Supporting decision-making in the sugar industry with integrated seasonal climate forecasting

Roger C. Stone, Neil Cliffe, Shahbaz Mushtaq, University of Southern Queensland; and Yvette Everingham, James Cook University, Australia

An integrated approach has been developed linking seasonal climate forecasting models to sugar yield, production and sugar content models in order to improve predictability of the size of the Queensland sugar crop in any year.

Queensland produces 90 per cent of the Australian sugar crop, most of it destined for export. In this respect, approximately 32 million tons of cane and 5 million tons of raw sugar is produced in a 'normal climate year'. To produce this amount of sugar there are approximately 4,000 cane farms, 24 sugar mills and six bulk storage ports, making export agency Queensland Sugar Limited (QSL) the third-largest sugar supplier in the world. Climate extremes, especially excessive rain during the harvesting period (June to November) can result in massive losses for the entire industry – from the farm production component through to the milling and especially the marketing and export components. For example, in 2010, one component alone of the sugar industry suffered a loss of Au$500m following excessive rain through the entire harvest period, due to the development and continuation of the major La Niña event. This resulted in yield downgrading and inability to harvest many crops due to wet weather and flooding. Appropriate climate forecasting systems, especially those that have the capability to be integrated into sugar yield models and core decision systems, are urgently required to be developed and included at various stages of the management cycle in the sugar industry.

QSL requires precise forecasts of total yield, the likelihood of 'standover cane' (cane that cannot be harvested) and other likely disruptions due to weather and climate, especially excessive rain and lack of potential for dry spells. Other industry sectors are also closely involved, particularly all the sugar mill owners and operators in Queensland but also the cane growers themselves and their farming organizations such as the Queensland Cane Growers' Council. Direct knowledge of seasonal climate forecasting opportunities will allow farmers to make better decisions for the coming seasons about:

- Planting and harvesting
- Farm equipment purchases, which need to be more aligned to the season ahead – such as the purchase of irrigation equipment in potentially excessively dry seasons compared with purchase of tractors with wide tyres in potentially excessively wet seasons
- Scheduling of harvesting operations in potentially wet seasons to harvest the wet blocks first.

For farming and mill production, the following types of climate information are used:

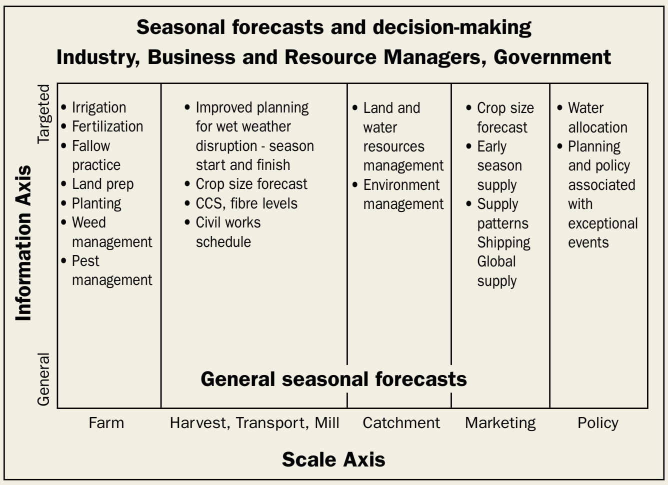
- Southern Oscillation Index (SOI)-derived seasonal forecasting (SOI phases)[1] for regional-scale forecasts updated each month on a rolling three-month basis
- Outputs from the new generation of seasonal forecast outputs locally and internationally, such as Bureau of Meteorology general statements of likely El Niño Southern Oscillation (ENSO) conditions, amd US Climate Prediction Center outputs on potential for El Niño and La Niña events
- Specific web-based services of the University of Southern Queensland (USQ), Bureau of Meteorology and other bodies
- Regular production of targeted climate forecast newsletters that provide reviews of the various climate forecast products currently available, specifically written for local regions and incorporating 'farmer jargon' where possible.

Export and marketing agencies use a fully integrated yield production model incorporating crop simulation model input (such as the Agricultural Production Systems Simulator (APSIM) and Canegrow) integrated with statistical climate forecast systems (SOI phases etc.), but also likely soon to incorporate aspects of the model code associated with Global Climate Model seasonal forecast systems such as Bureau of Meteorology POAMA/ACCESS; UK Met Office and European Centre for Medium-Range Weather Forecasts (ECMWF) seasonal forecast output downscaled to local regions. This type of output is in research mode only at this stage. Once deemed suitable for operational use, a direct operational system may be developed emanating directly from the climate agency itself.

The climate forecast information issued for growers and millers is tailored to the extent that the timing of issue of key aspects of the forecast is closely aligned with the major decisions being made across the state both 'on-farm' and at the mill production level:

- Close attention is paid to the output of probabilistic forecasts of likely extreme conditions, especially the potential for excessive rainfall according to the user's pre-defined criteria, but also in terms of aspects such as forecasts of numbers of frosts through the growing season and the need for extra irrigation activity

The relationships between scale, information, content and decision makers in defining a systems-based approach to applying seasonal forecasts in agriculture – a key example from the sugar industry



Source: After Hammer, 2000; Everingham et al., 2002; Stone and Meinke, 2005

An example of climate forecasting-yield forecasting output from a past year, using both targeted seasonal climate forecasting and crop modelling for each of the terminal mill regions in Queensland

Terminal Region	Forecast (t/ha)	Standard error (t/ha)	Historical Mean (t/ha)	Simulated Yield Component	Comment
Bundaberg	11.4	0.937	11.0	Biomass	Sugar yield forecast is unchanged from last month
Mackay	11.7	1.141	10.8	Biomass	Sugar yield forecast is slightly down (0.2 t/ha) from last month
Townsville	17.0	0.915	17.1	Biomass	Sugar yield forecast is unchanged from last month
Lucinda	10.9	1.109	10.6	Biomass	Sugar yield forecast is slightly down (0.2 t/ha) from last month
Cairns/ Mourilyan	10.3	0.860	10.5	Biomass	Sugar yield forecast is slightly down (0.1 t/ha) from last month

Source: Y. Everingham and QSL, 2012

- The more targeted forecasts are provided by USQ's climate scientists and agronomists using peer reviewed and verified climate forecast systems, mostly developed in-house
- Aspects associated with gathering the exact needs of growers and millers are derived from exhaustive workshops held in every growing region of the state. These workshops are highly effective and facilitated by a well-recognized extension specialist, who is also versed in climate forecasting systems and their output.

Stakeholder involvement

Stakeholders were identified following extensive meetings and workshops with the leading marketing and export agency and the leading grower representative body in the Queensland sugar industry. The following stakeholders were consulted within a focused meeting and workshop environment:

- QSL
- The Queensland Cane Growers' Council and each of its local branch offices
- Each of the eight sugar mill managers and key staff
- Some individual growers known to the project managers though previous research project activity.

The focused meeting and workshop process distilled the key issues, although this took a number of months to achieve.

Key agencies including the UK Met Office (Hadley Centre), the Centre for Australian Weather and Climate Research, James Cook University (JCU) and USQ were among the agencies consulted on the research and 'product' output process, with USQ leading the project.

Climate forecast information and associated research is provided by climate scientists at USQ in collaboration with the Bureau of Meteorology (Australia) and the UK Met Office. Aspects related to ECMWF involvement are negotiated through the UK Met Office.

Targeted output for the sugar industry is provided by USQ's Australian Centre for Sustainable Catchments through the auspices of QSL specialist management staff and local branch offices of the Queensland Cane Growers' Council and the Queensland Department of Agriculture, Forestry and Fisheries. More specific output will be provided through focused workshops conducted directly with various agencies involved with the sugar industry.

USQ (previously through the Queensland government) has established its own published and verified targeted seasonal climate forecasting system and this forms the mainstay of the required detailed seasonal climate forecasting outputs for the sugar industry. Importantly, this system can be seamlessly integrated into (sugar) crop simulation models such as APSIM and other yield forecasting models.[2]

With regard to the 'new generation' of climate model outputs (GCM) to be incorporated in a research framework for long-lead decision-making, agreements have

Example of forecasting probability values of excessive rainfall – Macknade Sugar Mill, North Queensland (values shaded in green are statistically significant)

on	lead (mths)	response	SOI period	32032 Macknade Neg	Pos	Fal	Ris	Neu
on	0	rainfall	aug/sep	0.05	0.47	0.10	0.23	0.22
on	1	rainfall	jul/aug	0.00	0.46	0.30	0.32	0.21
on	2	rainfall	jun/jul	0.00	0.56	0.13	0.26	0.16
on	3	rainfall	may/jun	0.00	0.41	0.25	0.43	0.10
on	4	rainfall	apr/may	0.06	0.32	0.21	0.39	0.19
on	5	rainfall	mar/apr	0.13	0.29	0.06	0.38	0.30
on	6	rainfall	feb/mar	0.23	0.29	0.13	0.25	0.30

Source: USQ/JCU

been made or are being made with the UK Met Office and Bureau of Meteorology for the development of suitably designed, more targeted output systems.

Funding

The above programme for the Queensland sugar industry is directly funded as a research and development project by QSL ($A2.7m plus all data and travel costs). Thus, following earlier funding by a research and development corporation through levies made on the value of crops harvested in any year, the funding is now being provided directly from the private sector. This process was necessary because climate science and developments in seasonal climate forecasting could provide obvious benefits to all sectors of the Queensland sugar industry, which was suffering massive losses, especially in La Niña years.

The project has a five-year timescale with plans to provide continuous funding beyond that if the research and development and ongoing output is deemed to be successful in aiding decision-making across the industry, especially in the exporting and marketing sectors.

Making it happen

There are four key institutions involved in climate forecast and crop modelling provision:

- USQ — climate science, engineering, remote sensing, aspects of downscaling, farmer education, and project leadership
- JCU — key aspects of crop simulation modelling
- UK Met Office (through a research agreement) — research involving the capability of a new generation of climate models (UK Met Office and ECMWF) for the sugar industry in Queensland; provision of data feeds from current GCM outputs
- Bureau of Meteorology — provision of outputs from POAMA/ACCESS model into an integrated overall modelling system; provision of generalized output involving the Madden Julian Oscillation, including information provided by the Tropical Climate Bulletin.

The current project development involves QSL, Queensland Cane Growers' Council (head office and all branch offices) and the Queensland Department of Agriculture, Forestry and Fisheries (both head office and the Mackay regional office).

It should be noted that the above activity is currently within a research and development framework. If deemed successful by all sectors of the sugar industry, especially the marketing and export sections of the overall value chain, then an operational system involving regular provision of output will be provided by a combined team comprising the UK Met Office and the Australian Bureau of Meteorology, the current operational statistical seasonal climate forecast system in use in Queensland and also used by the Queensland Government, and crop model output runs developed by USQ and JCU.

Evaluation

A full feedback process conducted through intensive workshops is an integral part of the project. The research project will be evaluated against agreed milestones in October 2012. Each workshop is evaluated through use of a carefully designed questionnaire provided to each participant. The project and project funding (and follow-up services) will be adjusted in light of the evaluation received, especially by the donors. Aspects related to climate change are not directly included in the project.

Capacities

At present, mostly existing personnel have been engaged in the research project and development stages of this work. These include two climate scientists (one at PhD level), one mathematics/statistics specialist (at PhD level) one sugar cane crop simulation modelling specialist (PhD level), one specialist extension office (at MSc level) and computer programming project support staff.

It is probably a mistake to regard the separation of capabilities according to whether individuals are 'users' or 'developers'. In this project there are two climate scientists with very extensive research publication and operational capabilities, located at USQ. They interact with key climate scientists at the UK Met Office and the Bureau of Meteorology, and they also have the capacity to liaise directly with agronomists and crop modellers engaged at JCU. Key user agencies such as QSL or Queensland Cane Growers' Council do not have climate scientists on their staff; rather, they employ chemical engineers or environmental scientists.

Some capacities are lacking. It can be difficult to locate climate scientists within national organizations who have the required breadth of understanding of the computerized interfacing needs in linking a climate model to a crop simulation model, for example. Rather complex software development is needed that can integrate all modelling and output systems involving a wide range of expertise. Additional challenges involve the sheer effort required in developing legal agreements between agencies and associated activity.

A massive amount of innovation is needed if one is serious about linking climate science with real decision-making, especially if the output required is much more than normal climate variables, such as 'tons of sugar per hectare' or similar. The key innovation is in development of engineering and software systems that can provide the integration necessary for complex outputs — which is often where the decisions exist.

What next?

The project's goals are to ensure continued improvement to the provision of yield and other outputs which involve climate forecast systems as opposed to mere 'outputs'. This means there is a need for awareness of breakthroughs and developments in seasonal forecast systems (especially coupled models) and that these must be created in such a way as to allow integration into decision systems.

The research programme and operational outputs described here could easily be scaled up for application in any region where sugar, or other crops, is grown.

The project's main challenges are:

- The need for continued funding — it is easy to lose ongoing funding with the result that the same industry unnecessarily suffers from the same impacts for a number of years
- The need for closer interaction with key industry sectors (not necessarily the ones first thought of such as farmers, but to address issues across the entire value chain in production)
- Keeping all relevant agencies 'on side' as it may not necessarily be the local agency that has the best research capacity in integrated climate systems research and development.

This project satisfies the principles of the Global Framework for Climate Services. All countries could easily benefit from the approach and the model outlined here can be applied for all countries, although aspects related to the value of climate systems to marketing and trade would need further evaluation for certain countries. The programme addresses all three geographic domains identified in the principles: local farmers and mills, regional production issues, and global trading and marketing issues. Operational climate services are the core element of the project — but there is a need to recognize the importance of the capability of the underlying system to be integrated into other systems such as agricultural models.

A climate forecasting fact sheet provided to QSL for the use of millers, farmers and other general users of the information that will be provided both during the course of the research and development stage and when the process becomes operational

Source: QSL, USQ, JCU

A real-world farmer example

Sugar farmer Darren describes his decision-making in his own words, in early winter 2009, after attending a 'Managing for Climate' workshop in Mackay, Queensland, Australia:

"Climate pattern in transitional stage so I keep a watchful eye on the climate updates."

"I take special interest in the sea surface temperatures (SST) particularly in the Niño 3 region."

"There is currently some indication of warming in the Niño 3 region which hints at a possible El Niño pattern developing."

"Replant would be kept to a minimum."

"Harvest drier areas earlier, even if commercial cane sugar may be affected."

"We don't run the farm based solely on climate information and forecasts, it's just another tool to consider when making decisions."

Darren's decision-making concerns use of seasonal climate forecasting information in sugar cane harvesting and replanting. Note the detail of understanding and ownership of climate information and forecasting this farmer has gained through involvement in participatory research and focused workshop activity.

Source: USQ/JCU

Notes and References

I: Agriculture

Climate science and services to support decision-making

1. http://www.climate.go.kr

Climate services for agricultural production in Guinea Bissau

1. Quoted in the 2006 National Action Plan for Adaptation, 2006
2. Rui Nené Djata Mane, Manuel Indi; Analise da Fileira do Arroz, 2003
3. Project GBS/87/013/B/01/16

Supporting decision-making in the sugar industry with integrated seasonal climate forecasting

1. Stone, R.C., Hammer, G.L., and Marcussen, T. (1996) 'Prediction of global rainfall probabilities using phases of the Southern Oscillation Index'. Nature 384, 252-255.
2. Stone, R.C. et al (1996) ibid.

Everingham, Y.L., Muchow, R.C., Stone, R.C., Inman-Bamber, G., Singels, A., and Bezuidenhout, C.N. (2002) 'Enhanced risk management and decision-making capability across the sugarcane industry value chain based on seasonal climate forecasts'. Agric. Systems 74, 3, 459-477.

Fawcett, R.J.B. and Stone, R.C. (2010) 'A comparison of two seasonal rainfall forecasting systems for Australia.' Australian Meteorological and Oceanographic Journal, 60, 1, 3-11.

Further reading:

Hammer, G.L. (2000) 'A general systems approach to applying seasonal climate forecasts'. In Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems: The Australian Experience (eds. G.L. Hammer, N, Nicholls, and C. Mitchell), pp51-66. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Stone, R. C., and Meinke, H. (2005) 'Operational seasonal forecasting of crop performance'. Philosophical Transactions of the Royal Society, B 360, 2109-2124.

Seasonal climate prediction in Chile: the Agroclimate Outlook

1. Barret, B.S., J.F. Carrasco and A.P. Testino, 2012: 'Madden-Julian Oscillation (MJO) modulation of atmospheric circulation and Chilean precipitation'. Journal of Climate, 25, 1678-1688
2. Montecinos, A. and P. Aceituno, 2003: 'Seasonality of the ENSO related rainfall variability in central Chile and associated circulation anomalies'. Journal of Climate, 16, 281-296.

Quintana, J. and P. Aceituno, 2012: Changes in the rainfall regime along the extratropical west coast of South America (Chile): 30 – 43°S. Atmósfera 25 (1), 1-22.

3. CEPAL (Comisión Económica para América Latina y El Caribe), 2009: La Economía del Cambio Climático en Chile: Síntesis, 88 pp.
4. Martinez, R. and A. Mascarenhas, 2009: 'Climate risk management in western South America: implementing a successful information system', Bulletin WMO: Weather, Climate, Water. Vol. 58(3), 188-196.
5. www.meteochile.gob.cl
6. www.minagri.gob.cl/agroclimatico
7. www.minagri.gob.cl/agroclimatico/informacion_agrometeorologica.php
8. www.agroclima.cl

Climate services and agriculture in the Caribbean

1. Toba N (2009) 'Potential Economic Impacts of Climate Change in the Caribbean Community'. Latin America and Caribbean Region Sustainable Development Working Paper No. 32 In: Assessing the Potential Consequences of Climate Destabilization in Latin America, W Vergara (ed.). World Bank, pp 35-47.
2. Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: 'Regional Climate Projections'. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
3. Organisation of Eastern Caribbean States (OECS). 2004 Grenada: Macro-Socio-Economic Assessment of the damages caused by Hurricane Ivan. September 7, 2004. OECS.
4. Farrell, D., Trotman, A. & Cox, C. 2010, Drought Early Warning and Risk Reduction: A Case Study of the Drought of 2009-2010, UNISDR, Geneva, Switzerland.
5. ECLAC, 2005. Guyana Socio-Economic Assessment of the Damages and Losses Caused by the January-February 2005 Flooding. Economic Commission for Latin America and Caribbean.
6. ECLAC, 2006. Guyana: The impact on Sustainable Livelihoods Caused By the December 2005 – February 2006. Flooding Economic Commission for Latin America and Caribbean.
7. CAMI: www.cimh.edu.bb/cami
8. CIMH, 2012. http://www.cimh.edu.bb/pdf/CariCOF_Summary_Report.pdf
9. McKee, T.B.; N.J. Doesken; and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.

Gibbs, W.J.; and J.V. Maher. 1967. 'Rainfall deciles as drought indicators'. Bureau of Meteorology Bulletin No. 48, Commonwealth of Australia, Melbourne.

10. The Climate Predictability Tool is a product of the International Research Institute for Climate and Society (IRI)
11. http://63.175.159.26/~cimh/cami/national_bulletin.html

Further reading

World Bank, 2007. World Development Indicators Online. World Bank, Washington, DC.

MOSAICC: an interdisciplinary system of models to evaluate the impact of climate change on agriculture

1. Confiño, A. S., San-Martín, D. and Gutiérrez, J. M. (2007). 'A web portal for regional projection of weather forecast using GRID middleware', Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 4489 LNCS(82-89.
2. Hsiao, T. C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D. and Fereres, E. (2009) 'Aquacrop-The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize', Agronomy Journal, 101(3), 448-459.

Raes, D., Steduto, P., Hsiao, T. C. and Fereres, E. (2009) 'Aquacrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description', Agronomy Journal, 101(3), 438-447.

Steduto, P., Hsiao, T. C., Raes, D. and Fereres, E. (2009) 'Aquacrop-the FAO crop model to simulate yield response to water: I. concepts and underlying principles', Agronomy Journal, 101(3), 426-437.

3. Aerts, J. C. J. H., Kriek, M. and Schepel, M. (1999) STREAM (Spatial tools for river basins and environment and analysis of management options): set up and requirements, Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 24(6), 591-595.
4. Notebaert, B., Verstraeten, G., Ward, P., Renssen, H. and Van Rompaey, A. (2011) 'Modeling the sensitivity of sediment and water runoff dynamics to Holocene climate and land use changes at the catchment scale', Geomorphology, 126(1–2), 18-31.
5. Bouwer, L. M., Aerts, J. C. J. H., Droogers, P. and Dolman, A. J. (2006). 'Detecting the long-term impacts from climate variability and increasing water consumption on runoff in the Krishna river basin (India)', Hydrology and Earth System Sciences, 10(5), 703-713.
6. Winsemius, H. C., Savenije, H. H. G., Gerrits, A. M. J., Zapreeva, E. A. and Klees, R. (2006) 'Comparison of two model approaches in the Zambezi river basin with regard to model reliability and identifiability', Hydrology and Earth System Sciences, 10(3), 339-352.
7. Ward, P., Renssen, H., Aerts, J. and Verburg, P. (2011) 'Sensitivity of discharge and flood frequency to twenty-first century and late Holocene changes in climate and land use (River Meuse, northwest Europe)', Climatic Change, 106(2), 179-202.

Ward, P. J., Renssen, H., Aerts, J. C. J. H., Van Balen, R. T. and Vandenberghe, J. (2008) 'Strong increases in flood frequency and discharge of the River Meuse over the late Holocene: Impacts of long-term anthropogenic land use change and climate variability', Hydrology and Earth System Sciences, 12(1), 159-175.

8. Thornthwaite, C. W. (1948) 'An Approach toward a Rational Classification of Climate', Geographical Review, 38(1), 55-94.

Thornthwaite, C. W., Mather, J. R., Carter, D. B. and Drexel Institute of, T. (1957) Instructions and tables for computing potential evapotranspiration and the water balance, Centerton, N.J.: Drexel Institute of Technology, Laboratory of Climatology.

9. Löfgren, H., Harris, R. L. and Robinson, S. (2001) A standard