Les Changes de l’Environment; le defi scientifique
(Environmental change; the scientific challenge.)

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<u>Preface</u>

C’est un tres grand honneur devenir un docteur honoris causa à l'Institut National Polytechniue de Grenoble. Cet honneur me donne de plaisir exceptionnel parce que j’ai boucoup des associations avec Grenoble, et maintenant beaucoup des amis. Moi et ma femme ont visité René Moreau dans ces laboratoires à Ave Felix Viallet en ’64. Plus tard nous avons organisé un colloque Europeén pres d'ici à Villard de Lans. J’ai participé dans quelques congrés et conferences internationals à Grenoble, notamment le conferences organisé pour Marcel Lesieur et Olivier Metais sur les structures coherentes en turbulence en 1989. Aussi j’ai visite Grenoble avec mon père en ’86, et ma fille a passé deux semains dez Moreau pour apprendre le Francais. Je suis surque mes connections fructueuses continueront au futur.

1. Les changes actuelles dans le climat et l’environment globale
(1. Actual changes in climate and the global environment)

2. Le base scientifique de modelisation de climat et environment
(2. Scientific basis for modelling)

3. Le utilisation pratique des modeles et les donnéer
(3. Practical utilisation of models and data)

4. Les choix pour l’adaptation generale contre la change de climat; les problémes pour modelisation.
(4. Choices for adaptation to climate change and problems for modelling)

1. Changes in Global Environment and Climate

The climate and the general environment on the surface of the Earth has had many large changes over the history of this planet. Some of the variation in global temperature in the past 10,000 years of as much as 5^oC have been associated with changes in the composition of the 'greenhouse gases' in the atmosphere, especially CO_2, and to a lesser extent with variation in solar radiation reaching different parts of the Earth's surface.

Arrhenius first pointed out in 1860 that the rate of human production of CO_2 would become comparable with that by natural processes and would have a significant effect on the world's climate which we now expect to lead to a 2-3^oC rise over the next 100 years.

As we shall see, accurate calculation of these effects have required the development of numerical models using scientific concepts, electronic computers and new measurement techniques. These models have shown how other phenomena are also attributable to climate change, the most serious for many countries of the world is the rise in sea levels which is expected to be about 0.3m over the next 100 years.

A longer term change in the oceans that has occurred in the past and is likely to occur again, over the next four hundred years, is the reduction in the currents that bring warm water to N.W. Europe – the thermohaline circulation. Already the temperature in southern Greenland has fallen by 1^oC over the past 50 years.

Research in the polar regions of the world has revealed that another equally serious change has been developing in the global environment, namely the reduction in stratosphere ozone caused by artificial emissions of chlorine gases. This reduction leads to increasing ultra-violet radiation and damage to human health. Although governments have taken action to reduce the release of chlorine gases, modeling suggests that this will take as much as 100 years before the state of the stratosphere is restored.

2. Modelling

There are some aspects of the global phenomena that can be understood by qualitative dynamics, such as the Hadley circulation or by average models, such as Arrhenius calculations of the greenhouse effect. In fluid mechanics we call these latter box models or control surface models. They have limited predictive powers, so we need to use reductionist models built up from calculations of processes in elemental volumes, for the atmosphere and oceans these are based on the dynamical equation of Novier and Stokes, and the theories of thermodynamics and radiation of Carnot, Kelvin, Stefan and others. Until electronic computers arrived mathematical analysis using these equations could only account for local phenomena such as undulations in the atmosphere, waves on the ocean and some aspects of fronts that we all experience in our daily weather that divide warm and cold air, and determine moving patterns of rainfall.

Although the discoveries of approximate methods for solving these equations by L.F. Richardson and others, and of the beginnings of electronic computers with Fleming's thermionic valve (both at University College London) took place before 1920, it was not until the 1970's that computation by electronic computers were relied on by weather forecasters and by those researching into global climate change. The calculations for the atmosphere are done within thin slices that are, for weather forecasting, now about 50km wide. For very long calculations of climate change over 100-200 years the slices have to be larger, typically 200km. The depth of these slices are about 10m at the surface and 1km at the top of the atmosphere.

Local predictions of serious environmental effects are necessary such as the air pollution and the heat islands in urban areas more detailed (which actually causes more deaths than any other weather effect in the U.S.A. and China). Here modeling is required, with the computational boxes being less than 100m, and the chemical processes have to be considered as well.

The numerical models are based on approximate representation of physical processes within these boxes. So the effects of clouds or turbulent eddies or building in an urban area have to be calculated and then averaged. Research by academic groups makes vital contribution to the large numerical models such as those developed at the Meteorological Office or Meteo France. Recently studies of turbulent flow over low hills have shown how these produce quite a significant drag on the atmosphere circulation, but have a much weaker effect on heat and mass transfer. Also for mountains on the scale of the Pyrenees and the Alps the original estimates of drag were too low by a factor of about 5 (actually proportional to the inverse of the Froude number). This was because the earlier calculation did not allow for the effect of the Earth's rotation – an effect well understood at Grenoble with your rotating flow facilities.

Research at Grenoble led by Professor Lesieur and Hopfinger is playing an important part in the development contributing to new models of turbulence processes, and particularly how these processes depend on coherent structures. Combining these studies with progress in the two-phase flow, we now have better understanding of how small rain droplets move and accumulate in turbulent clouds. This should soon make a decisive improvement in forecasts of rain and the effects of aerosols on precipitation.

3. Practical uses and limitations of models

Environmental models differ from those used in the laboratory or in idealized research studies because they are applied in situations where the state of the environment at the beginning of the calculation is not completely known; nor is it accurately specified in the areas surrounding the region to be modeled. For example, the chemical state of the atmosphere in the flow approaching urban areas has a critical effect on calculations of local air pollution. For short term forecasting, the techniques of control theory, based on the mathematical theory of J.L. Lions are being applied. Optimal approximations have to be made with the given data, and continually updated as new data arrives. This is essential to incorporate the huge amount of satellite and aircraft data now becoming available. For predictions of climate over the next hundred years precise comparisons with data is much less important than having the correct representation of processes in the numerical model.

What is the evidence that these computational models are improving in accuracy? In 1990 the error in the prediction of tropical cyclones or hurricanes in the next 24 hours was about 220km. Now the average error is 130km. Climate models can now simulate the mean values and fluctuations in global average temperature over the past 150 years to within an error of about 0.2^{o}C; the errors in fluctuations have reduced by 50% since 1995.

Numerical models for describing and predicting local environments have also improved in the past four years. For example by allowing for the non-Gaussian structure of convective turbulence the predictions of the maximum ground level concentration from sources of pollution have improved by 100%. The old Gaussian methods tended to seriously underestimate these values.

4. Choices for adaptation to climate change and problems for modelling

So if we can predict with increasing accuracy how the climate and local environments are changing, we can apply scientific knowledge to enable communities and industry to mitigate the worst effects of environmental change.

Some of the scientific problems mitigation and adaptation are distinct and some are connected. Some example of the technological and mitigation research needed to reduce greenhouse gas emission, are the more efficient combustion, or using weather forecasts connected to heating systems to reduce fuel, etc.. The future (on a similar 50 year time scale similar to that of climate change) design of cities and transportations systems to minimise energy use and pollution in the urban environment (with reduced air pollution, noise, urban heat islands) will notably mitigate the production of CO_2 and other greenhouse gases but will adapt urban areas to the climate change. Most weather related deaths are caused in the U.S. because of temperatures 10^oC above that of the surrounding areas.

However urban design makes a difference because in New Delhi and Phoenix Arizona, in which there are well irrigated areas which cool the air through evaporation, the temperatures are 1^o below those of the surrounding areas.

Much the greater challenge of climate adaptations is for low level islands states, such as the Maldives and for European coastal areas, caused by the progressive rise in sea level by over 0.5m in the next 100 years. Understanding these developments and making the right decisions requires extensive research, for example on wave and currents in these coastal areas, the natural habitats and geology of these areas as they become flooded. The economic and social problems will be immense. My belief is that a vital task for physical scientists and engineers to provide fast and user friendly computational systems (for PCs) that synthesise scientific knowledge to enable communities, industry, an government to receive and interrogate date, to examine model predictions and then to explore possible ‘design’ solutions. Then these groups can come to their own decisions about how best to adapt to the quite rapidly changing environment.