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Hydrology and Earth System Sciences Discussions

Interactive comment on "Defining the climatic signal in stream salinity trends using the Interdecadal Pacific Oscillation and its rate of change" *by* V. H. McNeil and M. E. Cox

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RESPONSE TO EDITOR AND REFEREES

Editor

The typographical and detailed considerations pointed out by the editor and referees are accepted and appreciated. It is also accepted that the final sections need a fuller and clearer explanation.

With respect to rigour of analysis, for the sake of brevity, the methodology as originally presented does not include previous work leading up to this investigation, in which the

SOI and raw IPO were extensively tested as indicators before the use of the rate of change of the IPO was considered. It was not realised that there would be such a degree of concern among some researchers about the use of this indicator. It has been made plain that that the processes relating the IPO and local climates are not clear at present, but at least one author, as quoted below, has reviewed the available research on the topic and mentioned some possible mechanisms.

It is also acknowledged that statistical significance cannot be determined for the models produced, but this is unavoidable when working with autocorrelated time series with very long periodicity which is only partially recorded. The findings can still be indicative and useful, even in a mainly qualitative sense.

The authors believe that this work is relevant to the title of the Special Issue because it is directly related to the observation and definition of very broadscale patterns in regional data (groundwater levels and stream EC), and the relating of these to patterns in a natural phenomenon (climate). The results can be directly used to guide catchment management and sustainable development. The methods used include novel approaches as well as building on the work of other researchers in a multidisciplinary field.

This paper resulted originally from a recognition of pattern on a regional basis. While the paper does not specifically discuss the neighbourhood of a singularity, it does offer one approach to how the underlying environmental pattern evolves over time. The authors realise that a more comprehensive description of the project and previous work would improve both the adequacy of the methods and the relevance of the paper.

Referee 1

Firstly, the technical considerations pointed out by Referee 1 are accepted and appreciated. It is also accepted that the final sections need a fuller and clearer explanation. Briefly, stream EC time series are corrected for flow before trend analysis, because over a limited period, short term noise due to dilution overwhelms the underlying changes in salt concentration at a given flow rate which indicate changes to salt sources in the catchment. The Thorburn equation is one of a number of algorithms proposed in the literature for flow correction, depending on the conceptual mechanism assumed to be dominant. The Thorburn equation produces a reverse S shaped curve, which assumes that the mean EC of low flows is asymptotic to a limit related to local groundwater, whereas the lower mean of high flow EC approaches that of overland flow. A rank based trend analysis (seasonal Kendall Tau) is performed on the EC residuals after flow correction.

Referee 2

It is accepted that the discussion on climate variables in section 2 paragraphs 1 and 2 needs to be revised, and the guidance offered by Referee 2 in this regard is appreciated. (In particular the works of Kiem et al.(2002) and Kiem and Franks (2004) and reference to the PDO.)

To address the concerns of referees 2 and 4, the 50 year trendline on Figure 1 can be removed from this figure.

In respect of the concerns of Referee 2, Section 3.2 Paragraph 3, the reason for using differences between the January IPO for the rate of change is that it represents a simple change from wet season to wet season. It was considered that the rate of variation in both the IPO and the decadal scale changes being modelled in the data were sufficiently gradual that the actual method of defining annual difference was not critical for this exploratory study. However, it is accepted that different methods of measuring the change, as well as different styles of modelling suggested by other referees, may be beneficial. The authors could include the derived time series, which is representative of a very large spatial dataset, as supplementary material.

The model calibration and verification data points are shown together on figures 5 and 8. They can be shown differently, with separate R2 values as suggested by Referee 2.

Referees 3 and 4

Firstly, it is deeply regretted that Referee 4 received a copy of the paper without references and Figure 11 attached. The authors are at a loss to understand how this occurred, as all other referees apparently received the references. McNeil and Cox (2002) is a conference paper produced at an earlier stage of this project which is available on request. It uses a randomisation approach to detect the degree of correlation with the derived groundwater level climate signal in Queensland bores.

Secondly, to address the referee's concerns about the heavy smoothing of the Interdecadal Pacific Oscillation, the IPO is a smooth series, because of the way in which it is derived using CEOF functions to detect slow decay of variance in noisy data. The IPO series presented in Figure 1 is as it was provided by Dr Jim Salinger of NIWA (National Institute of Water and Atmospheric Research New Zealand) as stated in the acknowledgements. It is this smooth, low periodicity that is such a useful property for analysing the decadal scale variations in hydrologically related time series when the focus is not on short term variability or prediction. Micevski et al. (2006) have included a similar figure illustrating the same IPO series as is presented in this article.

It is obvious that the IPO was higher during the 1980s to 1990s than it was during the 1950s and 1970s, each of which had very wet periods. In fact the phases of variation of the IPO about its mean has frequently been used by other authors such as Verdon et al. (2004) and Micevski et al.(2006) in their hydrological studies.

Whilst it would be possible to carry out a more stringent analysis of the Burdekin flow record with the IPO, it has been included in the paper mainly to illustrate that patterns in the rate of change of the IPO reflected patterns in Queensland hydrology in accordance with the theme of the Special Edition, and because both present and antecedent stream discharge are major factors contributing to stream EC. The discussion of the Burdekin could be replaced by a summary of the EC trend study described in QDPI (2004), which first revealed broadscale patterns in stream EC which were opposed to

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that expected from landuse, particularly a falling trend throughout the 1980s. This was a decade when clearing and irrigation were still expanding, and principles of catchment management had not yet been implemented on a large scale. The main topics of this paper are not the relationship between the IPO and stream flow, which is already discussed by other authors such as Verdon et al. (2004), but rather the use of the IPO and its derivatives as an indicator of climatic effects on groundwater tables and stream salinity.

The Referees 3 and 4 have a particular concern that there is no conceptual model presented of how the IPO affects the hydrometeorology of Queensland. It is never inferred in this paper that there is a cause and effect relationship between the IPO and the hydrology and EC, but rather that the patterns displayed in each were responding to similar underlying global trends. The use of the IPO as an indicator would therefore seem reasonable considering that it has already been applied to published hydrological studies including those mentioned above. It is a rational extension of the methodology to use the rate of change of the IPO rather than the phase change when working with time series.

In relation to the conceptual aspects, Micevski et al. (2006), whilst acknowledging that the effects of the IPO on eastern Australian rainfall and climate are poorly understood, reviewed the literature pertaining to the reasons for the effects of the IPO on Australian rainfall. Some of the hypotheses put forward are summarized as follows:

* Interdecadal sea surface temperature (SST) variations may affect convection in the equatorial Pacific Ocean leading to shifts in the rising branch of the Walker circulation, which may then influence ENSO's effect on Australian rainfall;

* There may be increased atmospheric subsidence over Australia, i.e. lower rainfall, resulting from an anomalous regional Hadley circulation that may form above the warmer, western Pacific SSTs.

* Movement of the regional convergence zones such as the South Pacific Convergence

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Zone (SPCZ) and the Intertropical Convergence Zone (ITCZ) about their mean positions. The IPO has been shown to be associated with the location of the SPCZ in a similar manner to ENSO, except on multidecadal timescales, and it is expected that the IPO has a marked effect on the location of the ITCZ, similar to that on the SPCZ.

In justification of the method of analysis, and particularly the climatic indicators used as requested by the Editor and Referees 3 and 4, this paper has been developed from earlier work summarised in an unpublished manuscript which can be made available on request. As a consequence of this work, the IPO and its rate of change were selected as being the most useful broadscale climatological indicators among the several that were examined. The first approach was to model the extracted hydrological and EC time series with the SOI, but no relationship was found, despite the use of lags, means, quarterly averages, running means and Fourier analysis. It soon became apparent from examining the SOI and the water table and stream EC time series that fluctuations in the SOI were of too high a frequency.

It was then that the IPO was investigated as a smoothed decadal scale indicator which was evidently considered by other authors with climatological expertise as being relevant to Queensland hydrological conditions as quoted above. Again, neither linear nor non-linear regression produced a relationship between the raw IPO and the water table time series. However, when the two series were examined together, it was obvious that the water tables reflected not the actual value of the IPO, but rather the way the series was changing at the time.

In the previous work, a run of Principal Component analyses were used to aid indicator selection. They showed that although stream flow is closely associated with the SOI (and the IPO second derivative), water tables are closely aligned with the δIPO. The EC (COND) is between the IPO and the δIPO.

For this previous work, data for the time series was only available to about 1995, and at that stage, satisfactory linear models were derived for both the water tables and the

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EC.

Since then, more data has been digitised and been incorporated into the databases for both EC and water levels, covering the state better and adding about seven years to the time series, so it was decided to re-do the model before submission for publication. However, given the short duration of the records (mentioned by referee 3) covering only a few peaks in the decadal data, the models for the current paper were kept to the minimum number of relevant parameters to reduce the risk of over-fitting. When the models were rerun with more recent data, it was found that the δIPO and IPO were sufficient for the groundwater level model. The analysis could certainly be redone using multiple regression and consolidating equations 1 and 2 if required, but makes little difference to such a simple model.

In reference to the suggestion by Referee 3 that the time series approach be abandoned for the EC data, it is necessary to use a time series approach to meet the objective of the study. This is because the simulated time series are the only means of separating the climate pattern out of a salinity record so that the landuse signal can be defined. At the local community scale, landuse practices may be managed whereas climate risk must be accommodated. Similarly, it would not be appropriate to the study to relate monitored records to local rainfall and temperature data, because the real value of the climate indicator is in areas with very little reliable long term local data. The authors believe that the foregoing discussion justifies the approach taken and the climatological indicators used, but more information about the testing and evaluation could be provided if required.

Conclusion

In summary, it is accepted that the models used in this study are exploratory at this stage, and that other climatic variables and modeling techniques might improve the results. However the authors feel that enough has been done to demonstrate:

* That climatic influences on groundwater tables and stream EC can be broadscale

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and with decadal time scales;

* That these climatic effects can be revealed in the patterns of time series derived from the medians of very large, noisy and irregular data sets with reasonable spatial continuity, because local weather is cancelled out;

* That the climatic nature of these decadal patterns can be verified by modeling with suitable climatic indicators, and the model used as a tool to separate climatic effects from the landuse record (usually also decadal) from records at individual sites where local controls are not available.

* That the IPO and its rate of change can be used as indicators for this modeling. It is accepted that there may be other, possibly better climatic indicators, but this would require further study, as the SOI and raw IPO have already been tested.

* The derived time series could be provided as supplementary material for the interest of other researchers.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 2963, 2006.