INSURING FOR RESILIENCE IN EXTREME CONDITIONS USING CLIMATE MODES AND REANALYSIS PRODUCTS

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1. INTRODUCTION

In many sectors (e.g. urban air quality, agriculture, energy markets), high-impact extreme events often result from the confluence of several contributing causes and can herald major and sustained changes in behaviour of the physical and socio-economic environments. They are often preceded by a short window of “increased predictability” in an otherwise essentially non-stationary environment.

This review of the characteristics of extremes in weather-sensitive, agricultural systems addresses the overlap of seasonal forecasting and alternative risk transfer techniques, and the importance of information content in climate histories. Estimated return periods and measures such as probable maximum loss (PML) play a critical role in reinsurance and risk assessments; these procedures are often quite sensitive to the statistical nature of the process (including the quasi-periodicities), the dependence between variables (especially for distribution tails) and the weaknesses imposed by both short-term observation sets and the realisation process from event precursors to measured outcome.

Recent work on the necessary conditions for agricultural extremes in Australia and elsewhere suggests that various climate modes and indicators (singly or in combination) can provide efficient explanatory variables at various timescales and act as suitable bases for seasonal or longer-term forewarning of exceptional circumstances for vulnerable communities.

The shortcomings caused by the paucity of observations and the uncertainties in predictive capacities may be partially overcome by using (a) extended historical information (such as the forthcoming 20th Century Reanalysis products) in evaluations of likely return periods and influences of internal climate variability, (b) integration of past risk profiles with event projections from climate models of “known” explanatory powers and (c) better downscaling or higher resolution outputs from baseline weather products, such as historical reanalyses.

Just finding sufficient sets and time evolutions of climate indicators should assist identifying transition periods in various agricultural and energy regimes in Australasia, aid seasonal forecasting of exceptional circumstances in various sectors and promote a common currency between insurers, farmers, climatologists and other industries for developing regional and global climate risk products.

2. CURRENT RISKS

This paper outlines for comment some of the issues reviewed at the start of a “Managing Climate Variability” project (2009-10) on “Extremes, climate modes and reanalysis-based approaches to agricultural resilience”; the main project objectives at the local level are to:

- facilitate the production of reliable, long-term, site-specific databases of important extreme “parameters” and response (transfer) functions;
- link these with potential forecasting/scenario systems (both seasonal and “climatic”);
- suggest new ways of overcoming some of the inherent problems of sustaining weather/climate-based insurance and other finance risk products (including geographical basis risk, the influence of climate variability and the offsetting of systemic risks such as widespread drought), at various levels of the insurance/finance industries; and
- incorporate some of the project results in available, farmer-friendly software presentations of recent modelling predictions of climate for the next decades.

The project is considering four core areas of agricultural risk (Table 1); multi-day heat stress events that affect the mortality and well-being of Confined Animals in beef Feedlot, poultry and dairy Operations (CAFOs); episodic hazards from convective storms that can lead to crop and infrastructure damage; prolonged meteorological droughts as they affect the yield and quality of produce; and the multi-scale extremes that can reduce the profitability and even viability of vertically-integrated agribusinesses (such as irrigation and larger multi-resource companies). The near future may require more innovative “insurance” actions in many of these areas. Larger, globally-based businesses are including weather and climate risks in studies of enterprise sustainability and may already be hedging their expected errors in decision-making by using a portfolio of weather risk products (e.g. derivatives, insurance and bonds).

In Australia, the majority of agricultural weather insurance is for loss due to hail and frost (~70%) and fire and spray drift (~10%), with minor amounts on transit and livestock. Government actions such as “exceptional circumstances” relief have a long history but are under review as costs mount and their effectiveness is questioned as climate change evolves. Non-agricultural insurance for flooding is a recent development in Australia.

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In reality, the current physical and financial environments seem to require resilience to multiple shocks of quite different natures; agribusinesses may face in rapid succession not only extreme weather events (EWE such as heatwaves, droughts of various types, flooding, pollution episodes, cyclonic winds/rain and frost/hail) but energy shocks (especially oil with its links to fertiliser usage and world crop prices), and water and energy shortages.

At the same time, producers and distributors must adjust to new market mechanisms including carbon costs and constraints and a global environment of rapidly-appearing and unexpected financial and political upheavals. Interactions of governments and reinsurers are also essential for treating systemic extremes and changing characteristics when dealing with disaster management, encouraging robustness and ensuring realistic land-use planning.

3. AGRICULTURE IN A SPACE-TIME FLUX

Climate-related agricultural resilience involves the capacity of the various levels of farming and husbandry activities (e.g. single farms, cooperatives, distributors, financiers, government agencies and commodity markets devoted to primary industries) to recover after a series of weather shocks, those unusual meteorological events that can affect productivity, connectivity (physical and/or financial) and organisational structure. Whilst a given level may be sensitive to a single EWE of a particular type, repeated extreme events of similar or quite different types can either slow the recovery of agricultural systems to the previous "equilibrium state" or, for more vulnerable systems, auger a regime shift, with possibly abrupt changes in system characteristics and a different probability distribution of outcomes.

Agriculture and the associated sectors (e.g. irrigation, chemicals, transportation, other commodities and energy) have a long tradition of using insurance and/or forecasting to manage the risks of “acute” weather extremes such as localised storms and the longer-term “chronic” extremes such as drought. The understanding of climate variability has always been important in agricultural decision-making and risk transfer in Australia.

Anthropogenic climate change reduces not only the confidence in assuming stationarity in system properties but also the utility of historical records for insurance product evaluation. Climate change has already led to alterations in agricultural insurance profiles (fewer frost, more hail policies), innovations such as risk transfer via indices of soil moisture or simulated crop yield and the consideration of new mitigation or forewarning technologies (e.g. high-resolution Dual-Doppler radars for determining suitable clouds for rain promotion or hail suppression, and identifying explosive growth in hurricane intensity, such as occurred when Tropical Cyclone Larry devastated the Queensland banana industry).

Changes in agricultural operations due to climate change may be fundamental: crop types and husbandry practices change; renewable energy and sustainable irrigation become integral; carbon offsetting and harvesting provide alternative income; multi-peril insurances morph into multi-indexed risk transfers over longer timescales. Agricultural sectors in Australia have recently responded, employing short-term and seasonal forecasts (e.g. heat stress for CAFOs, monthly rainfall distributions for grain) and undertaking more strategic approaches (e.g. by partial relocation to regions previously considered unsuitable); in both cases a revisiting of insurance cover may be encouraged by more comprehensive “long-term records” and risk management innovations trialled elsewhere.

Precision agriculture in Eastern Australia has over two decades of experience in seasonal forecasting (30-180 day horizons) for management decisions on issues of climate variability. More detailed predictions, extensions of time horizons and better understanding of the uncertainties throughout the forecasting chain from weather to triple-line accounting should strengthen decision-making portfolios and encourage the hedging of forecasting errors by weather/climate derivatives (Best et al 2007, Robertson et al 2008).

Many developing (and indeed some developed) countries are hindered by the lack of historical databases of meteorological variables, and detailed records of environmental, production, societal and economic losses. The problems of basis/credit risks and the high costs of loss assessments (from 10-40% of premiums) have led to trials of index insurance for agricultural disaster management (Skees et al 2007), especially for those vulnerable communities too poor to afford conventional insurance but accepting of microfinance techniques. The current project targets adding to this process new weather reanalysis products (predictions of weather forecast models initialised on available historical information for the last 150-250 years), downscaling to finer spatial resolution and achieving some synthesis with forward projections from reliable, regional climate models.

Insurers may then join agriculture in covering much wider windows of climate risk. Avoiding to some degree loss-based products, agricultural enterprises can integrate more with other risk management sectors (e.g. in energy, water supply, currency and disaster management); new services and products may reach across sector and geographical boundaries, especially in countries with less historical presence in the insurance industry. Climate change re-engineering is likely to be a great integrator.

4. CLIMATE MODES AND EXTREMES

EWE do not have a generally agreed taxonomy (Stephenson 2008); they may be severe (significant loss), rare (low probability of occurrence), extreme (having high or low values of meteorological parameters) and/or high-impact (either by being severe or long-lasting). Acute extremes are those with rapid onset and of a short-lived nature (e.g. case studies 1-2). Chronic extremes are usually long-term events resulting in agricultural system failure (e.g. cases 3-4).

Characteristics	1. Heat stress in CAFOs	2. Episodic disruption	3. Drought for grain crops	4. Resilience of agribusinesses
Critical conditions	Multi-day "heatwaves" with poor night-time relief	Short-lived events such as hail, wind, and frost	Multi-season moisture deficit	Multi-season aberrations
Key climate & meteorology?	Synoptic blocking	Mainly strong convection	Cut-off lows with mode blocking	Decadal persistence
Key parameters	Accumulated Temp, Rain, Black Globe T	Surface and profiles of stability	Rain, temp, SPI, PDSI	Detailed socio-econ. response functions
Key indices (illustrative)	MJO, STR ….	MJO, ENSO, SAM ..	SAM, ENSO, IOD, PDO ….	ENSO, SAM.....
Current insurance	Mortality only	Main products in Australian agr.	Yield, exceptional circumstances	Self, "charity"
Index products?	Some in Asia	WBO, Munich etc	O/S SOI, rainfall, vegetation index	"Reservoir" levels in India, Phillipines
Use of reanalysis for insurance & adaptation?	Strategic risk and forecast validation	Pricing in new areas; reduce IBI basis risks	Full weather risk history in product development	Reinsurance pricing; forecast-contingent risk.

Table 1 **Four types of agricultural case studies for insurance, forecasting and adaptation.**

Characteristics	Important determinants	Insurance interactions
Return periods	Cycles, STM, LRD	Pricing, client education
Clustering, temporal distrib.	LRD, "intermittency"	Reinsurance layering
Spatial distributions	Process characteristics	Insurance cycles and pricing?
"Loss" measures	PML, CVAR, shortfall	Risk management, all sectors
Interdependence	Multivariate copulas?	Catastrophe reinsurance
Asymptotes	Outliers, kings, black swans & iceberg risks	Reinsurance viability
Climate variability	Interannual and decadal cycles	Pricing
Climate change	Trends, change in system characteristics	Viability of reinsurance and adaptation measures

Table 2 **Characteristics of extremes that can affect insurance/adaptation measures**

Property	Comments
Single index	CAI, rainfall, yield, palaeoproxy, biological etc
Multiple indices	CAIs for extremes; CAI + site for basis risk?
Contract period	Usually seasonal, preferably multi-year?
Contract payout	Usually piecewise linear and capped; curvilinear better?
Transparency	CAI verified independently
Payment	Rapid, minimises loss assessment
Risk offsets	CAI give regional and cross-sector opportunities
Information risks	Coverage and duration increase, costs decrease
Predictability	CAI an international effort

Table 3 **Characteristics of index-based insurance (especially with climate anomaly indices, CAIs)**

The IPCC reports define complex extremes as severe weather associated with particular climate phenomena, often involving a critical combination of variables.

Extreme events have many other important attributes (Table 2): their probability of occurrence; their magnitude or intensity; their temporal duration and timing; their spatial extent and the multivariate dependencies between various parameters. Recent climatological studies of extremes in Australia (e.g. Nicholls 2008, Alexander and Arblaster 2008, Chambers and Griffiths 2008, Nicholls and Alexander 2007) tend to focus on an agreed set of single parameters defined over a short time period (i.e. acute events) whereas agricultural concerns cover all the types of extremes above; it is often the chronic extremes which tax the resilience of any well-established system or organisation.

The clustering in time of extremes (to produce "burstiness" in time series – Goh and Barabasi 2008) is important for resilience considerations. This suggests that intermittency should be added to the presence of short-term memory (STM) and long-range dependence (LRD), trend and cycles in the characterisation of insurable processes, such as return periods and the conditional value-at-risk (CVAR).

EWE appear to be increasing in severity and frequency, either due to long-term natural cycles in climate (e.g. ENSO, PDO, SAM and STR/L in Australia, NAO, ENSO and AMO in the Northern Hemisphere), anthropogenically-induced climate change, or a mix of the two. Losses and restoration costs due to single EWE are usually covered by state emergency services, community organisations and short-term financial relief measures (e.g. government subsidies, insurance claims). Multiple EWE (e.g. sustained and multi-year droughts) may threaten the sustainability of rural communities and require a major reorganisation of resources, strategies and long-term vision.

The estimation of return periods for extreme events is a key constituent of insurance appraisal; for the past half-century extreme value theory has tended to concentrate on independent events and the description of the tails of the probability distributions of single parameters, perhaps with CAIs as covariates (Smith 2009). Insurance operators have tended to view “normal” events as occurring every 1-5 years, “extreme” if the estimated return period is 100 years and “catastrophic” for a 1 in 1000 year recurrence. Insurance pricing has usually been based on a 100 year return period, with reinsurance considerations often seeking the 1000 year outlier/king event, the unforeseen “black swan” or the underestimated “iceberg risk” categories.

Despite antiquarian references to ENSO-type cycles and the need for pre-emptory strategies, it is only recently that the estimation of return periods and insurance pricing have recognised the sensitivity of estimates to “the joint phases in climate cycles”, the presence of LRD in climate time series and their importance in pricing weather derivatives (Fraedrich 2006, Jewson and Brix 2005, Carraquiry and Osgood 2008). The presence of various types of memory (e.g. in land/ocean responses or via spatial aggregations such as in catchment stream flows) can have profound effects on system response; this year’s response may be influenced by events in previous seasons (e.g. via persistence of moisture in various soil types); LRD can lead to the appearance of quasi-periodicities and/or regime shifts in event characteristics.

5. FINE-SCALE, EXTENDED REANALYSIS

Predicting the temporal and spatial evolutions of the probability distributions of key parameters as required for seasonal climate forecasting (SCF), strategic climate risk assessment and insurance design may be greatly advanced by the integration of new historical reanalyses (where daily or more frequent values with uncertainties give considerable information content over a 1-2 century period), palaeo-tempestology (event markers or seasonal aggregates over multi-century or millennial periods) and regional climate models of demonstrated credibility (preferably validated over the reanalysis period and projected forward over several decades).

One such set of reconstructed history of six-hourly 4D weather variables is the 1891-2006 global coverage being produced this year by the 20th Century Reanalysis Project, led by the US partners of the international Atmospheric Circulation Reconstructions over the Earth (ACRE) initiative (Figure 1 – Allan 2008). Surface observations of synoptic pressure, monthly sea surface temperatures and sea ice distribution are assimilated in a novel “ensemble filter” data assimilation system that facilitates the computation of the analysis and its associated errors. The products to date have covered 1908-1958 and show excellent agreement with independent radiosonde profiles, with overall quality similar to that of current three-day NWP forecasts (Compo et al 2006). This process provides a long-term reconstruction of 4D global weather, which can be used to address extreme event prediction by determining long-term trends in the frequency and severity of meteorological phenomena such as severe storms, floods, cold spells and heat waves. Our current project investigates the skill and reasonableness of raw or refined reanalysis outputs to describe agricultural extremes in the Australian region.

Reanalysis data sets can thus provide consistent and detailed daily or finer resolution weather histories over a multi-century horizon; they provide a test-bed for predictability of site parameters (by various types of downscaling techniques) and for producing long-term daily records of simple climate anomaly indices (CAIs) useful to the non-specialist as a “risk transfer language”. ENSO effects are pervasive (Compo and Sardeshmukh 2009). The relative importance and various interactions of such modes (as found important in many applications and regions: ENSO+MJO, ENSO+PDO, SAM+IOD for convective events, streamflow, and monsoonal influences) can be better investigated if data lengths are now an order of magnitude longer than the “mode cycle length”. Daily values of CAIs also contain significant information (e.g. Petroni and Ausloos 2008 report meaningful spectral peaks of SOI at periods of 24, 27, 37, 76 and 100 days) that may aid associations with system responses and suggest new underlyings for statistical prediction methods.

The information generated in the ensemble filtering approach (Whitaker et al 2009) for a long series of reanalyses may also give additional information on the statistical dependence between extreme parameters. For example, major flooding in a given area often depends on extreme rainfall in multiple parts of a catchment (e.g. an extensive storm system over time). The assessment of extreme events may then require the estimation of the tails of the multivariate distribution of rainfall at important catchment locations. Reanalysis results may yield this tail dependence as well as the marginal distributions (and hence provide the copulas sometimes required in insurance pricing). Other uses of the copula framework in climate research (Scholzel and Friederichs 2008, Wong et al 2008) include the estimation of bivariate extremes (e.g. maximum daily wind gusts at different locations), trivariate copulas (e.g. characterization of the intensity, duration and severity of drought) and different meteorological parameters at the same location (e.g.

complex extremes such as in heat stress where it is important to look at multiday temperature, rainfall and humidity during blocking events without night cooling). The multivariate dependence may also be important in the downscaling of reanalysis results for extreme values at a given location.

6. INSURANCE ISSUES

Weather and climate extremes can affect a wide geographical area; such correlations of losses counter many of the fundamental premises of insurance and risk diversification. If the return periods decrease as a result of climate change, premiums on insurance or interest rates will rise; it will become attractive to offer discounts to clients who take weather and climate change risks into account when selecting sites or crops, designing and constructing projects and maintaining their assets over the long-term (Climate Risk 2008).

In many cases it is assumed that government is the ultimate risk manager, especially in cases where legal liabilities are uncertain or when extreme events are encountered. Alternative public-private partnership roles in adaptation include hazard reduction, resilience-enhancing measures, assisting vulnerable sectors and communities, risk transfer, disaster relief, capacity building, technology for adaptation, economic stability and financial markets. For example, simple arrangements for dealing with catastrophic events (such as index-based insurance and weather derivatives) can assist in providing rapid financial relief without the often long delays from loss assessment procedures.

The challenges for the insurance part of the financial sector in the treatment of EWE include:

- representing the full range of uncertainty,
- determining what useful signals there are in the available indicators of atmospheric/ocean behaviour (at various scales of time and space) and
- estimating how system characteristics have and will change over time (mainly to determine the relevance of past information to the pricing of current and future insurance products).

Insurance mechanisms (e.g. storage, prediction services, and risk management products) have a long history in dealing with climate variability and, to a lesser degree until very recently, with regional climate change; they form a major component in building resilient communities and institutional robustness. Rapid climate changes/fluctuations, as appearing now in many parts of the world, require responses of mitigation to anthropogenic contributions and adaptation to the consequence of the spectrum of changes on many timescales - some of them no doubt due to natural variations in climate.

The vulnerability of communities and indeed insurance providers (insurers, re-insurers, government and private aid organisations) can very geographically; recent applied research has focused on providing some measure of income insurance to agricultural agents in those developing countries experiencing large (and sometimes increasingly severe) weather extremes as well as social and economic vulnerabilities. Financial mechanisms such as index-based insurance (IBI), micro-finance and micro-insurance can provide more appropriate long-term support than the traditional climate risk management techniques (direct loss-based insurance, weather derivatives and exceptional-circumstances disaster relief) more prevalent in developed countries for agricultural, energy and water sectors.

Insurance of all types includes contracts or actions that make some projections of the probability distributions over time (and timing) of various outcomes (events, threshold exceedances, consequences, losses etc) into socio-economic derivatives. The predictions are based on a view of the degree of stationarity in the relevant (stochastic) process, the essential workings of the relevant systems and the suitability and/or reliability of past and present information to the prediction process. Data sets for insurance purposes are usually required to have a timespan of at least 30 years and no more than 1% of missing information. Prediction models have many inherent errors including the limitations of computational schemes, the accuracy of “current knowledge” or initial conditions, the degree of explanatory power in the chosen forecasting methods; and the relevance of any response functions (physical or economic) chosen for the next stages in any decision or adaptation process.

Climate-related insurance, reinsurance and derivatives will be more successful if the most relevant spatio-temporal qualities are isolated:

- From a time horizon perspective, what are the dominant types of quasi-periodicities and mechanisms of memory, intermittencies and trend in the important quantities? Do the interlinkages suggest connectivity, correlation and/or causality? Can the processes be split into manageable “deterministic” and relevant noise components (hopefully “white” for the ease of computation)?
- What degree of predictability is there at various junctures in time (and are these associated with cycle phase, blocking, regime shifts etc)?
- Are return periods relevant, computable and/or open to misinterpretation because of low-frequency variability, LRD and/or systemic changes?
- What geographical variability is there in underlying parameters, response functions, correlations and predictability?
- Which parameters or vectors are useful for product liquidity and the sustainability of risk insurers, at levels from bilateral arrangements through to global reinsurance and governments?
- How do these choices affect the viability of agreed risk instruments, from financial, legal and community perspectives?
- If the resulting costs of premiums/assessment etc are more than the willingness to pay or redeem (especially as losses due to climate

extremes escalate in populated areas), are there practical incentives that can reduce stakeholders' vulnerabilities and lower the cost to achieve sustainable operations over the necessary timescales?

- If information risks (e.g. insufficient length of time series, poor spatial coverage, poor data quality, high information costs) are significant, can alternative schemes based on atmospheric reanalysis products, palaeo-proxy information or down- and up-scaling techniques reduce these "basis risks" to manageable levels? If they prove to be the most incisive, should reanalysis products in ensemble and downscaling modes replace more traditional observational-based measures of the atmosphere?
- Can forecast-contingent insurance schemes and approaches be included in decision-making processes, using the estimated errors in predicted outcomes to hedge the risks in model selection or operation?

Catastrophe modelling (in general and including EWE) faces many issues in the next decade:

- Is the current suite of sensitivity tests adequate for assessing the variability in events and the scale and resilience of affected properties and commercial systems?
- Does loss modelling need a proper accounting of the deterministic and stochastic elements of system response?
- Are parameter and model risks well accounted for?
- Are there heuristic or semi-quantitative techniques that can be applied to the assessment of various disaster scenarios?
- Is it appropriate to assume the independence of extreme events or does clustering of unusual events occur (and is this signalled beforehand)?
- What knock-on effects (extreme correlations) can affect insurance contingency and the failure of financial subsystems?
- What risks are unpredictable or very difficult to model in a meaningful way?
- How can we treat such events (with little precedent information) for quite complex systems that are changing sometimes faster than human institutions (such as finance/insurance organisations)?

7. INDEX-BASED INSURANCE

Weather-climate insurance, reinsurance and disaster relief can gainfully include products and payouts based on related indices rather than just demonstrated loss. These indices can be based on general circulation descriptors (e.g. SOI), satellite measurements (e.g. areal rainfall or vegetation status), model predictions (e.g. potential crop yields for a community), regional determinants (e.g. reservoir or groundwater levels) or even biological responses (e.g. tree ring widths). Considerations of causality, measurability, transparency and relevance to other sectors and countries are likely to influence which indices form the optimal choice for weather risk management. Weather derivatives have so far met little interest in Australia, perhaps because of the limited opportunities to offset the risks based on, for example, rainfall in capital cities (Best 2007).

To date, IBI contracts have been used only outside Australia (although recommended in a very recent national review on climate variability and insurance); they have generally employed piecewise linear functions of a single index (although the response may be more non-linear and require other characteristics or multiple parameters – see Table 3).

A wider pooling of climate risks (to achieve offsetting, improve reinsurance activities and increase the resilience of insurance groups themselves) can use atmosphere-ocean teleconnection indices (either singly or in combination) if the variance of fluctuations in responses at many locations is accounted in a significant way by intra- and inter-annual, decadal and long-term components.

For such instruments to be practical, various types of risk need consideration. Basis risks (e.g. spatial or temporal factors that limit the offsetting of losses), data risks (e.g. incompleteness, integrity, duration), system characterisation risks (e.g. incomplete or misleading attribution) and prediction risks (model selection, initialisation, regime shifts) can all be aided by an extension of the observation base.

Palaeo-proxy information may be especially important for investigating the viability of catastrophe insurance and adaptation measures whilst detailed and extensive reanalysis datasets should find applications in most insurance design procedures.

8. HEDGING OF EWE PREDICTION ERROR

In the context of anticipating Australian climate extremes, the sources of predictability are only now becoming evident. Whilst studies over the last 25 years have shown strong associations of various ENSO parameters with seasonal variability of many climate and production outcomes in much of Australia, only the last decade of research has depicted the role of MJO, IOD, SAM and more regional indices (e.g. Rakich et al 2008, Williams and Stone 2008) and important phenomena such as cut-off lows in producing rainfall events. These associations can be readily employed within prediction schemes based on statistical methods of various types, pattern recognition and artificial intelligence techniques (e.g. Verdon-Kidd and Kiem 2008).

Skilful deterministic schemes usually await a better parameterisation of underlying processes and couplings (with considerable implications for initialisation and boundary/surface conditions). Coupled models are beginning to describe some teleconnections in a useful way. Whilst coupled ocean-atmosphere models such as POAMA generally show acceptable skill at 1-3 month horizons, model drift and limitations on incorporating soil moisture histories currently seem to limit longer-horizon skill. It is unclear whether the spread produced by ensemble prediction schemes gives a reliable indicator of forecast errors.

The short-term forecasting (out to 20 days) of EWE is the province of traditional numerical weather prediction models, now operating in ensemble, multi-model and downscaling modes to timescales of hours and spatial scales of kilometres. The utility of forecasts will improve with the increasing availability of remote-sensing information, model developments, computing power and skill in communicating the uncertainties and risks in forewarnings to agribusinesses. Prediction skill decays initially linearly and then in a power-law fashion with prediction horizon.

Medium-term predictions (1 to 18 months) or SCF are important for the anticipation of EWE, strategic decisions (e.g. what and when to plant, fertiliser and harvest), risk pricing (insurance/reinsurance policies and claims), resource optimisation (e.g. irrigation scheduling, carbon farming) and provision of government support. With the competing influences of climate cycles, memory, non-stationarity and nonlinearity on the larger prediction horizons, there can be an increase in predictability. Dependent on application and time horizon, numerical modelling may be usefully augmented by statistical hybrid schemes, use of analogues (either instrumental or palaeoproxy) and consideration of other forcing mechanisms (e.g. particulate or gaseous pollutants and solar variability).

The choice of approach to trust is not straightforward. Numerical models tend to whiten weather noise too much and forsake some of the predictability. Statistical models are limited by their reliance on the available historical information and its relevance if non-stationarity is increasingly evident, either due to low-frequency variability or climate change effects. SCF is more concerned with various characteristics of univariate or multivariate probability distributions, especially the tails for EWE considerations.

Decadal forecasting (2 to 20 years) becomes important in strategic decision-making (e.g. moving agriculture to different climatic zones), catastrophe modelling of possible insurance losses (e.g. Leslie et al 2008 for hail losses) and many aspects of climate adaptation. Numerical methods now require global and regional climate modelling, emissions scenarios, fuller treatment of atmosphere-ocean-land couplings and extensive performance testing to ensure a reasonable treatment of the features of EWE shown in Table 2.

Insurance and forecasting are natural partners, but forecasting has only recently been promoted as the “missing link” in risk management and adaptation of extremes (Osgood 2008). This synthesis can occur in many ways (e.g. Figure 2). Predictions of various types can generate forward curves of demand, volume and prices of weather-sensitive products that are then used in strategic farm decisions and the purchase of “optimal” insurance. The selection and costs of prediction method are tied to the likely errors in the forecasts; if the systematic errors are available, portfolio optimisation can be based on minimising their impact. This can extend to the purchase of forecast-contingent insurance or index-based contracts that can offset some of the consequences of forecast errors. To date, such agricultural work has used the categorical forecasts of SCF (e.g. the three ENSO phases as in Cabrera et al 2006) but Australian research using MJO phases or POAMA error distributions may soon address the effects of EWE for seasonal production and optimal risk cover.

9. CLIMATE ADAPTATION FOR THE 2020s?

If the climate for the next 20 years is dominated by a relatively unknown mix of natural variability and the forcing due to past anthropogenic emissions, climate risk information for adaptation and development planning (Wilby et al 2009) should be of two types; the encouragement of (a) scientific and socio-economic capacities to elicit meaningful signals to aid strategy and (b) climate scenario tools and data sets that represent well the changes in risk over various timescales. As with farmers appraising risk from seasons to decades ahead, there are many possible approaches with few clearly-enunciated conceptual frameworks for evaluation (Preston et al 2009). For many systems, there is surprisingly little progress in dealing with EWE of the current climate, and with effective ways to treat the spectrum of uncertainties (CREW 2008). Indeed, the issues of evaluation costs and relative importance of errors in climate and impact models are rarely detailed.

As teleconnections become better understood from a variety of methods (including historical reanalysis) and as annual to decadal forecasting becomes more skilful, new avenues for risk sharing will arise (Linneroth-Bayer et al 2008) and may redirect the current focus on loss-based insurance within countries and sectors that can afford the rising premium rates.

10. SUMMARY

- Data needs and risks are not yet satisfied for agricultural or insurance sectors, especially for medium to long-term horizons.
- Loss-based insurance may not be as viable in the future, especially if adaptation measures are not encouraged or rewarded financially.
- IBI has many advantages in widening the risk offset pool, the ease-of-use and assessment, the payment at times of crisis and its feasibility at many scales of communities and organisations.
- Insurance pricing and liquidity are bedevilled by data and basis risks and the lack of historical information in many parts of Australia and the world. Reanalysis datasets can provide long-term daily records of surface and upper-level weather information at near-global coverage, together with estimates of information reliability.

- Whilst predictions of <u>site conditions</u> will become easier as the output of downscaled, coupled global models becomes publicly available, there is a definite role for simpler and regional weather/climate indicators such as CAIs, especially for agribusinesses already well-versed in such ideas.
- System responses often require the use of multiple climate indicators to explain the behaviour over extended timescales and to form the basis of more reliable and comprehensible forecasting schemes.
- Multiple-index climate insurance could be based on a single multivariate payoff function, a linear combination of single-index contracts or more sophisticated copula-based schemes.
- Reanalysis datasets will reduce the data costs and risks for insurance and forecasting, as well as providing ready access to users worldwide.
- In particular, forecast-contingent insurance may provide a more natural approach to climate risk management than at present, as a way of hedging the consequences of uncertainties in the climate knowledge and the incompleteness of prediction schemes at all the time scales relevant to agricultural resilience.
- Coping and risk management of extreme weather events will require a combination of insurance, forecasting, adaptive operation strategies and full use of historical information (e.g. reanalysis), together with appropriate consideration of community vulnerabilities, uncertainties and communication requirements.

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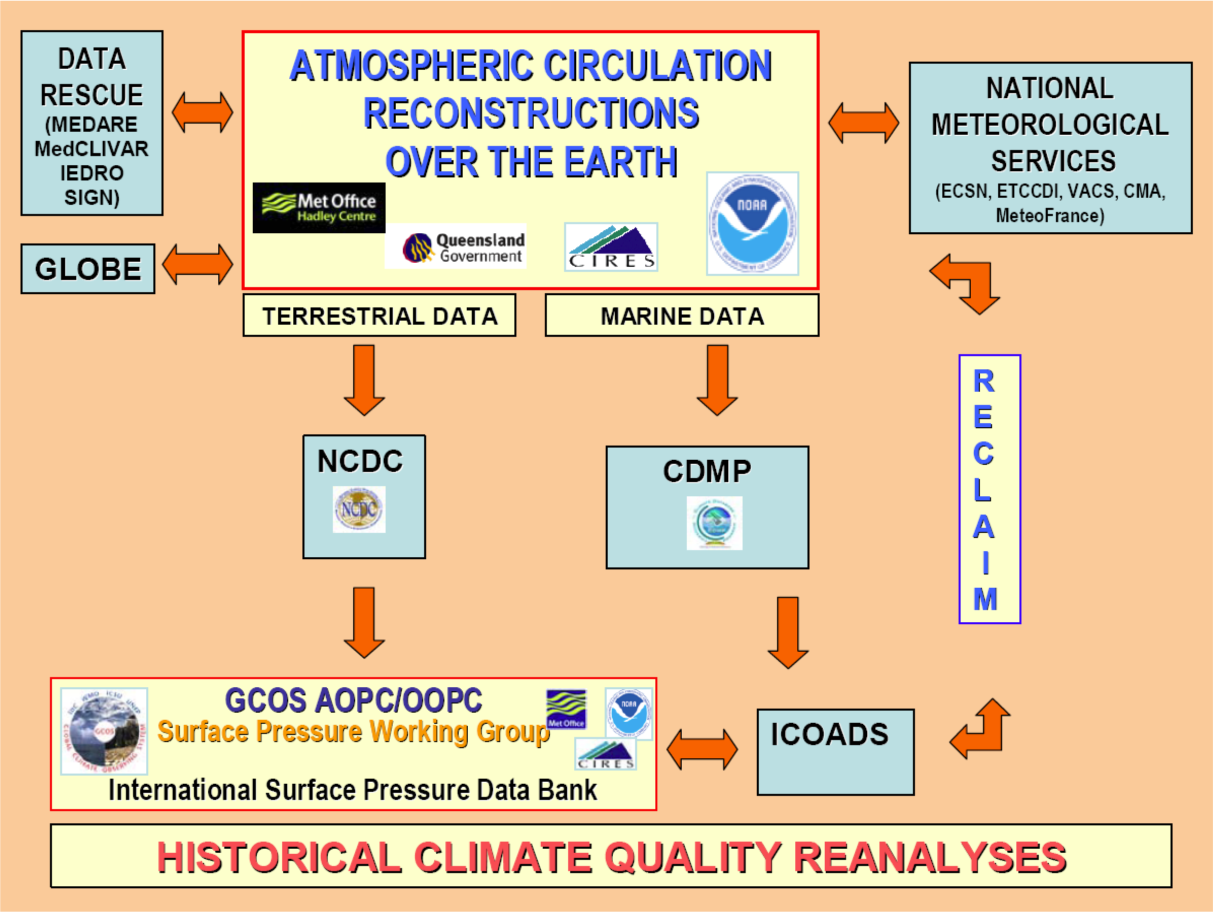

International infrastructure supporting and linking data requirements for ACRE and the surface input reanalyses it is supporting.

Figure 1 **Schematic of organisational structure underlying the ACRE project**

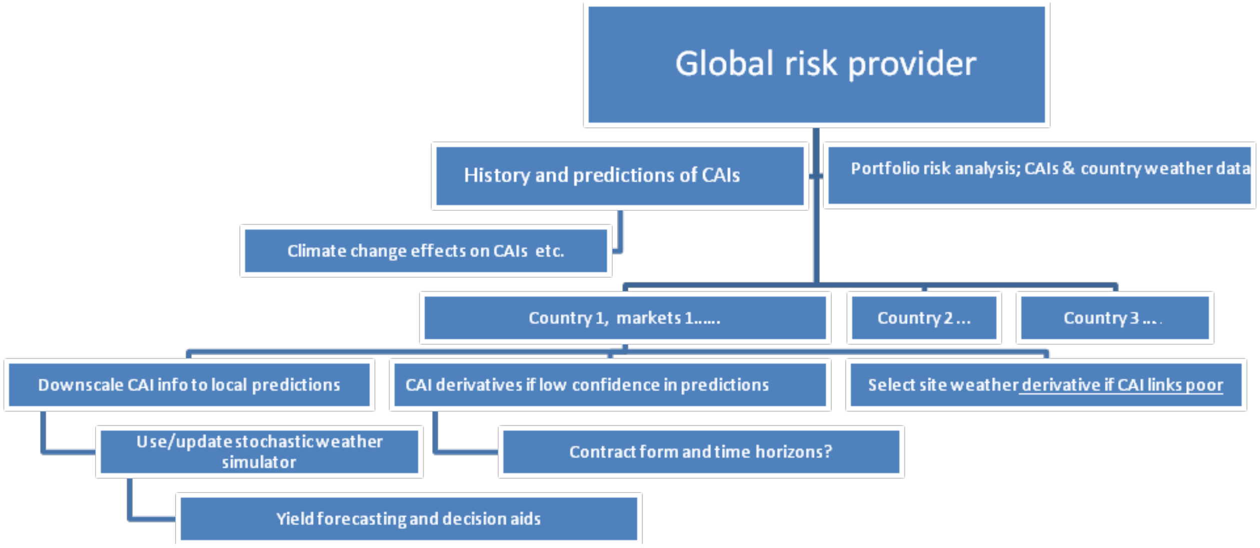

Figure 2 **Suggested use of CAI products for insurance and forecasting synthesis**

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