SYMPOSIUM OP'24

ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Analysing Surface Atmospheric Forcing Distributions and Potential Extreme Events

Ghani, Mahmud Hasan and Pinardi, Nadia

Department of Physics and Astronomy, University of Bologna

Introduction

The analysis of the probability distributions of atmospheric variables is a significant step in understanding ocean forecasts and minimizing associated uncertainties. The study has investigated the characteristics of density distributions using high-resolution atmospheric model forecast analysis data (ECMWF). After removing the seasonal cycles from 15-years time-series, the transformed anomaly dataset of surface atmospheric variables- wind components (U, V), wind amplitude, air temperature (T2M), dew point temperature (D2M), and mean sea-level pressure (MSL-P) are analyzed with probability distribution functions (PDFs). The distribution parameters are estimated with the Maximum Likelihood Estimate (MLE) method.

The study reveals that a three-parameter skew-normal PDF captures the variance and asymmetric tails (skewness) well. It is found that the PDF parameters vary largely between different regions, both the shape (connected to the asymmetric tails) and the scale (connected to the spread of the distribution). Potential extreme values, 95th and 5th percentiles, are computed from the inverse Cumilitative Density Funtion (CDF).

Dataset and Methodology

ECMWF analysis dataset: -spatial resolution 0.125 degree, daily mean resolution (converted from 6-hourly)
Observed variables: D2M , T2M, MSL-P, U10M, V10M

Pre-processing:

Seasonal Climatology (Ct) = $\frac{1}{N}\sum_{j=1}^{N} X_{t,j}$ (1)

Anomalies $(\widetilde{X})$ = $X_t - C_t$ (2)

PDF models :

The Weibull PDF (3) comprises shape and scale parameters, and the support is x > 0, +∞ . The Skew-normal PDF (4) has shape parameter, α, location parameter, μ, and scale parameter, λ, and its support is $x\in(-\infty, +\infty)$.

$$f\,(x;\ k,\lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} exp^{\ -\left(\frac{x}{\lambda}\right)^{k}} \quad (3)$$

$$f\,(x;\alpha,\mu,\lambda) = \frac{2}{\lambda}\,\phi\left(\frac{x-\mu}{\lambda}\right)\Phi\left(\frac{\alpha(x-\mu)}{\lambda}\right) \quad (4)$$

Schematic diagram of the tool:

Initial pre-processing → Removal of seasonal climatology at the grid point

Grid point selection → Retreive time series of selected grid points: $X_{i..n}$

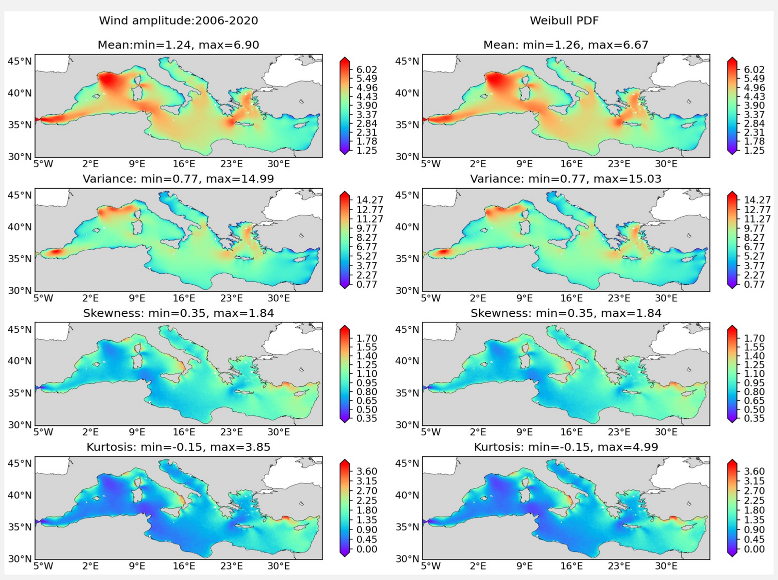
PDF modelling → PDF model fit and parameter estimation

Validation → Comparison of the statistical moments

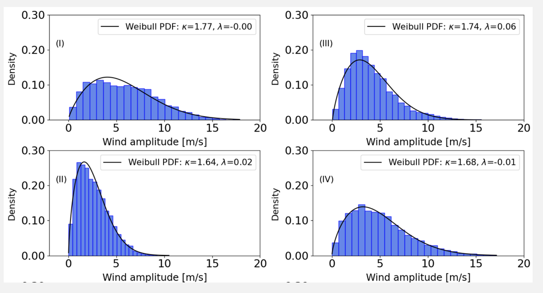
Weibull PDF fit on wind amplitude

Anomaly of wind amplitude, W is defined as

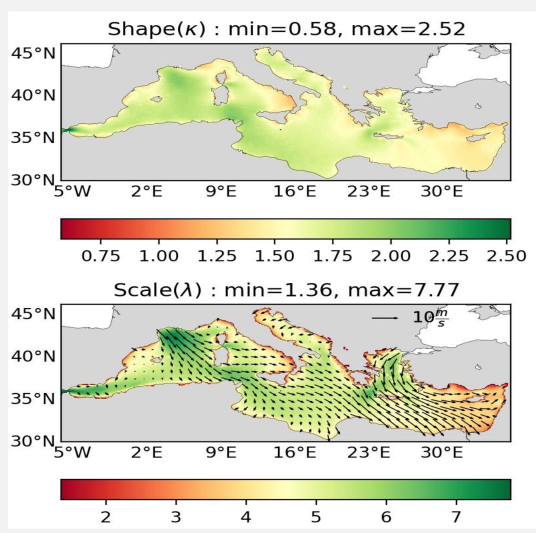
$$W = \sqrt{(U-\bar{U})^2+(V-\bar{V})^2} \quad (5)$$



Distributions of the statistical moments (from top to bottom: mean, variance, skewness, kurtosis): left panel estimated from anomaly data), right panel estimated from Weibull fitted distributions

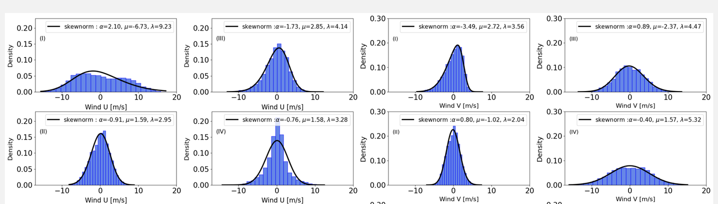


The single grid point distributions for W: (i) Alboran Sea, (ii) Gulf of Lion (iii) Adriatic Sea (iv) Ionian Sea

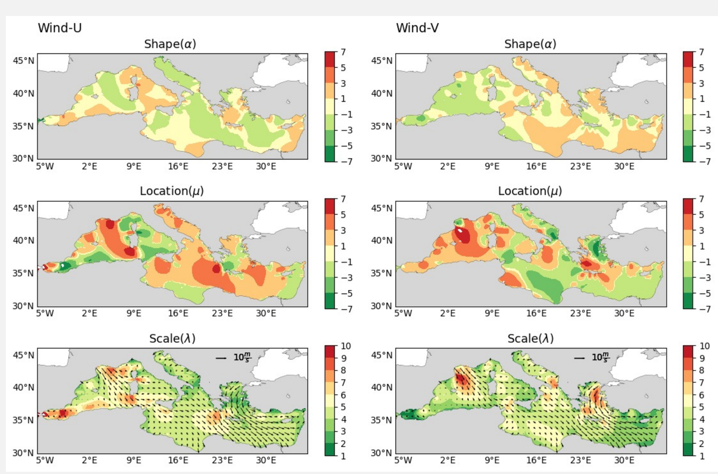


Shape and location parameter for wind amplitude (W)

Skew-normal PDF fit on wind components (U, V)

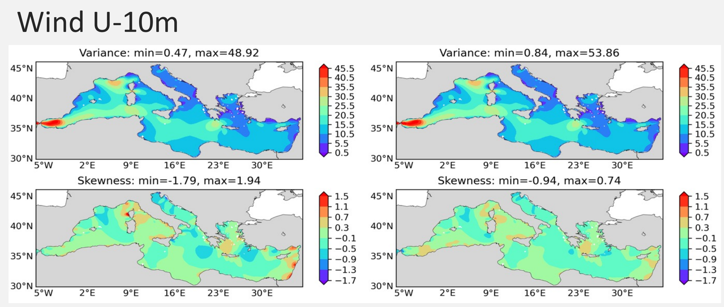


The single grid point distributions for wind (U, V): (i) Alboran Sea(ii) Gulf of Lion (iii) Adriatic Sea (iv) Ionian sea



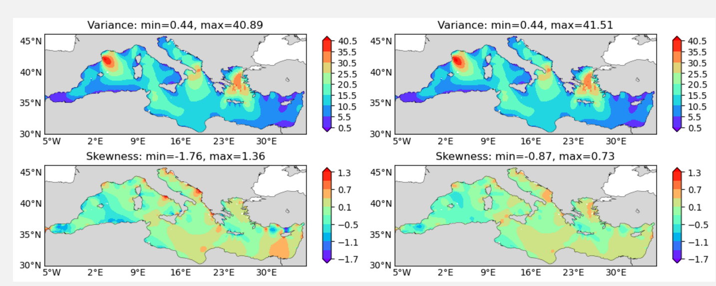
Shape, location and scale parameter distribution for wind-U-10m and wind-V10m

Wind U-10m

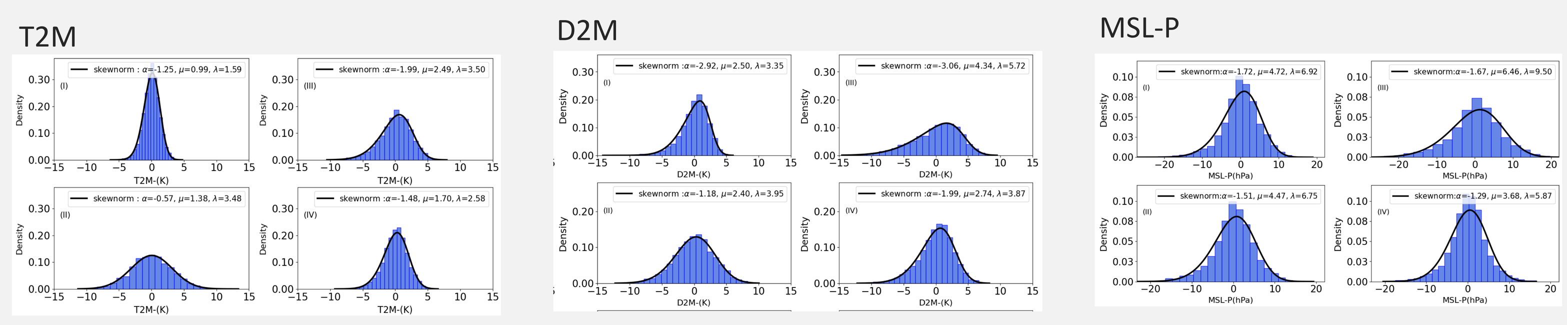


Distributions of the statistical moments (variance and skewness) estimated from data and skew-normal fitted distributions [Up: Wind-U10m, Bottom: Wind-V10m]

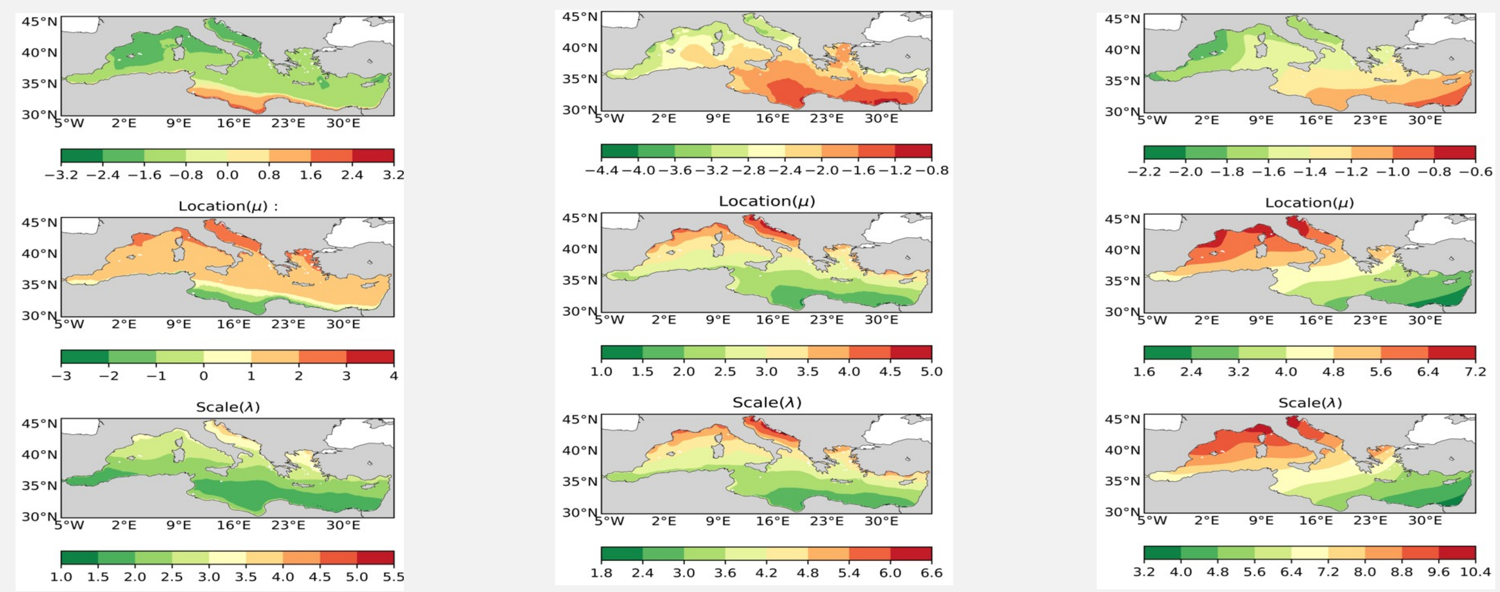
Wind V-10m



Skew-normal PDF fit on T2M, D2M and MSL-P

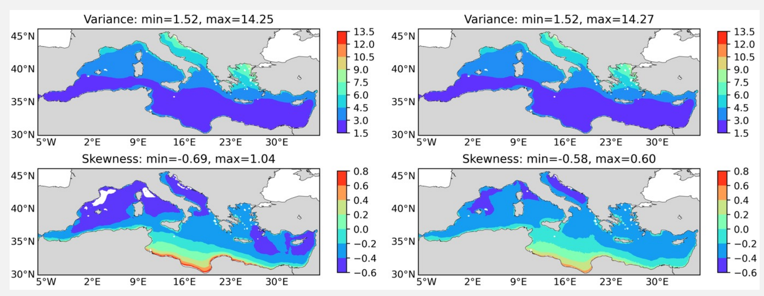


The Single grid point histograms for T2M, D2M and MSL-P: (i) Alboran Sea (ii) Gulf of Lion (iii) Adriatic Sea (iv) Ionian Sea

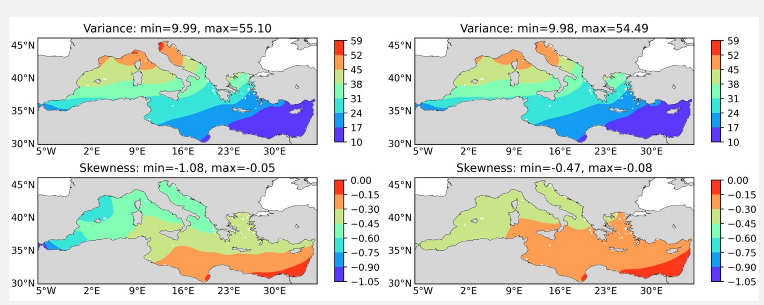


Distributions of shape, location and scale parameter of T2M (left), D2M (middle) and MSL-P (right)

T2M

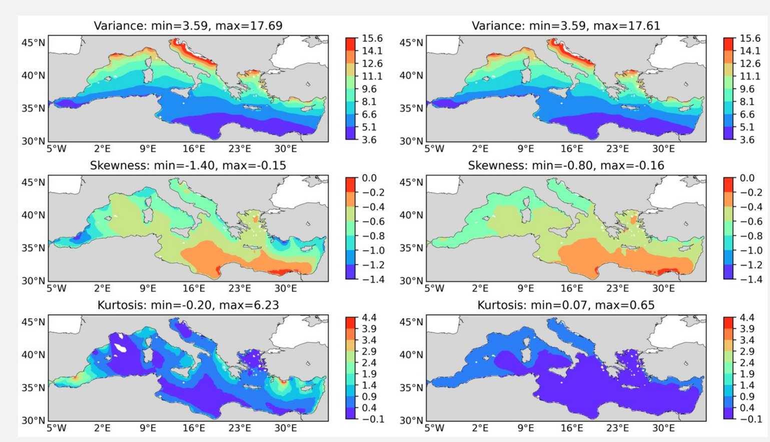


MSL-P



Distributions of the statistical moments estimated from anomaly data (T2M, D2M and MSL-P) and skew-normal fitted distributions

D2M

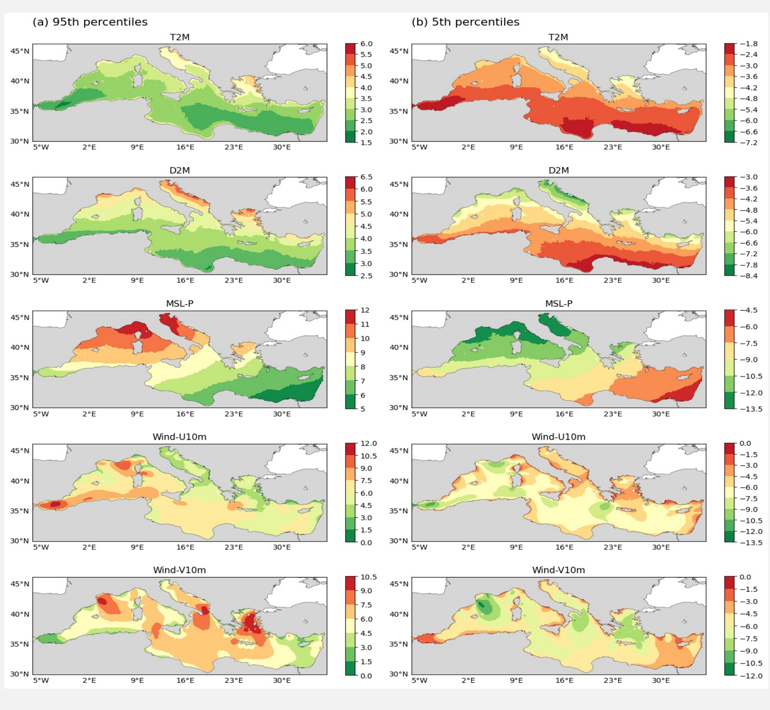


Potential Extremes

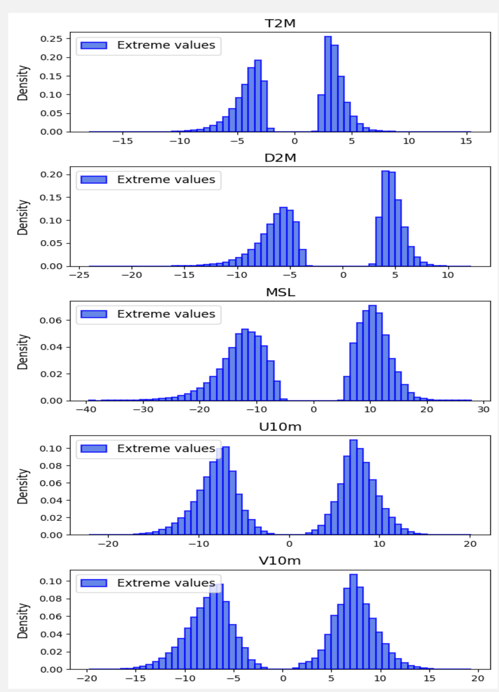
Percentile values are computed from the estimated PDFs at each grid point using the inverse Cumulative Density Function (CDF).

$$f\,(x;\alpha,\mu,\lambda) = \Phi\left(\frac{x-\mu}{\lambda}\right) - 2T\left(\frac{(x-\mu)}{\lambda},\alpha\right) \text{ ....(6)}$$

Where, Φ(z) is the CDF of a normal distribution and T $(z;\alpha)$ auxiliary function related to skewness parameter α



95th percentile (or 0.95 quantile) and 05th percentile (or 0.05 quantile) value distributions of selected atmospheric variables



Histograms of combined 95th percentile (or 0.95 quantile) and 5th percentile (or 0.05 quantile) excluding normal range

Conclusions

- Weibull PDF is confirmed to be the correct PDF for wind amplitude over all the Mediterranean Sea
- The skew-normal PDF is instead emerging as a potential best fit PDF for wind (U, V) components, T2M, D2M and MSL-P.
- Skewness for all the variables is moderate with large differences across the Mediterranean region with the largest skewness values in the Northern Mediterranean Sea areas
- The extreme values show a relevant difference between the northern and southern Mediterranean, especially for T2M, D2M and MSL-P, with the latter a contrast between the western and eastern Mediterranean
- Potential extremes are concentrated mainly in Alboran Sea, Gulf of Lion, Adriatic Sea and Aegean Sea

References

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- Peter C. Chu. (2009). "Statistical Characteristics of the Global Surface Current Speeds Obtained from Satellite Altimetry and Scatterometer Data". In: IEEE Journal of selected topics in applied Earth observations and remote sensing, Vol. 2, no. 1 (2009).

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