

5.2 Description, Techniques, Protocols, and Methodologies of Photosynthetically Available Radiation

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Contents

1. Overview of Photosynthetically Available Radiation (PAR)

- Importance in oceanic processes, photosynthesis, ecosystem dynamics, and energy transfer.
- Accurate measurement vital for understanding primary productivity, ecological interactions, and climate dynamics.
- PAR attenuation, spectral characteristics, temporal variability.
- Contextualizes subsequent discussions on techniques, protocols, and methodologies for PAR validation.

2. Techniques for PAR Measurement

- Underwater radiometers, autonomous buoys, spectroradiometers, remote sensing platforms.
- Advantages, limitations, deployment considerations.
- Calibration, data processing, practical considerations.

Contents (cont.)

3. Protocols for PAR Validation

- Established protocols and standards for PAR measurements and validation.
- Standardization, quality assurance, quality control for reliable and comparable data.
- Protocol development, calibration, data acquisition, uncertainty analysis.

4. Methodologies for PAR Validation

- Approaches for assessing accuracy, precision, and reliability of PAR measurements.
- Intercomparison studies, cross-validation, comparison with model simulations.
- Validation against in situ measurements, satellite-derived estimates.
- Spatial/temporal variability, sensor characteristics, environmental factors.

Significance of PAR in Oceanic Processes

1. Primary Productivity:

- PAR drives primary productivity
- Phytoplankton utilize PAR for organic matter synthesis, forming marine food webs.

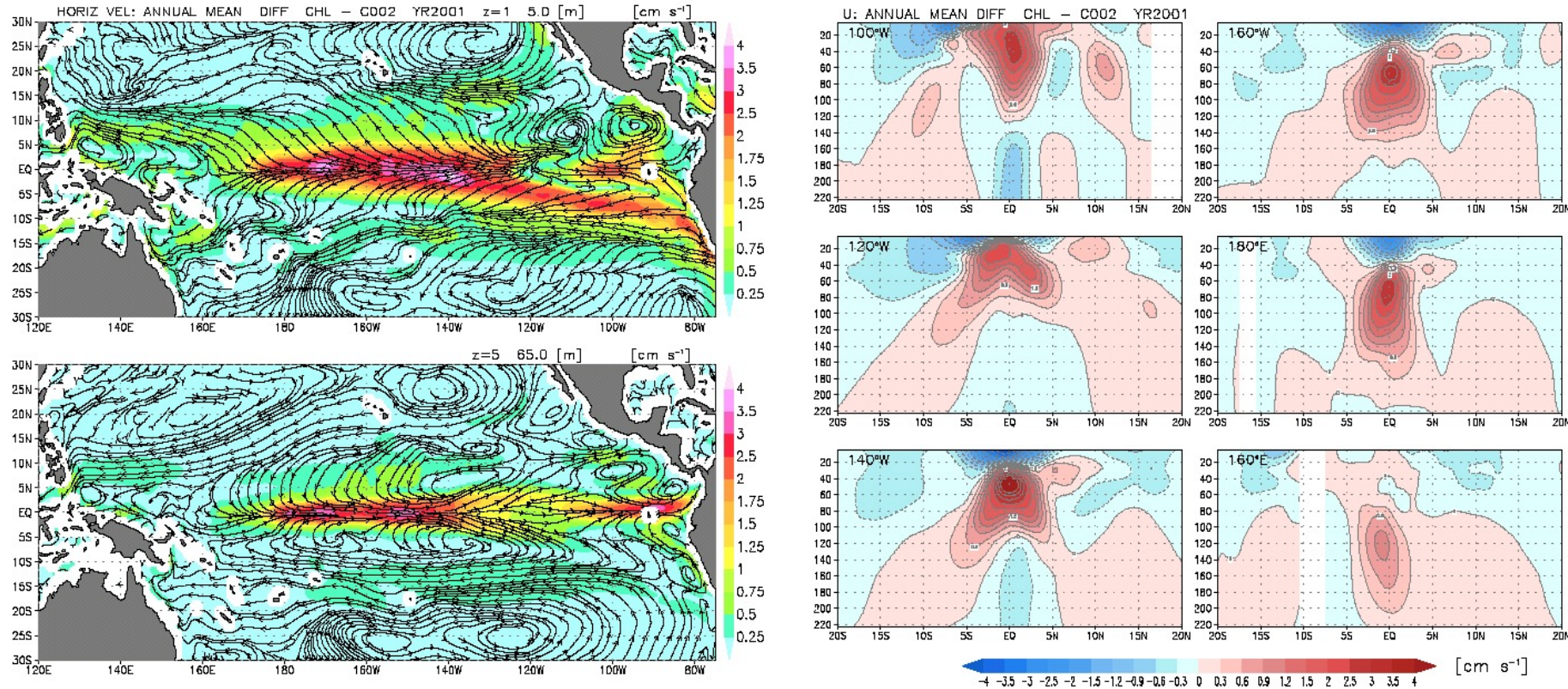
2. Ecosystem Dynamics:

- PAR shapes ecosystem structure and dynamics.
- Influences distribution, abundance, biodiversity, and resilience of organisms.

3. Climate Regulation:

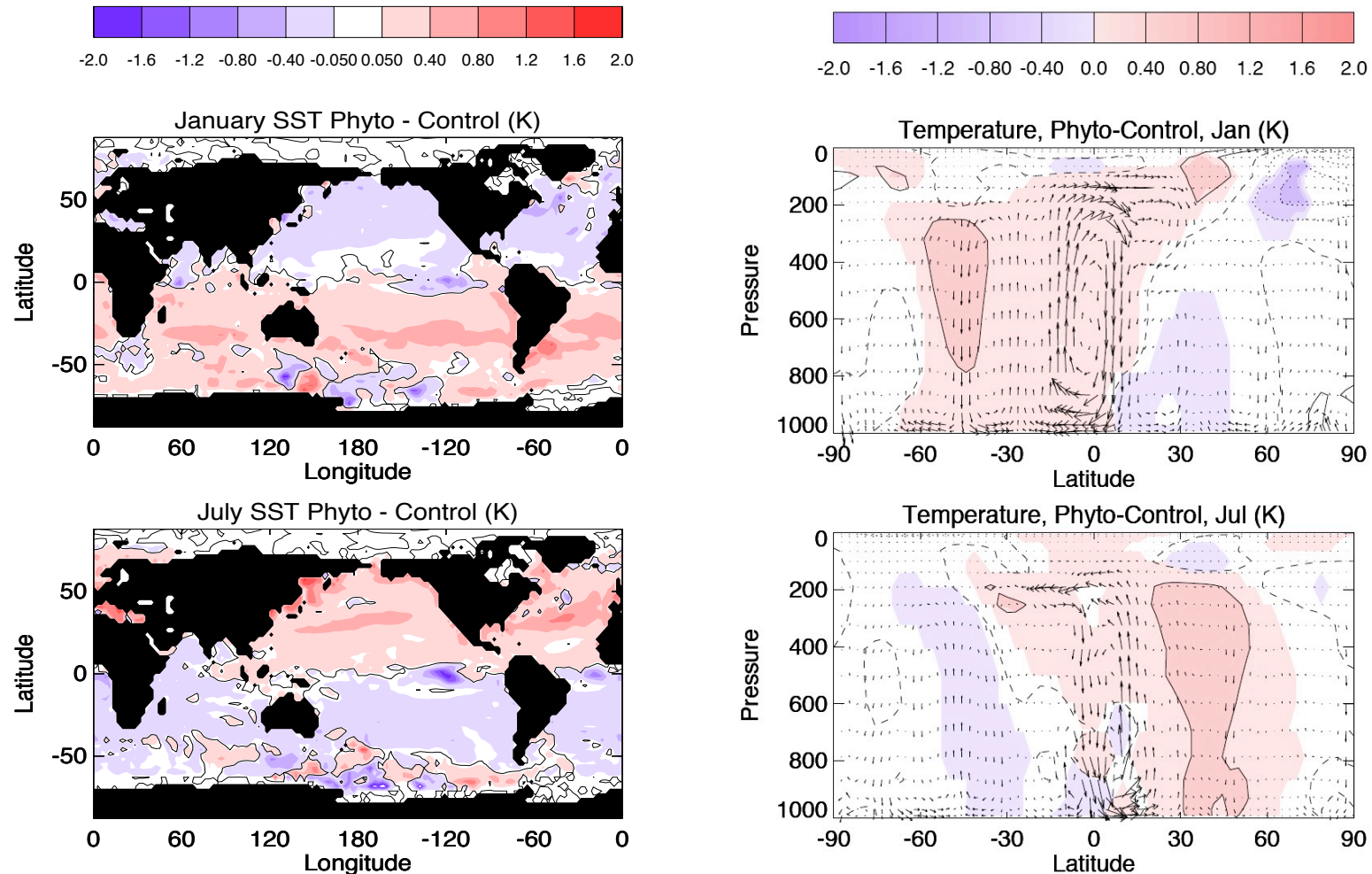
- PAR regulates Earth's climate.
- Contributes to carbon sequestration, influences temperatures, and ocean circulation patterns

Effect of phytoplankton-radiation forcing on Equatorial currents



Horizontal velocity difference between MIT OGCM model runs with and without phytoplankton-radiation forcing in the tropical Pacific at 5 m depth (top) and 65 m depth (bottom). In this region, heat trapping by phytoplankton causes the mixed layer to shallow and isotherms to shoal toward the equator, generating geostrophic currents that enhance the south equatorial and equatorial undercurrents. (After Ueyoshi et al., 2005)

Atmospheric response to solar radiation absorbed by phytoplankton



Difference between phytoplankton and control runs (OPYC and CCM3) for January and July. Left: SST; Right: Longitudinally averaged air temperature and circulation. The seasonal cycle of SST and air temperature is amplified. Increased subsidence in mid-latitudes during summer traps heat. (After Shell et al., 2003.)

Fundamental Principles Underlying PAR

1. Role in Photosynthesis

- Photosynthesis: Conversion of light energy to chemical energy
- Chlorophyll absorbs photons in PAR range (400-700 nm)
- Drives synthesis of organic compounds (e.g., glucose)
- Releases oxygen as byproduct
- PAR intensity and spectral composition influence photosynthesis rate

2. Ecosystem Dynamics

- PAR drives ecosystem dynamics in marine environments
- Dictates distribution, abundance, and productivity of photosynthetic organisms
- Includes phytoplankton, macroalgae, and seagrasses
- Primary producers form foundation of marine food webs
- Influence trophic interactions, species diversity, and ecosystem structure

Fundamental Principles Underlying PAR (contd.)

3: Energy Transfer

- PAR facilitates energy transfer through trophic levels
- Primary producers convert light energy to chemical energy via photosynthesis
- Energy transferred to herbivores and higher trophic levels through consumption
- Sustains biological processes like growth, reproduction, and metabolism
- Governs physiological processes in marine organisms, influencing behavior and ecological interactions

Importance of Accurately Measuring and Validating PAR Data

Accurate measurement and validation of Photosynthetically Active Radiation (PAR) data are essential for understanding fundamental processes shaping aquatic ecosystems and informing management strategies.

1. Understanding Primary Productivity

- PAR serves as the primary energy source for photosynthesis in aquatic environments.
- Accurate measurement of PAR allows scientists to quantify the amount of light available for photosynthetic organisms.
- Enables precise estimates of primary productivity rates.
- Helps assess the efficiency of photosynthetic processes, track seasonal variations in productivity, and monitor ecosystem responses to environmental changes.

Importance of Accurately Measuring and Validating PAR Data (contd.)

2. Evaluating Ecological Interactions

- PAR governs ecological interactions and trophic relationships within aquatic ecosystems.
- Variations in PAR availability influence the distribution, abundance, and behavior of photosynthetic organisms and their consumers.
- Accurate PAR measurements facilitate investigation of species-specific responses to light gradients, identification of critical habitats, and assessment of trophic cascades and ecosystem resilience.

3. Assessing Climate Dynamics

- PAR data provide insights into the impacts of climate change on aquatic ecosystems.
- Changes in PAR intensity, spectral composition, and temporal variability influence marine organism productivity, distribution, and phenology.
- Accurate measurement and validation of PAR data are essential for detecting long-term trends in light availability.

Key Concepts in PAR Analysis

1. PAR Attenuation

- PAR attenuation refers to the decrease in light intensity as it penetrates through water.
- Influenced by depth, water clarity, and the presence of dissolved and particulate matter.
- Understanding PAR attenuation is vital for estimating light availability at different depths and its impact on photosynthetic organisms.
- Techniques for measuring PAR attenuation include underwater radiometry and light transmission experiments.

2. Spectral Characteristics

- Spectral characteristics describe how light energy is distributed across different wavelengths within the PAR range (400-700 nm).
- Influences photosynthesis efficiency and marine organism photophysiology.
- Spectroradiometers and spectrophotometers measure spectral characteristics, aiding in understanding how light quality affects ecosystem dynamics.

Key Concepts in PAR Analysis (contd.)

3: Temporal Variability

- Temporal variability in PAR refers to fluctuations in light availability over time.
- Driven by diurnal, seasonal, and spatial factors.
- Understanding temporal variability is crucial for characterizing ecosystem dynamics and marine organism responses.
- Time-series measurements using data loggers or sensors provide insights into daily and seasonal patterns in light availability.

4: Techniques, Protocols, and Methodologies for PAR Validation

- Cross-calibration of sensors using reference standards.
- Deployment of multiple sensors to capture spatial variability.
- Comparison of in situ measurements with satellite-derived estimates.
- Integration with environmental datasets to elucidate relationships.
- Long-term monitoring programs for assessing temporal trends.

Techniques for PAR Measurement and Validation in Marine Environments

1. Underwater Radiometers:

- In situ PAR measurements.
- Sensors mounted on underwater housings.
- Advantages: Real-time measurements at various depths, capturing vertical light profiles.
- Limitations: Deployment challenges in remote or deep-sea locations, susceptibility to biofouling and physical damage.

2. Autonomous Buoys:

- Continuous monitoring of PAR.
- Equipped with sensors, data loggers, and telemetry systems.
- Advantages: Long-term monitoring at fixed locations, insights into temporal variability.
- Limitations: Challenges in rough or offshore environments, data transmission and power supply constraints.

Techniques for PAR Measurement and Validation in Marine Environments (contd.)

3. Spectroradiometers:

- Measure spectral distribution of PAR.
- Advantages: High-resolution measurements, detailed spectral information.
- Limitations: Expensive, specialized training required, bulky size, limited field deployment.

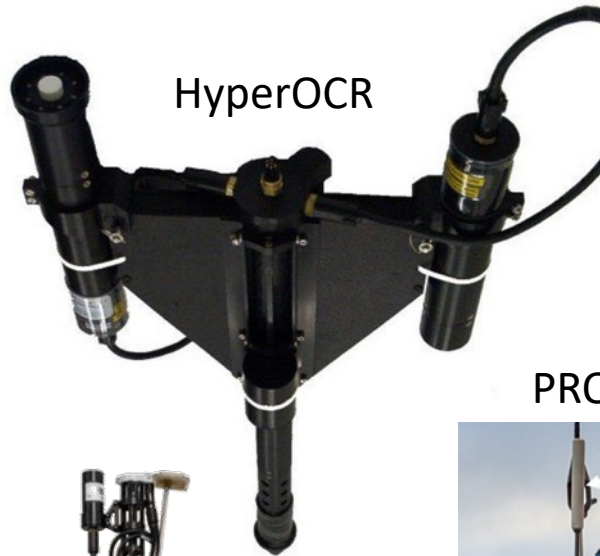
4. Remote Sensing Platforms:

- Satellites and aircraft provide synoptic views of PAR distribution.
- Advantages: Broad-scale monitoring, assessment of ecosystem dynamics.
- Limitations: Limited spatial and temporal resolution, accuracy

Considerations:

- Deployment: Accessibility, maintenance, calibration.
- Data Processing: Specialized analysis for different techniques.
- Practical Considerations: Cost, training, suitability for environment.

Irradiance sensors



HyperOCR



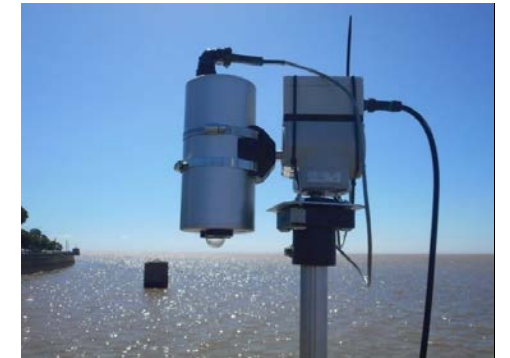
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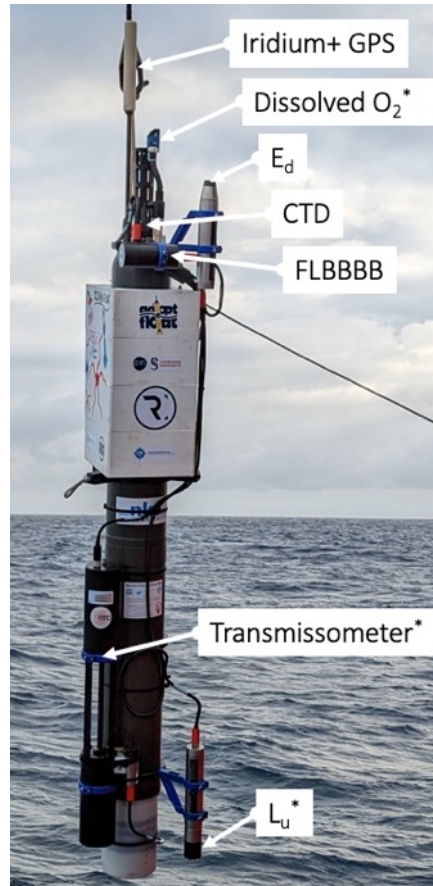


LICOR 192



HYPERSTAR

PROVOR



Iridium+ GPS

Dissolved O₂*

E_d

CTD

FLBBBB

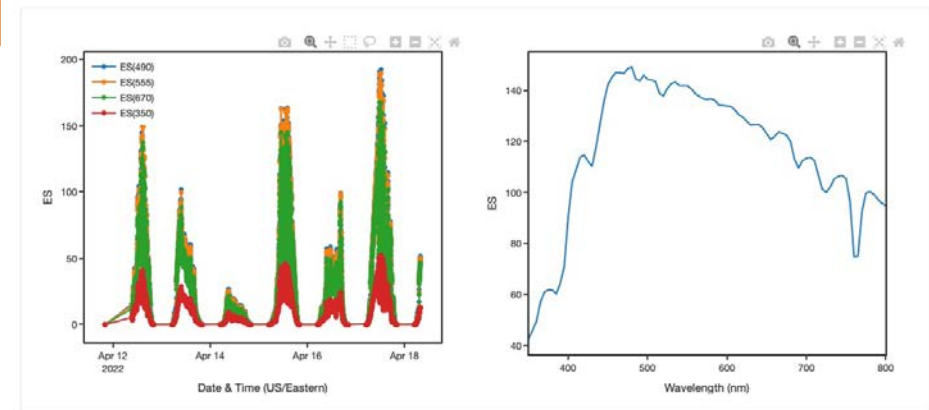
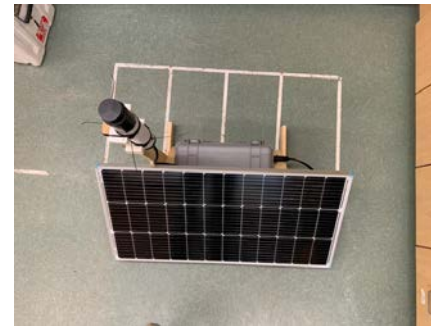
Transmissometer*

L_u*

Prototype Es automated station

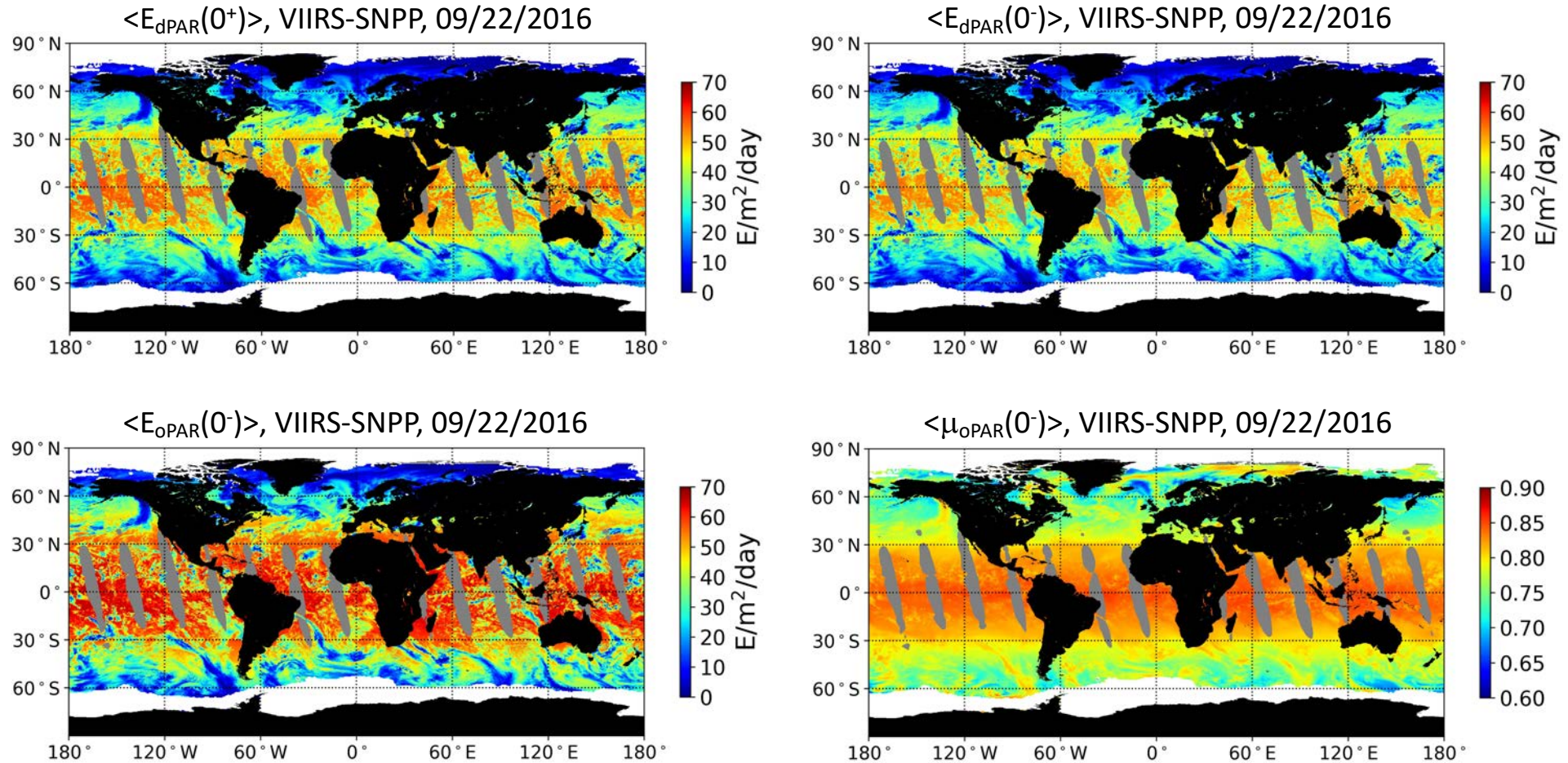
<https://misclab.umeoce.maine.edu/es-stations/site/umaine>

Temporal Window	2022-04-12 → 2022-04-18	Station Name	University of Maine Station
Temporal Resolution	<input checked="" type="radio"/> minute average <input type="radio"/> daily average	Latitude (°N)	44.901209
Data Product(s)	<input checked="" type="checkbox"/> Es	Longitude (°E)	-68.670612
Wavelength(s)	<input checked="" type="checkbox"/> 490 <input checked="" type="checkbox"/> 555 <input checked="" type="checkbox"/> 670 <input checked="" type="checkbox"/> 350	Elevation (m)	285
	Only applies to specific products.	Timezone	US/Eastern
		First data received (UTC)	2022-03-10 10:04
		Last data received (UTC)	2022-04-18 11:49
		Principal Investigator(s)	Robert Froin (Scripps)
		Site Manager(s)	Nils Haëntjens (University of Maine)



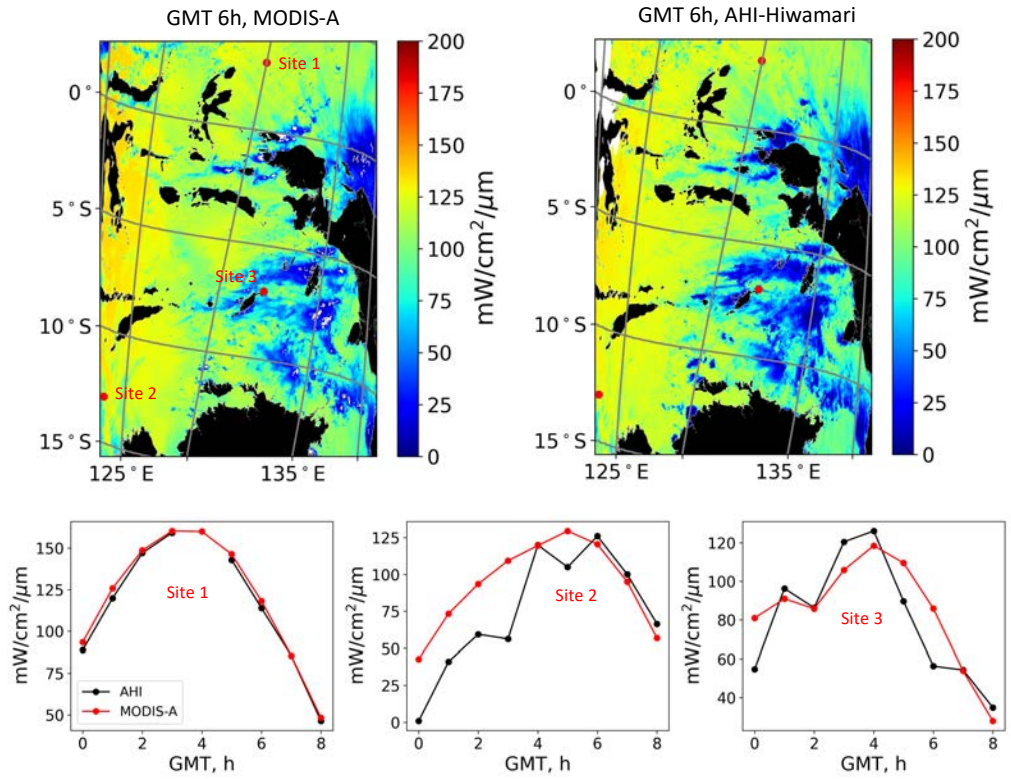
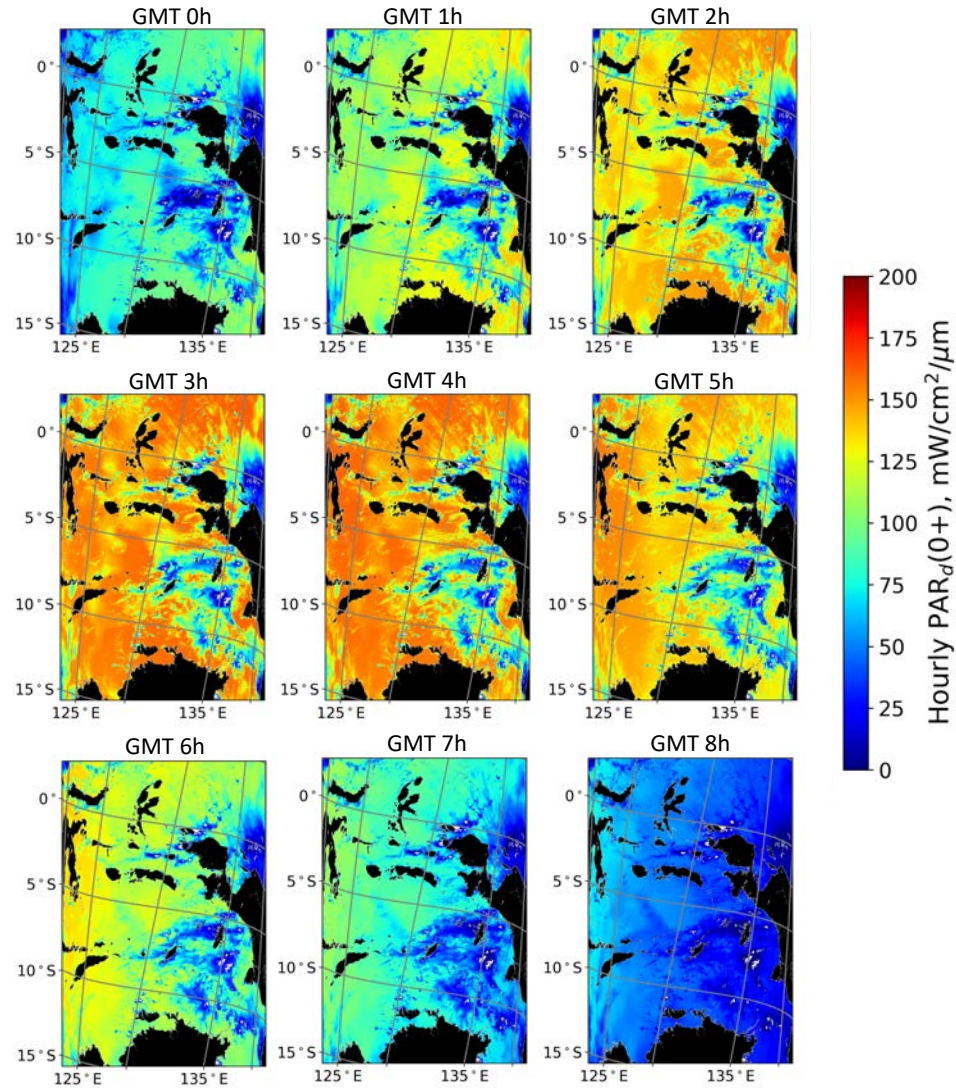
HyperNav

Examples of satellite PAR products (daily mean)



Global maps of VIIRS-SNPP $\langle E_d(PAR, 0^+) \rangle$ (top left), $\langle E_d(PAR, 0^-) \rangle$ (top right), $\langle E_o(PAR, 0^-) \rangle$ (bottom left), and $\langle \mu(PAR, 0^-) \rangle$ (bottom right). Date is September 22, 2016. The below-surface scalar irradiance and average cosine values were obtained from $\langle E_d(PAR, 0^+) \rangle$ values using LUTs according to Frouin et al. (2018)

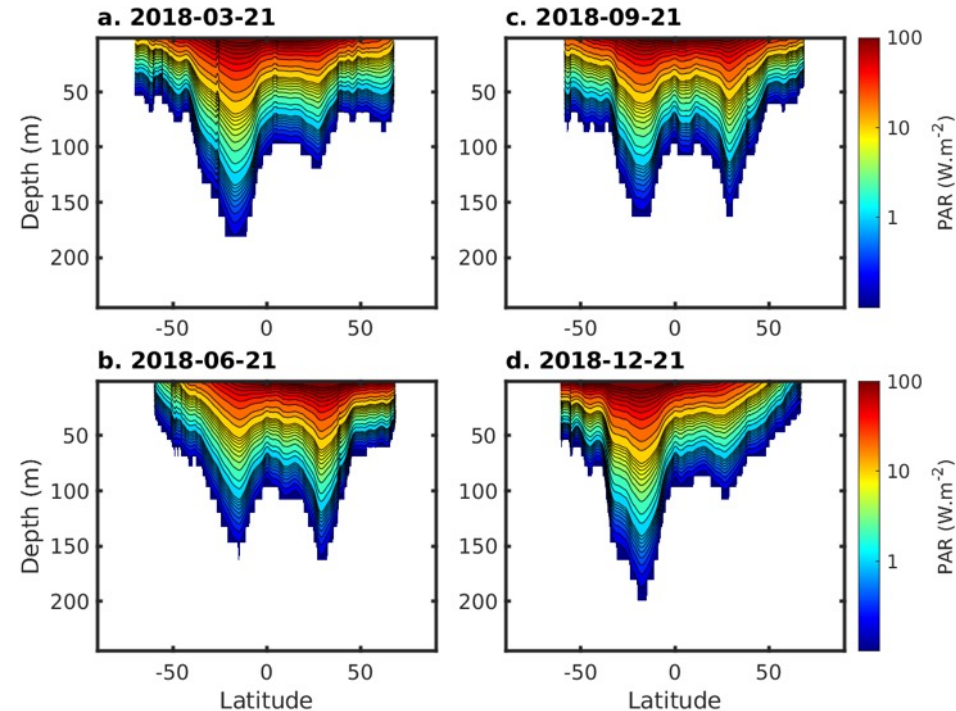
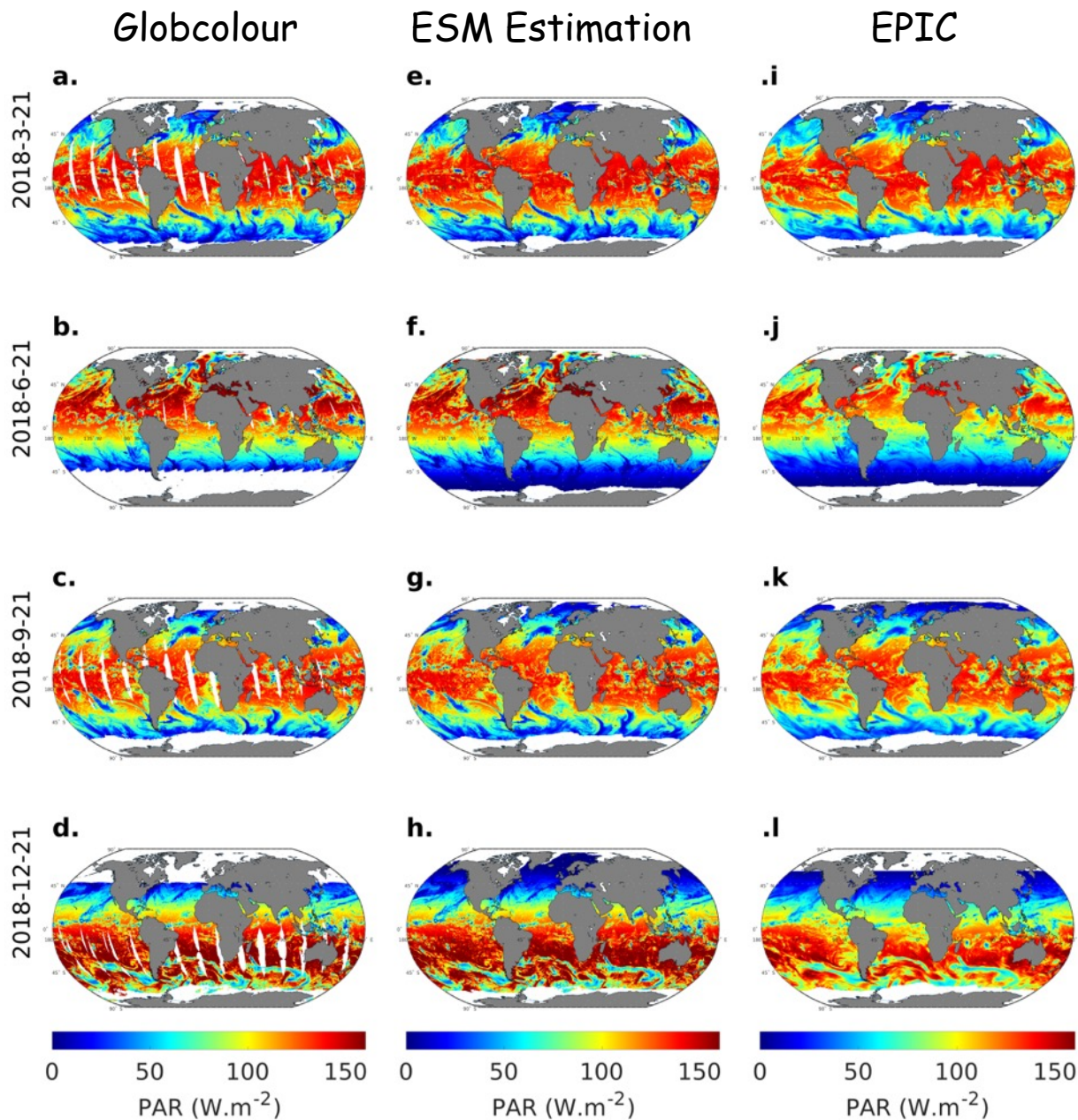
Examples of satellite PAR products (hourly)



Top: Hourly $E_d(PAR, t, 0^+)$ derived from MODIS-A and AHI-Hiwamari-8 data for 2018/03/20 in the Eastern Tropical Pacific at $t = 6$ h GMT. Bottom: Diurnal variability of $E_d(PAR, t, 0^+)$ at 3 sites

Hourly $E_d(PAR, t, 0^+)$ derived from MODIS-A data for 2018/03/20 in the Eastern Tropical Pacific at various GMT times.

Gap filling; PAR as a function of depth



Left: Global spatial distribution of $\text{PAR}(0^+)$ for four days in 2018 (Spring and Autumn Equinoxes, Winter and Summer Solstices) observed by Globcolour (a-d), completed with the ESM (e-h) and observed by EPIC DSCOVN (i-j). Right: $\text{PAR}(z)$ using $\text{PAR}(0^+)$ and $K_d\text{PAR}$ as a function of latitude at 27°W .

(Castant et al., 2024)

Protocols and Standards for PAR Measurements and Validation Studies

1. Protocol Development:

- Creation of standardized procedures and methodologies.
- Clear objectives, appropriate techniques, and documentation for consistency.
- Considerations: Environmental conditions, instrument specifications, stakeholder input.

•2. Instrument Calibration:

- Crucial for accuracy and reliability.
- Specifies calibration procedures, reference standards, and intervals.
- Quality assurance ensures proper functioning and traceability.

3. Data Acquisition Procedures:

- Standardized procedures for consistency and comparability.
- Includes site selection, sensor deployment, and measurement protocols.
- Quality control measures for validation and data quality assessment.

Protocols and Standards for PAR Measurements and Validation Studies (contd.)

4. Uncertainty Analysis:

- Quantifies reliability and confidence levels.
- Incorporates uncertainty estimation techniques and error propagation models.
- Uncertainty budgets document sources of uncertainty for transparency.

Benefits of Adherence:

- Reliability, comparability, and scientific validity of PAR data.
- Enhanced confidence in results and data interoperability.
- Support for evidence-based decision-making in marine ecosystem management.

Protocol for Conducting PAR Measurements in Marine Environments

The objective of this protocol is to standardize the procedures for accurately measuring PAR in marine environments, ensuring consistency, comparability, and reliability of data.

1. Equipment and Materials:

- Underwater PAR sensor (e.g., LI-COR LI-192 or similar)
- Waterproof data logger
- Deployment platform (e.g., buoy, tripod, or underwater housing)
- GPS device for georeferencing deployment locations
- Calibration standards (e.g., LI-COR LI-190R Quantum Sensor Calibrator)
- Deployment tools (e.g., wrenches, zip ties, and ropes)
- Protective gear for fieldwork (e.g., wetsuit, gloves, and goggles)

Protocol for Conducting PAR Measurements in Marine Environments (contd.)

2. Pre-Deployment Preparation:

- Calibrate PAR sensor according to manufacturer's instructions using calibrated reference standards.
- Perform pre-deployment checks to ensure proper functioning of equipment and data logger.
- Record calibration coefficients and calibration date for reference.
- Prepare deployment platform and secure PAR sensor in a position that minimizes shading and obstruction.
- Check weather forecasts and sea conditions to ensure safe deployment and data collection.

Protocol for Conducting PAR Measurements in Marine Environments (contd.)

4. Post-Deployment Retrieval:

- After the deployment period, return to the deployment site and retrieve PAR sensor and data logger.
- Document retrieval location, depth, and time for data processing and analysis.
- Handle equipment with care to prevent damage or contamination during retrieval.
- Download data from data logger and store in a secure location for subsequent analysis.

Protocol for Conducting PAR Measurements in Marine Environments (contd.)

5. Data Analysis:

- Process raw PAR data using appropriate software to remove outliers and apply calibration coefficients.
- Calculate average PAR values over specified time intervals (e.g., hourly, daily) to characterize light availability.
- Perform quality control checks to identify and correct any data anomalies or inconsistencies.
- Validate data against known environmental conditions and compare with concurrent measurements from nearby sensors or remote sensing products.

Protocol for Conducting PAR Measurements in Marine Environments (contd.)

6. Reporting and Documentation:

- Prepare a comprehensive report documenting all aspects of the PAR measurement campaign, including deployment details, data processing procedures, and results.
- Include metadata such as calibration information, deployment locations, and environmental conditions for transparency and reproducibility.
- Share findings with relevant stakeholders, collaborators, or scientific community through publications, presentations, or data repositories.

Methodologies for PAR Validation

1. Intercomparison Studies:

- Intercomparison studies involve comparing PAR measurements obtained from different instruments or measurement techniques deployed simultaneously at the same location.
- This approach allows for the assessment of agreement and consistency between different measurement platforms, identifying potential biases, and evaluating the robustness of PAR data across instruments.

2. Cross-Validation with Independent Datasets:

- Cross-validation involves comparing PAR measurements with independent datasets collected using alternative methods or sources.
- This approach provides an additional layer of validation by confirming the consistency and reliability of PAR data across different measurement platforms or sources.

Considerations for PAR Validation Studies

- **Spatial and Temporal Variability:** Account for spatial and temporal variability in PAR availability, considering factors such as diurnal cycles, seasonal changes, and localized environmental conditions.
- **Sensor Characteristics:** Consider the specifications and limitations of PAR sensors, including spectral response, dynamic range, and sensitivity, when interpreting validation results.
- **Environmental Factors:** Evaluate the influence of environmental factors such as water clarity, depth, and optical properties on PAR measurements, ensuring that validation studies account for potential confounding variables.
- **Data Processing and Analysis:** Implement rigorous data processing and analysis techniques, including quality control checks, uncertainty assessment, and error propagation analysis, to ensure the reliability and robustness of PAR validation results.