High-Quality Optical Observations (H-Q2O): Improving Atmospheric Correction and Remote Sensing of Water Quality and Biodiversity in the Coastal Zone

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Abstract

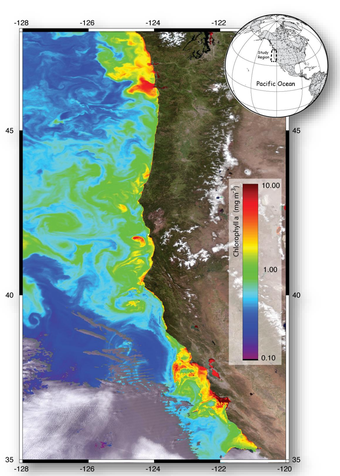
H-Q2O seeks to demonstrate novel measurement capabilities from the air and ground with combined use of a new airborne sensor suite (NASA HOPE-COAST, described below) to characterize coastal atmospheric and aquatic properties through an end-to-end assessment of image acquisition, atmospheric correction, algorithm application, plus sea-truth observations from new state-of-the-art instrument systems. Water-leaving radiances, denoted $L_W(\lambda)$, in the blue region of the visible (VIS) domain and in the ultraviolet (UV) domain—which are critical for discriminating pigments from colored dissolved organic material (CDOM) and potentially useful for both atmospheric correction and identification of features such as "red tides," respectively—exhibit a low signal to noise ratio (SNR) and often have negative values using standard reprocessing methods. Additionally, atmospheric correction schemes used for satellite ocean color remote sensing are problematic for productive coastal waters.

The coastal ocean is one of the most difficult places to accurately retrieve ocean color and benthic ecosystem reflectance. Radiance signal magnitude is highly variable, ranging from very dark values in clear, deep water to very bright values at water's edge. Signals are also highly variable in space and time, due to many dynamic processes. Aerosol and trace gas plumes from continental sources complicate the task of atmospheric correction.

Monterey Bay

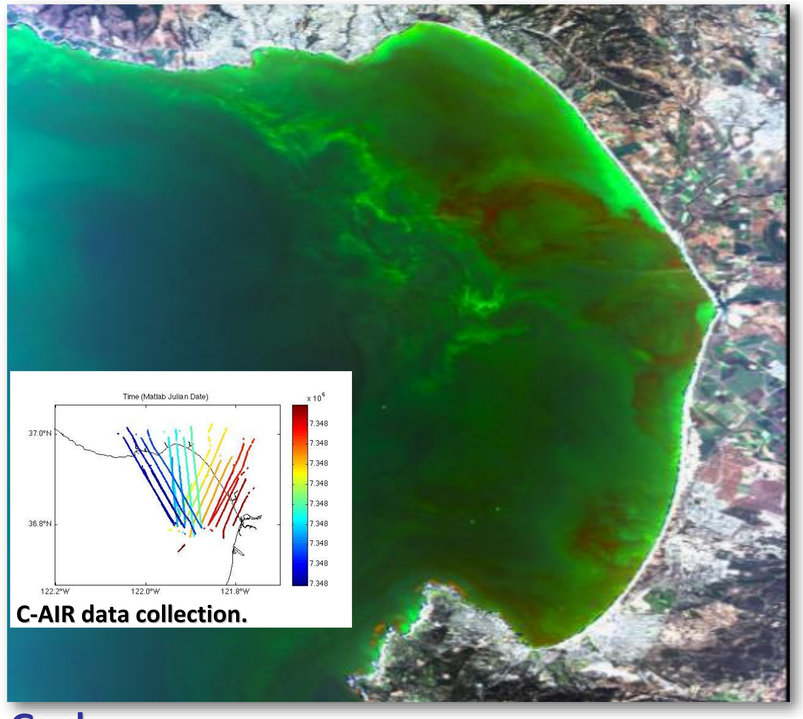
There are many properties of biological interest in the coastal ocean, e.g., river plumes, kelp beds, and phytoplankton including harmful algal blooms (HABs), and similar targets at the land/sea interface (e.g. estuaries, coastal lakes). These properties are associated with salinity, temperature and radiation gradients but are spatially aliased with conventional 1 km resolution data. This project will build on ~5 years of airborne campaigns in the Monterey Bay region as part of the NOAA COAST program, NASA COAST-HOPE, NASA SARP, and NASA HyspIRI Airborne Preparatory Project.

Monterey Bay is well characterized oceanographically, provides rich historical and ongoing observations, and has been used in the past for both cal/val and science airborne operations including the October 2011 NASA Coastal and Ocean Airborne Science Testbed (NASA COAST) mission conducted using similar parameters proposed here. Based on past experience and typical conditions, we expect that an autumn (October) mission will maximize the likelihood of data collection days, minimize cloud cover, and will provide a range of scientifically interesting features, including tidal exchange with Elkhorn Slough, red tides, upwelling versus oceanic conditions, and, potentially, a "first flush" rain event. This is also the peak cyanobacteria harmful algal bloom (cyanoHAB) period in local lakes and reservoirs. Complementary data collection in other seasons will provide an opportunity to document diatom-dominated upwelling in the coastal ocean (spring), and low biomass (low signal) conditions in winter. This proposal directly builds on the expertise and experience of previous NASA airborne remote sensing programs, including the NASA COAST project.



Monterey Bay as a Testbed

- Monterey Bay has both open ocean and optically complex water masses, so the full dynamic range of the sensor suite and protocols being used in the field can be evaluated
- Monterey Bay has been used for COAST 2006 (SAMSON sensor), HOPE-COAST 2011 (Headwall and C-AIR sensors), PRISM (2012), SARP (MASTER, 2010), and GLIMMER (2012) as well as numerous AVIRIS overflights
- Ongoing time-series by UCSC, MLML, MBARI, with moorings and shore stations
- Features include Elkhorn Slough, Case 1 and 2 waters, red tides, kelp beds, river plumes



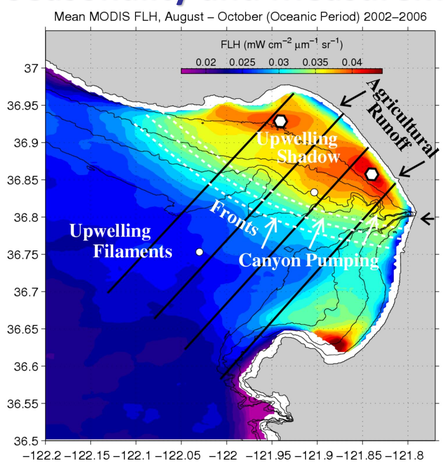
C-AIR data collection.

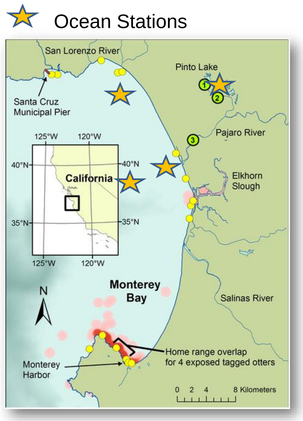
Goal

The primary goal of H-Q2O is to demonstrate the following in support of calibration and validation exercises for satellite coastal ocean color products:

a) the utility of a multi-sensor airborne instrument suite to assess the biological properties of coastal California, including water quality; and
b) the importance of contemporaneous atmospheric measurements to improve atmospheric correction in the coastal zone.

Seasonality and Measurement Sites





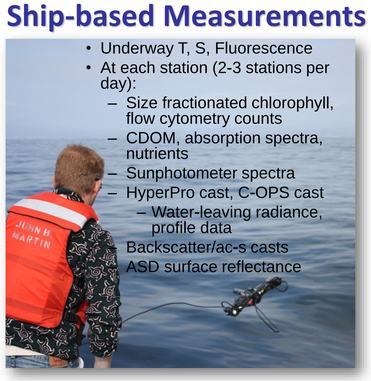
Spring (March), Summer (July), and Fall (October) provides a range of scientifically interesting features, including tidal exchange with Elkhorn Slough, red tides, fall transition, upwelling versus oceanic conditions, and, potentially, a "first flush" rain event.
Seasonality in Monterey Bay can be delineated by

- upwelling (April-August),
- oceanic (September-October), and
- Davidson (November-March) seasons.

Satellite Data

During flights, we obtained MODIS Aqua and Terra and HICO, data corresponding to contemporaneous deployment of the ship-based measurements from the R/V John Martin (Moss Landing Marine Lab). Satellite observations will be used to compare accuracy of radiance retrievals and derived products versus the Headwall imaging spectrometer and the *in situ* measurements.

Ship-based Measurements



- Underway T, S, Fluorescence
- At each station (2-3 stations per day):
  - Size fractionated chlorophyll, flow cytometry counts
  - CDOM, absorption spectra, nutrients
  - Sunphotometer spectra
  - HyperPro cast, C-OPS cast
    - Water-leaving radiance, profile data
  - Backscatter/ac-s casts
  - ASD surface reflectance

Coastal Airborne In-situ Radiometers (C-AIR)

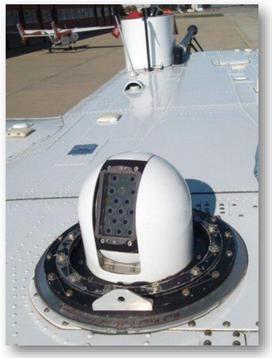
Three 19-channel microradiometers:
1. with cosine collector for measuring solar irradiance (Es)
2. Sky radiance (Li) and
3. Total radiance (Lt)

Spectral range: 320-780 nm with 10 nm bandwidth to include channels centered around 412, 443, 490, 510, 555, 665, and 683 nm to match satellite (NASA MODIS) bands used for ocean color remote sensing.

Physical FOV radiance instrument: 1.25° half-angle, 0.7° slope angle

The Es and Li radiometers are mounted within a fairing on top of the aircraft. The Li radiometer is mounted 40 deg off zenith. The Lt radiometer is mounted at 40 deg off nadir alongside the imaging spectrometer.

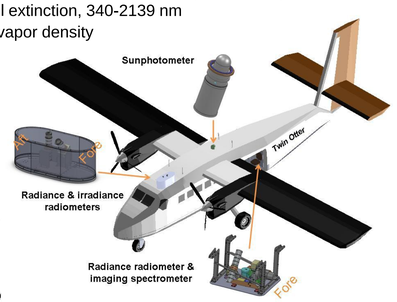
Ames Airborne Tracking Sunphotometer (AATS)



Measures:
Solar direct-beam transmission (T) at 14 wavelengths, 353-2139 nm

Data products:

- Aerosol optical depth (AOD) at 13 channels, 353-2139 nm
- Water vapor column content [using T(940 nm)]
- Aerosol extinction, 340-2139 nm
- Water vapor density

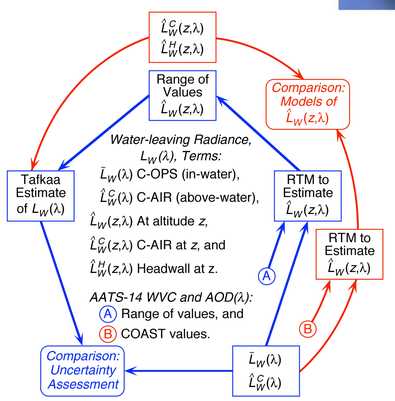


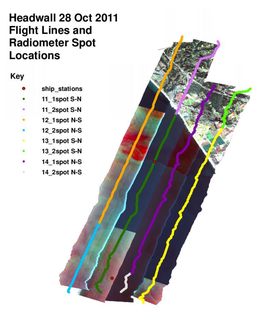
Imaging Spectrometer Specifications

Spectrometer: Concentric Pushbroom (Offner-ty
Spectral Range: 380 – 760nm*
$\Delta\lambda$ = 10 nm (@ off-chip binning of 1.5nm pixels)
Bands: 40*
Spatial Elements: 700
IFOV: 1.23 mrad
FOV: 46.7 degrees
Weight: 20+ lbs; Power: 30 Watts

Array: 1600 x 1200 pixels (7.4μm) @ -30C
Grating optimized at 450 nm
Spectral Smile: <0.25 Pixel (0.625nm)
Keystone: <0.9 pixel (6.6μm)
Dispersion: 100 nm/mm, linear to <0.5%**

* No order-sorting
** Modeled values





H-Q2O general data processing steps. From the COAST overflights, radiances from the Headwall and C-AIR at altitude (top) and from the C-OPS and C-AIR at lowest safe flight level (i.e. essentially no atmosphere; bottom right) are used to initiate the atmospheric correction and comparison. The COAST data (B) will be adjusted to at-sea-level water-leaving radiances (C-OPS, lowest safe flight C-AIR, and Headwall after atmospheric correction using Tafkaa), and will also be compared at-sensor (z) after adjustment for atmospheric effects. The C-OPS and lowest safe flight C-AIR data will then be merged with a range of atmospheric profiles from AATS-14 measurements over Monterey Bay not collected during COAST (A) and compared after atmospheric correction using Tafkaa. This suite of evaluations will provide uncertainty estimates between the C-AIR and Headwall, between the airborne sensors and in-water measurements (the latter considered to be "truth"), and between the various sensors under a range of typical atmospheric conditions. WVC = water vapor column.

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