Uncertainties assessment and MODIS validation from multi- and hyperspectral measurements in coastal waters at Long Island Sound Coastal Observatory (LISCO)

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Coastal Water Ocean Color Remote Sensing

Constituents of the water (phytoplankton biomass, sediment, …) can be estimated through Ocean Color Radiometry (OCR)…

…makes possible the atmosphere-ocean interaction quantification, the sediments, pollutants fluxes and ecosystem monitoring …

…at a global scale thanks to satellite observation.

→ Need for reliable ocean color satellite data

Ocean Color Satellite Sensors

Current missions

- **SeaWIFS** (NASA) on GeoEye's satellite (*8 spectral bands (from 412 to 865 nm) with 1.1 km resolution)*
- **MODIS** (NASA) on Terra and Aqua satellite (*36 spectral bands (from 412 to 15 μm) with 250m - 1km resolutions)*
- **MERIS** (ESA) on ENVISAT satellite (*16 spectral bands (from 412nm to 14.4 um) with 250m - 1km resolutions)*
- **HICO** (NASA) Hyperspectral Imager for the Coastal Ocean
- **PARASOL, MISR, OCM2, …**

Future missions

- **VIIRS** (NASA) future replacement of MODIS, planned to launch in 2011 (*22 Spectral bands (370nm to 12.5 um) with 650m resolution)*
- **OLCI** (ESA) next generation of MERIS on Sentinel-3

Ocean Color Satellite Validation

Complex atmosphere over coastal area
and non zero water signal in the near-infrared

→ gives difficulties in the atmospheric correction procedures

→ **Satellite data must be validated against *in situ* measurements, especially in coastal water area**

Ocean Color Satellite Calibration

Vicarious Calibration accounts for :

1. systematic biases in the atmospheric correction algorithm
2. changes to the prelaunch calibration resulting from the transfer to orbit.

Calibration at MOBY site provides only ~15 matchup points per year → **need for alternative sources of ground-truth data**

Biases in the atmospheric correction algorithm are different in open ocean and coastal area → **need for sources of ground-truth data in coastal area**

→ **Long Island Sound Coastal Observatory (LISCO)** unique site in the world continuously providing multi and hyperspectral data from collocated instrumentation in coastal water area

→ LISCO as reference site for validation/calibration of Ocean Color Satellite mission

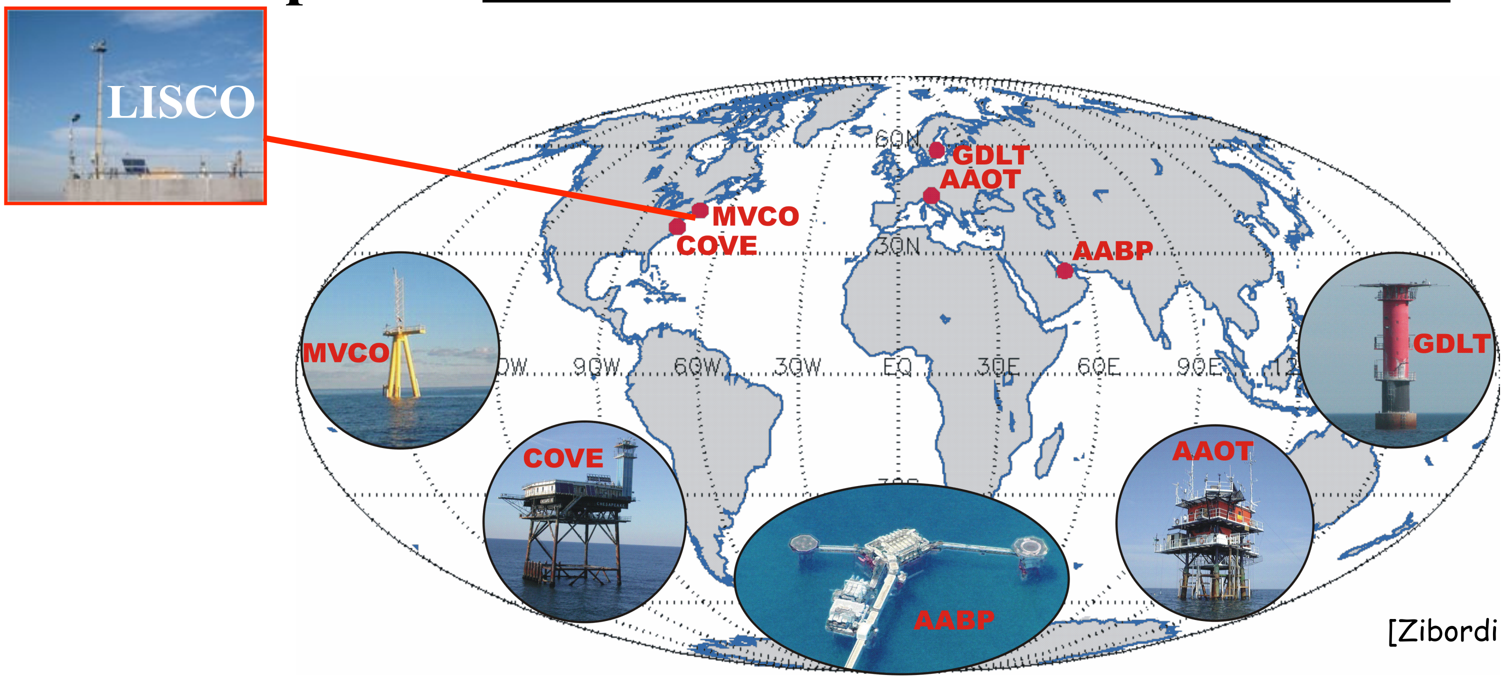
Contents

- Long Island Sound Coastal Observatory (LISCO) characteristics
- Multispectral (SeaPRISM) and hyperspectral (HyperSAS) data processing
- LISCO Data Uncertainty of the collocated SeaPRISM and HyperSAS measurements
- LISCO Ocean Color Radiometry Product Quality and application to MODIS
- LISCO high quality data: Towards a Satellite Cal/val Site
- Conclusion and perspectives

LISCO Site Characteristics

LISCO Multispectral SeaPRISM system

as part of AERONET – Ocean Color network



[Zibordi et al., 2006]

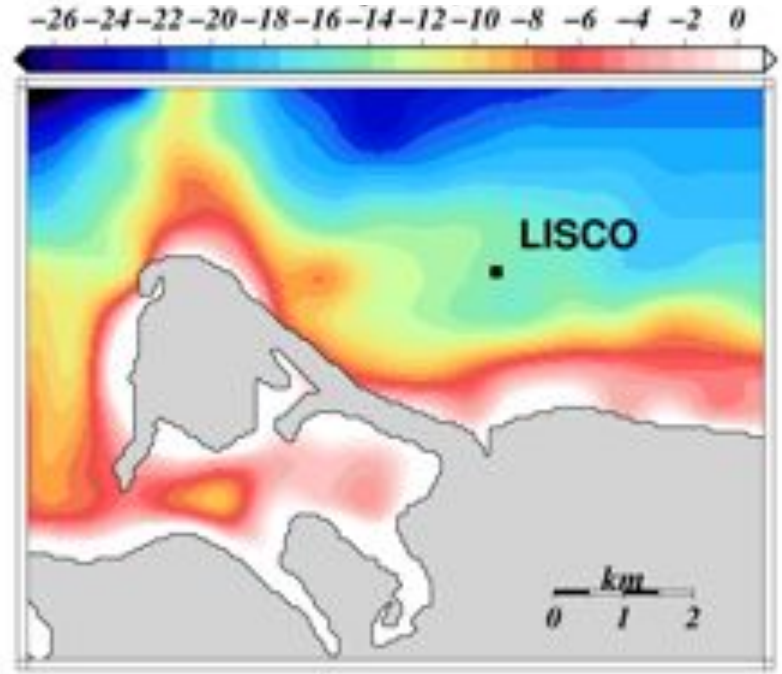
- Identical measuring systems and protocols, calibrated using a single reference source and method, and processed with the same code;

→ **Standardized products of exact normalized water-leaving radiance and aerosol optical thickness**

LISCO Site Characteristics

Location and Bathymetry

Depth in meters (GEBCO data)

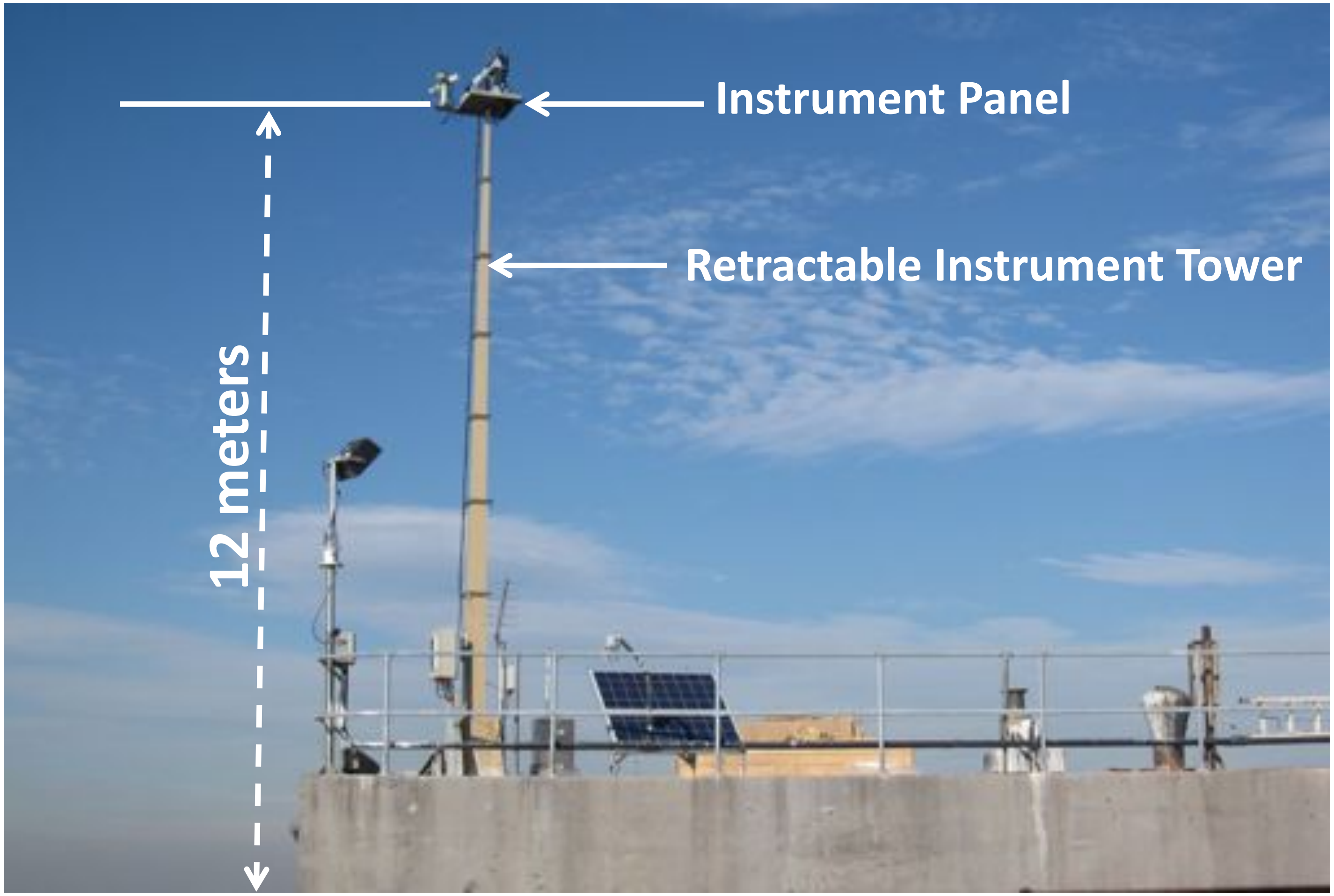


Water type: Moderately turbid and very productive (Aurin et al. 2010)

Bathymetry : plateau at 13 m depth

LISCO site Characteristics

Platform: Collocated multispectral **SeaPRISM** and hyperspectral **HyperSAS** instrumentations since October 2009

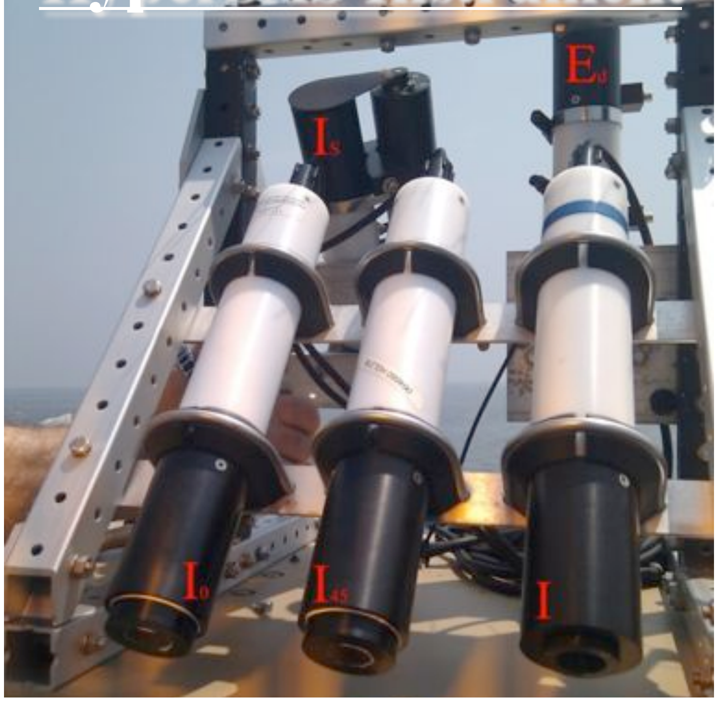


LISCO Instrumentation

SeaPRISM instrument

- Sea Radiance
- Direct Sun Radiance and Sky Radiance
- Bands: 413, 443, 490, 551, 668, 870 and 1018 nm

HyperSAS Instrument



- Sea Radiance
- Sky Radiance
- Downwelling Irradiance
- Linear Polarization measurements
- Hyperspectral: 180 wavelengths [305,900] nm

Data acquisition every 30 minutes for high time resolution time series

Multispectral (SeaPRISM) and hyperspectral (HyperSAS) data processing

Comparison of SEAPRISM and HyperSAS

Above Water Signal decomposition

Total radiance

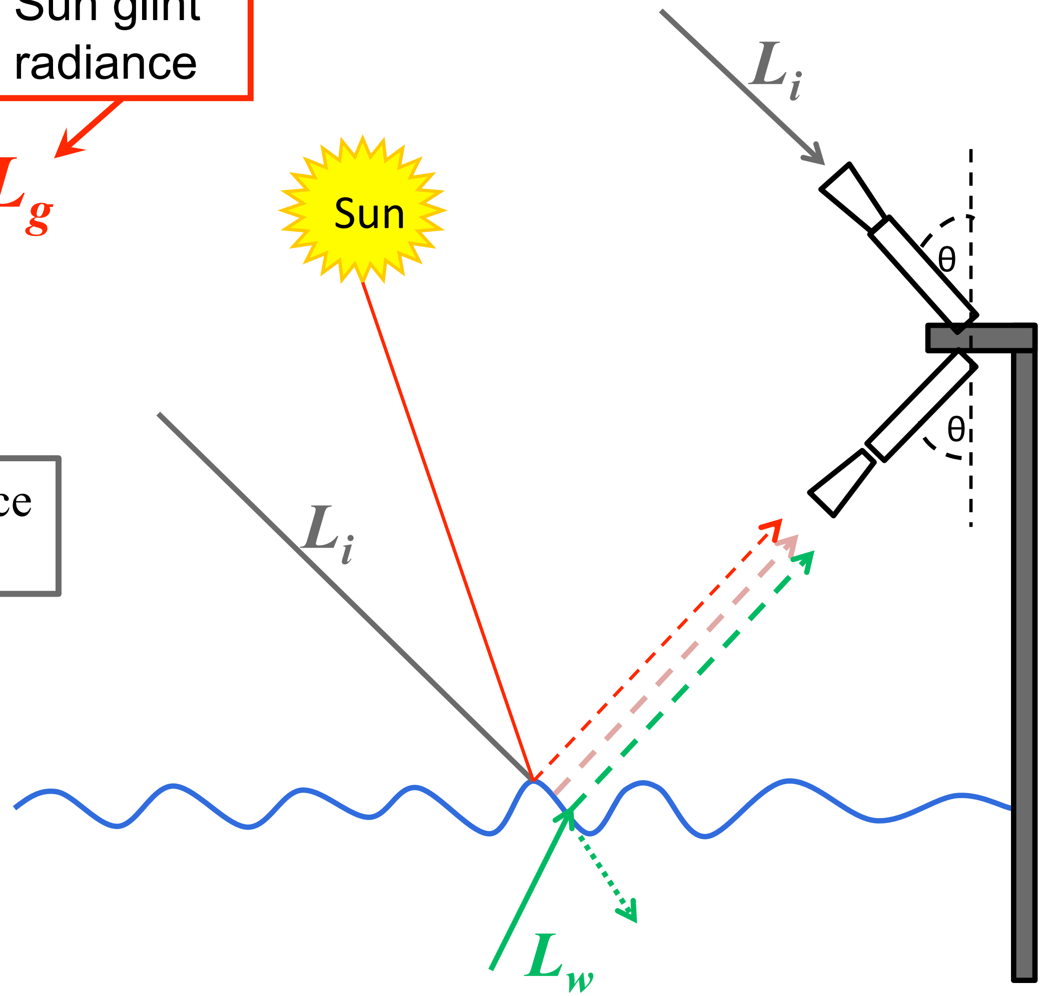
Sky radiance

Sun glint radiance

$$L_T = L_w + \rho(W)\, L_i + L_g$$

Water leaving radiance

Sea surface reflectance factor



Comparison of SEAPRISM and HyperSAS

Above Water Signal Processing

i. $L_T = L_w + \rho(W)\, L_i + L_g$
measured by numerous acquisitions within 2-minute time window (11 for SeaPRISM and > 44 for HyperSAS)

ii. *The lowest 20% are taken, to minimize* L_g *(~ 0) impact*

iii. L_i *is measured*
ρ *is calculated for a given wind speed* [Mobley et al., 1999]

iv. L_w *is corrected for the bi-directional effect (BRDF,* [Morel et al., 2002]*) and for the atmosphere transmittance to get:*

→ L_{WN} *the exact normalized water-leaving radiance*

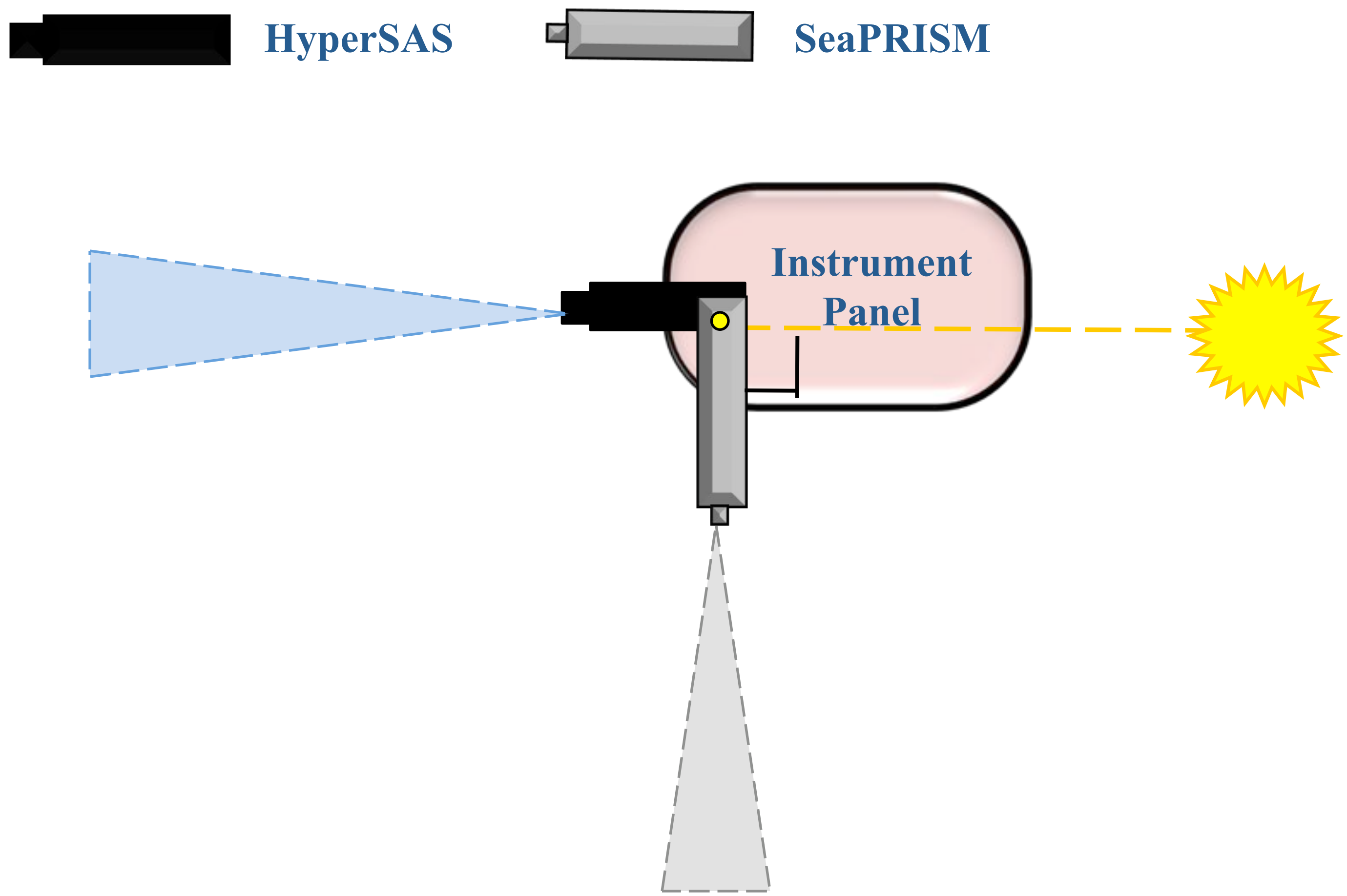
(i.e. radiance for a nadir view and the sun at the zenith without atmosphere)

Comparison of SeaPRISM and HyperSAS systems

Technical Differences between HyperSAS and SeaPRISM

Two Geometrical Configurations

Instrument Set Up Looking Down on Instruments

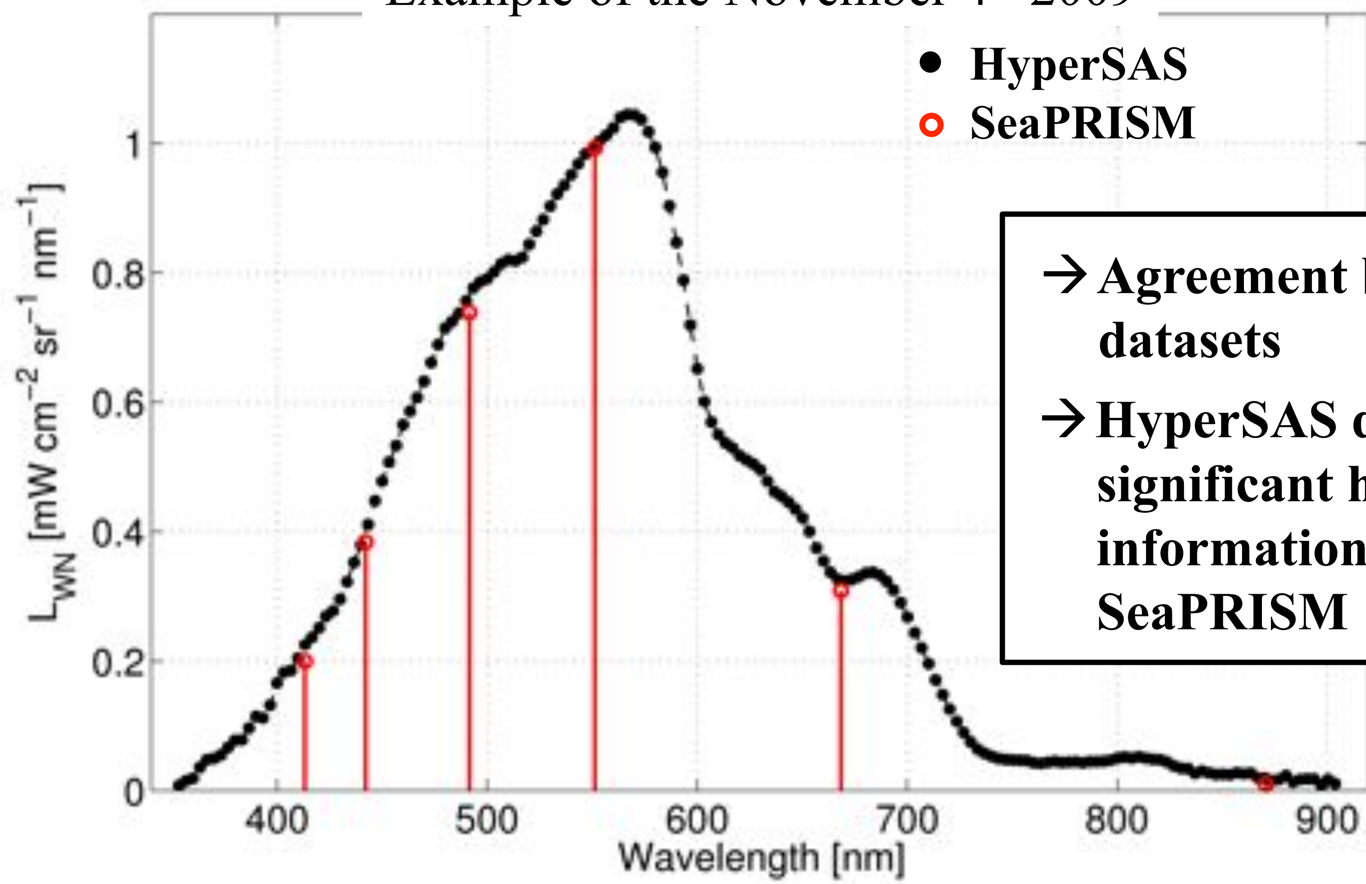


SeaPRISM and HyperSAS data intercomparison

Comparison of SEAPRISM and HyperSAS data

Example of data derived from HyperSAS and SeaPRISM measurements

Example of the November 4th 2009

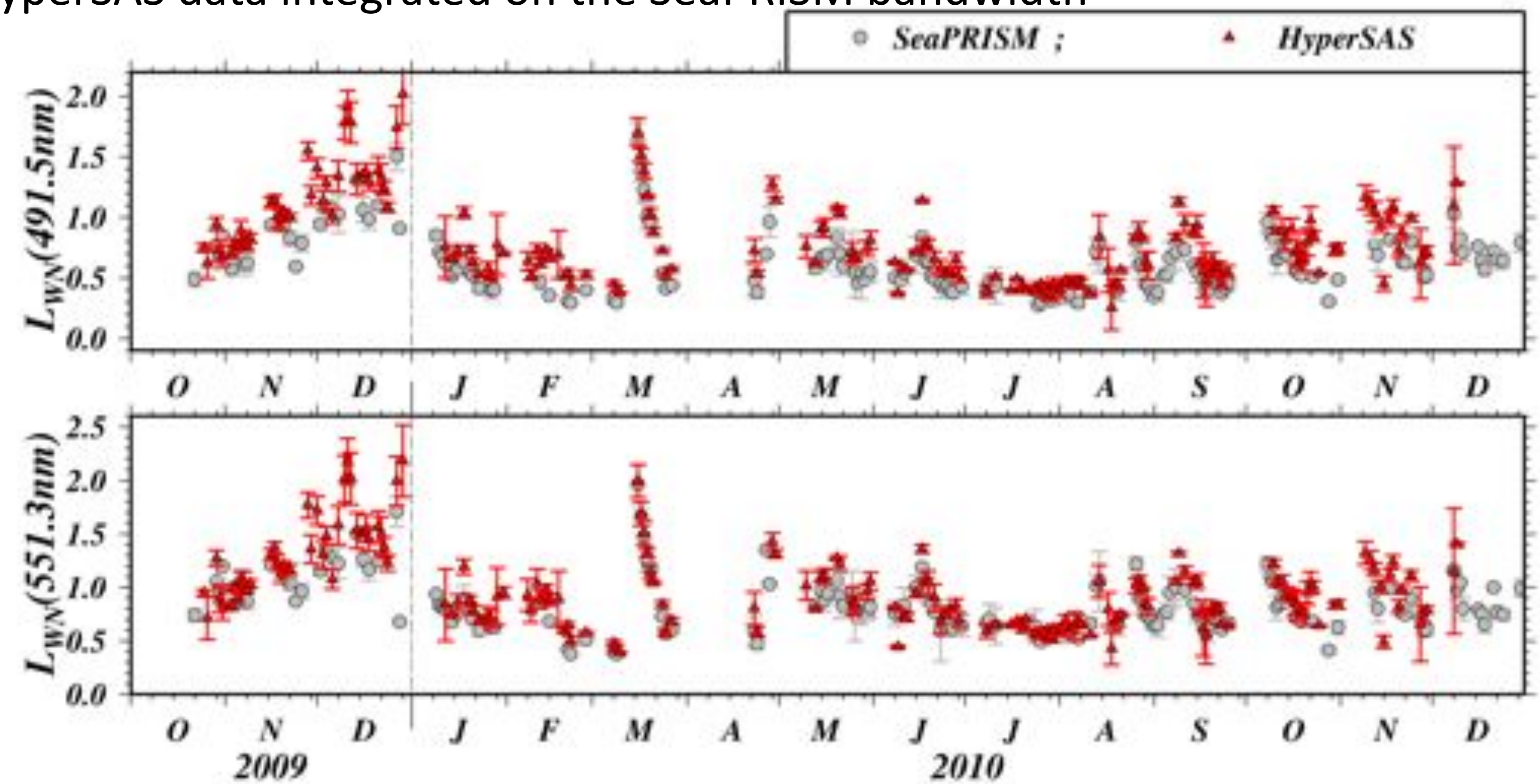


- → **Agreement between the two datasets**
- → **HyperSAS data contain significant hyperspectral information not sensed by SeaPRISM**

HyperSAS data → Possibility of satellite spectral band matching by spectral integration

Intercomparison of SEAPRISM and HyperSAS data

- from October 2009 up to January 2011
- HyperSAS data integrated on the SeaPRISM bandwidth



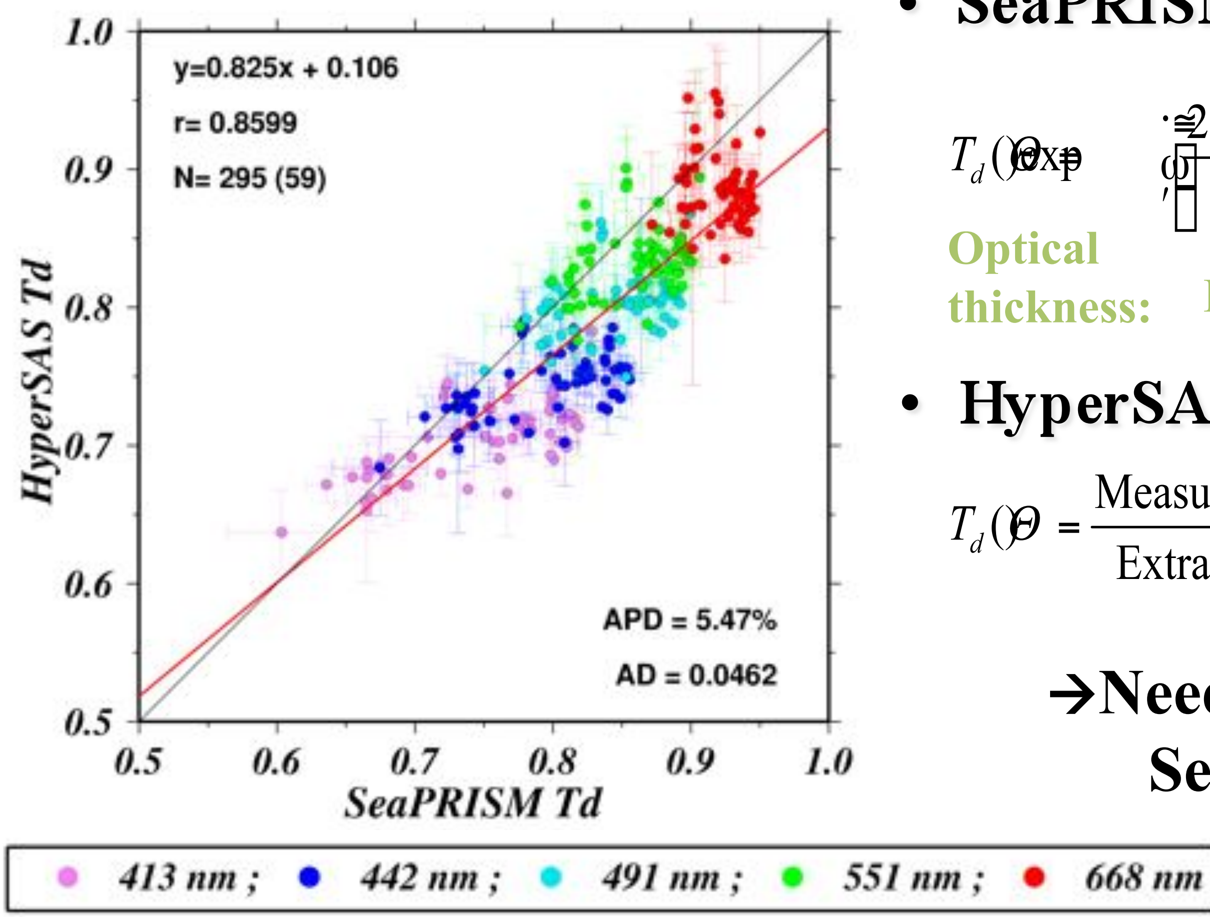
→ Satisfactory agreement over more than one year period encompassing a large range of environmental conditions

→ **Consistency of the multi- and hyper-spectral datasets**

Comparison of SEAPRISM and HyperSAS

Differences between HyperSAS and SeaPRISM

Two Atmospheric Transmittance (T_d) Computations



- **SeaPRISM** (parametrization)

$$T_d(\theta) = \exp\left[-\frac{\tau_R(\theta) + \tau_A(\theta) + \tau_O(\theta)}{\cos\theta_0}\right]$$

Optical thickness: Rayleigh Aerosol Ozone

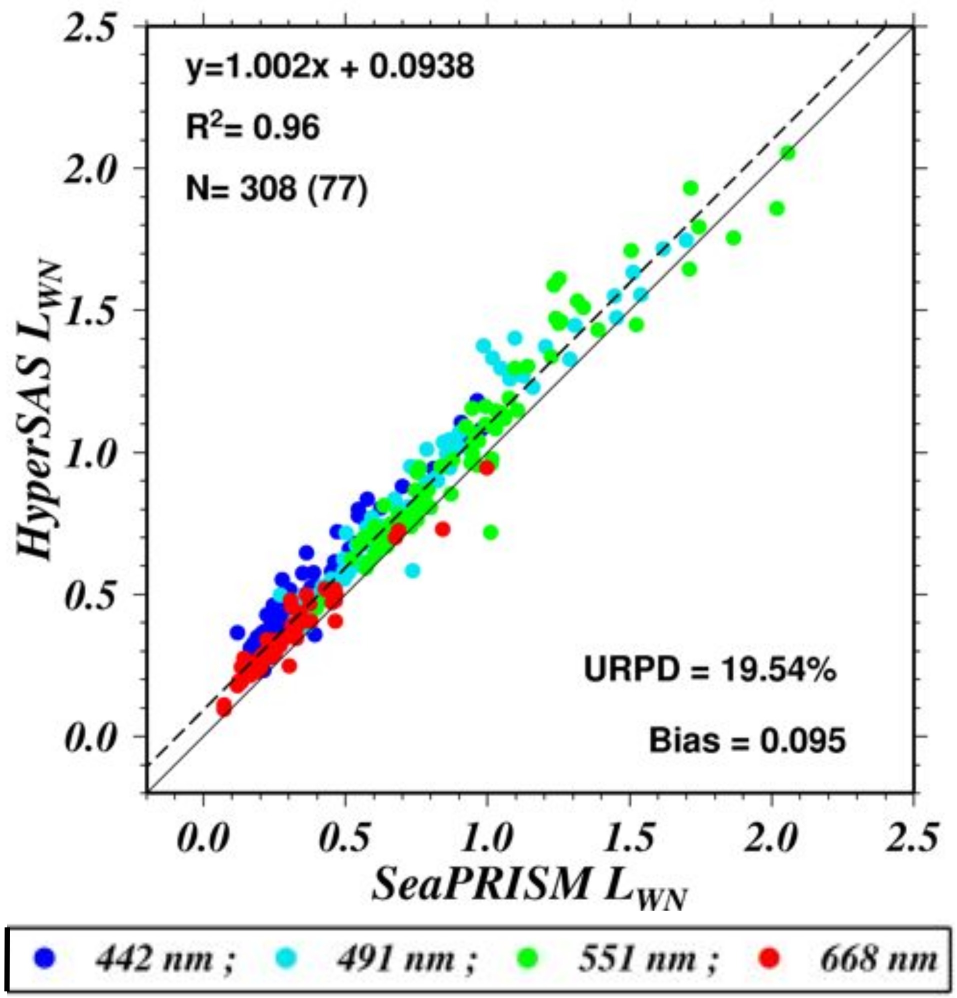
- **HyperSAS** (direct measurement)

$$T_d(\theta) = \frac{\text{Measured Downwelling Irradiance}}{\text{Extra-terrestrial Solar Irradiance}}$$

→Needs to improve the SeaPRISM model

Collocated SeaPRISM and HyperSAS Data Comparison

Uncertainty Estimation



- → Strong Correlation
- → Regression Line Slope ~1
- → Dispersion induced by
  - Sun glint: 2.5%
  - Sky glint: 6%
  - Bidirectionality: -1.5%
  - Atm. Transmittance: 5%
- → Positive Bias in HyperSAS induced by the different Atmospheric Transmittance Derivations of the two systems

[Harmel et al., Appl. Opt., In Rev.]

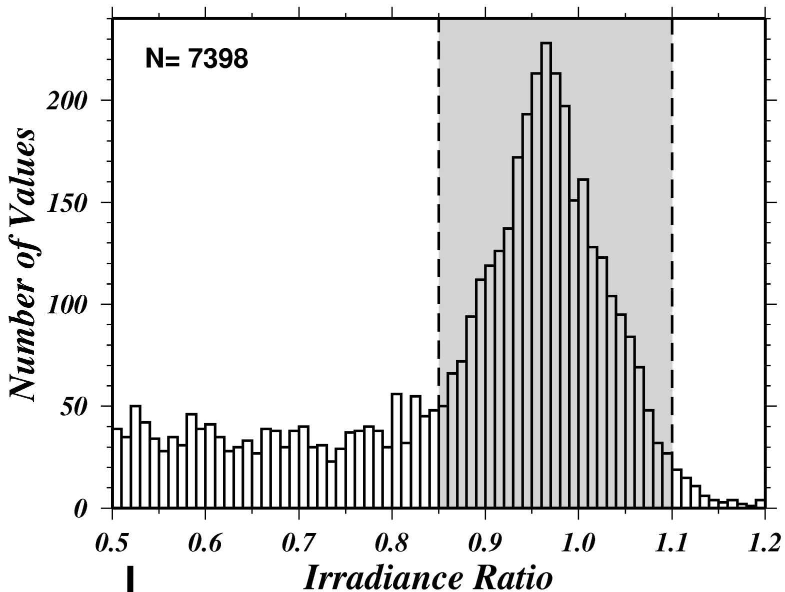
Hyperspectral (HyperSAS) data quality and uncertainty

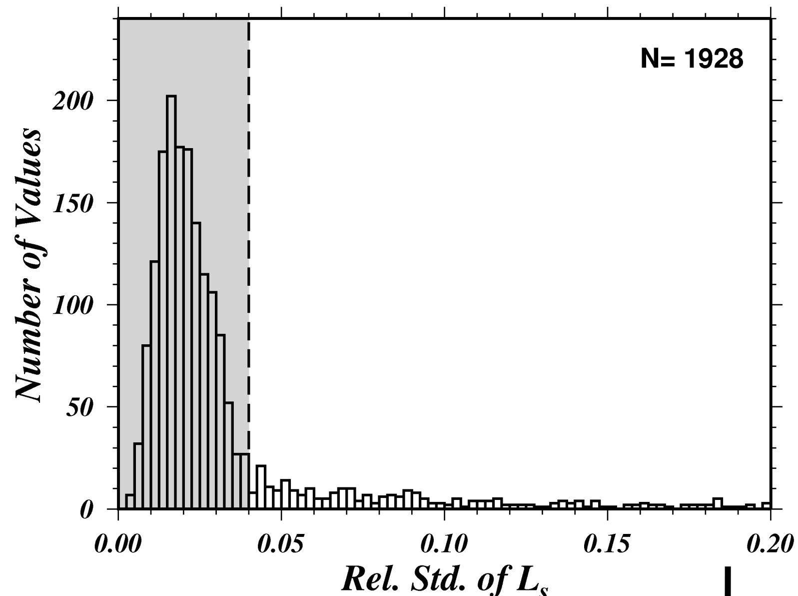
HyperSAS data processing

Data Quality Process

Ratio of the irradiance measured at 443 nm by HyperSAS to its theoretical clear-sky value

Relative standard deviation of sky radiances L_s having passed the Irradiance ratio filter





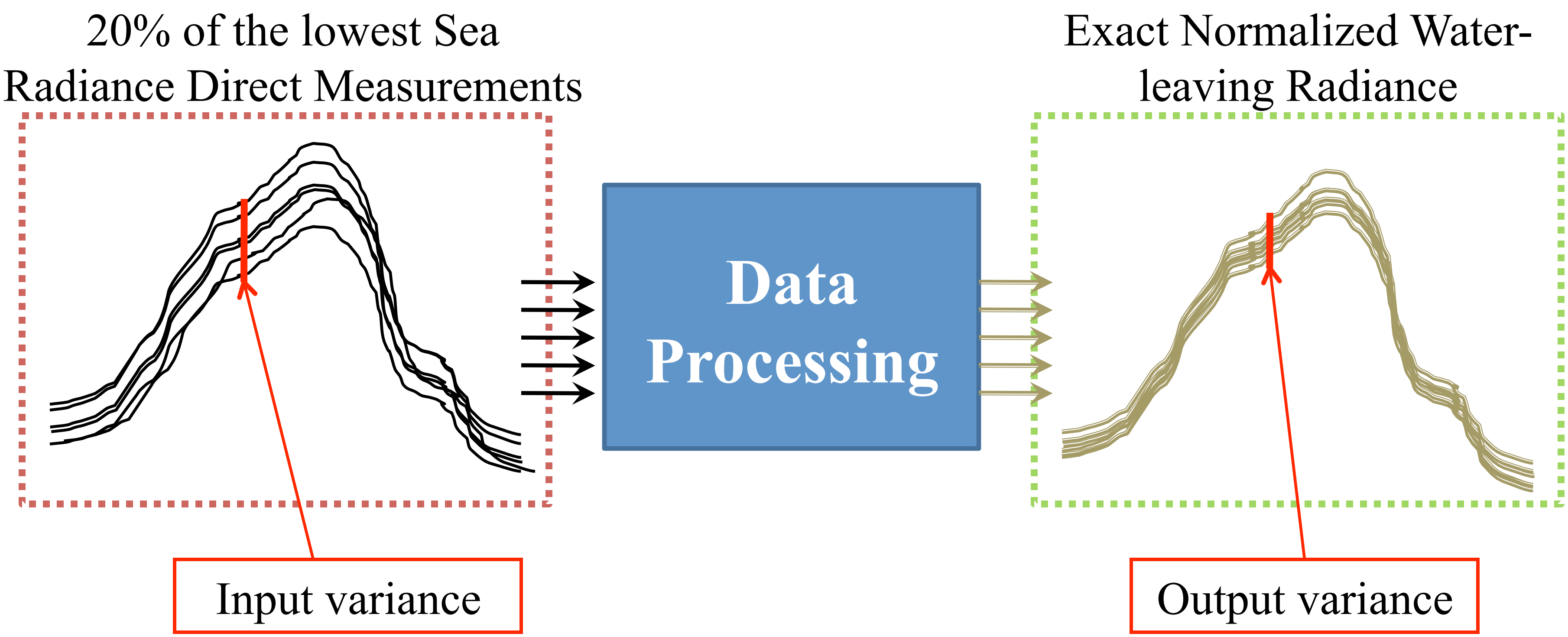
Values in shaded area pass the data quality process

Elimination of overcast conditions

Elimination of fast sky variation: scattered clouds, birds…

HyperSAS data Intrinsic Uncertainties

Uncertainty estimation scheme



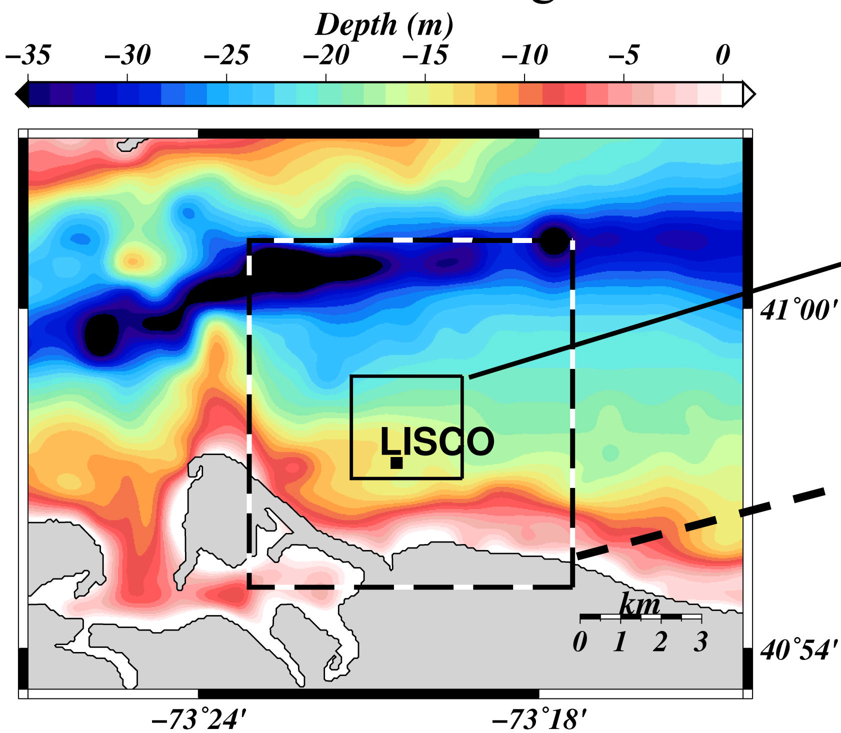
- Data Processing applied to each direct measurements of a sequence separately
- **Intrinsic Uncertainty = Output Standard Deviation**

Multispectral Satellite Data Validation at LISCO Site

Satellite Validation

Satellite Pixel Selection for Matchup Comparison

Validation of **MERIS, MODIS-Aqua** and **SeaWiFS** against the **LISCO** Data
Satellite Data Processing: Standard NASA Ocean Color Reprocessing 2009



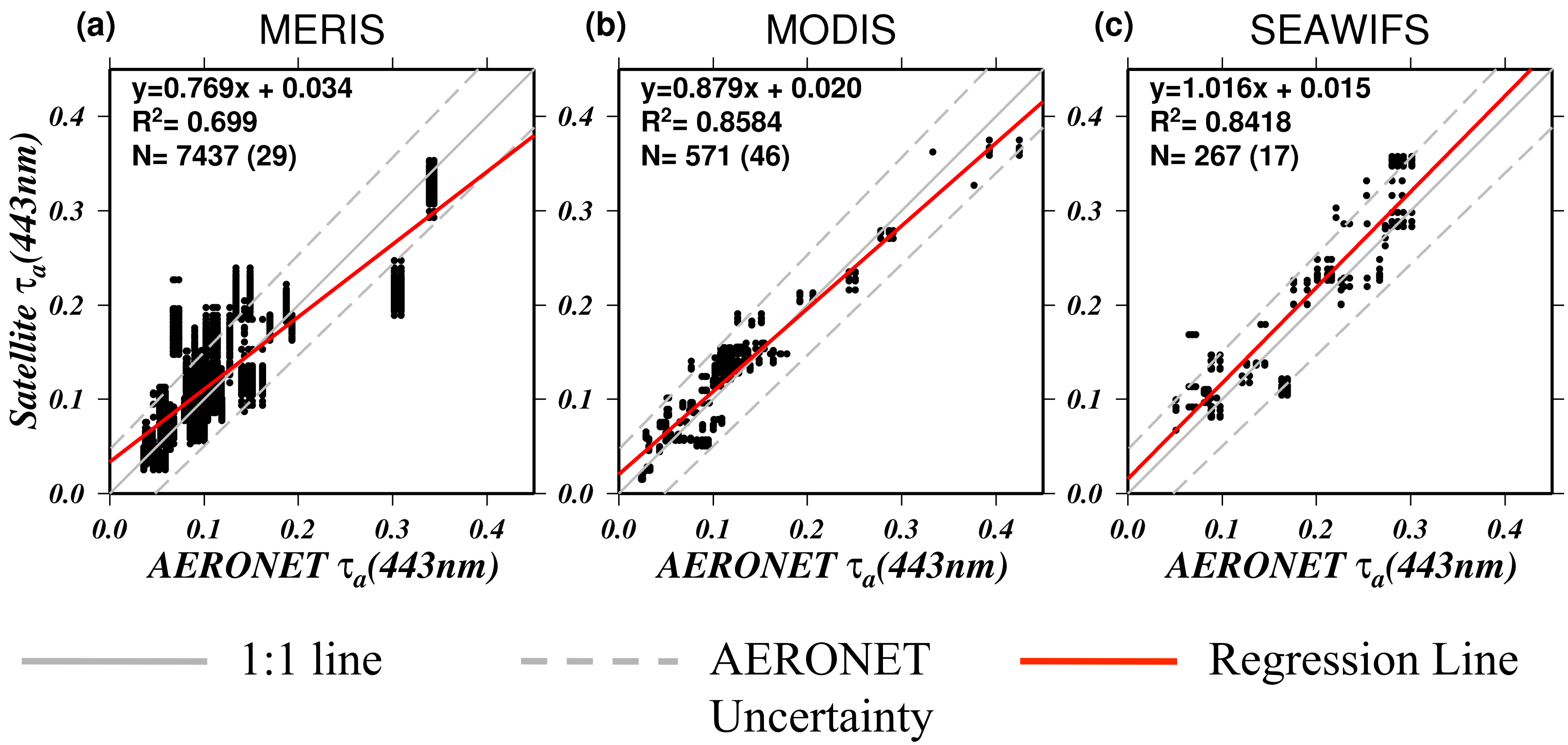
3km×3km pixel box for **matchup comparison**

Exclusion of pixel box if presence of **cloud-contaminated** pixels in this 9km×9km pixel box

Also exclusion of any pixel flagged by the NASA data quality check processing (Atmospheric correction failure, sun glint contamination,…)

Satellite Validation

Aerosol Optical Thickness Validation

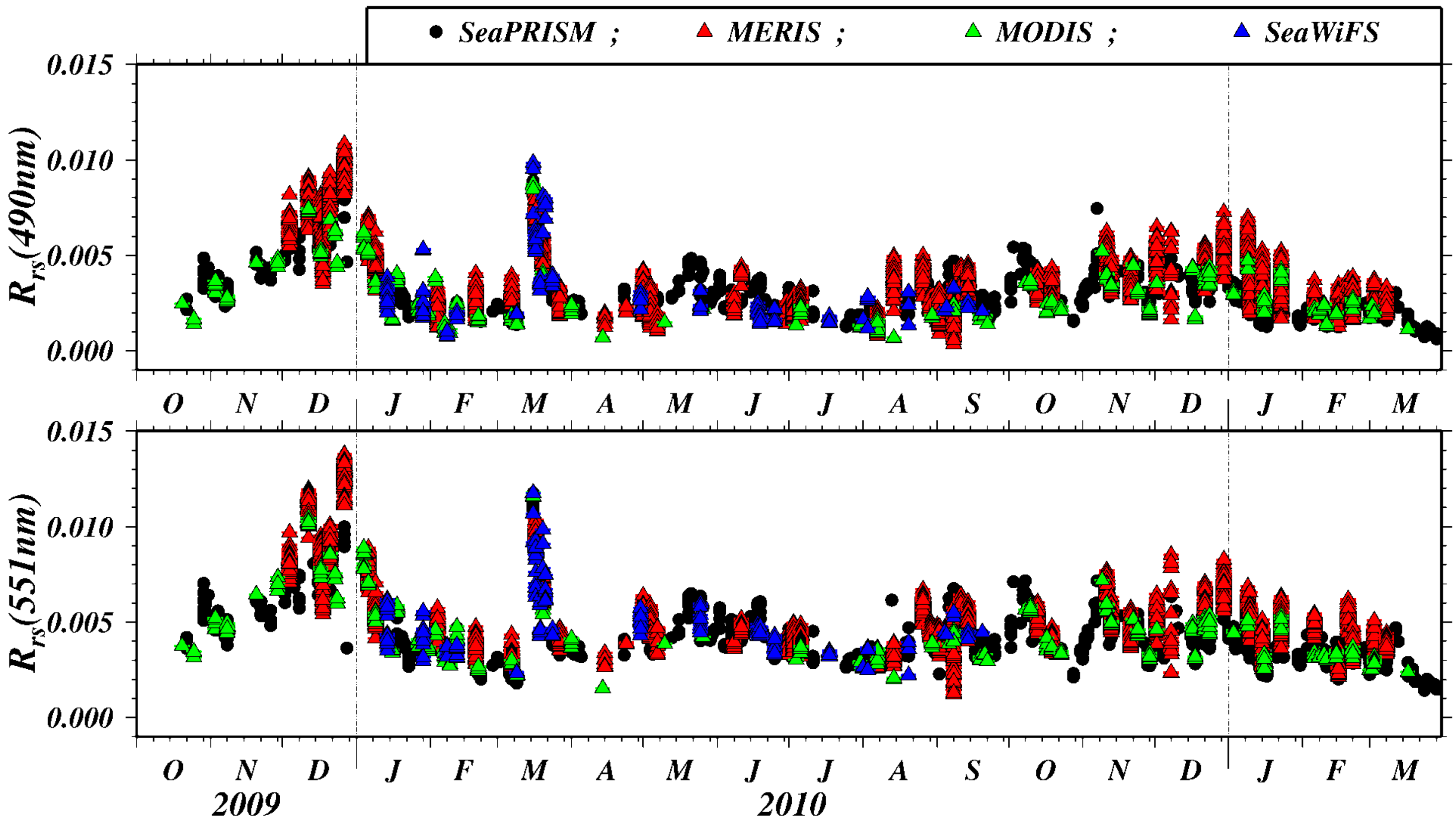


Strong Correlation and most of the matchup points are within the AERONET uncertainty for all satellite (best performance for MODIS-AQUA)

→ Representativeness of LISCO site - suitable for aerosol retrieval

Satellite Validation

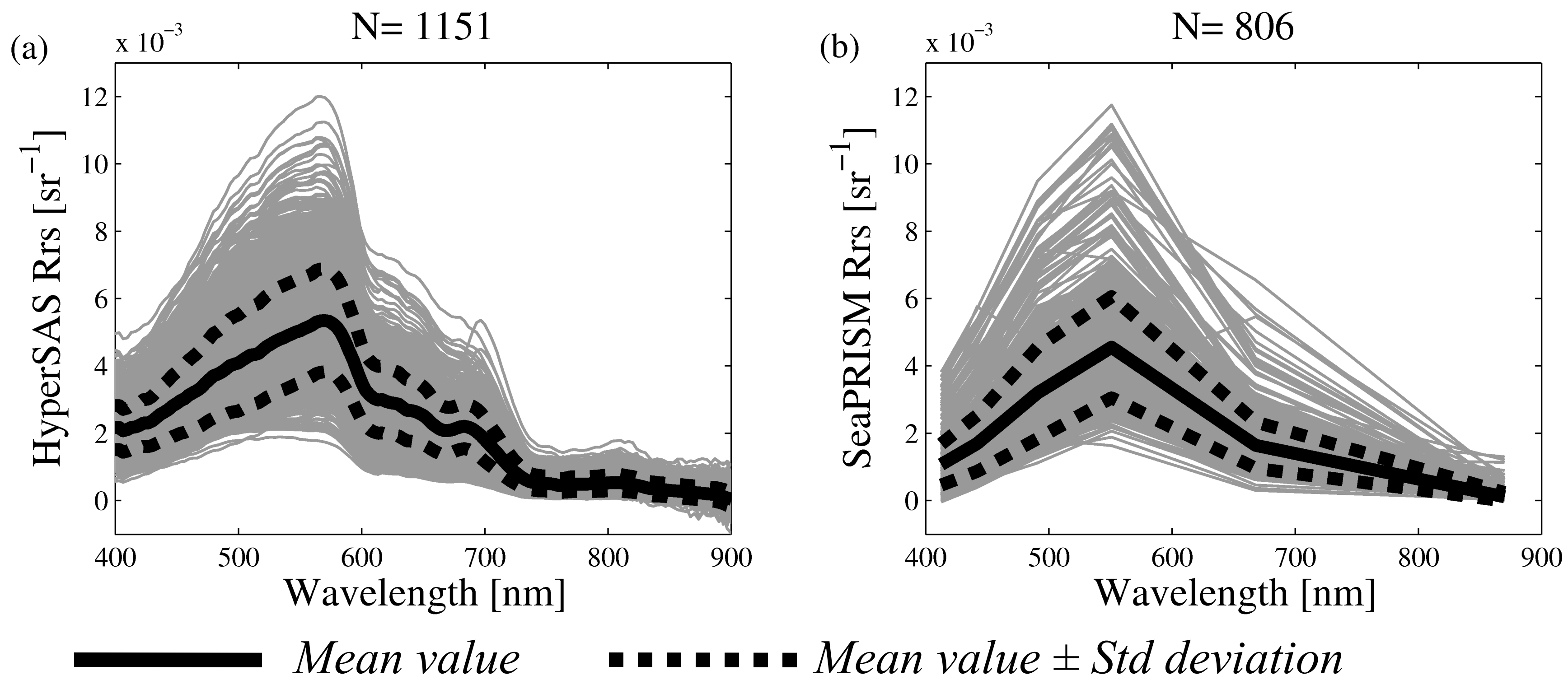
Time Series of Water Remote Sensing Reflectance (R_{rs}) [sr^{-1}]



→ **Consistency in seasonal variations observed from the platform and from space**

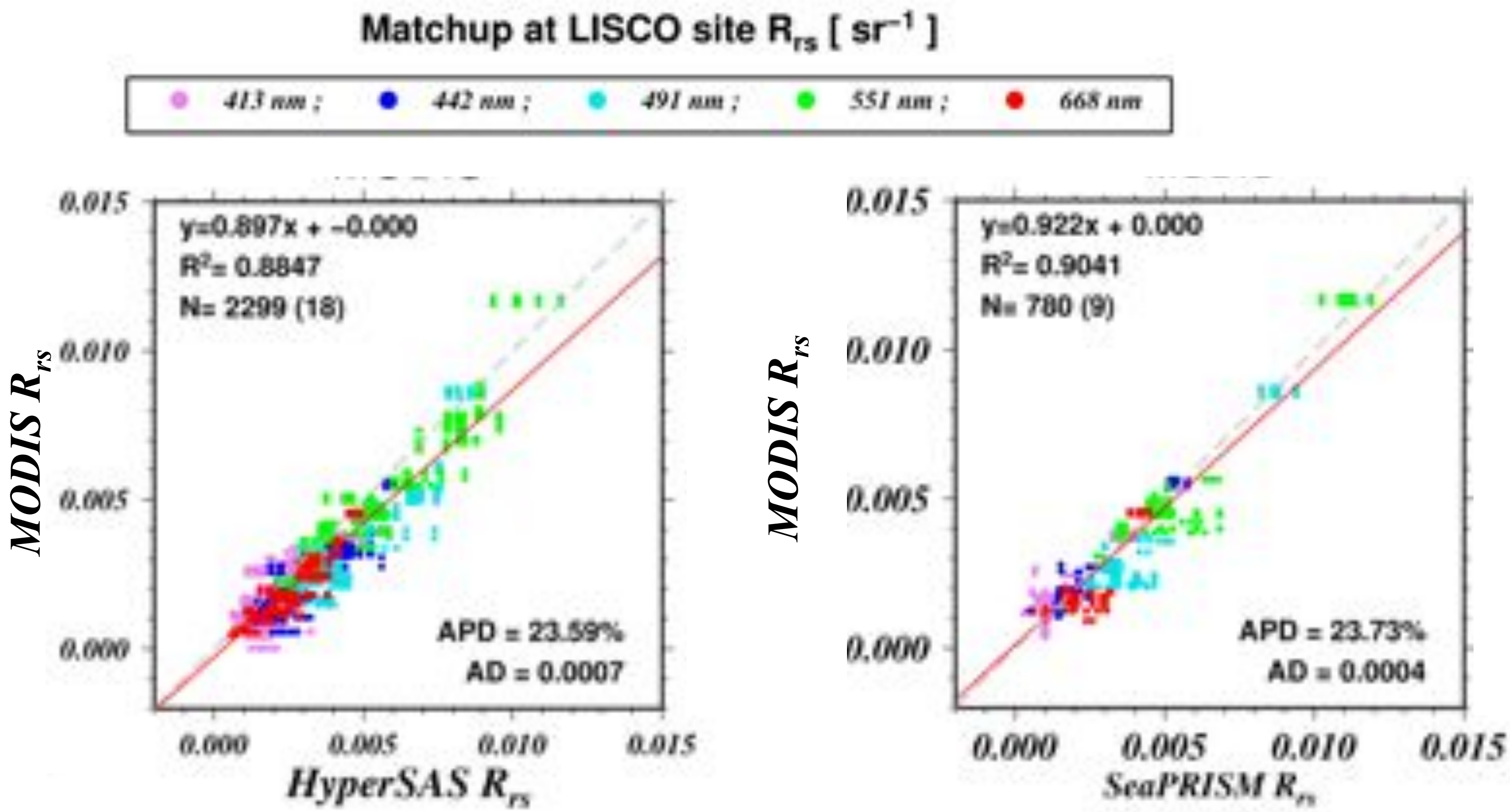
Satellite Validation

LISCO Data used for Satellite validation



Hyperspectral and multispectral spectra exhibit similar patterns over 1.5-year period

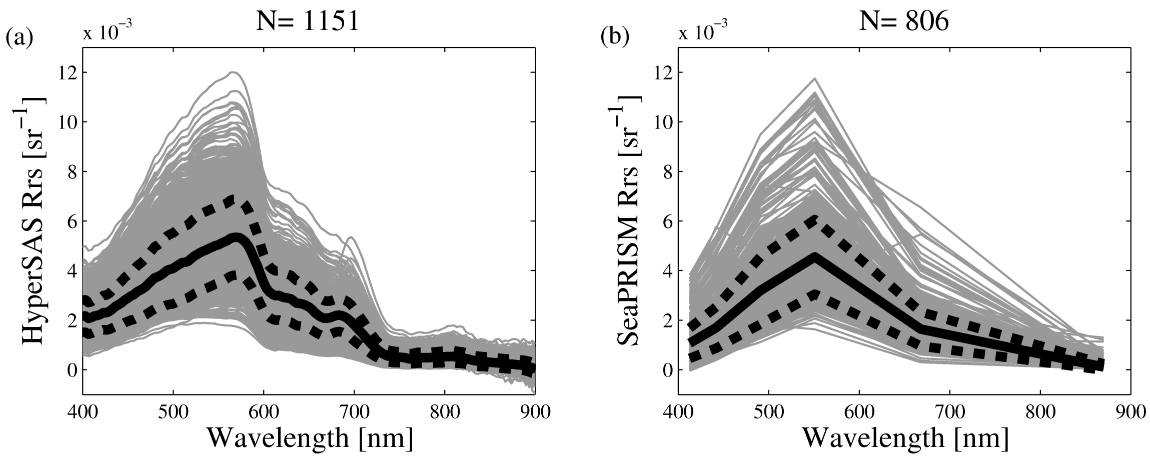
Satellite Validation

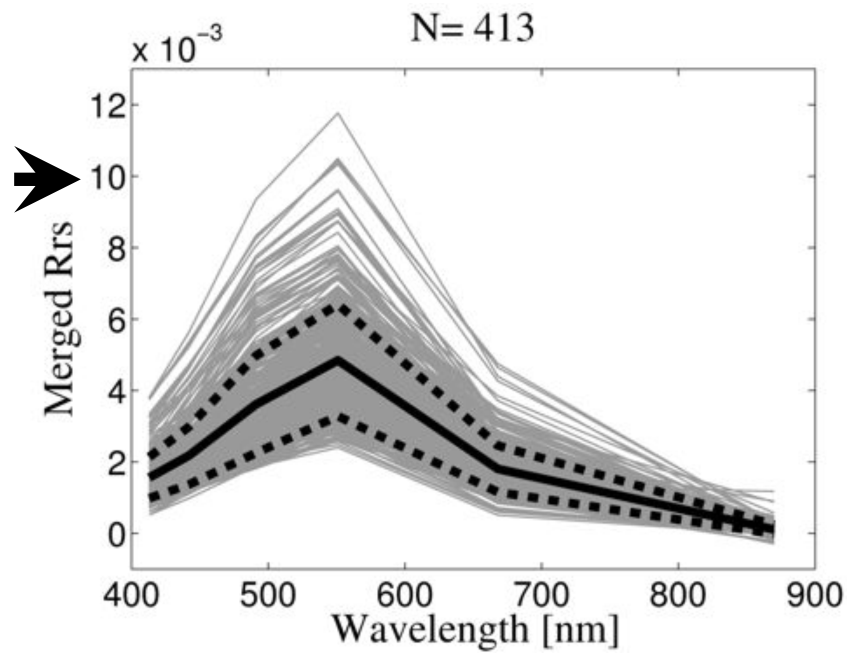


→Same order of Absolute Percentage Difference (APD) and Absolute Difference (AD) as the other sites of AERONET-OC [Zibordi et al., 2009]
→ indicating reliable use of the hyperspectral information to validate satellite data is possible

Satellite Validation

LISCO Data Merging





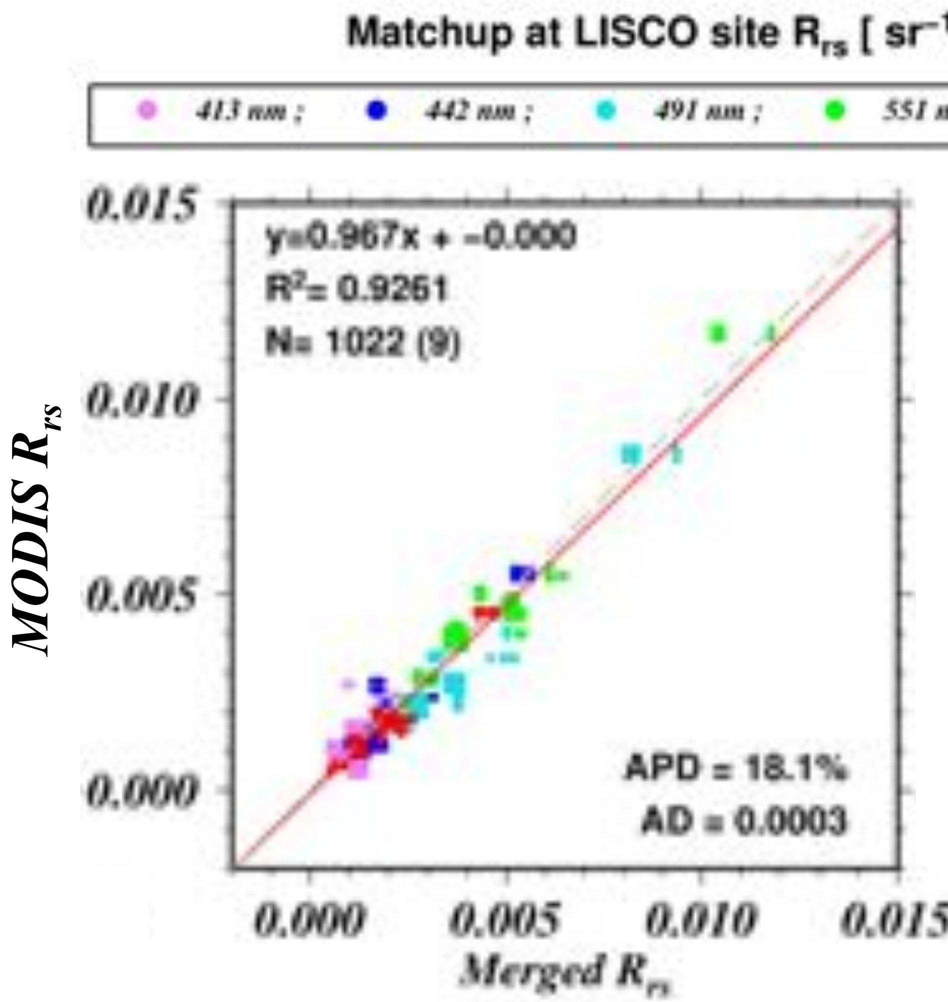
Time coincident HyperSAS and SeaPRISM spectra are averaged

→Minimization of respective biases

→ Powerful data filtering

→Provide high quality data for calibration of Ocean Color Satellite

Satellite Validation



Use of merged in situ data:
1. Improve correlation and regression
2. Reduce dispersion

in comparison to the two datasets taken separately

HyperSAS APD=23.6%

SeaPRISM=23.7%

Merged APD =18.1%

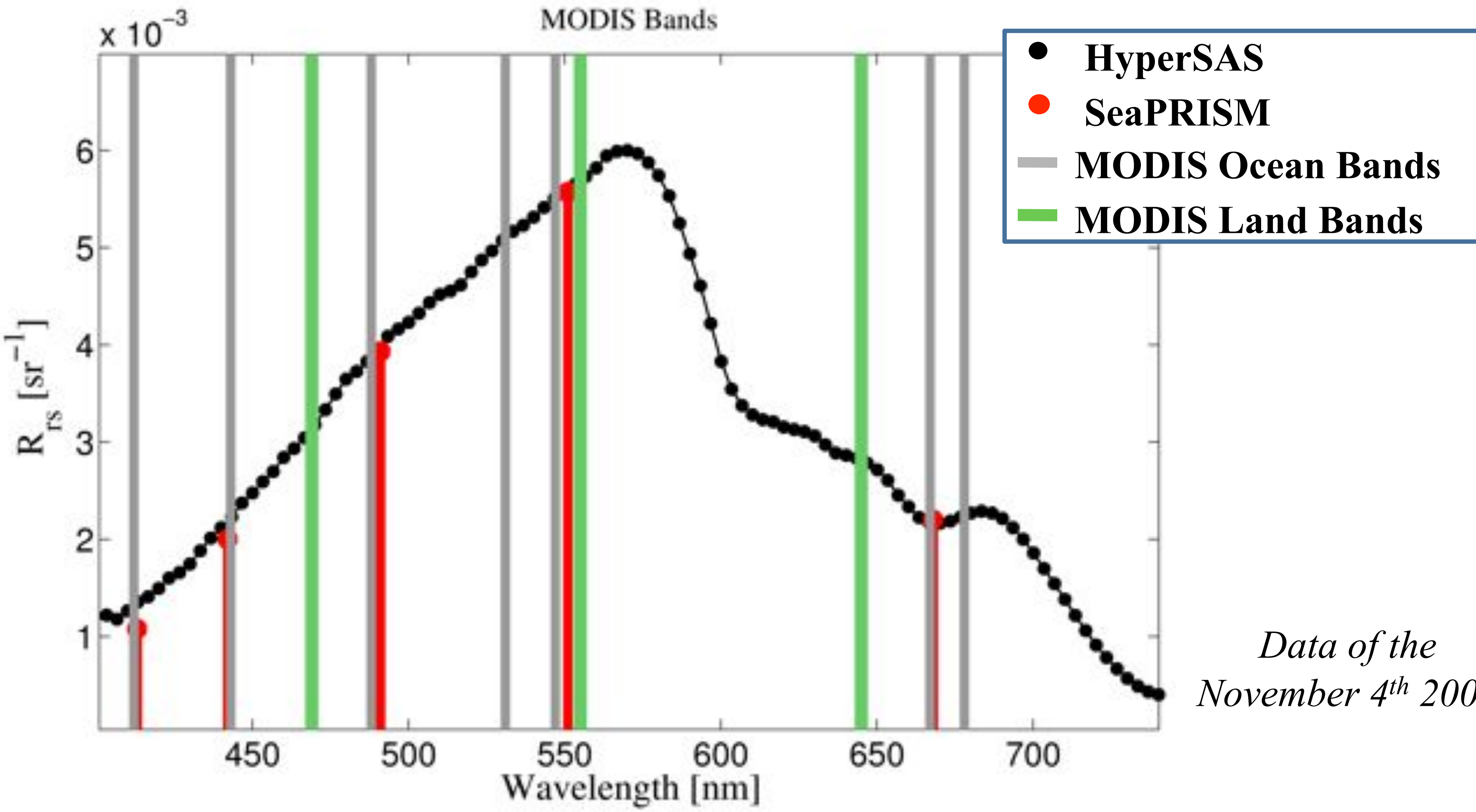
(APD is driven by very low values, but the Absolute Diff. stays very low in respect to the radiometric resolution of the satellite)

→Collocated instruments permit data quality assurance

→ Very high-quality data for calibration purposes

Use of hyperspectral data

MODIS-Aqua Bands



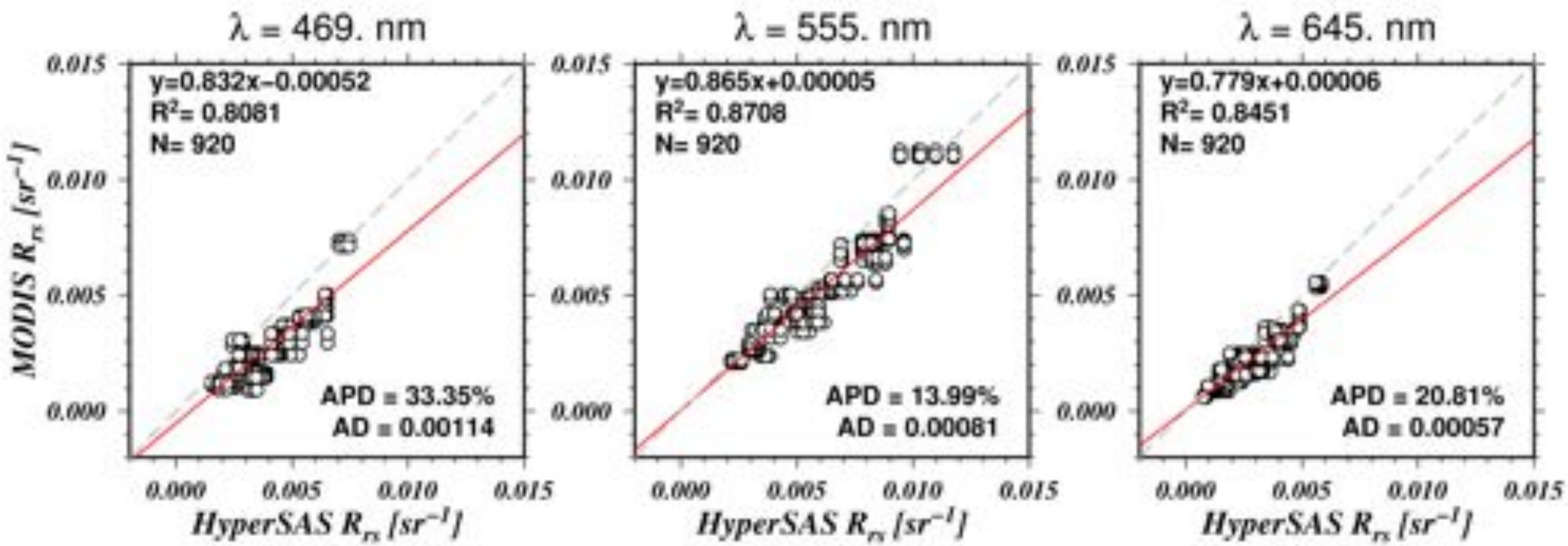
Data of the November 4th 2009

→ HyperSAS data provide supplementary bands for the MODIS data validation
Especially for the MODIS Land Bands at 469 and 645 nm

Use of hyperspectral data

Validation of MODIS-Aqua Land Bands

HyperSAS data have been convolved with the MODIS Spectral Response functions



Satisfactory agreement at 555 and 645nm, but MODIS underestimates the water-leaving radiance at 469nm.

→**Important use of hyperspectral data for : (i) making match-up for MODIS data out of the SeaPRISM bands; (ii) taking into account the specific Spectral Response functions**

Conclusions

- **LISCO unique site in the world with collocated multi and hyperspectral instrumentation for coastal waters monitoring**
- **Comparison between multi and hyperspectral data of SeaPRISM and HyperSAS shows excellent consistency.**
- **Collocated instruments give us the quality assurance data to compare with the satellite remote sensing data. Data merging → very high-quality data potentially for calibration purposes**
- **Co-located Hyperspectral instrument gives us the advantage in making match-up for multiple satellites data with different center wavelengths.**
- **Results, over 1.5-year time series, proved that the LISCO site is appropriate for effective validation & potentially calibration of the current and future ocean color remote sensing sensors in coastal water area as a key element of the AERONET-OC network**

Ongoing work

- Improvement of the bi-directionality models for the normalized water-leaving radiance derivation by using radiative transfer calculation for typical coastal waters
- Measurements of the polarization properties of coastal waters
- Development of a web tool designed for near-real-time comparison of satellite and LISCO data (Collaboration with NRL)
- Application to the validation and calibration of hyperspectral satellite imagery of HICO
- LISCO as a basis for the validation scheme of the future VIIRS satellite mission
- Satellite Vicarious Calibration from high-quality LISCO data

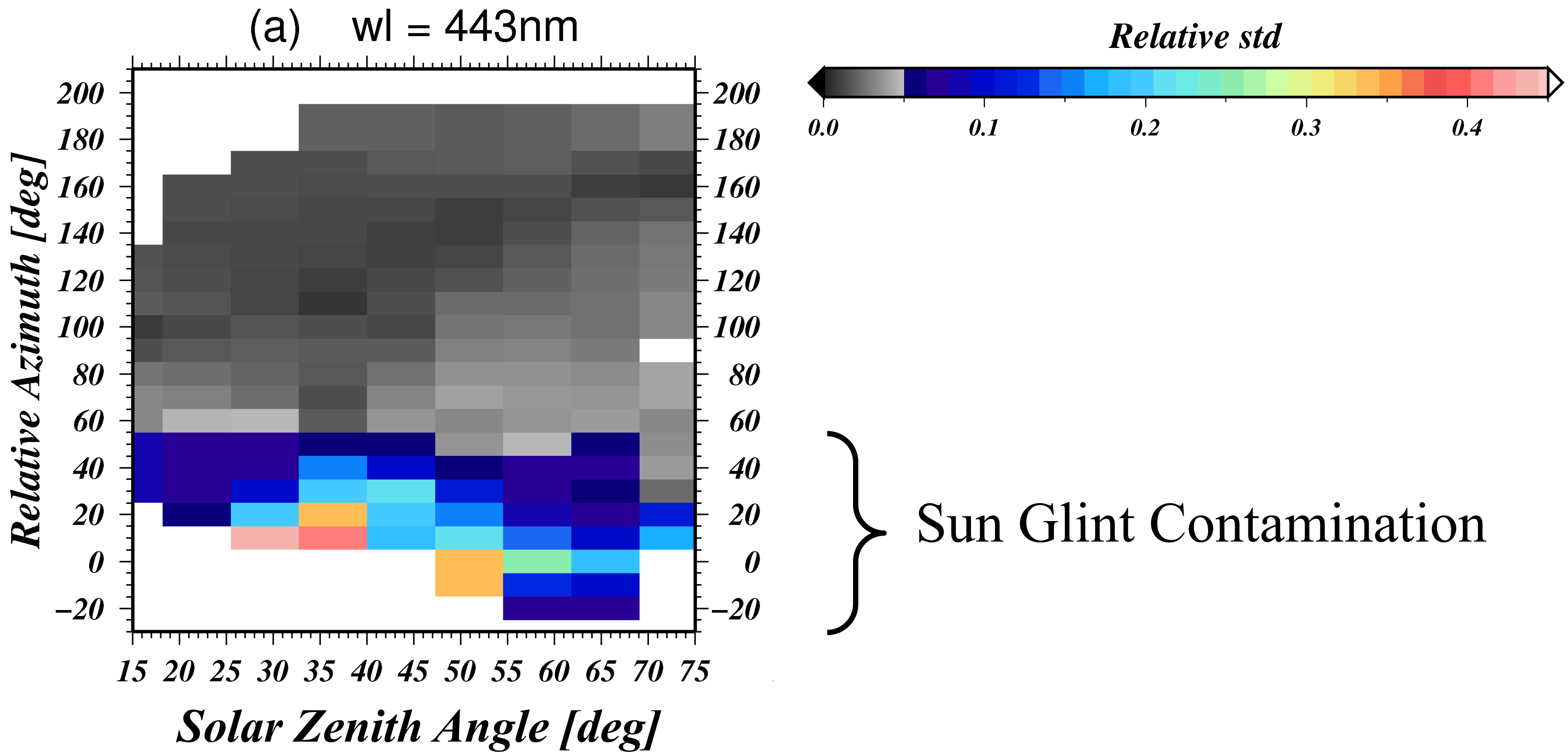
Acknowledgment

Partial support from:

- **Office of Naval Research**
- **National Oceanographic and Atmospheric Administration**

HyperSAS data Intrinsic Uncertainties

Intrinsic Uncertainty (in grey when < 5%)
in respect to the sensor viewing configuration

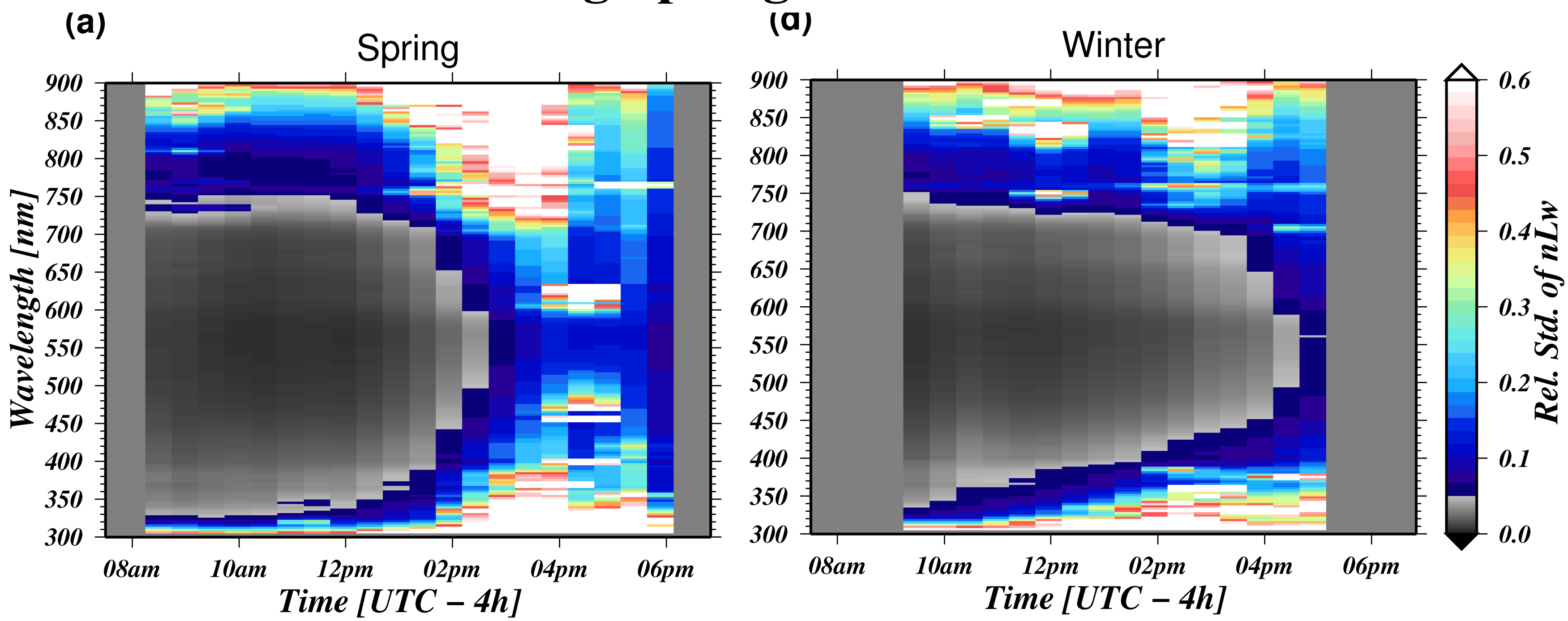


→ Consistency with theoretical results [Mobley, 1999]

→ Satisfactory data quality for large azimuth range [60°;200°] regardless of Sun elevation

HyperSAS data Intrinsic Uncertainties

Intrinsic Uncertainty (in grey when < 5%) during Spring and Winter



→ uncertainties are below 5% for the spectral range of 330 to 750 nm until 2pm

→ after 2:30pm the contribution of the sun glint is strongly increasing and no data remain sufficiently accurate in Spring

→ **Satisfactory Data Quality for Satellite spectral range and time overpass**

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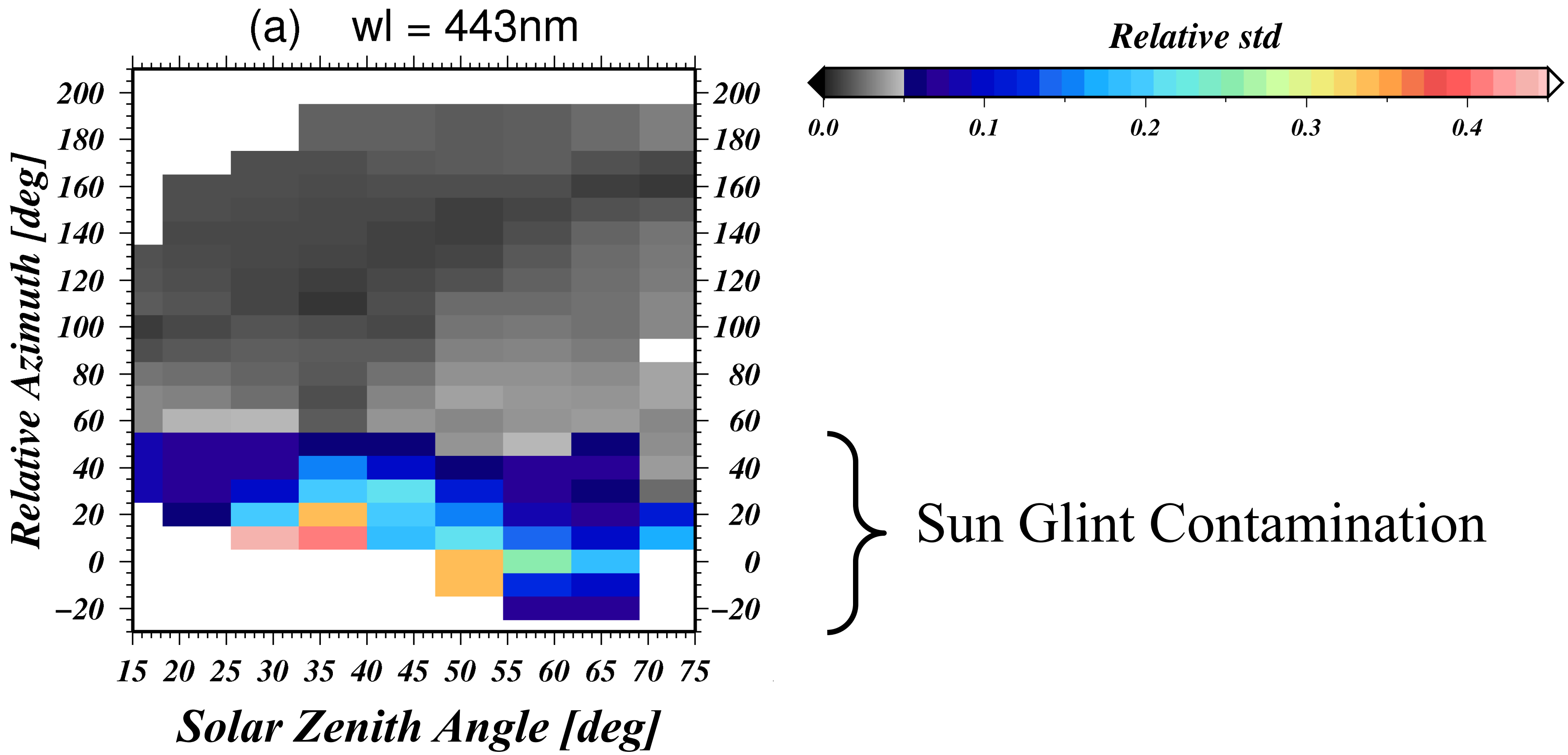

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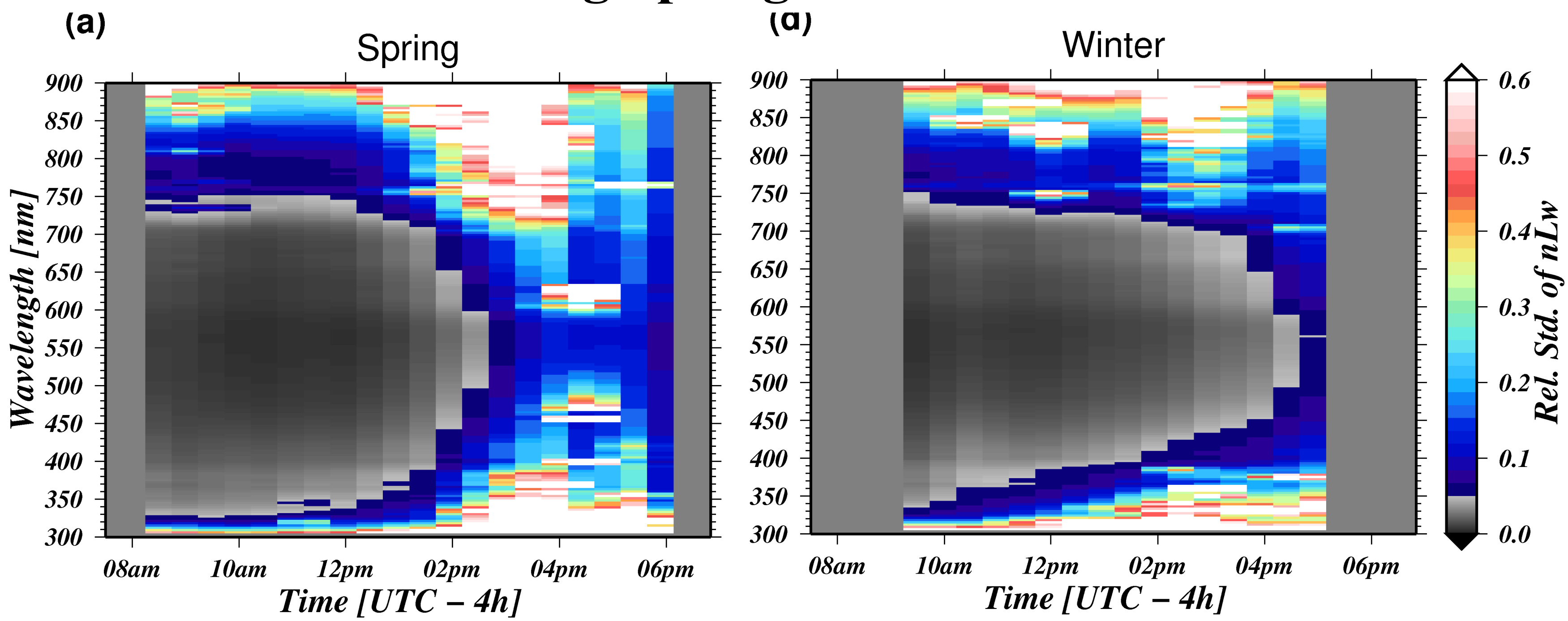

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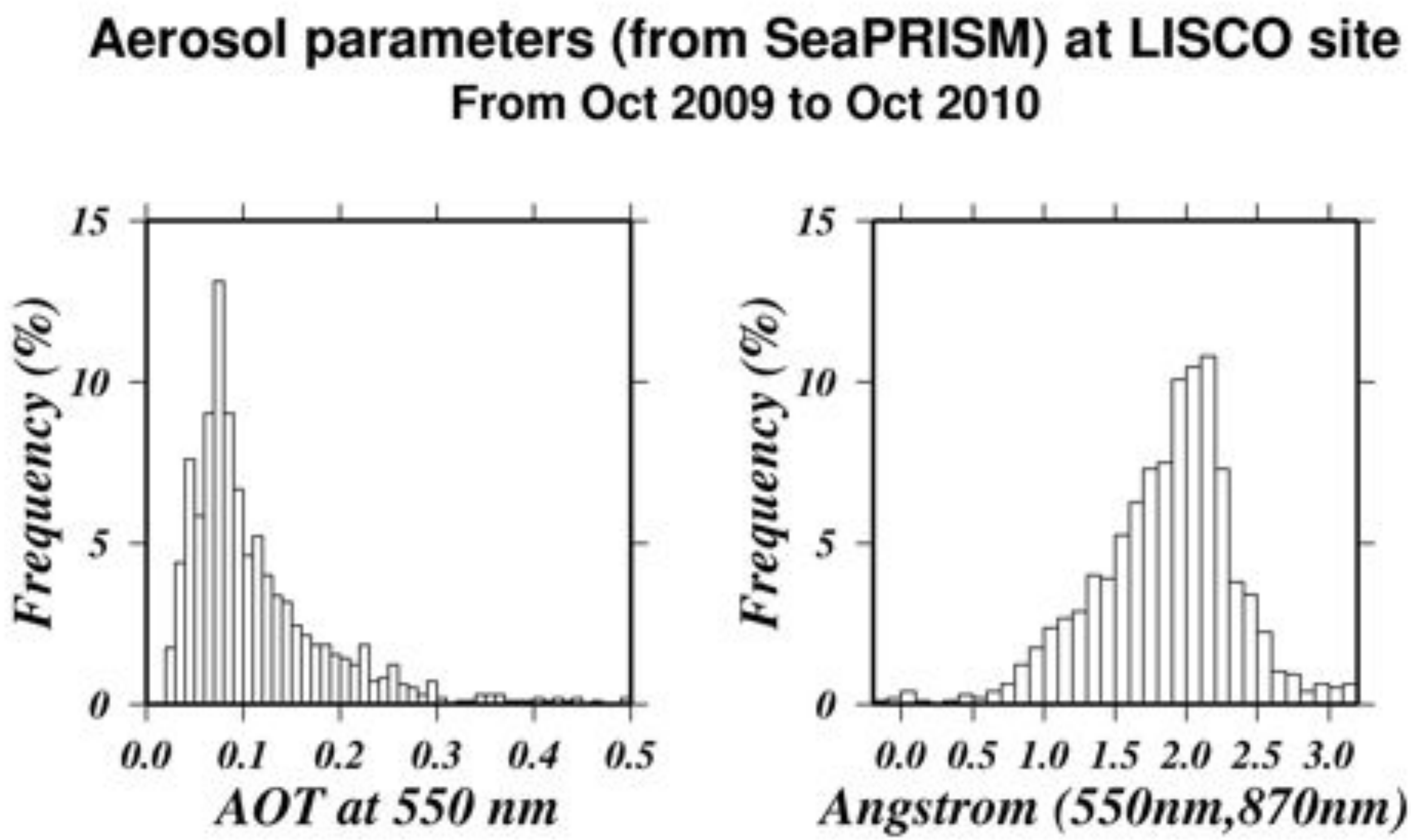
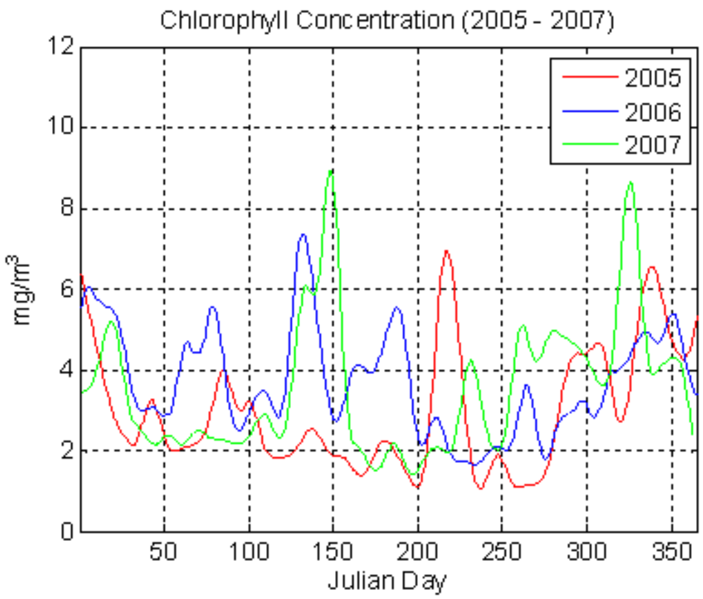
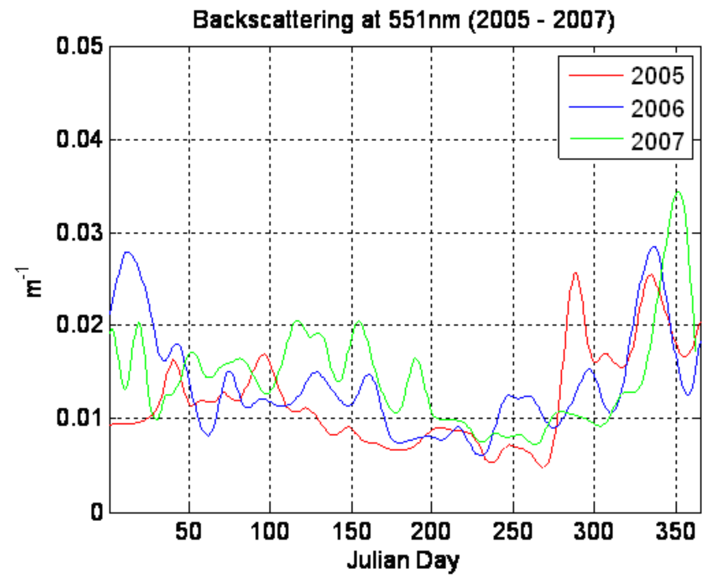
Aerosols characteristics over the platform

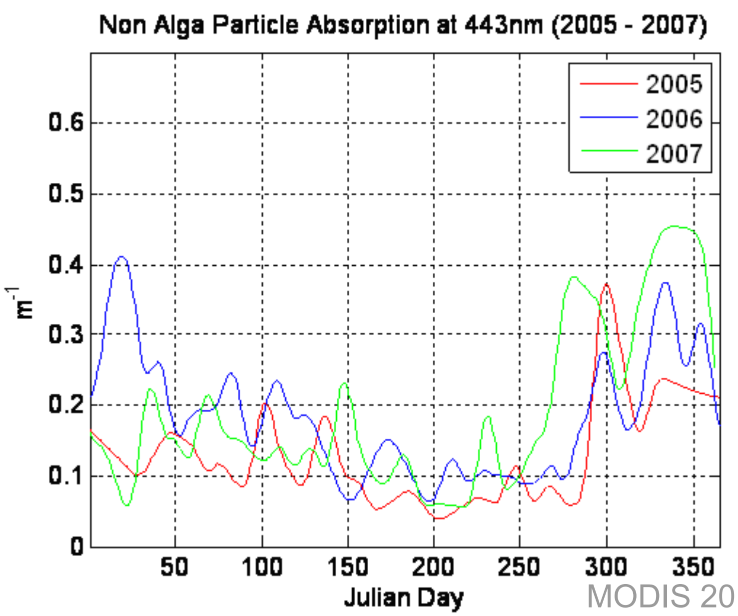


→ Predominance of fine mode aerosols

Water quality in the area of platform







- **Data from MODIS Level 2 Images spanning for three years (2005-2007)**
- **Data were extracted from 9 km^2 area centered on the platform**
- **Large spectrum of Optical Properties.**
- **No clear seasonal tendencies but strong variations**