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Interactive comment on "Atmospheric Conditions Leading to an Exceptional Fatal Flash Flood in the Negev Desert, Israel" *by* Uri Dayan et al.

Uri Dayan et al.

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1. General comments

The study "Atmospheric Conditions Leading to an Exceptional Fatal Flash Flood in the Negev Desert, Israel" by Uri Dayan, Itamar M. Lensky and Baruch Ziv presents a thorough analysis of the synoptic and sub-synoptic patterns which produced a major storm in southern Israel, causing the death of 10 people. To my view, the significance of the paper is clear, given that there seems to be no sufficient knowledge to alert people ahead of such storms. Although analyzing one case study, the study has a substantial contribution to the understanding of flood-bearing rainstorms in Israel and its vicinity, as general conclusions are drawn and using a comparison to another eleven spring

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storms that caused floods in the area. I find the analysis done along the cyclone track (MCV, speed) especially interesting, as it shows this cyclone intensified over Israel, and was therefore specifically intense over this region, and as it gives sort of reference values that can help in forecasting of severe storms. Furthermore, I think that the study of the atmospheric conditions during flood-bearing storms is much needed as these are the biggest natural hazard causing fatalities in the region. The scientific and presentation quality is good, although I have quite a few comments on both topics. Overall, I think that this study is interesting and important, and is worth publication in NHESS after addressing the points raised below. Three of my comments worth specific attention and are written under "specific comments". Other comments are smaller in nature (even if some are also conceptual) and most of them are technical in nature.

Response: We want to thank the reviewer for his/her valuable comments and considerable contribution for improving the quality of the research.

2. Specific comments

2.1 L160-174: These lines present an interesting idea; however, I am not sure the support given to it is enough. It is not clear to me if the slowing of the cyclone occurs every time there is a closed cyclone over the region or only when there is a dipole pattern.

Response: The present study analyzes the 25-26 April rainstorm as a case study, with a reference to previous storms in the same season (to which a sub section will be devoted in the results section), it does not aim to generalize the behavior of upper-level cyclones producing rain over the region. Thanks for the comment, we will make this point clear in the text.

2.2 If the dipole is needed, I am not sure whether the 500 hPa GPH anomaly can explain the dipole. The way I understand it from your description is that both the southern part of the high and the northern part of low induce easterly flow and slow the propagation of both systems. However, examining the actual synoptic maps (and not the anomaly maps), I cannot see the highs. I can observe two ridges, one from to the west of the low and the other to the east of it (extending in Fig. 2c to the north of the cyclone). Do you account the ridge from the east for the slowing of the systems? I am not sure the pressure gradient is represented well enough by the anomaly maps.

Response: We agree that the credibility of the 500 hPa maps for reflecting the dipole is questionable. Alternatively, based on Hoskins et al. 1985 and Yamazaki and Itoh (2013) 'PV thinking', we superposed the conceptual diagram of a dipole type block (fig.5 in the original manuscript) on 3 300hPa PV maps every six hours. (see below Fig. 1).

This figure will replace the original Figs. 5 and 6, with the following explanation: The power of PV maps stems from the feature of PV anomalies (in the spatial sense) to induce circular flow out of their boundaries, cyclonic for positive and anticyclonic for negative. The induced easterlies, extending south of the negative anomaly (in the north) and these induced by the positive anomaly (to the south), slowed the propagation of both anomalies eastwards. These charts show a lobe of negative PV (blue) over the Balkans, north of the cutoff low, lingering over the Nile delta. The PV charts were extracted from the 0.25 deg resolution ERA5 reanalysis data (Copernicus Climate Change Service (C3S) 2017): ERA5: Fifth generation of ECMWF atmospheric reanalysis of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), https://cds.climate.copernicus.eu/cdsapp#!/home).

2.3 L189-196: What is the timing of the rainfall that produced the flood? Rainfall is observed in the region of "Tzafit" both on 06-12UTC and in 12-18UTC, while significant omega is only seen in 15UTC. Please address this point, as it is crucial to understand whether ERA5 omega values are indeed accurate enough to capture such a small-scale rain spot.

Response: The rain that led to the Tzafit flood took place at April 26 and lasted ∼1.5 hours, around 0930 UTC. Hence the Omega and MKI maps for 09 UTC (Figs 7b and

7j in the original version, respectively) intended to show the relevant mesoscale background for the event. The blue color in the Omega map at the pertinent region indicates (Fig. 7b in the original version) upward motion in the order of 0.5 Pa/s, which cannot explain such an intense convection. We therefore shifted our focus to the instability (MKI) as the direct triggering factor, showing values (>30C), which are favorable for intense thunderstorms (Harats et al. 2010), the maximal for entire Israel. We modified the text accordingly, omitted Omega from the new version of Fig. 7 (now Fig. 5) and replaced the six hours RADAR integration with one-hour integration, to fit satellite images, which were added to the figure (see below Fig. 2).

2.4 L225-236: I am wondering about the Tropical moisture source. Fig. 8 as well as Fig. 2c (and to some degree 2b) show southwesterly flow to Saudi Arabia, all consistent with your “tropical” source attribution. However, examining Fig 2a (and 2b) I can see convection triggered close to the cyclone’s center, with northerly (Mediterranean) flow at low elevations. This makes me think the moisture source could have been Mediterranean to begin with, and this moisture (combined with the deep convection along the cyclone’s track) could be the only moisture source to precipitation from this cyclone. The southwesterly flows in Saudi Arabia (Fig. 8 and Fig. 2c) existed probably at the night of the 25th of Apr, but to reach this region with sufficient moisture, you would probably had to look for southwesterly flows prior to this night, and this does not seems to be the case (Fig. 2a and b). Moreover, 18-24 h before arrival to “Tzafit Creek” the position of the red backtrajectory is in southern Syria. Going further back in time with the red trajectory gives Iraq (ground level) as the origination of the track. I am not familiar enough with this region, but I would expect it to be rather dry, and anyway, the track does not go all the way back to tropical latitudes. Please add some support for your moisture source determination, or correct this part of the text, as I suspect the Mediterranean could possibly be the only source in this case. One possible solution is to plot moisture content along the back-trajectory, and another one could be plotting a matrix of trajectories arriving to close-by locations.

Response: Following your comment, we further elaborated the possibility that tropical moisture contributed to the rain through highly detailed back-trajectories (see figure below for 26 April 09 UTC). Back-trajectories of 120 – h were derived using 50 km resolution ERA5 data, in 20 hPa interval from the surface up to 500 mb and are colored according to the specific humidity (g/kg). We now agree with you that the main moisture source was the Mediterranean. Additional moisture was transported in the mid-levels from Jordan through Syria, represented by the yellow band of trajectories in this attached figure and the red trajectory in Fig 9 (now 7). We modified the text accordingly (see below Fig. 3).

3. Technical (and more specific) comments

3.1 L10: Please state either that the ten casualties were among the people that die during the event (to the best of my knowledge, three more people died in other streams in Israel during the same event) or that among the flash floods one was specifically deadly, killing 10 people.

Response: We appreciate your attention very much as regarded to the number of casualties. Actually, 10 young people died in Tzafit in April 25, but another two people were killed in 25 April and one more in April 27, in spite of weakening of the rains during that day. We corrected the text accordingly.

3.2 L11-12: “The timing of the storm is also unique, at the end of the rainy season, when rain is relatively rare and spotty”. Is it unusual to get extreme storms at the transitional seasons at the Negev desert? If not, please correct.

Response: The rainy season in the northern half of the Negev desert (Arad, Beer-Sheva, and Sde-Boker based on data from IMS for 1981-2010) are specified in the table below (mm). Source: Israeli Met. Service. Total May Apr Mar Feb Jan Dec Nov Oct Site/Month 132 1 6 20 28 31 23 13 10 Arad 190 4 4 29 40 48 38 18 9 Beer-Sheva 79 1 6 16 18 27 - 7 4 Sde-Boker During the late spring (Apr-May), the rainfall over the northern and central parts of the study area (5 - 10 mm) constitutes 4 - 9%

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of the annual average. In spite of these negligible rain amounts, the number of flash flood events cannot be ignored. Based on 37 hydrometric stations operated by the Israeli Hydrological Service, covering the entire Negev desert, Kahana (1999) identified 59 “major floods”. A “major floods” is a flood in which the recorded peak discharge reached the magnitude of a 5-year recurrence interval for the period 1947- 1994. Eight (14%) of these major floods occurred during April and May. The text will be modified accordingly. Ref: Kahana R. 1999: Synoptic Hydro-climatology of Major Floods in the Negev and Arava, Southern Israel. M.Sc Thesis, Institute of Earth Sciences, The Hebrew University of Jerusalem.

3.3 L13: Please rephrase “one of the latest spring severe events in the region during the last 3 decades” to “one of the most severe latest-spring events in the:” or something in that spirit.

Response: In the revised version we entitled the months April-May as "late spring". Accordingly, the phrase was changed to "one of the most severe late spring storms".

The same holds for L46-47. - L17: consider rephrasing “latest” to “last”.

Response: Changed to "late", following our term "late spring".

3.4 L36-37: consider rephrasing “most weather-related fatal hazard” to “most fatal weather-related hazard”.

Done.

3.5 L40-44: It is not clear whether most rainfall in the desert areas occurs during Dec-Feb or only over the non-desert parts of Israel. Please clarify this point.

Response: Most of the rainfall occurs in DJF all over Israel and the northern half of the Negev desert, as can be inferred from the table in our response to comment #2 above. The relevant text now reads: "... majority of the annual precipitation in Israel, excluding its southern most 100 kilometers, is associated with Mediterranean cyclones . . ... two-thirds of which occur during December through February".

3.6 L55: “over which floods took place” during this event? In general? Please explain.

Response: The phrase "over which floods took place" was changed to "in which the Tzafit flood took place".

3.7 L58: Please explain how “maximum intensity” is defined.

Response: After further consultation, we arrived at the conclusion that from a meteorological point of view, no distinct difference can be noted in the rain intensity between April 25 and 26. The relevant notions were removed, and the text modifications are: In L58: The phrase "when it reached its maximum intensity" was replaced by "when the Tzafit flood took place". In L117: The phrase "reached its maximum intensity at April 26" was removed.

3.8 L58: Can you please elaborate on the 11 storms? Are these the only storms during Apr-May over this period? Are these the highest discharge storms (as suggested in L66)? Are these the same storms listed in Table 1? If these are the same storms, please number the different storms in the list, as it is hard to find 11 storms in it. If they are not the same storms, please list these storms in a table as well.

Response: The storms referred to in line 58 are the same as these mentioned in line 66. To avoid ambiguity the phrase "to other 11 storms, spread over 28 days, in which discharge was observed over the study area, during April and May for the years 1986 – 2018, entitled hereafter the ’reference period’" was changed to: "to a set of 11 storms (including the one studied here), spread over 30 days, in which discharge was observed over at least one of the 37 hydrometric stations of the Israeli Hydrological Service that has been operative during 1986 – 2018 over the study area. These storms, which occurred during April and May, are hereafter entitled as the ’reference storms’". We listed the storms as requested and changed the text accordingly. In addition, we now devote a subsection in the "results" section for a brief description of the remaining 10 storms.

3.9 L61: what is the spatiotemporal resolution of the radar data used? If I am not mistaken, Marra & Morin (2015) data come from another radar in the region.

Response: The spatial resolution of the radar is 250 m in the radial direction and 1ïĆř in the azimuthal. This data is rectified to 1×1 Km grid. The radar temporal resolution is 5 min, but in the images shown in Fig. 6 (new version) the data are integrated over 1 hour. The radar used belongs to the Israel Met. Service, located in Beit Dagan. This is added to the text.

3.10 Figure 1: It is not clear whether this map comes from accumulated IMS radar data ("RADAR" is stated in the figure's caption) or from the "rain measuring network" (L60). The shape of the contours looks as if coming from an interpolation of gauges. Please explain and change the text referring the figure or the figure's caption accordingly. It seems radar data is more appropriate to use since rain gauges in the analyzed region seems scarce.

Response: The RADAR images indeed incorporate rain gauges measurements, based on the integration method identical to that used by the INCA system (Haiden et al. 2011). We added this to the text (L61-62) and to the captions of Figs. 1 and 7 (now 6). We also added the appropriate reference: Haiden, T., A. Kann, C. Wittmann, G. Pistotnik, B. Bica, and C. Gruber, 2011: The Integrated Nowcasting through Comprehensive Analysis (INCA) System and Its Validation over the Eastern Alpine Region. Wea. Forecasting, 26, 166–183, https://doi.org/10.1175/2010WAF2222451.1.

3.11 L66: What do you mean in "the data of floods"? Does this refer to hydrographs? Peak discharge?

Response: The flood data for the reference storms is the discharge based on 37 hydrometric stations that were operated by the Israeli Hydrological Service covering the entire Negev desert (see our response to comment 3.8).

3.12 L70: please add a reference to this statement. Consider one (or more) of the following for this specific region:

Response: We modified the relevant text and added refs, for the general context, and specific region, as follows: "In general, the atmospheric processes responsible for flash flood-producing rainstorms act in concert at the synoptic and sub-synoptic scales (Bardossy and Filiz, 2005). Severe convection during the spring over the Negev desert region are often created as a combination of sub-synoptic processes imbedded in synoptic systems that may affect this region (Dayan and Morin, 2006; Armon et al.,2018)." Refs: Armon, M. Morin, E., and Enzel,Y.: Overview of modern atmospheric patterns controlling rainfall and floods into the Dead Sea: Implications for the lake's sedimentology and paleohydrology, QUATERNARY SCIENCE REVIEWS, Volume: 216, Pages: 58-73 DOI: 0.1016/j.quascirev.2019.06.005, 2019. Bardossy, A., and Filiz, F.: Identification of flood producing atmospheric circulation patterns, J. of Hydrology, Volume 313, Issues 1–2, 5 November 2005, Pages 48-57, https://doi.org/10.1016/j.jhydrol.2005.02.006. Dayan, U., and Morin, E.: "Flash ïňĆood–producing rainstorms over the Dead Sea: A review." New frontiers in Dead Sea paleoenvironmental research 401 (2006): 53.

3.13 L69-74: please explain why you use different datasets (ERA5 and NCEP/NCAR). Do coarse scale ERA5 data the same (or very similar) to NCEP/NCAR data? If not, the use of ERA5 data both in the synoptic scale and in the meso-scale is probably better.

Response: The reason for using different data sources is availability. Unfortunately, we have no access to ECMWF data of 2.5×2.5 deg on the one hand, and there is no fine resolution NCEP data of 0.25×0.25 deg on the other. However, a comparison of several parallel maps from the two data bases used shows a satisfying fit (see example of SLP below). The latter is mentioned now in the text. (see below - Fig 4.)

3.14 L83: What are the units of the cyclone depth? is it m or hPa? Do you measure the depth at the 500 hPa as well? Does V refer to the 500 hPa?

Response: The cyclones' depth was derived from the 500 hPa GPH and are expressed in m. In the text, before "The tangential. . ." we inserted "The cyclone depth (in meters) is the difference between the central height and that of the outer most closed isohypse".

3.15 L90: "usually 500 hPa" – is this the case here or do you consider another pressure level?

Response: The text has been changed to "Lifted Index (LI, Galway 1956): Temperature difference between the environment and an air parcel lifted adiabatically from 2 m above the surface to 500 hPa. Negative values indicate instability."

3.16 L98-103: did you consider using the Beit Dagan sounding data for the MKI index as well? This could help understanding whether there are significant differences in ERA5 data in respect to the sounding data, which is not situated within your study area.

Response: The MKI calculated from Beit Dagan sounding for 26 April 12 UTC was 13.2 deg, lower than that implied by the map (Fig. 7j, now 6j, which correspond to 09 UTC). However, the values in this map for Tzafit creek was 10 deg higher (>30 deg). This difference can be attributed to the warming of the air while moving inland about 100 Km. The correspondence between the maxima in MKI and the major rain cells is now incorporated in our explanation for the timing and location of this rain event, and the other one, in the Jordan Valley. Thank you for drawing our attention to this point.

3.17 L104-105: Where does PW come from? Is this based on ERA5? Please indicate it in the text.

Response: The PW was taken from the soundings of Beit Dagan. We now state it in the text.

3.18 L107-109: Can you describe what kind of back-trajectories did you used? Which atmospheric model was used (NCEP/NCAR reanalysis / ERA5 / Other data)? What kind of levels did you use (model / pressure / isentropic)?

Response: The derivation of the trajectories shown in of Fig. 9 (now 7) is based on the Global Data Assimilation System (GDAS 1° by 1°), which is used by the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) model to place observations into a gridded model space for initializing weather forecasts with observed data. The vertical motion used is the "Model vertical velocity" that is derived from the gridded data. The level used is pressure level. This is now added to the text.

3.19 Fig. 2: Could you please describe the MODIS imagery? Does the image come from 12UTC as well? Is it from a specific MODIS (Terra/Aqua)? If so, please write it.

Response: We apologize for missing this information as regarded to the satellite used: the satellite imagery in Fig. 2 were retrieved from the NASA Worldview (https://worldview.earthdata.nasa.gov/). The satellite, operated by NOAA, is the Suomi National Polar-orbiting Partnership (Suomi NPP), a polar orbiting weather satellite carrying, among other instruments, a Visible/Infrared Imager Radiometer. The satellite imageries displayed are along the following NPP passes: April 24 (Fig. 2a) – 11:50 UTC, 25 April (Fig.2b) – 11:30 UTC, 26 April (Fig. 2c) – 11:15 UTC, and 27 April (Fig. 2d) – 10:55 UTC. The missing information is added to the caption of Fig. 2.

3.20 L131- 149 and Fig. 3: It is not clear to me how did you track the cyclone at the 500 hPa. Was it through the large scale NCEP/NCAR data or the ERA5? Or possibly using satellite images? Please explain it either in the materials or specifically when referring to the cyclone's movement.

Response: The 500 hPa cyclone center was tracked according to the large scale (2.5×2.5 deg) NCEP/NCAR data in a 12-hours increment. This notion is now added to the caption of Fig. 3.

3.21 Fig. 4: Please correct the caption ("with maximum of K: : :"), consider choosing a more appropriate color scale (centered at zero or starting at zero), a better in-figure-caption units (currently it is "10ËĘ1 K m**2 kg**-1 s**-1"), and possibly use PVU units instead.

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Response: We updated the figure as suggested (see below last figure - Fig 5).

3.22 L141: “This is rather exceptional: : :” – did you compare the value to other values from your reference period? This could be interesting and could also put the results in a broader context.

Response: In the new version, the April 26, 2018 storm is compared to the other 10 reference storms in a special sub-section in the results section (see also our response to comment 3.8). It is shown that in terms of curvature vorticity, approximated by the MCV, this storm is the most intense (see Table 1). However, we now refrain from giving the storm any title, except for a brief description of some quantitative aspects of its weather phenomena in the introduction.

3.23 L185 please replace the square sign with a degree sign.

Done.

3.24 Figure 7, middle panels: Do these panels represent radar, gauges or a combination of radar and gauges? Panel f seems to be some combination of gauges and radar, but this is not clear from the caption or “materials” section.

Response: The RADAR images in this figure incorporate rain gauges measurements, based on the integration method identical to that used by the INCA system (Haiden et al. 2011), as in Fig. 1 (see our response to comment 3.10). We added this to the figures’ captions.

3.25 L181: what do you mean by “integrated”? Does this refers to the combination of sources or to the accumulation of rainfall? Please add units to the MKI legend or caption.

Response: The radar data and the rainfall measurements, on which the "radar" images in Fig. 7 (now 6) are based, were temporally integrated over 6 hours each in the original figure, and now are integrated over one hour (will be added to the text, see also our response to comment 2.3). The MKI units are degrees. It is added to the figure caption.

3.26 L194: “-10 Pa s-1” do you mean -1 Pa s-1? If not, please correct Fig. 7’s legend.

Response: Pascal s-1 is correct. Unfortunately, we found a factor 10 error in line 187 and corrected "10" to "1".

3.27 L244: Please see previous comment about the “unique timing” of the storm.

Response: Please see our response to comment 2.3.

3.28 L245: This paragraph seems to me as a summary paragraph, however the term “Syrian low” was only introduced in L245. Could you please either remove this line from the summary or describe this term in the introduction/results sections?

Response: Thank you for the suggestion. The ’Syrian Low’ is now presented and explained in the introduction, following yours and the comments of the other reviewers.

3.29 L285: Cape values in Fig. 2 reach to 909 and not to 1000. Please correct or explain this notion.

Response: The phrase "values reached 1000 J K g-1" is now replaced by "values exceeded 900 J K g-1."

3.30 L286-289: Contribution of tropical moisture was shown in a number of studies; however, I am not sure this is the case here. Please address the previous comments about this subject. If you are certain about the tropical origins, please add more references or add “e.g.”. –

Response: We agree with this comment, as is reflected from our response to comment 2.4.

3.31 L290-294: The point raised here is interesting and fits well a discussion section. Since this section of the paper is written in bullets, it looks like a summary or a conclusion. Please give a better distinction between the summary and the discussion. This will help readers to understand which parts in this section should only be treated as a discussion and are therefore introduced firstly in this section, and which are summarizing prior sections. Perhaps the discussion can remain as one section and the summary can go with the conclusions, and in this way you will reduce redundancy.

Response: Following your suggestion we separate the last section to "discussion" and then - "summary".

3.32 L299: Please either add “not shown” after the “-5 K” or show this anomaly. Currently, there is an impression this anomaly is given in Fig 6.

Response: We modified the phrase "a -5 K temperature anomaly over the region" to "a -5 K temperature anomaly in the 500 hPa level over the Levant (not shown)".

3.33 L303-L310 “unique intensity”, “exceptionally severe rainstorm”, “severity of this rainstorm”: what exactly all of these expressions refer to? Do you mean the MCV? The rainfall (is it really that rare)? The casualties (were they influenced by the extreme severity, bad luck, or bad circumstances)? Please explain this point, and better to do it in previous sections of the paper.

Response: We now briefly describe some quantitative aspects of the weather phenomena of the storm in the introduction, and refrain from giving it any title, such as "exceptional", "unique" (see also our response to comment 3.22).

3.34 L313-314: Is this the case here? Was it written previously?

Response: We omitted this point.

3.35 L315-317: Please see previous comments about tropical moisture origins (although this conclusion seems reasonable anyway).

Response: Due to the omission of the tropics as a relevant moisture source, the sentence is modified to: "The average distribution of rain associated with Syrian low is shown by Saaroni et al. (2010) under the title "deep low to the east". This distribution shows maximum rain in the coastal plain and along the mountain ridges facing the north westerly winds, i.e., orographic. The distribution of the rain in the present storm has maxima over low terrains, such as the one that caused the fatal flash flood in Tzafit creek. The explanation for that may be the instability that dominated the event and intrusion of moisture in the mid-level that could skip over the mountain ridges."

3.36 L318-320: Please also see previous comment regarding L189-196.

Response: As we responded to comment 2.3, the new version of Fig. 7 (now Fig. 5) does not contain Omega maps anymore. Moreover, the Omega field is not referred to as a basis for explaining the development of major rain cells.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2020-94, 2020.

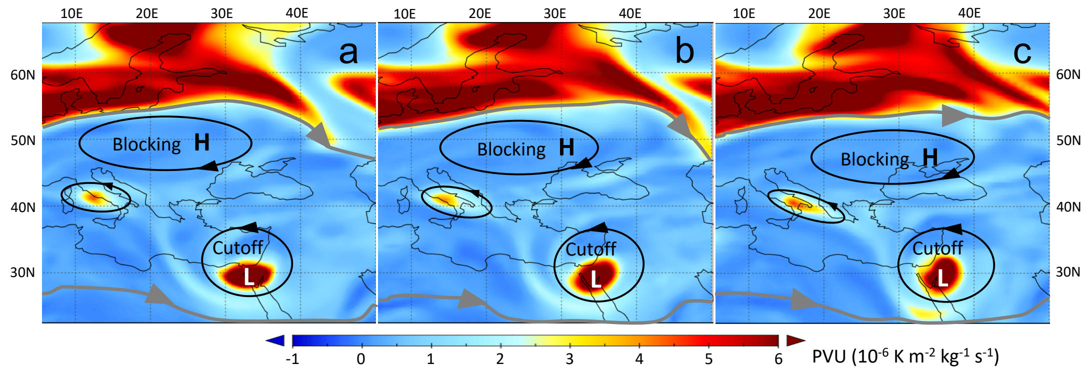

Fig. 1. PV distribution on 300 hPa, starting from April 25, 2018, 12 UTC, in 6-hour intervals, covering Europe and the Mediterranean Basin, on which a conceptual diagram of a dipole type block (following Yama

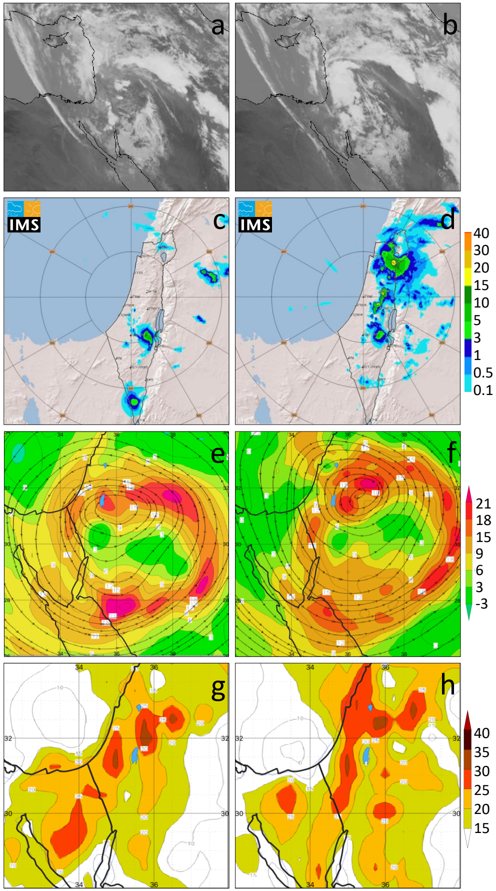

Fig. 2. Fig. 5. Set of maps for April 26 2018, 09 and 12 UTC: Satellite image of MSG ch9 (10.8 um) (a,b); Radar imagery of one hour integrated rain depth (mm), (c,d); Relative vorticity and wind (e,f) and MKI

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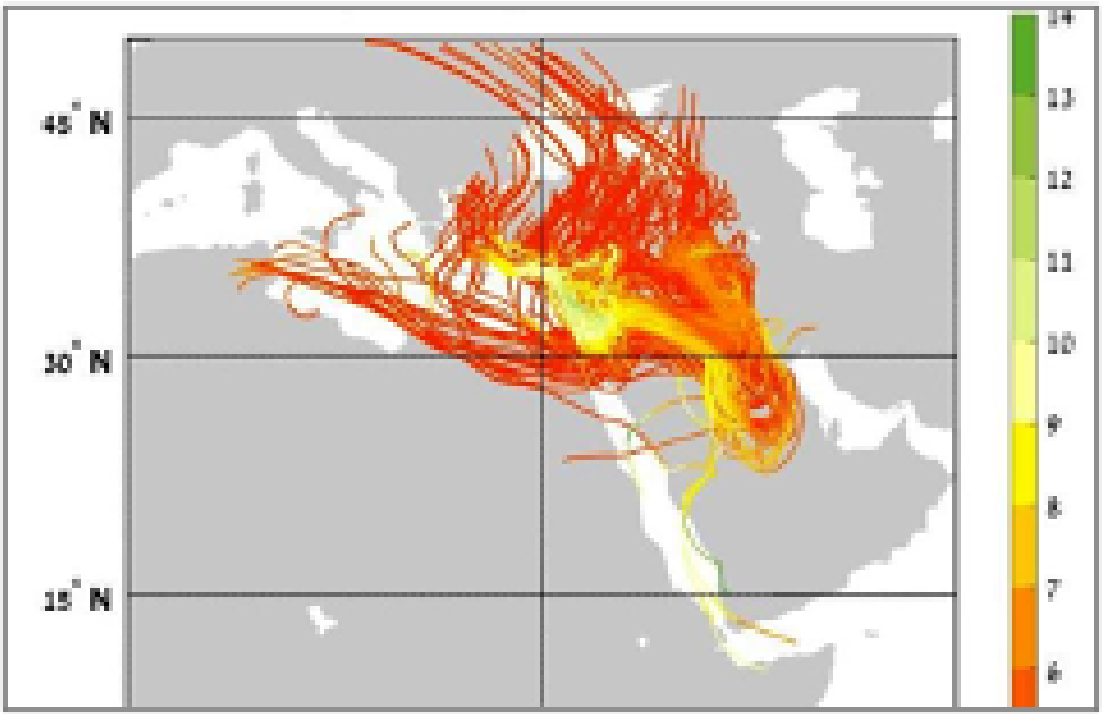

Fig. 3. Air back-trajectories arriving at Tzafit (31.1N, 35.2E) in 26 April 2018 09 UTC. The colors denote specific humidity along the trajectory (g/Kg).

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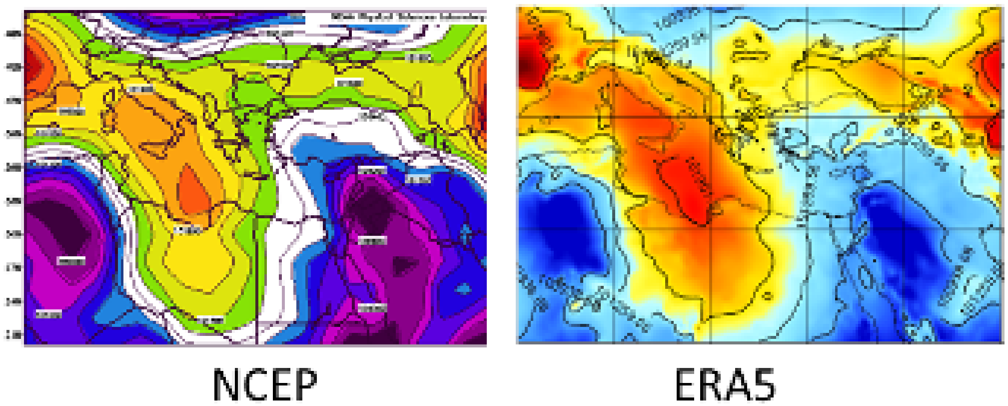

Fig. 4. example of SLP

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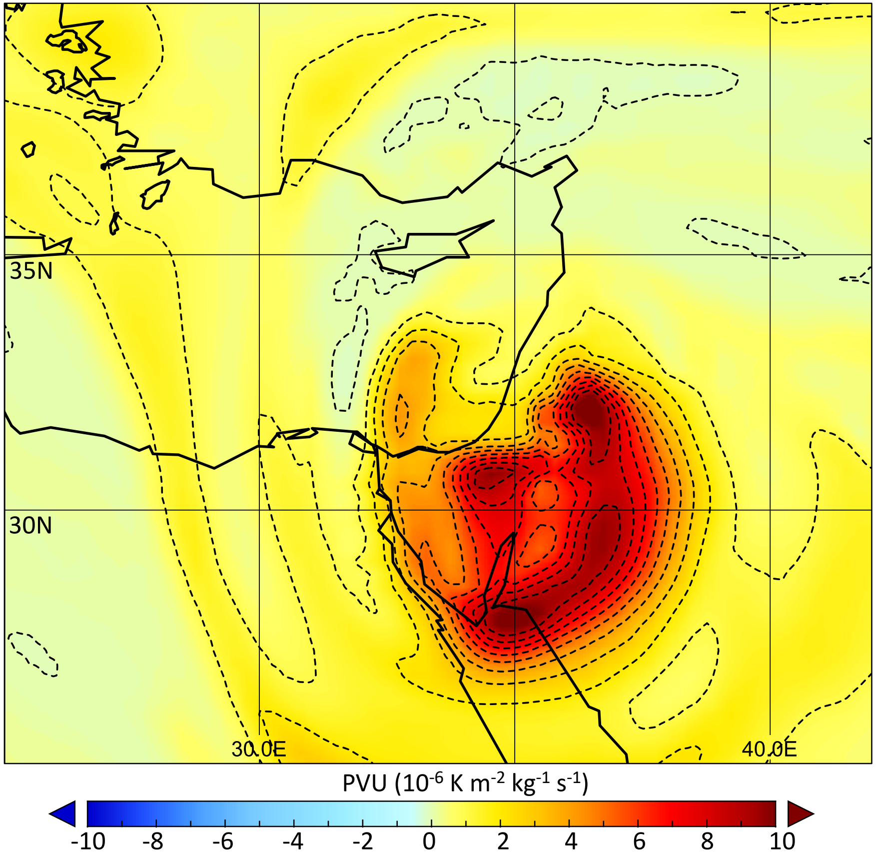

Fig. 5. Figure 4