Norwegian Meteorological Institute

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factsheets

Extreme weather events in Europe: preparing for climate change adaptation

Introduction: Climate science – the basis for information about extreme weather

The best possible information about climate and extreme events is necessary for making judgements about future climate change and how global warming may affect extremes. Climate science is the principal source of such information.

Climate science provides descriptions of known aspects of the main climatic phenomena and gives indications about areas of incomplete understanding. It provides information about our current capabilities in assessing current climate and recent trends, and in predicting how these phenomena might change in the future. It also suggests the implicit value of climate services (the provision of science-based information about climate and prospects for future change) for decision makers and the public.

The degree to which data and theory reflect the real world is key to how successful climate scientists will be at making skilful forecasts.

Climate science can also provide answers to questions about how robust our knowledge is. This can be done, for example, through experiments based on computer simulations, which, by working through a range of different assumptions, enable us to explore the sensitivity of predictions to different factors.

Investments in climate science can be hugely beneficial to society in reducing costs, for example from unexpected damage caused by failure to

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anticipate change or from misguided decisions based on wrong information.

Describing Earth's climate

Knowledge about our climate rests on several independent sources of information: observations, measurements, physical theory, mathematics, statistics and geography. These can be described in terms of two broad categories: empirical evidence (observations and measurements) and theory (mathematics and laws of physics). The synergy between different information sources gives a more robust understanding of our climate than the sum of the individual sources.

Mathematical truths and statistical laws provide a frame for analysing measurements and describe relationships between different quantities. Together with our understanding of physics and chemistry, we can infer a likely picture of how different aspects of physical systems are interconnected. Our theoretical understanding and empirical facts can be synthesised into computer codes known as numerical models, which then calculate the values for energy, motion and mass according to the laws of physics.

The general picture of the climate system

Climate has varied in the past and, according to physical considerations, there has always been a cause for these variations. Temperature is a measure of heat (energy), and higher temperatures can only be explained by an energy input. Gas molecules in the Earth's atmosphere absorb radiation at particular wavelengths, and greenhouse gases are efficient absorbers of infrared radiation within certain frequency bands. Changes in the concentrations of these greenhouse gases will warm or cool the atmosphere.

Our understanding of the general circulation of energy and mass (water) in the Earth's atmosphere provides a basis for our understanding of extreme events. The hydrological cycle is driven by evaporation near the surface, cloud formation and precipitation. It plays a role in the energy flow from the Earth's surface to heights where the energy may escape into space in the form of electromagnetic radiation.

Both past experience and theory provide a link between cloud formation and a range of weather extremes, including extreme precipitation, tornadoes, lightning and hail as well as droughts. According to theory, the process of evaporation and condensation constitutes a mechanism for substantial energy transformation involving latent heat. Storm systems involve clouds through which condensation fuels rapid vertical motions. Change in temperatures also affects motion because temperature is related to density and pressure.

Data analysis suggests that soil moisture and evaporation affect temperatures, so that heatwaves are often associated with dry conditions. Droughts tend to be associated with high-pressure regions, which are areas of subsiding air. The theoretical picture is that the atmospheric circulation is constrained by limited accumulation of mass in a specific region, as mass and pressure are related, and the resulting pressure differences between places drive motion and redistribute mass. Air ascending in regions with convection or low pressure implies sinking motion in other areas.

Persistent high-pressure regions, associated with droughts, heat waves and cold spells, are often associated with quasi-stationary planetary waves, which are governed by Newton's laws and the Coriolis effect. It is still not well understood what makes these waves quasi-stationary and persistent, though large topographic obstacles such as mountain ranges and land-ocean temperature contrasts appear to be strongly implicated.

Numerical models as tools of investigation

Many aspects of natural variations, such as the Hadley cell circulation, the jet stream, the El Niño Southern Oscillation, the Madden-Julian Oscillation and the Asian Monsoon are understood to some degree. Many of these phenomena are present in climate model simulations, where they emerge from the mere representation of known physical laws in the numerical models. These phenomena tend to have a model character that to some degree differs from the real phenomenon, for example in terms of spatial extent and timescales.

It is difficult – if not impossible – to predict the *exact timing* and intensity of many weather phenomena. Atmospheric processes, similar to those represented in atmospheric models, exhibit features that have provided profound insight into nature, for instance in terms of the 'chaos effect'. This effect (and the related 'butterfly effect') explains why atmospheric and climate models, although they can reproduce the statistics of some extremes reasonably well, cannot predict the exact time and intensity of events beyond a certain time horizon. Atmospheric models are also able to reproduce features seen on other planets.

The atmospheric models are not designed to predict local details, and only include small-scale processes, such as clouds, in a simplified way. Furthermore, the spatial resolution in ocean models is still insufficient for describing the heat transfer associated with ocean currents. The timescale of temperature change in the oceans is also fundamentally different from the atmosphere. As a consequence, the sea surface temperatures in coupled ocean-atmosphere models tend to be somewhat inaccurate.

Analysis of weather data shows a close link between sea surface temperatures and tropical storms, convection and cloud formation. Moreover, the sea surface temperatures play an important role in the hydrological cycle. This relationship is also explained by theory and reproduced by numerical models.

Limits to our understanding

There are still gaps in our understanding of how cloud condensation nuclei are able to grow to raindrops within minutes and hours. Although we know that lightning is a result of a separation of electrical charges in the clouds, it is difficult to explain exactly how this happens. Several processes may play a role in the initiation of precipitation and formation of hail, but the degree of complexity makes it difficult to explain exactly what happens and to predict the precise outcome.

The large-scale environment has an effect on many extreme phenomena. The fact that there is a clear seasonal cycle in storm statistics, as well as in lightning and tornadoes, indicates that there are some influences that favour these events. In fact, the key driving forces of tornadoes are well understood and so therefore are their general seasonal and geographical distributions. Forecasting them, however, remains very difficult.

Many of the extreme phenomena also tend to exhibit geographical dependencies, which provide additional indications of their likelihood being sensitive to certain conditions. Thunderstorms are a summer phenomenon in some regions, and are influenced by atmospheric instability and the availability of moisture and energy.

The statistics of extremes also vary from year to year. Partly, these irregular variations are due to their stochastic nature and to statistical fluctuations, but part can also be attributed to variations in the large-scale environment. The North Atlantic Oscillation has a modulating effect on mid-latitude storms in the North Atlantic and on the storm tracks (the relatively narrow zones along which most extratropical cyclones travel). Storms also play a role in the poleward energy flow, and in the temperature differences between the polar regions and the lower latitudes.

Statistical models are developed to calculate the range and probability of data describing a process with a certain set of characteristics. Extreme value distributions are often used to describe the statistics of extremes (*see Factsheet 1*).

Taken together, the elements of climate science and the insights they provide are required to develop effective policies to address climate change. For example, the economic assessment that mitigation is hugely beneficial in reducing the costs of adaptation, given in the 2006 Stern review on the economics of climate change (executive summary at http://www.hm-treasury.gov.uk/d/CLOSED_SHORT_executive_summary.pdf), has its basis in climate science.

In short, climate science tells us about interdependencies between the key factors. These include whether greenhouse gases, land surface conditions and changes in the probability density functions of the climate elements like wind, precipitation or temperature are caused by external factors, some of which are associated with human activity.

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