Generation of Object-Centric Datasets with Adaptive Sky

Earth Science Technology Conference

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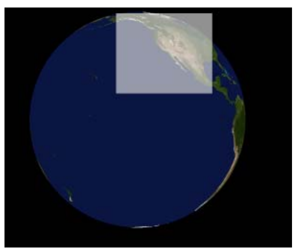
Outline

- Introduction
  - Why Sensor Webs?
  - Adaptive Sky Objectives
  - Science Scenarios
- ASKY Capabilities
  - Footprint Collisions
  - Low- and Mid-Level Feature Detection
  - Image Registration
  - Stabilization
  - Tracking
- Google Earth Visualization
- Bezymianny Ash Clouds
- Conclusion

Why Sensor Webs?

- Timeliness – respond quickly to short-lived events
- Deficiency – overcome limitations of individual sensing agents
- Provide rich multi-modal observations, particularly of objects that evolve in space and time, such as clouds.
- Generate "**Object-Centric Datasets**"

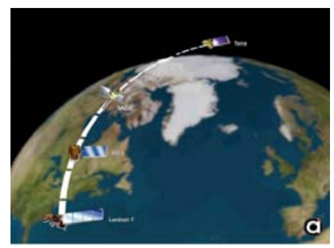
Geostationary Satellites
GOES-West



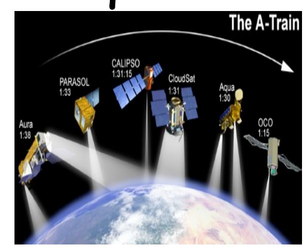
+ wide area coverage
+ dwell over one location
+ dense temporal sampling (15-30 min)
-lower spatial resolution
-lack of specialty instruments

Polar Orbiters

Terra et al.



Aqua et al



+ high spatial resolution
+ specialty instruments
  - Lidar, Multi-angle imager, Cloud Profiling Radar

-cannot dwell over one location
-infrequent revisits (16 day repeat)

Combine into Sensor Webs to Overcome Individual Weaknesses and Exploit Strengths

Credits: A. Kelley (Morning); A. McCLung (A-Train); J. Zehnder CuPIDO

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Earth Observing System

- Conceived in late 1980's
- Increase understanding of Earth and its processes through use of new sophisticated spaceborne sensors
- Fundamentally important to use Multiple instruments
  - MODIS (Moderate Resolution Imaging Spectrometer)
  - MISR (Multi-angle Imaging Spectroradiometer)
  - CALIOP (Cloud Aerosol Lidar with Orthogonal Polarizations)
  - CPR (Cloud Profiling Radar)
  - High-resolution Hyperspectral Imagers (ASTER, Hyperion)
  - Many others (and many new instruments in the works)

EOS "Report Card"

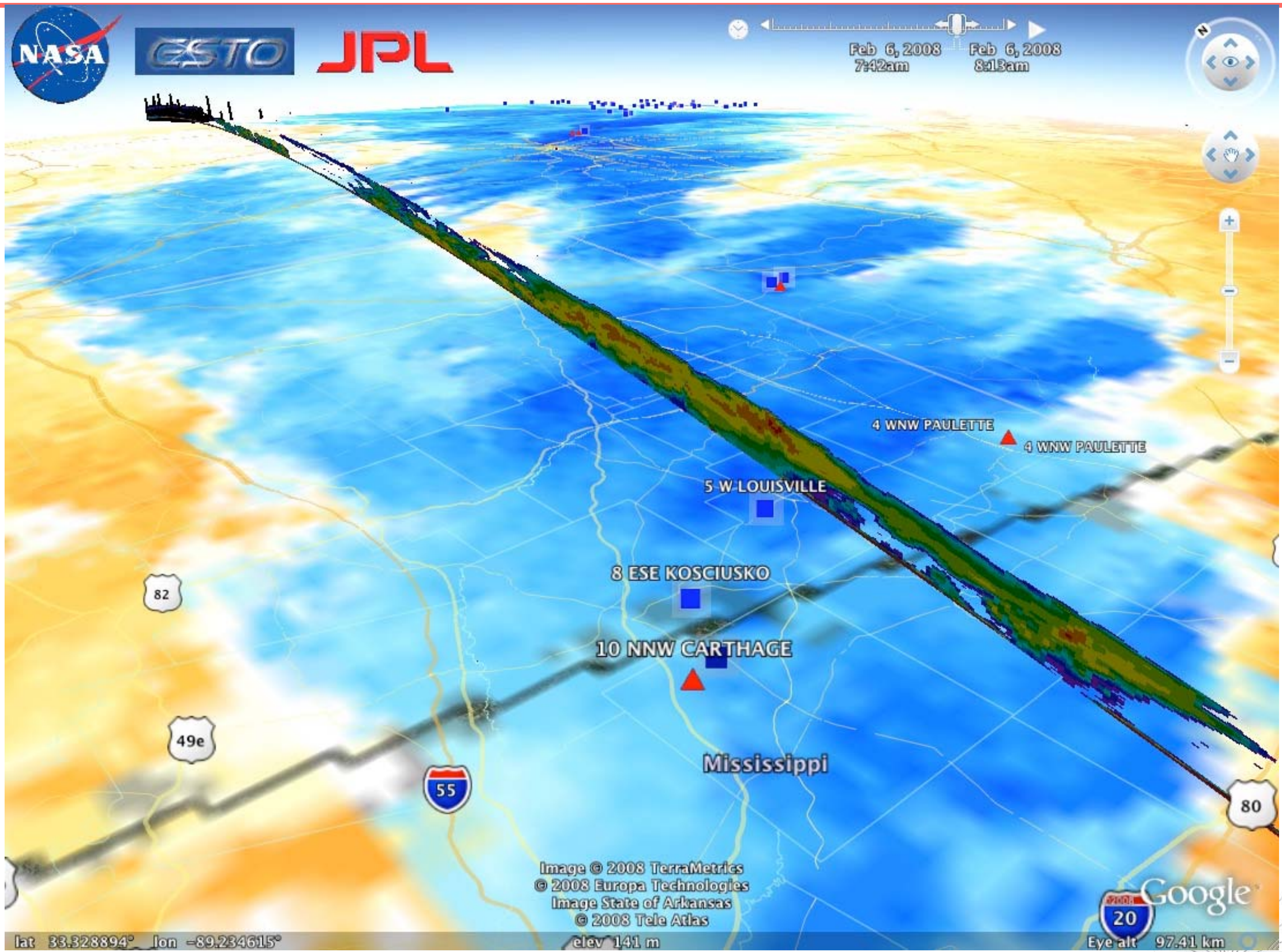
- EOS has been very successful in many respects; however, still significant untapped potential.
- Very few studies combine high-resolution information from multiple instruments. Why?

- Data analysis frequently funded through instrument-specific science teams doing stovepipe analysis on "their" instrument data.
- Disparate instrument-specific data organization and packaging schemes, e.g., granules, blocks, images, swaths.
- Difficult even to use data from two instruments on same platform such as MISR and MODIS on Terra due to different way of breaking data into manageable chunks.

- Don't timestamping and georeferencing solve all these issues? (No!)

- Good for ingestion into coarse-scale models (e.g., GCMs with 250km cells) or for processes that are spatially stationary
- Many important natural objects (hurricanes, tornadoes, clouds, etc.) occur at finer scales and are not bound to any particular (lat,lon) location.

Recent Severe Thunderstorm Complex



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CloudSat CPR Profile with SPC Reports

524 Reports:
131 tornadoes
267 severe winds
126 large hail

23 Reports within +/- 15 minutes of A-Train Overpass

Only ONE report falls within 10km of the effective 1km swath of CPR

Message: A lot of interesting stuff going on; we didn't see much of it!

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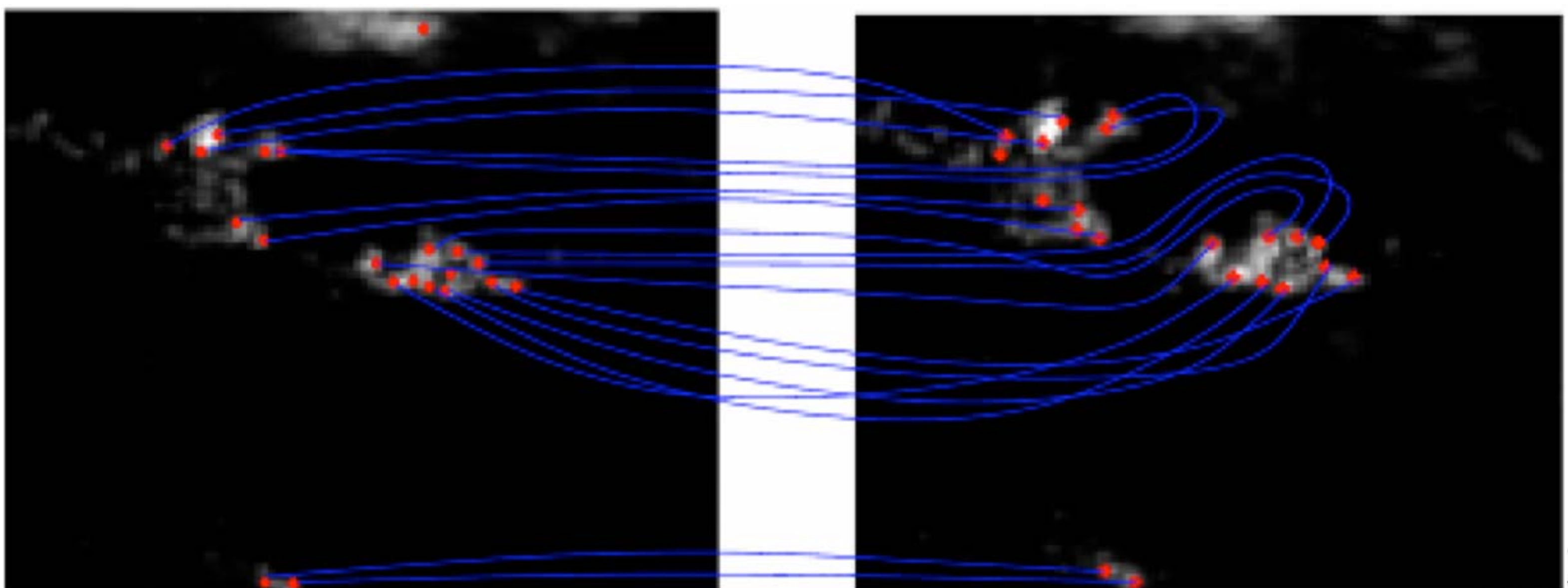
Adaptive Sky Objectives

- Enable observations from multiple sensing assets (satellites, in-situ sensors, etc.) to be dynamically combined into “sensor webs”.
- Develop an efficient, trusted C-language feature correspondence toolbox that serves sensor web development as LINPACK has served numerical computing.
- Demonstrate collection and fusion of multi-instrument observations forming novel data products of high scientific value.

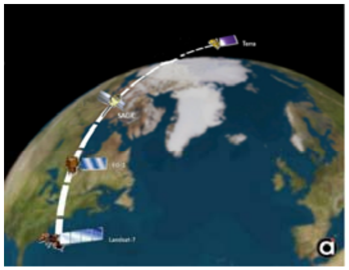


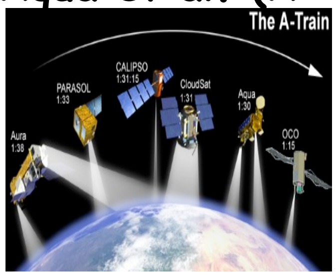
Adaptive Sky Sensor Web Scenarios

Combining multi-instrument, multi-platform observations.

EOS Match-ups

Terra et al. **Aqua et al. (A-Train)**





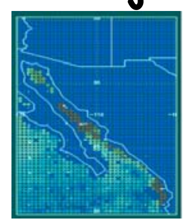
Spatially-coincident observations (Dt < 3 hrs)

Satellite and CuPIDO Observations

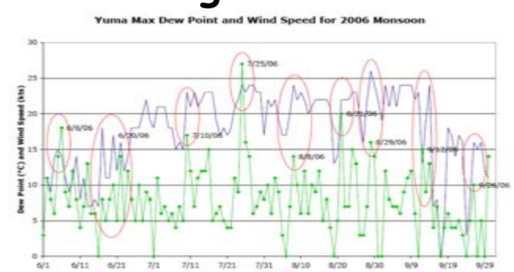
CuPIDO = Cumulus Photogrammetric, In-situ, and Doppler Observations

Houston Air Pollution

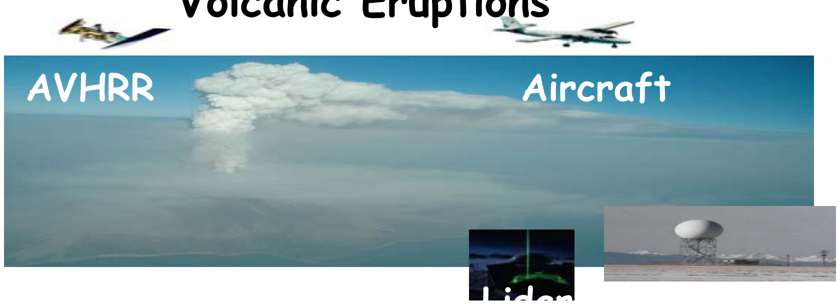
Baja Moisture Surge Events



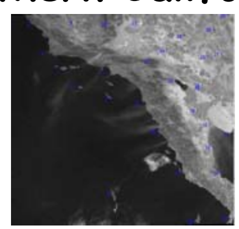
QuikSCAT Winds



Volcanic Eruptions



Southern California Fires (Oct 2007)



GOES-West image.

Credits: A. Kelley (Morning); A. McCLung (A-Train); J. Zehnder CuPIDO

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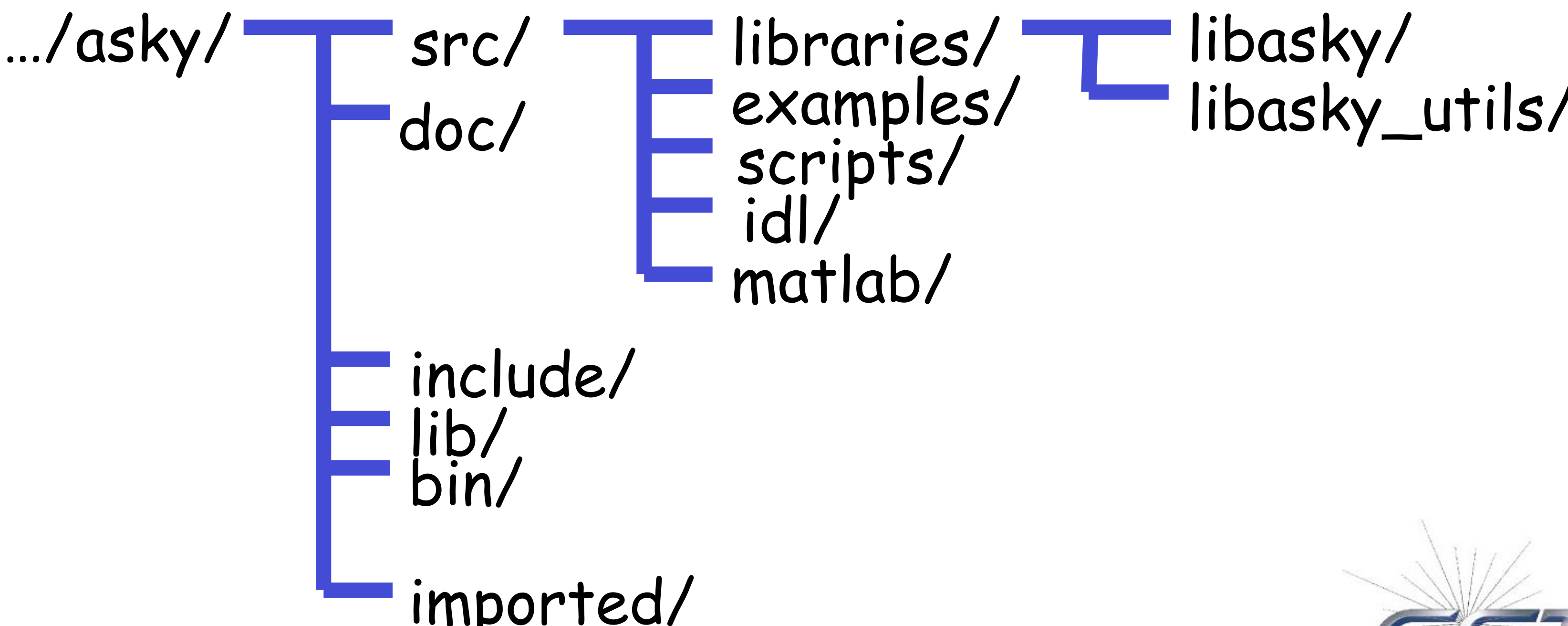
ASKY Capabilities

ASKY currently contains:

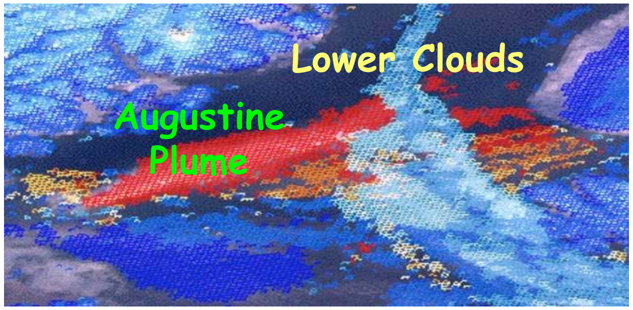
- ~20,000 source lines of code (SLOC).
- several full-scale, stand-alone executable programs with source code to demonstrate major features and capabilities.
- additional utilities under libasky_utils support the example programs, but are not part of libasky proper. (e.g. command-line parsing utilities, image input and output (I/O), etc.).



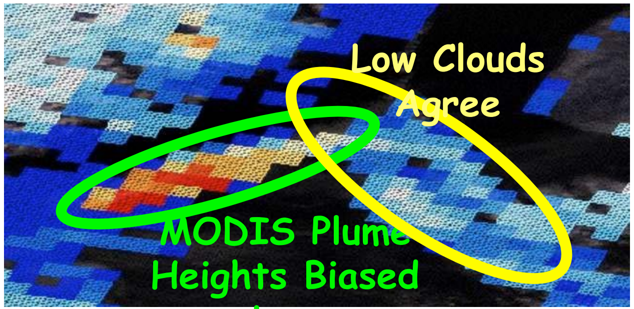
EOS-Matchups: Scientific Benefits

- Multi-instrument, multi-platform measurements are fundamental to EOS program, but few combined studies.
- Comparisons between EOS-Terra (10:30 LT* equatorial crossing on descending node) and EOS-A-Train (13:30 LT* equatorial crossing on ascending node) provide information about sensor intercalibration ; increased science due to the variety of sensors available.

MISR* Stereo-Derived Cloud-top Heights



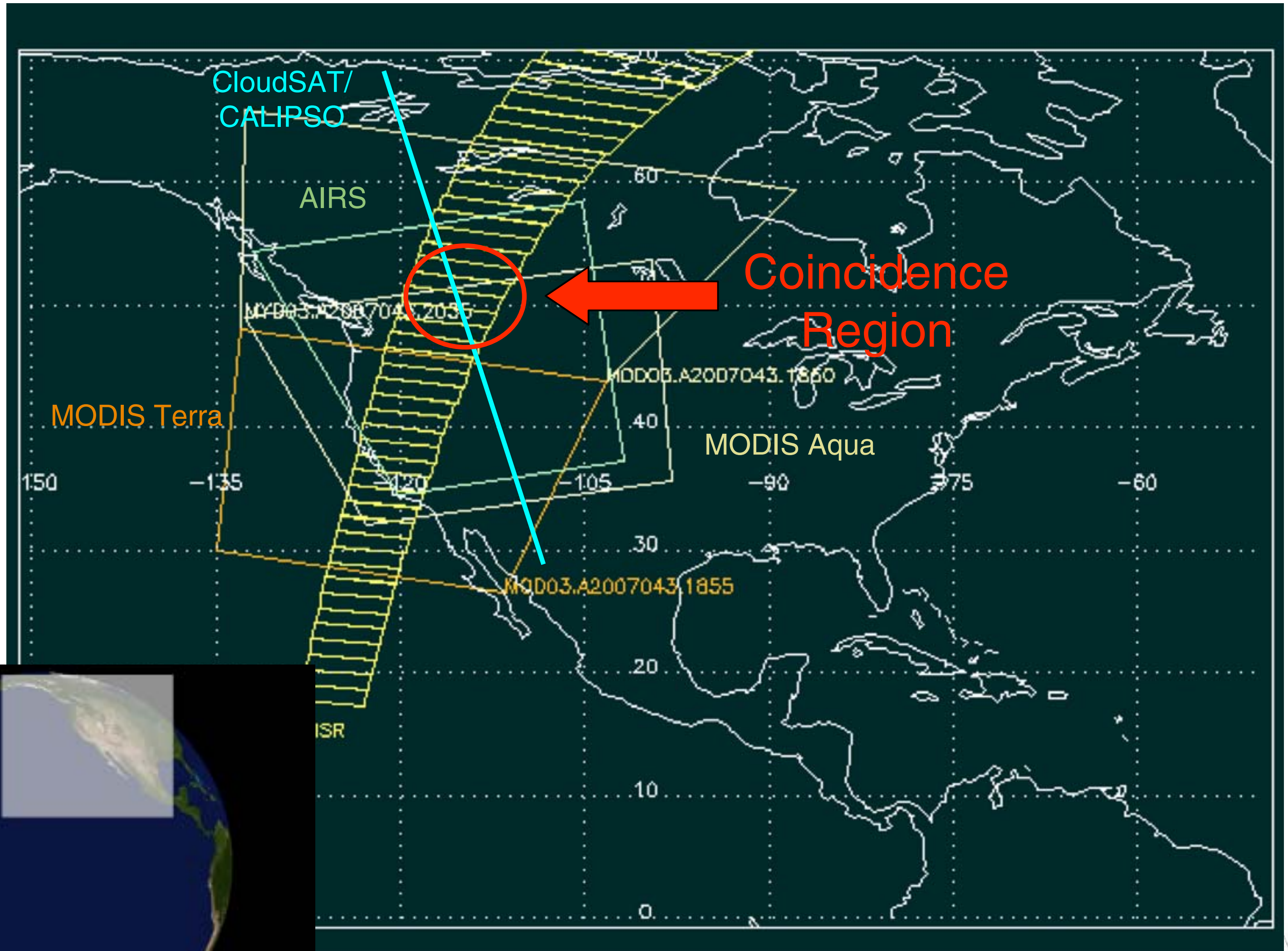
MODIS* Cloud-top Heights from Pressures



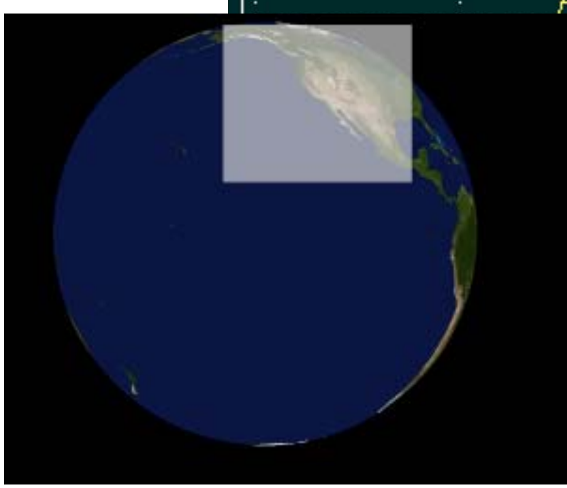
- Comparisons between EOS-Terra and EOS-Aqua have only been done using global data in a mean sense.
- Detailed comparisons raise questions about stationarity of the data, due, in particular, to diurnal and sampling effects.
- Object-centric datasets.

*LT = local time

Instrument Coincidences



GOES
West



(2007/02/12)

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Going Deeper than Metadata (Data-level Match-ups)

Δt = 100min

MODIS - Terra ⟷ MODIS - Aqua

Data-level Match-ups:

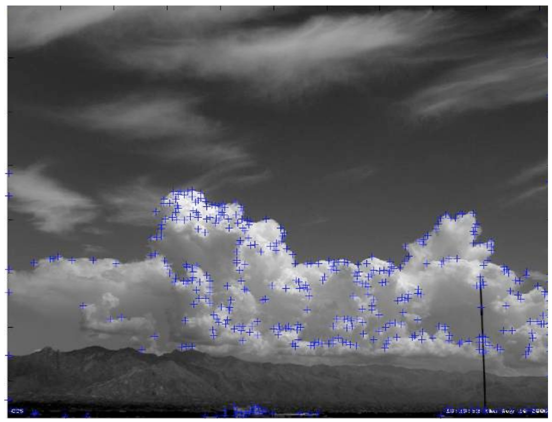
- Many observations take the form of images.
- Need fast, robust method for automatic registration.
- Sensor web constraints.

Challenges:

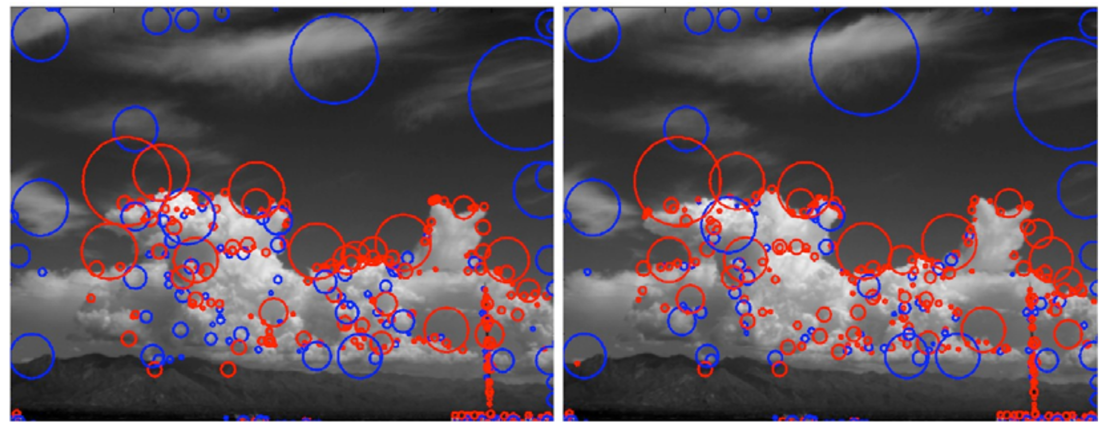
- Different viewpoint; some lighting change.
- Registration.
- Multiple independent, complex motions.
- Non-rigid objects.
- Splits/Merges
- Births/Deaths

Feature Detectors and Descriptors

Corners



Blobs



Affine- and Illumination-Resistant Descriptors (e.g., SIFT)

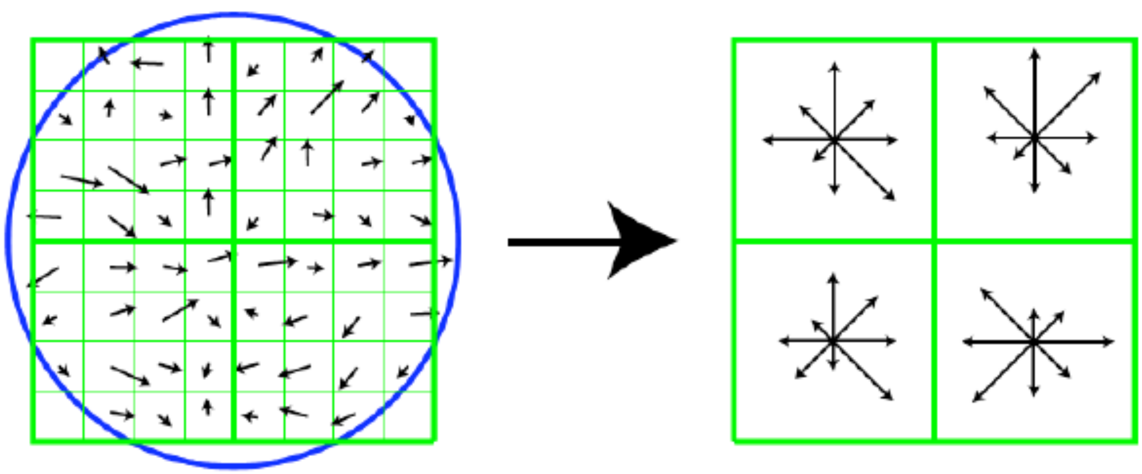
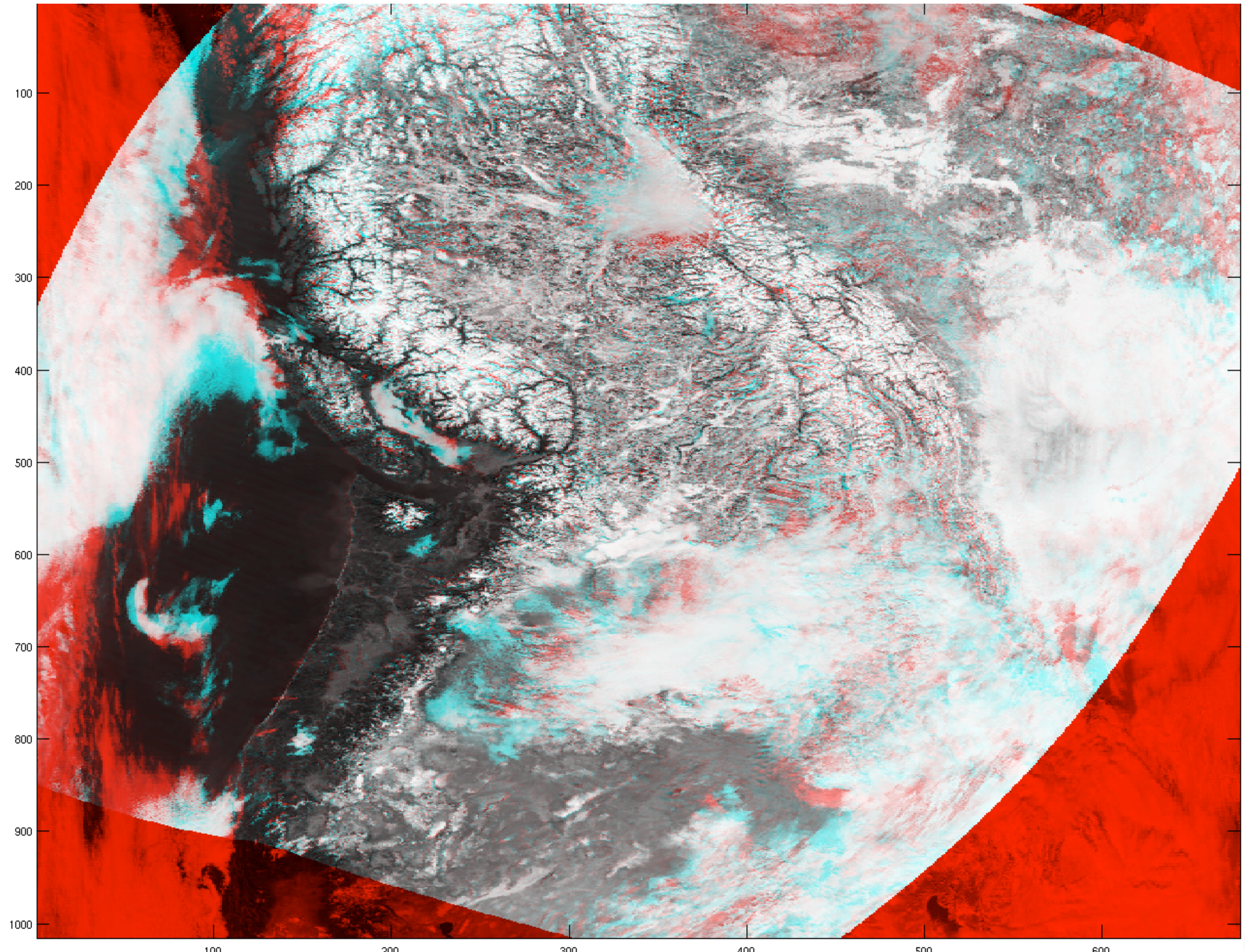


Image gradients   Keypoint descriptor

*SIFT figure from D. Lowe (IJCV, 2004)

Registration using Thin Plate Spline (TPS)



Δt = 100min

cyan = MODIS-TERRA
red = MODIS-AQUA

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Southern California Fires

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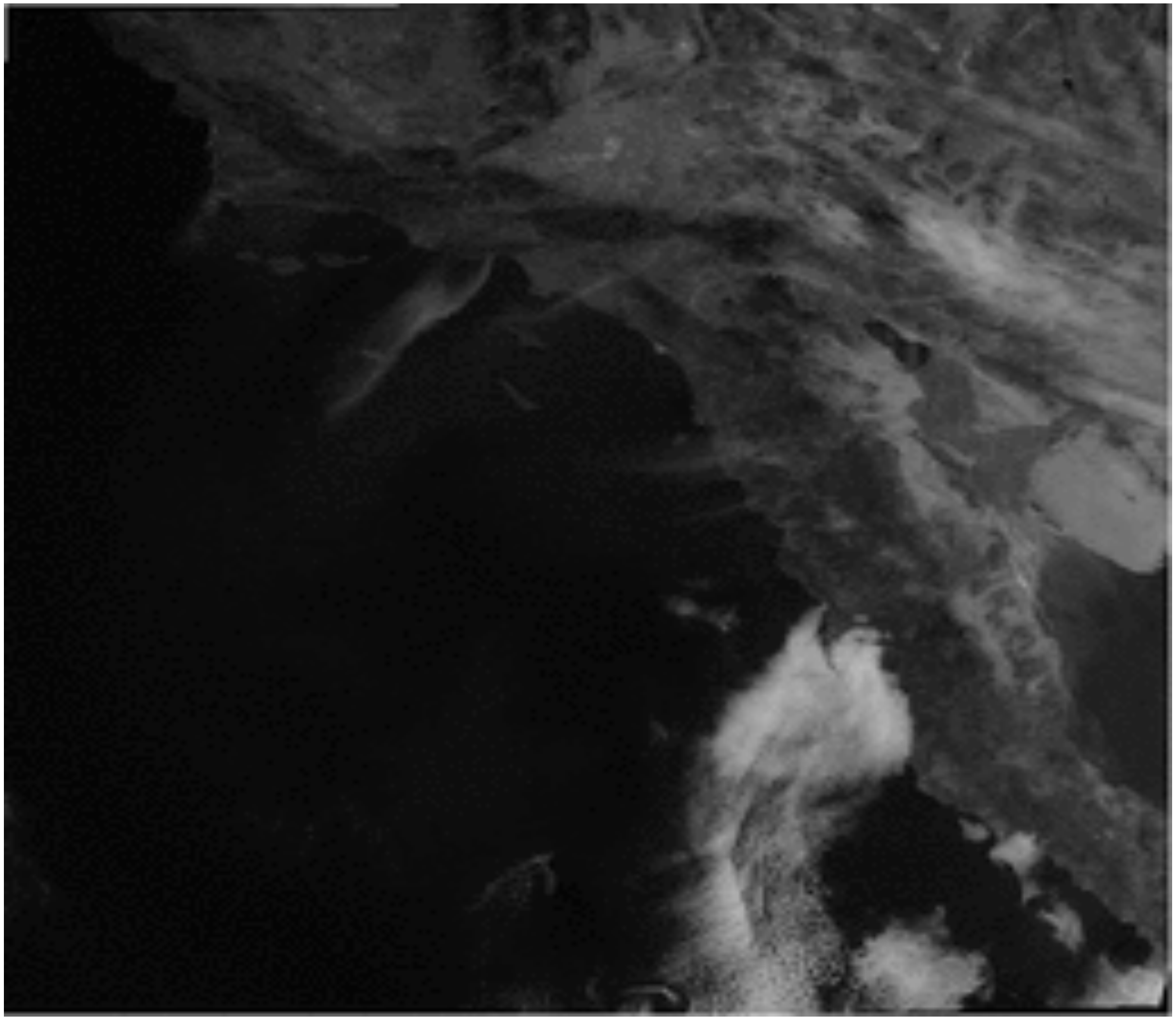
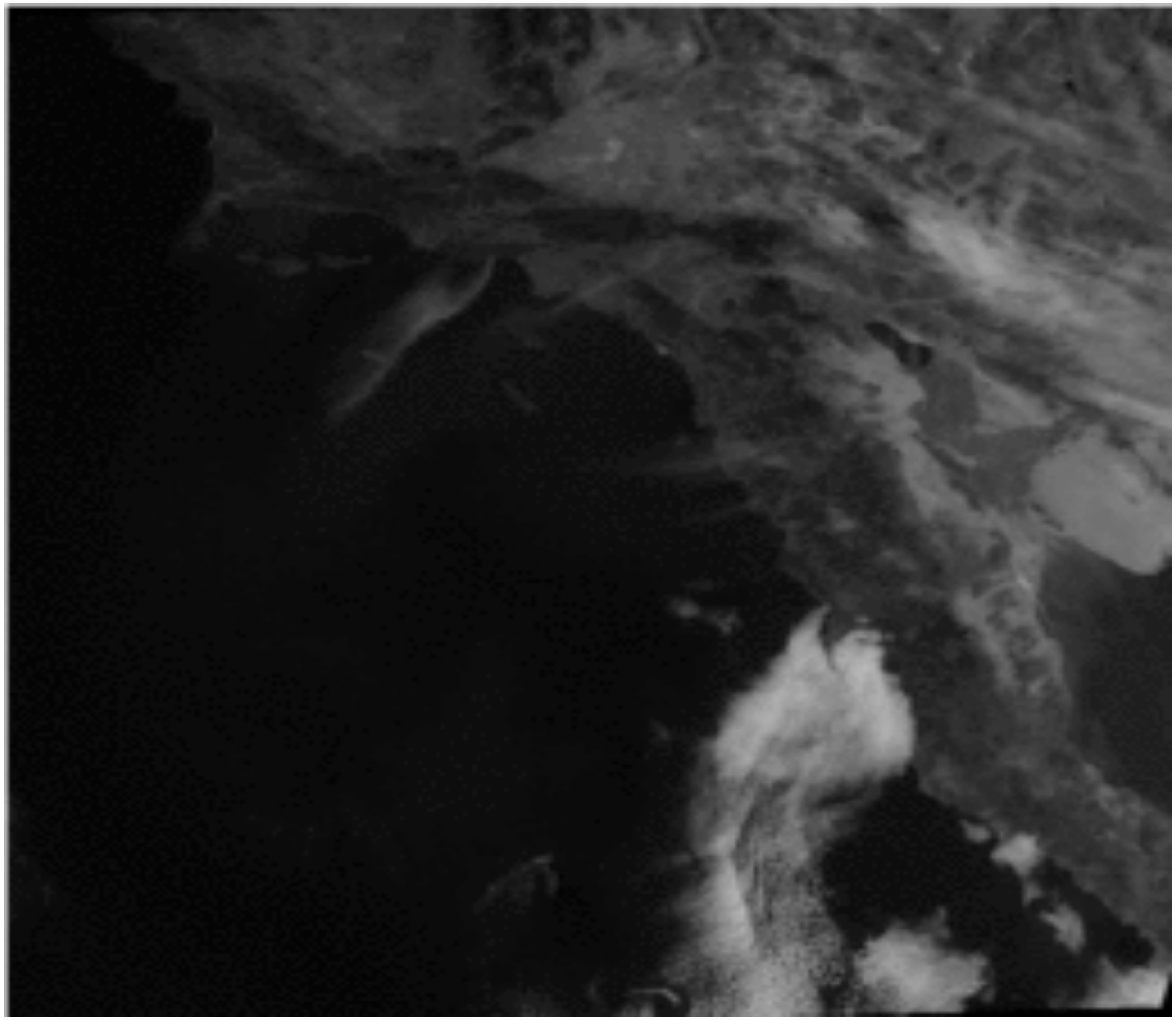
GOES Raw Image Sequence



Raw GOES-West sequence during October 2007 Southern California fires.

GOES Stabilized Sequence



Auto-registered sequence during October 2007 Southern California fires.

Segmentation and Tracking

18:15:02

18:18:02

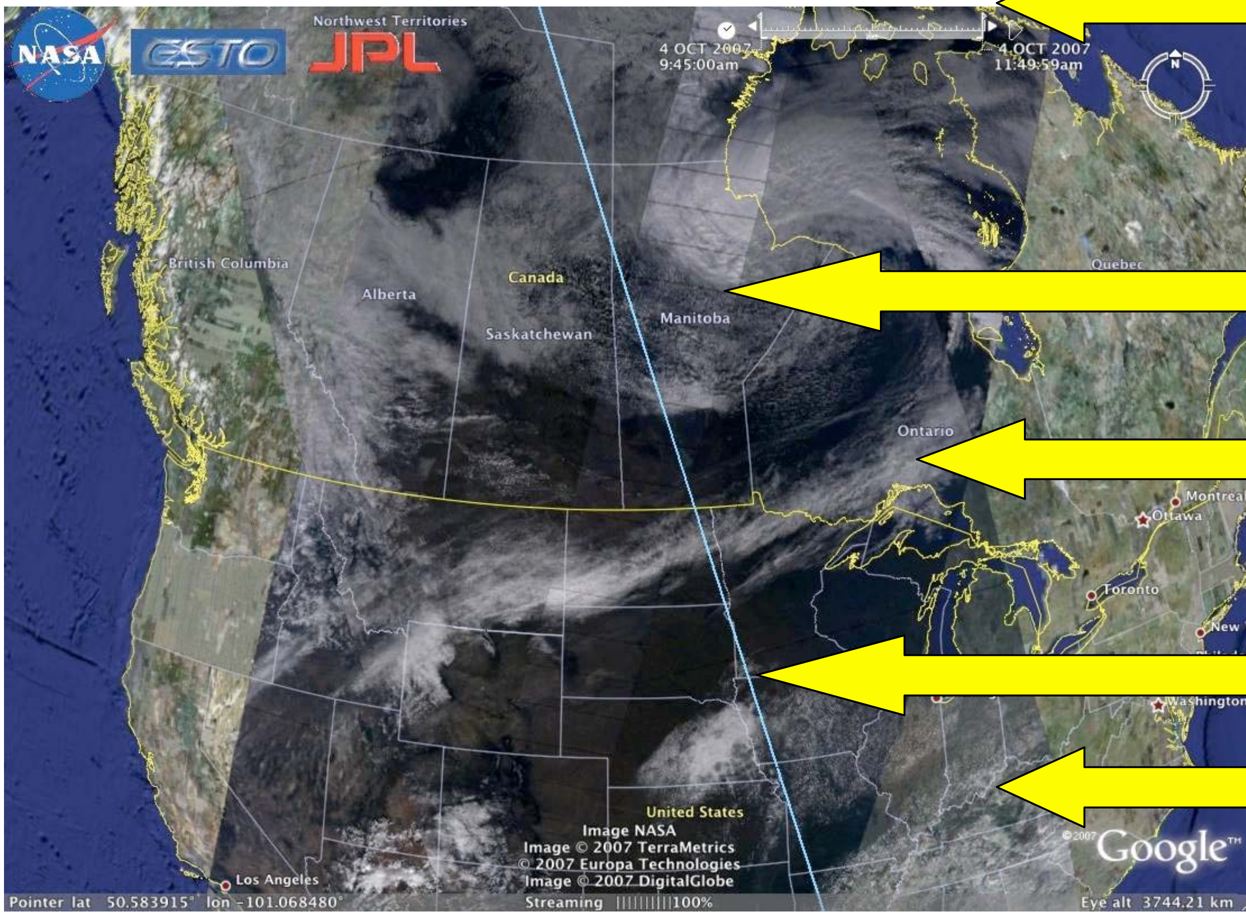
18:21:02

18:24:02

18:27:02

Image sequence from single CuPIDO ground camera.

Google Earth Visualizations



Google Earth Animation Player, demonstrates actual time of satellite instrument data acquisition

MISR-Terra Blocks

MODIS-Terra Granules

CloudSat ground track

MODIS-Aqua Granules

Google Earth Example from October 28, 2007 showing Terra/A-Train overlap. Time-tagging shows when the individual sensors acquired data relative to one another.

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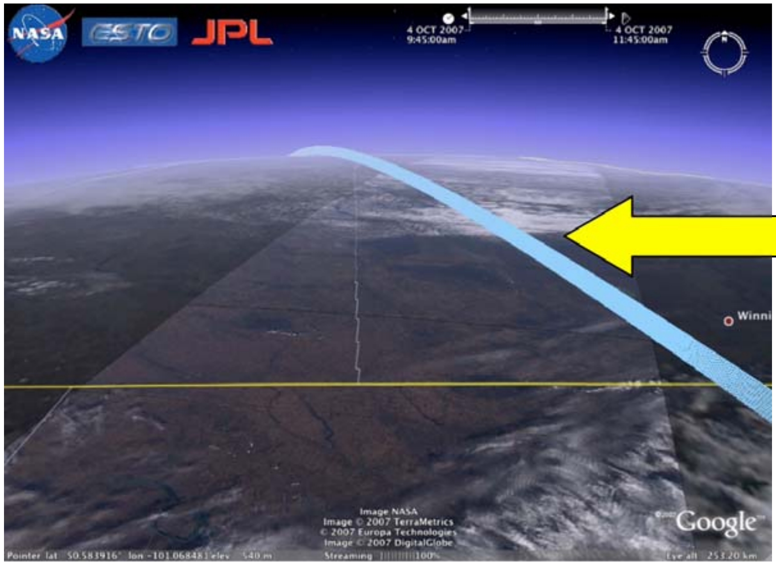
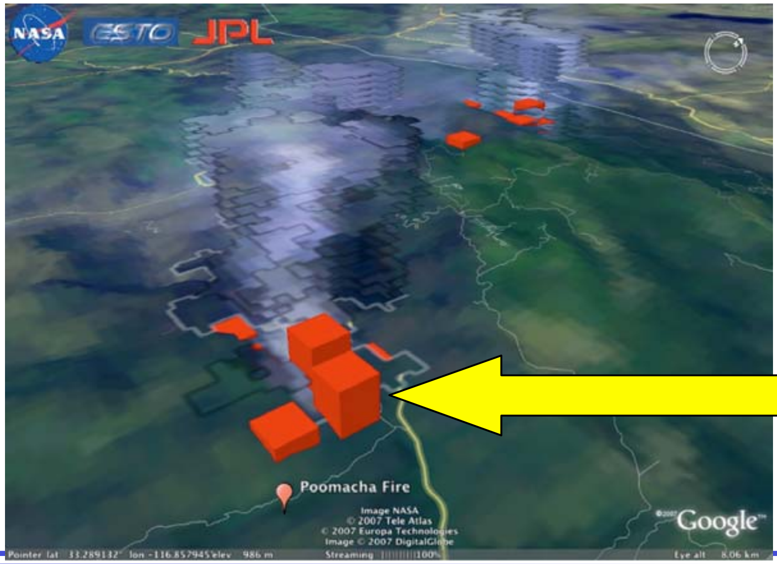
Google Earth Visualizations



Extruded CloudSat ground track, which emphasizes the vertical nature of the CloudSat data relative to the horizontal MODIS and MISR data.



MODIS-derived fire power shown as SketchUp Columns whose height is proportional to the fire power. This indicates the relative intensity of the fire at that location as seen by the instrument from space.

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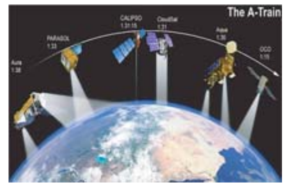
Adaptive Sky Demonstration Overview

Bezymianny Volcano
55.978°N,160.587°E,
Kamchatka

Earthquake:
2007/10/14
14:37:05 UTC

Seismic Signal Trigger



Check for Next EOS Overpass

A-Train Overpass:
15:35 - 15:40 UTC
(Nighttime)

Plume Evident in MODIS Band31-Band32 Signal

Initiate Adaptive Sky Feature Tracking using GOES BTD* Data

2007/10/15

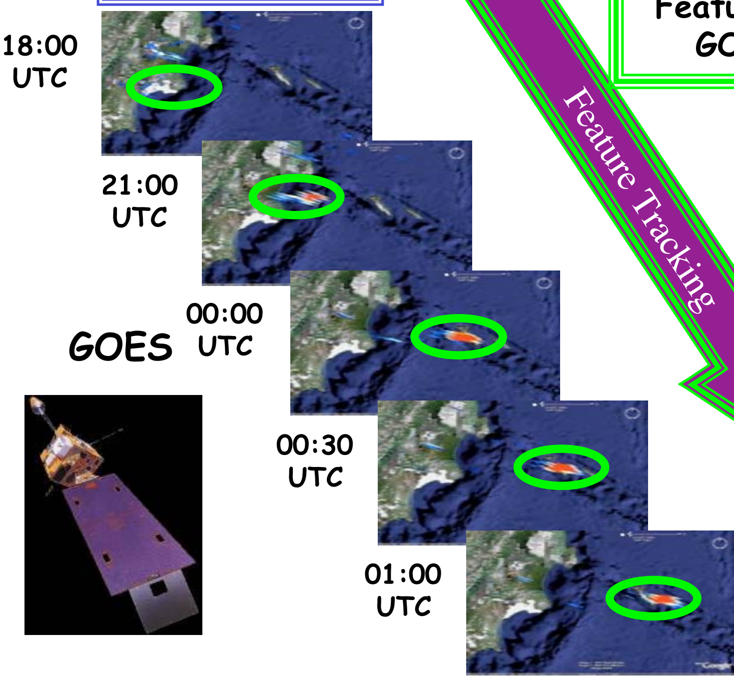
18:00 UTC

21:00 UTC

00:00 UTC

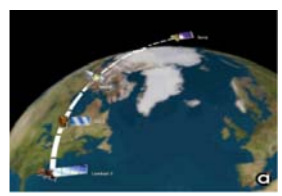
00:30 UTC

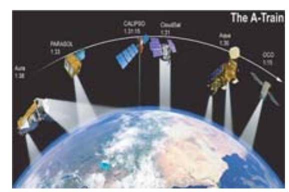
01:00 UTC



GOES

Feature Tracking





Check for footprint collisions between EOS instruments and tracked ash clouds

Acquire additional observations of ash clouds using the specialized, high-resolution instruments on the EOS polar orbiters

*BTD = Brightness Temperature Difference

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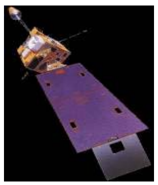
Bezymianny Timeline

Physical Processes

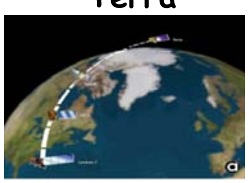
Seismic Sensor

GOES West



A-Train

Terra



2007/10/14

14:37:05
- Eruption (presumed)
- Seismic Event Detected
- Ash Cloud #1 (AC1)

15:00:00 - GOES does not see AC1

15:35:00 - Aqua-MODIS sees AC1

18:00:00 - GOES first sees AC1

21:00:00 - GOES sees AC1

2007/10/15

00:00:00
- Ash Cloud #2 (AC2)
- GOES sees AC1

00:30:00 - GOES sees AC1

01:00:00
- GOES sees AC1
- Terra-MODIS sees AC2

01:10:00 - Aqua-MODIS sees AC2

01:30:00
- GOES sees AC1
- GOES first sees AC2

02:00:00 - GOES sees AC1 and AC2

02:30:00 - GOES sees AC1 and AC2

02:40:00 - Ash Cloud #3 (AC3)

02:50:00 - Aqua-MODIS sees AC3

03:00:00 - GOES sees AC1 and AC2

03:30:00 - GOES sees AC1 and AC2

2007/10/15 (cont)

04:00:00
- GOES sees AC1 and AC2
- GOES first sees AC3

04:30:00 - GOES sees AC2 and AC3

05:00:00 - GOES sees AC2 and AC3

05:30:00
-GOES sees AC2 and AC3
-End of Visible GOES

• • •

07:30:00 - GOES sees AC3

• • •

2007/10/16

00:05:00
-Terra-MODIS sees AC3
-Terra-MISR sees AC3

01:50:00
-Aqua-MODIS sees AC3
-CloudSAT CPR sees AC3
- CALIPSO CALIOP sees AC3

02:00:00- GOES sees AC3

*All times are UTC

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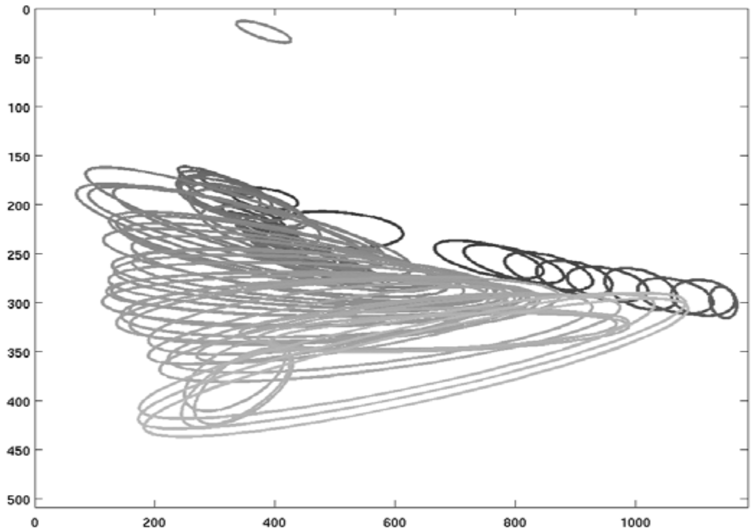
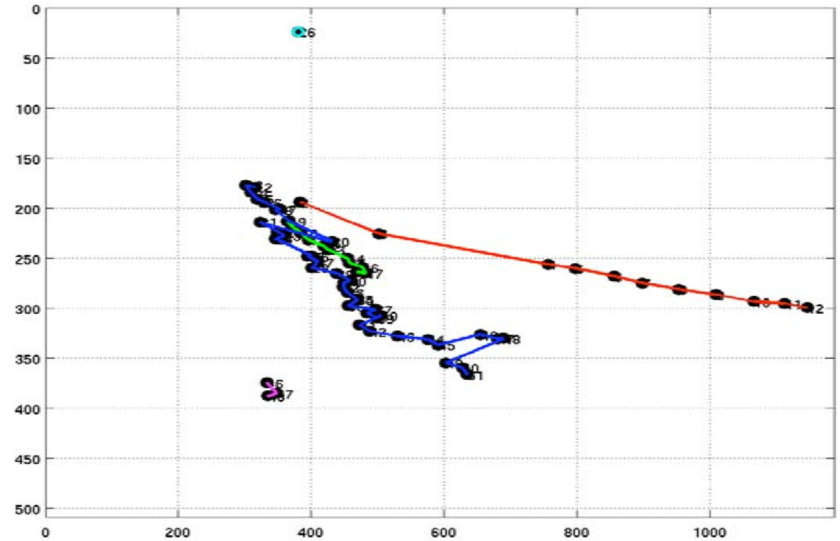
Tracking through GOES Sequence

Superposition of Detected Blobs

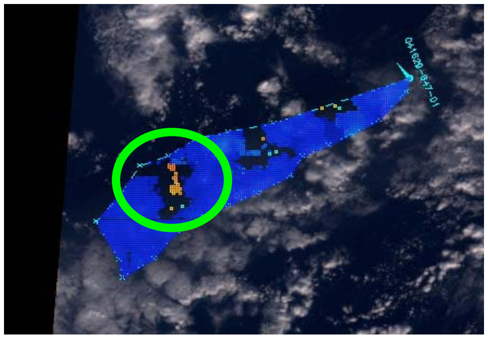


Ash Cloud Tracks (30 hours)

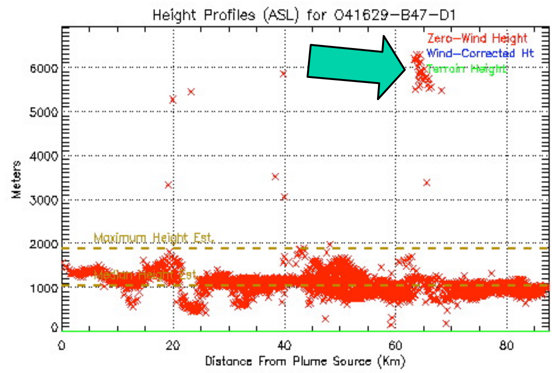


Follow-up Observations of Ash Cloud 3

Terra Overpass
20071016T00:05 UTC



MISR Height Profile



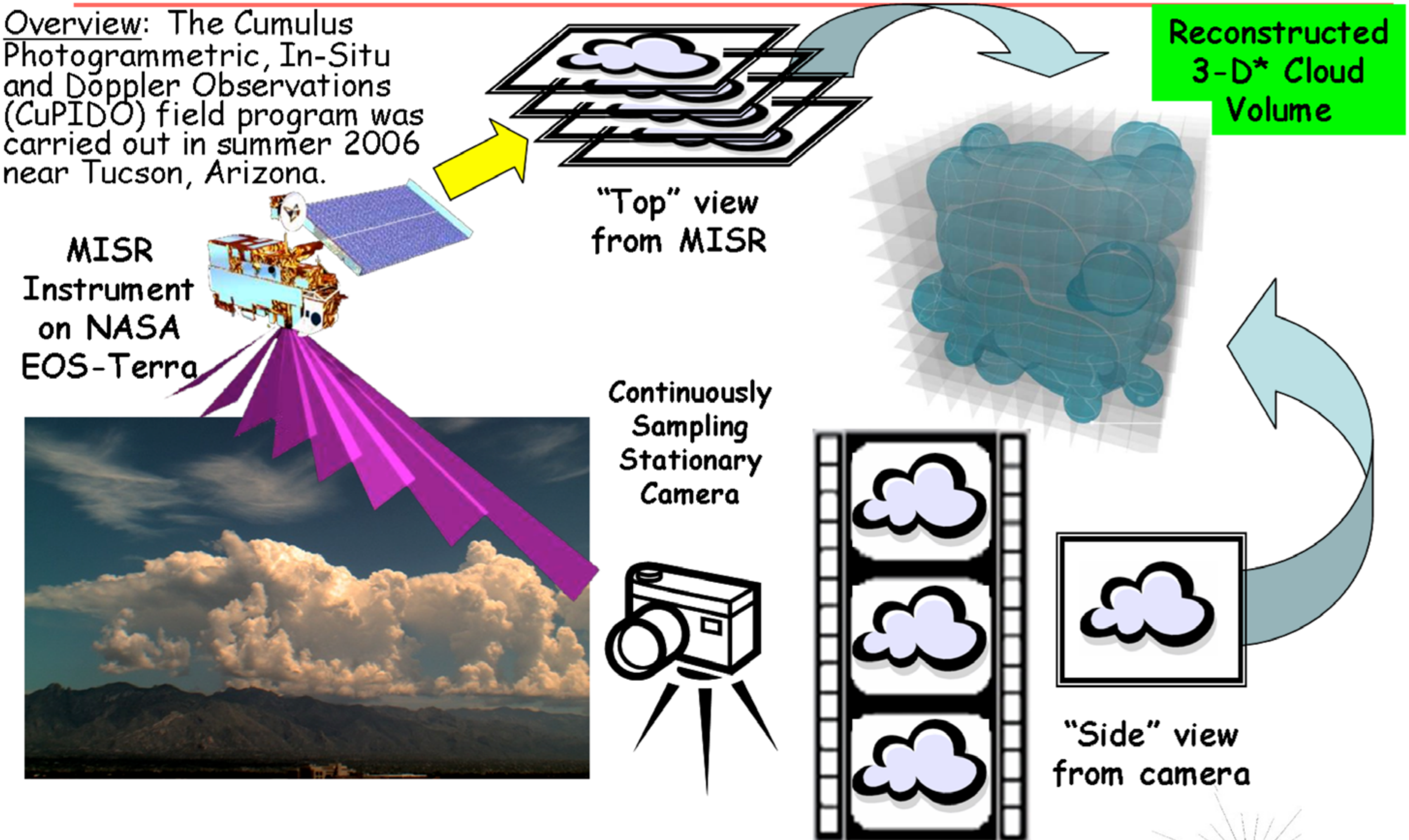
- MISR Stereo Heights indicate a Cloud at ~6 km, with lower clouds at 1-2 km.
- MISR Aerosol Retrievals indicate non-spherical particles in this region, consistent with ash

A-Train Overpass
20071016T01:50 UTC

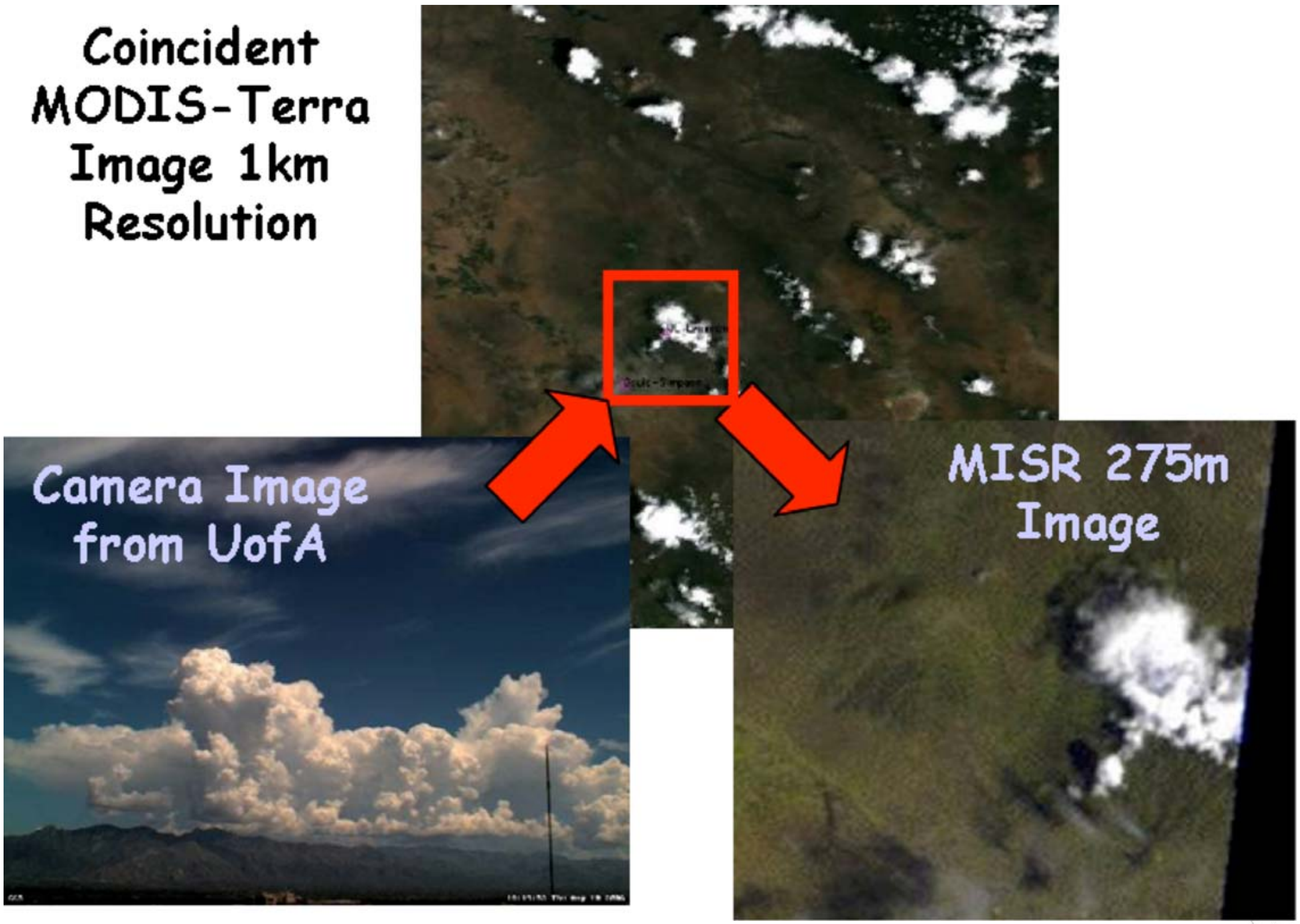
- CALIOP lidar indicates an extremely thin aerosol layer at an altitude of ~6 km in the region.
- The CloudSat radar does not have any returns in this area, indicating extremely small particles.

Future Work

Overview: The Cumulus Photogrammetric, In-Situ and Doppler Observations (CuPIDO) field program was carried out in summer 2006 near Tucson, Arizona.



Linking Ground/Satellite Views



Conclusions

- Adaptive Sky feature tracking allowed observations made in mid-ocean to be associated unambiguously with an ash cloud from the Bezymianny eruption, even with a time difference of ~30 hrs and a spatial separation of ~400 km.
- First observations of a volcanic ash cloud from the CALIOP lidar on CALIPSO and first *joint observations* with both CALIOP and MISR.
- Without tracking through the GOES BTD sequence, the returns would likely have been attributed to cirrus clouds.
- MISR stereo-derived heights for the ash cloud can be compared directly to the CALIOP lidar heights; MISR aerosol product lends confidence to the assertion this is indeed an ash cloud.