MISR overview, Observational principles, Data, Products and Applications

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MISR Tutorial
Cape Town, South Africa
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Outline of the Tutorial

1. Rationale for multi-angle measurements, anisotropy primer and MISR mission overview

2. The MISR instrument and operations

3. Top of atmosphere (L1B2) products and applications

4. Geophysical products (L2) and scientific applications
   - Atmosphere
   - Ice fields
   - Land

5. High level products (L3) and their applications

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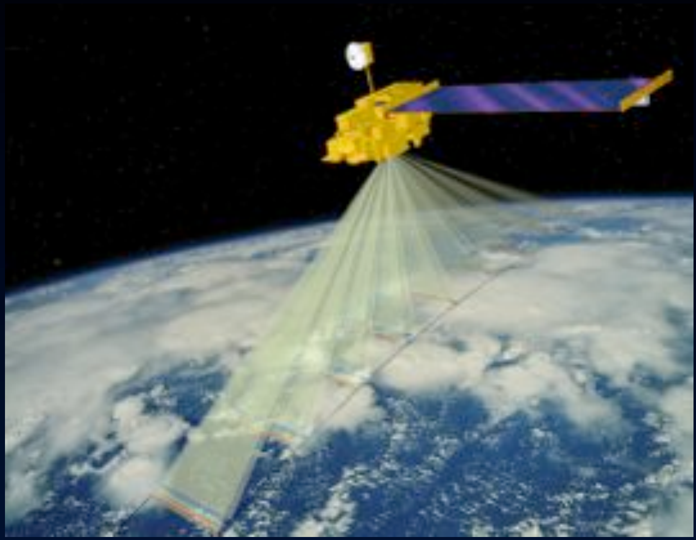
Why multi-angle?

1. Change in reflectance with angle distinguishes different types of aerosols, and surface structure

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

3. Stereo imaging provides geometric heights of clouds and aerosol plumes



4. Cloud motion, derived from time lapse (6.6 min) between cameras (forward to backward views), serves as indicator of winds aloft

5. Different observation angles enable sun glint avoidance or accentuation

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

Anisotropy primer (Examples from space)

Photo from STS-36 mission

MODIS picture over Suriname

Ref: http://www.astronautix.com/graphics/0/10063854.jpg and
http://veimages.gsfc.nasa.gov/4779/Suriname.A2002262.1405.1km.jpg

Anisotropy primer (1)

- Solar illumination is highly directional, especially under clear skies
- All surfaces and media, natural or artificial, and in particular clouds and aerosols, water, soils, vegetation, snow and ice, are anisotropic (i.e., reflect light differently in different directions)
- Anisotropy is controlled by the structure and optical properties of the geophysical media
- Hence, the reflectance of geophysical media is bidirectional (Ω_0, Ω)
- Atmospheric constituents also interact anisotropically with the radiation fields (Rayleigh, Mie scattering)
- Anisotropy is itself a spectrally-dependent property
- Examples: specular reflectance, hot spot, Lambertian panel

Anisotropy (Examples from field)

Anisotropy primer (2)

- Imaging instruments with a small IFOV sample the reflectance of the surface-atmosphere system in the direction of the sensor, measure the hemispherical-conical reflectance of the geophysical system

- These measurements thus depend on the particular geometry of illumination and observation at the time of acquisition

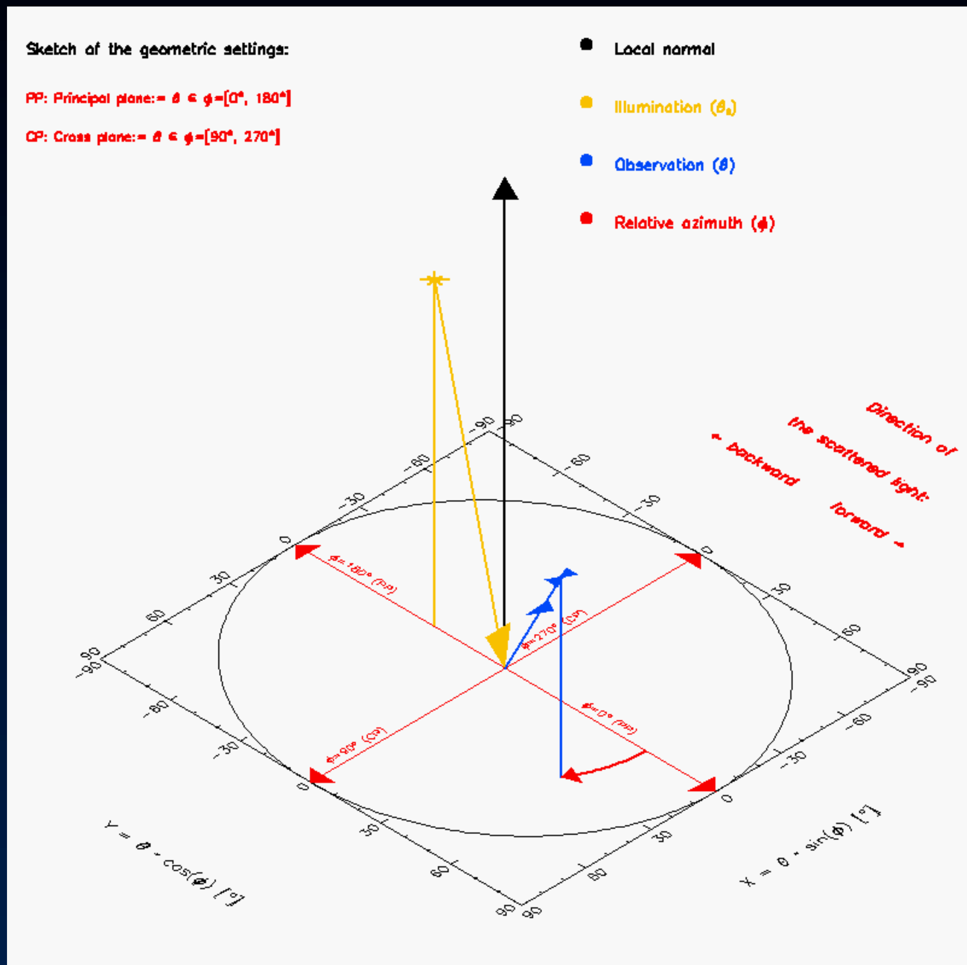
  – each and every measurement across the swath of an instrument takes place at specific and different observation angles

  – all sensors, including ‘nadir-looking’, are affected by the anisotropy, but most do not sample it enough to document it

  – applications that do not exploit anisotropy must nevertheless account for these effects

  – unique information on the observed media (e.g., structural characteristics) can be derived from observations of these angular variations

Illumination and observation geometry



Illumination direction:
$\Omega_0 = [\theta_0, \varphi_0]$

Observation direction:
$\Omega = [\theta, \varphi]$

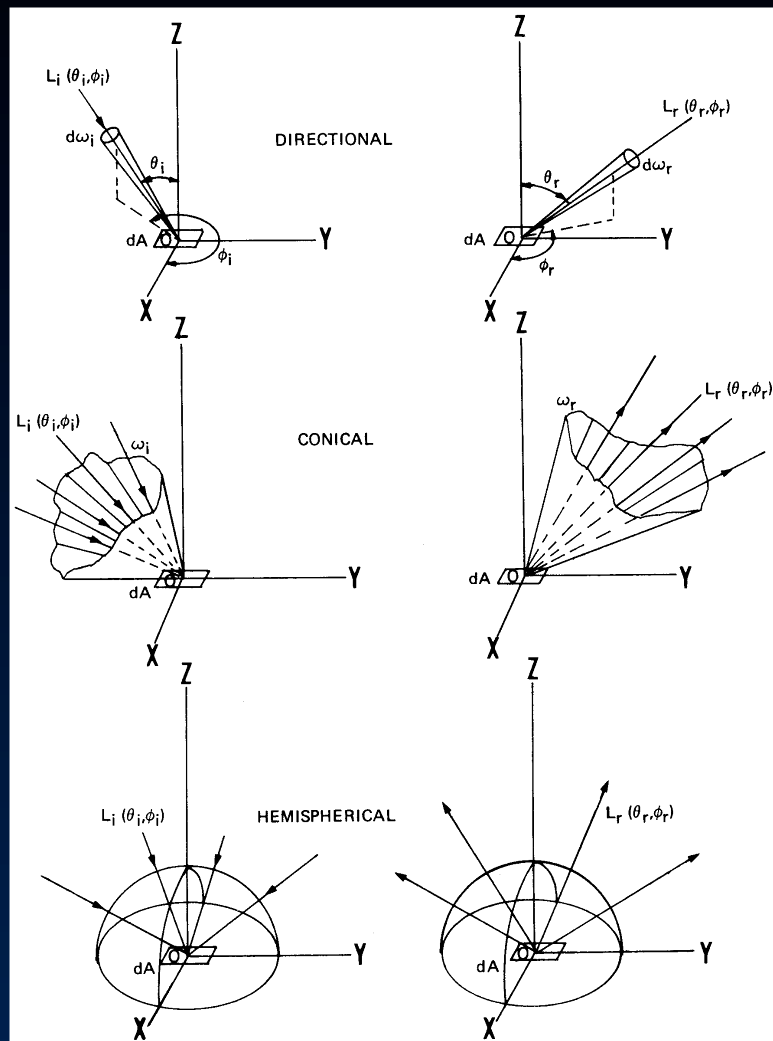
$\mu_0 = \cos \theta_0$

$\mu = \cos \theta$

Ref: Vogt and Verstraete (2002, 2009) AnisView: An RPV IDL tool

Nomenclature (1)

Incoming



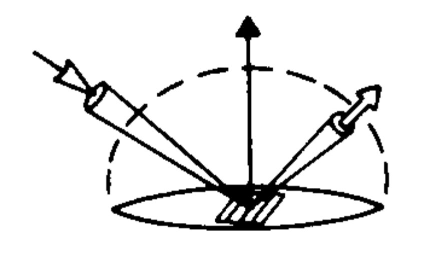
Outgoing

Ref: Nicodemus et al. (1977) NBS Monograph

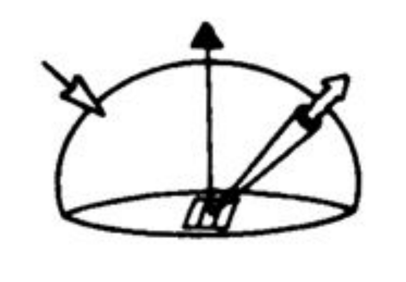
Nomenclature (2)

- BRDF: Bidirectional Reflectance Distribution Function. Units: [sr^{-1}], non-measurable

- BRF: Bidirectional Reflectance Factor, is BRDF normalized by the reflectance of a reference Lambertian surface, identically illuminated and observed. Units: [N/D], approximately measurable in the laboratory as a biconical reflectance factor

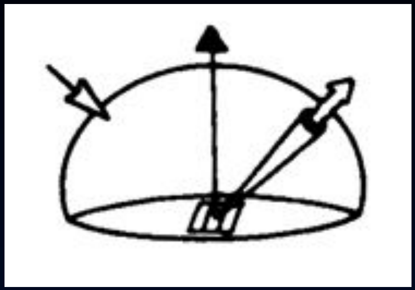


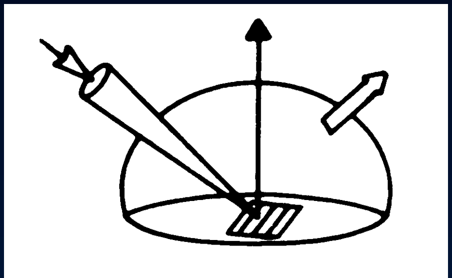
- HCRF: Hemispherical Conical Reflectance Factor. Units: [N/D], common measurement



Ref: Nicodemus et al. (1977) NBS Monograph

Nomenclature (3)





- HDRF: Hemispherical Directional Reflectance Factor, single integral of BRDF on the incoming directions (i.e., direct + diffuse illumination)
- DHR: Directional Hemispherical Reflectance, single integral of BRDF on the outgoing directions ("black sky albedo")
- BHR: Bi-Hemispherical Reflectance, double integral of BRDF
- Note: The MODIS "white sky albedo" is often confused with the BHR but actually assumes a uniform illumination

Ref: Nicodemus et al. (1977) NBS Monograph

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MISR instrument

Family portrait

The “V-9” optical bench

Undergoing test

JPL’s Space Simulator Facility

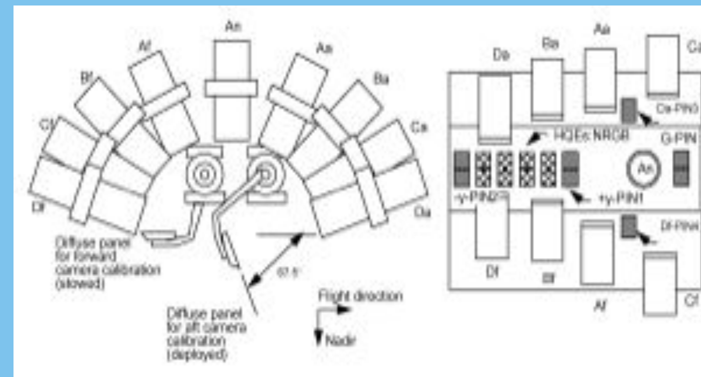
MISR on Terra spacecraft

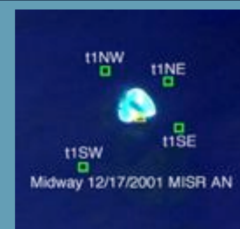
Terra launch
18 December 1999

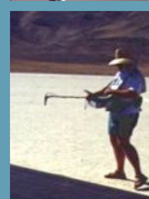
MISR calibration

Absolute radiometric uncertainty 3%
Relative radiometric uncertainty 2%
Temporal stability 1%
Geolocation uncertainty 50 m
Camera-to-camera registration < 275 m

MISR On-Board Calibrator



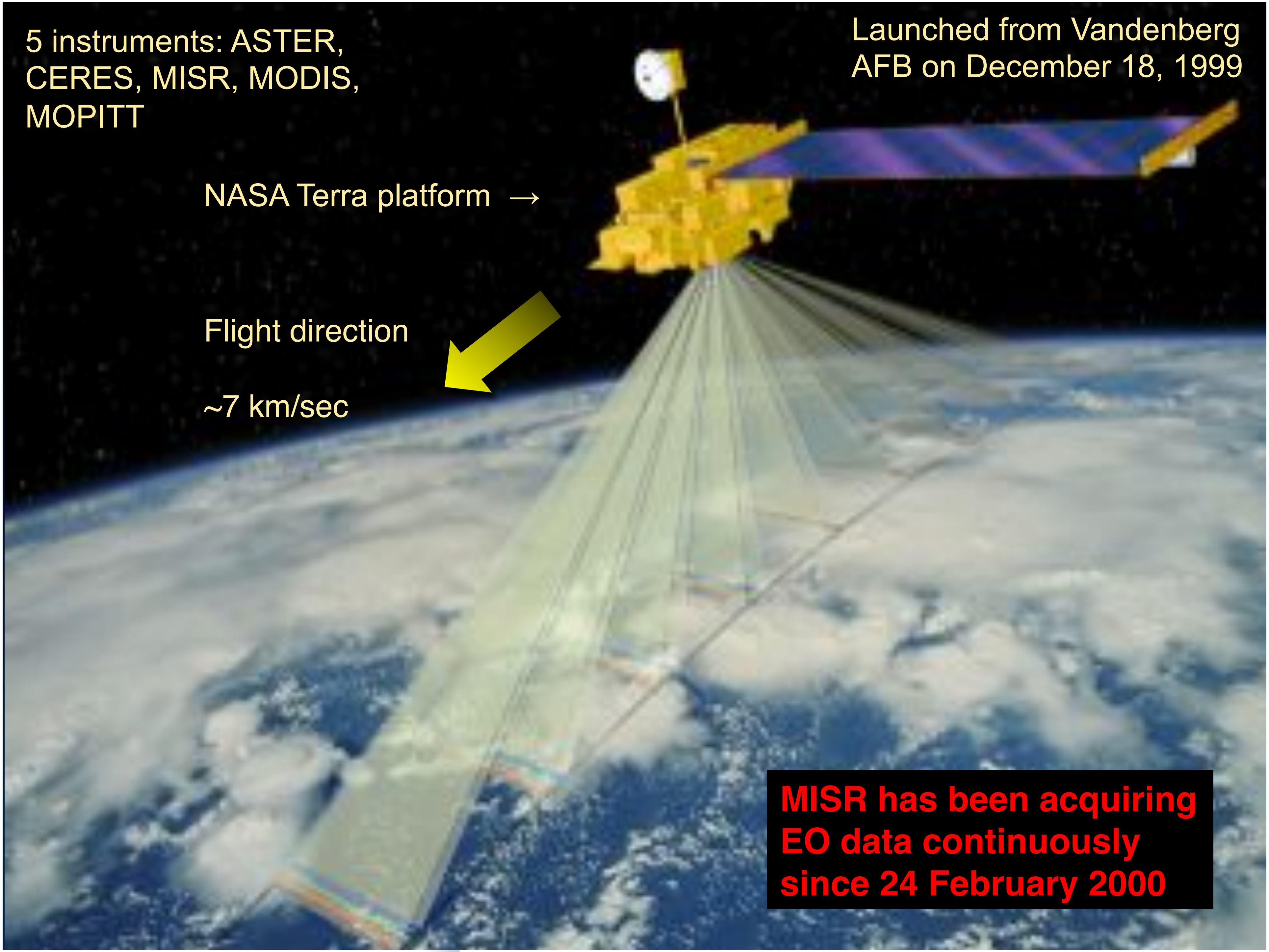


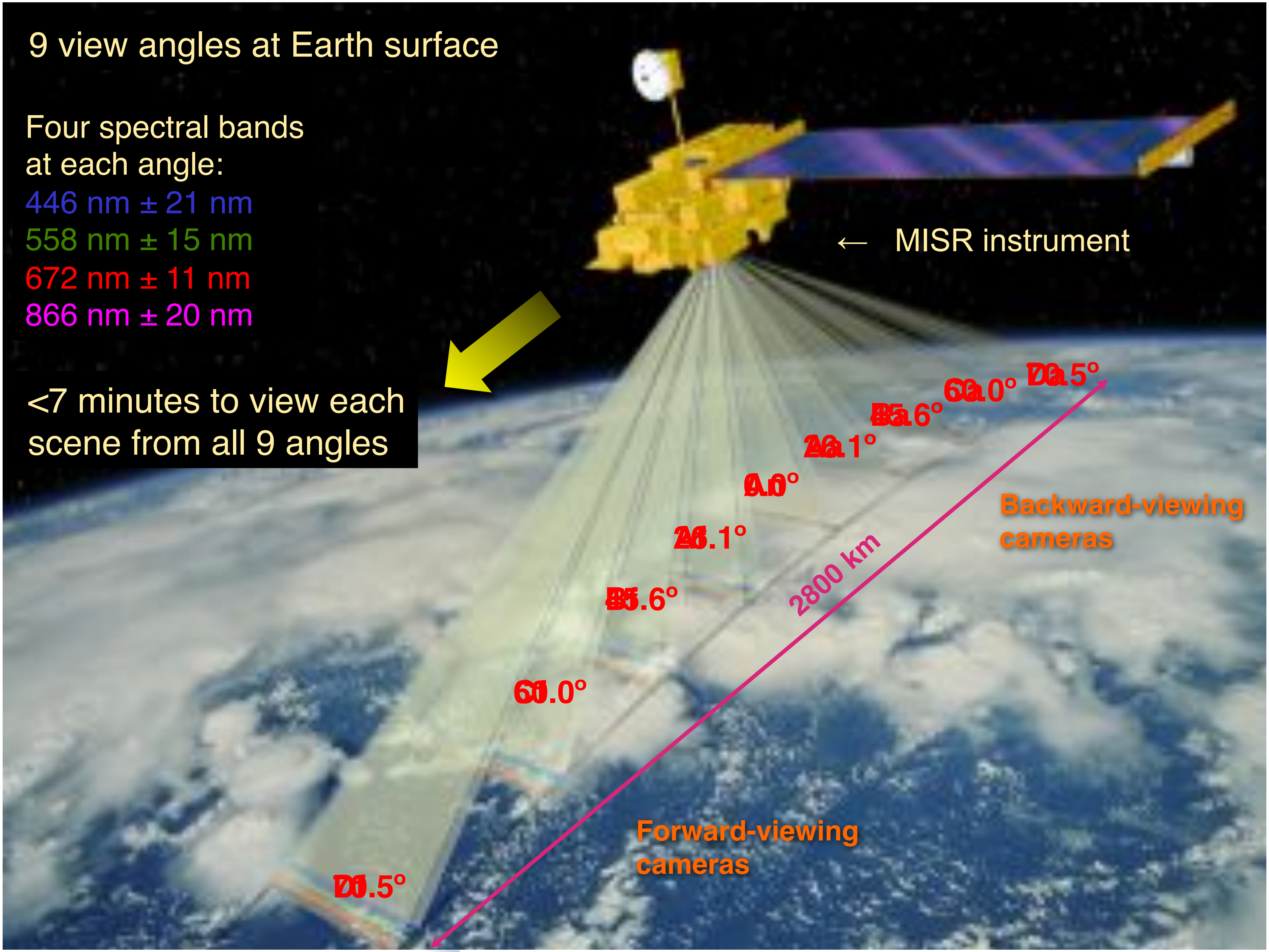


Vicarious calibrations and validations over desert playas and dark water sites

AirMISR

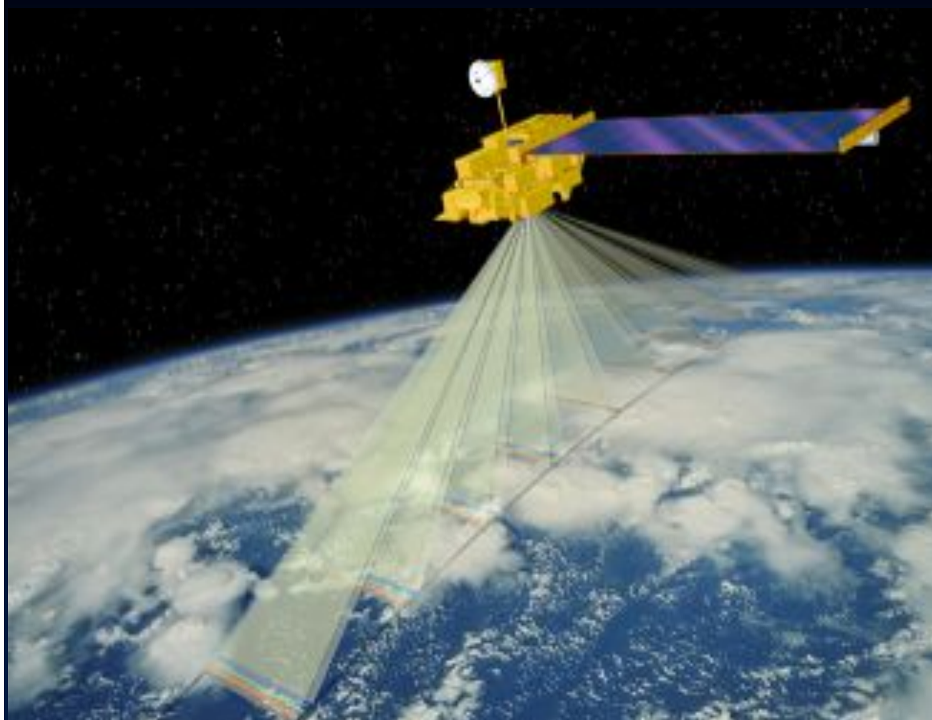
MISR lunar images


5 instruments: ASTER, CERES, MISR, MODIS, MOPITT
Launched from Vandenberg AFB on December 18, 1999
NASA Terra platform →
Flight direction
~7 km/sec
MISR has been acquiring EO data continuously since 24 February 2000



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

MISR observation modes



Global Mode (continuous):
• Pole-to-pole coverage on orbit day side
• 12 data channels at 275m spatial sampling:
– 4 spectral bands (nadir camera)
– 8 red spectral bands (off-nadir cameras)
• 24 data channels (off-nadir, non-red) at 1.1km spatial sampling

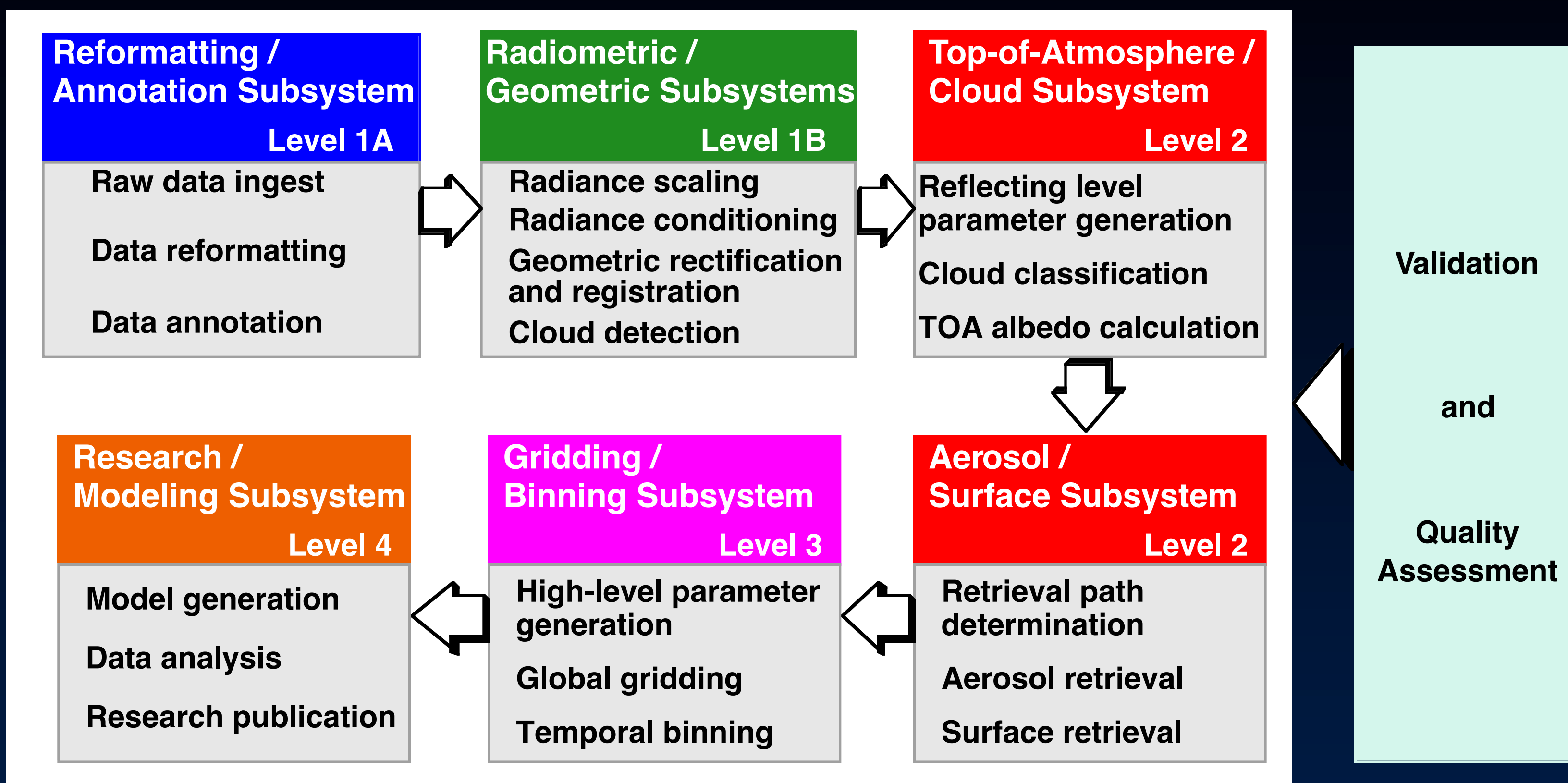
Local Mode (targeted):
• Implemented for pre-established targets
• 36 data channels at 275m spatial sampling (all 4 spectral bands of all 9 cameras)
• Pixel averaging is inhibited sequentially from camera Df to camera Da over targets approximately 300 km in length

380km common swath width, ensuring complete zonal coverage in 9 days at the equator and 2 days at the poles

14-bit A/D quantization

Geometrically and radiometrically calibrated (bi-monthly)

MISR data product generation



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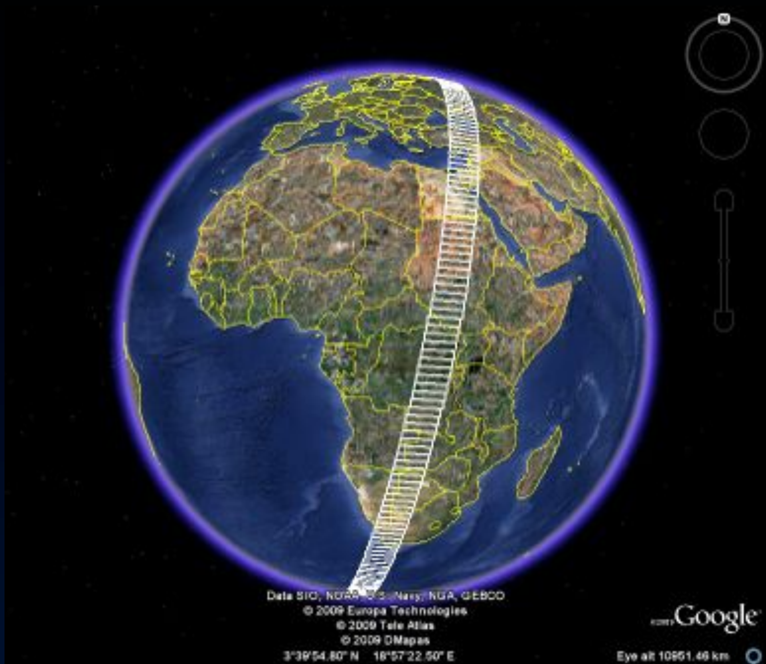
Level 1 Standard Products

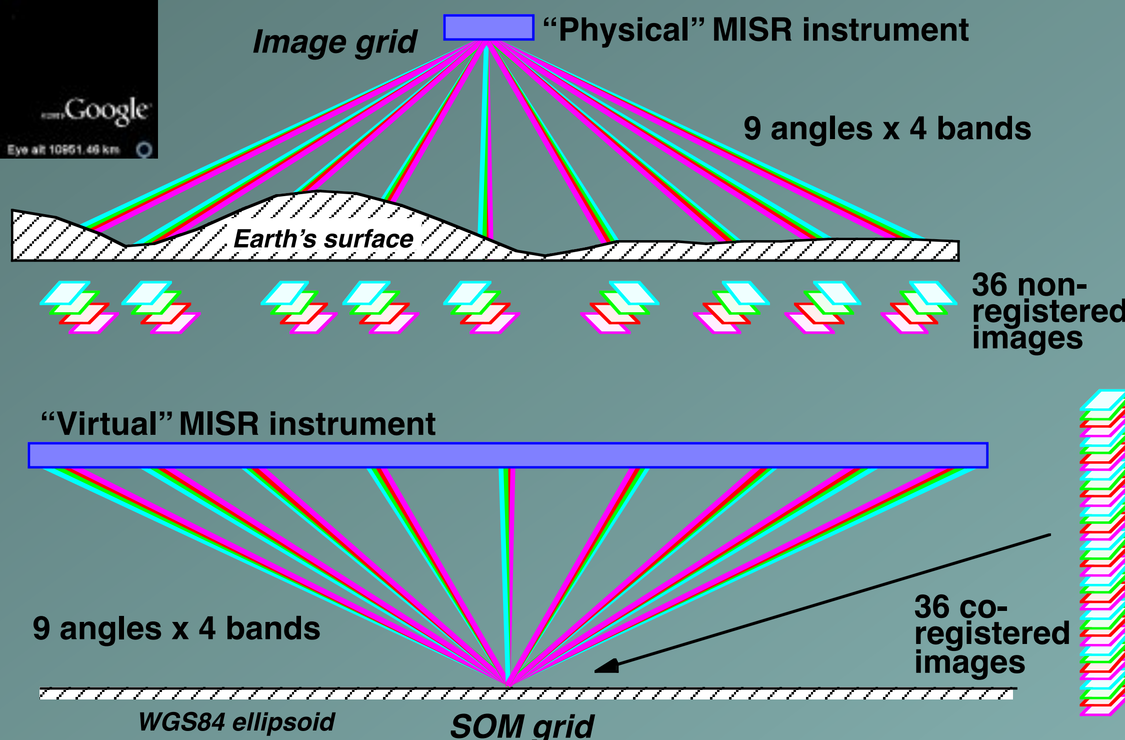
Level 1 standard products

- Level 1A reformatted, annotated product
- Level 1B1 radiometric product
- Level 1B2 georectified radiance product, global and local modes:
  - ellipsoid projected
  - terrain (blocks containing land only) projected
- Level 1B2 browse (JPEG)
- Level 1B2 geometric parameters
- Level 1B2 radiometric camera-by-camera cloud mask

Level 1 processing operates on each camera individually



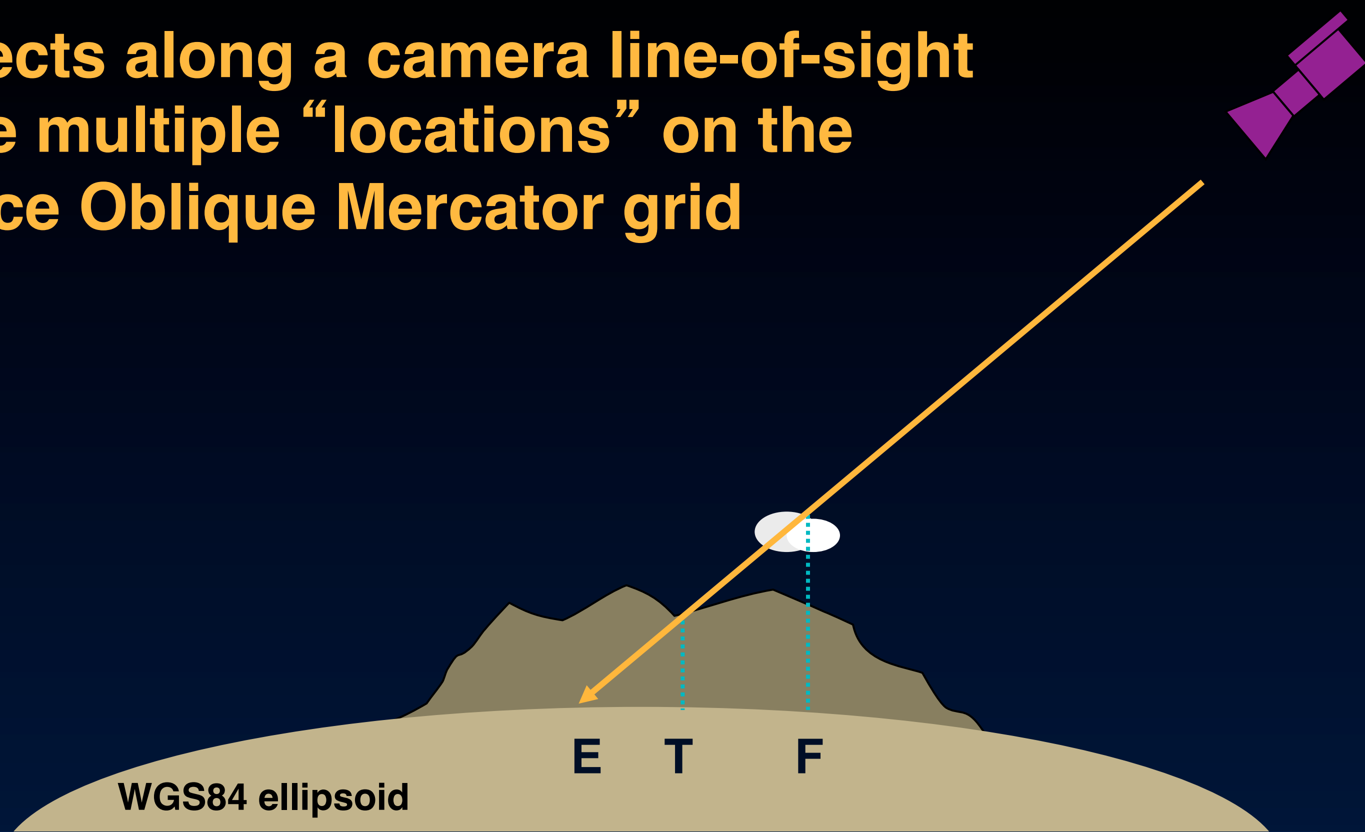
MISR geo-location and angle-to-angle co-registration on Space Oblique Mercator (SOM) projection



Space Oblique Mercator projection minimizes re-sampling distortions

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

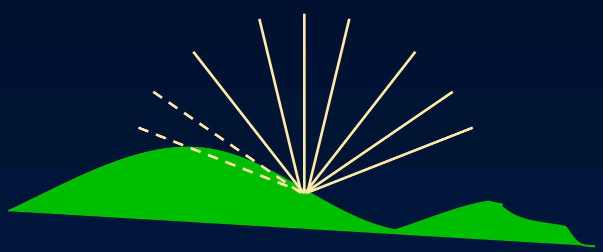


E = ellipsoid-projected location
T = terrain-projected location
F = feature-projected location

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

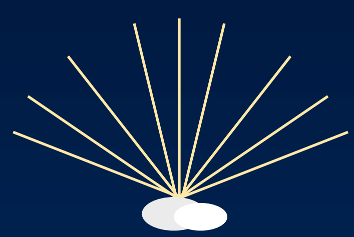
"Ellipsoid projection" is to the WGS84 ellipsoid

- performed during Level 1 processing
- used as input to stereoscopic processing



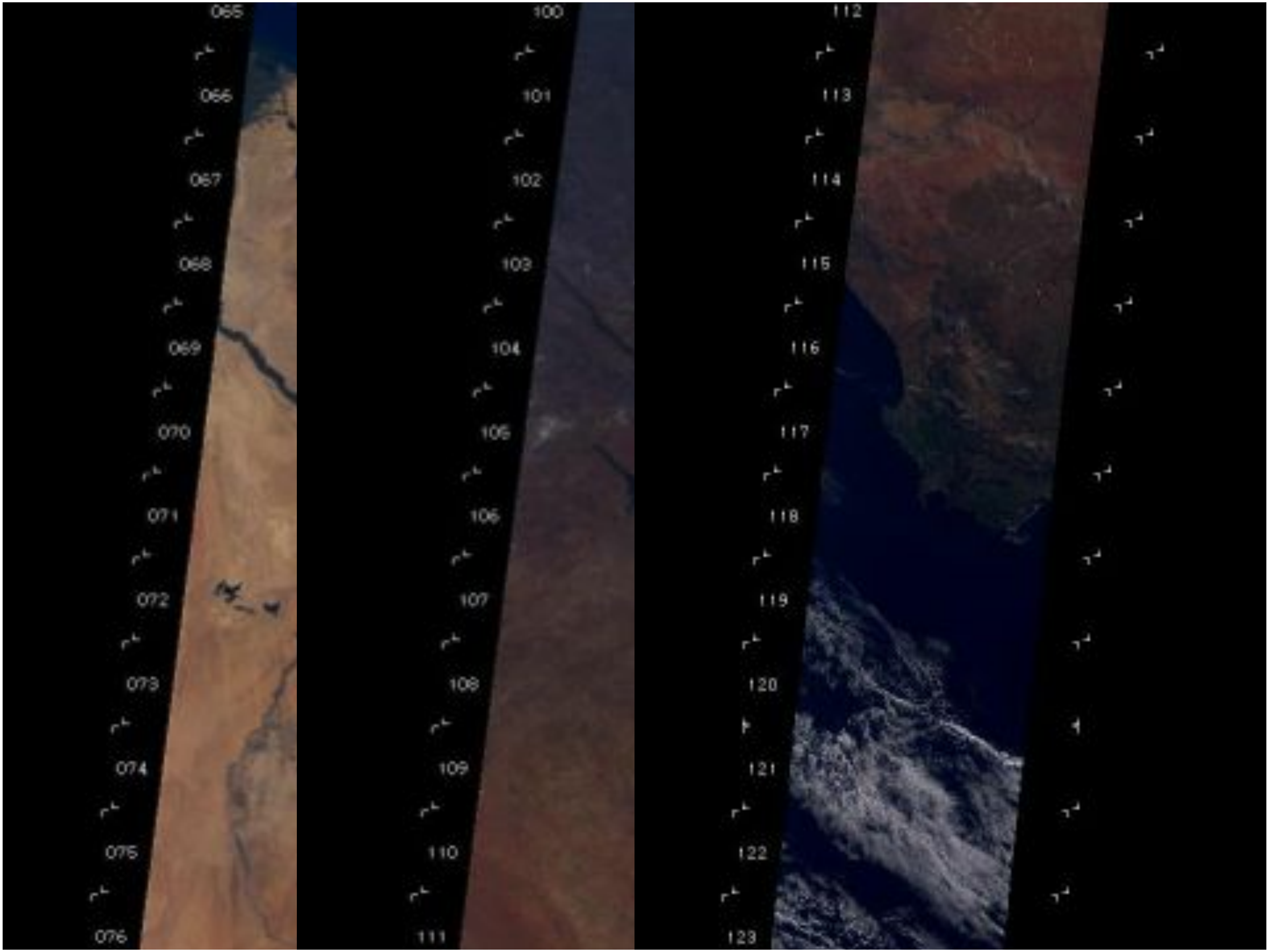
"Terrain projection " is to a digital elevation model

- 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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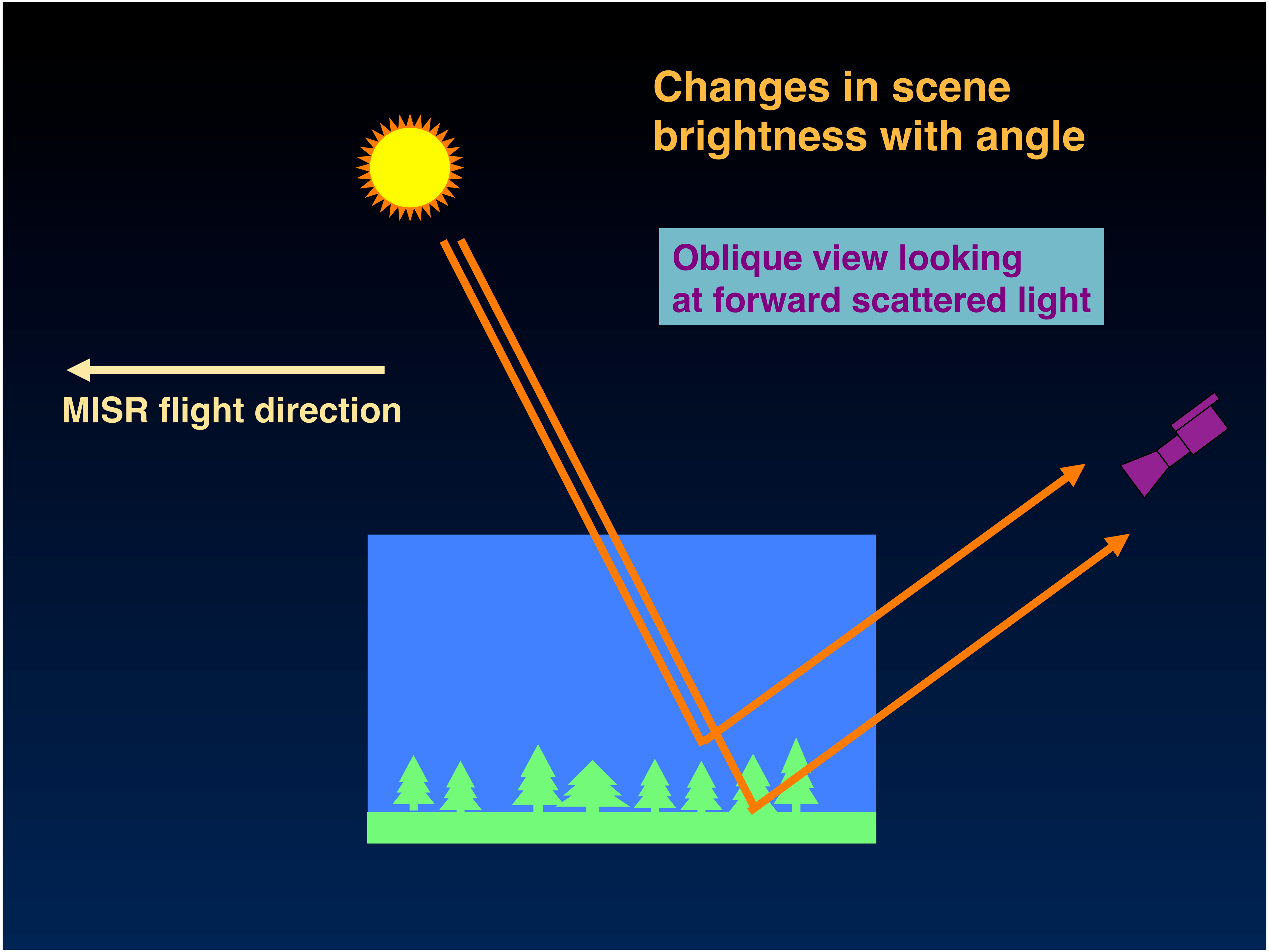
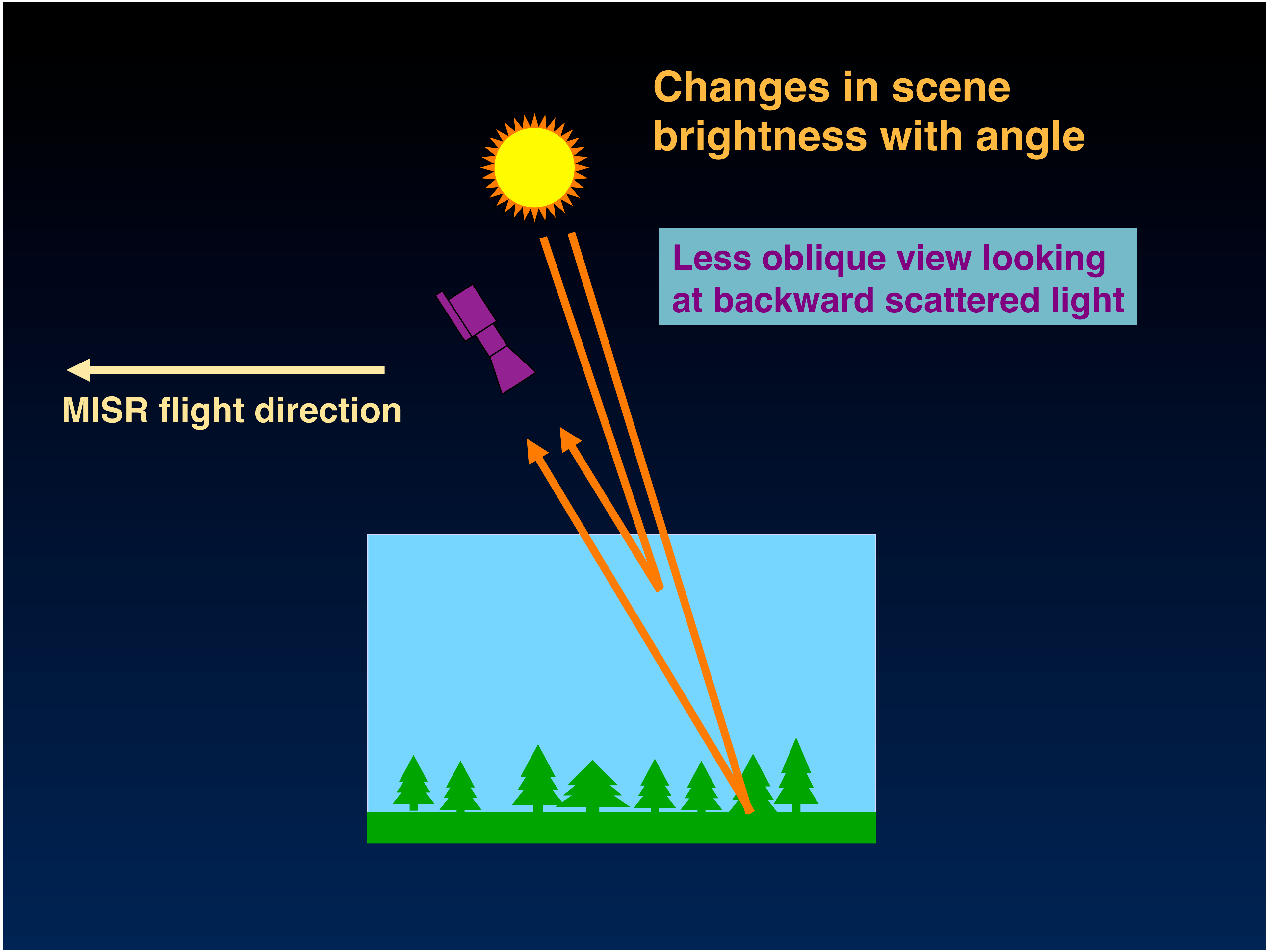

Changes in scene
brightness with angle
Oblique view looking
at forward scattered light
MISR flight direction


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

Visualizing surface texture

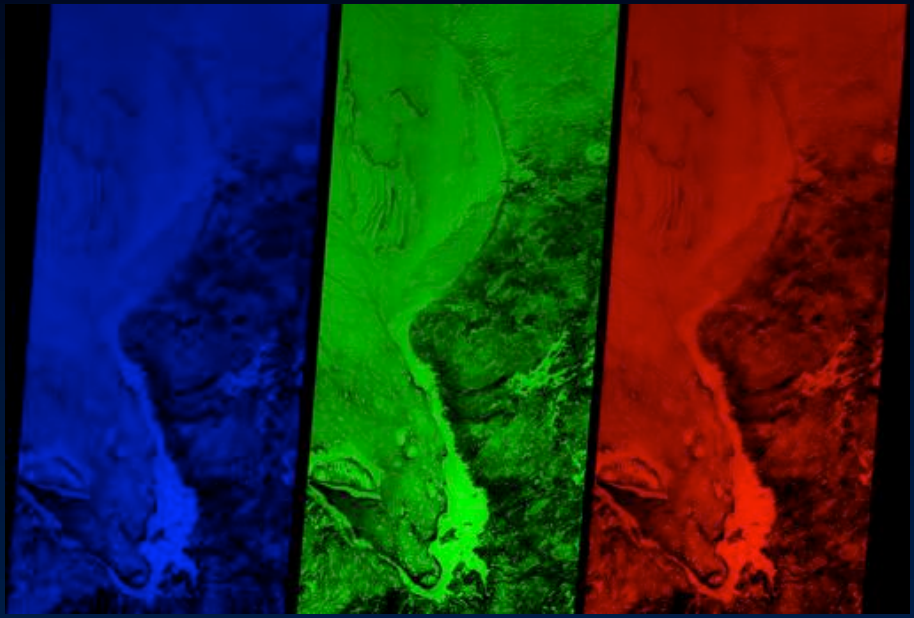
multi-spectral compositing

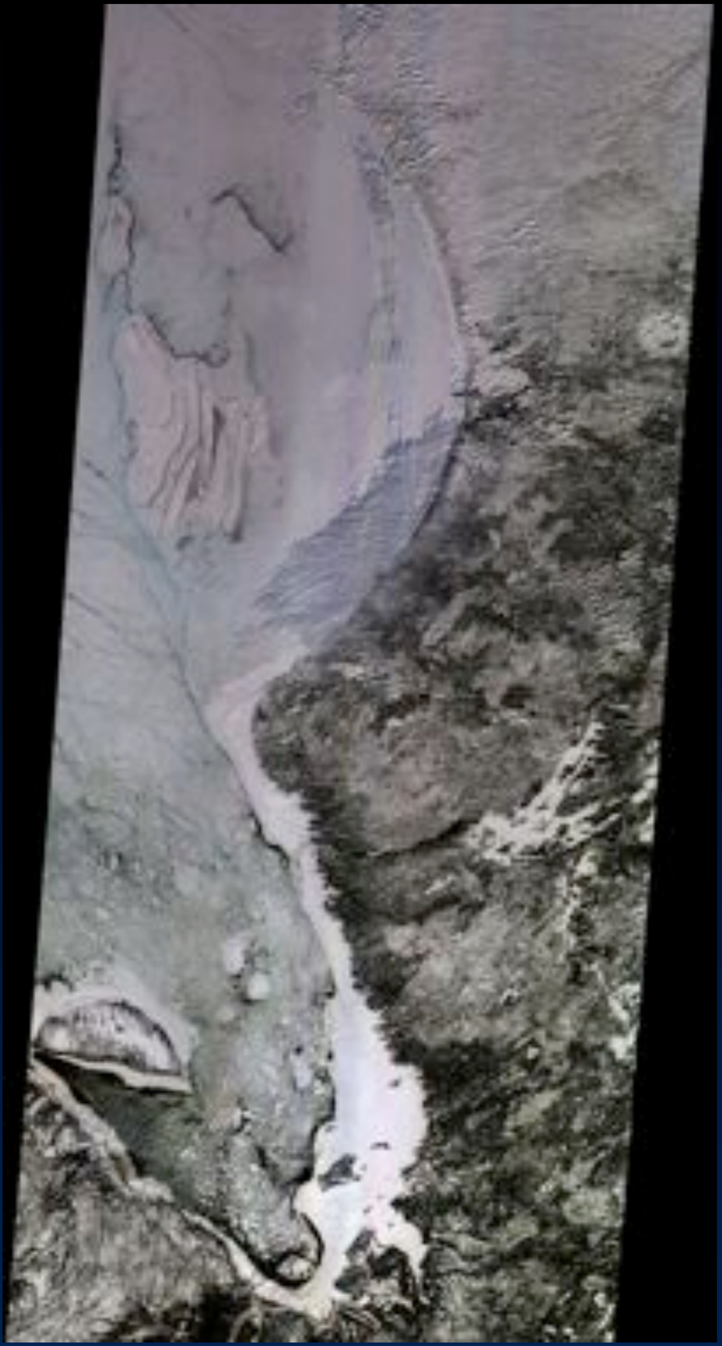
Hudson and James Bays
24 February 2000

nadir
blue band

nadir
green band

nadir
red band

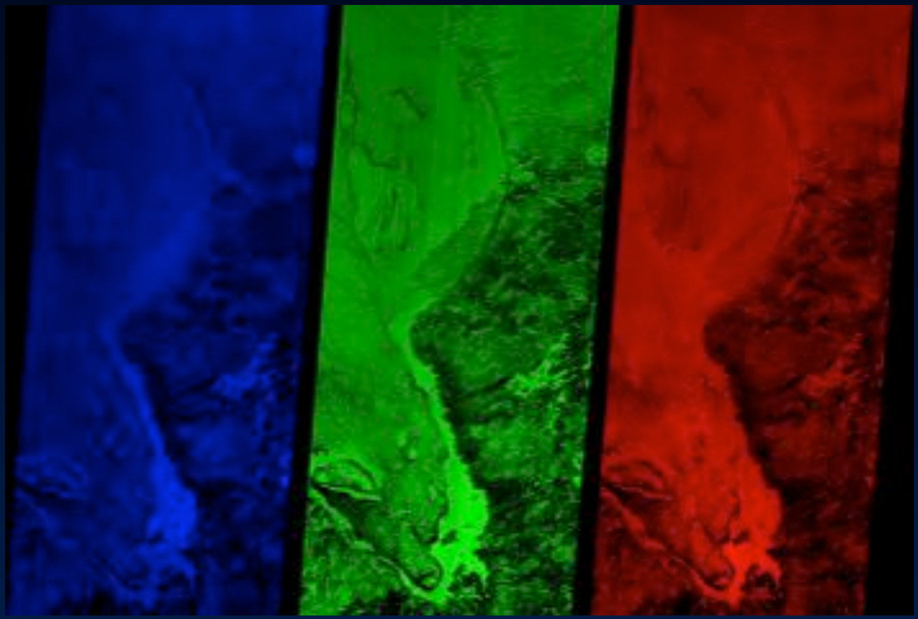




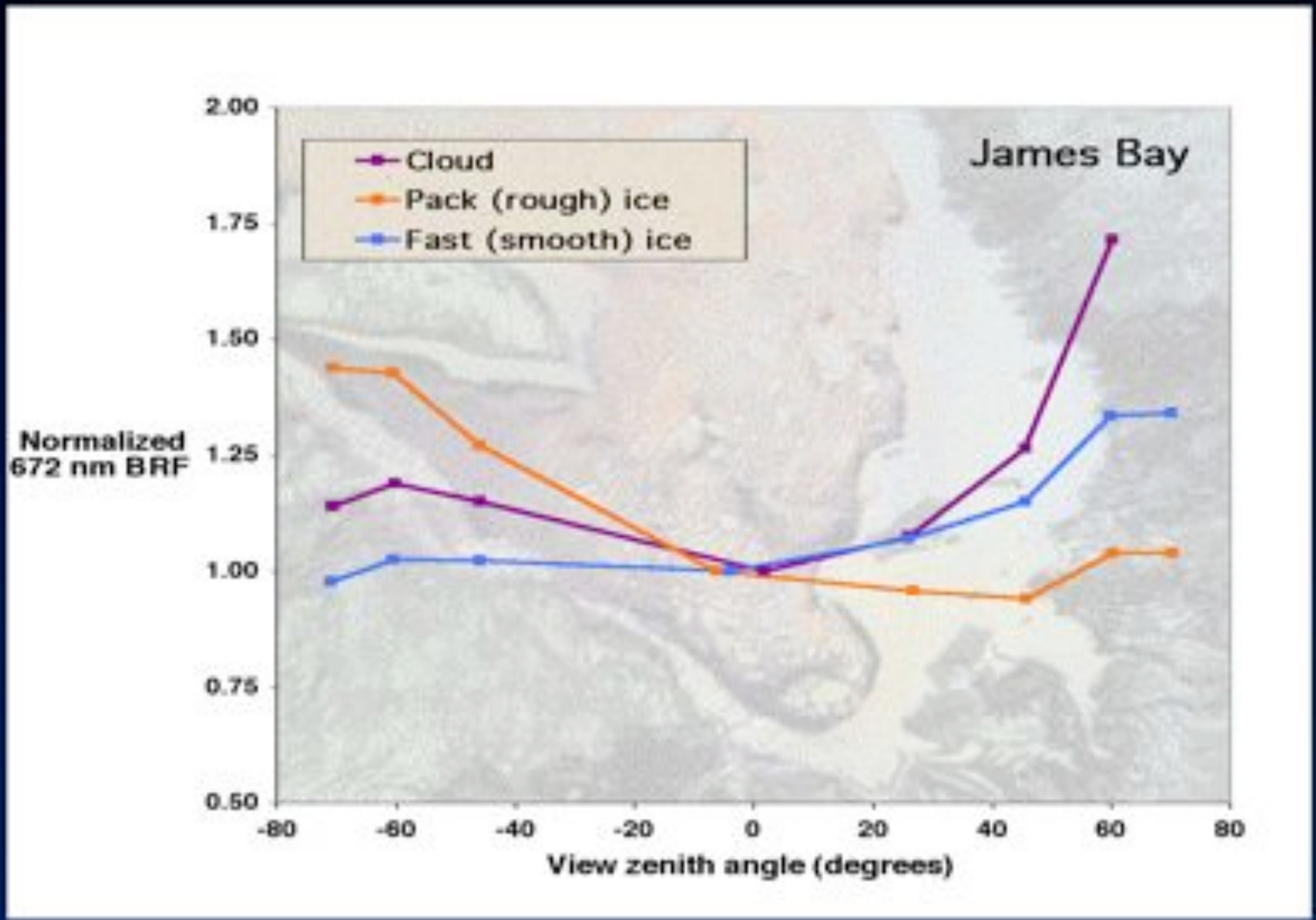
Visualizing surface texture

multi-angle compositing

Hudson and James Bays
24 February 2000

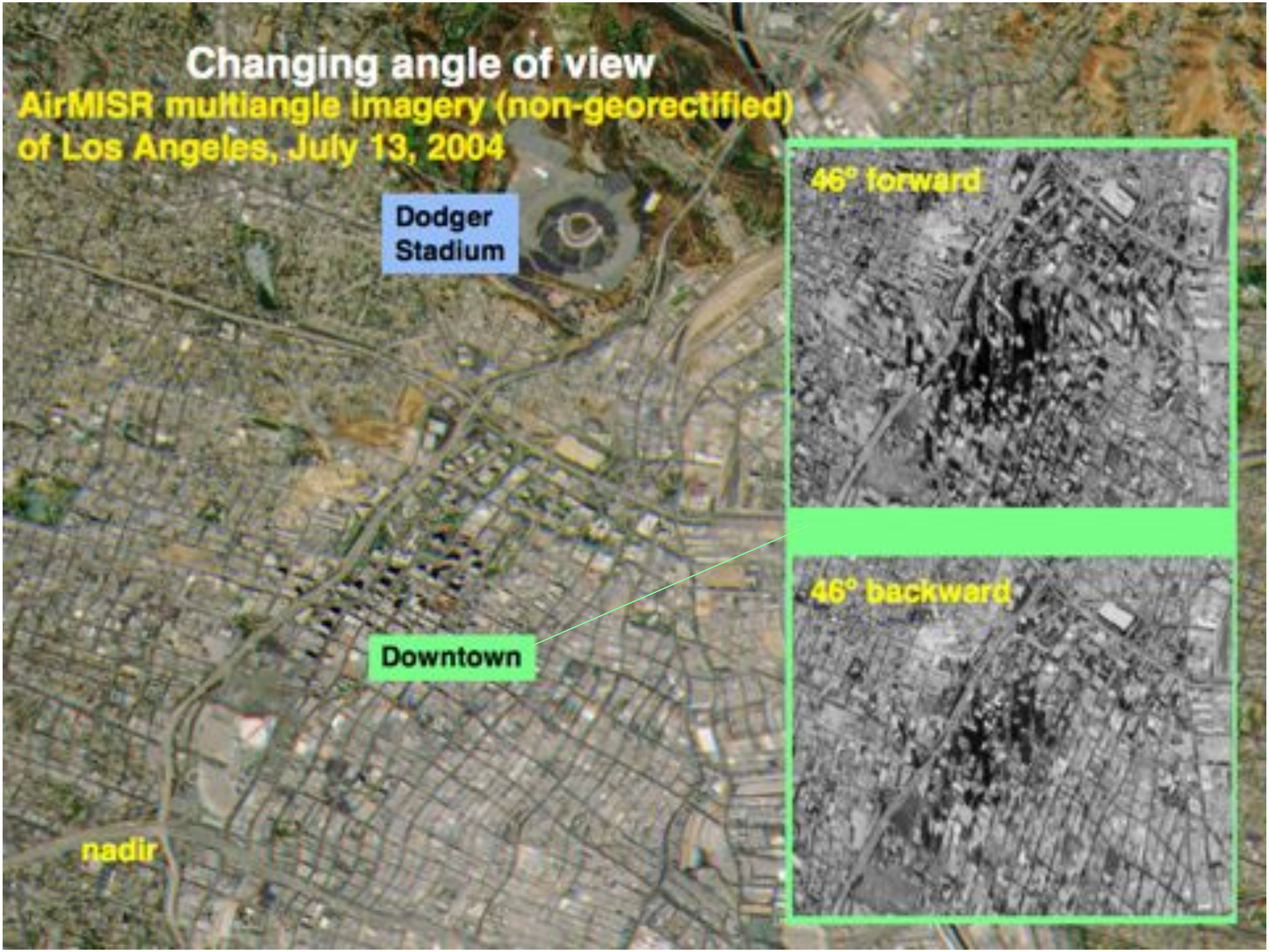


Cloud and ice anisotropy

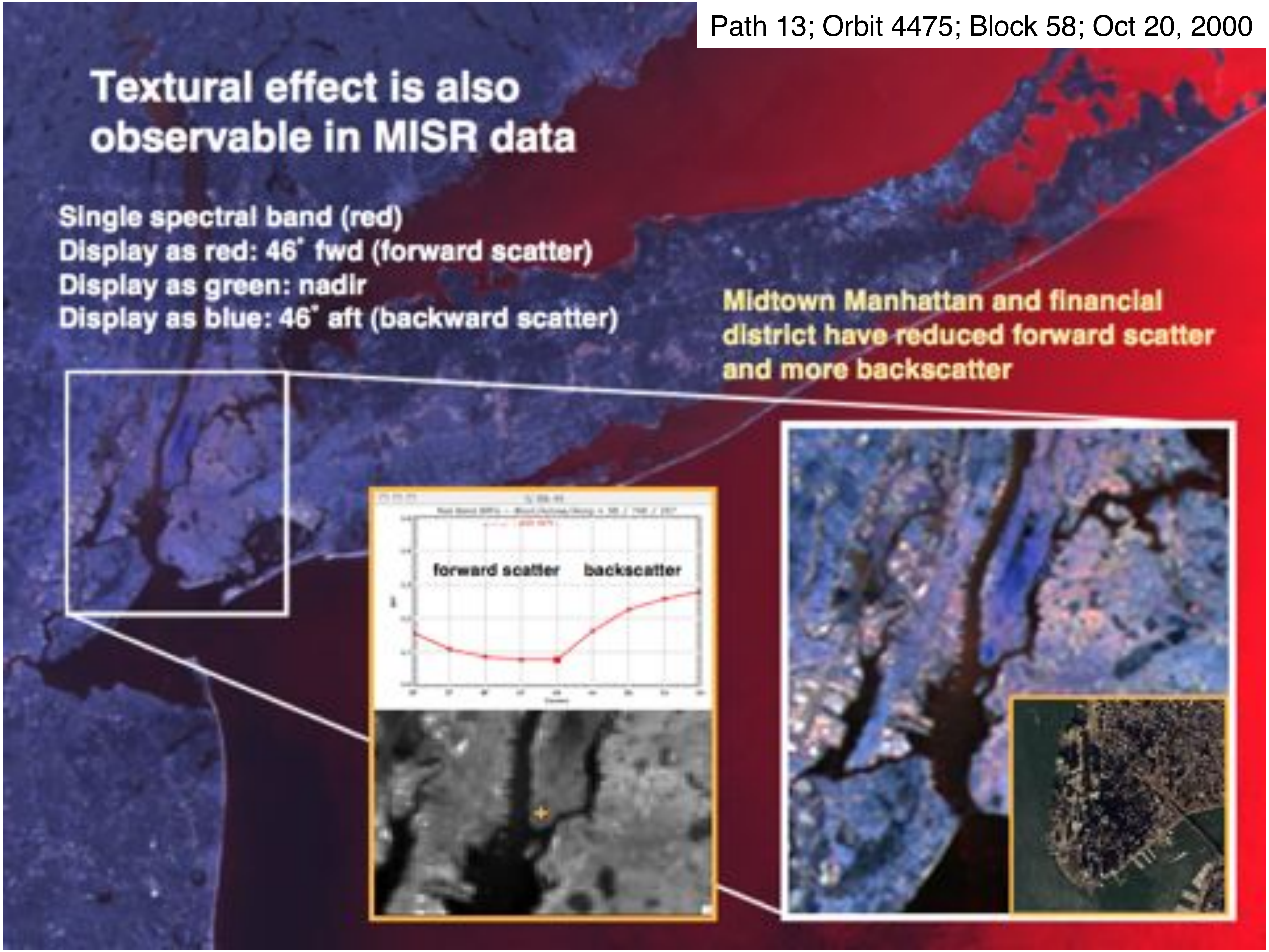


Backward scattering

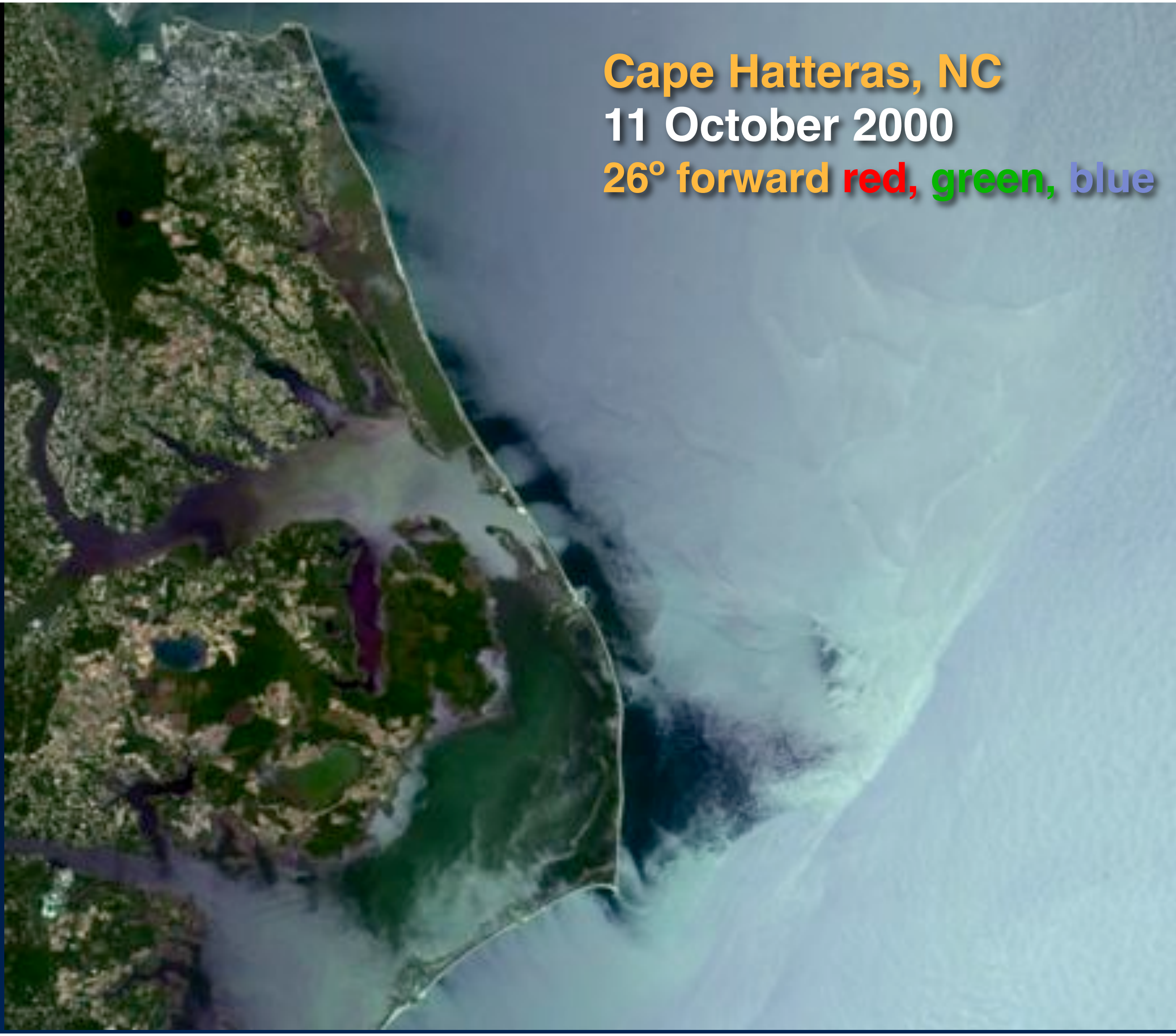
Forward scattering

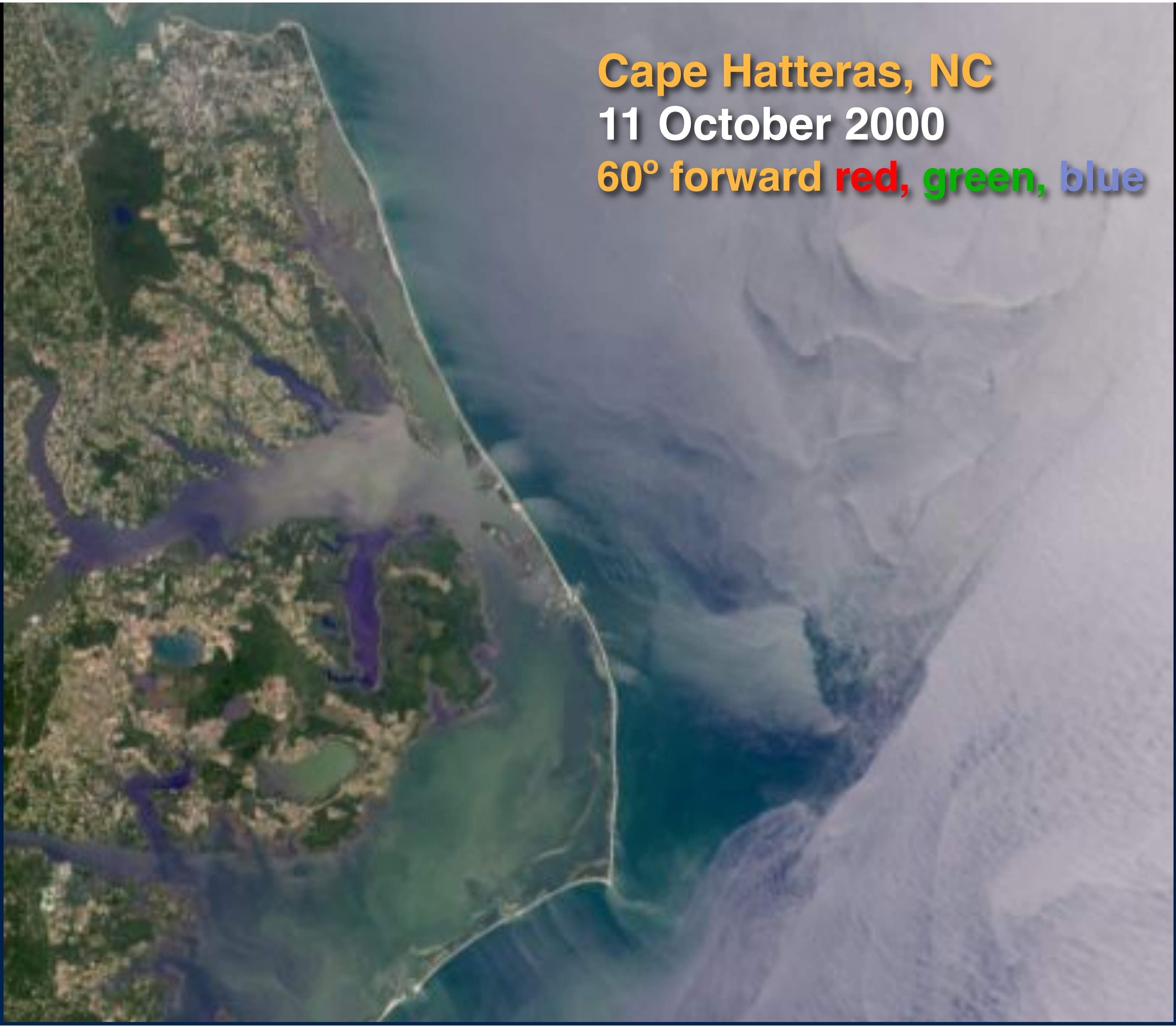

Changing angle of view
AirMISR multiangle imagery (non-georectified)
of Los Angeles, July 13, 2004
Dodger
Stadium
Downtown
nadir
46° forward
46° backward

Path 13; Orbit 4475; Block 58; Oct 20, 2000




Cape Hatteras, NC
11 October 2000
26° aft red, green, blue

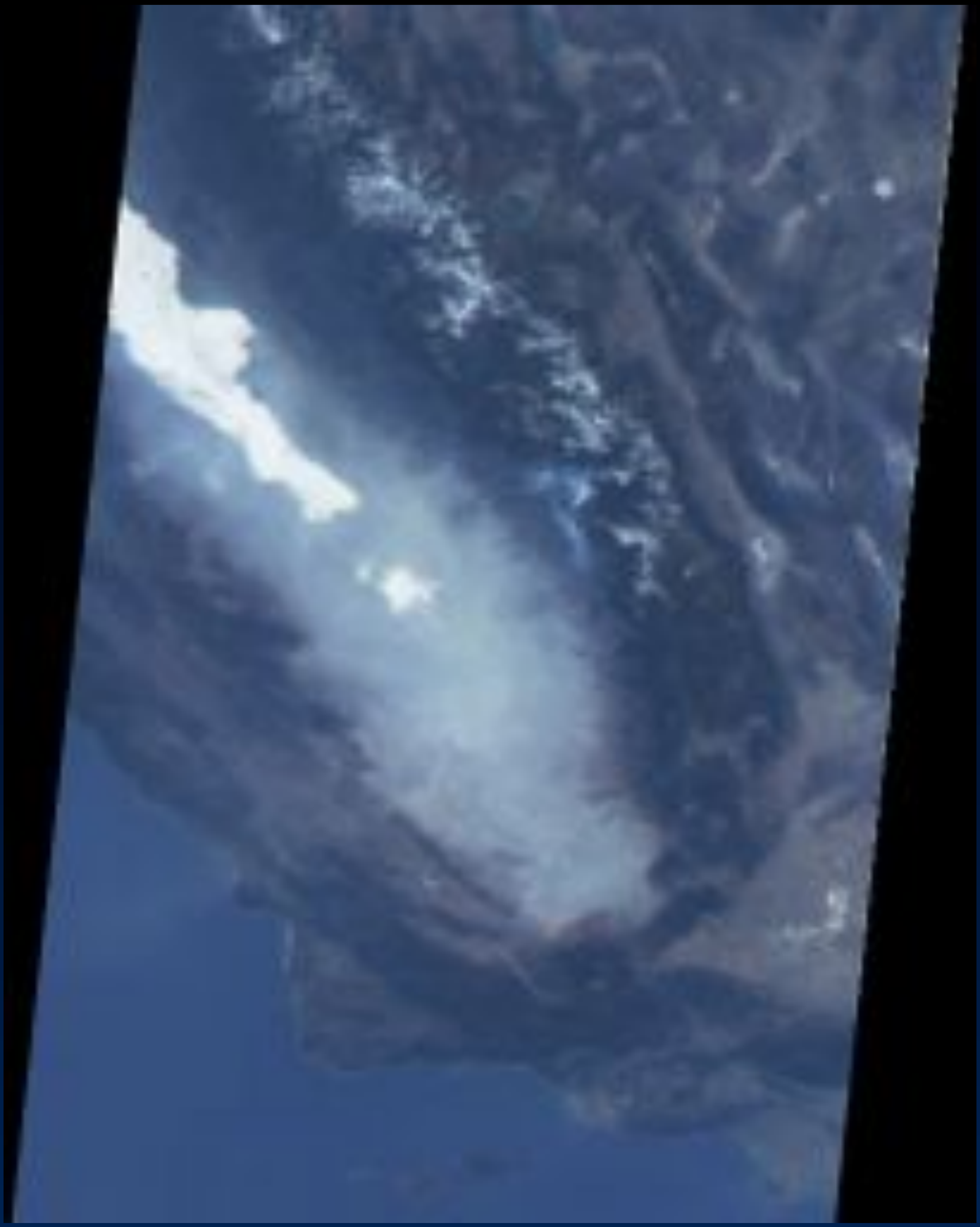

Cape Hatteras, NC
11 October 2000
26° forward red, green, blue


Cape Hatteras, NC
11 October 2000
60º forward red, green, blue

Bidirectional reflectance at top-of-atmosphere

San Joaquin Valley
3 January 2001

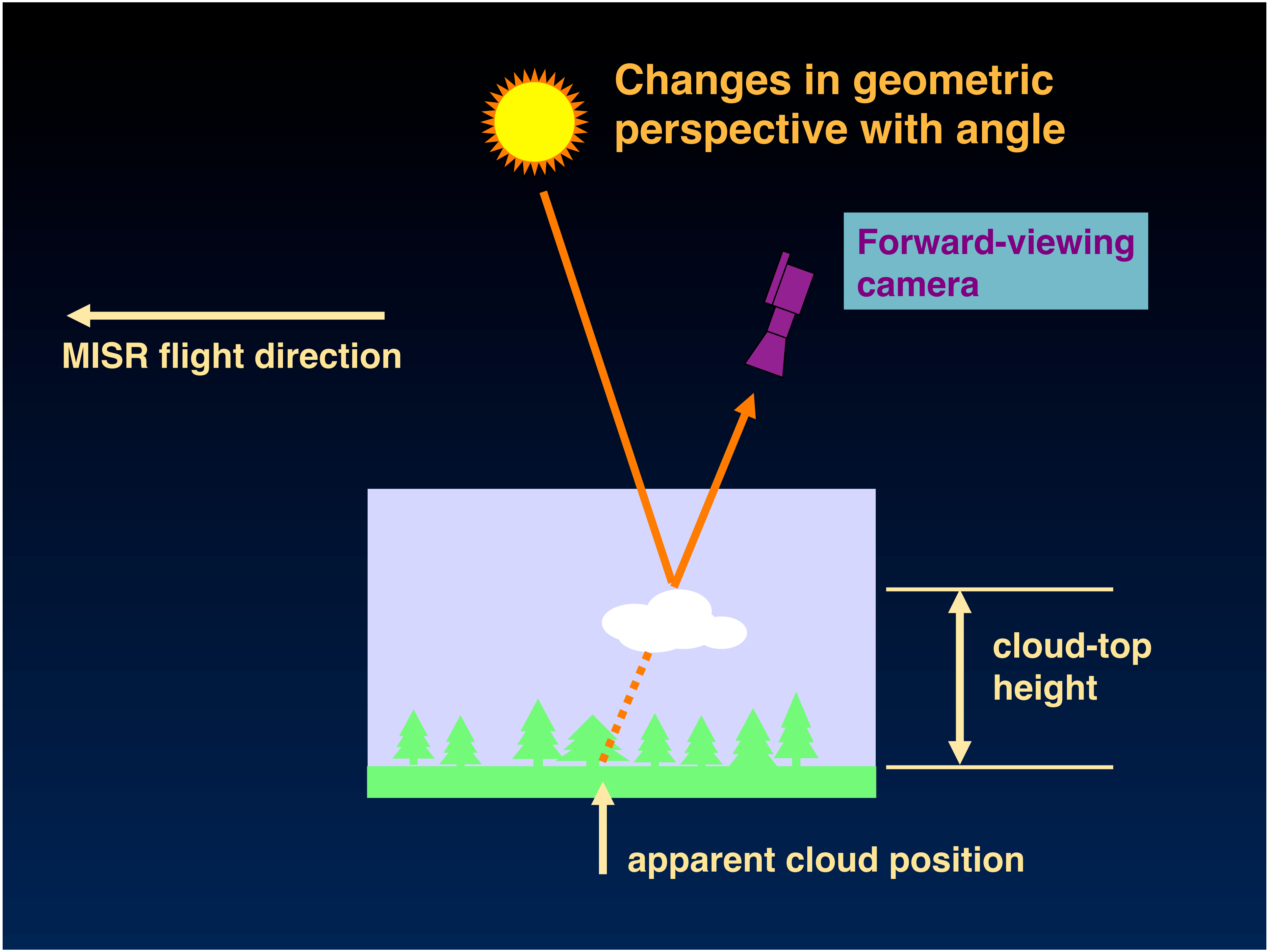
nadir



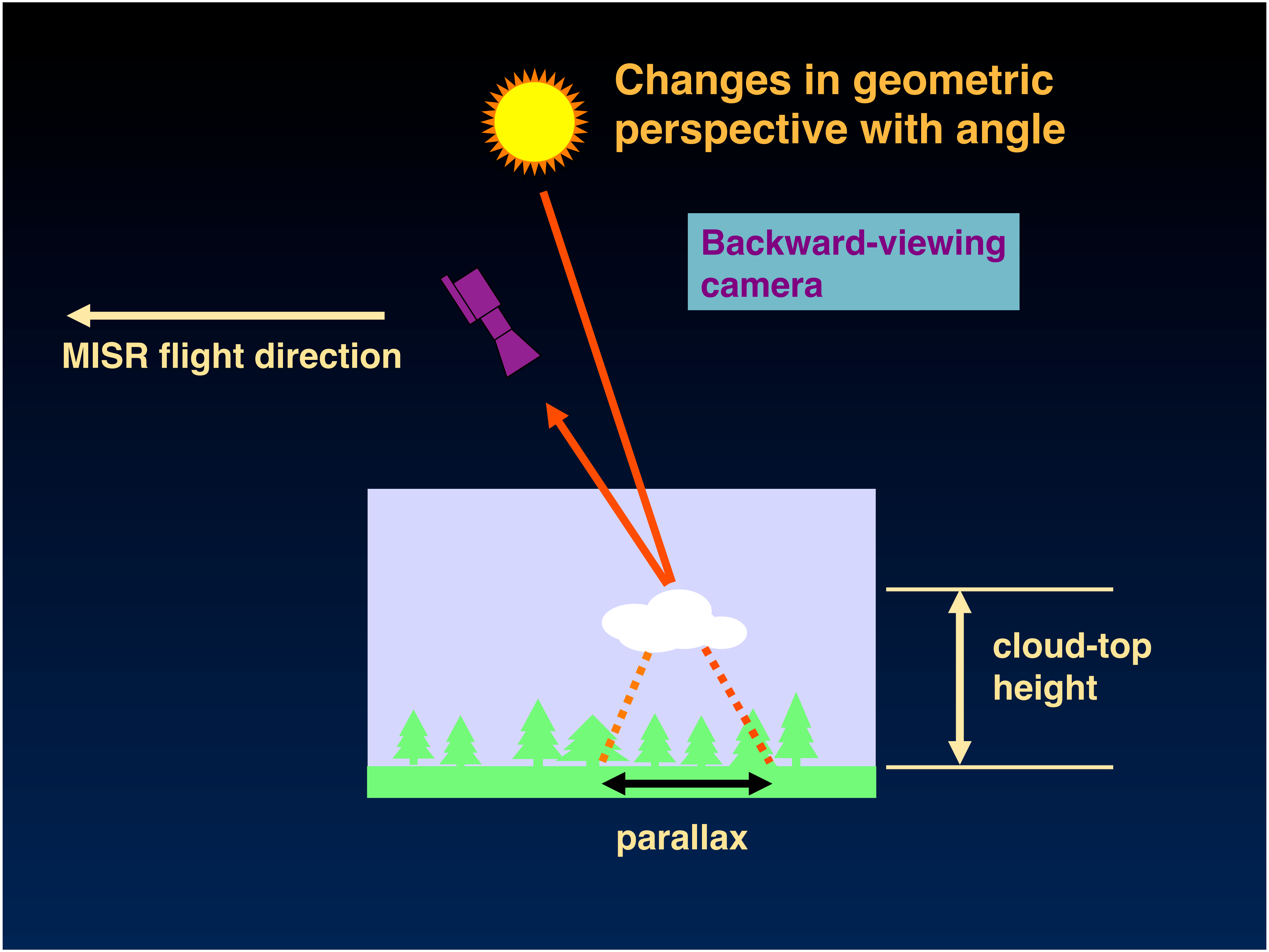
Bidirectional reflectance at top-of-atmosphere

San Joaquin Valley
3 January 2001

70º forward



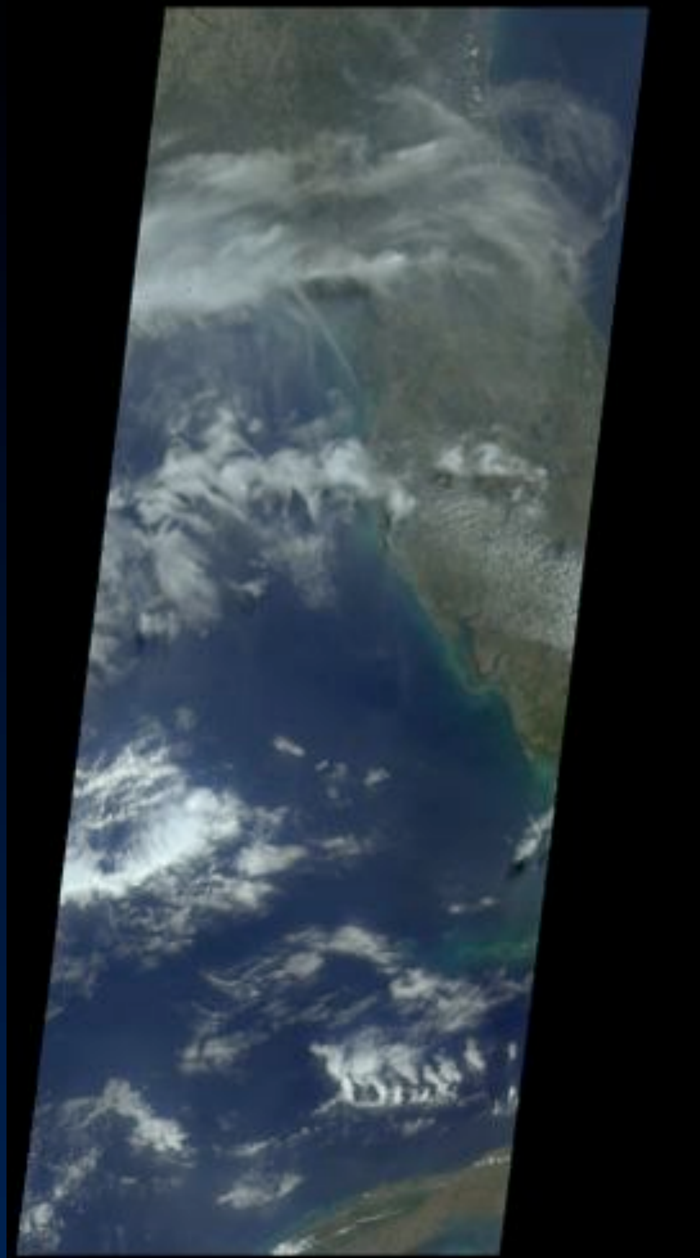
Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
cloud-top height
apparent cloud position


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

50 km

Multi-angle “fly-over” of Hurricane Carlotta thunderclouds

19 August 2000



Multiangle “flyover”
Florida and Cuba
6 March 2000

Georgian Bay, Ontario, 6 March 2000

Nadir (An)

70° forward (Df)

Georgian Bay, Ontario, 6 March 2000

Nadir (An)

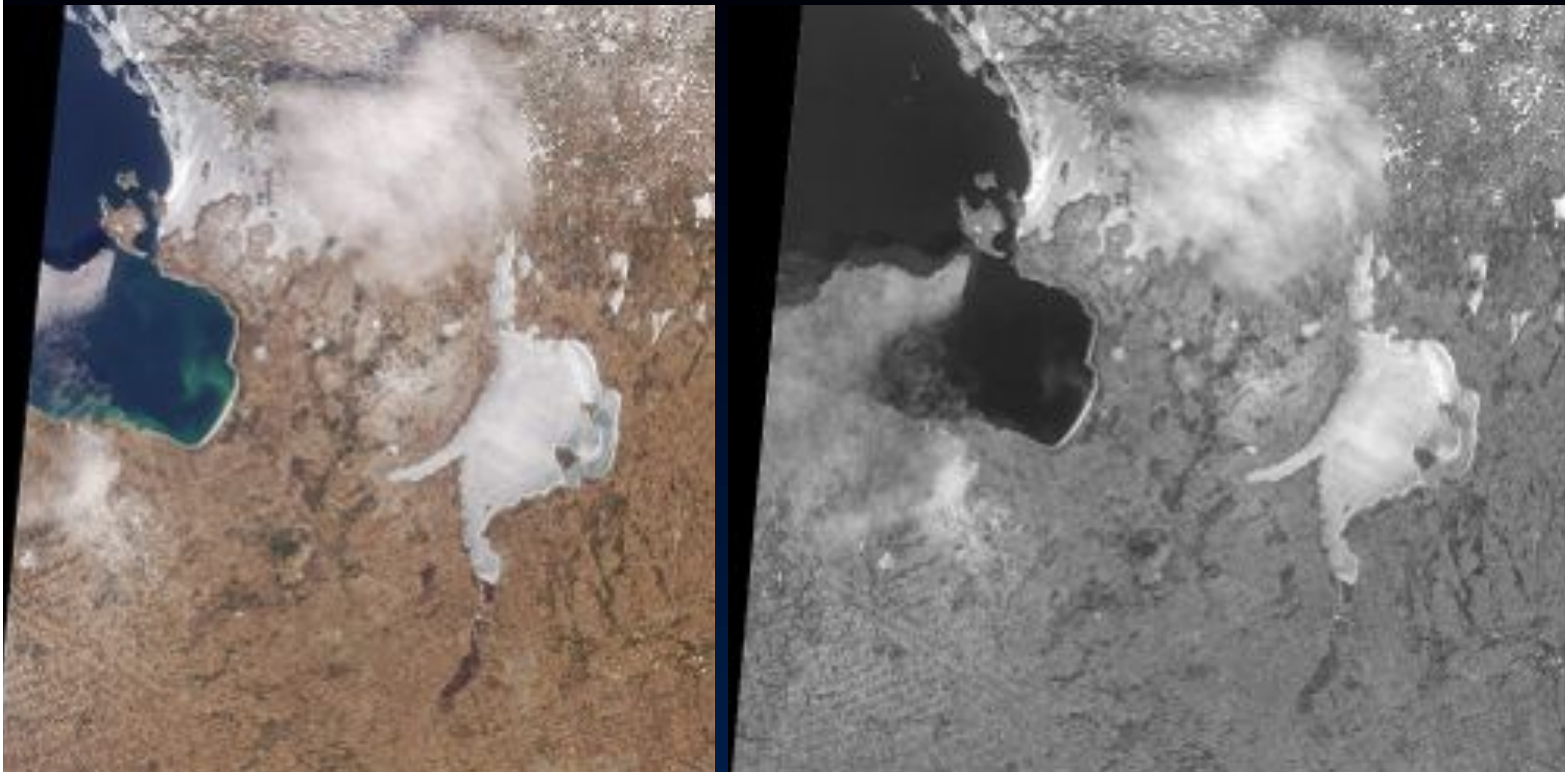
60° forward (Cf)

Georgian Bay, Ontario, 6 March 2000

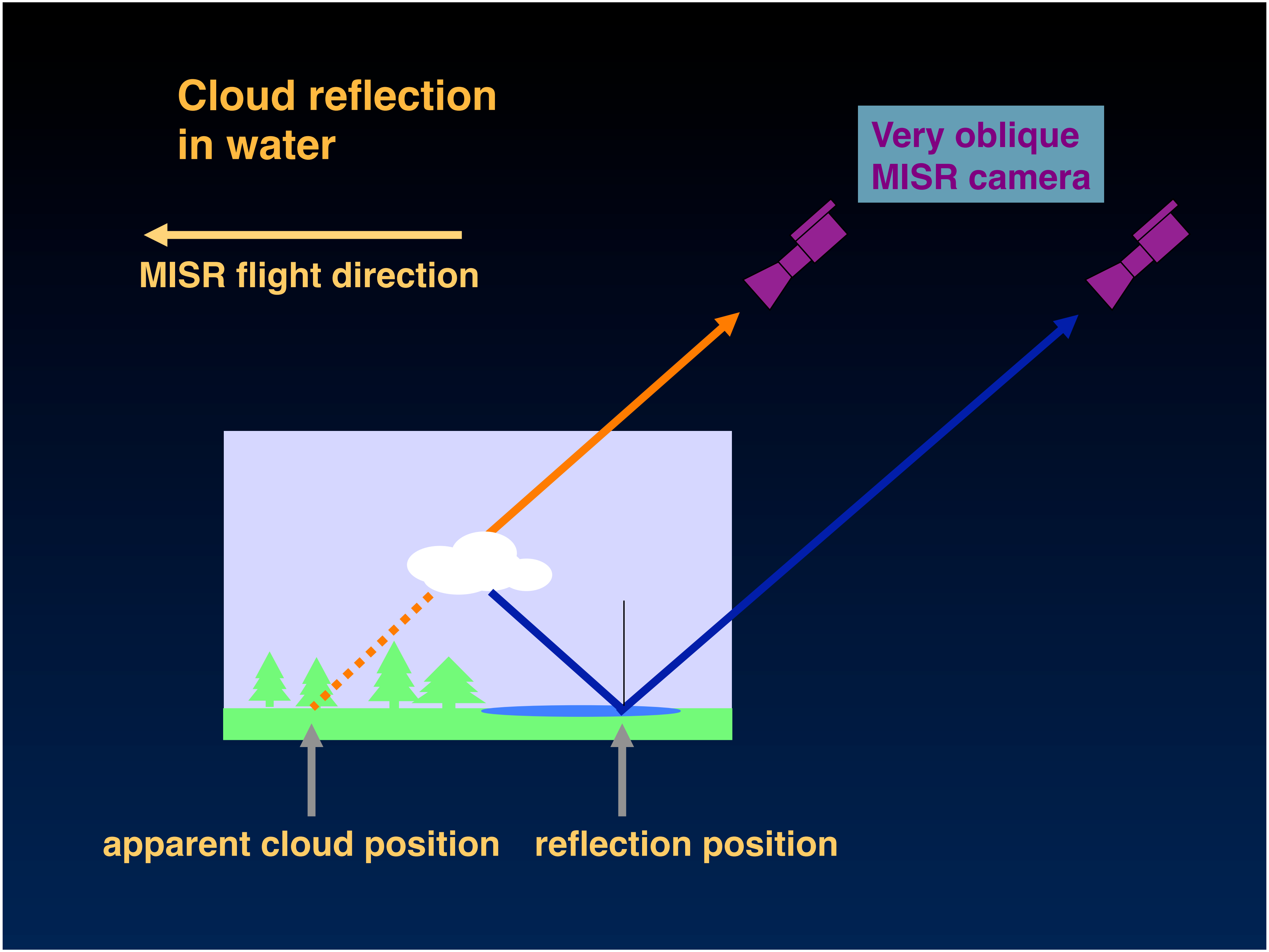
Nadir (An)

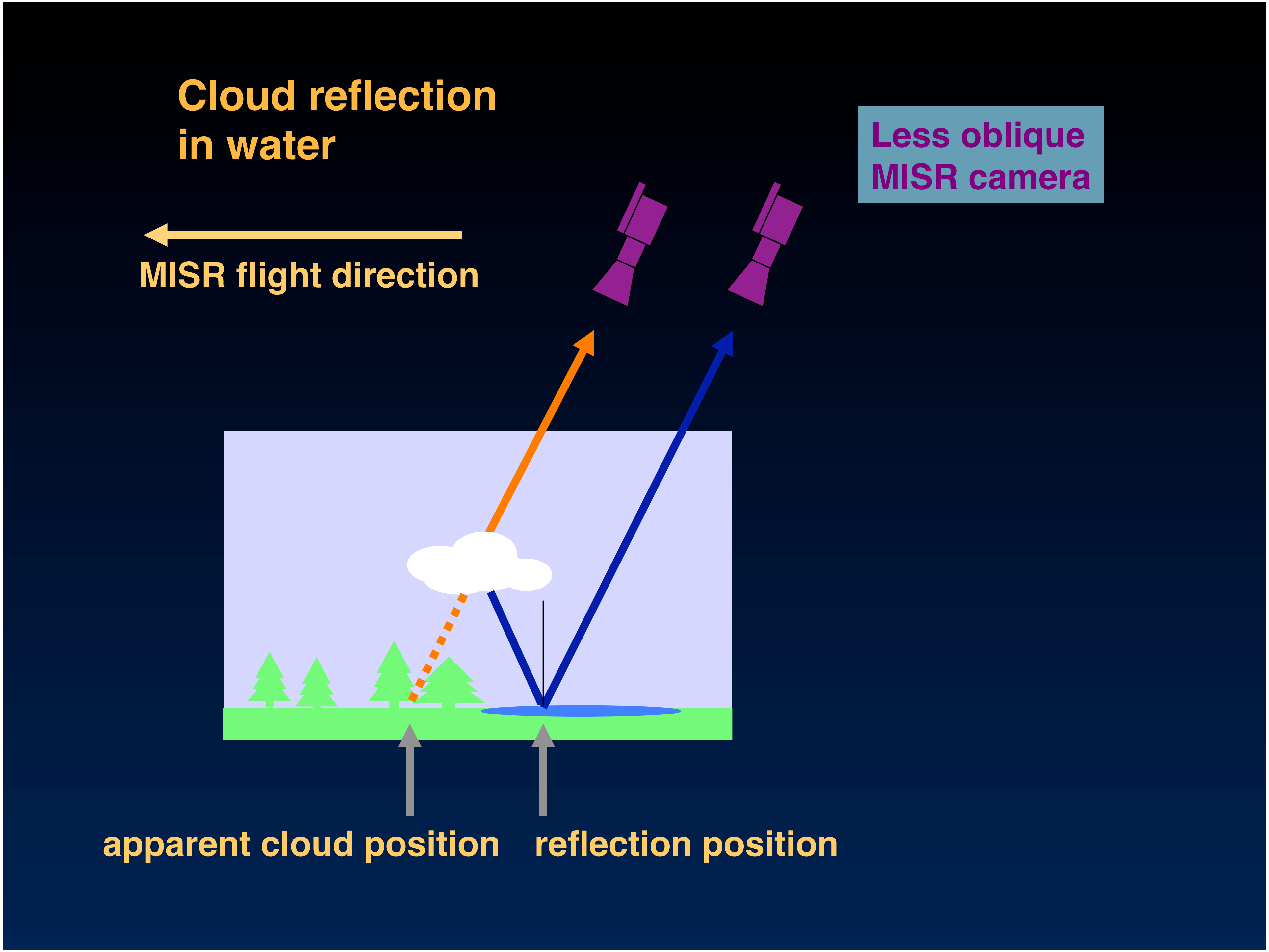
46º forward (Bf)

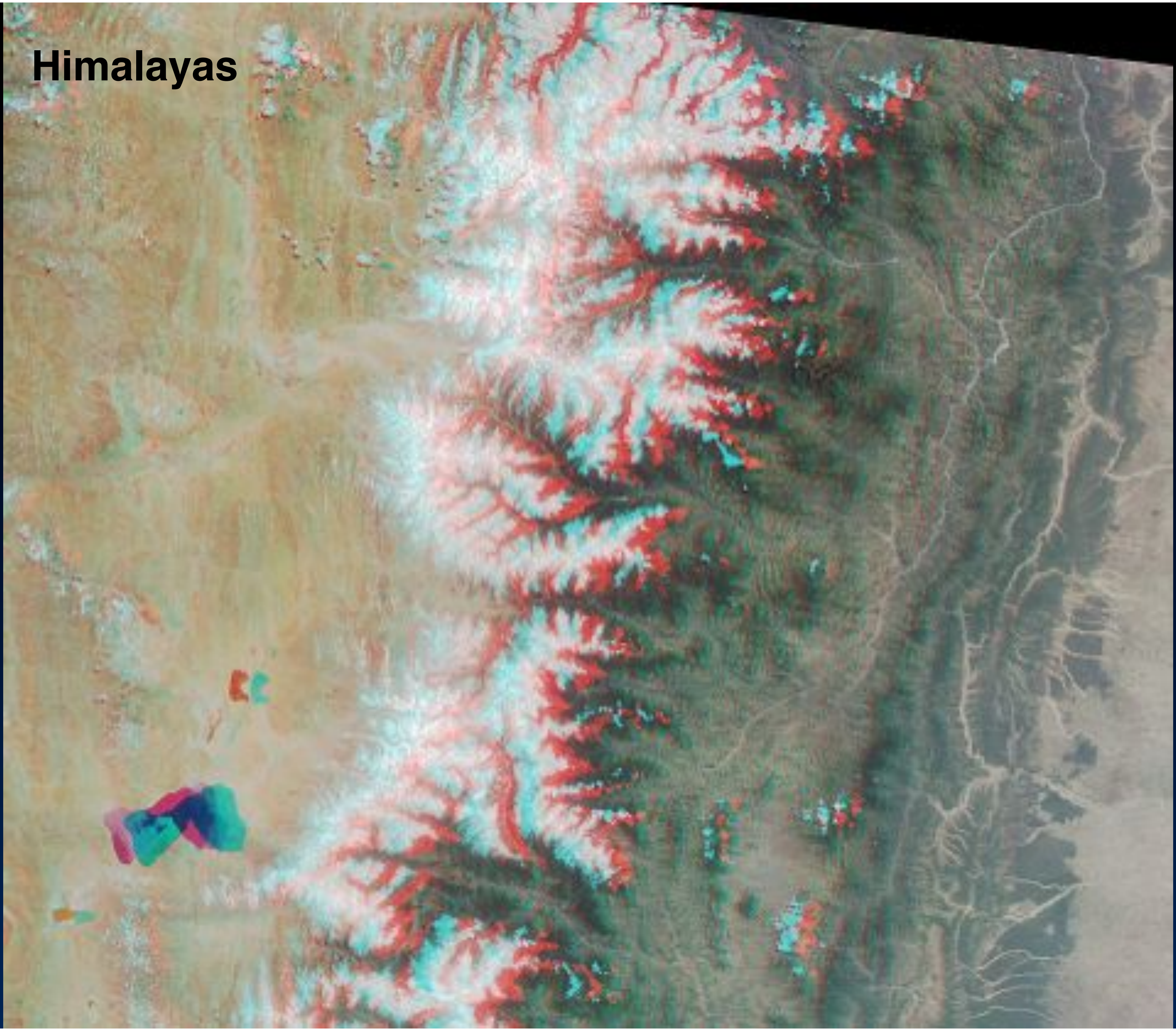
Georgian Bay, Ontario, 6 March 2000



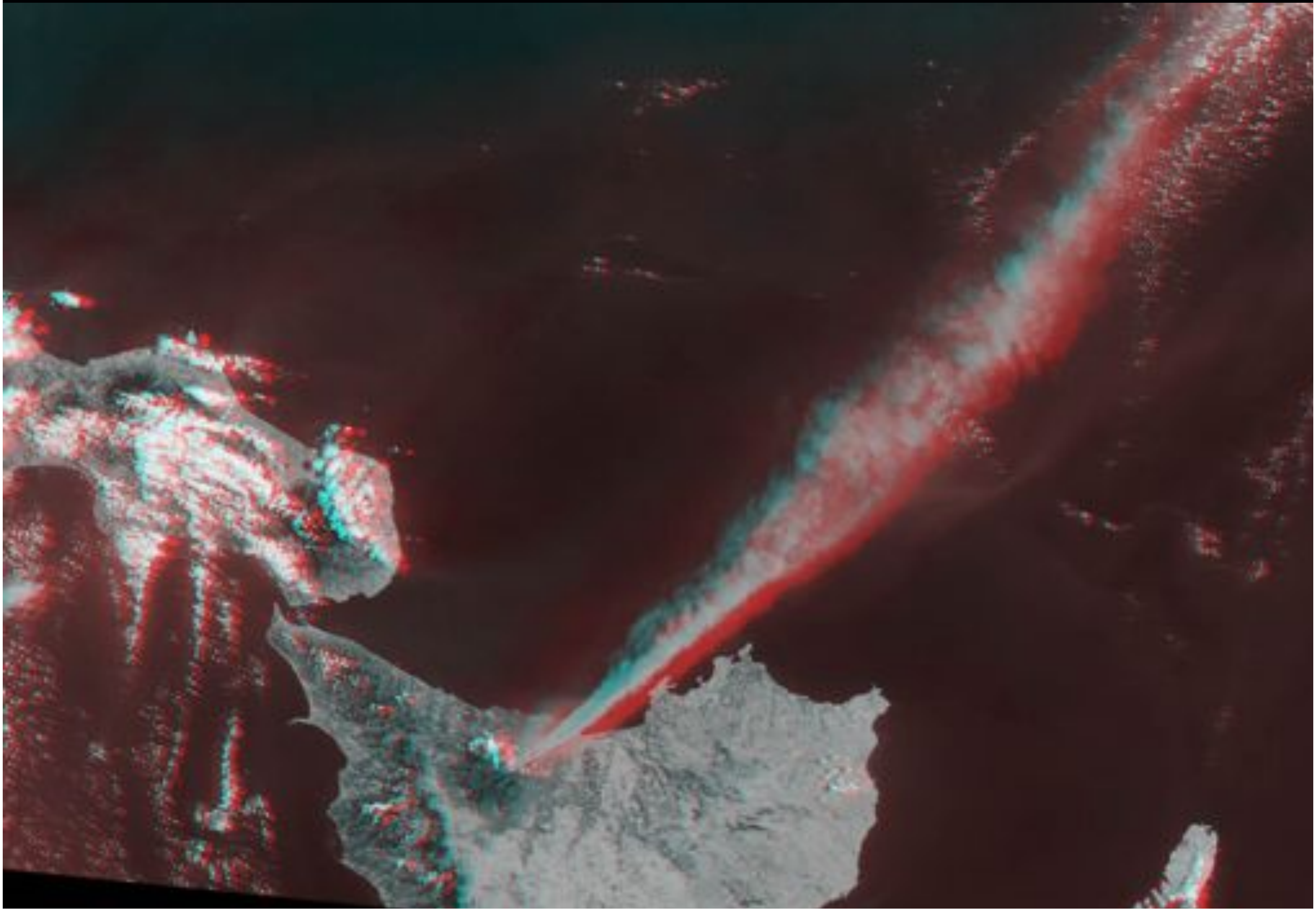
Nadir (An) 26° forward (Af)

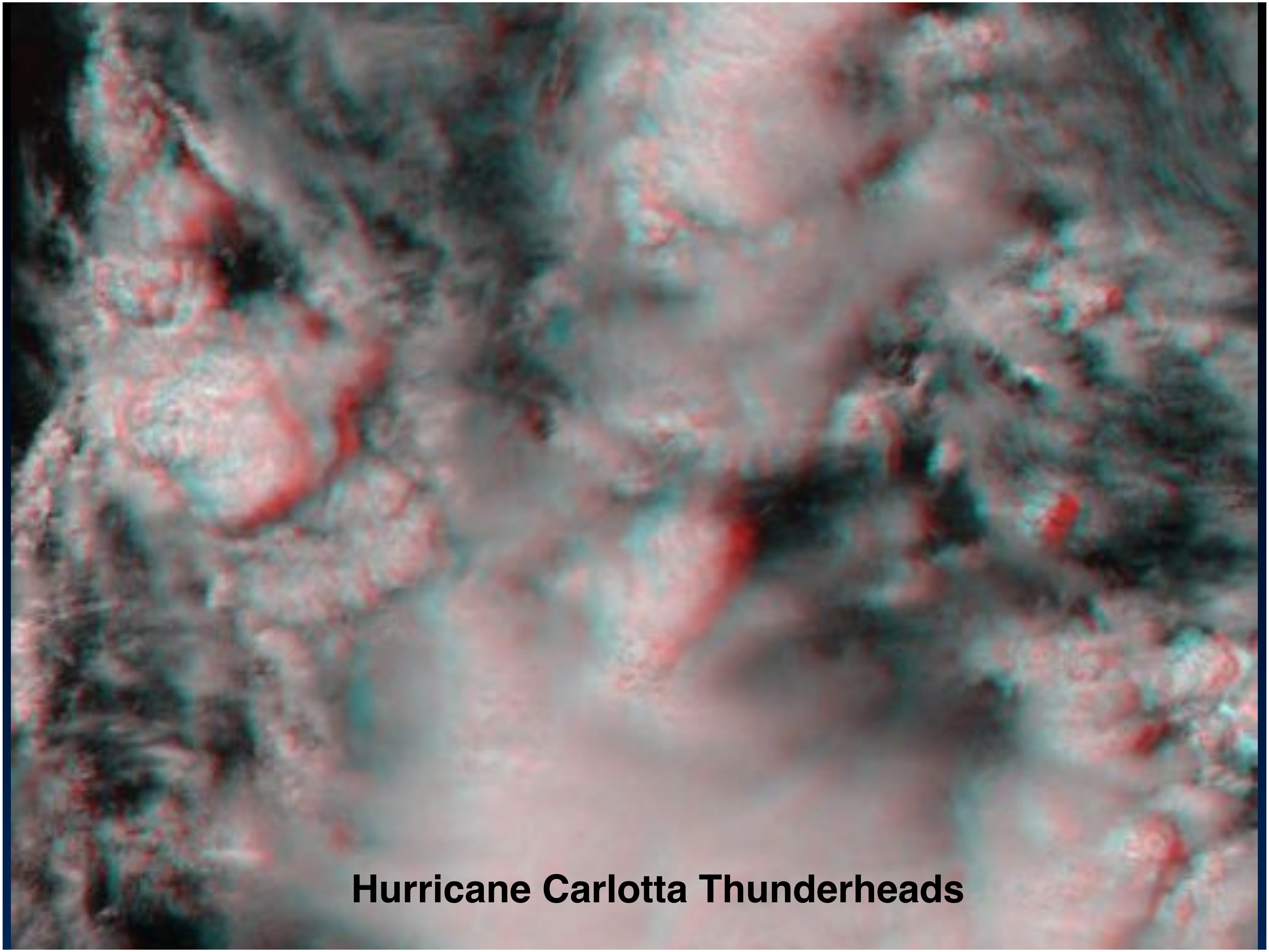

Cloud reflection
in water
MISR flight direction
Very oblique
MISR camera
apparent cloud position
reflection position


Cloud reflection
in water
Less oblique
MISR camera
MISR flight direction
apparent cloud position
reflection position

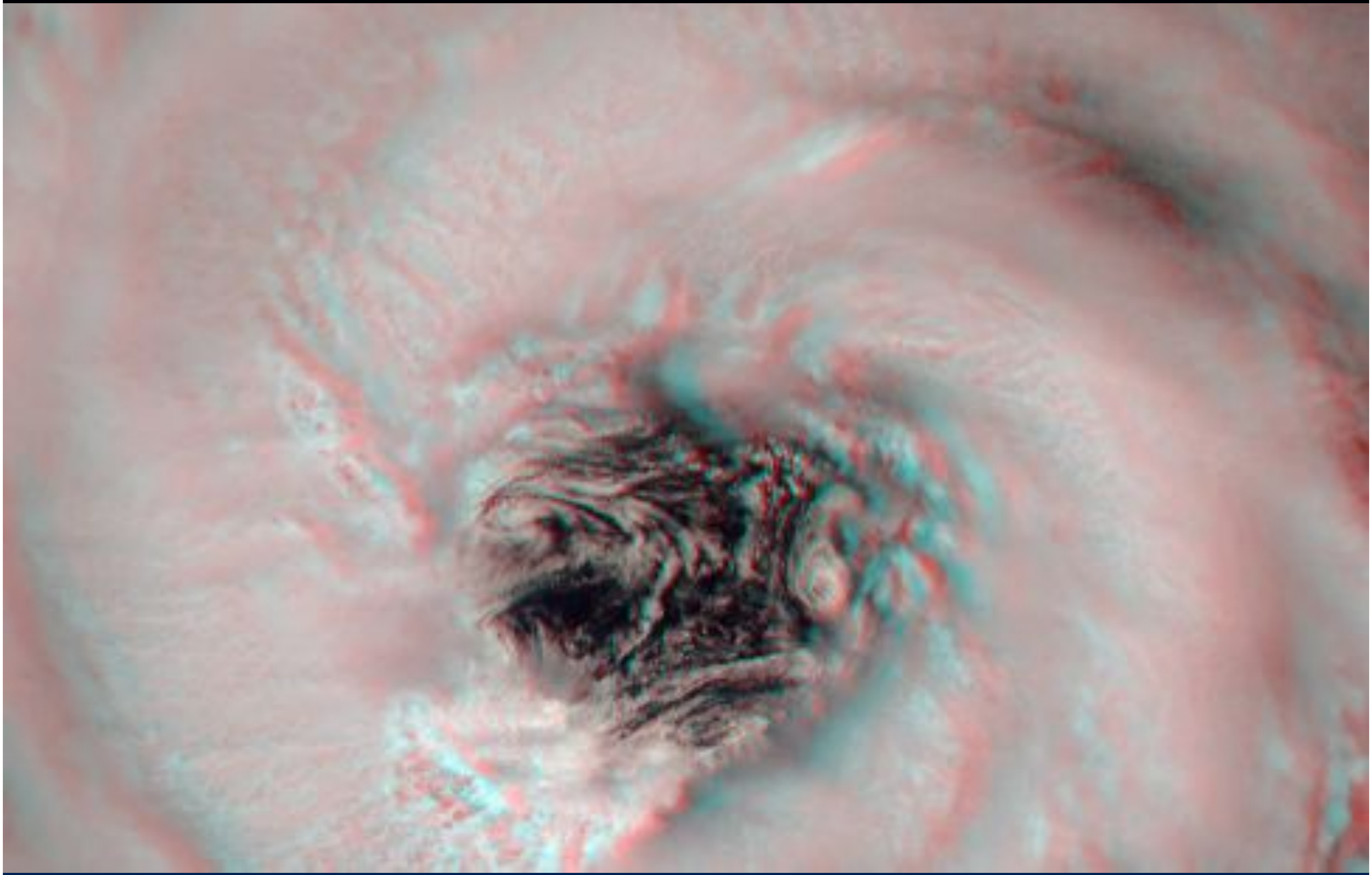

Himalayas

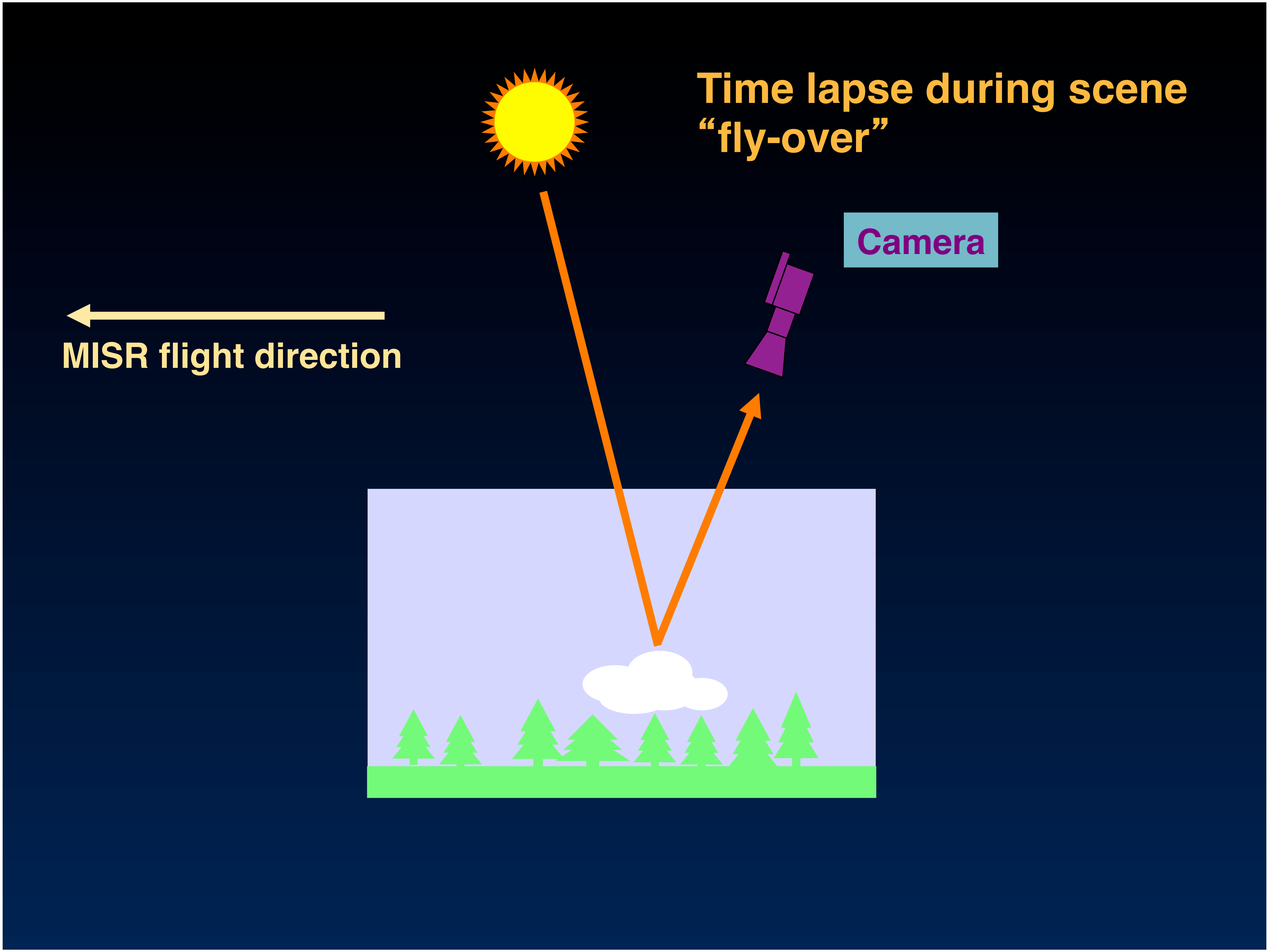
Eruption of Mt. Etna, 22 July 2001

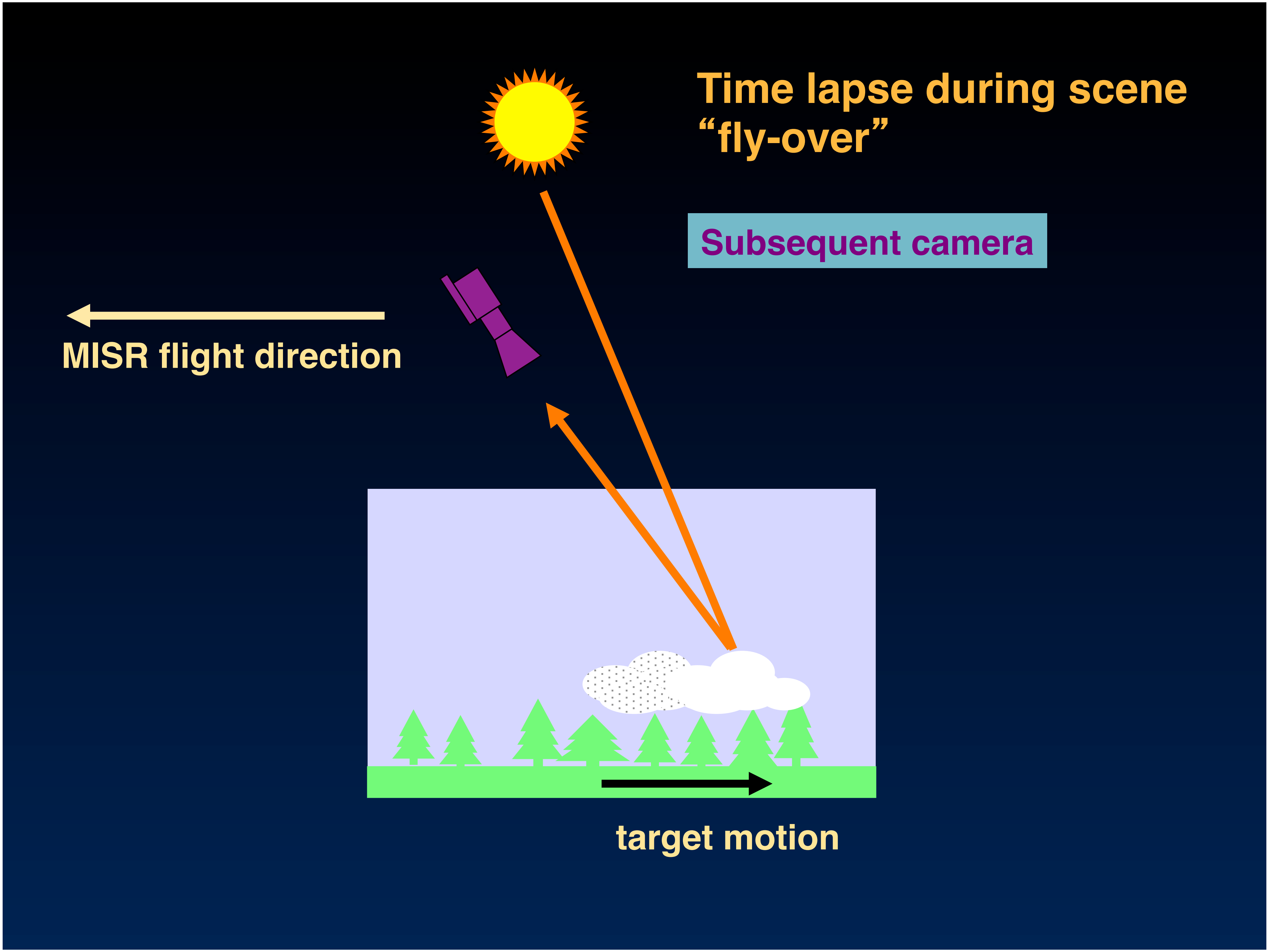



Hurricane Carlotta Thunderheads

Hurricane Alberto Eye




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

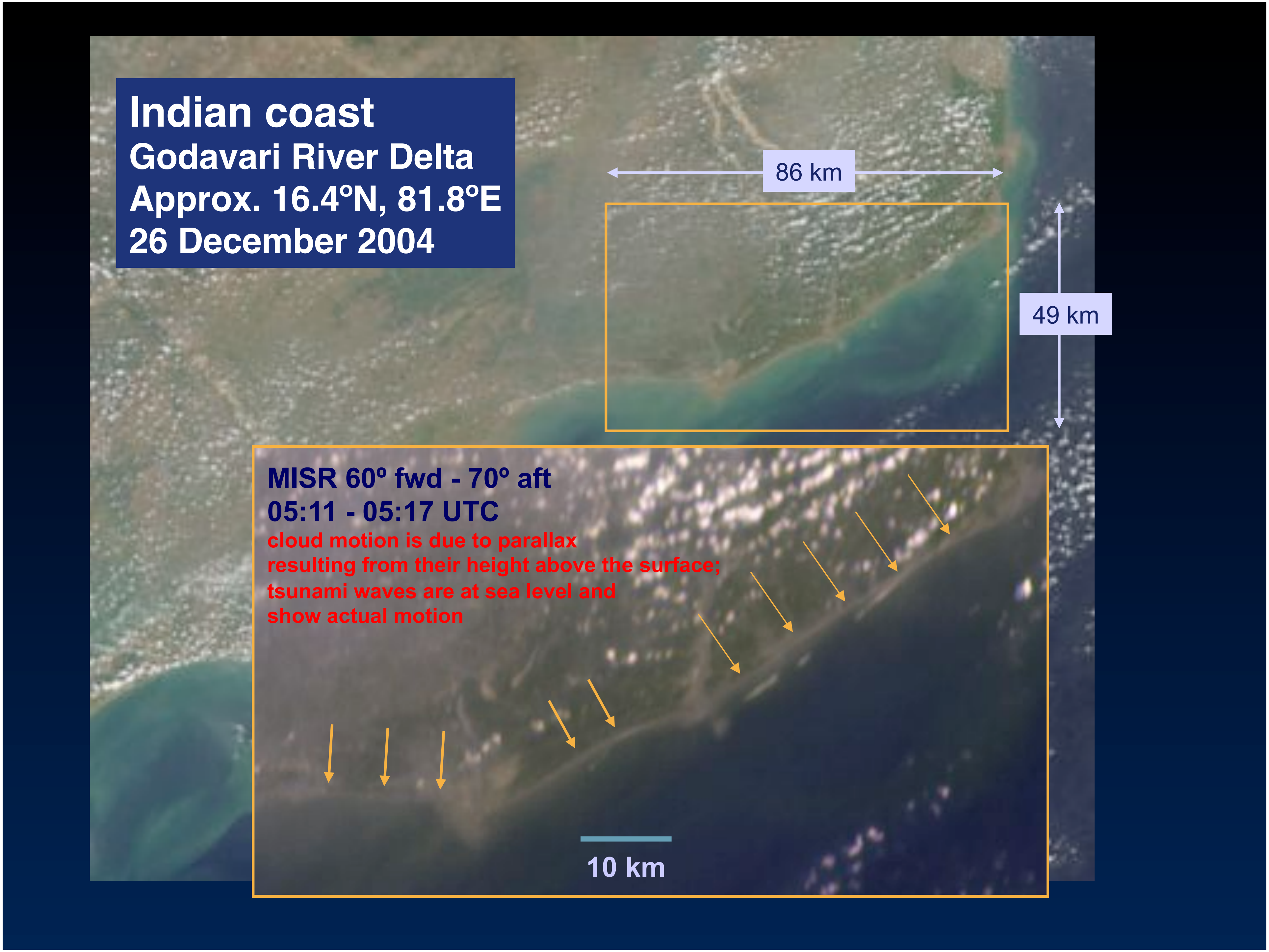

Time lapse during scene
“fly-over”
Subsequent camera
MISR flight direction
target motion

Moving ships off the North Carolina Coast

11 October 2000

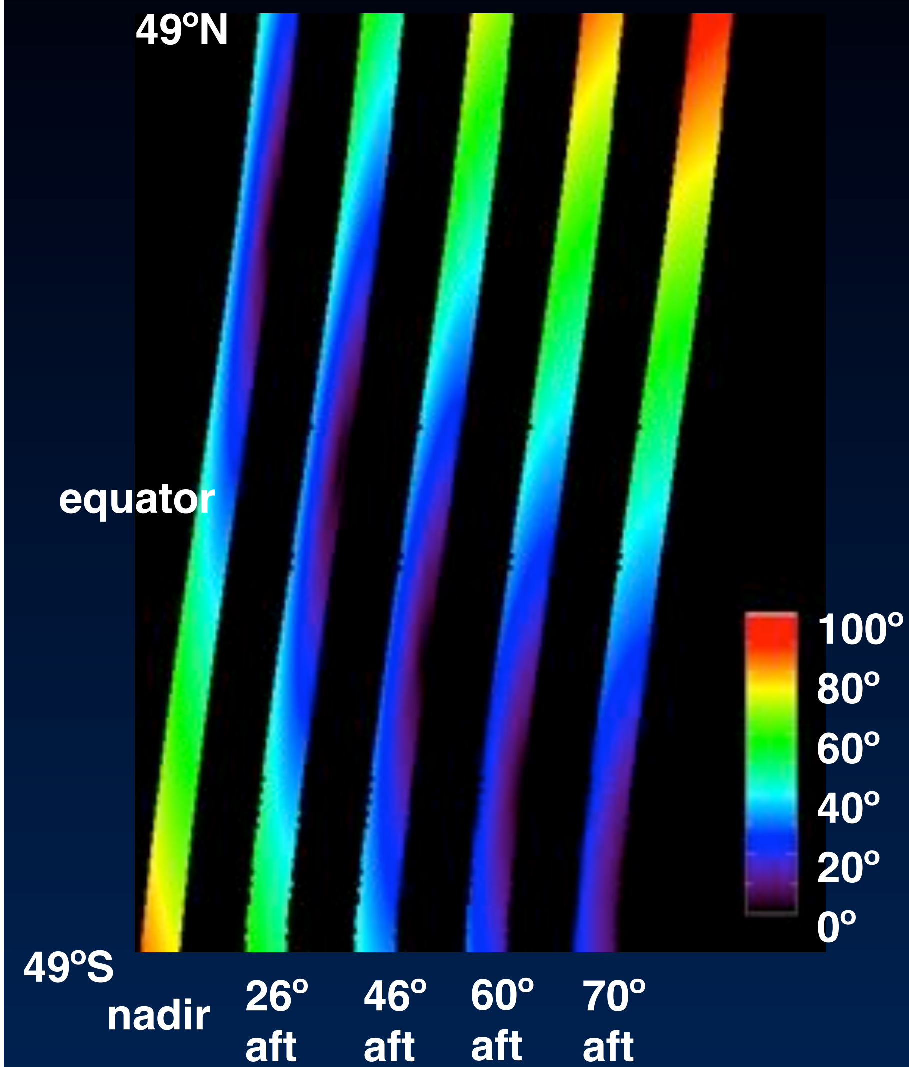
Von Karman vortex street near Jan Mayen Island

6 June 2001


Indian coast
Godavari River Delta
Approx. 16.4ºN, 81.8ºE
26 December 2004
86 km
49 km
MISR 60º fwd - 70º aft
05:11 - 05:17 UTC
cloud motion is due to parallax
resulting from their height above the surface;
tsunami waves are at sea level and
show actual motion
10 km

L1B2 Geometric Parameters

Provided on 17.6-km centers



Example of glitter angle July 3

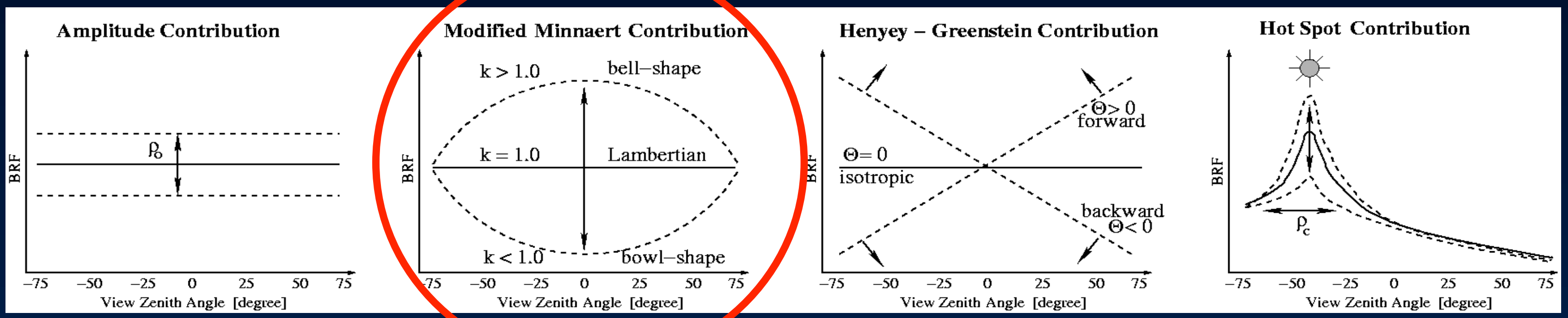
CONTENTS

- 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

Interlude: RPV BRF model

$$BRF\ (z, \Omega_0 \rightarrow \Omega) = \rho_0\ \ Mi\ (k)\ \ FHG\ (\Theta)\ \ H\ (\rho_c)$$

- ρ_0 - controls the amplitude level
- *k - controls the bowl/bell shape*
- Θ - controls the forward/backward scattering
- ρ_c - controls the hot spot peak (optional)



Ref: Rahman et al. (1993) JGR

Interlude: AnisView

- AnisView is a small, self-standing, user-friendly (GUI-based), platform-independent (Linux, Mac, Windows), open source and freely available tool to explore anisotropy issues
- It is based on the parametric RPV BRF model that is also used in the MISR ground segment
- A copy of this software tool is available on the USB key distributed to the participants and containing the materials of this Tutorial

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4. Geophysical products (L2) and scientific applications
   - Atmosphere
   - Ice fields
   - Land

5. High level products (L3) and their applications

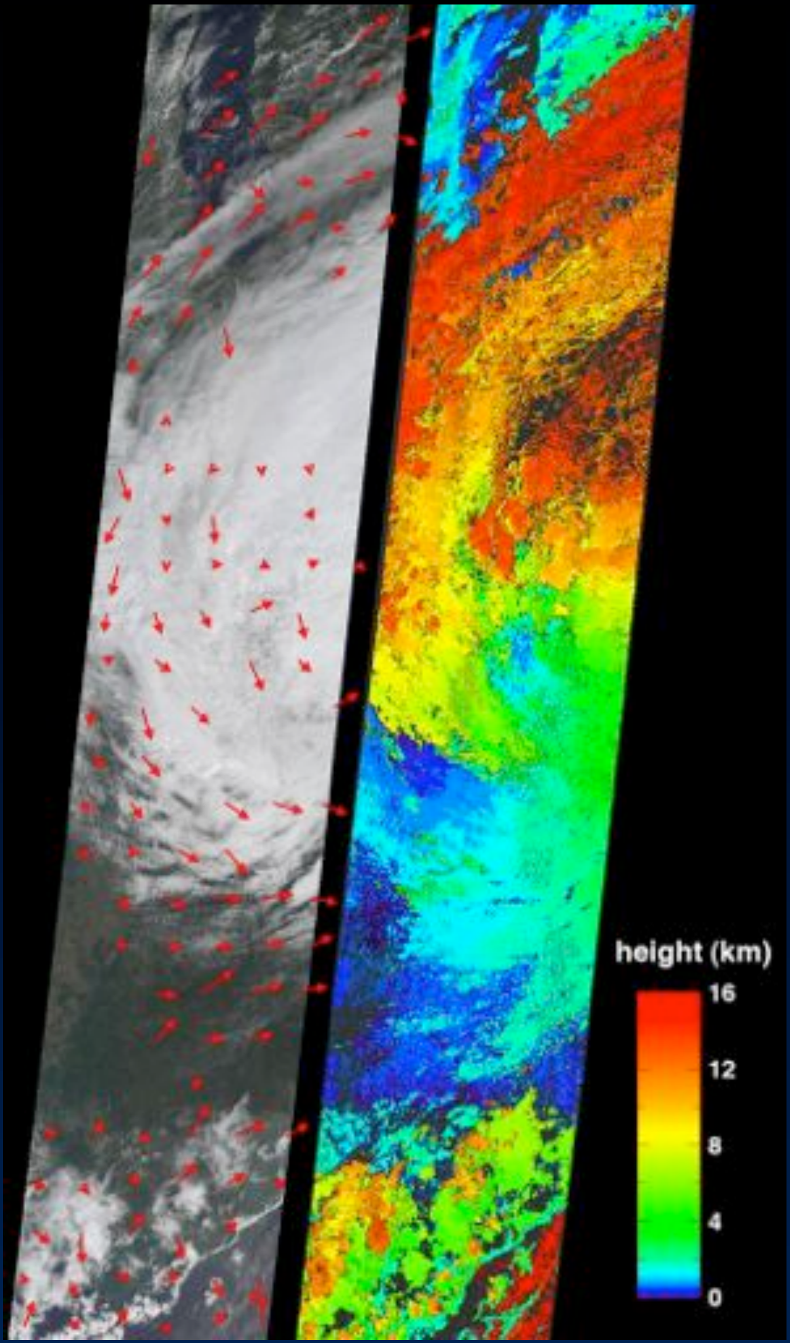
Level 2 Standard Products

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 2 processing uses multiple cameras simultaneously

- Angular radiance signatures
- Geometric parallax
- Time lapse



L2 TOA/Cloud Stereo Product

Cloud heights and cloud-tracked winds

HEIGHT ATTRIBUTES

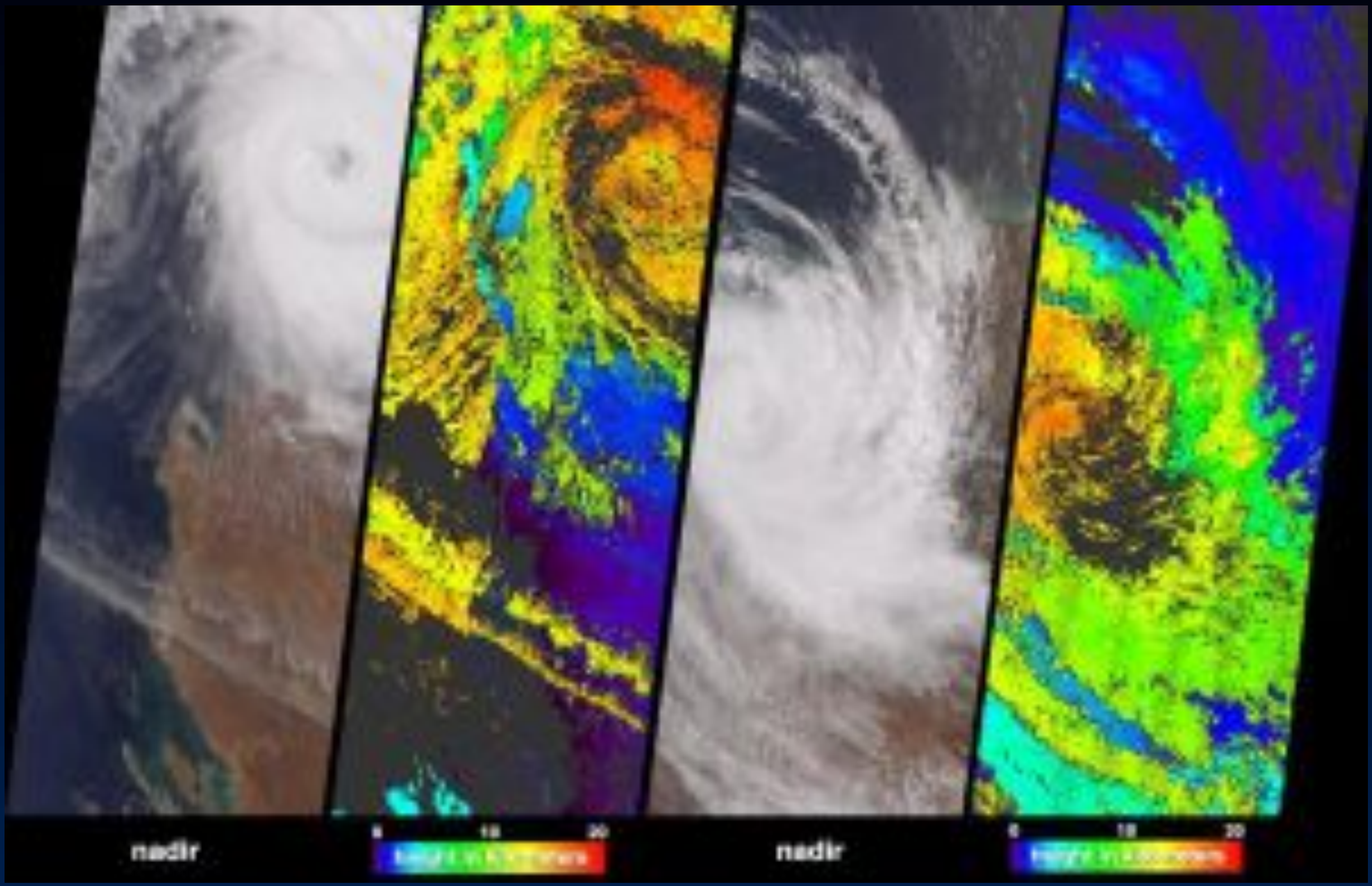
- 1.1-km resolution
- Purely geometric retrievals of height
- Independent of temperature profiles and cloud emissivity
- Independent of radiometric calibration
- Accuracy 500 -1000 m

WIND ATTRIBUTES

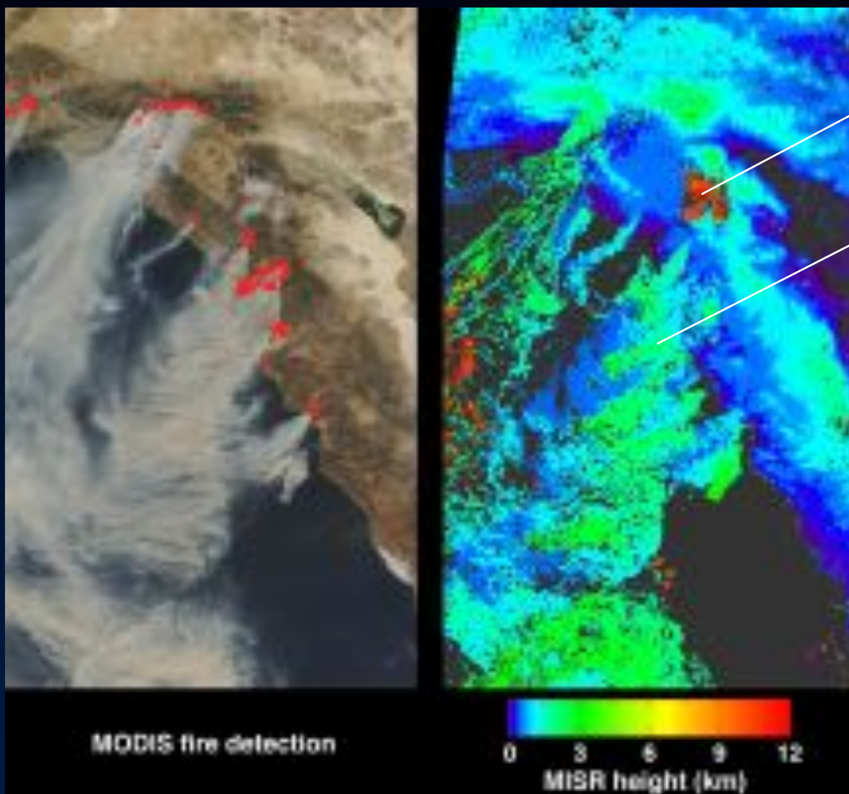
- 70.4-km resolution
- Uses stereo triplets
- Accuracy 1-3 m/s with 300 m height resolution

Hurricane Katrina
30 August 2005

Tropical Cyclone Monty in Western Australia
29 February and 2 March 2004



Measuring wildfire smoke plume injection and transport heights

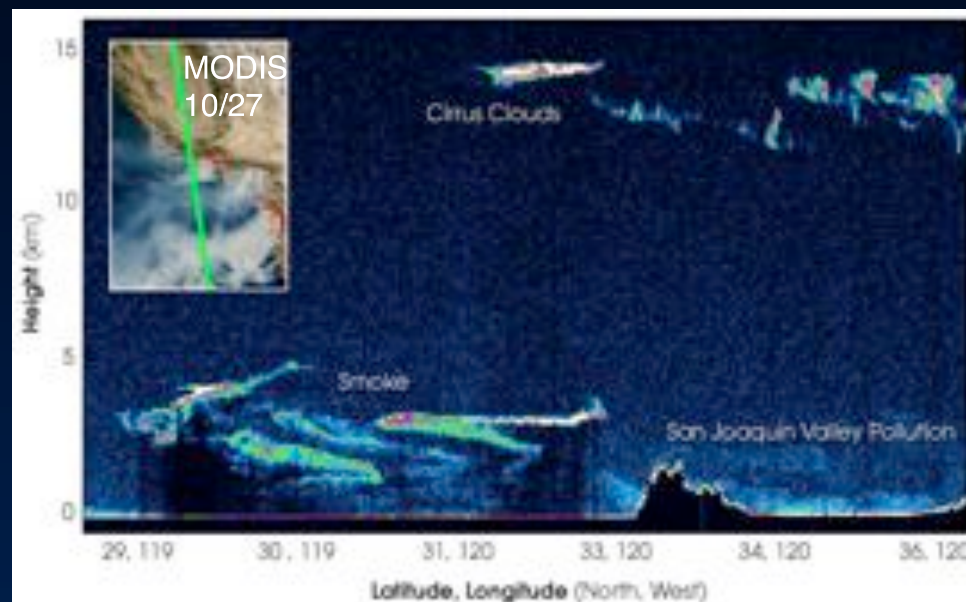


cirrus

smoke

MODIS/MISR data from Terra
26 October 2003

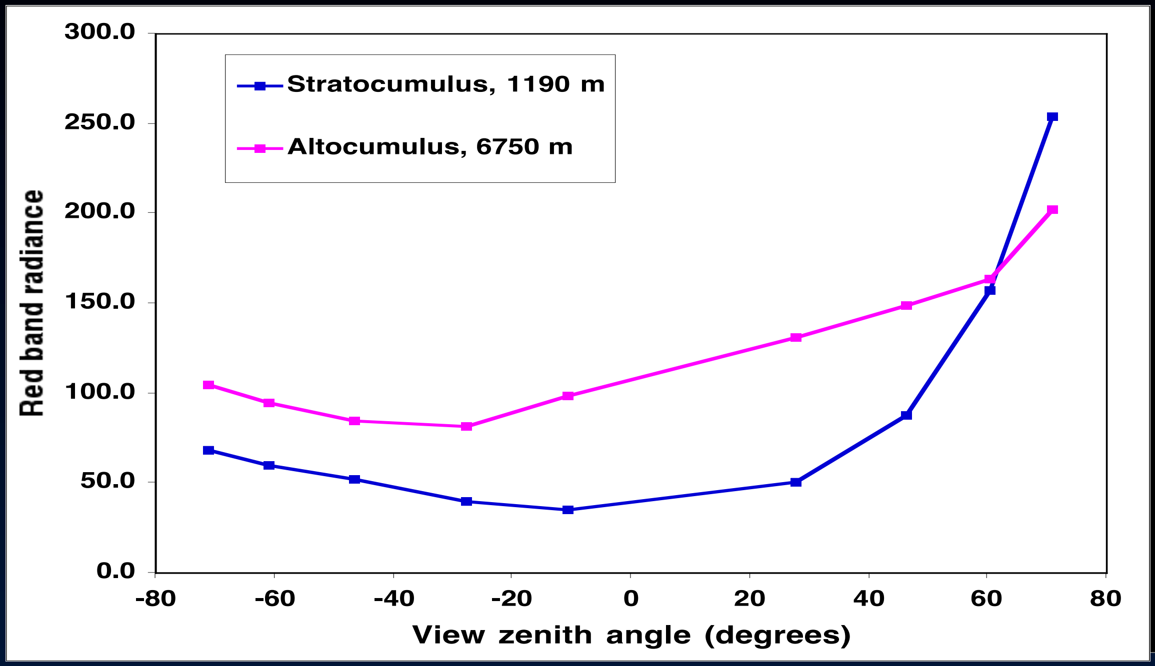
GLAS vertical profiles
28 October 2003

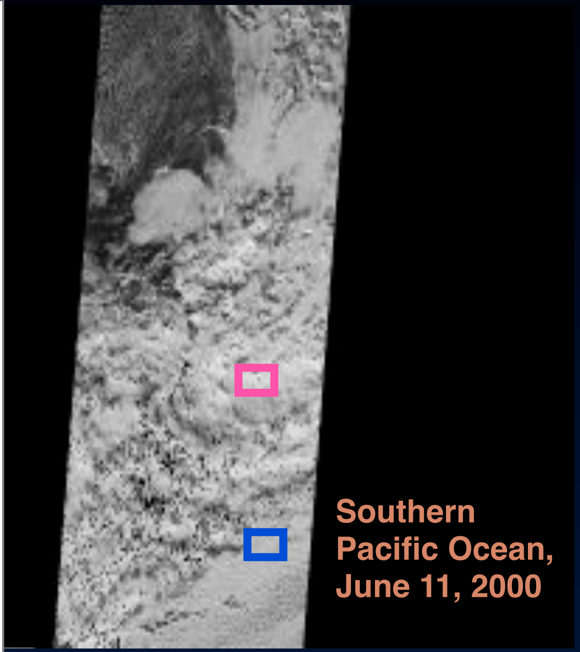


Geoscience Laser Altimeter System (GLAS) hosted on the ICESat platform, launched on 13 January 2003

L2 TOA/Cloud Albedo Product

Cloud-top-projected TOA albedo and bidirectional reflectance

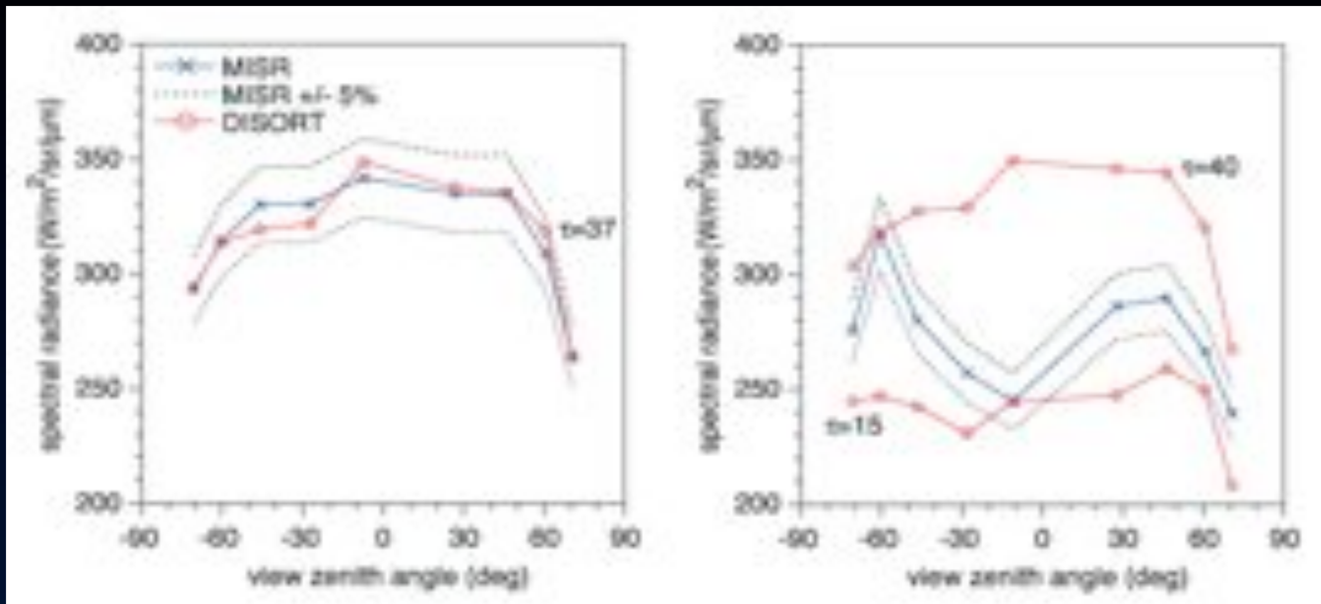


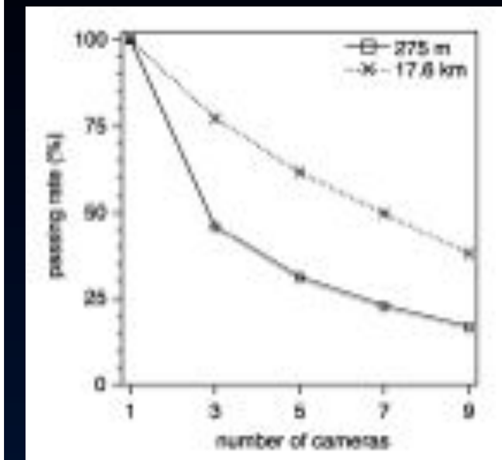


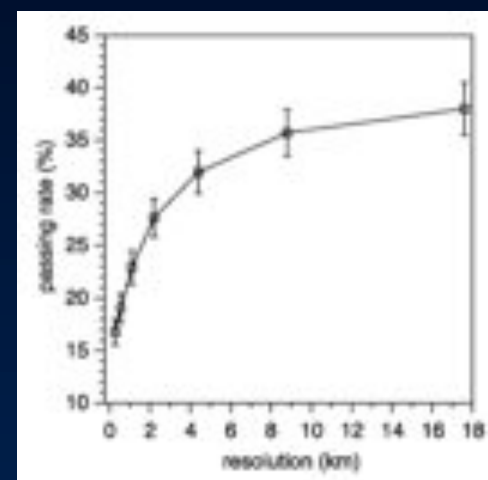
CONTENTS

- “Feature-referenced” top-of-atmosphere bidirectional reflectances
- Includes TOA albedos at fine (2.2. km) resolution for scene classification, and coarse (35.2 km resolution) for mesoscale radiation budget

Multiangle tests of cloud homogeneity







1-D theory fits MISR observations

1-D theory does not fit MISR observations

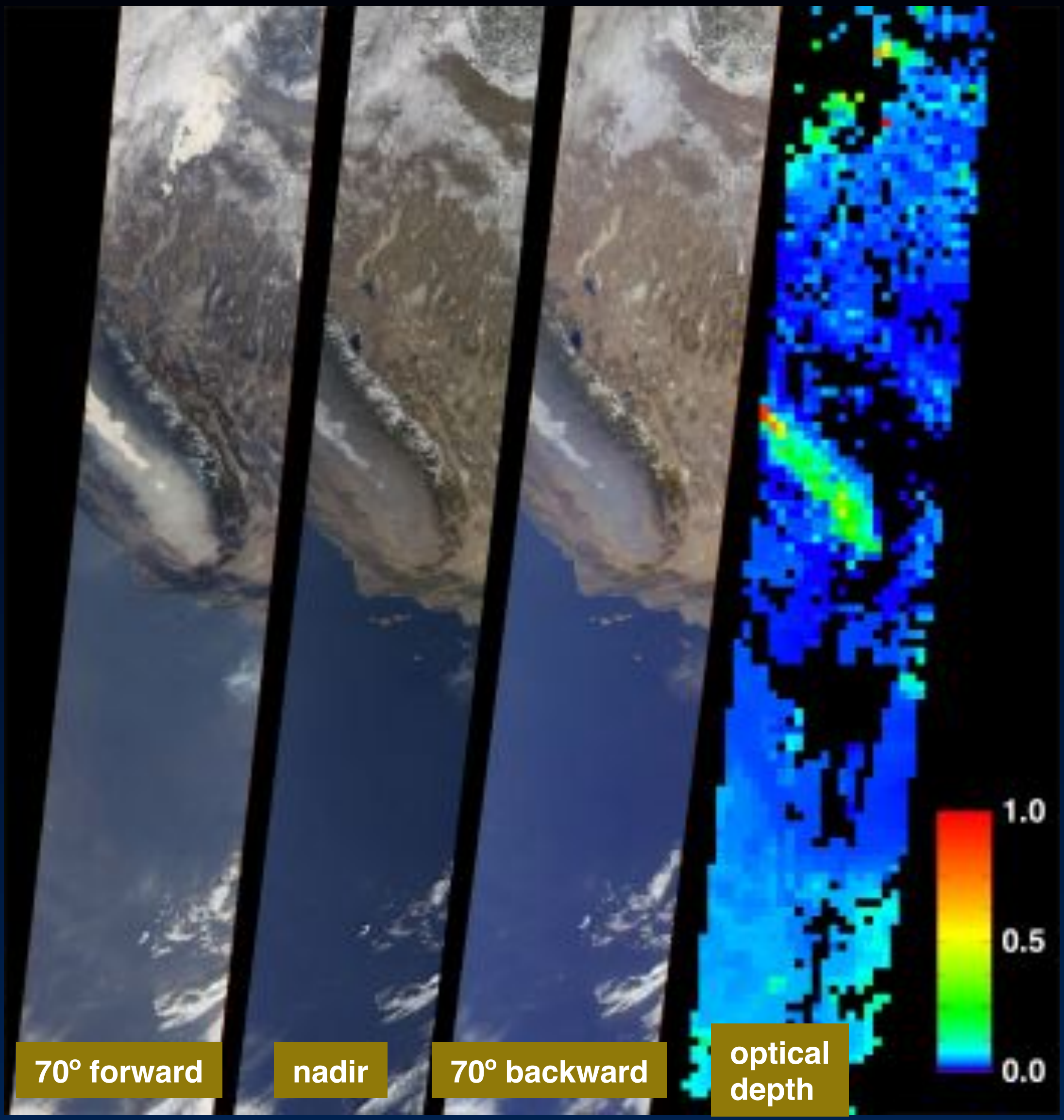
Multiangle data provides a physical consistency check on MODIS 1-D cloud retrieval assumption

Cloud morphology, not just cloud microphysics, plays a major role in determining TOA bidirectional reflectance

A. Horvath, R. Davies (2004), GRL

L2 Aerosol/Surface Product

Aerosol parameters



J. Martonchik et al. (2002), TGARS

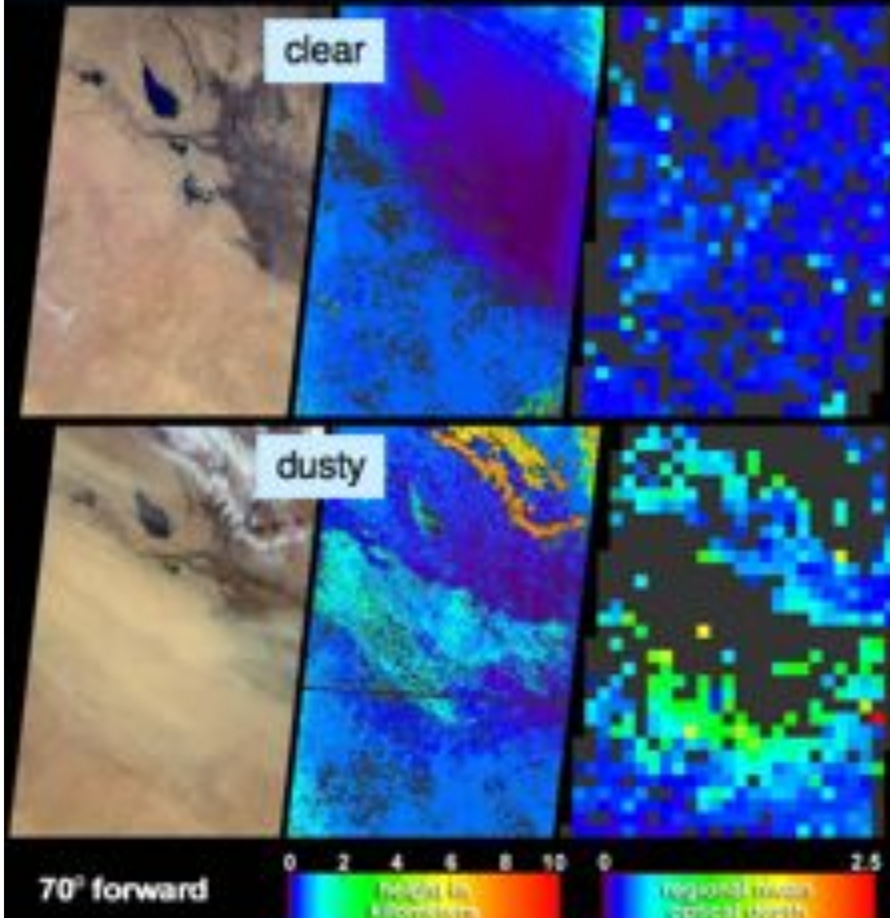
ATTRIBUTES

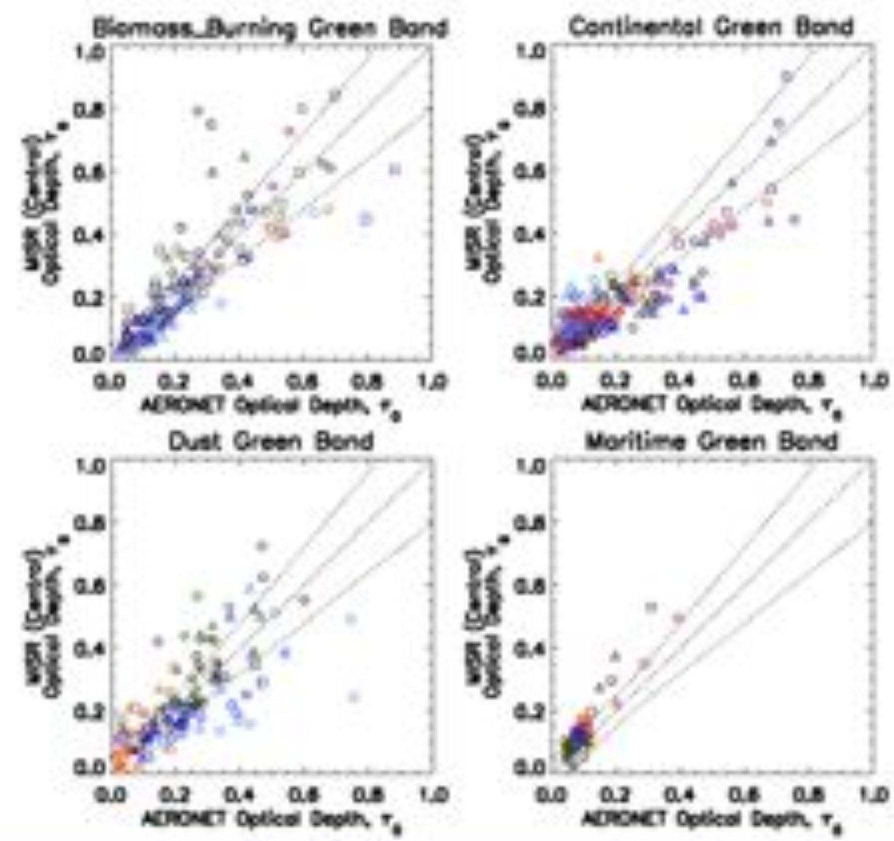
- Validation and quality assessment of aerosol optical depth performed
- Validation of aerosol particle properties in progress

  --Angstrom exponent
  --Size binned fractions
  --Single-scattering albedo
  --Sphericity

Southern California and Southwestern Nevada
January 3, 2001

Retrieval of aerosol optical depth over a wide range of surface types

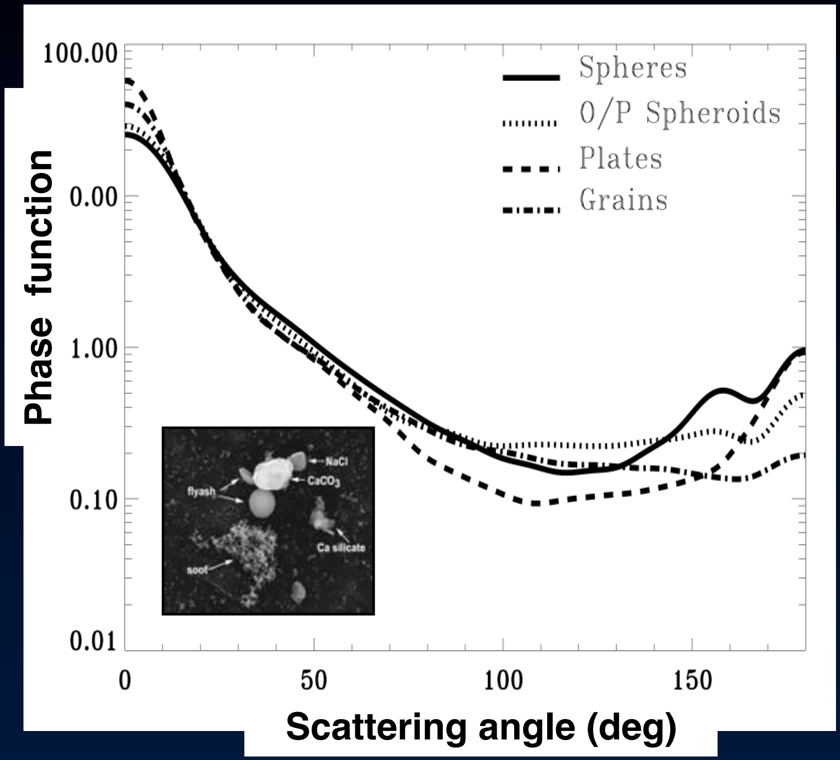


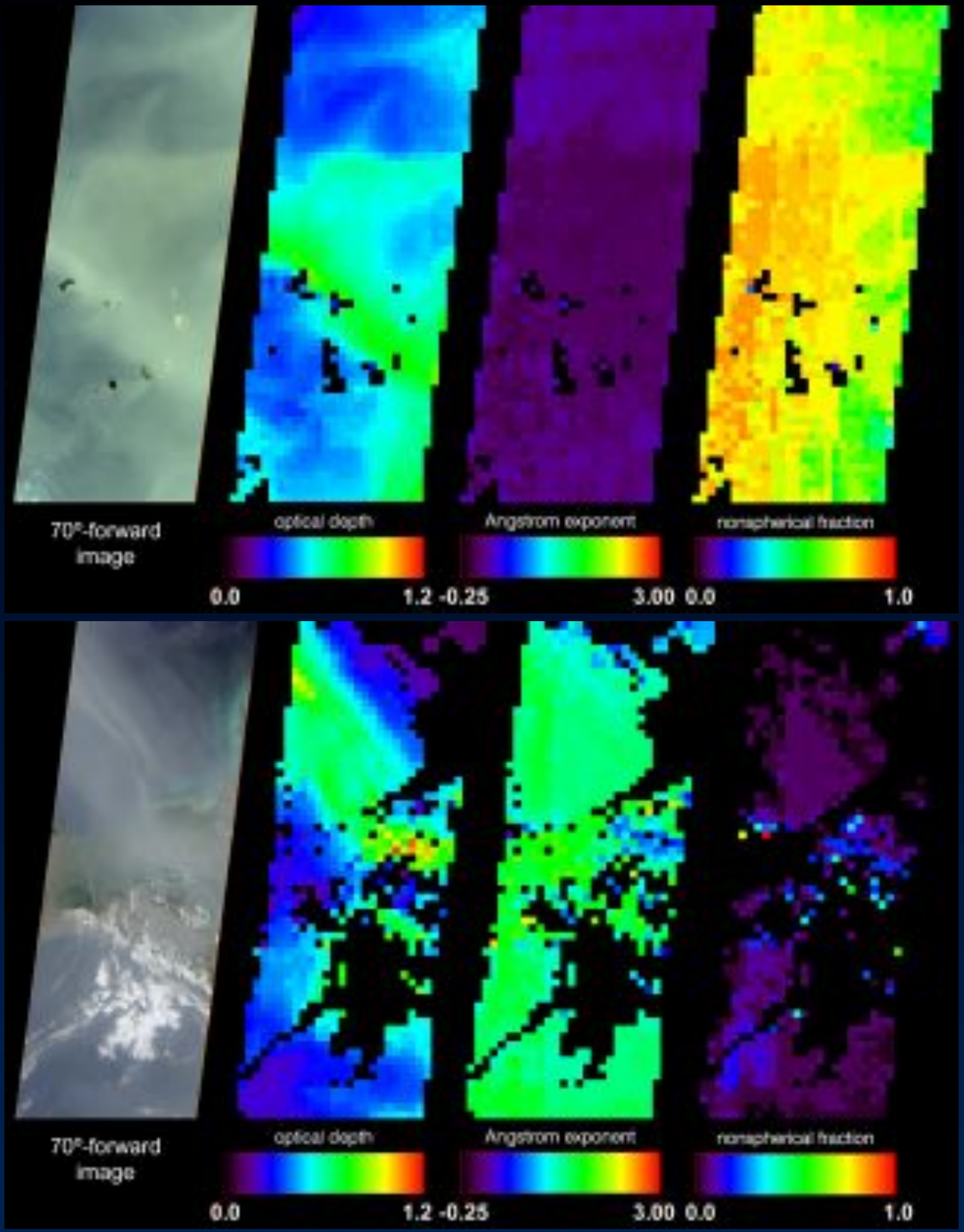


Iraq and Saudi Arabia, April 2004 (top) and May 2004 (bottom)

Global optical depth comparisons With AERONET

MISR sensitivity to aerosol particle properties

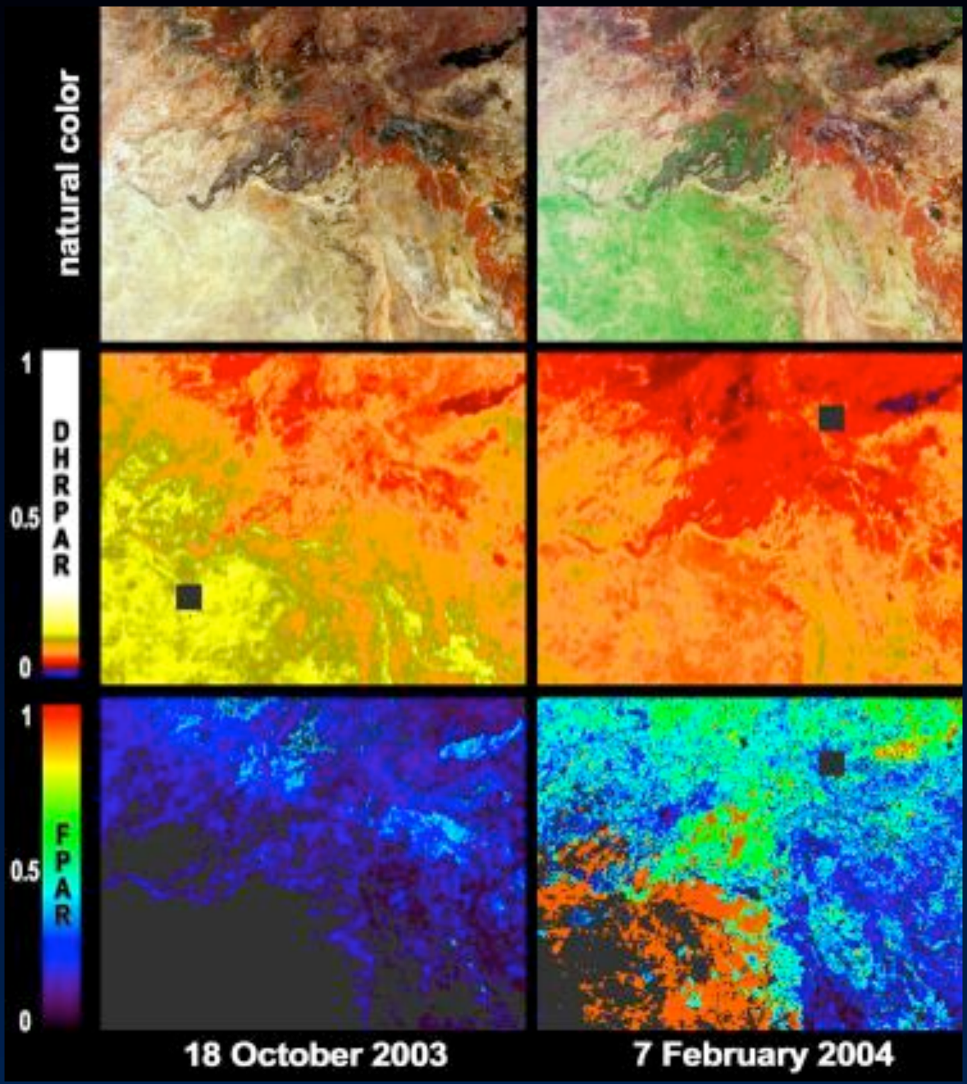




O. Kalashnikova et al. (2005), JGR

L2 Aerosol/Surface Product

Surface parameters



Surface greening from summer rains in Northern Queensland

CONTENTS AND ATTRIBUTES

- Radiometric surface parameters (directional reflectances, albedos)

  Derived from single overpass--no temporal compositing

  Atmospherically corrected

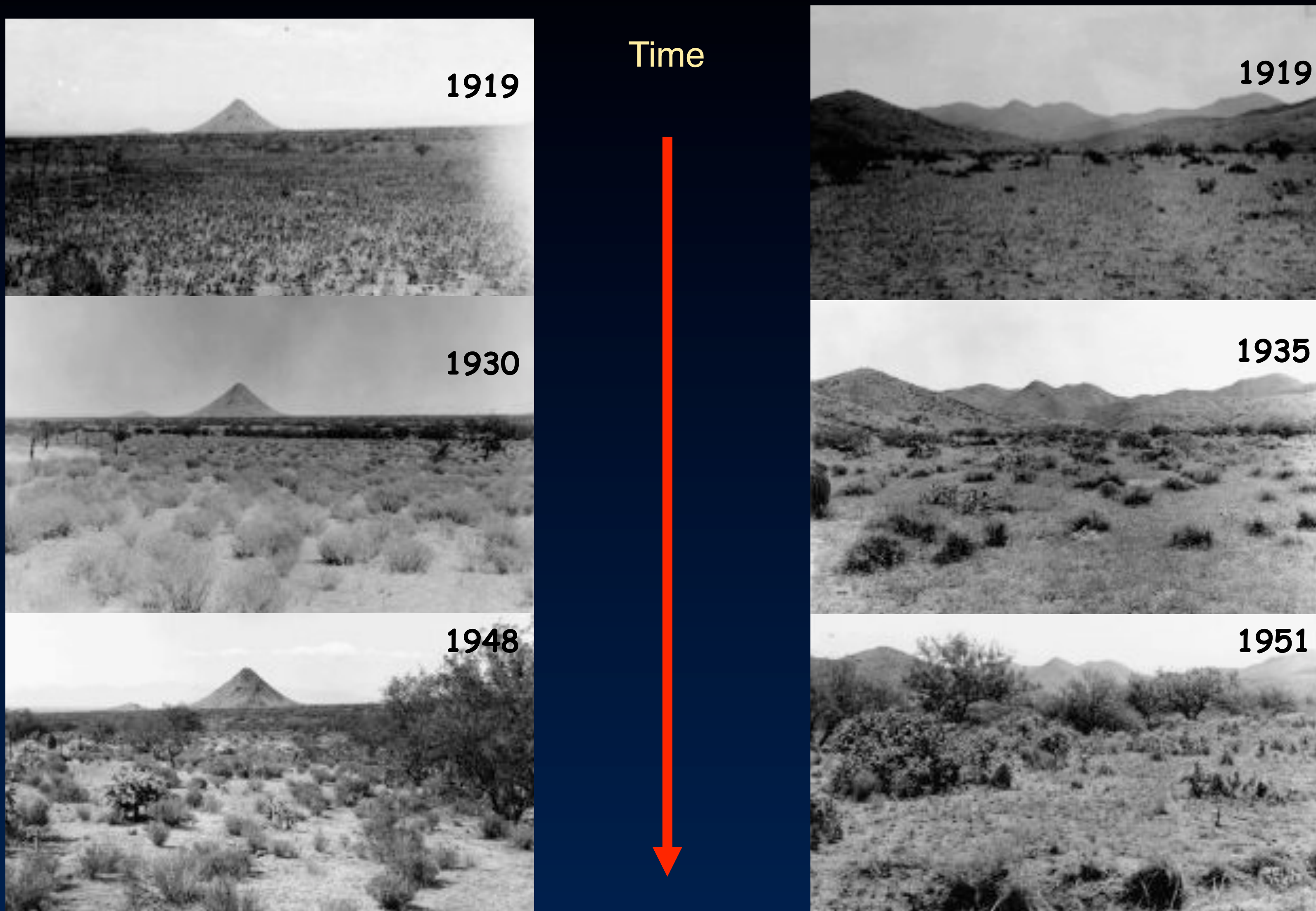
- Vegetation-related quantities (LAI, FPAR)

  LAI-FPAR retrievals are based on 3-D RT models

  Prescribed biome map is not required

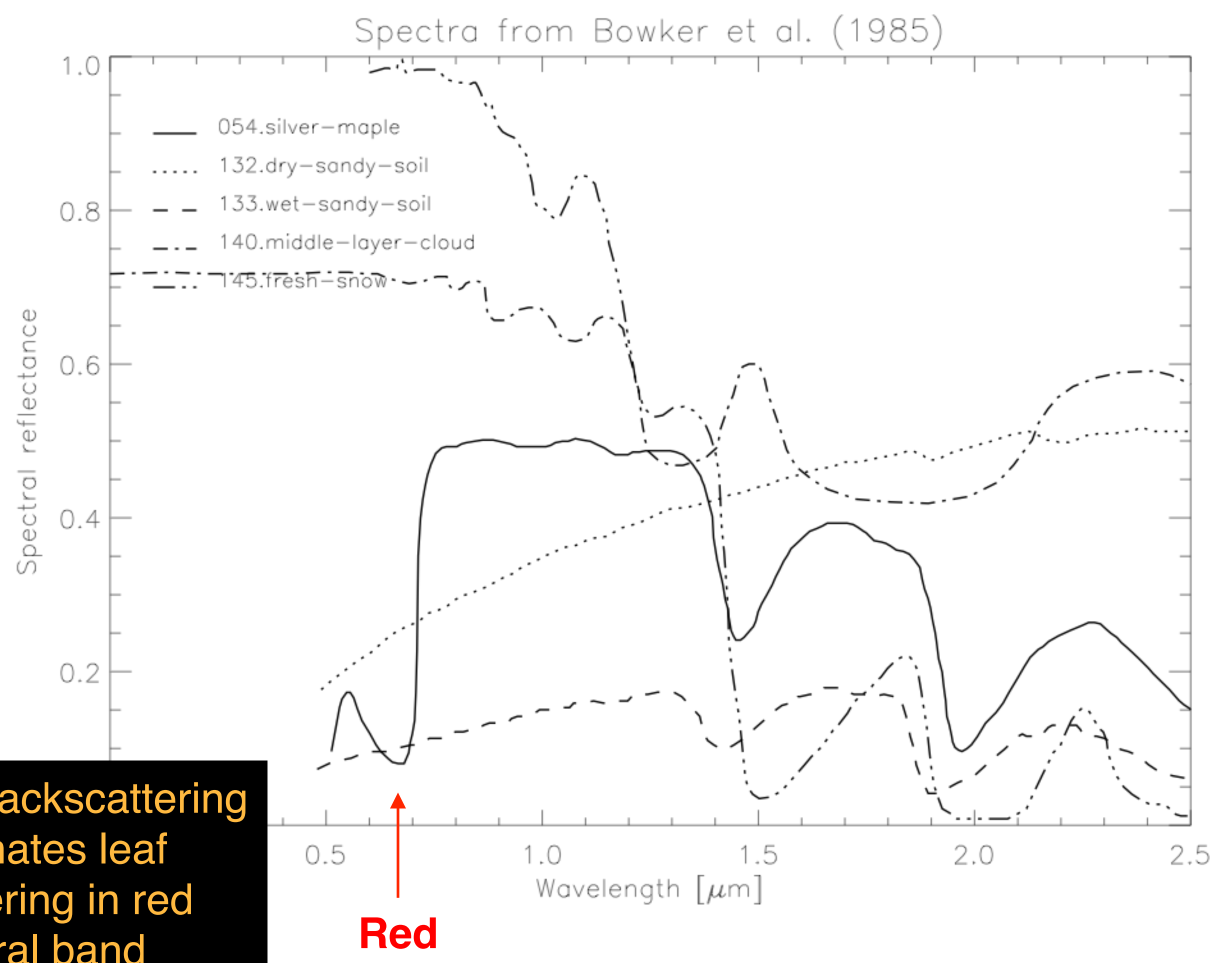
- BRF model parameters

Vegetation structure can change in time



Source: http://ag.arizona.edu/SRER

Spectra from typical surfaces



Soil backscattering dominates leaf scattering in red spectral band

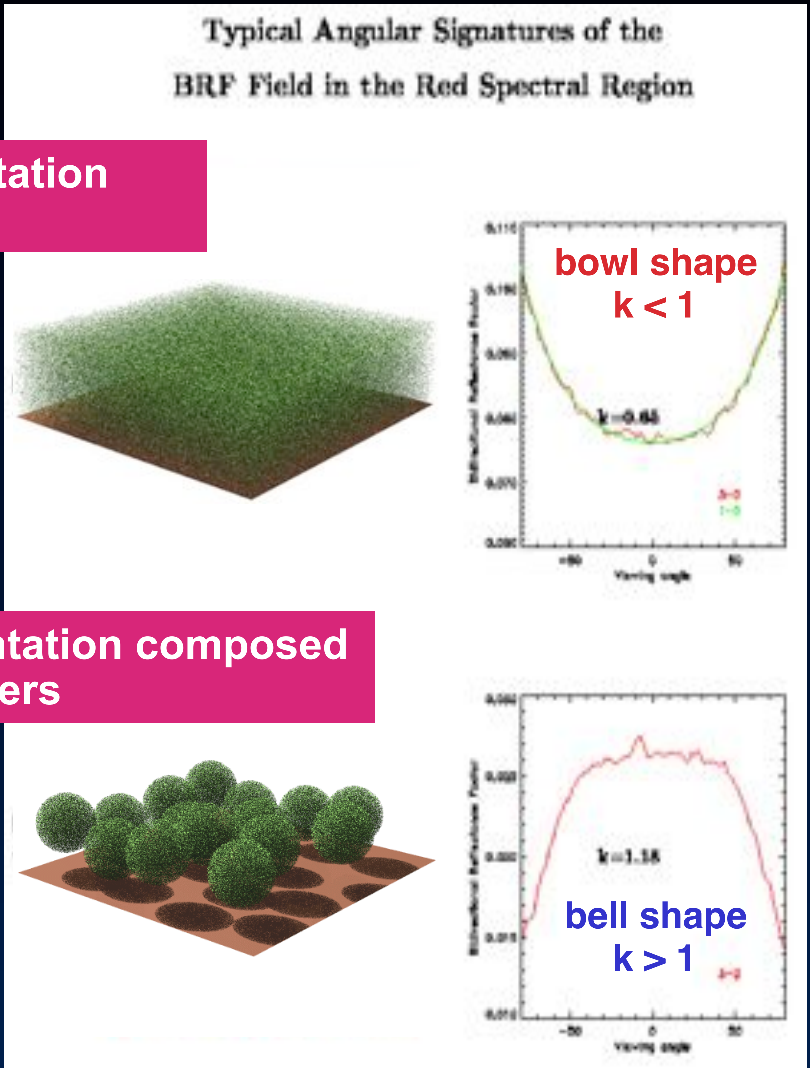
Dependence of bidirectional reflectance on surface vegetation subpixel structure: parametric approach

Structurally homogeneous canopy representation composed of finite-sized scatterers

Parametric model
(e.g., Rahman-Pinty-Verstraete function)
$BRF = BRF_0$ * Shape term * Asymmetry term
Shape term = $[\mu\mu_0(\mu+\mu_0)]^{k-1}$

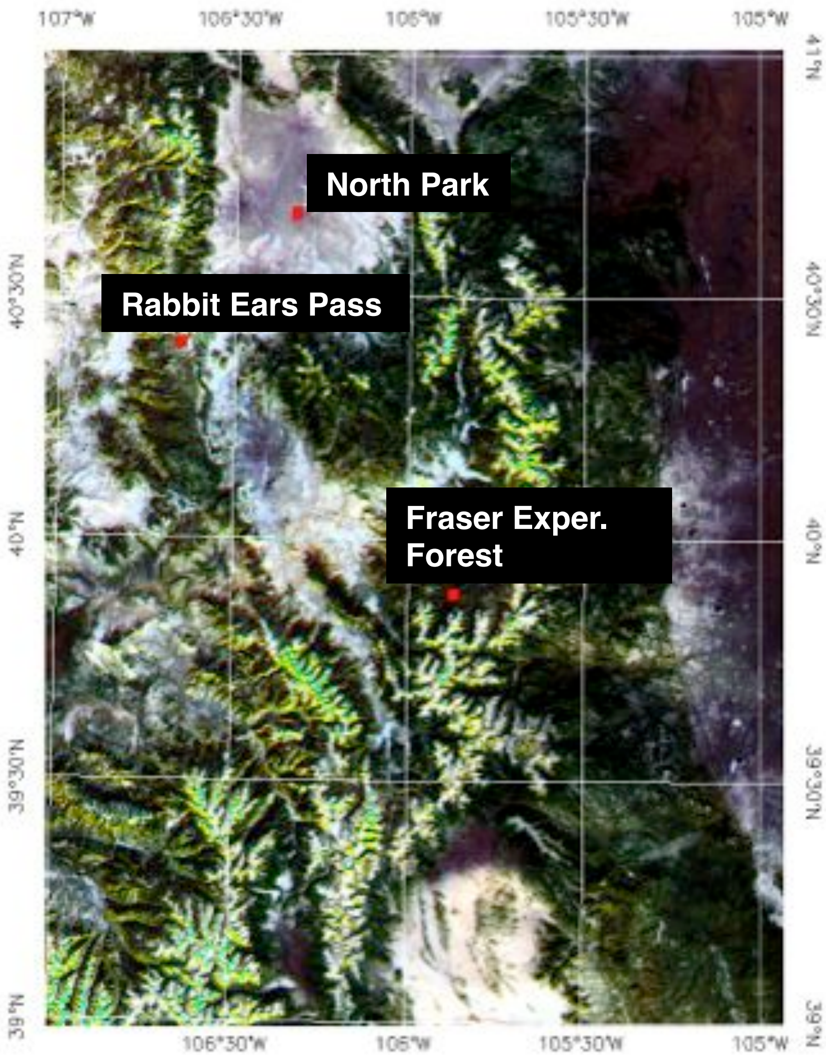
Structurally heterogeneous canopy representation composed of clumped ensembles of finite-sized scatterers

Exponent k establishes whether BRF angular signature gets darker off-nadir (bell-shaped, k > 1) or brighter off-nadir (bowl-shaped, k < 1)

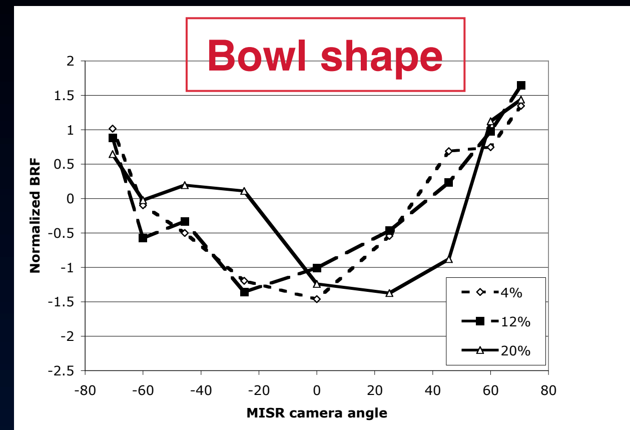


B. Pinty, N. Gobron, J-L. Widlowski, M. Verstraete

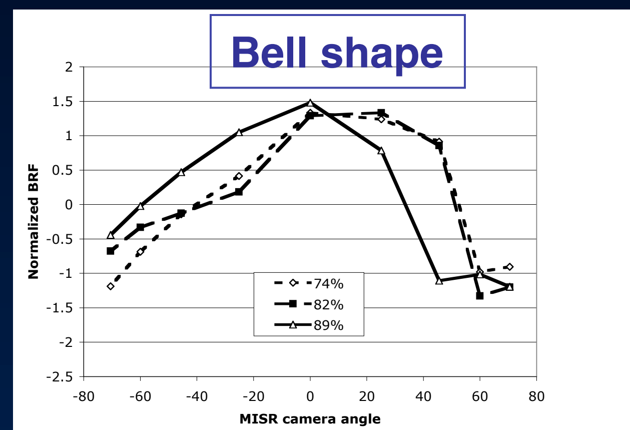
Mapping forest density over snow



MISR multiangle composite

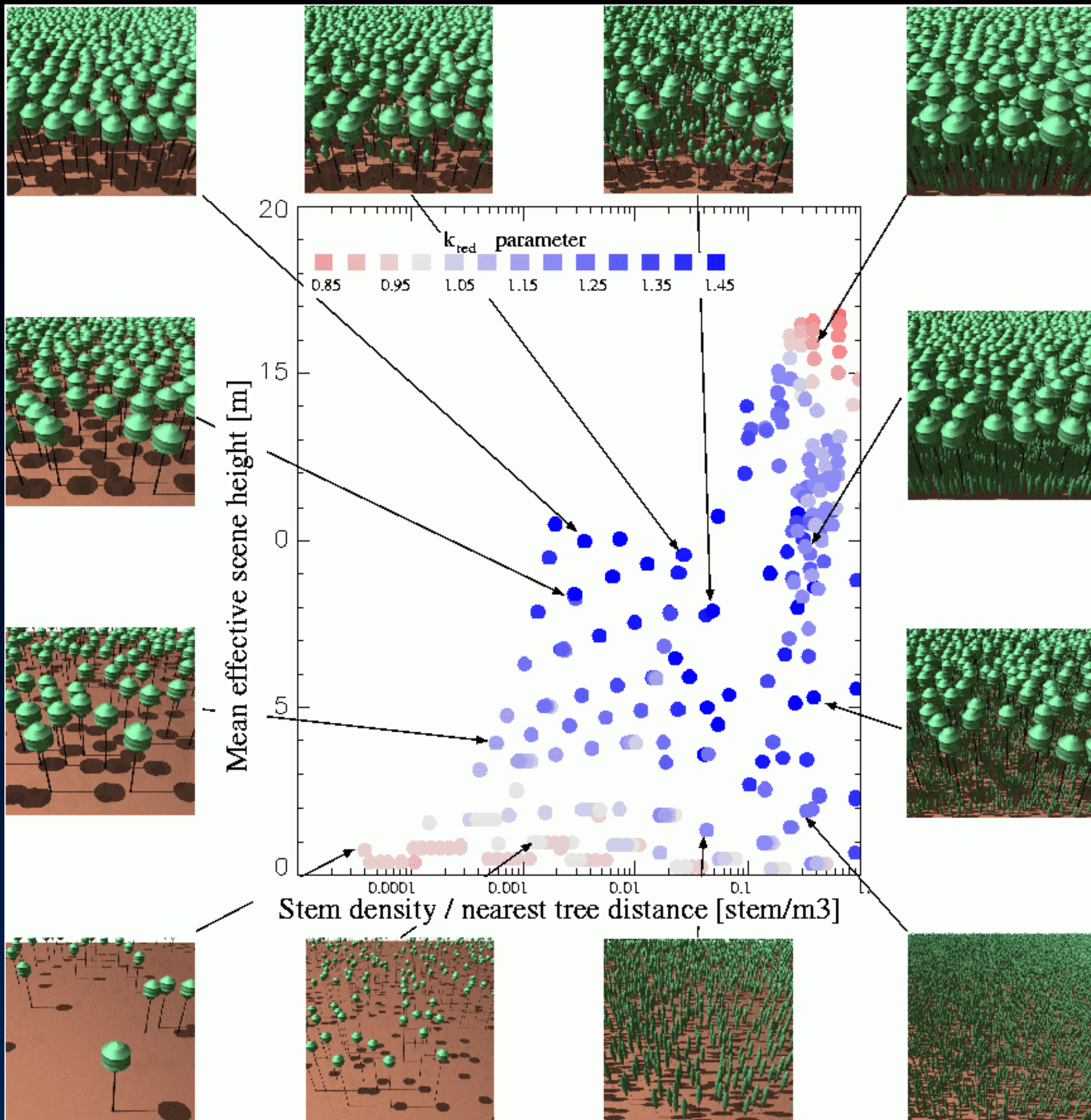


non-forested, low density



lodgepole pine, medium/high density

A. Nolin (2004), Hydrol. Proc.



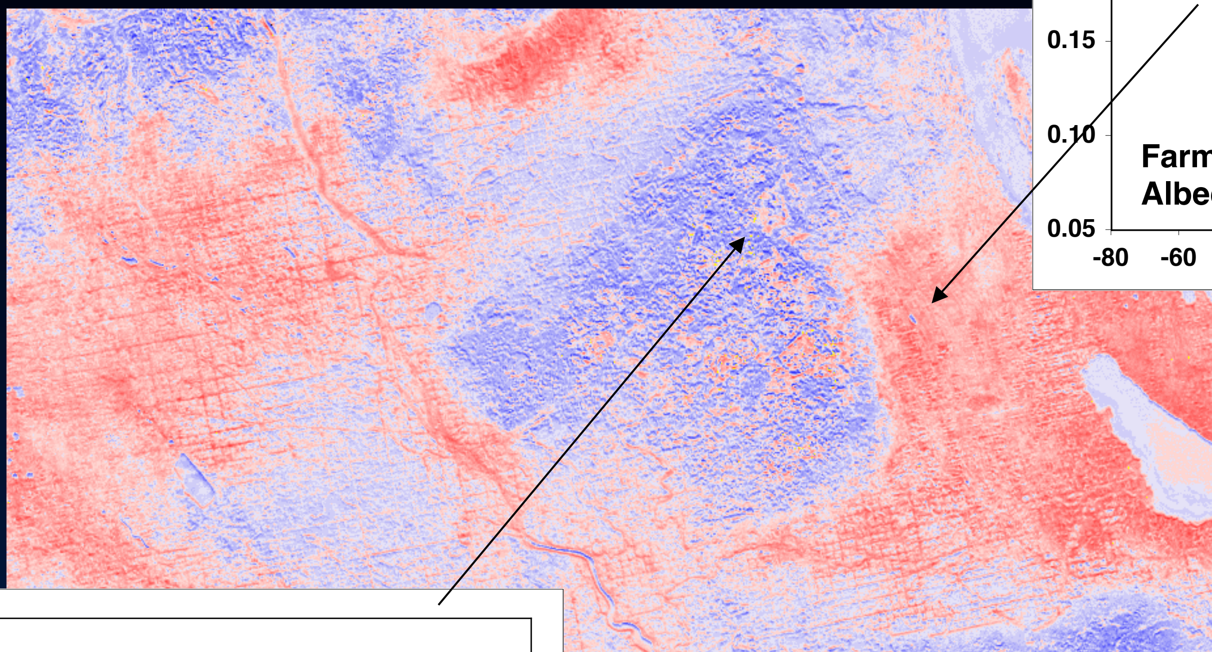
Relating bowl-shaped and bell-shaped BRFs to measures of canopy structure

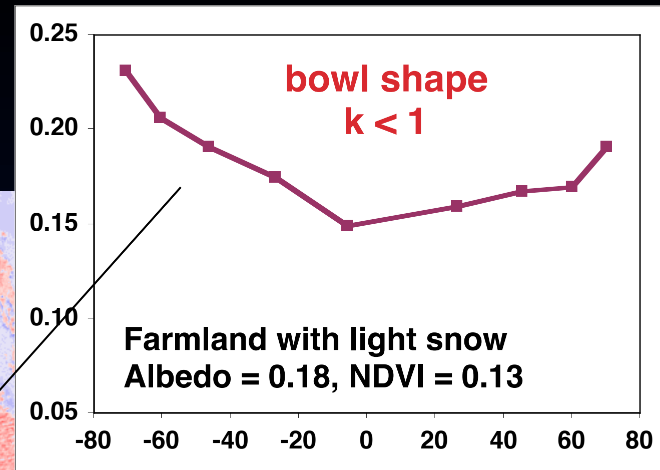
Bell-shaped BRF:
Tree crowns of medium-high density against bright background

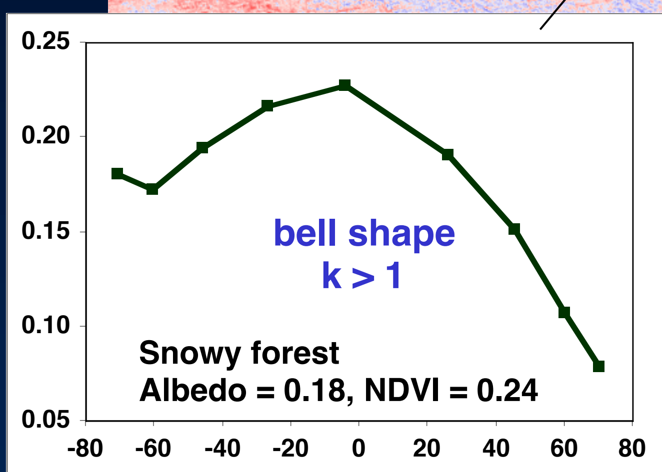
Bowl-shaped BRF:
Sparse vegetation and dense, closed canopies

J-L. Widlowski et al. (2004), Clim. Change

Bidirectional reflectances of surface vegetation as observed by MISR







Manitoba and Saskatchewan, 17 April 2001

k-parameter

B. Pinty, N. Gobron, J-L. Widlowski, M. Verstraete

Mapping of woody shrub encroachment in arid grasslands with MISR

The abundance of woody shrubs in arid grasslands of the southwest US has been changing rapidly, altering carbon and energy fluxes

Strengths of multiangle remote sensing include:

- Sensitivity to vegetation structure, owing to effects of shadowing
- Ability to distinguish canopy and understory reflectance due to contrast differences between nadir and oblique views
- Accuracy improvements in vegetation community and land cover classifications

Looking in the *Backscattering* direction: shadows are HIDDEN

Looking in the *Forward-scattering* direction: shadows are VISIBLE

M. Chopping

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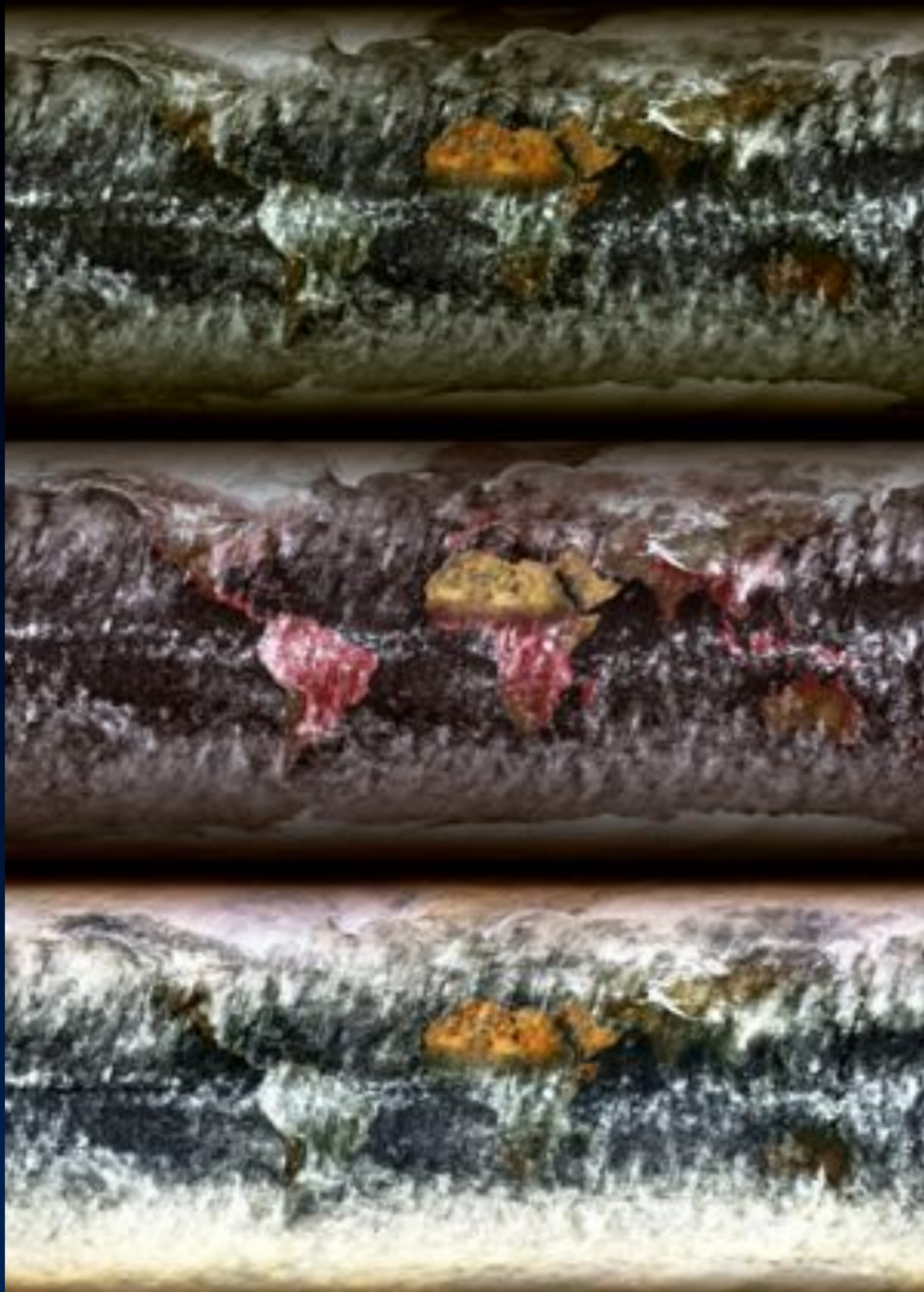
L3 Gridded Radiances

Means, variances, and covariances



Nadir red, green, blue

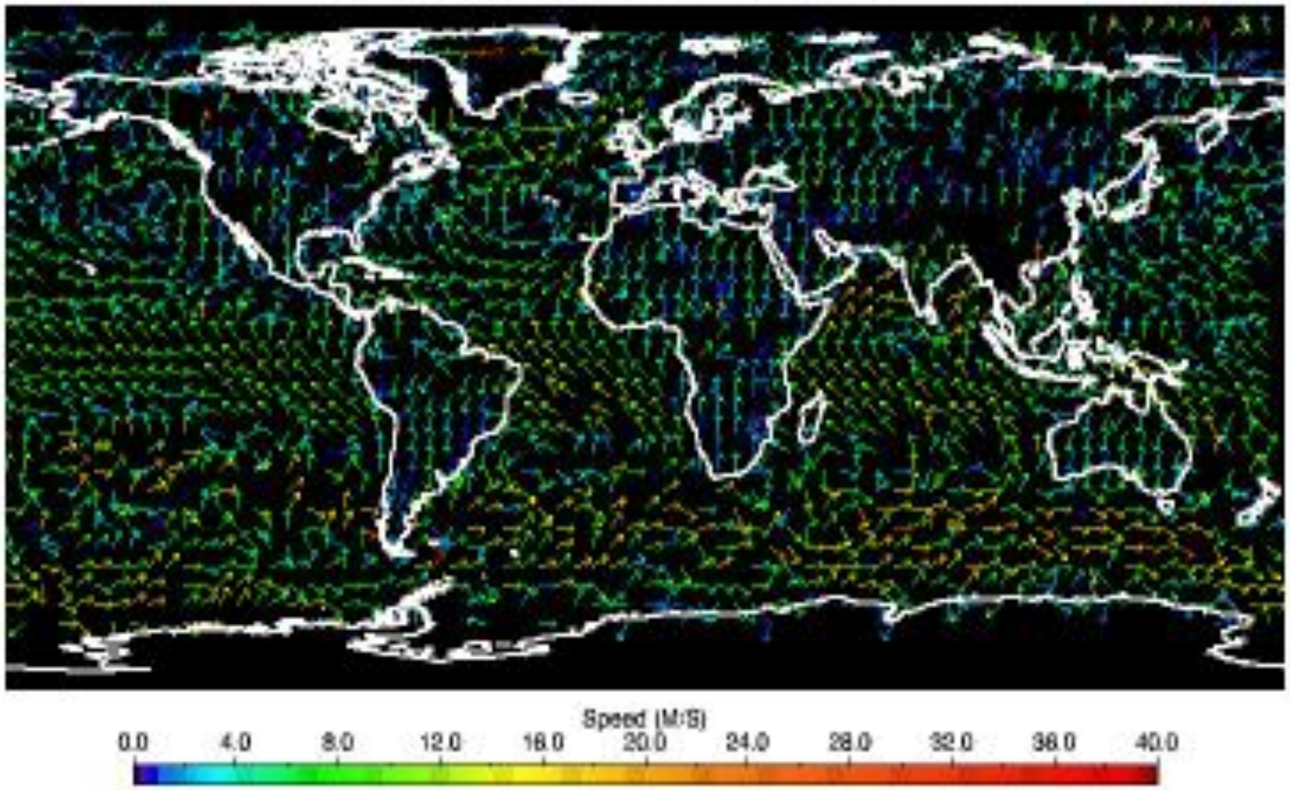
Nadir near-infrared, red, green

March 2002

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

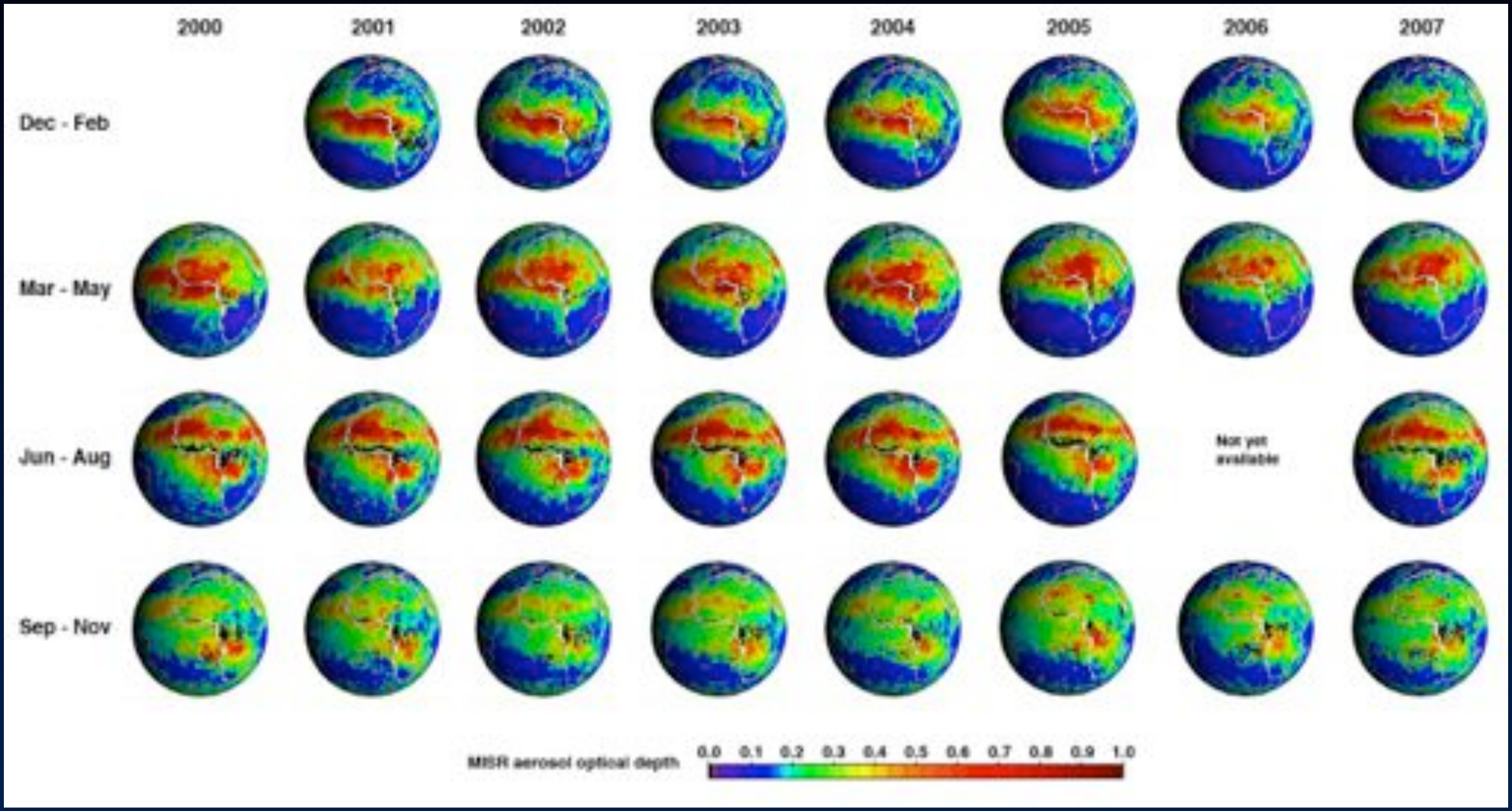
L3 Gridded Height-Resolved Winds

Monthly mean winds August 2005 (0.5-1 km altitude)



L3 Gridded Aerosol Properties

Global optical depths



Additional products you might need

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

Geometric Parameters Product

- Illumination (Solar) zenith and azimuth angles
- Observation zenith and azimuth angles for each of the 9 cameras
- Scatter (Sun and camera directions) and glitter (camera and specular reflection direction) angles for each of the 9 cameras

Data quality and 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 studies.

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

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

Be sure to read the quality statements!
eosweb.larc.nasa.gov/PRODOCS/misr/Quality_Summaries/misr_qual_stmts.html

Where to get help and information

Scientific publications
http://www-misr.jpl.nasa.gov/mission/pubs/mipubjournal.html

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/

We welcome your feedback and questions!
"Ask MISR" feature on the MISR web site