Reply to the Reviewers' Comments prof. Picotti Vincenzo (Referee 1)

General comments

1) This is a novel dataset of peak precipitations in the mountain area of the Northern Apennines of Italy. The authors discuss a well calibrated core and compare it with part of existing data in the region. Although the topic is of paramount interest for the scientific community and the results interesting, the manuscript is poorly written and it requires a deep reworking prior to the final publishing. A first problem is the language, that in some cases is coupled with or it enhances problems in the flow of the arguments. I urge the authors to polish the paper making the reasoning easier to the reader. I have tried to polish the abstract, but, in the text, I did it here and there, and I mostly highlighted some parts where the meaning was obscure.

   Reply: the final version text will be edited by native English translator according to the Reviewer's suggestions.

2) An important general scientific problem is the interpretation of the core deposits. From the map of Figure 2, the Lake Moo spill point has an elevation of 1114.2, the S1 core was drilled at 1121. The authors interpret the deposits as lacustrine until – 0.9 m. This implies a lake level at 1120 m around 200 to 60 years ago. The spill point should have incised 6 m in around 100 years. I think this is not possible, in any case I urge the authors to consider in their manuscript the relationships between the spill point and the lake level, a topic completely overlooked. In my opinion, given the young age and the elevation with respect to the spill point, it is very likely that the units 3 and 4 were formed in a subaerial environment, that is the fan environment visible today. From the point of view of the peak precipitation, this is maybe not changing much, but the sedimentological interpretation, such as the hyperpycnal flows, should be completely changed. Interbedded fine- and coarse-grain deposits is something typical of colluvial fans, where dense flows, such as debris flows and grain flows, are common, but there is always the reworking of previous deposits by running water, that winnows the matrix and brings about fine-grained intervals.

Reply: This is a good point. Following the Reviewer's observation, we have precisely measured the elevation of key points using Garmin eTrex 10 to improve and better explore the relationship between the spill point, lake level and core stratigraphy. The results are:

- S1: 1120.2 m a.s.l. instead of 1121 m a.s.l.
- Spill point: 1116m a.s.l. instead of 1114.2 m a.s.l..

The difference is about 4m and not about 7m as shown in "CTR."

After a confrontation with the municipality and the Carabinieri forest ranger of Ferriere, it emerged that the area of the emissary was modified by human interventions lowering its altitude to encourage grazing over the years. These activities were carried out by the owners of the area, and there is no official documentation.

We suggest moving the limit of the underwater deposits (now at the base of unit 4) to a depth of 2.3m. Also, unit 3 has been divided into two sub-units: 3a and 3b. Unit 3a retains its depositional characteristics as described in the first version of the article, in a shorezone environment affected by coarse material input through floods. Unit 3b changes its interpretation from a relatively deep lake environment (as shown in Figure_4_new) to a shorezone environment with low coarse debris input due to flooding.

Moreover, we have analysed the palinological content of unit 3 to refine its interpretation better (Table pollen new in SM). In all three samples P12, P13, P14 the presence of typical wetland plants is discretely, particularly herbaceous hygrophytes with values between 11.9 and 19.5%. This group is made up of plants living in marginal lacustrine areas such as cyperaceae and sedges.

3) I also recommend the authors not to use the categories proximal/distal to describe grain size variations in this fan or fan-delta, given they have a spatial meaning, and here the spaces are amazingly tight.

Reply: We have replaced the concept of proximal and distal with that of "mature" and "immature" deposits (Mutti, 1992)

4) Another problem is the missing correlation of pollens with the good record of the Lake del Greppo of Vescovi et al. (2010), located in a similar setting (high elevation counterslope related

to deep landslide, Northern Apennines) around 100 km to the southeast. This correlation is also hampered by the author's choice to merge data of Pinus and Abies into a common group, therefore making it impossible to appreciate the decline of Pinus and the growth of Abies during the HTM.

Reply: this is a good point. Following the Reviewer's suggestion, we have referred to the pollen record of the Lake del Greppo (Vescovi et al., 2010) in the discussion and we have distinguished *Pinus* from *Abies* in our record. For what concerns the correlation of the two pollen records, we are inclined to proceed with caution because of the different stratigraphic/depositional context and the highly different degree of resolution of the two dataset (Figure_7_new).

5) Finally, the authors announced in the text and the abstract the occurrence of 2 cores and an interesting trench. These data are not presented, only located in the Fig. 2 small version, but not reported in the Fig. 2 larger version. What is the reason for this? A trench would help a lot understanding the sedimentary processes!

Reply: In order to optimise the activities, we have focused our attention on the S1 core because it is the most representative and complete of the sedimentary succession. The other core (S2) and the trench were used in support to the stratigraphic and sedimentological study (and a consequence of the second point) of the selected core (S1), on which all the laboratory analyses were undertaken.

6) On the other hand, what is the role of Table 1? Does the forest composition play any role in the story? The pollen data are not referring to it!

Reply: For the sake of clarity, we deleted Table 1 and moved all the available data about the present-day vegetation cover of Lake Moo in text (section 2.1). In our opinion these data, which represent a general overview potentially useful to the readers, cannot be directly compared with the pollen record as they derived from a botanic study.

Specific comments

- Geographic coordinates and elevation of the drilling are missing.

Reply: done and the data has been added to the text.

S1 elevation: 1120.2 m

S1 geographic coordinates: 44° 37’ 25”N - 9° 32’ 43”E

- Fig. 1 Middle frame, graphic scale is wrong.

  Reply: the figure has been modified according the Reviewer’s suggestions (Figure_1_new).

- Fig. 2 geologic/geomorphic map: very poor! In the published 1:50000 map, the geology of the catchment is given by large olistoliths of serpentinite embedded into “Complesso di Monte Ragola” an Upper Cretaceous blocky clayshale. This latter unit is not mentioned in the map or in the text. The surficial units are not sound: the hillslopes of the Lake (beside one mapped as serpentinite bedrock) consist of two units.

  The first, a “detritical (it should be detrital) cover, from boulder to granule, Holocene”. Granule is not an official grain size: what does it correspond to? (valid for the colluvium too). Does granule imply mud, or should it be something larger? Is there any mud in this detritus? Second, most of this field is mapped as serpentinite in the published small-scale map. Finally, if this is detritus, where is it coming from? If not transported, then it could be the in-situ weathering of the substrate. In fact, the weathered blocky clayshales of the Complesso di Monte Ragola, when removing the fines, would make it visible on the surface only the blocks of any size, without the clay, transported toward the Lake Moo. In any case this field should not be named “detritus”, but eluvial or colluvial cover, or simply weathered bedrock, if the thickness is less than 1 m or so.

  The second surficial unit in Fig. 2 consists of a large field named “Complex landslide, from cobble to silt”. Again, strange there is no clay in this unit, whereas in the depression it is full of clay. In any case, does this field refer to a landslide body? Coming from where, the south? And what created this topography? Is this the original landslide topography? Or has it been subsequently eroded? The steep wall on the eastern margin of the map is steep, suggesting bedrock. I think the two fields represent the same feature: a deeply

weathered bedrock, but I never was there in the field.

In the northwest side of the depression three alluvial fans are mapped that are missing a supplying channel. This is odd: they are clearly fan and wedges of colluvium, not alluvium. Actually, given the size and the mass flow processes, also the fans mapped at the end of channels should be considered colluvial, but this is a matter of debate, therefore I could accept them mapped as they are, except for the small sign of fan to the west of the main fan: this is clearly part of the main fan and there is no feeding channel, therefore it should be cut. Finally, the classic symbol for the fan are fanning lines that should be perpendicular to the contour: in the main fan they are badly drawn. The author should better map the area.

Reply: the figure 2 has been modified as follows (Figure_2_new): we used the latest update of the geological database of the Emilia-Romagna Region, scale 1:10.000 (available at the following link: https://geo.regione.emilia-romagna.it/cartografia_sgss/user/viewer.jsp?service=geologia) and on this geological basis, the flood deposits of 13 - 14 September 2015 have been reported. In this way we have also simplified the map and made it functional to the objectives of the article.

- Fig. 5 scale is missing

  Reply: Done (Figure_5_new)

- Fig 6 It would be interesting to have the stratigraphic units plotted in the figure, since the change in sedimentation rate at the end of unit 2 should be better placed at the unconformity.

  Reply: the figure will be modified as required (Figure_6_new). The limit between unit 2 and 3, placed on the basis of the facies analysis, is in accordance with the change in the sedimentation rate observed in the age-depth model.

- Fig. SUP1. In the profile BB', the core S1 is wrongly reported at 22 m at depth, instead of 12.5 m. Unclear why the authors did not calibrate the profile with the core. After a simple graphic correlation, one can appreciate that the substrate starts at around

1800 m/sec, therefore providing a much simpler and more likely geometry of the substrate/ sediment contact. Please reconsider your interpretation.

Reply: the figure has been modified according the Reviewer's suggestions (Figure_1_New).

- Literature cited

  Vescovi, E., B. Ammann, C. Ravazzi,and W. Tinner. 2010 a. A new Late-glacial and Holocene record of vegetation and fire history from Lago del Greppo, northern Apennines, Italy. Vegetation History and Archaeobotany 19: 219– 233.

  Reply: Included in references

Specific comments on the annotated manuscript

- **Line 18 to 19:** As consequence, several geomorphological processes, like widespread debris flows along the slopes and hyperconcentrated flood in the stream channels….

  Referee: why putting debris flows in the slopes and hyperconcentrated flows in the channel? This subdivision is odd! Debris flows require channels! On the other hand hyperconcentrated flows are defined by the density contrast with ambient fluid, being fresh- or marine water. But in the continent every flow is denser than air! Therefore, I urge the authors to make it clearer the definition and nomenclature of flow regimes.

  Reply: The sentence "like widespread debris flows along the slopes and hyperconcentrated flood in the stream channels" has been replaced as follows:

  …like debris avalanches and debris flows (Hungr et al., 2013), ……

- **Line 27:** flows into the plain.

  Referee: which plain?

  Reply: …..flows into the Lake Moo plain.

- **line 27 to 30:** Our main assumption is that, in such a small drainage basin (area <2 km2), with favourable geologic and geomorphic characteristics implying advantageous sediment transfer into lake, high density flood can be triggered only by high intensity precipitation events (HIP) lasting enough time for water to infiltrate and mobilize large quantities of debris.

Referee:

1) Unclear concept. Or unclear wording. Or both;
2) The concept of threshold precipitation is well established in the literature. Why do the authors present it as their assumption? what's different/new?

Reply: the paragraph has been modified according the Reviewer's comment as follows:
In accordance with the literature (Milliman and Syvitski, 1992; Mulder and Syvitski, 1995; Mutti et al., 1996), in such a small drainage basin (area <2 km^2), high density flood can be triggered only by high intensity precipitation events (HIP) lasting enough time for water to infiltrate and mobilize large quantities of debris.

- **line 49**: In particular, on the northern Apennines, more than sixty percent of total precipitation of the year is concentrated in days with moderate to high-intensity precipitation (Isotta et al., 2014).
  Referee: few days? unclear!
  Reply: The sentence has been replaced as follows:
  In particular, on the northern Apennines, more than sixty percent of total precipitation of the year is concentrated in a few days of moderate to high-intensity precipitation events (Isotta et al., 2014).

- **line 86**: ….. generated by a small stream that flow into the plain.
  Referee: which plain?
  Reply: The sentence has been replaced as follows:
  …..generated by a small stream that flow into the Lake Moo plain.

- **line 90 to 97**: In the Trebbia-Nure case, a detailed analysis of precipitation (Grazzini et al., 2016) 90 over Lake Moo site microbasin showed that the observed debris flow occurred with a peak intensity of 112mm/3h. This is a very high value compared to shallow landslide and debris flow thresholds find in literature for nearby areas, like the Apuane and Garfagnana regions (Giannecchini et al., 2012), which can be explained by the dense vegetation cover present now in the area. In addition, the absence of surrounding anthropic activities, the vicinity of the lake to the main Apennines crest, very exposed to maritime moist airflow coming from the central Mediterranean Sea, make this site

particularly 95 suitable for a detailed reconstruction of HIP events over the Holocene in terms of frequency, sedimentary expression and forcing factors.

Referee: the phrasing is unfortunate here… I suggest to split the long sentences and make it clear what conditions occur in the study area with respect to the other areas. F.i the Apuane are a crest even close to the sea.

Reply: the paragraph has been modified as follows:

In the Trebbia-Nure case, a detailed analysis of precipitation (Grazzini et al., 2016) over Lake Moo site microbasin showed that the observed debris flows occurred with a peak intensity of 112mm/3h.

The absence of surrounding anthropic activities, the vicinity of the lake to the main Apennines crest, very exposed to maritime moist airflow coming from the central Mediterranean Sea, make this site particularly suitable for a detailed reconstruction of HIP events over the Holocene in terms of frequency, sedimentary expression and forcing factors.

- **line 126**: HIP conditions are more frequent in Autumn months due to a particular synergy of higher frequency of synoptic disturbances and mesoscale convective systems which could still develop in high thermodynamic unstable environment (Grazzini et al., 2019).

  Referee: unclear phrase

  Reply: We rephrased in the following way. “HIP conditions are very favourable in Autumn months due to a particular synergy of mid-latitude synoptic disturbances, which are more frequent towards the cold season, and strong convective systems, which could still develop at the end of summer and in Autumn over the warm Mediterranean sea (Grazzini et al., 2019)”.

- **line 143 to 145**: From this point of view, the main factor controlling the morphological evolution of the area of Lake Moo, is the river incision produced by the Nure stream during the Holocene (Gunderson et al., 2014). This incision triggered the development of gravitational phenomena on the slopes

  Referee: unclear citation: No Holocene incision in Gunderson et al., 2014

  Reply: citation has been replaced by Elter et al., 1997.

- **line 185 and 187**:

  1) the position in the facies tract with respect to the whole fluvial-hyperpycnal system;
  2) relative flood event magnitude;
  3) expected related facies types in more proximal and distal areas

  Referee:

  1) unclear, please reword it
  3) expected based on what? it seems circular…

  Reply: points 1, 2 and 3 have been deleted and replaced by the following sentence:
  The facies tract approach is important because allows, along the vertical of the S1 core, to recognize and reconstruction how the flood deposits change in time at a fixed location.

- **line 264**: high density flood

  Reply: replaced with debris flows

- **line 309**: ……is like to the infill of a structural depression produced by gravitational block sliding that was induced by post-glacial fluvial incision (Gunderson et al., 2014).

  Referee: odd quotation! again, Gunderson et al., 2014 do not deal with Holocene incision

  Reply: citation has been replaced by Elter et al., 1997.

- **line 314 to 316**: The 27 deposits interpreted as instantaneous events representing a total of 374.5 cm were removed, the remaining were used to build an event-free 315 sedimentary record.

  Referee:

  1) what percentage of the fine-grained deposits belong to the "instantaneous deposits"?
  2) The authors should better explain why they built these two curves… (scope and methods);

  Reply:

  Initially, we proposed two age-depth model curves, with and without the coarse-grained levels ("instantaneous events"). During the review of the article we reflected on the following:

1) Within the stratigraphic interval with radiometric data, there are many different stratigraphic intervals without sediment data, for a total thickness of 107cm;

2) The difficulty in putting the top limit of the "instantaneous events" in an objective way. This limit marks the passage to regular lake sediments. It is therefore subject to interpretation because it is often transitional.

The set of these factors do not allow us to evaluate the validity of the curve without the coarse levels. For these reasons, we have chosen the age-depth model curve with "istantaneous events" for caution reasons.

All this will be included in the material and methods chapter.
However, it is interesting to observe that in the age-depth model curve with "istantaneous events", the change in sedimentation at the end of unit 2 is at a depth of 500cm, while it is at a depth of 403cm in the age-depth model curve without coarse-grained levels. Based on the analysis of facies, the limit of the end of unit 2 was placed at a depth of 445cm.

- **line 317 to 319**: Four radiocarbon dates were rejected: one (LTL18275Abis code) because it was not possible to date the sample for poor presence of organic matter, the others (LTL18275A, LTL18575A and LTL18272A codes) because it was not possible to identify a calibrate age.
  Referee:
  1) in this case, this is not rejected…;
  2) unclear without the measured data in a table.
  Reply: Text and the table TS2 have been modified according the Reviewer's comments

- **line 337**: ……and June (red) - December (blue) insolation values records reported for 45° Nord.
  Referee: source missing
  Reply: done. From Samartin et al., 2017.

- **line 341 to 342**: Caption figure 7. The stratigraphic succession of the S1 core compared with the most relevant climate proxy available from literature for the area of interest.
  Referee: here you should recall all the various proxies with sources.
  Reply: done

- **line 357**: **……..**characterized by a period of apparent inactivity of the fluvial system.
  Referee: why are you calling yours a fluvial system?
  Reply: the sentence has been modified according to the Reviewer's comment as follows:
  ….. characterized by a period of apparent floods inactivity.

- **line 379 to 381**: This rise of temperature is associated also with a comparable unprecedented intensification of fluvial deposition, testified in the core, by the deposition of units 4 and 5, which marks the transition (in a short time) from marshy to fluvial 380 sheet-flood deposits (Fig. 5).
  Referee: why are you calling yours a fluvial system?
  Reply: the sentence has been modified according to the Reviewer's comment as follows:
  This rise of temperature is also associated with a comparable unprecedented intensification of floods deposition, testified in the core, by the deposition of units 4 and 5, which marks the transition (in a short time) from marshy to sheet-flood deposits (Fig. 5).

- **line 406**: In this section, we introduce the pollen data to fully exploit the multidisciplinary approach.
  Reply: removed sentence

- **line 419**: This occur in response to warmer conditions and pluvial phase, as indicated by Regatieri et al., 2014;
  Referee: phase is not appropriate, I would use warmer and wetter conditions.
  Reply: done. This occur in response to warmer and wetter conditions, as indicated by Regatieri et al., 2014

- **line 430**: These coarse grained deposits are expressing of proximal facies (LM4 to LM6, in Fig. 10).

Referee: I don't find wise to use proximal/distal categories in this case study of such tiny catchment.

Reply: Distal and proximal terms are related to the moo lake plain. However we understand that it is not wise to use these categories in such tiny catchment and why Lago Moo area is only a step in the evolution of debris flow along its down-slope motion. We have replaced the concept of proximal and distal with that of "mature" and "immature" deposits (Mutti, 1992).

- **line 445 to 446**: **Capttion figure 10.** The stratigraphic intervals I1 and I2 from S1 core compared with the original pollinic data and the relevant climate proxy available from literature for the area of interest.

  Referee: also in this caption the authors should recall all the proxies with the sources.

  Reply: done

- **line 472 to 481**: HIP increase in response to higher temperature is already detectable in observation series, especially in seasons when moisture availability is not limited, like in Autumn (Brönnimann et al., 2018; Prein et al., 2017). We found evidences that this occurred also in the past, especially during HTM testified by higher deposition of large size sediment in to the lake. A comparison with the past help understanding future projections on the area, although we are aware that past evolution cannot be taken as an analogous for future due to the different forcing and consequent response of climate system (D'Agostino et al. 2019). As temperature will continue to increase on the Mediterranean area precipitation intensity would keep increasing over the Northern Apennine. We hypothesize that precipitation intensity increase will be evident in months with cooler and moist air masses, like in Autumn as it already emerging (see Fig.9), but gradually extending towards Winter. In summer, increasing conditions of moisture limitations will induce a decrease in frequency and intensity of precipitation (Dobrinski et al. 2016a and 2016b)

  Reply: we will use uppercase letter for seasons

Captions

Figure 1. (a) Location area stricken by the rainfall event of September 13th and 14th 2015 (red square) and Lake Moo plain position **(b)** The landscape view of the Lake Moo plain taken from the southern side.

Figure 2. Location of the geognostic investigations, geophysical surveys tracks, and detailed geomorphological mapping of the flood deposit occurs between 13 and 14 September 2015 (upper Trebbia and Nure valleys, province of Piacenza, Italy).

Figure 3. Sediment core description (see legend), radiocarbon dates and samples pollen.

Figure 4. Idealized genetic facies tract interpretation of clastic deposits associated with S1 core.

Figure 5. Though the exposure is quite small, these graded pebble-sand couplets could be interpreted as a sheet-flood deposit (Unit 5).

Figure 6. Right: Age-depth model obtained from radiocarbon dates. Black and grey line represents the two-sigma probability envelope depth without coarse grained events. Red and orange line represents the two-sigma probability envelope depth with coarse grained events. Left: S1 core.

Figure 7. Stratigraphy of core S1, main palynological features and microcharcoal content. Relative abundances of pollen groups, explained in text (sub-section 3.4), are reported along with the frequencies of hygrophilous herbs and aquatics. Asterisks point to samples containing coprophilous fungi and other spores like *Sporormiella*, *Dicrocoelium* and *Ascaris*. These data are compared with the most relevant paleoclimate reconstructions available from literature for the area of interest. Panel (a) Reconstructed mean July air temperature from Lago Verdarolo (from Samartin et al., 2017); Panel (b) δ18O speleothem records and reconstructed precipitation trends (mean anomaly time series) from Renella cave (slightly modified from Combourieu et al., 2013; Regattieri et al., 2014; Zanchetta et al., 2011; Zhornyak et al., 2011) and Panel (c) June (red) - December (blue) insolation values

records reported for 45° Nord (from Samartin et al., 2017). Main Holocene climate phases and events are also shown. Available radiocarbon ages are reported as calibrated years BP.

Figure 10: Sedimentological and palynological features of two key stratigraphic intervals (intervals 1 and 2) from core S1 compared with the most relevant paleoclimate data available from literature for the area of interest (for references please see Figure 7). The Anthropic Index (AI) has been calculated as: (Anthropic indicators/tree percentage)*100 following Accorsi et al. (1998).

Figure SUP1. Seismic tomography of the underground lake Moo basin. For geophysical surveys tracks see Fig.2.

Table TS2. Full list of Radiocarbon sample age and description details.