographic correction; Data inputs; MODIS-T, HIRIS, MISER

Surface Temperature (Wan)

Atmospheric corrections will be required for the thermal channels. Surface emissivity to be determined. MODIS-N bands 31-36; Spatial resolution, 856 m; Temporal resolution, global. Utilities; atmospheric correction/radiative transfer, spatial heterogeneity. Data inputs; land cover, spatial heterogeneity.

Snow Cover (Salomonson/Hall)

Methods of determining snow cover, and discriminating between snow and clouds discussed. MODIS-N bands, all reflective, and several thermal; Spatial resolution, 10 km; Temporal resolution, weekly; Space scale, global. Utilities; topographic correction. Data inputs; MODIS-T, BRDF, high resolution microwave data.

Land Cover Type (ALL)

It was decided by the land working group to eliminate the term, biome. They discussed categories of "natural units" oriented towards biological characteristics. Group needs to define categories of "natural units". Product would be used to monitor vegetation dynamics and for many higher level products. Spatial resolution, 5 km, 25 km, 0.5°; Temporal resolution, twice yearly. Data inputs; NDVI, MODIS-T, spatial heterogeneity, LAI, length of growing season, DTM.

Thermal Anomalies (Kaufman)

Anticipated use of product is for detecting fires, occurrence and size. MODIS-N bands 21, 31, 32; Temporal resolution, diurnal, night and day images needed; Space scale, global. Data inputs; water vapor concentration, land cover, MODIS-T, HIRIS.

DESIRED AT LAUNCH UTILITY & SUPPORT ALGORITHMS

Sensor Data Quality/
Characterization, Calibration (Barker)
At Satellite Radiance (Barker)
Surface Directional Reflectance (Kaufman/and team)
Derived from atmospheric corrections

Spatial Heterogeneity (Barker)

Not a well defined concept, but would involve using the high spatial resolution bands to produce a measure of surface spatial heterogeneity for the courser resolution bands. This product could be used to assess variability within pixels and be a part of browse data. Will require that all spatial resolutions be co-registered in some way to create this heterogeneity measure for different resolutions.

Topographic Correction (Muller)

Consensus of group was that there be a Digital Terrain Model (DTM) in place at time of launch. Topographic corrections are very important for many science applications, and for improving data products. Need 100 m horizontal resolution topographic data combined with 214 m resolution MODIS data to produce a good correction. One point concerning DTM that was not addressed was what earth location method to use. Muller says geocentric earth located would be best method.

Townshend brought up the point that image mapping between resolutions (GIFOV's) presents an applications problem. Ground resolutions would need to be co-registered.

Cloud mask, cloud shadow (Barker)

Input from outside the group is needed to develop a cloud mask. Specifics of a cloud mask are TBD. Expected to be done at the 214 m spatial resolution.

Geometry issues (Justice/Townshend/Barker)
Jitter (system issue)
Both concerned with orientation and stability of the platform earth location and registration of pixels.

POST LAUNCH DATA PRODUCTS

Level-1 Topographic Corrections, for surface radiance (Muller)
Incident PAR (TBD)

Bidirectional Reflectance, BRDF (Muller/Barnsley/Strahler/Hall)
Requires "corrected" MODIS-T data. BRDF product constructed from many MODIS-T passes at different tilts; many technical issues and problems involved with constructing these data sets.

Albedo (Muller/Barnsley/Strahler/Hall)
A surface albedo product that could be developed from several data products and utilities was discussed, the final form of an albedo product was not specified but left open to research and development. An albedo product may require; MODIS-T data, atmospheric corrections, known surface albedo maps, and DTM.

Soil Brightness Index (Huete)
Requires MODIS-N bands 1-7, MODIS-T, HIRIS, and soils data.

Length of Growing Season	(Justice)
Surface Emissivity	(Wan)
Primary Production (above ground)	(Running)
LAI	(Running)
Surface Diffusion Resistance	(Running)
Thermal Inertia	(Huete)
Surface Roughness	(Muller/Barnsley)
Polarization-improved vegetation index	(Vanderbilt)
Evapotranspiration	(TBD)
CO_2 Balance	(Running)
Vegetation Decomposition	(Huete)

MODIS SCIENCE TEAM MEETING ATMOSPHERE DISCIPLINE MINUTES

Attendees:

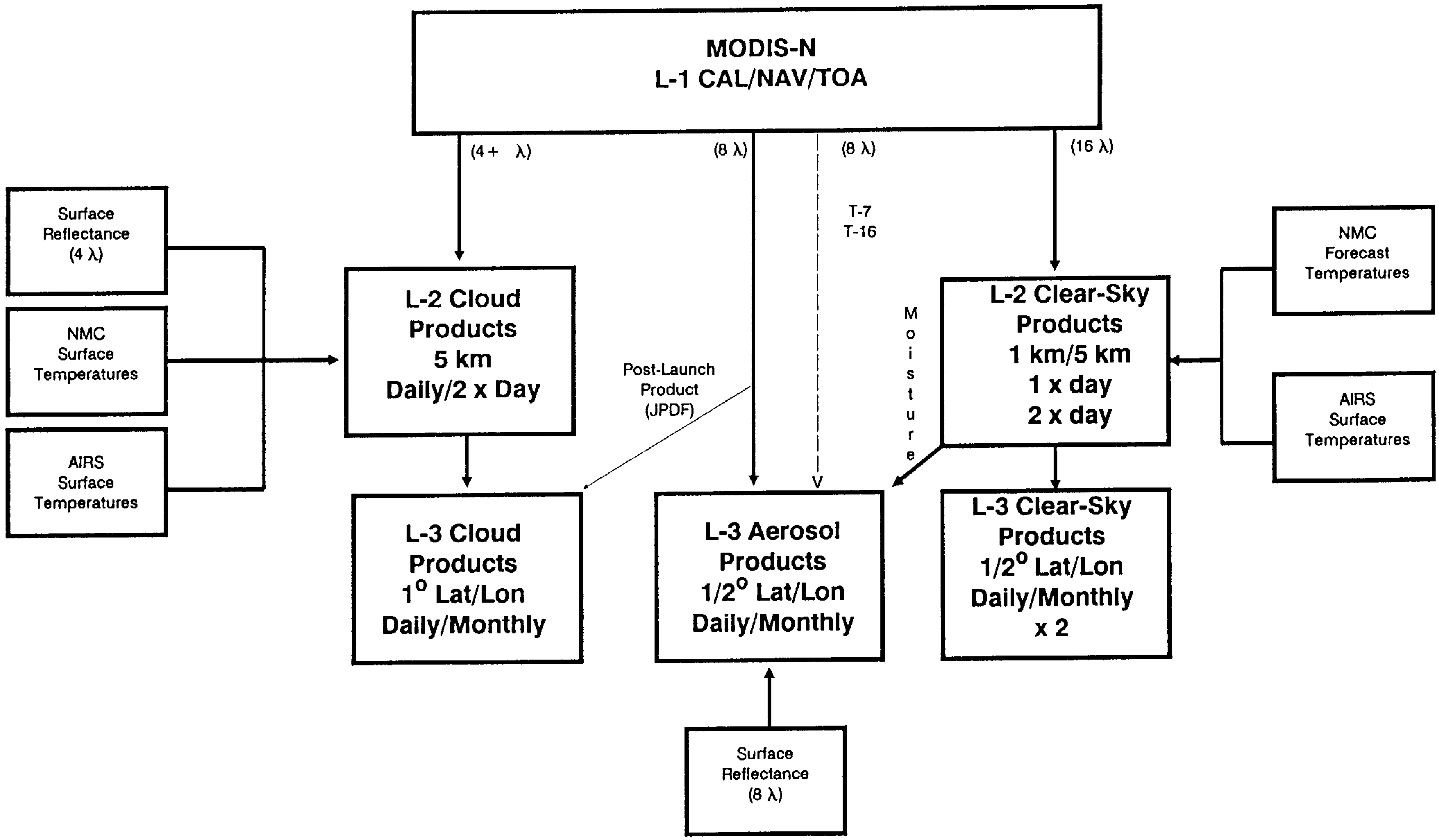
MODIS Science Team Members: Mike King (Group Leader), Yoram Kaufman, Paul Menzel, Didier Tanre

Others: Locke Stuart, Lee Kyle, Philip Ardanuy, Mike Andrews

MODIS AT-LAUNCH/CORE ATMOSPHERIC DISCIPLINE DATA PRODUCTS			
PRODUCT DESCRIPTION	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RESPONSIBLE INVESTIGATOR
Cloud 0.66 μm Optical Thickness	5 km Level-2 1° Level-3	Daily Level-2 Daily/Monthly Level-3	King
Cloud Fractional Area	5 km Level-2 1° Level-3	Daily Level-2 Daily/Monthly Level-3	Utility/King
Cloud Effective Emissivity	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel
Cloud-Top Temperature	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel
Cloud-Top Pressure	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel
Cloud Particle Effective Radius	5 km Level-2 1° Level-3	Daily Level-2 Daily/Monthly Level-3	King
Cloud Particle Thermodynamic Phase	5 km Level-2 1° Level-3	Daily Level-2 Daily/Monthly Level-3	King
Aerosol Optical Depth (0.41 to 2.13 μm)	0.5° Level-3	Daily/Monthly Level-3	Tanre (ocean) Kaufman (land)
Aerosol Size Distribution	0.5° Level-3	Daily/Monthly Level-3	Tanre/Kaufman

Aerosol Mass Loading	0.5° Level-3	Daily/Monthly Level-3	Kaufman/Tanre
Atmospheric Stability	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel
Total Precipitable Water	1 km Level-2 (day) 5 km Level-2 (day and night) 1° Level-3	Daily Level-2 Twice Daily Level-2 Daily/Monthly Level-3	Kaufman/Tanre (day) Menzel/Barton (night)
Total Ozone	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel
Layer-Mean Temperatures (at 3 to 4 layers)	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel (secondary product)
Layer Mean Moisture (at 2 to 3 layers)	5 km Level-2 1° Level-3	Twice Daily Level-2 Daily/Monthly Level-3	Menzel (secondary product)

MODIS ATMOSPHERIC AT-LAUNCH PRODUCTS AND DATA FLOWS



I. CLOUD AT-LAUNCH/CORE DATA PRODUCTS

There will be seven at launch cloud products all of which will be produced at Level-2 with 5 km resolution.

There will be a Level-3 daily and monthly products with 1° resolution. The 0.66 μm Cloud Optical Thickness and Cloud-Droplet Effective Radius will be simultaneously calculated in a single algorithm during daytime only. Dr. King will be responsible for these products and intends to add a test to determine the Thermodynamic Phase to the existing algorithm. The products will be generated at 5 km by selecting one or several individual pixels to process in an area of approximately (5 km)^2 pixels. A priori supplied surface reflectance at four wavelengths will be required ancillary data.

Dr. Paul Menzel will be responsible for producing Cloud Effective Emissivity, Cloud Top Pressure/Height, and Cloud-Top Temperature by means of an existing CO_2 slicing algorithm. The Level-2 products will be generated at 5 km resolution by sub-sampling and averaging. Atmospheric profiles of temperature and moisture for the first guess (this is a "physical" scheme) are required ancillary data, as is the surface temperature. These ancillary data may come from operationally NMC forecast fields, or from AMSU as EOS Level-3 product data.[1] Required clear-sky radiances will be obtain either from a "nearby" clear pixel or a previous observation.

The final cloud product is Fractional Area. This product will be generated with 5 km resolution by summing or otherwise interpreting the cloud flags. A utility algorithm is proposed to generate the cloud flags. Hence, this product will likely be jointly produced by King and collaborators and the MODIS team leader. A "reflected-solar" Cloud Fractional Area product could be generated during the day and a thermal-IR product during both day and night.

II. CLEAR SKY AT-LAUNCH/CORE DATA PRODUCTS

There will be two basic sets of clear sky products at launch. The first set of products will be Aerosol Optical Depth, Mean Particle Size (and dispersion), and Aerosol Mass Loading. These algorithms will be developed by Tanre and Kaufman. The Aerosol Optical Depth (at eight wavelengths) requires either that the surface reflectance

[1]Discussions with Joel Susskind, Bill Smith, and others have indicated that AIRS data will be promptly included in NMC's global data assimilation scheme as soon as its value and capabilities beyond TOVS are demonstrated. Therefore, AIRS sounding data may be routinely available hours after acquisition without any EOS timeliness conflicts.

be known or that the observing geometry by repeated[2]. As a result, several different methods will be applied to determine the optical depth. Since the aerosols do not vary rapidly in space and significant averaging will be required, all of the aerosol products will be generated at Level-3 directly from the Level-1 data during the daytime only. The products may take the form of daily updates to a global aerosol map.

Dr. King suggested that Aerosol Size Distribution product be changed to an Effective Particle Radius to save computation.[3] The only input data required for this product is the Optical Depth.

The Aerosol Optical Depth and Size Distribution products will be used to calculate the Aerosol Mass Loading. Producing this product will also require knowledge of Total Precipitable Water. Total Precipitable Water will be produced as a Level-2 product with 1 km resolution during the day by MODIS as a standard data product.

Dr. Menzel will produce an Atmospheric Stability Index (e.g., lifted index), Total Precipitable Water, and Total Ozone Content. These products will be generated during both daytime and night-time with 5 km resolution. The corresponding Level-3 products will have 1° resolution and will be generated as daily and monthly fields.

The Total Precipitable Water product is to be produced twice-daily at Level-2 a second, more-accurate algorithm will also be employed for daytime only. Only one Level-3 daily product will be generated.

III. POST LAUNCH DATA PRODUCTS

There were three post-launch products discussed in the working group. (Dr. King added a fourth product for his presentation.) The Aerosol Single Scattering Albedo is proposed to be generated as a Level-3 product for clear-sky regions over land only during the day. The product will be generated daily, and monthly averages or statistics will be produced.

The Cloud Area and Perimeter stays a post-launch product. There are well developed algorithms to generate this product. However, it is not known which bands should be used and exactly what statistics are most useful. Kaufman is working in this area.

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[2]This requirement, for repeated views of the same territory on multiple days (perhaps separated by 7 or 16 days when the viewing geometry is most similar) is a processing system driver.

[3]Note that at 50 km resolution, the size distribution algorithm would demand a processing capacity of approximately 10 MFLOPS.

The Cloud Characterization Joint Probability Distribution Function (JPDF) was conceptualized during the working group meeting. This product will be generated at Level-3 with 1° resolution and is intended to be a multi-variable distribution of all the observed cloud properties, and some Level-1 radiances.

IV. TEAM MEMBER INVOLVEMENT IN IMPLEMENTATION

The MODIS science team members from the atmospheric discipline will develop their proposed algorithms and deliver working code. The team members are not interested, and therefore may not be involved in, integrating the code to run in the CDHF facilities and may not fully perform the required/desired optimization. The team members will be involved in testing the implemented code and validating the products. The cloud fraction product is viewed by the team members as a "utility product," to be provided by the team leader with team member (King and Menzel) assistance.

The MODIS Science Team Calibration Group

31 January - 2 February 1990

As a part of the second MODIS Science Team meeting held at Goddard Space Flight Center from 31 January through 2 February 1990, a few Science Team Members interested in MODIS instrument calibration met to discuss instrument calibration activities and define appropriate activities for the MODIS Science Team Calibration Group. Bruce Guenther served as group chairman. The Calibration Group meetings were generally sparsely attended; primary Science Team Member attendance was at the individual science discipline groups (land, ocean, and atmospheric sciences), where data product implementation responsibilities were being discussed among the team members.

The first issue considered by the calibration group relates to the definition of appropriate activities for the group and the appropriate division of product validation activities among the members of the calibration group and the Science Team Members responsible for individual products. It was agreed that the primary focus of the calibration group must be the basic Level-1 radiance product of the instrument. All activities relating to the spectral, radiometric, and geometric calibration of the instrument are included. The validation of derived geophysical parameters (Level-2 products and above) is primarily the responsibility of the Science Team Members implementing the corresponding products. Calibration activities can include the examination of selected Level-2 products for which the accuracy and reasonableness of the derived Level-2 product can confirm or deny the accuracy of calibration parameters used during Level-1 processing. Instrument calibration problems are sometimes first detected as anomalies or inconsistencies in derived geophysical products.

The instrument calibration activity consists of prelaunch characterization done in the laboratory before instrument launch and performance validation done once the instrument is in orbit. Prelaunch calibration support includes the provision of common instrument calibration standards for use with all Eos radiometric instruments and the provision of a single, transportable, high-accuracy reference standard to which all instrument calibration standards are compared to ensure absolute and relative accuracy among the instrument calibration standards themselves. In-orbit calibration and performance validation will likely include the use of instrument on-board calibration systems and cross-calibration to external references such as the moon, other satellite-borne radiance-measuring sensors, airborne sensors, cold space, and perhaps the dark side of the earth (for the visual bands).

The basic procedures for MODIS-N calibration will be proposed and executed by the instrument contractor. To a large extent, procedures for MODIS-T can imitate the MODIS-N procedures. The Science Team Calibration Group will review and approve all procedures applied for instrument calibration. The Calibration Group may also recommend calibration procedures that go beyond those proposed by the instrument contractors.

The Calibration Group serves as the coordination point for Science Team Member input on instrument calibration. Besides the obvious need to receive and act on Team Member concerns relating to calibration, the Calibration Group can also serve as a communications facilitator for matters related to calibration and product validation. Examples of this sort of activity might include the tabulation of (perhaps conflicting) desires of Team Members for adjustments in calibration parameters and perhaps the sponsorship of an early-results conference soon after instrument launch at which Team Members can compare notes on the apparent validity of their products and the initial radiometric calibration of the MODIS instrument.

The MODIS Science Team Calibration Group may also develop and distribute a set of common definitions and data system conventions relating to MODIS data quality. One objective of this effort is to develop suitable definitions of data quality categories that can be understood and applied by all members of the MODIS Science Team and the ultimate data product user. Another objective is to specify a common set of data formatting conventions that can be used to implement the quality definitions and designate MODIS data quality throughout the data system.

The Calibration Group may also coordinate an effort to relate specific MODIS calibration accuracy requirements to corresponding accuracy requirements for derived geophysical products. The intent of this effort is to justify specified instrument accuracy requirements in terms of the underlying data product accuracy required for acceptable earth and environmental science. This justification will be developed primarily by the science team members developing the individual products, and in this effort, the Calibration Group will serve primarily as coordinator and advisor.

The Calibration Group intends to prepare a "MODIS Calibration Management Plan" which will specify overall MODIS calibration procedures and the activities of MODIS Science Team Calibration Group. This document will be one of the first deliverables of the Calibration Group.

Accuracy Requirements for Wind Speeds
for MODIS Ocean Color Data Processing

Wind speed is required to determine radiance contributions due to sun glitter and sea foam to the total radiance received by MODIS. Wind speeds are known to relate to sun glitter by the theory of Cox and Munk (1954) and to sea foam by the observations of Koepke (1984). However, it is not presently known how reflectance from sea foam will relate to remote sensing (Gordon, 1987). Thus this discussion will concentrate on the effects of sun glitter on the proposed MODIS ocean color atmospheric correction algorithms, and the accuracies of wind speeds required to reduce this sun glitter contamination.

Near the latitude of solar declination, MODIS-N will be at times uncorrectably contaminated by sun glitter. MODIS-T has a tilt capability enabling it to avoid areas of maximum sun glitter (i.e., the solar spectral point), but it, too, will encounter uncorrectably high sun glitter contamination at times. For these situations knowledge of wind speeds will be of no help in retrieving the water-leaving radiance. However, in areas of mild sun glitter, knowledge of wind speeds will enable more accurate atmospheric corrections and increase the area of useable Earth coverage.

For CZCS processing, a 6 m s^{-1} global averaged wind speed was assumed. Then from orbital geometries and Cox and Munk (1954) wave slope distribution probability, a threshold sun glitter radiance was set, above which no processing was performed. This conservative scheme rejected for processing pixels that probably were useable, but at least provided a "hands-off", automated procedure for estimating sun glitter. MODIS, with its higher radiometric sensitivity, will require a better approach, one that explicitly computes sun glitter as a function of wind speed, and removes this contribution to the total radiance.

Effects of Sun Glitter on Water-Leaving Radiance

Figure 1 illustrates the effect of sun glitter on the total radiance received by the sensor at low chlorophyll concentration. For this illustration we used the bio-optical model of Sathyendranath and Platt (1988) to determine the optical properties of ocean water containing various concentrations of chlorophyll, and the radiative transfer model of Gordon et al. (1988) to estimate the radiance emanating from the water. Sun glitter reflectance was 0.0132, which resulted from solar and spacecraft zenith angles of 30°, and a wind speed of 14 m s^{-1}. These values were taken from Viollier, et al. (1980). Aerosol radiance was estimated at 0.19 mW cm^{-2} μm^{-1} sr^{-1} at 875 nm, with an Angstrom

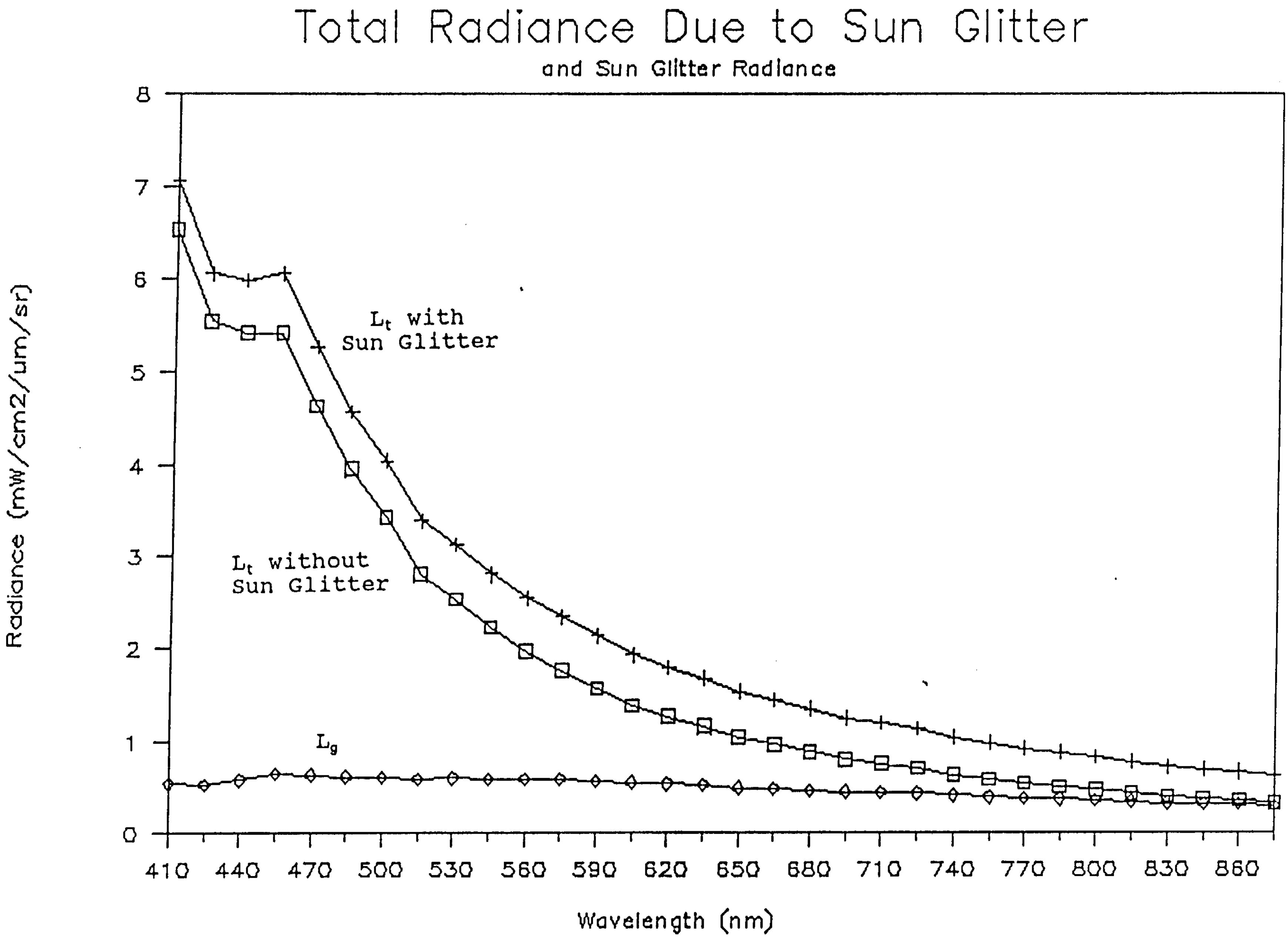

Figure 1. Total radiance L_t with and without sun glitter, and the sun glitter radiance L_g at wind speed of 14 m s^{-1}, and low (≈0.03 mg m^{-3}) chlorophyll concentrations.

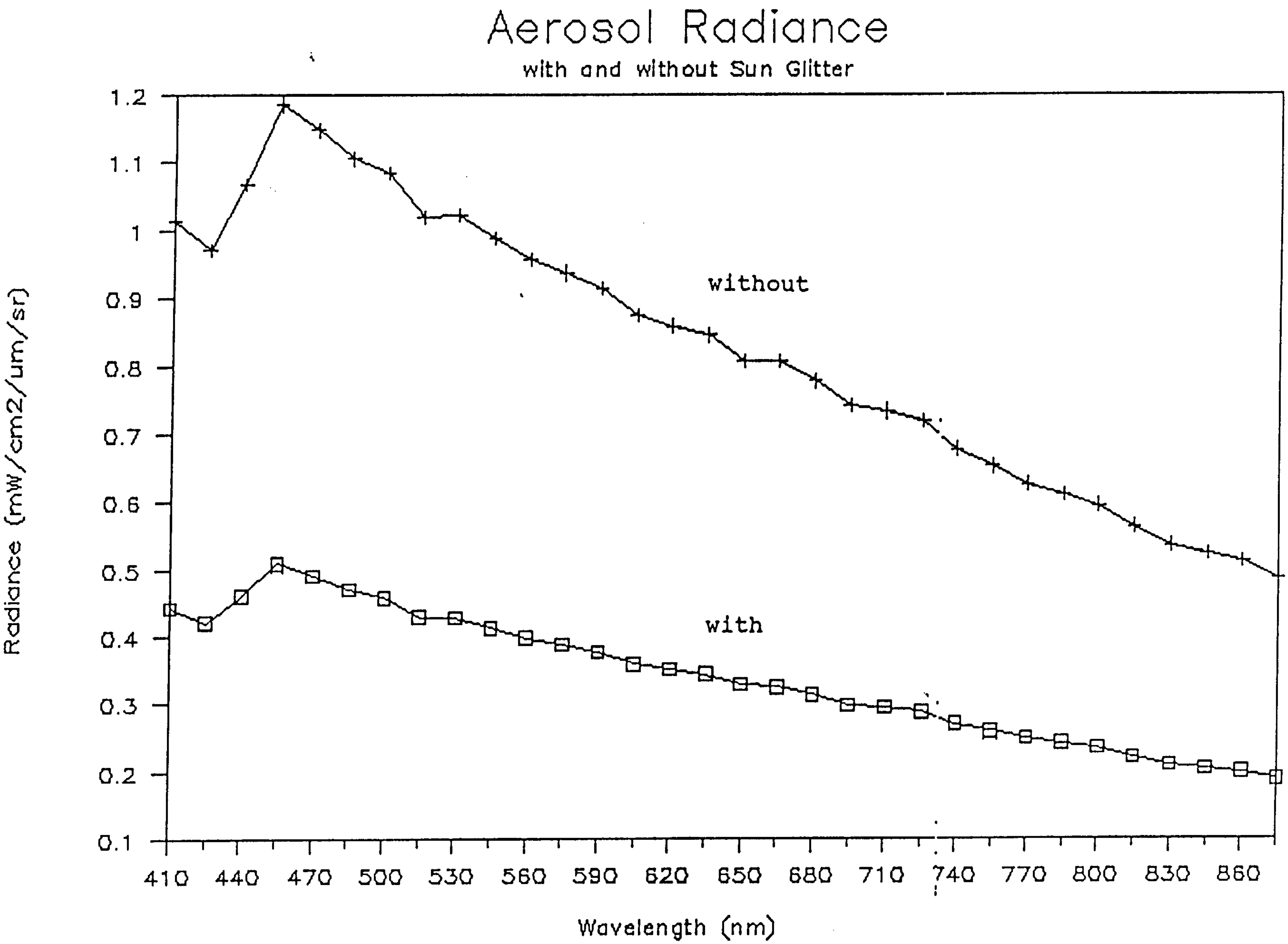

Figure 2. Aerosol radiances computed by the MODIS proposed atmospheric correction algorithm with and without a sun glitter correction.

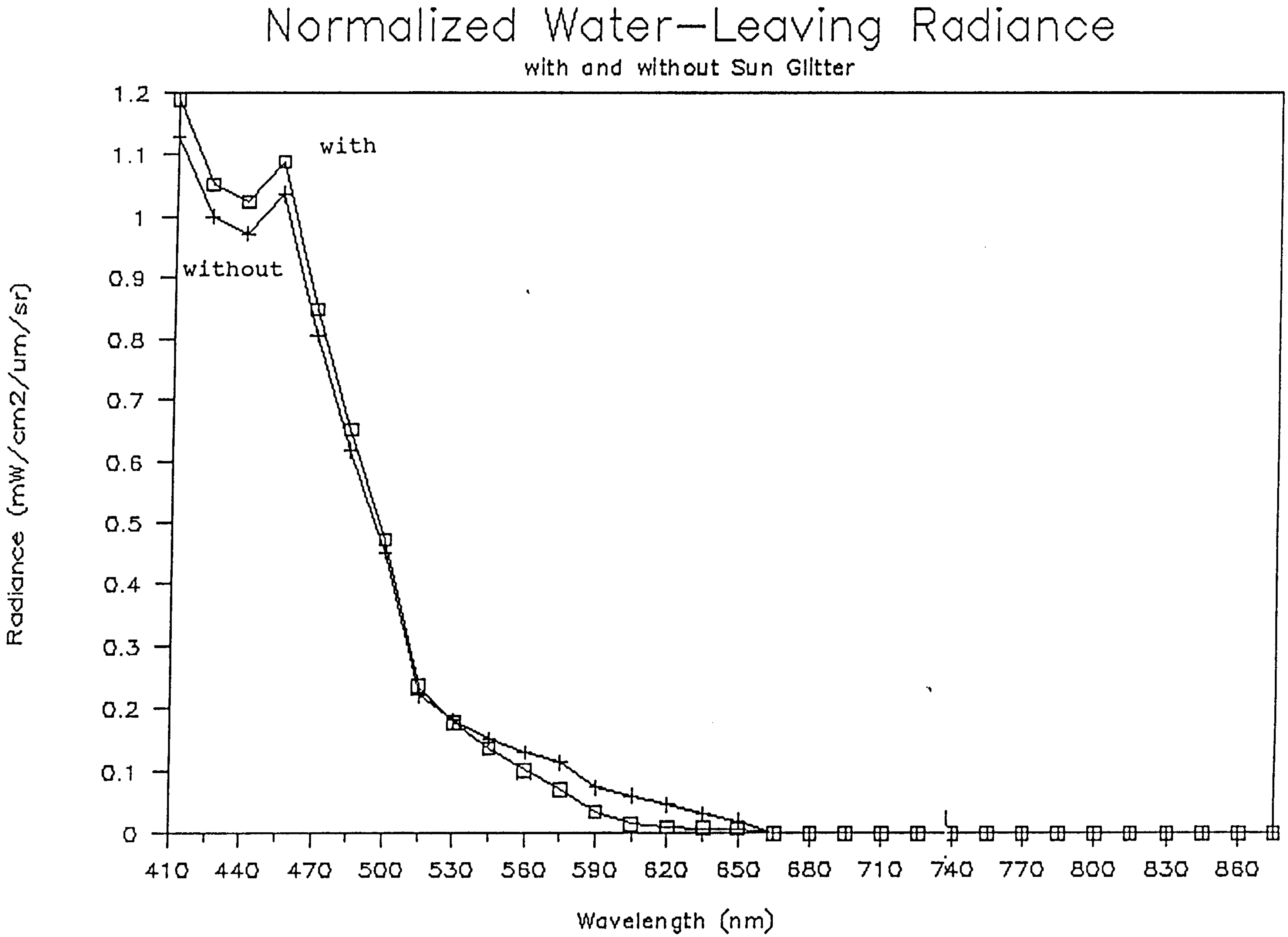

Figure 3. Normalized water-leaving radiances with and without a sun glitter correction.

exponent of 0.3, considered typical of maritime atmospheres (von Hoyningen-Huene and Raabe, 1987).

Using the Cox and Munk (1954) theory, we simulated the effects of wind speed on sun glitter, and using the proposed atmospheric correction algorithm of Gordon (1989), we simulated the effects of wind speed on subsequent determinations of water-leaving radiances. In the proposed atmospheric correction method, radiance contributions from Rayleigh scattering, aerosols, sun glitter, and the water are considered independent according to

$$L_t = L_r + tL_g + L_a + tL_w \tag{1}$$

(wavelength dependence has been neglected for convenience) where L_t is the total radiance detected by MODIS, L_r is the Rayleigh scattering radiance (single scattering assumed for these simulations), L_g is the sun glitter radiance, L_a is the aerosol radiance, t is the diffuse transmittance through the atmosphere, and L_w is the water-leaving radiance.

Because the water-leaving radiance is computed as the residual after contributions by Rayleigh, sun glitter, and aerosols have been removed, an error in estimating sun glitter (due to an incorrect estimate of wind speed) will result in an incorrect determination of water-leaving radiance. An error in sun glitter, however, does not translate linearly into an error in water-leaving radiance. This is because the method for determining aerosol radiance (described in the MODIS Core Data Product and Algorithm Report, MODIS Data Study Team, October 6, 1989) allows the aerosol to absorb some of the error in sun glitter, resulting in a smaller water-leaving radiance error. This can be seen in Figure 2, where approximately 90% of the uncompensated sun glitter shown in Figure 1 was taken as aerosol radiance. Thus, for this situation, a sun glitter error of 0.6 mW cm^{-2} μm^{-1} sr^{-1} at 410 nm resulted in a normalized water-leaving radiance error of $\approx$0.08 mW cm^{-2} μm^{-1} sr^{-1} (Figure 3) (numbers do not strictly add up because of the normalization of the water-leaving radiances to zenith solar angle and removal of the atmosphere).

Eos Orbital Simulation

The effect of uncompensated sun glitter on aerosol radiances was simulated using realistic Eos orbits in order to ensure meaningful and realistic simulations. Orbital geometries were computed using the CZCS Geolocation Algorithm Report (Wilson et al., 1981) into which Eos orbital parameters were substituted (Table 1).

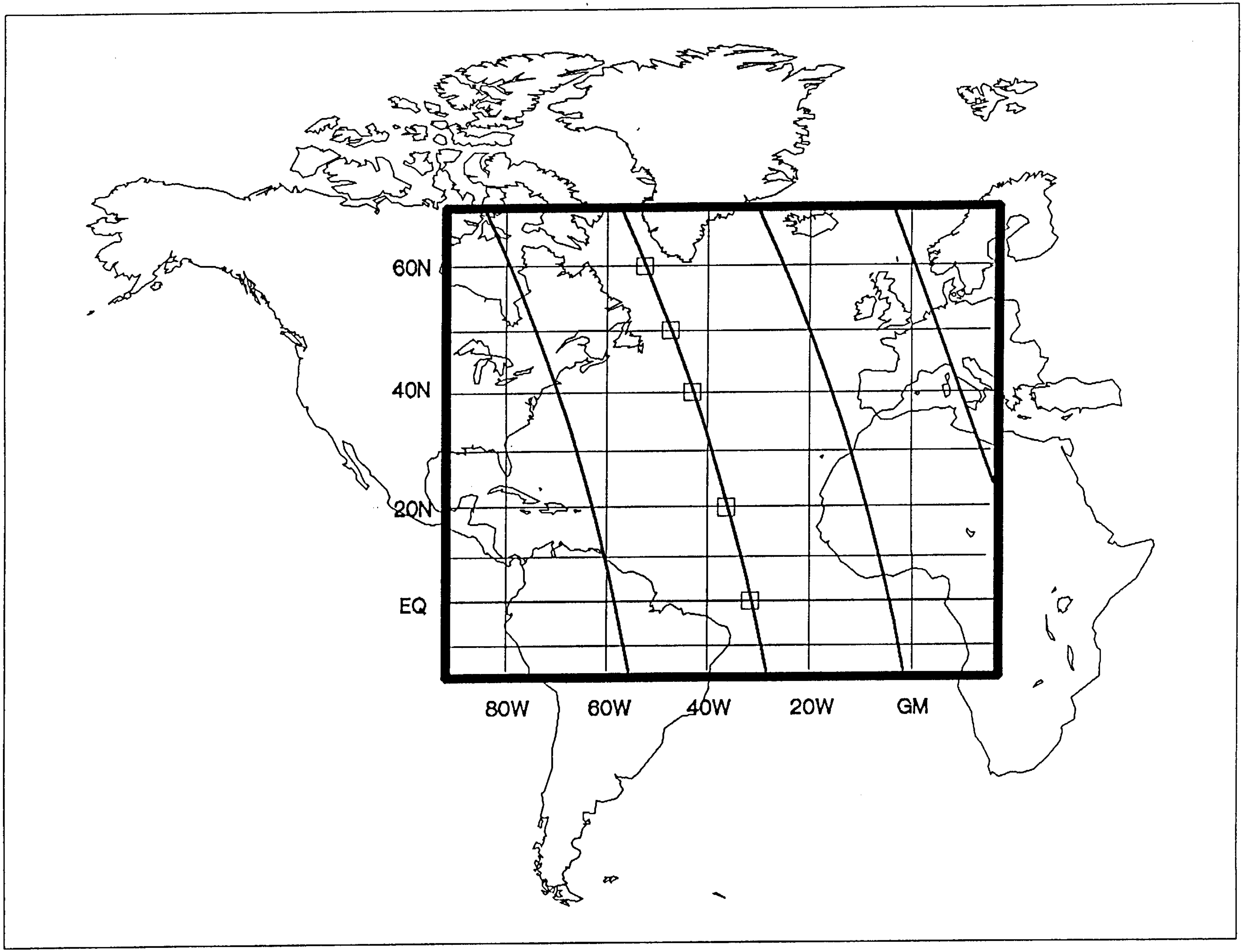

Figure 4. Representation of Eos orbital tracks used in the simulation analyses. Boxes indicate Earth locations where of the sub-satellite ground point where

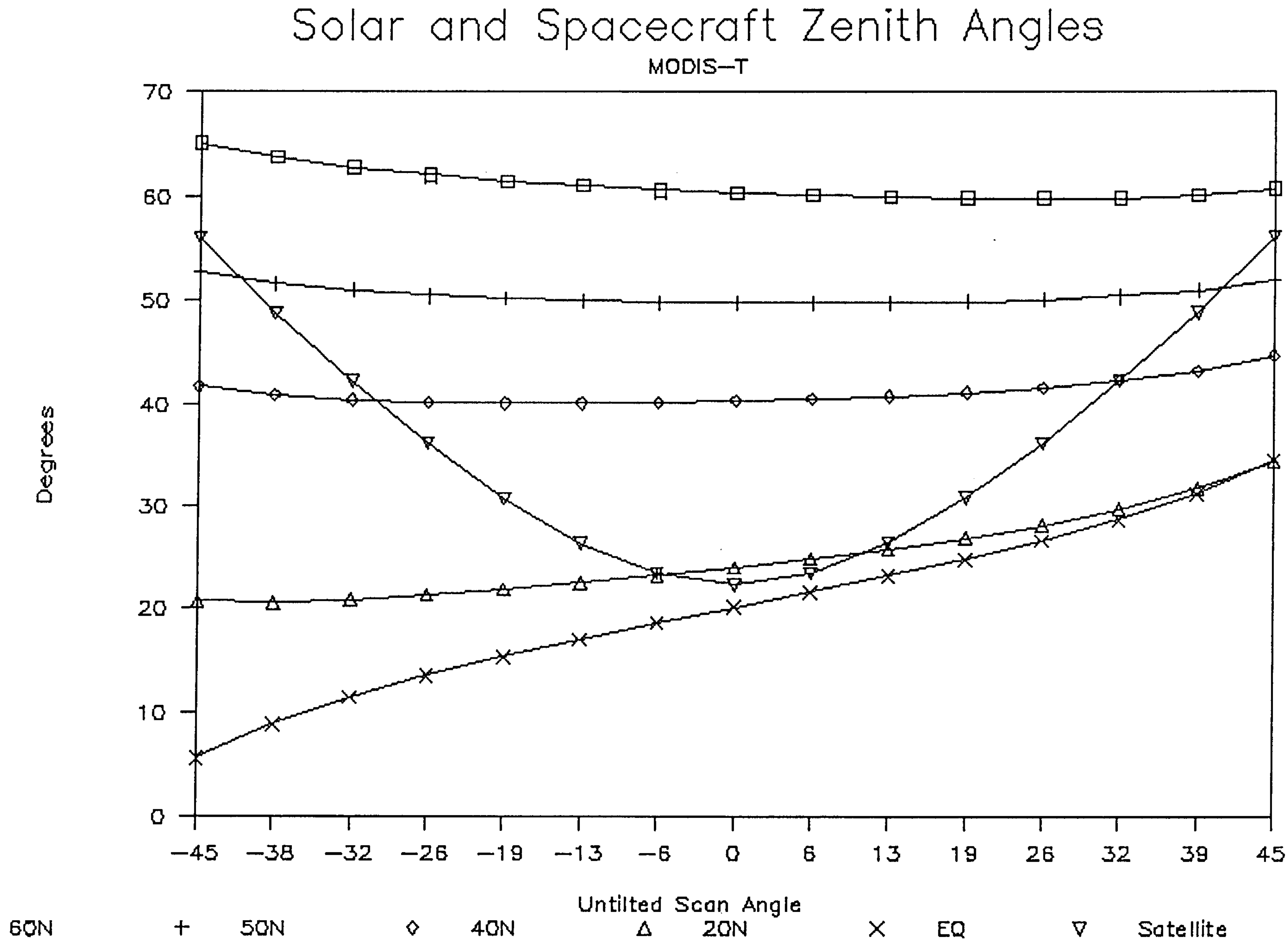

Figure 5. Distribution of solar zenith angles at Earth pixels across the satellite scan.

Table 1. Orbital parameters of Earth Observing System (Eos) platform used for MODIS orbital simulation.

Altitude	705 km
Inclination	98.25°
Equator Crossing Time	1:30 PM
Swath Width (Degrees)	
--MODIS-T	$\pm 45^{\circ}$
--MODIS-N	$\pm 55^{\circ}$

A series of typical Eos orbits are diagrammatically represented in Figure 4. We chose five locations along the orbit from the Equator northward, denoted by the boxes along the center orbit in Figure 4. These positions correspond to sub-satellite ground points at the Equator, 20°N, 40°N, 50°N, and 60°N. Spacecraft zenith and azimuth angles for these positions were computed using the CZCS Geolocation Algorithm Report (Wilson et al., 1981), modified for the Eos orbital parameters. The sensor scanned across the Earth ground points (pixels) according to MODIS specifications. Solar zenith and azimuth angles were computed from knowledge of the Earth latitude/longitude of the pixel under examination. Computations were performed for the vernal equinox. In the following, MODIS-T was simulated and a tilt of 20° forward was assumed. Solar and spacecraft zenith angles for Earth pixels across the satellite scan are shown in Figure 5 for the five sub-satellite points.

Effect of Wind Speed on Glitter Error and Water-Leaving Radiance Error

The effects of errors in the estimation of wind speed on sun glitter and water-leaving radiances were assessed by simulating the differences in these quantities at wind speeds of $\pm$ 1, $\pm$ 2, and $\pm$ 5 m s^{-1} from the global mean wind speed of 6 m s^{-1}. Estimates of error in sun glitter were assessed at 500 nm because initial analyses showed the errors were largest here after atmospheric attenuation was incorporated. Errors in water-leaving radiance were assessed at 410 nm again because initial analyses showed the error due to uncompensated glitter to be largest at this wavelength.

Error in estimated sun glitter at 500 nm due to various over- and underestimates of wind speed are depicted in Figure 6 for a sub-satellite point at the Equator and a 20° tilt. With such tilt the scan does not encounter the specular point, but there is still substantial error in glitter radiance. The maximum error occurred by overestimating the wind speed by 5 m s^{-1}.

These glitter errors resulted in water-leaving radiance errors as

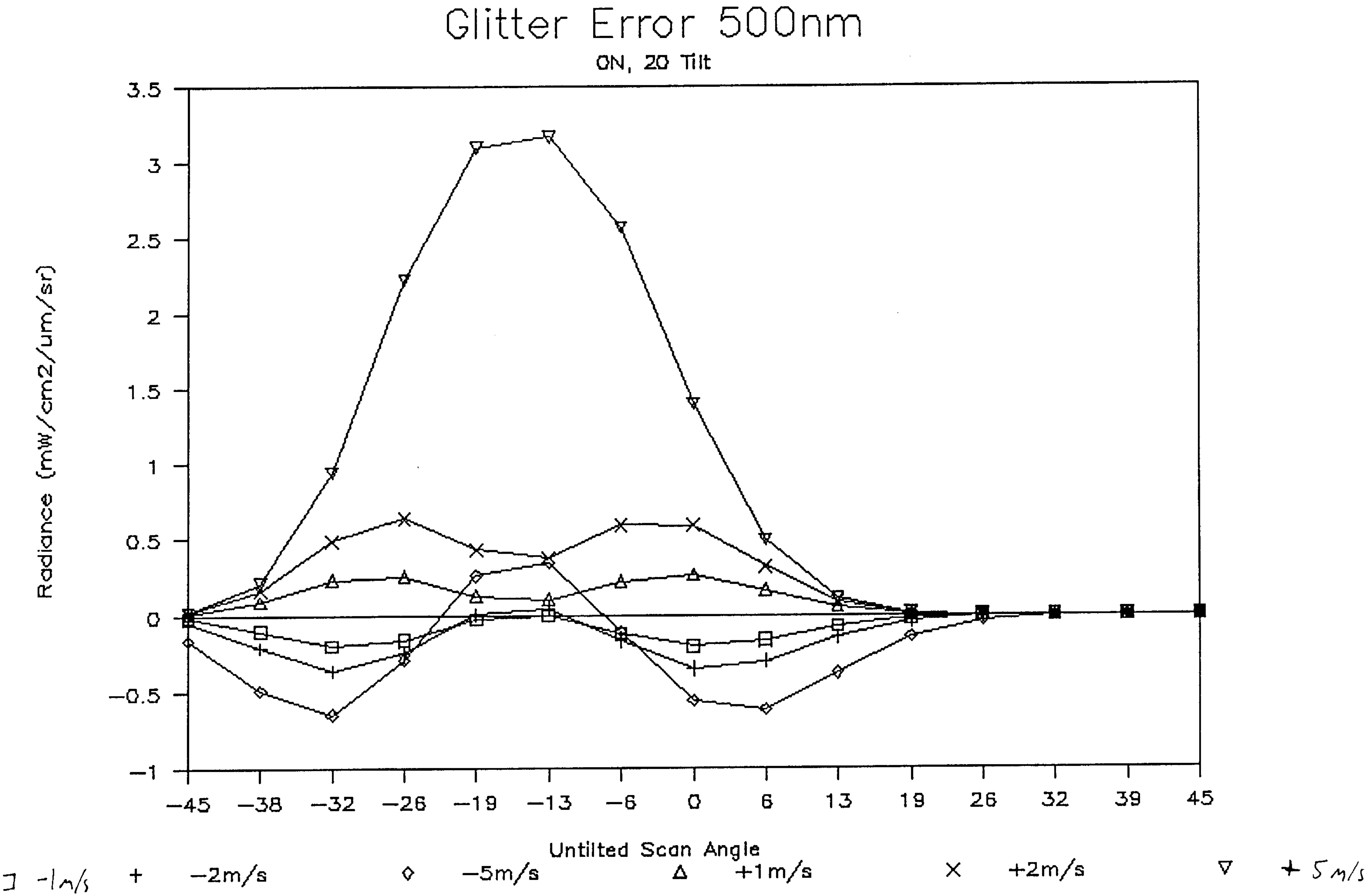

Figure 6. Glitter error at 500 nm due to over- and underestimating wind speed for a sub-satellite point at the Equator, with a 20° forward tilt.

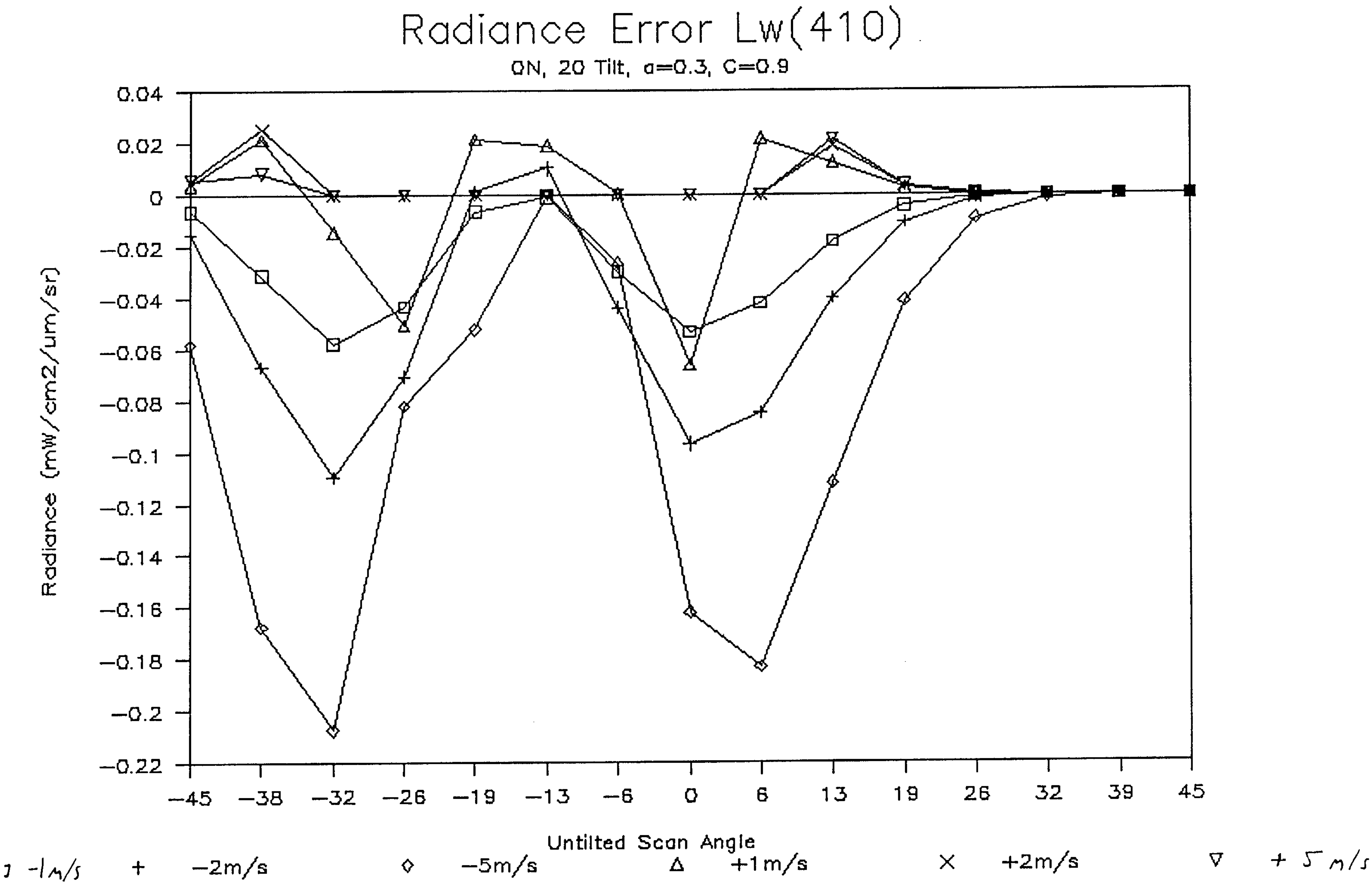

Figure 7. Error in normalized water-leaving radiance at 410 nm due to over- and underestimating wind speed for a sub-satellite point at the Equator, with a 20° forward tilt. This assessment was made for an aerosol Angstrom exponent of 0.3 and medium chlorophyll concentration (~0.9 mg m^{-3}).

shown in Figure 7 after atmospheric correction. Given a MODIS NEdL of 0.005 mW cm^{-2} μm^{-1} sr^{-1} at 410 nm (Preliminary Specification for MODIS-N, Sept. 1989 and MODIS-T Specification for Phase-B Study, July, 1989), that MODIS radiometric requirements are met only at the extreme right edge of the scan, even for a wind speed error of $\pm$ 1 m s^{-1}. (Note: the apparent zero errors near the center of the scan are not actually zero, but rather the water-leaving radiance became negative due to the error in glitter). Recall that these errors resulted from a tilted sensor, and thus illustrate a "best case" for wind speed/glitter error.

Glitter errors (Figure 8) become reduced for a sub-satellite point at 20N (still tilted 20°), as do water-leaving radiance errors (Figure 9), but still errors exceed MODIS NEdL near the center of the scan, even for a wind speed error of $\pm$ 1 m s^{-1}. However, a larger proportion of the scan is useable at this latitude.

At a sub-satellite ground point at 40N, water-leaving radiances errors at 410 nm are within MODIS NEdL for wind speed errors up to $\pm$ 5 m s^{-1} (Figure 10). At an overestimate of 5 m s^{-1}, the error is within 2 NEdL. Thus the problem of sun glitter contamination is negligible at 40N, given knowledge of wind speeds to within about 5 m s^{-1} and a 20° tilted sensor.

However, a 10° tilt at 40N does not meet MODIS NEdL (Figure 11). In such case, even wind speed errors of $\pm$ 1 m s^{-1} will produce errors in L_w exceeding the NEdL.

Thus water-leaving radiance retrievals are very sensitive to sun glitter contamination, and wind speeds must be known to high accuracy in order to correct for it. Even at 40N a 10° tilted sensor will not meet MODIS NEdL unless the wind speed is known to better than 1 m s^{-1}. Such requirements pose high demands on the ancillary data requirements for MODIS.

These simulations were run for aerosols typical of marine conditions and moderate chlorophyll concentrations. Different chlorophyll concentrations did not change the error assessments substantially, but changing the aerosol type (i.e., the Angstrom exponent) did. At a sub-satellite ground point at 20N with a 20° tilt, an Angstrom exponent of 1.0 increased the error due to a $\pm$ 1 m s^{-1} wind speed error by about a factor of 2. At greater wind speed errors the error in water-leaving radiances increased by about a factor of 5. Thus the error in wind speed depends upon the aerosol type. However, Angstrom exponents of 1.0 tend to be the exception for maritime atmospheres, and the value of 0.3 is more typical.

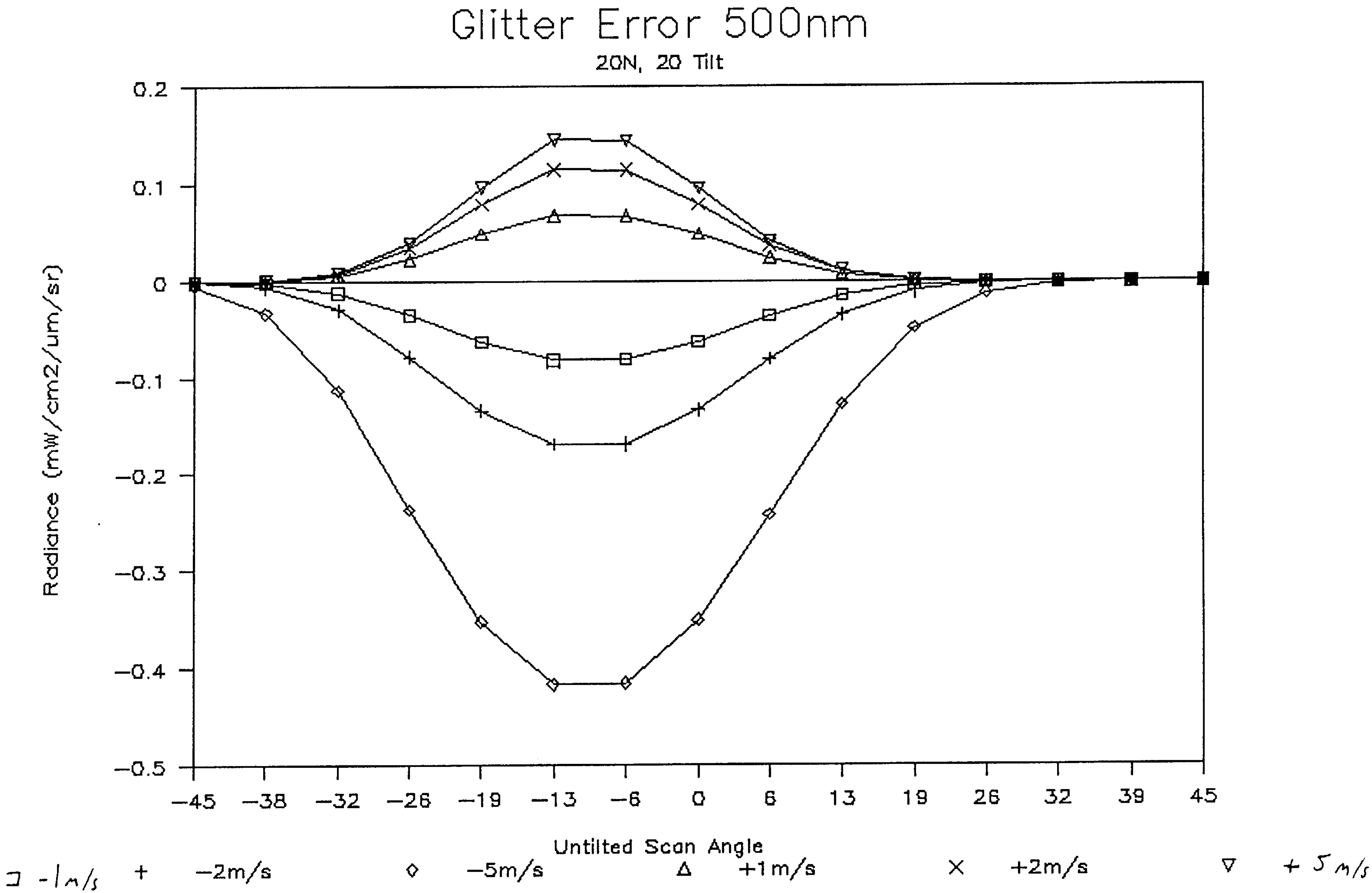

Figure 8. Glitter error at 500 nm due to over- and underestimating wind speed for a sub-satellite point at 20N, with a 20° forward tilt.

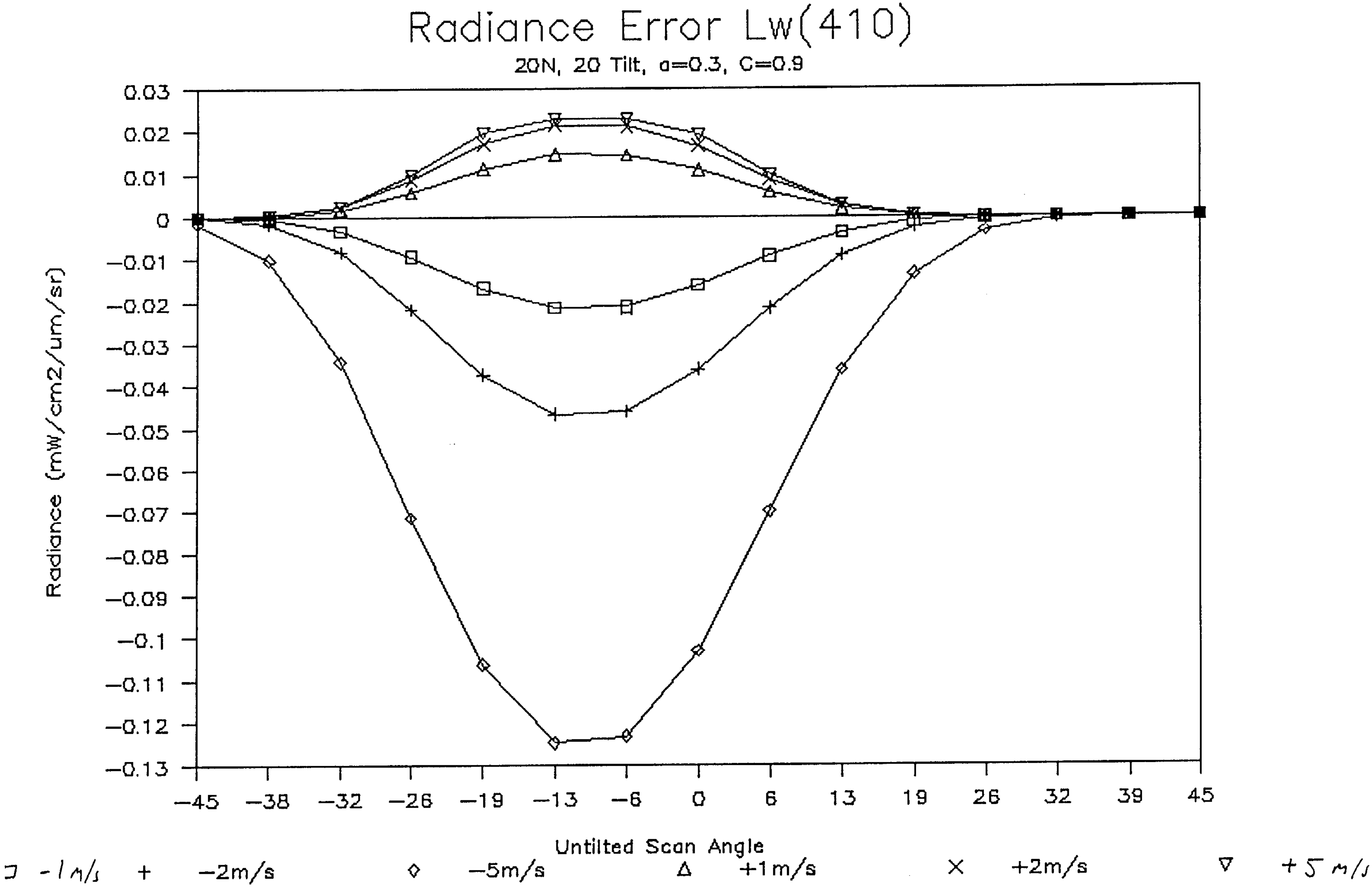

Figure 9. Error in normalized water-leaving radiance at 410 nm due to over- and underestimating wind speed for a sub-satellite point at 20N, with a 20° forward tilt.

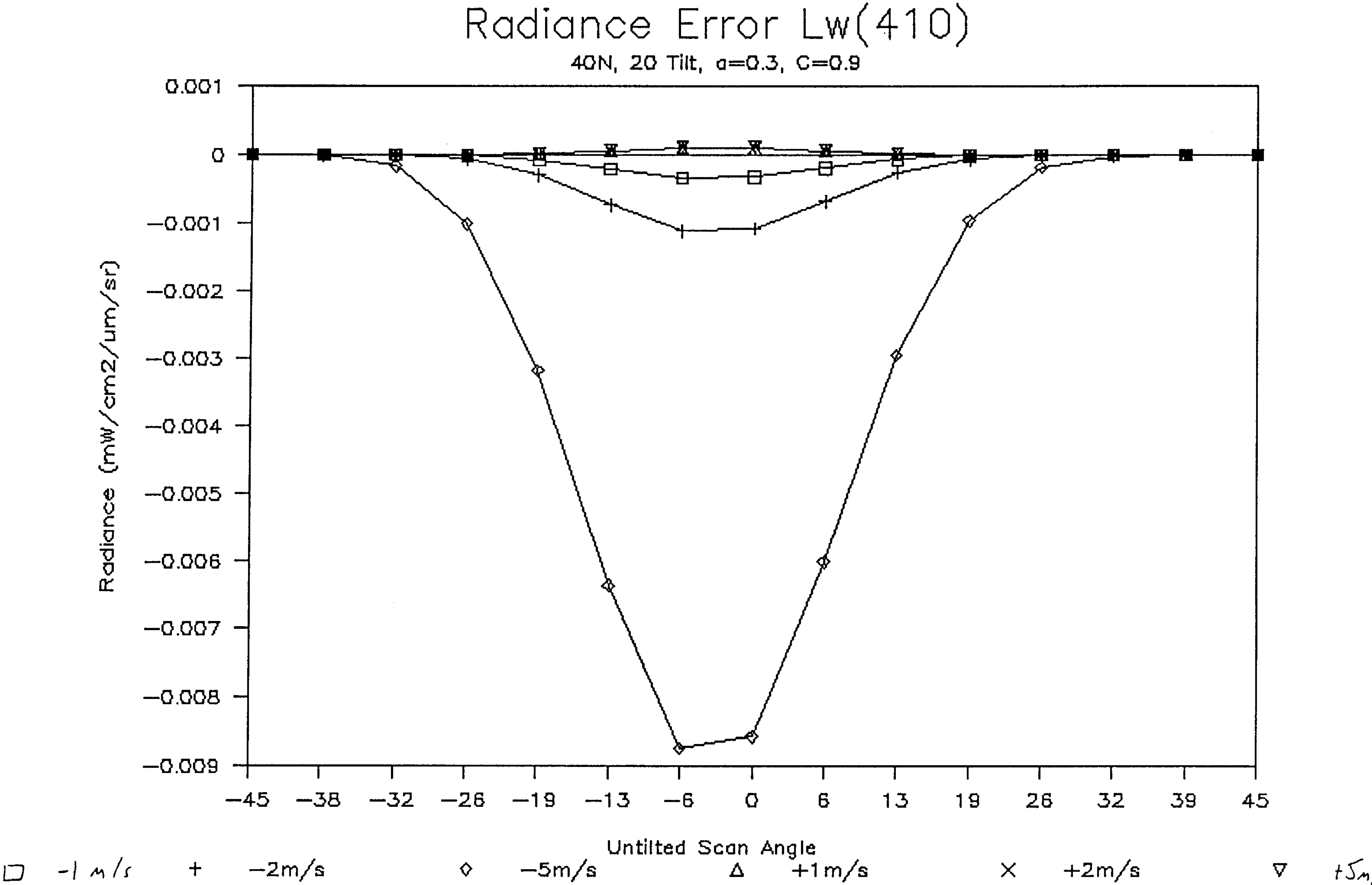

Figure 10. Error in normalized water-leaving radiance at 410 nm due to over- and underestimating wind speed for a sub-satellite point at 40N, with a 20° forward tilt.

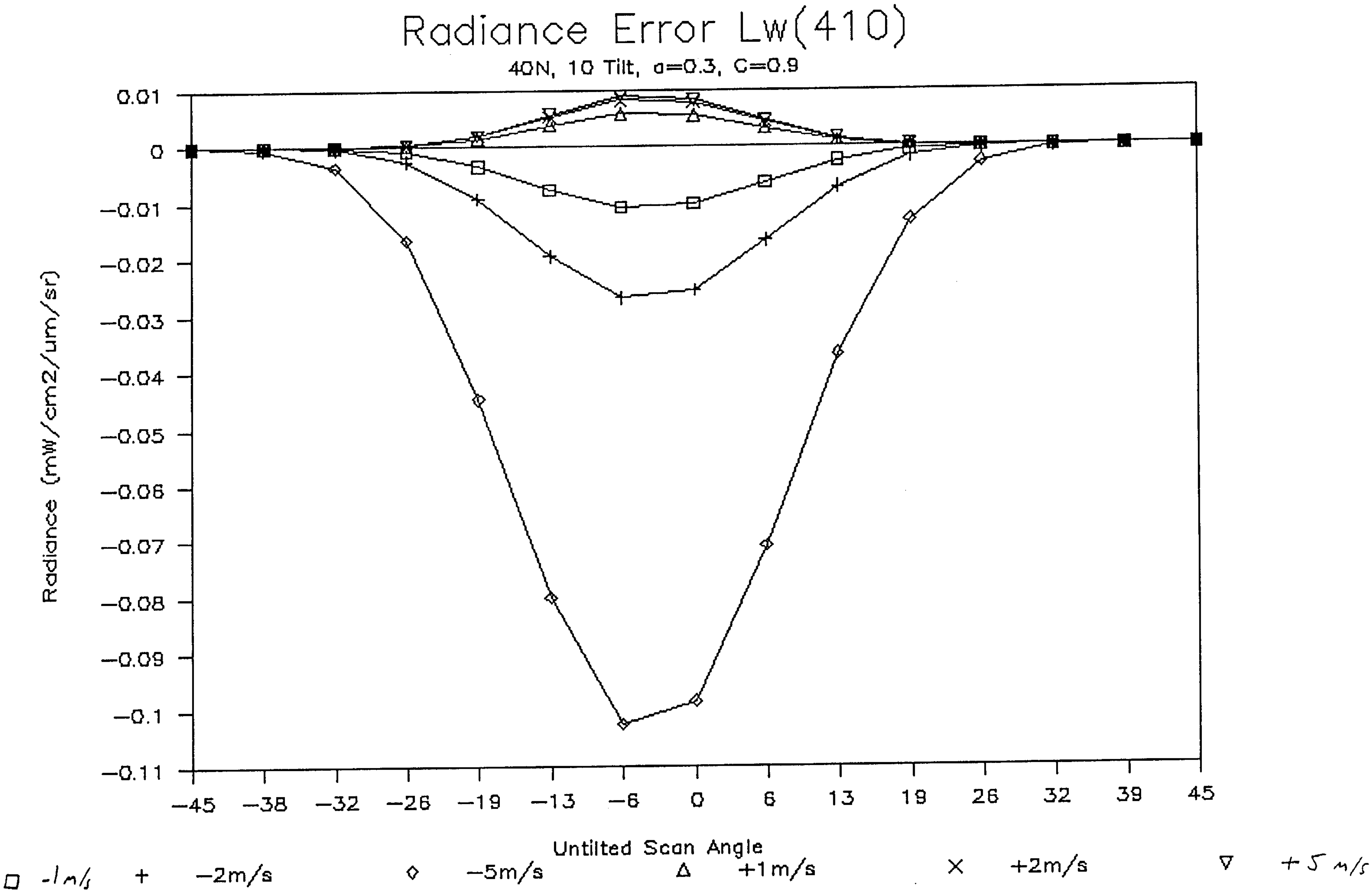

Figure 11. Error in normalized water-leaving radiance at 410 nm due to over- and underestimating wind speed for a sub-satellite point at 40N, with a 10° forward tilt.

Sources and Error of Available and Future Wind Speed Data

Sources[1] and estimated errors of possible wind speed data are summarized in Table 2.

Table 2. Sources and accuracies of wind speed data.

Source	Accuracy
NMC	$\pm$ 5 m s^{-1}
SCANSCAT	$\pm$ 1-2 m s^{-1}
LAWS	$\pm$ 1 m s^{-1}

Wind Speed Requirement

Given that even a $\pm$ 1 m s^{-1} error in wind speed will produce substantial error in MODIS water-leaving radiances (> MODIS NEdL), these analyses suggest that, to meet MODIS NEdL requirements over a significant portion of the scan for a significant portion of the Earth: wind speed must be known to the **highest possible accuracy.**

Final Note: At a mean wind speed of 6 m s^{-1}, the Cox and Munk theory contains an inherent error of $\pm$ 0.8 m s^{-1}. This is due to the neglect of wind direction and atmospheric stability (P. Ardanuy, personal communication), among other variables, in the Cox and Munk relation. Thus even if future wind speed accuracies are improved beyond the $\pm$ 1 m s^{-1} limit, a threshold of 0.8 m s^{-1} accuracy stands as the ultimate accuracy level required by MODIS, unless simultaneous improvements are made in the relation between sea surface roughness and sun glitter.

[1]If remotely sensed satellite data are used to determine wind speeds, stringent timeliness requirements may not be met. Dr. Esaias suggested using forecast or conventionally analyzed winds, running Level 2 processing for a "quick-look" output, then going back and re-running Level 2 (a week or two?) later using the updated wind speeds. Such a scenario would likely produce very good results, but has a major impact on EosDIS, requiring two Level 2 runs and a doubling of storage requirements (quick-look Level 2 would be held in storage for use in comparison studies with the final Level 2 product).

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TWO AEROSOL SIZE DISTRIBUTION ESTIMATES: REASONS FOR DIFFERENCES

Two estimates of the processing requirements for aerosol size distribution were made at MODIS meeting of January 12, 1990. The first estimate equalled 5.6 MFLOPS for the Level 2 processing without any other overhead considerations. The second estimate equalled 12.6 MFLOPS and included I/O and re-mapping calculations not included in the first estimate. The first estimate used eight iterations in the processing for about 47000 operations per pixel; the second method used two iterations for about 5000 operations per pixel. The first method used six wavelengths; the second method used five wavelengths. The first method did not include the calculation of any Angstrom coefficient; the second method included these calculations. The first method used 60 pixels per second; the second method actually used about 360 pixels per second.

The primary reasons for differences in the two estimates are 1) The first method had more operations per pixel since more iterations were assumed. This would tend to increase the first method's CPU requirements. 2) The second method actually had more pixels than the first by a factor of six, which counterbalanced the lower number of operations per pixel. The net effect was to increase the overall CPU estimate in the second method to be twice the first method.

If we adopt 47000 operations per pixel and assume 1% or 120 pixels per second are analyzed, the Level 2 processing for the aerosol size distribution will be 5.6 MFLOPS. With 0.5% of the pixels or 60 per second, the CPU requirement is actually 2.8 MFLOPS.

All algorithms can have their CPU requirements sized by these procedures. Errors in the method arise from 1) uncertainties in how the algorithm will actually work with MODIS data (e.g., how many iterations per pixel will be made) and 2) uncertainties in how the algorithm will be applied (e.g., what spatial resolution or subsampling strategies will be pursued). The product of the number of operations per pixel and the number of pixels per second analyzed will give the number of operations per second leading directly to an estimate of the MODIS CPU requirements. This methodology appears to be accurate to within a factor of two for any one data product. It also leads directly to estimates of the Level 2 data volumes.

TIMING TESTS OF THE IBM 3081
USEFUL FOR CALIBRATING THE CPU REQUIREMENTS OF MODIS

Some algorithms used by MODIS, such as the calculations of cloud optical thickness, have been run on the IBM 3081. If we have the run times for these algorithms, the number of pixels analyzed, and know the level of optimization used by the compiler, it is possible to derive such things as the number of floating point operations per pixel. Some of the basic floating point operations were timed on the IBM 3081, using the opt = 3 option on the compiler. The times in seconds fro one million operations are summarized in the table below.

Table 1. Relative computational times on IBM 3081 (opt = 3); Numbers are time in seconds to perform one million operations:

Addition time =	.6
Substraction time =	.5
Multiplication time =	.7
Division time =	1.1
Sine time =	5.7
Cosine time =	5.8
Tangent time =	6.6
Log time =	4.6
Log base 10 time =	5.6
Power time =	.7
Exponential time =	.4
Do nothing loop time =	.1
If statement time =	.7

Ten million of each operation were timed. These timing tests indicate that under normal operating conditions, the IBM performs 1.4 million operations per second (1.4 MFLOPS). The Linpack rating for the same machine is 2.1 MFLOPS, which is higher than this estimate because fewer divisions were used in the Linpack test.

These results were useful for finding the number of operations per pixel for Mike King's cloud optical depth. Since each pixel required 0.02 seconds of CPU time, this indicated that about 28000 operations per pixel were being performed. A similar analysis for NDVI indicates that about 20 operations per pixel are being performed in the Level 2 analysis.

Processing Estimate Optical Depth EFFective Radius

1. Analysis of CLDOP8

CLDOP8 is a functioning algorithm for the simultaneous estimation of cloud optical depth and effective particle radius. The algorithm uses radiance in two or three spectral bands. The 0.75 and 2.16 μm bands are always used and the 3.70 μm band can be used. The third channel is required to resolve an ambiguity in effective radius for clouds with optical depth less than an approximately four. The algorithm will be applied to daytime data only.

The algorithm uses a large look-up table for the reflectance function. This is done to avoid doing time consuming and redundant radiative transfer calculations as a part of this algorithm. The table contains three reflectance functions as a function of 3 wavelengths, 9 particle radii, 39 solar zenith angles, 26 satellite nadir angles, 33 sun satellite azimuth angles, and 4 optical thicknesses. The setup of the algorithm requires approximately 400 floating operations (FLOP) plus 2,500,000 data reads. As currently implemented, the algorithm requires approximately 15 megabytes of memory.

This is a large storage requirement. However, with this data in memory the solution can be recovered for many measurements. The only additional data required for each solution are the two or three radiance values and the satellite and solar zenith and azimuth angles.

The bulk of the computations are contained within two nested DO loops which run over the nine radii and the two or three wavelengths. A logical IF is used, so that some of the calculations are done only for the 0.75 μm wavelength. There are additional logical tests contained inside the DO loop which branch the program based upon the magnitude of the optical depth and other parameters. This estimate assumes that the path requiring the most computation has been taken and hence provides a maximum estimate. (That this is probably not a large overestimate is shown by the comparison with the run time data.)

The processing requirement is estimated at 32,000 (41,000) FLOP for two (three) input wavelengths. It is difficult to estimate the fraction of the pixels to which this algorithm will be applied. The two-wavelength method can only be applied for optical depths larger than approximately four. The three-wavelength method may be applied if the optical depth is in the range of one to four.

2. Timing Tests on the IBM 3081

We have obtained a run-time estimate for this algorithm from Dr. T. Nakajima, who developed the code while working with Dr. King. Dr. Nakajima estimates that 0.02 seconds are required for the calculation part of the processing (for one pixel) on the IBM 3081 with the maximum optimization applied. For the 3081 and maximum optimization, the actual performance is estimated at between 1.4 MFLOPS (Doug Hoyt's timing runs) and 2.1 MFLOPS for Linpack. The former estimate corresponds to 28,000 FLOP/pixel, which is in excellent agreement with the above estimate.

3. Estimation of the Processing Requirement

It is possible to use a single equation to estimate the processing requirement. The result is:

P = # * { %2 * 32,000 + %3 * 41,000 }/A

where
- \# = number of fields of view per second
- %2 = fraction of pixels processed using 2 wavelengths
- %3 = fraction of pixels processed using 3 wavelengths
- A = number of pixels in the resolution cell

If the assumption is made that %2 = 0.25 and %3 = 0.10 with #=12,000 and A=1, then P=145 MFLOPS. This is a big number which is only appropriate for daytime data. There are a moderately large number of operations done on a significant fraction of all pixels. (It may be possible to reduce the resolution or coverage of this product.)

The number of operations per scan is the above number multiplied by 1.02, or 148 MFLOP. If we consider the fact that this algorithm would be applied only during daytime, and perhaps for only 80% of the most direct overhead sun observations during daylight, (40% to 50% of the orbit) and use a scaling factor of 6[1], this algorithm would require a computer with an effective capacity of between approximately 350 to 440 MFLOPS.

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[1]A factor of three comes from the desire to simultaneously process new data, and be able to reprocess at twice the normal data rate. A factor of 1/0.7 comes in due to the need not to saturate a machine to 100% capacity. A further allowance of 40% is included for down time, simultaneous near-real-time processing of perhaps 10% of the data, and other competing MODIS applications.