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Deliverable: D10.5- Provision of quantitative data for inclusion in the visualisation tool (HELIXScope) and advice to stakeholders on implications for European climate monitoring efforts and mitigation and adaption policy

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D10.5 - Provision of quantitative data for inclusion in the visualisation tool (HELIXScope) and advice to stakeholders on implications for European climate monitoring efforts and mitigation and adaption policy

Executive Summary

This report presents information from the HELIX workpackage on tipping points for illustrating the implications of climate system tipping points. Part 1 provides data which can be used in the HELIXscope visualisation tool – HELIXscope will focus mainly on projections of impacts from standard climate change simulations without tipping points, but alongside this it is important to recognise that those results do not capture the full range of possibilities, so the information on the likelihood of passing tipping points should be provided. Part 2 discusses the implications of potential climate tipping points for climate monitoring activities – key aspects of the system need to be monitored in order for the possibility of an early warning to be realised. Part 3 discusses the implications of considering tipping points in economic modelling to establish carbon pricing – the key finding is that consideration of tipping points implies higher carbon prices as their is stronger motivation for climate change mitigation.

1. Data Provision: Likelihood of tipping under SWLs from expert elicitation

Tipping points in the climate system are generally high impact, low probability events. This makes their study important, particularly with regard to their impacts, how likely they are and the potential for early warnings of these events. So far in previous WP10 deliverables we have found new methods for detecting tipping points in the climate, assessed early warnings and impacts of Arctic sea-ice and AMOC collapse in particular through simple to state of the art models globally and for the focus regions of Europe, South Asia and Sub-Saharan Africa. These studies have needed carefully controlled conditions to cleanly study their impacts rather than the typical specific warming level (SWL) scenarios used in the majority of HELIX impact work.

Ideally, HELIXScope will provide a simple coherent subset of information for policy makers regarding climatic impacts under each SWL. This makes including many of WP10 results undesirably complicated due to the need for extra explanation and health warnings over their correct interpretation. The wish is to keep the message as clear and uncluttered as possible in HELIXScope. With this is mind, the most relevant results from WP10 for inclusion in HELIXScope are from deliverable D10.1 (HELIX D10.1, 2015) in which imprecise probabilities of passing five tipping points were calculated for the three SWLs which were then translated as being either virtually certain, very likely, likely, about as likely as not, unlikely, very unlikely and exceptionally unlikely using the IPCC conventions. Probabilities were calculated in this deliverable from a hazard rate used in the HELIX publication Cai et al., (2016) which in turn was derived from an existing expert elicitation (Kriegler et al., 09). These results are provided as tables to HELIXScope. We have included the tables and the relevant details below (more details can be found in HELIX D10.1, 2015).

1.1 Summary of relevant results from D10.1 for inclusion in HELIXScope

In D10.1 we undertook of an analysis of tipping point probabilities based on an existing expert elicitation (Kriegler et al., 2009), which provides imprecise probability assessments of the likelihood of passing a subset of five different tipping points identified in Lenton et al., (2008) for three different temperature (SWL) scenarios. The five tipping points are those triggering collapse of the AMOC, meltdown of the Greenland ice sheet, collapse of the West Antarctic ice sheet, dieback of the Amazon rainforest, and a shift in ENSO variability (Table 1). From the expert results of probabilities by 2200 it was possible to derive a 'hazard rate' (Cai et al., 2016) for each of the five tipping points which is a likelihood of tipping per year per degree of warming above a baseline (/yr/K), where we took the baseline to be 1°C warming above pre-industrial. The resulting hazard rates were found to be internally consistent – that is the hazard rates inferred from different temperature trajectories are found to be in agreement (Lontzek et al., 2015).

Table 1 – Tipping elements and their potential tipping point considered herein (reproduced from HELIX D10.1, 2015)

Label	Tipping element	Tipping point scenario(s)	Brief description
Tipping points in the original list (Lenton et al., 2008) and expert elicitation (Kriegler et al., 2009)			
AMOC	Atlantic Meridional Overturning Circulation	Collapse of the AMOC	Shutdown of Labrador Sea convection and >80% reduction in deep water overflow across the Greenland-Scotland ridge
GIS	Greenland Ice Sheet	Meltdown of the GIS	Excess of melting and discharge over accumulation and altitude-melt feedback lead eventually to a nearly ice-free state
WAIS	West Antarctic Ice Sheet	Disintegration of the WAIS	Grounding line retreat and altitude-melt feedback leads to ice sheet loss
ENSO	El Niño Southern Oscillation	ENSO amplification	Increase in the amplitude of ENSO variability including more frequent extreme El Niño and extreme La Niña events
AMAZ	Amazon rainforest	Dieback of the Amazon rainforest	Regional drying and vegetation-water cycle and vegetation-fire feedbacks lead to widespread dieback (at least 50% loss of rainforest)
BOFO	Boreal forest	Dieback of boreal forests	Regional summer warming, insect pests and fires lead to widespread dieback (at least 50% loss of boreal forest)
Tipping points in the original list (Lenton et al., 2008) but not the expert elicitation			

SAM	South Asian Monsoon	Disruption of the SAM	Aerosol pollution leads to reduction in rainfall and doubling of drought frequency
WAM	West African Monsoon	Collapse of the WAM	Warming in the Gulf of Guinea leads to locking of monsoon rainfall to the West African coast, starving the Sahel of rainfall
ASI	Arctic sea-ice	Rapid summer sea-ice loss	Rapid (but reversible) loss of Arctic summer sea-ice
Tipping points considered here in additional to the original list			
ASI	Arctic sea-ice	Abrupt winter sea-ice loss	Irreversible loss of year-round Arctic sea-ice
EAIS	East Antarctic ice sheet	Partial disintegration	Removal of ice plug and grounding line retreat leads to drainage of ice from Wilkes Basin
Yedoma	Yedoma permafrost	Runaway breakdown	Self-sustaining breakdown of Yedoma due to biochemical heat release

To convert the hazard rates into tipping point probabilities at particular times they have to be combined with temperature scenarios. In essence this generalises the expert elicitation results to any temperature scenario. We constructed idealised scenarios of 2°C, 4°C and 6°C warming above pre-industrial, based on previous results from the HELIX project with regard to the likely timing of these specific warming levels (HELIX D2.1, 2014). The idealised scenarios are: 2°C warming followed by stabilisation, 4°C warming followed by stabilisation and 6°C warming followed by stabilisation (Figure 1). We calculated the probability of each tipping event in each scenario, on time horizons of 2100 and 2200. We also calculated the combined probability of any of the five tipping points occurring in each scenario on these time horizons.

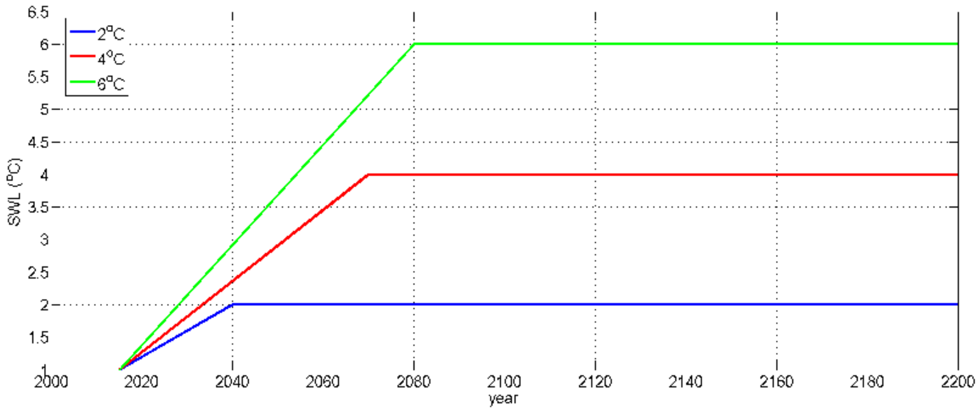

Figure 1 – Specific warming level (SWL) scenarios used to calculate the probabilities of tipping in table 2

A summary of the likelihood of different tipping points under 2°C, 4°C, 6°C warming scenarios on a time horizon out to the year 2200 is given in Table 2. Here we adopt the IPCC likelihood scale where in probability terms, virtually certain = 0.99-1, very likely = 0.9-1, likely = 0.66-1, about as likely as not = 0.33-0.66, unlikely = 0-0.33, very unlikely = 0-0.1, exceptionally unlikely = 0-0.01. The summary highlights that under a 2°C warming scenario most individual tipping points remain unlikely, but the joint probability of at least one tipping point occurring is about as likely as not this century and becomes likely by 2200. Under a 4°C (stabilised) warming scenario several tipping points become likely and the joint probability of at least one tipping point occurring becomes likely this century and virtually certain by 2200. Under a 6°C (stabilised) warming scenario all tipping points become at least as likely as not by 2200 and their combined likelihood correspondingly increases.

Table 2 – Summary of tipping point likelihoods under different scenarios (reproduced from HELIX D10.1, 2015)

Tipping element	2°C stabilisation scenario		4°C stabilisation scenario		6°C stabilisation scenario	
	Likelihoods quantified from expert elicitation derived hazard rates*					
Year	2100	2200	2100	2200	2100	2200
AMOC	Very unlikely	Unlikely	Unlikely	Unlikely	Unlikely	About as likely as not
GIS	Unlikely	Unlikely	Unlikely	Likely	About as likely as not	Virtually certain
WAIS	Very unlikely	Unlikely	Unlikely	About as likely as not	Unlikely	Likely
ENSO	Very unlikely	Very unlikely	Very unlikely	Unlikely	Unlikely	About as likely as not
AMAZ	Unlikely	Unlikely	Unlikely	Likely	About as likely as not	Virtually certain
(any of 5)	About as likely as not	Likely	Likely	Virtually certain	Likely	Virtually certain
	Subjective judgement of likelihoods based on literature review*					
Year	2200		2200		2200	
Boreal forest	Unlikely		Likely		Very likely	
W African Monsoon	Unlikely		About as likely as not		Likely	
Arctic ice summer	About as likely as not		Very likely		Virtually certain	
Arctic ice winter	Exceptionally unlikely		Unlikely		Likely	
EAIS (Wilkes)	Unlikely		Likely		Virtually certain	
Yedoma permafrost	Very unlikely		Unlikely		Likely	

*Here we adopt the IPCC likelihood scale where in probability terms, virtually certain = 0.99-1, very likely = 0.9-1, likely = 0.66-1, about as likely as not = 0.33-0.66, unlikely = 0-0.33, very unlikely = 0-0.1, exceptionally unlikely = 0-0.01.

The expert elicitation is a few years old now and subsequent research would suggest some revisions. Notably the expected change in ENSO is now somewhat different to that considered in the elicitation, which would be expected to change the results. Also, new ice sheet modelling research suggests that the WAIS is vulnerable to peak global warming in excess of 2°C (Golledge et al., 2015; Winkelmann et al., 2015), which is more pessimistic than the expert elicitation. The risk of Amazon dieback has also been looked at since using the same expert elicitation survey in Kriegler et al, (2009) as part of the EU project AMAZALERT (Kay et al., 2014). This suggested a small decrease in mean estimated probability of dieback.

2. Advice on climate monitoring efforts

Quantitative modelling of thresholds in the climate system is inherently challenging because these are low-probability, high impact events so that well-observed analogues in the instrumental period are hard to find. While ensemble-based approaches to estimating the likelihood of crossing thresholds in future have been tried, the results of such exercises may be dependent on both the details of the method and the underlying models (e.g. Challenor et al. 2006, Schlesinger et al. 2006). The low-probability nature of the events means that simplified models are usually needed to explore parameter space, and these may omit processes that are important for the threshold (Wood et al.2006). One possible way around this problem is to use statistical emulators, trained on small ensembles of complex climate models, as the basis for exploration of parameter space (Williamson et al. 2013). However obtaining robust estimates of the probability of future threshold crossing is likely to remain extremely challenging for some time. An alternative approach to managing the risk of threshold events accepts that the probability may not be quantifiable, but adopts a monitoring approach to detect when the system is close to a threshold.

Depending on the nature and timescale of such early warning there may be time for aggressive mitigation action to reduce the driving climate change before the threshold is passed, or if this is not feasible the early warning will at least give extra time to put adaptation actions in place.

Early warning indicators that have been proposed fall into three classes:

1. Initialised climate predictions. This simply uses generic seasonal or decadal prediction systems to give an indication of impending unusual behaviour in the system. This builds on existing observing infrastructure (e.g. Argo and satellite altimetry) to initialise climate model ensembles. The method has shown some success in recent years in prediction of large scale climate anomalies (e.g. Smith et al. 2007). However lead times and skill are limited and this method gives no information on whether predicted changes are reversible or not.
2. Timeseries analysis. This method uses generic properties of timeseries deriving from dynamical systems that contain threshold or bifurcation behaviour. Timeseries show increasing autocorrelation as the system approaches a threshold. By analysing observed timeseries it is in principle possible to detect when a threshold is being approached in the real world. This approach has been proposed for various abrupt climate changes (e.g.

Amazon dieback, Boulton et al. 2013). Its advantage lies in its simplicity. A possible limitation is that often an impractically long observed timeseries is needed in order to detect the autocorrelation change. Further, the timeseries analysis does not in itself identify the *nature* of any threshold that it detects.

3. Detecting key physical indicators of thresholds. In this approach a hierarchy of models is used to determine key observable properties of the climate system that are closely linked to the climate threshold.

Monitoring of thresholds in particular elements of the climate system must be underpinned by basic observation of those elements. For example, Arctic sea ice satellite measurements of ice extent and thickness provide the key indicators rapidly evolving of the state of the system. Altimetric and gravitational observations of ice sheet topography provide the baseline information on the evolution of these elements. Here we discuss three potential tipping elements in the Earth System where monitoring is actively taking place, and should be maintained.

2.1 Monitoring the Atlantic Meridional Overturning Circulation

For the Atlantic MOC, the overturning fresh water transport by the ocean, at the southern boundary of the Atlantic basin (34°S) is an observable quantity that is linked to the mono- or bi-stability of the MOC. In a range of climate model simulations this quantity evolves as 21st Century climate change develops (Drijfhout et al. 2011). This approach is attractive in that in principle it allows direct monitoring of the approach to a specific physical threshold. However the definition of the indicator variable must ultimately be derived from models which may contain structural errors or omissions, and the detection time for the threshold may require a long timeseries. The RAPID-MOCHA array has now delivered over 10 years of continuous observation in the Atlantic at 26.5°N.

Where specific indicators of thresholds are proposed (approach 3 above), direct monitoring of these indicators is called for, e.g. monitoring of the MOC and fresh water transport at 34°S in the Atlantic for AMOC stability (SAMOC/SAMBA).

All approaches to monitoring also depend on the broader development of the general climate observing and monitoring system. Key observational elements include Argo and satellite altimetry to help define the state of the ocean where most of the memory of the climate system resides. An essential element of the monitoring approach is the development of reanalysis systems which assimilate multiple data sources to provide a full 4-dimensional state estimate of the climate system. These reanalyses complement direct observations of specific elements above, to put changes into a broader context in both space and time (e.g. Jackson et al. 2016 which uses a reanalysis to place the RAPID observations of the AMOC since 2004 in a longer term context and link them to changes at other latitudes).

2.2 Monitoring the Amazon forest

Tropical forests, including the Amazon, are monitored both from ground at networks of local observation sites, and by satellite

(i) Site-Level Monitoring

Fluxes

There are nine eddy covariance flux tower in the Brazil Flux Net. These flux towers measure carbon, water and energy fluxes, and meteorological variables at fine temporal resolution. The Net Ecosystem Exchange of carbon between the ecosystem and atmosphere is measured, from which the gross fluxes (Gross Primary Production and Respiration) can be derived. In addition, Latent heat (evapotranspiration) and sensible heat fluxes are recorded. The information is extremely usual to understand the processes driving the temporal fluxes from these individual ecosystems at timescales from diurnal, annual, interannual up to decadal scales. A disadvantage is that there are few flux sites, each which have a modest footprint of the local vegetation.

Carbon stocks

The Amazon Forest Inventory Network mission is to understand the dynamics of Amazon ecosystems. Rainfor (http://www.rainfor.org/) systematically monitors individual trees at ca. 320 forest plots across the Amazon basin and 25 years of data, using common protocols and standardized techniques. Rainfor is co-ordinated through the University of Leeds, UK. The central permanent forest plots track individual trees biomass and stem growth and measure some soil and plant biogeochemical data. There are 120 core Rainfor sites across the Amazon basin. Analyses based on rainfor data can elucidate changes in basin-wide carbon stocks over time, understanding the net change in terms of growth versus mortality. It also shows the spatial variability across the basin which can be related to nutrient and rainfall gradients.

Furthermore, the Global Ecosystem Monitoring network, co-ordinated through the University of Oxford, UK, represents a subset of intensive monitoring sites for carbon allocation and cycling. This information is invaluable to understand detailed plant physiological processes. These sites have measured during periods of climate extremes, and therefore give useful information on forest response to short-term extremes, and perhaps help us understand possible future forest responses under climate change.

Tall towers

The Amazon Tall Tower Observatory (Andreae et al., ACP 2015) comprise two 80m towers (since 2012) and one recently erected 325m tall tower (in 2015) near Manaus. The 325m tall tower will measure greenhouse gas concentrations, trace gases, aerosols and meteorological variables over a large foot print of around 1000km, which is representative of regional-scale processes. This offers an amazing new ability to understand and monitor the carbon cycle over Amazonia at large spatial scales. This is a collaborative effort between the Max Planck Institute for Chemistry, Mainz, Germany, and Instituto Nacional de Pesquisas da Amazonia (INPA) in Manaus, and the Universidade do Estado do Amazonas in Manaus.

Manipulation experiments

Rainfall Exclusion Experiments have been conducted at two locations in the Brazilian Amazon, at the Caxiuanã National Forest (CAX) and Tapajós National Forest (TAP). The former is ongoing since 2001. This gives excellent ecophysiological understanding of the impact of long-term drought. Recent findings have shown that it is in fact the tall (high biomass) trees that are preferentially most vulnerable to drought via hydraulic failure (inability to supply sufficient water from the roots to the leaves).

Recently a Free-Air-Carbon-Enrichment (https://amazonface.org/), has been proposed at the Manaus ZF2 site. The aim is to assess and monitor the effects of increased CO_2 on Amazon forest growth and resilience. This will give an analogy of the response of forests to future environmental conditions of elevated CO_2. Fumigation is yet to start.

(ii) Satellite Monitoring

Deforestation and Degradation

Brazil has an extensive monitoring program for annual deforestation (PRODES), near-time deforestation (DETER), forest logging (DETEX) and forest degradation (DEGRAD). PRODES uses 233 LANDSAT (optical) images (resolution 30m) to provide an annual deforestation inventory over the Amazon basin. A main limitation as with most optical system is cloud cover contamination. However, the problem with this system is that the damage is already done, i.e. it does not help deter deforestation. The DETER, near real time monitoring system was introduced to provide daily revisits (MODIS @ 250m resolution), and can be considered a deforestation early warning system. With reductions in deforestation in recent years, there is an increasing relative importance of forest degradation in the land-use C emissions. Degradation acts to reduce modify forest structure (e.g. carbon stocks) through illegal logging and fire. Forest composition and structure will diminish with severity of degradation, where the end-point, i.e. severe degradation, can be considered deforestation. Brazil monitors and maps areas of forest degradation and selective logging, and logging intensity, using optical sensors. DETEX monitors forest logging, whereas the DEGRAD monitoring system produces annual inventory of forest degradation (more severe changes in forest structure).

Forest Cover Change

In addition to the Brazilian monitoring efforts, Hansen et al., Science 2013 produced a global tree cover extent, loss and gain using Landsat fat 30m resolution for the period, 2000-2012.

Biomass

Two Amazon basin-wide biomass products became available at roughly the same time: Saatchi et al., PNAS, 2011, and Baccini et al., Nature Climate Change, 2012. Baccini et al produced a pantropical above-ground biomass dataset @ 500m resolution whereas Saatchi et al., 2011 a map @ 500m resolution. Both use a combination of products, including scattered LiDAR footprints to measure canopy height, allometric equations to translate height into biomass, with calibration against several hundred field plots. Subsequently, Avitabile et al., GCB 2016 produced an integrated pan-tropical biomass map using these two satellite products fused with ca. 15000 estimates from other sources, including plot data (e.g. rainfor). This fused product is better able to capture the observed spatial variability in East -West Amazon gradient in above-ground biomass across the basin than the original remote sensed products.

Forest area change products combined with above-ground biomass, give an estimate of C emissions, and are both usual products in measurement reporting and verification (MRV) of REDD+ schemes, and thus land-based climate mitigation.

Fire (area burnt and emissions)

The global fire emission database (GFED) is a multi-year product that uses satellite remote sensed data of area burnt, together with a terrestrial biosphere model to generate regional emissions (http://www.globalfiredata.org/). Recent research has looked to produce a real time fire risk product for the Amazon basin, e.g. http://www.ess.uci.edu/~amazonfirerisk/ForecastWeb/SAMFSS2016.html

2.3 Monitoring Himalayan Glaciers

The glaciers of the Hindu Kush Himalaya region (HKH) produce the water for around 40% of the world's population. Over the past century these glaciers have lost around 25% of their mass in response to recent climate change and they are predicted to lose more in the future. The precise ways in which glaciers will respond to future climate change are still unknown; many will melt entirely, but some will undergo a transition to debris-covered glaciers which will retard melting, and others will undergo a further transition to form rock glaciers whose response to atmospheric warming and changes in precipitation is as yet unclear. As a result, obtaining data on glacier dynamics and monitoring glacier activity and status is an important, but challenging, scientific endeavour if we are to better assess the impact of climate change on water resources in central Asia. However, long-term data on glacier mass balance (ie over more than about 10 years) is very sparse for the HKH and only available for one glacier (Chhota Shigri glacier in the Himachal Pradesh region of India).

The importance of assessing glaciers as a means of understanding their role in regional and catchment hydrology and as the focus of natural hazards is now widely recognised. They constitute Essential Climate Variables (ECV) within the Global Climate Observing System (GCOS) and its terrestrial component, the Global Terrestrial Observing System (GTOS), part of the United Nations

Framework Convention on Climate Change (UNFCCC). GCOS and GTOS were set up in 1992 and 1996 respectively. From this, glacier monitoring in all the world's major mountain regions is carried out by several interrelated scientific groups. The World Glacier Monitoring Service (WGMS) was developed in 1986 from two related organizations (the Permanent Service on Fluctuations of Glaciers, and the Temporal Technical Secretariat/World Glacier Inventory). It now operates under the auspices of several bodies including UNEP, UNESCO, the International Union of Geodesy and Geophysics (IACS/IUGG) and the World Meteorological Organisation (WMO), and collates glacier length measurements on around 1800 glaciers globally, and mass balance measurements on 230 glaciers.

WGMS runs the Global Terrestrial Network for Glaciers (GTN-G) in collaboration with the National Snow and Ice Data Center (NSIDC) at Boulder, Colorado, and the Global Land Ice Measurement from Space (GLIMS) initiative. GLIMS is a consortium made up of sixty global organisations aiming to produce inventories and analyses of the world's 160,000 glaciers and has produced detailed outlines of nearly 60,000 of these. As a supplement to GLIMS the Randolph Glacier Inventory (now the RGI 5.0) was motivated by the IPCC Fifth Assessment Report and has produced a global inventory of glacier outlines.

GTN-G has three methodologies for assessing glacier change: in situ measurements, remote sensing and numerical modelling. In situ measurement data include use of index stakes on a small number of glaciers giving annual resolution of glacier changes, precise mapping using laser altimetry, and GPS to develop three-dimensional analyses of glacier volume and repeat mapping and altimetry at decadal scales. Remote sensing uses aerial photographs and, more recent, satellite imagery to upgrade glacier inventories and analyse glacier behaviour over time. The development of the GLIMS programme using ASTER imagery has enhanced this work by allowing digital terrain information to be used to create automated image analyses and to establish the basis for spatial analysis and modelling of glaciers. Numerical modelling has used 2-dimensional or GIS-based spatial energy/mass balance models to assess the sensitivity of glacier mass balance to climate forcing. These models can be coupled with GCMs and downscaled to local and regional scales using RCMs to assess climate change impacts and to analyse water runoff.

Given the importance of mountain glaciers in the HKH as water towers for huge and growing populations there is a clear need for a much more comprehensive monitoring programme of glaciers as climate change progresses. There should also be a focus on the different responses of debris-covered and clean ice glaciers to climate forcing and the need to treat them differently in climate modelling. There should be a better recognition of the role that debris fluxes to glacier surfaces plays in creating glacier lakes and, over time, glacial lake outburst floods that pose a risk to vulnerable communities and infrastructure. All this could be done with a targeted monitoring programme on selected glaciers. The Committee on Earth Observation Satellites has identified certain regions where satellite monitoring of potential hazards could be targeted and these include Nepal.

3. Implications of tipping points for climate policy

Most studies of the economic implications of climate change take a deterministic approach, assuming that impacts and hence their costs can be predicted, and use these to establish optimal climate policy levers such as carbon taxes. Accounting for deep uncertainties, including the passing of climate tipping points, is problematic. In a new approach involving HELIX input, Lontzek et al (2015) developed a stochastic version of the DICE (Dynamic Integrated Climate and Economy) model, representing the decision maker's uncertainty by a stochastic formulation of a tipping event. The new version of the model, DSICE, used a hazard rate – the conditional probability of the tipping point being passed in a particular year given the temperature in that year – as derived from the expert elication by Kriegler et al (2009) described in section 1 above. DSICE was used to quantify optimal levels of carbon price, trading off climate change mitigation against consumption and savings. The model was used to compare the carbon price with and without consideration of climate tipping points (Figure 2). It should be noted that the underlying DICE model underwent further development since the version used in this study, so the absolute values of carbon price should not be taken as best estimates – the focus here is on the difference in price due to considering tipping points.

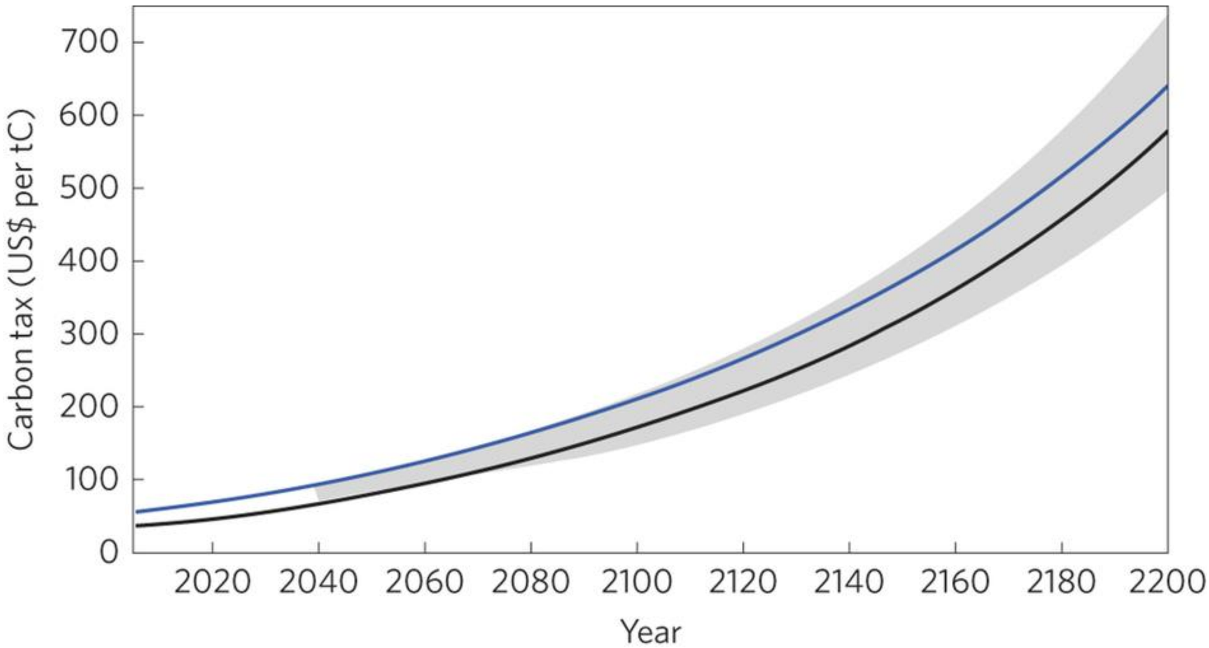

Figure 2. Carbon price (tax) assessed by the DSICE model when climate tipping points are neglected by decision makers (black curve) and when tipping points are considered (blue curve). Reproduced from Lontzek et al (2015).

When tipping points were considered, the carbon price was higher than when tipping points were neglected, reflecting the increased appreciation of risk of damage from climate change and hence greater benefit of stronger and/or earlier mitigation.

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