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Characterising the agro-meteorological implications of climate change scenarios for land management stakeholders

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ABSTRACT: Developing a shared understanding of the specific climate change challenges for a particular sector is a vital precursor to effective, research-based support for adaptation in policy and practice. Without processes for developing such shared understandings, serious comprehension gaps between research, policy and practice communities can arise. A social-learning approach to reducing this comprehension gap is presented, undertaking a cooperative assessment with land management stakeholders of preferences for agro-meteorological metrics and co-developing a framework of climate change indicators. The assessment process deliberated on prospective agro-meteorological metrics for case-study locations in Scotland. The preferences and parameterisation for indicators and their presentation were elicited in group interviews and focus groups. A coherent set of indicators was identified to serve as a framework to support awareness-raising activities and stimulate debate on possible adaptation strategies. While the meteorological summaries were effective in highlighting the nature of the change, the agro-meteorological metrics were more effective in encouraging stakeholders to consider possible impacts on their land-use systems and how they might adapt. The credibility of the indicators and the case study data were enhanced through debate and customisation. The authors recommend including a strong social-learning-based component within any climate change research communication strategy. Communicating the outcomes of research in a credible and relevant way increases the likelihood of stimulating positive adaptive change.

KEY WORDS: Climate change · Agriculture · Metrics · Indicators · Stakeholders

1. INTRODUCTION

1.1. Background

The interactions between climate change and land use are increasingly seen as a key issue for policy makers across the EU, within individual member states and for regional governments, each recognising 3 interlinked aspects: mitigation (reducing the net release of green house gasses), impacts and adaptation (HM Government 2006). While mitigation is the most immediately pressing issue, there is political recognition that the form and magnitude of likely impacts needs to be anticipated and support provided for land managers and others to adapt (Scottish Executive 2006).

The outcomes of climate change research are strongly contested, both in the definitions of future emissions scenarios and the forecasting of their consequences by global and regional climate models (GCMs and RCMs). While there are significant ongoing advances in quantifying and communicating the uncertainties inherent in all forecasts (Rivington et al. 2008b), this alone does not guarantee effective processes of adaptation. The authors argue that there is a serious (and increasing) gap between researchers and stakeholders (those with direct or indirect interests in an outcome), hampering the use of research-derived knowledge within practice and policy. This is doubly dangerous. First, if decisions are not circumscribed by information, then it is difficult to challenge powerful vested interests and ensure that re-

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sponses to climate change are timely and proportionate with equity of opportunity and burden sharing. Secondly, if public-good research is seen as irrelevant, then it will cease to be funded, making society as whole more vulnerable to unforeseen hazards. In closing this gap there is the need to step back from research that tries, within self-referential frameworks designed by scientists, to specify answers. Such a linear model of 'knowledge generation' followed by 'knowledge dissemination' has demonstrably and consistently failed in a wide range of circumstances (Solesbury 2001). A science-stakeholder 'knowledge co-construction and sharing' model, however, recognises the richness of experiential knowledge found in stakeholder communities and their ability to evaluate and positively influence both the research questions being asked and research outputs.

Developing a shared understanding of an issue is repeatedly identified as a vital precursor to research-based support for adaptation of policy and practice (Kolkman & van der Veen 2006). Processes for developing such shared understandings in conventional disciplinary research are, however, infrequent or tokenistic. The emerging trans-disciplinary research paradigm seeks to reconcile the rigour required of academic research with reducing the comprehension gap by using social learning methods (Tait et al. 1999). These methods recognise that change in behaviour depends on changes in actors' values, which, in turn, depends on genuinely inclusive deliberation to make sense of available evidence.

1.2. Research objectives

While the issues and the implications identified above are not new, there are few peer-reviewed reports in which transdisciplinary climate change research combining computer-based modelling and social learning has been undertaken rather than recommended (see the review by Marjolein & Rijkens-Klomp 2002, and examples from Tompkins & Adger 2004). The authors undertook a cooperative assessment of stakeholder preferences for agro-meteorological metrics and developed a framework of climate change indicators[1] intended to support awareness-raising activities and deliberation on possible adaptation strategies. A coherent indicator framework is potentially valuable since ad hoc collections of arbitrarily chosen metrics reduce the likelihood that stakeholders will understand and use the research-derived information (Gahin et al. 2003).

Using climate change as an example of a complex, contested issue with significant and irreducible uncertainty, the research was conducted firstly to critically assess the benefits and limitations of using a social learning approach and to try to draw wider conclusions for researcher–stakeholder communications. The secondary objective was to compare the effectiveness of agro-meteorological metrics with meteorological summaries as a basis for communicating the climate change pressures likely to be faced by land management stakeholders. The paper presents the insights gained from developing the indicator framework with key stakeholders and initial conclusions on the use of the framework with a wider audience.

2. RELATED RESEARCH

This section sets out the previous research findings that have motivated the authors and shaped the approaches and methods adopted. It brings together materials from a range of disciplines for which there is extensive experience in using research outputs to enable policy and practical outcomes. The synthesis of this related research also shapes the interpretations of the research outputs. The section also provides a brief summary of previous research findings by the authors that while published elsewhere are particularly relevant to this paper.

2.1. Challenges for researchers seeking to influence policy or practice

For complex societal problems, the issue of using the outcomes of research in a way that influences the actions of a range of stakeholders is one that continues to tax both research and policy maker communities (Scottish Executive 2005, McNie 2007). Marginalisation of researchers in important debates can leave the way open for politically powerful vested interests to dominate decision making to the detriment of wider society. The influence of research, however, depends on 3 closely related factors salience, legitimacy and credibility (Cash & Buizer 2005).

Salience means that research outputs must be seen by stakeholders as relevant to their decision making process. Salience can be seriously compromised when research outputs refer to geographic, temporal, or organisational scales that do not match those of decision making. The localisation of research outcomes through the use of appropriately scaled case studies has been shown to be a key factor in increasing the

[1]Metric in this paper refers to any measurement or estimation of a system property. Indicator is used more narrowly to refer to metrics accepted to have a role in decision making, often with a standard or norm against which the value of an indicator is compared

apparent salience of research outcomes (Carberry et al. 2002). Research outputs thus have to be couched in units that make sense to stakeholders' management practices. Other limits on the salience of research may, however, be more fundamental. French & Geldermann (2005) identify 4 issue types, known, knowable, complex and chaotic. For the latter 2 types, all that the outputs of research may be able to deliver is a range of options or a framing of the issues rather than a single definitive solution.

Yet, even for knowable problems, researchers have questioned whether more or better quality information inevitably results in better decisions or altered behaviours[2] (McCown 2002b, McCown et al. 2005). McCown's comparison of 2 mature research fields, industrial and agricultural decision support, concluded that the outcomes of research on complex issues need to be tailored to fit within the social processes of decision making, taking a role that does not detract from the agency of the decision maker. That is, for research to be influential, it must be seen by stakeholders as legitimate, supporting or empowering decision making processes rather than dictating outcomes. Legitimacy is further complicated when issues involve multiple stakeholders, each with direct or indirect interests and influence. For such cases, subjective decisions on the selection and assessment of evidence may be as important as the accuracy of the measurement or forecasting of particular phenomenon. In a milieu with conflicting interests, researchers cannot simply deliver discrete packages of evidence, but need to provide support for inclusive processes that support deliberation (reason-based debate) on particular issues (Dryzek 2000). The role for research is in making explicit the trade-offs either between outcomes, or between stakeholders (Matthews et al. 2006). Failure to include stakeholder views by adopting technocratic processes of decision making simply means that both the legitimacy of the process and any decisions are simply challenged through other channels such as the courts or in the media (Stilgoe et al. 2006).

However, the interactions between researcher, stakeholder and decision maker are organised, a key factor in the research being influential is credibility (McCown 2002a). While the credibility of research-based forecasts may partially be met by formal processes of validation and peer review, there is also the need for outcomes not to contradict existing stakeholder knowledge of systems gained through experiential learning (Carberry et al. 2002). Credibility has also been seen to depend on the transparency of the methods used and on adequate auditing and quality assurance of models and data (Scholten & Kassahun 2006, Hutchins et al. 2008). While transparency is often used to imply simplicity, this would be to misunderstand what is desired by stakeholders. It is the openness of assumptions (what was excluded as well as what was included) that may be the key to transparency and thus credibility. Two credibility challenges are apparent. The first is overcoming the idea that all uncertainty is the result of errors or mistakes within research processes rather than an inevitable outcome of bounded knowledge, scenarios chosen, model parameterisation, model structure, how the system is represented and practical limits on the availability of data (Rauschmeyer & Wittmer 2006). The second is that, however good the research is, it is still only the currently best available answer, and may be a partial answer where systems are complex. Together these challenges mean researchers need to be careful in managing stakeholders' expectations. This is particularly problematic when vested interests can exploit uncertainty to sensationalise an issue or to preserve the status quo.

Where researchers are seeking to influence or even inform communities of practice and policy, the issues of salience, legitimacy and credibility pose challenges for both content and design of processes. When both researcher and stakeholder knowledge is partial, there are opportunities for cooperation and knowledge sharing. In these processes the role of research-based information is not as an outcome to be communicated, but as a boundary object (Jakku & Thorburn 2004) through which information can be exchanged. Researchers can have a key role facilitating such interactions, but need to recognise that the role(s), institutions and epistemologies of an experimentalist, hypothetico-deductive paradigm are much less useful in participatory, action and transdisciplinary research, and that alternative ways of conducting research are more appropriate (Kay et al. 1999, Gunderson & Holling 2002, Walker & Salt 2006). Against this background, the intention of this research was to initiate and, through a series of iterations, demonstrate a credible process of climate change knowledge sharing with stakeholders in the land-use and management domain.

2.2. Previous climate change assessments and downscaling of climate change data

To increase the salience and credibility of climate and climate change (CC) assessments used with stakeholders, the authors have preferred localised case studies (Rivington et al. 2007). The use of localised case studies, however, raised questions of how well raw RCM data represent particular local conditions.

[2]An information deficit model of science–stakeholder interactions

The authors tested the fit of hindcast HadRM3 RCM data against observed station data for daily maximum and minimum temperatures (T_{max} and T_{min}), solar radiation (S_o) and precipitation (P), for 15 sites across the UK (Rivington et al. 2008b). While some of the differences between the HadRM3 RCM and observed station data were simply due to representation (HadRM3 data is for 50 × 50 km grid, while the observed data were for metrological stations), there remained systematic differences that pointed to limitations in the RCM's ability to represent particular localised climatic regimes (particularly coastal areas and mountains) and phenomena[3]. Clearly the intention of the HadRM3 RCM is not to provide such localised estimates, and it has been parameterised to give the best fit over a wide geographic area (the whole of Europe) so it is not the authors intention to criticise the model. It was, however, concluded that the use of raw RCM cell data could lead to erroneous conclusions about the agro-meteorological impacts of the CC scenarios, and the poor fit of some hindcast data with the reality of experienced phenomena at particular sites could reduce the credibility of all analyses with stakeholders.

To support the site-specific comparisons of current and change scenarios, the HadRM3-A2c scenario data were downscaled using empirically derived downscaling factors (DF) for each month and per variable (Rivington et al. 2008a)[4]. These DFs apply simple linear shifts to T_{max}, T_{min} and S_o values such that the long-term monthly mean values for the HadRM3-A2c hindcast data better match those of the observed data. For P the HadRM3 is corrected for a consistent underestimation of the number of dry days (too many small rainfall events) and subsequent correction for differences in long-term monthly means. For a broader consideration of downscaling issues see Fowler et al. (2005), Haylock et al. (2006) and Christensen et al. (2007).

3. MATERIALS AND METHODS

3.1. Climate data

The range of possible agro-meteorological metrics was constrained by restricting the analysis either to RCM variables identified as most reliable (Hulme et al. 2002), such as temperature and rainfall, or those identified by the authors as key drivers of agricultural processes, such as S_o (Rivington et al. 2006). The data used in the implementation of, and consultation on, the framework of CC indicators were provided by the British Atmospheric Data Centre[5] (BADC). The observed variables were P (mm), T_{max} and T_{min} air temperature (°C) and total downward surface shortwave flux, S_o (direct and diffuse MJ m^2 d^{-1}). The data are for the period from 1960 to 1990 for 5 meteorological stations in Scotland (Fig. 1). Sites for the observed data were chosen where there were long-term (n > 20 yr) consecutive runs of data for all 4 variables. Where otherwise complete records had small numbers of missing records (n < 33 consecutively and/or n < 50 in total within the growing season), the gaps were filled using simulated data[6] and also flagged as such. The observed records were also checked for errors, duplicates and other anomalies in the original data, and these were also corrected during the gap-filling process. The total number of sites available is limited by the availability of S_o data. As the HadRM3 model treats a year as having 360 d (i.e. 12 mo of 30 d), the last 5 d of the observed data were omitted from the analyses[7].

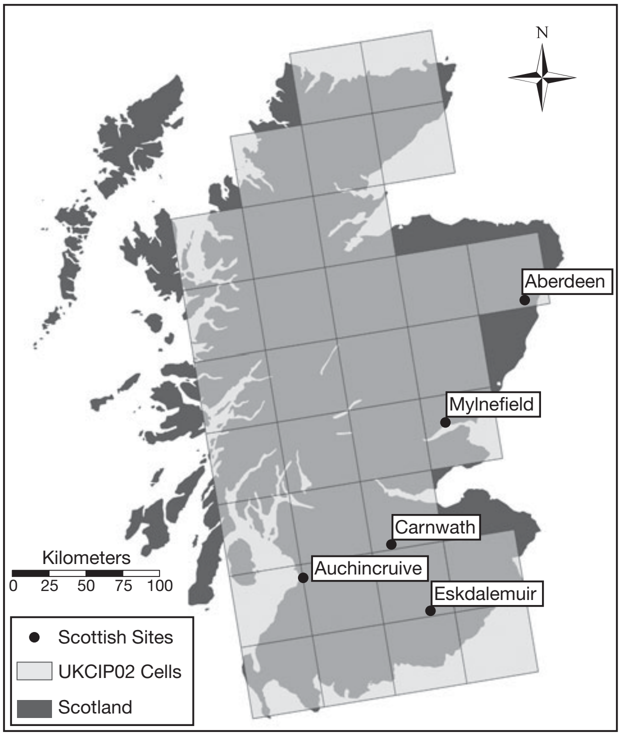

Fig. 1. Case study sites used for the development and testing of the framework in Scotland

[3]Available at www.macaulay.ac.uk/LADSS/climate_change/testing (supporting materials from Rivington et al. 2008b)
[4]See also http://www/macaulay.ac.uk/LADSS/climate_change/downscaling

[5]Available at http://badc.nerc.ac.uk/home/index.html
[6]The procedures use a simple pattern-matching approach and are available at www.macaulay.ac.uk/LADSS/reference.html
[7]This approach has the consequence of introducing a small but increasing warm bias to later monthly averages. This was accepted to preserve the continuity of daily data on which some of the metrics depend

The BADC also provided hindcast data for 1961 to 1990 from the HadRM3 RCM configured for the Special Report on Emissions Scenarios (SRES) A2c (medium to high, Run c) for the period from 2070 to 2100 (UKCIP02 2002). DFs for the RCM data were derived as outlined in Section 2.2. These DFs were then applied to the future data. The need for and effect of downscaling the RCM data is illustrated with examples in Fig. 2. Notice in particular the removal of systematic bias in the S_o data (Fig. 2d), the reduction in seasonal bias in the T_{min} and T_{max} data (Fig. 2c) and the changes to the size distribution of rainfall events (Fig. 2a,b). (Further examples of the use of the DFs are available from the author's website.[8])

The research reported here anticipates the release of the UKCIP08 data that will present CC scenarios in probabilistic terms based on ensembles of GCM/RCM runs thus making the uncertainty in prediction explicit. While such data will undoubtedly be significantly superior to the UKCIP02 data used here (a single emissions scenario, from a single RCM–GCM combination), it is important to recognise that researchers will still face the same questions of which variables, combinations and derived data products are relevant and how to present them optimally for land-use stakeholders. The limitations of the CC data used were made explicit to the stakeholders and extensively debated during interactions with stakeholders. The probabilistic UKCIP08 data, once released in October 2008, will form the basis of further research with land management stakeholders.

3.2. Metrics

The statistical summaries of the meteorological data implemented are median, minimum, maximum, range, inter-quartile range and, where meaningful, standard deviation. The metrics were calculated for the 30 yr climate normal period from 1961 to 1990 for both observed and RCM data, with yearly, monthly and daily temporal resolution. For each variable, in addition to monthly summaries, a time series was presented, since this was consistent with other recent presentations of meteorological data in the public domain (Barnett et al. 2006). The time-series graphs were intended to illustrate any trends and the variability about mean conditions (which had been voiced as a concern for practitioners in piloting the research). For the temperature (T) variables, the mean, maximum, minimum and range were plotted. For P, the yearly total and largest single daily event were used. The 2 time periods were plotted on the same graph to allow for comparison, with the category labels (dates) for the future datasets added to the top of the graphs. Other presentations of the data were also tested, for example ordering the time-series data by magnitude and attaching date labels to the points. This, in theory, allowed a direct comparison of the distribution of a metrics value, specifically between low, average and high values. Other summary plots prepared were inter-quartile ranges and statistical measures distribution and probability of exceedence graphs.

Since the intention was not to test innovative metrics, candidates were drawn from both older agro-climatic sources (Francis 1981) and more recent sources with a CC focus (Barnett et al. 2006). In addition there are metrics derived from research sources, such as the CropSyst multi-crop simulation model (Stockle & Donatelli 2003) and the P seasonality and heterogeneity indicators from the IRENE model testing suite (Bellocchi et al. 2002).The agro-meteorological indicators and associated metrics implemented are grouped by type and set out in Table 1. The 4 metric types are date, where the first or last incidence of a phenomenon is calculated; count, which records the number of days on which a criterion is met; the accumulation of a variable above or below a threshold value; and, finally, indices, where an index value is calculated and compared against a standard. The table also notes if the metric is derived from one or more variables (the S/M column).

Within each of the metric types in Table 1, most relate to a single variable. To illustrate where the interactions between variables are important to land use, metrics for the soil water balance were implemented. This allowed the authors to assess the utility of metrics, which, while more complex to derive, are perhaps closer to those used by land management stakeholders. The soil moisture metrics are derived using a simple soil moisture balance model illustrated in Fig. 3. This model is based conceptually on that used to derive the agro-meteorological statistics by Francis (1981), which, in turn, is based on early models by Smith (Ministry of Agriculture, Fisheries and Food 1967, 1971). While these simple models have been superseded by models with more sophisticated representations of soils[9], e.g. NIRAMS (nitrogen risk assessment model for Scotland) (Dunn et al. 2004), or the interaction of climate and soils, e.g. MOSES (Met office surface exchange scheme) (Cox et al. 1999), they have the advantage of having relatively modest data requirements that may be met from data easily available either via the BACD archives supplemented by regional (Wosten et al. 1999) or stakeholder provided

[8]Available at www.macaulay.ac.uk/LADSS/climate_change/downscaling

[9]In particular the handling of lateral flows and groundwater

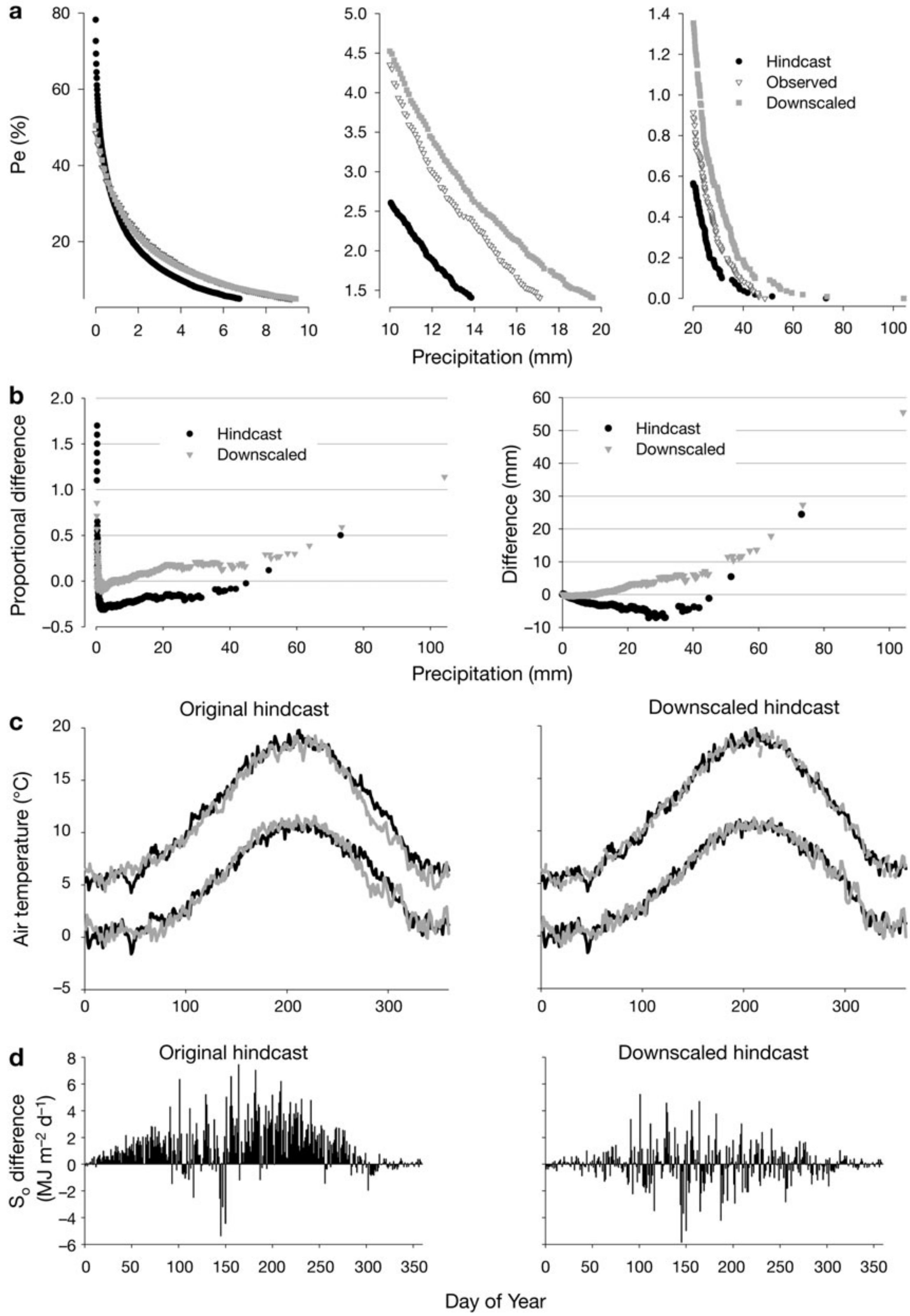

Fig. 2. Effects of using downscaling with HadRM3 data. (a) Precipitation probability of exceedence, Pe (%) for Mylnefield. Note differing Pe scales. (b) Precipitation differences (observed–modelled) as a proportion and absolute value (mm). (c) Observed (black) and modelled (grey) maximum and minimum air temperature (°C) before and after downscaling. (d) difference in mean daily solar radiation, S_o (modelled – observed)

Table 1. Candidate metrics for the climate change communication framework. *Italics*: metrics that can be customised for particular circumstances or activities. S: based on single climate variable; M: multi-variable; SMD: soil moisture deficit; FC: field capacity; *P*: precipitation

Type	Indicator	Metric	S/M	Units
Date	*Start of growing season*	Day when 5 consecutive days T_{avg} > 5.6°C (from 1 Jan)	S	Day of year
	Start of field operations	Day when T_{avg} from 1 Jan > 200°C (T_{sum}200)		
	End of field capacity	Day when soil moisture deficit (SMD) > 5 mm (from 1 Jan)	M	
	Last air frost (spring)	Day when T_{min} < 0.0°C (from 1 Jan)	S	
	Last grass frost (spring)	Day when T_{min} < 5.0°C (from 1 Jan)		
	Date of maximum SMD	Day when SMD at maximum	M	
	Wettest week	Mid-week date when maximum 7 d value of *P* occurs	S	
	First grass frost	Day when T_{min} < 5.0°C (from 1 Jul)	S	
	First air frost	Day when T_{min} < 0.0°C (from 1 Jul)		
	Return to field capacity	Day when SMD < 5 mm (after date of max. SMD)	M	
	End of growing season	Day when 5 consecutive days T_{avg} < 5.6°C (from 1 Jul)	S	
Count	Air frost	Days when T_{min} < 0.0°C	S	days
	Grass frost	Days when T_{min} < 5.0°C		
	Growing season range	Days between start and end of growing season		
	Growing season length	Days when T_{avg} > 5.6°C between start and end of growing season		
	Access period range	Return to FC–end of FC	M	
	Access period length	Days when soil moisture < field capacity		
	Dry	Days when *P* < 0.2 mm	S	
	Wet	Days when *P* > 0.2 mm		
	Plant heat stress	Days when T_{max} > 25.0°C		
	Dry soil days	Days when soil moisture < permanent wilting point	M	
	Very dry soil	Days when soil moisture < air-dried soil		
Degree days	Accumulated frost	Sum of degree days where T_{min}< 0.0°C	S	deg day
	Growing degree days	$\sum T_{avg}$ > 5.6°C		
	Heating degree Days	Sum of 15.5°C – T_{avg} where T_{avg} < 15.5°C		
Water	*Excess winter rainfall*	Sum of *P* > soil saturated capacity (runoff and drainage)	S	mm
	Wettest week—amount	Maximum amount of *P* (7 consecutive days)		
	Minimum soil water	Maximum SMD	M	
Waves	*Heat wave*	Maximum count of consecutive days when T_{max} > Avg T_{max} (baseline year) + 3.0°C (minimum 6 d)	S	n
	Cold spell	Maximum count of consecutive days when T_{min} < Avg T_{min} (baseline year) – 3.0°C (minimum 6 d)		
	Dry spell	Maximum consecutive count *P* < 0.2 mm		
	Wet spell	Maximum consecutive count *P* > 0.2 mm		
Indices	*P* intensity	$\sum P$ > 0.2 mm / count days *P* > 0.2 mm		index
	P seasonality	*S* = winter *P* – summer *P* / total *P*[a]		
	P heterogeneity	Modified Fournier index		

[a] *S* < –0.13 (wetter winters); –0.13 < *S* < 0.13 (uniform) and *S* > 0.13 (wetter summers)

site-specific soil data. The Smith model has been updated by the authors, particularly in relation to the estimation of soil parameters and the calculation of surface runoff.

Metrics were generated for 5 localised sites that were likely to be of interest to the various focus groups (see Fig. 1) using observed data and downscaled HadRM3-A2c cell data. For the agro-meteorological metrics, 2 forms of tabular summary were tested. In both cases it was the changes from the 1961 to 1990 baseline that were presented rather than the absolute values for the metrics. In the simplest case only the trends were presented (earlier, later, more, less, or no change). A second summary presented the magnitude and direction of change and had the statistical significance values (*t*-test values) as probabilities of no change. By presenting several sites it was intended that the consistency of outcomes between sites could be seen and conclusions drawn that the changes were not an artefact of site choice. In addition to the tabular summaries a series of graphical representations were tested as ways to communicate the metrics. Summary plots for the date and day count metrics were prepared with the intention of providing a means of comparing the range of values for the baseline and future scenarios. Time-series plots of the agro-meteorological metrics were also used in the focus groups. These were intended to communicate both the year-to-year vari-

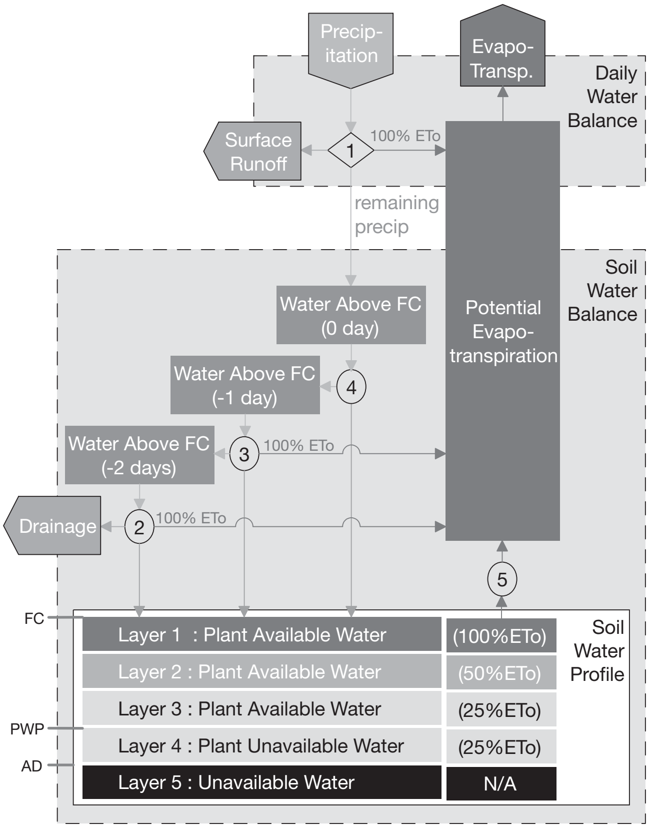

Fig. 3. Schematic for the soil moisture balance model used. FC: field capacity, PWP: permanent wilting point, AD: air dried, ETo: evapotranspiration

ability (which can be substantial for some metrics) and any trends present. Specialised presentations were developed for the soil water balance metrics, with the progressive draw down and recharge shown per day with the plant available and unavailable water identified. The water lost though drainage or runoff and the evapo-transpiration were also visualised as negative values. Wettest, median and driest conditions were shown for observed and future time periods. Other presentations were attempted in piloting the soil moisture metrics, in particular, the use of polar/spider charts, which were useful in showing that return to field capacity could occur into the next calendar year for the future scenarios. Options for using hydrological years (1 October to 30 September) as the basis for presentation are being considered for future workshops.

3.3. Testing the utility of metrics with land management stakeholders

The testing of the metrics with stakeholders was conducted either through group interviews (2 with 3 to 5 participants each) or in focus groups (2 with 12 and 20 participants). The individuals chosen were either existing contacts from research partner organisations with an interest in CC or were recommended as participants by the existing contacts. The research partner organisations involved were National Farmers Union, Scotland (NFUS), Soil Association (SA) and Farming and Wildlife Advisory Group (FWAG). These are membership organisations representing communities of interest — NFUS for small- to medium-sized agricultural businesses, SA for organic farming and FWAG for land managers with a strong interest in wildlife. The stakeholders thus represented a range of perspectives from strongly commercial agribusiness to environmental protection. Individuals attending were either targeted invitees (who were known to be influential within their peer groups) or were self-selecting based on prior publicity from partner organisations. The events were held in 4 locations across the main agricultural regions of Scotland to increase the range of land-use systems being represented. The land management interests present in the research were thus diverse and inclusive without being comprehensive or necessarily representative. There was a bias in favour of individuals with practical land management backgrounds, but there were also smaller numbers of attendees with academic, consulting, or policy backgrounds. There is an inevitable trade-off between the quality of interactions with stakeholders and the number and size of events that can be supported particularly by research teams demonstrating proof of concept[10]. In any case, the power of social learning approaches depends not on the size or how representative the sample is, since the intention is not to generalise to a population, but rather to understand the thinking associated with particular archetypes chosen for their significance as decision makers.

For both group interviews and focus groups, the stakeholders were provided with a briefing containing example outputs and supporting explanatory materials before the meeting. Within the interview or focus group the initial phase was a discussion of the stakeholders' interest in CC. This was followed by either a group interview or a focus group discussion of the utility of metrics and how best to communicate them. Specific issues addressed were the number and form of indicators and preferences for presentation. The metrics usefulness as indicators was assessed, using case-study examples on a simple 4 point scale to allow for some interpretation of degrees of utility. The outcome of the interviews and focus groups was a prioritised list of agro-meteorological indicators (reported in Section 4.3). Assessing of the utility of the metrics served as a means of coming to a definite conclusion from broader deliberation and questioning.

[10]A further series of 4 climate change workshops are planned in remote rural areas in early 2008

4. RESULTS AND DISCUSSION

4.1. Meteorological summaries

Fig. 4 shows an example of the meteorological summaries used in the focus group discussions (with specific groups shown as examples from their region). All the temperature graphs show a consistent upward 'shift' over the year, with a small additional widening between the scenarios in July to October. For S_o, there is only a marginal change, but for P there is distinctive change in the pattern of distribution even though the change in the yearly total amount of P is small (+20 mm). The change in the distribution of P is not consistent between sites, with initial analyses indicating a difference between eastern and western Scotland (compare the P of Aberdeen, Fig. 4e with that of Auchincruive, Fig. 4f). The meteorological summary graphs were useful in starting the process of discussing CC and agriculture, since the graphs were considered easy to comprehend and encouraged participants to ask questions that could only be answered by other datasets or formulations of the meteorological data. There is a need for care, however, when designing the

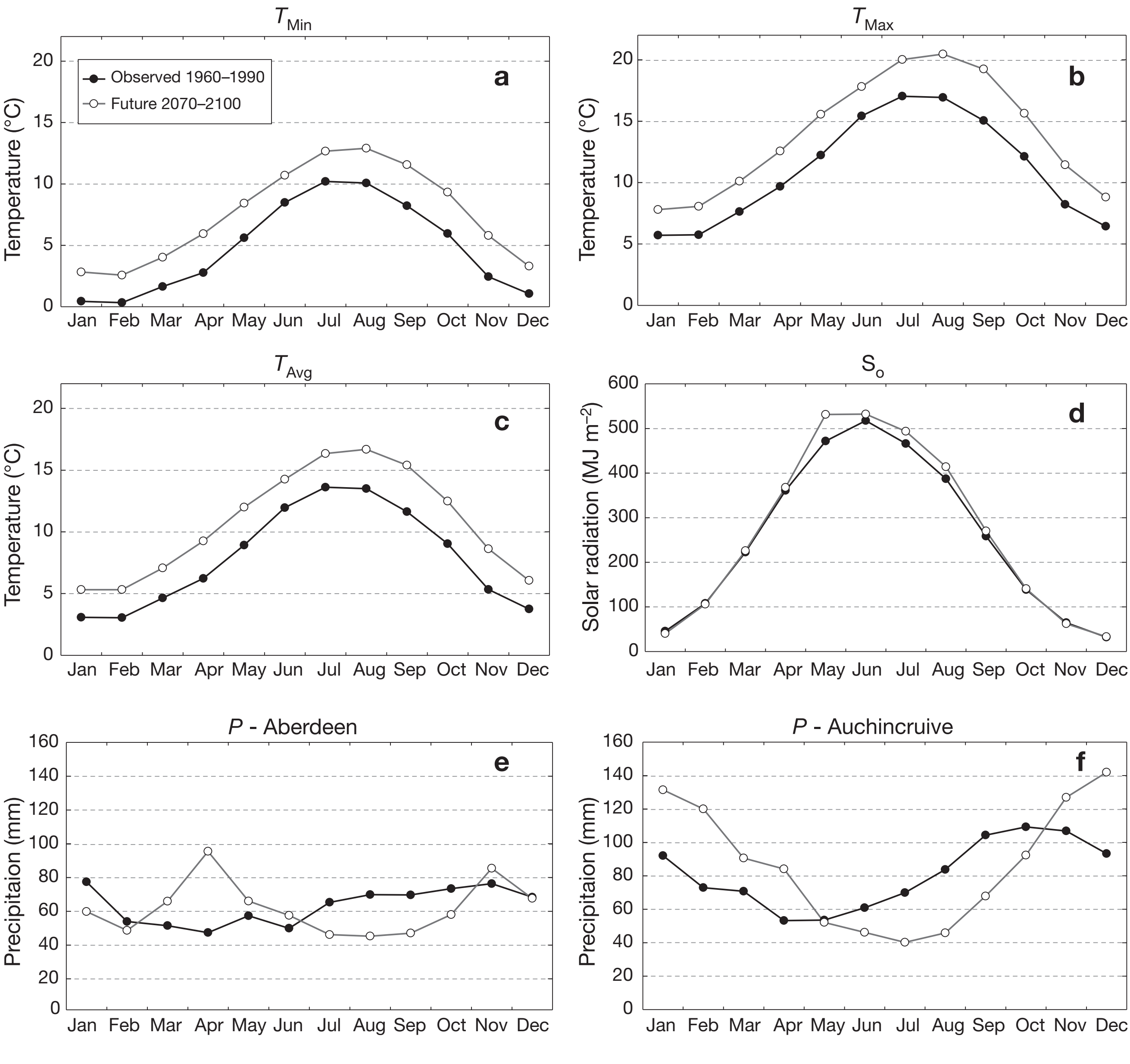

Fig. 4. Metrological metric monthly summaries used in the focus groups. The figure shows plots of monthly average values for (a) T_{min}, (b) T_{max}, (c) T_{avg}, (d) S_o and P—for (e) Aberdeen (Dyce) and (f) Auchincruive—for the periods from 1960 to 1990 and 2070 to 2100

scaling of the graphs so as not to over-emphasise changes, for example over-scaling the changes in *P*.

An example of the time-series graphs for the observed and future datasets used with stakeholders is shown in Fig. 5. Since the datasets are not for the same period, it was not possible for stakeholders to make point-by-point comparisons between the datasets in contrast with the summary statistics. These, on occasion, caused confusion in audiences, but with the assistance of the research team all were quickly able to comprehend the data. Useful conclusions were drawn by stakeholders from the time-series plots—particularly that despite changes in the mean conditions, there was no marked change in within-year or between-year variability. Despite the successful use of other presentational formats to answer specific questions in the workshops, the stakeholders view was that these were too 'scientific'. For example, the magnitude-based rather than time-based ordering of data points (see Fig. 5 'ordered totals') were seen as useful, but would be 'too complex for others' if presented without the support of the research team. This emphasises that researchers who are communicating potentially complex, conflicting, or nuanced findings and expect to influence stakeholder actions, need to invest time in building the capacity of audiences through processes of social learning. Otherwise alternative models of advice delivery that deny stakeholders the opportu-

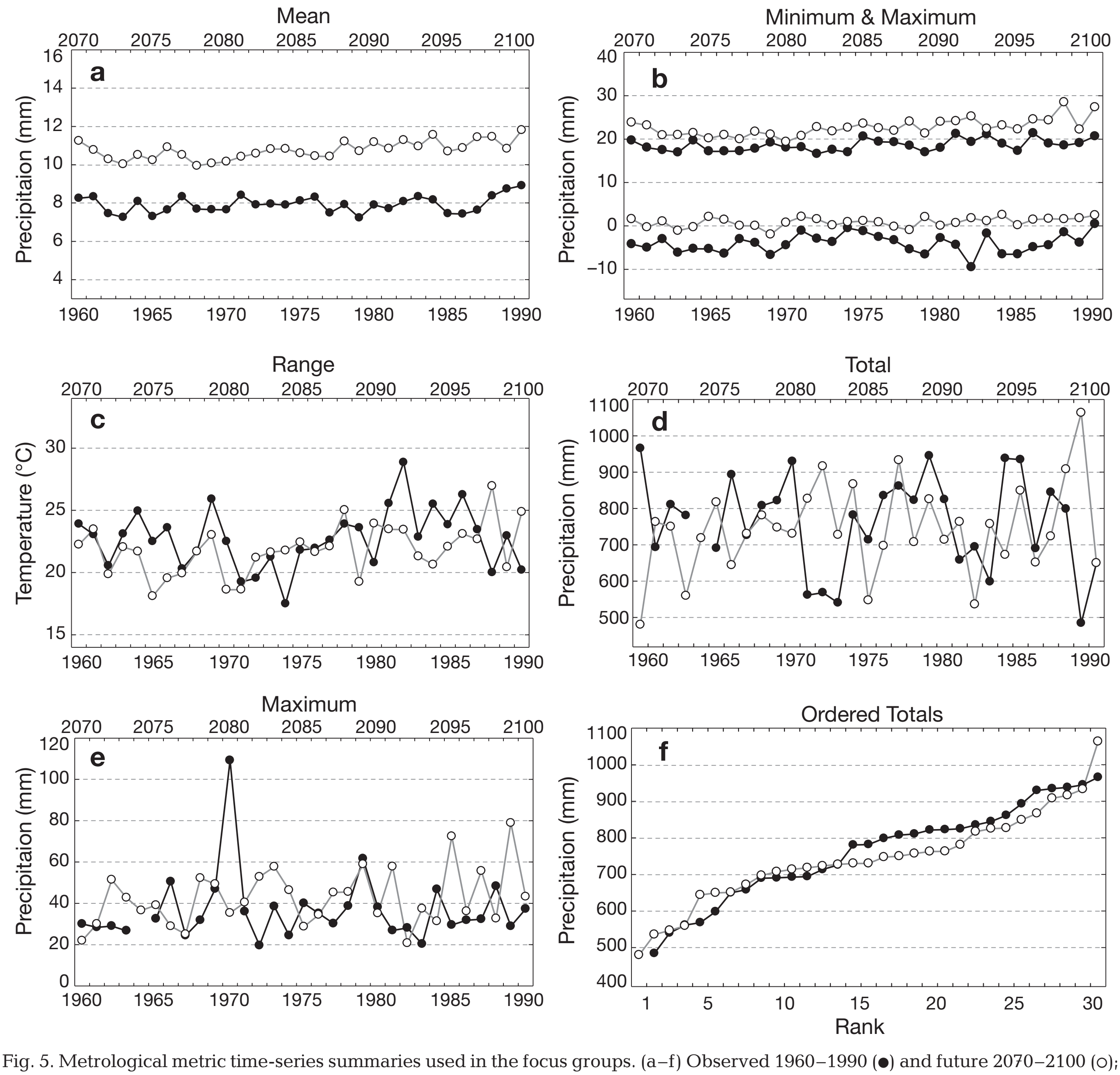

Fig. 5. Metrological metric time-series summaries used in the focus groups. (a–f) Observed 1960–1990 (●) and future 2070–2100 (○); (a–e) years on lower (●) and upper (○) *x*-axes, respectively

nity for dialogue, deliberation and learning can effectively be limited to the 'lowest-common-denominator' of mutual (in)comprehension and become 'dialogues of the deaf' (Verweij & Thompson 2006).

Overall the usefulness of the metrological metrics was strongest and stakeholder interest greatest where there were large differences between current and future conditions. Despite the publicity of CC in the media, a mind set persists in which weather changes but climate stays the same (despite stakeholders' awareness of anecdotal evidence of consistent changes at a decadal scale). Information that confirms something stays the same was seen as less salient, perhaps as it requires no action from stakeholders. The lack of salience may also reflect the anticipated role of researchers as creating 'new' knowledge rather than confirming the status quo. Yet, against the background of a changing climate, communication of no change still needs to be effective.

4.2. Ouputs from the agro-meteorological analysis

Even the simplest tabular presentation of the direction of change in agro-meteorological metrics (see Table 2) was effective in engaging the stakeholder's interest. From the outset the stakeholders saw the agro-meteorological metrics as more salient since they were less 'abstract' than the climatic summaries, and assisted stakeholders in interpreting what climatic changes could mean for land-use systems. The stakeholders presented with Table 2 quickly began to question the formulation and parameterisation of the metrics and expressed a desire to see how the magnitude of change differed between sites, thereby anticipating follow-up presentation, see Table 3 (magnitudes and statistical significance of the changes). This summary stimulated many observations on the nature of the changes and the usefulness of the metrics as indicators. The data in Table 3 led to extended and often ani-

Table 2. Agro-meteorological metrics—simple trend summary for 5 sites. SMD: soil moisture deficit; ▲: increase; ▼: decrease; ◀: earlier; ▶: later; =: no significant change; –: no data

Type	Indicator	Sites				
		Aberdeen	Mylnefield	Carnwath	Eskdalemuir	Auchincruive
Dates	Start of growing season	◀	◀	◀	◀	◀
	$T_{sum}200$	◀	◀	◀	◀	◀
	End of field capacity	=	=	–	=	=
	Last air frost (spring)	◀	◀	◀	◀	◀
	Last grass frost (spring)	◀	◀	◀	◀	◀
	Date of maximum SMD	▶	▶	–	▶	▶
	Wettest week	=	=	=	=	=
	First grass frost (autumn)	▶	▶	▶	▶	▶
	First air frost (autumn)	▶	▶	▶	▶	▶
	Return to field capacity	▶	▶	–	▶	▶
	End of growing season	▶	▶	▶	▶	▶
Day Counts	Air frost	▼	▼	▼	▼	▼
	Grass frost	▼	▼	▼	▼	▼
	Growing season range	▲	▲	▲	▲	▲
	Growing season length	▲	▲	▲	▲	▲
	Access period range	▲	▲	–	▲	=
	Access period length	▲	▲	–	▲	▲
	Dry	▲	▲	▲	▲	▲
	Wet	▼	▼	▼	▼	=
	Plant heat stress	▲	▲	▲	▲	▲
	Dry soil	=	▲	▲	▲	▲
	Very dry soil	=	=	=	=	=
Degree days	Accumulated frost	▼	▼	▼	▼	▼
	Growing degree days	▲	▲	▲	▲	▲
	Heating degree days	▼	▼	▼	▼	▼
Water	Excess winter rainfall	=	=	–	=	=
	Wettest week amount	=	=	▲	=	=
	Maximum SMD	▲	▲	–	▲	▲
Waves	Heat wave	=	▲	=	▲	▲
	Cold spell	▲	=	=	=	=
	Dry spell	=	▲	▲	▲	▲
	Wet spell	=	=	▼	=	▲
Indices	Precipitation intensity	▲	▲	▲	▲	▲
	Rainfall seasonality	▼	▼	▼	▼	▼
	Rainfall heterogeneity	=	▲	▲	▲	▲

mated discussion of adaptation strategies ('what would we have to do'), comparisons with historical cases ('the drought of 1976') and anecdotal evidence of recent events with similarities to the future scenarios ('its already happening'). The credibility of the data in the historical cases reinforced that of the future scenarios and, thus, stimulated serious discussion of adaptation options. The preference for a step-by-step approach building in complexity during discussion was a recurrent theme, with comprehension and preferences often dependent on the order in which materials were presented. Ceding agency to stakeholders by visibly adapting either the current or future processes in response to their inputs significantly enhances the salience and legitimacy of the research.

The range of alternative graphical presentation formats used was also significant in communicating and stimulating discussion centred on the current and future variability of phenomena. Examples of the summary plots for dates and day counts are shown in Fig. 6 for the Aberdeen (Dyce) site. Whilst these plots were more complex than the meteorological summary plots, the stakeholders found them useful in assessing variability in both means and ranges. The specialist time-series plots for the soil moisture metrics were well received and seen as helpful in communicating considerable information in an accessible way. Other formats such as polar/spider plots were less successful, since there were difficulties in judging the magnitude of events making the plots harder to comprehend. For complex presentations of research data to be successful they need to strengthen the interactive nature of the relationship between the parties. The presentations should thus enhance stakeholders' capacity to discuss the issues rather than render them dependent on researchers' interpretations or judgements.

For all the metric formulation and presentation issues, the social learning process, with iterative rather

Table 3. Agro-meteorological metrics—full summary of changes for 5 sites. SMD: soil moisture deficit; ■: not significant; –: no data

		Sites									
Type	Indicator	Aberdeen	p	Mylnefield	p	Carnwath	p	Eskdalemuir	p	Auchincruive	p
Date	Start of growing season	−63	0.00	−48	0.00	−39	0.00	−55	0.00	−15	0.02
	T_{sum}200	−24	0.00	−20	0.00	−22	0.00	−27	0.00	−17	0.00
	End of field capacity	−12	0.07	−6	0.50	–	–	−11	0.50	−6	0.51
	Last air frost (spring)	−38	0.00	−44	0.00	−46	0.00	−45	0.00	−31	0.00
	Last grass frost (spring)	−35	0.00	−31	0.00	−24	0.00	−21	0.00	−22	0.00
	Date of maximum SMD	35	0.01	30	0.00	–	–	34	0.00	31	0.00
	Wettest week	−6	0.84	4	0.93	−57	0.17	−41	0.93	18	0.32
	First grass frost (autumn)	72	0.00	63	0.00	79	0.00	79	0.00	63	0.00
	First air frost (autumn)	48	0.00	34	0.00	69	0.00	64	0.00	35	0.00
	Return to field capacity	28	0.00	31	0.00	–	–	18	0.00	31	0.00
	End of growing season	20	0.00	16	0.00	27	0.00	31	0.00	15	0.00
Day counts	Air frost	−51	0.00	−36	0.00	−56	0.00	−58	0.00	−31	0.00
	Grass frost	−75	0.00	−77	0.00	−68	0.00	−72	0.00	−64	0.00
	Growing season range	82	0.00	56	0.00	47	0.00	82	0.00	36	0.00
	Growing season length	67	0.00	60	0.00	59	0.00	66	0.00	52	0.00
	Access period range	31	0.00	35	0.00	–	–	18	0.00	28	0.33
	Access period length	26	0.01	34	0.00	–	–	36	0.00	63	0.00
	Dry	30	0.00	30	0.00	32	0.00	20	0.00	14	0.00
	Wet	−31	0.00	−30	0.00	−32	0.00	−19	0.00	−10	0.07
	Plant heat stress	5	0.00	15	0.00	11	0.00	11	0.00	12	0.00
	Dry soil	0	0.11	0	0.00	0	0.04	0	0.00	0	0.04
Degree days	Accumulated frost	−131	0.00	−91	0.00	−249	0.00	−185	0.00	−70	0.00
	Growing degree days	787	0.00	833	0.00	701	0.00	755	0.00	843	0.00
	Heating degree days	−906	0.00	−874	0.00	−928	0.00	−950	0.00	−755	0.00
Water	Excess winter rainfall	−59	0.30	−44	0.19	–	–	−101	0.19	16	0.84
	Wettest week amount	14	0.04	4	0.21	10	0.01	14	0.21	12	0.13
	Maximum SMD	22	0.00	26	0.00	–	–	44	0.00	38	0.00
Waves	Heat wave	1	0.81	2	0.01	1	0.70	0	0.01	4	0.00
	Cold spell	0	0.02	−1	0.92	−2	0.24	−1	0.92	1	0.62
	Dry spell	1	0.13	3	0.01	2	0.02	1	0.01	2	0.00
	Wet spell	−2	0.18	−1	0.77	−3	0.01	−4	0.77	−5	0.00
Indices	Precipitation intensity	0.95	0.00	0.90	0.00	1.00	0.00	0.60	0.00	0.60	0.00
	Rainfall seasonality	−0.20	0.00	−0.34	0.00	−0.34	0.00	−0.27	0.00	−0.32	0.00
	Rainfall heterogeneity	30	0.29	56	0.05	110	0.00	155	0.05	177	0.00

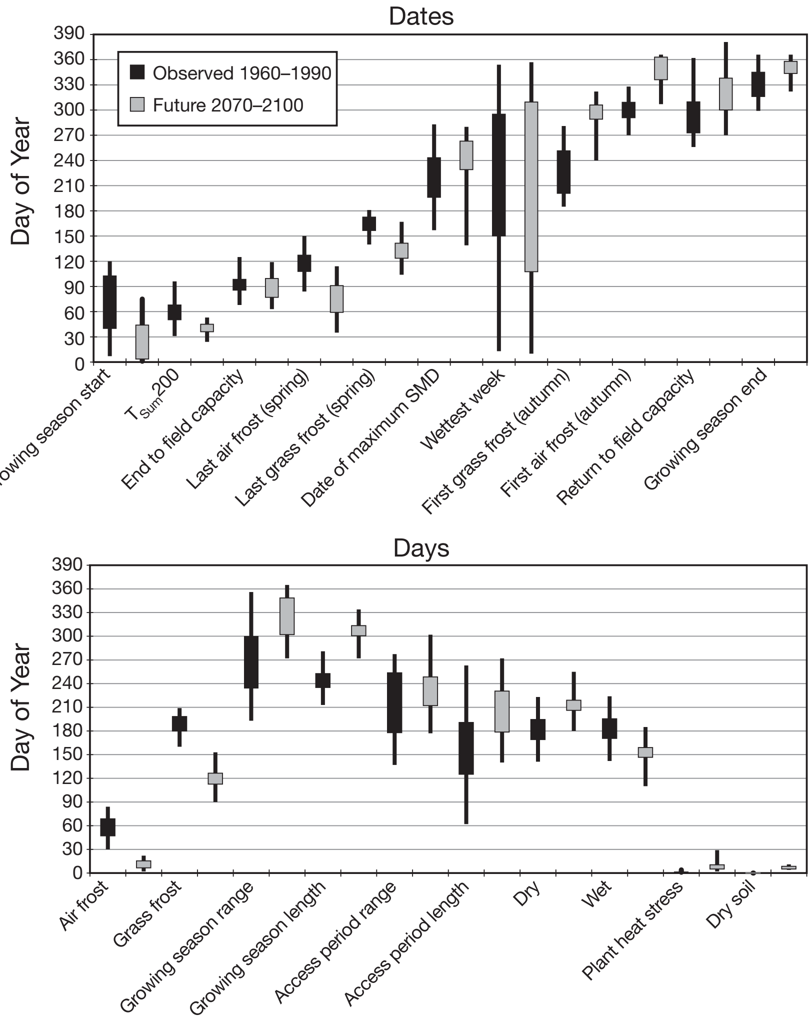

Fig. 6. Summary plots of agro-climatic metrics for Aberdeen. For the plot of dates the metrics are ordered by season, except for wettest week and date of maximum SMD (soil moisture deficit), which are shown in the middle of the year. The day counts are grouped by themes. Boxes show the 25th to 75th percentiles, with the minimum and maximum values shown by the tails

than one-off contact with stakeholders, was particularly effective in eliciting relevant content and intuitive presentation formats. The research team was able to continuously improve the content and clarity of information based on feedback from the workshops and focus groups. Stakeholders with repeated access to the research team (the leaders of the organisations) also began to act as advocates for the data, helping others in the group and pushing for more complex combinations of metrics that would be informative for decision making.

4.3. Utility of the metrics

Results of the deliberations on the utility of the metrics as indicators are reported in Table 4, with votes by each focus group shown by a checkmark. Some focus groups were keen to differentiate by sector for usefulness, and this information is also presented as superscripts. The reduced set of metrics that make up the indicator framework are highlighted in grey. These metrics were chosen since they were categorised by at least 1 group as very useful for decision making. While there are clearly a range of opinions on the relative importance of particular metrics, it was possible to start to identify a sub-set of metrics that could form the basis of a indicator framework for subsequent use with other stakeholder groups.

From Table 4 it can be seen that the metrics related to dates were most frequently seen as useful indicators. This is particularly evident for the end of and return to field capacity, since this is a fundamental constraint on access to land both for machinery and livestock; and was strongly salient with stakeholders in Scotland. There was interest in the particular pattern of change (similar dates for access in the spring but with longer access in the autumn). Presentations of the distributions of access days per month (alone or in combination with growing season) were seen as the most useful since they combined metrics of how often and when access was available (to coincide with particular operations or activities). There was also interest in the start and end of the growing season, but concerns with the formulation of the metrics. The start of field operations metric ($T_{\mathrm{sum}}200$) overcame this issue, producing less erratic predictions and could be used in place of the start of the growing season indicator. There was, however, no equivalent metric for the end of the growing season. Also of utility was the growing degree days metric, but this needed to be related to specific crop requirements (phenological thresholds). The frost-related metrics were seen as important for particular land-use systems (soft fruit and horticulture were identified). The decrease in accumulated frost under the predicted CC scenario was seen by some as a potential opportunity, but also as a problem with increased incidence of pests and disease likely (particularly by those concerned with organic agriculture). An indicator for plant heat stress was seen as very desirable if it could identify events with yield or quality consequences. A

Table 4. Utility of selected agro-metrological metrics as assessed by the stakeholders. The reduced set of metrics that make up the indicator framework are highlighted in grey. (✓) vote by a focus group. Superscripts differentiating utility by sector (as requested by some focus groups) are as follows—F: fruit (soft and orchard); H: horticulture; A: arable; G: grassland; C: conservation; P: polytunnels

Type	Indicator	Utility			
		Very	Quite	Marginal	Not
Dates	Start of growing season	✓✓	✓	✓	
	Start of field operations	✓✓	✓✓		
	End of field capacity	✓✓✓✓			✓[P]
	Last air frost (spring)	✓[F]✓✓[H]	✓[C]	✓✓✓	
	Last grass frost (spring)	✓[F]✓[H]	✓	✓[C]✓[A]✓	✓
	Date of max. SMD		✓		✓✓✓
	Wettest week				✓✓✓✓
	First grass frost (autumn)		✓[F]✓[C]	✓	✓✓
	First air frost (autumn)		✓[F]✓	✓[C]	✓✓
	Return to field capacity	✓✓✓✓			
	End of growing season	✓✓	✓[P]	✓	
Day counts	Air frost			✓✓✓	✓
	Grass frost		✓	✓✓	✓
	Growing season range		✓	✓✓✓	
	Growing season length	✓	✓[G&H]✓✓	✓	
	Access period range	✓		✓✓✓	
	Access period length	✓	✓	✓✓	
	Dry		✓✓✓✓		
	Wet		✓✓✓✓		
	Plant heat stress	✓✓	✓	✓	
	Dry soil days	✓✓✓✓			
Degree days	Accumulated frost	✓[C]✓	✓	✓	✓
	Growing degree days		✓[G]✓✓✓	✓[A]	
	Heating degree days		✓	✓✓	✓
Water	Excess winter rainfall		✓	✓✓	✓
	Wettest week—amount		✓	✓✓	✓
	Min. soil water	✓✓	✓	✓	
Waves	Heat wave			✓✓✓	✓
	Cold spell			✓✓✓✓	
	Dry spell		✓	✓✓	✓
	Wet spell			✓✓✓	✓
Indices	*P* intensity		✓	✓	✓✓
	P seasonality		✓✓		✓✓
	P heterogeneity				✓✓✓✓

model-based indicator of plant stress would be acceptable.

The soil water balance metrics were in general highly rated by the stakeholders despite their greater complexity and being based on a simple soil–water model. Previous reference has been made to the accessibility metrics (driven by soil wetness), but the potential for soil moisture deficits that have an impact on cropping and other activities meant that the dry soil days metric was seen as a very useful indicator. More specialised indicators of the consequences for particular crops, and, for the more valuable crops, their irrigation requirements were also seen as priorities, were the indicator framework to be extended.

4.4. Benefits and limitations of social learning processes

The social learning process was successful addressing the issues of salience, legitimacy and credibility identified in Section 2.1. The process had utility first in eliciting suggestions for customisations, both for the formulation of the metrics and how they were presented. Beyond modifications of the existing tools, the social learning process was successful in eliciting more sophisticated composite indicators using recombinations of simple metrics presented. This is a key outcome for a social learning approach, since stakeholders had ceased to be passive recipients of information and were beginning to work in partnership with the research team directing the process. For this to happen the research-based information had to be salient, the research team credible and the process legitimate.

The localised, case-study-based, analysis was effective in ensuring that the stakeholders were able to engage with the research data being presented. Use of the 2080 climate data had been anticipated as problematic; such long-term forecasts clashing with decision making driven by experiences in the recent past or expectations of the near future. Stakeholders were, however, quick to recognise that there is significant uncertainty in the rate of change (and thus date by which the scenario may be experienced) and the nature of change (the potential for step change rather than gradual evolution). The use of a range of cases in the tabular data presentations was seen as helpful since it provided both a local case to compare with experience and others with which to assess the consistency of changes. The expertise of stakeholders in taking the data presented and relating it to their personal circumstances was evident as was their ability to translate the metrics into risks for their enterprises. The use of a roundtable format using workbooks or large format printouts was effective in establishing and maintaining the active participation of the attendees in contrast to a seminar format where results are presented to, rather than discussed with, attendees. Such a format is, however, limited in the numbers of stakeholders that can be accommodated.

The stakeholders were very keen to explore the details of projected changes (magnitudes and significances), the nature of the modelling process that produces the data and particularly the uncertainties in estimates. There is a strong interest in the implications of CC, but other drivers such as rural development policy were seen as more immediately pressing as they are open to direct influence by stakeholders. There is a growing recognition, however, that, whatever the drivers, climate (rather than weather) is dynamic, that the dynamic may have discernable trends and that these will need to be managed for. Despite recognising the dynamic nature of climate there is, perhaps paradoxically, little desire for information on what may stay more or less the same. This presents researchers with a quandary, which data sets show significant change? This is particularly difficult when significance depends, not on statistical measures, but on the interpretation within particular and often localised circumstances. In this situation it is inevitable that some redundant (from a stakeholder perspective) data gets presented.

The nature of the analysis (with a small number of workshops) emphasises depth in terms of the quality of deliberation over the breadth that could have been achieved with a survey-based approach. Yet, it is unlikely the richness of communication and the social learning could have been achieved using large-scale processes alone. The authors experience both in this research and previously (Matthews et al. 2000, 2002, 2006) is that successful social learning requires interactive and iterative processes, with considerable flexibility required on the part of researchers. Where it is necessary to achieve a wider dissemination of the messages, then perhaps this can be achieved by conducting the in-depth and ongoing dialogues with key opinion formers, advisers and representatives and using their well-developed networks of contacts to pass on and interpret the research outcomes. Through eliciting stakeholder preferences for the content and format of presentations, it may also be possible to tailor some of the research outcomes for dissemination via the mass media, while retaining some of the salience benefits. What would be lost, however, is credibility and legitimacy, since new stakeholders could not question the assumptions underpinning the data or be able to discuss what it meant for them individually or collectively.

5. CONCLUSIONS

Developing a framework of agro-meteorological indicators with land management stakeholders as part of a social learning process is an effective means of characterising and communicating the implications of CC. While meteorological summaries highlight the nature of the change, the agro-meteorological metrics are more effective at encouraging stakeholders to consider possible impacts on their land-use systems and stimulate thinking on how they might adapt. Indicators that directly inform management decisions such as: access periods, growing seasons and the potential for losses in yield or quality due to drought are most salient. The coherence and credibility of an indicator framework is enhanced by an interactive process of explanation, where the basis of the indicators can be debated and, if necessary, changes made to formulation or presentation. This is particularly important where research addresses issues such as CC that are complex, contested and to which there are at best partial and uncertain answers. This is doubly important when research delivers knowledge that confronts conventional wisdom.

Social learning is at its most powerful once there is a partnership established between researchers and practitioners or policy makers in which each has the confidence to both contribute knowledge and question assumptions. If such a positive environment can be created then research-derived knowledge can become applied knowledge and become influential in decision making. One key measure of success for a social-learning-based approach is to begin to recruit stakeholder advocates to champion the research within their networks. Another is for researchers to be actively sought out by stakeholders to contribute to their deliberations. Stakeholders are able to engage with the more complex, research-based tools and information, but only where they can see clear potential benefits for decision making. In particular there is no problem in using model-based indicators where the credibility of the model can be established, by an adequate explanation of what the model does (if not the particular details of how) and by adequately characterising events within the experience of stakeholders. Caution needs to be exercised in the use of models, however, since there is strong evidence from other research domains that model-based approaches that prescribe an adaptive response are much less likely to be credible.

For the challenge of communicating the outputs of CC so that there are outcomes in terms of stakeholders' responses, this research reinforces lessons from other research domains. Deliberately seeking stakeholders' views on the utility of research-based outcomes is a key to establishing a legitimate process of cooperation and learning between researchers and stakeholder groups. Given the resource constraints on both researchers and stakeholders such social learning programmes need to focus on recruiting key opinion formers within particular stakeholder communities to assist in disseminating the outcomes of the processes.

The authors thus recommend including a strong social-learning-based process within any CC research communication strategy. This will require additional skills (e.g. deliberation and capacity building) to be included within some CC research teams. The active participation in such programmes by researchers is, however, essential as only they have both the expertise to give the research credibility and the resources to support reworking and revision of research outcomes in response to practitioner and policy maker inputs.

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