Temperature and latitude analysis to predict potential spread and seasonality for COVID-19

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Abstract
A significant number of infectious diseases display seasonal patterns in their incidence, including human coronaviruses. We hypothesize that SARS-CoV-2 does as well. To date, Coronavirus Disease 2019 (COVID-19), caused by SARS-CoV-2, has established significant community spread in cities and regions only along a narrow east west distribution roughly along the 30-50 N" corridor at consistently similar weather patterns (5-11^{O}C and low specific and absolute humidity). There has been a lack of significant community establishment in expected locations that are based only on population proximity and extensive population interaction through travel. We have proposed a simplified model that shows a zone at increased risk for COVID-19 spread. Using weather modeling, it may be possible to predict the regions most likely to be at higher risk of significant community spread of COVID-19 in the upcoming weeks, allowing for concentration of public health efforts on surveillance and containment.

Background:

Many infectious diseases show a seasonal pattern in their incidence. An onerous burden for health care systems around the globe, influenza is the characteristic example.[1] The influenza virus shows significant seasonal fluctuation in temperate regions of the world but nevertheless displays less seasonality in tropical areas.[2-4] Despite the multitude of possible mechanisms proposed to explain this variation, our current understanding of this phenomenon is still superficial.[5]

Coronavirus Disease 2019 (COVID-19), caused by SARS-CoV-2, initially came to attention in a series of patients with pneumonia of unknown etiology in the Hubei province of China, and subsequently spread to many other regions in the world through global travel.[6] Because of geographical proximity and significant travel connections, epidemiological modeling of the epicenter predicted that regions in Southeast Asia, and specifically Bangkok would follow Wuhan, and China in the epidemic.[7] More recently, the World Health Organization has declared this as a pandemic. (WHO, 2020) For many the biggest concern is not how large the problem but what will happen in the coming months and which areas and populations are most at risk.

A number of studies, both laboratory,[8] epidemiological studies,[9] and mathematical modelling,[10] point to role of ambient temperature on the survival and transmission of viruses. The tremendous level of research supporting both ambient temperature and humidity in its role in transmission and infection motivated this study to examine the influence of environmental factors on COVID-19. We sought to determine whether climate could be a factor in the spread of this disease.

Methods:

2-meter (2m) temperatures, relative humidity (RH), specific humidity (Q), and absolute humidity (AH) were based on data from the ECMWF ERA-5 reanalysis. Climatologic (1979-2019) and persistence forecasting (2019 data) was used to analyze latitude and temperature trends globally and for affected areas using ERA-3 (Interim) and ERA-5. ERA-3 reanalysis data obtained from Climate Reanalyzer (https://ClimateReanalyzer.org), Climate Change Institute, University of Maine, USA. ERA-Interim reanalysis data (https://doi.org/10.1002/qj.828) cover the earth with a resolution of 80 km x 80 km. The analysis of 2-meter temperature is performed in separate analysis following the upper air 4D-Var analysis. ERA-5 reanalysis data (C3S, 2017) covers the earth with a resolution of 30 km x 30 km. Preliminary daily updates are available 5 days of real time though quality-assured monthly updates are published within 3 months of real time. 2m temperature was calculated by interpolating between the lowest model level and the Earth's surface, taking into account the atmospheric conditions.

2-meter Temperature (2m) is Temperature at the height of 2 meters, 1000 hPa Temperature is the temperature at the pressure level of 1000 hPA and is calculated by interpolation from the numerical model levels. Relative humidity (RH) is the percentage of the maximum amount of water vapor that the atmosphere can hold at a given temperature (saturation). Specific humidity (Q) is defined as the mass of water vapour in a unit mass of moist air (g/kg). Absolute humidity (AH) is defined as the total mass of water vapor present in a given volume or mass of air (g/m^3). Significant community transmission is defined as >6 reported death as of March 5, 2020.

Results:

Through March 5, 2020, significant community transmission has occurred in a consistent east and west pattern. The new epicenters of disease were all roughly along the 30-50^{o} N" zone; to South Korea, Japan, Iran, and Northern Italy (Figure 1).[11] After the unexpected emergence of a large outbreak in Iran, we first made this map in late February. Since then new areas with significant community transmission include the Northwestern United States and France (Figure 1). Notably, during the same time, COVID-19 failed to spread significantly to countries immediately north and south of China. The number of patients and reported deaths in Southeast Asia is much less when compared to more temperate regions noted above.[11]

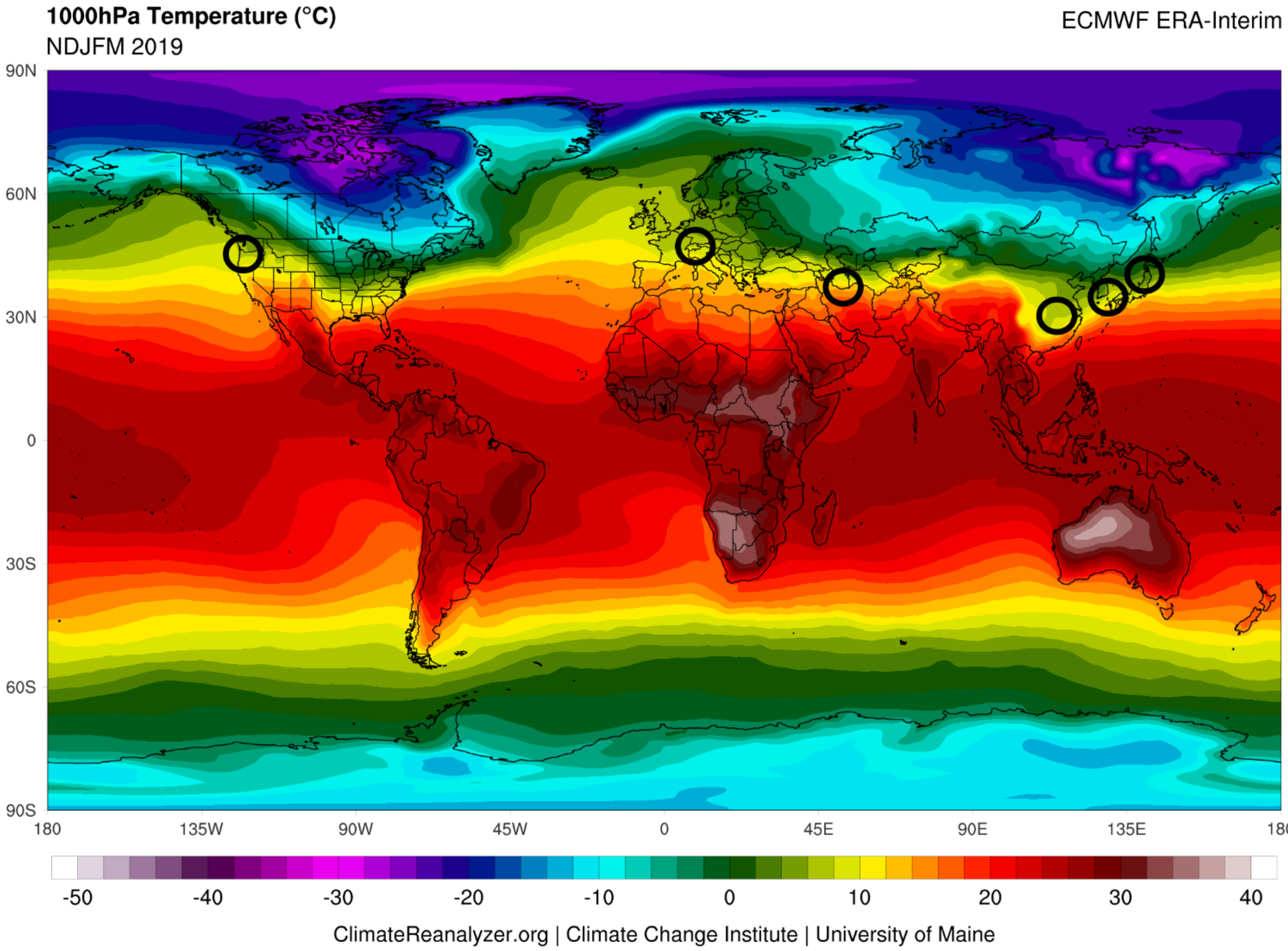

Figure 1. World temperature map November 2018-March 2019. Color gradient indicates 1000hPa temperatures in degrees Celsius. Black circles represent countries with significant community transmission (> 6 deaths as of 3/5/3019). Image from Climate Reanalyzer (https://ClimateReanalyzer.org), Climate Change Institute, University of Maine, USA.

Further analysis using 2-meter (2m) temperatures from 2020 rather than hPa temperatures yields similar results (Figure 2). In the months of January 2020 in Wuhan and February 2020 in the other affected, there is a striking similarity in the measures of average temperature (4-9 ^{o}C at the airport weather stations, and with city temperatures slightly higher due to urban effect,[12] they are within a range of 5-11^{o}C) and low specific and absolute humidity (Table 1). In addition to having similar average temperature, humidity, and latitude profiles, these locations also exhibit a commonality in that the timing of the outbreak coincides with a nadir in the yearly temperature cycle, and thus with relatively stable temperatures over a more than a one month period of time (Table 1).

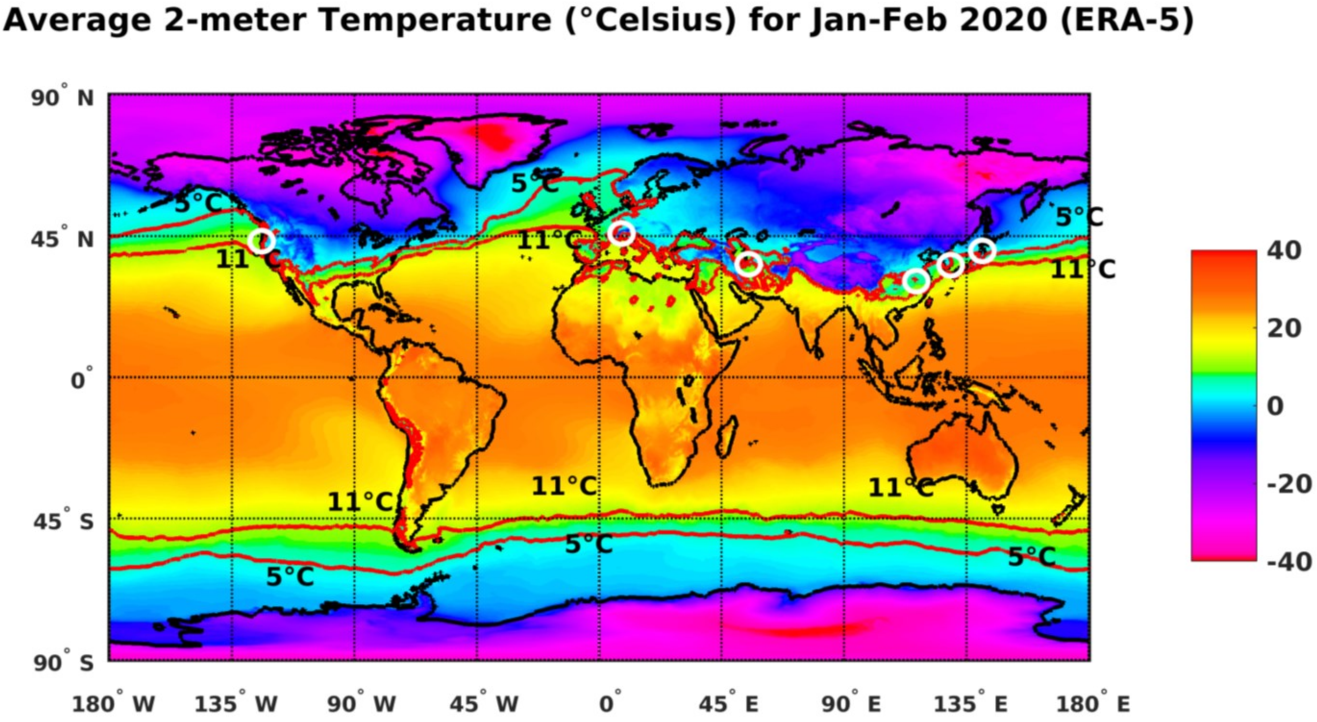

Figure 2. World temperature map January 2020-February 2020. Color gradient indicates 2-meter temperatures in degrees Celsius based on data from the ECMWF ERA-5 reanalysis. White circles represent countries with significant community transmission (> 6 deaths as of 3/5/3019), and red isolines areas with temperature between 5-11ºC. Generated using Copernicus Climate Change Service Information 2020.

Given the temporal spread among areas with similar temperature and latitude, some predictions can tentatively be made about the potential community spread of COVID-19 in the coming weeks. Using 2019 temperature data for March and April, risk of community spread could be predicted to affect areas just north of the current areas at risk (Figure 3). These could include (from East to West) Manchuria, Central Asia, the Caucuses, Eastern Europe, Central Europe, the British Isles, the Northeastern and Midwestern United States, and British Columbia. However, this simplified analysis does not take into account the effect of warming temperatures. The marked drop in cases in Wuhan could well be linked to corresponding recent rising temperatures there (Table 1).

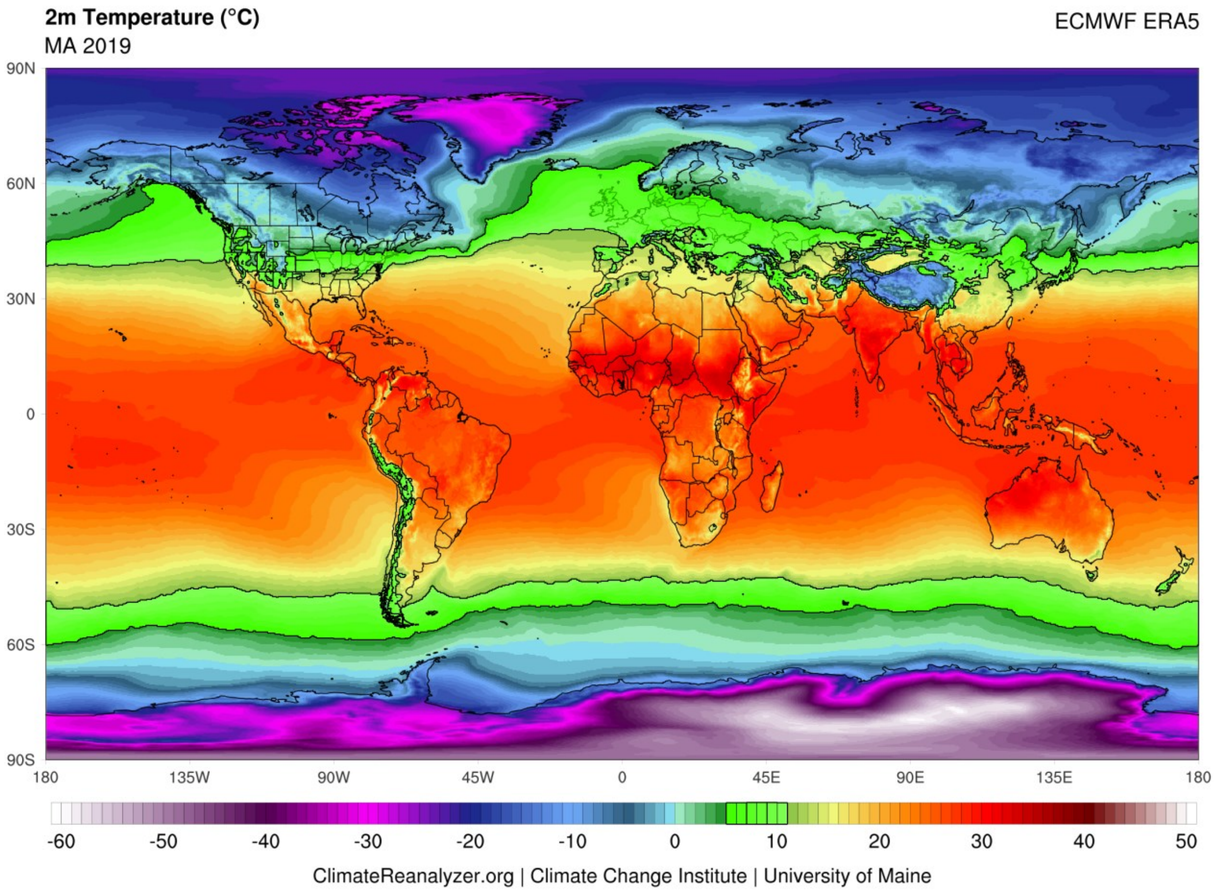

Figure 3. World 2 meter average temperature map March 2019-April 2019 predicting at risk zone for March-April 2020. Color gradient indicates average 2M temperatures in degrees Celsius. Tentative zone at risk for significant community spread in the near-term include land areas within the green bands, outlined in dark black (showing 5-11°C zone based on 2019 data), and will change based on actual average temperatures during this time period. Image from Climate Reanalyzer (https://ClimateReanalyzer.org), Climate Change Institute, University of Maine, USA. Digital manipulation by Cameron Gutierrez and Glenn Jameson.

City	Nov 2019				Dec 2019				Jan 2020				Feb 2020			
	2M (°C)	Rh (%)	Q (g/kg)	AH (g/m^3)	2M (°C)	Rh (%)	Q (g/kg)	AH (g/m^3)	2M (°C)	Rh (%)	Q (g/kg)	AH (g/m^3)	2M (°C)	Rh (%)	Q (g/kg)	AH (g/m^3)
Wuhan	14	66	6	8	8	74	5	6	5	84	4	6	10	77	6	7
Tokyo	14	72	7	9	10	73	5	7	8	72	5	6	9	66	5	6
Qom	9	61	5	5	7	72	5	6	4	69	4	4	8	44	4	4
Milan	9	85	6	8	7	80	5	6	5	77	4	5	8	60	4	5
Daegu	9	68	5	6	2	62	3	4	3	67	3	4	4	62	3	4
Seattle	7	84	5	7	7	88	5	7	7	85	5	7	6	82	5	6
Mulhouse	7	89	5	6	7	87	5	6	2	87	4	5	6	73	5	6
Large cities tentatively predicted to be at risk in the coming weeks																
London	7	90	6	7	7	89	5	7	7	89	6	7	7	81	5	6
Manchester	6	92	5	7	5	91	5	6	6	90	5	7	6	84	5	6
Berlin	6	88	5	7	4	84	4	6	4	84	4	5	6	77	5	6
Prague	6	86	5	6	3	82	4	5	2	84	4	5	5	72	4	5
Hamburg	6	91	5	7	5	87	5	6	5	89	5	6	6	82	5	6
Vancouver	8	81	5	7	6	85	5	6	5	82	5	6	5	81	4	6
New York	7	65	4	5	3	74	4	5	3	69	4	4	4	69	4	5
Warsaw	6	88	5	7	3	86	4	5	2	87	4	5	4	79	4	5
Glasgow	5	88	5	6	6	89	5	7	7	86	5	7	5	85	5	6
Kiev	5	84	5	6	3	87	4	5	1	86	3	4	2	77	4	4
St. Louis	5	71	4	5	3	75	4	5	2	78	4	4	2	72	3	4
Beijing	5	53	3	4	-3	54	2	2	-3	58	2	2	1	62	2	3
Previously predicted city where COVID-19 failed to take hold																
Bangkok	28	70	16	19	26	70	15	17	28	74	17	20	28	70	16	19

Table 1. November 2019 to February 2020 average 2m temperature (°C), relative humidity (RH, %), Specific humidity (Q, g/kg), and absolute humidity (AH, g/m^3) data from cities with community spreading of COVID-19 and those at potentially at risk (as of 3/5/20). Temperature and humidity based on data from the ECMWF ERA-5 reanalysis.

Discussion: The association between temperature in the cities affected with COVID-19 deserves special attention. There is a similarity in the measures of average temperature (5-11ºC) and RH (47-79%) in the affected cities and known laboratory conditions that are conducive to coronavirus survival (4ºC and 20-80% RH).[13] In the time we have written up these results, new centers of significant community outbreak include parts of Northeastern United States, Spain, Germany, and England, all of which had seen average temperatures between 5-11ºC in January and February 2020, and included in either the Jan-Feb 2020 map (Figure 2), or Mar-Apr risk map (Figure 3).

Temperature and humidity are also known factors in SARS-CoV, MERS-CoV and influenza survival.[14-17] Furthermore, new outbreaks occurred during periods of prolonged time at these temperatures, perhaps pointing to increased risk of outbreaks with prolonged conditions in this range. Besides potentially prolonging half-life and viability of the virus, other potential mechanisms associated with cold temperature and low humidity include stabilization of the droplet and enhanced propagation in nasal mucosa, as has been demonstrated with other respiratory viruses.[8,18] Finally, even colder areas in the more Northern latitudes have been relatively free of COVID-19 pointing to a potential minimum range for the temperature, which could be due to avoidance of freeze-thaw cycles that could affect virus viability or other factors (at least one human coronaviruses tested is freeze-thaw resistant).[19] All of the above points to a potential direct relation between temperature and SARS-CoV-2 environmental survival and spreading. This hypothesis can be tested in experimental conditions similar to work that has been done before,[13] environmental sample testing from areas of ongoing infection, and close epidemiologic and climate studies in the coming weeks.

In the coming 2 months, temperatures will rise dramatically across many areas in the Northern Hemisphere. However, areas to the north which develop temperature profiles that may now overlap the current areas at risk only transiently as they rapidly warm (with possible exception of areas such as the Northwest United States and British Columbia, which can show prolonged cyclical nadirs). Furthermore, as the virus moves further north it will encounter sequentially less human population densities. The above factors, climate variables not considered or analyzed (cloud cover, maximum temperature, etc.), human factors not considered or analyzed (impact of epidemiologic interventions, concentrated outbreaks like cruise ships, travel, etc.), viral factors not considered or analyzed (mutation rate, pathogenesis, etc.), mean that although the current correlations with latitude and temperature seem strong, a direct causation has not been proven and predictions in the near term are speculative and have to be considered with extreme caution.

Human coronaviruses (HCoV-229E, HCoV-HKU1, HCoV-NL63, and HCoV-OC43), which usually cause common cold symptoms, have been shown to display strong winter seasonality between December and April, and are undetectable in summer months in temperate regions.[20] Some studies have shown that the alphacorona virus HCoV-229E peaks in the fall, while HCoV-OC43 (a betacoronavirus in the same genera as SARS-CoV-2) has a winter predominance.[21,22] Although it would be even more difficult to make a long-term prediction at this stage, it is tempting to expect COVID-19 to diminish considerably in affected areas (above the 30º N") in the coming months and into the summer. It could perhaps prevail at low levels in tropical regions similar to influenza, cause outbreaks in the Southern Hemisphere at the same time, and begin to rise again in late fall and winter in temperate regions in the upcoming year. One other possibility is that it will not be able to sustain itself in the summer in the tropics and Southern Hemisphere and disappear, just as SARS failed to do so in 2003; however, the ever-increasing number of cases worldwide make this increasingly less likely. MERS has pointed to as a case of a betacoronavirus that is able to spread in all seasons. However, it should be remembered that the vast majority of cases were in the Arabian Peninsula, which has a Hot desert climate (Koppen classification), and that influenza infection there does not follow the same pattern as more temperate climates.[23] In the upcoming summer months in the Northern Hemisphere, surveillance efforts for

SARS-CoV-2 in currently affected areas will be important to determine if there is a viral reservoir (such as prolonged stool shedding). Similarly, surveillance efforts in the tropics, as well as New Zealand, Australia, South Africa, Argentina, and Chile between the months of June through September may be of value in determining establishment in the human population.

An avenue for further research involves the use of integrated or coupled epidemiological-earth-human systems models, which can incorporate climate and weather processes and variables (e.g., dynamics of temperature, humidity) and their spatiotemporal changes, as well as simulate scenarios of human interactions (e.g., travel, transmission due to population density). Such models can assimilate data currently being collected to accelerate the improvements of model predictions on short time scales (i.e., daily to seasonal). This type of predictive approach would allow to explore questions such as what are population centers most at risk and for how long; where to intensify large scale surveillance and tighten control measures to prevent spreading; better understanding of limiting factors for virus spreading in the southern hemisphere; and making predictions for a 2021-2022 virus season. A better understanding of the cause of seasonality for coronaviruses and other respiratory viruses would undoubtedly aid in better treatments and/or prevention, and be useful in determining which areas need heightened surveillance.

Conflict of interest: None to declare.

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