Storm Daniel fueled by anomalously high sea surface temperature

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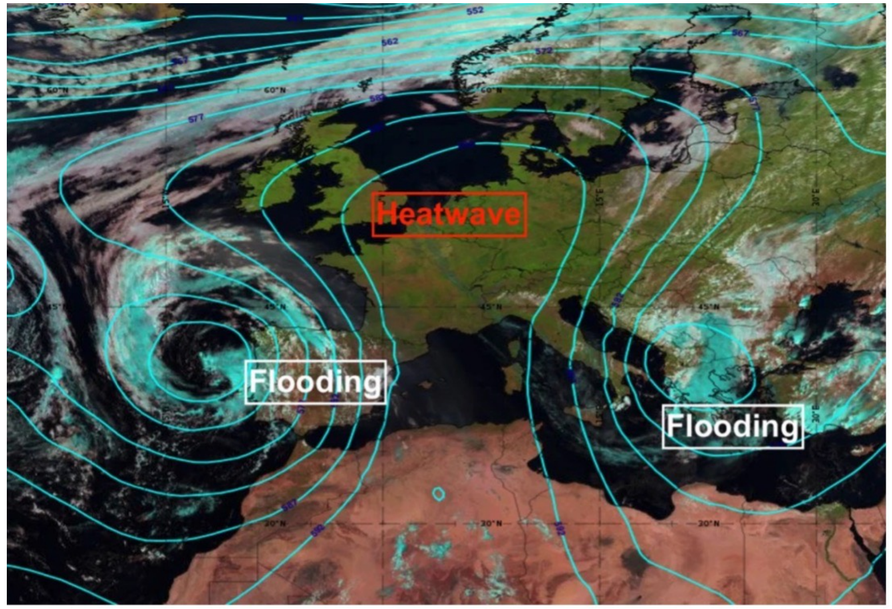
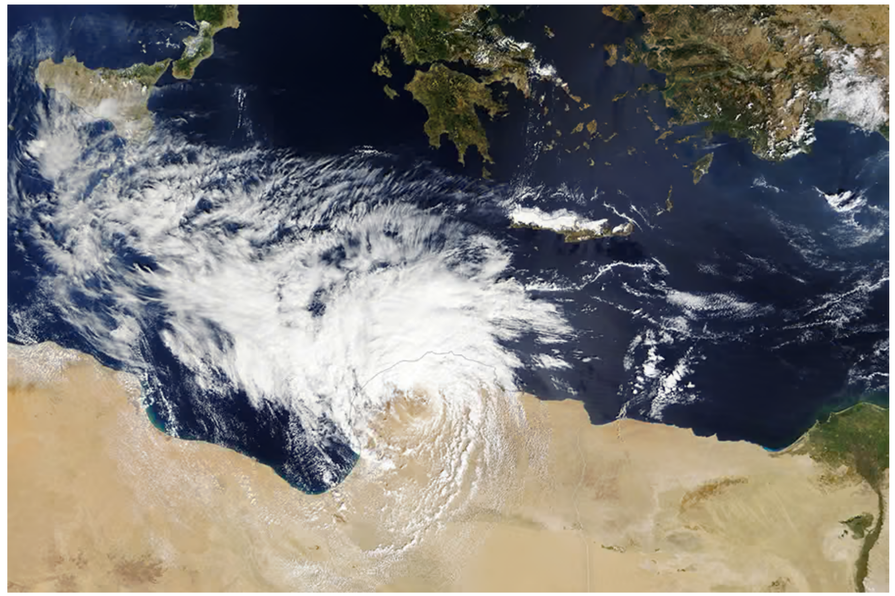
Storm Daniel: Omega block turned into Medicane





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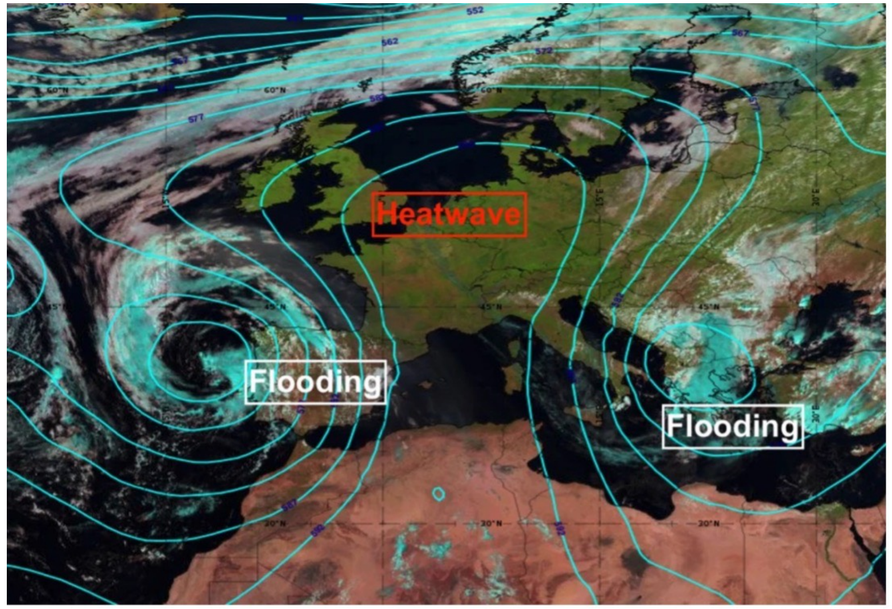
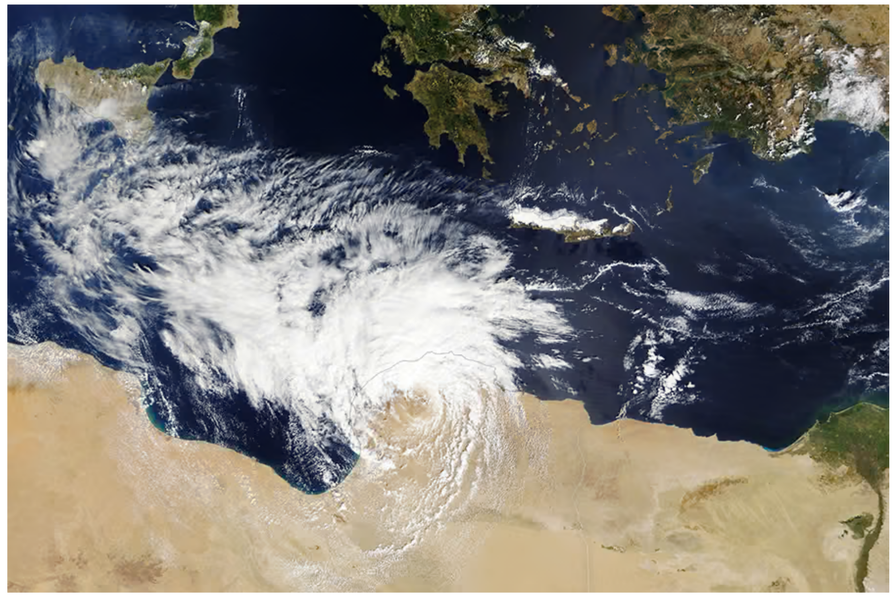
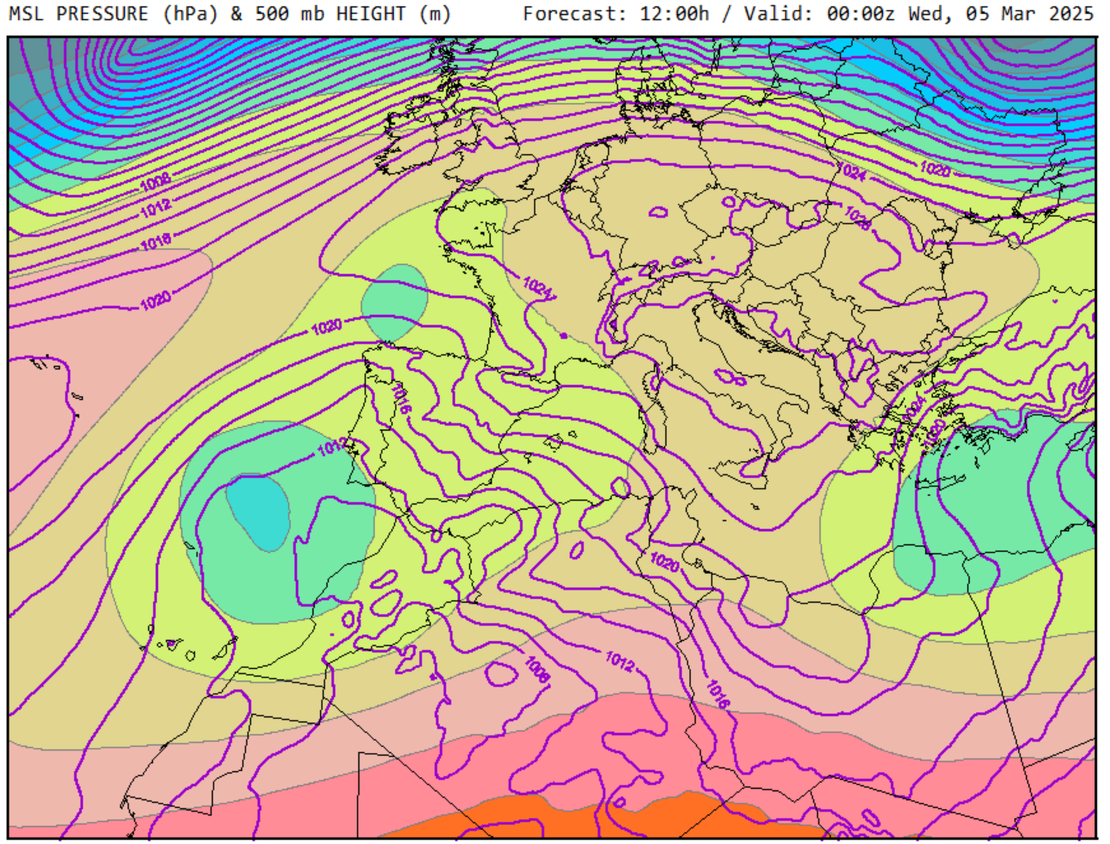
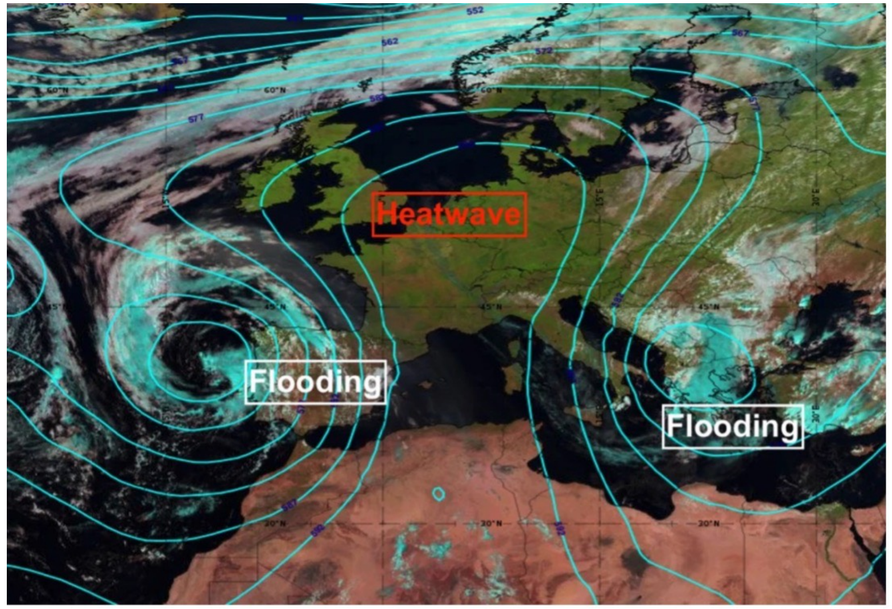


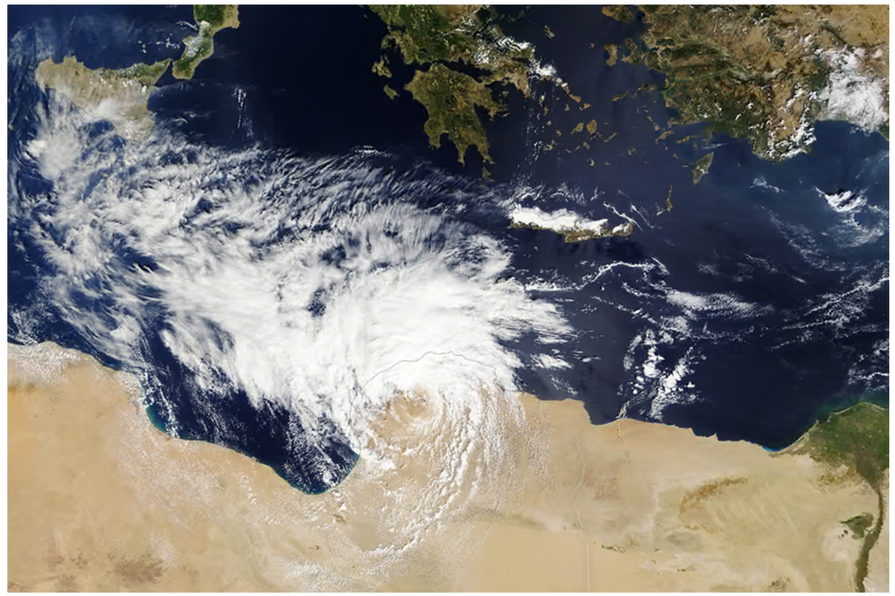


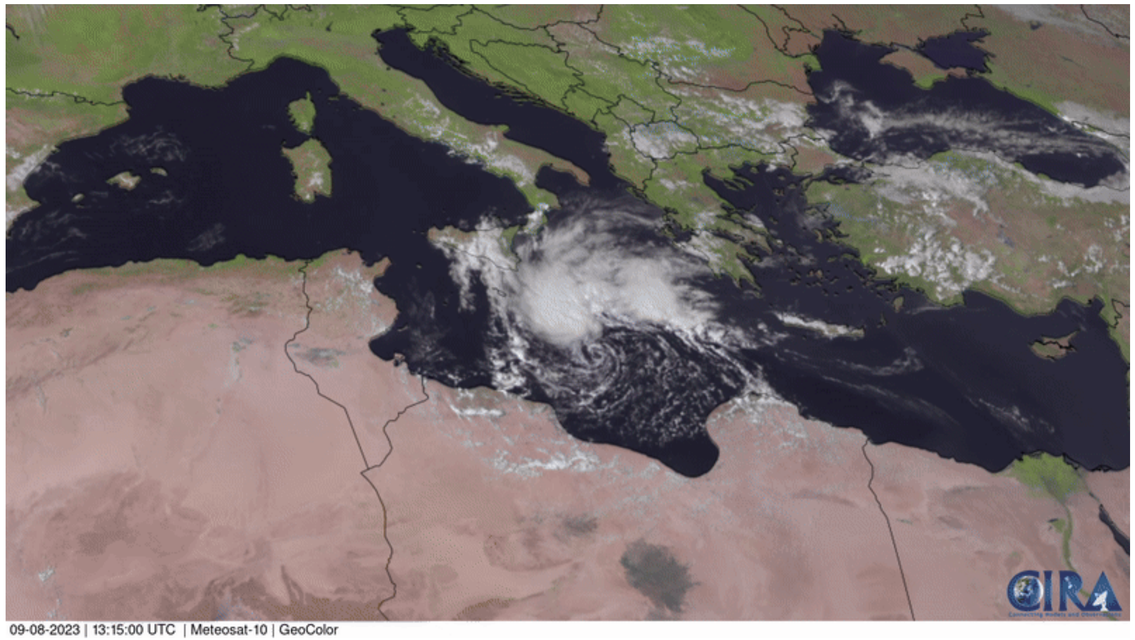


Synoptic situation March 2025
TRAM model forecast (Romero 2024 QJRMS)

Storm Daniel: Omega block turned into Medicane





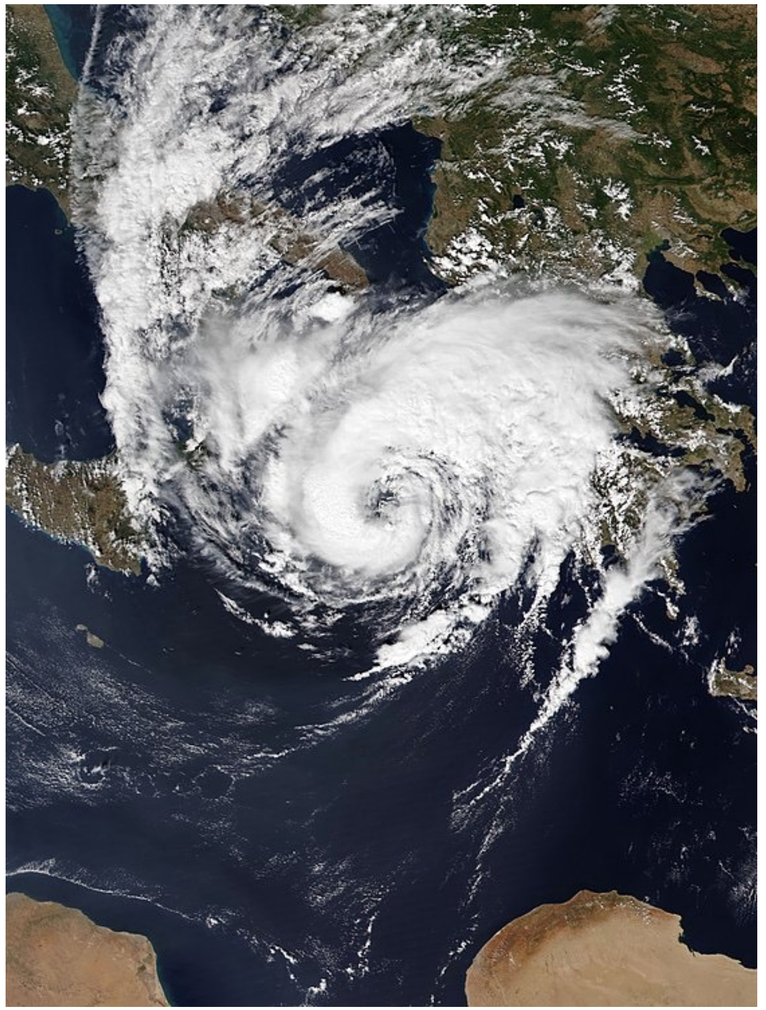


09-08-2023 | 13:15:00 UTC | Meteosat-10 | GeoColor

What is a Medicane?

Mediterranean tropical-like cyclone

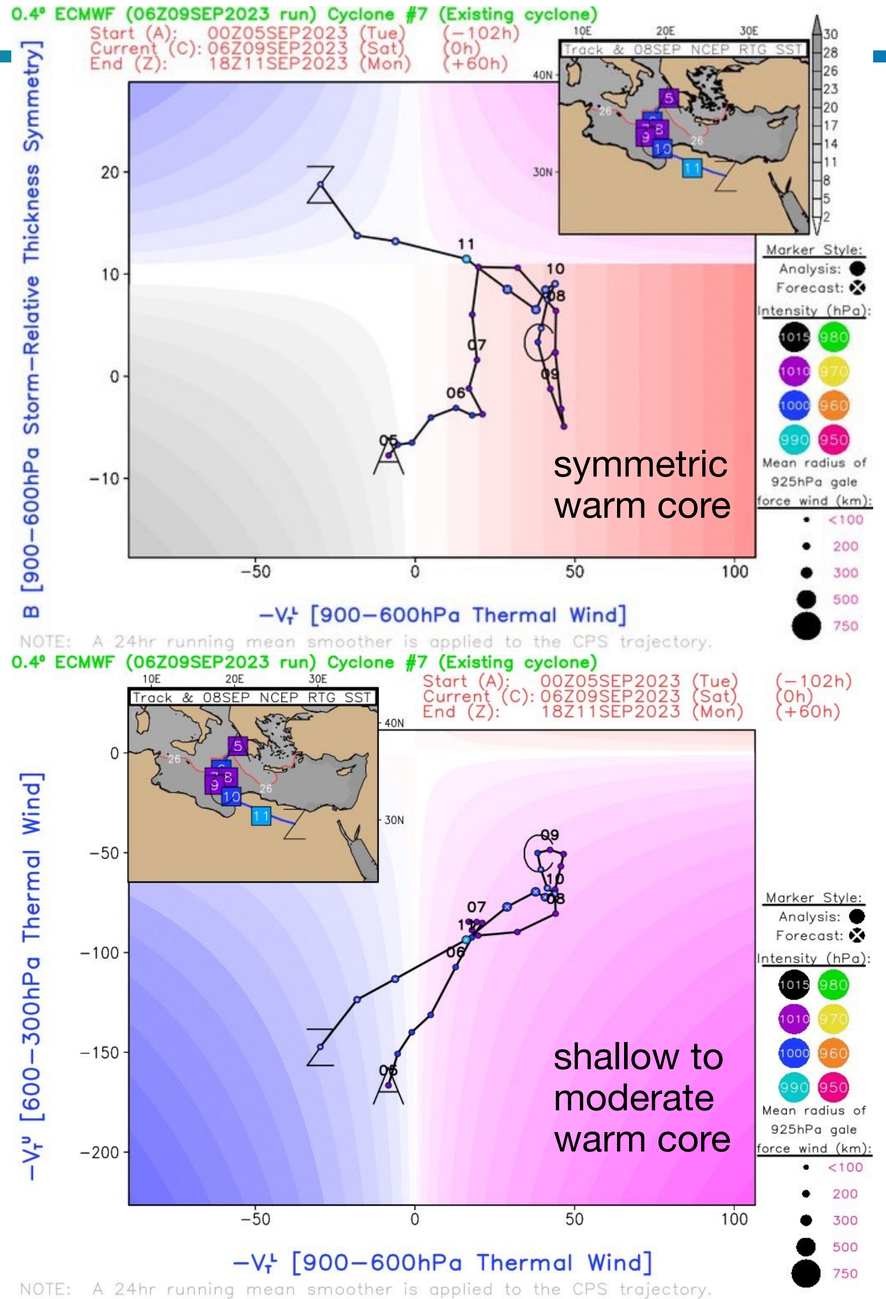
- Systems with tropical characteristics in the Mediterranean:
  - Some symmetrical structure and clearly visible cyclone eye
  - Warm core (usually shallow)
  - Upper tropospheric outflow
  - Convection and latent heat release
  - Rain bands, no frontal structure
- **But** Baroclinic origin, smaller size, no need for very warm SST
- Peaking in September-January
- Two main regions: Northwestern Mediterranean and Ionian Sea
- Large impacts due to topography surrounding Med Sea.



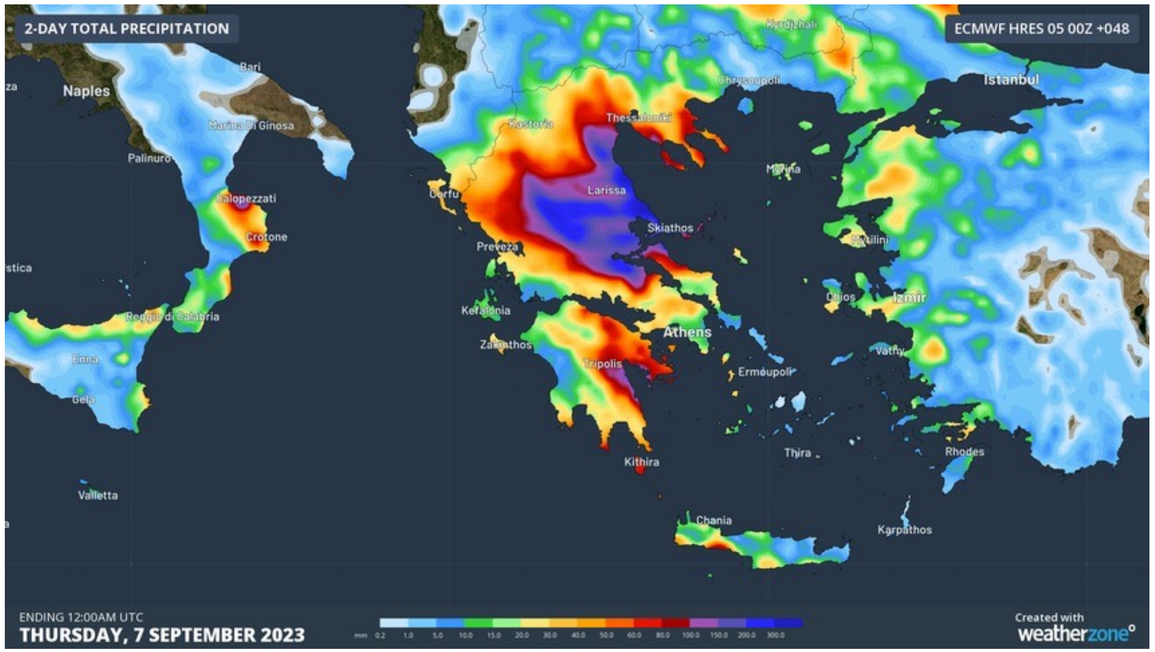
Medicane Ianos Sep 2020

Storm Daniel as a Medicane

- Septemper 2023
- Two main phases: Greece and Libya
- Record-breaking rainfall at daily and sub-daily scales
- Characteristics of tropical cyclone/storm (symmetric and shallow warm core)



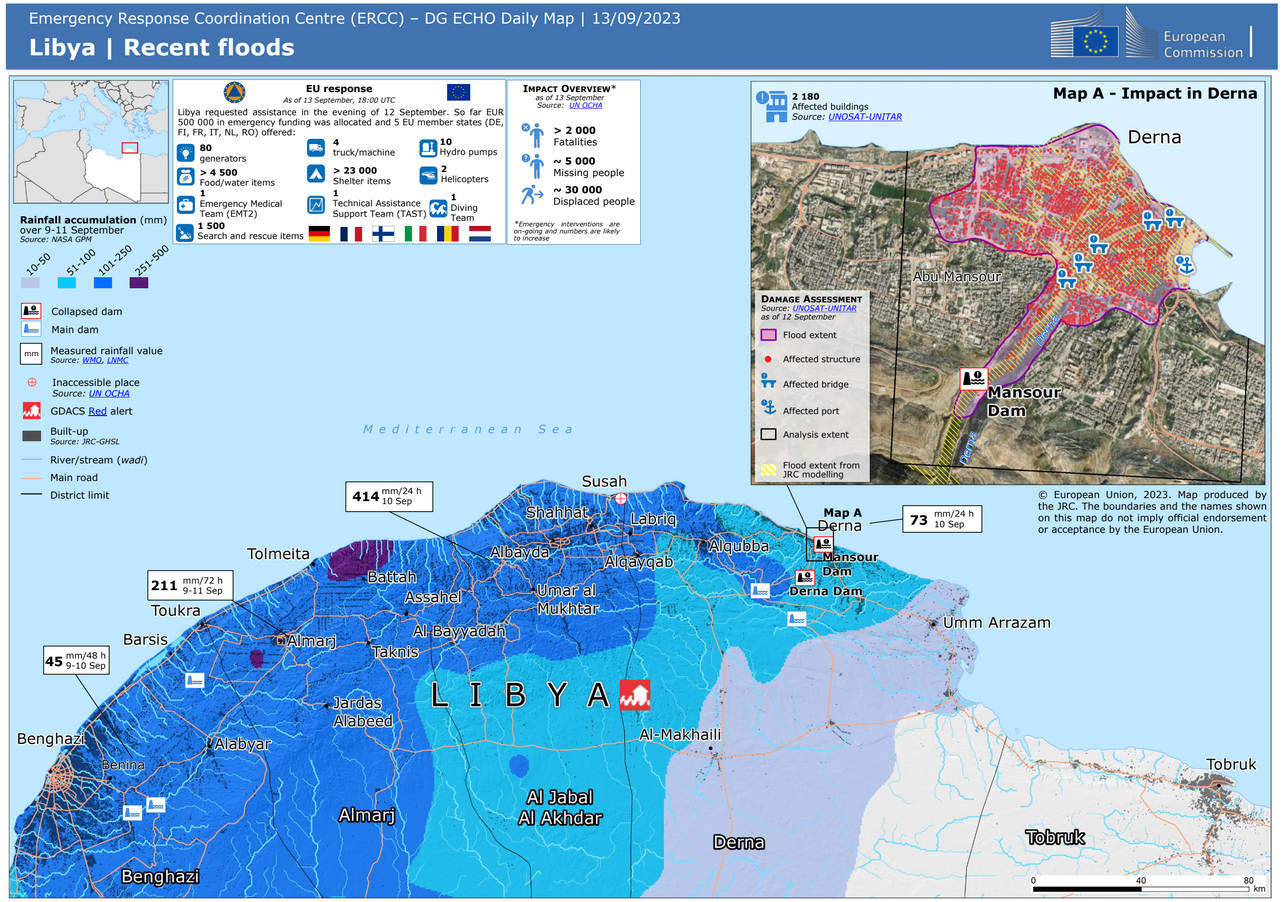
Greek Phase 4-7 September 2023



Zagora: 754 mm in 18 h

Greek national record

Libyan Phase 8-12 September 2023

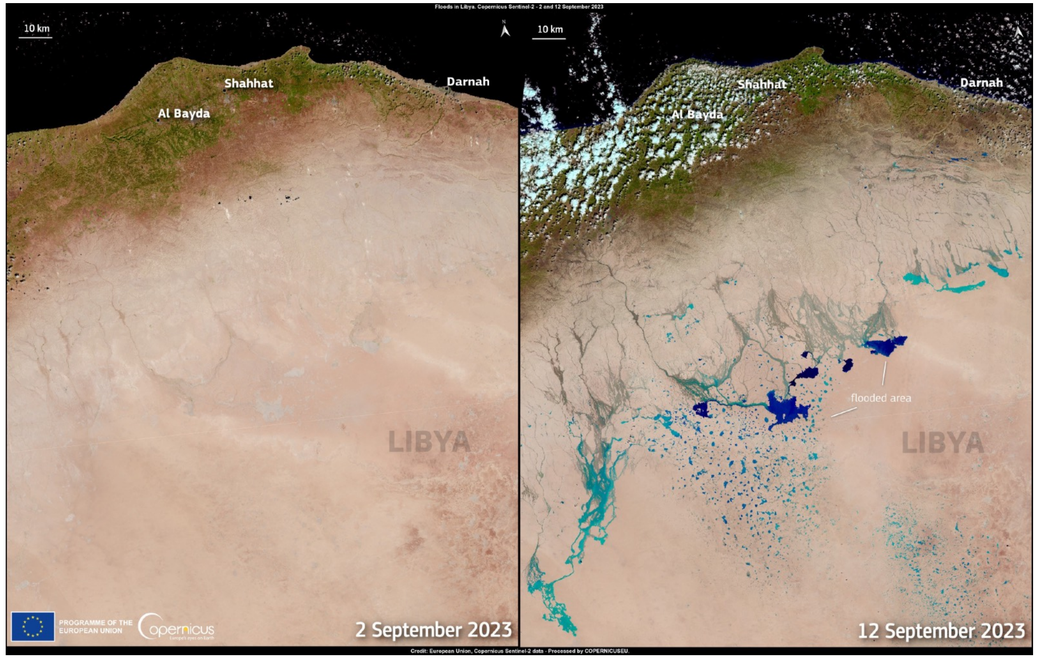


Al-bayda: 414 mm in 24 h

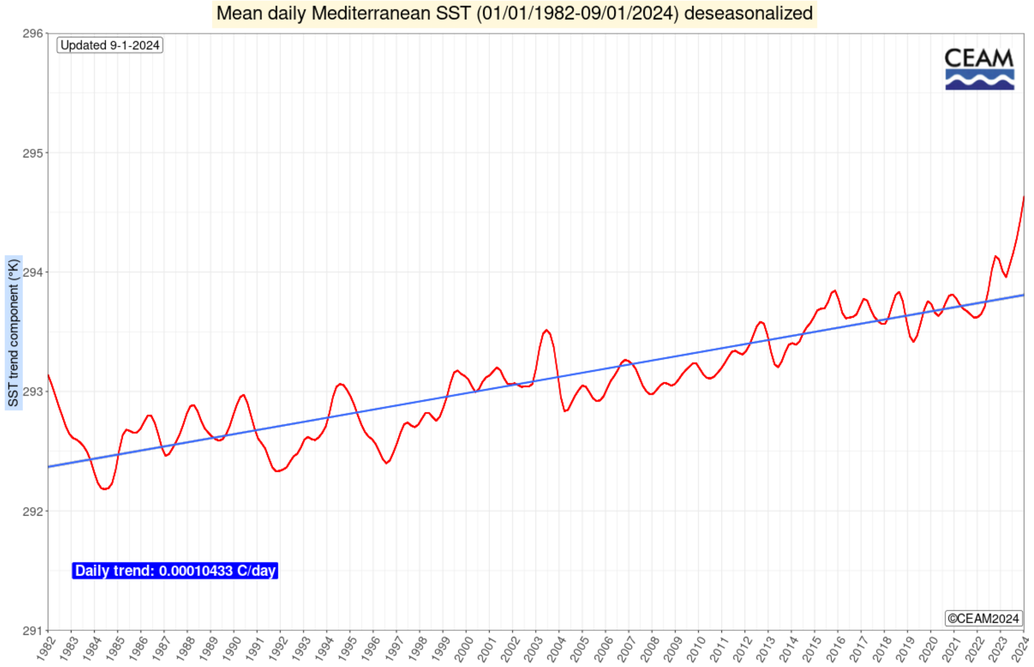
Libyan national record

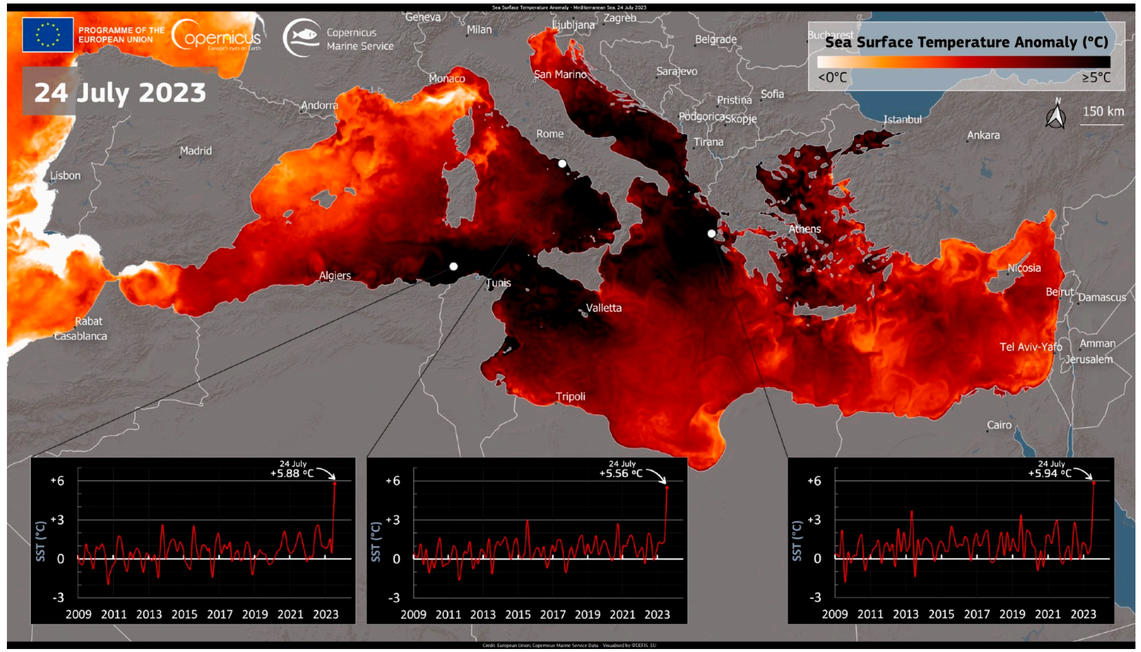
Deadliest storm in recorded history

Nearly 6000 killed

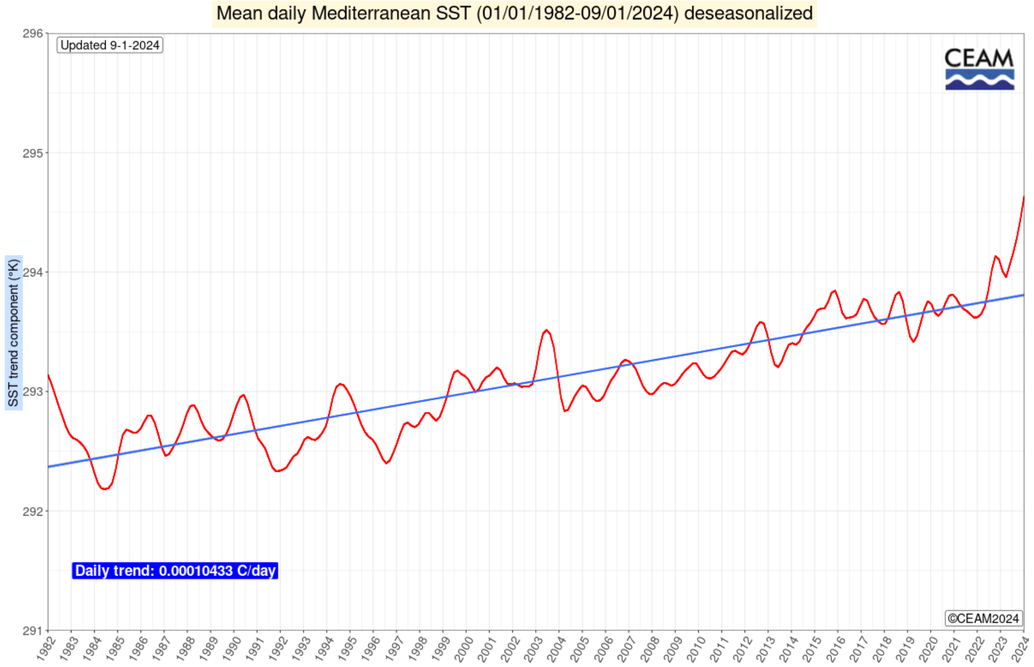


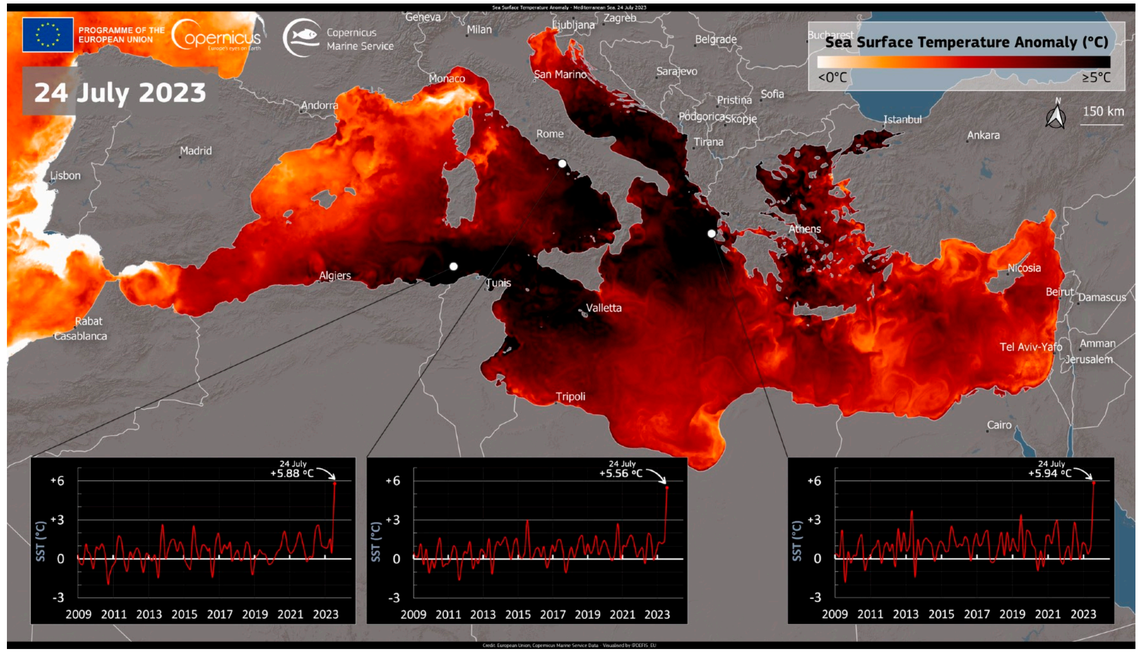
High Mediterranean SST before the storm





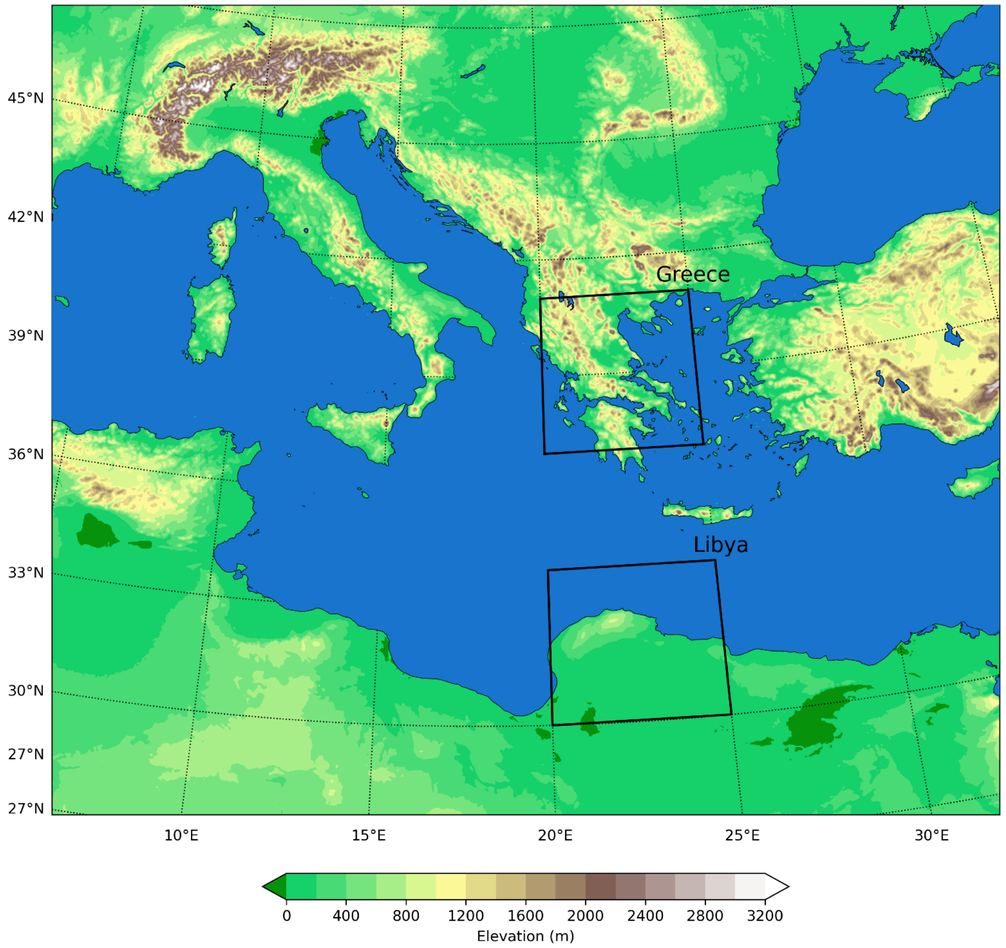
High Mediterranean SST before the storm





What was the role of local SST?

Model experiments



WRF 4.5.1 at 3 km spatial resolution

First experiment:

CTL

ERA5

ERA5

16-member time-lagged ensemble
30 h apart: 22/08/23 to 09/09/23

22/08/23 00:00

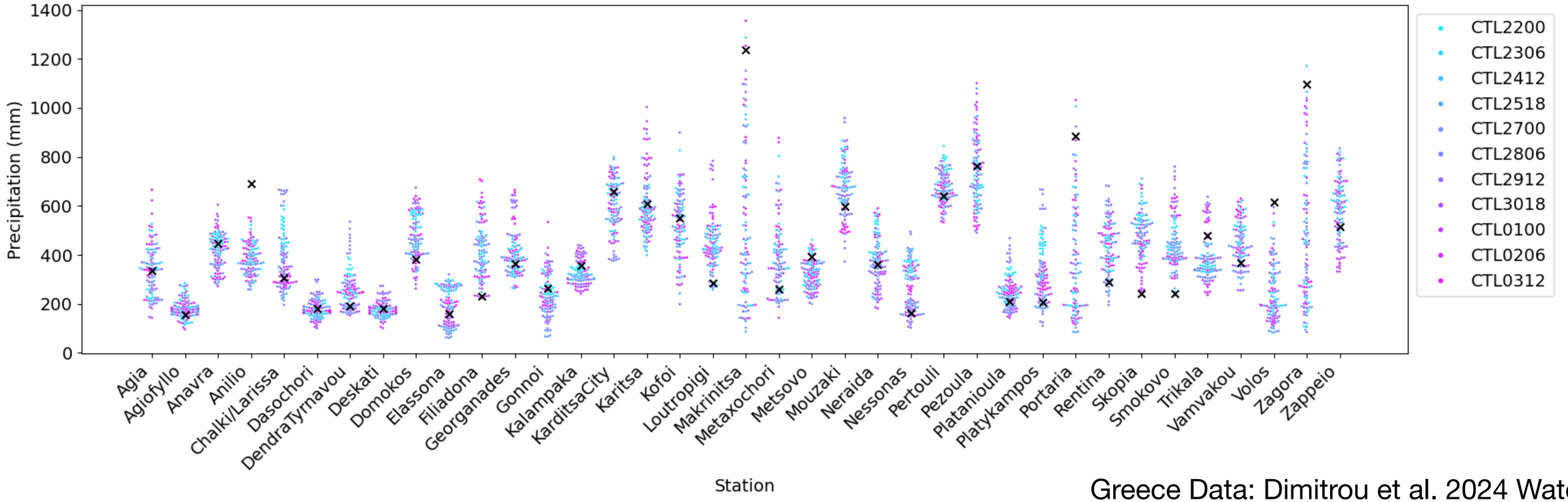
23/08/23 06:00

08/09/23 12:00

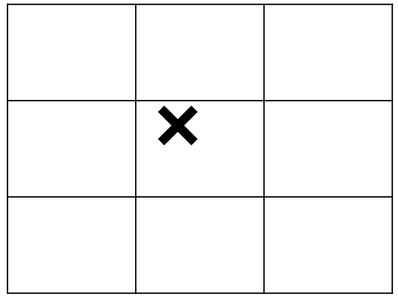
09/09/23 18:00

Argüeso et al. 2024 NPJ Climate and Atmospheric Science

Model performance

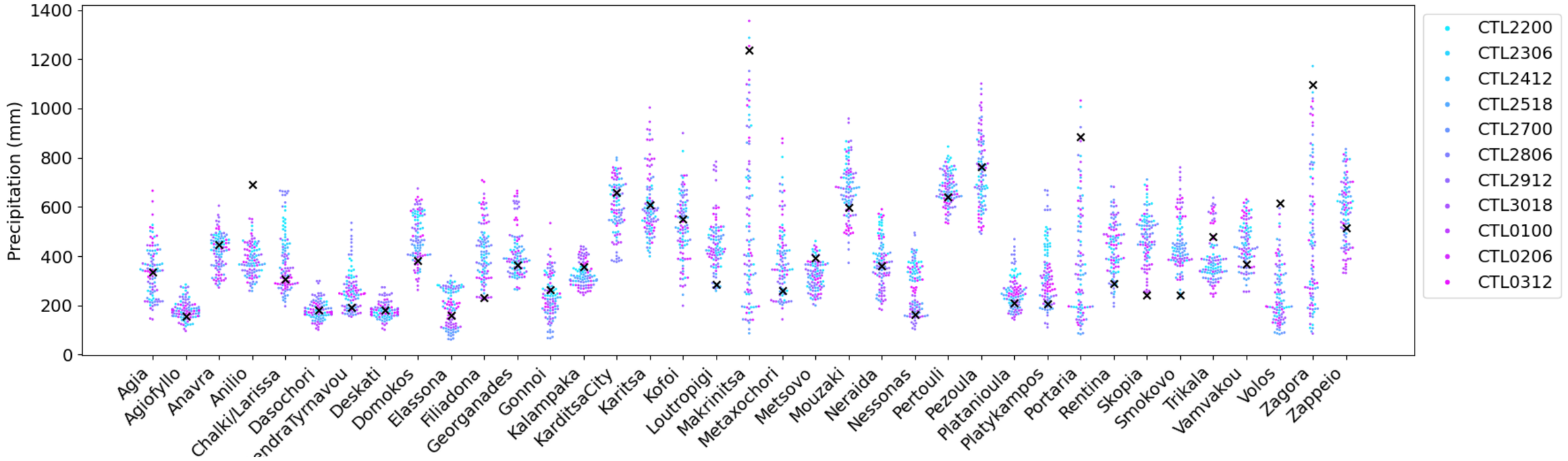


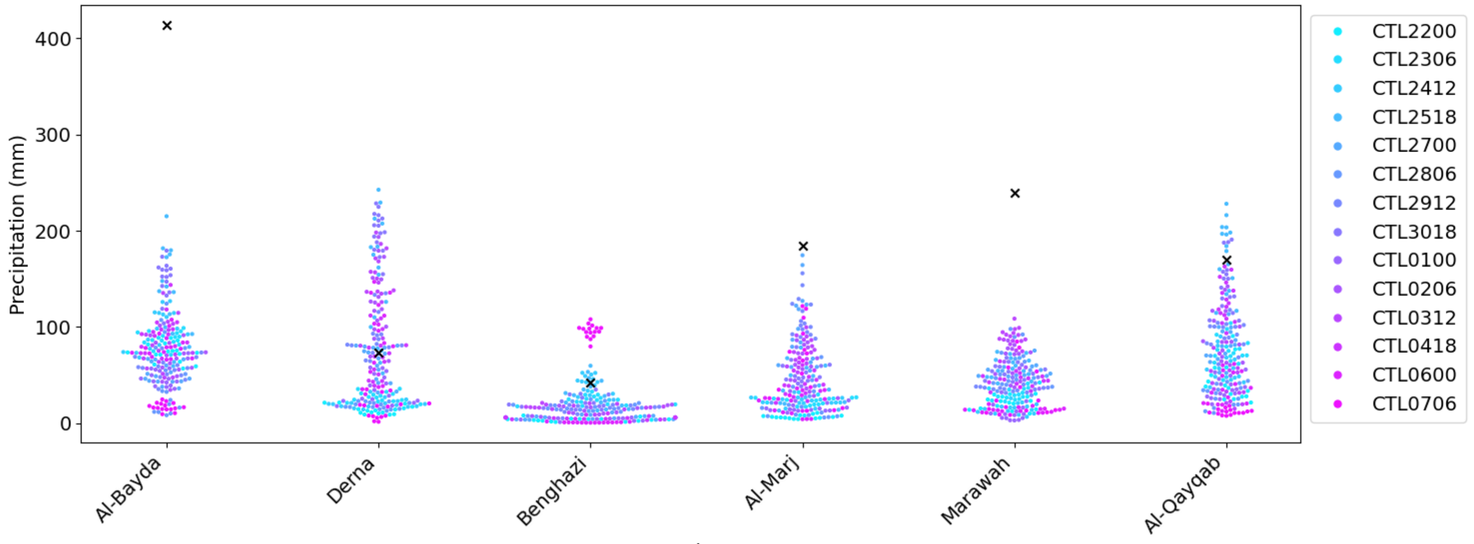
Greece Data: Dimitrou et al. 2024 Water



Accumulated rainfall 4-7 September

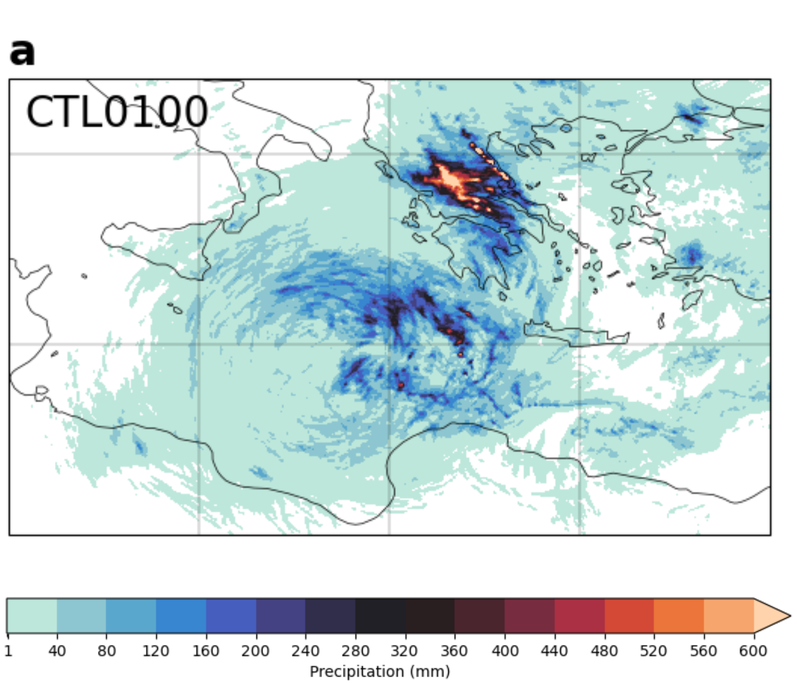
Model performance

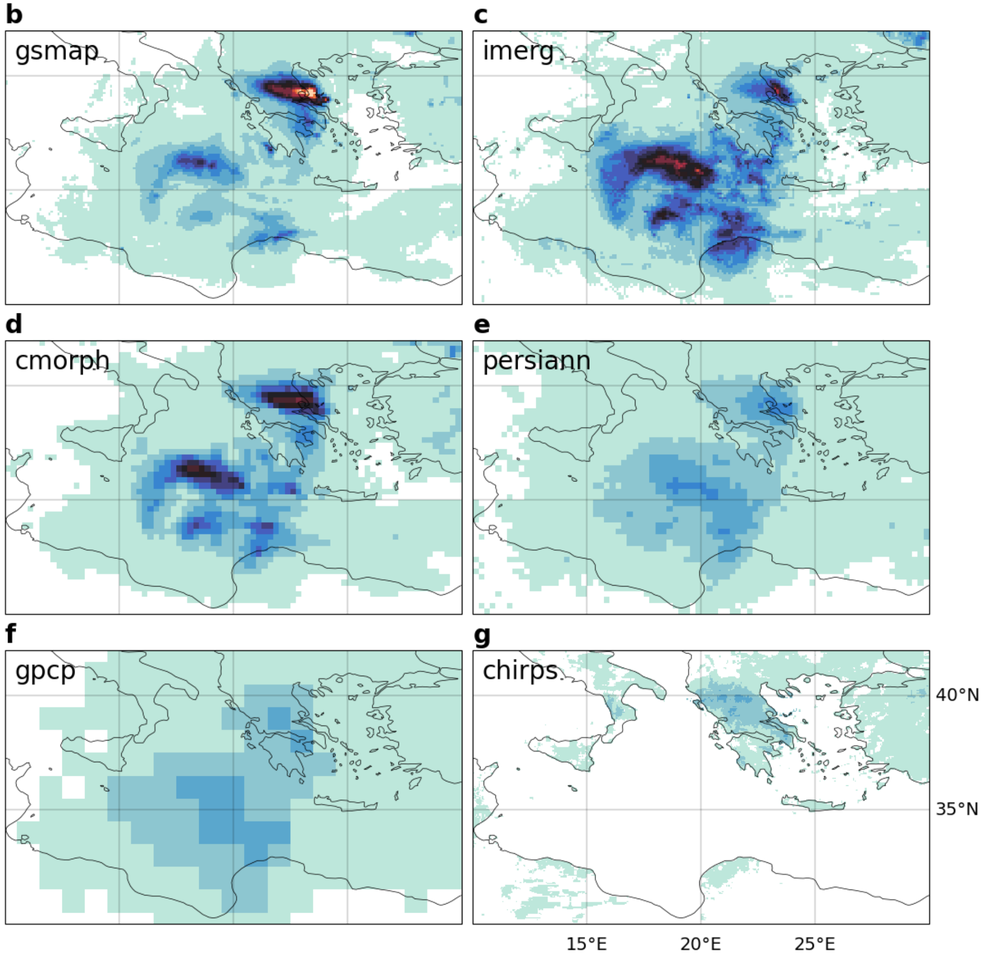




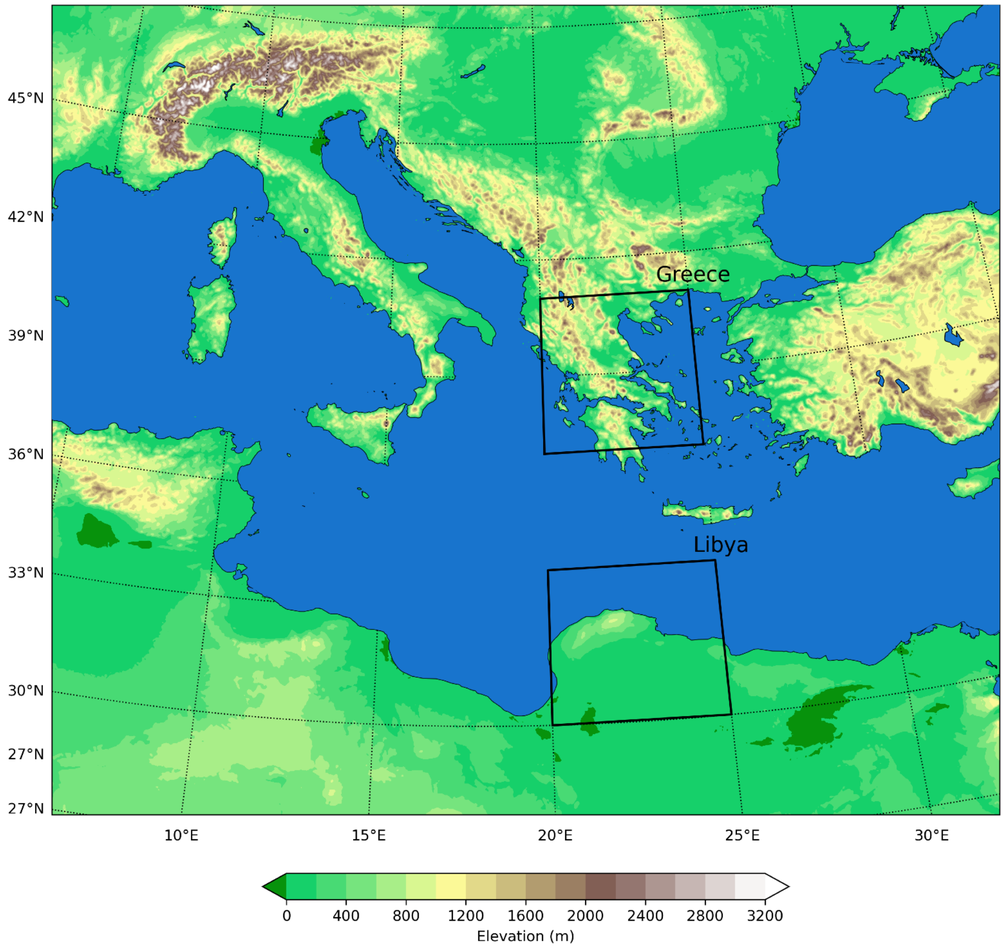
Accumulated rainfall 8-12 September

Model performance





Model experiments

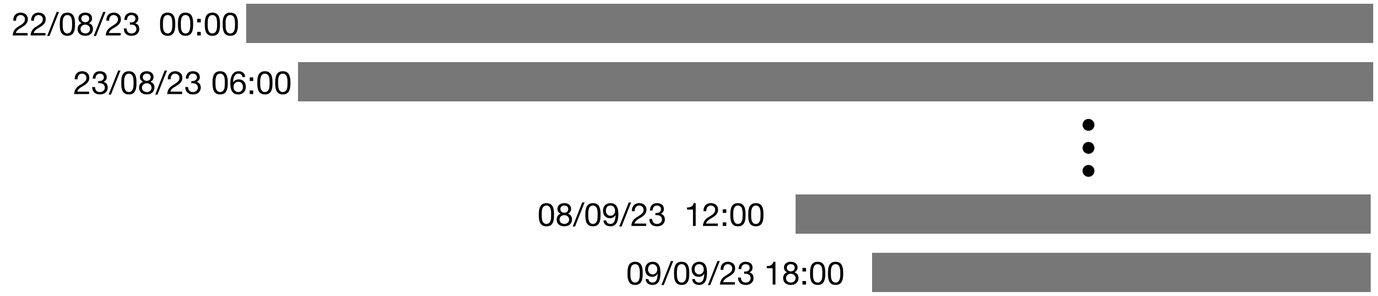


WRF 4.5.1 at 3 km spatial resolution

2 experiments (Control & Counterfactual):

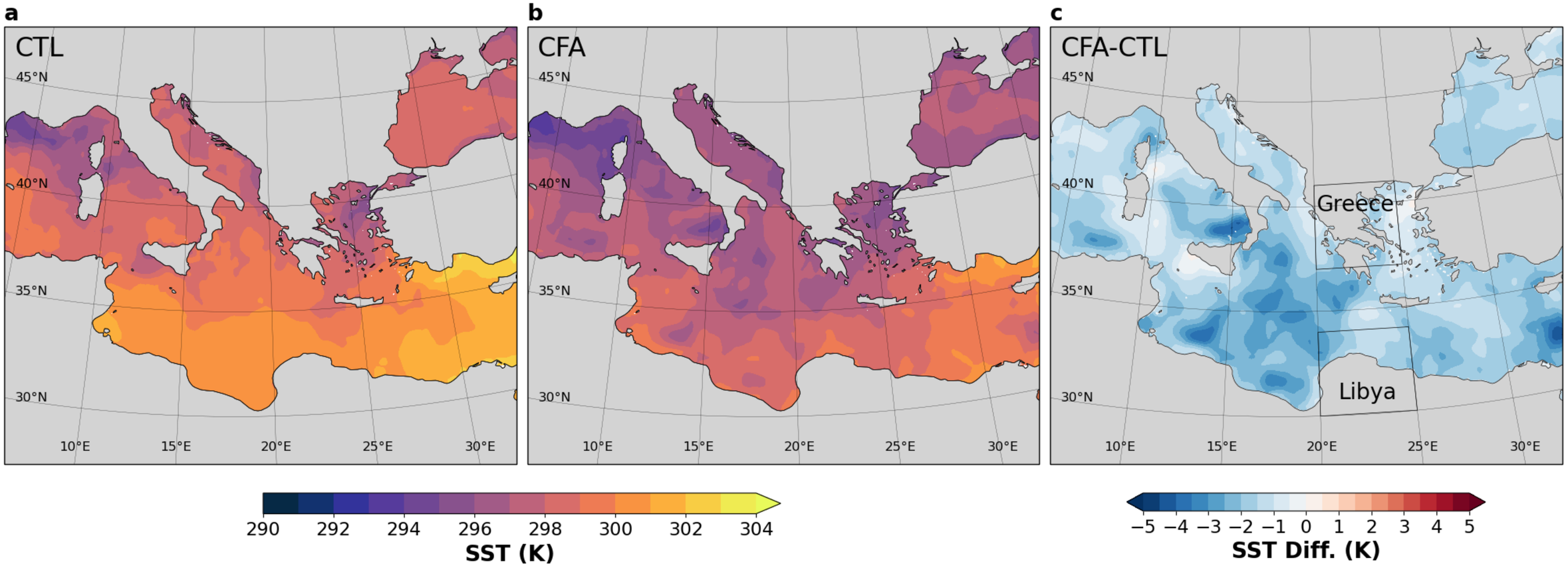
CTL	CFA
ERA5	ERA5
ERA5	Counterfactual SST

16-member time-lagged ensemble
30 h apart: 22/08/23 to 09/09/23

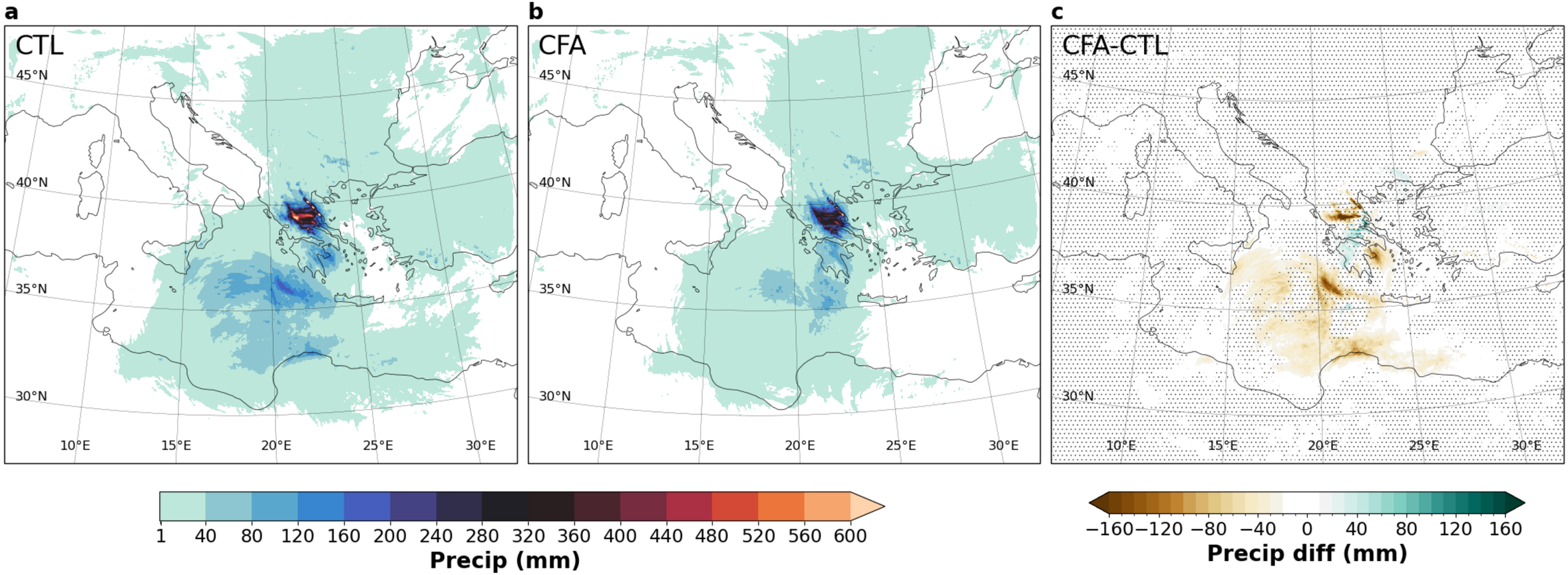


Counterfactual method: Marcos et al. 2025, *PNAS*

SST differences between experiments

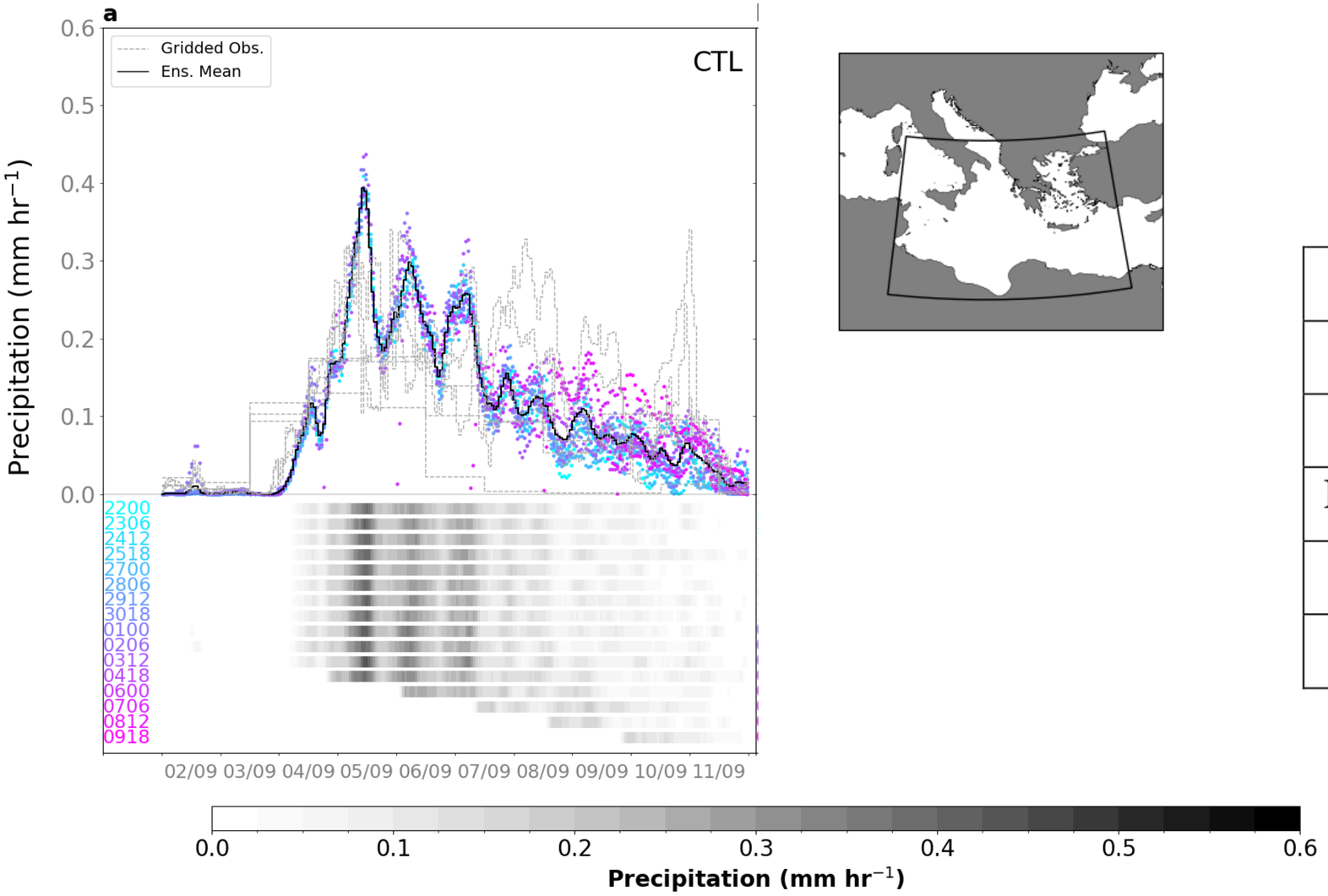


Precipitation differences between ensembles



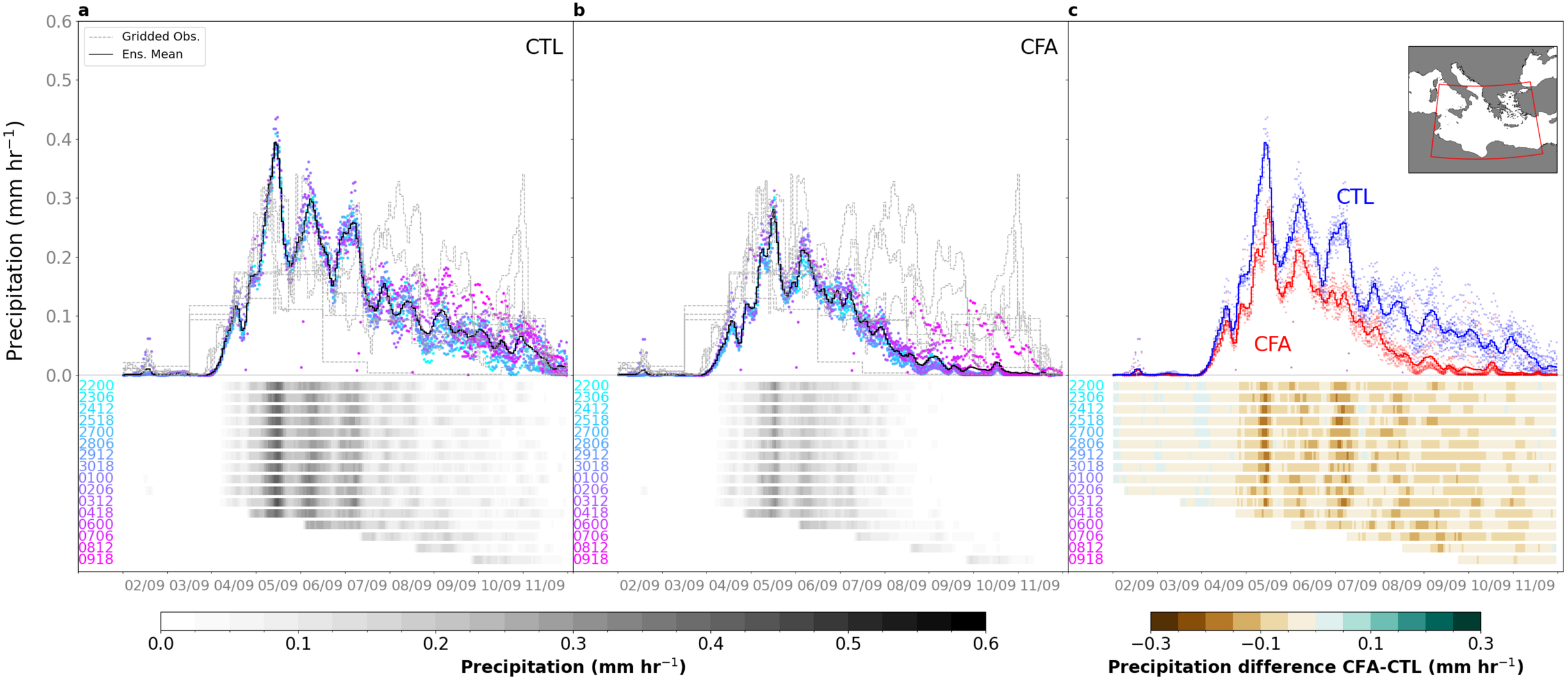
Domain-average ensemble mean difference of 42%
Greece 17%
Lybia 81%

Differences in rainfall time series: Domain



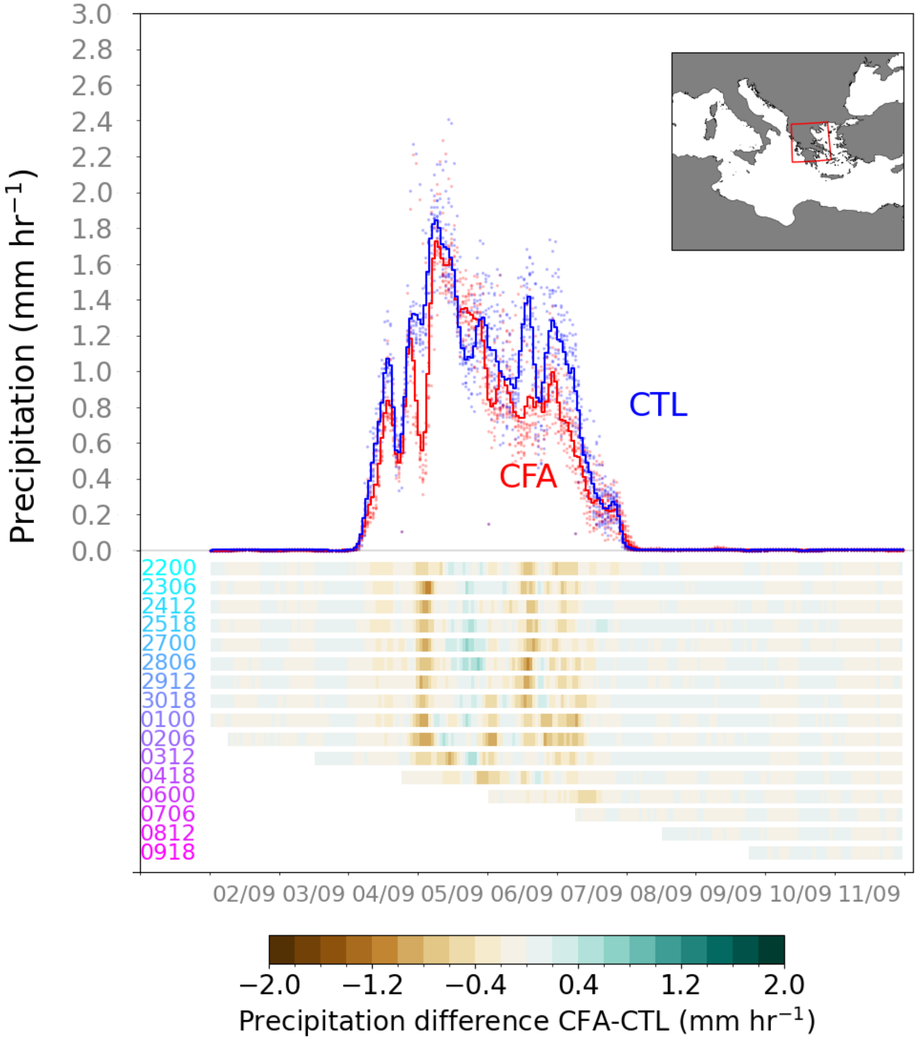
	Cen. Mediterranean	
	r	RMSE (mm hr^{-1})
GSMAP	0.82	0.058
IMERG	0.77	0.084
CMORPH	0.82	0.056
PERSIANN	0.95	0.040
GPCP	0.85	0.050
CHIRPS	0.76	0.085

Differences in rainfall time series: Domain

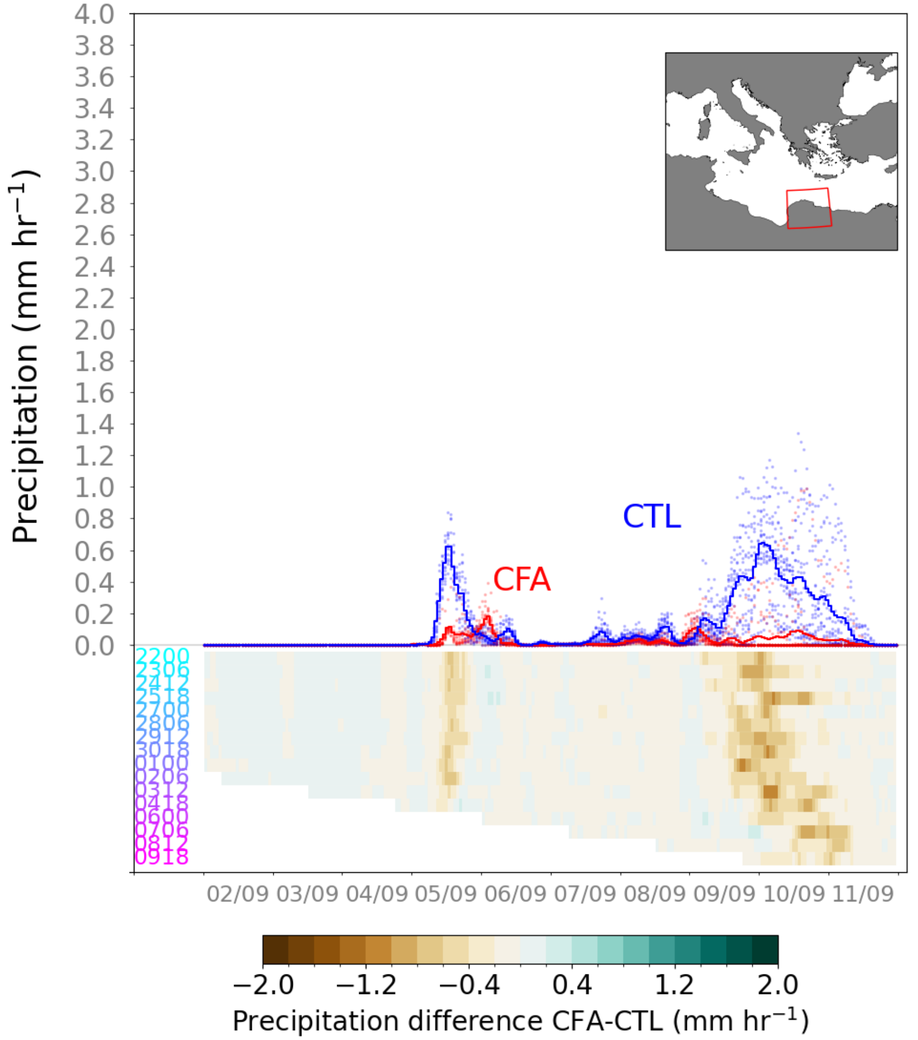


Differences in rainfall time series: Greece and Libya

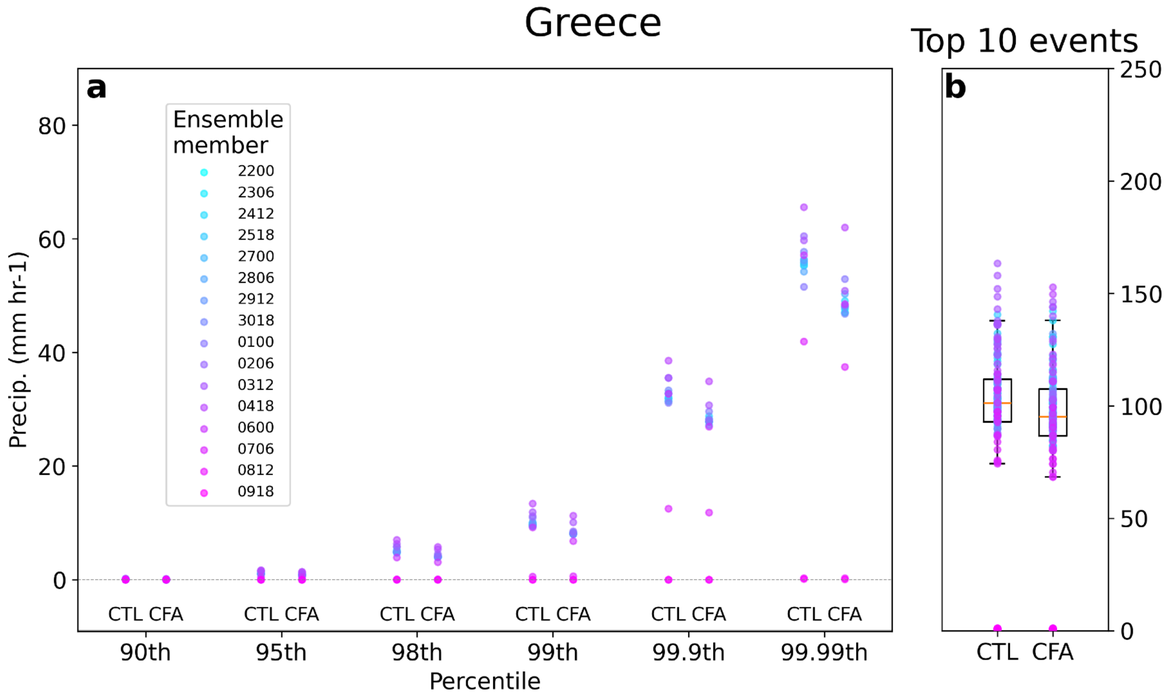
Greece

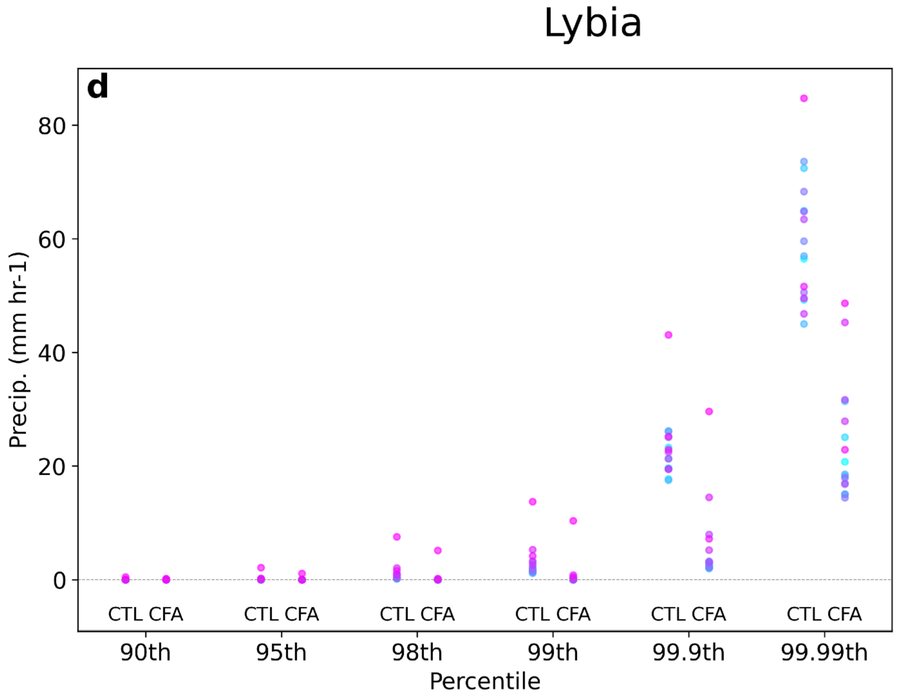


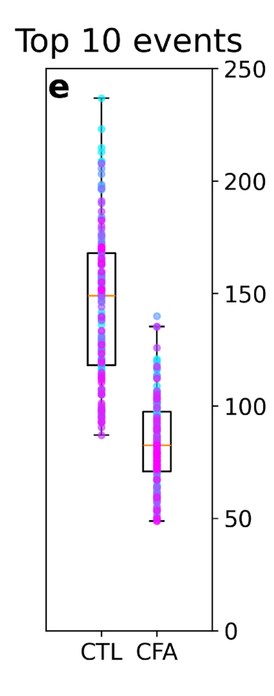
Libya



Significant impacts on hourly extremes





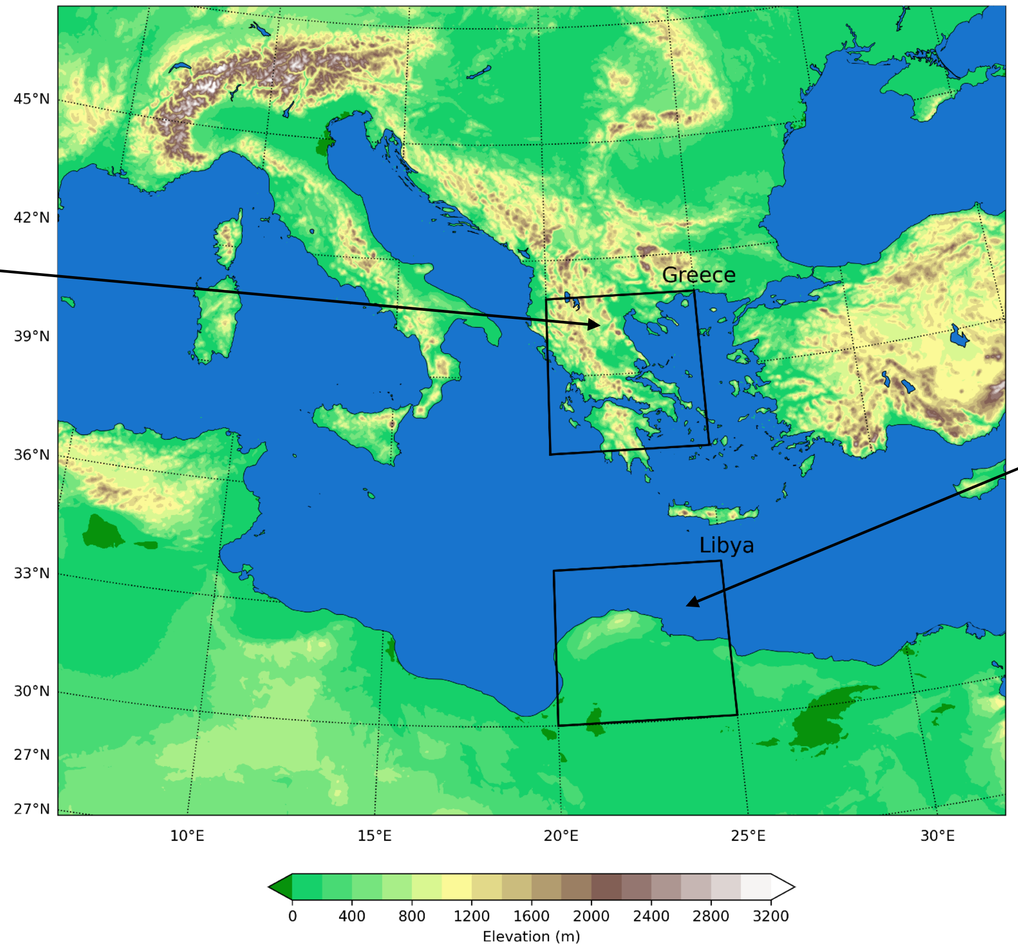


Reduction of two upper percentiles:
-20% to -5% in Greece
-90% to -40% in Libya

Where did the rain come from?

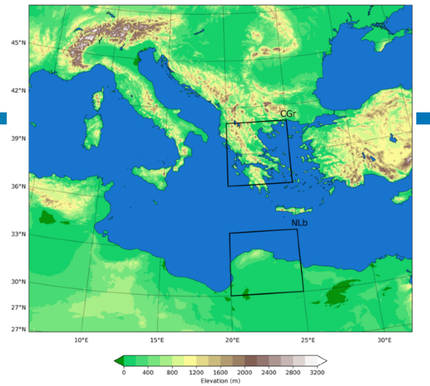
Backtracking moisture sources back to 22 August using ERA5 and WAM2layers tracking algorithm

Greek Phase (3-9 Sep)



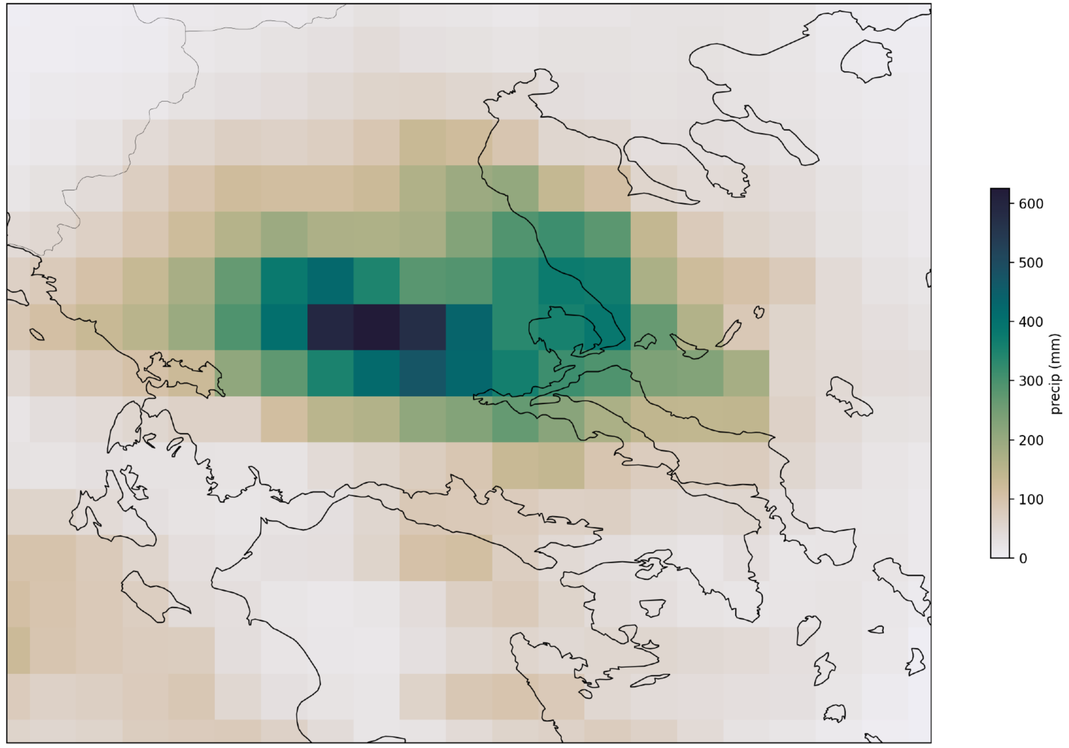
Libyan Phase (7-12 Sep)

Where did the rain come from?

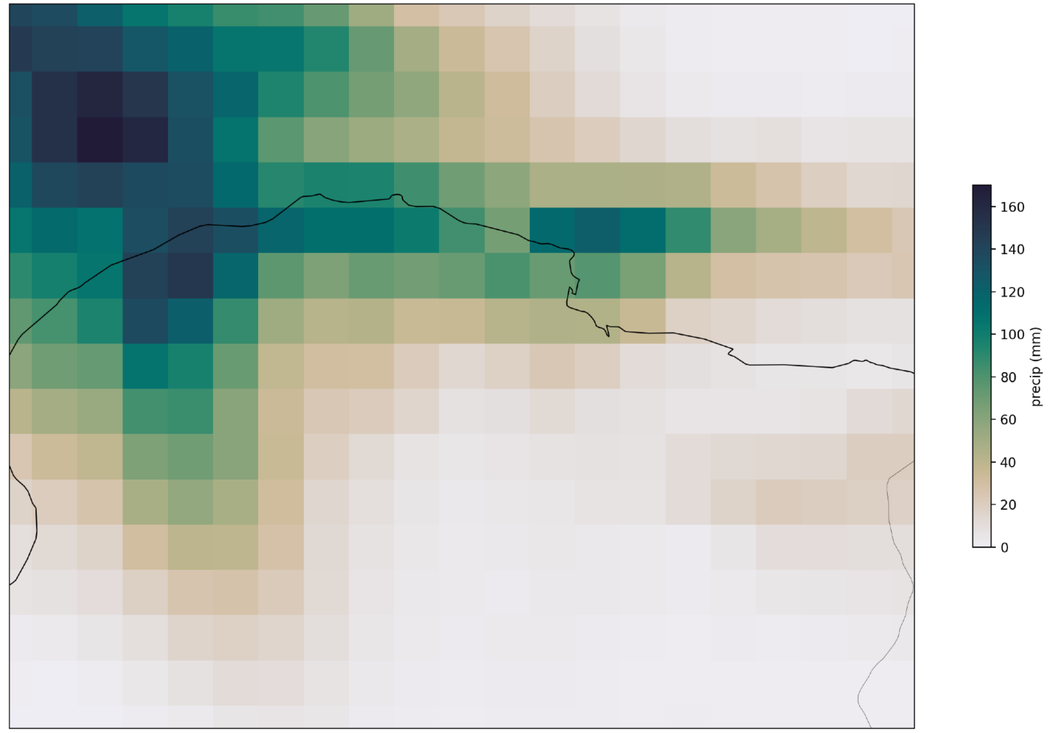


Events used to backtrack moisture

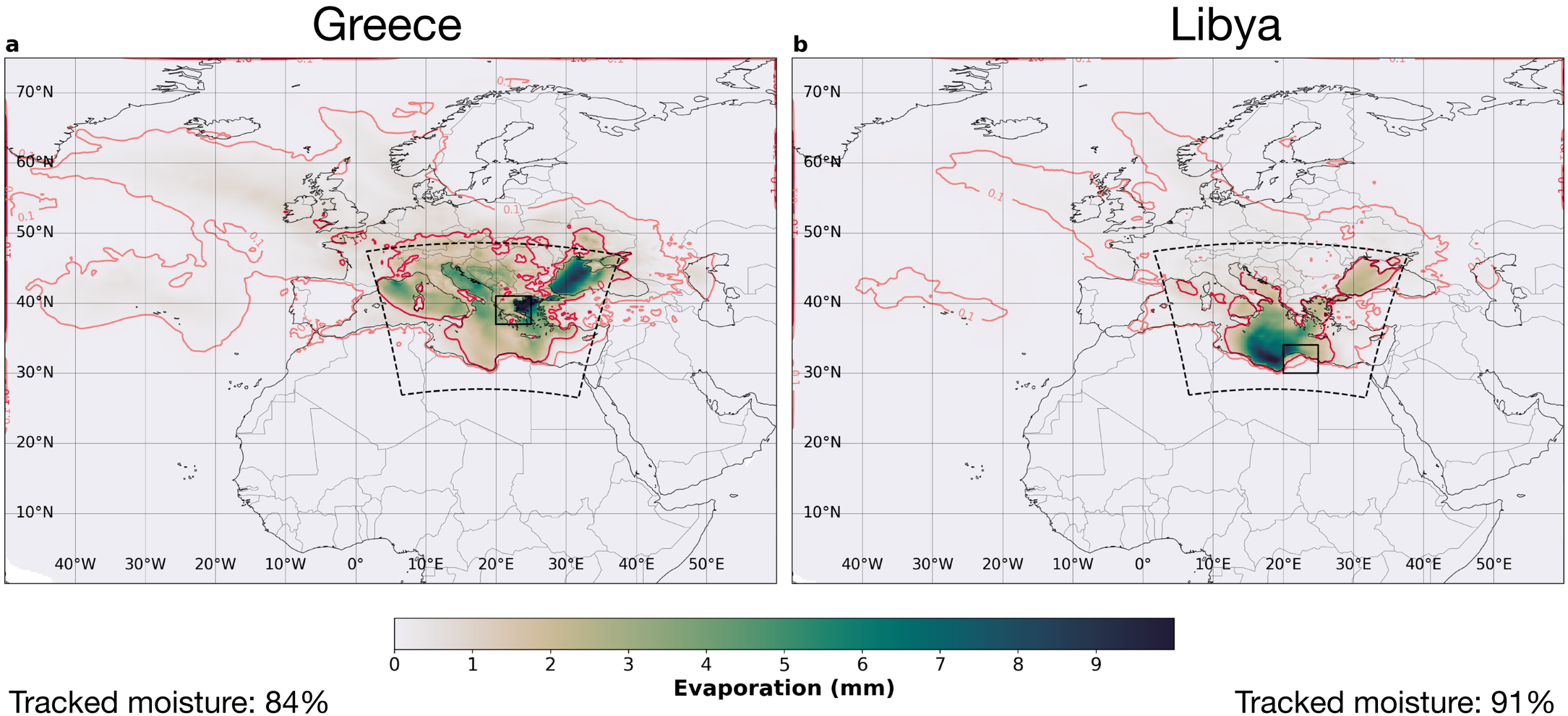
Greek Phase (3-9 Sep)



Libyan Phase (7-12 Sep)



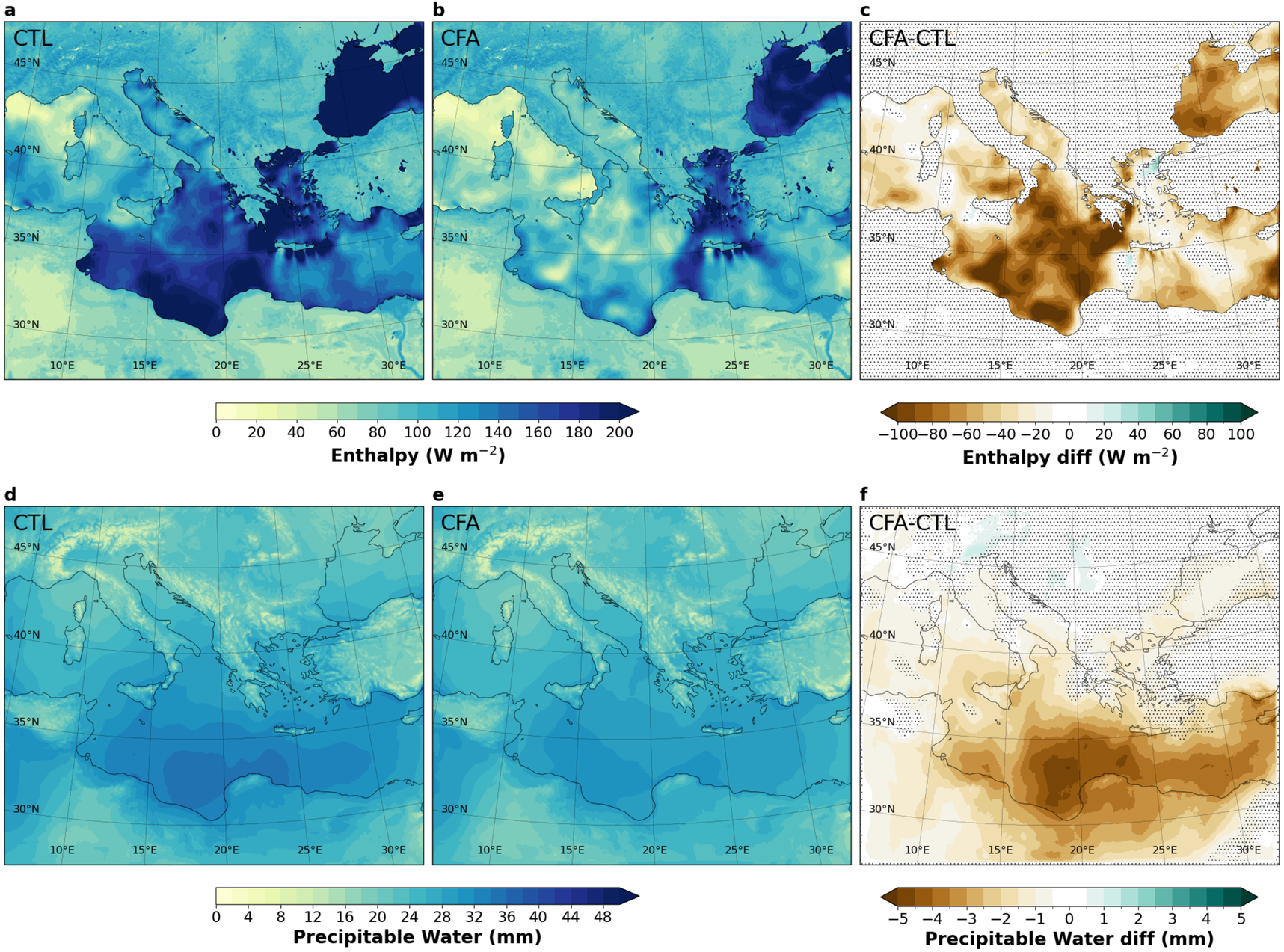
Where did the rain come from?



Tracked moisture: 84%
Contribution from:
- Within domain: 53%
- **Local SST: 36%**
- All ocean areas: 56%

Tracked moisture: 91%
Contribution from:
- Within domain: 68%
- **Local SST: 59%**
- All ocean areas: 74%

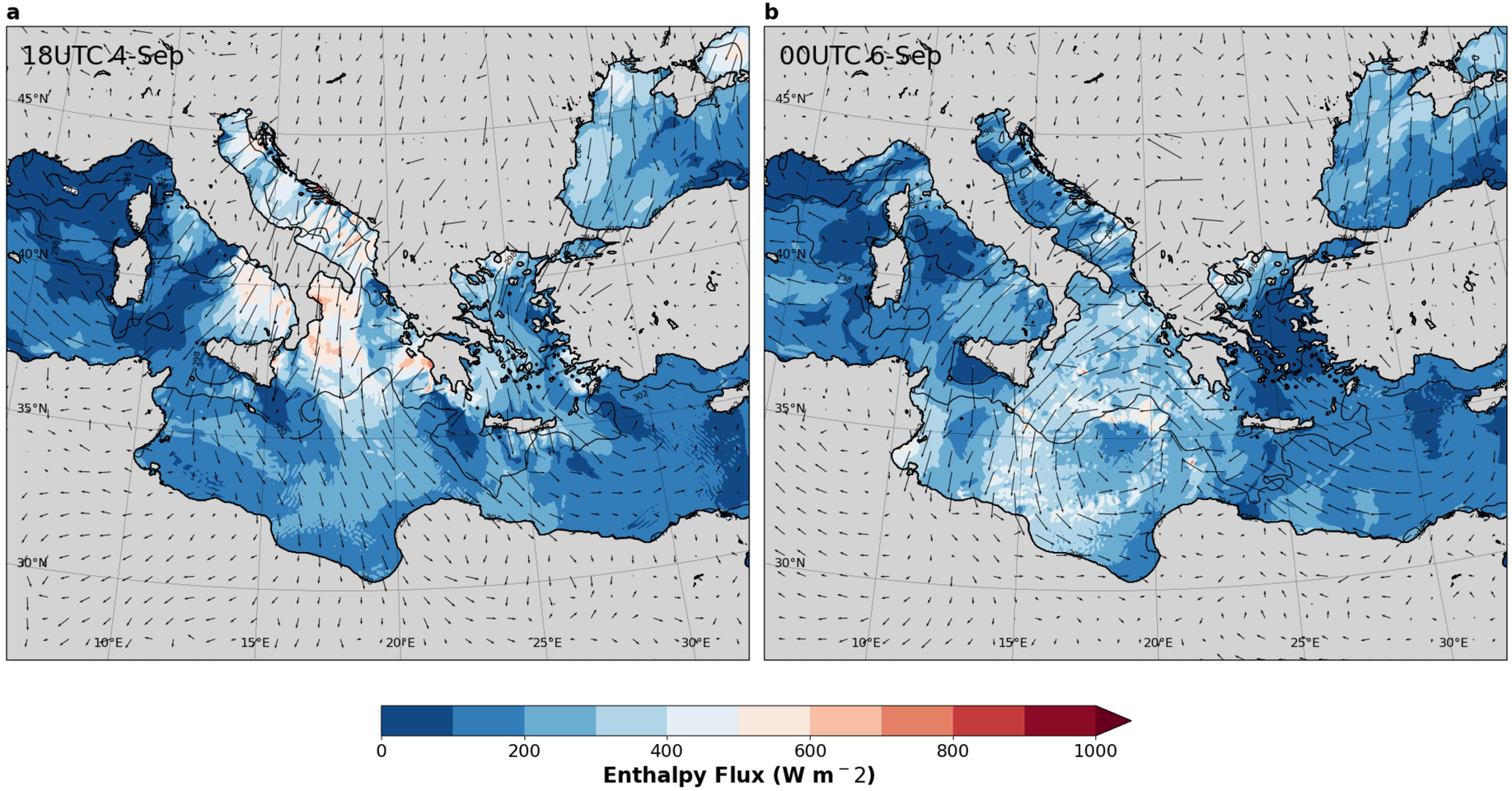
Differences in Surface Enthalpy and Precip. Water



Mixed mechanisms

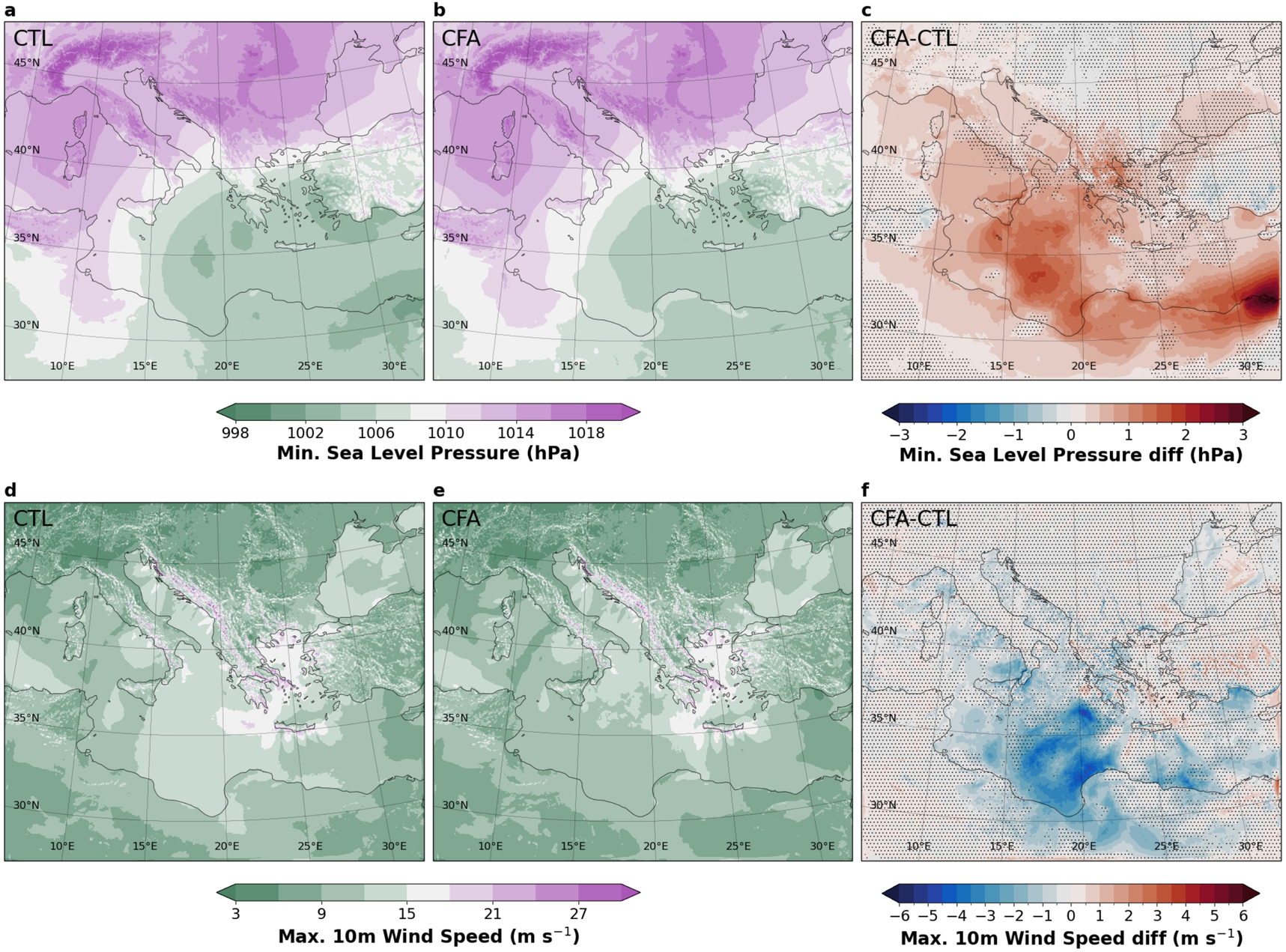
Bora and Etesian winds driving
Wind Induced Surface Heat Exchange (WISHE) type mechanism

Direct link between surface heat fluxes and vortex circulation

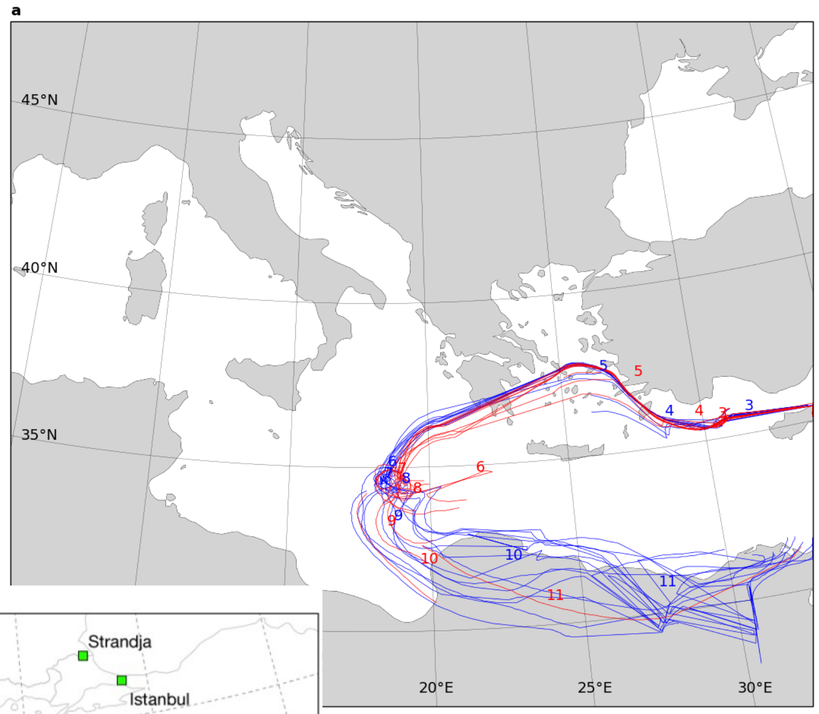


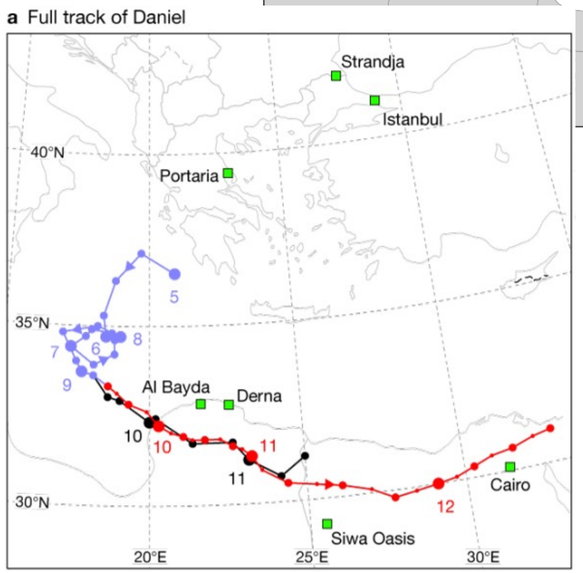
Similar to Miglietta and Rottuno 2018 *QJRMS*

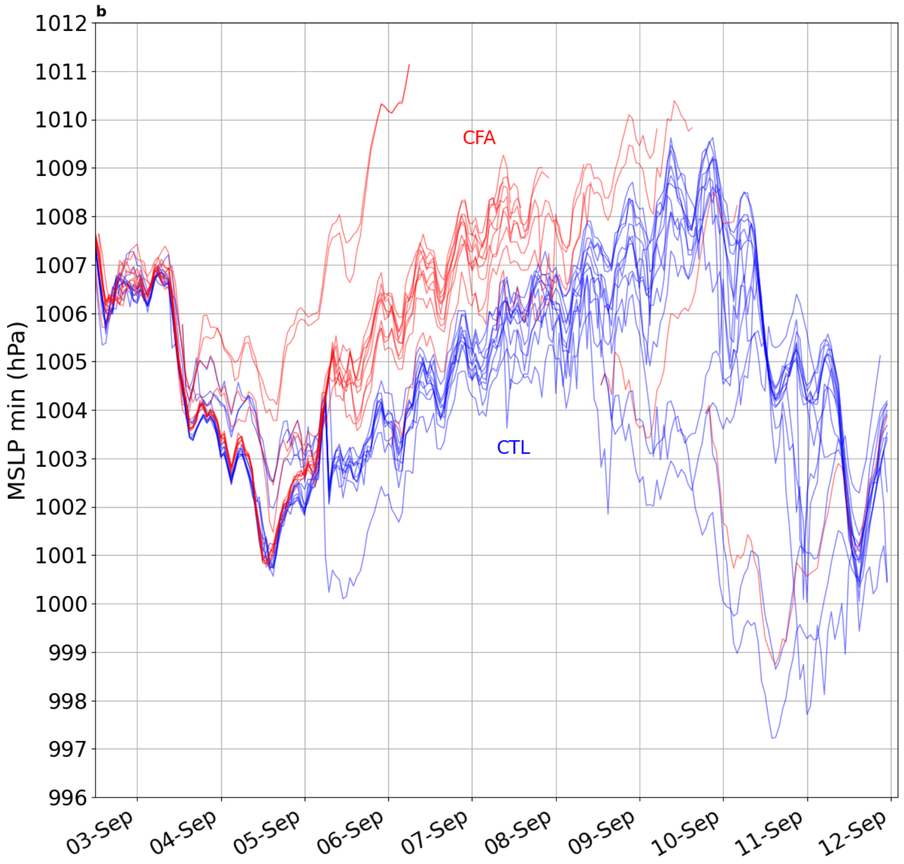
Differences in Sea Level Pressure and Wind Speed

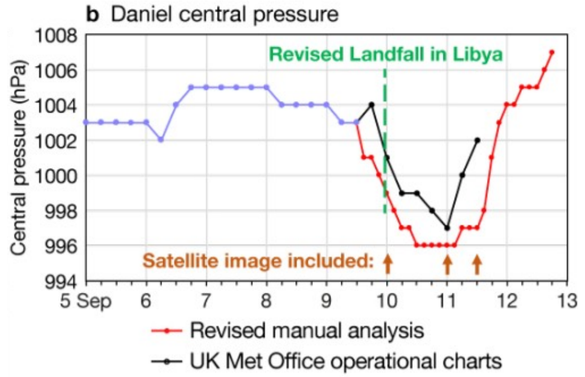


Differences in the track and depth



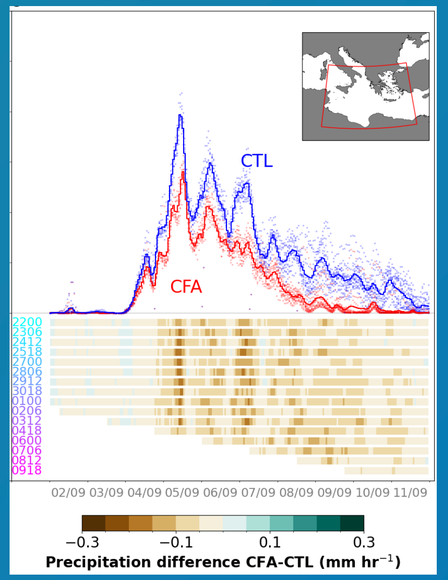






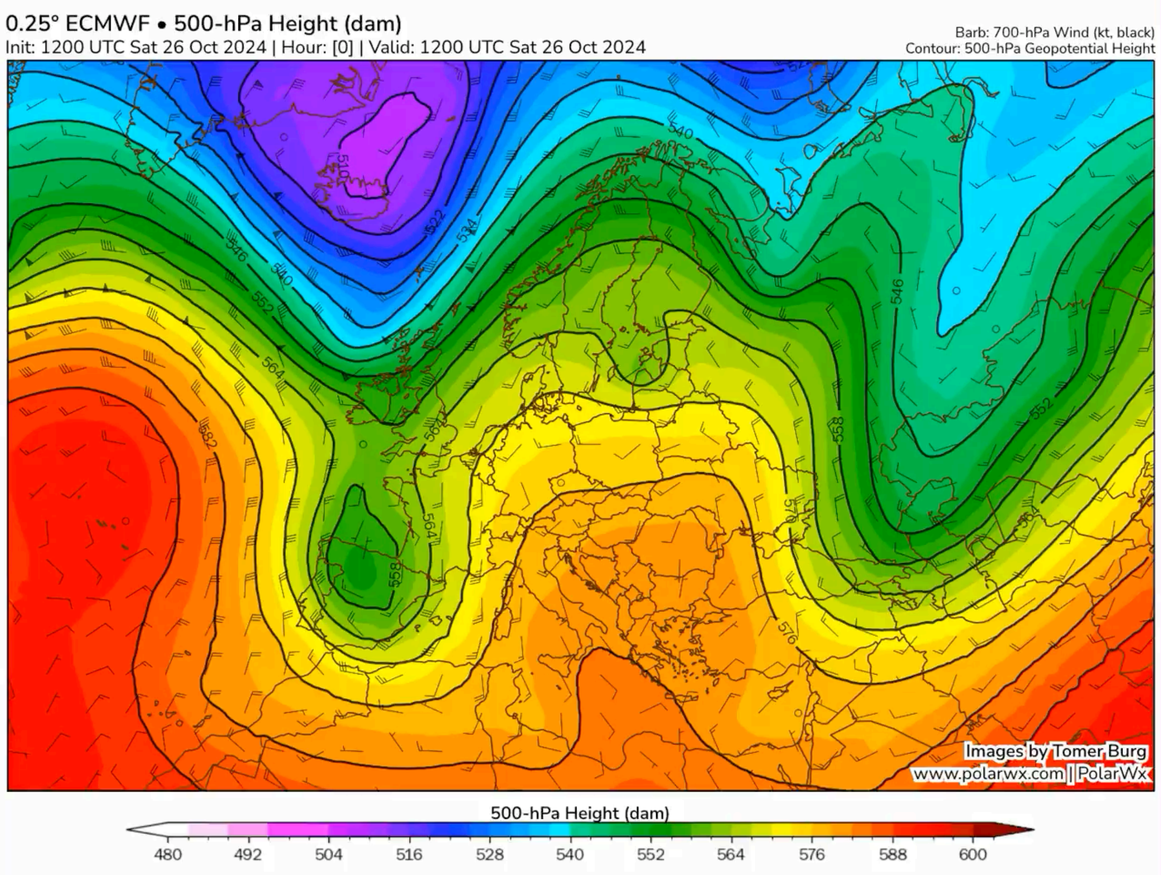
Conclusions

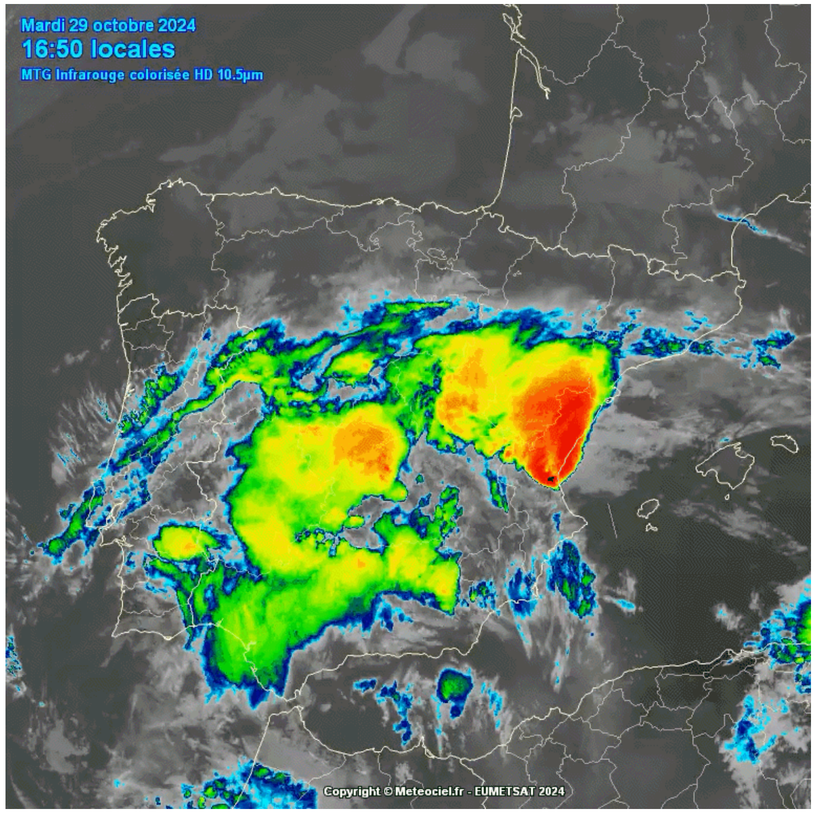
- Total domain rainfall significantly reduced (42%) without CC signal in SST
- Mean rainfall during:
  - Greek phase largely driven by either atmosphere or remote SST
  - Libyan phase strongly influenced by local SST
- Role of local SST on Extremes:
  - Substantial impact on extreme rainfall in Libya
  - Limited impact on Greece
- Now exploring MPAS to remove dependence from boundary conditions (MPAS)



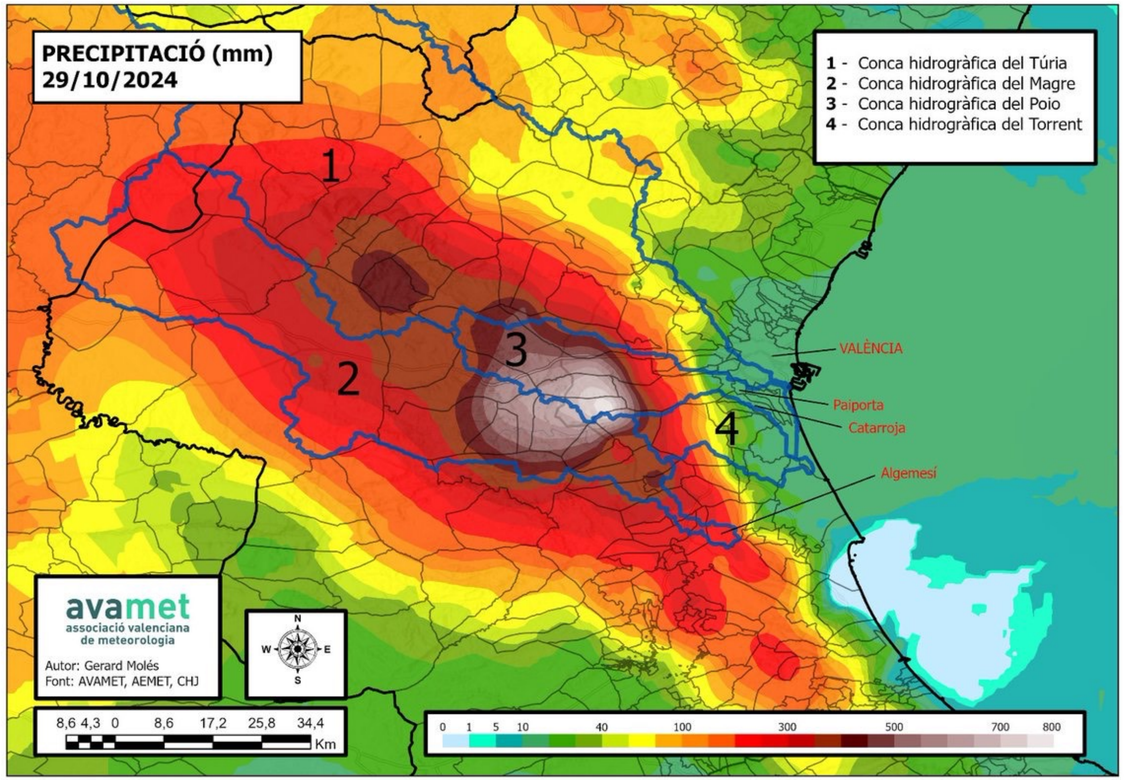
Undergoing research

Cut-off lows in the western Mediterranean





Cut-off lows in the western Mediterranean: Valencia 2024



232 fatalities

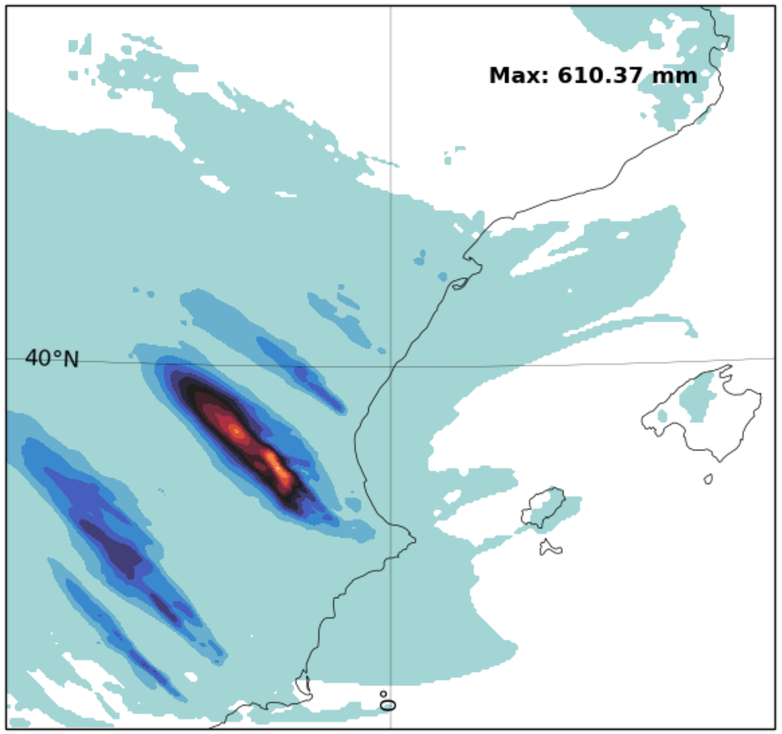
Multiple national records

Time	Rainfall
10-min	42 mm
30-min	103 mm
1-hour	185 mm
2-hour	320 mm
3-hour	476 mm
6-hour	620 mm
12-hour	720 mm
24-hour*	772 mm

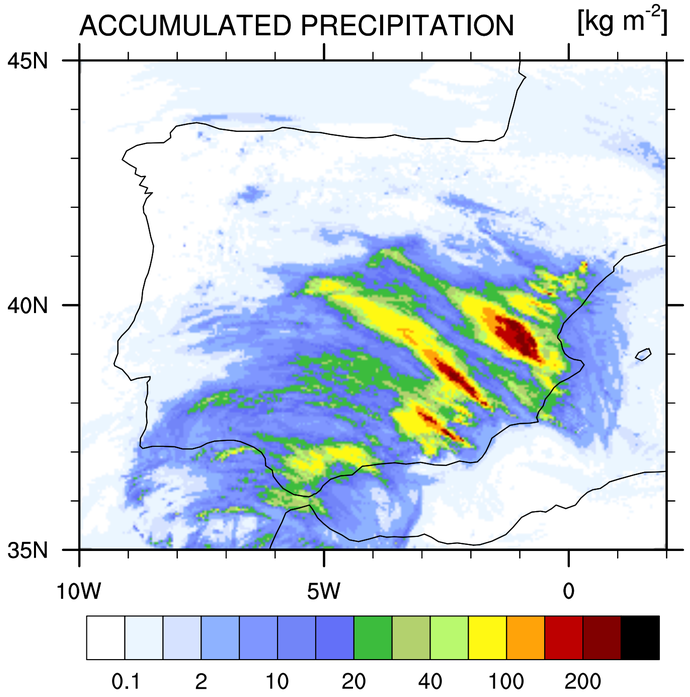
*National 24h record: 817 mm Oliva (Valencia) Nov-1987

Cut-off lows in the western Mediterranean: Valencia 2024

WRF 2-km



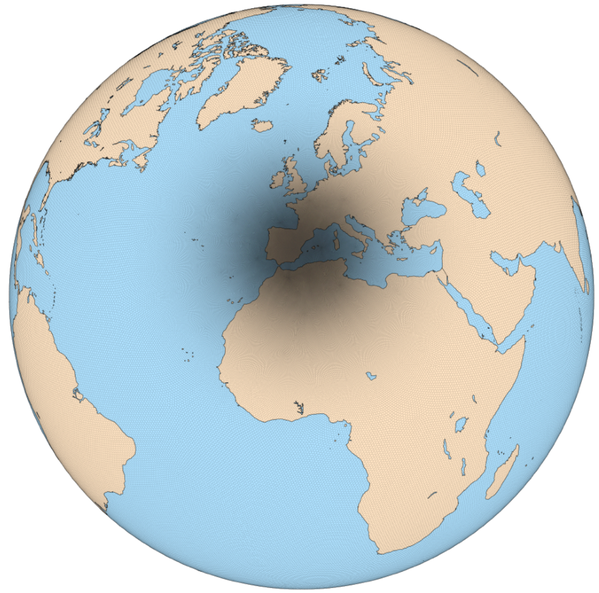
Accumulated precipitation 24h (2024-10-29)



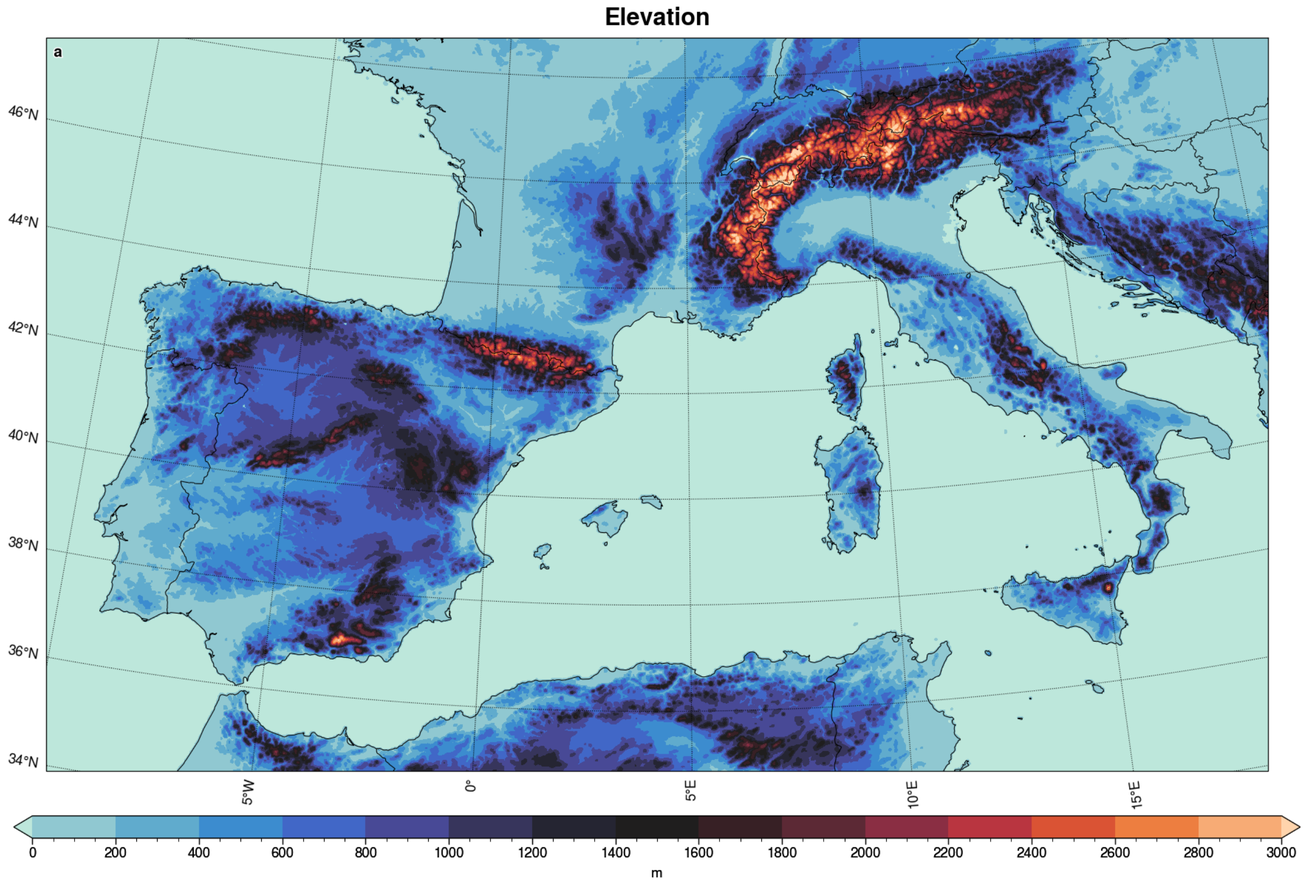
MPAS 60-3km

mesoscale reference

Max 400 mm in 24h



Pseudo Global Warming (PGW) to study extreme rainfall



WRF Experiments

Present

- 10 years at 2km
- ERA5 boundary conditions

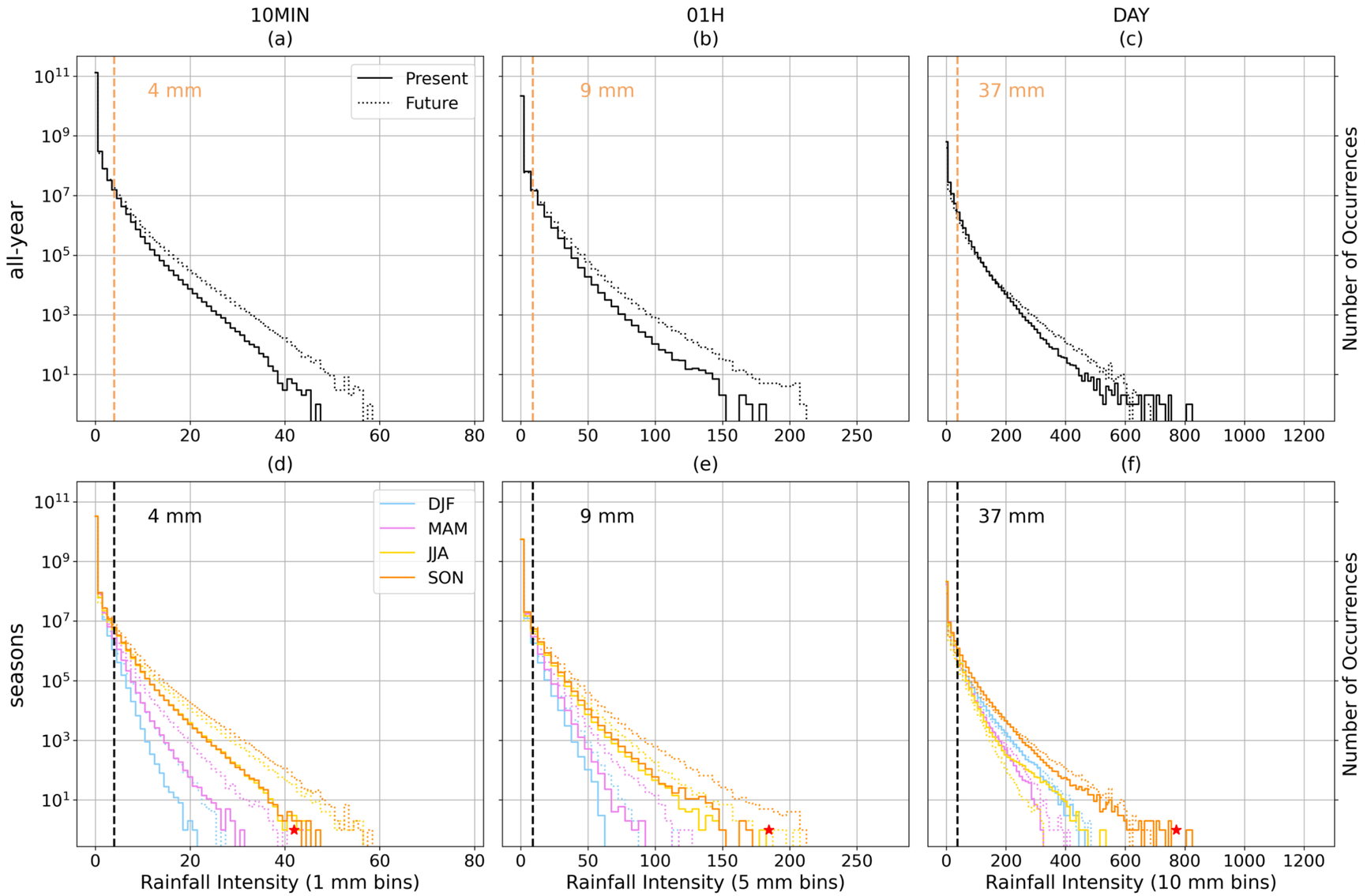
Future

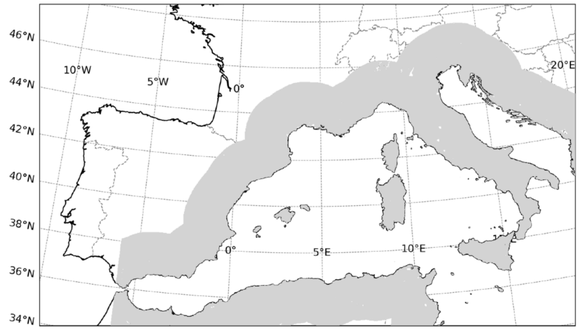
- 10 years at 2km
- PGW (ERA5 + 27 GCMs)

Both

- Explicit convection
- 10-min output for precip.

Pseudo Global Warming (PGW) to study extreme rainfall



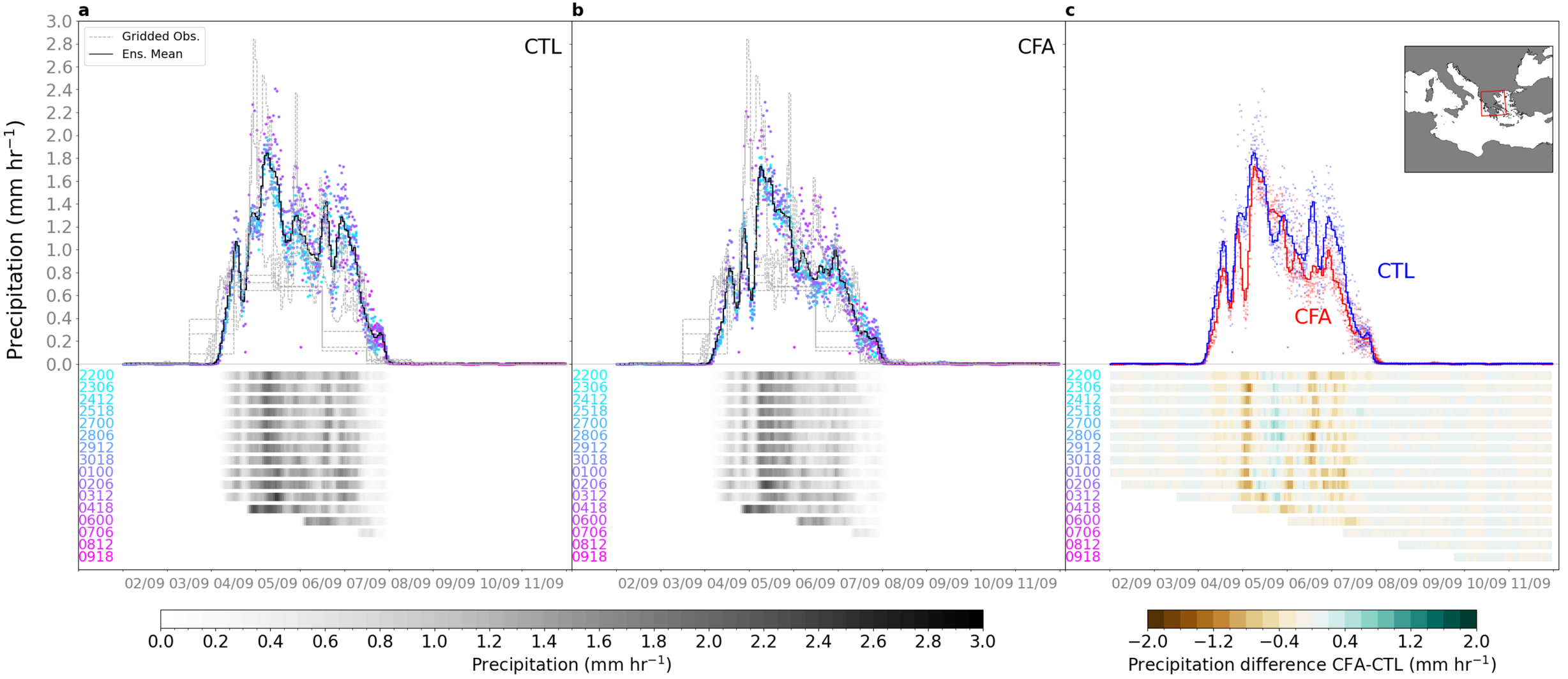


Time	Rainfall
10-min	42 mm
1-hour	185 mm
24-hour	772 mm

Work by Y. Bahuet-Bourret

Gràcies!

Rainfall timeseries Greece



Rainfall timeseries Libya