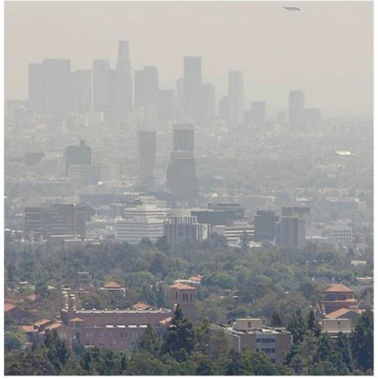



MAIA

Spectropolarimetric Measurements from the Multi-Angle Imager for Aerosols: From Climate to Air Quality



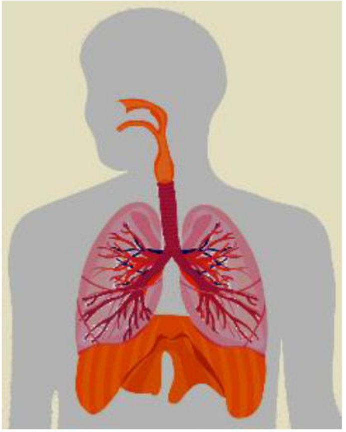
Michael J. Garay, Olga V. Kalashnikova, and David J. Diner

10th Anniversary Yoram Kaufman Memorial Symposium
NASA GSFC, Greenbelt, MD

21 June 2016

What are we measuring and why?

MAIA maps airborne coarse, fine, sulfate, nitrate, organic carbon, black carbon, and dust particles, and assesses their impacts on human health.



Coarse particles irritate and inflame our respiratory systems. **Fine** particles penetrate deep into our lungs and carry toxins into our bloodstreams.

#1 risk
Ranking of PM as an environmental risk factor

3 million
Annual number of deaths due to outdoor PM

(Source: Global Burden of Disease)

Airborne **particulate matter (PM)** is a well-known cause of cardiovascular and respiratory diseases, heart attacks, low birth weight, lung cancer, and premature death. However, the relative toxicity of specific **PM types** is poorly understood.

International science policy and government organizations have stressed the need to acquire this knowledge. Primary motivations include improved health outcomes, streamlined regulations, reduced societal costs, and **saved lives**.

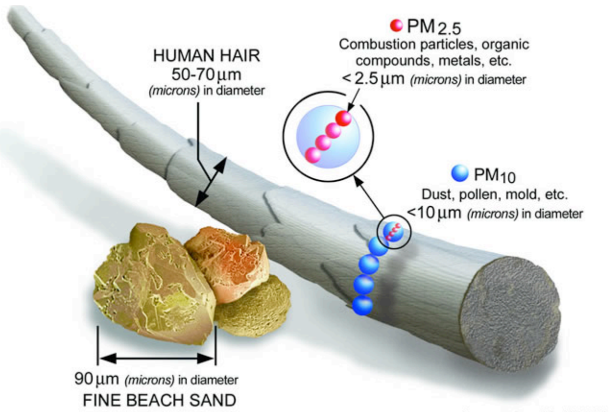
Science Questions

For which PM types:

Q1: Is maternal exposure linked to adverse birth outcomes?

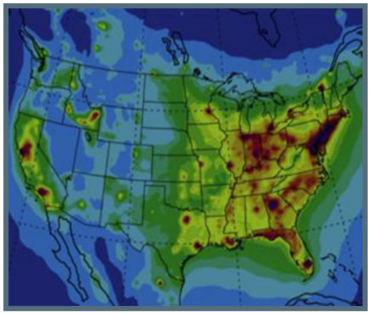
Q2: Is short-term exposure linked to illness and premature death?

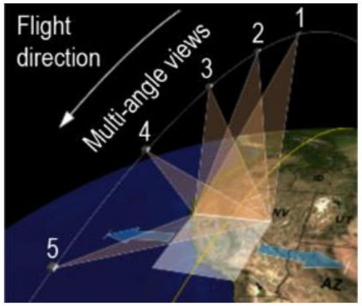
Q3: Is chronic exposure linked to cardiovascular and respiratory disease?

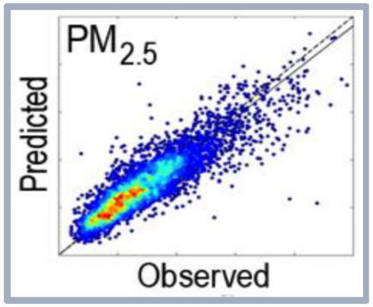


How are we measuring and what will we do with the data?

MAIA's spaceborne observations of PM concentrations in major cities around the globe wield enormous statistical power for associating PM exposure and disease.







A state-of-the-art chemical transport model (CTM) provides initial estimates of the abundances of different aerosol types, along with their vertical distributions.

+

The MAIA instrument uses the proven power of multi-angle and multispectral radiometry and polarimetry to eliminate CTM biases and retrieve fractional aerosol optical depths of different particle types.

+

Geostatistical models (GSMs) derived from collocated surface and MAIA measurements relate these fractional aerosol optical depths to near-surface concentrations of major PM constituents.

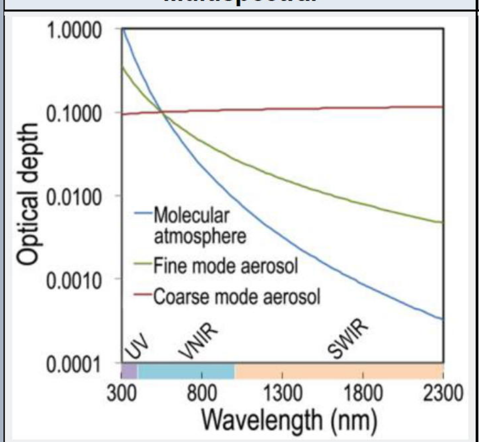
+

Geocoded birth, death, and hospital records and established epidemiological methodologies are used to associate PM exposure with adverse health outcomes.

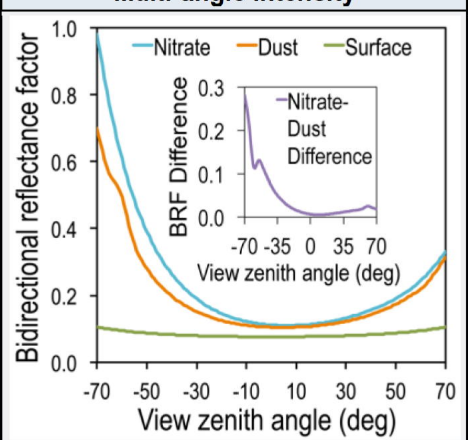
=

The MAIA investigation addresses NASA's EVI-3 goal of using observations from space and interdisciplinary Earth science research to benefit society.

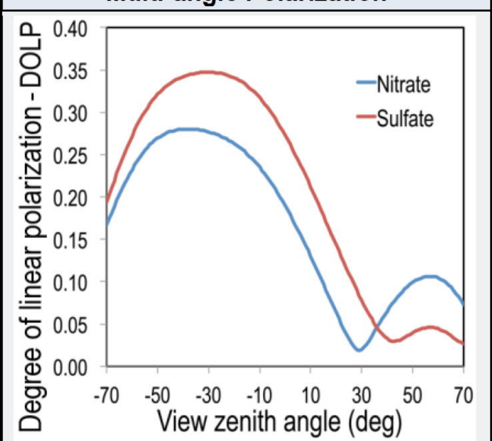
Multispectral



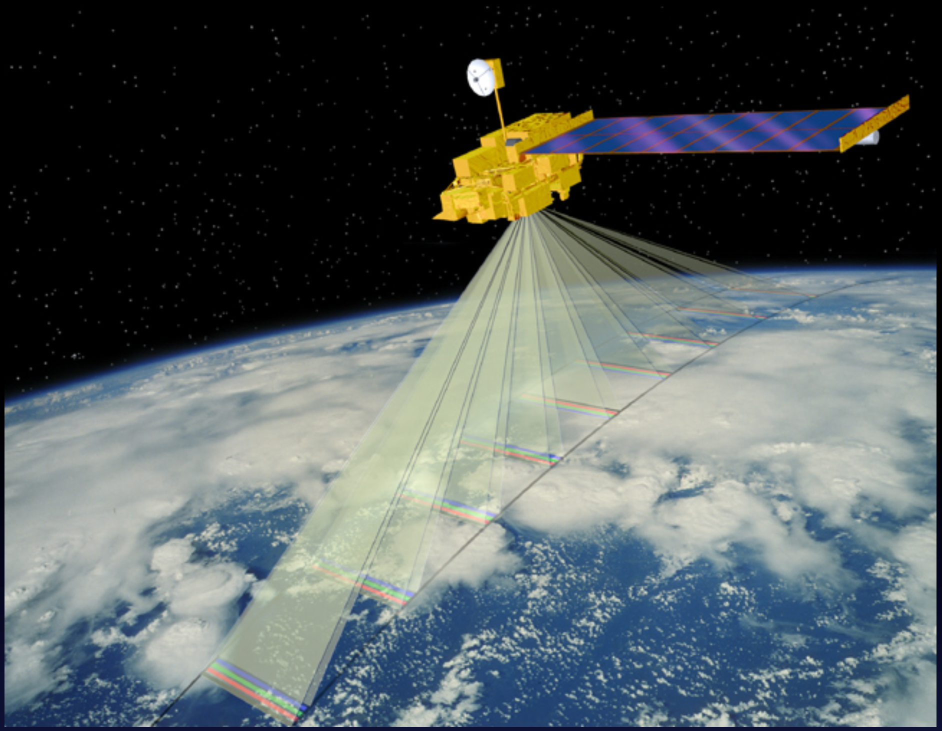
Multi-angle Intensity



Multi-angle Polarization



Multi-Angle Imaging SpectroRadiometer (MISR)



Nine view angles at Earth surface: 70.5° forward to 70.5° backward

Nine 14-bit pushbroom cameras

275 m - 1.1 km sampling

Four spectral bands at each angle: 446, 558, 672, 866 nm

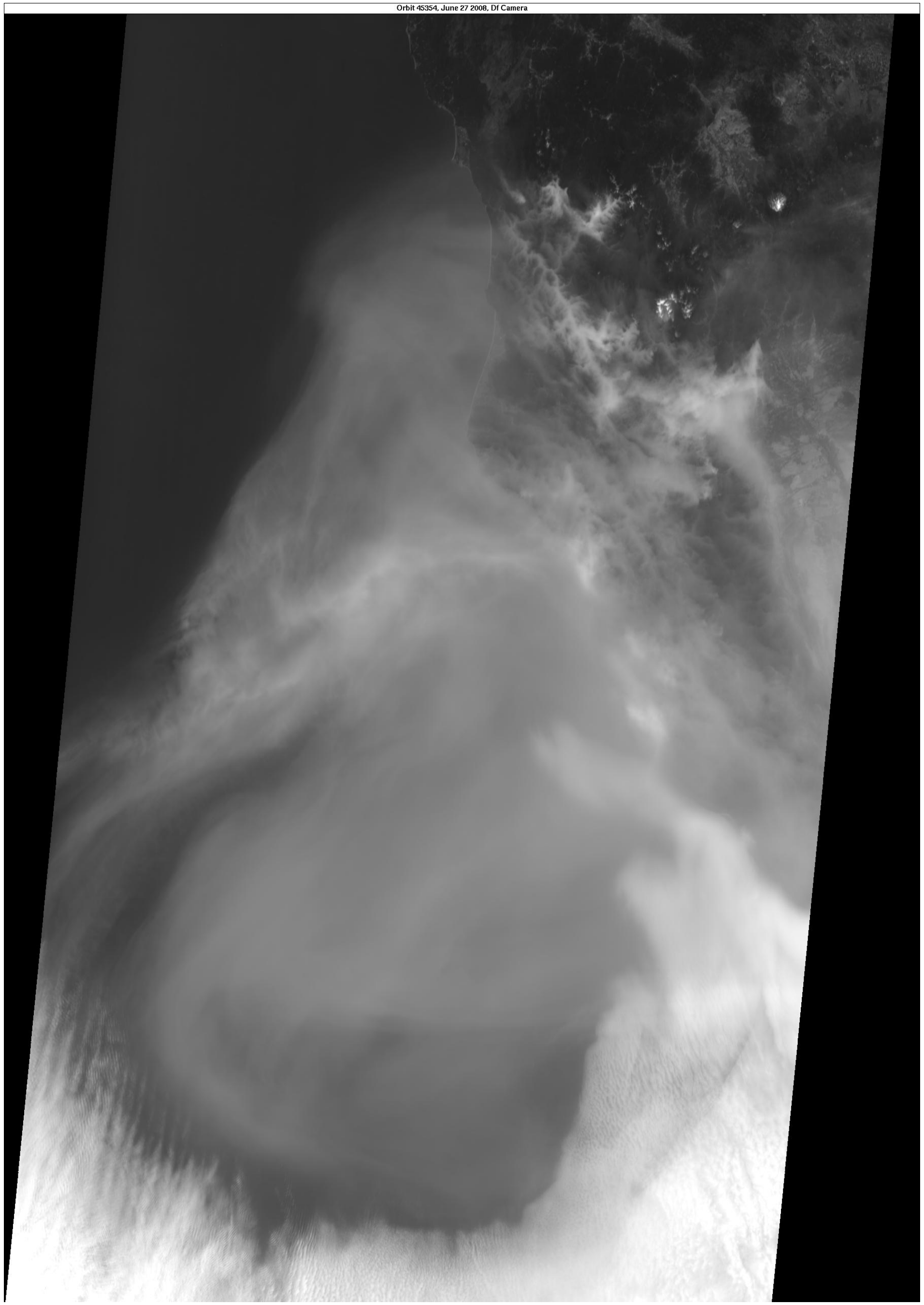
400-km swath: 9-day coverage at equator, 2-day at poles

7 minutes to observe each scene at all nine angles

Operational from early 2000 to present

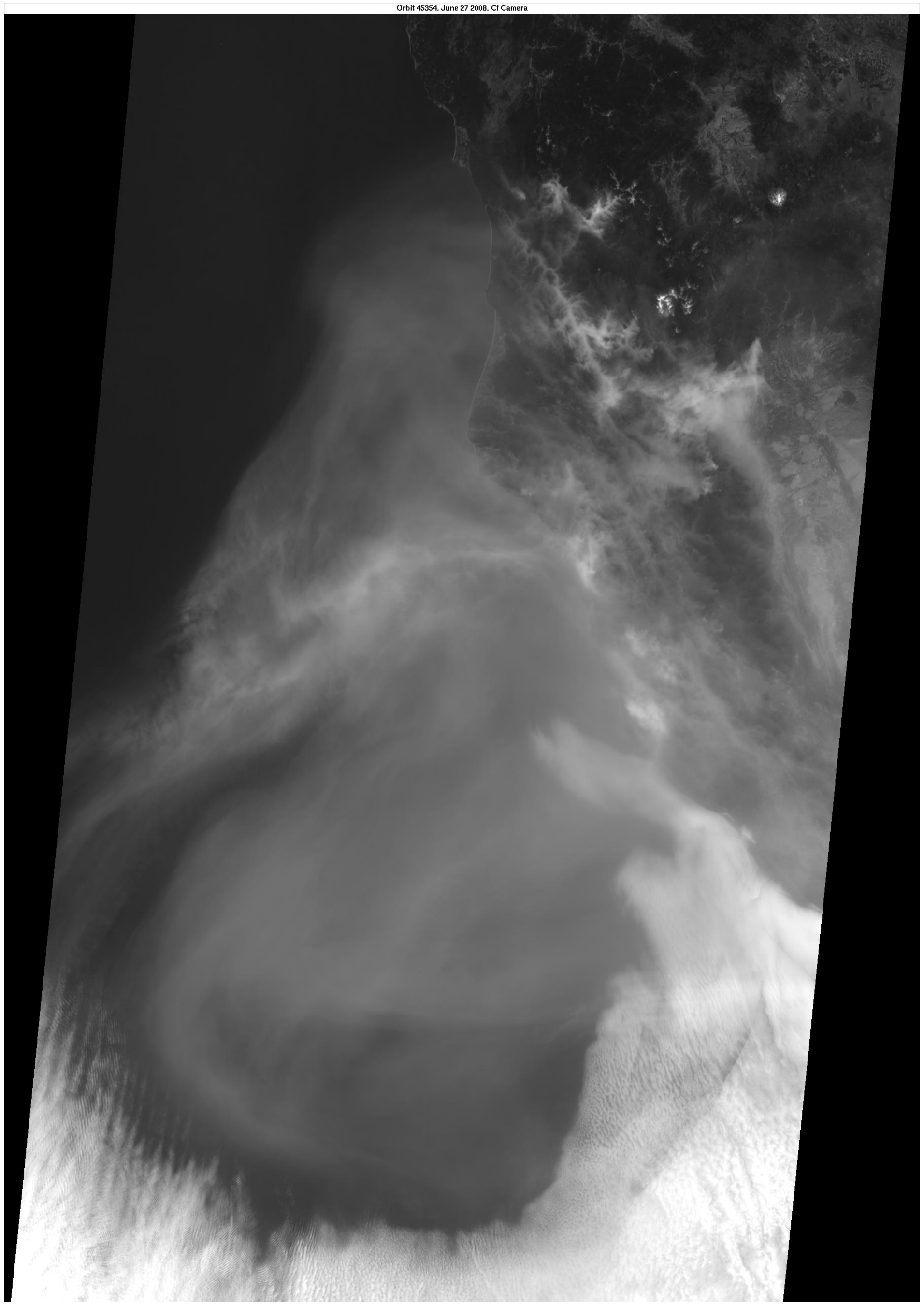
MISR Df

Orbit 45354, June 27 2008, Df Camera



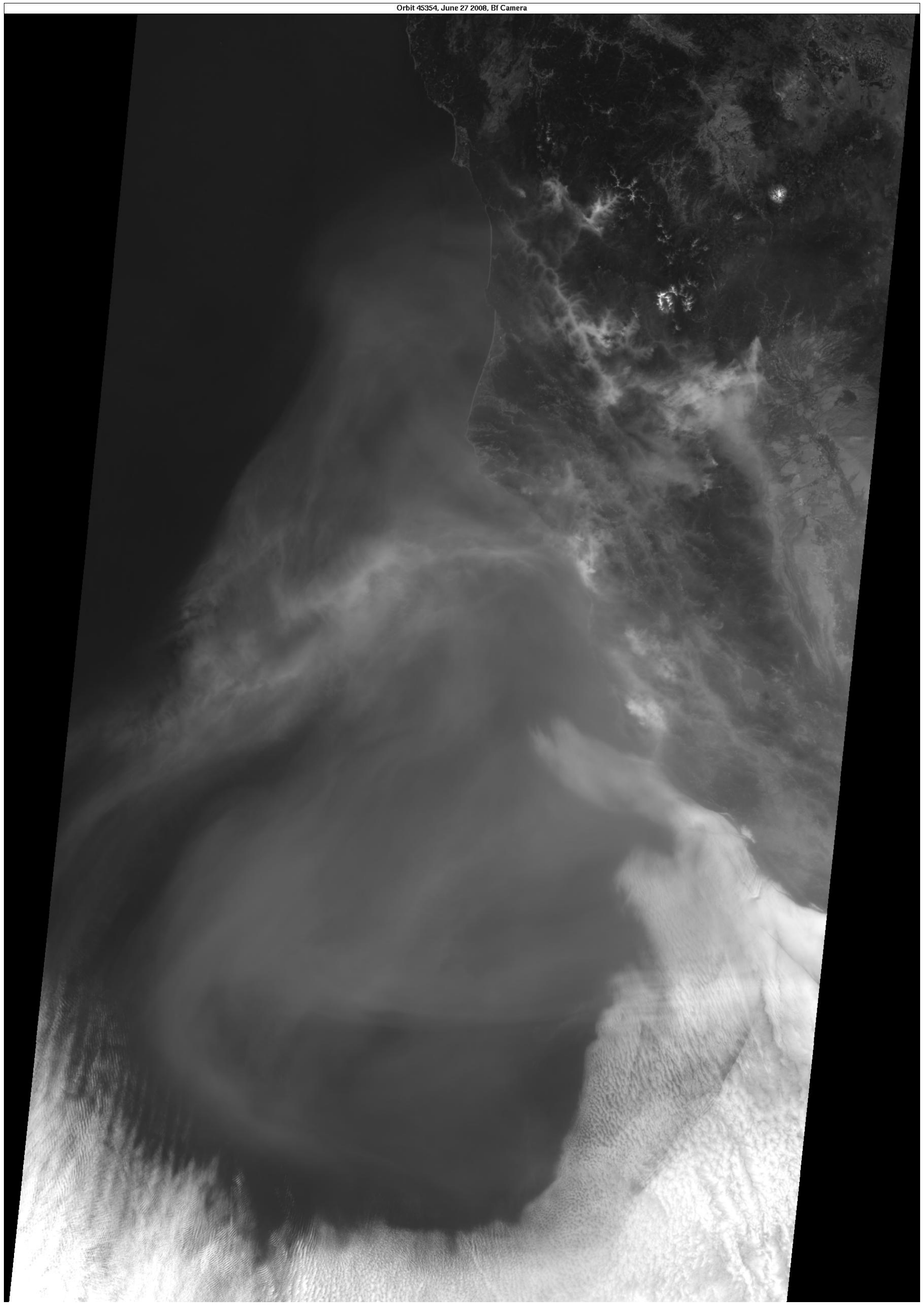
MISR Cf

Orbit 45354, June 27 2008, Cf Camera



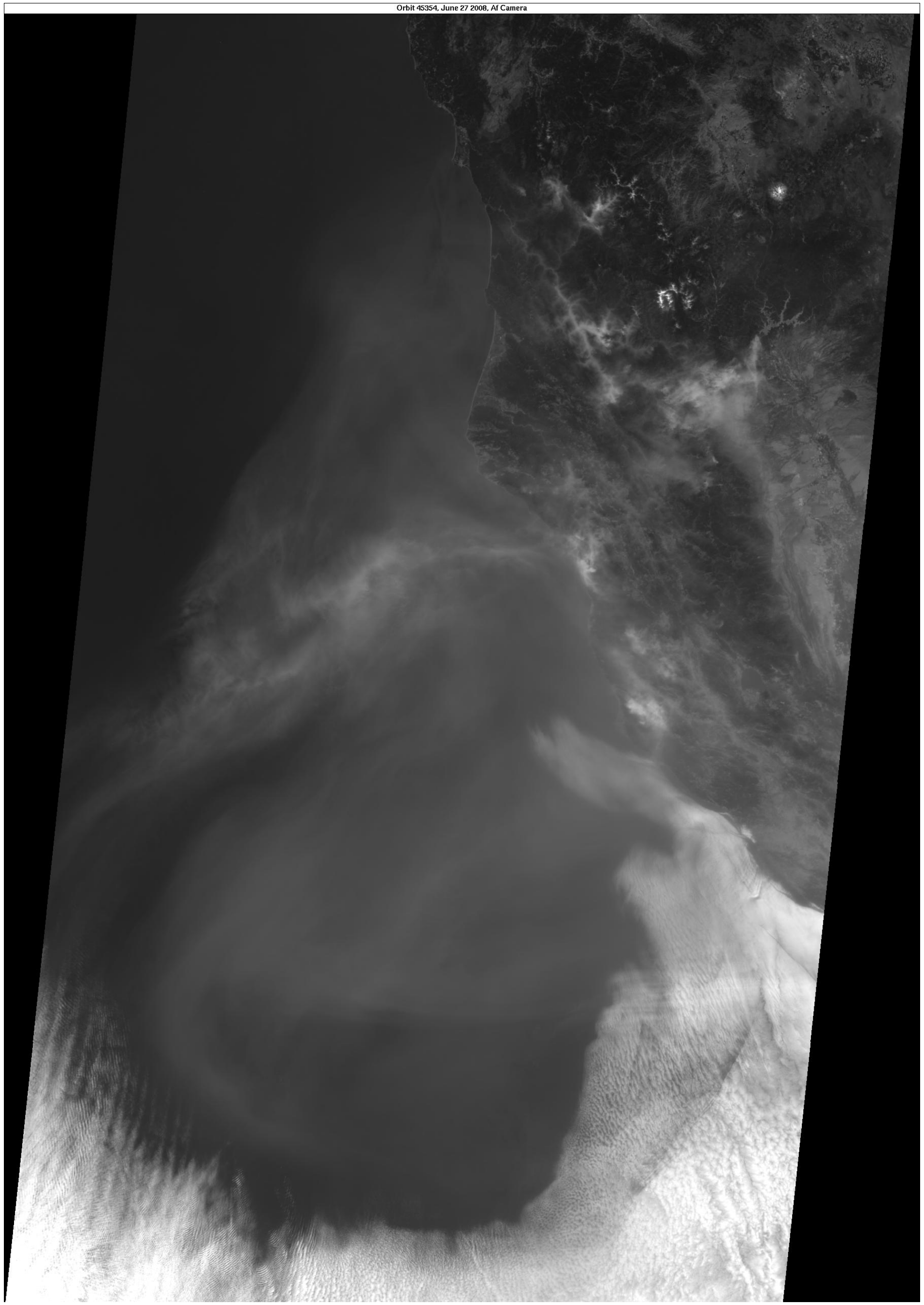
MISR Bf

Orbit 45354, June 27 2008, Bf Camera



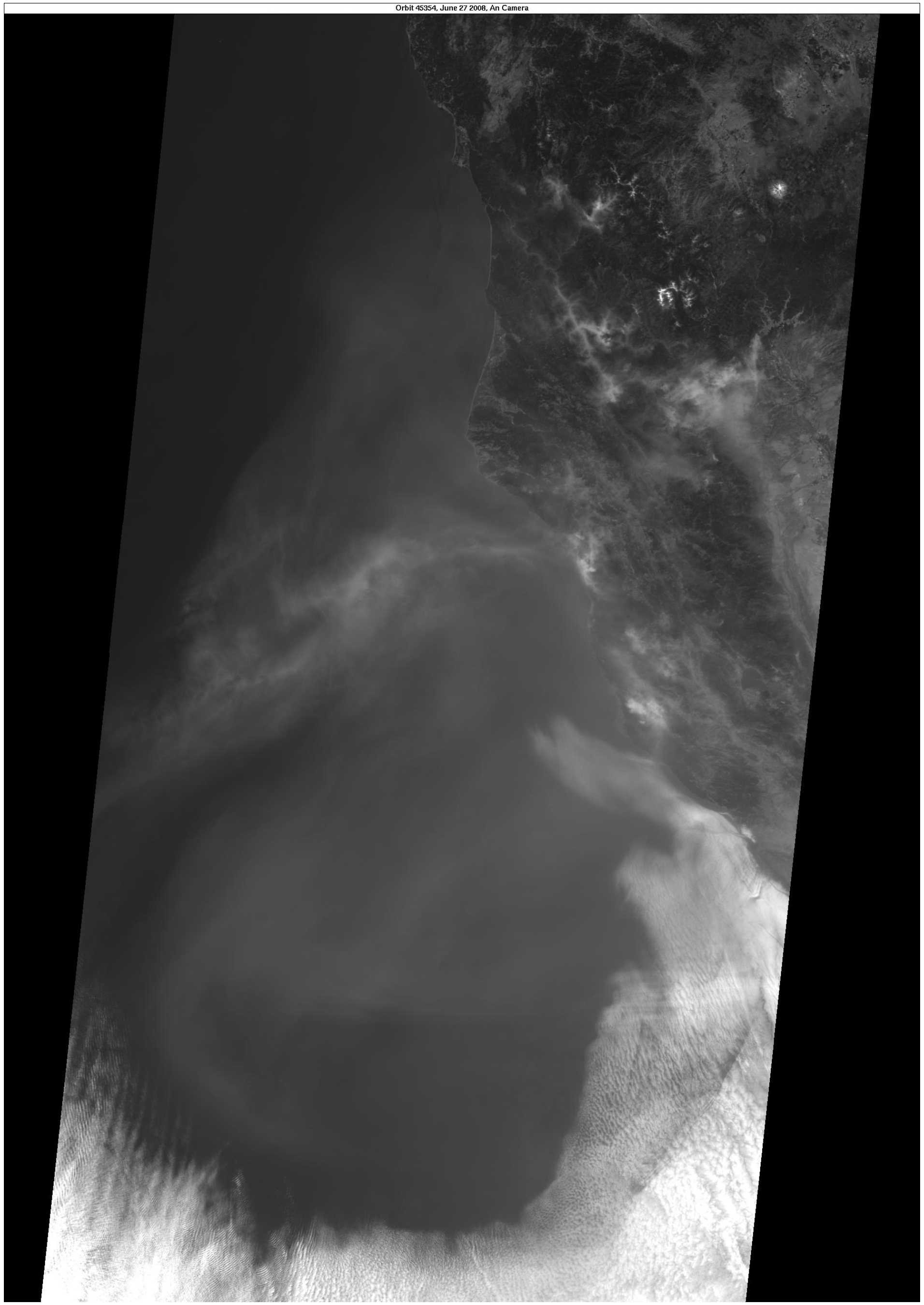
MISR Af

Orbit 45354, June 27 2008, Af Camera



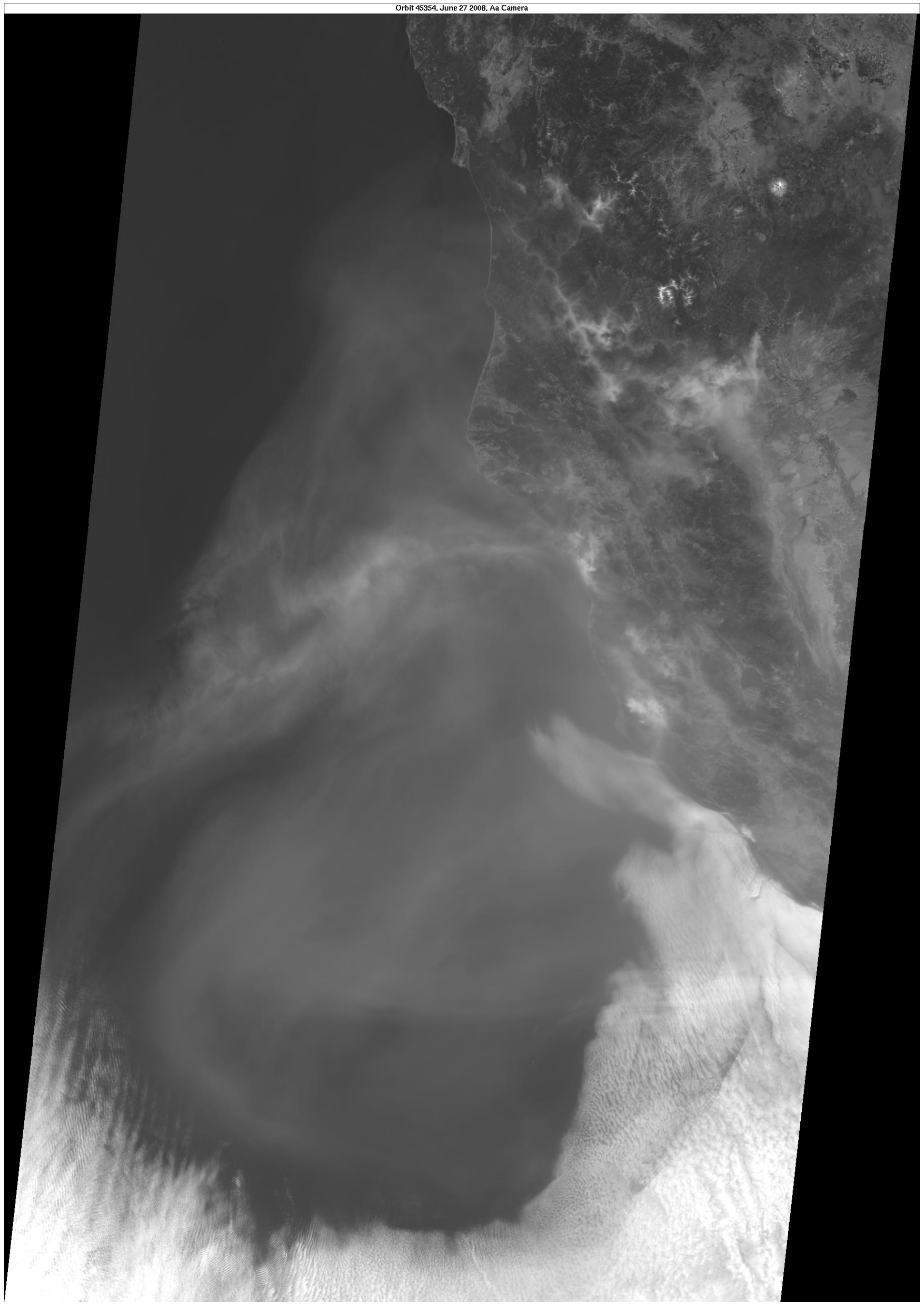
MISR An

Orbit 45354, June 27 2008, An Camera



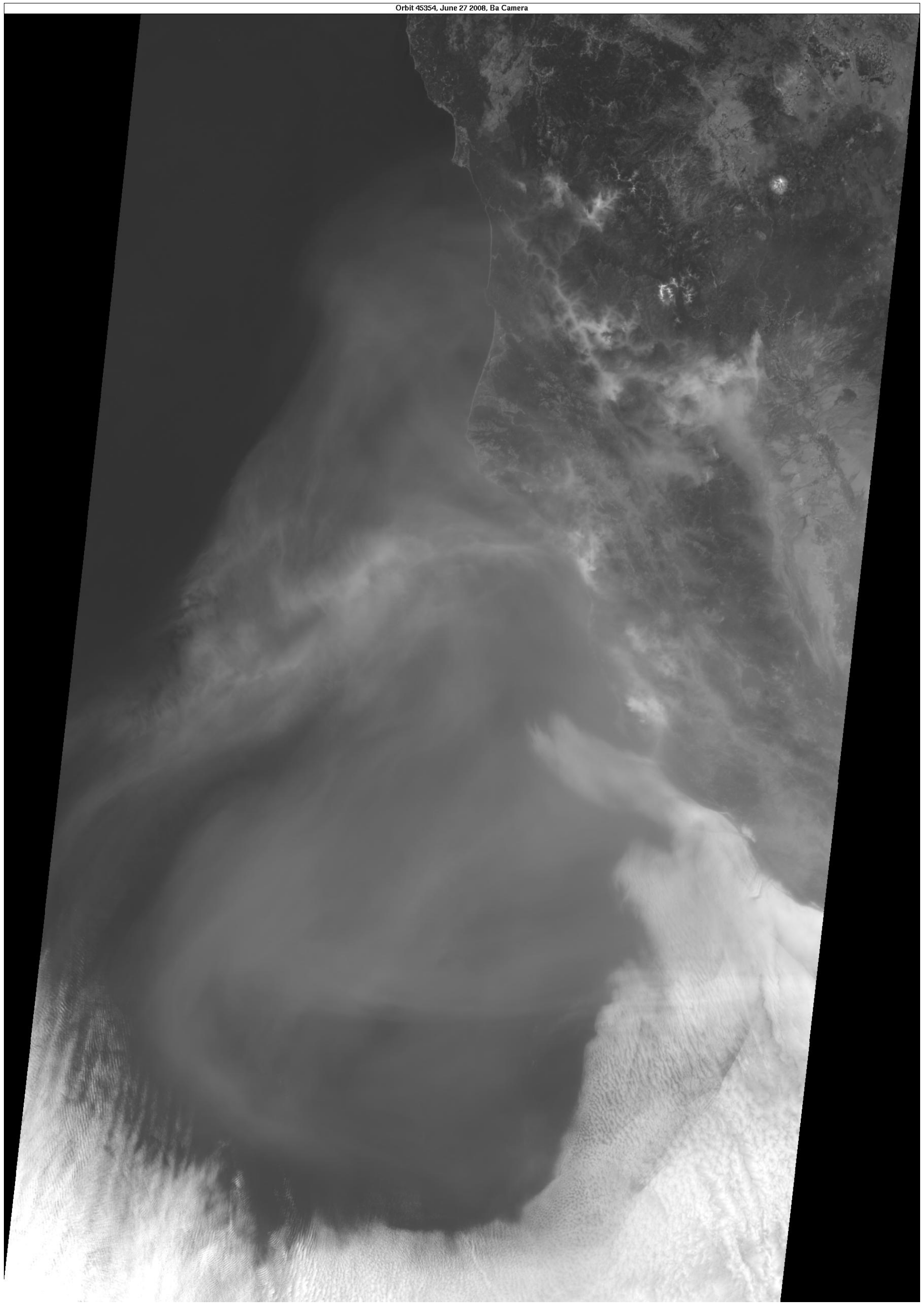
MISR Aa

Orbit 45354, June 27 2008, Aa Camera



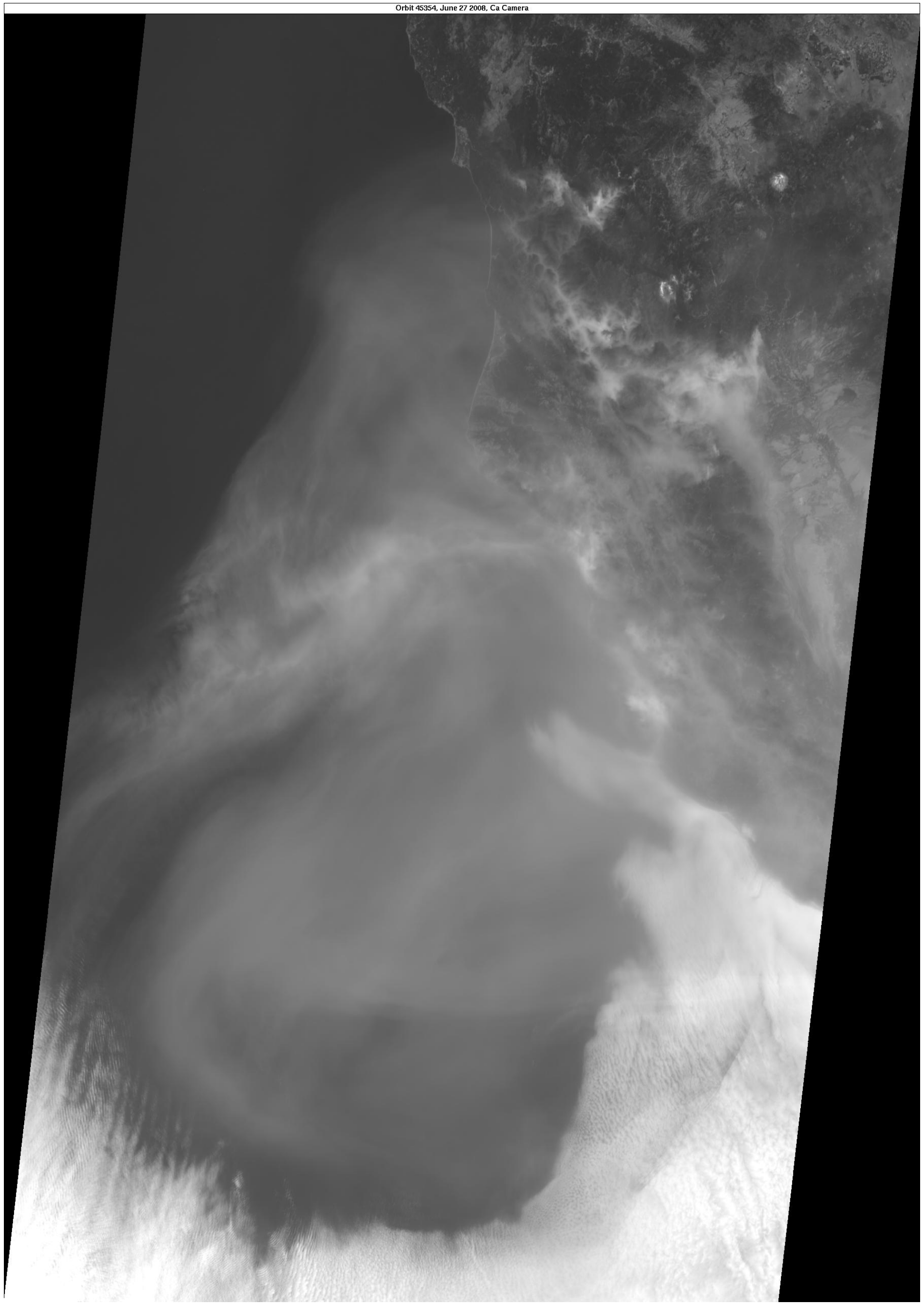
MISR Ba

Orbit 45354, June 27 2008, Ba Camera



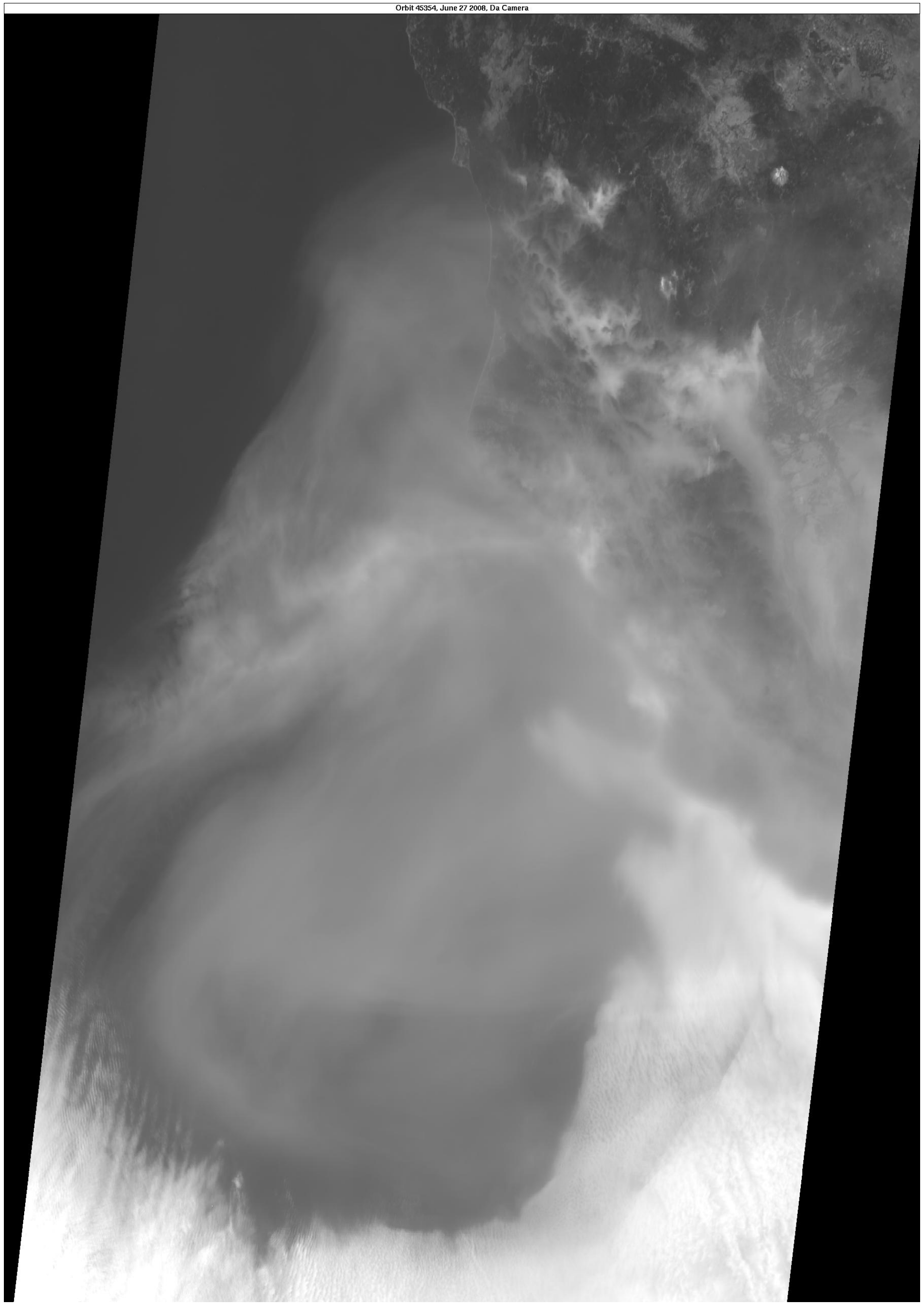
MISR Ca

Orbit 45354, June 27 2008, Ca Camera

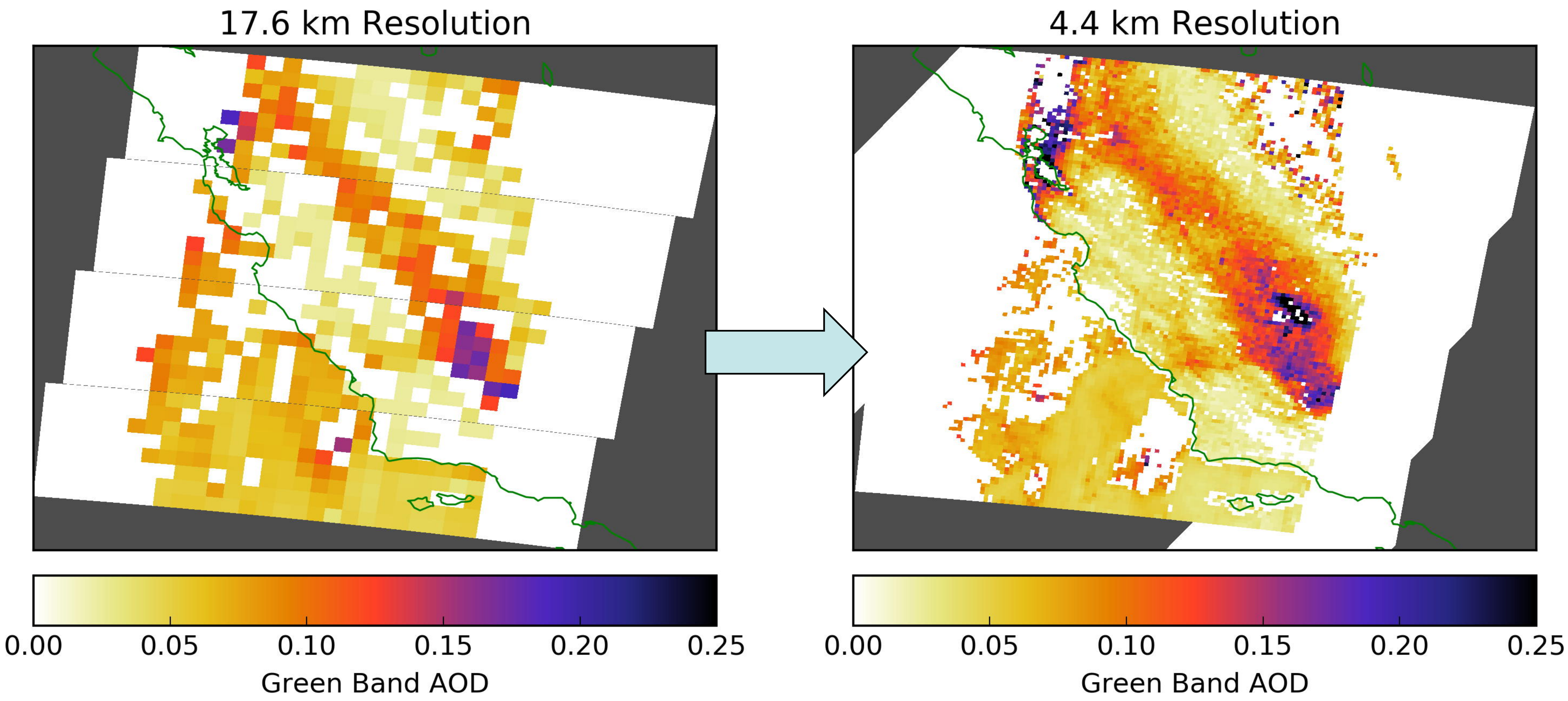


MISR Da

Orbit 45354, June 27 2008, Da Camera

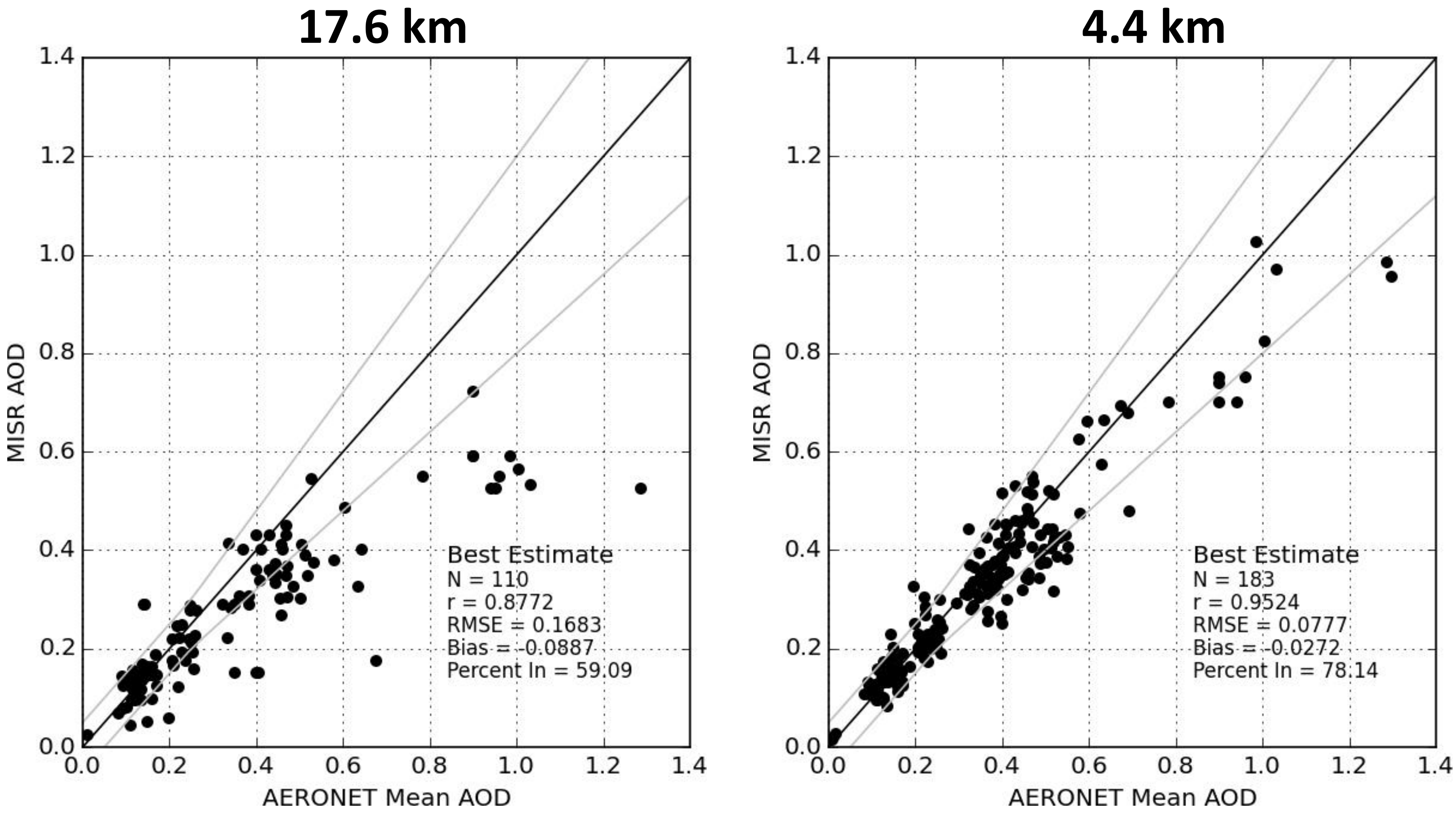


Higher Resolution



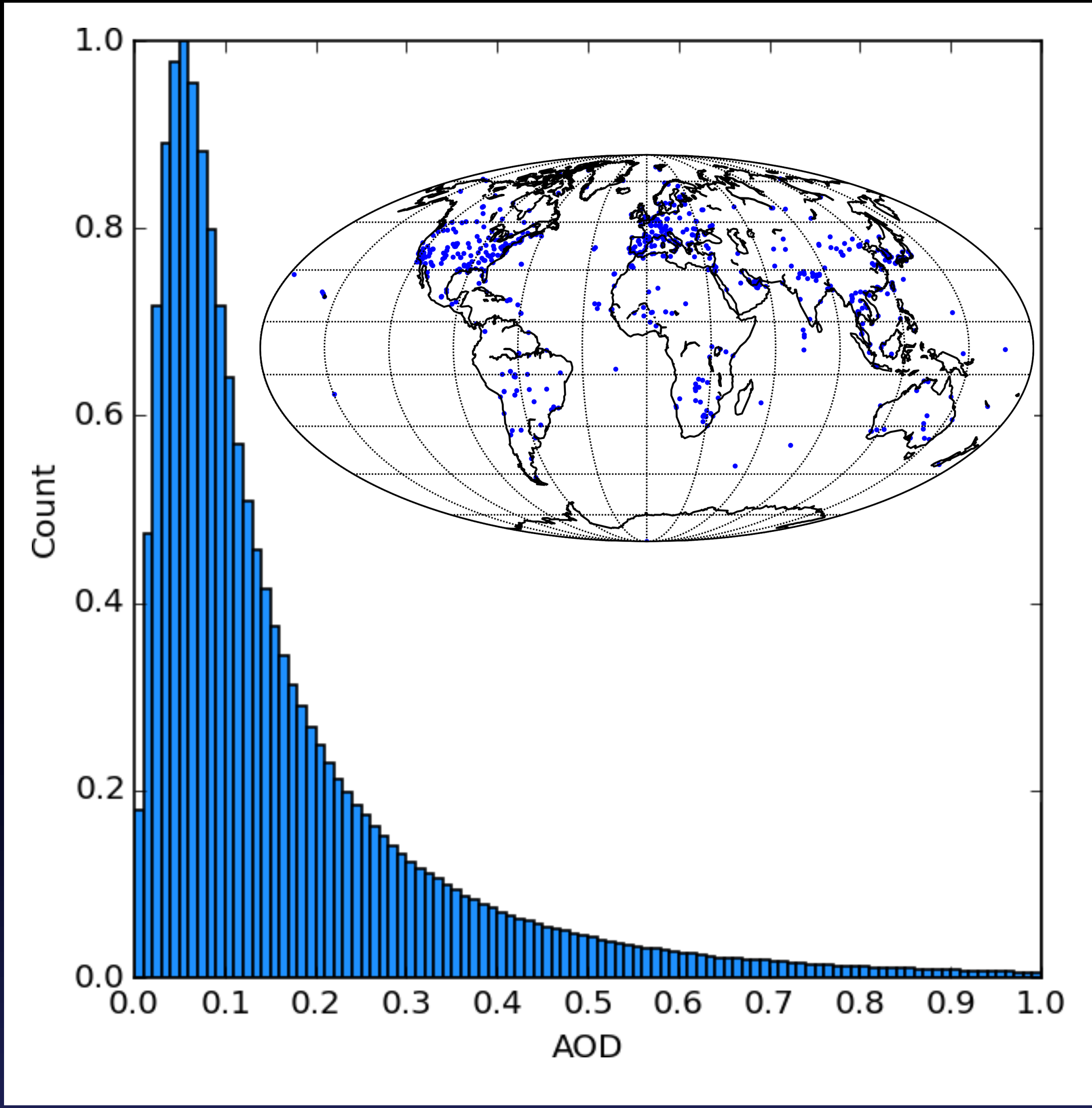
Orbit 85823, Path 043
2016-02-05

Comparison to AERONET-DRAGON

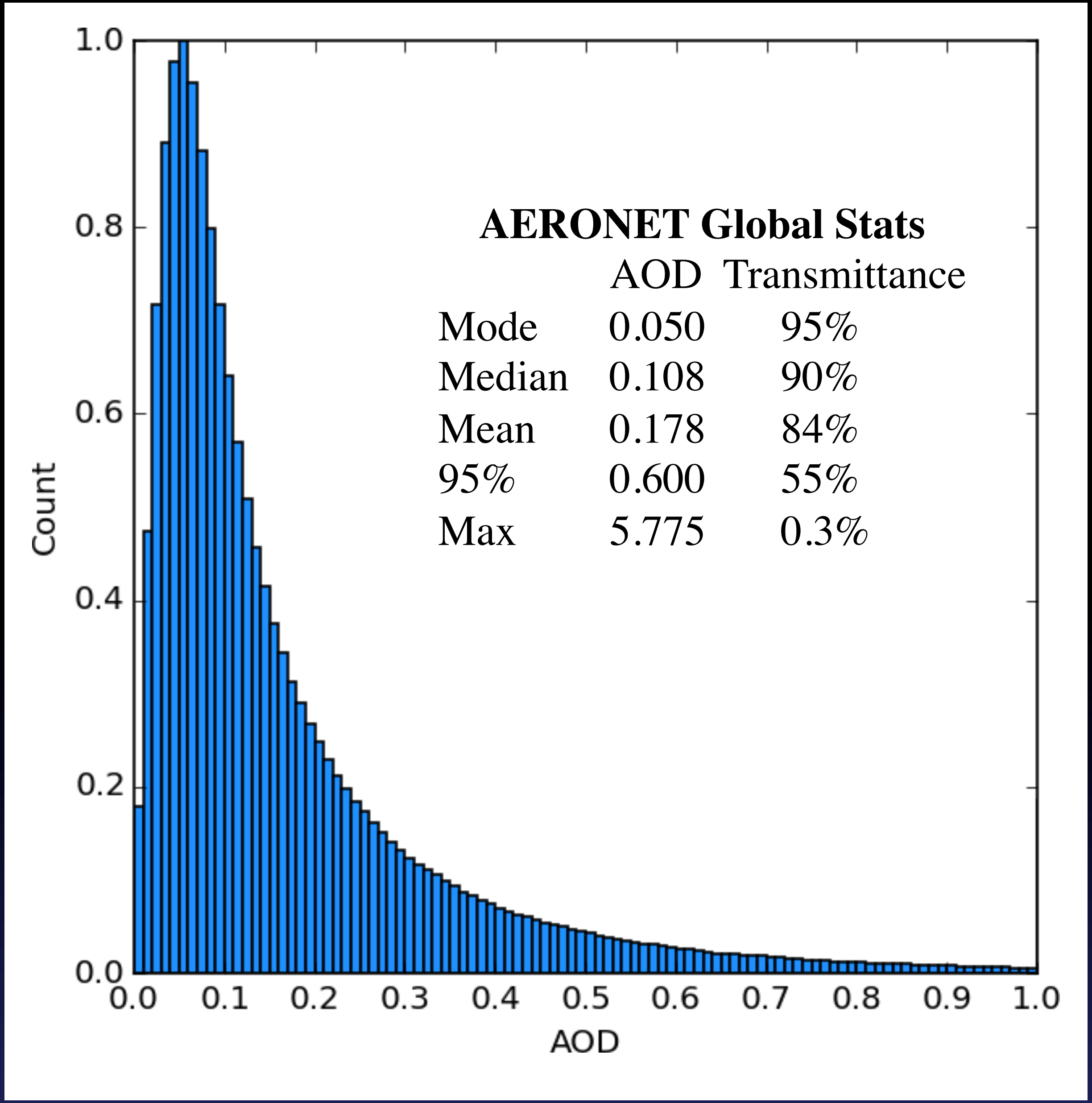


Match to Nearest AERONET Observation Relative to MISR Overpass Time

Aerosol Robotic Network (AERONET)

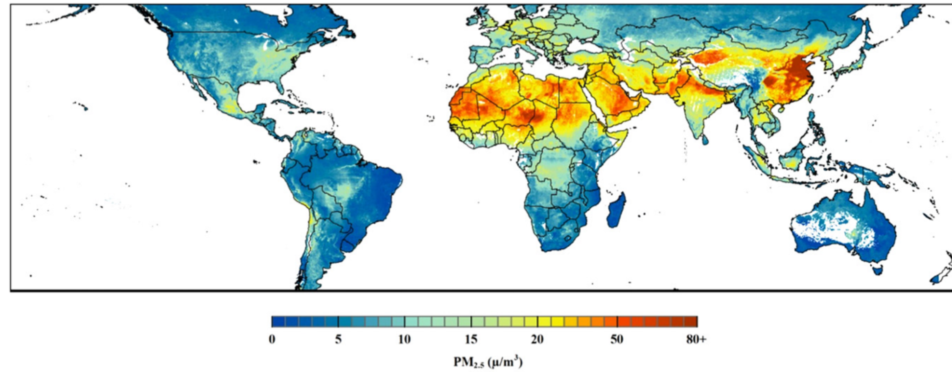


Aerosol Robotic Network (AERONET)

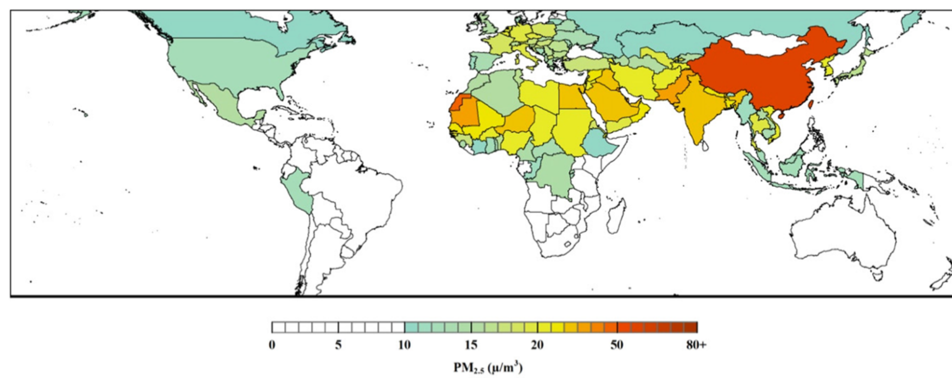


Uses of Global, Satellite-Derived AOD

- Environmental indicators summarize scientific complexity in ways helpful to decision makers
- Advisory group had members from the World Bank, Millennium Challenge Corporation, and the US EPA, in addition to academics and specialists from NOAA and NASA
- Satellite observations fill important data gaps left by ground-based-only observation networks such as that for particulate matter ($PM_{2.5}$)
- $PM_{2.5}$ is important because these particles can penetrate deep into the lungs and have significant deleterious health effects, and as many as 1.4 billion people worldwide breathe air with pollution levels exceeding World Health Organization (WHO) guidelines
- Satellite-derived aerosol optical depth is a proxy for $PM_{2.5}$ and population weighting provides human health policy relevance



MISR and MODIS satellite-derived annual average surface-level $PM_{2.5}$ concentrations at 50% relative humidity (2001–2006).



Population-weighted annual $PM_{2.5}$ concentrations by country (2001–2006).

de Sherbinin, A., M. A. Levy, E. Zell, S. Weber, and M. Jaiteh, Using satellite data to develop environmental indicators, Environ. Res. Lett., 2014

Instrument Development from MISR to MAIA

GroundMSPI

Portable field instrument on astronomical mount

Used for surface and atmospheric characterization

AirMSPI

Flies in nose of NASA ER-2 with 1-axis gimbal for multiangle viewing ±67º

Has flown in multiple field campaigns observing aerosols and clouds

355, 380, 445, ***470***, 555, ***660***, ***865***, 935 nm

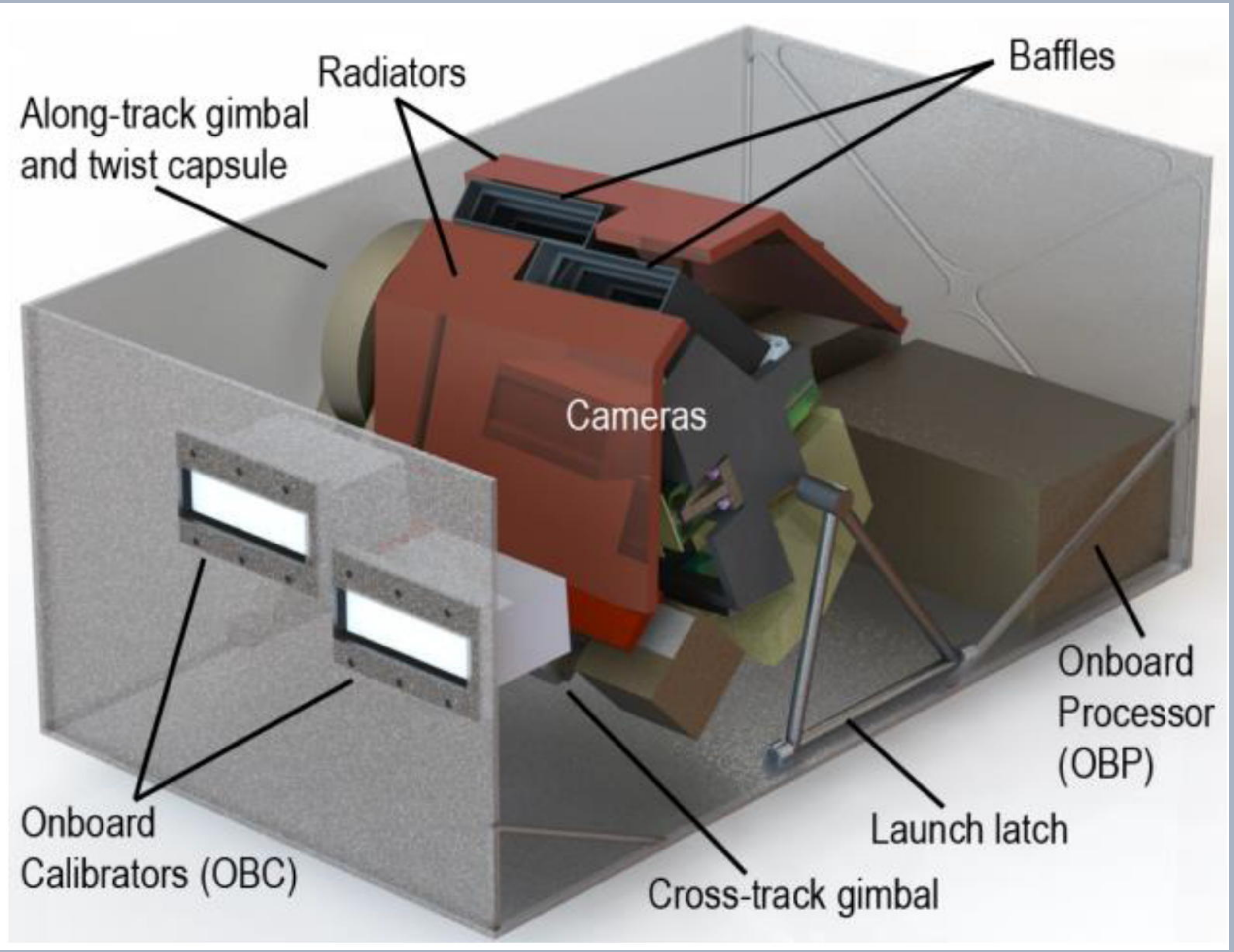
AirMSPI-2

Has demonstrated extension of spectral coverage into the SWIR through ground tests

Engineering test flights on the ER-2 held in October 2015

367, 386, ***445***, 543, ***645***, 751, 763, ***862***, 945, ***1620***, 1888, ***2185*** nm

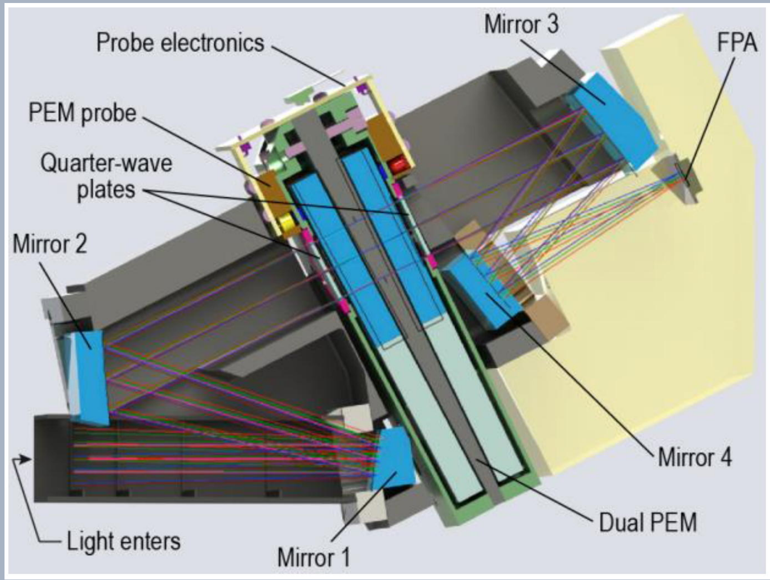
Instrument Development from MISR to MAIA



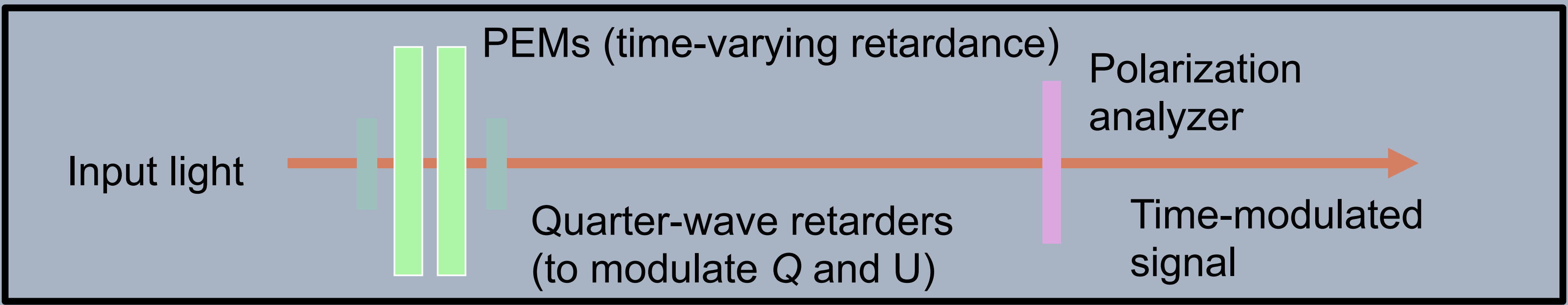
MAIA

367, 386, ***445***, 543, ***645***, 751, 763, ***862***, 945, ***1620***, 1888, ***2185*** nm

Polarization Modulation

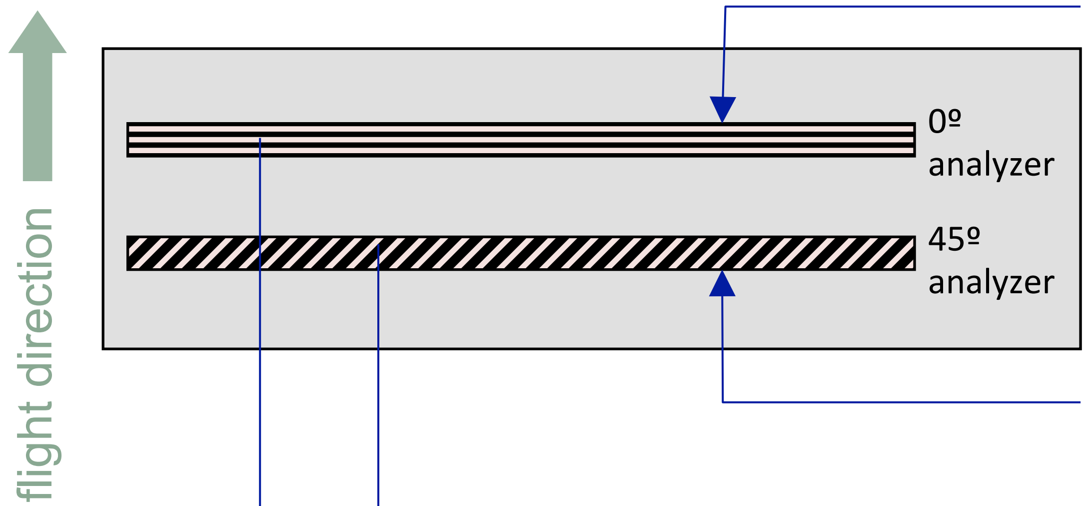


- "The most simple and stable modulators with the best optical properties are the piezoelastic [photoelastic] modulators (**PEMs**)." – Povel et al. (1990)
- "**Polarization modulation** is essential to accurate polarimetry in the optical region...one strives to modulate only the polarization preference, leaving the Stokes *I* sensitivity constant."
  Tinbergen (2005) *Astronomical Polarimetry*



- Measurements of *Q* and *I* share the **same optics and detector for each pixel** (similarly for *U* and *I*) enabling accurate imaging of degree of linear polarization (DOLP) as *relative* measurements

Polarization Modulation



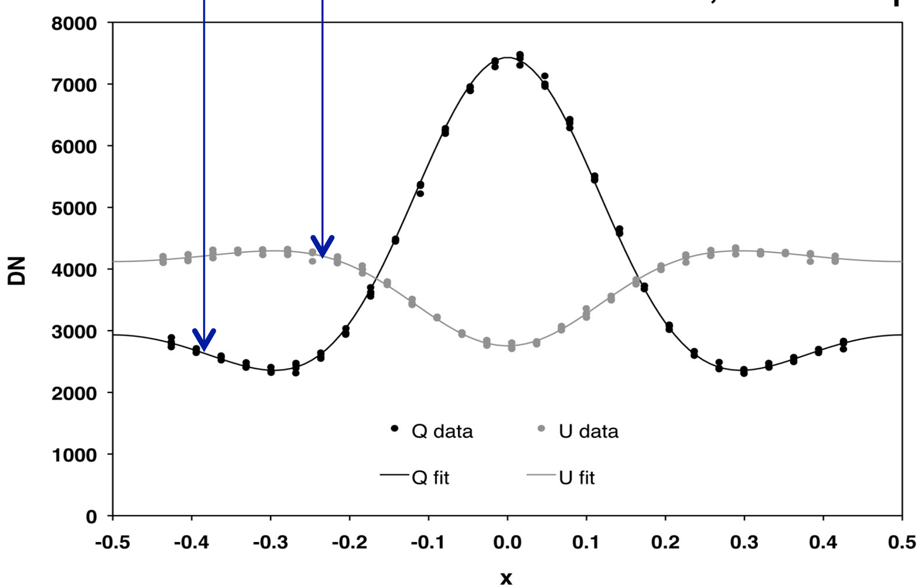
$S_0 = 0.5\ [I\ +\ Q \bullet F(t)]$

→ q = Q/I from each pixel

$S_{45} = 0.5\ [I\ +\ U \bullet F(t)]$

→ u = U/I from each pixel

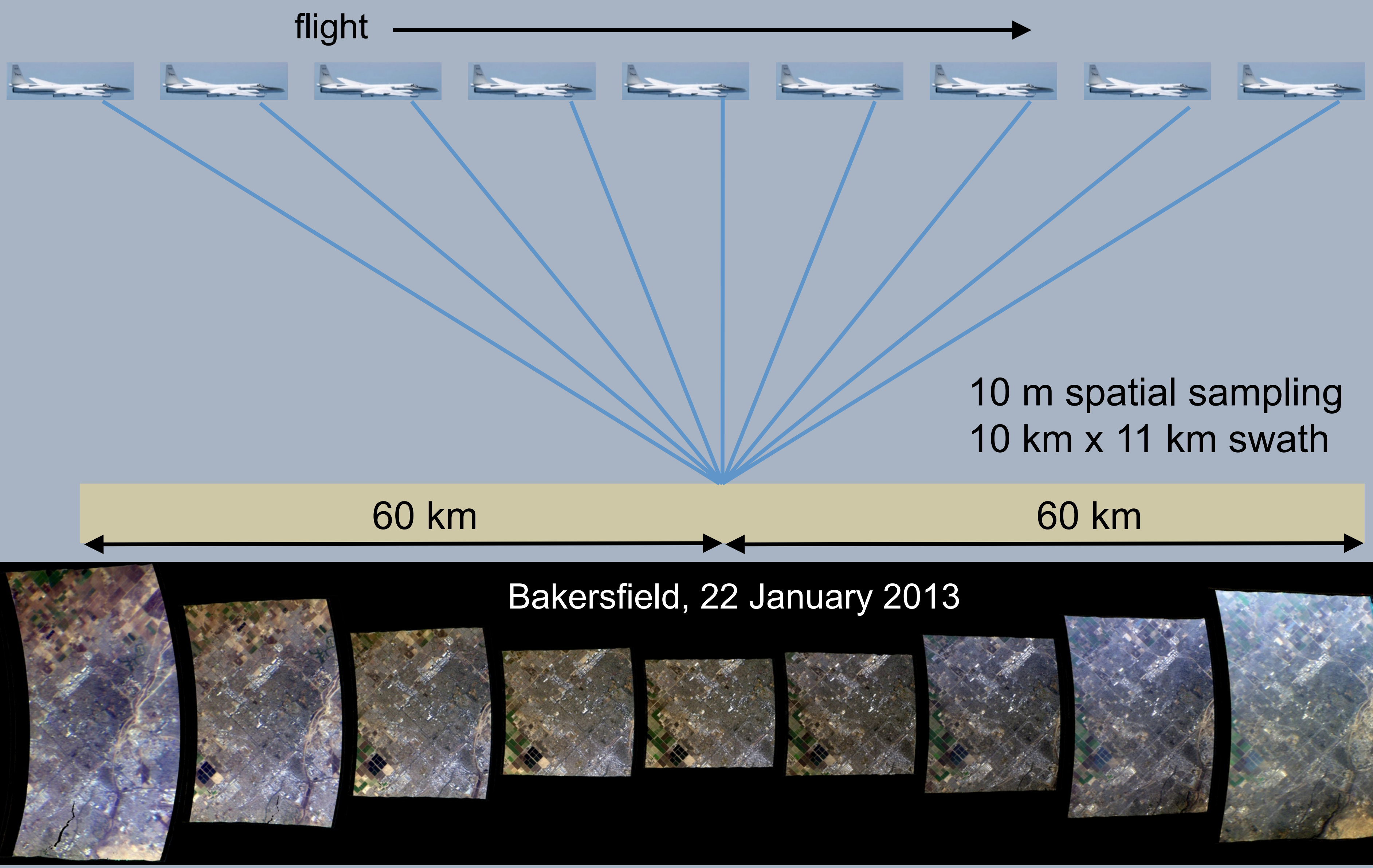
1 frame = 40 ms; 20 samples read out for each frame

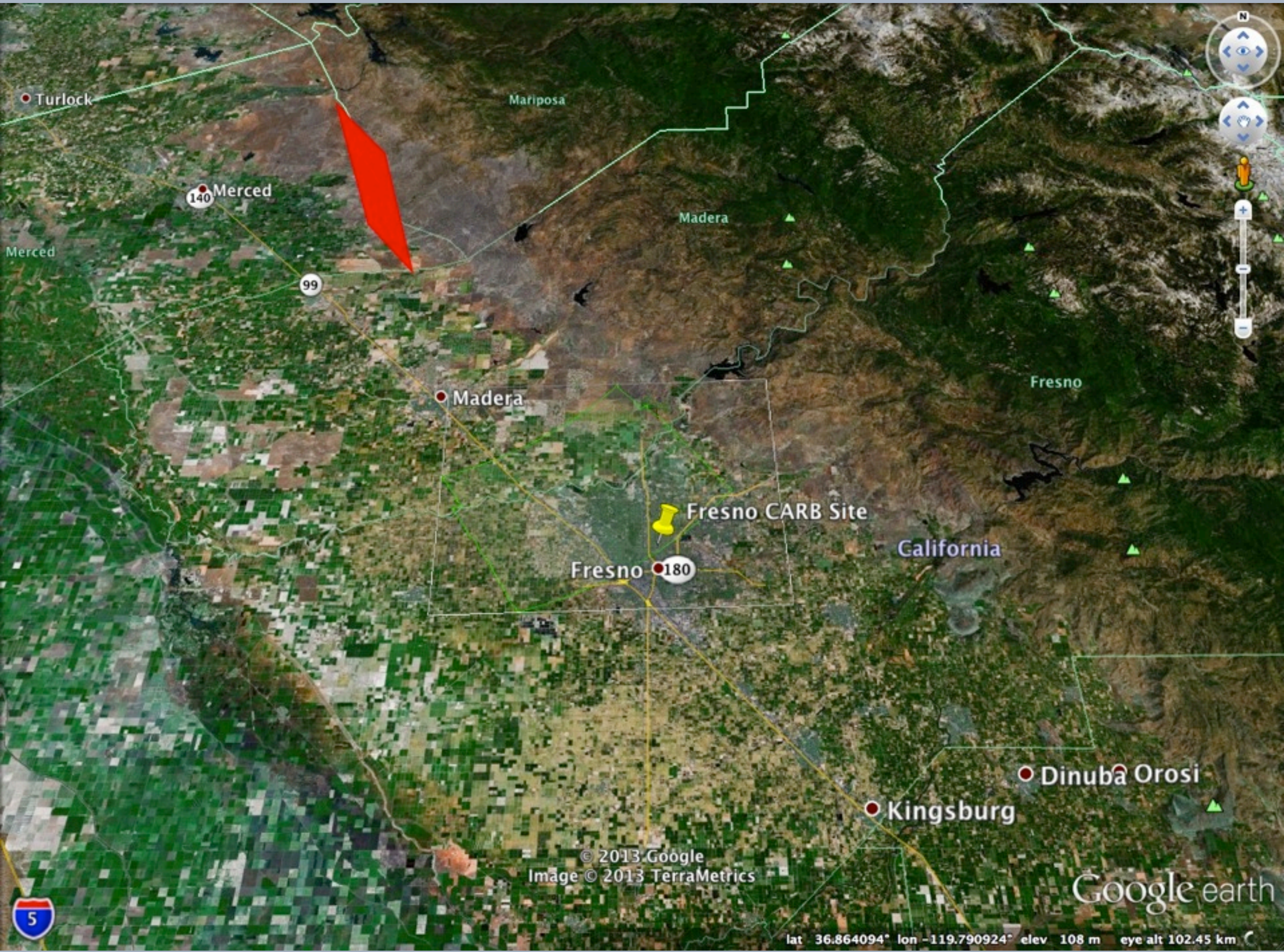


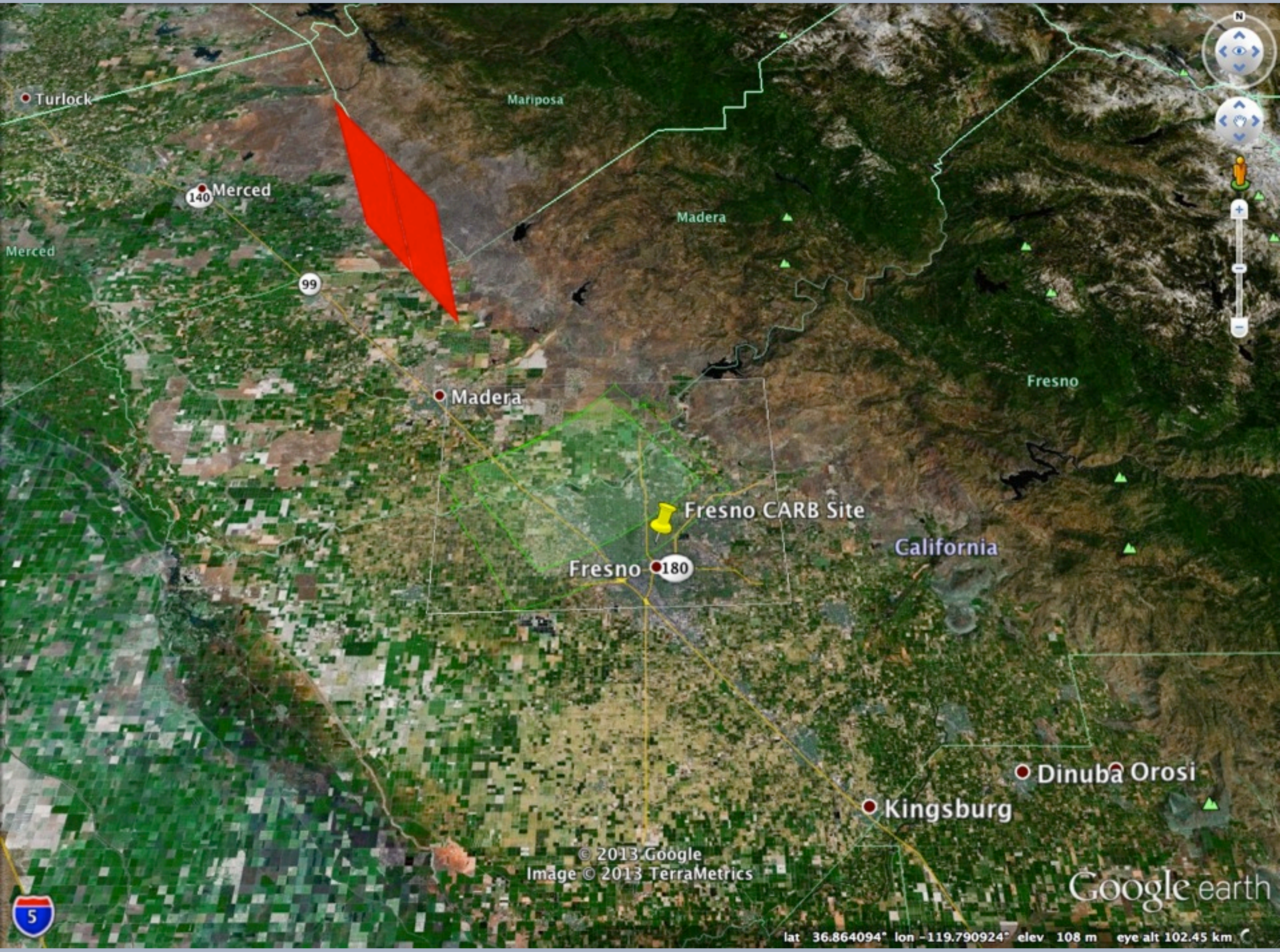
q and *u* are obtained as *relative* measurements independent of absolute radiometric calibration

Diner et al. (2007), (2010)

AirMSPI Step-and-Stare Acquisition

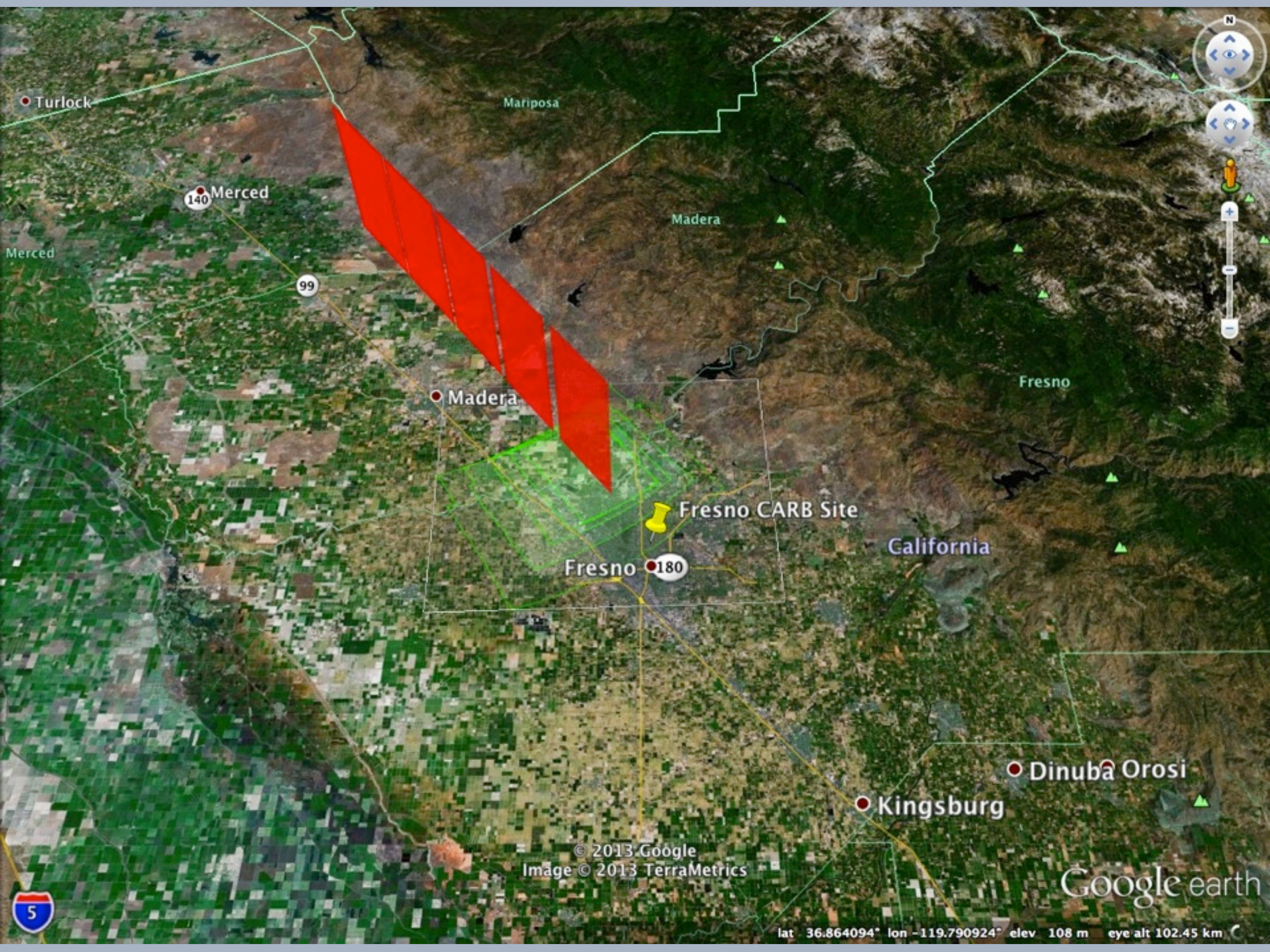



Turlock
Mariposa
Merced
140
Merced
Madera
99
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
© 2013 Google
Image © 2013 TerraMetrics
Google earth
5
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

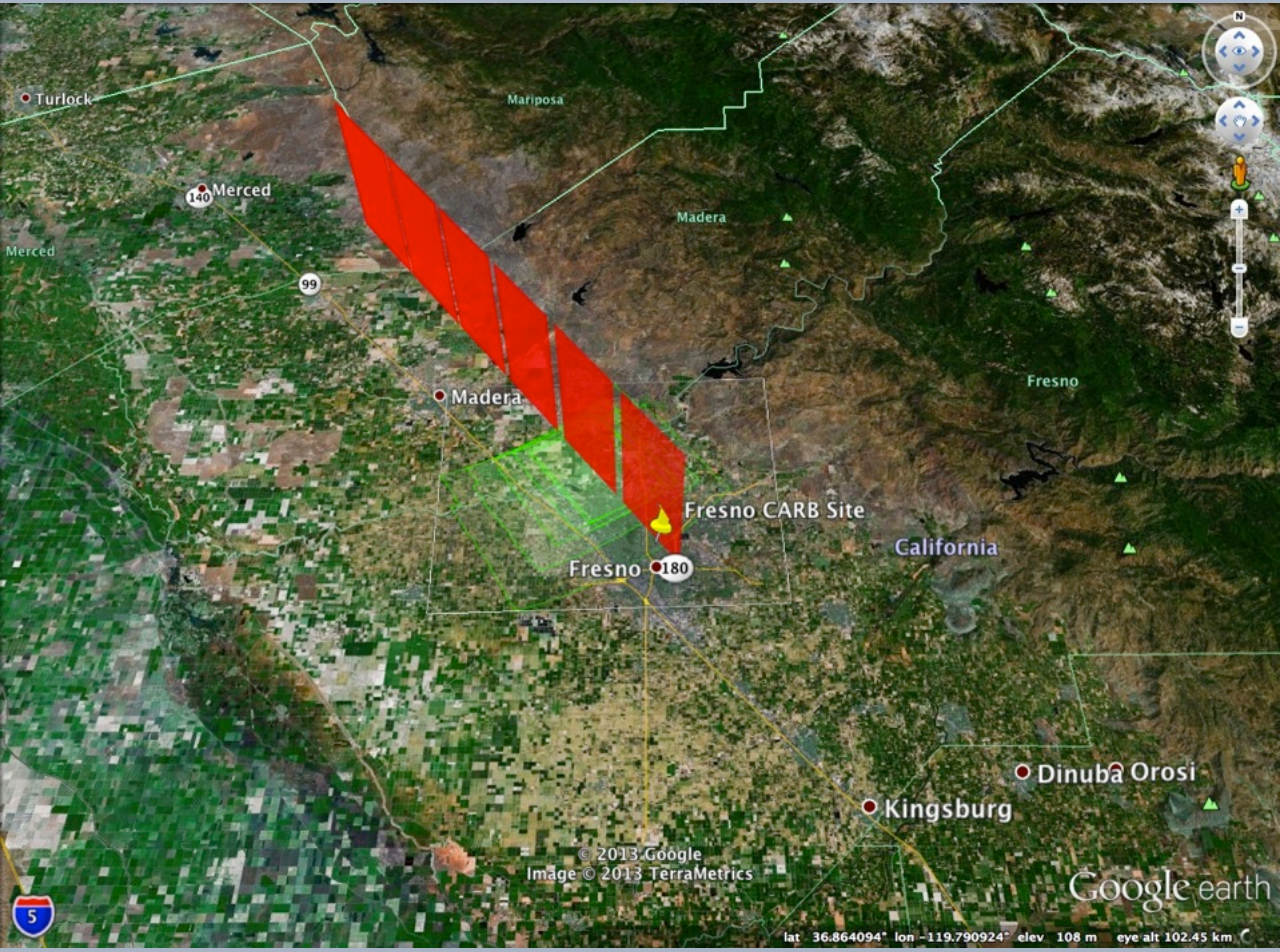

Turlock
Mariposa
Merced
140
Madera
Merced
99
Fresno
Madera
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
© 2013 Google
Image © 2013 TerraMetrics
Google earth
5
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

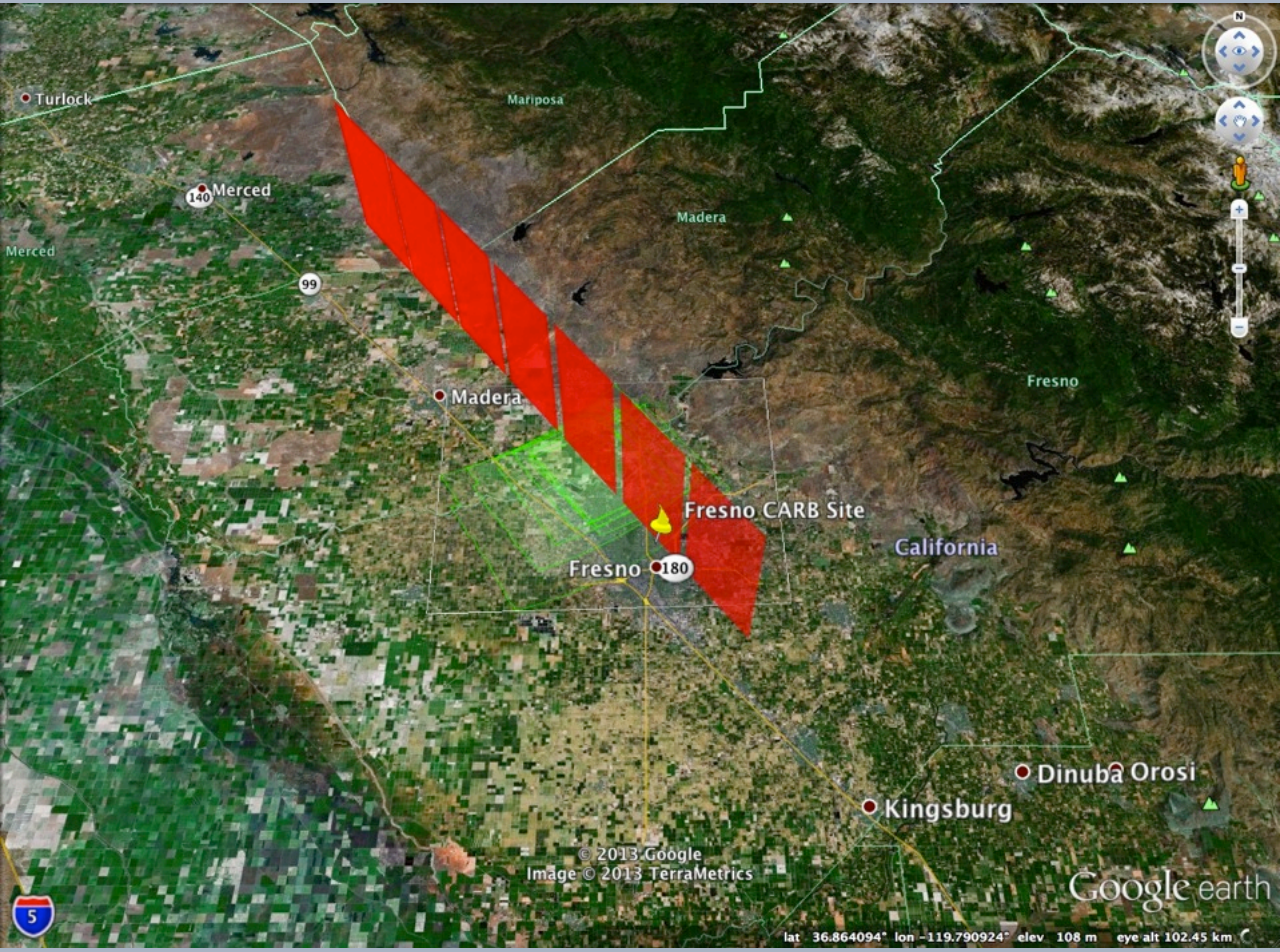
Turlock
Merced
140
Merced
99
Mariposa
Madera
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
5
© 2013 Google
Image © 2013 TerraMetrics
Google earth
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

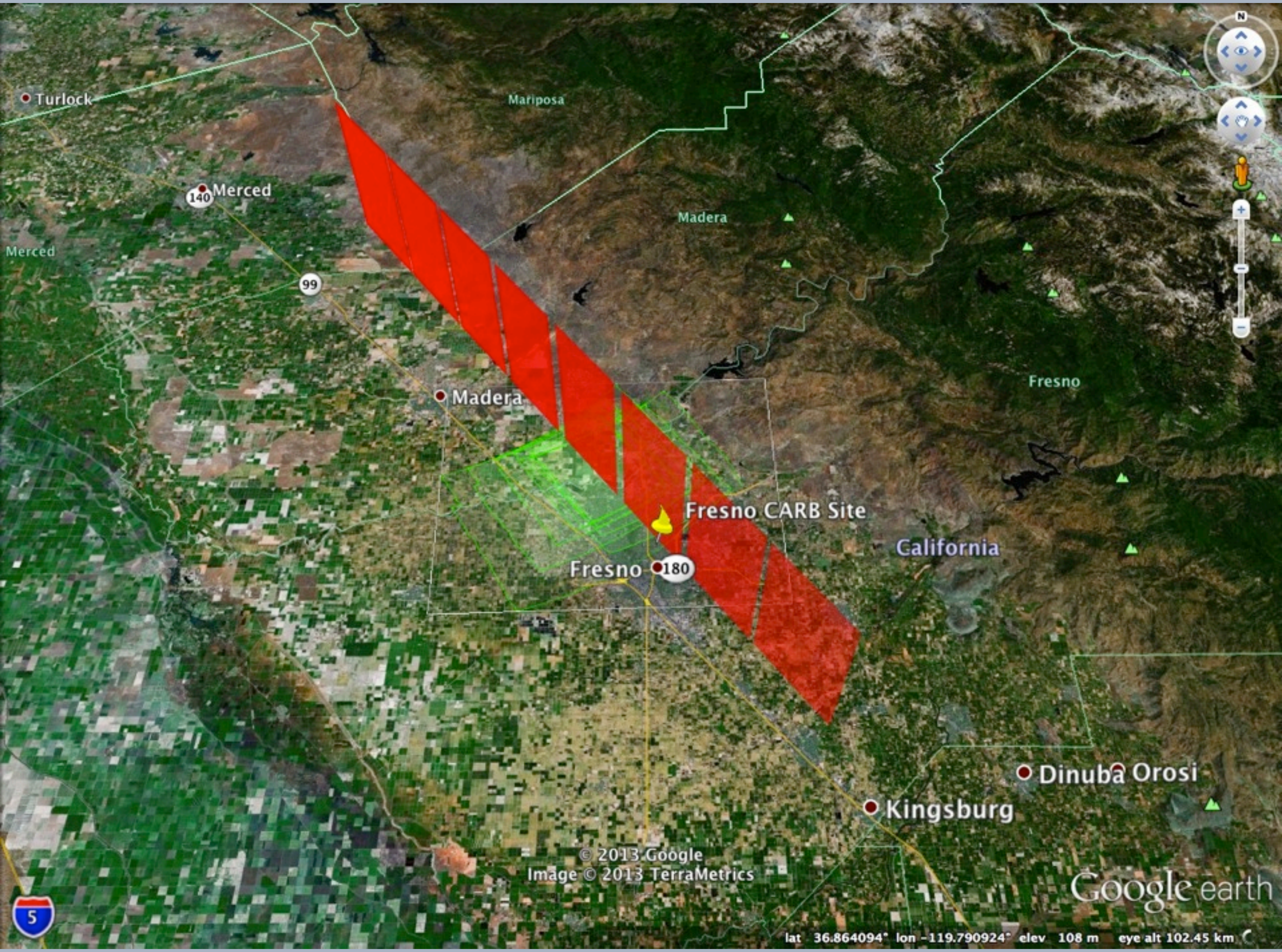
Turlock
Mariposa
Merced
140
Merced
Madera
99
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
© 2013 Google
Image © 2013 TerraMetrics
Google earth
5
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km



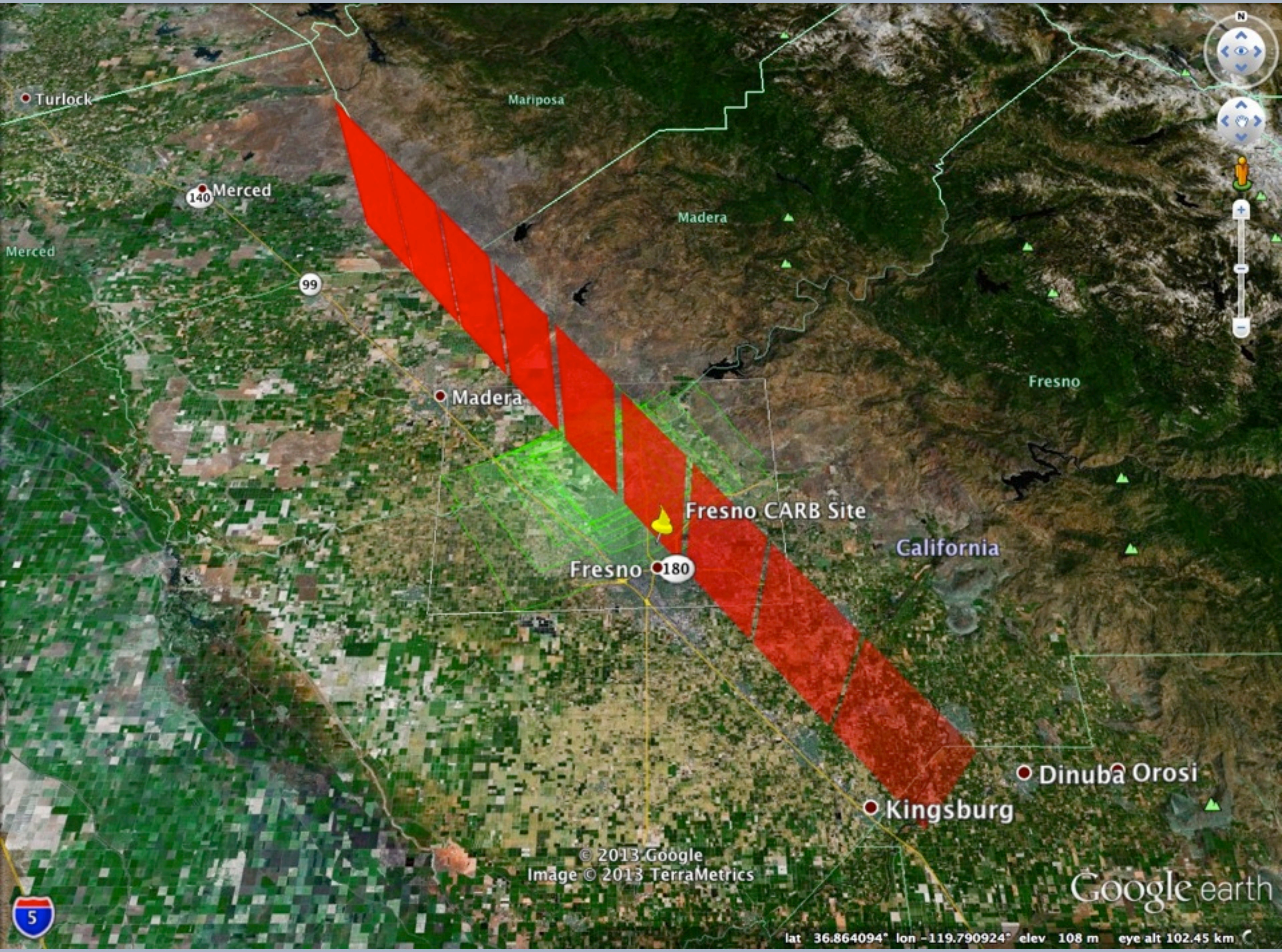
Turlock
Merced
140
Merced
99
Mariposa
Madera
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
5
© 2013 Google
Image © 2013 TerraMetrics
Google earth
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km


Turlock
Mariposa
Merced
140
Madera
Merced
99
Madera
Fresno
California
Fresno CARB Site
Fresno
180
Dinuba
Orosi
Kingsburg
© 2013 Google
Image © 2013 TerraMetrics
Google earth
5
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

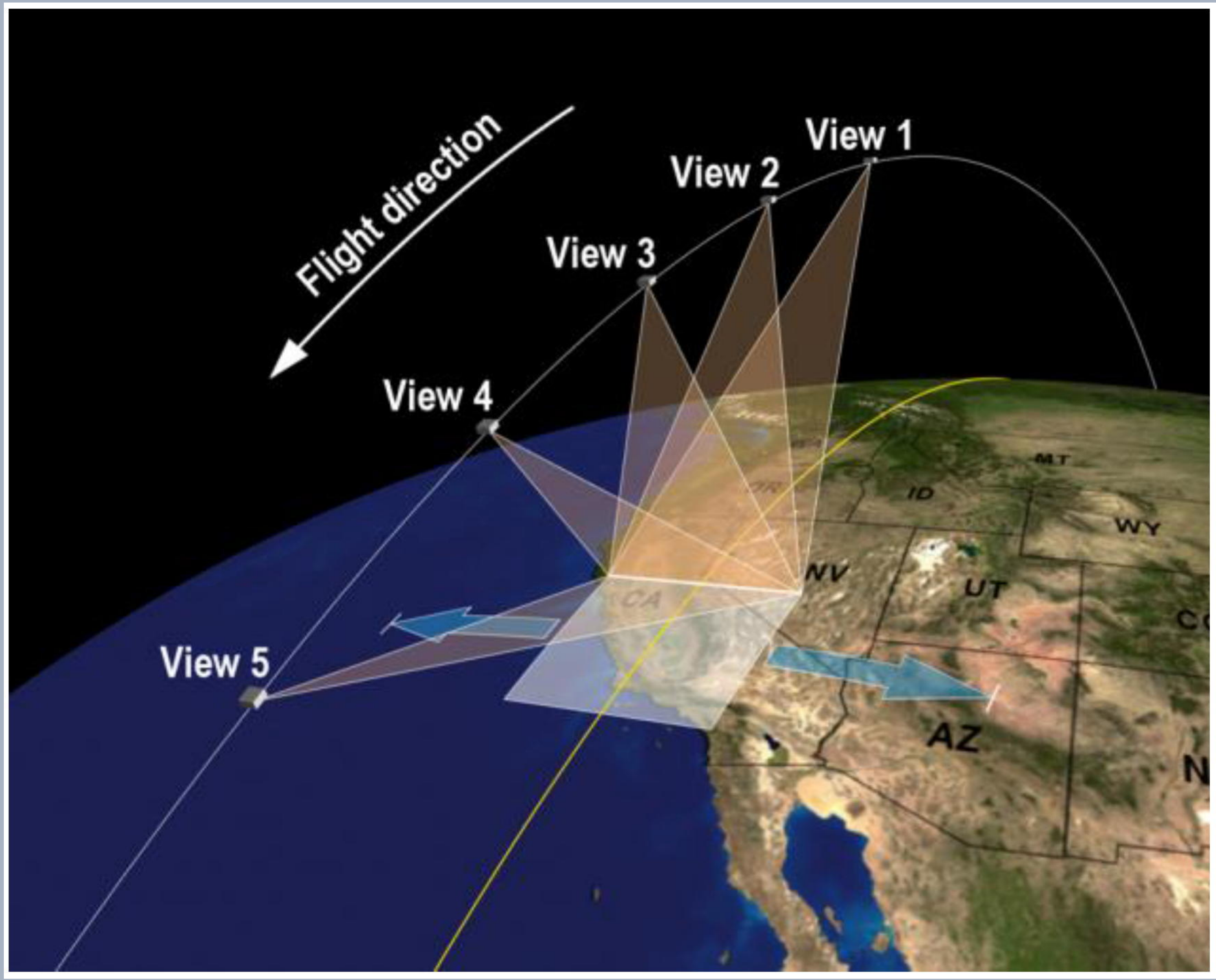

Turlock
Merced
140
Merced
99
Mariposa
Madera
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
5
© 2013 Google
Image © 2013 TerraMetrics
Google earth
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km



Turlock
Mariposa
Merced
140
Merced
Madera
99
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
5
© 2013 Google
Image © 2013 TerraMetrics
Google earth
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

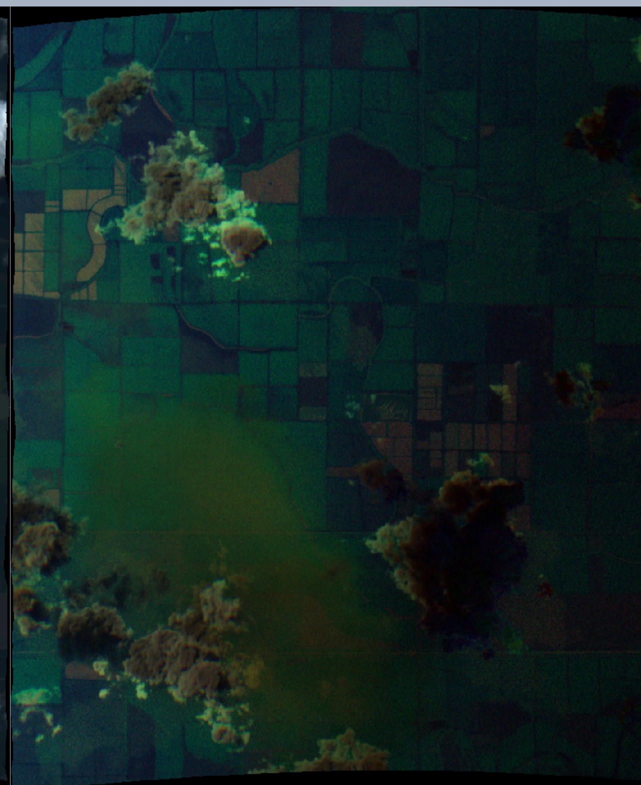

Turlock
Mariposa
Merced
140
Merced
Madera
99
Madera
Fresno
Fresno CARB Site
California
Fresno
180
Dinuba
Orosi
Kingsburg
© 2013 Google
Image © 2013 TerraMetrics
Google earth
5
lat 36.864094° lon -119.790924° elev 108 m eye alt 102.45 km

MAIA Step-and-Stare Acquisition

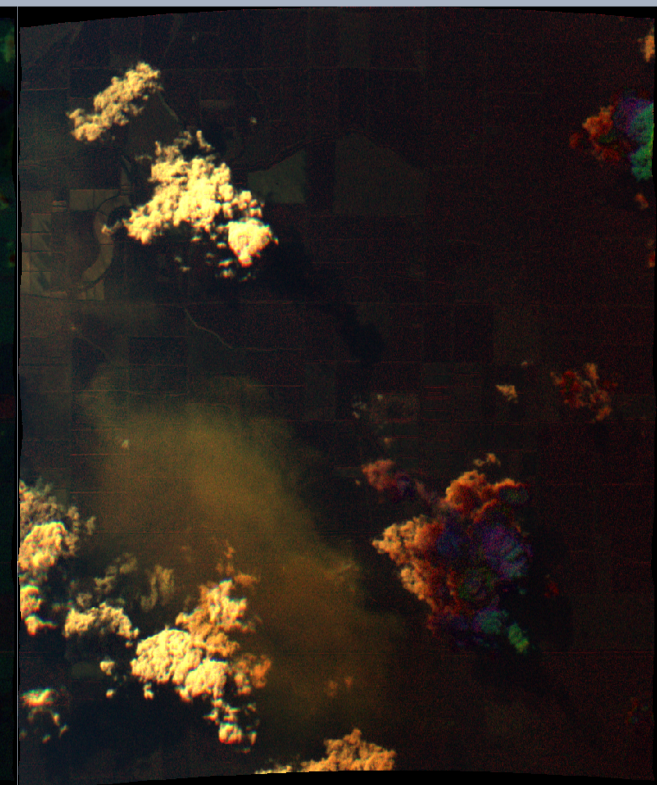


Effect of Aerosols on Polarization of Light

Intensity



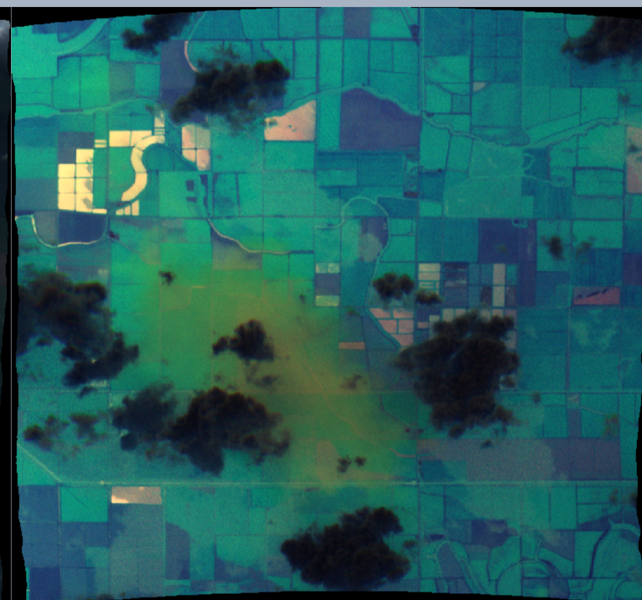
Degree of Linear Polarization



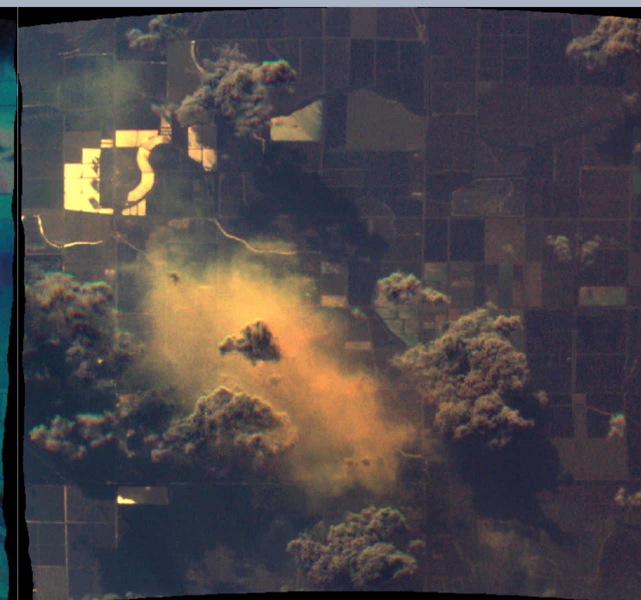
Polarized Intensity

Effect of Aerosols on Polarization of Light

Intensity

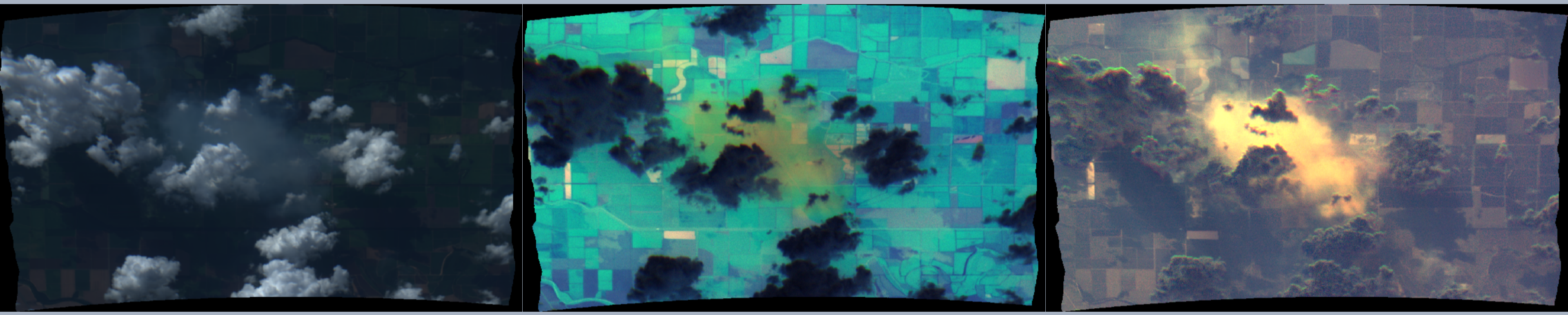


Degree of Linear Polarization



Polarized Intensity

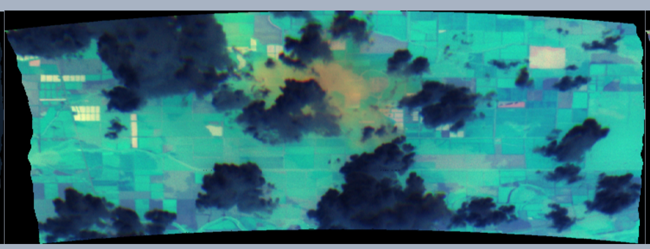
Effect of Aerosols on Polarization of Light



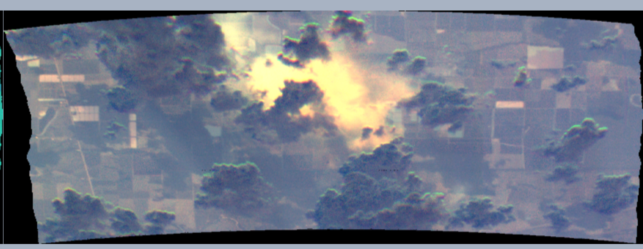
Intensity　　Degree of Linear Polarization　　Polarized Intensity

Effect of Aerosols on Polarization of Light

Intensity



Degree of Linear Polarization

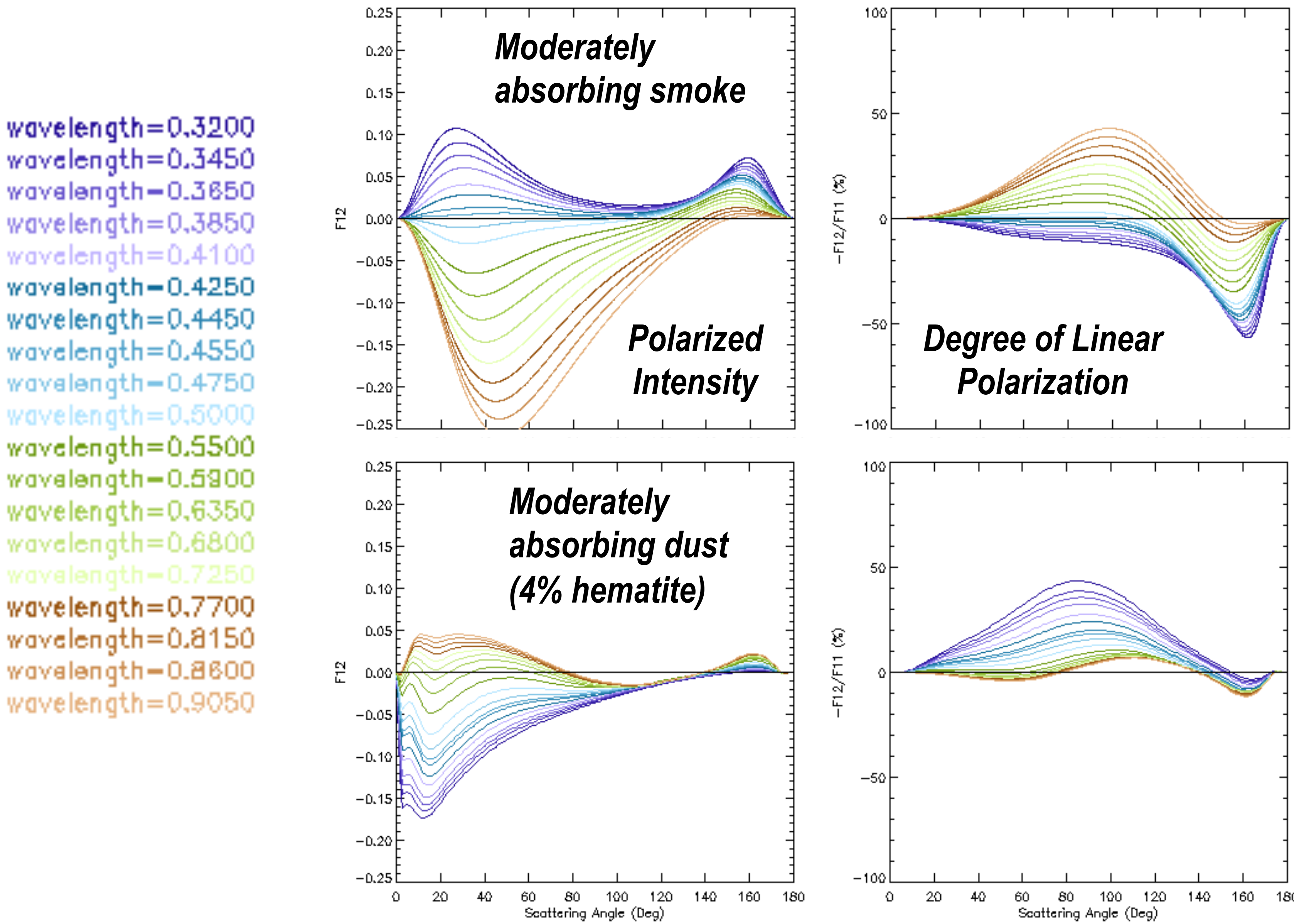


Polarized Intensity

Effect of Aerosols on Polarization of Light

Intensity Degree of Linear Polarization Polarized Intensity

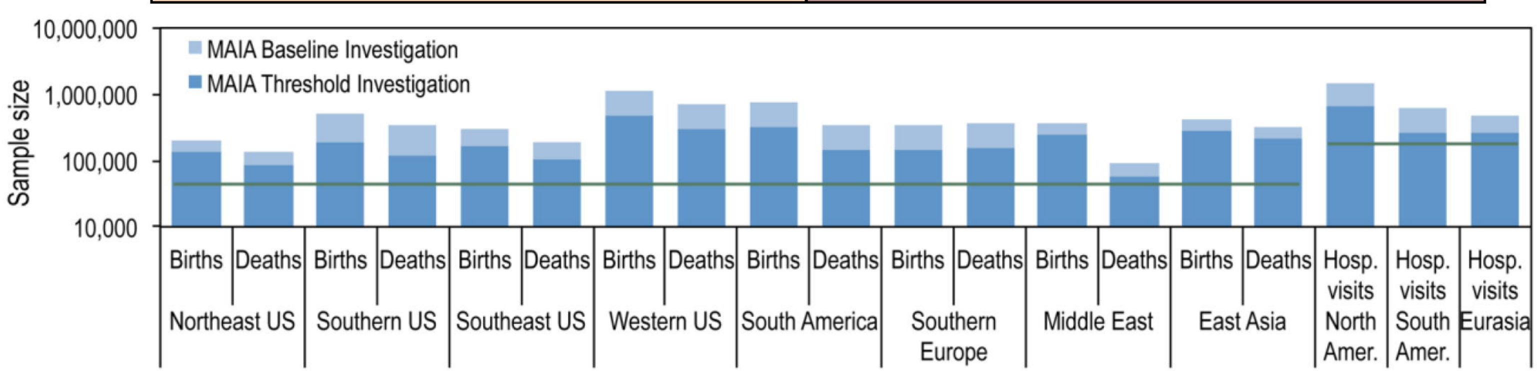
Effect of Aerosols on Polarization of Light



MAIA Candidate Primary Target Areas

Candidate Primary Target Area (PTA)	Representative Cities (Population, Millions of People)	Annual Mean PM Range (μg m^{-3})		Dominant PM Types	Study Objectives and Health Data Record Providers
		$PM_{2.5}$	PM_{10}		
Northeastern US	Boston, Worcester, Springfield (5.4)	9–10	15–16	Sulfates, OC	MA Dept. of Public Health, Medicare Normative Aging Study, Framingham Heart Study, other cohorts
Southern US	Dallas, Houston (13.7)	12–13	20–21	OC, sulfates	Dallas-Ft. Worth Hospital Council Foundation, TX State Health Services
Southeast US	Atlanta, Macon, Birmingham (7.7)	8–18	16–30	Sulfates, OC	GA Hospital Association, GA State Health Dept., individual hospitals
Western Europe	Amsterdam, Mülheim, Essen, Bochum (3.4)	18–19	25–30	Sulfates, OC, dust	European Study of Cohorts for Air Pollution Effects (ESCAPE) [137] (§D.2.4)
Southern Europe	Rome, Milan (12.3)	21–33	32–37	Sulfates, dust	ESCAPE [137] (§D.2.4)
South America	São Paulo, Rio de Janeiro (17.5)	17–36	35–67	OC, sulfates	City Vital Statistics Prospective Urban and Rural Epidemiological Study (PURE) [158] (§D.2.4)
Western US	San Francisco, Fresno, Los Angeles, Bakersfield (28.8)	10–45	16–74	Nitrates, OC, BC/sulfates	CA Dept. of Health, Office of Statewide Health Planning and Development
Middle East	Tel Aviv, Nes Ziona, Jerusalem (4.7)	31–42	59–67	Dust, sulfates	Ministry of Health
Eastern Asia	Taipei, Taichung, Kaohsiung (14.6)	23–48	42–77	Sulfates, OC	Ministry of Health and Welfare
South Africa	Johannesburg, Pretoria (7.4)	41–51	60–98	Dust, sulfates, OC	PURE [158] (§D.2.4)
Southern Asia	Delhi, Kanpur, Jaipur (17.9)	24–153	55–286	Dust, sulfates, OC	PURE [158], Public Health and Air Pollution in Asia (PAPA) [67] (§D.2.4)

Impact of short-term exposure on birth outcomes, deaths, emergency department visits, and hospitalizations	Impact of chronic exposure on cardiovascular and respiratory morbidities and mortalities



Rationale for MAIA Candidate PTAs

Target areas for studying
- short-term PM exposure
- chronic PM exposure

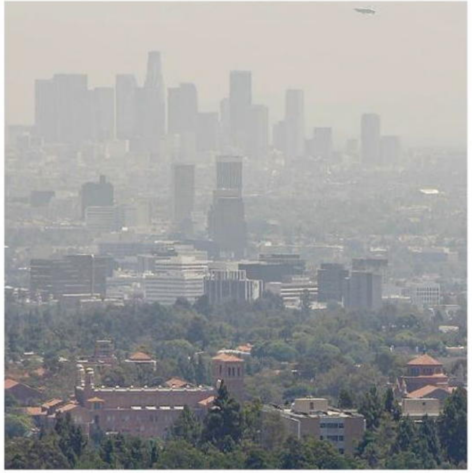
- Include major population centers on five continents
- Cover a wide range of PM concentrations and particle types
- Include AERONET sunphotometers and PM size/speciation monitors to complement the MAIA instrument
- Are associated with available geocoded birth, death, emergency department, and hospitalization records
- Enable epidemiological sample sizes of tens to hundreds of thousands of cases, yielding the statistical power needed to assess health impacts

Strawman MAIA Weekly Operations Scenario

Target Area Designation	Target Locations	No. of Targets	Average Revisits/ Week	Allocated Orbits/ Week
Primary	Primary Target Areas for health studies	11	3–6	50
Secondary	Area of interest for aerosol and cloud science, e.g., (a) cities with elevated pollution, (b) aerosol source regions, (c) ground monitor sites, (d) cloud regimes affected by aerosol pollution	10	3	30
Calibration/ Validation	Railroad Valley, NV; AERONET sites	8	2	16
Opportunistic	Volcanic eruption, major wildfire, dust storm, industrial accident	Varies	2	4

Assumes 100 orbits/week, 1 target/orbit

A mechanism to solicit science community input to selection of Secondary Targets will be established (e.g., MAIA Science Team Meeting in October 2016)



MAIA

Spectropolarimetric Measurements from Multi-Angle Imager for Aerosols: From Climate to Air Quality