MODIS DATA STUDY
TEAM PRESENTATION

May 19, 1989

AGENDA

1. Team Member Proposed Data Products
2. Effects of Atmospheric Defraction on Earth Location Determinations for MODIS
3. Digital Elevation Model Requirements for the MODIS Data System According to Dr. Jan-Peter Muller
4. Core MODIS Data Products List Update
5. Summary of Level-1 Processing Requirements

TEAM MEMBER PROPOSED DATA PRODUCTS

This is a summary of the data products which have been proposed by members of the MODIS science team. The following information is supplied for each team member who has proposed to use MODIS data to produce data products.

1. Requires MODIS data.
2. Required data from other sources.
3. Proposed MODIS data products and MODIS data products needed.
4. Algorithms to be used.

Some of this information is not yet well developed. In particular, there is not much information available on the algorithms to be used.

Each team member is presented in the section that corresponds to the primary interest of that investigator. This produces some overlap in data products between the sections of the summary.

After the presentation of the individual investigators, there is a list of data products for each of the three disciplines: atmosphere, ocean, and land. This list contains all of the products proposed by the team members plus additional products that we expect to be produced. There are also MODIS data products required by some of the team members that have not been proposed by any of the team members.

It is anticipated that material will be expanded and appear in the Preliminary Team Member Science Product Report.

ATMOSPHERE

Kaufman

MODIS-N and -T

Other data
- HIRIS, AVHRR, GOES (mostly for validation)

Data Products
- Aerosol maps, Level-3
  - -Optical thickness, single scattering albedo, particle size, aerosol mass loading
- Clouds, Level-2, -3
  - -Temperature, brightness (or optical depth), particle size, cloud size, cloud perimeter size
- Surface temperature, Level-3?
- Surface reflectance, Level-3
- Biomass burning, Level-3, -4
  - -Fire number, fire characteristic, aerosol and trace gas generation
- Correlation of aerosols and cloud albedo, Level-4

Algorithms
- Aerosol determination (different algorithms over land and ocean)
- Atmospheric corrections
- Biomass burning

King

MODIS-N approximately 20 channels

Data Products
- Clouds, Level-2 and -3, both will be produced
  - -Optical thickness
  - -Thermodynamic phase (i.e., ice, water, snow)
  - -Effective particle radius
- Degree of polarization over Oceans, Level-2
- Aerosols over oceans, Level-2 and -3
  - -Optical thickness
  - -Size distribution
  - -Single scattering albedo

Algorithms
- Clouds
- Aerosols

Menzel

MODIS-N (channels 35-40), MODIS-T (channels 14-16, 20-23)
- Carbon Dioxide channels

Other data
AIRS temperature, moisture profiles
LAWS cloud height
NMC temperature and moisture fields

Data products
Cloud products (wants to generate products in Near-Real-Time), Level-2 and -3
-% cloud cover
-Cloud type
-Cloud emissivity
-Cloud height and/or cloud top pressure

Algorithm
CO_2 algorithm

Susskind

MODIS-N thermal channels, Level-1

Other data
AMSU, AIRS, Level-1
GOMR ozone profiles, Level-2
ERBI OLR for validation, Level-2

Data products (wants to generate some or all of the products in Near-Real-Time, AIRS and MODIS data to be processed together)
Cloud parameters, Level-2 product with reduced resolution
-fractional cloud cover
-cloud top pressure
-cloud emissivity
Temperature-humidity-ozone profiles, Level-2 as above
Surface temperature (land and ocean), Level-3
Cloud-free albedo, Level-3
Outgoing Longwave Radiation, OLR, Level-3 or -4
Precipitation, Level-4

Algorithms
TBD

Tanre

MODIS-N

Other data
- HIRIS, LASA, MODIS-T, in-situ (for validation)

Data products
- Atmospheric corrections, Level-2
  - -Rayleigh scattering, absorption
- Aerosols (over ocean and perhaps land), Level-3 or -2
  - -size distribution
  - -index of refraction
  - -optical depth
- Ocean Color, Level-3
- Land surface parameters, Level-3
- Dynamics of desert aerosols, Level-4 or -3
- Aerosol climatology, Level-4
- Vegetation development, Level-4

Algorithms
- 5S code
- Ocean color and ocean aerosols
- Aerosol parameterization
- Atmospheric correction

end of atmosphere section

OCEAN

Abbot

MODIS-N and -T
- water leaving radiance, WLR
- (Level-2 contains atmospheric correction)

Other Data (validation only)
- in-situ
- Level-3 from ALT & SCAT
- SST from AMRIR & AMSU

Products
- Chlorophyll fluorescence, Level-2
- Primary Production, Level-3
- Time and space variation of the above, Level-4
- New Production, Level-4
- Relationship of production and physical forcing, Level-4

Algorithms
- Determine fluorescence
  - -estimate pigments, primary production
- Estimate new production
- Examine data for time and space variations, correlate variations.

Barton

MODIS-N WLR, Level-2

Other data
- AMRIR
- AMSU, AIRS, SCATT, ALT, ?

Products
- Fast delivery (near-real-time) Sea Surface Temperature, SST, with high resolution, 0.5 km, over limited regions to be produced on demand only, Level-2 or -3 if mapped
- Weekly average SST with 25-50 km resolution and global coverage, Level-3

Algorithms
- Fast SST
- Weekly composite SST

Brown (NOTE: the Miami group wishes to get raw data and do their own calibration and atmospheric correction)

MODIS-N Thermal channels

A) Level-0
   do calibration + atmospheric correction + SST
B) Level-1B
   do atmospheric correction + SST
C) Level-2 WLR
   do SST calculation

Products
   SST weekly average with 18-km resolution, Level-3
   Model of long-term variations in SST

Algorithm
   Weekly composite SST
   Model fitting

Gordon (Evans is included since he proposes to run Gordon's programs)

MODIS-T and -N? visible channels calibrated Level-1 (or L-2 WLR)

Other data
   SCAN-SCAT (wind speed), GOMR (ozone), ocean surface pressure

Products
   Water leaving radiance (this is atmospheric correction), Level-2
   Aerosol optical depth, Level-2
      -aerosol radiance, Level-2
      -aerosol characteristics, Level-2
   Phytoplankton pigments, Level-2?
      -coccolithophores, Level-3
   Concentrations of detached coccoliths, Level-3?
   Model the relationship of ocean biological activity and clouds, Level-4

Algorithms
   Aerosol determination
   Surface properties and biological content
   Model fitting

Carder

MODIS-T 17 channels, MODIS-N 7 channels, Level-2 WLR

Other data
- Ancillary data from HIRIS, AVHRR
- Requires Ozone profiles altimetry and scatterometry

Products
- Chlorophyll, Level-2
- Gelbstoff, Level-2
- Backscattering coefficient @ 565nm, Level-2
- Case II water type flag maps, Level-3
- Chlorophyll maps, Level-3
- Degradation product maps, Level-3
- Suspended sediment maps, Level-3
- Backscattering coefficient maps, Level-3

Algorithms
- Use 3 or 4 channels to estimate chlorophyll, gelbstoff, and 565 nm backscattering
- Use a full spectrum predictor-corrector algorithm for chlorophyll, degradation products, suspended sediment, and backscattering coefficients

Clark

-ground measurements and production of in-situ data only

Esaias

MODIS-T all channels tilted to avoid glint, MODIS-N at latitude within 20 degrees of solar latitude 7 channels, L-2 WLR

Other data
SCAN-SCATT, GOMR (ozone), in-situ data

Products
Primary production maps, 5 day, monthly, annual, Level-3
Modeling and analysis of productivity and carbon flux, L-4
- Primary production
- Phytoplankton Biomass
- Carbon fixation
- Carbon lost to deep ocean (Abbot's new production)

NOTE: Dr. Esaias states that he will use a number of intermediate products in his analysis which have not been proposed by other investigators.
- Incident spectral irradiance, Level-2
- Mixed layer depth, Level-3
- Diffuse light attenuation, Level-3
- Population structure, Level-3 or 4
- Physical history of oceans, Level-4

Algorithms
TBD

Hoge

MODIS-? visible channels, WLR Level-2

Other data
    AOL data from aircraft

Products
    Maps of chlorophyll, phycoerythrin, phycocyanin,
        suspended sediment, Level-3
    Species diversity images, Level-3
    Determine biomass, primary productivity, Level-3
    Model the Carbon and Nitrogen cycles, Level-4

Algorithms
    One for each product? (may not be available till after
        launch)
    Model fitting

Parslow

MODIS-T all ? channels, WLR Level-2

Products
    Ocean surface constituents, Level-3 or 2
        -Chlorophyll and other pigments
        -Gelbstoff
        -Particulates and dissolved constituents
    Carbon flux, Level-4 or 3
    Model the relationship of physical, chemical, and biological
        ocean processes, Level-4

Algorithms
    Determine surface constituents
    Model fitting

end of ocean section

LAND

Huete

MODIS-N cloud-free ground leaving radiance, GLR Level-2

Other data
- some MODIS-T and HIRIS for validation

Data Products
- Soil and Plant maps, Level-3
- Organic Carbon in biota and humus, Level-3
- Organic Carbon flux, Level-4

Algorithms
- Determine soil and plant characteristics from clear sky data
- Search for time changes in data

Justice

MODIS-N Level-1b or GLR Level-2

Other Data
- some MODIS-T, HIRIS primarily for validation
- will use HMMS, SAR data products

Data Products
- Global phenology, Level-4
- Interannual variability, Level-4
- Biome Annual Production, Level-4
- Land degradation estimates, Level-4
  - normalized difference vegetative index, NDVI, required as input, Level-2

Algorithms
- largely TBD time series analysis will be required
- Analysis will start from NDVI in cloud-free pixels

Muller (Interdisciplinary Proposal)

MODIS-?

Other data
- SAR, HIRIS, LASA, plus ?
- requires the use of a Digital Elevation Map (DEM)

Data Products
- Spectral Bidirectional Reflectance Distribution Function
  - SBRDF, Level-3
- 3-dimensional models of surface, Level-4
  - Plant cover
  - Surface type and mineral content
- Changes in surface, Level-4

Algorithms
- TBD. automated 3-dimensional mapping
- ATIUS, Monte-Carlo ray tracing algorithm

Running

MODIS-T approximately 7 channels

Other data
- HIRIS for validation
- requires a land coverage map

Data Products
- Vegetative Indices, NDVI, Level-2
- Weekly composites or averages of, Level-3 or 4
  - Evapotranspiration (ET)
  - Net photosynthesis
  - Fractional cloud cover
  - Daytime and nighttime ground temperature, LST
    (Wants ground temperature at 500 m resolution)
- Yearly maps of ET and Net Primary Production, Level-4

Algorithms
- Vegetative Indices
- Compositing and averaging
- Model fitting

Salomonson

MODIS-N and -T coordinated observations, Level-1b radiances or Level-2 clear-sky GLR

Data Products
- Snow cover maps, Level-3
- SBRDF, Level-3
- Thermal emission, Level-2 or -3
- Radiation Balance, Level-4 or -3
  - incoming and outgoing short and long wavelength radiation
- Snow/water dynamics (surface water balance), Level-4 or -3
  - requires incident solar radiation

Algorithms
- Select clear sky
- Select snow cover
- Generate composite maps
- Thermal emission
- SBRDF
- Radiation balance
- Water balance

Strahler

MODIS-T multiple tilt views, states Level-1b data required but appears to want atmospherically corrected data, Level-2

Other data
- HIRIS for validation and sub-pixel sampling

Data Products
- Spectral directional radiance, Level-2
- Atmospherically corrected spectral directional radiance, L-2
- LAI, Level-2 and 3
- BRDF, Level-3
- Plant canopy structure, level-4 or 3
  - leaf size, layering, size and spacing of plant crowns
- Ecological Parameters, Level-4
  - intercepted photosynthetically active radiation
  - green biomass
  - standing woody biomass
- Hemispheric albedo from "albedo mode" observations, Level-3

Algorithms
- Registration and Rectification
- Atmospheric correction
- BRDF
- Canopy structure
- Ecosystem parameters

Vanderbilt

MODIS-N Level-1b or Level-2 GLR

Data Products
- Polarized vegetative indices, Level-2
- Atmospherically corrected polarized and specular radiances, Level-2
- Photosynthetic capacity, Level-4 or -3
  - (Products mentioned but not actually proposed at Level-4: green foliar biomass, primary production Carbon flux)

Algorithms
- Atmospheric correction with polarization
- Separate specular and polarized returns
- Polarized vegetative indices

Wan

MODIS-N multiple thermal channels

Other data
- HIRIS for mixed pixel solutions
- SAR

Data Products
- Land Surface Temperature, LST, Level-2 and -3
- Surface emissivity, Level-4 ?
- Mixed-pixel model, Level-4

Algorithms
- Land surface temperature
- Emissivity model
- Mixed-pixel model

end of land section

Data Products - Atmosphere

There will be a fundamental difference in the atmospheric processing when compared to the land or ocean functions. There is a requirement not only to obtain the geophysical parameters of interests but to correct the data for atmospheric effects as a starting point for the land and ocean product generation. This implies that most of the atmospheric parameter determination will be done on a pixel-by-pixel basis. Level-2 products will probably be produced for most, if not all, atmospheric parameters. Furthermore, there will be at least some demand for cloud parameters in Near-Real-Time for use by forecasters.

Basic Level-1B quantities: Calibrated radiance

Basic Level-2 goal: Surface leaving radiance

Level-2 products
Cloud flag

Clear Sky
- Scattering
- Absorption
- Aerosols
  - Optical Depth
  - Single scattering albedo
  - Particle size distribution
  - Index of refraction

Clouds
- Optical depth, brightness
- Height, pressure
- Type
- % coverage by type
- Temperature
- Thermodynamic phase
- Effective particle radius
- Emissivity
- Plus products similar to those for clear sky

Level-3 products: Maps of Level-2 products to include time and space averaging or compositing.
- Aerosol mass loading
- Trace gas densities and distribution
- Cloud statistics
- Outgoing Longwave Radiation (OLR)
- Temperature-Water Vapor-Ozone profiles
- Precipitation estimates from cloud data

Level-4 products
- Correlation of aerosols and cloud albedo
- Aerosol dynamics and climatology, sources and sinks
- Trace gas dynamics and climatology
- Precipitation

Data Products - Ocean

It is assumed in this and the following section that the determination of Ocean and Land data products will begin from atmospherically corrected data. It is further assumed that a cloud flag(s) have been set so that data can be easily selected.

Basic Level-2 quantities
- Incident radiation (direct and scattered)
- Reflected radiation (specular and diffuse)
- Emitted radiation (including fluorescence)

Maps, Level-3
- Sea surface temperature (SST)
- Chlorophyll and other pigments
- Gelbstoff and suspended matter
- Biological characteristics
  - -species, biomass, activity
- Sea surface characteristics
  - -waves, etc.
- Ice coverage and properties

Level-4 products
- Primary production
- Radiation balance
- Carbon flux, includes Carbon lost to deep ocean
- Gas dynamics: Carbon, Nitrogen, Oxygen, trace gasses
- Aerosols of ocean origin

Eventually produce a 4-dimensional model of the physical, chemical and, biological interactions of the ocean with the land and atmosphere.

Data Products - Land

Basic Level-2 quantities
- Incident radiation (direct and scattered)
- Reflected radiation (specular, diffuse, and polarized)
- Thermal emission
- Vegetative indices, NDVI, LAI
- Polarized vegetative indices

Maps, Level-3
- Averaged or composited temperatures: day and night, LST
- Average cloud cover
- Spectral, Bidirectional Reflectance Distribution Function, SBRDF
- Coverage maps: plants, soil, minerals
- Snow and ice coverage
- Surface fires and fire characteristics

Level-4
- Evapotranspiration (Level-3?)
- Plant canopy structure
- Intercepted photosynthetically active radiation
- Primary production and net photosynthesis
- Carbon flux
- Standing woody biomass
- Global phenology and interannual variability
- Organic Carbon in humus
- Land degradation
- Radiation balance
- Water balance
- Biomass burning
- Aerosol sources

EFFECTS OF ATMOSPHERIC REFRACTION ON EARTH LOCATION DETERMINATIONS FOR MODIS

One requirement on the MODIS experiment is that pointing accuracy will be determined to an accuracy of a tenth of a pixel. For the 840 meter channels, this requirement means that any pixel must be located on the Earth to within 0.084 kilometers. For the 420 meter and 210 meter channels, the pointing accuracies are 0.042 and 0.021 kilometers respectively.

If MODIS were viewing the Earth's surface through a vacuum, pointing accuracy would be only a function of geometry requiring knowledge of time, the NPOP-1 state vector, and digital elevation models (DEM's). However, since the Earth has an atmosphere and the index of refraction of the atmosphere is not one, but ranges from 1.0002982 to 1.0002726 in the 0.4 to 14.2 micron wavelength range, the light rays in the atmosphere will be bent, causing further uncertainty in the pointing. The atmosphere acts like a lens, with pixels being moved towards the center of the field of view. The path rays can be bent as much as 0.025 degrees for a slant path of 55 degrees. Although this seems small, in fact, a portion of the Earth viewed at this angle will appear to be about 4 kilometers closer to nadir than it would be if no atmosphere existed.

The lensing distortion by the atmosphere is dependent on atmospheric pressure and temperature so latitudinal and seasonal variations will occur. For a normal sea level pressure of 760 mm Hg, variations in surface temperature from -10 to +30 degrees Celsius cause changes in apparent position of as much as about 0.7 km. at a 55 degree viewing angle. Thus the refraction correction will be dependent on latitude and on season. Tables 1 through 3 list changes in location for atmospheres with surface pressure of 750, 760 and 770 mm Hg respectively. Within each table, surface temperatures of -10, 0, 10, 20, and 30 degrees Celsius are used. Apparent pointing angles of 0, 10, 20, 30, 40, 45, 50, and 55 degrees were chosen for each of these model atmospheres. The changes in location are then tabulated. The changes are always such as to move the apparent location closer to nadir.

To maintain a pointing accuracy of 0.084 kilometers, any observation beyond a viewing angle of 45 degrees will require measurements of surface temperature as input.

The tables are calculated for an effective wavelength of about 2 microns. Since the index of refraction varies with wavelength, the determination of correct earth locations will also be wavelength dependent. As a rule of the thumb, dividing the distance corrections in the tables by 10 will give a good approximation of the difference in distance corrections between 0.4 microns and 14.2 microns.

Table 1. The pointing error in kilometers for NPOP-1 at an orbital elevation of 705 km. is given in the third column of the tables below. The second column gives the true pointing direction assuming no atmosphere whereas the first column gives the actual pointing when atmospheric corrections are included. For a surface pressure of 750 mm Hg, the pointing errors are tabulated for surface temperatures of -10, 0, 10, 20, and 30 degrees Celsius.

Surface pressure is 750. mm Hg; temperature is -10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0030	0.707
20.0000	20.0062	1.104
30.0000	30.0101	1.493
40.0000	40.0145	2.019
45.0000	45.0175	2.482
50.0000	50.0207	3.151
55.0000	55.0249	4.405

Surface pressure is 750. mm Hg; temperature is 0. deg. C.

0.0000	0.0000	0.000
10.0000	10.0028	0.676
20.0000	20.0060	1.062
30.0000	30.0097	1.432
40.0000	40.0139	1.938
45.0000	45.0168	2.380
50.0000	50.0199	3.028
55.0000	55.0239	4.229

Surface pressure is 750. mm Hg; temperature is 10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0027	0.652
20.0000	20.0057	1.021
30.0000	30.0093	1.377
40.0000	40.0134	1.864
45.0000	45.0161	2.291
50.0000	50.0192	2.913
55.0000	55.0230	4.072

Surface pressure is 750. mm Hg; temperature is 20. deg. C.

0.0000	0.0000	0.000
10.0000	10.0026	0.629
20.0000	20.0055	0.982
30.0000	30.0090	1.328
40.0000	40.0129	1.796
45.0000	45.0156	2.209
50.0000	50.0185	2.809
55.0000	55.0222	3.916

Surface pressure is 750. mm Hg; temperature is 30. deg. C.

0.0000	0.0000	0.000
10.0000	10.0025	0.605
20.0000	20.0053	0.946
30.0000	30.0086	1.281
40.0000	40.0125	1.733
45.0000	45.0150	2.126
50.0000	50.0178	2.712
55.0000	55.0214	3.777

Table 2. The pointing error in kilometers for NPOP-1 at an orbital elevation of 705 km. is given in the third column of the tables below. The second column gives the true pointing direction assuming no atmosphere whereas the first column gives the actual pointing when atmospheric corrections are included. For a surface pressure of 760 mm Hg, the pointing errors are tabulated for surface temperatures of -10, 0, 10, 20, and 30 degrees Celsius.

Surface pressure is 760. mm Hg; temperature is -10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0030	0.715
20.0000	20.0063	1.116
30.0000	30.0102	1.510
40.0000	40.0147	2.047
45.0000	45.0177	2.512
50.0000	50.0210	3.194
55.0000	55.0252	4.461

Surface pressure is 760. mm Hg; temperature is 0. deg. C.

0.0000	0.0000	0.000
10.0000	10.0029	0.688
20.0000	20.0060	1.073
30.0000	30.0098	1.452
40.0000	40.0141	1.967
45.0000	45.0170	2.412
50.0000	50.0202	3.066
55.0000	55.0242	4.285

Surface pressure is 760. mm Hg; temperature is 10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0028	0.660
20.0000	20.0058	1.032
30.0000	30.0094	1.395
40.0000	40.0136	1.893
45.0000	45.0164	2.323
50.0000	50.0194	2.950
55.0000	55.0233	4.123

Surface pressure is 760. mm Hg; temperature is 20. deg. C.

0.0000	0.0000	0.000
10.0000	10.0027	0.637
20.0000	20.0056	0.994
30.0000	30.0091	1.346
40.0000	40.0131	1.818
45.0000	45.0158	2.235
50.0000	50.0187	2.846
55.0000	55.0225	3.971

Surface pressure is 760. mm Hg; temperature is 30. deg. C.

0.0000	0.0000	0.000
10.0000	10.0026	0.617
20.0000	20.0054	0.960
30.0000	30.0088	1.299
40.0000	40.0126	1.756
45.0000	45.0152	2.158
50.0000	50.0181	2.742
55.0000	55.0217	3.840

Table 3. The pointing error in kilometers for NPOP-1 at an orbital elevation of 705 km. is given in the third column of the tables below. The second column gives the true pointing direction assuming no atmosphere whereas the first column gives the actual pointing when atmospheric corrections are included. For a surface pressure of 770 mm Hg, the pointing errors are tabulated for surface temperatures of -10, 0, 10, 20, and 30 degrees Celsius.

Surface pressure is 770. mm Hg; temperature is -10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0030	0.727
20.0000	20.0064	1.133
30.0000	30.0103	1.531
40.0000	40.0149	2.071
45.0000	45.0179	2.545
50.0000	50.0213	3.231
55.0000	55.0256	4.519

Surface pressure is 770. mm Hg; temperature is 0. deg. C.

0.0000	0.0000	0.000
10.0000	10.0029	0.695
20.0000	20.0061	1.088
30.0000	30.0099	1.471
40.0000	40.0143	1.991
45.0000	45.0172	2.443
50.0000	50.0205	3.102
55.0000	55.0246	4.342

Surface pressure is 770. mm Hg; temperature is 10. deg. C.

0.0000	0.0000	0.000
10.0000	10.0028	0.672
20.0000	20.0059	1.047
30.0000	30.0096	1.416
40.0000	40.0138	1.916
45.0000	45.0166	2.354
50.0000	50.0197	2.993
55.0000	55.0236	4.179

Surface pressure is 770. mm Hg; temperature is 20. deg. C.

0.0000	0.0000	0.000
10.0000	10.0027	0.645
20.0000	20.0057	1.008
30.0000	30.0092	1.364
40.0000	40.0133	1.841
45.0000	45.0160	2.265
50.0000	50.0190	2.882
55.0000	55.0228	4.022

Surface pressure is 770. mm Hg; temperature is 30. deg. C.

0.0000	0.0000	0.000
10.0000	10.0026	0.621
20.0000	20.0055	0.970
30.0000	30.0089	1.314
40.0000	40.0128	1.778
45.0000	45.0154	2.184
50.0000	50.0183	2.780
55.0000	55.0219	3.876

DIGITAL ELEVATION MODEL REQUIREMENTS FOR THE MODIS DATA SYSTEM ACCORDING TO DR. JAN-PETER MULLER

The following enclosed four pages were sent by Dr. Muller to all the MODIS team members. It discusses the requirements for Digital Elevation Models (DEM's) for MODIS and other sensors. In particular, it emphasizes that DEM's are required before the NPOP-1 launch. He proposes that SPOT images and other sensors combined with present DEM's can be used to create a global DEM.

A copy of reference 23 in his bibliography and some information on the Alvey project were also included with his letter.

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Dear Colleague,

NASA Eos Requirement for global topography BEFORE NPOP-1 launch

Following the recent Eos *All Hands* meeeting at GSFC, 19-24 April it is becoming increasingly clear that there is a key weakness in the current science and data plans for almost all land applications of the Eos mission (NASA, ESA and NASDA) - the lack of any topography BEFORE the launch of the first platform in December 1996.

1. Requirements
Topography is required AS THE DATA IS RECEIVED for the following examples:
1. MODIS/MISR (IFOV:216-1000m)
1.1 Determination of surface reflectances (across-track for T & N and along-track for T)
1.2 Extraction of directional reflectances from MODIS/N and above all, MODIS/T
1.3 Use by IDS of orthoimages in Advanced GIS in EosDIS and PI Computing Facilities
2. HIRIS(IFOV:30m)
2.1 Determination of surface reflectances and inter-terrain slope reflectances
2.2 Extraction of directional reflectances
2.3 Use by IDS of orthoimages in Advanced GIS in EosDIS and PI Computing Facilities
3. SAR (IFOV:20-500m)
3.1 Radiometric calibration
3.2 Correction for radar layover effect
3.3 Correction of radar backscatter signatures for slope effects
3.4 Use by IDS of orthoimages in Advanced GIS in EosDIS and PI Computing Facilities
4. IDS
4.1 Vegetation biome as a function of elevation and slope apsect
4.2 Hydrological network extraction and runoff calculations
4.3 Snow and ice thickness calculation
4.4 Climate and meteorological simulations

2. Existing Topographic Databases
The only existing topographic data-bases for global or near-global coverage in the public domain are woefully inadequate for these purposes, being at best 100m in plan:
A. NOAA National Geophysical Data Centre (NGDC) 5-minute global data (≈10km)
B. NOAA NGDC 30-second data for conterminous US (≈100m)
DMA also has a non-public domain (DTED level 1) 30-second elevation data-base for most longitudes in the latitude band 20-80ºN (derived also from digitisation of 1:250 000

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maps). However, most of Africa, South America, Antartica and Australia are not included. USGS/DMA are also involved in producing a global 1km land-DEM (from 1:1 000 000 Operational Navigation Charts). USGS does have an incomplete 30m DEM for the US from 1:24 000 digitised maps but similar data is not available outside the US.

3. Possible Solutions

3.1 Pre-launch

3.1.1 Public release of DMA 30-second DEMs for 20-80ºN

3.1.2 Digitisation of remaining 1:250 000 maps by DMA and release of 30-second DEMs

3.1.3 Creation of global topographic database at 30m grid-spacing from the NASA Large Format Camera (15m-absolute height accuracy(z_{rms})), SPOT (10m-IFOV/10m-z_{rms}), and ESA Spacelab Metric Camera (25m-z_{rms}) and from 1992 using the Japanese ERS-1 (18m-IFOV/20m-z_{rms}) to fill in the gaps in coverage.

3.2 Post-launch

3.2.1 NPOP-1 (December 1996)

GLRS - 75m footprint every 150m known to within ±20m in plan (($z_{rms} \approx 0.1$m)

MISR - 216m IFOV along-track for limited area ($z_{rms} \approx 200$m?)

MODIS/N - 216m IFOV across-track ($z_{rms} = 200$m?)

MODIS/T - 1km IFOV along-track ($z_{rms} \approx 1$km?)

ITIR - 15m IFOV along-track ($z_{rms} \approx 15$m?)

3.2.2 NPOP-2 (December 1998)

SAR - interferometry mode ($z_{rms} \approx 200$m?)

3.2.3 EPOP-2 (2000)

UK OMI - 5m (& 2.5m) IFOV along-track ($z_{rms} \approx 2.5$m)

I believe that the most accurate, most highly-sampled, cost-effective, efficient and practical means to provide global DEM data BEFORE NPOP-1 launch is by automated processing of SPOT, digitised LFC and SMC data and from 1992, JERS-1. The UK through the Alvey initiative has developed a unique system potentially capable of handling global data-sets owing to the very high processing rate afforded by a reconfigurable array of transputers. An announcement will shortly be made of a UK national processing facility to begin operations in 1991. Please find enclosed a list of publications from this Alvey project, a brochure describing the workpackages and a recent review paper highlighting the achievements.

If you are concerned that global topography is needed for your scientific research programme and that it is needed BEFORE NPOP-1 launch, write to the NASA Eos Project Scientist, Dr Gerald Soffen (Goddard Space Flight Center - Code 600, NASA, Greenbelt, Maryland 20771, USA) listing your requirements both in terms of when DEMs will be required and what accuracy and sampling density you need for your application.

If on the basis of reviewing the literature concerning the automated processing system developed at University College London, you would like to collaborate with my group (as Dr David Pieri, JPL and Dr Jeff Dozier, UCSB are already doing) to investigate how this new data source might be useful to you, write to me at the above address. If you would like to learn more about the UK national processing facility, write to Dr Alan Haskell, Manager, Space Technology Division, Q134 Building, Royal Aerospace Establishment, Farnborough, Hampshire, GU14 6TD, UK (FAX:+44-1-252-377121).

Thanking you in kind anticipation of your attention in this matter,

Yours sincerely,

Jan-Peter Muller

Dr Jan-Peter Muller

MODIS Team Member (NASA-Eos), Technical Project Manager, Alvey MMI-137

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CORE MODIS DATA PRODUCTS

Revision A: April 14, 1989; Comments of Dr. Vince Salomonson incorporated.

Revision B: April 24, 1989; Comments of Dr. Michael King incorporated.

Revision C: May 9, 1989; Comments of Dr. Wayne Esaias incorporated.

Revision D: May 16, 1989; Comments of Dr. Christopher Justice incorporated.

1. INTRODUCTION

It is the intention of the MODIS science team to have in place and implemented on the Central Data Handling Facility (CDHF) at NASA/GSFC by launch of NPOP-1 a set of algorithms capable of producing a complete set of "core" MODIS data products. We define the term Core MODIS Data Product as a product that: (a) is of interest to the scientific community, particularly the members of the MODIS science team, other Eos instrument science teams, and the interdisciplinary investigations; (b) would be an important contribution towards meeting the scientific objectives of Eos; (c) can be produced using primarily, though not exclusively, MODIS data; and (d) is sufficiently well understood such that retrieval algorithms already exist or will be fully developed within the next several years using simulated MODIS data.

Standard products produced at the CDHF during the lifetime of the MODIS-N and MODIS-T instruments will consist of both the core products, which will be implemented and ready at launch, and other products which will be implemented after launch during the course of the mission. Thus, we expect that the number of standard MODIS data products will increase with time.

Special data product algorithms will also play a major role in the mission. These algorithms will reside at the various MODIS Team Member Computing Facilities (TMCFs). Many of these experimental algorithms may, in fact, also be in place (at the TMCF) at launch; however, they will generate experimental, non-standard, data products. Some of these special data product algorithms will later be implemented (months to years after launch) on the CDHF to generate the additional MODIS standard products.

This list of the core MODIS data products is being developed to fulfill several crucial requirements. First, the list will highlight the importance of the MODIS instrument (both MODIS-N and MODIS-T) when presented as a part of the upcoming nonadvocacy review. Second, the list will ensure that the MODIS instrument adequately supports the requirements of the Eos interdisciplinary investigations, many of which have very specific requirements for MODIS data products. Third, emphasis on the processing, storage, and data requirements for these core MODIS products will provide accurate (initial) sizing estimates to be used in the specification of EosDIS components including the CDHF, DADS, and IMC.

2. RELEVANT ISSUES

The early identification of these core MODIS data products has identified some relevant issues which must be resolved before a final list of the data products, along with a complete set of their attributes, can be completed. The primary objective in resolving these issues is the identification, implementation, and generation of a set of core MODIS data products with the widest possible application and user community.

2.1 Data Product Domains

With its global and spectral coverage and relatively high spatial resolution, the MODIS instrument is a key component of the Eos. The MODIS science team is the largest of any facility instrument, and MODIS data will be used by the majority of the facility, PI, and interdisciplinary investigation teams. However, many of the MODIS science team members have proposed key data products to be produced only over very limited portions of the Earth. As core data products, it will be necessary to consider producing the MODIS products over expanded (and probably global) domains to satisfy the requirements of the general science community.

2.2 Selection of Standard Algorithms

There are a number of MODIS data products for which two or more members of the MODIS science team have proposed alternative algorithms based on somewhat different, radically different, or even unspecified (at this time) retrieval techniques. To gain wide acceptance by the general scientific community, and to be able to provide a "standard" core MODIS data product, it will be necessary for the MODIS science team to agree on a standard algorithm for each of the core products.

2.3 Compatibility with Requirements of Other Teams

At this time, certain interdisciplinary investigation and instrument teams are requesting calibrated Level-1 MODIS radiance data so that they can, in effect, generate "MODIS data products." In most and perhaps all cases, these alternative products (such as cloud coverage) replicate standard data products to be routinely produced by EosDIS for the MODIS science team. Though coordination with each of the other teams, and an understanding of the other teams' requirements with respect to timeliness, spatial resolution, algorithm compatibility, and other issues, it will be possible to reduce and perhaps eliminate these product redundancies.

Dr. Christopher Justice has the following comment:

1. Steve Running is defining the IDS land product requirements from MODIS to determine any gaps in our core products. It is not clear at this time who will be responsible for producing IDS required products if they are not in our core list. My feelings are that the Team will be responsible for the core products. Individual team members will be responsible for their own R&D products as they were proposed and accepted by the AO process.

2.4 Standard Grids

To optimize the utility of the MODIS data products, not only for the MODIS science team members but for other investigators as well, it is important to define a set of standard grids. These Level-3 grids should be common for many of the core products. There may be requirements to generate MODIS core products at more than one spatial resolution. In the science team members' proposals, there is a wide range of spatial resolutions with little consistency between the investigators.

Dr. Michael King has the following comment:

1. Some global data products be produced on Hammer projections of latitude and longitude, as in the ERBE data analysis displays. These global grids are equal area, thereby representing the area of the earth's ocean and land surface without distortion. The data products that go into this mapped product might be produced as averages on a 1° by 1° latitude-longitude grid.

Dr. Wayne Esaias has the following comment:

1. One standard grid for ocean data products should be a global 2,048 by 1,024 element grid, which varies linearly in latitude and longitude (0.18° per grid element). At the equator, the resolution of the grid is approximately 19.5 km. Data on this grid are easy to transform to other projections, and subsetting of the data into ASCII files is also simple.

Dr. Christopher Justice has the following comment:

1. It is essential to have MODIS data products at varying spatial resolutions. These will have to be defined in the next few years by product. The decision to retain existing data set resolution for compatibility or to change to new configurations needs to be made. The data system must have flexibility in both spatial and temporal products.

3. TYPES OF PRODUCTS AND ALGORITHMS

The core MODIS data products and their corresponding algorithms may be allocated into six general areas: (1) Core MODIS "utility" algorithms; (2) Level-1 radiances at the top of the atmosphere and Level-2 radiances at the bottom of the atmosphere; (3) core terrestrial data products; (4) core oceanic data products; (5) core clear-sky data products; and (6) core cloud data products.

4. CORE MODIS "UTILITY" ALGORITHMS

There are a number of algorithms, over and above those required to produce the individual data products, which are essential to the reduction of the Level-0 MODIS data and the successful generation of higher-level products. These include standard: (1) calibration algorithms; (2) Earth location algorithms; (3) cloud identification algorithms; (4) atmospheric correction algorithms; (5) time and space averaging and rectifying/overlaying algorithms; and (6) display and processing algorithms.

4.1 Calibration Algorithms

Calibration algorithms will include: (1) instrument data monitoring algorithms; (2) analysis of internal calibration data; (3) analysis of instrument models; (4) comparison to in-situ and ground-truth data; (5) comparisons to other Eos and non-Eos instrument data; and (6) assignment of the MODIS calibration coefficients for production.

4.2 Earth Location Algorithms

Earth location algorithms will include: (1) navigation of the IFOV centers to the Earth geoid; (2) interpolation of the Earth locations from a sparse array of anchor points to each IFOV; and (3) a correction for surface topography.

4.3 Cloud Identification Algorithms

For the analysis and retrieval of data products at the Earth's surface, it will be necessary to identify the presence of clouds. In addition to cloud identification algorithms, it may also be necessary to delineate the cloud shadows as well.

Dr. Christopher Justice has the following comment:

1. Cloud identification would be part of the cloud/atmosphere core products which then can be fed into the decision process. The flagging of cloud cover should not appear too high up the decision tree for processing.

4.4 Atmospheric Correction Algorithms

For the analysis and retrieval of data products at the Earth's surface, and particularly for oceanic products which provide only a small contribution to the total radiance signal as measured, it will be necessary to remove the atmospheric "contamination." The sources of contamination to be considered (for clear skies) include: (1) Rayleigh scattering; (2) aerosols; (3) ozone; and (4) total precipitable water.

Dr. Christopher Justice has the following comment:

1. Atmospheric correction over land surfaces is critical. The different scenarios for correction and different levels of input need extensive discussion. Similarly, if correction is intended throughout the spectrum, this is a major research activity.

4.5 Time and Space Averaging Algorithms

Other algorithms will be required to remove the effects of bidirectional anisotropy in the measured radiance field, limb darkening, and the dependence of albedo on solar zenith angle. In addition, standard algorithms averaging product data to standard MODIS grids may be required. It will be necessary to develop algorithms that can overlay observations taken from different viewing angles (side-to-side and fore-to-aft) with varying footprint sizes. Averaging to week, month, season, and year will be required for many Level-3 products.

Dr. Christopher Justice has the following comment:

1. It is not clear where this fits in to the core product discussion. BRDF will not be provided globally.

4.6 Display and Processing Algorithms

Display algorithms will include land, ocean, and coastal region overlays, which can be used to extract desired data and to identify regions for a specific type of processing (e.g., generate a product at 1 km resolution for coastal regions, and 4 km for oceanic regions). Other algorithms in the category remain to be identified at this time.

Dr. Christopher Justice has the following comment:

1. As a general point we need to move away from a scene-oriented processing system to a global mapping system. A wide range of map projection options should be available for all products with topographic, political, and physiographic ancillary data.

5. CORE (LEVEL-1 AND LEVEL-2) RADIANCE DATA PRODUCTS

MODIS radiances will be taken over 104 different spectral bands spanning the shortwave, near-infrared, medium-infrared, and thermal-infrared spectral regions. The general science community has an interest in both the Level-1 radiances at the top of the atmosphere and the Level-2 radiances at the bottom of the atmosphere. This Eos-wide requirement for MODIS radiances is not fully known at this time, but is presumed to extend over most (if not all) of the spectral bands, include both the top and bottom of the atmosphere, and be for a range of spatial resolutions (from the instrument's IFOV to a variety of Level-3 meshes).

6. CORE TERRESTRIAL DATA PRODUCTS

The core terrestrial MODIS data products can be categorized into those which apply to all terrestrial surfaces (e.g., surface temperature or snowcover) and those which apply to the surface vegetation (e.g., vegetative index or net primary productivity). The candidate core terrestrial MODIS data products identified to date include:

6.1 Surface Emissivity

6.2 Surface Temperature

6.3 Surface Albedo

6.4 Surface Radiation Budget (SW up, SW down, LW up, and LW down)

6.5 Surface Snowcover

6.6 Normalized Difference Vegetative Index

6.7 Polarized Vegetative Index

6.8 Leaf Area Index

6.9 Absorbed Photosynthetically Active Radiation

6.10 Net Photosynthesis

6.11 Net Primary Productivity

6.12 Evapotranspiration

Following the review of these terrestrial core products with the MODIS science team leader, Dr. Vince Salomonson, the following revisions are suggested:

1. Of these candidate core products, it is likely that a surface effective blackbody temperature will be generated (the product of 6.1 and 6.2) as a core product.

2. Candidate products 6.3, 6.4, 6.8, 6.9, 6.10, 6.11, and 6.12 may not be generated as core products unless specific team members strongly advocate them.

3. Candidates 6.5, 6.6, and 6.7 are likely core products.

4. New candidate core products include:

6.13 Surface Effective Blackbody Temperature

6.14 Weekly/Seasonal Land-Cover (maps)

6.15 "Land-Leaving" Radiances (bidirectional, spectral radiance at the bottom of the atmosphere)

Dr. Michael King has the following comments:

5. 6.3 Surface Albedo - should be spectral surface albedo at best, as MODIS is not a broadband instrument like CERES.

6. 6.4 Surface Radiation Budget - estimating the longwave up and down fluxes at the surface is exceedingly difficult (because of clouds), and I would be hesitant to propose that we adopt this as a core data product.

Dr. Christopher Justice has the following comments:

1. 6.1 and 6.2 I am not clear how these products will be derived and whether MODIS provides the spectral channels needed. The comments by Dr. Wan made at the last meeting need to be expanded upon. I suggest he be invited to the next meeting and be given 15 minutes to outline his approach. I am awaiting a copy of his proposal.

2. 6.3 Spectral Albedo

3. 6.4 Who is proposing this product and how will it be done?

4. 6.5 OK. What EOS sensor data other than MODIS will be required to produce this?

5. 6.6 OK, with some development required.

6. 6.7 This needs further elaboration.

7. 6.8, 6.9, 6.10, and 6.11 are presumably derived from NDVI and may not be required at this time. Those in favor of such products need to come forward. They fall more into the category of R&D at this time.

8. 6.12 What is the proposed method for production of this variable.

Comments on Team leaders revisions:

9. 1. Agreed.

10. 2. It is likely that albedo will be requested by IDS members. Further discussion required.

11. 6.13 OK

12. 6.14 It is highly unlikely that land cover maps weekly/ seasonal will be produced and validated. It would be an operational task beyond the current interest of NASA (or so my observations of recently rejected proposals tells me).

13. 6.15 Is this a core (global) product or an R&D product? Several of the Core Clear-Sky Data Products will be needed within the land atmosphere correction procedure. Interdependency of products needs reviewing.

7. CORE OCEANIC DATA PRODUCTS

The core oceanic MODIS data products can be categorized into those which are not directly related to biological activity (e.g., sea surface temperature and suspended sediment) and those which describe the biological activity (e.g., chlorophyll pigment and dissolved organic matter concentration). The candidate core oceanic MODIS data products identified to date include:

7.1 Sea Surface Temperature

7.2 Water-Leaving Radiances; Ocean Color (see Section 5 above)

7.3 Suspended Sediment Concentration

7.4 Chlorophyll Pigment Concentration

7.5 Phycoerythrin Pigment Concentration

7.6 Phycocyanin Pigment Concentration

7.7 Gelbstoffe Concentration

7.8 Detached Cocolith Concentration

7.9 Primary Productivity

7.10 Dissolved Organic Matter

7.11 Case II Waters Dissolved Marine Humus

7.12 Case II Waters Suspended Detritus

Following the review of these oceanic core products with the MODIS science team leader, Dr. Vince Salomonson, the following revisions are suggested:

1. Candidate products 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, and 7.12 may be generated if the team members strongly advocate them.

2. Candidates 7.1, and 7.2 are likely core products.

3. New candidate core products include:

7.13 Sea-Ice Coverage

Dr. Wayne Esaias has the following comments:

1. The number of core ocean data products that will be available at launch depends crucially on whether SeaWIFS is launched. Just as "at-launch" SeaWIFS data products will be generated using recoded Nimbus-7 CZCS algorithms, so many of the proposed MODIS core products will be generated using recoded algorithms that use the potential of the vastly more capable SeaWIFS instrument.

2. At least five water-leaving radiances are required in product 7.2; however, water-leaving radiances from most of the MODIS spectral regions will be required at the MODIS TMCFs for algorithm development work, particularly if SeaWIFS is not flown prior to the Eos. Also, more (longer) wavelengths may be required for this product for coastal regions than for the open ocean.

3. A core pigment product may replace chlorophyll and chlorophyll degradation products.

4. Product 7.4 should be renamed "Chlorophyll-A Concentration."

5. Product 7.5 should be renamed "Non Chlorophyll-A Absorptance (Gelbstoffe Concentration)."

6. Products 7.5 and 7.6 should be combined and termed "Accessory Pigments."

7. Product 7.9 will require: (1) the incident radiance integrated over the 0.40 to 0.70 micron spectral region; (2) the mixed layer depth; (3) K_{490} (new product 7.15) and K_{PAR} (new product 7.16); and (4) the sea surface temperature (7.1). The core primary productivity may be a simpler, but still desireable, version of a special product (at launch).

8. It may be possible to obtain core product 7.8 even without SeaWIFS data.

9. Products 7.1, 7.2, 7.4, 7.7, 7.8, 7.9 are definite core products, and probably 7.13.

10. Product 7.10 is the only really questionable product, even with SeaWIFS.

New candidate core products include:

7.14 Aerosol Radiances, total minus Rayleigh radiances for at least three spectral bands around 0.665, 0.765, and 0.865 microns.

7.15 K_{490}, the attenuation coefficient at 0.49 microns.

7.16 K_{PAR}, the spectrally integrated attenuation coefficient (both K_{490} and K_{PAR} are required for Primary Productivity)

7.17 Chlorophyll Fluorescence

8. CORE CLEAR-SKY DATA PRODUCTS

The core atmospheric MODIS data products can be divided into clear-sky and cloud products. The core clear-sky MODIS data products, in turn, can be categorized into those which apply to aerosols (e.g., single scattering albedo and optical depth) and those which do not apply to aerosols (e.g., degree of polarization and Rayleigh scattering). The candidate core clear-sky MODIS data products identified to date include:

8.1 Aerosol Single Scattering Albedo/Radiance

8.2 Aerosol Optical Depth

8.3 Aerosol Mass Loading

8.4 Aerosol Size Distribution

8.5 Polarization Over Oceans

8.6 Rayleigh Scattering Radiance

Following the review of these clear-sky core products with the MODIS science team leader, Dr. Vince Salomonson, the following revisions are suggested:

1. Candidate product 8.6 may not be generated as core products unless strongly advocated by a team member.

2. Candidates 8.1, 8.2, 8.3, 8.4, and 8.5 are likely core products.

3. No new candidate core products exist at this time.

Dr. Michael King has the following comments:

4. 8.1 Aerosol Single Scattering Albedo/Radiance - this is a difficult, and I believe, controversial product to produce everywhere. I propose that this be a core data

product but I also realize that it may fail at some locations and be hard to validate everywhere.

5. 8.4 Aerosol Size Distribution - The size distribution describes the number of particles as a function of radius, and thus is an array for each pixel. It can best be determined by inversion of aerosol optical depth measurements as a function of wavelength from 0.4 - 1.6 micrometer in wavelength. I know that this is too complicated to do for each pixel, made even more complicated by the errors in the optical depths that will result due to uncertainties in the spectral surface albedo and single scattering albedo. This is an interesting research product that can probably be produced on some occasions, or in support of some research investigation, but should not be promised as a core data product. Perhaps an effective particle radius could be routinely estimated, as it represents some moment of the size distribution. It seems probable that a second moment such as a dimensionless effective variance can also be routinely retrieved. Perhaps these two parameters can be produced routinely and promised as core data products.

6. 8.6 Rayleigh Scattering Radiance - this can be calculated better than it can be measured, and is an ancillary piece of information in retrieving the aerosol component of the spectral reflected radiance.

7. 8.7 Number of fires, average fire size, and fire temperature - this could be a product of use in studying deforestation and environmental impact that is not difficult to achieve and could thus be produced as a core, and I think useful, data product.

9. CORE CLOUD DATA PRODUCTS.

The candidate core MODIS cloud data products identified to date include:

9.1 Cloud Emissivity

9.2 Cloud Fractional Area

9.3 Cloud Optical Depth

9.4 Cloud Type

9.5 Cloud Area and Perimeter

9.6 Cloud Albedo/Brightness

9.7 Cloud-Water Thermodynamic Phase

9.8 Cloud-Droplet Effective Radius

9.9 Cloud-Top Pressure

9.10 Cloud-Top Temperature

9.11 Cloud-Radiative Forcing

Following the review of these cloud core products with the MODIS science team leader, Dr. Vince Salomonson, the following revisions are suggested:

1. Candidate product 9.1, 9.3, 9.4, and 9.11 may not be generated as core products unless strongly advocated by a team member.

2. Candidates 9.2, 9.5, 9.6, 9.7, 9.8, 9.9, and 9.10 are likely core products.

3. No new candidate core products exist at this time.

Dr. Michael King has the following comments:

4. 9.3 Cloud Optical Depth - this should be determined routinely for each cloudy pixel. I feel it is also extremely important, and not at all difficult, to produce a histogram of the probability distribution function for each gridded region (1 degree by 1 degree). Thus the meaning of cloud fractional area can be left to the user to define a critical cloud-no cloud optical depth threshold. The probability distribution function can be more useful in improving climate model simulations than most other parameters to be produced by MODIS.

5. 9.5 Cloud Area and Perimeter - statistics on cloud characteristics, such as albedo, area, and perimeter as a function of cloud size can be produced using an algorithm developed by Yoram Kaufman.

6. 9.6 Cloud Albedo/Brightness - this should be spectral albedo, not broadband albedo.

7. 9.11 Cloud-Radiative Forcing - this should be produced by the CERES team, and not the MODIS team, as this is a difference in broadband radiation budget with and without the clouds.

8. 9.1 and 9.3 should be produced as core data products.

9. 9.5 and 9.6 are questionable core data products in my mind, although statistics from 9.5 can be core products.

Dr. Wayne Esaias has the following comments:

1. The photosynthetically active incident radiance (I_0) at the ocean surface is required to compute primary productivity. I_0 will be required even on cloudy days. For this reason, products 9.2, 9.3, and 9.4 are required by the MODIS oceans scientists, and certainly products 9.3 and 9.4 are strongly advocated. Water vapor profiles (e.g., from AIRS) and haze/aerosol information may also be required.

10. ACTION ITEMS

10.1 Develop a table of core products stating proposed algorithms and proposing investigator(s). Consider mechanisms for developing trade-offs for identifying "standard" MODIS team algorithms from proposed alternatives.

10.2 Concisely list the MODIS team members (and other parties) strongly interested in the calibration of MODIS.

10.3 Provide a table relating core product, proposing investigator, and proposed grid resolutions (for the Level-3 core products).

10.4 Work with Jim Heirtzler to identify anticipated digital elevation data sets and sources for the MODIS Level-1 IFOV navigation.

10.5 Review the requirements of the Eos interdisciplinary investigations to ensure that MODIS meets them; begin discussions with the PI's for the investigations to converge to a common understanding of the role of the core MODIS data products.

Dr. Michael King has the following comments:

1. I concur with the action items, namely I would like to see a list of core data products, and algorithm, stating which investigators on the MODIS team have signed up to work on developing or implementing the different products. This summary should include a reference to published descriptions of the methodology, if available.

Dr. Christopher Justice has the following comments:

1. 10.3 This is an area for definition stage FUNDED research.

2. 10.4 Muller should be contacted concerning DEM data. His note to Vince and team members is a good place to start.

3. 10.5 Running should be contacted to make a presentation on this at the next meeting.

Notes on Kings response to the memo:

4. No disagreements.

5. I would like to suggest that we have a good chance to get our teeth into some of these issues at the next meeting with presentations on how products will be derived and validated. We need to spend as much time on identifying the R&D products if we don't want to alienate those whose RESEARCH PROPOSALS FOR MODIS were ACCEPTED. We are in danger here of redefining the AO process.

REVIEW OF LEVEL-1 PROCESSING REQUIREMENTS

As a starting point for the development of top-level data system structures for Level-1 processing, EosDIS and MODIS Level I and II requirements documents were reviewed and summarized for this report. The basic intent of this effort was to bring formally stated system requirements clearly to mind as Level-1 processing structures are specified, and to provide a review of requirements that may have changed or been superseded by events occurring since requirements were originally specified.

Requirements that occur and recur throughout the documents that were reviewed are summarized in the initial section of this document. Requirements not universally acclaimed or needing re-examination from the present-day system perspective are discussed in the second portion of this document.

Requirements Synopsis

The basic object of Level-1 processing is to generate observed radiance values for the MODIS-N and MODIS-T instruments from the data stream returned by the spacecraft. Processing must be completed and results made available within 48 hours after the original observation, with not more than 10% of the data requiring reprocessing due to failures in initial production. Level-1 browse data (products that support user selection of data suitable for his purposes) is also required within the 48 hour time limit.

Metadata (data describing other data) for Level-1 products must be provided as the products are delivered to the DADS, so Level-1 metadata must also be provided within 48 hours. All data products shall employ a common identification structure and format adhering to recognized NASA, CCSDS, and data system standards. Delivered data products shall include a pedigree of the data and algorithms used in their production, including such items as input data used, calibration coefficients and other parameters applied, system configurations and algorithm versions used, and an identification of anomalies in data collection or transmission that might affect data quality.

Ephemeris and other data needed to generate MODIS products that is not in the original instrument data stream shall be added to that data. [It is envisioned that all location activities required to locate the pixels of the basic, original MODIS image in an earth-referenced grid will be done as a part of Level-1 processing.]

Algorithm developers are responsible for the quality of products produced using their algorithms. Standard products shall meet criteria specified by the developer and certified by the science team. Facilities shall be made available to those individuals responsible for the processes/algorithms used for the generation of standard products to monitor in a timely manner the quality of products generated using that algorithm. The criteria used for routine data quality evaluation shall be archived.

To support field experiments, the requirements documents define Near-Real-Time processing, with products delivered within 3 to 8 hours of the observation. The requirements allow the possibility of modified or reduced data quality requirements for Near-Real-Time data, if relaxed quality requirements are necessary to achieve required data turn-around times.

A number of instrument support data products are required in addition to the basic Level-1 products that are the object of Level-1 processing. Since data returned by the MODIS instrument will be in a format chosen to minimize on-board processing requirements, engineering data will need to be reformatted, and special engineering data packets will be created. Level-0 data must be made available to designated science investigators on request. Since Level-0 data will not be archived, algorithms to recover Level-0 data from archived Level-1(A) data will be required. Instrument support requirements also include the production of an instrument calibration support product that contains the MODIS data needed for instrument calibration.

Requirements Needing Clarification

A few of the formally stated requirements need clarification or reexamination before they are implemented. We shall directly quote several of the requirements whose meaning is unclear or that appear to contradict some aspect of basic system design as it has been envisioned thus far. The quote will then be followed by questions or a discussion of design issues inherent in the requirement.

MODIS Level-1 Requirements paragraph II,C,31 states:

"The GDS [Ground Data System] shall allow immediate generation of any products from newly acquired data."

Does this mean that routine generation of products is to be suspended to allow the immediate generation of specially needed products? Or does this requirement really mean that the system shall support the generation of products in Near-Real-Time [within 3 to 8 hours]? Who will decide that products are to be generated "immediately"?

A number of requirements relate to the need to monitor instrument and data system operation for the purpose of providing real-time control. It is also required that instrument and data system history be archived and provided to data users upon request. An issue relating to Level-1 processing has to do the origin of the archived information. Since monitoring and control information is needed immediately or nearly immediately, are data quality compromises necessary to achieve required operational turn-around times at the ICC? Could an improved operations history be generated if time constraints were relaxed? Should an improved or modified instrument operations history be generated at the CDHF from data received through regular channels? Does Level-1 MODIS processing need to support the generation of an instrument history product specifically intended for retention in the permanent record?

MODIS Level II Functional Requirements paragraph 3.4.1.1 FNR137 states:

"The CDHF shall receive Level-0 data and ancillary data from the DHC. The Level-0 data shall be in a form that is sequenced by time, by focal plane, by along-track distance, and by band configuration along the scan direction. Ancillary data shall have been checked, at the DHC, against high and low limits, and validated by comparisons with orbit and attitude reference profiles."

It now appears that MODIS Level-0 data will be formatted to optimize the on-board processing and storage problem rather than to optimize ground processing. Data will not likely be in the required format.

MODIS Level II Functional Requirements paragraph 3.4.2 FNR155 states:

The Levels-1A and -1B data products shall have appended to the various levels of data organization (from the basic product length to the lowest level of segmentation) subsets of the following ancillary data (the resolutions in time and space are to be determined):

a. MODIS-N/MODIS-T sensor identification
b. Product sequence number/version number
c. Processing date
d. Calibration algorithm identification number/version number
e. Product start and stop times
f. Orbit number(s)
g. Geographical boundaries of the product
h. Channel identification
i. Data quality flags
j. Calibration quality flags
k. Housekeeping data
l. Engineering data
m. Land/ocean flags
n. Measure of cloudiness
o. Instrument tilt information (MODIS-T)
p. Scan number(s)
q. Attitude information
r. Platform ephemeris
s. Time code
t. Solar and satellite zenith angle information
u. GPS time correction

v. Platform structure telemetry
w. Calibration coefficients (Level-1B)

This list of metadata parameters will need to be further examined and refined before actual implementation begins.