CHAPTER 2

A Rapidly Changing Climate in an Era of Increasing Global Carbon Emissions

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Introduction

Humanity continues to blaze the path towards the increased extraction and burning of fossil fuels without a full understanding of its consequences. With seemingly no end to this finite resource, new drilling and increased extraction opportunities have brought the price of this commodity down. Meanwhile, current assessments on the impact of increased levels of CO$_2$, which are primarily generated from the burning of such fuels, point towards the consequential effects of extreme natural events in light of heatwaves and droughts, heavy rainfall, floods and sea level rise on communities (IPCC, 2014). Climatologists highlight the urgent need to cut down drastically CO$_2$ emissions in view of the longevity of airborne carbon present in the atmosphere (Archer, 2005) and have subsequently placed a red flag on the resulting persistence of the induced warming (Solomon et al., 2010) which can entrench inevitable and highly undesirable consequences.

Vigilance of the Climate System

The climate system is defined as an interactive and multi-component system consisting of the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, all of which are influenced by various external forcing factors, such as the sun. The direct effect of human activities on the dynamics of the climate system is termed as internal forcing (IPCC, 2016).

The vigilant monitoring of the climate system is continuously garnering new empirical evidence of its rapidly changing nature. The future prediction of a positive trend in global warming from increasing atmospheric levels of greenhouse gases (GHGs)$^\dagger$ is now robust (IPCC AR5, 2014). This change is quickly moving outside the boundaries of human experience, with the occurrence of unpredictable, geographically distant and disastrous events, which are already stressing societies around the world (NOAA, 2016). This does not exclude the fact that cyclic fluctuations of our climate during the past million years did not disrupt salient land and ocean processes. There is now ample scientific evidence to prove that the climate with time widely fluctuated between Ice Ages and warm interm periods, as a result of which there have already been major biological extinctions.

So why is so much concern given to our climate system in view of its perennially changing nature? Put succinctly, the difference between today's global temperature and the last Ice Age$^2$ lies only in an increase of 5°C. As a result the answer to this legitimate question is provocatively straightforward; one need only focus on this temperature range and compare it with the present-day rate of temperature increase. The similarity in the variation between the current post-glacial temperature (i.e. pre-industrial global air temperature) and the predicted increase in global temperature up till 2100 under moderately high anthropogenic forcing conditions is striking (IPCC, 2013). One may instantly realize that the rate of increase in temperature will occur in just over 100 years as opposed to 7000 years. The airborne CO$_2$ concentration that has already accumulated in the atmosphere will continue changing the Earth's radiation budget in centuries to come, let alone its expected increased levels.$^3$ So far the global temperature anomaly of 0.87°C since 1880 is considered to be quite significant. In certain parts of the world, such as the central Mediterranean (Fig. 2.1), this rate of increase has been shown to be higher during the past recent years (Galdies, 2012).

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The latest 'long-term' simulations of future climate were produced by the Coupled Model Inter-comparison Project Phase 5 (CMIP5).\textsuperscript{5} Simulations are made of both the 20th century (based on past, natural and anthropogenic forcing) and of the 21st-century climate (based on four assessments called Representative Concentration Pathways – RCPs; van Vuuren \textit{et al}., 2011). CMIP5 simulations of the global annual mean temperature show that it is expected to increase over time (Fig. 2.2), especially over particular geographical regions. For example, under the RCP 2.6 scenario the annual mean temperature values produced by the HadGEM2-ES model are projected to increase especially over the northern hemisphere, unlike that simulated under RCP 8.5, which shows an overall increase of temperature worldwide. Taking the UK as an example, the projected mean CMIP5 model temperature increase is expected to be between 2°C and 8°C (Fig. 2.2) depending on the RCP used by the model.

The crux of the matter lies in the speed at which the current climate is changing in that it is greater than any previous changes detected in what are known as proxy indicators of the ancient climate (such as ice and sediment-cores). Suffice to say that at the time of writing, the current global concentration of CO\textsubscript{2} to 405.75 ppm\textsuperscript{v} was last seen around 15 million years ago\textsuperscript{7} (Tripati \textit{et al}., 2009). This rapid perturbation to the entire climate system is making it more difficult for both humankind and nature itself to adapt quickly to altered states of its various components. While climate sceptics invoke the role of natural forcing behind such a rapid change, an overwhelming majority of scientists rule out any natural changes in external forcing by the sun, volcanic activity, or variations such as the El Niño-Southern Oscillation (ENSO; EPA, 2016) as being the main culprit of the present change in the climate.

The long-term, irreversible shift of the climate system as a response to continued carbon emissions is now well documented in the scientific literature (IPCC, 2013). A total of five IPCC assessments in 1990 have mainly assessed the projections of climate change and their impact for the 21st century. The group of experts responsible for these two tasks continues to uphold its views on matters relating to the time lag invoked by an increasing carbonized atmosphere, in other words, even if carbon emissions are kept constant or reduced by 2100, atmospheric CO\textsubscript{2} concentrations and surface temperatures would remain high, and that sea level would continue to increase for thousands of years to come. This situation will remain so unless an efficient and large-scale carbon sequestration and storage mechanism is used to immediately capture all of the surplus airborne carbon as well as that produced at source. Carbon sequestration occurs very slowly by a variety of natural processes, which stands in stark contrast with the hundreds of millions of years in order to produce the fossil fuels reserves we have at our disposal today (National Research Council, 2015).

Ironically, the advance in climatology is sometimes impacted by perplexing discoveries that challenge our current understanding of the magnitude of anthropogenic forcing on our climate system. The scientific process is obliged to unravel such conflicting results and review them in the light of further experimentation and understanding. Xie (2016) took up this important task by attempting to explain how the observed recent slowdown in global warming (better known as the ‘climate hiatus’) came about during periods of increased carbon emissions. This occurred at a time when the rate of global mean temperature decreased by a factor of two during the period 1998–2012 when compared to the previous 15 years. This has of course become embroiled in scientific and political debate (Fyfe \textit{et al}., 2016).

Xie (2016) documented the required theoretical and practical studies and observations made on Earth's energy balance of the ocean in order to explain this discovery. This thorough analysis has placed the tropical Pacific decadal variability\textsuperscript{8} in an important position as a modulator of the climate system and as being the main cause of this climate hiatus; however, its mechanisms still need to be elucidated. For many researchers this unexpected discovery was seen as an opportunity for further research, highlighting the need to continue understanding the climate system as a precondition for its accurate prediction.
Climate Change Impacts and their Implications on Global Security

Anthropogenic climate change has been linked to an increase in the frequency and intensity of a range of disruptive environmental events (IPCC, 2014). Such events are already discernible and causing stress to communities (Fig. 2.3) in the form of damage to local and globally integrated systems that support human well-being, such as public health (Mellor et al., 2016), ecosystem health and services, food supply (Tripathia et al., 2016) and infrastructure. NASA's Global Climate Change Portal (2016) cites the lengthening of growing season, changes in precipitation patterns, increased incidences of droughts and heatwaves, intensification of hurricanes, sea level rise, and de-icing of the Arctic Ocean as distinctive current and future impacts. Another equally significant impact is mass extinction, brought about by the inability of the biosphere to adapt so quickly to new climatic conditions. On land, shifts in the timing of the seasons and life-cycle events such as blooming, breeding and hatching are causing mismatches of biological interactions that disrupt patterns of feeding, pollination and other key aspects of food webs (Tripathia et al., 2016). In the oceans, ocean stratification is increasing resulting in less water-mixing between the upper warmer and cooler, deeper waters (Hansen et al., 2016) and linked to an inability for marine life such as phytoplankton found near the surface to access nutrients from below. Phytoplankton constitutes the very foundation of the ocean food web. Readers should refer to additional sources of information for additional impacts such as ocean acidification, coral bleaching and increased incidence of vector-borne diseases.

[Fig. 2.3]

Adaptive governance requires adequate information on the nature of these impacts in order to respond effectively to related risks. Significant improvements have been made in quantifying future temperature trends on the basis of the current and future emission scenarios of GHGs, and are now helping policy and decision makers to act accordingly. From this adaptation standpoint, the main requirement needed is the evaluation of expected risks by taking into account a range of possible future climate conditions and their associated impacts, and whether the cost of limiting the harm is acceptable. However, due to the current limitations in technology and knowledge of the climate system it is still not possible to predict the precise timing, magnitude and location of these events from decades in advance; there is instead considerable improvement in the equally useful knowledge concerning their nature, risk and social vulnerability.

A timely publication by National Research Council (2013) describes how the initial impact of a warming climate takes the form of disconnected clusters of extreme events. However, with time these sporadic extreme impacts will start taking their toll on integrated socio-economic and environmental systems, which can potentially trigger an internal cascade reaction of negative events with yet unknown consequences if their exposure and susceptibility are sufficiently high and repetitive, and our response is inadequate. Under such situations, national security might be better off if it applies a scenario-based approach of altered integrated systems rather than focus on isolated, individual extreme events, which perhaps are more predictable. In this context, experts argue that it would now be more appropriate to consider security risks that are able to disrupt, even at low but chronic levels, the internal linkages of global systems rather than simply prioritize risk on the basis of the magnitude of these extreme events. Therefore understanding how integrated systems are internally connected and how vulnerable they are to impacts of climate change is without a shadow of doubt the most important aspect of climate change from a national security point of view. Incidentally, this approach has so far received very little scientific attention (National Research Council, 2013).

Current Quick Fixes

Despite warnings of impending climatic extreme events, fossil fuels remain the world's primary energy source. Economic and technological progress continue to determine significantly CO₂ emissions (Kais and Sami, 2016). Solace in minimizing the effects of climate change is being sought in the slow but continuous application of mitigation measures and by the use of advanced technologies that are able to harness energy from renewable sources. This strategy started since UNFCCC came into force in 1994 and is periodically revisited at the Conferences of the Parties (COP) to the UNFCCC by means of lengthy negotiations aimed at keeping to the pre-determined emissions goals till 2100. Such targets are indeed
very important and are considered as tangible steps towards shifting towards clean technologies, energy efficient processes and a low carbon economy.

However, this strategy fails to recognize the nature of the threat posed, the recognition of which many top climatologists ascribe as being too little, too late. Clark et al. (2016) argue that assigning emission targets and introducing new technologies is short-sighted and is unlikely to have a major impact on emissions, especially if the general ‘political’ perspective of anthropogenic climate change continues to limit itself till 2100.

Climatologists view perspective as a political and strategic gridlock, which in turn myopically identifies the climatic problem as being only relevant to the next 100 years, and that the expected negative impacts of a changing climate can be reversed if cuts (which some consider to be not overly drastic) are made to current rates of emissions. Consequently, the current proposals and agreements to drastically curb emissions remain limited in scope and effectiveness simply because they are short-term in nature and do not take into account the lag of the climate system to respond to the current levels of GHGs in the atmosphere (Clark et al., 2016). Even if we were to entertain the idea of keeping to the current rates of GHG emissions, the climate would still continue to warm up well beyond the 0.87°C already observed and capable of drastically changing its dynamics for the next 10,000 years.

With the help of historical data going back hundreds of thousands of years and the latest climate models, scientists are now able to obtain highly probable long-term scenarios even if their precise timing remains uncertain. Their findings point towards the need for humankind to act fast and bring about the necessary change by 2040.

An interesting study that is hot off the press is a study made by Hansen and 18 other co-authors published this year in the journal *Atmospheric Chemistry and Physics*. They used climate simulation models, palaeo-climatic data from the past 120,000 years and modern observations to study the effect of growing ice melt from Antarctica and Greenland. Continued high GHG emissions until 2100 are predicted to yield an imbalance in the ocean heat budget and to the global thermohaline circulation in such a manner as would result in increasingly powerful storms and an exponential increase in sea level rise. Similar conditions have prevailed some 120,000 years ago during which huge swaths of polar ice melted down and resulted in a sea level rise of from 6 to 9 m (Hansen et al., 2016). Nothing new so far; sea level rise is a sure thing that is already ongoing. However, this study presents a sea level rise scenario that is diametrically opposed with what we have been hearing so far – one which will only require 50 years to unfold and not centuries. Results also show that this expected melting will be exponential. The resultant costs incurred by coastal communities and megacities are yet unknown.

Realistic visualizations of the impact of sea level rise can be derived from inundation maps modelled for important, low-lying coastal areas. Venice lagoon, for example, represents a focal area of immense art and cultural value because of its unique location, landscape, as well as its cultural history. One can process satellite-derived topographic data (ASTER GDEM) to simulate the projected impact of sea level rise within the lagoon (Fig. 2.4). With a total sea level rise of 5 m (as modelled under RCP 8.5 conditions), much of the current coastline within the lagoon area will already be under water.

**[Fig. 2.4a-c]**

Huge tracts of low-lying countries (some of which below sea level) such as Belgium may not survive climate change. On 24 March 2016, Nicholas Kristof from the *New York Times* argued to having a political system that is as sensitive to such risks as it is to homeland security. Clark et al. (2016) illustrated how 50–75% of the people living in Indonesia residing in low-lying areas will eventually be submerged (Fig. 2.5).

**[Fig. 2.5a-c]**
Short- Versus Long-term Actions

It is important that policy makers now place what we have learnt so far about the climate system, i.e. since the last Ice Age till the next 10,000 years, into an appropriate climate action. The sole consideration of a 250-year period since pre-industrialization is inappropriate since it is unable to account for all possible perturbations of the climate system as a response to increased rates of CO₂. Climatologists instead are forcing policy makers to opt for complete de-carbonization of the world’s energy systems as soon as possible, which is different from IPCC’s efforts to reduce global GHG emissions by at least 50% until 2050 (Clark et al., 2016; Zhou and Wang, 2016). Irrespective of the timeframe, a ‘carbon quota’ on future cumulative CO₂ emissions should already be in place in order to keep the global temperature to 2°C from pre-industrialized temperatures, which would correspond to a global mitigation rate of over 5% per year with a 50% probability of success (Raupach et al., 2014). In quantitative terms, this amounts to a remaining emission quota of 1500 GtCO₂ starting from 2015, or of 1300 GtCO₂ as of 2020 (Friedlingstein et al., 2014). This quota implies that near future cumulative CO₂ emissions consistent with a given warming limit will be a common and finite resource that must be somehow shared among countries on the basis of equity, and institutionally guided by an international policy, economics and financing.

There are several key opportunities to achieve the expected high mitigation rate. These range from land-based bio-sequestration or bioenergy with carbon capture and storage to the use of low- and zero-carbon economy. Interim opportunities that limit demand for goods and services that require energy as well as improving energy efficiency should be sought, such as: (i) changes in abatement technologies, fuel quality and fuel switching; (ii) changes in the structure and efficiency of the energy systems; and (iii) changes of the total economic activity (Andreoni and Galmarini, 2016). Governments have a pivotal role to play in influencing key stakeholders through effective policies and incentives addressing both private sector investments and consumer behaviour, backed by complementary policies.

The 2015 Paris COP 21 merits a special mention. For the first time, producers of 20% of the world’s oil and gas (including BP, Shell, Saudi Aramco and Total among others) expressed their willingness to assist in the 2°C temperature limit by committing themselves to reduce the GHG intensity of the global energy mix. This will be done through improved efficiency of their own production by giving preference to natural gas over coal, by investing in carbon capture and storage as well as through the harvesting of renewable energy.

A paradigm shift is needed in order to implement the COP 21 agreement’s ambition (Obergassel et al., 2016) and its fate is linked to the decoupling of economic growth and the use of fossil fuels as early as possible. However, critics of the Paris Agreement expressed that the financial part of this agreement is weak and does not go beyond what has already been agreed at the Copenhagen Summit in 2009 to mobilize an annual US$100 billion of financial flows by 2020 and beyond. Its effectiveness depends on whether the momentum gained during the December 2015 Conference can be translated into a major political force. This depends entirely on the willingness rapidity of nations to fulfil their declared pledges.

Conclusion

So far the journey from the 1997 Kyoto Protocol to the Paris 2015 Agreement has been problematic and more work remains on the implementation of binding agreements. Decoupling economic growth from continued carbon emissions is an ambitious objective at all three national, international and supranational levels (OECD, 2013). This chapter discussed the reason why there should be a drastic reduction of GHG emissions. Environmental economists support a system of ‘negative emissions’ up till 2050 in order to limit warming to 2°C over pre-industrial levels by the end of the century (Zhou and Wang, 2016). Huge capital investment in large-scale technologies such as carbon sequestration and storage, assisted by massive harnessing of renewable energy could make this possible. At the same time, another important fact has to be considered in all major decisions: an ever-growing global population that needs food, energy, access to basic necessities, and an environment that promotes economic growth and social justice.
Notes

1 GHGs are referred to as positive forcing agents because of their ability to shift the planet’s energy balance towards the higher side of internal energy. The forcing power of every GHG can be calculated on the basis of their atmospheric levels over time and on their energy transfer through the atmosphere.

2 The level of atmospheric CO₂ was higher in the distant past, with higher global temperatures and sea level. The CO₂ level in the atmosphere reached today’s levels some 3–5 million years ago, a period when global average temperature is estimated to have been about 2–3.5°C higher than in the pre-industrial period. The level of CO₂ may have even reached 1000 ppm around 50 million years ago, linked to a global average temperature of around 10°C higher than current one. Under those conditions, the sea level was at least 60 m higher than it is today (Clark et al., 2016).


4 The pathway with the highest GHG emission (i.e. RCP 8.5) represents ‘business as usual’ – strong economic development for the rest of this century, driven primarily by dependence on fossil fuels, where the concentration of airborne CO₂ exceeds 1000 ppm CO₂ eq. (Riahi et al., 2011).

5 CMIP5 is an international climate model inter-comparison exercise involving more than 20 modelling groups and over 40 global models. It was set up to provide a basis for coordinated climate change experiments for IPCC’s assessment reports through the World Climate Research Programme (WCRP). Its objective is to provide projections of future climate change on a time scale up until 2100 and beyond, and in doing so, understand some of the factors responsible for differences in model projects. http://regclim.coas.oregonstate.edu/visualization/gccv/cmip5-global-climate-change-viewer/index.html (accessed 17 April 2016).


7 Here it is important to keep in mind the uncertainties embedded in the techniques used to understand our ancient climate. A high CO₂ level could well have been one of the other key factors in controlling the palaeo-climate.

8 The Pacific Decadal Oscillation (PDO) is a pattern of Pacific climate variability similar to the El Niño–Southern Oscillation (ENSO) in character, but with a duration of 20 to 30 years, in contrast to ENSO’s phase of around 6 to 18 months. The PDO consists of a warm and cool phase, which alters upper level atmospheric winds. It has been found that shifts in the PDO phase can have significant implications for global climate and weather. Experts also believe that the PDO can intensify or diminish the impacts of ENSO (Xie, 2016).

9 An estimated 374 billion t of carbon has been released to the atmosphere since 1751. Half of the CO₂ emitted by fossil fuels has occurred since the mid-1980s. The 2011 global fossil-fuel carbon emission was 9449 million t of carbon. This represented so far a record high and was 3.4% higher than the global 2010 emissions. These are the latest figures released in the public domain (Boden et al., 2015).


References


**Figure Captions**

**Fig. 2.1.** Temperature anomalies at the Mediterranean level based on synoptic meteorological observations by WMO climate stations (1960s–2014). Inset graphs show temperature anomalies at various WMO Climate Centres in the region and thus climatic variability of the region (Galdies, 2015). WMO recommends 30 years as a standard period for the analysis of climate anomalies (Folland *et al.*, 1990), and the climate period between 1961 and 1990 at the individual locations was used as a typical baseline to calculate site-specific temperature anomalies, in conformity with the IPCC and other official Climate Centres.
Fig. 2.2. (a) projected change (°C) of the mean temperature surface air temperature at the end of this century (2075–2095) relative to the recent past (1986–2005) for the lower RCP2.6 (top left) and (b) for the higher RCP 8.5 scenarios (bottom left). Individual figures were generated by the author and adapted using USGS CMIP5 Global Climate Change Viewer. Both projections shown have been produced by UK’s HadGEM2-ES climate model. The sets of graphs on the right show the resultant mean monthly temperature produced from all CMIP5 models for the UK (Alder et al., 2013a, b).

Selected Significant Climate Anomalies and Events in 2015

**ARCTIC SEA ICE EXTENT**
During its growth season, the Arctic had its smallest annual maximum extent. During its melt season, the Arctic reached its fourth smallest minimum extent on record.

**EUROPE**
Europe as a whole experienced its second warmest year on record, behind 2014. Several countries had a top 5 year: Spain (warmer), Finland (warmer), Austria (2nd), Germany (2nd), France (3rd), and The Netherlands (5th).

**ASIA**
Much warmer than average conditions were present across much of the continent. 2015 was the warmest year since continental records began in 1910. Russia had its warmest Jan-Sep since national records began in 1936. China had its warmest Jan-Oct, with Hong Kong experiencing its warmest Jan-Aug period on record.

**CHINA**
Heavy rain from May–Oct caused floods that affected 75 million people. Provinces in southern China experienced their wettest May in 40 years.

**WESTERN PACIFIC OCEAN**
**TYPHOON SEASON**
Above average activity 28 storms, 21 typhoons

**CYCLONE CHAPALA**
(October 28-November 4, 2015)
Maximum winds - 250 km/h
Chapala was the first hurricane-strength storm (Category 1) in the Saffir-Simpson scale on record to make landfall in Yemen.

**AUSTRIAN CYCLONE SEASON**
Near average activity 9 storms, 7 cyclones

**SOUTH INDIAN OCEAN CYCLONE SEASON**
Near average activity 3 storms, 2 cyclones

**SOUTH WEST INDIAN OCEAN CYCLONE SEASON**
Near average activity 13 storms, 6 cyclones

**AUSTRALIA**
Experienced its 5th warmest year since national records began in 1910. The month of October was exceptionally warm, recording the largest anomaly for any month on record.

Please Note: Material provided in this map was compiled from NOAA's NCDC State of the Climate Reports and the WMO Provisional Status of the Climate in 2015. For more information please visit: https://www.ncdc.noaa.gov/sotc
Fig. 2.4 a-c. Inundation maps of part of the Venice lagoon at varying sea level rise. Legend shows height above sea level in metres. Topographic data are based on ASTER GDEM data (ASTER GDEM is a product of METI and NASA). (a) Current coastline of Venice lagoon, Italy; (b) 5 m above current sea level; and (c) 10 m above current sea level.

Fig. 2.5a-c. Inundation maps of part of Jakarta area (Indonesia) at varying sea level rise. Legend shows height above sea level in metres. Topographic data are based on ASTER GDEM data (ASTER GDEM is a product of METI and NASA). (a) Current coastline of Jakarta area, Indonesia; (b) 5 m above current sea level; and (c) 10 m above current sea level.