Revisiting the Moisture Budget of the Mediterranean Region in the ERA5 Reanalysis

Roshanak Tootoonchi[1,2], Simona Bordoni[1] & Roberta D'Agostino[3]

[1] University of Trento, [2] Edmund Mach Foundation (FEM-C3A), [3] ISAC-CNR

I Motivation

The climate of the Mediterranean region (**MedR**) is characterized by mild-wet winters and dry-hot summers. Recent studies have identified the MedR as a climate change "hotspot" [1,2] marked by intensifying temperature and precipitation reduction. This precipitation reduction cannot be simply attributed to the thermodynamic "wet-gets-wetter" response, pointing to the importance of circulation changes. However, exact dynamical mechanisms are yet to be understood.

II Data & Method

We study the moisture budget in the MedR using the 5th generation ECMWF reanalysis (**ERA5**) [3].

The steady-state moisture budget in pressure coordinates is written as **Eq.(1)**:

$$\overline{P}-\overline{E} = -\frac{1}{\rho_w}\nabla\cdot\int_0^{\overline{p_s}}\overline{\vec{u}q}\,\frac{dp}{g}$$

Here in Eq.(1), ρ_w is the density of water, g is gravitational acceleration, p_s denotes surface pressure, $\vec{u}$ is the vector horizontal wind velocity, and q is specific humidity. Overbars represent monthly-means.

Using Reynolds' decomposition we divide the budget into monthly mean (shown by overbar) and variations from the monthly mean (shown by prime), such that $(.) = \overline{(.)} + (\acute{.})$, and thus the time-mean moisture budget becomes (**Eq.(2)**):

$$\overline{\overline{P}}-\overline{\overline{E}} \approx -\frac{1}{\rho_w}\nabla\cdot\int_0^{p_s}\overline{(\overline{\vec{u}}\,\overline{q}+\overline{\acute{\vec{u}}\,\acute{q}})\,\frac{dp}{g}}$$

Here in Eq.(2), the 1st term on the right is the moisture flux convergence (**MFC**) by the mean-flow contribution, and the 2nd term is the MFC by the transient eddies. Double overbars represent climatological means.

We are interested in decomposing the budget furthermore into zonal-mean (shown by [.]) and stationary components (shown by (.)*) such that $\overline{(.)} = [\overline{.}] + (\overline{.})^*$. The budget then becomes (**Eq. (3)**):

$$\frac{1}{\rho_w}\nabla\cdot\int_0^{\overline{p_s}}\overline{\overline{\vec{u}q}\,\frac{dp}{g}} = -\frac{1}{\rho_w}\nabla\cdot\int_0^{\overline{p_s}}\overline{[\overline{\vec{u}}][\overline{q}]\,\frac{dp}{g}} - \frac{1}{\rho_w}\nabla\cdot\int_0^{\overline{p_s}}\overline{\overline{\vec{u}}^{\dagger}\overline{q}^{\dagger}\,\frac{dp}{g}} - \frac{1}{\rho_w}\nabla\cdot\int_0^{\overline{p_s}}\overline{(\overline{\acute{\vec{u}}\,\acute{q}})\,\frac{dp}{g}}$$

Where (**Eq. (4)**): $\overline{\vec{u}}^{\dagger}\overline{q}^{\dagger} = \overline{\vec{u}}^{*}\overline{q}^{*} + [\overline{\vec{u}}]\overline{q}^{*} + [\overline{q}]\overline{\vec{u}}^{*}$

In Eq. (3), the 1st term on the right is the MFC by the zonal-mean circulation, and the 2nd term is the MFC by the total stationary eddies [4], that is the sum of all terms including stationary eddies (see Eq.(4)).

III Moisture Budget Analysis

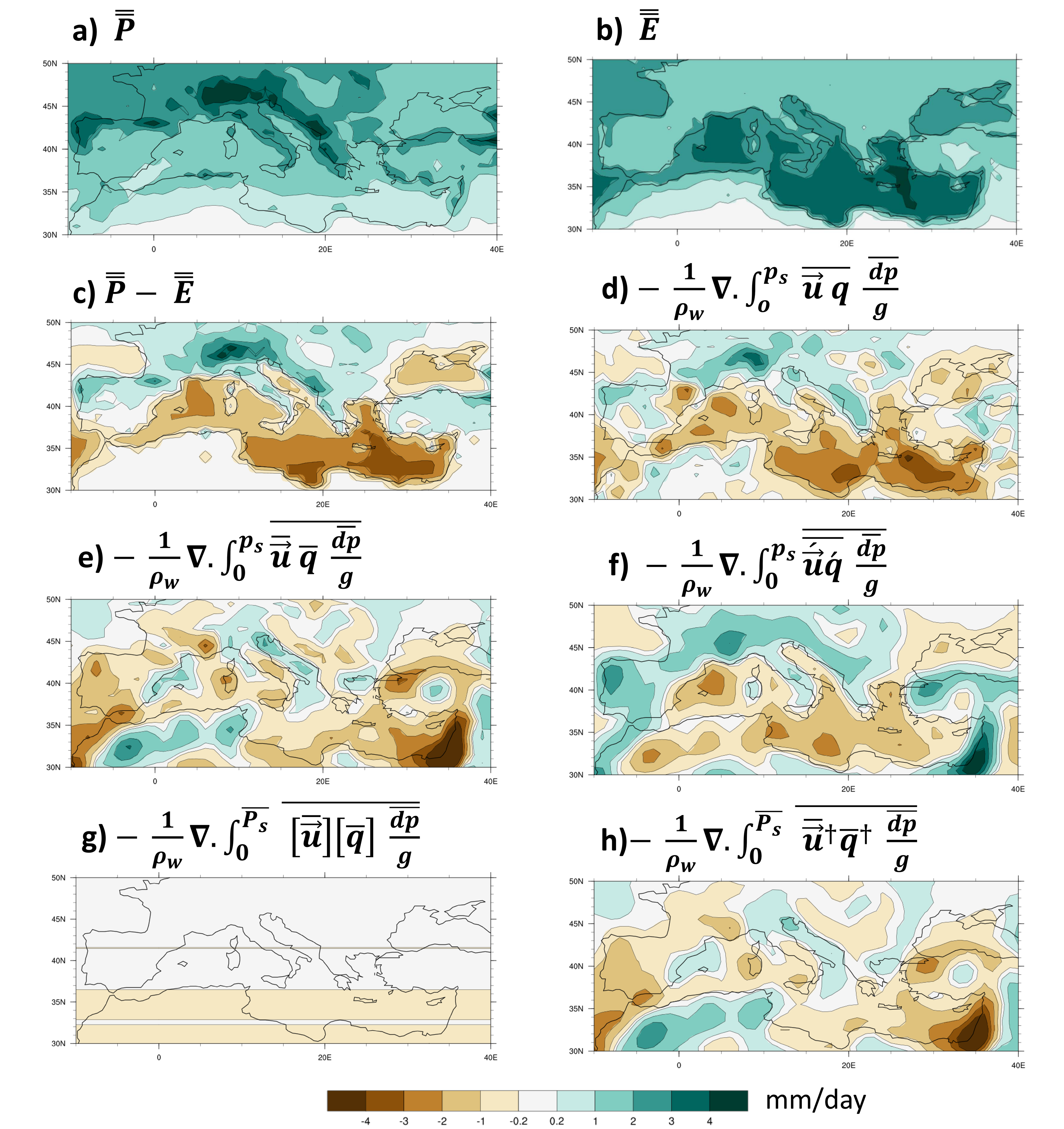


Fig. 1. The annual MedR climatological moisture budget in the *ERA5*: (a) P, (b) E, (c) P – E, (d) vertically integrated MFC (total), and contributions to the MFC by the (e) mean flow, (f) transient eddies, (g) zonal-mean circulation and (h) stationary eddies.

Positive P – E over the Mediterranean land regions (**Fig.1c**) is predominantly sustained by the sub-monthly transient eddies (i.e., storm systems, extratropical cyclones) converging moisture that originates from the Mediterranean Sea (**Fig.1f**). On the annual average, transient circulations converge moisture over the Iberian Peninsula as well. In contrast, the annually averaged mean flow diverges moisture over most of the MedR (land and sea), except Adriatic Sea and north-western Africa (Tunisia, northern Algeria) (**Fig.1e**).

The zonal-mean circulation is dominated by the Hadley cell in lower latitudes, which results in removal of moisture from the subtropics. According to **Fig.1g**, the zonal-mean circulation has very little diverging contribution over the MedR. Stationary waves, analogous to the mean flow, converge moisture over north-western Africa and Adriatic sea, and diverge moisture from the MedR (**Fig.1h**).

Due to the diminutive contribution from the zonal-mean circulation, the stationary eddies explain the mean flow moisture convergence quite well.

IV Trend Analysis

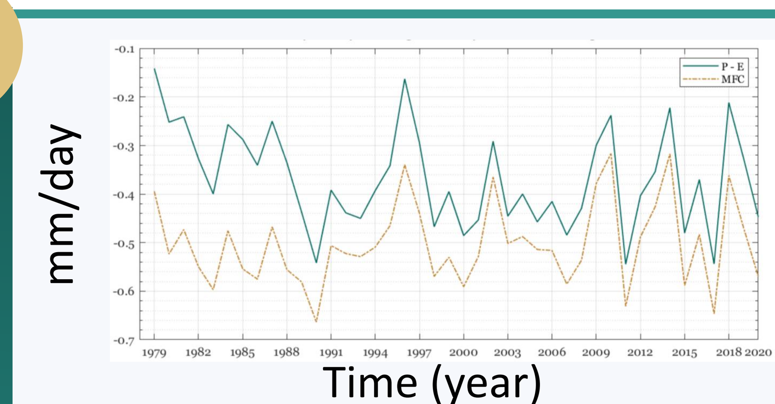


Fig. 2. Temporal evolution of P – E and MFC in the ERA5 over the MedR in the 1979 – 2020 period. P – E has the mean value of **-0.367** mm/day, and MFC has the mean value of **-0.503** mm/day.

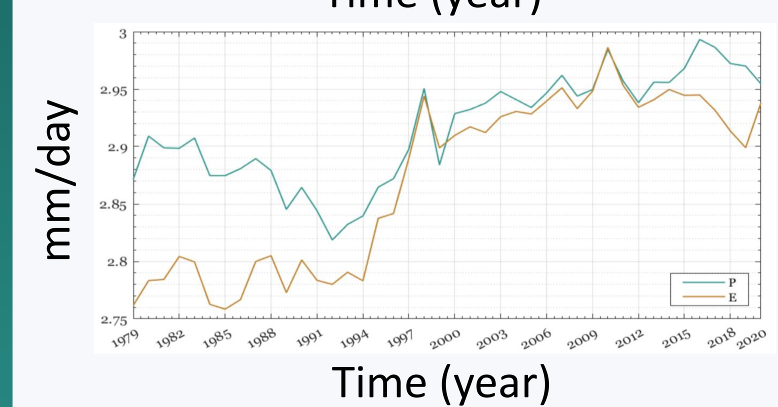


Fig.3. Temporal evolution of globally averaged (land/ocean) P and E in the ERA5. Strong but unrealistic trend is observed in both P and E. Given the obvious surplus of global P, the budget is not ideally closed in the ERA5.

According to ERA5, P – E in the MedR undergoes a significant decreasing trend owing to significant increase in E and a rather steady P in the 1979 – 2020 period (**Fig. 2**). This is highly in line with previous works which highlighted that the projected drying in the MedR is already detectable [2]. On a global scale, P and E within the ERA5 dataset show significant but unrealistic increasing trend during the mentioned period. The increase in globally averaged E agrees well with the previous reanalysis product (i.e., ERA-Interim). However, according to the literature, the increase in global P in ERA5 is unrealistic [5] and probably an artefact of this product.

Evidently, ERA5 comes with caveats, however, improvements have been made since mid-1990s, where P and E start conforming.

References:

[1] D'Agostino, R., & Lionello, P. (2020). The atmospheric moisture budget in the Mediterranean: Mechanisms for seasonal changes in the Last Glacial Maximum and future warming scenario. Quaternary Science Reviews, 241.

[2] Seager, R., Liu, H., Henderson, N., et al. (2014). Causes of increasing aridification of the mediterranean region in response to rising greenhouse gases. Journal of Climate, 27(12), 4655–4676.

[3] Hersbach, H., Bell, B., Berrisford, P., et al. (2023): ERA5 monthly averaged data on pressure levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.6860a573

[4] Wills, R. C., & Schneider, T. (2015). Stationary Eddies and the Zonal Asymmetry of Net Precipitation and Ocean Freshwater Forcing. *Journal of Climate*, *28*(13), 5115–5133.

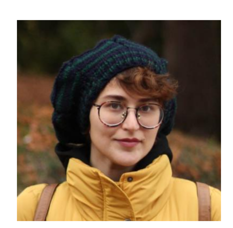
[5] Mayer, J., Mayer, M., & Haimberger, L. (2021). Consistency and Homogeneity of Atmospheric Energy, Moisture, and Mass Budgets in ERA5. *Journal of Climate*, *34*(10), 3955–3974.

Contact:

Roshanak Tootoonchi | PhD Student

Email: roshanak.tootoonchi@unitn.it

Twitter: @roshanak_t



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