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Climate change and civil engineering challenges

The greatest challenge facing civil engineers today is how mitigate and adapt to climate change. However, as discussed in this paper, there are still considerable uncertainties about the trends of some critical aspects of climate change and thus doubts about the mechanisms controlling them. In developing future strategies, a major contribution of civil engineers will be through providing practical and financial evidence about projects and systems which work and do not work. Engineers also know about risk, which is intimately related to system design. The paper concludes that the UK engineering profession needs to be more closely involved in developing effective integrated policies, working with scientists, business and government agencies.

The civil engineering profession's greatest challenge now is to reduce the human impact on the global environment, and to help civilisation adapt judiciously and effectively to the serious and damaging changes that are now inevitable over the next decades and beyond.¹

Human understanding of climate change has been transformed over the past few decades by ever more detailed and comprehensive measurements of the oceans, atmosphere and land surface. These are made possible by progressively more complex and ingenious scientific instruments and then delivered as useful data through engineering systems.

Research centres are now receiving climate data at the rate of a hundred million items daily. In situ measurements are still important, but now the majority are taken remotely. These provide global monitoring as well as critical local data, for example of tsunami waves, hurricanes, ozone variations and the detailed temperature profile of the atmosphere.

Sadly few people know the names of the engineers and scientists who pioneered climate measurement systems and interpreted the original data, though some have become famous for other reasons. These include Arthur C. Clarke, the science-fiction writer who first proposed geo-stationary satellites, or Sir Robert Watson-Watt who developed aviation radar, but also its applications for weather.

Even US president George Bush has emphasised the critical role of data when he recently confirmed the ending of the controversy about whether or not global warming is a reality. The upward trend of temperatures recorded by thermometers at ground stations and on weather balloons now agrees with those recorded by microwave sounders on satellites, which were developed in Oxford by Sir John Houghton. As the theory predicted, the troposphere—the atmosphere up to 10 km—is warming and the stratosphere above is cooling.



Fig. 1. Himalayan mountains where, like other mountain ranges, snow fall is reducing and levels of precipitation generally are affected by climate change, with serious consequences for local communities (NASA)

Considerable uncertainties still exist

However, there are still considerable uncertainties about the trends of some critical aspects of climate-related changes in the atmosphere, ocean, biosphere and even the land. Correspondingly there are doubts about the mechanisms controlling these changes, for example concerning how aerosols coming from combustion, sea salt and dust might be affecting precipitation in different countries of the world, including that of the Indian monsoon (Fig. 1).²

There are serious concerns about the effects of emissions of methane from the Russian and Canadian Arctic as the permafrost retreats northwards at about at 10–15 km/year. Since methane is a potent greenhouse gas, this could lead to a further 1–2 °C rise in global temperatures, according to some estimates.³

The new generation of satellite instruments that can monitor a wider range of gas and particles in the atmosphere are thus vital. UK government departments and universities are participating in monitoring programmes around the world, including those recording the shrinking regions of Arctic ice with CryoSat⁴ (Fig. 2), and ocean buoys for measuring early detection of seasonal weather patterns. These patterns are associated with devastating variations in precipitation and temperature in developing countries in the tropics.

However, traditional ground-based measurements are still essential to detect the detailed changes that have a huge influence on local communities. Ghanaian experts highlighted this in 2006 at a conference organised by their government and by the Advisory Committee on the Protection of the Sea (Fig. 3).⁵

Data distribution failures

Regrettably the data is not always distributed to the main African monitoring and forecasting centres, such as those in Niger and Kenya, which could use it to provide drought warnings and climate policies.

It is also regrettable that data and current publications from developed countries are not reaching local institutions that need them, though the situation is

better in medicine and agriculture. It is hoped that ICE can join other national and international institutions in remedying this situation.

Also, more public recognition is needed of the leading scientists and engineers in developing countries who are making globally important contributions to the technology and policies of sustainable development.

Developments in modelling

Understanding and policy also require modelling and prediction. The first reasonable predictions of global temperature rise of a few degrees caused by industrial and other human emissions of greenhouse gases (CO₂, methane and so on) by Arrhenius⁶ in the nineteenth century have had to become much more extensive



Fig. 2. Planned European CryoSat satellite (2008) for monitoring polar ice fields (ESA/P.Carril)



Fig. 3. Coastal zone of west Africa where global warming and reduced rainfall are exacerbating the deterioration of the local environment

to take account of the complex processes of human–nature interaction.

Climate predictions have relied on the important discoveries of engineers who invented electronic computers, now running at 10^{15} floating-point operations/s (flops) on some systems, and the new computational techniques that primarily engineers developed for applying computers to very complex flow problems. Only now are meteorological models using the adaptive-mesh techniques that have been standard in aeronautical and civil engineering. However, whereas the physical scale represented by computational meshes might be of the order of 1 cm in engineering models, they are typically as large as 100 km wide in climate models (though only 1 km in the vertical).

As Olec Zienkiewicz has remarked, Lewis Richardson (1881–1953),⁷ working then at University College London, was the originator of both developments. He was the first to use finite-difference methods to solve a partial differential equation—in fact for stresses in the proposed Aswan dam (Figs 4 and 5).

Improving reliability of predictions

However, meteorology might repay its debt to engineering with the significant



Fig. 4. Lewis Richardson (1881–1953) invented numerical methods for engineering and weather forecasting while he was at University College London and the Met Office

developments that have emerged over the past ten years for improving the reliability of predictions from very complex numerical models.

For weather and climate prediction, the new approach involves running slightly different models at a number of climate-modelling centres. The calculations differ in their initial and boundary conditions and in the assumptions about the physical, chemical and biological processes in the models (Fig. 6).⁸ The results have been shown to provide more accurate weather forecasts and climate predictions with better error estimates.

The more collaborative and open approach of multi-centre modelling has also ensured that all models around the world incorporate new discoveries soon after they are made. This occurred in the 1990s following John Mitchell’s discovery at the Met Office of the crucial effect of industrial aerosols of reducing slightly the rise of global temperatures.⁹ However, where there are significant uncertainties about processes, a diversity of model prediction is useful for decision makers.¹⁰

Other areas of science and technology are also beginning to apply the approach, such as in hydrological models and computational heat dynamics.

The results of the massive worldwide investment in computers and measuring systems, as well as the research manpower involved—probably £70 million a year in the UK alone and ten times that worldwide—is that the quantitative modelling and prediction of global environmental changes over the past five years have significantly improved. For example

- the calculated changes of global average temperatures in the atmosphere now follow the observed significant decadal fluctuations over the past 150 years, including those caused by natural variability, human influence and perturbations caused by volcanic eruptions and solar variability⁹
- the models are consistent with 0.05 °C warming of the surface layers of the oceans—which the US Scripps Oceanographic Institute concluded could only have been caused by humans effects over the past century
- the models demonstrate the horizontal and vertical variability in the temperature trends (e.g. 3 °C rise over 50 years in the Antarctic peninsular leading to massive break up of the ice sheets).¹¹

Models still have limited use

In terms of the effects on crucial processes affecting society and therefore affecting engineers, the global-scale models are useful for planning for the average, local and fluctuating temperature rise and its effect on sea level rise, coastal flooding, sea-ice extent, evaporation, air quality, urban heat island effects, hurricanes, animals and plants.¹¹

For other crucial aspects of climate change, however, such as the effects on precipitation, wind storms, hurricanes, land/ice processes and the varying periods of ocean circulation, the numerical model results have to be treated with more caution. They produce a wider range of results and sometimes have conflicting trends.

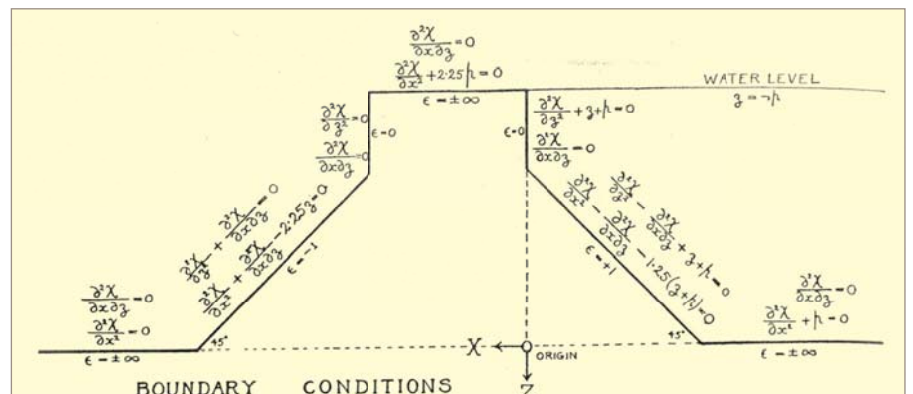


Fig. 5. Richardson's formulations for calculating the Aswan Dam in 1910

However, short-range weather forecasts for rainfall and high-wind events are now considerably more reliable. For example, errors in hurricane tracks 24 hours ahead were about 200 km in 1992; as a result of Chan's work with the Met Office¹² these errors are now on average only 140 km and sometimes less, as they were with Hurricane Katrina.

Similarly, seasonal three-monthly predictions of droughts or extreme precipitation and storms in many, but not all, parts of the world are now reliable enough on average for aid agencies, agriculturists, insurance companies and water agencies to plan ahead (Fig. 7).¹² Regrettably, governments in developed as well as developing countries do not always get or make best use of these data.

Value of short-range forecasts

Making use of improved short-range and seasonal forecasts is an essential part of dealing with the effects of climate change. This is because climate change is not just a gradual year-on-year change in temperature, sea level, precipitation and so on. In fact, like other unsteady non-linear systems, small external influences can cause large fluctuations between different conditions.

Structural engineers familiar with buckling and fluid dynamicists understand the changes in a saucepan as they vary the stirring, heat applied or thermal conductivity of the pan—a subject of recent research at UCL.¹⁵

For societies to adapt to fluctuations

in the global and regional environment, they need the best possible short-term warning systems as well as long-term climate predictions. This is what the UN emphasised in Kobe in January 2005, and the UK Department for International Development recognised in its latest policy document, informed no doubt by David King's task force following the tsunami disaster.¹⁴

Dealing with uncertainties

For guiding decisions over the future periods of significant climate change stretching out into centuries, a simple 'risk' table proposed by Stephen Schneider of Stanford University provides a good way to think about the uncertainties involved.¹⁵ He compares different scenarios.

The first envisages reducing the long-term human and economic risks associated with significant climate change through taking precautionary actions to deal with the likely worst-case climate scenario. It is also assumed that current technology can be applied on a timescale to avert the worst environmental effects.

The alternative scenario is based on the assumptions that the best-case climate scenario may occur with limited and slow rise in the average global temperature, and also that technology will develop fast enough to avert these changes—or at least moderate their effects—without

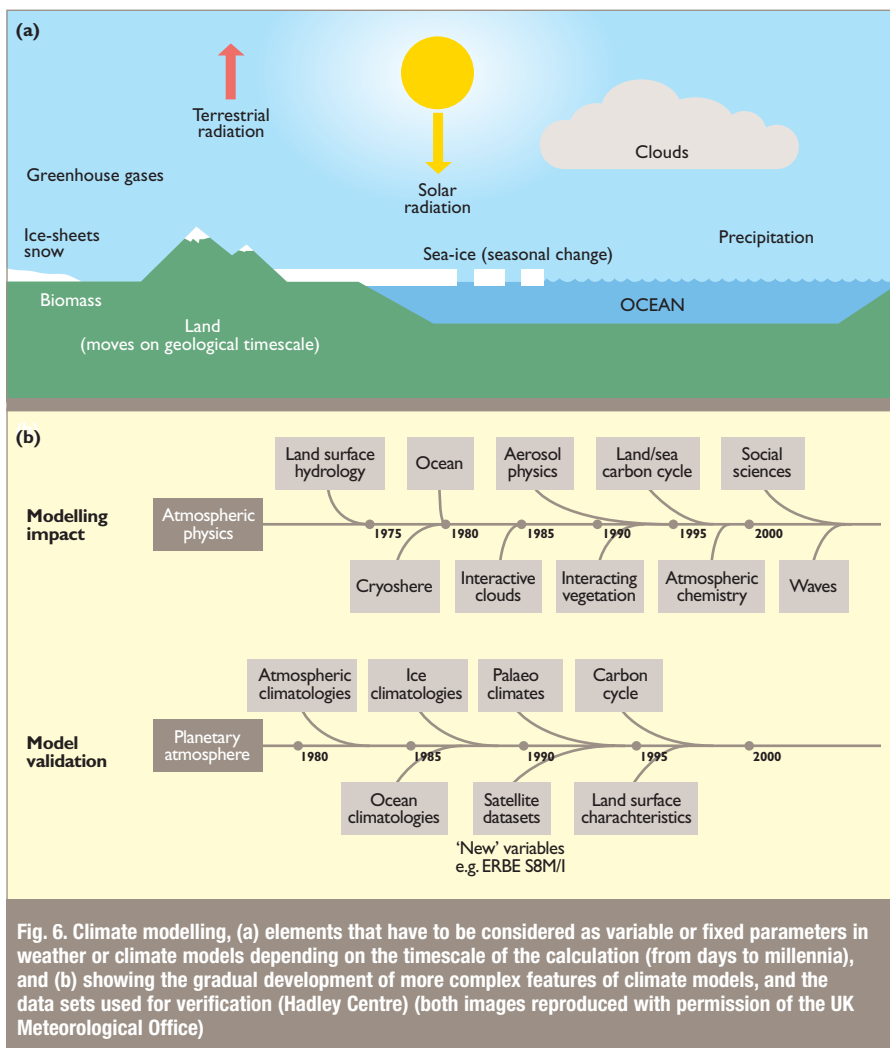


Fig. 6. Climate modelling, (a) elements that have to be considered as variable or fixed parameters in weather or climate models depending on the timescale of the calculation (from days to millennia), and (b) showing the gradual development of more complex features of climate models, and the data sets used for verification (Hadley Centre) (both images reproduced with permission of the UK Meteorological Office)

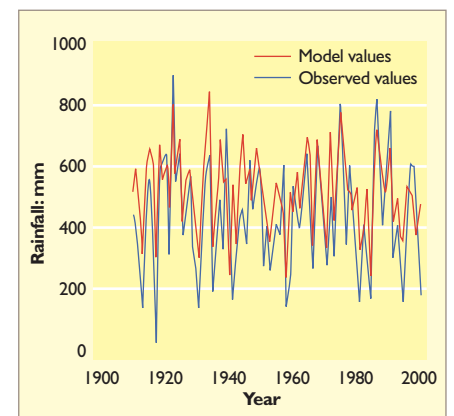


Fig. 7. Example of how climate models can be used to make seasonal forecasts for 3 months in advance—for north-east Brazil these are very reliable, but less so for other parts of the world (reproduced with the permission of the American Meteorological Society)

major government intervention through financial or regulatory instruments.

He argues that the costs of the former will not be excessive—which the UK Treasury concluded in 2001 and is currently re-examining—and that the side benefits of environmental precautionary action will be worth having anyway, such as reducing the risk of floods, or building houses with better insulation. By contrast, adopting the alternative optimistic scenario would be very difficult and costly for society to deal with in terms of cost and disruption if the worst-case climate scenario was to happen.

The debate between the two views in the UK is hotting up even in the House of Lords. The first, lower-risk approach advocated by Lord May, president of the Royal Society, and earlier by the Royal Commission on Environmental Pollution was criticised by a former UK chancellor as alarmist. He advocated the alternative optimistic strategy favoured by the US president, with its exclusive emphasis on technological development driven by market forces.¹⁶

The role of engineers

In developing future strategies, a major contribution of engineers will be that they can provide practical and financial evidence about projects and systems which work and do not work. Also engineers know about risk, which is intimately related to system design.

In particular, engineers can help determine to what extent a strategy should be based on highly integrated plans and

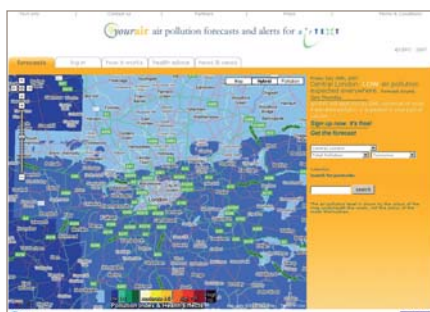


Fig. 8. An example of daily predictions of air pollution concentrations near main roads in London, made as part of the EU and European Space Agency programmes for environmental monitoring and prediction (www.airtext.info)

systems, and which aspects can be dealt with more effectively in a disaggregated way through devolved bureaucracies and market approaches.¹⁶

In terms of sustainable energy policies, most governments have now concluded, following Sokolow, that a full range of energy resources and technologies is needed.¹⁵ However, whether the strategies are integrated or disaggregated they have to work with the physical and social networks of modern society—energy, water, transport as well as communication, the communities, professions and so on.

The great civil engineering projects from the 1700s to 1900s provided—with huge financial investment—networks of canals, railways, roads, water supply, sewage, electricity and, finally, electronic communications. The question now is whether and how these will be transformed to accommodate growing populations, urbanisation and the global necessity of using less resource of every kind, particularly materials, energy and water.¹⁷

The transformations are fastest in the developing countries, for example non-functioning, fixed-line telephone networks are being abandoned in favour of mobile phones. India's disaster warnings are translated by computer into 14 languages and disseminated to the mobile phones of millions of people.

In London too, new systems are being introduced: air-pollution warning messages are now being texted to the mobile phones of those suffering from breathing difficulties, through the Global Monitoring for Environment and Security (GMES) programme of the European Commission and European Space Agency (www.gse-promote.org) (Fig. 8). The UK Government's new energy policy will be based on local networks, as well as the national electrical networks, making use of the Woking initiative. This showed how, using a local grid, renewable energy and combined heat and power could provide more reliable as well as safer energy with 70% less carbon emission.¹⁸ The Tyndall Centre in the UK has studied some of these issues.

The need for integration

As the recent Brunel and Telford celebrations reminded us, the great eight-

eenth- and nineteenth-century networks were initially fragmentary and highly competitive. They only reached total coverage through capitalism and various government monopolies. As government influence recedes, the networks may again become fractured, though interlinked.

The impact of climate change places special emphasis on effective integration and prioritisation of interlinked networks and planning. This is not a political agenda: it should have the environmental goal of minimising the use of resources and carbon emissions.

Effective air and surface transport systems and communication systems could improve business efficiency, minimise air pollution—which kills 1.2 million a year according to the World Health Organisation¹⁹—reduce carbon emissions, and so on. These objectives are currently frustrated by international regulations—for example the Chicago convention of 1944 that precludes tax on aircraft fuel—and the timescale needed by governments to explain and introduce new regulations and taxes.

The UK needs to reduce its carbon emissions from energy by 60% to make its equitable contribution to meeting international targets for a sustainable global atmosphere. This target could be reached through coordinated construction, planning and energy networks; for example through improved energy conservation in buildings, which are currently responsible for about 50% of carbon emissions.

Nuclear energy—an example

One hopes that the excellent British and French engineering and scientific community that has collaborated successfully with Airbus, and recently with the climate-impact programme, will be able to collaborate in the exciting engineering and technological challenges of developing advanced nuclear-energy systems. This objective was included in the statement issued by the academies of the G8 and associated countries for the heads of government meeting at St Petersburg in July 2006, because of the need to deliver energy while minimising carbon emissions.²⁰

Several national and international studies reviewed by the French parliament and an explanatory statement by Lord

Sainsbury in June 2006 have all pointed out that the possibility of long-term minimisation of nuclear wastes or their transmutation into less dangerous forms could be practical technologically. The former objective has been proposed by General Atomics through efficient high-temperature gas-cooled nuclear fission reactors; the latter by a working group at the International Atomic Energy Agency exploring the combined use of nuclear fission and fusion systems.²¹

Such technologies would avoid the dangers of 10 000 y nuclear wastes. Unless people and politicians are informed about the issues, they cannot possibly make the right decisions—and politicians and engineers should be very suspicious of current public opinion polls. For example, many anti-nuclear politicians are simply unaware that technologies exist and are being developed to reduce the very long lifetime of radiation from nuclear waste. When informed, they sometimes take a more measured position.

However, where communities do understand controversial technologies, it provides an opportunity for further investment. Both in France and the UK, communities situated near existing nuclear power stations generally support new investment. In Germany and Denmark, communities support wind power in a way that they clearly do not in many parts of the UK.

An approach based on 'horses for courses' is advocated by the International Energy Agency and the World Bank in their recent report and public statements on energy and sustainable development.²² They recognise the controversial nature of the decisions, but they conclude that a flexible and regionally based energy policy is a political necessity to achieve the overall policy of global sustainable development.

Conclusions

The UK engineering profession needs to be closely involved in developing effective integrated policies working with scientists, business and Government agencies.

Perhaps some new initiative by the engineers' institutions could be connected to the UK Government's recent proposal for a climate-change task force or agency,

and to the Sustainable Development Commission.

In the UK, institutions tend to work more openly than in other countries. However, in France, the highly effective social and political networking of leading engineers successfully coordinates their planning of nuclear energy, fast trains and so on. There are perhaps some lessons here for the UK profession.

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