Impact of the Ocean – Atmosphere coupling on extratropical cyclone around the Mediterranean basin

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PhD SDC SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE

Background

Objective

Investigate the added values of the ocean-atmosphere coupling in reproducing the Mediterranean cyclones and their dynamical processes on a climate scale.

Projects

❖**MedCyclones COST Action (CA19109)** - European network for Mediterranean cyclones in weather and climate.

❖**Med-CORDEX** initiative (Ruti et al. 2016): **FPS air-sea** modelling pillar.

Context

- The **Mediterranean basin** is well recognized as one of the main climate change hotspots and one of the most active cyclogenetic area of the Northern Hemisphere with a large number of intense cyclones occurring every year.
- The **Mediterranean cyclones** present weaker intensities, smaller sizes and shorter lifetimes than other mid-latitude cyclones. Nevertheless, they are often responsible for extreme precipitation and strong wind events leading to **severe socio-economic and environmental impacts** over populated coastal areas.
- The **climatology** of Mediterranean cyclones has been deeply investigated in the past years, leading to a high agreement on the seasonal cycle and favourite locations of cyclogenesis.
- Open questions still remain on **the effects of the air-sea coupling** in cyclones dynamics that are associated with rapid exchanges processes and local scale patterns of Sea Surface Temperature (SST) rather than with large-scale distribution and spatial patterns.

  We expected that the detailed representation of such processes are necessary to correctly simulate the extreme events in the Mediterranean basin.

Models and Methods

➢**2 Simulations**: ENEA – REG regional Earth system model

Domain: Med-CORDEX; time period: 1982-2014; atmospheric horizontal resolution of 12 km and 51 vertical levels in the atmosphere.

1. **Standalone**: WRF model with prescribed SST from ERA5 (forced every 3 hours).
2. **Coupled**: WRF model coupled with the MITgcm ocean model, 1/12° resolution, 75 vertical levels (Fig.2).

➢**Method**:

❑ Storm track method based on mean sea-level pressure (MSLP), (CycloTRACK, Flaounas et al., 2014).

❑ We selected the 500 most intense cyclones, in terms of minimum MSLP, that present their mature stage within the area outlined by black lines in Fig 1.

❑ Within the 500 intense cyclones we have selected the same cyclones between the simulations to compute the same total area of influence of the cyclones where the associated fields are compared.
The analysis is shown for winter (DJF) and spring (MAM) where the cyclones are more frequent. In winter there are 150 same cyclones, while in spring 102 cyclones.
I.e. The area of influence of each cyclone is defined by a circular disk, with a radius of 500 km, centred in the minimum MSLP track point. The total area in winter and spring is shown in fig. 5a and fig. 6a.

➢**Analysis**:

1. Validation of the seasonal and spatial distribution of the 500 most intense Mediterranean cyclones against ERA5 dataset.
2. Comparison between coupled and standalone simulations in terms of cyclone associated fields, i.e. precipitation, evaporation, specific humidity and wind speed and their sensitivity to air-sea feedbacks and SST differences in winter and spring seasons.
I.e. The precipitation differences are normalized by the (spatial) 95th percentile of the mean precipitation to enhance the differences where the precipitation is higher.

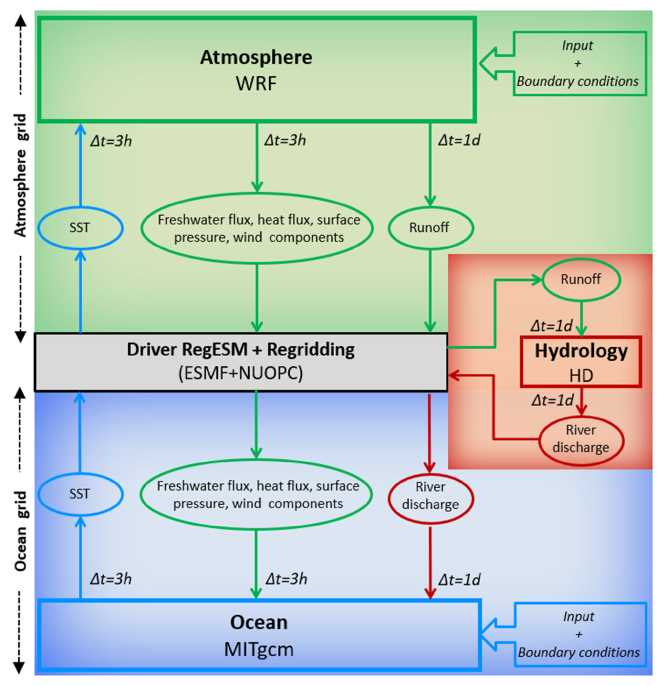

Fig. 2 ENEA – Reg regional Earth system model. (Anav et al., 2021)

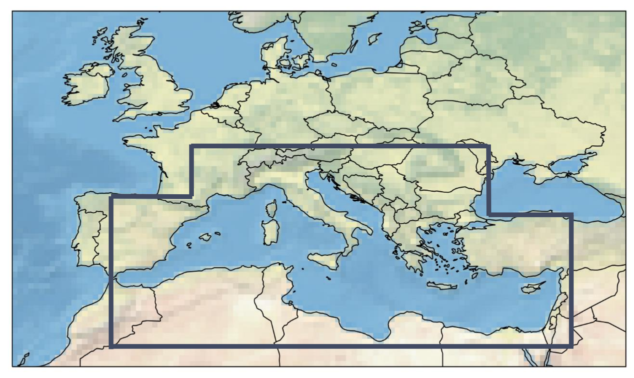

Fig. 1 Med-Cordex domain. Cyclone tracks have been retained if their mature stage is located within the area outlined by black lines. (Reale et al., 2021).

Results

500 most intense cyclones climatology – validation with ERA5

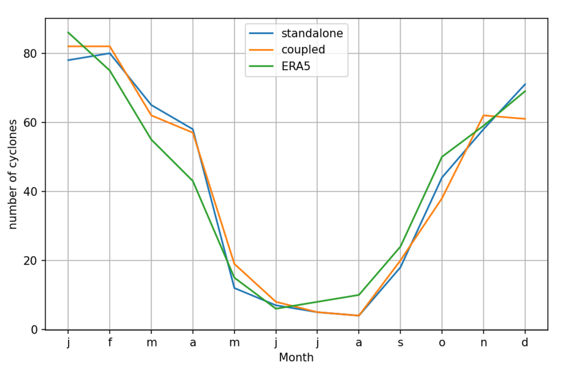

Fig. 3 Seasonal distribution of 500 most intense cyclones.

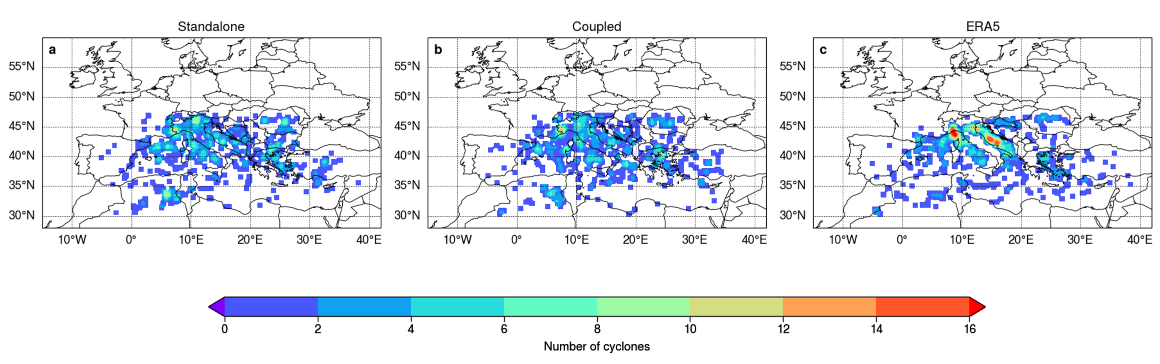

Fig. 4 Spatial distribution of 500 most intense cyclones.

- **Cyclone climatology, validation with ERA5:** (**Fig. 3** and **Fig. 4**):
  The most intense cyclones occur mainly during winter and spring and are similarly reproduced in RCMs and ERA5 both in terms of spatial and temporal distributions.
- **Cyclone associated fields:**

❑ **Winter (DJF)**, **Fig. 5**:
The coupled model present a warmer SST mostly over the entire Mediterranean Sea, except for the north part of the Adriatic Sea. The higher SST clearly promotes a higher evaporation over the sea and could also explain the higher specific humidity and wind speed over some sea areas. In fact, the stronger evaporation lead to a higher humidity and total precipitation over the sea as well as over costal area linked with the stronger wind, especially in Italy and Balkans regions. These areas are bathed by the north part of the Tyrrhenian and Adriatic Sea where the most intense cyclones are more frequent and probably, thanks to the air-sea feedbacks, they cause stronger heat and moisture surface losses in the coupled model. These processes need to be further investigate in future analysis.

❑ **Spring (MAM)**, **Fig. 6**:
Compared to the winter season, the coupled model still presents a warmer SST but with lower differences. However the wet behaviour is still visible and the difference over land are even more pronounced, because the lower overall SST difference is a balance between March and April where the SST is higher and May where it is lower. So, over some areas, the SST difference could explain also the higher specific humidity and precipitation in the coupled model, but other processes, like air-sea feedbacks, a stronger surface diabatic processes in spring and/or the stronger wind, could be the drive of the seen differences between models.

Cyclone associated fields: precipitation, evaporation, wind speed, specific humidity at 2m and SST

Winter (DJF) differences [coupled – standalone] (150 cyclones)

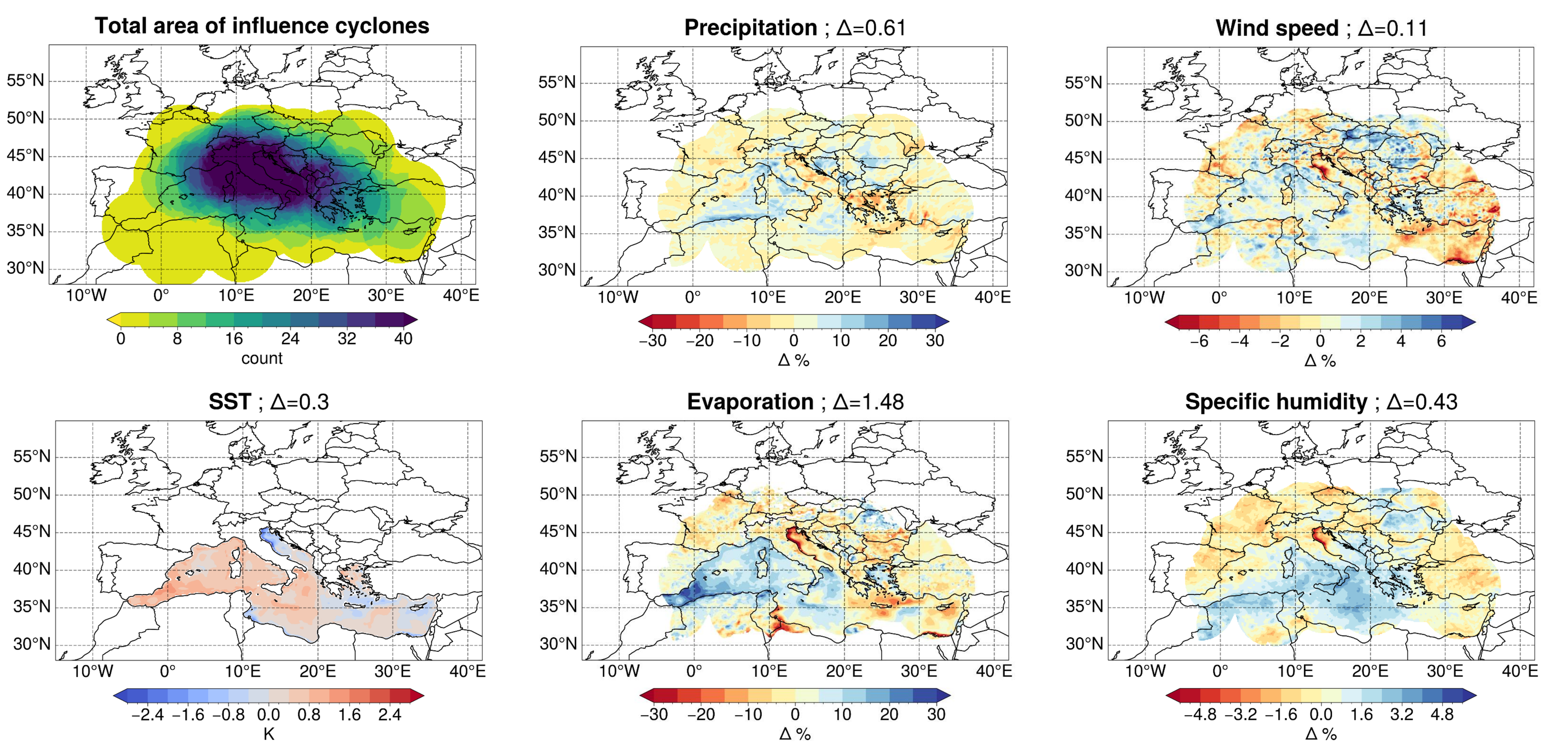

Fig. 5 Cyclone associated precipitation, evaporation, specific humidity at 2m and SST differences in winter.

Spring (MAM) differences [coupled – standalone] (102 cyclones)

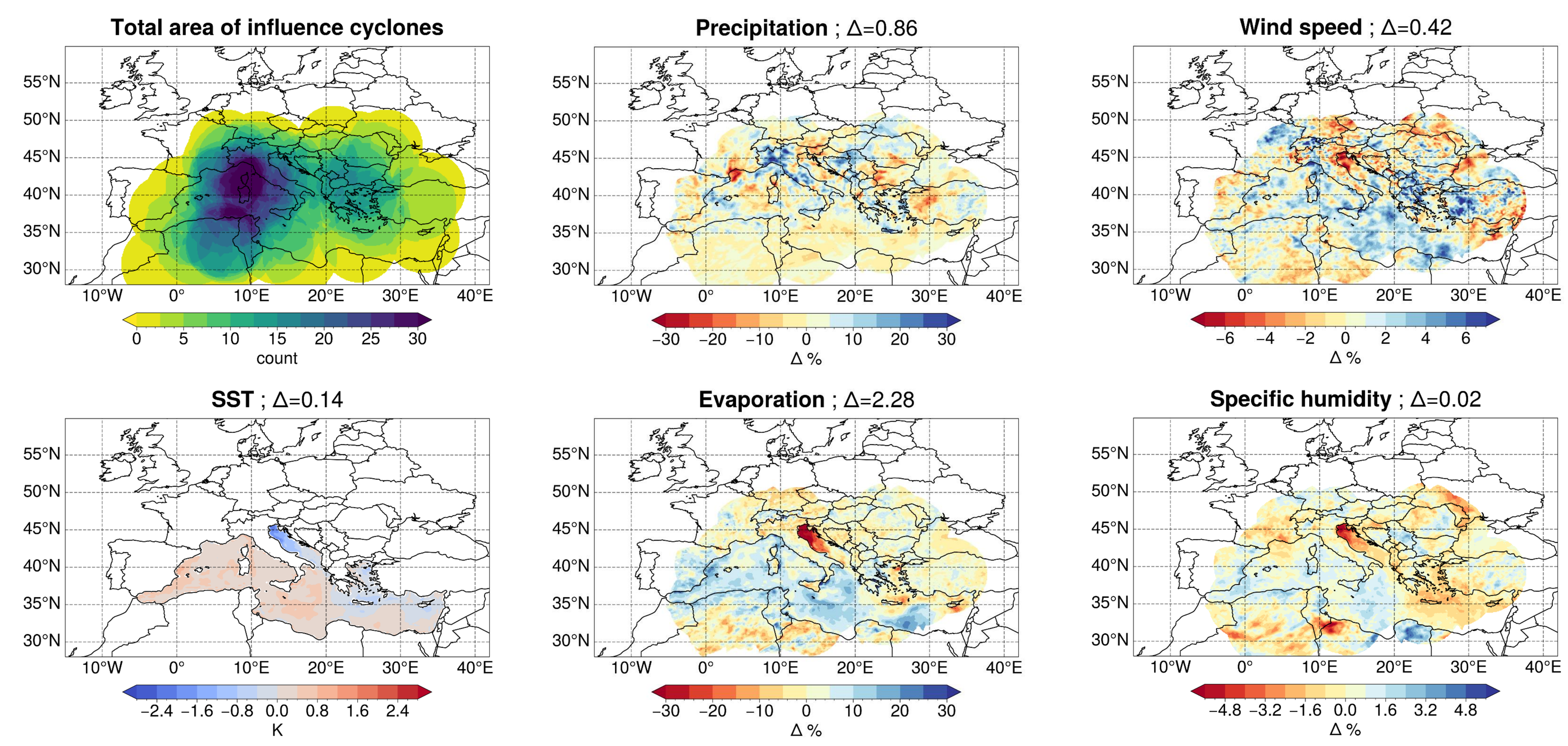

Fig. 6 Same as Fig. 5 but for the spring season.

Scatter plots cyclone associated fields differences in the Mediterranean Sea

Winter (DJF)

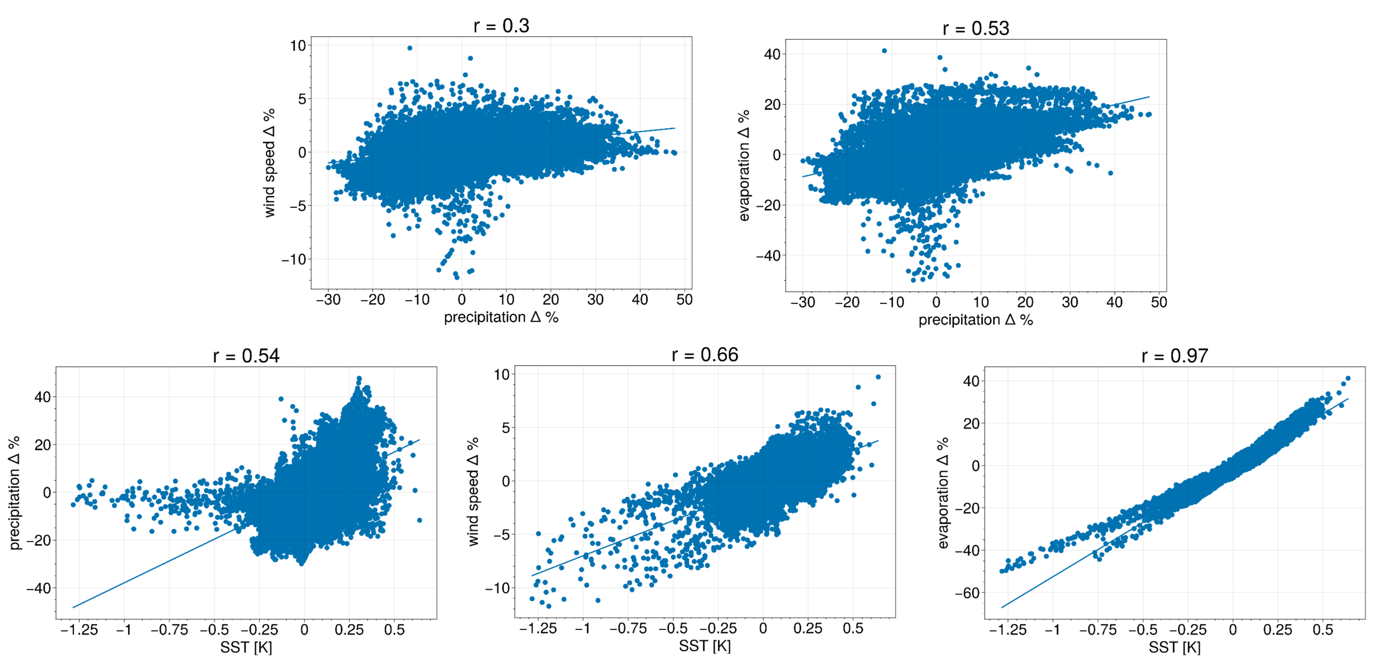

Fig. 6 Scatter plot of cyclone associated fields differences in Winter.

Spring (MAM)

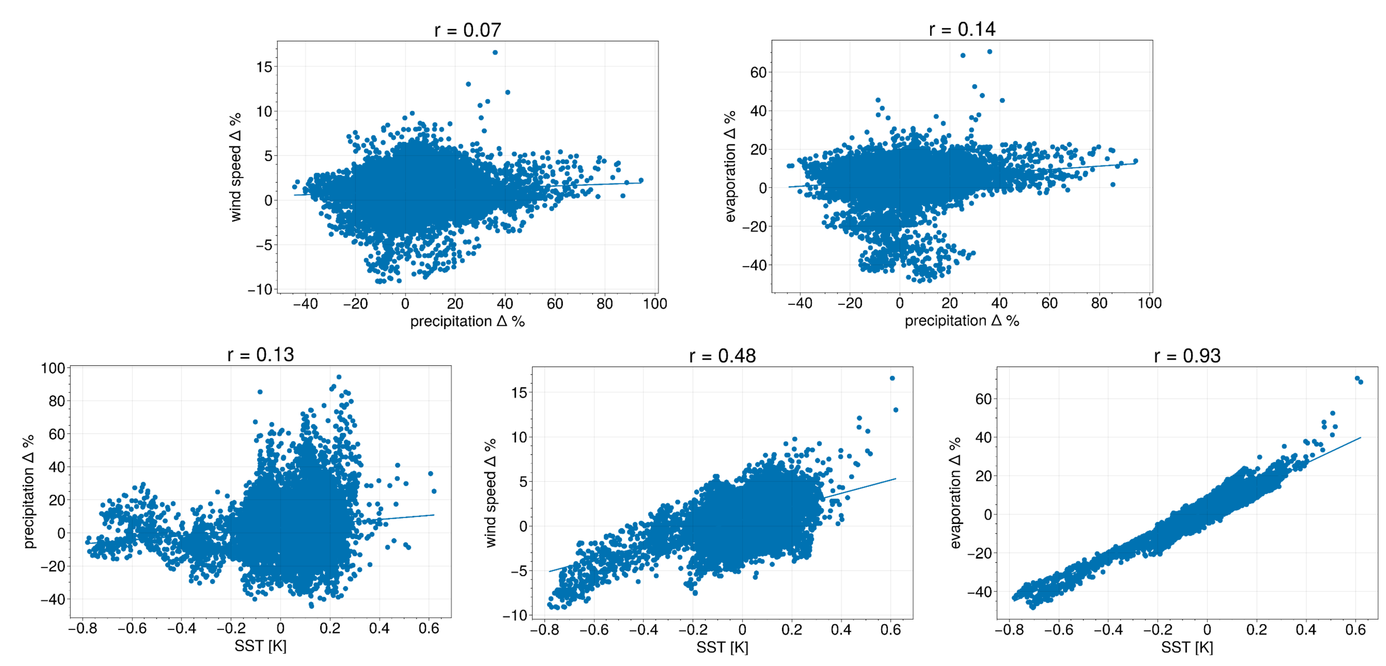

Fig. 8 Same as Fig. 7 but for the spring season.

- **Correlation between the difference in cyclone associated fields (Fig. 7 and Fig. 8)**:

❑ In both seasons both evaporation and wind speed are highly correlated with the SST, while precipitation does not appear linearly correlated with the other fields differences (SST, evaporation and wind speed)

❑ Spring shows lower correlation between variables compared to winter. This might be due to a more variability of the SST from march to may but also to a higher active diabatic surface processes that enhance the difference of the coupled model and lead to a higher spatial variability of the analysed fields (wind speed and precipitation) shown in fig. 6.

Conclusions

- In both seasons, the SST differences appear to promote evaporation and wind speed in the coupled compared to the standalone model.
- Over some areas, the difference in SST could explain also the higher specific humidity and precipitation in the coupled model, but other processes, like air-sea feedbacks and/or the stronger wind, could be the drive of the seen differences between models. However further analysis are required to proved it.
- To this end we will investigate some specific cyclones, medicanes, where the surface processes are dominant during the development of the cyclones, to find new insight on the beneficial impacts of the high resolution air-sea coupling.

References

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