John Tyndall: glaciers, mountains and climate

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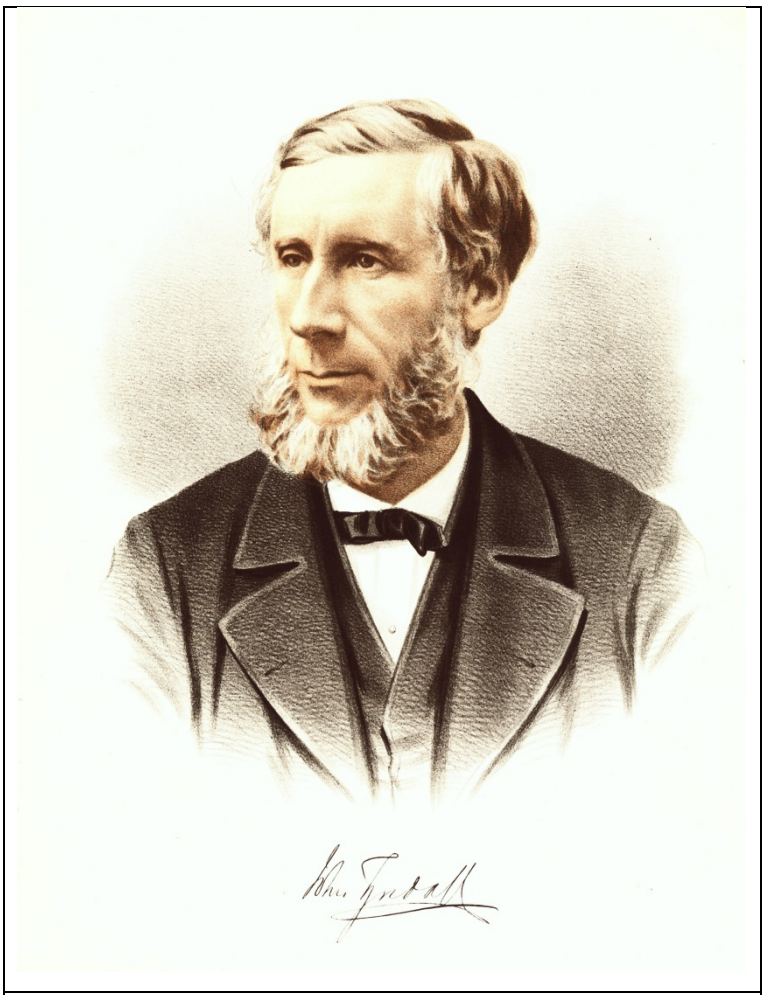
I think Tyndall would approve of my starting this piece with a sideways look. Today's scientists take over where yesterday's left off; today's knowledge is the evolution of yesterday's understanding. In one way this is obvious but the thought highlights that however much we may emphasise what we are doing now and are aiming for in the future, our work is intimately connected with what our predecessors did in the past. The elusive 'whole picture' involves past, present and future.

This almost philosophic introduction is prompted by the fact that we are not very good in the UK at remembering our scientific past by the very public means of naming major research institutions or government laboratories, or even universities, in honour of our influential scientific predecessors. They are better at it on the Continent. France, for example, has Universities named after Descartes, Pascal, Diderot, Fourier, Pierre et Marie Curie and various historical characters. In Britain, Isaac Newton just makes it as the name of an Institute in Cambridge and we have the Rutherford Laboratory near Oxford but where in the UK is the Darwin Institute, the James Clerk Maxwell Institute, the Rayleigh Institute …?. When I last looked there were 118 Nobel Prize winners credited to the UK across all the Nobel areas and have any apart from Rutherford had their name attached to a high profile scientific centre?



John Tyndall from a portrait in the author's possession

Clearly in the UK you have to be very exceptional to merit an Institute being named after you. The subject of this piece, John Tyndall (1820 – 1893), certainly does merit his recognition in the title of the 'Tyndall Centre for Climate Change'. He is also commemorated in the 'Tyndall National Institute' in Ireland. If they could ever knock on my door, there are some historical figures I'd be glad to welcome in for their humanity, their enquiring minds and for their diverse interests: Thomas Young and James Clerk Maxwell are two from the 19th century; John Tyndall is another. There is a substantial biography of Tyndall on my shelves (*Life and Work of John*

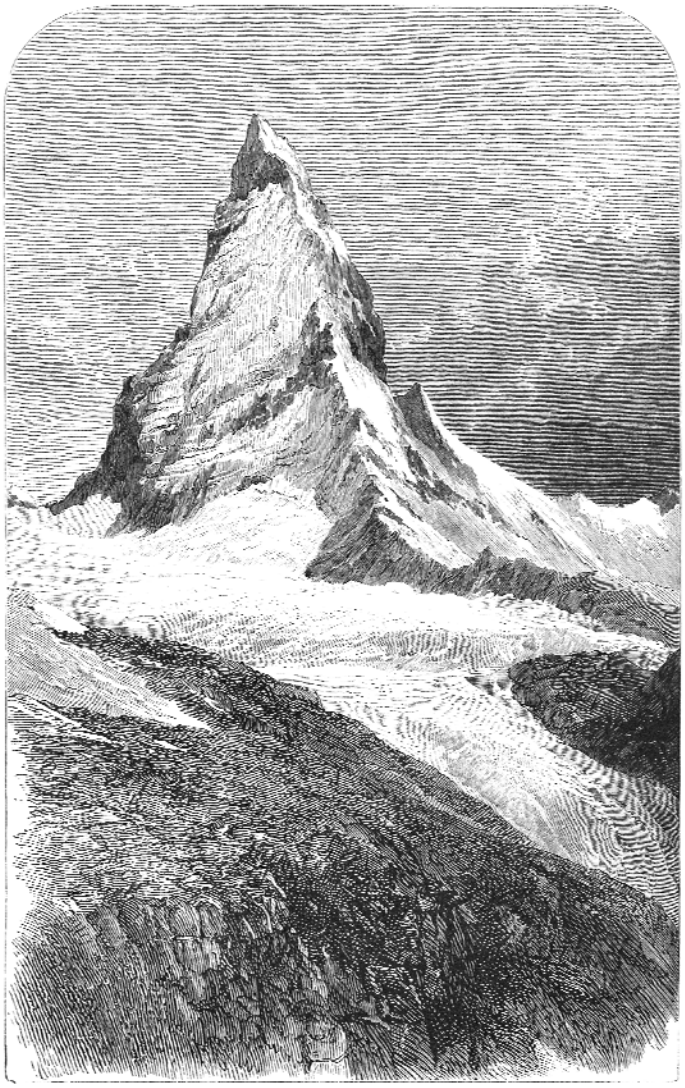
Tyndall, A.S. Eve and C.H. Creasey, Macmillan & Co. Ltd., London, 1945) but I don't want to quote from that or indeed create a potted biography of Tyndall here. I'd just like to give some feeling for what he said and did and saw in relation to mountain climate and landscape appearance.

I have a dozen other books by Tyndall on my shelves - his job as Professor of Natural Philosophy at the Royal Institution was to develop, explain and popularise science – and the one most directly concerned about weather and climate is *The Forms of Water in Clouds and Rivers, Ice and Glaciers* (Henry S. King, London, 1873). It is aimed at a young audience. Most of the book is about snow, ice and glaciers, for Tyndall was passionate about the Alps. He confessed that he had his share of the strain and worries of academic life but '*for such derangements I know nothing better than a dose of the glaciers*'. He studied them at length: how they flow down a valley, what happens when glaciers merge; the formation of crevasses, the various appearances of ice and moraines; the long-term growth and contraction of glaciers. He wasn't the first to study glaciers but he commented that it was the 19th century interest in the science of glaciers and mountain weather that helped open up the world of Alpine tourism. It's not that most tourists were scientists, just that the fascinating accounts of the Alps written by scientists made people realise that there was a dramatic and almost unexplored world on their doorstep in Western Europe. *Glaciers of the Alps* (Longmans, Green & Co., London, 1860) narrates at length some but not all of his glacial experiences. The frontispiece shows one of his favourite haunts, the *Mer de Glace*, or as he says, better described as a 'river of ice', on the north side of Mont Blanc.

THE MER DE GLACE

Tyndall was a first-rate mountaineer too. He tells many of his experiences in *Hours of Exercise in the Alps* (Longmans, Green & Co., London 1873). I'm not that familiar with Alpine

topography but the names I recognise – Weisshorn, Mont Blanc, Mattterhorn, Eiger, Jungfrau, Finsteraarhorn, Monte Rosa, whose peaks are over 4000 m in height – and others were all climbed by Tyndall, some with pioneering routes. He frequently took his 'boiling water apparatus' to the top to assess the temperature of boiling water at height (not a trivial undertaking) and was a perpetual student of the forms taken by ice and snow at various heights.



THE MATTERHORN.

So much for the introduction.

Tyndall's observations

In *Forms of Water* Tyndall begins: *The human mind is not satisfied with observing and studying any natural occurrence alone, but takes pleasure in connecting every natural fact with what has gone before it, and with what will come after it.* 'Climate change' was almost a century ahead in being articulated as a two-word concept but with such an attitude he was well equipped to notice the effects of climate change.

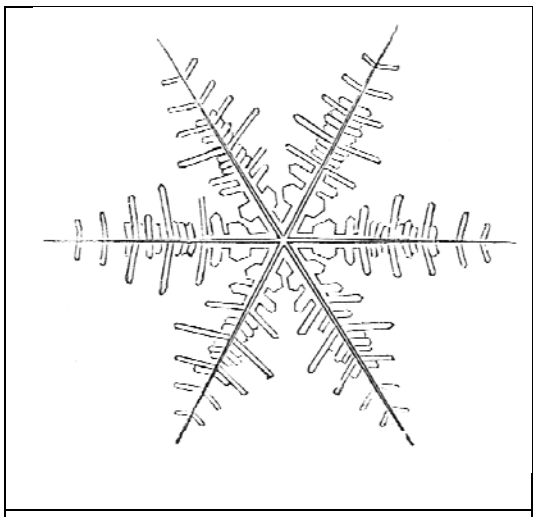
Proof by experiment was Tyndall's weapon of investigation. He was instrumental in pointing out that sunlight didn't melt glaciers. What did was the infra-red from the Sun. He described how you could take a beam from an electric light (an arc light in 1870, for the light bulb hadn't been invented), filter it using a water cell to remove the infra-red and focus it by a concave mirror onto a wad of gun-cotton. Nothing happens. Now change the filter to one of iodine dissolved in carbon disulphide that cuts out the visible light and lets through the infra-red. Bang! The gun-cotton explodes. Tyndall calls the infra-red 'dark light' or 'dark waves'. *At the same dark focus sheets of platinum are raised to vivid redness; zinc is burnt up; paper instantly blazes; magnesium wire is ignited; charcoal within a receiver containing oxygen is set burning; a diamond similarly placed is caused to glow like a star, being afterwards gradually dissipated. And all this while the air at the focus remains as cool as in any other part of the room.* Tyndall doesn't cheat in that he points out that the light source emits a greater portion of its radiation in the infra-red than the Sun does, but the point is made very clearly by the experimental demonstration. Of course the gun-cotton is for dramatic effect. You may say that the effect is partly due to the white gun-cotton reflecting most of the incident light but perhaps not reflecting

the infra-red. Tyndall says in effect 'fair enough' but do the same experiment with a plate covered with hoar frost. With the water cell, *not a spicula of the frost is dissolved*. Remove the cell to allow through the infra-red and in a moment the frost starts to melt.

There are writers who seem to regard science as an aggregate of facts, and hence doubt its efficacy as an exercise of the reasoning powers. But all that I have here taught you is the result of reason, taking its stand, however, upon the sure basis of observation and experiment. And this is the spirit in which our further studies are to be pursued.

Tyndall continues by discussing evaporation and condensation. The glaciers are fed by snow; snow is condensed water vapour; water vapour comes from a source via evaporation generated by solar radiation. *Curious then as the conclusion may be, the cold ice of the Alps has its origin in the heat of the sun.* The point is that one can't discuss bits of the system in isolation. The whole cycle needs to be understood to understand the phenomenon. That is modern meteorology and climate studies in a nutshell.

Tyndall liked to point out when phenomena were not as they seemed. *In connection with the formation of clouds by mountains, one particularly instructive effect may be here noticed. You frequently see a streamer of cloud many hundred yards in length drawn out from an Alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blown away? It is blown away; its permanence is only apparent. At one end it is incessantly dissolved, at the other end it is incessantly renewed: supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling. When the red sun of the evening shines upon these cloud-streamers they resemble vast torches with their flames blown through the air.*



Snowflake illustrated in '*Forms of Water*'

The regularity of snow crystals fascinated him, for how the symmetry in solids came to be from the chaos of liquids and gases was not understood in the 1870s. On the top of Monte Rosa [4634 m] with one companion, having measured the boiling point of water as 184.92°F [85°C] *After a few fitful efforts to dispel the gloom, the sun resigned the dominion to the dense fog and the descending snow, which now prevented our seeing more than 15 or 20 paces in any direction. The temperature of the crags at the summit, which had been shone upon by the unclouded sun during the earlier portion of the day, was 60° Fahr.; hence the snow melted instantly wherever it came in contact with the rock. But some of it fell upon my felt hat, which had been placed to shelter the boiling-water apparatus, and this presented the most remarkable and beautiful appearance. The fall of snow was in fact a shower of frozen flowers. All of them were six-leaved; some of the leaves threw out lateral ribs like ferns, some were rounded, others arrowy and serrated, some were close, others reticulated, but there was no deviation from the six-leaved type. Nature seemed*

determined to make us some compensation for the loss of all prospect, and thus showered down upon us those lovely blossoms of the frost; and had a spirit of the mountain inquired my choice, the view, or the frozen flowers, I should have hesitated before giving up that exquisite vegetation. It was wonderful to think of, as well as beautiful to behold. Let us imagine the eye gifted with a microscopic power sufficient to enable it to see the molecules which composed these starry crystals; to observe the solid nucleus formed and floating in the air; to see it drawing towards it its allied atoms, and these arranging themselves as if they moved to music, and ended by rendering that music concrete. Surely such an exhibition of power, such an apparent demonstration of a resident intelligence in what we are accustomed to call "brute matter", would appear perfectly miraculous. And yet the reality would, if we could see it, transcend the fancy.

Recalling the incident years later, he offered an aside that a modern climate scientist could not put into print. *But while we thus acknowledge our limits, there is also reason for wonder at the extent to which science has mastered the system of nature. From age to age, and from generation to generation, fact has been added to fact, and law to law, the true method and order of the Universe being thereby more and more revealed. In doing this science has encountered and overthrown various forms of superstition and deceit, of credulity and imposture. But the world continually produces weak persons and wicked persons; and as long as they continue to exist side by side, as they do in this our day, very debasing beliefs will also continue to infest the world.* Later Tyndall cited an example of religious explanations of natural phenomena being peddled with a certitude that tolerated no disagreement. W*e are here warned of the fact, which is too often forgotten, that the pleasure or comfort of a belief, or the warmth or exaltation of feeling which it produces, is no guarantee of its truth*. His stance brought him a hostile reputation in some of mid-Victorian society where religious observance, or at least its apparent observance, was deeply rooted.

Glaciers are very much in focus in modern climatology. The changes in them are conspicuous over decades not days, reflecting the time constant of climate rather than weather. Tyndall was well aware that glaciers are phenomena controlled by balance. His *snow line* was the height at which precipitation equalled the quantity of water melted during the year. Above the snow-line was the *névé* (in the French speaking Alps). Snow would accumulate there were it not for its tendency to slide downwards. Below the snow-line was the glacier, which would shrink if not fed from the *névé*. That the balance wasn't constant was clear to him for in 1873 he would write about the Mer de Glace *close to the existing glacier, for example, we have repeatedly seen the mountain side laid bare by the retreat of the ice. This is especially conspicuous just now, because for the last fifteen or sixteen years the glaciers of the Alps have been steadily shrinking; so that it is no uncommon thing to see the marginal rocks laid bare for a height of fifty, sixty, eighty, or even one hundred feet above the present glacier.* This was before a single car, airplane or power station existed in the world. It was through changing glaciation that Tyndall was able to make the point that climate was not a constant. *In the Highlands of Scotland, among the mountains of England, Ireland, and Wales, the ancient glaciers have written their story as plainly as in the Alps themselves.* The valley profiles, the chiselled rocks, the glacial lakes, the erratic boulders told Tyndall of glacial landscapes now softened by millennia of vegetation.

On the *Mer de Glace* Tyndall had his helpers place stakes in a line directly across the glacier and, armed with a theodolite, he surveyed them 24 hours later. It was easy to determine the glacier flow even over such a short space of time, for near the centre the glacier moved by over a half metre and near the edges much less. *The actual observation of the motion of a body apparently so rigid is strangely interesting. And not only does the ice move bodily, but one part of it moves past another*. When the valley is curved, as it mostly is, the fastest motion is beyond the mid-line nearer the concave bend, just as with a river. Looking from surface to base, the surface moves faster than the base, which is retarded by friction. *And now, having informed our minds by these observations, let our eyes wander over the whole glorious scene, the splintered peaks and the hacked and jagged crests, the far-stretching snow-fields, the smaller glaciers which nestle on the heights, the deep blue heaven and the sailing clouds. Is it not worth some labour to gain command of such a scene? But the delight it imparts is heightened by the fact that we did not come expressly to see it; we came to instruct ourselves about the glacier, and this high enjoyment is an incident of our labour. You will find it thus through life; without honest labour there can be no deep joy.*

Here we have cause for reflection, and facts are comparatively worthless if they do not provoke this exercise of the mind. It is because facts of nature are not isolated but connected, that science, to follow them, must also form a connected whole. The mind of the natural philosopher must, as it were, be a web of thought corresponding in all its fibres with the web of fact in nature.

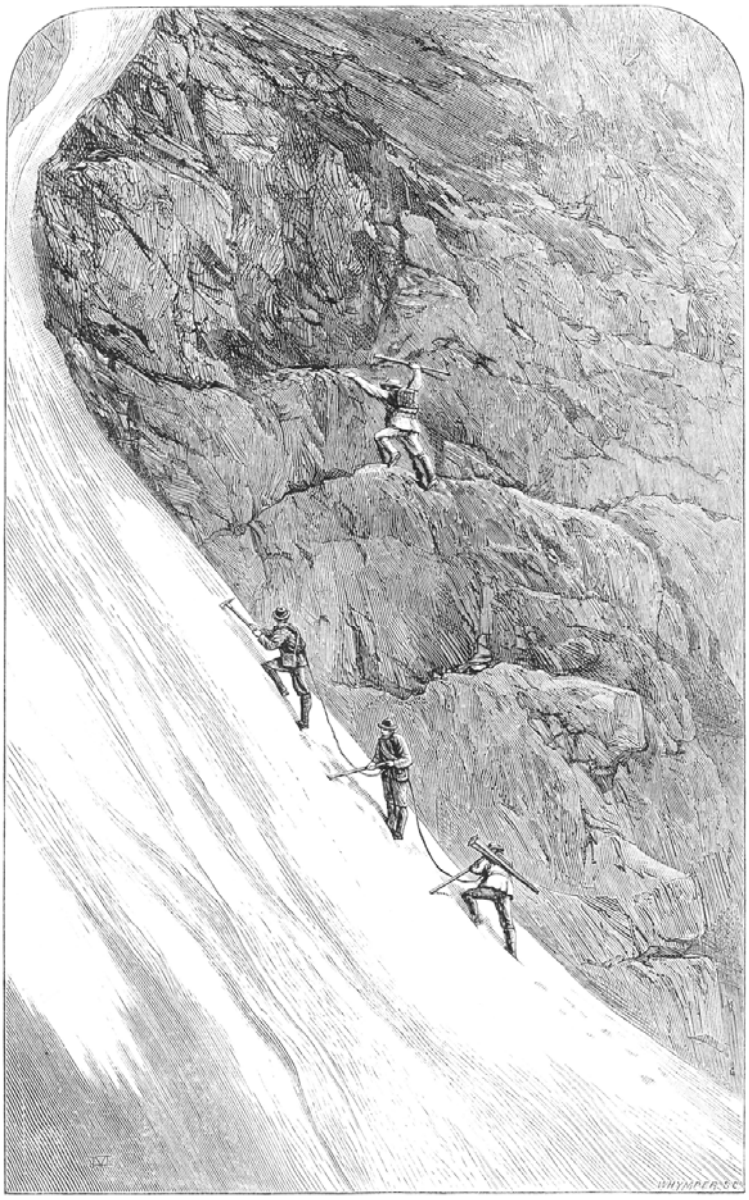
Tyndall's works are full of revelations. Sometimes they are quite simple, for example that glaciers in a valley are higher in the middle simply because heat from the enclosing mountains melts the glacier sides more than the middle. Air is not much heated by solar radiation. *Snow absorbs the solar heat, and on a sunny day you may see the summits of the high Alps glistening with the water of liquefaction. The air above and around the mountains may at the same time be many degrees below the freezing point in temperature.* Moraine ridges are not produced by a swelling of the ice underneath but by melting of ice on either side that is not protected by the moraine from the sun. I can't resist including a fine example of a *glacier-table* on the Mer de Glace illustrated by one of Tyndall's predecessors in glacial studies, the Edinburgh professor James D. Forbes who was particularly active in the 1840s and 1850s. Tyndall pointed out that *glacier-tables* are mainly tilted down at the South end and up at the North because of differential heating.

Glacier table on the Mer de Glace illustrated by James D. Forbes

I think I've said enough about glaciers to give a flavour of Tyndall's enthusiasm and contributions. It was unfortunate that he spent a lot of effort arguing with the conclusions of Forbes, making enemies in the process. In retrospect it was partly a matter of semantics

Tyndall's mountaineering

This piece is supposed to be as much about Tyndall as about mountain environment but in a way the mountains made the man. In the laboratory, Tyndall was a brilliant experimentalist; in the lecture theatre an enthralling lecturer; in his books an expositor of clarity. In the Alps, though, with a chill wind on his cheeks he seemed to feel more alive than in any other circumstances. I'm going to finish this piece with a few quotations of his experiences.



Tyndall preferring the rocks in his ascent in 1860

Here he is, having explored how the white colour of ice is not its true colour but the result of scattering by air bubbles and internal irregularities. *On the 6th of August* [1858] *there was a long fight between mist and sunshine, each triumphing by turns, till at length the orb gained the victory and cleansed the mountains from every trace of fog. We descended to the Märjelen See, and, wishing to try the floating power of its icebergs, at a place where masses sufficiently large approached near to the shore, I put aside a portion of my clothes and retaining my boots stepped upon the floating ice. It bore me for a time, and I hoped eventually to be able to paddle myself over the water. On swerving a little, however, from the position in which I first stood, the mass turned over and let me into the lake. I tried a second one, which served me in the same manner; the water was too cold to continue the attempt, and there was also some risk of being unpleasantly ground between the opposing surfaces of the masses of ice. A very large iceberg which had been detached some short time previously from the glacier lay floating at some distance from us. Suddenly a sound like that of a waterfall drew our attention towards it. We saw it roll over with the utmost deliberation, while the water which it carried along with it rushed in cataracts down its sides. Its previous surface was white, its present one was of a lovely blue, the submerged crystal having now come to the air. The summerset of this iceberg produced a commotion all over the lake; the floating*

masses at its edge clashed together, and a mellow glucking sound, due to the lapping of the undulations against the frozen masses, continued long afterwards.

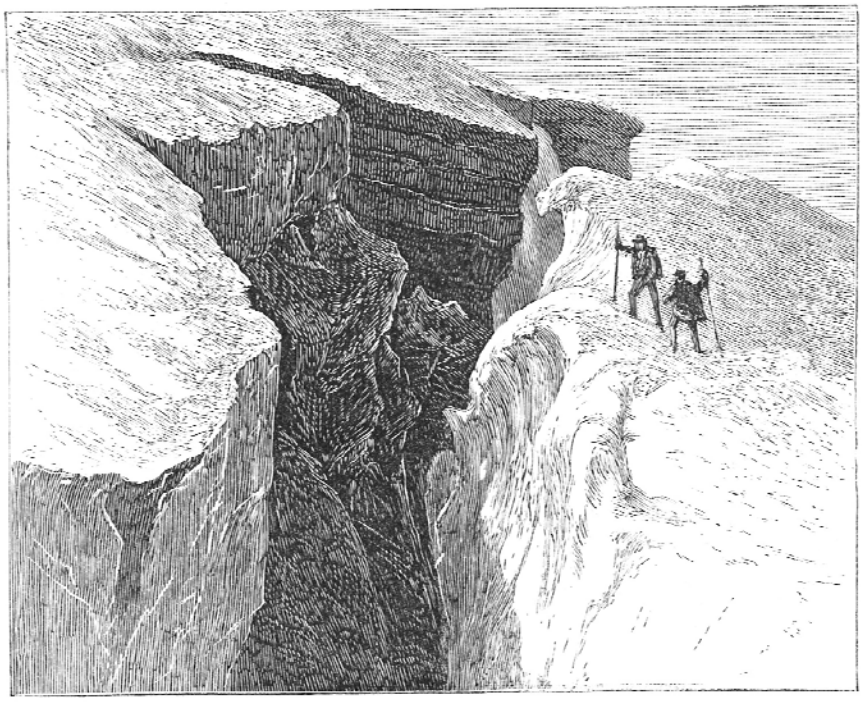
Tyndall's self-imposed experiments at times created additional hazards. In this account he is almost at the summit of Mont Blanc (4800 m, the highest Alp) with another experienced Alpinist Alfred Wills, his guide Balmat and porters. *As we approached the summit the air thickened more and more, and the cold, resulting from the withdrawal of the sunbeams, became intense. We reached the top, however, in good condition, and found the new snow piled up into a sharp arête, and the summit of a form quite different from that of the Dos d'un Ane, which it had presented the previous year. Leaving Balmat to make a hole for the thermometer, I collected a number of batons, drove them into the snow, and, drawing my plaid round them, formed a kind of extempore tent to shelter my boiling-water apparatus. The covering was tightly held, but the snow was as fine and dry as dust, and penetrated everywhere: my lamp could not be secured from it, and half a box of matches was consumed in the effort to ignite it. At length it did flame up, and carried on a sputtering combustion. The cold of the snow-filled boiler condensing the vapour from the lamp gradually produced a drop, which, when heavy enough to detach itself from the vessel, fell upon the flame and put it out. It required much patience and the absence of muscular action caused the cold to affect our men severely. My beard and whiskers were a mass of clotted ice. The batons were coated with ice, and even the stem of my thermometer, the bulb of which was in hot water, was covered by a frozen enamel. The clouds whirled, and the little snow granules hit spitefully against the skin wherever it was exposed. The temperature of the air was 20° Fahr. below the freezing point. I was too intent upon my work to heed the cold much, but I was numbed; one of my fingers had lost sensation, and my right heel was in pain: still I had no thought of forsaking my observation until Mr. Wills came to me and said that we must return speedily, for Balmat' s hands were gelées. I did not comprehend the full significance of the word; but, looking at the porters, they presented such an aspect of suffering that I feared to detain them longer. They looked like worn old men, their hair and clothing white with snow, and their faces blue, withered, and anxious-looking. The hole being ready, I asked Balmat for the magnet to arrange the index of the thermometer: his hands seemed powerless. I struck my tent, deposited the instrument, and, as I watched the covering of it up, some of the party, among whom were Mr. Wills and Balmat, commenced the descent.* On the descent if became clear that Balmat's hands were frostbitten and Tyndall became mortified *The idea that I should be in some measure the cause of his losing his hands was horrible to me*. The guide's hands were continually rubbed, beaten and thrust into the snow. It was near thing but *at Chamouni he had skilful medical advice, by adhering to which he escaped with the loss of six of his nails—his hands were saved.*

Tyndall was very aware that the weather in the high Alps brings real danger. In his *Exercises* he gives over a chapter to an account by fellow Alpinist Philip Gossett of how Tyndall's closest friend as a guide, Johann Bennen, for whom he had a huge respect, died in an avalanche. Gossett, his friend Boissonet, Bennen and three local guides from the nearby village of Ardon were crossing a snowfield near the top of a high culoire that the local guides had declared safe though Brennen didn't like it. *We had all come to the false conclusion that the snow was accidentally softer there than elsewhere. Boissonet then advanced; he had made but a few steps when we heard a deep, cutting sound. The snow-field split in two about fourteen or fifteen feet*

above us. The cleft was at first quite narrow, not more than an inch broad. An awful silence ensued; it lasted but a few seconds, and then it was broken by Bennen's voice, 'Wir sind alle verloren'. His words were slow and solemn, and those who knew him felt what they really meant when spoken by such a man as Bennen. They were his last words. I drove my alpenstock into the snow, and brought the weight of my body to bear on it; it went in to within three inches of the top. I then waited. It was an awful moment of suspense. I turned my head towards Bennen to see whether he had done the same thing. To my astonishment, 1 saw him turn round, face the valley, and stretch out both arms. The ground on which we stood began to move slowly, and I felt the utter uselessness of any alpenstock. I soon sank up to my shoulders and began descending backwards. From this moment I saw nothing of what had happened to the rest of the party. With a good deal of trouble I succeeded in turning round. The speed of the avalanche increased rapidly, and before long I was covered up with snow and in utter darkness. I was suffocating, when with a jerk I suddenly came to the surface again. The rope had caught most probably on a rock, and this was evidently the moment when it broke. I was on a wave of the avalanche, and saw it before me as I was carried down. It was the most awful sight I ever witnessed. The head of the avalanche was already at the spot where we had made our last halt. The head alone was preceded by a thick cloud of snowdust; the rest of the avalanche was clear. Around me I heard the horrid hissing of the snow, and far before me the thundering of the foremost part of the avalanche. To prevent myself sinking again, I made use of my arms much in the same way as when swimming in a standing position. At last I noticed that I was moving slower; then I saw the pieces of snow in front of me stop at some yards distance; then the snow straight before me stopped, and I heard on a large scale the same creaking sound that is produced when a heavy cart passes over hard-frozen snow in winter. I felt that I also had stopped, and instantly threw up both arms to protect my head in case I should again be covered up. I had stopped, but the snow behind me was still in motion; its pressure on my body was so strong that I thought I should be crushed to death. This tremendous pressure lasted but a short time, and ceased as suddenly as it had begun. I was then covered up by snow coming from behind me. My first impulse was to try and uncover my head but this I could not do: the avalanche had frozen by pressure the moment it stopped, and I was frozen in. Whilst trying vainly to move my arms, I suddenly became aware that the hands as far as the wrist had the faculty of motion. The conclusion was easy, they must be above the snow. I set to work as well as I could; it was time, for I could not have held out much longer. At last I saw a faint glimmer of light. The crust above my head was getting thinner, and it let a little air pass, but I could not reach it any more with my hands; the idea struck me that I might pierce it with my breath. After several efforts I succeeded in doing so, and felt suddenly a rush of air towards my mouth; I saw the sky again through a little round hole. A dead silence reigned around me; I was so surprised to be still alive, and so persuaded at the first moment that none of my fellow-sufferers had survived, that I did not even think of shouting for them. I then made vain efforts to extricate my arms, but found it impossible; the most I could do was to join the ends of my fingers, but they could not reach the snow any longer. After a few minutes I heard a man shouting: what a relief it was to know that I was not the sole survivor! to know that perhaps he was not frozen in and could come to my assistance! I answered; the voice approached, but seemed uncertain where to go, and yet it was now quite near. A sudden exclamation of surprise! Rebot had seen my hands. He cleared my head in an instant, and was about to try and cut me out completely, when I saw a

foot above the snow, and so near to me that I could touch it with my arms, although they were not quite free yet. I at once tried to move the foot; it was my poor friend's. A pang of agony shot through me as I saw that the foot did not move. Poor Boissonnet had lost sensation, and was perhaps already dead. Rebot did his best: after some time he wished me to help him, so he freed my arms a little more, so that I could make use of them. I could do but little, for Rebot had torn the axe from my shoulder as soon as he had cleared my head (I generally carry an axe separate from my alpenstock - the blade tied to the belt, and the handle attached to the left shoulder). Before coming to me Rebot had helped Nance out of the snow; he was lying nearly horizontally, and was not much covered over. Nance found Bevard, who was upright in the snow, but covered up to the head. After about twenty minutes the two last-named guides came up. I was at length taken out; the snow had to be cut with the axe down to my feet before I could be pulled out. Bennen and Boissonnet had lost their lives in the avalanche. Gossett had been lucky to escape with just bruises. The weather and its consequences require the utmost respect in the high mountains.

There are many passages in Tyndall's accounts of his Alpine experiences worth quoting but it is appropriate to end this tribute by mentioning that it was in the laboratory not in the Alps that he made perhaps his most significant contribution to climatology. He was the first to measure the infra-red absorption of various gases and vapours and in so doing demonstrate that water vapour makes the largest contribution to the greenhouse effect in the Earth's atmosphere. He found carbon dioxide ('carbonic acid gas') largely transparent except in two wavebands where it absorbed very strongly. You can still see some of his apparatus in the basement museum at the Royal Institution. Tyndall's books are long out of copyright but I'm sure can now be found on the web.



CREVASSE ON GRAND PLATEAU.

JSR