CLIMATE CHANGE - WHERE SCIENCE MEETS SOCIETY

Rede uitgesproken bij de aanvaarding van het ambt
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Disaster Risk Reduction aan de Universiteit Twente
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1. INTRODUCTION[1]

On April 10, 1815, one of the largest natural disasters in recorded history occurs on Dutch territory. The Tambora volcano, located on the island of Sumbawa, part of the then Dutch East Indies, erupted with an enormous explosion, equivalent to the simultaneous detonation of 1,000 Hiroshima-type atomic bombs. On the magnitude scale of volcanic eruptions, developed by geologists in analogy to the Richter scale for earthquakes, the Tambora event is rated with a Volcanic Explosivity Index of 7 (on a scale from 1 to 8). What used to be the highest mountain in the - then very young - Kingdom of the Netherlands, with an estimated altitude 4300 meters, was reduced to one of only 2850 meters. Approximately 70,000 people died, and some 150 km³ of volcanic ash was ejected into the atmosphere. These numbers carry a considerable margin of uncertainty, of course.

The Tambora eruption had a world-wide impact[2]. The volcanic ashes shielded the sun's radiation in such a way that global temperatures dropped by 0.5 °C in 1816 and 0.4 °C in 1817. This led to failed crops, famine, the end of some vineries in Northern France, refugee streams and it has even been suggested that the cold, heavy rain and floods in those years triggered the fall of Imperial China in the early 19th century. Surprisingly, also the mobility of people was affected. Failed crops resulted in a lack of food for horses, then the most important means of transportation. This is believed to have been at the basis of the invention of the bicycle by Von Drais. Note that these dramatic effects on the weather were caused by a relatively small ($1.2\ 10^{-5}$) contamination of the atmosphere.

Last year, the carbon dioxide (CO_2) levels in the atmosphere increased beyond the value of 400 ppm, which is caused - as is well known - by human activities on our planet. Whereas volcanic ash *reflects* solar radiation

1 *Inaugural lecture presented on the occasion of the appointment of the author as professor of "Meteorological and Climatological Disaster Risk Reduction" at the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente in the Netherlands.*
2 *J. Zeilinga de Boer and D.T. Sanders, Volcanoes in Human History, Princeton University Press (2002); and Philip Dröge, De Schaduw van de Tambora, Spectrum (2015).*
3 *Assuming a total mass of the atmosphere of $5\ 10^{18}$ kg and an estimated $6\ 10^{13}$ kg for the total mass of the volcanic ashes ejected by the Tambora volcano, the relative mass contribution is $1.2\ 10^{-5}$.*

COLOFON
Prof. dr. Gerard van der Steenhoven (2016)

Oktober 2016

and leads to a *lowering* of global temperatures, CO_2 has the opposite effect. It has the effect of a greenhouse, and therefore leads to global *warming*. Whereas the Tambora event faded out in only a few years - the time it took before all volcanic ashes dropped back on the surface of the Earth, CO_2 stays in the atmosphere for at least 30 years[4]. This makes the effects of continuously rising CO_2 levels in the atmosphere much more worrying. Hence, it is no surprise that the World Economic Forum in its most recent risk report identified the failure to develop adequate measures against climate-change as its risk number 1. This makes it obvious why - when discussing meteorological and climatological disaster risk reduction, the subject of the academic chair I am honored to occupy - today's inaugural lecture is focused on climate change. There is a second reason for having made this choice. When I started as new director general of KNMI in the beginning of 2014, I already had my solar cells and hybrid car as a common part of my household for a couple of years. In other words, I was aware of the importance of sustainability and the threats of global warming. However, what I learned on climate change in the last (almost) three years at KNMI was quite overwhelming - both in terms of the scientific evidence for a changing climate and the impact it has on our society. In my opinion climate change represents one of the largest challenges to humankind of our times. In this lecture, I want to share with you what I learned on this subject in the last couple of years, and what - in my opinion - needs to be done to reduce the risks associated with climate change.

Before proceeding it is important to remind you about the key difference between weather and climate. The weather is what we experience everyday: rain, sunshine, wind etc., while the climate is the average weather in a certain region taken over a 30 year period.

The lecture is organized as follows:
- Section 2 discusses the science of climate change: the observations, the physical mechanism, future scenarios, and the potential impact.
- In section 3 the question is addressed what needs to be done to reduce the risks associated with climate change; how much time is left, what kind of research is needed, what measures can be taken? In other words: a research and policy agenda is presented. Although climate change is a worldwide problem, the agenda presented in section 3 is focused on the work that can be done in the Netherlands.
- In section 4 my role as new part-time professor at the University of Twente is described in pursuing this science and policy agenda. Clearly, my role can only be a modest one, but given the importance of the subject, I hope to convince you that it is worth the effort.

The lecture is concluded with some personal remarks.

4 *IPCC, AR4, Working Group I, TS.2.1.1: half of a CO_2 pulse to the atmosphere is removed in about 30 years, a further 30% is removed within a few centuries, and the remaining 20% will stay for a much longer time period.*
5 *World Economic Forum, The Global Risks Report 2016, 11th Edition, Genève (2016)*

2. CLIMATE CHANGE: OBSERVATIONS, SCIENCE AND IMPACT

OBSERVATIONS

The World Meteorological Organization (WMO), which is the United Nations' weather agency, conducts an annual assessment of the state of the global climate. In its most recent report[6] WMO summarized their climatological observations over 2015 in the following way:

- warmest year on record by far: at 0.76 °C above the 1961-1990 average (see figure 1)
- global temperature was 1 °C above the pre-industrial era
- the 2015 El Niňo event[7] was one of the strongest on record
- extreme events: heatwaves, droughts, floods, strong tropical cyclones
- CO_2 concentration reaches symbolic benchmark of 400 ppm in the northern hemisphere

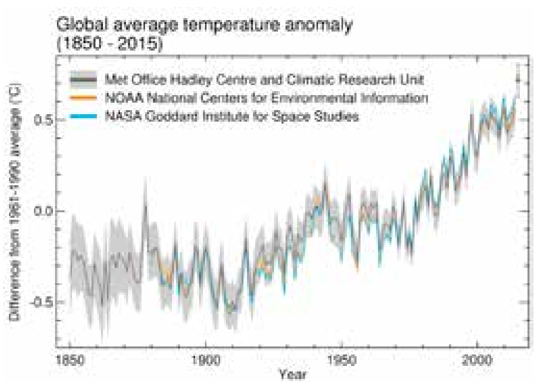

Figure 1. Global annual average temperature anomalies (relative to 1961 - 1990) for 1850 to 2015. The sources of the three data sets displayed are listed in the top. (Taken from ref. 6.)

6 WMO Statement on the Status of the Global Climate in 2015, WMO-No.1167, 2016
7 El Niňo is a natural phenomenon occurring every couple of years in the eastern part of the Pacific, where a large body of water along the equator is exhibiting elevated temperatures.

- 93% of the excess energy from greenhouse gas emissions is stored in the oceans.

I would like to add two remarks: (i) the peak in the global temperature observed in 2015 is not only caused by the ongoing effect of climate change, but as well by the strong El Niňo of 2015 as it is known from the past that strong El Niňo events lead to higher global temperatures[8]. (ii) The information on the heat content of the deep oceans is relatively young. It has been obtained through measurements (since 2003) with a large array of autonomous profiling floats, known as the Argo project, in which KNMI participates[9]. The project has distributed more than 3700 floats in all the oceans around the globe. Each one of them measures the temperature and salt concentration in the upper 2,000 m of the oceans every 10 days. This network of floats has shown that the bulk of the effect of global warming is to be found in the oceans - the 93% quoted above; this had been assumed already for some time on the basis of the much larger heat capacity of water as compared to that of air.

Many more effects of climate change are reported; just to mention a few: the reduction of the sea ice cover extent of the North-Pole, the reduction in size of glaciers around the world, changing growth seasons, animal migration, extreme rainfall and - very important for the Netherlands - sea level rise. The rise in sea level is considered to be one of the more robust metrics of climate change as it combines the effect of ocean warming, which results in an expansion of the water volume, and the effect of ice and snow melt, in both the polar and mountainous region. (For clarity: only melting of *land ice* as occurring in Greenland, for instance, will result in a sea level rise. When sea ice melts there is no change in the water levels.)

8 No relation between the intensity and frequency of El Niňo's and global warming has been reported so far.
9 The European part of the Argo Collaboration (www.argo.net) was one of the first EU recognized European Research Infrastructure Consortia (ERIC). It was established in 2014. See: www.euri-argo.eu.

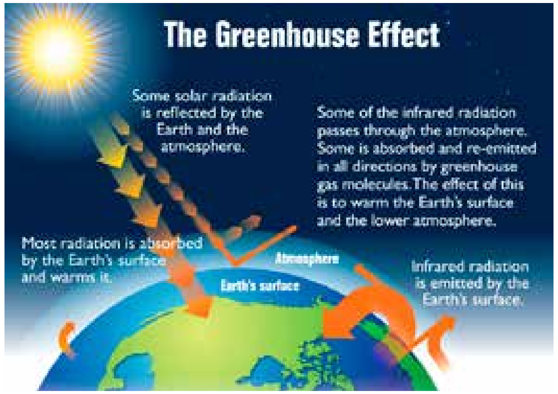

Figure 2. The greenhouse effect is caused by atmospheric gasses such as CO_2, CH_4 and H_2O which capture the infrared radiation emitted by the earth. As the greenhouse gasses re-emit the radiation in all directions, part of that heat is redirected to the Earth, thus leading to global warming.

SCIENCE

The idea that an increase of the CO_2 concentration in the atmosphere might lead to a rise of global temperatures was first introduced by the Swedish scientist (and Nobel prize winner) Svante Arrhenius (1859 - 1927), long before the effect was actually observed[10]. His explanation is still valid and illustrated in figure 2. The earth is continuously warmed by solar radiation. The accumulated heat is emitted again as thermal radiation, i.e. at a longer wave length (infrared) as the Earth has a lower temperature than the sun. This thermal radiation is captured by CO_2 molecules (or those of other greenhouse gasses) in the atmosphere. After a little while, the CO_2 molecules emit the radiation again, but now in all directions. Consequently, part of the radiation is redirected to the earth. This causes a heating effect on Earth, which increases when the CO_2 levels go up. Hence, the greenhouse effect grows once more CO_2 has been brought into the atmosphere. It should be noted that the atmosphere of the Earth has always been acting like a greenhouse without which the temperature on earth would have been considerably lower. At the other extreme, a planetary atmosphere with very high CO_2 levels like exists on Venus (up to 96% CO_2), results in average surface temperatures of about

10 Svante Arrhenius, Über den Einfluss des Atmosphärischen kohlensäuregehalts auf die Temperatur der Erdoberfläche, Proceedings van de Koninklijke Zweedse Academie van Wetenschappen 22 (IN.1), 1-101 (1896).

460 °C. The atmospheric greenhouse effect is thus a scientifically well-established phenomenon based on a fully understood physical mechanism. Uncertainties remain with respect to the precision by which we know the quantitative effect of individual greenhouse gasses (expressed in their so-called radiative forcing[11]) and their interactions with land and seas masses.

IMPACT

Climate change has considerable influence on our entire world as illustrated in figure 3. There is hardly an element of our living environment that is not affected. Hence, the impact of climate change on society is very large. This is probably best seen from the threat it represents to Small Island States such as Tuvalu, for instance. The average elevation of this island is less than 1 m above sea level. A sea-level rise of 20-40 cm by the end of this century combined with frequent spring and king tides may already make this island state virtually inhabitable[12]. Similarly, many harbor cities located in low-lying areas near the sea are threatened to become submerged.

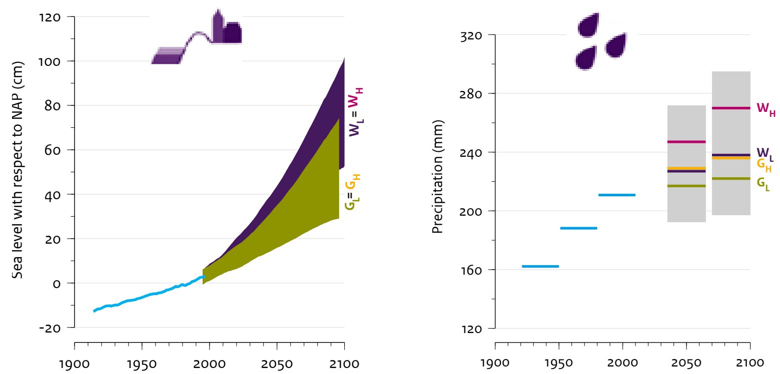

Figure 3. Two results from the KNMI'14 climate scenarios for the Netherlands. On the left the expected sea level for two scenarios is displayed. On the right the increased winter precipitation is shown for each of the four scenarios described in the text, G_L, G_H, W_L and W_H. The grey band represents the natural variability of the weather over a 30 year period.

11 Radiative forcing or climate forcing is defined as the difference of sunlight absorbed by the Earth and the energy radiated back to space. It is expressed in Watts/m2 and measured at the Tropopause.

12 S.S. Patel (2006), A sinking feeling, Nature 440 (7085), 734-736; doi:10.1038/440734a. PMID 16598226.

In order to study the likely effects of climate change in a given region, forward looking analyses - such as the climate scenarios for the Netherlands published by KNMI[13] - need to be carried out. These studies are based on the large body of knowledge represented by the Assessment Reports of the UN International Panel on Climate Change (IPCC) and on carefully calibrated and homogenized series of climate observations extending over more than 100 years. In the IPCC reports a judicious choice is made regarding the likely development of CO_2 emissions up to the year 2100. In order to be able to translate the four IPCC AR5 scenarios to the anticipated climate in the Netherlands, two values of the global temperature increase (G_L and G_H) and two values of the average wind direction (W_L and W_H) were chosen. The result of this KNMI'14 analysis is expressed in likely ranges of the sea-level rise, temperature and precipitation patterns. Two examples taken from the KNMI'14 scenarios are shown in figure 3. These examples show that we may anticipate a sea level rise up to 100 cm in 2100 and an increase in the amount of winter rainfall of about 30%. Decision makers use these results when discussing future infrastructural works, for instance.

Another consequence of global warming, which cannot be derived so easily from the climate simulation studies described above, is the increased occurrence and increased intensity of extreme weather events such as intense downpours, convective summer storms or heat waves. As the societal impact of such extreme weather events is large, two kind of studies are devoted to them:

- Future weather studies, in which both the likely intensity and frequency of such events is studied in large scale simulations using advanced climate models.
- Event attribution studies, where an actually occurring extreme weather event is being analyzed both within the context of the "new climate" and the "old climate" in an effort to assess whether climate change has influenced the likelihood of this particular event.

13 A.M. Klein Tank et al, KNMI14 Climate Scenarios for the Netherlands, KNMI, De Bilt, The Netherlands (2015)

Event attribution studies represent a relatively new development in the field[14]. They can provide more rigorous scientific information, including possible uncertainties and untoward conclusions, into the public discourse. Moreover, sound background information is made available for news coverage on extreme weather events in relation to climate change.
In my view this represents a very timely development. Attribution study outcomes enable both the media, general public and policy makers to obtain quick and reliable information on recognizable effects of climate change. In other words it plays an important role in transferring the results of climate science, which is usually only accessible in peer-reviewed journals, to society.

The scientists involved in event attribution science have launched a dedicated website[15] where the results of individual studies are presented. In case such studies apply to events in the Netherlands, they are usually also reported at **www.knmi.nl.** Two examples:

- The first part of November 2015 was unusually warm in the Netherlands: for a number of days the average temperature was in excess of 15 °C. An event attribution study showed that the probability of this type of weather has increased by two orders of magnitude as compared to the probability that such event occurred in the old climate, and can thus most likely be attributed to climate change[16]. (A similar analysis applied to the unusually hot days in mid-September 2016 revealed that the probability of such an event had increased by a factor 8 due to climate change.[17])
- Near the end of May 2016 both southern Germany and northeastern France suffered from torrential rainfall. The river Seine reached its highest levels in over 30 years and in Bavaria floods caused severe damages, which were estimated to cost in excess of 1 billion euros. An event attribution study[15] revealed that climate change has increased the probability for such events by 40 - 80% in France, while the results for Germany were inconclusive.

14 Originally the concept attribution studies was used to describe research efforts aimed at identifying observed global warming effects to human activities. Only more recently event attribution studies as discussed here have been initiated.
15 Scientists from Oxford University, KNMI, the University of Melbourne and Red Cross Red Crescent Climate Central have jointly launched wwa.climatecentral.org which contains many recent climate attribution studies.
16 G.J. van Oldenborgh et al., http://www.knmi.nl/kennis-en-datacentrum/achtergrond/bijdrage-klimaat-verandering-aan-zachte-novemberdagen.
17 S. Philip and G.J. van Oldenborgh, http://www.knmi.nl/kennis-en-datacentrum/achtergrond/klimaat analyse-van-septemberhitte-in-nederland

In general it can be stated that in the Netherlands the probability of heavy downpour has increased by about a factor three as compared to 100 years ago. The underlying mechanism is based on the fact that hot air can contain more humidity than cold air, leading to an increase of the intensity of heavy rainfall by some 14% per degree temperature increase[18].

When discussing the impact of climate change, it has to be realized that rising average temperatures, extreme weather, and shifted precipitation regimes may have consequences that go well beyond those discussed so far. Here a few examples are mentioned. More information can be found in the references[19].

- Liability for climate change[20]. If your property is damaged due to - for instance - a flood that can clearly be attributed to climate change, will it then be possible to sue anyone for causing this damage? This is clearly very difficult as greenhouse gasses are emitted everywhere around the world, and are completely mixed in the atmosphere. Your neighbor's car contributed as much to the problem as a cow in China (through its methane emissions).
- Climate refugees. Due to sea level rise the life on low-lying islands, such as Tuvala and the Carteret Islands in the Pacific and the Maldives in the Indian Ocean becomes very difficult[21]. In fact, refugees are leaving the Carteret Atol since 2009 for the nearby Island of Bougainville, while first refugees from Tuvala have reached New Zealand in 2014. Moreover, in January 2016 the US Department of Housing and Urban Development announced that the community living on Isle de Jean Charles, close to New Orleans, will have to be relocated to another area as their islands will soon be unreachable and submerged due to the effects of climate change[22]. According to Robert Nicholls et al. a temperature rise of 4 °C might lead to a forced displacement of 72 to 187 million people[23] in 2100. Even if such high temperatures might not be reached, large refugee streams are to be expected as some regions in the world will be exposed to rising sea levels, extremely high temperatures or frequent droughts and therefore become inhabitable in the future[24]. This may actually already be happening today in Syria. The civil war in that country - which has led to a large number of refugees - may in part be caused by the extended drought in that area from 2006 to 2011- the worst on record. It destroyed agriculture, causing many farm families to migrate to cities[25].

It is appropriate to add a word of caution at the end of this section. Although the basic science and actual evidence for climate change is very strong and convincing, substantial uncertainties remain. This applies in particular to future projections and scenarios. These suffer from two main uncertainties: (i) climate scenarios are usually produced by global and regional climate models which are being evaluated on global grids with a distance between individual lattice points of at best 16 km, but usually larger. This means that in particular the physics of cloud formation - which occurs at smaller length scales - is only included via parametrizations in the simulations. The success of climate models in reproducing the observed climate changes in the last 30 years implies that these parametrizations are not badly chosen, but when the effects of climate change increase in the future this inadequacy (and there are more) may show up. (ii) climate scenarios assume certain emission scenarios. As long as no unambiguous signal for a reduction of the rise of CO_2 levels in the atmosphere is observed, a wide range of emission scenarios needs to be considered. This creates a large margin of uncertainty when projecting out to the year 2100 as can easily be seen in figure 3. This uncertainty can only be reduced if fast decisions are taken to reduce the worldwide greenhouse gas emissions as quickly as possible.

18 This argument is based on the Clausius-Clapeyrona relation between saturated water vapor pressure and temperature. See: G. Lenderink en J Loriaux, Zwaardere Plensbuien verwacht, NTvN mei 2016 (82) p. 132. In this paper several mechanisms are discussed that may help understand the quoted 14%/deg, intensity increase of heavy rainfall, while de Clausius-Clapeyron relation would only give 7%/deg.

19 The handbook of Global Climate and Environment Policy, Ed. Robert Falkner, Wiley-Blackwell, Chichester, West-Sussex, UK (2013)

20 Myles Allen, Liability for climate change, Nature 421 (2003) 891. It is noted that concerns about liability claims also triggered interest in the event attribution studies described in this section.

21 Greg Harman, Has the great climate change migration already begun?, The Guardian, 15 Sept 2014

22 C. Davenport, C. Robertson, Resettling the First American Climate Refugees, New York Times, May 3rd, 2016.

23 Robert J. Nicholls, Phil. Trans. Royal Society A, 369 (2011) issue 1934; DOI: 10.1098/rsta.2010.0291.

24 Elliott Negin, Think today's refugee crisis is bad? Climate change will make it a lot worse. The Huffington Post, June 30, 2016.

25 See for instance: Mark Fischeti, Climate Change Hastens Syria's Civil War, Scientific American, March 2, 2015; and Francesca De Châtel (2014), The Role of Drought and Climate Change in the Syrian Uprising: Untangling the Triggers of the Revolution, Middle Eastern Studies, 50:4, 521-535, DOI: 10.1080/00263206.2013.850076

INTERMEZZO

The University of Twente has a good reputation in the domain of educational reforms. The rector magnificus, prof. Ed Brinksma, has played a leading role in introducing the *Twente Education Model (TOM)*, that has been successfully introduced in all bachelor programs. One of the corner stones of TOM is the reduced emphasis on the traditional lecture. Hence, it is fitting to interrupt this lecture as well with an innovative element. I derive this idea from the European Ted-X conference, that was held this spring in The Hague on the occasion of the Dutch EU Presidency. The idea is simple: ask your audience, to retell one story that you learned today. You may tell this story to anyone you like, a friend, colleague, relative or neighbor, but at least once. And the story should be a simple one. Here it comes. Once I met an important person, and he believed that climate change was a hoax. I told this man to think about a romantic walk at night along the beach. What would he feel, or - easier - what did he feel below his bare feet? The warm sand that is radiating the heat it received during the hot summer day. I asked the man whether the heat would escape a greenhouse. His answer was no, it would heat the greenhouse. Correct. Now he understood the essence of global warming. So whenever you wonder about global warming: think about a romantic nightly walk on the beach.

3. CLIMATE CHANGE: HOW MUCH TIME IS LEFT AND WHAT CAN BE DONE?

The potential influence of climate change on society is large. Hence, it is appropriate to develop measures to reduce the extent by which the climate will change - known as mitigation measures - and to develop techniques to reduce the impact climate change anyhow will have on our lives - known as adaptation measures. Before discussing such measures, two preliminary questions need to be addressed:

- Is it possible at all to limit the greenhouse gas concentrations in the atmosphere?
- How much time is left before climate change takes on dramatic forms?

IS IT POSSIBLE TO LIMIT THE GREENHOUSE GAS CONCENTRATIONS IN THE ATMOSPHERE?

The atmosphere is a complex mixture of gasses subject to many interactions both with the sun, the seas, land, all vegetation and fauna, and 7.4 billion human beings and all the artefacts they constructed. Modelling the evolution of the chemical composition of the atmosphere is therefore challenging. Moreover, the effectiveness of possible measures introduced to restore the chemical composition to previous states is also subject to political and societal processes. Are all people around the globe willing to agree to take certain measures? In view of these uncertainties it is more convincing to address the question by giving an example. And such an example exists: the ozone hole above the South Pole.

Ozone (O_3) plays an important role in the atmosphere as it absorbs potentially harmful ultraviolet radiation (200 - 310 nm) which may cause sunburn, skin cancer and damage to other living organisms. Hence, when first observations of a reduction of the total amount of ozone in the atmosphere were reported (in the nineteen seventies), this was a source of considerable concern. The reduction was largest above Antarctica, where it was coined as the “ozone hole”. This reduction was caused by the release of chlorofluorocarbons (CFCs) and other ozone-depleting substances

(ODS) such as carbon tetrachloride. At that time CFCs (and ODSs) were widely used as refrigerants, solvents and propellants. In response to these concerns in 1987 the Montreal Protocol on Substances that Deplete the Ozone Layer was agreed, which was subsequently ratified by 197 parties - thus being the first universally ratified UN treaty.

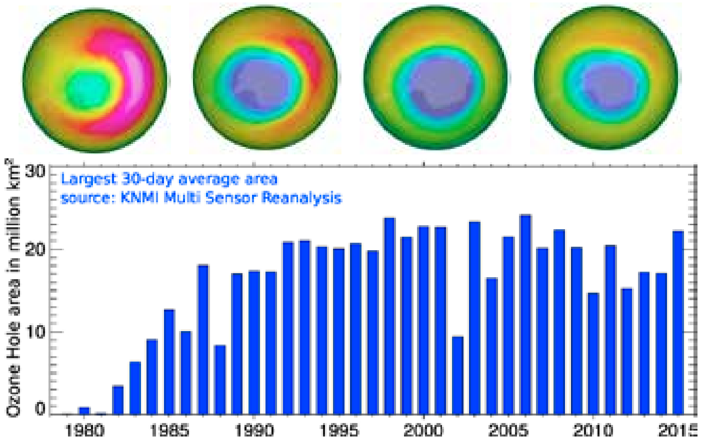

Figure 4. Results of satellite observations of the ozone hole above Antarctica. The observations are obtained by the Ozone Measuring Instrument (OMI), a KNMI-led project on the NASA Aura satellite, and its predecessors. The pictures on top represent the size of the ozone hole in October 1979, 1989, 2006 and 2010 – from left to right. On the bottom the surface extent of the ozone hole (30-day average of days with largest ozone hole) since 1979 is shown, revealing a flattening of the size of the ozone hole since the mid-nineties. (Figures have been provided by A.T.J. de Laat, KNMI – 2016.)

The consequences of this treaty are shown in figure 4, where the observations from satellite instruments are shown since 1979. The surface area of the ozone hole is seen to increase until the early '90s, whereafter the data show a clear flattening. The growth of the ozone hole is stopped, demonstrating the beneficial effect of the Montreal Protocol. The year-to-year fluctuations of the ozone hole are caused by rather large annual variations in the meteorological circumstances in the South-Pole area. The actual decline of the ozone hole is not anticipated before 2050, because of the large time of residence of CFCs in the atmosphere. Hence, the monitoring of the ozone concentrations needs to be continued in the future, for which purpose the TROPOMI satellite has been developed[26].

26 *TROPOMI is the Dutch earth observation instrument flying on the Sentinel 5P satellite mission of the ESA Copernicus program. It will be launched in early 2017 and it is aimed at measuring column densities of ozone and a range of "small" greenhouse gasses. KNMI serves as the Principle Investigator of this project.*

The history of the ozone hole demonstrates that it is possible to take world-wide action against environmentally unfriendly substances in the atmosphere (and monitor the effect of such actions). A word of caution is appropriate, however. As compared to the hazards represented by CFC emissions, the fight against increasing CO_2 emissions is much more complex. While the replacement of CFCs - in refrigerators and other technical systems - is relatively easy and affordable, the transformation from a fossil-fuel based economy to a sustainable CO_2-neutral economy represents a much larger challenge. Nevertheless, the ozone-hole example demonstrates the technical and societal feasibility of atmospheric mitigation measures.

HOW MUCH TIME IS LEFT?

Next, we need to consider how much time is left before the effects of climate change induced by CO_2 emissions become disastrous. The way that this question is phrased already shows that it is difficult to define a precise limit (in terms of global temperature rise) beyond which the problems are too large to be handled by mankind. In certain areas of the world it will be easier to accommodate a few degrees higher average temperature than in other areas. This depends on whether flooding, bush fires, droughts or heat waves - to name a few - is the most prominent risk in a given area. Hence, it should be realized that science cannot provide a fixed ceiling on the global temperature rise that could serve as a guaranteed safe target. This means that the 2 °C limit that is used in the recent COP21 climate agreement in Paris, is not a scientifically based limit but rather a policy goal[27]. Nevertheless, I will use it below in the absence of any other globally agreed limit.

In order to calculate the time left before the 2 °C ceiling is reached, it is important to realize that the temperature rise is linearly proportional to the cumulative amount of CO_2 that has been emitted since pre-industrial times, as is illustrated in figure 5. Making use of this relation an estimate can be made of the remaining amount of CO_2 that needs to be released before the 2 °C limit is reached[28]. Following this reasoning prof. Detlef van Vuuren[29]

27 *An excellent discussion on the history and ambiguity of the two-degree climate change target can be found in R. Knutti, J. Rogelj, J. Sedlacek and E.M. Fischer, Nature Geoscience, 7 Dec 2015 | DOI: 10.1038/NGEO2595.*
28 *M. Tavoni et al, Nature Climate Change 5, p 119–126. doi:10.1038/nclimate2475.*
29 *Detlef van Vuuren, Verschillen in schattingen tussen koolstofbudgetten nader bekeken, PBL Planbureau voor de Leefomgeving, Den Haag (2016), PBL-publicatienummer: 2385*

(PBL) calculated that the world population can emit in total another 600 - 1200 GTon of CO_2 before temperatures increase 2 degrees globally, which is reduced to less than 600 GTon if a 1.5 °C limit is assumed. As the global annual CO_2 emissions are 35 - 40 Gton, the remaining time varies between 15 and 35 years. If a steep linear decrease of the annual emissions is realized worldwide, the remaining time period doubles. However, this reasoning does not include the effect of other greenhouse gasses such as CH_4 (even less time available) or the possible use of CO_2 capture and storage (more time available). Given the ambitious targets of the Paris agreement and the uncertainties involved in calculations of this type, it makes sense to make a conservative estimate and take 30 = (2 x 15) year for the time period needed to arrive at a CO_2 neutral economy, i.e. latest by 2050.

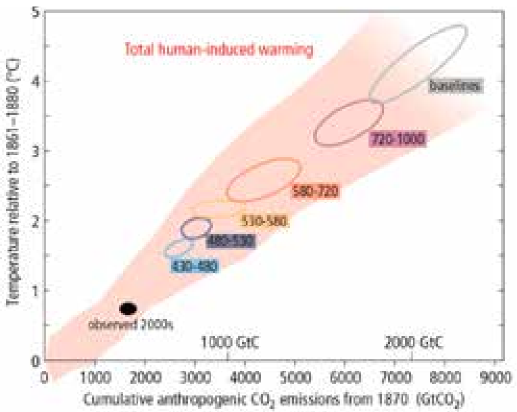

Figure 5. Relation between the global temperature rise and the cumulative CO_2 emissions (expressed in $GtCO_2$) since pre-industrial times. The pink area is a measure of the uncertainties involved. The actual situation at the beginning of the 21st century is indicated by the black dot, while the various ellipses represent the expected combination of cumulative CO_2 emission and global temperature rise. Each ellipse is marked by the corresponding range of CO_2 concentrations in ppm. (From IPCC AR5, 2013.)

Before proceeding it is useful to note that apart from anthropogenic CO_2 emissions, there are also natural sources of CO_2. These include soil, plants, animals and volcanos. (Deforestation also leads to additional emissions, but this is also caused by human activities.) From pre-industrial times we know that the natural emissions are on average balanced by natural carbon sinks (trees and oceans).

WHAT CAN BE DONE?

In order to reduce the risks associated with climate change, a continuous cycle of policy measures, observations, further studies and societal changes is required. The reason why this process is cyclic is illustrated by figure 6, in which the KNMI risk-reduction cycle is displayed. The idea is that preventing measures, warnings and alerts for a given geophysical risk - whether it is a regular storm, an extreme weather event or a volcanic eruption - need to be improved stepwise, learning from each successive concrete event. This concept can be applied to climate change as well. Policy measures need to be evaluated, and the way society is informed about more extreme future weather events need to be assessed as well such that climate actions can be improved continuously. Moreover, the scientific knowledge - although the basics are well established as discussed in section 2 - needs to be further developed as well. Are the calculated scenario's realistic, can extreme weather events be better predicted, or do we need revisions once climate change - and its various effects - is further progressing? All of this requires the cyclic approach depicted in figure 6.

The measures to be taken to reduce the risks of climate change, fall into three categories: policy measures, scientific research and societal changes - which are discussed separately below.

- ***Policy measures.*** As climate change is a worldwide threat, global policy measures are required. In this respect 2015 saw two important breakthroughs: both the Sendai Framework for Disaster Risk Reduction (March 2015) and the UN Framework Convention on Climate Change (COP21, Paris, December 2015) were unanimously adopted by all nations. World leaders agreed to limit the increase of the global temperature to 2 °C as compared to pre-industrial values, and pursue efforts to reduce this limit to 1.5 °C. Moreover, the Sendai Framework commits the partners - albeit on a voluntary basis - to realize a substantial reduction of disaster risk and losses in lives, livelihoods and health in the 2015 - 2030 period. These agreements provide the right starting point and the appropriate urgency when discussing measures that can be taken by (and in) the Netherlands to limit the effects of climate change.

Figure 6. The KNMI risk-reduction cycle. Society is advised or warned for potential geophysical risks such as storms or weather extremes. Each event is evaluated with the aim of improving the knowledge on these risks. Using this knowledge preparations are made to improve future advices or alerts in order to reduce the risks of - and possibly even prevent -future disasters.

Measures to reduce the effects of climate change fall into two broad categories: *mitigation* measures to reduce the emission of greenhouse gasses and *adaptation* measures to reduce the impact of climate change on society. These two categories are not entirely independent as is illustrated in figure 7, taken from the 2001 IPCC assessment report. In short, the figure demonstrates how increased mitigation activities reduce the required adaptation measures. In the discussion below of the various measures that need to be taken in The Netherlands, a third category is added: *international* measures. These are required given the global nature of climate change, although strictly speaking they concern adaptation and mitigation activities as well.

- *Mitigation.* In the Netherlands a clear time frame for the reduction of greenhouse gas emissions needs to be established, preferably within a European framework. This applies - among others - to power stations, industry, cars, public transport, housing and the government itself. Emission trading systems and/or a carbon tax need to be (further) developed. The urgency of mitigation measures becomes apparent once it is realized that greenhouse gas emissions in the Netherlands have increased by 5% in 2015 as compared to 2014[30].

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30 *Announcement by the Netherlands' Central Statistical Agency (CBS) and the Dutch Emission Authority, De Telegraaf, 6 September 2016*

Moreover, sustainable energy at present contributes less than 6% to the overall energy production in the Netherlands. The scope of the mitigation challenge is such the Netherlands' Agreement on Energy[31], although a good start, is no longer adequate. The growth rate of renewable energy sources needs to be doubled as compared to the rate quoted in the Agreement in order to arrive at a CO_2 neutral economy in 2050. Hence, a substantially higher level of ambition and a correspondingly broader scope of measures is being called for[32].
In the weeks preceding the present lecture four independent reports have been published also explaining the urgency of measures that need to be taken in order to arrive at a CO_2 neutral economy in 2050. These reports - originating from four independent organizations[33] - also describe various mitigation scenarios.

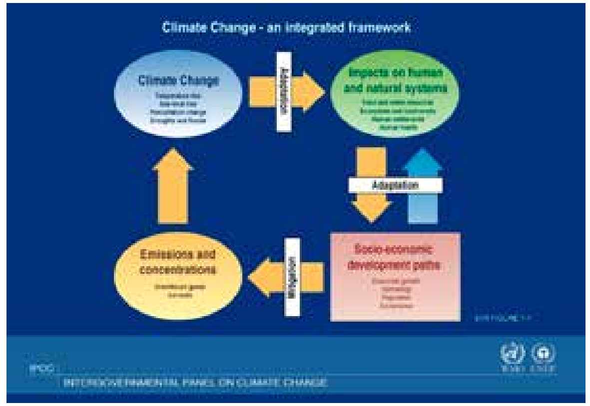

Figure 7. Framework showing the relation between the causes of climate change (emissions and concentrations in the lower left), the actual changing climate (upper left), the impacts it has on human and natural systems (upper right) and the influence of society on this system (lower right). Policy measures are labeled by the white rectangles. Taken from IPCC 2001 assessment report.

- *Adaptation*. The Netherlands is fortunate in having established an important element of a national adaptation strategy already several years ago: the so-called Delta-program. This program is aimed at

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31 *Nederlands energieakkoord voor duurzame groei: http://www.energieakkoordser.nl/*
32 *According to the Agreement on Energy the fraction of renewable energy should grow to 16% in 2023, or corresponding to a growth rate of 14% per 10 years, while a rate of about 27% per 10 years is needed.*
33 *McKinsey&Company, Accelerating the energy transition: cost or opportunity: a though starter for the Netherlands, September 2016; PBL report 1838, Balans van de Leefomgeving, September 2016; ABN Prinsjesdagrapport, Na aardgas komt zonneschijn, September 2016;TNO Energievisie 2030, Versneld naar een duurzame energievoorziening, June 2016.*

strengthening the dikes and dunes and ensuring adequate fresh water supplies. It has been designed in an adaptive fashion and is thus able to change its priorities depending on the way climate change is affecting the country. However, a comprehensive National Adaptation Strategy (NAS) - as required from each country by the Paris Climate Agreement - needs to cover many other policy domains as well. To name a few: food security, biodiversity, bush fires, energy supplies, health, infrastructure and mobility[34]. At the time of this writing a NAS is not available in the Netherlands. In addition to this program, measures need to be taken to reduce the risks associated with extreme high-impact weather, which will occur more frequently in the new climate - also in the Netherlands. For that reason both the Sendai meeting and the Paris agreement[35] (COP21) called for the establishment of Early Warning Centers to ensure that the population is warned or alerted in time in case high-impact weather events are forecasted. Although primarily aimed at Small Island Developing States (SIDS) and Least Developed Countries (LDCs), many OECD countries are establishing climate risk early warning systems as well[36]. As the Netherlands is also exposed to climate extremes, an early-warning center should also be established here.

- *International policy.* A two-degree limit (or less) can only be reached if all countries around the world are able to develop climate policy measures. As this is extremely difficult in some parts of the world, the World Meteorological Organization (WMO) is calling upon OECD countries to support non-OECD countries in developing such services and transferring know-how, making use of the expertise of local National Meteorological (and Hydrological) Services in OECD countries such as the Netherlands. This may require a redirection of Official Development Aid (ODA) funds at the Foreign Office.

The discussion above shows that climate actions are influencing many policy domains: infrastructure, mobility, energy, safety, agriculture, foreign policy etc. It is important that these measures are coherent and mutually coordinated. In fact, the complexity and interdependence of climate actions is such that the next Dutch cabinet needs to prepare a dedicated

34 Klimaatverandering. Samenvatting van de het vijfde IPCC assessment en een vertaling naar Nederland, PBL-KNMI, Den Haag, 2015, PBL-publicatienummer 1405.
35 At COP21 the Climate Risk Early Warning System (CREWS) initiative was launched: the governments of Australia, Canada, France, Germany, Luxembourg and The Netherlands have agreed to support equipping up to 80 countries with better climate risk early warning systems. See: https://www.unisdr.org/archive/46913.
36 Peter Bissolli, Ivan Cacic, Hermann Mächel and Stefan Rösner, WMO Bulletin, Vol. 65(1) – 2016, p. 28.

"Climate Act"[37]. Moreover, the corresponding policy measures should be coordinated by one minister.

- ***Scientific research.*** Given the societal impact of climate change and the large remaining uncertainties, it is first of all crucial to maintain and further develop the basic knowledge in meteorology, climatology and atmospheric chemistry. The general aim should be to refine our knowledge in such a way that uncertainties are reduced (or at least better understood), and our scientists remain at the forefront of their field. In this way the risks associated with climate change can best be reduced. More specifically, a number of issues needs to be addressed - also in light of the COP21 agreement:
  - *Climate monitoring.* This involves three subjects: (i) Monitoring of emission sources, which increasingly relies on satellite observations as the most objective method to determine the density of greenhouse gasses, their sources and sinks. Apart from CO_2 also the "small" greenhouse gasses such as methane and ozone need to be monitored, which is one of the purposes of the previously mentioned Tropomi satellite mission[26]. (ii) Monitoring of the meteorological consequences of climate change. This requires careful multi-annual measurements of temperature, precipitation, wind, sea levels, etc. including trend analyses. Reliable climate series and assessments are at the basis of climate science, and hence of (adaptive) policy measures. (iii) Monitoring the impacts of climate change in terms of - for instance - water management in low lying parts of the country, health effects[38], mobility etc. This type of monitoring is important in order to evaluate the effectiveness of policy measures taken.
  - *Extreme weather.* Future climate scenarios indicate that extreme weather events, such as heavy rainfall, droughts and heat waves, will occur more frequently in the new climate. This is confirmed by the observations presented in section 2. Further investigations are needed to identify the expected frequency, geographic distribution and intensity of such events. The challenge is to develop realistic scenarios of future weather taking local (urban) conditions and complex interactions into account.

37 Renée Postma, "Klimaatwet moet niet te wild zijn", NRC Handelsblad, 15 augustus 2016, p. S9
38 Climate change may also influence our health, as the known adverse health effects of exhaust gasses such as NOx increases significantly with temperature.

- *Improved forecasting.* In order to reduce the risks associated with a changing climate, forecast skills need to be improved - especially in areas with a high population density such as the Netherlands[39]. This can be achieved in three ways. (i) KNMI and other NMSs in Europe are continuously improving their instruments and computing infrastructure. New instruments (radars, ceilometer, crowd sourcing) lead to improved data sets. New high-performance computers (HPCs) make it possible to attach realistic probabilities to forecasts. (ii) Large amounts of meteorological data will be produced in the coming years by new satellite[40] and airplane instrumentation[41]. This is expected to lead to considerable improvements in the short-range forecasts once these data are assimilated in the so-called Limited Area Models. (iii) Moreover, at the European Weather Centre (ECMWF) a research program[42] has been started aimed at (a) making skillful (ensemble) predictions of high-impact weather up to two weeks ahead of time; (b) predicting large-scale weather patterns and regime transitions up to four weeks ahead of time; and (c) predicting global-scale anomalies (such as El Nino) up to one year ahead of time. The Netherlands, as one of the members of ECMWF, will be involved in and profit from these developments.
- *Climate of the 22nd century (climatology).* The effect of climate change will persist well beyond the year 2100, since the residence time of CO_2 in the atmosphere and the response time of the oceans are very long. Hence, the adverse effects of high CO_2 concentrations will continue well into the 22nd century. As the life time of new sustainable infrastructures, such dikes and locks, is in the order of 100 years, the effect of climate change in the next century needs to be taken into account as well. For those reasons studies of the climate in the 22nd century are needed. In order to study this a model has to be made of the possible mitigation scenarios, which is quite challenging as it requires the modeling of socio-political processes[43].

39 *The previously mentioned Early Warning Centers, which the Sendai Framework for Disaster Risk Reduction and the COP21 climate agreement are calling for, will also be more effective if forecast skills are improved.*
40 *The European Space Organization (ESA) is developing (in collaboration with EUMETSAT) a new family of missions called Sentinels, of which the first satellites have already been launched recently. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric observation: http://m.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4.*
41 *Jan Sondij & Siebren de Haan, Aircraft as a meteorological sensor using Mode-S Enhanced Surveillance data to derive upper air wind and temperature information, http://mode-s.knmi.nl/documents/KNMI_Mode-S_EHS_September_2013.pdf.*
42 *ECMWF strategic program 2016 – 2025: http://www.ecmwf.int/en/about/who-we-are/strategy.*
43 *Bart van den Hurk (VU, KNMI), private communication.*

- ***Societal changes.*** The COP21 climate agreement calls for *Climate Education*, being aware of the fact that the measures to be taken against climate change require the support of every individual. The attitude of our society with respect to the atmosphere has to change. Just like children are being taught to clean up their rooms, wash their hands, and not throw any litter on the street, we have to explain to them that it is inappropriate to pollute the atmosphere. Such a change in cultural values will take several decades, and may have a substantial impact. In the meantime the public awareness of the effects of climate change and the fragility of our atmosphere has to increase through frequent updates on the state of the atmosphere and climate, and e.g. by continued event attribution reports. Scientific research on climate change communication[44] may provide new insights in this domain. The US national weather service has recently initiated such a social science study to improve the response to weather information[45].

The last item deserves additional attention as the effectiveness of climate education and climate warnings and/or alerts is by no means self-evident. In fact, separate studies are being conducted in the social sciences in order to investigate how messages on climate change are perceived in the class room, the media or once such a warning or alert has been issued by a National Weather Agency. Below one such example is being discussed in more detail, as it occurred in the Netherlands.

CODE ORANGE FOR THE CLIMATE

A few weeks before the start of the COP21 meeting in Paris, KNMI issued a "code orange" climate alert in recognition of the severity of the situation and in order to draw public attention to this important event. In the 8 'o clock news on Nov 22nd, I was interviewed on national television about climate change[46]. During this interview I announced - metaphorically - that the concerns about climate change could be expressed with a *code orange*, in analogy with the usual weather warnings and alarms issued by KNMI. This statement was seen by approximately 3 million viewers and led to a massive response in the media in subsequent weeks, including positive comments, cartoons and some very critical statements[47].

44 *See for instance: Yale Program on Climate Change Communication, http://climatecommunication.yale.edu/, and non-profit organizations such as Climate Communication, https://www.climatecommunication.org/.*
45 *See: NOAA news bulletin 4 August 2016 (research.noaa.gov); the project has been initiated in collaboration with the US Federal Highway Administration.*
46 *Heleen Ekker, http://nos.nl/artikel/2070717-knmi-code-oranje-voor-klimaat.html*
47 *See for instance: Hans Labohm, http://climategate.nl/2015/11/24/48955/*

The justification for this announcement is easily given. Just as KNMI is entitled and obliged to issue a weather alarm once the conditions of the atmosphere in the coming 12 - 24 hours force us to do so, the scientific information on the status of a changing climate called for issuing a climate warning. In both weather and climate, it is information from the natural sciences in combination with the primary task of a National Weather Service (to inform, alert or warn society in case of geophysical hazards), that drove the decision. Ensuing criticism either focused on denying climate change as such (Ref. 43) or disputing whether it is the task of a public agency such as KNMI to issue a climate warning[48]. The analogy with weather alarms usually was considered to be a valid counter argument in the latter case.

It is impossible for me - as object of discussion - to give an assessment of the climate alert issued by KNMI on national television in November 2015. It is therefore very fortunate that a German research group with expertise in the social sciences[49] has decided to investigate the code orange case, in particular with the aim of studying the effectiveness of the chosen medium for conveying information about a complex issue such as climate change. The results of this investigation are expected to be available in the form of a PhD Thesis and a scientific paper by the beginning of 2017.

The Code-Orange case highlights an important aspect of the science of disaster risk reduction (DRR). When communicating about a given hazard with the general public both the technical sciences (providing quantitative information about the hazard) and the social sciences (providing information about communication methods) are involved. A thorough understanding of the interaction between the two domains, so characteristic for the University of Twente with its slogan *High Tech Human Touch*, is essential for a good disaster-risk reduction policy. This can also be turned around: by collecting information on the effectiveness of weather alerts, e.g. by issuing alerts through an *app* that also collects feed-back from the receiving citizens, the effectiveness of communication techniques used in disaster risk reduction can be investigated. At KNMI such an interactive weather and climate app is under development. Big data techniques will be used to analyze the data that will be collected[50] - yet another example where science meets society in the domain of climate change.

48 http://www.volkskrant.nl/binnenland/kritiek-op-knmi-na-afgeven-code-oranje-voor-klimaat~a4192958/
49 Simon Hirsbrunner and Asher Boersma, Research Group "Locating Media", University of Siegen.
50 Jan Dekker & Corline Koolhaas, private communication

4. HOW DOES THE NEW CHAIR CONTRIBUTE TO THIS AGENDA?

The science (and policy) agenda described in the previous section goes well beyond the scope of a single (part-time) research chair. Still, the connection established through this chair between the national meteorological service of the Netherlands, KNMI, and the faculty of Geo-Information Science and Earth Observation (ITC) at the University of Twente, will make it possible to address several aspects of this agenda as explained below.

POLICY MEASURES: INTERNATIONAL CLIMATE ACTION

KNMI is an agency of the ministry of Infrastructure and the Environment, and as a National Meteorological Service largely aimed at informing, warning and alerting Dutch society once it is faced with hazards of atmospheric or seismic origin. On the other hand the work carried out at the ITC in Twente is mostly aimed at studying geophysical hazards and the associated disaster risks in less developed countries outside Europe. Education and research at the ITC is also aimed at training future experts, i.e. capacity building for these countries. The new chair, which is officially inaugurated today, intends to bridge the activities of the two institutes. This is important as the effectiveness of a national climate policy requires an international involvement, and hence forces KNMI to bring its knowledge and expertise (mostly in the form of climate services) to non-OECD countries - as requested by WMO. At the same time, the meteorological and climatological expertise (and data) at KNMI will be beneficial for the ITC programs.

A concrete example of such an international climate action (or service) is the *Joint Collaboration Project* (JCP) in Indonesia. ITC, KNMI, Deltares and Alterra are jointly developing and improving the disaster risk reduction infrastructure in Jakarta. By collecting and homogenizing historic data, analyzing changes in the growth season, building flood protection systems and educating local people (capacity building), the JCP project helps in developing climate adaptation infrastructure in a foreign country. This project, which is financed by the Netherlands' Foreign Office, will enter its third phase in 2017.

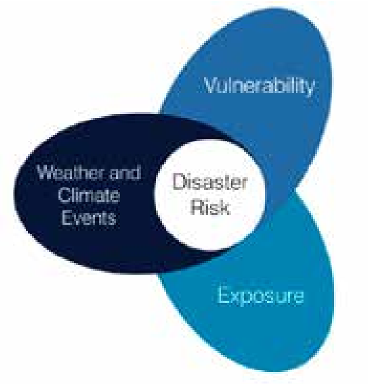

Figure 8. The risks associated with a given (weather or climate) disaster depends on the actual hazard (here indicated by the dark blue ellipse), the vulnerability of the region or infrastructure affected by the disaster (middle blue) and the exposure of people and property (light blue) in the affected area.

SCIENTIFIC RESEARCH: CLIMATE EXTREMES

As discussed before, climate extremes are among the most threatening aspects of climate change. Hence, it is important to study their frequency of occurrence, intensity and other features that might help decision makers to reduce the associated risks. The problem encountered when studying these extremes is that the original distribution function driving the probability of such events is changing due to climate change. Hence, a statistical tool kit has to be developed that will enable us to study climate extremes in a changing environment. Using such a tool kit - as a concrete application - the occurrence of droughts in Indonesia will be studied. It will be investigated to what extent (seasonal) forecasting and decision making can be improved, thus reducing the associated disaster risk. This is the topic of a recently started PhD project[51] at the University of Twente.

The subject of this thesis highlights an importance aspect of disaster risk reduction research. In order to reduce the risks of climate extremes, it has to be realized that such risks are the product of the actual climatological hazard, the vulnerability of the society or infrastructure affected by such an extreme weather event and the exposure, i.e. the density of people, livestock, buildings, roads etc. in the affected area (see figure 8). Whereas KNMI research focusses on the evaluation of the actual meteorological or climatological hazard, the ITC faculty at the University of Twente has considerable expertise in assessing the other elements (vulnerability and exposure) of the disaster risk.

51 *A joint ITC-KNMI graduate student, Vasily Kokorev, has been appointed recently on this project. The project is supervised by Dr. Janneke Ettema (ITC/UT) and Dr. Peter Siegmund (KNMI).*

SOCIETAL CHANGE: IMPROVING COLLABORATION ALONG THE CHAIN OF KNOWLEDGE

As was explained previously, societal change requires a high level of climate change communication, i.e. truly reaching out to society. In order to realize this, a connection needs to be made between the natural and social sciences. This requires the development of research lines encompassing both the physical and social sciences. This is also recognized by the Science Vision of the Dutch Government (2014), in which the importance of collaboration along the entire knowledge chain from fundamental research to applied and policy-relevant research was emphasized. Moreover, this is also reflected in the National Science Agenda (NWA) that was developed in 2015, which - among others - resulted in approximately 25 Science Routes centered around one common theme - such as the energy transition, for instance. In a Science Route researchers from universities teams, national research institutes (NWO), applied technical institutes (TO2) and public governmental institutes like KNMI work together. In practice, however, many obstacles remain in the Netherlands preventing researchers from different institutes to collaborate in a seamless fashion as envisioned by the National Science Agenda. In fact, at present in many cases it is not possible for a KNMI researcher and a University researcher to submit a joint project to the National Research Council NWO. This limitation does not only apply to KNMI researchers, but to all scientists employed by public research institutes that are part of the central government[52]. In order to put this subject - and others - on the agenda, a network of public research organizations was founded - under the name *RKI network*[53] - that includes the public research institutes RIVM, NFI, WODC, NVWA, RKD, RWS/WVL, KIM and KNMI and the planning agencies PBL, SCP and CPB. At present, these RKI institutes are excluded from most NWO research programs, while they are allowed to participate in EU funding schemes. Brussels is ahead of The Hague in this case! The RKI network aims to remove the hurdles that presently exist in the Dutch research landscape, a subject we are trying to put on the agenda of the next cabinet. Moreover, the RKI network represents a part of the knowledge infrastructure of the Netherlands that hitherto was usually omitted in national science discussions.

52 *Het gaat hier om Rijkskennisinstellingen en Planbureaus met medewerkers die in dienst van het Rijk zijn.*
53 *The chairman and secretariat of the RKI network are provided by KNMI.*

5. CONCLUDING REMARKS

I started this lecture by telling you about the largest natural disaster in recent history: the eruption of the Tambora volcano in present-day Indonesia. The eruption showed how a relatively small contamination of our atmosphere had dramatic effects worldwide: famines, refugees, casualties and even an invention: the bicycle. As we have seen climate change has an even more overwhelming influence on essentially all inhabitants of planet Earth. The effects are larger and will last for a much longer time. Immediate action is called for, both by the next government in the Netherlands, scientists and society at large[54].

Before concluding this lecture with some acknowledgements and a short summary, I would like to share with you a glimpse of good news - if only to counterbalance the enormity of the climate change challenge. On July 25th, 2016, an article was published in Nature Geoscience[55] with some remarkable information. In the months preceding the Paris 2015 agreement, the president of China (Xi Jinping) announced that the growth of their CO_2 emissions would peak latest in the year 2030. In the mentioned article it was shown that CO_2 emissions actually were reaching the highest level in 2014, and declined since then. At the same time a substantial growth in solar (+28%), nuclear (+25%) and hydropower (13%) was realized, implying that it is likely that the changes in China are structural and represent a true turning point. Hence, it may well be that China actually reached its CO_2 peak emissions well before 2030. This is good news as China is the largest CO_2 producer in the world. Moreover, this positive trend was further strengthened when on September 5, 2016, both China and the U.S. announced in Hangzhou that both nations had ratified the Paris Climate Agreement[56] and the agreement reached by the EU Council of Ministers of the environment or September 30, 2016 in Brussels to ratify the Paris Agreement as well.

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54 While focusing on climate change, the potential risks represented by volcanos should not be under-estimated, even in the Netherlands. Apart from the large number of volcanos on Iceland, which may lead with steady north-westerly winds to ash or SO_2 clouds reaching our country, the Netherlands also carries responsibility for two potentially active volcanos: the ones on the islands Saba and St. Eustachio in the Caribbean.

55 Y. Qi, N. Stern, T. Wu, J. Lu and F. Green, Nature Geoscience 9 (2016) p. 471, doi:10.1038/ngeo2777

56 WMO News 5 Sept 2016: http://public.wmo.int/en/media/news/historic-ceremony-un-chief-hails-china-us-formally-joining-paris-climate-agreement

ACKNOWLEDGEMENTS

With this encouraging news, it is time to summarize - but first I want to thank a number of people without whom I would not be standing here:

- I start by thanking the rector magnificus, prof. Ed Brinksma, the ITC dean, prof. Tom Veldkamp, and the leaders of the Earth Systems Analyses department, prof. Victor Jetten and prof. Freek van der Meer for their trust, confidence and friendship by appointing me on this chair. I hope that our plans and ambitions are realized.
- secondly, I would like to thank the Secretary General and Director Generals of the Ministry for Infrastructure and the Environment for hiring me as Director General of KNMI, knowing that I had no experience as a civil servant in The Hague, and allowing me to keep the ties with the University of Twente through this chair. I hope that I can contribute some know-how of the academic world in our policy discussions at the department, and you are willing to continue to accept my behavior as a rebel-with-a cause.
- all my colleagues at KNMI deserve a warmly felt word of thanks. First of all, I owe a great deal to all colleagues who subjected me to crash courses on meteorology, climatology, earth observation and seismology and had to live with all my inpatient questions. I really appreciated this! Moreover, since 2014 we worked together on essentially redrawing KNMI from scratch - a wonderful opportunity. We all believed in the success and uniqueness of our institute. And I must say that it is great experience for me - and I hope you feel so too.
- it is a great pleasure for me to see so many former colleagues in the audience: from the Faculty of Science and Technology of the University of Twente, from KVI in Groningen, from the FOM-institute Nikhef in Amsterdam. You all contributed to my development, by correcting and stopping, by stimulating and pushing me, by publishing and laughing together. I had the fortune to always have lots of great colleagues around me, and be assured that I am still confusing Nikhef for KNMI sometimes, and TNW for ITC!
- the students have the future, and this applies in particular to the ITC students who form a kind of mini world-population coming from many places around the globe. I do hope that your work and study will bring you what you need to make your home country more resilient against climate change.

- the importance of friends and relatives is known to each human being. We have the fortune of having many friends and relatives, whether we know each other from our school or student days, or just a few years ago because our children fell in love with each other. All of you have taken the effort to come here, and I appreciate that very much. We have laughed and cried together, but we never forget to come together again.
- my own family deserves the final word before the summary: Janneke, Jaap & Leontien, Harmen & Sharon: it is a lucky man who can call the five of you his inner family.

LADIES AND GENTLEMEN,

This lecture is almost finished, but I will not stop without summarizing the key notions I tried to convey today:

- The climate of our planet is changing now and the effects are clearly visible every day.
- Policy measures: the next government in the Netherlands is requested to
  - introduce laws or rules that will result in a CO_2 neutral society in 2050
  - create a level playing field for all knowledge institutes in the country
- Scientific research:
  - to monitor & study climate change, in particular extreme weather events
  - to improve forecasting skills for early warning purposes
- Societal change:
  - climate education: create awareness and knowledge of climate change
  - employ social science techniques to improve climate communication

And to underline my optimism that humanity will succeed in tackling climate change, let me conclude this lecture with the following quote:

The climate will improve, once science meets society.

Thank you for your attention.