Validation of ENVISAT-AATSR SST retrievals for the study of trends associated with climate change in the Mediterranean Sea

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1. Objectives
2. Datasets and methods
3. Results and conclusions

Primary objective: evaluate a split-window algorithm to accurately retrieve SST data with ≤0.3K uncertainty from ENVISAT-AATSR and analyse SST trends associated with climate change

Final aims

- Generate monthly sea surface temperature (SST) maps for the Mediterranean Sea (2003-2011)
- Our aim here is to have a total uncertainty of less than 0.3K.
    - We want an uncertainty of <0.3K as this is what is used for climate studies (TOGA) (Barton, 1992)
- Assess spatio-temporal trends in the Mediterranean SST for this period.
- Compare results with previous works.

Motivations

- The AATSR dataset had not yet been used to detect SST trends using an accurate emissivity-dependent split-window algorithm.

The study area was the Mediterranean Sea.

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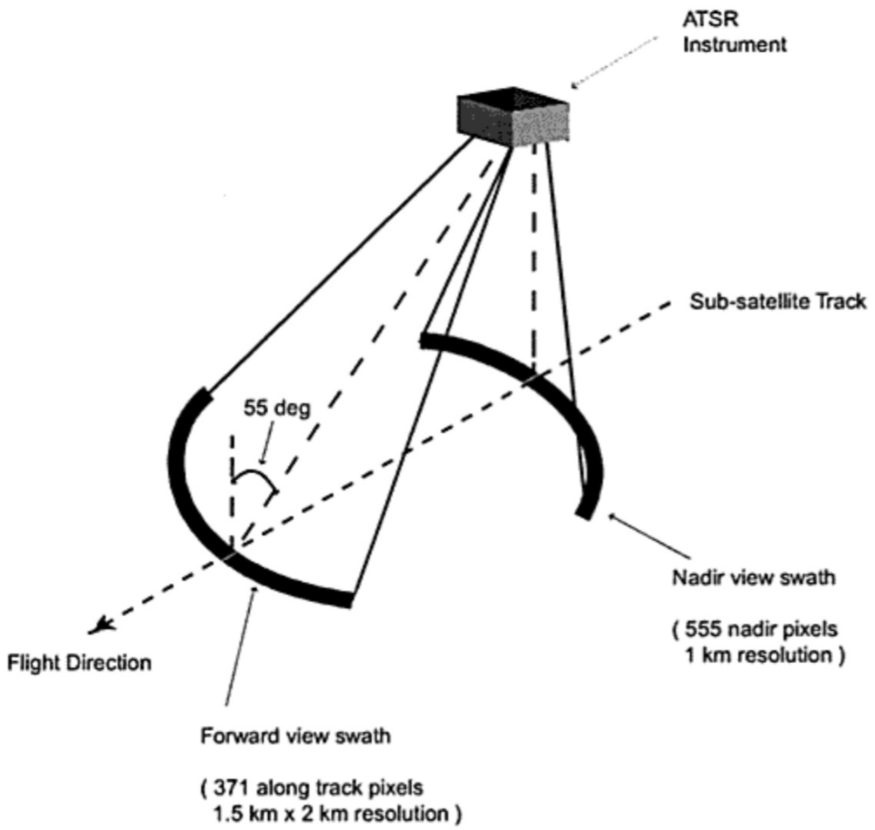
Satellite data was collected using **AATSR onboard ENVISAT**

- Two channels in TIR:
  - 11µm, 12µm
- Nominal spatial resolution: 1km (nadir view)
- Temporal resolution over Mediterranean Sea: 4-5 swaths (500km wide) per day



ESA. AATSR Product Handbook. 2007.

For satellite measurements, we used an Angular and Emissivity Dependent Split-Window Algorithm (Niclòs et al., 2007)

- $SST = T_i + (a_1 S + a_2)(T_i - T_j) + (b_1 S + b_2)(T_i - T_j)^2 + (c_1 S + c_2) + (\alpha_2 W^2 + \alpha_1 W + \alpha_0)(1 - \varepsilon) - (\beta_2 W^2 + \beta_1 W + \beta_2)\Delta\varepsilon$

- Emissivity determination following the model proposed in Niclòs et al. (2009).

T_i, T_j	Brightness temperatures
S	$sec(\theta) - 1$, θ = observation angle
W	$W_0/_{\cos(\theta)}$, W_0 = atmospheric water vapour content
ε	Average sea surface emissivity
$\Delta\varepsilon$	Emissivity difference between channels

R. Niclós, V. Caselles, C. Coll, and E. Valor. Determination of sea surface temperature at large observation angles using an angular and emissivity-dependent split-window equation. Remote Sensing of Environment, 111(1):107–121, 2007.

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We used a five step procedure to **generate monthly SST maps from satellite data**:

Procedure:

1. Cut original AATSR images to the Mediterranean Sea for the 2003-2011 period.

2. Cut images of the same time period from MODIS, just to extract values of W.

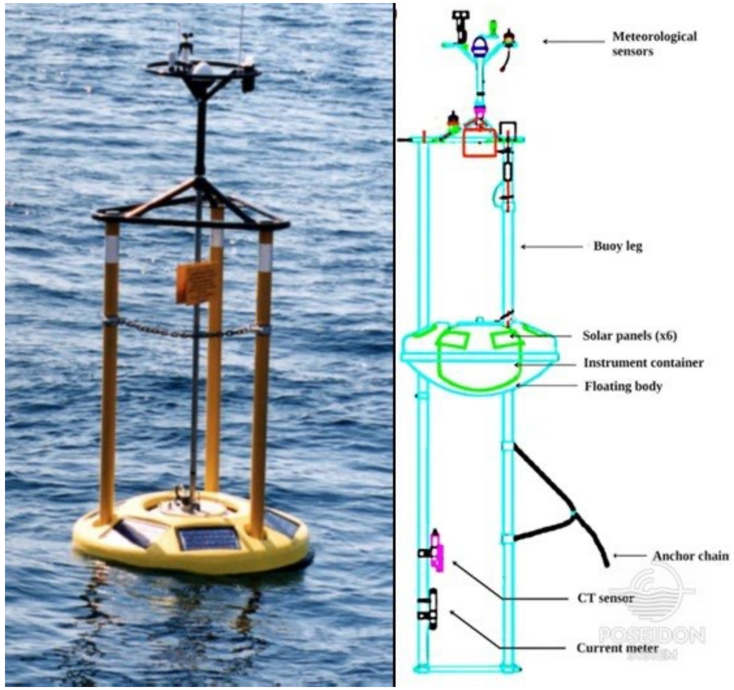
3. Apply various filtering techniques to ensure good quality data (quality flags and cloud removing).

4. Make monthly mosaics for the Mediterranean Sea and apply the proposed algorithm.

5. Statistical analysis and evaluation of trends.

In Situ data was collected using the **Poseidon buoy system** in the Aegean Sea (1/2)

- We used data collected by these buoys at 1m depth.
- Buoys used are situated in 10 different locations across the Aegean Sea.



https://poseidon.hcmr.gr/

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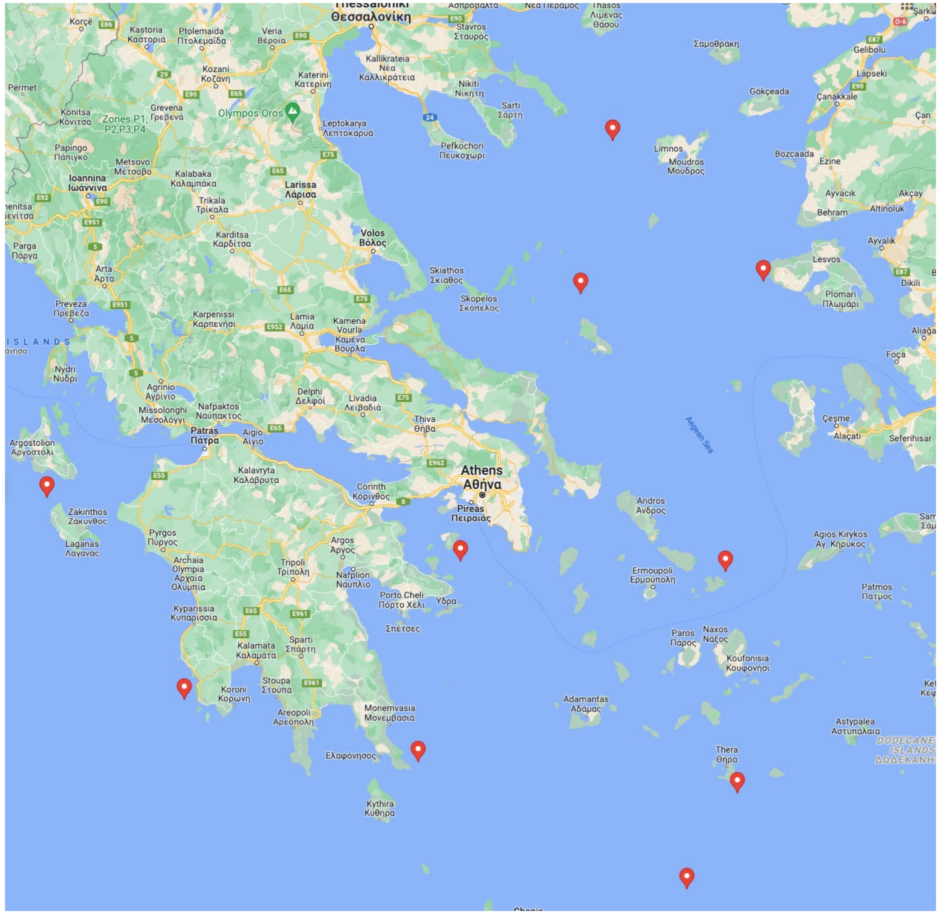
In Situ data was collected using the **Poseidon buoy system** in the Aegean Sea (2/2)



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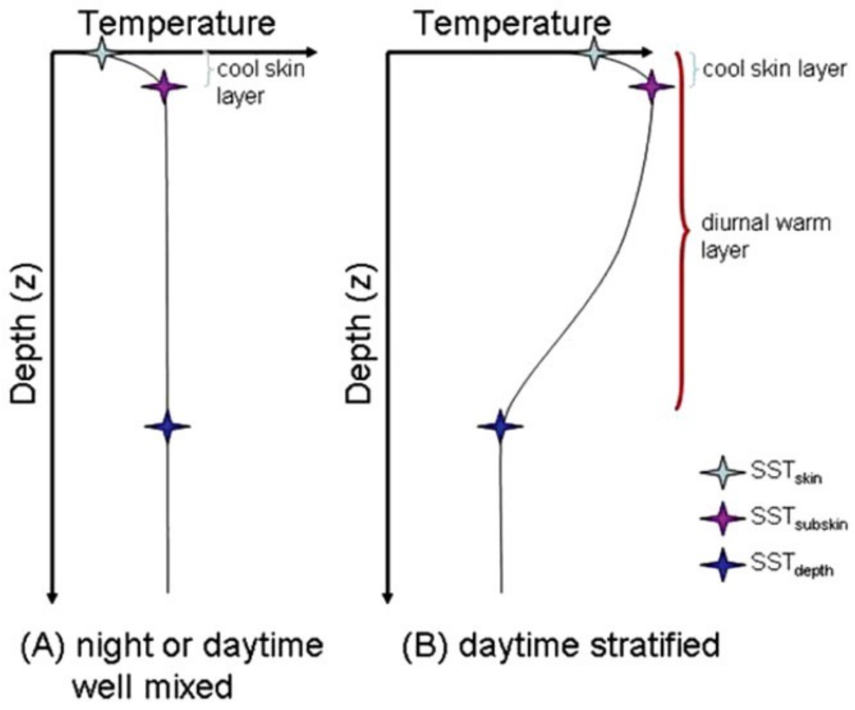
When comparing *in situ* and satellite measurements, we must remember the bulk-skin effect

- When the wind speed is above 6m/s, we get mixing and a more uniform temperature, and the following equation can be used to correct the effect (Donlon et al., 2002):

$$SST_{skin} = SST_{depth} - 0.17$$



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We used two key uncertainty metrics in our analysis

- Median difference in satellite and buoy SST

- Robust root mean square error (R-RMSE) (Wilrich, 2007), defined as:

$$R - RSME = \left(median\left(SST_{satellite} - SST_{buoy}\right)^2 + RSD^2 \right)^{0.5},$$

$$RSD = median(\left|(SST_{satellite} - SST_{buoy}) - median\left(SST_{satellite} - SST_{buoy}\right)\right|) * 1.483$$

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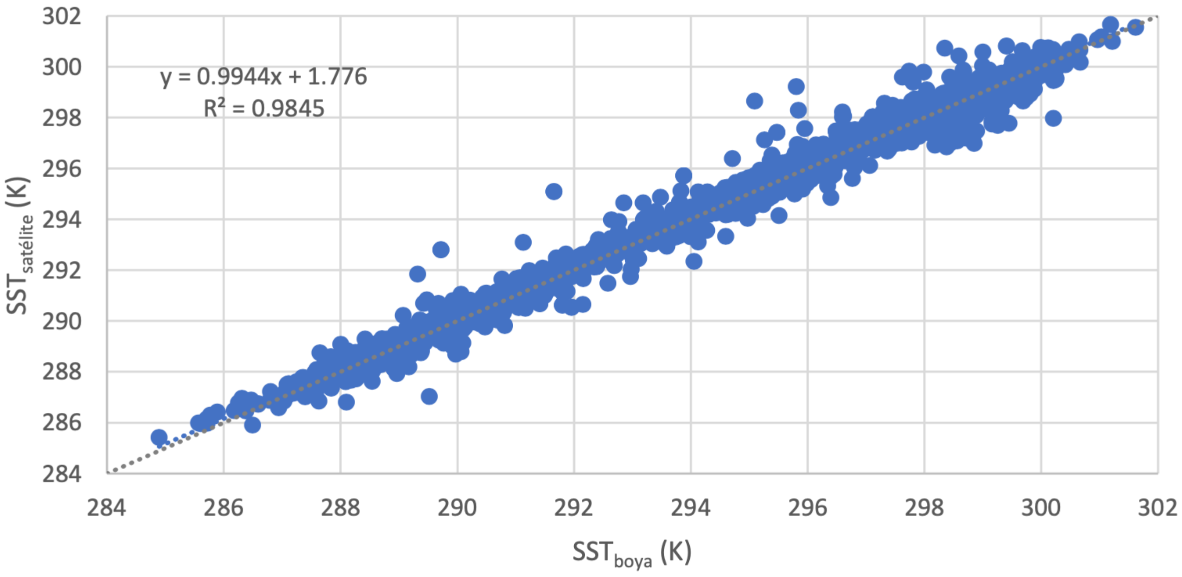
Results of the proposed SST algorithm when using the AATSR nadir-view and *in situ* data with wind speeds > 6m/s. For 7/10 buoys, the uncertainties were equal or lower than our target of 0.3K.

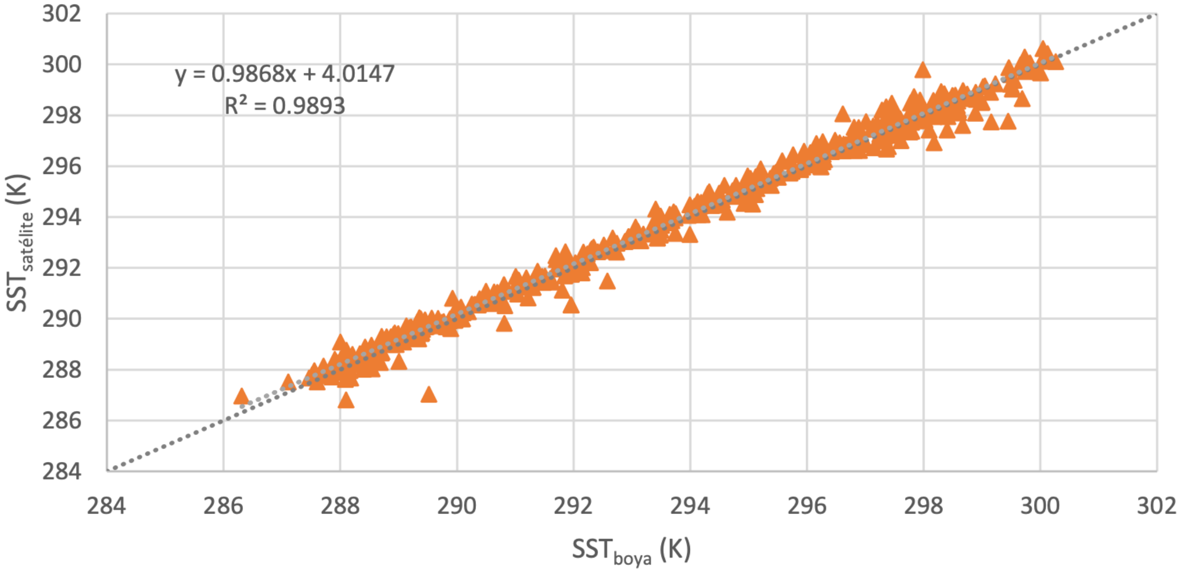
Buoy code	**Median (K)**	**R-RMSE (K)**	**No. of data points**
612	0.0	0.5	46
684	0.2	0.3	36
ATH	0.4	0.5	32
LES	0.1	0.3	68
MYK	0.2	0.3	125
SAN	0.3	0.5	65
SAR	0.2	0.3	46
SKY	0.0	0.2	31
STR	0.1	0.3	34
ZAK	0.4	0.5	31
All buoys	**0.2**	**0.3**	**514**

The reduced number of matchups was due to the filtering of data by clouds, quality and wind speed.

Removing values for which wind speed < 6m/s improves the accuracy of our algorithm, although the number of matchups is reduced to 30%.



Satellite SST vs in situ SST with no filtering.



Satellite SST vs in situ SST with removal of measurements taken with < 6m/s of windspeed.

When using forward-view AATSR data and no wind-speed filtering, the uncertainties were higher than 0.3 K.

Buoy code	Median (K)	R-RMSE (K)	No. of data points
612	0.3	0.7	183
684	0.1	0.8	158
ATH	0.2	0.7	177
LES	0.0	0.5	218
MYK	0.1	0.5	252
SAN	0.1	0.5	194
SAR	0.2	0.6	195
SKY	0.2	0.6	205
STR	0.2	0.8	205
ZAK	0.2	0.8	112
All buoys	**0.1**	**0.6**	**1889**

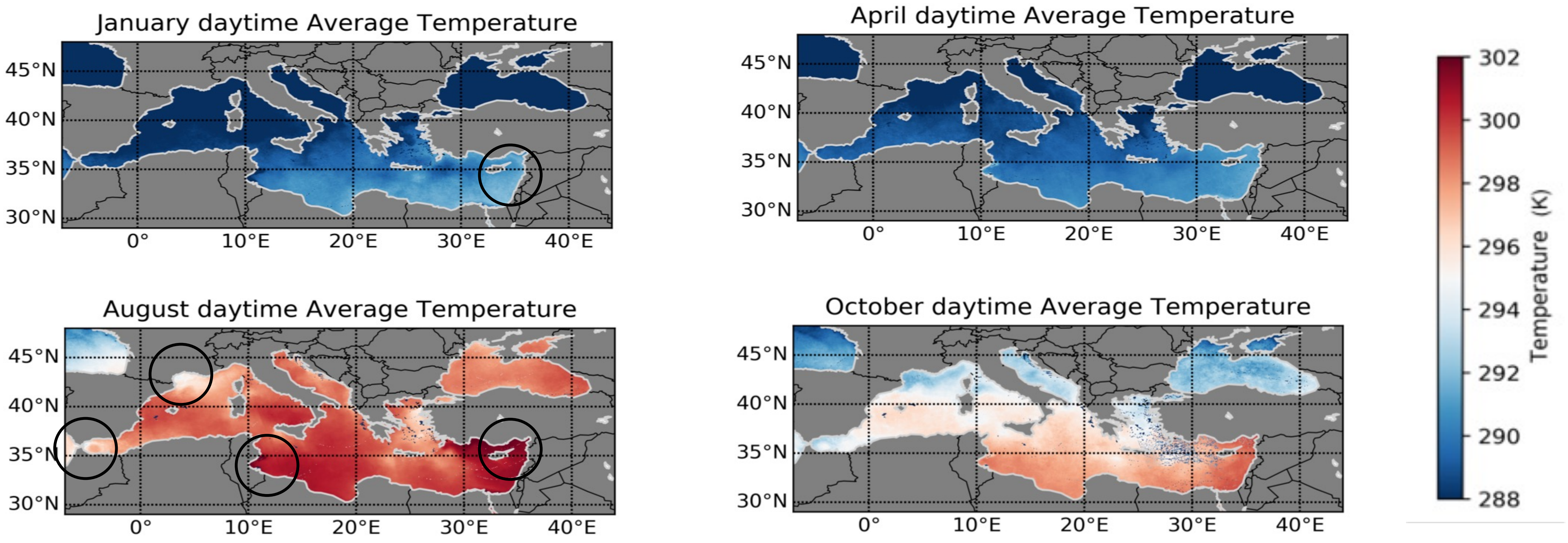
The uncertainty is driven by the AATSR view used and the windspeed filtering

- For a forward view, the atmospheric path to the sea surface is longer, and this introduces more uncertainties in the atmospheric correction.

- At low windspeed, there is little mixing between the bulk and skin waters, meaning that the bulk-skin effect is much more prevalent, and satellite and buoy measured temperatures are different.

We conclude that **SSTs retrieved from nadir-view AATSR data using the proposed split-window algorithm achieve the accuracy of 0.3 K**, which was defined as suitable for analyzing trends in SSTs associated to climate change (Barton , 1992).

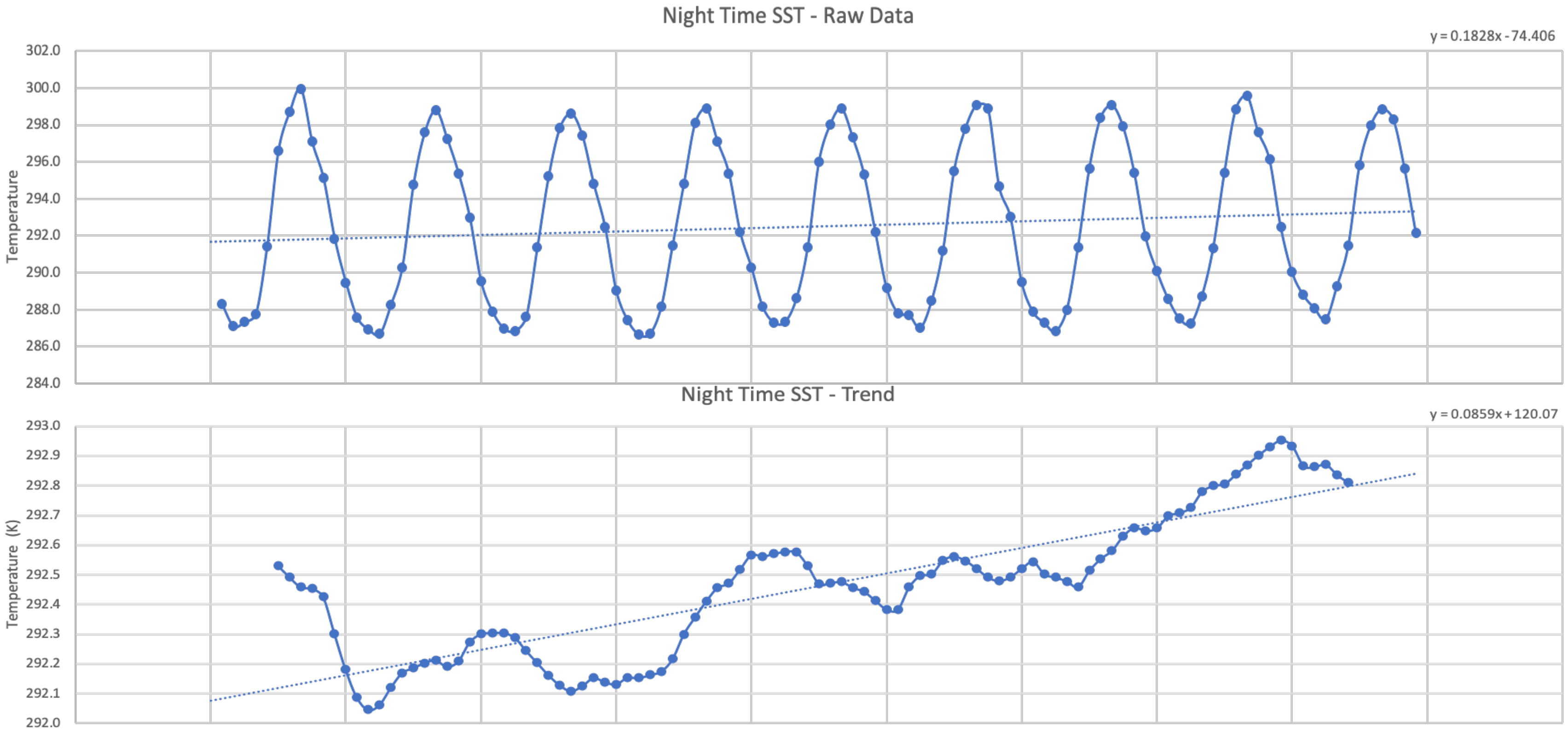
We were therefore able to use the proposed algorithm with nadir-view AATSR data to map the Mediterranean Sea SSTs for the period of 2003-2011 and discern trends



Clear warming trends were detected, even using our short time period

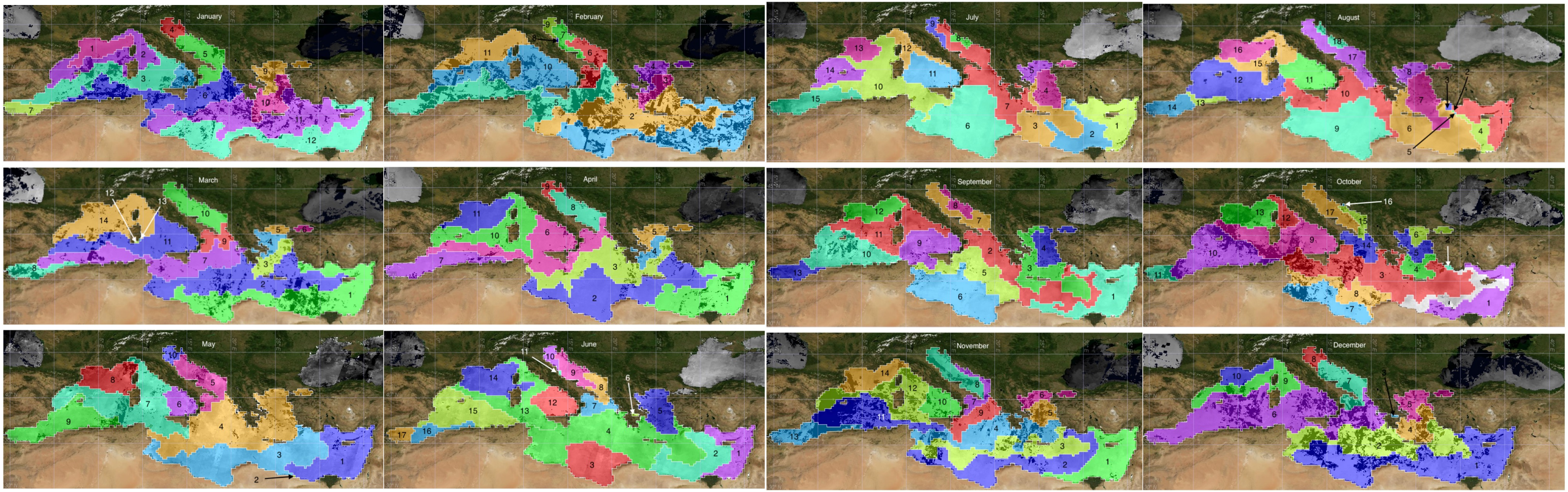
After series decomposition:

- Trend of $\mathbf{0.086 \pm 0.005}$℃/$\mathbf{yr}$ were detected
- Total increase of 0.77 ± 0.05℃ (2003-2011).
- In accordance with other works (e.g., ~0.9℃ for the same period using AVHRR data; Pastor et al., 2018).



F. Pastor, J. A. Valiente, and J. L. Palau. Sea Surface Temperature in the Mediterranean: Trends and Spatial Patterns (1982-2016). Pure and Applied Geophysics, 175:4017–4029, 2018.

We also did a cluster analysis. Of the 172 clusters analysed, 77 showed warming trends.



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Month	Trend	Number of Clusters	Number of Positive Trends (%)	Number of Negative Trends (%)
January	Positive	13	6 (46)	0 (0)
February	Positive	12	5 (42)	2 (17)
March	N/A	15	9 (60)	1 (7)
April	Positive	12	11 (92)	0 (0)
May	Positive	11	2 (18)	1 (9)
June	N/A	18	3 (17)	12 (67)
July	N/A	16	4 (25)	5 (31)
August	N/A	19	6 (32)	0 (0)
September	Positive	14	13 (93)	0 (0)
October	Positive	16	12 (75)	0 (0)
November	N/A	15	1 (7)	6 (40)
December	Positive	11	5 (45)	0 (0)
Total	Positive	172	77 (45)	26 (15)

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We conclude that:

- The proposed split-window equation is accurate (i.e., accuracy around 0.3 K) to retrieve SST from nadir-view AATSR data for analysing climate-change trends.
- Our trend analysis has also shown a clear warming trend in the Mediterranean Sea between 2003-2011.
- The study is extensible to Sentinel 3 – SLSTR data.
- In order to further the validation, we would like to extend the study to other *in situ* measurements across the Mediterranean Sea.

Acknowledgements

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