PROJECT 1.1: DETECTION AND ATTRIBUTION OF CHANGES TO WEATHER SYSTEMS AND LARGE SCALE CIRCULATION DRIVERS

Principal Investigators

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Milestone 1.1.3: Report on observed changes in low frequency weather systems affecting WA in both observations and models

Completed 31/12/2010

This milestone has been completed and was reported on extensively in the IOCI3 Report 2.

Milestone 1.1.4: Report on possible projected changes in SH circulation and WA weather systems under future IPCC scenarios

Completed 31/12/2010

This milestone has been completed and was reported on extensively in the IOCI3 Report 2.

Milestone 1.1.5: Formulation, development and documentation of an inverse modelling technique for attribution studies

Progress Report – due to be completed 31/12/2011

Key research findings

Climate models simulate the response of the atmosphere and oceans to some forcing agent. Some examples of forcing agents include greenhouse gases, aerosols, and changes in solar and volcanic activity as well as land use. One way of attributing climate change to a particular agent is to specify a forcing in a climate model and observe the response of the system to that forcing. If the response is similar to the observed response then one can infer that the observed change is indeed due to that particular forcing agent. A more elegant and systematic way of attributing climate change is to directly calculate the forcing from the dynamical equations, given a particular observed climatic response. This is an inverse model of climate.

An inverse climate model may be formulated iteratively. In this method, one starts with a guess of what the forcing should be and calculates the response of the model climate to that forcing. If the model response is different to the observed response then one adjusts the forcing by an amount proportional to the difference between the observed and model climates. In this way the model climate in the next step is then nudged closer to the observed climate. One can continue this process until the model climate is as close to the observed climate as desired. At this stage, then, the iterated forcing can be said to be consistent with the observed climate, and indeed is the driver of the observed climate. Thus, the inversion procedure has been accomplished. Figure 1 shows the anomalous (1975–1994 - 1949–1968) vertically averaged July zonal wind climate as obtained by this iterative method using a two level spherical quasigeostrophic model. In this model the two vertical levels are taken to be the 300 hPa and 700 hPa pressure levels and vertical averages refer to averages of data over these levels.

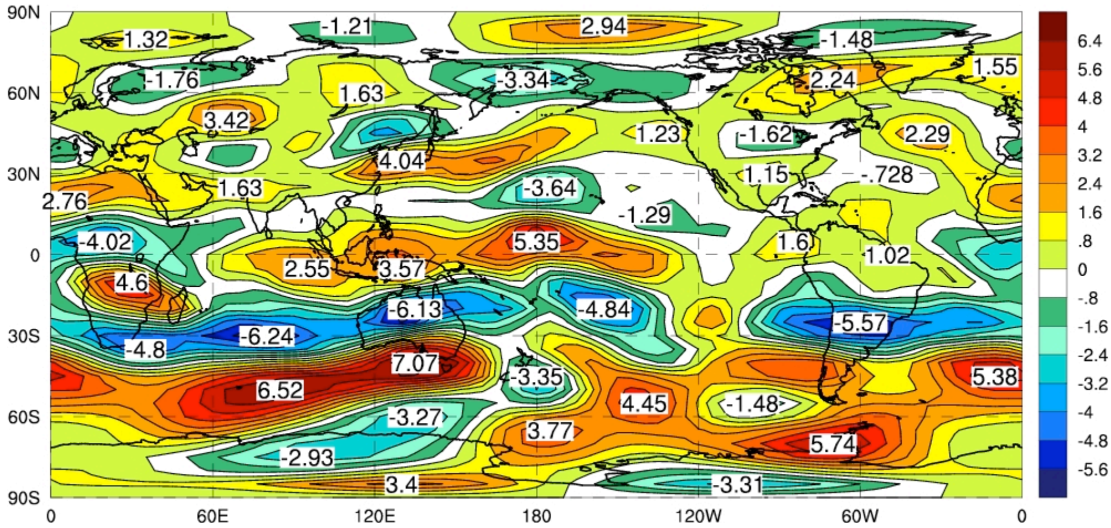

Figure 1: Simulated anomalous (1975-1994 – 1949-1968) vertically averaged July zonal wind climate.

The simulated climate anomaly, obtained after 22 iterations, compares very well with the observed climate anomaly over the same period, obtained from NCEP/NCAR reanalysis data, as shown in Figure 2. A similar anomalous pattern, albeit with reduced magnitudes, is obtained over the shorter period (1975–1984 - 1959–1968) showing that the pattern is unrelated to the lack of data over the Antarctic region prior to 1958 as shown in Figure 3.

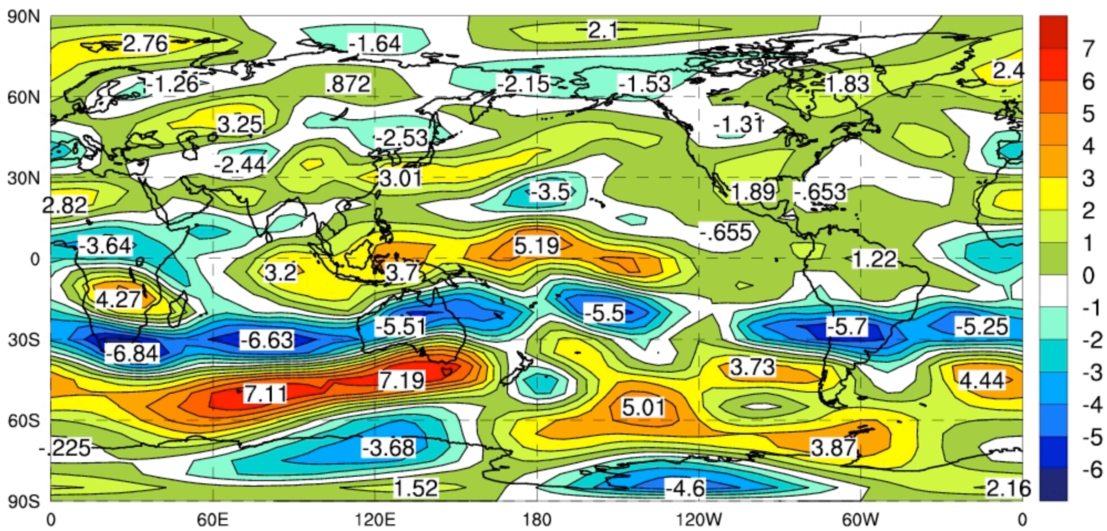

Figure 2: Observed anomalous (1975-1994 – 1949-1968) vertically averaged July zonal wind climate.

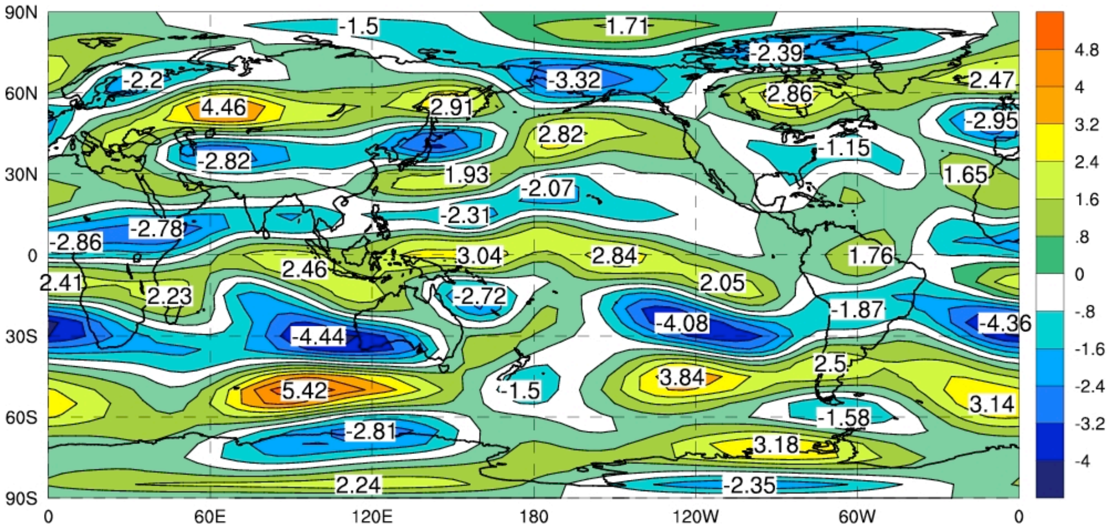

Figure 3: Observed anomalous (1975-1984 – 1959-1968) vertically averaged July zonal wind climate.

Figure 4 shows the forcing function anomaly corresponding to the anomalous climate of Figure 1. This is the pattern of the driver responsible for the climate anomaly. From this pattern climate change may then be attributed to one or more forcing agents.

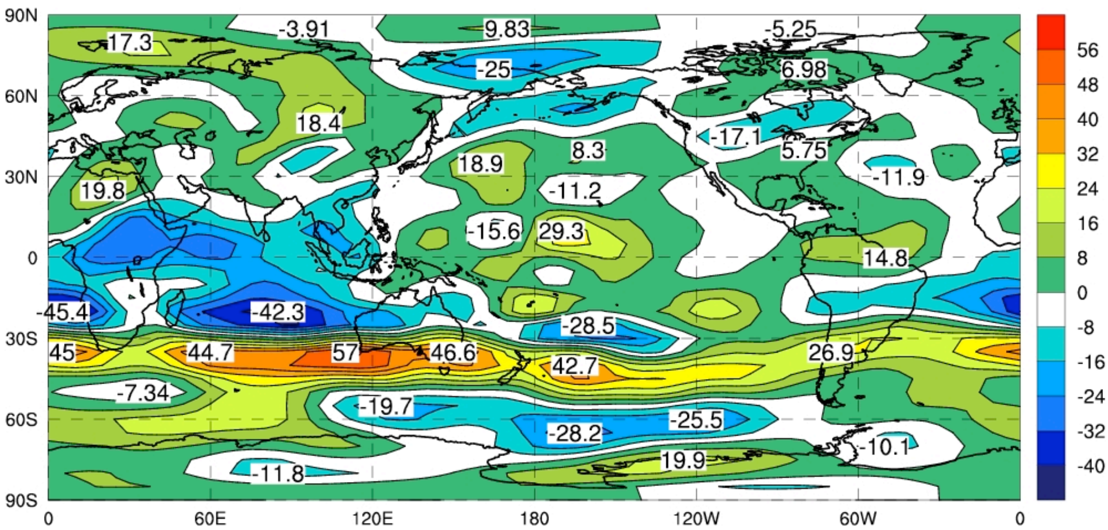

Figure 4: Simulated anomalous (1975-1994 – 1949-1968) vertically averaged July zonal wind climate forcing function.

The iterative method is a simple and reliable way of obtaining the forcing functions responsible for climate change. However, it can be computationally expensive as it takes several iterations for the model climate to approach the observed climate. This is particularly true if the parameter that controls how rapidly the climate responds to its forcing is small as is the case in the oceans for example. Our experiments also suggest that the error between the observed and simulated climates tends to saturate after a certain number of iterations. This implies that the iterative method might not be the optimal method under some circumstances.

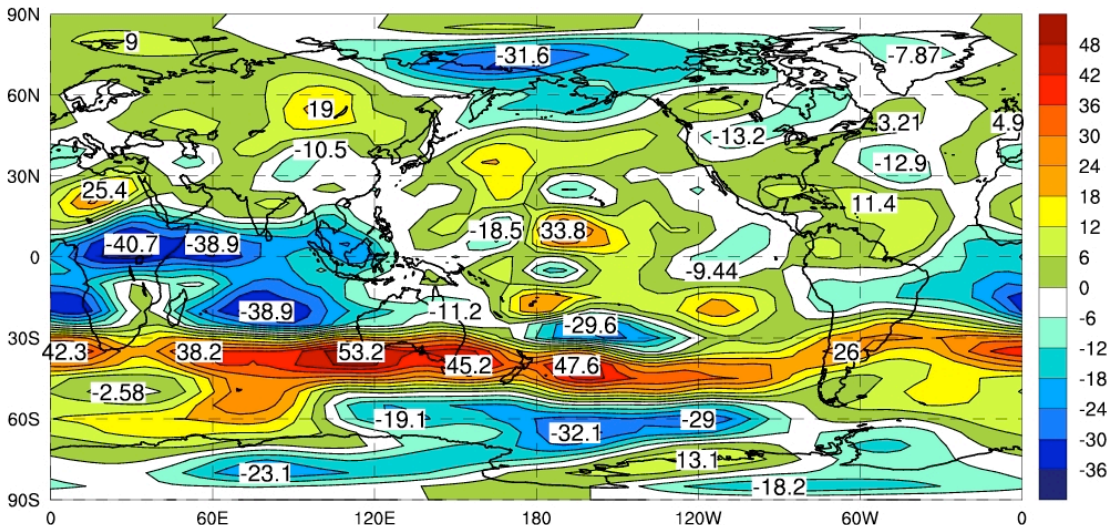

Figure 5: Anomalous (1975-1994 – 1949-1968) vertically averaged July zonal wind climate forcing function as reconstructed by closure based inverse model.

With these considerations in mind, we have formulated and developed another inverse method that is more computationally efficient. This method is motivated by a statistical dynamical closure model called the Quasi Diagonal Direct Interaction Approximation (QDIA). To determine information about climate from numerical simulations statistical information needs to be calculated from simulated time-series data. In a closure model however the statistical information is obtained directly by solving the closure equations. This means that an inverse model of climate can be formulated by simply inverting the closure equations and no simulations are required as in the iterative method. The difficulty with this approach is that the QDIA equations are quite complicated and computationally intensive. However, it is possible to formulate a closure model that has the same basic form as implied by the QDIA but in which some of the complicated and computationally intensive terms are not explicitly calculated. They are instead parameterised in terms of other model variables. The parameters of the model are then determined from just a few simulations of slightly perturbed climate states. This is the approach that we have taken to overcome the closure problem in formulating the alternative inverse model. Once the parameters of the model have been determined the forcing functions can then be calculated directly from a given climate state. Figure 5 shows the anomalous forcing function corresponding to the climate anomaly of Figure 1, this time calculated using the closure based inverse model. The agreement between the iteratively obtained forcing function (Figure 4) and the closure-model based forcing function (Figure 5) is very good. There is some error in the estimation of the magnitudes but the overall pattern of the climate driving is well reproduced by the closure-model based method.

The climate driving pattern obtained by both methods suggests that a combination of global (longitudinally invariant) and local effects are responsible for the observed climate change. It highlights the importance of identifying driving patterns in attribution work, as these patterns are in general different to the actual climate response (Figure 1). Having established the feasibility and importance of this methodology to attribution work within the context of the quasigeostrophic model, the next step is to apply it to more complex models such as the primitive equation model.

List of Publications Accepted and Submitted

Zidikheri, M.J. and J. S. Frederiksen, 2011: *Inverse methods for attribution of climate change*, ANZIAM J., (submitted).

Frederiksen, J.S. and C.S. Frederiksen, 2011: *Role of dynamical modes in changing Southern Hemisphere climate.* ANZIAM J. **52**, C72-C88.

http://anziamj.austms.org.au/ojs/index.php/ANZIAMJ/article/view/3892

Frederiksen, J.S. and C.S. Frederiksen, 2011: *Twentieth century winter changes in Southern Hemisphere synoptic weather modes.* Advances in Meteorology, (submitted).

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2011: *Australian Winter Circulation and Rainfall Changes and Projections.* Int.

Journal of Climate Change Strategies and Management, Paper 4, Vol. 3, Issue 2.

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and Projections in Australian Winter Rainfall and Circulation: Anthropogenic forcing and internal variability.* International Journal of Climate Change: Impacts and Responses, **2**, 143-162.

Frederiksen, J.S., C.S. Frederiksen, S.L. Osbrough and J.M. Sisson, 2010: *Causes of changing Southern Hemispheric weather systems.* GH2009 book, CSIRO publication. "Managing Climate Change", Chapter 8, 85-98, Eds. Imogen Jubb, Paul Holper and Wenju Cai, CSIRO Publishing.

List of IOCI-Related Presentations at National and International Conferences, Symposia and Workshops

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and projections in southern hemisphere climate and weather systems.* 19th Australian Institute of Physics Congress, Melbourne, Australia, Session 1D: Meteorology, Oceanography, Environmental Physics & Climate Change, 5-9 December, 2010

Zidikheri, M.J. and J.S. Frederiksen, 2010: *Inverse method for attribution of climate change*. The 15th Biennial Computational Techniques and Applications Conference, Sydney, Australia, 28th November – 1st December, 2010.

Frederiksen, J.S. and C.S. Frederiksen, 2010: *Role of dynamical modes in changing Southern Hemisphere climate.* The 15th Biennial Computational Techniques and Applications Conference, Sydney, Australia, 28th November – 1st December, 2010.

Frederiksen, J.S. and C.S. Frederiksen, 2010: *Changes in Southern Henisphere climate and weather systems during the 20th century.* Australia-New Zealand Climate Forum 2010 Conference, Hobart, Tasmania, Australia, 12-15 October, 2010.

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and projections in southern Australian winter rainfall and circulation.* Australia-New Zealand Climate Forum 2010 Conference, Hobart, Tasmania, Australia, 12-15 October, 2010.

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and Projections in Australian Winter Rainfall and Circulation:*

Anthropogenic forcing and internal variability. 2nd International Climate Change Conference, Qld. Univ., Queensland, 8-11 July, 2010.

Zidikheri, M.J., Frederiksen, J.S., and Frederiksen, C.S., 2011: *Attribution of Southern Hemisphere climate change and projections.* Greenhouse 2011 Conference, Cairns, Australia, 4th – 8th April, 2011.

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2011: *Observed Changes and Projections in Southern Hemisphere Mid-latitude Storm, Rainfall and Circulation,* European Geosciences Union (EGU) General Assembly, Vienna, Austria, 3-8 April, 2011.