

Advancing climate science

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1. Climate Monitoring

Advances in climate science and the technologies that climate scientists exploit can assist in increasing the usefulness of climate information for important decision-making by international agencies, governments, government agencies, industry and the general public.

Fundamental to the advancement of climate science has been the maintenance of long-standing observing systems together with the development of new systems for observing, transmitting and managing climate data. As an illustration of current capabilities consider the ocean monitoring system that operates in the Bureau of Meteorology:

<http://www.bom.gov.au/climate/current/>

<http://www.bom.gov.au/bmrc/ocean/results/climocan.htm>

In this system ocean data is collected from a wide variety of sources. This includes measurements taken from: instruments dropped from the side of commercial ships; satellites; the impressive U.S. funded TOGA-TAO array in the Pacific Ocean. The latter is a moored array of ocean and atmosphere data collecting instruments that spans the equatorial Pacific. This vast amount of data is transmitted to the Bureau and other major centres where it is quality monitored and merged into three dimensional ocean models to provide a very useful gridded analysis of the current situation. This ocean monitoring system is augmented with a vast array of atmospheric monitoring networks. Together these systems and the rapid and effective transmission of the data they gather, provides the backbone to our ability to monitor the state of the climate system. Further enhancements of this system e.g. through the ARGO float program, will be described.

Morning teas in meteorological agencies now routinely feature scientists discussing the current status of the Pacific Ocean at depths of 250m as

their counterparts might have done with clouds above them thirty years ago.

At the same time there has been a revolution in our ability to disseminate information relating to the current status of Australia's climate. For example, the National Climate Centre now provides hundreds of thousands of maps of rainfall, temperature and other quantities on a routine basis to the general public through the web:

<http://www.bom.gov.au/climate/>

See also:

<http://www.bom.gov.au/silo/>

for an integrated source of weather and climate information primarily for the agricultural sector.

Numerous other agencies are also exploiting this relatively new technology to disseminate climate information as part of broader communication strategies, e.g. through state government departments:

<http://www.vic.gov.au/>

(click "Drought Information and guidance") and CSIRO:

<http://www.dar.csiro.au/>

2. Climate Modelling and Prediction

The information from the observing systems obtained is used in a variety of ways, one of which is to initialize computer models of the earth's climate. These models are, in turn, used to predict climate variations over coming seasons. Australia has recently developed a forecast system called the "Predictive Ocean-Atmosphere Model for

Australia” – POAMA – through a joint effort between the Bureau, CSIRO and the Climate Variability in Agriculture Program administered by Land and Water:

<http://www.bom.gov.au/bmrc/ocean/JAFOOS/POAMA/exproducts/>

This system is now run routinely with nine month outlooks initiated once per day. POAMA is capable of producing a wide range of forecasts for variables including ocean temperature and rainfall for example. At the present time, however, the skill of such systems in predicting continental rainfall directly is limited. Such systems are, on the other hand, quite good at predicting ocean temperatures in key locations like the tropical Pacific. This is the centre of action for ENSO and is well known as a region that can influence Australian rainfall. So novel statistical approaches are being developed to try and bridge the things that are forecasted with skill (e.g. ocean temperatures) to variables that people want predicted like Australian rainfall.

POAMA in its current form was not a feasible proposition as little as 10 years ago because computers back then did not crunch numbers fast enough. In fact climate scientists eagerly look forward to more computing power as it allows them to increase the resolution of the models they use. This can help improve simulations of ocean currents through narrow straits and channels as well as ubiquitous relatively small-scale ocean eddies which are a fundamental feature of the ocean. Ocean eddies are not explicitly modelled in most global atmosphere-ocean climate models running today simply because we are awaiting computers powerful enough to include the eddies. Increased computer power also allows us perform a larger number of forecasts at a given resolution and this helps to better quantify the range of possible futures. The Bureau will soon be acquiring a new supercomputer through a partnership with CSIRO and we have already begun to plan ways in which we can take advantage of this to improve the forecast and research tools we use.

Models similar to POAMA though typically lower in resolution are also used to better understand the reasons why climate varies. The models can be run for many years – centuries in fact – and this can provide an extremely useful

tool for understanding the nature of our complex climate system and the variability it exhibits. This is partly because of the remarkable result that the mathematical, physically based computer models of our climate system *spontaneously* generate mathematical solutions that resemble ENSO together with associated rainfall changes over Australia.

The models can also be used to help determine why our climate varied over the past century. In recent years climate models have been forced with observed changes in greenhouse gases, sulphate aerosols and ozone concentrations together with naturally occurring changes in volcanic activity and solar insolation to estimate the impact that these forcing mechanisms had on our climate. Inclusion of such a large number of forcing terms has only been accomplished recently. The technique looks very promising and will hopefully help to explain the changes we have seen in Australia’s climate over the past century – the warming of our continent, and the recent decline in rainfall over SW WA and parts of SE Australia, for example. This detangling of causes should prove very useful in part because it will shed light on how the changes will evolve in years to come. Future climate change will be the subject of the next talk.

Another exciting advancement made in climate science is our recognition of the importance of the ocean’s thermohaline circulation to the earth’s climate. The thermohaline circulation is a global current system that drives the exchange of vast amounts of water, heat and salt between ocean basins. The volume of water involved dwarfs all of the world’s rivers combined. Climate models are improving in their ability to model this complex system. We have come to the realisation over the past decade or so that the thermohaline circulation is not an unchanging steady system of ocean currents. Instead we now believe that it can exhibit pronounced variability on multidecadal timescales. There are hints that this variability may modify southern Australia’s climate on the same time-scale in a partially predictable way - though it is very early days and further research is needed to examine this possibility further.

In summary we have seen that there has been a major advancement in our ability to understand, model and predict variability in the earth’s climate due to both natural and human-induced

causes. The advancement will continue into the coming decade. We know for example that increased computer power will enable greater resolution in our ocean models and this will help improve simulations.

Given the scale of the task, the level of international cooperation required and the extent to which mathematics, science and technology developed over centuries has been utilized, our ability to monitor, model and predict the earth's climate probably ranks amongst the major human achievements.

3. Limits to our ability to predict

While there has been impressive advancement there are a number of fundamental constraints on our ability to predict future climate. Chief amongst these is the partially chaotic nature of the climate system itself. Our ability to predict ENSO for example varies from time to time but it is always limited to some extent. These limits become more severe the further into the future we look. Furthermore Australia's climate is only

partially driven by ENSO. While it is partially driven by sea-surface temperature changes elsewhere, an even larger fraction is driven by essentially unpredictable, internally generated variability in the atmosphere. So the rainfall R at a future time (say next season) is given by

$$R=R_1 + R_2,$$

where R_1 is predictable and R_2 is not. R_2 is never zero. In Australia R_1 tends to be greater than zero at various locations at various times of the year. It is for this reason that the seasonal climate outlooks issued by the National Climate Centre each month are framed in terms of probabilities. No amount of advancement in climate science or observing systems is expected to overcome this fundamental limitation though we have probably not yet milked the climate system for all the predictability it possesses.

Communication issues relating to the dissemination and use of probabilistic information would seem to be unavoidable both now and into the foreseeable future.