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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Atmospheric Moisture Effects on Heavy Precipitation During the HyMeX IOP16 Using GPS Nudging and Dynamical Downscaling" *by* Alberto Caldas-Alvarez and Samiro Khodayar

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Answers to reviewer 2 (Paper-IOP16-NHESS)

GENERAL COMMENT

We would like to thank the anonymous reviewer for the valuable comments, suggestions and questions. We have considered all minor and major comments. We believe that the quality of the manuscript has increased, thanks to the comments of the reviewer and acknowledge how answering the raised questions was crucial for a better

exposition of our key messages.

R2C1. The impact of evapotranspiration over North-Africa for this event is shown, even if not quantified.

We give a description on how much moisture evaporates from North-Africa between lines 344 and 361 using our model simulations and the GLEAM product (combination of different satellite measurements). We give values on how much moisture evaporates per day in the days prior to the event at Corsica. For example, on line 359 we state "Suite to the precipitation event, daily evapotranspiration over the area reached spatial averages of 1.4 mm as shown by GLEAM, lasting for seven days, well above the mean evapotranspiration values during this season (0.5 mm). Albeit differences in the 360 magnitude of evaporation, COSMO-CLM well captures this period of anomalous evapotranspiration".

How the moisture is further transported north towards Corsica is explained in the following paragraphs of Section 3.3.

A quantification of the contribution of evapotranspiration over north Africa in relation to the advected moisture is presented in our answers to the reviewer.

MAJOR POINTS

R2C1.a) The authors must clarify that this is a diagnostic study and not prognostic. The impact of assimilating GPS-ZTD is quantified by comparing two simulations: the first doesn't assimilate GPS-ZTD, while the second assimilates GPS-ZTD continuously. While this is an important comparison, it must be clarified that the paper doesn't assess the role of GPS-ZTD in a prognostic approach for the case study.

We agree with the reviewer that this point could be better clarified to the reader, for that reason we have included this information in several relevant places in the manuscript:

In the Abstract "In this study, we use a diagnostic approach to assess the sensitivity of precipitating convection and underlying mechanisms during a heavy precipitation event

(HyMeX intensive observation period 16) to corrections of the atmospheric moisture spatio-temporal distribution.”

In Section 2.2.2 of the Methods. The GPS-ZTD Nudging Sensitivity Experiments “The Nudging scheme is used to assimilate GPS-ZTD data to assess the sensitivity of heavy precipitating convection to corrections of the spatio-temporal distribution of atmospheric moisture. We use a diagnostic approach as opposite to commonly use data-denial experiments.”

R2C1.b) Also the importance of sub-hourly data assimilation is not shown. To do that a comparison between two simulations one assimilating GPS-ZTD on an hourly basis and the other one assimilating GPS-ZTD every 10 minutes (as in the paper) should be performed. However, I understand that this requires adding new simulations, which can be avoided deleting the sentences where the importance of sub-hourly assimilation is emphasised.

We agree that this is a very interesting question that needs to be addressed in our paper.

We have performed supplementary simulations, initialized on the 20-Oct-2012 with no GPS-ZTD nudging (CTRL), 10-min frequency nudging (NDG-7 and NDG-2.8) and 1 h frequency nudging (NDG-7-1h and NDG-2.8-1h) where the temporal resolution of the GPS data is of 1 h (NDG-7-1h, NDG-2.8-1h). The only difference between the 1h nudging and the 10min nudging simulations is the frequency of assimilation. All other settings are the same. We have performed these experiments starting the simulations on the 20-Oct-2012 at 0000 UTC, to reduce the computational costs of running the complete season.

In the following we show graphs and analysis for the comparison between the runs with nudging frequency of 10 min vs. 1h.

Figure 1. Spatially averaged IWV (a, c) and Precipitation (b, d) for the 7 km simulations

(a, b) and the 2.8 km simulations (c, d) during the event. The area for averaging is Corsica. The model output has been upscaled to a common coarser grid of 8 km. The period shown is 26-Oct 0000 UTC to 28-Oct 0000 UTC. The comparison is between the runs using a temporal nudging frequency of 10 min (NDG-7, NDG-2.8) against nudging at a temporal frequency of 1h (NDG-7-1h, NDG-2.8-1h).

The results show no differences on the temporal evolution of IWV. This holds for 7 km and 2.8 km. This can be explained by the fact that we calculate the spatially averaged IWV at sharp hours (i.e. 0000 UTC, 0100 UUTC, 0200 UTC, etc.), precisely is at those times when the GPS-ZTD data is assimilated in the NDG-7-1h and the NDG-2.8-1h runs.

For precipitation, there is a slight impact for the 7 km runs, but not for the 2.8 km. The NDG-7-1h simulation shows somewhat larger precipitation than NDG-7 at 2000 UTC on the 26-Oct (Fig. 1b) corresponding to an increase from 30 mm to 50 mm at the western shore of the island Fig.2.b and Fig. 2.c

Figure 2. COSMO-CLM accumulated precipitation over Corsica between 26-Oct 1300 UTC and 27-Oct 1500 UTC i.e. during the period of precipitation over the island and RG.

To delve further into which aspects of precipitation representation have been improved we present in Table 1 further validation metrics using the Rain Gauges (RG) as reference.

Table 1 shows the RMSE of the anomalies of hourly precipitation rates (first column), the differences (OBS-MOD) of the standard deviations of hourly precipitation (second column) and the spatially averaged differences of accumulated precipitation during the whole event, i.e. between 26-Oct 1300 UTC and 27-Oct 1500 UTC (third column). The last three metrics are obtained after interpolating the COSMO-CLM precipitation values to the location of the RG stations. On the contrary, columns four and five of Table 1, show differences of the standard deviation and maximum value of precipitation for COSMO-CLM over land without interpolation. That means, we have obtained all 27h-accumualeted precipitation values simulated by COSMO-CLM over land and have calculated the standard deviation and the maximum. We have done the same for all RG measurements and the differences are shown. We do this to avoid double-penalty problems due to a possible misrepresentation of the maxima location (Wernli, et al., 2008; Gilleland, et al., 2009). The formulas used are included in Table 2.

Table 1. Metrics of the precipitation validation against RG. The model precipitation has been interpolated to the location of the RG for the first three columns and all precipitation values simulated by COSMO-CLM over the island of Corsica are used in the last two columns. This is done to avoid double-penalty problems due to a shifting of the precipitation maxima. N is the number of RG stations and M the total number of grid points. The units are mm.

Table 2. Precipitation validation metrics.

Overall, we see that nudging GPS-ZTD data is beneficial for the 7 km grid with little difference between nudging with 1h frequency or 10 min. If any, we see a slight advantage in nudging GPS-ZTD data with 10 min for the representation of the hourly standard deviation rates. The same holds for the 2.8 km, assimilating with a 10min frequency shows very weak differences with respect to assimilating with 1h frequency.

These analyses will be included as an additional subsection in section 4.1 (Nudging effects on Precipitation).

R2C2) In the section 3.3 emphasis is given to the transport of humidity from North Africa for the event. It would be interesting to give a comparison between this source of moisture and that coming from the western Mediterranean Sea to define better this contribution. We agree with the reviewer that a quantification of the different terms of Evaporation and moisture flux over the investigation area NA and the Mediterranean would be most interesting. We have obtained the terms, described in Lamb et al. (2012) over the investigation areas NA (North Africa) and MED (Mediterranean Sea)

for this purpose, see Fig. 3.a.

The calculation of these terms entails simplifications for example, of the turbulent and microphysical processes that introduce relevant uncertainties. Hence, what we provide here is an estimation of the different contributions.

$\triangle$IWV=E+(-P)+MFC (1)

All terms of Eq. 1 are expressed in mmh-1, where positive signs of the Evaporation (E) and Integrated Moisture Flux Convergence (MFC) imply an increase of Integrated Water Vapour variations ($\triangle$IWV>0) within the NA and MED volumes. On the contrary, if precipitation and water vapor divergence occur (MFC<0) IWV decreases ($\triangle$IWV<0). The volumes cover the areas in Fig. 3.a where the integrations of IWV and MFC are performed from the first to the last model levels.

Fig. 3.b shows similar information to Fig.6.c of the manuscript. Intense precipitation occurs over NA on the 20-Oct-2012 with the subsequent decrease of IWV, and intense evaporation over the area on the 21-Oct and 22-Oct at midday. This is the moment when solar radiation is strongest, hence evaporation is intensified over this wet soil. Please note the change in the axis scales between the different panels of this figure and those of Fig.6.c of the manuscript, expressed in mmd-1. The order of magnitude of those evaporations over NA is the same as those over the Mediterranean Sea, up to 0.15 mmh-1. This is better seen in Fig. 3.c. The evaporated moisture is advected with the wind flow, merging with the Atlantic and Mediterranean moisture.

To quantify how much the Mediterranean Sea contributed to the changes of atmospheric moisture at that location, Fig. 3.c shows the contribution from each of the moisture equation terms over the selected volume MED. We can see that between 22-Oct and 26-Oct 1200 UTC there is a positive, homogeneous evaporation from the Sea at a rate of 0.25 mmh-1 that picks up from 26-Oct 1200 UTC to 0.5 mmh-1 by 28-Oct 0000 UTC. The time of the evaporation pick up coincides the occurrence of precipitating convection over the Mediterranean Sea west of Corsica. The intensification of the evaporation is brought by the intensified drag of horizontal winds close to sea surface. âĂČ

Figure 3. Analysis of the moisture budget terms. (a) Simulation domains as Fig.1 of the manuscript including the NA and MED areas for calculation of averaged evaporation, precipitation and moisture convergence. (b) Spatial average of hourly IWV variations (dotted grey), Evaporation (blue), Precipitation (red) and Moisture flux Convergence (green) in mmh-1, over investigation area NA between 20-Oct and 23-Oct 0000 UTC. All variables are obtained from the CTRL-7 runs. (c) is as panel (b) but showing the averages over the investigation area MED between 22-Oct and 28-Oct 0000 UTC. (d) is as panel (b) but showing the spatial averages between 21-Oct and 23-Oct 0000 UTC. Mind the changes in the y-axis scaling.

R2C3.a) Considering the nudging scheme there is no information on the parameters of the Second order autoregressive function. How they are determined?

We have added a short clarification in the revised version of the manuscript. In Eq. (1.b), ∆r stands for the distance between the observation location and the target grid point. The other parameter, s, is the correlation scale that is defined in tables with a pressure level dependency for the different variables (Schraff & Hess, 2012). For example, for temperature (s_T) and humidity (s_q) these values are: Table 3. Correlation scale (s) for temperature (T) and specific humidity (q) at different pressure heights

The correlation scale, thus, is larger in the stratosphere than in the troposphere and lowest levels. As an example, at 500 hPa, the weight for the horizontal spreading is halved (w_xy=0.5) at a horizontal distance of about 135 km from the station location.

The revised explanation in the manuscript reads “The weight for spreading in the horizontal direction w_xy, is a second-order autoregressive function dependent on the distance between the observation and the target point (∆r) and the correlation scale (s), see Eq. (1.b). The correlation scale is dependent on the pressure level and is largest for the stratosphere (100 km) and shortest for the PBL (58 km). This implies

that the horizontal weight is halved (w_xy=0.5) at a distance of 135 km at the 500 hPa level”

R2C3.b) Line 217 has a comment on the vertical adjustment that doesn’t apply to the specific case.

We have adapted these lines in the manuscript to give this information in a clearer way. How the assimilated observation is adjusted in the vertical direction is indeed relevant since each GPS observation is used to construct a specific humidity profile that is treated as such in the nudging scheme. Hence, what is used for nudging is this “constructed” profile based on the issued GPS-ZTD value. This sentence has been rewritten as: “The vertical interpolation of the observed data is performed assuming a Gaussian decay in height differences. The vertical interpolation is also applied in the case of GPS-ZTD nudging since a profile of specific humidity is constructed from the derived GPS-IWV value. This constructed profile shall be treated by the nudging scheme as an upper-air measurement in the remainder of the process.”

R2C3.c) It also unclear how the qv profile is constructed iteratively (Lines 230-232). Do you mean that it is modified by nudging until a difference is attained or something different?

For a certain GPS-ZTD observation at time t and location x âČŮ the ZTD value is converted to IWV. This is described in the paper following Schraff and Hess (2012). Given IWV, as opposite to specific humidity, is not a prognostic variable of the model, the IWV observation has to be transformed into a profile of specific humidity. This is done for each single observation by means of an iterative process. To express this process in a more understandable way the whole paragraph has been rewritten.

“The observations are assigned to a grid point in the model space, provided the altitude difference of the GPS station and model surface lays within the range -150 to 600 m to allow for extrapolation and interpolation, respectively and are converted to a specific humidity profile (q_vˆmod). This is needed given IWV is not a model prognostic variable as opposite to specific humidity. The profile is constructed by means of an iterative process that scales the observed IWV (ãĂŰIWVãĂŮˆobs) with the modelled one (ãĂŰIWVãĂŮˆmod) until a sufficiently low error is reached or up to 20 iterations. Eq. (2) describes the iterative formula. The first profile (q_(v_i)ˆmod) used as the first guess for the iterative process, is the modelled specific humidity profile. Hence, the profile used for nudging depends on the vertical humidity distribution simulated by the model at the beginning of the nudging time-window. “ q_(v_(i+1))ˆmod=q_(v_i)ˆmod·ãĂŰIWVãĂŮˆobs/(ãĂŰIWVãĂŮ_iˆmod)

MINOR POINTS

All minor corrections mentioned by the reviewer have been accepted and included in the revised version of the manuscript. When needed, a short clarification is included here.

R2C4. Line 33: During heavy precipitation events, rain rates can be much higher than 20 mm/h.

Yes, thanks for the comment. As reported for example in Röhner, et al., (2016) and Ducrocq, et al., (2014), some extreme past events have shown precipitation totals reaching 500 mm in 6 h to 12 h in the Mediterranean area. This is however very exceptional cases. We have adapted the sentence in the manuscript, now it reads.

“During these events, daily accumulated precipitation over 150 mm is not rare and precipitation rates can be well over 20 mm h-1 (Röhner, et al., 2016; Ducrocq, et al., 2014)“ R2C5. Line 244: Check the sentence “given the large precipitation reduction”. Do you mean when you assimilate GPS-ZTD?

Yes. This sentence has been rephrased to express the information in a clearer way. In it we were referring to a large reduction of maximum precipitation that was induced by the GPS-ZTD nudging. We have added more details so that this sentence is not out of context. The sentence now reads.

“Within the 80-day period of simulation, there were several events, which were largely affected by the GPS-ZTD nudging. IOP16, the case study of this paper, is one of them which is especially interesting given the large reduction of maximum precipitation (-20 %) induced by the GPS-ZTD nudging over the investigation area of Corsica in the course of 26 h. IOP16 is also suitable to assess the benefit of atmospheric moisture corrections with GPS-ZTD nudging given the important role of the local orographic and instability factors in triggering and maintaining convection rather than the large-scale upper level forcing.”

R2C6. Line 248: I suggest giving more details about the Agreement Index (AI).

The formula for AI calculation has been included in the revised version of the manuscript. Together with the Agreement Index, more validation metrics are used for precipitation. They are contained in Table 2.

R2C7. Line 577-578: This sentence is rather unclear. It is important to note that, in general, the adjustment introduced by GPS-ZTD could be a function of the height if variational approaches are considered, through the background error matrix. Indeed, generalizing to other assimilation schemes is not possible from our study. This conclusion relating to the difficulties of the nudging scheme to correctly improve the vertical distribution of humidity when using GPS should be constrained to this type of observation and assimilation method, exclusively. In the sentence mentioned by the reviewer it is explicitly said “GPS-ZTD nudging”. We agree, nevertheless, that it would be very interesting extending these experiments to other assimilation schemes. This was one of our initiatives in the project that could sadly not be finished due to missing forcing data from the ICON ensemble for the year 2012.

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Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-319/nhess-2019-319-AC2-supplement.pdf

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