Being a Teacher and Scientist in Times of "Big Science"
Connecting Data and Theory
Playing in the Field of a Passion

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Introduction

This essay has three titles, which reflect my concerns and thoughts about present day science. This essay marks the end of my career as a university teacher. It meanders through a part of my life, examining the origins of my passion for wanting to understand the workings of the atmosphere, my interest in weather and climate, and my interest in the human process, with trial and error, both individual and collective, of reaching an understanding of the world around us.

My life as a scientist has been somewhat lonely due to an inclination and desire to remain independent. In the postscript of her novel "*The Sea, the Sea*" (1978), Iris Murdoch states that *we must live by the light of our self-satisfaction, through that secret vital busy inwardness, which is even more remarkable than our reason*. I feel exactly that. But, I think it is now high time to share some aspects of *that secret vital busy inwardness*. The intention of this essay is to inspire the invited speakers at my farewell symposium in the spring of 2023 to share their ideas about the topics embodied in the three titles of this essay.

This essay has its origins in a presentation, entitled "*Lost connection between data and theory*: *the Science of Weather Extremes cannot exist without the older discipline of Dynamical Meteorology*", given on 25 May 2021 to the members of the German "*ClimXtreme* Research Network", as a member of its Scientific Advisory Board. The *ClimXtreme* Research Network is an example of *Big Science*. In *Big Science* many research institutes cooperate to find answers to scientific questions that are deemed important to society. *ClimXtreme* consists of 4 modules. Six German research institutes, among them the University of Hamburg, the Free University of Berlin and Karlsruhe Institute of Technology, participate in module "A" of *ClimXtreme*, which is entitled "Physics and Processes". The overall aim of module "A" is to address the following two central research questions.

1. Has past climate change caused more extreme weather events?
2. Will future climate change modify the occurrence of extreme weather events?

The first question should, in my opinion, be divided into the following two separate questions.

1a. Is the frequency of extreme weather events, such as heat waves, extreme cold, droughts, floods, wind storms and hail storms, increasing?
1b. If so, can this increase be attributed to "human-induced climate change"?

The record-breaking "heat waves" in Western Europe in 2018, 2019 and 2022 and in Western Canada in 2021, as well as the the vanishing cold winters in Western Europe, can with little doubt be attributed to "climate change" due to anthropogenic greenhouse warming. But, what about the recent frequent occurrence of cold air outbreaks in the Midwestern USA, Eastern USA and Central and Eastern Canada? Altered circulation patterns play a role here. Are these altered circulation patterns linked to human activities, such as CO_2-emissions, methane emissions, stratospheric ozone depletion and altered land use? If so, how? In the light of these questions, questions **1a** and **1b** should be simplified to the following more general questions, omitting the question of more frequent extremes.

1a. In which way is weather changing and why?
1b. If so, can this change be attributed to (which) human activities?

Are present day young climate researchers equipped with enough knowledge of Atmospheric Dynamics, Radiation Transfer Theory, the Water Cycle and the Physical, Chemical and Biological Processes occurring near the Earth's Surface to tackle these and similar research questions? I am not so sure about this. Many present day *Climate Scientists* are led only by Data, Statistics and Machine Learning. Some even say that theory is not needed in the age of "Big Data". In an essay, entitled "*The End of Theory*", Chris Anderson

(2008) states, "*the new availability of huge amounts of data, along with the statistical tools to crunch these numbers, offers a whole new way of understanding the world. Correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all*". Computer scientists are claiming that Artificial Intelligence (AI)-based weather forecasts are faster and better than weather forecasts based on the forecasting system of the European Centre for Medium Range Weather Forecasts (ECMWF), which, they say, is the "most accurate deterministic operational weather forecasting system in the world" (https://arxiv.org/abs/2212.12794). Such trust in AI-based weather forecasts is absurd. An AI-based (statistical) weather forecasting system needs "Data" to be trained, while this "Data", in this case the "ERA5-Reanalysis" of the past state of the atmosphere (Herzbach et al., 2020), would not exist without the data-assimmilation system of the aforementioned "most accurate deterministic operational weather forecasting system". Reanalysis is a 4-dimensional (in time and space) interpolation of instrumental observations of very diverse type using a state of the art numerical weather prediction model, which is based on the Theory of Physics and Chemistry. A Reanalysis would be very innacurate without this theoretical framework. A recent reanalysis, which goes back in time as far as 1836 (Slivinsky et al., 2021), is probably constrained more by theory than by instrumental measurements.

In a paper entitled "Big Data Needs Big Theory Too", Sauro Succi and Peter Coveney (2019) (two computer scientists, based in Rome and London) pointed out that "*a statistical result is no more than useful information requiring a theoretical interpretation*". I could'nt agree more! "Theory" turns "Useful Data" into "Knowledge and Wisdom". Here I wish to make a passionate plea for the Theoretical Interpretation of Reanalysis Data and other data, hopefully pointing the way to new Theories, new concepts and better understanding.

"Big Science" and the Science of "Weather and Climate Extremes"

Slowly we have entered the era of "Big Science". "Big Science" is extremely successful, especially when it is connected to the formation of dedicated institutes, such as the ECMWF (https://www.ecmwf.int). The ECMWF, which exists since 1975, is financed by 23 Member states and 12 co-operating states, forming a very vibrant scientific community. Similar examples of very successful European cooperation, with a specified and clear goal in science, are the European Space Agency (ESA) (https://www.esa.int/), Eumetsat (https://www.eumetsat.int/), and CERN (https://home.cern/).

The *ClimXtreme* Research Network (https://climxtreme.net/), although vibrant also, has a less well-defined goal. This has to do with the definition of the terms "weather extreme" and "climate extreme". "Weather extremes" are weather events, which are associated with, for example, temperatures (high or low), or precipitation-sums, which are seldomly observed. Are we observing more extreme weather events? If so, for how long will we continue to qualify such weather events as "extreme", thereby qualifying the study of these events as part of a new discipline called "*The Science of Weather and Climate Extremes*" (**figure 1**)? What exactly is a "*Climate Extreme*"? Is the "*The Science of Weather and Climate Extremes*" science?

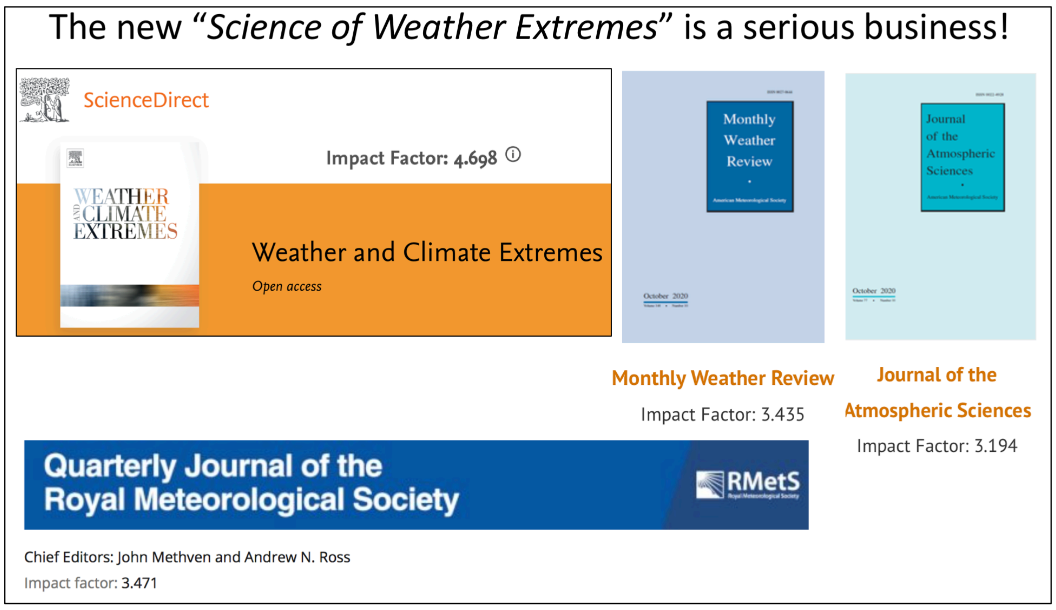

Figure 1. Papers published in the journal, *Weather and Climate Extremes*, have a higher " Impact Factor" than papers published in well-known old scientific journals representing the mother discipline of Dynamical Meteorology (slide shown at the *Clim-Extreme* meeting of 25 May 2021).

A journal with the title, *Weather and Climate Extremes*, launched in 2013, is now ranked higher, in terms of *impact factor*, than well-known traditional journals, such as *Monthly Weather Review*, *Journal of the Atmospheric Sciences* and *Quarterly Journal of the Royal Meteorological Society*, which contain most of the seminal papers of the older discipline of "*Dynamical Meteorology*" (van Delden, 2017). Unfortunately, the "*Science of Weather and Climate Extremes*" exists largely without the theoretical framework of "*Dynamical Meteorology*", or in any case, without contributing much to this theoretical framework.

The scientific goal of the *ClimXtreme* Research Network is guided strongly by the relatively superficial research agenda of funding agencies, related to *Climate Change Attribution*. This agenda interferes with the main goal of universities, which is teaching and preparing students for their future career and role in society, doing research supporting this teaching, and helping *basic science* forward by formulating theories and doing experiments to support these theories. I hope to make myself clear on this point in this essay.

Why are prolonged extreme cold spells in the Netherlands becoming less frequent?

Let me start with with a relatively simple example of *Climate Change Attribution*. The example is concerned with explaining the remarkable winter warming in Western Europe over the past 80 years **(left panel of figure 2)**. In the Netherlands this is manifest in an average rise of the January-mean surface temperature at a rate of nearly 4°C per century, much faster than the rise of the *global* and *annual* average surface temperature in the same period (in the order of +1°C per century).

The Dutch are good speed skaters. They take most of the Olympic medals for long distance speed skating. Skating in the Netherlands is popular because a large part of the country, especially the north and the west, consists of shallow lakes and canals, which freeze easily. For example, in the recent mild winter a 5 days period with an average temperature of about -4°C, a daily minimum between -5°C to -10°C and a daily maximum temperature close to 0°C, was sufficient to make skating possible on many lakes, even on the large ones (right panel of **figure 2**). Many local ice skating clubs compete in organising the first or earliest speed skating marathon. The most popular one-day skating tour is the "elfstedentocht" ("eleven cities tour"), spanning a distance of nearly 200 km in the province of Friesland in the north-west of the country. The tour is held only if ice thickness is at least 15 cm along the entire course. This requires sub-zero temperatures for at least two weeks. Between 1909 and 1963 the tour was held on average once every 5 years. The most famous edition of the tour occurred on 18 January 1963. It is known as "The Hell of 63", due to strong easterly winds, blowing snow and temperatures consistently below -15°C. Only 69 of the 9292 participants completed the tour on that day. The next tour might have been held in 1979, if not for bad ice conditions due to snow on the ice and freezing rain. It took 23 years before the next tour was held in 1986. Remarkably, the following "elfstedentocht" was held a year later, in 1987. The last "elfstedentocht" was held in 1997.

The "elfstedentocht" is in danger of extinction now, because persistent low temperatures are becoming less frequent. Looking back in time as far as into the Little Ice Age **(figure 3)**, we observe that extreme low monthly mean temperatures in the winter (December, January and February) in the Netherlands are vanishing. Very cold winter months with an average temperature well below 0°C are becoming very rare. Is this indicating a transition to a more equable winter climate in the Netherlands?

Figure 2. Ice skating on a canal in the Netherlands, painted by Andreas Schelfhout in 1856 (left panel) and at Fort Blauwkapel (Utrecht) on 18 December 2022 (right panel).

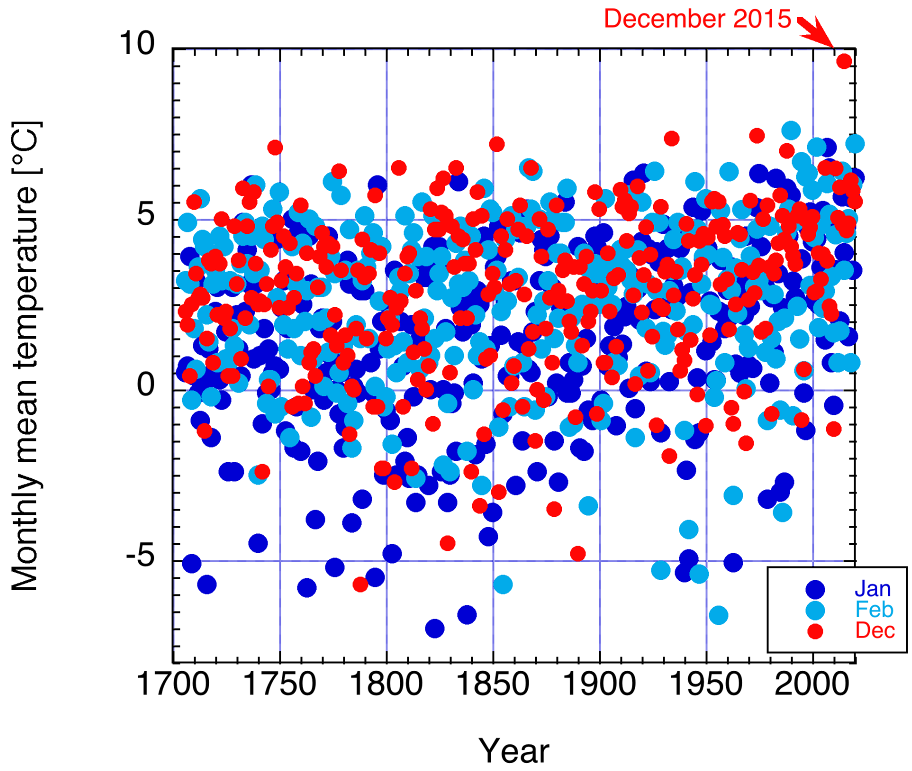

Figure 3. Left panel: Monthly mean surface air temperatures at De Bilt in **December**, **January** and **February** between 1706 and 2020, based on Delft/Rijnsburg (1706-1734), Zwanenburg (1735-1800 & 1811-1848), Haarlem (1801-1810) and Utrecht (1849-1897), reduced to De Bilt', and De Bilt (1898-now, homogenised 1906-2020). Source of the data: Climate Explorer ("Labrijn time series").

Figure 4 shows the January mean temperature at Groningen airport, in the North of the Netherlands at a latitude of 53°N, as function of the year between 1942 and 2019. Mild months with an average temperature above 0°C are indicated by open circles, while cold months with an average temperature below 0°C are indicated in blue. The linear regression to *all* data points (the red line) exhibits an upward trend from 0.3°C in 1942 to 3.1°C in 2019, equivalent to an average temperature trend of 3.75°C per century. The upward trend in Groningen is due principally to the vanishing of cold months (blue dots in the left panel). Between 1942 and 1992, one in three January months was "cold" (T<0°C). After 1992, this frequency was one in ten! Cold winter months are becoming less frequent. Is this due to "human induced climate change"?

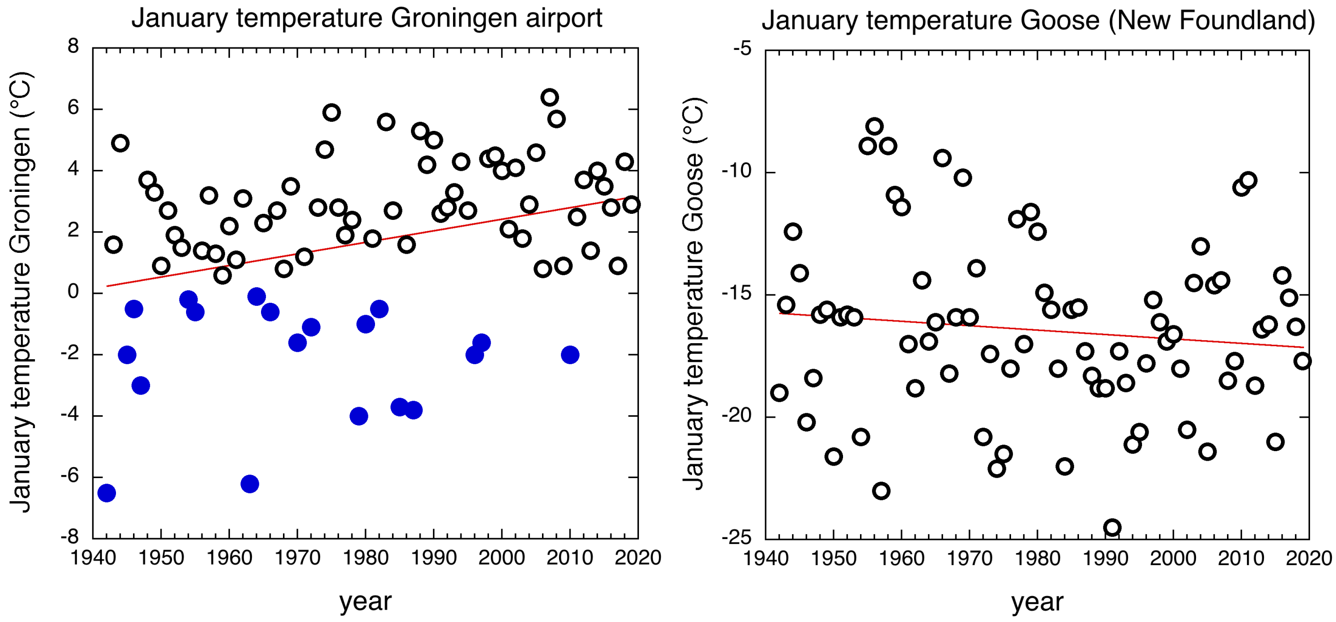

Figure 4. Left panel: Monthly mean surface air temperatures at Groningen Airport (Eelde) at a latitude of 53°N in January between 1942 and 2019 with cold months (T<0°C) highlighted in blue. The red straight line represents the best linear fit to the 77 data points. The slope this line is 3.75°C per century and correlation coefficient, r=0.31. **Right panel:** Monthly mean surface air temperatures at Goose (Labrador and New Foundland) in January between 1942 and 2019. Goose (53°N, 61°W) is at the same latitude as Groningen (53°N, 6.5°E). The slope the best linear fit to the data is -1.8°C per century and correlation coefficient, r=0.12. The significance of this weak correlation is discussed on page 5. Source of the data: Climate Explorer.

The correlation coefficient associated with the best linear fit to the temperature time series, shown in the left panel of **figure 4**, is r=0.3, which would classify as "weak". Hence we cannot be certain about the existence of an upward temperature trend in January in Groningen. The significance or standard error, SEr, of a correlation coefficient, r, depends on the number of "samples", N, and r itself (Rowntree, 1981). In this example, N=77 and r=0.3. The standard error of r is

$$\mathrm{SE}r = \frac{1-r^2}{\sqrt{N}} = \frac{1-0.3^2}{\sqrt{77}} \approx 0.1$$

Therefore,

$$r = 0.3 \pm 0.1.$$

Hence we can be reasonably confident that the January-mean temperature in Groningen is increasing. This agrees with radiative transfer theory, which attributes rising temperatures to the rising CO_2 concentration.

However, in Goose, which is at the same latitude as Groningen (53°N) and also near the sea, but at the other side of the Atlantic Ocean in the Canadian province of New Foundland and Labrador, the January mean temperature has *decreased* at a rate of 1.8°C per century, with $r = 0.1 \pm 0.1$ (right panel of **figure 4**). Although a correlation coefficient of 0.1 is qualified as "very weak", we can say with reasonable confidence that the January-mean temperature in Goose is *not* increasing. Other factors than rising CO_2 concentration are playing a role in causing the different temperature trends on either side of the Atlantic Ocean. Are atmospheric circulation changes strengthening the hypothetical, radiation-induced, temperature rise in Groningen and counteracting the same radiation-induced temperature rise in Eastern Canada? I discuss this question with my students.

The opposition between the temperature anomalies on either side of the North Atlantic Ocean, which has been known at least since the missionary Hans Egede Saabye made notes of it in his diary, which he kept in Greenland between the years 1770 and 1778 (van Loon and Rogers, 1978), was attributed later to the so-called "North Atlantic Oscillation" (NAO) (Walker and Bliss, 1932). The intensity of the NAO is measured in terms of the sea-level pressure difference between Reykjavik (the subpolar low) and Lisbon (or Gibraltar) (the subtropical high) (Jones, et al., 1997).

By applying a statistical technique, called *Principal Component Analysis* (PCA), which is very popular with Climate Scientists, we are able to implicate the NAO in *both* the increase of the winter temperatures in the Netherlands and the decrease of the winter temperatures in Eastern Canada. The large-scale circulation change over the North Atlantic Ocean is reflected in a recent more positive phase of the NAO associated with both a more intense subtropical high and also a more intense subpolar low, with more intense westerly surface winds in between these pressure-systems. Do we understand these circulation changes over the Atlantic Ocean? Are they related to changing CO_2-concentrations? Could CO_2-induced stratospheric *cooling*, which will intensify the polar winter *stratospheric* vortex, also intensify the westerly winds in the troposphere in middle latitudes, also near the surface of the earth? Hence, are we going to see more winters characterised by strong westerly winds, more equable (mild) temperatures and abundant rainfall in North-Western Europe with simultaneous winter drought a lower latitudes, such as in the Mediterranean region, due to higher sea-level pressure at these latitudes? Our tentative theoretical answer to these questions, based on the technique of *piecewise potential vorticity inversion*, is "*yes*" (Hinssen et al., 2010).

Or can we expect a different distribution of monthly mean winter temperatures with recurring very *warm* winter months in North-Western Europe, like December 2015, now still a strange and unlikely outlier (**figure 3**)? The tentative answer to this question may be related to the recent strong warming of the Arctic, known as "Arctic amplification". Some researchers, such as Jennifer Francis (*Woodwell Climate Research Center*, Massachusetts), think that Arctic amplification has led and will lead to more weather extremes in middle latitudes, because Arctic amplification, they say, "induces planetary waves with larger meridional amplitudes".

The unlikely high temperatures in December 2015 in the Netherlands and elsewhere in Western Europe were indeed associated with a deep stationary trough over the Eastern Atlantic Ocean with an associated stationary *Atmospheric Moisture River* persistently bringing abundant rainfall to the UK, while spectacular positive temperature anomalies were recorded just to the east over continental Western Europe.

In a semi-popular article, entitled "*Meltdown*", published in *Scientific American* in April 2018, Jennifer Francis states the following. "*Large waves in the jet stream, along with strong Arctic warming, can disrupt the polar vortex, prolonging deadly deep freezes or parades of snowstorms, including the long stretch of severe cold that gripped the northern U.S. in early January of this year. A polar vortex collapse can also perpetuate wild jet-stream swings that deliver crazy heat waves to Alaska and the far north, creating yet another vicious cycle that accelerates Arctic warming. Some studies suggest that Arctic warming is closely connected with these wavy patterns; others say proof of the connection is still tenuous. Research on this hot topic is advancing quickly*".

With the adjectives, "*deadly*", "*wild*", "*crazy*" and "*vicious*" Jennifer Francis is not aiming to captivate fellow scientists, but rather to attract the attention of politicians and funding agencies, indeed an important task of scientists in these days, but certainly not promoting a nuanced scientific discussion.

In a paper entitled "Heated debate on cold weather", published in *Nature Climate Change* (2014), Erich Fischer and Retto Knutti (ETH, Zurich) are very critical about the idea that Arctic amplification and weather extremes in middle latitudes are linked. They state the following. "*The debate about the recent cold spells followed the familiar pattern that characterises public reaction to surprising events such as disasters, aircraft accidents or crimes. A causal explanation is immediately called for, and experts are tempted (or forced) to speculate, even though little is known. The media happily runs the resulting stories, hypotheses further develop in the blogosphere and sometimes become accepted as facts despite a lack of evidence. It is natural to ask for explanations quickly after events happen. It is also valuable to publish hypotheses and propose causal mechanisms based on simple correlation and regression analyses. Thereafter, however, these hypotheses need to be scrutinized with observational evidence, confronted with the existing body of literature and rigorously quantified to test whether they play a dominant role in determining cold spells. Such a scientific debate can be stimulating and fruitful, but it takes time*".

As an exercise in one of my courses I confront students with these quotes and ask them to write an essay which focusses on (1) the scientific evidence for the proposed and debated link between Arctic and mid-latitude weather, and/or (2) the role, as actors in this debate, of scientists, politicians, journalists and funding agencies.

My work as a teacher is strongly connected to my work as a researcher

Let me introduce myself. I grew up in and near Barcelona, Spain, where I received an English language school education. From 1962 until 1971 I attended the Anglo-American School in Castelldefels. From 1971 until 1974 I went to Kensington School in Barcelona. Classes were never larger than 20 pupils. At age 18 I started studying *Electrical Engineering* and *Technical Physics* at the Technical University of Twente in Enschede, near to the German-Dutch border.

After first overcoming the shock caused by gloomy weather and the eternally setting sun (if it was shining) in late autumn and winter in the Netherlands, and missing the lively big Mediterranean city of my youth, I quickly discovered that I did not want to become an engineer. So, I moved to the University of Utrecht to focus on Geophysics, finally following my early and active interest in meteorology.

I started my professional career with a PhD-research project on *Cellular Convection in the Atmosphere*, supervised by Hans Oerlemans and Sjef Zimmerman, aimed at explaining the existence of shallow cumulus cloud patterns, such as "cloud-streets", "closed cells" and "open cells", observed especially over the high-latitude oceans. Open cells (**figure 5**) are characterised by relatively *thin* rings of clouds surrounding relatively *large* cloud-free areas. I constructed a hierarchy of idealised models of thermal convection of increasing complexity. I found multiple steady state solutions, each resembling one of the observed convection patterns. I was very much impressed by this exhibition of order in a non-linear system with many degrees of freedom. I discovered that convective pattern selection depends largely on initial conditions.

After finishing this PhD project, I became assistant professor at the *Free University of Amsterdam*. I discontinued research on convection pattern selection, because I thought it was too much at the periphery of Meteorology, and also too mathematical. Nevertheless, after the year 2015 my knowledge of the nonlinear dynamics of thermal convection in fluids has served as the inspiration for my part of a third-year bachelor course *on Turbulence in Fluids* (van Delden, 2022a), aimed at attracting theoretically interested Physics Bachelor Graduates in Utrecht to the *Climate Physics* master programme.

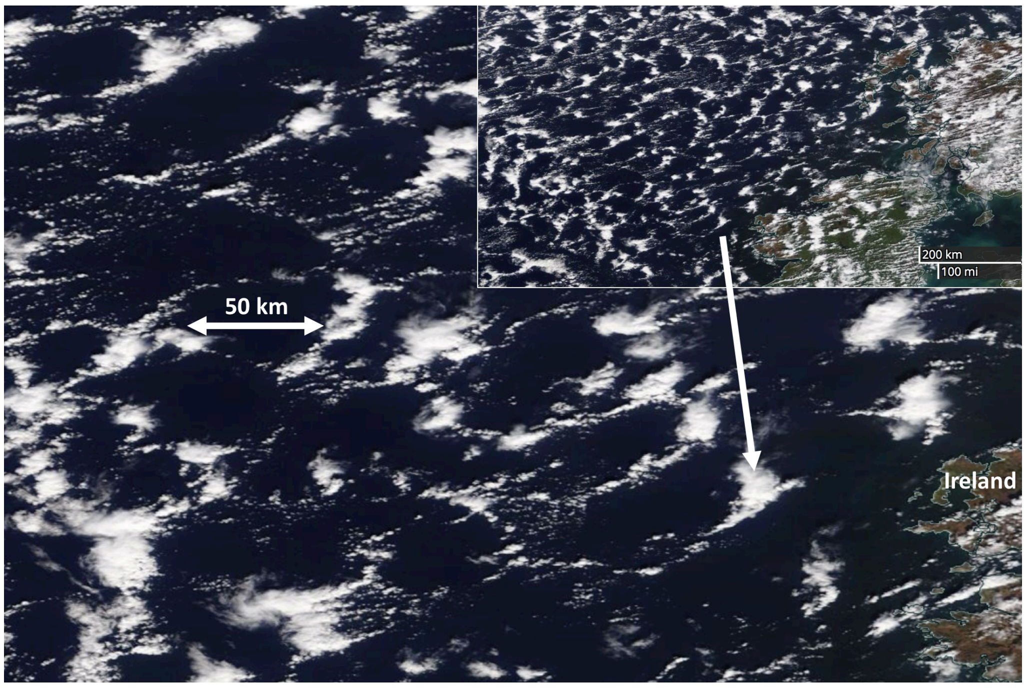

Figure 5: An example of *self-organisation* in the atmosphere: open convection cells over the Atlantic Ocean west of Ireland on 6 April 2020 (NASA MODIS Aqua satellite image with a resolution of 1 km). The lower panel is a close-up of the central-lower part of the panel in the upper right corner. The open cell diameter is about 50 km while the depth of the convective layer is probably no more than 4 km (https://worldview.earthdata.nasa.gov).

In the 1980's and 1990's the department of Meteorology within the faculty of Earth Sciences at the *Free University of Amsterdam*, was specialised in doing and evaluating measurements in the atmospheric boundary layer, usually as part of a large international meteorological field experiment. After the retirement of its two professors (Hans Vugts and Henk Tennekes), meteorological research in Amsterdam was gradually transformed into climate (change) research. This led to the formation of the *Institute of Environmental Studies of the Free University of Amsterdam*, which focuses on climate change and the impact of climate change on society and the economy.

I am an associate professor at the department of Physics in Utrecht. Perhaps I am an "old-fashioned" professor, because my research is unfettered and curiosity-driven. I am attracted to "fundamental questions", known as *Blue Skies Research*. The topic of my research is strongly inspired by what I think I should teach the students. Students should hear about the most recent developments in theory and practice. My attempts to combine teaching and research have led to a rather surprising (at least, to me) discovery that some fundamental problems, which are presented in textbooks as *solved problems*, with *very polished theories*, are actually not solved or explained. Worse: some questions, which should be fundamental, are avoided in standard textbooks.

The question of the *cause, intensity and position of the sub-tropical jet stream* (STJ) (**figure 6**) is one of these unsolved problems. In standard textbooks the STJ is treated very superficially. Its strength is usually explained by applying the principle of *angular momentum conservation* to air parcels moving poleward from the equator in the upper leg of a hypothetical zonally symmetric Hadley circulation cell. This is obviously not correct. Large-scale *tropical* eddies and waves have a large influence on the Hadley circulation, in particular also on the STJ! Yvonne Hinssen and myself (van Delden and Hinssen, 2012) provide an explanation of the STJ, which does not refer to the Hadley circulation. In our view the position of the STJ is determined first by radiation. Radiative cooling in the extra-tropics creates a massive dome of cold air, centred over the Pole. The mass needed to create the dome of cold air is extracted from higher layers, hence creating a layer with a mass deficit, which is referred to as the *lowermost stratosphere*. The STJ forms at the equatorward edge of the *lowermost stratosphere*, consistent with thermal wind balance.

Students should be made aware of the fact that theories, even textbook theories, could be incomplete or even incorrect. Students should hear about scientific controversies in the past and at present. Many scientific controversies are rooted in misunderstandings about terminology, about concepts and in too simplified "story telling".

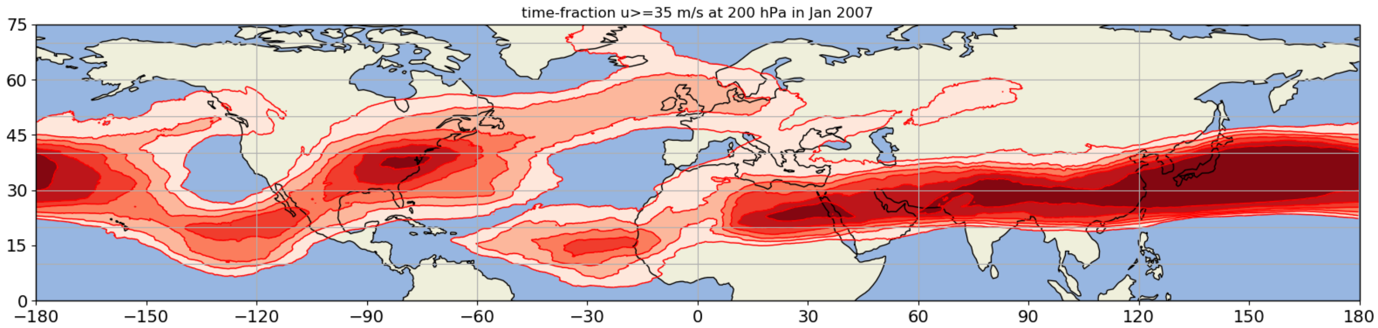

Figure 6: Fraction of time in which the eastward wind velocity at isobaric level corresponding to 200 hPa (about 10-12 km above sea level), exceeds 35 m s^{-1}, in January 2007. The contour interval is 15%, starting at 15%; darkest red shading corresponds to a fraction>75%. A fraction larger than 75% is observed in a narrow region centred at about 30°N running from Northern India to the Central Pacific Ocean: the most intense and persistent part of the subtropical jet stream (STJ). The STJ is "broken" over the Eastern Pacific and Eastern Atlantic Ocean, especially in January 2007 (upper panel), as a huge "breaking wave planetary wave". The metaphor of a "breaking wave" (**figure 7**) is indeed used in this context in scientific explanations of the dynamics of the STJ. Horizontal axis: longitude in degrees; vertical axis: latitude in degreees. Based on the ERA-5 reanalysis with a resolution of 1 hour (Herzbach et al., 2020).

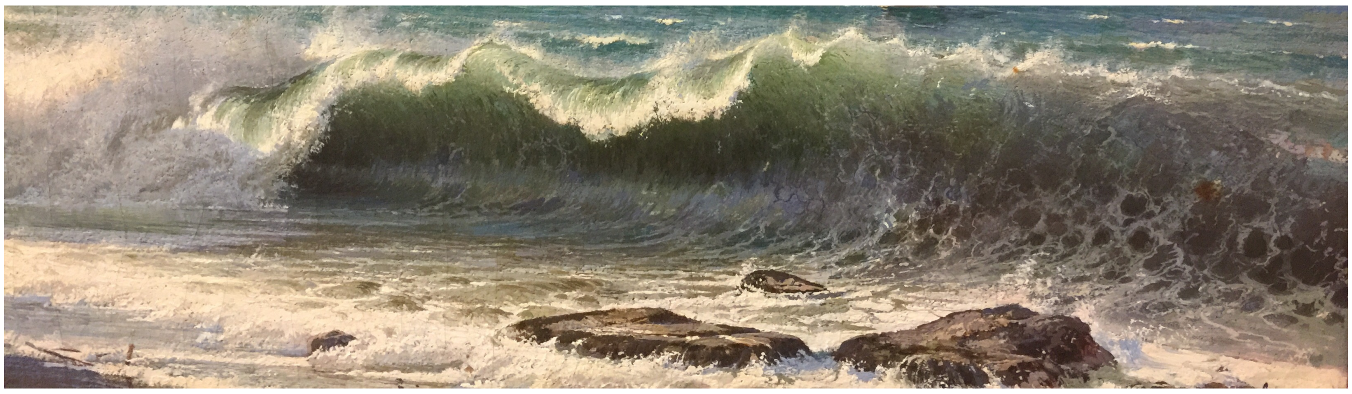

Figure 7: Breaking waves in the painting, "*Mountains and Sea*" (1872), by Fyodor Vasilyev (1850-1873). Picture taken in the Russian museum, Saint Petersburg, on 5 June 2017.

Why do tropical cyclones receive so little attention in standard textbooks on *Atmospheric Dynamics*? This is because it is a controversial topic in the research community, which, since the end of the 1980's, has been divided on the question of the best theory of the mechanism explaining the intensification and maintenance of a tropical cyclone. The confusion about the correct theory of tropical cyclone intensification and maintenance is the reason why tropical cyclones are treated very superficially in textbooks, like Holton's (2004) classical textbook.

I spend much time on designing and preparing courses, such as the master course on *Dynamical Meteorology*, which I have given for more than 25 years. I have also given courses on *Geophysical Fluid Dynamics*, *Mesocale Meteorology*, *Dynamics of Planetary Waves, Simulation of Ocean, Atmosphere and Climate*, *Turbulence in Fluids*, *Climate Dynamics* and *Boundary Layers, Transport and Mixing*. The latter course includes a course on the role of transfer of radiation, water, mass and vorticity in shaping the *General Circulation of the Atmosphere*. This includes the question of the formation of atmospheric jet streams (see my lecture notes at https://webspace.science.uu.nl/~delde102/AtmosphericDynamics.htm, especially chapter 12). In this advanced course I am open and honest to students about research questions that are still unanswered, about theories that I do not understand, or believe, such as certain aspects of the interpretation of the quasi-geostrophic theory of *Eliassen-Palm* fluxes (Edmon et al., 1980), which have led to an oversimplified interpretation of the influence of planetary waves on the polar vortex and the sub-tropical jet stream, and also an oversimplified explanation of the reason for the existence of the *Brewer-Dobson* circulation (Butchart, 2014). Quasi-geostrophic theory is the core theory of Dynamical Meteorology, but this theory is unfortunatley employed very loosely in explaining phenomena, such as the intensity variations of the stratospheric Polar night vortex connected to Sudden Stratospheric Warmings (SSW's), while it is obvious that conditions during SSW's are well outside the range of validity of this theory. It is surprising to me that the correctness of these theoretical explanations is hardly checked rigorously with Reanalysis data, our "best representation of observations".

The trouble with Physics in Utrecht

In 2014 I became programme-leader of the master programme, *Climate Physics*. Between October 2018 and October 2021, I was also director of education of the *master programme of physics* in Utrecht, which includes programmes in *Theoretical Physics, Experimental Physics* and *Climate Physics*.
After financial cutbacks in the Physics Department in Utrecht in the years 2007-2012, leading to the disappearance of the Institute for Astronomy, and the Medical Physics and Solar cell Research Groups, the then head of the department tried to unite the remaining Physics research groups in Utrecht under the name, "*Extreme Matter and Emergent Phenomena*". However, communication between the representatives of all three research directions is difficult. We seem to have little in common. The master programme in *Theoretical Physics* has a solid reputation, due to the 1999-Nobel Laureates, Martinus Veltman and Gerard 't Hooft. *Theoretical Physics* is built on two mandatory courses: *Quantum Field Theory* and *Statistical Field Theory*, together 20 ECTS. Remarkably, these courses are not mandatory in the *Experimental Physics* programme. Are these courses too specialised and difficult for students of *Experimental Physics*?

Despite its difficulty, *Theoretical Physics* is immensely popular with the graduate students from the physics bachelor programme in Utrecht. In past years, *Theoretical Physics* received about 60 students per year, while *Experimental Physics* had only about 15 students per year. Why is *Theoretical Physics* so popular? One reason might be, because *Theoretical Physics* has a reputation of being difficult. To many students, doing *Theoretical Physics* represents a real aptitude test. *Theoretical Physics* also appeals to students because it addresses "The Big Questions" (Hawking, 2018). Theoretical Physicists have high expectations of their research, being satisfied only "*when a new particle is discovered, a new force is found, or a new phenomenon is encountered*" (Smolin, 2006). Yet there is a lot to learn about Emergent Phenomena and Self-Organisation in non-linear systems from applying established theories to complex systems, such as Earth's climate.

Experimental Physics in Utrecht, especially Sub-Atomic Particle Physics, on the other hand, is going through an identity crisis due to lack of new experimental data. Experimentalists in Utrecht are now reorienting their research agenda, finding new challenges in Gravitational Physics and Biophysics under the new logo, "*studying the extremes of matter and space-time*", and soliciting help from theorists. But theorists are not very responsive, not wanting to jeopardize the carefully built reputation of *Theoretical Physics* in Utrecht. A significant part of the crowd of *Theoretical Physicists* seems to be guided, not by *experiments*, but by *Mathematics*, as has been noted by many in recent years, most recently by Sabine Hossenfelder (2018). The 2020 Physics Noble laureate, Roger Penrose, has a lot to say about the relation between mathematics and physics in his books entitled, "*Fashion, Faith and Fantasy in the New Physics of the Universe*", published in 2016, and "*The Road to Reality*", published in 2004.

The trouble with Climate Physics

The third master programme of Physics in Utrecht is *Climate Physics*. Over the past few years this programme has welcomed about 40 students per year, most from outside Utrecht. *Climate Physics* is an application of *Classical Physics*, especially *Fluid Mechanics* and *Thermodynamics*. Unfortunately, most *Theoretical* and *Experimental Physicists* in Utrecht think that *Fluid Mechanics* is not part of the core curriculum of University Physics. *Fluid Mechanics* is not a mandatory course in the Physics Bachelor programme in Utrecht. I have heard one Theoretical Physicist say that *Fluid Mechanics* "is not generic". This opinion is echoed by Theoretical Physicist, Sabine Hossenfelder (2022), in her book, entitled "*Existential Physics*": "*the Navier-Stokes equation is not fundamental; it emerges from the behavior of the particles that make up the gas or fluid. And we already know that fundamentally—on the deepest level—the gases are described by quantum theories*". I am afraid that many of my colleagues in the department of Physics in Utrecht think in this way about "fundamental".

Starting in the 1950's much effort in this field has gone into developing numerical models for weather prediction and for studying earth's climate. An impressive family of global models has emerged. These models solve the set of non-linear coupled equations of Fluid Mechanics, Thermodynamics and radiative transfer, based on the laws governing the budgets of mass, momentum and energy, which were developed by the *theoretical physicists* before the beginning of the twentieth century, and applied to rotating, stratified fluids, such as the atmosphere or the ocean.

Gradually more and more sub-systems of the climate system are included in climate models, such as atmospheric chemistry, the biosphere, the cryosphere and a high-resolution representation of the oceans. These very complicated climate models are now called "Earth System Models". The outcome of an Earth System Model requires an interpretation. But, even though the theoretical framework needed for this interpretation is available, little use is made of it, in my opinion. For example, as far as Atmospheric Dynamics is concerned, we can and should go further and deeper than the traditional quasi-geostrophic approximation. Joseph Smagorinsky (1964), one of the pioneers of the General Circulation Model, formulates this problem as follows. "*Our lack of theoretical understanding of the model elements is perhaps a more serious deterrent than the lack of adequate computational apparatus*."

The problems associated with numerical modelling of complex systems, like Earth's climate, which were so succinctly identified by Smagorinsky in the early days of General Circulation Modelling, are still valid today (Held, 2005) (Jacob, 2014). Smagorinsky, who was the mentor of the 2021 Physics Nobel Laureate, Syukuro Manabe, was an advocate of applying Ockham's razor as a guiding rule to developing models to understand the General Circulation of the atmosphere, as the final words of his 1964-paper demonstrate: "*We must guard against the massive outputs of high-speed computers with understanding. The computer at best is a very convenient laboratory tool – but it is not the end in itself. The design of experiments and the devising of perceptive methods for diagnosing and interpreting the results are still primitive. However, experience in the past few years indicates that numerical methods potentially have an elegance comparable to that of traditional analytical methods – but that its full realization is yet to be achieved. ... Finally, as we isolate the essential processes responsible for the characteristics of the general circulation, ultimately one would expect to be able to dispense with unnecessary and irrelevant detail – thereby reversing the trend toward more complex models and larger computers*."

The Ice and Climate Research Group at the Institute for Marine and Atmospheric Research in Utrecht (IMAU) has an excellent reputation for conducting field experiments on Glaciers and Ice Caps and devising (remote sensing) equipment for continuous unattended automatic measurements of all kinds of meteorological variables in cold and inhospitable regions, such as Antarctica and Greenland. Unfortunately, it is increasingly difficult to obtain financial support for this valuable experimental work, because it is not considered as "original" by funding agencies.

Experimental work in *Climate Physics* is being reduced or becoming less popular, because of lack of financial support for this type of work. Although field experiments over ice are still conducted by IMAU, part of the research focus at IMAU has switched to Earth System Modelling. A large part of the *Climate Physics* research field is now dominated by research employing very complex climate models, which produce huge data sets, the statistical analysis of which may have less to do with reality than desired. The community of theoreticians in *Climate Physics* is relatively small, and is not benefitting very much from this work, or is just not interested, which means that comparatively little theoretical progress is being made in *Climate Physics*, especially in *Dynamical Meteorology*.

Playfully becoming a scientist

At a young age I was fascinated by light and colour in the sky and the illumination of landscapes below. I remember the daily schoolbus rides to Castelldefels just south of Barcelona, sitting beside the window and dreaming while admiring the Mediterranean coastal landscape. I enjoyed observing the reflection of sunlight on a rippling water surface. I still do. There is something divine in it, as if looking into my bright future, bringing a feeling of optimism. Paintings that catch the summer light at midday through the reflection of light on water droplets have the same effect on me **(figure 8)**. In my student years I wrote a poem, called "Cascade in Spring", which conveys this feeling of optimism.

Today's light is so sharp,
Spring's green so light,
Fresh leaves so green,
And hue's so bright.
My skin feels red.
Red! not blue!
The sky is blue!
While dew glistens,
Sparkling forever
In the shining sun,
Beside the morning shade

Figure 8. **Left panel**: Summer heat in the painting entitled, "*Midday*" (1961), by Arkady Plastov (1893-1972). **Right panel**: A rippling water surface in the sun with children in the wind in the foreground in the painting entitled, "*Children*" (1957-1960), by Alexei Tkachev (1925-). Children are symbols of *unfettered curiosity*. Truly, very admirable paintings!

The inspiration for "Cascade in Spring" came from playing with my brothers in small fast flowing mountain streams in the Pyrenees, not far from Barcelona, building dams, creating small lakes and torrents, and observing water crashing down on stones and rocks at the bottom of a cascade. The inspiration for "Cascade in Spring" also came from an assignment, which was given to me by my English language teacher, Miss McShane, later Mrs Prenefeta when she married into a Spanish family: *write a poem, which contains as many words as possible starting with the same letter*. Assignments like this one, which stimulate creativity, are, I think, highly appreciated by many students.

My passion for weather came naturally in my early teens, out of my imagination, out of playing games, pretending to live in an imaginary, sometimes future, world, in which I was a poet, or a writer of novels, or a journalist and newspaper editor, or indeed, a scientist. Remarkably: not a musician. At my request I received a *Six's maximum and minimum thermometer* as a present from my parents on my 13th birthday. I quickly discovered that temperatures should be measured in the shade. So, I fixed this instrument to the wall facing north on our large balcony on the first floor (British English) of our house in San Justo Desvern, a town just outside the city limits of Barcelona. I recorded my measurements and noted the daily weather in a notebook starting on 23 November 1968 **(figure 9)**. Not long afterwards I made a rain gauge. I recorded daily precipitation on the same balcony. I compared all my measurements with the official measurements at the airport of Barcelona.

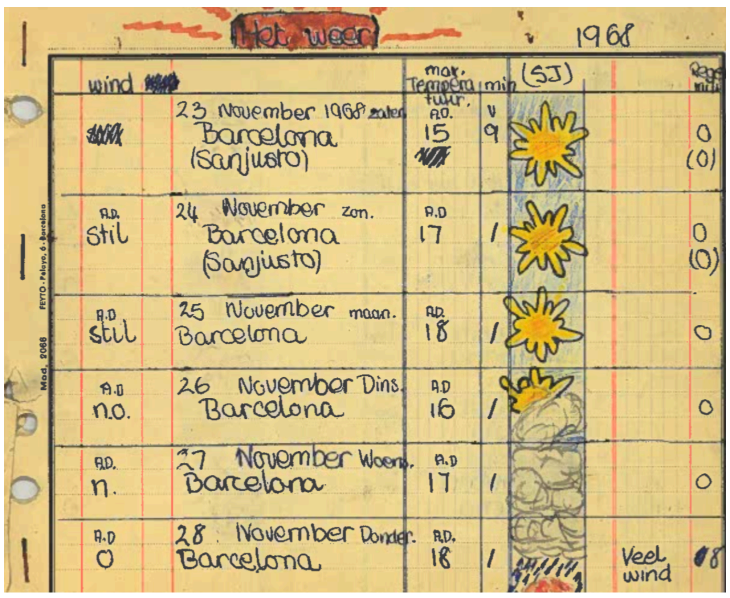

Figure 9. The first page of my weather logbook starting on 23 November 1968. The temperatures shown are not my own. My own measurements started on 25 April 1969, after receiving a Six's maximum and minimum thermometer for my 13th birthday.

Figure 10. Images of the destruction of the bridge over the *Llobregat river*, at Molins de Rei (Barcelona), a few kilometres from my home, as a result of a torrential rain event in December 1971. The bridge was part of the main road between Madrid and Barcelona. These images are taken from my scrapbook, which I made in my early teens.

As any typical weather-enthusiast, I was in awe of thunderstorms. Thunderstorms in the north-east of Spain, and also elsewhere in the Western Mediterranean, at the end of summer, especially in September, are frequently accompanied by torrential rain. Flash floods in the heavily populated Llobregat river valley and its tributaries, near my hometown just outside Barcelona, regularly caused much destruction and many casualties, simply because of lack of protective measures against these floods (**figure 10**).

The most severe flash flood in this area occurred on 26 September 1962, exactly one week after the birth of my younger brother in Barcelona. In a recent paper in *Journal of Hydrology* (Martín-Vide and Llasat, 2018), it is concluded that this event, which was the worst ever to take place in Spain, in terms of loss of life and destruction, was not an outlier, nor was it extreme, in terms of total rainfall, return period and discharge. It was extreme because of the damage it caused, which was due to bad and irresponsible "urban planning". "Immigrants" from other parts of Spain, attracted by work in the growing textile industry around Barcelona in the 1960's, were living in quickly erected neighbourhoods on the ephemeral flood plains of the Llobregat river and its tributaries.

People should not be allowed to live on flood plains. The the high death tole due to the flash flood of the Ahr river in Germany in July 2021 might also be attributed to irresponsible urban planning, which allowed people, even elderly and/or disabled people, to live very close to the banks of the river Ahr. The authorities apparently learned nothing from history. A similar Ahr river flood in 1910 was equally deadly. I now understand why many centuries-old towns in Italy, Spain and France are built on hill tops.

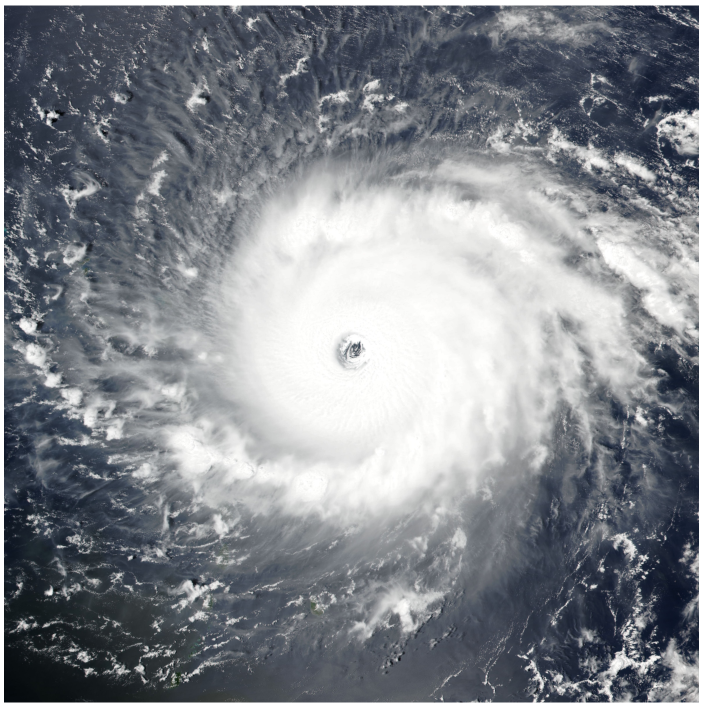

Figure 11. A beautiful example of an emergent phenomenon in the atmosphere. Satellite image of tropical cyclone "Irma" approaching the Leeward Islands on 5 September 2017. The eye of Irma in the centre (the cloud-free area) has a diameter of about 40-50 km. A layer of air, at least 10 km in depth and several hundreds of km in width, rotates around the eye with an amazing coordination. (https://worldview.earthdata.nasa.gov .

In my teens I was also fascinated by tropical cyclones (**figure 11**). I was interested not just in the statistics of tropical cyclones, such as extreme wind velocities, but also in the physics of tropical cyclones. What makes huge volumes of air rotate in such an amazingly coordinated fashion over distances of hundreds of kilometres to form a tropical cyclone? During my PhD-years I could not refrain from investigating this theoretical question, even though it was officially not part of my PhD-project. I wanted to understand the physics of tropical cyclones. This led to the writing of a paper entitled *On the Deepening and Filling of Balanced Cyclones by Diabatic Heating* (van Delden, 1989). The tropical cyclone research community in 1989 was in the middle of a heated debate, initiated in 1986 by Kerry Emanuel of MIT (Boston), about the question of the mechanism maintaining intense tropical cyclones. I was framed by two of the three reviewers of my paper as a defender of the old theory of the growth of tropical cyclones, which, in fact was due to two giants of *Dynamical Meteorology*: Jules Charney (1917-1981) and Arnt Eliassen (1915-2000). My paper was rejected for publication by the editor of the *Journal of the Atmospheric Sciences*. Ultimately, I managed to get my paper published in the "less impactful" European Journal, *Meteorology and Atmospheric Physics*.

I am still proud of this paper, but I also acknowledge that, unfortunately, the main message of this paper, namely that warm core cyclones intensify by diabatic heating, whereas cold core cyclones weaken by diabatic heating, was buried in technical detail. I discovered that a paper should have a simple main message and that this message should be conveyed as clearly and concisely as possible. I also discovered that it is very difficult to get your work accepted in a specialised research community if you do not invest much time in going to the corresponding specialised conferences, in this case conferences on tropical cyclones, and write more papers on the same topic. A scientist has to invest time in advertising his/her work. Presumably, I have not done this sufficiently.

In the 1990's I turned to *thunderstorms* as a subject of research. I was particularly interested in the conditions, which lead to the formation of Thunderstorms. Three basic ingredients are needed to produce a long-lived thunderstorm: **(1)** Convective Available Potential Energy (CAPE), **(2)** high levels of moisture in the atmospheric boundary layer and **(3)** forced lifting of the potentially unstable air. My principal research question was: what type of large-scale flow configuration is conducive to produce these ingredients simultaneously? What are the right or optimal conditions for the formation of convective storms with a long lifetime? Finding the answer to these questions requires, not only data, but also knowledge of Atmospheric Dynamics, which includes an understanding of the potential mechanisms that forces air to move upwards to overcome the potential barrier, which is usually present in the form of a temperature inversion at the top of the atmospheric boundary layer.

About 20% of the students that come to study *Climate Physics* in Utrecht are most interested in weather. This certainly includes the topic of severe convective thunderstorms! Many students have performed a master-research project on severe convective thunderstorms under my supervision. We used data for the years 1990 to 2000 from the UK Met Office European-scale lightning detection array, radiosonde data with a time resolution of 6 hours and gridded analyses from the ECMWF, in master research projects designed to obtain insight into the circumstances under which severe thunderstorm form. Papers based on these master research projects (e.g. Haklander and van Delden, 2003) are cited much more frequently than any of my theoretical papers.

Attribution of extreme weather to climate change is impossible and irrelevant

Climate Change broke through on the research agenda after James Hansen's US-Congressional testimony on climate change in 1988. Funding of Climate research grew explosively in the 1990's. In the past years the Dutch National Meteorological Institute (KNMI), is trying to fit weather research into this research agenda. KNMI has adopted the phrase, "Extreme weather due to climate change", to attract the attention of the Dutch government, and has recently obtained a large sum of money to erect a so-called "*Early-Warning Centre*". Let me say first that warning the public for oncoming extreme weather is a good cause in itself, regardless of the question of attribution of this extreme weather to climate change.

Recently, an international team of scientists, named *World Weather Attribution consortium* (WWA), has drawn up a roadmap for the *attribution of weather extremes*. This roadmap consists of answering the following questions.

1. What events are we going to investigate?
2. Which aspects of the extreme weather event were most relevant?
3. How rare was this event and how has this changed?

4. Which models can represent extreme weather conditions?
5. Which part of the observed trend can be attributed to climate change?
6. What is the overall picture of the role of climate change?
7. How important are other (social) factors?
8. How do we ensure that the results are communicated both comprehensibly and truthfully?

In my opinion, research should concentrate on question 4, which represents a call for improving non-hydrostatic models of the atmosphere and would fit into the purpose of the "*Early-Warning Centre*".

Questions 5 and 6, represent the central questions of WWA, i.e. the attribution of extreme weather to human induced climate change. The existence and central purpose of WWA has been endorsed at the Sharm-el-Sheikh UN Climate Change Summit in November 2022, where an agreement was reached to create a fund to compensate poor nations for the "loss and damage" they experience due to Climate Change. Will WWA play a central role in answering the question of attribution of a particular extreme weather event in a "poorer nation"? This is, I think, a difficult if not impossible task.

Take the deadly the Ahr river flood on 14 and 15 July 2021. In the popular media, even in *Scientific American*, this extreme event is linked to enhanced greenhouse warming by simply stating that "*because a warmer atmosphere can "hold" more water vapour, these extreme precipitation events will occur more frequently*", or *"..the tropical North Atlantic Ocean has been abnormally warm, creating excess evaporation that fuels strong hurricanes*". These are a very silly interpretations of the water cycle! The sources and sinks (i.e. evaporation and precipitation) of a reservoir do not necessarily depend on its content (i.e. the water content of the atmosphere). The intensity of the water cycle is coupled to the radiation balance at the earth's surface, which responds to greenhouse warming in unexpected ways (Hegerl et al., 2015).

As stated earlier, an equally deadly Ahr river flood occurred on 12 and 13 June 1910 (Roggenkamp and Herget, 2014) at much lower CO_2 concentration, but under very similar meteorological conditions as the Ahr river flood of 14 and 15 July 2021! Important insights into the dynamics of these severe floods can be obtained from the Reanalysis data sets. A quick inspection of the ERA5 Reanalysis in the 2021-case and the ERA20C Reanalysis in the 1910-case reveals that both the floods of 1910 and of 2021 were associated with heavy rain connected to a surface cyclone, travelling very slowly north-eastwards from Northern France into Germany. This surface cyclone, or low pressure area, was connected to an upper level positive potential vorticity anomaly and associated upper level cold core cyclone.

The intense rain leading to the 2021-Ahr river flood was connected to transport of warm and moist air masses from the east into the disaster-area. According to the ERA5-Reanalysis, most of this moisture came from evapo-transpiration over land (Eastern Europe). The intense sustained rain, which occurred before the actual Ahr-river flood (in the evening of 14 July 2021), was due in part to orographic lifting of the moist air. Later during this episode (on 15 July 2021), the rain was sustained by large-scale cooling of the atmosphere over the area in question due to the approach of the aforementioned upper level positive potential vorticity anomaly. Insights like these, derived from case studies, can help to predict and be prepapred for the next extreme flood so that timely warnings can be issued.

The idea that extreme weather events can be attributed to anthropogenic climate change with any confidence is wishful thinking. Records of past climate are simply too short and weather and climate-models are not to be trusted as far as precipitation is concerned. The spatial resolution of weather models, even those with the highest resolution, is far too coarse to represent clouds and preciptation with the desired accuracy. Moreover, large uncertainties exist concerning the modeling of evaporation of water from the earth's surface and from the biosphere.

Attribution of specific extreme weather events to climate change is in fact quite irrelevant. We must face the fact that our overcrowded world, with its huge differences in wealth, is becoming more and more vulnerable to the *ever-present* risk of extreme weather. We must reduce this vulnerability by taking adequate protective measures, which should include not only a better warning system, based on better forecasting of severe weather, but also fair trade, allowing poorer nations to participate in the world economy on an equal footing with the richer nations.

The Advancement of Science

This essay is drawn from my experience as a scientist, between the years 1981 and 2023, and as a university teacher starting in the year 1987. I have thoroughly enjoyed my career both as a teacher and as a researcher. I realise that I have been very lucky to earn my living by *playing* in the field of my passion, together with many inspiring peers of all ages.

My scientific career started in the year that I wrote my first scientific paper together with my master thesis supervisor and later PhD thesis supervisor, Hans Oerlemans (van Delden and Oerlemans, 1982). This paper describes and interprets the results of numerical simulations of several life cycles of a population of shallow cumulus clouds in the atmospheric boundary layer. The model outcome looks very realistic, even "beautiful" (**figure 12**). I wrote the model code in FORTRAN from scratch. Creating virtual clouds was like playing in a fast flowing river in my youth. I was delighted with the model outcome. But, even though the model equations stem from theory, the "physical interpretation" of the model simulations in our paper is rather superficial and not well routed in theory. I was aware of this, even in this early "naïve phase" of my career. Moreover, I was not so sure about the realism of the numerical result. What role did the imposed boundary conditions play in determining the numerical result? We should perhaps have been more careful and critical about these results.

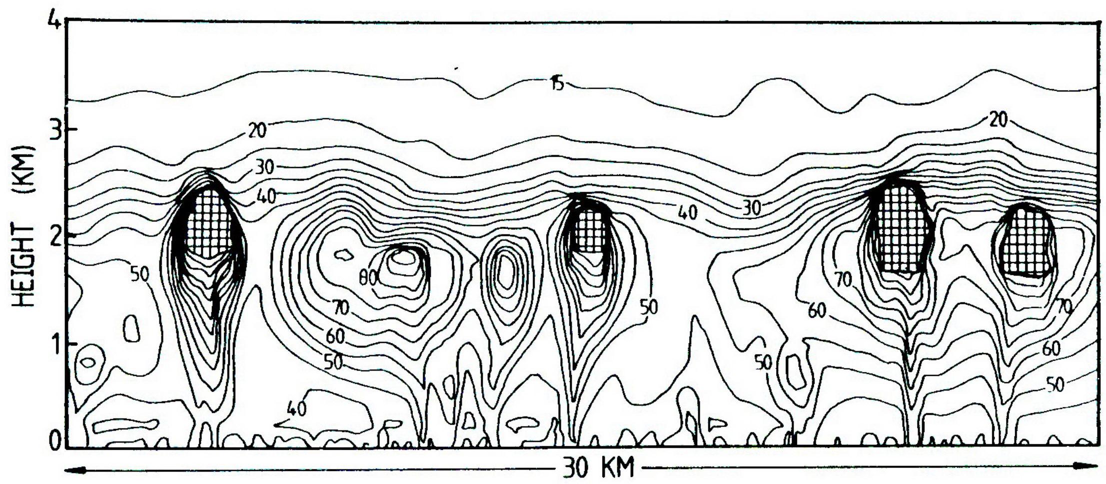

Figure 12. Relative humidity in the convective atmospheric boundary layer in the Netherlands at midday in June, according to a numerical model simulation. The hatched regions correspond to clouds (regions where the relative humidity is 100%) (van Delden and Oerlemans, 1982).

Later in my career I discovered that my first scientific paper is in fact a typical paper of the present time in *Climate Science*, in which the outcome of a computer simulation is identified, which seems interesting and new, but was not exactly anticipated on the basis of a hypothesis or a theory beforehand. Many research papers of this kind have appeared in serious scientific journals, especially since the 1980's. These papers with little or no grounding in a theory-based hypothesis, are flooding the *Climate Science* literature. The idea that theory of physics and chemistry, with all the differential equations that come with it, is *not* needed in this "Age of Big Data", although not always made as explicit as Chris Anderson did in 2007, is unfortunately gaining a strong foothold in *Climate Science*. This is not helping the advancement of *Climate Science* and in particular not helping the advancement of *Dynamical Meteorology*.

The difficult debate about the physical nature of the *North Atlantic Oscillation* (NAO) and its analogues, the *Arctic Oscillation* (AO) and the *Northern Annular Mode* (NAM), illustrates this point (see p. 2156 of the most recent full report of IPCC working group 1 at https://www.ipcc.ch/report/ar6/wg1/). This debate has great difficulty in making contact with physics. The amplitude of the NAO is measured in terms of an index called "NAO-index". The NAO-index is defined as the difference in sea level pressure between Reykjavik and Lisbon, or between Reykjavik and Gibraltar. The long observational time series of sea level pressure that exist at these locations (Jones et al., 1997) are anticorrelated: lower than average pressure at Reykjavik is associated with higher than average pressure at Lisbon, and vice versa. What is the physical explanation of this interesting long distance anticorrelation, sometimes mysteriously referred to as a "teleconnection", which is associated with European winter weather extremes? Unfortunately, because the NAO-index cannot be linked to any physics-based differential equation, this question can hardly be answered. Therefore, out of necessity, research on the NAO is restricted to running numerical models and to simple statistical comparisons of the model output with reality or with output from other models (e.g. Blackport and Fyfe, 2022). The debate about the physical nature of the NAO will not be resolved as long as the concept is not part of a physics-based theory.

Science is all about the quest for a robust common theoretical language about reality. This implies that scientists should give priority to looking for a more precise and useful description of reality. After many years of teaching science, which entails being precise about what you tell students, I have discovered that most scientists are not so precise. Most scientists construct attractive storylines by using metaphors, or images of reality, in order to easily communicate about the workings of complex phenomena under collective study. This informal communication also guides further advances in theory and understanding, even when the concepts and metaphors are not yet clearly defined and understood. An example is the concept of "heat", which was ill-defined for a very long time in the nineteenth century, being given de rank of a substance, until this idea was definitively rejected under leadership of James Clerk Maxwell (1871). The situation at present is no different. Why would it? Climate Science is infested with concepts ill-defined physical concepts, such as the often (mis)used concept, "*Planetary Wave Drag*", which is a misleading metaphor for a very complicated set of interactions between the zonal mean westerly flow and planetary waves. Nevertheless, this metaphor is an important part of a generally accepted story explaining the slow poleward drift of air in the stratosphere, the upper branch of the *Brewer-Dobson* circulation. A fundamentally different explanation of this poleward drift of air, not invoking "*Planetary Wave Drag*", is given in section 1.41 of my lecture notes on Dynamical Meteorology (van Delden, 2022b).

Constructing or building a common scientific language, consisting of well-defined and understood concepts, which are not (only) metaphors of reality, with which we describe and understand "The World", is the central task of all scientists. Less and less scientists are participating in this process, probably because this is not an easy task. It takes time, a very precious commodity to a university scientist. Unfortunately, the time of a university scientist is often wasted due to myriad modern responsibilities, such as the fight to obtain funding for research. Moreover, many data-oriented scientists are not contributing to the building of a common language based on physics, because they often do not have a good background in physics. Instead, data-oriented scientists are uncritically using the existing imperfect common language, sometimes not knowing that it is imperfect, or otherwise not caring that it is imperfect, to construct a pretentious story studded with statistics for a "high-impact journal".

The advancement of *Climate Science* needs *Blue Skies Research*, which starts with an interesting and important research question regarding the basic understanding of earth's atmosphere, followed by a proposed explanation to the question "why", linking causes and effects, i.e. a hypothesis, based on existing concepts and theory. This hypothesis is tested with data, which might be either observational or model derived. This process will sometimes lead to new concepts and new theory, or at least to a better understanding of existing concepts and theory.

Summary

For those wanting to take a quick note of the main message of this essay, here is a list of claims it makes.

1. The "*Science of Weather and Climate Extremes*" and the encompassing "*Science of Climate Change*" exist largely without contributing much to the basic theoretical framework of "*Dynamical Meteorology*".

2. The idea that extreme weather events can be attributed to antropogenic climate change with any confidence is wishful thinking. Because of this, therecently created UN "loss and damage fund" is bound to be a messy business.

3. Poorer nations should be aided directly by breaking trade and subsidy "barriers", making trade fair.

4. Papers with little or no grounding in a research question, connected to a theory-based hypothesis, are flooding the *Climate Science* literature.

5. The principal goal/agenda of universities is teaching and preparing students for their future career and role in society, doing research supporting this teaching and helping the theoretical framework of *basic science* forward.

6. Students should practice in formulating an interesting and important research question and an associated hypothesis, and they should learn to present their work, both in oral and in written form.

7. Creativity of students should be stimulated by teachers.

8. Students should be made aware of the fact that textbook theories, could be incomplete or even incorrect.

9. A teacher should be honest to students about theories that he/she does not understand, or believe.

10. Students should hear about scientific controversies in the past and at present. Many scientific controversies are rooted in misunderstandings about the meaning of terminology and theoretical concepts, and in too simplified or unclear "story telling".

11. Clarifying the meaning of (existing) theoretical concepts and terminology should be an important element of teaching *and research* at universities.

12. Constructing or building a common language with which we describe and understand "The World" is the central task of all scientists with a genuine interest in "This World".

13. Doing scientific research, being creative and communicating about it with colleagues and students is an adventure, like playing with your friends: it is fun (after Rein Haarsma).

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