Hyperspectral radiometric device for accurate measurements of water leaving radiance from autonomous platforms for satellite vicarious calibrations (aka HYPERNAV)

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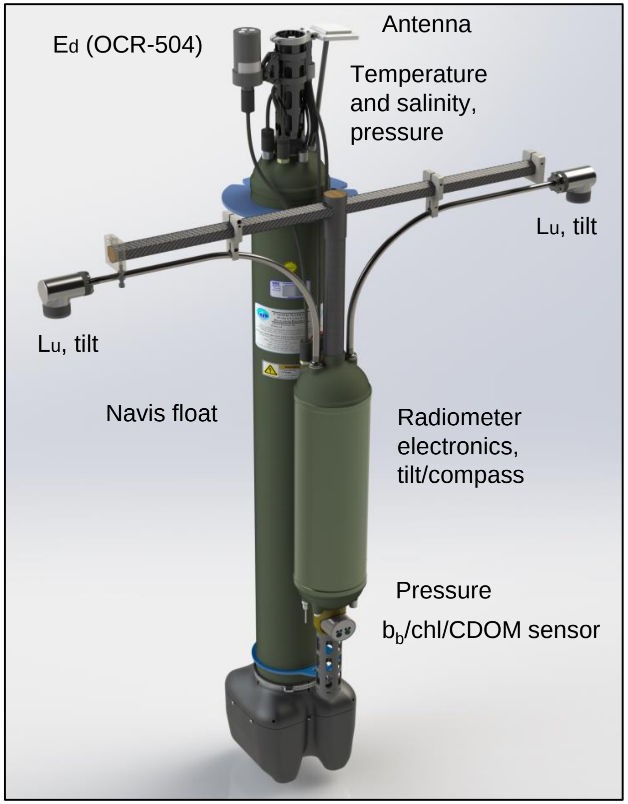
Project Overview

Goals

- Next-generation hyperspectral radiometric sensors for calibration/validation.
- Utilize autonomous floats as a platform to collect hyperspectral radiometric to minimize uncertainty.
- Develop an end-to-end system/strategy for new ocean-color satellite calibration – including float deployment, radiometric data quality assurance, data delivery and satellite inter-comparison.



HyperNav autonomous float system advantages

- Risk reduction approach to the vicarious calibration program for PACE and other missions.
- Deployment floats at the start of a satellite mission - Rapid characterization of in flight satellite radiometer.
- Provide radiometric measurements across a broader range of solar angles and geographic regions, to assess the satellite dependencies on out-of-band response, BDRF, etc.
- Augments other moored cal/val sites throughout satellite lifetimes, enables rapid collection of vicarious calibration data.

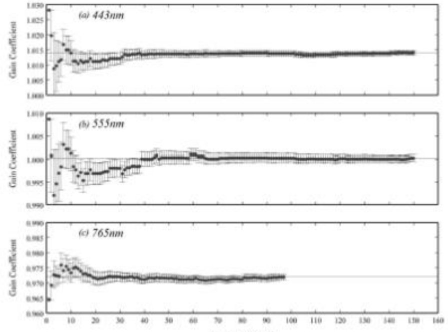


Fig. 6. Mean vicarious gains, $g(\lambda)$, derived for SeaWiFS bands at 443, 555, and 765 nm based on calibration samples spanning the mission lifetime from September 1997 to March 2006. Individual gains from the mission-long set of calibration match-ups were randomly sampled, growing the sample set one case at a time and averaging to show the effect of increasing sample size on $g(\lambda)$. Vertical error bars show the standard error on the mean at each sample size.

High Level Requirements Matrix

REQUIREMENT	CAPABILITY
Spectral Range 350-900 nm	350 to >900 nm
Resolution < 3 nm	<=2.2nm (350-800nm), <=2.35nm (800-900nm)
Radiometric Uncertainty < 4% in blue-green	< 4% in the blue-green. < 6% in red. Uncertainty due to extrapolation from L(z) to L(0).
Radiometric Stability O(1%) per Deployment	System will park at 1000 m depth, inhibiting biofouling.
Autonomous Field Operation	Excellent history of long-term float deployment. Float scheduling can be updated after deployment.
Fully Lab and Field Characterized	Radiometers will be fully characterized (stray light, temp, linearity, etc) Calibrated with NIST-calibrated lamps.
Fully Autonomous Data Delivery to Enable the NASA Mission Science.	A full end-to-end system with automated Prosoft processing scripts.

Design of Hypernav Systems

HyperPro
Profiler

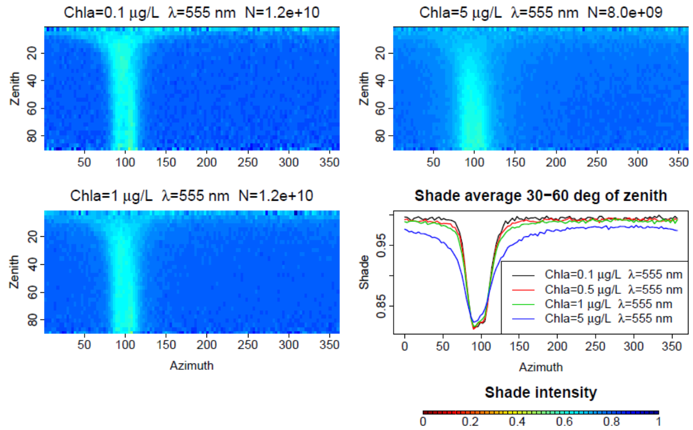
Hypernav
Freefall Profiler & TSRB

HyperNav on Navis Float

Radiometric Design and Freefall profiling mode – Upwelling radiance system

Design of Radiometric System

1. Dual radiance heads -> sun-side radiometer & intercomparison.
2. Heads on arms reduce self-shading.
3. Right-angle design -> near surface.
4. Reduced errors in extrapolation to Lu(0-).
5. Tilt sensors for alignment and to monitor position.
6. Shutters for collecting darks.
7. Depolarizer to remove uncertainty in the fore optics.
8. 2.2 nm nominal resolution, 350-900 nm

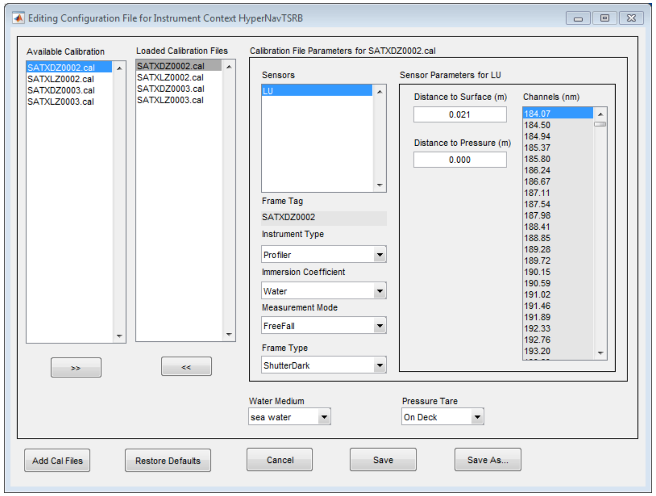


Supercomputer simulations of shading vs zenith, azimuth, depth, wavelength, chl-a using SimulO software by Edouard Leymarie (LOV)

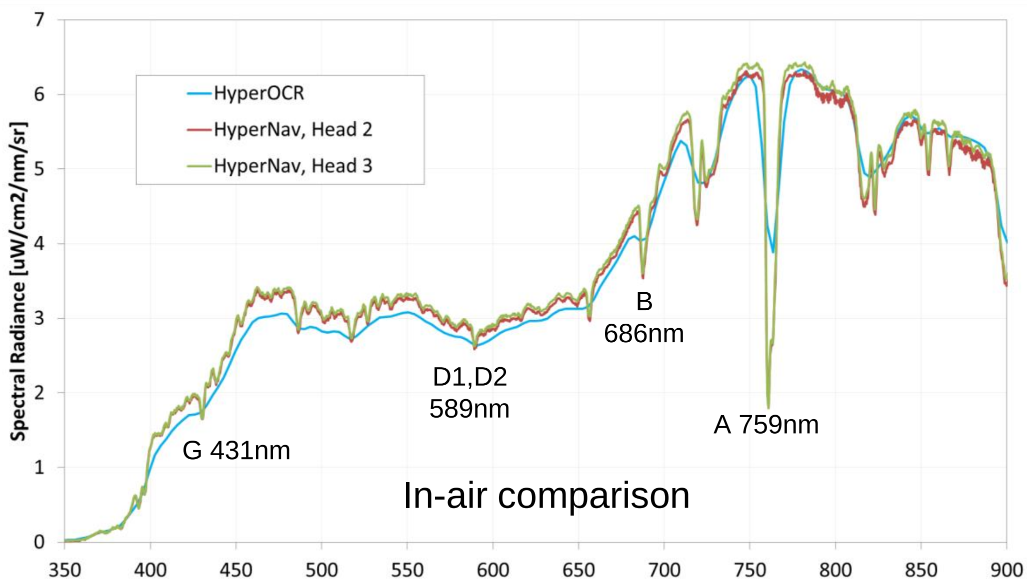
Electronics/Firmware and Data processing

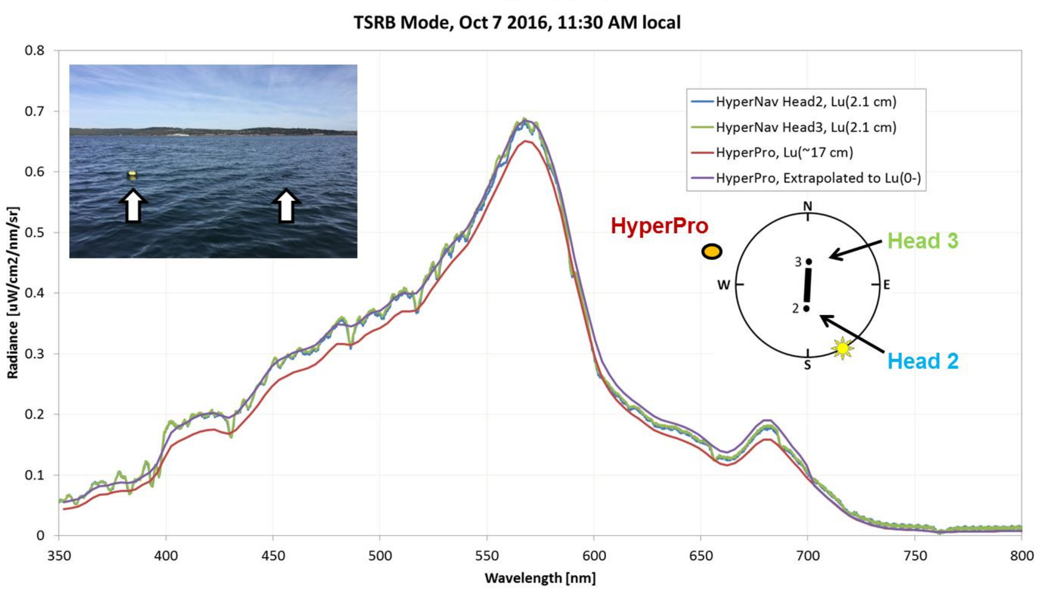
- Two processors to share tasks
- Real-time firmware
- Control of spectrometers, Ed, pressure, tilt/heading, modem
- Data storage and transmission
- Capability to include onboard QC
- Modes for streaming data and autonomous operation

- Real-time data visualization using SatView; data processing using SatCon/ProSoft.
- Runs on MatLab and Linux with a command line interface for automated processing.



Initial HyperNav Comparisons (2016)





In-air, sun incident on Spectralon plaque.

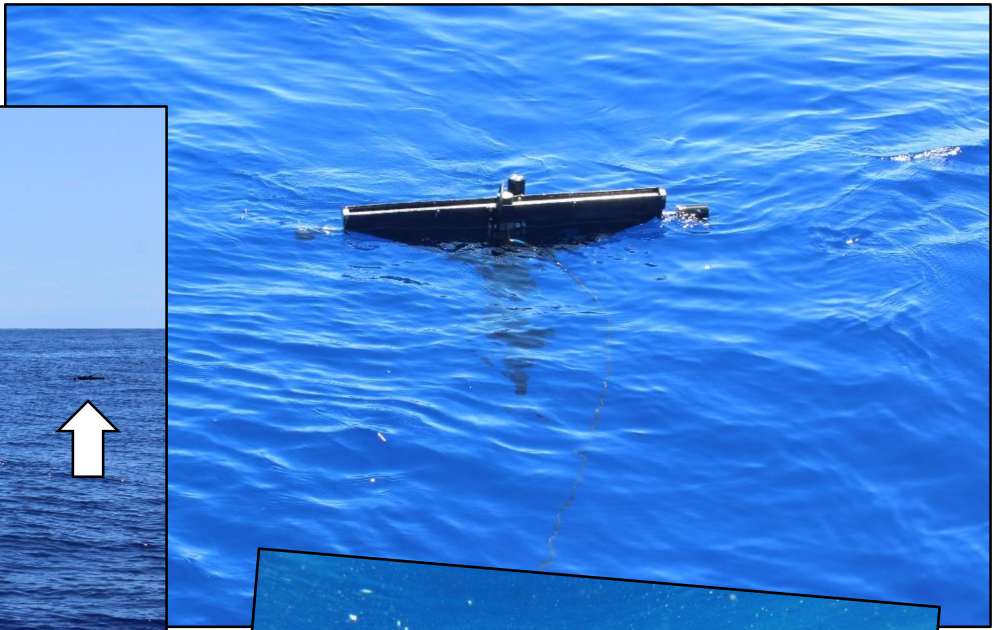
A neutral density filter was needed to prevent HyperNav from saturating.

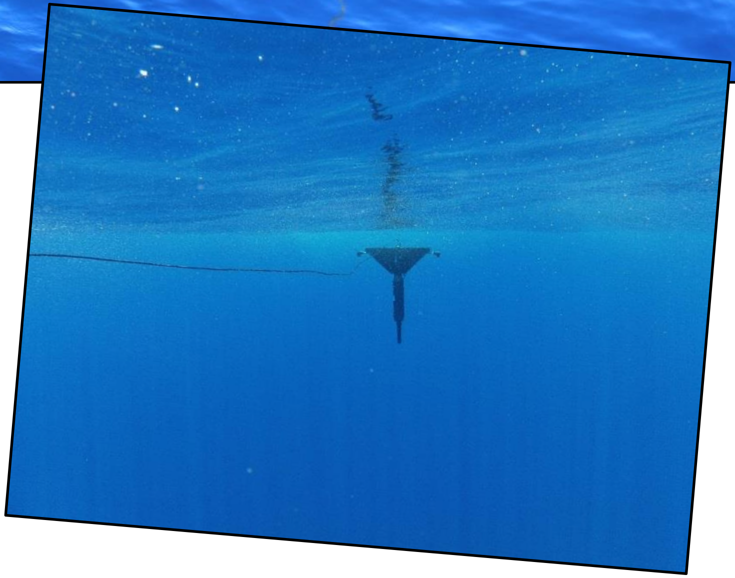
HyperNav in surface mode comparison with HyperOCR.

HyperPro extrapolation to Lu(0-) uses spectral k estimation (Austin Petzold 1981 & Morel 2001)

Good agreement (once extrapolated to surface) with HyperOCR.

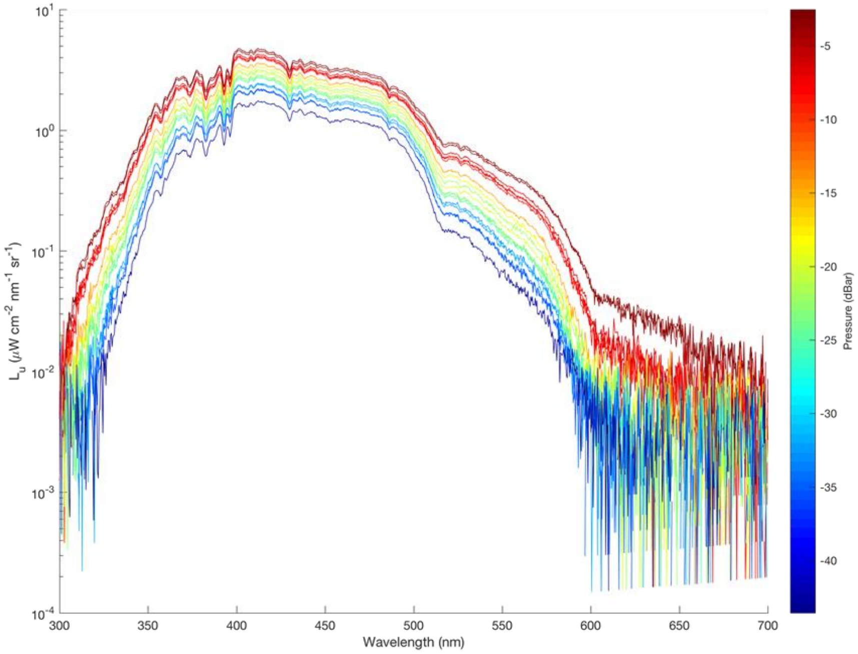
Freefall Deployment at MOBY(2017)



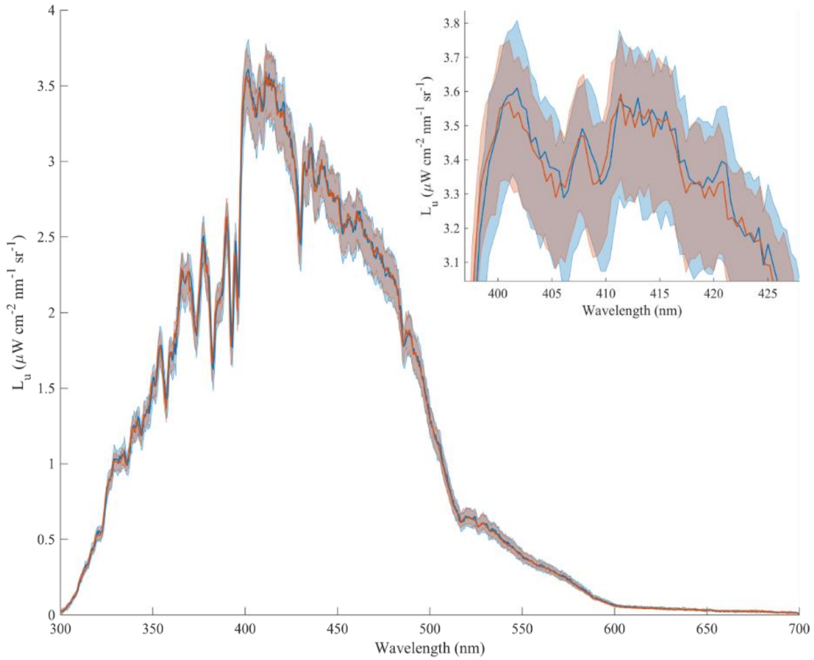


Three days of deployments (August 7-9 2017) at MOBY.
2 HyperNav systems, 1 HyperPro system.
Calm seas, generally thin cloud, but some clear periods.
Deep casts, multicasts, and TSRB mode.

HyperNav Profile Data MOBY

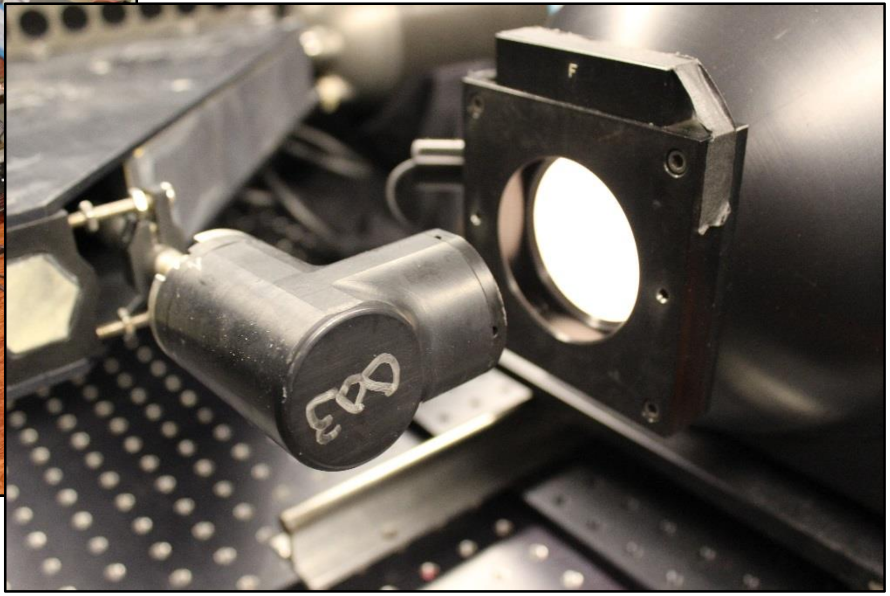


PROFILE: $L_u(\lambda)$ spectrum as function of depth. Deep cast from sensor 2 of HyperNav 1 on August 8, 2017 at 14:06 local. Data with a tilt > 3º is ignored.



SURFACE: $L_u(\lambda)$ spectrum. Median, 5 and 95 percentiles of L_u tilt > 3º is excluded. Wavelengths are shifted as shown in the zoomed section of the plot (investigating pixel registration).

HyperNav at MOBY Radiance Source



Data processing ongoing. Provides check point for our system against known MOBY standard.

Many thanks to the entire MOBY team for allowing us to make some reference measurements in front of their radiance source!

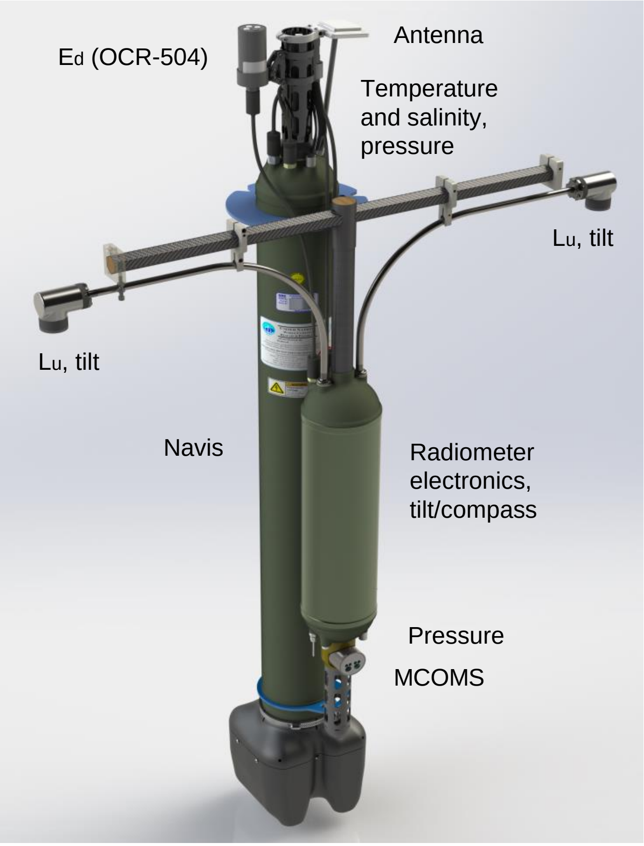
Hypernav + Navis – float integration, configuration and testing: off Kona, HI, 15 Nov – Dec 4 2017

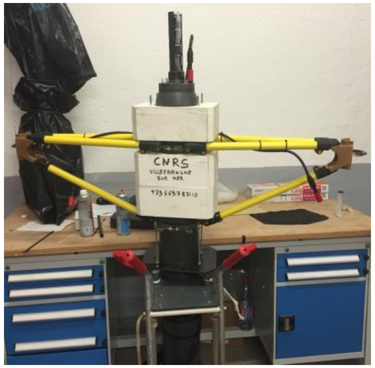
HYPERNAV+float System Overview

SENSOR	LOCATION	PURPOSE
OCR-504	Top of Navis mast	(380nm, 490nm, 590nm, PAR) Validation, sky conditions
MCOMS	Base of radiometer	(Chl, 700 BB, FDOM) Data validation
Pressure	Base of radiometer	High accuracy & resolution depth for surface extrapolations
Temperature and Salinity	Top of Navis mast	For use with pressure for depth calculation
Tilt/Compass	Radiometer body	Quality control, orientation to the sun
Tilt	Radiometer heads	Head alignment and monitoring

Key Aspects:

- Dual independent radiometers – relative drift
- Lu very close to surface
- Pressure rated to ~ 1000m
- Improved pressure accuracy sensor – used for upper radiometric measurements
- Minimization of self shading
- Ability to extend at surface acquisition time
- Tilt data utilization for power saving





Courtesy of LOV, E. Leymarie

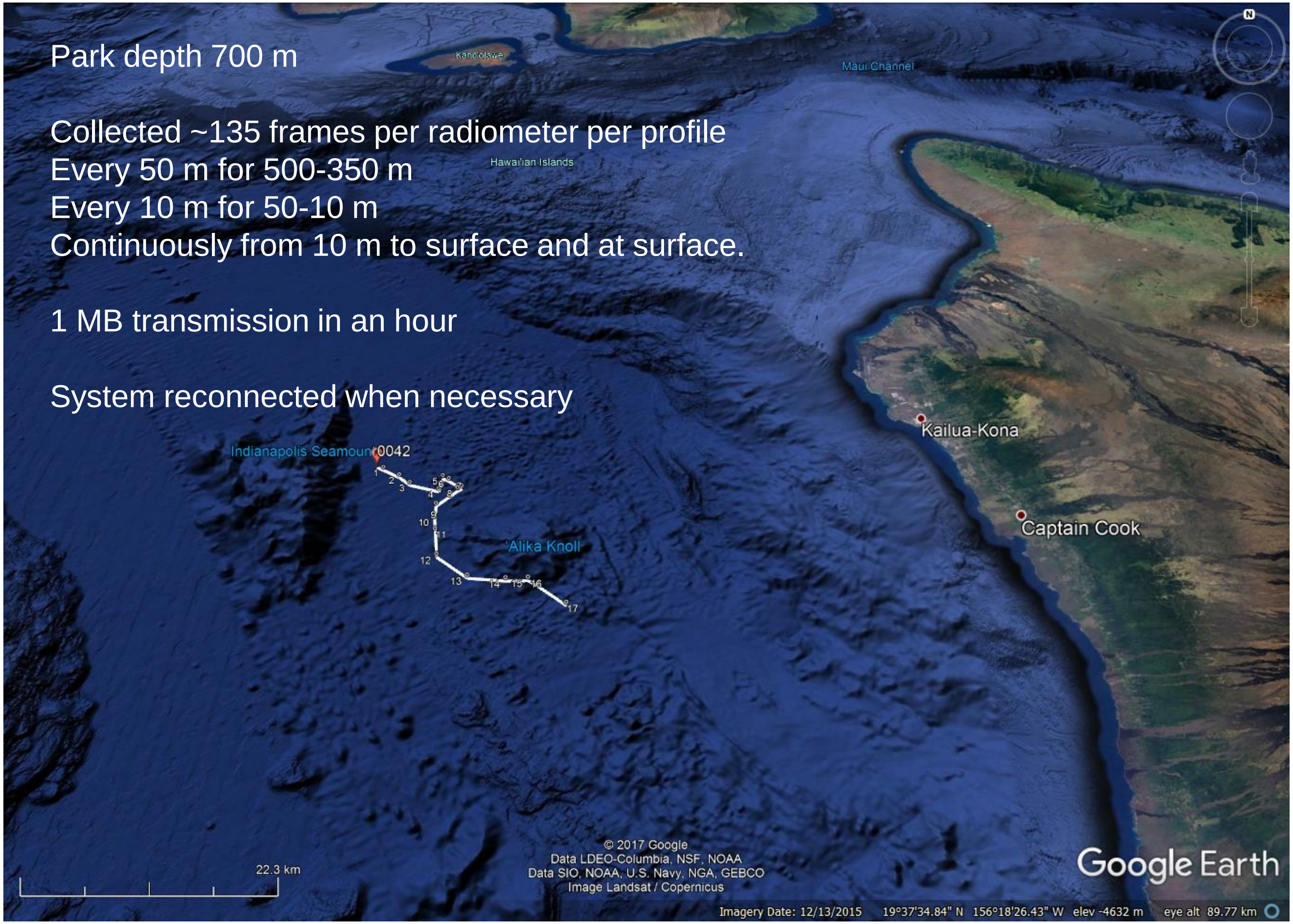
Nov 15 – Dec 4, 2017 Float Path

Park depth 700 m

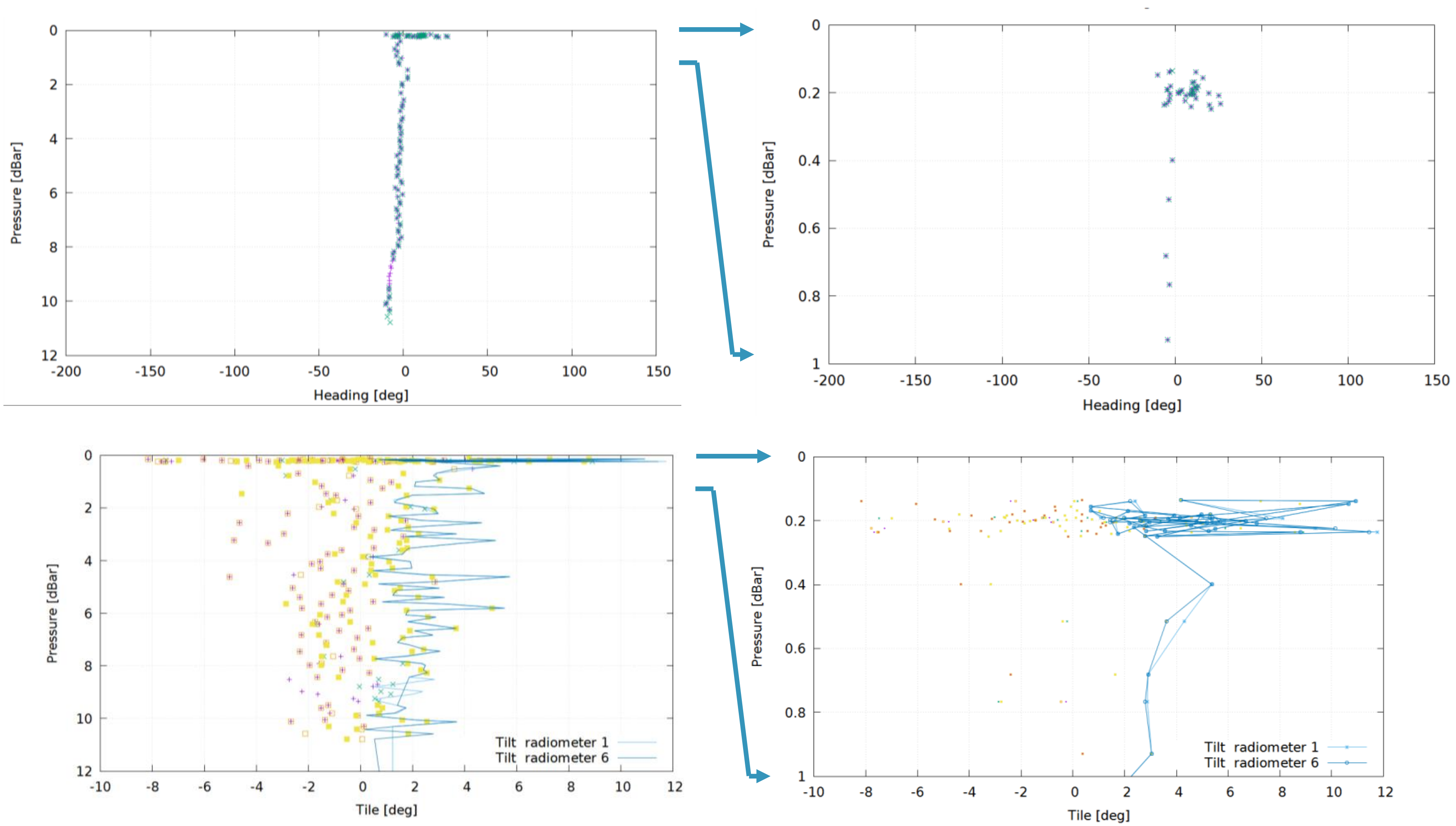
Collected ~135 frames per radiometer per profile
Every 50 m for 500-350 m
Every 10 m for 50-10 m
Continuously from 10 m to surface and at surface.

1 MB transmission in an hour

System reconnected when necessary

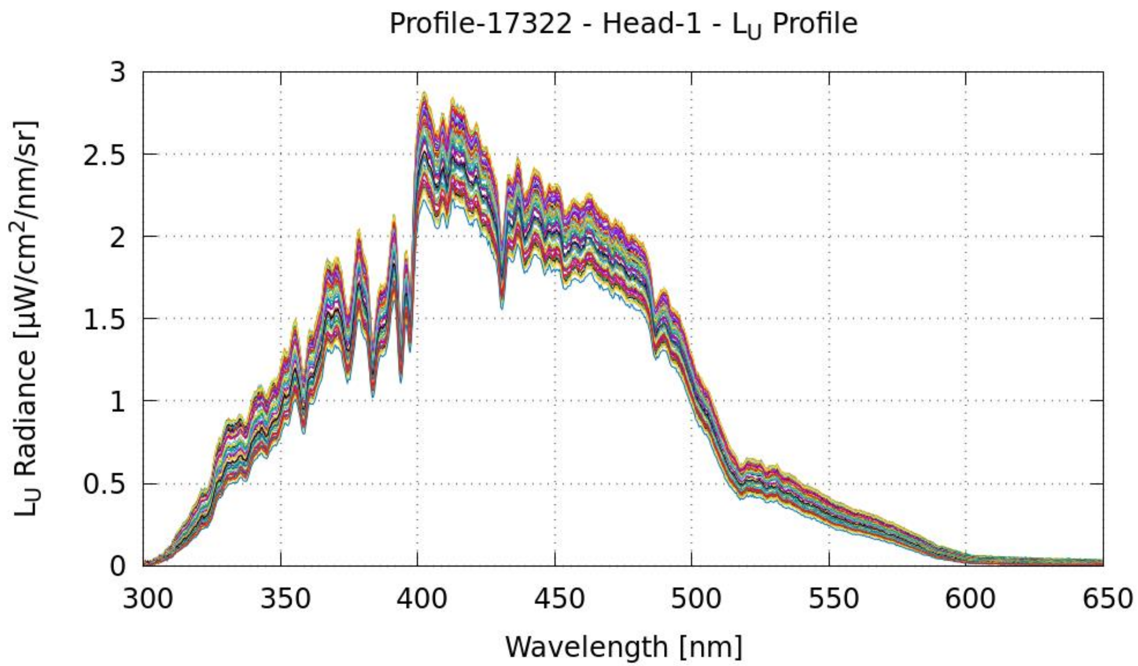


Profiling Float – Heading and Tilt



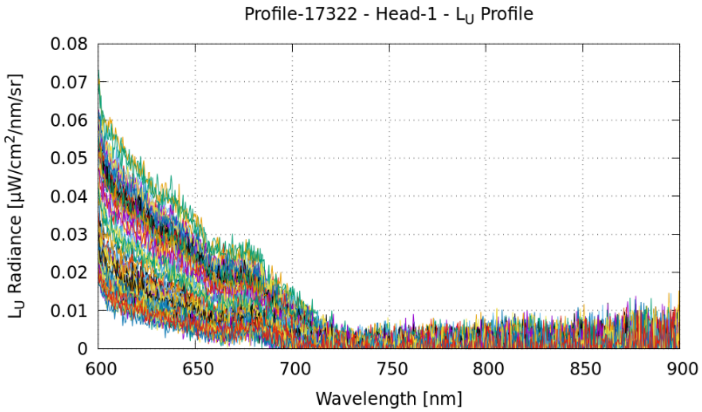
Future work will include recording only frames with good tilts, to reduce data transmission.

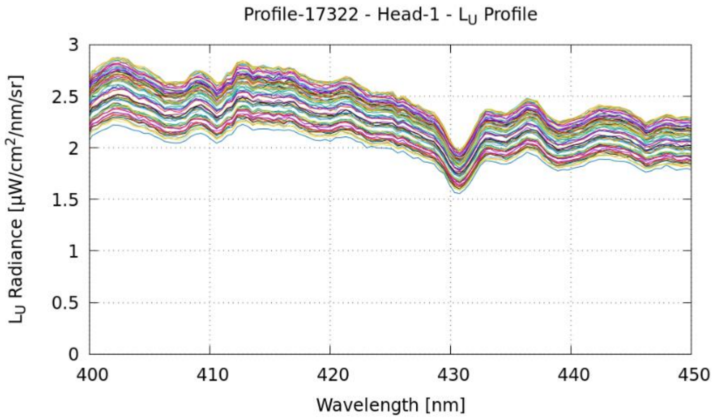
Profiling Float - Spectra



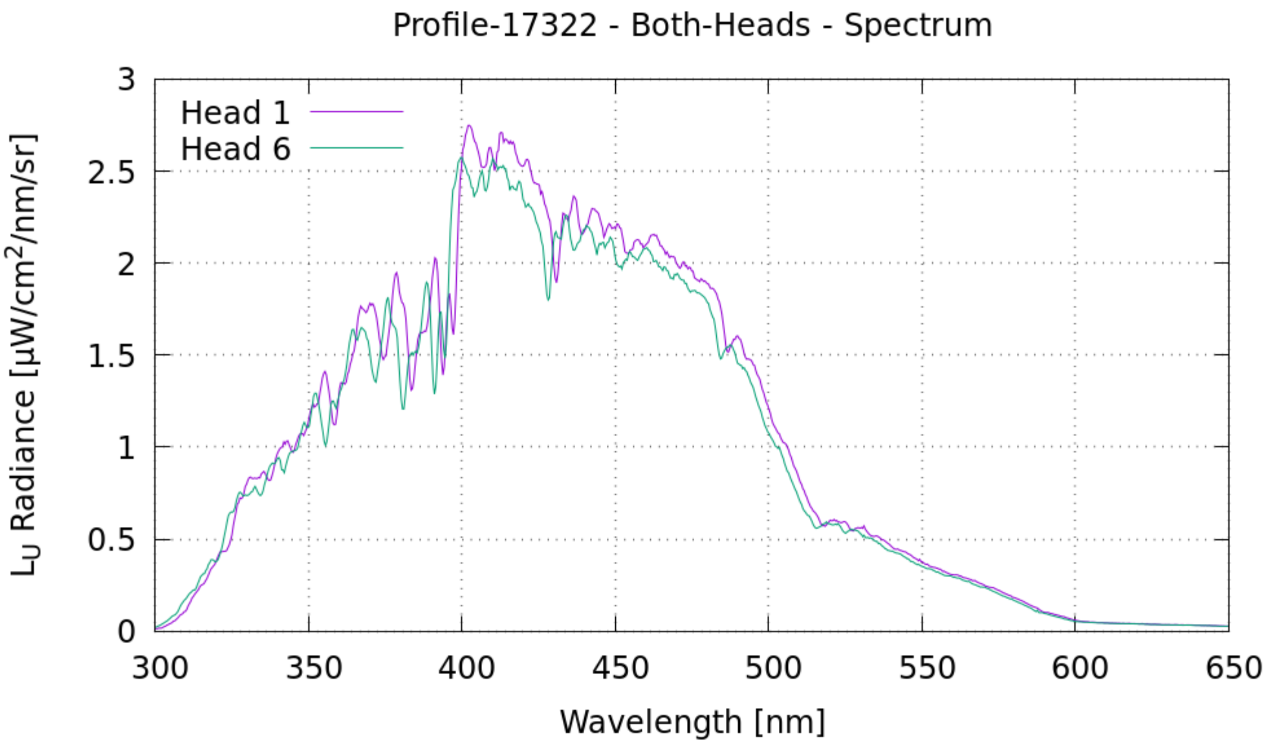
Spectra from the upper 10 m and at the surface.

Surface data not filtered for tilt.





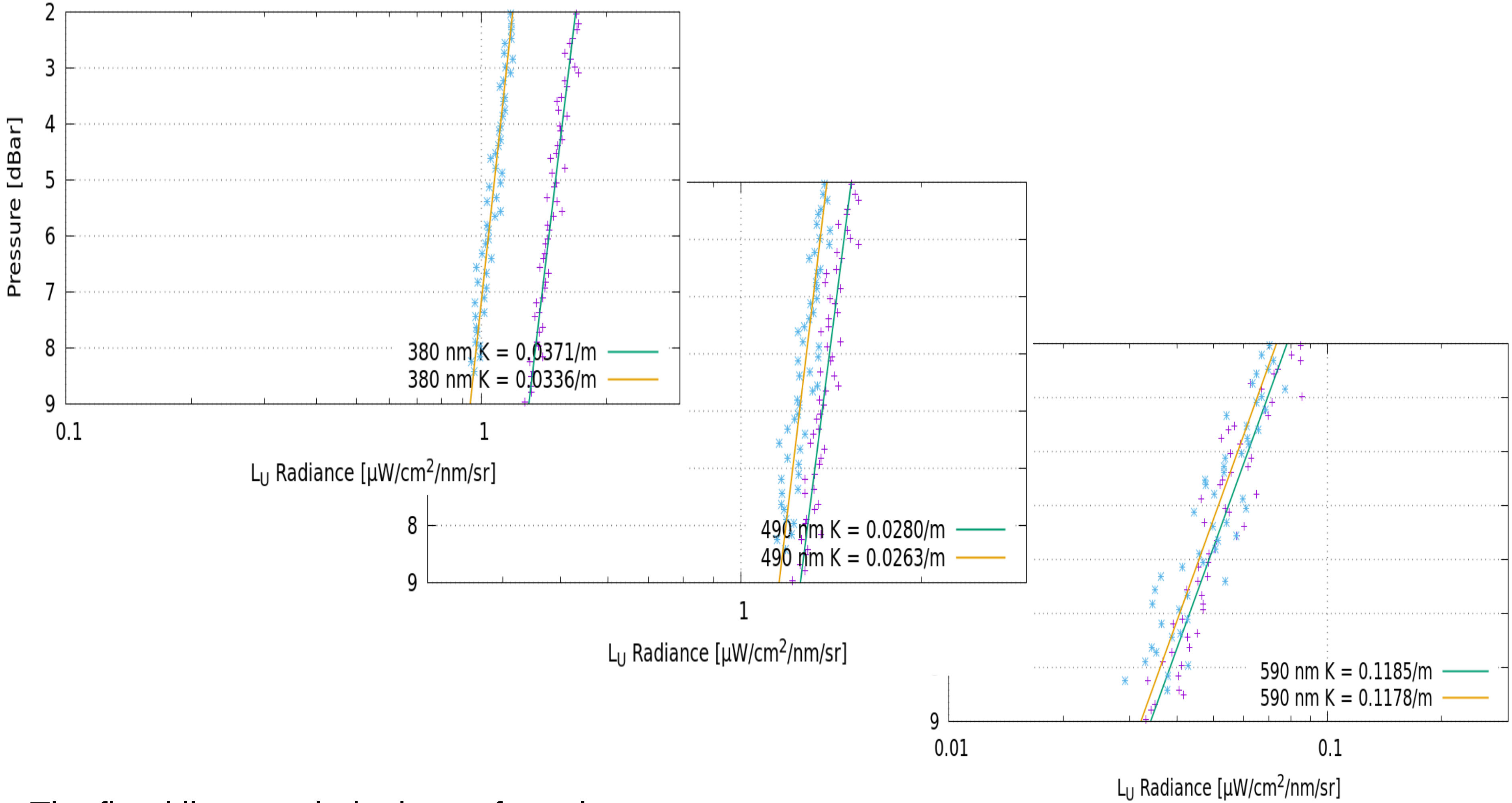
Profiling Float – Comparing Heads



There is an issue with wavelength registration and calibration – likely linked (likely a FW/HW issue).

This impacts the following plots of K.

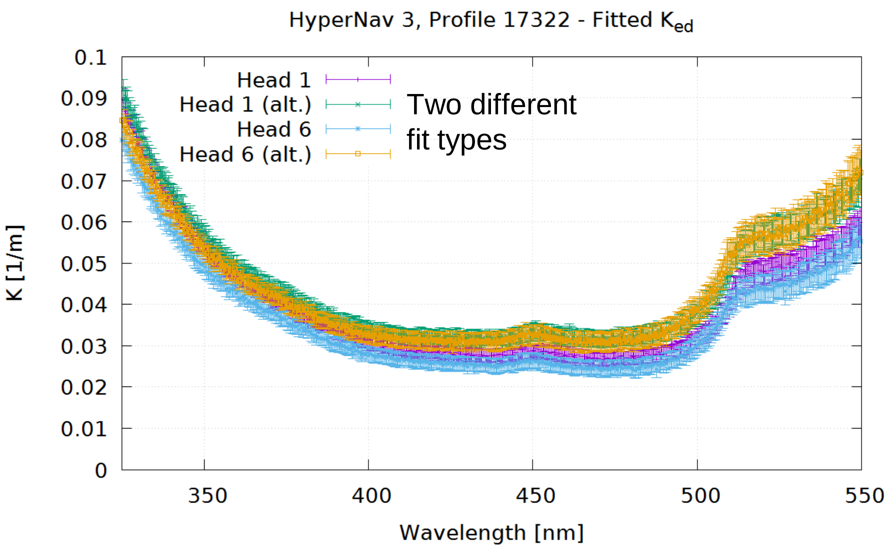
Profiling Float – K_{Lu} 380, 490, 590 nm

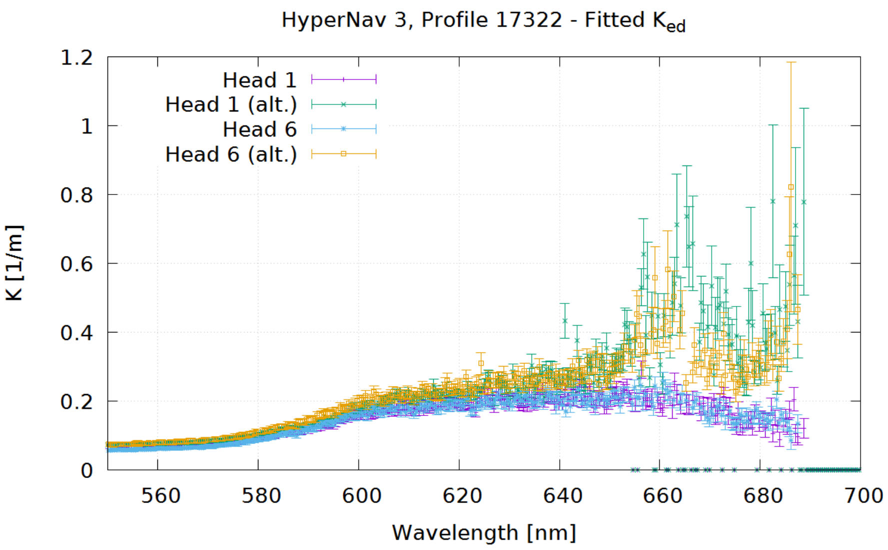


The fitted lines exclude the surface data.

Poor match between the two heads likely due mostly to calibration issues.

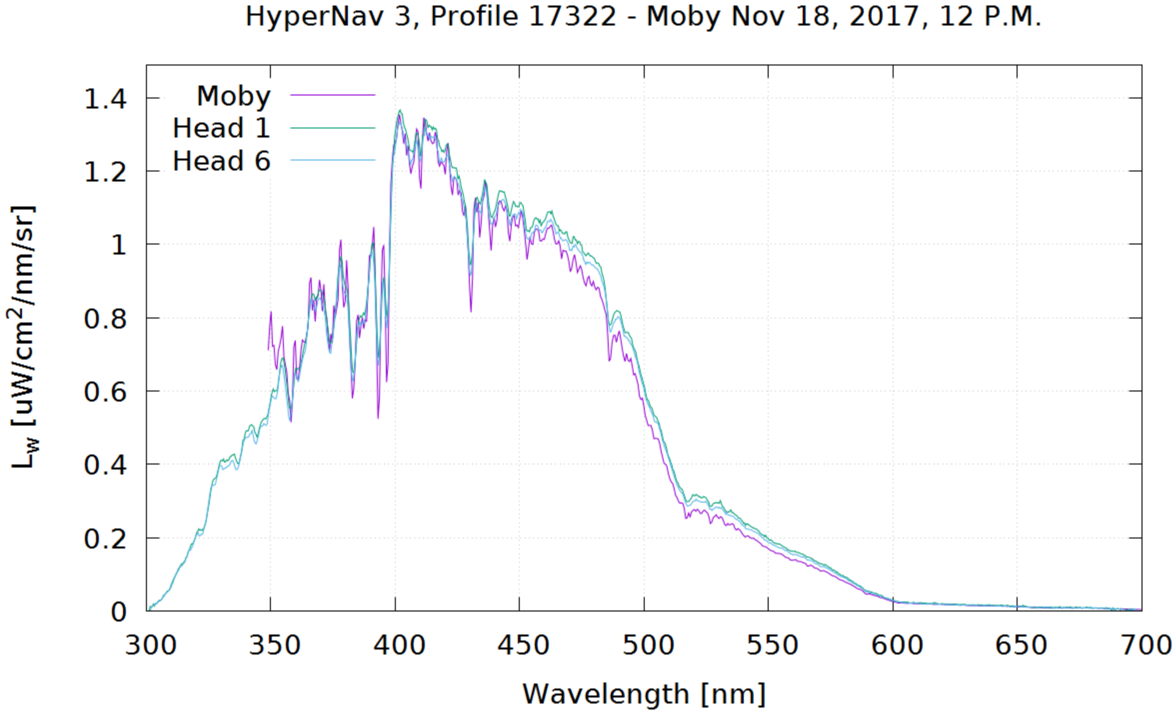
Profiling Float – K_{Lu}





Data fitted over 2-9 m, assuming constant k_{Lu}.

Initial Comparison with MOBY



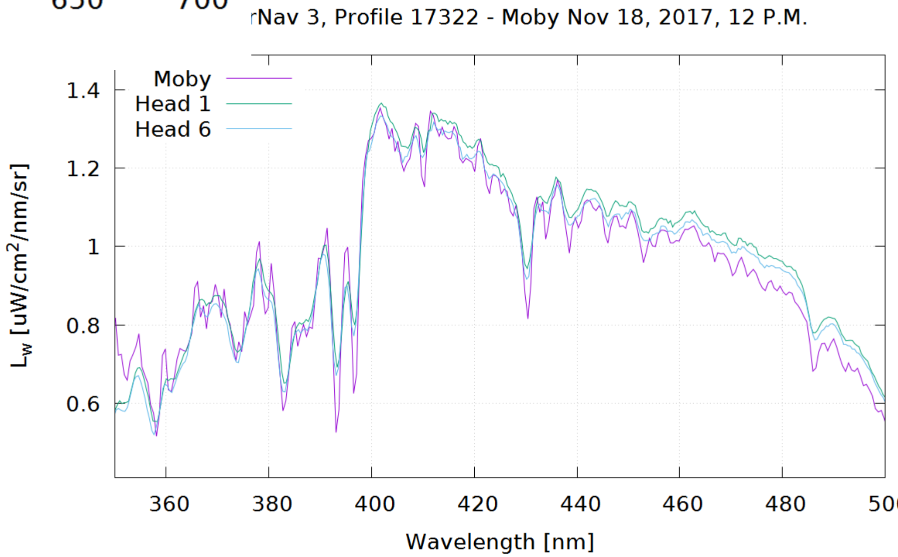
Nov 18, 2017

Hypernav float system located some 70 miles or so apart.

Matchup with satellite data in progress.

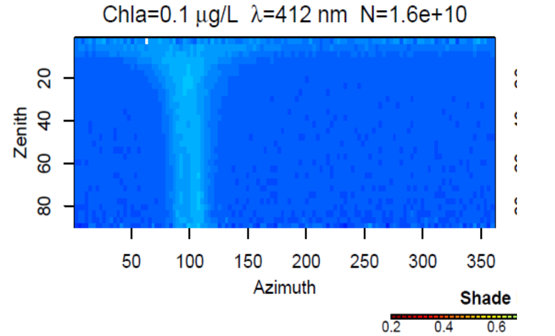
Hypernav Lw data calculated by best fit of the 1-5m profile data to constant k, then extrapolated to surface and transmitted through water surface (Quan & Fry, 1995)

Note: Minimal corrections have been applied (stray light, linearity, etc).



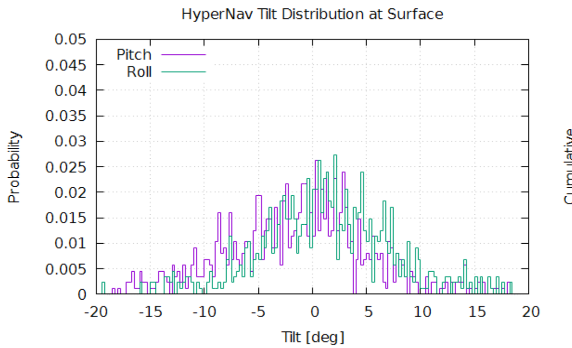
Other Uncertainties

Self Shading - Simulations by Nils Haëntjens on the U. Maine supercomputer using the SimulO software (Edouard Leymarie, LOV). Provides ability for lookup correction table.



Tilt Effects – Field data shows 20-40% < 2 degrees tilt.

Biofouling – Brown *et al.* 2007 report 1% for MOBY for 3 months. Being generally at depth, we estimate it to be this level.



Wave Focusing – Related to integration time (HyperNav is 11 ms at the surface). We need to do more work here.

Depth Uncertainty – Effects extrapolation to $z=0^-$. Observing HyperNav in TSRB mode, we can say the heads vary +/-12 cm (average depth is 12 cm). This is a problem at the long wavelengths (0.5% in blue, 4% @ 665 nm). Requires more study or countermeasures.

Surface Transmittance – ProSoft uses a wavelength independent transmittance value. To reduce uncertainty we need it dependent on λ, S, T.

Uncertainties Matrix – < 4% blue-green

SOURCE	TARGET %@412nm	TARGET %@443nm	TARGET %@510nm	TARGET %@550nm	TARGET %@665nm	METHOD OF VALIDATION	MITIGATION
Calibration							
Irradiance standard	0.51	0.48	0.42	0.40	0.34	Provided by NIST	Use NIST calibrated lamp
Reflectance target	0.01	0.01	0.01	0.01	0.01	Provided by manufacturer	Use corrections for 0-45deg
Geometric Effects	1.4	1.4	1.4	1.4	1.4	Past measurements	None, could correct in future
Reproducibility	1.5	1.5	1.5	1.5	1.5	Repeated calibrations	Careful lab procedures
Instrument							
Polarization	0.5	0.4	0.06	0.07	0.5	Measured at cal station	Characterize
Immersion factor	0.43	0.45	0.44	0.42	0.40	Theory and experiment	Careful lab procedures
Grayscale linearity	0.1	0.1	0.1	0.1	0.1	NIST beam conjoiner	Characterize and correct
Integration time linearity	0.05	0.05	0.05	0.05	0.05	At cal station	Characterize and correct
Stray light	0.10	0.09	0.06	0.04	0.09	NIST laser scanning	Characterize and correct
Thermal effects	0.08	0.08	0.08	0.08	0.08	At cal station over 4-30 C	Characterize and correct
Wavelength accuracy	0.1	0.1	0.1	0.1	0.1	Use stray light data	Characterize
Field							
Wave focusing	0.2	0.2	0.2	0.2	0.2	Use past studies	High frame rate at surface
Self-shading	0.26	0.26	0.5	0.5	0.5	Monte Carlo	Model corrections
Tilt effects	2.2	2.2	2.2	2.2	2.2	Tilt sensors in heads	Only send data w/ good tilts
Depth uncertainty	0.56	0.54	0.82	1.14	4	Modelling	Ideas for future improvements
Surface transmission	0.1	0.1	0.1	0.1	0.1	Modelling	Characterize and correct
Biofouling (6 mnths)	1	1	1	1	1	Other studies, pre/post cal	Park in aphotic zone
Total	**3.5**	**3.4**	**3.4**	**3.5**	**5.8**		

Measured/modeled | **Rough estimate, need improved estimate** | **Estimated, to be measured**

Future Steps & Recommendations

Next Steps

- Finalize characterizations – NIST starting 1/19-1/26. Stray light and linearity.
- Post field deployment calibrations of radiometers to finalize instrument uncertainties.
- FW/HW improvements: integration timing and wavelength registration.
- Continue to reduce the noise in the > 700nm wavelength measurements. Depending on PACE needs, may need to consider dedicated spectrometer for this wavelength range.
- Complete matchup analyses with MOBY and satellite sensor data.
- With these in hand, the system achieves TRL 7.

Recommendations

- Development needs to be continued to address improvements in FW/HW.
- More field deployments are necessary to assess repeatability and long term data uncertainties.
- Recommending a series of pilot phase deployments (multiple floats in same location; floats in different locations). More deployments at MOBY.
- Currently looking for field opportunity collaborations.

Thank You