Jet Propulsion Laboratory
California Institute of Technology

Remote Visible / Shortwave Imaging Spectroscopy for Terrestrial Ecology

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Abstract

Visible / Shortwave Infrared Imaging Spectroscopy for Terrestrial Ecology

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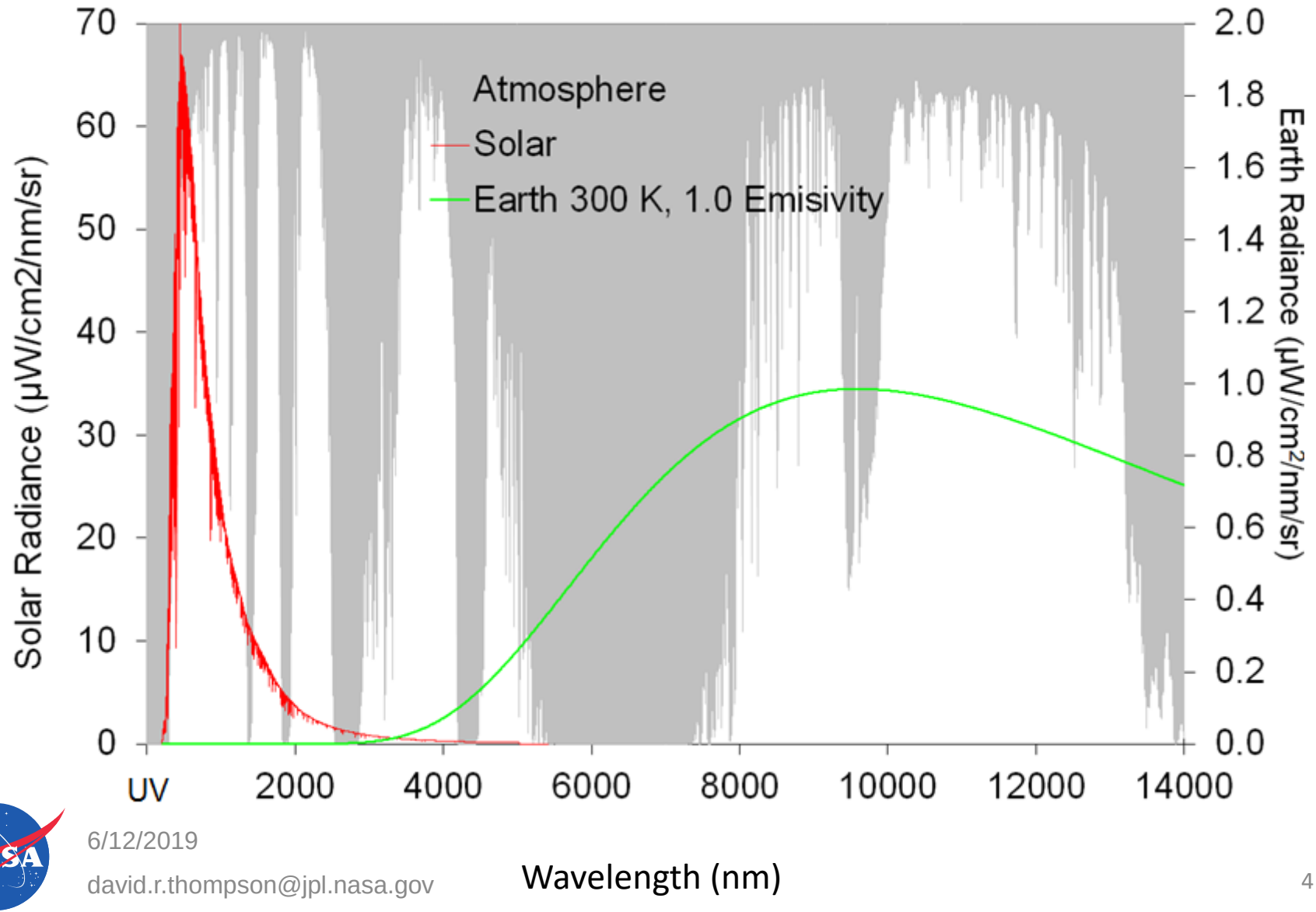
Imaging spectrometers enable quantitative maps of physical and chemical properties at high spatial resolution over large areas. They have a long history of deployments for mapping terrestrial and coastal aquatic ecosystems. Measurable parameters include ecosystem functional type, health, and productivity. This talk will provide an introduction to remote imaging spectroscopy in the Visible and Shortwave Infrared, describing the measurement strategy and data analysis considerations including atmospheric correction. We will investigate prior successes in terrestrial ecology and agriculture domains, and describe latest developments in algorithms and instrument sensitivity.

David R. Thompson is a researcher in the Imaging Spectroscopy group at the NASA Jet Propulsion Laboratory. He is science software lead for the NEAScout mission, autonomy software lead for the PIXL instrument, and leads the algorithm development for JPL airborne imaging spectrometers such as PRISM and AVIRIS-NG. He is recipient of the NASA Early Career Achievement Medal and the JPL Lew Allen Award.

Agenda

- Basic principles
- Historical instruments
- Atmospheric correction
- A survey of ecosystem applications
- Fresh data
- Future directions

Dramatis Personae



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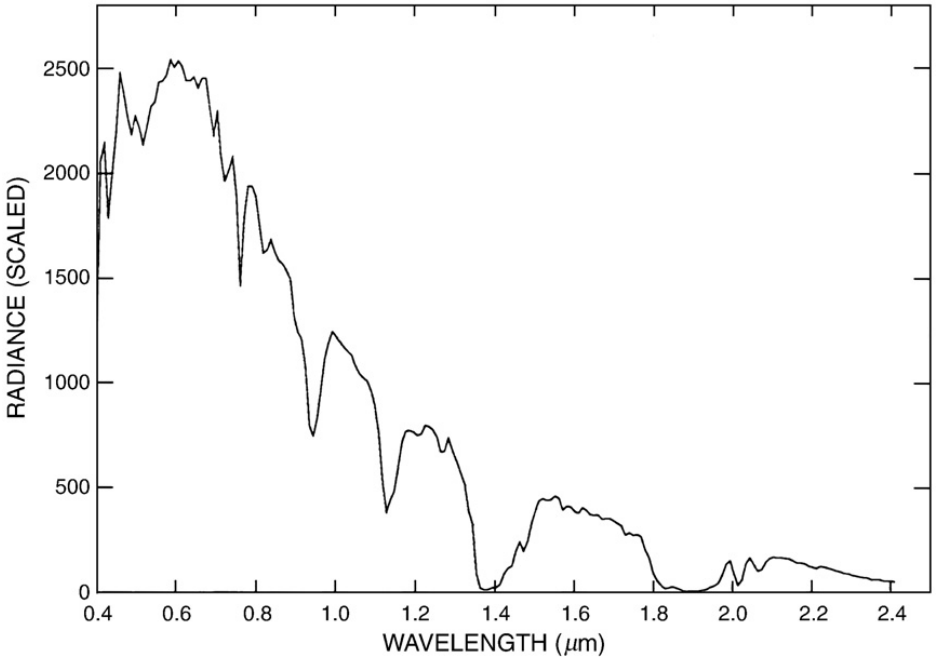
Imaging spectroscopy: 1000s of parallel spectrometers to map the invisible

Detector Array

B.-C. Gao et al. / Remote Sensing of Environment 113 (2009) S17–S24



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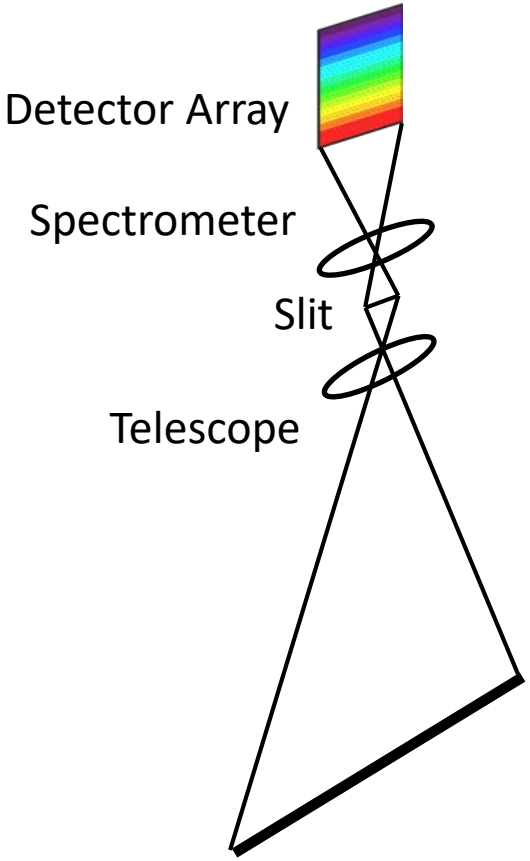

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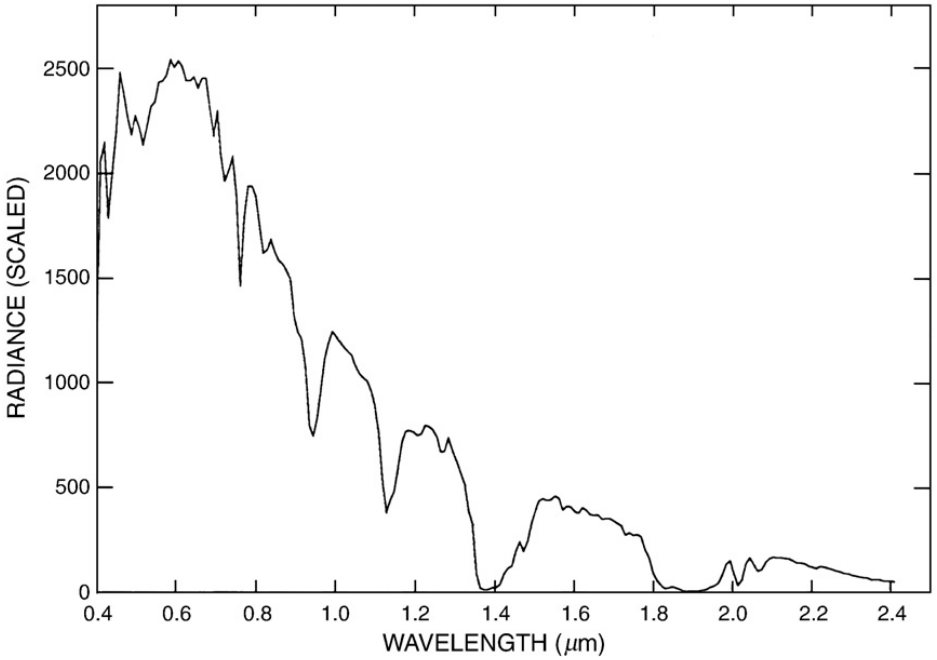

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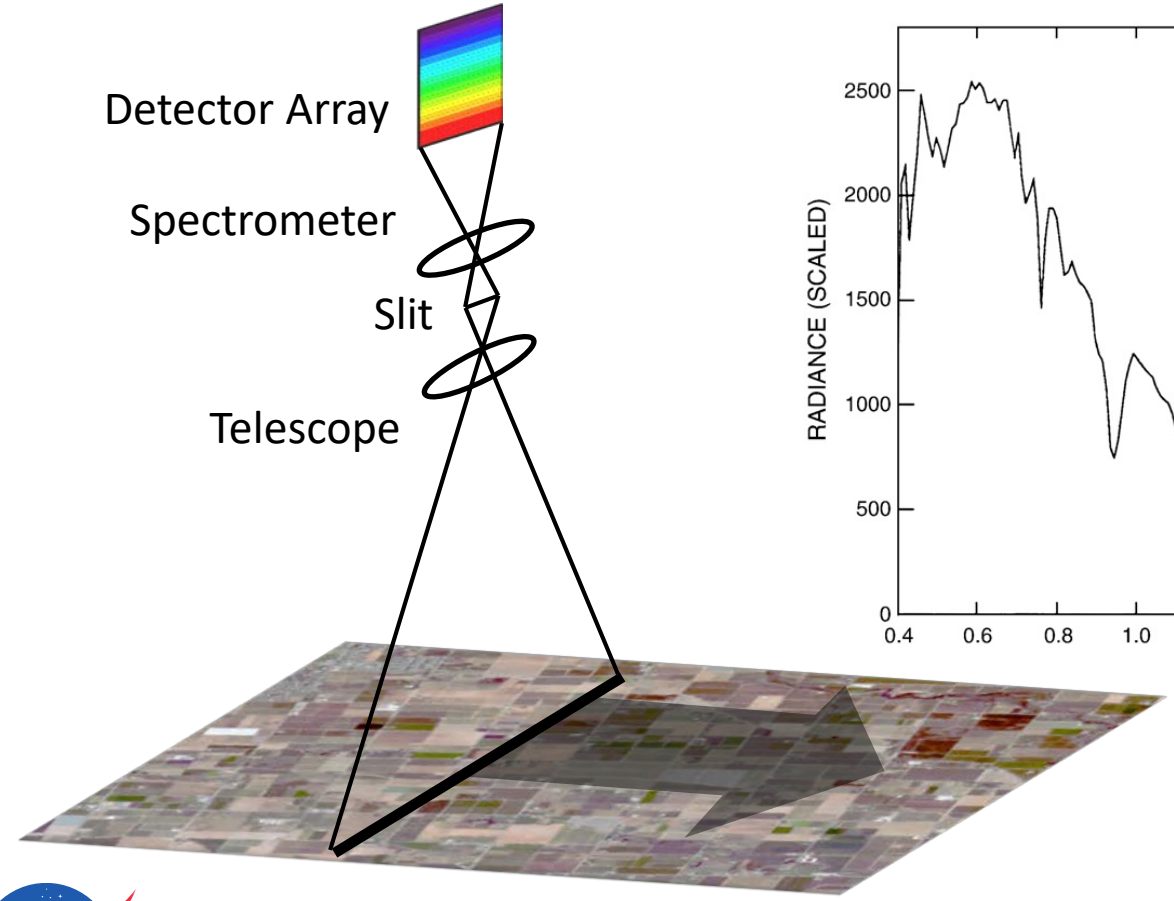
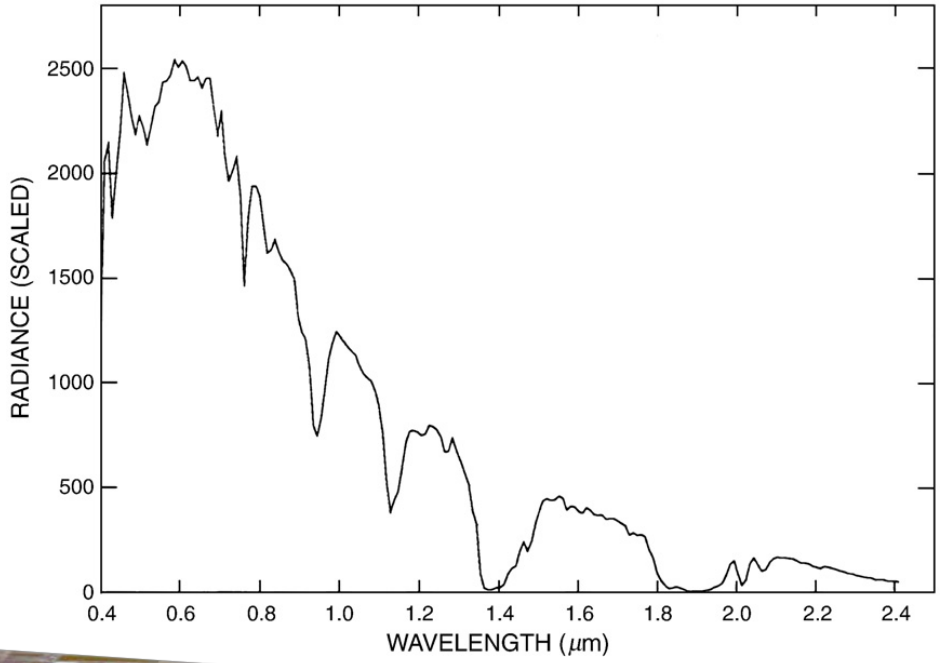
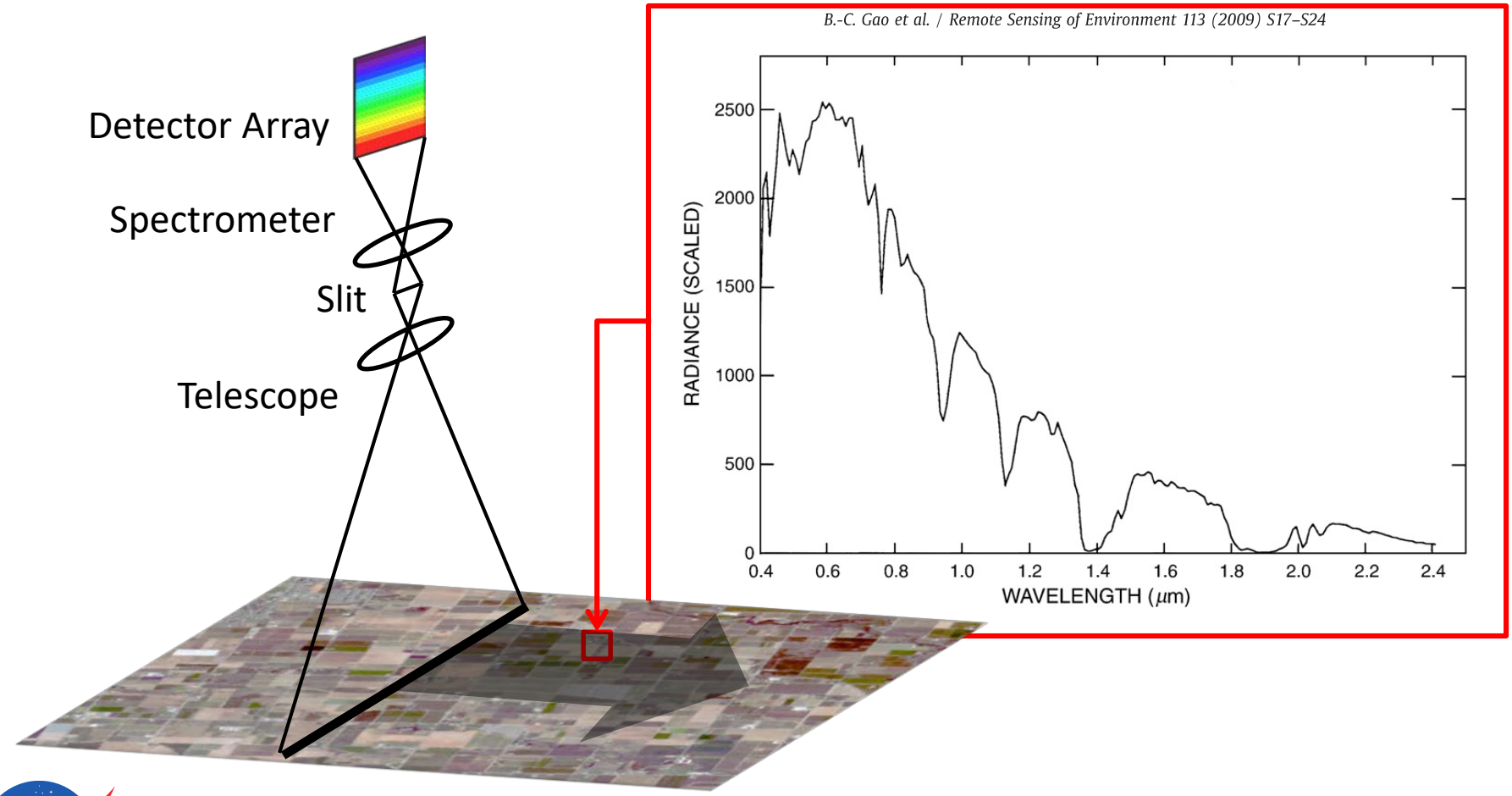


B.-C. Gao et al. / Remote Sensing of Environment 113 (2009) S17–S24



Imaging spectroscopy: 1000s of parallel spectrometers to map the invisible



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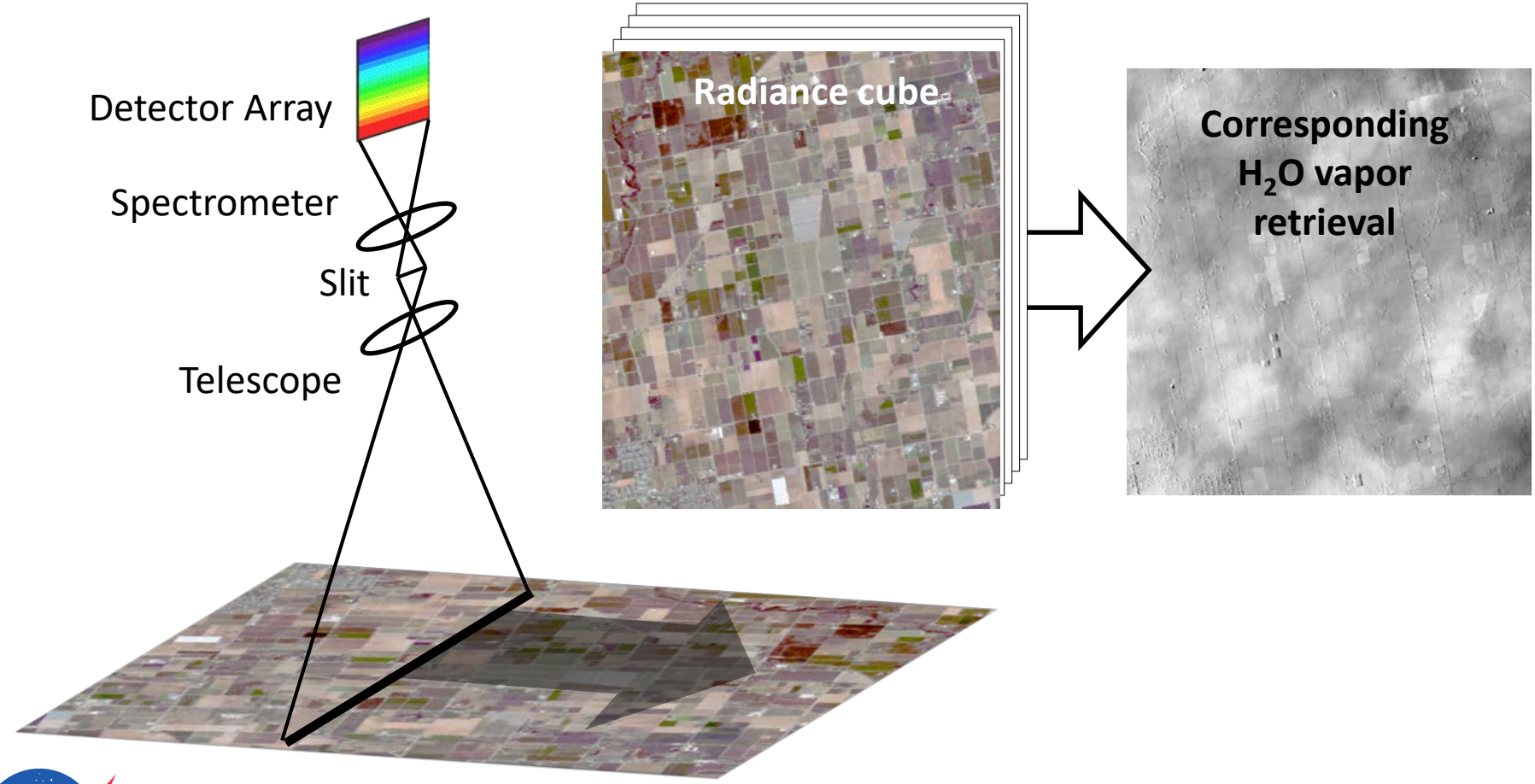
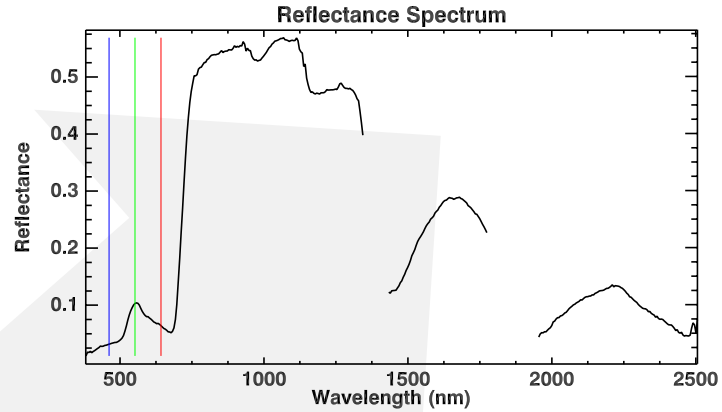
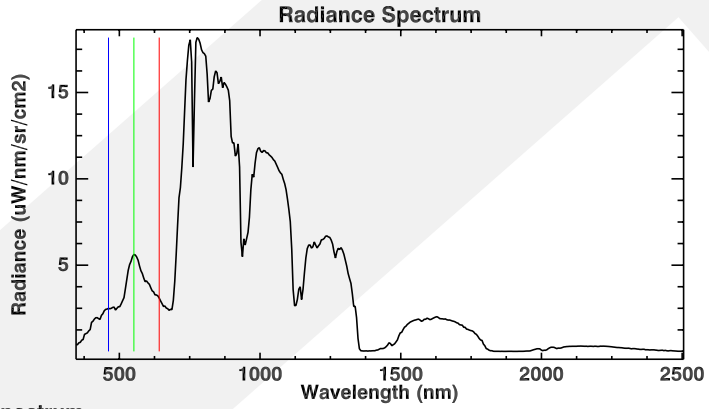
Imaging spectroscopy: 1000s of parallel spectrometers to map the invisible



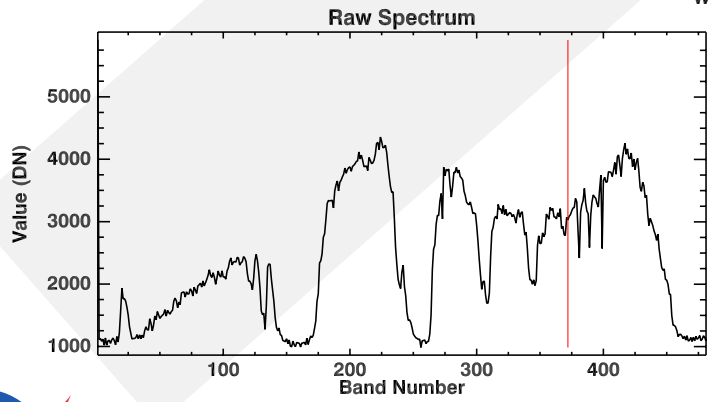
Atmospheric correction



Lambertian Reflectance (HDRF)



Radiance at sensor mW/nm/cm^2/sr



Raw Digital Numbers

[Gao et al., 1993; Green et al., 1998, Thompson et al., RSE 2015]

Atmospheric correction

Solar spectrum F (modified Kurucz)

Aerosol particle type distribution, AOD at 550nm

Top of atmosphere apparent reflectance ρ

$$\rho = \frac{\pi L}{F\ cos(\theta)}$$

Retrieve pressure altitude, H_2O vapor, liquid by fitting absorption features

Calculate molecular & aerosol scattering w/6s radiative transfer code

Gaseous transmission T_g

Aerosol transmission T_dT_u, Spherical sky albedo s, Path reflectance r_a

Reflectance spectrum

$$r_s = \frac{\rho/T_g - r_a}{T_dT_u + s(\rho/T_g - r_a)}$$

Residual suppression via a reference target

Corrected reflectance spectrum

Traditionally bifurcated into RTM and empirical methods

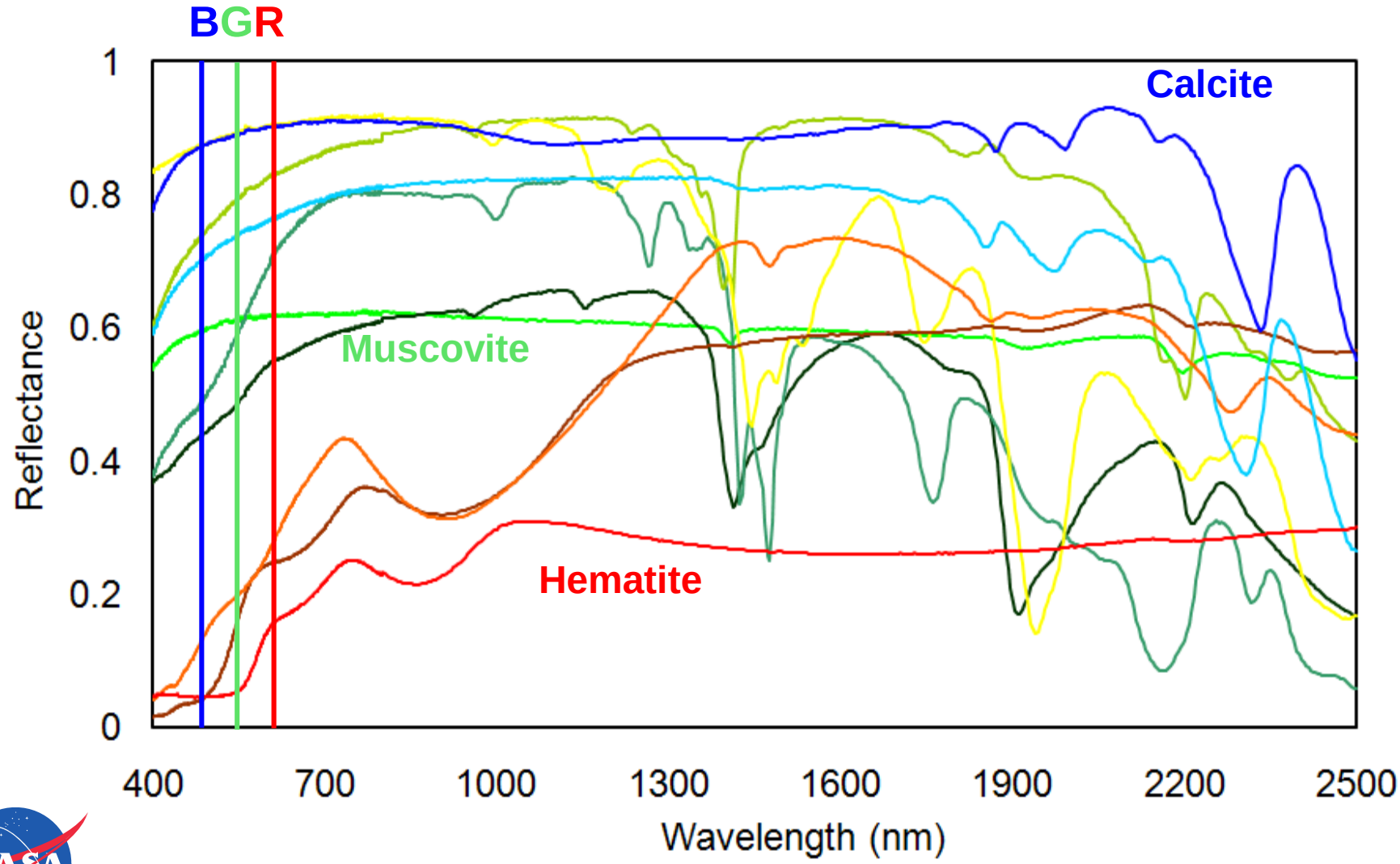
RTM (model-based)

- No in-situ measurements needed
- Stable and physically Interpretable
- Can be inaccurate if model assumptions are violated

Empirical

- Highly accurate when provided many in situ spectra
- Tedious field measurements
- Unstable with few spectra
- Heterogeneity assumption

Mineral features from reflectance



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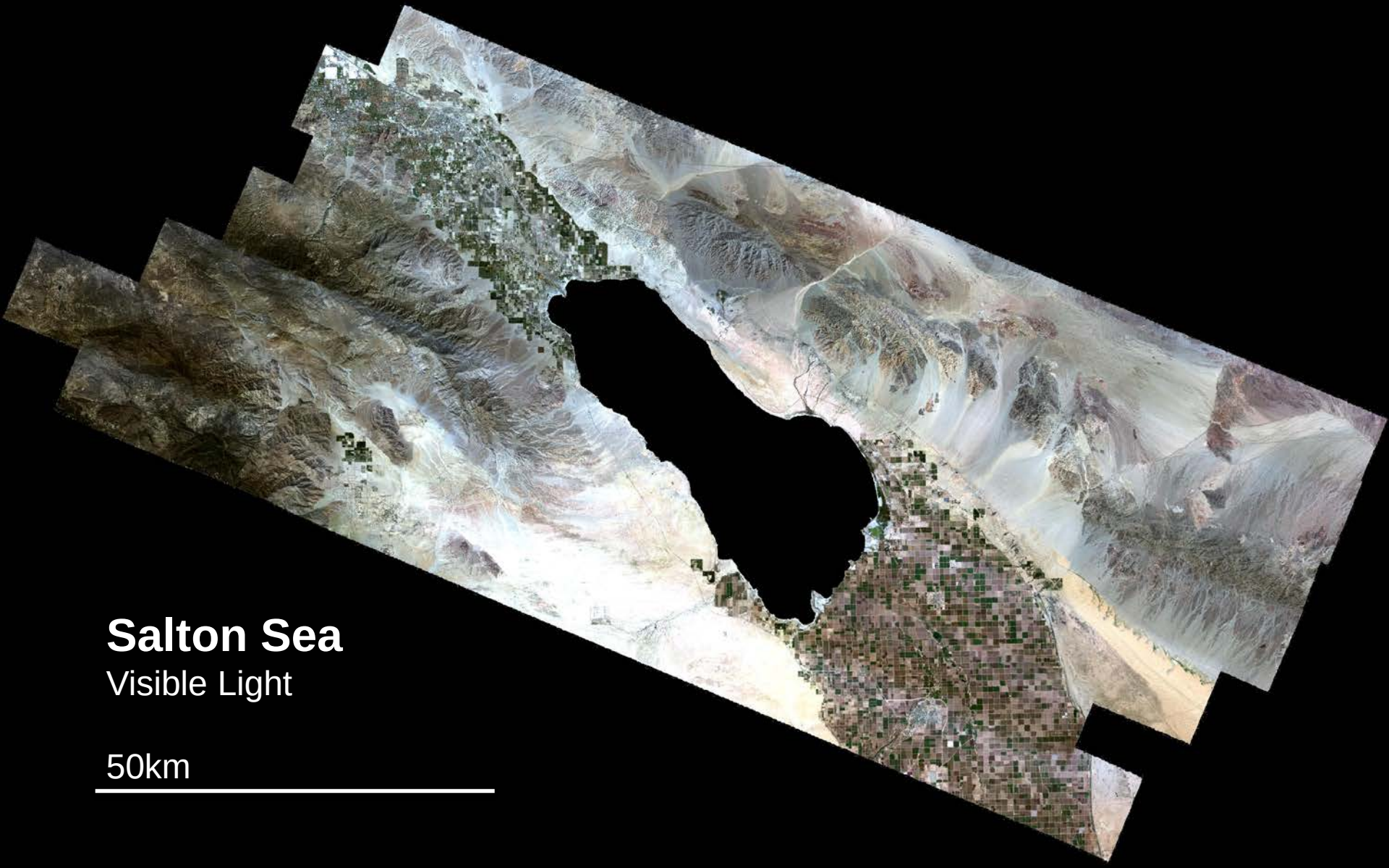
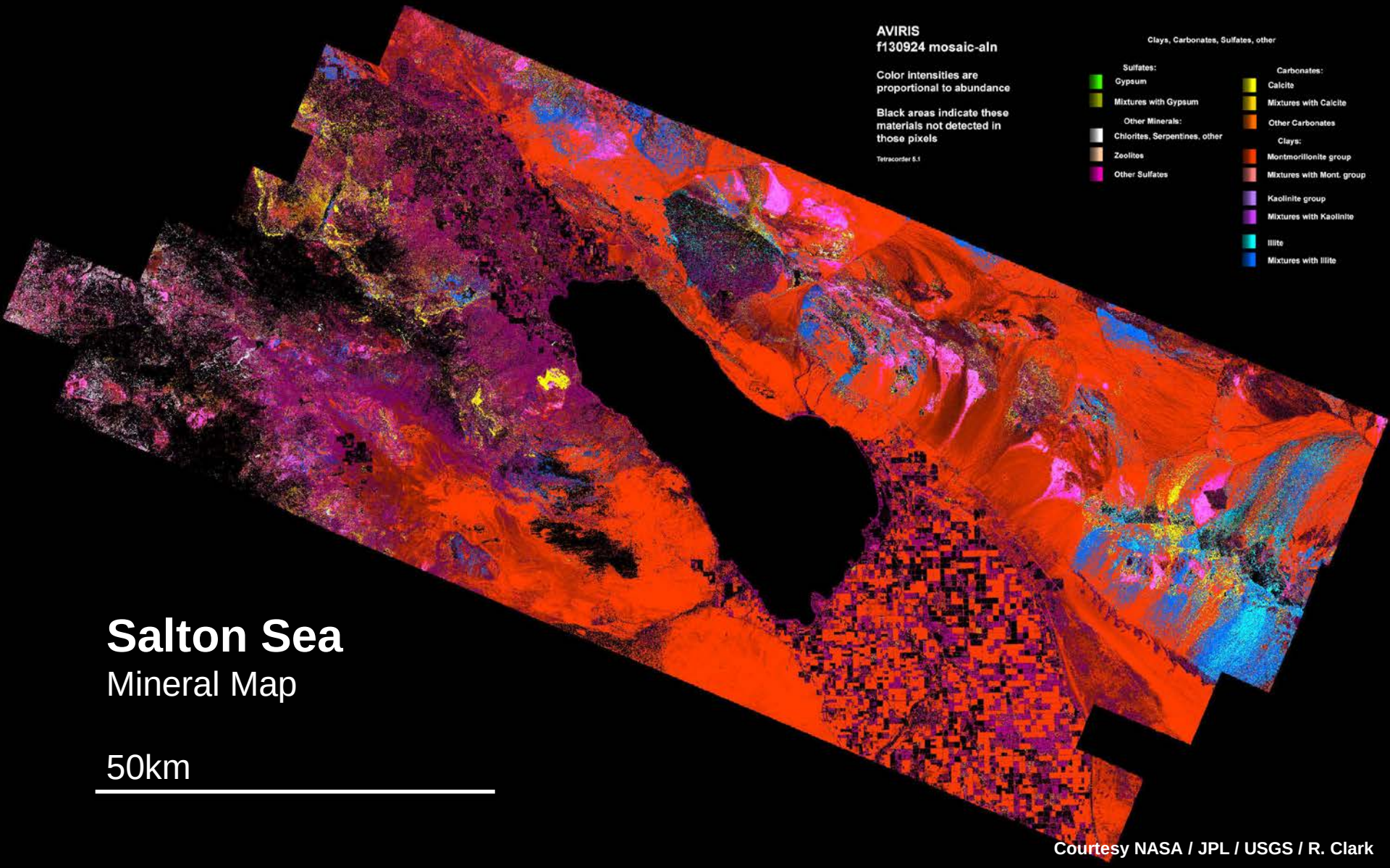

Salton Sea
Visible Light
50km



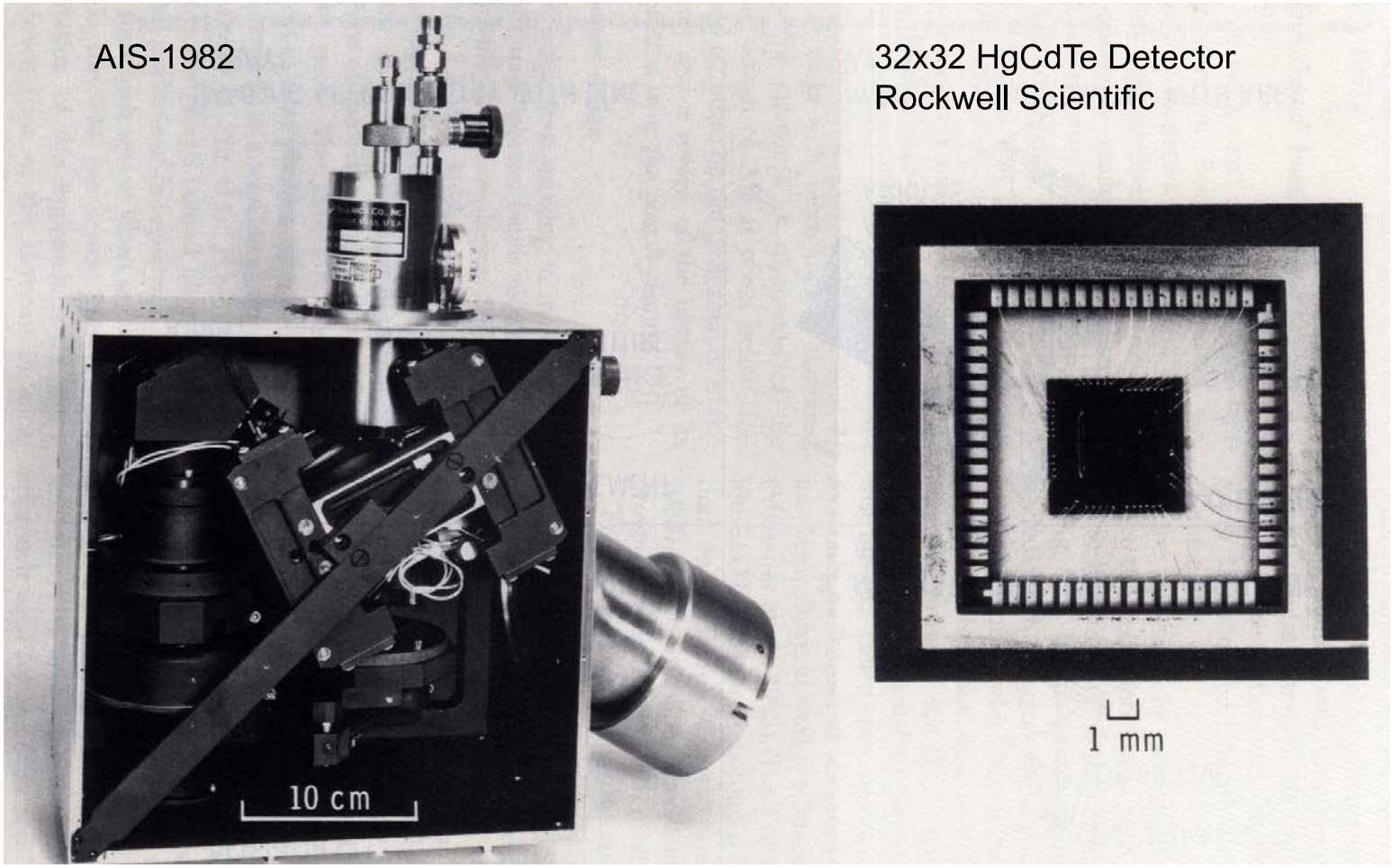
Salton Sea

Mineral Map

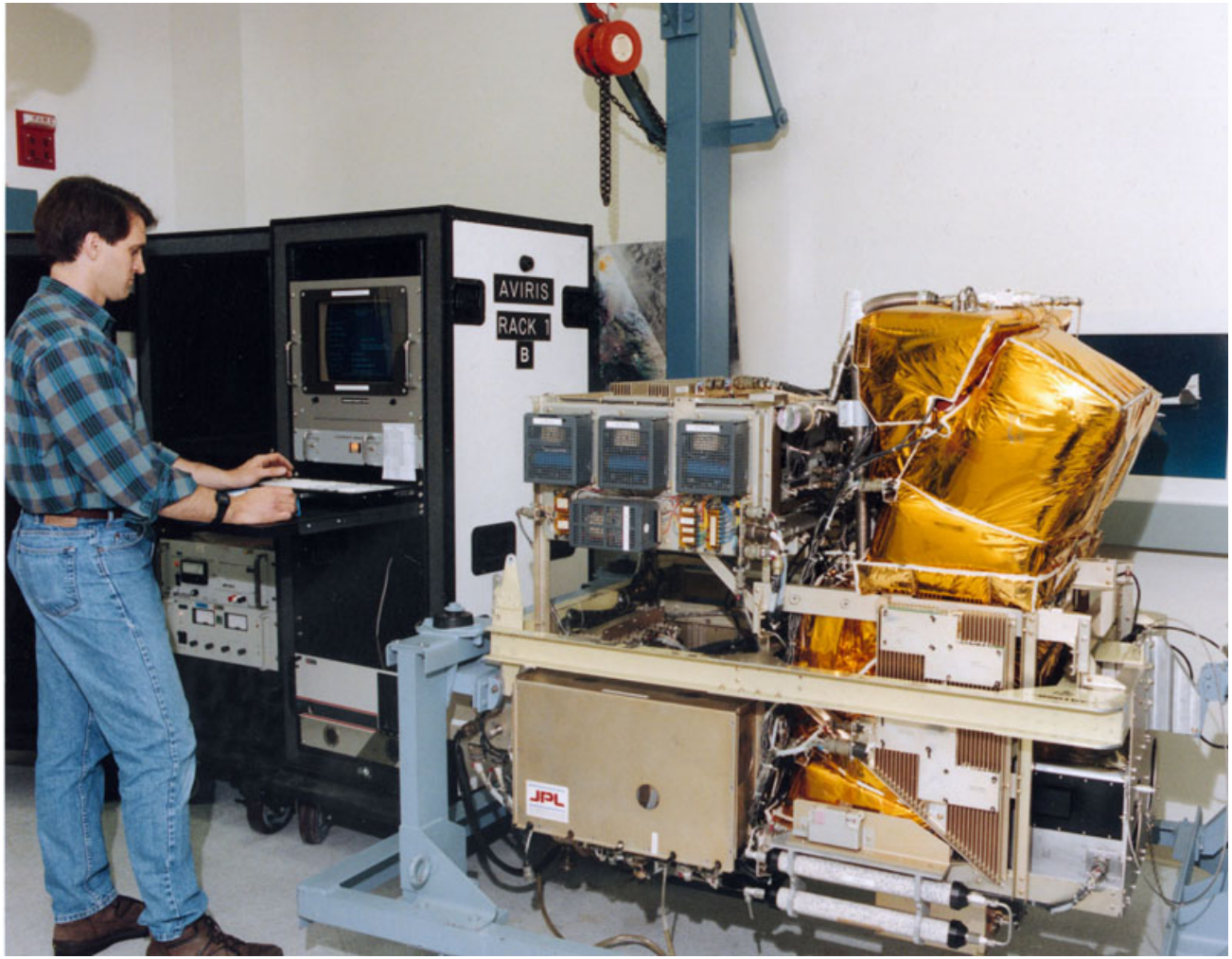
50km

Courtesy NASA / JPL / USGS / R. Clark

JPL Spectrometers (1982)



JPL Spectrometers (1986)

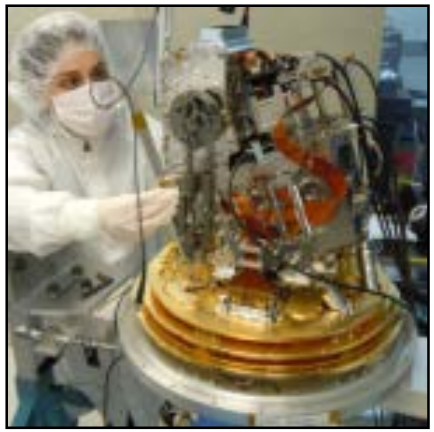


airbornescience.nasa.gov

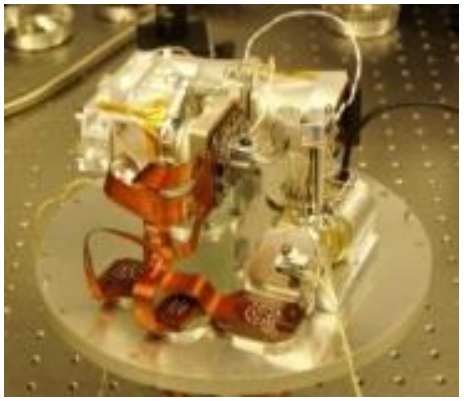
Recent instruments

MSS 2011

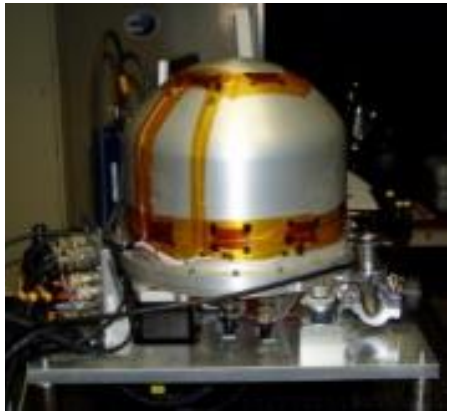
AVIRIS-NG 2012



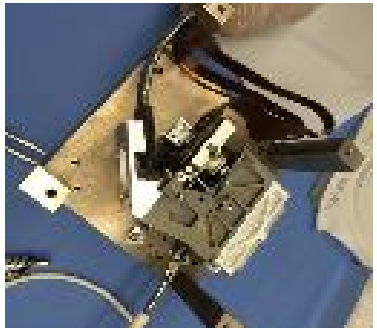
UCIS 2013



PRISM 2012

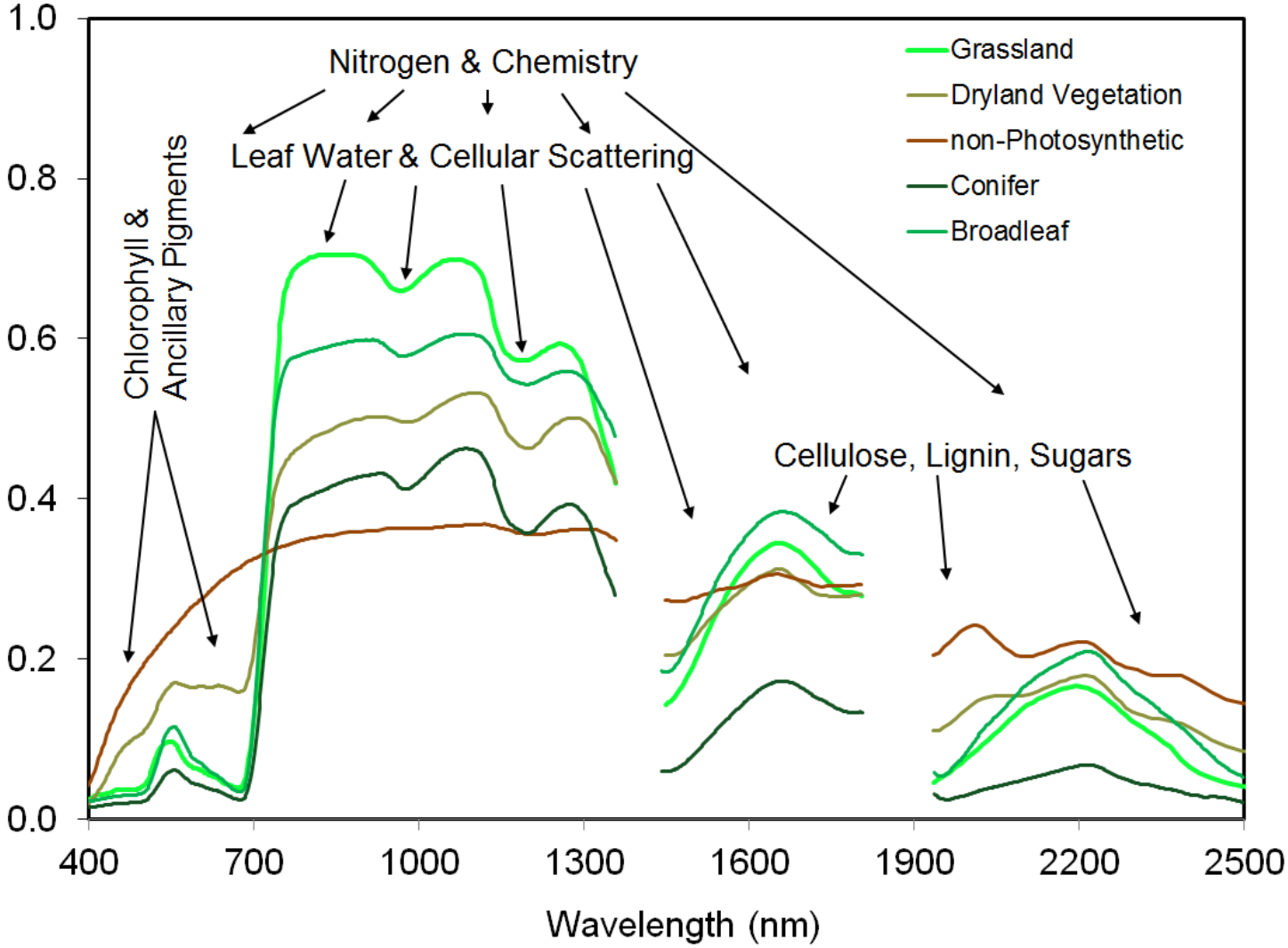


ESWIRS 2014



CWIS 2015

Vegetation signatures



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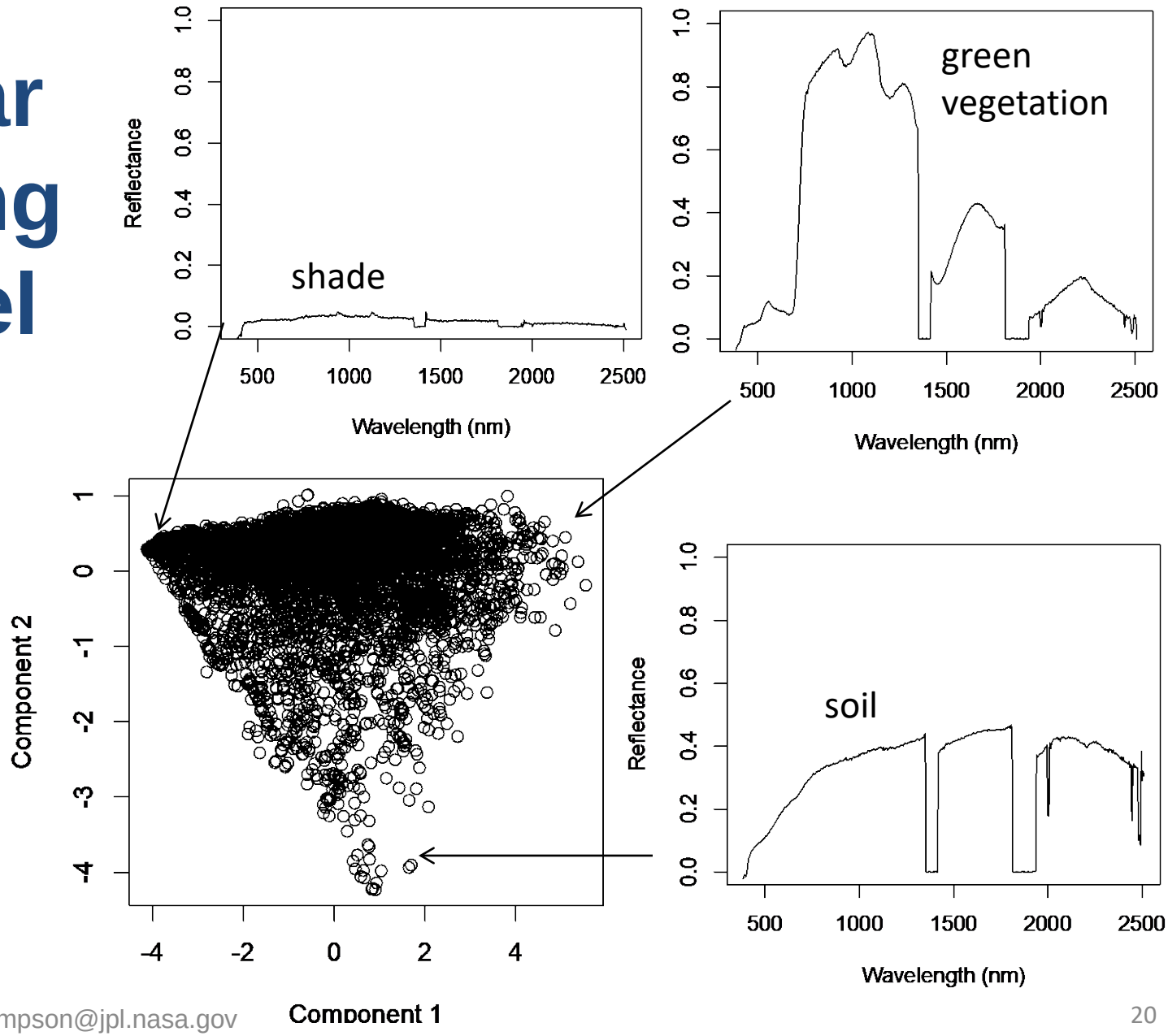
Linear mixing model



Linear mixing model

$$\rho_j = \sum_{i=1}^{\ell} \mathbf{a}_{i,j} b_i + \epsilon_j$$

Observed reflectance in wavelength j

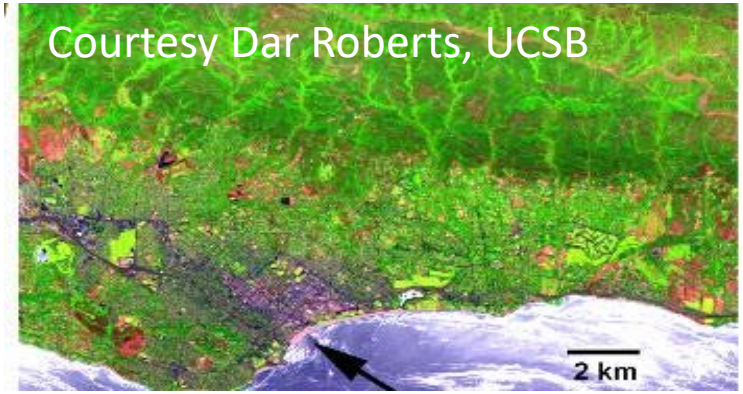
Library spectrum

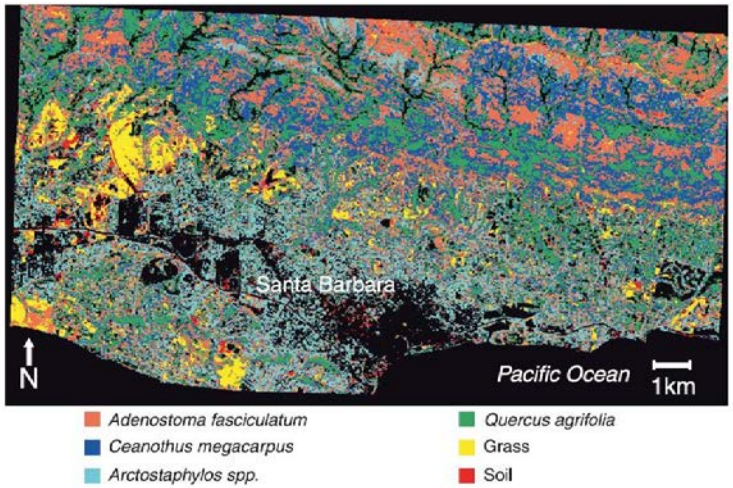
Mixing fraction

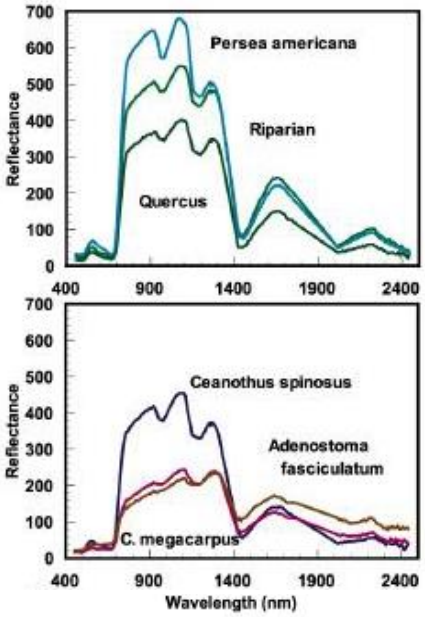
Measurement noise

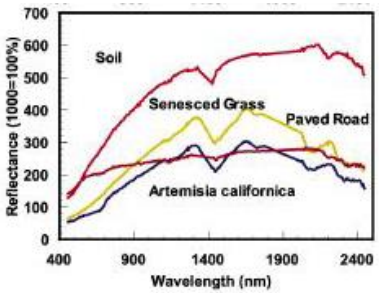
- A nonnegative least squares problem (all $b_i \geq 0$)
- MESMA (Roberts et al., RSE 2003) finds the optimal *compact* combination of library endmembers to reproduce observations
- Minimizes per-channel RMSE

Santa Barbara species maps

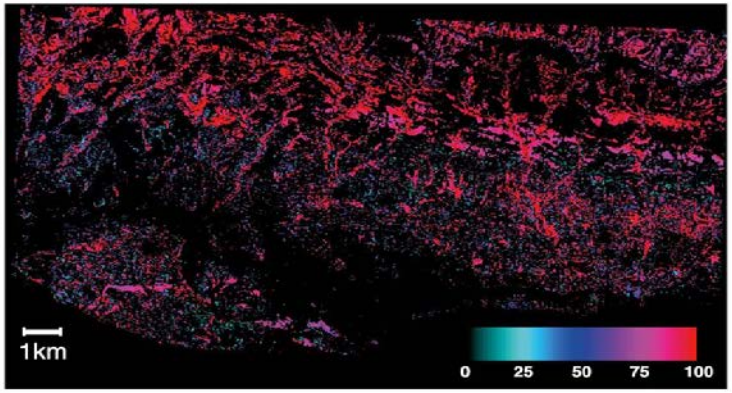








Species Fractional Cover Quercus agrifolia



Airborne Imaging Spectroscopy, Santa Barbara, CA

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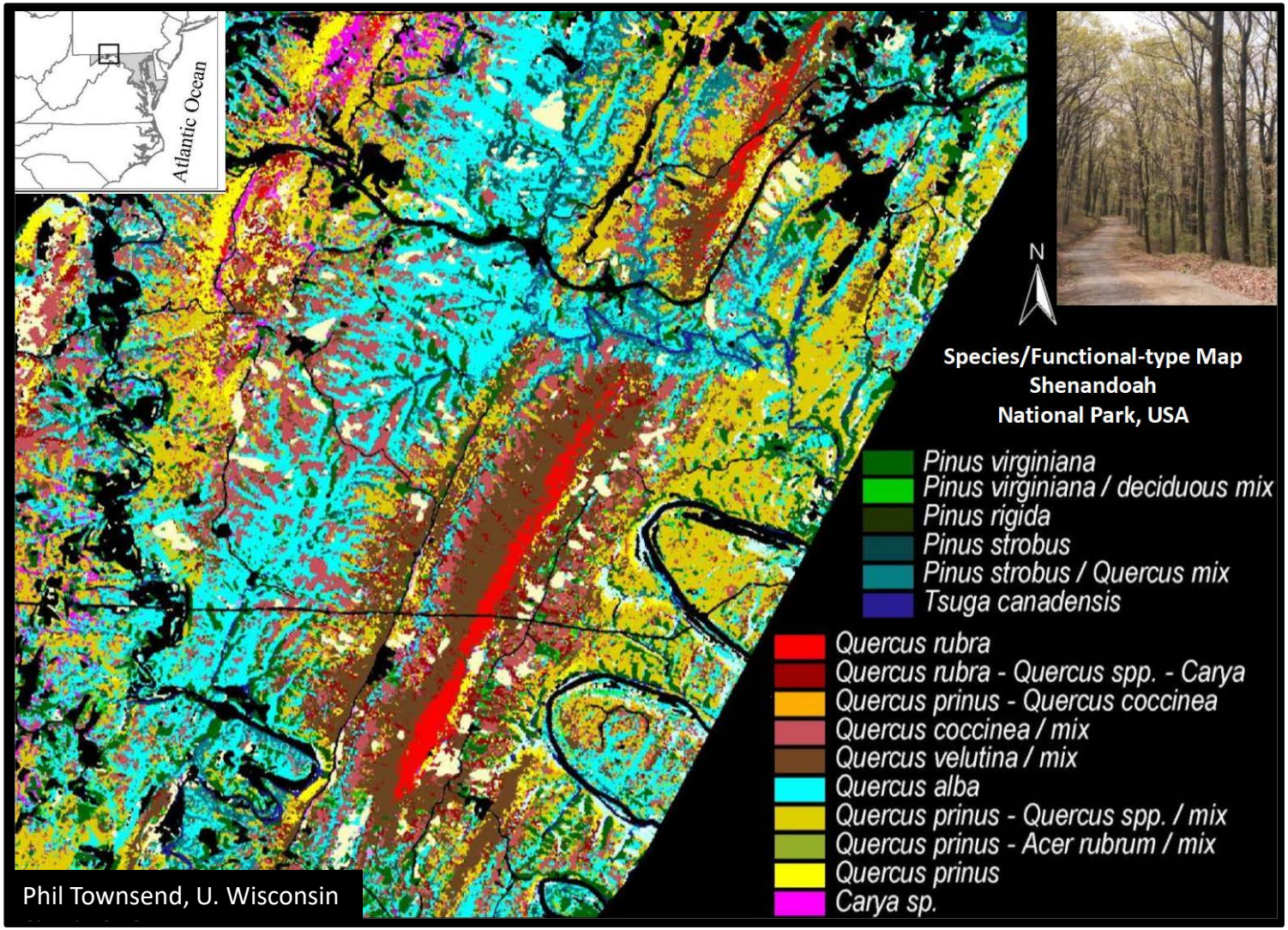
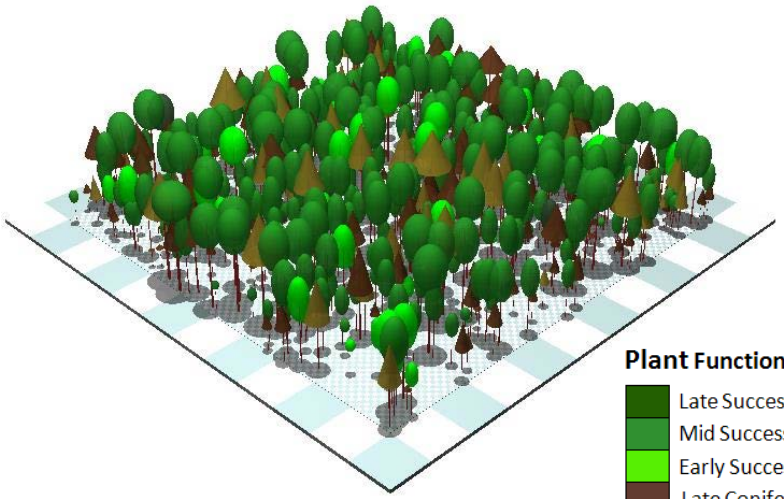
Shenandoa species maps



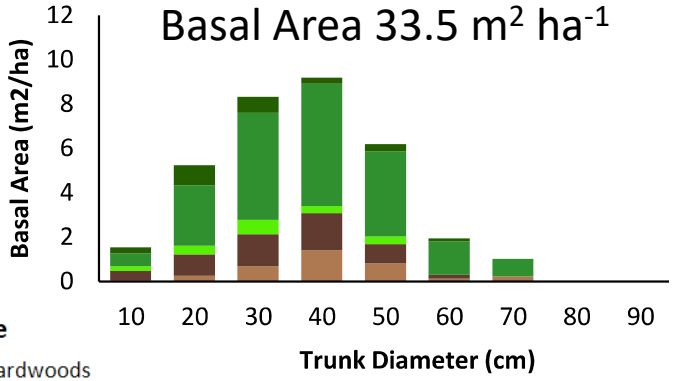
Phil Townsend, U. Wisconsin

Canopy structure models



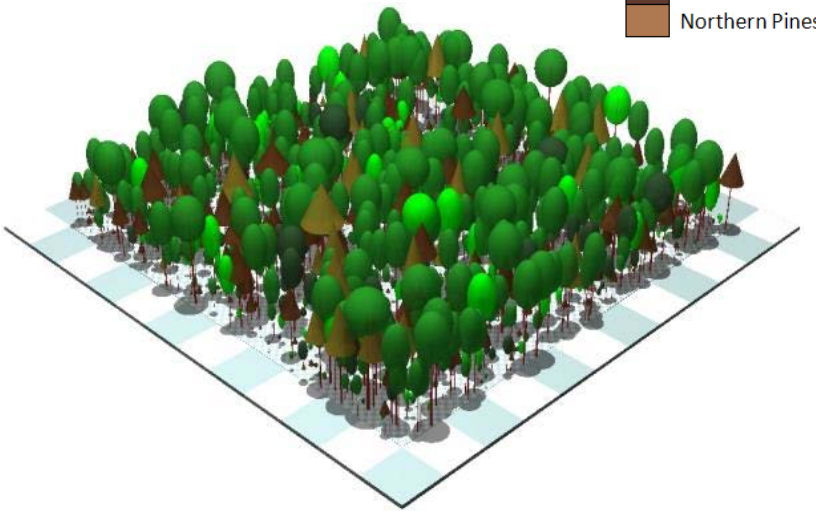
Field survey

Basal Area 33.5 m^2 ha^{-1}



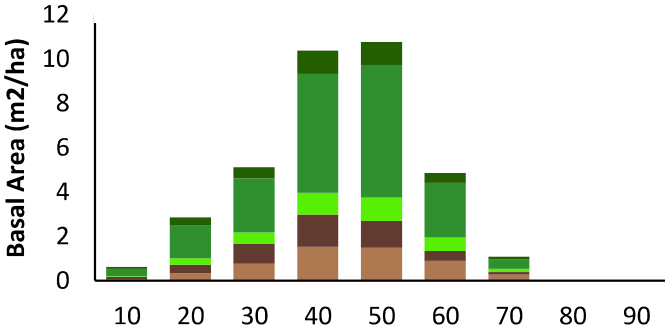
Plant Functional Type

- Late Successional Hardwoods
- Mid Successional Hardwoods
- Early Successional Hardwoods
- Late Conifers
- Northern Pines



GORT Spectroscopic model

Basal Area 35.6 m^2 ha^{-1}



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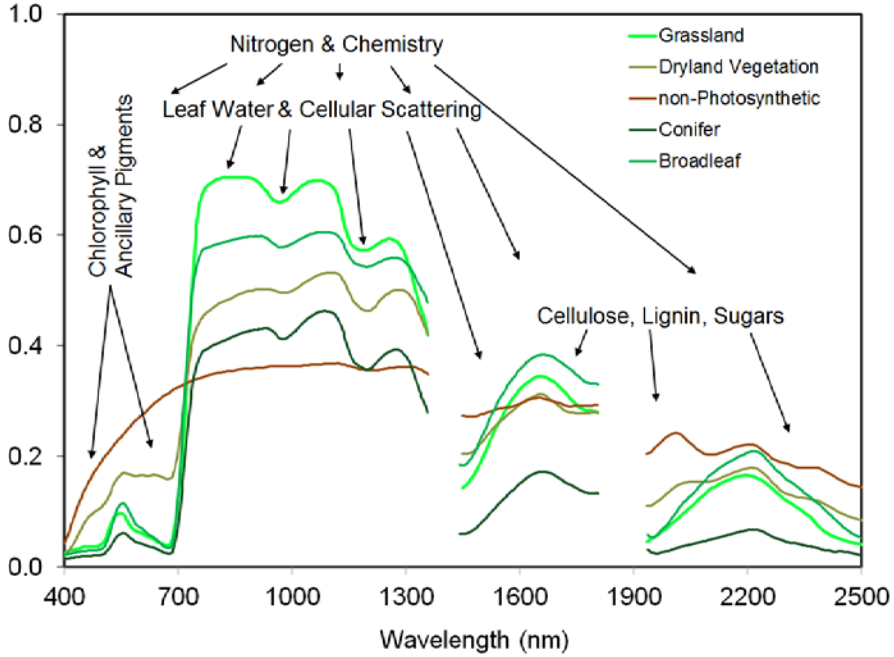
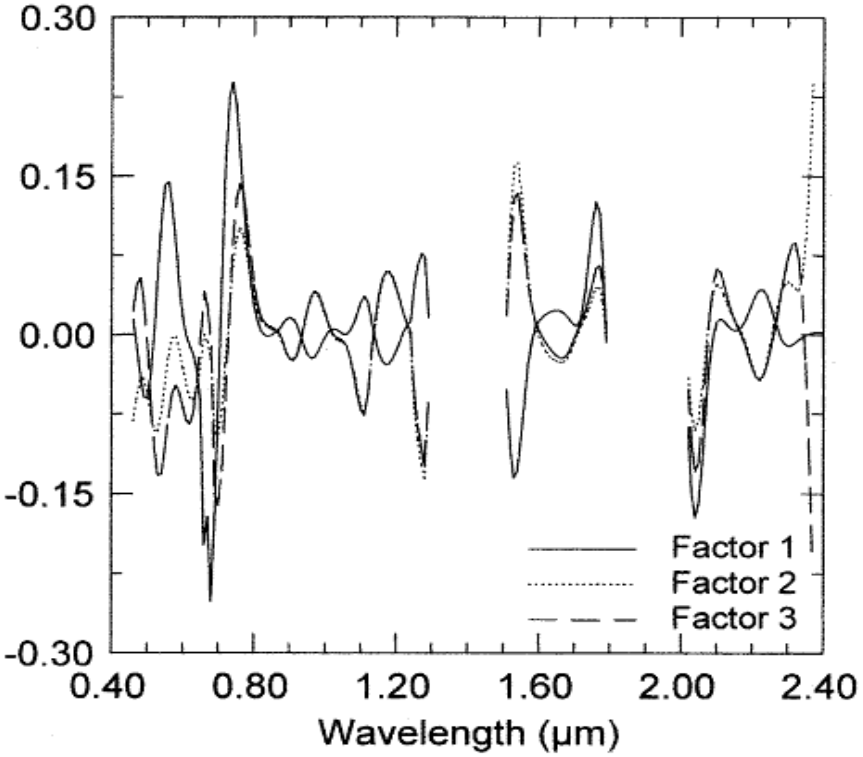
Predicting canopy nitrogen via PLS regression

Vegetation spectral features



Discriminative factor loadings



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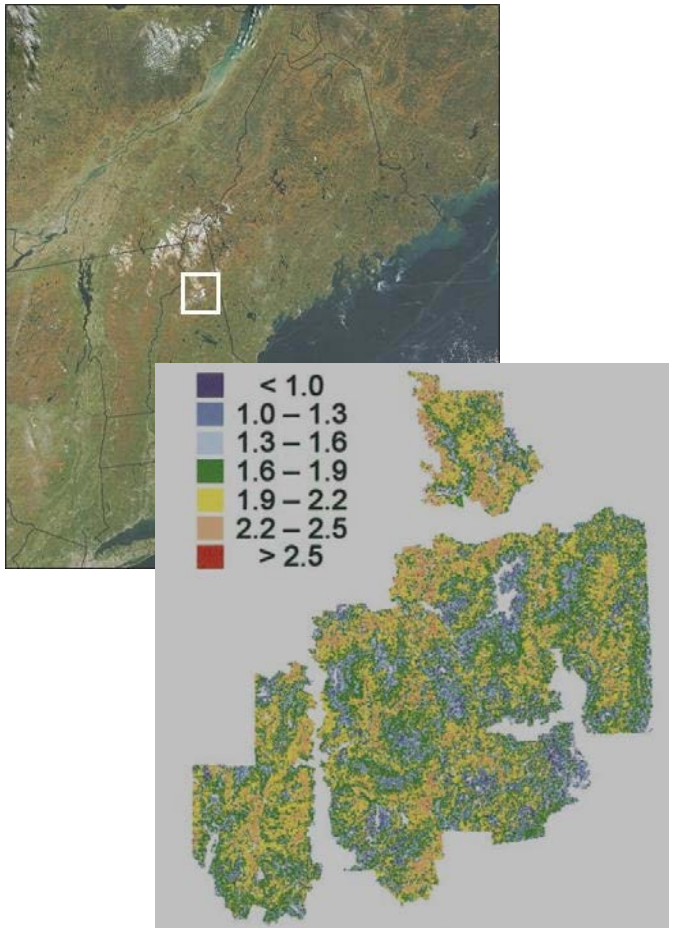
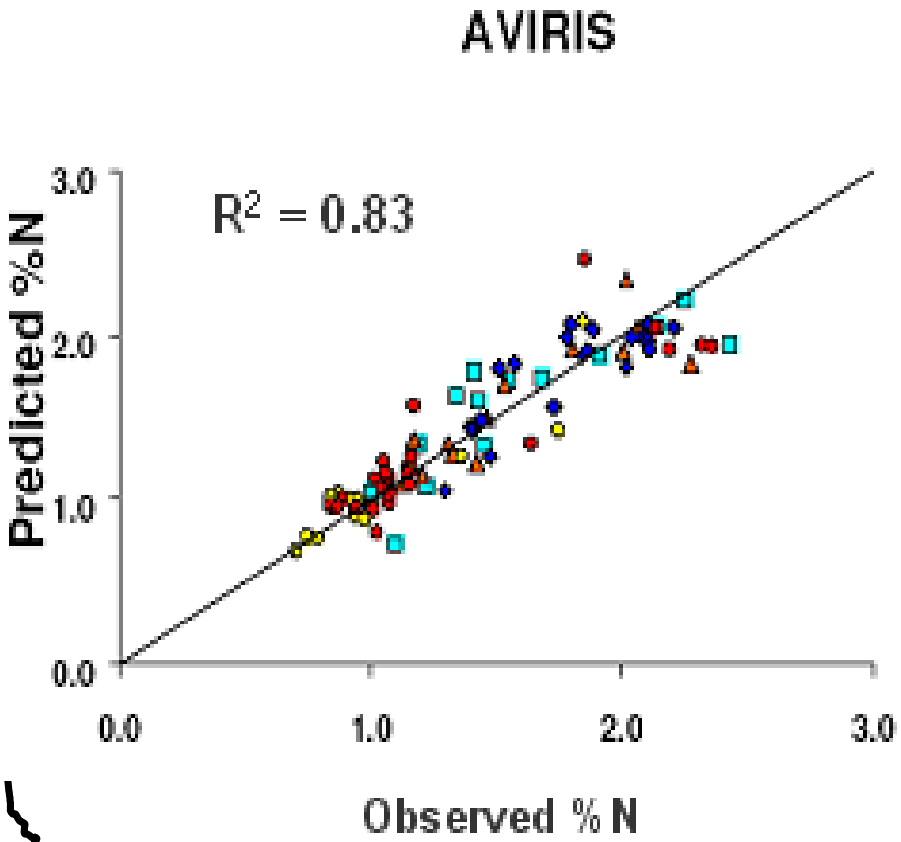
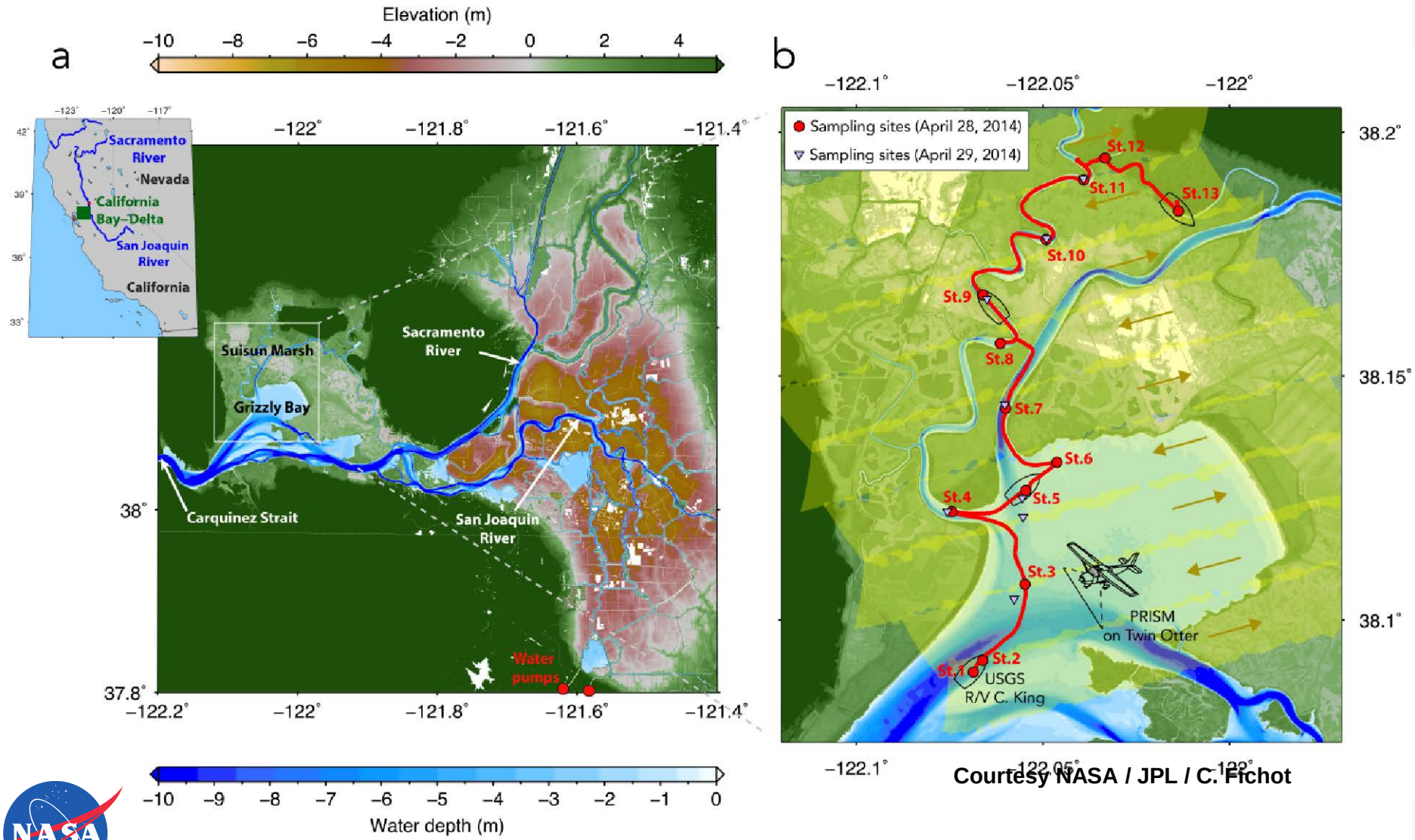
Predicting canopy nitrogen



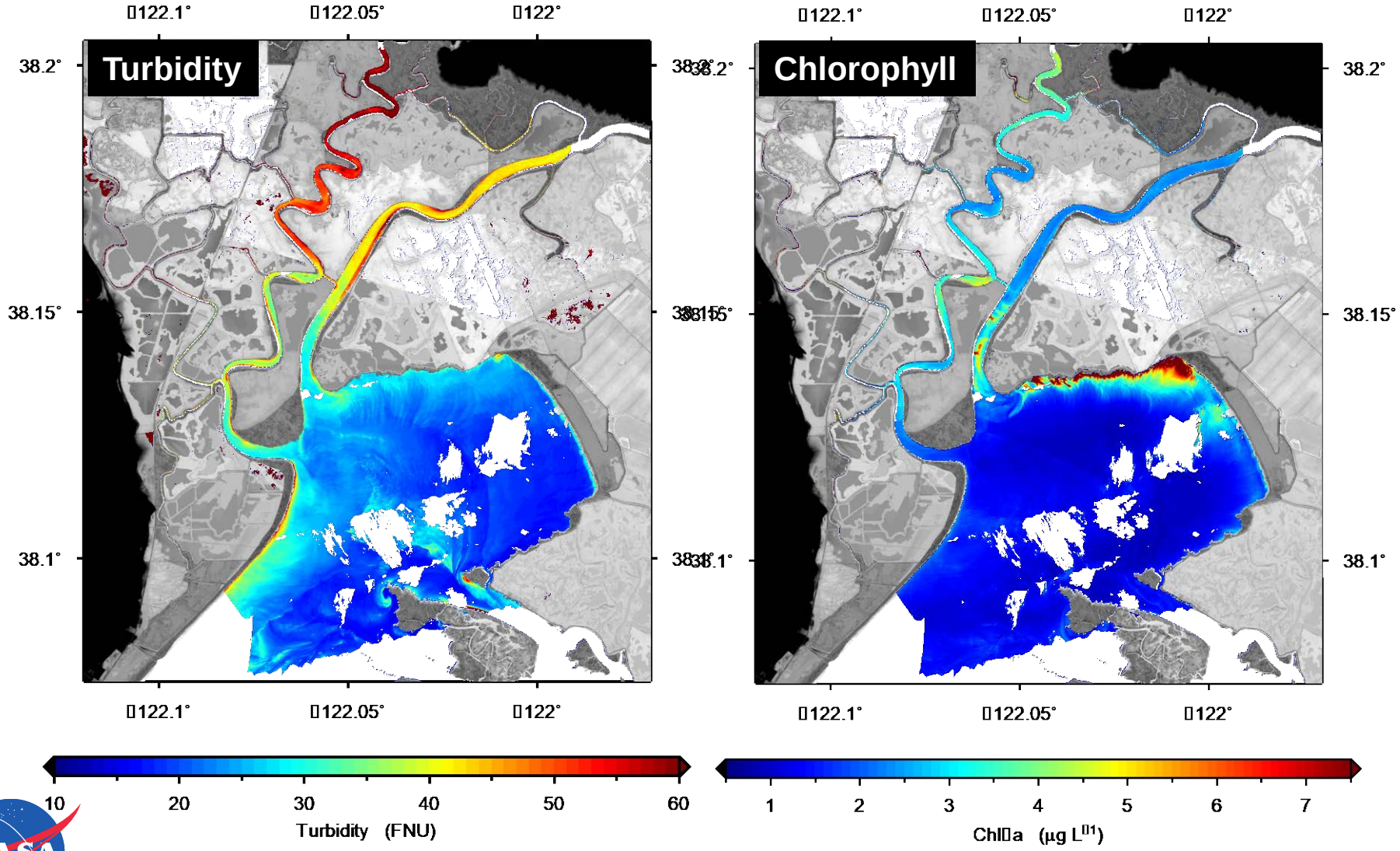


Water quality estimation via PLS



Courtesy NASA / JPL / C. Fichot

Water quality estimation via PLS



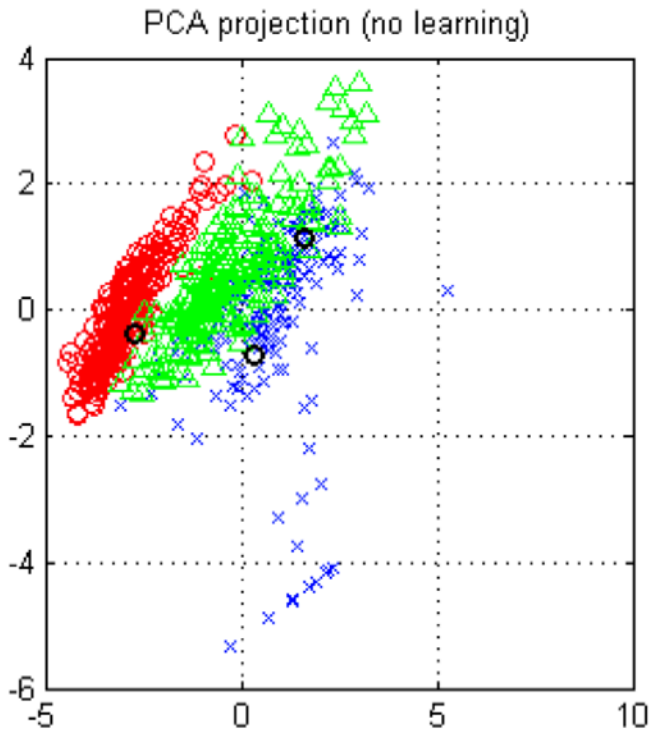
Courtesy NASA / JPL / C. Fichot

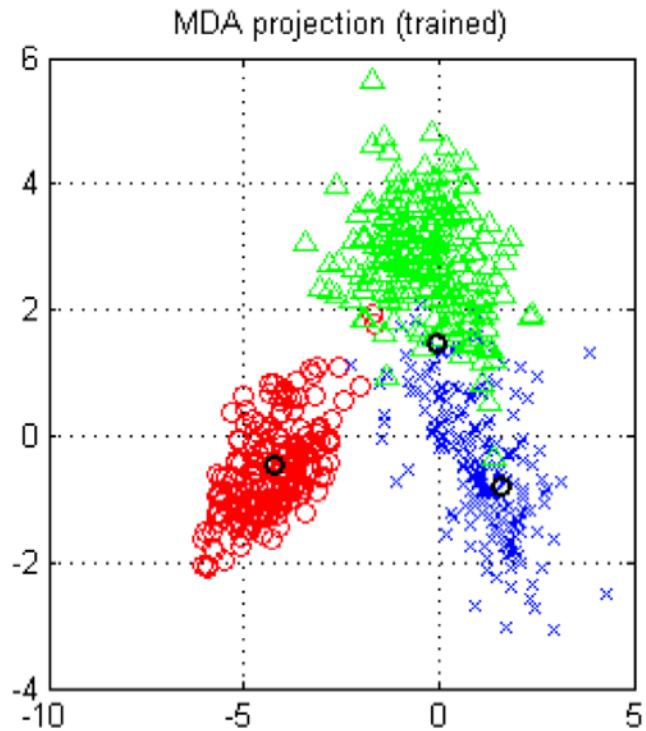
Metric learning for areal mixtures

Project the data to a representation that best discriminates a training set of labeled examples.

objective

$$f(\mathbf{A}) = \frac{\det(\mathbf{A}^T \mathbf{M}_B \mathbf{A})}{\det(\mathbf{A}^T \mathbf{M}_W \mathbf{A})}$$





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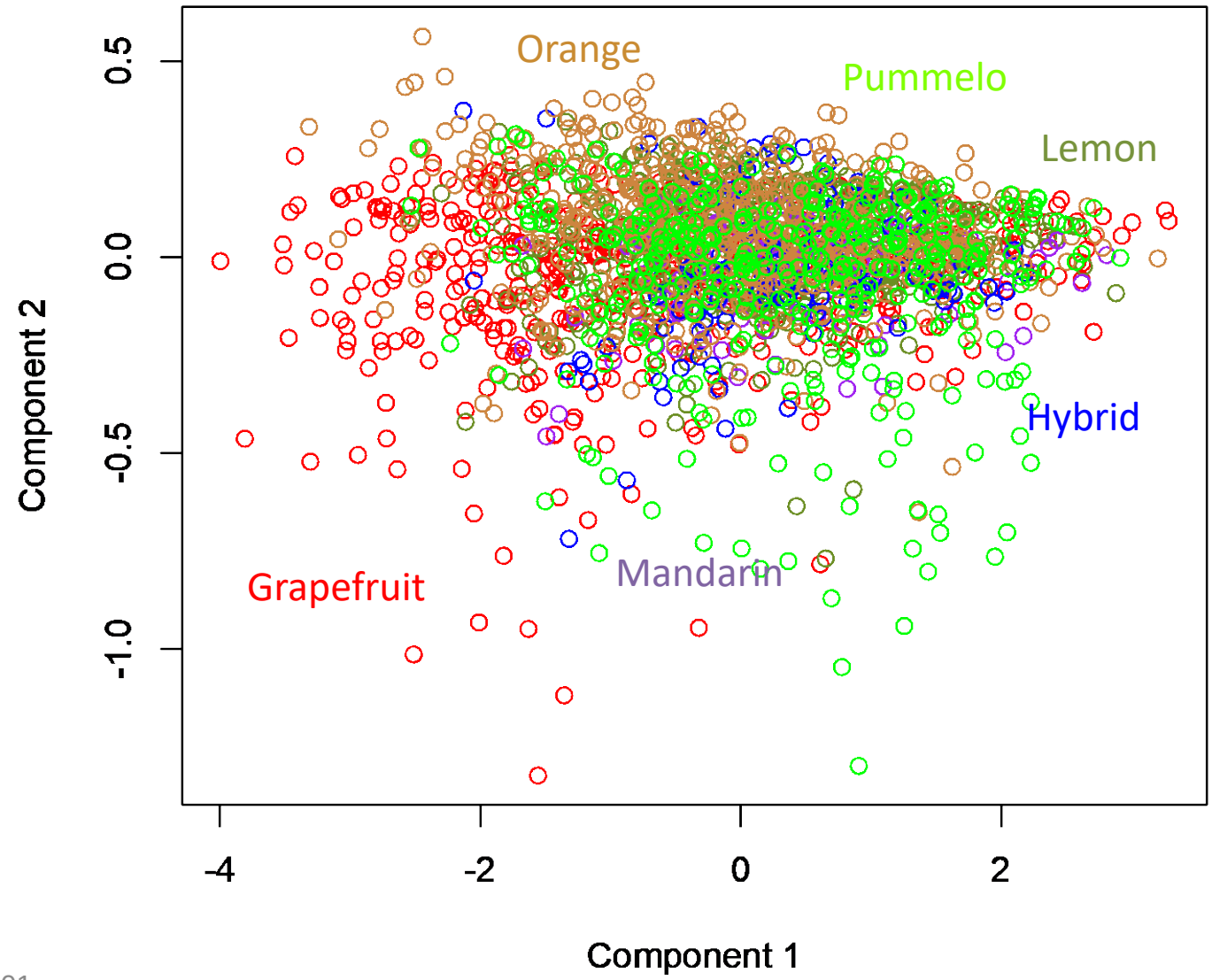
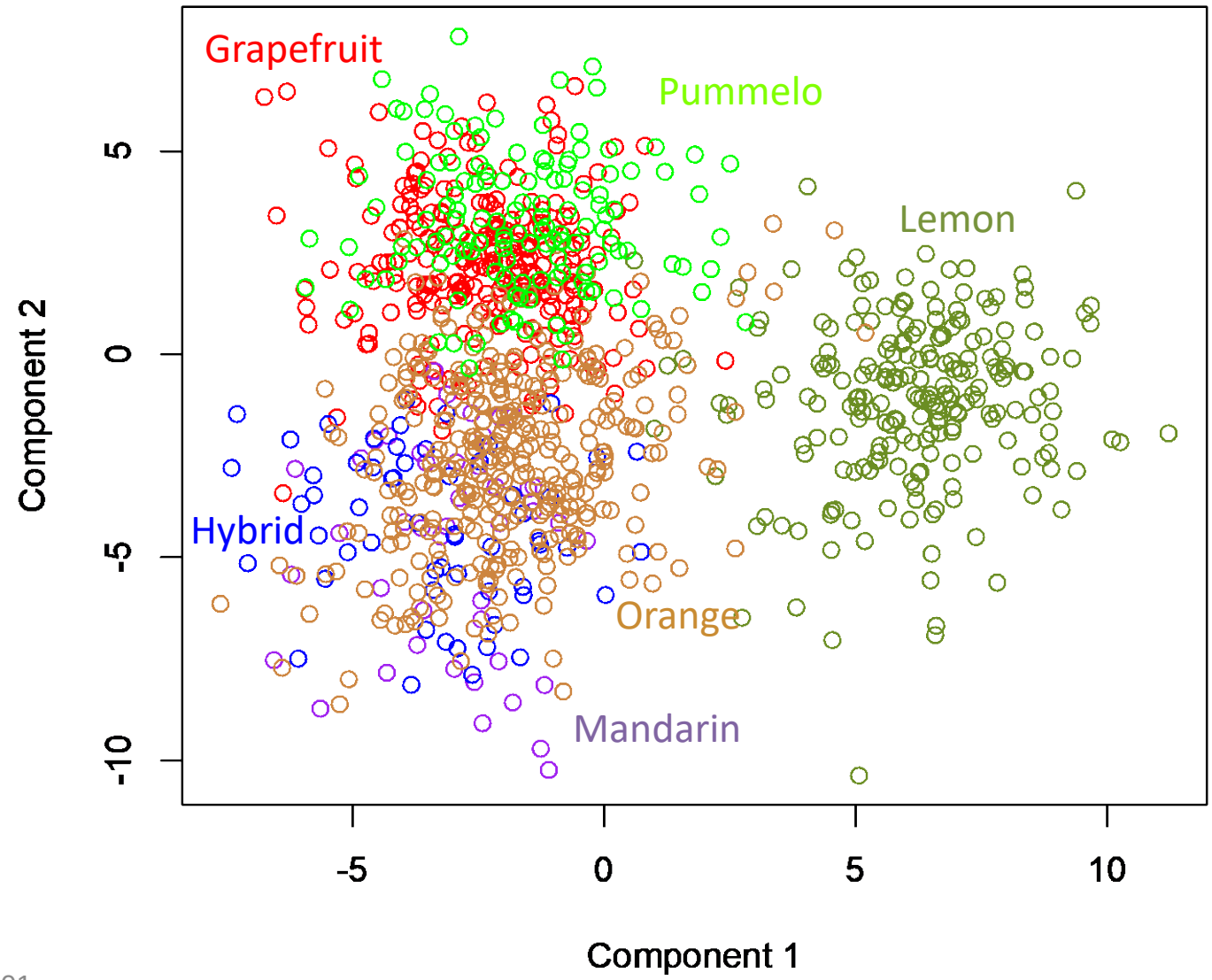
Species and subspecies via MDA

Bue, Thompson et al., *J. Photogrammetry and Remote Sensing* 2015

PCA projection



LDA projection



Species and subspecies via MDA

Original confusion matrix

	Citron	Mandarin	Papeda	Pummelo	Grapefruit	Lemon	Lime	Rangpur	Sour Orange	Sweet Orange	Trifoliate	Citrus Relative
Citron	206	97	24	64	121	494	132	0	2	143	36	64
Mandarin	18	1384	23	144	102	457	106	14	52	430	11	237
Papeda	12	121	185	113	64	358	81	1	3	221	3	74
Pummelo	62	245	92	1199	672	902	238	5	45	772	18	156
Grapefruit	31	215	59	269	902	397	141	1	7	263	49	88
Lemon	238	773	313	1383	895	6025	1282	52	124	1868	95	390
Lime	65	243	81	244	228	829	417	20	43	552	22	97
Rangpur	0	4	7	6	2	22	37	46	1	6	1	13
Sour Orange	2	28	21	27	14	62	16	0	0	44	0	8
Sweet Orange	37	522	122	510	329	850	454	16	33	2149	11	136
Trifoliate	27	26	15	37	226	141	36	18	13	22	1544	27
Citrus Relative	26	398	45	139	94	397	114	3	13	155	12	269

Revised confusion matrix

	Citron	Mandarin	Papeda	Pummelo	Grapefruit	Lemon	Lime	Rangpur	Sour Orange	Sweet Orange	Trifoliate	Citrus Relative
Citron	500	42	6	7	7	576	109	13	0	22	0	53
Mandarin	10	2186	1	23	20	75	15	11	21	257	4	297
Papeda	22	45	533	45	1	308	105	0	1	31	5	102
Pummelo	4	81	10	3438	304	199	29	0	21	262	5	4
Grapefruit	3	64	0	197	1906	45	12	0	12	201	1	6
Lemon	608	313	193	204	93	10765	616	38	7	173	1	77
Lime	180	101	183	37	20	676	1180	22	1	111	3	66
Rangpur	9	7	0	0	0	9	1	104	0	1	1	13
Sour Orange	0	52	0	9	15	17	8	0	15	71	1	0
Sweet Orange	17	274	3	241	179	236	57	2	39	3928	1	34
Trifoliate	0	4	7	38	73	20	5	1	0	44	1938	3
Citrus Relative	61	393	35	34	0	126	51	18	2	11	6	904

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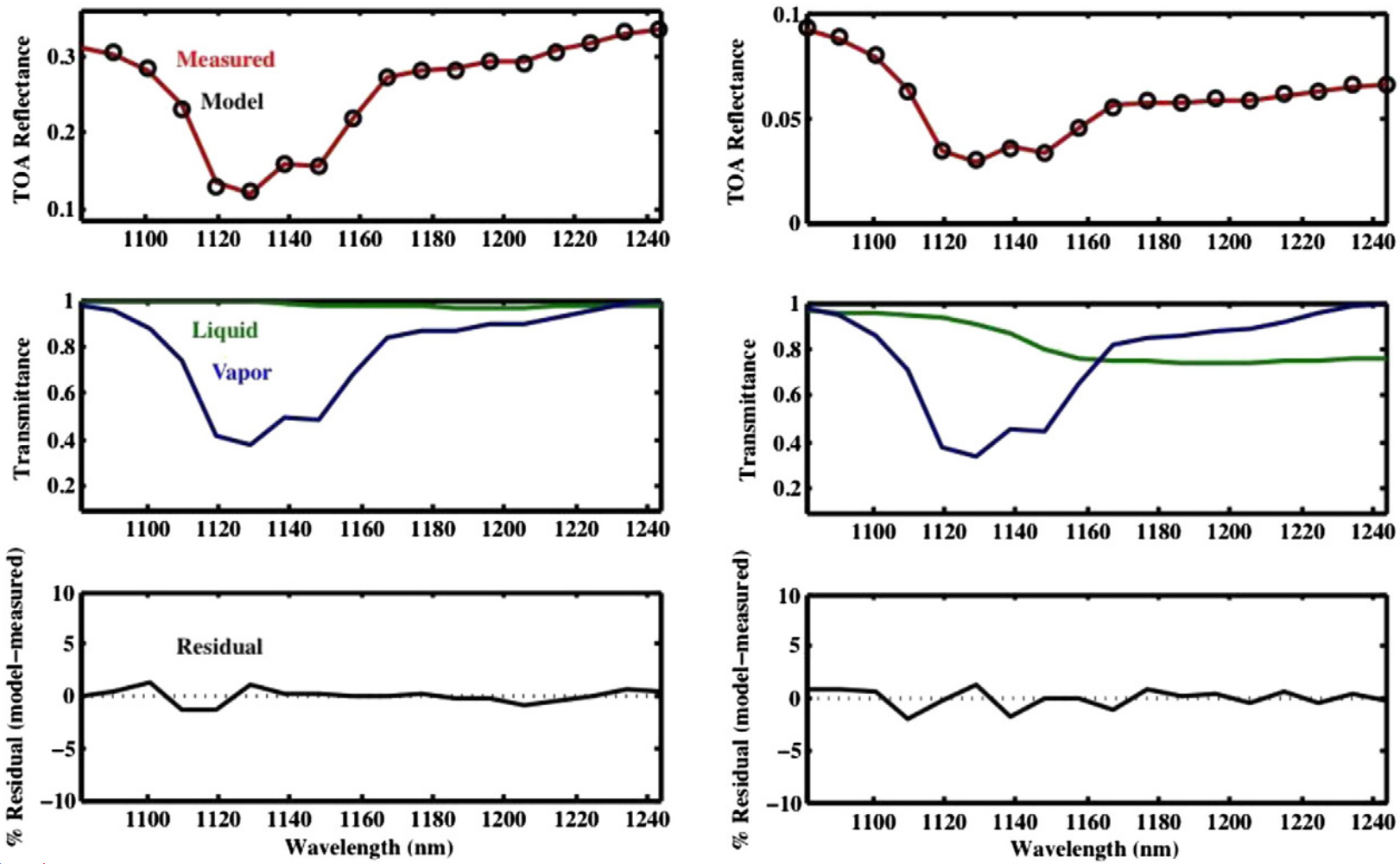
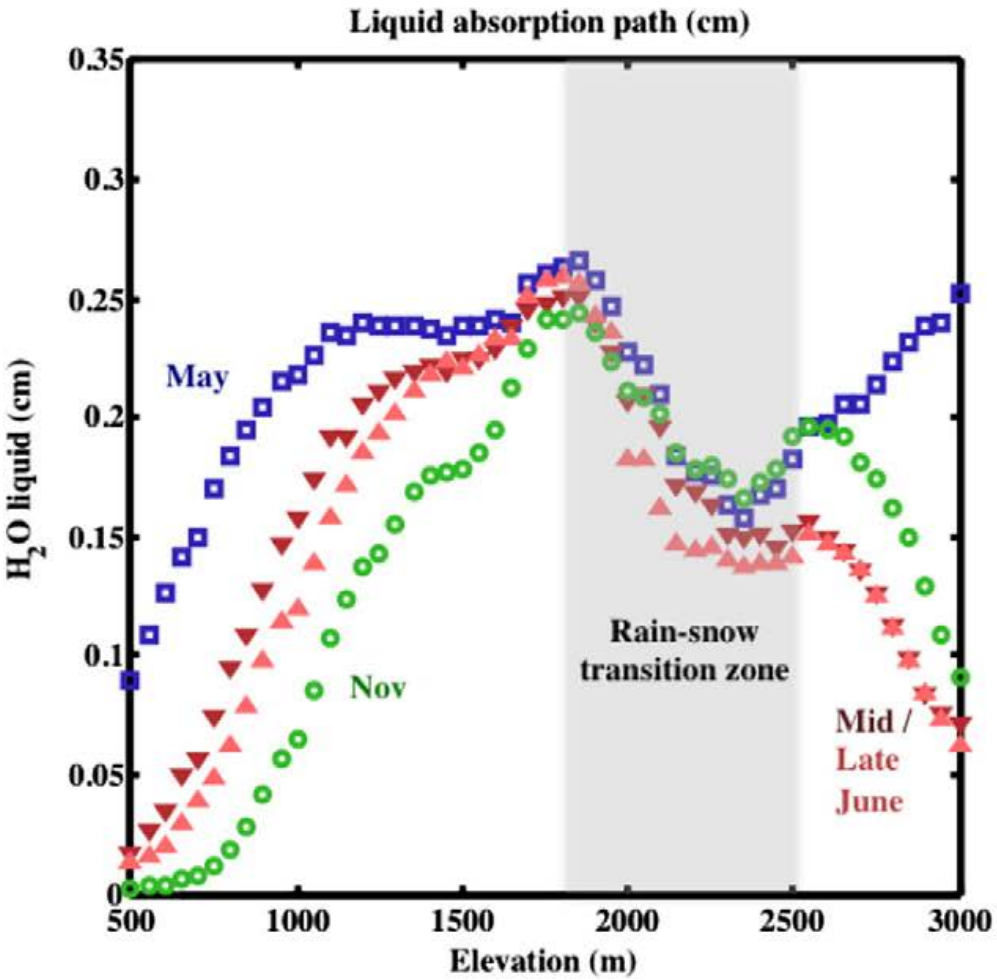
Equivalent liquid H_2O thickness



Thompson et al., Remote Sensing of Environment 2015

Equivalent liquid H_2O thickness

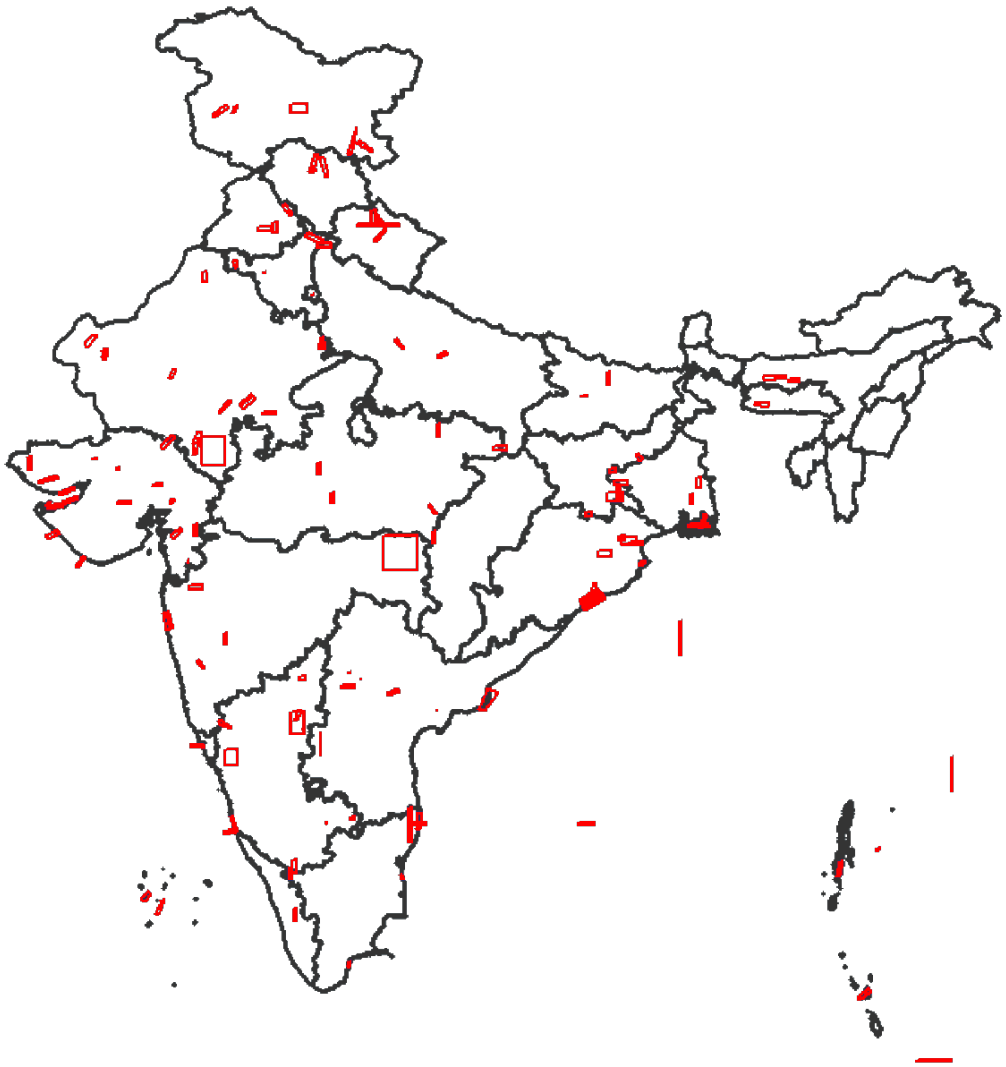


Thompson et al., Remote Sensing of Environment 2015

Agenda

- Basic principles
- Historical instruments
- Atmospheric correction
- A survey of ecosystem applications
- Fresh data
- Future directions

The AVIRIS-NG India campaign



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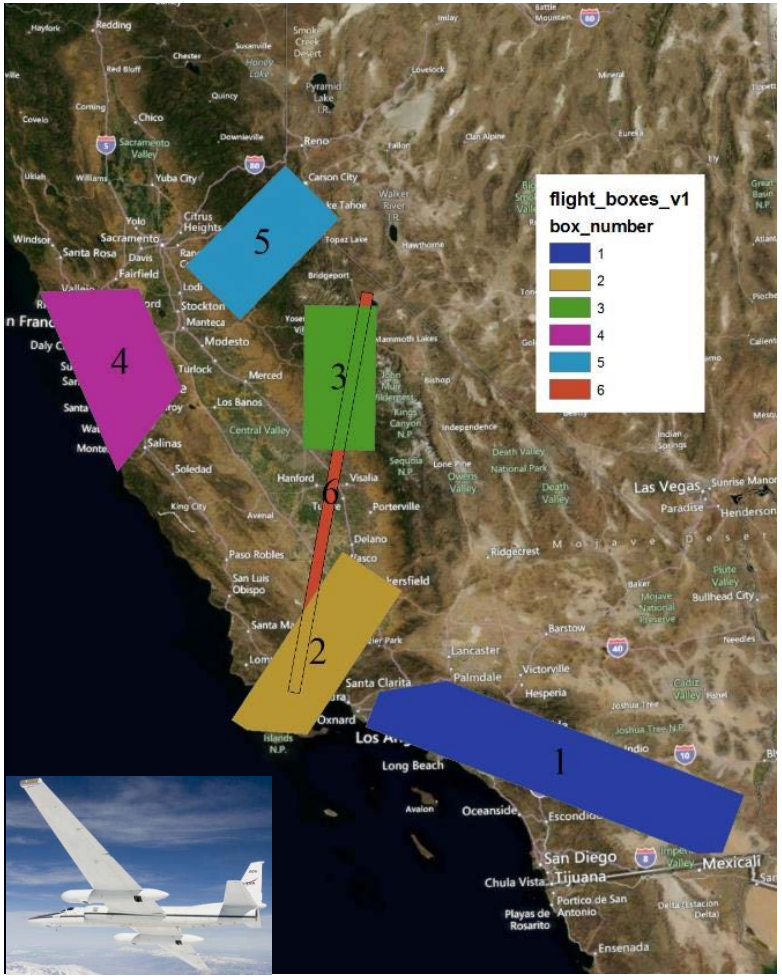
HyspIRI preparatory campaign

3 years, 3 seasons, 2 repeats

Objectives

- Ecosystem composition,function, biochemistry, seasonality, structure, and modeling
- Coastal ocean phytoplankton functional types, habitat
- Urban land cover, temperature, transpiration
- Surface energy balance
- Atmospheric characterization and local methane sources
- Surface geology,resources, soils, hazards



Three ways to get started

http://avirisng.jpl.nasa.gov

http://aviris.jpl.nasa.gov

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