Translation by W M Connolley of: Fourier 1827: MEMOIRE sur les temperatures du globe terrestre et des espaces planetaires

or/ou

Traduction par W M Connolley de: Fourier 1827: MEMOIR on the temperature of the earth and planetary spaces

This is a translation, with footnotes, of Fourier 1827, "MEMOIRE sur les temperatures du globe terrestre et des espaces planetaires", [rest of exact ref here]. My french is adequate to allow me to understand 95% of the original; for the remaining 4.9% I thank Miriam, which leaves 0.1% for errors...

Read my introductory burble below, or jump straight to the text.

Before trying to understand this paper, it is necessary to understand that Fourier is *not* a climatologist attempting to provide useful information on terrestrial temperatures. Oh no indeed. I started off assuming that, and got very confused. And I thought he was silly. But he's not (well, mostly not. The stuff about heat from interplanetary space is silly): he's just interested in something different, namely an interesting application of his theory of heat transfer. This means, inter alia, that he tends to concentrate on (what would seem today rather uninteresting) matters that *can* be dealt with by his theory. Also, by "temperature of the earth" he includes (indeed gives priority to) the interior of the globe and wurbles on at vast length on results that are nowadays of very little interest concerning said interior temperature.

It may help to know that I got rather impatient with his wurbling and repetition a few times - forgive the odd intemperate footnote. It is possible - suggested by this phrase - that this memoir is actually the transcription of a talk. In which case one could forgive some of the repetitions. On the other hand, this is supposed to be a reporint of an 1824 article, which suggests otherwise. Unless the 1824 article was a talk. Arghhhhh...

Thanks: RMG for causing me to read this.

In the following, references [1] are to footnotes containing "helpful" additions by me. Smaller comments are added within the text [like this]. Sometimes I have added the original word [lit: mot], either because I am unsure of the correct translation or because I have been deliberately rather free in translation or because the word is for some reason interesting.

I have made no great effort to produce a free-flowing translation; in general I have been quite literal even when this makes for stilted english.

I have broken the lines roughly where the line breaks were in the original (of course you can't see this in html but you can if you look at the source). Page numbers are indicated (thus) and are links to jpegs of the photocopies, taken with a nikon 950 at "normal" 600x800 res. Most of the fuzziness is due to the UL's photocopying, not the camera.

Links to particular phrases:

1. the effects of human industry

2. human societies ... can notably change ... the state of the surface

The text

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The question of the terrestrial temperature, one of the most important and most difficult of all natural philosophy, is composed of diverse elements which can be considered under a general point of view. I thought that it would be useful to reunite in a single text the principal consequences of this theory; the analytical details which one omits here can be found for the most part in works which I have already published. I wish above all to present to physicists, in a short tableau, the ensemblage of phenomena and the mathematical relations between them.

The heat of the earth derives from three sources which it is necessary first to distinguish.

1. The earth is heated by solar radiation, whose unequal distribution produces the diversity of climates [3]

2. It participates in the communal temperature of the planetary spaces, being exposed to the irradiation of innumerable stars which surround all parts of the solar system [4]

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3. The earth conserves in the interior of its mass a part of the original heat, which it contained when the planets were formed [5].

In considering each of these three causes and the phenomena which they produce, we will understand as clearly as is possible, insofar as the state of science permits today, the principal characters of these phenomena.

Our solar system is placed in a region of the universe of which all the points have a communal and constant temperature, determined by the rays of light and heat which come from the surrounding stars. This cold temperature of the planetary sky is a little less than that of the polar regions of the globe [6] The earth would have the same temperature as the sky, if two causes did not act to warm it. One is the interior heat which the earth has possessed since the planets were formed, and of which only a part has been dissipated across the surface. The second cause is the continual action of the solar radiation which has penetrated all the mass [7], and which entrain in the surface the different climates.

The original heat of the globe doesn't cause any sensible effect at the surface; but it can be immense in the interior of the earth. The surface temperature does not exceed by one thirtieth of a degree centigrade the value to which it will come: it at first diminished very rapidly; but, in its actual state, this change continues with extreme slowness [8].

The observations received to this day indicate that the diverse points of a single vertical prolonged into

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the solid earth are hotter when the depth is greater, and one has evaluated an increase of a degree per 30 or 40 meters. Such a result supposes a very elevated interior temperature; this cannot come from the action of solar radiation; it is naturally explained by the heat which the earth holds from its origin.

This increase, about one degree per 32 meters, will not always be the same, it diminishes progressively; but a great number of centuries (much more than 30,000 years) before it is reduced to a half of its current value.

If other causes ignored today can explain the same facts, and it there exist other sources (either general or accidental) of terrestrial heat, one will discover this by comparison of the results of this theory with observations [9].

The rays of heat which the suns sends incessantly to the globe there produces two effects which are very distinct: one is periodic and is accomplished in the exterior envelope, the other is constant; one observes it in deep places, for example, 30 meters below the surface [10]. The temperature of these places does not change sensibly during the year, they are fixed; but they are very different in different climates: they result from the perpetual action of solar radiation and the unequal exposition of the surface, from the equator to the poles. One can determine the time which must pass for this solar radiation to produce the diversity of climates that we observe today. All these results accord with the dynamical theories

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which have told us of the stability of the rotation axis of the earth [11].

The periodic effect of the solar heat consists of diurnal and annual variations. This order of facts is represented exactly and in all its details by the theory. The comparison of the results with observations serves to measure the conductivity of the material of which the earths envelope is formed [12].

The presence of the atmosphere and the waters has the general effect of rendering the distribution of heat more uniform. In the ocean and the lakes, the coldest molecules, or those of the highest density, travel continually towards the lower regions, and the movements of heat due to this cause are much more rapid than those in solid masses which occur due to conduction [13]. Mathematical examination of this effect would require exact and numerous observations: they would serve to know how these interior movements prevent the effects of the original heat of the globe being sensible in the depths of the waters [14].

Liquids conduct heat very badly; but they have,like the airy regions, the property of transporting heat rapidly in certain directions. It is this same property which, combined with the centrifugal force, displaces and mixes all parts of the atmosphere and the ocean; it causes regular and immense currents.

The interposition of the air greatly modifies the effects of the heat at the surface of the globe. The solar rays, traversing the atmospheric layers compressed by their own

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weight, heat them quite unequally: those which are most rarified are also coldest, because they extinguish and absorb a smaller part of these rays [15]. The heat of the sun, arriving in the state of light, has the property of penetrating diaphanous solids or liquids, and loses this property nearly entirely when they are converted, by their interaction with terrestrial bodies, into IR [16].

This distinction of SW [17] and IR explains the elevation of temperature caused by transparent bodies [**gh?**]. The mass of water which covers a great part of the earth, and the polar ice, present less obstacles to the SW than to the IR, which returns to exterior space. The presence of the atmosphere produces an effect of the same type, but which, in the current state of theory and because of the lack of observations, cannot be exactly defined [18]. Whatever, one cannot doubt that the effect due to the impression of SW onto a solid body of enormous size greatly surpasses that which one would observe in exposing a thermometer to the light of this star [19].

The radiation from the highest levels of the atmosphere, whose cold is very intense and nearly constant, influences all the meteorological things which we observe: it can be rendered more sensible by reflection in the surface of concave mirrors. The presence of clouds which intercepts the rays tempers the cold of nights [20].

One sees that the near-surface of the earth is placed between a solid mass who central temperature can

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surpass that of incandescent matter, and an immense encircling region whose temperature is less that the freezing point of mercury.

All the preceding arguments apply to other planetary bodies. One can consider them as placed in a enclosure, whose temperature is communal and constant, and a little less than that of the terrestrial poles. This same temperature of the sky is that of the surface of the most distant planets; because the impression of the rays from the sun, even augmented by the disposition of the surface regions, would be too feeble to cause sensible effects; and we know, from the state of the earth, that, on the planets (whose formation cannot be less ancient), there remains no elevation of the surface temperature due to the original heat [21].

It is equally likely that, for most of the planets, the temperature of the poles is a little above that of the inter-planetary space. As to the average temperature which each of these bodies has due to the action of the sun, it is not exactly known, because it depends on the presence of an atmosphere and the state of the surface. On can only assign in an approximate manner the average temperature that the earth would acquire, if it was transported into the same place as the other planet.

After this exposition, we will successively examine the different parts of the question, and we must first insert a remark which appertains to all these parts, because it is founded on the nature of the differential equations of heat transport. It is that the effects which come from the three causes

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which we have indicated can be calculated separately, as if each of the causes existed alone. It then suffices to reunite the partial effects: they superpose freely like the natural oscillations of bodies [22].

We describe, firstly, the principal results due to the long-term effects of solar radiation on the earth.

If one places a thermometer at a considerable depth below the surface of the solid earth, for example, at 40 meters, this instrument shows a fixed temperature [23].

One observes this fact at all the points of the globe. This temperature of deep places is constant for a given place; but it is not the same in the diverse climates. It decreases in general as one moves polewards.

If one observes the temperature of points much closer to the surface, for example at one meter or 5 or 10 meters depth, one sees very different effects. The temperature varies during a day or a year: but we shall make first of all the abstraction of this envelope where these variations occur, and supposing that this envelope is removed, we will consider fixed the temperatures on the new surface of the globe [24].

One can conceive that the state of the mass has varied continually according to the heat received from the "oven" [lit: foyer]. This variable state of the interior temperatures is altered by degrees, and approaches a final state which is not subject to change. Thus each interior point of the solid sphere acquires and keeps a determined temperature

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which only depends on the location of the point [25].

The final state of the mass, when the heat has penetrated all the parts, is exactly comparable to that of a vase which receives liquid from upper openings which furnishes it with a constant source, and escapes an equal quantity by one or more outflows.

Thus the solar heat accumulates in the interior of the globe, and renews itself constantly. It penetrates the parts of the surface near the equator, and dissipates from the polar regions. The first question of this genre which was subjected to calculus, is found in a memoir which I read at the Institut de France at the end on 1807, article 115, page 167: this piece is deposited in the archives of the Academy of Sciences. I treated this first question then to offer a remarkable example of the application of the new theory explained in the memoir, and to show how analysis can allow us to know the routes which the solar heat follows through the earth.

If we now reestablish the suppressed envelope around the earth, in which points are not deep enough for temperatures to be fixed, one notices a set of more complex facts to which our analysis gives complete expression. At a medium depth, like 3 or 4 meters, the temperature observed does not vary during one day; but it changes very sensibly in the course of the year; it rises and lowers successively. The range of these variations, that is to say the difference between the maximum and the minimum, is not the same at all depths; it is less as the distance to the

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surface is bigger. The different points on a single vertical do not show the extremes at the same times [phase lag]. The range of the variations, the times of year which correspond to the greatest, to the average or minimum, changes with the position of the point in the vertical. It is the same with the quantities of heat which descend and rise alternatively: all these values have certain relation between them, which experience indicates and analysis explains very distinctly. The observed results conform to the theoretical predictions; there is no natural effect more completely explained. The average temperature of a point anywhere on the vertical, that is to say the mean value of all those observed in the course of a year, is independent of the depth, and by consequence that which one observes immediately below the surface: this is the same as the fixed temperature of the depths [26].

It is evident that, in the enunciation of this proposition, we have abstracted the interior heat of the earth, and for strong reasons accessory causes which could modify this result in certain places. Our principal object is to understand the general phenomena [14].

We said above that the diverse effects could be considered separately. We must also observe, with respect to all the numerical evaluations cited in this memoir, that they are only presented as examples of calculus. The meteorological observations necessary to furnish the necessary data, those which would tell us the heat capacity and the permeability of the matter of which

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the globe is composed, are too uncertain and too circumscribed to allow us, now, to deduce from calculus precise results; but we indicate the numbers to show how the formulas could be applied. As approximate [lit: approchee] as these evaluations are, they are better used to give a good [lit: juste] idea of the phenomena than general expressions stripped of numerical applications.

In the parts of the envelope nearest the surface the thermometer rises and falls during each day. These diurnal variations cease to be sensible at a depth of 2 or 3 meters. Below this one can only observe annual variations, which themselves disappear deeper down.

If the rotation of the earth about its axis became incomparably faster, and the same occurred for the movement of the earth about the sun, the diurnal and annual variations would cease to be observed; the points of the surface would acquire and keep the same fixed temperature as the deeps. In general, the depth which must be attained for the variations to cease to be sensible has a very simple relation with the period which drives the same effects at the surface. This depth is exactly proportional to the square root of the period. It is for this reason that the diurnal variations do not penetrate further than a depth 19 times less than that observed for the annual variations [27].

The question of the periodic movement of solar heat was treated for the first time and resolved in a separate text which I submitted [lit: remis] to the Institut of France in October 1809.

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I reproduced this solution in a piece sent at the end of 1811, which was published in the Collection of our [the Institut's?] Memoirs.

The same theory gives the means of measuring the total quantity of heat which, in the course of a year, determines the alterations of the seasons. One has the aim, in choosing this example of the application of the formulae, to show that there exists a necessary relation between the law of periodic variations and the total quantity of heat which accomplishes this oscillation; so that, this law being known, by the observations made in a given climate, one can conclude the quantity of heat which is introduced into the earth and returned to the air.

Considering thus a law similar to that established for the interior of the globe, one find the following results. One eighth of the year, after the temperature of the surface is elevated to its mean value, the earth begins to warm; the solar radiation penetrate for 6 months. Following this the heat of the earth takes an opposing course; it comes out and into the air and the exterior space; but the quantity of heat which causes [lit: subit] these oscillations in the course of a year is explained by calculus. If the terrestrial envelope was formed of a metallic substance, forged iron (I chose this example having measured the specific coefficients), the heat which produced the alternation of the seasons would be, for the climate of Paris and for a square meter of surface, equivalent to that which would melt a cylindrical column of ice having for base a square meter, and whose height would be about 3.1 m [lit: 3m, 1]. Although no one has yet measured the value of the correct coefficients for the materials of which

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the globe is formed, on easily sees that they would give a result much less than that which was just indicated. It is proportional to the square root of the product of the heat capacity divided by [rapportee au] volume and permeability [exact formula here?].

Let us now consider the second cause of the terrestrial heat which resides, according to us, in the planetary spaces. The temperature of this space, exactly defined, is that which a thermometer would mark, if one could conceive that the sun and all the planetary bodies which accompany it ceased to exist, and if the instrument were placed in a point of the region of the sky currently occupied by the solar system.

We will indicate the principal facts which have indicated to us the existence of this proper heat of the planetary spaces, independent of the presence of the sun and independent of the original heat conserved in the earth. To understand this singular phenomenon, one must examine what would be the thermometric state of the terrestrial mass if it only received solar heating; and to render this examination easier, one first supposes that the atmosphere is suppressed. But if there did not exist any cause to give to the interplanetary spaces a communal and constant temperature, that is to say if the globe and all the bodies of the solar system were placed in a heatless surrounding, one would observe effects entirely contrary to those which we know. The polar regions would suffer an immense cold, and the decrease of temperatures between the equator to the poles would be incomparably more rapid and more extended [etendu] than observed [28].

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In this hypothesis of the absolute cold of space, if it is possible to conceive it, all the effects of heat, such that we observe on the surface of the globe, would be due to the presence of the sun. The least variation in the distance from this star to the earth would occasion very considerable changes in temperatures, the eccentricity of the orbit would give birth to diverse seasons.

The intermittence of days and nights would produce effects sudden and totally different to those which exist. The surface of bodies would be suddenly, on the commencement of night, exposed to an immense cold. Animated bodies and plants could not resist at all an action so strong and prompt, which would reproduce in an opposite sense at the rising of the sun.

The original heat conserved in the earth could not supplement the heat from space, and would not impede any of the effects which one has just described; because we know with certainty, by theory and observations, that this central heat has for a long time been insensible at the surface, although it could be important at a medium depth.

We conclude from these diverse remarks, and principally from the mathematical examination of the question, that there exists an ever-present physical cause which moderates temperatures at the surface of the globe, and gives to the planet a fundamental heat independent of the action of the sun, and the original heat conserved in the interior. This fixed temperature which the earth receives from space differs little from that which one would measure at the terrestrial poles. It is necessarily less than the temperature

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of the coldest countries; but, in this comparison, one cannot admit any but certain observations, and not consider the accidental effects of a very-intense cold occasioned by evaporation, by violent winds and an extraordinary dilation of the air.

Having realised the existence of the fundamental temperature of space without which the effects of heat observed at the surface of the globe would be inexplicable, we interject that the origin of this phenomenon is evident. It is due to the rays from all the bodies of the universe, whose light and heat can arrive at us. The stars which we see with the eye, the innumerable multitude visible by telescope or the obscure bodies which fill the universe, the atmospheres which surround the immense bodies, the rarified material spread in the diverse parts of space, combines to form rays which penetrate all parts of the planetary space. One cannot conceive that there exist such a system of luminous or heated bodies, without admitting that a point anywhere in space containing them would acquire a determined temperature.

The immense number of bodies compensates for the inequalities in their temperatures, and renders the radiation uniform.

This temperature of space is not the same in different regions of the universe; but it does not vary in those parts where the planetary system is, because the dimensions of this space [the solar system] are incomparably smaller than the distances separating the radiating bodies. And so, on all points of the earths orbit, the planet finds the same sky [space] temperature.

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It is the same for the other planets of our system; they all participate equally in the communal temperature, which is more or less augmented, for each of them, by solar radiation, according to the distance of the planet from the sun. As to the question of finding the temperature of each planet, here are the principals which furnish an exact theory. The intensity and the distribution of heat at the surface of these bodies results from the distance from the sun, the inclination of the axis of rotation and the state of the surface. It is very different, even in its average value, than that which an isolated thermometer would show if placed in place of the planet; because the of the solid state, the very big size, and without doubt the presence of the atmosphere and the nature of the surface combine to determine the average value.

The original heat which is conserved in the interior of the mass has long ago ceased to have a sensible effect at the surface [this is only about the 10th time he's said this]; the present state of the terrestrial envelope allows us to know with certainty that the original heat of the surface is nearly entirely dissipated. We regard as very probable, according to the constitution of our solar system, that the temperature of the poles of each planet, or at least most of them, is little different to that of space [wrong]. This polar temperature is sensibly the same for all the bodies, even though their distance to the sun is very unequal.

One can determine in an approximate [lit: approchee] manner the degree of heat that the earth would acquire if it was substituted for [in the orbit of] each of these planets; but the temperature of the planet itself cannot be assigned; because it would

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be necessary to know the state of the surface and the atmosphere. Anyway this uncertainty does not exist for bodies at the extremities of the solar system like the planet discovered by Herschell [didn't it have a name yet?]. The solar radiation on this planet is nearly insensible. The temperature of the surface is thus very little different to that of the planetary spaces. We have indicated this last result in a public discourse given recently in the presence of the Academy. One sees that this consequence only needs to apply to the most distant planets. We do not know a means of assigning with similar precision the average temperature of the other planetary bodies.

The movements of the air and the waters, the extent of the seas, the elevation and the form of the surface, **the effects of human industry** [29] and all the accidental changes to the terrestrial surface modify the temperatures in each climate. The characters of phenomena due to general causes remain; but the thermometric effects observed at the surface are different to those which would take place without the accessory causes.

The mobility of the waters and that of the air tends to modify the effects of heat and cold; it renders the distribution more uniform; but it would be impossible that the action of the atmosphere could make up for the universal cause which upholds the communal temperature of planetary space; and if this cause did not exist, one would observe, non withstanding the action of the atmosphere and the oceans, enormous differences between the temperatures of the equatorial and polar regions. [30].

It is difficult to know up to what point the atmosphere influences the average temperature of the globe, and one ceases

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to be guided in this examination by a regular mathematical theory. We owe to the celebrated voyager M. de Saussure an experiment which appears very important in illuminating this question. It consists of exposing to the rays of the sun a vase covered by one or more layers of well transparent glass, spaced at a certain distance. The interior of the vase is lined with a thick envelope of blackened cork, to receive and conserve heat. The heated air is sealed [contenu] in all parts, either in the box or in each interval between plates. Thermometers placed in the vase and the intervals mark the degree of heat acquired in each place. This instrument has been exposed to the sun near midday, and one saw, in diverse experiments, the thermometer of the vase reach 70, 80, 100, 110 degrees and beyond (octogesimal division[30.5]). Thermometers placed in the intervals acquired a lesser degree of heat, and which decreased from the depth of the box towards the outside.

The effect of solar heat on the air trapped by the transparent envelopes has been observed long since. The apparatus which we have just described has the objective of taking the heat acquired to its maximum, and above all to compare the solar effect on a high mountain to that taking place on the plain beneath. This observation is principally remarkable for the sound [juste] and extensive consequences [results?] that the inventor has been able to make: it has been repeated several times at Paris and Edinburgh, and has given analogous results [31].

The theory of this instrument is easy to understand. It suffices

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to remark, firstly that the heat acquired is concentrated, because it is not immediately dissipated by the renewing of the air; secondly that the heat emanating from the sun has different properties to that of IR. The SW is nearly completely transmitted by the panes of glass [in all capacities] to the bottom of the box. It heats the air and the walls which contain it: then their heat thus communicated ceases to be luminous; it only conserves the properties of IR. In this state it cannot freely traverse the panes of glass which cover the vase; it accumulates more and more in a space enveloped in poorly conducting material, and the temperature rises until the incoming heat is exactly compensated for by that which dissipates. One could verify this explanation, and render the consequences more sensible, if one varied the conditions, in employing glasses coloured or blackened, and if the spaces which hold the thermometers are emptied of air. When one examines this effect via calculus, one finds results entirely conforming with those given by observations. It is necessary to consider attentively this order of facts and the results of calculus when one wishes to know the influence of the atmosphere and the waters on the temperature of the earth.

In effect, if all the levels of the air of which the atmosphere is formed were to retain their density and transparency, and lose only their mobility, this mass of air thus becoming solid, being exposed to the rays of the sun, would produce an effect of the same type as that which one has just described. The heat, arriving as SW

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at the surface of the earth, would suddenly lose entirely the faculty which it had of traversing diaphanous solids; it would accumulate in the lower levels of the atmosphere, which would thus acquire elevated temperatures. One would observe at the same time a diminution of the degree of heat acquired, above [a partir de] the surface of the earth [31.5]. The mobility of the air which moves rapidly in all directions and which rises when heated, the radiation of IR in the air, would diminish the intensity of the effects which would take place under an transparent and solid atmosphere, but would not entirely remove these effects. The decrease of heat in the higher regions of the air does not cease to take place; it is thus that the temperature is augmented by the interposition of the atmosphere, because the heat finds fewer obstacles in penetrating the air, when it is SW, than in repassing when converted into IR.

We will now consider the original heat which the earth had former epochs after the planet had formed, and which continues to dissipate through the surface under the influence of the cold temperature of the interplanetary sky.

The idea of an interior fire, the perpetual cause of many grand phenomena, is re-introduced in all the ages of philosophy. The thing that I propose is to understand exactly following what laws a solid sphere, heated by a long immersion in a medium, would lose this original heat if it was transported into a space with a constant, lower, temperature. This difficult question, which does not belong [encore] to the mathematical sciences, was resolved by

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a new method of calculus which applies to divers other phenomena [32].

The form of the terrestrial spheroid, the regular disposition of interior layers made manifest by experiments with pendula, their density increasing with depth and diverse other considerations together prove that a very intense heat previously penetrated all parts of the globe. This heat dissipates by radiation into surrounding space whose temperature is very much less than that of the freezing point of water [on p574, its the freezing point of mercury...]. But the mathematical expression of the law of cooling shows that the original heat contained in a spherical mass as big as the earth diminishes much more rapidly at the surface than in the depths. These conserve nearly all their heat for an immense time [oh go on; how long?]; and there is no doubt of the truth of the results, because I have calculated these times for metallic substances more conductive than the materials of the earth [33].

But it is evident that the theory alone can only teach us the laws to which phenomena are subject. It remains to examine if, in the levels of the globe where we can penetrate, one finds any indication of this central heat. One must verify, for example, if below the surface, at the distances where diurnal and annual variations have entirely ceased, the temperatures of a vertical increase with depth: but all facts received and discussed by the most skilled observers show that this increase exists: it has been estimated at about a degree per 30 or 40 meters.

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The mathematical question has the object of discovering the certain consequences which one can discover from this single fact, in admitting it as given by direct observation, and to prove that it determines, firstly the situation of the source of heat, and secondly the excess of temperature which still subsists at the surface.

It is easy to conclude, and it results anyway from an exact analysis, that the augmentation of heat in the sense of depth cannot be produced by the prolonged action of sunlight. The heat emanating from this star is accumulated in the interior of the globe; but the progress has nearly entirely ceased; and if the accumulation were still continuing, one would observe an increase in a precisely opposite sense to that we have just indicated.

The cause which gives to the deepest levels a higher temperature is thus an interior source of heat constant or variable [!!! if only he had gone on to consider this !!!] placed below the points of the globe where one has been able to penetrate. This cause elevates the temperature of the surface above that due to the sun alone [has he forgotten his favourite "planetary sky" radiation?]. But this excess temperature of the surface has become nearly insensible, and we are assured, because their exists a mathematical rapport between the value of increase per meter, and the quantity by which the surface temperature still exceeds that which would have place if the interior cause did not exist. It is for us the same thing to measure the increase per unit of depth or to measure the excess of temperature at the surface [except the latter, of course, cannot be measured].

In a globe of iron, the increase of a thirtieth of a degree per meter gives only a quarter of a degree

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centigrade for the actual elevation of the surface temperature. This elevation comes directly from the conductivity of the substance of which the envelope is formed, all other conditions being the same. And so the excess temperature which the surface has presently because of this interior source is very small; it is probably below a thirtieth of a degree centigrade. One must remark that this last consequence applies to all suppositions which one could make about the nature of the cause, whether one regards it as local or universal, constant or variable.

When one examines attentively and according to the principals of dynamic theories, all the observations relative to the figure of the earth, one cannot doubt that this planet received at its origin an elevated temperature, and, from another side, thermometer observations show that the actual distribution of the heat in the terrestrial envelope is that which occur if the globe had been formed in a milieu with a very high temperature, and which subsequently has continually cooled.

The question of the terrestrial temperatures has always appeared to me to be one of the great objectives of cosmological studies, and I had it principally in view whilst establishing the mathematical theory of heat. I firstly determined the variable state of a solid globe which, having been plunged for a long time in a heated medium, is transported into a cold space. I also considered the variable state of a solid sphere which, having been plunged successively and for a certain time in two or more milieu of diverse temperatures, then is subject to a final cooling in

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a space of constant temperature. Having remarked the general consequences of the solution to this question, I examined more specially the case where the original temperature acquired in the heated milieu becomes common to all the mass; and attributing to the sphere a very large size, I found what would be the progressive dimunitions of temperatures in the layers closest to the surface. If one applies the results of this analysis to the earth to understand what would be the successive effects of an initial formation like that which we have just considered, one sees that the increase of a thirtieth of a degree per meter, considered as a result of the central heat, has been previously much bigger, and that it varies now extremely slowly. As to the excess of the surface temperature, it varies according to the same law; the secular diminution or the quantity by which it decreases during a century is equal to the actual value divided by twice the number of centuries which have past since the beginning of the cooling, and as a limit to this number is given by historical monuments, one concludes that, between the greek school of Alexandria and now, the temperature of the surface has not diminished, by this cause, by as much as three hundredths of a degree. One finds here the character of stability which all the great phenomena of the universe present. This stability is anyway a necessary result, and independent of all considerations of the initial state, since the actual excess of the temperature is very small, and this cannot but diminish during an indefinitely prolonged time. The effect of the original heat which the earth has conserved

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has thus become insensible at the surface; but it manifests in the accessible depths, since the temperature of the levels increase with their distance from the surface. This increase, reported per meter, would not have the same value at much greater depths; it diminishes with depth; but the same theory shows that the temperature excess, which is nearly nothing at the near-surface, can be enormous at the distance of several ten-thousands [lit: myria] of meters, so much so that the heat of the intermediate levels could greatly surpass that of incandescent materials.

The course of centuries would cause great changes in these interior temperatures; but at the surface these changes are [already] accomplished, and the continual loss of original heat cannot cause any further cooling of climate.

It is important to observe that the average temperature of a place can be subject, for other accessory causes, to variations incomparably more sensible than those which are provided by the secular cooling of the globe.

The establishment and progress of human societies, the action of natural forces, can notably change, and in vast regions, the state of the surface, the distribution of water and the great movements of the air. Such effects are able to make to vary, in the course of many centuries, the average degree of heat; because the analytic expressions contain coefficients relating to the state of the surface and which greatly influence the temperature [34].

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Although the effect of the interior heat is no longer sensible at the surface, the total quantity of this heat which dissipates in a given time, such as a year or a century, is measurable, and we have determined it: that which in a century traverses a square meter of surface into the celestial spaces, would melt a column of ice with a base of a square meter and a height of about 3 meters.

This result derives from a fundamental proposition which relates to all questions of the movement of heat, and which applies above all to terrestrial temperatures: I wish to speak of the differential equation which expresses for each instant the state of the surface. This equation, whose veracity is sensible and easy to demonstrate, establishes a simple relation between the temperature of an element of the surface and the normal flux of heat. What makes this result important and more useful than any other in casting light upon the questions which are the object of this Memoir, is that it is true regardless of the form and dimensions of the body, and whatever the nature of the homogeneous or diverse of which the interior mass is composed. And so the consequences which one deduces form this equation are absolute; they whatever may be the material constitution and the original state of the globe [35].

We [we?] have published, in 1820, an extract from a Memoir on the secular cooling of the earth (Bulletin des sciences, Societe philomatique, year 1820, pag. 58 and following). One reported there the principal formulae, and notably those which deal with the variable state of a solid uniformly heated up to a certain great depth.

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If the initial temperature, in place of being the same up to a great distance from the surface, results from a successive immersion in several milieu, the consequences are no less simple or remarkable. Anyway, this case and many others [spare us] which we have considered are contained in the general expressions which have been indicated.

The reading of this extract gives me the opportunity to remark that the formulae (1) and (2) which are reported there have not been exactly transcribed. I will make up at a later date for the mistake [lit: omissions], which, anyway, doesn't change any other formulae, nor any consequences announced in the extract.

To describe the principal thermometric effects which come from the presence of seas, let us first of all consider what would happen if the waters of the oceans were to retire from their basins, leaving immense cavities in the earth. If this state of the surface, deprived of atmosphere [?] and oceans, had lasted a great number of centuries, the solar heat would produce alterations of temperature similar to those observed on the continents, and subject to the same laws. The diurnal and annual variations would cease at a certain depth [below the surface], and in the lower layers there would be a constant state which would consist of continual transport of equatorial heat towards the polar regions [36].

At the same time, the original heat of the globe dissipating across the exterior surface of the basins, one would observe there, like all the other parts of the surface, an increase of temperature in penetrating to greater

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depths, following a line normal to the surface [continues: du fond].

It is necessary to remark here that the increase in temperature due to the original heat depends principally on the normal depth. If the surface was horizontal, one would find equal temperatures in a lower horizontal level: but if the surface is concave, these levels of equal temperature are not horizontal, and differ entirely from level levels. They follow the sinuous forms of the surface: it is for this reason that, in the interior of mountains, the original heat can penetrate to a great height. Its a compound effect which one determined by mathematical analysis, having regard to the form and the absolute elevation of the masses.

If the surface is concave, one would observe an analogous effect in the inverse sense, and this would have place in the hypothesis which we are considering. The levels of equal temperature would be concave, and the state would continue as long as the earth was not recovered by waters.

Consider now that this state having continued a great number of centuries, one re-established water in the bottom seas and lakes, and that they were non withstanding exposed to alternating seasons. When the temperature of the upper levels of the liquid became less than that of the lower parts, although several degrees higher than the melting point of ice, the density of the upper levels would increase; they would descend further and further, and would come to occupy the depths of the basins which they

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would cool by contact: in the same time, the warmer and lighter water would rise to replace the upper waters, and in the liquid masses there would establish infinitely varied movements whose general effect would be to transport heat towards elevated regions.

These phenomena are more compound in the interior of big seas,because there the inequalities of temperature occasion currents directed in contrary senses, and thus displace the water of the furthest regions [?].

The continual action of these causes is modified by another property of water, which limits the increase of density, and makes it vary in a sense opposite when the temperature continues to decrease and approaches the freezing point [i.e., waters density does not increase monotonically towards freezing]. The bottom of the seas is thus subject to a special action which always renews itself, and which perpetually cools it since an immense time by contact with a liquid of a temperature only a few degrees about the freezing point. One finds that the temperature of the water diminishes according to the increase in depth of sondes; this temperature is in our climates about 4 degrees at the bottom of most lakes. In general, if one observes the temperature of the sea at increasing depths, one approaches the limit corresponding to the greatest density; but one must, in questions of this type, have regard to the nature of the water, and above all to the communications established by currents: this last cause can totally change the results.

This increase in temperature, which we observe in Europe in carrying a thermometer into the interior of the globe

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to great depths, thus doesn't occur in the interior of the seas, and usually the order of temperatures is reversed.

As to the parts immediately below the bottoms of the seas, the law of increasing heat is not that which holds on the continents [37]. These temperatures are determined by a special cause of cooling, the vase [?] being exposed, as one said, to perpetual contact with a liquid which keeps the same temperature. It is to illuminate this part of the question that I determined, in the analytical theory of heat (chapter IX, page 495 and following), the expression for a solid, originally heated in some manner, whose surface is kept for an indefinite time at a constant temperature. The analysis of this problem shows distinctly according to what law the exterior cause can vary the temperatures of then solid. In general, after establishing the fundamental equations for the movement of heat and the method of calculus which serves to integrate them, I devoted myself to resolving interesting questions of the study of terrestrial temperatures and to know the relations between this study and the system of the world.

After having separately explained the principals of the question of the terrestrial temperature, one must reunite under a general point of view all the effects which one has just described, and thus one will form an accurate idea of the ensemble of the phenomena.

The earth receives solar radiation, which is absorbed by [lit: penetrent] its mass and is there converted into heat [lit: chaleur obscure]; it also possesses an original heat retained from its origin, and which

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continually dissipates at the surface; finally the planet receives rays of light and heat from innumerable stars amongst which the solar system is placed. These are the three general causes which determine the terrestrial temperatures. The third, the influence of the stars, is equivalent to the presence of an immense encircling region closed in all parts, whose constant temperature would be a little less than that which we would observe in the polar countries of the earth.

One could without doubt attribute to the radiant heat properties currently unknown, which would stand in place of this fundamental temperature which we attribute to space; but in the current state of physical sciences and without recourse to other properties than those which derive from positive observations, all known facts are naturally explained. It suffices to represent the situation as the planetary bodies being in a space whose temperature is constant. We have thus sought to know what would be this temperature so that the thermometric effects would be similar to those observed: but they would be entirely different if one admitted an absolute cold to space; but if one progressively elevates the communal temperature of the surrounding, one sees born effects similar to those we know [bollocks]. One may affirm that the actual phenomena are those that would be produced if the rays from the stars gave to space a temperature of about 40 degrees below zero. (division octogesimale).

The original heat of the interior, which is not yet dissipated, does not produce more than a very small effect at the surface

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of the earth; it manifests itself by an augmentation of temperature in the deep levels. Further from the surface, it can surpass the highest temperatures which we have measured so far.

The effect of solar radiation is periodic in the superficial levels of the terrestrial envelope; it is fixed in all deep places. This fixed temperature of the lower parts is not the same for all; it depends principally on the latitude.

The solar heat accumulates in the interior of the earth [38], whose state becomes invariable. That which penetrates in the equatorial regions is exactly compensated by the heat which flows across the polar regions. Thus the earth returns to space all the heat which it receives from the sun, and adds a part from its original heat.

All the terrestrial effects of the solar heat are modified by the interposition of the atmosphere and the presence of the waters [39]. The great movements of these fluids renders the distribution more uniform.

The transparency of the waters and the air augments the degree of heat acquired, because the SW penetrates easily into the interior of the mass, and the IR leaves with more difficulty.

The alterations of the seasons are maintained by an immense quantity of solar heat which oscillates in the terrestrial envelope, passing below the surface for six months, and returning from the earth into the air during the other half of the year. Nothing can have more effect in clarifying this

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part of the question than the experiments which aim to measure with precision the effect produced by the rays of the sun on the terrestrial surface [39.5].

I have reunited, in this memoir, all the principal elements of the analysis of terrestrial temperatures. It is formed of many results from my researches, which have been published some time ago. Before I set out to treat this genre of question, there did not exist a mathematical theory of heat, and one might even have doubted if such a theory was possible. The memoirs and works in which I established it contain the exact solution of the fundamental questions; they have been placed and communicated publicly, or printed, and analysed in scientific journals for several years.

In the present paper I proposed another aim, that of calling attention to one of the greatest objects of natural philosophy, and to present the general views and consequences. I hoped that the geometers would not only go in their researches into questions of calculus, but that they would consider also the importance of this subject. One cannot today resolve all doubts in a matter so extensive which comprises, as well as the results of a difficult and new analysis, very varied physical notions. One should follow-up by making more exact observations; by studying the laws of the movement of heat in liquids and in air. One would perhaps discover other properties of radiant heat [aha! so he does know that he doesn't know the law of radiative emission?], or causes which modify the temperatures of the globe. But all the principal laws of the movement of heat are known; this theory, which rests on invariable foundations,

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forms a new branch of mathematical science: it is composed today of the differential equations of the movement of heat in solids and in liquids, the integrals of these first equations, and theorems relating to the equilibrium of the radiant heat.

One of the principal characteristics of the analysis which explains the distribution of heat in solid bodies, consists of the composition of simple movements [linear superposition, I think]. This property derives from the nature of the differential equations of the movement of heat, and it applies also to the normal modes of oscillation of bodies [22]; but it belongs more specially to the theory of heat, because the most complex effects really resolve into simple movements. This proposition is not a law of nature, and I do not attribute it as such; it explains a remaining [lit: subsistant] fact, and not a cause. One would find the same result in the questions of dynamics where one considers the resistant forces which rapidly cause-to-cease the effect produced.

The applications of the theory of heat have required long analytical research, and it is first of all necessary to form the method of calculus, regarding as constants the specific coefficients which enter into the equations; because this condition establishes itself and lasts for an infinite time, when the differences in temperatures have become small enough, as one observes in the question of terrestrial temperatures. Besides which, in this question which is the most important application, the demonstration of the principal results is independent of the homogeneity and the nature of the interior layers [what *does* this all means?]

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One could give to the analytical theory of heat all the extensions which explain the most varied applications. Here is the enumeration of the principles which serve to generalize this theory.

1. The coefficients being subject to very small variations which observations show us, one determines, by the process of successive substitutions, the corrections which one must make to the results of the first calculation.

2. We have shown numerous general theorems which do not depend on the form of the body, or on its homogeneity. The general equation relative to the surface is a proposition of this genre. One finds another very remarkable example if one compares the movements of heat in similar bodies, whatever may be the nature of the bodies.

3. Since the complete resolution of the differential equations depends on expressions that are difficult to discover or on tables [of observations?] which are not yet formed, one determines the limits between which the unknown quantities are necessarily bounded; one also arrives at certain consequences on the object in question.

4. In researches on the temperatures of the earth, the grandeur of the dimensions gives a special form to the results of calculus, and renders the interpretation easier. Although one ignores the nature of the interior masses and their properties relative to heat, one can deduce from the only observations made in accessible depths, strongly important consequences on the stability of climates, on the excess of heat due to the original heat, on the secular variation in the increase of temperature

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with depth. It is thus that we have been able to demonstrate that this increase which is, in diverse places of Europe, about one degree in 32 meters, has previously had a much bigger value, which has diminished insensibly, and which would take thirty thousand years before it would be reduced to half its present value. This consequence is not uncertain, although we ignore the interior state of the globe; because the interior masses, no matter what their temperature or state, do not communicate more than an insensible amount of heat to the surface during an immense lapse of time. For example, I wished to know what would be the effect of an extremely heated mass, of the same extent of the earth, placed below the surface at some depth. Here are the results of this research.

If, below a depth of twelve leagues, one replaced the earth by some matter whose temperature would be equal to five hundred times that of boiling water [50000 oC?], the heat communicated by this mass to the parts close to the surface would remain for a very-long-time insensible; it would certainly cool more than two hundred thousand years before one could observe at the surface an increase of a single degree. Heat penetrates solid masses so slowly, and above all those of which the earth of formed, that an interval of a very-small number of leagues suffices to render inappreciable for twenty centuries [no, I didn't get it wrong above, he's dropped a factor of 10] the impression of the most intense heat [40]. The attentive examination of the conditions to which the system of the planets is subject allows us to conclude that these bodies

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were part of the sun [?!?], and one can say that there is no phenomenon which does not allow us to found this opinion. We do not know how much the interior of the earth has lost of this original heat; one can only affirm [all together now...] that at the surface, the excess of heat due to this sole cause has become insensible; the thermometric state of the globe does not vary anymore except with extreme slowness; and if one could conceive that below a depth of a few leagues one replaced the interior masses with a frozen body, of by portions of the substance even of the sun at the temperature of this star, it would take a great number of centuries before one could observe any appreciable change in the temperature of the surface. The mathematical theory of heat furnishes many other consequences of this type whose certitude is independent of all hypotheses of the interior state of the earth.

These theories will acquire in the future many more extents, and nothing will contribute more to their perfectioning than numerous series of precise experiments; because the mathematical analysis (from which permit us to introduce here this reflection) (1) can deduce from general and simple phenomena the expression of the laws of nature; but the application of these laws to complex effects requires a long series of exact observations.

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(1) *Discours preliminaire de la Theorie de la chaleur*

OK folks, thats it for the text. Thank-you for staying with old Joseph this far. Its footnotes by me from here on down...

Footnotes

[1] This, for example, is a footnote.

[2] Suppressed as too unhelpful.

[3] So: if its the solar radiation that produces diverse climates, why bother with points 2 and 3? Because, **he is not interested principally in the diverse climates**. Coming from a climatological background, it is hard to realise this.

[4] This is essentially wrong: stellar radiation (excluding the sun) is totally negligible, and

interplanetary space has a temperature nearly indistinguishable from zero and contributes just about no radiation to the earth (I think). Anyone who knows better is invited to comment. For the wise: of the tiny radiation that is non-solar (and non-lunar: solar radiation reflected from the moon does have a very small but measurable effect), which (stellar; cosmic microwave background; whatever) has the largest effect?

[5] OK, so he doesn't know about radioactive decay heating the earth: this is fair enough.

[6] Clearly, this is wrong. Also, you might think: he doesn't know the temperature of the north pole (in summer much less in winter) and doesn't even know if the south pole is land or sea. Nor does he know the interplanetary temperature. But, be patient: later on he explains why he thinks these (unknown) temperatures need to be the same.

[7] The assertion that "the solar radiation which has penetrated all the mass" reads oddly, since insofar as heat flow is concerned the flow is from the interior of the earth, as F was well aware and goes into in great detail later. But this claim is repeated later. See-also [38].

[8] I think what he means is: looked on as a mathematical problem; assuming a constant heat input to the surface from solar radiation and a given initial heat distribution, with the interior being very hot, one can calculate the change in surface temperature with time. Of course, this assumes no change in solar constant, orbital parameters, etc. If you do this, you conclude that the earth has already cooled far enough to be within 1/30 oC of its final surface temperature. This is probably a disappointment to those hoping to use the change of this temperature as some kind of measure of the age of the earth.

[9] This rescues him (if such were needed) from the comment [5]. Although radioactivity was not discovered by people trying to find what kept the earths interior warm. Or was it?

[10] This is a bit odd, because after all the two regions are not really distinct: there is just a depth beyond which diurnal/annual variations become too small to measure. And, perhaps, another region beyond which geothermal heat becomes important. But, this comment prefigures some later analysis where he considers the two regions separately.

[11] Was this in question? I guess what he is saying is that the stability of the interior temperatures proves that the surface temperatures has not varied too wildly in the past (but this then becomes a bit odd, because whatever analysis he has done has failed to pick up the last ice age, only 10,000 years ago). Maybe a change of only 5-10 K is too small to see?

[12] Yes, I think you can deduce the conductivity by measuring the annual cycle within the earth. A useful application of his theory, I guess.

[13] If only the coldest molecules descend, no heat will be transferred down...

[14] Yet again, we see what he is really interested in.

[15] This is quite wrong. To first order, the higher layers of the troposphere are colder because most of the solar radiation is absorbed at the surface, not differentially in the atmosphere as he suggests. Furthermore, mass-for-mass, higher layers absorb just about as much radiation as the lower (assuming the lesser water vapour in the higher layers does not affect this too much).

[16] No, of course he doesn't say infra-red (IR) radiation. He says "chaleur rayonnante obscure". But

here and in future, I shall translate this as IR.

[17] And he doesn't say short-wave (SW) either, he says "chaleur lumineuse", but thats going to be SW in what follows.

[18] I would argue that the transmission of IR through the atmosphere is rather distinct from its transmission through the ocean (or ice!?!). Water (liquid) is essentially 100% opaque to IR. Nobody puts a radiation scheme into an ocean model. By contrast the atmosphere is somewhat, but not totally, opaque, and is thus a much harder problem.

[19] "star" is presumably the sun. There may possibly be a negative in this sentence. But either way round, I have no idea what he is trying to say.

[20] Bit of an odd paragraph. He is talking about IR radiation, and the observation here that makes sense is that it trapped by clouds, resulting in warmer nights. Quite true.

Other observations make less sense: "the higher levels of the atmosphere are most cold" is wrong: temperatures in general decrease from the surface to the tropopause (at about 200 hPa / 8 km) then increase into the stratosphere then...

The assertion that the temperature of these layers is nearly constant (day-to-night) is true, because their radiative timescale is long, but does he know this?

As for reflecting IR from concave mirrors: is this right?

See-also the extrasolar heat stuff on p 580.

[21] In fact, the arguments don't apply to the gas giants at all... (insert ref to planetary temperatures here if I can find one) the temperature of Neptune and Uranus is about 60K, that of Saturn about 90K, that of Jupiter about 120K (figures from memory from a talk recently), the difference, I think, principally arising precisely from internally generated heat of compression which is sort-of equivalent to "original heat" (***check all this sometime***). The pole-to-equator temperature difference of the gas giants is tiny: a few degrees, as compared to tens of degrees for earth.

[22] Firstly, "natural oscillations of bodies" is my awkward translations of "dernieres oscillations des corps", by which I think he is referring to normal modes of oscillation.

But anyway: what he is saying in this paragraph is that he is assuming that the different forcings can be considered to be linearly superposable. This would not nowadays be an obvious thing to think about the climate system, which is often non-linear, but it is done when no choice exists or existed: for example, flux-corrected AOGCMs run for CO2-changed scenarios.

Note: this is an important paragraph for understanding what follows. When it looks like he has forgotten about, say, internal heat, this is because he is doing this considering-effects-separately stuff.

[23] This is, in fact, a very useful fact for measuring the annual average temperature of the surface of the ice sheets: drill a core down to 10 m depth and measure the temperature there: it is very close to the annual average at the surface.

[24] This can appear rather obscure. What he is doing is transforming the question into a

boundary-value problem on the sphere, where the temperatures on the surface are fixed and one thereby deduces the heat-flow through the globe. Once again, we see that he is *not* interested in the surface temperature - the climatology of the earth - except as a means to doing some interesting mathematics.

[25] Some slight doubts about the translation of this paragraph. But I think what he is saying is, that if we start from an earth with an arbitrary temperature, then impose constant solar forcing, then we end up with the interior temperatures trending towards fixed values. You might say, aha, but what about the seasonal variations, but no, remember that he has already suppressed the region in which seasonal changes occur and is considering a boundary value problem with fixed surface temperatures on the new "surface".

[26] Since he has gone to such great lengths to say how exact his theory is, it seems only fair to point out that this is only correct if the annual cycle repeats exactly: if temperatures shift year-to-year then there are slight variations in the average. In fact, deep borehole temperatures can be used to track (approximately) temperature histories back into the last ice age.

[27] Spiffy. So in fact several pages of repetitive and near-incomprehensible prose could be more comprehensibly summarised by one simple formula. So where is it?

[28] As far as I can see, this paragraph is a rather simple (and incorrect) assertion unsupported by any evidence whatsoever.

Next para: Why does he believe this? As for the eccentricity, he must be perfectly well aware that it is tiny. Why does he think that tiny variations in the solar distance should be so important? He is quite well aware of things like heat capacity, and of the oceans, and so ought to know about them "buffering" temperature changes. Its all in his theory, after all.

Next para: this is all getting a bit odd. he knows - see p 573 - that IR radiation from the sky and clouds exists and tempers the cold nights, so why has he suddenly forgotten it? All this has the hallmarks of an argument got up to demonstrate a point - the temperature of space - regardless of inconvenient facts. In fact p 573 directly contradicts this stuff, in that it points out (correctly) that clouds temper cold nights, whereas what he is saying here should suggest that clouds make the nights colder, by intercepting this mysterious radiation.

If you feel tempted to believe any of his arguments, remember that the temperatures of the outer planets - see [21] - are much less than those at the terrestrial poles.

[later:] I have just noticed that he considers what the situation would be with no extrasolar radiation, assuming that the atmosphere has been removed "to make things easier". But this removes a vital part of what does keep the planet warm at night...

[29] Aha! this appears to be the source of the assertion - which I've seen somewhere - that Fourier was the first to notice the possibility of human modification of climate. This would appear to be supported by this, but from the context I think he is probably talking about land-use and albedo changes, not about release of "greenhouse" gases. See-also a later, less ambiguous, reference.

[30] Yet another repetition of this assertion unsupported by facts or arguments.

Incidentally, yet another disproof of his idea is the fact that the diurnally-averaged insolation on the polar regions during summer is actually greater than in the tropics, due to the constant daylight. Thus, according to his no-memory ideas, the summer pole should be warmer than the tropics. Since this fact depends only on the earths axial geometry, which he knew, he could have been aware of this. [***check this sometime***]

[30.5] The "octogesimal division" or Reaumur temperature scale had 0 and 100 oC as fixed points like the centigrade scale, but 80 divisions not 100. See here for more (thanks to E Bard).

[31] Well go on then: tell us the result: how do the results up a mountain compare with those on the plain (and where will you find a mountain near Paris?). From what I know, I would expect higher interior temperatures up a mountain (on the grounds that less solar radiation would have been absorbed by the atmosphere at a height).

I remain somewhat uncertain as to the translation of "consequences" from the french. As done here, as "consequences" (the EB translation has "inferences", which would mean the same), it implies that it is these remarkable consequences that matter; if so it is odd that they are not specifically mentioned: on this reading, it is the fact that IR cannot penetrate transparent things (arbitrarily extrapolated to the atmosphere from glass, I've just realised) that is the consequence. On the other hand, "consequences" can be read as "results", and he may just be commenting on the excellent repeatability of the experiment.

[31.5] This would only be the first-order effect: in time, as heat was conducted up, (all?) levels of the atmosphere would become warmer.

[32] Notice that he is being a bit imprecise here. He cannot solve the problem as stated accurately, because he does not know Stephans law, i.e. that R=sT^4, i.e. that radiation is proportional to the fourth power of temperature (and then it can only be done accurately if you pretend the atmosphere doesn't exist). I presume he is going to solve it assuming conductive losses only, not particularly relevant to the earth in space. This point should be remembered as the discussion progresses (or repeats...) in the following pages: his much-vaunted exact solution is the exact solution to an approximate problem.

[33] "There is no doubt as to the truth of the results, because I have used the wrong values..." ;-)

Sorry, couldn't resist that. What he means is, that in practice he can be sure that the real times would be longer, because the earth is less conducting than the material he has assumed.

However, he appears to be wrong on two counts:

1. Most of the earths interior *is* indeed liquid iron [isn't it?]
2. Since its liquid, it can conduct by convection as well as conduction, hence much faster than he says

Not to mention radioactive decay...

[34] This would appear to be the bit where one can say "he anticipated the possibility of humans changing the climate". However, from this section (unlike a previous glancing ref, it is clear that he means modification of the surface, not the atmosphere). The bit about "great movements of the air" is unclear.

[35] But this marvellous result, sadly, does not have any importance for determining the temperature of

the real world, heated as it is mostly by solar radiation.

[36] The fraction of solar heat that is conducted polewards through the earth is so tiny that it is invariably ignored: most would be transported through the atmosphere or ocean. If you suppressed both of these, pole-to-equator temperature gradients would increase.

[37] The *laws* may not be the same, but the results are indistinguishable, since the "original heat" nowadays has so little effect. However, I think that what he is saying is that over the continents the "original heat" problem is to solve for the cooling, given an initial temperature and some law of cooling of the surface (he is a bit coy about this latter part. He doesn't know the law of radiative cooling, so I wonder what he did use. Presumably one would have to read his Oeuvres to find out). Whereas, over the oceans, the problem is to solve, given a fixed boundary temperature at the top. An interesting question is whether his maths allowed him to solve both-at-once for the earth, or if he had to do all-land, then all-ocean problems separately.

[38] He *keeps* saying this and it just isn't true. Its a hangover in his mind from him trying to decompose the problem. The interior of the earth is hotter than the surface, so heat doesn't flow from the surface to the interior, but the other way round. He knows this.

[39] In his discussion, the SW is assumed to penetrate the atmosphere without hindrance, and its only the IR that the atmosphere affects. That means that the atmosphere is just as relevant to, say, the original heat loss, but he doesn't seem to have noticed this.

[39.5] The EB translation adds here: "For this reason, we heard with the greatest interest the reading of the memoir presented by Prof Pouillet; and if in the course of this article we have not mentioned his experimental researches, it is simply from the wish not to anticipate the report which will soon be made.". It would be interesting to know why Prof Pouillets stuff was omitted 3 years later, when priority was no longer a problem.

[40] Of course, this is only valid if you follow his rules. In the real world, replacement of the interior by a body this hot (apart from, probably, vapourising the rock) would cause convection to start which would presumably lead to a shorter transfer time for the heat.

WMC | June, Lescun / July, Marcham and Coton / August, Coton.

1. Version 1.0 August 11th 2000: original
2. Version 1.01 June 30th 2001: minor spelling; link direct to text; remove link to hi-res version of first page.
