25/05/2022, EGU (Vienna)

DISPLAY MATERIAL.

Data assimilation for advanced cross-scale ocean modelling.

A novel 1° order recursive filter algorithm for unstructured mesh.

Marco Stefanelli, Eric Jansen, Ali Aydogdu, Ivan Federico, Giovanni Coppini, Nadia Pinardi

Contact: marco.stefanelli@cmcc.it

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A NOVEL 1° ORDER RECURSIVE FILTER ALGORITHM FOR UNSTRUCTURED MESH

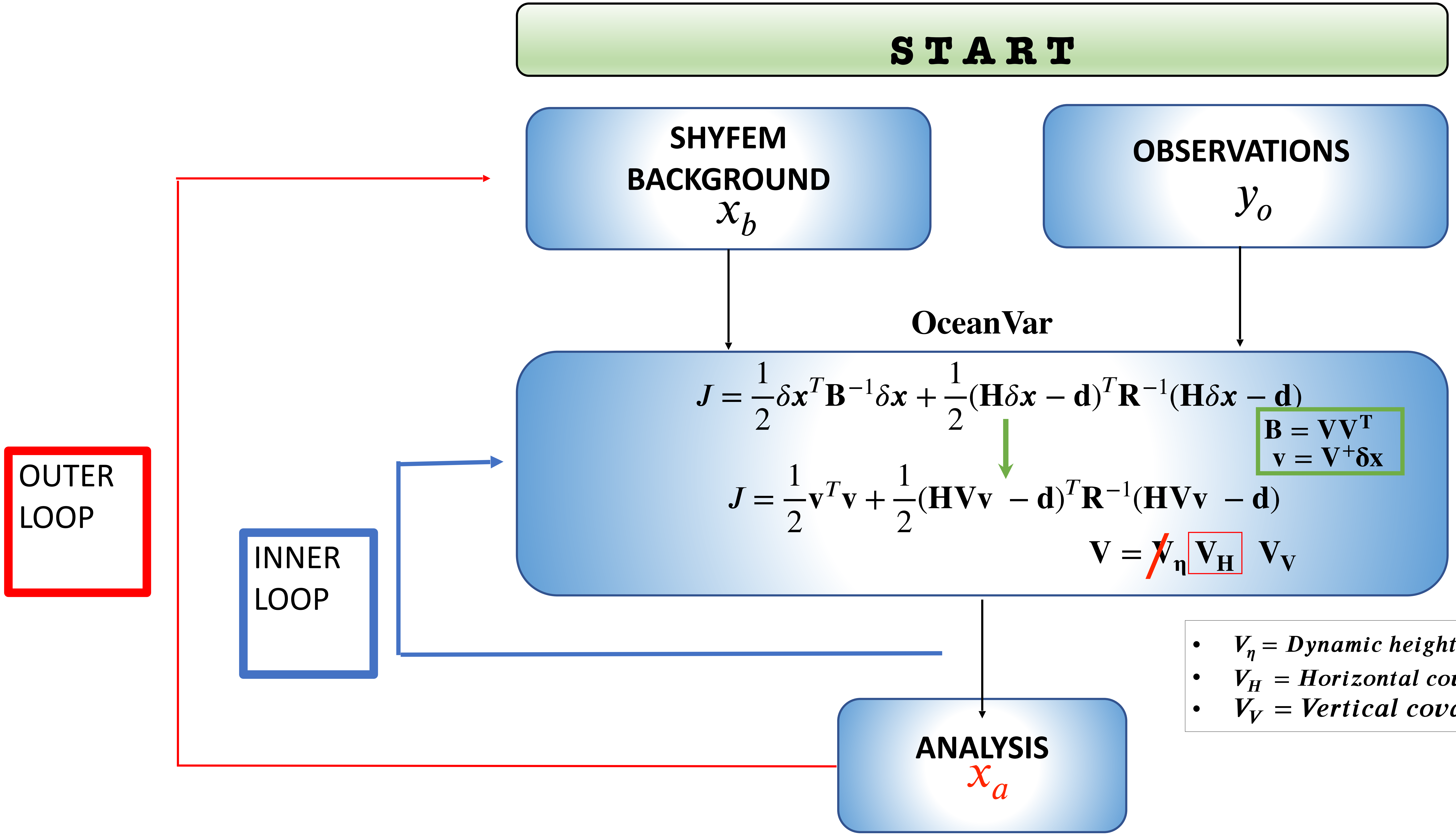
OUTLINE

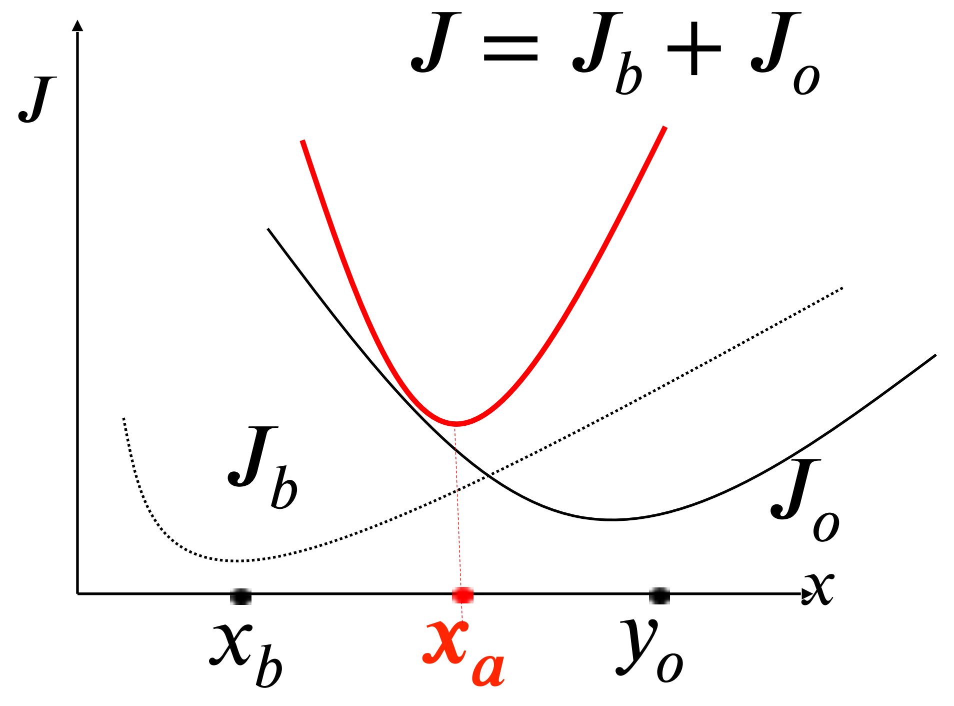
1. HORIZONTAL COVARIANCE: 1° ORDER RECURSIVE FILTER (RF).
   A NOVEL ALGORITHM FOR UNSTRUCTURED MESH
   - THE RF ALGORITHM ON REGULAR GRID
   - A NOVEL ALGORITHM FOR UNSTRUCTURED MESH

2. TEST THE NEW ALGORITHM
   - IDEALIZED TESTS CASES: REGULAR GRID, DELAUNAY FRONTAL
   - REALISTIC TEST CASE: SANI GRID

MAIN GOAL

Introduce variational DA techniques (3DVar, OceanVar) in models with unstructured grid (SHYFEM)





- V_η = *Dynamic height operator*
- V_H = *Horizontal covariance (RF)*
- V_V = *Vertical covariance (EOF: SVD decomposition)*

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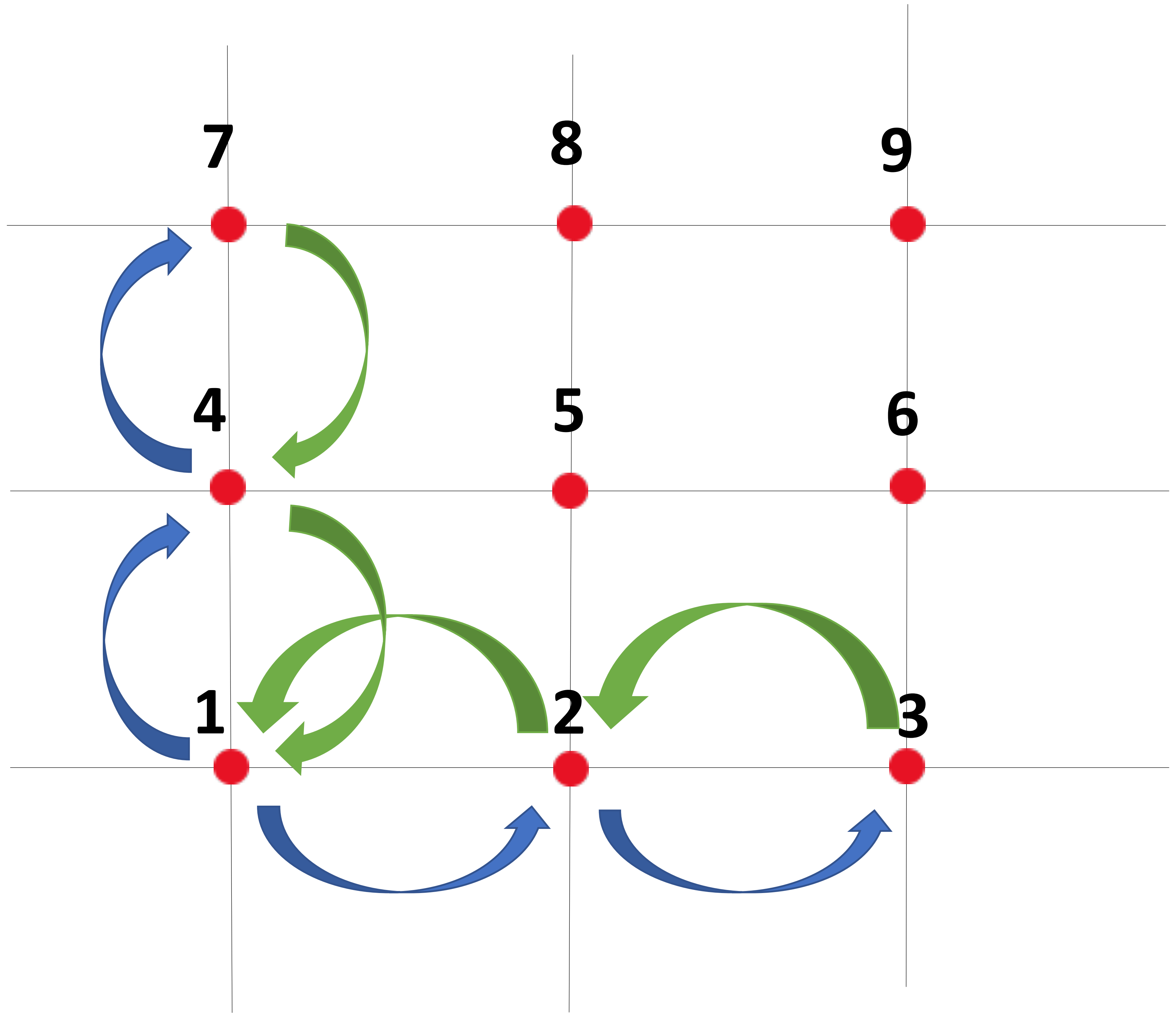
HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER
REGULAR GRID IMPLEMENTATION

A is the initial field

FW ⟶ $B_i = \alpha B_{i-1} + (1-\alpha)\, A_i$ i=1,…N   N=N° of nodes

BW ⟶ $C_i = \alpha C_{i+1} + (1-\alpha)\, B_i$ i=N,…1   N=N° of nodes



$$\alpha = 1 + E - \sqrt{E(E+2)}$$

$$E = \frac{2 N_{Iter} \delta^2}{4R^2}$$

δ = Resolution

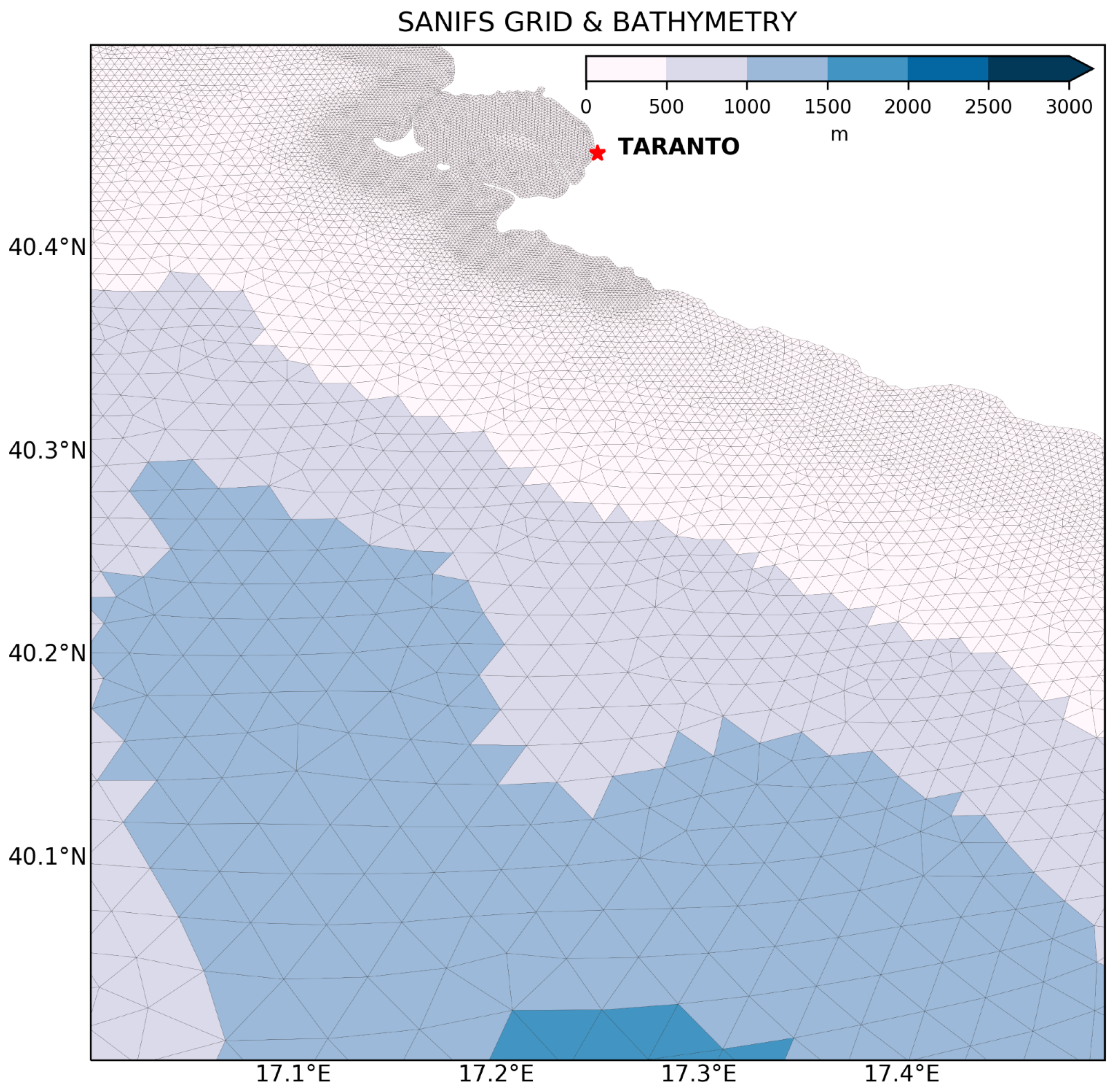
R = Correlation radius

❖ **ADVANTAGES:**

1. Intrinsic ordering of the grid nodes

2. **Strong symmetry inherited by its 1D formulation on a infinite line**

HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER UNSTRUCTURED GRID IMPLEMENTATION



❖ **DISADVANTAGES:**

1. **NO** intrinsic ordering of the grid nodes
2. **NO** constant symmetry features

HORIZONTAL COVARIANCE → 1° ORDER RECURSIVE FILTER
RF ON REGULAR GRID IN LITERATURE

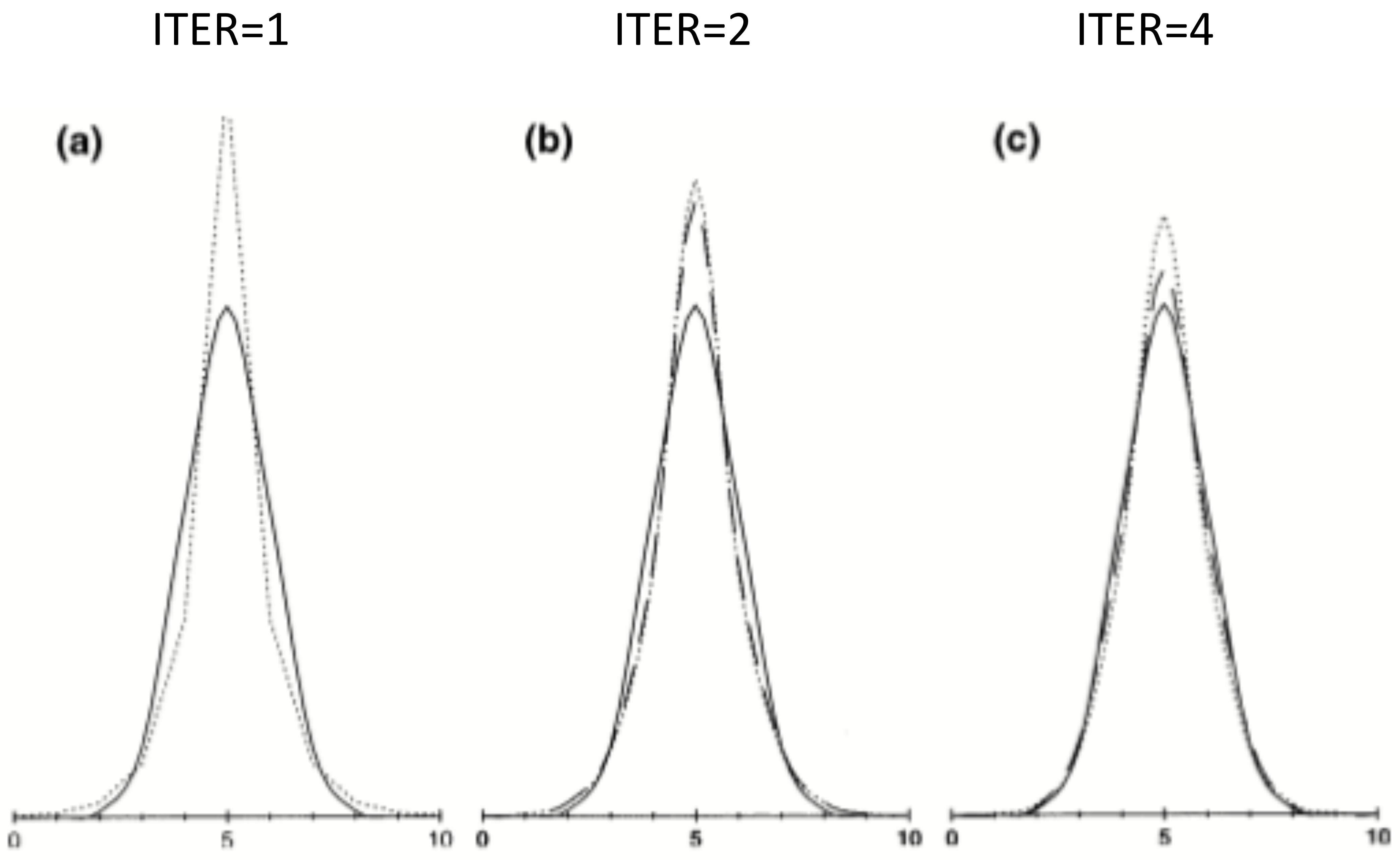


FIG. 1. Comparison of one-dimensional applications of recursive filters approximating a Gaussian (shown solid). Dashed curves show filter approximations: (a) order $n = 1$, (b) $n = 2$, and (c) $n = 4$, with (long dashes) and without (short dashes) the off-diagonal b coefficient refinements.

Purser et al. 2003

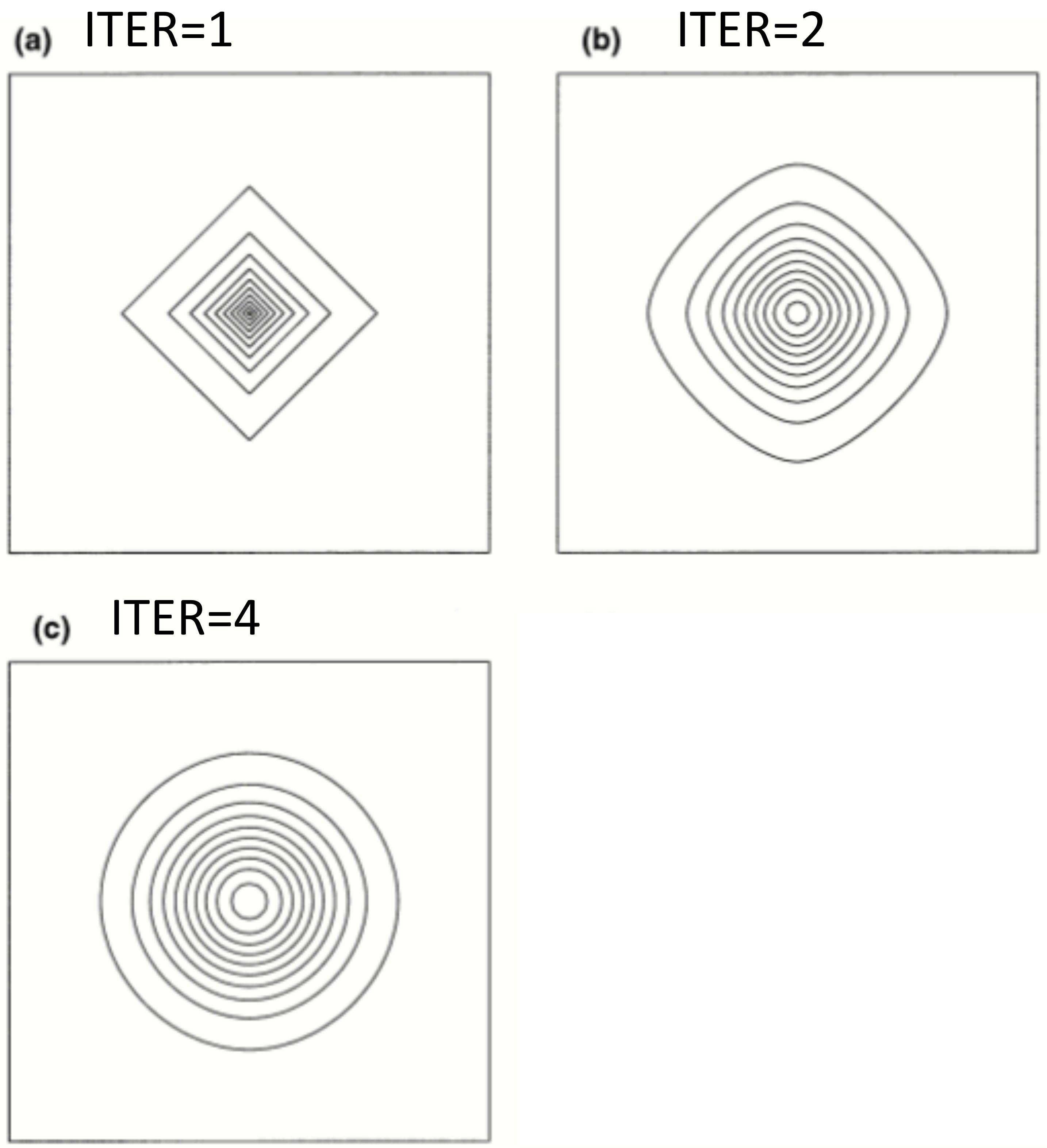


FIG. 2. Sequential application of quasi-Gaussian recursive filters of order n in two dimensions: (a) $n = 1$, (b) $n = 2$, (c) $n = 4$, and (d) four applications of filters with $n = 1$ with scale parameter adjusted to make the result comparable with the other single-pass filters.

Purser et al. 2003

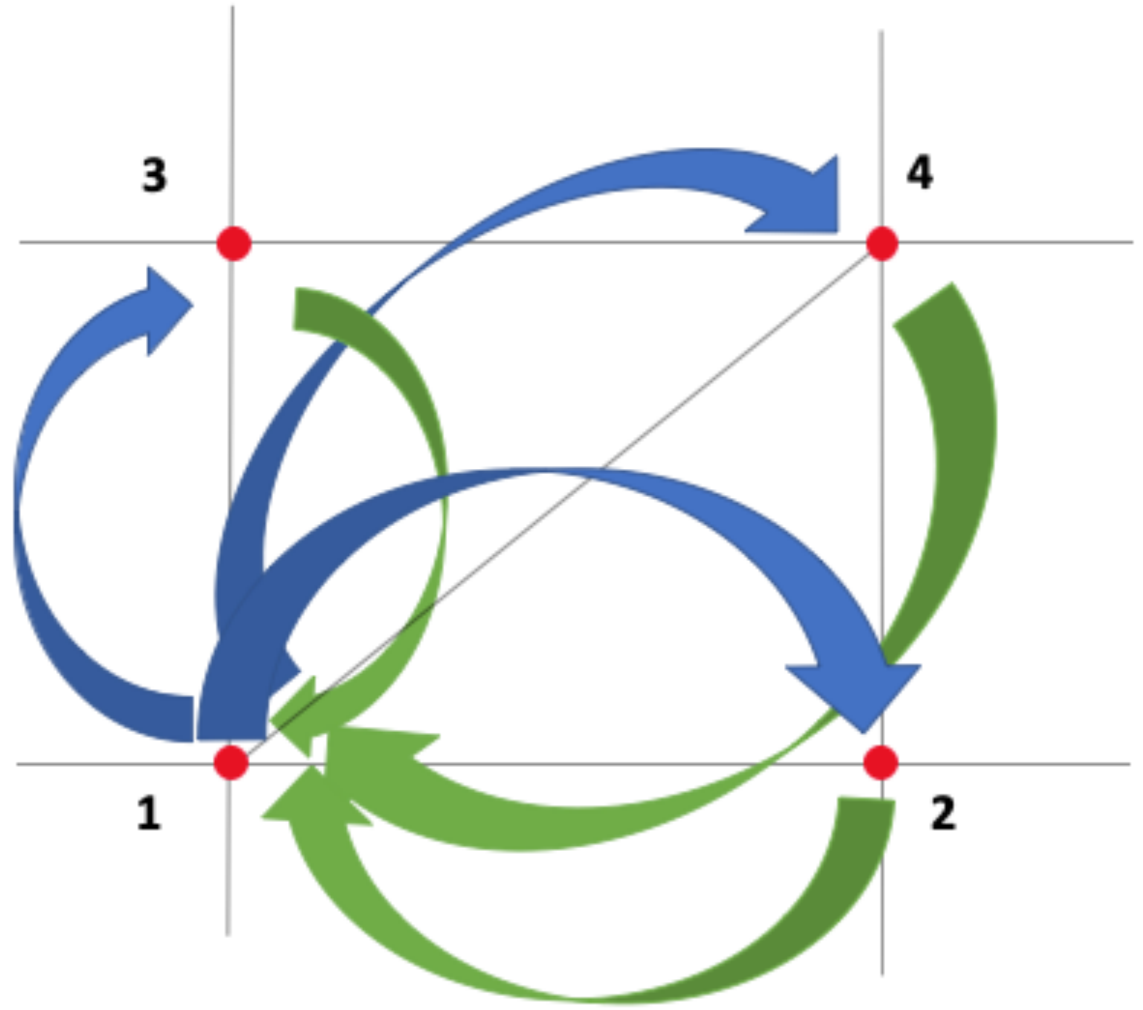
HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER

A NOVEL ALGORITHM FOR UNSTRUCTURED MESH

The algorithm must have the same characteristics as that on regular grids:

1. REPRODUCE THE SYMMETRY

To reproduce the symmetry we have to emulate the x and y application of the regular algorithm for fw and bw pass



2. NODE ORDERING

To give an ordering in the nodes steps we can order the triangle's edges respect the longitude and the latitude

FW ➞ $B_i = \alpha B_{i-1} + (1- \alpha)\, A_i$ i=1,…N N=N° of nodes

BW ➞ $C_i = \alpha C_{i+1} + (1- \alpha)\, B_i$ i=N,…1 N=N° of nodes

$$\alpha = 1 + E - \sqrt{E(E+2)}$$

$$E = \frac{2 N_{Iter}\, \delta^2}{4 R^2}$$

δ = Resolution

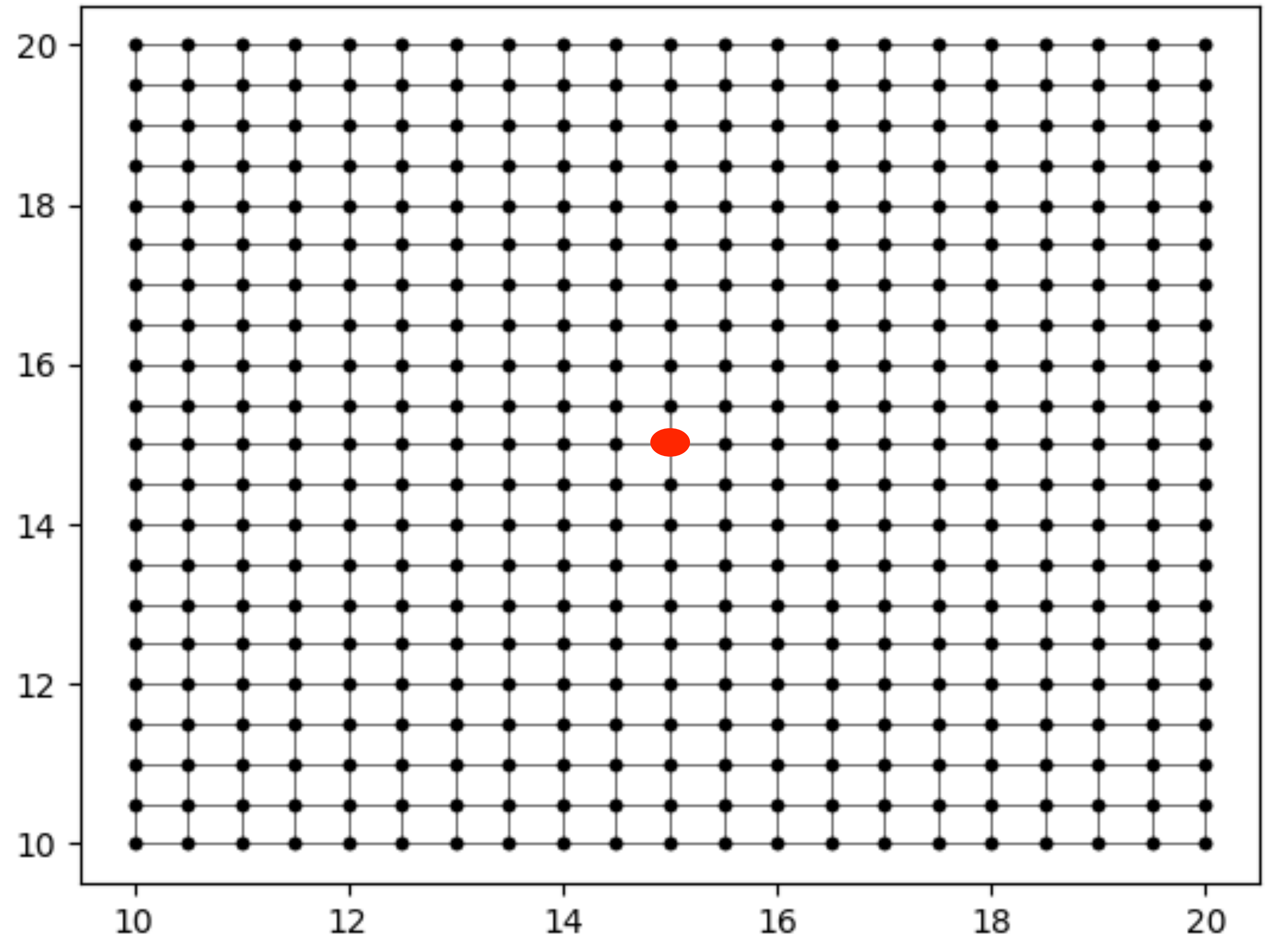
R = Correlation radius

HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER
TEST THE ALGORITHM

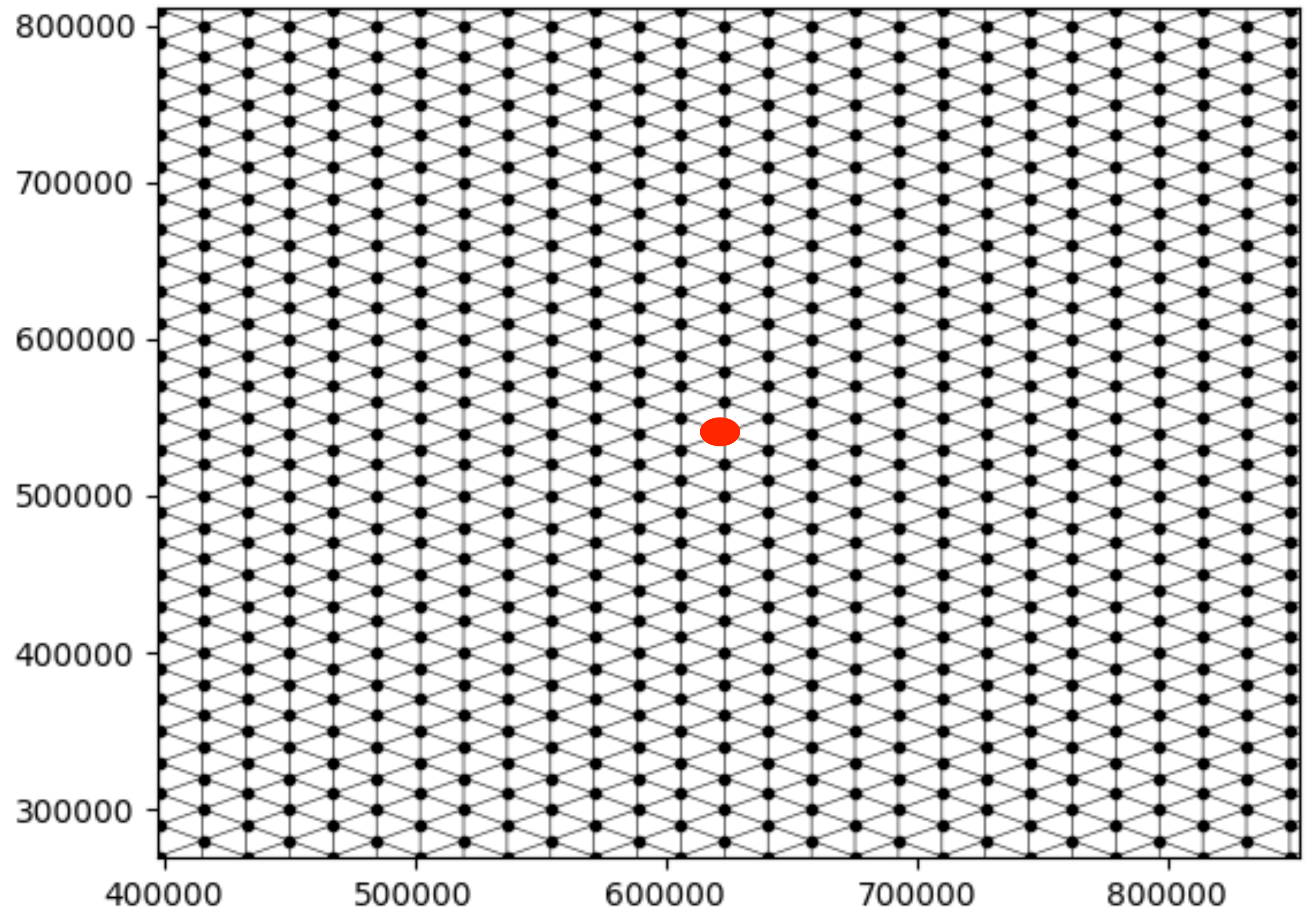
1. REGULAR GRID (resolution: 0.5°)
2. DELAUNAY FRONTAL (resolution: 20 Km)
3. SOUTH ADRIATIC - NORTHERN IONIAN (SANI) DOMAIN

● Starting value = 100

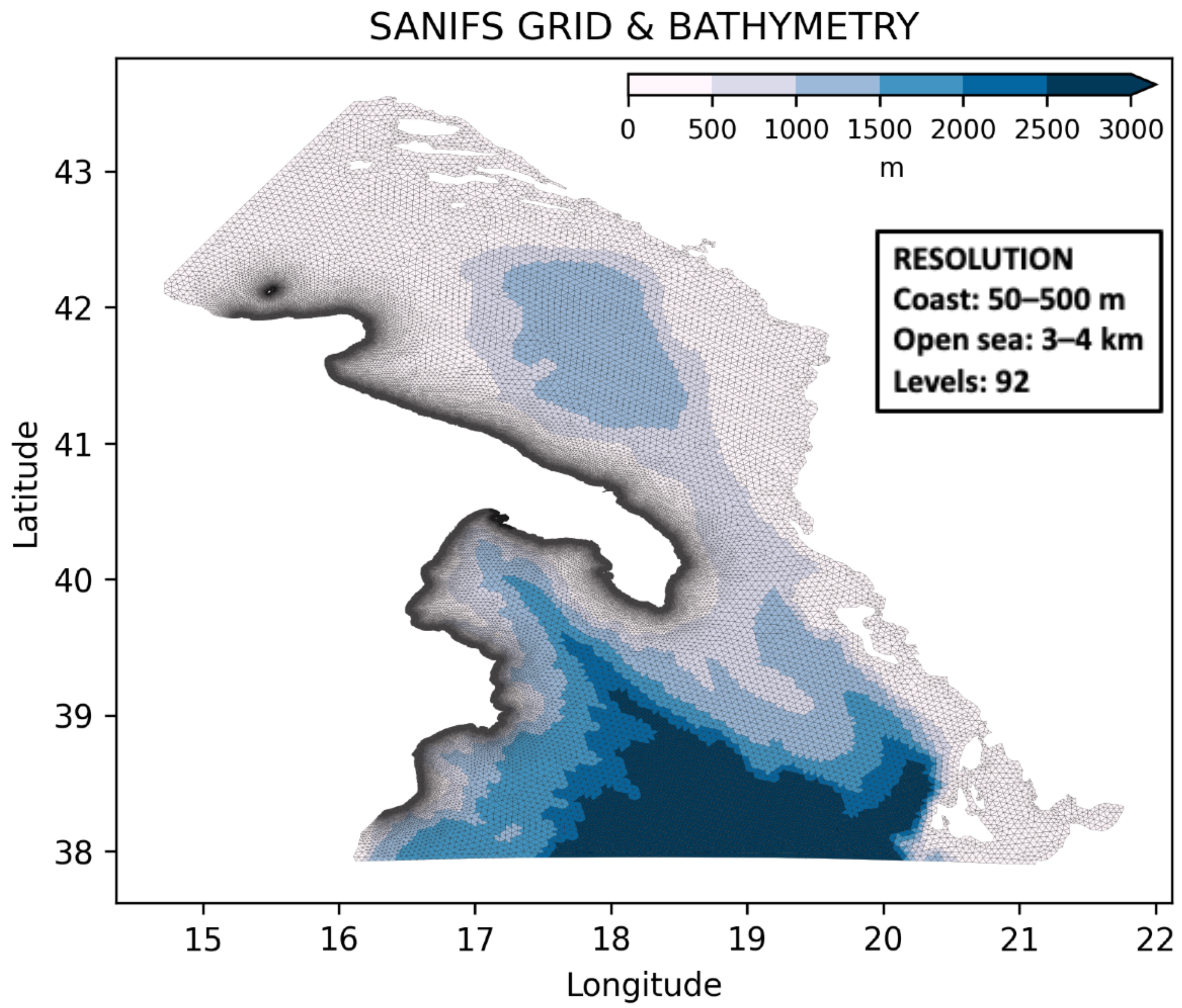
REGULAR



DELAUNAY FRONTAL



SANI



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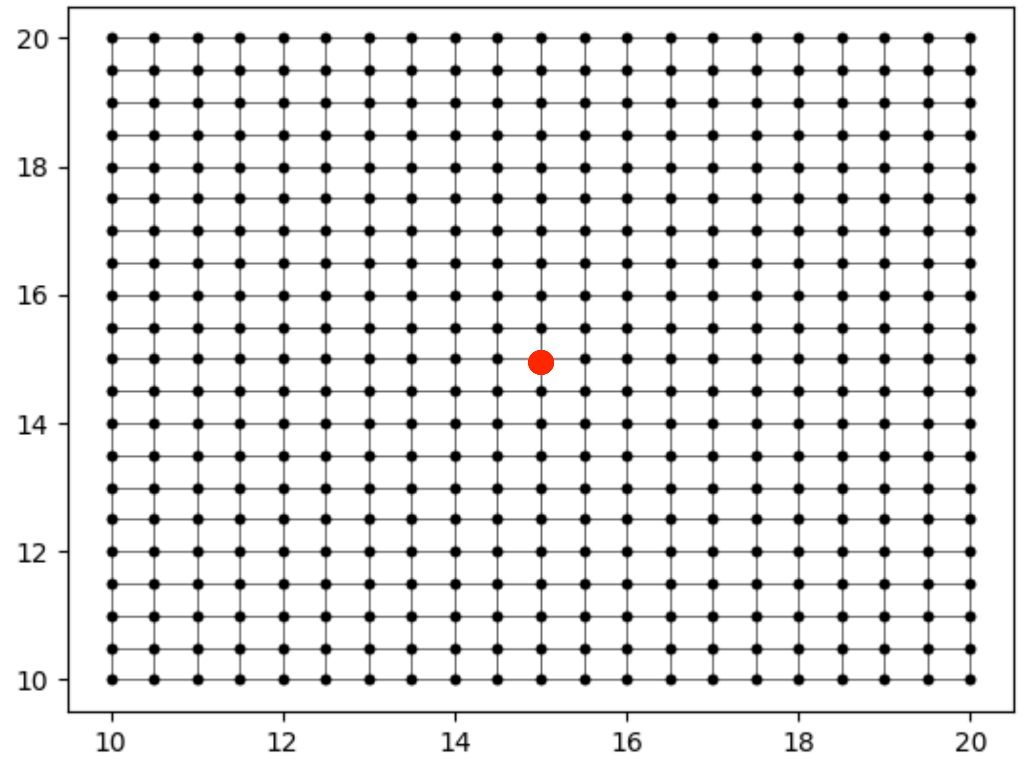
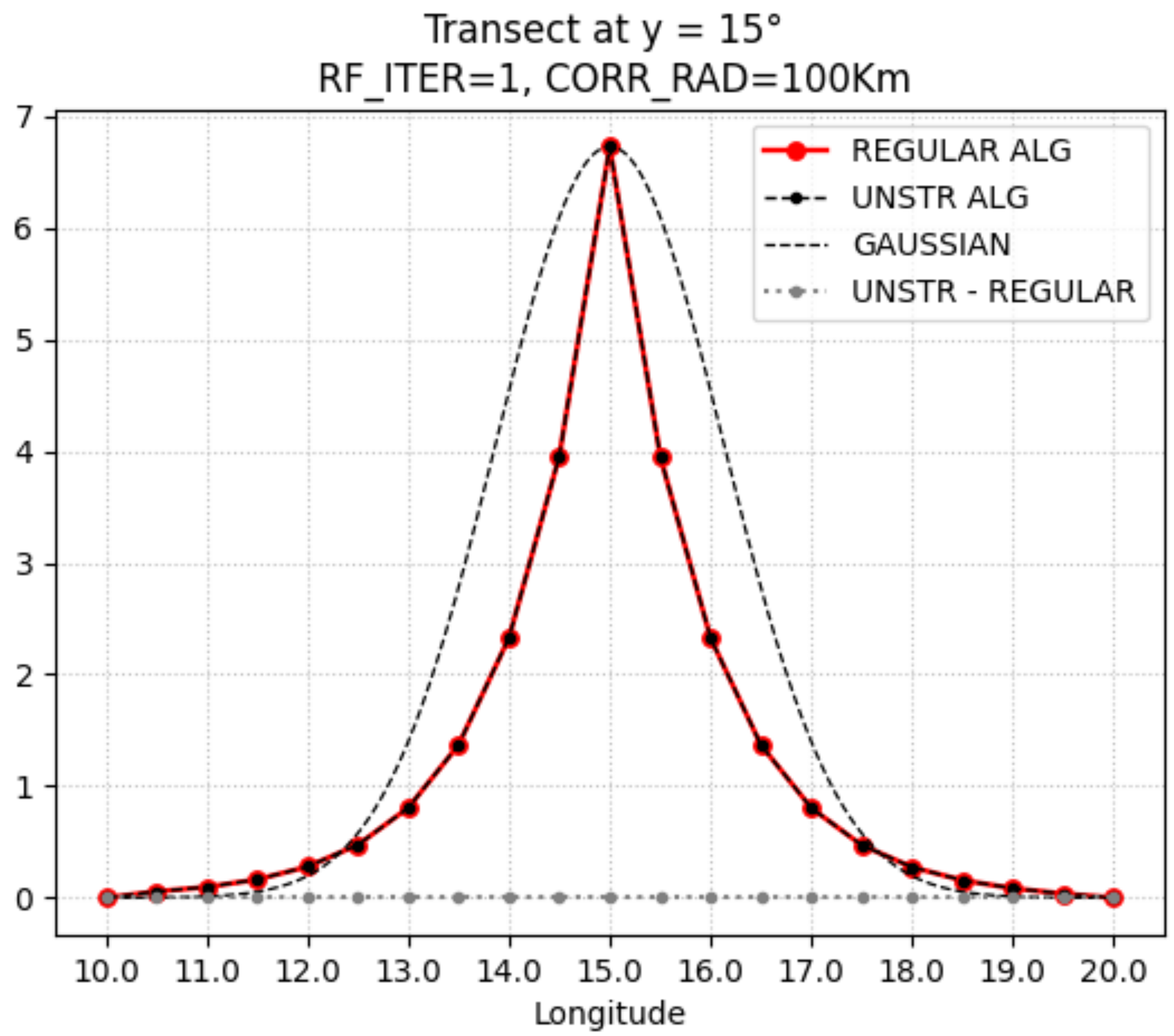
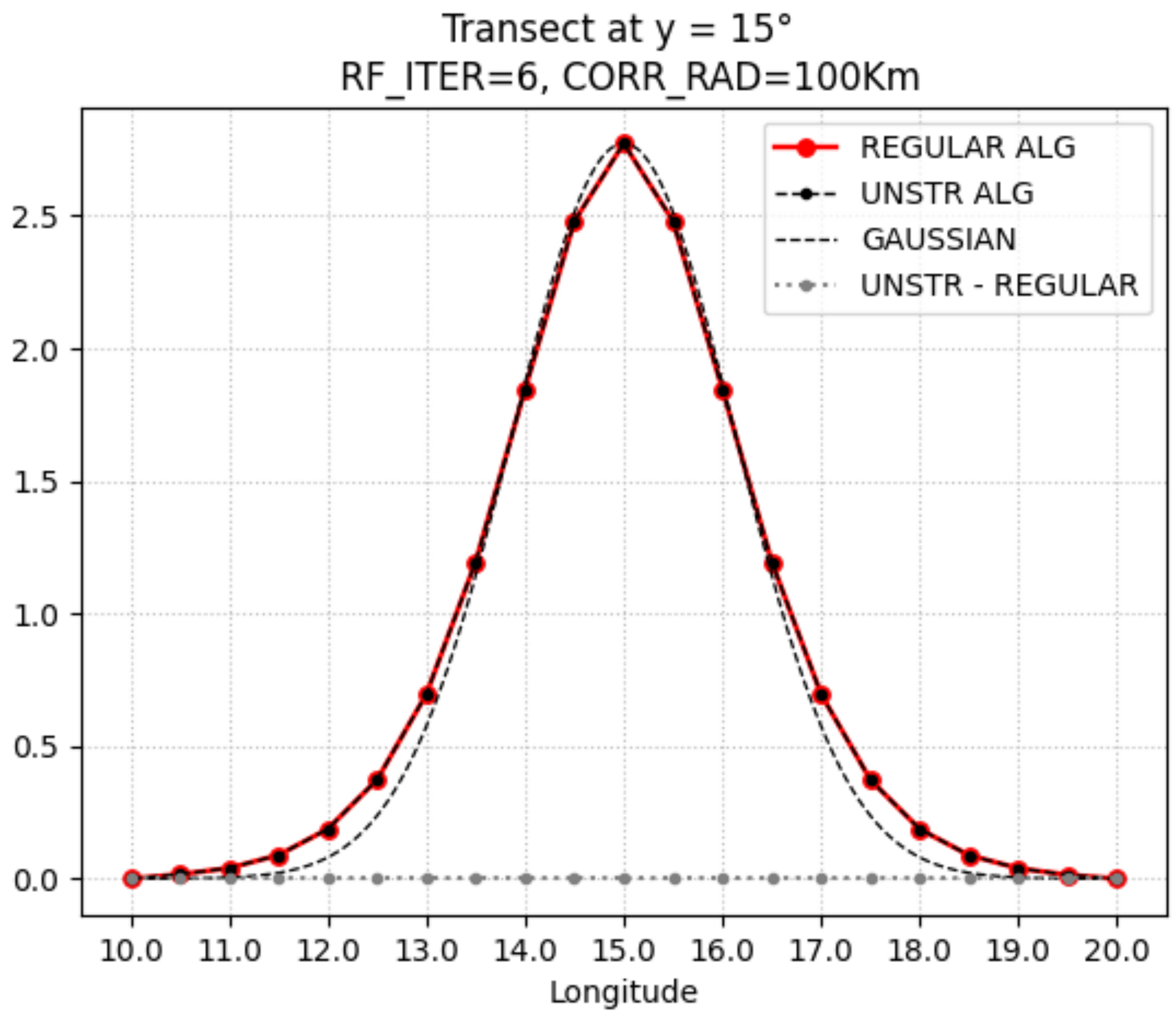
HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER
TEST THE ALGORITHM: REGULAR GRID







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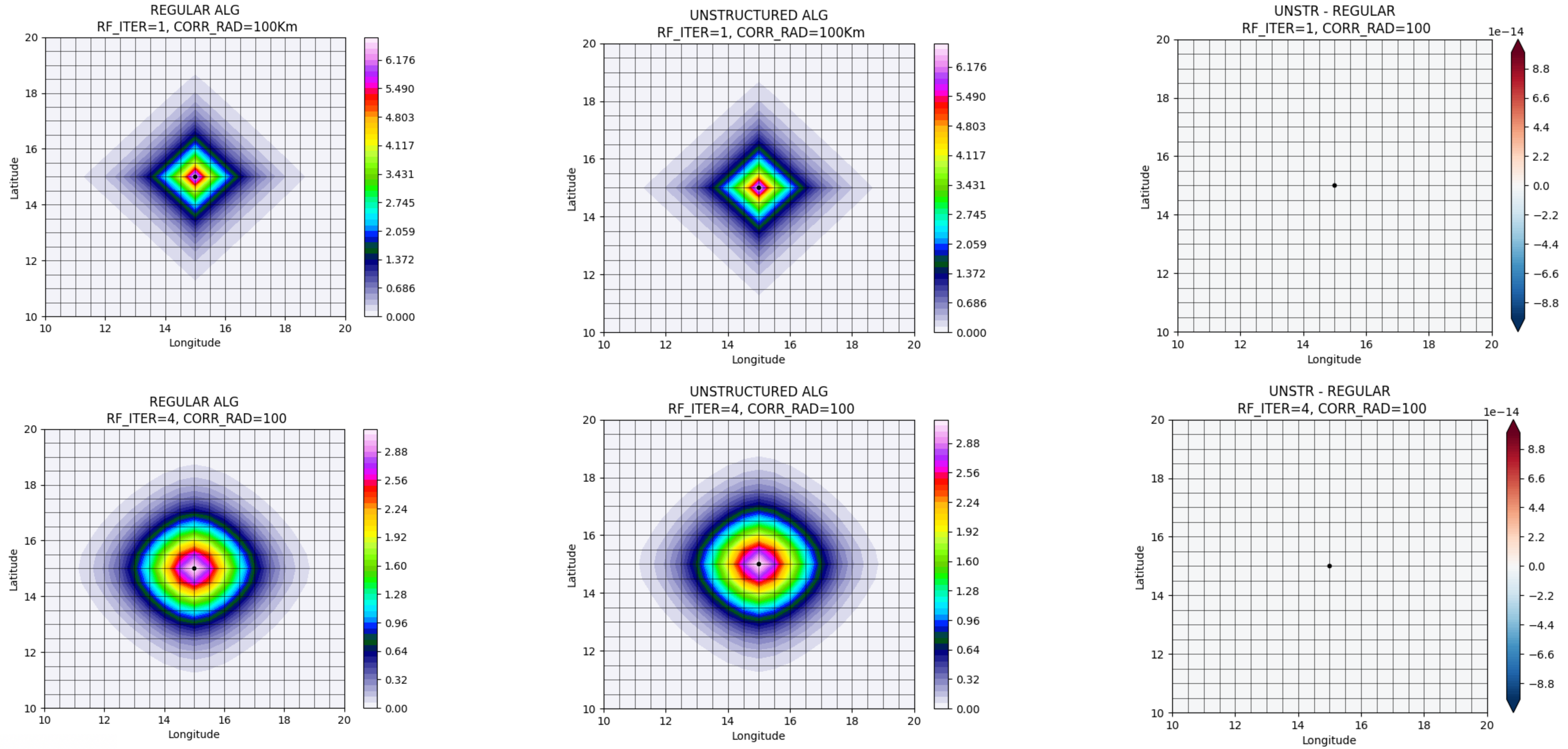
HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER
TEST THE ALGORITHM: REGULAR GRID

Regular RF | Unstructured RF | DIFFERENCE

Iteration #1

Iteration #4



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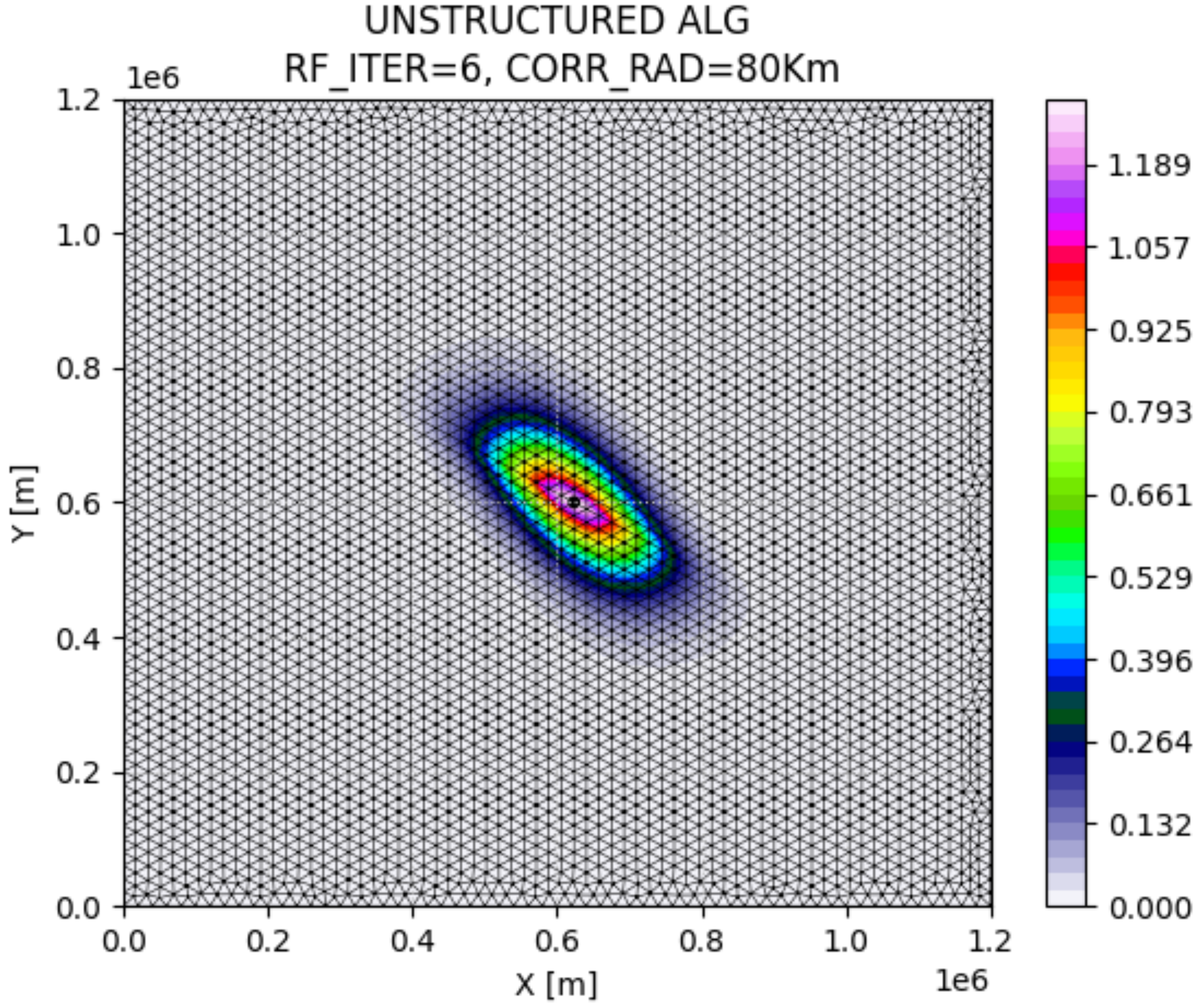
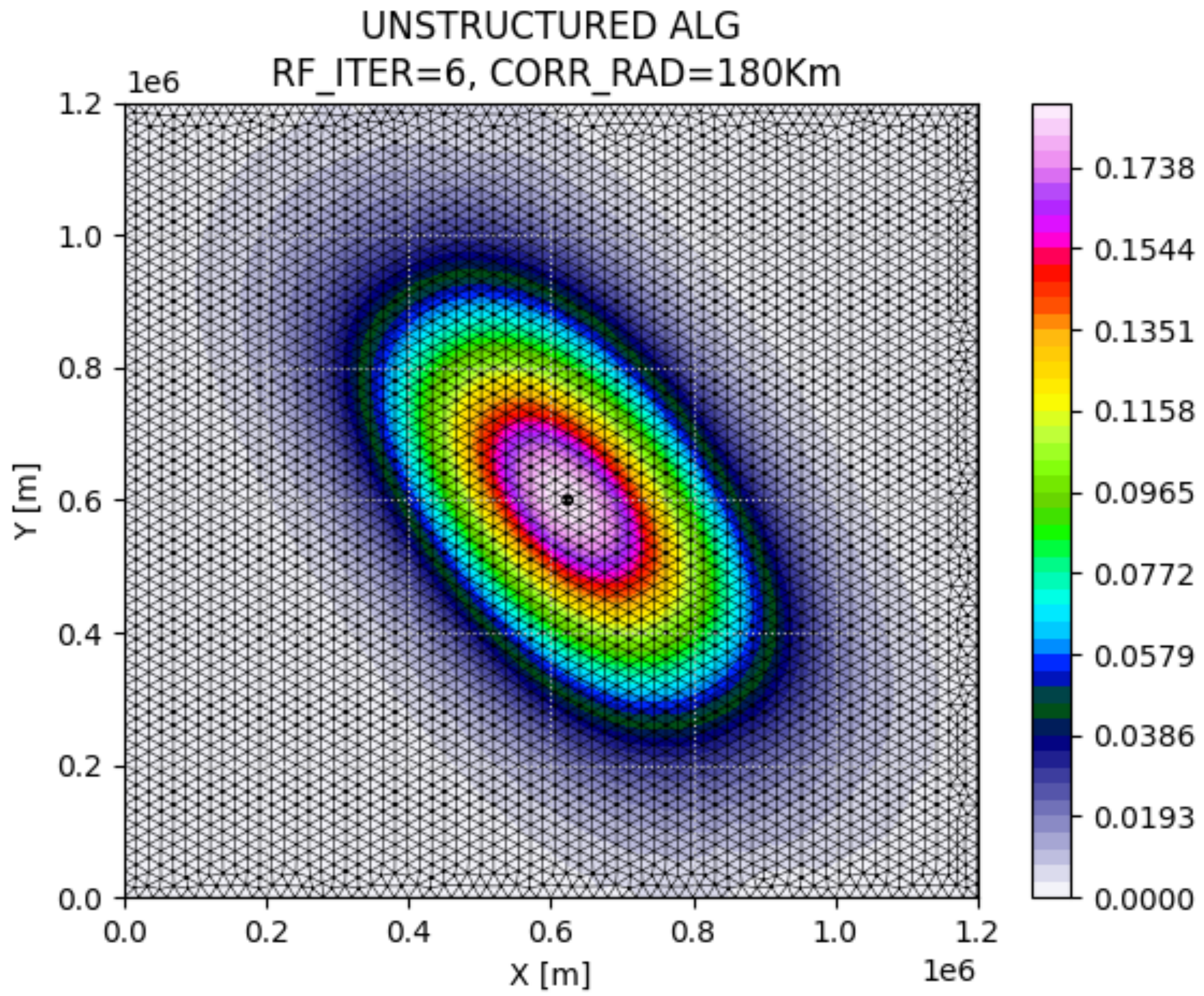
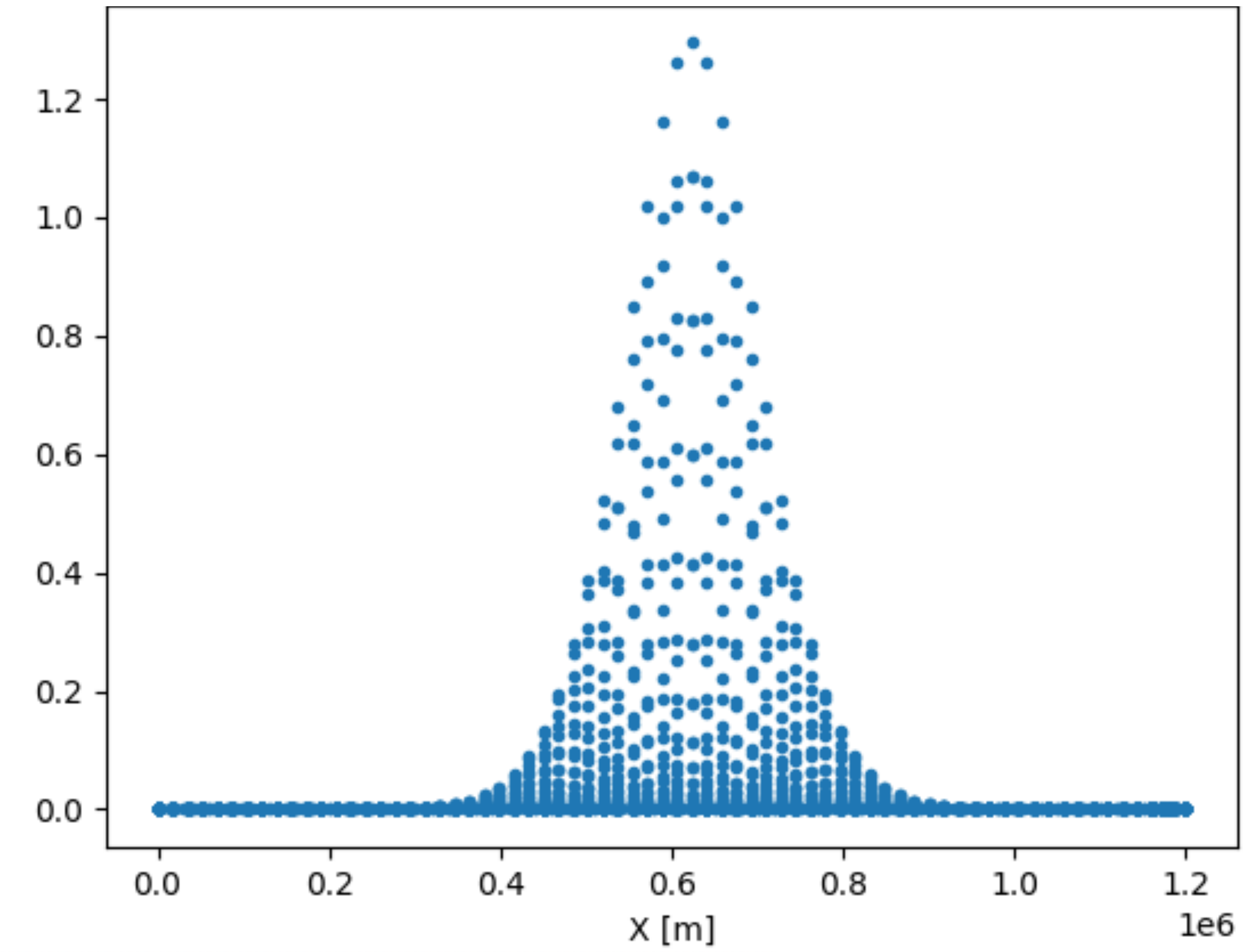
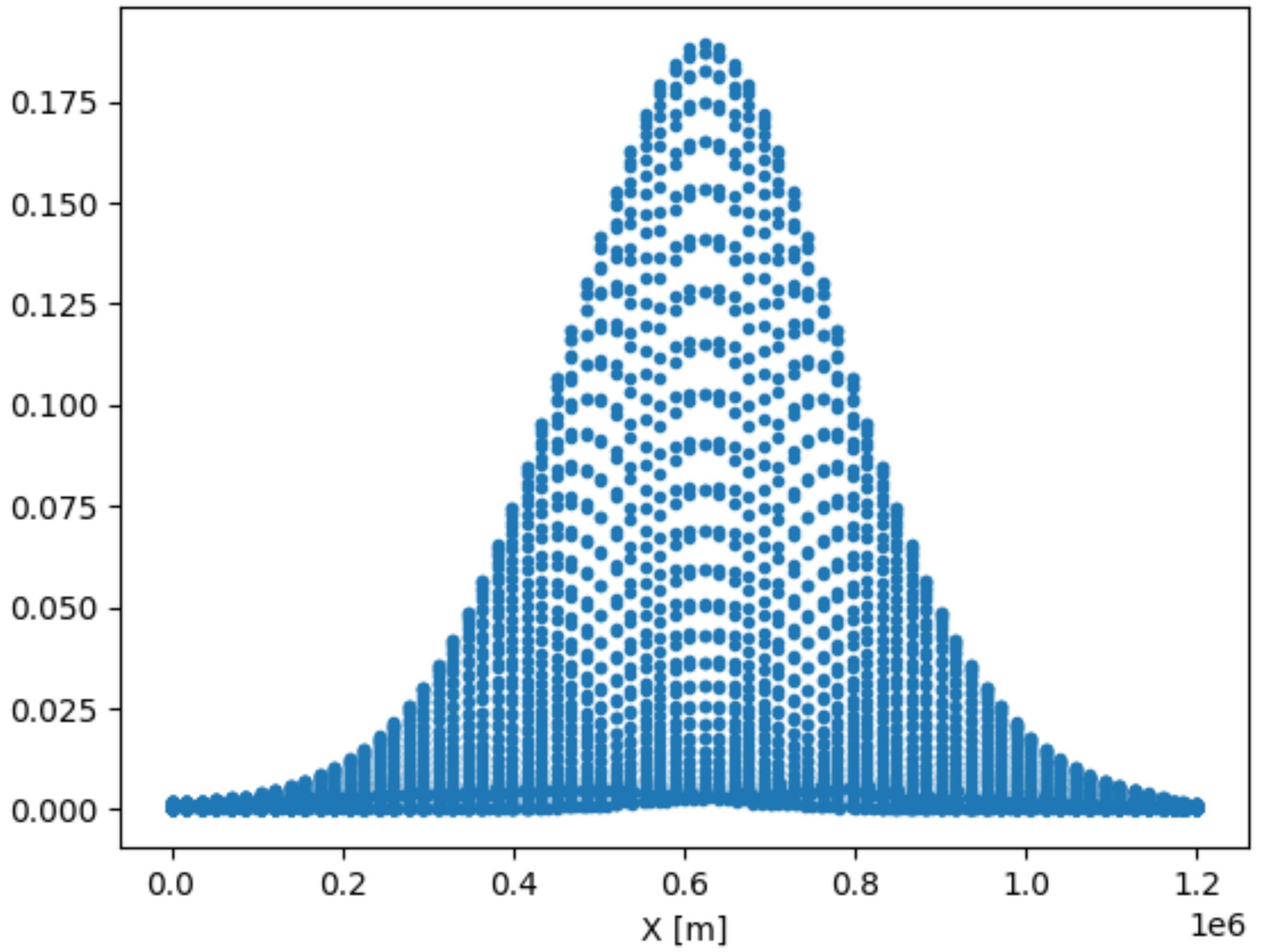
HORIZONTAL COVARIANCE → 1° ORDER RECURSIVE FILTER
TEST THE ALGORITHM: DELAUNAY FRONTAL GRID









SCALING FACTOR

$$\sigma_i = \frac{R_i}{\delta_i}$$

where i refers to the edge.

σ_i : gaussian variance

R_i: correlation radius

δ_i: edges measure

ALGORITHM:

1- Set the initial R

2- Compute σ as:

$$\sigma = \frac{R}{MAX(\delta)}$$

3- Compute R_i as:

$$R_i = \sigma * \delta_i$$

4- Compute α_i

Comments:

In order to have a local symmetry on unstructured grid a scaling factor has to be applied.

The resulting spreading shape is a gaussian with an elongation which is expression of the peculiar grid symmetry.

HORIZONTAL COVARIANCE ⟶ 1° ORDER RECURSIVE FILTER
TEST THE ALGORITHM: SANI UNSTRUCTURED MESH

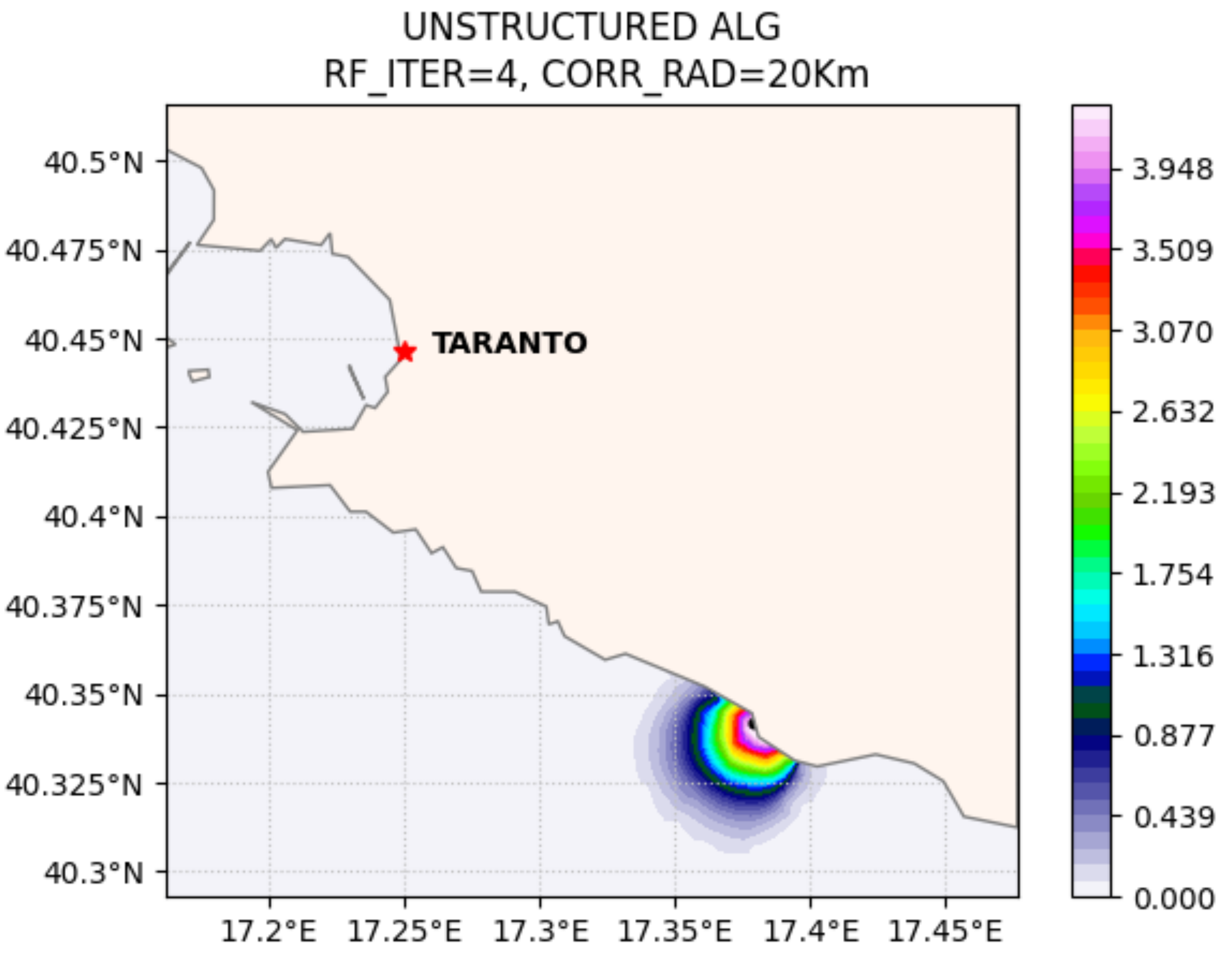


Fig. 1

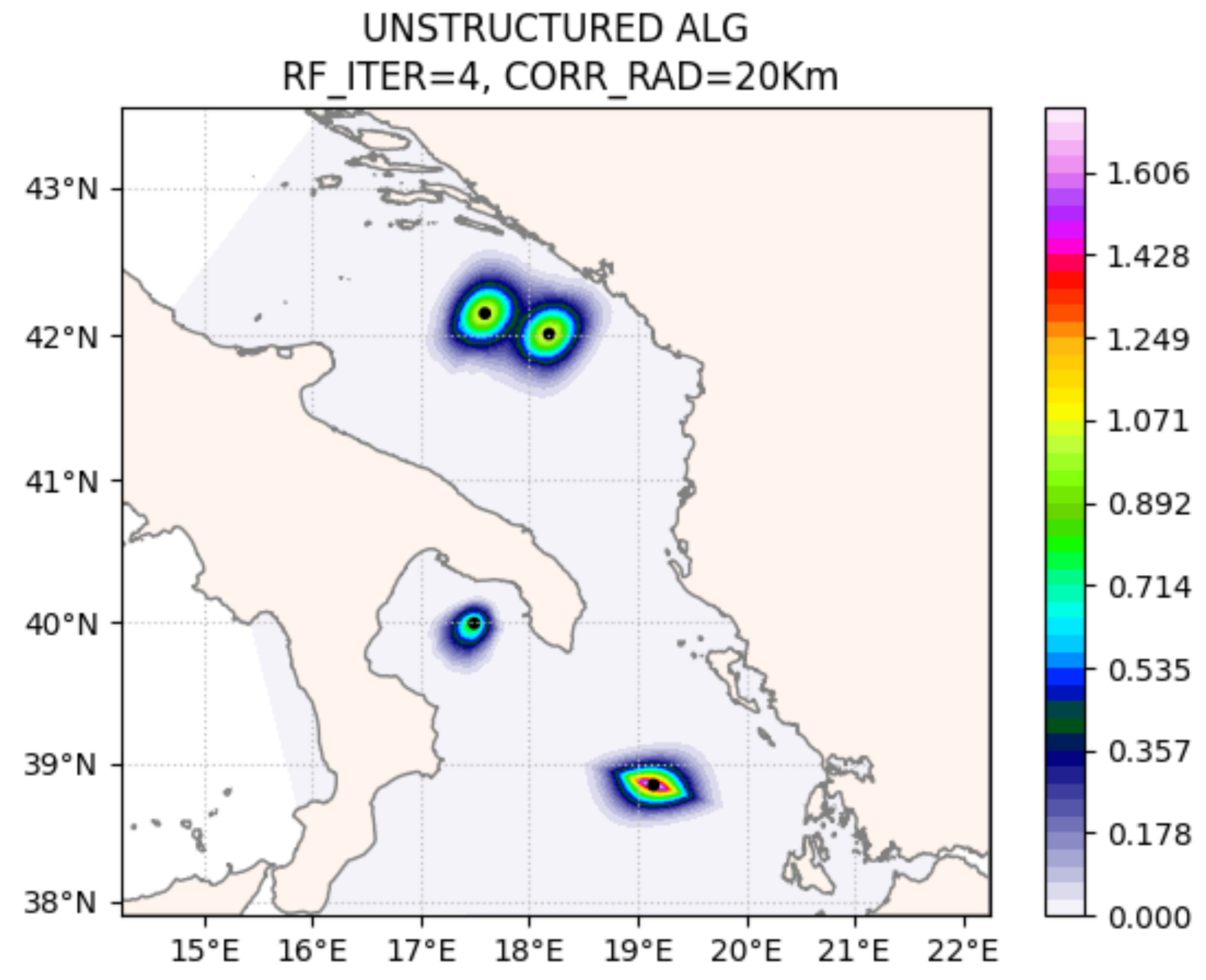


Fig. 2

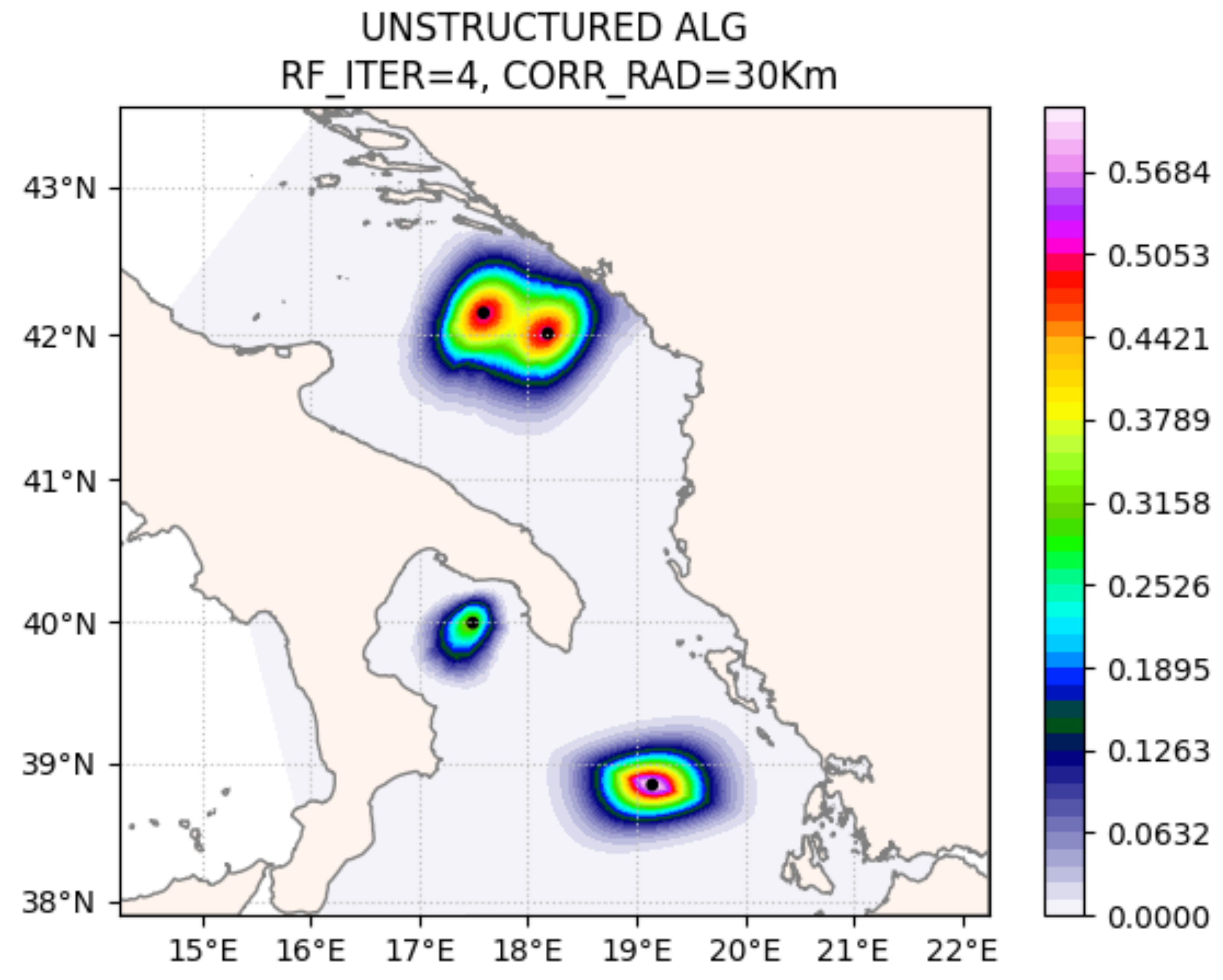


Fig. 3

Comments:

As commented in the previous slide our RF algorithm is sensible to the local grid symmetry, e.g. Northern-Ionian open sea (see Fig.2, Fig.3). However, in coastal areas (Fig.1), Southern-Adriatic open sea and gulf of Taranto sea the algorithm works good (Fig.2, Fig.3). See next slide for grid details.

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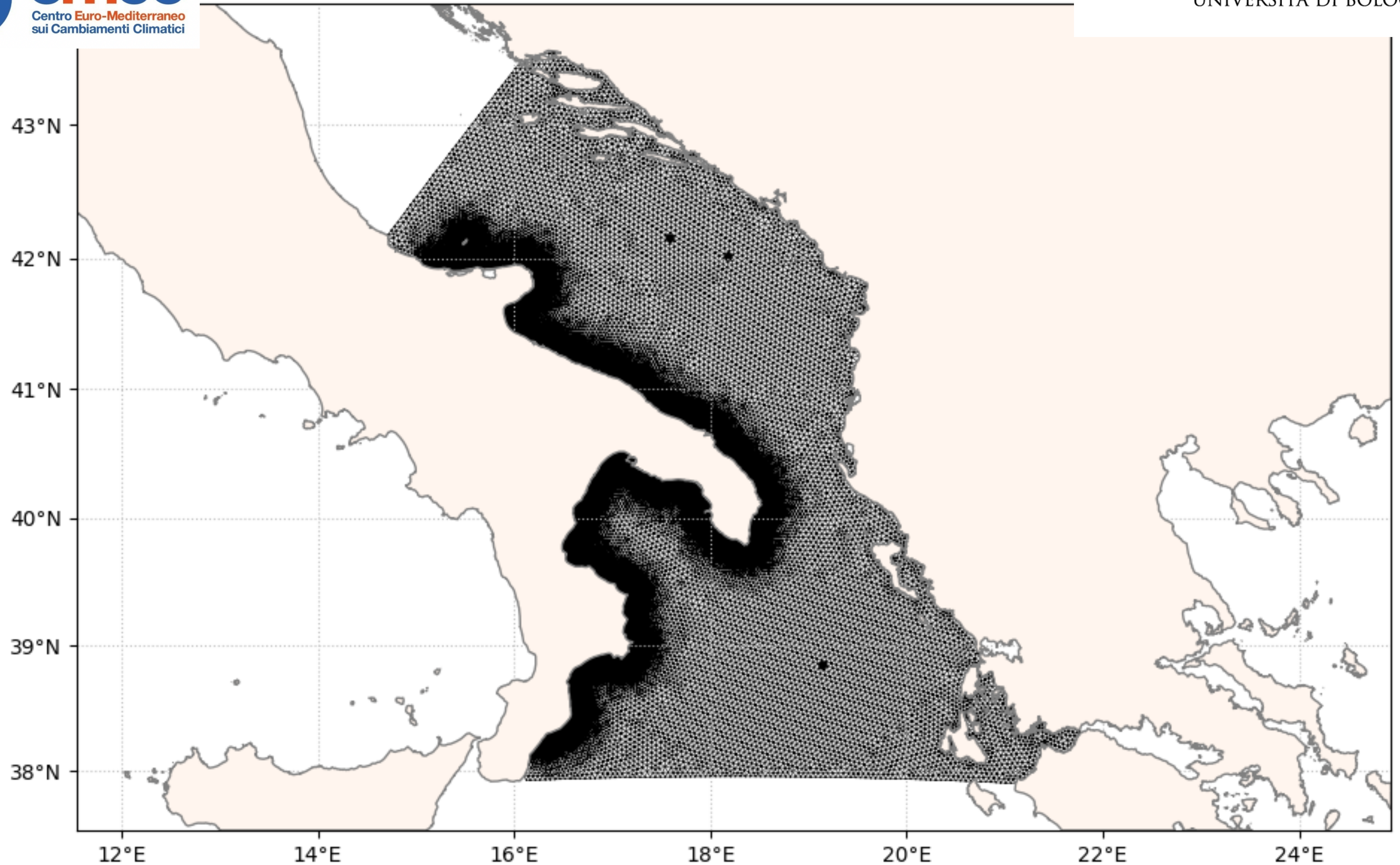
43°N
42°N
41°N
40°N
39°N
38°N
12°E
14°E
16°E
18°E
20°E
22°E
24°E

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Sharing is encouraged

Data assimilation for advanced cross-scale ocean modelling

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MAIN GOAL

Introduce variational DA techniques (3DVar, OceanVar) in models with unstructured grid (SHYFEM)

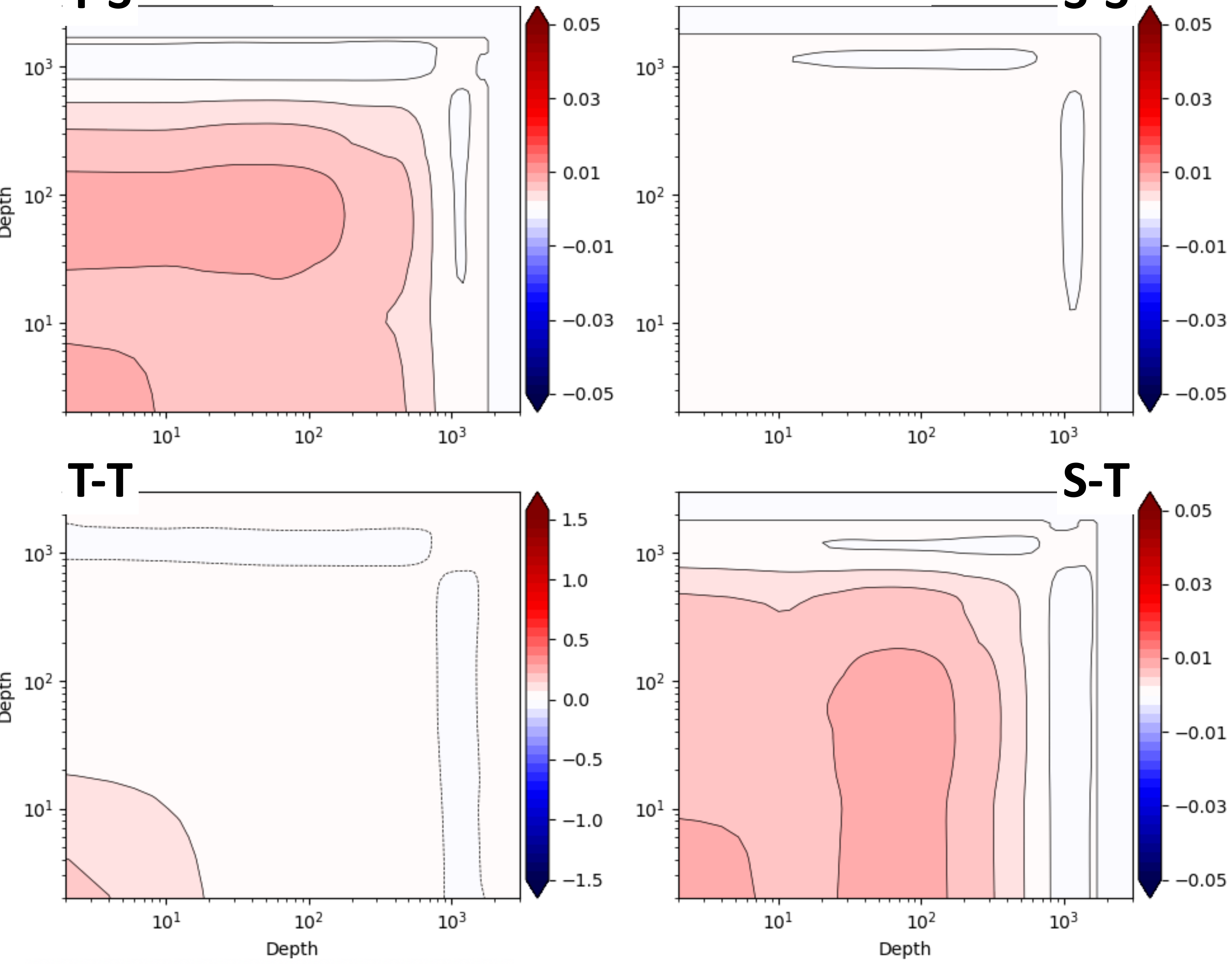
- **OceanVar:** developed at CMCC implements a 3DVar methodology modelling the background error covariance matrix using linear operators (Recursive Filter for horizontal and EOF for vertical error covariance matrix) (Dobricic and Pinardi, 2008; Storto et al., 2014).

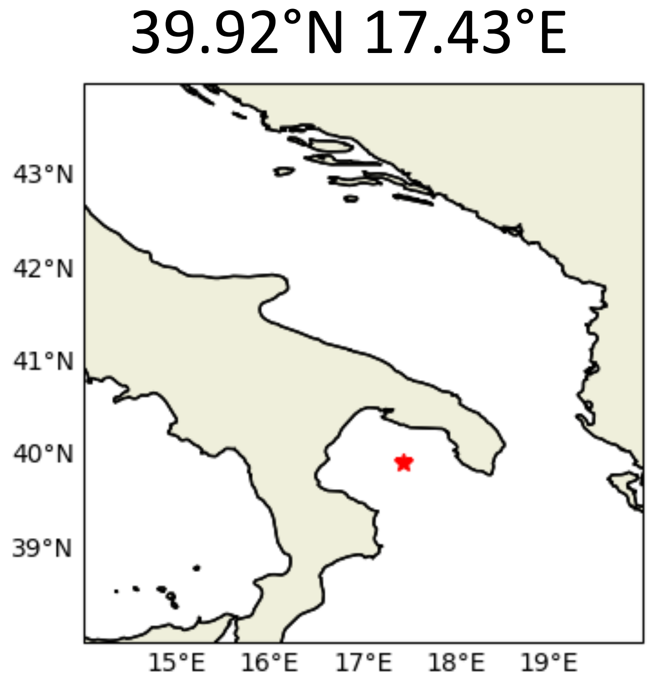
- **SHYFEM:** fully-baroclinic finite-element unstructured-grid model (Umgiesser et al., 2004)

VERTICAL COVARIANCE V_V → EMPIRICAL ORTHOGONAL FUNCTION

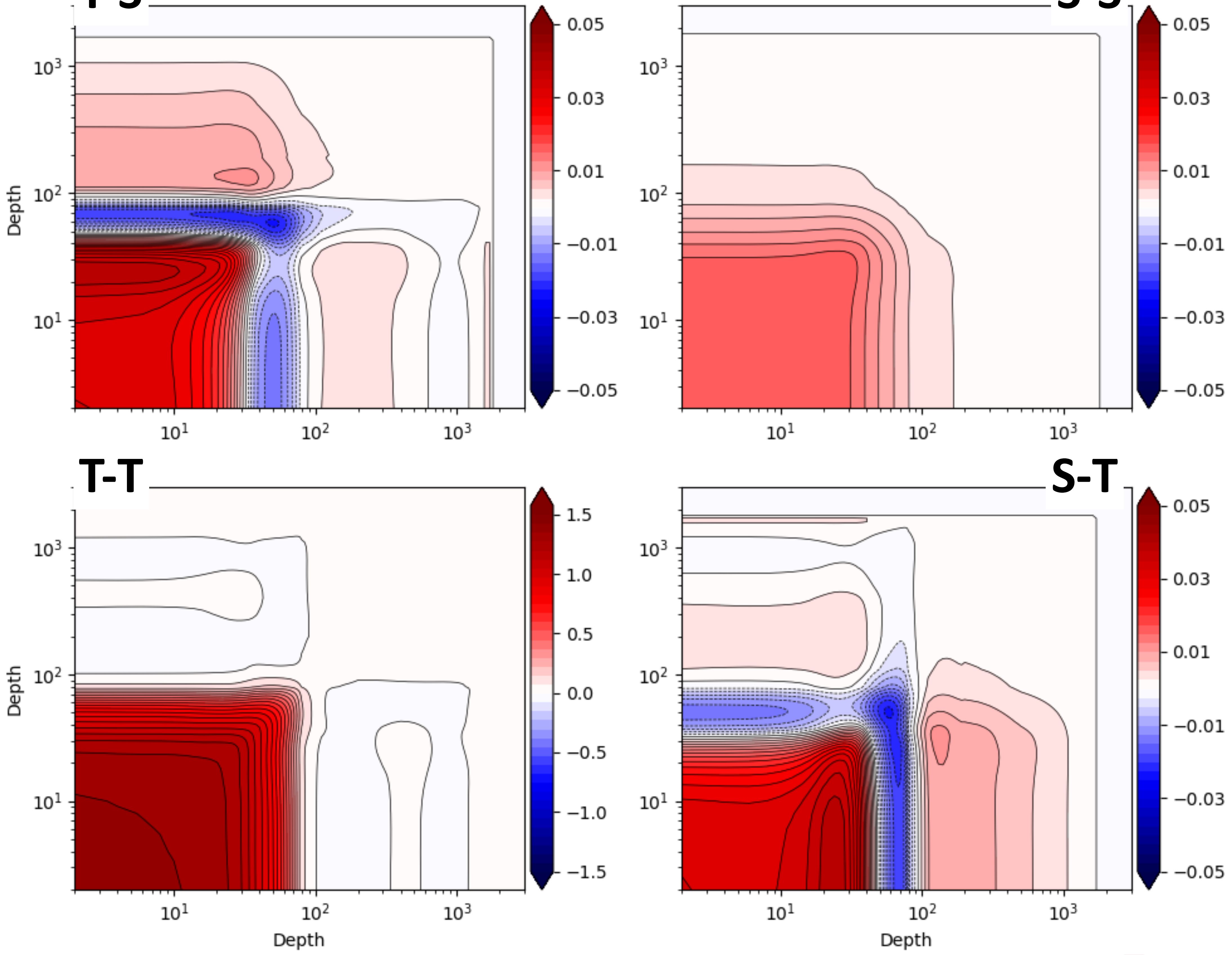
- ➢EOFs: 25 EOF using SVD decomposition of an anomaly matrix
- ➢Derived from the variations in a long SHYFEM integration: 4yr in this study
- ➢Grouped by month and unique to each node

MARCH COVARIANCE





OCTOBER COVARIANCE



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HORIZONTAL COVARIANCE → 1° ORDER RECURSIVE FILTER

A NOVEL ALGORITHM FOR UNSTRUCTURED MESH

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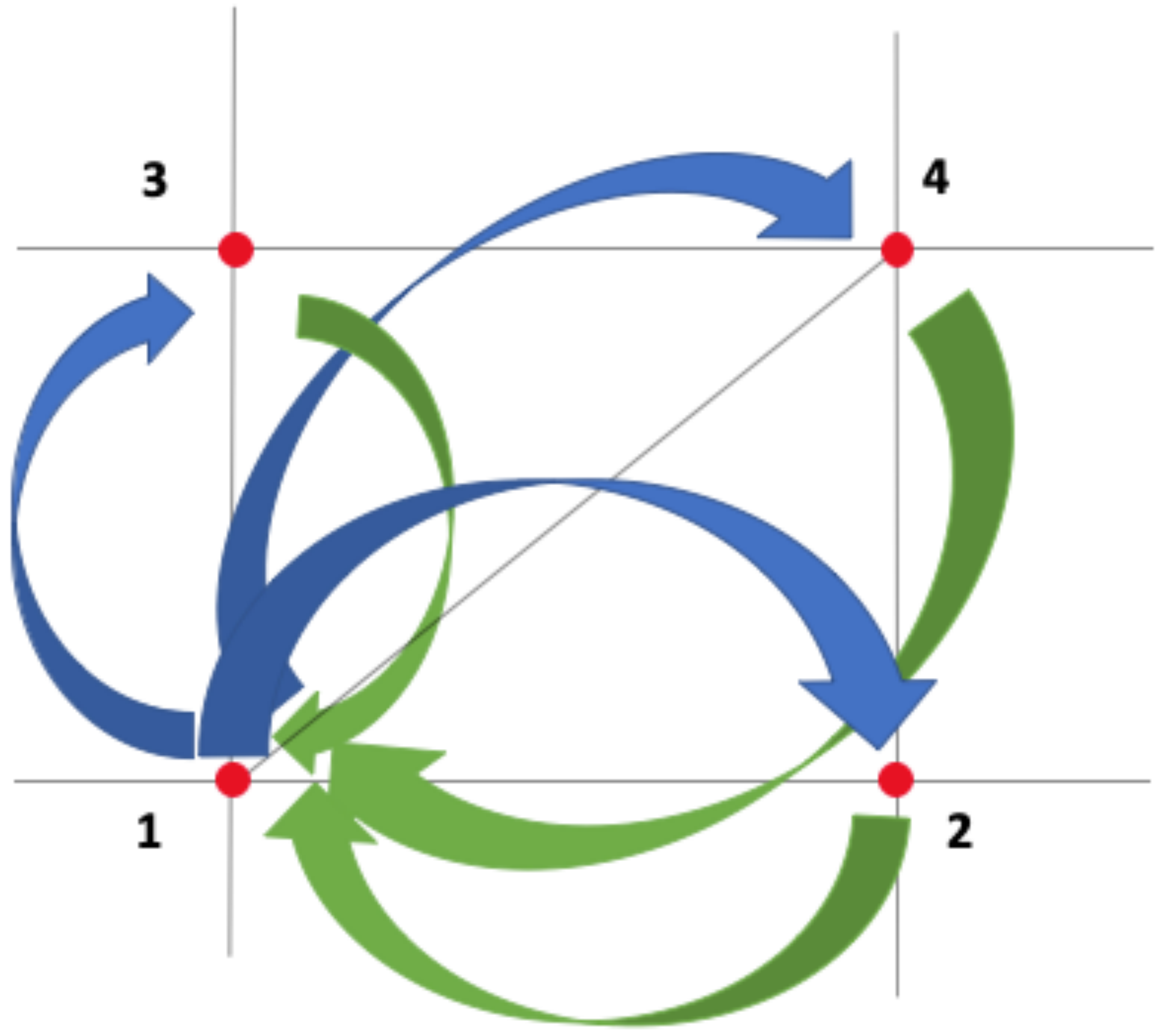
To reproduce the symmetry we have to emulate the x and y application of the regular algorithm for fw and bw pass



2. NODE ORDERING

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$$\alpha = 1 + E - \sqrt{E(E+2)}$$

$$E = \frac{2 N_{Iter} \delta^2}{4R^2}$$

δ = Resolution

R = Correlation radius

See display material for insights.

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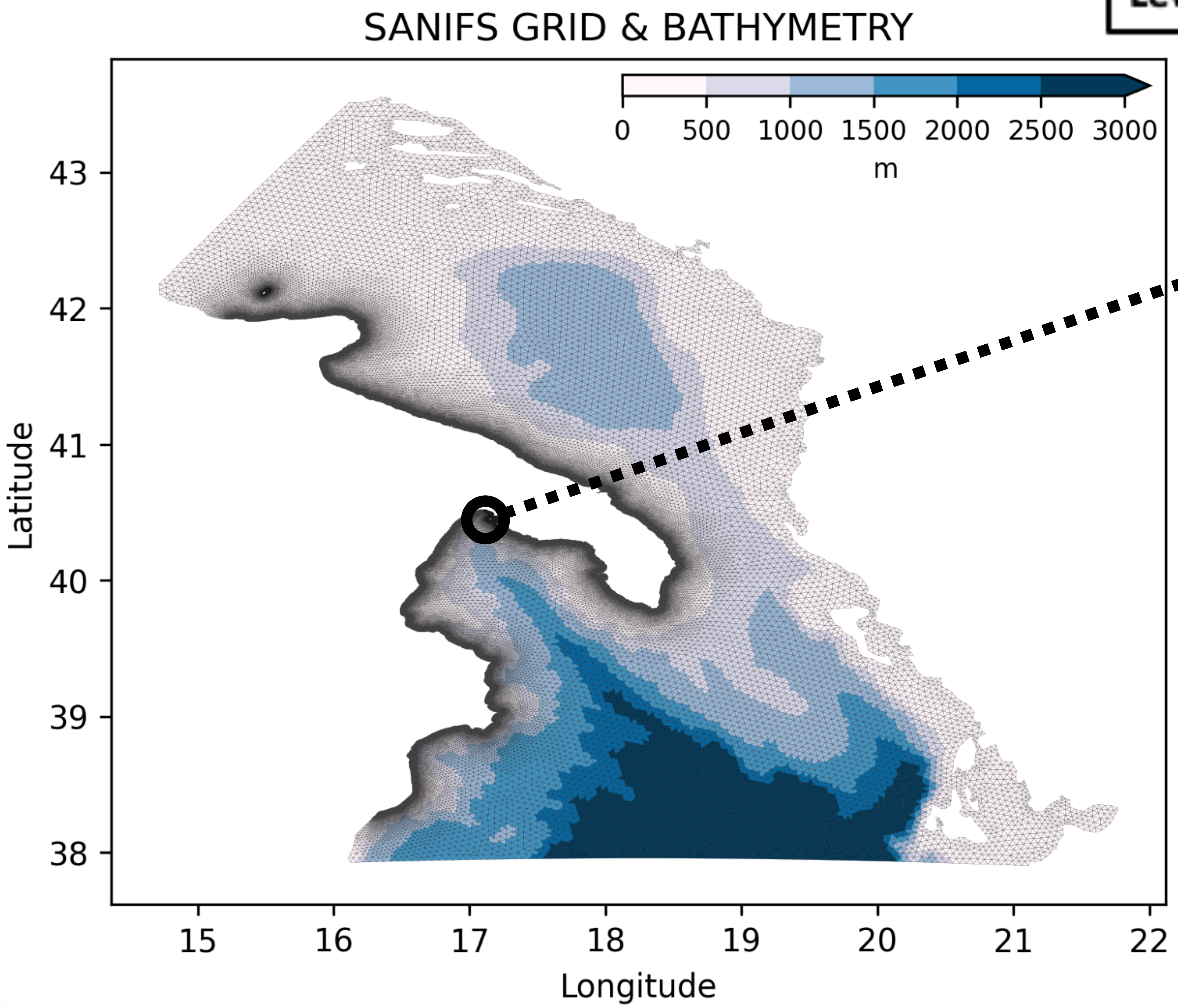
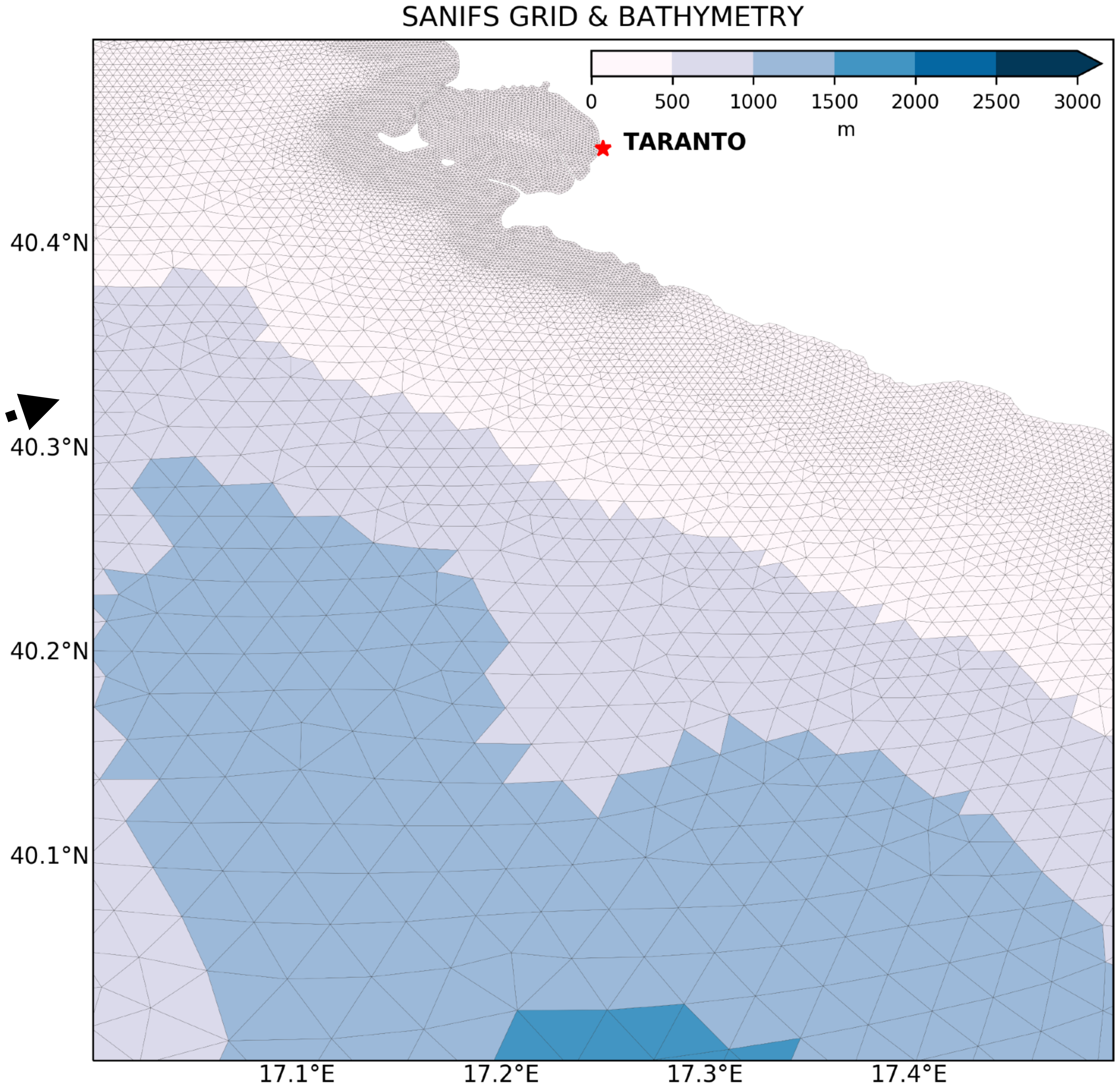
EXPERIMENT: 1 YEAR RUN (2017)

- ✦**DOMAIN**: SANI (SOUTHERN ADRIATIC - NORTHERN IONIAN)
- ✦**CORRELATION RADIUS** = 8Km
- ✦**RECURSIVE FILTER ITERATIONS** = 6
- ✦**ASSIMILATION WINDOW** = 24h

RESOLUTION
Coast: 50–500 m
Open sea: 3–4 km
Levels: 92





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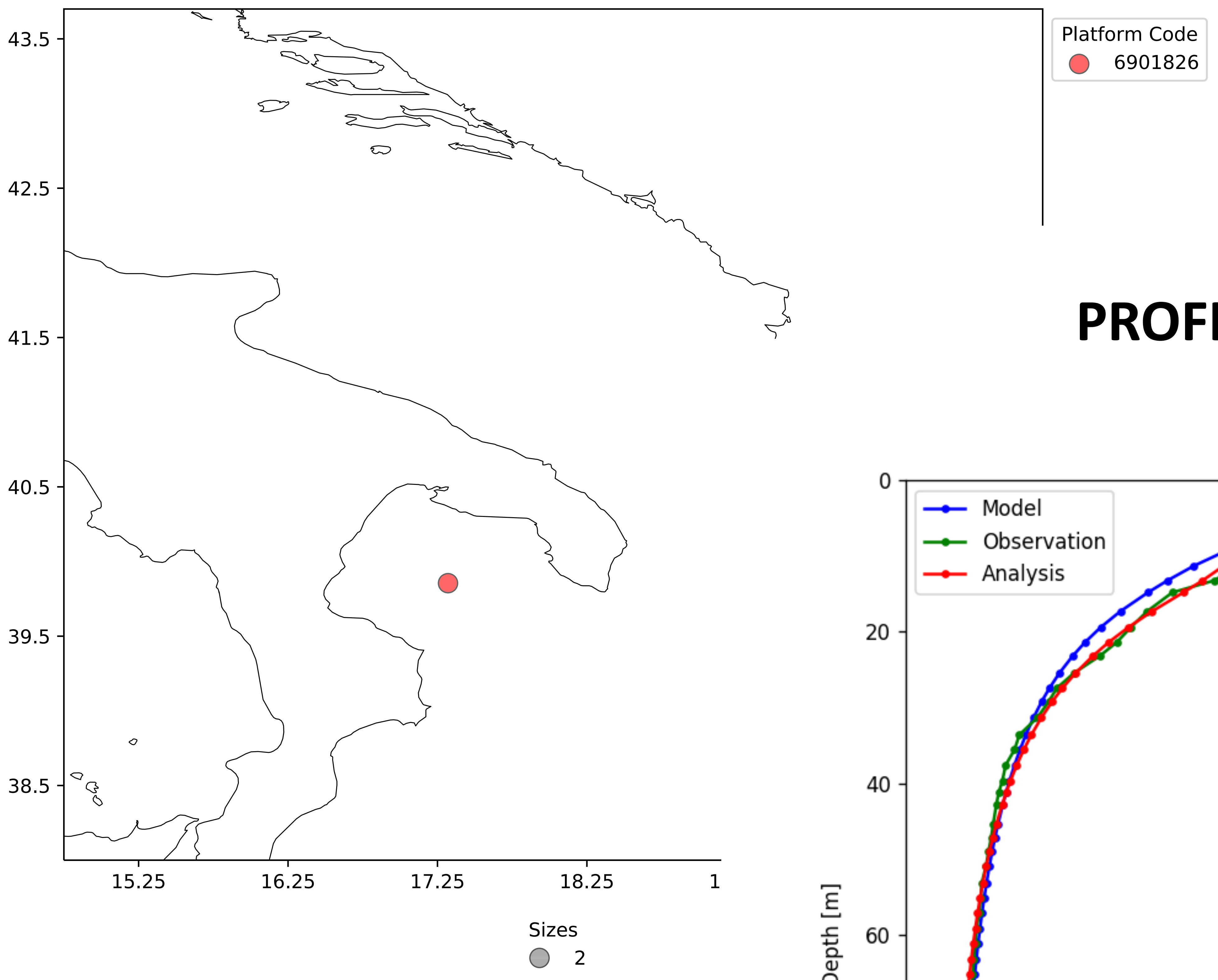
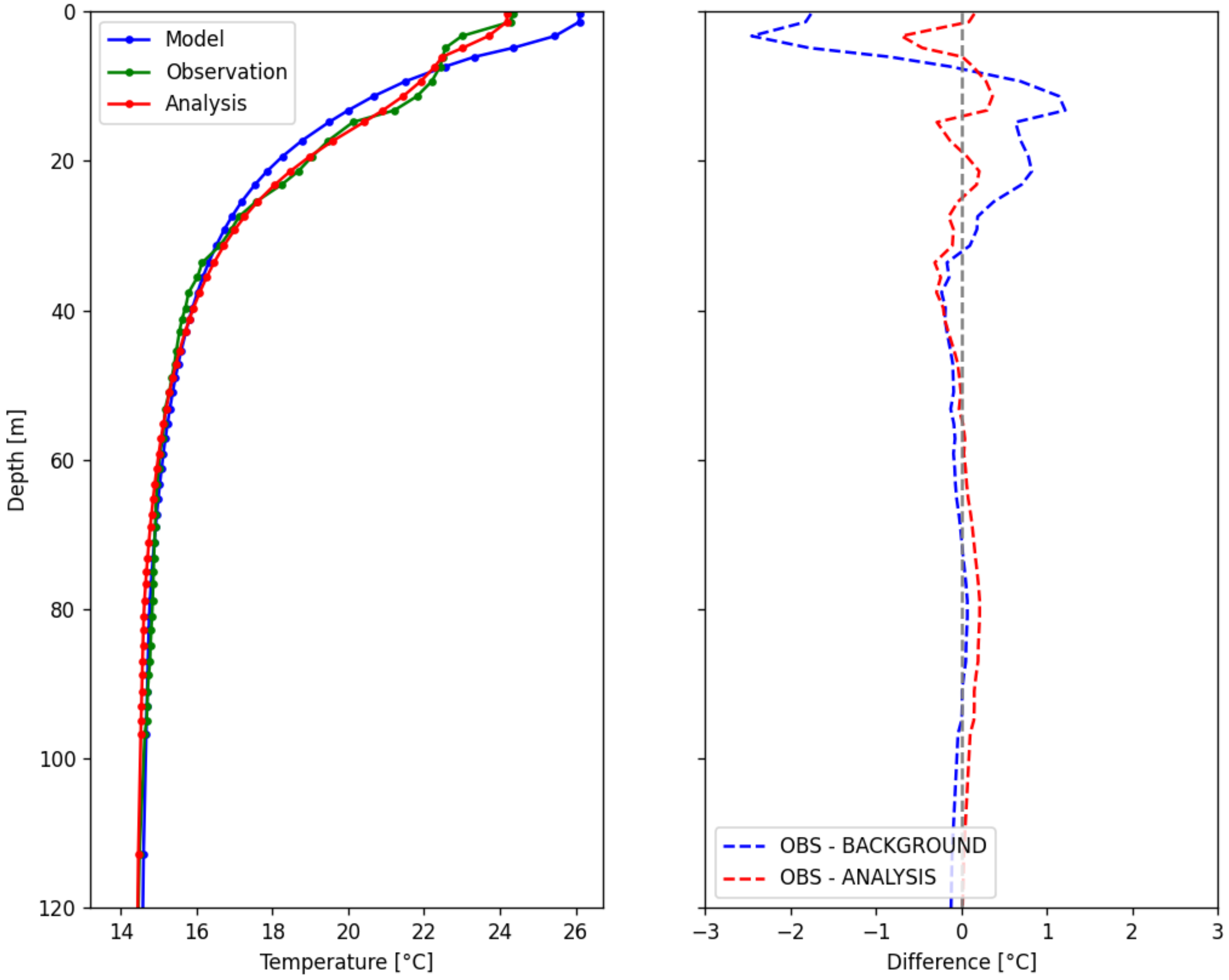
RESULTS: 15/06/2017

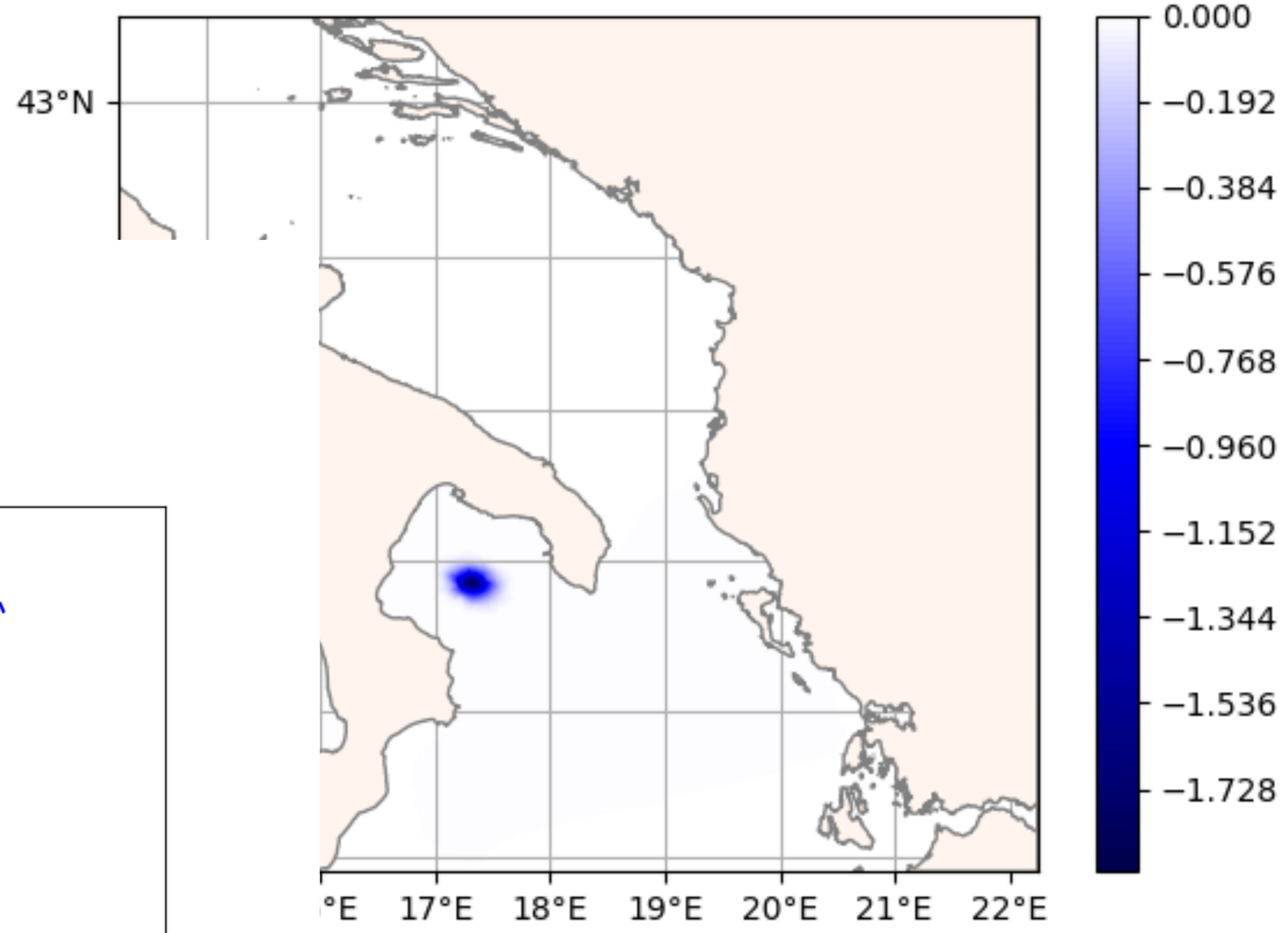
OBSERVATION LOCATION



PROFILE ON THE NODE CLOSER TO OBS LOCATION



RECURSIVE FILTER SPREADING



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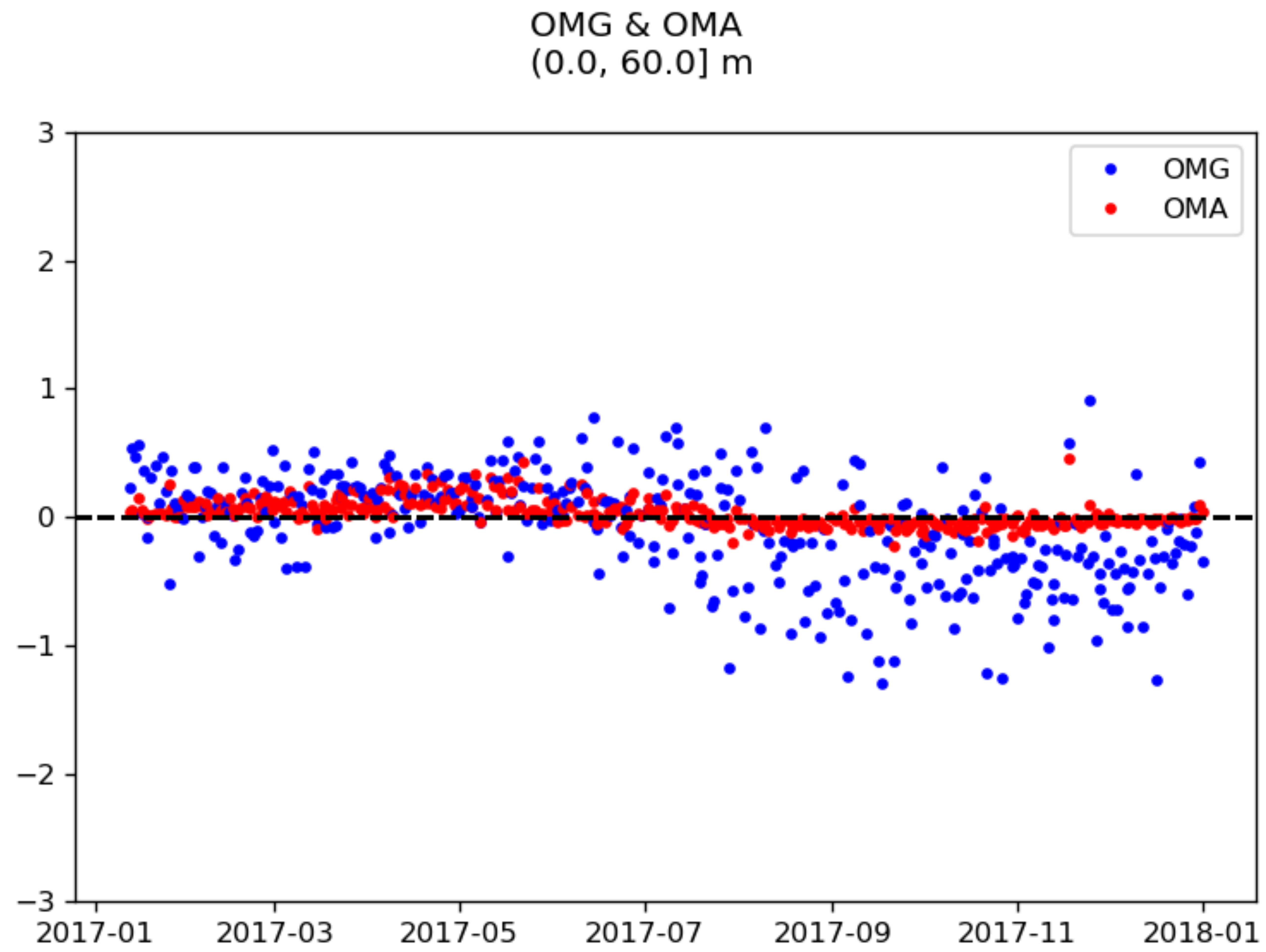
TEMPERATURE BACKGROUND & ANALYSIS ERROR AVERAGE ON LAYER (0,60] m

OMG = OBSERVATION - BACKGROUND

OMA = OBSERVATION - ANALYSIS



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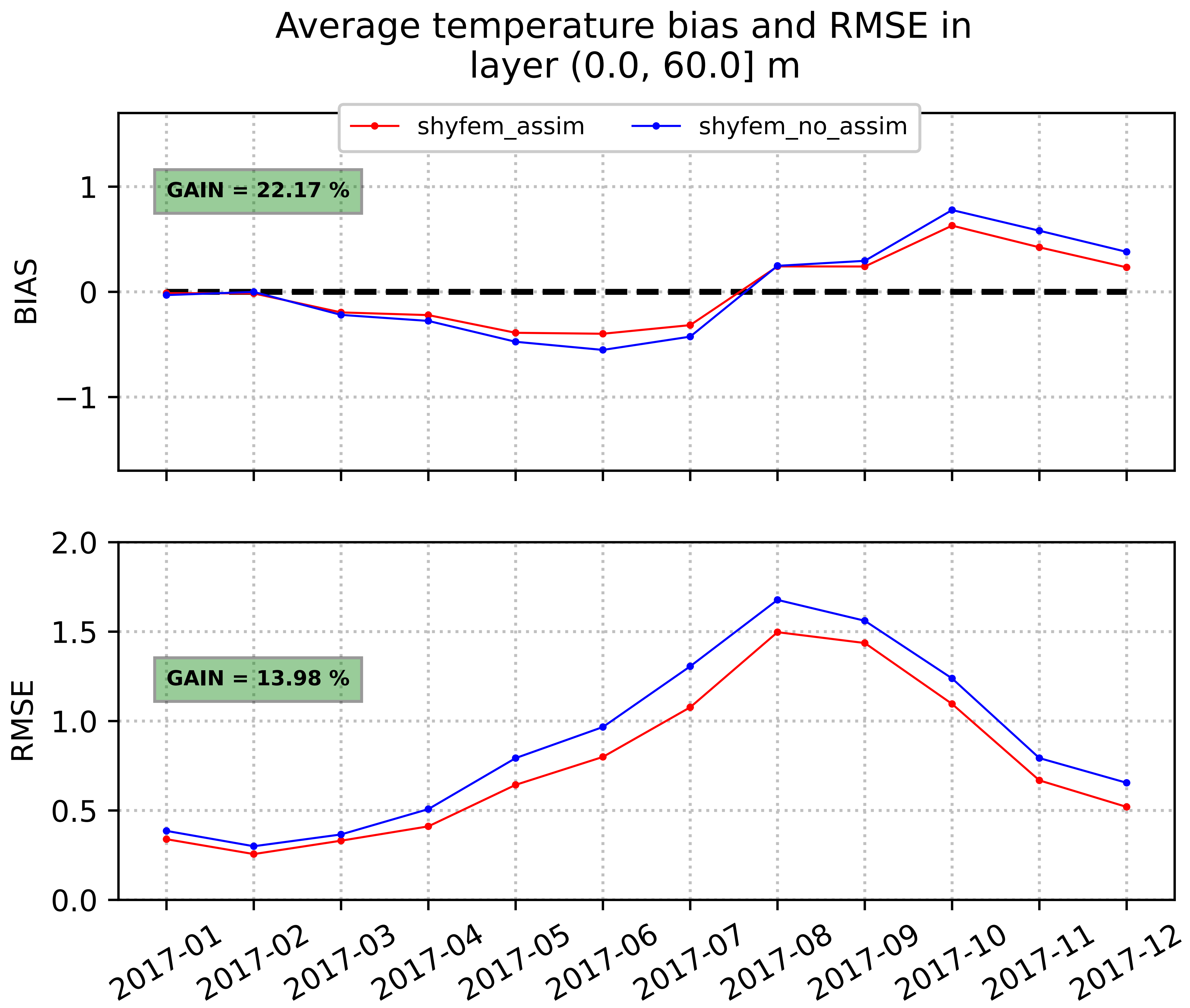
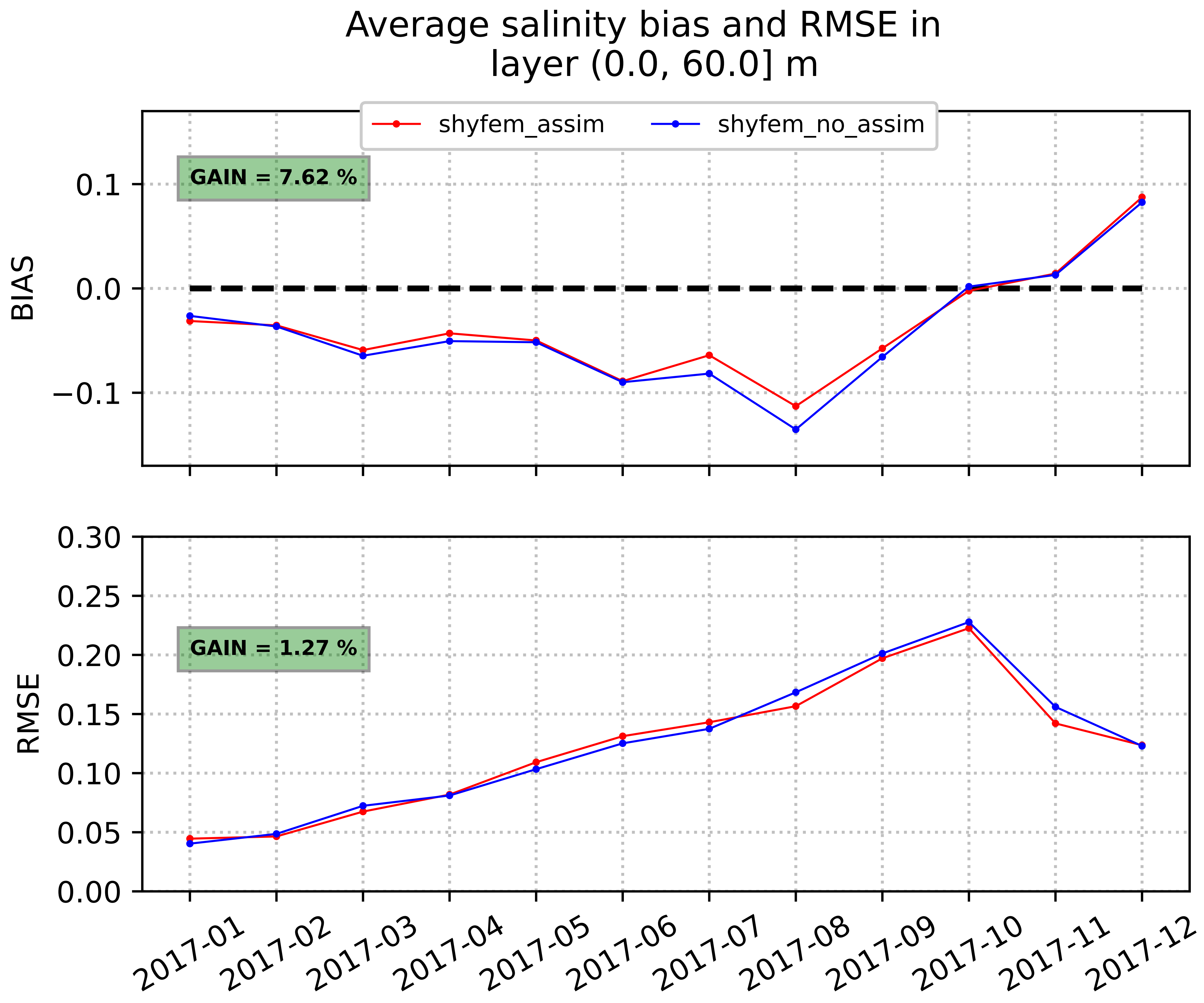
MONTHLY T & S BIAS AND RMSE ON LAYER (0,60] m





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CONCLUSIONS

1- In order to model vertical covariance we used EOF SVD decomposition of an anomaly matrix.

2- For the horizontal covariance on unstructured grid we implemented a novel 1° order recursive filter algorithm that reproduce the result of the regular one.

3- Our RF algorithm is sensible to the local grid symmetry, showing really good results in coastal regions.

4- The first experiment using 8Km of correlation radius, 6 iterations for RF and an assimilation window of 24h shows an improvement of the model skills of around 20% in temperature and 7% in salinity in the first 60 m layer.

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Thank you.