Back-Up Charts for the MCST Presentation

to the

Land Working Group

of the

MODIS Science Team

from

MCST (MODIS Characterization Support Team)

John L. Barker, Head
301/286-9498 or GSFCmail: JBarker
Joann M. K. Harnden
301/286-4133 or GSFCMail:JHarnden
Code 925 - Sensor Development and Characterization Branch
Steven G. Ungar
301/286-4007 or GSFCmail: SUngar
Brian L. Markham
301/286-5240 or GSFCmail: BMarkham
Code 923 - Biospheric Sciences Branch
NASA / Goddard Space Flight Center, Greenbelt, Maryland 20771
FAX: (301) 286-9200

Presented by:
John L. Barker
Contributions by
Harold Geller, Jon Burelbach, Barbara Grant, Doug Hoyt, Janie Nall
(301)286-9412 or (301)982-3700 GSFCmail:BGrant, JNall,
Research and Data Systems Corporation (RDC)
7855 Walker Drive, Greenbelt, MD, 20770
Fax: (301)286-9200 or (301)982-3749

1615 Tuesday, 14 April 1992
Management Conference Center, Bldg 8 , Goddard Space Flight Center

Attachment 4.2

Overview of Back-up Charts

Geometric Requirments
- Definitions Related to Geometric Requirements
- Error Budgets from SBRC
  - Band-to-Band
  - Pointing Knowledge
- Salomonson and Barker Georeferencing Text

MODIS/MCST Utility Data Products
- Texture Algorithm
  - Comments on Development & Methodology
- Classification Overlay/Masking Algorithm
  - Scene Identification Fields and Masks

MCST-Related MODIS Scene Simulation Activities
- Procedure for Spatial Simulation of MODIS Data
- Chernobyl MODIS Results from TM Imagery
- Chugach, Alaska MODIS Results from TM

Land Science Objectives by Instrument

Definitions related to MODIS Geometric Requirements

Pointing Precision

Pointing Precision refers to the precision associated with the LOS pointing angle of the scanner during the linear scan portion of the scanner motion. This linear scan takes place during a time interval of 0.0655 sec. The remainder of the scanner motion consists of flyback and settling time. All angles are LOS, not mechanical angles. The linear scan covers a LOS range of +/- 3.415 degrees. The center of the linear scan can be located at any offset angle within a LOS range of +/- 8.7 degrees. Pointing specifications apply to operation of the scanner in vacuum. However, provision shall be made for testing (or other verification) in atmosphere.

Calibration of the scanner will be accomplished after the scanner is attached to the legs (for mounting to the ITIR structure). The legs provide the mechanical integrity required to meet pointing precision requirements. (This design approach is necessary in order to minimize scanner weight.)

Pointing Jitter

Jitter is the variation in the LOS pointing accuracy over any single linear scan. As a goal, the pointing jitter shall be not more than 13 urad, 3-sigma.

Off-axis Motion

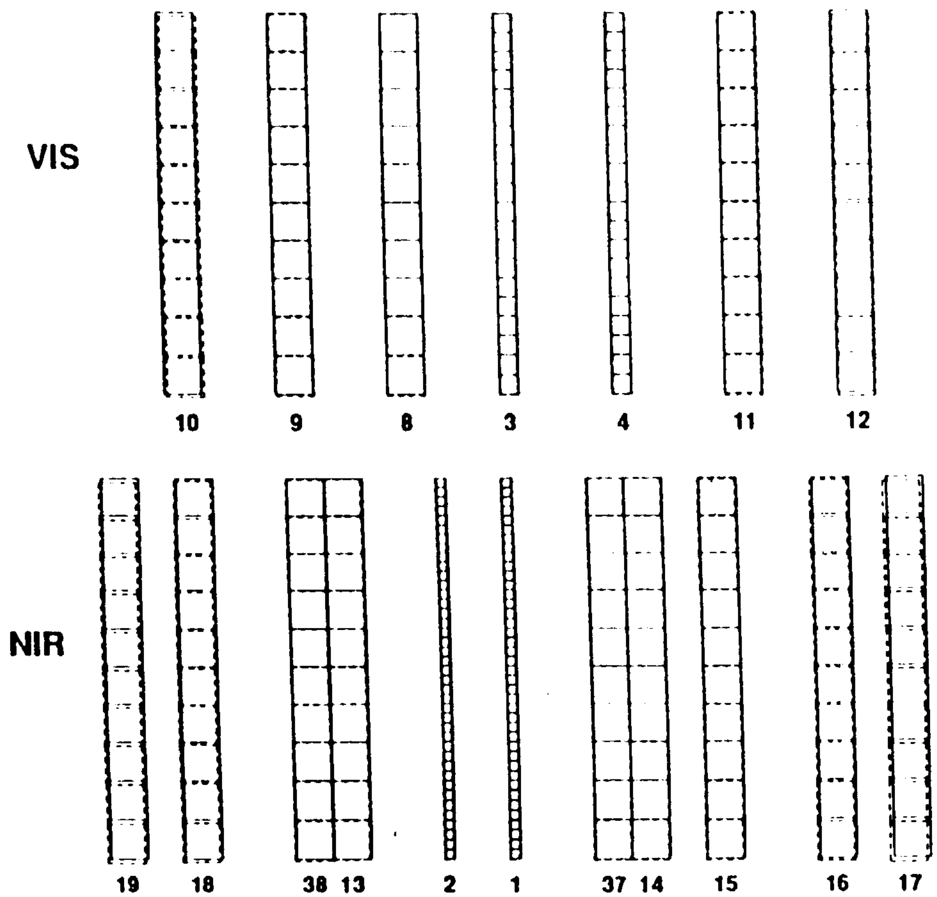
Off-axis motion is the variation of the LOS pointing angle in the direction normal to the scanning direction, during any single linear scan. As a goal, the off-axis motion shall be not more than 13 urad, 3-sigma.

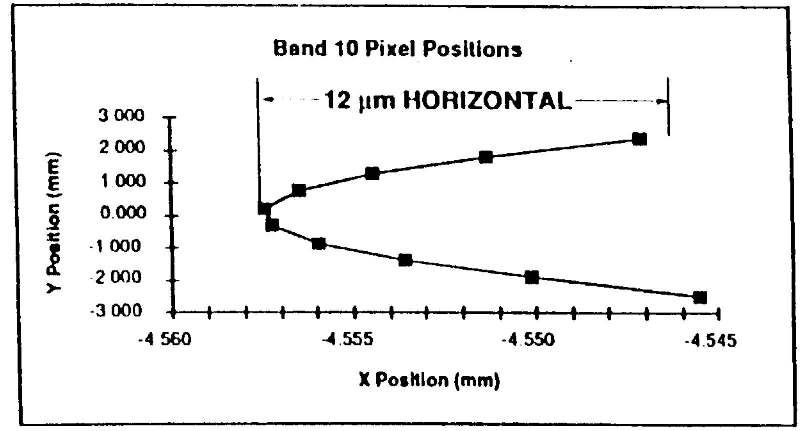
Position Reporting Accuracy

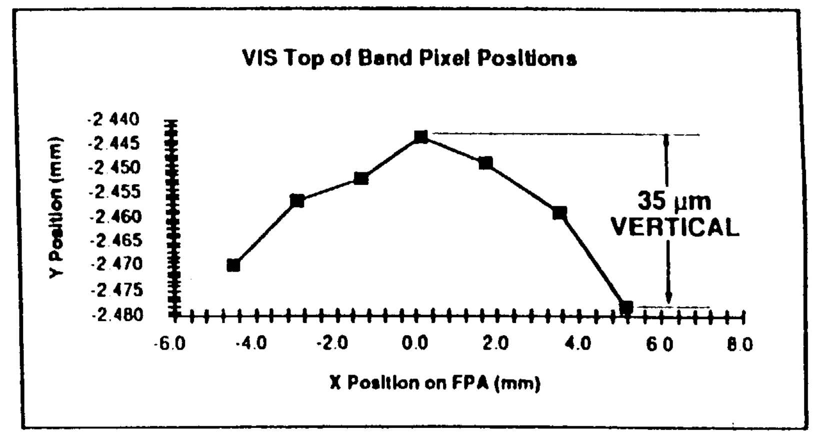
Reporting accuracy is the accuracy of determination of the actual LOS direction of the scanner, after calibration, with respect to a calibrated encoder reference point, over any 8 minute period. This represents short term thermomechanical stability. As a goal, the position reporting accuracy shall be not more than 13 urad, 3-sigma.

Spectral Band Registration Requirements are tough for SBRC to meet

- **SYSTEMATIC OPTICAL DISTORTION REMOVED BY PROPER PLACEMENT OF PIXELS**





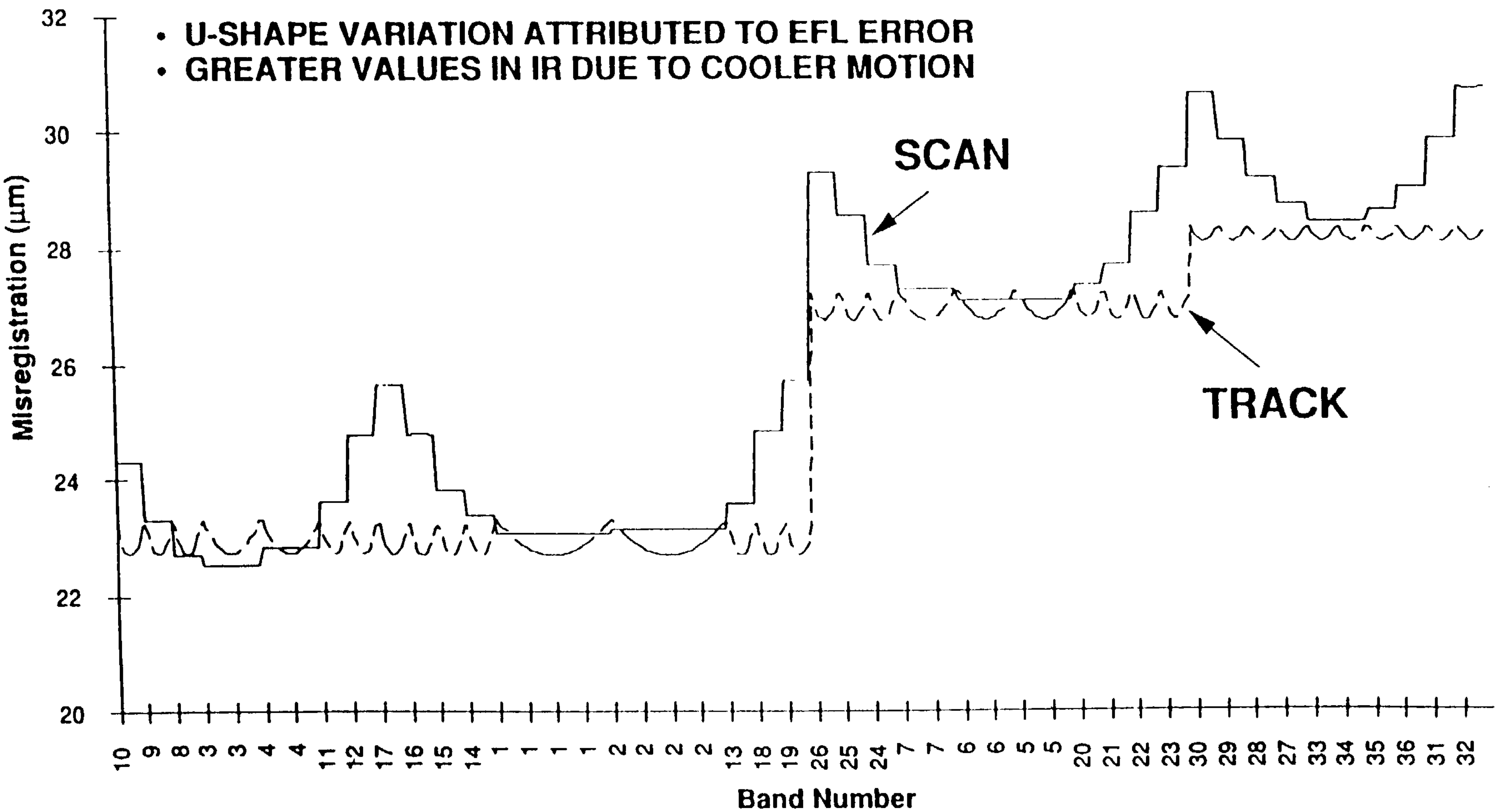


Predicted Band Registration Error Budget by SBRC

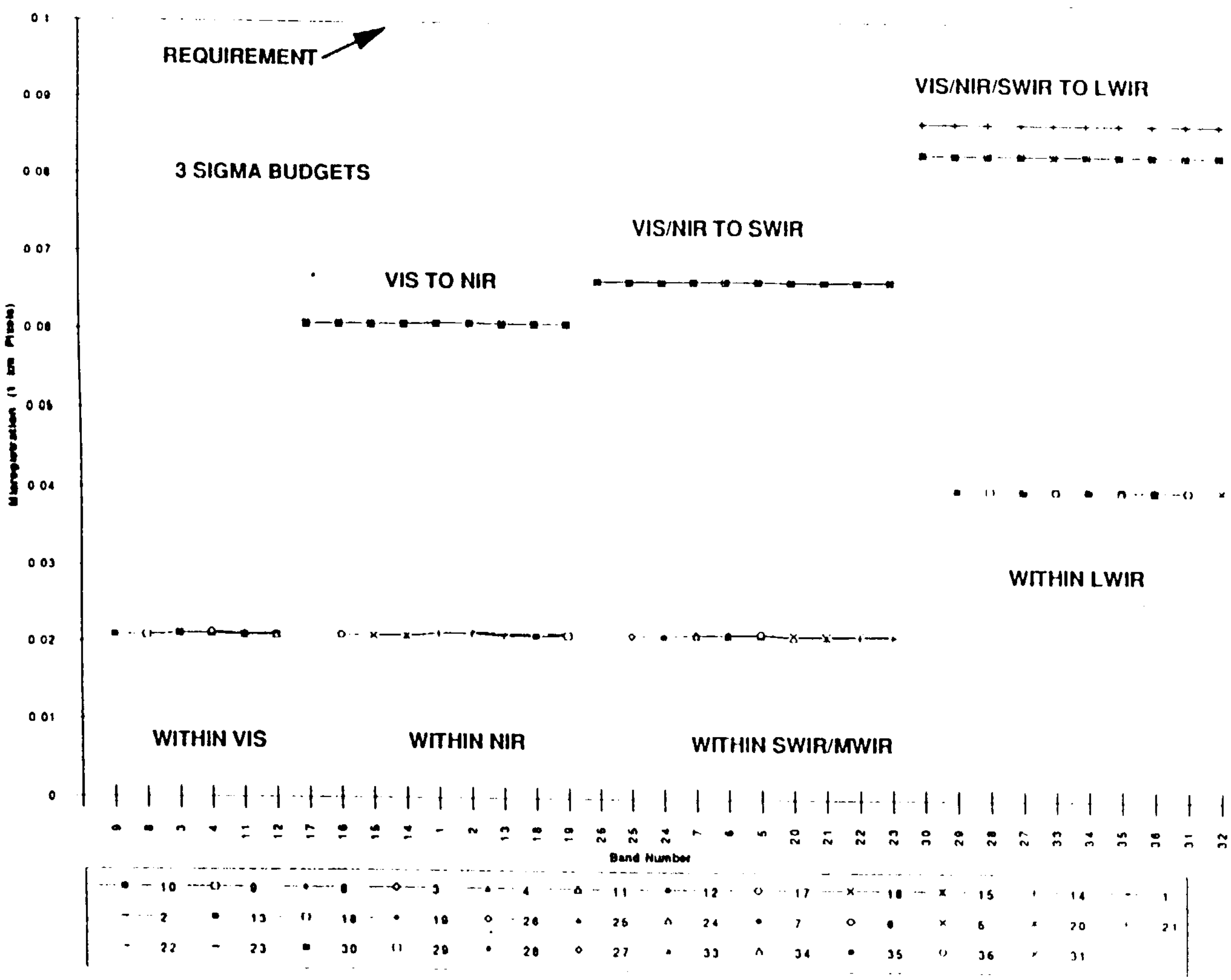
Band	**32**			
Worst Case Pixel	1			
Pixel Position (mm)	5.87765	-1.89277		

CONTRIBUTOR	SCAN (µm)	TRACK (µm)	FOCUS (µm)	SYS/RAN
Within-FPA Contributors				
OPTICAL_DISTORTION	.00	.00	.00	S
EFL_ERROR	-11.76	3.79	.00	R
SCAN_VEL_ERRORS(±0.0017_radps)	4.81	.00	.00	R
EARTH_ROTATION_ERRORS	1.86	.00	.00	R
SAMPLE_TIMING_ERRORS	1.00	.00	.00	R
FPA_ROTATION_PLACEMENT_ERROR	.00	3.26	.00	R
LWIR_SCA_PLACEMENT_ERRORS	10.00	10.00	10.00	R
FILTER_TILT_ERROR	2.00	2.00	2.00	R
Total Within-FPA				
SYSTEMATIC	.00	.00	.00	S
RANDOM	16.43	11.36	10.20	R
Between-FPA Contributors				
OBJ_ALIGNMENT_TO_OPT_AXIS	20.00	20.00	20.00	R
LW_OBJ_MOTION(STRCT_THERM)	5.00	5.00	5.00	R
LW_FPA_MOTION(STRUCT_THERM)	5.00	5.00	5.00	R
COLD_PLATFORM_MOTION	15.00	15.00	15.00	R
Total Within and Between-FPAs				
SYSTEMATIC	.00	.00	.00	S
RANDOM	30.74	28.35	27.91	R
REQUIREMENT	40.00	40.00	N/A	

Current Band Registration Error Budget from SBRC
Random Errors to ≤ 32 μm

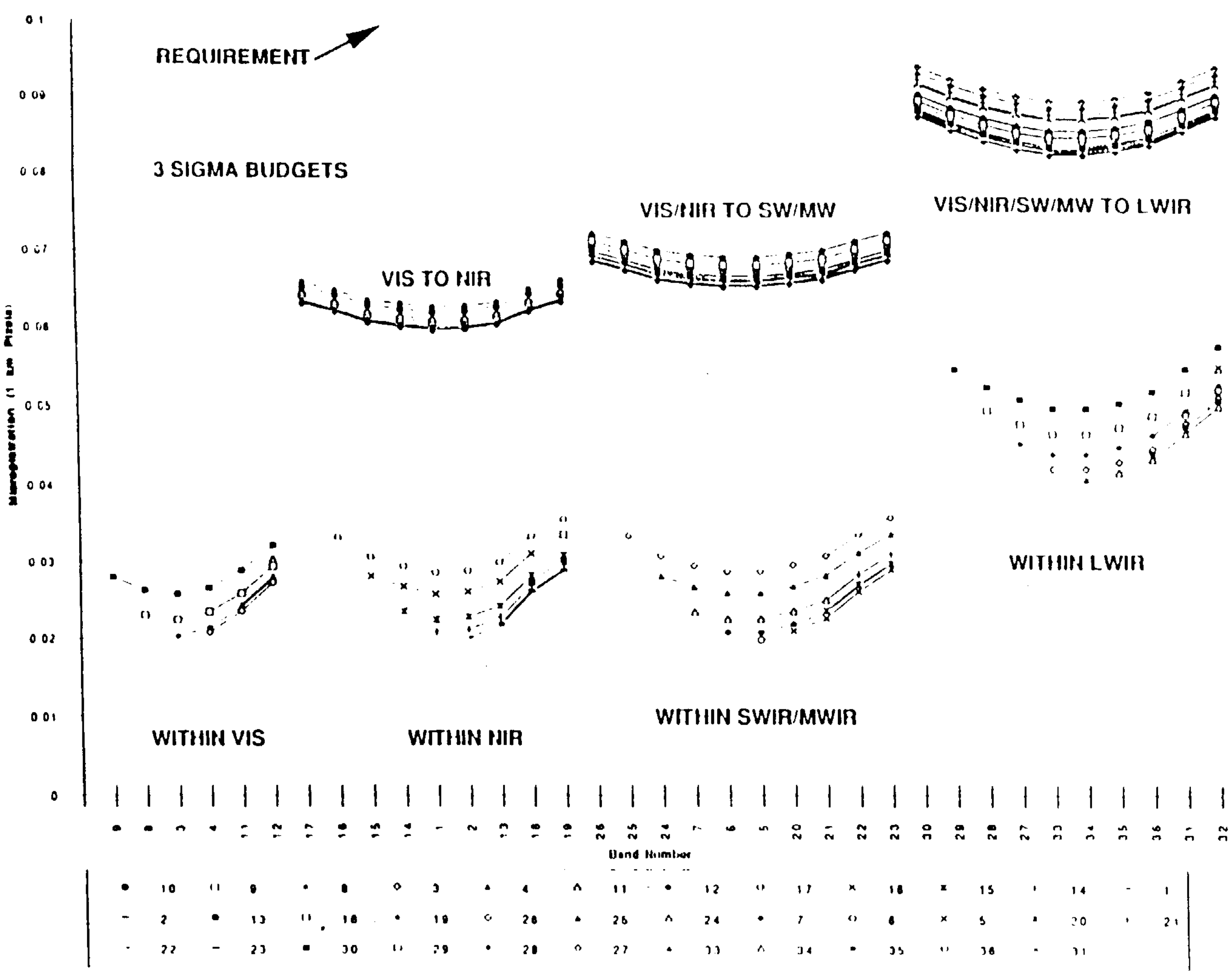


Along-Track Registration Met with New Error Budgets (SBRC)



- OPTICAL DISTORTION REMOVED
- TOP OF BAND
- OTHERS COMPARABLE
- EVERY POSSIBLE COMBINATION OF BANDS IS PLOTTED

In-Scan Registration also Meets Requirements (SBRC)



- OPTICAL DISTORTION REMOVED
- TOP OF BAND
- OTHERS COMPARABLE
- EVERY POSSIBLE COMBINATION OF BANDS IS PLOTTED

Along-Scan Pointing Knowledge Error Budget from SBRC

CONTRIBUTOR	STATIC / RANDOM	VALUE
• Scan Mirror to Encoder (Aligned to ±22 μr)	S	4 arc-sec
• Pixel-to-pixel Knowledge (±.03 IFOV)	S	9 arc-sec
• Alignment Cube to Scan Mirror	S	25 arc-sec
• Mirror Position Uncertainty (30 μr in mirror space)	R	12 arc-sec
	RSS Total	29 arc-sec
	Requirement	30 arc-sec

Along-Track Pointing Knowledge Error Budget from SBRC

CONTRIBUTOR	STATIC / RANDOM	VALUE
• Pixel-to-pixel Knowledge (±.03 IFOV)	S	9 arc-sec
• Along Track Wedge of Mirror (±0.001" axial centering)	S	9 arc-sec
• Alignment Cube to Optical Axis	S	25 arc-sec
• Bearing Runout (12 arc-sec, 40% corrected by clocking)	R	7 arc-sec
	RSS Total	29 arc sec
	Requirement	30 arc-sec

Georeferencing Considerations for MODIS Data
(Salomonson and Barker, 1992)

When considering the georeferencing requirements for MODIS-N data, one should consider several factors including those specifically defined below [7]. In this paper, the emphasis will be on pointing knowledge. Studies done by one of the authors (J. Barker) have shown the sensitivity of some derived information to pointing accuracy and knowledge derived from the EOS spacecraft.

Pointing Knowledge (PK): The accuracy of the determination of the actual pointing direction per axis of a selected reference frame with respect to the true target frame (the Orbit Reference Coordinate Frame).

Pointing Accuracy (PA): The ability to align the actual pointing direction of the observatory coordinate reference frame with respect to the true target frame (the orbit reference coordinate frame).

Orbit Position Knowledge (OPK): The ability of the observatory's navigation system to estimate the location of its center of mass relative to the true orbit reference coordinate frame.

Pointing Jitter/Stability (PJS): The peak-to-peak angular motion of the observatory during given periods of time. The convention is that "jitter" refers to motions over relatively short periods of time while motions over relatively long (e.g., 1000 seconds) is referred to as "stability."

Georeferencing Considerations for MODIS Data

(Salomonson and Barker, 1992)

(continued)

Figure 2 illustrates that Pixel Geolocation Knowledge (PGK) is principally a function of the PK and the OPK. Of these two, PK is the primary factor on the EOS spacecraft. In addition, the boresighting of the instrument relative to the instrument alignment cube on the instrument must be considered (Fig.3). The EOS spacecraft is expected to provide 90 arc-second (3s) pointing knowledge at the instrument mounting cube.[8] The nominal pointing knowledge of the EOS spacecraft at the navigation base is 0.01° or 36 arc seconds (3s). This compares with the TIROS spacecraft flying the NOAA operational sensors such as the AVHRR, where the nominal capability is 360 arc seconds. The Landsat 4 and 5 spacecraft have a capability very similar to the EOS. The MODIS-N boresight requirement is 90 arc seconds.

Tables 3 summarizes the requirements for MODIS-N with regard to georeferencing. The requirements in Table 3 when contrasted against the spacecraft pointing knowledge capabilities noted above indicate acceptability. Pointing accuracy provided by EOS observatories are expected to be well within MODIS-N requirements.

Georeferencing Considerations for MODIS Data

(Salomonson and Barker, 1992)

(continued)

In the case of PK, however, more accuracy is desired and some pragmatic goals are listed in Table 4. The MODIS-N georeferencing goals were derived from studies such as those indicated in Fig. 4. In these studies, images of the Normalized Difference Vegetation Index (NDVI--the ratio of the near infrared radiance minus the red radiance over the sum as observed by a simulated MODIS-N) were created from Landsat Thematic Mapper images taken at different times over the Chernobyl region in the former U.S.S.R. and then misregistered by varying amounts to estimate the error encountered in making change estimates of NDVI. Using the coefficient of variation of these differences as a measure of error, Fig. 4 provides an example of the results obtained by showing that a 20% error as estimated by twice the coefficient of variation is related to about the capability provided by the EOS spacecraft. If one asserts that 10% error must be the limit, then the figures for the goals listed in Table 4 are obtained.

Georeferencing Considerations for MODIS Data (Salomonson and Barker, 1992)

(continued)

These requirements discussed above are still liberal given that they represent approximately 0.3-0.5 pixel misregistration relative to a 1000 meter pixel. The existing capability of the EOS spacecraft represents greater than one pixel error for the 250 meter MODIS-N bands which, coincidentally, are the bands that are applicable to estimates of NDVI. There appears to be some hope of achieving the goals indicated in Table 4. If this happens, then the situation improves in that the observatory capability for pixel knowledge represents one pixel error for the 250 meter pixels and 0.25 for the 1000 meter pixels.

The georeferencing capabilities, both existing estimates and possibilities, of the spacecraft are still of concern. It is clear that ground control points will have to be used on occasion to achieve the geodetic and scene-to-scene registration accuracies required in certain situations to measure a real or temporal change. In addition, consideration is being given to the possibility of adding an instrument-mounted star tracker or similar device to improve the pointing knowledge that would be applicable to MODIS-N observations.

MODIS/MCST Texture Utility Algorithm
Additional Comments on Development

Spectral Texture Measure Development

Use the two MODIS-N 250 m bands in the red and near-IR to prepare individual estimates of some useful measure of texture.

Geophysically Based Texture Measure Development

Prepare a single combined measure of texture.

Examine the utility of producing geophysically based texture measures by combining the two bands into a spectral transform such as **NDVI = [(near-IR - Red) / (near-IR + Red)]**, then compare the texture of that variable versus the combination of texture images of the two individual bands.

Determine which approach has the highest sensitivity.

MODIS/MCST Texture Utility Algorithm
Additional Comments on Methodology

Pure and Mixed Pixel Determination

- Prepare a texture measure (e.g. variances) of the texture image itself in order to identify homogeneous "pure" pixels by thresholding.
- Determine measure of texture that allows for accurate thresholding of pure and mixed pixels.
- Use the pure pixel determination to label pixels as pure or mixed.
- Alternatively, define a continuum of % mixed pixel, or a set of classes, from 0% to 100%. ("Pure pixel" definitions will depend on the classes and resolution used.)
- Define "pure" classes from these texture measures to label the classes.

Creation of Texture Mask

- If a continuum of values is created from 0% to 100% mixed pixels from the texture data, then we can carry out a research activity to prepare an error image of degree of uncertainty in standard deviation for each pixel.
- This measure of error would be helpful in explicity indicating within low contrast scenes, the certainty with which mixed pixels can be indetified.
- Use the pure/mixed pixel images, and their associated error images, as input to the MCST Utility Mask Algorithm.

Classification Overlay/Masking Utility Algorithm
Scene Identification Fields and Masks

Technical Approach

- Use multiple "parallel" algorithms
- Identify cloud and snow/ice covered areas
- Discriminate clouds from snow/ice in near-IR
- Identify pure cloud and pure clear regions, and mixed IFOVs
- Collaborate with MODIS and CERES TMs

User Community

- MODIS Disciplines
- CERES
- Other EOS instrument teams (e.g., ASTER, AIRS, MISR)
- EOS IDS Teams
- Science Community

Procedure for Spatial Simulation of MODIS Data from TM Imagery

LANDSAT TM vs. MODIS-N bands/resolution:

	TM Band		Corresponding MODIS-N Band	MODIS-N Resolution
1	0.45-0.52 mm	3	0.470 ± 0.005 mm	500m
2	0.52-0.60 mm	4	0.555 ± 0.005 mm	500m
3	0.63-0.69 mm	1	0.659 ± 0.005 mm	250m
4	0.76-0.90 mm	2	0.865 ± 0.005 mm	250m
5	1.55-1.75 mm	6	1.640 ± 0.008 mm	500m
6	10.40-12.50 mm	31	11.030 ± 0.055 mm	1000m
7	2.08-2.35 mm	7	2.130 ± 0.010 mm	500m

LANDSAT TM data (at 28.5m resolution) is spatially filtered by performing the following steps:

Perform a Fourier transform on the TM data
Multiply by the transfer function of an appropriate Gaussian blur filter
Perform an inverse Fourier transform

Detail of MCST MODIS Scene Simulation Procedure

1) A LANDSAT TM quad is subset to produce a 2500x2500 array.

2) A Gaussian blur filter is produced using:

$$\text{filter} = \exp(-2 \bullet p^2 \bullet n^2 \bullet (d/m)^2)$$

m = the size in pixels of the image,
n is a filtering factor to match the MODIS MTF at the Nyquist frequency,
n= 123.5 for 250m, 247.0 for 500m, and 494.0 for 1000m,
d = DIST(m)/m,

and

DIST is a function that produces a NxN floating array, in which:

$$\text{result}(i,j) = \text{sqrt}(F(i)^2 + F(j)^2)$$

where,

$$F(x) = x \text{ if } 0 <= x <= N/2$$

or,

$$F(x) = N - x \text{ if } x > N/2$$

Detailed Procedure
(continued)

3) A Fast Fourier Transform is then applied to the n x n image array to convert the image from the spatial domain to the spatial frequency domain. This created an array in complex format which could then multiplied by the filter array.

fftimg = FFT(img2,-1)

4) The filter array and the image array are multiplied together.

ft = fftimg * filter

5) An inverse Fast Fourier Transform is then applied to the product image to return the image to the spatial domain.

imgout = FFT(ft,1)

6) Since the imaginary portion of the transformed image equals zero, it is truncated to obtain a real image.

Detailed Procedure
(continued)

7) The image is then converted to TM radiance values using the following from Markham and Barker, 1986:

$$L_\lambda = LMIN_\lambda + \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX}\right) QCAL$$

QCAL	= Calibrated and quantized scaled radiance in units of DN (digital number)
$LMIN_l$	= Spectral radiance at QCAL=0
$LMAX_l$	= Spectral radiance at QCAL=QCALMAX
QCALMAX	= Range of rescaled radiance in DN
L_l	= Spectral radiance

8) Next the data are adjusted to reflect the differences in MODIS and TM bandwidths and then scaled to a 12-bit MODIS-N dynamic range. (0-4096)

Differences between MODIS and TM bandwidths were accounted for using :

$$L_{cloud} / L_{solar(TM)}$$

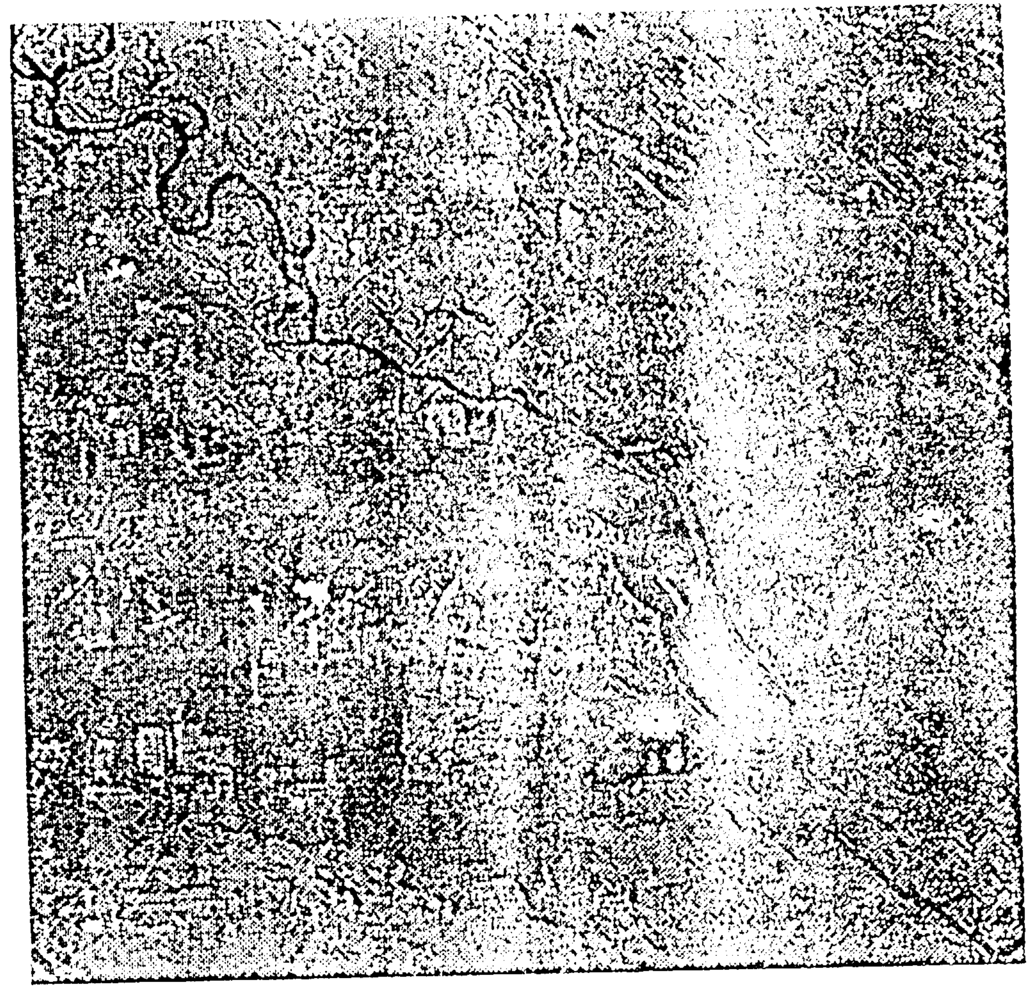
L_{cloud} = MODIS Spectral Radiance for clouds from the MODIS Spec., and
$L_{solar(TM)}$ = TM Solar Radiance from EOSAT TECH Notes, Aug. 1986.

9) This resulting image is 2500x2500 pixels and thus oversampled by a factor of 10, so the image is then reduced using a nearest neighbor resampling to 285x285 pixels for the 250m images, and finally saved as 16bit integers in an unformatted dataset.

Chernobyl MODIS Simulation 30m Resolution

TM Channel 3

(0.63 - 0.69 μm)

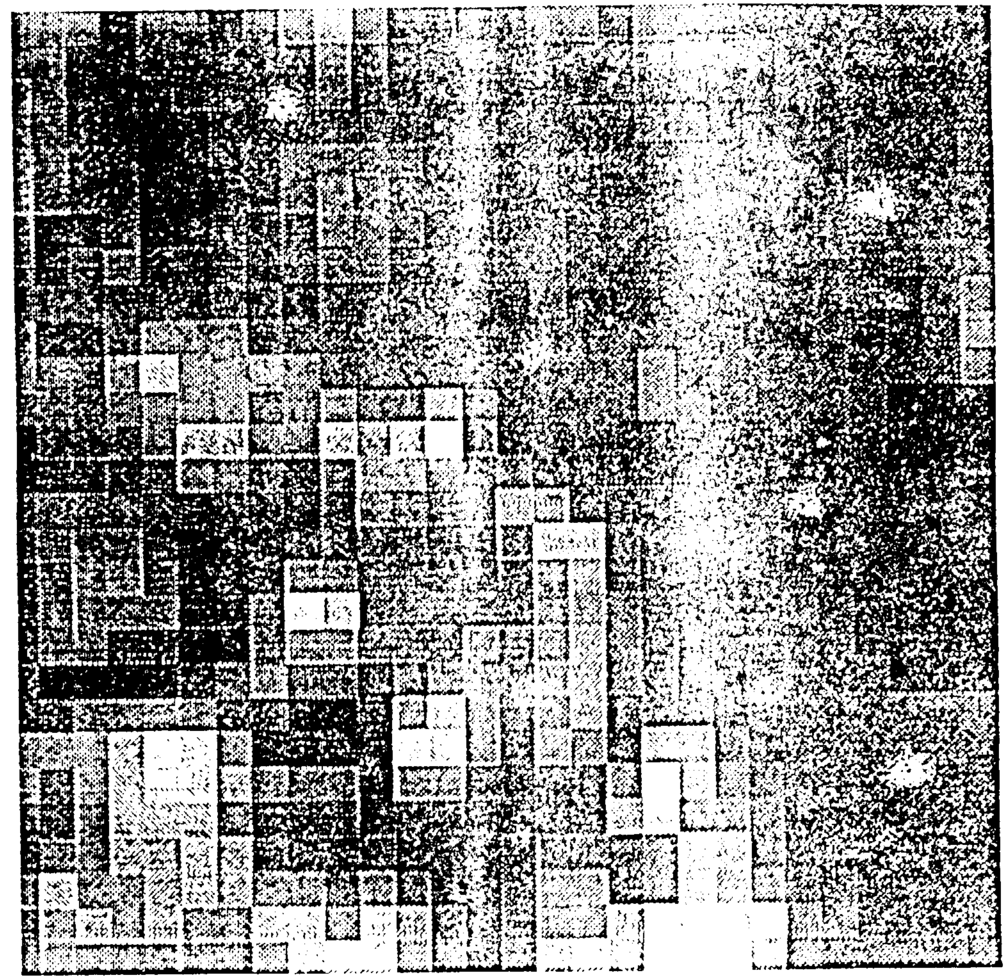


TM Channel 4

(0.76 - 0.90 μm)

Chernobyl MODIS Simulation

250m resolution



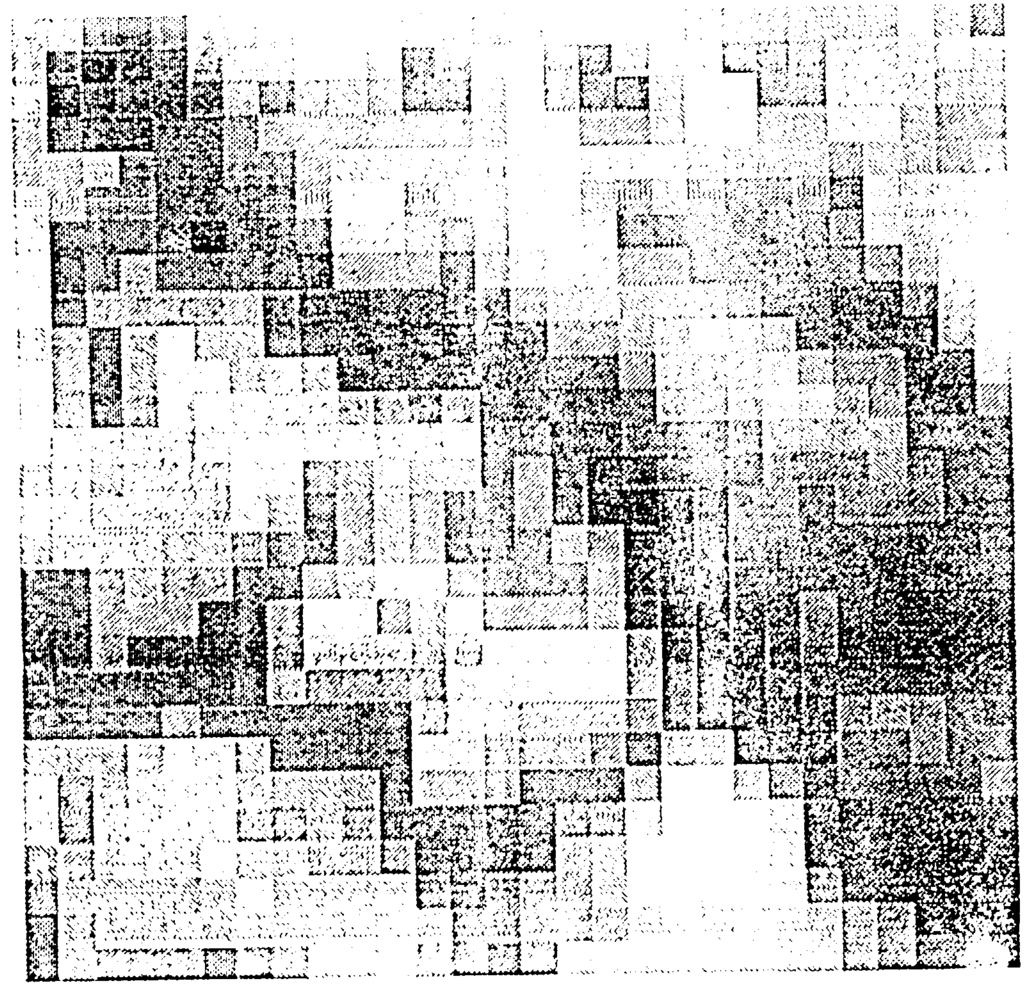
1100m resolution

TM Channel 3

(0.63 - 0.69 µm)

Chernobyl MODIS Simulation

250m resolution

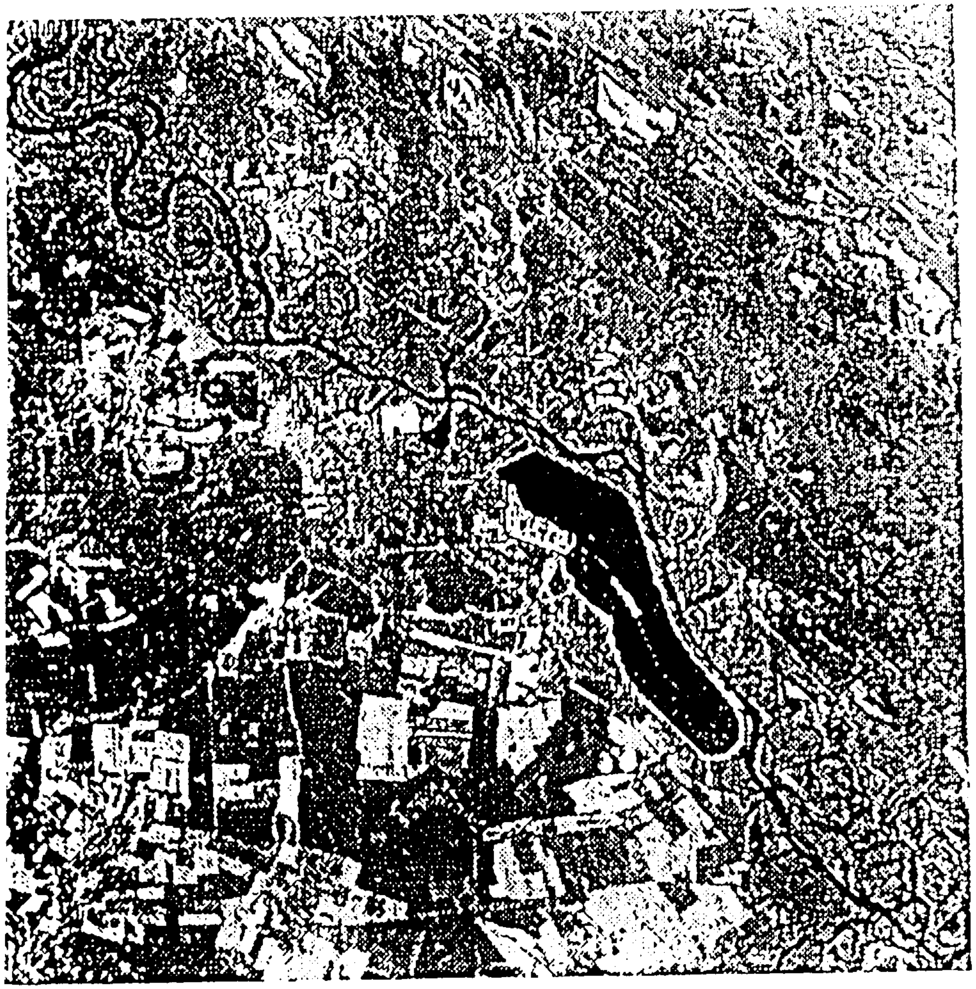


1100m resolution

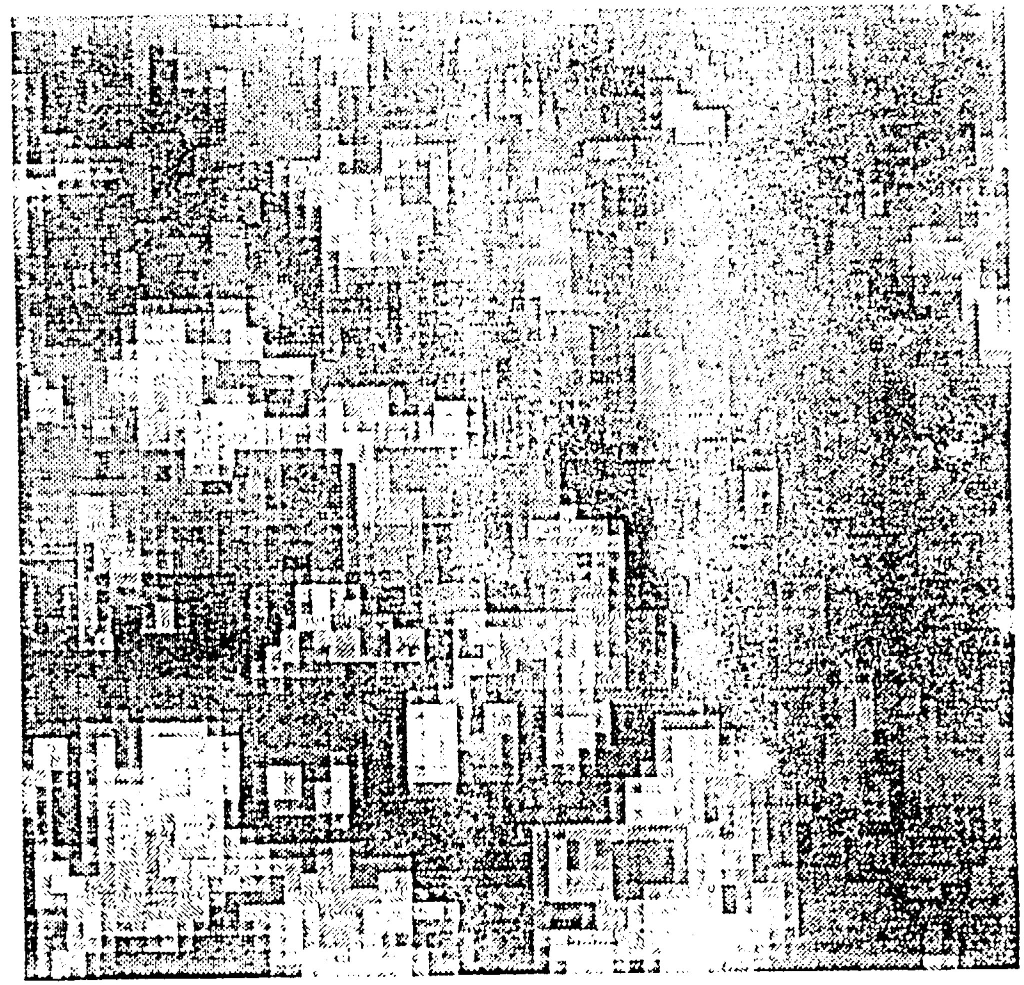
TM Channel 4

(0.76 0.90 μm)

Chernobyl MODIS Simulation



30m resolution

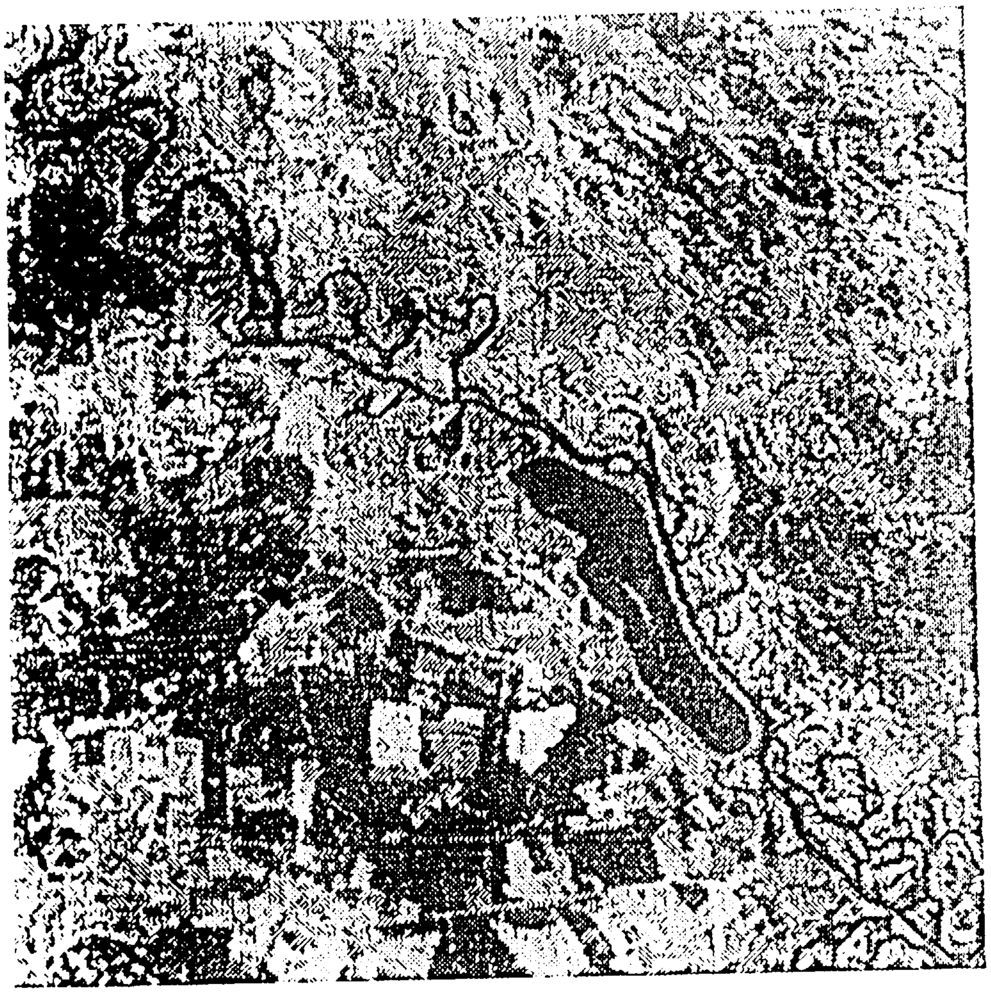


500m resolution

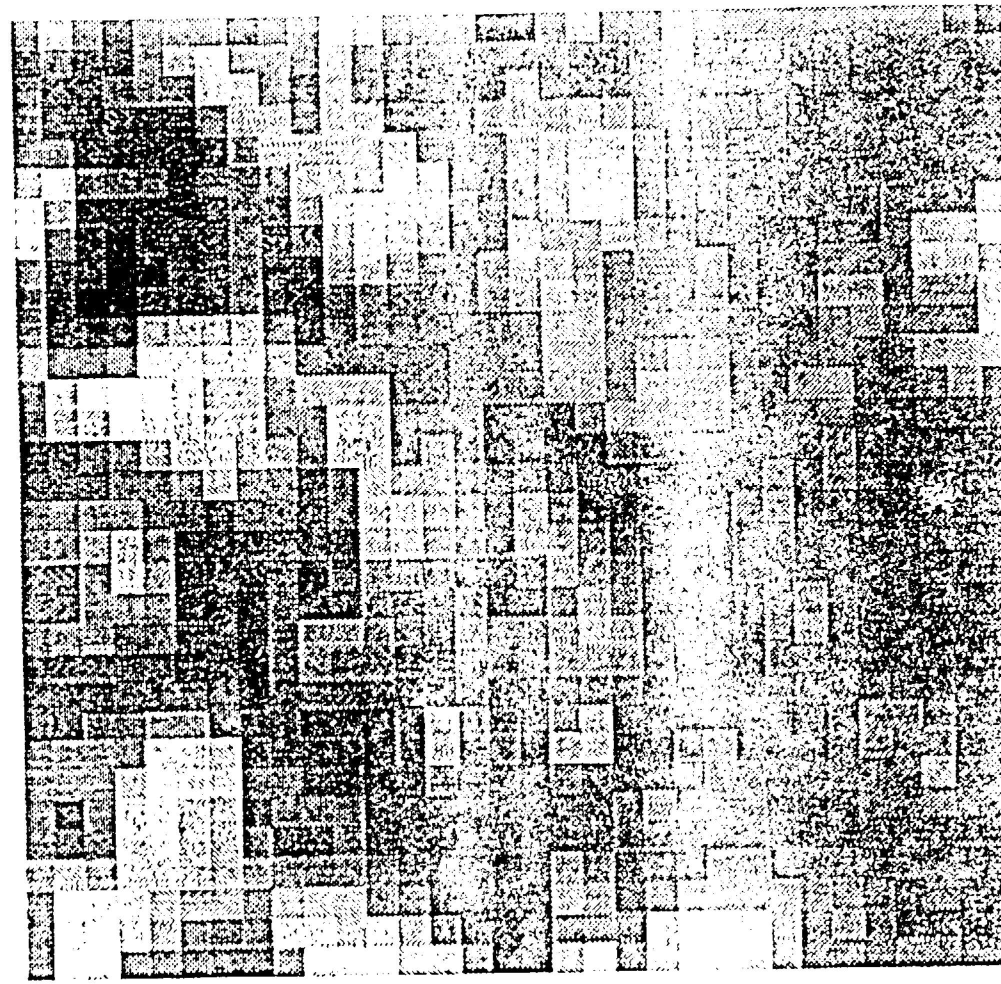
TM Channel 5

(1.55 – 1.75 μm)

Chernobyl MODIS Simulation



120m resolution sampled at 30m



1000m resolution

TM Channel 6

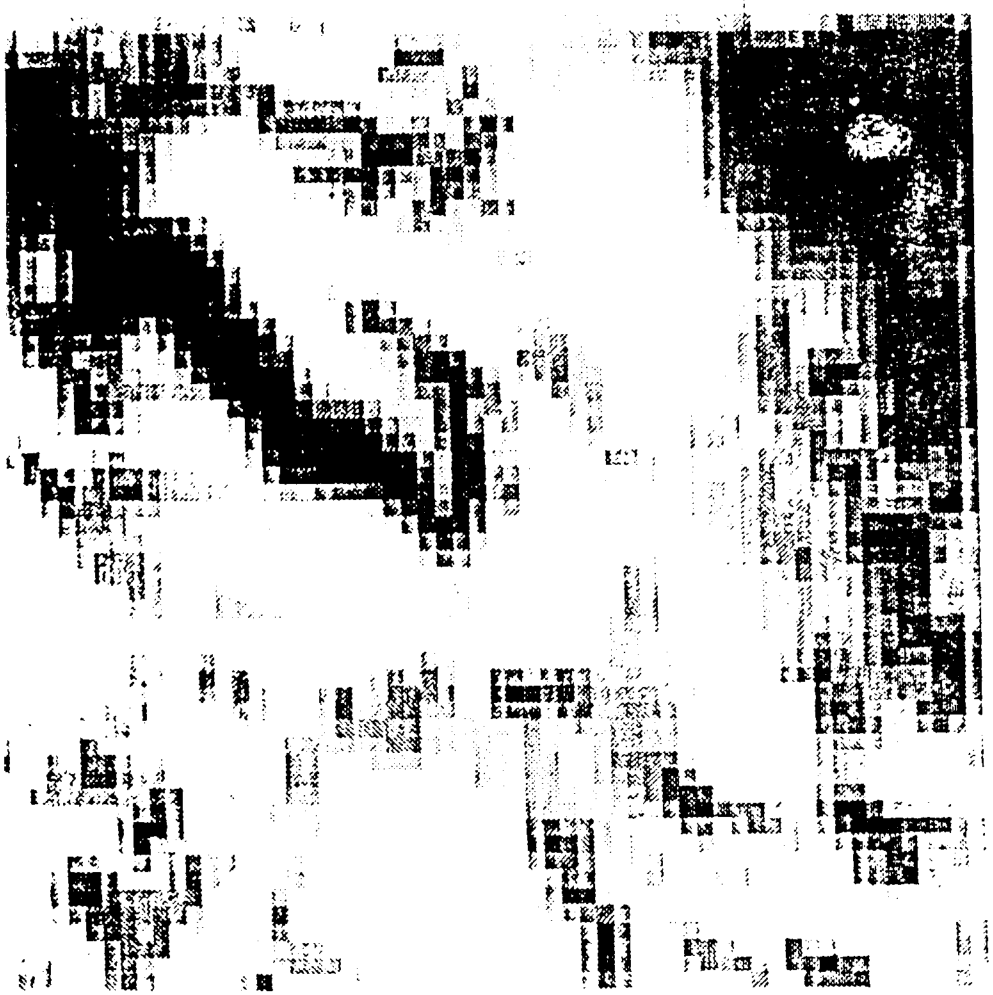
(10.4 - 12.5 μm)

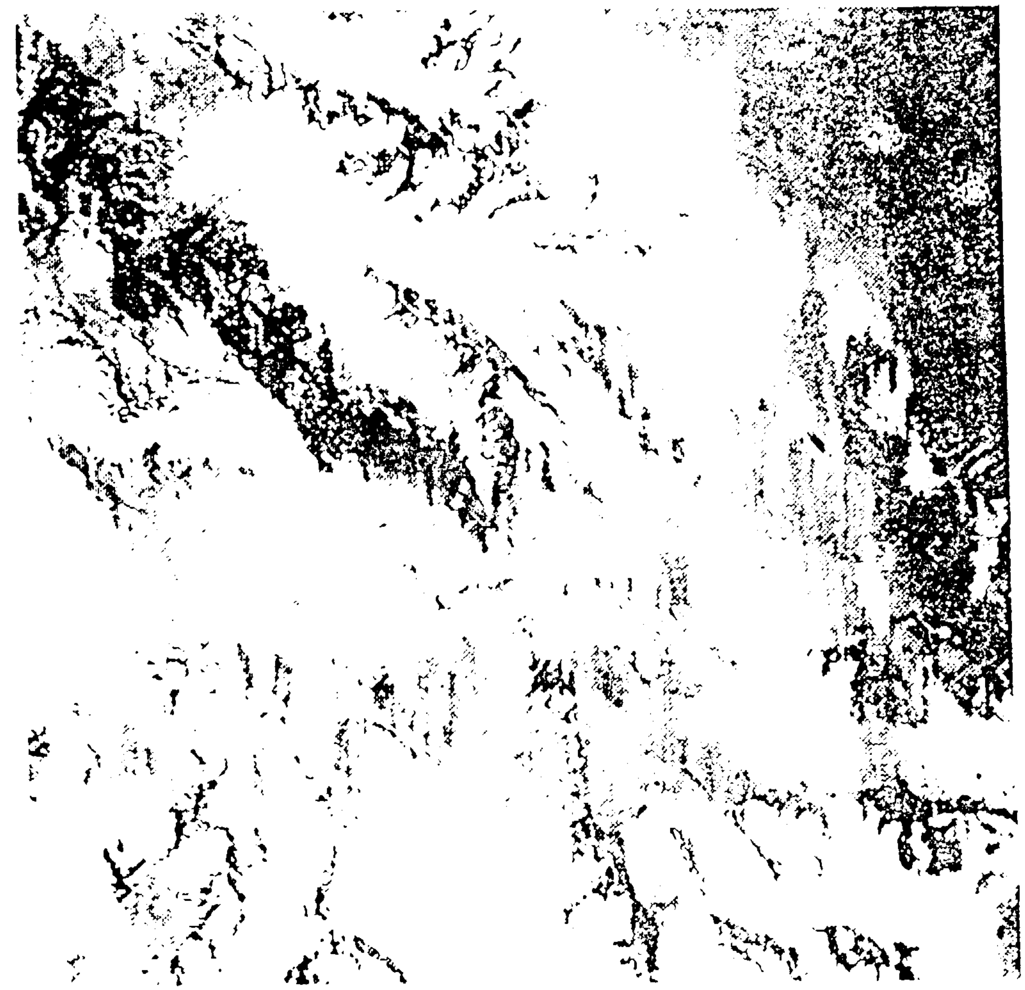
Chugach, Alaska MODIS Simulation

Simulated MODIS Band 3 (500m)
(0.470 ± 0.005 μm)

TM Band 1 (0.45 - 0.52 μm) (28.5m)

Chugach, Alaska

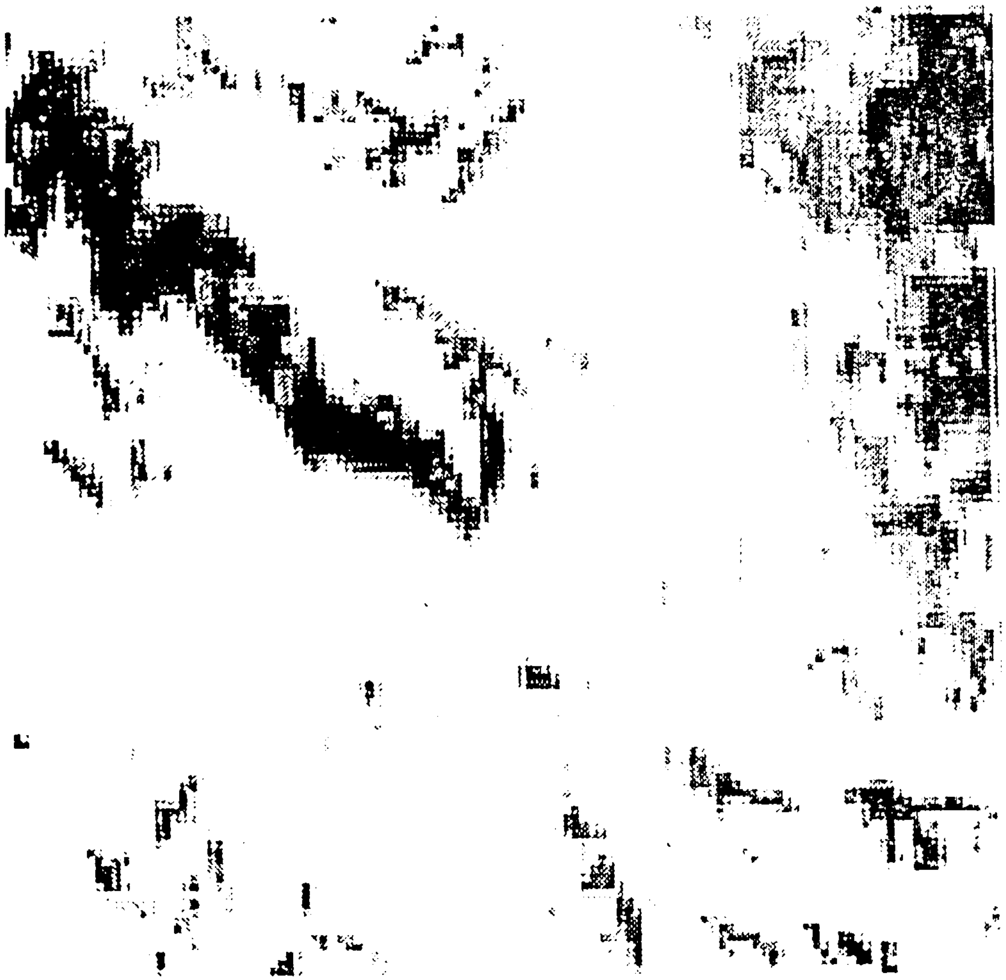




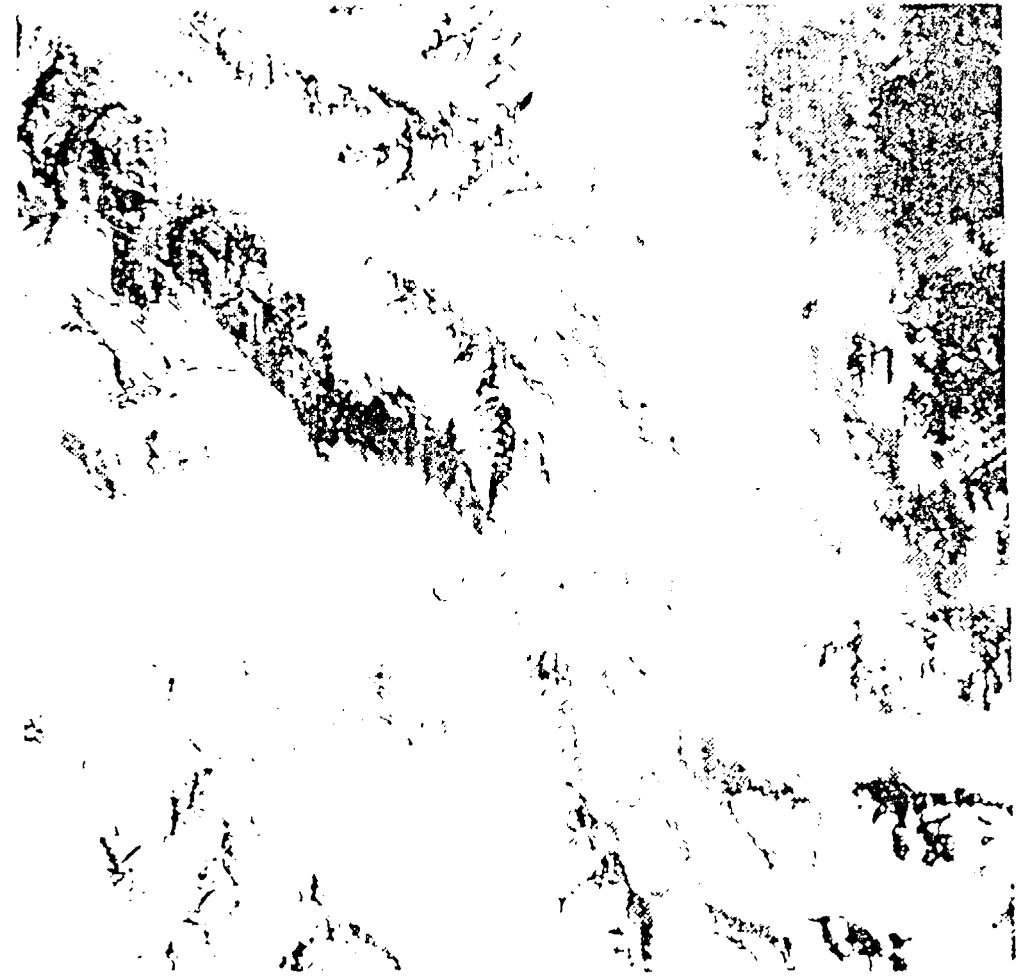
Simulated MODIS Band 4 (500m)
($0.555 \pm 0.005\ \mu m$)

TM Band 2 (0.52 - 0.60 μm) (28.5m)

Chugach, Alaska

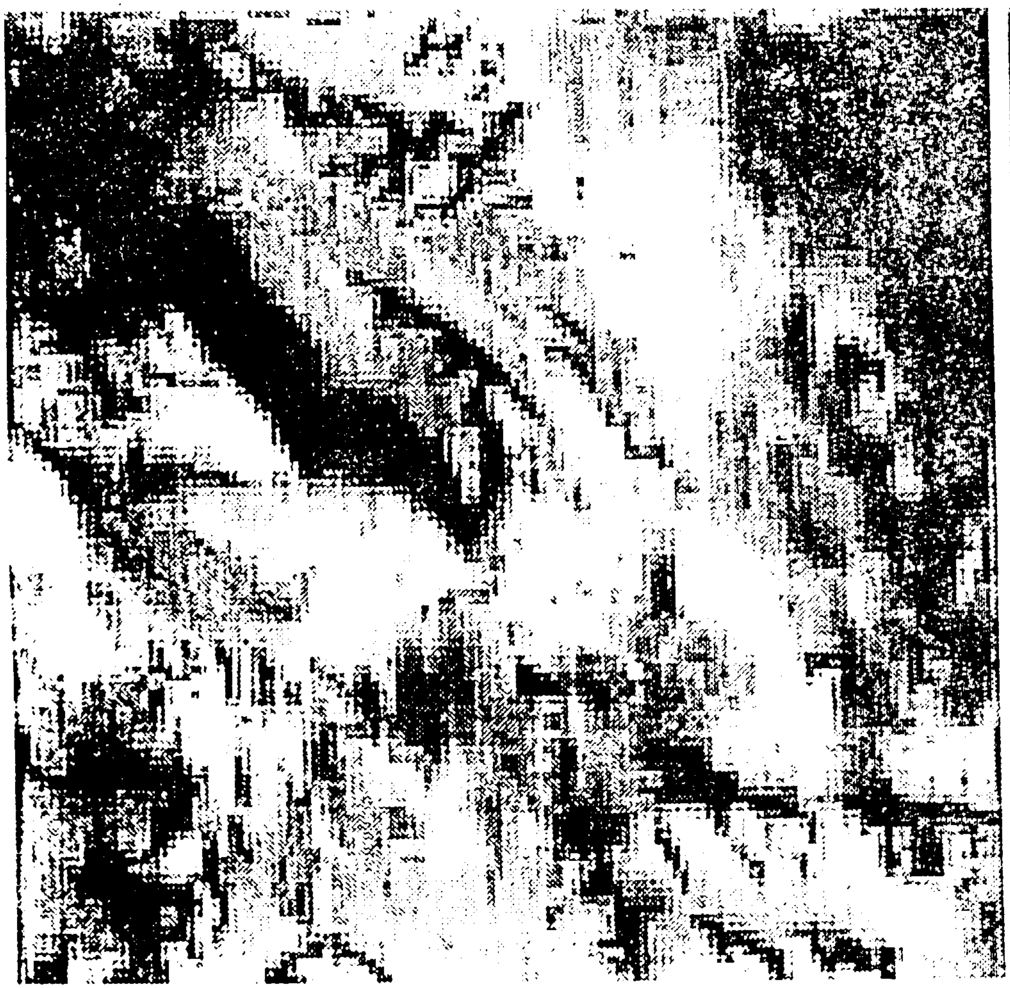


Simulated MODIS Band 1 (250m)
($0.659 \pm 0.005\ \mu m$)



TM Band 3 ($0.63 - 0.69\ \mu m$) (28.5m)

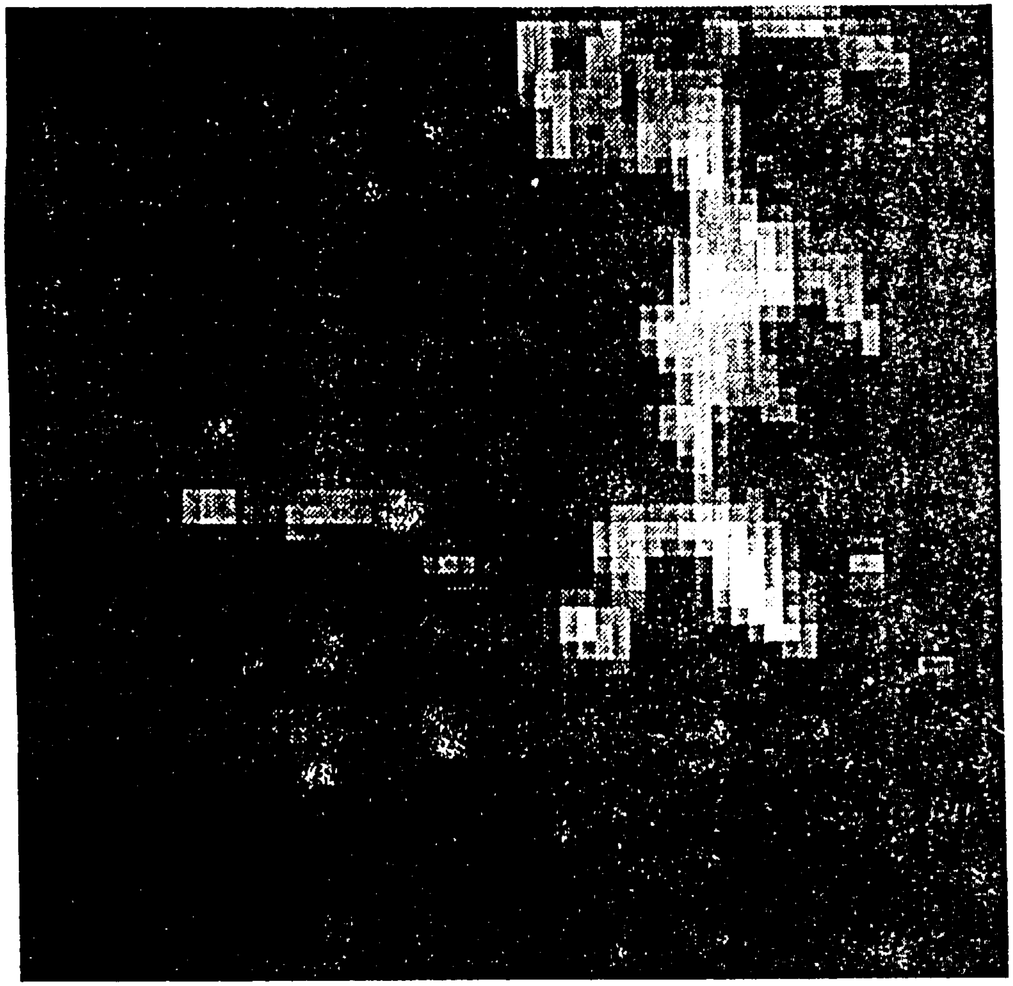
Chugach, Alaska



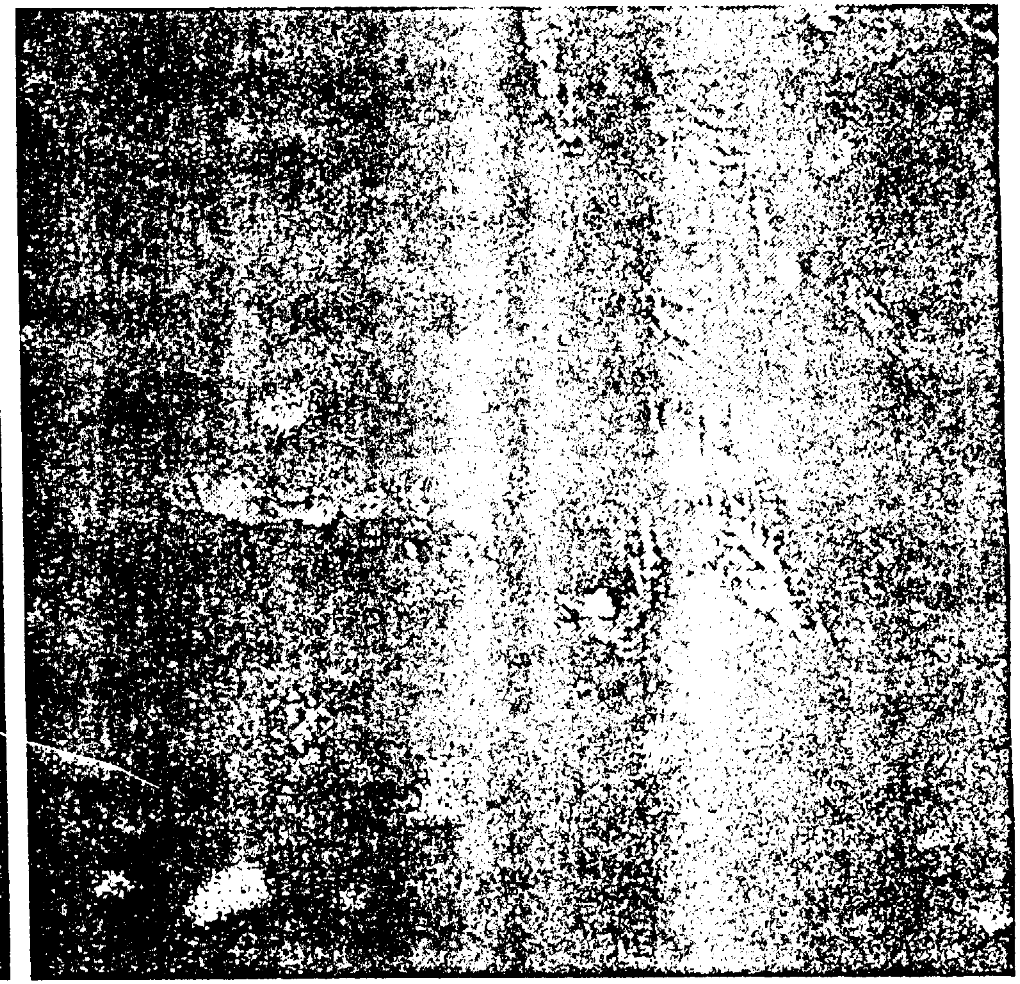
Simulated MODIS Band 2 (250m)
(0.865 ± 0.005 μm)

TM Band 4 (0.76 - 0.90 μm) (28.5m)

Chugach, Alaska

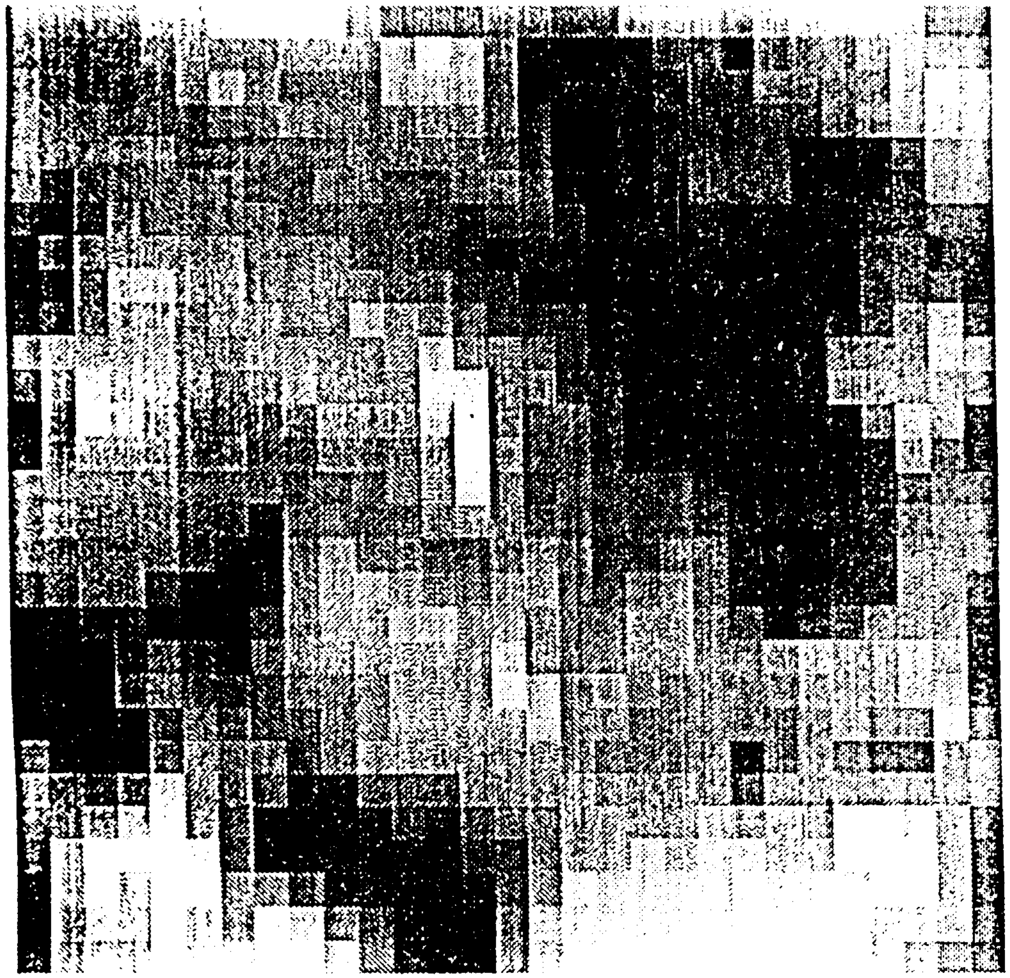


Simulated MODIS Band 6 (500m)
(1.640 ± 0.008 μm)

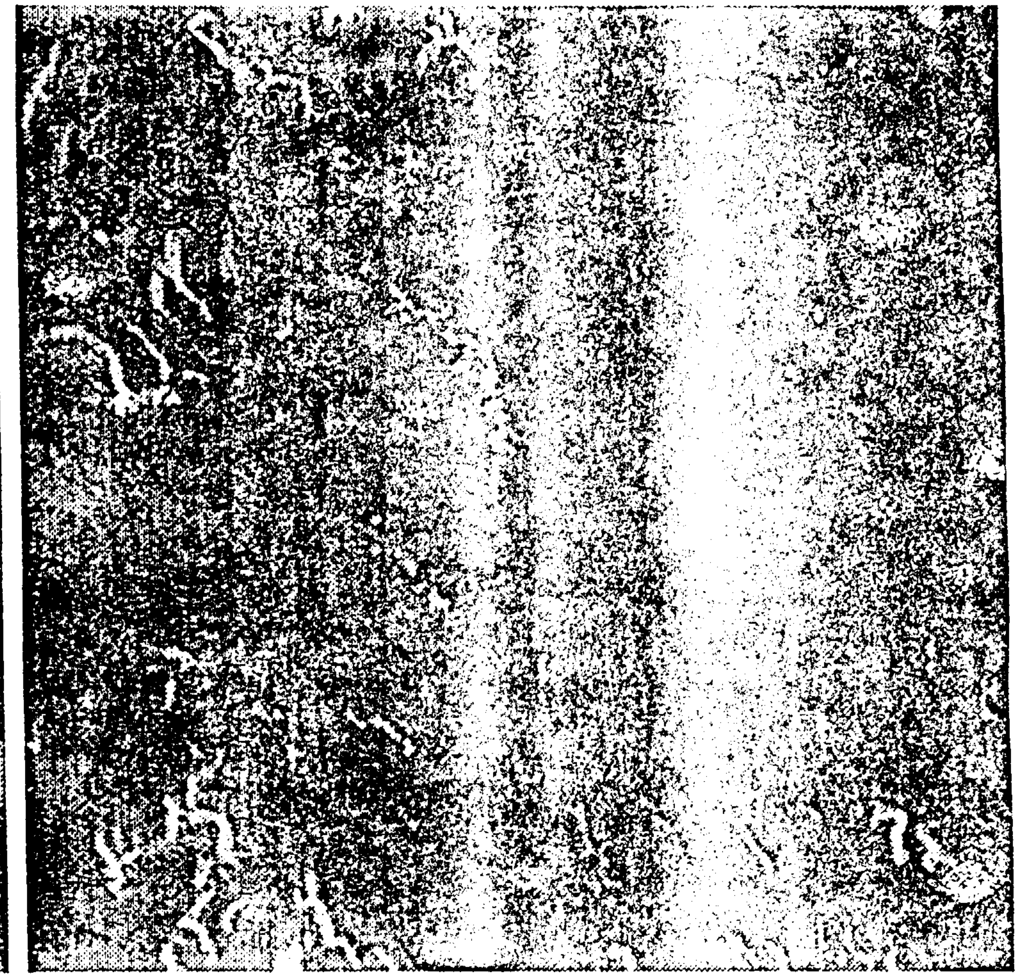


TM Band 5 (1.55 - 1.75 μm) (28.5m)

Chugach, Alaska

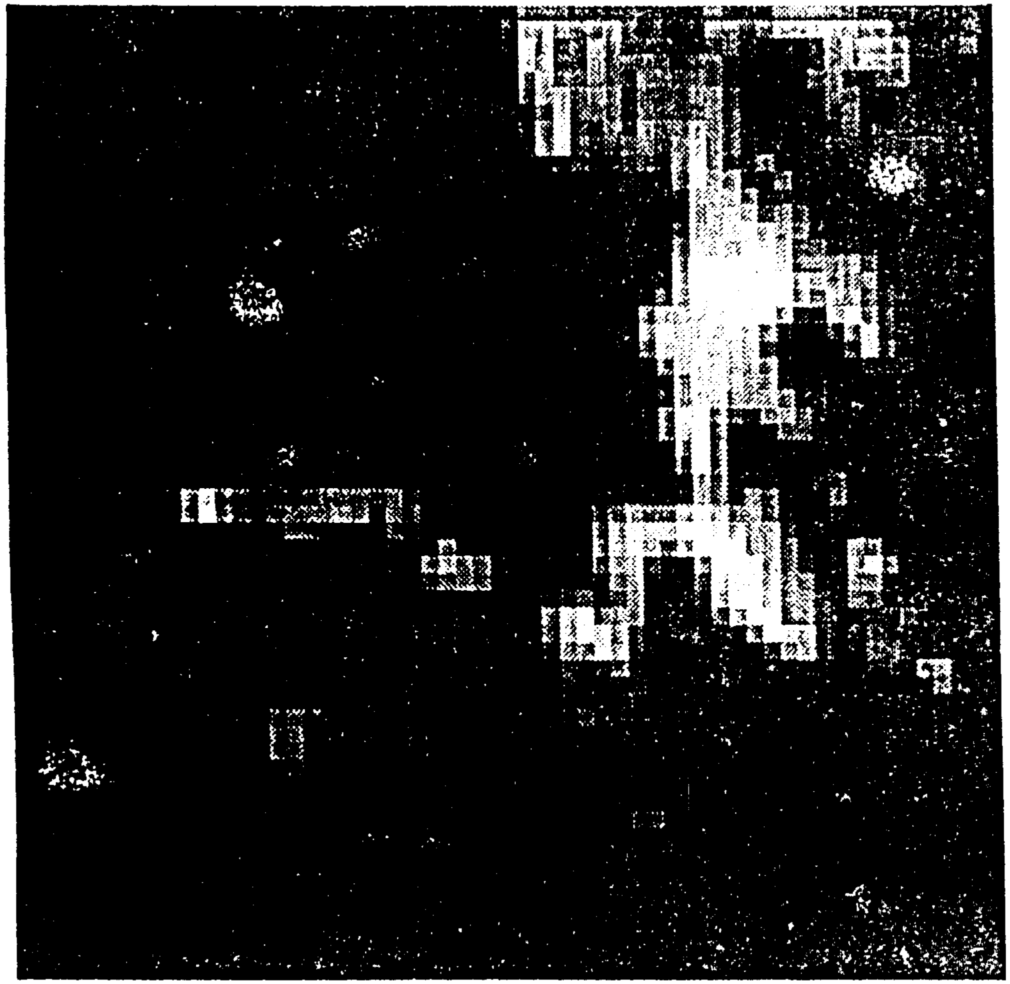


Simulated MODIS Band 31 (1000m)
(11.030 ± 0.055 µm)

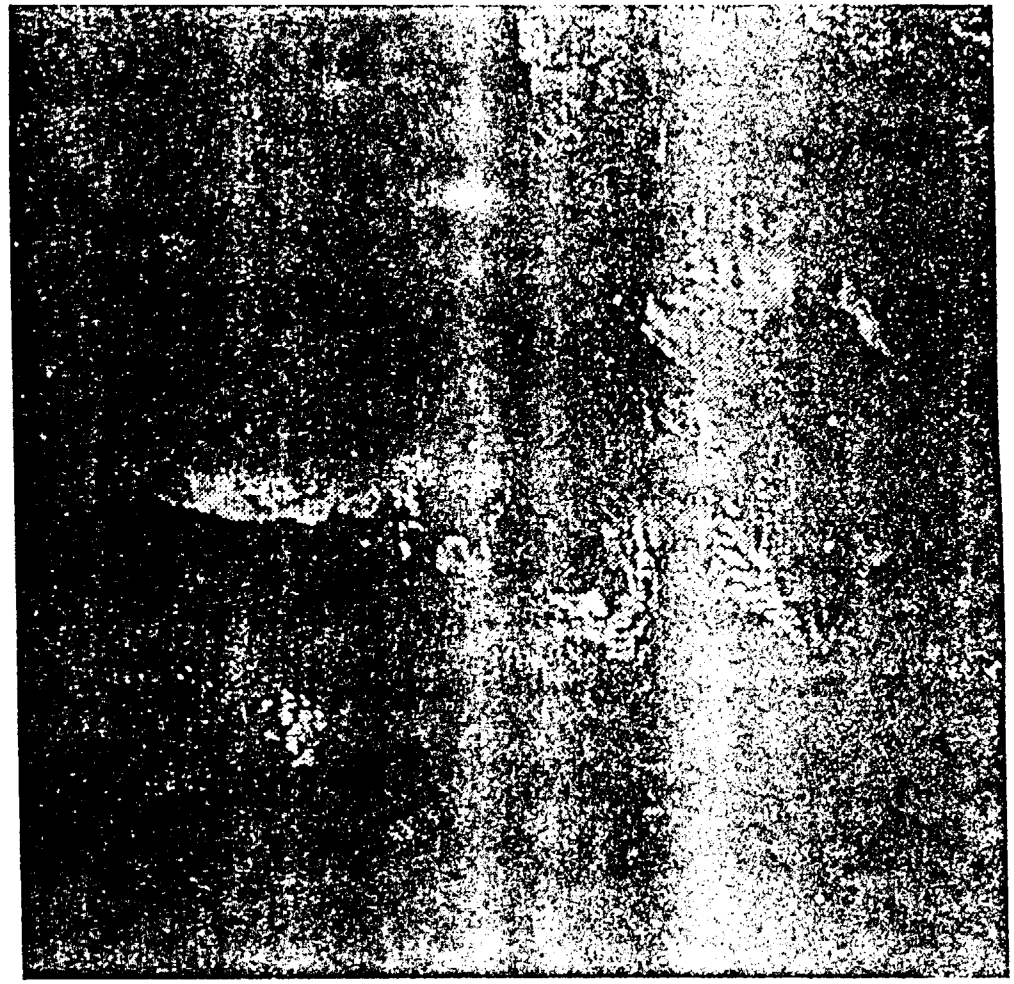


TM Band 6 (10.4 - 12.5 µm) (120m)

Chugach, Alaska



Simulated MODIS Band 7 (500m)
(2.130 ± 0.010 μm)



TM Band 7 (2.08 - 2.35 μm) (28.5m)

NOAA/AVHRR Land Science
Advanced Very High Resolution Radiometer: 1978-1998

Variable	Numerical Value	Comments
Vegetation Change		
Radiance-Based Vegetative Index (e.g. NDVI)		Includes atmospheric effects
Spectrometry:		
2 Visible/Near Infrared Bands	0.53, 0.91 µm	Pigment absorption and leaf reflectance with atmospheric water
Spectral Band Widths	100, 375 nm	Very broad relative to spectral peaks for vegetation
Radiometry:		
Relative Radiometric Precision	+/- 0.1%	10 bits
Absolute Radiometric Accuracy	+/- 10-20%	No In-orbit calibration monitor
Geometry:		
Geometric Resolution (IFOV)	1 Km	At-nadir
Instrument Pointing Knowledge	+/- 5 Km	+/- 5 pixels
Location by Scene-Matching	+/- 0.5 Km	Over land and coasts (+/- 0.5 pixels)
Coverage:		
Global Acquisition Frequency	1 day	Selected tape transmissions Most global data at 4 Km
Surface Brightness Temperatures		
Absolute Accuracy in Global Product	+/- 1 K	Water vapor corrections

Landsat/TM Land Science
Thematic Mapper: 1982-1997

Variable	Numerical Value	Comments
Vegetation Change		
Radiance-Based Vegetative Indices		No corrections for atmosphere
Spectrometry:		
4 Visible/Near Infrared Bands	0.49, .57, .66, .84 μm	Pigment absorption and leaf reflectance
2 Shortwave Infrared Bands	1.7, 2.2 μm	Leaf moisture
Spectral Band Widths	60-250 nm	Spectrally broad relative to peaks for vegetation
Radiometry:		
Relative Radiometric Precision	+/- 0.4%	8 bits
Absolute Radiometric Accuracy	+/- 5-10%	On-board internal calibration
Geometry:		
Geometric Resolution (IFOV)	30 m	Resampled to 28.5 meters
Location by Ground Control Points	30-60 m	+/- 2 pixels
Coverage:		
Global Acquisition Frequency	16 days	10-30% duty cycle
At-Satellite Brightness Temperatures		
Absolute Accuracy	+/- 0.5 K	No global product No atmospheric correction

EOS-A1/MODIS-N Land Science

Moderate Resolution Imaging Spectrometer-Nadir: 1998-2013

Variable	Numerical Value	Comments
Vegetation Change		
Reflectance-Based Vegetative Indices (TBD)		Atmospheric-free state function of surface
Spectrometry:		
4 Visible/Near Infrared Bands	0.47, .55, .66, .86 μm	Pigment absorption and leaf reflectance
3 Shortwave Infrared Bands	1.2, 1.7, 2.1 μm	Leaf canopy and moisture
Spectral Band Widths	20-50 nm	Appropriate for spectral peaks for vegetation
Radiometry:		
Relative Radiometric Precision	+/- 0.03%	12 bits
Absolute Radiometric Accuracy	+/- 2-5%	Permits atmospheric corrections with solar and lunar calibrators
Geometry:		
Geometric Resolution (IFOV)	250-500 m	At-nadir
Instrument Pointing Knowledge	+/- 0.5 Km	RSS 90 and 108 arc seconds at nadir
Location by Scene-Matching	+/- 0.1 Km	Over land (+/-0.5 pixel)
Coverage:		
Global Acquisition Frequency	1 day	Global acquisitions day and night
Surface Brightness Temperatures		
Absolute Accuracy	+/- 0.2 K	After atmospheric corrections for water, clouds & aerosols

Required Land / MCST-Related WG Action

Need Land WG endorsement of up-dated list of **utility products**

- Report that texture and classification utility algorithms are under development
- Confirm 1990/1991 MCST lower priority for land-related utility products than for calibration-related products
- Develop schedule for peer review and delivery of utility algorithms
- Indicate intent to provide peer-reviewed and working S/W to MSDST
- Identify possible additional collaborators on utility products

Indicate support and collaboration with MCST **simulation activities**