Multiangle remote sensing from MISR: Overview and observational principles

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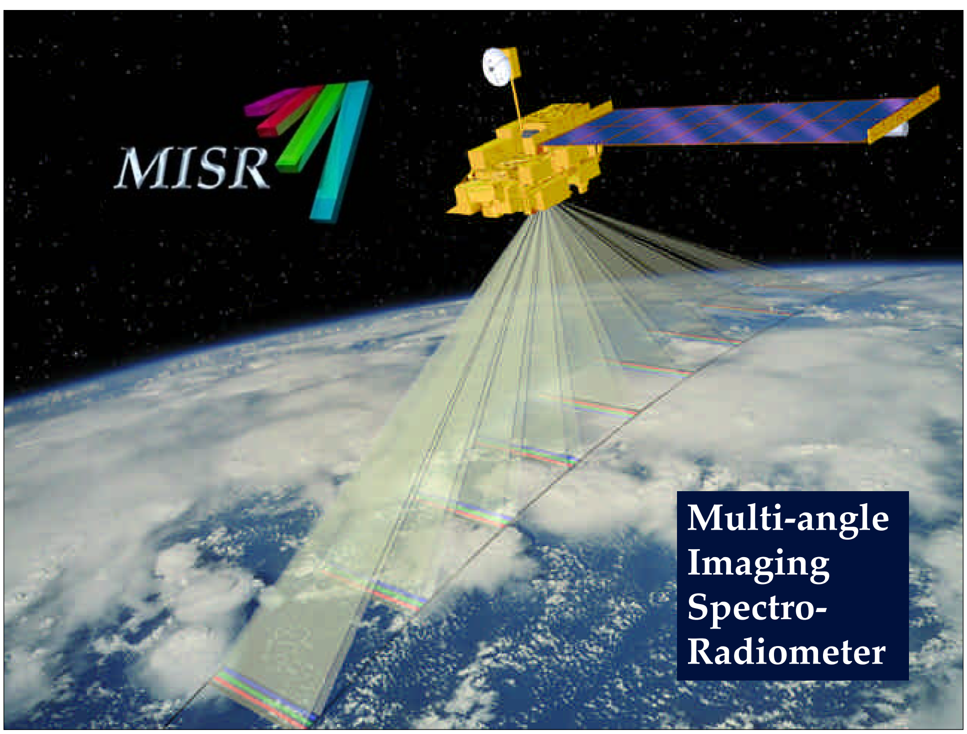
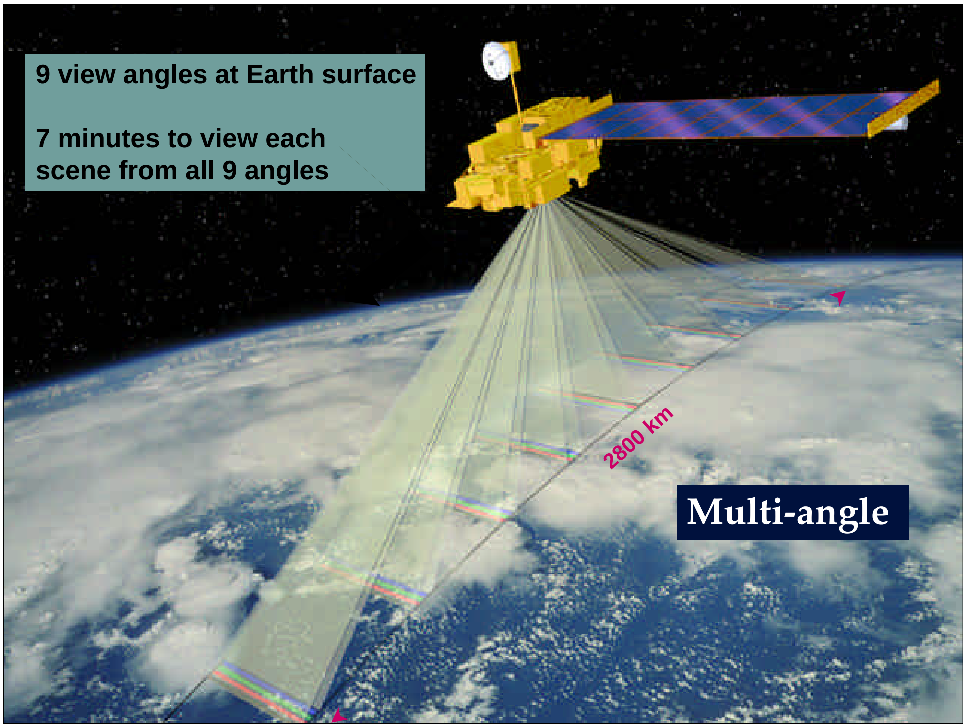
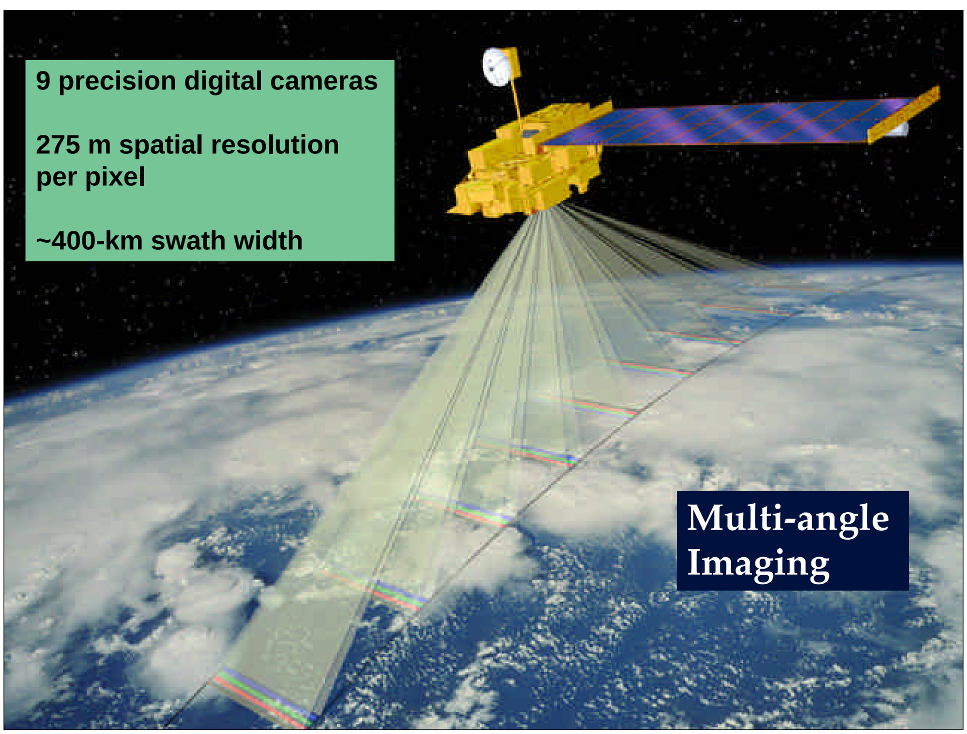
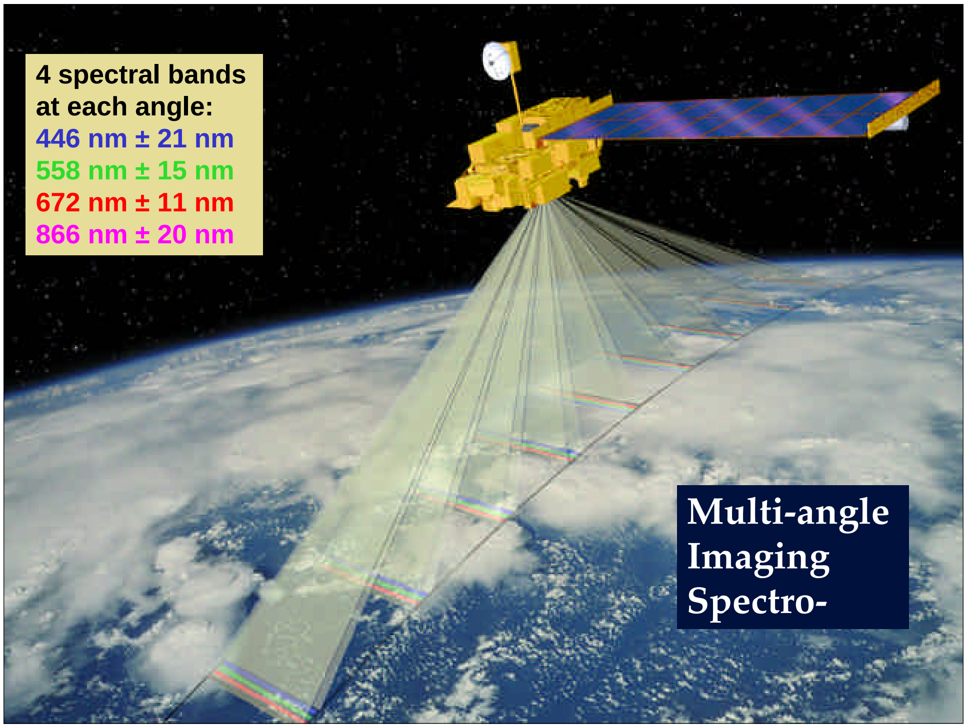
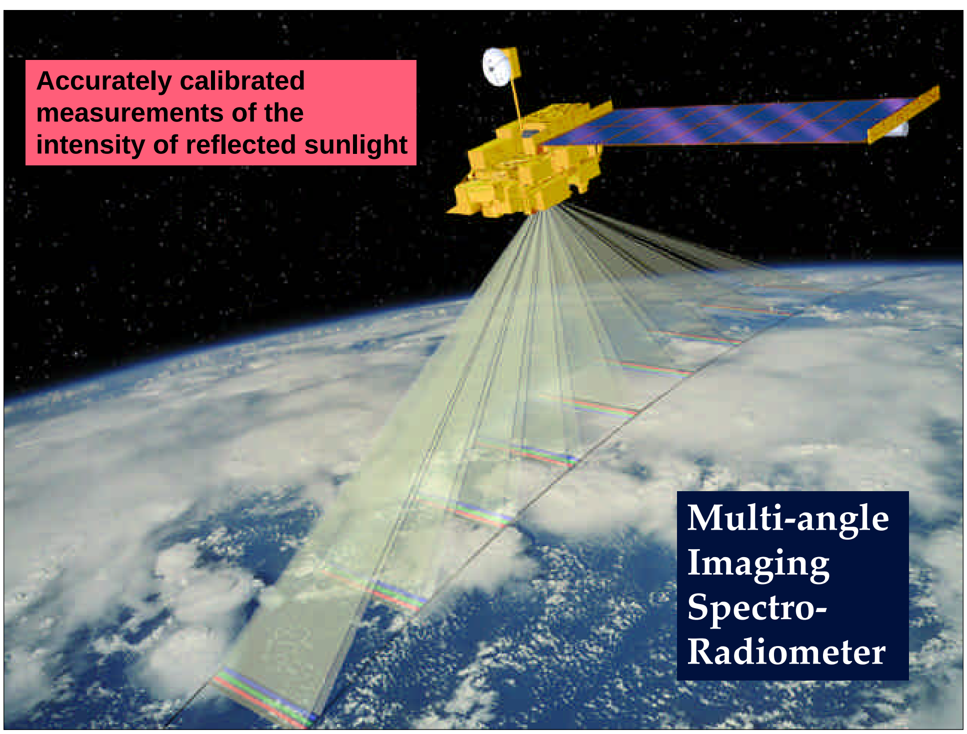
International course on
Remote Sensing of the Earth's Environment from Terra
Scuola Superiore Reiss Romoli, L'Aquila, Italy
August 29, 2002




9 view angles at Earth surface
7 minutes to view each scene from all 9 angles
2800 km
Multi-angle


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-


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

“Family portrait”

Four unique lens designs of different focal lengths

Lenses

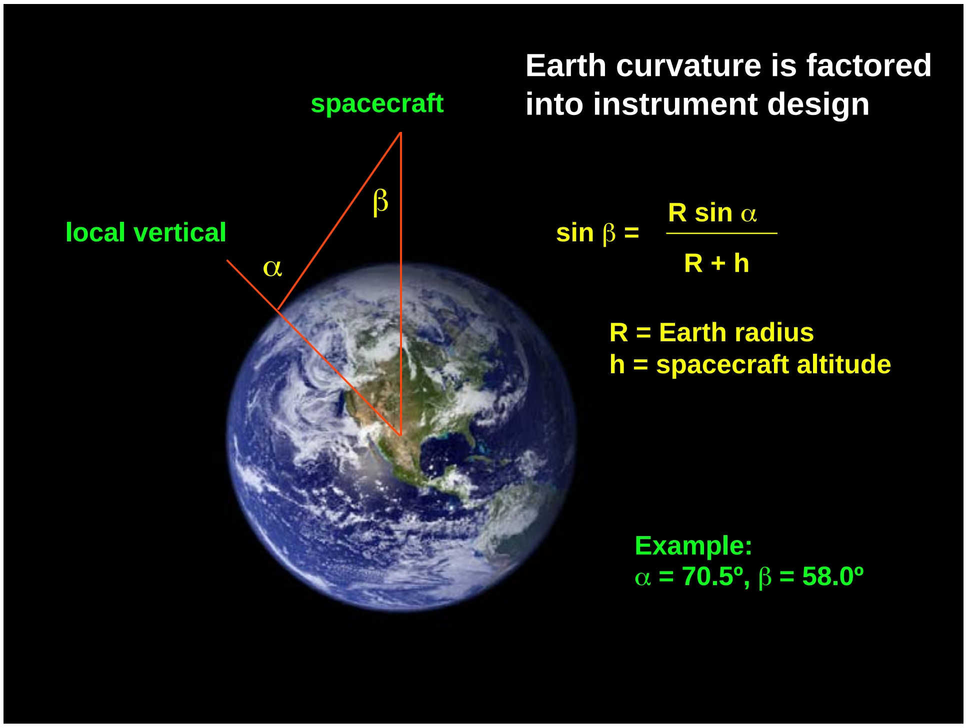
- 7 element, f/5.5 refractive superachromats: Maintain focus at all wavelengths

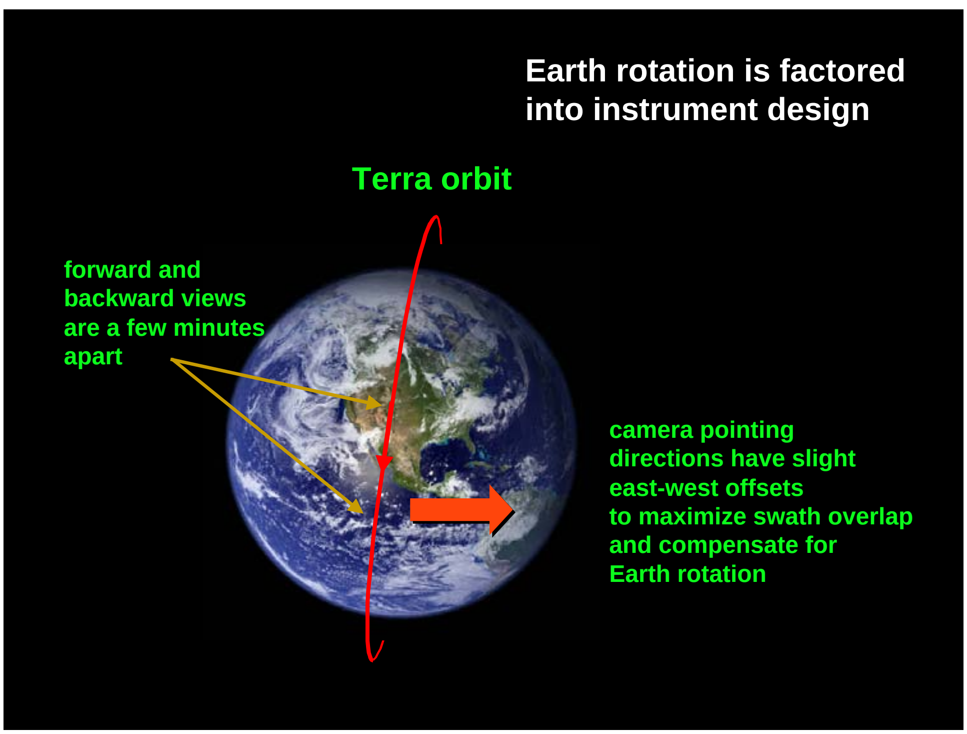
- Telecentric: Rays traverse spectral filters at near-normal incidence to preserve spectral performance uniformity across the fields of view

- Polarization insensitivity: Achieved by including Lyot depolarizer

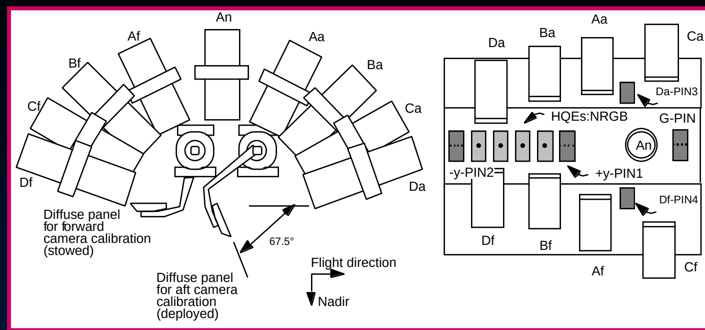
MISR instrument

MISR in the
10-foot Space Simulator Facility


Earth curvature is factored into instrument design
spacecraft
local vertical
β
α
sin β = R sin α / (R + h)
R = Earth radius
h = spacecraft altitude
Example:
α = 70.5º, β = 58.0º


Earth rotation is factored into instrument design
Terra orbit
forward and backward views are a few minutes apart
camera pointing directions have slight east-west offsets to maximize swath overlap and compensate for Earth rotation

Radiometric and geometric calibration



On-board calibrator (OBC):

- Deployable Spectralon panels monitored by stable photodiodes
- Provides camera flat-fielding, camera-to-camera and band-to-band calibration, and temporal stability
- Supplemented by vicarious field calibrations to establish absolute scale

Camera geometric models (CGM's) are established using image tie-pointing between MISR and Landsat

- CGM's are used in the automated map projection of MISR data

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

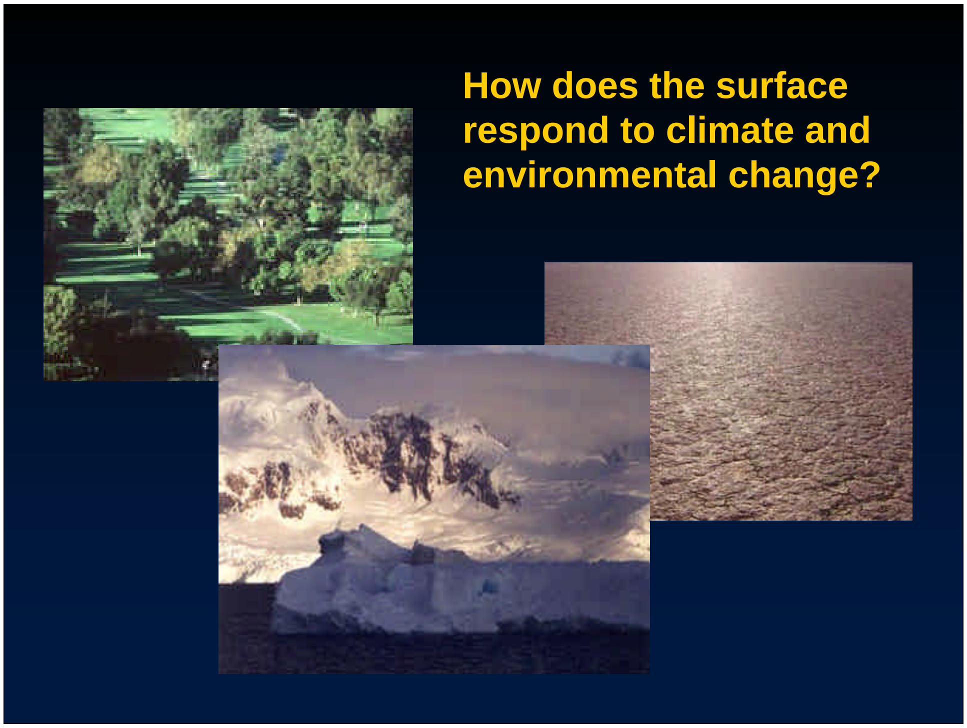
- Implemented bi-monthly
- Spectralon solar diffuser panels are deployed near poles and observed by cameras and a set of photodiodes

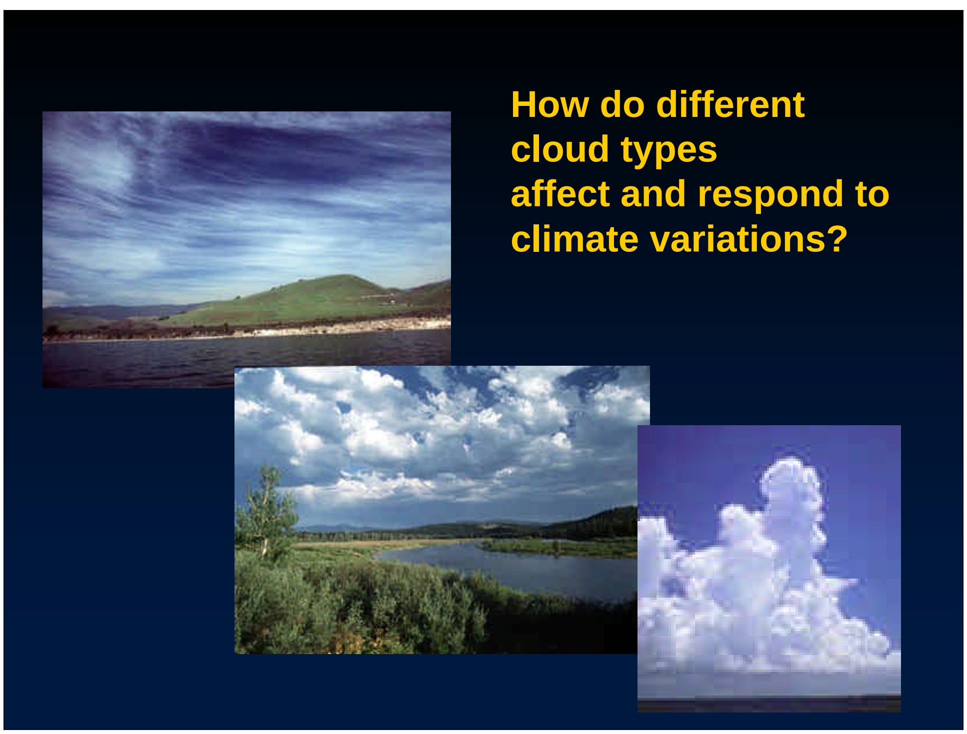
MISR Science Team

Thomas P. Ackerman	PNNL
Carol J. Bruegge	JPL
Eugene Clothiaux	Penn. State
James E. Conel	JPL
Roger Davies	JPL
Larry Di Girolamo	University of Illinois
David J. Diner (PI)	JPL
Siegfried A. W. Gerstl	Los Alamos National Lab
Howard Gordon	University of Miami
Ralph A. Kahn	JPL
John V. Martonchik	JPL
Jan-Peter Muller	University College London
Ranga Myneni	Boston University
Anne W. Nolin	University of Colorado/NSIDC
Bernard Pinty	Joint Research Center
Piers Sellers	Johnson Space Center
Michel M. Verstraete	Joint Research Center

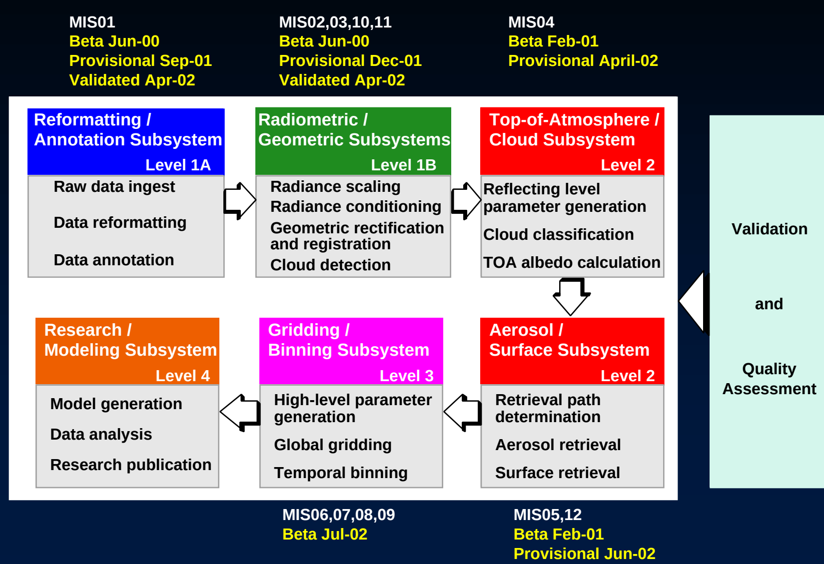
What are the climatic and environmental impacts of airborne particulates (aerosols)?




How does the surface
respond to climate and
environmental change?


How do different
cloud types
affect and respond to
climate variations?

MISR data product generation



Level 1 Standard Products

Level 1 standard products

- Level 1A reformatted, annoted 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

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

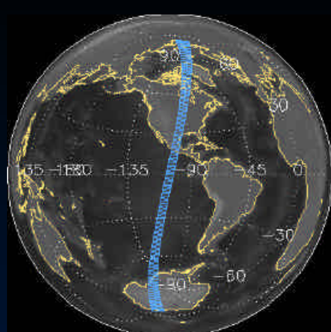
Ancillary products

Ancillary Radiometric Product

contains extrasolar irradiances at MISR standard wavelengths

Ancillary Geographic Product

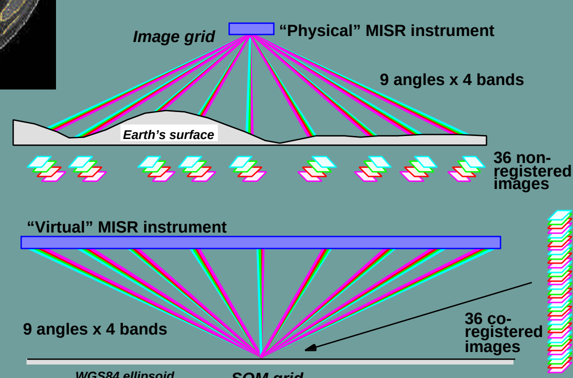
contains latitudes, longitudes, elevations, scene classifiers for each 1.1-km pixel on the Space Oblique Mercator grid

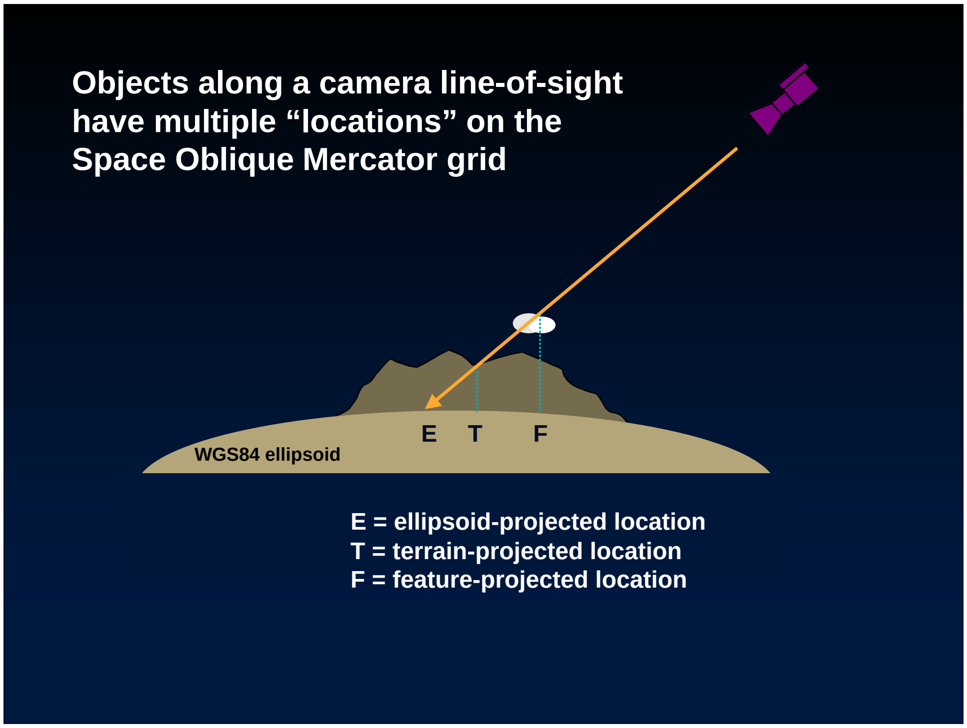


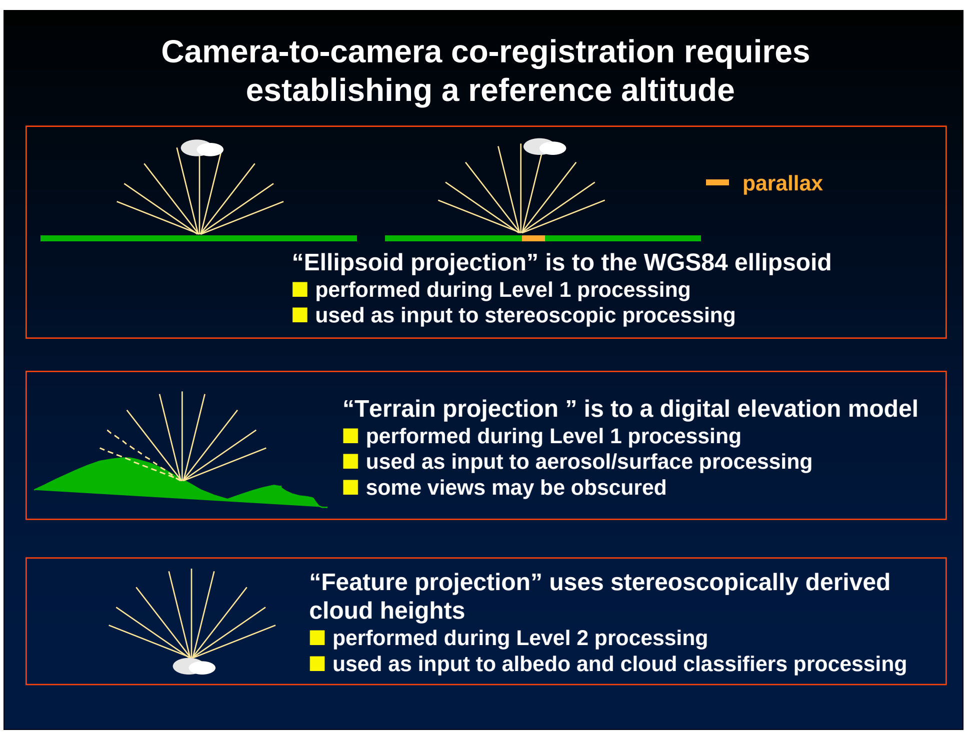
Geolocation, resampling, and co-registration occurs during Level 1 processing

Space Oblique Mercator projection

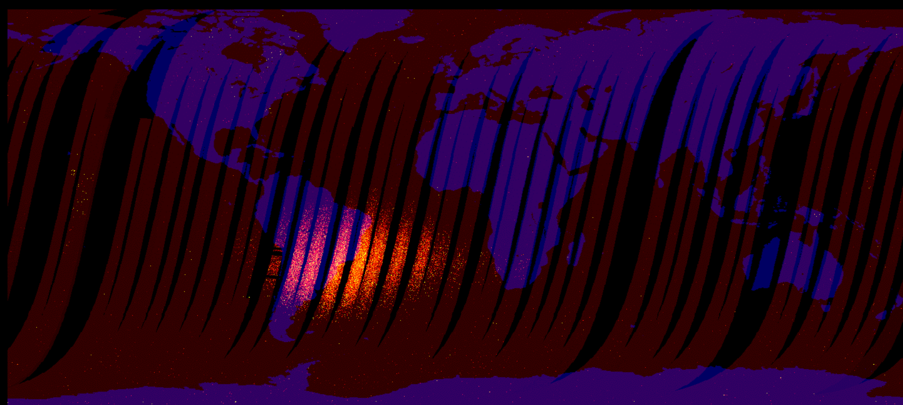
233 unique paths in 16-day repeat-cycle of Terra orbit

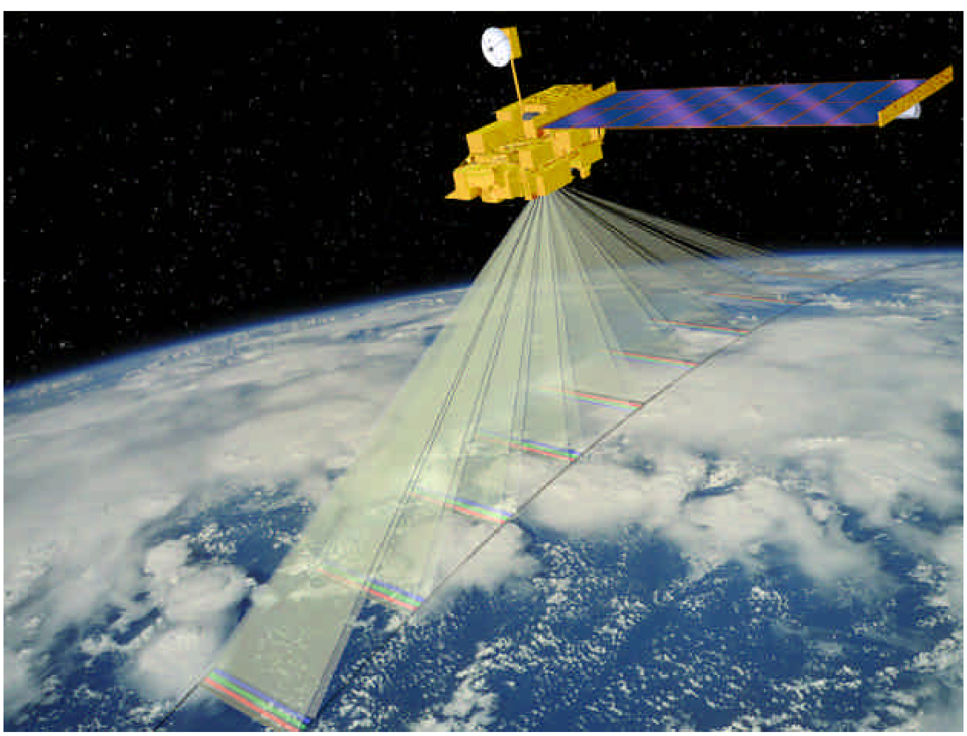


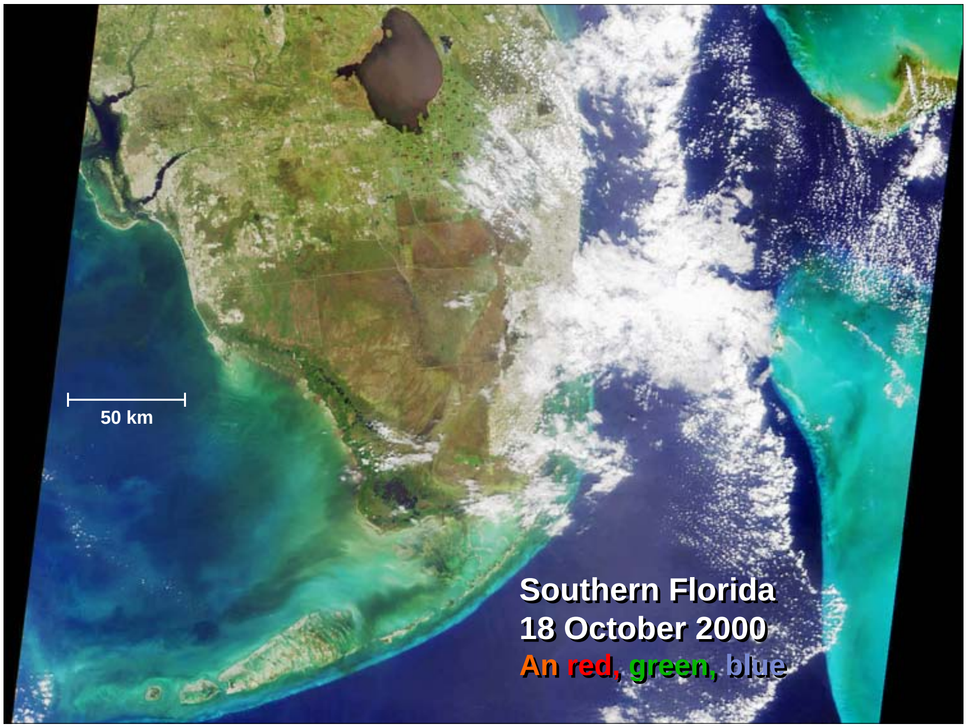

Objects along a camera line-of-sight
have multiple "locations" on the
Space Oblique Mercator grid
E
T
F
WGS84 ellipsoid
E = ellipsoid-projected location
T = terrain-projected location
F = feature-projected location

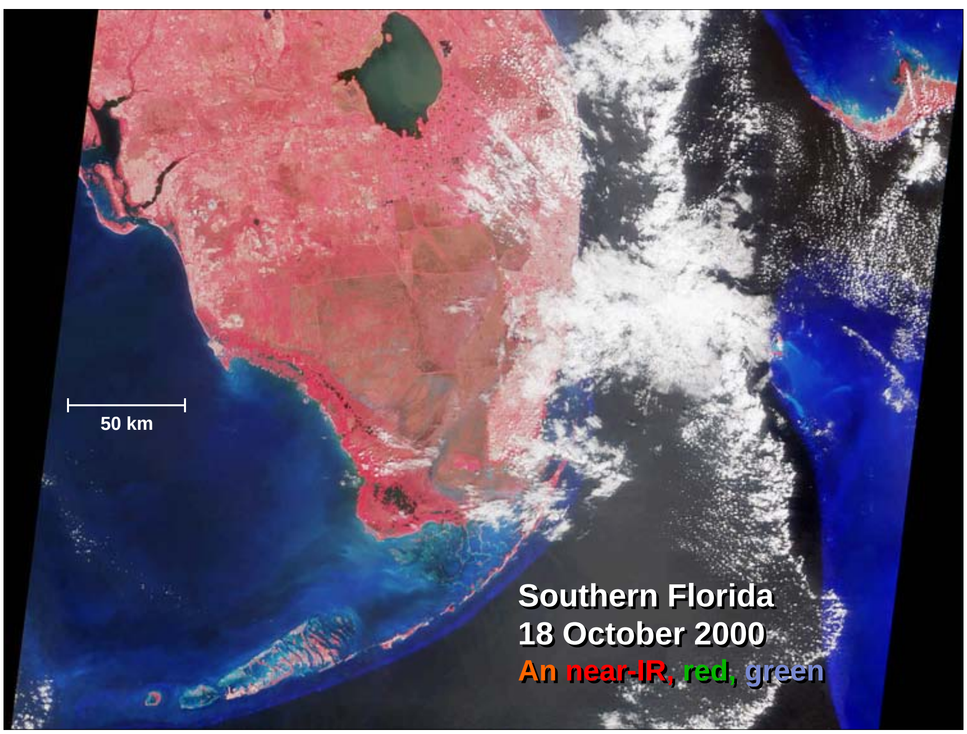

Camera-to-camera co-registration requires
establishing a reference altitude
parallax
"Ellipsoid projection" is to the WGS84 ellipsoid
performed during Level 1 processing
used as input to stereoscopic processing
"Terrain projection " is to a digital elevation model
performed during Level 1 processing
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

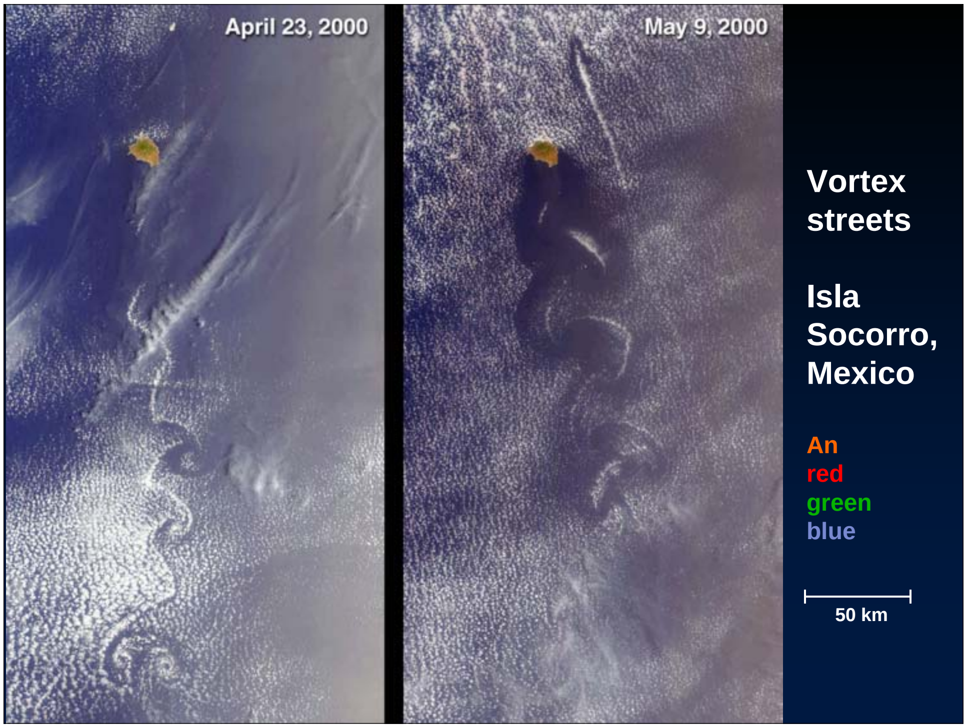
Pre-cover opening
MISR detects the South Atlantic Anomaly
3 - 15 February 2000

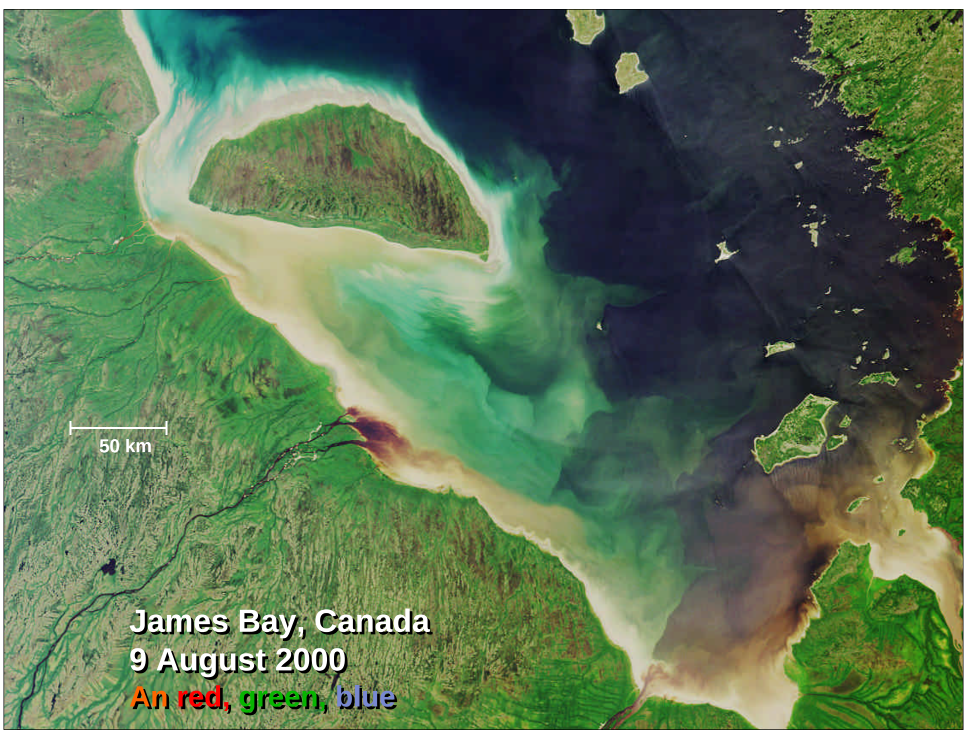





50 km
Southern Florida
18 October 2000
An red, green, blue


50 km
Southern Florida
18 October 2000
An near-IR, red, green


April 23, 2000
May 9, 2000
Vortex streets
Isla Socorro, Mexico
An
red
green
blue
50 km


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

Khartoum, Sudan,
18 August 2000 - 4 July 2001
Time sequence animation
An
near-IR
green
blue

50 km

Some definitions

Radiance: Radiant energy per unit area per unit solid angle per unit wavelength

Flux: Radiant energy per unit area integrated over all solid angles in a hemisphere

Specular reflector: A target which reflects a beam of incoming radiation into a single direction, with the angle of reflection equalling the angle of illumination (e.g., a mirror)

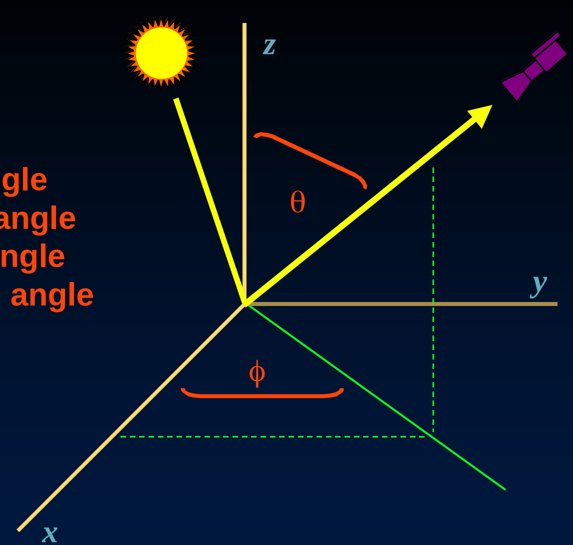
Lambertian reflector: A target which reflects a beam of incoming radiation isotropically into all directions with the same radiance (a “perfect diffuser”)

Hemispherical reflectance, or albedo: Ratio of reflected to incident flux

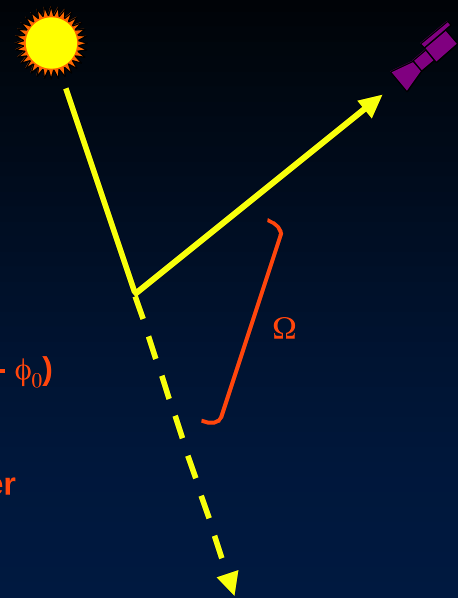
Rayleigh scattering: Scattering of light by particles much smaller than the wavelength of the incident light

Geometric definitions

θ = view zenith angle
ϕ = view azimuth angle
θ_0 = solar zenith angle
ϕ_0 = solar azimuth angle



Geometric definitions



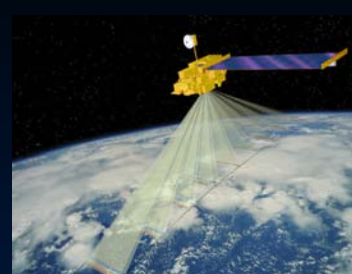
Ω = scattering angle

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

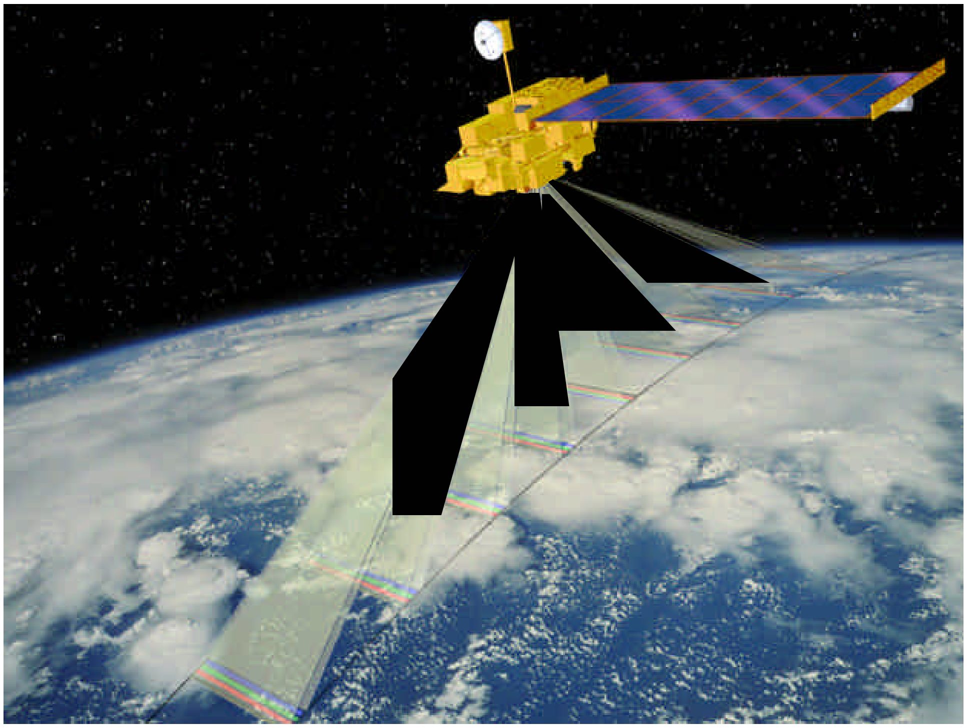
$\Omega < 90^o$ forward scatter

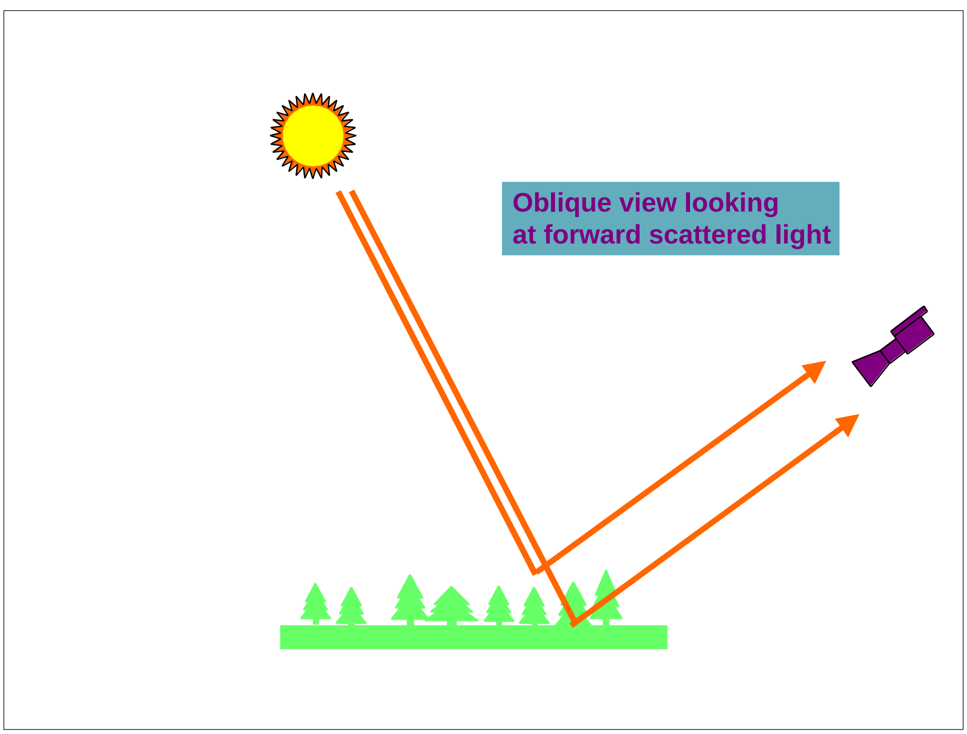
$\Omega > 90^o$ backward scatter

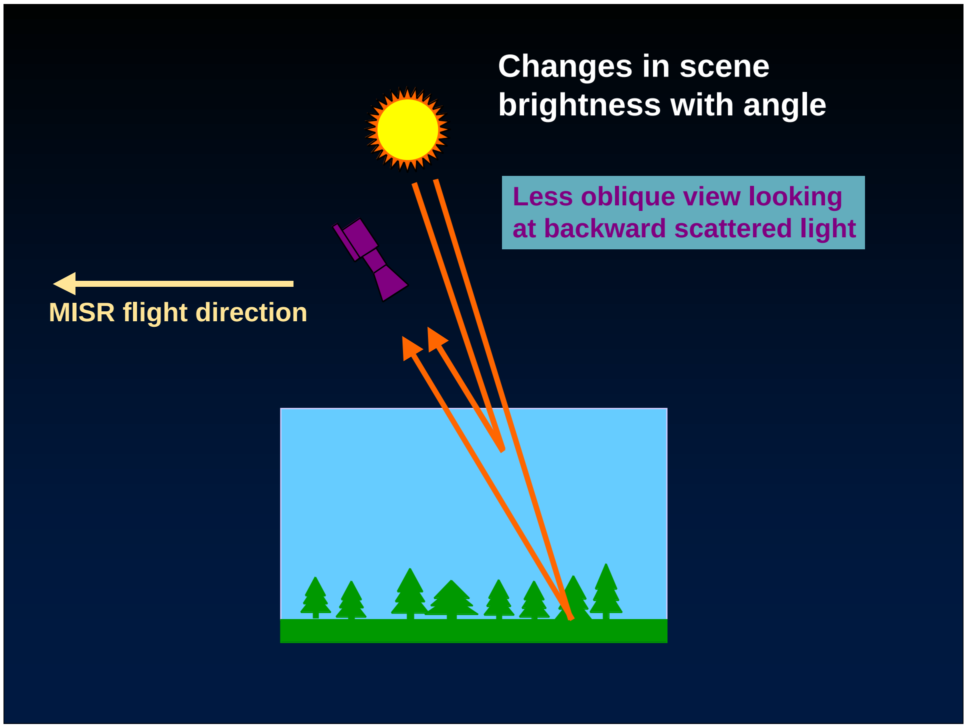
Why multi-angle?



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




Oblique view looking
at forward scattered light


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

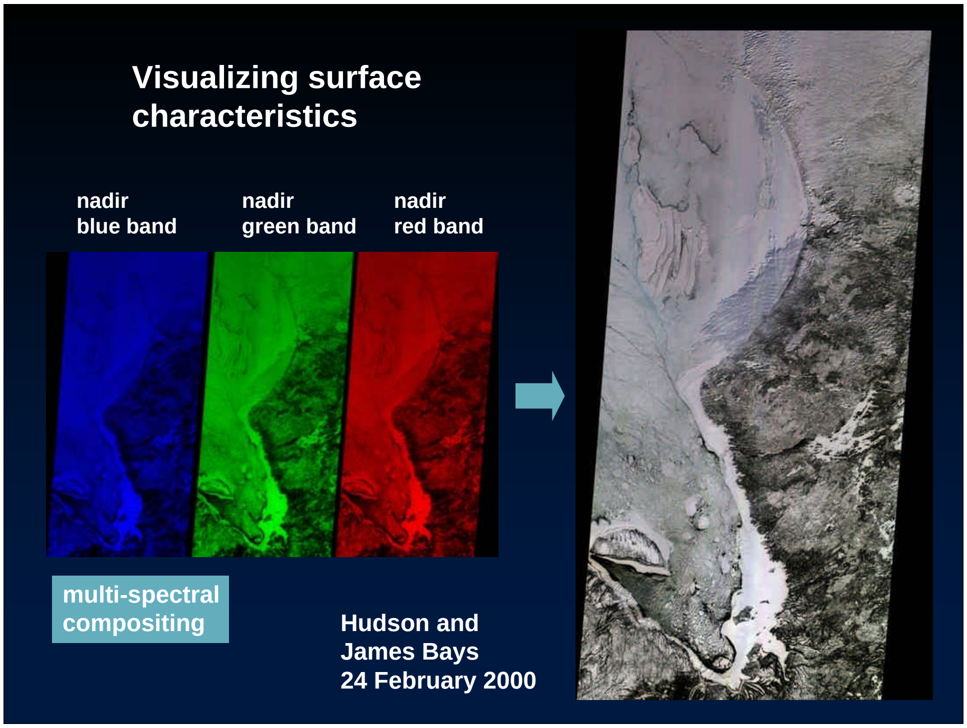

San Joaquin Valley
3 January 2001
nadir

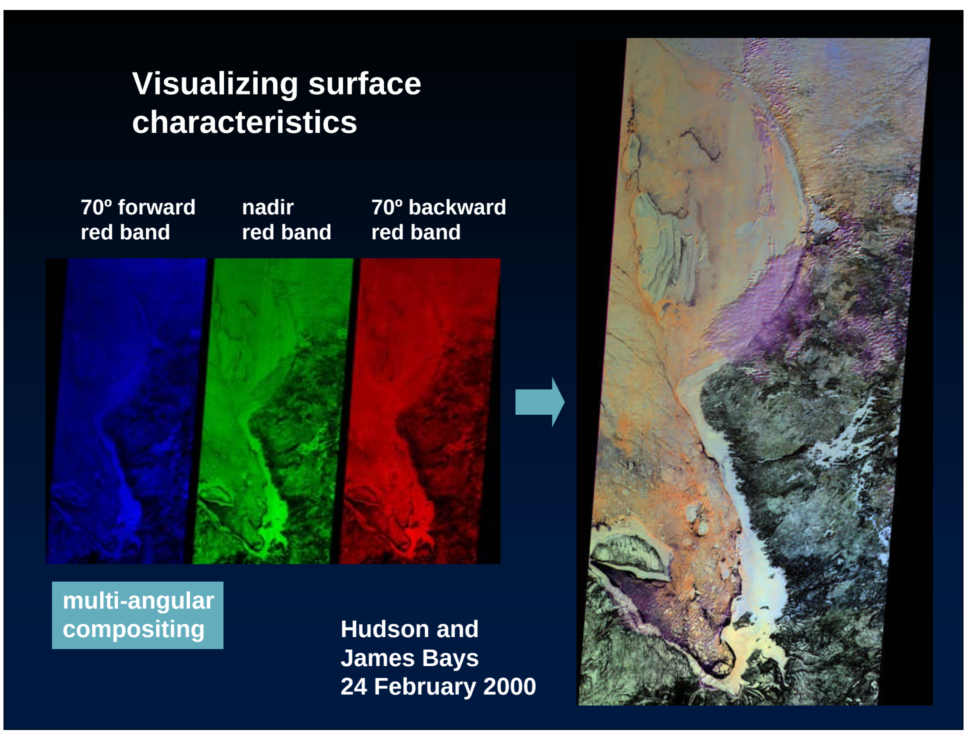
San Joaquin Valley
3 January 2001

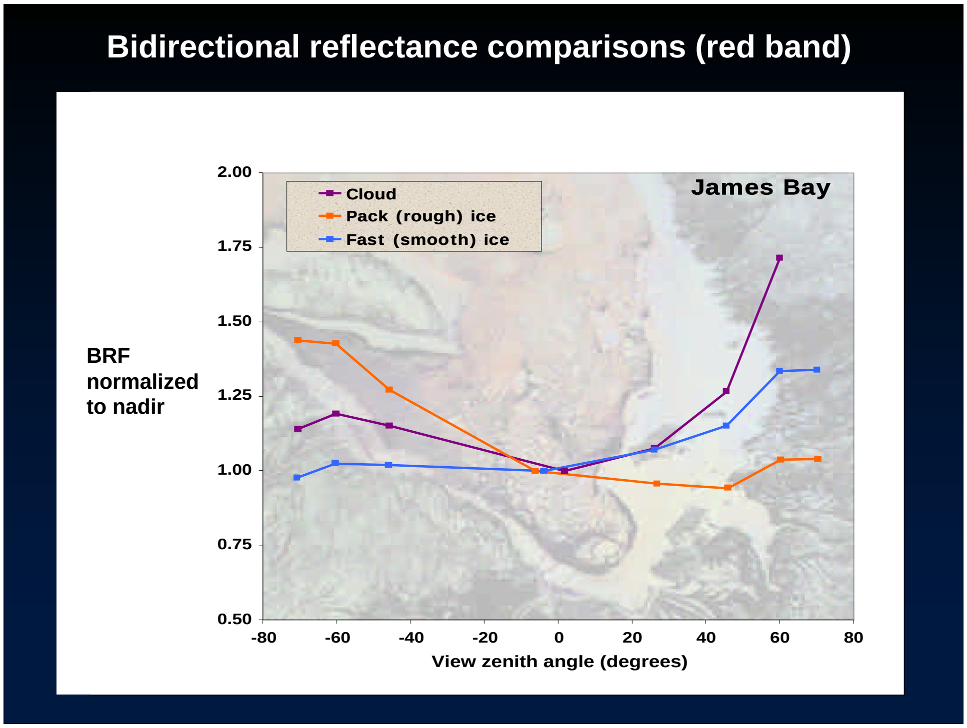
70º forward

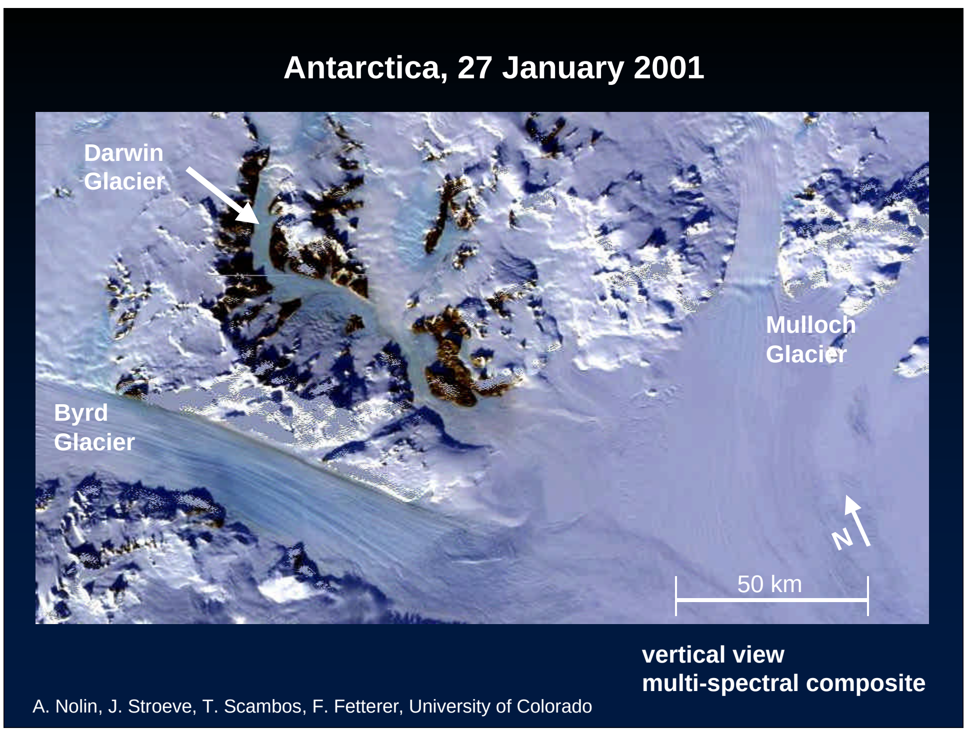
San Joaquin Valley
3 January 2001

70º forward

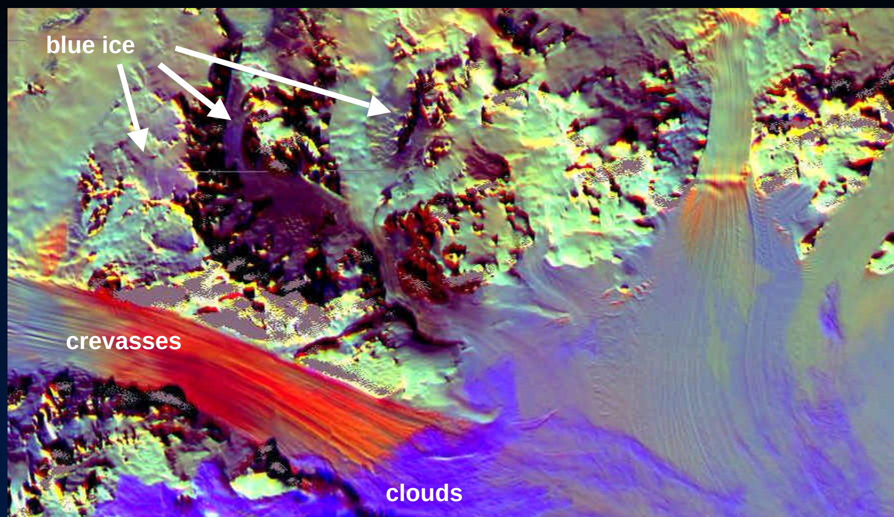

Visualizing surface characteristics
nadir blue band
nadir green band
nadir red band
multi-spectral compositing
Hudson and James Bays
24 February 2000


Visualizing surface characteristics
70º forward red band
nadir red band
70º backward red band
multi-angular compositing
Hudson and James Bays
24 February 2000


Bidirectional reflectance comparisons (red band)
James Bay
Cloud
Pack (rough) ice
Fast (smooth) ice
BRF normalized to nadir
2.00
1.75
1.50
1.25
1.00
0.75
0.50
-80
-60
-40
-20
0
20
40
60
80
View zenith angle (degrees)


Antarctica, 27 January 2001
Darwin Glacier
Mulloch Glacier
Byrd Glacier
N
50 km
vertical view
multi-spectral composite
A. Nolin, J. Stroeve, T. Scambos, F. Fetterer, University of Colorado

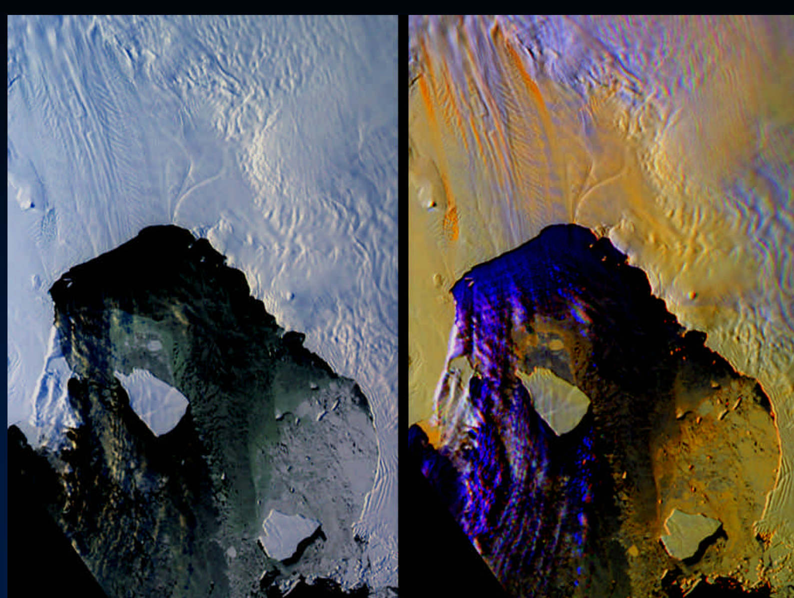
Antarctica, 27 January 2001



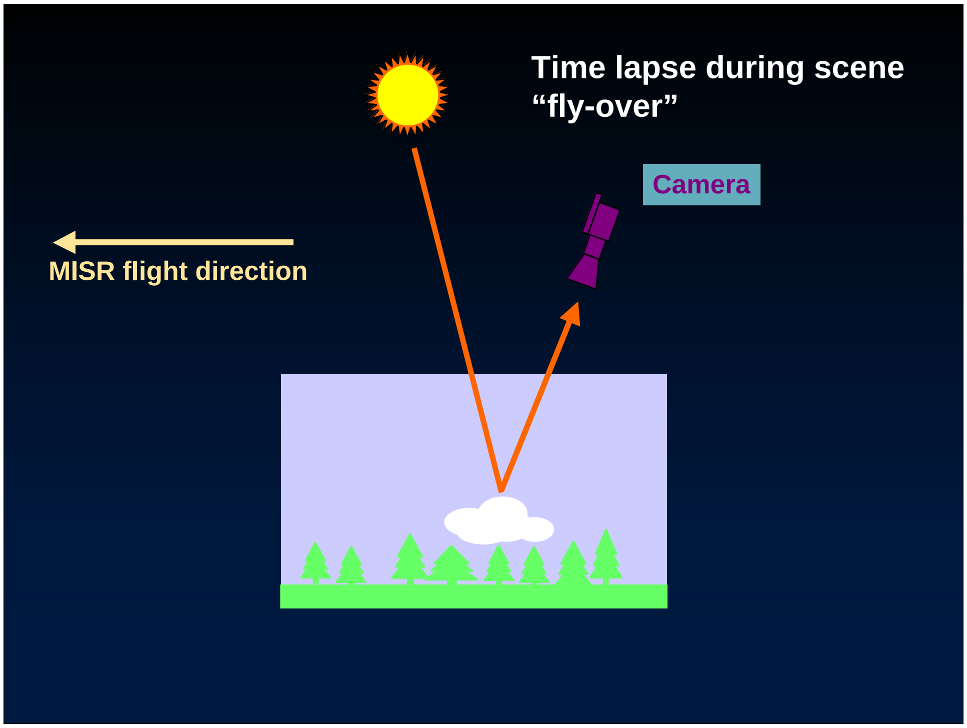
red band
multi-angle composite

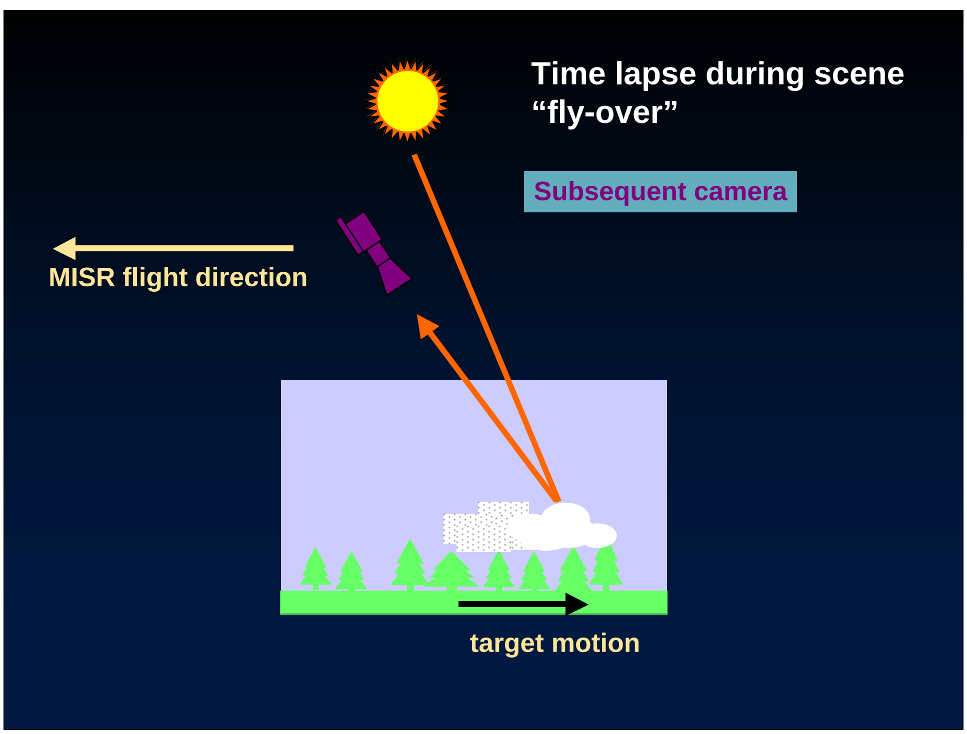
A. Nolin, J. Stroeve, T. Scambos, F. Fetterer, University of Colorado

Pine Island Glacier time lapse



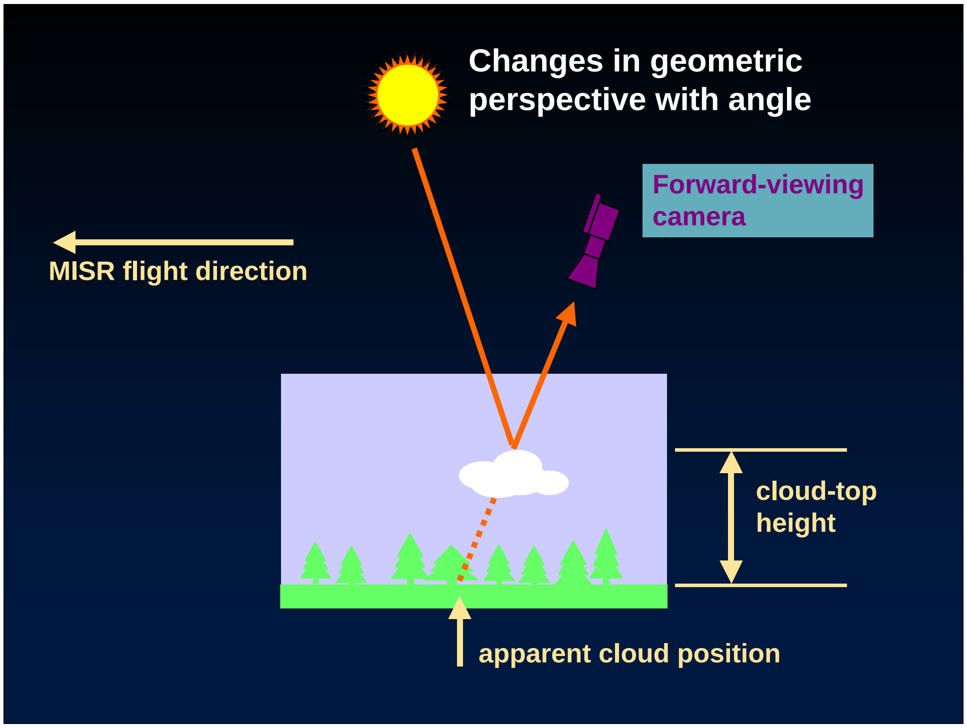
nadir true color | multi-angle false color

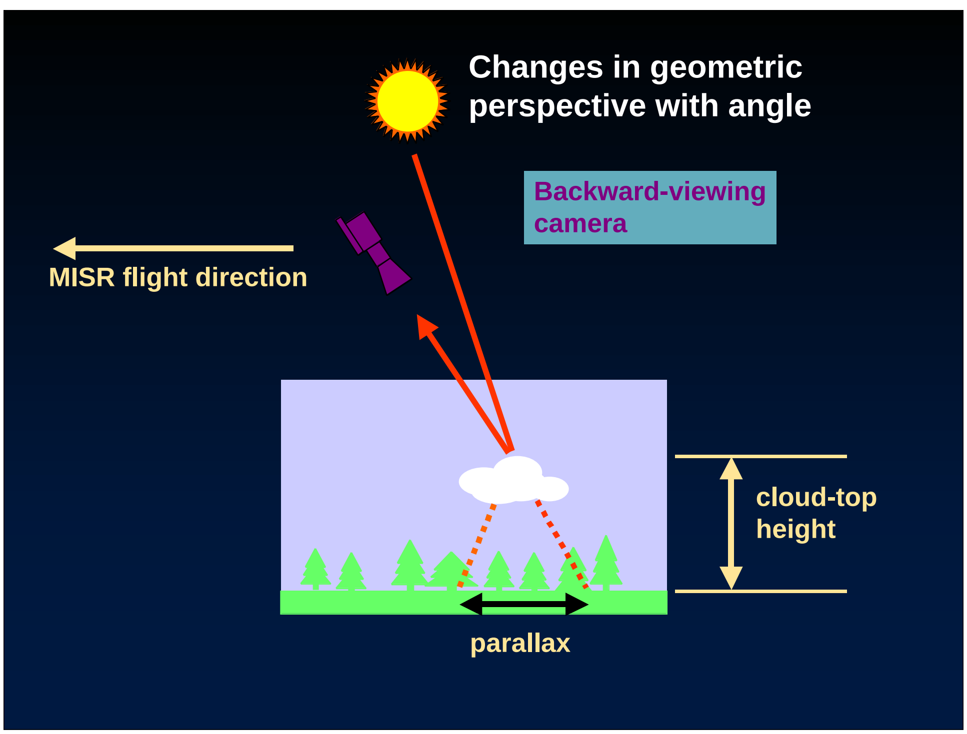

Time lapse during scene
“fly-over”
Camera
MISR flight direction


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

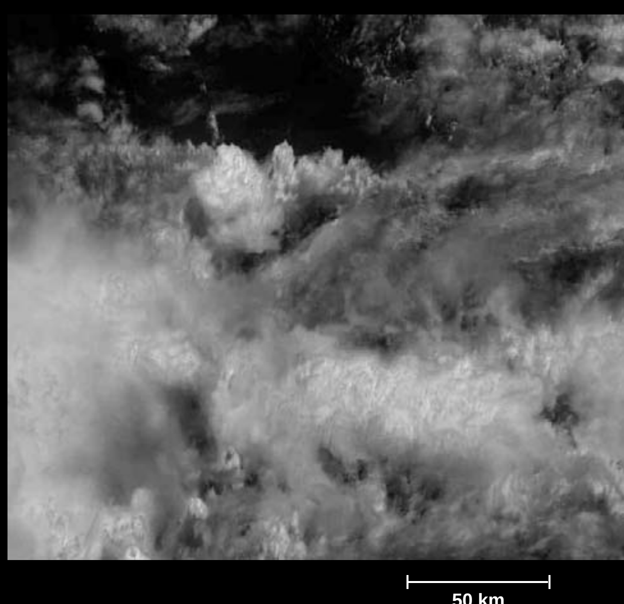

Moving Ships
off the
North Carolina
Coast
11 October 2000


Von Karman vortex street near Jan Mayen Island
6 June 2001

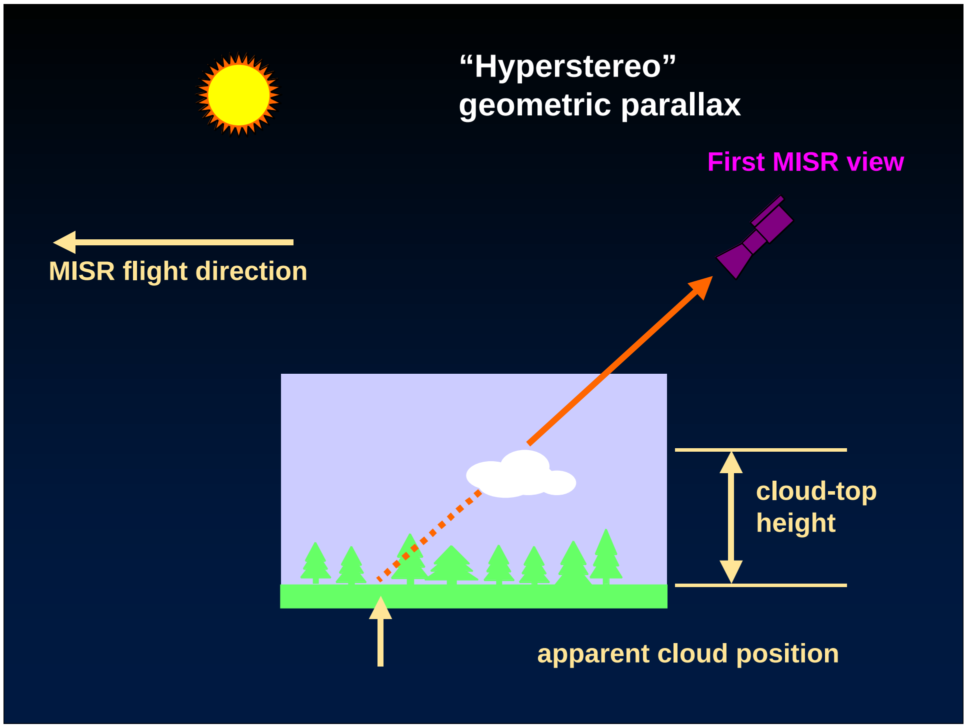

Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
cloud-top height
apparent cloud position

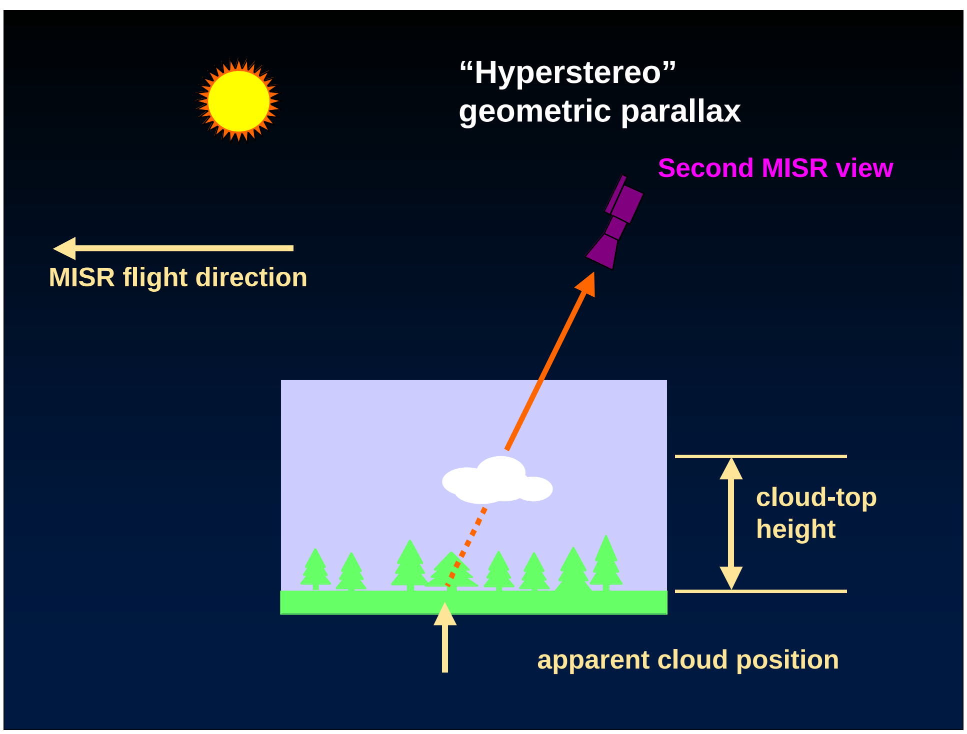

Changes in geometric perspective with angle
Backward-viewing camera
MISR flight direction
cloud-top height
parallax

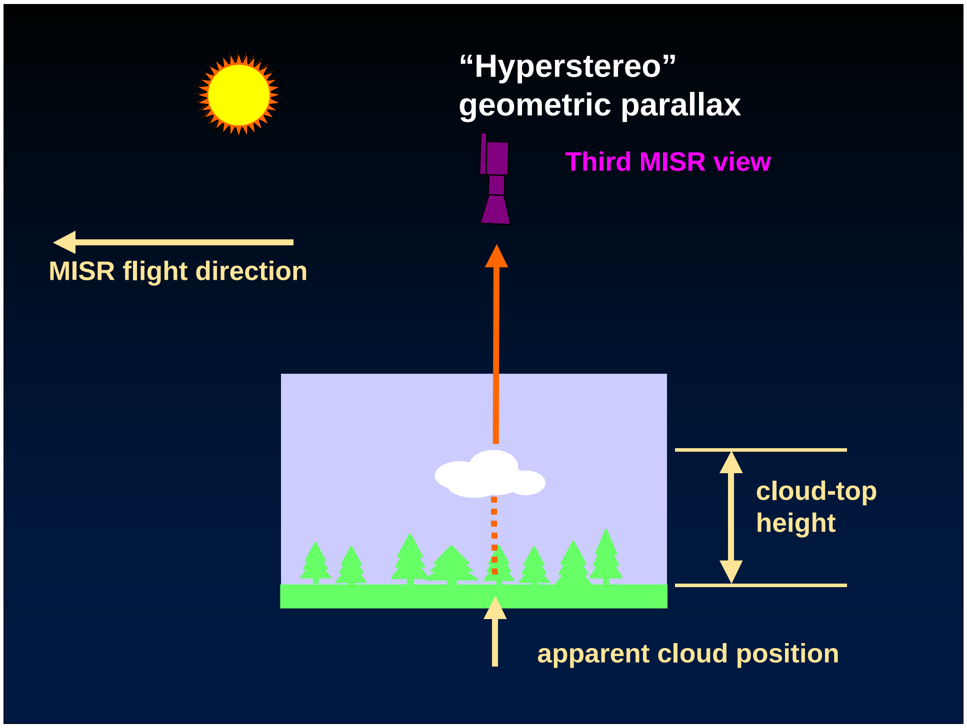
Clouds over Florida and Cuba
6 March 2000

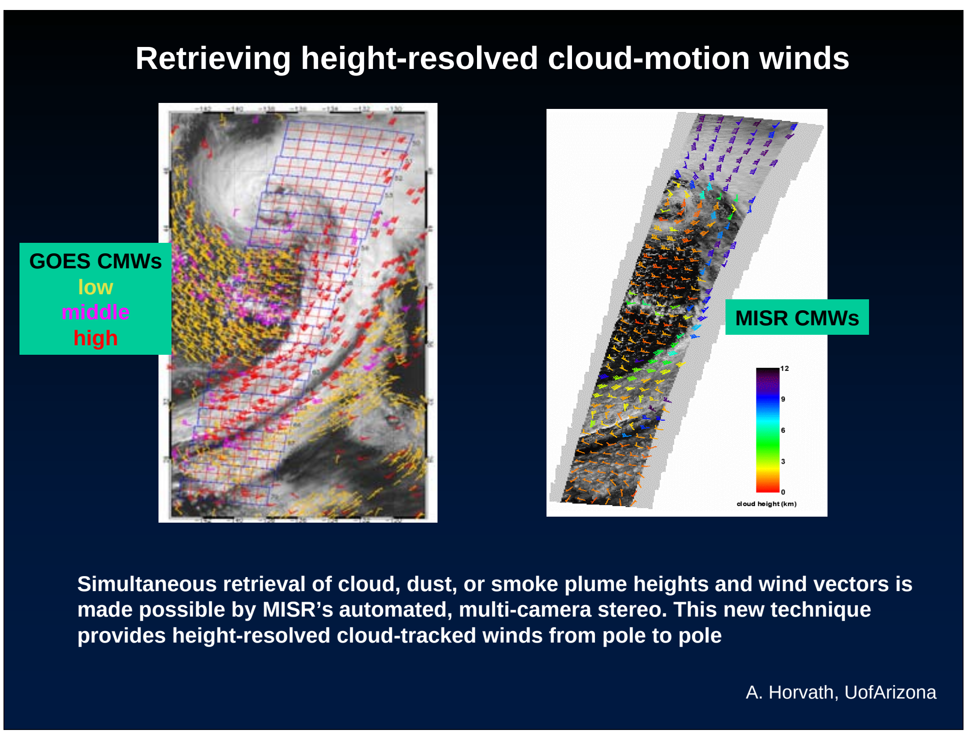


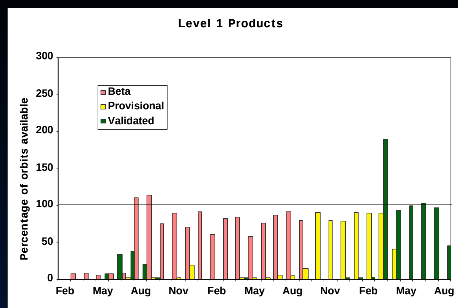
Multi-angle "fly-over" of Hurricane Carlotta thunderclouds
19 August 2000


"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

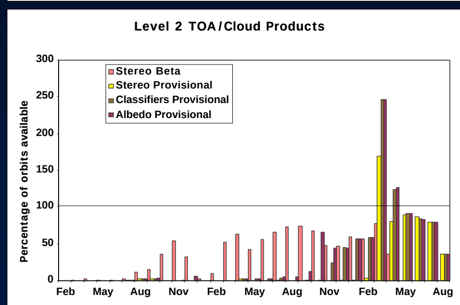

"Hyperstereo"
geometric parallax
Third MISR view
MISR flight direction
cloud-top
height
apparent cloud position

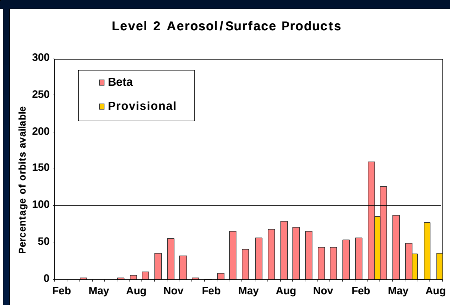

Retrieving height-resolved cloud-motion winds
GOES CMWs
low
middle
high
MISR CMWs
Simultaneous retrieval of cloud, dust, or smoke plume heights and wind vectors is made possible by MISR's automated, multi-camera stereo. This new technique provides height-resolved cloud-tracked winds from pole to pole
A. Horvath, UofArizona



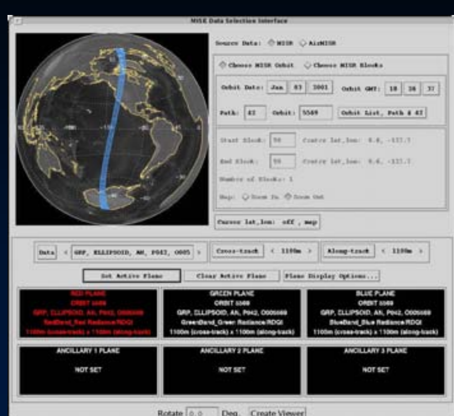
MISR data product availability vs. product maturity

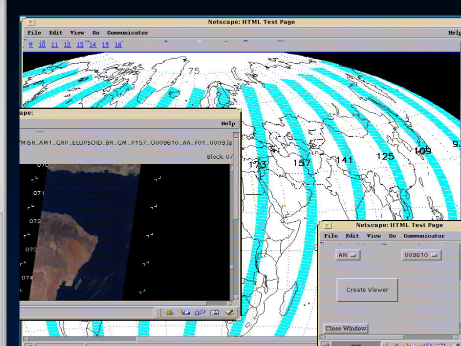
Values above 100% indicate multiple versions available due to reprocessing





Data visualization and analysis tools





Color, multi-angle browse products and on-line interactive viewer
http://eosweb.larc.nasa.gov/MISRBR/

- misr_view (IDL-based)
- HDF-to-binary converter
- HDF-EOS to GeoTIFF converter

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

Useful addresses

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

LaRC DAAC User Services
larc@eos.nasa.gov

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

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suggestions@mail-misr.jpl.nasa.gov