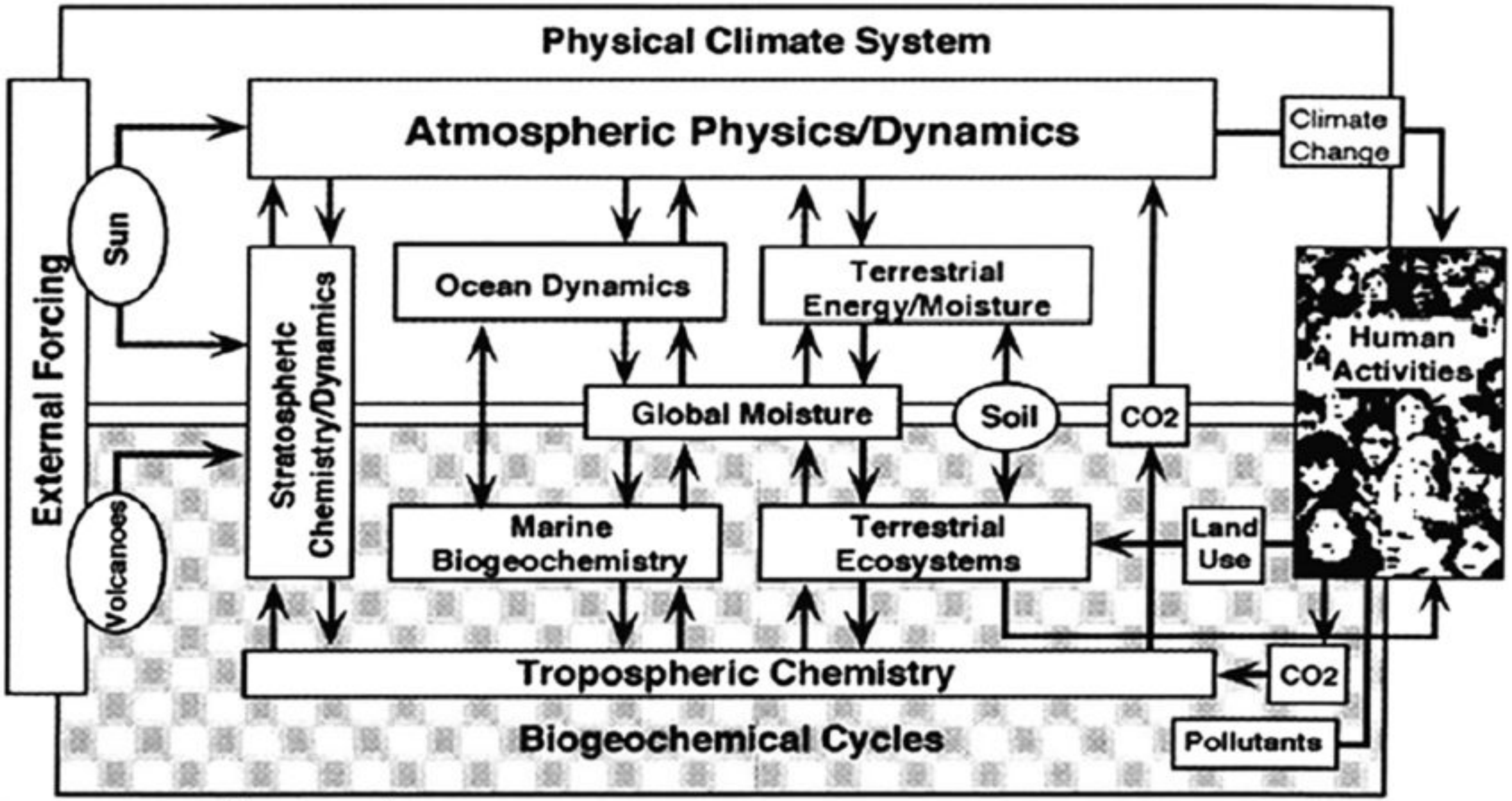
MODIS ‘Land’ Retrospective and Prospective

Chris Justice

University of Maryland



Source: NASA (1986, 19).

The Bretherton Diagram

Aug 1984

Technical Memorandum 86129

EARTH OBSERVING SYSTEM

SCIENCE AND MISSION R
WORKING GROUP FOR TH
OBSERVING SYSTEM

Dixon M. Butler, Chairman
Richard E. Hartle, Executive Secretary
Mark Abbott
Steve Ackley
Raymond Arvidson
Robert Chase
C. C. Delwiche
John Gille
Paul Hays
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Volker Mohnen
Berrien Moore III
Roger Phillips
Albert Rango
Gordon deQ. Robin
Verner Suomi
Paul Zinke

NAS

National Aerona
Space Administ

Goddard Spac
Greenbelt, Mary

TABLE 4 EOS Instruments

Instrument	Measurement	Spatial Resolution	Coverage
1. Automated Data Collection & Location System (ADCLS)	Data and command relay and location of remotely sited measurement devices	Location to 1 km for buoys, to 1 m for ice sheet packages	global, twice daily
SISP—Surface Imaging & Sounding Package			
2. Moderate Resolution Imaging Spectrometer (MODIS)	Surface and Cloud imaging in the visible and infrared .4 nm-2.2 nm, 3-5 µm, 8-14 µm resolution varying from 10 nm to .5 µm.	1 km × 1 km pixels (4 km × 4 km open ocean)	global, every 2 days during daytime plus IR nightime
3. High Resolution Imaging Spectrometer (HIRIS)	Surface Imaging .4-2.2 nm. 10-20 nm spectral resolution	30 m × 30 m pixels	pointable to specific targets, 50 km swath width
4. High Resolution Multifrequency Microwave Radiometer (HMMR)	1-94 GHz passive microwave images in several bands	1 km at 36.5 GHz	global, every 2 days
5. Lidar Atmospheric Sounder and Altimeter (LASA)	Visible and near infrared laser backscattering to measure atmospheric water vapor, surface topography, atmospheric scattering properties	vertical resolution of 1 km, surface topography to 3 m vertical resolution every 3 km over land	global, daily atmospheric sounding; continental topography total in 5 years
SAM—Sensing with Active Microwaves			
6. Synthetic Aperture Radar (SAR)	L, C, and X-Band Radar images of land, ocean, and ice surfaces at multiple incidence angles.	30 m × 30 m pixels	200 km swath width daily coverage in regions of shifting sea ice
13. Energy and Particle Monitors	Solar Emissions from 150-400 nm, 1 nm spectral resolution. Earth radiation budget Total Solar irradiance Particles & fields environment	total solar output	roughly continuous sampling, at least twice daily for solar observations

In the beginning …..

- 1984 NASA formed instrument panels to develop science requirements and sensor concepts for each facility sensor – the MODIS concept called for two instruments MODIS Nadir (Land surface) and MODIS Tilt (Ocean color)
  - MODIS-N was a conventional imaging filter radiometer with 35 spectral bands
  - MODIS-T was a 64-band imaging spectrometer capable of tilting fore and aft to avoid sun-glint from the ocean’s surface

MODIS INSTRUMENT PANEL MEMBERS

WAYNE ESAIAS, CHAIRMAN	GSFC
WILLIAM BARNES, EXECUTIVE SECRETARY	GSFC
MARK ABBOTT	JPL
JIM BRECKENRIDGE (R)	JPL
STEVE COX	CSU
ROBERT EVANS	U-MIAMI
ALEX GOETZ	JPL
CHRISTOPHER JUSTICE	U MD
MARVIN MAXWELL	GSFC
PAUL McCLAIN	NOAA/NESDIS
ROBERT MURPHY	NASA HQ
JOSEPH PROSPERO	U-MIAMI
BARRY ROCK	JPL
STEVE RUNNING	U MONTANA
RAYMOND C. SMITH	UCSB
JERRY SOLOMON	JPL

MEETINGS

JULY 30 - 31, 1984	SILVER SPRING, MD
OCTOBER 17 - 19, 1984	NEW CARROLLTON, MD
DECEMBER 6 - 7, 1984	SANTA BARBARA, CA
FEBRUARY 17 - 1985	(TO BE HELD IN SURROUNDINGS CONDUCIVE TO WRITING)

GSFC

W.E. 10/30

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

FILE 13544

Reply to Attn of:

JUL 6 1984

Dr. Christopher O. Justice
University of Maryland
Department of Civil Engineering
College Park, MD 10742

Dear Dr. Justice:

As you are probably aware from recent telephone conversations with either Bill Barnes or me, we are getting ready to start our EOS/MODIS Instrument Panel activities. You should be receiving your letter of invitation from Dr. Shelby Tilford in the next 1-2 weeks. In the meantime, I would like to use this opportunity to supply you with some background material and to acquaint you with our near-term plans.

We plan to have our first meeting on July 30 and 31. The meeting will be at the Sheraton Hotel in Silver Spring, Maryland. Birch and Davis and ORI will be furnishing administrative and technical support to the Panel. A letter from Birch and Davis' representative Brenda Moldawer describing the procedure for obtaining airplane tickets and per diem reimbursement is enclosed.

I am enclosing a copy of the Panel mailing list. You will notice that a Telemail ID is included together with the telephone number of each member in the second column. Members who are unable to utilize Telemail should let Bill Barnes know as soon as possible. The members of the panel can be addressed as a group by sending to MODIS. Once we are underway, Telemail will speed up our interchange of material and meeting notices.

Also enclosed are a copy of the Panel Statement of Work, a copy of the EOS Science and Mission Requirements Working Group Report with the Scientific Background Appendix, a copy of the Multispectral Imaging Science Working Group Final Report, and for those members who may not have it, a copy of the Marine Resource Experiment Program (MAREX) Report.

MODIS SCIENCE OBJECTIVES

- VEGN < Biomass / Temp
-
- ATMOSPHERE – Aerosol
-

- OBTAIN COMPREHENSIVE AND CONSISTENT GLOBAL DATA BASE IN THE VISIBLE AND IR REGIONS FOR EARTH SCIENCES
- OBTAIN GLOBAL COVERAGE FREQUENTLY — POTENTIALLY EVERY 2 DAYS
- SPATIAL RESOLUTION AT 0.5 - 1.0 KILOMETERS
- ENHANCE AND AUGMENT CURRENT AND PLANNED "OPERATIONAL" SENSOR SPECTRAL CAPABILITY FOR ADVANCED GLOBAL ALGORITHM DEVELOPMENT
- PROVIDE LARGE RESOLUTION, HIGH SAMPLING FREQUENCY TO COMPLEMENT HIRIS
- PROVIDE HIGH TEMPORALLY SAMPLED GLOBAL DATA BASE FOR BIOGEOCHEMICAL INVESTIGATORS

GSFC

W.E. 10/30

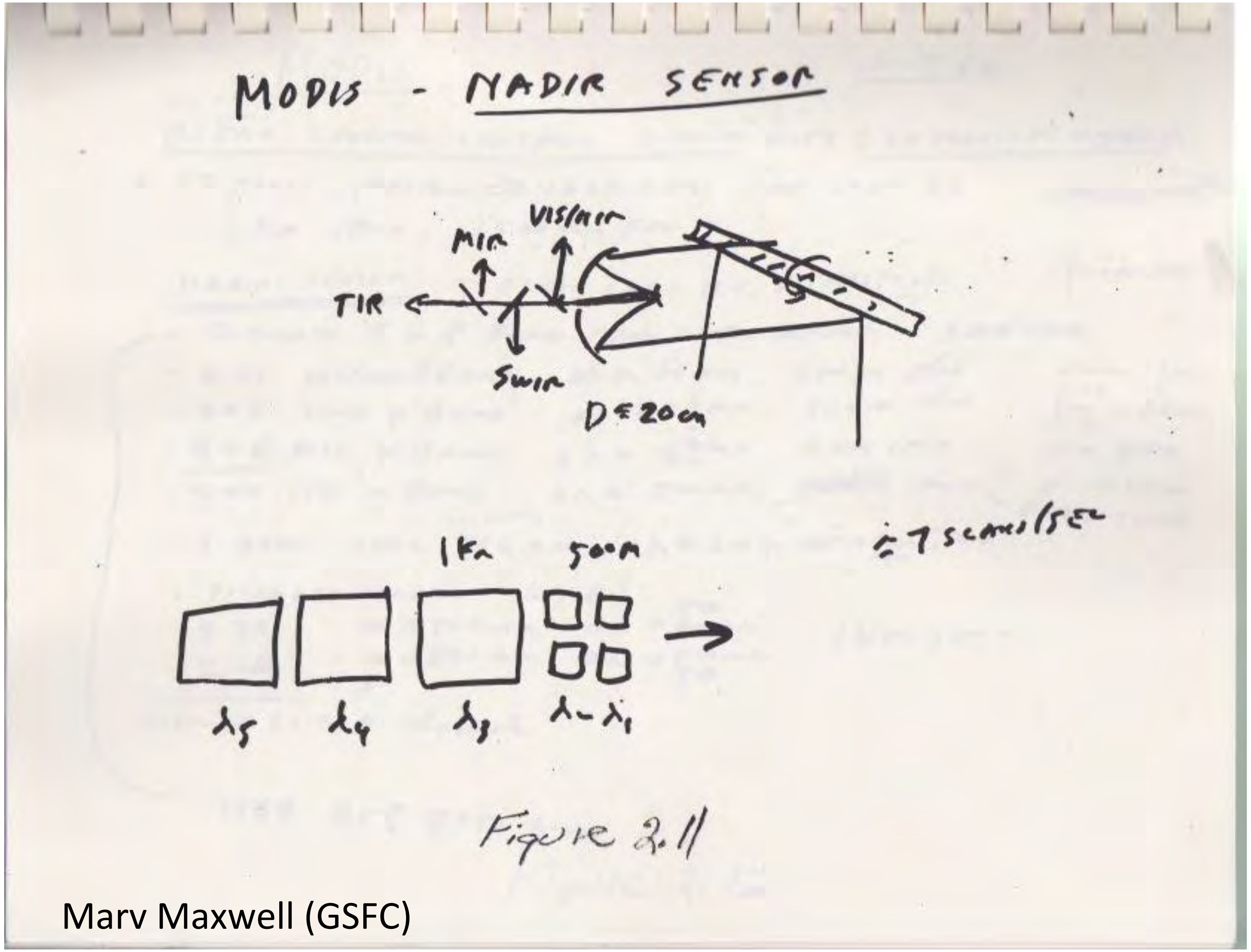
SCIENCE OBJECTIVES

- PHYTOPLANKTON BIOMASS DISTRIBUTIONS AND VARIABILITY
  - —PRODUCTIVITY VARIABILITY AND DYNAMICS
  - —SPECIES GROUP DISTRIBUTIONS
  - —C,N,P,S, OCEANIC FLUXES
  - —FLOW VISUALIZATION
  - —RESOURCE UTILIZATION AND ASSESSMENT
- MESOSCALE, REGIONAL FEATURE LOCATION AND DYNAMICS
- LAND/OCEAN RIVERINE FLUXES
- SEDIMENT TRANSPORT AND FLUXES
- TERRESTIAL VEGETATION DISTRIBUTIONS AND TEMPORAL VARIABILITY
- SEASONAL AND INTERANNUAL CHANGES
- SURFACE CLIMATOLOGY
  - —LAND AND SEA SURFACE TEMPERATURE
  - —HUMIDITY
  - —SNOW COVER
  - —VEGETATION CLASSIFICATION (WITH HIRIS)
- OCEAN POLLUTION INDICATORS
- FOOD CHAIN RESEARCH
- AEROSOL OPTICAL DEPTH / EARTH SURFACE

GSFC

W.E. 10/30

MODIS Instrument Panel Meeting, October 1984



Marv Maxwell (GSFC)

Table 15. MODIS-N – Example of Performance Calculations (Channel 25)

Satellite Height	705 km	Surface Reflectivity	0.10
Ground Resolution	500 m	Quantum Efficiency	0.40
Swath Width	1,513 km	Saturation Radiance	0.71 mw/cm^2-sr-µm
Wavelength	2.13 µm	(Integration Time)/(Dwell Time)	1.0
Spectral Bandwidth	20 nm	Time to Map the Earth	2 days
Solar Zenith Angle	22°	Number of Detectors Per Spectral Band	2
Sensor Look Angle	0°	Scanning Efficiency	0.25
Optical Transmission	0.35	Calculated	247
Detector Size	382 µm		
Telescope Diameter	39.8 cm		
Optical f-Number	1.35		

Table 16. MODIS-N Visible/Near IR Channels (Preliminary)

Channel	λ (nm)	Δλ (nm)	IFOV (m)	Surface Reflectance (%)		S/N Calculated	Comments
1	470	20	500	3	(B)	740	Soil-Vegetation Differentiation
2	550	20	500	10	(B)	920	Green Peak Chlorophyll
3	670	20	500	6.5	(B)	770	Chlorophyll Absorption
4	710	20	500	9	(B)	830	RED-NIR Transition
5	880	20	500	25	(B)	850	Vegetation Max Reflectance
6	960	20	500	24	(B)	520	H_2O Peak
7	435	10	1,000	5.1	(C)	1,480	Low Chlorophyll
8	490	10	1,000	3.5	(C)	1,520	Nonlinear Chlorophyll
9	520	10	1,000	2.8	(C)	1,390	High Chlorophyll
10	565	10	1,000	1.8	(C)	1,290	Chlorophyll Baseline
11	590	10	1,000	0.6	(C)	1,160	Sediment
12	665	10	1,000	0.17	(C)	950	Atmosphere/Sediment
13	765	10	1,000	0.1	(C)	720	Atmosphere Correction
14	865	10	1,000	0.1	(C)	470	Atmosphere Correction
15	754	1.2	1,000	30	(D)	920	Cloud Altitude
16	761	1.2	1,000	90	(D)	1,550	Cloud Altitude
17	763	1.2	1,000	50	(D)	1,160	Cloud Altitude
18	500	100	1,000	2.5	(B)	2,880	Polarization
19	500	100	1,000	2.5	(B)	2,880	Polarization
20	1,080	20	500	25	(B)	1,120	Leaf Morphology
21	1,131	20	500	10	(A)	520	Cloud H_2O Absorption
22	1,240	20	500	10	(A)	750	Leaf H_2O Absorption
23	1,550	20	500	14	(B)	480	Leaf H_2O Absorption
24	1,640	20	500	10	(A)	375	Snow/Cloud Differentiation
25	2,130	50	500	10	(A)	250	Cloud Penetration

References (A) Colwell, 1983 (B) Hack *et al.*, 1984 (C) Wolfe and Zissis, 1978 (D) Personal Communication, W.l. Barnes

Table 17. MODIS-N Thermal Channel S/N Calculation (Channel 35)

Satellite Height	705 km	Telescope Diameter	39.8 cm
Ground Resolution	1,000 m	Optical f-Number	1.35
Swath Width	1,513 km	Surface Temperature	270 K
Wavelength	12.0 µm	Responsivity	4.8 amps/watt
Spectral Bandwidth	0.5 µm	(Integration Time)/(Dwell Time)	1.0
Solar Zenith Angle	22°	Time to Map the Earth	2 days
Sensor Look Angle	0°	Number of Detectors Per Spectral Band	1
Optical Transmission	0.35	Scanning Efficiency	0.25
Optical Depth of Atmosphere	0.10	Expected NEΔT	0.011 K
Detector Size	763 µm		

Table 18. MODIS-N Thermal Channels (Preliminary)

Channel	λ (nm)	Δλ (nm)	IFOV (m)	NEΔT (K@ 270 K)	Comments
26	3,750	90	1,000	0.14	Clouds & Surface Temp*
27	3,959	50	1,000	0.14	Clouds & Surface Temp
28	4,050	50	1,000	0.13	Clouds & Surface Temp
30	8,550	500	1,000	0.01	Stratospheric Aerosol Detection
33	10,450	500	1,000	0.01	Stratospheric Aerosol Detection
34	11,030	500	1,000	0.01	Clouds & Surface Temp
35	12,020	500	1,000	0.02	Clouds & Surface Temp

* Temperature

1986

Table 20. Compositing Scales

Property	Spatial Bins	Temporal Bins
LAI	0.5 km	week
Ocean Pigment	10 km	week, month, annual
Temperature Land	0.5 km	week
Sea Temperature	10 km	week
Ocean Aerosol	100 km	week

be provided as well as routine production and archiving of standard products. The real-time distribution could be effected in several ways, including:

1. Onboard processing to quick-look products with direct transmission

2. Some rapid data center processing and transmission to users via communication satellites

3. Distribution (possibly of selected channels) of Level 1A data to networked processing centers for the purposes of large-scale regional studies, algorithm development where such development requires substantial volumes of data, and global studies requiring specialized processing not compatible with standardized, central service-produced products

Table 21. MODIS Data Requirements–Expected Requests for Data

Requests	Users	Requests/Year	Comments
Access to Level 1B	1. Algorithm developers	50-75	all channels, regional time series (1,000 km)
	2. Field experiments anywhere	2-5, anytime	<1 day, level 3, 1,000 km
	3. Demand for special Level 3	10, up to 50	highest resolution, random regions
	4. Operational product improvement	10	1 month, all data, selected regions
	5. Reprocessing of Level 3 sets	once every 1 to 3 years	improved algorithms, data updates
	6. Regional distributed archives		rapid access to all storage limited, up to 50 centers
Level 2 cloud masks		2-3	regional requests/yr
–every Level 1B special request			
–cloud statistics			
Level 3 (No. of requests depends on success of regional centers)			
–surface temperature			
land		60	
ocean		75	(subset of chlorophyll pigment)
–vegetation indices			
land		100s	
ocean		250	
–aerosols		50-100	
–others–undefinable, less than above, potentially nearly equal			

APPENDIX A: ATMOSPHERIC CORRECTIONS OVER LAND

Satellite measurements of the characteristics of land surfaces depend significantly on the optical effects of the atmosphere. This section discusses such effects for a cloudless atmosphere and methods for correcting for the effects in the spectral range below 3 μm. The essence of the atmospheric effects can be discussed with the aid of the following accurate expression for the radiance (L) of the Earth-atmosphere system:

$$L = L_o + Tr$$

where L_o is the path radiance of the atmospheric column, T is the transmission of sunlight to the surface and then to a satellite, and r is the surface reflectance. All quantities are functions of wavelength, polar angles from the surface to both the sun and the satellite, location, and time. Since the radiance is nearly a linear function of the surface reflectance, if the latter is known for dark and bright surfaces, then the two atmospheric parameters L_o and T can be estimated from the satellite measurements of radiance. Although the method seems simple, it is difficult to apply because the surface reflectance is not usually known with enough accuracy.

The optical effects of the gaseous components of the atmosphere alone can be calculated accurately. The MODIS spectral bands will be chosen in the atmospheric windows, where molecular absorption is weak. McClatchey *et al.* (1971) and Kneizys *et al.* (1983) give methods for calculating atmospheric transmission. Well developed radiative transfer models exist for calculating molecular and aerosol scattering (Lenoble, 1977). Since aerosols are always present in the atmosphere, the molecular scattering should not be considered independent of light scattered by aerosols, when the aerosol optical density is large on either the path from the ground to the sun or to a satellite.

The difficulties in making atmospheric corrections are caused by aerosols, since their optical properties are difficult to estimate during satellite observations: their properties are not known accurately and they are variable. The aerosol optical parameters are their optical thickness, single scattering albedo, and scattering phase matrix. The scattering phase matrix, which accounts for the polarization properties of scattered light, is required instead of just the phase functions, if any of the following three conditions apply:

1. The MODIS radiometer is sensitive to polarization

2. The polarization of light reflected from plants is measured

3. Accurate atmospheric corrections are calculated for atmospheres containing moderate amounts of haze

Some idea of the accuracy required for the aerosol optical parameters can be given for two atmospheric states and observations near the nadir direction. Assume that the surface reflectance will be measured with an accuracy of 0.01. A rather common state is one where the aerosol optical thickness is 0.2, its albedo of single scattering is 0.96, and the surface reflectance is 0.1. The required accuracy of the optical thickness is 0.1, and an accurate value of the single-scattering albedo is unimportant. This implies that atmospheric corrections are not required for near-nadir observations, if the aerosol optical thickness is less than 0.2 (Schowengerdt and Slater, 1979). To take another example, consider the problem of dense haze (an optical thickness of 0.6) that is common in such places as the eastern United States during the summer, or the Sahara region. The optical thickness is still an important parameter, but now the radiance is sensitive to the aerosol single-scattering albedo, which has to be specified with an accuracy of 0.02, when the surface is bright ($r = 0.4$) (Fraser and Kaufman, 1985). The reflectance measured at a satellite, however, depends on both the optical thickness and the single-scattering albedo when the zenith angle at the ground of a ray from the ground to either a satellite or the sun is large.

The aerosol optical properties are a function of wavelength, but the correlation of the same parameter at two different wavelengths is generally good. The aerosol optical thickness can vary from hundredths to values large enough to obliterate surface features. Usually, the visible optical thickness range over land is 0.05 to 1.0. The aerosol single-scattering albedo ranges from 0.5 in some urban environments to 0.99 in rural environments (Shettle and Fenn, 1979). The scattering phase matrix depends on molecular scattering and on aerosol size, composition, and shape. This matrix has large variations (Sekera, 1957).

The small amount of experimental data indicates that the spatial gradients of aerosol parameters may be important when moderate to dense haze is present. The vertical profiles of the parameters are important for calculating the transfer of radiant energy from outside to inside the instantaneous field-of-view (IFOV); but this adjacency effect is significant for IFOVs smaller than that of MODIS (Kaufman, 1984). The vertical profiles become more important with increasing amounts of haze and large polar angles from the point of observation to either the sun or satellite. The horizontal gradients of the optical parameters depend on the locations of

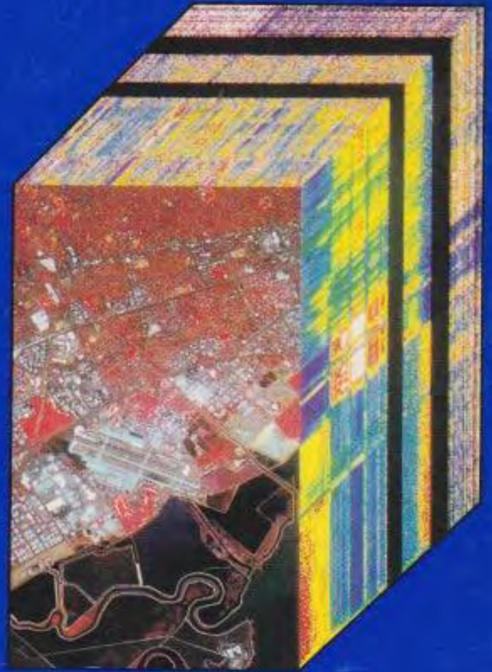
HYDROLOGIC CYCLE
ATMOSPHERE
BIOSPHERE
SOLID EARTH
BIOGEOCHEMICAL CYCLES
CRYOSPHERE
HYDROSPHERE
CLIMATIC PROCESSES

Volume IIc

HIRIS

High-Resolution Imaging Spectrometer: Science Opportunities for the 1990s

EARTH OBSERVING SYSTEM



Instrument Panel Report

NASA
National Aeronautics and Space Administration

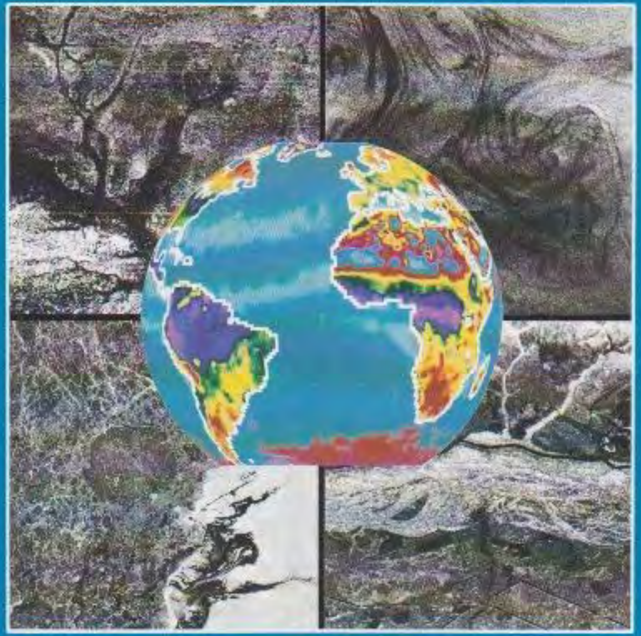
HYDROLOGIC CYCLE
ATMOSPHERE
BIOSPHERE
BIOGEOCHEMICAL CYCLES
CRYOSPHERE
HYDROSPHERE
CLIMATIC PROCESSES

Volume IIf

SAR

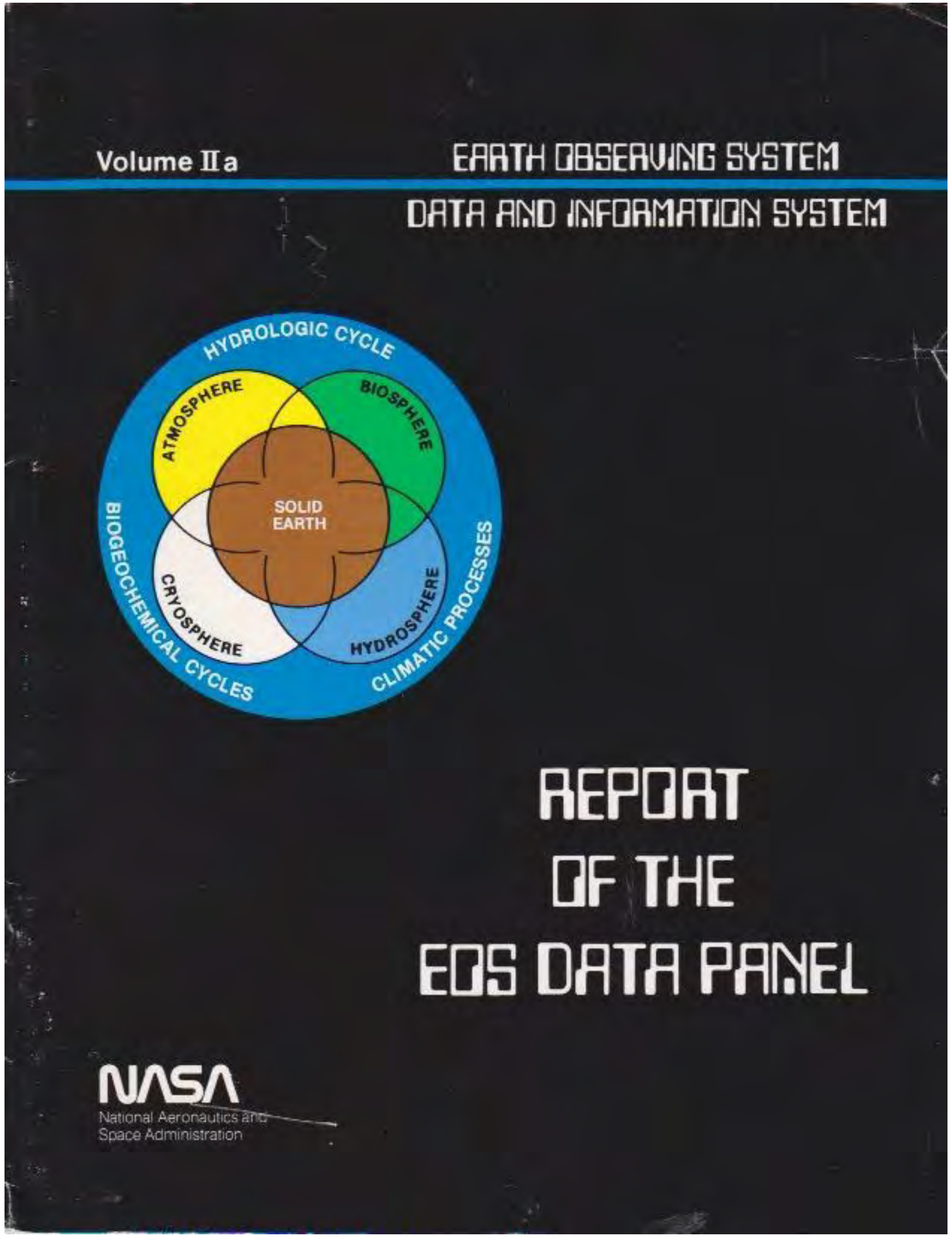
Synthetic Aperture Radar

EARTH OBSERVING SYSTEM



INSTRUMENT PANEL REPORT

NASA
National Aeronautics and Space Administration



A Long, Long Journey...

An Eos data and information system must be a system that includes geographically distributed sites of varying capabilities and responsibilities. We expect that by the 1990s local processing capabilities, combined with network technologies, will allow such a geographically distributed system to become a reality. In fact, we envision the key objective of an Eos data and information system to be providing remote and electronic access to the variety of capabilities and services that the system offers. We consider the management of this data and information system to be considerably more difficult to implement successfully than the technological aspects.

Earth Observing System Data and Information System, Report of the EOS Data Panel, NASA Technical Memorandum 87777, 1986

MODIS-N Specification for a Phase-B Study 11/7/86

4.12 Reliability

4.12.1 Operational Life

The design goal for operational lifetime of the MODIS-N is 10 years. The required probability of success is 90%. The design of the instrument shall be such that the design goal can be met using available reliability techniques (redundancy, part derating, hi-rel parts selection, etc.) and any planned orbital repair/replacement operations provided by the Space Station. Verification of the design life shall be accomplished by a reliability analysis which is supported by existing parts, materials and component test data on identical or similar designs. The reliability

A REVIEW OF THE MODIS-N PHASE C/D SPECIFICATIONS
FOR THE MODIS SCIENCE TEAM
JULY 5, 1989
(with emphasis on recent changes/during 1989)

1. Flight altitude is now 705 km; it was 824 km (Section 1)
-spatial resolutions are now 824, 428 and 214; used to be 1000, 500 and 250 (the instrument would continue to be able to provide these types of resolutions at 824 km.

- equator-crossing time, ascending node is 1:30 P.M.

2. Phase C/D will build to satisfy all contractural requirements, a protoflight model and a flight model (maybe 2) (Section 3.1.4). They are to be built to last 5 years (Section 3.2.4).

3. Instrument shall scan +/- 55 degrees (used to be +/- 45 degrees). Change was by programmatic direction.

4. Several changes have taken place since at least March 1989 in the placement and characteristics of spectral bands. The motivation for these changes are primarily due to the guidance provided by the MODIS Science Team in the March 1989 meeting (see below). See comparison of March 1989 spectral band and characteristics table in March 1989 (IEEE Transactions on Geoscience and Remote Sensing) versus comparable June 1989 tables. Information is the same, basically, as given in the June 1989 Phase C/D specifications. (Section 3, Tables 3.3.3, 3.3.4.1, and 3.3.4.2)

a) Remove channels 15 and 16 (1.2 nm Oxygen A-band channels).
-done

b) Widen channel 26 to 0.18 micrometers FWHM.
-done

c. Use a bi-linear gain in channels 26 and 35 so as to detect very hot objects.
-this has been put in the spec. In the sea surface temperature part of the range the NEDT must be maintained, at the expense of the forest fire part of the range, if necessary. The forest fire part of the range will extend from 335 degree K to 700 degrees K (band 26) or 400 degrees K (bands 35 and 36). Bands 35 and 36 have been treated identically to facilitate split window efforts.

d) Replace channel 9 (620 nm) with a 15nm wide channel at 410 nm.
-done

e) Move channel 5 (435nm) to 443nm.
-done

f) Move channel 12 (765nm) to 750nm
-done

g) Broaden channel 13 (0.865 nm) to 15nm FWHM.

1989

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Bitnet I.D. ZWYJK @VPFVM

July 3, 1989

NEAR-IR WATER VAPOR CHANNELS

Two channels in the reflective near-IR were proposed for remote sensing of total water vapor in a cloud free atmosphere (0.908 µm 35 nm wide and 0.95 µm 20 nm wide). In addition a third narrow channel (0.936 µm 6 nm wide) was proposed for remote sensing of water vapor in clouds and partially cloudy pixels. The method can be used to measure the water vapor amount with an error of ±0.15 g/cm^2 for water vapor amount less than 2.5 g/cm^2 and 0.5 g/cm^2 for water vapor amount more than 2.5 g/cm^2. The third channel is used to determine the subpixel cloud fraction, which is used to determine the true cloud temperature and optical thickness (see appendix).

Total water vapor in a cloud free atmosphere

JUSTIFICATION: This channels are designed to estimate the total water vapor in the atmosphere over land, based on attenuation of reflected solar light in the near IR. This remote sensing technique is needed due to the relatively low sensitivity of the IR sounding to boundary layer humidity. The total humidity is important to correct other MODIS channels (e.g. 3.7µm). Boundary layer humidity is important in assessing the interaction of the atmospheric humidity with the surface, and for estimating the effect of the humidity on atmospheric aerosol, thus increasing the accuracy of atmospheric corrections and derivation of fluxes of particulate air pollution. From the total water vapor, obtained from these channels, the boundary layer water vapor can be obtained by subtracting the amount of water vapor in higher layers using the MODIS-N IR channels. The results can be compared on a local basis with the analysis of water vapor from HIRIS. From this point of view, the MODIS N new remote sensing technique will serve fill the gap between the HIRIS local total water vapor amounts and the current MODIS-N and AIRS global water vapor data that are not sensitive to the lower troposphere.

THE METHOD

We studied several surfaces (vegetation, soils, sands) in order to simulate the sensor radiance and estimate the accuracy with which the water vapor can be derived under varying surface spectral characteristics. In order to design a fast remote sensing technique that is suitable for global data sets, the following hypothesis was tested:

All surfaces have a simple spectral reflectance in the 0.87µm - 0.96µm region. Therefore, the following function g : $g = L_2^2/(L_1 L_3)$
is independent of the surface cover (here L_1, L_2 and L_3 are the average surface reflectances in the 0.87-0.89 µm, 0.89-0.925µm and 0.94-0.96 µm region, respectively).

Since L_1 and L_2 are not very sensitive to water vapor, while L_3 is (see example in Fig. 1 and 2), if the hypothesis is correct, the function g will increase as a function of the water vapor in the atmosphere. The hypothesis was tested for 10 soil/sand surface covers , 7 vegetation surface covers and 2 snow surfaces. The test was performed using LOWTRAN-7 radiance simulation for these surface covers. Figure 3 shows the dependence of the function g on the amount of water

MODIS-N SPATIAL RESOLUTION - OPTIONAL CONFIGURATIONS

Option A	250m Globally	Very high data rates. Could be reduced by limiting no. of spect. bands.
Option B	250m locally 500m globally	Direct transmission to ground receiving stations and/or on-board recording. Limit to key spectral bands ? High data rates.
Option C	500m globally	Simpler than B or D. High data rates.
Option D	250m locally 1km globally	Would restrict use of sensor for direct global monitoring of land cover change.
Option E	500m locally 1km globally	As for D, but local use more restricted and global monitoring capability restricted.
Option F	1km globally	Still significant improvement on current capability (4km) but reliable monitoring of land transformations much inhibited.

Registration

Data rates for sensing systems with different spatial resolutions.

System	IFOV (m)	Radiometric Resolution (bits)	No. of spectral bands	=	Data Rate (megabits per second)
MODIS*	4000	10	1		.007
	2000				.03
	1000				.11
	500				.44
	250				1.76
	125				7.04
MODIS N	+	10	40		8.7
MODIS T		12	64		8.5
**AVHRR					
LAC	1100	10	5	=	0.62
GAC	(5x3km)	Resampled		=	0.04
***LANDSAT					
MSS	79	8	4	=	15.06
TM	30	8	7	=	84.90
SPOT					
HRV	20/10	8	3/1	=	25.00
****EOSSAR					300.00
HIRIS:	30	12			512.00
HIRIS: Proposed Editing to					300.00

* Calculated by IFOV/FOV x Scanning Rate 1.4 x Radiometric Resolution

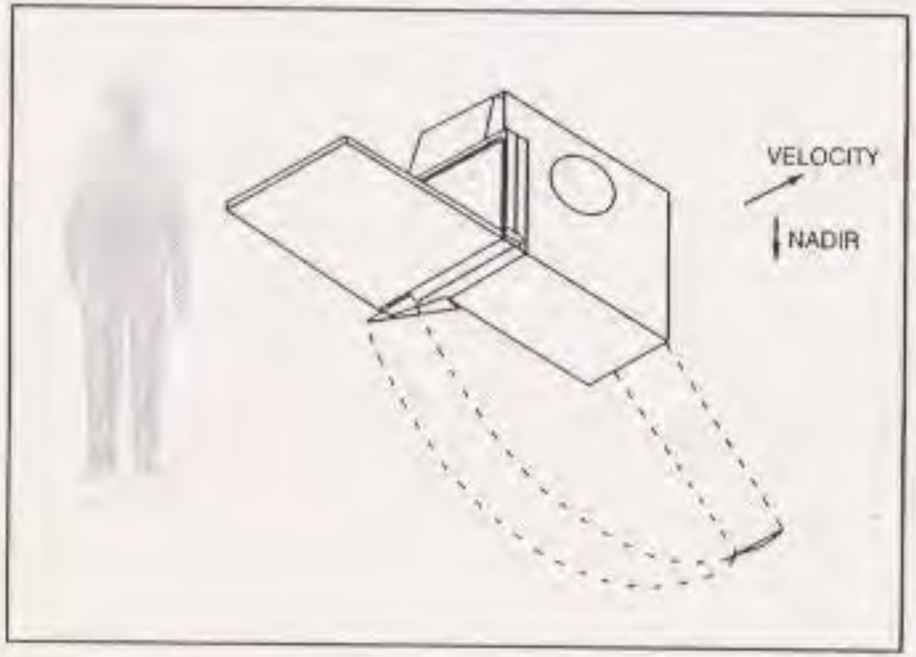
** After Kidwell (1984)

*** After Baylis and Brush (1985)

\+ Daylight Cycle - 13 Channels @500m
- 27 Channels @1000m

++ MODIS T and N Day and Night Cycles

MODIS-N
MODERATE RESOLUTION IMAGING SPECTROMETER (NADIR)



INSTRUMENTATION

MEASUREMENT
- ATMOSPHERE, LAND AND OCEAN PROCESSES

SPECTRAL RANGE 0.4 - 14.2μm

36 SPECTRAL BANDS (10 TO 500 nm BANDWIDTHS)

2 @ 214m IFOV	BOUNDARY (LAND, WATER AND CLOUDS)(659 & 865nm)
5 @ 428m IFOV	LAND AND CLOUDS (470-2130nm)
9 @ 856m IFOV	OCEANS (415-865nm)
3 @ 856m IFOV	ATMOSPHERE (905, 936 & 940nm)
17 @ 856m IFOV	ATMOSPHERE & SURFACE TEMPERATURE (3.7-14.2μm)

S/N 500 OR GREATER

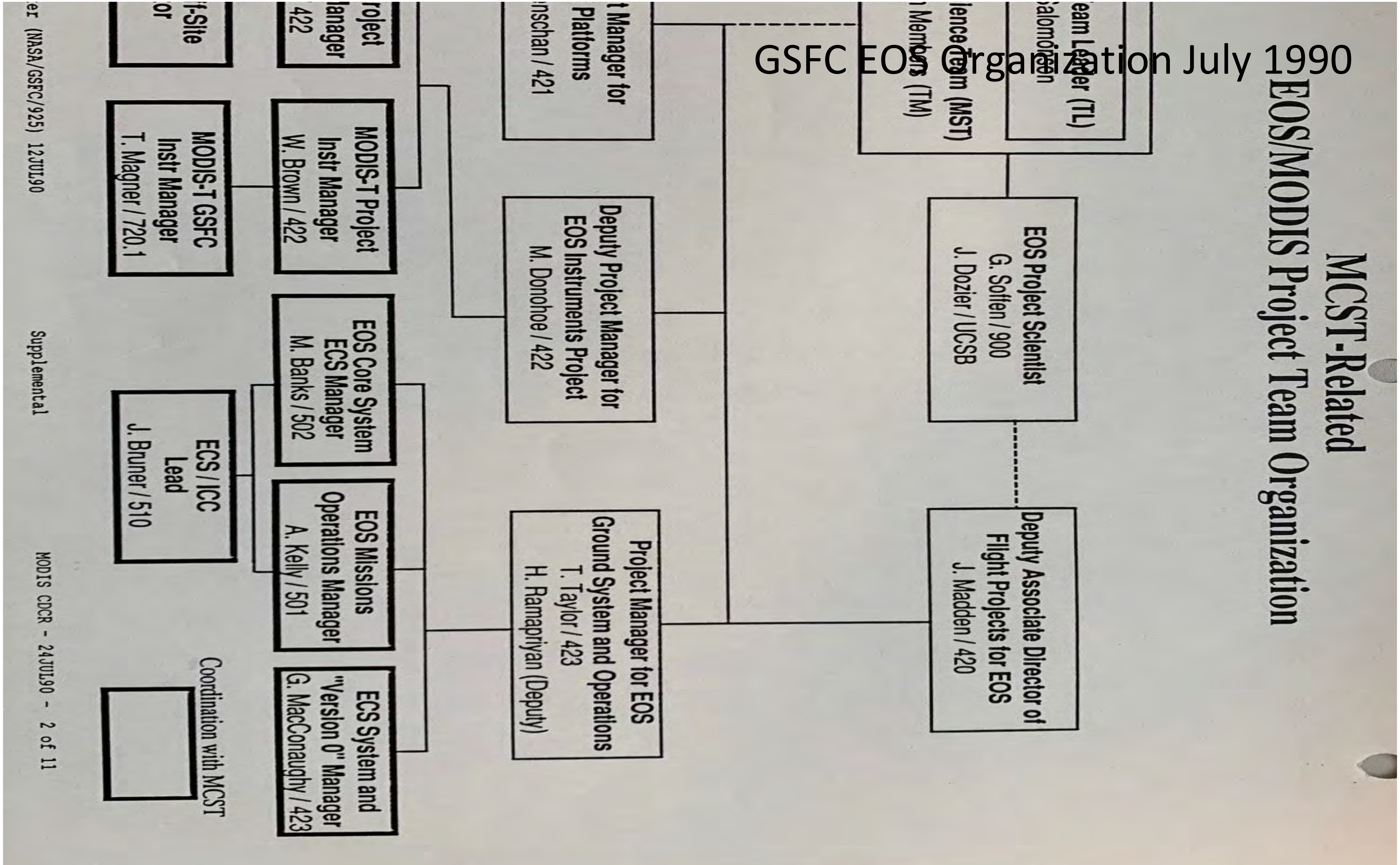
7.5 Mbps ORBITAL AVERAGE DATA RATE

2330 KM SWATH WIDTH

$\pm$55° VIEW ANGLE

C430.001

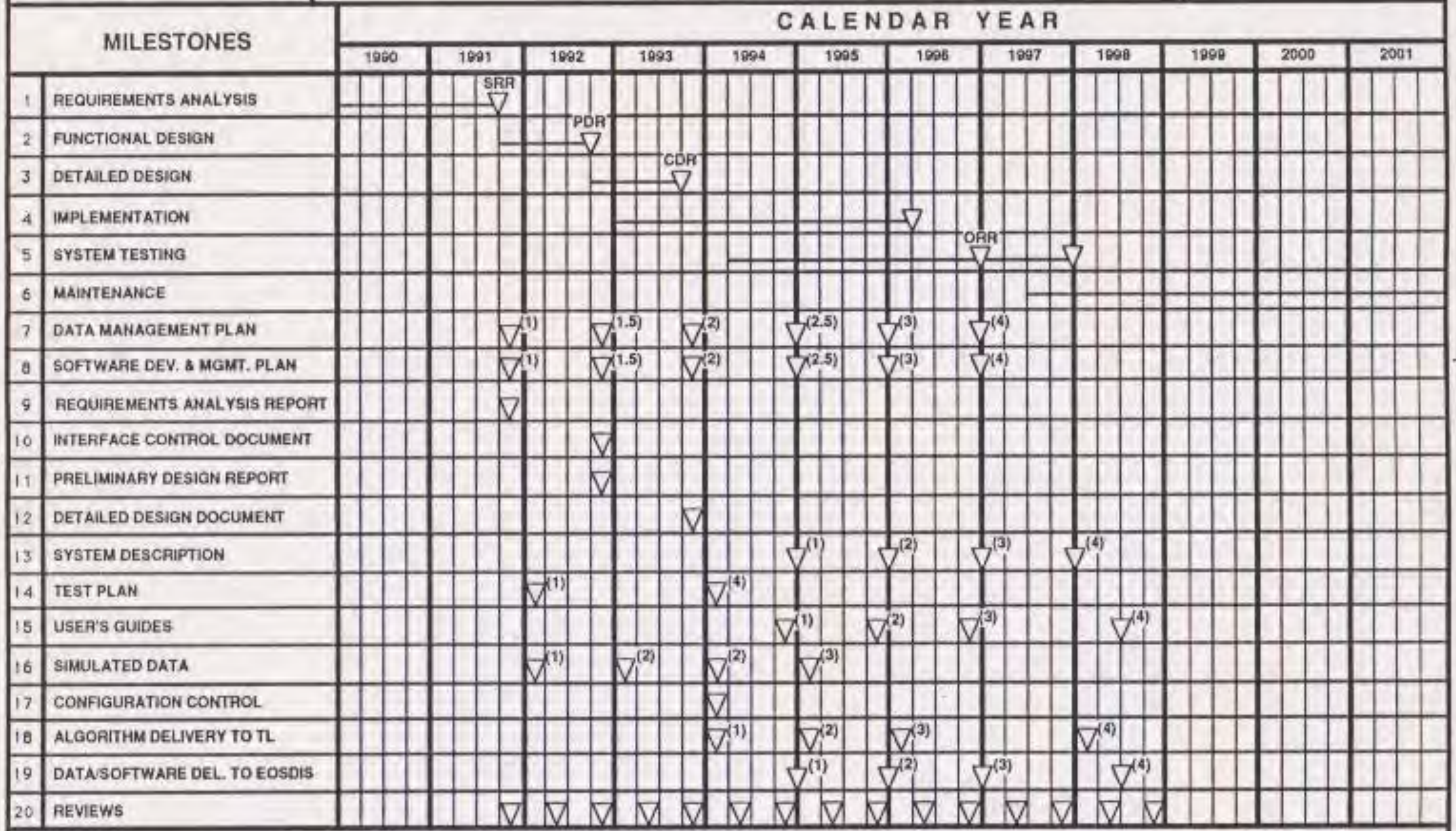
GSFC EOS Organization July 1990



GSFC GODDARD SPACE FLIGHT CENTER
RESPONSIBILITY:
APPROVAL:
ACCOMPLISHMENT:

MODIS DATA PRODUCT PROCESSING SYSTEM DEVELOPMENT TASKS

STATUS AS OF: 7/24/90

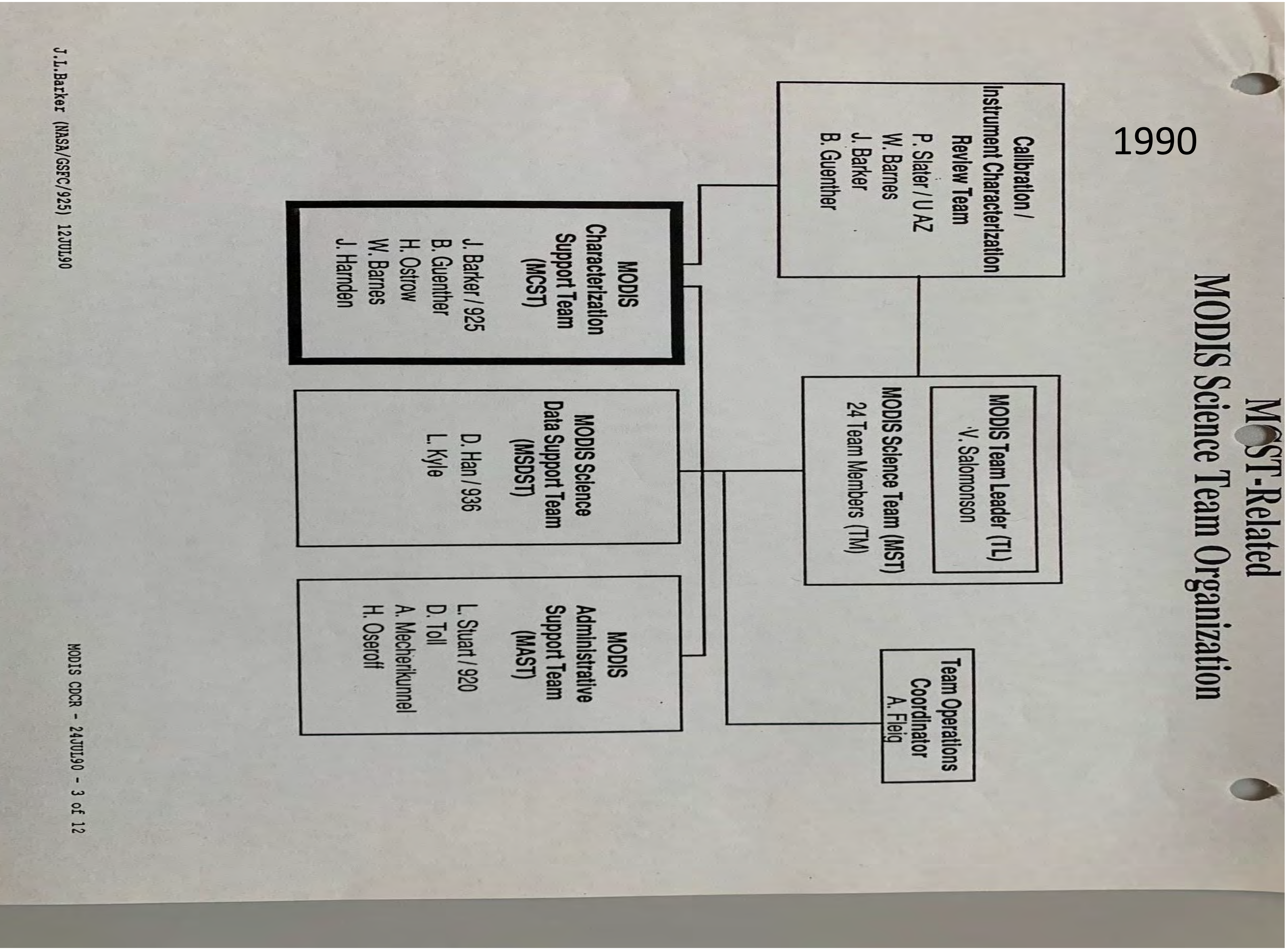


NOTES:

SRR: System Requirements Review
PDR: Preliminary Ddesign Review
CDR: Critical Design Review
ORR: Operational Readiness Review

(1) Draft
(2) Update
(3) Update
(4) Final

1990



MCST-Related MODIS Science Team Organization

Calibration / Instrument Characterization Review Team
P. Slater / U AZ
W. Barnes
J. Barker
B. Guenther

MODIS Team Leader (TL)
V. Salomonson

MODIS Science Team (MST)
24 Team Members (TM)

Team Operations Coordinator
A. Fleig

MODIS Characterization Support Team (MCST)
J. Barker / 925
B. Guenther
H. Ostrow
W. Barnes
J. Harnden

MODIS Science Data Support Team (MSDST)
D. Han / 936
L. Kyle

MODIS Administrative Support Team (MAST)
L. Stuart / 920
D. Toll
A. Mecherikunnel
H. Oseroff

J.L.Barker (NASA/GSFC/925) 12JUL90

MODIS SCIENCE TEAM MEETING

MINUTES

24 -26 SEPTEMBER, 1990

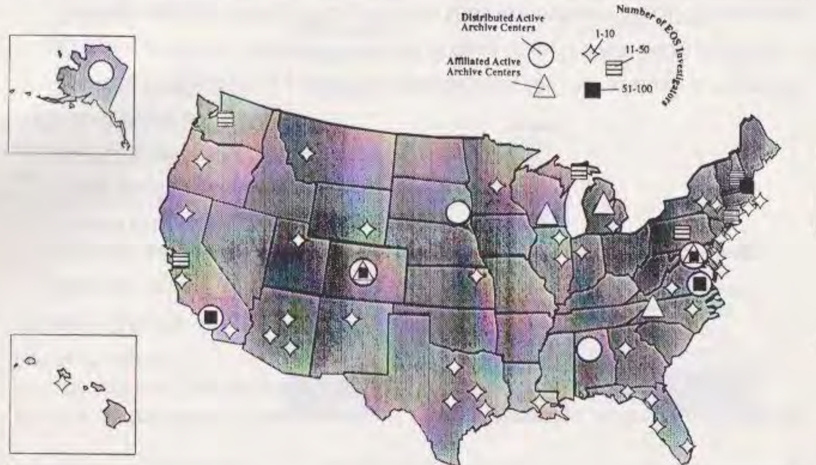
NASA/Goddard Space Flight Center

Greenbelt, Maryland

EOSDIS | Disciplines and Instruments by Site

Site	Discipline	# of Inst
ASF	Sea Ice (SAR)	1
EDC	Land Processes Imagery	5
GSFC	Upper Atmosphere, Meteorology, Ocean Color	15
JPL	Physical Oceanography, Air-Sea Interactions	3
LaRC	Radiation Budget, Aerosols	6
MSFC	Hydrologic Cycle	2
NSIDC	Snow and Ice (Non-SAR)	5

EOSDIS Active Archive Centers



ESAD

The MODIS Science Team - 1990

MODIS SCIENCE TEAM

OCEANS

MARK ABBOTT (UNIV OF OREGON)
IAN BARTON (CSIRO/AUSTRALIA)
OTIS BROWN (UNIV OF MIAMI)
KENDALL CARDER (UNIV OF S FLA)
DENNIS CLARK (NOAA/NESDIS)
*WAYNE ESAIAS (NASA/GODDARD)
ROBERT EVANS (UNIV OF MIAMI)
HOWARD GORDON (UNIV OF MIAMI)
FRANK HOGE (NASA/GODDARD)
JOHN PARSLOW (CSIRO/AUSTRALIA)

LAND

ALFREDO HUETE (UNIV OF ARIZONA)
*CHRIS JUSTICE (UNIV OF MD)
JAN-PETER MULLER (UNIV OF LONDON)
STEVE RUNNING (UNIV OF MONTANA)
**VINCE SALOMONSON (NASA/GODDARD)
ALAN STRAHLER (BOSTON UNIV)
VERN VANDERBILT (NASA/AMES/TGS)
ZHENGMING WAN (U C SANTA BARBARA)

ATMOSPHERES

YORAM KAUFMAN (UNIV OF MD)
*MIKE KING (NASA/GODDARD)
PAUL MENZEL (NOAA/NESDIS)
DIDIER TANRE (FRANCE/LILLE)

CALIBRATION/INSTRUMENT CHARACTERIZATION

WILLIAM BARNES (NASA/GSFC)
*PHIL SLATER (UNIV OF ARIZONA)

** TEAM LEADER
* GROUP LEADER

1990

- 1991 E … ly compe … al variab … at the MODIS … mid-af … nabling global
- 1991 H … r the MODIS
  - Imr … eng

RELAXED SPECTRAL BAND REGISTRATION REQUIREMENTS WOULD IMPROVE MARGINS

HUGHES
SANTA BARBARA RESEARCH CENTER
a subsidiary

- The specification (Para 3.4.6.3) presently requires ±0.1 IFOV coregistration between "any two corresponding detector elements from different spectral bands having the same IFOV".
  - The requirement applies equally to bands in different focal planes, and bands within the same focal plane. However, it is significantly easier to meet the requirement within the same focal plane.
  - The specification for the Thematic Mapper recognized the difference in difficulty by requiring ±0.2 IFOV coregistration within a focal plane, while allowing ±0.3 IFOV coregistration between focal planes.
  - If the MODIS-N requirement were changed to ±0.1 IFOV coregistration between corresponding detector elements within an focal plane and ±0.2 IFOV coregistration between corresponding detector elements in different focal planes, we would have resonable margins for both conditions.
- Would this change significantly affect the science?

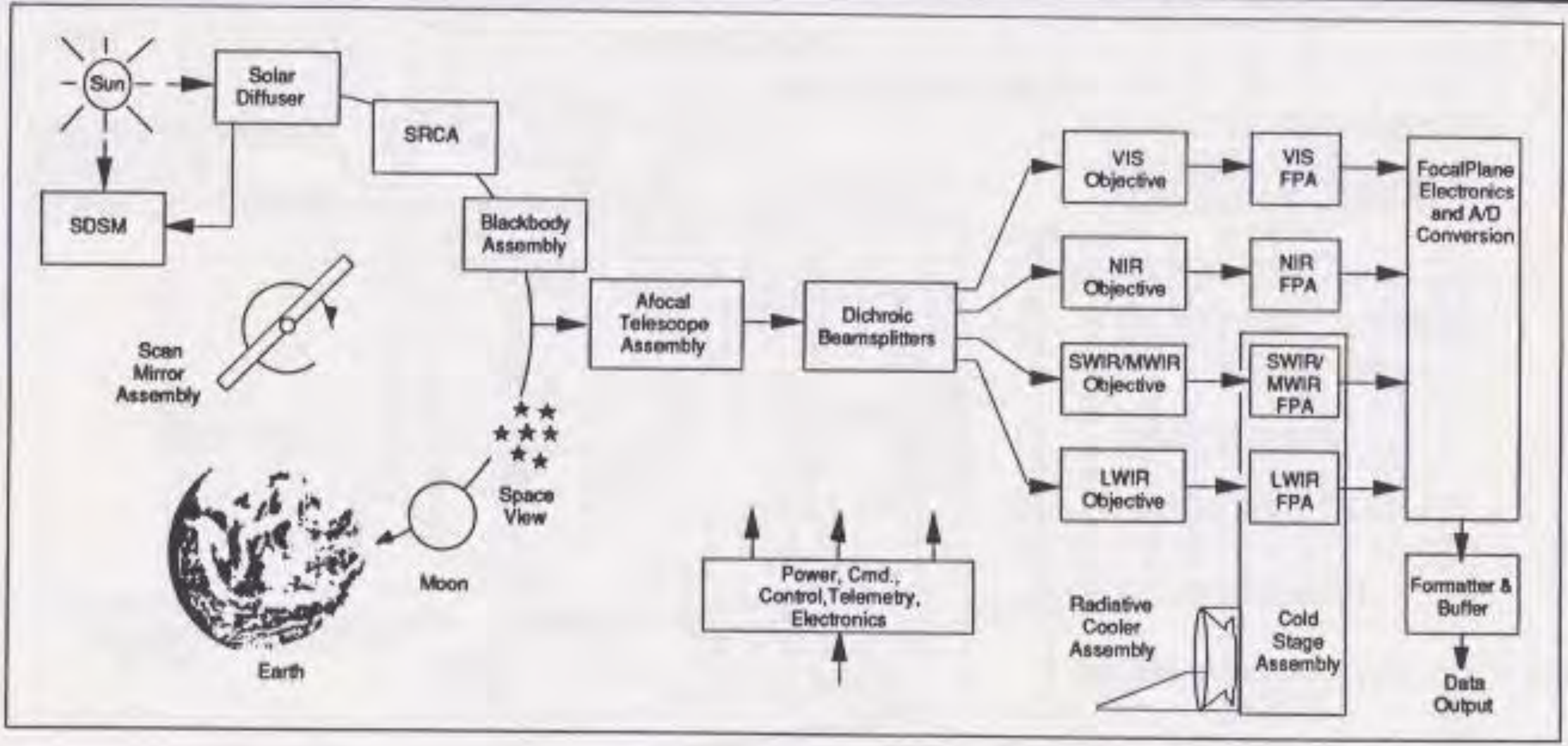
Jack Engel 1991 SBRC

MODIS DESIGN FROM PHOTONS TO DATA

HUGHES

SANTA BARBARA RESEARCH CENTER

a subsidiary

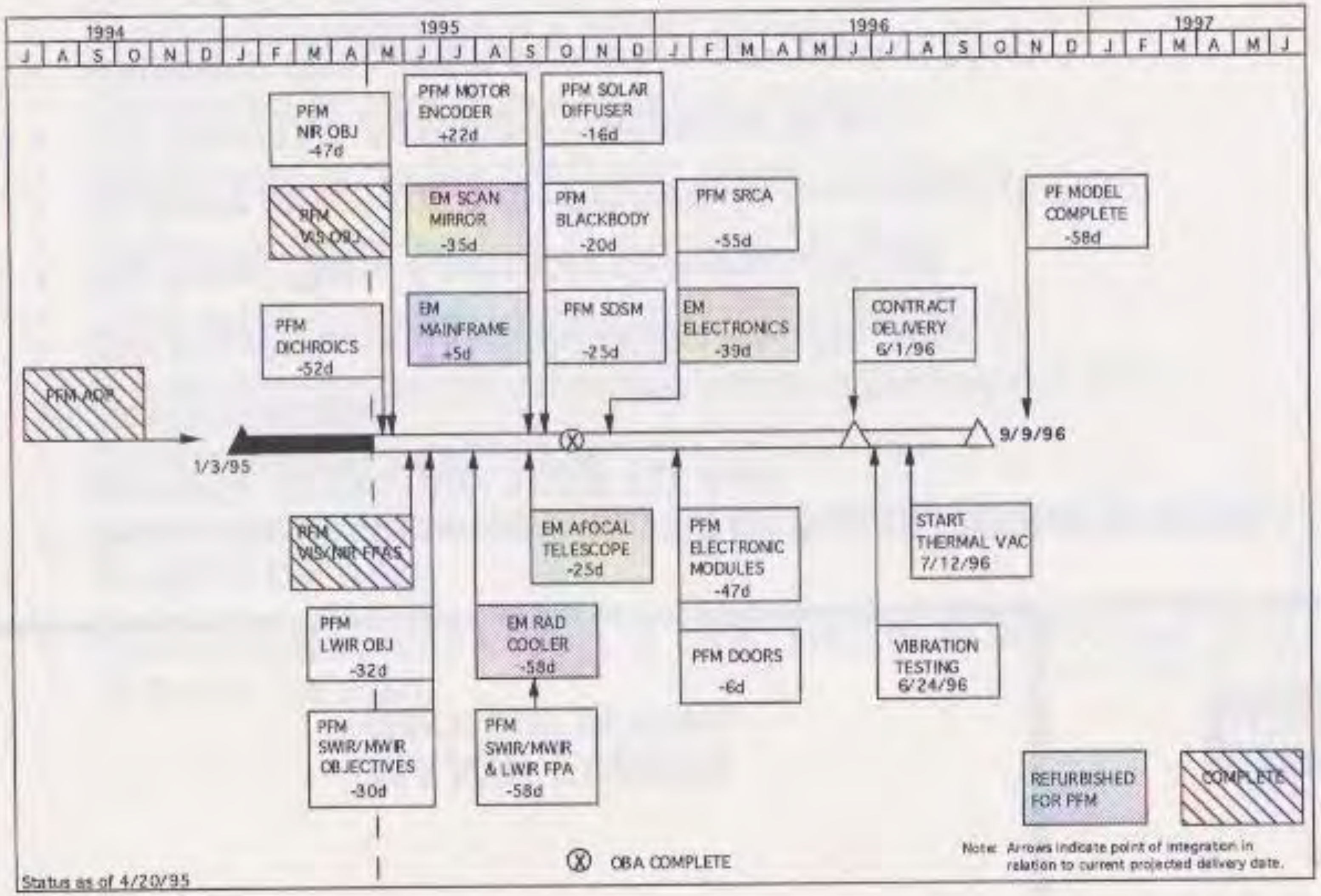


1992

SCHEDULE OVERVIEW
PROTOFLIGHT MODEL

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary



1995

TLCF 1995-2000

1995

modis-xl	4 processors R4400 150MHz (300MFLOPS)
	memory 1GB 2 way interleaved, 125GB disk
modis-pc	4 processors R8000 75MHz (1,200MFLOPS)
	memory 2GB 4 way interleaved, 50GB disk

80GB FDDI attached RAID

STANDA
PRODU

4 × 3½.

3.5 gigaflops per day

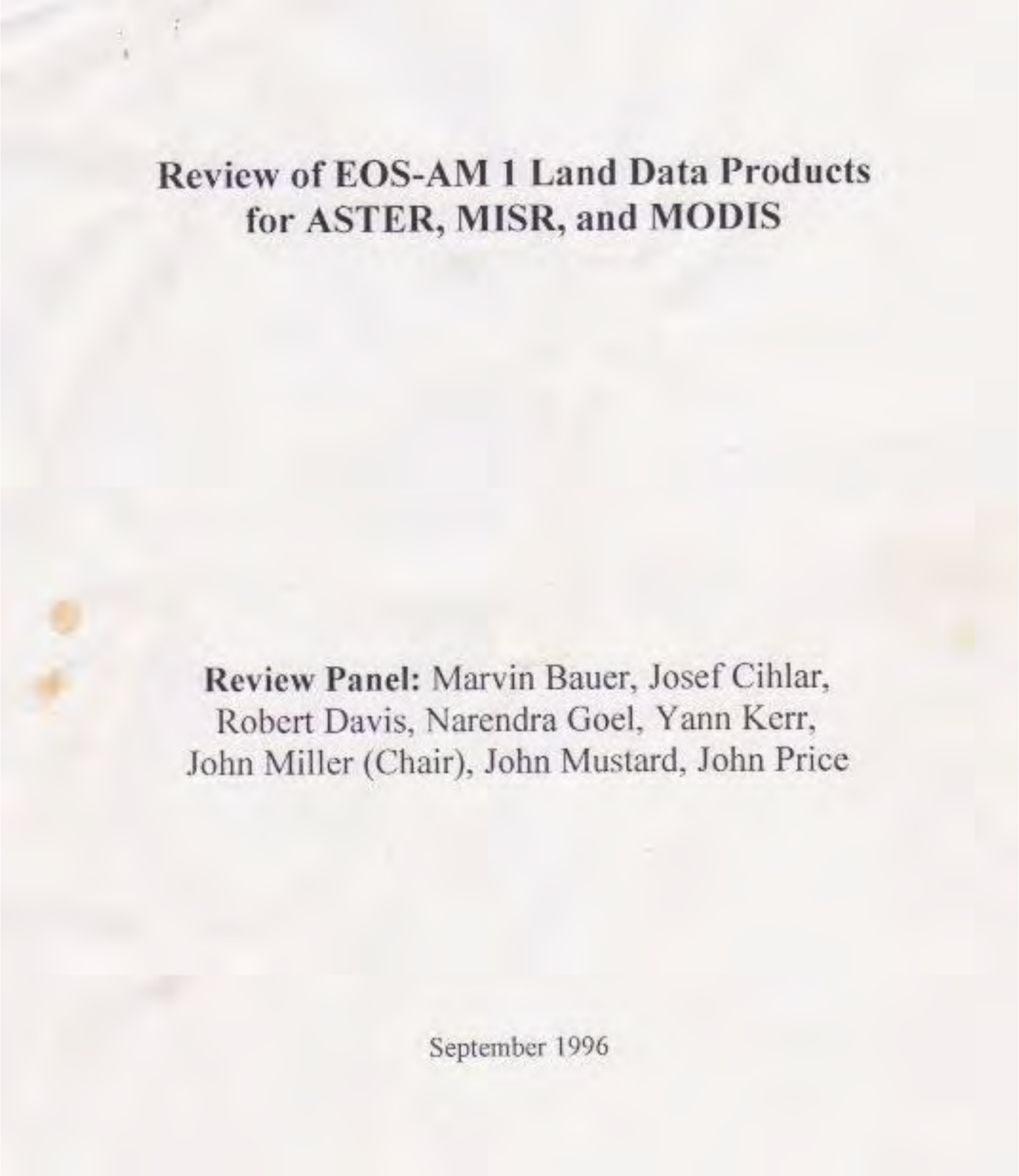
1996

modis-xl	no change 15/40
modis-pc	8 processors (4 new ones are R8000 90MHz)
	memory 4GB 8 way interleaved

160GB network attached RAID (total RAID is 240GB)

6TB Ampex DST tape library with 2 drives, 15MBps each

Ed Masuoka / Al Fleig 1993



Review of EOS-AM 1 Land Data Products
for ASTER, MISR, and MODIS

Review Panel: Marvin Bauer, Josef Cihlar,
Robert Davis, Narendra Goel, Yann Kerr,
John Miller (Chair), John Mustard, John Price

September 1996

Product Peer Review Process

Land Products Reviewed in 4 Categories

- Level 1 products, radiances at sensor
- Surface Reflectance, BRDF Products
- Thermal Emissivity, Fire, Snow Products
- Classification and Biophysical Products

Each Category Assigned a Review Leader and 2-3 Reviewers assigned for each ATBD

MODIS Early Processing

MODIS "1-on-1"

"May we live in interesting times"

E. Masuoka 12/16/97

MODIS PGE Delivery Priorities

- Priority 1 - Level 1 products (3 PGEs)
  - Level 1 products and Cloud Mask
- Priority 2 - PGEs for EGS Certification (15 PGEs)
  - Test EGS features needed to make MODIS products
- Priority 3 - At-launch PGEs (16 PGEs)
  - Remaining at-launch PGE's
  - Total of 44 at-launch PGEs (Priorities 1-3)
- Priority 4 - Post-launch PGEs (24 PGEs)
  - PGEs which make monthly, quarterly, yearly and Climate Modeling Grid products
- Total PGEs → 68

1997

Goals of Emergency Backup

- Produce initial MODIS products in support of Q/A and validation of MODIS algorithms
- Distribute limited volume of products to MODIS Science and Validation teams & other instruments
- Develop a system which could be scaled up to function as an alternative to EOSDIS

Modis Emergency Backup System (MEBS)

MODLAND Volumes and Loads - June 1997

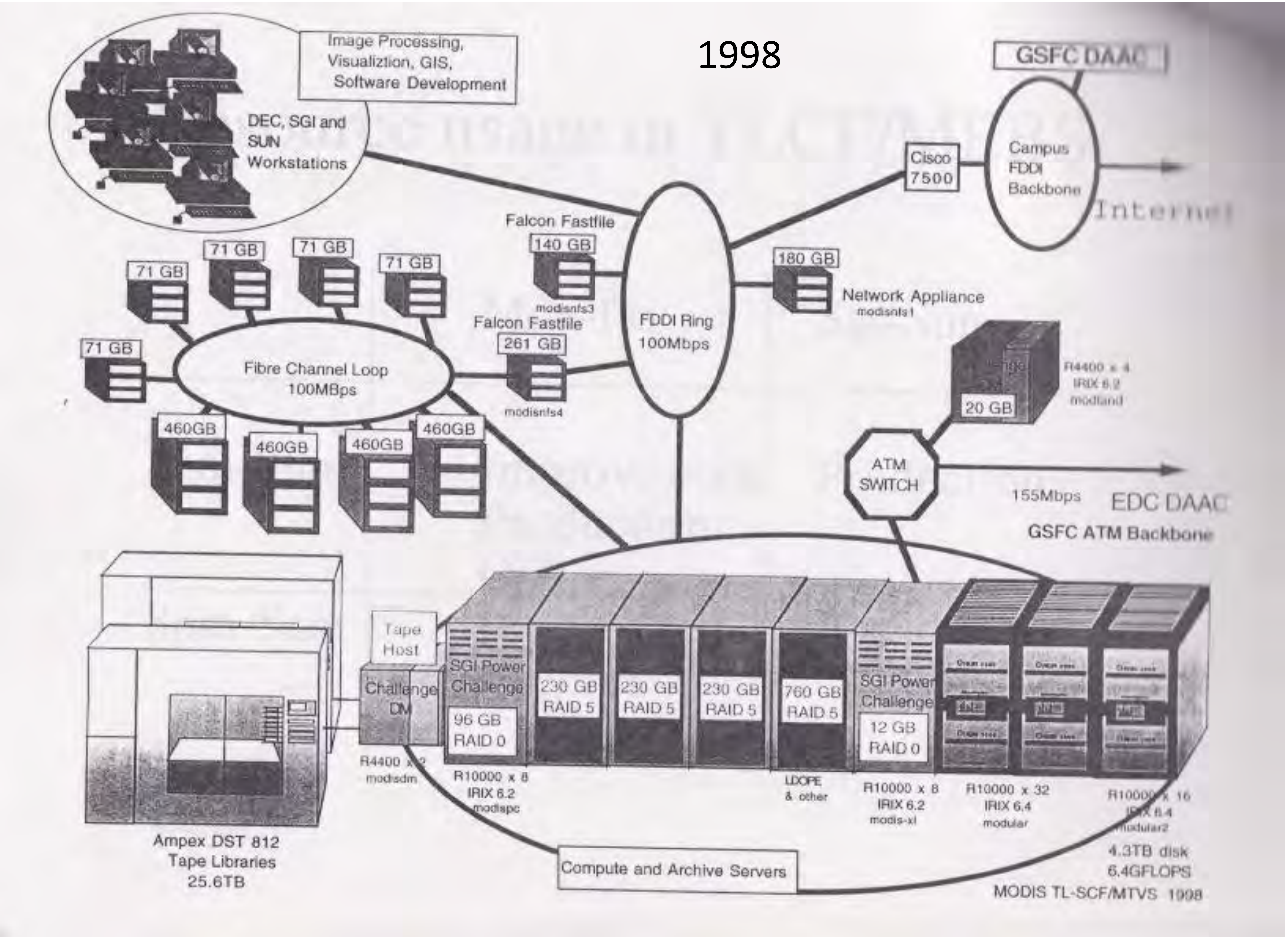
Robert Wolfe, Aug. 29, 1997

Product ID	Product Name (level, time cover)	Vol	Note	Load	Note
	GSFC				
MODMGGA	Tiled Geolocation Angular Data (L2G, day)	5		38	
MODMGPNTR	L2G Pointer Map - 250m (L2G, day)	9		627	
	L2G Pointer Map - 500m (L2G, day)	2		0	#2
	L2G Pointer Map - 1km (L2G, day)	1		0	#2
MOD09	Surface Reflectance (L2, granule)	0	n/a	74	
MOD09G	Tiled Surface Reflectance - 250m (L2G, day)	104		187	
	Tiled Surface Reflectance - 500m (L2G, day)	0	n/a	0	#3
MOD10	Snow Cover (L2, granule)	2		1	
MOD10G	Tiled Snow Cover (L2G, day)	0	n/a	32	
MOD11	Land Surface Temperature/Emissivity (L2, granule)	7		7	
MOD11A1	Gridded Daily Land Surface Temp/Emissivity - 1km (L3, day)	0	n/a	15	
	Gridded Daily Land Surface Temp/Emissivity - 5km (L3, day)	0	n/a	0	n/a
MOD14	Thermal Anomalies (L2, granule)	0	n/a	0	#1
MOD14G	Tiled Thermal Anomalies (L2G, day)	12		17	
MOD29	Sea-ice Max Extent (L2, granule)	2		5	
MOD29G	Tiled Sea-ice Max Extent (L2G, day)	0	n/a	29	
	GSFC Total	144		1032	
	EDC				
MOD09A	Gridded Surface Reflectance - 250m (L3, day)	0	n/a	0	n/a
	Gridded Surface Reflectance - 500m (L3, day)	0	n/a	0	n/a
MOD11A2	Gridded 8-day Land Surface Temp/Emissivity - 1km (L3, 8-day)	8		0	n/a
	Gridded 8-day Land Surface Temp/Emissivity - 5km (L3, 8-day)	0	n/a	0	n/a
MOD11C1	Gridded Daily Land Surface Temp/Emissivity - CMG (L3, day)	0		0	n/a
MOD11C2	Gridded 8-day Land Surface Temp/Emissivity - CMG (L3, 8-day)	0		0	n/a
MOD11C3	Gridded Monthly Land Surface Temp/Emissivity - CMG (L3, month)	0		0	n/a
MOD12M	Monthly Land Cover Database (L3, month)	4		14	
MOD12Q1	Quarterly Land Cover Type (L3, 3-month)	1		0	n/a
MOD12Q1	Quarterly Land Cover Change (L3, 3-month)	0		0	n/a
MOD12C1	Land Cover Type - CMG (L3, 3-month)	0	n/a	0	n/a
MOD12C2	Land Cover Change - CMG (L3, 3-month)	0	n/a	0	n/a
MOD13A1	Gridded Vegetation Indices - 250m (Max NDVI and Integrated MVI, 16-day (L3, 16-day)	13	#5	404	
MOD13A2	Gridded Vegetation Indices - 1km (Max NDVI and Integrated MVI, 16-day (L3, 16-day)	0	n/a	0	n/a
MOD13A3	Gridded Vegetation Indices - 1km (Max NDVI and Integrated MVI, monthly (L3, month)	2		81	
MOD13C1	Gridded Vegetation Indices - CMG (Max NDVI and Integrated MVI, 16-day (L3, 16-day)	0		0	n/a
MOD13C2	Gridded Vegetation Indices - CMG (Max NDVI and Integrated MVI, monthly (L3, month)	0		0	n/a
MOD14A1	Gridded Daily Thermal Anomalies (Fire Size and Temp) (L3, day)	5		27	
MOD14A2	Gridded 8-day Thermal Anomalies (Fire Size and Temp) (L3, 8-day)	1		0	n/a
MOD14A3	Gridded Monthly Thermal Anomalies (Fire Size and Temp) (L3, month)	0		0	n/a
MOD14C1	Gridded Daily Thermal Anomalies (Fire Size and Temp) - CMG (L3, day)	0		0	n/a
MOD14C2	Gridded 8-day Thermal Anomalies (Fire Size and Temp) - CMG (L3, 8-day)	0		0	n/a
MOD14C3	Gridded Monthly Thermal Anomalies (Fire Size and Temp) - CMG (L3, month)	0		0	n/a

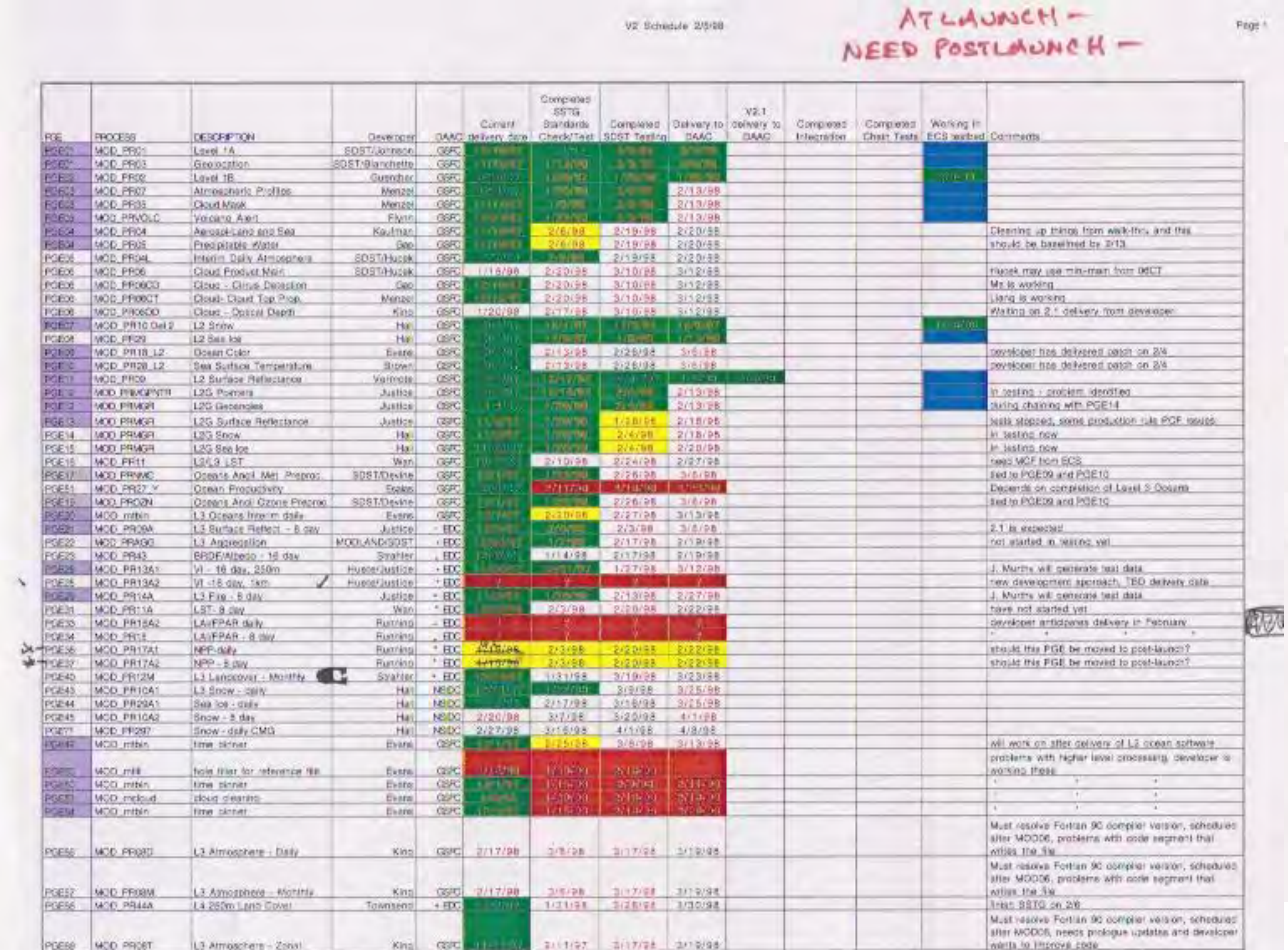
Post-Launch Production

- All of Level 1 and Cloud Mask
- Oceans - All products
  - Global 4km
  - Coastal US and validation sites at 1km
- Atmosphere - All products
  - one week per month full resolution
- Land - All products
  - Full resolution, regional production
    - North America, South America, portion of Africa...
  - Global, full resol., 1 month during first 6 months

1998


GSFC DAAC
Image Processing, Visualiztion, GIS, Software Development
DEC, SGI and SUN Workstations
Cisco 7500
Campus FDDI Backbone
Internet
Falcon Fastfile
140 GB
modisnfs3
180 GB
Network Appliance
modisnfs1
71 GB
71 GB
71 GB
71 GB
71 GB
Fibre Channel Loop 100MBps
Falcon Fastfile
261 GB
modisnfs4
FDDI Ring 100Mbps
20 GB
R4400 x 4
IRIX 6.2
modland
460GB
460GB
460GB
460GB
ATM SWITCH
155Mbps
EDC DAAC
GSFC ATM Backbone
Tape Host
Challenge DM
R4400 x 2
modisdm
SGI Power Challenge
96 GB RAID 0
R10000 x 8
IRIX 6.2
modispc
230 GB RAID 5
230 GB RAID 5
230 GB RAID 5
760 GB RAID 5
LDOPE & other
SGI Power Challenge
12 GB RAID 0
R10000 x 8
IRIX 6.2
modis-xl
R10000 x 32
IRIX 6.4
modular
R10000 x 16
IRIX 6.4
modular2
Ampex DST 812 Tape Libraries 25.6TB
Compute and Archive Servers
4.3TB disk
6.4GFLOPS
MODIS TL-SCF/MTVS 1998

The Beginning of MODAPS
(built on TLCF, MEBS)



V2 Schedule 2/5/98

Page 1

AT LAUNCH –
NEED POSTLAUNCH –

PGE	PROCESS	DESCRIPTION	Developer	DAAC	Current delivery date	Completed SSTG Standards Check/Test	Completed SDST Testing	Delivery to DAAC	V2.1 delivery to DAAC	Completed Integration	Completed Chain Tests	Working in ECS testbed	Comments
PGE01	MOD_PR01	Level 1A	SDST/Johnson	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					
PGE01	MOD_PR03	Geolocation	SDST/Blanchette	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					
PGE02	MOD_PR02	Level 1B	Guenther	GSFC	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	
PGE03	MOD_PR07	Atmospheric Profiles	Menzel	GSFC	[illegible]	[illegible]	[illegible]	2/13/98					
PGE03	MOD_PR35	Cloud Mask	Menzel	GSFC	[illegible]	[illegible]	[illegible]	2/13/98					
PGE03	MOD_PRVOLC	Volcano Alert	Flynn	GSFC	[illegible]	[illegible]	[illegible]	2/13/98					
PGE04	MOD_PR04	Aerosol-Land and Sea	Kaufman	GSFC	[illegible]	2/6/98	2/19/98	2/20/98					Cleaning up things from walk-thru and this
PGE04	MOD_PR05	Precipitable Water	Gao	GSFC	[illegible]	2/6/98	2/19/98	2/20/98					should be baselined by 2/13
PGE05	MOD_PR04L	Interim Daily Atmosphere	SDST/Hucek	GSFC	[illegible]	[illegible]	2/19/98	2/20/98					
PGE06	MOD_PR06	Cloud Product Main	SDST/Hucek	GSFC	1/16/98	2/20/98	3/10/98	3/12/98					Hucek may use min-main from 06CT
PGE06	MOD_PR06CD	Cloud - Cirrus Detection	Gao	GSFC	[illegible]	2/20/98	3/10/98	3/12/98					Mr is working
PGE06	MOD_PR06CT	Cloud- Cloud Top Prop.	Menzel	GSFC	[illegible]	2/20/98	3/10/98	3/12/98					Liang is working
PGE06	MOD_PR06OD	Cloud - Optical Depth	King	GSFC	1/20/98	2/17/98	3/10/98	3/12/98					Waiting on 2.1 delivery from developer
PGE07	MOD_PR10 Del 2	L2 Snow	Hall	GSFC	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	
PGE08	MOD_PR29	L2 Sea Ice	Hall	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					
PGE09	MOD_PR18_L2	Ocean Color	Evans	GSFC	[illegible]	2/13/98	2/26/98	3/6/98					developer has delivered patch on 2/4
PGE10	MOD_PR28_L2	Sea Surface Temperature	Brown	GSFC	[illegible]	2/13/98	2/26/98	3/6/98					developer has delivered patch on 2/4
PGE11	MOD_PR09	L2 Surface Reflectance	Vermote	GSFC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
PGE12	MOD_PRMGPNTR	L2G Pointers	Justice	GSFC	[illegible]	[illegible]	[illegible]	2/13/98					In testing - problem identified
PGE12	MOD_PRMGR	L2G Geoangles	Justice	GSFC	[illegible]	[illegible]	[illegible]	2/13/98					during chaining with PGE14
PGE13	MOD_PRMGR	L2G Surface Reflectance	Justice	GSFC	[illegible]	[illegible]	1/28/98	2/18/98					tests stopped, some production rule PCF issues
PGE14	MOD_PRMGR	L2G Snow	Hall	GSFC	[illegible]	[illegible]	2/4/98	2/18/98					In testing now
PGE15	MOD_PRMGR	L2G Sea Ice	Hall	GSFC	[illegible]	[illegible]	2/4/98	2/20/98					In testing now
PGE16	MOD_PR11	L2/L3 LST	Wan	GSFC	[illegible]	2/10/98	2/24/98	2/27/98					need MCF from ECS
PGE17	MOD_PRNMC	Oceans Ancil. Met. Preproc.	SDST/Devine	GSFC	[illegible]	[illegible]	2/26/98	3/6/98					tied to PGE09 and PGE10
PGE51	MOD_PR27_Y	Ocean Productivity	Esaias	GSFC	[illegible]	2/17/98	[illegible]	[illegible]					Depends on completion of Level 3 Oceans
PGE18	MOD_PROZN	Oceans Ancil Ozone Preproc	SDST/Devine	GSFC	[illegible]	[illegible]	2/26/98	3/6/98					tied to PGE09 and PGE10
PGE20	MOD_mtbin	L3 Oceans Interim daily	Evans	GSFC	[illegible]	2/20/98	2/27/98	3/13/98					
PGE21	MOD_PR09A	L3 Surface Reflect. - 8 day	Justice	EDC	[illegible]	[illegible]	2/3/98	3/6/98					2.1 is expected
PGE22	MOD_PRAGG	L3 Aggregation	MODLAND/SDST	EDC	[illegible]	[illegible]	2/17/98	2/19/98					not started in testing yet
PGE23	MOD_PR43	BRDF/Albedo - 16 day	Strahler	EDC	[illegible]	1/14/98	2/17/98	2/19/98					
PGE24	MOD_PR13A1	VI - 16 day, 250m	Huete/Justice	EDC	[illegible]	[illegible]	1/27/98	3/12/98					J. Murthy will generate test data
PGE25	MOD_PR13A2	VI -16 day, 1km	Huete/Justice	EDC	?	?	?	?					new development approach, TBD delivery date
PGE26	MOD_PR14A	L3 Fire - 8 day	Justice	EDC	[illegible]	[illegible]	2/13/98	2/27/98					J. Murthy will generate test data
PGE31	MOD_PR11A	LST- 8 day	Wan	EDC	[illegible]	2/3/98	2/20/98	2/22/98					have not started yet
PGE33	MOD_PR15A2	LAI/FPAR daily	Running	EDC	?	?	?	?					developer anticipates delivery in February
PGE34	MOD_PR15	LAI/FPAR - 8 day	Running	EDC	?	?	?	?					" " " "
PGE36	MOD_PR17A1	NPP-daily	Running	EDC	[illegible]	2/3/98	2/20/98	2/22/98					should this PGE be moved to post-launch?
PGE37	MOD_PR17A2	NPP - 8 day	Running	EDC	[illegible]	2/3/98	2/20/98	2/22/98					should this PGE be moved to post-launch?
PGE40	MOD_PR12M	L3 Landcover - Monthly	Strahler	EDC	[illegible]	1/31/98	3/19/98	3/23/98					
PGE43	MOD_PR10A1	L3 Snow - daily	Hall	NSIDC	[illegible]	[illegible]	3/9/98	3/25/98					
PGE44	MOD_PR29A1	Sea Ice - daily	Hall	NSIDC	[illegible]	2/17/98	3/16/98	3/25/98					
PGE45	MOD_PR10A2	Snow - 8 day	Hall	NSIDC	2/20/98	3/7/98	3/20/98	4/1/98					
PGE77	MOD_PR29?	Snow - daily CMG	Hall	NSIDC	2/27/98	3/16/98	4/1/98	4/8/98					
[illegible]	MOD_mtbin	time binner	Evans	GSFC	[illegible]	2/25/98	3/6/98	3/13/98					will work on after delivery of L2 ocean software
[illegible]	MOD_mfill	hole filler for reference file	Evans	GSFC	[illegible]	[illegible]	[illegible]						problems with higher level processing, developer is working these
[illegible]	MOD_mtbin	time binner	Evans	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					" " "
[illegible]	MOD_mcloud	cloud clearing	Evans	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					" " "
[illegible]	MOD_mtbin	time binner	Evans	GSFC	[illegible]	[illegible]	[illegible]	[illegible]					" " "
PGE55	MOD_PR08D	L3 Atmosphere - Daily	King	GSFC	2/17/98	3/5/98	3/17/98	3/19/98					Must resolve Fortran 90 compiler version, schedules after MOD06, problems with code segment that writes the file
PGE57	MOD_PR08M	L3 Atmosphere - Monthly	King	GSFC	2/17/98	3/5/98	3/17/98	3/19/98					Must resolve Fortran 90 compiler version, schedules after MOD06, problems with code segment that writes the file
PGE56	MOD_PR44A	L4 250m Land Cover	Townsend	EDC	[illegible]	1/31/98	3/28/98	3/30/98					finish SSTG on 2/6
PGE69	MOD_PR08T	L3 Atmosphere - Zonal	King	GSFC	[illegible]	3/11/97	3/17/98	3/19/98					Must resolve Fortran 90 compiler version, schedules after MOD06, needs prologue updates and developer wants to improve code

Coarse Resolution Satellite Time Series: MODIS

Terra Launch: Dec. 18, 1999
First Image: Feb. 24, 2000

Aqua Launch: May 04, 2002
First Image: June 26, 2002

Terra Launch

MODIS Science Team January 2001

Initial MODIS Land Team Emphases

ATBD / SCF Development

Algorithm Development and Testing, Initial Coding

Instrument Performance Evaluation

Algorithm revision/recoding

Initial Code Delivery / Integration

Product Testing and Beta Generation > Provisional Distribution

Initial PR and Outreach / Code Revision

MODIS Land Team - 2001 Post Launch

Science Team Members / Science Data Support Team / DAAC Reps

Standard MODIS Land Product Suite

Energy Balance Product Suite

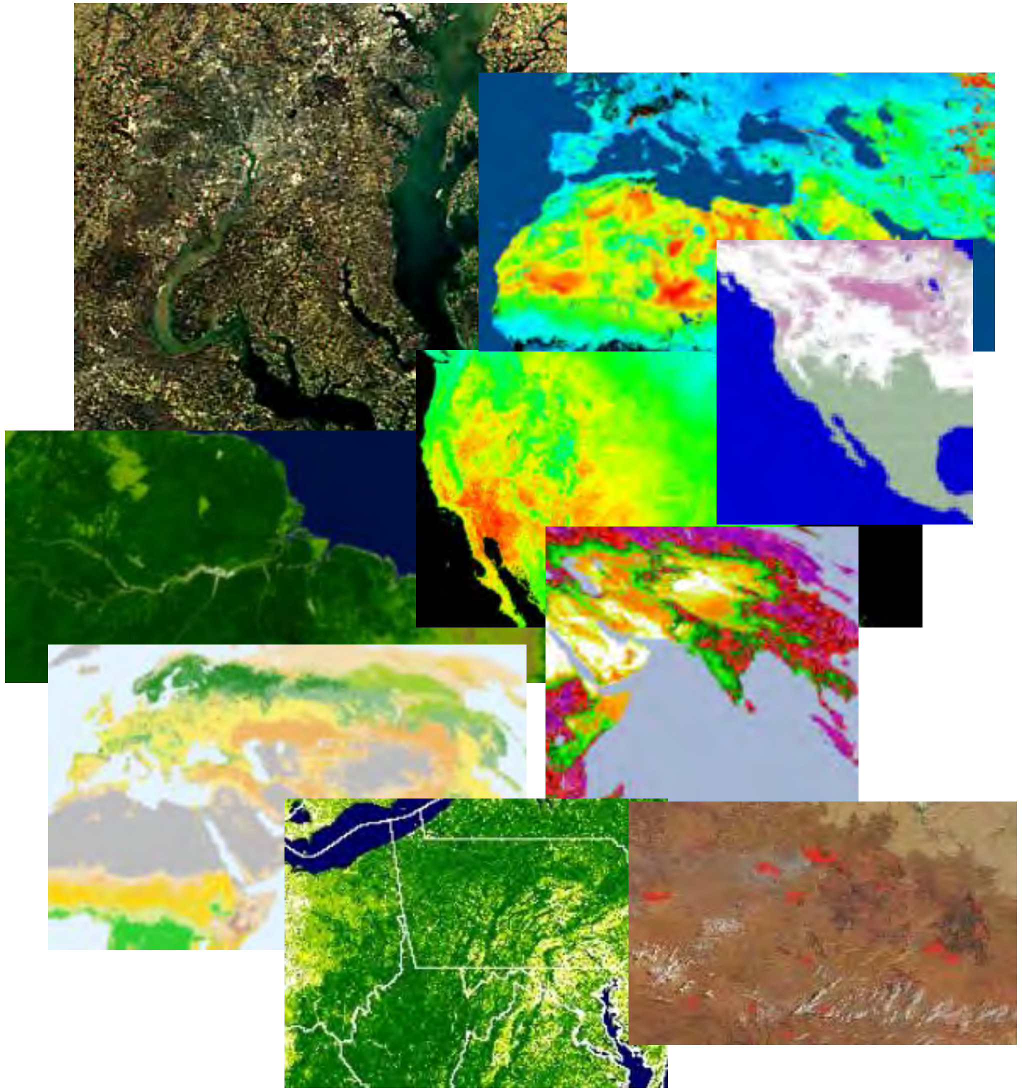
- Surface Reflectance
- Land Surface Temperature, Emissivity
- BRDF/Albedo
- Snow/Sea-ice Cover

Vegetation Parameters Suite

- Vegetation Indices
- LAI/FPAR
- Gross and Net Primary Production

Land Cover/Land Use Suite

- Phenology
- Land Cover
- Vegetation Continuous Fields
- Active Fire
- Burned Area



https://modis-land.gsfc.nasa.gov/

MODIS QUALITY STATUS

Beta products

- early release product, minimally validated and may still contain significant errors
- available to allow users to gain familiarity with data formats and parameters
- product is not appropriate as the basis for quantitative scientific publications

Provisional products

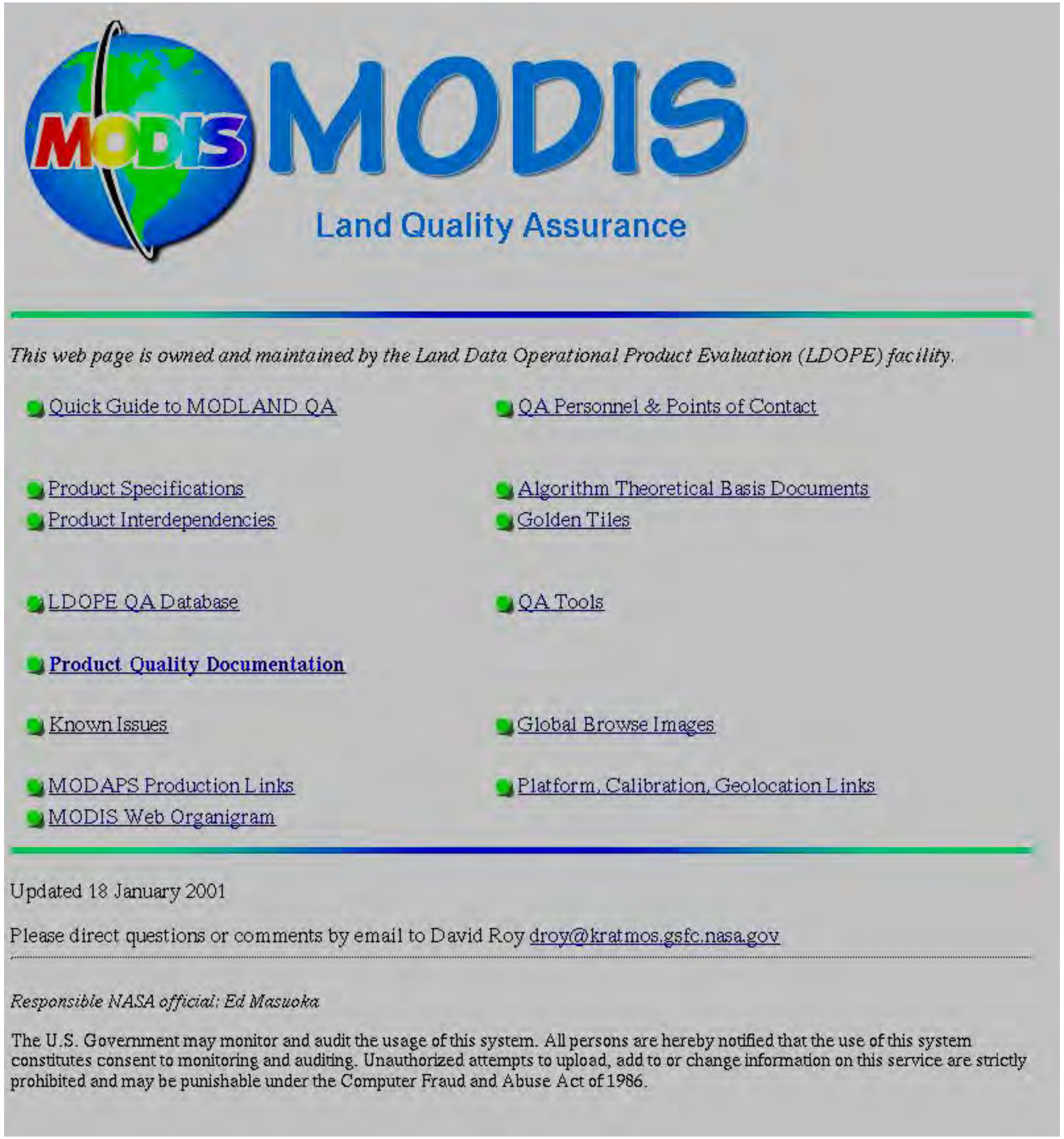
- product quality may not be optimal
- incremental product improvements are still occurring
- general research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
- users are urged to contact science team representatives prior to use of the data in publications
- may be replaced in the archive when the validated product becomes available

2001

QUALITY STATUS

Surface Reflectance	Provisional
BRDF/Albedo	Provisional
Temperature/Emissivity	Beta
Vegetation Indices	Provisional
LAI/FPAR	Provisional
Thermal Anomalies/Fire	Provisional
Land Cover	Beta

Calli Jenkerson and Brad Reed (EDC DAAC)


MODIS

Land Quality Assurance

This web page is owned and maintained by the Land Data Operational Product Evaluation (LDOPE) facility.

- Quick Guide to MODLAND QA
- QA Personnel & Points of Contact
- Product Specifications
- Product Interdependencies
- Algorithm Theoretical Basis Documents
- Golden Tiles
- LDOPE QA Database
- QA Tools
- **Product Quality Documentation**
- Known Issues
- Global Browse Images
- MODAPS Production Links
- MODIS Web Organigram
- Platform, Calibration, Geolocation Links

Updated 18 January 2001

Please direct questions or comments by email to David Roy droy@kratmos.gsfc.nasa.gov

Responsible NASA official: Ed Masuoka

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LDOPE

Land Data Operational Product Evaluation

providing a leadership role in establishing QA as an integral part of the data system

documenting product quality leading to algorithm updates

addressing product dependencies and establishing time series QA record

2001

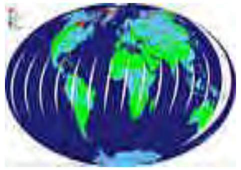
MODLAND - Roy, Devadiga et al.

MODIS Land Products: Browse (Day: 9/29/00)

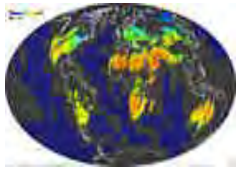
April 2001

TOA Visible Radiance
MOD02

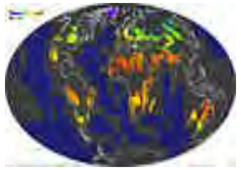
Surface Reflectance
Daily MOD09



Snow Cover
Daily MOD10 L2



Surface Temp (Day)
Daily MOD11



Surface Temp (N)
Daily MOD11

Active Fire /Surface
Reflectance Daily

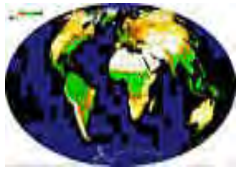
MOD14 w. MOD 09

Leaf Area Index
Daily MOD15A1

Fractional PAR
Daily MOD15A1

8-day Land Surface

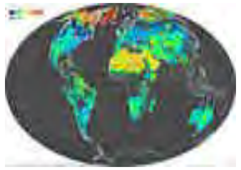
Reflectance MOD09A1



16-day Enhanced Vegetation

Index MOD13A2

16-Day Nadir BRDF-Adj
Reflectance MOD43B4



16-day Shortwave Broad-
band White-Sky Albedo
MOD43B3

Modland/J.Descloitres

MODIS Known Issues Page

Detailed description

Color Key	Case pending	Case closed	Case reopened	QA note

Case #: DR_MOD43_01012 **Opening date:** 01/12/01 **Last update:** 01/12/01
Status: Note

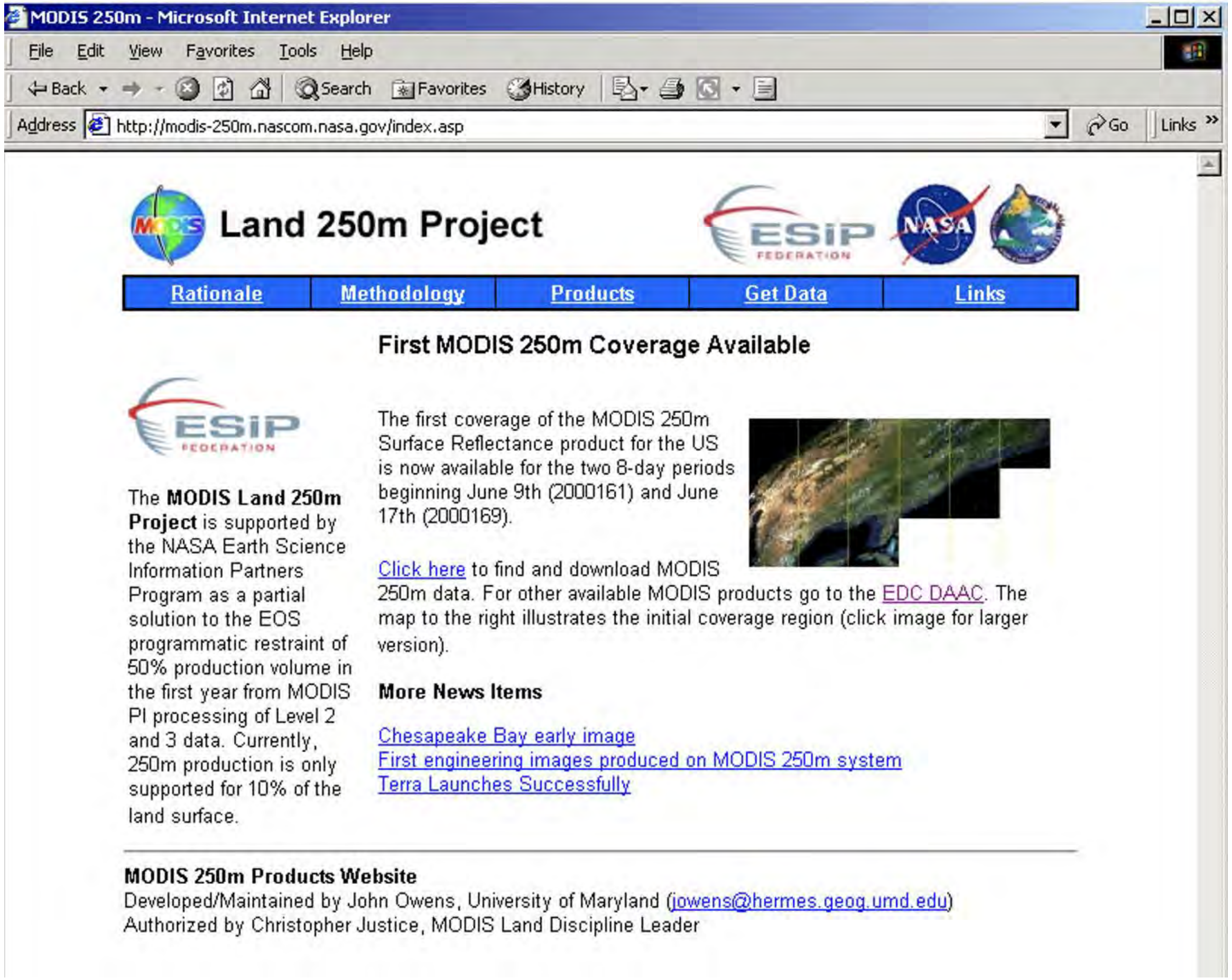
MOD43 is not produced when there are insufficient observations to invert the BRDF model. The cloud mask has been found to systematically label some desert transition regions as cloudy even when they are clear . MOD43 production is precluded in these regions. For example, the transition zone between grass savanna and desert shrubland across North Africa is seen to be all fill values in the mosiac image below.

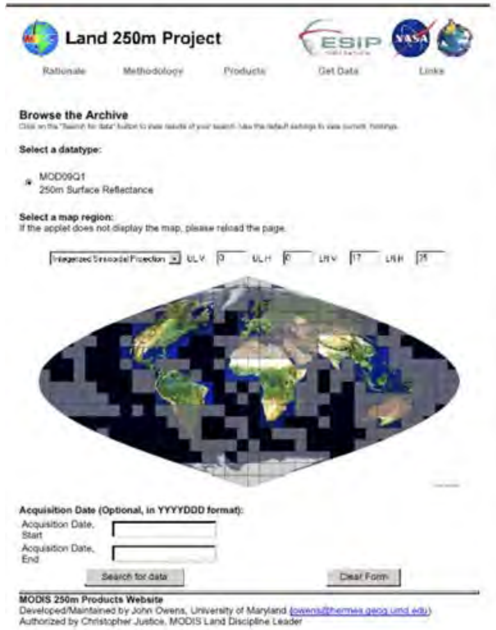
MOD43B4.A2000305.h16v07.001.2001010133426.hdf MOD43B4.A2000305.h17v07.001.2001010135420.hdf
MOD43B4.A2000305.h18v07.001.2001010135906.hdf MOD43B4.A2000305.h19v07.001.2001010140948.hdf
SDS: Nadir_Reflectance
(True-color composite with fill values in white)

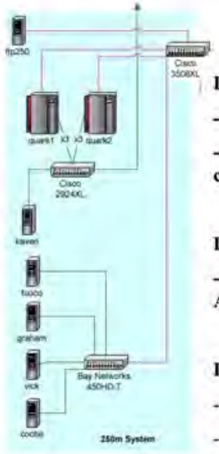
Occurence: TBD
PGE: 2.2.9

Devadiga

Land 250m Production System (2001-2003)







250m System Design

Data Processing

--Compaq AlphaServer ES50 Server (1.5TB Disk)

--SGI Origin 2000 Server (MODAPS contributions)

Data Distribution

--Windows 2000 PC Web, Database, online Archive Server (1TB Disk)

Lessons Learned

-- Don't count on vendors for support

-- Disk is cheap – keeping data online speeds up processing

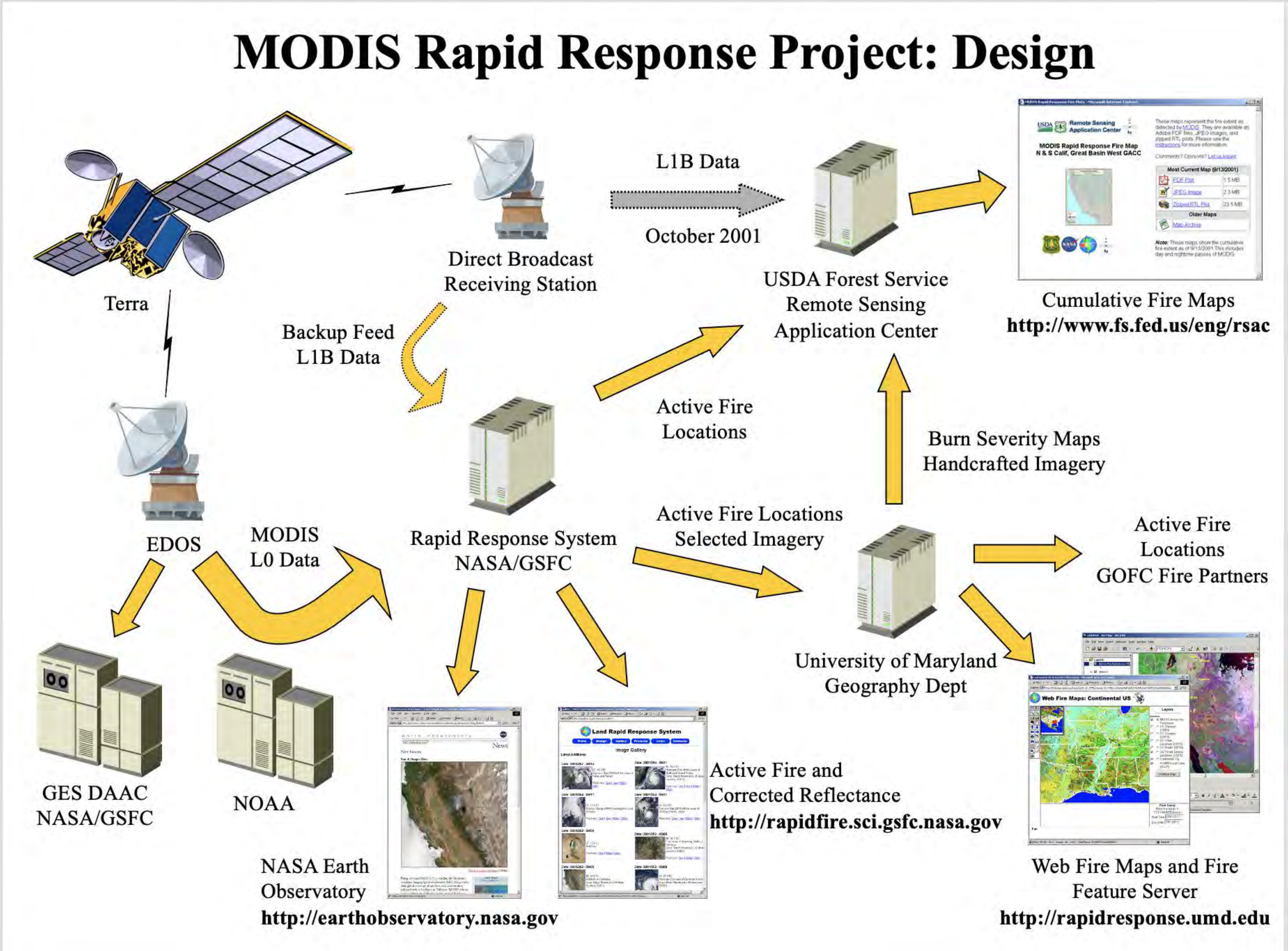
M

et al.)

Rat
MO
MO
Nee

App
Hard
Rap
Star

No I
L0 t
Fire
RGB



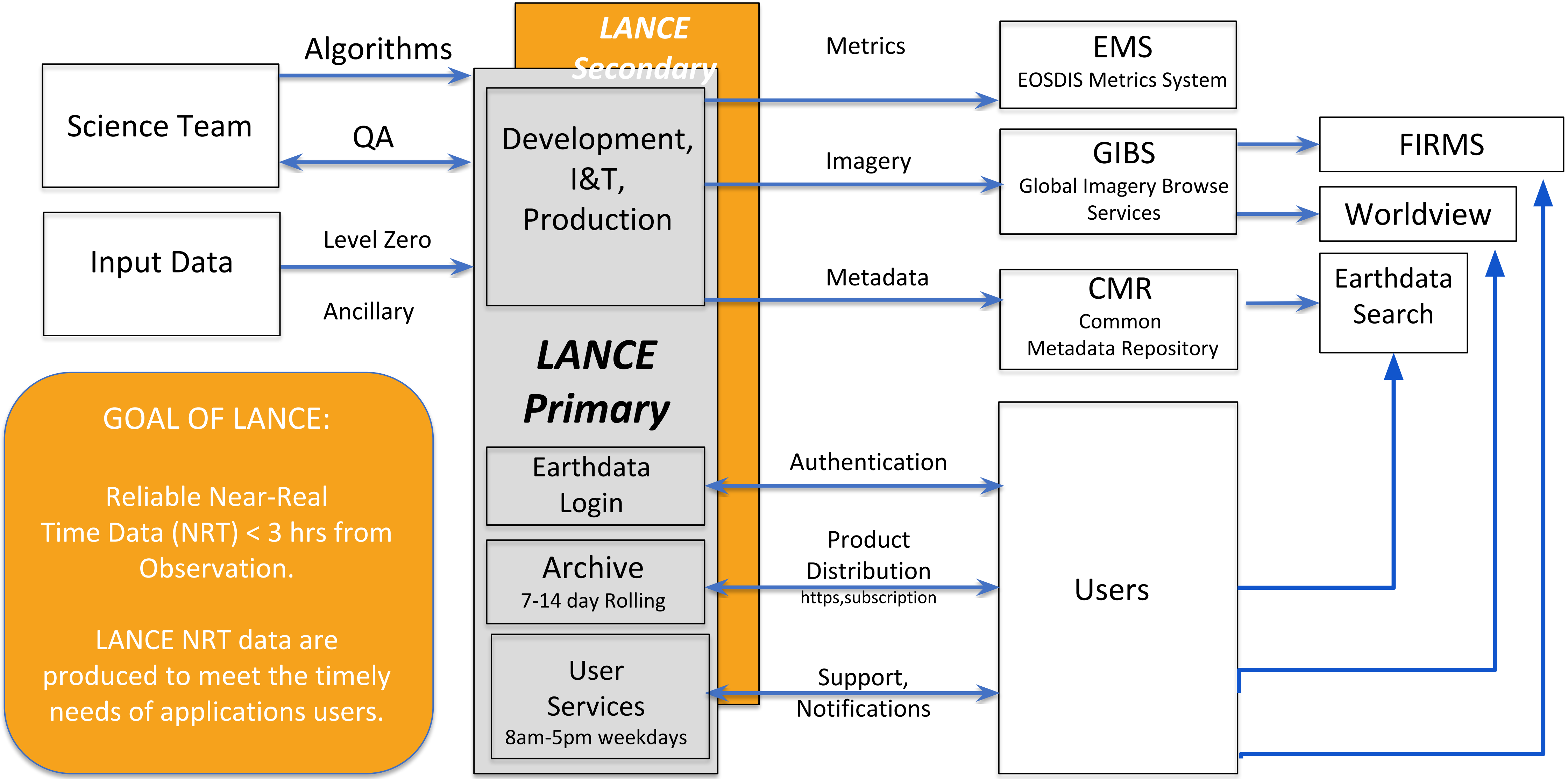
lovember 2001

Fire Information for Resource Management System (FIRMS)

Originally developed at the University of Maryland. It was funded by NASA's Applied Sciences and the United Nations (UN) Food and Agriculture Organization (FAO) using data from MODIS Rapid Response

FIRMS became part of LANCE in 2012. In 2020 the USFS approached NASA to develop FIRMS US/Canada. The prototype was released in January 2021.

Land Atmosphere Near real time Capability for EOS



MODIS land team

- Land Validation Coordination
- PI Validation Plans
- Validation data collection protocol – BIGFOOT (Cohen)
- MODIS/EOS Land Core Sites
    - High resolution acquisition (L7, Aster, Ikonos w/ SDP)
- Field Data coordination – w. ORNL – Mercury System
- Other correlative data e.g. ASTER, SeaWiFs
- Validation campaign support SAFARI 2000, LBA
- International Validation Program Representation
    - CEOS Land Product Validation WG (w. Belward)
    - Validation Stage 1-3

MODIS / VIIRS Land Team 2008

Evolution of ESDIS and the 'Land' DAACS – EDC, NSIDC, ORNL

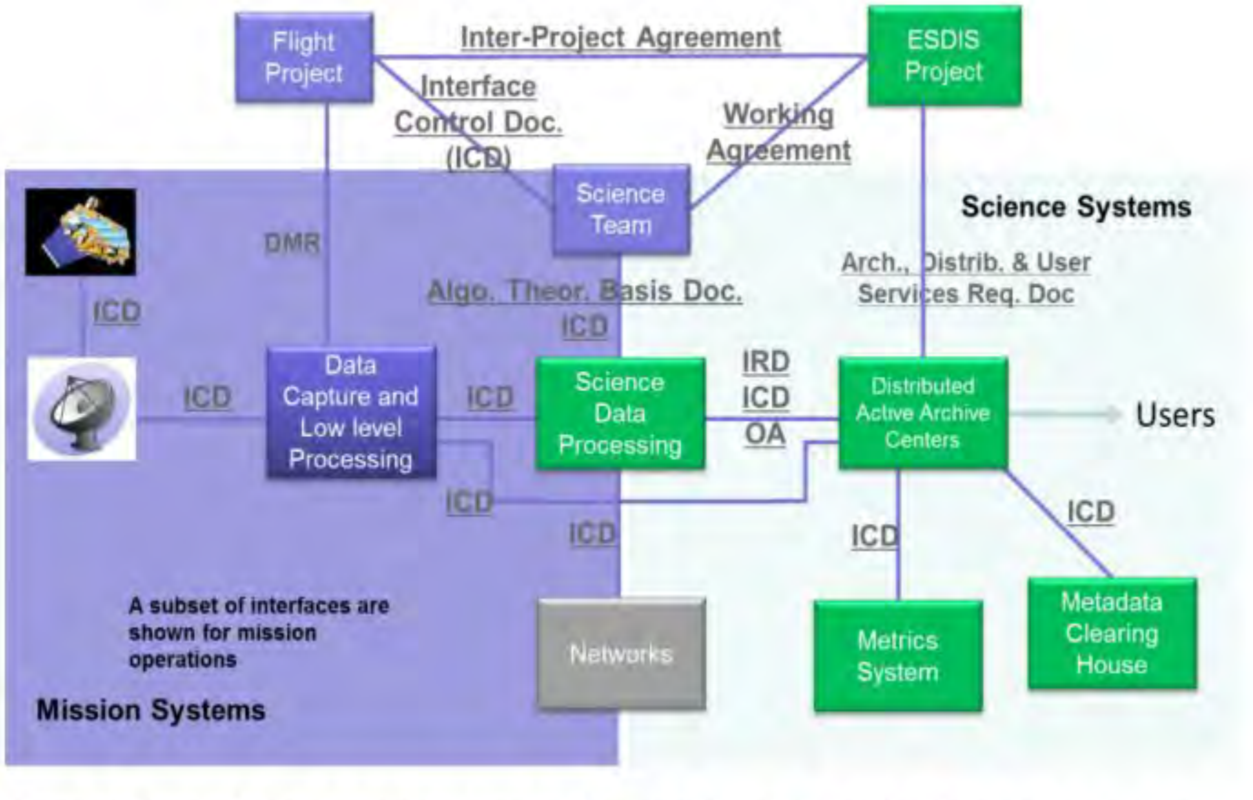
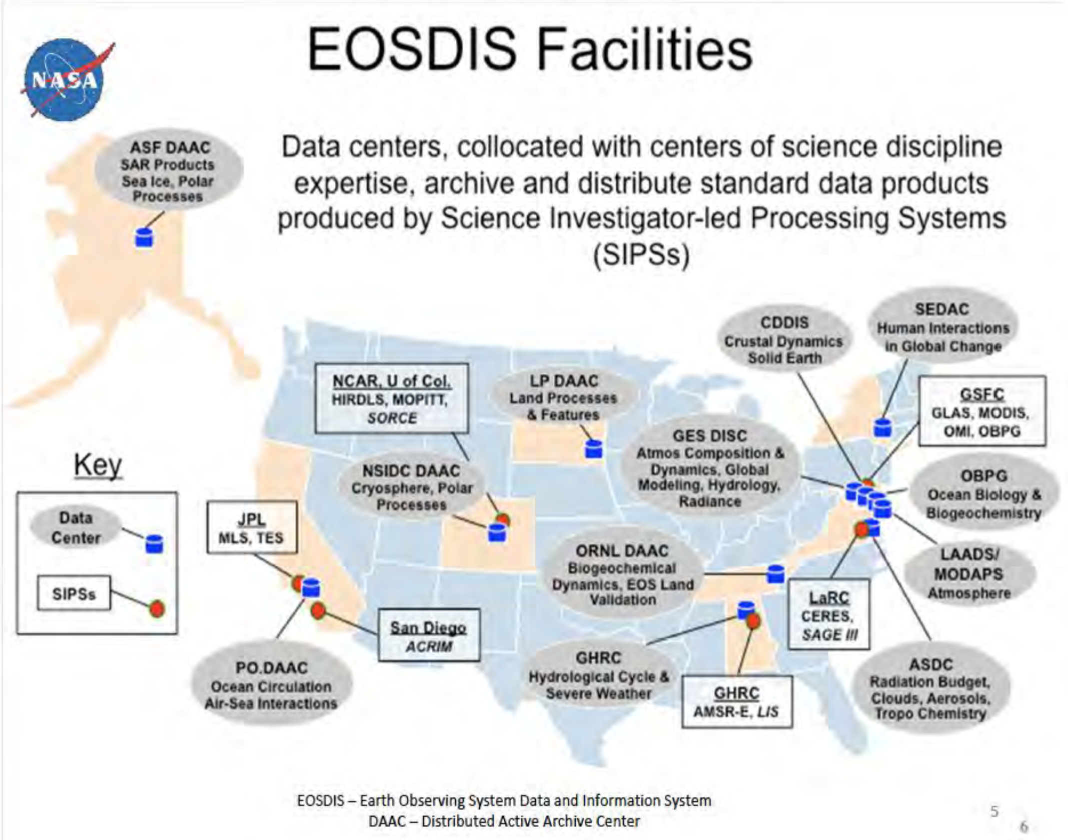


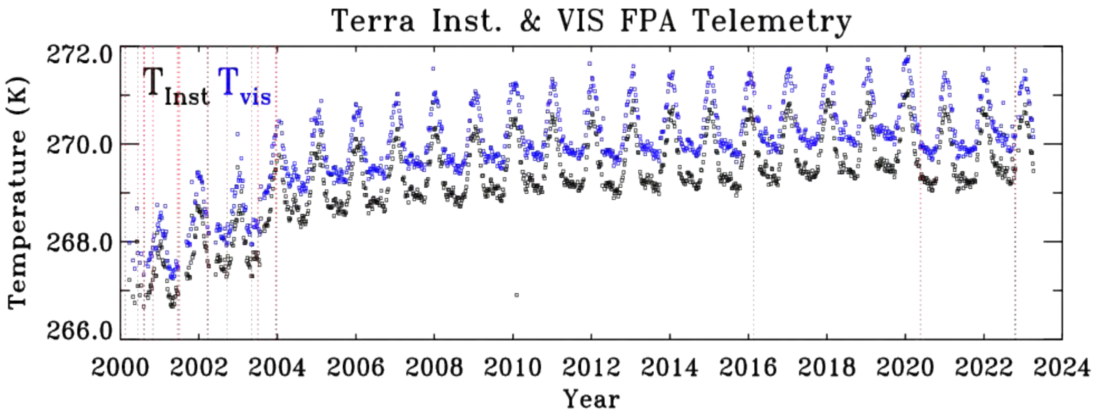
Figure **2. Organizations and Interfaces to Support Satellite Mission Data Management**

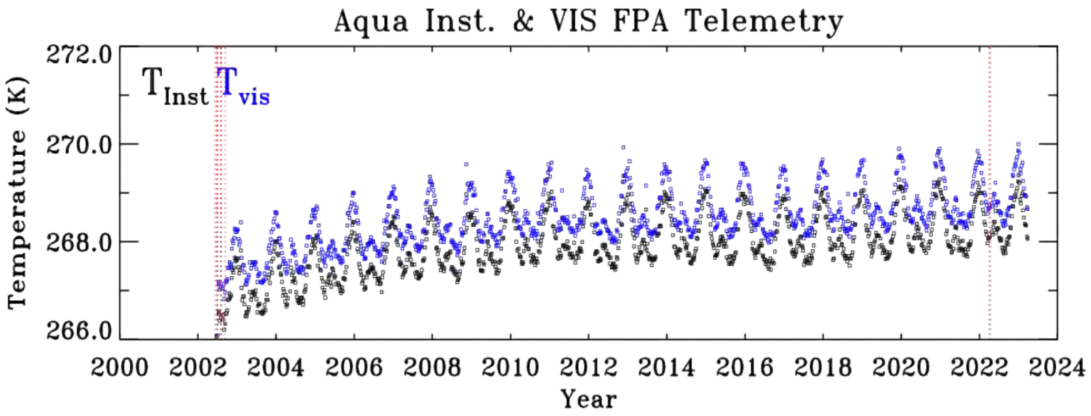


Lowe 2010

2011

Modis Calibration Support Team - Instrument Calibration





Shifting MODIS Land Team Emphases

Algorithm Development and Testing, Initial Coding

Instrument Performance Evaluation – Algorithm revision/recoding

Product Testing and Beta Generation > Provisional Distribution

Initial PR and Outreach / Code Revision

Major Reprocessing > Product QA and Validation

Stage 1 Validated Product Distribution > Feedback

Increased Outreach – Science/Application – Publications

Completion of Stage 3 Validation

Collection 6 (5th) Reprocessing

Product Maintenance > End of Life Planning

Decommissioning Deliberations

MODLAND Summary (2023)

- MODIS Terra launched Dec 18 1999
- MODIS Aqua launched May 4 2002
    - *Kudos to the engineers and MCST*
- A suite of land products driven primarily by global modeling community
    - SR, VI,BRDF/Albedo, Surface Temperature, LAI/FPAR, NPP, ET, Fire/Burned Area, Snow and Ice/MAIAC
    - BRDF, LAI, Fire products rely on AM and PM observations
    - *Kudos to the MODLAND Team*
- PI and LDOPE QA and Validation integral part of the land product activities
    - *Kudos to LDOPE*
- 5 full record reprocessing of the data – C7 in planning
    - *Kudos to SDST, MODAPS*
- Efficient Data Dissemination and User Services – ESDIS, EDC, NSIDC, ORNL DAACs
    - *Kudos to LAADS, Science Teams and the 'Land' DAACs*
- Data also available via Google Earth Engine, AWS
- MODIS instruments in the 2023 NASA Senior Review > the opportunity for Orbital Decay Science?
- EOS Data Continuity Study underway. For Land:
    - Aqua > VIIRS on SNPP, NOAA 20, NOAA 21 ……….
    - Terra Continuity Analysis underway w. ESA Sentinel 3 (Devadiga, Vermote, Giglio)

NOAA moving beyond the AVHRR (1990)

NOAA REQUIREMENTS

DRAFT

FOR

SUPPORT FROM

POLAR-ORBITING SATELLITES

JUNE 1990

products; and product evaluation and science studies.

This report represents one of the five Product Development Plans produced as a result of the Workshop. While rough drafts were prepared at the Workshop, the reports were finalized under the direction of the Product Advisory Team Chairs and their NESDIS Team Contacts. The Chairs of all the Product Advisory Teams are listed below, and the members of the Team that prepared this report are listed in the Appendix. These Plans will provide the initial guidance for the development and implementation of the Operational Measurements component of the NOAA Climate and Global Change Program.

Product Advisory Team Chairs

Oceanic variables	Dr. Peter Cornillon University of Rhode Island
Land surface variables	Dr. John Townshend University of Maryland
Earth radiation budget, clouds, and aerosols	Dr. Tom Vonder Haar Colorado State University
Tropospheric circulation variables	Dr. Wayman Baker NOAA National Meteorological Center
Stratospheric variables	Dr. John Gille National Center for Atmospheric Research

Start of the NPOESS Era

Date: Dec 1995

FINAL

INTEGRATED OPERATIONAL REQUIREMENTS DOCUMENT (IORD) I

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

ACAT LEVEL I

Deputy Under Secretary of Commerce for Oceans and Atmosphere	Vice Chairman, Joint Chiefs of Staff

Associate Administrator for Mission to Planet Earth

OPR: JOINT AGENCY REQUIREMENTS GROUP
(JARG) Administrators:
DoD: Maj Michael G. Bedard
DSN 692-9605, Comm (719) 554-9605
DOC: Mr Jamison Hawkins
Comm (301) 457-5125
NASA: Mr Charles E. Cote
Comm (301) 713-3578

Dec 1995

(Chris)

Climate Measurement Requirements for the National Polar-orbiting Operational Environmental Satellite System (NPOESS)

WORKSHOP REPORT

Feb 1997

NPP Mission Characteristics

- **Joint mission between NASA & the Integrated Program Office (IPO) providing:**

  The Visible Infrared Imaging Spectroradiometer Suite (VIIRS) extends the measurement series initiated with the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS Terra & Aqua

  Design is evolutionary from MODIS

  Murphy Feb. 2002

- **Launch in late 2005 (Western Test Range)**
- **824 km polar sun-synchronous orbit**
  - **10:30 AM descending node**
  - **Compatibility with EOS Terra (Similar Repeat, Crossing Time)**
- **All data down-linked to polar ground station once per orbit & via TDRSS**
- **Continuous direct broadcast of all data at X-band**

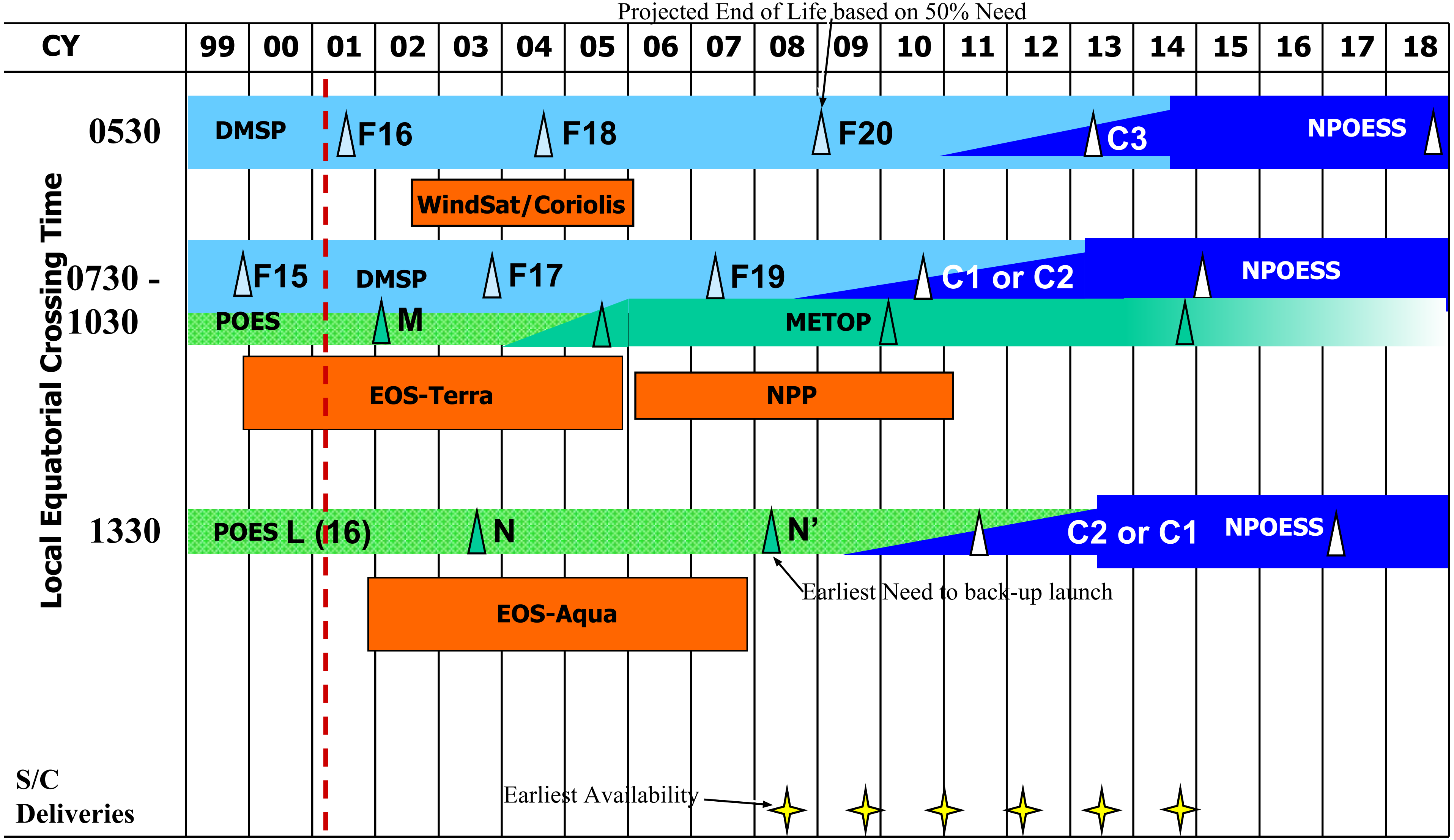
http://jointmission.gsfc.nasa.gov

2001

Satellite Transition Schedule

(9 March 2001)

Slopes indicate 10-90% need (NPOESS GAP 5b)



NPP SDS/NewDISS Retreat

- Informal retreat held in Manassas, VA on March 6-7, 2001
  - 25 participants from NASA HQ, NASA GSFC, Science Community
  - Science, Data Managers, Engineers, Program & Project Management
- Conveners: Mark Abbott, Dan DeVito, Martha Maiden, Bob Murphy
- Chair: Chris Justice

Objectives

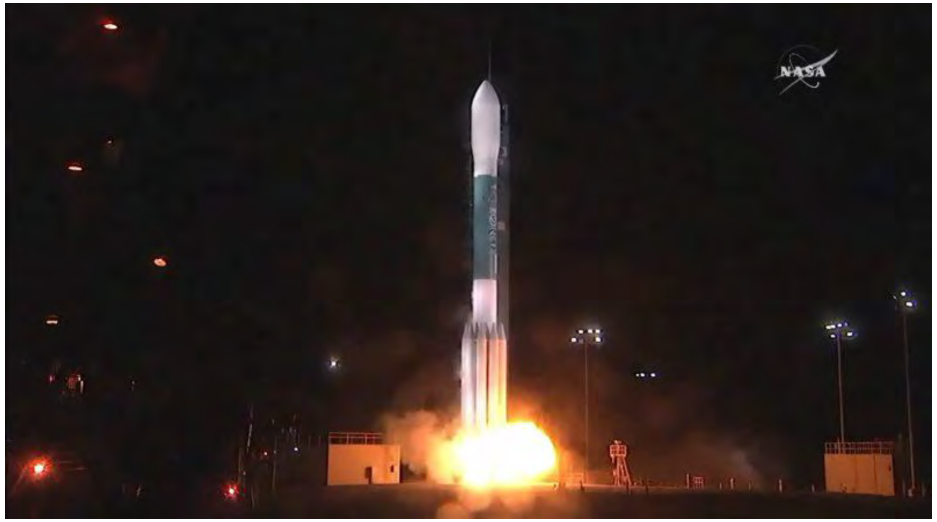
- Develop an approach for the NASA production of NPP data sets
  - Consistent with data sets from legacy systems
  - Consistent into the NPOESS era
- Assess NewDISS objectives for SDS
- Assess the appropriateness of acquisition plan for the elements of SDS
- Discuss NPP Science Team issues

NPP launched – NASA VIIRS Science Team selected

- NPP VIIRS launched Oct 28 2011
  - 1.30pm Overpass
  - NPOESS Preparatory experience – a bridge to JPSS

ROSES 2010 A.22 "NASA requests investigations to continue the evaluation and improvement of NPP/NPOESS Environmental Data Records (EDRs), to develop new scientific approaches for extending key data records that cannot be continued by NPP/NPOESS, and to demonstrate applications of NPP data. "

- NASA VIIRS Science Team formed in 2011 to evaluate NPP EDR's
- Named Soumi-NPP (S-NPP) in 2012
- First Science Team Meeting May 2012



S-NPP and JPSS Data Products From NOAA available in real-time

VIIRS (24)

ALBEDO (SURFACE)
CLOUD BASE HEIGHT
CLOUD COVER/LAYERS
CLOUD EFFECTIVE PART SIZE
CLOUD OPTICAL THICKNESS
CLOUD TOP HEIGHT
CLOUD TOP PRESSURE
CLOUD TOP TEMPERATURE
ICE SURFACE TEMPERATURE
OCEAN COLOR/CHLOROPHYLL
SUSPENDED MATTER
VEGETATION INDEX, FRACTION,
HEALTH
AEROSOL OPTICAL THICKNESS
AEROSOL PARTICLE SIZE
ACTIVE FIRES
POLAR WINDS
IMAGERY
SEA ICE CHARACTERIZATION
SNOW COVER
SEA SURFACE TEMPERATURE
LAND SURFACE TEMP
SURFACE TYPE

CrIS/ATMS (3)

ATM VERT MOIST PROFILE
ATM VERT TEMP PROFILE
CARBON (CO2, CH4, CO)

ATMS (11)

CLOUD LIQUID WATER
PRECIPITATION RATE
PRECIPITABLE WATER
LAND SURFACE EMISSIVITY
ICE WATER PATH
LAND SURFACE TEMPERATURE
SEA ICE CONCENTRATION
SNOW COVER
SNOW WATER EQUIVALENT
ATM TEMPERATURE PROFILE
ATM MOISTURE PROFILE

OMPS (2)

O_3 TOTAL COLUMN
O_3 NADIR PROFILE
SO2 and Aerosol Index

GCOM AMSR-2 (11)

CLOUD LIQUID WATER
PRECIPITATION TYPE/RATE
PRECIPITABLE WATER
SEA SURFACE WINDS SPEED
SOIL MOISTURE
SNOW WATER EQUIVALENT
IMAGERY
SEA ICE CHARACTERIZATION
SNOW COVER/DEPTH
SEA SURFACE TEMPERATURE
SURFACE TYPE

Blue - currently available in CSPP

Goldberg, Csiszar 2014

JPSS Program Status

Suomi NPP is producing outstanding data

- The satellite is healthy and producing a high availability of data (~99.99%)
- Operations of the satellite transferred from NASA to NOAA in 2013
- Suomi NPP is the primary operational polar-orbiting satellite for NOAA

JPSS-1 is executing as planned

- Instruments and spacecraft are proceeding well
- Instruments are assembled and undergoing testing; two have been delivered for integration
- The spacecraft bus is built and undergoing testing
- Development and implementation of the new ground data processing system are underway

JPSS-2 procurement activities are progressing well

- The VIIRS sensor is under contract and others are in evaluation
- The spacecraft bus procurement is underway

Goldberg, Csiszar 2014

1st Suomi-NPP Land Workshop, GSFC

Dec 2014

It is now time for the Suomi NPP ST to direct its attention to developing the refined and/or alternative data products yet needed to ensure high-quality data records for Earth system science and applications that enable continuity with EOS data products **(ROSES 2013 A.29)**

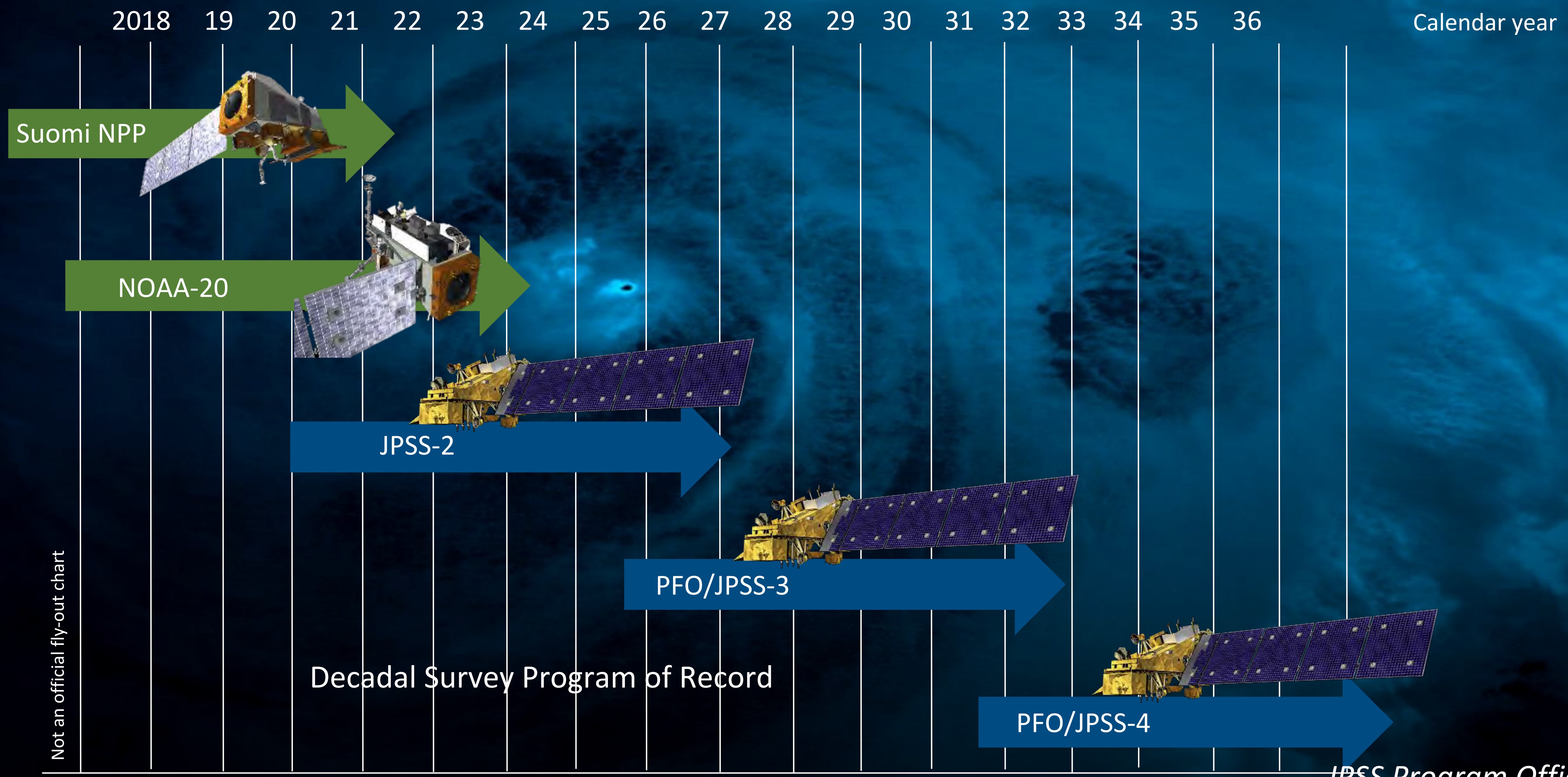
- 3 years after launch - we have the green light to generate and distribute NASA VIIRS Land Science Products
- We have a very good instrument for land monitoring, which in some aspects is an improvement over MODIS
- The MODIS land community has been integral to the development of the NOAA VIIRS EDR's and Validation
  - In the case of SR and Active Fire the MODIS algorithms were used as the basis for the EDR's
- EDR's designed to meet the needs of NOAA's operational user community (NWS, etc)
  - Uptake of EDR's by the land science community has been limited to date
- Goal now is to move quickly and efficiently to get a series of NASA VIIRS products out to the community, providing 'dynamic continuity' with the MODIS land products

MODIS Research to VIIRS Operations

- JPSS-1/NOAA 20 launched Nov 18 2017, JPSS-2 Nov 10 2022
  Both missions with PM overpass
  Kudos to the IPO for pushing MODIS continuity
- S-NPP Radiometric Inter-comparisons with MODIS (MCST/VCST)
- A suite of NOAA operational land products (EDR's) driven primarily by NWS
  - SR, LST, Albedo, VI, Green Veg Fraction, Veg Health, Surface Type, Active Fire
  - IDPS > NDE
  - Data from NOAA CLASS system
- A suite of NASA VIIRS Science (CDR's) products focused on MODIS Continuity
  - SR, VI, BRDF/Albedo, LST, LAI/FPAR, Day Night Band, Active Fire, MAIAC

  Kudos to the LandSIPS and LDOPE for helping transition MODIS>NPP>JPSS1 (NOAA 20) continuity
- PI and LDOPE QA – little to no new validation, intercomparisons with MODIS
- Data dissemination and user services – ESDIS: LAADS, EDC, NSIDC, DAACs
- Data processing of JPSS1 supported (V2 L1B) – LandSIPS dissemination via LAADS
  - currently porting SNPP Land Code to JPSS1

"Goal: Earth System Data Records - Continuity (MODIS to VIIRS 2038)"



2018 MODIS VIIRS ST Meeting LAND Break Out Discussion

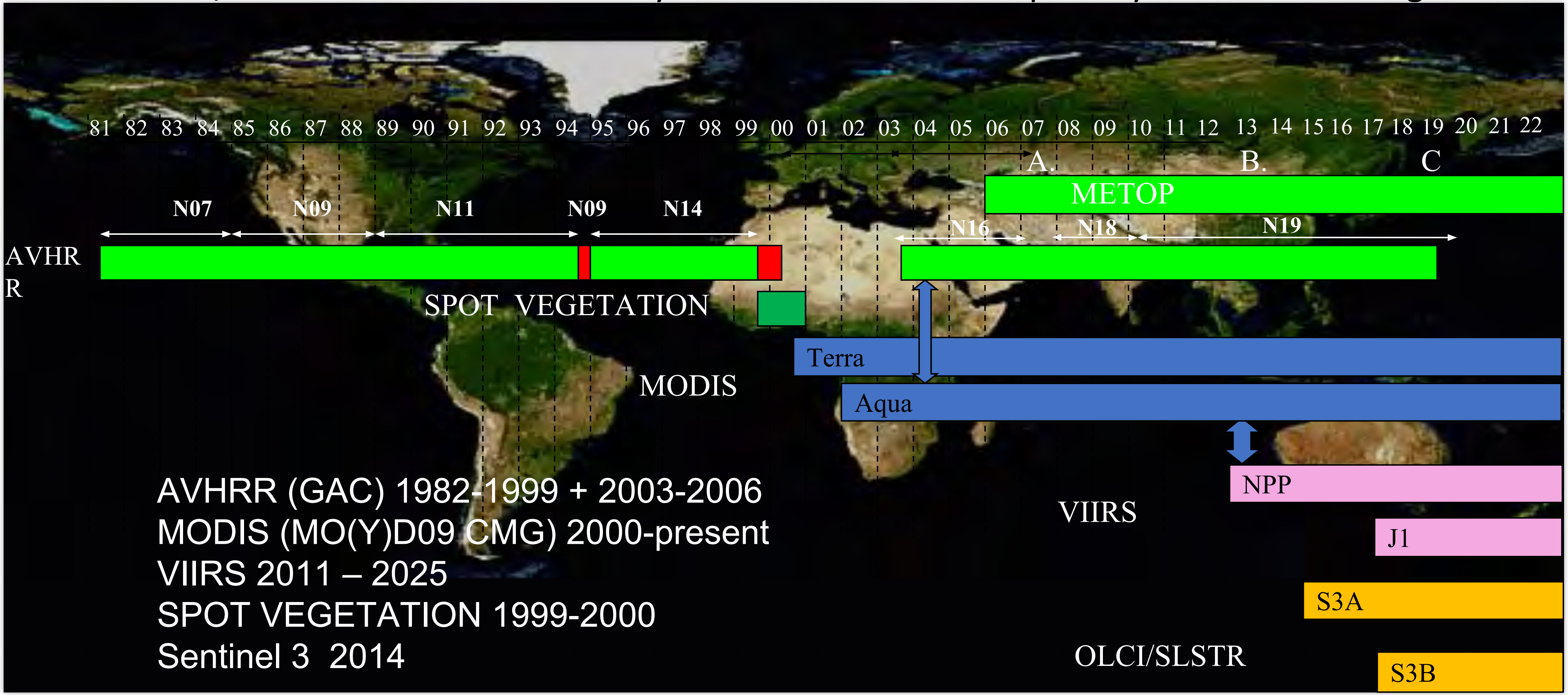
- Suomi NPP VIIRS – "assessments" of continuity data products (& new)
- Are all VIIRS created equal (MODIS-T v. MODIS-A) if continuity to JPSS
  - YES BUT ONCE TERRA IS GONE (2022) THEN SOME PRODUCTS WILL REQUIRE AN AM SOLUTION – S3A/B
- Does VIIRS have the capability to produce all MODIS/EOS continuity data products?
  - If it does not, what is the solution?
  - If it does, then great, but there may be challenges to producing a given product (no PI to maintain/improve, time needed for assessment and continuity, etc.)
  - YES IT DOES - SUGGEST THE OUTSTANDING NEEDS BE HIGHLIGHTED IN THE NEXT ROUND
- Uncertainties associated with data products (more to come…)
  - YES QUANTIFICATION SHOULD EXPECTED FOR ALL FULLY FUNDED PRODUCTS
  - *UNCERTAINTIES SHOULD BE POSTED FOR EACH PRODUCT*
- NOAA Data products – different? Better? Worse? Funding?
  - SOME ALGORITHMS (FIRE, SR) ARE THE SAME – DATA ACCESS DIFFERENT
  - *NOAA ANNUAL SURFACE TYPE NEEDS EVALUATING BY LAND PI'S*
  - EXPLORING A FUNDED PARTNERSHIP WITH NOAA FOR JPSS 1 > 4 FOR LAND PRODUCTS AND DATA SERVICES TO MEET BOTH NOAA AND NASA NEEDS – WAS PROPOSED. THERE WAS SOME SCEPTICISM THAT THIS COULD HAPPEN
  - NOAA MOVING TO ENTERPRISE ALGORITHM DEVELOPMENT (Common Code Base)

Comparison of VIIRS, MODIS, METimage, Sentinel 3 SLSTR, OLCI, VIIRS, and AVHRR/3 bands

VIIRS			MODIS			METimage MetOp - SG			Sentinel 3 SLSTR			Sentinel 3 OLCI			AVHRR-3		
Band DNB	tral Range .600 - 0.900	dir HSR	MODIS Band	Range	HSR	Band NO DNB	Spectral Range	HSR (m)	Band	Range	HSR	Band	Range	HSR	Band	Range	HSR
M1	.402 - 0.42	750	8	0.405 - 0.420	1000								412.5 (10nm)	300m			
M2	.436 - 0.45	750	9	0.438 - 0.448	1000	1 (VII 4)	443 (30nm)	500					442.5 (10nm)	300m			
M3	.478 - 0.49	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000	2 (VII 4)							490 (10nm)	300m			
M4	.545 - 0.56	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000	3 (VII 4)	555 (20nm)	500		0.555 (20nm)	500m		510 (10nm),560 (10n	300m			
I1	.600 - 0.68	375	1	0.620 - 0.670	250	4 (VII 4)							620 (10nm)	300m	1	0.572 - 0.703	1100
M5	.662 - 0.68	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000	5 (VII 4)	670 (20nm)	500		0.659 (20nm)	500m		665 (10nm), 673, 68	300m	1	0.572 - 0.703	1100
						6 (VII 4)	752 (10nm)	500					708,753,761,764	300m			
M6	.739 - 0.75	750	15	0.743 - 0.753	1000	7 (VII 4)	763 (10nm)	500					767, 778	300m			
I2	.846 - 0.88	375	2	0.841 - 0.876	250	8 (VII 4)	865 (20nm)	500							2	0.720 - 1.000	1100
M7	.846 - 0.88	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250	9 (VII 4)				0.865 (20nm)	500m		865 (20nm)	300m	2	0.720 - 1.000	1100
						10 (VII 4)	914 (20nm)	500					885,900,940 (10nm)	300m			
M8	.230 - 1.25	750	5	SAME	500	11 (VII 4)	1240 (20 nm)	500					1020 (40nm)	300m			
M9	.371 - 1.38	750	26	1.360 - 1.390	1000	12 (VII 4)	1375 (40 nm)	500		1.375 (15nm)	500m						
I3	.580 - 1.64	375	6	1.628 - 1.652	500	13 (VII 4)	1630 (20 nm)	500		1.61 (60nm)	500m						
M10	.580 - 1.64	750	6	1.628 - 1.652	500	14 (VII 4)									3a	SAME	1100
M11	2.225 - 2.27	750	7	2.105 - 2.155	500	15 (VII 4)	2250 (50 nm)	500		2.25 (50nm)	1000						
I4	.550 - 3.93	375	20	3.660 - 3.840	1000	16 (VII 4)	3740 (180nm)	500							3b	SAME	1100
M12	.660 - 3.84	750	20	SAME	1000	17 (VII 4)				3.74 (380nm)	1000				3b	3.550 - 3.930	1100
M13	.973 - 4.12	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000	18 (VII 4)	3959 (60 nm)	500		3.74 Fire(380nm)	1000						
						19 (VII 4)	4040 (60 nm)	500									
						20 (VII 4)	6725 (370nm)	500									
						21 (VII 4)	7325 (290nm)	500									
M14	.400 - 8.70	750	29	SAME	1000	22 (VII 4)	8540 (290nm)	500									
M15	.263 - 11.2	750	31	10.780 - 11.280	1000	23 (VII 4)	10690 (500 nm	500		10.85 (900nm)	1000				4	10.300 - 11.300	1100
I5	.500 - 12.4	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000	24 (VII 4)				10.85Fire (900nm)	1000				4 5	10.300 - 11.300 11.500 - 12.500	1100 1100
M16	.538 - 12.4	750	32	11.770 - 12.270	1000	25 (VII 4)	12020 (500 nm	500		12.0 (1000nm)	1000				5	11.500 - 12.500	1100

Land Climate Data Record

Multi instrument/Multi sensor Science Quality Data Records used to quantify trends and changes



https://ltdr.modaps.eosdis.nasa.gov

Vermote 2023

A Land Sentinel 3 AM Continuity Pilot underway – thanks to Kevin Murphy, Katie Baynes (NASA HQ) and Karen Michael, Dawn Lowe, Jenny Hewson (GSFC) for their support

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