Diminished windstorm frequency in southwest British Columbia: A possible association with the Pacific Decadal Oscillation regime shift of 1976-77

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Outline

• Brief background on the PDO

• Issues with long-term wind records

• Exploration of the windstorm climatology at CYVR & (briefly) other stations

• Proxy data: The geostrophic wind triangle

• Some results for sea-level pressure data from CYYJ, CYVR and CYXX
The Pacific Decadal Oscillation
Pacific Decadal Oscillation

Warm Phase

Cool Phase

- The PDO index is a measure of monthly sea-surface temperature variability poleward of 20° N (Mantua 2000)

Pacific Decadal Oscillation

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Pacific Decadal Oscillation

monthly values for the PDO index: 1900 - August 2011

- Positive values = warm conditions (red)
- Negative values = cool conditions (blue)
Pacific Decadal Oscillation

monthly values for the PDO index: 1900 - August 2011

“The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period).” (Mantua 2000)
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- The “Victoria Pattern” may have assumed a stronger role in recent decades, a reality that could have implications for fall-winter forecasts using the PDO index.

Main take-away thoughts:
- The PDO is somewhat nebulous
- There are still many unanswered questions about the PDO

Pacific Decadal Oscillation

monthly values for the PDO index: 1900 - August 2011

1976-77 Transition
Pacific Decadal Oscillation

monthly values for the PDO index: 1900 - August 2011

1976-77 Transition

1983-1988 Strong Warm Phase
Pacific Decadal Oscillation

monthly values for the PDO index: 1900 - August 2011

1976-77 Transition
1983-1988 Strong Warm Phase
1989-Present Slow Cooling?
Wind Record Time-Series
Wind Record Time-Series

Monthly Maximum Wind and Gust at CYVR, 1953-2008

- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008
Wind Record Time-Series

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Active Period

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Monthly Maximum Wind and Gust at CYVR, 1953-2008

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Monthly Maximum Wind and Gust at CYVR, 1953-2008

What about instrumental and observational consistency?

- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008
Wind Record Time-Series

Monthly Maximum Wind and Gust at CYVR, 1953-2008

- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008
- With key instrument changes noted
Wind Record Time-Series

- The 45B anemometer
- “Anemovane”
- Developed in the 1920s
- Used primarily from the 1930s to early 1960s by Meteorological Service of Canada (MSC)
- Display included direct reading dial gauges and a blinking light for averaging


Wind Record Time-Series

- The U2A anemometer
- MSC’s primary wind sensor from roughly the 1960s-1990s
- Display: Direct reading dials and chart-recording systems
- Some still in operation today
Wind Record Time-Series

- The 78D anemometer (D = digital)
- Completed in 1978, and employed by MSC from the mid-1990s to present
- A cup-based system—in fact, the 45B, U2A and 78D use the same cup design
- Sonic anemometer sensors are next in line
Wind Record Time-Series

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Different anemometers might explain inflections (trends) that appear in long-term data series.
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Pinpointing the exact time of an instrument change is important.
Wind Record Time-Series

- We know that different anemometers were used over time
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- MSC records of when a specific anemometer type became operational are not always specific
Wind Record Time-Series

• We know that different anemometers were used over time

• MSC records of when a specific anemometer type became operational are not always specific

• However, a new anemometer often resulted in a change of observational methodology
Wind Record Time-Series

- Specific observational methodology can result in detectable signals in the long-period wind record.
Wind Record Time-Series

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- Inflections in these signals can then be used to identify when an instrument change has occurred.
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Wind Record Time-Series

- The frequency of even numbers is higher than odd numbers in the record
Wind Record Time-Series

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- There is also a bias for 5s and 10s, depending on the station.
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Some of this has to do with human psychology.
Wind Record Time-Series

A large part of the bias during the 45B era has to do with methodology
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For average wind speeds, observers counted a flashing light for 30 seconds.
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For average wind speeds, observers counted a flashing light for 30 seconds.

Often, observers halved the required time by counting blinks for 15 seconds and then doubling the result.

When an odd number is doubled, it becomes even:

$$2 \times 2 = 4$$
$$3 \times 2 = 6$$
With the introduction of the U2A and increased use of chart-recorders, the blinking light was gradually replaced, reducing the even-number bias.
Wind Record Time-Series

- With the introduction of the U2A and increased use of chart-recorders, the blinking light was gradually replaced, reducing the even-number bias.

- However, a psychological preference for even numbers, 0s and 5s remained.
Wind Record Time-Series

- With the automated 78D, even-number bias is finally eliminated from the wind record
Even-wind proportion is the frequency that even numbers appear in the wind record: $0.7 = 70\%$ of the time.

An inflection in even-wind proportion points to a methodological, and likely, an instrumental change.
Wind Record Time-Series

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An inflection in even-wind proportion points to a methodological, and likely, an instrumental change.

This inflection is due to a change from recording wind in mph to knots.
Wind Record Time-Series

This method can sometimes be used on monthly counts

Proportion of Even-Numbered Wind Speeds Among 2-40 mph Reports at CYVR on a Monthly Basis, 1959-1965

- 45B Anemometer in Service
- U2A Anemometer Implemented May or Jun 1962 Confirmed in-place by Dec 1963 (Metadata)
Wind Record Time-Series

- This method can sometimes be used on monthly counts.

- A step change in even-wind proportion suggests that the U2A became dominant during the summer of 1962.
Wind Record Time-Series

- Here is the change from U2A to 78D
Wind Record Time-Series

Here is the change from U2A to 78D

There is still a slight bias in favor of even numbers for the 78D

Why?
Wind Record Time-Series

Here is the change from U2A to 78D

There is still a slight bias in favor of even numbers for the 78D

Why? Thresholding: Lowest wind speed reported 2 knots, not 1 knot
Wind Record Time-Series

Key ideas to keep in mind when considering the next part of this presentation:

- Over the past 60 years of wind record, anemometer types have changed
- Observational methodology has also changed
- This means that, when inflections in long-period wind records are detected, the cause of the deflection must be considered very carefully
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Key ideas to keep in mind when considering the next part of this presentation:
- Over the past 60 years of wind record, anemometer types have changed
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And anemometer height has not yet been mentioned (19.5 m vs. 10 m)
Windstorm Climatology at CYVR
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

Maximum Wind of All Wind Advisory (>47 km/h) and Stronger Storms at CYVR, 1953-2007

- These are discrete windstorm events, not daily, weekly, monthly or some other arbitrary time-length
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Used hourly and special observations, supplied from Environment Canada.
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

- This is entirely different data compared to what was used in the previous sections (monthly maximums)
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

48 km/h (>25 kt) cutoff for “windstorm” (arbitrary)
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

Maximum Wind of All Wind Advisory (>47 km/h) and Stronger Storms at CYVR, 1953-2007

The “Great Calm” 1976-1990
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

Maximum Wind of All Wind Advisory (>47 km/h) and Stronger Storms at CYVR, 1953-2007

1981-1990
A decade without a single high-wind criteria event

The “Great Calm” 1976-1990
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

- The “Great Calm” follows the 1976-77 PDO transition.
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

- The “Great Calm” follows the 1976-77 PDO transition
- The 1976-77 transition is well documented (Mantua et al 1997, Hare & Mantua 2000, Overland et al 2008)
The Great Calm persists through the strong PDO warm phase of the 1980s
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

- The Great Calm persists through the strong PDO warm phase of the 1980s
- Both frequency and magnitude appear to reduce
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

Maximum Wind of All Wind Advisory (>47 km/h) and Stronger Storms at CYVR, 1953-2007

- Significant anemometer changes as described earlier
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events

- Significant anemometer changes as described earlier
- However, era of U2A operation (1962-1992) contains much of the signal
Vancouver International (CYVR) Windstorms

Different ways of characterizing the “Great Calm” at CYVR

Events Per Year
1962-1975: 6.9
1976-1992: 3.5
Ratio: 2.0
Preliminary Multi-Station Analysis

Victoria International Airport

- Pattern also present at Victoria (CYYJ) and Abbotsford (CYXX)
- Not present further north, such as at Port Hardy (CYZT)
Washington and Oregon Data
Interior Stations KMFR to KBLI

Timing and Magnitude (If Available) of Major Windstorms in the Pacific Northwest USA
1948-2008

- Mass & Dotson (2010) used hourly observations only; some major events missed (e.g. 02 Oct 1967)

Washington and Oregon Data
Interior Stations KMFR to KBLI

Timing and Magnitude (If Available) of Major Windstorms in the Pacific Northwest USA
1948-2008

- Major windstorm = At least two stations with ≥65 km/h wind

Data from Mass & Dotson 2010
There appears to be a large gap between the late 1960s and early 1990s, a suggestion of the pattern

*1976-77 Transition*

Timing and Magnitude (If Available) of Major Windstorms in the Pacific Northwest USA 1948-2008

- Max Wind Interior Stations
- Max Wind Undetermined (at least 65 km/h)

N = 33

Major Windstorm = At least two stations with ≥85 km/h wind using hourly data

Data from Mass & Dotson 2010

The “Great Calm” 1976-1990
A lower cutoff and the use of special observations would have captured more storms, perhaps better defining any signal.
Washington and Oregon Data
Interior Stations KMFR to KBLI

Timing and Magnitude (If Available) of Major Windstorms in the Pacific Northwest USA 1948-2008

Very Rough Approximations (depends on station)

- Era of High Sensors (>10 m)
- Many Masts Lowered (<10 m)
- Standardized to 10 m

- Also, anemometer changes could explain some of this pattern
- Many were above 10 m before ~1960, then below 10 m after
Further Evidence From American Stations

- Ebbesmeyer (1989) looked at wind direction and speed in the Puget Sound Basin
- Using 5-year averages for *winter* wind speed parameters and the Pacific North American Index (PNA) these correlation coefficients were returned for the time series 1972-84:

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- Given the narrow span of years with the 1976-77 transition right in the middle, such high correlations are perhaps not that surprising
• Negative PNA reflects an Aleutian low further west, and a zonal upper-air pattern conducive to winter-storminess in the Puget Lowlands (Ebbesmeyer 1989)

The PNA appears to have a strong relationship to the PDO (see Tuller 2004 for one discussion)

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Negative PDO is often associated with negative PNA.

Digression: The PNA & a Possible Mechanism
The PNA appears to have a strong relationship to the PDO (see Tuller 2004 for one discussion)

Negative PDO is often associated with negative PNA

This opens the door for increased windstorm frequency
Proxy Data For Wind
Proxy Data For Wind

• Is the observed pattern at CYVR, CYYJ and CYXX real?

• Or is the trend an artifact of instrumental and/or methodological changes?
Proxy Data For Wind

- To support the idea that the Great Calm is a natural wind response vs. due to instrumental/measurement change, proxies can be used.

Pressure Triangle Wind Speed Method

- Geostrophic wind potential calculated from the three datapoints is most reliable near the center of the triangle, with confidence diminishing toward the edges.

Comox 97.8 kPa

Vancouver 98.1 kPa

Victoria 98.4 kPa
Proxy Data For Wind

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• “Pressure triangle wind speeds” (Tuller 2004)

• Geostrophic wind potential is calculated using pressure data from three (or more) stations

• Barometers do not have the same issues as anemometers

Proxy Data For Wind

- Tuller used the geostrophic wind potential based on hourly pressure data from Vancouver, Victoria and Comox
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• However, 1955-1965, a very active storm period in the wind record, also had average wind speeds nearly as low as 1976-1990
Proxy Data For Wind

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- Trends in wind speed based on geostrophic wind potential also point to a decrease during the Great Calm.

- However, 1955-1965, a very active storm period in the wind record, also had average wind speeds nearly as low as 1976-1990.

- While somewhat supportive of a natural cause for the Great Calm, these data are certainly not conclusive.
Proxy Data For Wind

- Tuller’s analysis is based on annual averages
- What about discrete windstorm events?
Proxy Data For Wind

- Used hourly sea-level pressure data for CYYJ, CYVR and CYXX Jan 1953-Jul 2008 (Supplied by Environment Canada)
Proxy Data For Wind

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- Calculated the geostrophic wind potential ($M_g$) via a right triangle interpolated between stations
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• Surface wind speeds during windstorms tend to fall between 0.25 and 0.40 of $M_g$
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- Sorted out all events with 0.40 \( M_g \) >47 km/h
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- Sorted out all events with 0.40 $M_g > 47$ km/h

- This cutoff is very close to a 4.5 hPa/100 km pressure gradient
For 1953-2007, the total number (358) is in approximate agreement with total from surface wind data (367)
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However, only 28.1% of events match up exactly date-wise (probably would be higher if ±1 day is allowed for)
• Reduced frequency and magnitude of events appears to occur at least weakly post-1976-77
Storm frequency appears to return to pre-1976-77 levels between 1994 and 2001, then falls off again.
CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results

Number of Discrete Storm Events With Peak Gradients ≥4.5 hPa/100 km by Year
For the CYYJ-CYVR-CYXX Geostrophic Wind Triangle

- A different way of looking at some of the data
- Does not account for magnitude

Annual number of events

10-Sample Average

- A different way of looking at some of the data
- Does not account for magnitude
The 10-Year average number of events $\geq 4.5$ hPa/100 km appears to drop from 10 to less than 5.

1976-77 Transition
However, the reduction appears to begin ahead of the 1976-77 transition by many years (like the Mass & Dotson data)

And, the SD is fairly high, reducing confidence in the mean
CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results

Number of Discrete Storm Events With Peak Gradients ≥4.5 hPa/100 km by Year
For the CYYJ-CYVR-CYXX Geostrophic Wind Triangle

- Ratio between the two eras is similar to that for the surface wind data: 1.8 vs. 2.0

1976-77 Transition

Events Per Year
1962-1975: 7.6
1976-1992: 4.3
Ratio: 1.8
CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results

- Ratio between the two eras is similar to that for the surface wind data: 1.8 vs. 2.0
- To “test the waters”: F-test for 1953-76 vs. 1977-00: $p = 0.044$ (1-tail), 0.087 (2-tail)

Events Per Year
- 1962-1975: 7.6
- Ratio: 1.8

1976-77 Transition
In any event, the proxy data do not disagree with the surface observations, and do show some correlation.
In any event, the proxy data do not disagree with the surface observations, and do show some correlation. A windstorm frequency/magnitude relationship to the PDO/PNA seems to be a real possibility.
Summary

• The instrumental wind record has many issues of consistency that need to be addressed when undertaking long-term analyses.

• Sea-level pressure can provide a useful proxy for evaluating the veracity of inflections in the wind record.

• A reduction in the frequency and magnitude of windstorms in SW BC from 1976-1990, as indicated by surface wind data, may be related to the 1976-77 PDO transition.

• Proxy data for wind, via a pressure gradient triangle using CYYJ, CYVR and CYXX, seem to reflect the same trend, but are not as conclusive.

• This is a work in progress.
Thank You