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Extreme cyclones in a global and regional climate model in the central Mediterranean

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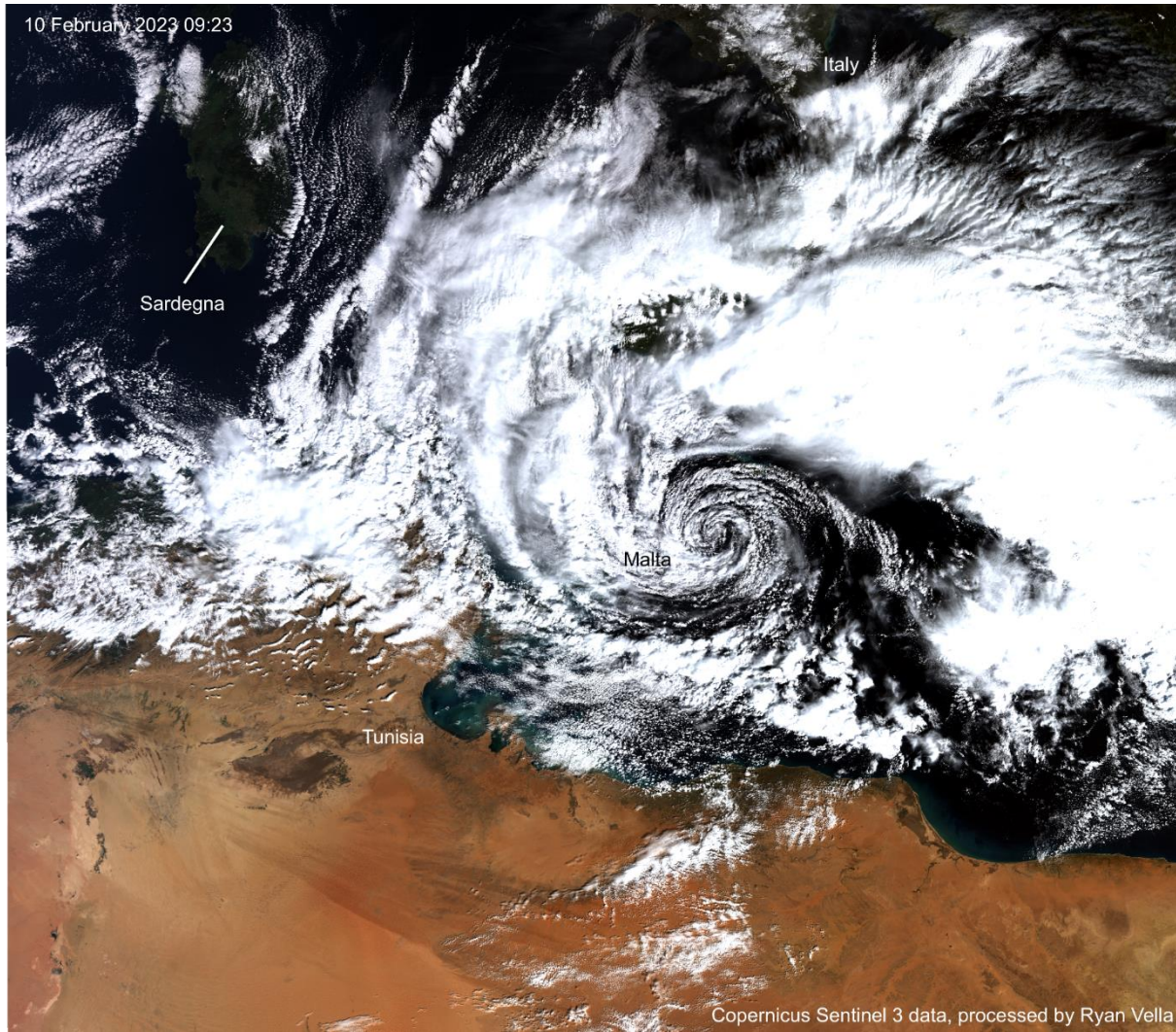

Why study cyclones in the Mediterranean?

- Cyclones play dominant role in the Mediterranean
  - Important source of water
- Causes of extreme weather.
  - Extreme wind and precipitation
  - Floods
- Mediterranean heavily influenced by climate change
  - Hotter, drier and less cyclone activity
  - Impact of future climate change on extreme cyclones not well-known
  - Impact of past climate changes on Mediterranean cyclones not understood

El Atazar Dam in Spain

Aftermath of storm Minerva in Italy May 2023

Outline

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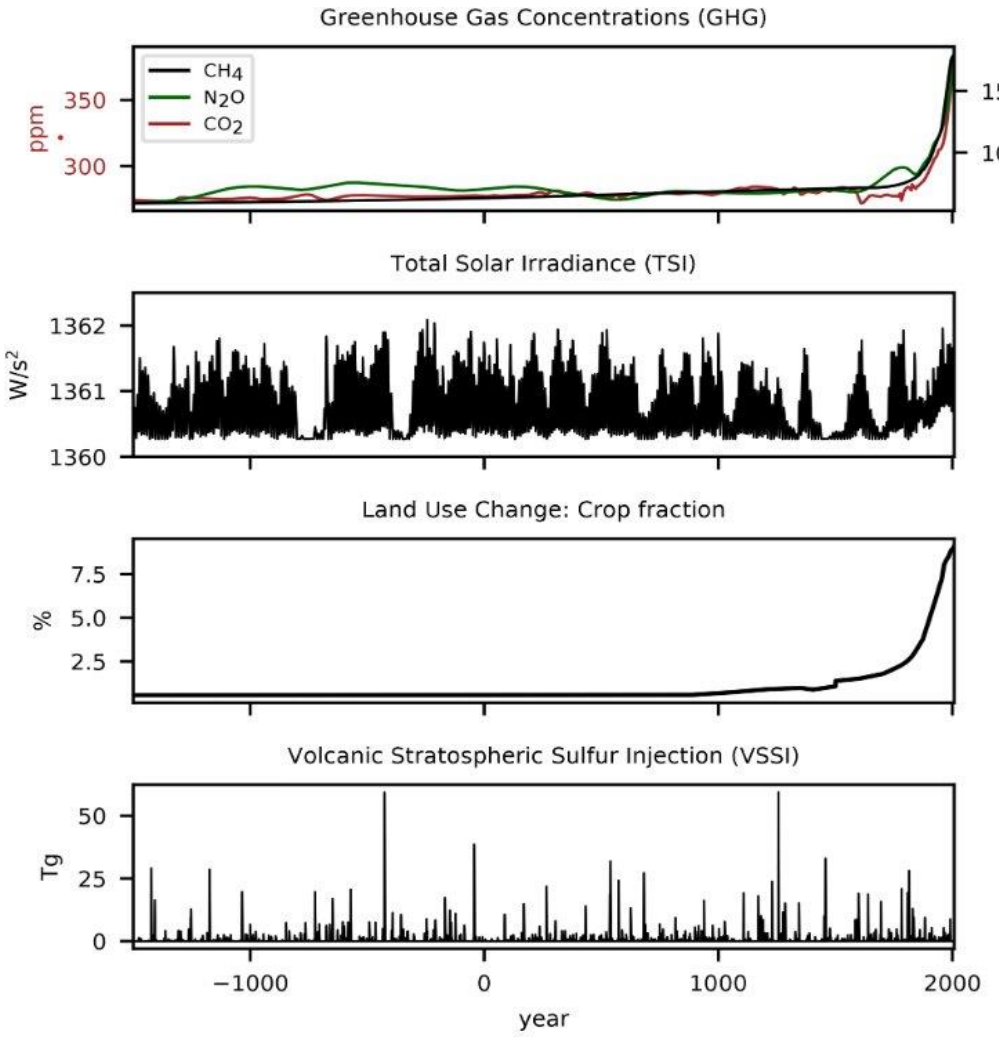
- Part 1: Extreme cyclones in the central Mediterranean during the late Holocene
  - Coarse global circulation model for last 3500 years
  - Cyclone variability
- Part 2: Extreme cyclones in the central Mediterranean in the recent past and future
  - Downscaling using regional model
  - Impact of future climate change on central Mediterranean cyclones
- Conclusion and Outlook

Community Earth System Model (CESM)

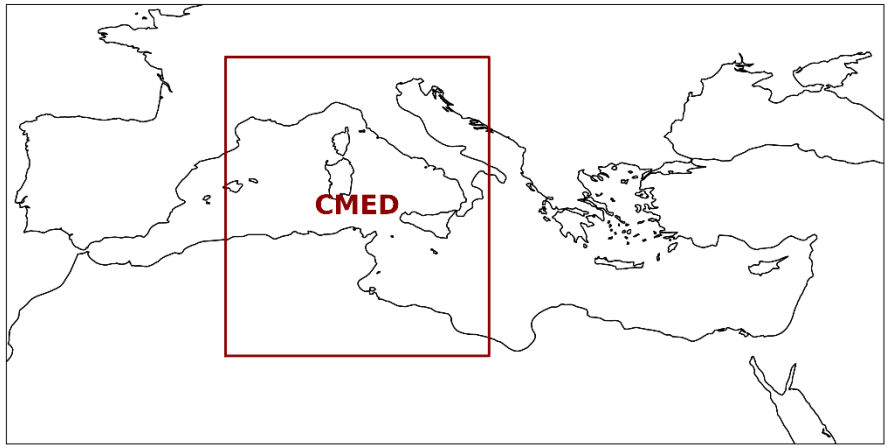
- 1.9º x 2.5º – 30 vertical levels
- 1500 BCE – 1850 CE (2100)
- 6-hourly temporal resolution
- Forcings based on historical data
  - GHG concentrations
  - Solar irradiance
  - Land use change
  - Volcanic Eruptions
- Reanalysis data
  - ERA5
  - Regridded to 1.9º x 2.5º

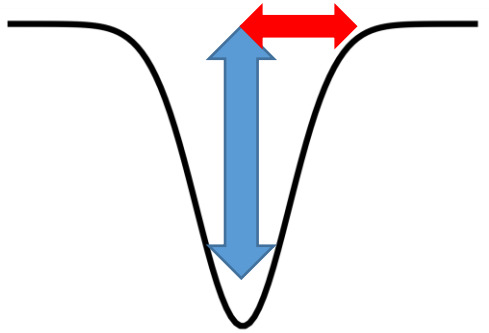


Kim et al. (2021)

Study region and cyclone tracking algorithm

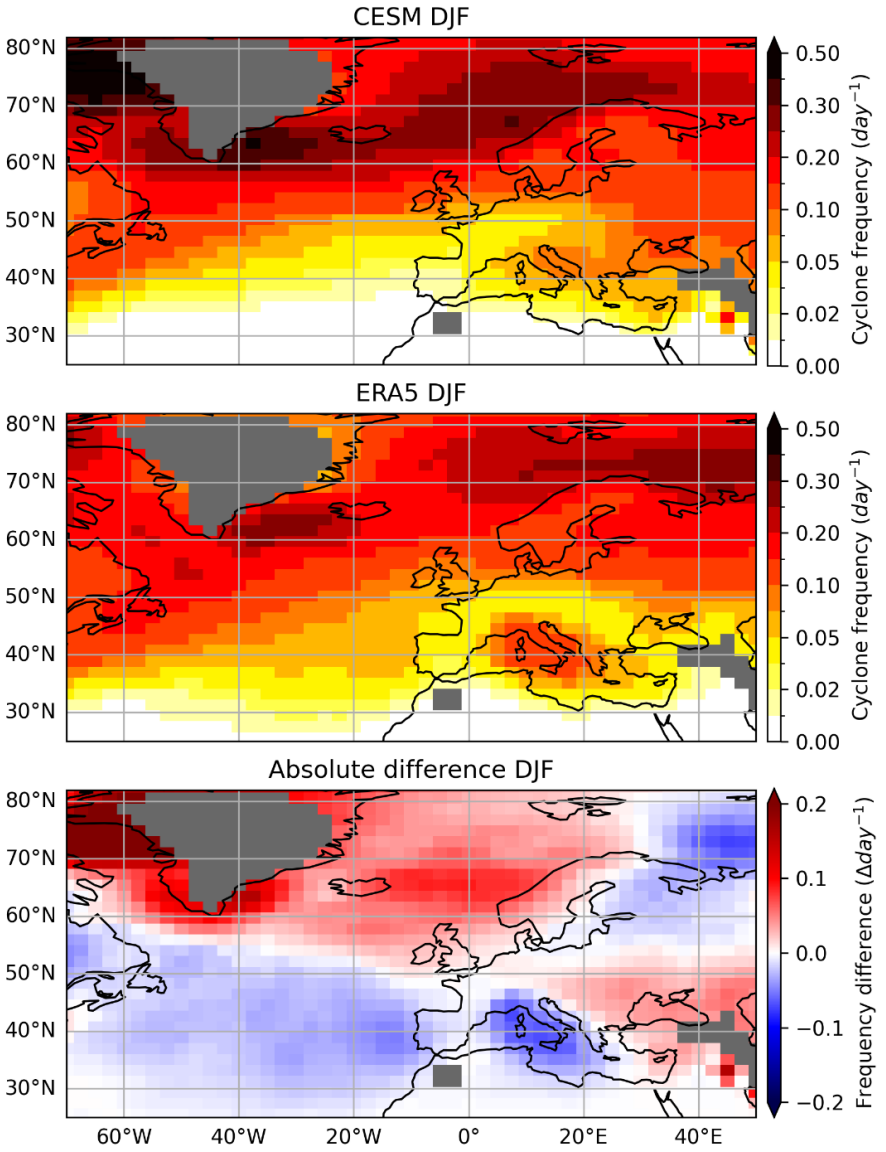
- Focus on central Mediterranean
  - Between 30º - 47º N and 2.5º - 17.5º W
- Cyclone tracking algorithm
  - Blender et al. (1997)
  - Minima in 1000 hPa geopotential height
  - Orography < 1000 m
  - Minimum gradient along track
  - Minimum lifetime of 24h
- Output
  - Depth – Radius – Gradient
  - Cyclone-related precipitation and wind speed
- All analysis for DJF





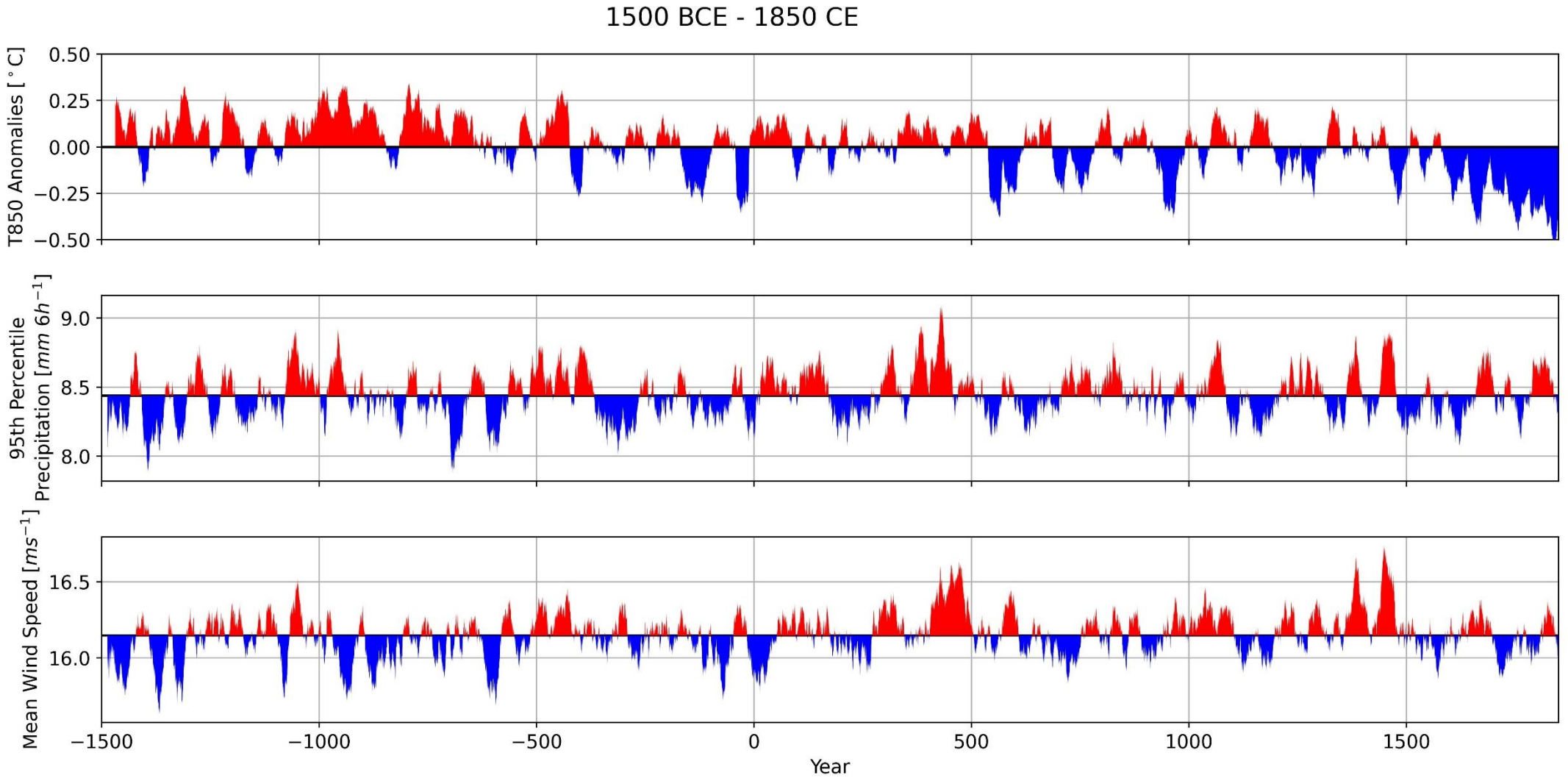
Cyclone Frequency: CESM vs ERA5

- Cyclone frequency per day
  - Common period (1981 – 2010)
  - Gray shading: grid cells > 1000 m
- CESM captures general storm tracks, however:
  - CESM is too zonal and northward shift of storm tracks
- Large underestimation of cyclone frequency in central Mediterranean



Doensen et al. (in review CP)

Cyclone variability in the late Holocene



Doensen et al. (in review CP)

Part 2: Extreme cyclones in the central Mediterranean in a regional climate model.

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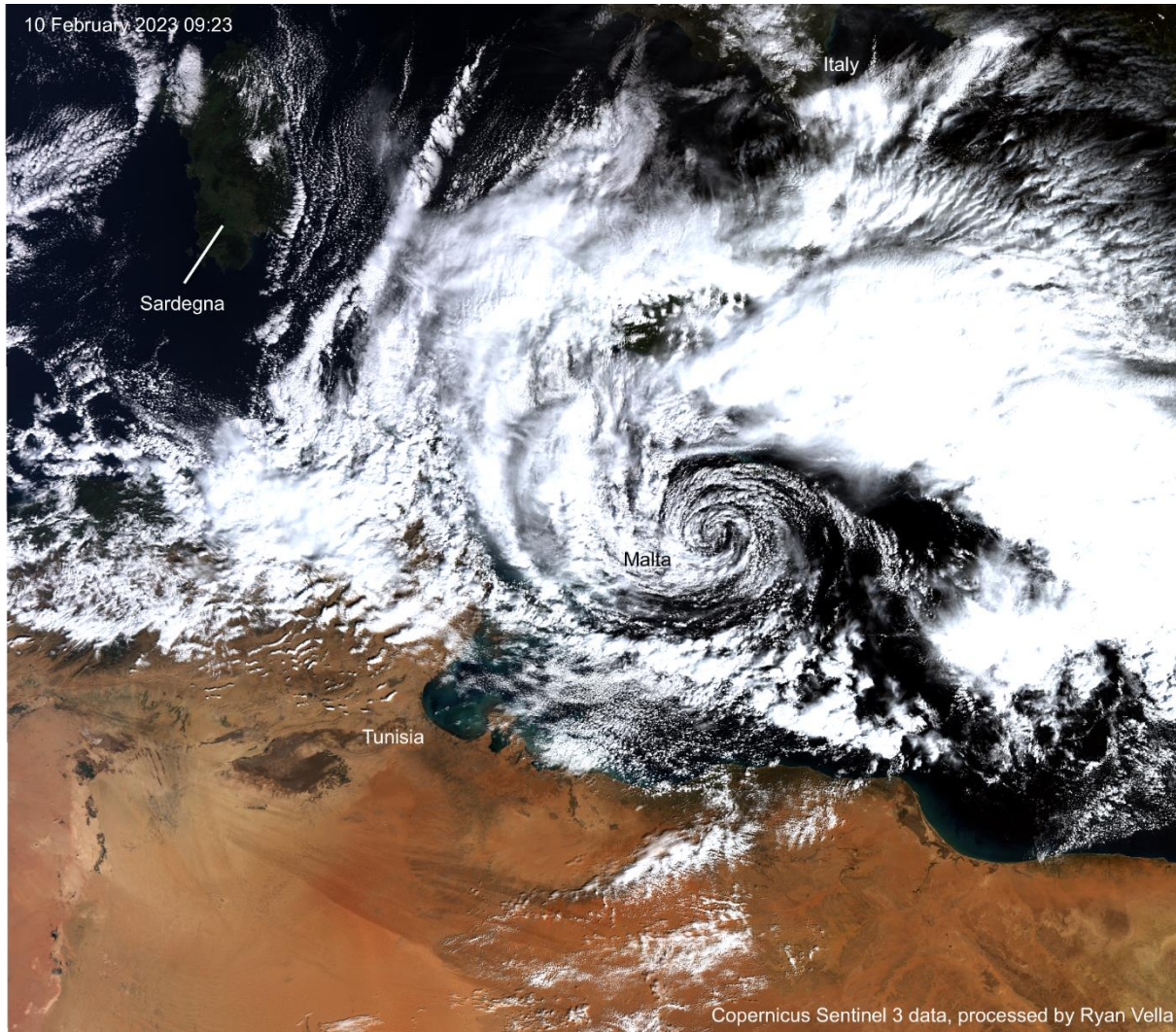
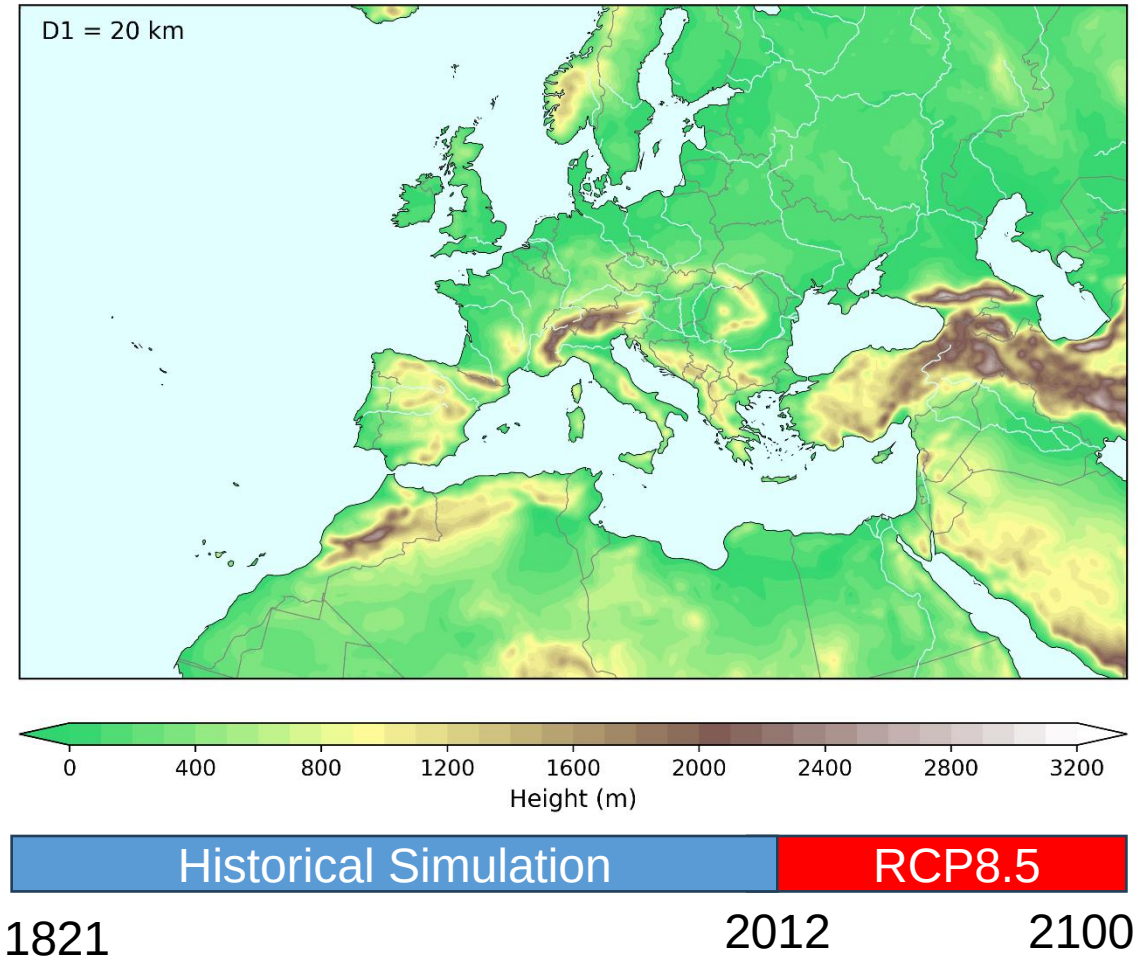


Downscaling from global to regional scales

- Weather Research & Forecasting (WRF) model
  - CESM provides input and boundary conditions
  - Single domain with 20 km horizontal resolution
  - 1-hourly temporal resolution
- 280 years of data (1821-2100)
- Tracking algorithm same as for CESM
  - Regridding to 100 km resolution
  - 850 hPa geopotential height
  - Minimum lifetime of 12 hours



Cyclone Frequency in WRF

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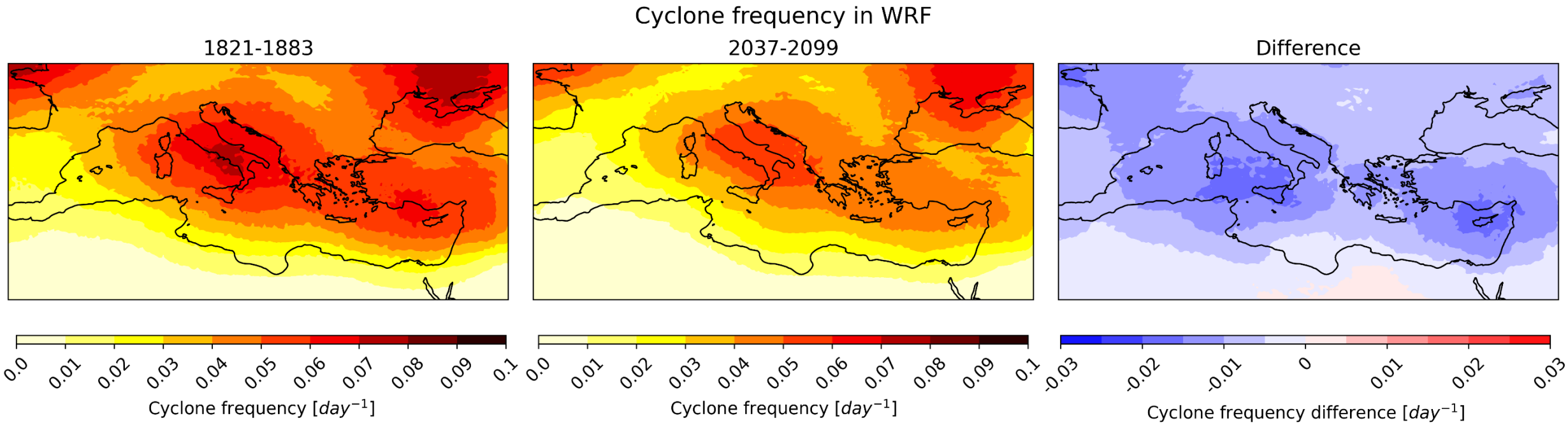
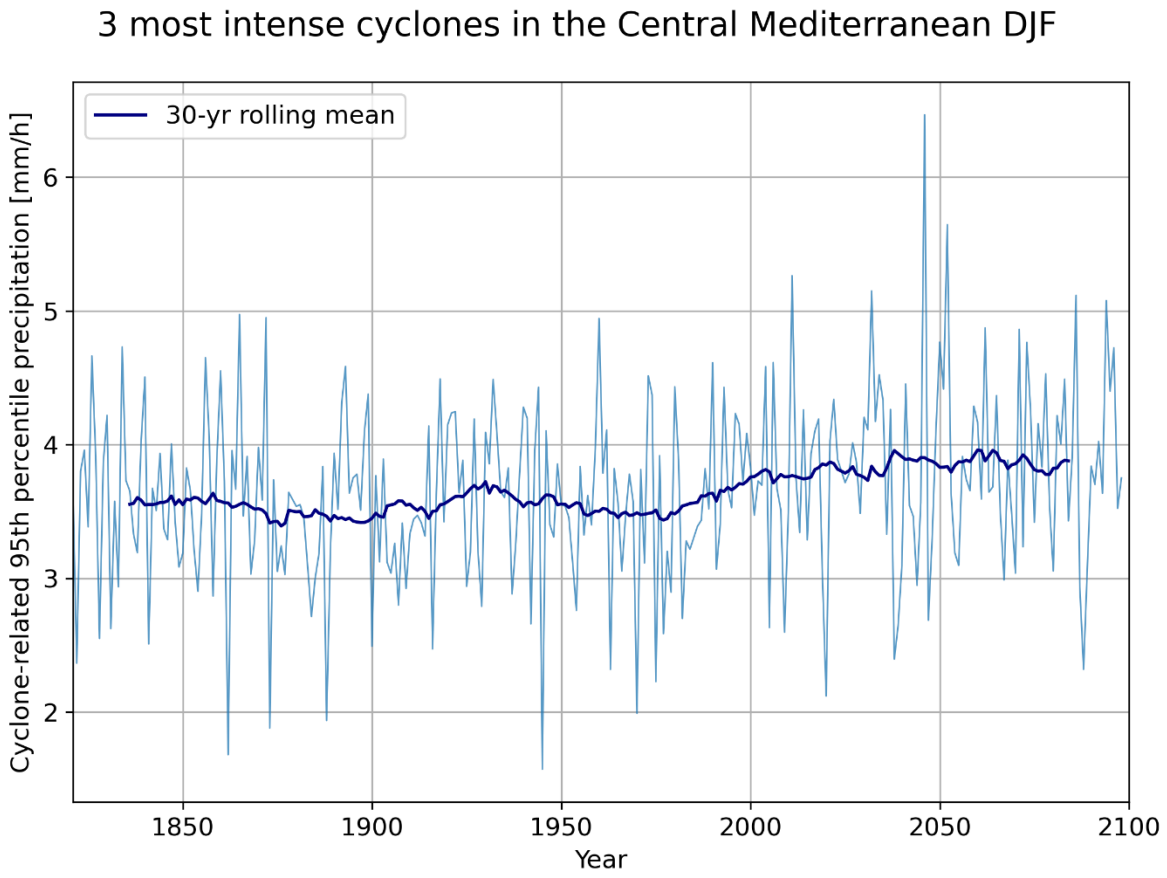


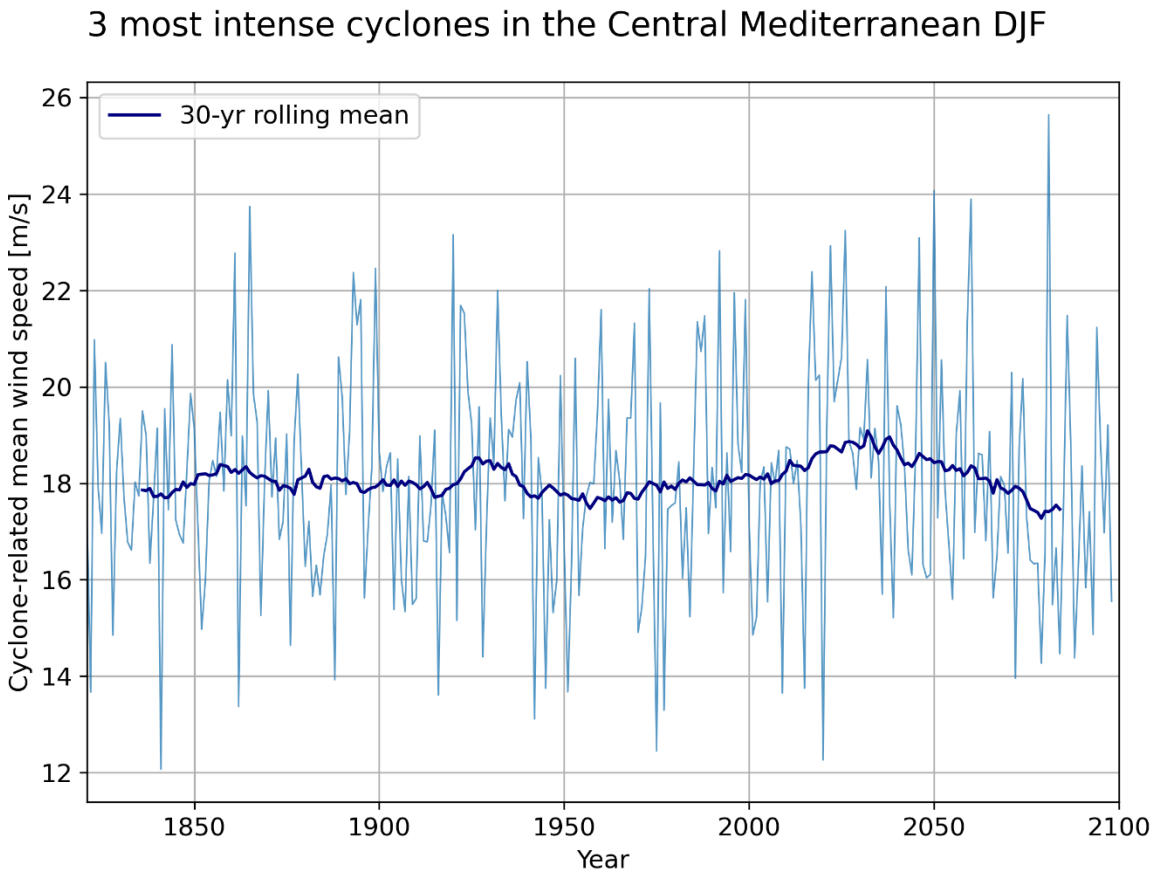
Cyclone-related precipitation in winter

- 3 most intense cyclones with respect to precipitation
  - Average 95th percentile cyclone-related hourly precipitation
  - High year-to-year variability
- Rising temperatures lead to more intense cyclone-related precipitation.
  - Increase 10-15%



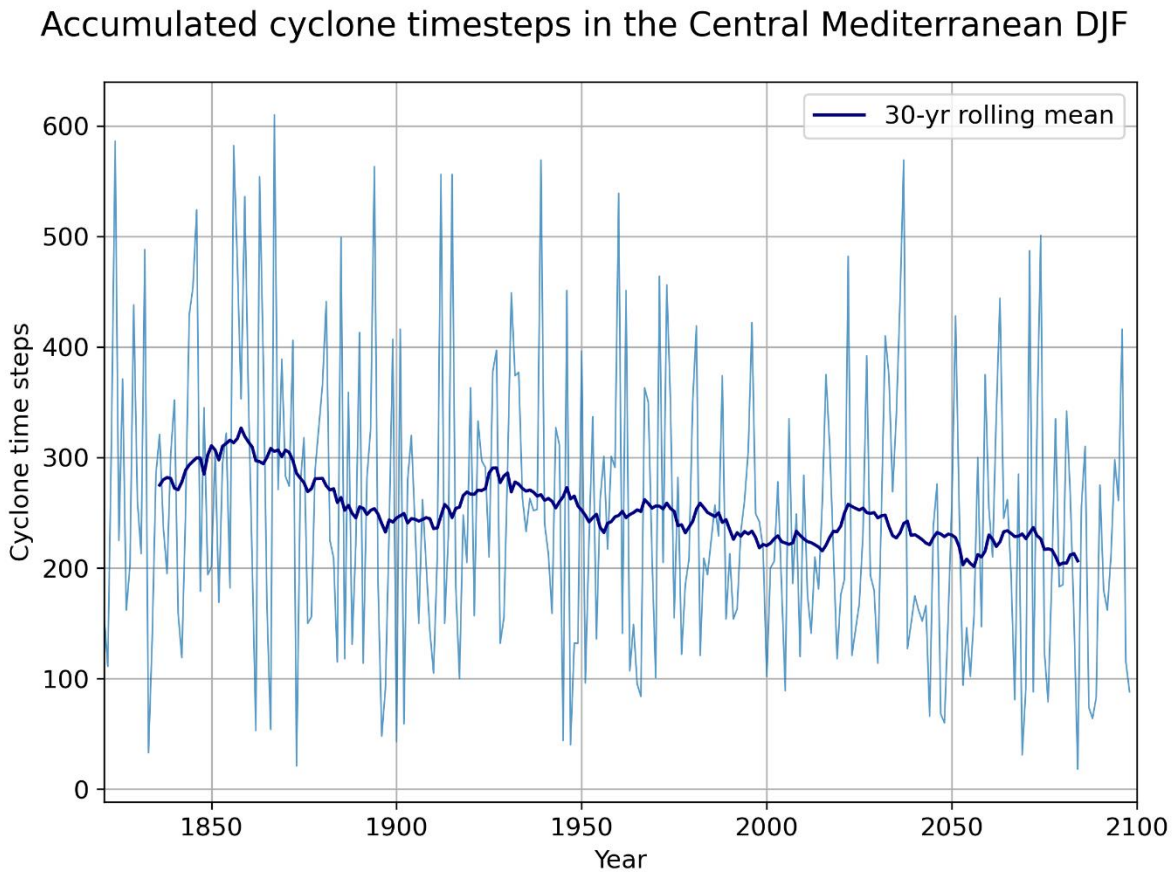
Cyclone-related wind speed in winter

- 3 most intense wind cyclones per year
  - Mean cyclone-related wind speed at minimum cyclone pressure
- No clear impact of climate change
  - More intense wind cyclones
  - Climate change or natural variability?

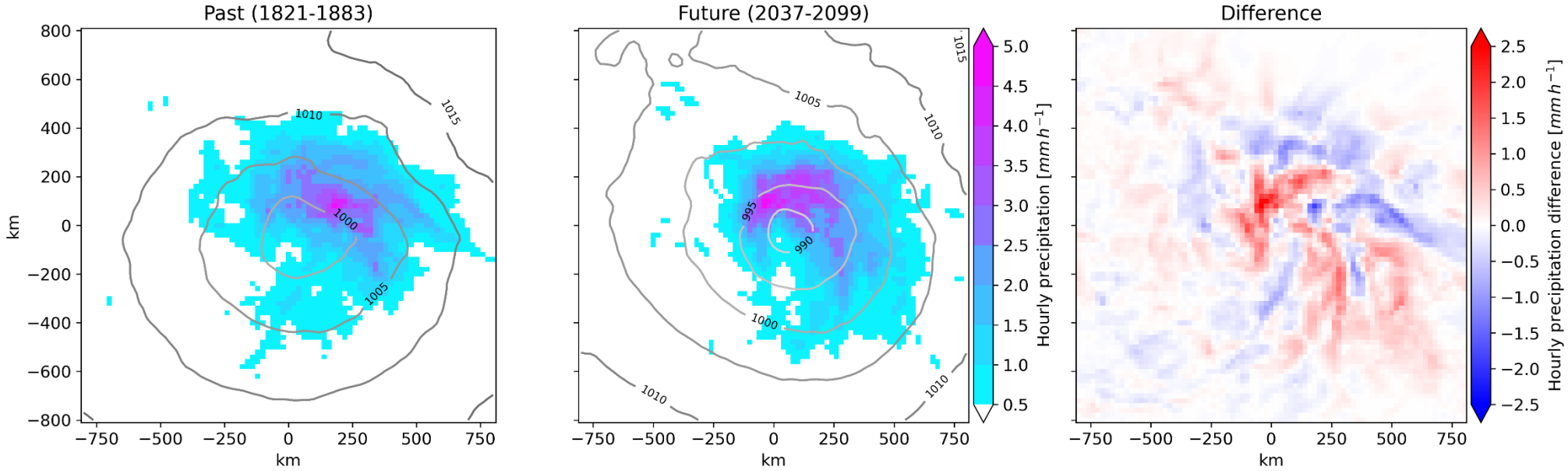


Cyclone Frequency in winter

- Accumulated cyclone timesteps within central Mediterranean
- Clear decrease in cyclone frequency due to climate change
  - Up to 33% reduction
  - Reduction already apparent in 20th century

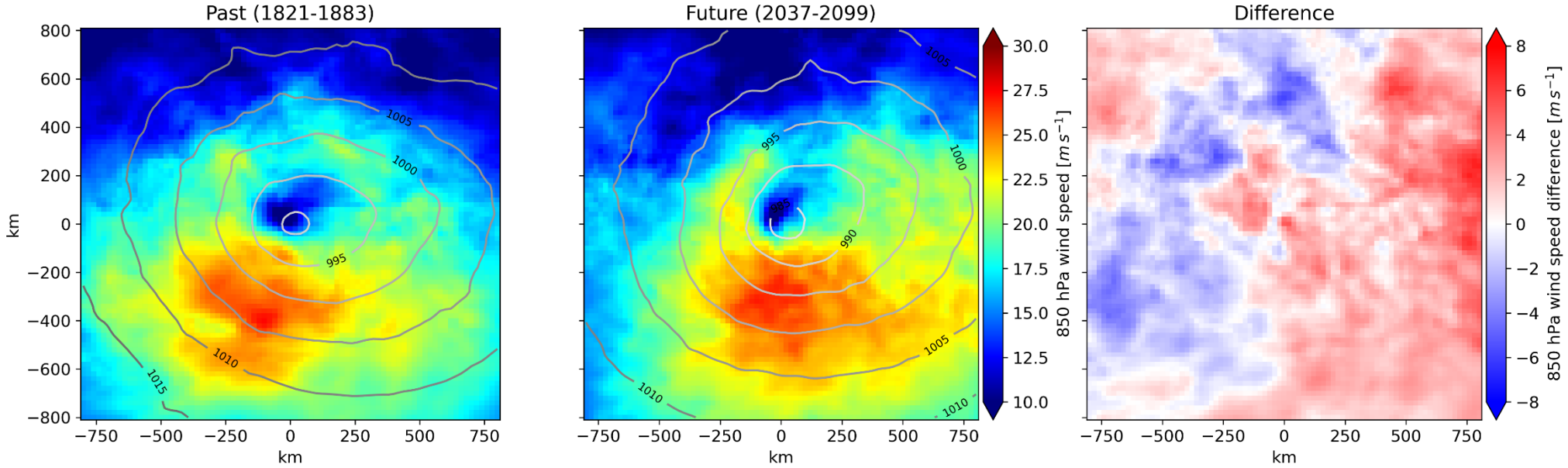


Extreme precipitation cyclones composites: past vs future



- 20 most extreme cyclones with respect to 95th percentile cyclone-related precipitation
- Highest precipitation north of cyclone core
- Clear precipitation increase in the future
  - Largest intensification north and east of core
  - Increase of up to 50%
- Deepening of cyclone core pressure

Extreme wind cyclones composites: past vs future



- 20 most extreme cyclones with respect to mean cyclone-related wind speed
- Highest wind speeds south of cyclone core
- Wind field gets more intense.
  - Increase around 10%.
  - Eastward shift.
- Decrease of cyclone core pressure.
- Natural variability

Conclusion

- Central Mediterranean cyclones exhibit clear multi-decadal variability in CESM
- In the future the central Mediterranean impacted by fewer cyclones, but:
  - Clear increase in cyclone-related precipitation due to climate change.
  - Not clear impact of climate change on cyclone-related wind speed.
- Socio-economic impact of extreme cyclones in the central Mediterranean will increase, mainly because of precipitation.

Outlook

- Extend analysis to more regions in the Mediterranean.
- Find relation between extreme cyclones in the regional model and the global model.
  - When are cyclones extreme in both models, and when are they not?
- Downscale extreme cyclones in the global model to convective permitting resolution.

Thank you very much!

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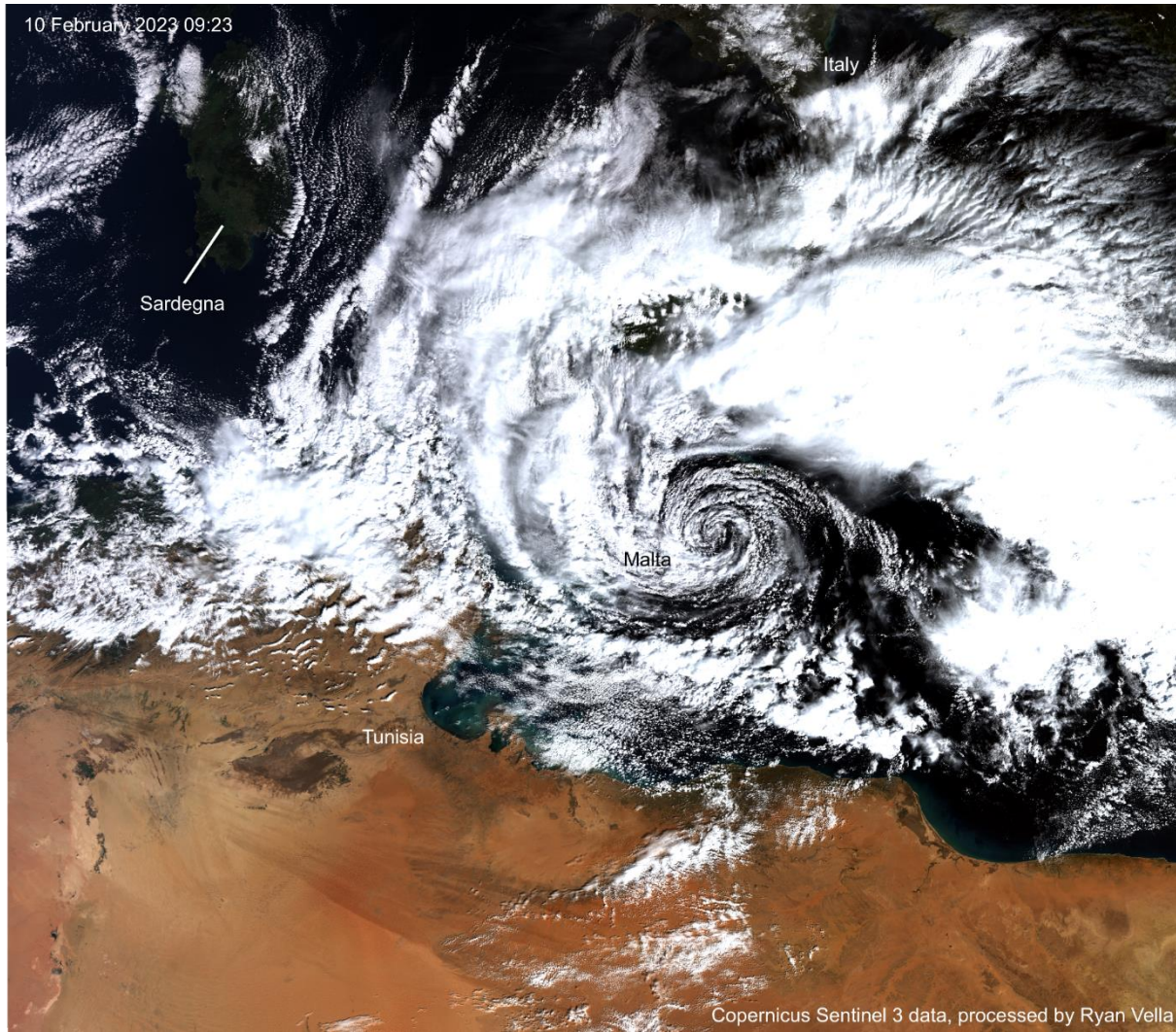
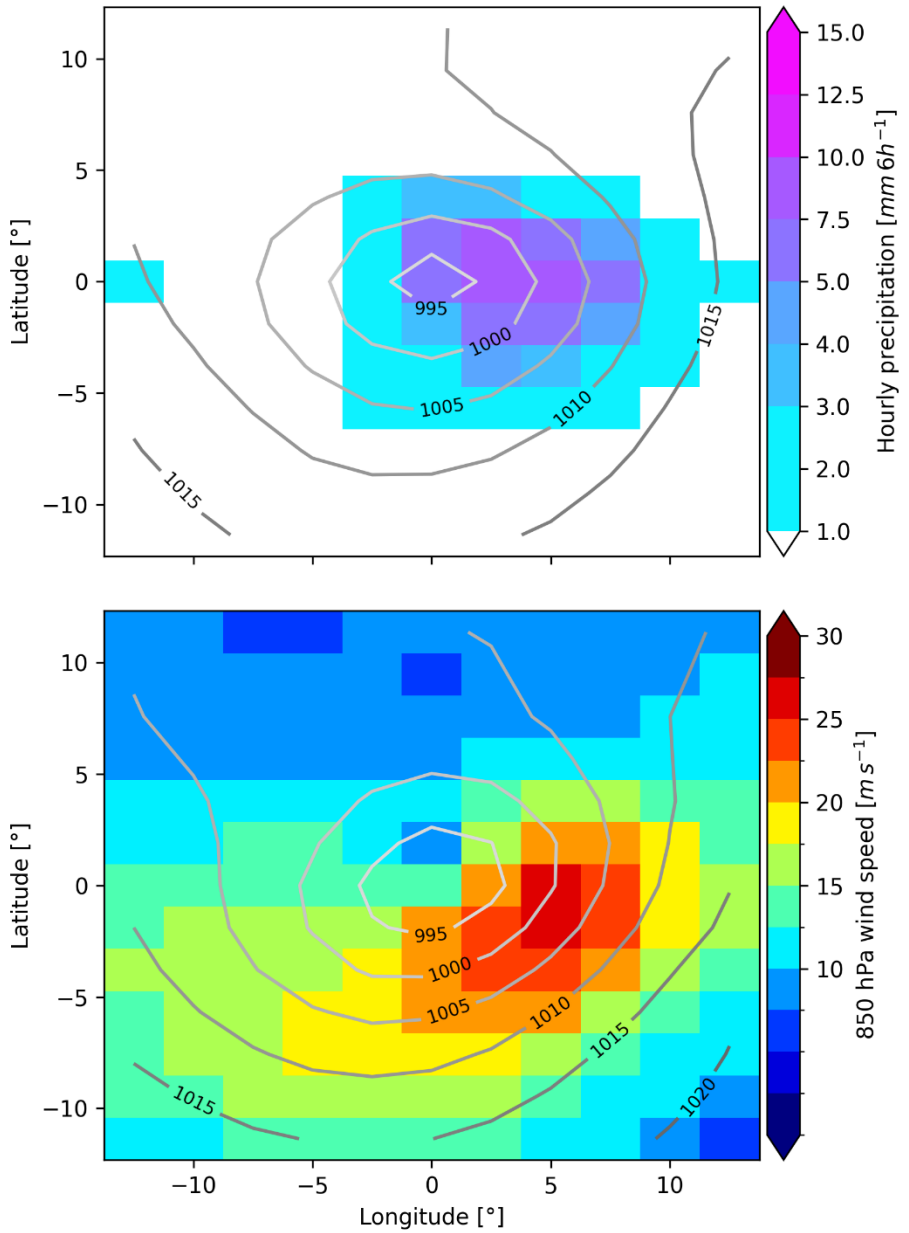
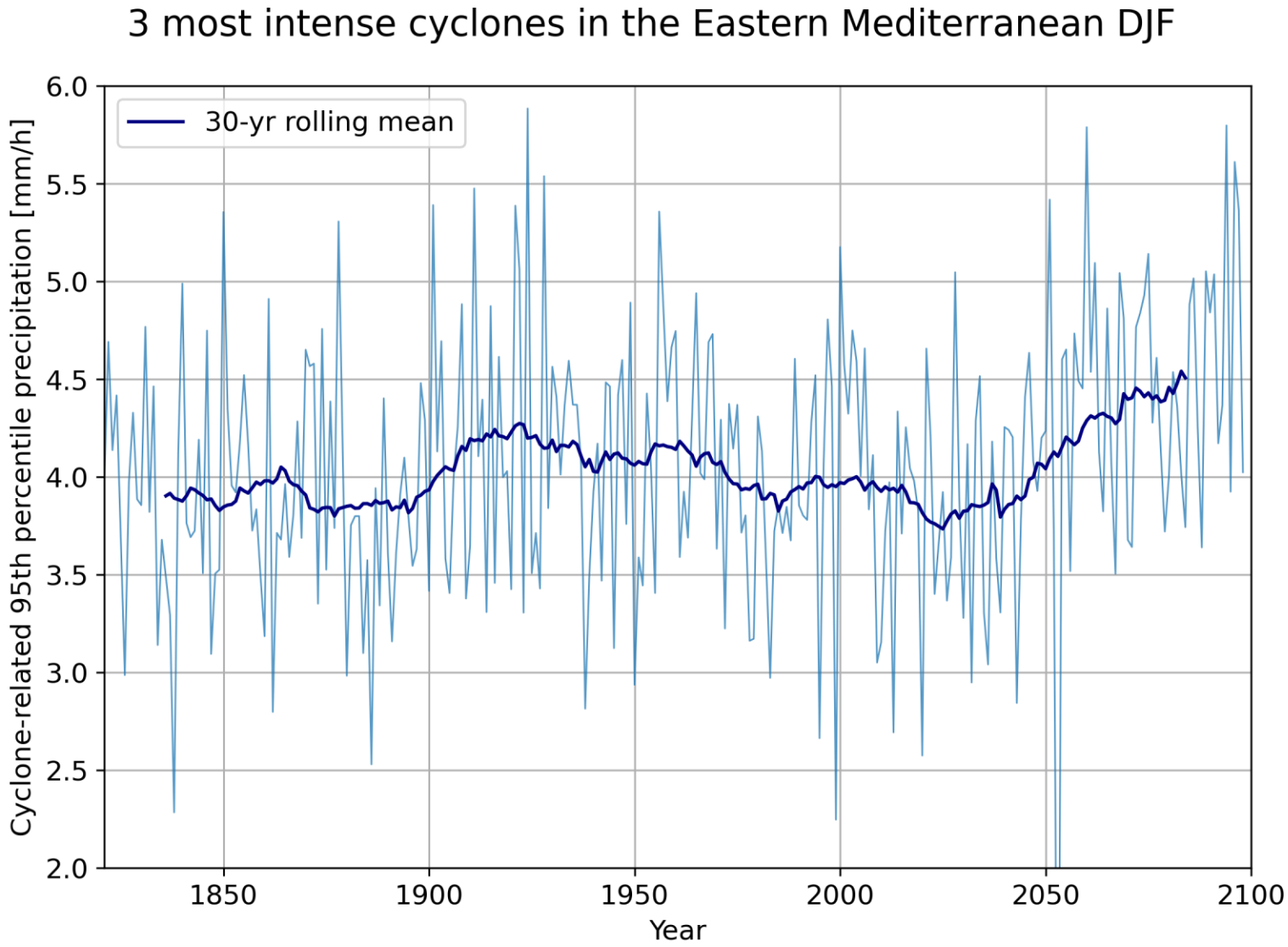
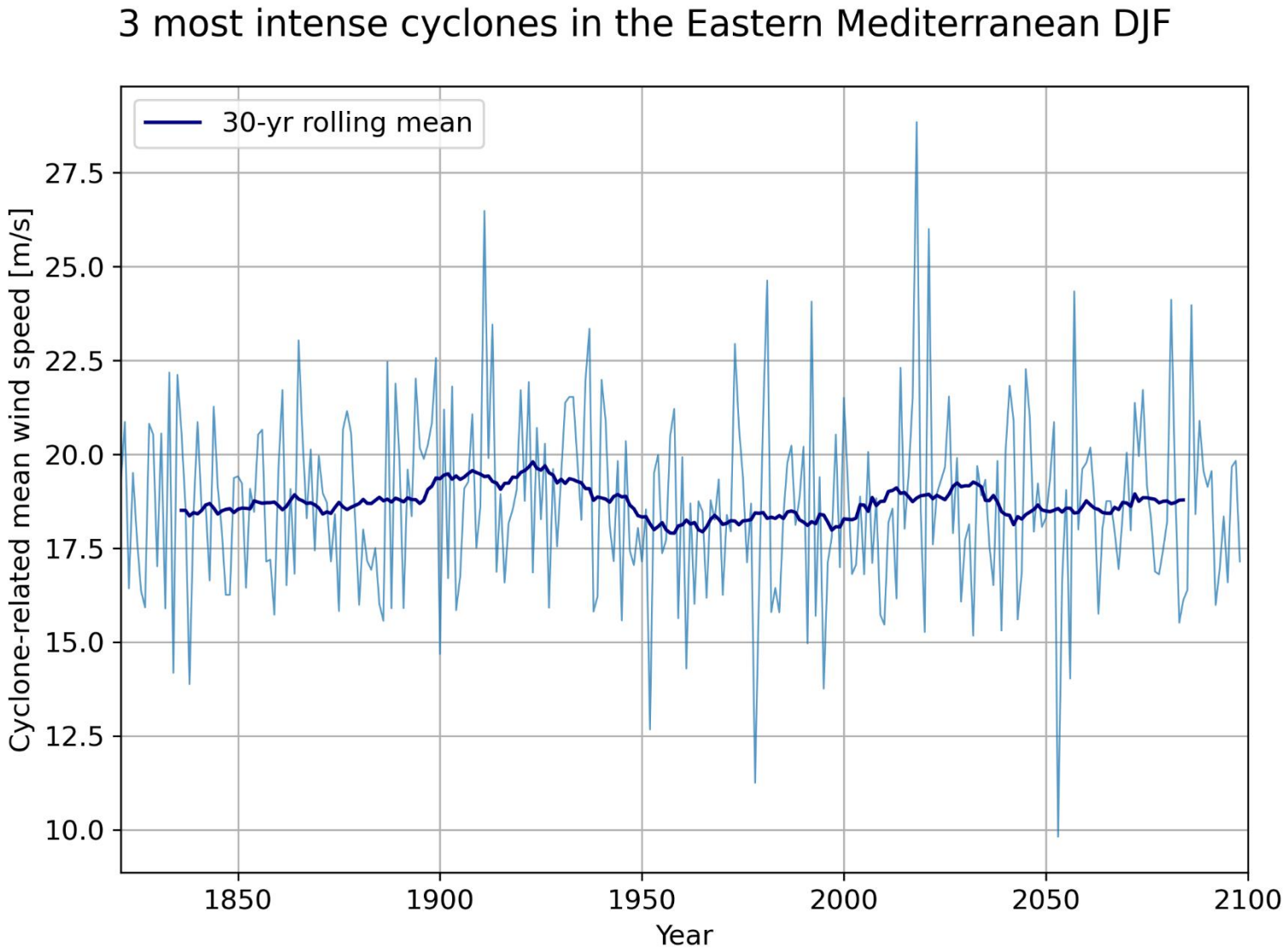
Characterization of the mean and extreme Mediterranean cyclones and their variability during the period 1500 BCE to 1850 CE.
Doensen et al. 2024 – Climate of the Past (in review)

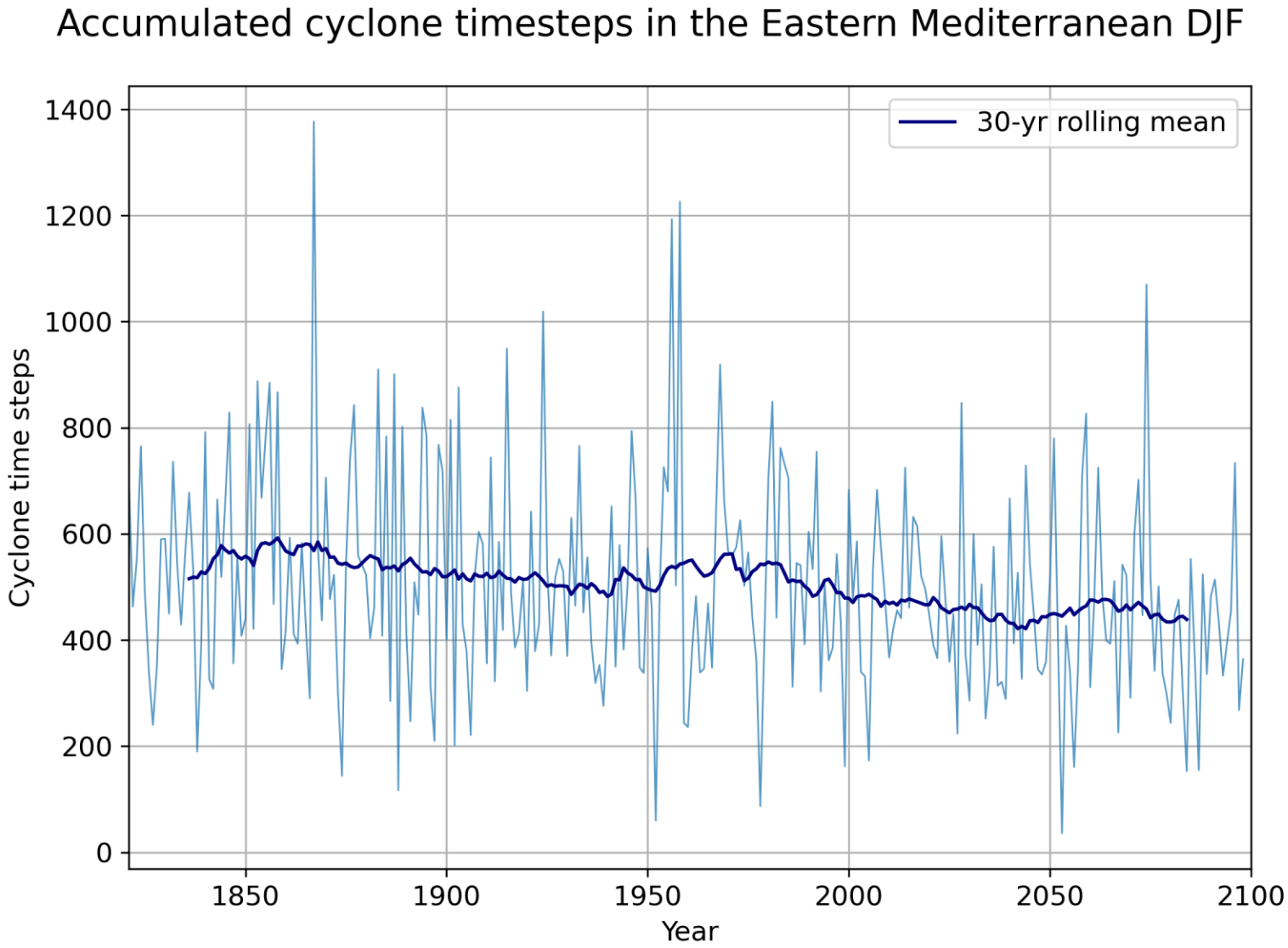


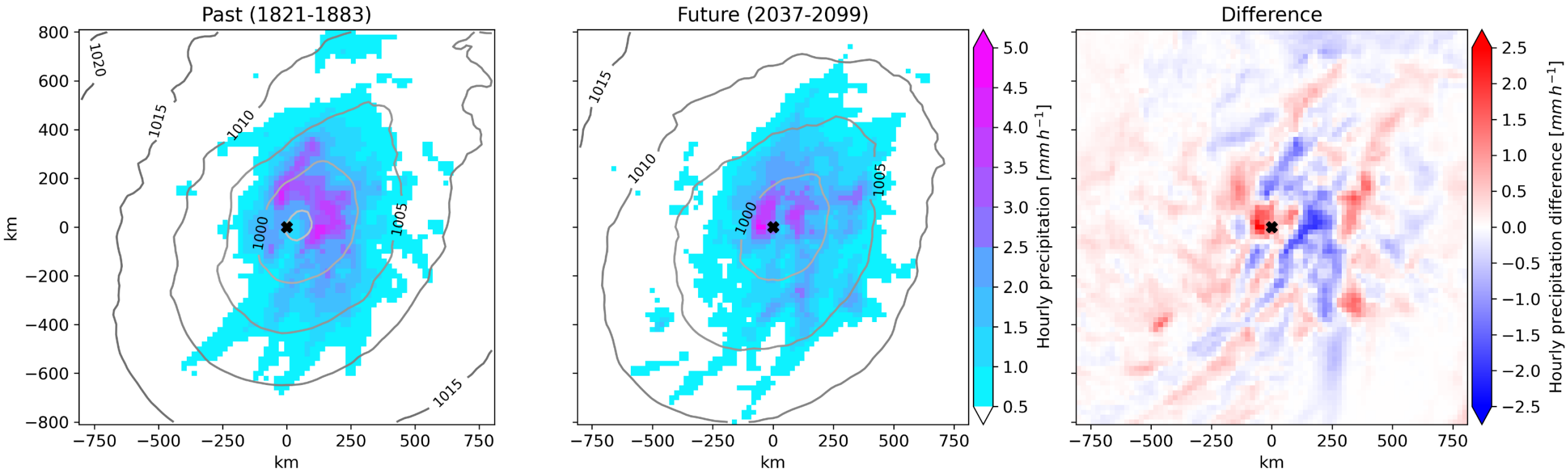
100 most extreme cyclones in the Central Mediterranean in CESM

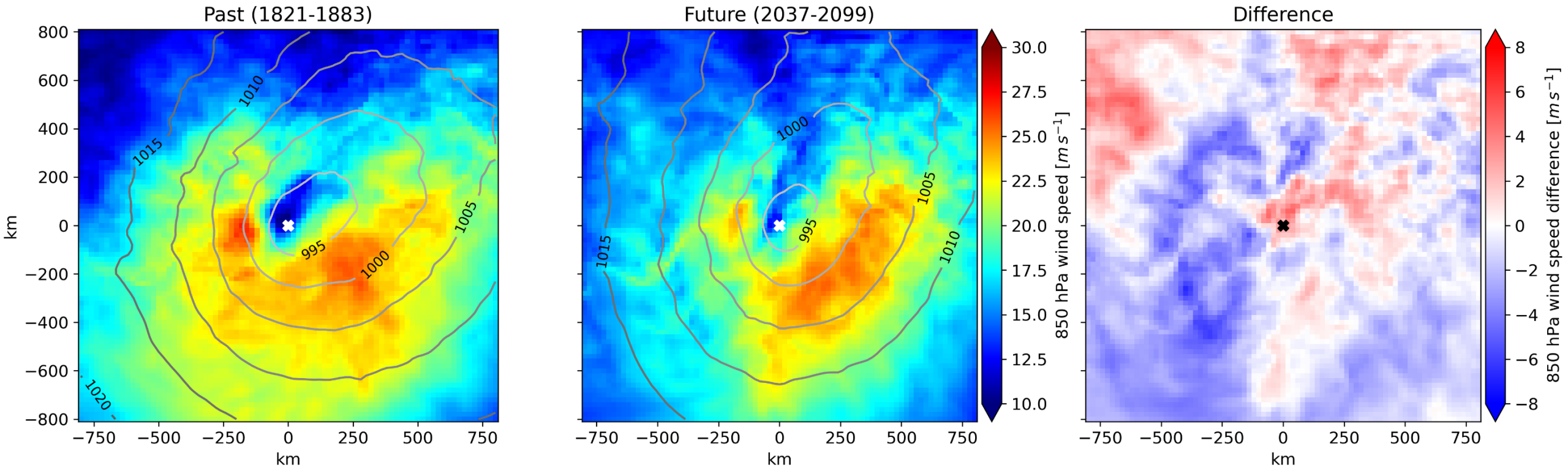



3 most intense cyclones in the Eastern Mediterranean DJF
30-yr rolling mean
Cyclone-related 95th percentile precipitation [mm/h]
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1850
1900
1950
2000
2050
2100
Year


3 most intense cyclones in the Eastern Mediterranean DJF
30-yr rolling mean
Cyclone-related mean wind speed [m/s]
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
1850
1900
1950
2000
2050
2100
Year


Accumulated cyclone timesteps in the Eastern Mediterranean DJF
30-yr rolling mean
Cyclone time steps
0
200
400
600
800
1000
1200
1400
1850
1900
1950
2000
2050
2100
Year


Past (1821-1883)
Future (2037-2099)
Difference
km
km
km
Hourly precipitation [mm h⁻¹]
Hourly precipitation difference [mm h⁻¹]
1020
1015
1010
1005
1000


Past (1821-1883)
Future (2037-2099)
Difference
km
km
km
850 hPa wind speed [$m\,s^{-1}$]
850 hPa wind speed difference [$m\,s^{-1}$]
1010
1015
995
1000
1005
1020