What is winter?

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Skip M^c^Kinnell (right, photographed with Ian Perry at the ESSAS Symposium) is Deputy Executive Secretary of PICES. He is frequently found as a Guest Editor of PICES-sponsored special issues in various primary journals, and had a non-trivial role in the development of the first PICES North Pacific Ecosystem Status Report. This PICES Press article is the second in what may become a series of articles on climate, data, indices, and biology. It is an abstract of some ideas presented during an invited seminar at the PICES CFAME workshop in Victoria in May 2005, and at the Centre de Recherche Halieutique Méditerranéenne et Tropicale in Sète, France, in June 2005.

It is common practice in our business to define *winter* as a mean of some climatic variable of interest during some often variable period of time, typically centered on January. The practice is so widely accepted that the appearance of *djf* (December, January, February average) is rarely questioned. Whether it is the PDO (Pacific Decadal Oscillation), the NPI (North Pacific Index), the ALPI (Aleutian Low Pacific Index), the SOI (South Oscillation Index) or any number of climate indices, winter is defined as the average of the winter monthly values of these indices. The arithmetic mean is the most widely used measure of central tendency, and as such it is supposed to be, and we would like it to be, representative of something meaningful. But is it always? The particular thought-tangent is laid out in the examples that follow.

Let us define the monthly intensity of the Icelandic Low (IL) as the latitude-adjusted integral of sea-level pressure (SLP) of all grid points < 1007 mb within the domain (70°N - 30°N, 70°W - 2.5°W), calculated from the monthly mean data (http://www.cdc.noaa.gov/cdc/reanalysis/reanalysis.shtml) from the NCEP/NCAR re-analysis. The weights compensate for the convergence of grid points with increasing latitude, and were set to range in values from 1.0 for grid points at 20°N to 0.36 at 70°N. The resulting index is a time-series of measurement of the IL from 1948 to 2005 for each winter month. Comparing Decembers with Januarys and Januarys with Februarys, it immediately becomes apparent that there is no within-year persistence in the intensity of the IL during the winter months (Fig. 1). Correlations among months range from –0.18 to 0.02. This means that the intensity of the IL in any month provides no indication of its intensity in subsequent months.

There is also no within-year persistence in the mean latitude of the IL; correlations between winter months range from –0.15 to 0.2 among months across years, and there is no within-year persistence in the mean longitude of the IL; correlations range from –0.16 to 0.07 among months across years. This means that the location and intensity of the IL in any month is independent of the previous month. Perhaps this result is trivial because it is not unexpected from a "white-noise" climate system, but the implications are not so trivial for the study of the relations between climate and marine ecosystems especially when winter averages (*e.g. djf*) are so commonly reported as the climate index of interest.

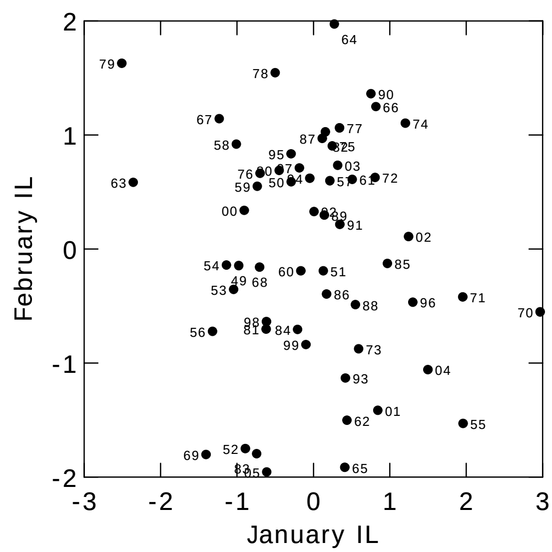

Fig. 1 Index of the intensity of the Icelandic Low (IL) in February (measured in standard deviations, positive is stormier) versus intensity of the IL in January from 1948-2005. Plot point symbols indicate years.

An average *djf* IL winter index can arise from various scenarios: three consecutive months of average conditions, a very stormy December, a moderately windy January, and a calm February, or from a year with a calm December, a moderately windy January, and a very stormy February. Although the annual *djf* values of these scenarios are identical, the implications for the marine ecosystem are not, because both the physical and the biological components of the system have a high amplitude annual cycle. Indeed, the annual cycle is the dominant forcing cycle in the temperate/subarctic latitudes, so the temporal evolution of events is important. The consequences for the annual survival of a marine species that spawns in February, for example, may depend on whether it is stormy or calm during that particular month. Yet if we compare the annual survival of the species against *djf* winter averages, there may be no apparent effect of climate because the "winter" average was not the most important feature for this species.

Years with average values of the IL (*djf*) do indeed include some of the most stormy and most calm months in the time-series. December 1970 was very calm (3 s.d. less than the mean), while December 1998 exceeded the mean by 3 s.d., yet the winter IL (*djf*) values for both years are near average. This problem occurs in part because the mean of a small sample (n=3 months) is not well determined and in part from the stochastic nature of Sea Level Pressure (SLP) data in this region. But the main conclusion is that the winter IL (*djf*) is not a consistent index of "winter". This same phenomenon occurs in the North Pacific with various measures of the intensity and location of the Aleutian Low.

A convenient example of potential problems with climate indices landed on my desk as I wrote this. The over-winter survival of least auklet (*Aethia pusilla*) near the Aleutian Islands is reported to be better in years when the August to April average values of the NPI were low, *i.e.* during stormy August-April periods (Jones *et al*. 2002). However if the climate index is disaggregated by month and compared with annual survival, there is indeed a significant relationship between survival and late winter/early spring pressures (Fig. 2), but it leads to the opposite conclusion. Calm, rather than stormy months of February and March are associated with better survival. As it is not known when the birds actually die, neither hypothesis is falsified by this result, but disaggregating the climate index allows a greater range of potential hypotheses to be explored.

The degree to which a multi-month average index is representative of a period in question at an arbitrary location can be approximated from the temporal e-folding scale, *i.e.* how quickly does the autocorrelation decay? Where there is persistence in some features among months, time-averaged indices of monthly data are more representative of conditions over the interval than if there is no persistence. The 1-month lag correlation at all grid points in the NCEP/NCAR SLP data indicates that the tropical latitudes and the Southern Ocean are regions where SLP persistence is greater (Fig. 3). Seasonal indices of SLP in these regions are probably more representative than elsewhere.

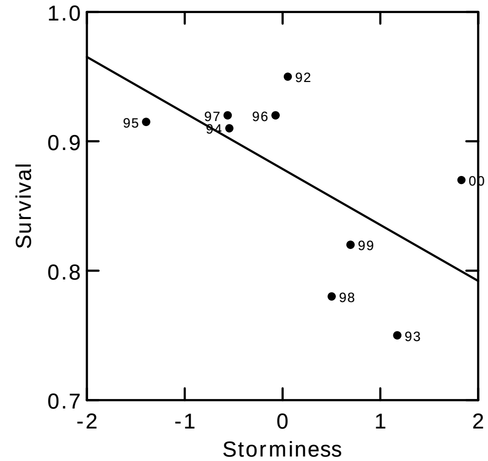

Fig. 2 Least auklet over-winter survival versus an inverse variant of the North Pacific Index for March (+ values are stormy); years indicated.

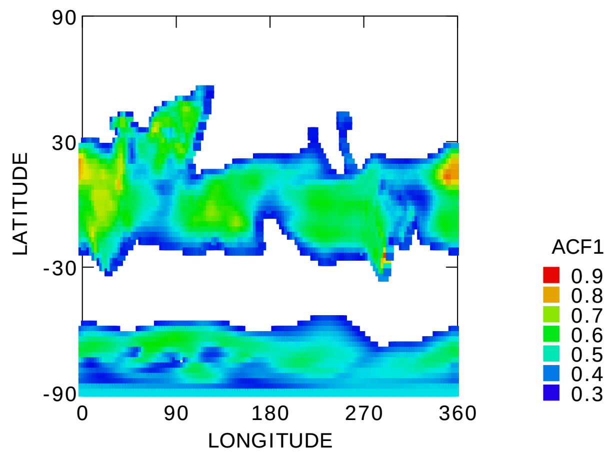

Fig. 3 Magnitude of 1-month lag correlations (greater than |0.3|) at all grid points in the NCEP/NCAR SLP re-analysis data from 1948-2005.

An example of a winter SLP index with some promise to explain SST variation in the Northeast Pacific has emerged in the western tropical Pacific warm pool region, where SLPs are rather autocorrelated (r ~ 0.5-0.6) among winter months. For convenience, let's call it the WTP Index. The point of maximum correlation between the WTPI and Northeast Pacific SSTs is located near the Solomon Sea (7.5°S 152.5°E), essentially embedded within the WTP warm pool. Winter average values of the WTPI (*djf*) at this location are substantially better correlated with spring SSTs in the Northeast Pacific than are the classical indices (SOI, NINO 3.4 SST) of tropical climate (Fig. 4). It suggests that the physics of the teleconnection between the tropics and

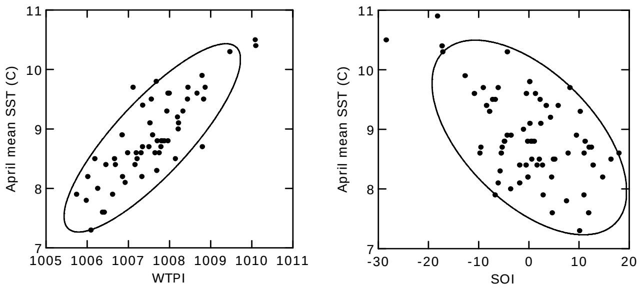

Fig. 4 Kains Island SST in April versus (a) winter Western Tropical Pacific Index and (b) Southern Oscillation Index from 1948-2004.

the mid-latitude Northeast Pacific is more closely associated with the annual ocean/atmosphere physics of the western tropical Pacific than to ENSO *per se*.

Figure 4b suggests that Northeast Pacific SSTs in spring are affected by the state of the tropics only during ENSO years *i.e.* if the El Niños are removed from this panel, there is no significant correlation, whereas Figure 4a indicates that variation in winter SLP in the western tropical Pacific is the major determining factor of spring SSTs in the Northeast Pacific, throughout the full range of variability in both variables. Stripping off the El Niños does not affect the statistical significance of this relationship; it holds even in non-ENSO years. The hypersensitive response of the Northeast Pacific SSTs in spring might be the result of several correlated responses, each contributing to affect SST anomalies in a similar way (*e.g.*, heat fluxes and advection), and this should be investigated.

Climate indices aspire to distill complexity to its essence. But it seems that the distillation process is equally capable of producing black sludge as perfume, and the bottles are not always clearly labeled. So we might benefit from a bit of circumspection before the contents of these bottles are used for ecological problem-solving. In particular, it seems that the spatial and temporal integrals over which the indices are computed require greater attention to ensure that they represent the major features of a process/forcing of interest. The consequences of not getting this right could be a prolonged academic diversion down a dead-end in our search for better understanding. I encourage the development and exploration of better indices, and the thoughtful application of the ones we have.

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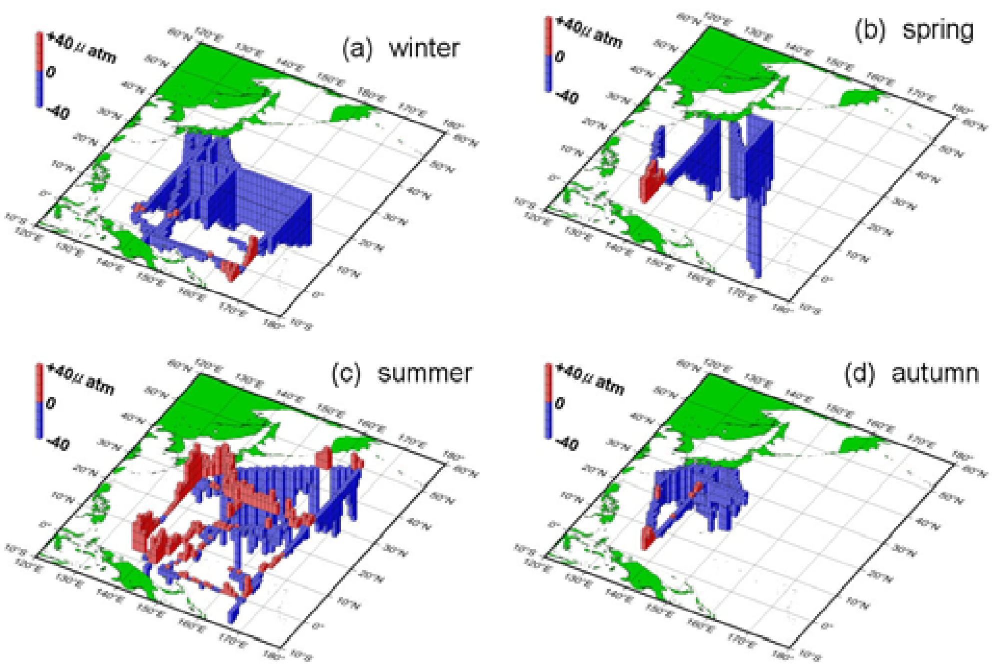

Fig. 4 Difference in the CO_2 partial pressure between the ocean and the atmosphere in the western North Pacific in 2004. Red/blue pillars show that oceanic pCO_2 is higher/lower than atmospheric pCO_2.

In the western subtropical Pacific, oceanic pCO_2 was lower than atmospheric pCO_2 in winter, spring and autumn 2004, implying that the ocean acted as a sink for atmospheric CO_2, whereas this region changed to be a source in the summer. In the western subarctic Pacific, oceanic pCO_2 was lower than atmospheric pCO_2 in wide areas in summer 2004. In the equatorial Pacific, the ocean usually acts as a source for atmospheric CO_2. Oceanic pCO_2 in the region, however, has been at low levels since 2002, and was greatly lower than atmospheric pCO_2 in winter 2004.