Airborne TIR Hyperspectral Imaging with High Spatial Resolution and Wide Area Coverage

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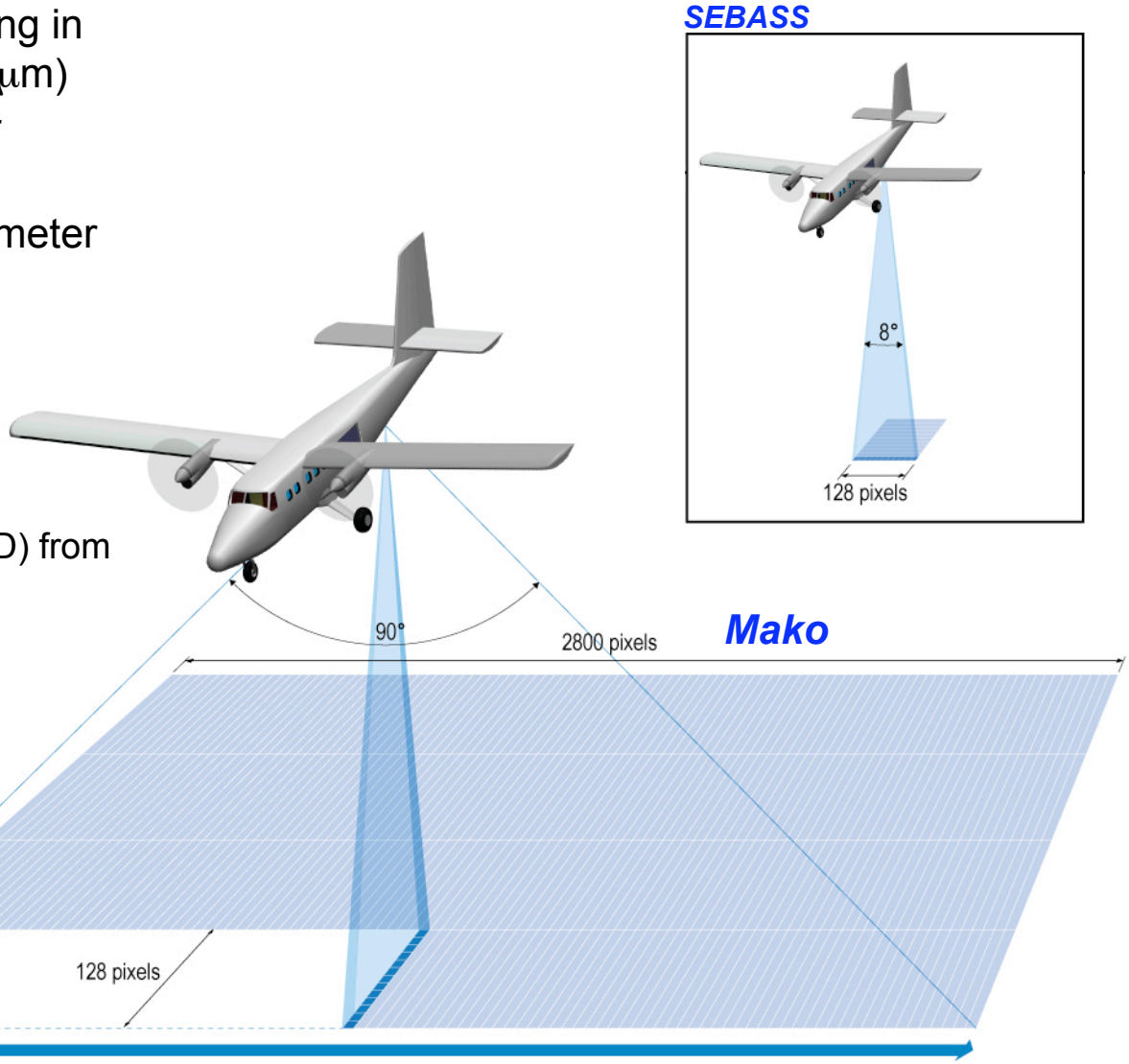
Mako: a New Thermal IR Imager

- Airborne spectral imager operating in the thermal infrared (7.8 to 13.4 μm)
  - *Deploys aboard Twin Otter aircraft*
- 128-band grating-based spectrometer
  - *0.044 μm per channel (or ~4 cm^{-1} resolution at 10 μm)*
- Large area coverage mode
  - *Scan to ± 40° around nadir*
    - 20 km^2 per minute (at 2-m GSD) from 12,500 ft (3.8 km) AGL
    - 8-minute duration datasets demonstrated
- Follow-on to SEBASS sensor
  - *Uses whiskbroom rather than pushbroom scanning*
  - *0.5 mrad pixel IFOV (vs. 1.0 mrad for SEBASS)*

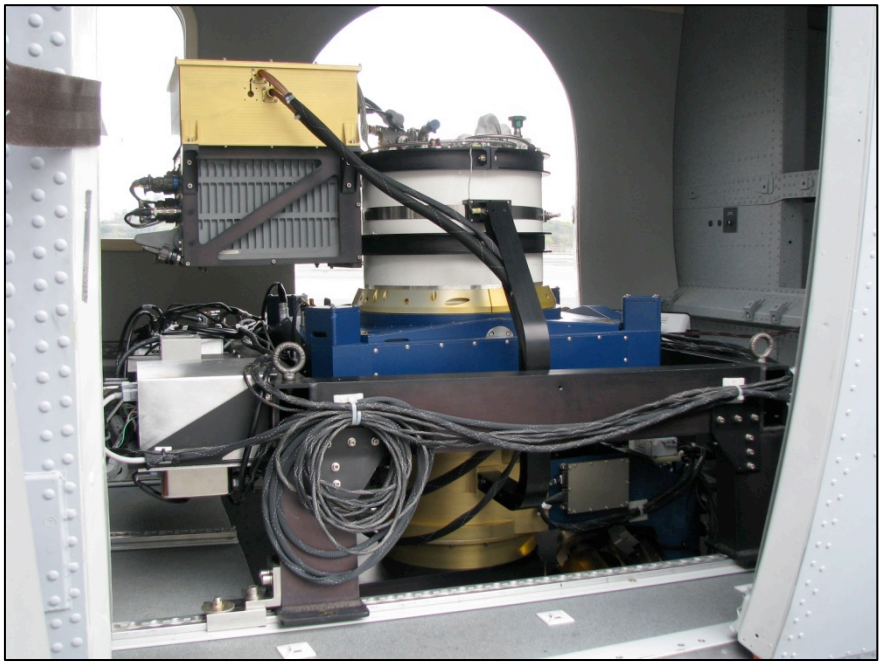


Sensor Details (cont.)

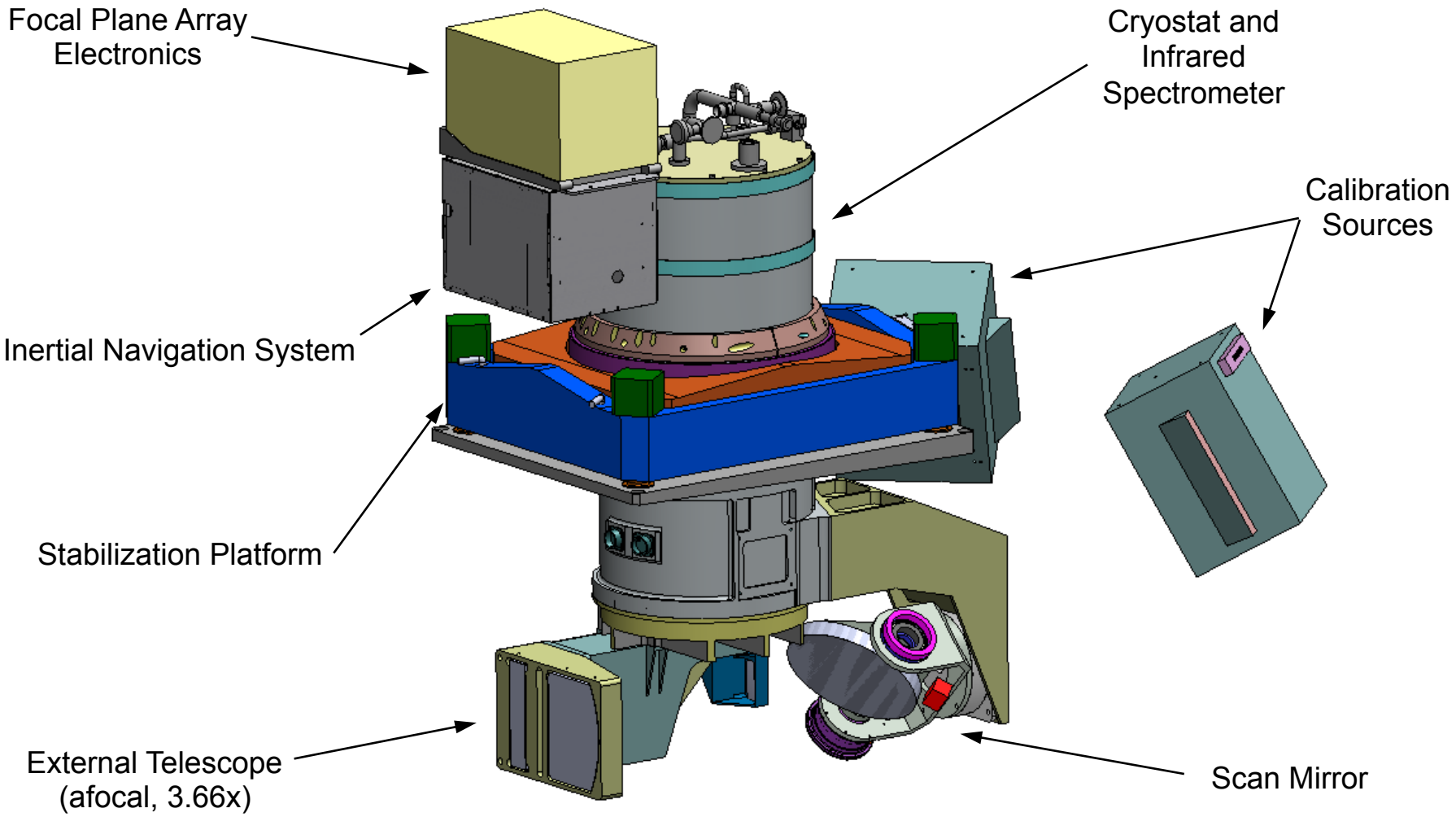
- Uses a commercial 3-axis stabilization mount
  - *Intergraph Z/I mount*
  - *High frequency jitter removed by physical vibration dampeners*
  - *Low frequency jitter removed by active control*
    - Stabilizes up to ±5° range in pitch and roll
  - *Up to ±12° yaw offset can be accommodated in Mako installation*

- Sensor attitude measured with Litton LN-100G INS and KVH DSP-3000 fiber-optic gyros (x3)
  - *Estimated pixel geolocation uncertainty is <10 meters from 12,000 ft AGL*
    - With separate differential GPS

- Gimbal mirror pitch control provides additional capability
  - *Bi-directional whisking*
  - *High-sensitivity (low area coverage) scans ("stare" mode)*



Sensor Details



Spectrometer Details

- *Mako* uses a DRS Si:As Blocked Impurity Band 128x128 FPA
  - *75 μm pixels*
  - *Cooled to 10K using LHe*
  - *99.93% operable*
  - *4 kHz max. frame rate (Mako currently at 800 Hz); 16 output taps*

- Spectrometer based on Dyson lens and concave grating
  - *Low distortions ("smile" and "keystone") at fast f-numbers*
    - *Mako* is an f/1.25 system

- Cooled optics (LHe blow-off) for improved sensitivity and increased dynamic range
  - *48-hour dewar hold time*

Quickbird - True Color Image

Urban Mapping: Los Angeles

Whisk Footprints

Image Courtesy:
Digital Globe - 06/18/2009
Universal Transverse Mercator Projection
Zone 11 - North - WGS84 Datum/Spheroid

0 0.25 0.5 1 Miles

Latitude / Longitude Graticule

MAKO 23 WHISK MOSAIC - PRIMARY COLLECTION

12k ft. AGL - ~2m GSD
El Segundo, CA - 09/15/2010
Flat Field Corrected - 10.6 μm Thermal Band

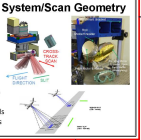
MAKO Overview

- 3 year corporate IR&D
- Highly capable LWIR HSI airborne sensor
- Si:As array for best operability
  - *DRS 128x128x75μm pixel 16.4.3MHz outputs = 4000Hz maximum frame rate*
  - *10K operating temperature == liquid helium cryostat*
- Maximize optical throughput
  - *At fast f/ratio (f/1.25) Dyson spectrometer is best for image quality & distortion*
  - *128 Spectral bands 7.8-13.4μm*
  - *128 x 1m GSD from 6000 ft AGL*
- Agile pointing system
  - *Extra(~16x)signal can be allocated between area coverage and improved S/N*

MAKO Twin Otter Flight Configuration

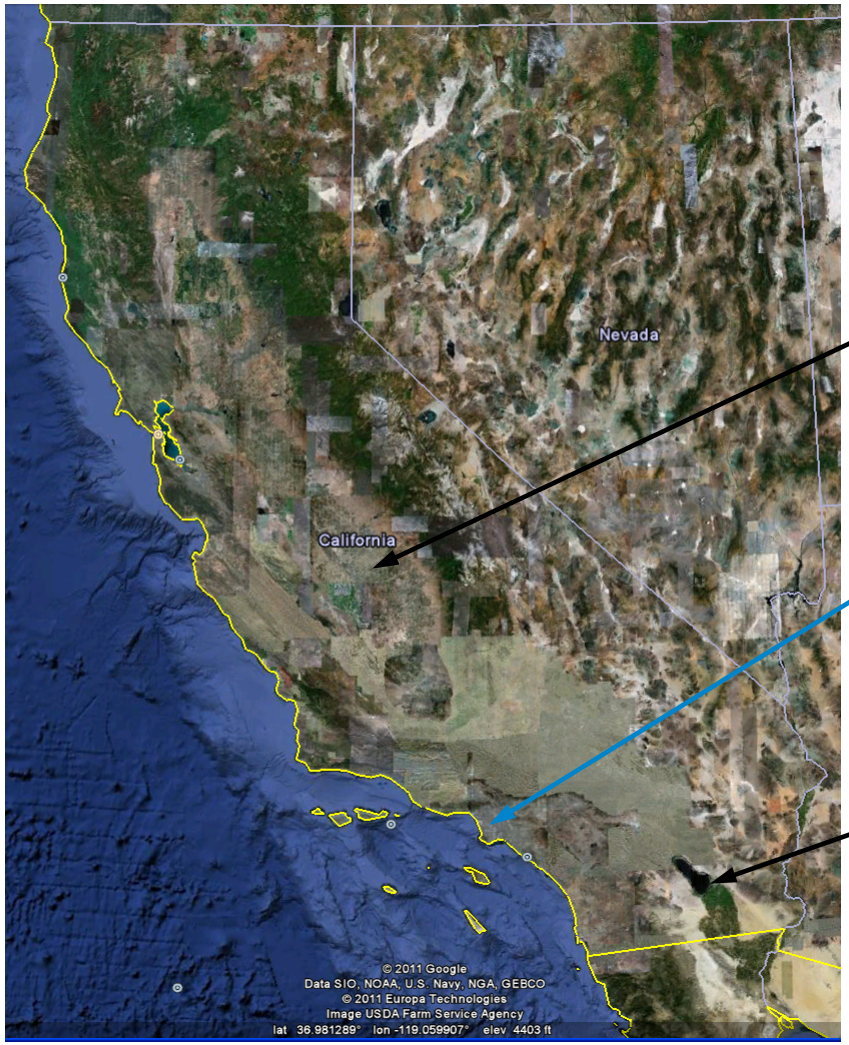
MAKO Pointing System/Scan Geometry

- ±45° X-track (Roll)
- ±10° In-track (Pitch)
- Nominal Whisk Scan 25°/sec in Roll ±45° =3.6sec
- 0.55sec Flyback (Roll)
- Pre-programmed Rolls To View Cal Blackbodies



UTM Easting and Northing Grid

Mako Science Flights



San Joaquin Valley

(Home base in Los Angeles)

Salton Sea Geothermal Field (SSGF)

(*Google Earth*)

SSGF – SE shore of Salton Sea, Background Image

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SSGF – *Mako* Thermal Radiance Overlay (1-m GSD)

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SSGF – Thermal Radiance and Ammonia Retrievals

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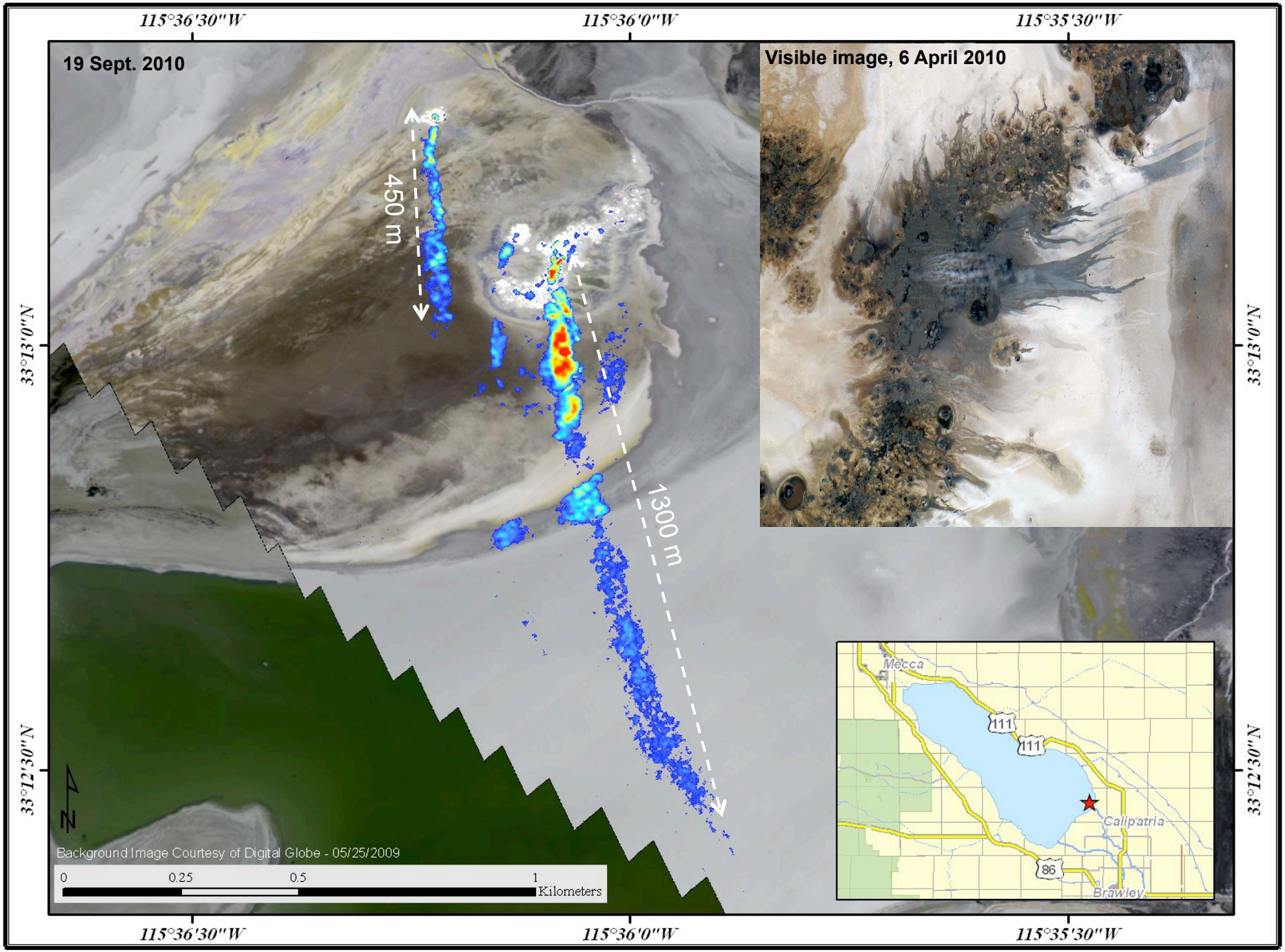
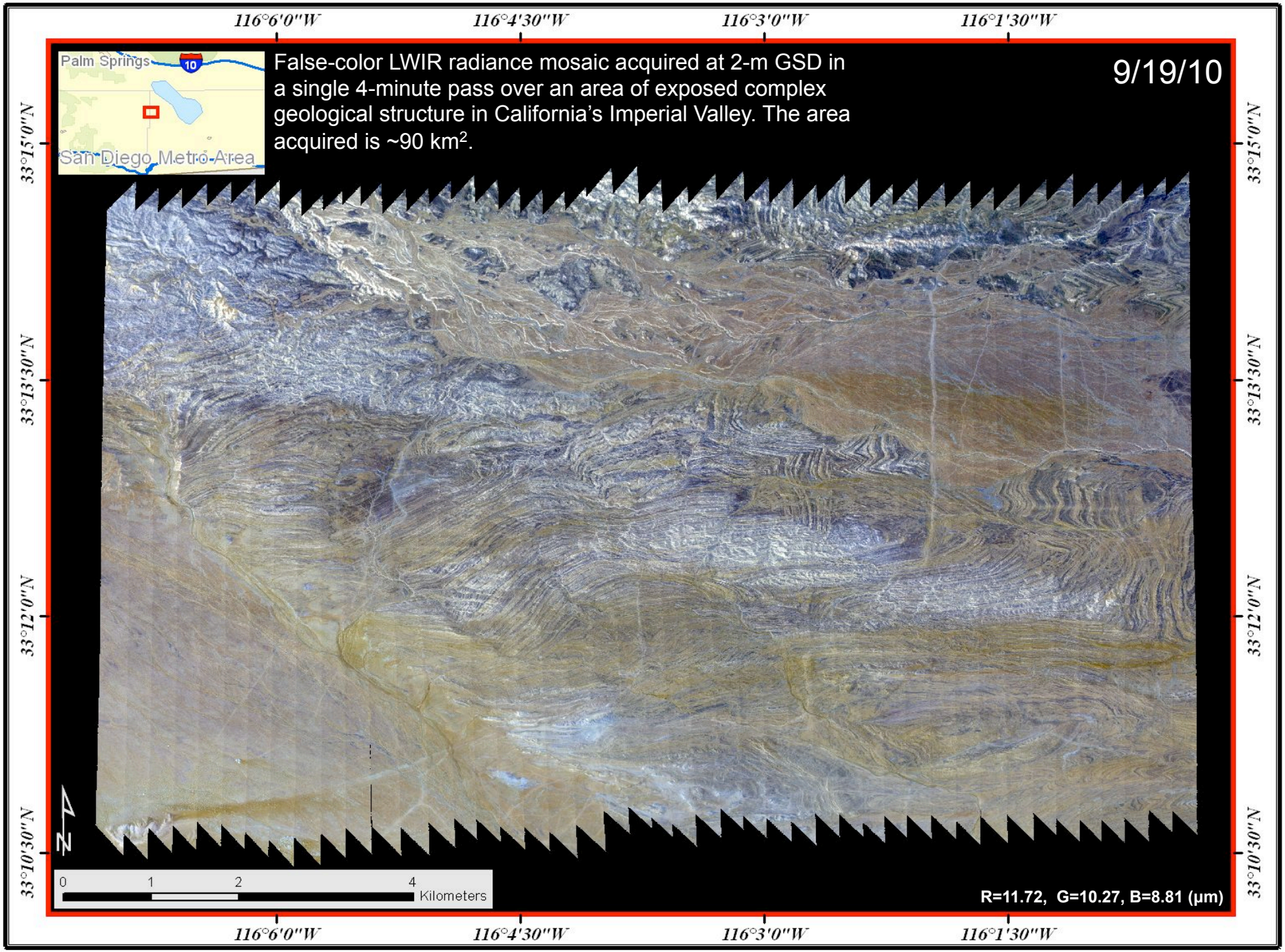

115°36'30"W
115°36'0"W
115°35'30"W
33°13'0"N
33°12'30"N
19 Sept. 2010
450 m
1300 m
Visible image, 6 April 2010
Mecca
111
111
Calipatria
86
Brawley
N
Background Image Courtesy of Digital Globe - 05/25/2009
0
0.25
0.5
1
Kilometers

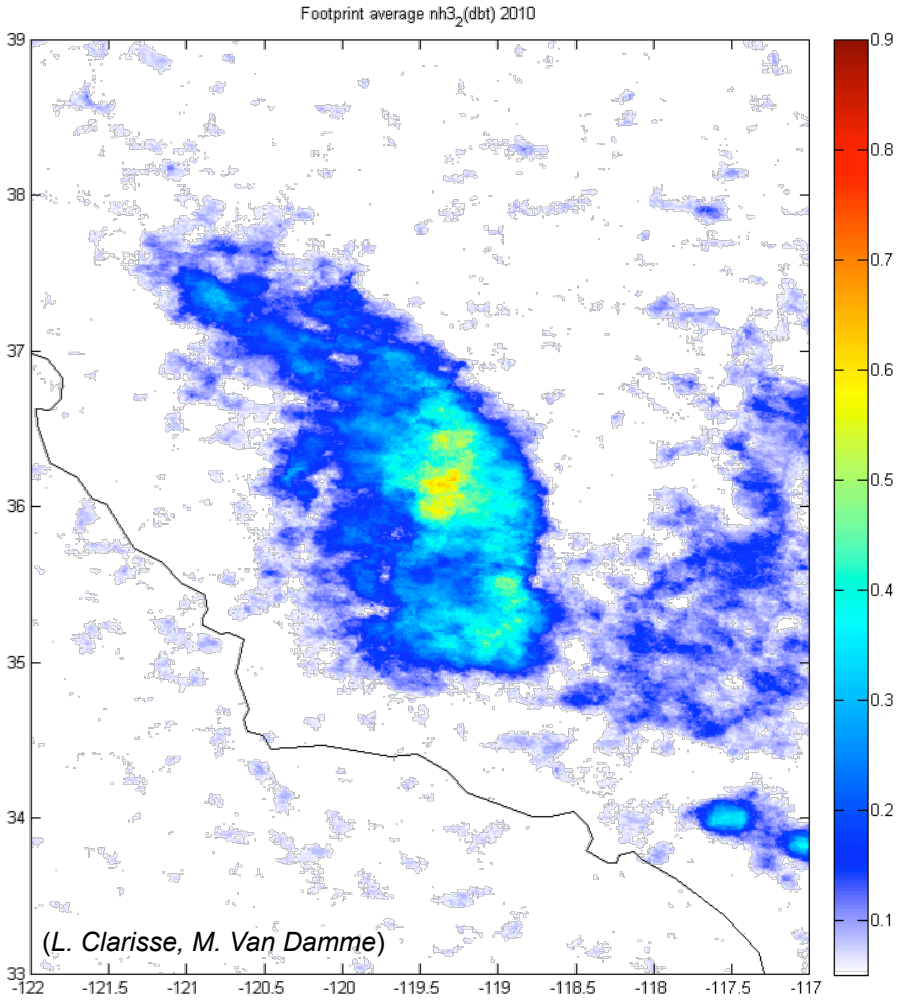

116°6'0"W
116°4'30"W
116°3'0"W
116°1'30"W
33°15'0"N
33°13'30"N
33°12'0"N
33°10'30"N
Palm Springs
10
San Diego Metro Area
False-color LWIR radiance mosaic acquired at 2-m GSD in a single 4-minute pass over an area of exposed complex geological structure in California's Imperial Valley. The area acquired is ~90 km².
9/19/10
N
0
1
2
4
Kilometers
R=11.72, G=10.27, B=8.81 (µm)

Agricultural Ammonia in the San Joaquin Valley

- *Mako* was flown over California's Central Valley on 17 Sept. 2010
- Flights were conducted in Tulare and Kings Counties primarily between the towns of Visalia and Delano
- Altitude was 3.8 km AGL → 2-m GSD
- Collections coordinated with overflights of the European IASI (Infrared Atmospheric Sounding Interferometer) sensor aboard Europe's MetOp-A
- Integrated ammonia column densities in the dairy farm regions near Visalia varied between 25 and 45 ppm-meters
- The airborne data clearly showed prominent plumes of ammonia emanating from some of the dairy facilities

This work being done in collaboration with the IASI team based at *l'Université Libre de Bruxelles* in Belgium

IASI annual average for 2010



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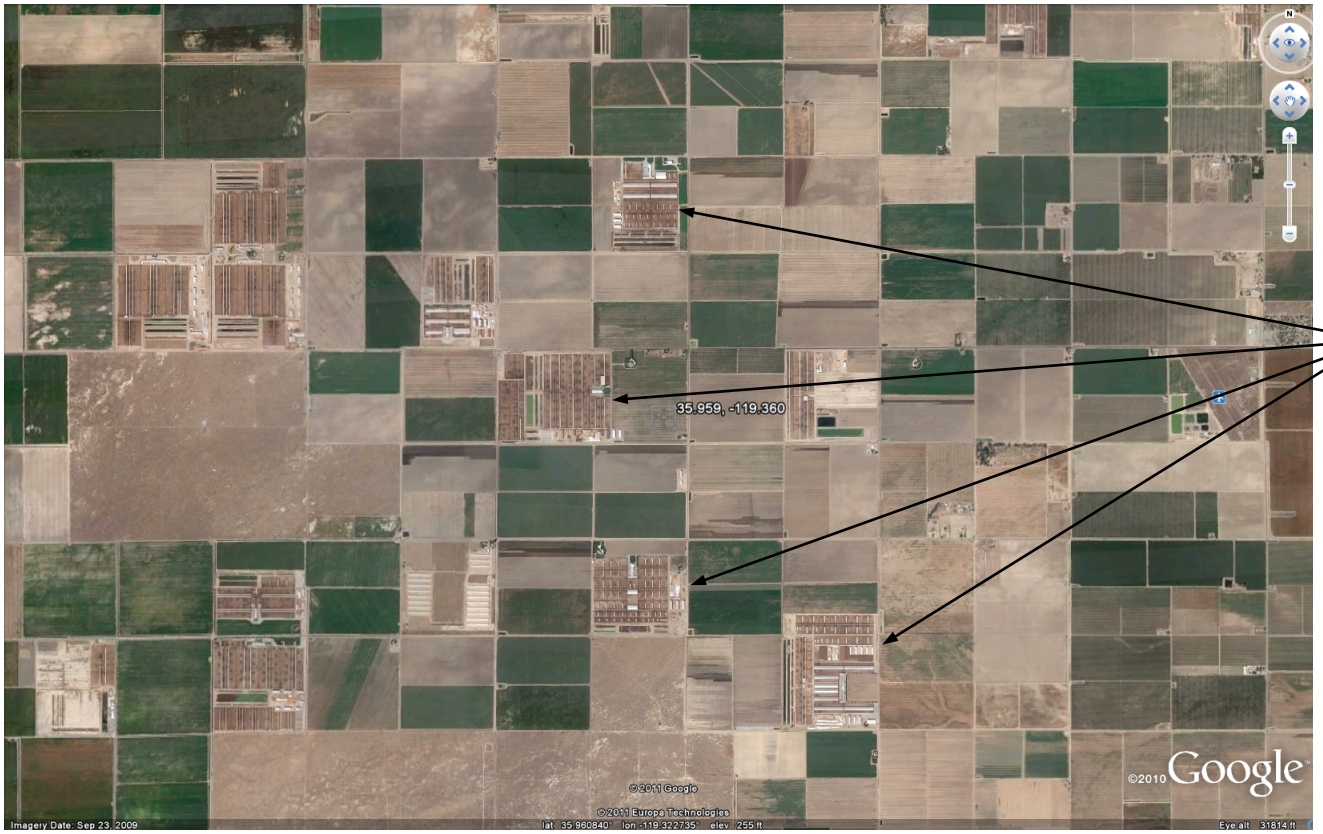
Google Earth Image for Flight CV01



Dairy farms

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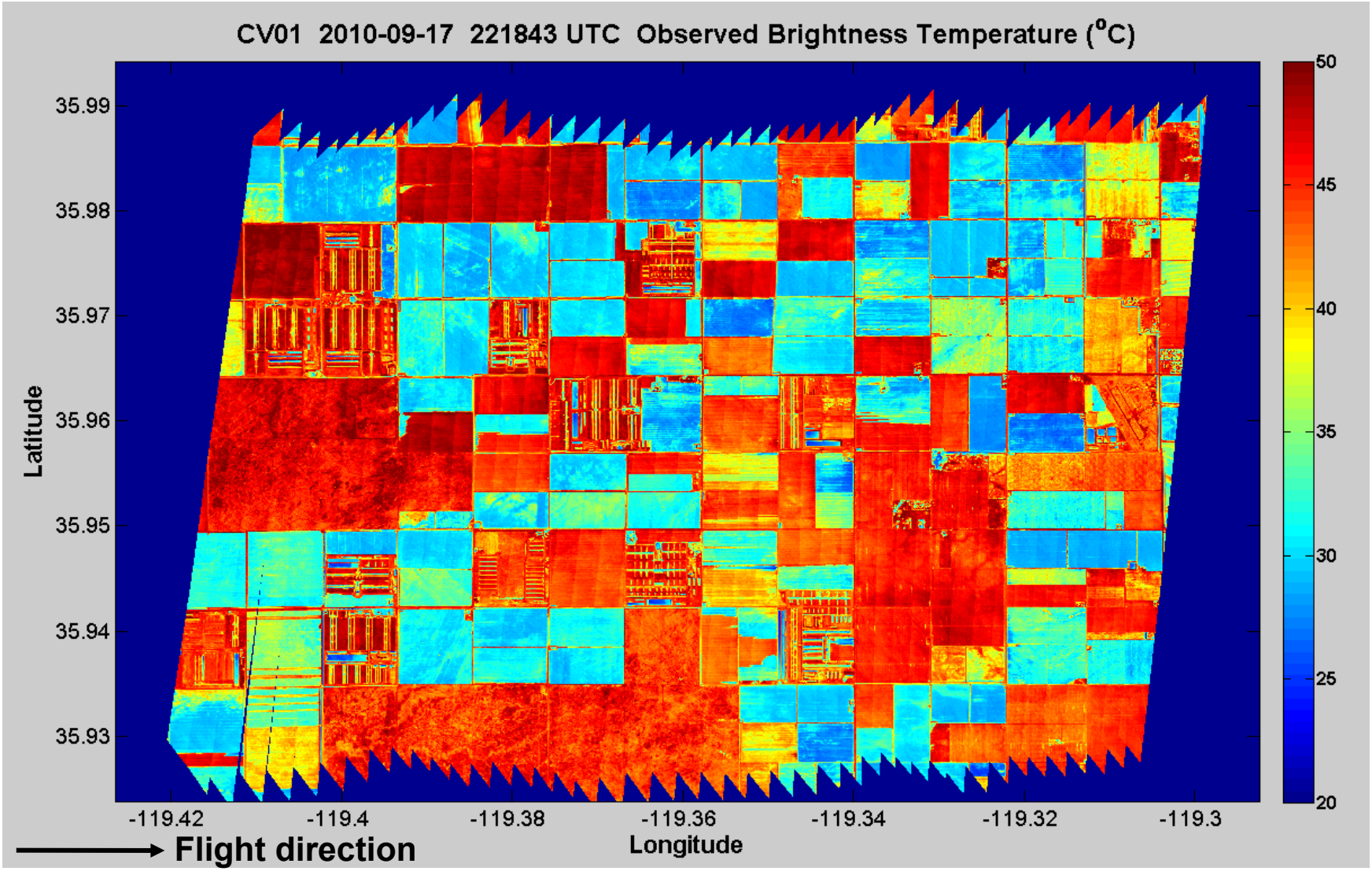
CV01 – Brightness Temperature Map



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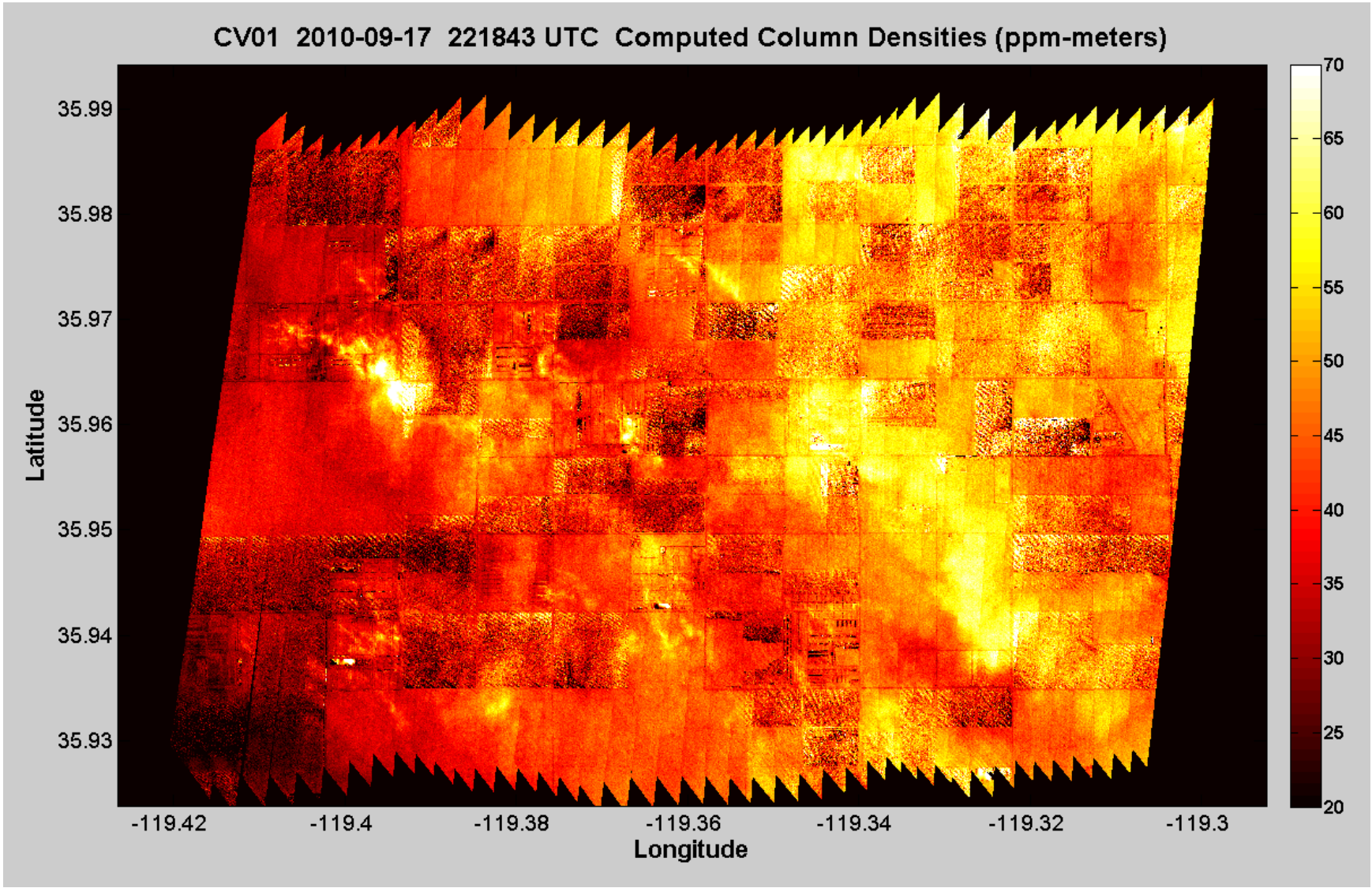
CV01 – Computed Column Density Map



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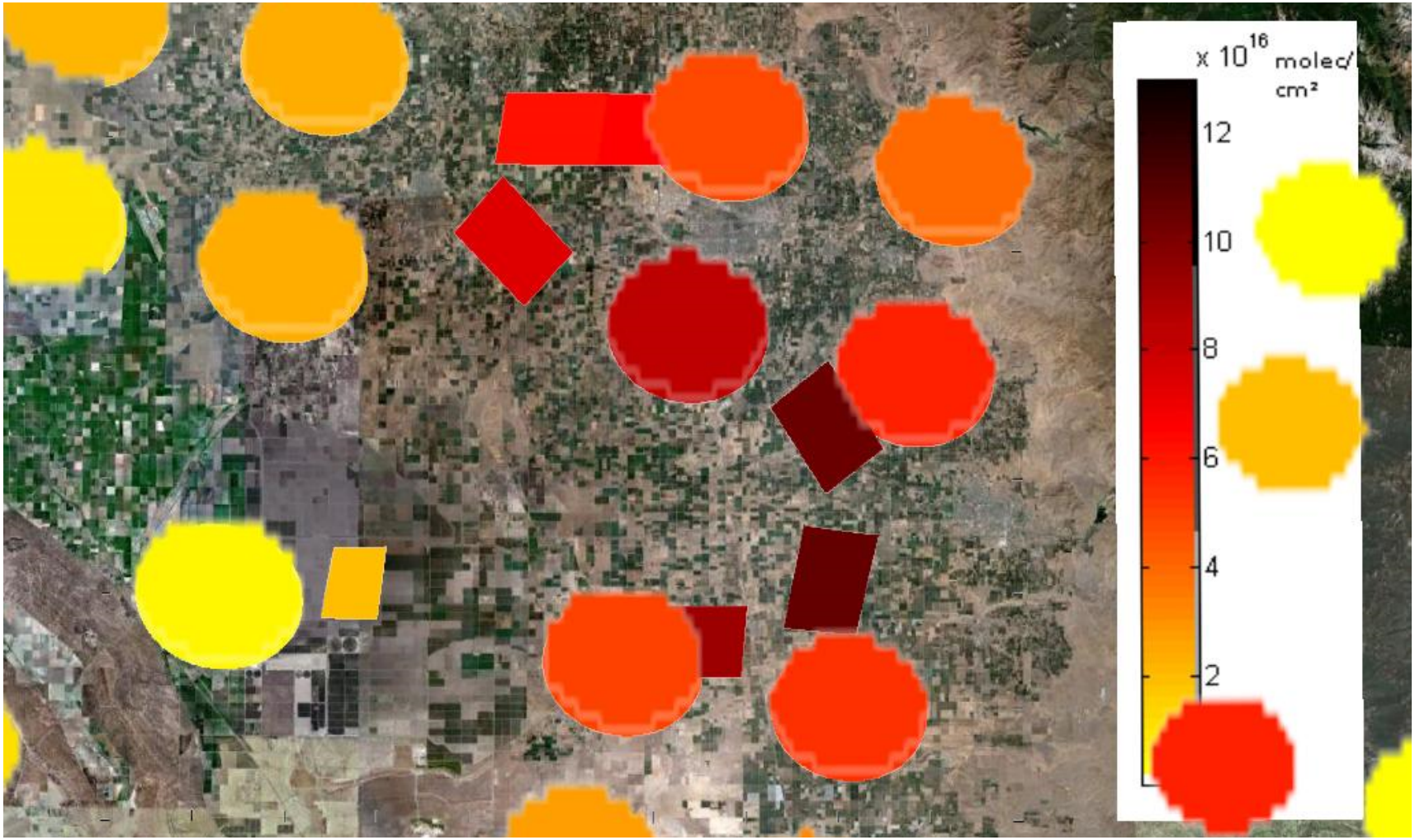
Regional comparison between IASI and *Mako* NH_3



(*L. Clarisse, M. Van Damme*)

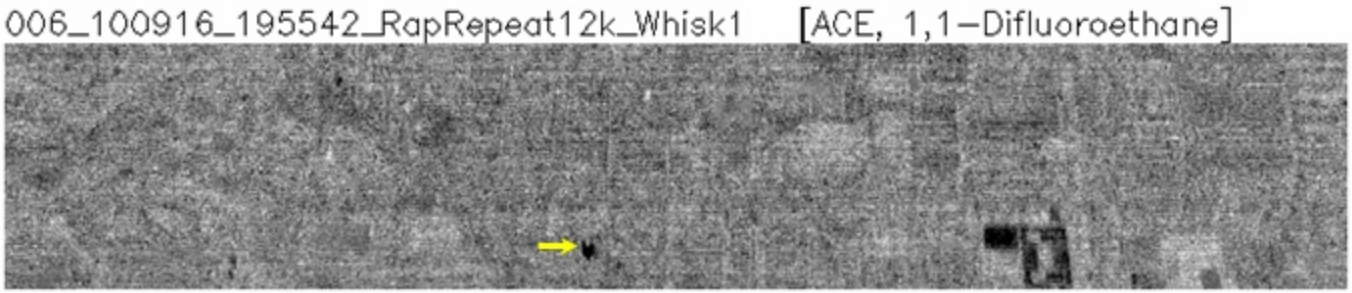
IASI: Polka dots
Mako: Parallelograms

09/16/2010 19:55:42

Thermal image

Plume tracking from 12 kft (3.8 km) AGL (GSD 2 m)

200 m



ACE filter

Continuous tracking of controlled tracer release

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Summary & Future Plans

- A new high-performance thermal infrared spectral imaging sensor has successfully completed its inaugural flights
- Flights over California's Imperial and San Joaquin Valleys have demonstrated the utility of large area coverage
- Modifications ongoing to improve the frame rate and sensitivity
  - *Current NEΔT is ~0.1 K at 10 μm*
- *Mako* is available to participate in field studies

Acknowledgements

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