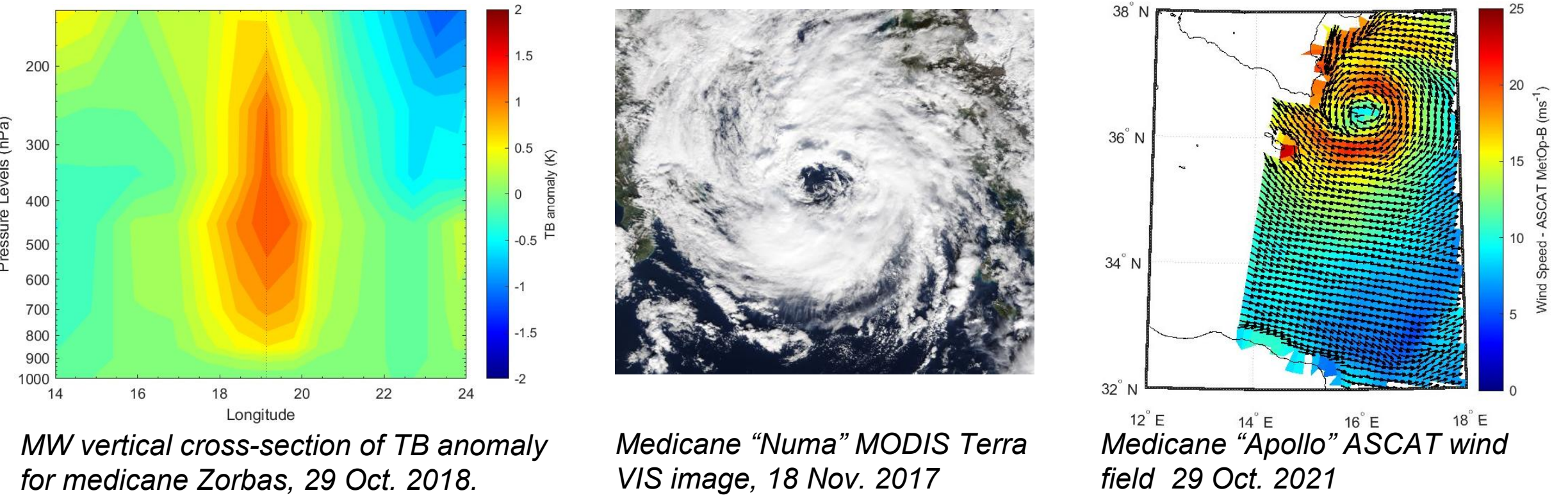


## 1. Introduction

Medicanes (Mediterranean Hurricanes) are mesoscale cyclones typical of the Mediterranean area that display characteristic similar to tropical cyclones (TLC) phase during their mature stage (i.e., the presence of a warm core – WC, a spiraling cloud structure and rainbands around an almost-cloudless ‘eye’, and a nearly-closed surface wind field with maximum speed within a few tens of km from the center – Miglietta et al., 2025). Satellite passive microwave (PMW) radiometers provide useful measurements for identification and characterization of phenomenological features and physical processes in medicanes (e.g., Presence and origin of the warm core, presence of the closed eye, deep convection strength and organization).



This study details the development of an automated WC identification system in the context of the ESA MEDICANES project (<https://medicanes.isac.cnr.it/>). The system that exploits passive microwave measurements from Low Earth Orbit (LEO) satellites, uses four channels within the oxygen absorption band as input. Based on the research outlined in the paper "Reconstruction Error-based Anomaly Detection with Few Outlying Examples" (Angiulli et al., 2023), this research uses a convolutional autoencoder model (AE-SAD: Semi-supervised Anomaly Detection through Auto-Encoders).

## Warm core detection

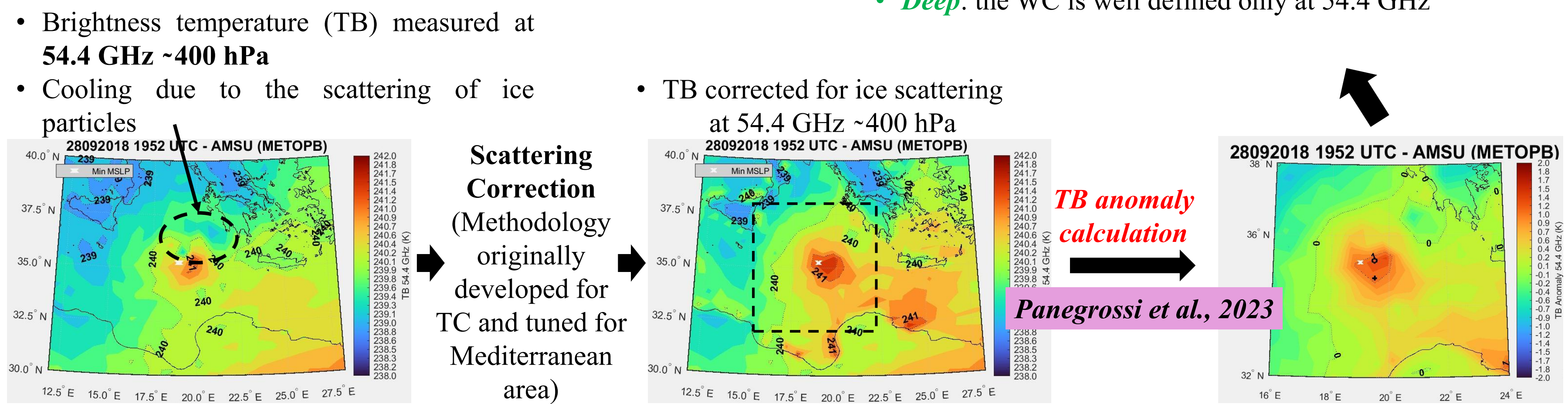
- AMSU-A + MHS sensor**
- 4 channels considered: 53.596, 54.4, 54.94 and 55.5 GHz
- ATMS sensor**
- 4 channels considered: 53.596, 54.4, 54.94 and 55.5 GHz
- SSMIS sensor**
- 3 channels considered: 53.506, 54.4 and 55.5 GHz

### WC depth from visual inspection

The WC can be identified as positive TB anomaly region around the cyclone's center. The shape, the size and the intensity of TB anomaly provide indications about the WC's strength. Currently, these features are deduced by visual inspection of TB anomaly maps (for the MW channels considered – the state of art does not include the analysis of 53.596 GHz channel).

Three different categories are identified:

- Extremely Deep:** the WC is well defined at all three channels (i.e., 54.4, 54.94 and 55.5 GHz)
- Very Deep:** the WC is well defined at 54.4 and 54.94 GHz
- Deep:** the WC is well defined only at 54.4 GHz



## 2. Methodology

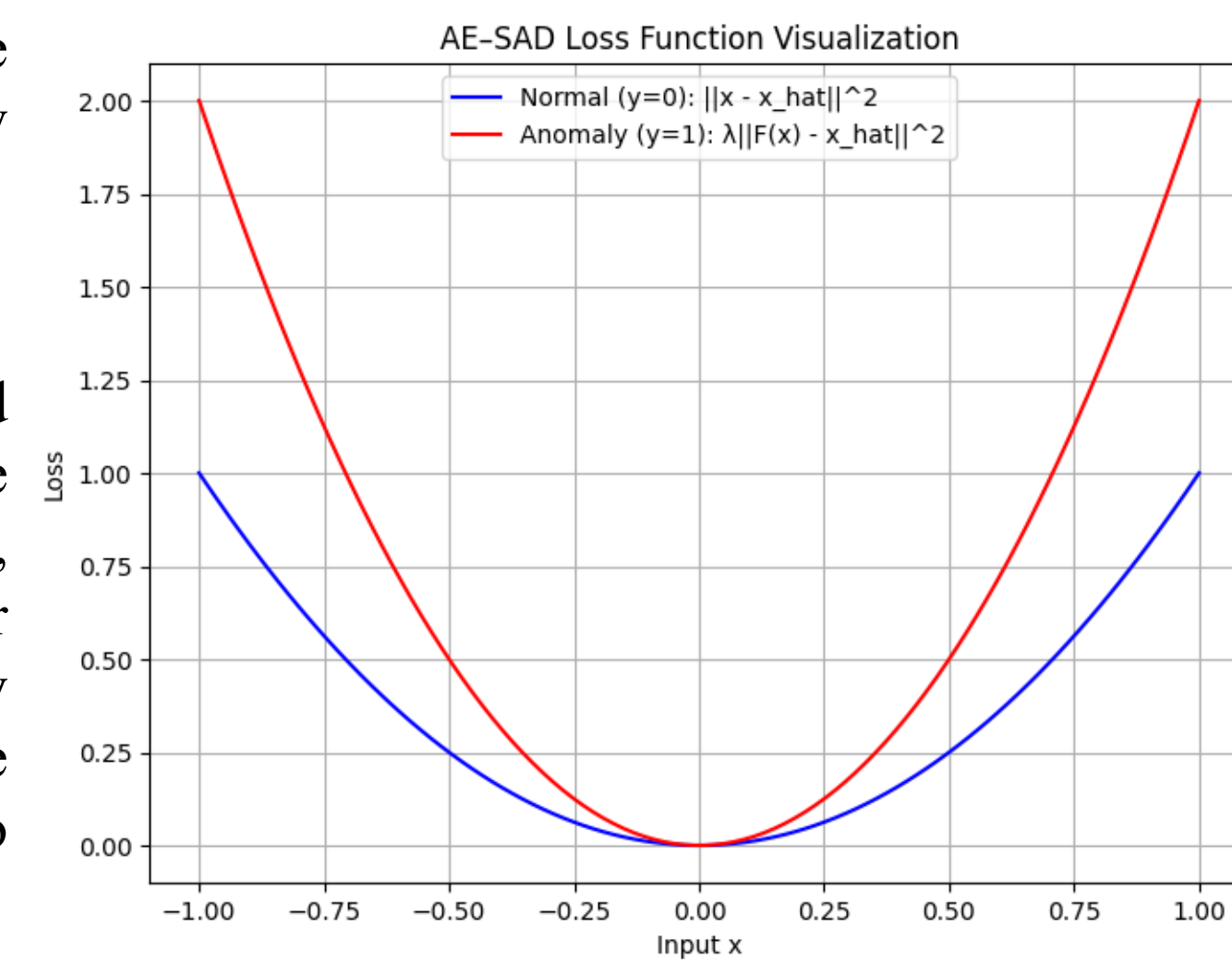
Traditional Autoencoders aim to minimize reconstruction error for all training samples, which often leads them to reconstruct anomalies almost as well as normal data—making anomaly detection less effective. AE-SAD addresses this weakness by exploiting the presence of a few labelled anomalies during training.

The core idea is to train the Autoencoder to reconstruct normal data accurately while deliberately distorting the reconstruction of anomalies. This is achieved through a new loss function:

$$L_F(x) = (1 - y) \cdot \|x - \hat{x}\|^2 + \lambda \cdot y \cdot \|F(x) - \hat{x}\|^2$$

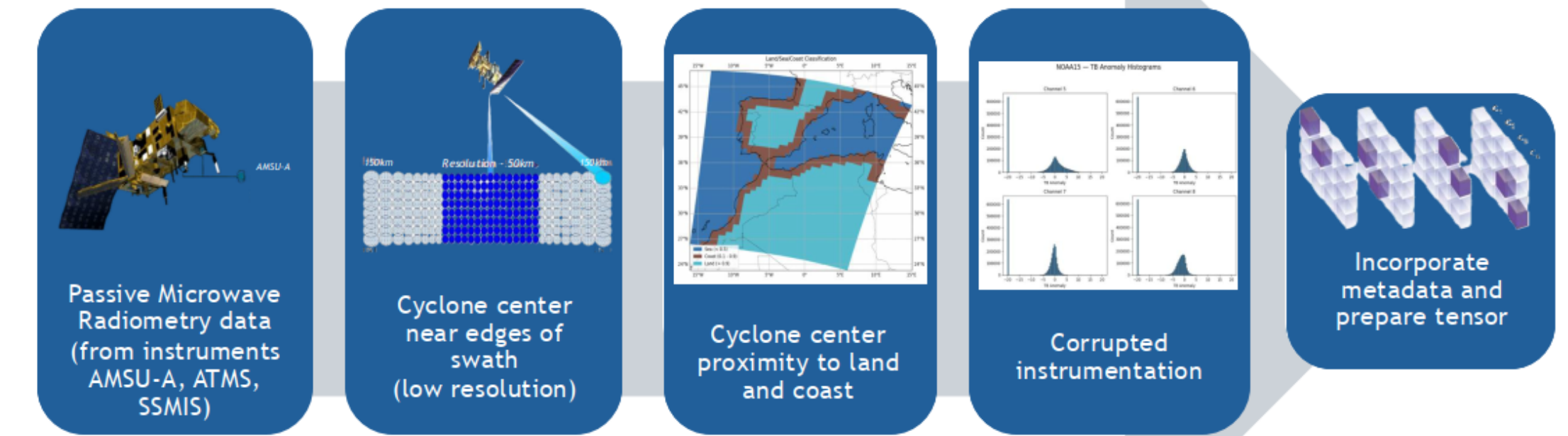
Here,  $y$  is the label (0 for normal, 1 for anomaly),  $\hat{x}$  is the reconstructed output, and  $F(x)$  is a transformation applied to anomalies—typically the negative image of  $x$ . The parameter  $\lambda$  controls the relative weight of anomalies in the loss. For normal samples, the Autoencoder behaves as usual, minimizing the reconstruction error. For anomalies, however, it tries to make the output resemble  $F(x)$ , which is intentionally very different from the original input. This strategy ensures anomalies are reconstructed poorly, amplifying their reconstruction error and making them easier to detect.

Importantly, AE-SAD uses this modified loss only during training. At test time, anomaly scores are computed using the standard reconstruction error, which now effectively separates normal and anomalous data thanks to the training strategy.



## 3. Dataset

- 875 cyclones for 20,000+ AMSU-A overpass analysed
- Preprocessing of data: removing overpasses with cyclones' centre at the edge of the swath or closer than 100 km from coastal lines (or over land), or with corrupted channels.



### Criteria for filtering out overpasses (data) due to instrument limitations

- Manual labelling of WC applied to the 35% of the dataset to be used during the training phase.

## 4. Preliminary Results

Encoder → Bottleneck → Decoder

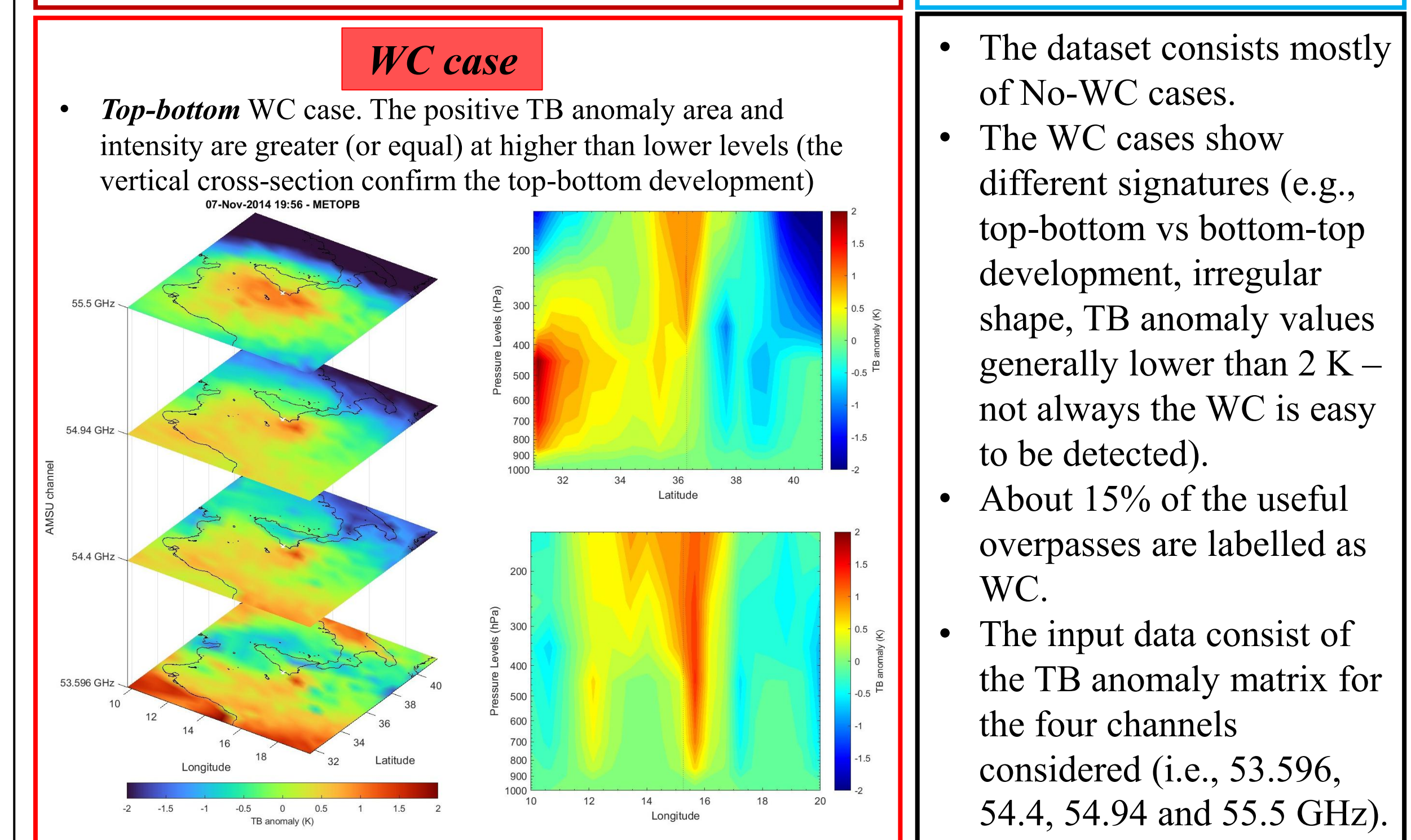
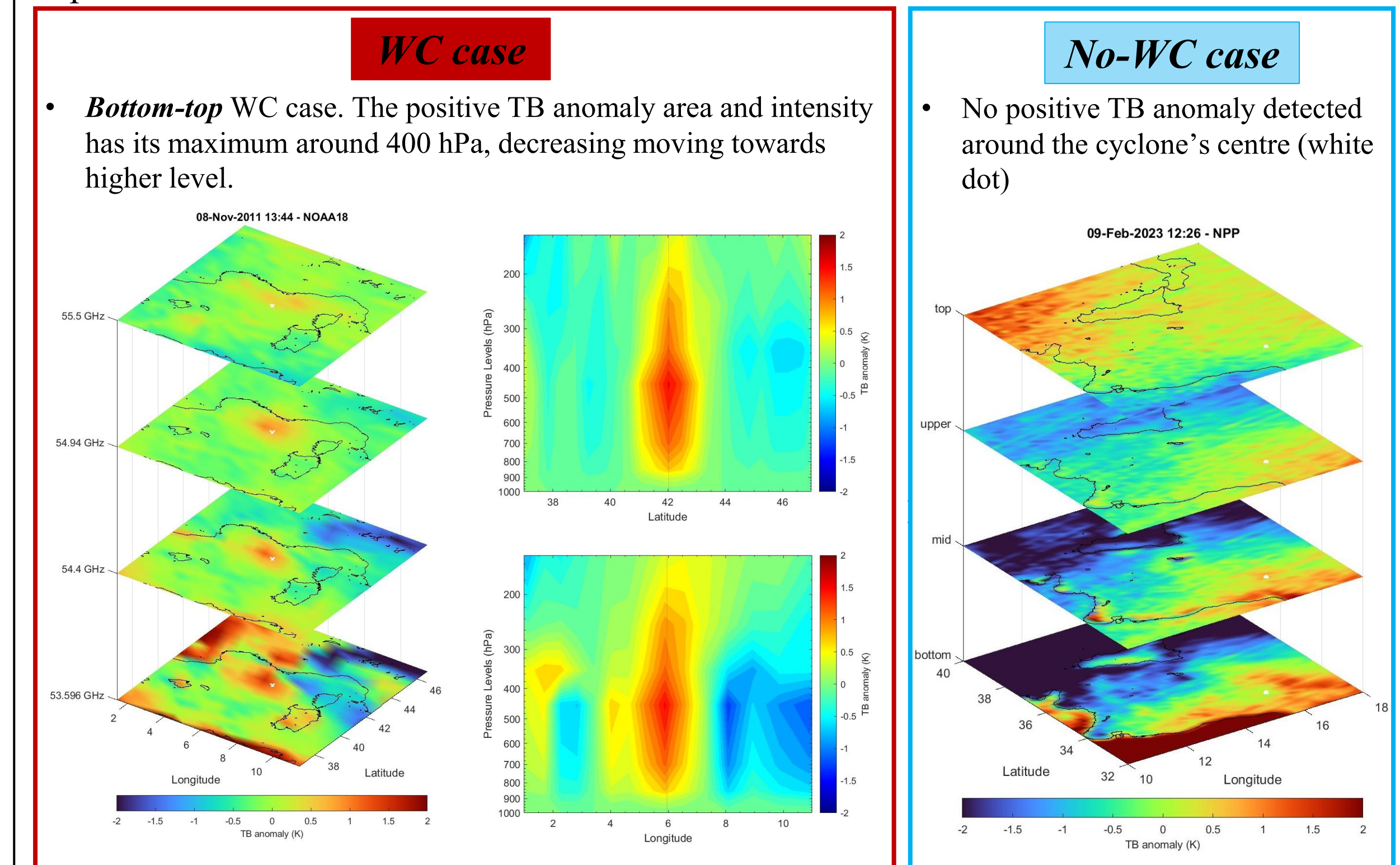
Contingency Table from Test Set

Medicane Forecast	Medicane Observed		Total
	Yes	No	
Yes	13	7	20
No	3	105	108
Total	16	112	128

Examples of correct predicted WC, Examples of false alarm WC, Examples Predicted as Anomalies, Examples of miss WC.

## 5. Conclusions and Future Developments

- Promising performances of the AE-SAD model for the automatic detection of the WC (low miss and false alarm).
- Labelling of a larger part of the AMSU-A dataset.
- Retrain the model on the new labelled dataset.
- Apply the model to ATMS and SSMIS data.
- Consider to train a model using ATMS and SSMIS data (i.e., a single model for each radiometer).
- Consider the application of alternative models (DDPM/Score-Based)



- The dataset consists mostly of No-WC cases.
- The WC cases show different signatures (e.g., top-bottom vs bottom-top development, irregular shape, TB anomaly values generally lower than 2 K – not always the WC is easy to be detected).
- About 15% of the useful overpasses are labelled as WC.
- The input data consist of the TB anomaly matrix for the four channels considered (i.e., 53.596, 54.4, 54.94 and 55.5 GHz).

## 6. References

Angiulli F., Fassetti F., Ferragina L., Nisticò S., Explaining anomalies through semi-supervised Autoencoders, *Array*, Volume 28, 2025, 100537, ISSN 2590-0056, <https://doi.org/10.1016/j.array.2025.100537>.  
 Miglietta, M. M., and Coauthors. 2025. Defining Medicanes: Bridging the Knowledge Gap between Tropical and Extratropical Cyclones in the Mediterranean. *Bull. Amer. Meteor. Soc.*, 106, E1955–E1971, <https://doi.org/10.1175/BAMS-D-24-0289.1>.  
 Panegrossi, G.; D'Adderio, L.P.; Dafis, S.; Rysman, J.-F.; Casella, D.; Dietrich, S.; Sanò, P. Warm Core and Deep Convection in Medicanes: A Passive Microwave-Based Investigation. *Remote Sens.* 2023, 15, 2838. <https://doi.org/10.3390/rs15112838>

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