Influence of Temperature on the Global Spread of COVID-19

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Abstract.

This article investigated whether the atmospheric temperature had any role in the spread and vulnerability to COVID-19 worldwide and how that knowledge can be utilized to contain the fast-spreading disease. It highlighted that temperature was an important factor in transmitting the virus, and a moderately cool environment was the most favourable state for its susceptibility. In fact, the risk from the virus is reduced significantly in high temperature environment. Warm countries and places were likely to be less vulnerable. We identified various degrees of vulnerability based on temperature and specified countries for March and April. The maximum reported case, as well as death, was noted when the temperature was in the range of around 275°K (2°C) to 290°K (17°C). Countries like the USA, UK, Italy and Spain belonged to this category. The vulnerability was moderate when the temperature was less than around 275°K (2°C) and countries in that category were Russia, parts of Canada and few Scandinavian countries. For temperature 300°K (27°C) and above, a significantly lesser degree of vulnerability was noted. Countries from SAARC, South East Asia, the African continent and Australia fell in that category. In fact, when the temperature was more than 305°K (32°C), there was a unusually low number of reported cases and deaths. For warm countries, further analyses on the degree of vulnerability were conducted for the group of countries from SAARC and South East Asia and individual countries were compared. We also showed countries can switch from one

vulnerability state to another based on the variability of temperature. We provided maps of temperature to identify countries of different vulnerability states in different months of the year.

That influence of temperature on the virus and previous results of clinical trials with similar viruses gave us a useful insight that regulating the level of temperature can provide remarkable results to arrest and stop the outbreak. Based on that knowledge, some urgent solutions are proposed, which are practically without side effects and very cost-effective too.

1. Introduction:

The recent pandemic of COronaVIrus Disease 2019 (COVID-19) and its rapid spread worldwide[1,2] brought the whole human civilization to a standstill. The responsible virus for the disease is Severe Acute Respiratory Syndrome CoronaVirus 2 (**SARS-CoV-2**) [3]. Detailed analysis of the characteristics of the virus and the nature of the disease is outlined in current research[4, 5].

The disease first originated in the Wuhan Province of China. The case of hospital admission was first reported on 12th December 2019 and since then till 15th March there were 80,995 reported cases in China with 3,203 confirmed deaths[2]. Various analyses on the COVID-19 spread in China were detailed in a recent study[6]. That figure all over the globe reached 1,000,249 and 51,515 respectively[2] on 3rd April 2020, since 31 December 2019. Geographic distribution of COVID-19 cases worldwide are presented in Fig.1a. Because of the highly contagious in nature [3,7],

 doi:10.20944/preprints202003.0366.v3

most of the countries worldwide started lockdown situation from around third week of March[8].

Several facts highlighted that the spread of recent Coronavirus pandemic showed some geographical preferences (Fig.1). Countries and cities with moderately cold winter temperature indicated a rapid spread (UK, Italy, Spain, northern USA etc.) compared to warm countries (e.g., countries from the African continent, Indian subcontinent and, Australia) [1,2]. Moreover, very cold countries like Canada, Russia and Scandinavian countries only showed moderate severity. Interestingly, the countries that suggested moderate severity started showing the sign of more severity from the end of April. More importantly, it is happening in spite of a global lockdown situation. Over the same time, some warm countries (e.g, Brazil, Chilli) also suggested a rise in severity[1,2].

On a regional basis, compared to warmer places, colder regions were seen more affected. During February and January 2020, a sub-zero minimum temperature was noted in the Wuhan province of China where the outbreak was reported first. Wuhan experienced maximum severity in terms of the death toll and the rapid rise of infected patients. In February this year, the following cities (Rome in Italy, Tehran in Iran, Seoul in South Korea) all experienced a sub-zero minimum temperature and coincidentally showed a sharp increase in the number of infected patients. Those cities were the epicentres of the outbreak of respective countries. The numbers of infected people in Italy, Iran, South Korea are reported to be 115242, 50468 and 10062 (as of 3rd April 2020 since 31 December 2019) [2].

Close connections between epidemics and seasons are previously identified for mid-latitude temperate regions; which is November till March in the Northern Hemisphere, while May upto September in the Southern Hemisphere [9,10,11]. In temperate regions, absolute humidity minimizes in winter alongside temperature which becomes more susceptible to certain virus transmission and survival[10].

A laboratory study using a seasonally dependent endemic virus that has close resemblance with Coronavirus also confirmed the dependence of temperature and humidity on the spread of disease[11]. It showed that at a temperature of 5 ºC and relative humidity (RH) 35% to 50% the infection rate was very high (75-100%). Whereas, when the RH was still kept at 35%, but only temperature was increased to 30°C the infection rate surprisingly reduced to zero[11]. As the infection rate was reduced to zero at temperature 30 °C and humidity 35% that estimation may be useful for arresting spread of similar viruses and needs further exploration.

Another virus named the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) that share genetic similarity with COVID-19 was shown to remain active for a long time in low humidity and low temperature[12]. Studies with a different Coronavirus SARS-CoV (Severe Acute Respiratory Syndrome Coronavirus) also noted the same connection [13,14,15]. MERS-CoV and SARS-CoV both belong to the Coronavirus genus in the Coronaviridae family[16].

Research also studied strength and activity for a similar generic Coronavirus (viz. SARS-CoV) using a variable level of temperature and humidity[14]. It found that inactivation of the virus was faster at all humidity level if the temperature was simply raised to 20°C from 4°C. Also, the inactivation was more rapid if the temperature was further increased to 40°C from 20°C, suggesting **the virus is extremely sensitive to high temperature**. SARS could, however, be active for at least five days in typical airconditioned environments which has relative humidity 40-50 % and room temperature 22 -25°C [13]. The strength of the virus was lost rapidly when relative humidity was >95% and temperatures were 38°C or higher[13]. Studies with various Coronavirus generic categories other than MERS and SARS also confirmed that low temperature significantly contributes to the survival and transmission of the virus[14,17].

COVID-19 is an extremely contagious disease [3,7] as it invaded almost all parts of the globe in less than two months[1,2]. The nature of its transmission under variable temperature condition also needs attention. A lab experiment was conducted using guinea pigs to examine the contamination of a similar seasonal air-borne virus[11]. It studied the effect of temperature on airborne transmission as well as contact transmission. Increasing the temperature prevented airborne transmission but could not stop contact transmission. When guinea pigs were kept in separate cages for 1 week at a temperature of 30°C, no infection took place among recipient guinea pigs. But to simulate contact transmission, if those were kept in the same cage, between 75% and 100% became infected. They, however, found no role of humidity in these experiments.

Though the knowledge of temperature sensitivity to the similar seasonal virus is recognised, whether any early warning systems can be proposed on various space and time scales is yet to be determined[18]. The role of weather on the spread of COVID-19 was also studied in various analyses. Research confirmed dependencies on temperature and humidity [14,15] ; wind speed and surface pressure[19] for the spread of virus. A systematic review to understand the effect of temperature on COVID-19 was also conducted[21] . It collected numerous recent journal submissions (around 16 in number) and almost all of them indicated a strong dependence on temperature. There are potential that the knowledge of such analyses can be used for the benefit of human society in the current emergency situation. The role of global temperature on the transmission of COVID-19 worldwide was mentioned first by the author in a recent work [22]. That knowledge was further elaborated in a subsequent study by presenting a global temperature spatial map and comparing with vulnerability worldwide[23]. The current analysis is an extension work to investigate that effect further. It also identifies countries that are more vulnerable/ favourable than others in various seasons.

It is an extremely contagious disease[3,7] and has very high epidemic potential. Scientists from different fields are working tirelessly to mitigate the crisis. Clinical trials and laboratory experiments are time consuming. Lockdown and social distancing can be a temporary solution, as the economy and mental health also need attention. With those emergency situations in mind, some effective solutions are proposed. These additional measures, apart from existing guidelines [3,7] , can greatly benefit to overcome the crisis.

This article is based on the idea whether the variable global temperature has any role in the transmission of virus globally and to arrest the rapidly spreading disease, how that knowledge can be used.

2. Methodology and Data:

We analysed global air temperature data from NCEP/NCAR Reanalysis product[24], a joint product from the National Center for Atmospheric Research (NCAR) and National Centers for Environmental Prediction (NCEP). The data is freely available[25]. It has a temporal coverage of Monthly as well as Daily values from 1948 January till recent dates. The long-term monthly mean of this data is available and derived for years 1981 - 2010. The spatial coverages extend all over the globe and has 17 vertical levels. In this analysis, we only considered the lowest level near the surface which is 1000mb. For air temperature, we calculated climatology (30 years average), as well as some daily composites using compositing technique. We also used the Method of Mean Differences to analyse the result and to find differences between two sets of data. The level of statistical significance was derived using the student's t-test. Data related to COVID-19 are freely available and all listed underneath.

3. Results:

3.1 Analyses based on Temperature and spread of the Virus

As temperature played a very key role in spreading Coronavirus [12,13,14,15,17] and also especially COVID-19 [19,20, 21] we analysed it further by using a spatial plot of global monthly mean air temperature (Fig 2). Later it was compared with the vulnerability to the disease worldwide.

3.1.1. Mean Spatial Temperature Globally

Mean global temperature spatial plot for March 2020 is shown in Fig 2a, when lockdown started[8] and the disease affected most of the countries globally. Fig.2b is for the very recent month (April 2020) and Fig. 2c for the period when the disease made its presence globally (15th Feb) till the last day of recent month (30th April 2020).

Temperature threshold: Cold temperature

Different vulnerability situation was observed for moderate cold countries and extreme cold countries.

Moderate cold: The first ten countries (and number of death counts till 3rd April) in descending order are mentioned: Italy (13,917), Spain (10003), United States (6,053), France (4,503), China (3,326), Iran (3,160), United Kingdom (2,921), Netherlands (1,339), Belgium (1011) and Germany (872)[2]. These countries showing maximum vulnerability, belonged to the moderate cold category. Mean temperature varied between the range of around **275°K (2°C) to 290°K (17°C)**.

Severe cold: Though Laboratory experiments to our knowledge did not conduct any study relating to lower temperature threshold, but Fig. 1 and 2a suggested, lower temperature threshold may also be important. Here are some statistics[2] for reported case (and death) for countries below 275°K (2°C), e.g., Iceland 1319(4), Finland 1518(19) and Canada 11268 (138); all those showed comparatively low death count till 3rd April.

Temperature threshold: High temperature

Interestingly, countries having temperature more than **300°K (27°C)** showed unusually low death rate compared to the overall statistics. Countries from the South Asian Association for Regional Cooperation (SAARC), South East Asian Countries (SEAC), the African continent and Australia all lied in that zone and all have low death counts (Fig. 1, Fig. 2a). African countries lying in that temperature zone reported insignificant infected cases as well as deaths. That temperature zone excluded countries with higher reported case among African continent (countries of northern boundaries e.g., Algeria, Egypt and Morocco and Southern boundaries e.g., South Africa). For Australia, that statistics of the reported cases (and deaths) were 5224 (23); in fact, no death was reported till 3rd of April[1] in regions when the temperature is higher than 300°K (27°C). Almost all reported cases and deaths for Australia were around South West part of the country where the temperature was below 300°K (27°C) (Fig. 1 and Fig. 2a). Few other countries falling in that temperature threshold with reported cases (and deaths) were Malaysia 3116 (50), Singapore 1049(5) and Thailand 1875 (15).

Certain clinical tests found the infection rate for some seasonal air borne virus was **reduced to zero at temperature 30 °C at certain humidity level[11]. Here we show that the vulnerability to COVID-19 is reduced drastically even at 27°C,** without considering any effect of humidity. In addition to that, when the temperature was above 305°K (32°C), an unusually low number of the reported cases, as well as deaths, was observed[1].

These analyses indicated some rough temperature threshold for the spread and vulnerability to COVID-19 as follows: i) 275°K (2°C) to 290°K (17°C) - maximum reported case as well as death; ii) <275°K (2°C)- death reporting was low; iii) 300°K (27°C) and above- significantly less number of reported death compared to overall population; iii) >305°K (32°C)- an unusually low number of reported cases as well as deaths.

Fig. 2b is the spatial plot of global temperature for April which is tested again and the main conclusion relating to temperature threshold and vulnerability remain the same. Climatology of temperature is prepared globally for different months (Fig. 3-8). Following the current analyses, it would indicate predictive maps of vulnerability for different months based only on temperature. We find Fig 2b is consistent with Fig 3 (bottom) and Fig. 2c with Fig 3 (top), which are for the month of February and March respectively. As we verified the last February and March 2020 with the climatology of those two months, we may expect the predictive maps would be very similar for other months too. Thus, climatology map of temperature can give ideas of vulnerability level to different countries month-wise and the direction of transitions. It will be important for every country for future preparedness.

The vulnerability to the disease worldwide was analysed based on certain data on the day of 1st May. To examine that data till the 1st of May (Table 1) we compared global temperature map from 15th Feb till the end of April (Fig. 2c). We find the result is again consistent.

3.1.2. Examining Reported Cases and Deaths

Based on location, testing and other various reasons reported cases are likely to vary. Until a high number of populations is tested the case reporting may be sometimes meaningless. As death reporting is usually authentic, we considered 'deaths' as a better metric. Moreover, the absolute number of deaths vary based on population. Hence to analyse the degree of vulnerability, death/Million population of a country is chosen as the best indicator in this analyse.

In Table 1, we have presented a few statistics showing situation update/ performances of various chosen countries [26]. Some countries, especially those are developing could have poor reporting strategy and inadequate facilities. Tests /Million population are expected to be comparatively low for those countries, as also reflected in Table 1 (last column). We should note that data or statistics presented in Table 1 could vary slightly and may not be accurate. However, those limitations do not affect the main results of our analyses.

Test /Million populations were maximum for Iceland, which was reflected in the highest number of infected cases per million (column 4). Death/Infected (column

5) is a parameter that could indicate the performance of medical treatment country-wise and expected to be lower for developed countries. However, it is also linked with the number of more overaged population and number of testing etc. Death/Infected (%) was highest in European countries in spite of advanced health care system, that may indicate a high ageing population. The same was the lowest for Singapore (.1%), which had high testing rates amongst all warm countries.

Data of all countries from South Asian Association for Regional Cooperation (SAARC) were presented which are Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. All countries of South East Asian region were also presented in Table 1. Those are Singapore, Cambodia, Malaysia, Vietnam, Thailand, Indonesia, Philippines and Myanmar. Among those, some are very popular tourist spots and some are popular international business hubs where more transmission of the disease by foreign travellers are expected. In spite of the varied level of testing, infrastructural facility, population density, varying degree of lockdown restriction and many dissimilarities among each country there was still one common factor. All those countries had very less death per million population. For SAARC countries it was 2 and under; whereas, for South East Asian countries (SEAC) it was 6 and under. Among these countries, Singapore did maximum testing per million, which was even comparable with developed countries. That large count was reflected in the higher count for infected per million compared to other countries in that group, though not in the death count. Among that group of countries, the number of deaths in one day (01/05/2020) was higher in India and Pakistan compared to the rest (column 6), which was a common reflection of their high population.

Following Table 1, we found the least vulnerable countries had a very less count of death per Million, which was under 1. That count for less vulnerable countries were 10 and under. Result of few Moderate cold countries and very cold countries were also presented. For moderate cold countries, the deaths per million was very high which even exceed 400 in some countries. Though the USA ranked first in terms of total number of deaths and reported cases[1], but being 3rd largest populated countries in the world[27], the ranking of the USA in Table, 1, column 3 was lower than in European countries. For very cold countries that count was less than 100 for most cases.

Following temperature thresholds, we categorised countries based on vulnerability as follows:

Category I: Moderate Cold - between 275°K (2°C) to 290°K (17°C) - Most Vulnerable.

Category II: Very Cold – less than 275°K (2°C) - Moderate Vulnerable

Category III: Moderate warm – greater than 300°K (27°C) - Less Vulnerable.

Category IV: Very warm – greater than 305°K (32°C)- Least Vulnerable.

There could still be a very few countries suggesting as outliers. Those could be related to relaxed/ effective social isolation policy and preventive measures, low/high testing facility, relaxed/ regulated overseas arrivals, poor/advanced infrastructure, inadequate/ appropriate medical intervention on time, other favourable/ unfavourable atmospheric conditions etc.

3.1.3. Statistical Analyses

Fig.9 showed vulnerability to COVID-19 measured in terms of Deaths per Million, upto 1st of May, 2020. Fig.9a suggested all Warm countries together (SAARC and South East Asian countries (SEAC), continents of Australia and Africa) had significantly low death rates compared to cold countries. Mean and standard deviation of moderately cold (395.8, 125.0), very cold (41.5, 34.8) and warm countries (2.1, 2.4) suggested a clear distinction. In the group of warm countries, there were enough dissimilaities among each other in various respect (varied testing level, popular tourist destination, infrastructural facility, other atmospheric conditions, developed/developing status of countries etc.). The low mean and standard deviation clearly indicated how strong was the role played by temperature. The method of mean difference is applied among the three categories and to test the level of statistical significance 't' test is used. The difference between each other in the three categories are significant even at the 99% level. In Fig. 9b, we further elaborated on warm countries and presented box plots focusing on countries from SAARC and SEAC. Each group comprises of a total of 8 countries. The SAARC group of countries indicate the lower mean value (1.0) and standard deviation (0.8) than the group of SEAC (2.6 and 2.2, respectively). Fig. 9c further focused each individual countries from Fig. 9b. Among SAARC countries, Pakistan, Afganisthan and Maldives showed highest rate; while from SEAC, countries with high death counts are Combodia and Philipines. Fig.S1 is same as Fig. 9 though considered reported Cases per million instead of Death. Countries with more number of testing sometimes report more cases (e.g., Singapore, Maldives and Iceland).That is one of the reasons for large standard deviations in Fig S1a. Like Death, there is a very clear distinction between three categories (Fig S1a). In Fig.S1b, we excluded two outlier countries Singapore and Maldevis those did very high testing compared to the rest. The boxplot of SAARC and SEAC do not differ much. In Fig.S1c too, we excluded those two outliers for general comparison. As the reported case is heavily dependent on number of testings and other factors, rankings of individual countries in Fig.S1c differ to that from Fig.9. Among SAARC countries, the ranking of Pakistan was highest for both, the death as well as reported cases per million.

3.2. Effect of Temperature Regionally and Transition Phase:

Regional temperatures within a country can vary to a large degree, (even ~ 25°C for the USA, Fig. 2). Hence vulnerability of any country will also depend on regional variations of temperature. In Fig. S2a, we showed that the southern part of Canada was mostly affected compared to the rest of the country. Interestingly, that region only lied in the most vulnerable temperature zone (Fig. 2c). A transition was noticed from March to April and more parts of southern Canada are now entered in moderately cold category in May indicting a rise in vulnerability. The spatial plot of Canada (Fig. S2a) and temporal pattern (Fig. S2b) indicated such features. The daily death count increased during the beginning of April (Fig. S2b). A very high number of daily deaths were reported on the 1st of May (Table 1, 6th column), which was comparable to most vulnerable countries.

In spite of a lockdown situation globally[8] if there was an increase in vulnerability to some countries that needs attention too. Since the end of April, many countries started moving from one vulnerability state to others, e.g., Russia, Canada and some Scandinavian countries. For Russia, new cases reported on 7th May is

10,559, which is 2nd highest reported case after the USA[26]. Canada also reported very high death on that day, which was 189, and again comparable with vulnerable countries[26]. For Sweden, the death reported on 7th May was 87 which was relatively high compared to the overall population of 10,089,795[26]. These countries were very cold in March and at the beginning of April and now phasing out to moderate cold phase.

A recent research[19] studied the effect of temperature on the spread of COVID-19 in Italy. It showed only 2°C rise in temperature can have a comparable effect on the transmission of the virus. The effect of small change in temperature even for 2°C to 2.5°C was analysed and discussed for a few continents in Fig S3 (Europe), Fig. S4 (Africa) and Fig. S5 (South America).

A spatial plot particularly focused on Europe (Fig. S3) suggested that UK was still in the most vulnerable zone in April; whereas, southern Europe turned warmer (Fig. S3 a and b). Scandinavian countries like Sweden started entering into most vulnerability zone from moderate vulnerability state (Fig. S3 a and b).

For Africa, the region of least vulnerability was marked (Fig. S4). The temperature increased around latitude 15°N in April and Table 1 (6th column) showed no new death was reported to those countries. Questions could be raised about poor testing and reporting in those African countries. One reason could be as death was reported zero, those underdeveloped countries may not have considered testing a priority. Moreover, in Australian continents without much of an issue of testing and reporting also suggested similarly. In fact, part of western Australia and northern territory (least vulnerable region, Fig. 1) did not have deaths and practically few reported cases [1] (hence not shown in Table 1). A shift in high temperature region

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 June 2020 doi:10.20944/preprints202003.0366.v3

in Africa from south to north during March to April gave an indication of how the vulnerability can shift regionally and gave rough time estimations of that transition.

As 2°C change of temperature can influence the transmission of the disease[19], we wanted to confirm that for South America (Fig. S5). Some countries from South America suddenly started an increase in deaths and reported cases. On 7^{th} May, Brazil reported new daily death 667, the 2^{nd} highest after USA[26]. The lowering of temperature in Southern Brazil (297°C to 291°C in April) is clearly distinct in Fig. S5b to that from Fig. S5a.

In terms of population, three highly populated countries are considered the USA, Brazil and India (world ranking 3^{rd} , 6^{th} and 2nd respectively)[27]. A plot of recent daily death was presented for those three countries (Fig. S6). The USA, a vulnerable country showed a very high daily count, Brazil now in a transition phase from warm to cooler state, suggested high death count with a comparatively steeper rise in very recent periods. India the less vulnerable country is now moving from warm to warmer. It reported much less death count compared to the rest two.

Fig. 10 showed daily confirmed COVID-19 deaths per million in a form of rolling 7-day average. Those statistics were consistent with the number of death counts per million (Table 1, 3^{rd} column). There are clear distinctions throughout the time period among moderately cold, very cold and warm countries. All warm continents e.g., Asia, Africa and Australia, those belonged to the less vulnerable category, suggested a very nominal daily death count rate compared to the rest (not visible as merges with X axis). The bottom three curves are for Russia, Brazil and Canada respectively. All three are showing a rising trend and we discussed earlier those three are in the transition state. Russia and Canada are turning from very cold to moderate cold; whereas, Brazil from warm to cold. For the USA, UK, Italy and

Spain all suggested very high count throughout and all achieved a peak and now in the declining state. During the declining phase, the temperature was also increasing.

Based on the discussion, it is possible to determine the vulnerability of a specific country as a whole and region-wise during different time periods. Another point is worth mentioning that this is an extremely contagious disease and single contamination through a foreign career/traveller can multiply exponentially among locals. Megapolises like New York, Mumbai, London are expected to be infected more than its suburb and it is, in fact, the case. All those factors were also considered while analysing the statistics.

3.3. Possible Solutions:

The above analyses highlighted that temperature plays an important role in transmissions of Coronavirus[12,13,14,15,17] that include COVID-19 [19,20,21]. Warm temperature drastically reduces its impact. Hence following urgent measures (also mentioned earlier [22, 23]) are proposed to arrest and stop the outbreak:

i) *Using the Sauna facility:* Usually hotels, gyms, leisure centres have existing Sauna facilities which people can start taking advantage of immediately. Mobile and Caravan Sauna facilities can also be thought of by higher authorities.

ii) *Using Blow dryers:* The virus enters through the nose and sticks and attack the nasal cavity [3,7]. Intake of hot air through the nose a few times a day can be useful.

iii) *Portable Room Heater:* People can be close to a portable heater with comparative high temperature say, twice a day and preferably for half an hour. Being portable in nature, it can be moved around and many people can avail that facility in a flexible way. Room heaters can also be useful for disinfecting purposes.

iv) *Disinfect any place using high temperature:* Before the start and end of offices, school or business, the air-conditioning temperature of the premise may be kept, say, 40 ºC or above for sometimes (say, half an hour) to disinfect. The optimal level (temperature and time) can be tested very easily. For airports, train and bus, that method of disinfecting could be useful. For any external object or material, disinfecting using high temperature could be a useful solution.

The main point in this analysis is that the virus is very sensitive to temperature. Based on that knowledge these few measures are proposed. Many simple, easy procedures serving the purpose can be thought of; some could be applicable to warm countries and poor, remote, rural communities.

Study showed SARS-CoV-2 is more infectious than some other Coronaviruses[34]. The usual incubation period for COVID-19 is around 14 days[7]. The virus can stay in the human body for a few days without showing symptoms though they still could be a carrier [3,7]. As it is difficult to trace mild or pre-symptomatic infection, it has greater epidemic potential [34]. These measures described above could be very effective when people are in the asymptomatic or pre-symptomatic state. It is noteworthy that when people already developed major symptoms then this method will not be effective and proper medical advice need to be solicited. Given the emergency situation, lots of treatment/ medicines are desperately tried which are fraught with risks of serious side effects. On the contrary, this solution has practically zero side effects. This study suggests the majority of world populations need to be well prepared before the coming winter. This is an extremely contagious disease[3,7]. Social isolation and lockdown can be a temporary solution, as the economy and mental health also need attention.

These four measures alongside other similar simple solutions are likely to reduce the spread dramatically. If few of these measures are implemented worldwide, it will have a major impact to arrest the spread of the virus.

4. Conclusions:

This article investigated the influence of temperature globally in the spread and vulnerability to COVID-19. It indicated that temperature was a crucial factor in transmitting the virus. For the spread of the virus, the most favourable state was moderately cool places; whereas warm countries and places were likely to be less vulnerable. Similar temperature dependency was also noticed in previous clinical trials those involved other Coronavirus (MARS, SARS etc.) and seasonal influenza/ flu virus. Four different categories of vulnerability are identified based on temperature variations - which are moderate cold, very cold, moderately warm and very warm. For analysing vulnerability, death per million population was considered as a useful and effective metric. The maximum reported case, as well as death, was noted when the temperature was between the threshold of around 275°K (2°C) to 290°K (17°C). Based on temperatures of March and April we specified some countries too; the USA, UK, Italy, Spain belonged to this category. The vulnerability was moderate when the temperature was less than 275°K (2°C) and countries in that category for March and April were Russia, parts of Canada and Scandinavian countries. A significantly lesser degree of vulnerability was noted for countries with temperatures 300°K (27°C) and above. SAARC countries, South East Asian countries (SEAC), African continent and Australia belonged to that category during March and April. In fact, when the temperature was more than 305°K (32°C) there was an unusually very low number of reported cases as well as deaths. Some parts of Australia and African continent showed such behaviour in March, April. The vulnerability to the disease is significantly different, between each other, for moderately cold, severe cold and warm countries. For warm countries, further analyses on the group of SAARCs and SEAC were conducted and individual countries were also compared.

We provided maps of temperature to identify countries of different vulnerability state in different months of the year. We discussed that based on temperature variation, countries can move from one vulnerability state to the other. For e.g., parts of Russia, Canada started entering from severe cold to moderate cold state at the end of April; whereas, Brazil and few warm countries from South America moved from warm to less warm state. In spite of lockdown situation worldwide, those countries reported a sudden rise of death and infected cases at the beginning of May.

We discussed daily confirmed COVID-19 deaths per million over the period, in a form of rolling 7-day average. It was consistent with the number of total death counts per million. There were clear distinctions throughout the time period among moderately cold, very cold and warm countries. All warm continents e.g., Asia, Africa and Australia, those belonged to a less vulnerable category, suggested a very nominal daily death count rate compared to the rest. The USA and European countries showed a decline in the recent period, while Russia, Canada and Brazil are showing a rise.

Our analyses can also give some idea for regional variation of vulnerability of various countries and we specifically discussed that for Canada. Spatial variation within continents were discussed for Europe, South America and Africa for the month of March and April. Our analyses could indicate, which countries are in favourable/ worsening state in the coming months based only on temperature variation. As regional temperature played a very important role in the transmission and spread, our result and future predictive maps have a major implication for future planning.

We discussed that, like other similar category viruses, this virus is also very sensitive to temperature. It gave us a valuable insight that regulating temperature level can provide a useful strategy to arrest and stop the outbreak. Based on that knowledge, some urgent solutions are proposed. It is very cost effective and practically without side effects. To adopt these solutions no vast amount of funding is required. Another novelty of such an approach is- it can be applied overnight and implemented immediately across the globe. These measures are likely to reduce the spread of the disease dramatically.

Acknowledgement. This study did not receive any funding and there is no conflict of interest (financial or non-financial). Figures (2 - 8) and Fig. S3-S5 are generated from the NOAA/ESRL Physical Sciences Division, Boulder Colorado web site at https://psl.noaa.gov/data/composites/day/. This article was submitted to Plos on 17.05.2020 and lied with them till 19.06.2020 and was not sent for review. It has two earlier preprint version Commentary; i) Roy, I. (2020), Combating recent pandemic of COVID-19 - An urgent Solution. March, 17th 2020, DOI: 10.13140/RG.2.2.22632.83208 and ii) Roy, I. (2020), Atmospheric Variables and Additional Urgent Solutions for Combating COVID-19 dt 9th April. https://www.preprints.org/manuscript/202003. 0366/v2

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Supplementary Section

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Table 1: Reported Cases and Deaths of few Countries as of 1/5/2020

Category	Countries	Deaths /Million population	Infected /Million population	Death/ Infected (%)	New Deaths on the day 1/5/2020	Tests /Million population
I **Most Vulnerable**	USA	199	3,417	5.8	1,897	20,241
	Europe					
	Spain	531	5,197	10.2	281	32,699
	Italy	467	3,431	13.6	269	33,962
	UK	405	2,614	15.5	739	15,082
	France	377	2,564	14.7	218	16,856
II **Moderate Vulnerable**	Canada	90	1459	6.2	207	22,050
	Russia	8	784	1.0	96	25,354
	Finland	39	912	4.3	7	17,615
	Iceland	29	5269	.55	0	143,988
III **Less Vulnerable**	***SAARC Countries***					
	India	.9	27	3.3	69	654
	Sri Lanka	.3	32	.93	0	1,047
	Pakistan	2	82	2.43	56	825
	Afghanistan	2	60	3.3	4	272
	Bangladesh	1	50	2.0	2	426
	Bhutan	0	9	0	0	13,091
	Maldives	2	908	.22	0	14,815
	Nepal	0	206	0	0	2,072
	South East Asian Countries					
	Singapore	3	2923	0.1	1	24,600
	Cambodia	6	138	4.34	21	2057
	Malaysia	3	188	1.59	1	5215
	Vietnam	0	3	0	0	2681
	Thailand	.8	42	1.9	0	2551
	Indonesia	3	39	7.7	8	374
	Philippines	5	80	6.2	11	992
	Myanmar	.1	3	3.3	0	152
	African Continent					
	Egypt	4	58	6.9	14	897
	South Africa	2	100	2.0	13	3668
	Algeria	10	95	10.5	3	148
	Morocco	5	124	4.03	1	1,003
	Australia	4	265	1.5	1	23,093
III **Least Vulnerable**	***African Continent (Central region)***					
	Uganda	0	2	0	Nil	739
	CAR	0	15	0		
	Eritrea	0	11	0		
	Ethiopia	.03	1	3		181
	Chad	.3	4	7.5		

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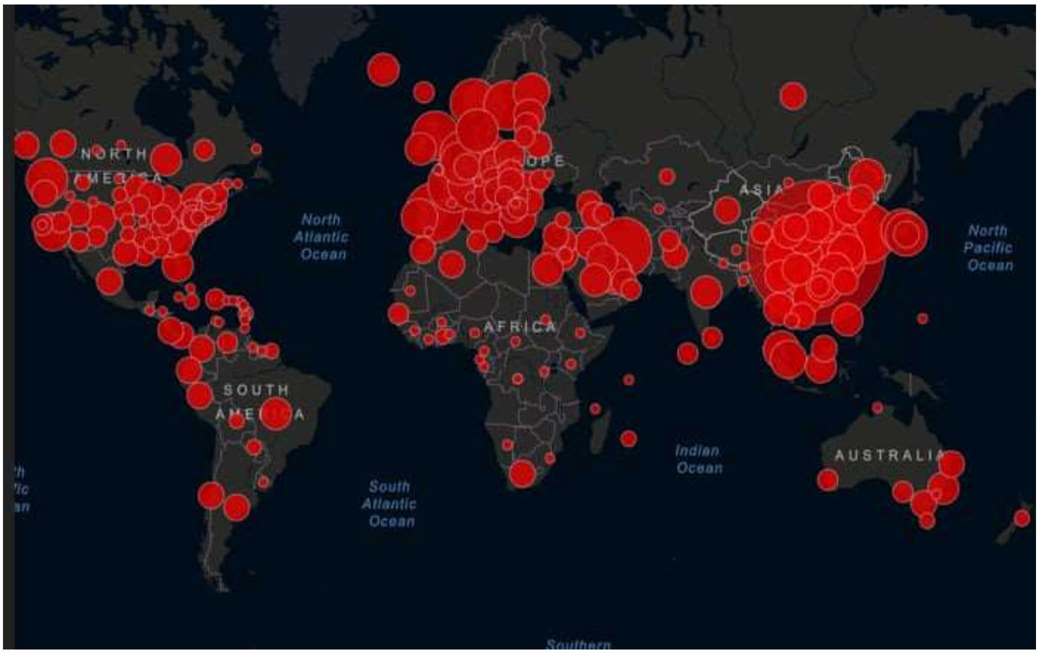

Fig. 1. Geographic distribution of COVID-19 reported cases worldwide, as of 16th March 2020 and the pattern is very similar till end of April[1]

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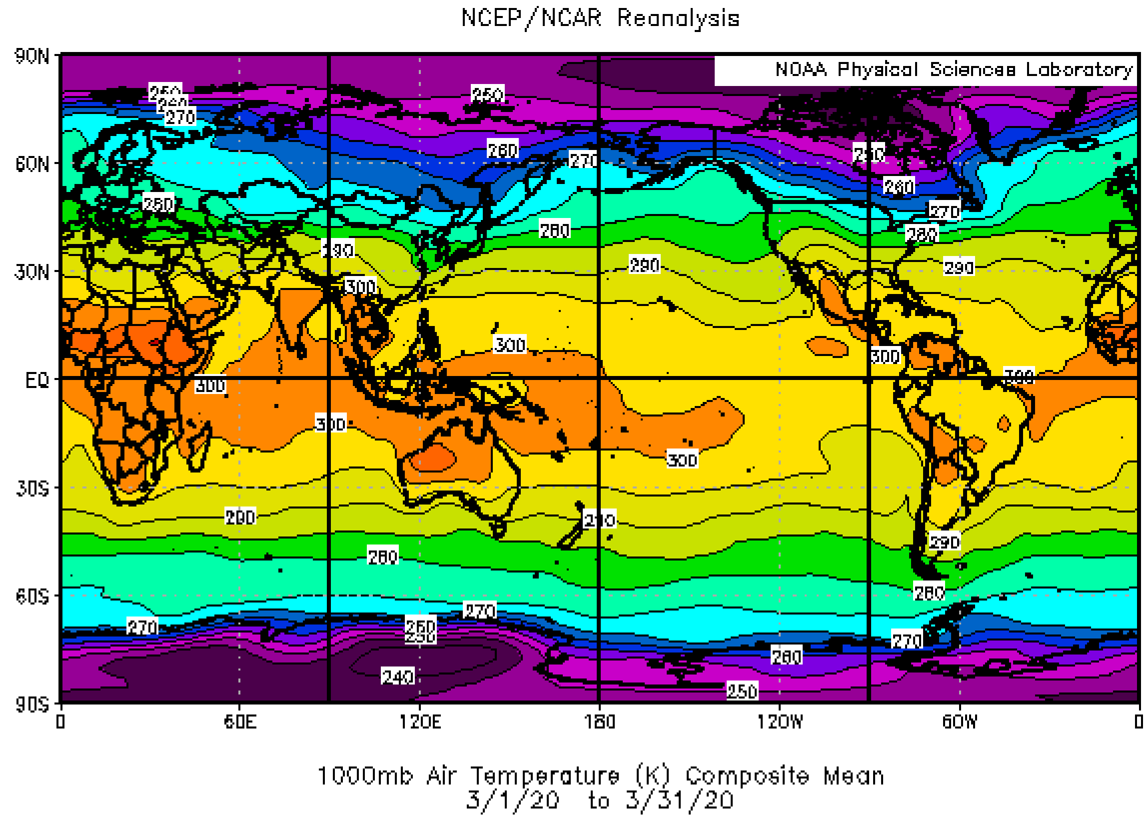
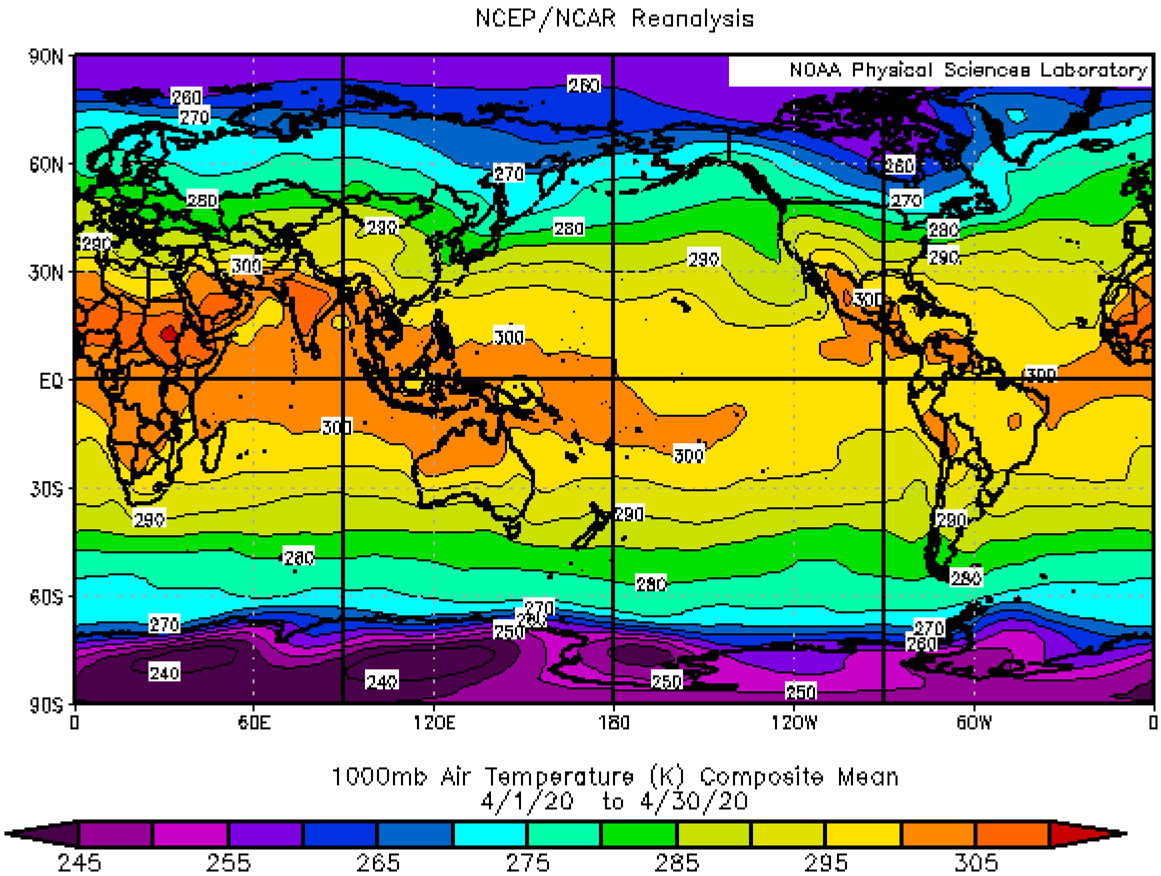
a)



b)



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c)

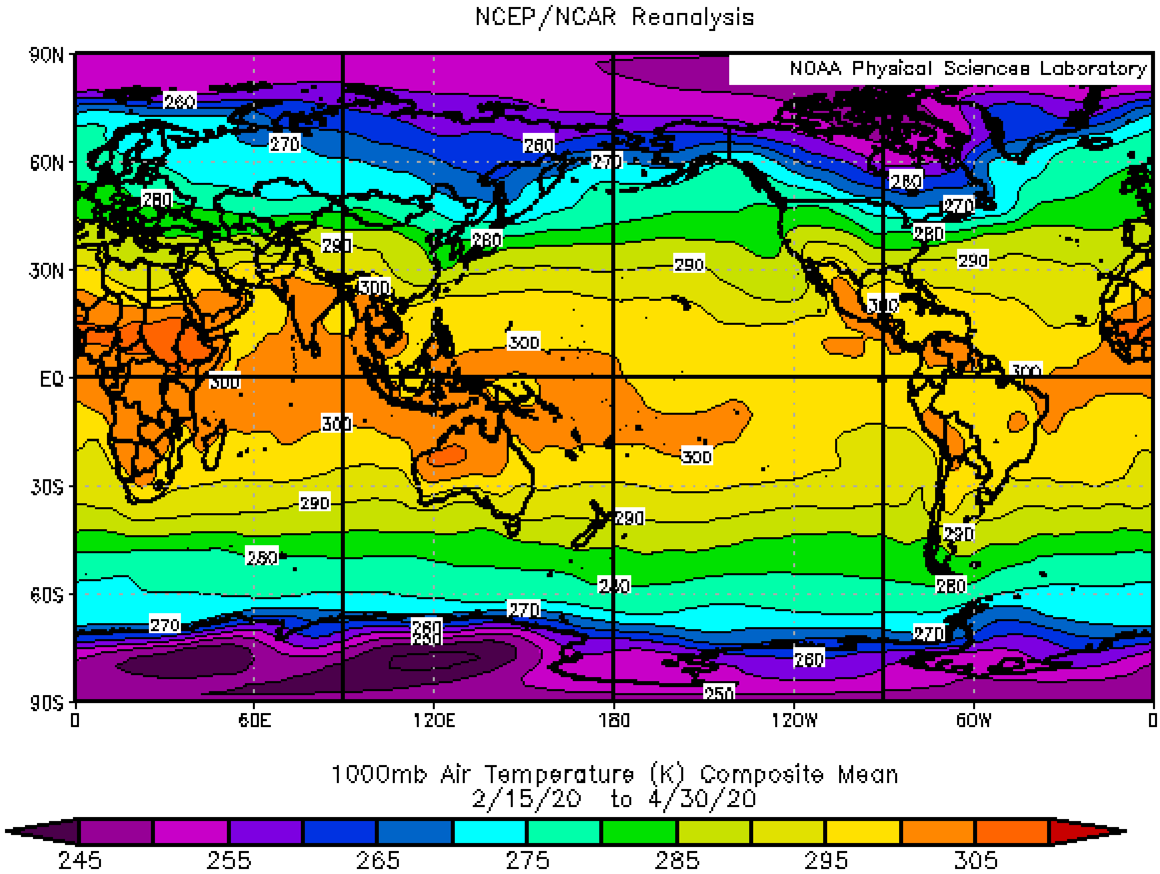
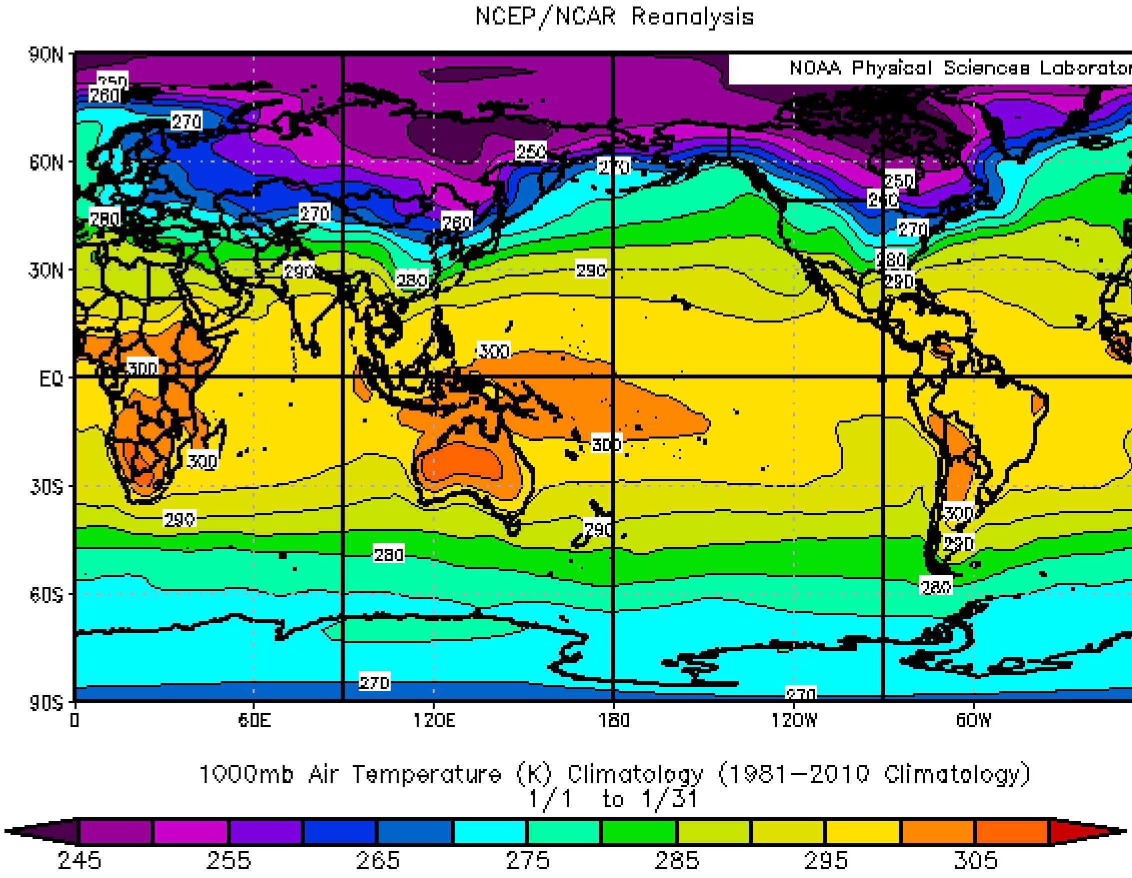


Fig. 2. Monthly average air temperature (ºK) spatial plot **Globally** for: a) March 2020; b) April and c) Feb 15 till April 2020. Plots are generated from the NOAA/ESRL Physical Sciences Division, Boulder Colorado web site at https://psl.noaa.gov/data/composites/day/



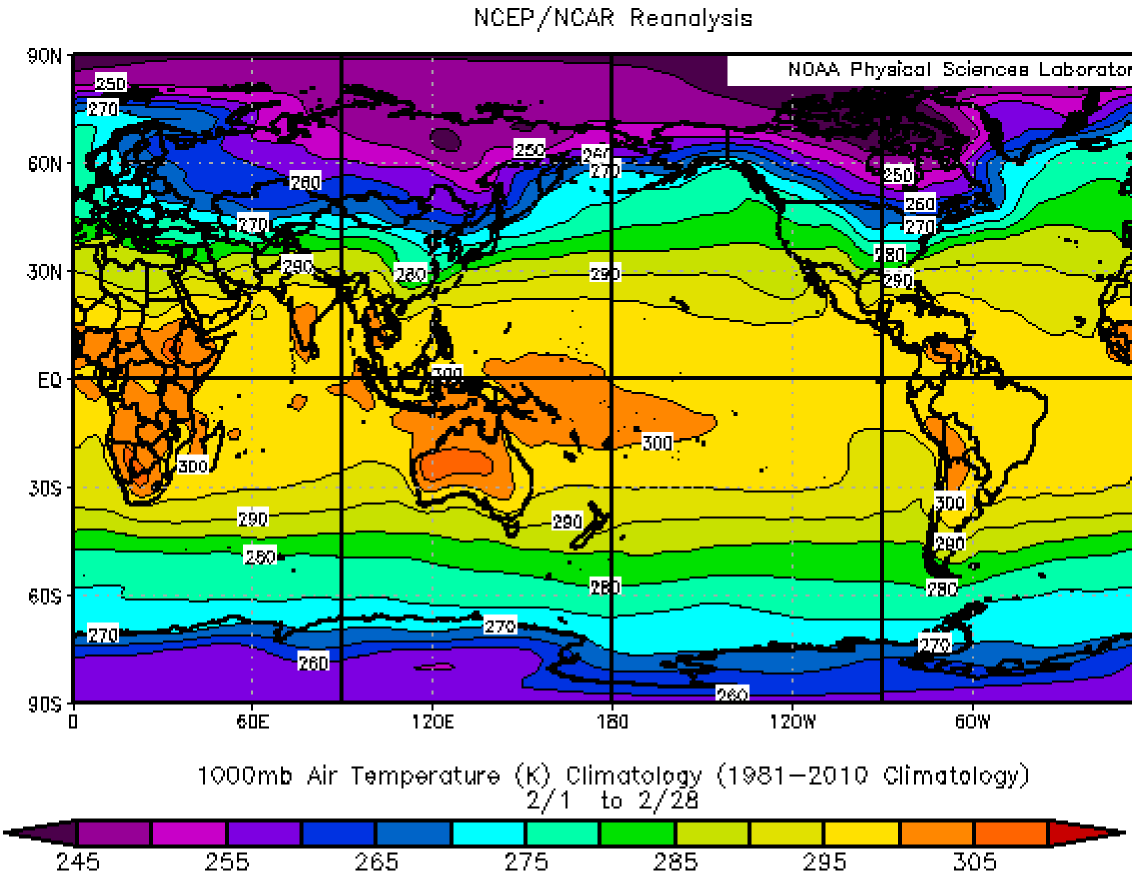
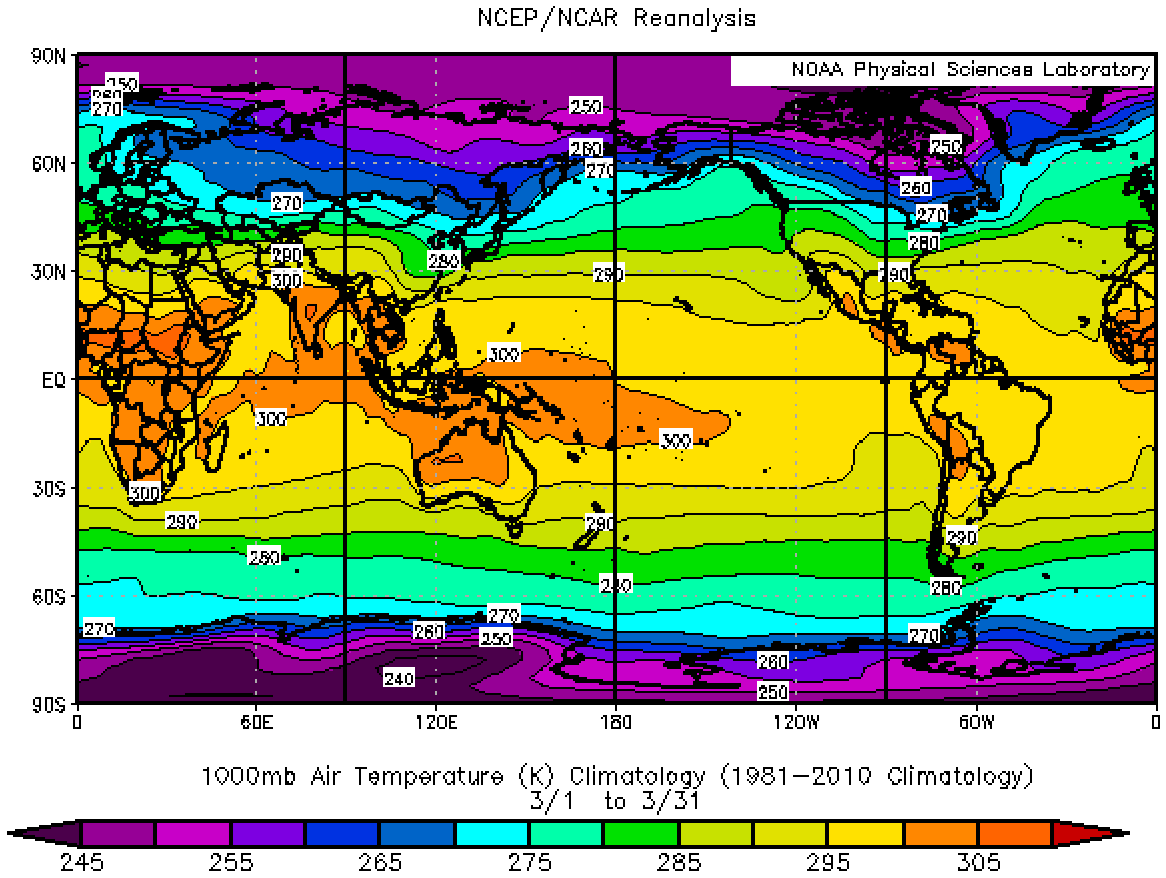


Fig. 3. Climatology of global temperature for January (top) and February (bottom).



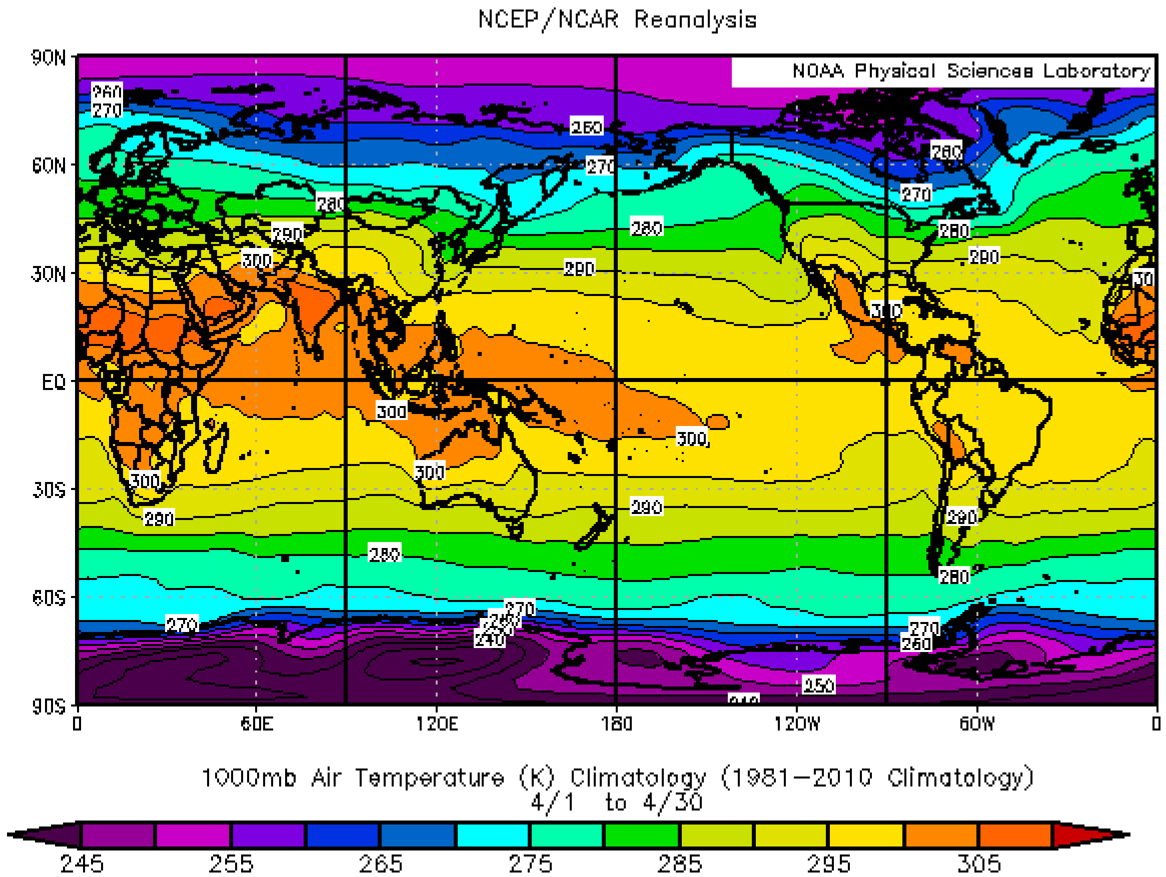
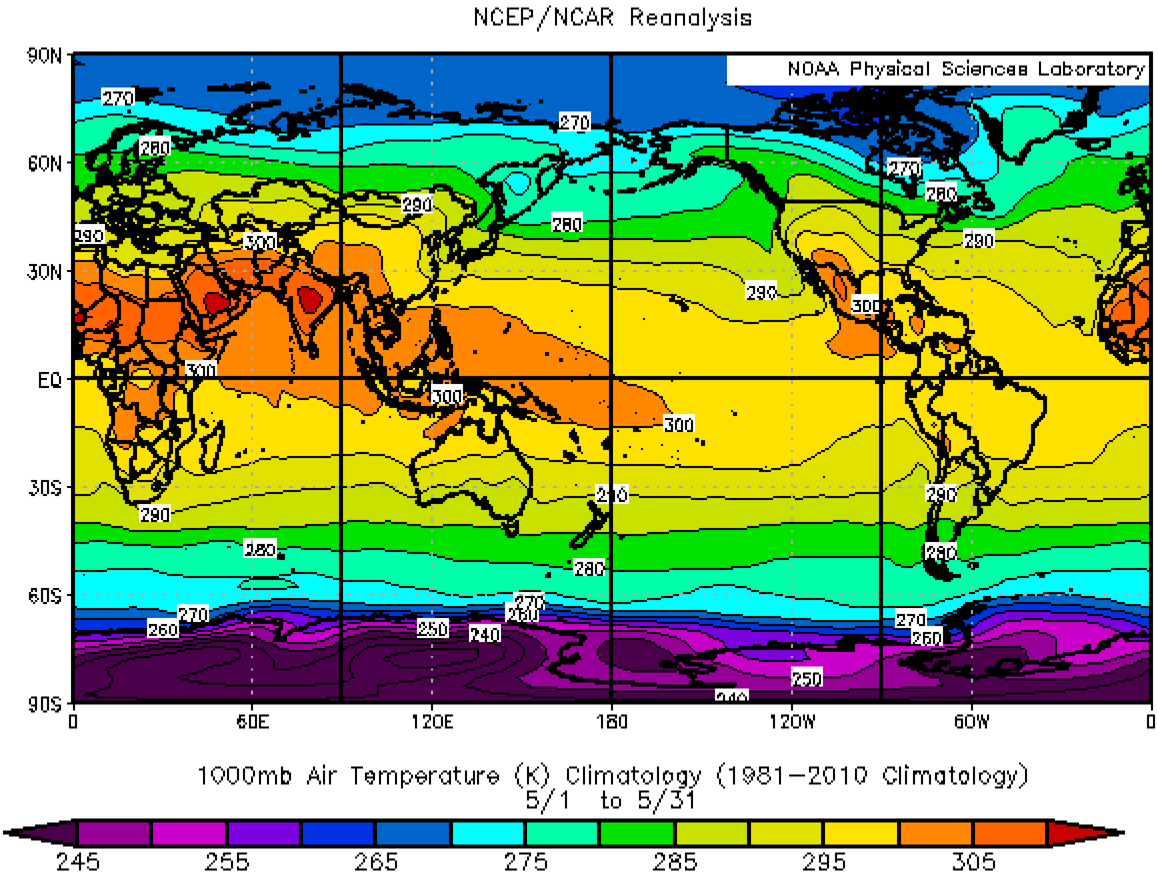


Fig. 4. Climatology of global temperature for March (top) and April (bottom).



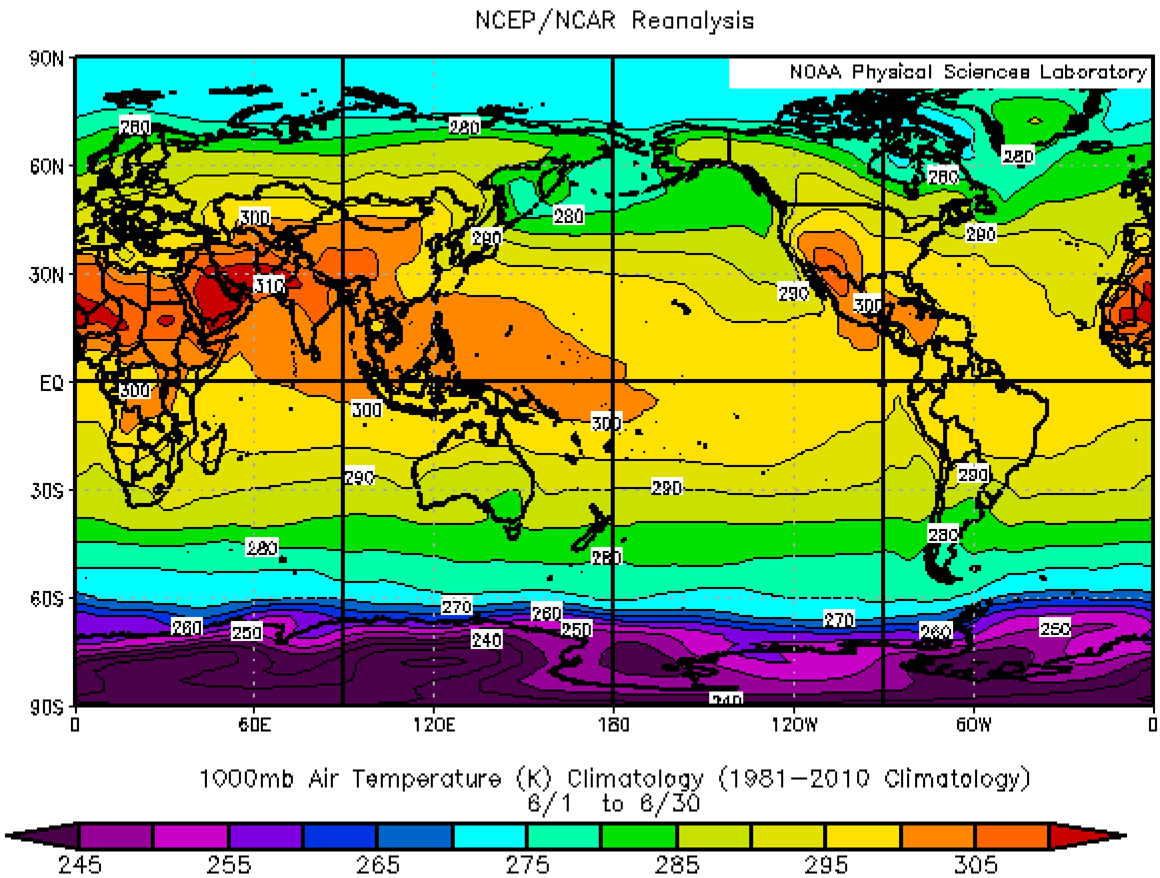


Fig. 5. Climatology of global temperature for May (top) and June (bottom).

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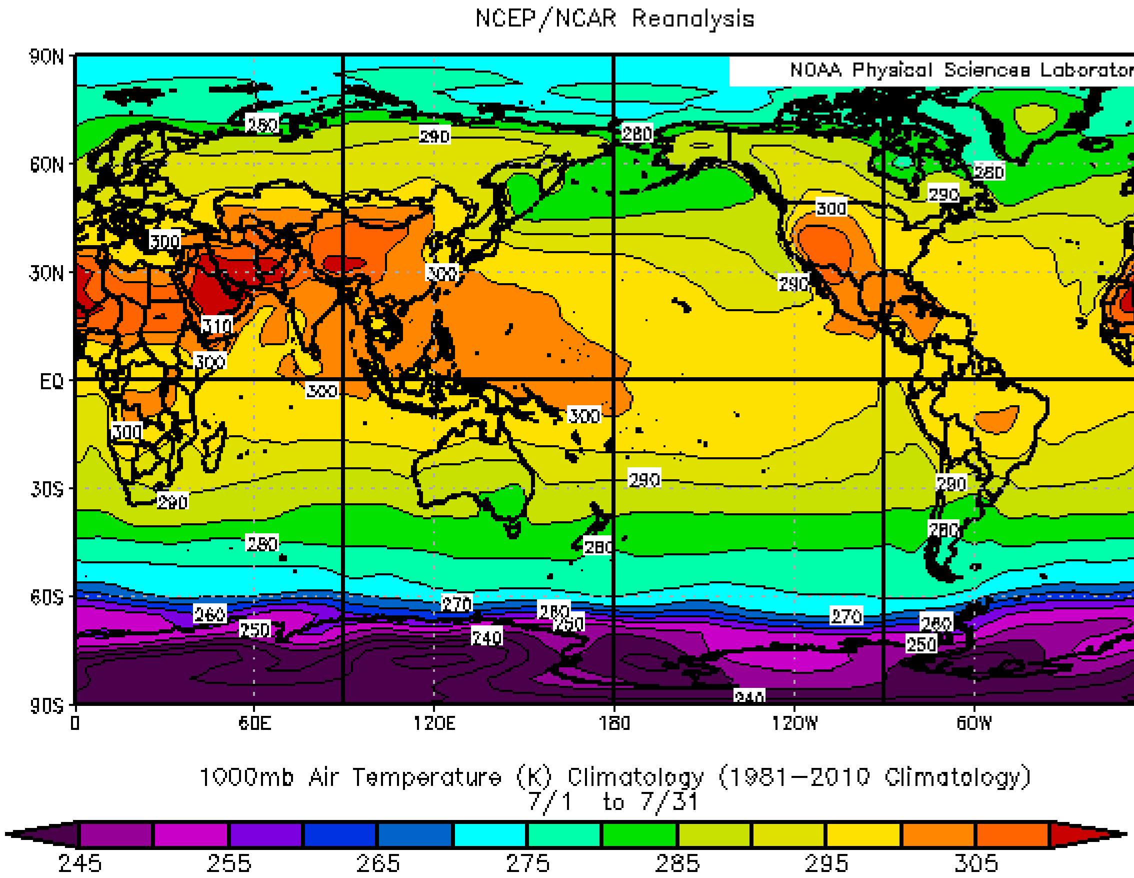

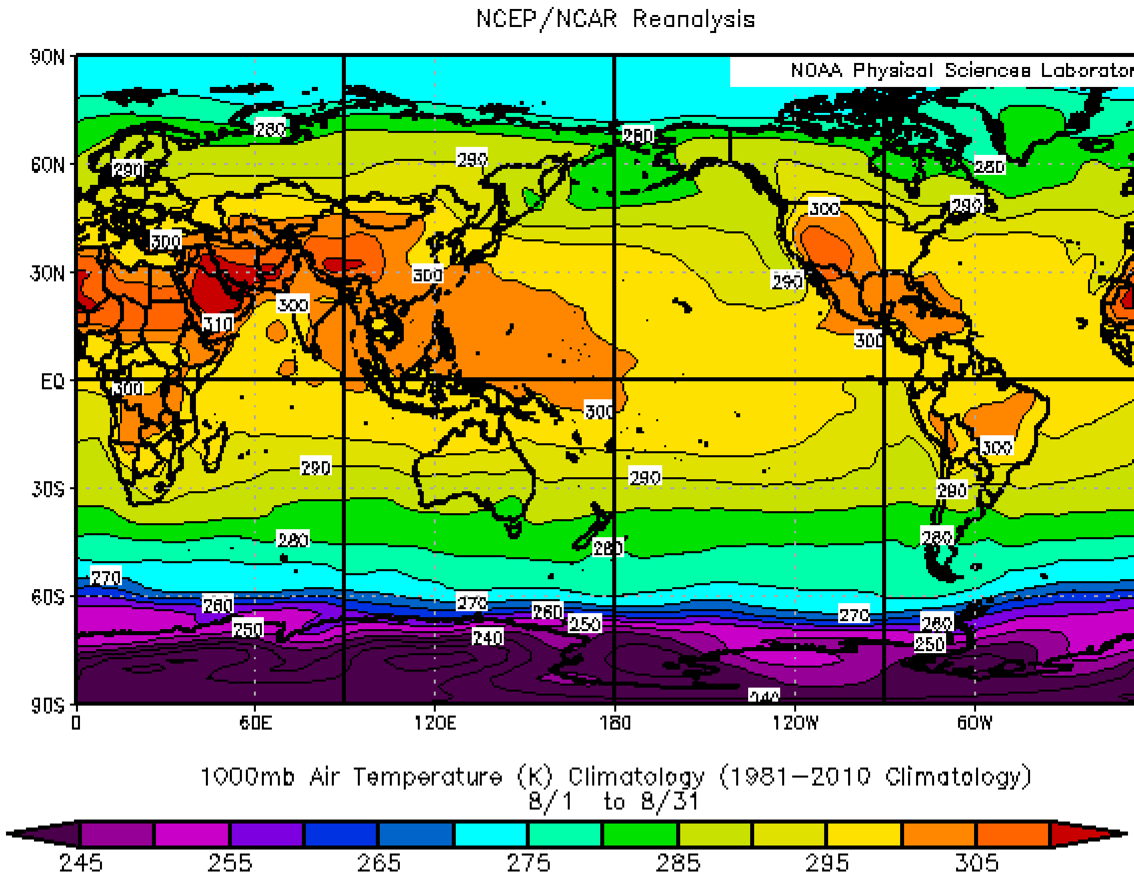

Fig. 6. Climatology of global temperature for July (top) and August (bottom).

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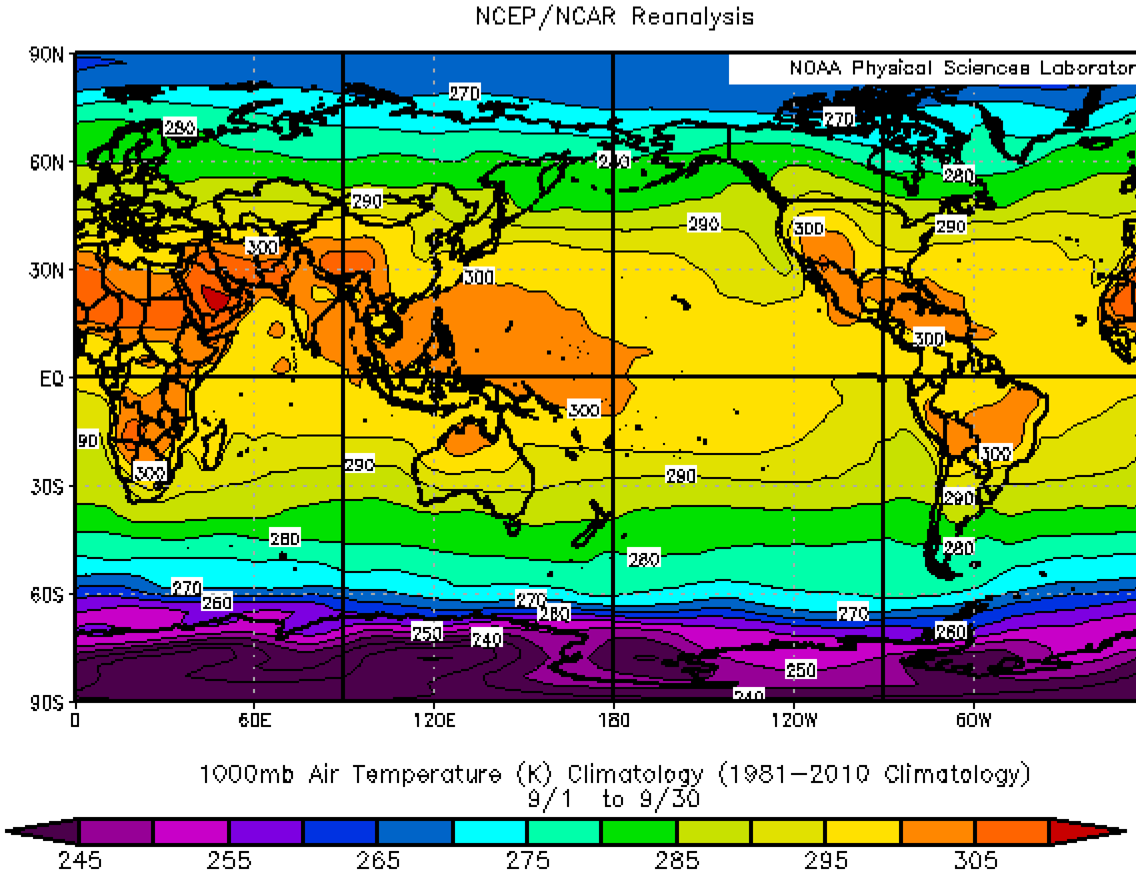


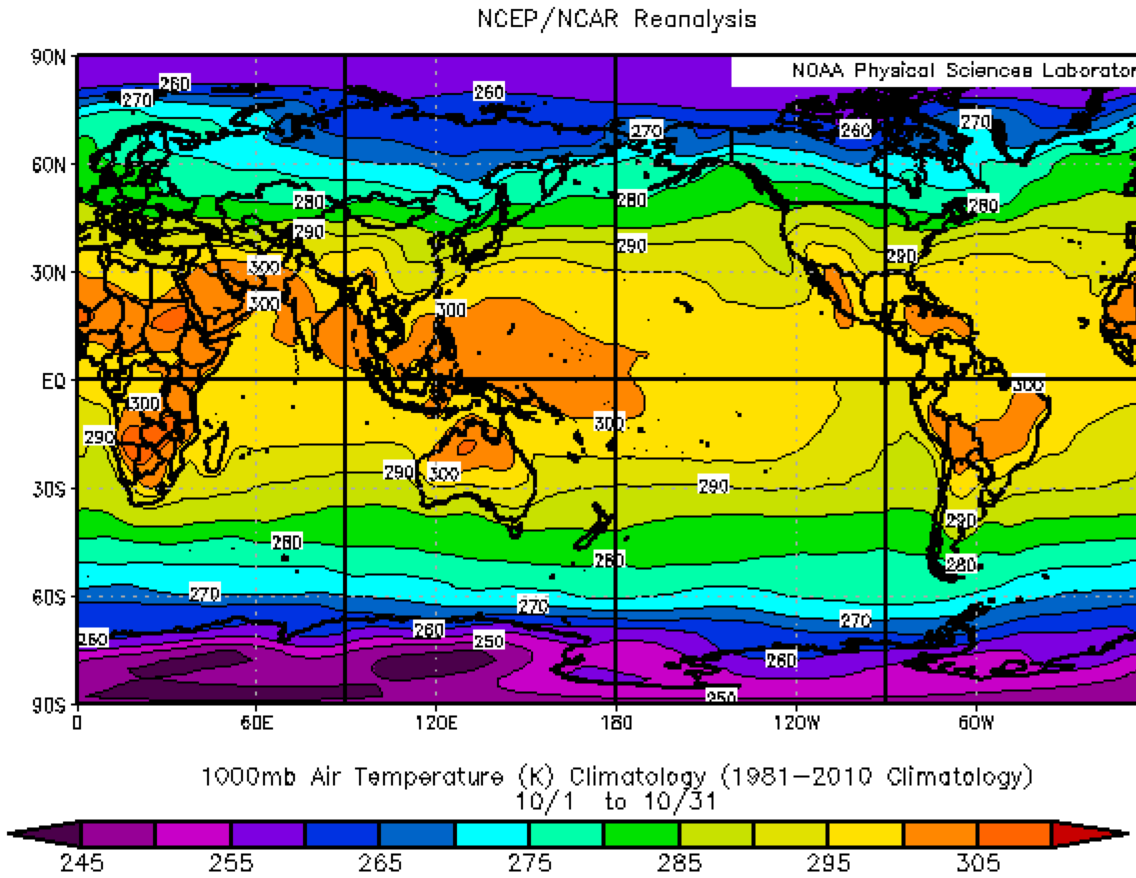
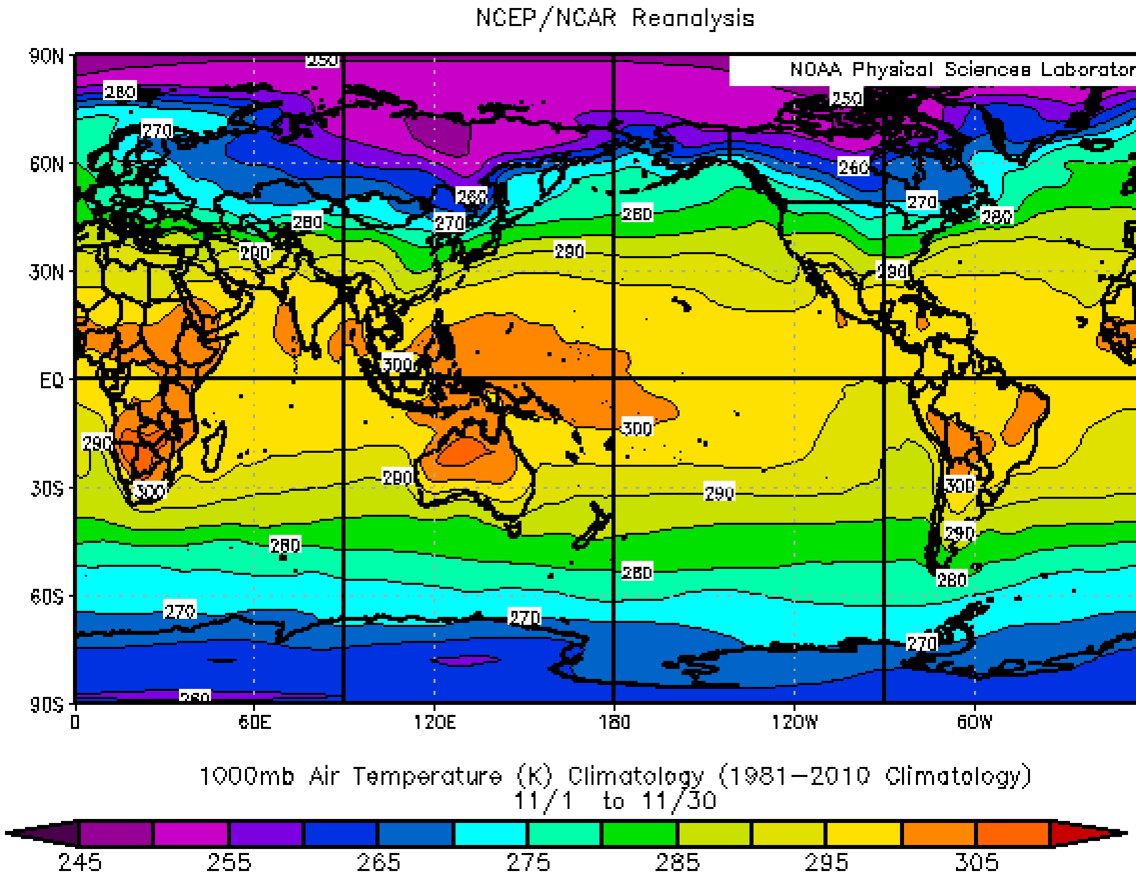


Fig. 7. Climatology of global temperature for September (top) and October (bottom).



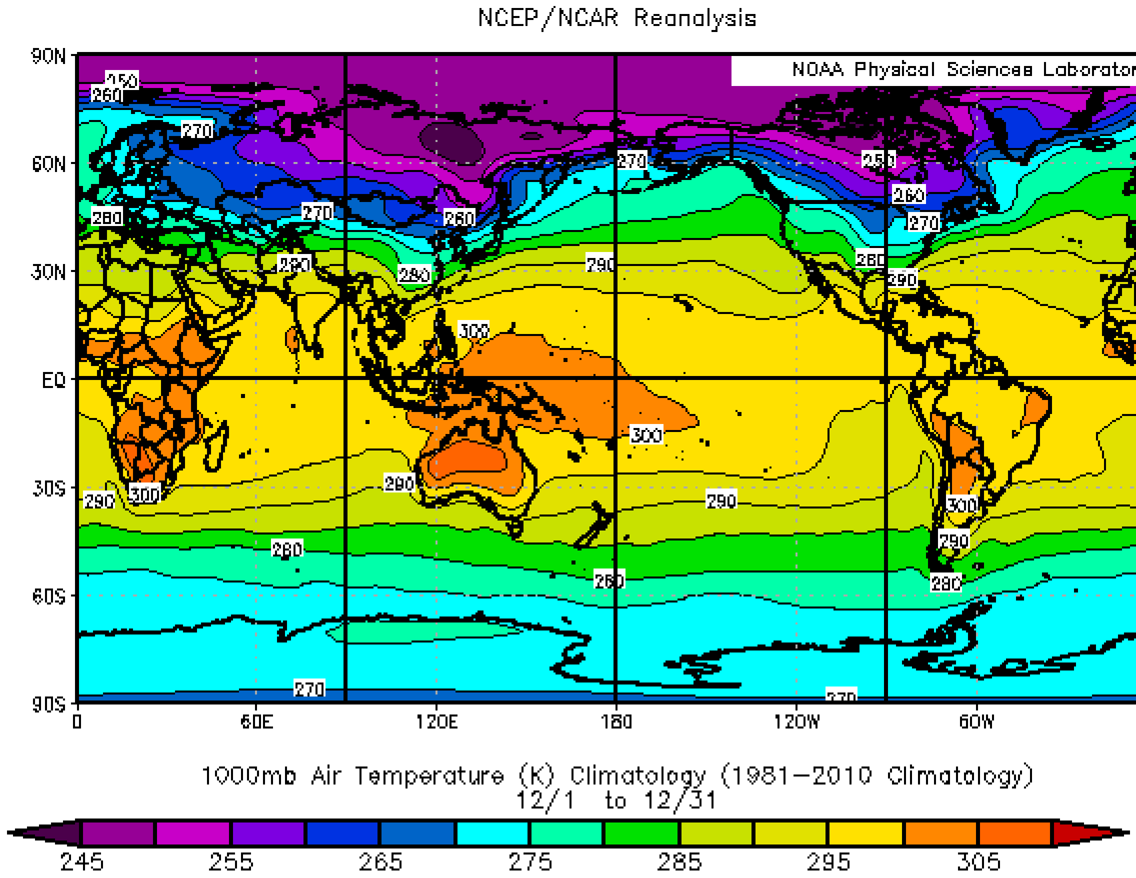
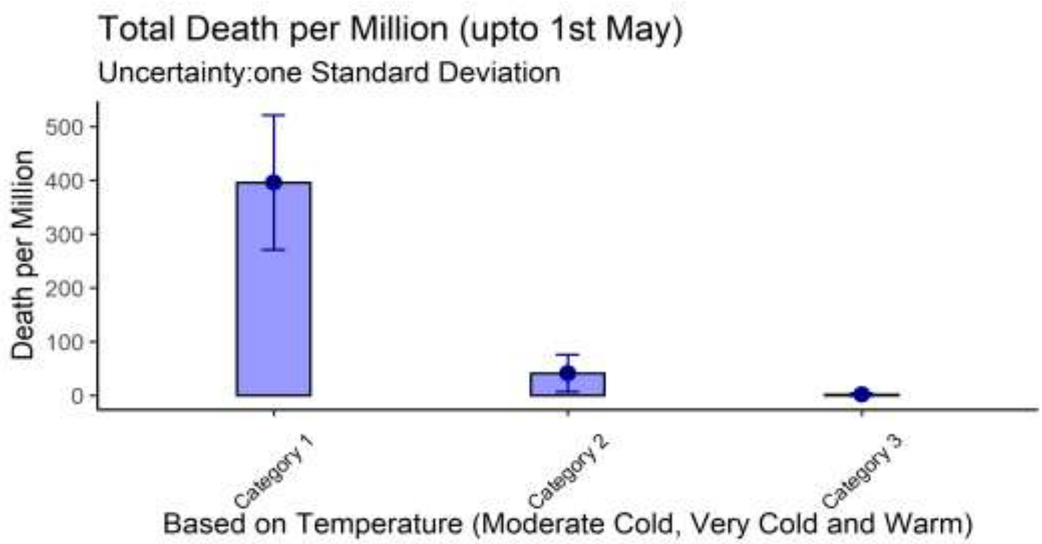
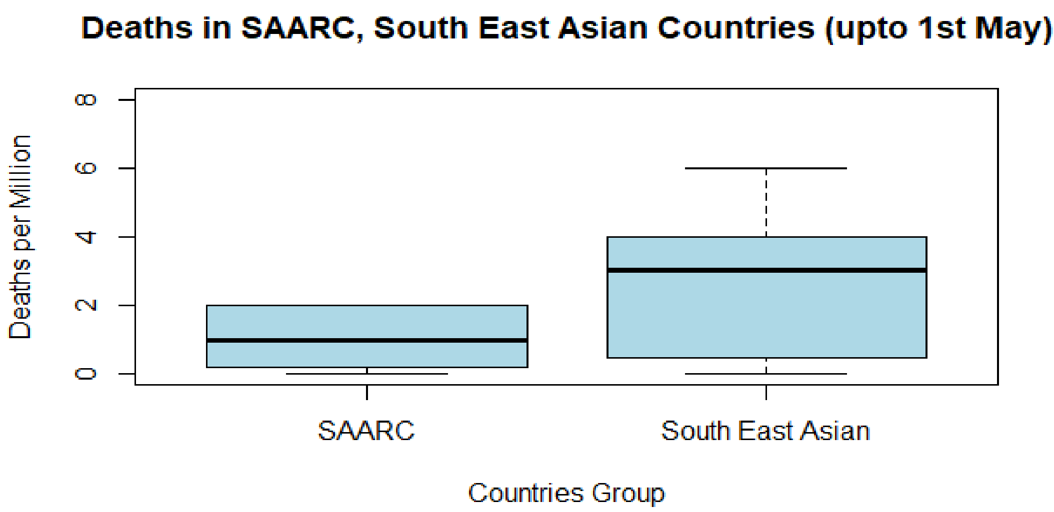


Fig. 8. Climatology of global temperature for November (top) and December (bottom).

a)


Total Death per Million (upto 1st May)
Uncertainty:one Standard Deviation
Death per Million
500
400
300
200
100
0
Category 1
Category 2
Category 3
Based on Temperature (Moderate Cold, Very Cold and Warm)

b)


Deaths in SAARC, South East Asian Countries (upto 1st May)
Deaths per Million
8
6
4
2
0
SAARC
South East Asian
Countries Group

c)

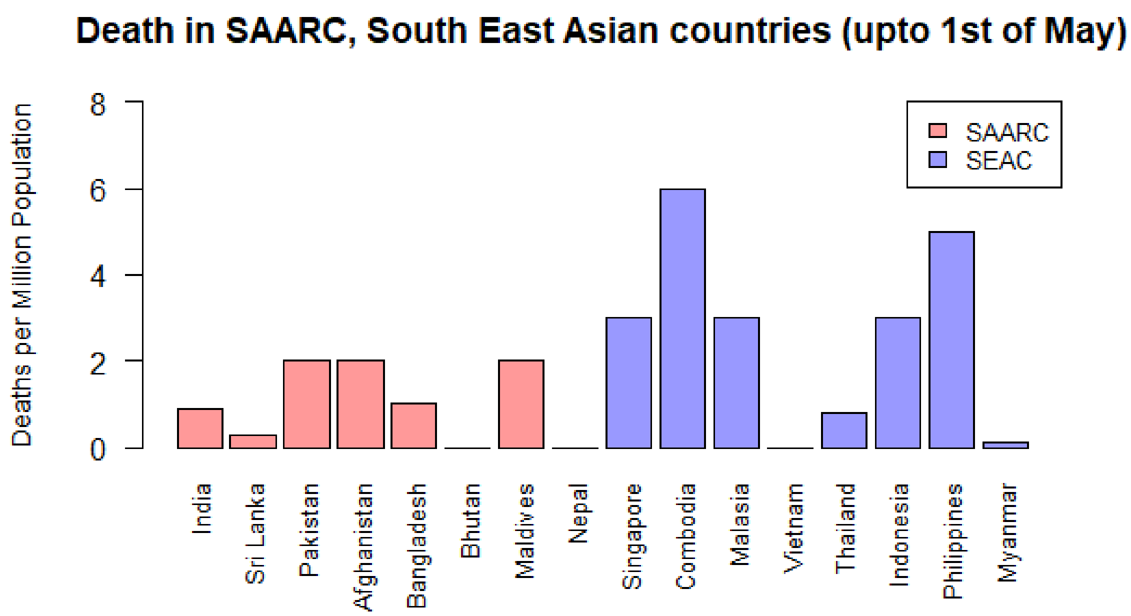

Death in SAARC, South East Asian countries (upto 1st of May)
Deaths per Million Population
8
6
4
2
0
SAARC
SEAC
India
Sri Lanka
Pakistan
Afghanistan
Bangladesh
Bhutan
Maldives
Nepal
Singapore
Combodia
Malasia
Vietnam
Thailand
Indonesia
Philippines
Myanmar

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Fig.9. Vulnerability to COVID-19 measured in terms of Deaths per Million, upto 1st of May 2020. a) Deaths in Moderately cold, Very cold and Warm countries are shown. In category 3, all Warm countries (SAARC and South East Asian countries (SEAC), continents of Australia and Africa) together are presented. Uncertainty at one standard deviation level is marked. b) Box plot with particular focus on SAARC and SEAC groups. c) Record of each individual country from b.

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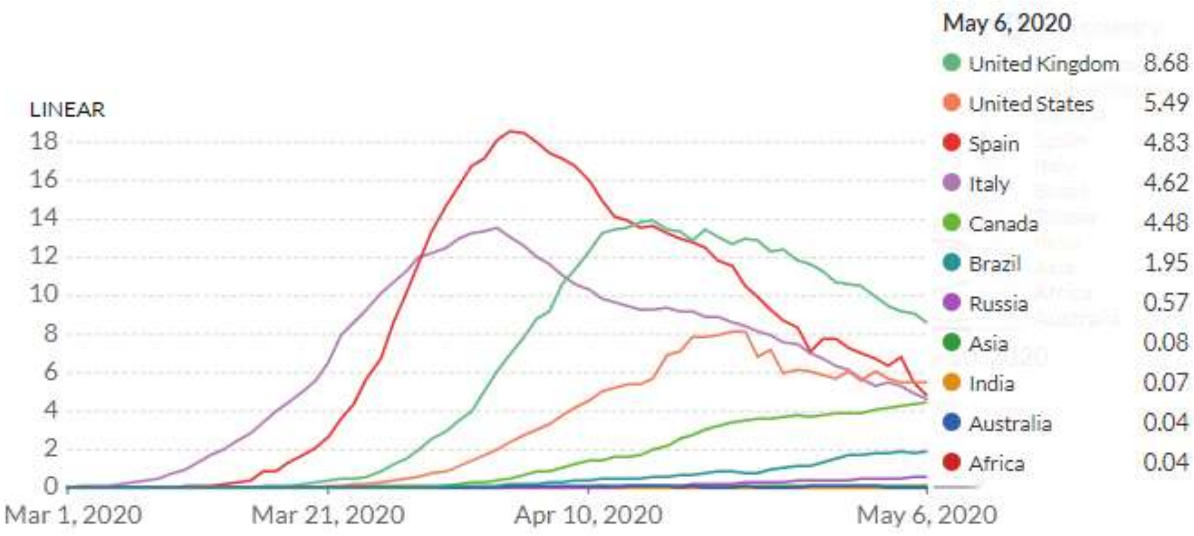
Rolling 7-day average of daily confirmed COVID-19 deaths per million



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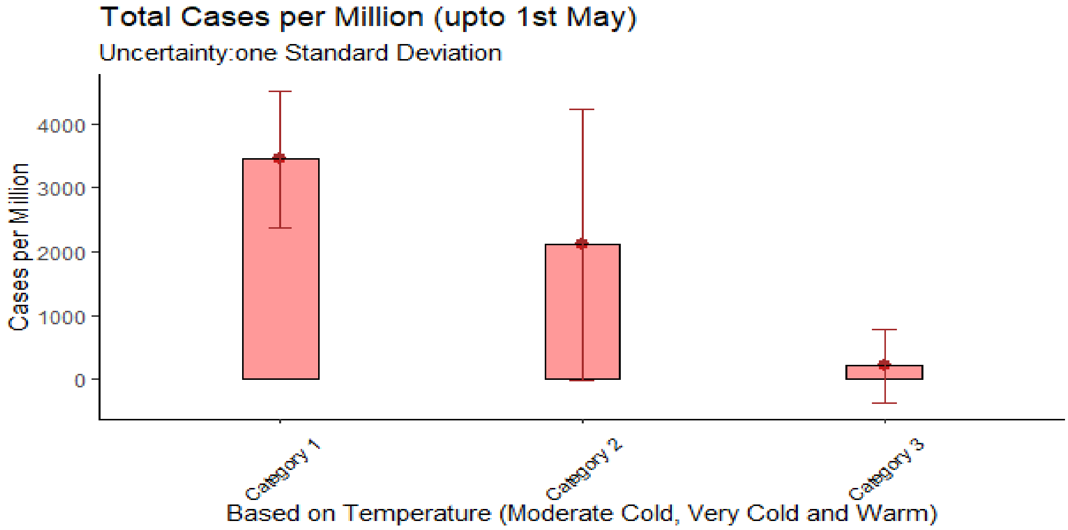
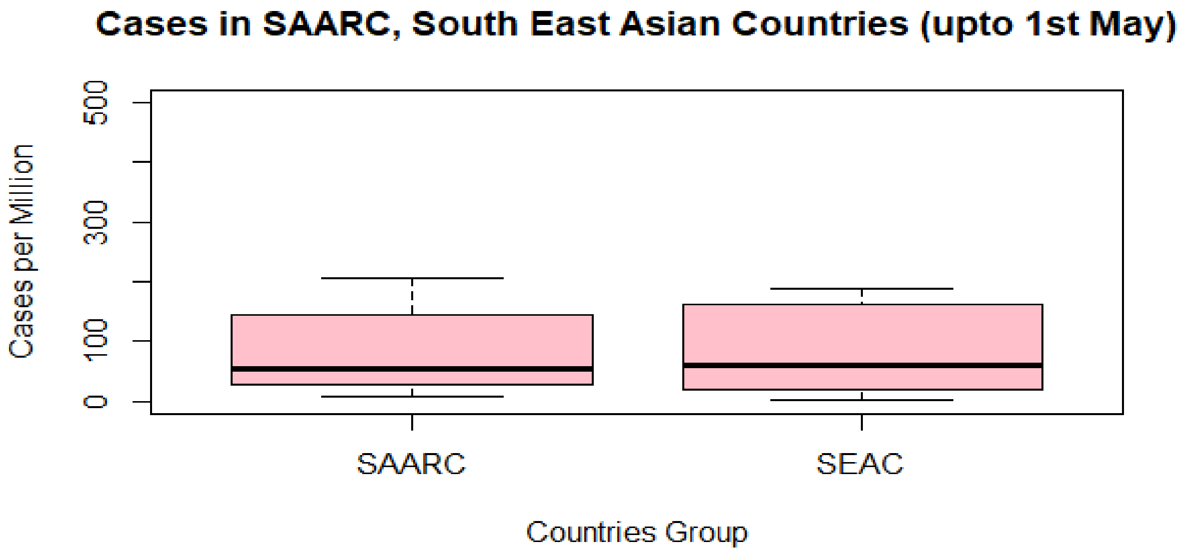
a)



b)



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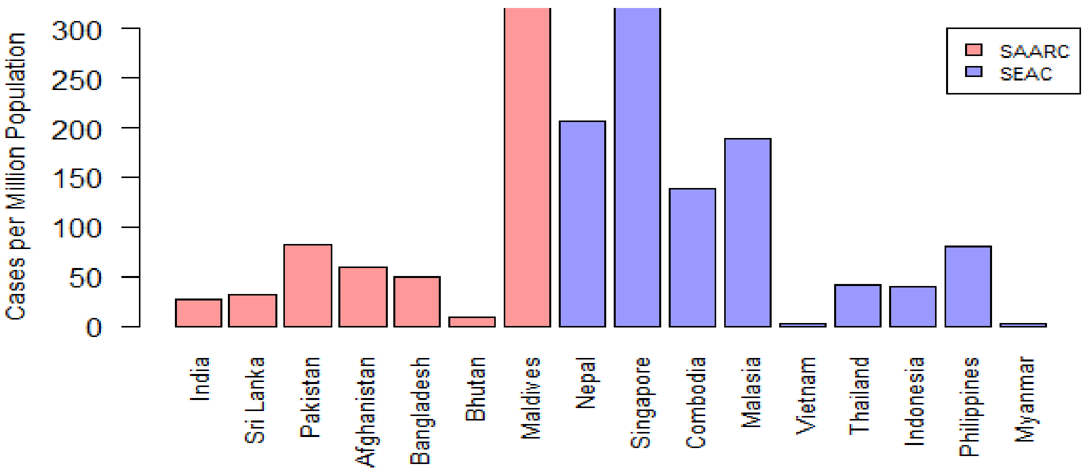

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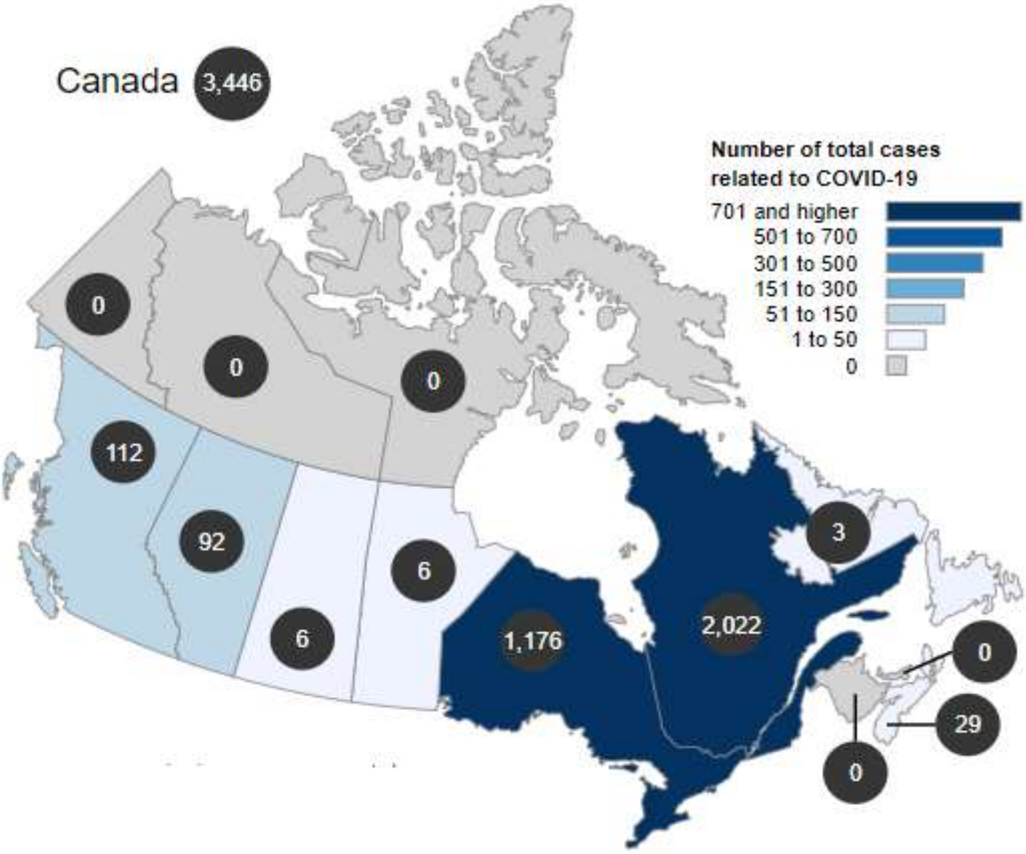
a)



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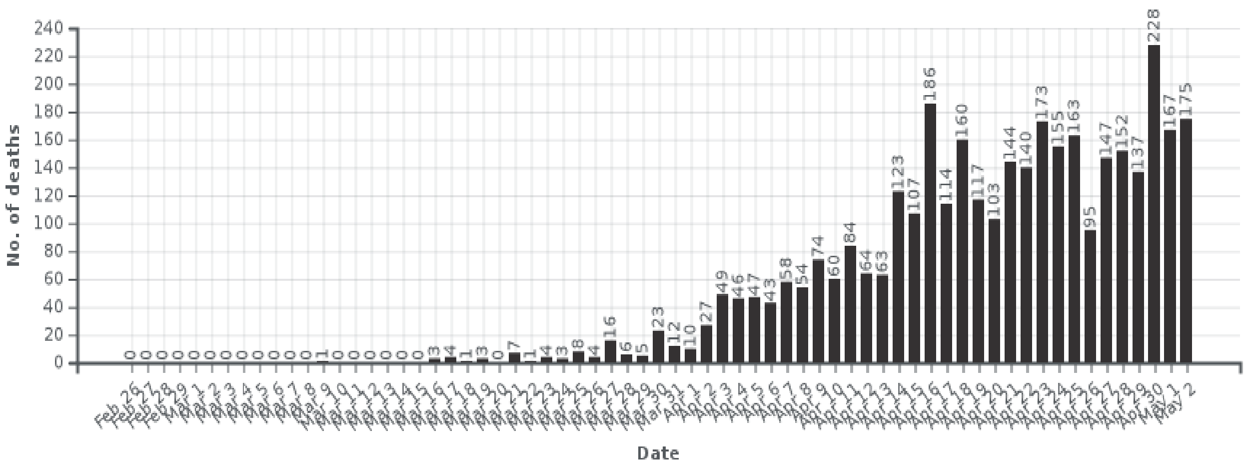

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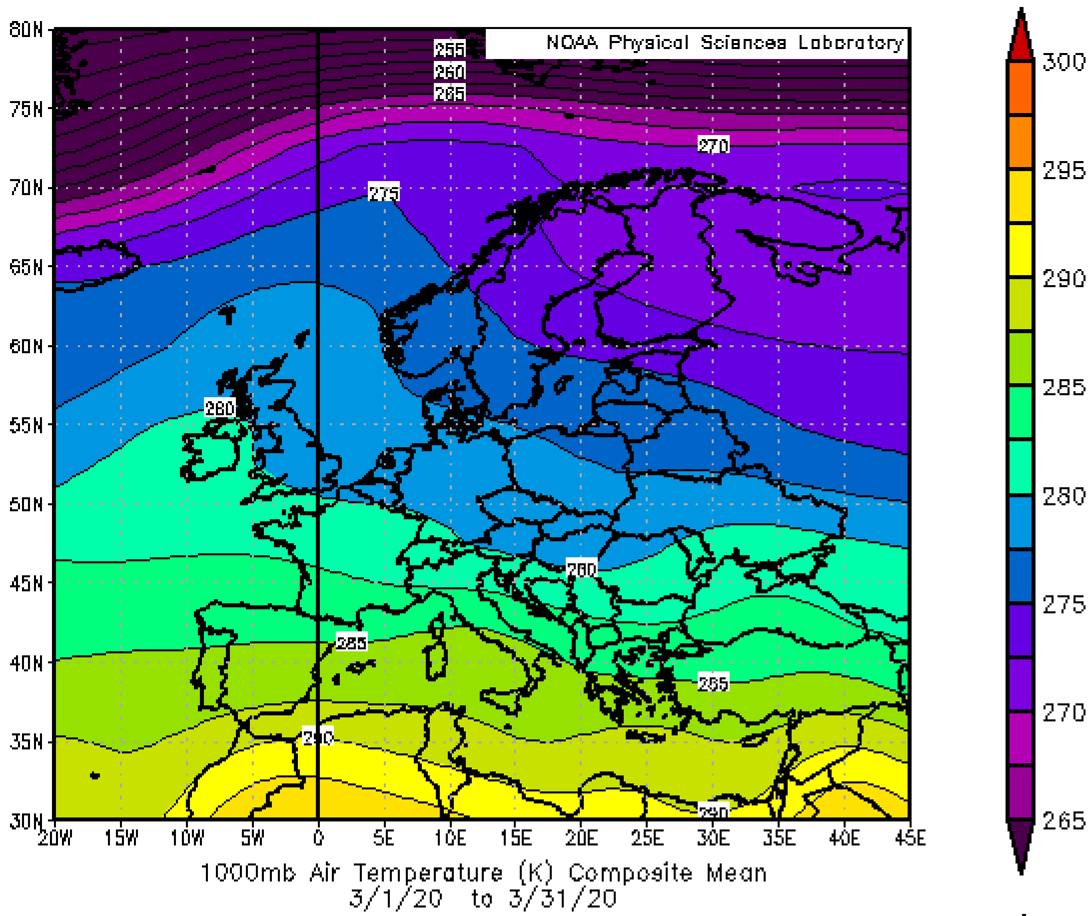

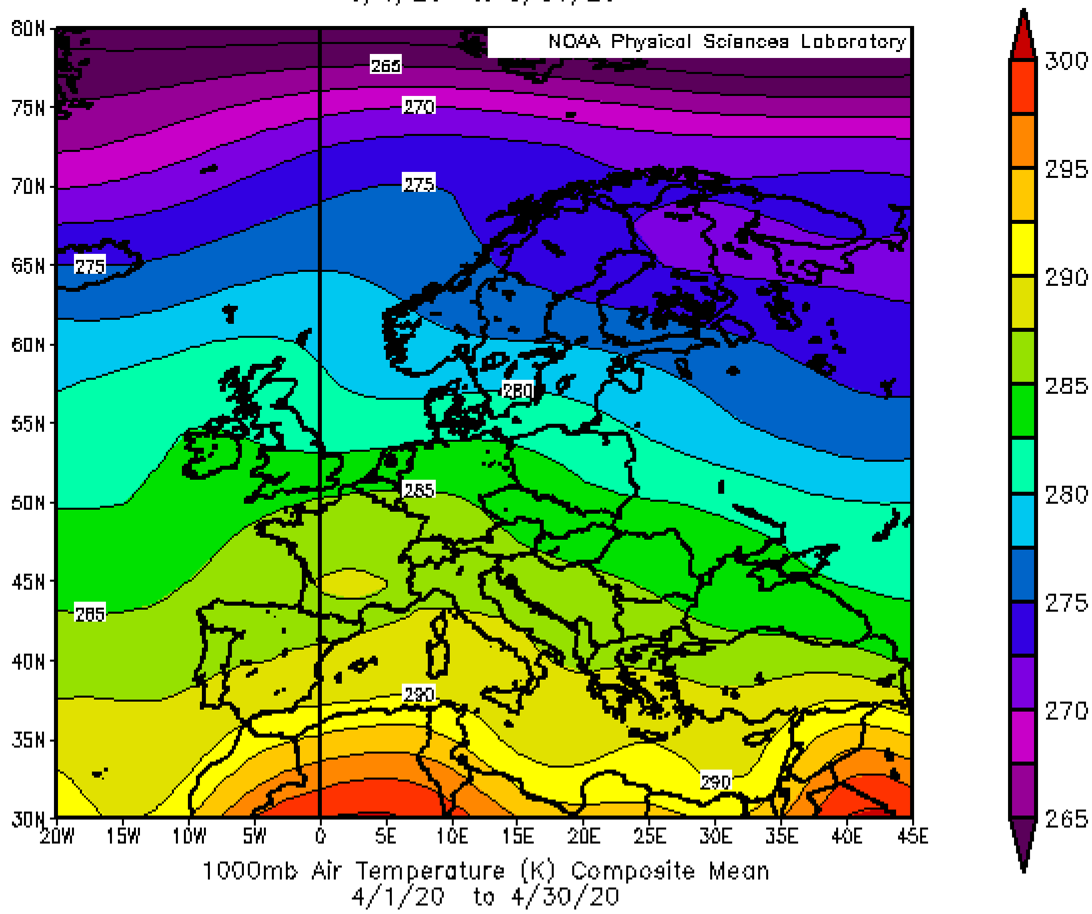

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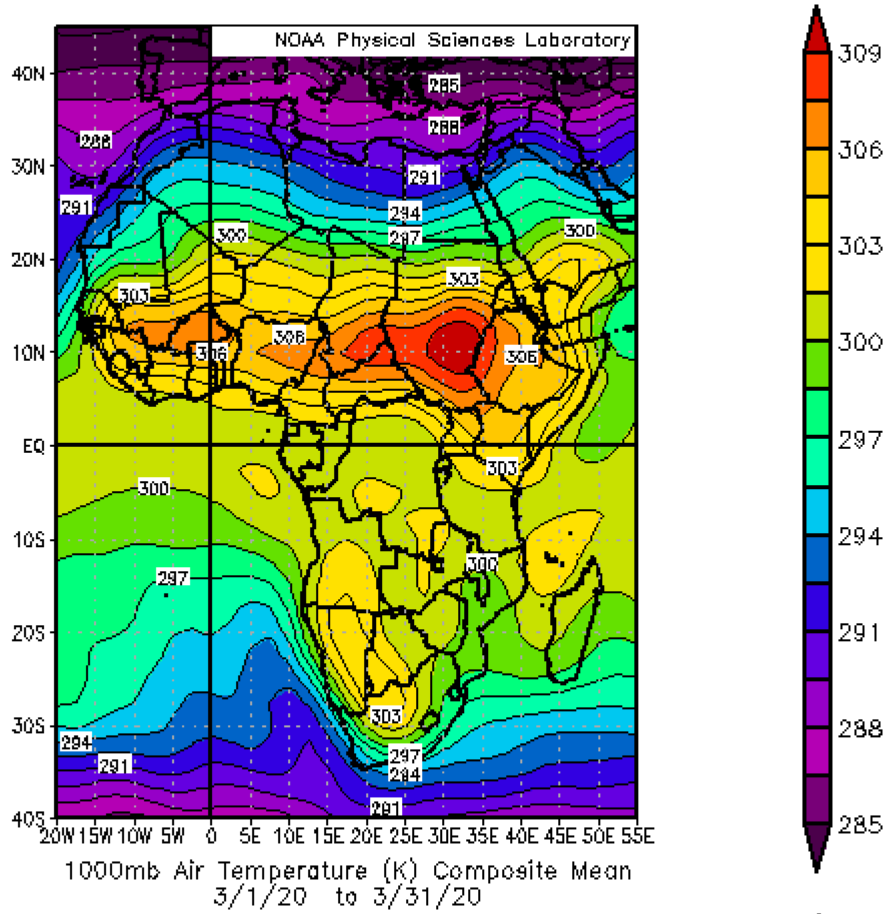

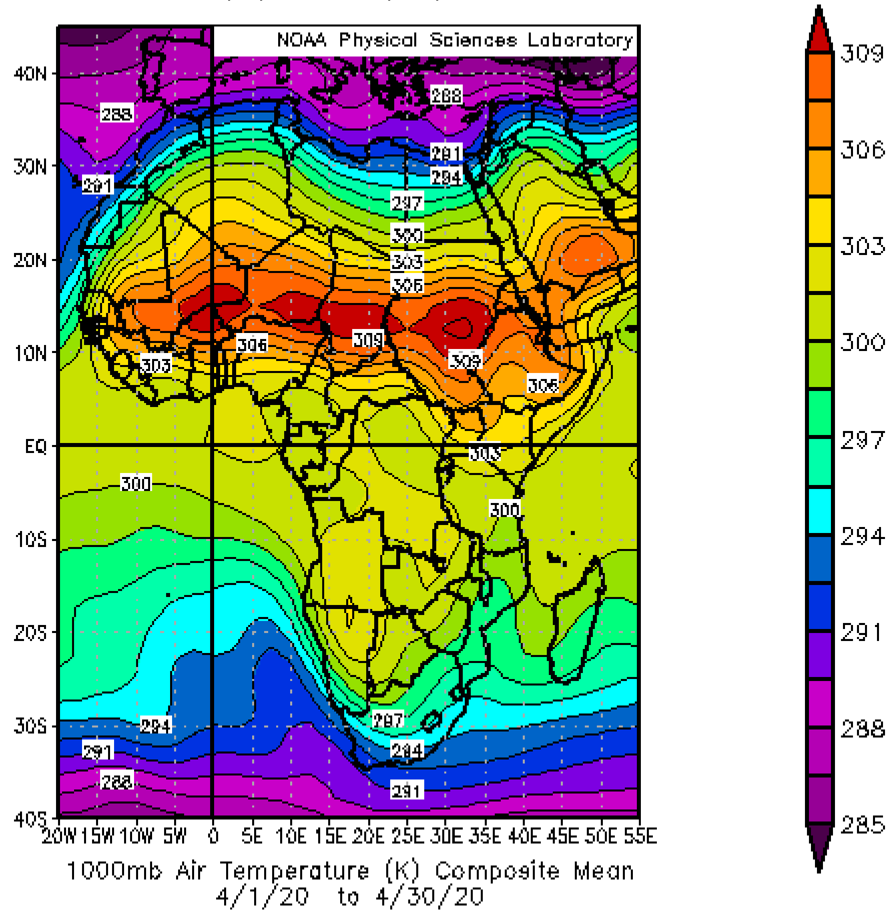

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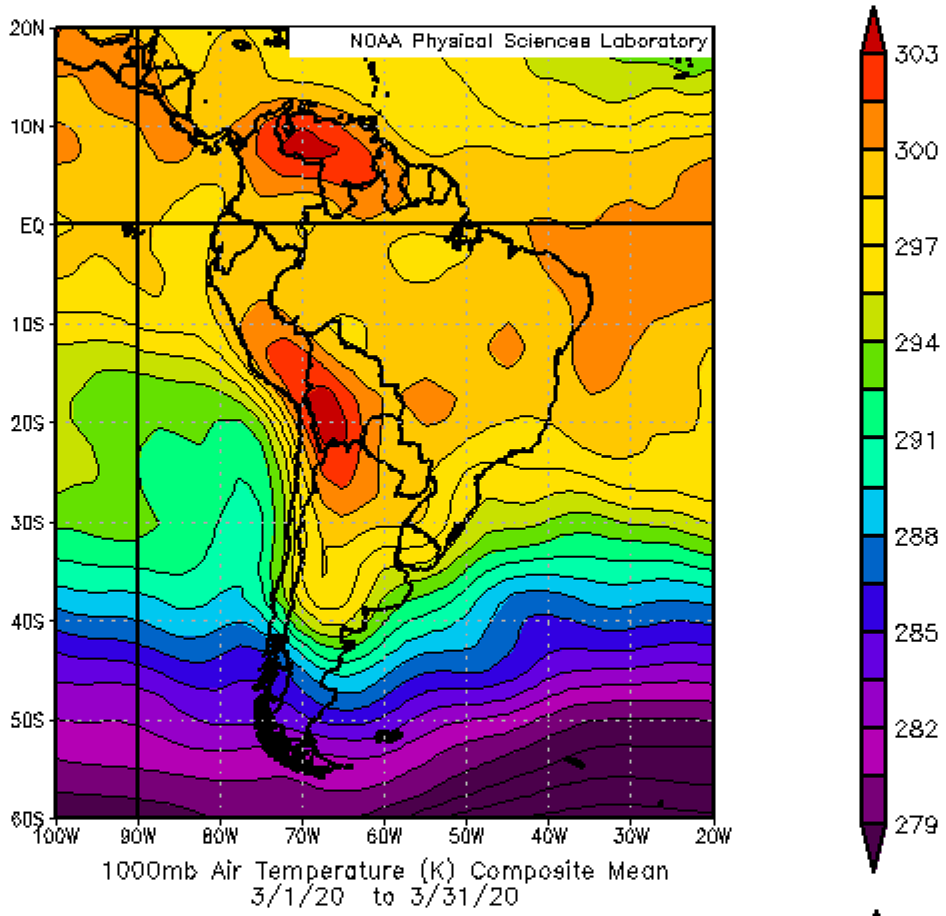
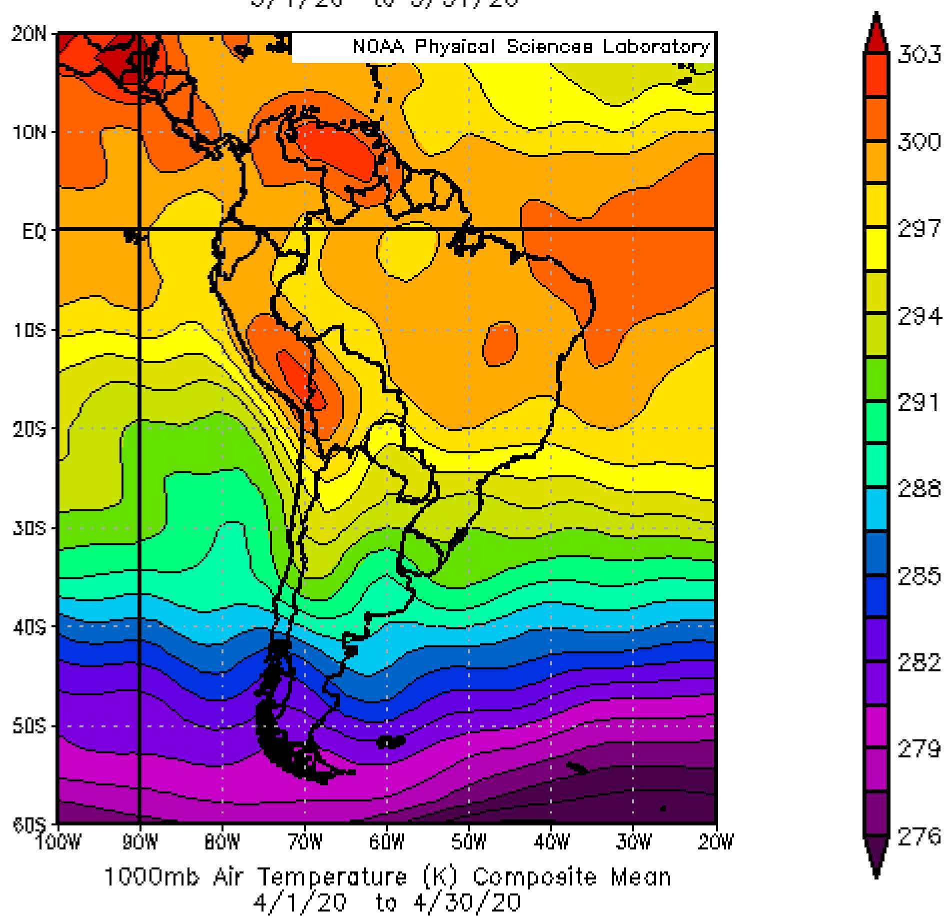
Fig. S4. Mean Air temperature in March (Top) and April (Bottom) for Africa in NCEP/NCAR Reanalyses


NOAA Physical Sciences Laboratory
20N
10N
EQ
10S
20S
30S
40S
50S
60S
100W
90W
80W
70W
60W
50W
40W
30W
20W
303
300
297
294
291
288
285
282
279
1000mb Air Temperature (K) Composite Mean
3/1/20 to 3/31/20


NOAA Physical Sciences Laboratory
20N
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EQ
10S
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90W
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70W
60W
50W
40W
30W
20W
303
300
297
294
291
288
285
282
279
276
1000mb Air Temperature (K) Composite Mean
4/1/20 to 4/30/20

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Fig. S5. Mean Air temperature in March (Top) and April (Bottom) for South America in NCEP/NCAR Reanalyses.

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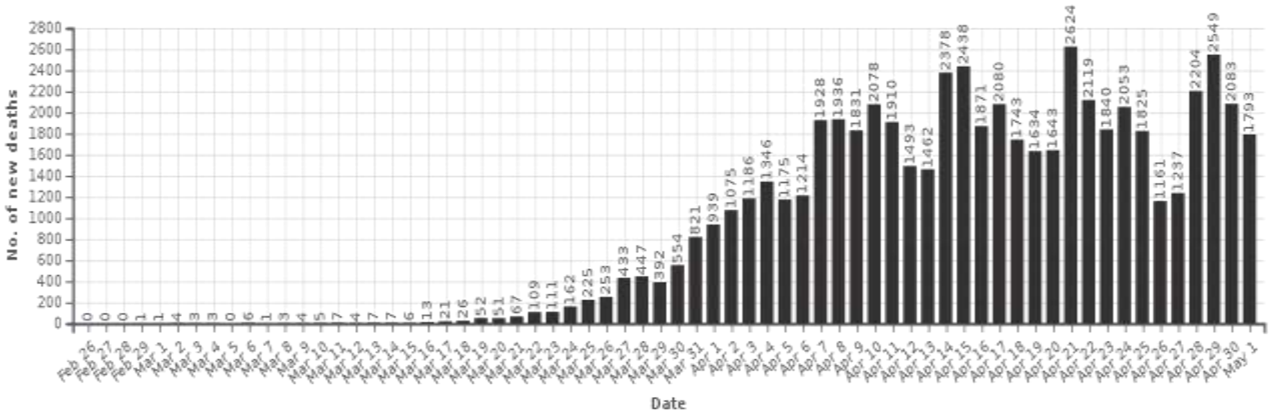
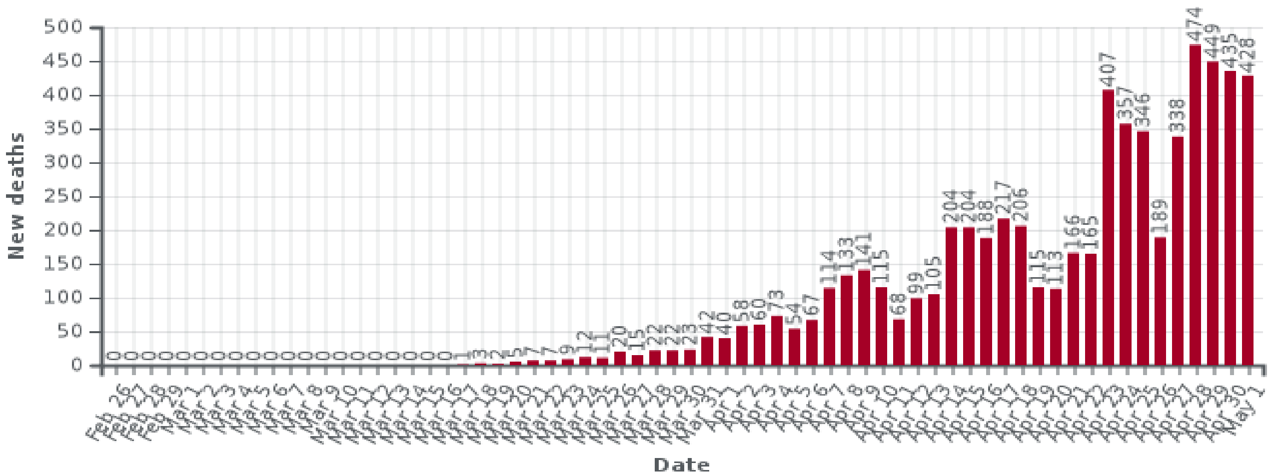
USA



Brazil



India

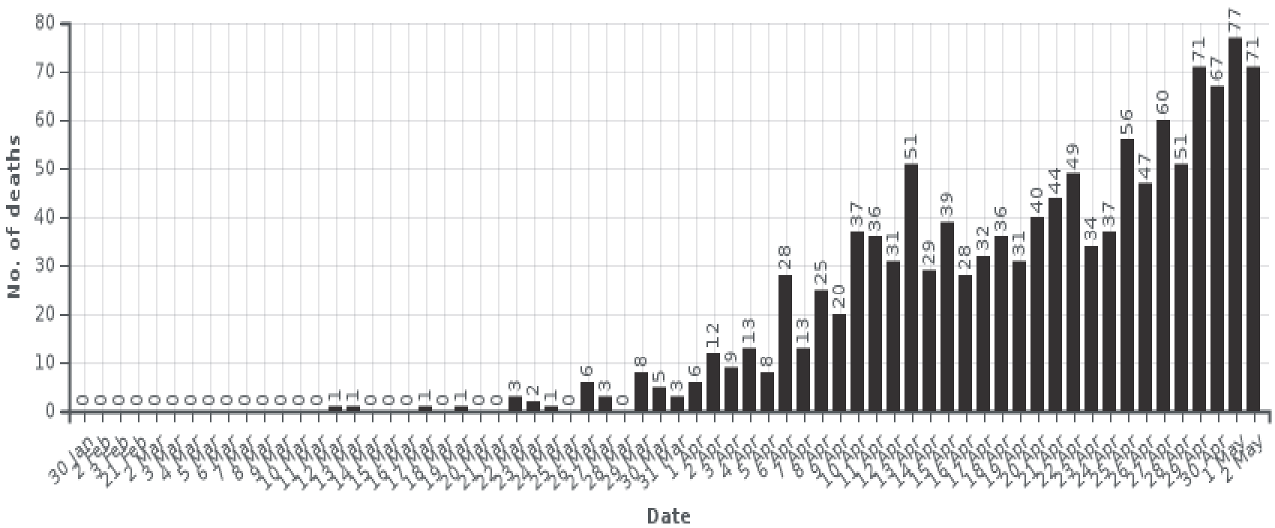


Fig. S6. Daily death counts of three very high populated countries e.g., USA[30], Brazil[31] and India[32] till 2nd May 2020. Note three different ranges of Y axis of three countries. The USA shows very high range (maximum 2624), Brazil moderate (maximum 474) and India low (maximum 77). The USA currently suggests a plateau, Brazil shows a sharp rise while India shows a moderate rise.