MISR overview and observational principles
Data products
Example data applications

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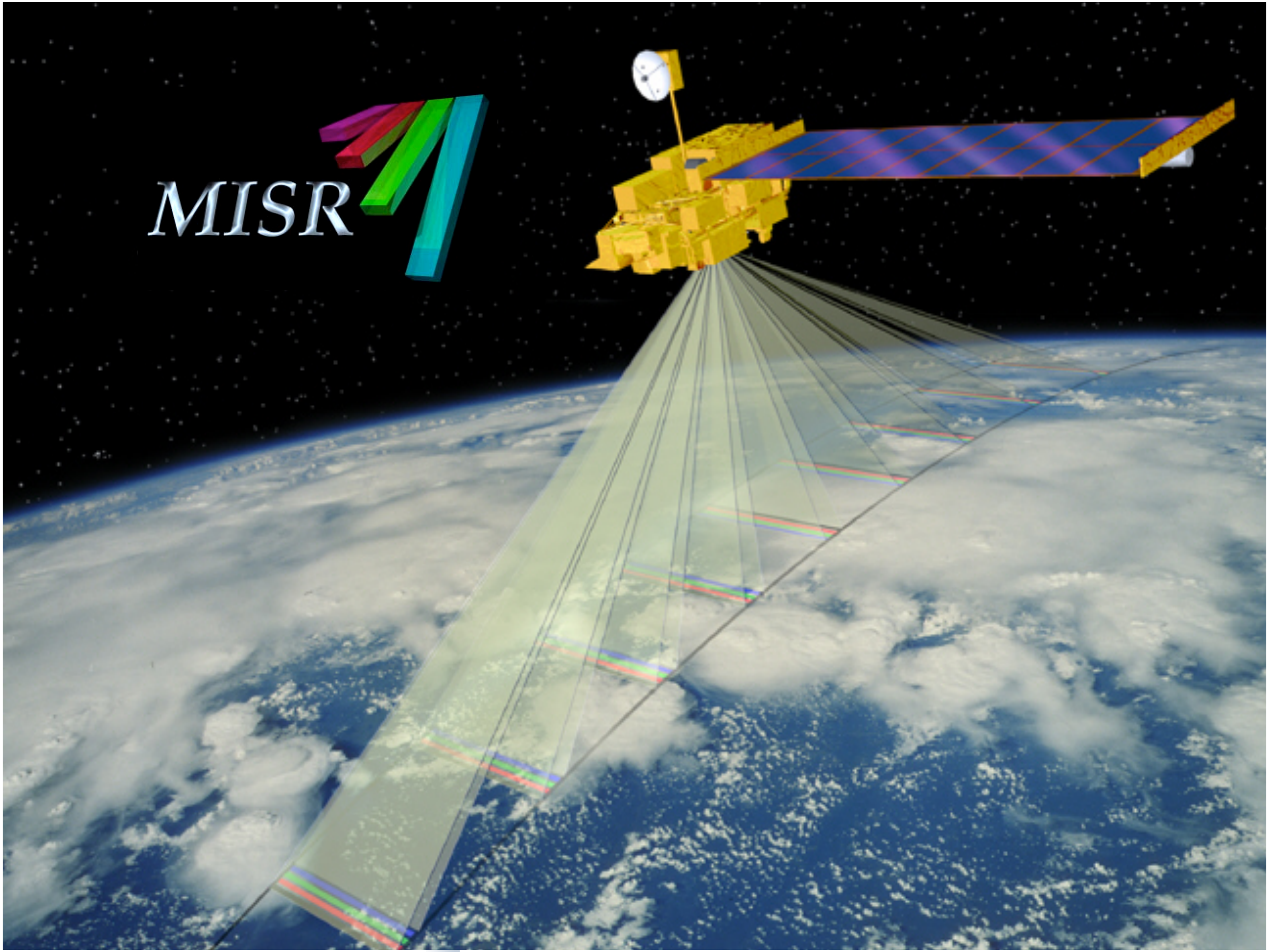
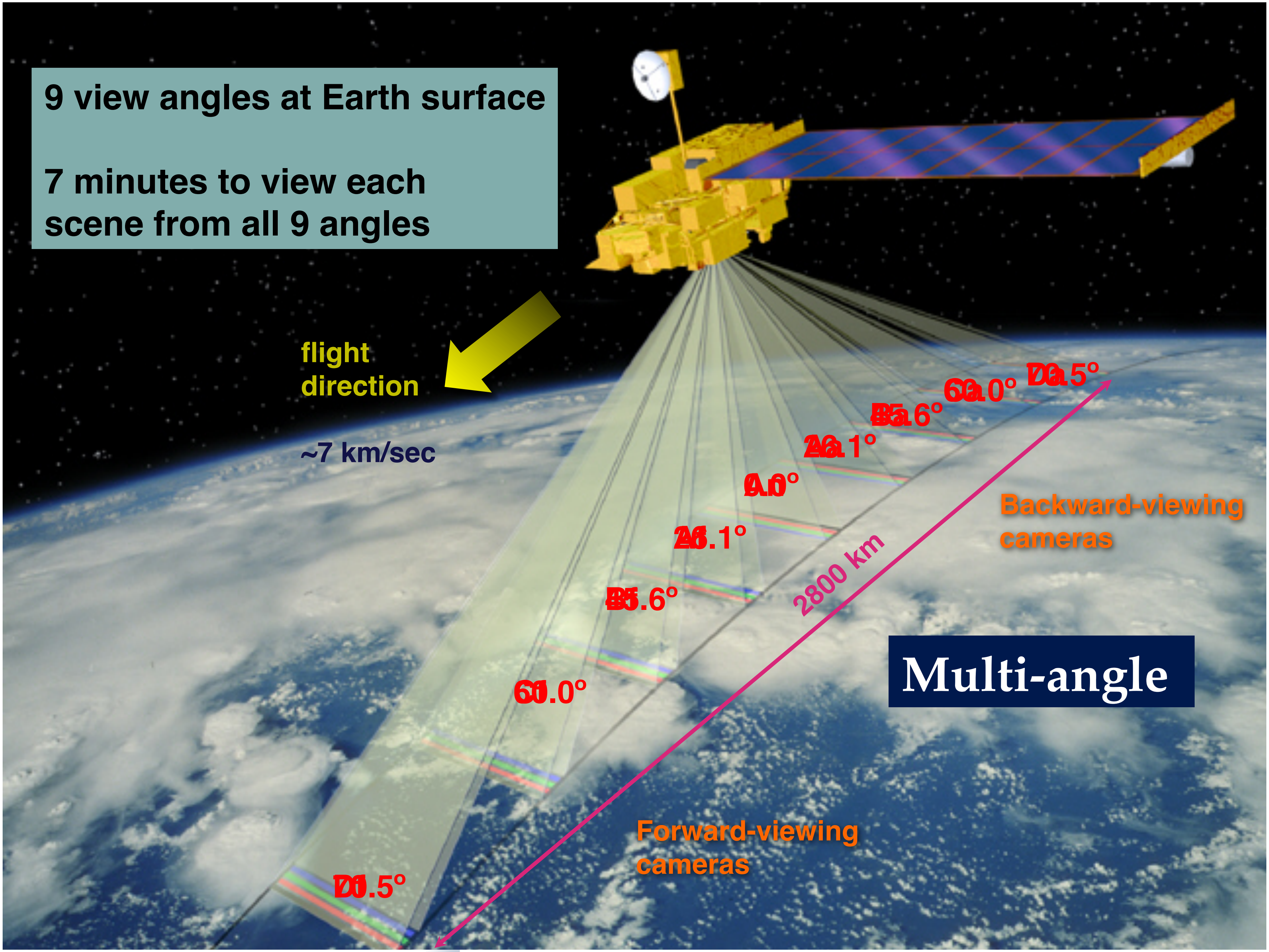
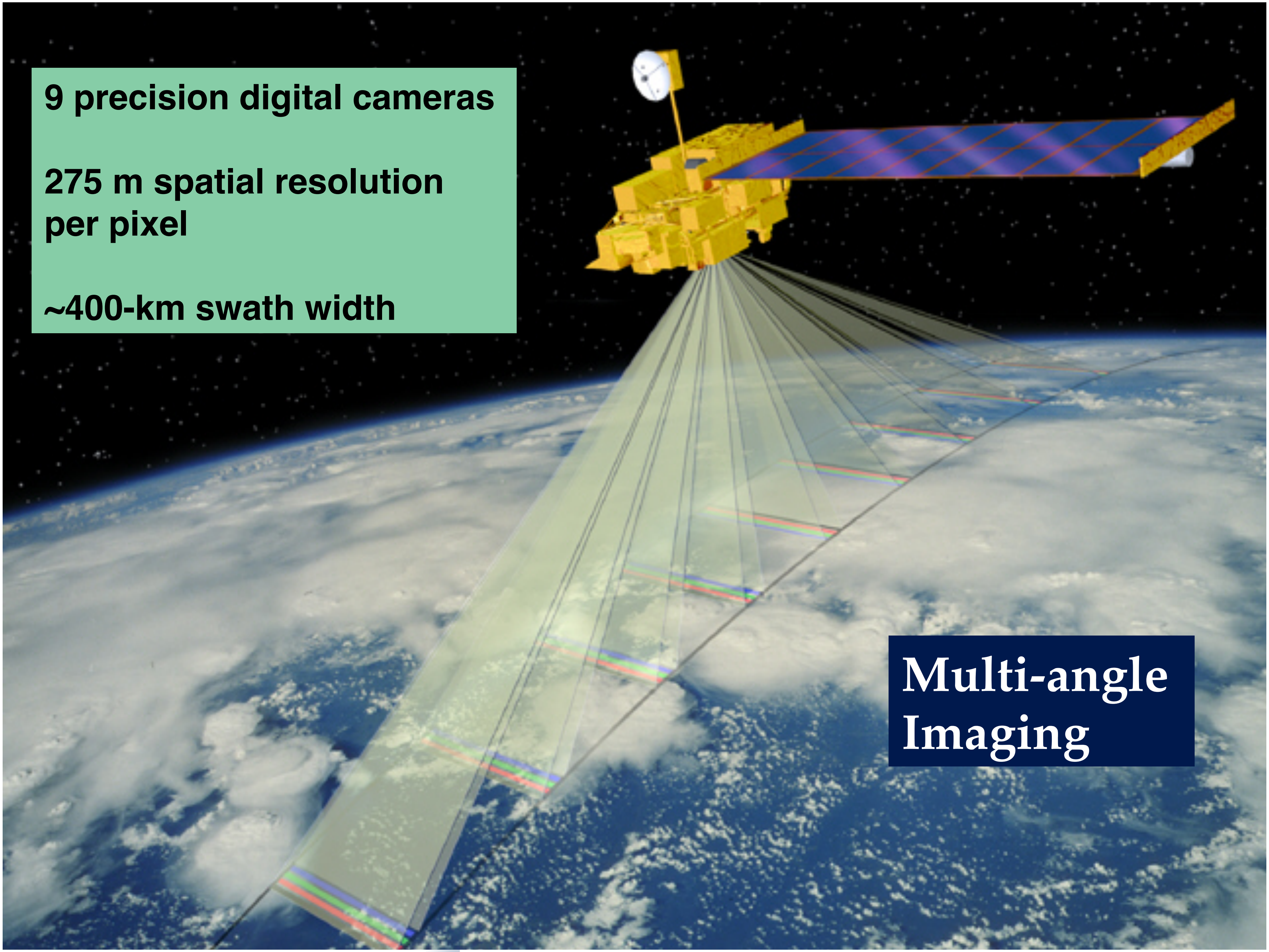
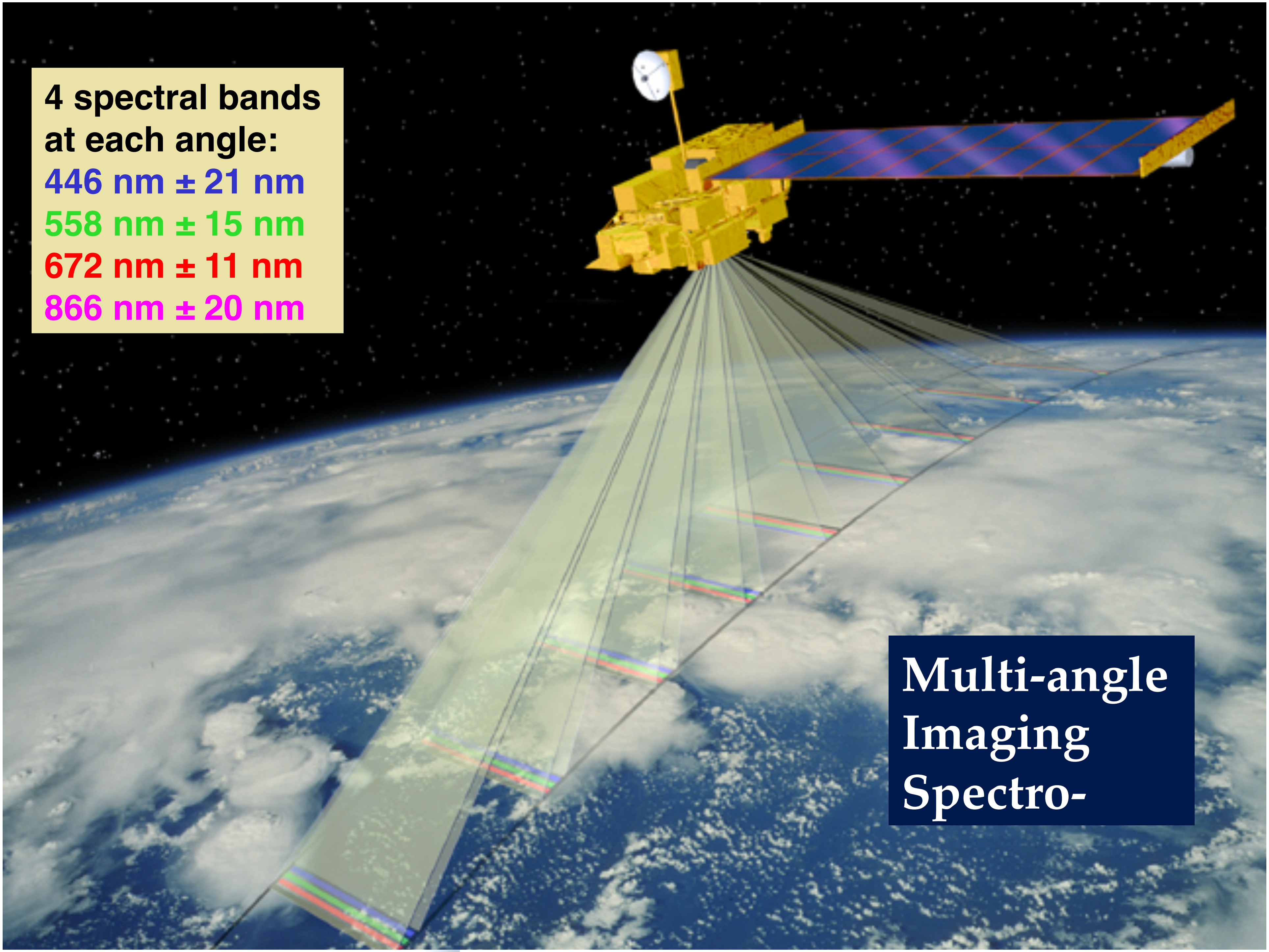
AMS Short Course on Exploring and Using MISR Data
Long Beach, California
9 February 2003

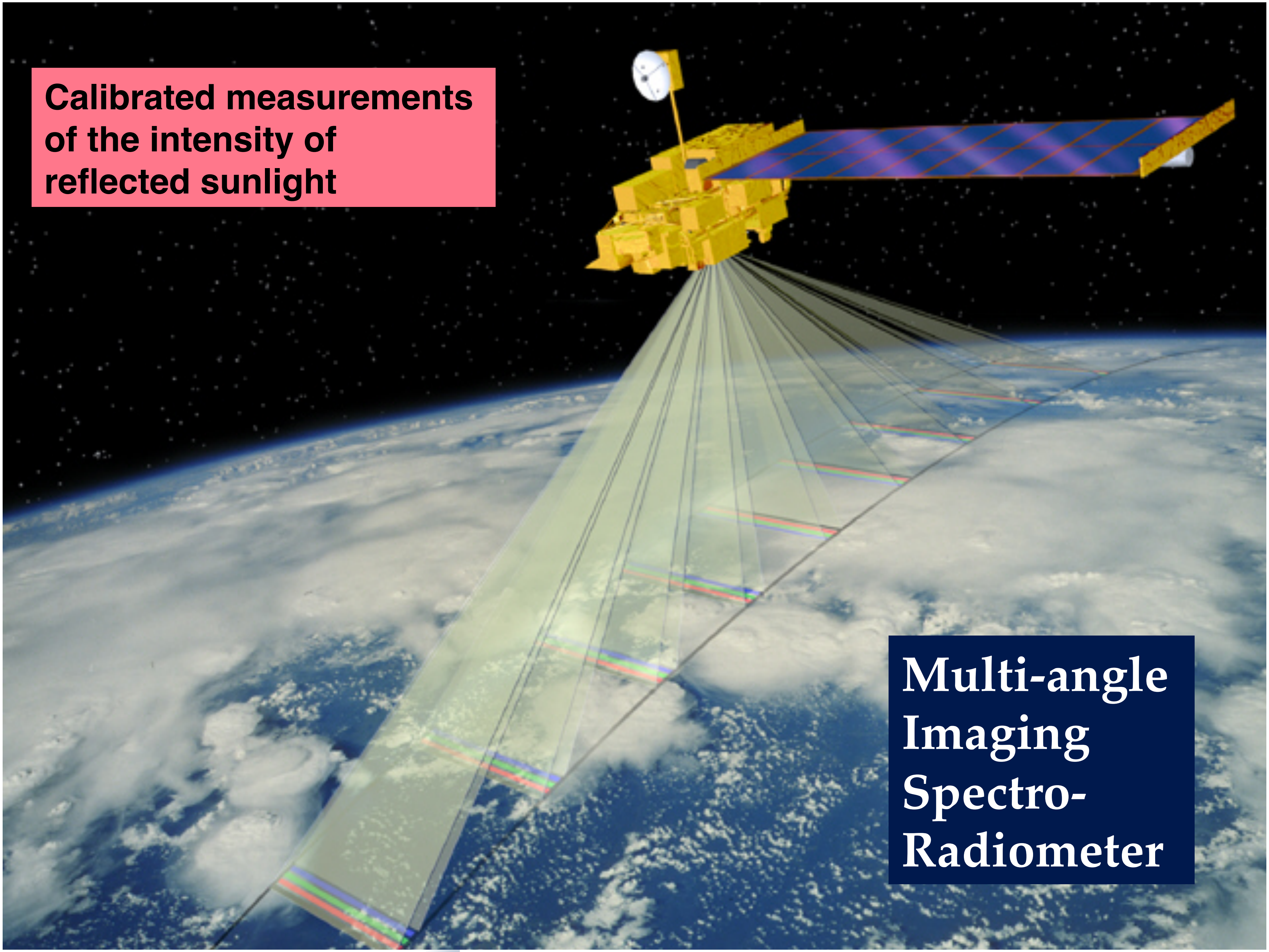

MISR



Distributed by the Atmospheric Science Data Center
http://eosweb.larc.nasa.gov


9 precision digital cameras
275 m spatial resolution per pixel
~400-km swath width
Multi-angle Imaging


4 spectral bands
at each angle:
446 nm ± 21 nm
558 nm ± 15 nm
672 nm ± 11 nm
866 nm ± 20 nm
Multi-angle
Imaging
Spectro-


Calibrated measurements of the intensity of reflected sunlight
Multi-angle Imaging Spectro-Radiometer

MISR “family portrait”

MISR’s nine cameras consist of four unique refractive lens designs of different focal lengths

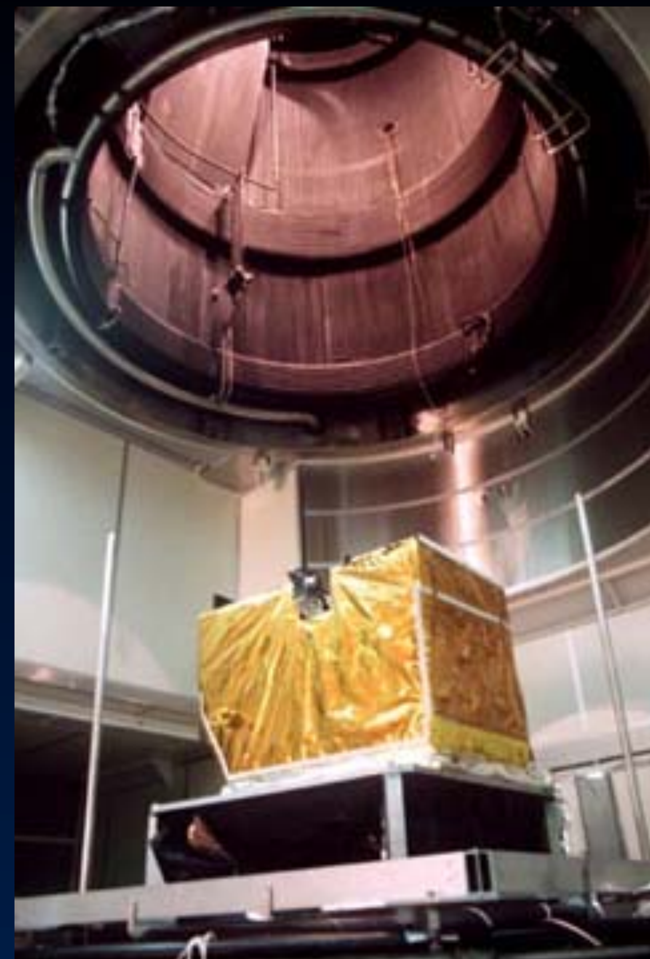
Cross-track footprint
250 m nadir; 275 m off-nadir

Instantaneous along-track footprint
214 - 700 m from nadir to 70º

Along-track sampling
275 m at every angle (i.e., off-nadir angles are oversampled)

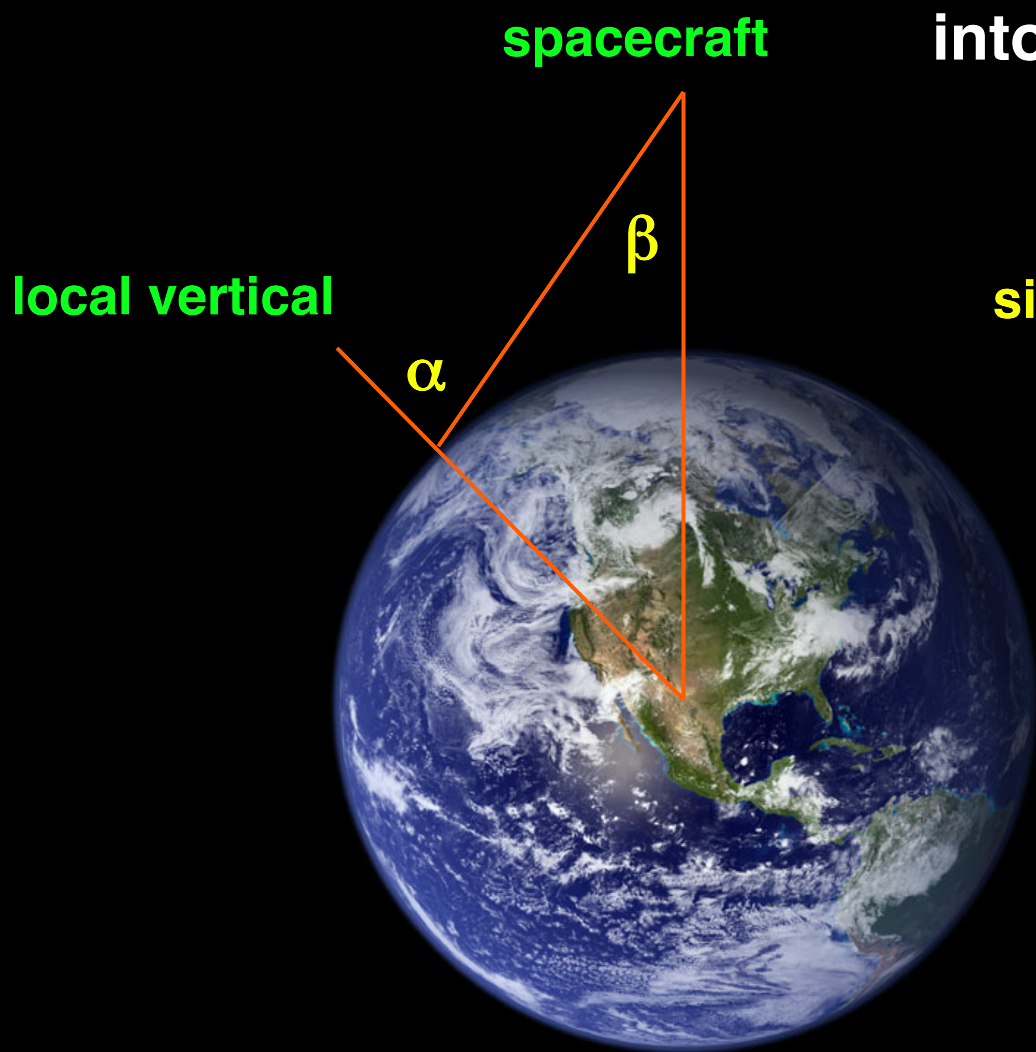
MISR instrument

The “V-9” optical bench



MISR in JPL’s
Space Simulator Facility

Earth curvature is factored into instrument design

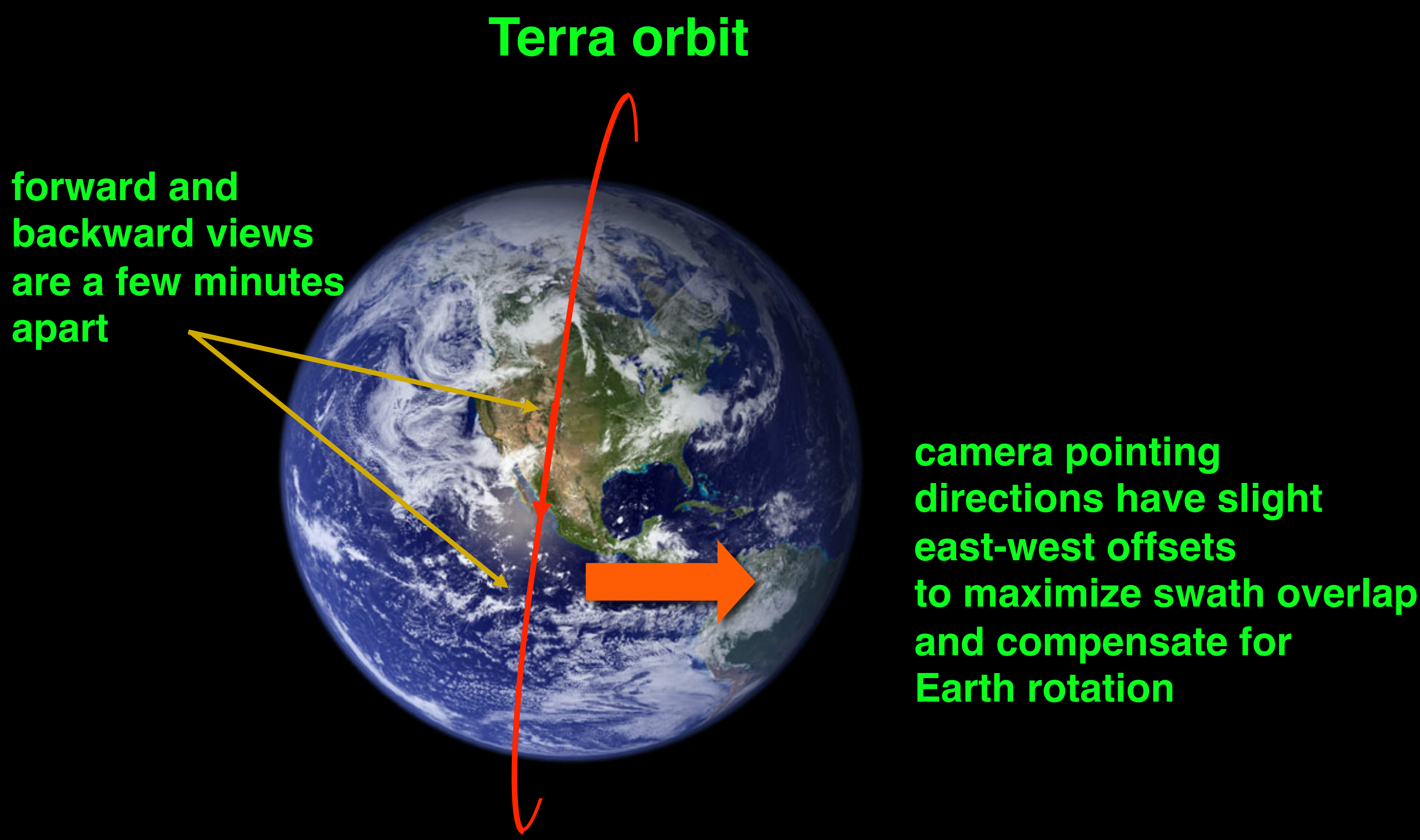


$$\sin\beta = \frac{R \sin\alpha}{R + h}$$

R = Earth radius
h = spacecraft altitude

Example:
$\alpha = 70.5°$, $\beta = 58.0°$

Earth rotation is factored into instrument design



Areas of research

MISR produces a set of original data products, with little prior heritage. Ongoing efforts include: developing algorithm improvements, implementing them in the product software, and validating the results.

New ways of using MISR data are still likely to be discovered.

Research using MISR measurements has direct application to Earth System Science questions.

MISR is a prototype for potential operational applications.

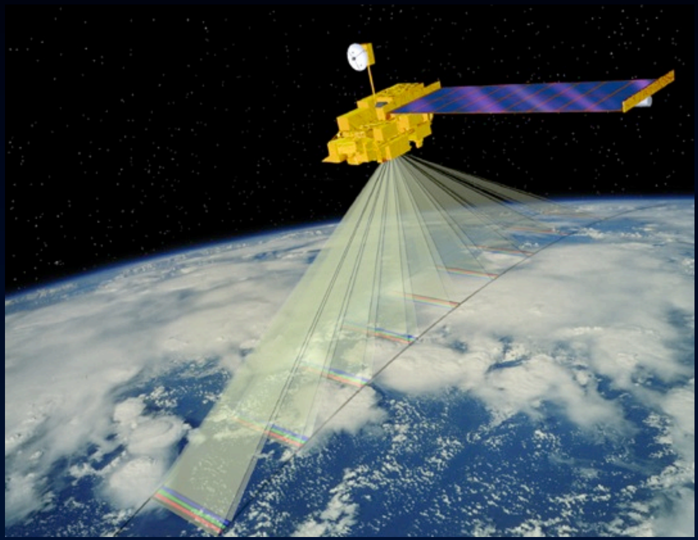
Climatic and environmental impacts of tropospheric aerosols

Cloud-radiation-climate interactions in 3-dimensions

Changes in climatically important surfaces

Why multi-angle?

1. Change in brightness, color, and contrast with angle helps distinguish different types of surfaces, clouds, and airborne particles (aerosols)



2. Oblique slant paths through the atmosphere enhance sensitivity to aerosols and thin cirrus

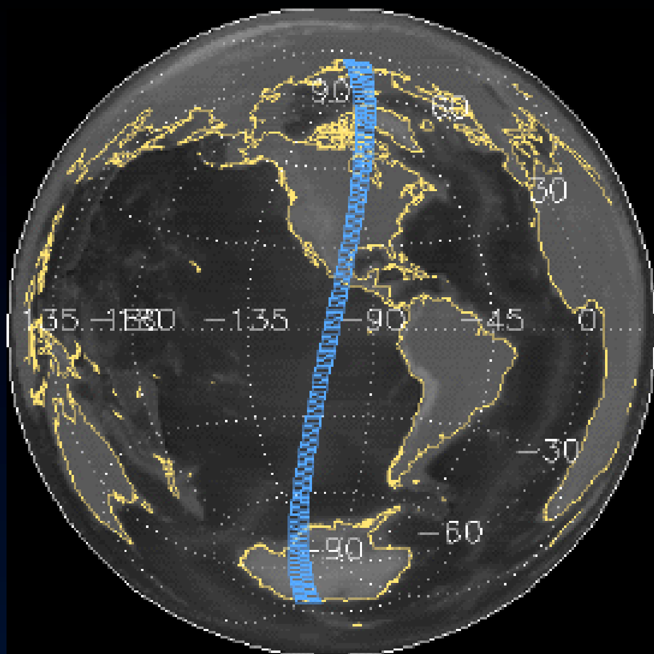
3. Changing geometric perspective provides 3-D views of clouds

4. Time lapse from forward to backward views makes it possible to use clouds as tracers of winds aloft

5. Different angles of view enable sunglint avoidance

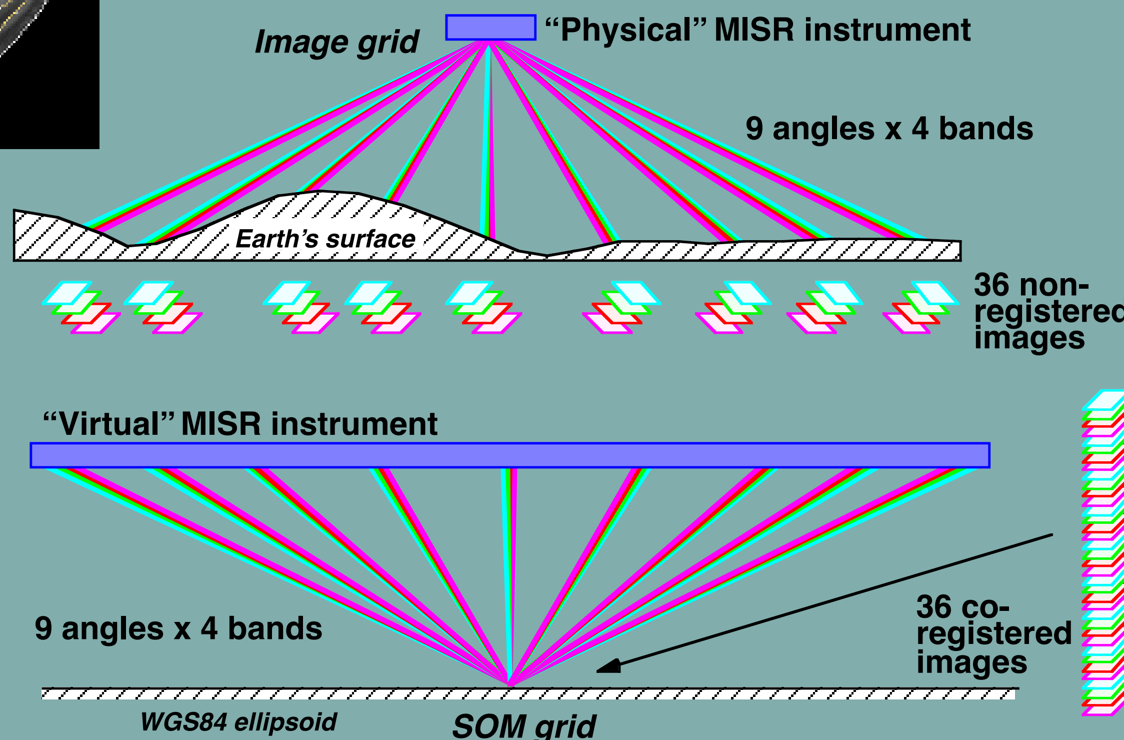
6. Integration over angle is required to estimate hemispherical reflectance (albedo) accurately

Geolocation, resampling, and co-registration occurs during Level 1 processing

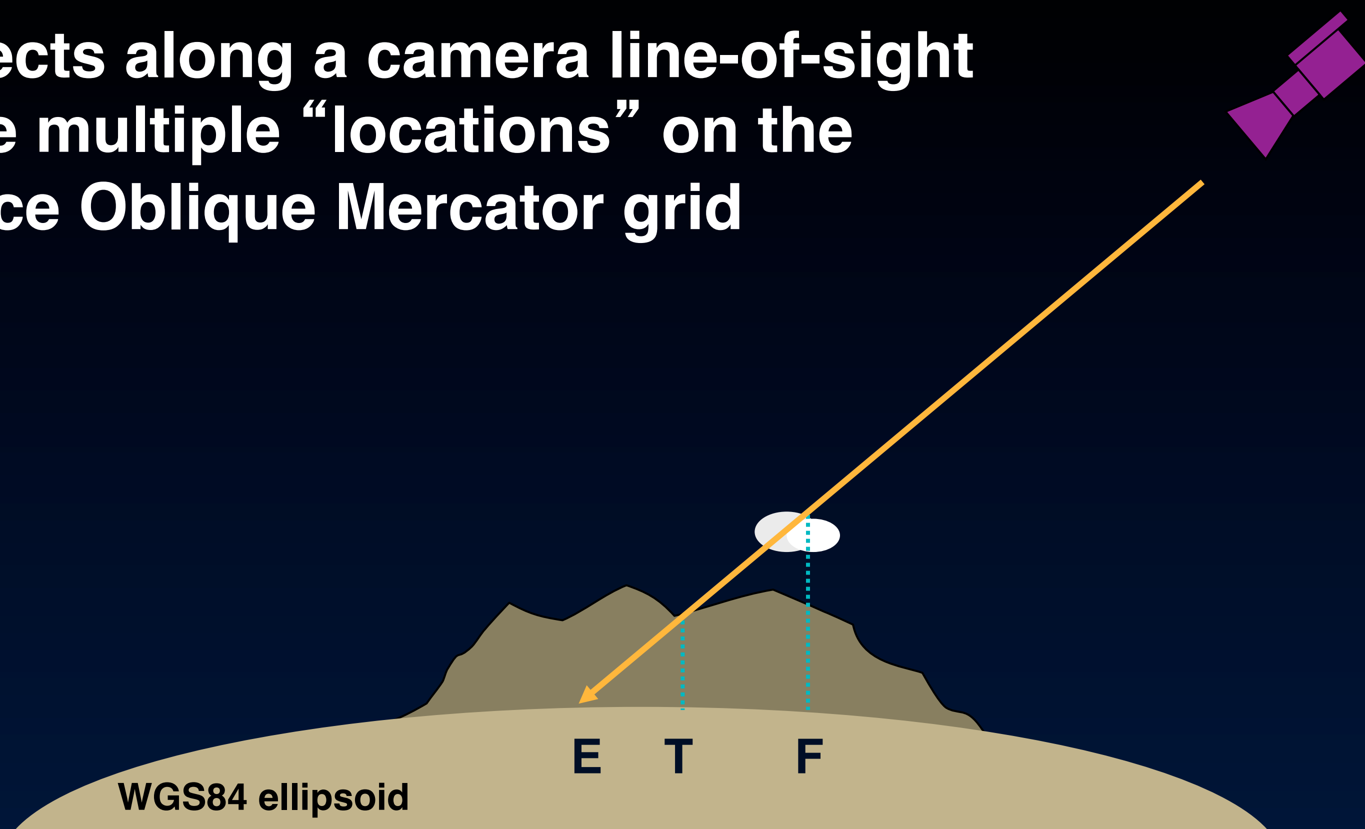


Space Oblique Mercator projection

233 unique paths in 16-day repeat-cycle of Terra orbit



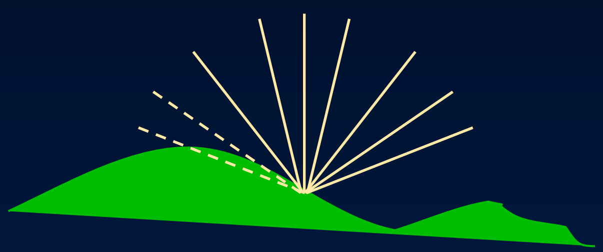
Objects along a camera line-of-sight have multiple “locations” on the Space Oblique Mercator grid



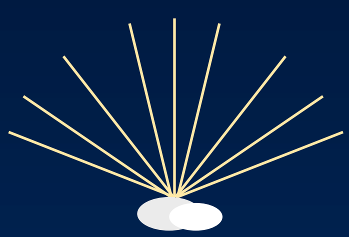
E = ellipsoid-projected location
T = terrain-projected location
F = feature-projected location

Camera-to-camera co-registration requires establishing a reference altitude

"Ellipsoid projection" is to the WGS84 ellipsoid
- performed during Level 1 processing
- used as input to stereoscopic processing



"Terrain projection " is to a digital elevation model
- performed during Level 1 processing
- used as input to aerosol/surface processing
- some views may be obscured



"Feature projection" uses stereoscopically derived cloud heights
- performed during Level 2 processing
- used as input to albedo and cloud classifiers processing

Data maturity levels

Terra data products are given the following maturity classifications:

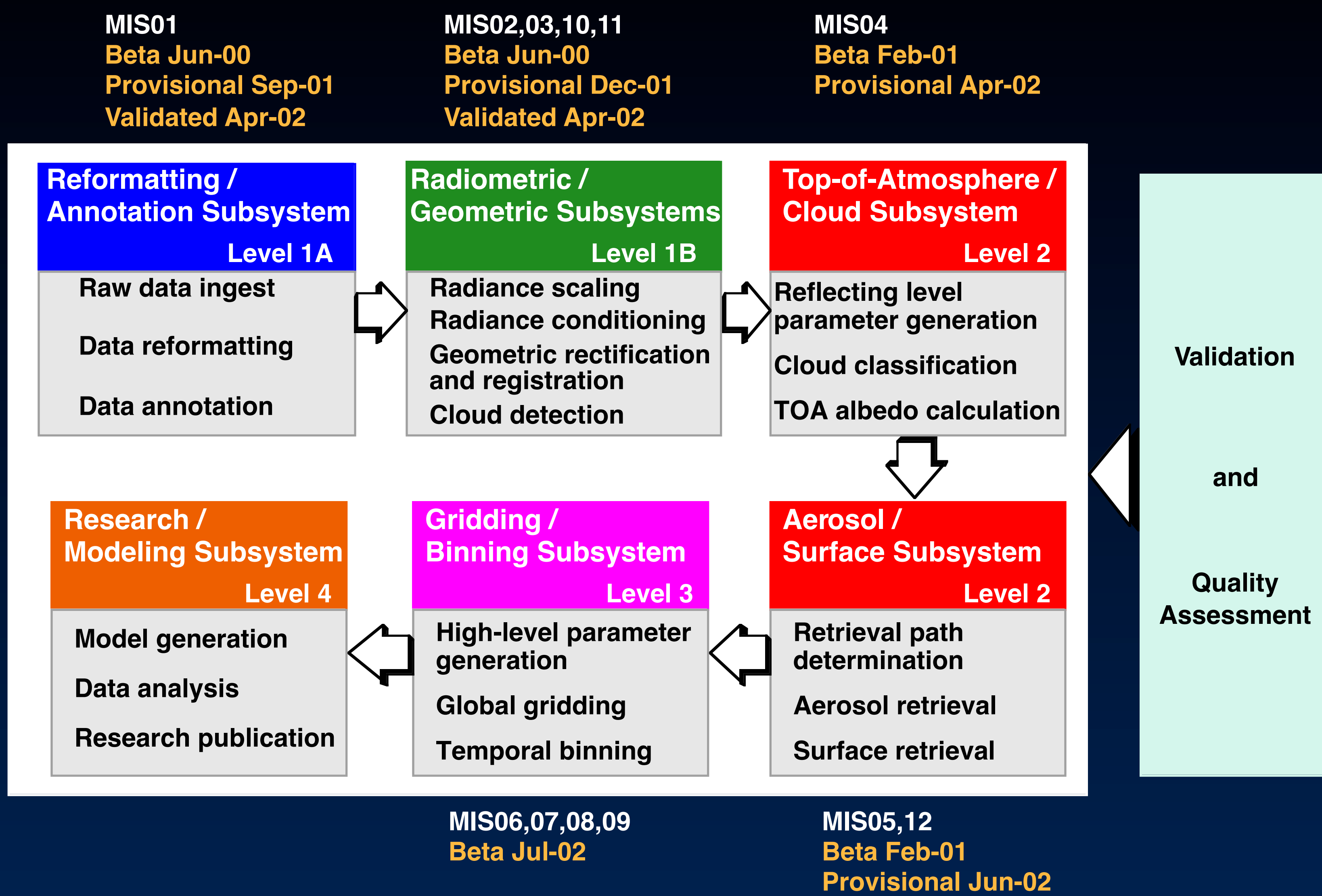
Beta: Minimally validated. Early release to enable users to gain familiarity with data formats and parameters. May contain significant errors.

Provisional: Partially validated. Improvements are continuing. Useful for exploratory and process studies.

Validated: Uncertainties are well defined, and suitable for systematic, long-term studies.

Mapping of data product maturity to version numbers found at:
http://eosweb.larc.nasa.gov/PRODOCS/misr/Version/version_stmt.html

MISR data product generation



Instrument science modes

Global

- Pole-to-pole coverage on orbit dayside
- Full resolution in all 4 nadir bands, and red band of off-nadir cameras (275-m sampling)
- 4x4 pixel averaging in all other channels (1.1-km sampling)

Local

- Implemented for pre-established targets (1-2 per day)
- Provides full resolution in all 36 channels (275-m sampling)
- Pixel averaging is inhibited sequentially from camera Df to camera Da over targets approximately 300 km in length

Calibration

- Implemented bi-monthly
- Spectralon solar diffuser panels are deployed near poles and observed by cameras and a set of photodiodes

Level 1 Standard Products

Level 1 standard products

- Level 1A reformatted, annotated product
- Level 1B1 radiometric product
- Level 1B2 georectified radiance product, in two flavors:
  - ellipsoid
  - terrain (blocks containing land only)
- Level 1B2 browse (JPEG)
- Level 1B2 geometric parameters
- Level 1B2 radiometric camera-by-camera cloud mask

Space Oblique Mercator is used as the projection to minimize resampling distortions

Level 1 processing operates on each camera individually

A data “granule” is an entire pole-to-pole swath

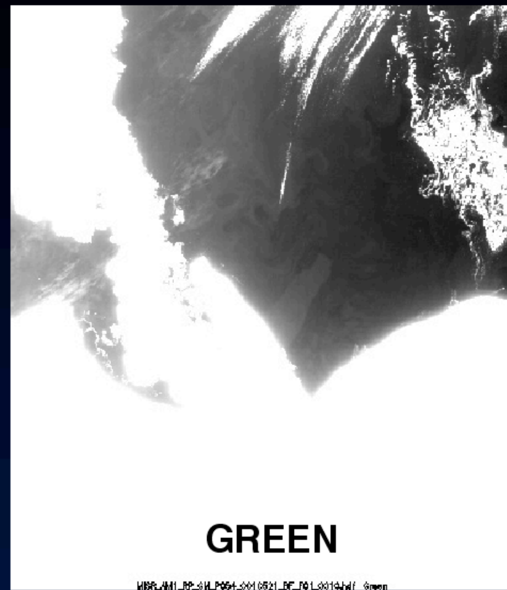
L1B1 Radiometric Product (MIS02)

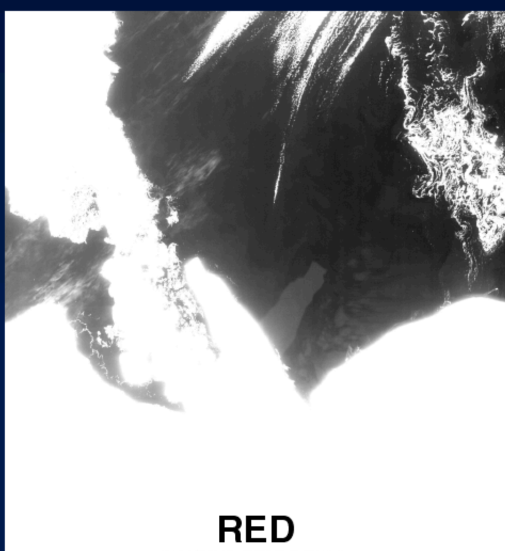
Radiometrically calibrated image data

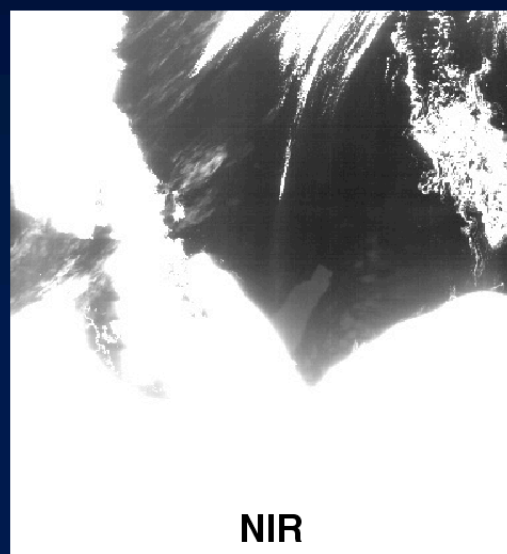
46° Aft Green, Africa, November 18, 2000

PRODUCT MATURITY: VALIDATED

- Formal uncertainty for uniform bright targets is ~ 4%, about twice this for uniform dark targets; validated by comparison against other sensors
- Other uncertainties: 2% angle-to-angle, 2% band-to-band, 0.5% pixel-to-pixel
- Low-level haloes containing 3-6% of point source energy are corrected by point-spread-function deconvolution
- Radiometry at low light levels for contrasty scenes degraded by image ghosts of magnitude 0.3% of the source signal



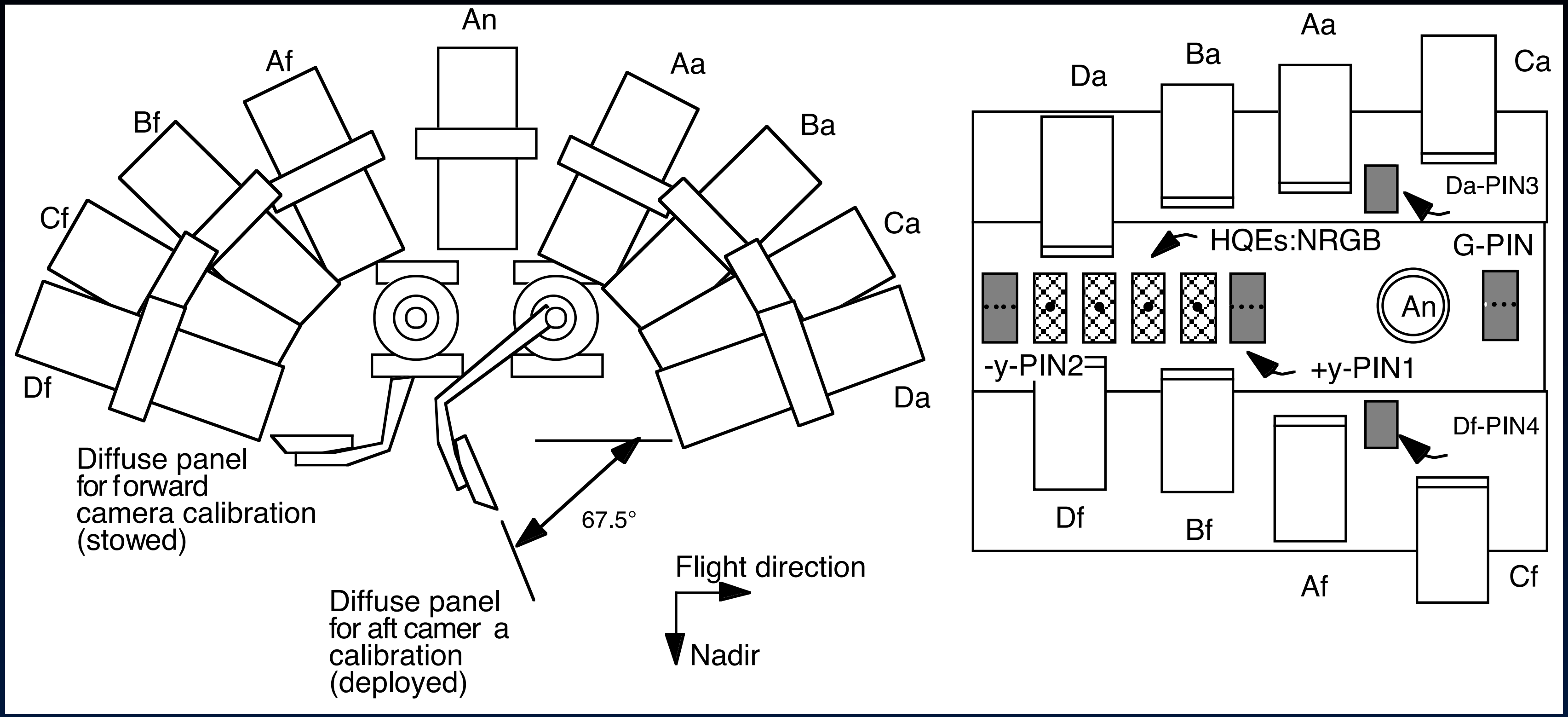




Example of ghosting in highly contrast-enhanced imagery

Antarctica
9 December 2001
P054, O10521

Radiometric calibration



On-board calibrator (OBC):

Deployable Spectralon panels monitored by stable photodiodes

--nadir PIN (p-intrinsic-n doped)

--nadir HQE (light-trapped high quantum efficiency)

--D fore/aft PIN

--goniometric PIN to measure panel BRF

OBC provides:

Camera flat-fielding

Camera-to-camera calibration

Band-to-band calibration

Temporal stability of calibration

Radiometric calibration

MISR image of
Lunar Lake and Railroad Valley

AirMISR image of
Railroad Valley target area

Vicarious calibration:
Lunar Lake and Railroad Valley surface reflectance and Sunphotometer measurements used to calculate top-of-Atmosphere radiances

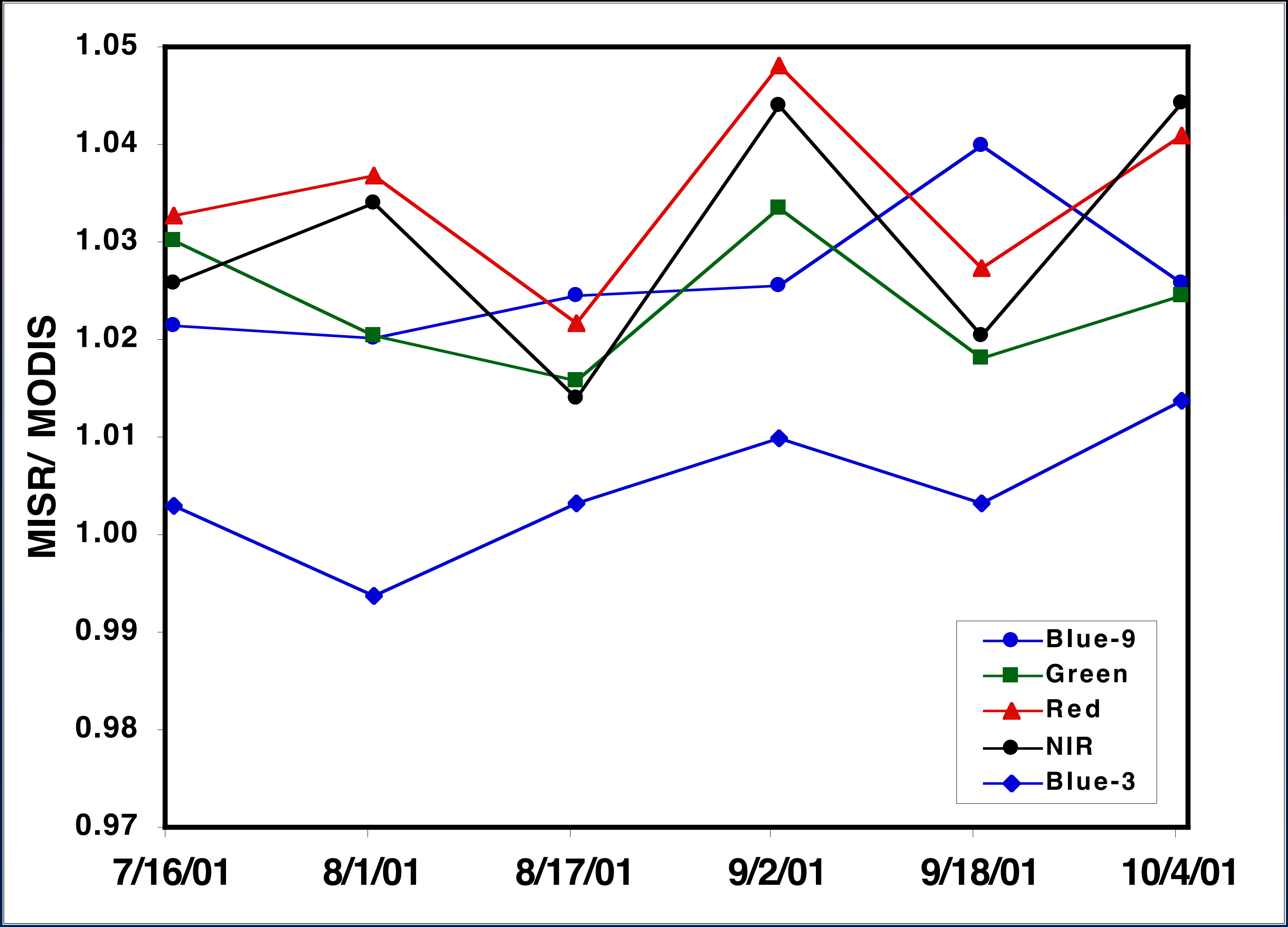
Validated with AirMISR

Vicarious calibration provides:
Absolute radiometric scale at nadir view, which is transferred to the other cameras using the OBC

Performed annually

Original plan to use on-board photodiodes as absolute standard was abandoned early in the mission due to low-confidence in their absolute radiometry (inadequate preflight characterization suspected)

Comparison of MISR and MODIS radiometry over Railroad Valley, NV



Historical radiometric calibration adjustments

Absolute radiometric scale established by the June 11, 2000 vicarious calibration (VC) experiment, Lunar Lake, Nevada

-was used to adjust the on-board primary photodiode standard
-radiances from all channels were increased by 9% for data processed after 2/01

Camera-relative calibration provided by views of flight diffuse panels

-goniometer scans of the South panel matches preflight panel bi-directional reflectance factor (BRF) database
-North panel BRF corrected by use of goniometer measurements
-this resulted in corrections to the aft camera calibrations beginning 8/01

Correction of 10% across-field trend error in the nadir camera

-tracked to coding error in calibration software
-fix in place since 10/02

Use of constrained linear calibration equation, replaces constrained quadratic

-in place since 10/02

Calibration coefficient updates are contained in the MISR Ancillary Radiometric Product (ARP); includes changes to calibration algorithm as well as routine compensation for instrument response changes

-historical information provided on MISR web site calibration page
http://www-misr.jpl.nasa.gov/mission/valwork/cal_reports/arp.html

L1B2 Georectified Radiance Product (MIS03)

Georectified (Earth-projected) radiance data

Multi-angle, multi-spectral composite
New Orleans and the Gulf Coast,
15 October 2001

PRODUCT MATURITY: VALIDATED

PRODUCT QUALITY

- Mean geolocation error is < 45 m
- 8 of 9 cameras typically co-register to < 1 pixel; Da camera shows time-variable co-registration errors of up to 2 pixels typically
- Reference Orbit Imagery has been implemented to provide consistently stable camera co-registration throughout the mission
- Orbit attitude and ephemeris quality flag included in product
- Scale factors to convert radiances to top-of-atmosphere BRF's included in product
- Per-block Geometric Data Quality Indicator (GDQI) to be added to product

Geometric calibration

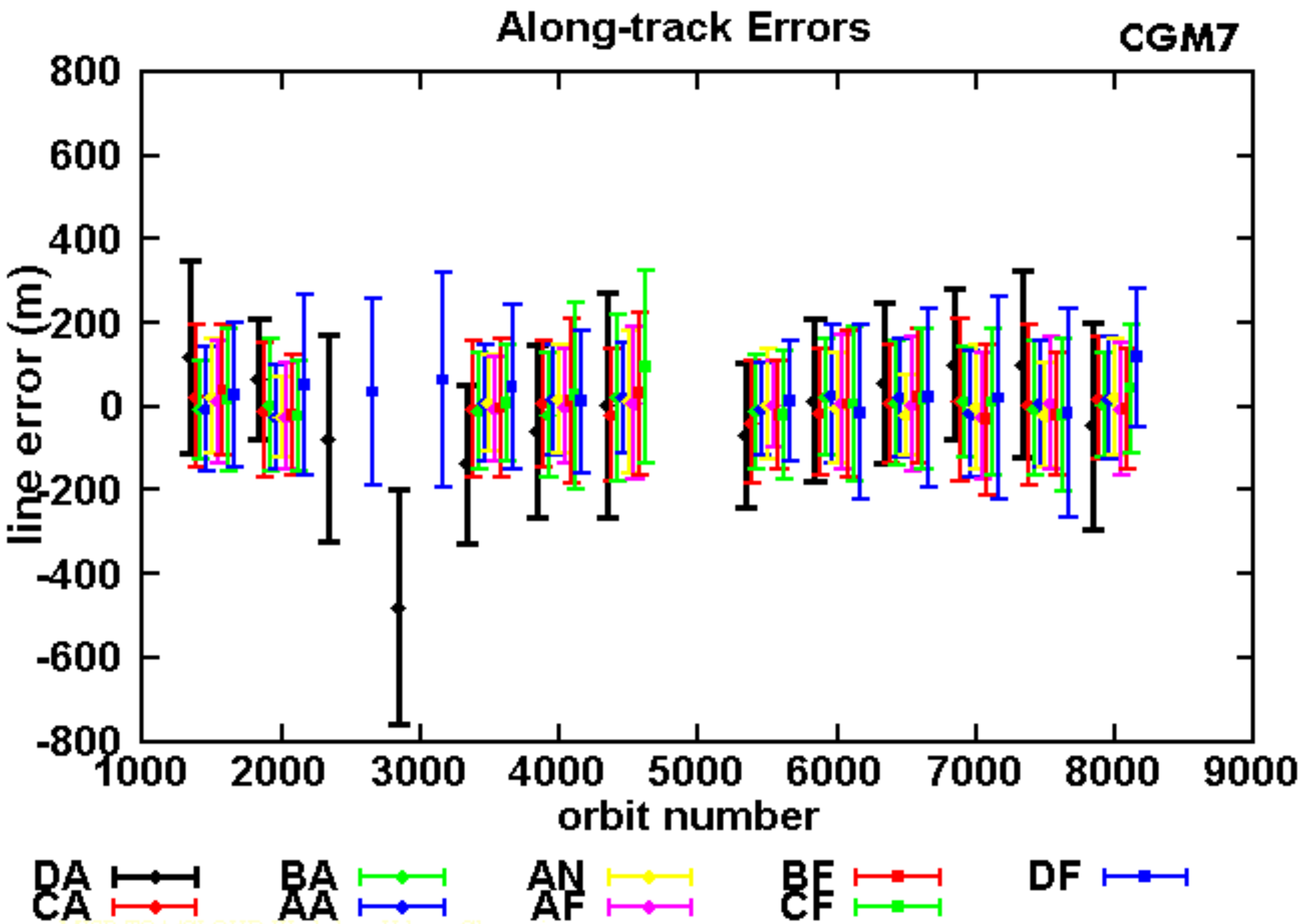
Image tie-pointing between MISR and Landsat-based ground control point image chips is performed to establish the camera geometric models (CGM's)

CGM's are used in the automated projection of MISR data to the Space Oblique Mercator grid

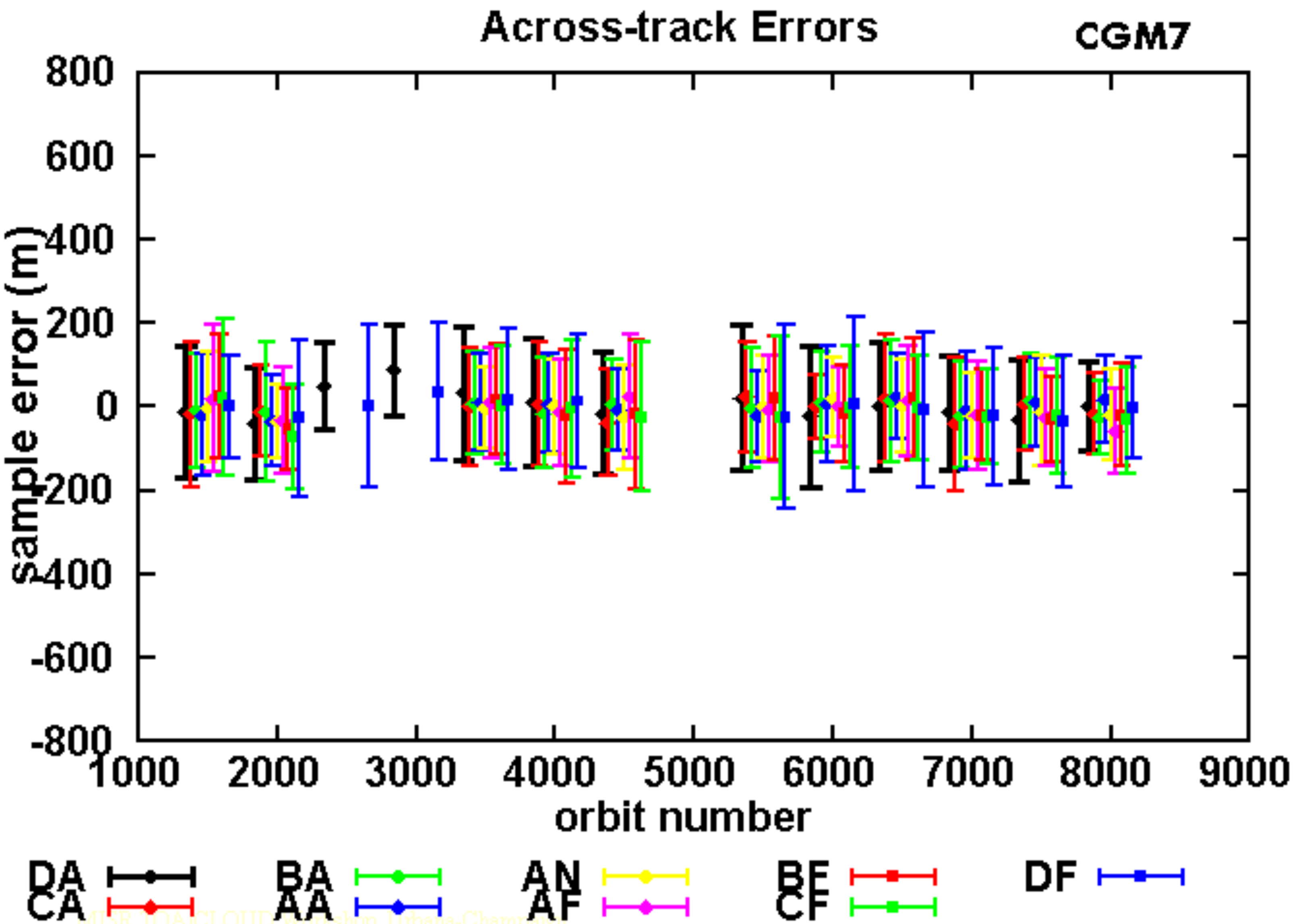
CGM6 was in use until April 2002 had a systematic problem in the Da camera

This has now been replaced with CGM7, which was derived using data from orbits 1752-8656 (about 16 months worth of data), excluding known *bad* orbits (bad or uncertain attitude or ephemeris) and orbits in range 2330 to 3500, which had systematic biases in Da pointing

CGM7 improved the Da camera model but time-dependent biases were still present



Along-track Errors
CGM7
800
600
400
200
0
-200
-400
-600
-800
line error (m)
1000
2000
3000
4000
5000
6000
7000
8000
9000
orbit number
DA
CA
BA
AA
AN
AF
BF
CF
DF



Across-track Errors
CGM7
800
600
400
200
0
-200
-400
-600
-800
sample error (m)
1000
2000
3000
4000
5000
6000
7000
8000
9000
orbit number
DA
CA
BA
AA
AN
AF
BF
CF
DF

Reference Orbit Imagery (ROI)

Accurate camera geolocation and camera-to-camera co-registration are essential for MISR geophysical retrievals

--Co-registration is particularly important for the oblique angles, which play a key role in stereoscopic height and wind retrievals

--Most of the time, "dead reckoning" image navigation and static camera models are adequate to geolocate and co-register MISR imagery. Occasional spacecraft maneuvers or data problems cause low quality ephemeris and attitude data

ROI is a set of cloud-screened camera-by-camera L1B1 reference imagery to which incoming data are image-matched in order to compensate for these problems

--Under nominal conditions the geolocation quality with ROI is very close to that with no ROI for all cameras except Da; ROI improves the Da geolocation

--ROI improves georegistration accuracy when there are camera pointing errors or reduced spacecraft pointing control accuracy

ROI case study: Orbit 9456

Over blocks 58-67, which contain clear land, stereo retrievals classified the area as cloud because retrieved 1500-2000 m heights, rather than surface height

--The Df, Da misregistration flags in stereo cloud processing showed 5-6 pixel misregistration along-track (for both cameras) and about 1 pixel crosstrack

--The previous pass, orbit 9223, showed no problem

Investigation showed that the provided spacecraft attitude/ephemeris data had large segments of interpolated attitude

--This provided a good test of the efficacy of ROI

--Inclusion of attitude/ephemeris data quality in the L1B2 metadata is planned

without ROI

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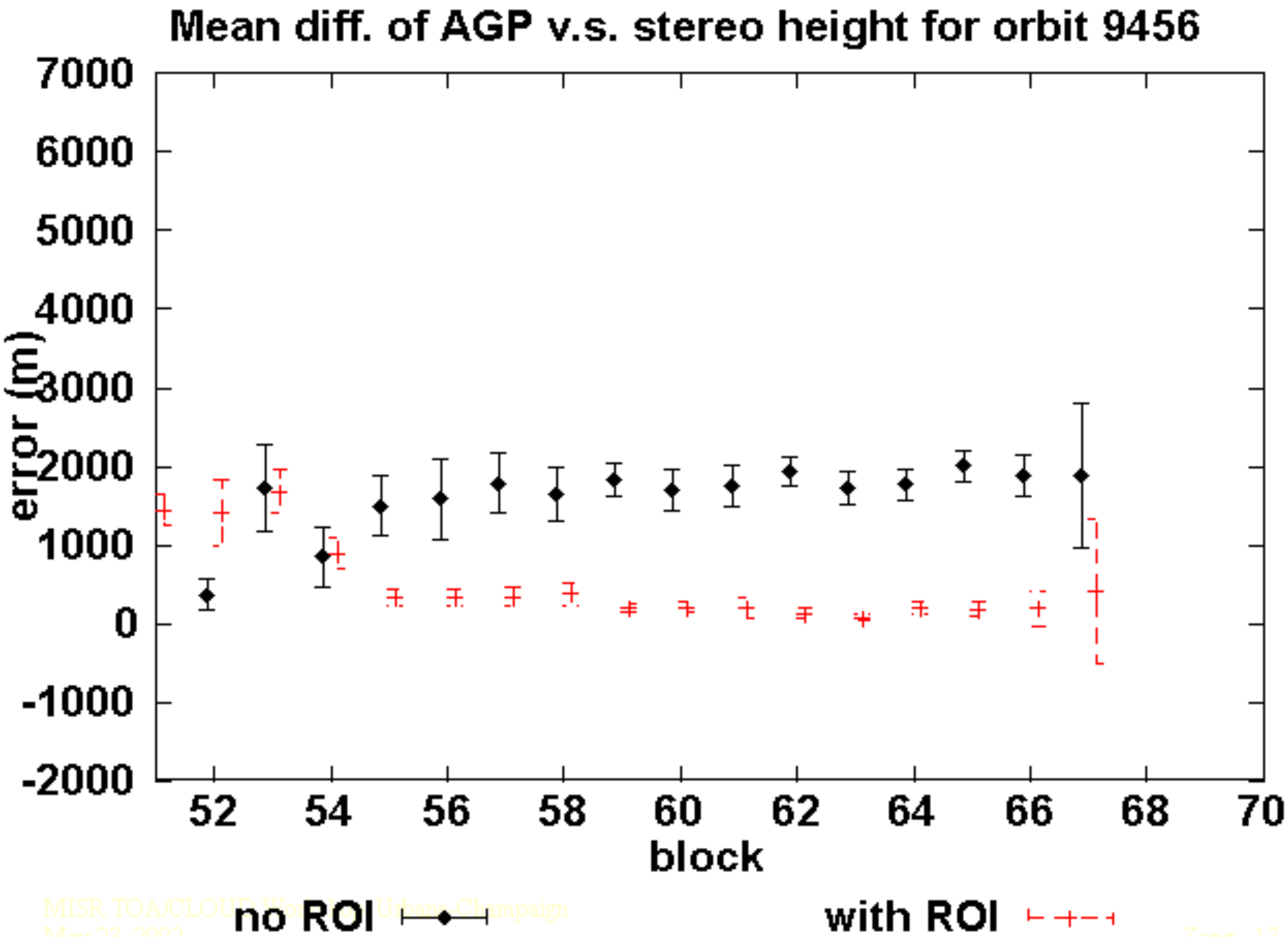
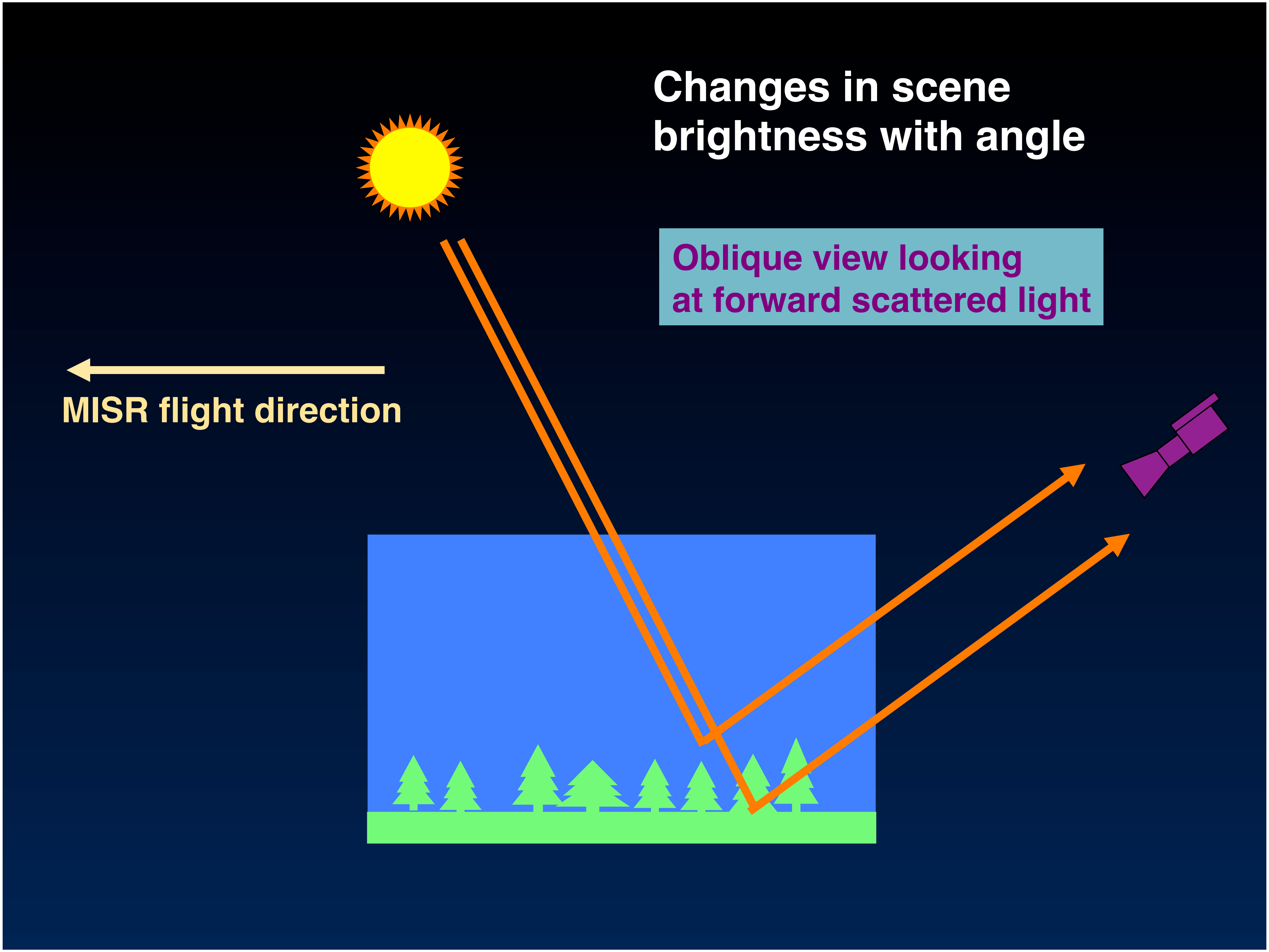
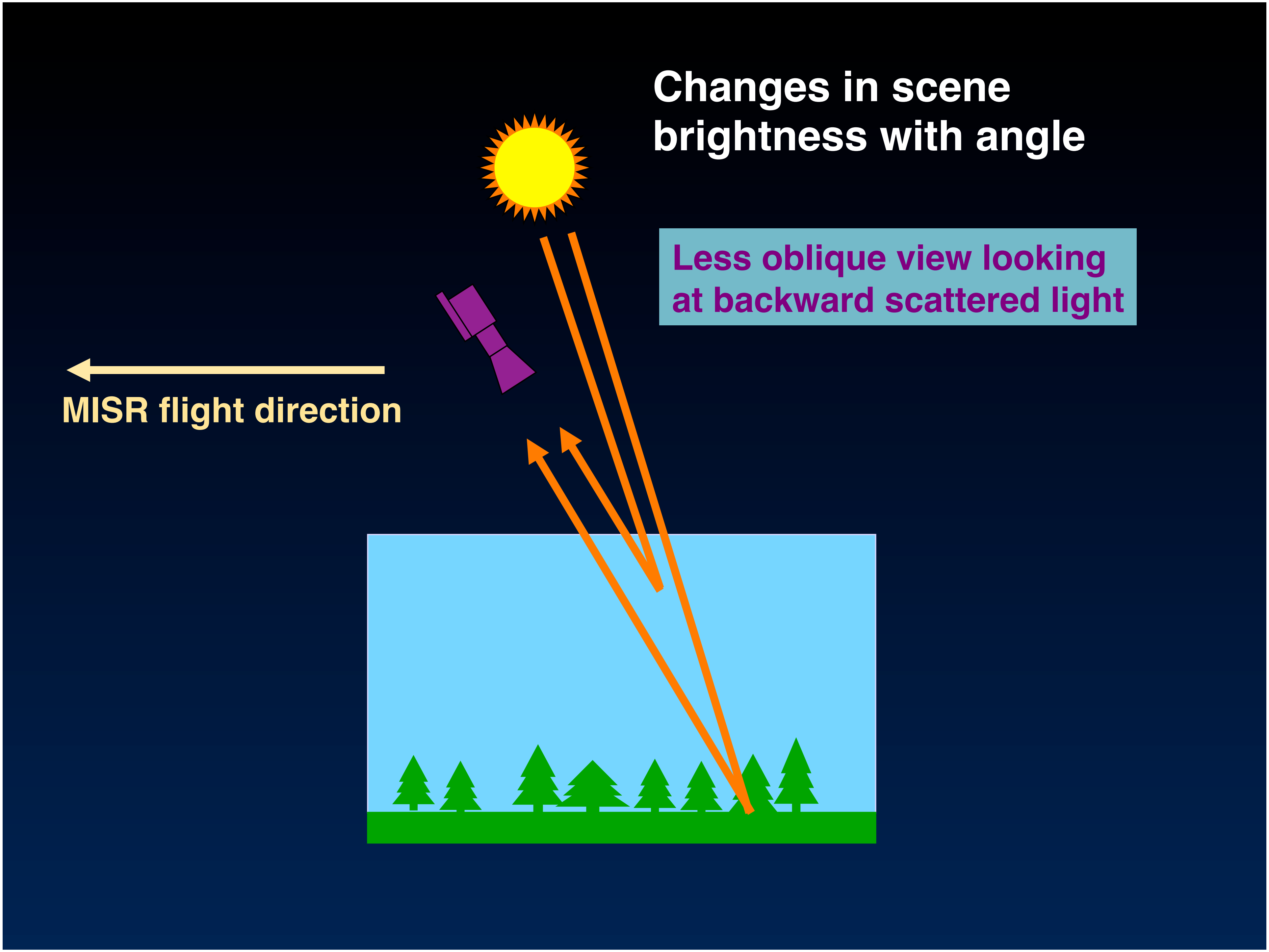
Example of Orbit 9456 – ROI corrections




50 km
James Bay, Canada
9 August 2000
An red, green, blue


50 km
James Bay, Canada
16 January 2001
An red, green, blue


Changes in scene
brightness with angle
Oblique view looking
at forward scattered light
MISR flight direction

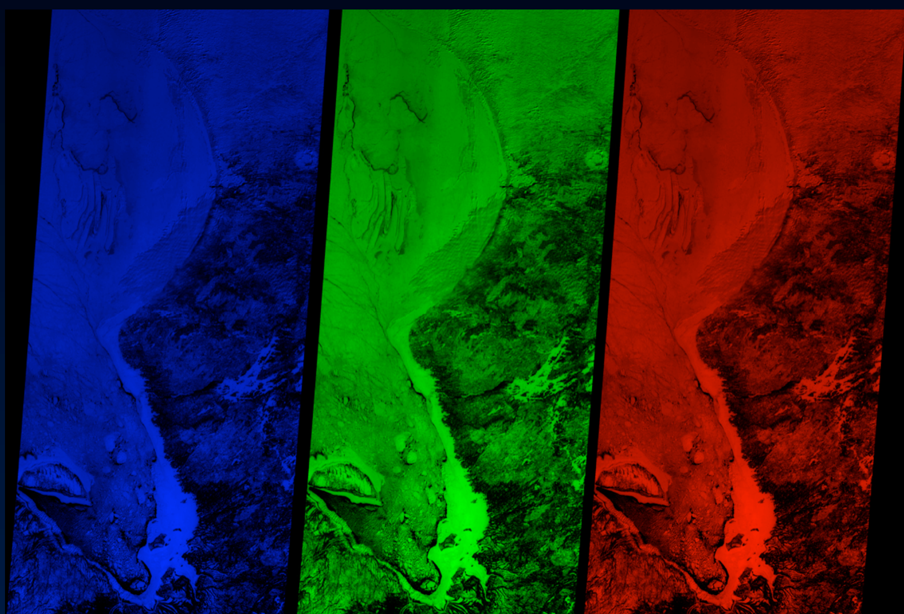

Changes in scene brightness with angle
Less oblique view looking at backward scattered light
MISR flight direction

Visualizing surface characteristics

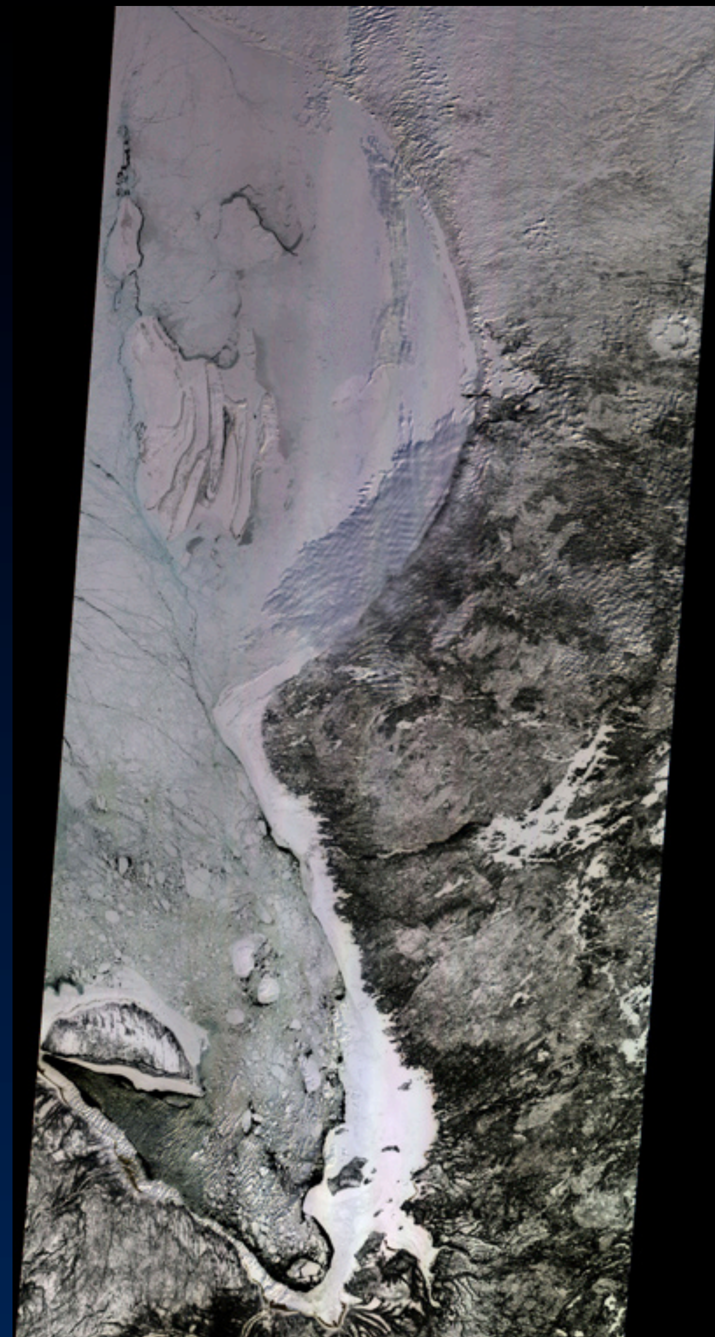
nadir
blue band

nadir
green band

nadir
red band



multi-spectral compositing



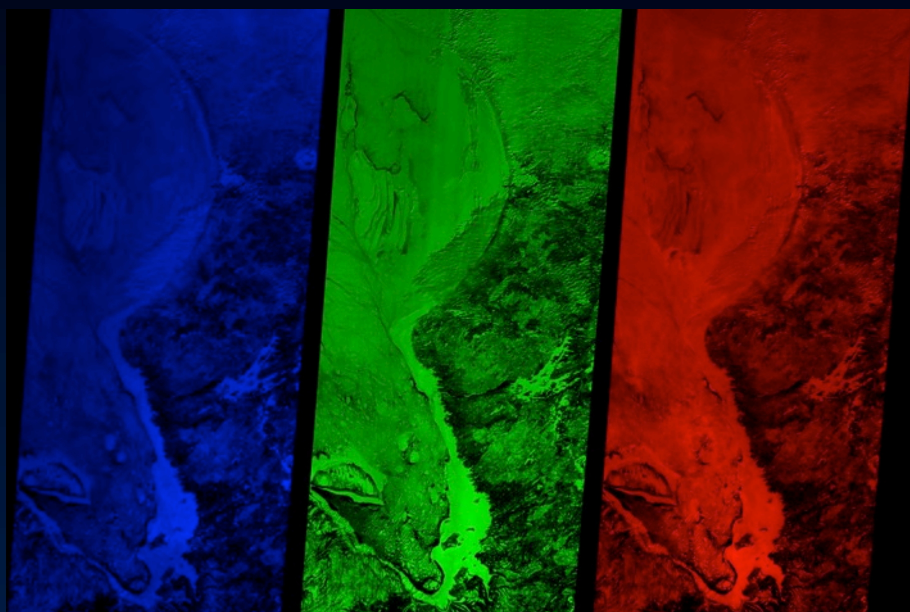
Hudson and
James Bays
24 February 2000

Visualizing surface characteristics

70° forward
red band

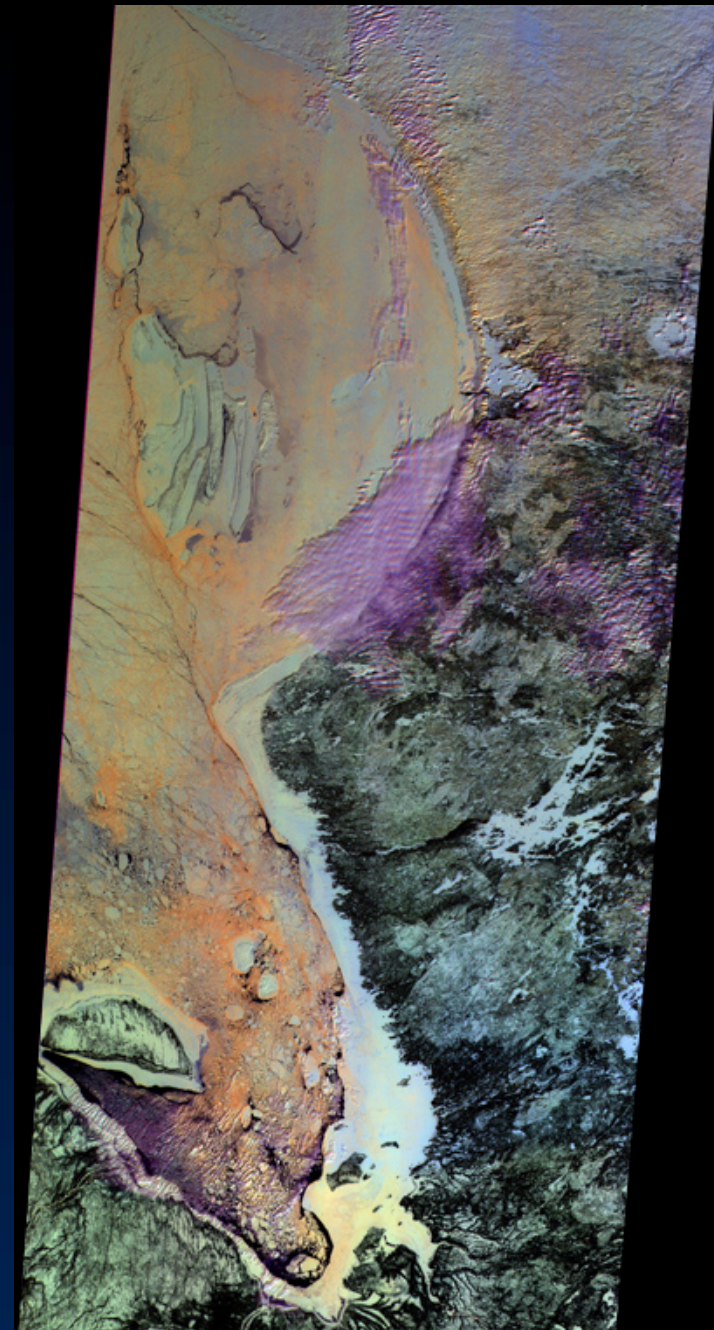
nadir
red band

70° backward
red band



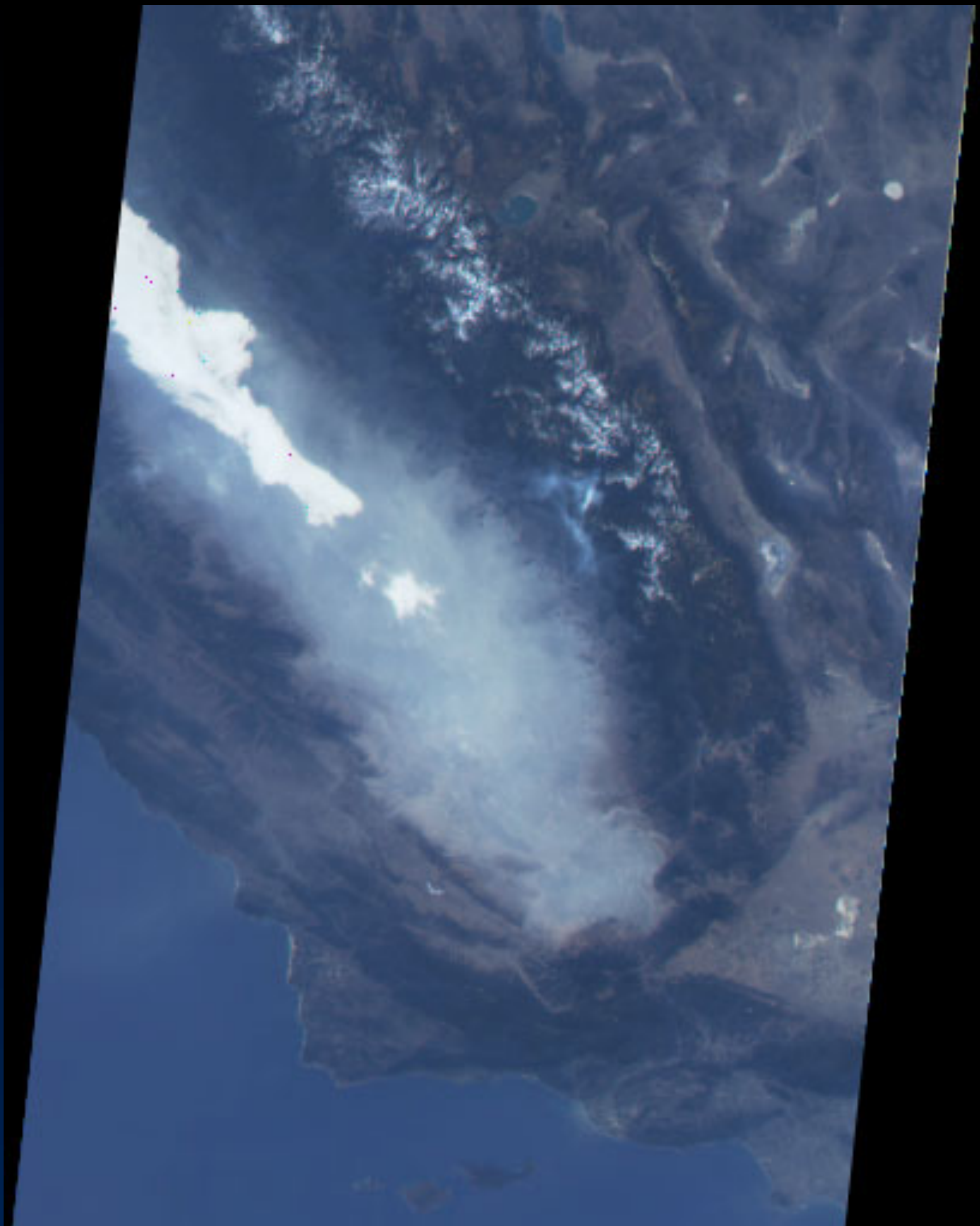
multi-angular
compositing

Hudson and
James Bays
24 February 2000



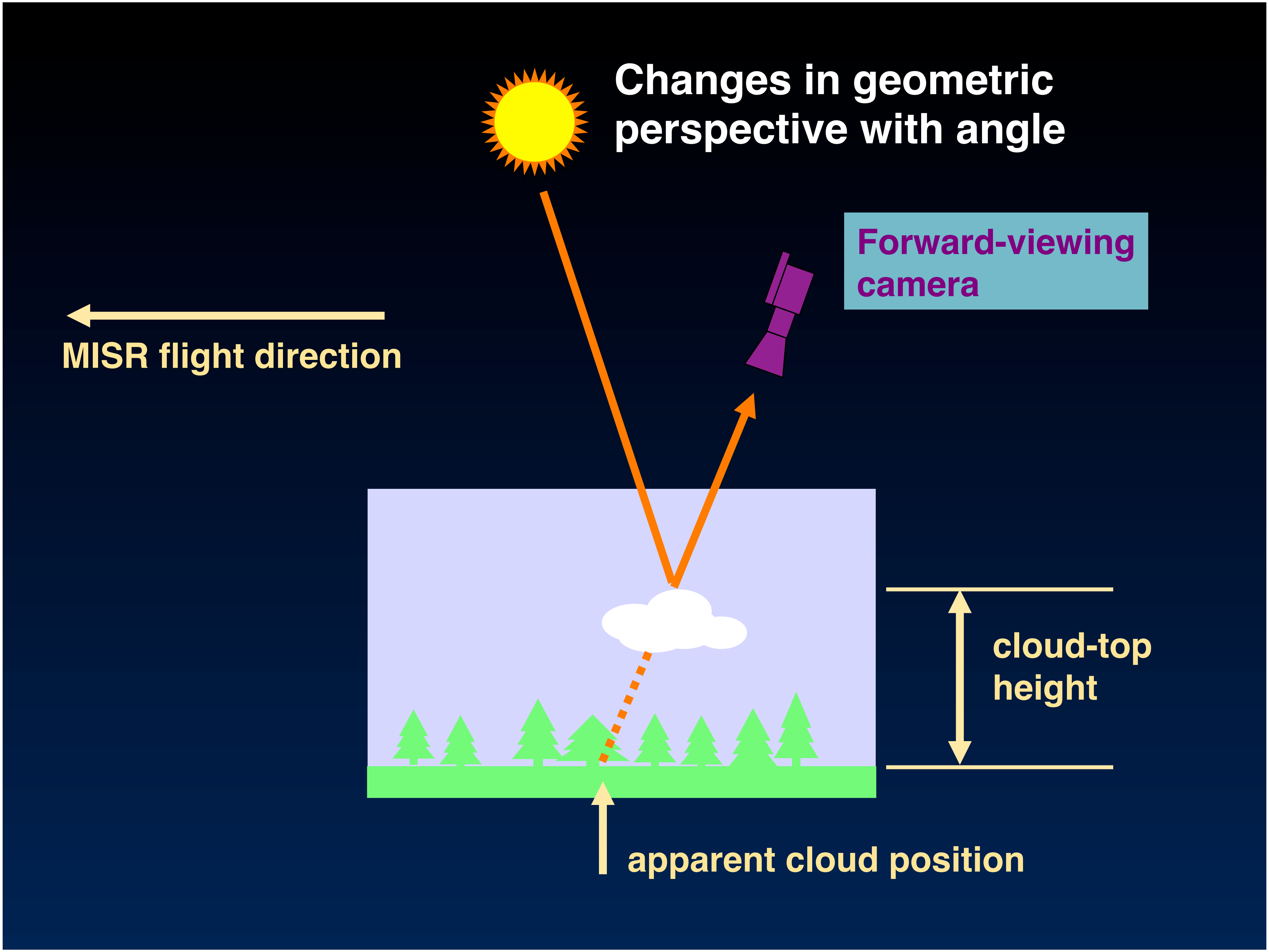
San Joaquin Valley
3 January 2001

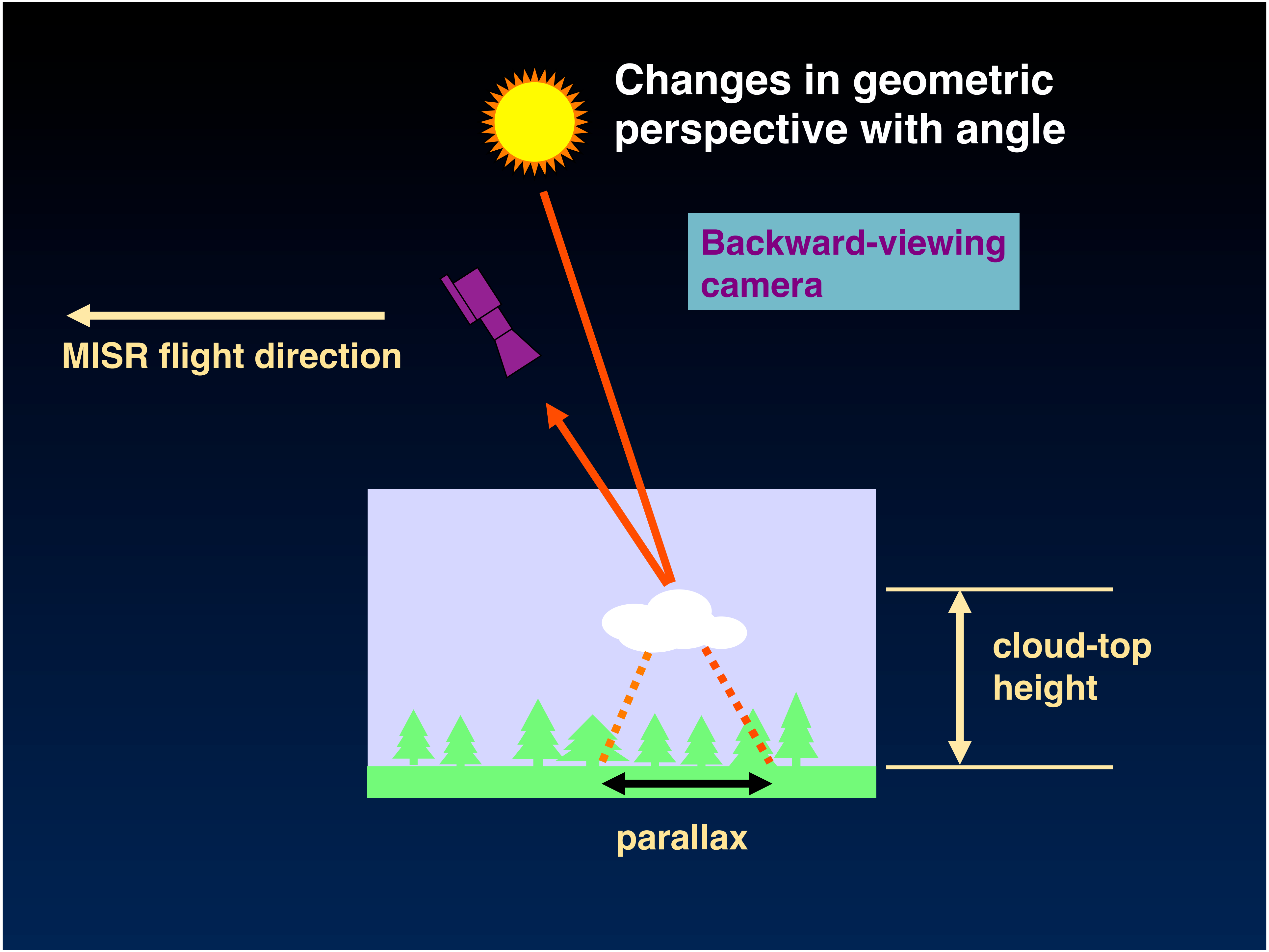
nadir

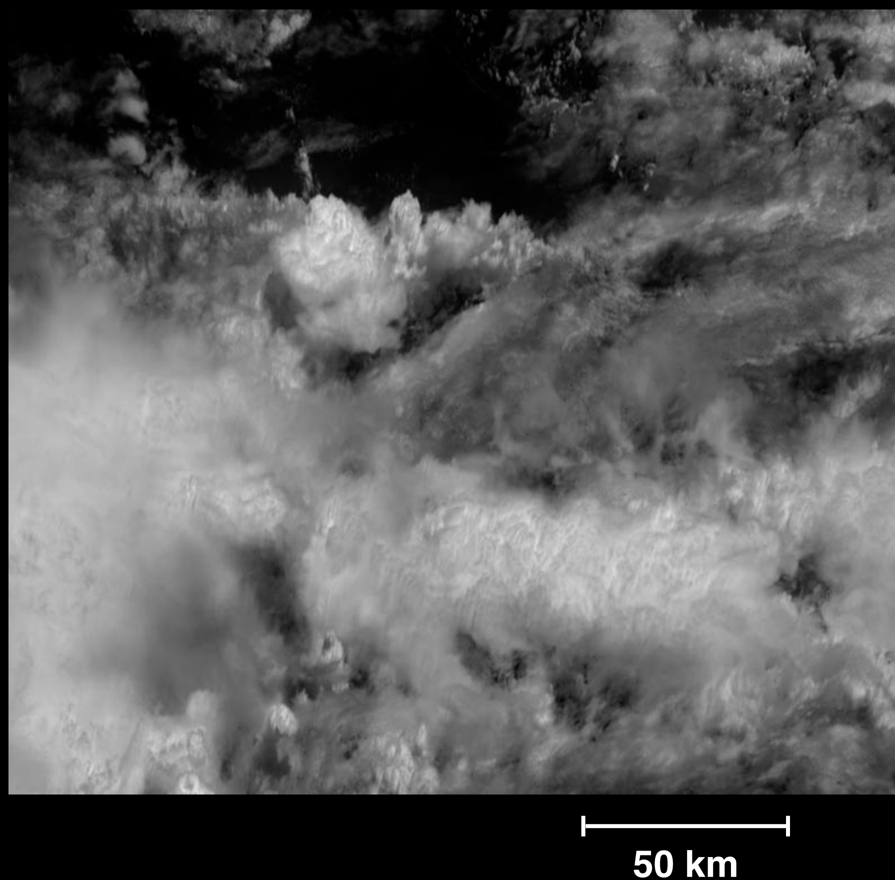


San Joaquin Valley
3 January 2001

70º forward

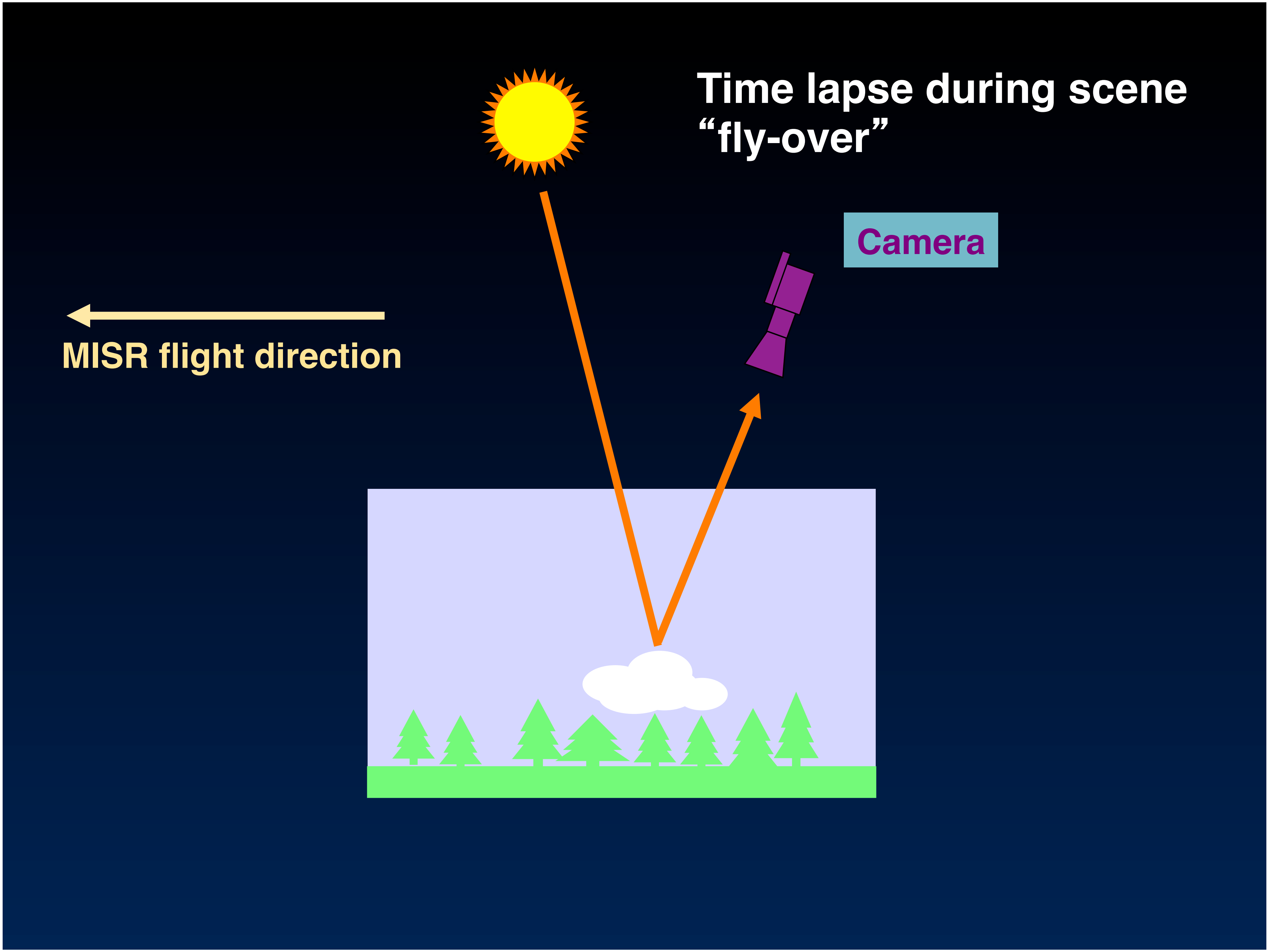

Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
cloud-top height
apparent cloud position

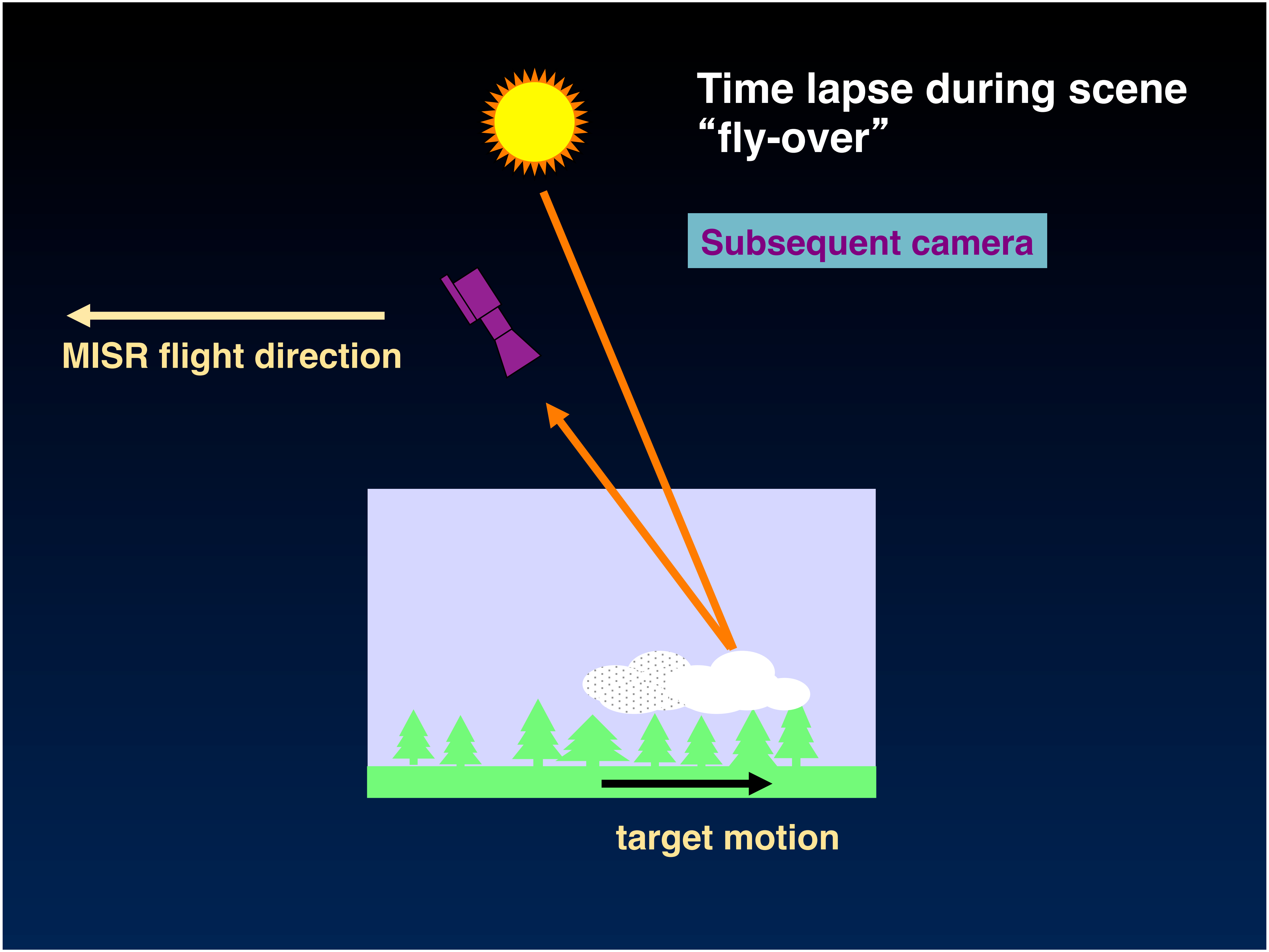

Changes in geometric perspective with angle
Backward-viewing camera
MISR flight direction
cloud-top height
parallax



Multi-angle "fly-over" of Hurricane Carlotta thunderclouds

19 August 2000


Time lapse during scene
"fly-over"
Camera
MISR flight direction

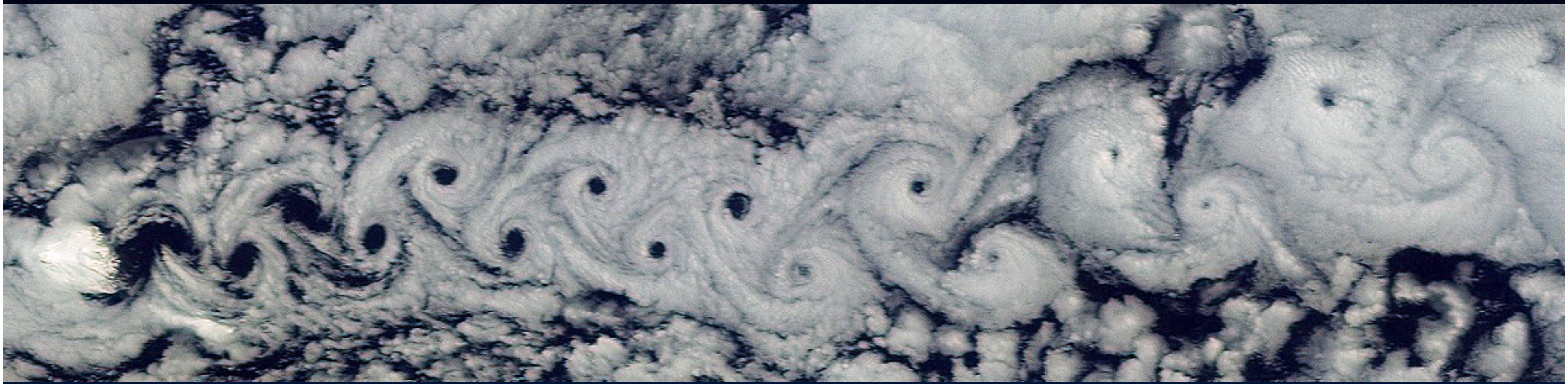

Time lapse during scene
“fly-over”
Subsequent camera
MISR flight direction
target motion

Moving Ships off the North Carolina Coast

11 October 2000

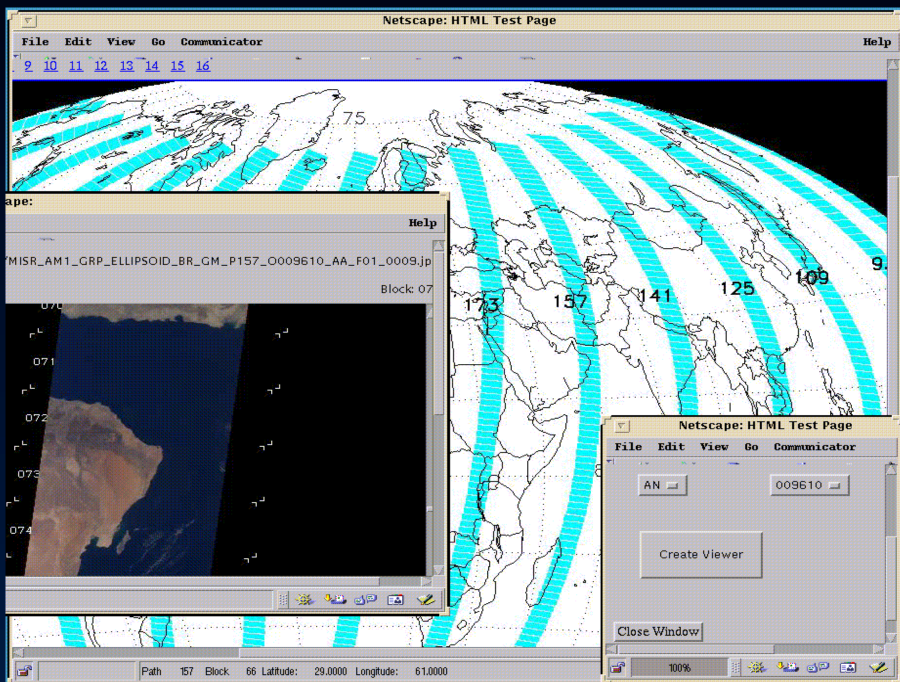
Von Karman vortex street near Jan Mayen Island

6 June 2001



L1B2 Browse Products

JPEG format true-color imagery, all 9 cameras, 2.2 km sampling

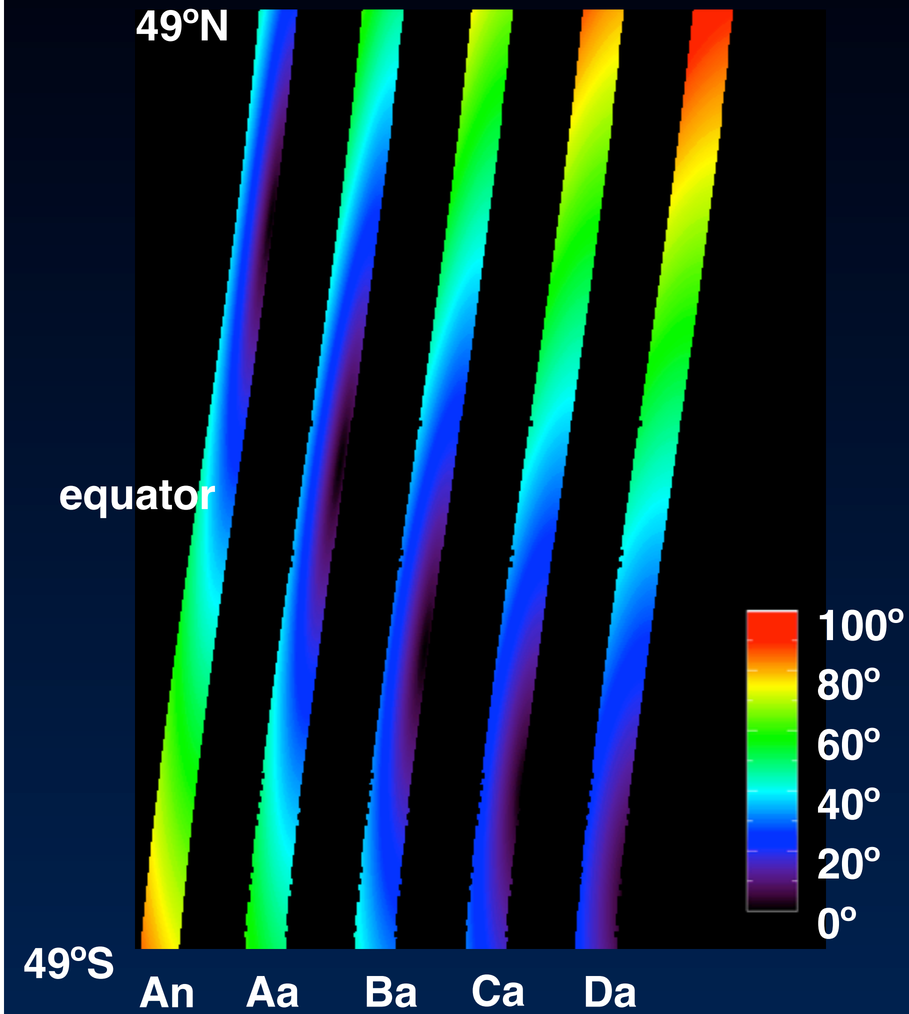


Color, multi-angle browse products and on-line interactive viewer

http://eosweb.larc.nasa.gov/MISRBR/

L1B2 Geometric Parameters (MIS03)

Provided on 17.6-km centers



Example of glitter angle July 3

PRODUCT MATURITY: VALIDATED

- View zenith and azimuth angles per camera; azimuths measured relative to local north
- Solar zenith and azimuth angles correspond to midpoint viewing time of only those cameras which observed the point
- Scatter and glitter angles also included in product

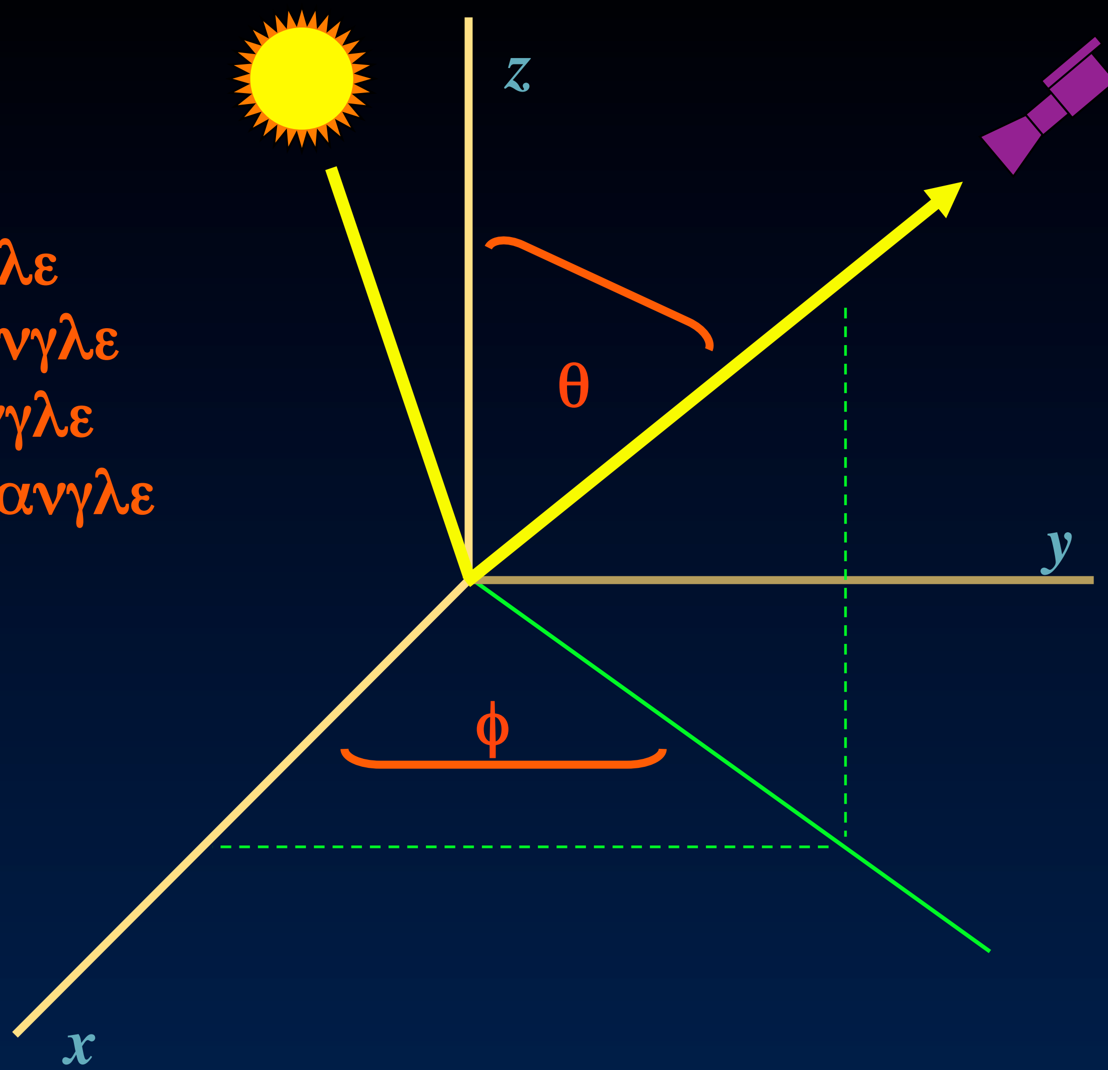
Geometric definitions

θ = ϖιεω ζενιτη ανγλε

ϕ = ϖιεω **azimuth** ανγλε

θ_0 = **solar** ζενιτη ανγλε

ϕ_0 = **solar azimuth** ανγλε



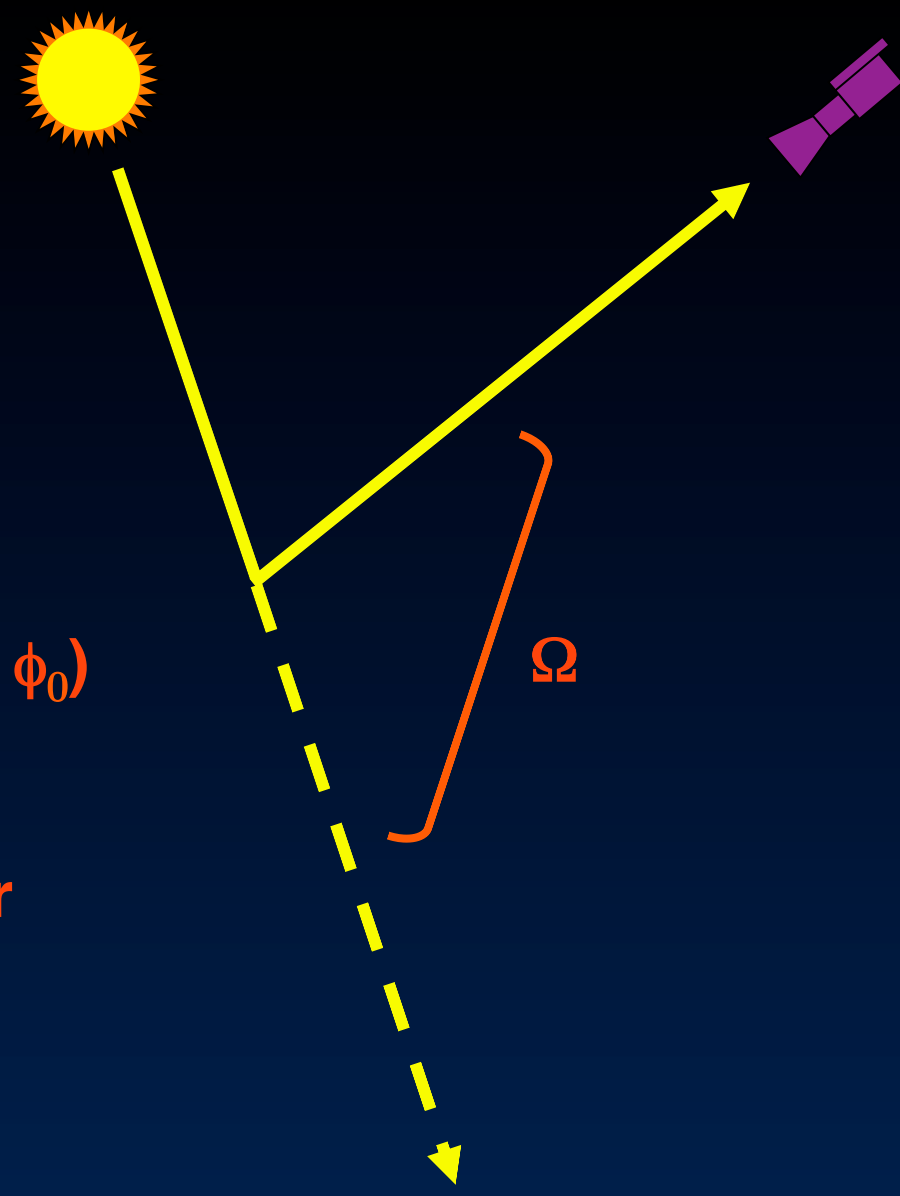
Geometric definitions

Ω = σχαττερινγ ανγλε

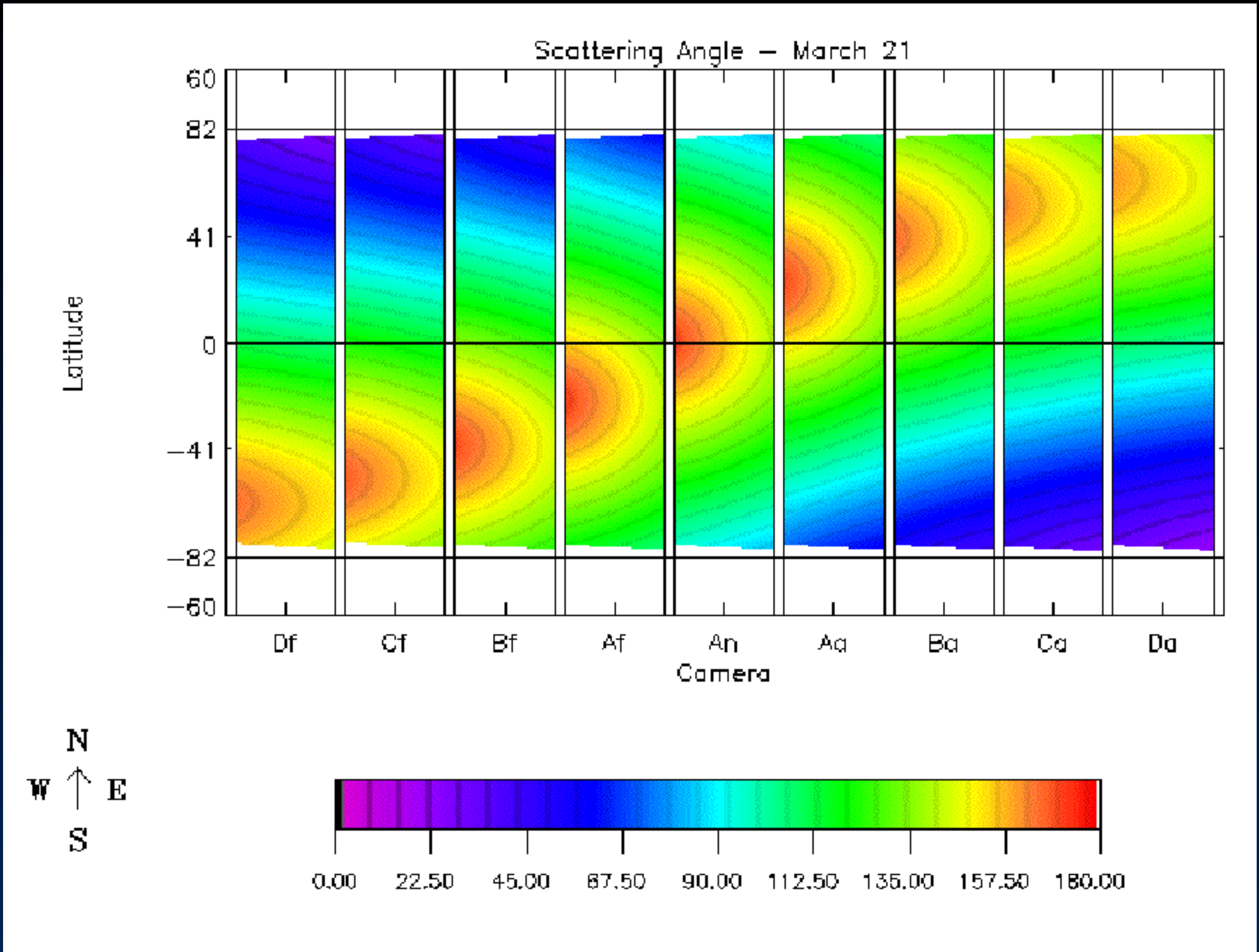
$$= - \cos(\theta)\cos(\theta_0) + \sin(\theta)\sin(\theta_0)\cos(\phi - \phi_0)$$

Ω < 90° forward scatter

Ω > 90° backward scatter

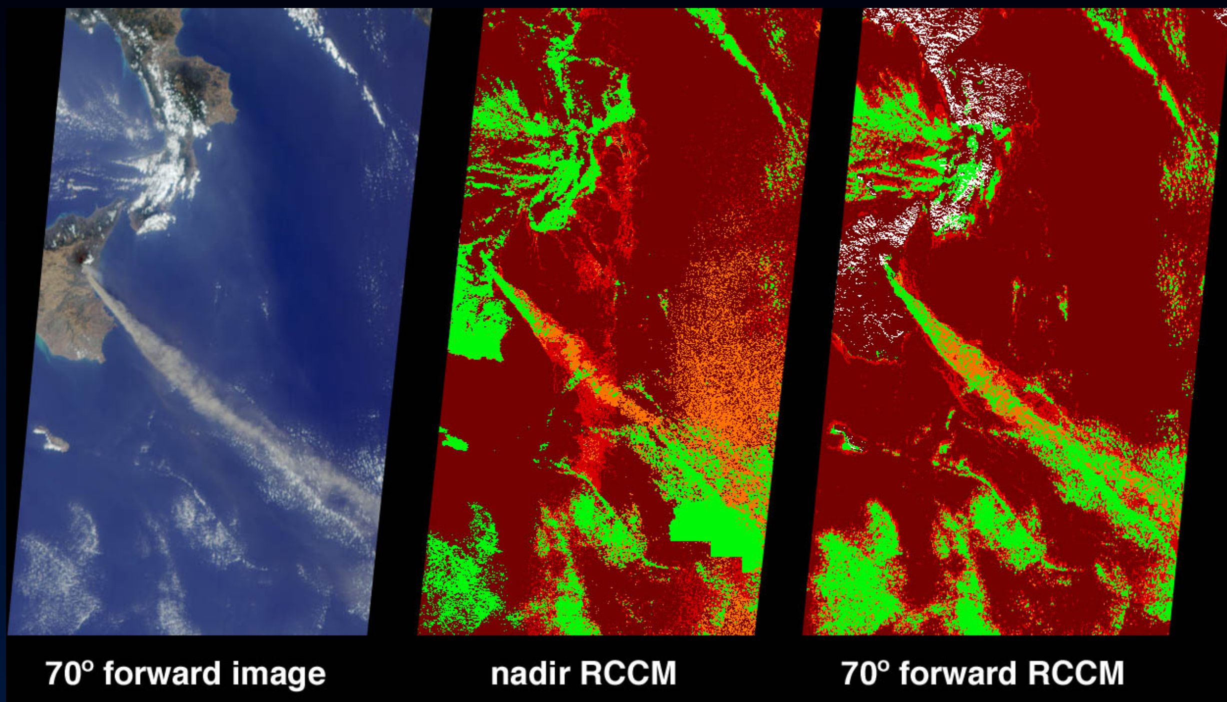


Example MISR scattering angle coverage (March 21)



L1B2 Radiometric Camera-by-camera Cloud Mask (MIS03)

Radiometric threshold-based cloud mask



Mt. Etna eruption,
22 July 2001

- No retrieval
- High confidence clear
- Low confidence clear
- Low confidence cloud
- High confidence cloud

PRODUCT MATURITY: PROVISIONAL OVER OCEAN, BETA OVER LAND

- Maturity designation over land to be upgraded after automated thresholding in place

Level 2 Standard Products / Ancillary Products

Level 2 standard products

Level 2TC stereo
Level 2TC cloud classifiers
Level 2TC top-of-atmosphere albedo
Level 2AS aerosol
Level 2AS land surface
Level 2AS ocean surface (not yet available)

Level 2 processing uses multiple cameras simultaneously

Angular radiance signatures
Geometric parallax

Ancillary products

Ancillary Radiometric Product

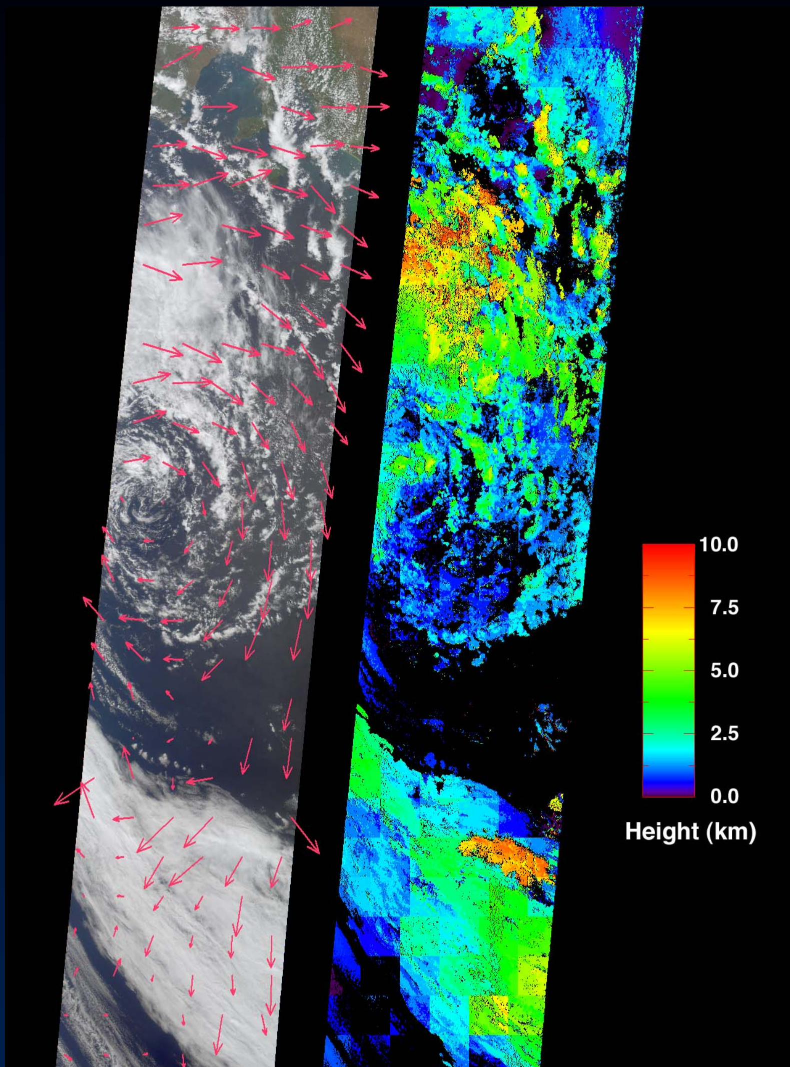
contains extrasolar irradiances at MISR standard wavelengths

Ancillary Geographic Product

contains latitudes, longitudes, elevations, scene classifiers
for each 1.1-km pixel on the Space Oblique Mercator grid

L2 TOA/Cloud Stereo Product (MIS04)

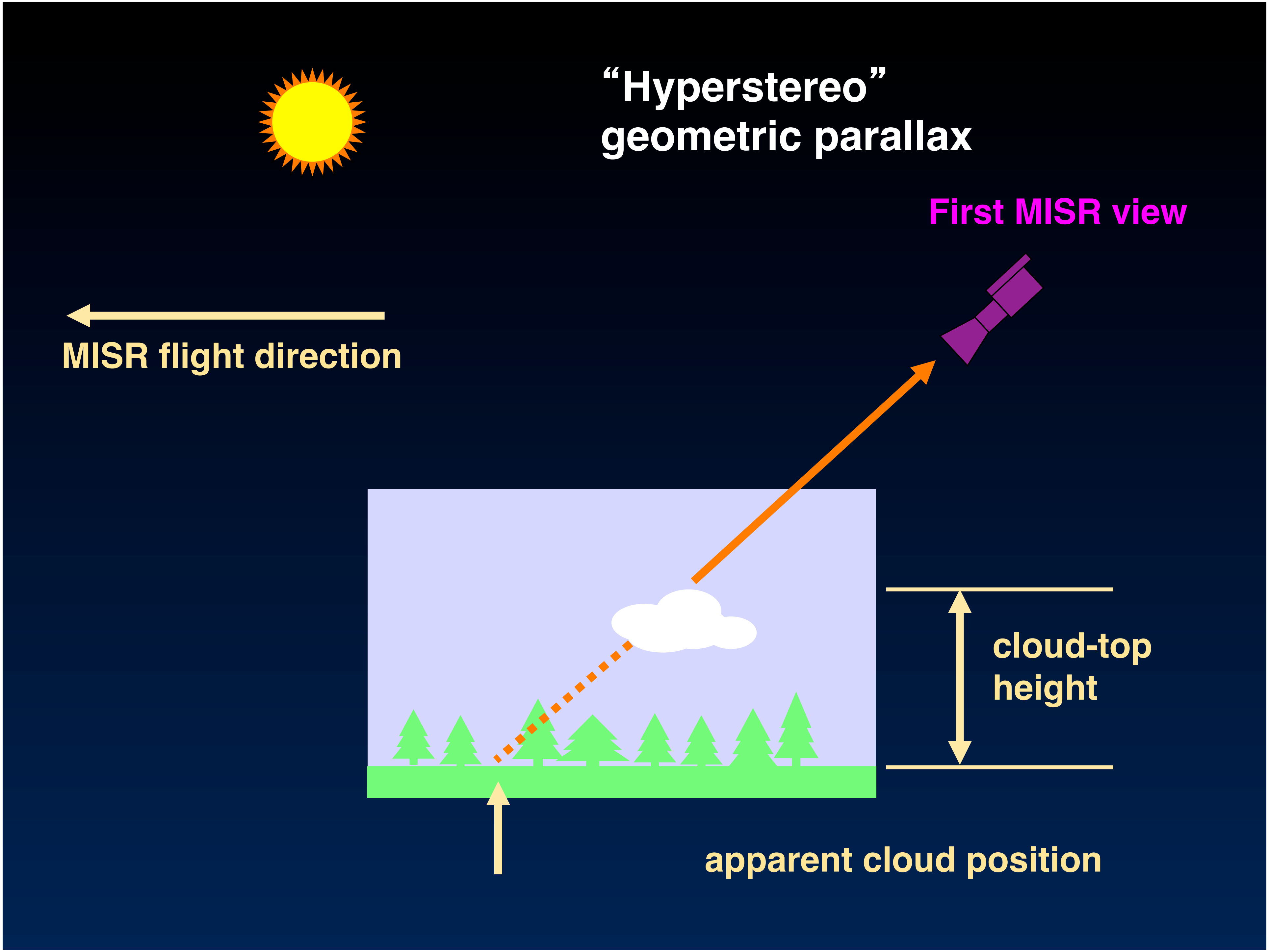
Retrieved cloud heights and cloud-tracked winds



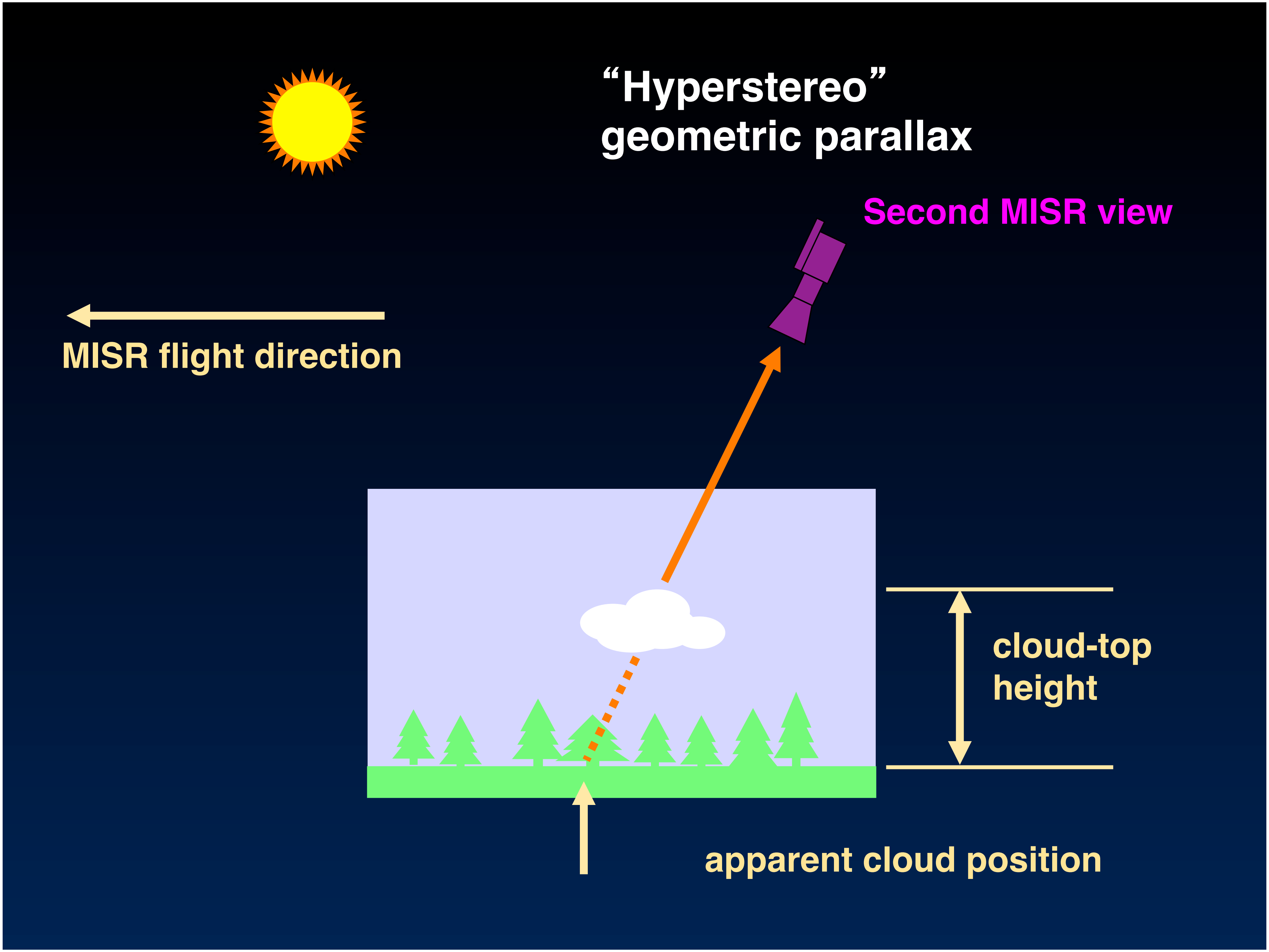
Southern Ocean, 20 August 2001

PRODUCT MATURITY: PROVISIONAL

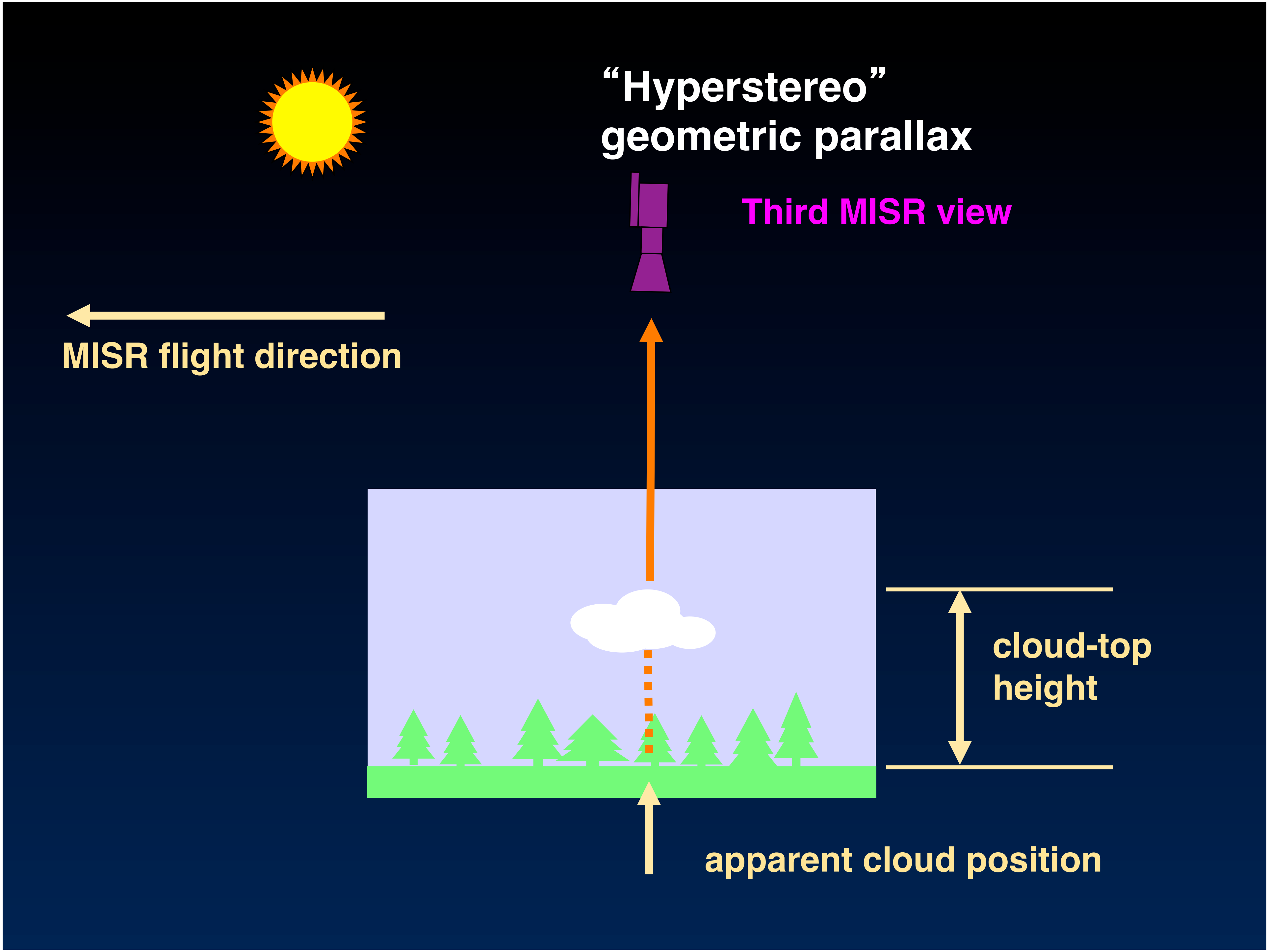
- Stereo matching errors cause occasional "spikes" in height fields
- Wind retrievals flagged with quality indicator
- Both "zero wind" and wind-adjusted height fields provided



"Hyperstereo"
geometric parallax
First MISR view
MISR flight direction
cloud-top
height
apparent cloud position

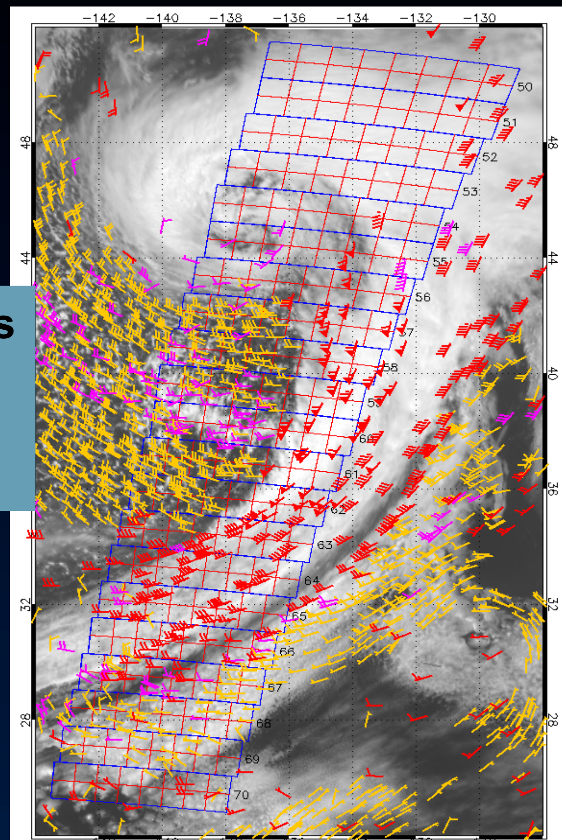


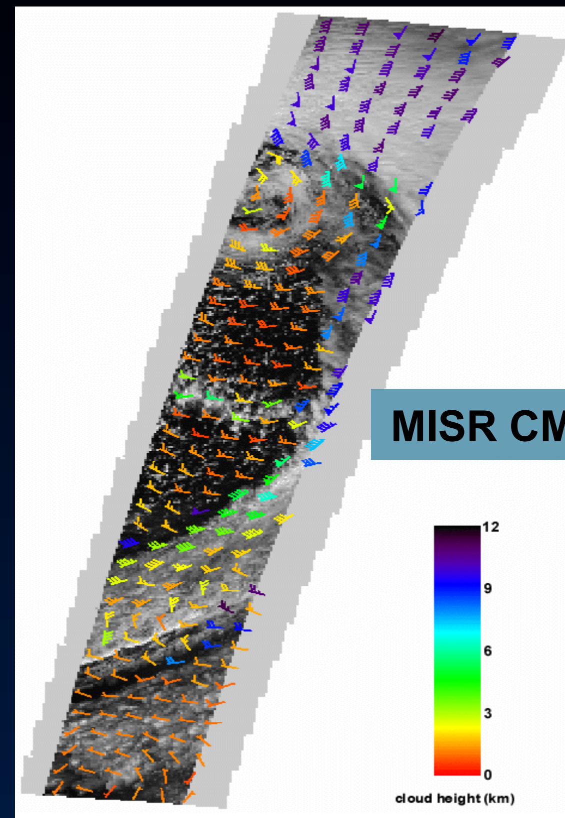
"Hyperstereo"
geometric parallax
Second MISR view
MISR flight direction
cloud-top
height
apparent cloud position


"Hypersterео"
geometric parallax
Third MISR view
MISR flight direction
cloud-top
height
apparent cloud position

Height-resolved cloud-motion winds

Extratropical cyclone

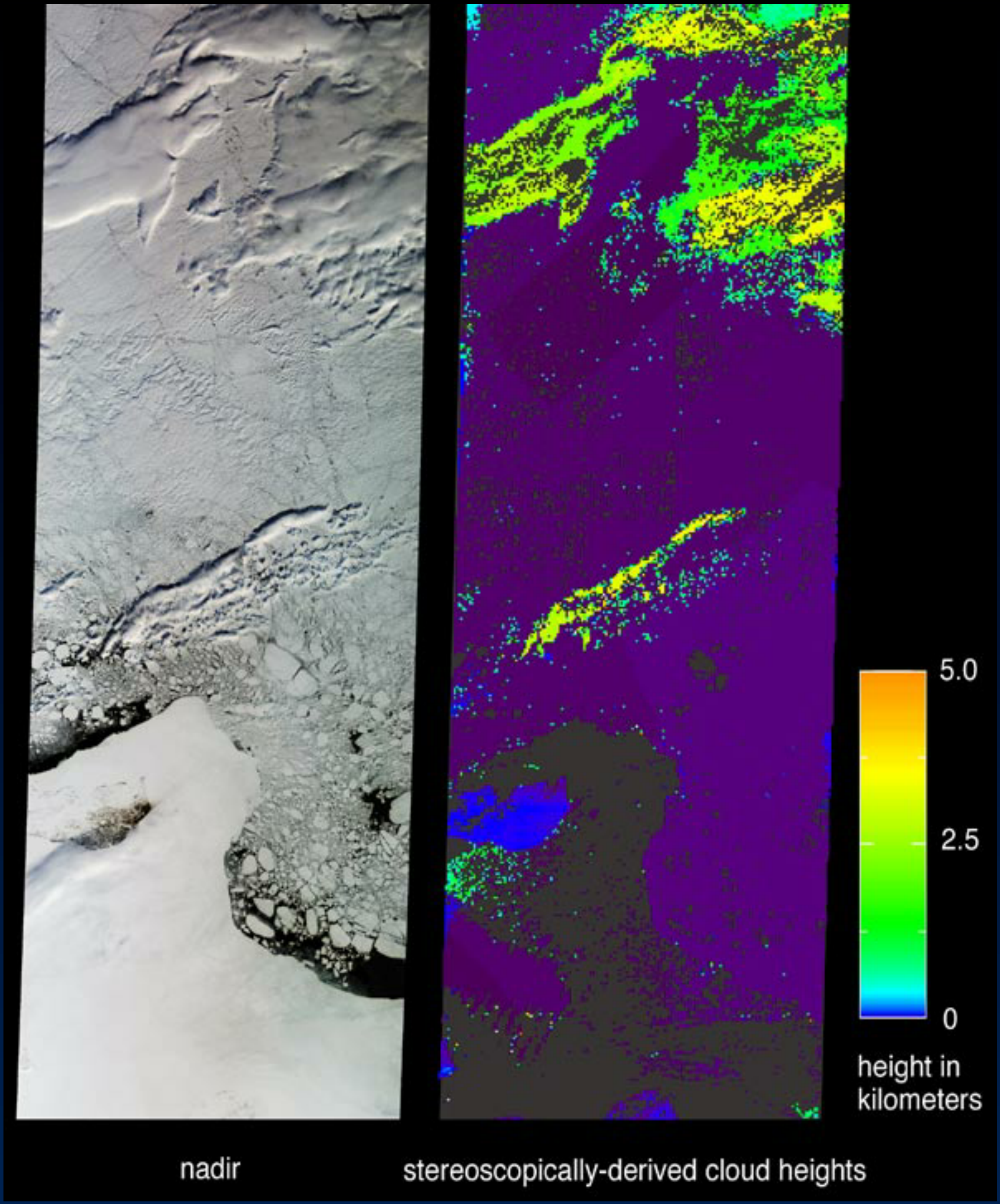




Height-resolved cloud-motion winds can be retrieved from pole to pole, which is potentially useful for NWP.

Acknowledgment: A. Horvath, UofArizona

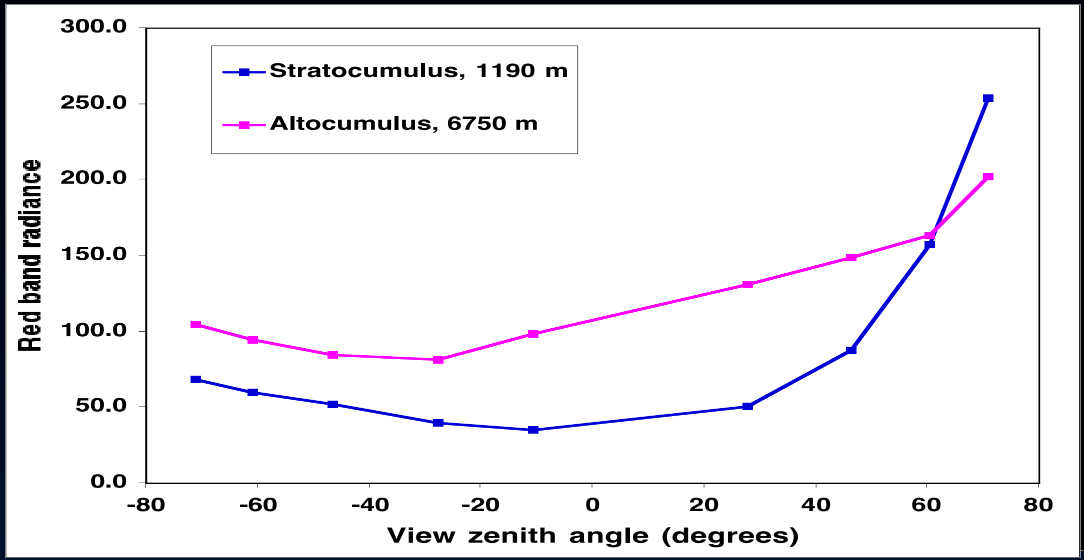
Distinguishing Clouds from Ice using Stereo

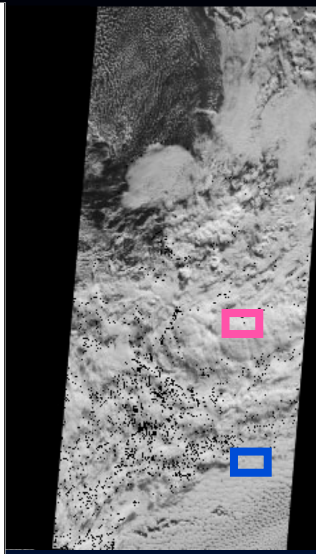


East Siberian Sea, Russia
May 28, 2002

L2 TOA/Cloud Albedo Product (MIS04)

Cloud-top-projected TOA albedo and bidirectional reflectance





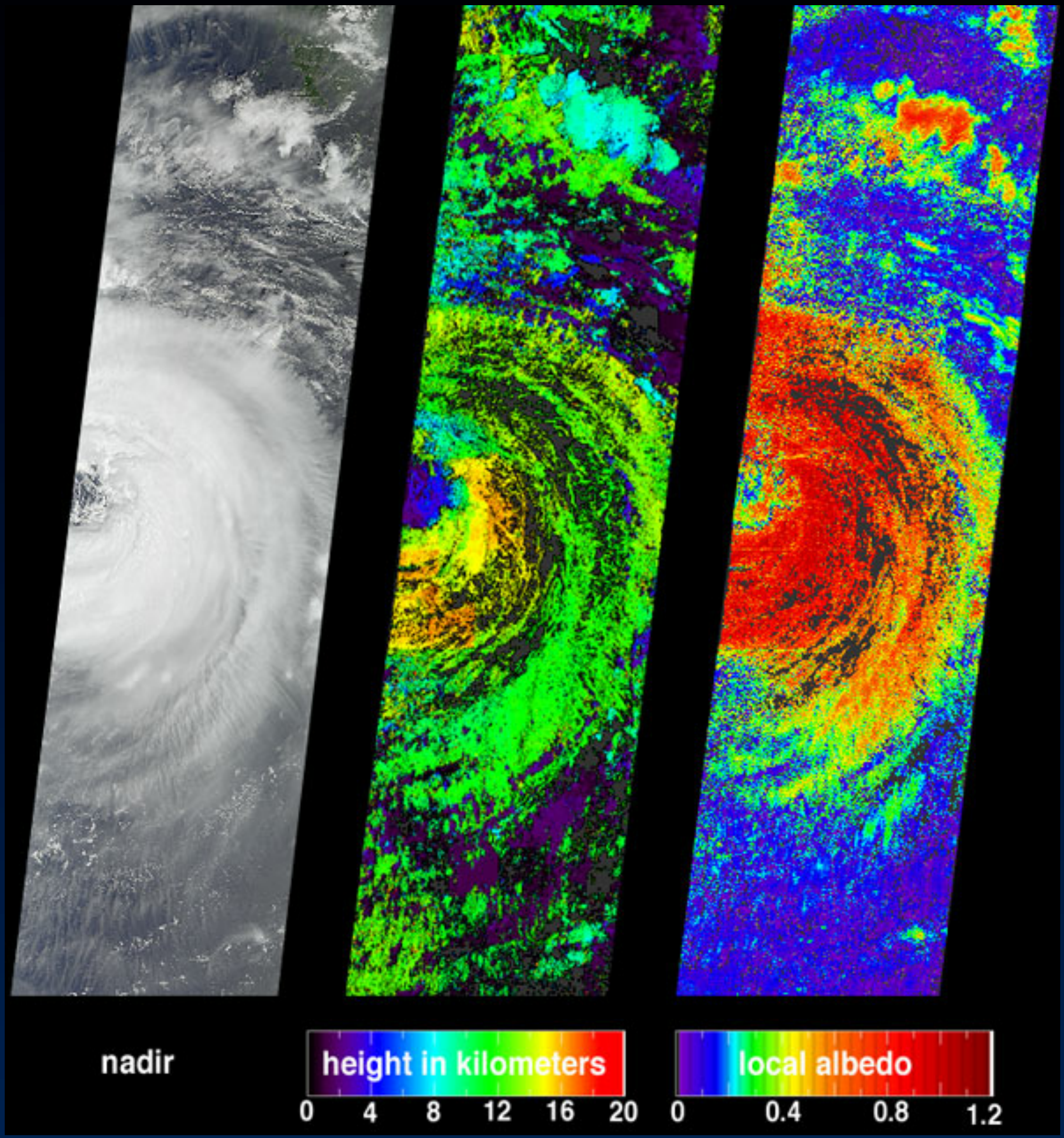
Southern Pacific Ocean, June 11, 2000

PRODUCT MATURITY: PROVISIONAL

- Contains “feature-referenced” top-of-atmosphere bidirectional reflectances
- Includes three types of TOA albedos in product:

-- local: 2.2 km sampling, for use with scene classification
-- restrictive: 35.2 km sampling, characterizes reflection within 35.2 km area
-- expansive: 35.2 km sampling, integrates reflection over large spatial area as if observed by a pyranometer above the atmosphere

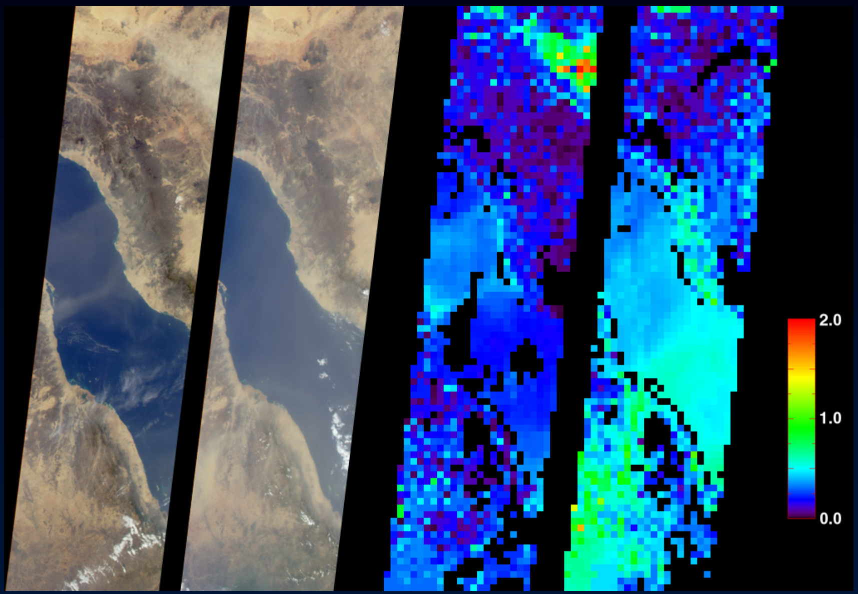
Example cloud products



Typhoon Sinlaku
September 5, 2002

L2 Aerosol/Surface Product (MIS05)

Aerosol parameters



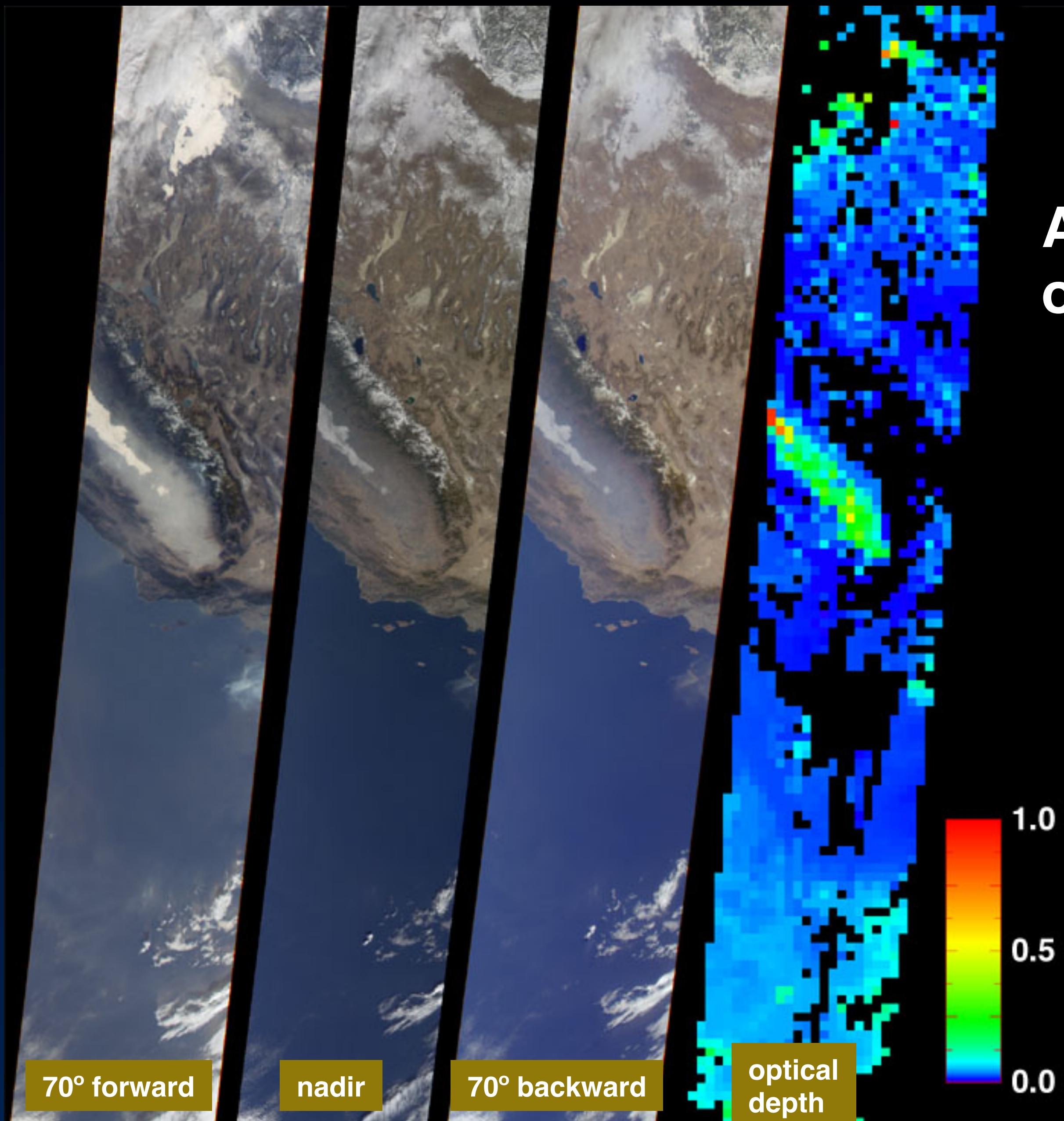
70° image retrieved optical depth

Saudi Arabia and the Red Sea

Left panel of each pair: March 25, 2001
Right panel of each pair: June 29, 2001

PRODUCT MATURITY: PROVISIONAL

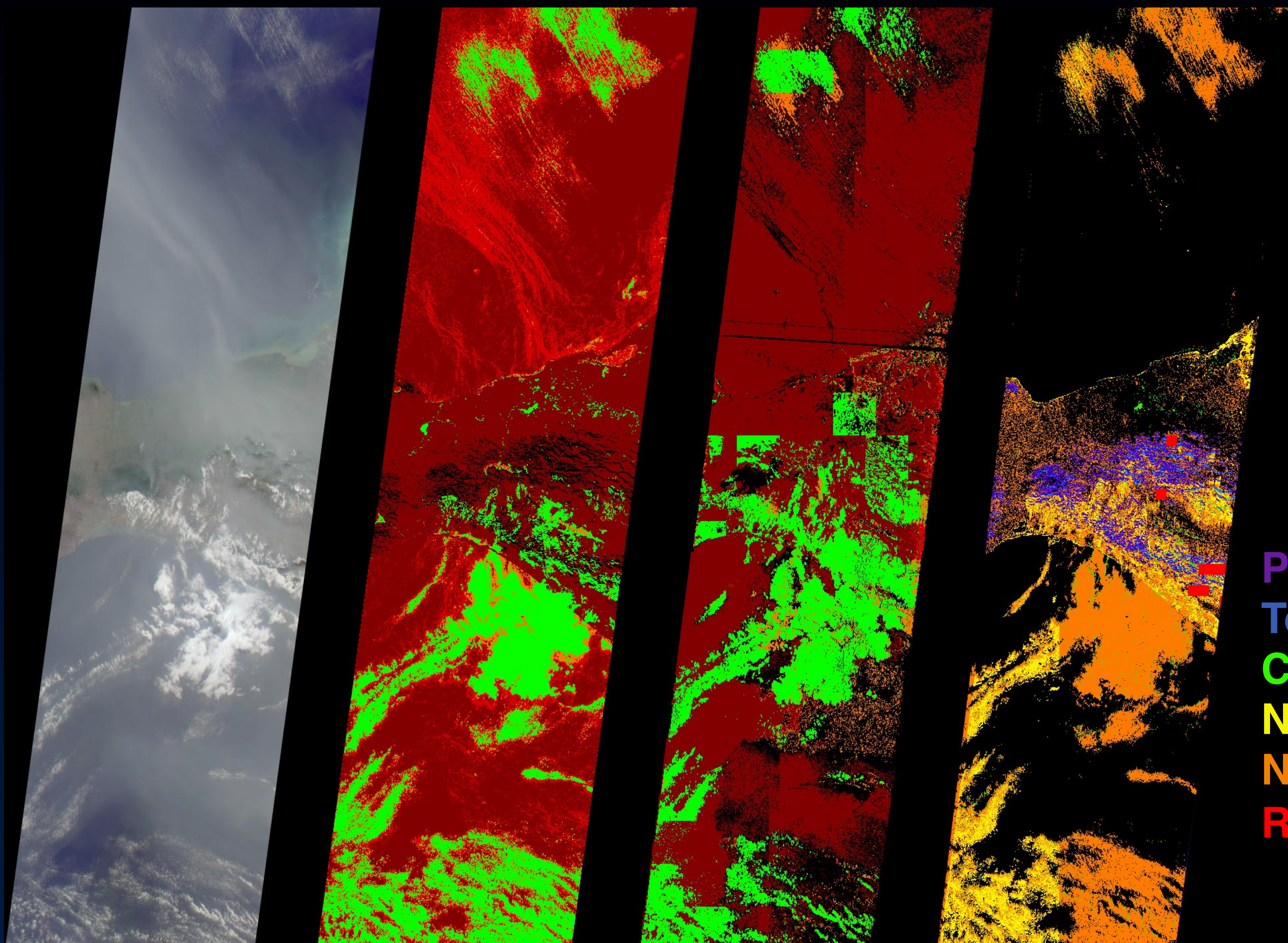
- Different algorithms used over land and water
- Multiple cloud screening methods used
- Detailed validation and quality assessment in progress



Aerosol Retrievals over Land and Water

Southern California and
Southwestern Nevada
January 3, 2001

Multiple cloud identification methods



Poor quality data
Topographically obscured
Cloudy
Not smooth with angle
Not correlated with angle
Region not suitable

70º backward image

RCCM

SDCM

ClearHC ClearLC
CloudLC CloudHC

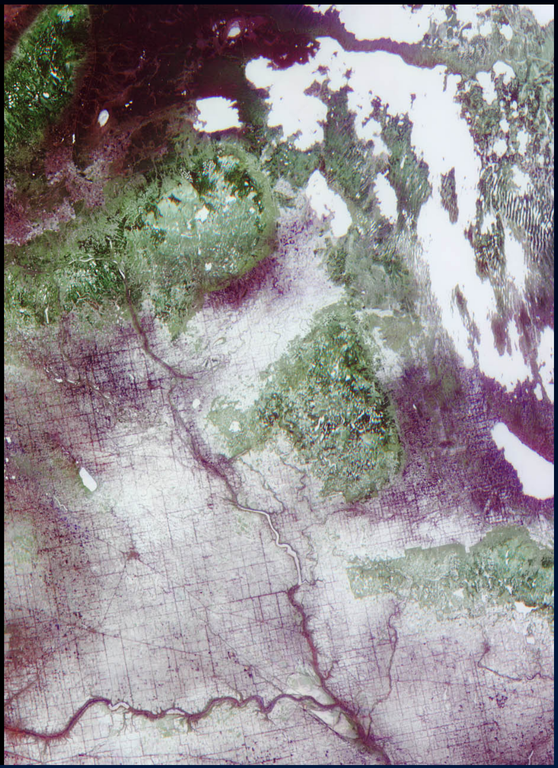
Retrieval applicability mask

Southern Mexico
May 2, 2002

L2 Aerosol/Surface Product (MIS05)

Surface parameters

Nadir NIR spectral
top-of-atmosphere composite



Multi-angle top-of-atmosphere
composite

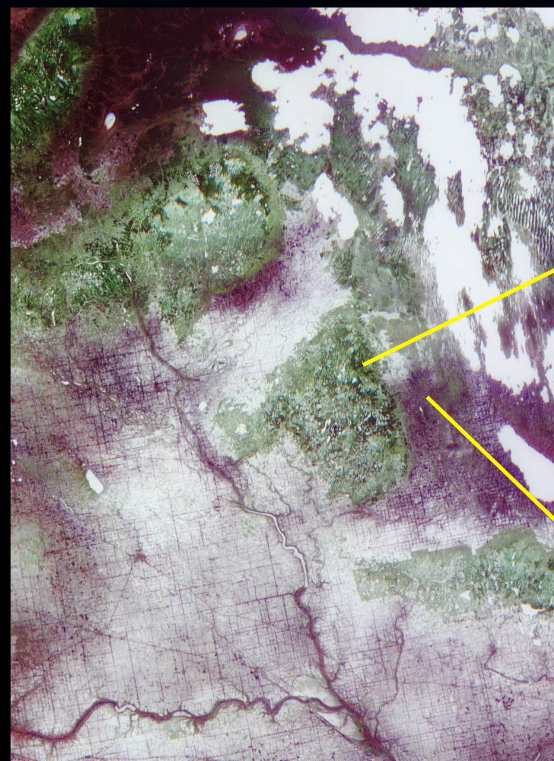
Manitoba and
Saskatchewan,
April 17, 2001

PRODUCT MATURITY: PROVISIONAL

- Includes radiometric surface parameters (directional reflectances, albedos) as well as vegetation-related quantities (albedo-based surface NDVI, LAI, FPAR)
- Surface product quality directly dependent on quality of aerosol retrievals over land

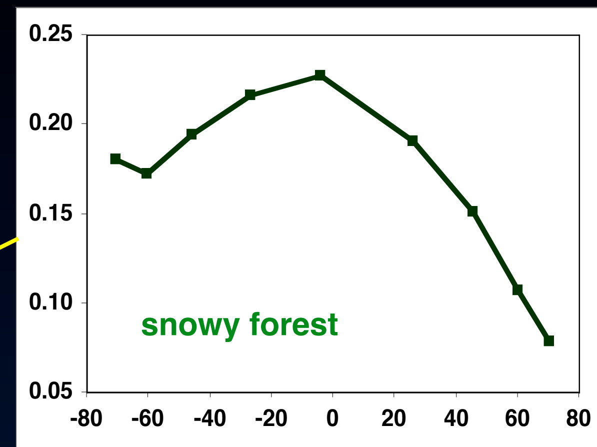
Bidirectional reflectance factors (BRF)

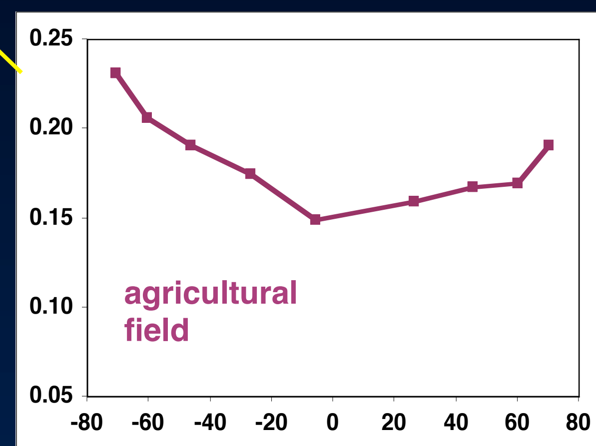
Nadir NIR spectral
top-of-atmosphere composite



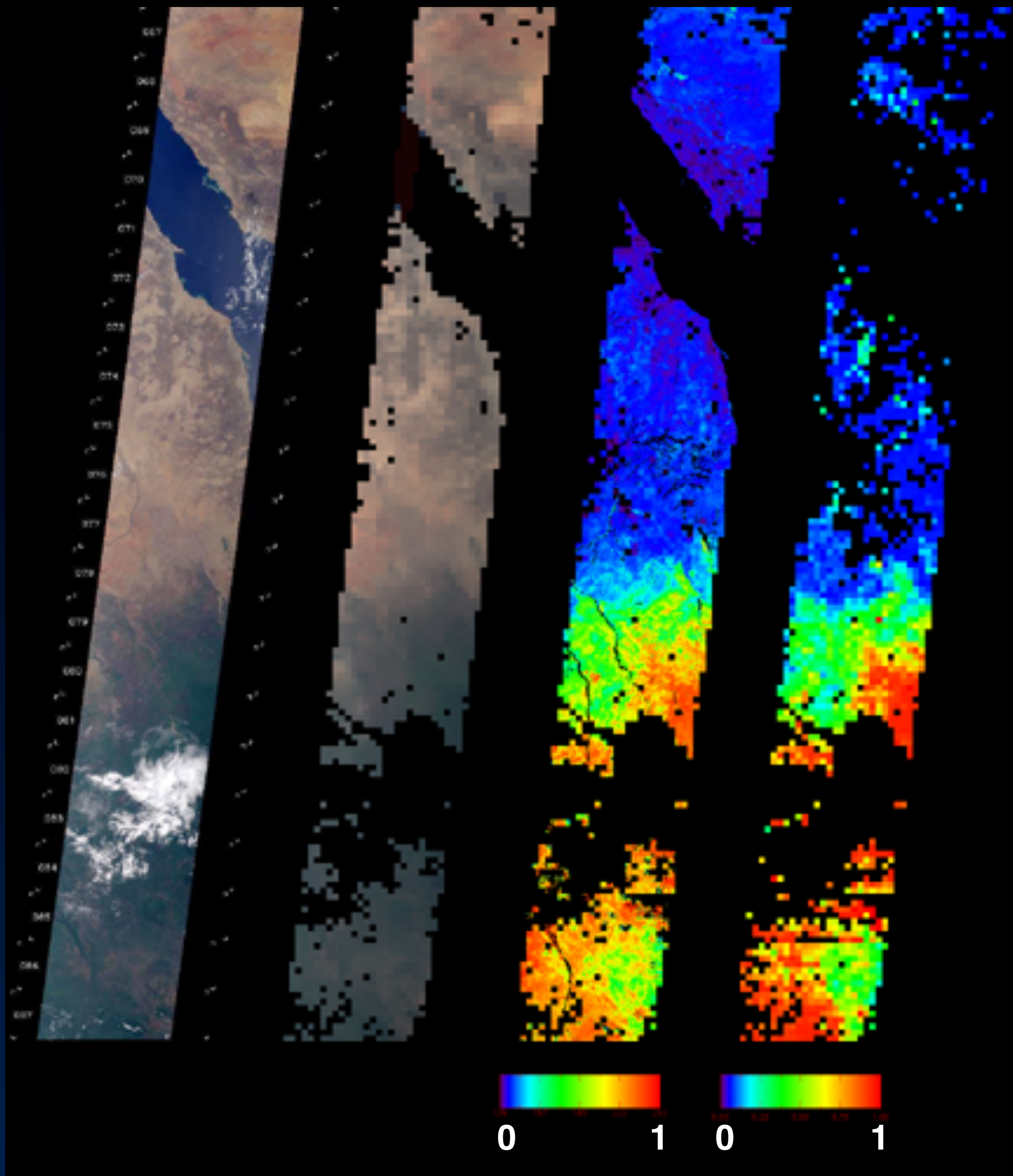
Multi-angle top-of-atmosphere
composite

Manitoba and
Saskatchewan,
April 17, 2001





retrieved surface
bidirectional reflectance
factor (672 nm) vs. view angle



A B C D

Vegetation parameters

A. Nadir TOA radiance

B. Cloud-screened nadir TOA reflectance

C. Retrieved albedo-based NDVI

D. Retrieved FPAR

MISR FPAR retrievals are independent of NDVI

Use retrieved albedos, bidirectional reflectances, and vegetation canopy models

Saudi Arabia
and Sudan
September 18, 2002

L3 Gridded Radiances (MIS06)

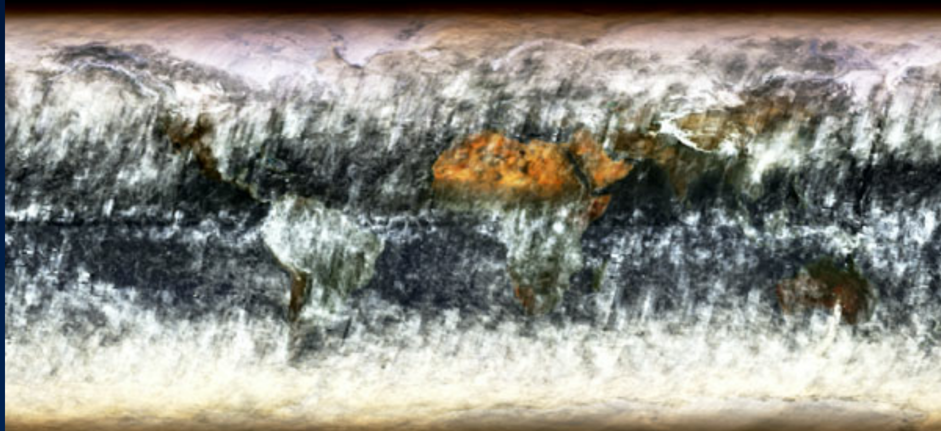
Means, variances, and covariances

Nadir red, green, blue

PRODUCT MATURITY: BETA

Nadir near-infrared, red, green

March 2002



70° forward: red, green, blue (N. hemisphere)
70° backward: red, green, blue (S. hemisphere)

Additional products you might need

Ancillary Radiometric Product

--contains extrasolar irradiances, standard wavelengths

--however, key information is being added to the L1B2 products to enable conversion from radiance to BRF

Ancillary Geographic Product

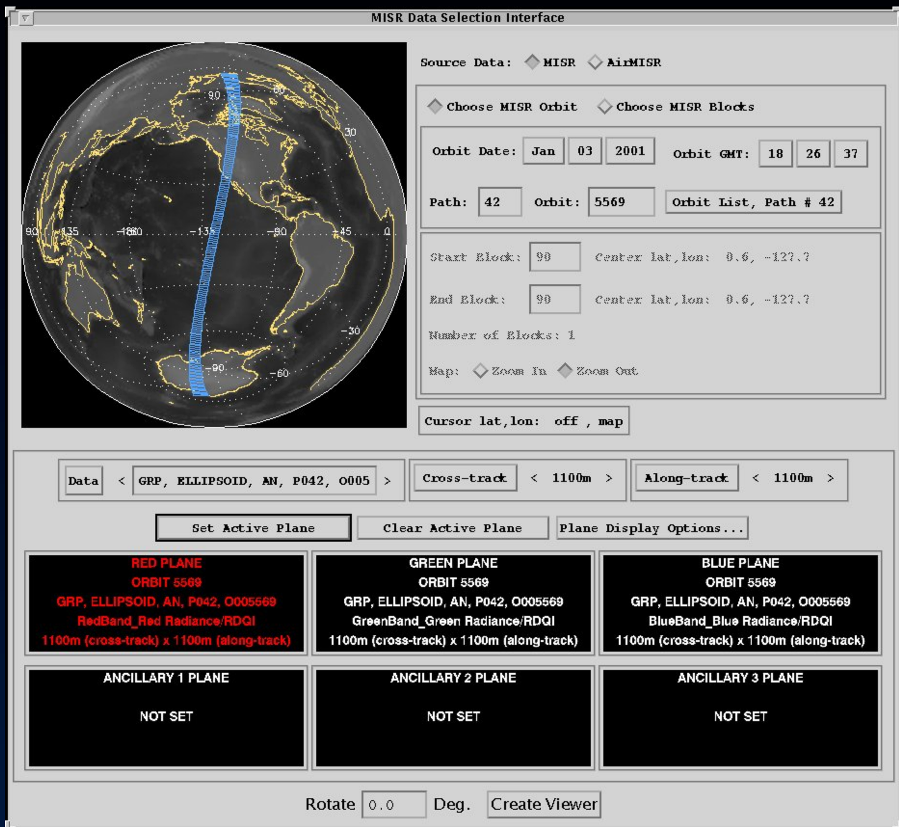
--contains latitudes, longitudes, elevations, scene classifiers for each 1.1-km pixel on the Space Oblique Mercator grid

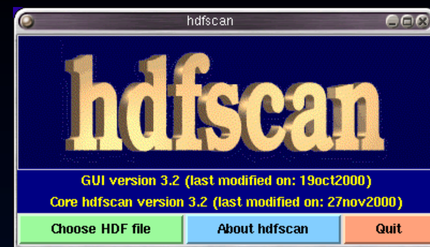
Aerosol Climatology Product

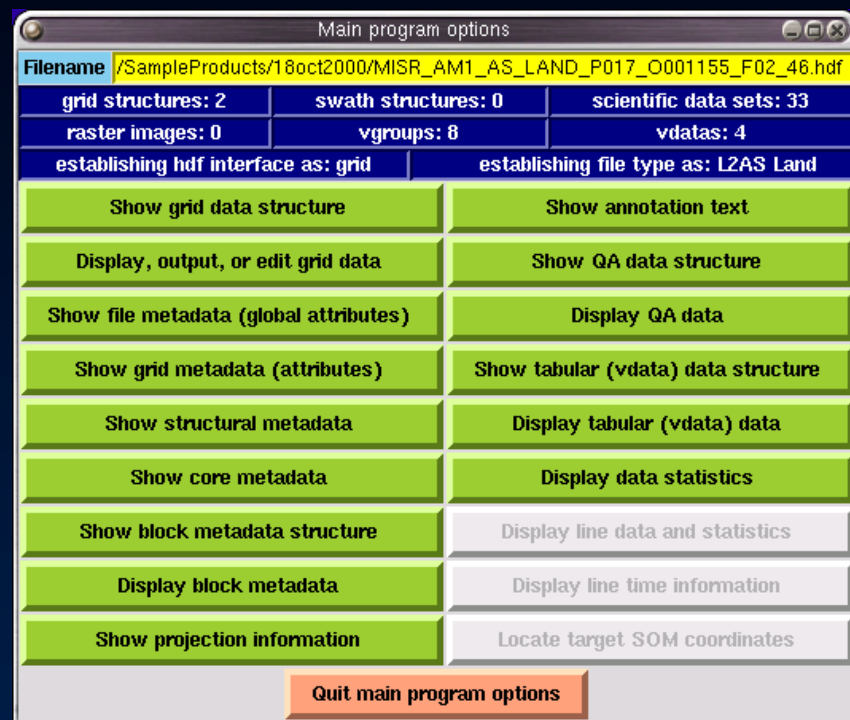
--Aerosol Physical and Optical Properties (APOP) contains characteristics of the component particles used in the aerosol retrievals

--Mixture file contains characteristics of the particle mixtures used

Data visualization and analysis tools







- misr_view (IDL-based)
- hdfscan (Tcl/tk and Fortran90 based)
- HDF-to-binary converter
- HDF-EOS to GeoTIFF converter

http://eosweb.larc.nasa.gov/PRODOCS/misr/misr_tools.html

Where to get help and information:

LaRC DAAC User Services
larc@eos.nasa.gov

Langley Atmospheric Sciences Data Center DAAC
http://eosweb.larc.nasa.gov

MISR home page
http://www-misr.jpl.nasa.gov

"Special Section on MISR" in July 2002
IEEE Transactions on Geoscience and Remote Sensing
17 papers about the instrument, data products, calibration, retrieval methods, and results

We welcome your feedback!
suggestions@mail-misr.jpl.nasa.gov