MODIS DATA STUDY
TEAM PRESENTATION

June 1, 1990

AGENDA

1. Notes from IGARSS '90 Concerning MODIS Land Data Products (Riggs)
2. Scenario for MODIS Land Level-4 Data Products (Ardanuy)
3. Data Rates (Volumes) Compared to MODIS (Ardanuy)
4. The Global Positioning System Master Control Station (Schols)
5. GPS Issues (Wolford)

NOTES FROM IGARSS '90 CONCERNING MODIS LAND DATA PRODUCTS

INTRODUCTION

Presentations were made by various MODIS Science Team Members at the 10th Annual International Geoscience & Remote Sensing Symposium (IGARSS), May 20-24, 1990, that contained relevant information about some of the MODIS data products. Presented here are a few salient points derived from those presentations, and presentations by other scientists, concerning some MODIS land data products.

ATMOSPHERIC CORRECTIONS (Land leaving radiance)

There are two general classes of atmospheric corrections that may be applied to remotely sensed data to calculate a land leaving radiance: they are; 1) radiative transfer models, and 2) corrections based on "invariant" surface targets. Presentations of both types of atmospheric corrections were given during IGARSS '90 and it is likely that an atmospheric corrections algorithm for MODIS will be developed from one of these classes. A very brief general description of each class is given below.

Radiative transfer models that model the effects of atmospheric constituents on the transfer of radiation through the atmosphere tend to be computationally intensive ("large" amount of code and mathematical operations involved) and require input data on the physical constituents in the atmosphere at time of image acquisition and possibly surface spectral reflectance data, or these input parameters are assumed for standard atmospheres. Corrections based on "invariant" surface features, features that are known to have a constant spectral reflectance over time, appear to be less computationally intensive than radiative transfer models and may not require *in situ* data, but are limited in application to images in which there is a known "invariant" feature(s) in the image.

BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION (BRDF)

Presentations on research of directional reflectance from vegetation given at IGARSS are evidence of the value of a BRDF for vegetation analysis in monitoring vegetation dynamics and changes. As data is collected and information extracted from these research efforts the BRDF product for MODIS will become more well defined; thus the viewing geometries, sensor tilt angles, and frequency of coverage required for constructing a BRDF from MODIS-T could be fully specified and planned for.

DIGITAL ELEVATION MODEL (DEM)

The effects of terrain relief on MODIS-N in respect to shifts in pixel location and the availability of DEM data were discussed by Dr. Jan-Peter Muller. Dr. Muller concluded that his analysis has demonstrated the importance of correcting imagery for topographic effects and the need for a global topographic data base before launch of EOS. The task at hand is to assemble or build this global topographic data set; a global DEM for use with MODIS-N and other EOS platform sensors. Currently there are DEMs available in the public domain, and DEMs can be built from stereo-matching of SPOT satellite images.

Open to discussion is the spatial resolution and accuracy requirements of a DEM(s) for EOS. Requirements for the spatial resolution and accuracy of a DEM should be driven by the data products that will use the DEM. The science team members need to specify the requirements (grid size, spatial resolution, accuracy) of a DEM before a functional DEM can be assembled.

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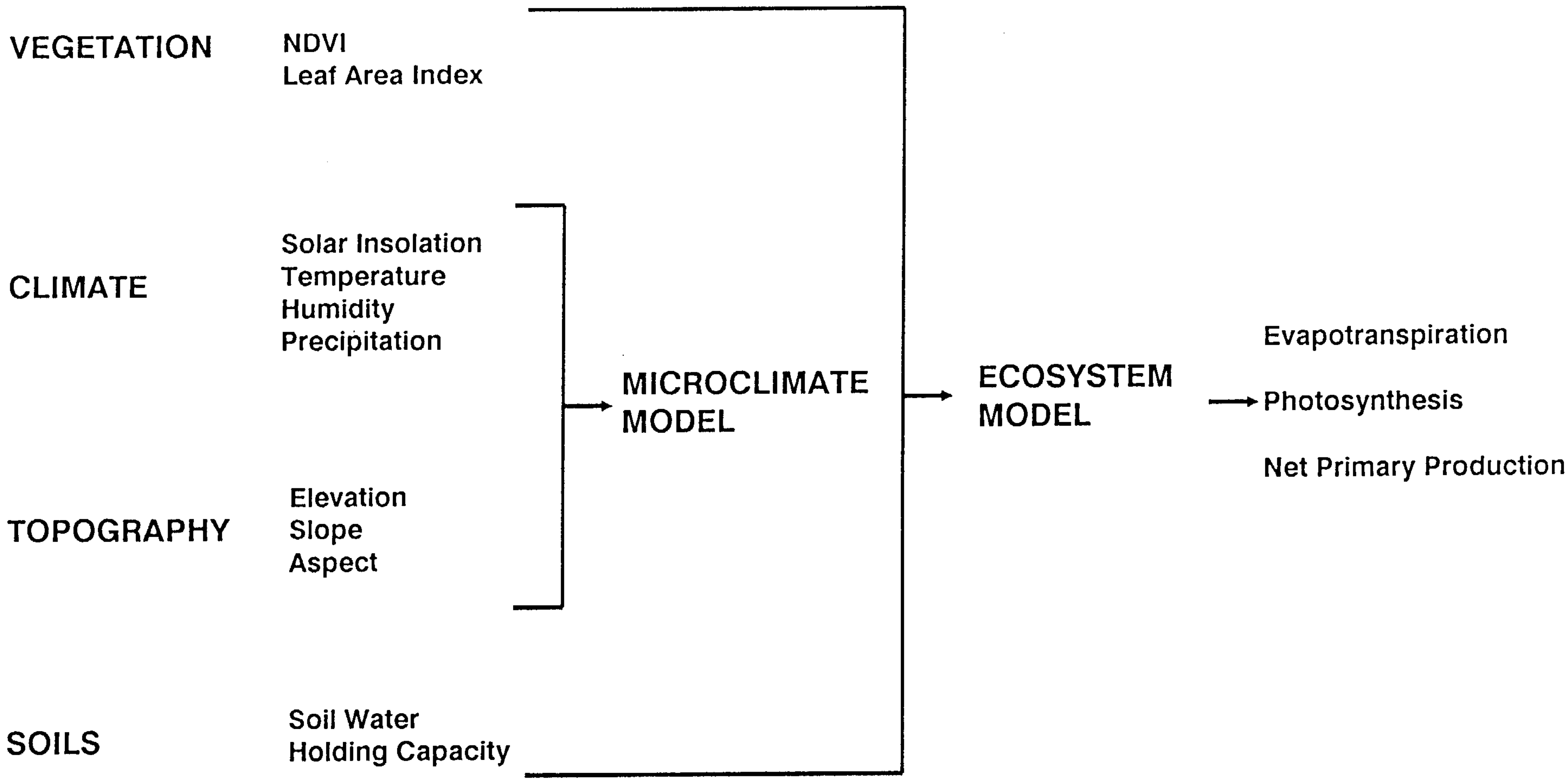
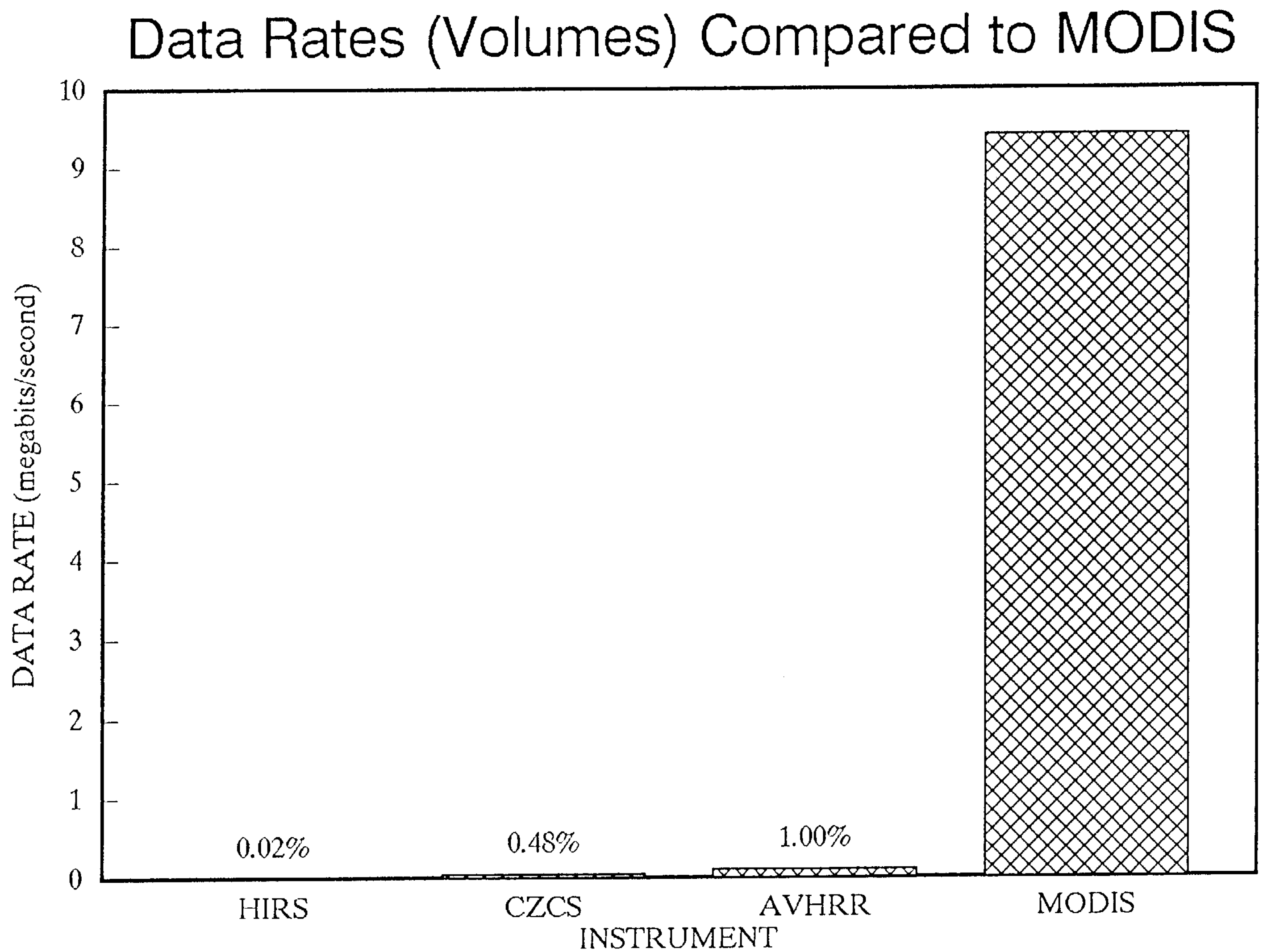


SCENARIO FOR MODIS LAND LEVEL-4 DATA PRODUCTS (RUNNING)



Data Rates (Volumes) Compared to MODIS
DATA RATE (megabits/second)
0
1
2
3
4
5
6
7
8
9
10
0.02%
0.48%
1.00%
HIRS
CZCS
AVHRR
MODIS
INSTRUMENT

	HIRS	CZCS	AVHRR GAC	AVHRR LAC	MODIS-T	MODIS-N
PIXELS/SCAN LINE	56	1,968	409	2,048	1,007	1,582
SCAN LINE/SECOND	0.2	6.0	2	6	6.5	8
VISIBLE BANDS	1	5	2	2	32	17
INFRARED BANDS	19	1	3	3	32	19
BIT QUANTIZATION	13	8	10	10	13	12
VISIBLE COVERAGE	100%	8%	50%	~~10%~~	50%	50%
IR COVERAGE	100%	8%	100%	~~10%~~	0%	100%
VIS RATE (KBPS)	0.1	37.8	8.2	24.6	1,360.1	4,252.4
IR RATE (KBPS)	2.2	7.6	24.5	36.9	0.0	3,796.8
AVG RATE (KBPS)	2.3	45.3	32.7	61.4	1,360.1	8,049.2

RATIO OF MODIS TO HIRS	4,136
RATIO OF MODIS TO CZCS	208
RATIO OF MODIS TO AVHRR	100
RATIO OF MODIS TO ALL ABOVE	68

The Global Positioning System (GPS) Master Control Station (MCS).

Introduction

The Navstar Global Positioning System (GPS) is a highly accurate, space based navigation system providing all weather 24 hour-a-day service to both civilian and military users. The Navstar system provides a Gaussian position solution with four satellites, each providing its ephemeris and clock offset with respect to GPS time. Currently there are about 12 satellites in orbit building toward a full 24 satellite constellation (21 operational satellites and 3 on-orbit spares).

The GPS Master Control Station (MCS) system promises a revolution to those users, civilian and military, requiring precise navigation and positioning. GPS signals will provide precise positioning services to authorized users of 16 meters spherical error probability and 100 meters circular error probability to standard positioning service customers.

GPS is made up of three segments. The space segment consists of orbiting satellites and provides L-band signals with modulated data to the world. The user segment is the customers who utilize the navigation data. The control segment comprises a system of L-band monitoring stations, S-band antennas and a control center (at Falcon Air Force Base, Colorado) to monitor the satellites health and periodically upload new navigation parameters. The navigation payload update consists of orbital parameters, atomic frequency standard states, and almanac data for broadcast to the user community.

A Kalman filter estimation process is used to determine, predict, and quality control each satellite's ephemeris and clock states.

REFERENCES

Information on GPS can be found in:

Global Positioning System. Volumes I, II, and III. Published by The Institute of Navigation, Washington DC., 1980.

Information on the design of the MCS Kalman Filter was obtained from:

Computer Program Development Specification for the MCS Ephemeris/Clock Computer Program: Appendix A. USAF Contract F04701-80-C-0011, Specification Number CP-MCSEC-302C.

Contibution to EOS

The article about the GPS MCS provides valuable information for the EOS platform on:

- Accuracy of state (position,velocity and time) of the platform.
- Kalman filter experience (filter reaction and response for anomalous clock behavior and trajectory perturbations).
- MCS efforts to improve Kalman filtering and orbital adjust modeling.
- 'Unhealthy' state flag (housekeeping (momentum dumps, attitude control, velocity control).
- Inertial transformation.
- Recommendations for future systems requiring precise ephemerides.

To obtain the orbital dynamics of the EOS platform in real-time, some type of optimal estimator must be used. Current technology uses a Kalman filter with a GPS receiver to combine known spacecraft dynamics with measured pseudorange and range-rate date updates to form an optimal estimate.

Using this scenario, the best estimate of the EOS platform's state (position, velocity and time) can then be used, with the platform's attitude determined by a star tracker, in calculating the platforms pointing vector. Current star tracker technology has the ability to provide the platform's orientation in an inertial frame at a 10 Hz rate (cf. handout).

The information obtained by the Kalman/GPS estimator and the star tracker must be converted into a conventional frame of reference for the calculation of the instrument pointing vectors. The frame best suited for this application is an Earth-Centered, Earth-Fixed (ECEF) coordinate frame of reference. This frame is convenient in that the Kalman/GPS estimator gives the platform state in the ECEF frame. The star tracker, which gives the platform attitude in an Earth-Centered Inertial (ECI) frame, is easily converted to an ECEF frame by a Eulerian transformation. By defining some epoch that the ECI and ECEF frames are exactly aligned (they align once every 24 hours) along the Earth's spin axis, the transformation can be as simple as calculating the Earth's angular rotation since the epoch, DELT, and doing a simple Eulerian transform:

X (ECEF) = X (ECI) * COS (DELT) + Y (ECI) * SIN (DELT)
Y (ECEF) = - X (ECI) * SIN (DELT) + Y (ECI) * COS (DELT)
Z (ECEF) = Z (ECI)

Some sizing estimates

Coordinate transformation

The transformation from an Earth-Centered, Earth Fixed (ECEF) frame to an Earth-Centered Inertial (ECI) frame can be accomplished by rotating the three orthogonal axes which make up a coordinate frame with respect to the axes which make up another coordinate frame. A general description of a transformation of some vector, VA, in coordinate frame A to a corresponding vector, VB, in coordinate frame B is given by

$$VB = TX * TY * TZ * VA \quad ,$$

where T is a rotation matrix, and X, Y, Z are the Eulerian axes about which the rotations took place. The transformation matrices for each rotation are

$$TX = \begin{vmatrix} 1 & 0 & \\ 0 & COS(X) & SIN(X) \\ 0 & -SIN(X) & COS(X) \end{vmatrix}$$

$$TY = \begin{vmatrix} COS(Y) & 0 & -SIN(Y) \\ 0 & 1 & 0 \\ SIN(Y) & 0 & COS(Y) \end{vmatrix}$$

$$TZ = \begin{vmatrix} COS(Z) & SIN(Z) & 0 \\ -SIN(Z) & COS(Z) & 0 \\ 0 & & 1 \end{vmatrix}$$

To construct each rotation matrix it takes 22 FLOP (2 FLOP for the determination of the angular rotation, viz. time difference times angular speed, and 20 FLOP for the two trigonometric functions). The multiplication of the matrices and the vector VA take 45 FLOP. The total number of operations for the above transformation is thus (3*22+45=) 111 FLOP.

KALMAN filter.

If the signal is known to be characterized by some number of parameters that vary only slowly, the formalism of Kalman filtering tells how the incoming, raw measurements of the signal should be processed to produce best parameter estimates as a function of time.

To understand the principle of the Kalman algorithm it should be compared to one of its special cases, the Recursive Least Squares Regression (RLSR) algorithm: A Least Squares solution is found for the parameters every time a new datum becomes available.

A disadvantage of the Kalman algorithm is its complexity.[1] An N by N matrix must be adapted and stored once per iteration, where N, the number of equalizer tap coefficients, may typically be on the order of a few hundred or so. Thus on the order of N * N operations must be performed per iteration. N is in fact a multiple of the number of signals to be updated and the number of data points per signal, which is used in the updating.

Fast Kalman algorithms exploit the "shifting property" of most sequential estimation problems. In equalization, this property expresses the fact that at each iteration the number of new samples entering and old samples leaving the equalizer is not N, but a much smaller integer p. For example, p=1 for a conventional linear equalizer.

A comparison between the number of operations, per iteration step, in a simple gradient, the conventional Kalman, and a fast Kalman algorithm is given in Table I.

Table I.

Algorithm	Multiplications	Additions
Simple gradient	2N	2N
Fast Kalman	$7Np+Np^2+3p^2+2N+(4/3)p^3-p/3$	$7Np+Np^2+p^2/2+4N+(4/3)p^3+(19/6)p$
Conv. Kalman	$3N^2+3N$	$2N^2+2N+1$

For a linear equalizer (p=1), and for large N, the computational load of the equalizer with fast Kalman updating is about 5 times that of the equalizer with simple gradient updating. The conventionally-implemented Kalman algorithm however is about N times as complex as the simple gradient algorithm.

We want to apply this concept to the EOS platform in order to estimate its position and orientation as accurate as possible using GPS data and star tracker data. We assume a sampling frequency of F=1/1.5 Hz, and a data accumulation period of 15 minutes, before the filtering is done, and I=100 iterations in the filtering process. The required processing speed for conventional Kalman and fast Kalman are respectively $I*F*(5N^2+5N+1)=120$ MFLOPS and $I*F*(22N+9)=0.9$ MFLOPS for each state parameter.

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[1]Falconer, D.D. and L. Ljung, 1978 : Application of Fast Kalman Estimation to Adaptive Equalization. IEEE Trans. Comm, vol. COM-26, no. 10, pp. 1439-1446.

GPS Issues

System Status

The GPS space segment has 6 Block I and 5 Block II satellites in operation. Another Block II satellite was scheduled for launch in January 1990. Block I satellites are the original style satellites. Block II satellites carry more instruments and have their station maintenance thrusters located along both the X- and Y-axes. Usually only the X-direction (roughly vertical) thrusters are fired. Block I satellites have only Y-axis thrusters (roughly horizontal). If properly spaced in orbit, these 12 satellites will give 24-hour, two dimensional (latitude and longitude) global positioning capability.

Additional launches this year, and the continued health of the older satellites, should bring the total number of functioning satellites to 18 by the year's end. This should be sufficient to provide global coverage for 3-dimensional positioning. The GPS system ground control segment has worked so well that little thought has been given to it.

The GPS receiver developments are driven toward smaller, lighter units. A recent survey shows that there are over 100 receiver models being manufactured by over 50 companies. Precision surveys and time transfer are the dominant applications driving the market. Marine and aviation applications are gathering momentum.

Issues

The overriding issue is the Department of Defense's commitment to provide GPS signals and related information to the civil community (including other government agencies). This service was planned from the outset. President Reagan formalized this arrangement in a 1983 statement shortly after a Soviet fighter shot down an off-course Korean airliner. The civil capabilities of the GPS standard positioning service has been published in the DOD/DOT Federal Radionavigation Plan for the last 10 years. A formal commitment is needed which states the U.S. Government's long-term position in this area.

Selective Availability (SA)

DOD's stated policy is that SA will be implemented on the Block II satellites after four or five have been placed in orbit and are operating properly. (Block I satellites do not have this capability.) SA is the planned provision of a civil signal at an accuracy level of 100 meters instead of the current 30-40 meters. This will be done by introducing errors into the clock and ephemeris data broadcast by the satellite. DOD has been testing this capability for the past six months and it seems clear that it will be implemented shortly. DOD is developing a network for distributing the keys that allow military and other authorized precise positioning service (PPS) users to receive clear signals. Differential techniques can be used to provide accuracies of a few meters over a large area. Differential techniques require at least two GPS receivers with one receiver's position known to a high accuracy.

Integrity Monitoring

Integrity monitoring ensures that the satellite information is valid. Users would be notified of out-of-tolerance signals by satellite or other data links. Integrity issues are now being evaluated by the Radio Technical Commission for Aeronautics' Special Committee 159 on GPS. One should recognize that integrity monitoring will have a significant cost impact upon the user. This issue must be carefully considered if we want to avoid constraining the implementation of GPS civil user equipment.