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# The use of the Pacific Atmospheric Classification system as an indicator of future long-term climate impacts on the early life history of salmon from the Fraser River.

by


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**ABSTRACT**

The Pacific Atmospheric Circulation classification incorporates three types of atmospheric circulation. The classification is based on the concepts of Russian meteorologists and classifies circulation into three types, Z, M1, and M2. The winter frequency of the M1 (northwesterly meridional flow) type was found to be a general indicator of the long-term pattern of Fraser River flows in this century. Above average northwesterly circulation (M1) is associated with increased winter precipitation and deeper snow pack in the Fraser River drainage. In general, the dominant periods correspond to periods of above average flows from the Fraser River. The M1 processes were dominant during the early 1900s, 1948-1973, and possibly beginning in the mid-1990s. The switch from dominant to non-dominant circulation patterns generally corresponded to the published regime shifts of 1925, 1947, 1977, and 1989. Fraser River salmon production accounts for approximately 40% of salmon production in British Columbia waters. Fraser River flows may affect salmon production during spawning, freshwater rearing and in the early marine period in the Strait of Georgia through the estuarine circulation. Changing flows, increased freshwater temperatures and changing ecosystem dynamics within the Strait of Georgia affect Pacific salmon production. Understanding when changes occur in the persistence of trends in atmospheric wind patterns will assist in the understanding of climate impacts on salmon produced in the Fraser River, including global warming.

## Background

The Strait of Georgia, located between Vancouver Island and the British Columbia mainland, is an important marine ecosystem on Canada's west coast and one of the most important juvenile salmon rearing areas in the Pacific Ocean. The Canadian portion of the Strait is 220 km long, 33 km wide, and has a surface area of about 6900 $km^2$ (Thomson 1981). The maximum depth is 421 m and the average depth is 155 m. It is a semi-enclosed sea that is connected to the Pacific Ocean in the north by Johnstone Strait and in the south by Juan de Fuca Strait. These two passages restrict the movement of water in and out of the Strait, resulting in reduced salinity and a temperature profile that is influenced on the surface by the Fraser River and on the bottom by inflowing deep water from offshore. The Fraser River contributes about 80% of the freshwater runoff into the Strait. Water circulation, mixing, and stratification in the Strait are largely influenced by its freshwater discharge, together with tides and wind. (Thomson 1981). The freshwater that is added to the Strait must eventually leave the Strait on the surface and is replaced by bottom water from offshore. This nutrient rich bottom water is eventually mixed into the surface, providing nutrients for phytoplankton that are food for other organisms in the food chain, particularly salmon. The Fraser River discharge starts to increase in March, reaches a maximum in June, gradually decreases in July, August, and September, and remains near minimum levels throughout the rest of the year.

Wind mixing is the dominant physical mechanism that entrains nitrates from the nitrate-rich deep water into the surface layer in the Strait of Georgia (St. John et al. 1993).

Increases in primary production were related to the wind mixing events and Fraser River discharge. For example, when Fraser River flows were reduced, wind mixing was more effective and productivity increased. Variations in river runoff have also been shown to affect the nutrient supply to the Strait of Georgia (Harrison et al. 1994). It is this period from April to September, when production is periodically nutrient limited, that we believe is important for salmon survival.

The pattern of Fraser River discharge affects the early marine survival of chinook and coho salmon in the Strait of Georgia (Beamish et al. 1994). In particular, extreme discharge events were closely related to extreme year to year variation in abundance of salmon. Beamish et al. (1995) observed an abrupt decrease in marine survival of hatchery reared chinook that was coincident with a major decline in annual Fraser River flows, despite a more than doubling of hatchery production of chinook smolts. In addition, the percentage of Strait of Georgia coho salmon remaining off the west coast of Vancouver Island was associated with the flow of freshwater from the Fraser River (Beamish et al. 1998a).

Moore (1991), Moore and McKendry (1996), and Mantua et al. (1997) showed that there were trends in the amount of runoff from large rivers on the west coast of North America that were related to trends in climate. Moore (1991) showed that the depth of the snowpack in the Fraser River basin declined by 22% over the same period that Fraser River flows declined by 28%. Thus, there is a clear relationship between the dynamics of the ocean ecosystem in the Strait of Georgia and climate.

Recently, Beamish et al. (1998b) described the relationship between six climate indices and trends in salmon abundance in the Pacific Ocean. The Atmospheric Circulation Index (ACI), although a global index of wind patterns in the northern hemisphere (Vangengeim 1952, Girs 1971, Beamish et al. 1998b), reflects climate/ocean conditions in the Pacific, probably through linkages with the Aleutian Low Pressure system. King et al. (1998) produced a Pacific Circulation Index (PCI) in a similar manner to the ACI, and concluded that the ability to forecast winter PCI would be useful in predicting ocean conditions and fish production in the Pacific Ocean. In this study, we examine the relationship between the new index of winter northwesterly atmospheric circulation states, and Fraser River discharge into the Strait of Georgia.

Since Fraser River salmon production accounts for approximately 40% of salmon production in British Columbia waters, forecasting the persistence of Pacific atmospheric circulation patterns may assist in understanding future salmon production in the Fraser River.

**Methods**

Daily sea surface level pressure fields were used to construct daily maps from December to March for the years 1900-1998 for the Pacific-North American region of the northern hemisphere. The AARI (Arctic and Antarctic Research Institute, St. Petersburg, Russia) used these maps to classify the daily atmospheric circulation processes visually according to the classification developed by Girs (1971). This Russian classification scheme characterises the atmospheric circulation process into three types, specifically identified as Z, M1, and M2. They use Z-type for westerly zonal flow, M2-type for southwesterly meridional flow, and M1-type for northwesterly meridional flow.

The number of days from the December-March period for each type of process was expressed as anomolies from the long-term mean (Fig. 1). An index of Pacific Circulation was developed using the winter M1 anomalies (King et al. 1998) and this index expresses climate and ocean region shifts in the north Pacific ocean. Therefore, we examined winter M1 anomalies in relation to Fraser River flows.
Fraser River flow data were obtained from the water Resources Branch, Environment Canada and were exposed as the average monthly flow in $m^3$ sec.

**Results**

The trends in winter Pacific Atmospheric Circulation and annual Fraser River flows are similar during this century (Fig 2A,B). The number of days of northwesterly circulation (M1) during the winter (Dec-March) varied without trend from 1900-1922, was well below average from 1923-1948, well above average from 1949-1975, except for a 3 year period from1959 to 1961, below average until 1988, and occilated between above and below average until 1998 although there may be a change to above average northwesterlies in the mid-1990s. A five-year running average through the data indicates change points in the mid-1920s, late 1940s, mid-1970s and early 1990s.

Similarly, increasing and decreasing annual Fraser River flows showed the same trends with low river flows (mid-1920s to early 1950s; mid-1970s to late 1980s) and high river flows (early 1950s to mid-1970s) corresponding to below and above average winter northwesterlies respectively. There appears to be a shift to more dominant northwesterly winds and higher Fraser River flow beginning in the mid-1990s. This relationship was significant at $p<0.05$.

**Discussion**

The pattern of trends in both northwesterly winds and Fraser River flows is similar to known patterns in climate that are both global and north Pacific wide (Beamish et al.1998b). Major shifts in climate and ocean conditions in the North Pacific Ocean have been identified around 1925,1947,1977, and 1989 (Ebbesmeyer et al. 1990, Yamamato et al. 1986, Francis and Hare 1994, Minobe 1997, Beamish et al. 1998b). These climate regime shifts have been shown to be synchronous with changes in salmon production (Mantua et al. 1997; Beamish et al. 1998b). Gargett (1997) suggested a relationship between the Aleutian low intensity, snowpack, and freshwater input to the Strait of Georgia. This would be expected to have consequences on the concentrations and cycling of nutrients in the Strait with cascading effects on salmon. Trends in Fraser River flows have been related to abundance and distribution of coho salmon (Oncorhynchus kisutch) (Beamish et al. 1998a, c). However, the relationships between wind patterns off the west coast of British Columbia and Fraser River flows has not been demonstrated. Moore and M^c^Kendry (1996) showed a relationship between atmospheric circulation pattern and snowpack conditions in British Columbia. They found that snowpack conditions in southern British Columbia were heavier during 1966 to 1976 and lighter during the 1977 to 1992 period, and were consistent with wind patterns over the North Pacific. These two periods correspond to dominant northwesterly winds and increased Fraser River flow, and weak northwesterly winds and decreased Fraser River flow, respectively. It is clear, therefore, that the relationship between wind patterns and Fraser River flows reported here are linked through variation in snowpack in the Fraser River drainage. In addition to the impact of Fraser River flow on Strait of Georgia circulation and nutrient cycling, changes in flow also affect the thermal habitat and oxygen availability for the freshwater phase of salmon (Northcote 1992; Arnell et al. 1996). Decreased flows reduce dissolved oxygen content and increase water temperatures. Northcote (1992) suggested that these conditions would have the greatest physiological stress on juvenile salmon during summer.

We believe this is the first study that links atmospheric circulation patterns with variation in snowpack and Fraser River flows. We show that classification of atmospheric pressures can be simple yet informative about environmental factors affecting salmon production. Recent studies have shown a link between Fraser River flows and Pacific salmon survival (Beamish et al. 1994, 1995, 1998c); however, the underlying mechanism remains to be identified. One possible mechanism is a direct link between flows and primary production, which is important to the mechanism prepared by Beamish and Mahnken. 1998. The ability to identify persistent trends in atmospheric processes also provides the link between freshwater discharge and ocean conditions, which Gargett (1997) proposes is important in regulating salmon production in British Columbia waters. Because the Fraser River is a spawning and rearing area for almost one half the salmon in British Columbia, and has been associated with processes affecting marine survival of salmon, we propose that the linkage between Pacific circulation (M1) processes and Fraser River discharge provides an opportunity for forecasting long-term trends in salmon production.

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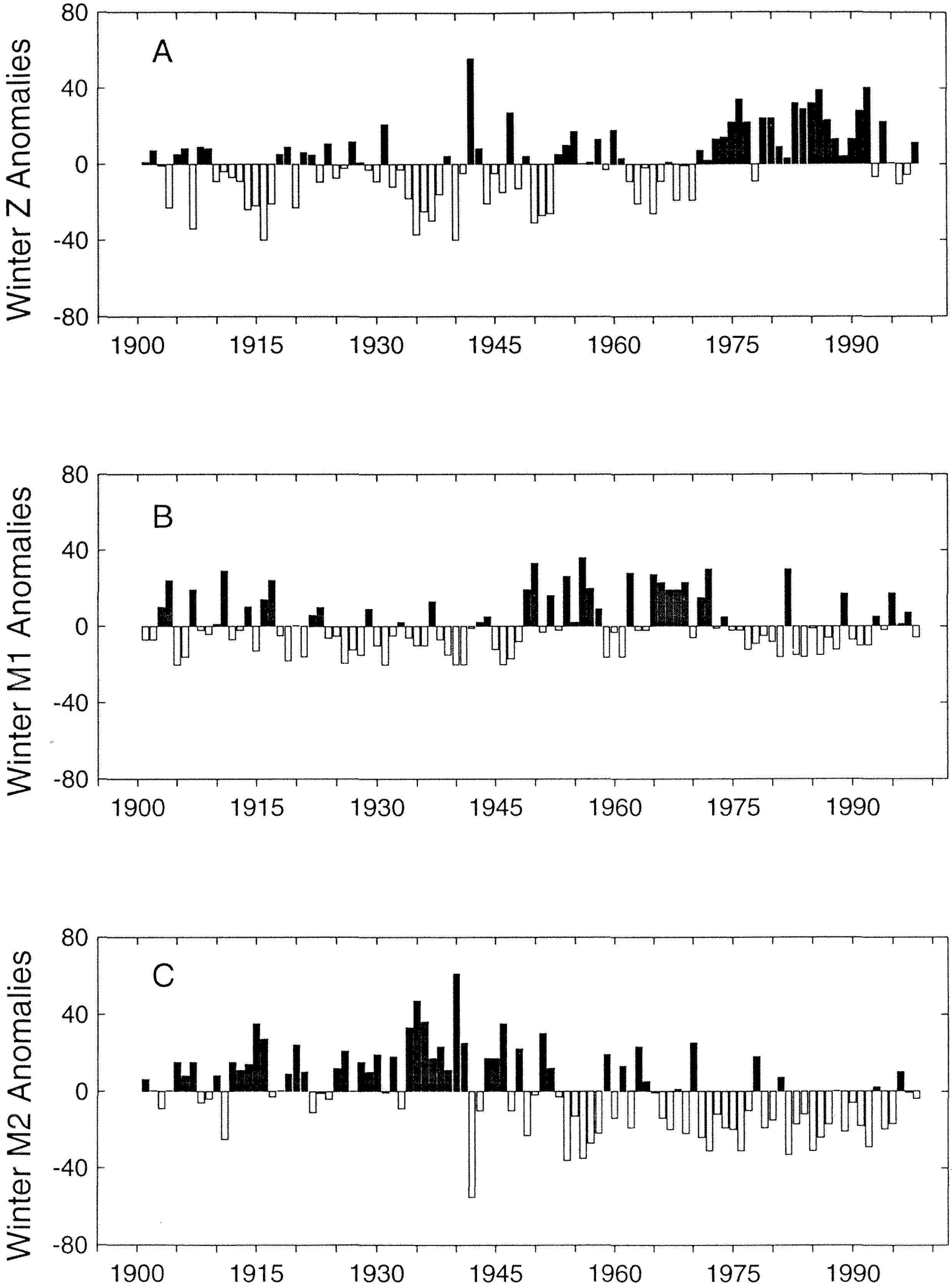
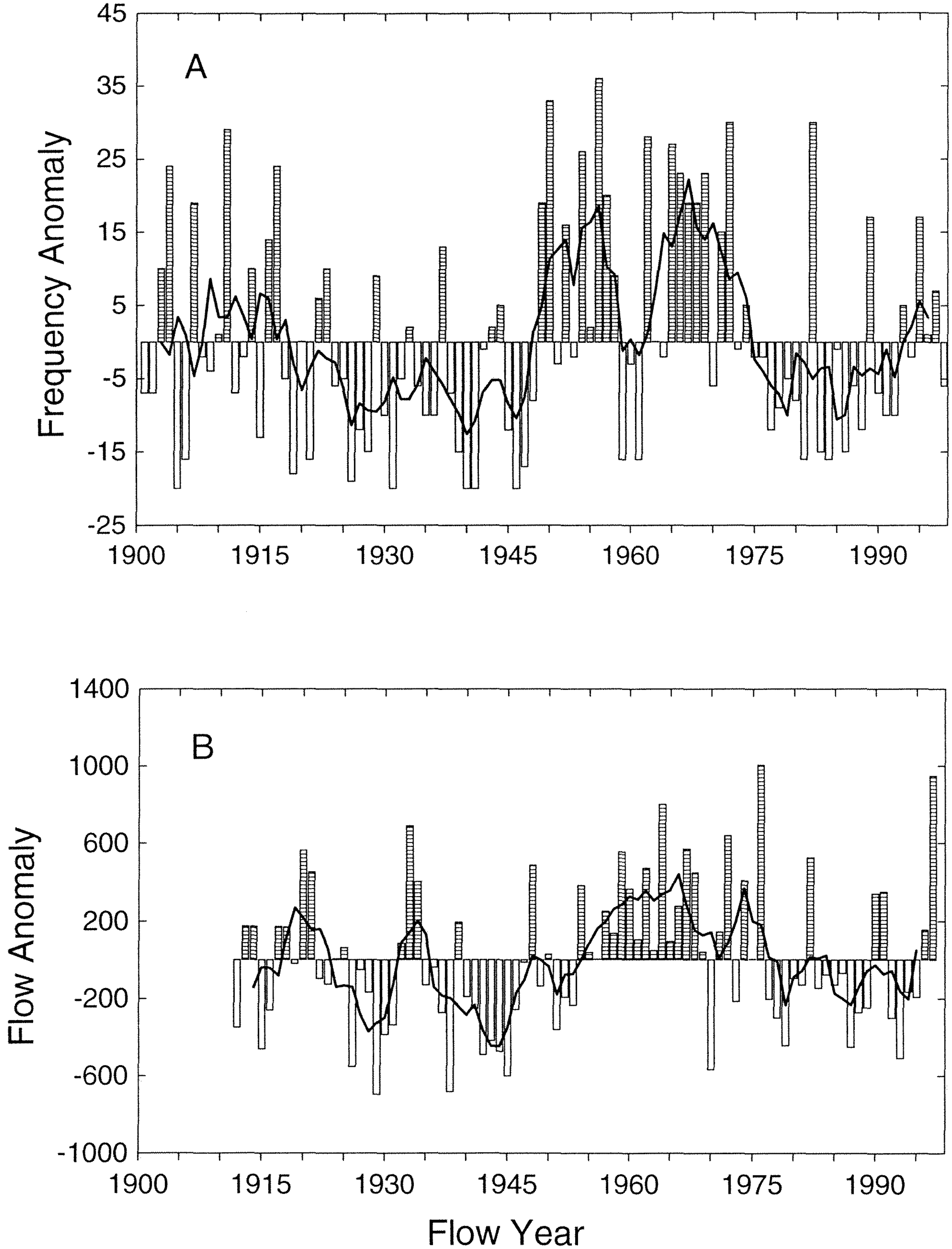
**Figure Captions**

Fig. 1. Anomalies of winter winds (Dec. – March) for the years 1900-1998: A) Z-type (zonal) winds, B) M1-type (northwesterly) winds, and C) M2-type (southwesterly) winds.

Fig. 2. A) Anomalies of annual flow from the Fraser River (1900-1998). B) Anomalies of the winter northwesterly winds (Dec. – March) for the years 1912-1998. Solid line is the five-year running average.



A
Winter Z Anomalies
B
Winter M1 Anomalies
C
Winter M2 Anomalies
80
40
0
-40
-80
1900
1915
1930
1945
1960
1975
1990


A
Frequency Anomaly
45
35
25
15
5
-5
-15
-25
1900
1915
1930
1945
1960
1975
1990
B
Flow Anomaly
1400
1000
600
200
-200
-600
-1000
1900
1915
1930
1945
1960
1975
1990
Flow Year