Author responses to Reviewer#2 comments for the manuscript: "Extremes floods of Venice: characteristics, dynamics, past and future evolution"

In the text below, Reviewer's comments are in bold characters, authors' responses are in slant characters.

The preprint paper (#nhess-2020-359), submitted to EGU's journal *Natural Hazards and Earth System Sciences (NHESS)*, presents an effort to review several aspects of the flood generating mechanism in Venice city center, i.e., by superposition of astronomical tides, seiches, storm surges, meteotsunamis, etc. All these factors are reviewed in terms of individually and/or cooperatively contributing to intense and/or extreme sea level elevation events, respectively. The main outcome of the review focuses on the following findings:

Extreme sea level events are mostly related to storm surges due to Sirocco winds, revealing a characteristic seasonal cycle, with the most important events occurring from November to March. The most intense historical events have been produced by western Mediterranean cyclogenesis, e.g., the Gulf of Genoa. Only a few extreme events of sea levels are caused by atmospheric circulation patterns deriving from the Euro-Atlantic sector. Tidal effects of the 11-year solar cycles appear to mildly contribute to sea level extremes, hidden by the rest of the factors. Relative sea level rise seems to drive a frequency increase of extreme sea levels 1850. Consecutively, it is assessed that the intensity and duration of flood events on Venice in the 21st century, will be affected by possible regional mean sea level rise (MSLR) equalizing and even overcoming the probable enfeeblement of extremes due to the projected storminess attenuation until 2100. High uncertainty of the evolution of global scale factors inducing MSLR, such as mass contributions in the Mediterranean due to Antarctica and Greenland ice melting, does not help in robustness of future projections. Extreme value analysis based on RCP climate projections provides estimations of increase up to 65% and 160% in 2050 and 2100, respectively, for the 100-year return level events at the North Adriatic coast. Geological and geotechnical factors, such as local subsidence due to tectonics or coastal aquifer drainage or overexploitation, are not discussed at all in terms of future increase of extreme flooding.

This is an interesting overall review endeavor of a very significant scientific and social issue with particular local interest, but the paper in its current form does not support scientific innovation, as it does not add new knowledge of permanent value on the subject of coastal flooding in general; it presents only a few new insights on previous findings for the Venice study area. The paper mainly recapitulates and tries to interblend existing knowledge from very remarkable past articles, with a specialized focus on certain aspects of the presented problem, by world experts on the field. Yet, in its current form, it does not build robust new arguments on the investigated subject. I believe that if the Editors should consider its publication, at least a major revision should take place, rewriting most of its parts supported by novelty aspects and fresh findings. Some graphs should be omitted (as they are reported elsewhere or refer to previously published literature) and new methodologies of interconnecting the existing knowledge should be proposed and applied. Moreover, some clarifications on the followed approaches are also deserved.

In the following, I present my major comments and some specific remarks in tandem with editorial changes and spellcheck needed.

We thank Reviewer#2 for the comments on our manuscript. Please, find below our answers.

Major Comments:

1) The paper is actually a full review of all the met-ocean physical parameters and mechanisms contributing to high sea levels and eventually the generation of Venice floods. This should be clearly stated in the Title. This is not a Research Article.

This is a review article. In fact, the manuscript is classified as a "Review article" in the journal submission system. We thought this was clear considering the initial sentence of the manuscript "This paper reviews current understanding on the extreme water levels that are responsible for the damaging floods affecting the Venice city center …". Further, the description of this special issue, which is available in the journal web page, clearly writes that "This special issue is composed of three review papers, addressing three different and complementary aspects of the hazards causing the flood of Venice. Review paper 1 describes the tools [...] Review paper 2 describes the factors leading to extreme events, their past evolution, and expected future levels under a climate change perspective. Review paper 3 considers the evolution of the mean relative sea level [...[". We apologize for having missed "Review article:" in the manuscript title and sorry for the following confusion. In order to further emphasize that this is a review article and avoid any misunderstanding, we agree that this information should be added to the revised title.

2) Flooding phenomena are by default considered as extreme events in literature, yet the authors present proper analysis based on univariate extreme value theory only for the storm surges and not all the other components of sea level variations. This perspective undermines the notion of a compound event. Moreover, the wave-induced component, i.e., the run-up, adding to the total sea-surface height, especially near the coastal front, is left out. Of course, its influence is limited to areas near the waterfront, whereas all the other components (surges, RSLR, etc.) can cause spatially extended inundation, yet all the above need to be discussed and explained to the reader.

A main novelty resulting from this review is the importance of the superposition of several different factors for understanding extreme sea levels. However, this is a review and NOT a research paper and being based on existing literature cannot include a multivariate probabilistic analysis, as this is not available in the scientific literature. We agree that a multivariate approach is important and we have added to the conclusions that "Furthermore, a multivariate statistical model that describes extreme water levels as a function of the various contributions would provide a more complete characterization of extreme water levels.". However, to perform such an analysis is beyond the scope of this review paper.

The comment of the reviewer shows that, indeed, a more extended explanation on the lack of relevance of wave induced components for the floods of Venice will be beneficial.
The city of Venice is located in the center of a large and shallow lagoon (Fig.1), with an approximate extension of 500km2 and an average depth of about 1 meter. The lagoon is connected to the Adriatic Sea by three inlets (500-1000m. wide and from 8 to17m. deep), through which high water levels propagate from the open sea, along a complex pattern of very shallow areas and canals (from 2 to 20 meters deep) to the city center. The lagoon is separated from the sea by two long (about 25 km in total) narrow (less than 200m average width) and sandy islands, reinforced with artificial barriers in the most vulnerable parts. The elevation of these islands is such that they separate the lagoon from the open sea also during the most extreme events, with the exception of the 4th November 1966 flood, when they were breached in several points.
The floods of Venice do not occur because water overtops coastal barriers or defenses. Therefore, wave run-up and infra-gravity waves and nearshore processes (though certainly relevant along the sea-side front of Lido under some conditions) have never been considered when computing sea level extremes inside the lagoon. Wave set-up at the Adriatic shore has been estimated only during some extreme events (e.g De Zolt et al., 2006), but not inside the lagoon inlets.
The elevation of the natural barriers separating the lagoon from the Adriatic Sea has so far prevented overtopping caused by wave run-up and infragravity-waves, except in the 1966 flood when waves may have contributed to total water levels. In the future this is unlikely to change as barrier islands will continue being protected by coastal defences and maintained by beach nourishment. Hence, waves do not need to be considered. It cannot be excluded that these factors will become relevant in case of extreme sea level rise in the future, but present evidence is that waves do not need to be considered.

A new version of Fig. 1 with a map of the lagoon and the three paragraphs above will be added to the introduction, section 2.3 and the conclusions, respectively.

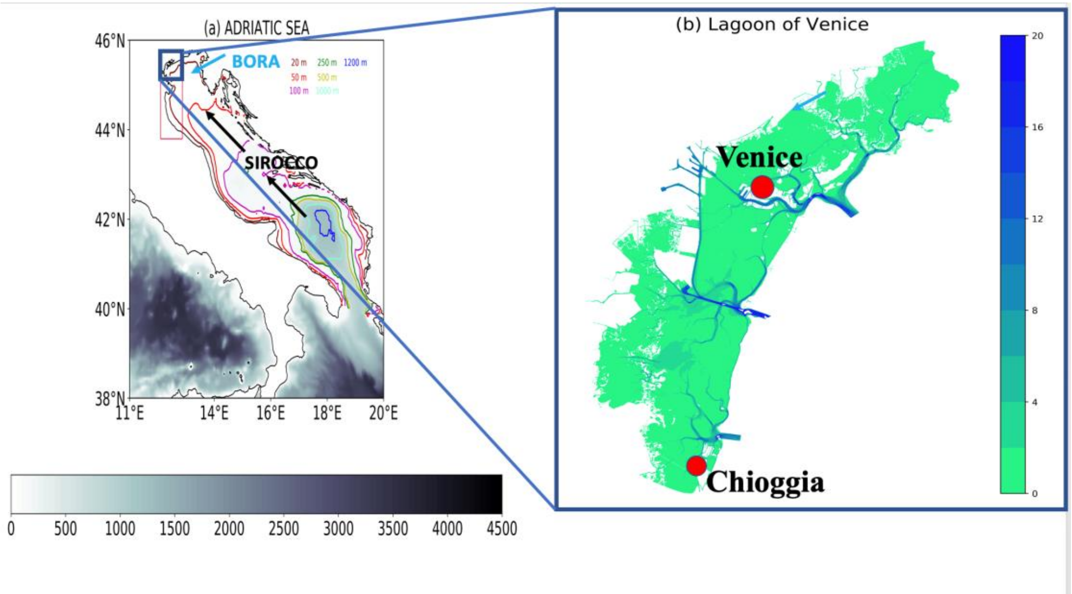

Figure 1: left panel: bathymetry of the Adriatic Sea with the position of Venice and arrows denoting the directions of the two main wind regimes affecting the North Adriatic. Right panel: morphology of the lagoon of Venice with the three inlets connecting it to the Adriatic Sea, and the position of the city and of Chioggia. The red box (which includes the whole lagoon in its northern part) denotes the area represented by the data in Figs. 8 and 9.

3) Figure 4: Please elaborate on the storm track algorithm and its previous validation. Does it treat proper identification of secondary lows in the wake of e.g., "Medicanes", as NASA's storm track algorithm to avoid double backing of storm center on itself over the course of 24 hours. Please further discuss the use of storm tracking technique.

The tracking scheme analyses MSLP or geopotential gridded fields, it identifies the pressure minima, the location where a cyclogenesis occurs and the following trajectory of the pressure minimum by associating low-pressure centers in successive maps by a minimum distance criterion. Shallow secondary minima with a small area are absorbed in the large nearest system. It has been already used in numerous studies assessing the climatology of Mediterranean cyclones such as Lionello et al. (2016) and Flaounas et al. (2018), in the IMILAST tracking scheme intercomparison analysis (Neu et al., 2013) and in a dedicated study considering the synoptic patterns leading to high water levels along the coast of the Mediterranean Sea (Lionello et al., 2019). We suggest that readers are addressed to those studies for details on the method and how it compares with other tracking schemes. We will add this information when discussing Fig. 4.

References

- *Lionello P., Isabel F. Trigo, Victoria Gil, Margarida L. R. Liberato, Katrin M. Nissen, Joaquim G. Pinto, Christoph C. Raible, Marco Reale, Annalisa Tanzarella, Ricardo M. Trigo, Sven Ulbrich & Uwe Ulbrich (2016) Objective climatology of cyclones in the Mediterranean region: a consensus view among methods with different system identification and tracking criteria, Tellus A: Dynamic Meteorology and Oceanography, 68:1, DOI: 10.3402/tellusa.v68.29391*
- *Flaounas E., Fanni Dora Kelemen, Heini Wernli, Miguel Angel Gaertner, Marco Reale, Emilia Sanchez-Gomez, Piero Lionello, Sandro Calmanti, Zorica Podrascanin, Samuel Somot, Naveed Akhtar, Raquel Romera, Dario Conte. (2018) Assessment of an ensemble of ocean–atmosphere coupled and uncoupled*

regional climate models to reproduce the climatology of Mediterranean cyclones. Climate Dynamics 51:3, pages 1023-1040.

- *Lionello, P., Conte, D., and Reale, M. (2019) The effect of cyclones crossing the Mediterranean region on sea level anomalies on the Mediterranean Sea coast Nat Hazards Earth Syst Sci 19:1541–1564, DOI:10.5194/nhess-19-1541-2019*
- *Neu U, Akperov MG, Bellenbaum N, Benestad R, Blender R, Caballero R, Cocozza A, Dacre HF, Feng Y, Fraedrich K, Grieger J, Gulev S, Hanley J, Hewson T, Inatsu M, Keay K, Kew SF, Kindem I, Leckebusch GC, Liberato MLR, Lionello P, Mokhov II, Pinto JG, Raible CC, Reale M, Rudeva I, Schuster M, Simmonds I, Sinclair M, Sprenger M, Tilinina ND, Trigo IF, Ulbrich S, Ulbrich U, Wang XL, Wernli H (2013) IMILAST – a community effort to intercompare extratropical cyclone detection and tracking algorithms: assessing method-related uncertainties. Bull Am Met Soc, 94:529-547. doi:10.1175/BAMS-D-11-00154.1*

None of these studies was meant to analyze medicanes. The capability of this tracking algorithm on detecting small features, such as medicanes, depends on the tuning of the parameter controlling the merging of small secondary systems in large circulation structures. However, we feel that this discussion is not really relevant for this subsection, though it might be considered in future studies in the wake of the analysis of the 19 November 2019 event.

4) The wind patterns in the Adriatic are defined as a crucial factor of surge-driven flood dynamics, but no data is presented to back this up. Thus, some kind of wind maps in extreme cases or anything else would help to relate wind set-up to certain flood events.

Following this comment of the Reviewer, Figs. 2 and 3 have been modified in order to show the wind fields over the Adriatic Sea during the evolution of the floods

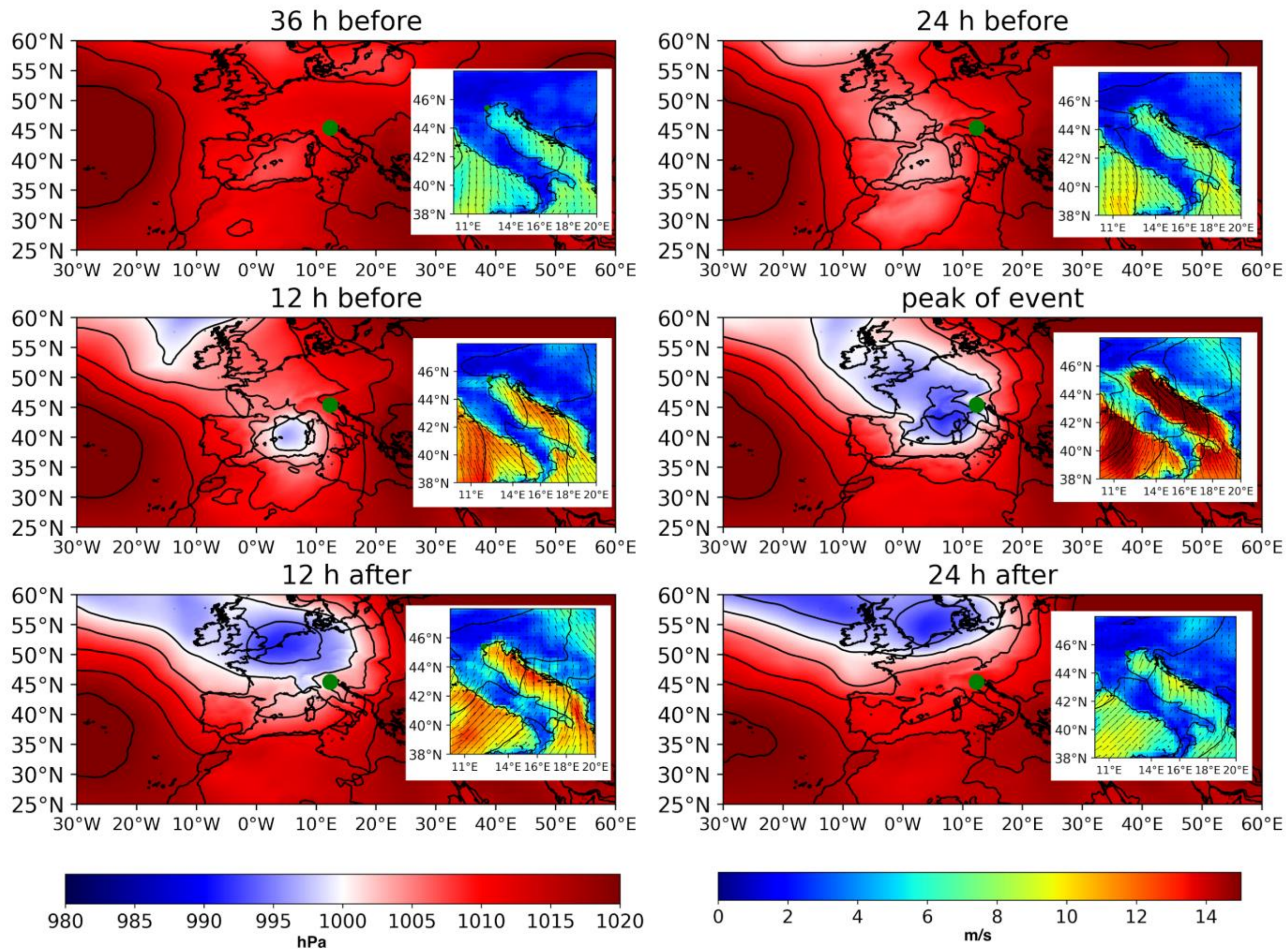

Figure 2: The large panels show the composite of SLP fields based on ERA5 (in hPa, left color bar) datasets associated with storm surges higher than 50 cm in Venice (see Table 1). Small panels show the corresponding wind fields over the Adriatic Sea (m/s, right color bar). The time lags chosen for the composites are 36, 24 , 12 hours before and 12, 24 hours after the peak of the event. The green dot shows the location of the city of Venice.

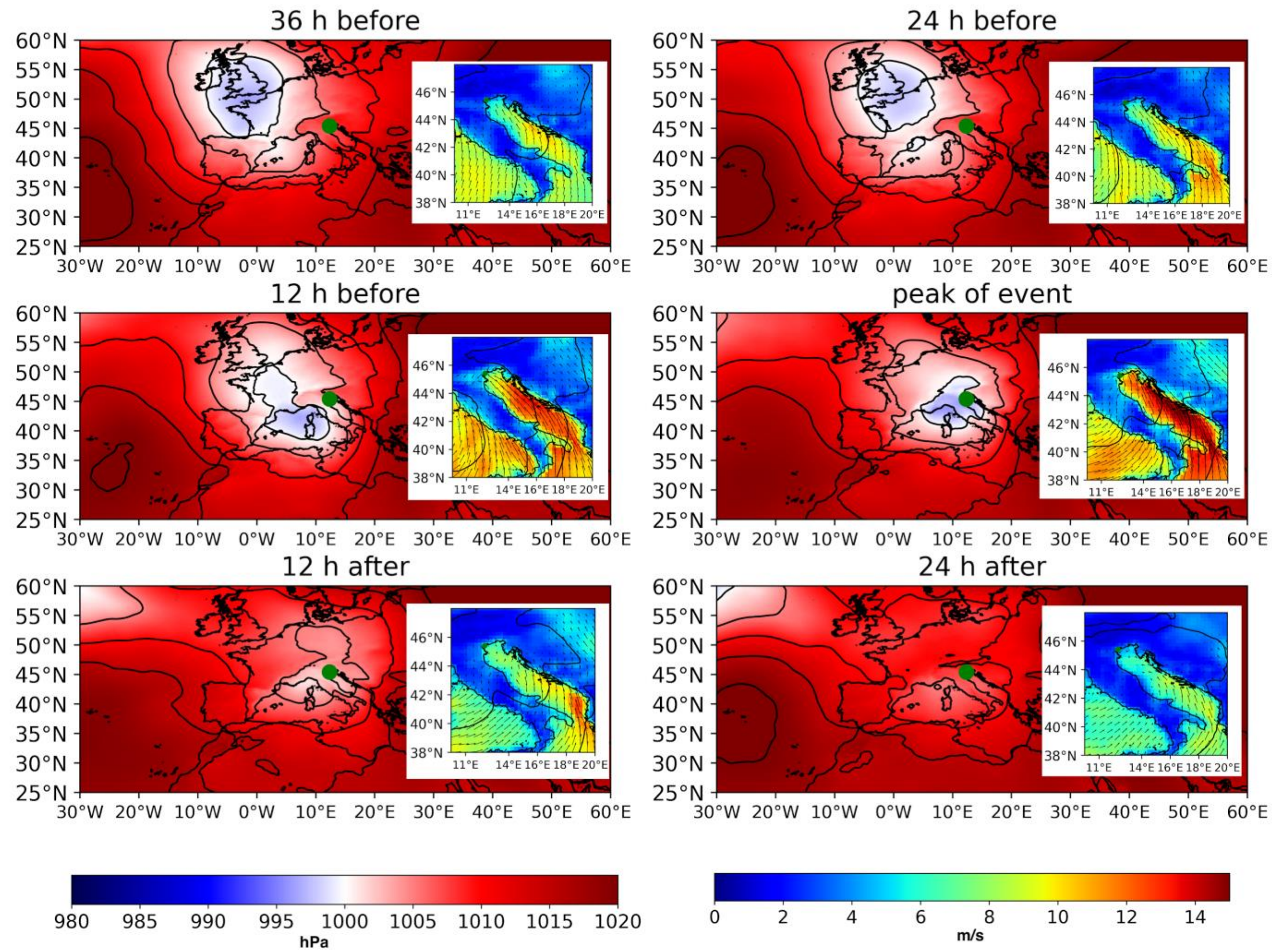

Figure 3: Same as figure 2, except it is based on the events in Table 1 with storm surge height lower than 50 cm

5) The geological and geotechnical aspects of Venice floods are totally overlooked, yet the low elevation of terrestrial land in the Venice area is the main factor for inundation, rather than changes in storminess patterns. It is reported in many papers that constant geotectonic land subsidence and potential overexploitation of coastal aquifers may drive sediment settlement and the urban environment's ever-evolving land sinking below MSL.

Loss of land level, subsidence and, in general, vertical land motions have been a key factors for increasing the vulnerability of the city in the past century contributing to about 50% of the observed RSL rise. This review article is a part of a special issue where another contribution (Zanchettin et al., 2021, nhess-2020-351) discusses extensively relative sea level rise including estimates of the past and future role of subsidence. This was, probably too shortly, mentioned in the RSLR paragraph in section 2.1. We will add a reference to it in the introduction.

6) Lines 169-176: present a classic methodology for signal processing of timeseries to separate storm surges, PAWs, meteotsunamis and IDAS, but the choice of cut-off frequency seems arbitrary, as the eventual durations of the reported phenomena are not "physically" fixed. These are known to occur at similar frequency bands (overlapping frequencies between several components) and this makes it difficult to

discriminate between different phenomena, especially between surges and meteotsunamis. This should be at least discussed in terms of results' robustness.

A number of processes contribute to the sea-level variability and their separation enables the extreme sea levels to be interpreted. When it comes to the signals characterized by peaks in the sea-level spectra (tides, seiches), the procedure is straightforward: they are readily isolated by applying the band-pass filters around the known frequencies. The situation is more complicated when considering the response of sea level to the atmospheric forcing because it is characterized by a continuous spectrum. However, it is still possible to distinguish between various processes contributing to the continuum due to their relationship with the mid-latitude atmospheric phenomena. Most often, the distinction is made on the basis of different space scales of the phenomena. Among a number of classifications developed for the purpose, one of the simplest appears to be that proposed by Holton (2004): he makes a distinction between the planetary-scale motions, of $O(10^7$ m), the synoptic-scale motions, of $O(10^6$ m), and the mesoscale motions, of $O(10^4$ m) – $O(10^5$ m). Moreover, he points out that the planetary atmospheric waves tend to move westward against the eastward zonal flow and are therefore characterized by relatively small speeds (1–10 m/s) whereas the synoptic-scale atmospheric systems tend to move eastward in the mean flow and are consequently marked by relatively large speeds (typically 10 m/s). As for the mesoscale atmospheric systems, their speeds are also relatively large, of O(10 m/s) (Markowsky and Richardson, 2010). By allowing for these space scales and speeds, it is easy to show that the time scales of various processes also differ, being for the planetary-scale atmospheric motions of O(10 days) – O(100 days), for the synoptic scale atmospheric motions of O(1 day), and for the mesoscale atmospheric motions of O(10 minutes) – O(1 hour). The differences between the space and time scales and the related speeds reflect the different dynamics controlling the atmospheric phenomena. At the planetary scale, the Rossby wave dynamics prevails. At the synoptic scale, motions are mostly driven by baroclinic instability. Mesoscale processes are either topographically forced or are driven by one of a number of instabilities operating at that scale.

The proposed filters are meant to be effective at isolating the processes related to the planetary-scale, synoptic-scale and mesoscale atmospheric phenomena. The selection of filters is further supported by some other findings. Orlić (1983) has performed cross-spectral analysis of the geopotential height of 500 hPa surface above the Adriatic and the sea level. The results showed that the coherence is high at periods surpassing 10 days (at which planetary-atmospheric-wave dynamics dominates) and is much weaker at periods smaller than 10 days (at which baroclinic instability in the atmosphere operates). On the other hand, Markowsky and Richardson (2010) stated that the time scales of mesoscale atmospheric phenomena range from the period of a pure buoyancy oscillation (roughly 10 minutes) to the inertial period (roughly 17 hours in the midlatitudes). That the 10-hour cutoff period allows one to distinguish between the processes related to the synoptic-scale and mesoscale atmospheric variability is also confirmed by Ferrarin et al. (2021): it enabled them to separate a cyclone moving in an eastward direction above the Mediterranean from a low-pressure system travelling in a northwestward direction above the west Adriatic coast and to reveal the difference between the responses of the sea to the two forcing mechanisms.

Therefore, while we agree with the Reviewer that establishing fixed thresholds is not possible, the adopted values allow for an effective separation of the different components in the northern Adriatic Sea. A paragraph with these arguments will be inserted in section 2.2

References:

- *Ferrarin, C., Bajo, M., Benetazzo, A., Cavaleri, L., Chiggiato, J., Davison, S., Davolio, S., Lionello, P. Orlić, M., Umgiesser, G. (2021): Local and large-scale controls of the exceptional Venice floods of November 2019, Progress in Oceanography, submitted.*
- *Holton, J. R. (2004): An Introduction to Dynamic Meteorology (Fourth Edition), Elsevier, Amsterdam, 535 pp.*
- *Markowsky, P., Richardson, Y. (2010): Mesoscale Meteorology in Midlatitudes, Wiley-Blackwell, Chichester, 407 pp.*

- *Orlić, M. (1983): On the frictionless influence of planetary atmospheric waves on the Adriatic sea level, Journal of Physical Oceanography, 13, 1301-1306.*

7) Lines 183-185: Are the authors sure that these are separate events? Which is the methodology of discrimination used? Defining the same event (with several peaks) as multiple cases may insert bias to the statistics of extremes.

After the exceptionally high water on 12 November, three successive events with water level values higher than 1.40 m occurred in just five days. As stated in Ferrarin et al. (2020), these events were driven by separate Sirocco wind episodes in succession in the Adriatic Sea, which did not trigger any significant seiche oscillations in the Adriatic Sea. Similarly to what happened on 12 November, these flood events were determined by the overlapping of the maximum meteorological contribution, the tide peak and a persistent above average mean sea level during the month in the northern Adriatic. This comment will be added in section 2.2

8) In general, the submitted paper feels more like a report (Figures can be enhanced) or a review more than a new research paper. Therefore, all past data on the reported phenomena should be "sewed" together in a comprehensive narrative with new clear scientific insight on the specifics of coastal inundation in Venice city center.

Several figures will be redrawn considering our answers to the comments of the Reviewers. We insist that this is indeed a review article, whose utility is presenting the available knowledge and gaps, repeating past analyses using new datasets and achieving a deep insight by merging the outcomes of published papers. We appreciate the synthesis that the Reviewer provided in the second and third paragraphs of the submitted comments and we feel that it shows the effectiveness of our effort.

Specific Comments:
Some literature of storm surges, waves, climatology, cyclogenesis, extremes etc. in the Mediterranean could be added to the state-of-the-art:
Bengtsson et al. (2006). Storm tracks and climate change. J Clim 9(15): 3518–3543.
Calafat et al. (2012). Comparison of Mediterranean sea level variability as given by three baroclinic models. J Geophys Res 117, C02009.
Campins et al. (2011). Climatology of Mediterranean cyclones using the ERA-40 dataset. Int J Climatol 31(11): 1596–1614.
Makris et al. (2016). Climate Change Effects on the Marine Characteristics of the Aegean and the Ionian Seas. Ocean Dyn, 66(12): 1603–1635.
Fernández-Montblanc et al. (2019). Towards robust pan-European storm surge forecasting. Ocean Mod, 133: 129-144.

Actually we think that these references are not really relevant for this review article. Calafat et al (2012) can eventually be relevant for the companion review on sea level rise and Fernández-Montblanc et al. (2019) for that on the prediction models. Bengtsson et al (2006) and Campins et al. (2011) consider storm tracks and cyclones and opening the related issues would require analysing a large number of papers and deserve a dedicated review article. Makris et al (2016) considers a different geographical area.

Line 44: No keywords are provided.
Proposed key words are: Venice, extreme events, floods, sea level, climate change, trends

Lines 23, 93, 98: The authors refer to planetary waves (e.g., Rossby and Kelvin waves) in the Mediterranean. Maybe this terminology could be avoided to prevent possible misinterpretations. The Kelvin waves'

mechanics could be approximately used to interpret small sea-level oscillations induced by large-scale tidal motions in the elongated Adriatic, but classic planetary wave motions usually refer to equatorial Rossby waves in global scale basins, such as the Atlantic Ocean etc., rather than a closed, marginal, regional aquatic body, as the Mediterranean Sea. Planetary waves depend heavily on global thermoclines etc. and their periods of oscillation are of monthly or yearly scales. This is hardly the case in the Mediterranean. The PAWs referred to in Lines 130 and on, are well established motions, but more likely treated as meteorologically driven long waves of fine temporal scales (hours to days) rather than actual planetary waves. The authors themselves do a good job clarifying that in Lines 133-135.

A distinction should be made between the planetary oceanic waves (POWs) and the planetary atmospheric waves (PAWs). We have documented the response of Adriatic and Mediterranean Seas to the forcing provided by PAWs, not the POWs in the Mediterranean and Adriatic Seas and the Reviewer acknowledges that the manuscript is very clear on this. The use of the PAW terminology is very well established in the literature and we do not think this is a source of confusion.

Line 24 and *elsewhere in the text*: The authors use the term Sea Level Anomaly (SLA) for any sea level variation investigated in the paper. However, in literature, the SLA term usually refers to large-scale long-term (even to climatological scales of analysis) deviations of the Mean Sea Level (MSL) from earth's geoid, not the episodic, short-term, meteorologically induced, coastal sea level elevations that the paper mainly discusses. According to NOAA, "*A sea level anomaly reveals the regional extent of anomalous water levels in the ocean that occurs when the 5-month running average of the interannual variation is at least 0.1 meters (4 inches) greater than or less than the long-term trend. The interannual variation is the monthly MSL after the trend and the average seasonal cycle are removed. The anomalies are usually mapped by month, using the mid-point of the 5-month running average. When the 5-month average is more than 0.1 meters above the trend, it is indicated as a positive anomaly...*". Thus, I would recommend using the term sea surface height or anything similar.

We agree that SLA can be used for large scale and long term deviations of the mean sea level, but we do not think that our use of SLA in a more general sense is a source of confusion. We have checked our text and it is not possible to replace sea level anomaly(ies) with sea level height(s) in our manuscript, without changing the meaning of the sentences.

Line 51 and 149: please provide the reference period of determining the RSLR in Venice. It is essential information for determining the robustness of the values presented, depending on the timeframe of continuous observations.

This is described in the first paragraph of section 2.2: "Since 1919 sea-level values have been referred to the mean sea level over the 1884-1909 period (central year 1897),which is usually called 'Zero Mareografico Punta Salute' (ZMPS), and referred to as relative sea level (RSL)."

Lines 276-282: Please elaborate on the methodology used here (RMSD of which parameter, explain k-means analysis, etc.). Are the authors sure that these are extreme events? Is the analysis based on some robust EVA method? Moreover, please explain how this correlates with the Venice flood events? It seems more of a cyclogenesis-surge association.

We used daily time series of MSL from 1872 to 2018 and retained the daily residuals after removing a low-frequency component (6-month filtered MSL). Then, we selected events (peaks above the 99.5th percentile threshold of the residuals series that are separated by at least 3 days), and saved the first day of the event. Considering the typical duration of surges, this approach would capture the occurrence of independent high surge events.

For the so-selected days, we used standardized anomalies of SLP over the Euro-Atlantic sector and 10-m wind vector over the Mediterranean Sea. A k-means clustering (e.g. Wilks 2006) of these daily fields was applied to group surge events with similar spatial patterns. Iterating from different initial random seeds, the algorithm proceeds until all days are classified in a given cluster. Clusters are constructed so that differences between the daily patterns are minimized within the same cluster and maximized between the clusters, according to a given distance metric (the sum of squared distances). Each cluster is characterized by its centroid (the composited spatial pattern of SLP and 10-m wind standardized anomalies for all days in the cluster). The RMSD shown in Fig. 5b is therefore the root mean squared difference between the daily standardized fields of SLP and 10-m wind vectors of all surge days and their corresponding centroid. In the revised version we will provide this additional details on the methodology before describing figure 5.

Line 334-337: these statements seem like speculations, not numerical facts. Please elaborate or rephrase.

Our analyses and our sentence do not demonstrate or reject a solar influence. The statement relies on the new evidence provided in the manuscript (updated assessment of Figure 7). The correlation between solar activity and the frequency of autumn surges reported elsewhere for the late 20th century is herein captured, but it is lost when we use a longer record, and recent measurements for the 21st century. This suggests that solar influences are non-stationary (effects detected for specific periods only), non-linear (e.g. confined to the recent Grand Modern Maximum), or that the apparent association between the 11-yr solar cycle and surge events was only circumstantial (i.e. caused by other factors). We have rephrased the sentence to emphasize that we are describing possible explanations for the new results: "These results suggest that if there is a solar signal it would likely be non-stationary (arguably masked by other sources variability) and/or non-linear (e.g. confined to Grand Maxima of solar activity). The alternative hypothesis is that the decadal variability of extreme surges is due to other causes, including internal variability"
As for the final sentence of this section, we do not think that we need numerical facts to support this. It just states that, regardless of the causes of the observed interannual-to-interdecadal variations in the frequency of surge events (solar, internal variability or other), one cannot reject that large variability will also occur in the future. In the revised text we have clarified that we are talking about surges and not flooding, whose future evolution is dominated by an increasing trend. "It is reasonable that, superimposed on the increasing frequency of Venice flooding due to the mean sea level rise, the frequency of extreme surges will experience large interannual-to-decadal variations in the future, as it has been observed in the recent period. However, the causes of this variability are still uncertain".

Line 354-358: This is an issue of time-framing, i.e., the choice of the right temporal window to trace statistically significant trends. Moreover, the approach based on stationarity or non-stationarity is also a big issue. Please elaborate and discuss further.

This review considers the frequency of floods using an extremely long time series of nearly 150 years duration of daily sea level -- from 1872 to 2018. Its analysis confirms previous studies that after subtracting the long term sea level mean, the frequency of extremes has no sustained trends (at multidecadal time scales) in spite of the presence of large fluctuations at multiple time scales. we have rephrased the sentence as "In summary, the amount of current evidence shows that while the frequency of floods has clearly progressively increased in time after the mid-twenty century, there is no clear indication of a sustained trend at multi-decadal time scales in either the frequency or the severity of extreme meteorological events. "

Line 407: All the presented material is in the form of an inventory of past hard work reported in older papers, but it does not integrate all the datasets together in a composite, coherent way to produce new knowledge on Venice flooding.

We insist that this is a review article. Further, the discussion of the literature has been complemented by the replica of previous analysis using new datasets (ERA5 in Figs. 2-4), longer time series that have been made recently available (Figs 5-7), extracting information specific for the Venetian floods from recent global datasets

(Figs. 8 and 9). We stress that all these figures have never been published before and are based on new data. The assessment of the scientific literature, complemented by the analysis of the most recent events, it has highlighted that the superposition of several different factors is fundamental for extreme sea levels, which was never highlighted in the previous literature. We further reinforce with longer time series that the increase in the frequency of extreme sea levels since the mid 19th Century is explained by relative sea level rise, with no long term trend in the intensity of the atmospheric forcing. Analogously, future regional relative mean sea level rise will be the most important driver of increasing duration and intensity of Venice floods through this century, overwhelming the small decrease in marine storminess projected during the 21 century. This will clearly pose unprecedented challenges for future flood management and the maintenance of effective coastal defences.

Lines 418-422: This analysis seems irrelevant to Venice city center floods and inundation of the surrounding areas. The wave set-up is a surf zone sea-level parameter in nearshore areas, but what would be important for flooding is the wave run-up on the coast. This is a different task to perform as it would require a huge amount of beachfront and coast cross sections treated with several different empirical relations depending on run-up calculation over engineered or natural beach types. Furthermore, as high waves are dissipated by depth-limited breaking and the specifics of the Venice lagoon topography do not allow very high waves to attack the waterfront, wave-induced would not be a crucial factor.

In general, we are a bit confused by the suggestion of the reviewer that wave run-up is relevant while wave set up is not, being the latter a component of the former, eventually increasing the maximum on-shore elevation reached by the waves. Our answer to comment 2 has clarified why wave run-up is not relevant. The wave set-up (the increase of mean sea level produced by wave breaking) might be relevant if it initiates sufficiently offshore to affect the sea level at the lagoon inlets. This has been argued having happened in the extreme flood of 4 November 1966 and being possible in future extreme storms. This is why it is cited in the review. We will add this short discussion to the paragraph considered in this reviewer's comment.

Figure 7: The Figure's results are most likely reported as is in Barriopedro et al. 2010.

Figure 7 provides an revisited version of a similar figure in Barriopedro et al. (2010), by considering a much longer series (since 1872) than that employed therein (since 1948), as well as updated data for the last decade (up to 2018, as compared to 2008, in Barriopedro et al. 2010). As stated above (comment on L276-282), our results confirm those reported in Barriopedro et al. (2010) for the second half of the 20th century, but also illustrate new findings (lack of coherence between the frequency of surges and the 11-yr solar cycle during the 21st century and before the mid-20th century).

Figure 8: This kind of information is already reported in Vousdoukas et al. (2017).
Figure 9: Plagiarism detected. This is the exact same Figure as Vousdoukas et al. (2018)'s

No plagiarism at all. It is the format of the figures that is similar, while the information is different.
Vousdoukas et al (2017) describes the results for the whole European coastline and some areas of the Mediterranean, and Vousdoukas et al (2018) describes the global 100y-ESL. Figs. 8 and 9 provide the results for the Venetian coastline (see line 393 of our manuscript). In order to stress the differences we have further restricted the area to the box from lon 12.1°W to 12.9°W; and from lat 43.8°N and 45.8°N. The new figures are here below and are clearly different from the previously published results. We will clearly explain this in the revised text

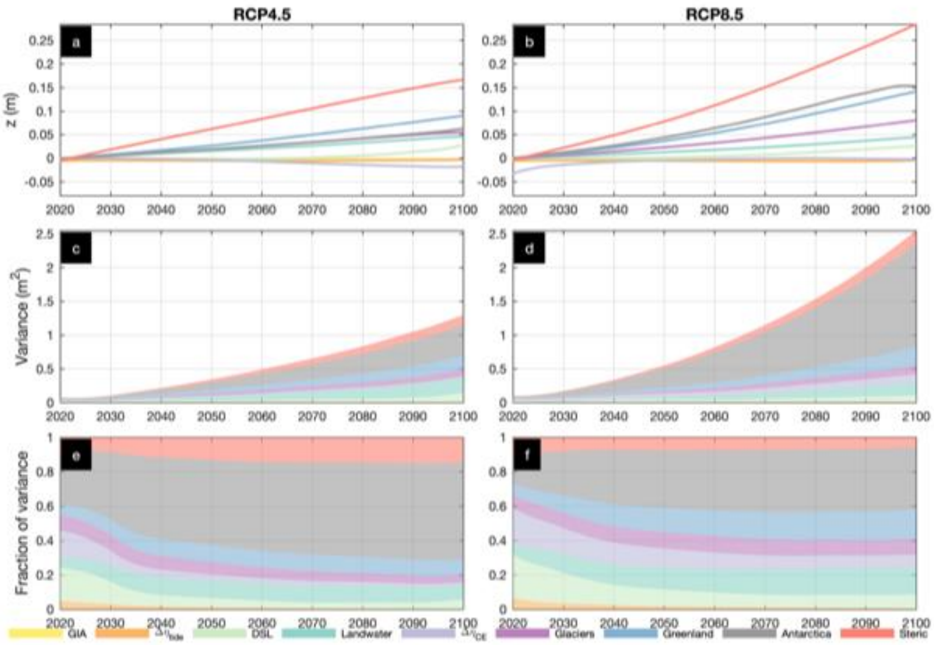

Figure 9 Break-down of projected 100y-ESL contributions in the North-West Adriatic Sea and of their uncertainty, under RCP4.5 (a, c, e) and RCP8.5 (b, d, f). Projected increase of the 100y-ESL from changes in climate extremes, the high tide water level, as well as from SLR contributions from Antarctica, land-water, Greenland, glaciers, dynamic sea level (DSL), glacial isostatic adjustment (GIA), and steric-effects (a, b); variance (in m2) in components (c, d) and fraction of components' variance in global 100y-ESL change. Colors represent different components as in the legend and values express the median at the Venetian coastline.

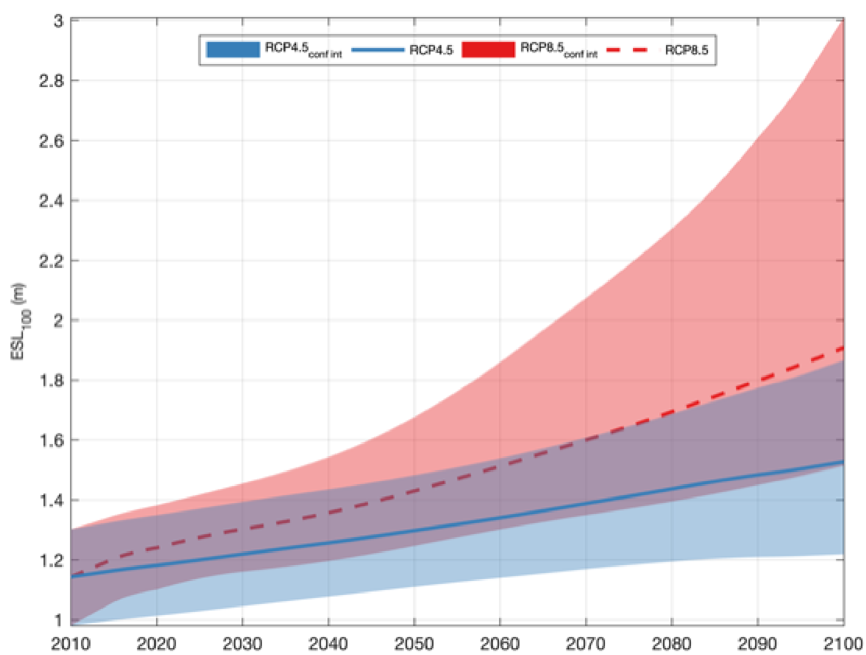

Figure 8 Time evolution of the 100y-ESL in the North-West Adriatic Sea under RCP4.5 (blue) and RCP8.5 (red). Lines show the corresponding medians and colored areas express the 5th-95th percentiles (very likely range).

Fig. 5. Moreover, it is not clear how this Figure's results correlate with local or even regional projections of mean Sea Level Rise focused on the northern Adriatic.

The title of the subsection where fig.5 is used is "Characteristics of cyclones producing storm surges and floods of Venice". This title should already make clear that this figure is not relevant for projections of mean sea level (which is further not the object on this review article). We will extend the information in our manuscript to better explain how this figure has been obtained and what is its meaning (see our answer to the comment of the Reviewer on Lines 276-282)

Figure A.1: Plagiarism detected. This is the same Figure as Barriopedro et al. (2010)' Fig. 2. It is also not clear how these results relate to Venice city center floods.

*Also in this case there is no plagiarism at all. First, Fig. A1 is based on the residual daily series of MSL (used for the identification of surge events, as described in L276-282), while Fig. 2 in Barriopedro et al. (2010) uses the seasonal frequency of high surge events. An updated version of the latter is provided in Fig. A2. However, Fig. A2 uses data for 1924-2018, therefore providing an assessment over a longer period than that analyzed in Barriopedro et al. (2010). Fig. A2 also allows identifying periodicities at much lower frequencies than in Barriopedro et al. (2010). The results of Fig. A2 over the 1948-2008 period are similar to those reported therein, supporting that the 99.5th percentile of the daily residual series of MSL captures well the high surge events defined in Barriopedro et al. (2010) from hourly data. For the new examined interval (not addressed in Barriopedro et al. 2010), we do not identify significant and robust decadal periodicities in support of an obvious 11-yr solar cycle effect in the frequency of surge events (in agreement with Figure 7).We openly refer to the previous stu*dy in the text and explain that we are repeating the same analysis using a longer time series. The allegation of plagiarism is fa*lse.*

Table 1: This is an interesting feature. Percentages of contribution by each component to the total RSL would be beneficial to the reader for supervisory purposes. Is that new knowledge or reported elsewhere? It should be clarified.

This table is a new compilation computed explicitly for this review article. We agree to integrate it adding percentages of the different contributions. The second part with this information is the following:

Percentage								
1936-04-16 20:35:00	147	14	10	43	1	18	7	7
1951-11-12 07:05:00	151	28	1	30	2	26	4	10
1960-10-15 06:55:00	145	21	3	44	2	8	8	14
1966-11-04 17:00:00	194	-6	11	56	8	10	10	11
1968-11-03 06:30:00	144	23	7	32	2	15	6	15
1979-02-17 00:15:00	140	24	-2	28	6	18	11	16
1979-12-22 08:10:00	166	10	8	48	9	8	2	13
1986-02-01 03:00:00	159	18	14	30	3	11	9	14
1992-12-08 09:10:00	142	30	6	21	1	24	1	16
2000-11-06 19:35:00	144	11	4	49	1	12	6	18
2002-11-16 08:45:00	147	29	-5	33	1	14	10	18
2008-12-01 09:45:00	156	25	14	27	1	12	3	19
2009-12-23 04:05:00	143	15	22	16	3	12	10	22
2009-12-25 03:00:00	145	20	15	15	2	14	12	21
2010-12-24 00:40:00	144	24	1	26	3	16	8	22
2012-11-01 00:40:00	143	14	1	38	1	19	6	22
2012-11-11 08:25:00	149	32	-3	42	1	1	5	21
2013-02-11 23:05:00	143	27	10	27	0	4	10	22
2018-10-29 13:40:00	156	16	1	32	8	19	3	22
2018-10-29 19:25:00	148	-22	16	51	9	20	3	23
2019-11-12 21:50:00	189	19	3	22	20	11	7	18
2019-11-13 08:30:00	144	33	3	10	5	16	10	24
2019-11-15 10:35:00	154	31	3	16	1	18	10	22
2019-11-17 12:10:00	150	23	0	23	7	15	10	23
2019-12-23 08:45:00	144	26	27	5	1	10	8	24
AVERAGE		19	7	31	4	14	7	18

We thank the Reviewer for the **Editorial Comments** *and we will introduce the required corrections and clarifications in the revised version of our manuscript*