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The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world

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Abstract
This is the translated and edited version of the paper "Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet" by W. Köppen, which originally appeared in 1884 in the Meteorologische Zeitschrift.

Superscript numbers indicate original footnotes (translated at the bottom of the page), E... numbers indicate editorial endnotes (at the end of the article), square brackets [] indicate editorial comments in the text.

Humans and the entire organic world depend on climate in two ways. On the one hand, heat and water supply directly affect vital functions. On the other hand, they have an indirect impact by favouring or suppressing other species. The direct dependence is most prominent for plants and cold-blooded animals; for warm-blooded animals, whose body temperature is almost entirely independent of ambient temperature thanks to a wonderful mechanism,[1] the indirect impact of the climate is more important. In fact it is not so much the unfavourable weather which restricts or entirely excludes human settlements in the ice deserts of the polar regions – we can find similarly cold conditions for parts of the year in areas with comparably dense population – but the difficulty or impossibility to find suitable organic food, due to the absence of food plants. Climatic illnesses [klimatische Krankheiten] are in-between these two groups of causes. Today, they are increasingly attributed to the impact of tiny organisms, whereas they used to be considered as direct effects of the climate or inorganic conditions.

The direct impacts of temperature that noticeably affect higher plant species are also diverse. The direct lethal effect of a certain temperature has to be distinguished from the impact of temperature (which is required to be within certain limits to enable life) on the speed and the intensity of vital functions. While some bushes are endangered of being killed by frost, the growth of others is impeded by a short or cold summer, during which the wood cannot mature, i.e., the neces-

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[1]Everybody knows from his or her own experience that the body temperature remains constant with low ambient temperature; however, it may be less known that the body temperature also remains constant when ambient temperature exceeds the normal blood temperature. This fact makes it possible for humans to travel through and to inhabit red-hot regions where ambient temperature exceeds 38 °C every noon, such as in the Colorado desert[E1] and in parts of the deserts of the Old World, sufficient water supply provided.

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sary life cycle of vital functions cannot be completed. In many cases, the available heat may be suff cient for individual existence, but not for the formation of mature seeds, so that the permanent existence of a species in a country is not possible without continued colonization or the support by humans. Even here, there are manifold linkages of causes, for instance, the wood that has not matured is more easily killed by frost. As a consequence, the plant that has partly been killed by frost can prof t less from the available heat. Since the studies by SACHS[E2], it is known that the germination and probably also the growth of plants is fastest at a certain temperature called the optimum, and it becomes slower the more the temperature differs upwards or downwards from that optimum, until, at a certain distance, growth stops and apparent death occurs. With increasing distance from the optimum, real death occurs ever faster.

All higher organisms can survive only if the temperature of their juices does not exceed a certain threshold, which is between 40 °C and 55 °C at the highest, and does not fall below a certain threshold, which is slightly below 0 °C, depending on the concentration of the juices. In the former case, the proteins coagulate, in the latter they freeze. However, the latter condition only suspends the life of many plants and animals of higher order, and is followed by a revival provided the thawing takes place suff ciently slowly.

As is well-known, it has often been tried to express the evident inf uence of the temperature on the rate of plant growth quantitatively by formulae. More complicated assumptions, such as for instance, that the duration of a development stage would be in proportion to the square or square root of the difference between the temperature and the freezing point, have not been met with approval. The f nding that only above certain thresholds, which are different for all plants and vital functions, the duration may compensate for the height of the temperature has also contributed to dissociate from focusing on the freezing point. However, the assumption that, above such a threshold, the product of time and temperature is a valid indication for the effect of heat on the plant, is still held by many strong advocates,[2] although even that assumption is undeniably based on arbitrary preconditions. In those cases where the threshold is not determined, it is not astonishing that by assuming different values for the threshold, one may f nd fairly consistent "sums of temperature" for the different years. This is because it cannot be denied that in warmer years, vegetation grows earlier than in colder years, and only the extent and the nature of the inf uence are problematic. However, the thresholds given by nature, where the comparison is carried out, are very narrow.

Under such circumstances, it seems more advisable to focus only on the duration of the period, during which the temperature is above a certain threshold or between certain thresholds respectively, apart from all preconceived assumptions. By studying the growing season of the respective plant, GRISEBACH[E3] contributed to the understanding of various important thresholds for the vegetation: He showed that the natural range ends where the period with favourable conditions for the growth of that plant is shorter than a certain value. When studying more closely the natural ranges of woody plants in Russia, I took a particular interest in a peculiarly shaped belt: It includes the borders of many of the most ordinary central-European trees and bushes and ranges from the Gulf of Finland[E1] eastwards to the Ural[E1], and from there southwards and then south-westwards to the lower reaches of the Volga[E1] and the Don[E1]. Within this belt of only about 300 km width, there are the borders of the natural range of the oak (Quercus pedunculata), the European white elm (Ulmus effusa), the Norway maple (Acer platanoides), the hawthorn (Crataegus Oxyacantha), the hazel bush (Corylus Avellana), the spindle tree (Evonymus verrucosus) and of the forest apple (Pyrus Malus). These are also the most north-eastwards advancing representatives of their genera, whereas some other types of wood, such as Alnus glutinosa, Prunus spinosa and Rhamnus catharticus, whose borders also fall within this belt, have close relatives (Alnus incana, Prunus Padus, Rhamnus Frangula), which extend further to the north. In western Russia, the lime and the European ash also reach the border of their natural range with the trees just mentioned. However, in the east, the lime reaches slightly further north, probably beyond the Ural, whereas the European ash remains further southwest, so that it only reaches the Volga in the area slightly below Nizhny-Novgorod[E1]. The northern border of the belt is located where the usual period with mean temperatures of more than 10 °C is shorter than 4 months, whereas the south-eastern border is given by the continental steppe where there is insuff cient rainfall for enhanced evaporation, which is hostile to any tree growth. There is no doubt that in both cases, historical (geological) conditions as well as competition with other organisms have contributed to determine the particular position of the borders, since humans were able to cultivate the same plants slightly further to the north and much further to the southeast than the natural ranges. There are cer-

[2]Cf. in particular A. v. OETTINGEN: Phänologie der Dorpater Lignosen (Dorpat, 1879)[E4]. In this publication, the author argues vigorously against the view that the use of the temperature sum postulates that growth is a linear function of temperature. His proof, however, only states that the dependency of the growth rate on the phase, i.e., an inhomogeneous growth with constant temperature, is compatible with the use of temperature sums (provided the threshold remains constant). However, he admits on p. 31 that with different constant temperatures, the growth rate in the same phase would have to be in proportion to the temperature (or the temperature deviation from the threshold; $t - s$); that this should be the case in reality is the arbitrary assumption that physiologists clearly reject. I sincerely regret that it is entirely impossible for me to take the position for which a scientist argues, whom I highly respect. Nevertheless, in spite of sincere efforts I have not succeeded in understanding its justif cation. It would take us too far away from our proper task to reply here to the substantial discussions by OETTINGEN.

tainly isolated spots in northern Russia and particularly in western Asia where the plants could also grow without the help of humans, but the vast distances between the spots and their minor extent, amidst an alien vegetation, much better adapted to the conditions, make the immigration and the continued existence of the species too diff cult in those regions.

The polar zone represents an even more important border to tree growth of a similar kind. It is close to the 10 °C isotherm of the warmest month. Where the usual period with daily temperature means above 10 °C is shorter than a month, trees do not even occur anymore in rudimentary state and in the tundra, the last forest islands are all close to that border. The cold of the winter, on the other hand, does not noticeably affect tree growth, and in the entire vast basin of the Lena[E1] and in a major part of the Yenisei river basin[E1], standard woods still grow, on a ground of which only the topmost layers thaw. The mean annual temperature apparently is in no way decisive for the vegetation conditions.

It becomes clear to what extent the living conditions of humans are inf uenced by the thermal boundaries just discussed, namely whether the period with mean temperature above 10 °C equals one or four months respectively, when we mention that the oak boundary line is almost identical with the wheat boundary line. Beyond the forest line, on the other hand, not only is cultivation not possible anymore at all, but huntable animals can almost exclusively only be found in the sea. It is evident that the shortening of the vegetation period in areas, where cultivation is still possible, even more directly inf uences humans. It means a concentration of all f eldwork on a few months and enforces different earnings during the long winter. Likewise, the contrast between the long winter and the dreamlike short summer in the north must have inf uenced the mental life of the Nordics.

Starting from such points of view, I tried to show the climatic zones of the Earth, based on the period during which the temperature remains above or between certain thresholds [Plate 1]. I did this according to the real conditions at the Earth's surface, without reducing the values to an ideal uniform level. It would have been much easier to draw the map according to temperature values reduced to sea level. However, I considered it much more informative to use the temperature conditions of the lowest air layer close to the real ground, in particular for using the map for plant, animal and cultural geography. I will come back to the method applied further down. Here, I will only mention that I deliberately refrained from considering small details in order not to disguise the essential characteristics by representing doubtful details. This means that I have included only mountains with a suff cient extension for representing a predominant region, and I have skipped the others.

I decided to use daily mean temperatures of 10 and 20 °C as threshold values and one and four months as def ning time periods, in accordance with the relationship between tree line and oak climate described above. The consideration of the daily temperature variation would indeed be an interesting completion of the picture; however, for a number of reasons it is practical not to complicate the basic characteristics of the picture by doing so. There are other factors in the behaviour of heat that must have a signif cant inf uence on the organic world, such as the variability in temperature according to DOVE[E5] or HANN[E6]. In fact, what we show on the map, based on multi-annual means, and consider to be offered to the plant, is not offered in a particular year; and where the heat conditions show large variation between different years, the occasionally occurring unfavourable years (and they often occur in series) will create living conditions that are worse than they appear to be according to normal values. An example for this may be the absence of the oak and coexisting wooden plants in south-western Siberia. There we can f nd a belt, albeit small, offering "oak climate" according to normal values in an area, where precipitation is quite suff cient for luxuriant tree growth. Nevertheless, the oak and coexisting wooden plants, which I mentioned above, do not cross the Ural. Only a couple of representatives (such as Alnus glutinosa) occur here and there in the outliers of the Altai[E1], whereas in the Barabà[E1], the luxuriantly growing birch tree is almost exclusively present.[3] Since in western Siberia, the mean variability according to DOVE[E5] (mean deviation for single years from the normal value) is larger than anywhere else in the world, we do not need to search for other reasons for the absence of the tree species mentioned. However, the effect of this factor may be reinforced by another, which is also extraordinarily strong in west Siberia, namely the variability according to HANN[E6], or the mean temperature change from day to day.

The number of possibilities for combining time periods (1, 4 and 12 months) and temperature values (10 and 20 °C) is considerable. However, in practice only some of them are possible and therefore, the annexed map [Plate 1] differentiates only between seven belts, six of which occur on the northern as well as on the southern hemisphere and are frequently segmented by mountains or by the contrast between land and sea.

1. According to our def nition, the tropical belt comprises those parts of the Earth's surface where the mean temperature of all months exceeds 20 °C. Furthermore, since – with a few exceptions – only in continental regions at the northern edge of the belt, the temperature reaches more than 30 °C in the warmest month, regularly high temperatures with small annual variation are characteristic and the division of the year depends on hydrometeors only. On average, the belt ranges from 20° N to 16° S. However, its width shows signif cant variation. On the one hand they are being limited by the cold currents on the west coasts of the continents and partly

[3]Cf. MIDDENDORFF, Mém. De l'Acad. De St. Ptrsbg., VII, 14 No. 9[E8]

by the radiation within the continents at times when the Sun is over the other hemisphere, and even more by elevation. On the other hand, the warm currents on the east coasts and the regular heat of the oceans shift the edge of the belt further polewards. In addition, in large parts of East Africa and America, the tropical zone is cut across by meridional mountain ranges. Islands and coasts close to the equator that are inf uenced by the trade wind show the character of this zone most distinctly. The following examples [Table 1] may show this.

2. In the subtropical belts, the temperatures are moderate during at least one and not more than eight months, while the high position of the Sun is predominant during a hot period of at least four months. In these belts, even more extreme heat is reached than near the equator due to longer days and less cloudiness. In many regions on the map, this belt is divided into two or three sections by a red and a blue line: First, an almost tropical belt can be distinguished, where the moderate, relatively cool season, with daily temperature means below 20° C, is short and lasts less than four months. In the rest of the belt, the hot season lasts less than eight months. On the southern hemisphere and on the oceans in general, this rest of the subtropical belt shows no really cool months with mean temperatures below 10 °C (with the exception of small bands on the eastern coasts of the continents). However, on the continents of the northern hemisphere, the subtropical belt includes extended regions, where the temperature of the coldest months is below the value mentioned and therefore, one can call it a proper winter. Inner China and the Southern states of the North-American Union belong, with the exception of the southern coast, to this part of the subtropical zone. Likewise, the southern section of the aralo-caspian basin[E1], the central parts of Persia[E1], Syria[E1] and Arabia[E1] as well as parts of Greece and southern Italy form part of it.

To identify the red line on the oceans and in the mountains in the lower latitudes would have required more material and furthermore, would have been worthless in those cases, where the total annual variation is very small. Because if the temperature deviates by 1 or 2 °C from 20 °C at the most, it hardly matters whether this happens for less or more than four months. Only where the annual temperature variation is large, such as in the Sahara[E1], both sections of the belt become broad and their distinction becomes important.

3. The temperate belts of both hemispheres include several sections, which have in common that moderate temperatures (10 to 20 °C) last for at least 4 months, and hot temperatures (> 20 °C) last for not more than 4 months. The f rst two sections of this belt, marked in violet and dark blue, complement each other. One of them, with no month above 20 °C or below 10 °C (called "constantly temperate") coincides with marine areas. The other, called "hot summer climate" where, nonetheless, temperatures fall below 10 °C for one or several months, coincides with continental areas. The third section, however, characterised by moderate summers and cold winters, forms an almost continuous belt around the entire Earth on the polar edges of the other two, distinguished from the constantly temperate section by the 10 °C isotherm of the coldest month, and from the "hot summer climate" by the 22 °C isotherm of the warmest month. It seemed more informative in this case to take a slightly higher value than 20 °C, because it results in a clearer climatic border. Otherwise, the following (temperate, hot summer climate) belt would have been reduced to a small band. However, here and there, a new in-between area emerges where temperatures remain above 20 °C during one to three months, but none of them reaches 22 °C. However, this area is too insignificant to require a representation on the map.

a. The temperate hot summer climate belt is closely related to the outer cold winter sections of the subtropical belt, from which it differs signif cantly only by the duration of the hot period. It was therefore intended to make the colours of the two belts similar. Only by an oversight, the colours for the hot summer climate and the constantly temperate area were interchanged, resulting in an exaggeration of the differences, particularly in the aralo-caspian region. Whereas, on the other hand, the contrast between the "eternal spring" of tropical mountains and the heat in the surrounding lowlands does not emerge as clearly as it would have been desirable. In this belt, the vegetation regularly suffers from drought, except for eastern North-America and East Asia, so that irrigation is required for horticulture as well as partly for cropping. High temperatures only indirectly affect the vegetation, namely by increasing evaporation; but since in these latitudes, high temperatures preferably occur in the summer of continental regions with little cloudiness and rainfall, heat and water shortage are closely related in major parts of this belt and draw a clear-cut line between the northern forest region and the deserts or steppes of the continental area. In the subtropical belt and the hot summer climate belt, the combination of heat and humidity, which characterizes the tropical belt for a major part of the year, only occurs in the monsoon areas of South and East Asia as well as at the south-eastern edge of North America and Brazil.

b. On the northern hemisphere, the areas continuously dominated by moderate temperatures form two separated areas on the Atlantic and on the Pacif c Ocean, aside from the tropical mountains. On the southern hemisphere, however, the so-characterized belt is cut at just one place by the South American continent, since it is located south of the southern ends of Africa and Australia. There, another striking irregularity shows instead, in that in the southern parts of the continents last mentioned islands-shaped can be distinguished. In those areas, due to the inf uence of the continent, the temperature of the coldest month is lower than on the sea at the continent's polar border. It falls below 10 °C. On the

Table 1: Coldest and warmest month (°C) at various locations close to the equator.[E7]

	Samoa[E1]	Cayenne[E1]	Para[E1]	Sansibar[E1]	Colombo[E1]	Batavia[E1]
Coldest month	24.1	26.1	26.0	25.2	26.5	25.3
Warmest month	26.7	27.7	27.7	28.1	28.6	26.4

southern hemisphere, the temperate hot summer climate belt is represented only on three small continental areas.

c. The third and outermost of the temperate belts, which we may call the "temperate cold summer climate belt", is characterized by moderate temperatures between 10 and 20 °C during at least four and at most eleven months and by temperatures below 10 °C during at least one and at most eight months. Months with mean temperatures above 22 °C do not occur. On our map, this belt, which currently is the main centre of human culture, is blocked in the East by the Altai mountains[E1] and only reoccurs in the Amur River region[E1]. This is indeed nearly the case and shows more prominently (see above) in the disappearance of almost all broadleaf trees already in the vicinity of the Ural and in the reappearance in the Amur River region. Inbetween, the Siberian coniferous forests reach to the steppes of Central Asia; in Western Siberia[E1], a birch forest region disconnects the coniferous forests in parts. However, the slope of the temperature curve will not be steep enough for causing the belt to disappear. It would require July temperatures of more than 22 °C with a mean temperature of the two months May and September of less than 10 °C. The required difference of 12 °C is not reached at any of the stations known, but still amounts to between 10.1 and 11.1 °C in Nerchinsk[E1], Blagoveshchensk[E1] and Selenginsk[E1], and between 9 and 10 °C in Semipalatinsk[E1], Barnaul[E1], Irkutsk[E1] and Urgá[E1]. Thus, the temperate belt with summers of suff cient length, but no regular heat, is not completely absent at the northern edge of Central Asia, but only represented by very small and irregularly formed bands (in particular due to the mountainous nature of this border region).

4. The cold belt neighbouring polewards, in which the number of temperate months is less than four but not less than one, and in which the vegetation period is much shortened, forms a continuous ring around the Earth on both hemispheres. The width of this ring is much more narrow on the southern than on the northern hemisphere because the annual temperature range is much smaller in the former. For this reason, the distance between the latitude, where the temperature of the coldest month is below 10 °C (ca. 40° S) and the latitude, where this is true for the warmest month (ca. 49° S), is much smaller than in Asia, where below the 100° longitude the former limit is on 22° N and the latter on 72° N. The distances are at a ratio of 1:5.5. In a major part of the northern belt, the ground, in which the temperature at a certain depth approximately (and at a depth of 23 m completely) maintains the mean annual temperature even in summer, does not thaw. Nevertheless, not only standard woods, but in parts also cornf elds grow quite well. The blue dotted line, which, however, may not be entirely precise, shows the extension of the frozen ground (permafrost). In view of the scarcity and limited accessibility of observation data, I have based the drawing on the calculation by WILD[E9], according to which the border of permafrost is roughly identical with the annual isotherm of –2 °C. I could not consider exclaves of this area of smaller extension, which must occur in any elevated mountain range.

5. Due to the scale of the map, representing the exclaves of greatest water shortage of the polar belt was also not possible; only the rough extension of large areas of this kind in Central Asia has been taken into consideration. The equatorial and the lower borders of this region do not always coincide with the tree line, because the lack of summer heat is the most important but not the only condition for the treelessness of these regions. The fact that in higher latitudes, the forest does not occur in close vicinity to the sea, is only partly caused by the reduced summer heat due to the sea. Partly this is also caused by the increased storm intensity, due to which, even in much lower latitudes, like for instance in North Western Germany, trees only grow in the vicinity of the sea where there is some protection against the storms. At exposed coasts and on islands, absolute treelessness therefore also occurs in regions where, to all appearances, temperatures reach 10 °C and more for longer than one month, e.g. on the Aleutian islands[E1]. Similarly, on barren plateaus and on summits in the mountains, gusty winds lower the tree line far below the elevation that is reached along protected slopes and in canyons. A nice example for this is the Crimean Jaila[E1] mountain range. It is easy to understand that in many cases, it is not one single factor that makes the growth of organisms impossible but the combination of many, because every harmful interference reduces the strength of an organism to overcome others.

In order to get a picture of the temperature distribution at the Earth's surface, there is no other way than calculating it by means of topographic maps and computing the height that corresponds to a certain temperature, based on the temperature of a single level and the vertical temperature decrease, as it has been determined for a region and a season or as it can be assumed in analogy. It would be pure nonsense to draw the lines according to the direct measurements at the few and accidentally distributed meteorological stations. Since the map, as the f rst of its kind, is only thought to give a rough representation, a subtle accuracy in these calculations was not required. The assumed temperature decreases varied for 1 °C between 150 and 200 meters; the much smaller decrease in winter in the continental northern regions was out of the question for our purpose, since it is far outside the vegetation period. The sea level and available isothermal maps or the level of one station or a group of stations, for which good measurements were available, served as base level. For the United States and for Norway, the representation was based on maps by SCHOTT[E10] and MOHN[E11], which already showed the actual temperature distribution at the Earth's surface. The maps by SCHOTT[E10], however, show the means of the seasons, which is why they f rst had to be reduced to the periods chosen. This was done by means of numerical values of neighbouring stations and graphical interpolation based on them. The following table may show the most important rounded numbers for the mountains of the Earth out of the calculated altitudinal limits [Table 2].

When we compare our map with the (now numerously) available representations of annual or monthly isotherms, we will f nd, even apart from the fact that they do not refer to the Earth's surface but to the ideal sea level, agreement only here and there which is, in other places, contrasted by signif cant differences.

Generally, the lines of our map, reduced to the same level, would agree much better with the circles of latitude than the annual isotherms, which is in accordance with the analogous behaviour of the majority of the borders of the natural range of plants. This was already discovered a long time ago and is frequently assigned to the inf uence of the light, the distribution of which depends on the latitude and not on the irregular distribution of heat. However, our map may show that a large part of the distribution areas can be directly explained by the temperature conditions during the vegetation period. In fact, the areas in Plate 1 often coincide with those in the plant-geographical maps by GRISEBACH (Vegetation der Erde[E3], also in Peterm. Mitth. 1866[E13]) and ENGLER[E14] (Geschichte der Pf anzenwelt, also in Meyers Convers.-Lex., Jahres-Supplem. V).

One will be able to extend this agreement with increasing mutual consideration of the geography of organisms and climatology. After all, today's climate is only one of the two most important factors in the distribution of organisms; the second, which is at least as important, is the historical factor. ENGLER[E14] has successfully spent his time on the grateful task to distinguish between the two factors both in investigation and in the cartographic representation. However, there remains a lot to be done in this f eld in order to further clarify the geography of organisms. To state more precisely the problem by structuring it into single factors will enhance science more than to make more and more classif cations of the Earth into f ora and fauna zones. Since, obviously, humans urgently depend on taxonomy, particularly as long as they little understand the matter, the strict realisation of different unilateral classif cations according to def ned consistent aspects might be very benef cial. In fact, it might be even more benef cial than the slightly premature attempt for increasingly better, natural classif cations that include all aspects.

Finally, let's have a look at the relationships between the climatic belts shown on our map, on the one hand, and human races and culture, on the other hand[E15]. At f rst, it catches one's eye how the Europeans and their descendants, who represent the current barer of civilisation, strongly depend on a cool season for refreshing their strength and for stimulating their needs in order to develop the unresting pursuit of a happy golden target, which is the basic foundation of their culture. A hot, even a very hot summer, does not prevent the breathless striving in North America. However, where the heat, even if it is more moderate, goes on for the entire year, where the stimulating winter does not occur, a Nordic may follow his ideal targets or great speculations brought along for several years. But inertness and unconcern is certainly the general characteristic of humans in those regions, which, the longer the safer, will also take hold of the immigrated Europeans. In addition, there is the notorious impossibility for Europeans to do hard physical work on the continent in that zone and to expose to the Sun unprotected. The causes of this constraint, which does not exist to a comparable extent on the sea, on board and on oceanic islands, are still inadequately understood. It makes the colonisation of those regions by purely European population impossible, and white people may only gain ground as masters of inferiors of a different race or only in singular lines of businesses[E16]. However, the map shows that the latitude is not absolutely decisive, since in all latitudes, there are landscapes at higher elevations in the mountains that offer the temperature conditions required by white people and that probably will be populated by a uniform European population as soon as the often lacking communication and suff cient legal protection have been established.

In the course of time, the enormous growth of traff c has increasingly shifted the centres of culture from the countries rich in natural products towards regions poorer in natural products, but favourable for traff c and inhabited by a population with a highly developed entrepreneurial spirit. Thus, the culture of the Old World moved from the subtropical belt, where it had its main centre until the VI. Century B.C., to the temperate hot summer climate belt, while the temperate cool summer climate belt was still characterized by barbarism[E15], except for the highlands neighbouring the old civilized cultures like Mesopotamia etc. In the course of the Middle Ages, the cultural difference between these two belts increasingly balanced. In the era of great discoveries, the shift of the centres of traff c and partly also of power from Italy and the Levant[E1] towards the

Table 2: Upper and lower level of the belts in meters.[E12]

	tropical	subtropical	temperate hot summer	continuously temperate	temperate cool summer
Mexico[E1]	0–500	500–1700	1700–1800	2200–2700	2700–3600
equatorial Andes[E1]	0–1000	1000–1500	–	1500–3400	3400–3600
Peru, western slope[E1]	–	0–200	–	200–1200	1200–2000
Rio de Janeiro[E1]	0–200	200–1100	–	1100–	
Guayana[E1]	0–1000	1000–1300	–	1300–	
Gabon[E1]	0–700	700–1000	–	1000–2400	2400–2800
Ethiopia[E1]	0–700	700–1600	–	1600–2300	2300–3300
Sri Lanka[E1]	0–1050	1050–1600	–	1600–2800	2800–3300
Sunda Islands[E1]	0–1100	1100–1300	–	1300–2800	2800–3000
Himalaya[E1]	–	0–1600	1600–1800	–	1800–3600
Caucasus[E1]	–	–	0–340	–	340–1350
Armenia[E1]	–	0–850	850–1600	–	1600–2600
Altai[E1]	–	–	–	–	0–1800
Alps, southern slope[E1]	–	–	0–500	–	500–1400
Algier[E1]	–	0–800	800–1650	–	1650–
Natal[E1]	–	0–500	–	500–950	950–2200
Cape of Good Hope[E1]	–	–	–	0–450	450–
Chile near 33° S[E1]	–	–	–	–	0–1700

Iberian Peninsula[E1] and from the Baltic Sea[E1] towards the North SeaE1 took place from east to west within the same belt. With the rapid fading of the bloom of Spain and Portugal, and the f owering of Holland and later of England, the shift of the centre of human civilisation towards the cooler zones was an accomplished fact, which cannot be changed even by the continued high and recently refreshed cultural status of the northern part of Italy.

In America, the analogue movement of culture from the warm towards the cooler countries has also been suff ciently noticeable since the beginning of European settlement. However, also the old indigenous culture of that continent was mainly located in the temperate climate by concentrating on the highlands in Peru[E1] as well as in Mexico[E1]; and only in Yucatan[E1], the ruins of grand constructions are overgrown by tropical primeval forests. Therefore, the advantage of the temperate climates in comparison to the hot climates regarding the entrepreneurial spirit and the pursuit of greatness shows even more distinctly in America than in the Old World. However, the more general this phrase is stated, the more the singular exceptions must attract our interest, which are the places where we f nd grand constructions and rests of comparably high civilisations in the tropical lowlands. In South-East Asia and Java[E1], they probably are located closest to the equator. As to Southern Asia and Yucatan, it shall be decided by others whether or not these exceptions can be explained by the fact that they are located in the vicinity of highlands with temperate climate and have a certain genetic relation with the inhabitants of those regions. Anyway, one should distinguish between undertakings enforced by individuals of a dominant caste[E15], as we can f nd it in hot countries predominantly, and undertakings by a people or a large proportion of it, as we can f nd it already with the Mediterranean peoples and later even more with Germans, Dutch, English etc. The former will f nd favourable conditions where abundance in natural products allow nourishing large human masses and where the people's inertness makes it possible to master them. On the other hand, the latter will mainly develop with opposite conditions.

The migration and drive of humans in the temperate zones has affected the geographical distribution of the animal kingdom to a degree, which is generally not suff ciently appreciated. Through the extinction of the large mammals in that zone, humans have divided tropical and arctic animals already in the early days of civilization far more than given by nature. Humans constrained the distribution area of those animals that belonged to the hot and temperate zone to the hot zone, and those that inhabited the temperate and cold zone to the cold zone. This is why the f ndings in quaternary caves are a mixture of animals of different climates, such as lion and reindeer, hyena and Arctic fox, hippopotamus and wolverine. This mixture would be inexplicable, if we did not f nd similar, however, not as far-reaching, combinations in regions of the temperate zone, which are currently very sparsely populated by people of a low level of civilization. I refer to the Amur River area where just recently, the tiger chased the reindeer, although on a small area only.

On the other hand, there are animals that increase their distribution area by following the dispersion of humans, namely towards the cold belt, and in fact not just parasites and domestic animals, but also animals much hunted by humans like the rabbit. The inference on

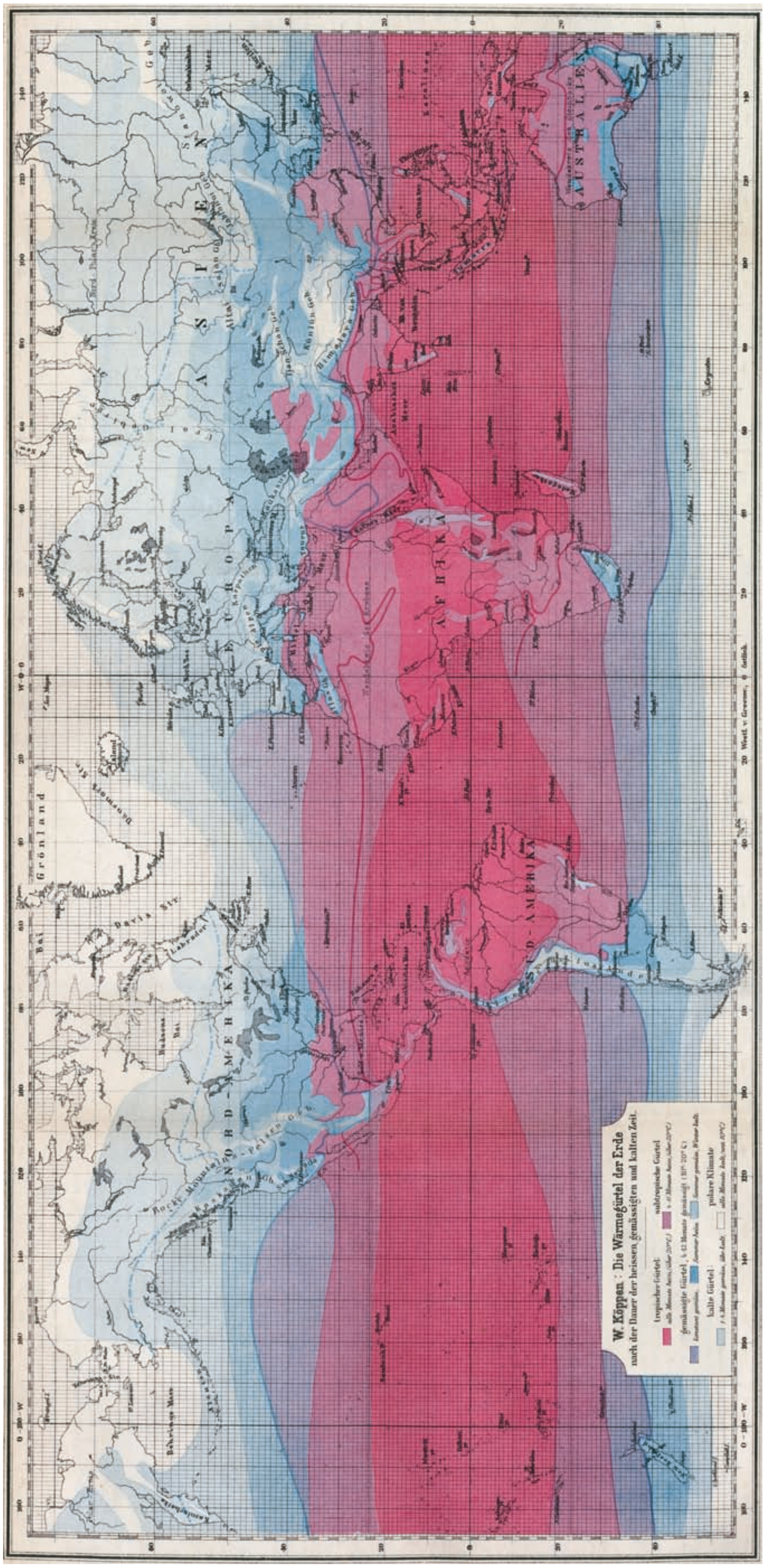

Plate 1: The thermal zones of the Earth according to the duration of hot, moderate and cold periods.

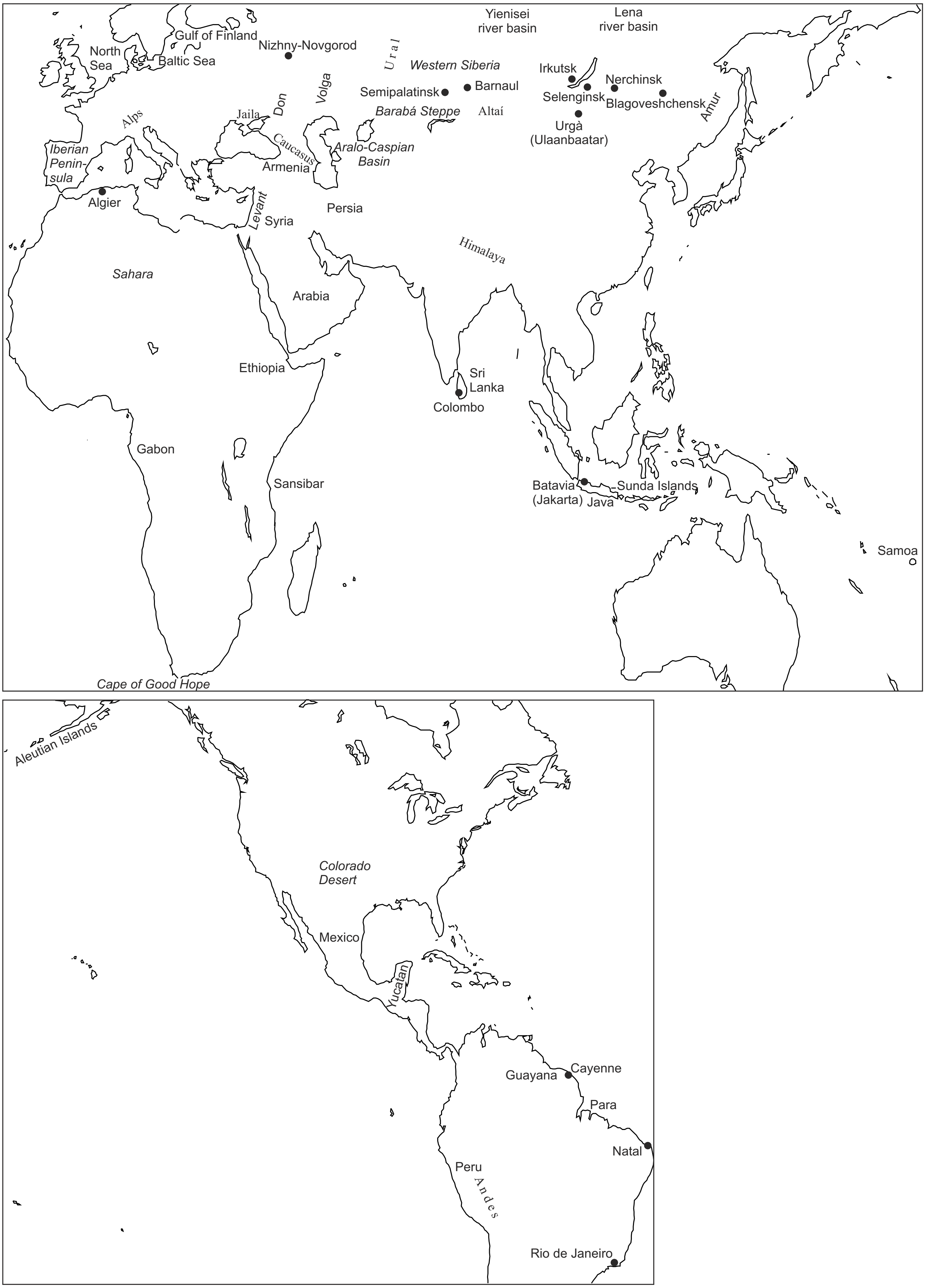

Figure 1: Map showing the locations mentioned in the paper.

climatic changes from the spatial distribution of higher animals is therefore only possible by considering the question comprehensively.

Endnotes

E1 Locations mentioned in the paper, see Fig. 1.

E2 The exact reference is not given. Following is a prominent example of SACHS' papers:
SACHS, J., 1859: Physiologische Untersuchungen über die Keimung der Schminkbohne (Phaseolus Multif orus). – Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathem.-naturw. Klasse **37**, 57–119.

E3 The exact reference is not given. Two inf uential works of Grisebach (see also E13) are:
GRISEBACH, A.H.R., 1838: Über den Einf uß des Klimas auf die Begrenzung der natürlichen Floren. – Linnaea **12**, 159–200.
GRISEBACH, A.H.R., 1872: Die Vegetation der Erde nach ihrer klimatischen Anordnung. Ein Abriß der Vergleichenden Geographie der Pf anzen. – W. Engelmann, Leipzig (2 Vols).

E4 VON OETTINGEN, A.J., 1879: Phänologie der Dorparter Lignosen: Ein Beitrag zur Kritik phänologischer Beobachtungs- und Berechnungsmethoden. – Arch. f. d. Naturkunde Liv-, Kur- u. Estlands, II Series, 8, 241–352.

E5 The exact source is not given. The topic is treated in many of DOVE's papers. Some often cited references are:
DOVE, W.H., 1840: Über die nicht periodischen Änderungen der Temperaturvertheilung auf der Oberf äche der Erde in dem Zeitraume von 1789–1838. – G. Reimer, Berlin. 131 pp.
DOVE, W.H., 1848: Temperaturtafeln nebst Bemerkungen über die Verbeitung der Wärme auf der Oberf äche der Erde und ihre jährliche periodische Verteilung. – G. Reimer, Berlin, 116 pp.
DOVE, W.H., 1848: Über den Zusammenhang der Wärmeveränderungen der Atmosphäre mit der Entwicklung der Pf anzen. – G. Reimer, Berlin, 136 pp.

E6 The exact source is not given. The topic is treated in many of HANN's papers as well as in his (then brand new) handbook:
HANN, J., 1883: Handbuch der Klimatologie. – Engelhorn, Stuttgart.

E7 The original table has no caption and is not labelled.

E8 ALEXANDER THEODOR V. MIDDENDORFF (*18 August 1815, † 24 January 1894) was a famous zoologist and explorer of Siberia. We could not locate the reference cited here.

E9 HEINRICH WILD, Swiss meteorologist. The reference could not be found.

E10 CHARLES A. SCHOTT, was an American meteorologist who produced climatological maps. The exact reference is not known. Two examples of Schott's maps include:
SCHOTT, C.A., 1874: Temperature chart of the United States. Showing the distribution by isothermal lines of the mean temperature for the year. Constructed under the direction of Prof. Joseph Henry, Sec'y. – Smithsonian Institution by Chas. A. Schott, Asst., U.S. Coast Survey in October, 1872. (Julius Bien, Lith., 1874).
SCHOTT, C.A., 1876: Tables, etc., of Atmospheric Temperature in the United States. Collected by the Smithsonian Institution and discussed by Chas. A. Schott, Washington. – Smithsonian Contributions to Knowledge, 1876. Folio, pp. 345, with Isothermal Charts.

E11 HENRIK MOHN, was a Norwegian meteorologist who produced several climatological maps and atlases, although most of the work was published after the paper of KÖPPEN discussed here.

E12 The original table is not labelled.

E13 GRISEBACH, A.R.H., 1866: Die Vegetations-Gebiete der Erde, übersichtlich zusammengestellt. – Petermanns Geographische Mitteilungen **12**, 45–53.

E14 ENGLER, A., 1879: Versuch einer Entwicklungsgeschichte der Pf anzenwelt. Vol 1. – Leipzig, Engelmann. 202 pp.
ENGLER, A., 1882: Versuch einer Entwicklungsgeschichte der Pf anzenwelt. Vol 2. – Leipzig, Engelmann. 386 pp.
MEYERS KONVERSATIONS-LEXIKON. Eine Encyklopädie des allgemeinen Wissens. Dritte (3.) gänzlich umgearbeitete Auf age. Band 21, Jahres-Supplement V (1883-1884). – Leipzig, Verlag des Bibliographischen Instituts, 1884.

E15 The original text has an attitude of climate determinism and racism. Environmental determinism was prominent in late 19th and early 20th century European science (see HULME, 2011). Just two years before KÖPPEN's paper appeared, FRIEDRICH RATZEL published his work "Anthropo-Geographie oder Grundzüge der Anwendung der Erdkunde auf die Geschichte". Later ELLSWORTH HUNTINGTON popularized climate determinism in the United States. Environmental determinism became discredited after the experience of World War II.
HULME, M., 2011: Reducing the Future to Climate: a Story of Climate Determinism and Reductionism. – Osiris **26**, 245–266.

E16 We translated the text as literally as possible. We distance ourselves from the views presented by KÖPPEN. It is not our intention to spread racist ideas.