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A proposal for isotherm world maps to forecast the seasonal evolution of the SARS-CoV-2 pandemic

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Abstract

This paper investigates whether the Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2) pandemic – also known as COronaVIrus Disease 19 (COVID-19) – could have been favored by specific weather conditions. It was found that the 2020 winter weather in the region of Wuhan (Hubei, Central China) – where the virus first broke out in December and spread widely from January to February 2020 – was strikingly similar to that of the Northern Italian provinces of Milan, Brescia and Bergamo, where the pandemic has been very severe from February to March. The similarity suggests that this pandemic worsens under weather temperatures between 4°C and 11°C. Based on this result, specific isotherm world maps were generated to locate, month by month, the world regions that share similar temperature ranges. From January to March, this isotherm zone extended mostly from Central China toward Iran, Turkey, West-Mediterranean Europe (Italy, Spain and France) up to the United State of America, coinciding with the geographic regions most affected by the pandemic from January to March. It is predicted that next spring, as the weather gets warm, the pandemic will likely worsen in northern regions (United Kingdom, Germany, East Europe, Russia and North America) while the situation will likely improve in the southern regions (Italy and Spain). However, in autumn, the pandemic could come back and affect the same regions again. The Tropical Zone and the entire Southern Hemisphere, but in restricted southern regions, could avoid a strong pandemic because of the sufficiently warm weather during the entire year. Google-Earth-Pro interactive-maps are provided as supplements.

Keywords: SARS-CoV-2; COVID-19; Pandemic geographical distribution; Epidemic forecasting; Weather conditions; Climatic zones.

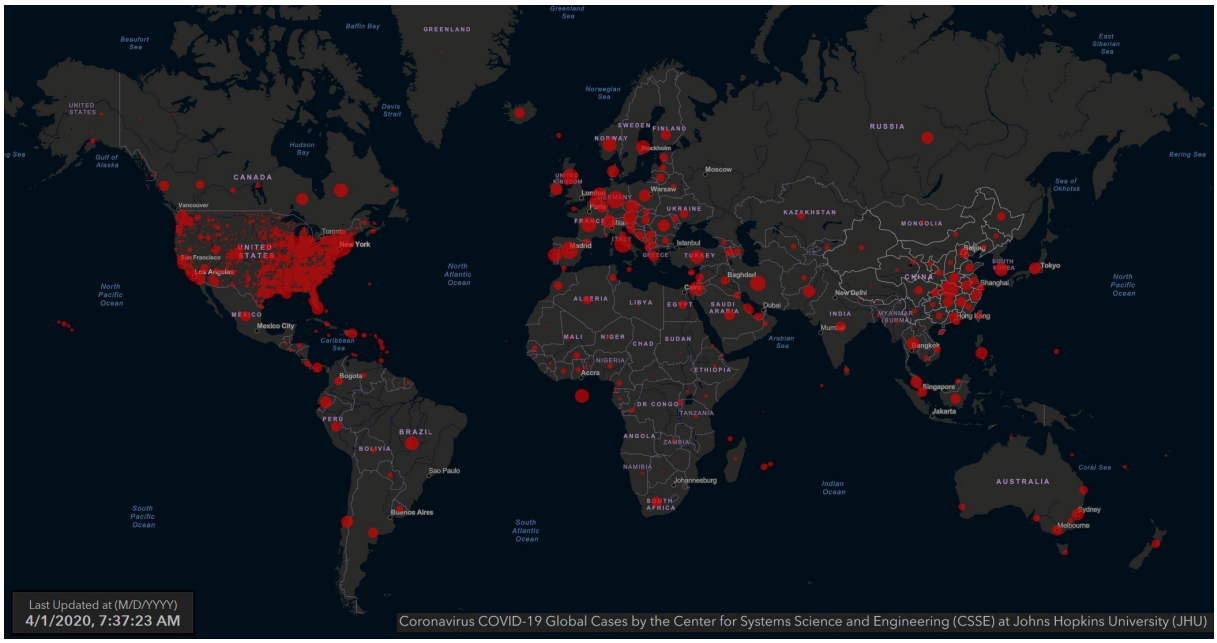

Figure 1: Geographical world distribution of COVID-19 pandemic.

1 Introduction

The Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2) pneumonia – also known as COronaVIrus Disease 19 (COVID-19) – allegedly broke out in a wet market of the city of Wuhan, the capital city of the Hubei Province, in Central China (30.60°N – 114.05°E). The first case of hospital admission was reported on December 12, 2019 [1]. Since January 2020 the pandemic rapidly spread throughout the whole province of Hubei, in other regions of China and, further, began to spread all over the world. The COVID-19 pandemic is being monitored by the World Health Organization (WHO).[1]

The high fatality rates of this pandemic require the development of epidemic control strategies such as lock-down of the infected region and others [2], which, however, in time can negatively affect the economy of a society. Thus, it is a priority to forecast how the COVID-19 pandemic could geographically propagate for optimizing these strategies.

Figures 1 and 2 show the geographic distribution and the country distribution of the current COVID-19 global situation prepared by the Center for System Science and Engineering at John Hopkins University (as of April 1, 2020).[2] Figure 3 shows global geographical distributions of the three indices referring to the coronavirus pandemic by country and territory: [A] confirmed cases per capita; [B] total confirmed cases by country and territory; [C] total confirmed deaths per capita by country and territory.[3]

The situation is severe and is worsening. As of the date – 04/01/2020 – there are more than 860,000

[1]WHO: Coronavirus disease (COVID-19) Pandemic. Web page: https://www.who.int/emergencies/diseases/novel-coronavirus-2019, accessed on 04/01/2020.

[2]Source: https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6, accessed on 04/01/2020.

[3]Source: https://en.wikipedia.org/wiki/2019–20_coronavirus_pandemic_by_country_and_territory, accessed on 04/01/2020.

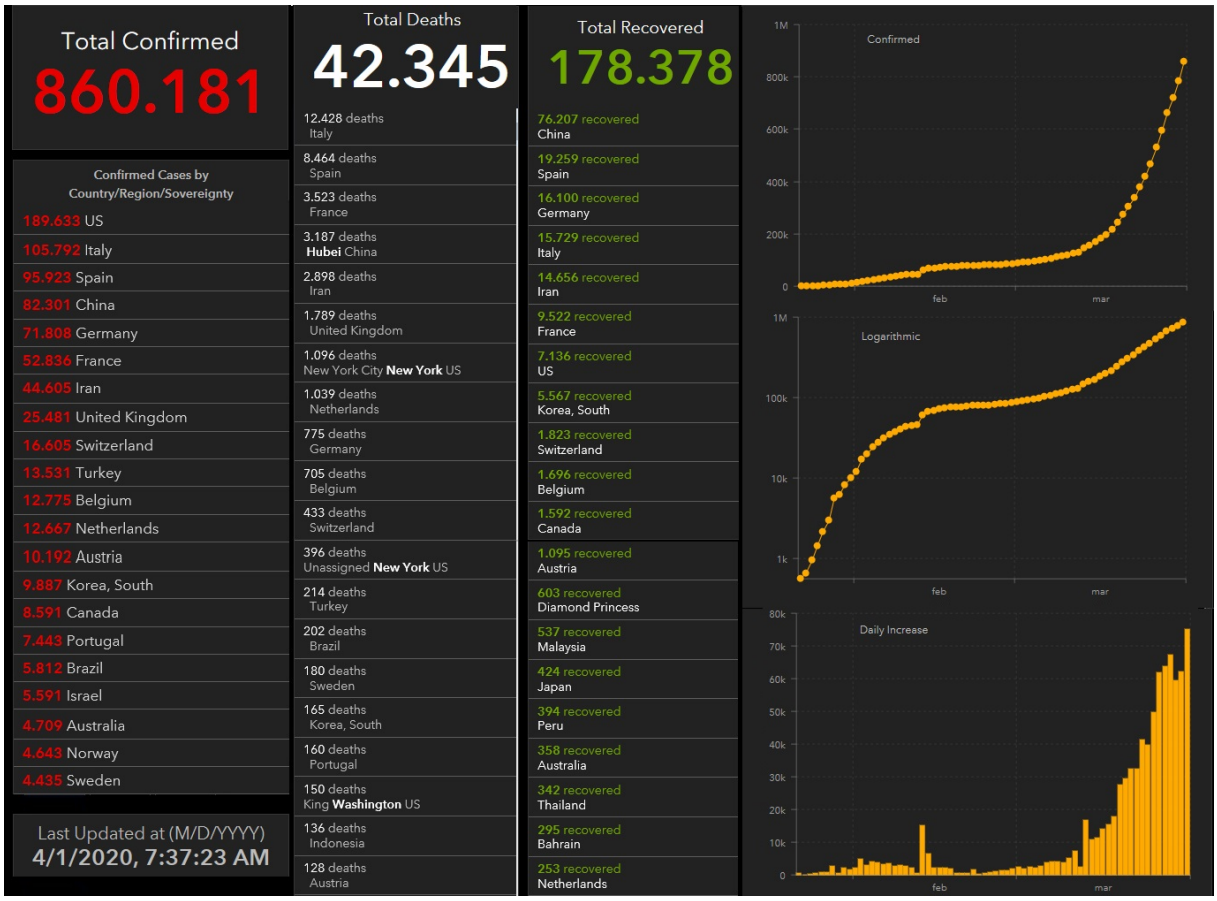

Figure 2: Statistics of the countries most affected by the COVID-19 pandemic.

people confirmed infected worldwide with 42,345 deaths versus only 178,378 people recovered. China, where the infection first broke out in December 2019, officially had about 82,301 cases infected with 3310 total deaths, of which 3187 came from the province of Hubei alone. The Chinese authorities have declared that there have been very few cases of new infections since the first weeks of March and claim that since then in China the pandemic is under control (cf. Report of the WHO-China Joint Mission on Coronavirus Disease 2019.[4]

However, at the beginning of February, the pandemic began to show up outside of China spreading all over the world. South Korea was the first country severely affected by the pandemic (9887 cases confirmed and 165 deaths), where since late March the pandemic appears mostly under control. Later, many other countries were affected such as Iran, Turkey, several European countries (mostly Italy, Spain, France, Germany and the United Kingdom). Since the 15th of March the COVID-19 pandemic has been rapidly spreading in the United States of America, where, as of April 1, there have been 189,633 cases with 4,081 deaths. In Europe, the situation is monitored also by the European Centre for Disease Prevention and Control.[5]

[4]Source: https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf, accessed on 04/01/2020.

[5]Web site: https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases, accessed on 04/01/2020.

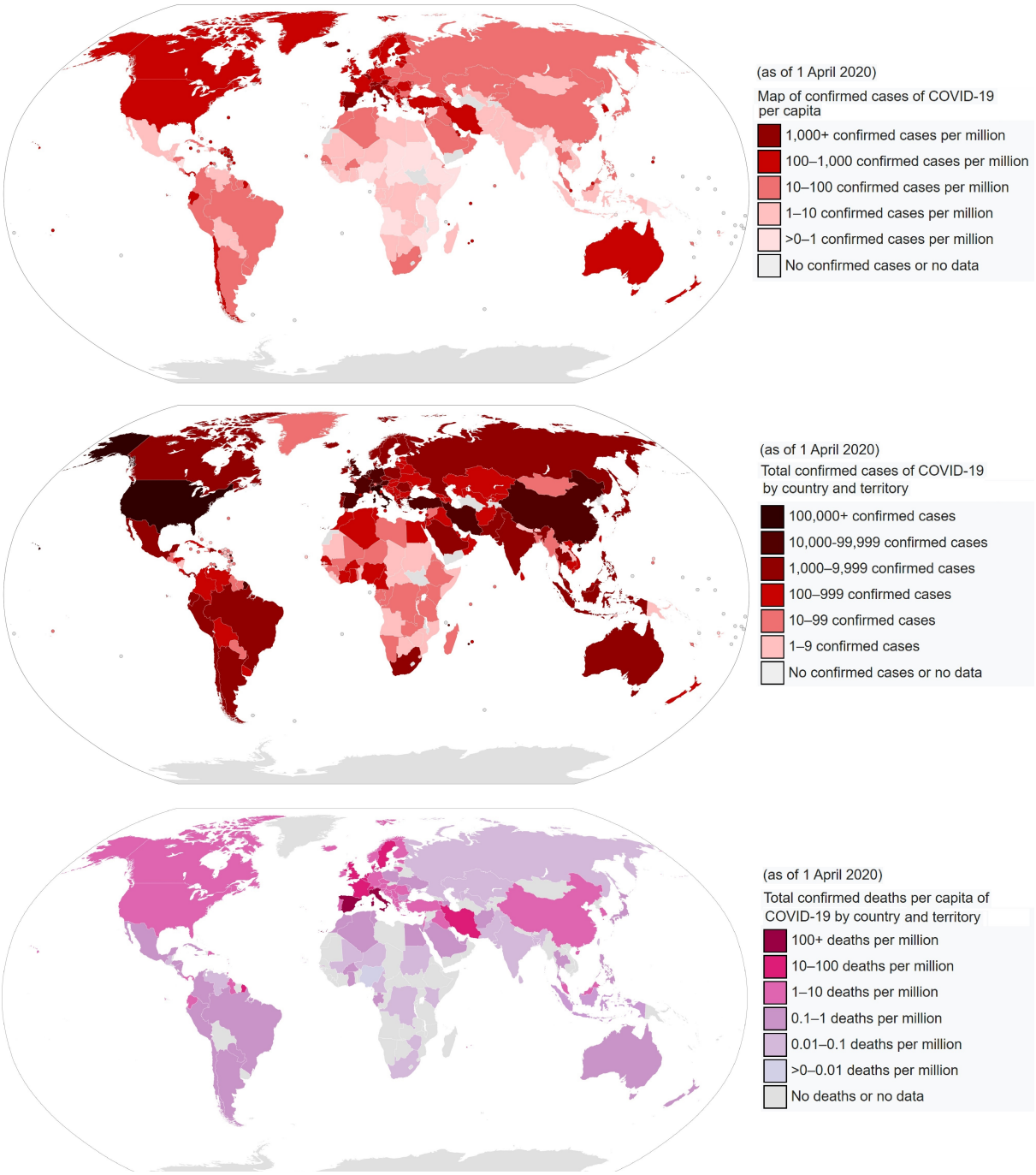

Figure 3: COVID-19 pandemic by country and territory: [A] confirmed cases per capita; [B] total confirmed cases by country and territory; [C] total confirmed deaths per capita by country and territory.

Until now, Italy is the most severely affected country by the CONVID-19 induced pneumonia.[6] The first three cases were identified on February 20 and, on April 1 there have been 105,792 confirmed infected people with about 12,428 deaths and only 15,729 recoveries. The most affected Italian regions have been the northern ones, those located in the Po Valley: Lombardia, 43,208 cases and 7199 deaths; Emilia Romagna, 14,074 cases and 1,443 deaths; Veneto, 8,358 cases and 392 deaths; Piemonte, 8,206

[6]The situation in Italy: http://www.salute.gov.it/portale/nuovocoronavirus/homeNuovoCoronavirus.jsp?lingua=english, accessed on 04/01/2020.

Regions	Deaths	Cases
Lombardia	7.199	43.208
Emilia Romagna	1.644	14.074
Veneto	477	9.155
Piemonte	854	9.301
Toscana	244	4.608
Marche	452	3.825
Liguria	428	3.416
Lazio	162	3.095
Campania	133	2.092
Trento	164	1.746
Puglia	110	1.803
Friuli V.G.	113	1.593
Sicilia	81	1.647
Abruzzo	115	1.401
Bolzano	76	1.371
Umbria	37	1.078
Sardegna	31	722
Calabria	36	659
Valle d'Aosta	56	628
Basilicata	7	226
Molise	9	144
TOTAL	12.428	105.792

Figure 4: Geographical distribution of COVID-19 pandemic in Italy.

cases with 684 deaths.[7] In Lombardia, the most affected provinces were Milan, Bergamo and Brescia with more than 8000 cases each.[8] See Figure 4.[9]

Although the propagation of a pandemic and its health severity may have several causes, Figure 3 shows that the spread of the recent pandemic could also have some geographical preferences. It appears to have spread quite fast in moderately cold places where the daily average temperature may have been roughly between 0°C and 15°C. On the other hand, up to April 1, countries with warm climates (e.g., India, Central America, South America, Southern Asia, Africa and Oceania), as well as very cold countries (e.g. Canada, Russia, North-Est Europe) appear to have been less affected. It is also noticeable that even when the number of cases is relatively large relative to the population, the number of deaths is usually lower in warm countries, as shown in Figure 3C. Thus, it is reasonable to ask whether geographical regions within a specific climatic/weather zone could be more vulnerable to this epidemic. Indeed, several studies have established that influenza virus transmission and virulence depend also on meteorological conditions such as temperature, relative humidity and wind speed, and also that, in the Northern Hemisphere, influenza is more widely spread during the winter seasons [3, 4, 5].

The influenza rate is seasonal [6] and, usually, the infection nearly disappears when the weather gets warm. Similar behavior has been observed for other SARS coronaviruses [7, 8, 9, 10] that belong to the

[7]Source: http://www.salute.gov.it/imgs/C_17_notizie_4370_0_file.pdf, accessed on 04/01/2020.
[8]Source: http://www.salute.gov.it/imgs/C_17_notizie_4370_1_file.pdf, accessed on 04/01/2020.
[9]COVID-19 Italy situation: http://opendatadpc.maps.arcgis.com/apps/opsdashboard/index.html, accessed on 04/01/2020.

same Coronaviridae family of SARS-CoV-2 [11]. The finding has always been that these viruses spread mostly within given ranges of meteorological conditions. For example, Yuan et al. [12] determined that the SARS virus identified in November 2002 in Guangdong Province, China, present a peak spread at a mean temperature of 16.9°C (95% CI, 10.7 °C to 23.1°C), with a mean relative humidity of 52.2% (95% CI, 33.0% to 71.4%) and wind speed of 2.8 m/s (95% CI, 2.0 to 3.6 m/s). Thus, also for the COVID-19 it has been proposed that a dry, cool environment could be the most favorable state for the spreading of the virus [13].

The seasonal, climate and weather-condition influence on the spread or slowdown of a pandemic induced by aerially transmitted viruses can have several biological, physical, solar-light mechanisms that involve both the virus survival and transmission in the air and the susceptibility of the host immune system [14]. Some of these results came from laboratory-experimental studies on how viral etiology and host susceptibility vary under different environmental conditions, while other findings are from epidemiological studies relating large-scale patterns to various climate signals and atmospheric conditions.

In this paper, I take the latter approach. I compare the weather conditions from January to March 2020 between the region of Wuhan and the Italian provinces of Milan, Brescia and Bergamo. The striking similarity between the weather conditions of the two regions leads us to reason that there is an optimal weather condition that could favor the spreading of the COVID-19 epidemic. Based on this reasoning, I propose a set of optimized monthly isotherm world maps from January to December 2020 to forecast the course of the pandemic timeline evolution by identifying the geographical regions that are likely to experience similar weather conditions as in Wuhan and Milan during the high peak of the COVID-19

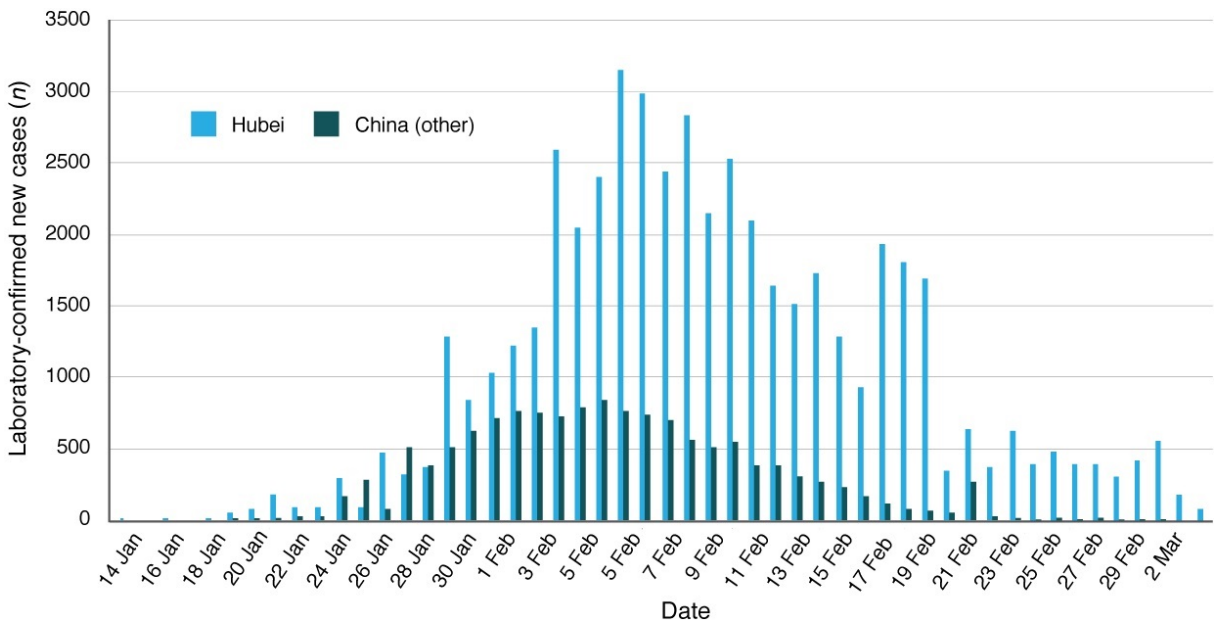

Figure 5: COVID-19 epidemic curve in Hubei and the rest of China. Data sourced from media reports, ProMED-Mail and WHO situation reports. [Adapted from 15]

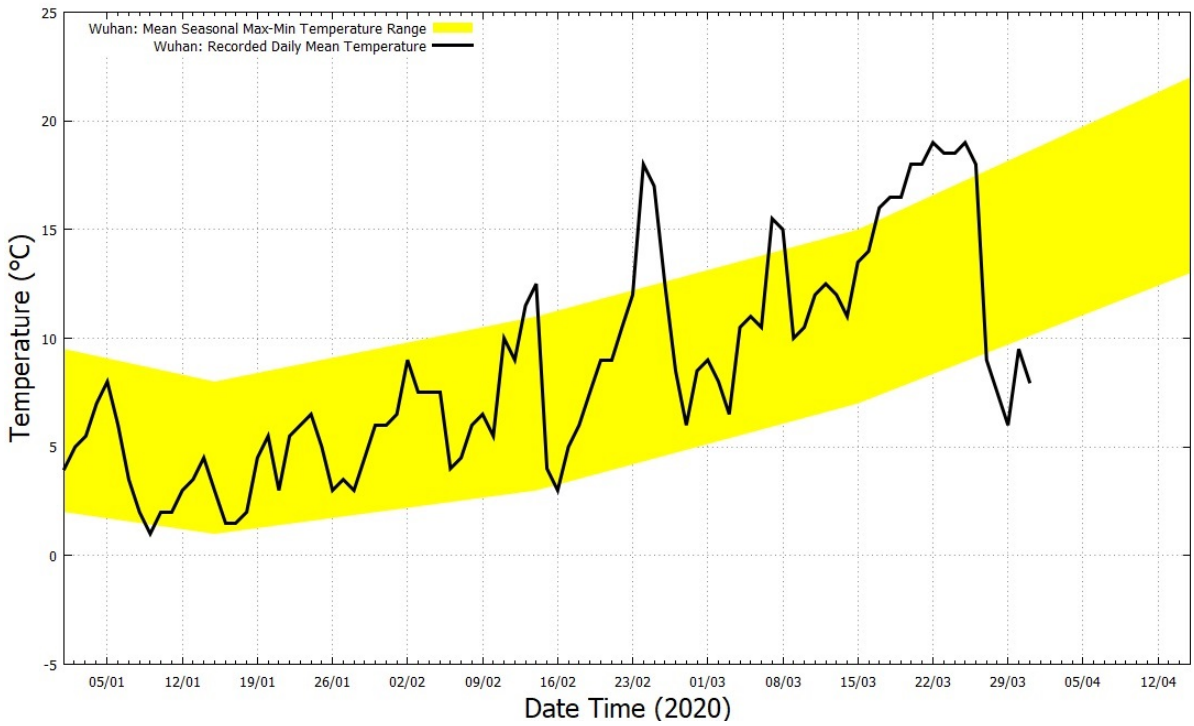

Figure 6: The daily mean temperature record of Wuhan (black) and its climatic temperature averages (yellow).

infection.

2 Temperature comparison: Wuhan versus Milan, Brescia and Bergamo

The COVID-19 epidemic curve in Hubei and the rest of China until the 3rd of March is shown in Figure 5 and its patterns are extensively commented in Macintyre [15]. It is observed that the epidemic peaked in the first week of February and the number of new infections rapidly decreased in March. Figure 6 shows the recorded mean daily temperature of Wuhan from 01/01/20020 to 03/31/2020 (black curve).[10] The figure also shows the mean seasonal Max-Min temperature range curve from Wuhan Airport, which is 23 kilometers from Wuhan (yellow area).[11] The temperature data show that in Wuhan the daily temperature roughly ranges between 1°C and 8°C in January, between 3°C and 11°C in February and 7°C and 15°C in March. During the period most affected by the CONVID-19 infection (January and February), the temperature in the region roughly varied between 0°C and 12°C. The seasonal average relative humidity in Wuhan was on average around 70% and the average wind speed was around 10 km/h, which are the typical humidity and high-pressure conditions that characterize Continental China during winter when only the weak monsoon winds blow.

[10]Source: https://www.accuweather.com/en/cn/wuhan/103847/current-weather/103847, accessed on 04/01/2020.
[11]Source: https://www.timeanddate.com/weather/china/wuhan/climate, accessed on 04/01/2020.

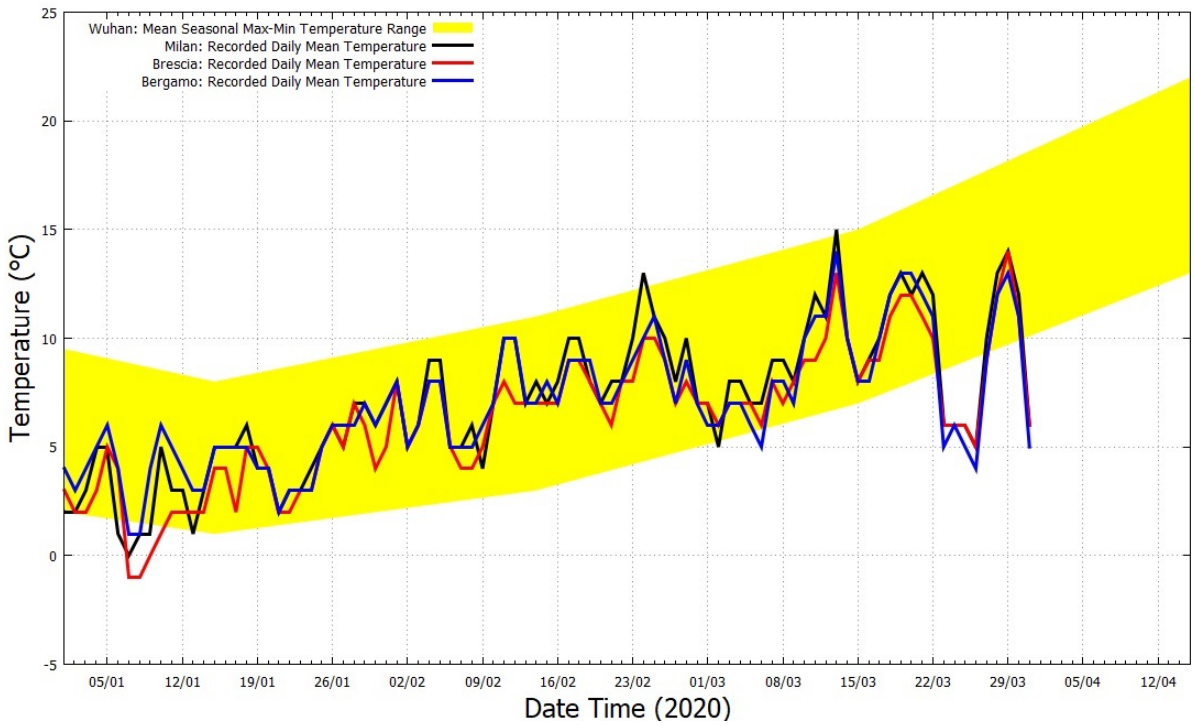

Figure 7: The daily mean temperature record of Milan, Bergamo and Brescia (black, blue and red) versus Wuhan's climatic temperature averages (yellow).

Figure 7 compares the seasonal mean temperature of Wuhan (yellow area) with the recorded mean daily temperature records of the Italian cities of Milan,[12] Bergamo[13] and Brescia[14] during the same months. It shows an excellent correlation between the temperature records. This temperature correlation occurred mostly for January and February when Wuhan experienced a mean temperature equal to 4.1 ± 3 °C and 8.4 ± 3.6 °C, respectively. The Italian cities experienced a mean temperature equal to 3.8 ± 2.0 °C and 8.1 ± 2.1 °C, respectively, in Milan; 4.3 ± 1.6 °C and 7.7 ± 1.7 °C, respectively, in Bergamo; and 3.2 ± 2.0 °C and 7.2 ± 1.6 °C, respectively, in Brescia.

However, Figure 8 also highlights that the three Italian cities experienced a relatively cold March with a mean temperature equal to 9.5 ± 2.8 °C in Milan, 8.8 ± 2.9 °C in Bergamo and 8.7 ± 2.4 °C in Brescia. In March, the daily mean temperature spanned between 4°C and 15°C. This temperature range fits well with the one measured in Wuhan in February where the mean temperature was equal to 8.4 ± 3.6 °C and the daily mean temperature spanned between 3°C and 18°C. In March, Wuhan was significantly warmer: its mean temperature was equal to 12.9 ± 4.1 °C and the daily mean temperature spanned between 6°C and 19°C.

The above results are summarized in Table 1 together with other meteorological indices such as monthly means of the relative humidity, wind speed and atmospheric pressure,[15] which are also found

[12]Source: https://www.ilmeteo.it/portale/archivio-meteo/Milano, accessed on 04/01/2020.
[13]Source: https://www.ilmeteo.it/portale/archivio-meteo/Bergamo, accessed on 04/01/2020.
[14]Source: https://www.ilmeteo.it/portale/archivio-meteo/Brescia, accessed on 04/01/2020.
[15]Source for Wuhan: https://www.worldweatheronline.com/wuhan-weather-averages/hubei/cn.aspx, accessed on 04/01/2020.

	Mean Monthly Temp. (°C)			Min Daily Temp. (°C)			Max Daily Temp. (°C)		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Wuhan	4.1 ± 3	8.4 ± 3.6	12.9 ± 4.1	1	3	6	8	18	19
Milan	3.8 ± 2.0	8.1 ± 2.1	9.5 ± 2.8	0	4	5	7	13	15
Bergamo	4.3 ± 1.6	7.7 ± 1.7	8.8 ± 2.9	1	5	4	7	11	14
Brescia	3.2 ± 2.0	7.2 ± 1.6	8.7 ± 2.4	-1	4	5	7	10	14

	Relative Humidity (%)			Wind Speed (km/h)			Pressure (mbar)		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Wuhan	74	66	66	10	10	11	1025	1024	1018
Milan	85 ± 8	67 ± 19	68 ± 11	5 ± 1	8 ± 4	8 ± 3	1026 ± 7	1020 ± 8	1017 ± 8
Bergamo	76 ± 10	61 ± 20	68 ± 11	6 ± 1	9 ± 3	8 ± 2	1026 ± 7	1019 ± 8	1016 ± 8
Brescia	85 ± 7	72 ± 16	77 ± 9	6 ± 2	8 ± 4	10 ± 5	1025 ± 7	1018 ± 8	1016 ± 8

Table 1: Monthly mean weather indexes for Wuhan, Milan, Bergamo and Brescia in 2020.

to be comparable in the two locations. It is to be noted that the observed low relative humidity (from 61% to 85%), low-speed wind (from 6 km/h to 11 km/h), high atmospheric pressure (from 1016 mbar to 1026 mbar) induce atmospheric stability facilitating the spreading of viruses.

In January and February, the two locations shared strikingly similar weather conditions but in March Wuhan got warmer fast while the Italian provinces experienced a cold weather similar to that of Wuhan in February. These facts could explain why the COVID-19 pandemic spread equally fast in both regions, but the Italian regions were more severely affected. As Figure 7 shows, in Italy the cold weather lasted longer with unusual cold weeks at the beginning and the end of March, favoring the pandemic spread. These considerations suggest that weather temperatures roughly ranging between 4°C and 11°C could be those that mostly favor the propagation of COVID-19 and/or aggravate the susceptibility of people to its secondary pneumonia.

3 Monthly isotherm world map analysis

Figures 6 and 7 suggest that the geographical regions most vulnerable to the COVID-19 epidemic could be those characterized by a mean temperature roughly between 0.5°C and 14°C. However, because of the seasonal cycle, the geographical regions most exposed to the infection continuously change in time. To identify them I propose in Figures 8, 9, 10 and 11 isotherm world maps for each month of the year from January to December. The temperature data used are from the Climatic Research Unit (CRU) Time-Series (TS) version 4.03 of high-resolution 0.5°x0.5° gridded data of month-by-month variation in land temperature, which are available from January 1901 to December 2018 [16]. Because of the changing climate, the depicted diagrams are based on monthly averages from 2000 to 2018.

To better highlight the geographical zone of interest, the chosen colors cover the following bands: light-green (0.5°C – 4.0°C); light-gray (4.0°C – 11°C), the likely most affected zone; and light-yellow (11°C – 14°C). The colder and warmer zones are colored differently, as indicated in the legend. The

figures also show a small x over China, which indicates the approximate position of Wuhan. Data and graphical tools to reproduce the graphs are available also on KNMI Climate Explorer.[16]

For the winter months of January, February and March, the isotherm maps depicted in Figure 8 show a geographical correlation with the COVID-19 pandemic patterns by country and territory shown in Figures 1 and 3. In fact, the light-gray area is the most affected, while the colored areas, both colder or warmer, are those that have currently experienced a less severe pandemic.

- January – Wuhan gradually turns from the light-green zone to the light-gray zone as this region gets warmer.
- February – when the pandemic affected the region most severely, Wuhan is found in the middle of the light-gray zone. The light-gray zone covers the region spanning from Iran to Italy, Spain and partially covers Southern-East France and North Algeria. In these countries, the epidemic has been observed to spread fast.
- March – Wuhan gets warmer fast as it enters the light-yellow zone and its infection rate drops. In the meantime, the light-gray zone moves slightly toward North-East involving other European countries such as Germany and the United Kingdom. The northern region of Italy where Milan, Brescia and Bergamo are located – just south of the Alps that are recognized in the figure by the dark green arc above Italy – is in the middle of the light-gray zone as Wuhan was in February. The light-gray zone also covers most of the United State of America. Indeed, in March 2020, all countries mentioned above have experienced a significant acceleration of the pandemic.
- April – the light-gray zone moves toward north-est Europe and Russia and, in North America toward Canada. In the United States, the east region gets warm fast and enters the light- and dark-yellow zone, while most of the west side remains in the light-gray zone. In the meantime, Chile and Southern Argentina enter the light-gray zone.
- May – the light-gray zone moves toward latitudes larger than 50°N mostly in the Scandinavian countries, Russia and Canada, as well Argentina, Chile and New Zealand.
- June – the only light-gray regions are those above 60°N latitude, the Tibet, part of Central Argentina and minor regions of Southern Australia and South Africa.
- July – the patterns are similar to those of June, although the Northern Hemisphere continues to get warm.

From August to December (Figures 10 and 11), the seasonal movements of the temperature patterns revert: August is similar to June; September is similar to May; October is similar to April; November is similar to March, and; December is similar to February.

[16]Source: https://climexp.knmi.nl/start.cgi, accessed on 04/01/2020.

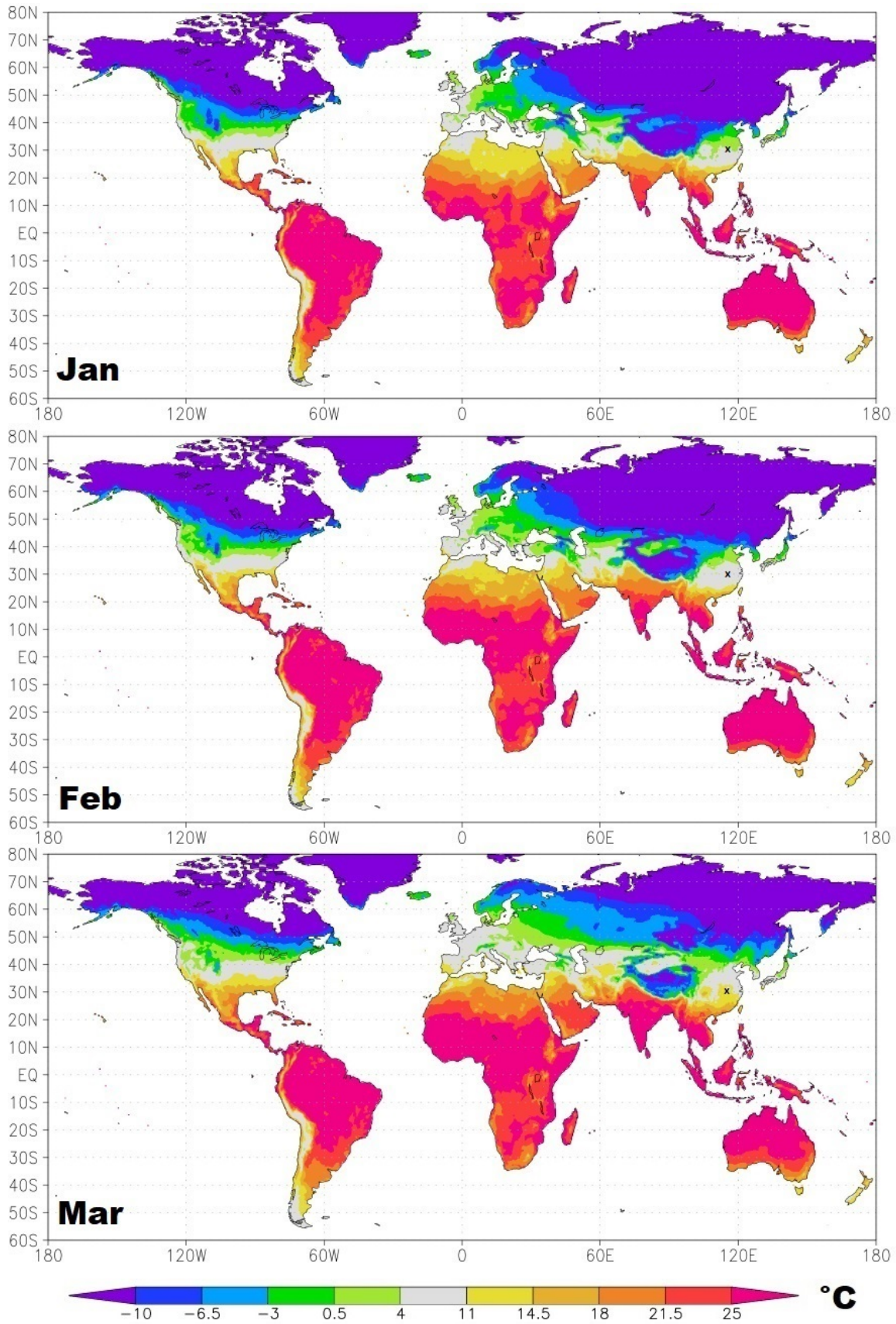

Figure 8: Winter isotherm world maps from January to March. The small x over China indicates the position of Wuhan. The light-gray zone represents the modeled most exposed regions to the COVID-19 pandemic.

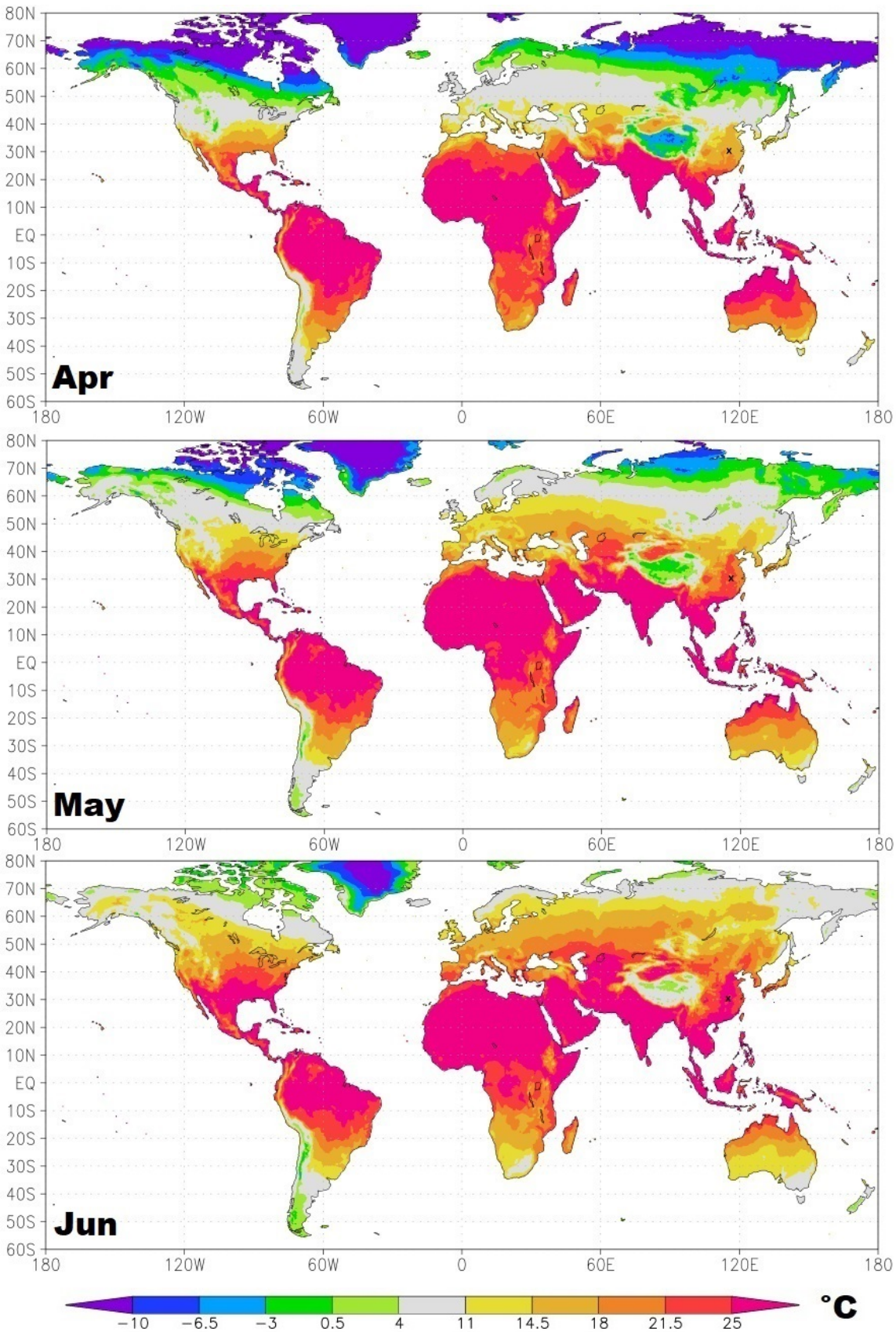

Figure 9: Spring isotherm world maps from April to June. The small x over China indicates the position of Wuhan. The light-gray zone represents the modeled most exposed regions to the COVID-19 pandemic.

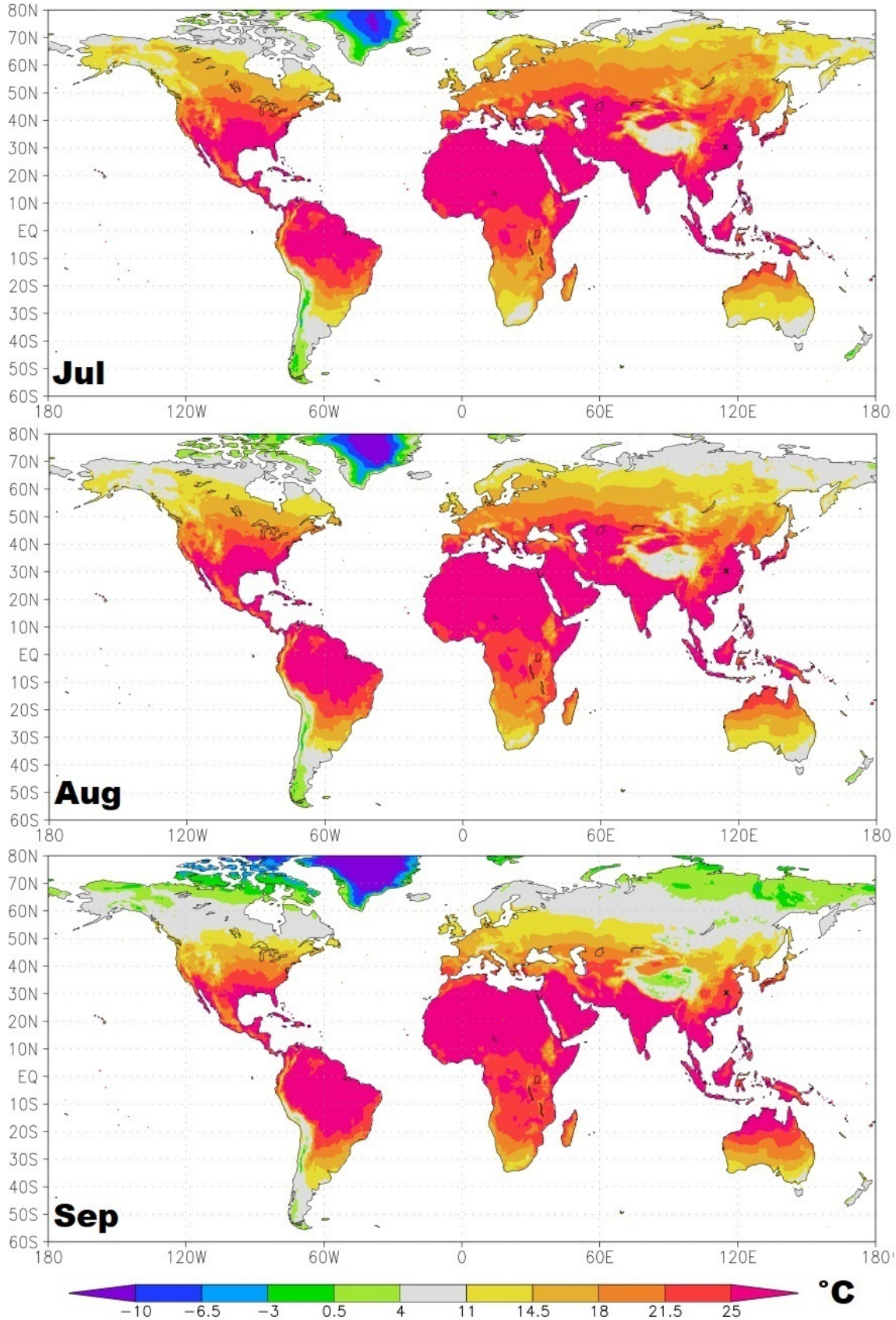

Figure 10: Summer isotherm world maps from July to September. The small x over China indicates the position of Wuhan. The light-gray zone represents the modeled most exposed regions to the COVID-19 pandemic.

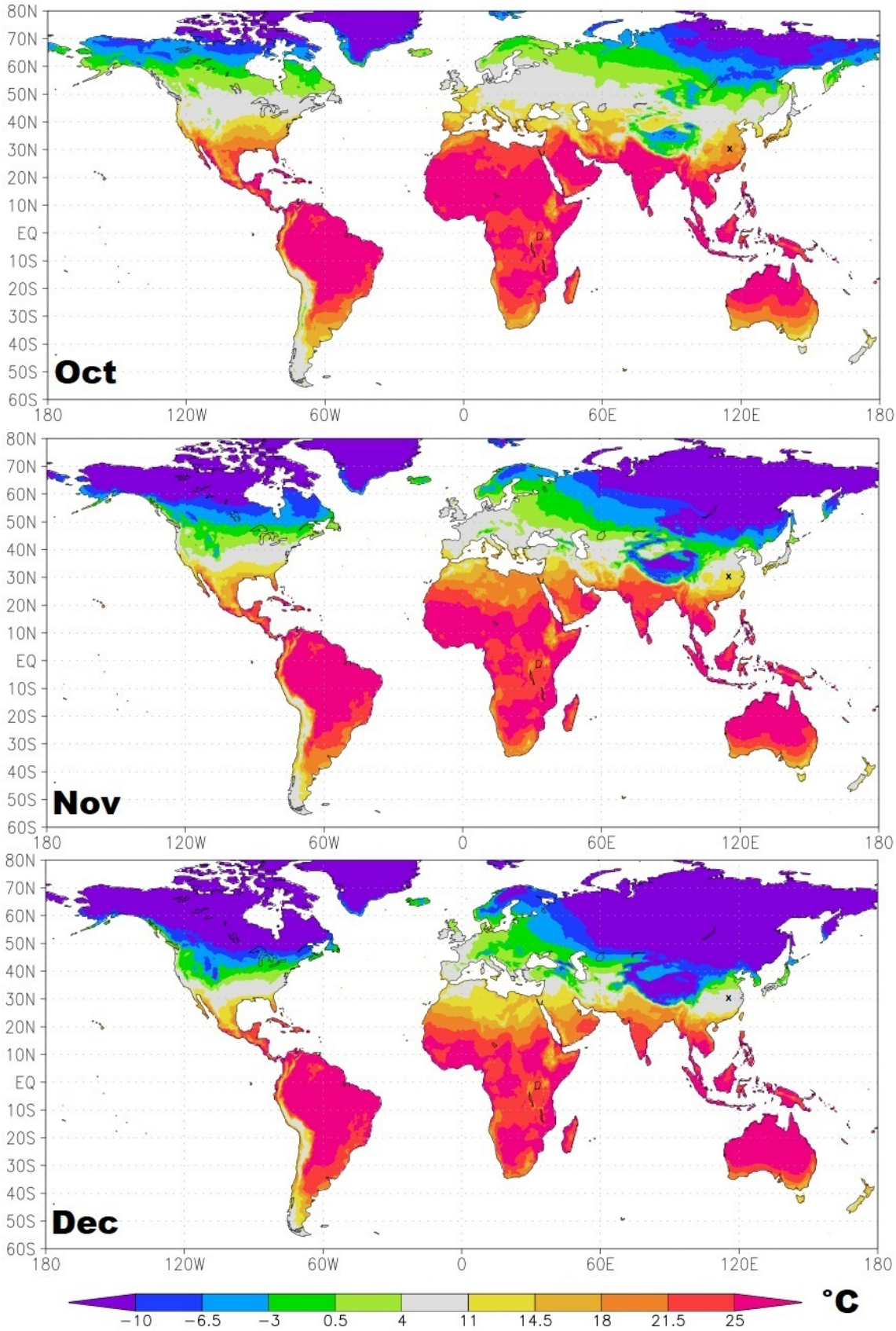

Figure 11: Autumn isotherm world maps from October to December. The small x over China indicates the position of Wuhan. The light-gray zone represents the modeled most exposed regions to the COVID-19 pandemic.

4 Discussion and Conclusion

Respiratory virus infection rate is usually seasonal [7, 8, 9, 10]. This applies also to the coronaviridae family of COVID-19 [11]. In general, there are likely several biological, physical and sunlight mechanisms that can seasonally influence the virus's survival and transmission in the air, as well as the susceptibility of the host immune system [14]. Usually, the weather conditions that facilitate this type of disease include cold and dry weather, high pressure, low-speed wind and modest rain, as it happened from January to March 2020 both in Wuhan and in Northern Italy.

The primary transmission route from person to person is through contact with respiratory droplets from the infected persons, generated when, for example, they blow their nose, cough or sneeze. Therefore, when relative humidity is low, as it happens in the winter in these regions, potential virus-carrying water-based droplets remain floating longer in the air because they shrink to smaller sizes, whereas high humidity or rain would facilitate their removal from the air. In the same way, high atmospheric pressure reduces the wind speed, and virus-carrying droplet density could increase in the urban area. In the Northern Hemisphere, winter also has fewer hours of sunlight and UV exposure that can have a sterilizing effect [17]. Besides, cold weather usually increases the susceptibility of people to virus attacks.

Atmospheric stability related to high atmospheric pressure and low-speed winds also causes a higher concentration of air pollutants [18] that could carry viruses. Air pollution increases the risk of respiratory diseases by reducing lung function making people living in particularly polluted areas more susceptible to asthma, respiratory infections, lung cancer and other diseases [19]. However, air quality real-time world-maps provided, for example, by Berkeley Earth[17] suggest that the air in regions such as China, India and Southern-East Asia is significantly more polluted than in the European and Northern American countries. Thus, the relatively low COVID-19 diffusion and mortality rates observed in the warm Asian countries relative to the high mortality levels of the colder Western European and American countries (see Figure 3) indicate that weather, not air pollution is the main cause for the diffusion of the COVID-19 pandemic.

Based on such findings, this work explored the possible link between COVID-19 pandemic and weather conditions. I showed that the region of Wuhan in the Hubei Province, in Central China, and the Italy provinces of Milan, Brescia and Bergamo – which to date have been the most affected by the COVID-19 pandemic – presented a striking similarity in weather conditions between January and March. In particular, the weather condition in Wuhan in late January and February – when the COVID-19 infection affected that region most severely – was nearly identical to the weather conditions between February and March experienced in the Italian northern provinces. This finding suggests that weather temperatures between 4°C and 11°C could be those that mostly favor the spread of COVID-19

[17] Web page: http://berkeleyearth.org/air-quality-real-time-map/, accessed on 04/01/2020.

and/or aggravate the susceptibility of the population to its secondary pneumonia.

I used this result to create a specific isotherm world map for each month from January to December to highlight the timing and the position of the world regions that could be most affected by the pandemic in the upcoming months. To date – 04/01/2020 – the model appears to have well described the pandemic evolution as, for example, it has well predicted the pandemic strong development from February to the end of March in Iran, Italy, Spain, France, Germany and United Kingdom, and United States of America, in order of time. Thus, it is possible that in absence of adequate prevention policies, as the weather gets warm, the pandemic is likely to move following the seasonal temperature cycle and could migrate toward northern regions of the Northern Hemisphere while weakening in the southern ones such as China and Italy. The Southern Hemisphere appears to be more protected because most of its land, except a few regions, is always sufficiently warm throughout the year.

Furthermore, the weather model suggests that in the Northern Hemisphere there may be a possible second wave of infections in the autumn following the return of the cold season and, in general, the pandemic could return in the middle latitude regions (roughly 30°N-60°N and 30°S-60°S) with a 6-month cycle and in the other regions with an annual cycle. Although the transmission of COVID-19 should go down as weather temperature goes up, the virus may not disappear completely. The infection rate could simply slow down, as suggested by the evidence that people get infected also in warm weather regions, although in these places the percentage of deaths per capita appears to be lower than in the cold weather regions (Figure 3). Thus, although the optimized isotherm maps proposed in the present work could be useful to optimize the timing of the required COVID-19 epidemic control policies that each country needs to implement, people and governments should be warned against lowering their guard.

Supplement

The online Supplement provides the same twelve isotherm maps shown in Figures 8, 9, 10 and 11 for each month of the year from January to December as Keyhole Markup language Zipped (kmz) files, that is, as Climate Explorer Google-Earth-Pro interactive and zoomable maps. Figure 12 shows an example of the produced maps. Google Earth Pro (used version: 7.3)[18] or equivalent Earth Viewer software is required to visualize the files.

Download the Sepplementary at the web page: https://www.preprints.org/manuscript/202004.0063/v1

Funding: None.

Conflicts of interest: None declared.

Availability of data and material: All data are freely available online.

Code availability: Freely available online.

[18]Web site: https://www.google.com/earth/, accessed on 04/01/2020.

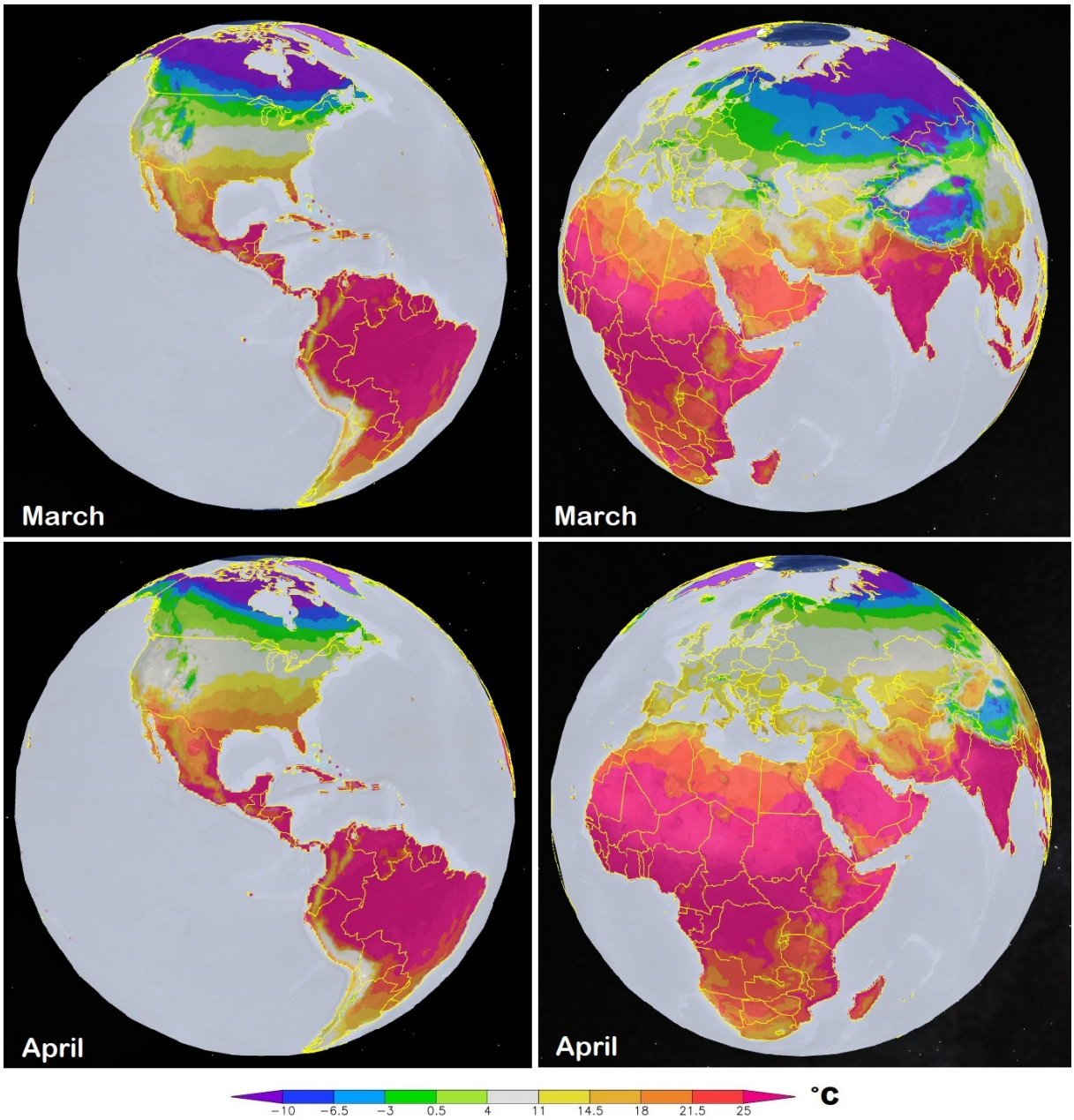

Figure 12: Examples of isotherm Google-Earth-Pro interactive-maps provided as online Supplement files.

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