1.4 Overview of the Importance of Satellite Ocean Color Validation

Robert Frouin
Scripps Institution of Oceanography
La Jolla, California

Contents

1. Introduction to Ocean Color Remote Sensing:

•Overview of ocean color remote sensing's significance in studying marine ecosystems.

•Explanation of satellite sensors' measurement of ocean color and extraction of water quality parameters.

2. Role of Satellite Ocean Color Data:

•Applications in marine science: monitoring phytoplankton, detecting harmful algal blooms, assessing water quality, and studying ocean dynamics.

3. Challenges in Satellite Ocean Color Retrievals:

•Common challenges: atmospheric correction, sensor calibration, and validation.

4. Validation Techniques and Methods:

•Techniques: in situ measurements, autonomous platforms, validation campaigns.

•Explanation of validation metrics and statistical approaches.

Contents (contd.)

5. Importance of Validation for Scientific and Operational Applications:

•Ensuring quality and credibility of satellite ocean color data.

•Impact on improving accuracy of satellite-derived products.

**6. Collaborative Initiatives and Programs**:

•Overview of international collaboration efforts: NASA's OBPG, ESA's OC-CCI.

•Role of partnerships in advancing validation activities.

7. Future Perspectives and Challenges:

•Emerging technologies: new sensor technologies, machine learning.

•Ongoing challenges and areas for future research.

Brief Overview of Ocean Color Remote Sensing

•Ocean color remote sensing is a branch of Earth observation science that utilizes satellite sensors to monitor the color of the ocean's surface.

•This color is primarily influenced by the presence and concentration of microscopic marine plants called phytoplankton, as well as other dissolved and suspended materials in the water.
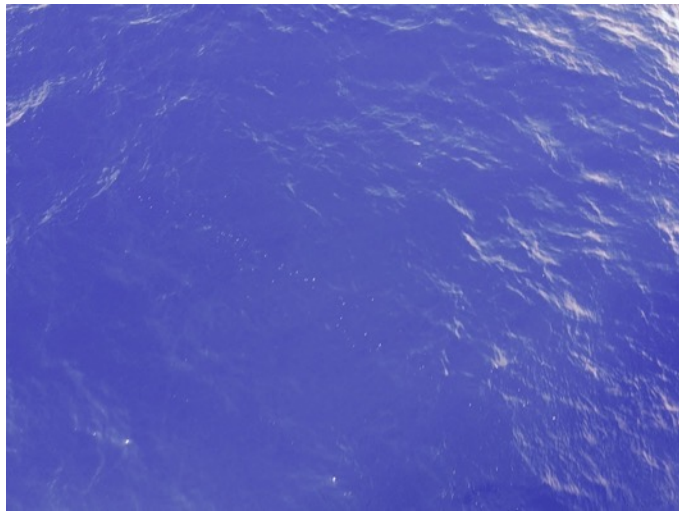
Southeast Pacific   *Salton Sea*   *Rio de la Plata*

Significance in Studying Marine Ecosystems

1. Phytoplankton Dynamics:

•Foundation of marine food webs

•Crucial role in global carbon cycling and oxygen production

•Ocean color remote sensing enables monitoring of distribution, abundance, and seasonal variations of phytoplankton populations on a global scale.

2. Ecosystem Health:

•Changes in ocean color indicate shifts in water quality, nutrient availability, and ecosystem health.

•Tracking these changes helps assess impacts of environmental factors like climate change, pollution, and human activities on marine ecosystems.

Significance in Studying Marine Ecosystems (contd.)

3. Biodiversity Monitoring:

•Ocean color data provides insights into spatial distribution of marine habitats and biodiversity hotspots.

•Essential for conservation efforts and sustainable management of marine resources.

4. Climate Studies:

•Contributes to understanding Earth's climate system by monitoring carbon uptake by phytoplankton.

•Vital for climate modeling and predicting future environmental changes.

5. Harmful Algal Bloom Detection:

•Certain phytoplankton species form harmful algal blooms (HABs) producing toxins harmful to marine life and human health.

•Satellite-based monitoring of ocean color helps detect and track HAB occurrences, enabling early warning systems and mitigation strategies.

Explanation of How Satellite Sensors Measure Ocean Color

1. Principle of Spectral Reflectance:

• Satellite sensors measure sunlight reflected off the ocean's surface across different wavelengths of light.

• Reflected light contains information about ocean color, influenced by constituents like phytoplankton, suspended sediments, and dissolved organic matter.

2. Spectral Bands:

• Satellite sensors have specific spectral bands capturing light across the electromagnetic spectrum.

• For ocean color sensing, focus is on visible and near-infrared wavelengths sensitive to phytoplankton pigments and other constituents.

Explanation of How Satellite Sensors Measure Ocean Color (contd.)

3. Atmospheric Correction:

•Satellite data undergoes atmospheric correction before extracting ocean color information.

•Corrects for scattering and absorption effects of Earth's atmosphere.

•Ensures accurate measurements of ocean color by removing atmospheric interference.

•Difficult process, because water signal is small compared to measured signal and atmosphere (e.g., aerosols) is highly variable.
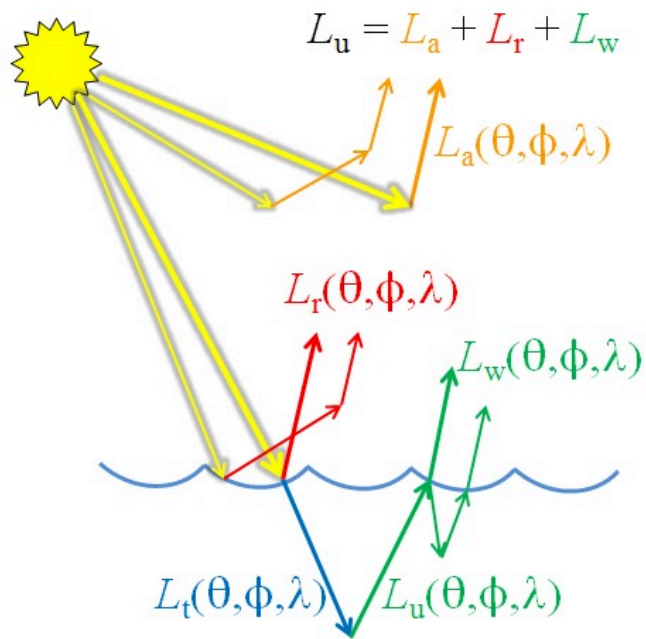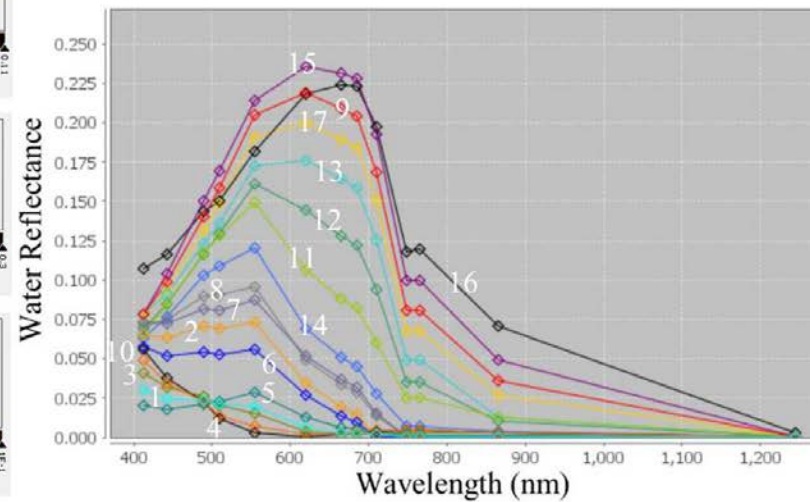

(Mobley, 2021)
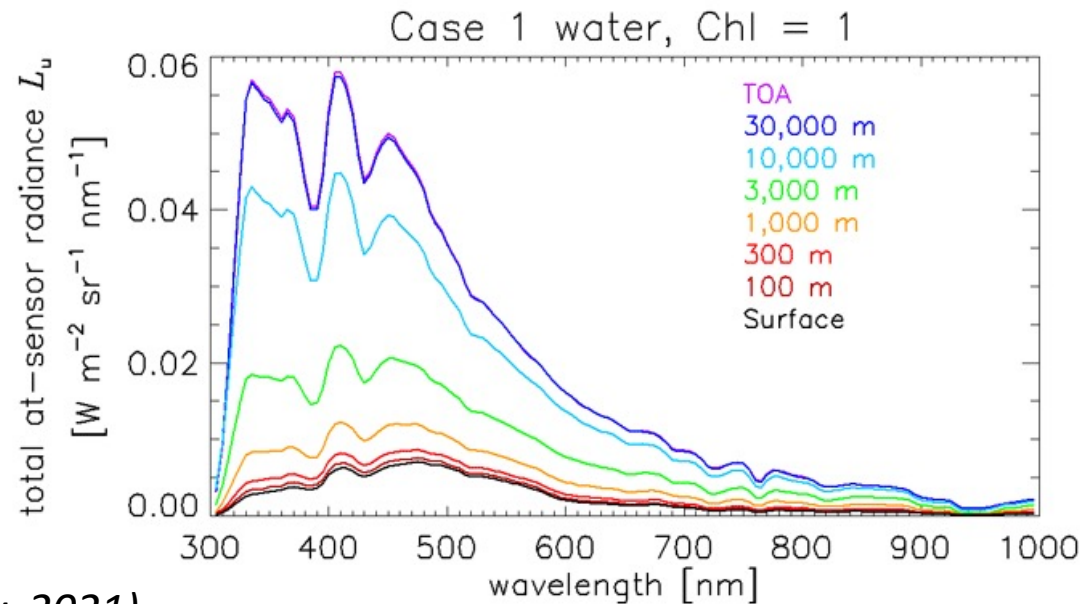
Water reflectance estimated with PCA-based AC algorithm from Sentinel-2 MSI data at 30 m resolution over the Gironde river estuary, France, on 21 October 2016.
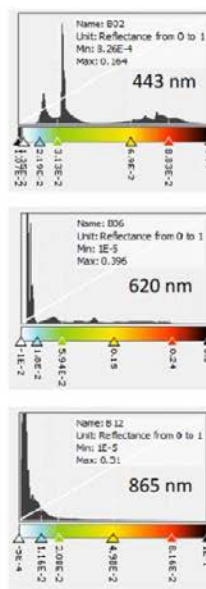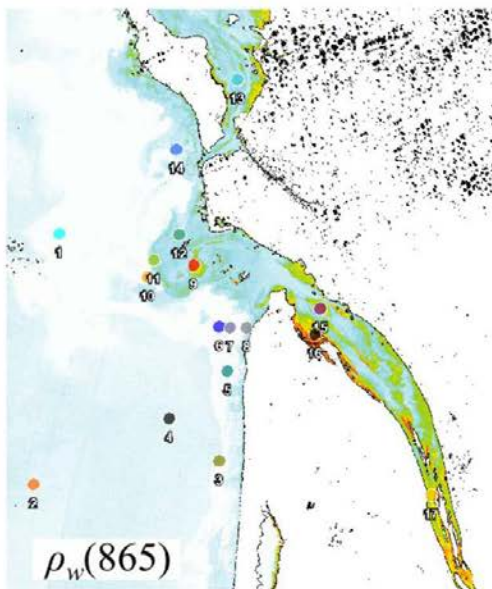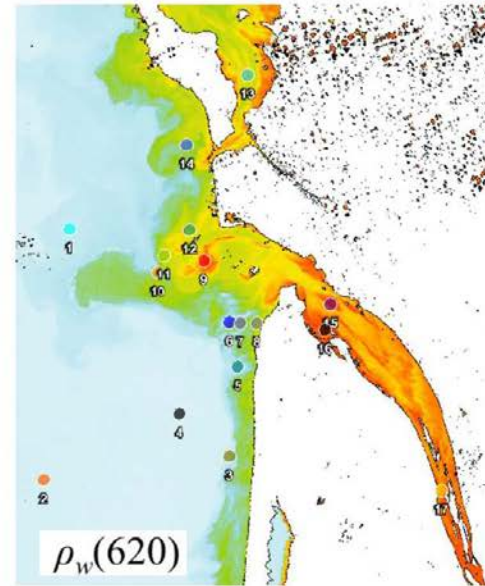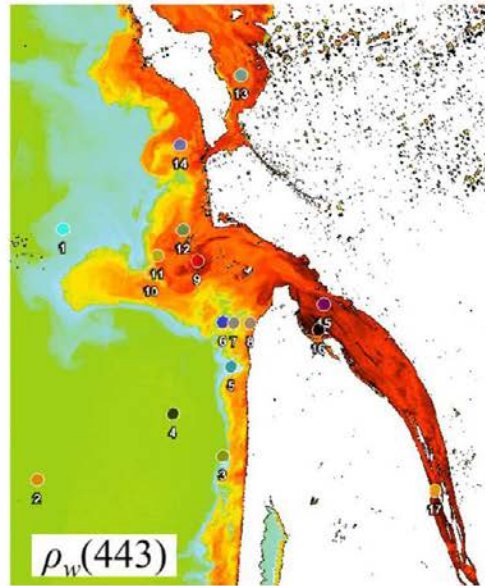
(Frouin et al., 2019)

Retrieval of water reflectance in the presence of glint and/or thin clouds

RGB   MERIS, 06/21/2005 ρ_w(443 nm)
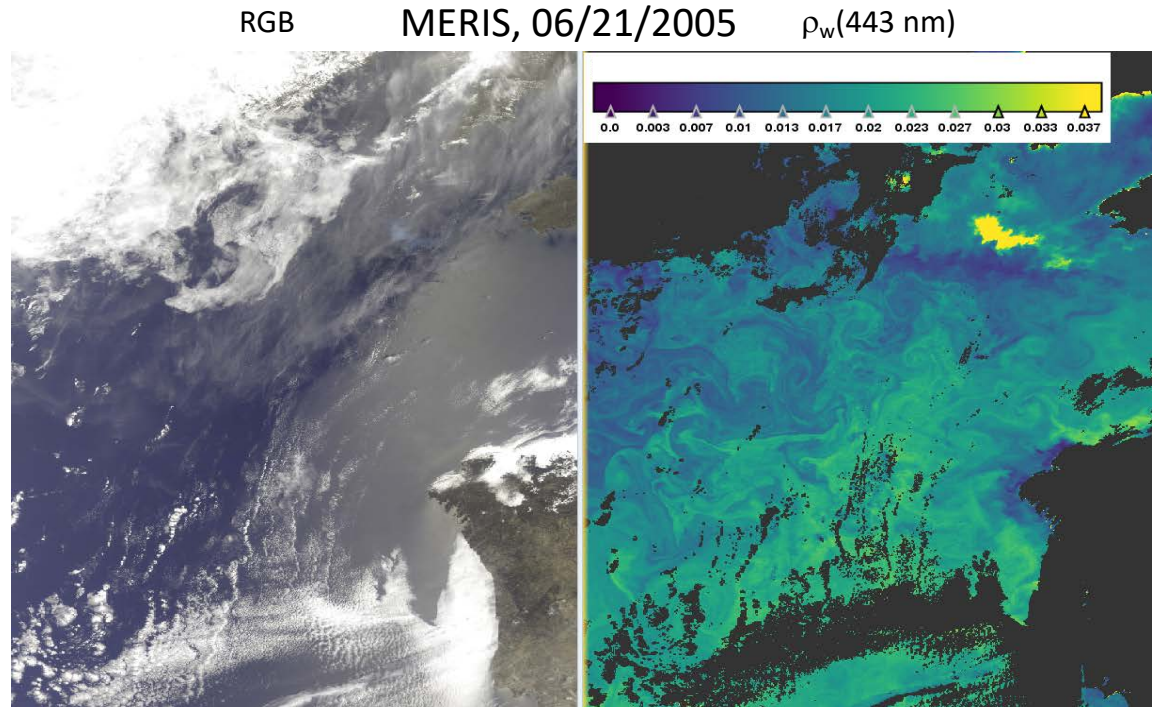
Clouds and glint signals, even though relatively high, are smooth spectrally, i.e., their can be separated from the more spectrally variable water signal.
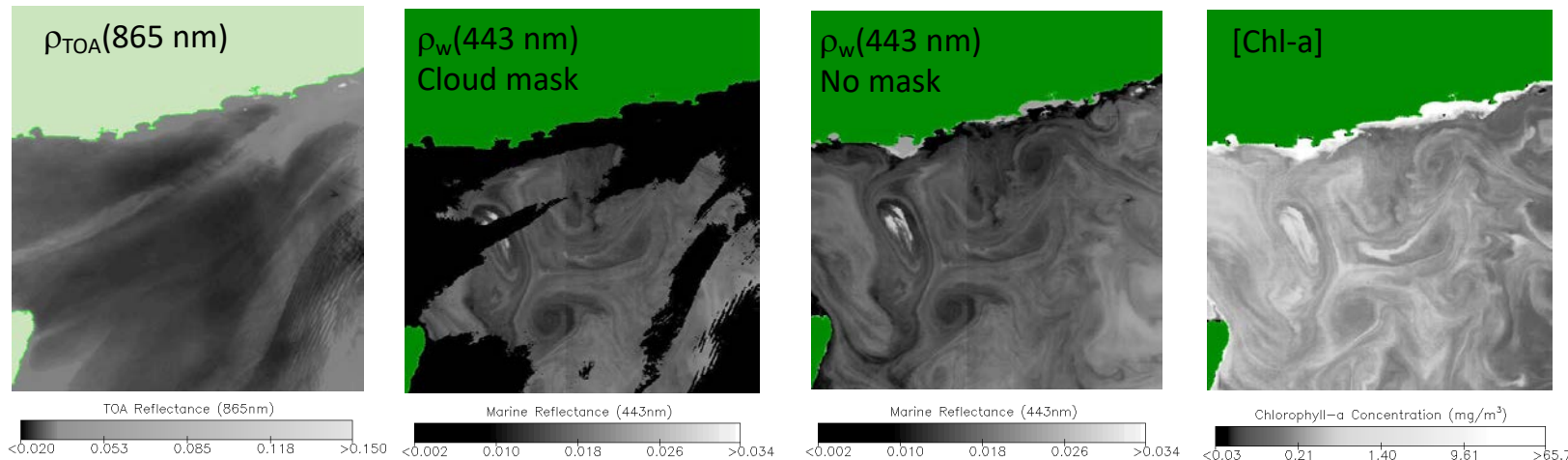
Water reflectance, ρ_w, patterns exhibit spatial continuity from cloud- and glint-free areas to adjacent cloud- and/or glint-contaminated areas.

MERIS, 11/09/2003

ρ_{TOA}(865 nm)

ρ_w(443 nm)
Cloud mask

ρ_w(443 nm)
No mask

[Chl-a]

Extraction of Information About Water Quality Parameters

1. Bio-optical Algorithms:

•After atmospheric correction, bio-optical algorithms are applied to satellite data.

•These algorithms use mathematical relationships between ocean color and biogeochemical properties.

•Estimate parameters like chlorophyll concentration, water clarity, and concentrations of other constituents.
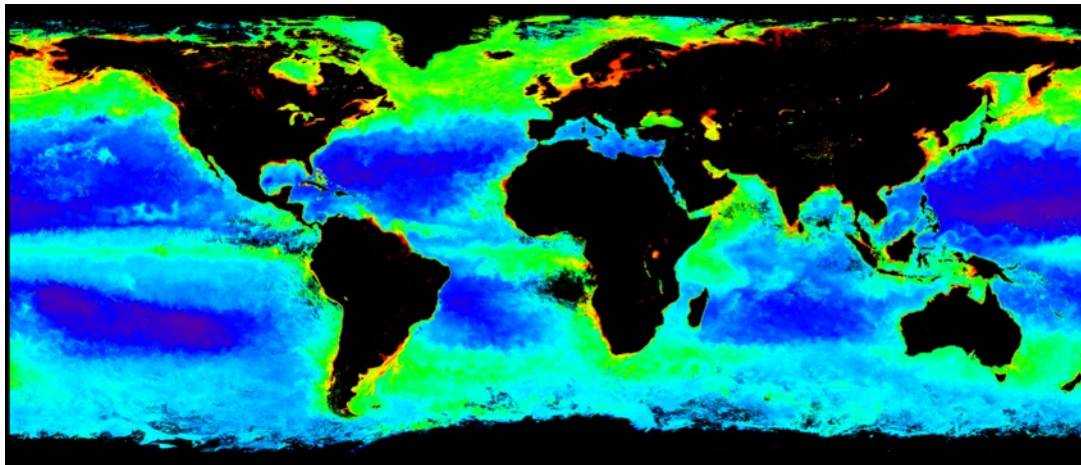
2. Chlorophyll-a Concentration:

•Primary pigment in phytoplankton, indicating phytoplankton biomass and primary productivity.

•Satellite-derived chlorophyll-a maps offer insights into spatial distribution and temporal dynamics of phytoplankton populations.

Extraction of Information About Water Quality Parameters (contd.)

3. Other Water Quality Parameters:

• Satellite ocean color data estimates various parameters:

   - Suspended sediment concentration

   - Colored dissolved organic matter (CDOM) absorption

   - Diffuse attenuation coefficient

• Provide insights into sediment transport, organic matter cycling, and ocean circulation processes.

[Chl-a], mg/m^3 *VIIRS, NOAA-20, September 2020* K_d, m^{-1} *(NASA OBPG)*

Chlorophyll Concentration, OCI Algorithm (mg m^{-3})

0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20
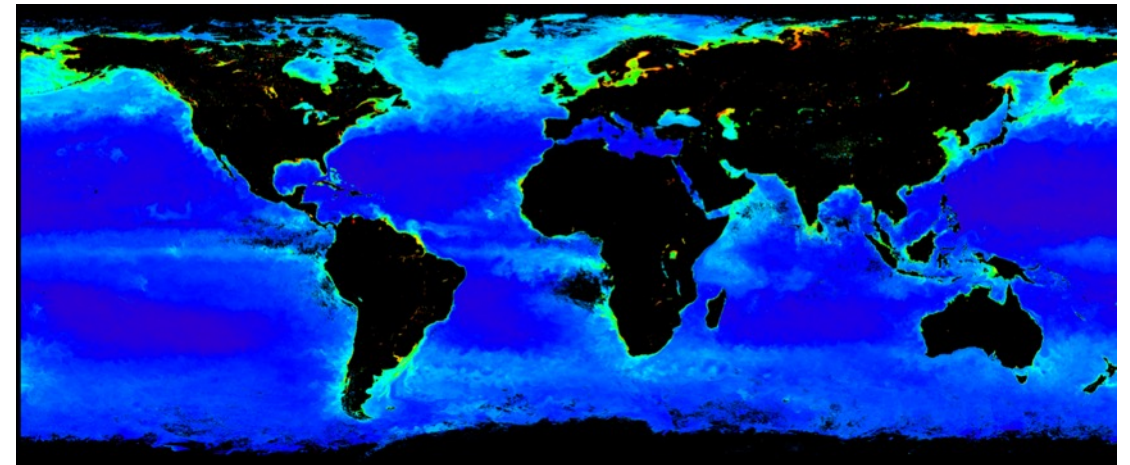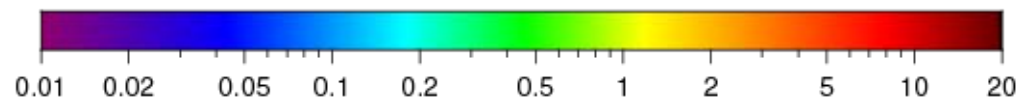
Diffuse attenuation coefficient at 490 nm, KD2 algorithm (m^{-1})

0.01 0.02 0.05 0.1 0.2 0.5 1 2 5
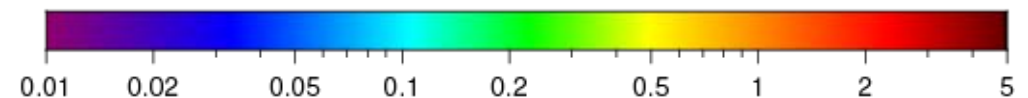
Challenges in Satellite Ocean Color Retrievals

1. Atmospheric Correction:

• Primary challenge: Removing Earth's atmosphere influence on observed ocean color signal.

• Atmospheric gases, aerosols, and Rayleigh scattering affect light propagation, leading to errors.

• Accurate algorithms essential for reliable satellite-derived ocean color data.

2. Sensor Calibration:

• Ensuring satellite sensors accurately measure and record incoming light signals.

• Calibration errors from sensor sensitivity changes, instrument degradation, and stray light contamination.

• Regular calibration and inter-calibration with reference instruments maintain data accuracy.

Challenges in Satellite Ocean Color Retrievals (contd.)

3. Validation:

- Critical for assessing satellite ocean color data accuracy.
- Involves comparison with ground truth measurements from in situ observations.
- Challenges include differences in satellite and in situ spatial/temporal scales, measurement uncertainties.
- Robust validation methodologies and networks are essential for reliability.

Addressing these challenges requires collaborative efforts among scientists, engineers, and stakeholders to develop innovative techniques, improve sensor technologies, and enhance validation capabilities.

Overcoming these obstacles will contribute to the advancement of satellite ocean color remote sensing and its applications in marine science and environmental monitoring.

Validation Techniques and Methods

1. In-Situ Measurements:

- Direct observations of ocean color and water quality parameters.
- Ground truth data for validating satellite-derived ocean color products.
- Common instruments: radiometers, spectrophotometers, fluorometers.

2. Autonomous Platforms:

- Buoys, floats, gliders, UAVs collect continuous and spatially distributed measurements.
- Complement traditional ship-based measurements.
- Useful for validating satellite data in remote or inaccessible regions.

3. Validation Campaigns:

- Coordinated field experiments for specific satellite missions or products.
- Deploy a suite of instruments and platforms in targeted regions.
- Facilitate direct comparison of satellite-derived data with in-situ measurements under controlled conditions.

Validation Metrics and Statistical Approaches

1. Matchup Analysis:

•Pairing satellite-derived data with corresponding in situ measurements.

•Utilizes validation metrics like bias, RMSE, correlation coefficient, and scatter plots to assess agreement.

2. Statistical Comparisons:

•Regression analysis evaluates relationship between satellite-derived and ground truth measurements.

•Regression models can derive empirical algorithms for calibrating and validating satellite ocean color data.

Validation Metrics and Statistical Approaches (contd.)

3. Uncertainty Analysis:

•Quantifies uncertainties associated with both satellite and in situ measurements.

•Considers factors like instrument errors, atmospheric variability, and spatial representativeness.

•Essential for interpreting validation results and assessing reliability of satellite-derived ocean color products.

[Chla] from k-NN algorithm, SeaWiFS, 10/26/2006, Southwest Atlantic
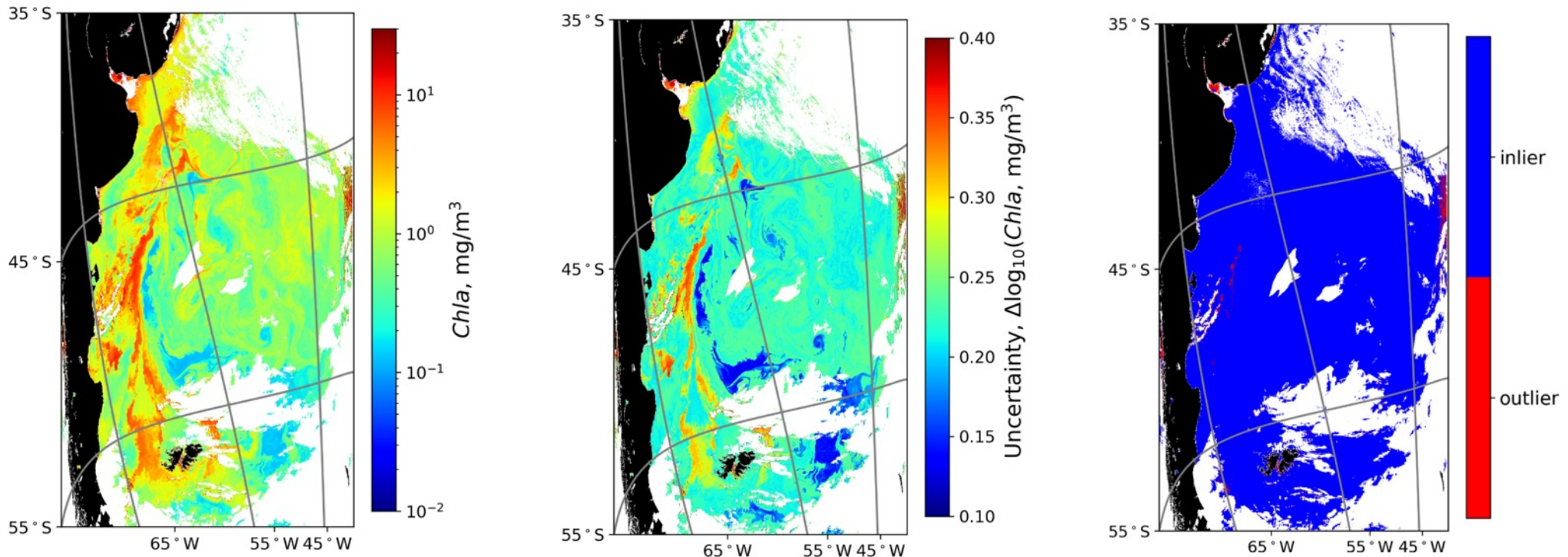
Importance of Validation for Scientific and Operational Applications

1. Ensuring Data Quality and Credibility:

•Validation verifies accuracy and reliability of satellite ocean color data against ground truth measurements.

•Essential for scientific research, environmental monitoring, and operational applications like marine resource management and disaster response.

2. Supporting Scientific Research:

•Validated data contribute to research on marine ecosystems, biogeochemical cycles, and climate dynamics.

•Enable investigation of ocean processes, ecosystem responses to environmental changes, and impacts of human activities.

3. Facilitating Operational Applications:

•Used in fisheries management, coastal zone monitoring, and water quality assessment.

•Decision-makers rely on accurate data for policy decisions, resource allocation, and effective management strategies.

Collaborative Initiatives and Programs

1. NASA's Ocean Biology Processing Group (OBPG):

• Responsible for processing, calibration, validation, and distribution of satellite ocean color data.

• Collaborates with international partners, research institutions, and government agencies.

• Develops high-quality ocean color products from NASA's Earth Observing System (EOS) satellites, Aqua and Terra missions, PACE, etc.

2. European Space Agency's Ocean Color Climate Change Initiative (OC-CCI):

• Led by the European Space Agency (ESA) for providing long-term, consistent, and validated ocean color products for climate research.

• Collaborative effort involving scientists, data providers, and stakeholders from European and international institutions.

• Develops and validates climate-quality ocean color datasets from ESA's Sentinel missions and other satellite platforms.

Role of Partnerships

1. Space Agencies:

• Collaborate on satellite missions, data sharing, and joint validation efforts.

• Ensures global coverage and continuity of satellite ocean color observations.

• Facilitates exchange of expertise, resources, and data, enhancing product quality and reliability.

2. Research Institutions and Universities:

• Conduct field campaigns, data analysis, algorithm development, and scientific research for validation.

• Collaborative projects between academia and government agencies advance understanding of ocean processes and improve validation methodologies.

Role of Partnerships (contd.)

3. Oceanographic Communities and Stakeholders:

•Collaboration with oceanographic communities and stakeholders is crucial.

•Validates satellite ocean color data against local observations and user needs.

•Ensures satellite products support decision-making and address societal challenges related to marine environments.

Partnerships with space agencies, research institutions, and oceanographic communities are vital. Collaborative efforts enhance the quality, reliability, and usability of satellite ocean color data. Stakeholder engagement ensures satellite products meet user needs and address societal challenges.

Future Perspectives and Challenges

1. Emerging Technologies and Methodologies:

•Integration of New Sensor Technologies: Advances in hyperspectral and multispectral sensors improve spatial and spectral resolution.

•Machine Learning Approaches: Neural networks and deep learning enhance validation accuracy and efficiency.

•Interdisciplinary Research Collaborations: Collaboration across disciplines facilitates addressing complex challenges in validation, algorithm development, and data interpretation.

Future Perspectives and Challenges (contd.)

2. Ongoing Challenges and Areas for Future Research:

• Atmospheric Correction: Enhancing accuracy in optically complex coastal waters and high aerosol regions.

• Sensor Calibration: Improving calibration procedures for long-term stability and accuracy.

• Validation in Optically Complex Waters: Developing methodologies for turbid coastal and inland waters.

• Uncertainty Quantification: Reducing uncertainties in satellite data, validation, and algorithm parameterizations.

By exploring emerging technologies, interdisciplinary collaborations, and ongoing challenges, we can identify opportunities for innovation and advancement in satellite ocean color validation, paving the way for improved understanding of marine ecosystems, environmental monitoring, and sustainable management of ocean resources.

Recapitulation of Key Takeaways

•Ocean color remote sensing is a powerful tool for studying marine ecosystems, assessing water quality, and monitoring global environmental changes.

•Satellite sensors measure ocean color by detecting reflected sunlight, providing insights into phytoplankton dynamics, harmful algal blooms, and water quality parameters.

•Challenges in satellite ocean color retrievals highlight the importance of rigorous validation efforts for data accuracy and reliability.

•Validation techniques such as in situ measurements, autonomous platforms, and collaborative initiatives are essential for assessing the accuracy of satellite-derived ocean color products.

Encouragement for Continued Learning and Involvement

• Continued learning and involvement in satellite ocean color validation efforts are vital for advancing understanding and supporting sustainable management practices.

• Stay informed about emerging technologies and research developments to contribute to improving data accuracy and reliability.

• Engagement in interdisciplinary collaborations, participation in validation campaigns, and utilization of satellite data tools enable meaningful contributions to scientific research and environmental conservation efforts.

Satellite ocean color remote sensing offers valuable insights into the dynamic and complex nature of marine environments. By embracing the challenges and opportunities in satellite ocean color validation, we can work together to enhance our understanding of ocean processes, protect marine ecosystems, and ensure the sustainable use of ocean resources for future generations.