JPL

Using Space, Air, Marine, and Ground Assets to Autonomously support Disaster Response and Environmental Monitoring

Steve Chien
Jet Propulsion Laboratory
California Institute of Technology

In collaboration EO-1, OASIS, OOI, Volcano, Flood, UAVSAR Sensorweb teams including: Goddard Space Flight Center, USGS/CVO/HVO, Washington State University, UCSD, Scripps, Rutgers, MIT, ASU, U. Arizona, MEVO/NMT, U. Iceland, Iceland Met. Office, HAII, U. Maryland, The Geophysical Institute of the National Polytechnic School of Ecuador (IGEPN), University of Florence, Dartmouth Flood Observatory, and the National Snow and Ice Data Center.

JPL Clearances: 10-2762, 11-0177, 11-0178, 11-2065, 11-2245, 12-0499, 12-1201, 12-1244, 12-2847

KISS Workshop: Satellites to the Seafloor: Autonomous Science to Forge a Breakthrough in Quantifying the Global Ocean Carbon Budget

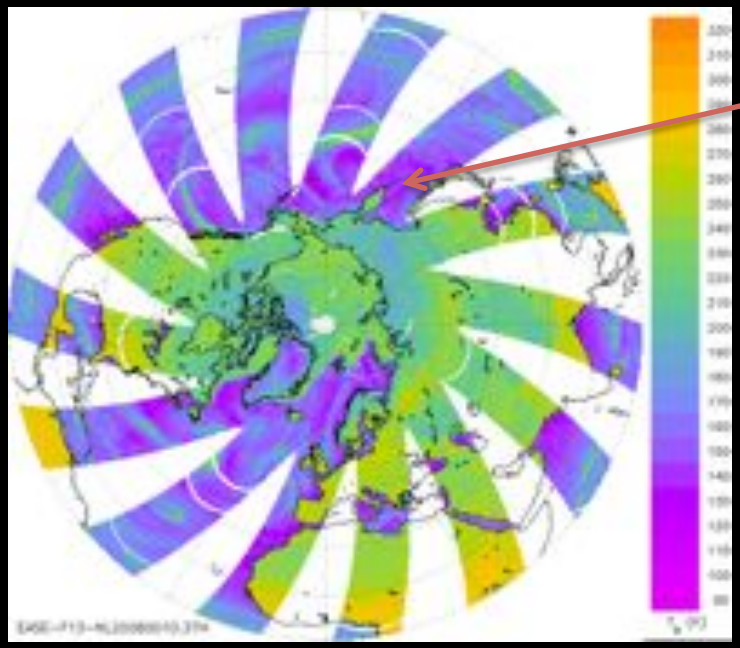
Adaptive Sensing and Sensorwebs

- Adaptive Sensing offers the potential to revolutionize environmental sensing
- Adaptive Sensing consists of several concepts:
  - Automatic interpretation of data to go from low-level or raw data to high –level descriptors
  - Automatic tasking, redirection, re-allocation of sensors based upon the above interpretations
- The above concepts apply to a wide range of sensors (space, air, marine, ground) and science applications (volcanology, forestry, hydrology, oceanography, …)

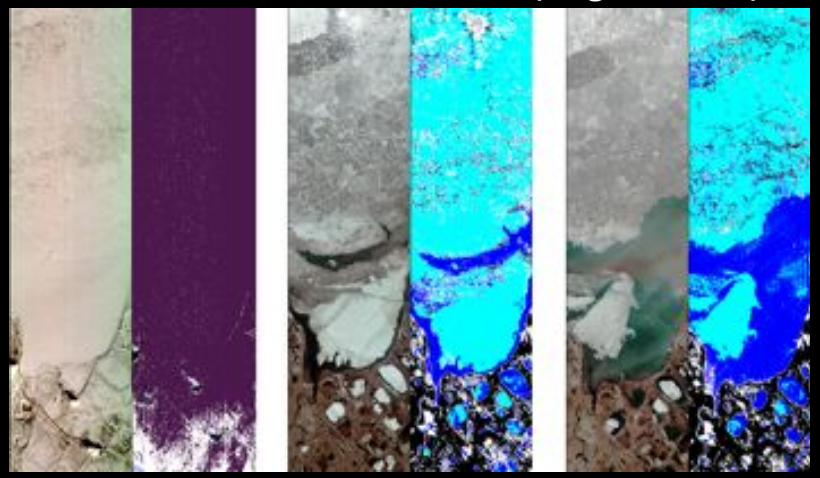
Environmental Monitoring

- Hydrology: Flooding is the most costly ($$ and humanitarian) natural disaster
  - 2011 Thailand Flooding: **600 deaths and $45.7 Billion USD damage** [World Bank 2011]
- Volcanology: Over two hundred million people live near volcanoes.
  - The Iceland volcanic eruption caused damages **1.9-3.3 billion USD** (EU Transport Commissioner Siim Kallas 27 April 2010) in air travel, tourism, and industrial disruption.

Cryosphere Tracking



- Automatically determine areas of greatest change
- Automatically target with higher resolution limited swath sensors (e.g. EO-1)



SSMIS sensor on DMSP
1 days data ***25km/pixel resolution***

Hyperion Sensor on EO-1
Ice breakup at Prudhoe Bay
30m/pixel resolution

T. Doggett, R. Greeley et al, Arizona State University

MODIS Rapidfire [Justice et al.]

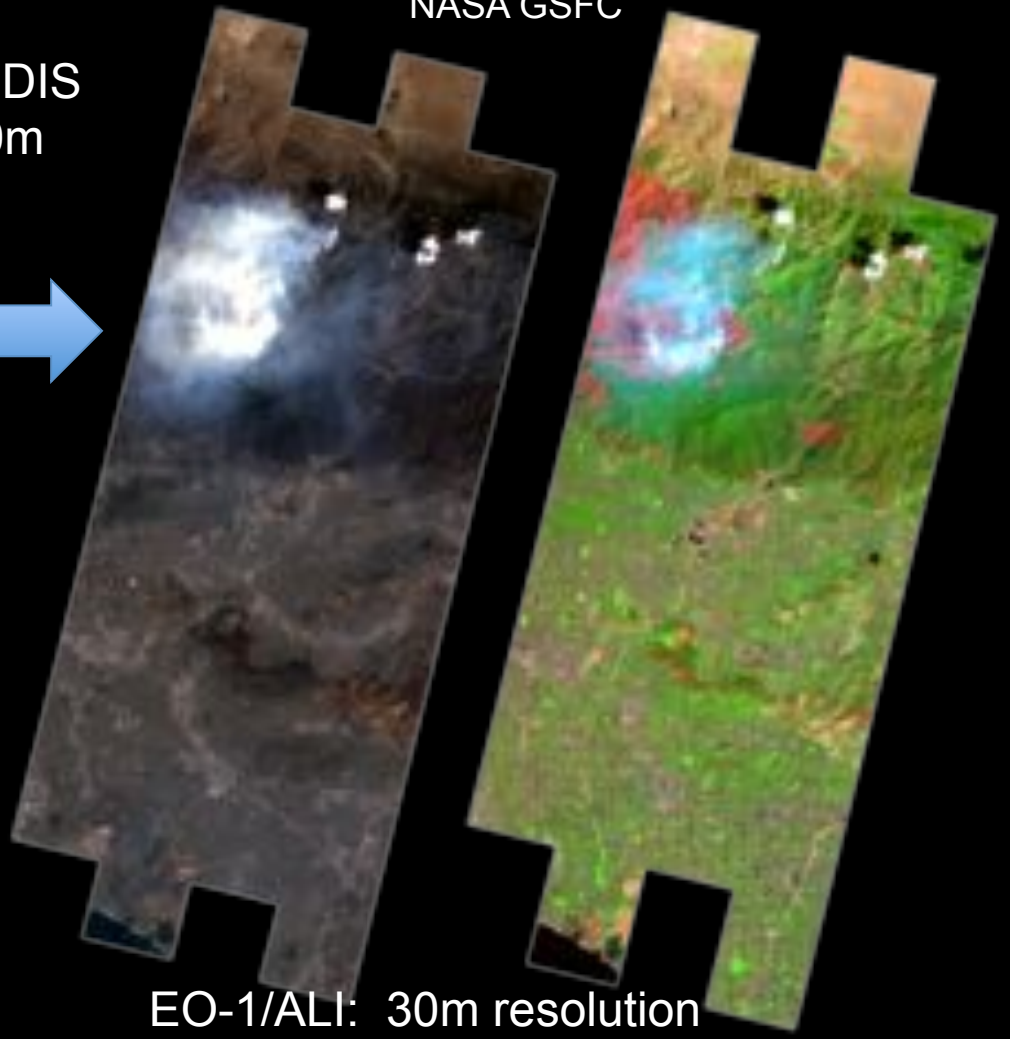
MODIS imagery courtesy NASA Earth Observatory

Wildfire

Visible and burn scar enhanced images from ALI instrument on EO-1 of Station Fire near Los Angeles 03 September 2009

Images courtesy EO-1 Mission NASA GSFC

MODIS 250m



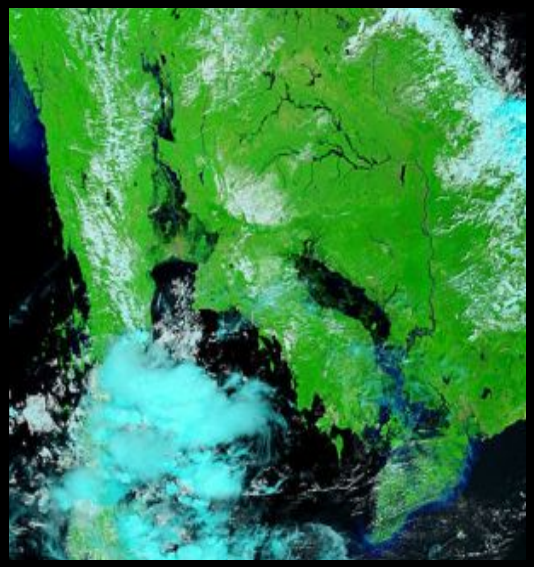
EO-1/ALI: 30m resolution

Station fire, La Canada, August 2009

Automatically detect areas of fire → direct higher resolution sensors to otrack, observe

Flooding

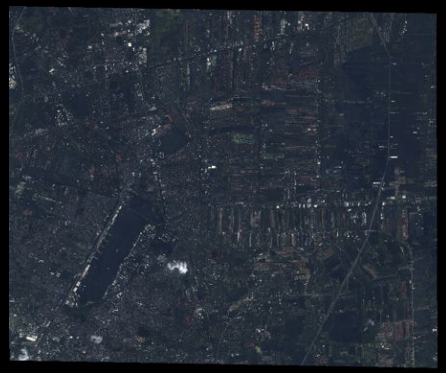
Dry



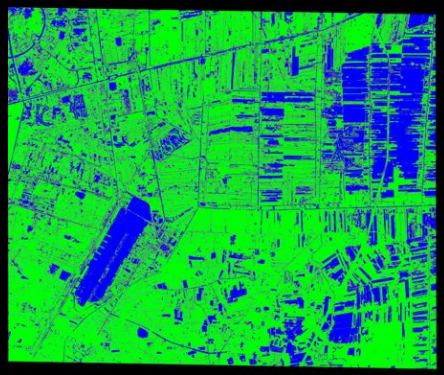
Flooded

MODIS, 250m resolution

Automatically detect flooded regions of interest
→
Direct narrow FOV higher spatial resolution sensors
Automatically derive end user products



Raw Image



SVM Classified
Surface Water Extent

Worldview-2,
2m resolution

Volcano Monitoring

- Volcanoes can erupt with little warning, sometimes after 100s of years or dormancy

Chaiten volcano, Chile in a 2008 eruption
image courtesy USGS

Automatically detect active volcanoes
→
Direct narrow FOV higher spectral spatial resolution sensors
Automatically derive end user products

Examples

EO-1 acquisition of Yom at Ban Kong TFS

ASE Operations [ase-oper...

To: dmclaren@jpl.nasa.gov; ase-operations@aig.jpl.nasa.gov

Attachments: EO1A1300482013278110KF_L1G.png (10 MB)

Saturday, October 05, 2013 2:29 AM

EO-1 acquired an observation of Yom at Ban Kong TFS (16.9297/99.9614) at approximately 2013-278/03:14:11.

Tungurahua Índice 2013 09 18

gviracucha [gviracucha@i...

To: informes@igepn.edu.ec; soporte@igepn.edu.ec; ase-operations@aig.jpl.nasa.gov

Attachments: Indice 2013 09 18.doc (1 MB) [Open as Web Page]

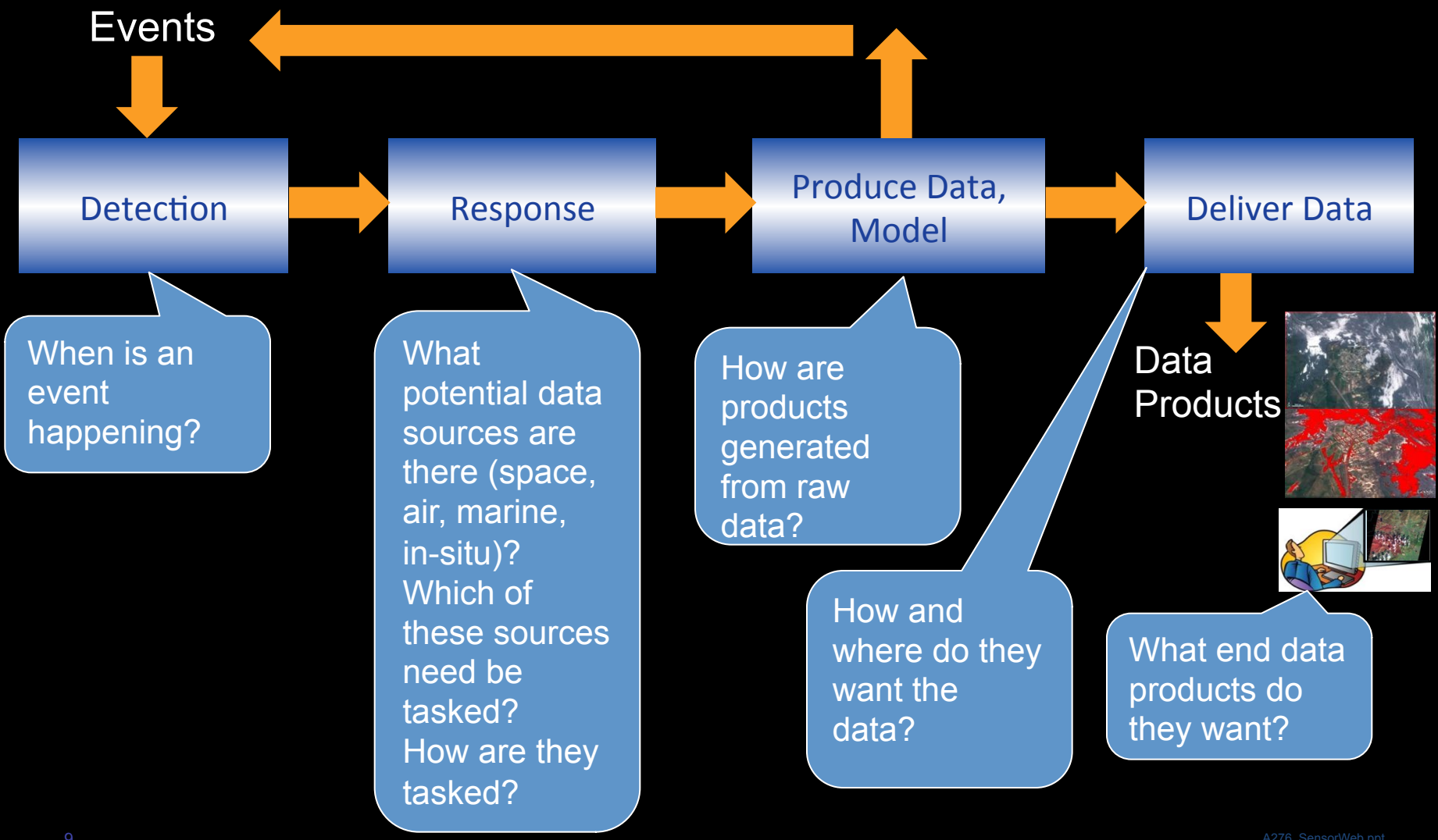
Thursday, September 19, 2013 9:12 AM

Saludos,

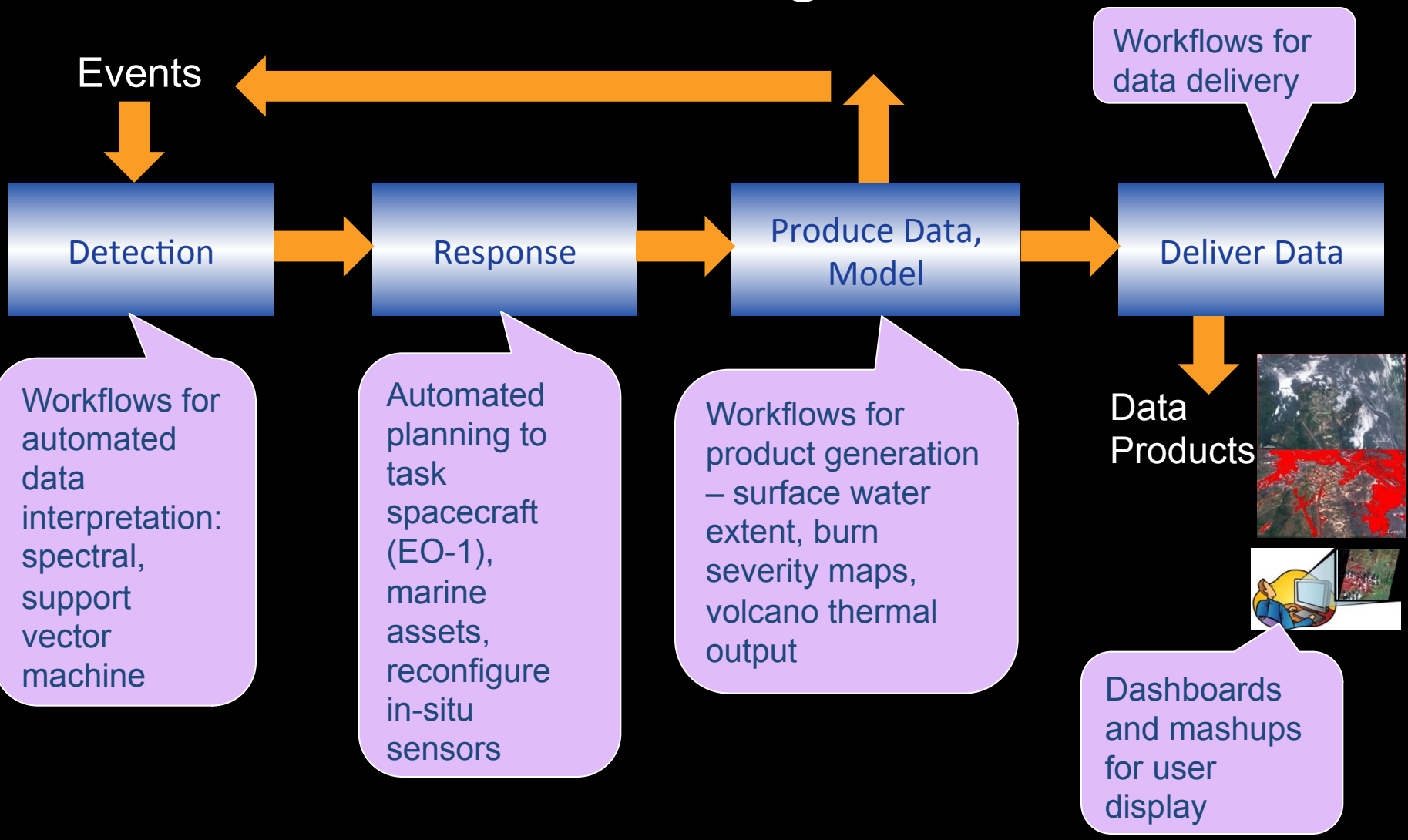
Con datos procesados hasta el día 18 de Septiembre 2013.

- Nivel del IAS:4
- Tendencia del IAS: Estable (pendiente: -0,01 +- 0,06)
- Velocidad: Dentro del rango 1999-2005
- Aceleración: Dentro del rango 1999-2005

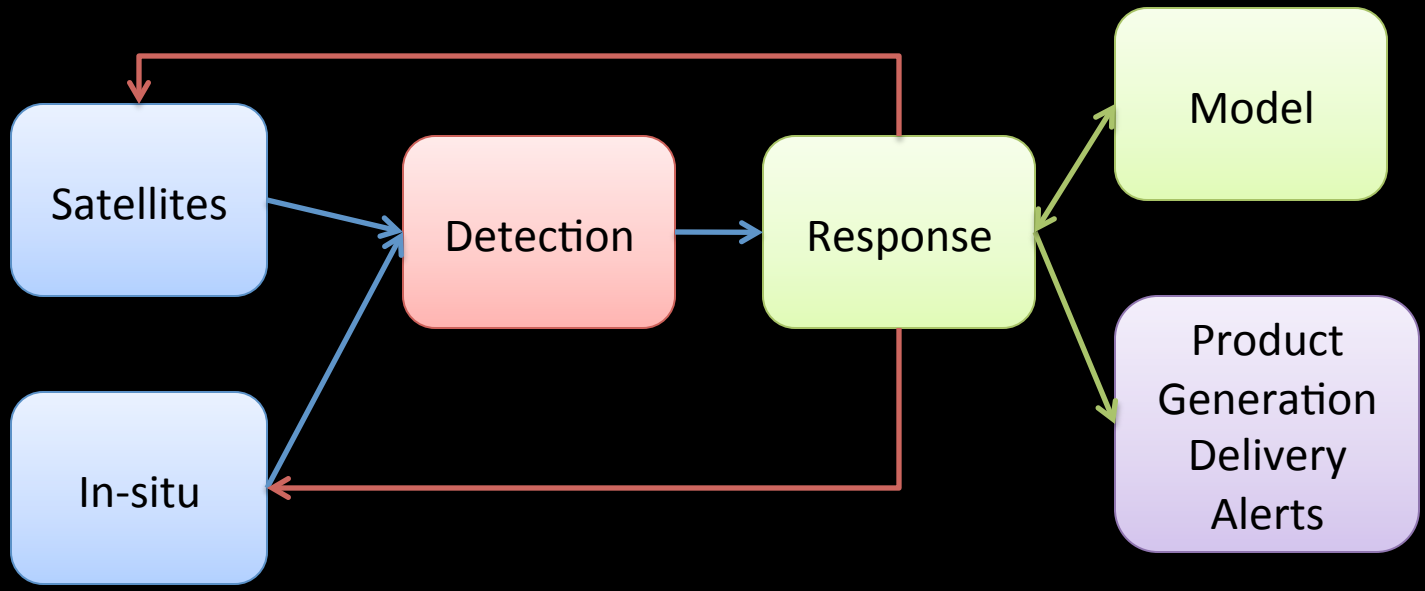
Process flow:



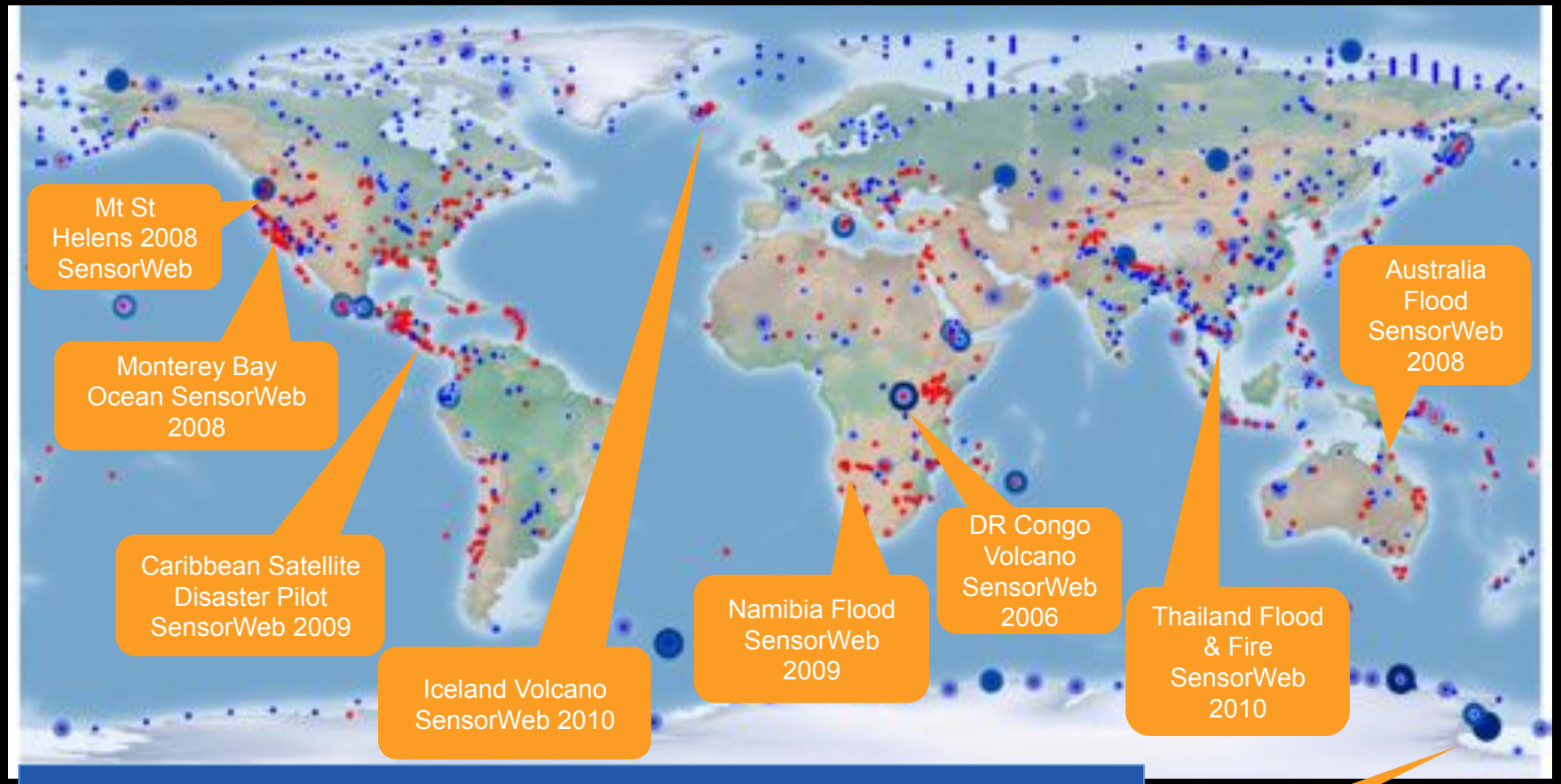
Technologies:



Sensorweb Paradigm



SensorWeb Imagery: EO-1 (2003 – pres.)



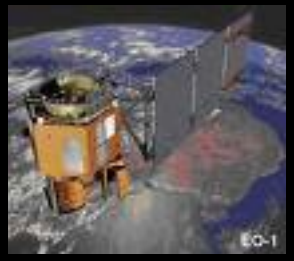
Worldwide coverage with many science disciplines flooding, oceanography, volcanology, forestry,…
Nearly 10,000 SensorWeb Images as of 5/20/11

In-situ Sensors

Inside an Agent

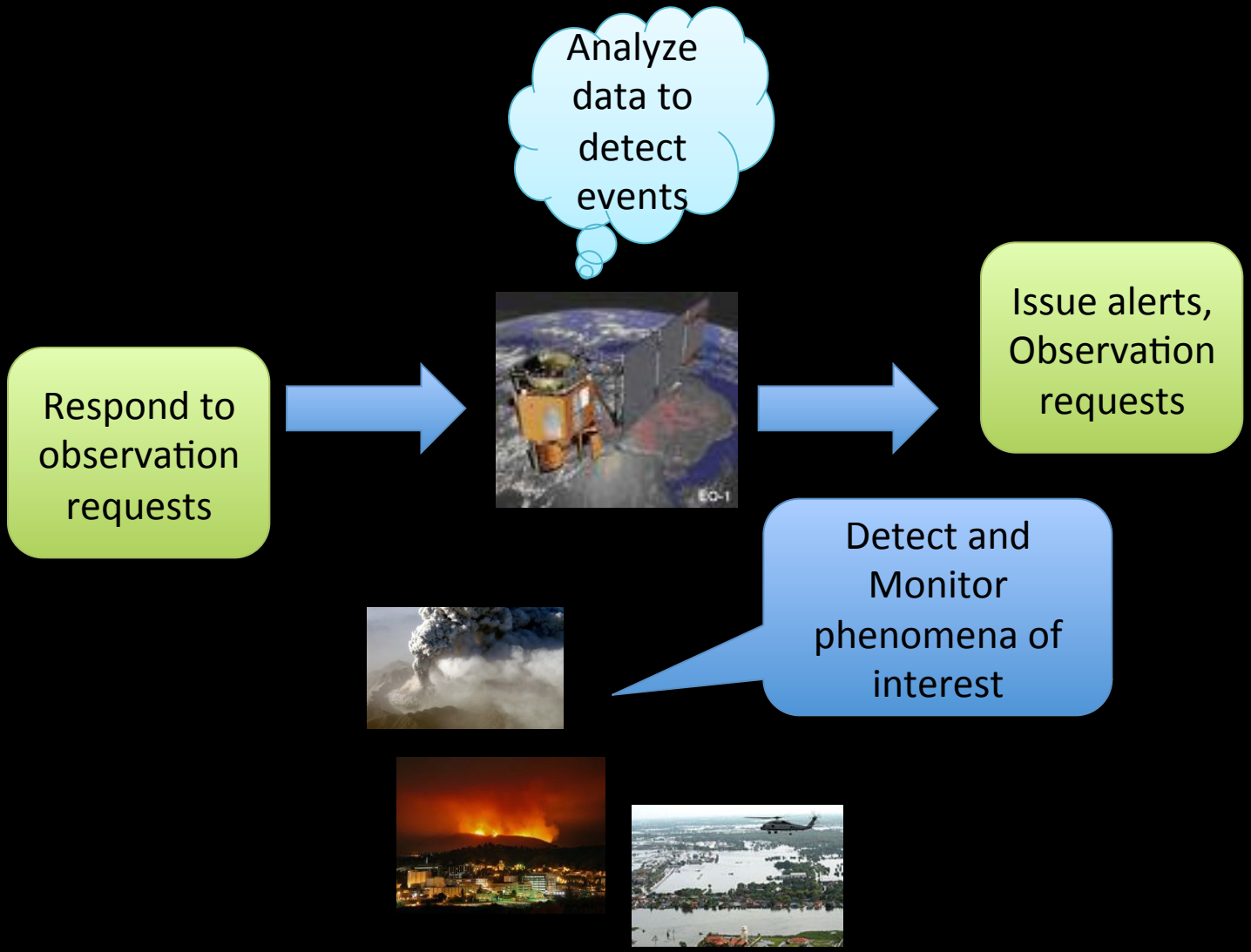
- Agents have internal mechanisms to support goal-directed behavior, such as
  - Automatic interpretation software: to detect events, interpret raw data → event notices
  - a mission planner to determine if the spacecraft can satisfy requests for imaging (or if higher priority activities prevent, or if resources are not available, etc.)
  - an execution system to achieve high level requests (such as imaging, or to reconfigure a ground network)
  - together these capabilities enable the asset to conform to pre-defined policies to monitor, respond, alert, etc.

Inside an "agent" – Autonomous Sciencecraft



For further information see [Chien et al. 2005 JACIC]

Agent Capabilities



Hierarchical Multi-agent Systems for Integrated, Intelligent, Space–Ground Volcano Monitoring

For further information see [Huang et al. 2010 JSTARS]

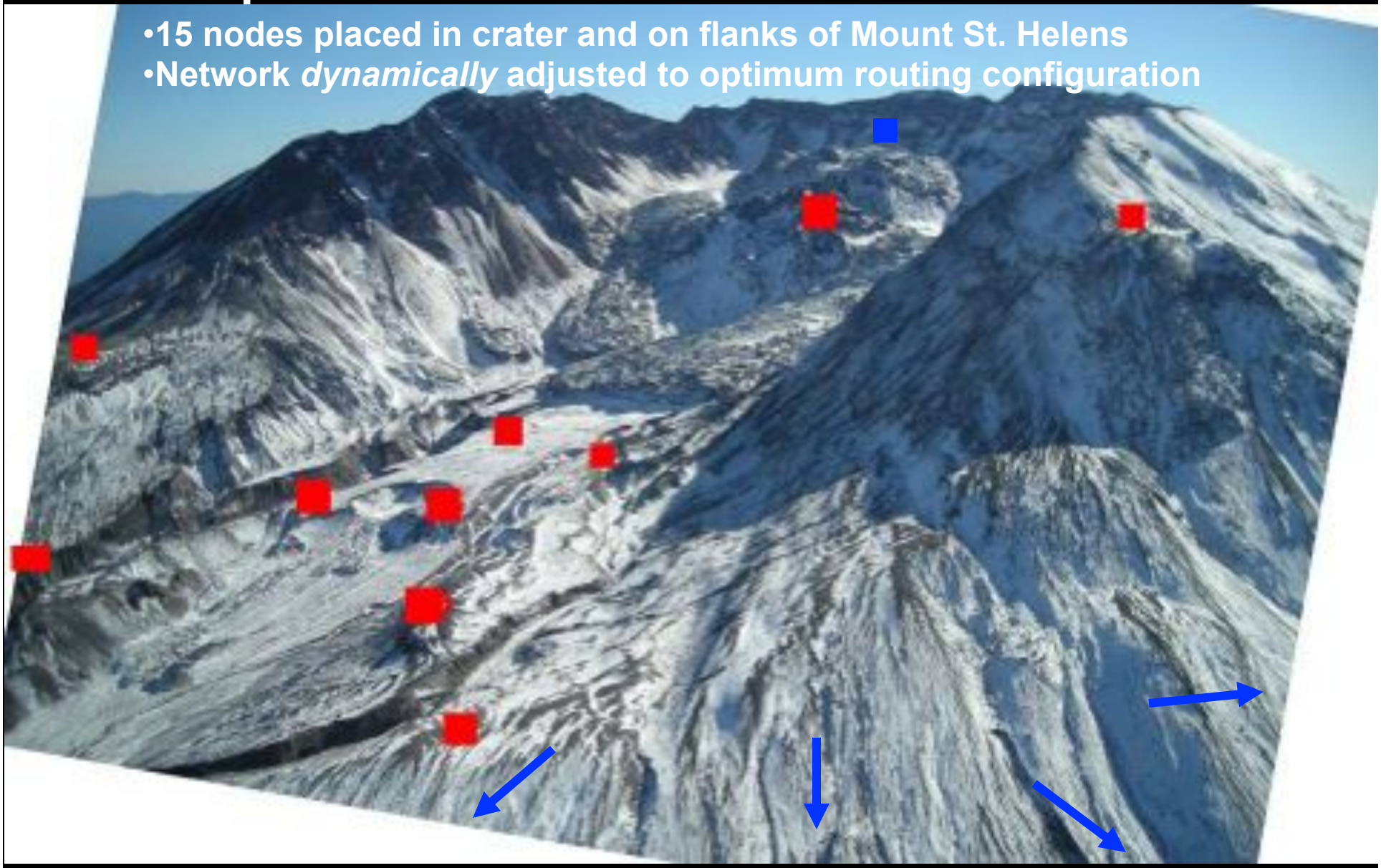
Integrated with multiple volcano observatories worldwide including: Iceland, Ecuador, Mount Erebus, Etna,…

Spider Sensors Hardware (USGS)

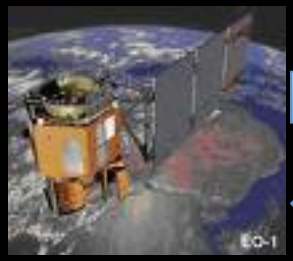
- MEMS accelerometer (seismographic)
- Acoustic Sensor
- GPS sensor
- Lightning Sensor
- Radio

Spider Node on Mt St Helens

Spider Node on Mt St Helens



Mount Saint Helens "Agent"



Goals

Alerts

C&C Network Autonomy

Bridge

Allocate resources (bandwidth) to sub-area of network based on global view

Filter and summarize data based on local view

Smart Node

Smart Node

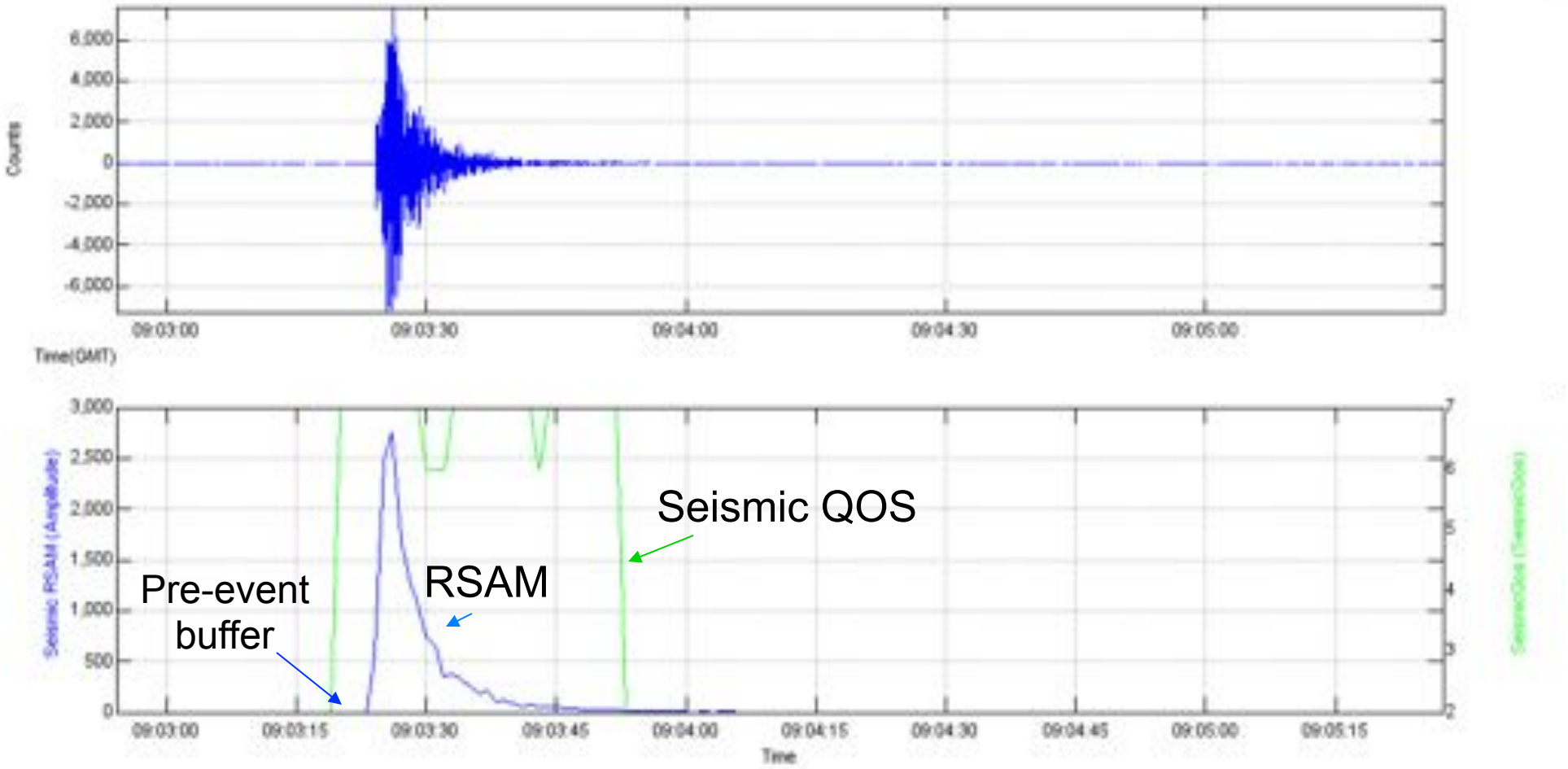
Smart Node

Smart Node

Smart Node

Onboard Node Smart Software

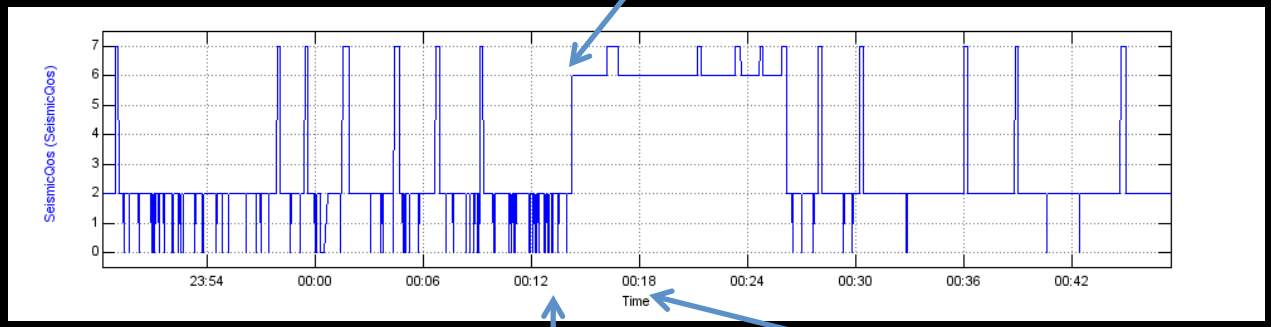
- **Onboard node software can detect events to change operating modes to capture critical events**
- **Quality of Service Node software ensures highest priority data is tranferred**
- **Example from OASIS Node 05 showing waveform, in-situ RSAM and in-situ event triggered QOS prioritization**

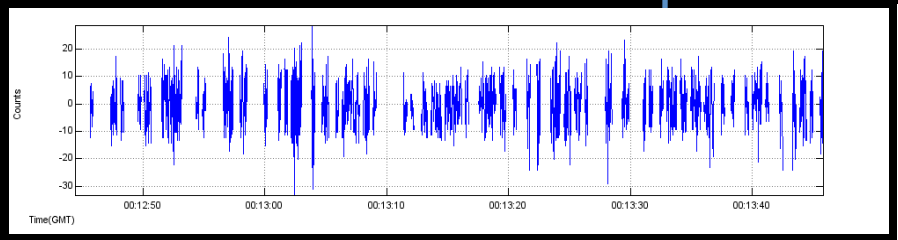


End-to-End ground and space cross-trigger

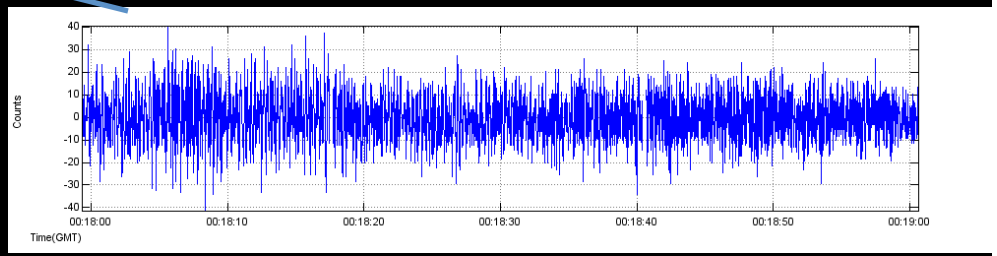
- Data autonomously delivered to Ground System and ingested into time-series DB.
- VAlarm detects new data and triggers autonomous ground response through C&C: heighten priority (QoS) of crater node (node 4) seismic data.

Thermal data detected / ground response





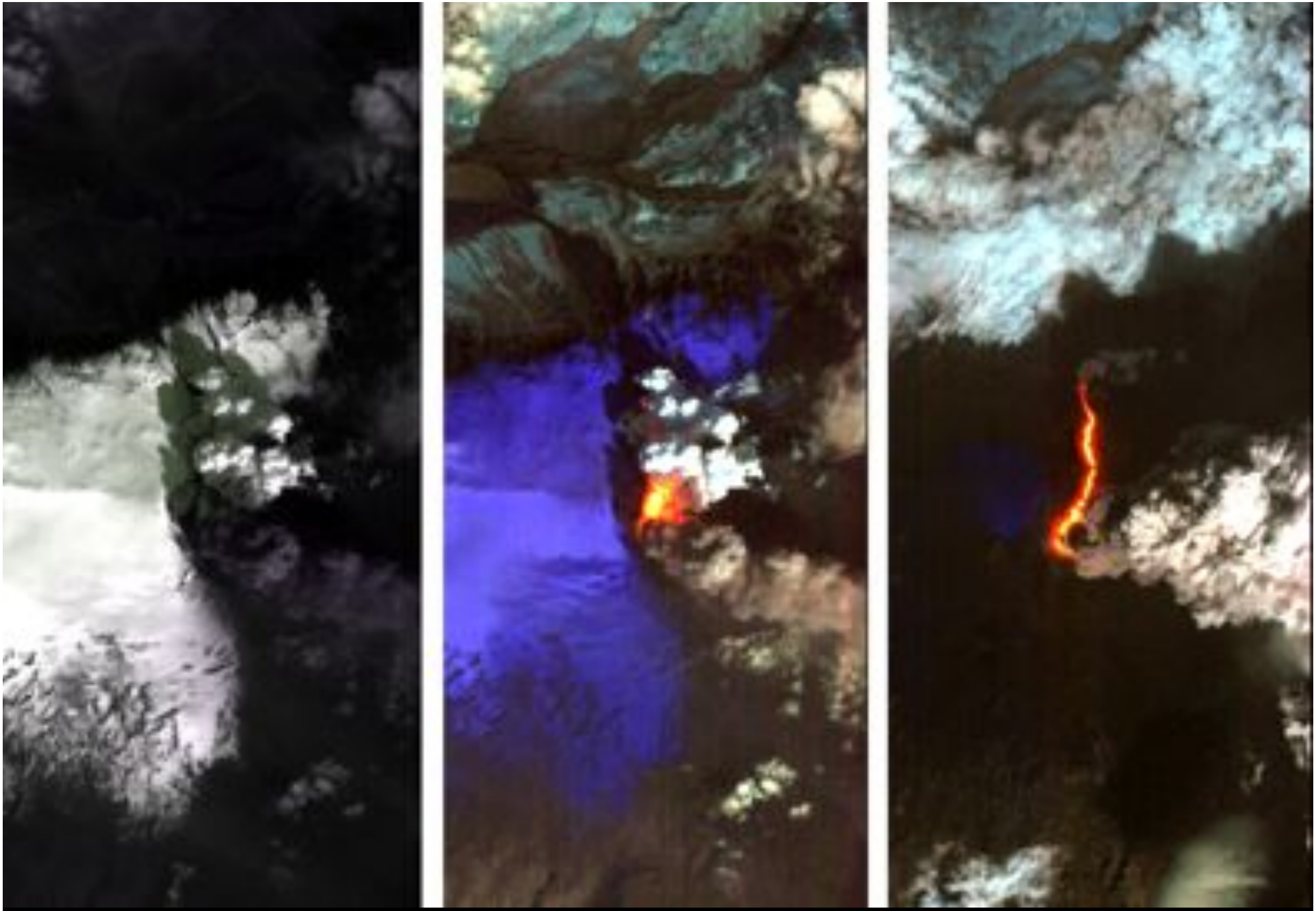
Data transmission loss at low QoS.



Increased QoS results in nearly continuous data, at node of interest.

Automated Workflows for Automatic Data Interpretaton

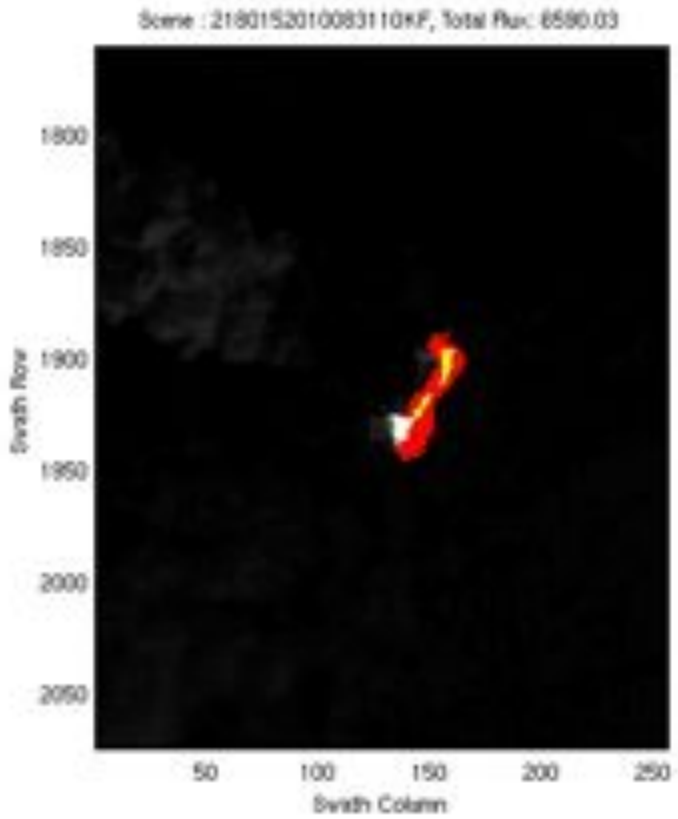
For further information see [Davies et al. 2006 RSE, Davies et al. 2008 JVGR, Davies et al. 2013 JGRI]

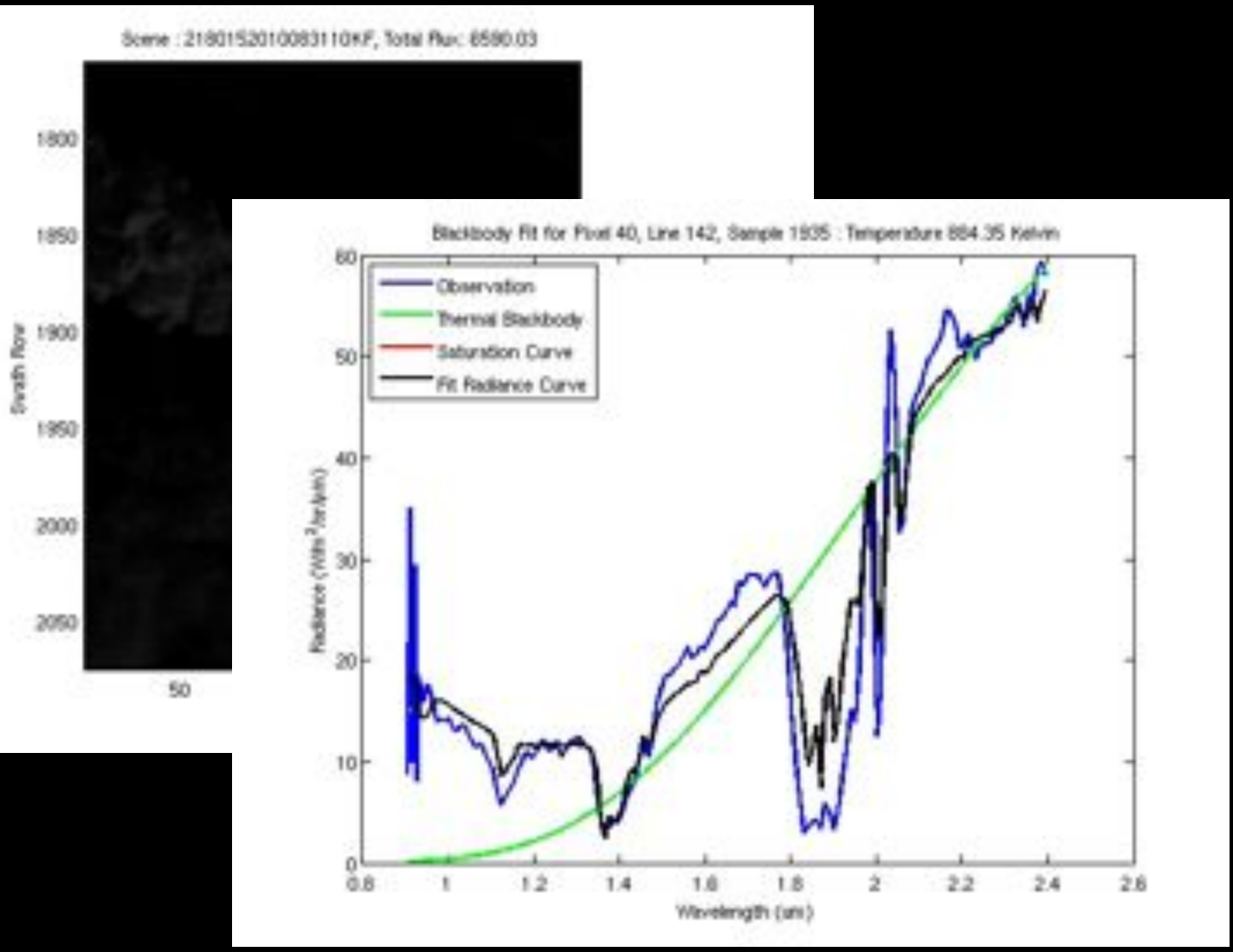


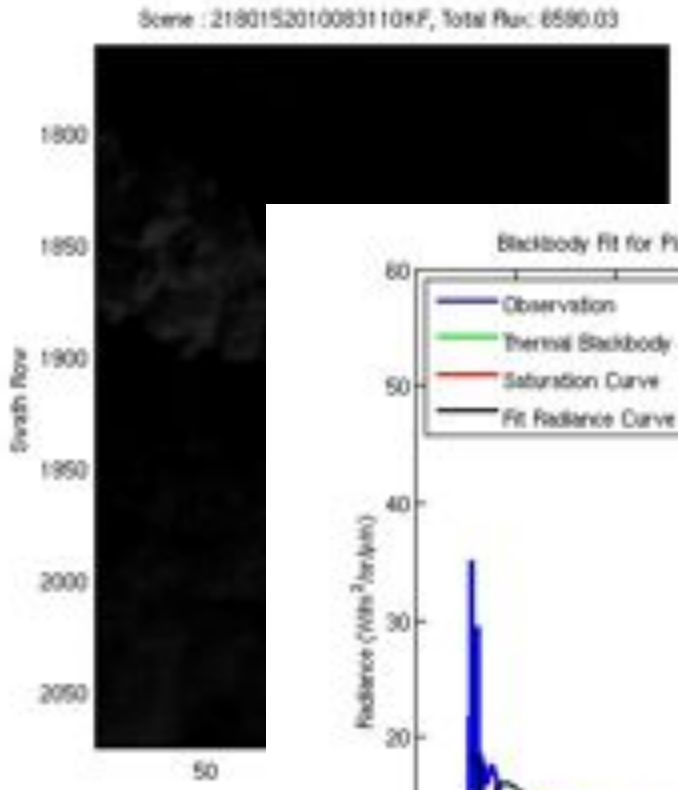
2 May 2010 – VIS

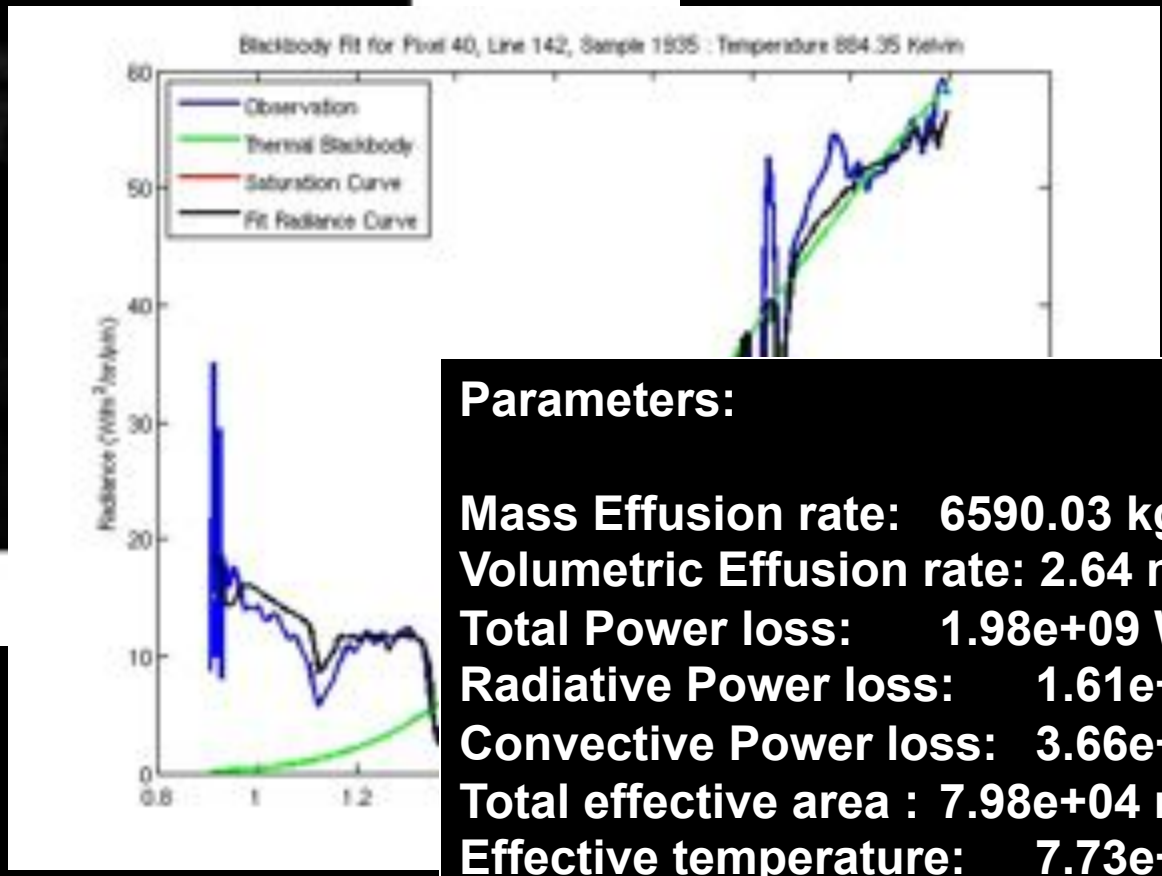
2 May 2010 – SWIR

4 May 2010 - SWIR


Scene : 21801520100831101F, Total flux: 6590.03
1800
1850
1900
1950
2000
2050
Swath Row
50
100
150
200
250
Swath Column

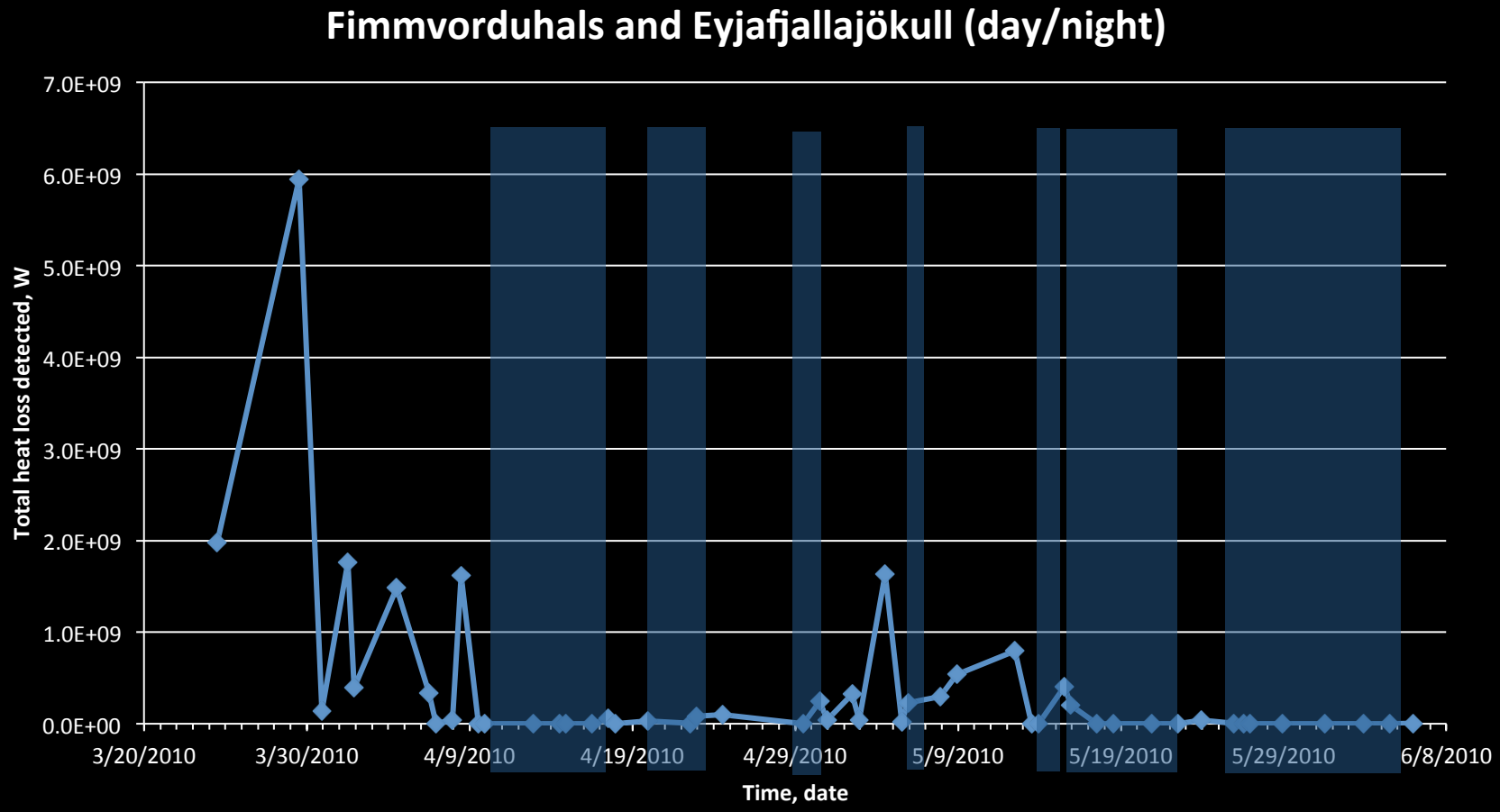

Scene : 21801520100831104F, Total Run: 6590.03
1800
1850
1900
1950
2000
2050
Swath Row
50
Blackbody Fit for Pixel 40, Line 142, Sample 1935 : Temperature 884.35 Kelvin
Observation
Thermal Blackbody
Saturation Curve
Fit Radiance Curve
Radiance (Watts/m²/sr/μm)
0
10
20
30
40
50
60
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
Wavelength (um)





Parameters:

Mass Effusion rate: 6590.03 kg/s
Volumetric Effusion rate: 2.64 m^3/s
Total Power loss: 1.98e+09 W
Radiative Power loss: 1.61e+09 W
Convective Power loss: 3.66e+08 W
Total effective area : 7.98e+04 m^2
Effective temperature: 7.73e+02 K
Look Angle: 12.63 deg.
Range to Ground: 705.85 km



Thermal emission estimate is minimum value:

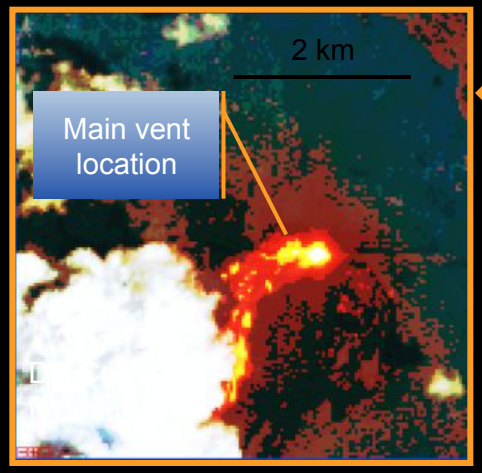
- estimates from short wavelength data
- thermal detections heavily impacted by cloud and/or plume…

… and we would like to know by how much!

Corroboration via ground measurements critical.

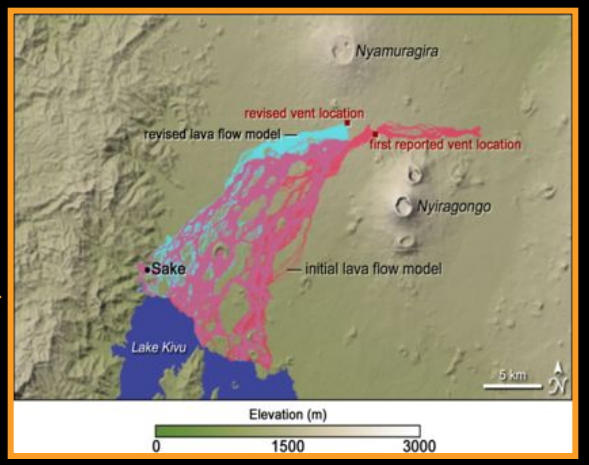
For further details see [Davies et al. JVGR Solid Earth 2013]

Volcano SensorWeb



EO-1 Hyperion SWIR image of destructive lava flows at Nyamuragira, DR Congo, 4 Dec 2006.

This vital data acquisition allowed pinpointing of the vent and enabled accurate modeling of likely lava flow direction.



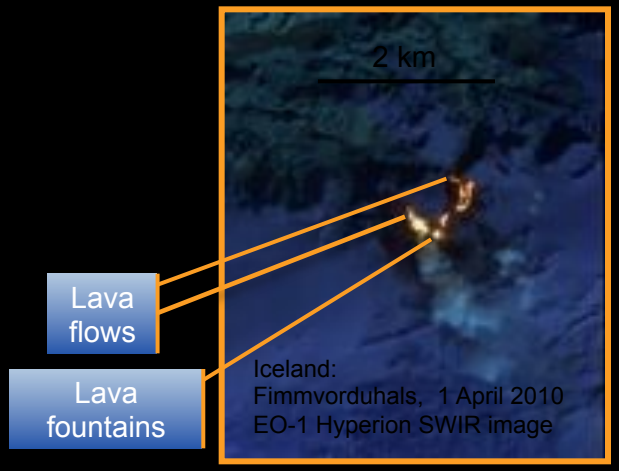
"This was a stunning demonstration of the capability of an autonomous system to obtain and provide vital information during a volcanic emergency."
- Gari Mayberry, Geoscience Advisor, USAid

Alert: Uses alerts from multiple sources (*in situ* sensors, MODIS, AFWA, VAAC, et al.)

Response: Alerts are used in a prioritized fashion to trigger follow up targeted satellite observations.

Product Generation & Delivery: Rapid data processing, thermal maps, modeling of eruption parameters, and posting to end users.

SensorWeb now includes in-situ sensor monitoring of Icelandic volcanoes: http://en.vedur.is/earthquakes-and-volcanism



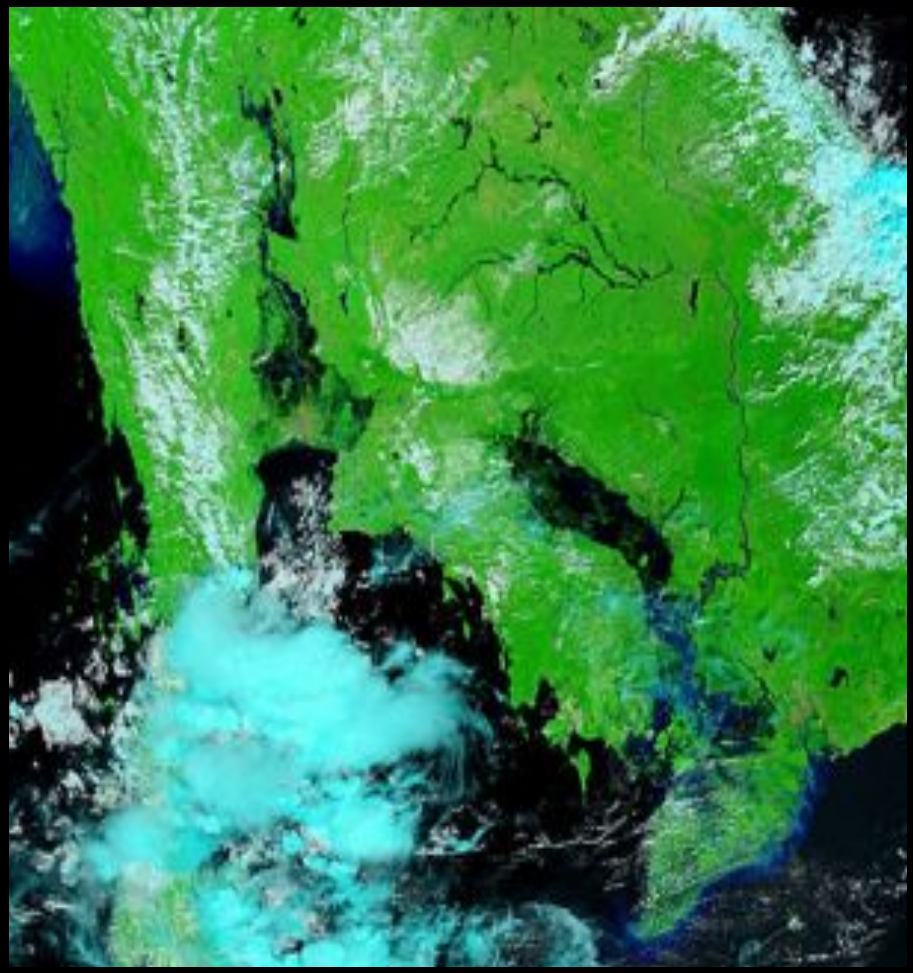
A. G. Davies / JPL

Machine Learning and Workflows for Automatic Data Interpretation

For further information see [Chien et al. 2011 IGARSS, Mclaren et al. 2012 SPIE, Chien et al 2012 i-SAIRAS, Chien et al 2013 JSTARS]

Flooding in Southeast Asia, Fall 2011

Dry: March 6, 2011
(MODIS)



Flood: October 27, 2011
(MODIS)

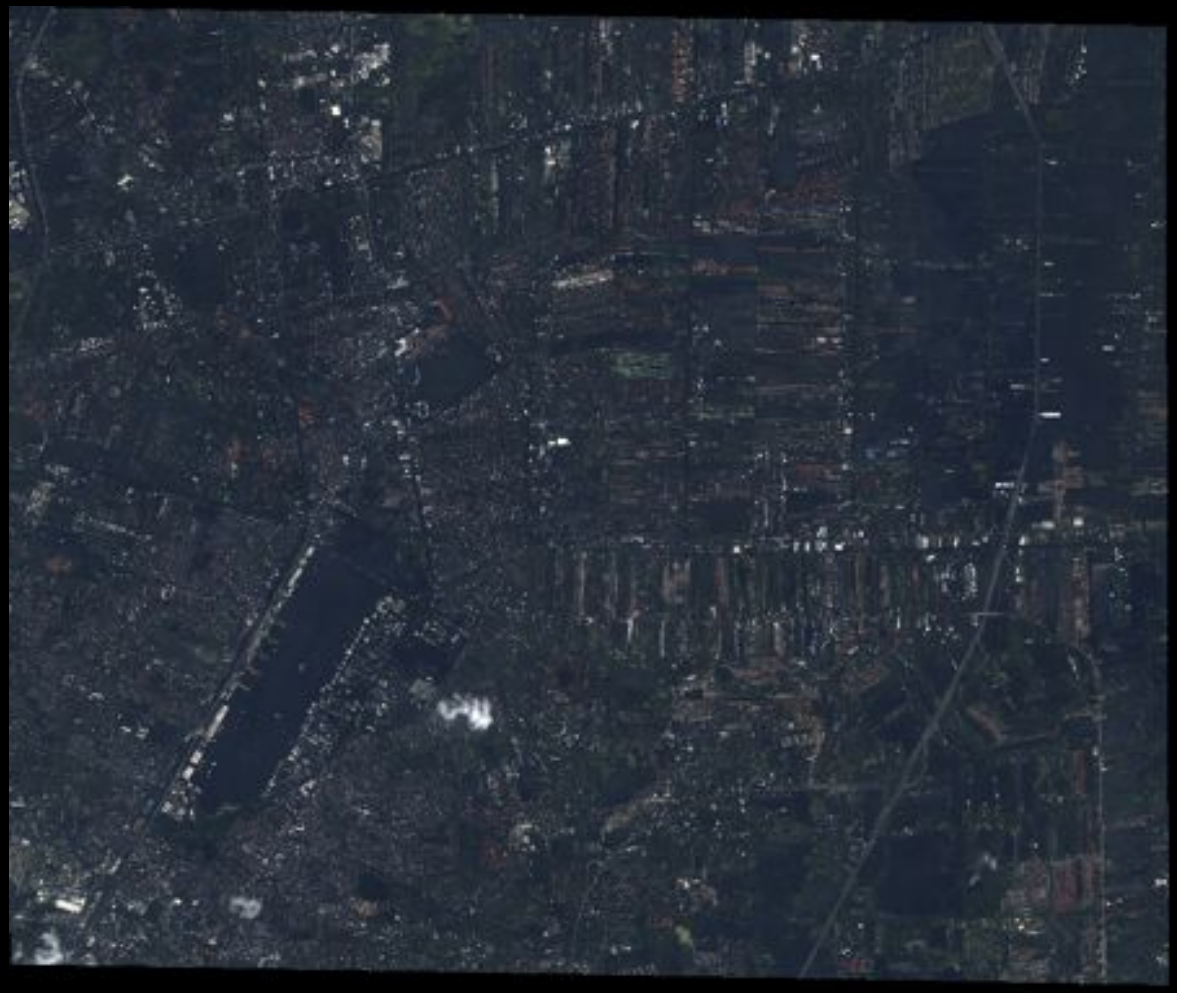
2011 Thailand Flooding

- Flooding in Thailand in late 2011: over 800 deaths, $45 Billion USD damage (according to World Bank), and over 13 million people affected as of January 2012
  - Threatened Bangkok and outlying areas
  - Disrupted industrial production and global supply chains

Thailand Flood Sensorweb (TFS): Overview

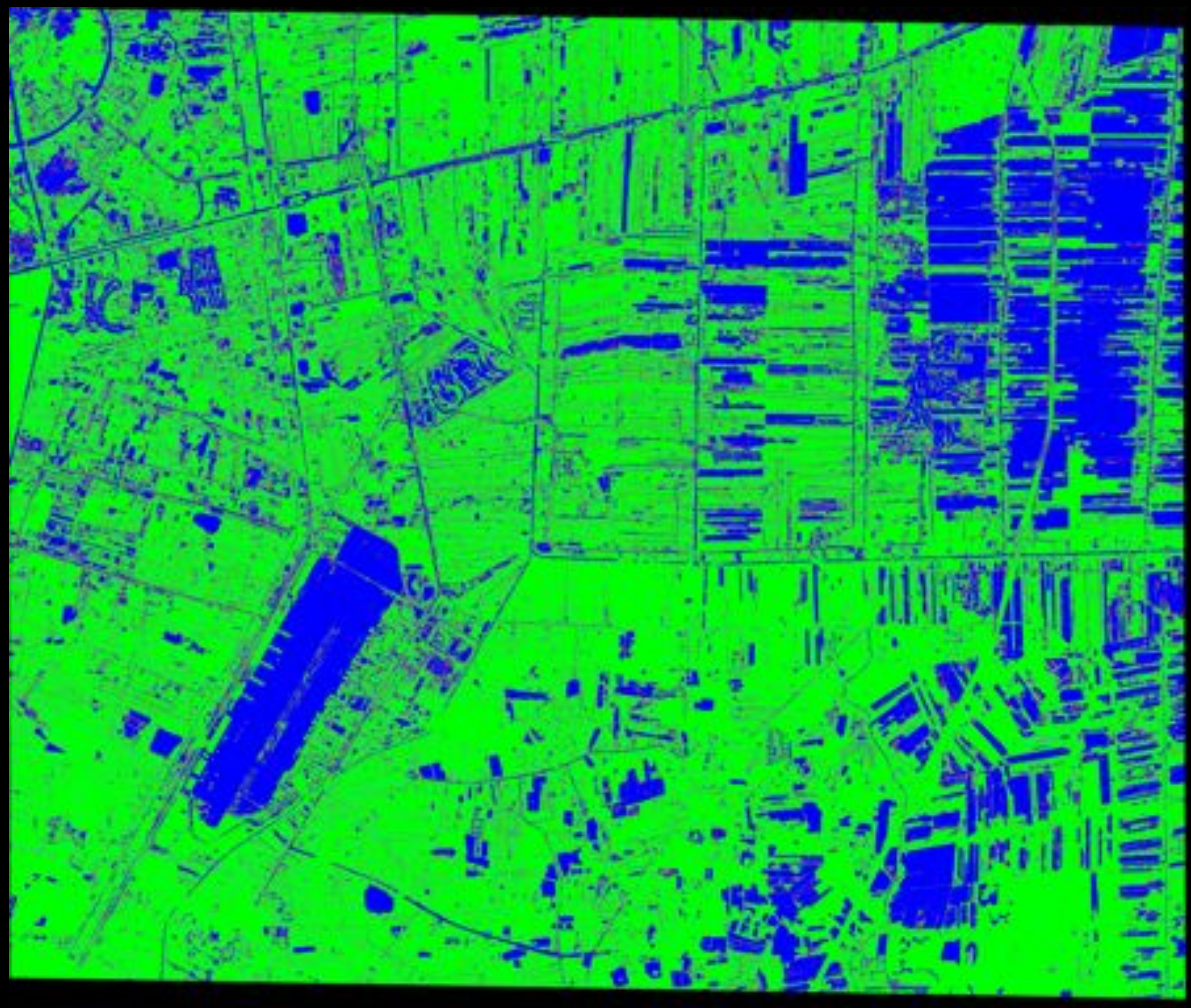
- Networked set of sensors (space), data from sensors used to reconfigure/task other parts of network
- In TFS, twice-daily Moderate Resolution Imaging Spectroradiometer (MODIS) imagery is classified, compared to a baseline, and used to request observations from EO-1
  - Automatically deliver data products for EO-1 Advanced Land Imager (ALI) images to end users
    - Thailand Hydro & Agro Informatics Institute (HAII)
- Manually retrieved WV-2, Ikonos-4, Geo-Eye, Landsat, Radarsat2 scenes can be automatically classified and combined with Digital Elevation Model (DEM) to estimate water volume

WV2 SVM Classification



Reflectance of WV2 scene of Bangkok w/ flooded Don Muang Airport, acquired 11.3.2011

WV2 SVM Classification



Surface water extent (blue) from SVM classifier using 5th degree polynomial kernel on 8 WV2 bands

WV2 SVM Classification

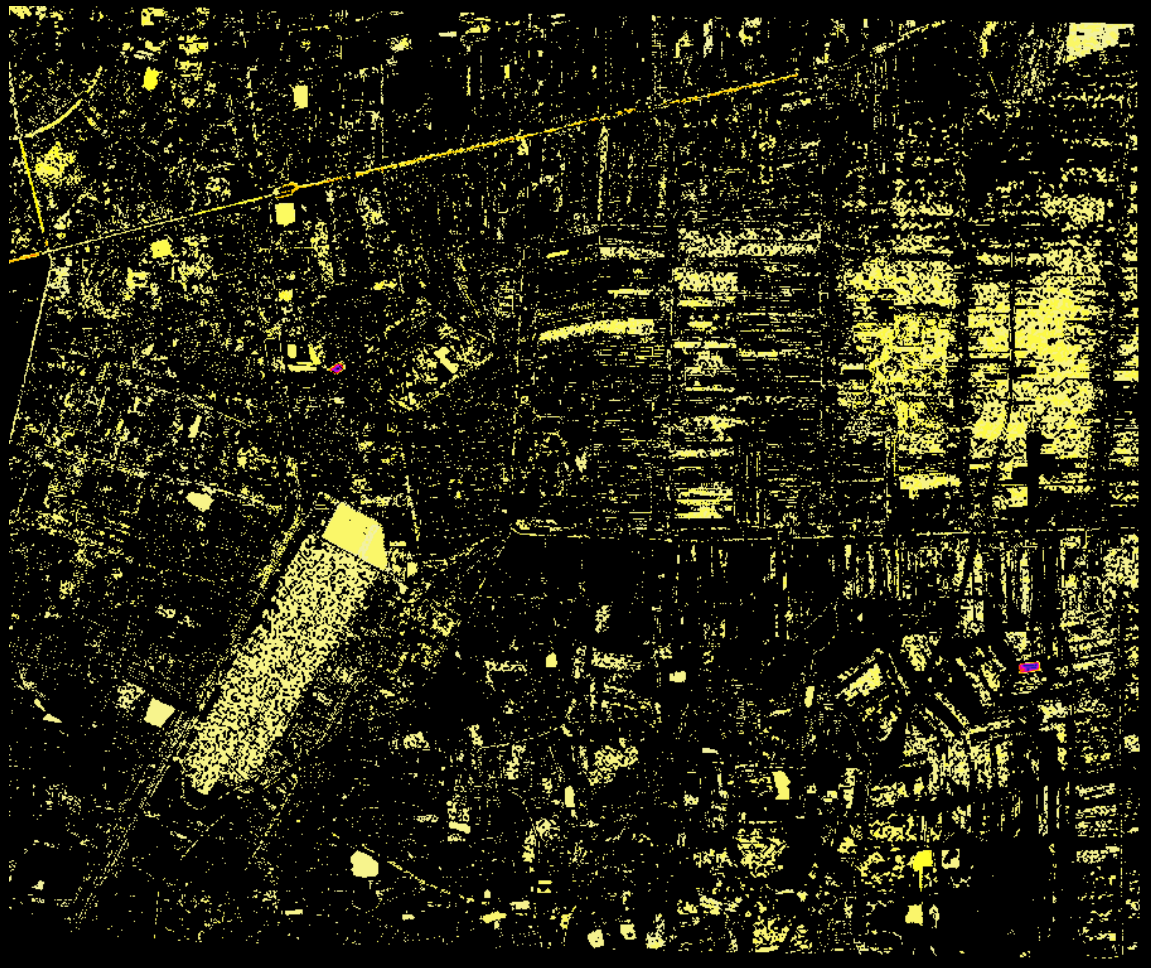
Class	Unlabeled	Border	Water	Land	Unlabeled	Border	Water	Land
Unlabeled	0	13156222	20395227	45959337	0.0%	16.5%	25.7%	57.8%
Border	0	223	0	0	0.0%	100.0%	0.0%	0.0%
Water	0	0	6847	338	0.0%	0.0%	95.3%	4.7%
Land	0	0	0	1044	0.0%	0.0%	0.0%	100.0%

Confusion matrix for 5th degree polynomial SVM for 8 features, run on hold-out scene acquired November 3, 2011. Overall classification accuracy: 96.0%.

Class	Unlabeled	Border	Water	Land	Unlabeled	Border	Water	Land
Unlabeled	0	25639043	12807455	22806048	0.0%	41.9%	20.9%	37.2%
Border	0	349	0	0	0.0%	100.0%	0.0%	0.0%
Water	0	0	2206	287	0.0%	0.0%	88.5%	11.5%
Land	0	0	3	3110	0.0%	0.0%	0.1%	99.9%

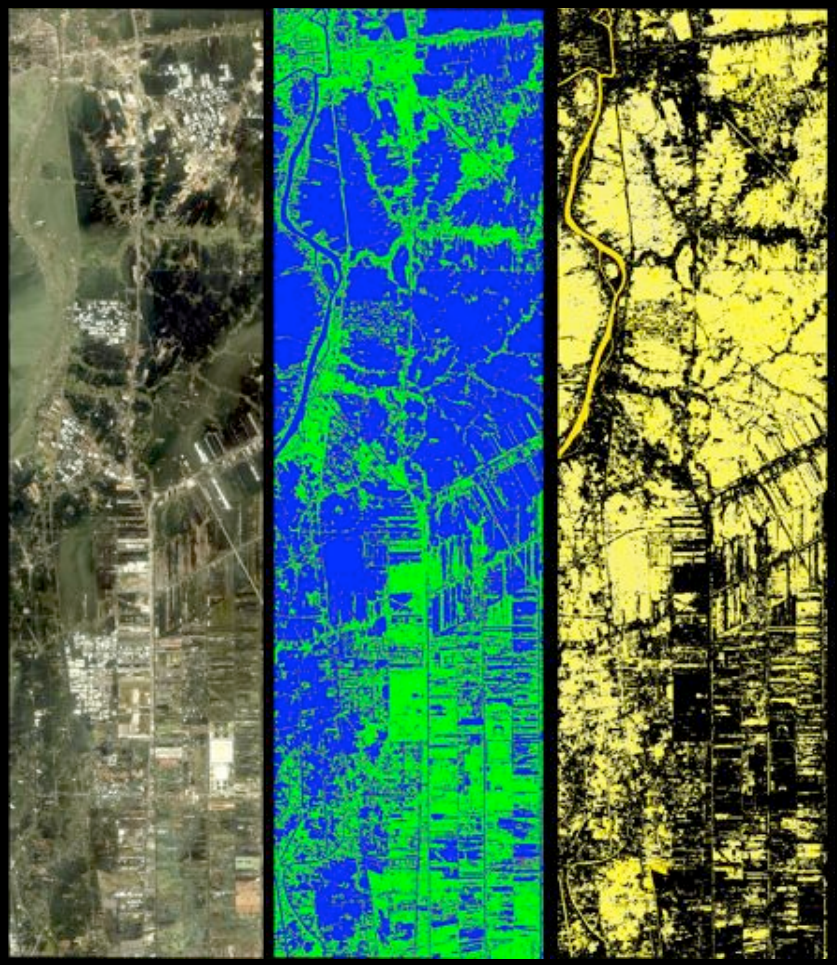
Confusion matrix for 5th degree polynomial SVM for 8 features, run for hold-out scene acquired November 8, 2011. Overall classification accuracy = 95.1%.

Water Volume Estimation



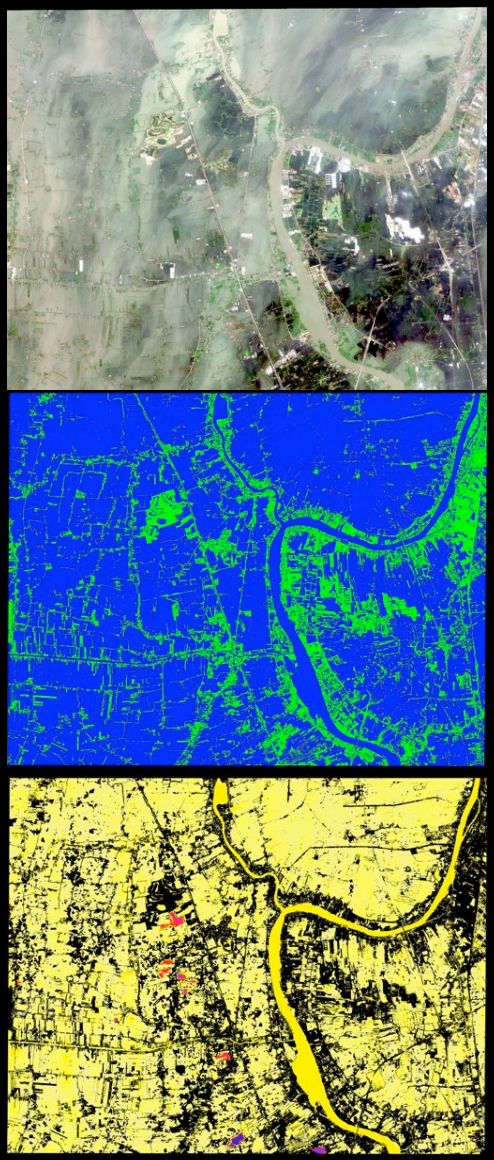
Resulting water depth map calculated using SVM-classified surface water extent map and DEM. Total water volume calculated: ~27,872,000 m^3; average flooded pixel depth: 0.64 m.

Ikonos-4, Geo-Eye

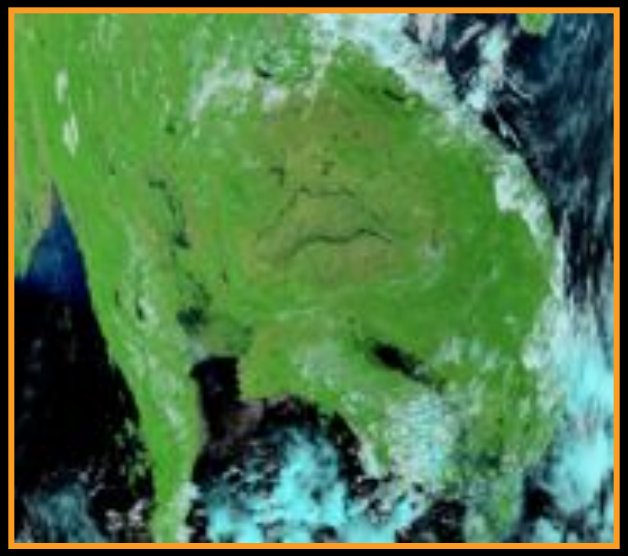


Ikonos RGB, SWE, depth

Geo-Eye
RGB
SWE
depth



Thailand Flood SensorWeb

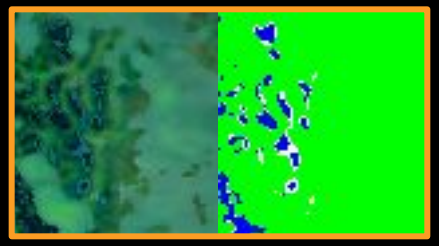


MODIS 28 Nov 2010 Imagery of Thailand Flooding (band 7-2-1)
Est. damage over $1.67B USD
[Thailand MCOT, CNN], Oct–Nov 2010

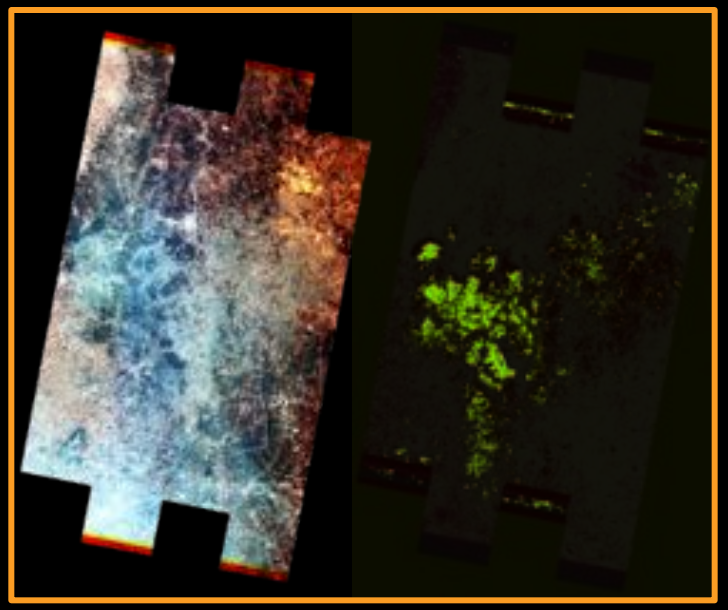
"The Thailand Flood SensorWeb provides a unique capability to detection, monitoring, response, and mitigation of flooding in Thailand"
Dr. Royol Chitadron, Director, HAII Thailand

S. Chien / JPL

- **Detect:** Pull 2x daily RAPIDFire subsetted MODIS data, support Vector Machine Learning (SVM) & band ratio methods of classifying gauging reaches against baseline dry scores
- **Respond:** Earth Observing 1 autonomously responds to acquire more detailed imagery
- **Product Generation & Delivery:** Data and flood products electronically delivered to Thailand Hydro Agro Informatics Institute (http://www.haii.or.th)



Detect:
(L) MODIS imagery of Bang Pla Ma from 20 Jan 2011
(R) Classified surface water extent from MODIS image



Respond → Generate → Deliver
(L) ALI imagery of Bang Pla Ma from 21 Jan 2011
(R) Classified surface water extent from ALI image

Thailand Flood Sensorweb in Operations

	2010: 6/2010-5/2011	2011: 6/2011-5/2012	2012: 6/2012-12/2012	Total per Instrument
MODIS (est.)	300	730	420	1450
EO-1/ALI	11	34	10	55
Worldview-2	0	55	32	87
IKONOS	0	5	5	10
Geo-Eye-1	0	3	3	6
Landsat-7/ETM	0	6	20	26
				Pointable:
Total Images	11	103	70	184

Integrating Aerial Assets
UAVSAR

For further information see [Doubleday, Lou, et al. Acta Future 2013]

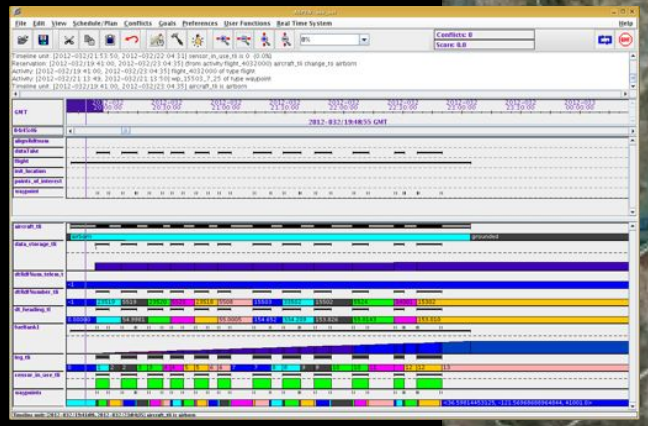
Aerial Assets

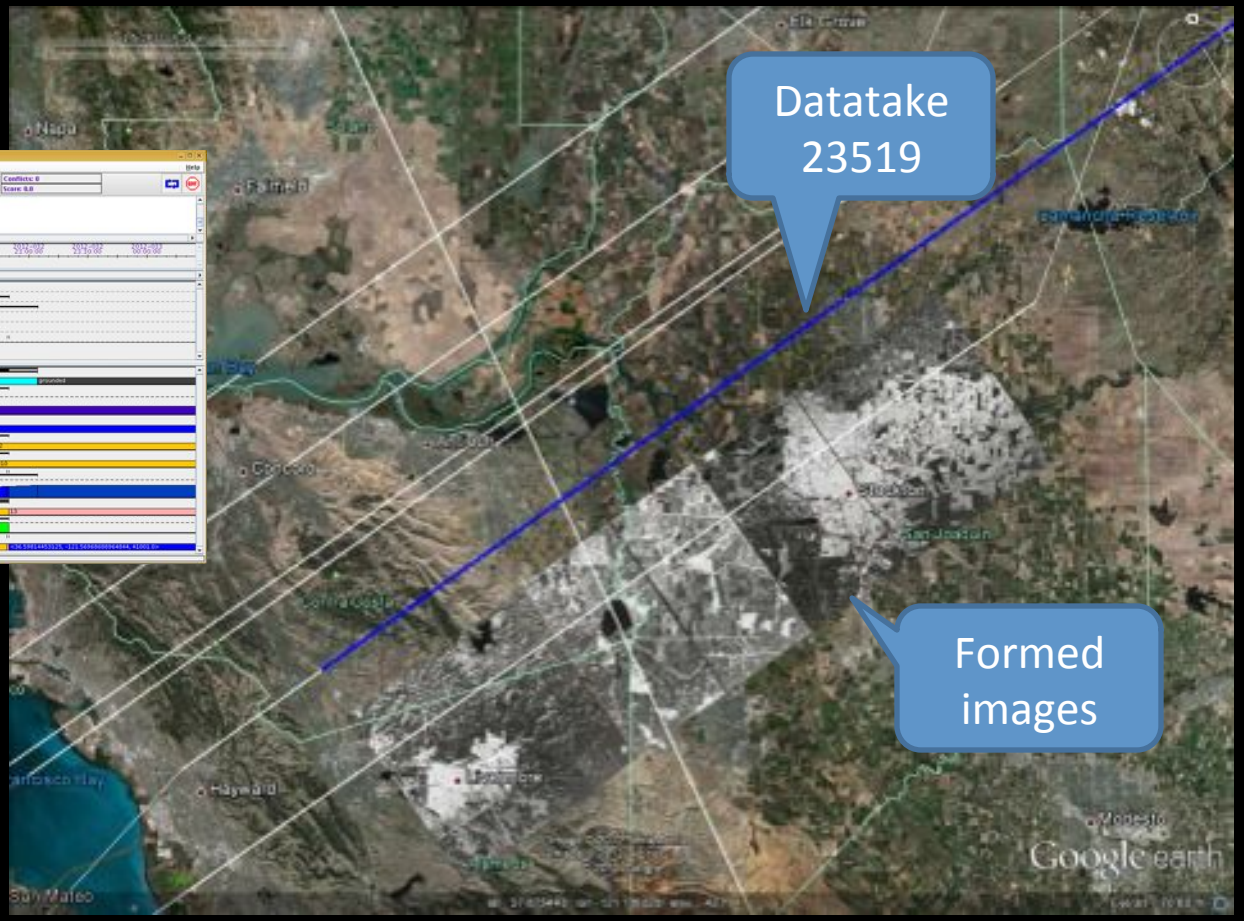
- Complementary to Space Assets
- Can Loiter
- Generally lesser spatial coverage
- Must pay per deployment cost

Algorithm	Applications	Notes
Soil moisture	Agriculture, Water resource management	Currently requires sparse vegetation; generalization of algorithms to variable/dense vegetation future work.
Surface water extent	Flood mitigation	Extensions to varied topography, rough waters, and smooth land are future work.
Repeat-pass disturbance	General	Requires expert/interpreter and prior imagery onboard.
Snow/ice vs land SVM classification	Transportation, Freeze-thaw monitoring	Vegetation can complicate classification.
Amplitude Correlation	Sea transportation, Glacial movement monitoring	Strong transportation application. Glacial studies would desire higher fidelity (sub-pixel motion, per pixel).

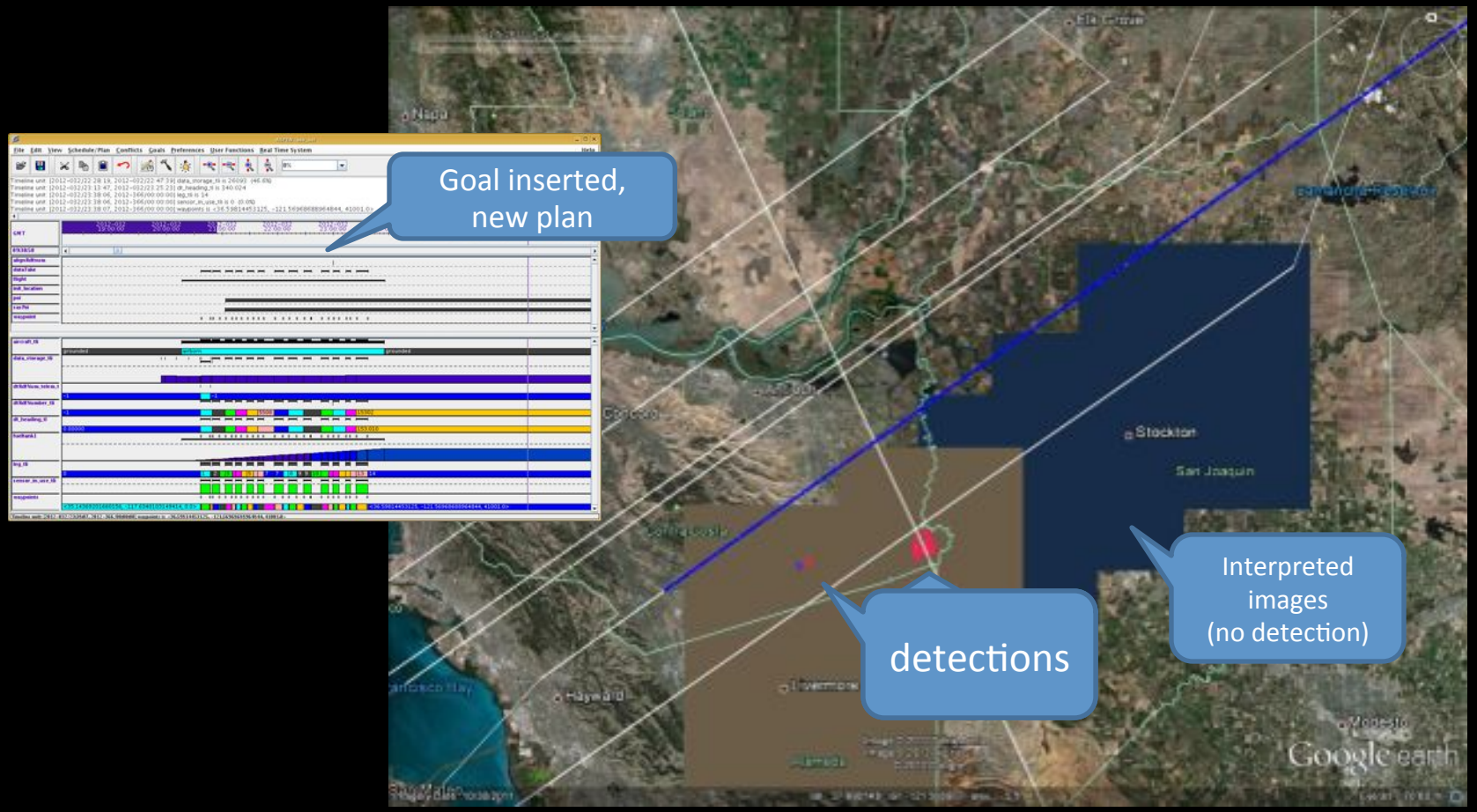
Algorithm	Applications	Notes
Soil moisture	Agriculture, Water resource management	Currently requires sparse vegetation; generalization of algorithms to variable/dense vegetation future work.
Surface water extent	Flood mitigation	Extensions to varied topography, rough waters, and smooth land are future work.
Repeat-pass disturbance	General	Requires expert/interpreter and prior imagery onboard.
Snow/ice vs land SVM classification	Transportation, Freeze-thaw monitoring	Vegetation can complicate classification.
Amplitude Correlation	Sea transportation, Glacial movement monitoring	Strong transportation application. Glacial studies would desire higher fidelity (sub-pixel motion, per pixel).

Images acquired



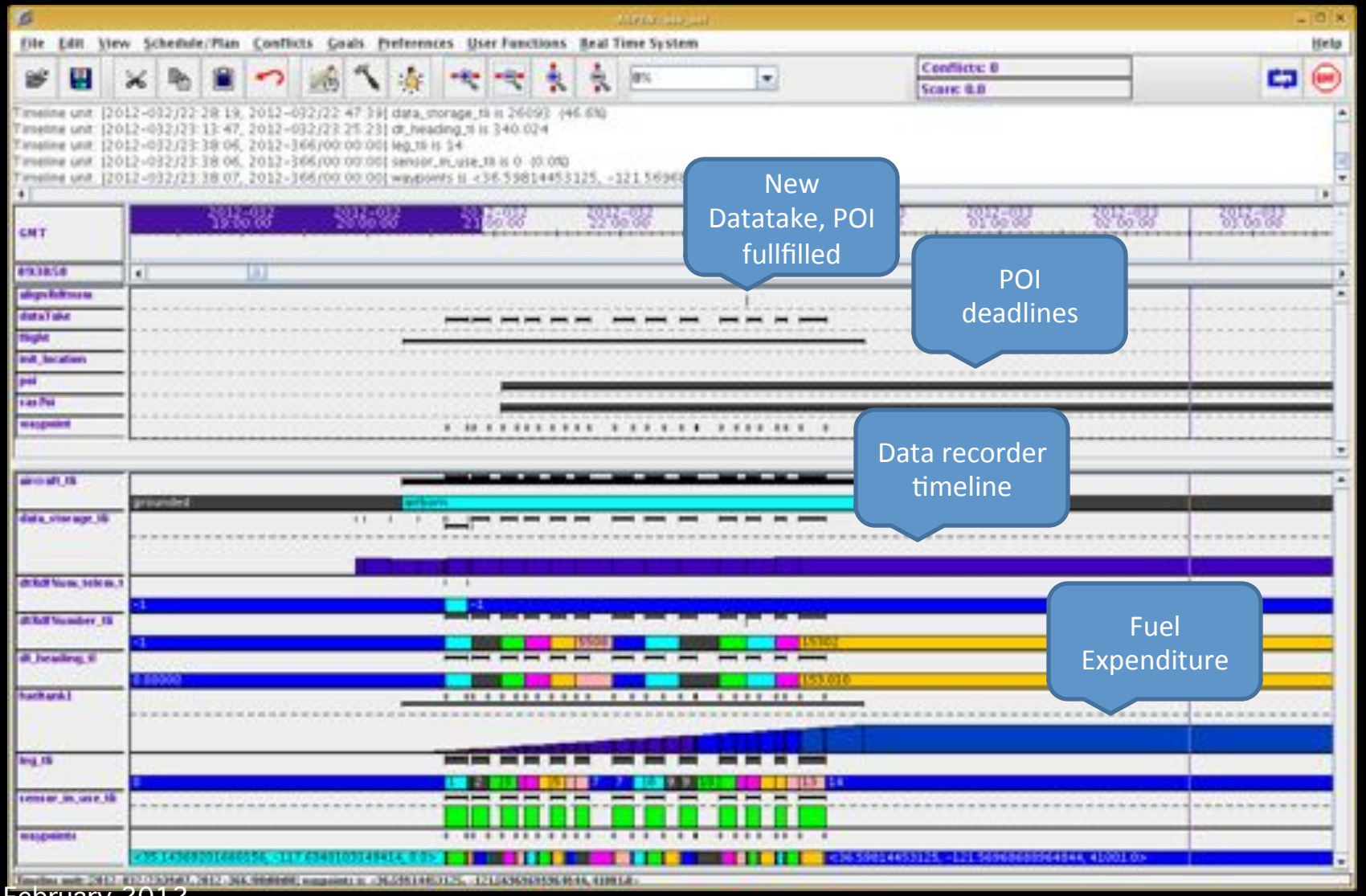


Images processed and alerts generated



February 2012

CASPER Replanning



Integration of UAVSAR into Sensorweb

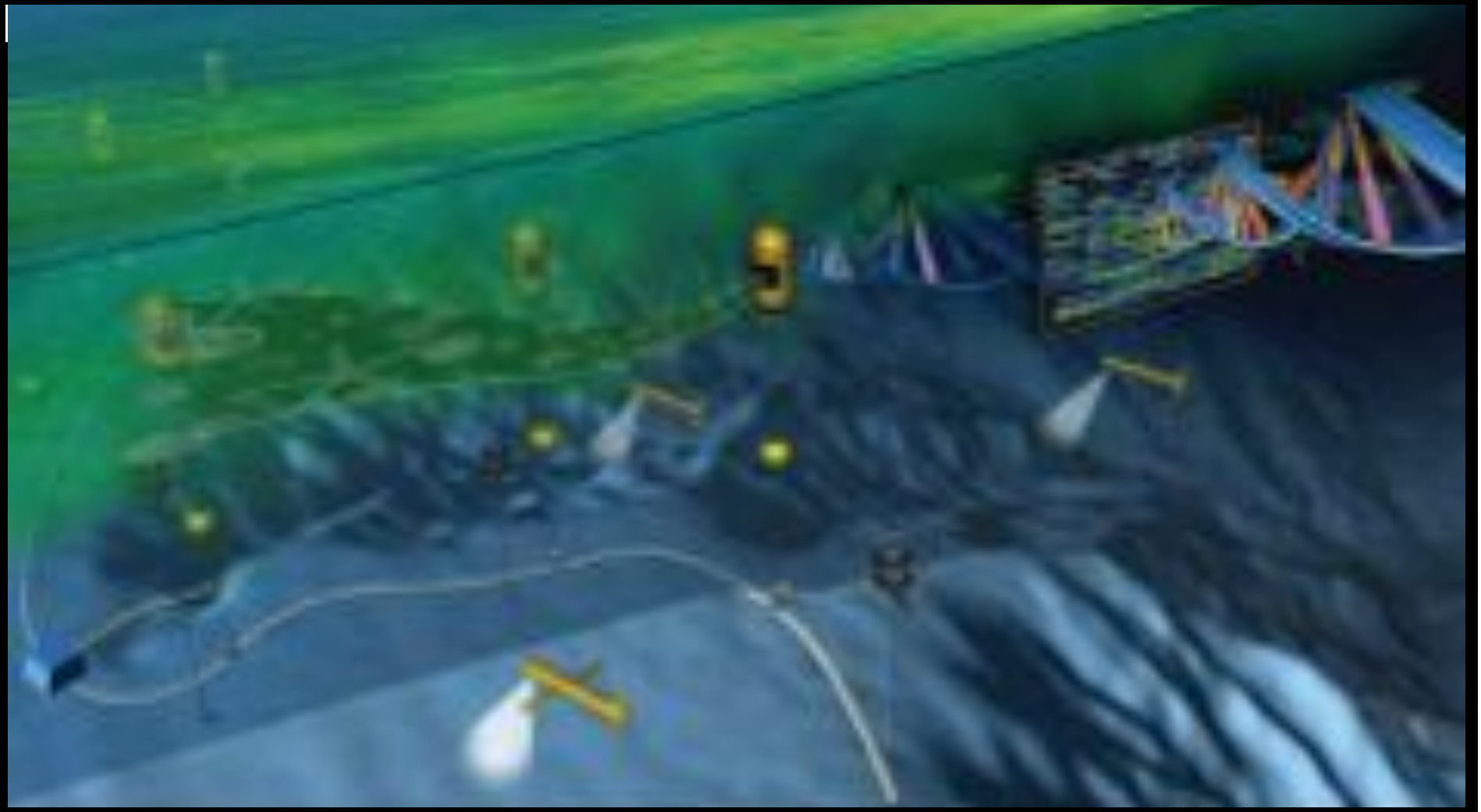
- Enables triggers from Ground → UAVSAR
- UAVSAR → Space
- Space → UAVSAR

- Used OpenGeospatial Consortium (OGC) web service standards (SWE)
  - Sensor Planning Service (SPS)
  - Sensor Alert Service (SAS)
  - Sensor Observation Service (SOS)

Ocean Sensorwebs

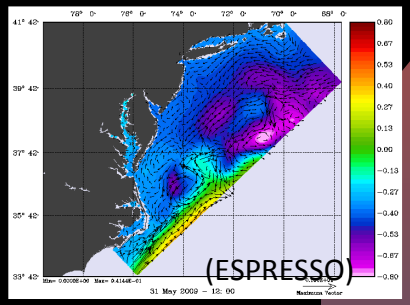
For further information see [Schofield et al. 2010 EOS, Wang et al. 2012 CR, Thompson et al. 2010 ICRA, Dahl et al. 2011 IROS]

Ocean Observatories Initiative



The Ocean Observatories Initiative

Ocean Models



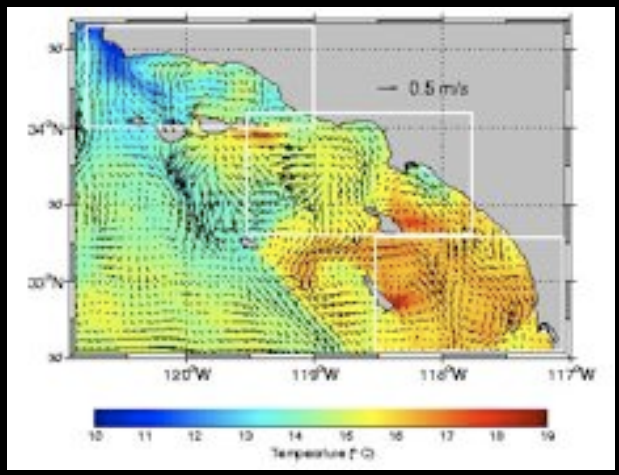
multimodal
model-driven
coodinated

CODAR

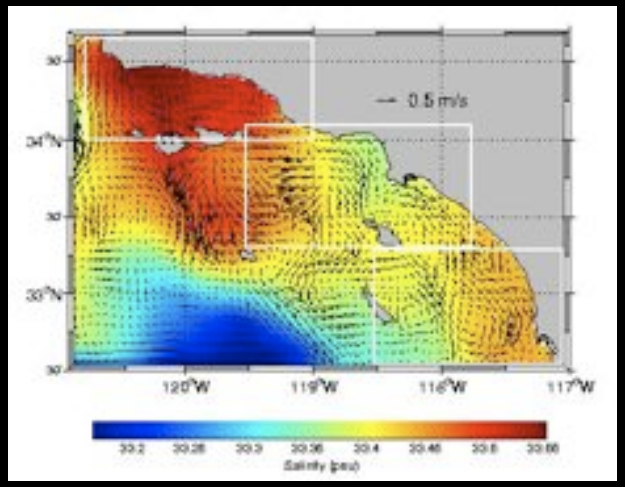
ROMS ocean model

- 4DVar assimilation and forecast
- Up to 1km horizontal resolution
- Variable depth resolution

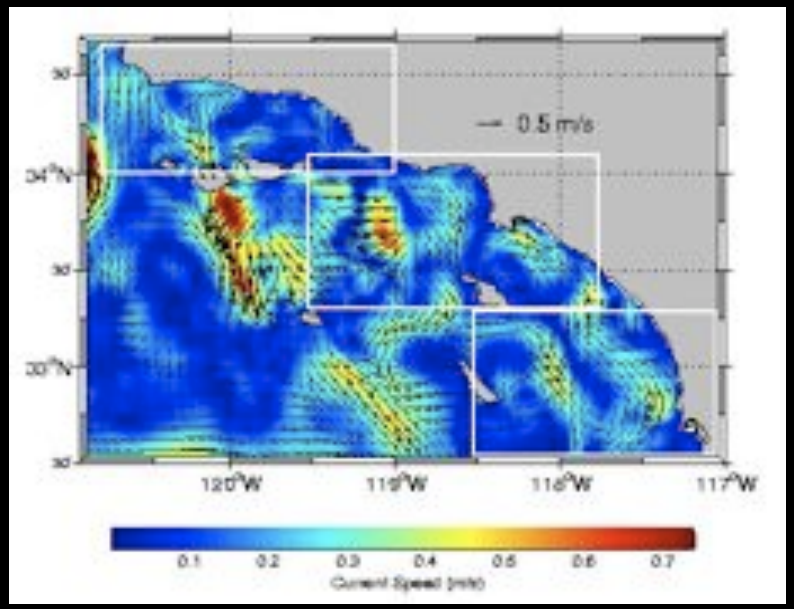
Temperature



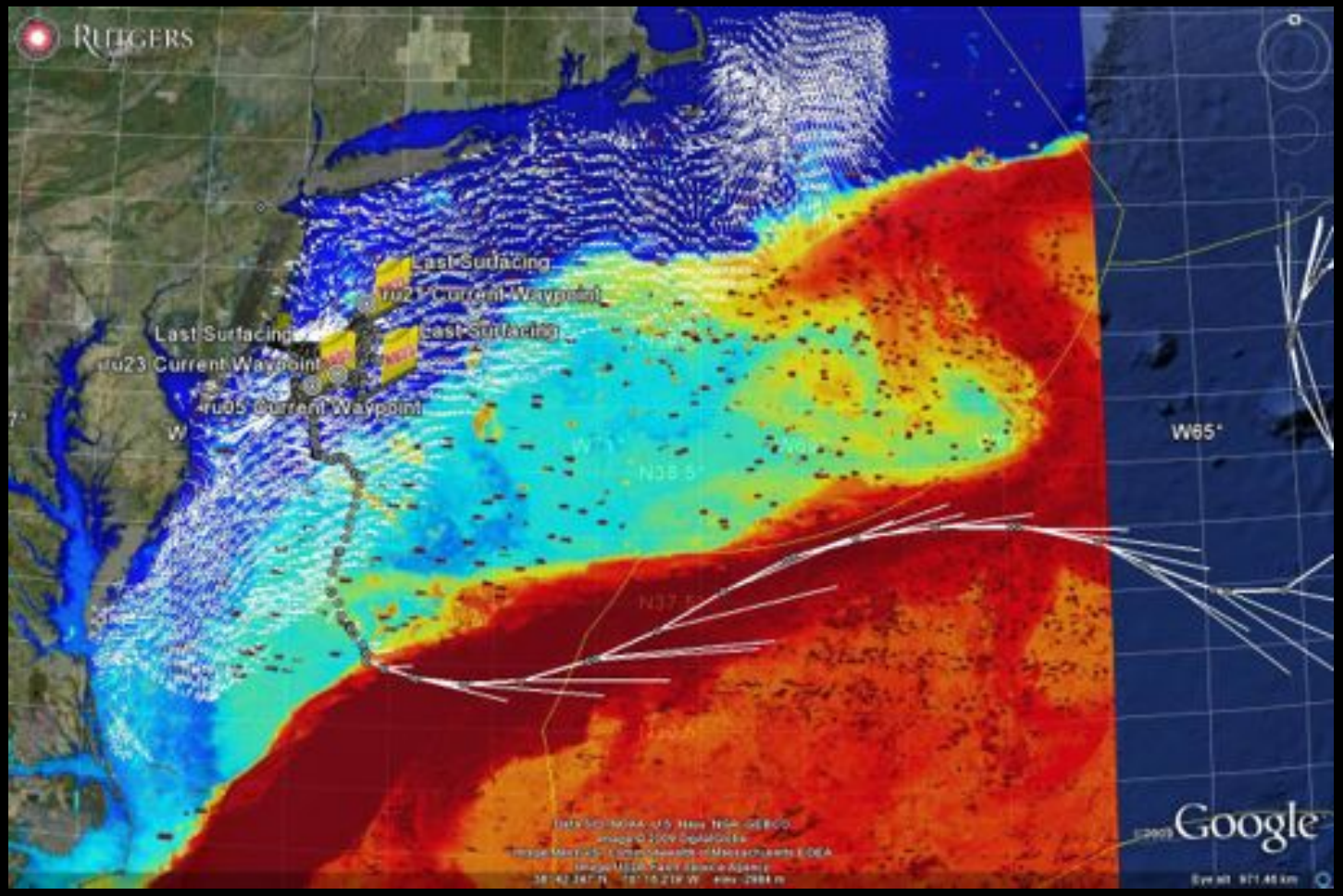
Salinity



Currents

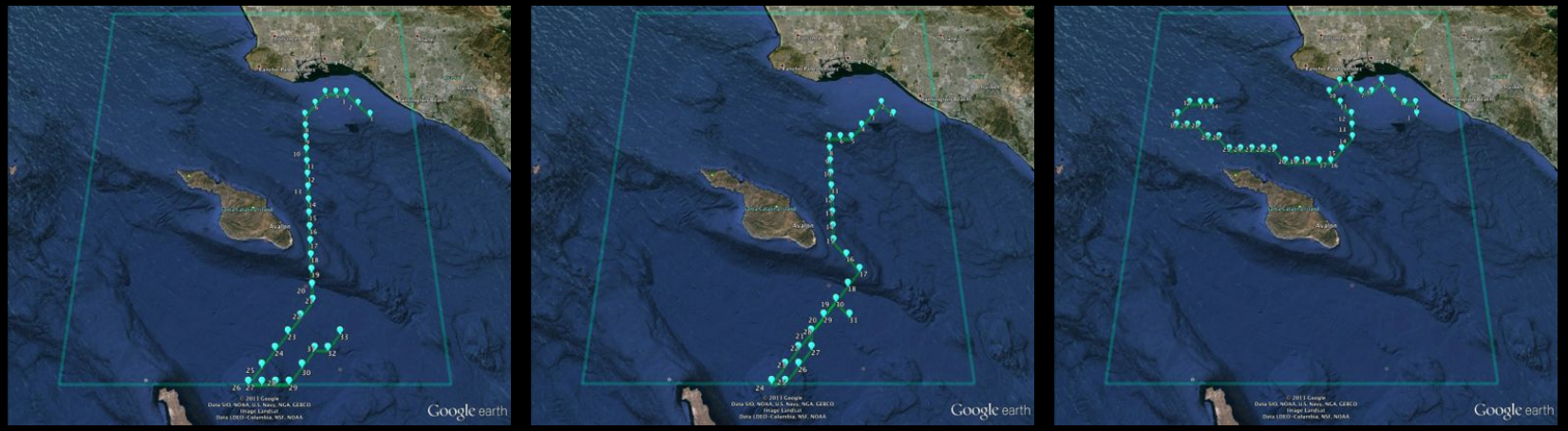


OOI OSSE MAB: (Nov 10-13 2009)



MAB 2009 Deployment

Model-driven sensing



Heuristic path planning using branch and bound for single AUV based on visiting ROMS grids with maximum uncertainty [Troesch et al. 2013].

Use ROMS uncertainty estimates + estimated covariances [Thompson et al. 2011]
→ direct sensing
→ fold new measurements into model
→ repeat

Conclusions

- Adaptive sensing is revolutionizing environmental monitoring –flooding, volcanology:
  - Automatic data interpretation: data → events
  - Autonomous response: local, global
  - Automatic alert generation; product generation
- Many of these technologies have been in use
  - Earth Observing Sensorweb 2004 – present 24/7
  - This above work has not delved into detailed modeling or spatiotemporal phenomena
  - These technologies are directly applicable to studying dynamic spatiotemporal phenomena: Oceanography