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Peer Review File

Climate-driven changes in Mediterranean grain trade mitigated famine but introduced the Black Death to medieval Europe

Corresponding Author: Professor Ulf Buentgen

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Professor Buentgen,

Your manuscript titled "Volcanically forced and climate-driven changes in Italian grain trade brought the Black Death to medieval Europe" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Jiaoyang Ruan
Editorial Board Member
Communications Earth & Environment

orcid.org/0000-0003-4733-1125

Alice Drinkwater
Associate Editor
Communications Earth & Environment
Consulting Editor
Communications Sustainability

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• Ecological, evolutionary & environmental sciences
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You can download the form here:
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Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

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All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
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- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

This is a fascinating and well-researched study that effectively bridges climatology, ecology, and social sciences to

elucidate the complex interplay between volcanic-induced climate change, grain trade, and the spread of the Black Death in medieval Europe. The interdisciplinary approach, combining high-resolution climate proxies with historical documentary evidence, provides compelling support for the hypothesis that volcanically forced cooling and subsequent grain imports from the Black Sea region facilitated the introduction of Yersinia pestis to Mediterranean harbors. The study makes a significant contribution to our understanding of how environmental and societal factors can converge to drive large-scale pandemics.

Suggestions for Improvement:
1. Temporal and Spatial Mapping of Plague Outbreaks: While the study highlights Venice as a key entry point for the plague, it would strengthen the argument to include data on the timing of outbreaks in other Italian and European ports (e.g., Genoa, Pisa, Marseille, etc.). If these ports also experienced outbreaks shortly after receiving grain shipments from the Black Sea, it would further corroborate the grain trade as a primary transmission pathway. Figure 3 could be enhanced by annotating the arrival dates of plague outbreaks in these ports alongside the grain trade routes.
2. Comparative Analysis: A brief comparison with other Mediterranean ports that did not engage in Black Sea grain imports (if any) could serve as a control, reinforcing the link between trade and plague introduction.

Reviewer #2 (Remarks to the Author):

Overall, I find the approach very valid and the article is well written. It is interesting how the scientific data have been processed and combined with detailed historical research, resulting in a fascinating comparison. The work of collecting and processing the data is undoubtedly challenging, yet the authors have managed to convey the information clearly and comprehensively. I hope that this line of research can be pursued further in other studies, by exploring the years and centuries preceding the plague with the same approach, in order to obtain an even more complete view of the complex natural and historical dynamics that contributed to the pandemic, and in general, of the life in the medieval times. This work also provides a valuable picture of trade dynamics and of the possible causes that may have brought the Black Death to Italy, as well as of how various climatic components interact. The hypothesis developed is truly intriguing, although it remains—certainly not due to any shortcomings of the authors, but simply because of the currently available data—still open to question. For this reason,I have some concerns I would like the authors to consider. I suggest adopting a less categorical nuance and leaving some issues open, starting from the title.

Other issues:
1. Blue rings and volcanic activity
At higher elevations, where the growing season is shorter and lignification occurs later, early autumn cooling could interrupt cell wall lignification, leading to the formation of blue rings. In contrast, at lower elevations—where the growing season starts earlier and lignification is likely completed before autumn cooling—such structures may not form even under similar temperature drops. Blue rings are therefore more likely in subalpine environments due to the timing of wood maturation relative to seasonal cooling.
Even small topographical differences, especially near the treeline, can significantly affect local climate conditions experienced by trees. Small changes in elevation can modulate the climatic response, and there is not always a direct correlation between blue ring formation and air temperature. Other variables, such as precipitation, should also be considered.
While a correlation between blue rings and certain historical volcanic eruptions is mentioned, the Pyrenean sequence clearly shows that blue ring formation does not always coincide with major recorded volcanic events.
I recommend interpreting the proposed blue ring data with caution or integrating them with studies from Italian regions (excluding the Alps), even though such studies may not exist for the period of interest. The issues related to blue ring formation—already noted in one of the cited studies—should be explicitly acknowledged in the text.
Although there is little doubt about the occurrence of low temperatures in Italy during the years of the Black Death—supported by both historical sources and the presented climate models—it seems rather speculative to establish a direct correlation between these conditions and the blue rings found in the Pyrenees.
Given the marked climatic variability in the Mediterranean region, the occurrence, formation, and dynamics of blue rings require further investigation before this proxy can be reliably used to reconstruct past Mediterranean climate or correlate it with volcanic activity.

2. Comments on Supplementary Text S1-S2-S3-S4
I appreciate the extensive research and numerous sources cited regarding astronomical events and descriptions of anomalous climatic occurrences.
My concern is not with the source selection itself, but with the interpretation of what these sources describe. From the extracted texts, the most credible phenomena appear to be planetary conjunctions.
While the inclusion of sources from Korea, Japan, and China enriches the analysis, I find them not entirely appropriate for the specific aims of the article and somewhat redundant.
I suggest clarifying in the main text (lines 117–126) that the data on lunar eclipses and other rare phenomena are not always fully reliable and may be indicative of other events.
Amplified descriptions with supernatural elements are quite frequent in both medieval and non-medieval texts. Often, imaginative phenomena are described alongside more realistic ones, either to emphasize the gravity of the context or to exorcise fears. It is therefore necessary to distinguish between natural events that may have actually occurred, for example (not cited in the article), the earthquake of 1348 and the severe storm/tsunami that destroyed Amalfi in 1343 and others that are clearly exaggerated or entirely fanciful, such as a rain of worms or enormous fires.
In contrast, I find that the data presented in Supplementary Texts S2, S3 and S4 are particularly relevant and significantly

enrich the understanding of the climatic and social situation, not only in Italy but also in comparison with other regions of the world.

3. Climate and Volcanoes

There is no doubt that these were years with lower temperatures, likely close to the beginning of the Little Ice Age, if not the very start of it. There is also no doubt that certain volcanic eruptions, even distant ones, can influence the climate and contribute to lowering temperatures. One or more small eruptions may not have affected the “normal” climate trend at all, whereas a sequence of eruptions occurring in a short time can lead to cooling that lasts for many years. I would not therefore exclude the possibility that the colder climate of those years could have been a consequence of closely spaced volcanic eruptions—such as Reykjanes (1226), Samalas (1257), and Quilotoa (1280)—which could have initiated the Little Ice Age, rather than being necessarily attributable to volcanic events around 1345.

I would also consider that sulphur trapped in ice cores is not always an indication of a volcanic eruption, and that it is always better to combine such data with other indicators, such as tephra and cryptotephra, as well as isotopes. Furthermore, the event around 1345, based on the data considered here, is not among those with the highest VSSI values, and it does not seem that the eruption(s) led to a temperature drop comparable to other major events, especially in Europe. I would also consider it important to analyse other works that take into account isotopic signatures, which detect an event in 1343 but not of great magnitude. I therefore believe that the event was very limited, not uniform, and easily masked by the variability of the medieval climate.

Figure Suggestions

Figure 1: I recommend removing the blue ring data from the figure, as their correlation with temperature for the whole of Italy remains uncertain. Instead, emphasize:

-The cooling period associated with the Black Death.

-The timing of major volcanic eruptions and their climatic impacts (at least in the case of Samalas).

The summer temperature reconstruction’s limited temporal range restricts the possibility of correlating climate effects with earlier significant eruptions. Extending this dataset would be valuable for future work.

Minor points, some indications to smooth the article

Line 30 cold and wet climatic conditions

Line 131 could be indicative of consecutive years of cooling.

Line 132 might have encompassed the entire west Mediterranean region

Line 167 delete “unusually”

Line 170-171 anomalous environmental and climatic factors impacted

Line 228 delete “Volcanologically forced”

Line 229 “may explain”

Line 261 delete “Volcanologically forced”

Line 282-283 enhanced by a cold and wet climate, possibly influenced by volcanic eruptions

Line 287-288 including climate and plausibly volcanic-forced changes

Some references I considered and that should be considered:

Barbante et al. 2013 “Greenland ice core evidence of the 79 AD Vesuvius eruption” doi:10.5194/cp-9-1221-2013

Benito et al. 2015 “Holocene flooding and climate Change in the Mediterranean” https://doi.org/10.1016/j.catena.2014.11.014

Burke et al. 2023 “High sensitivity of summer temperatures to stratospheric sulfur loading from volcanoes in the Northern Hemisphere” https://doi.org/10.1073/pnas.2221810120

Camuffo et al. 1995 “The analysis of two bi-millenary series: Tiber and Po River floods. In: Jones, P.D. (Ed.), Climatic Variations and Forcing Mechanism of the Last 2000 Years. NATO-ANSI Series, 1: Global Environmental Change, vol. 41”

Camuffo et a. 1998 “A critical analysis of the definitions of climate and hydrological extreme events” https://doi.org/10.1016/j.quaint.2018.10.008

Davies et al. 2010 “Tracing volcanic events in the NGRIP ice-core and synchronising North Atlantic marine records during the last glacial period” doi:10.1016/j.epsl.2010.03.004

Piovesan et al. 2023 “Bell-shaped tree-ring responses to air temperature drive productivity trends in long-lived mountain Mediterranean pines” http://dx.doi.org/10.1016/j.scitotenv.2023.164103

Sadori 2018 The Lateglacial and Holocene vegetation and climate history of Lago di Mezzano (central Italy) https://doi.org/10.1016/j.quascirev.2018.09.004

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Version 1:

Decision Letter:

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Dear Professor Buentgen,

Your manuscript titled "Climate-driven changes in long-distance grain trade not only alleviated famine in Italy but also brought the Black Death to medieval Europe" has now been assessed by the editorial team. We are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work. This includes including a 'methods' section in the manuscript.

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Best regards,

Alice Drinkwater, PhD
Associate Editor
Communications Earth & Environment
Consulting Editor
Communications Sustainability

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UNIVERSITY OF CAMBRIDGE
Department of Geography

Professor Ulf Büntgen
Professor of Environmental Systems Analysis

Dr Jiaoyang Ruan
Editorial Board Member *Communications Earth & Environment*

Dr Alice Drinkwater
Associate Editor *Communications Earth & Environment*

28th August 2025

Dear Drs Drinkwater and Ruan, dear Editors

We are excited to re-submit our carefully revised manuscript now entitled "**Climate-driven changes in long-distance grain trade not only alleviated famine in Italy but also brought the Black Death to medieval Europe**", which we hope is now suitable for publication as an original research article in your journal.

We are thankful to both referees for their positive evaluation of our work. We thoroughly considered all comments and suggestions and improved the manuscript accordingly.

We look forward to hearing back from you and seeing the manuscript published soon.

On behalf of the authors.
Yours sincerely

Ulf Büntgen

Reviewer #1
This is a fascinating and well-researched study that effectively bridges climatology, ecology, and social sciences to elucidate the complex interplay between volcanic-induced climate change, grain trade, and the spread of the Black Death in medieval Europe. The interdisciplinary approach, combining high-resolution climate proxies with historical documentary evidence, provides compelling support for the hypothesis that volcanically forced cooling and subsequent grain imports from the Black Sea region facilitated the introduction of Yersinia pestis to Mediterranean harbors. The study makes a significant contribution to our understanding of how environmental and societal factors can converge to drive large-scale pandemics.
Many thanks for this very positive and encouraging evaluation of our manuscript. We are delighted that our study is considered a significant contribution at the fascinating nexus between climate, environment and society.

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Temporal and Spatial Mapping of Plague Outbreaks: While the study highlights Venice as a key entry point for the plague, it would strengthen the argument to include data on the timing of outbreaks in other Italian and European ports (e.g., Genoa, Pisa, Marseille, etc.). If these ports also experienced outbreaks shortly after receiving grain shipments from the Black Sea, it would further corroborate the grain trade as a primary transmission pathway. Figure 3 could be enhanced by annotating the arrival dates of plague outbreaks in these ports alongside the grain trade routes.

We added a new Figure and caption: "Fig. 4. Onset of the Black Death in southern Europe. (A) The first reported plague outbreaks in 1347 CE in southern Europe (red stars), together with the assumed routes of Venetian and Genoese grain ships (black lines). (B) Subsequently reported plague outbreaks between January and May 1348 CE (orange stars), together with earlier outbreaks (red stars). (C) Plague outbreaks reported in June 1348 CE or with unspecified date in the same year (yellow stars), superimposed on earlier outbreaks (orange and red stars). (D) All known plague outbreaks in 1347 and 1348 CE (red, orange and yellow stars), together with major Italian cities and regions that were most likely not affected by the Black Death during this period (green stars). Supplementary Materials S4-5 and ref. 4 provide details on plague outbreaks, stars refer to cities while less specific locations are indicated by shadings of the same colour codes, and the map is an equal-area, pseudo-cylindrical Mollweide projection with greyscale referring to elevations above sea level.". We further added relevant information to the main text (see marked version of the revised manuscript).

Comparative Analysis: A brief comparison with other Mediterranean ports that did not engage in Black Sea grain imports (if any) could serve as a control, reinforcing the link between trade and plague introduction.

Again, we added a new Figure 4 plus caption and associated text in which we reinforce the link between grain trade and the introduction of the plague bacterium (see previous response and marked manuscript version).

Reviewer #2

Overall, I find the approach very valid, and the article is well written. It is interesting how the scientific data have been processed and combined with detailed historical research, resulting in a fascinating comparison. The work of collecting and processing the data is undoubtedly challenging, yet the authors have managed to convey the information clearly and comprehensively. I hope that this line of research can be pursued further in other studies, by exploring the years and centuries preceding the plague with the same approach, in order to obtain an even more complete view of the complex natural and historical dynamics that contributed to the pandemic, and in general, of the life in the medieval times. This work also provides a valuable picture of trade dynamics and of the possible causes that may have brought the Black Death to Italy, as well as of how various climatic components interact. The hypothesis developed is truly intriguing, although it remains—certainly not due to any shortcomings of the authors, but simply because of the currently available data—still open to question. For this reason, I have some concerns I would like the authors to consider. I suggest adopting a less categorical nuance and leaving some issues open, starting from the title.

Many thanks for this very positive and encouraging evaluation. We carefully revised the manuscript towards less definitive statements. We therefore changed the title to "Climate-

driven changes in long-distance grain trade not only alleviated famine in Italy but also brought the Black Death to medieval Europe". We also revised the abstract, significant statement and much of the main text (see marked version of the re-submitted manuscript).

Blue rings and volcanic activity

At higher elevations, where the growing season is shorter and lignification occurs later, early autumn cooling could interrupt cell wall lignification, leading to the formation of blue rings. In contrast, at lower elevations—where the growing season starts earlier and lignification is likely completed before autumn cooling—such structures may not form even under similar temperature drops. Blue rings are therefore more likely in subalpine environments due to the timing of wood maturation relative to seasonal cooling. Even small topographical differences, especially near the treeline, can significantly affect local climate conditions experienced by trees. Small changes in elevation can modulate the climatic response, and there is not always a direct correlation between blue ring formation and air temperature. Other variables, such as precipitation, should also be considered. While a correlation between blue rings and certain historical volcanic eruptions is mentioned, the Pyrenean sequence clearly shows that blue ring formation does not always coincide with major recorded volcanic events. I recommend interpreting the proposed blue ring data with caution or integrating them with studies from Italian regions (excluding the Alps), even though such studies may not exist for the period of interest. The issues related to blue ring formation—already noted in one of the cited studies—should be explicitly acknowledged in the text. Although there is little doubt about the occurrence of low temperatures in Italy during the years of the Black Death—supported by both historical sources and the presented climate models—it seems rather speculative to establish a direct correlation between these conditions and the blue rings found in the Pyrenees. Given the marked climatic variability in the Mediterranean region, the occurrence, formation, and dynamics of blue rings require further investigation before this proxy can be reliably used to reconstruct past Mediterranean climate or correlate it with volcanic activity.

We carefully revised the section associated with Blue Ring formation (as outlined in the marked version of the re-submitted manuscript), removed the BR image from Figure 1, and added a new supplementary Figure S1 that shows the entire MXD-based summer temperature reconstruction from the Pyrenees in tandem with the high-resolution Blue Ring thin section.

Comments on Supplementary Text S1-S2-S3-S4

I appreciate the extensive research and numerous sources cited regarding astronomical events and descriptions of anomalous climatic occurrences. My concern is not with the source selection itself, but with the interpretation of what these sources describe. From the extracted texts, the most credible phenomena appear to be planetary conjunctions. While the inclusion of sources from Korea, Japan, and China enriches the analysis, I find them not entirely appropriate for the specific aims of the article and somewhat redundant. I suggest clarifying in the main text (lines 117–126) that the data on lunar eclipses and other rare phenomena are not always fully reliable and may be indicative of other events. Amplified descriptions with supernatural elements are quite frequent in both medieval and non-medieval texts. Often, imaginative phenomena are described alongside more realistic ones, either to emphasize the gravity of the context or to exorcise fears. It is therefore necessary to distinguish between natural events that may have actually occurred, for example (not cited in the article), the

earthquake of 1348 and the severe storm/tsunami that destroyed Amalfi in 1343 and others that are clearly exaggerated or entirely fanciful, such as a rain of worms or enormous fires. In contrast, I find that the data presented in Supplementary Texts S2, S3 and S4 are particularly relevant and significantly enrich the understanding of the climatic and social situation, not only in Italy but also in comparison with other regions of the world.

We deeply value the acknowledgment of written sources as a crucial complement to paleoclimatological proxy data. We sought to explain better our source-critical approach in Supplementary Text S1 (Text 1), preceding the table. In addition, we emphasized that only a comprehensive assessment renders the existence of a factual background for the described phenomena plausible. The east Asian material was included because optical phenomena following a volcanic eruption must be assumed to have been visible globally, thereby further corroborating the presence of a volcanic dust veil. Through back-calculation, we evaluated the accuracy of reports on conjunctions as well as solar and lunar eclipses, thereby also testing the general reliability of the sources with respect to atmospheric phenomena. Following discussion, we restricted ourselves to phenomena that could plausibly indicate a volcanic eruption, deliberately excluding contemporary descriptions of earthquakes and other events that, while associated with plague in the perception of medieval observers, lack a demonstrable causal link.

Climate and Volcanoes

There is no doubt that these were years with lower temperatures, likely close to the beginning of the Little Ice Age, if not the very start of it. There is also no doubt that certain volcanic eruptions, even distant ones, can influence the climate and contribute to lowering temperatures. One or more small eruptions may not have affected the “normal” climate trend at all, whereas a sequence of eruptions occurring in a short time can lead to cooling that lasts for many years. I would not therefore exclude the possibility that the colder climate of those years could have been a consequence of closely spaced volcanic eruptions—such as Reykjanes (1226), Samalas (1257), and Quilotoa (1280)—which could have initiated the Little Ice Age, rather than being necessarily attributable to volcanic events around 1345.

Many thanks.

I would also consider that sulphur trapped in ice cores is not always an indication of a volcanic eruption, and that it is always better to combine such data with other indicators, such as tephra and cryptotephra, as well as isotopes. Furthermore, the event around 1345, based on the data considered here, is not among those with the highest VSSI values, and it does not seem that the eruption(s) led to a temperature drop comparable to other major events, especially in Europe. I would also consider it important to analyse other works that take into account isotopic signatures, which detect an event in 1343 but not of great magnitude. I therefore believe that the event was very limited, not uniform, and easily masked by the variability of the medieval climate.

Many thanks.

Figure 1: I recommend removing the blue ring data from the figure, as their correlation with temperature for the whole of Italy remains uncertain. Instead, emphasize:

-The cooling period associated with the Black Death.

-The timing of major volcanic eruptions and their climatic impacts (at least in the case of Samalas). The summer temperature reconstruction's limited temporal range restricts the possibility of correlating climate effects with earlier significant eruptions. Extending this dataset would be valuable for future work.
Done.

Line 30 cold and wet climatic conditions
Changed.

Line 131 could be indicative of consecutive years of cooling.
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Line 132 might have encompassed the entire west Mediterranean region
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Deleted.

Line 170-171 anomalous environmental and climatic factors impacted
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