Evaluation and Application of the AVIRIS Ocean Color Data for Study of Coral Reefs in Hawaii -- Initial Results

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AVIRIS Airborne Visible / Infrared Imaging Spectrometer

HyspIRI is needed

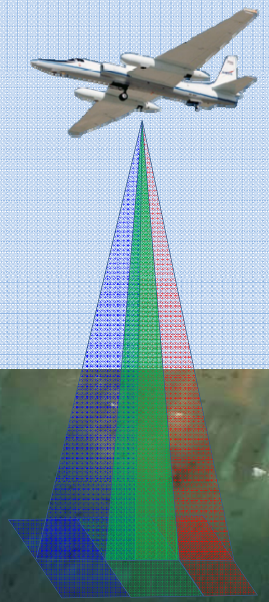
- **Our reefs face threats from runoff, overfishing, coastal development, climate change and even sunscreen.**
  - **Poor water quality:**
    From 2012-2014, 90% of the water samples collected in Maui coastal waters failed to meet State standards.
  - **Declining coral covers:**
    25% of Maui's surveyed reef sites are dead. Half of Maui's surveyed reef sites are declining in health.

- **The continuing loss of our coral reefs threatens the fabric of life.**

"HyspIRI will be an important tool with which to assess coastal bathymetry as well as water quality and the **distribution of different benthic habitats such as coral reefs, algae, sand, and other geological components**."

Challenges and Problems

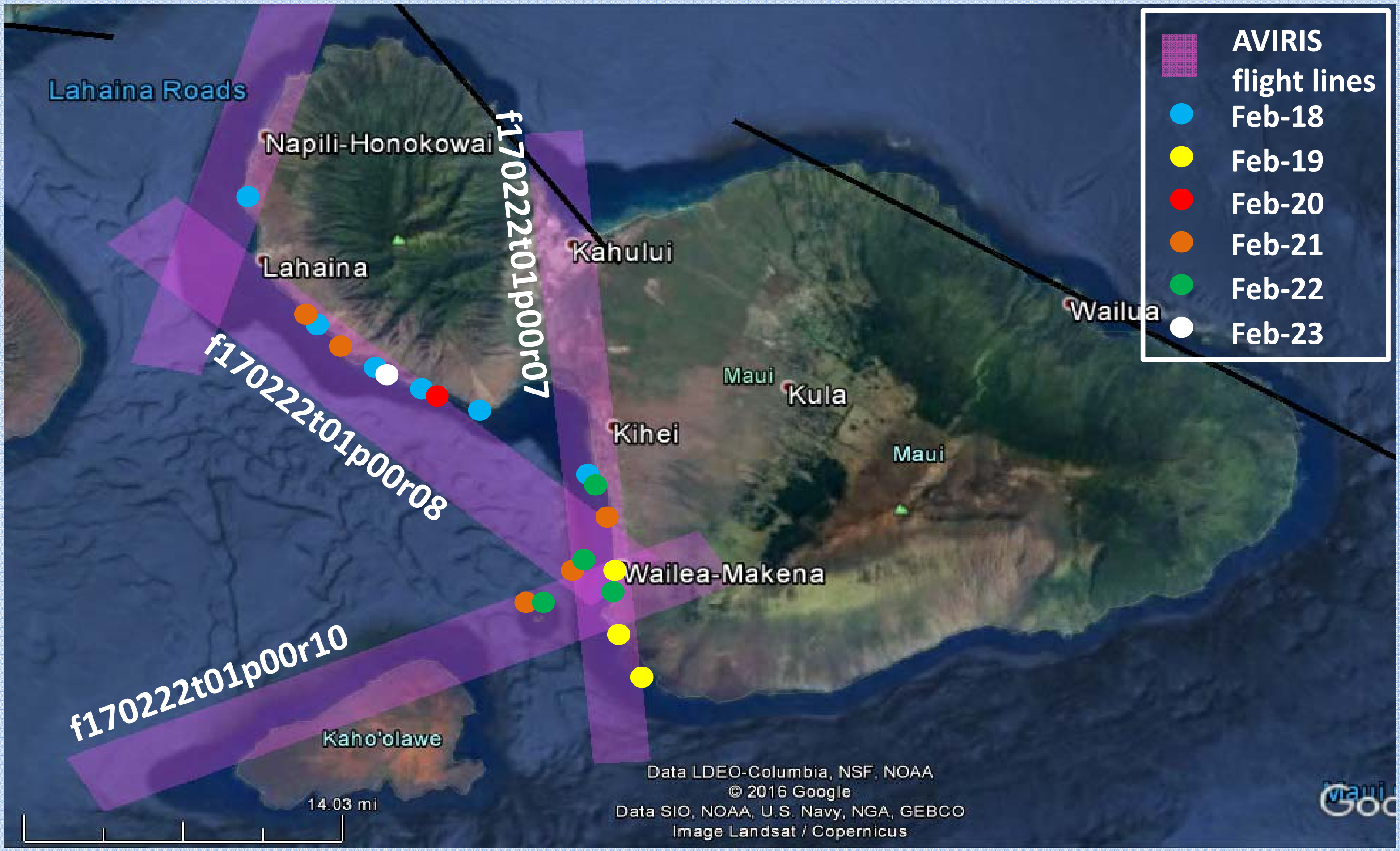
- **It is challenging to measure the water-leaving radiance from high altitudes.**
- **The AVIRIS overflights off productive coastal waters have been evaluated. But, the quality of the AVIRIS R_{rs} over shallow-water coral reef environments has remained unknown.**



- Because of the heterogeneous nature of coral reef ecosystems, **each pixel (16x16 m) of the AVIRIS image will be a mixture of substrates likely including corals, sand, algae, and seagrass**, it is thus important to know to what extent this mixture will dilute the spectral detection capability of coral reefs from AVIRIS measurements.

We report the data quality results for in-situ R_{rs} measurements and AVIRIS data in Hawaiian shallow waters.

In-situ Hyperspectral Optical Observations



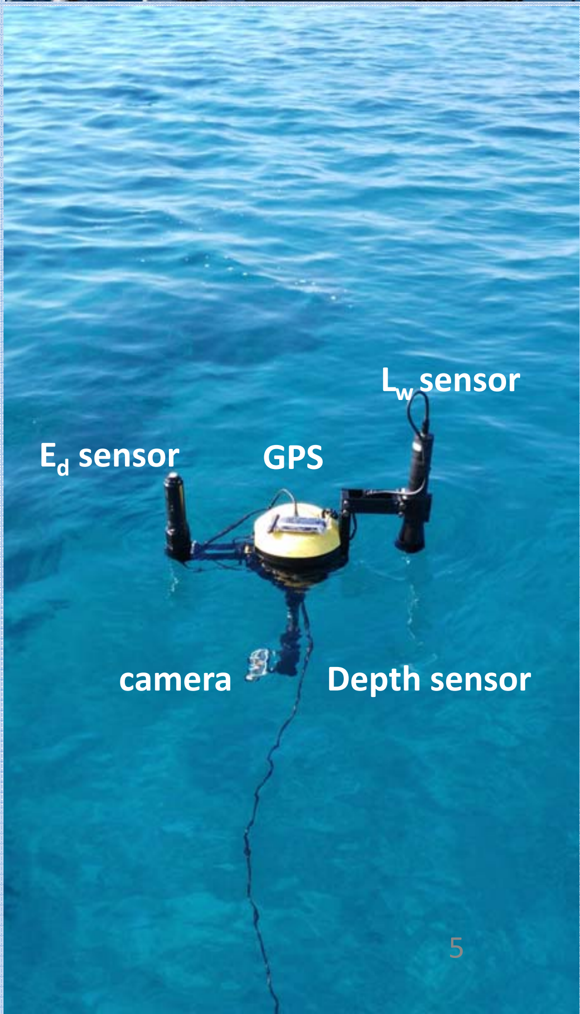
A fringing reef surrounds much of the island. However much of the live coral growth can only be found on the leeward west coast where the reef is protected from waves by the surrounding islands. Reef growth is limited on the windward northeast coast due to wave impacts.

Field Sampling Strategy

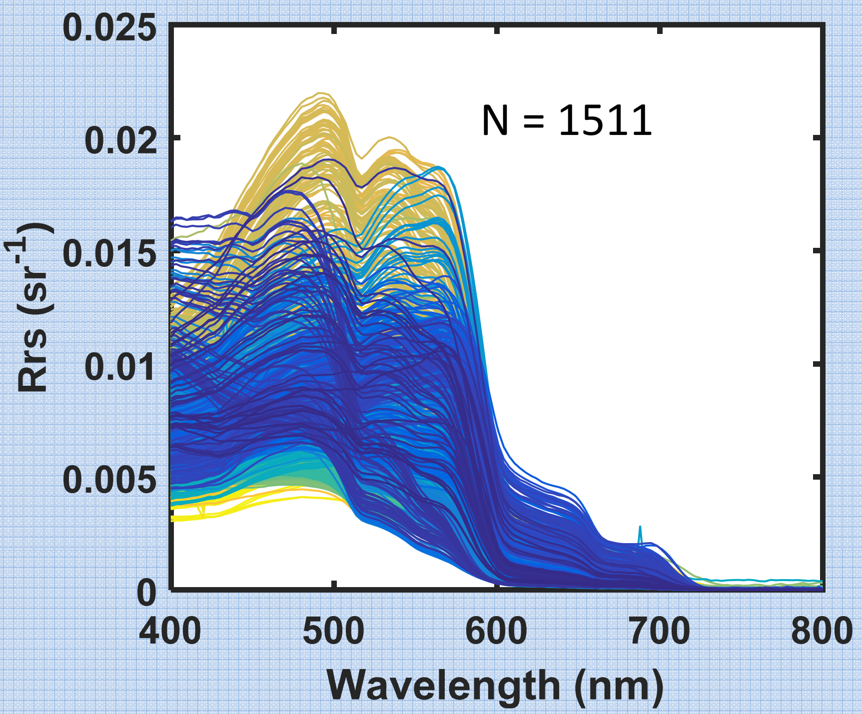
Hyperspectral radiometer incorporated with skylight blocking apparatus, 137 bands, 350-850 nm, 10 nm FWHM

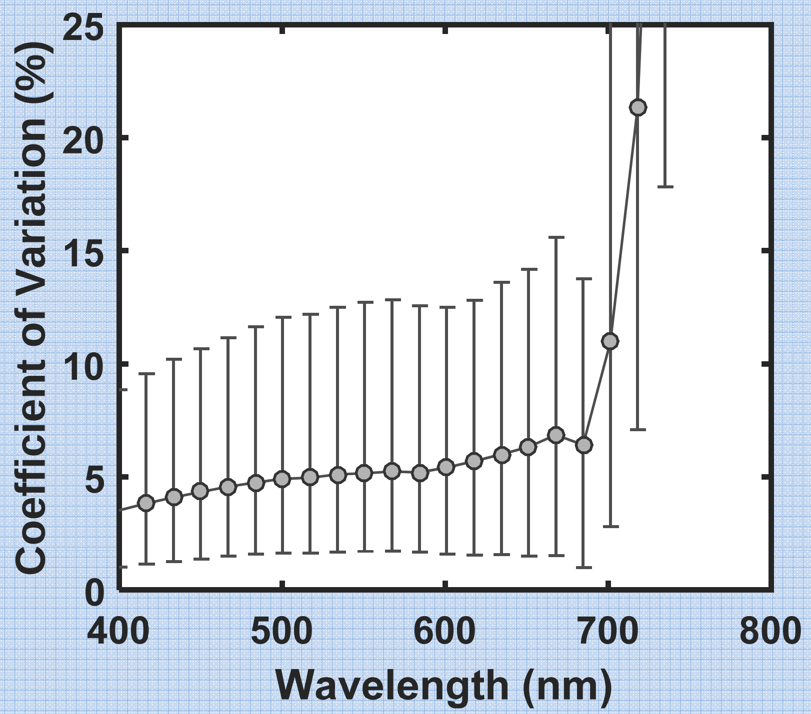
Lee et al. (2013), Wei, et al. (2015)

Reflectance spectra were measured continuously along transects (water depths vary from 2-15 m)



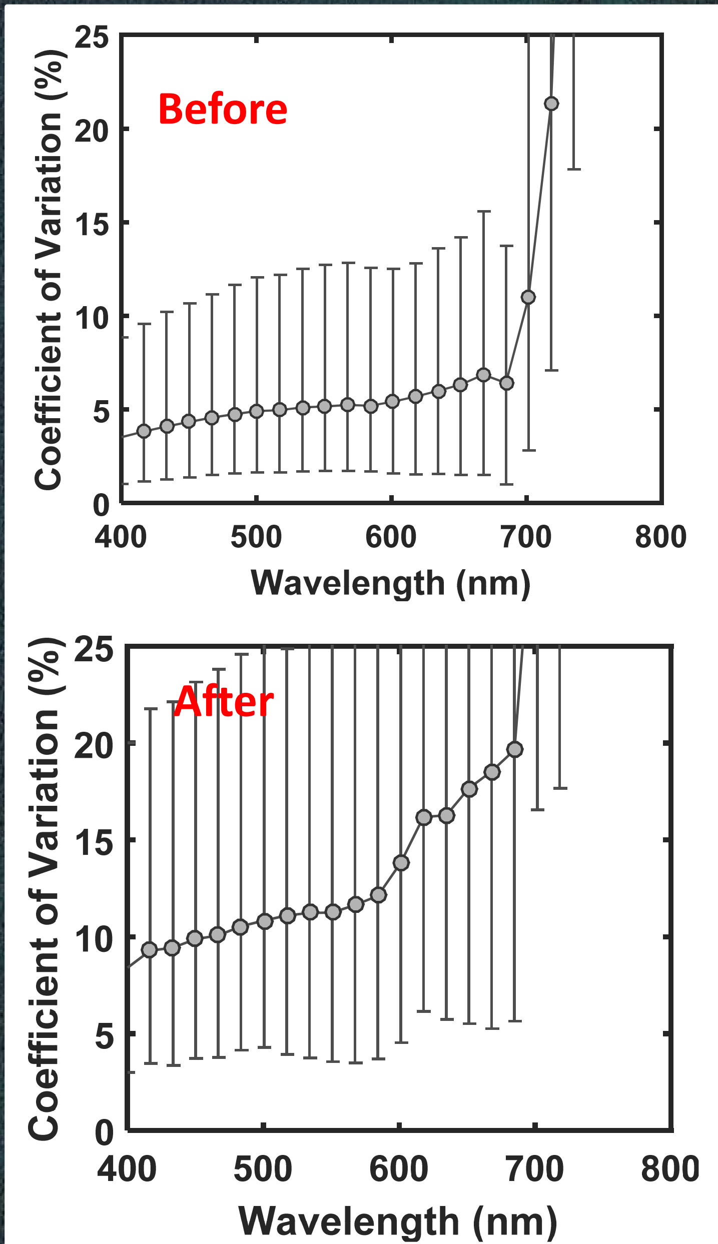
R_{rs} spectra were measured over ~1500 stations in the W-SW coasts of Maui during the HyspIRI Hawaii campaign in Feb 2017.

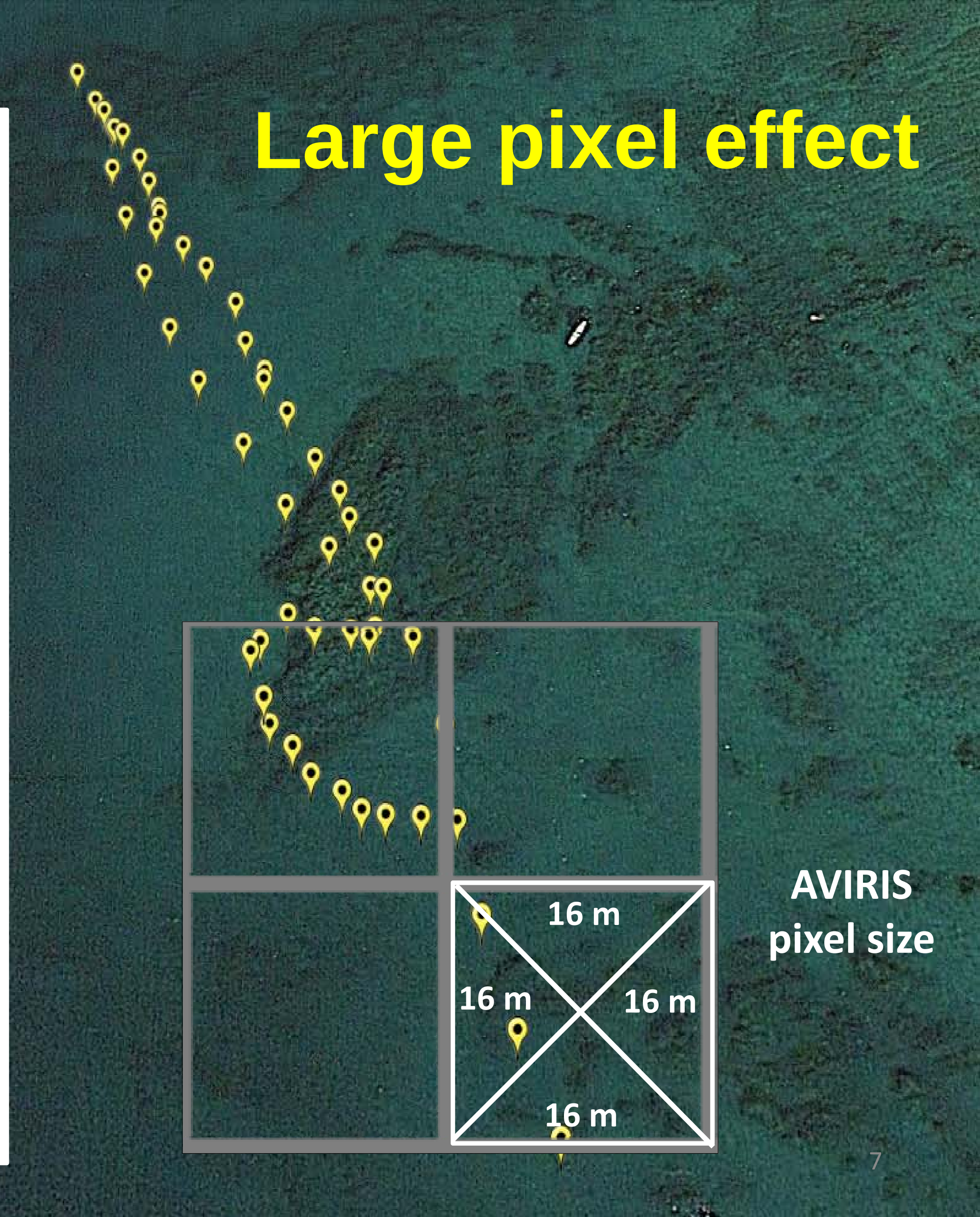




- ❑ Each R_{rs} spectrum of ~1500 stations corresponds to a restricted patch of waters (usually less than a few meters).
- ❑ The coefficient of variation (or "uncertainty") is small (with median values slightly larger than deep-water measurements).

Large pixel effect





Atmospheric Correction for Hyperspectral Images

- **Radiative Transfer Modeling Approach**
  - ATREM/Tafkaa, ACRON, FLAASH…
- **Scene-based Empirical Approach**
  - **Cloud Shadow Method:** *Lee et al. (2007), Zhang et al. (2017)*

Four elements:

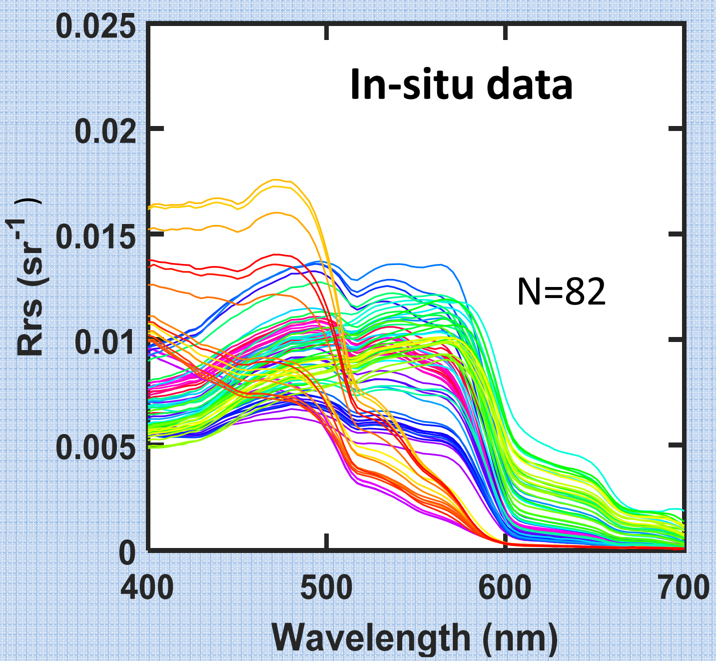
- Cloud pixel: L^{Cld}
- Sun pixel: L^{sun}
- Shadow pixel: L^{Sdw}
- Calibration pixel: R_{rs}^{cal}

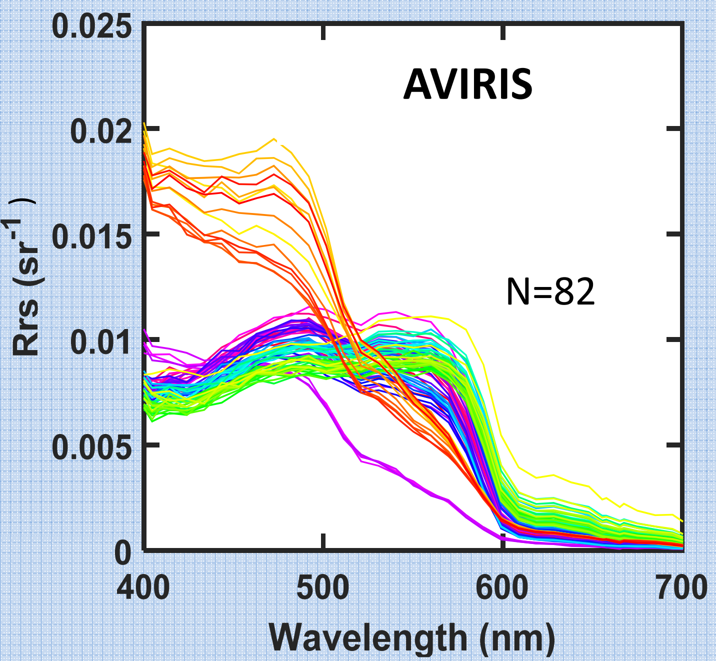
Path radiance: $$L_p = L^{sun} - \left(L^{sun} - L^{Sdw}\right) \Big/ \left(1 - \frac{E_{diff}}{E_d}\right)$$

Remote sensing reflectance: $$R_{rs} = \rho \frac{L^{sun} - L_p}{L^{Cld} - L_p}$$

1. E_{diff}/E_d ratio is estimated with a RT model and used for derivation of path radiance L_p;
2. Cloud reflectance is estimated with the aid of in-situ measured R_{rs}.

In-situ and AVIRIS Spectra

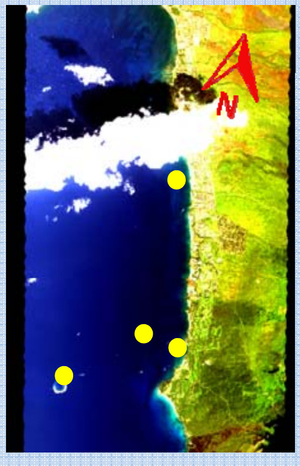




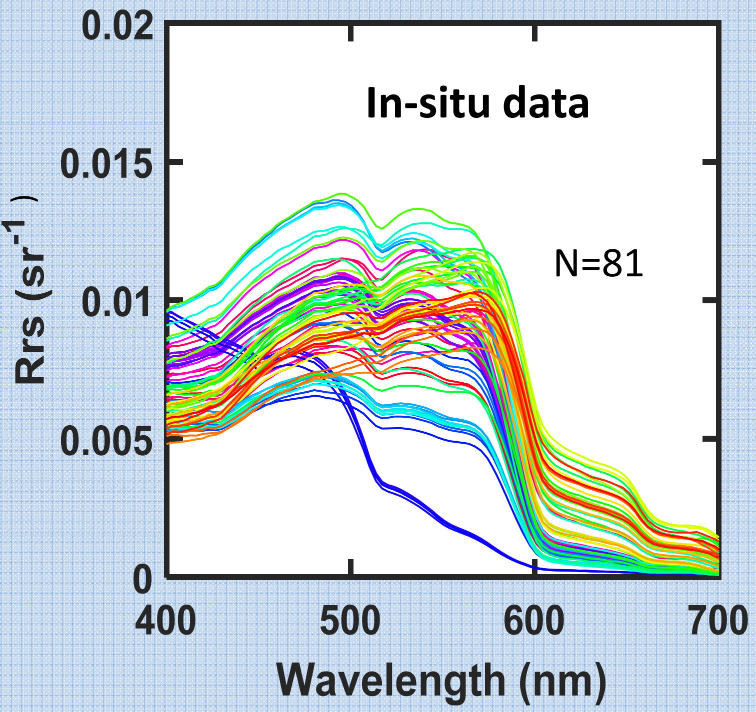
AVIRIS Overflight #1

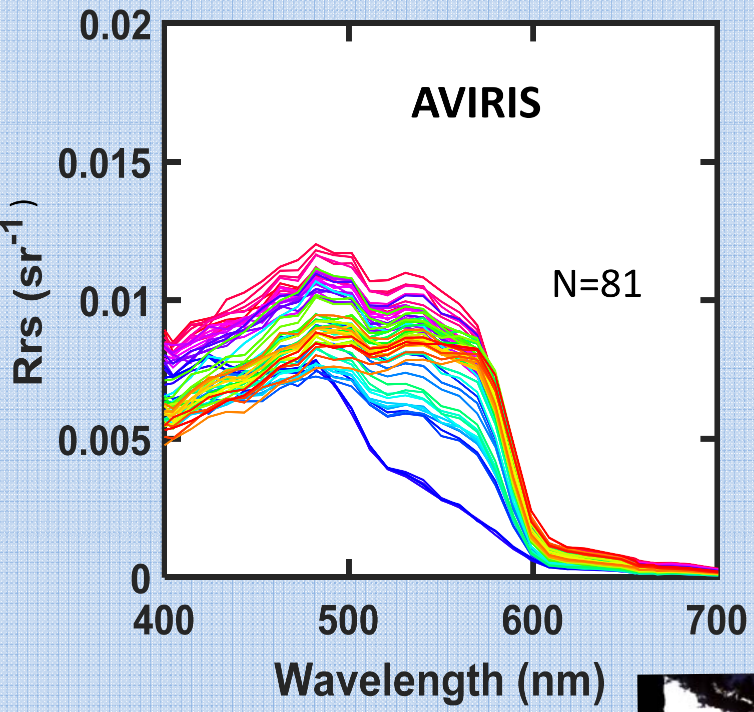
Local Time: 9:45 am

In-situ sampling areas: yellow circles



In-situ and AVIRIS Spectra



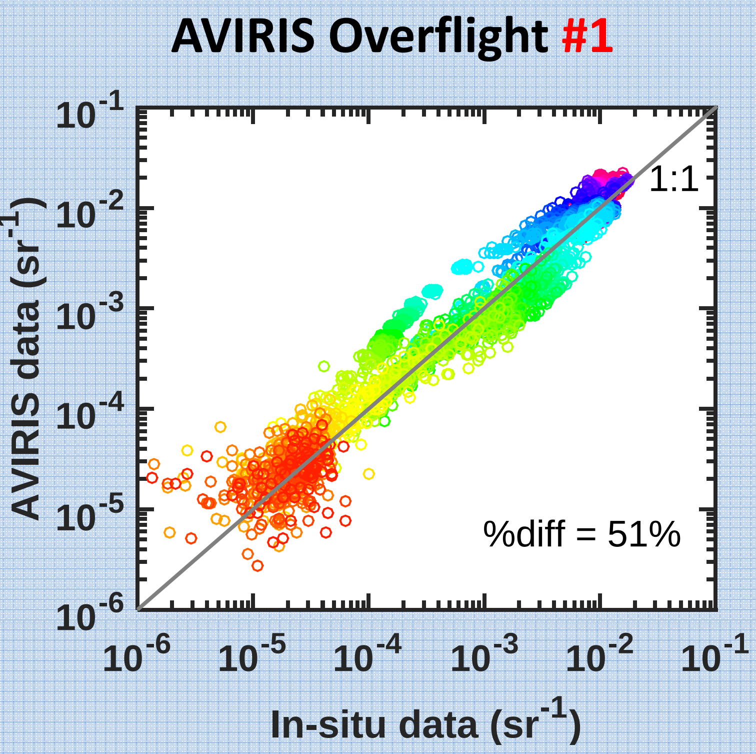


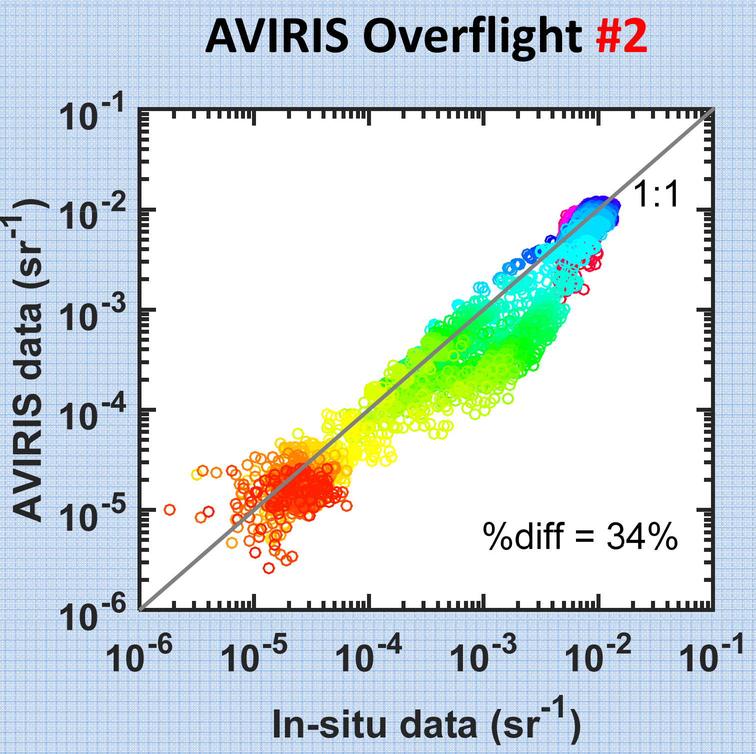
AVIRIS Overflight #2

Local Time: 10:00 am

In-situ sampling areas: yellow circles

Scatter Plots and Errors





1. **The R_{rs} data vary over an extremely wide dynamic range (~4 orders of magnitude!).**
2. **All wavelengths (360-800) are considered in the plots.**
3. **If only considering the visible bands (400-700 nm), %diff can be reduced to 40% and 24%, respectively, for the two AVIRIS overflights tested here.**

Hyperspectral Inversions for Shallow Waters

- **Each measured R_{rs} spectrum is contributed by at least 4 vector variables and 1 scalar variable:**

$$\begin{cases} R_{rs}(\lambda_1) = F\left[a_{ph}(\lambda_1), a_g(\lambda_1), b_{bp}(\lambda_1), \rho_B(\lambda_1), H\right], \\ R_{rs}(\lambda_2) = F\left[a_{ph}(\lambda_2), a_g(\lambda_2), b_{bp}(\lambda_2), \rho_B(\lambda_2), H\right], \\ \vdots \\ R_{rs}(\lambda_n) = F\left[\boxed{a_{ph}(\lambda_n), a_g(\lambda_n), b_{bp}(\lambda_n)}, \boxed{\rho_B(\lambda_n)}, \boxed{H}\right], \end{cases}$$

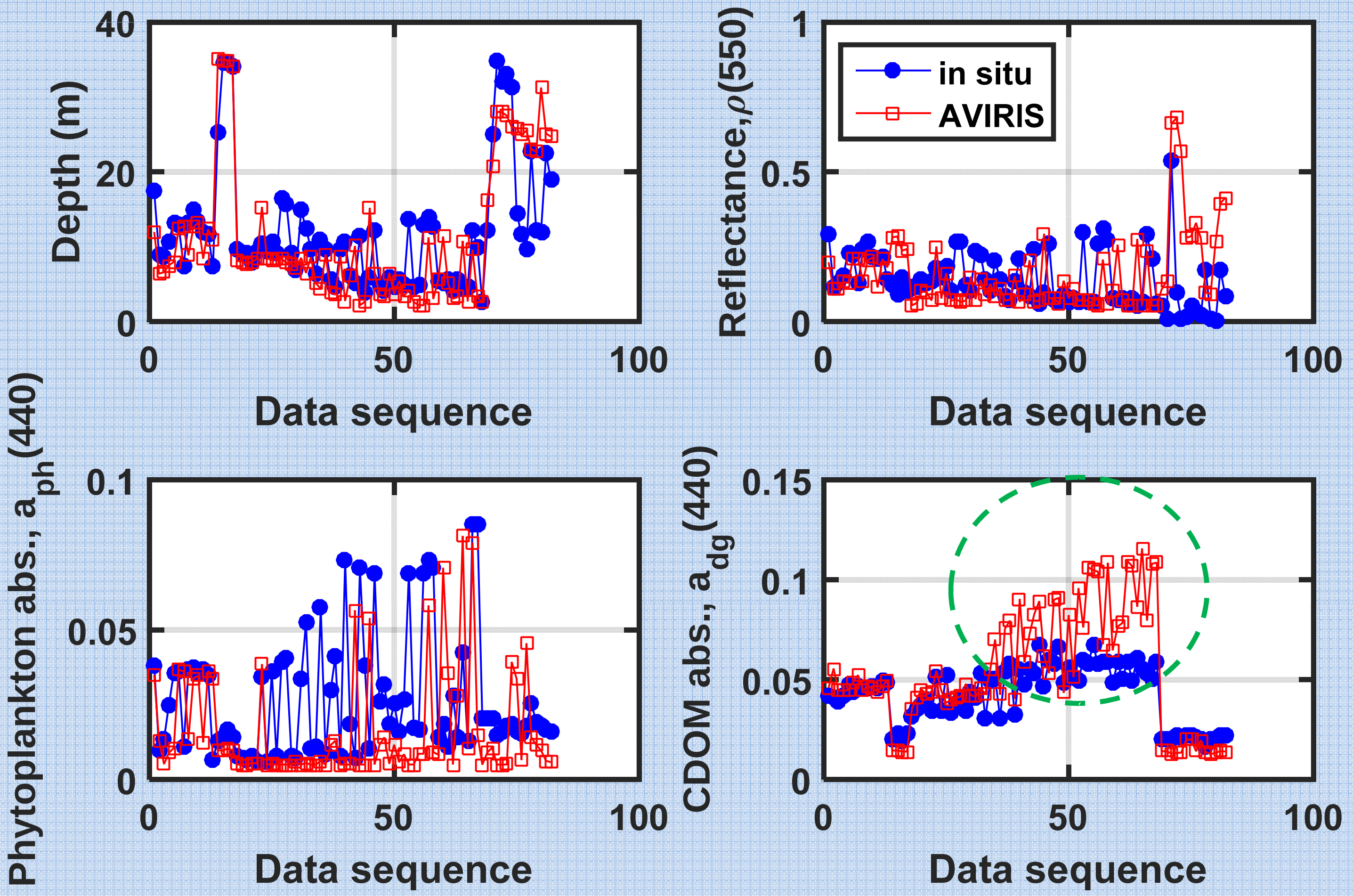
bio-optical properties   bottom reflectance   depth

a_{ph} **: Phytoplankton absorption**
a_g **: Colored dissolved matter absorption**
b_{bp} **: Particle backscattering**
ρ_B **: Bottom reflectance**
H **: Water depth**

- **HOPE: Hyperspectral Optimization Processing Exemplar**

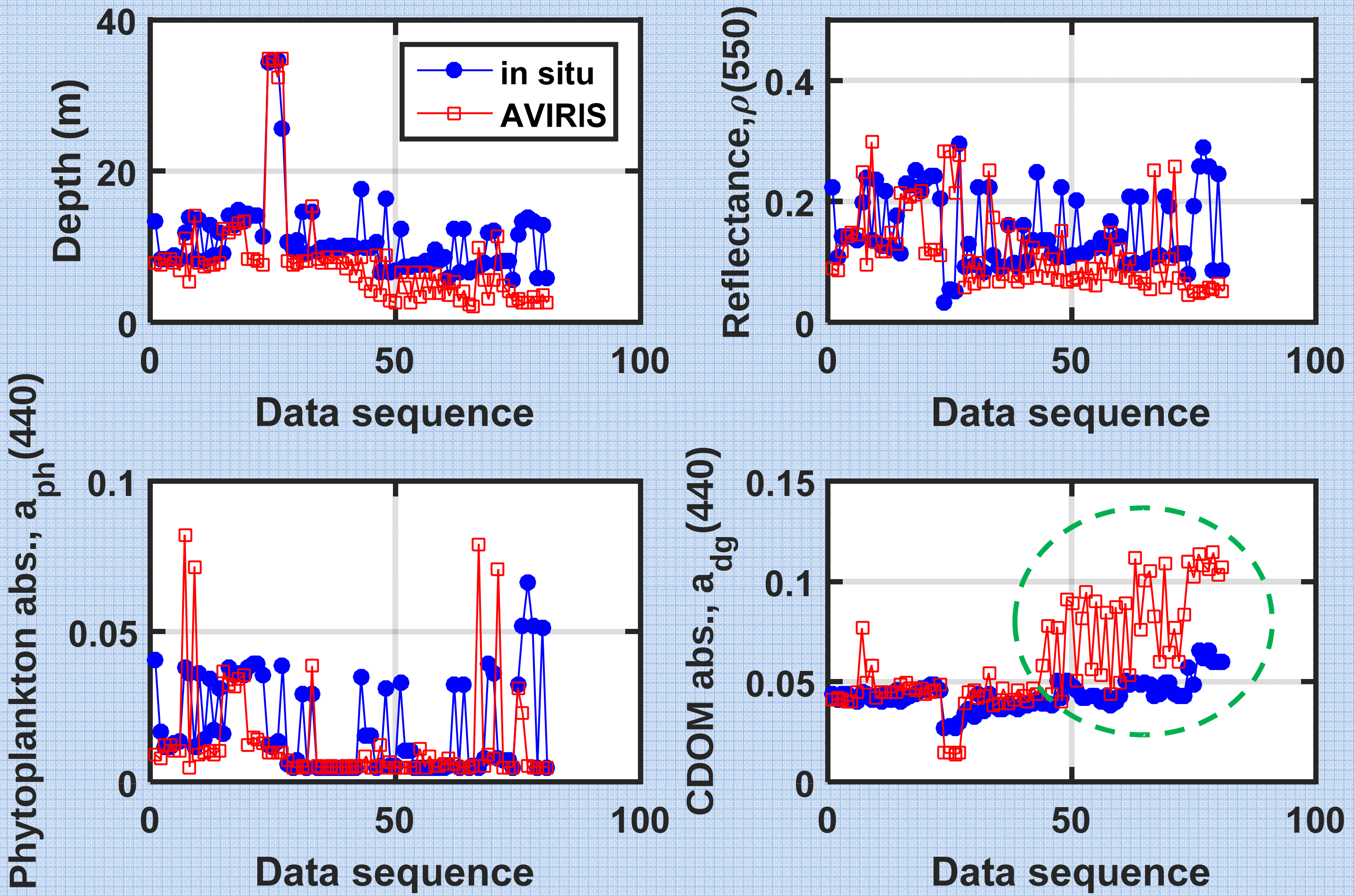
References: Lee et al. (1998; 1999)

AVIRIS Overflight #1



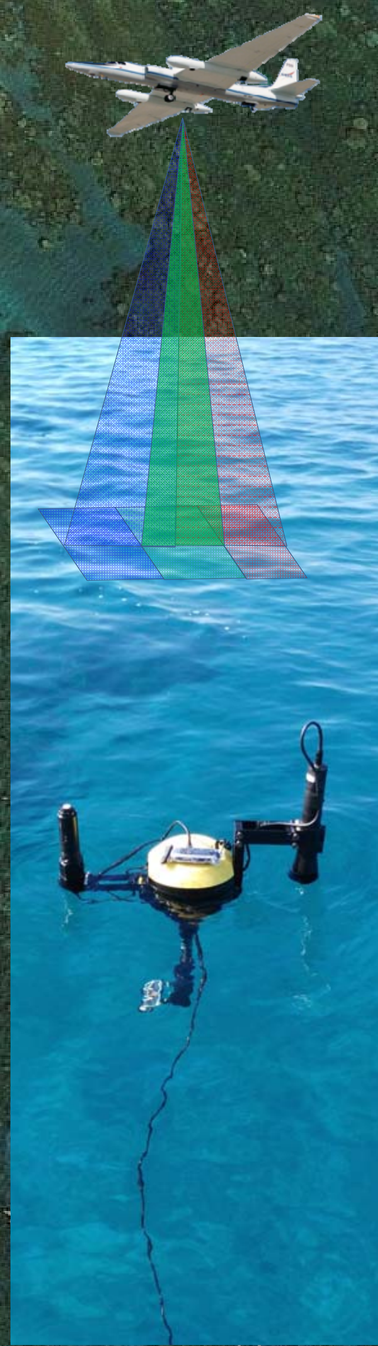
AVIRIS-derived products (bathymetry, bottom reflectance, phytoplankton absorption, and CDOM absorption) are generally consistent with in-situ derived products.

AVIRIS Overflight #2



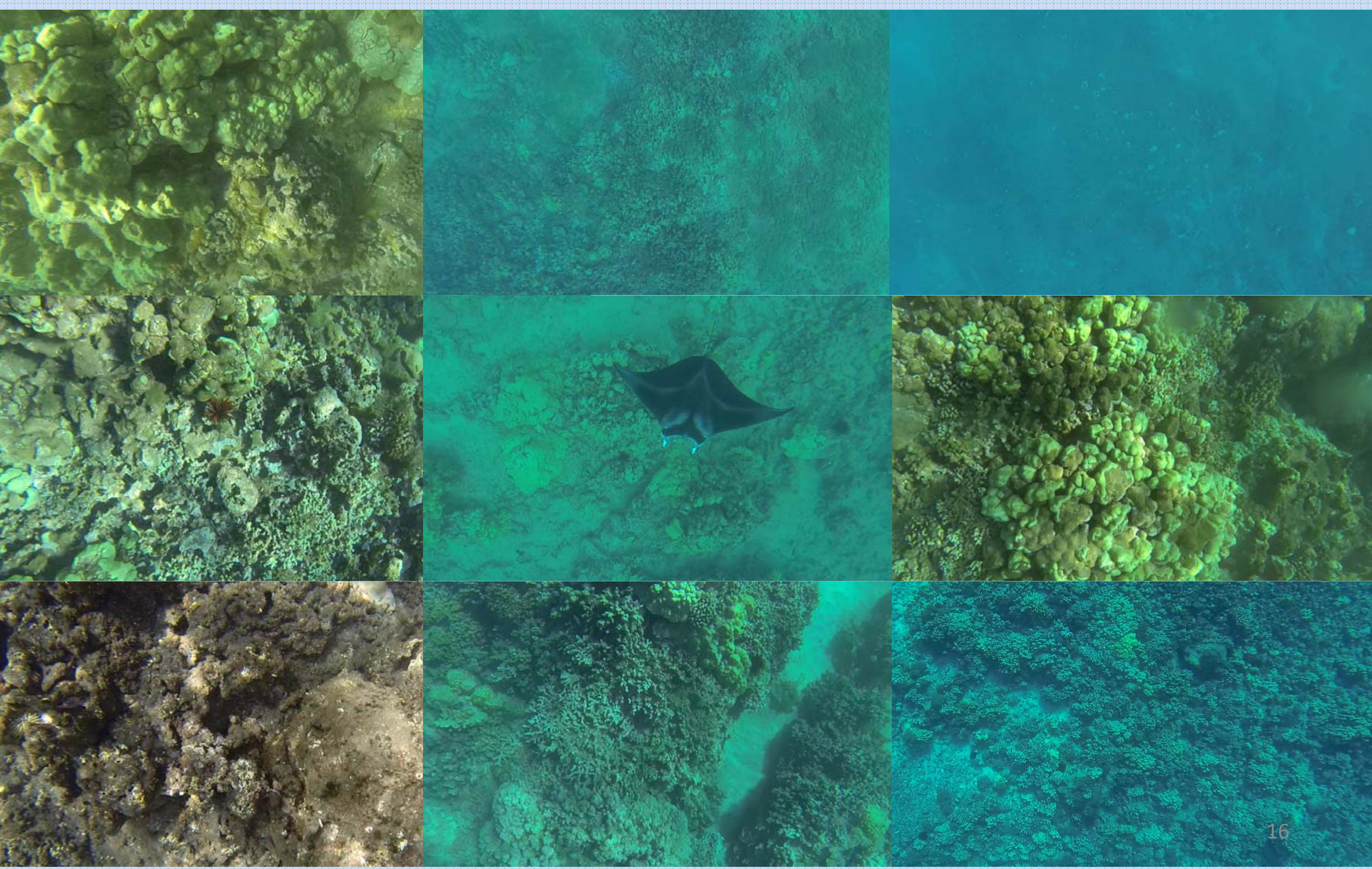
AVIRIS-derived products (bathymetry, bottom reflectance, phytoplankton absorption, and CDOM absorption) are generally consistent with in-situ derived products.

Conclusions

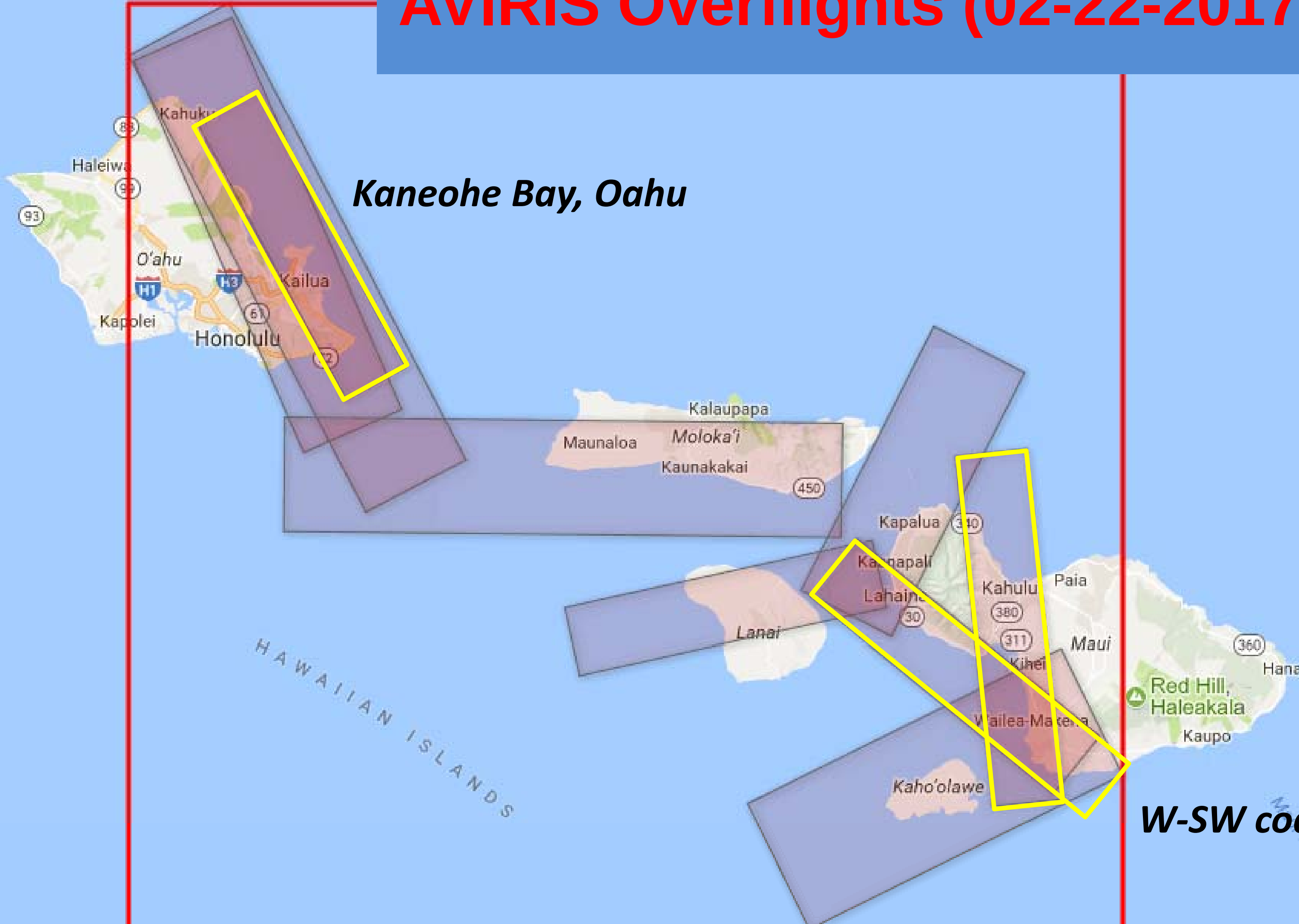


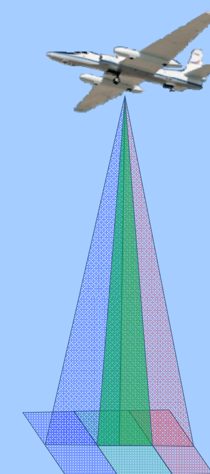
- Accurate hyperspectral remote sensing reflectance spectra (N=~1500) are collected for shallow waters .
- Cloud-shadow method is successfully applied to the AVIRIS hyperspectral images.
- Such-derived AVIRIS images are validated for the shallow waters in W-SW coasts of Maui.
- Shallow water products (bottom reflectance, water depth, phytoplankton light absorption , and CDOM light absorption) are derived from AVIRIS images, which are generally consistent with in-situ derivations.

Frames of benthic videos (24 fps)



AVIRIS Overflights (02-22-2017)





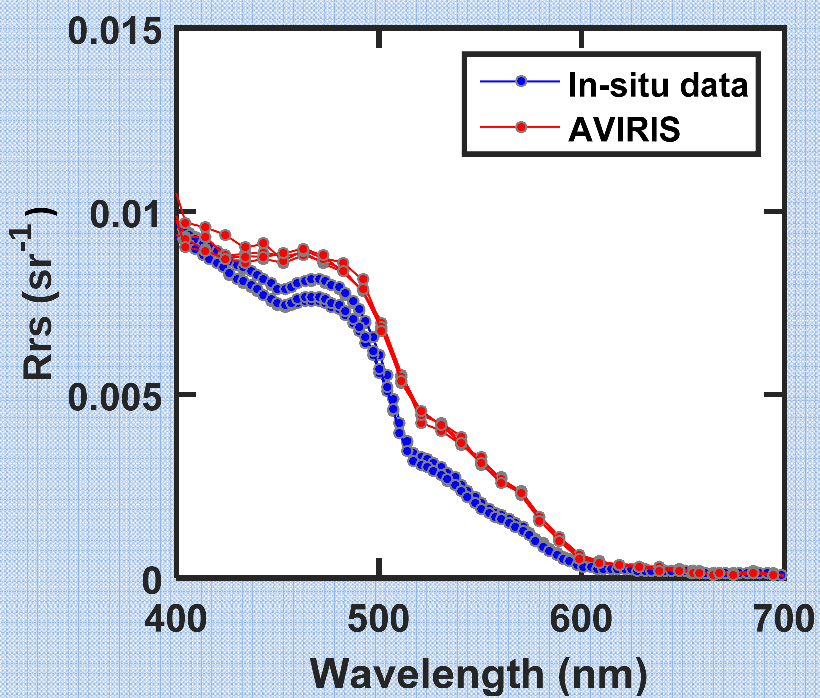
Two field teams are dispatched to Hawaii:

Team A: Kaneohe Bay, Oahu;

Team B: West-Southwest Coasts of Maui.

A closer look…

Blue deep waters (> 100m)



Blue-green shallow waters (< 5m)