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Miradas Diversas, Soluciones Comunes

Garcia-Espriu, A.; González-Haro, C.; González-Gambau, V.; Ruiz-Sebastian, A.; Olmedo, E.; Turiel, A. Observación terrestre de mayor resolución y más eficiente computacionalmente

A Resolution-Preserving Area Projection Algorithm for Multi-Mission Earth Observation

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ABSTRACT

We present a fast area projection algorithm for mapping satellite measurements onto geo-graphical grids while preserving the instrument's native spatial resolution. Standard interpola-tion methods either introduce white noise (Nearest Neighbor), smooth fine-scale features (Bi-linear), or are computationally prohibitive. Our approach tessellates each measurement foot-print into equal-area sub-elements and performs a single, weighted projection onto the target grid, avoiding the error cascading caused by successive coordinate transformations. As an example, we walidate on SMOS Sea Surface Salinity over three years: area projection meth-ods achieve lower biases and standard deviations than existing operational products, and maintain the correct spectral slope down to ~0.6°—close to the instrument's 35–50 km native resolution. We also apply this approach to Sea Surface Temperature and Brightness Tempera-ture maps, as well as for downscaling in numerical and machine learning models. It offers a general-purpose, computationally efficient solution for Big Data management in Earth observa-tion.

Keywords: *Big data, geographical data representation, remote sensing*

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Abstract: We present a fast area projection algorithm for mapping satellite measurements onto geographical grids while preserving the instrument's native spatial resolution. Standard interpolation methods either introduce white noise (Nearest Neighbor), smooth fine-scale features (Bilinear), or are computationally prohibitive. Our approach tessellates each measurement footprint into equal-area sub-elements and performs a single, weighted projection onto the target grid, avoiding the error cascading caused by successive coordinate transformations. As an example, we walidate on SMOS Sea Surface Salinity over three years: area projection methods achieve lower biases and standard deviations than existing operational products, and maintain the correct spectral slope down to ~0.6°—close to the instrument's 35–50 km native resolution. We also apply this approach to Sea Surface Temperature and Brightness Temperature maps, as well as for downscaling in numerical and machine learning models. It offers a general-purpose, computationally efficient solution for Big Data management in Earth observation.

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Un algoritmo de proyección por área con preservación de resolución para observación de la Tierra multimisión

Resumen: *En este trabajo se presenta un algoritmo rápido de proyección por área para mapear mediciones satelitales sobre mallas geográficas preservando la resolución espacial nativa del instrumento. Los métodos de interpolación estándar introducen ruido blanco (vecino más cercano), suavizan las estructuras de pequeña escala (bilineal) o resultan computacionalmente prohibitivos. En el enfoque propuesto, cada huella de medición se tesela en subelementos de igual área y se realiza una única proyección ponderada sobre la malla objetivo, evitando la propagación de errores causada por transformaciones de coordenadas sucesivas. Como ejemplo, validamos con salinidad superficial del mar (SSS) de SMOS durante tres años: los métodos de proyección por área tienen sesgos y desviaciones estándar más bajos que los productos operacionales existentes, y se mantiene la pendiente espectral correcta hasta ~0,6°, cerca de la resolución nativa del instrumento, 35–50 km. Aplicamos también el algoritmo al procesamiento de temperatura superficial del mar y temperatura de brillo, así como a la reducción de escala en modelos numéricos y de aprendizaje automático. El algoritmo es una solución de propósito general y computacionalmente eficiente para la gestión de grandes volúmenes de datos en observación de la Tierra.*

Palabras clave: *Big data, representación geográfica de datos, teledetección*

1. INTRODUCTION

Satellite dataset complexity grows with longer time series and greater instrument resolution, making efficient and accurate projection onto geographic grids a critical challenge. Converting measurements from one grid to another generates errors through successive projections, degrading the intrinsic spatial resolution, and requiring high computational cost. Standard interpolation methods have their own limitations: Nearest Neighbor is fast but noisy and spatially incoherent; Bilinear interpolation smooths fine-scale features; Optimal Interpolation and kriging are computationally expensive and over-smooth data-sparse regions. We present a novel, fast area projection algorithm that enhances spatial coherence. A first prototype was developed and tested on the SMOS Sea Surface Salinity (SSS) Level 2 processor, yielding promising results (Garcia *et al*. 2026). Here, we review those findings and present further applications of the methodology, which may benefit a broad range of communities—from remote sensing scientists to specialists of numerical modeling and machine learning–based data assimilation.

2. DATASETS

SMOS-Based SSS Products: Three years (2014, 2017, 2018) of L3 SSS daily maps with a 9-day moving window, 0.25° regular grid. We used four projection algorithms were compared: (1) Nearest Neighbor, (2) AP-IDW (Area projection, 24-triangle tessellation with inverse distance weighting), (3) AP-Bilinear (Area projection, with inverse Bilinear distance function), and (4) Bilinear interpolation. Two publicly available products were used: BEC SMOS SSS Global L3 v2.0 (Olmedo *et al*., 2021) and CATDS SMOS SSS L3 V10 (Boutin *et al*., 2024).

In-Situ Reference: PI-MEP Argo float data, quality flags 1-2 , “surface” taken as top 10 m.

Other satellite SSS Datasets. SMAP RSS SSS L3 V6.0 product (Remote Sensing Systems, 2024) as incorrelated error source for Correlated Triple Collocation (CTC) for 2017-2018.

Other datasets: ESA SST CCI and C3S Sea Surface Temperature (DMI & Met Office, 2024), used for downscaling applications (0.05º daily products). Copernicus Sentinel-3A/3B SLSTR Level-2 Sea Surface Temperature Product (EUMETSAT, 2016) used in level 3 Mediterranean Sea product generation.

3. CONTEXT ON THE SSS PROCESSOR

The SMOS mission acquires Brightness Temperature (TB) snapshots by 2D interferometry. Measurements are defined in cosine coordinates (xi, eta) over a hexagonal field of view. BEC Debiased Non-Bayesian (DNB) retrieval (Olmedo *et al*., 2017) works as follows. First, TBs and telemetry are georeferenced. Then, SSS is retrieved by direct inversion from each TB measurement and auxiliary variables as SST and wind speed. A multi-year SSS reference is computed at each geographical and antenna point; the difference between each retrieval and this reference yields SMOS debiased SSS anomalies. An external climatology (e.g., World Ocean Atlas) is added to produce the final SSS. Level 3 products are generated by filtering, projecting to an Earth grid, and aggregating into 9-day maps, with empirical corrections for temporal drifts and latitudinal-seasonal biases (Olmedo *et al*., 2021).

To implement the area projection algorithm, we redefined all algorithms to antenna coordinates. Retrieved SSS are kept in antenna coordinates with their geolocation stored as metadata. Auxiliary data are collocated to each geolocation. More details can be found in Garcia-Espriu et. al 2026.

4. PROJECTION METHODOLOGY

Each original-grid pixel is tessellated into equal-area sub-elements (in the SMOS case, 24 equilateral triangles; see Fig. 1). Each sub-element's center of mass is a linear combination of neighboring pixel centers, first in the original grid , and then mapped to Earth coordinates using two approximations: (1) Earth as a perfect sphere (~0.34% maximum radius error), and (2) local flatness of each pixel footprint (~70 km, negligible curvature error). Each value is interpolated at each sub-element using a distance function (inverse distance weighting or Bilinear) between the central pixel and its neighbors. Sub-elements are then projected to the final geographic grid using standard libraries, with measurements weighted by radiometric error. The number of discretization divisions controls the precision-computation trade-off, as illustrated in Fig. 2.

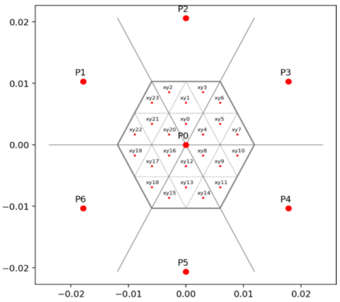

Figure 1. SMOS tesselation by 24 triangles. Adapted from Garcia-Espriu et. al 2026.

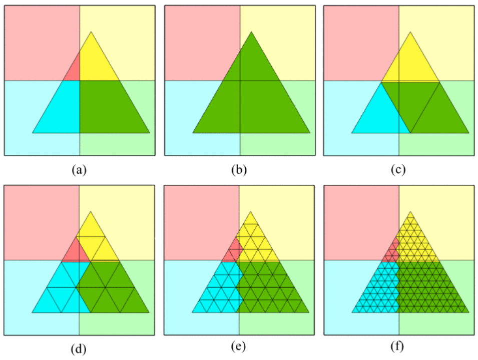

Figure 2. Impact on the tessellation trade-off. Adapted from Garcia-Espriu et. al 2026.

5. RESULTS

Different validation techniques have been applied: comparison to in-situ data, spectral validation and error analysis by CTC.

5.1. In-Situ Validation.

We performed a comparison with Argo data (3 years) to ensure that the processing chain introduces no errors or biases. Results show in all new algorithms that absolute biases are around 0.082 (smaller than BEC v2.0's 0.105) and standard deviations of ~0.20 for area projection methods, (BEC v2.0's ~0.279 and CATDS V10's are ~0.213) (Tab. 1).

Table 1. Mean and Standard Deviation of differences with respect to Argo.

Product	Avg Bias	Abs Bias	Avg STD
NN	-0.025	0.086	0.234
AP-IDW	-0.022	0.082	0.203
AP-BL	-0.024	0.082	0.201
Bilinear	-0.021	0.082	0.214
BEC	-0.011	0.105	0.279
CATDS	0.001	0.065	0.213

6. SPECTRAL VALIDATION.

We show the Power Spectral Density (PSD) (Hoareau *et al*., 2018) analysis over the region ARC, defined as [39º–45º S, 30º–94º E], but similar results were obtained when analyzing other regions. Fig. 3 shows that AP-IDW and AP-Bilinear maintain the expected spectral slope of $k^{-5/3}$ (Hoareau *et al*., 2018) down to wavelengths of ~0.6 degrees, close to the instrument's native resolution. By contrast, Nearest Neighbor flattens below 2 degrees (white noise), and BEC and CATDS products show energy loss at scales of 0.75-1.5 degrees, indicative of correlated noise artifacts. Area projection algorithms preserve fine-scale oceanographic features that other methods cannot resolve.

6.1. Error Analysis.

Correlated Triple Collocation (CTC) (González-Gambau *et al*., 2020) using SMAP as an uncorrelated reference shows that AP-IDW and AP-Bilinear exhibit the lowest error standard deviations (Fig 4.). AP-Bilinear achieves marginally lower noise but slightly reduces effective spatial resolution, suggesting a noise-resolution trade-off.

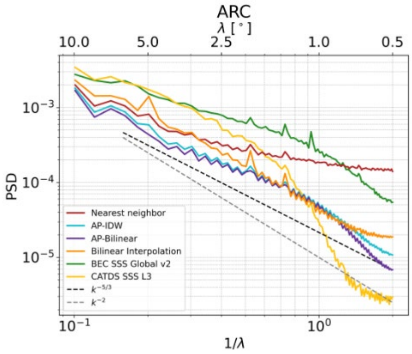

Figure 3. PSD function for three years of SSS. Adapted from Garcia-Espriu et. al 2026.

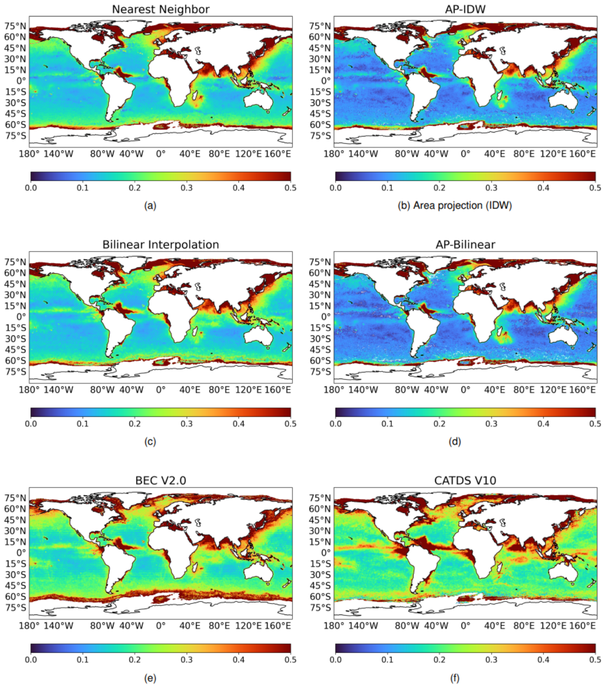

Figure 4. CTC SSS error estimation. Adapted from Garcia-Espriu et. al 2026.

7. FURTHER APPLICATIONS

The algorithm is been applied for the development of a Level 3 Mediterranean SST product based on Sentinel 3 data for ICATMAR (https://www.icatmar.cat/es/)(see Fig. 5), and also in the generation of a SMOS Brightness Temperature product.

Our algorithm can be used not only for the generation of Earth observation products, but for creating coarser-resolution fields suitable for ingestion in numerical and machine learning models. Owing to its capability to correctly representing spatial gradients, the area projection algorithm avoids having an extra loss of resolution due to smoothing.

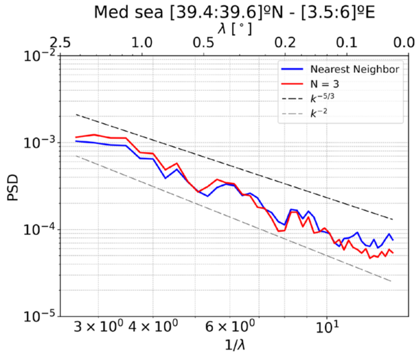

Figure 5. Combined level 3 SST product and PSD function for the region marked as 'R'.

Analysis of the PDS reveals that bilinear interpolation introduces noise at high wave-numbers, a behavior also present in the original data. In contrast, our method maintains consistent energy levels up to the target grid scale, effectively filtering out sub-grid noise, leading to a physically meaningful PSD (Fig. 6). Thanks to that, downstream models can produce more physically consistent, accurate forecasts.

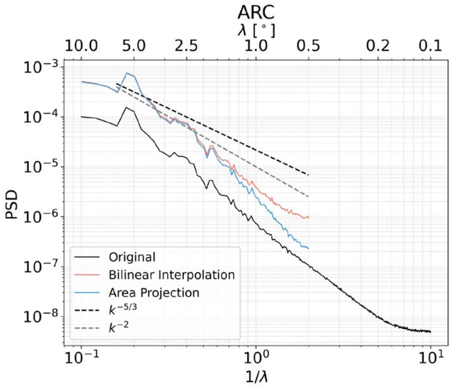

Figure 6. PSD of the original SST and two downscaled products using different projections.

8. CONCLUSIONS AND DISCUSSION

We have shown that the area projection algorithm is a robust, versatile framework that outperforms standard interpolation methods. It achieves ~0.25 degree resolution for SMOS, close to the 35-50 km native resolution, without the white noise of Nearest Neighbor or the correlated noise of existing products. AP-IDW provides the best trade-off between spatial resolution, noise level, and computational cost. The methodology is adaptable to other satellite missions and antenna geometries. Current work is focused in using this methodology for a TB processor, for the monitoring of other ECVs such as soil moisture or sea ice thickness.

Its application to the Level 3 Mediterranean SST and SMOS Brightness Temperature processors proves its versatility. When used for down-scaling, our approach outperforms bilinear interpolation by avoiding the injection of spurious high-frequency noise, making the resulting fields more suitable as inputs for numerical models and machine learning-based data assimilation schemes. Taken together, the further applications confirm that the area projection paradigm is not tied to a single mission or product type, but constitutes a general-purpose tool for Big Data management in Earth observation wherever spatial fidelity and computational efficiency must be balanced simultaneously.

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