Climate Change Impacts on Ecology and the Environment

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1 Aims and Scope

The purpose of the proposed workshop is to engage climate change researchers in the scientific enterprise of developing novel methods for addressing these problems. It is envisioned that the proposed workshop would build upon collaborative initiatives already conceived through the environmetrics collaborative research group. Gaps in methodological developments will be identified, for example, methods for isolating the species and ecosystems most vulnerable to climate change. In addition, some techniques discussed will cross several of the themes, for example, detection of changes when observations are available at several spatial and temporal scales. This workshop will also play the important role of providing opportunity for discussion of timelines and progress toward the goals identified in the collaborative research group application on "Georisk and climate change" by these organizers and will provide a forum for interim reporting on research objectives of that collaborative research group. It is envisaged that this workshop will bring together researcher in diverse scientific fields. It will also have a strong focus on student participation, bringing together students working in this area in a unique networking opportunity including both environmental and statistical sciences.

2 Presentation Highlights

Presentations covered most of the planned topics by a mix of subject area researchers and statistical scientists. Speakers included both junior and senior investigators. Discussions were lively as the records of the three roundtable discussion sessions, included below demonstrate. These records present a number of important current issues, challenges and research directions. Their depth derives in part from of the wide range of expertise of the meeting's participants.

Francis Zwiers, Director of the Climate Research Division, Environment Canada and co-winner of the Nobel Prize as a member of the IPCC panel, led things off. He gave a very informed, clear introduction to climate modeling. His presentation prepared the participants for a novel feature of the meeting on its second day when Myles Allen gave an interactive tutorial via Internet link from the UK. This worked extremely well, something that bodes well for the future when the organizers of this meeting plan to establish multi - centre graduate programs based at least partly on multi - centre simulcasts of lectures to be given at one centre and transmitted to the others.

Quite a number of talks focussed the climate models that have become so central to establishing a foundation for analyzing scenarios of climate change. Speakers explored the problems of differential scaling of measurement and models, of downscaling and of quantifying the uncertainty in the outputs of ensembles of such models. How are appropriate and meaningful measures of their spread to be computed?

Speakers from the UK imparted an international flavour to the meeting. They gave an overview of problems associated with monitoring climate to detect change on the one hand, and detecting impacts of change on the other.

Some of the presentations covered theory, others applications achieved through collaborative research. This gave the meeting variety and provided a profitable exchange of ideas between ”producers” and ”consumers” of statistical methods.

One planned topic not adequately covered was agroclimate risk management. Although that topic was linked into the Environmetrics CRG, it was to have been funded by the NICDS rather than PIMS. Although two papers were given on this topic, research was retarded due to a long delay in the start-up of funding, a result of NICDS's lengthy and time - consuming renewal application process.

The facilities provided by BIRS are generally excellent and they contributed much to the success of the meeting.

3 Best Practices approaches for characterizing, communicating, and incorporating scientific uncertainty in decision - making

Chair and Recorder: Jim Zidek

Peter Guttorp introduced the topic of the discussion paper, noting that he is organizing a future meeting on the topic of this session. Furthermore he noted that the US Climate Change Science Program is drafting a number of synthesis documents, each subject to public review and amendment on the basis of input received. Statisticians have been involved in writing the report but most of the authors are decision analysts. Tilmann Gneiting then introduced the report by going through a summary of its sections and highlighting selected issues found in them. Discussion followed on the following main themes:

1. Characterizing uncertainty
2. Defining probability, chance and likelihood
3. Combining expert opinion
4. The role of uncertainty in decision - making
5. Communicating uncertainty

Theme 1. Characterizing uncertainty

Surprises
The minimax approach in decision analysis captures the natural behavior of humans faced with the prospect of deeper uncertainty.

Communicating uncertainty
How you express uncertainty depends on the purpose and with whom you are communicating. For example, standard error has long been used as a measure of uncertainty about parameter estimates. Odds seem a basic language of uncertainty.

IPCC report
IPCC has done a good job and has been overly open and honest - opposite of exaggerated. Two ways of describing uncertainty - one calibrated by chance, the other based on likelihood. Chance, likelihood are however undefined.

Expert opinion
Some evidence shows uncertainty to be highly under-estimated, based on range of expert opinion.

Ensemble uncertainties
We need to revisit ensembles and start our assessment ”from the ground up” in order to

understand and characterize these uncertainties. In particular, we need to characterize the intrinsic uncertainty of the model components. However sensitivity analysis has a key role to play; model outputs may not be sensitive to the way uncertainties of some of those components are characterized. At the same time interactions may mean that sensitivity to one component may well depend on the level of another. From some perspectives these issues hardly matter - the issues of major concern will not be much affected by how uncertainty of these ensembles is expressed. Yet from others it does. After all plans are now being made about how to manage change and uncertainty would play into those plans such as adopting more efficient light bulbs or building sea walls.

In any case, as Myles Allen noted, much more planning needs to go into the design of ensembles instead of simply relying on the ones that come to hand, in order to address these issues. Myles Allen's grey error bands are not the same as confidence bands. For one thing, the builders of these models try to bring their models into line with those already available, making them "dependent" if regarded as outcomes of an experiment - the result: unduly narrow uncertainty bands.

Major research problem: Find valid ways of characterizing the uncertainty of ensembles.

Assessment of climate model uncertainty
Regional instead of global climate models may be useful in assessing uncertainties if they can be extrapolated to adjoining regions for comparisons of results.

Theme 2. Defining probability, chance and likelihood

Popular misconceptions
The general population does not understand probability let alone second order probability (probability expressing uncertainty about probability). Moreover when confronted by a variety of scenarios or possibilities as in climate projections, they will be perceived as equally likely.

Second order probabilities
Although second order probabilities are probabilities on uncertain probabilities, the result is quite complicated. However, there may well be a "philosophical" if not technical reason for preserving the distinction. However, communicating probability could then include the challenge of explaining the difference between first and second order probabilities.

Keeping a unified front
We do not all agree about how probability should be defined. However, advantages, including political advantages, will accrue from presenting a unified face in communicating uncertainty via probability, since credibility will be lost if we do not. In fact from a cynical point of view, such divisions will be seized on by nay - sayers and politicians with an agenda.

Chance
Its hard to know what true meaning to attach to ”chance” in the context of climate, owing to such thing as the complexity of the analysis, models, and the numerous types of uncertainties that obtain.

Expectation instead of probability?
Whittle bases his book on the notion of ”expectation” rather than ”probability”, pointing to the importance of the form in which we communicate random outcomes. For example, ”expected amount of precipitation” might be more informative than the ”probability of precipitation”, the latter giving the sort of information the public might better use. [At the same time probability is an expectation (of a 0 - 1 variable).] In his tutorial, Myles Allen distinguished between ”expected” vs ”average” weather. The loaded dice seems an excellent metaphor and could well be used to communicate this idea. For climate, it’s the expected degree of change that matters.

Behavioural definition
Probability has a behavioural interpretation. Yet generally people overestimate small probabilities. Moreover, assessments can be irrational as when, following Sep 11 people stopped flying to a steadily declining degree as time wore on.

Relative frequency definition
”One life - one replication” means the relative frequency definition of probability is challenging. But repeatedly running probabilistic simulation models could provide relative frequency estimates in some situations even in ”one - off” events like climate change. The value of such estimates will depend on the credibility accorded to the science built into the model.

Theme 3. Combining expert opinion

Although the report generally gives a ”academic” survey of relevant work, its coverage is weak on work and issues on combining expert opinion, in spite the great importance these days of multi -agent decision theory. In particular, scientific panels are becoming increasingly important, the IPCC being a particularly noteworthy example. The Delphi method is mentioned but more on its practical implementation in group decision-making needs emphasis. When that process does lead to multi- agent convergence to convergence, the result can be more a product of ”group think” rather than the exchanging of information. When that convergence does not take place beliefs will need to be combined (normative methods have been published for doing this) or a joint decision made (theories for doing this also exist).

A particular problem arises from the deliberately mixed disciplines of panel members. That can mean that components of a big decision problem are being assessed by individuals with varying levels of expertise leading to the need to weight their views according (and this can be done by the methods alluded to above). In general, the multi - agent problem has three levels. In the first, the group attempts to reach a consensus. If not controlled, as it is in the Delphi method, such things as group - think and psycho - dynamics can denigrate the contribution of individual experts and bias the outcome in favor of the dominant experts. At the next level in the so-called ”team approach”, the group is assumed to have a common objective (utility function), as in the case of a jury in Savage’s classic on the foundations of decision analysis. Then the goal becomes that of combining the beliefs of the agents into a single prior distribution. [See Genest, C. and Zidek, J.V. (1986). ”Combining probability distributions: a critique and an annotated bibliography.” Statistical Sciences, 1:114-148 for possible solutions.] More generally, the multi - agent problem becomes a group decision problem where the group must come to a joint decision, for example, an agreed upon standard. [See Weerahandi, S. and Zidek, J.V. ”Elements of multi-Bayesian decision theory.” Ann. Statist., 11:1032-1046, (1983).] Numerous papers have been written on this problem in the contexts of computer science.

Theme 4. The role of uncertainty in decision - making

Uncertainty plays a variety roles in decision - making. In particular, in an adversarial context, it can be exploited to argue in favor of maintaining the status quo. The report should therefore include advice on how the process of decision - making should be structured, especially when the level of uncertainty is high, to help insure a sensible outcome. In particular, in a multi - agent situation, emphasis should be placed on an ”estimation approach” rather than a ”hypothesis testing approach”; the latter will likely lead to non - rejection of the hypothesis.

Theme 5: Communication of uncertainty

Experts on communicating uncertainty need to be educated. That leads to the need for programs that do just that for such people as journalists, stakeholders, scientists and the general public. Australia has started a new project to educate politicians and journalists with scientists going out in teams to do that. The report under discussion tends to focus on analysis rather than communication. What is needed to ensure an honest expression of uncertainty? How can one compensate for the tendency nowadays for people to discount reported uncertainty on the cynical assumption that it has been inflated by hyperbole in the first place?

Important need: The education of both communicators of uncertainty and their audiences.

4 Climate Change and Impacts on Forest Disturbances

Chair: Dave Martell; Recorder: Douglas Woolford

The majority of the discussion can be grouped into the following main themes:

1. Dynamical systems models
2. Statistical/Quantitative methods for comparing maps
3. Simulation models and scaling issues
4. State space modelling and ecosystem modelling

Theme 1. Dynamical systems models

A different approach to the statistical models proposed in the workshop would to use dynamical systems models. However, these are currently fit using expert opinion/judgement and there appears to be a lack of statistical methodology for fitting in such models. As a result of this discussion, John Braun volunteered to give a brief presentation on related work where he has been fitting a dynamical systems process to fire data using results from experimental lab fires to fit parameters to the Prometheus fire growth model. In addition, he has been incorporating randomness into this model via smoothing/sampling of residuals.

Ron Smith has also done some work on model fitting related to fire data, indicating that there are several methods available that depend on the complexity of the model in question. The reference is ”Managing Uncertainty in Complex Models” (MUCM) out of the UK.

A hot area is using the Kalman filter to change a complex deterministic model into another type of model. This allows one to bring in statistics to improve upon the current model. Other related work is the convergence of the Kalman filter and convergence of dynamical systems with random perturbations, noting that these two topics can be united. In general this is ”easy” when the model is relatively simple (i.e., consists of a few differential equations), but becomes more difficult as the model complexity increases. Regardless as to whether or not a model can be fit, there are still questions of identifiability and goodness of fit testing. There also does not appear to be a robust method for sensitivity analysis for dynamical models.

Theme 2. Statistical/Quantitative methods for comparing maps

A common issue in forestry is the comparison of maps. For example, foresters may develop burn probability maps (i.e., a colour-coded, pixel-based map or the probability that a pixel will burn) under various scenarios/models. Foresters are looking for proper statistical methods for comparing maps. It was noted that this is a very active field of research in meteorology called ”object-based verification”. A possible reference is a special issue on forecast verification in Meteorological Applications that appeared sometime around early

2007.

Theme 3. Simulation models and scaling issues

Although there appears to be a push to build big simulation models, significant issue remain. In particular, scaling problems and compensating errors remain common. Furthermore, there have been instances where, upon further statistical analysis, large simulation models have been reduced to significantly simpler simulation models. However, simulation models, regardless of model complexity, are attractive to policy builders, since they perceive them as being easier to understand than a statistical model. A well-written critique comparing a simulation model to a related statistical model might be useful.

There are other issues with simulation models. A key issue is extrapolation, since, in many cases a simulation / dynamical-systems model can be somewhat useless when one hopes to extrapolate. The underlying hope is that if a physical model fits past data correctly, then it might produce a reasonable forecast in the future.

Theme 4. Incorporating randomness into deterministic models

A topic that was discussed more than once was the idea of incorporating randomness into deterministic models. A method for this was introduced by John Braun during his talk (for more details see Theme 1 above). In general, models for complex simulations likely only provide a limited amount of information, since some data will be masked or unmeasured. A possible solution would be to use models which sample from a set of possible solutions. That is, one can incorporate randomness into a deterministic model by varying the initial conditions. However, in this case a ”uniform” assumption for sampling is probably wrong. Hence, one needs a method for determining if one is sampling from the ensemble of models/conditions correctly. Another method for incorporating randomness would be via conversion of differential equations in a model to stochastic differential equations.

5 Climate Change Impacts in Ecology: Science and Government Policy

Chair: Rick Routledge; Recorder: Sylvia Esterby

The chair provided a list of issues that have emerged repeatedly (provided below) and opened the session with the suggested focus for the discussion: identifying high-priority statistical, scientific, and policy issues requiring further research. Most of the discussion was concerned with informing policy, drawing on experience in the UK, the United States and Canada.

An example: species at risk
Science question: Probability of extinction for a species at risk
Policy limitation: difficulty of getting a species on the endangered list

Policy making process
US example, Ozone Panel (Clean Air Act)

- Panel made up of external scientists
- Panel and EPA staff have clear roles and do not interact
- Open public consultation, largely interest groups
- Means of contributing is well-defined, with clear limitations
- Administrator makes final ruling

It was noted that this is the process for a panel operating under an Act. A different process applies if a panel addresses an issue not under an Act, and an example of an ecological panel operating very differently was mentioned.

UK process

- Peer review of government commissioned work
- Public participation through interest groups, with limits
- EU standards apply and must be approved across member countries
- UK example of air pollution standards - work to bring EU protocol in line with UK's previously developed protocols

In Canada the process seems less clearly defined. More is done internally by departmental scientists.

Other observations related to taking uncertainty into account in policy making:

- Policy makers find the less definitive approach of statistics difficult to embrace
- Uncertainty and a statistical approach presents difficulty for policy makers who want clear direction for helping them make decisions
- Precautionary principle allows action to be taken under uncertainty
- Europe is ahead of US and Canada in applying the precautionary principle

Models and communicating uncertainty:
How can we build models that allow for surprises (unanticipated events, future change in physical processes)

- Attempts to put surprise term in Bayesian models have not been successful
- Would mixture models work?
- Appears to be an open question

Maps are often problematic

- Visual nature makes them a powerful tool
- Should have ”error bars” since we know all predictions are uncertain
- Challenge is how to present just the right amount of information. The case of probabilistic forecasting, described earlier in the workshop, provides an example where this question has been carefully considered

Clarity on what different groups understand uncertainty to be is important in all cases.

6 Some Issues that have Emerged Repeatedly

Chair and Recorder: Rick Routledge

1. Quantitative research challenges
    (a) Assessing uncertainty in:
        i. Evidence on emerging trends
        ii. Inference on causal relationships (attribution)
        iii. Forecasts of potential impacts
    (b) Strategies for:
        i. Assessing impacts that may already be underway
        ii. Predicting future impacts
        iii. Combining more precise, extensive, physical data with less accurate, consistent, and rigorous biological data
        iv. Drawing inferences from a combination of (i) deterministic, primarily physical, and often larger-scale models, and (ii) data on biological systems typically operating in a more restricted geographic scale
        v. Dealing with severely skewed distributions
        vi. Handling informal censoring of non-occurrences
        vii. Designing monitoring networks
        viii. Improving the associated statistical analyses (with emphasis on spatio-temporal modeling, nonparametric smoothing, additive modeling, quantile regression, and repeated illustrations of the value of innovative approaches)
        ix. Fostering long-term consistency in labour-intensive monitoring systems
        x. Developing and assessing indices of environmental health
        xi. Designing meaningful and measurable objectives
2. Communication and policy issues
    (a) Creating meaningful summaries for informing public discussion and policy making
    (b) Methods for conveying estimates of uncertainty
    (c) Management strategies under uncertainty
        i. Adaptive management
        ii. Precautionary principle