Multi-Dimensional Dynamic Data Fusion System (M3DFS): Application to ORBTY's Metocean products

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ABSTRACT

Temporal averaging in satellite-based meteorological and oceanographic data can introduce artifacts due to sensor errors, cloud cover, and uncertainties, impacting spatial and temporal gradient analysis. ORBTY's science team developed the Multi-Dimensional Dynamic DataFusion System (M3DFS), an advanced method utilizing computer vision and photogrammetry to aggregate multitemporal Level 2 data from single or multiple sensors. M3DFS generates Level 3 maps with improved spatio-temporal accuracy, effectively reducing artifacts associated with traditional time-averaging. Validated across multiple geophysical parameters—including SST, Ocean Color, Wind, Atmospheric Water Vapor, and Sea Surface Height—using data from various satellite sensors (e.g., MODIS, VIIRS, AMSR-E, AMSR2, GMI, OLCI, SLSTR, and SWOT), M3DFS consistently enhances spatial and temporal gradient analyses. This advancement supports high-precision applications in environmental monitoring and climate research.

Key words — Satellite Metocean parameters, Multi-Sensor data fusion, M3DFS, Artifacts, SST/SSH

1. INTRODUCTION

Composite maps of satellite-based meteorological and oceanographic parameters, averaged over time (hourly, daily, weekly or monthly), may exhibit artifacts stemming from its temporal variability, sensor calibration errors, extended periods of cloud coverage, undetected clouds or uncertainties in Level 2 retrieval algorithms. These spatial discontinuities can impact downstream applications, including the analysis of gradients in space and time. In the context of Sea Surface Temperature (SST), this issue has been a central point of research within the Group for Very High Resolution Sea Surface Temperature (GHRSST) framework for both single sensor Level 3C (Collated), multi-sensor Level 3S (Super-Collated) and Level 4 SST datasets.

Recently, ORBTY's science team has developed the Multi-Dimensional Dynamic DataFusion System (M3DFS) using computer vision and photogrammetry principles. This new methodology seamlessly aggregates multitemporal Level 2 data from a single or multiple instruments, resulting in Level 3 maps with significantly improved spatio-temporal representation of satellite-based MetOcean parameters, i.e., without any compositing artifacts commonly seen when using conventional time-averaging methods.

The effectiveness of this novel approach has been tested on various geophysical parameters, (SST, Ocean Color, Wind Speed/Direction, Atmospheric Water Vapor, Sea Surface Height) and across a variety of satellite sensors (MODIS, VIIRS, AMSR-E, AMSR2, GMI, OLCI, SLSTR, SWOT), showing consistent improvement in the spatial distribution and temporal variability of gradients extracted from Level 3 products, regardless of their temporal resolution, i.e., hourly, daily or monthly.

2. MATERIAL AND METHODS

The M3DFS differs from other data fusion/merging/blending schemes used in satellite remote sensing in that it considers a geophysical parameter as a three dimensional gradient field rather than only a scalar field [1]. Denoting a Level 3 MetOcean parameter as a function f(ϕ,λ,t) defined in latitude ϕ, longitude λ and time t, the M3DFS aims to find a solution u that minimizes a cost function with the following form:

$$E(u) = E_1(u) + \mu E_2(u)$$

where:

$$E_1(u) = \int_\phi \int_\lambda \int_t ||\nabla(u - f)||^2 \, d\phi \, d\lambda \, dt$$

constitutes a geometrical constraint on the solution and

$$E_2(u) = \int_\phi \int_\lambda \int_t ||u - f||^2 \, d\phi \, d\lambda \, dt$$

is a standard statistical constraint that ensures that the obtained scalar field is statistically consistent with the satellite observations used as input. The balancing coefficient μ can be selected through a dyadic iterative scheme similar to that used in computer vision for applications such as image denoising, inpainting, super-resolution and stitching.

3. RESULTS

The M3DFS has been so far successfully applied to multiple Metocean parameters derived from sensors on both polar-orbiting [1,2] and geostationary satellites [3]. Metocean parameters include:

- Sea Surface Temperature (SST);
- Chlorophyll-a concentration (Chl-a);
- Sea Surface Height (SSH);
- Wind Speed and Direction;
- Atmospheric Water Vapor.

More recently [4], ORBTY has adjusted the M3DFS for the processing of data from NASA's SWOT mission. SWOT provides almost full global coverage over a period of 21 days and provides two dimensional estimates of ocean Sea Surface Height (SSH) at very high spatial resolutions.

In Figure 1, we illustrate the effects of conventional time-averaging methods on the magnitude of the SSH gradient, i.e., significant crossover/overpass artifacts seen as artificial discontinuities. The SSH data used was acquired by NASA's SWOT Karin instrument for the period from September 1st to September 21st of 2024. Figure 2 shows how the use of the M3DFS mitigates the generation of such artifacts leading to improved spatial representation of the SSH at global and regional scales.

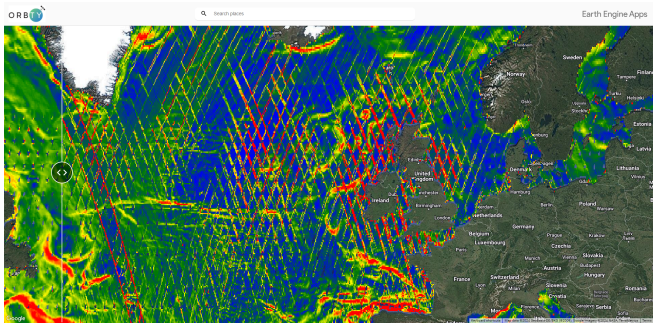


Figure 1. Magnitude of the Sea Surface Height (SSH) gradient field using 21 days time-averaged SSH from NASA SWOT Karin (1-21 September 2024)

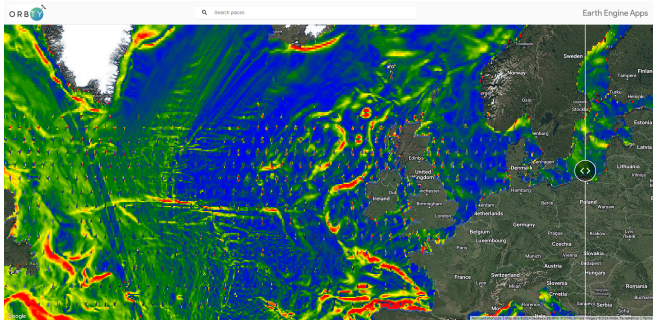


Figure 2. Magnitude of the Sea Surface Height (SSH) gradient field using 21 days of SSH from NASA SWOT Karin processed with the M3DFS (1-21 September 2024)

4. DISCUSSION

Applications that require accurate representation of the spatial distribution of Metocean parameters derived from satellite measurements could benefit from datasets produced using the M3DFS.

In the context of physical and biological oceanography for example, researchers can utilize these datasets for improved detection and characterization of ocean fronts which are crucial, as they often signify areas of enhanced biological productivity and can influence marine life distribution.

Mitigation of crossover/overpass artifacts in SSH data with the M3DFS will significantly improve the estimation of ocean (geostrophic and ageostrophic) surface currents, leading to major benefits for applications like fisheries management, marine navigation and oil spill response.The list of ORBTY's Metocean products is provided in Table 1.

Table 1. ORBTY's M3DFS Operational Metocean Products

Product	Processing Level	Satellite Sensors	Spatial Resolution
Sea Surface Temperature (SST)	Level 3S Multi-Sensor	Terra/Aqua MODIS NPP/N20/ N21 VIIRS Metop A/B AVHRR	1km (regional) 5km/10km (global)
Chlorophyll-a Concentration (Chl-a)	Level 3S	Terra/Aqua MODIS NPP/N20/N21 VIIRS Metop A/B AVHRR S3A/3B OLCI	1km (regional) 5km/10km (global)
Sea Surface Height (SSH)	Level 3C Single-Sensor	NASA SWOT Karin	>2km (on demand) 5km/10km (global)
Wind Speed	Level 3S	AMSR-2 GMI SMAP	25km (global)
Wind Speed and Direction	Level 3S	COWVR Metop ASCAT Windsat	25km (global)
Atmospheric Water Vapor	Level 3S	AMSR-2 GMI SMAP	25km (global)

5. CONCLUSIONS

ORBTY's M3DFS enables the synergetic use of the constellation of polar-orbiting and geostationary satellite sensors to derive spatially consistent maps of several Metocean parameters. The mitigation of feature artifacts, commonly seen in conventional time-aggregated satellite products allows improved detection and characterization of ocean fronts as well as more reliable estimation of ocean surface geostrophic and ageostrophic currents which can be used for the optimization of ship routes.

6. ACKNOWLEDGMENTS

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