Reply to the Anonymous Referee #1

REVIEW of « Water vapour fluxes at a Mediterranean coastal site during the summer of 2021: observations, comparison with atmospheric reanalysis, and implications for extreme events. »

This study describes the atmospheric measurements during the campaign MESSA-DIN during summer 2021, in particular comparing different observational data to ERA5 reanalysis estimates. The study investigates the differences between the two types of data, in the setting of previous literature assessing ERA5 performance. However, the manuscript lacks in preciseness and often omits the link between the data and scientific assertions. I am willing to recommend the publication of this work only after the language and scientific statements are reviewed across the whole text. The latter should fit with the contents of the study.

Thank you for your constructive feedback on our manuscript. We appreciate your valuable observations, which have highlighted areas for improvement and the need to strengthen the connection between our data and the scientific assertions. Below, we provide (in bold) a detailed response to each of the reviewer's comments.

GENERAL COMMENTS

- In the « Instruments and datasets » section please remove focus on the technicalities in favour of explaining more clearly how the measurements are to be interpreted, referring to the specific plots (e.g., how you infer presence of cloud cover).

Section 2 has been shortened and revised to achieve a better balance between providing sufficient technical details to ensure confidence in the measurements discussed in the manuscript and improving the clarity of their interpretation as presented in the figures.
The new version of Section 2 is reported below:

"The study employs a suite of advanced instruments for studying aerosol, water vapour, and clouds. The measurement site was equipped with several instruments, including a Ka-band Doppler radar, laser ceilometer, a UV polarization Raman lidar, a microwave radiometer complemented by an infrared radiometer, a sun photometer, a wind Doppler lidar, a total sky imager, and other near-surface measurements. This section describes the instruments and products used in the data analysis presented in this paper.

The CL51 ceilometer measured cloud base height and attenuated backscattering up to 15 km a.g.l. with high temporal (10 s) and spatial (10 m) resolutions using a 910 nm laser diode system, though limited by a low signal-to-noise ratio (Madonna et al., 2018). Data were processed via the ACTRIS-Cloudnet algorithm (Rosoldi, 2024) and provide the uncalibrated backscattering coefficient, which depends on the amount and size of particles at different altitude levels. Except for very thin clouds or huge aerosol outbreaks, this allows distinguishing between clouds and aerosol particles depending on the backscattering intensity.

The MIRA-36 Ka-band radar, designed for unattended long-term operation, provided range-resolved cloud reflectivity, vertical wind, and linear depolarization ratio up to 15 km with 30 m spatial and 30 s temporal resolutions. The radar is also crucial for cloud and large aerosol detection (Madonna et al., 2010, 2013). In this paper, the radar reflectivity factor, proportional to the sixth power of the observed particle size, is used to detect clouds and precipitation, related, in

the measurement campaign, to values larger than -30 dBZ, while values lower than -40 dBZ are referred to echoes from aerosols, including pollen or insects.

A Doppler lidar operating at 1.5 µm measured backscattered radiation and radial velocity up to 12 km, depending on atmospheric aerosol load, with a Doppler precision below 20 cm/s for SNR > -17 dB. Vertical wind profiles were retrieved using conical scans every 5 minutes, following Päschke et al. (2015).

The Radiometrics Microwave Profiler (MWP 3014) measured key atmospheric parameters, including integrated water vapor (IWV), liquid water path (LWP), brightness temperatures, and thermodynamic profiles (Cimini et al., 2018; Madonna et al., 2010). Measurements continued until a power supply failure on September 30. IWV and LWP were derived from brightness temperatures at 22.235–30.000 GHz, while temperature and humidity profiles were retrieved using neural networks trained on coastal and mountain radiosonde data (Solheim et al., 1998). Vertical resolutions reached 100 m below 1 km and 250 m above. Calibration was ensured via the tipping curve method, mitigating instrumental biases (Han and Westwater, 2000). Despite robust calibration, uncertainties were notable: temperature retrieval errors exceeded 1 K above the boundary layer (Bock et al., 2024), and relative humidity retrievals showed biases within 10–15% up to 7 km (Ware et al., 2003; Cimini et al., 2014; Xu et al., 2015; Caumont et al., 2016). RMSE for RH was below ~20% across profiles under all conditions (Cadeddu et al., 2018), although co-location issues between radiosonde and MWP measurements could contribute to further errors. These factors highlight the importance of refining retrieval methods for improved accuracy.

A polarization Raman lidar (Raymetrics LR111-D200) captured aerosol and cloud properties using 355 nm UV pulses, with processed data providing backscattering, extinction coefficients, and depolarization ratios via EARLINET's SCC (D'Amico et al., 2016).

Sun photometer (AERONET Lv2.0) measurements offered aerosol optical depth (AOD), particle size distribution, and water vapor estimates with stringent calibration and quality control (Boselli et al., 2012).

For comparison, the ERA5 reanalysis dataset, produced with ECMWF's Integrated Forecasting System Cy41r2, provided hourly atmospheric parameters at a 0.25° resolution, incorporating data from over 40 satellite systems (Hersbach et al., 2020; Essa et al., 2022; Lavers et al., 2022). Further, ERA5 combines a large variety of data sources, including more than 40 satellite sensors, such as AMSU-A and AMSU-B, IASI, and GNSS-RO, and uses advanced techniques to produce a coherent and detailed representation of past and present climate conditions. Despite its widespread use, ERA5 requires validation against high-resolution observational data to improve its applicability in sub-grid process-sensitive coastal areas."

- What do you mean by water vapour fluxes ? Are you talking about atmospheric transport or of fluxes from the surface to the atmosphere ? Please clarify in the whole text, as this is one of the main points you touch in the Introduction and Conclusions.

In the entire paper, we are referring to enhanced water vapour transport in the free troposphere due to anomalous evaporation from the sea surface, enhancing other remote sources. The updated version of the manuscript will be entirely revised to reflect this concept.

- In the conclusions you should acknowledge more clearly that the comparison with reanalysis is hindered by its coarse resolution compared to station measurements. In general, you also say that this highlights the need of better representations of coastal / orographic atmospheric processes (e.g. line 416). However, this is possible only with altogether different high-resolution models. We cannot expect a ~31 km resolution model to contain the topographic details that allow an improved comparison with your data.

The sentence at lines 415-418 has been rephrased as follows: "For both datasets, water vapour transport may be either overestimated or underestimated, potentially affecting the modeling of cloud formation in ERA5. ERA5 overestimated cold cloud presence, whereas ground-based instruments detected less frequent cloud cover. This discrepancy highlights the need for higher-resolution (regional) reanalysis with improved performance in capturing water vapour variability in complex coastal and orographic settings.". The assessment of the performance of regional reanalysis datasets, such as CERRA, does not show notable improvements for water vapour, either at the surface or in the free troposphere, in contrast to temperature and wind. For instance, see the comparative performance analysis of CERRA and ERA5 (Ridal et al., 2024, QJRMS). Furthermore, CERRA data are not yet officially available for the entire campaign period (up to June 2021). Moreover, the nearest grid point of ERA5 is at a distance from Soverato of about 7.8 km — Soverato (38.6894°N, 16.5453°E) and the ERA5 point (38.75°N, 16.5°E) — both over land. Given that we are not reporting single comparison profiles but a time series of more than 3 months and the variability of the water vapour field, it is unlikely that there is a significant bias related to the spatial mismatch of the two datasets. Additional details are provided in the response to the third general comment from anonymous reviewer #2.

TECHNICAL COMMENTS

The technical comments touch the problems of language and precision, which should be addressed more generally than in the individual comments, as indicated in the introductory paragraph of the review.

Line 35 : feeding the zonal or meridional air mass transport with what ? Representing a significant source of what ?

The sentence has been rephrased as: "The Mediterranean summer is often characterized by significant water vapor fluxes from the sea, driven by intense evaporation, which are a significant source of moisture for both zonal and meridional air masses."

Line 37: Are you saying that both remote water vapour sources and local moisture uptakes from intense evaporation are necessary for severe precipitation ? This is not clear in the sentence.

The sentence has been modified as follows as: "Severe precipitation in the Mediterranean Basin depends on both remote and local sources of anomalously intense surface evaporation"

Line 41 : substitute « while » with « and »

OK

Line 46 : remove « among the last decades »

OK

Line 50 : remove « and recent studies » if you are not including additional references.

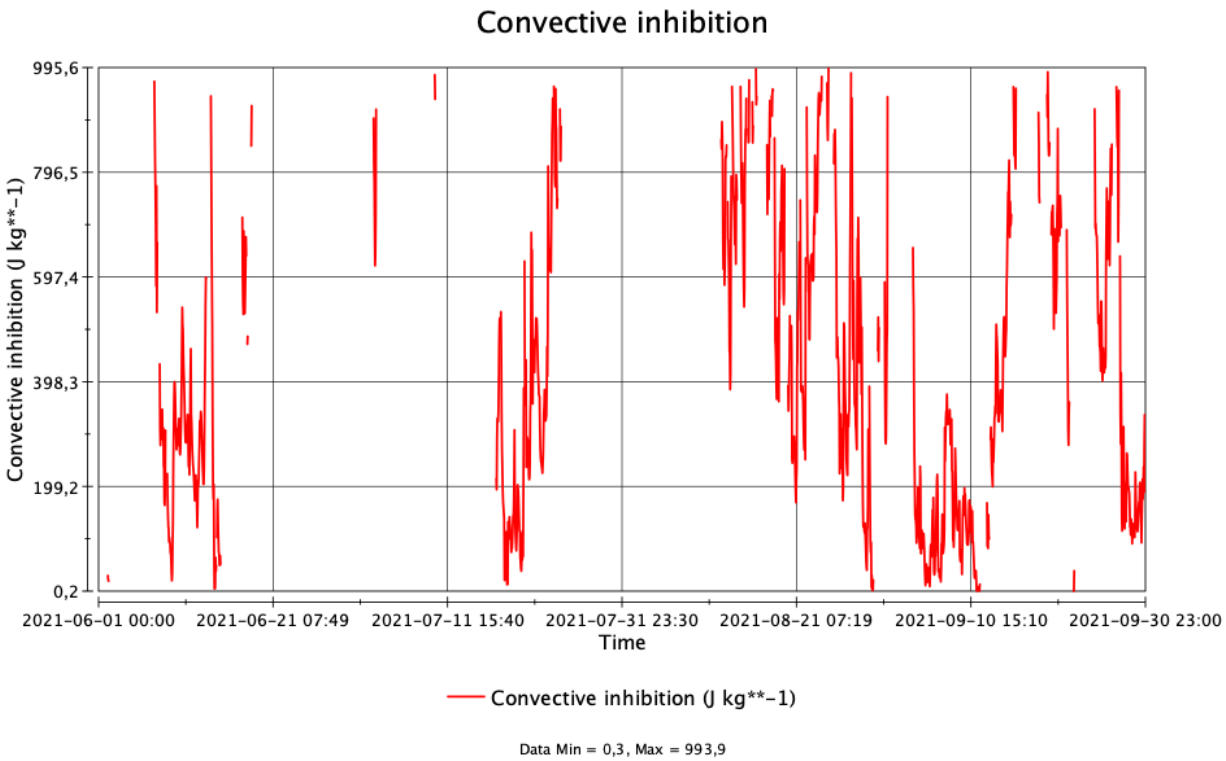
OK

Line 52 : I suggest to reformulate with « around or higher than the climatological values ».

OK

Line 55 : Expand acronym CIAO.

OK, CNR-IMAA Atmospheric Observatory
Line 57 : « at a coastal site the effect of... ».
OK
Line 64 : « collected with a microwave radiometer and an infrared thermometer over 24h/7days from June 24 to September 30 2021. »
OK
Line 65 : « In the time series, high values of relative humidity in the mid-troposphere were investigated... ». Note also repetition of term « contribution ».
OK, this will be fixed.
Line 68 : What do you mean by « local paucity of warm and cold cloud layers » ?
The sentence has been modified as follows
Line 73 : « provides » to replace « offers ».
OK
Line 75 : « the investigation of the role of aerosols... »
OK
Line 88 : remove « presented in this paper ».
OK
Line 102 : expand acronym SNR.
OK, Signal-to-Noise Ratio.
Line 175 : I do not agree with the sentence « A decrease in the RH values in the mid-troposphere often corresponded to an increase in the values within the boundary layer. ». In my opinion there is no clear pattern between RH in the mid troposphere and in the boundary layer, as BL-maxima seem to occur both with mid-tropospheric minima and maxima.
This sentence, as not essential to convey the most important message of the data analysis, has been removed.
Line 177 : What levels are you talking about ?
At this line, we just find the word "freezing level". Not clear the reviewer's comment; however, that part of the manuscript will be revised.
Line 195-197 : The sentence is badly structured. Please correct.
The sentence has been rephrased as follows: "In the first half of July there is, instead, not a good agreement between ERA5 and MWP measurements in range 300 hPa-550 hPa, for both the depth and the time evolution of the middle-tropospheric moist layer.
Line 200 : replace « in this light » with « Limitations of this kind ».
OK.
Line 202 : Add reference to figure in the first sentence in paragraph.
OK
Line 210-210 : Convection is linked to the presence of strong CAPE, but also depends on low values of convective inhibition (CIN) or on the presence of forcing overcoming CIN. For this reason you cannot directly relate CAPE and convection. In these sentences, you should moderate the strength of your assertions.
In the attached plot, the CIN for the Soverato site in the period June-September 2021 is reported. We will moderate the tone of the sentence, although it is evident that, for long periods of time (e.g. in June-July) the CIN values is frequently zero, but the convention is often (July) low-moderate.



Lines 215-217 : Insert ref to figure.

OK

Line 252-253 : I don't understand what you mean by « improved fit for temperature, wind and humidity in the troposphere in comparison with radiosonde data prior to assimilation ». Are you comparing the IFS performance with radiosonde data before and after data assimilation ? Please clarify.

The sentence refers faithfully to Hersbach et al., 2020, which introduce and assesses ERA5 performances. This will be clarified in the text.

Line 255-256 : please rephrase to « in the upper troposphere ERA5 is found to underestimate water vapour concentration and ice supersaturation ».

OK

Line 259 : « addressed » to replace « applied »

OK

Line 266 : the reference to the flood event is out of place here. If possible, remove mention of the Cy47r3 release. Or else clarify differences with respect to other versions in a separate sentence.

OK, the difference with respect to other versions will be clarified.

Line 271 : remove « comparator ».

OK

Line 272 : separate the two sentences. Note that the second is not in opposition with the first, as the term « though » would suggest.

OK.

Line 279 : « even in a different environment than … NAME FIRST ENVIRONMENT »

The sentence will be modified as follows: "These results suggest that, even in a mountain environment, ERA5 exhibits a clear bias in RH values and faces challenges in reproducing RH variability over time."

Line 293 : « MP3014, WHICH is compared in … ».

OK

Line 297 : Merge with previous paragraph. Also, in this and in the following paragraph, add ref to Figure 9.

OK

Line 315 : Not clear what you mean by « is the intensity of the IVT vector with the components

The sentence will be modified as follows: "... the ERA5 data have been used to estimate the total water vapour transport (IVT) and its zonal and meridional components."

Line 217 : if v is vector denote with vector symbol (arrow or bold).

OK.

Line 320 : note that decade means ten years. Please correct.

OK.

Line 319-321 : The sentence from « involving » to « Africa coast » is confused. Please separate from previous sentence and rephrase to make it comprehensible.

OK.

Line 323 : Please add label on plot corresponding to the position of Soverato.

OK.

Line 234 : « transport »

OK.

Line 235 : refer to Figure 13.

OK

Line 334 : « contributing ».

OK

Line 334-338 : replace « ; » with full stops. Also, please rephrase and create logical connections between the sentences. At the moment it is difficult to follow.

Line 341-344 : Only the first part of the sentence is relevant for this study. Please remove misleading reference to climate integrations.

Line 371-373 : Rephrase and separate sentence starting from « only because ».

Line 375 : replace « spreader » with « wider ».

OK

Line 375-376 : sentence is not clear.

The sentence has been rephrased as follows: "Properties of the fine particles are quite similar for both months, with a spreader distribution in September, except for the coarse mode.

Line 376-380 : The whole period is confused, and it is not clear on which data/analysis you base your statement. Please improve clarity and precision.

Summer 2021 has been replaced with Jun-Sep. 2021,

Line 385 : Since you have no direct measurement of the water-vapour greenhouse effect impact on temperature, you can cite this as a potentially amplifying factor.

OK, the sentence will include a "may" to mitigate the statement.

Line 408-410 : You should be more specific about the number of case studies. I believe you analyse water vapour transport rather than fluxes from the sea. Say « Two intense water vapour **transport** events were identified using the ERA5 data, one from the northwest Mediterranean (Spanish/French gulfs or Tyrrhenian Sea) and one from North Africa ».

OK

Line 416 : « compared to ground instruments detecting less frequent cloud cover. This emphasizes the need for improving reanalysis performance in complex coastal and orographic settings. »

See the replies to the general comments.

Line 428-433 : The whole period is impossible to follow. Please rephrase and separate in multiple sentences to make it clear.

The sentence has been rephrased as follows: "In light of the resolution and forecast models, having a km-scale forecast can significantly improve the ability to address mesoscale phenomena. Despite the computational challenges, this approach allows for the resolution of important processes such as convection, rather than relying on parameterization. Recent studies (Caldas-Alvarez et al., 2022; Fosser et al., 2024; Chang et al., 2024) have shown that this is beneficial for extreme events. Furthermore, such models have already been implemented in some early warning systems and meteorological services, including the Limited Area Ensemble Prediction System (COSMO-LEPS) developed by the COSMO consortium and the German National Meteorological Service (DWD)."

Line 440 : « affecting Central and Eastern Europe » Can you say this based on climatological studies ? If not, please specify you are talking of one example and do not generalise.

The sentence has been rephrased as follows: "Instead, according to the investigated cases, large amounts of water vapour becoming available under these transport events may have profound impacts, particularly, affecting Central and Eastern Europe."

Line 451-452 : The last sentence is badly structured. Please revise.

The sentence has been rephrased as follows: "Future work could focus on expanding this study to include additional cases, depending on observational availability, as well as conducting modeling experiments to improve data assimilation and model configurations, as discussed in this work."