論　文

# Theory of the Earth or Travelling Instruments[*]

Engelhard Weigl[**]

I was asked some time ago to give a talk on the use of scientific instruments, because I once wrote a book - more than ten years ago - with the title "Instruments of the Modern Age". The subtitle of that book was "Discovery of Modern Reality"[(1)]. And it is this subtitle that seems to fit our topic, because it deals with the question how to describe in detail the changes in our way of life caused by modern technology. Even if I Iimited myself to the scientific instruments of the early Modern Age, such as the telescope, the microscope, the air-pump, the thermometer and the barometer would the topic be too extensive to be dealt with in a short talk. But there are other problems too - of a more factual kind, because the history of science has in past usually only dealt with the development of scientific instruments, their technical production method and the theoretical implications of their application. Since the theory of science is geared to the analysis of theoretical structures, there is a tendency to equate the scientific achievements exclusively with the theories gained. Investigations into the philosophical assumptions preceding the development of certain instruments and their influence on the development of the science are only just beginning.

I would like to start with an area of research that is closely linked with the

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＊＊ University of Adelaide, Australia.
(1) Engelhard Weigl: Instrumente der Neuzeit. Die Entdeckung der modernen Wirkilchkeit. Stuttgart 1990.

names of La Condamine, Horace-Bénédict de Saussure, Jean-André Deluc and especially with Alexander von Humboldt. La Condamine from France, Saussure and Deluc from Switzerland and Humboldt from Germany. But all four scientists used the same language, they all wrote their papers and books in French and their main field of research were the mountains, for three of them - Saussure, Deluc and Humboldt - more precisely the Alps. In the 18th and early 19th century the scientific exploration of the earth was centred in Paris and Geneva. After his travels in America from 1799 to 1804 Humboldt did not return to Germany but worked in Paris until 1827. Only there did he find the necessary scientific and technical conditions for his gigantic studies. In my talk I will look at the way scientific instruments were used by these travellers, but we also have to be aware of the underlying scientific concept, a kind of physics that quite consciously set itself apart from analytical, mathematical physics. This system of physics proceeds from the assumption that all physical processes must be investigated in and then integrated into the total natural process. Meteorology thus becomes the great laboratory of nature, as opposed to the artificial laboratory created by man. According to Deluc, the true chemical process takes place in the earth atmosphere in direct contact with the light of the sun. This is what is called "Cosmic Physics" or "Physics of the Earth", an idea that Alexander von Humboldt explicitly adhered to.[(2)] Here the scientist is forced to constantly change positions and then draw conclusions from this change.

Most of the instruments taken along on journeys were invented in the 17th century, they were a characteristic outcome of the experimental sciences of that time, but their application within the scope of the new "Physics of the Earth" only happened in the 18th century. In 1735 a new type of consciousness emerged in Europe based on the publication of Linné's "Systema Naturae" and the insights gained from two great expeditions that had been sent out to determine the shape of the earth: One was Maupertius' expedition to the polar circle and the other Godin's and La Condamine's expedition to the equator in Ecuador to measure the degree of a meridian near the pole and near the equator. Linné devised a system to classify all the plants of the earth, whether they were known to Europeans or not.

(2) Alexander von Humboldt: Relation historique du Voyage aux Régions équinoxiales du Nouveau Continent. Tome Premiere. Paris 1814, p. 3

The two expeditions to the north and the south also allowed a view of the earth as a whole. Mary Louise Pratt rightly claims that a new type of consciousness evolved at that time, she called it "planetary consciousness".(3)

The year 1735, however, is also significant in regard to the development of scientific instruments. It was only then that through standardization of the instruments employed comparability of data became possible and with it a global network of recorded measurements. The expeditions undertaken by La Condamine, de Saussure and later by Humboldt also marked significant changes in the employment of instruments outside controlled laboratory conditions. The first period from 1730 to 1740 is characterized by a new ethos focusing on accuracy and precision and a far-reaching revolution of measuring practices begins to be accepted. It was the time when Rēaumur learnt to calibrate his instruments, thus making them comparable to each other. The first epoch-making instrument of the 17th century was, of course, the telescope, later came the air-pump and the microscope. In contrast to these instruments, however, which were employed for quantitative explorations, the success with instruments allowing quantitative measurements - such as scales, the barometer and the thermometer - was still limited. Since the first thermometers lacked a sufficiently clear definition of what they were actually measuring, the first experiments with them often revealed more of the qualities of the instruments themselfs rather than of the objects they were measuring.

In spite of the efforts of Robert Boyle, John Wilkins and Robert Hooke who had tried since 1663 to standardize thermometers the situation remained quite unclear well into the middle of the 18th century in regard to different thermometers. At least 71 different scales were in use at that time and the definition of the set point was often not clear or at least imprecise. For a long time it was believed that the problem of universality could only be solved by producing and employing as identical instruments as possible. The second period from 1780 to 1800 is centred around figures such as Saussure, Deluc and Humboldt and is characterized by a further increase in the tendencies already described. The employment of different instruments and their coordination gains in importance as do the demands regarding accuracy. Saussure developed some new instruments - such as a hygros-

(3) Mary Louise Pratt: Imperial Eyes. Travel Writing and Transculturation. London 1992, p. 15f.

cope which delivers comparable data - or he made improvements on existing ones. Out of a relatively unfocused curiosity - gathering all kinds of different data, without knowing what kind of natural laws could result from them - Saussure[(4)] and Humboldt started to develop a project which they called "Theory of the Earth". This project was quite in contrast to what later became known as "pure physics", instead, concentrating to the phenomena in their macroscopic natural context and hoping to gain insight into global natural laws in spite of the restrictions resulting from a limited position. The prerequisite for such high expectations, however, was a very privileged position or rather location. For Condamine, Saussure and Humboldt the mountains - more exactly the Alps and the Andes - became their preferred object and location of their explorations. For Saussure and what he calls "Physics of the Earth" the Alps are a natural laboratory par excellence, ideally suited, to observe a variety of different natural forces. Here the whole must be viewed in its most extensive connections rather than focusing on details.
Saussure thus recommends:

"You have to leave the well trodden paths and climb heights from where the eye can encompass a great deal of objects in one glance. Since one is looking down on earth from such a considerable height, one has the impression as if one had discovered the driving force which make it move and had seen - at least - as if from far away - laws according to which the great changes on earth usually happen.[(5)]"

Saussure then also suggests: "Every naturalist or geologist finds great food for an inquiring mind in the higher mountains. The long mountain ranges, whose summits pierce the higher regions of haze, seem to be the workshop or the container, from where nature takes the good and the evil, which it then spreads on the globe: streams sprinkling it, large rivers ravaging it, rain moistening it, storms causing havoc. All phenomena of general natural history present themselves there in such majesty and greatness of which the inhabitants of the flat parts of the earth have no idea. The effect of the winds and of the electricity in the air happen here in such force; the clouds are formed in full view of the observer, and often he watches the development of thunderstorms right below him, which ravage the

(4) Horace-Bénédict de Saussure: Voyage dans les Alpes. 4 Vol., Neuchatel-Geneva 1779-1796.
(5) Horatius Benedictus von Saussure: Reisen durch die Alpen, nebst einem Versuche über die Naturgeschichte der Gegenden um Genf. Erster Teil, Leipzig 1781, p. lXf.

plains while he is surrounded by sunshine and the sky above his head is visible - clear and bright."(6)

At the last part of the 18th century these scientists were interested in the variety of natural phenomena, which were observed and measured with an incredible array of different instruments. Instruments that didn't exist at the beginning of that century. The electricity in the atmosphere, the oxygen content of the air, the transparency of the atmosphere, the color of the sky - all of these were being studied in different locations. Cardwell describes the rush to the mountains as follows:

"Mineralogists, cristallographers, botanists and zoologists found much to interest them in the Alps, it was, in effect, a great natural physics laboratory in which physical progress was carried out on a gigantic scale. The conversion of snow into ice, resulting in the formation of glaciers, the motion of these ice-rivers down to warm valley, and the appearance of streams from underneath the ice at the very ends of the glaciers, posed an abundance of problems. It was phenomena of this sort which had led Joseph Black to formulate the concept of latent heat. Again, the mountains offered an obvious route to the study of the composition of atmosphere at different heights, the formation of clouds, the fall of rain, snow and hail; as well as atmospheric electricity and the properties of radiant heat. It would scarcely be an exaggeration to say that as the solar system was the celestial model for Newtonian mechanics, so the high Alps were to provide a good deal of the laboratory material for 18th and early 19th century physical science."(7)

The explorers of that time had to be very disciplined to meet these new demands, ever watchful that none of the numerous measurements was forgotten or omitted while travelling. Irreplaceable data could be lost forever if they happened to be distracted. And all these demands had to be met under conditions which made even normal travels quite difficult. Saussure reports: "One precaution I took which I believe was very helpful, was that I wrote a systematic plan in davance for every journey, containing everything I was going to investigate while travelling. Since the geologist usually observes and studies while he is travelling, the slightest distraction can cause him to miss an interesting object - and may be forever. But even without any distraction there are so many and varied objects to be

(6) Ibid., p. XIII.

(7) D. S. L. Cardwell: From wattto clausius. The rise of theromdynamics in the early industrial age. London 1971, p. 92.

studied, that it is easy to miss one of them. Often a seemingly important observation keeps all our attention and makes us forget others. At other times bad whether deters us and fatigue robs us our presence of mind, and the negligence resulting from all of this then leaves us quite ill at ease and often and often forces us to go back - tracking. If instead one looked into the carefuly planned diary from time to time, one would be reminded of all the investigations one wanted to undertake."(8) The early explorers divided their perception strictly into an aesthetic and a scientific one. While open for the aesthetic quality of the mountain scope, the sensory perception of scientific evidence is increasingly suspected of being deceptive. More and more perceptive functions are handed over to instruments. The explorer merges with his instrument - as it were - so that the loss of an instrument almost amounts to an amputation.

Connecting travelling and measuring relies first and formost on the portability of the instruments. Portable thermometers in leather cases were offered fairly early. The thermometers produced in 1688 was more of a baroque collector's piece, but at the same time it was a giant step forward in measuring varying temperatures in different locations, even though the measured readings were only comparable among themselves in the best cases. Not only weight was important, though, instruments had to be built in such a way that they were less sensitive to shock and less likely to break. This is true especially for the barometer and the watch. Condamine's expedition was indeed quite handicapped by the huge quadrant of 3 feet in demi-diameter, which had to be carried by two porters through dense forests and up inaccessible volcanoes. Humboldt already used a 12 inch quadrant made by Bird, which was not only considerably smaller and lighter but also more accurate. In 1730 a point was finally reached where instruments became comparable, thus allowing a world wide network of data collection. The expedition by Louis Godin and Charles de la Condamine to the equator in Equador in 1735 is the first and most prominent example for this expanding network. At the same time, Rēaumur starts to equip naturalists, agents of trading companies, engineers and colonial administrators with his thermometers and obliges the recipients of his presents - after having carefully given them detailed instructions - to register the

(8) Horatius Benedictus von Saussure: Reisen durch die Alpen, nebst einem versuche über die Naturgeschichte der Gegenden um Genf. Erster Teil, Leipzig 1781, p. XVIIf.

daily minimum and maximum temperatures in whatever area they happened to be and then send the results to Paris. He was most interested in the hotter regions of the earth. This project developed in such a way that every year a series of statistical tables was published over a period of 12 years. On the one hand the collection of extreme temperature data still served the taste of the public which was then Interested in strange phenomena and unique facts, but on the other hand Rêaumur wanted to provide data to the nation for possible colonial expansion. He writes:

"We would like to know what degrees of heat and cold people like us can bear."[9]

An inscription on a silver plaque, which Godin and Condamine left in Quito, reads as follows:

"The spirit of wine which starts where the cold begins at 1000 degrees in Rêaumur's thermometer and expands to 1080 degrees in boiling water. The expansion in Quito varied between 1008 and 1029 degrees, on the summit of the Pichincha it varied between 995 and 1012 degrees."[10]

These readings of extreme temperatures are cast in silver without any reference to the time the reading were taken, as if they were constant qualities inherent to the location. 50 years later Humboldt would harshly criticize on serveral occasions the arbitrariness of these measurements of extreme temperatures, which said little or even gave misleading ideas about the actual state of the climatic conditions.[11] At this time - from Rêaumur to Humboldt - the academy of science in Paris is the centre of the worldwide network, expanding radiantly. It is from there that the frontiers of the known world are pushed further and further. Precice and reliable data - since Condamine's expedition also including the measuring of mountain heights - are delivered from parts of the world, where previously only fables and legends were known. In the metropolitan centres the data are not only compiled and put into archives, often complicated calculations had to be carried out espe-

(9) Renê-Antoine Ferchaut de Rêaumur: Regles pour construire des thermometres dont les degrês soient comparables. In: Mêmoires de I'Acadêmie royals des sciences pour 1730 [1732]. p. 453.

(10) Geschichte der zehnjährigen Reisen der Mitglieder der Akademie der Wissenschaften zu Paris vornehmlich des Herrn condamine nach Peru in America in den Jahren 1735 bis 1745. Erfurt 1763, p. 158.

(11) Alexander von Humnboldt: Des lignes isothermes et de la distribution de la chaleur sur de clobe. In: Mêmoires de physique et le chemie de la Sociêtê d'Arcueil. Tome 3, 1817, pp. 462-602.

cially in regards to astronomical determination of locations and barometric height measurements. This huge surveying program is so successful, that Humboldt can be outraged around 1800 that there still were places between the Amazon and the Orinocco, that had escaped the surveying explorers.

In the revolutionary process of a re-evaluation of the mountains in the 18th century, whose wild, infertile and often life-threatening nature had been met traditionally with fear and horror, asthetic appreciation and natural sciences become closely interrelated. It can be safely assumed that the often extensive measuring program of the explorers played an important - until now probably underestimated - role in the overcoming of fear of heights or fear of nature in general, especially in the exploration of high mountain regions.

Pascal still had a hard time persuading his brother-in-law Perier to climb the Puy-de-Dome in order to observe the mercury column. Jacques Cassini and Jacques Maraldi also preferred to mearsure the height of the mountains geometrically by trianguations. The beauty of the mountains can not yet be perceived by them, they lack the right organ. In this regard, too, the expedition into the Andes of Ecuador in 1735 marked a deep divide in the attitude towards the mountains. Now curiosity reigns and extends in every direction. La Condamine's curiosity even became somewhat proverbial. In a German report one can find the following line:

"The attention and care of this man from the academy extends to absolutely everything."(12)

The gathering of new data is the driving force, enabling explorers to forge ahead ever more deeply into the unknown world of the high mountains, bearing great strains and even putting their lives or health at risk. And it is not the climbing of the mountains as such that is important, but reaching a new height with an instrument. Condamine reports on his ascent of the Pichincha, on top of which he even undertook trials with his pendulum and also measured the speed of sound. "As far as I know, nobody before us had seen the mercury in the barometer below 16 inches, that is 12 inches lower than at sea level, so that the air we breathed was extended by more than half compared to the air in France, where the barometer climbs to 29 inches. I, on my part, however, didn't have any difficulty breathing."(13)

(12) Geschichte der zehnjährigen Reise [...] Erfurt 1763, p. 32.
(13) Ibid., p. 133.

After the first failed attempt to climb the Montblanc Saussure comforted himself and his companions by writing:

"The barometer which I observed during the ascent showed me a height of 18 inches, 1 line and 14 of 16, and the thermometer measured 2 and a half degrees in the shade. If you take this temperature into account you have to deduce 432 feet if you follow Luc's formula. Even though I couldn't do my calculations on right I still knew that we had to be at a height of about 11.400feet. And I told my companions so and mentioned the fact that we had climbed higher than any known observer in Europe, which helped us to overcome the frustration and feel kind of comforted, even though we had to leave our venture uncompleted."(14)

Saussure, too, concluded his exploration of the mountains with some additional measurements.

"I observed my hygrometer, my electrometer and the rocks surrounding us, of which I took some speciment with me."

Humboldt, too, in close communication with competing naturalists, marked the moment during the ascent of the Antisana in the Andes, when the scale of the barometer could no longer be read. "I am sure that no one before us has seen the mercury in the barometer drop to 14 inches, 11 lines; the scale of my instrument didn't reach that far."(15)

The intruments entice scientists not only to climb great heights, that had never been conquered before, they also crawl into caves to measure the temperature there or they go out on unknown lakes in dens fog to measure the water temperature at the surface or deep down. No description of these adventures fails to hint at the dangers and the concern for the instruments. Humboldt writes in his travel journal: "We are more busy with our instruments than worried about our health."(16)

The description of the difficulties and sufferings reported by Maupertuis during his measuring of the meridian in Lapland was stylized into the modern martyrdom of man caused by curiosity. Condamine even lost his hearing, "because he observed day and night and often had to lie on the cold and wet floor." The instrument is not only the driving factor in the exploration of unknown regions of the earth, it

(14) Horatius Benedictus von Saussure: Reisen durch die Alpen [...] Vierter Teil, Leipzig 1788, p. 336.

(15) Alexander von Humboldt: Reise auf dem Rio Magdalena, durch die Anden und Mexico. Teil ll, Berlin 1809, p. 64.

(16) Alexander von Humboldt: Relation historique, Tome Primier, op. cit., p. 210.

seems to provide the user with some kind of security and orientation. It reduces the variety of phenomena by providing a clearly defined set of observational parameters. The instrument actually links the explorer - working in the isolation of inaccessible mountains - to the civilized world. This is even more the case when readings have to be taken synchronically. Saussure and Deluc are connected by their joint barometric measurings, one on the way to the summit of the Montblanc the other in Geneva. Saussure also knows that he is being watched by telescope from the valley. If the instrument should get lost, the whole strenuous journey would be in vain, the connection with the civilized world, the far away metropolitan centres, where new data are egerly awaited, would break down. The instrument provides the explorer with strength to look past abyses and overcome the hardships of altitude sickness, the loss of the instrument, however, deeply affects him.

Resting periods which are forced on explorers after failed experiments lower the threshold for the perception of fear, a feeling they thought they had long concquered. It is always the feeling of boundless isolation that overwhelms the naturalist. Telescope and parallel instrumental observations create a real or sometimes imaginary connection between the base-camp and the isolated explorers making his way through a wilderness of ice and snow paving the way for the generations of tourists to follow.

On the one hand the exponents of the "Theory of Earth" are always in danger of failing, because of the complexity of the phenomena to be investigated but on the other hand they are full of curiosity, always eager to extend their field of research and the instruments employed. Even before one question is sufficiently dealt with new technologies open up new questions. Since they were working on the assumption that nature was locally unique, they had to measure all the varied properties of nature all over the earth. Since insight into the laws of nature was expected to come from the extremes, their exploratory zeal was characterized by a kind of centrifugal dynamics, driving the explorer into the most out-of-the-way places.

The "Theory of the Earth", which established itself in some counties in the first half of the 19th century as a discipline under the name of "Cosmic Physics", was bound to disappear, however inspite of the popularity of Humboldt. More and more, physicists opted to inverstigate questions which allowed them to reduce phenomena to just a few basic cases and from these to find as simple basic laws as possible.

But "Cosmic Physics" or "Physics of the Earth" have contributed significantly to the homogenity of our world. The different continents, the height of mountains were governed by the same laws of nature. Today there is no longer local variation in nature and no real isolation. Orientation, knowing exactly where we are on this planet and communicating our position to "base-camps" is now technically possible from any location on earth.

# 地球の理論，あるいは旅行用機器について

エンゲルハルト・ヴァイグル

この論考は，18世紀末から19世紀にかけて近代科学の成立に寄与した「地球の理論」あるいは当時の表現によれば「コスミック・フィジックス」について扱う。そのなかで，ヨーロッパ・アルプスの登山と研究で知られるソシュールやデルク，および著名な探検旅行を通じて地理学の確立に貢献したアレクサンダー・フンボルトが大きな役割を果した。主要な論点は以下の通りである。

第一に，近代の科学的認識の形成における実験機器の重要性が強調される。とくに，時計，温度計，気圧計，四分儀などが小型化されて携帯可能となり，単位が統一され精度が向上した結果，地球上の各地点における測定データの比較が可能となった。第二に，探検旅行や登山によって人々の前に開かれた新たな自然環境が「自然の実験室」の役割を果した。そこに新たな測定機器が持ち込まれたことによって，17世紀以来，限られた実験室内で蓄積されてきた自然哲学的知見が地球上の多様な地域における事象によって検証され，普遍的な自然認識となっていった。

1735年以来，モーペルテュイをリーダーとするラプランド遠征とゴーダン，ラ・コンダミーヌらのエクアドル遠征が行われた。極地近傍と赤道付近とで子午線弧の長さを正確に測定して比較し，地球の形状に関する論争を決着させるためであった。同時に，寒冷地における越冬やアマゾン源流に近いアンデス山地での苛烈な体験があった。これらの探検にリンネによる地球上の全植物を分類するシステムが加わり，地球を一つの天体として認識する道が拓かれた。すなわち「地球の物理学」の誕生である。

ヨーロッパ・アルプスをフィールドとしたソシュールらは，地質学的知見に加え，高山地帯における気温や気圧等の気象データ，氷雪の物理学的性質，雷等の電磁気的現象に関する知見を蓄積し，平地とは全く異なる条件のもとで物理学の諸法則を検証した。

1799年から1804年にかけて中南米地域に探検旅行を行ったフンボルトは，地理学上の知見だけでなく，赤道直下のアンデスの高山地帯等において多数の測定をおこない，その成果を報告した。そのさい，携行した測定機器に関する貴重な見解をも記録している。フンボルトの目標がコスモスとしての地球に関する普遍的な学問の建設にあったことはよく知られているところである。

このようにして，初期の探検や登山は，近現代の多数の人々の生活のなかに旅行と登山という新たな活動領域をもたらす糸口になったと同時に，観測機器の開発や改良に基づく「地球の科学」を通して，近代科学の形成に重要な役割を演じたのである。

この論文では，18世紀から19世紀前半にいたる探険旅行や登山の実状と，同時におこなわれた観測・測定の実態を示して，このような生活と科学技術の結びつきの一端を明きらかにする。