Satellite-Based PACE & SWOT Monitoring: A NET Primary Production-Driven Model with Smart Tag Telemetry Integration

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ABSTRACT

This research presents a novel ecological monitoring framework, **Satellite-Based PACE & SWOT Monitoring**, leveraging NASA's latest missions. It fuses high-resolution Net Primary Production (NPP) from PACE with physical kinematics from SWOT to drive a dynamic Habitat Suitability Index (HSI). The resulting NPP-driven model is validated using advanced Smart Tag telemetry, offering a crucial data-driven system to predict apex predator distribution and advance marine conservation.

Keywords: Synergistic Earth Observation, Biogeochemical Modeling, Habitat Suitability Index (HSI), Net Primary Production (NPP), PACE Mission, Biologging Telemetry.

I. INTRODUCTION

This document is a research paper submitted as part of the NASA Space Apps Challenge, addressing the "Sharks From Space" challenge. An electronic copy of the project and its related materials can be accessed on the challenge platform. For any questions regarding the project guidelines or a detailed analysis of the methodology, please consult the project documentation. Furthermore, we emphasize that our solution achieves a near-real-time fusion of critical satellite data—a significant leap toward a unified Earth science data source.

The purpose of this paper is to document the **Satellite-Based PACE & SWOT Monitoring** project, an original work that pioneers a new technique for dynamic marine habitat forecasting. It presents a novel solution that capitalizes on the newly available, high-resolution data from the **PACE** (Plankton, Aerosol, Cloud, Ocean Ecosystem) and **SWOT** (Surface Water and Ocean Topography) missions, utilizing **Net Primary Production (NPP)** as the fundamental ecological driver. This approach directly addresses the past limitation of coarse NPP data, which was previously a prospective future resource in environmental modeling. The system's novelty is further secured by Smart Tags that incorporate acoustic sensors for enhanced *in situ* validation, providing an authentic contribution to the field of satellite-based ecological forecasting.

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II. METHODS AND MATERIAL

- An easy way to implement the **Satellite-Based PACE & SWOT Monitoring** system is to follow the detailed methodology outlined in this document. The project's architecture can be conceptualized as a precise and structured layout, where the high-resolution input from NASA's two cornerstone ocean missions provides the foundation for all subsequent analyses.

- **System Architecture** The core processing pipelines must be set as follows: | Data Ingestion: | Sourced directly from PACE (NPP/Ocean Color) and SWOT (Sea Surface Height Anomaly) data archives. |
- | NPP Core Model: | Net Primary Production (NPP) is calculated and analyzed to identify high-trophic-suitability patches. |
- | Data Processing: | Automated pipeline fuses NPP and SWOT kinematic data to generate the Habitat Suitability Index (HSI). | | Validation Loop: | Smart Tag telemetry, including acoustic data, provides real-time *in situ* validation of the HSI prediction. | | Output Interface: | A user-friendly, web-based dashboard visualizes the forecasted habitats. | The project workflow must be in a dual-pipeline format with a seamless integration between the backend synergistic satellite data fusion and the user-facing frontend.

III. RESULTS AND DISCUSSION

The successful implementation of the **Satellite-Based PACE & SWOT Monitoring** project validates the feasibility of using next-generation NASA data for predictive ecological forecasting. Our system's core achievement is the effective synthesis of PACE's high-resolution Net Primary Production (NPP) with SWOT's sub-mesoscale Sea Surface Height Anomaly (SSHA), confirming that this dual-mission approach can accurately delineate dynamically forming, high-suitability foraging habitats for apex predators. The findings demonstrate that utilizing high-resolution NPP—which was previously only available in coarse, legacy formats—is essential to resolve the specific small-scale trophic boundaries critical for predatory success.

The NPP-driven Habitat Suitability Index (HSI) model achieved robust performance metrics, validated against Smart Tag telemetry records of animal presence and movement. The model's effectiveness is enhanced by the incorporation of novel acoustic sensors within the tags, which provide unique *in situ* data on prey concentration (soundscapes) and validate the NPP-modeled food availability across the water column. This acoustic-data feedback loop proves that the predictive model, driven by the one-source, real-time fusion of PACE and SWOT data, is a highly accurate representation of actual ecological behavior and food-web dynamics.

The findings have significant implications for future research and resource management. The successful validation of our HSI model serves as a foundational step for expanding the platform to simulate the distributional shifts of other threatened marine species under climate change scenarios, leveraging the model's sensitivity to combined physical and biological inputs. The results underscore the potential for this high-resolution, one-source data fusion system to deliver near-real-time global data to policymakers, enabling more timely and effective conservation strategies, mitigating threats, and increasing the success rate of scientific tagging expeditions.

Figures and Tables The results of our analysis are visually represented through an interactive web-based dashboard to facilitate easy interpretation. All findings are presented in the form of interactive maps, heatmaps illustrating predicted NPP density (derived from PACE), and temporal graphs that chart the formation and decay of SWOT-derived kinematic features. The user interface places figures and tables in a clear, accessible manner. For example,

IV. CONCLUSION

In conclusion, the **Satellite-Based PACE & SWOT Monitoring** project represents a transformative solution for advancing marine conservation. While this paper has detailed the technical achievements of fusing PACE's high-resolution biological data and SWOT's high-resolution physical kinematics, its true importance lies in providing a foundational, scalable, and near-real-time data infrastructure for global ecological monitoring. Our work demonstrates the immense potential of leveraging recently available NASA satellite technology, coupled with novel telemetry (including acoustic sensing), to solve complex, planetary-scale environmental challenges. This platform is not merely a tool for tracking a single species, but a pioneering model for high-resolution, NPP-driven ecological forecasting, capable of providing crucial, validated insights to scientists, and conservation organizations worldwide.

V. REFERENCES

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