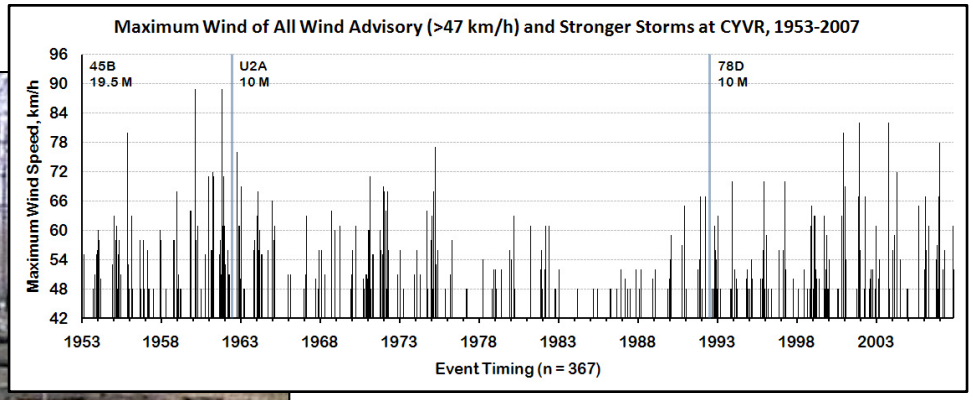
Diminished windstorm frequency in southwest British Columbia: A possible association with the Pacific Decadal Oscillation regime shift of 1976-77



Wolf Read

PhD Candidate

Forest Science

University of British Columbia

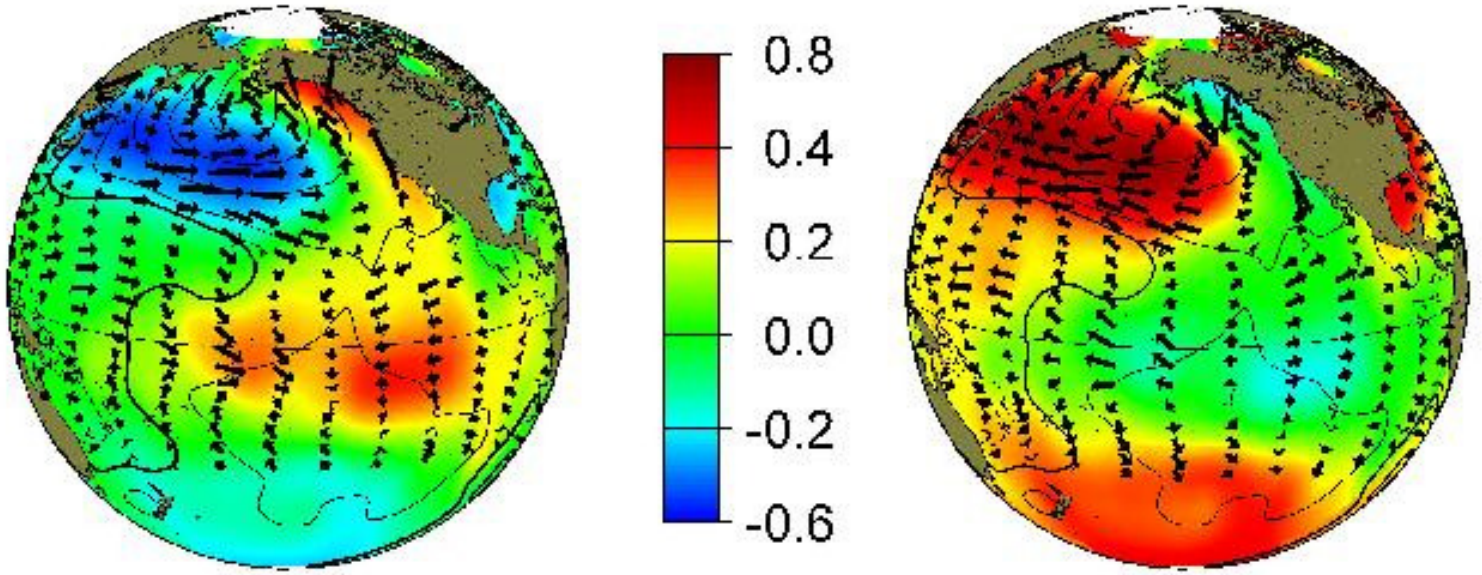
Outline

- 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

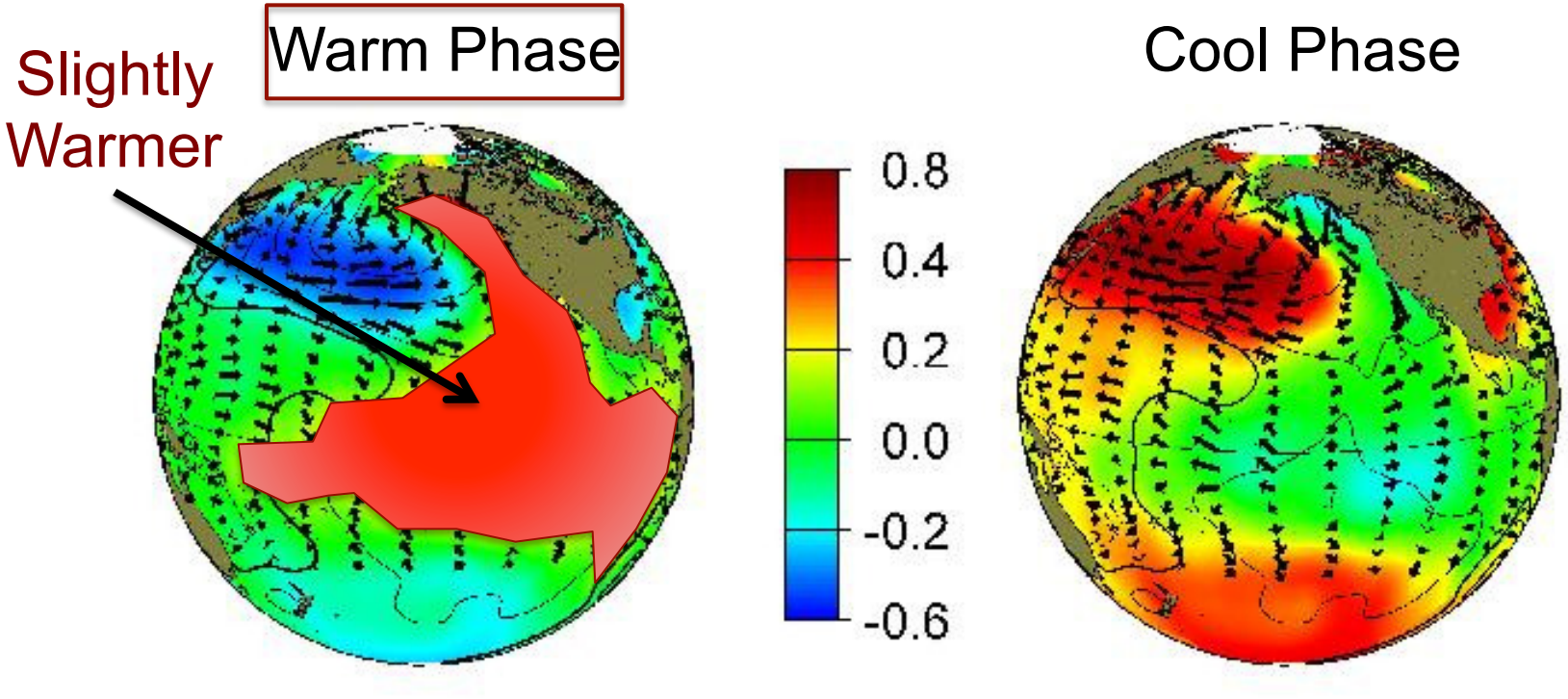


Cool Phase

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

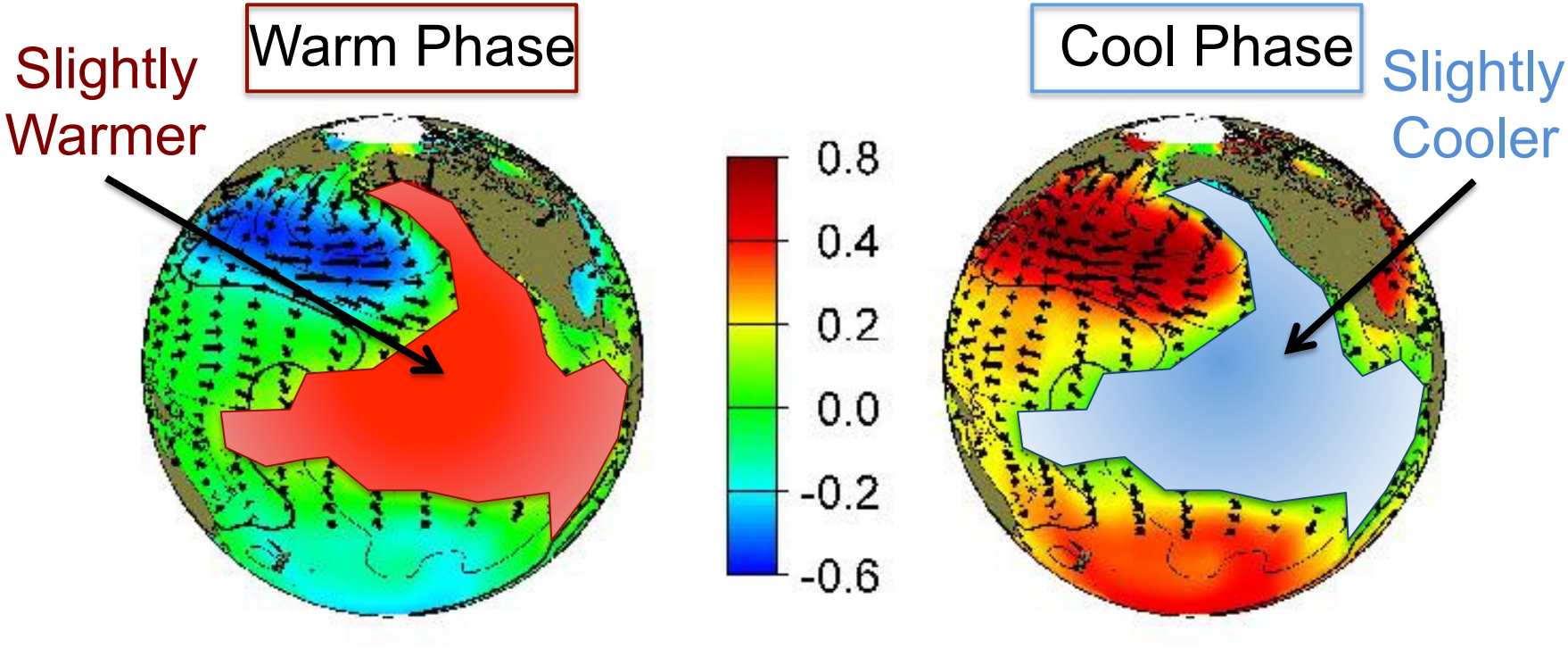
Mantua, N. J. 2000. "The pacific decadal oscillation (PDO)." January 2000. Joint Institute for the Study of the Atmosphere and Ocean, University of Washington. Accessed 23 Oct 2011 at http://www.jisao.washington.edu/pdo/

Pacific Decadal Oscillation



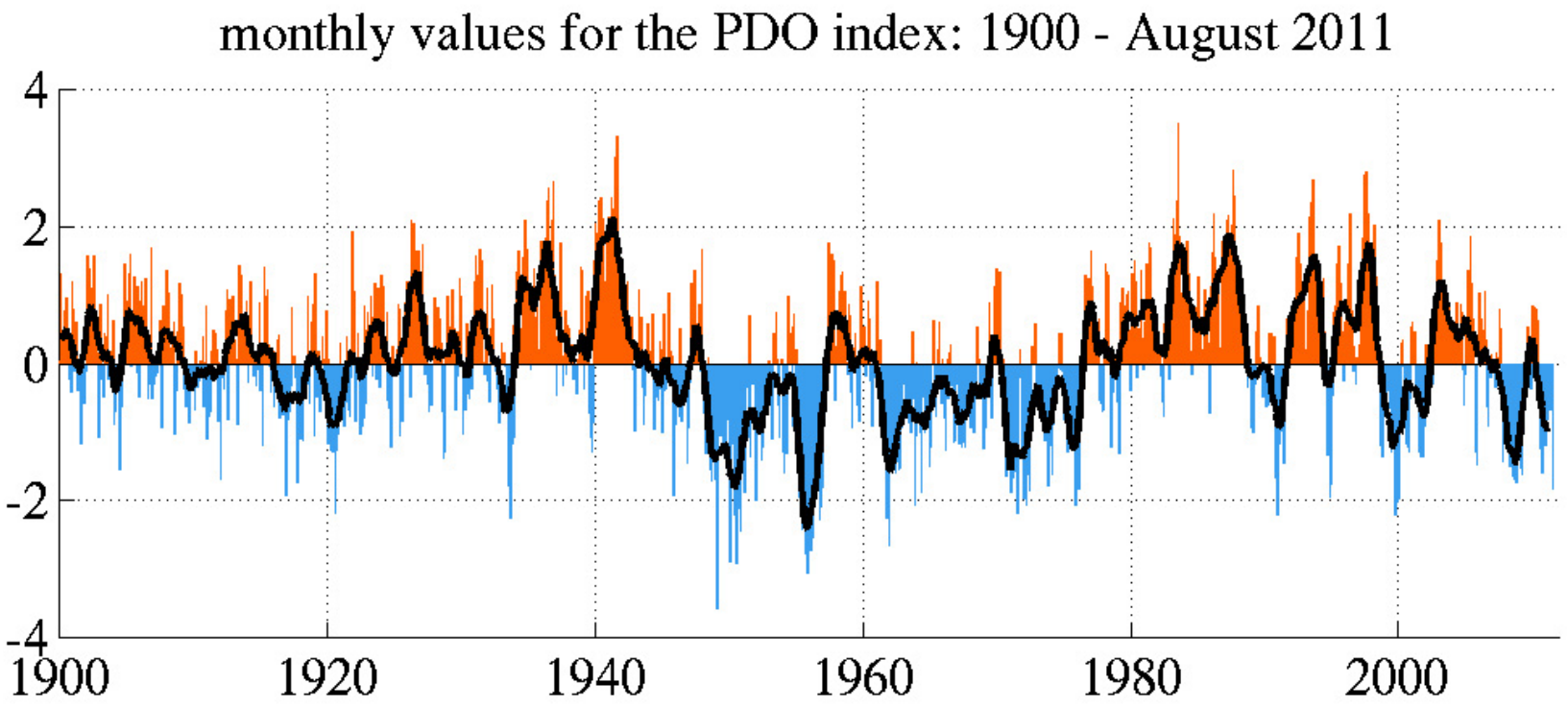
- The PDO index is a measure of monthly sea-surface temperature variability poleward of 20º N (Mantua 2000)

Pacific Decadal Oscillation



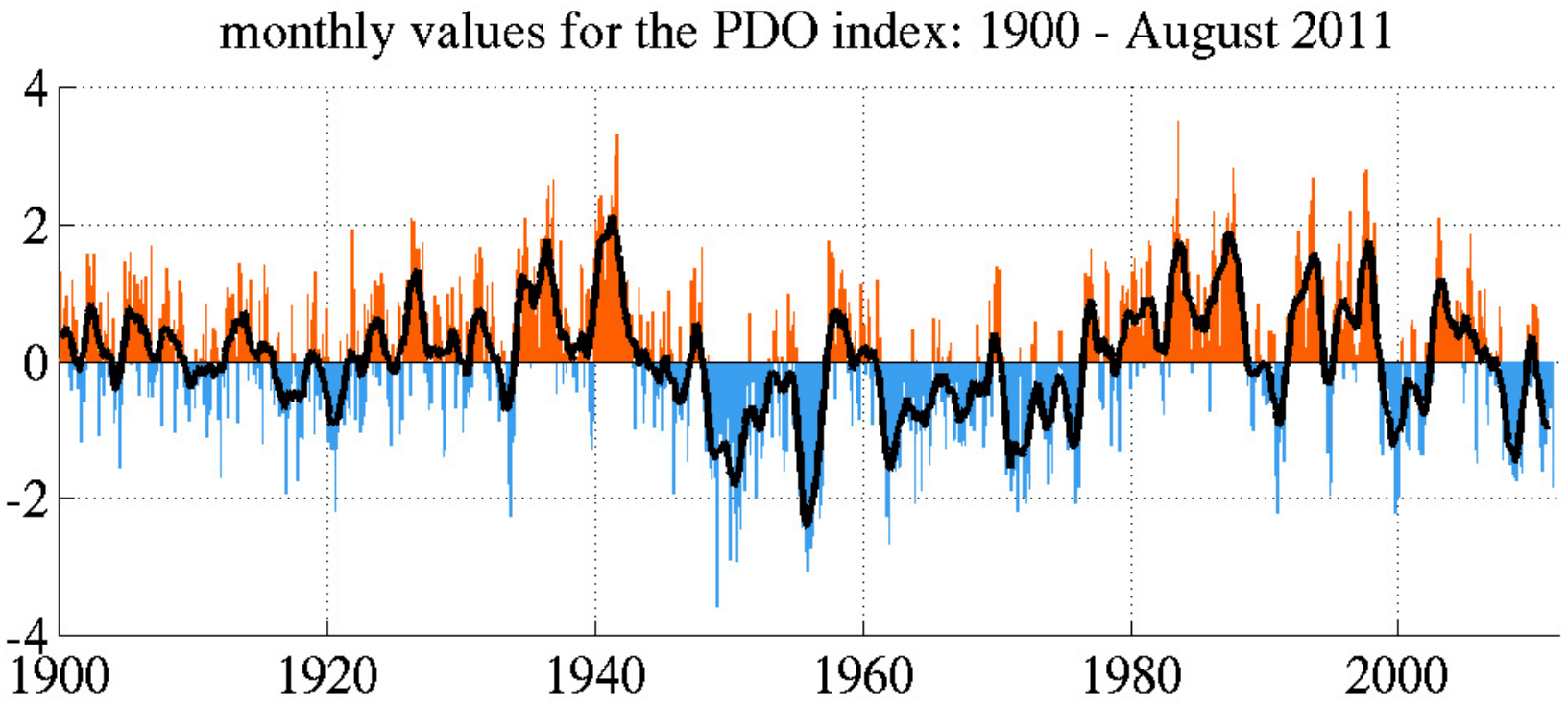
- The PDO index is a measure of monthly sea-surface temperature variability poleward of 20º N (Mantua 2000)

Pacific Decadal Oscillation



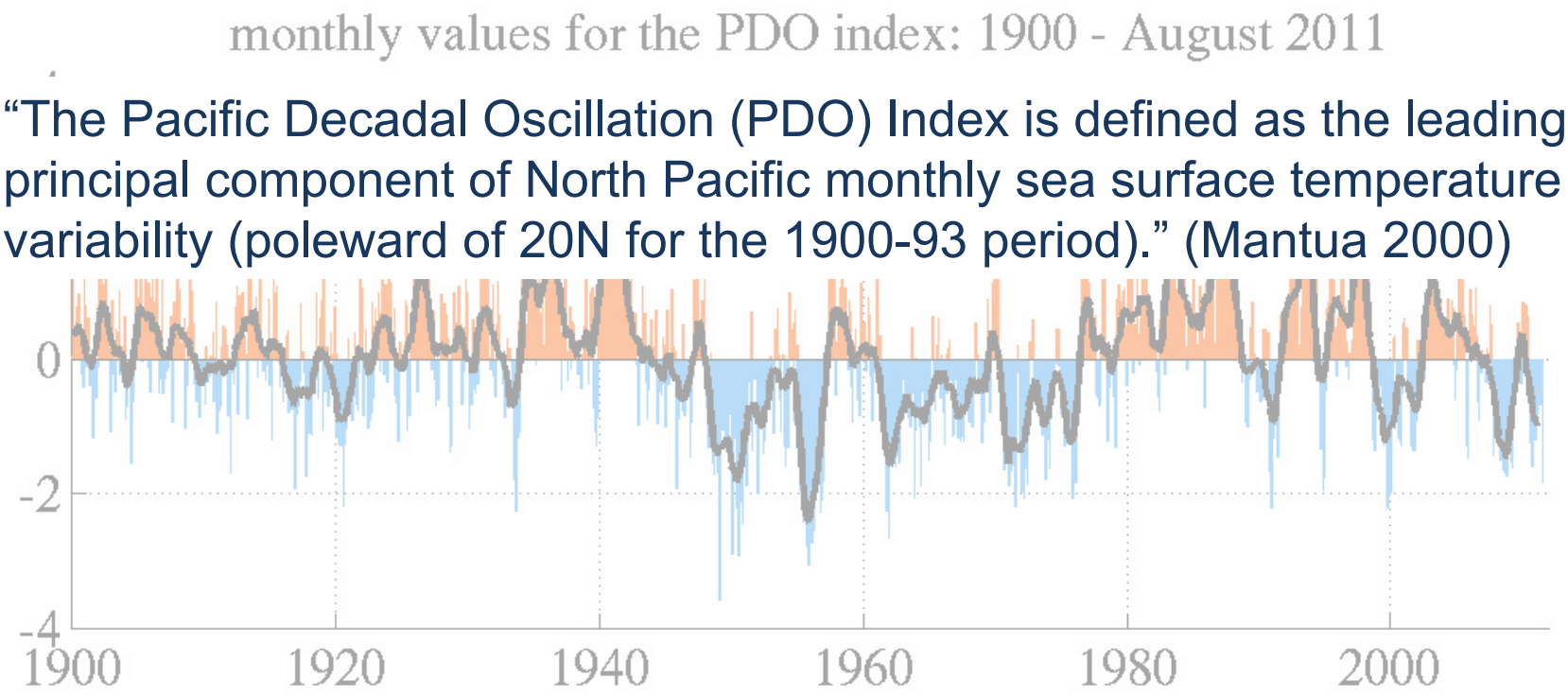
Mantua, N. J. 2000. "The pacific decadal oscillation (PDO)." January 2000. Joint Institute for the Study of the Atmosphere and Ocean, University of Washington. Accessed 23 Oct 2011 at http://www.jisao.washington.edu/pdo/

Pacific Decadal Oscillation



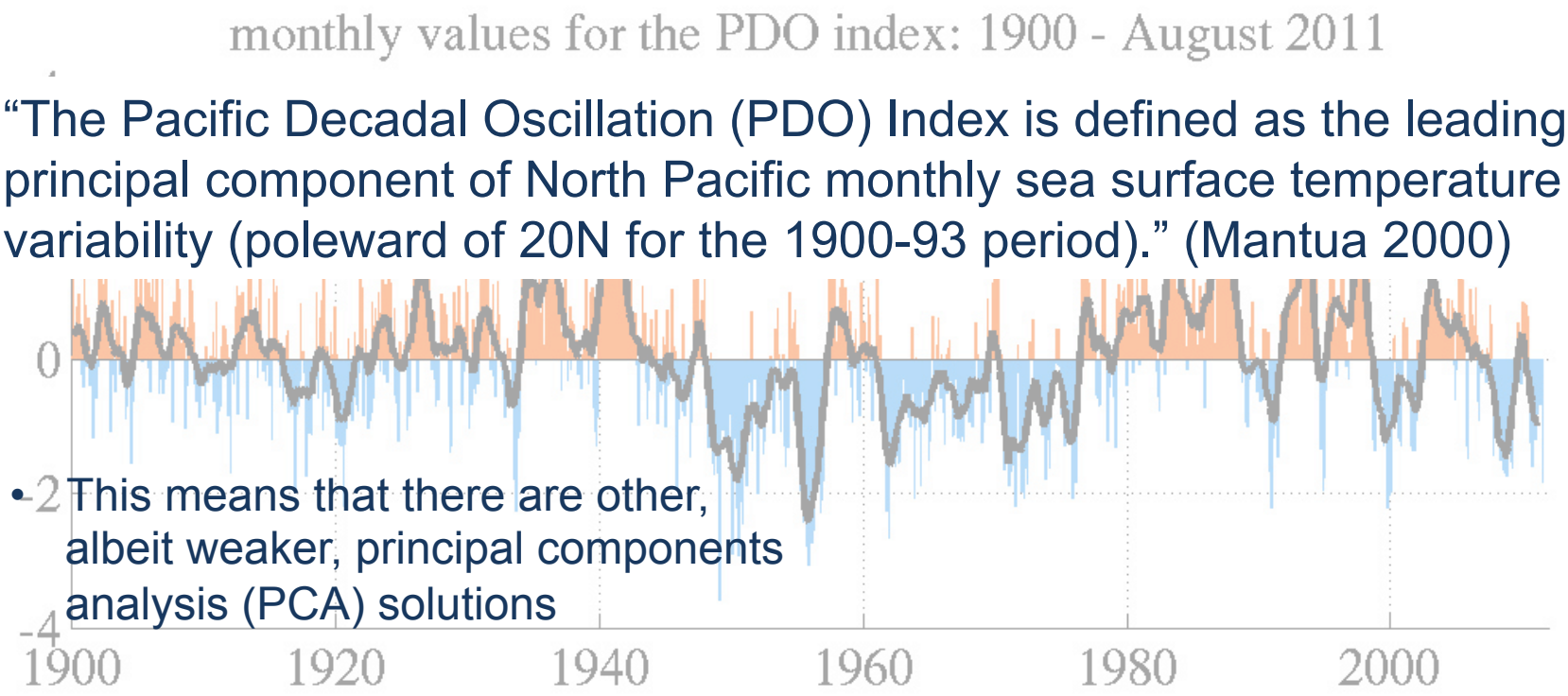
- Positive values = warm conditions (red)
- Negative values = cool conditions (blue)

Pacific Decadal Oscillation



"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)

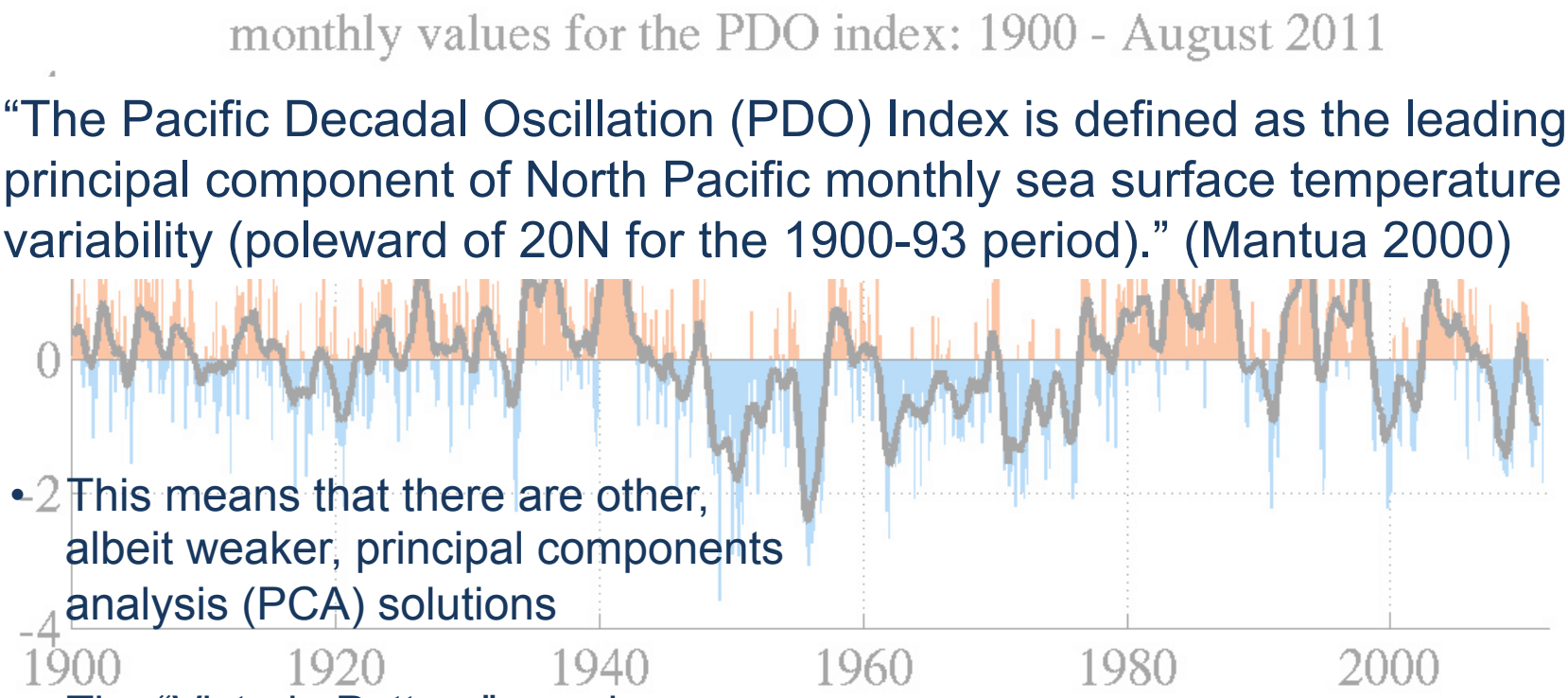
Pacific Decadal Oscillation



"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)

- This means that there are other, albeit weaker, principal components analysis (PCA) solutions

Pacific Decadal Oscillation



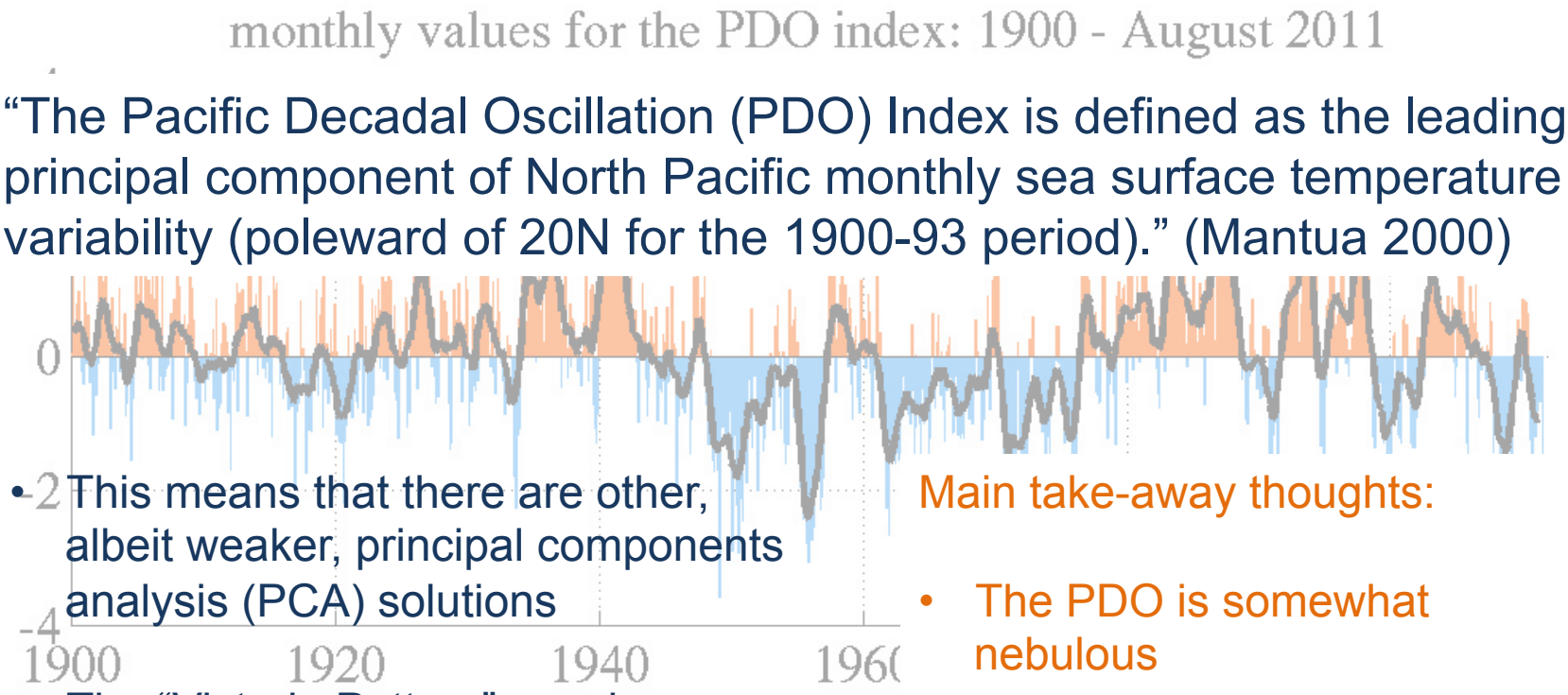
"The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period)." (Mantua 2000)

- This means that there are other, albeit weaker, principal components analysis (PCA) solutions
- 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

See

Overland, J., S. Rodionov, S. Minobe, N. Bond. 2008. "North Pacific Regime shifts: Definitions, issues and recent transitions." *Progress in Oceanography*, vol 77, p 92-102.

Pacific Decadal Oscillation



"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)

- This means that there are other, albeit weaker, principal components analysis (PCA) solutions
- 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

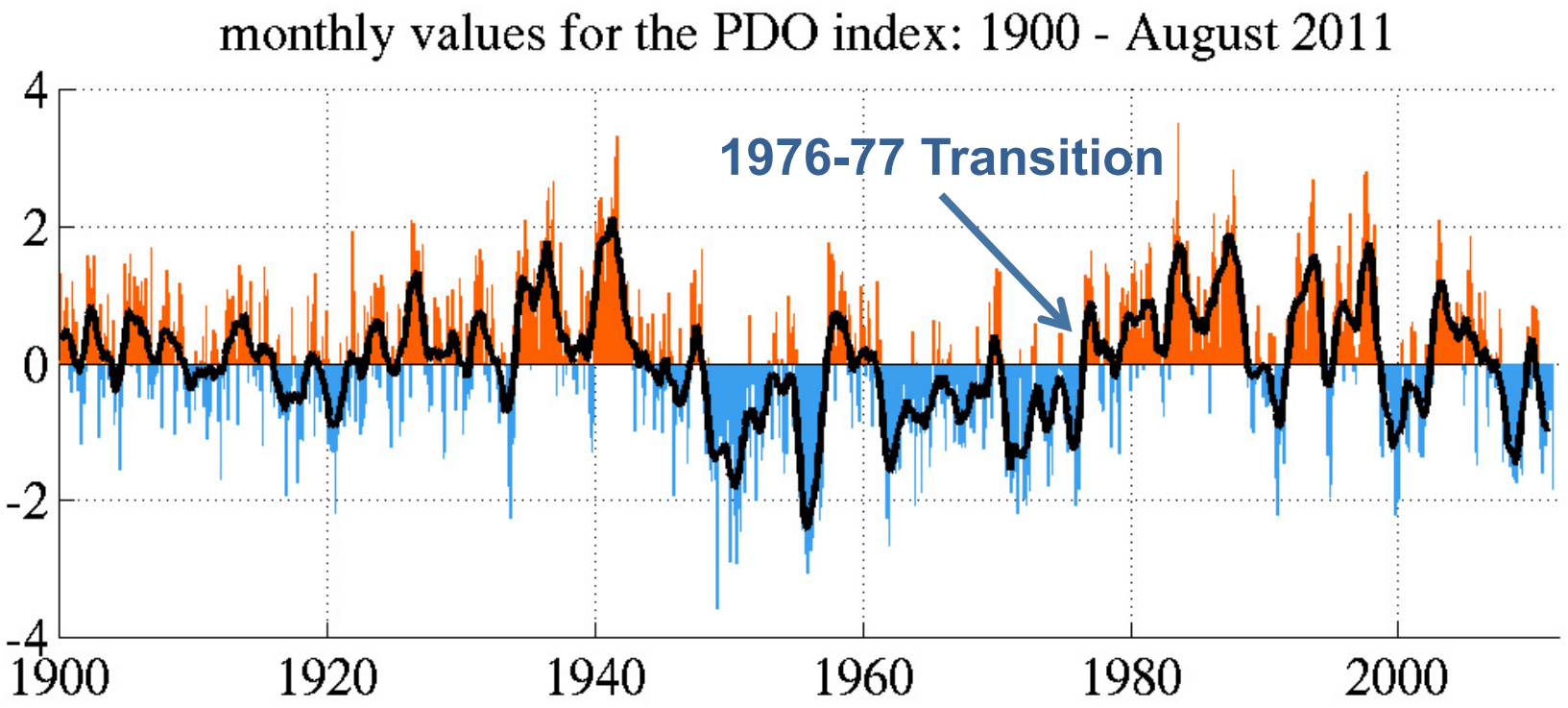
Main take-away thoughts:

- The PDO is somewhat nebulous
- There are still many unanswered questions about the PDO

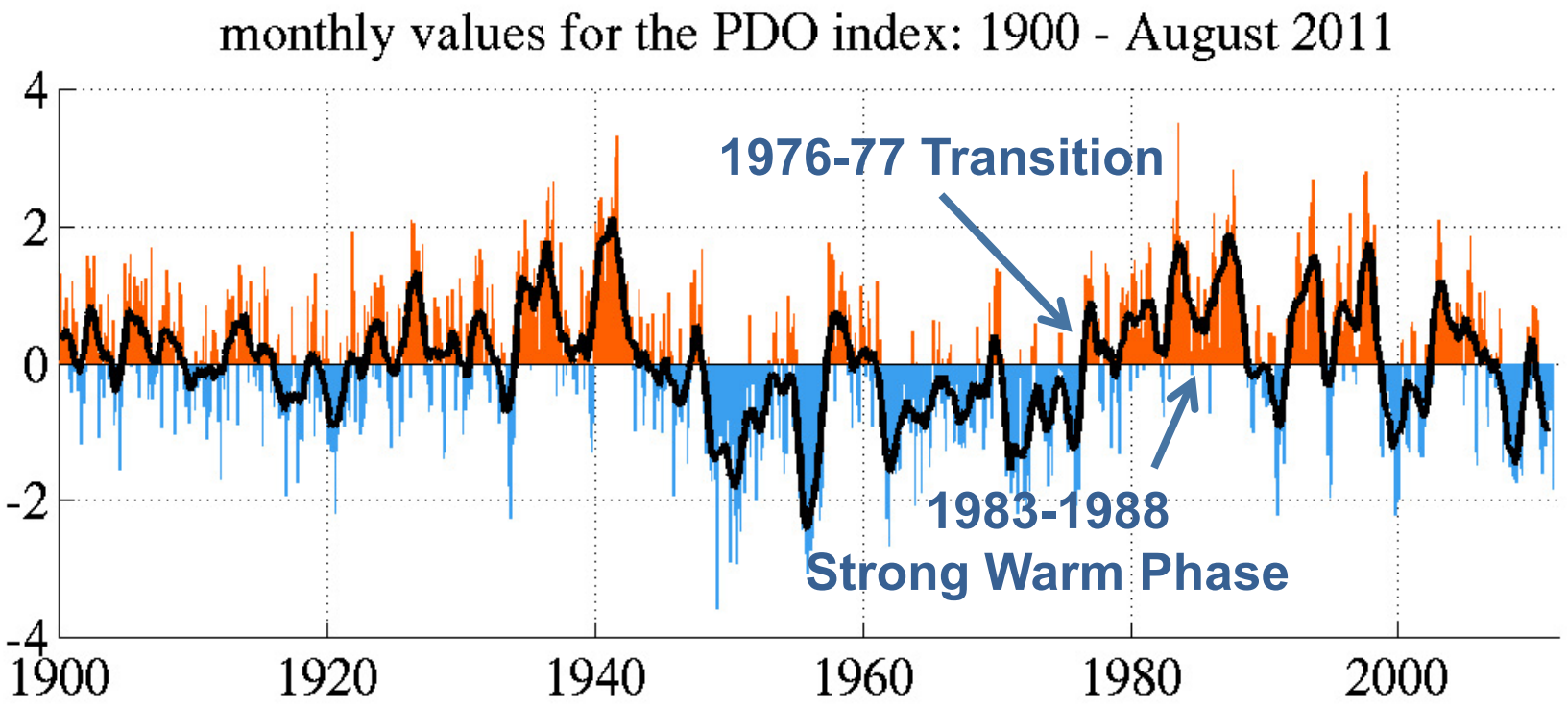
See

Overland, J., S. Rodionov, S. Minobe, N. Bond. 2008. "North Pacific Regime shifts: Definitions, issues and recent transitions." *Progress in Oceanography*, vol 77, p 92-102.

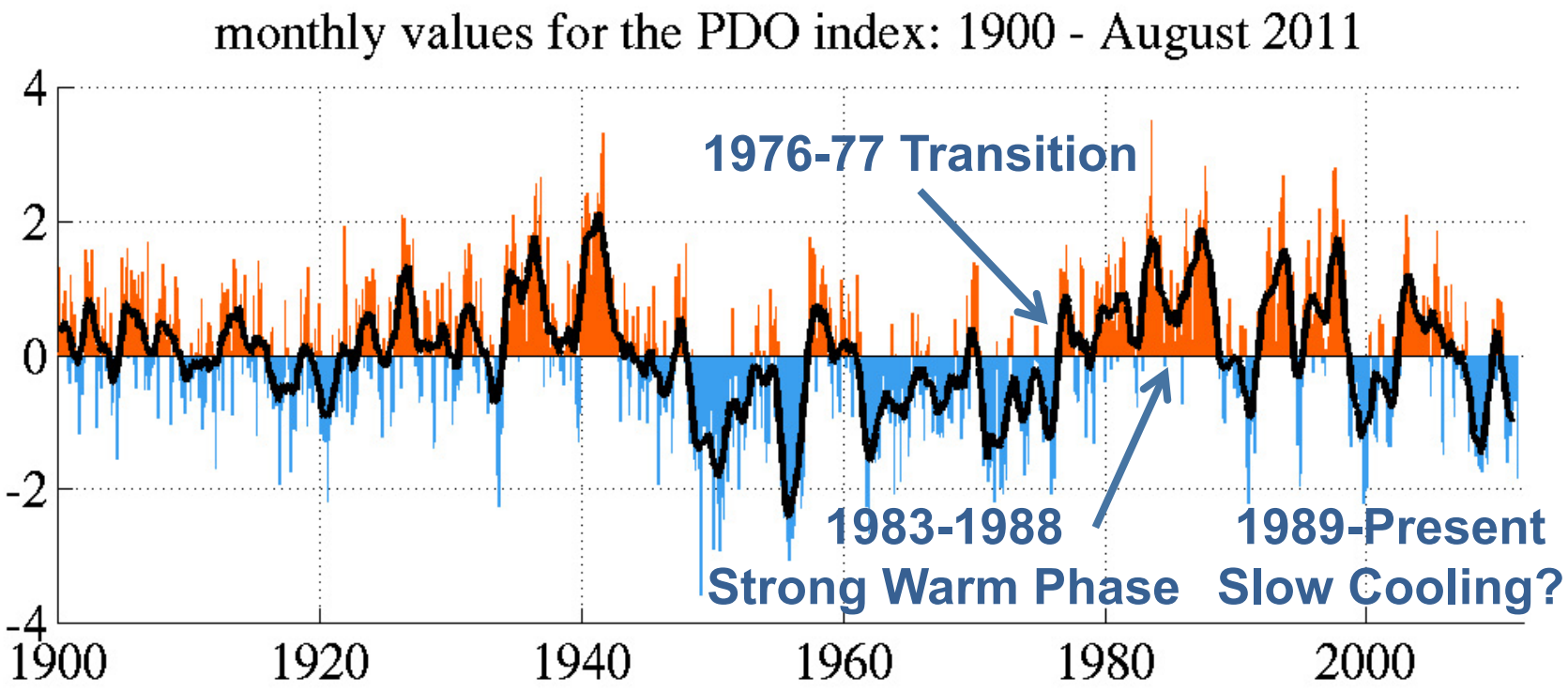
Pacific Decadal Oscillation



Pacific Decadal Oscillation

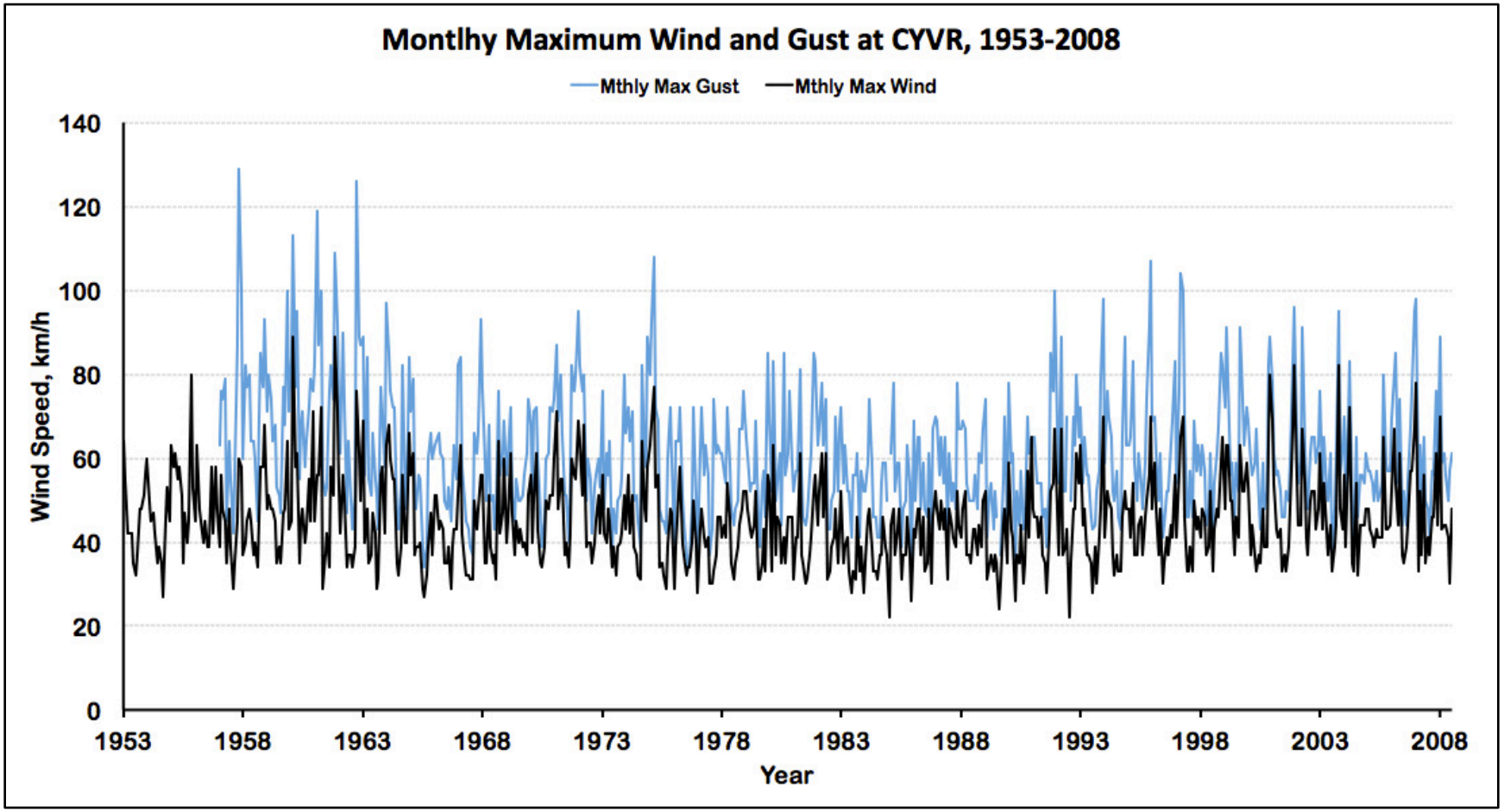


Pacific Decadal Oscillation



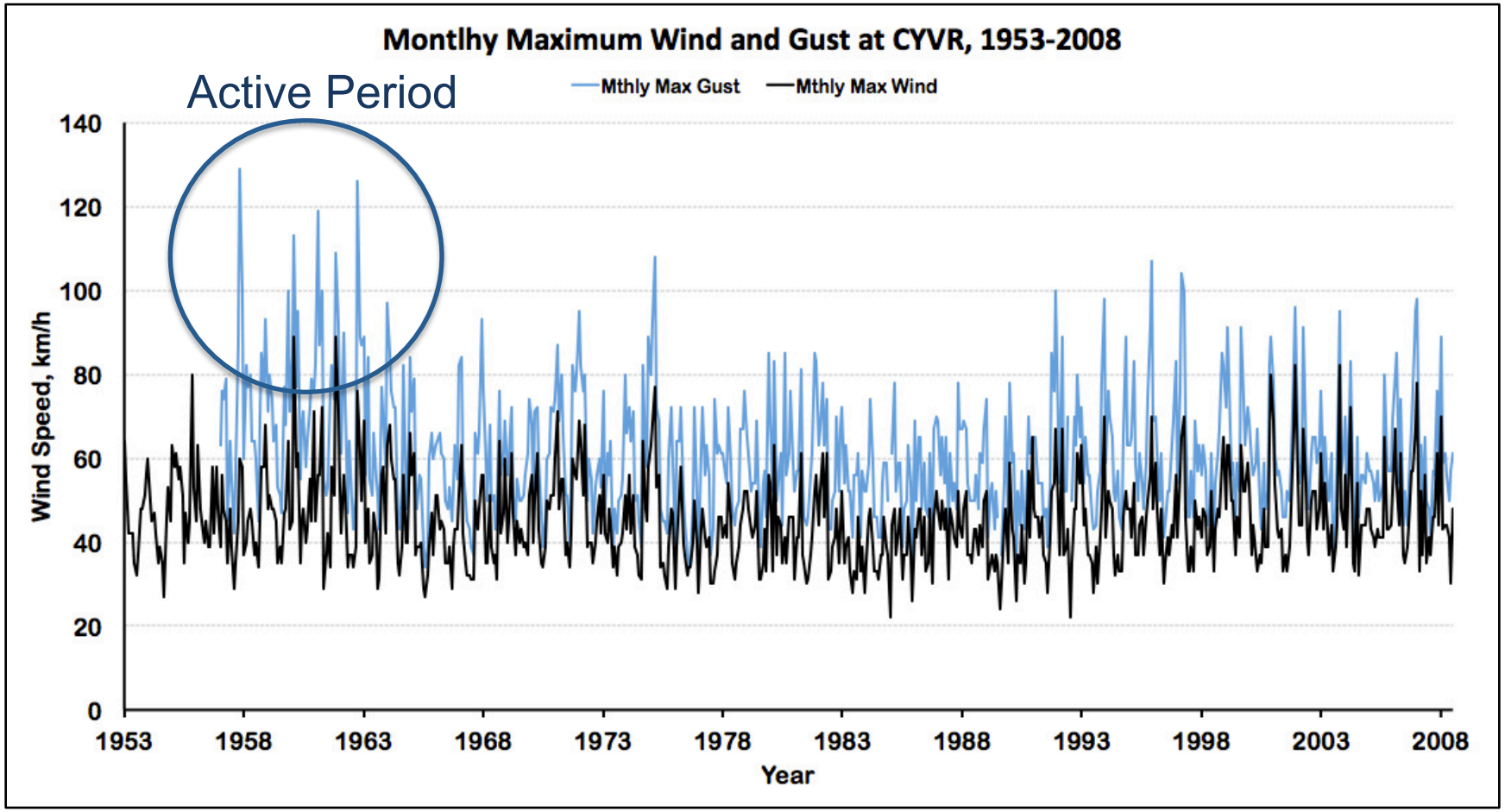
Wind Record Time-Series

Wind Record Time-Series



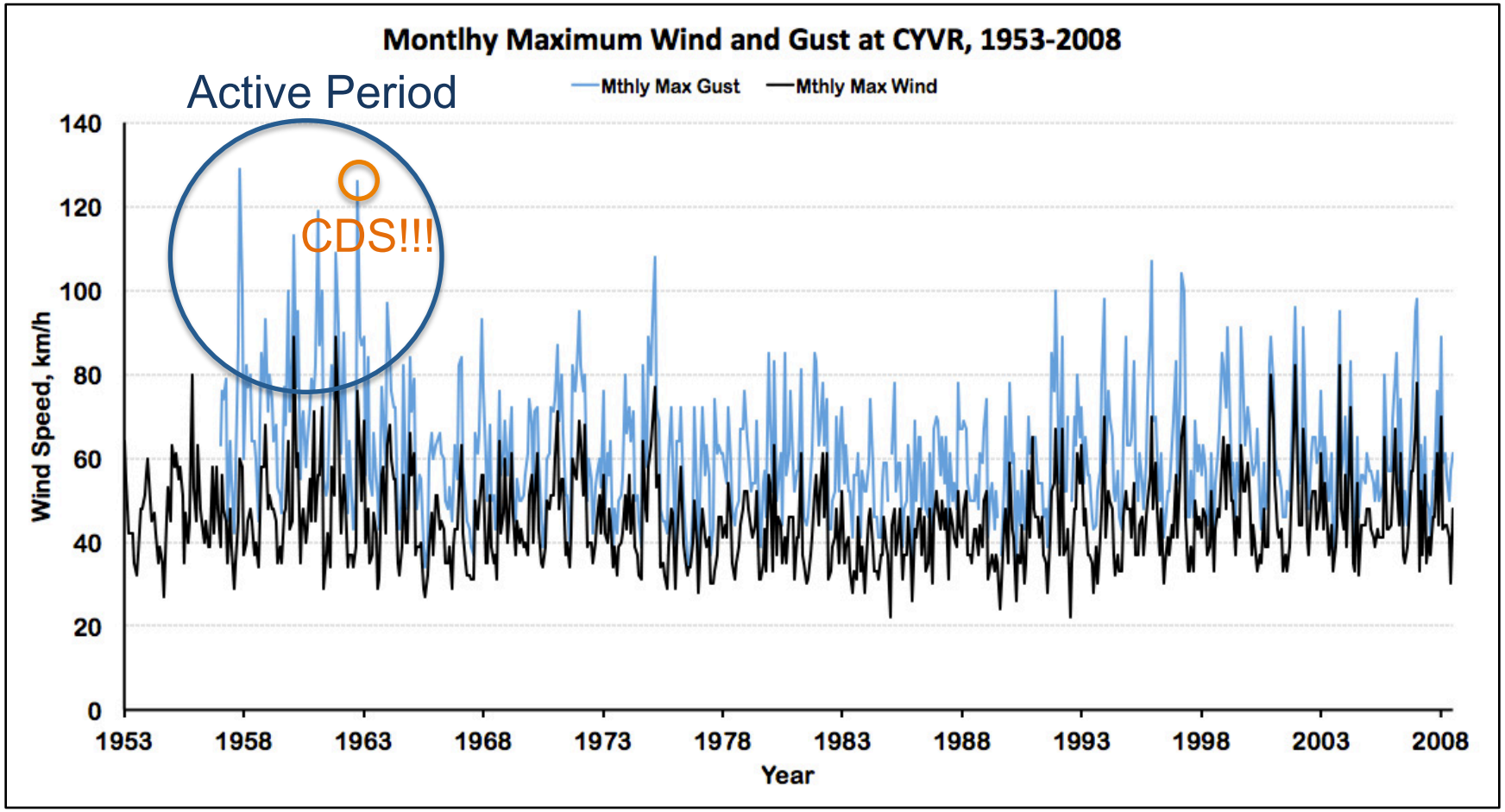
- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

Wind Record Time-Series



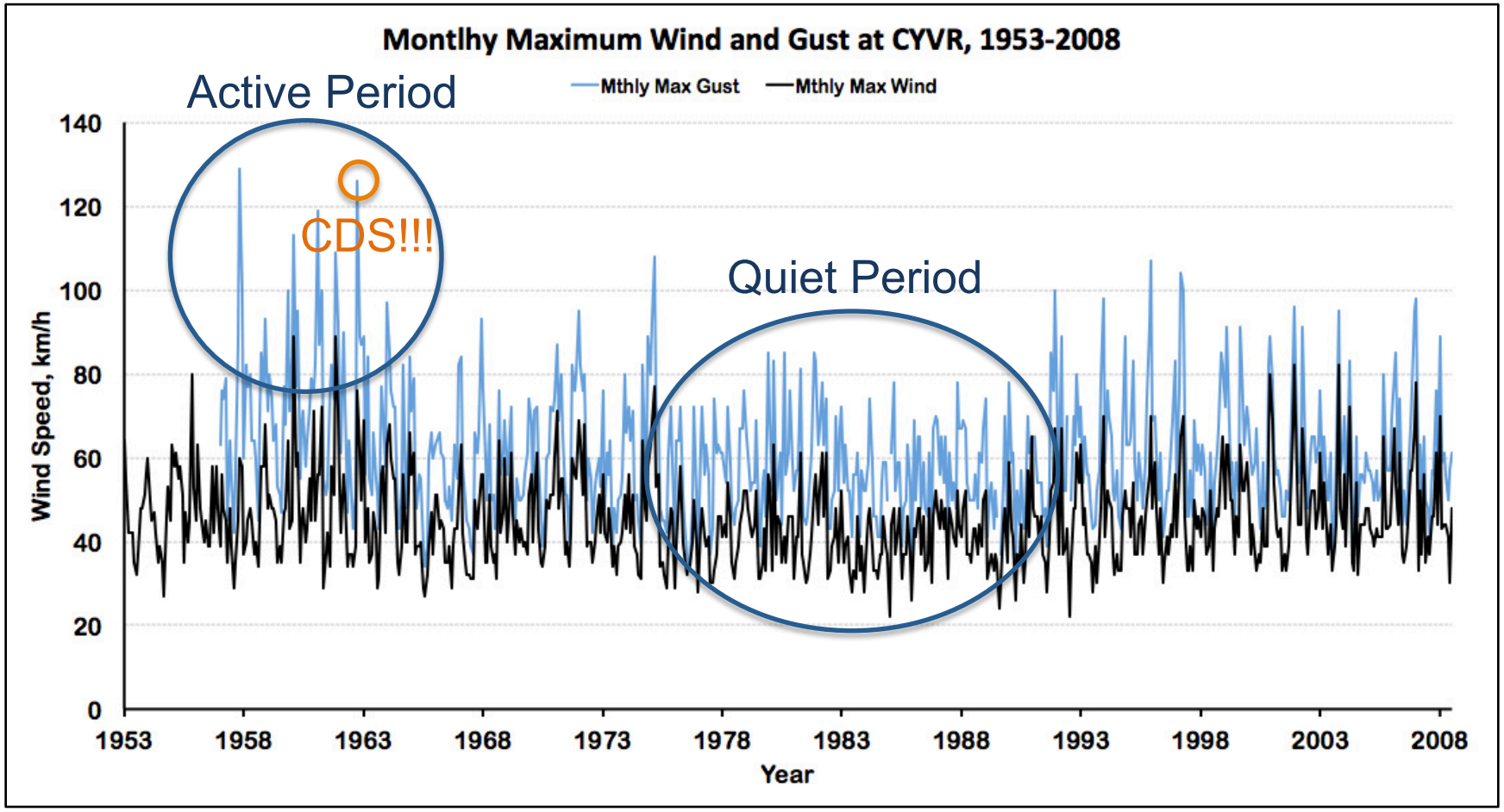
- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

Wind Record Time-Series



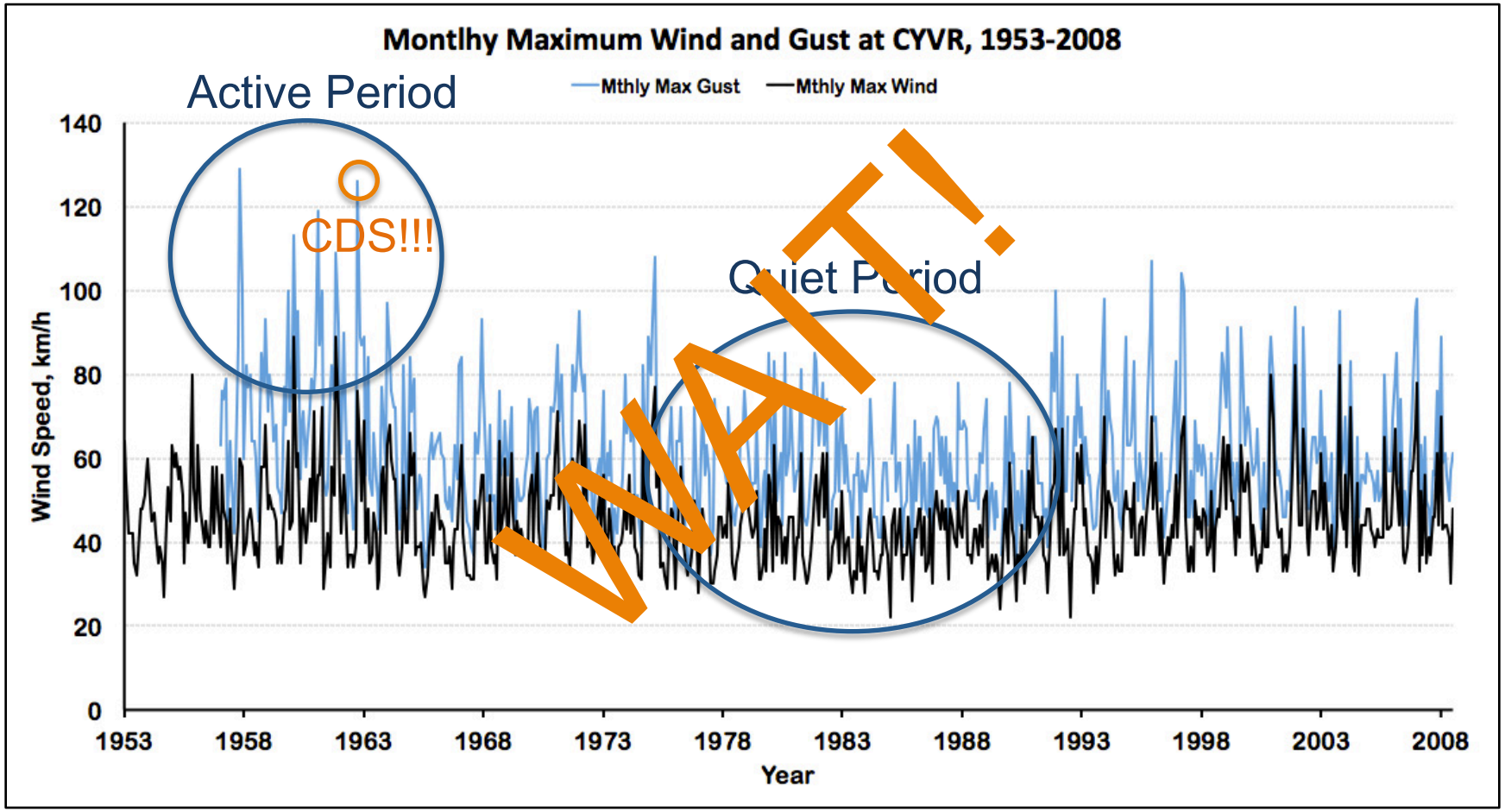
- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

Wind Record Time-Series



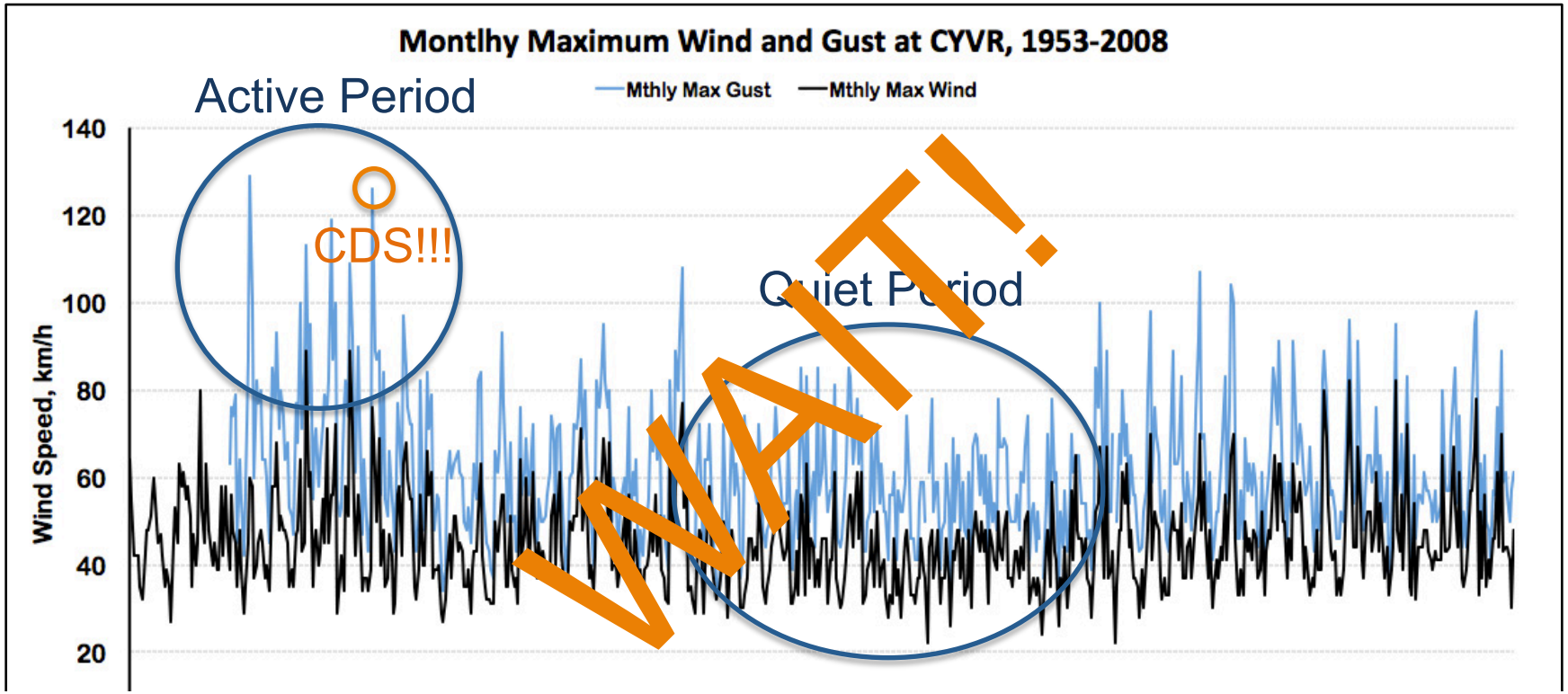
- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

Wind Record Time-Series



- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

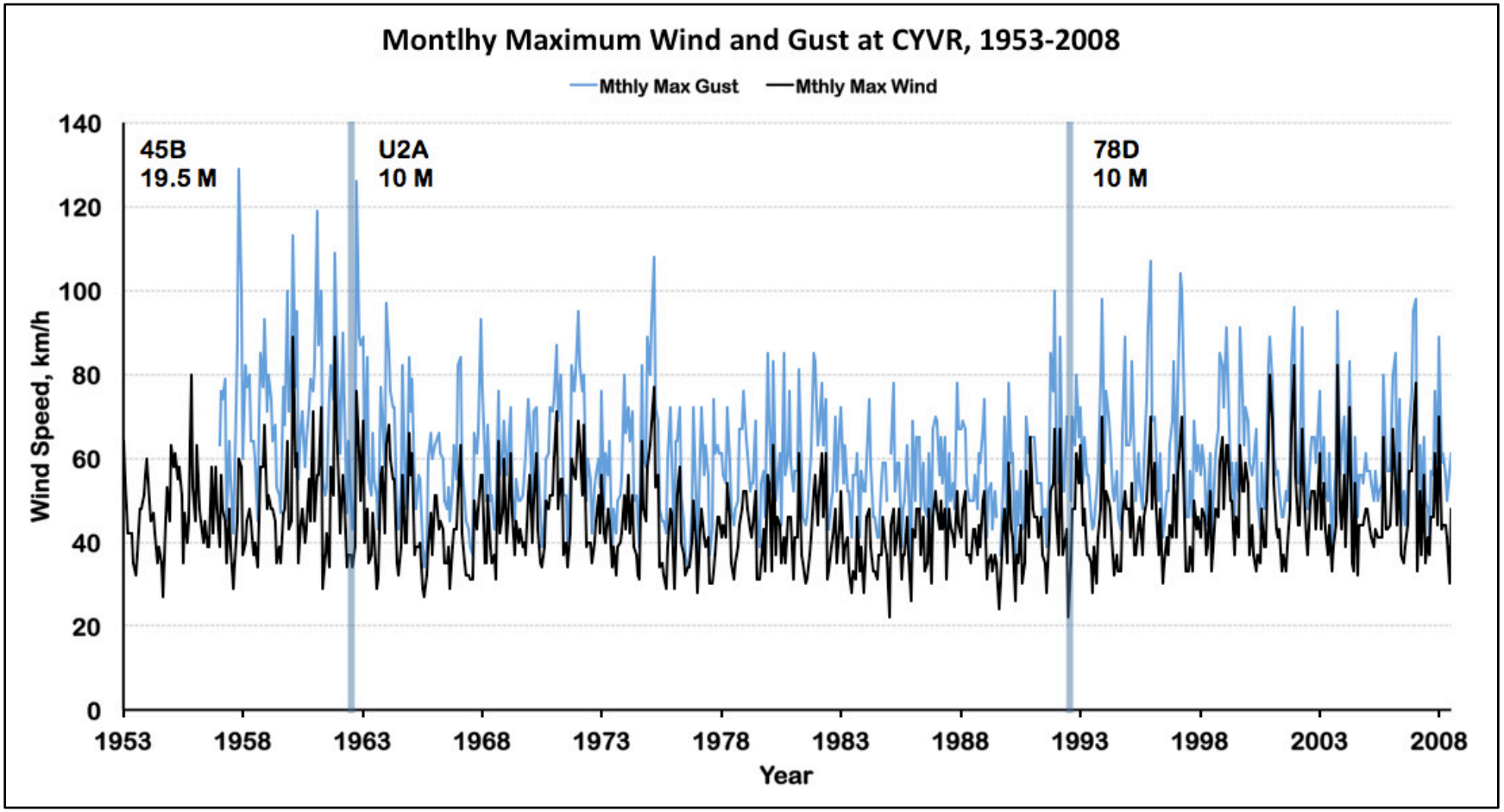
Wind Record Time-Series



What about instrumental and observational consistency?

- Monthly maximum wind and gust at Vancouver International (CYVR) 1953-2008

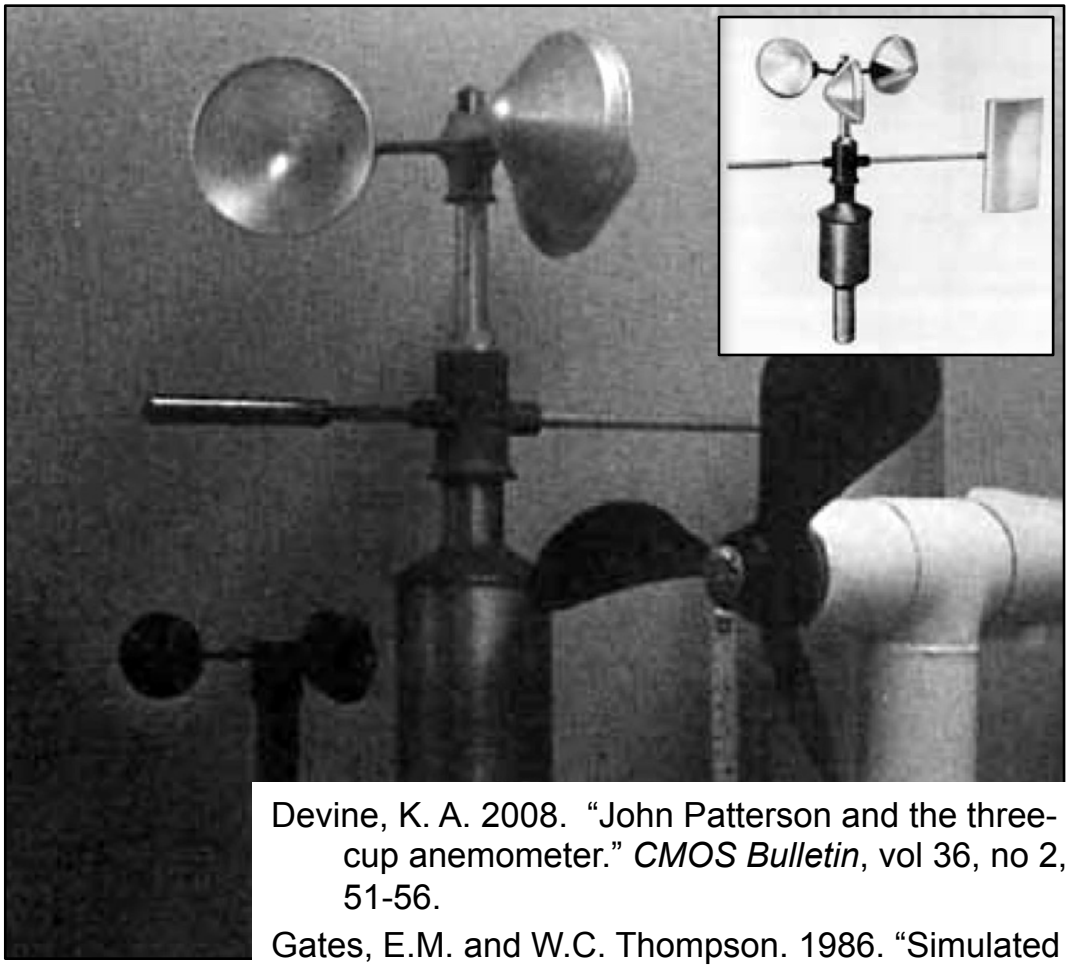
Wind Record Time-Series



- Monthly maximum wind and gust at 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



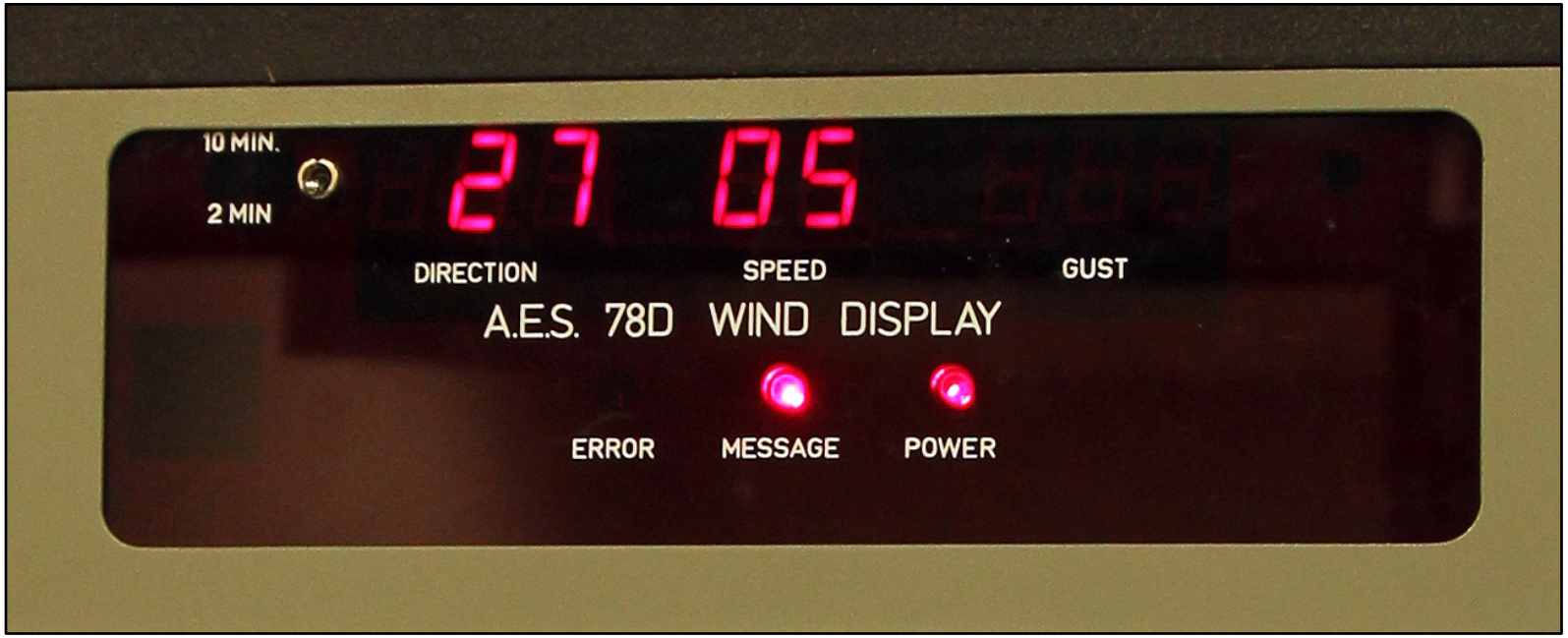
Devine, K. A. 2008. “John Patterson and the three-cup anemometer.” *CMOS Bulletin*, vol 36, no 2, p 51-56.

Gates, E.M. and W.C. Thompson. 1986. “Simulated atmospheric rime icing of some wind speed sensors.” *Journal of Atmospheric and Oceanic Technology*, vol 3, p 273-282.

Wind Record Time-Series

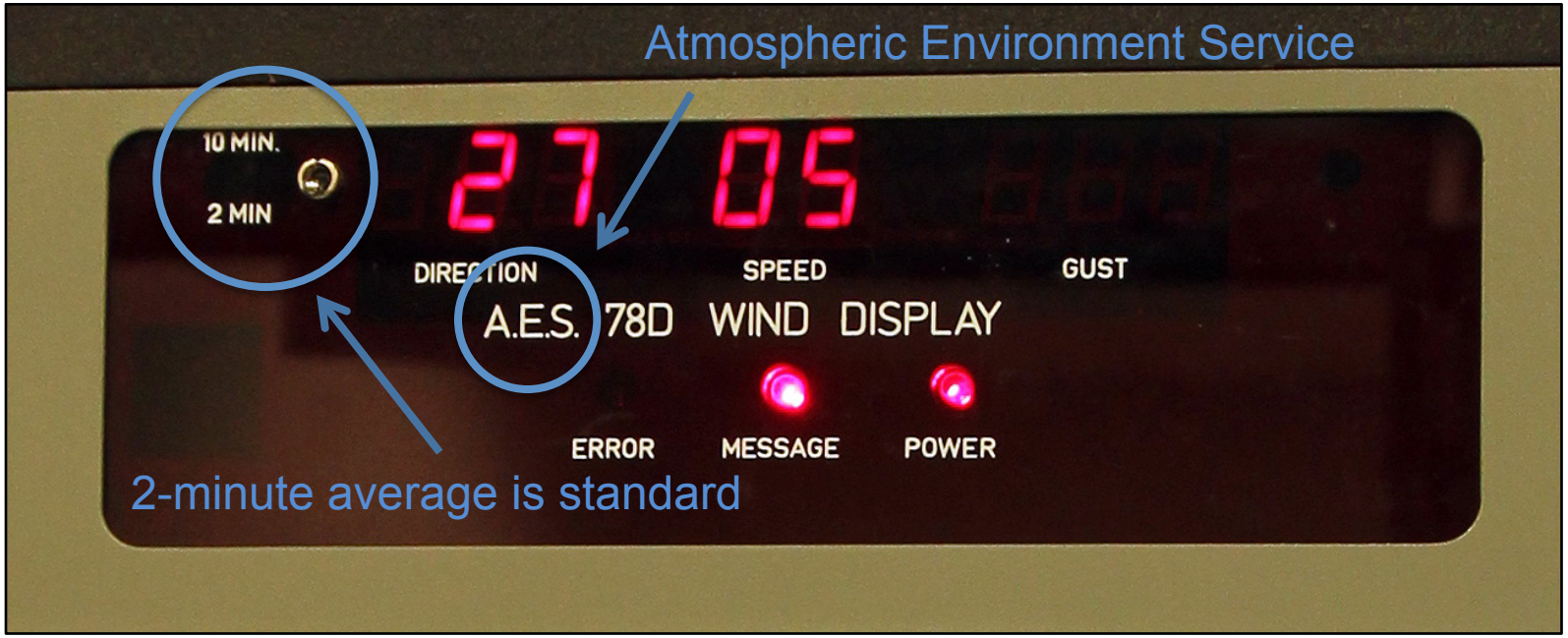
- The U2A anemometer
- MSC's primary wind sensor from roughly the 1960s-1990s
- Display: Direct reading dials and chart-recording systems
- Some still in operation today

Wind Record Time-Series



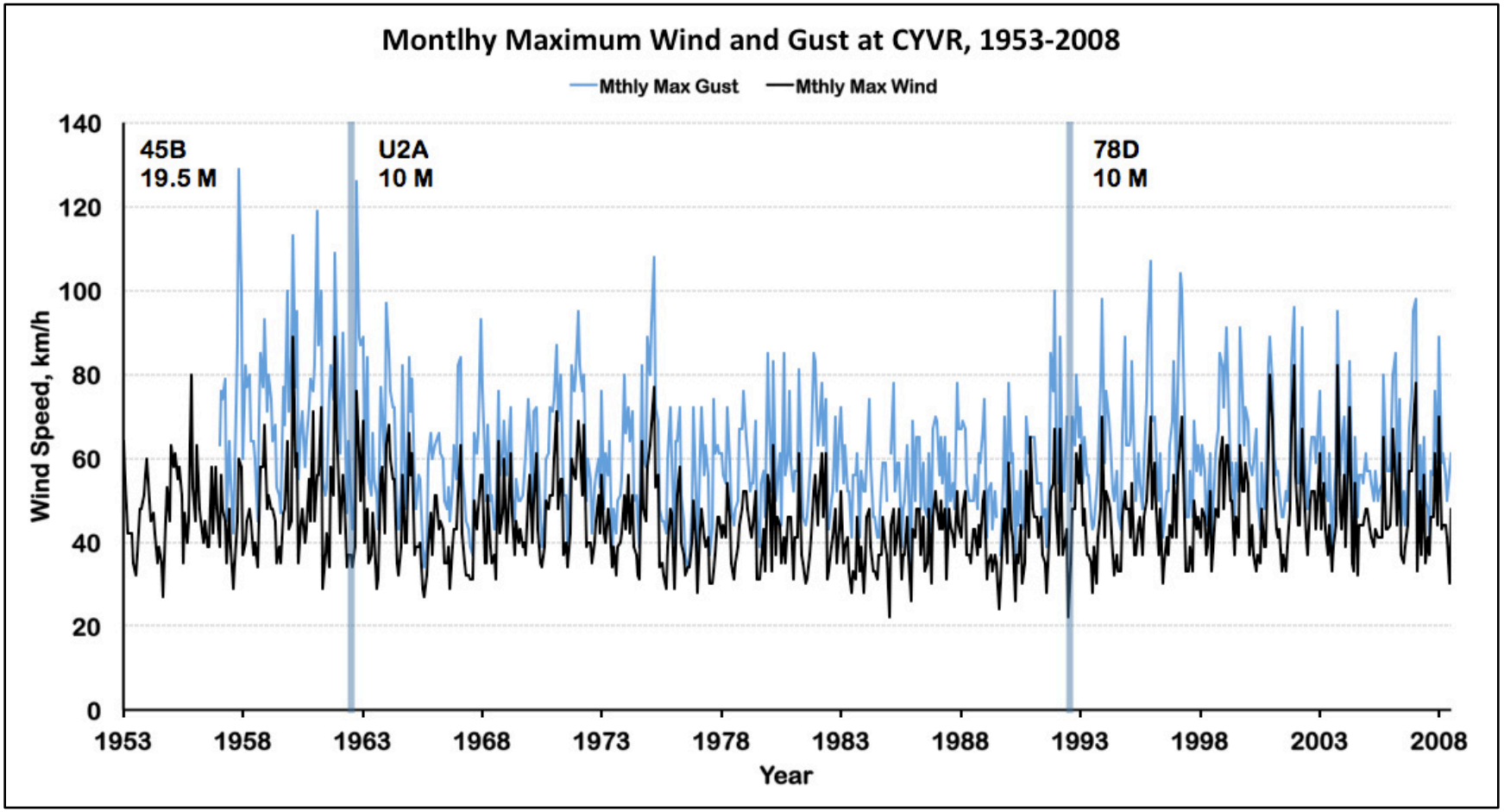
- The 78D anemometer (D = digital)
- Completed in 1978, and employed by MSC from the mid-1990s to present
- A cup-based system—in fact, the 45B, U2A and 78D use the same cup design
- Sonic anemometer sensors are next in line

Wind Record Time-Series



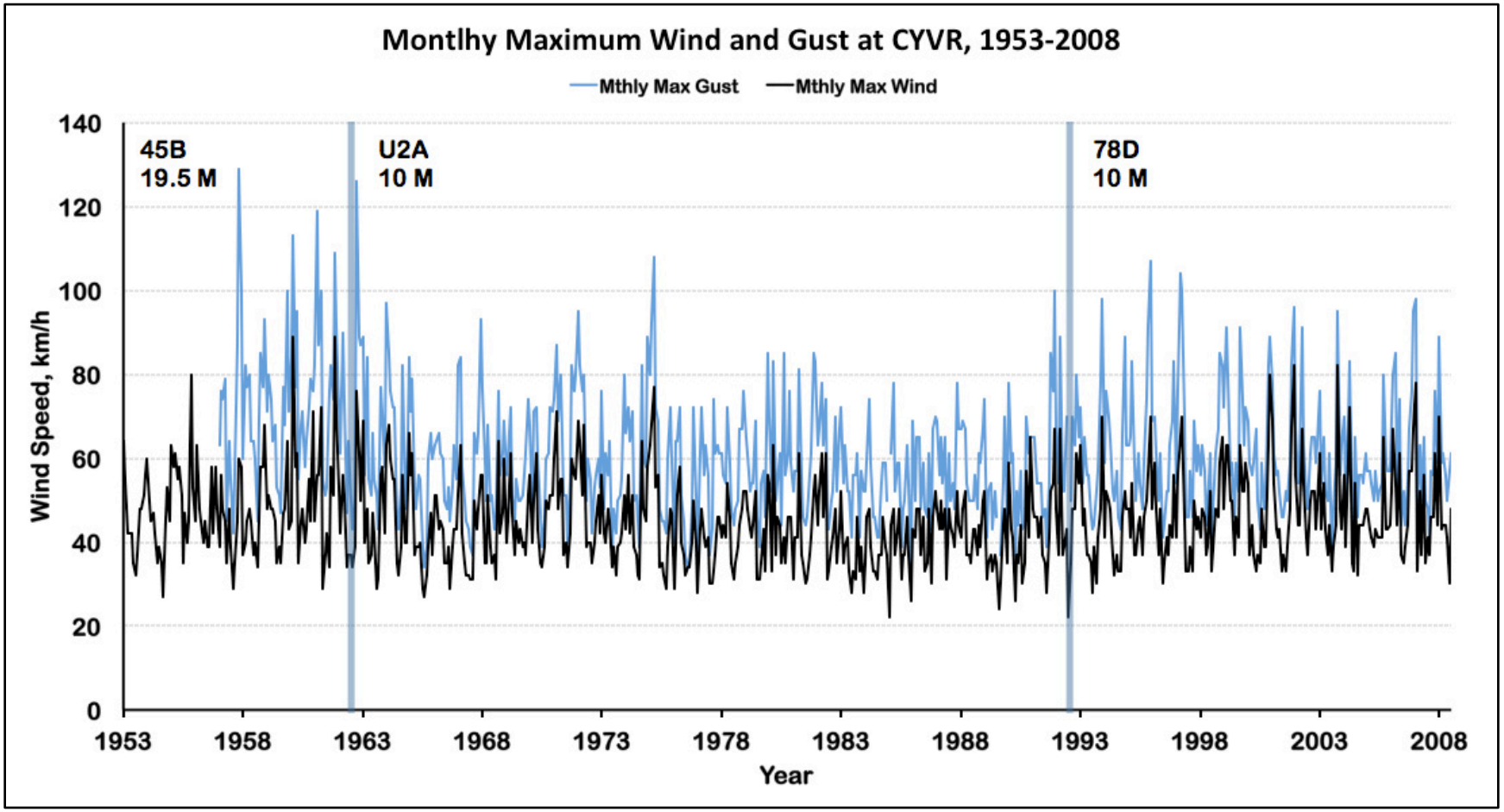
- The 78D anemometer (D = digital)
- Completed in 1978, and employed by MSC from the mid-1990s to present
- A cup-based system—in fact, the 45B, U2A and 78D use the same cup design
- Sonic anemometer sensors are next in line

Wind Record Time-Series



- Different anemometers might explain inflections (trends) that appear in long-term data series

Wind Record Time-Series



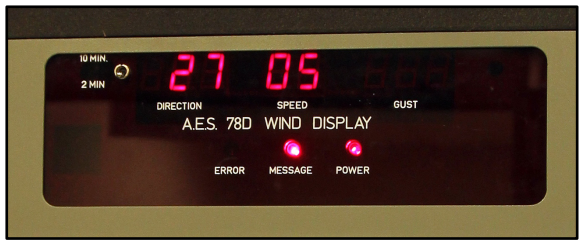
- Different anemometers might explain inflections (trends) that appear in long-term data series
- Pinpointing the exact time of an instrument change is important

Wind Record Time-Series

- We know that different anemometers were used over time

1933

1963



1993

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

1933

1963

1993

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

1933

1963

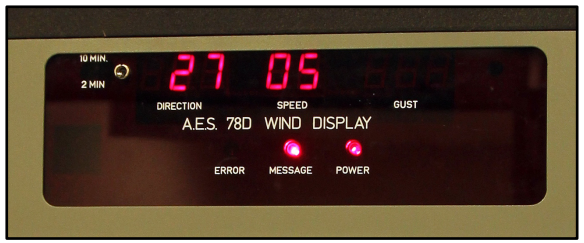
1993

Wind Record Time-Series

- Specific observational methodology can result in detectable signals in the long-period wind record

1933

1963



1993

Wind Record Time-Series

- Specific observational methodology can result in detectable signals in the long-period wind record
- Inflections in these signals can then be used to identify when an instrument change has occurred

1933

1963

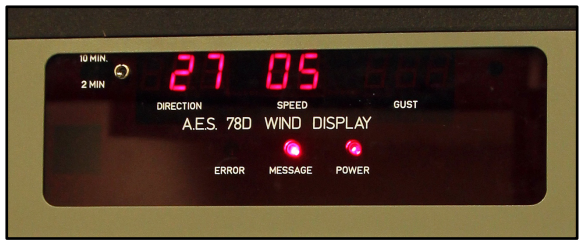
1993

Wind Record Time-Series

- Specific observational methodology can result in detectable signals in the long-period wind record
- Inflections in these signals can then be used to identify when an instrument change has occurred
- Stanton E. Tuller (1980): “The Even Wind Speeds of the British Columbia Coast”

1933

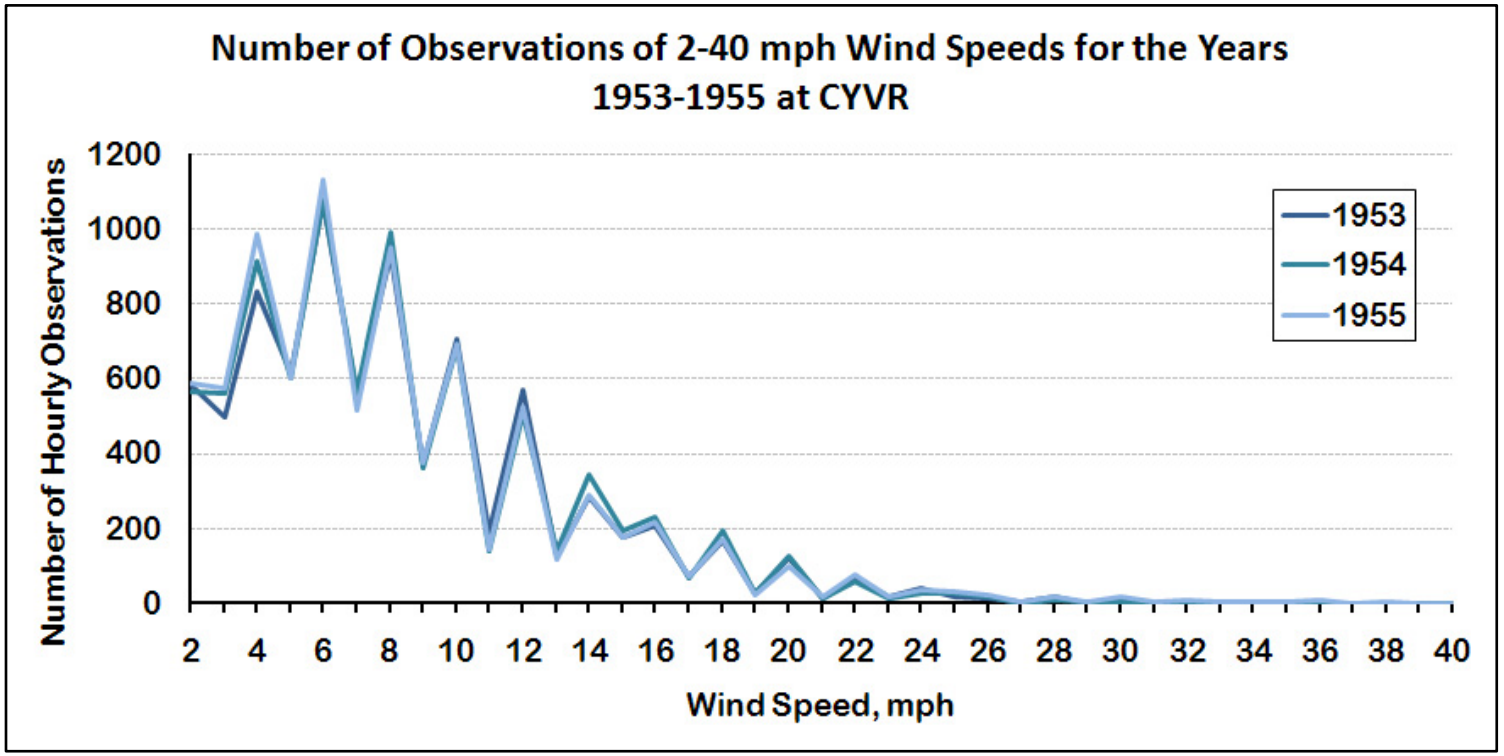
1963



1993

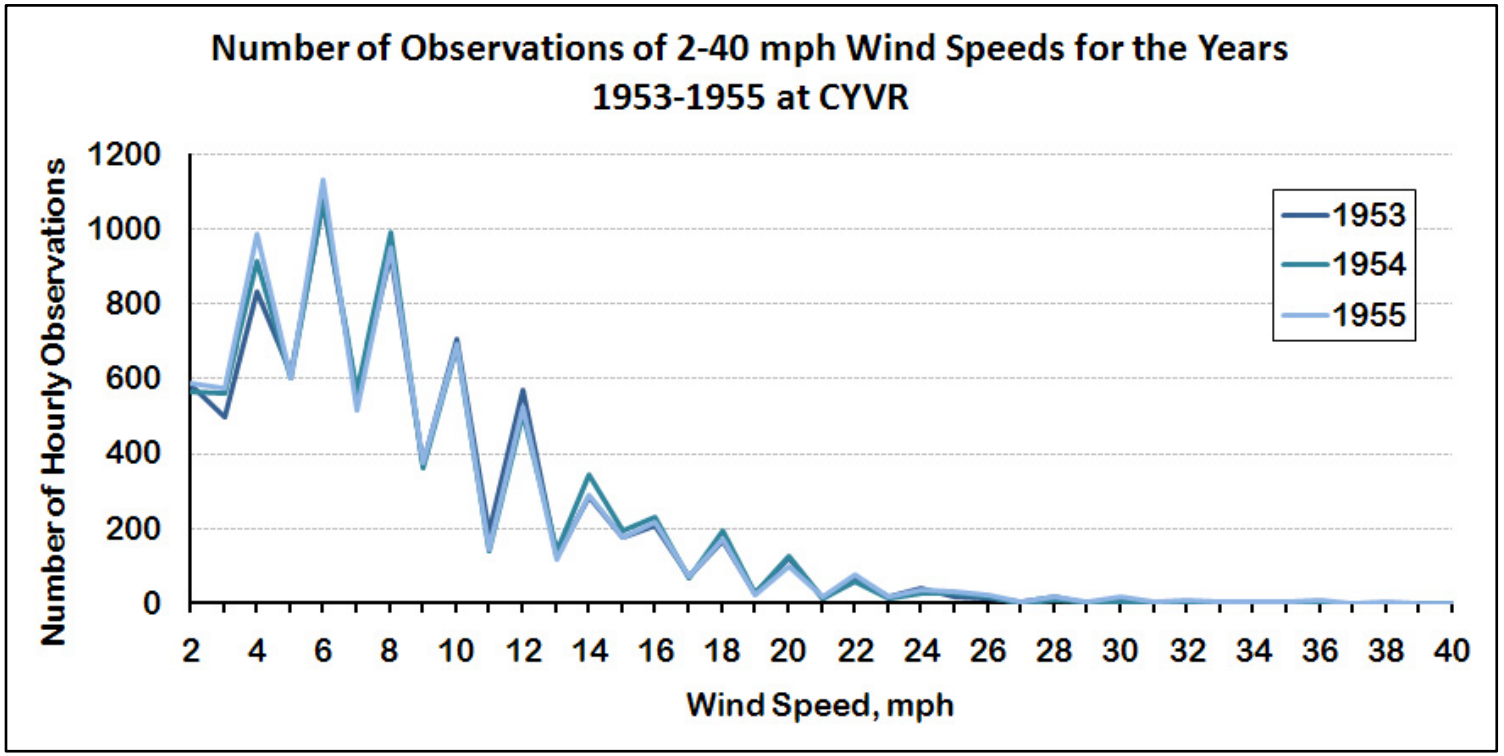
Tuller, S.E. 1980. “The even wind speeds on the British Columbia coast.” *Atmosphere-Ocean*, vol 18, no 4, p 322-328.

Wind Record Time-Series



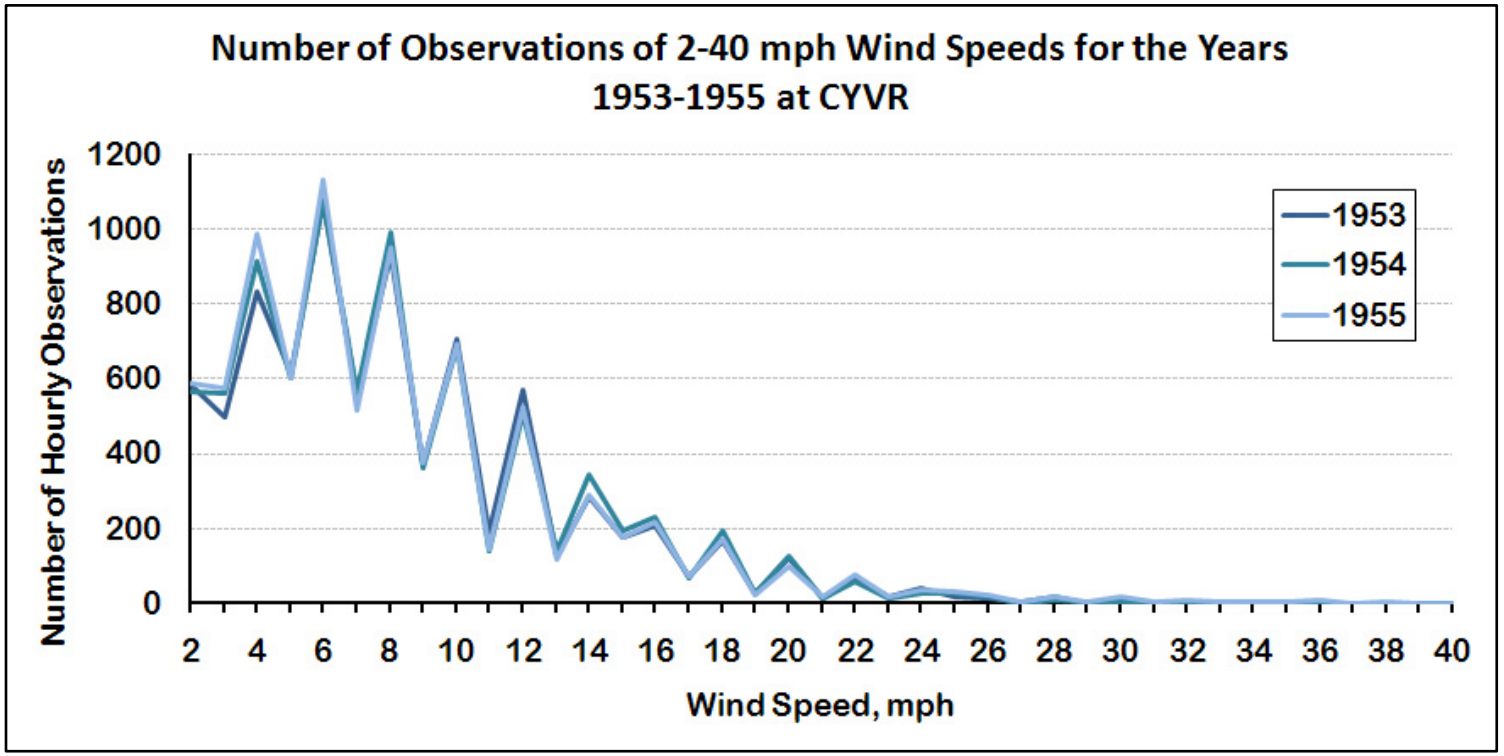
- The frequency of even numbers is higher than odd numbers in the record

Wind Record Time-Series



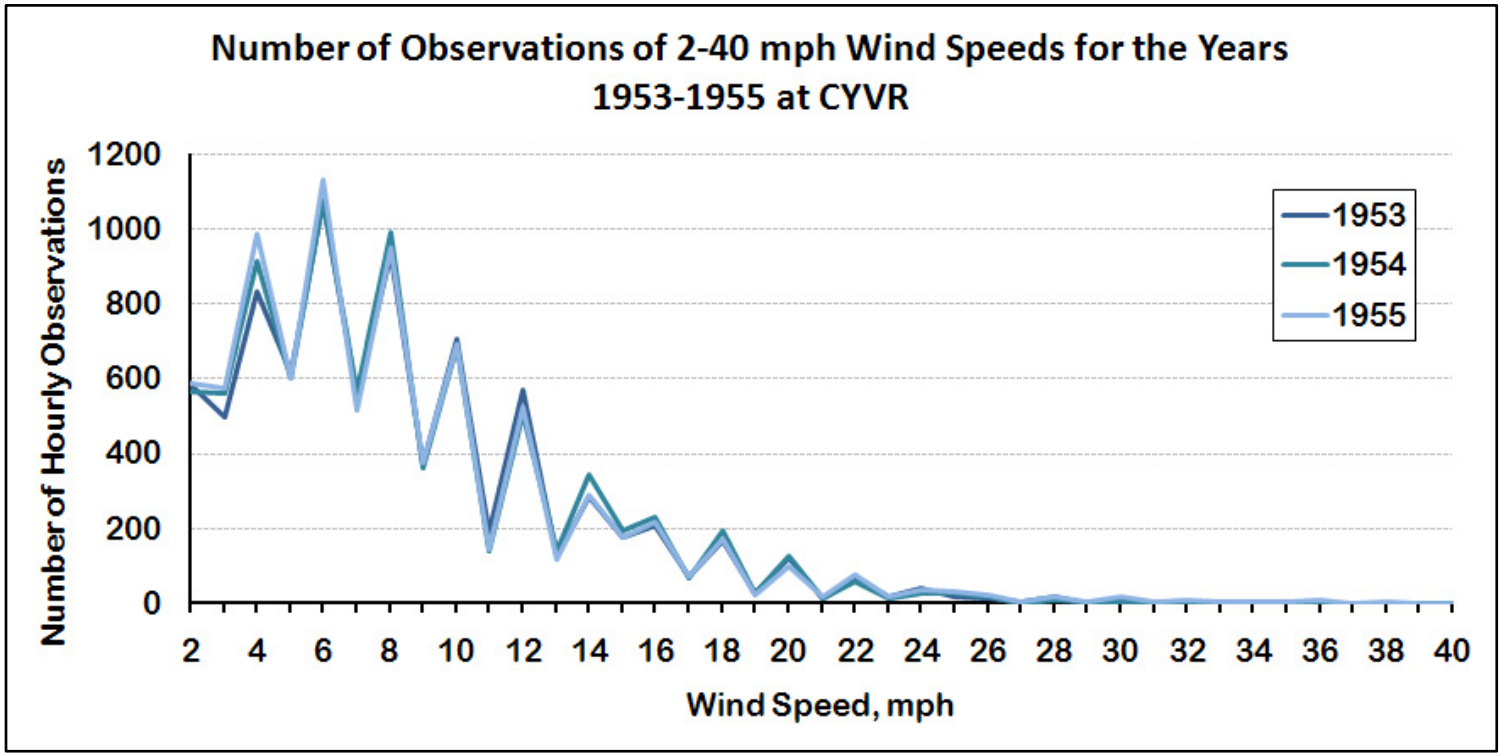
- The frequency of even numbers is higher than odd numbers in the record
- There is also a bias for 5s and 10s, depending on the station

Wind Record Time-Series



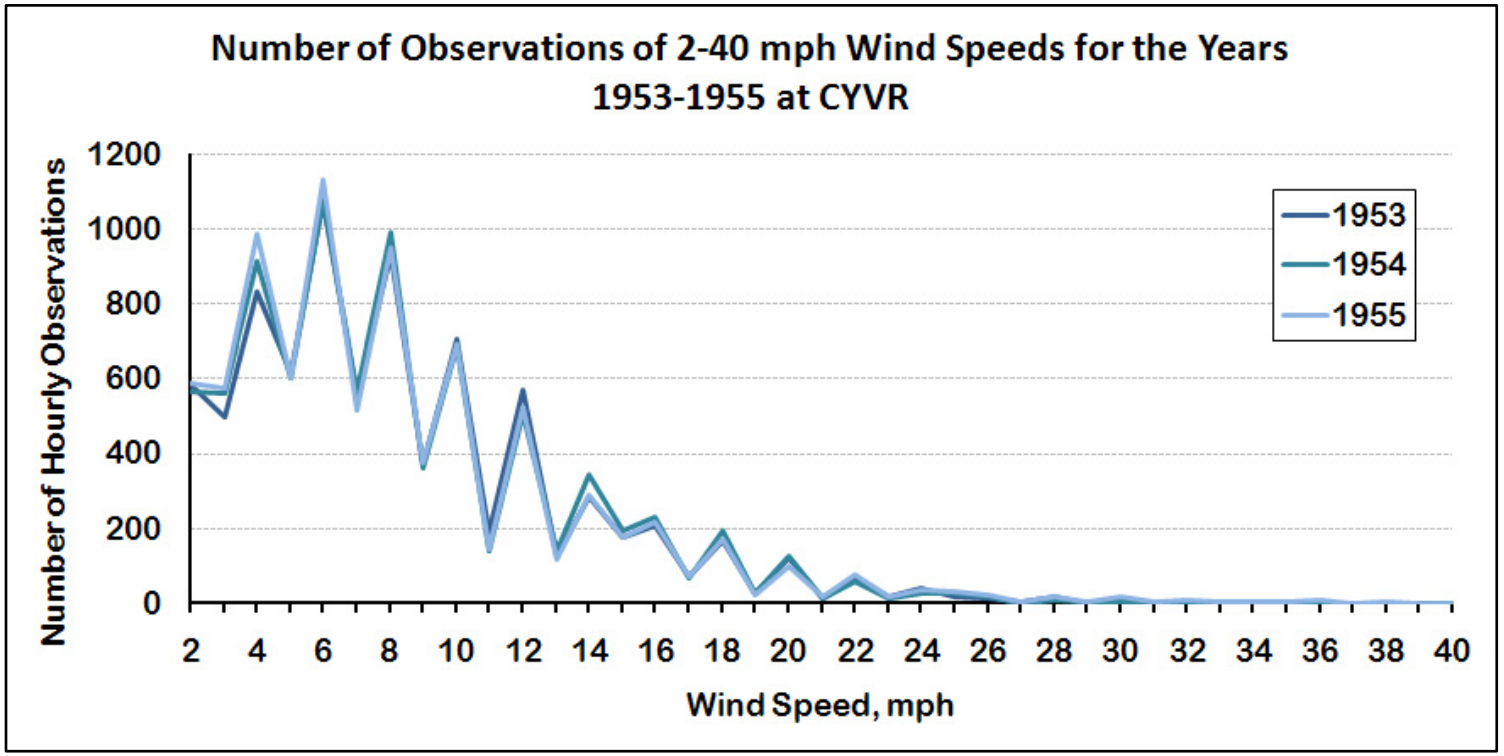
- The frequency of even numbers is higher than odd numbers in the record
- There is also a bias for 5s and 10s, depending on the station
- Some of this has to do with human psychology

Wind Record Time-Series



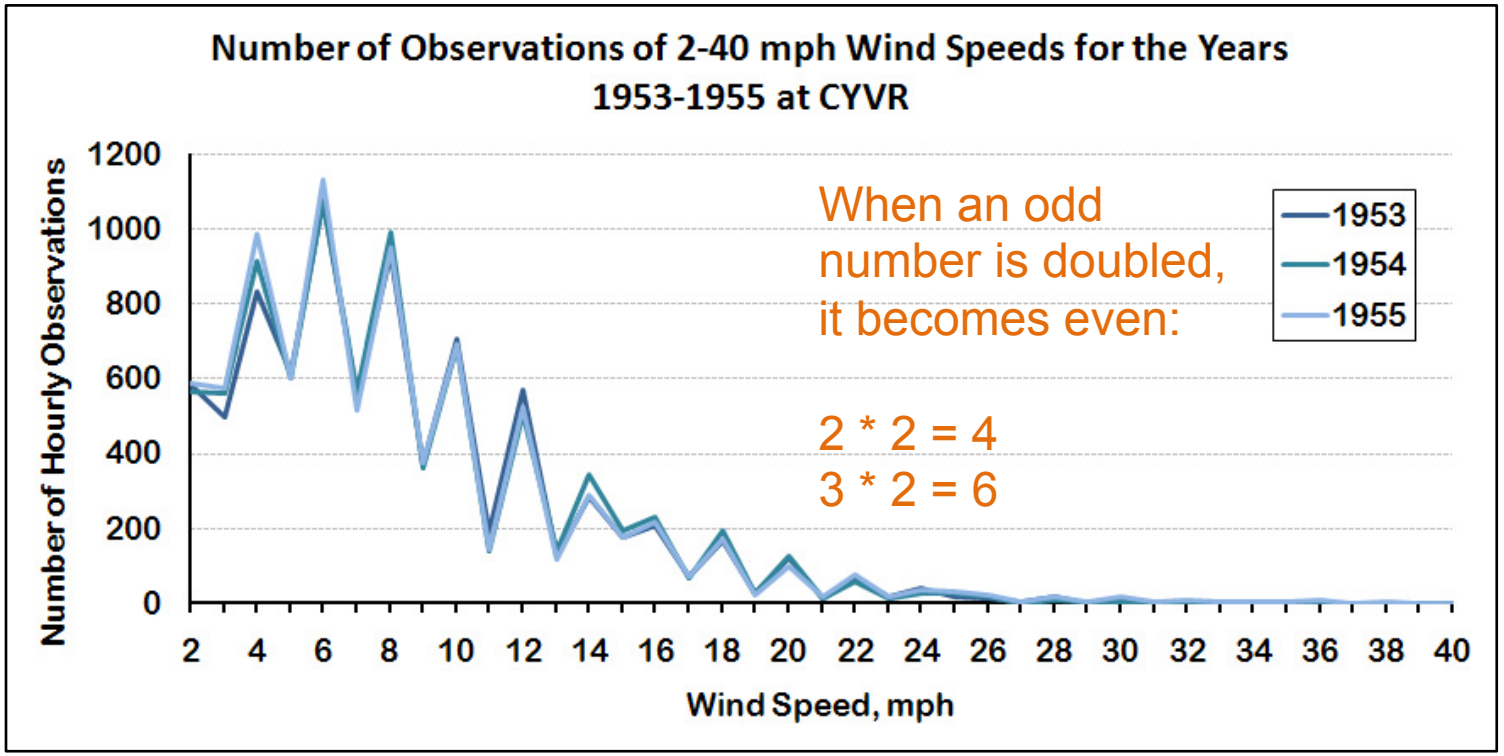
- A large part of the bias during the 45B era has to do with methodology

Wind Record Time-Series



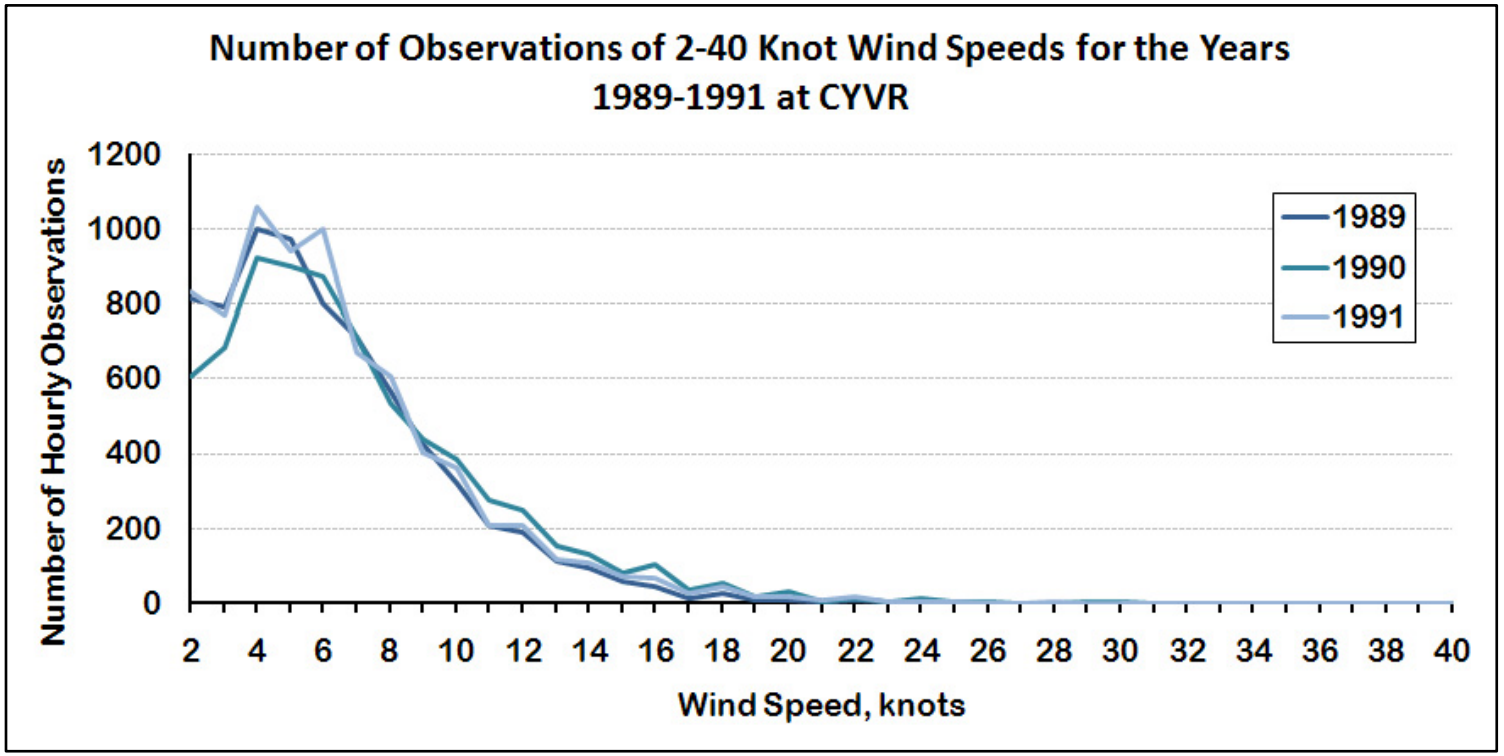
- A large part of the bias during the 45B era has to do with methodology
- For average wind speeds, observers counted a flashing light for 30 seconds

Wind Record Time-Series



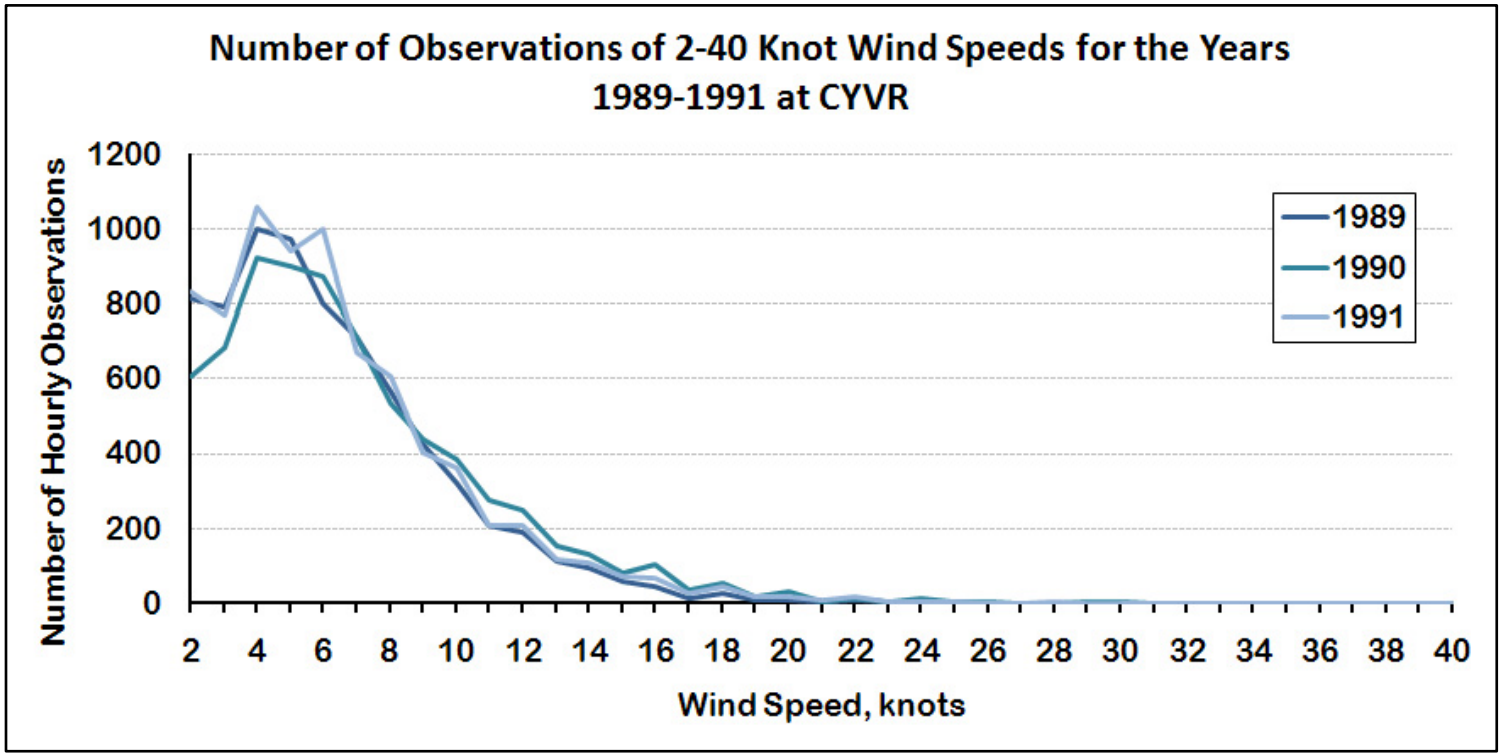
- A large part of the bias during the 45B era has to do with methodology
- For average wind speeds, observers counted a flashing light for 30 seconds
- Often, observers halved the required time by counting blinks for 15 seconds and then doubling the result

Wind Record Time-Series



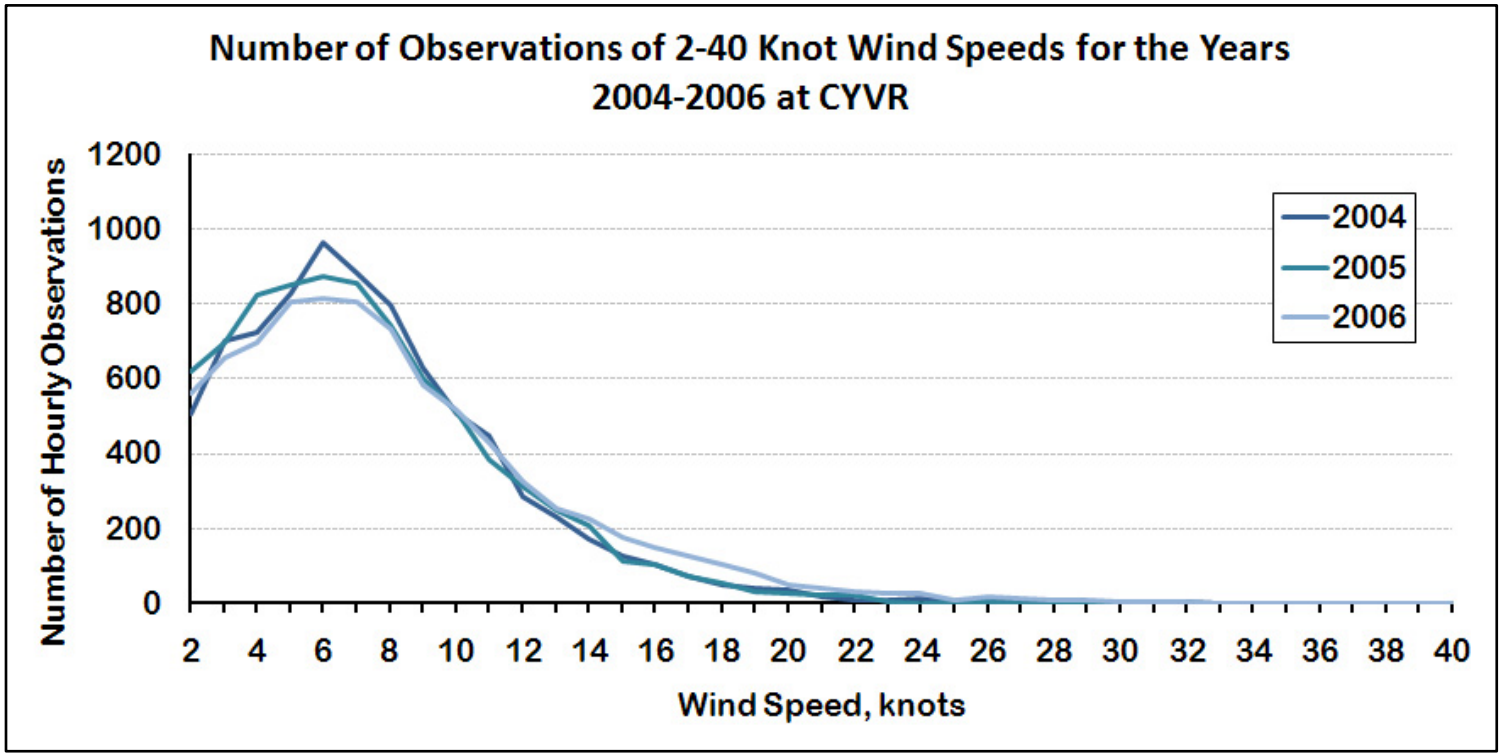
- With the introduction of the U2A and increased use of chart-recorders, the blinking light was gradually replaced, reducing the even-number bias

Wind Record Time-Series



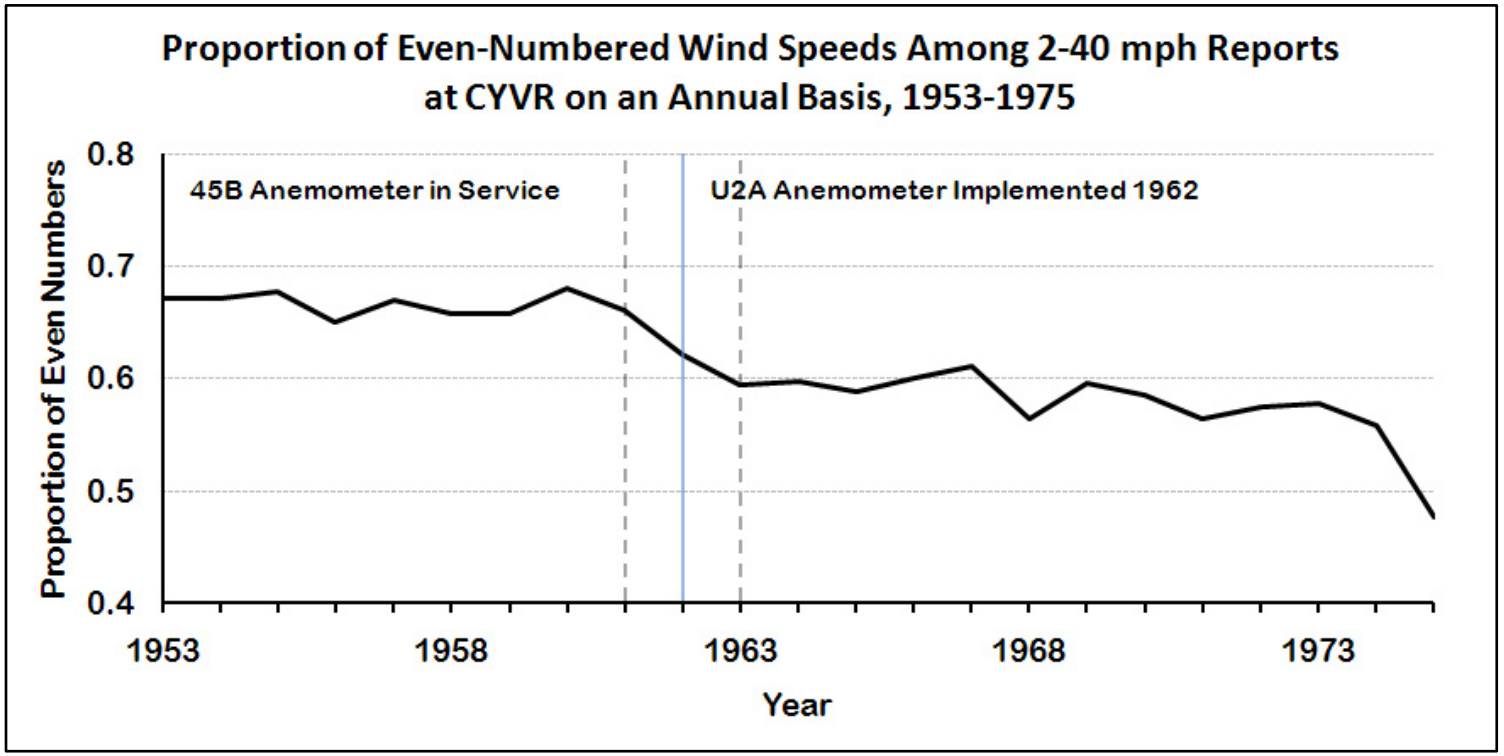
- With the introduction of the U2A and increased use of chart-recorders, the blinking light was gradually replaced, reducing the even-number bias
- However, a psychological preference for even numbers, 0s and 5s remained

Wind Record Time-Series



- With the automated 78D, even-number bias is finally eliminated from the wind record

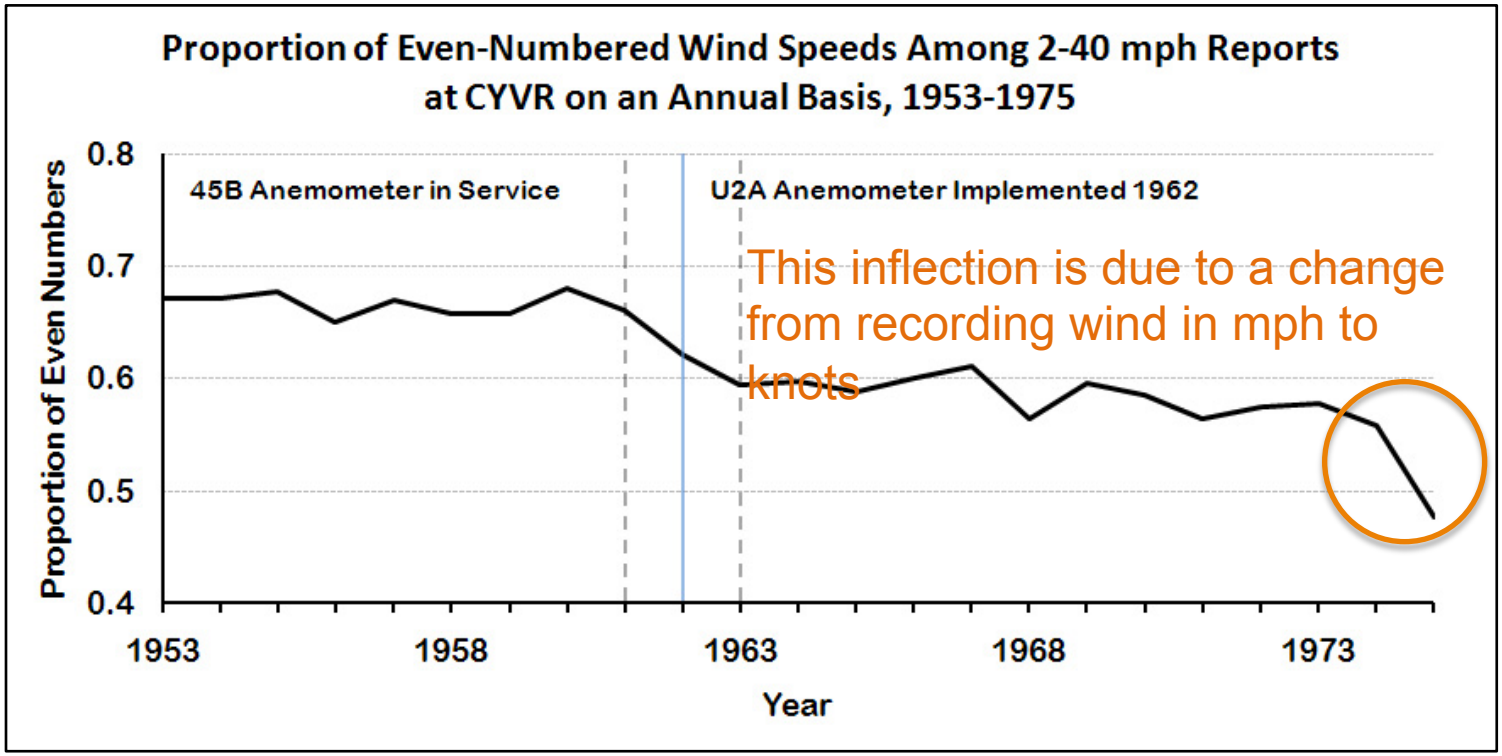
Wind Record Time-Series



- 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

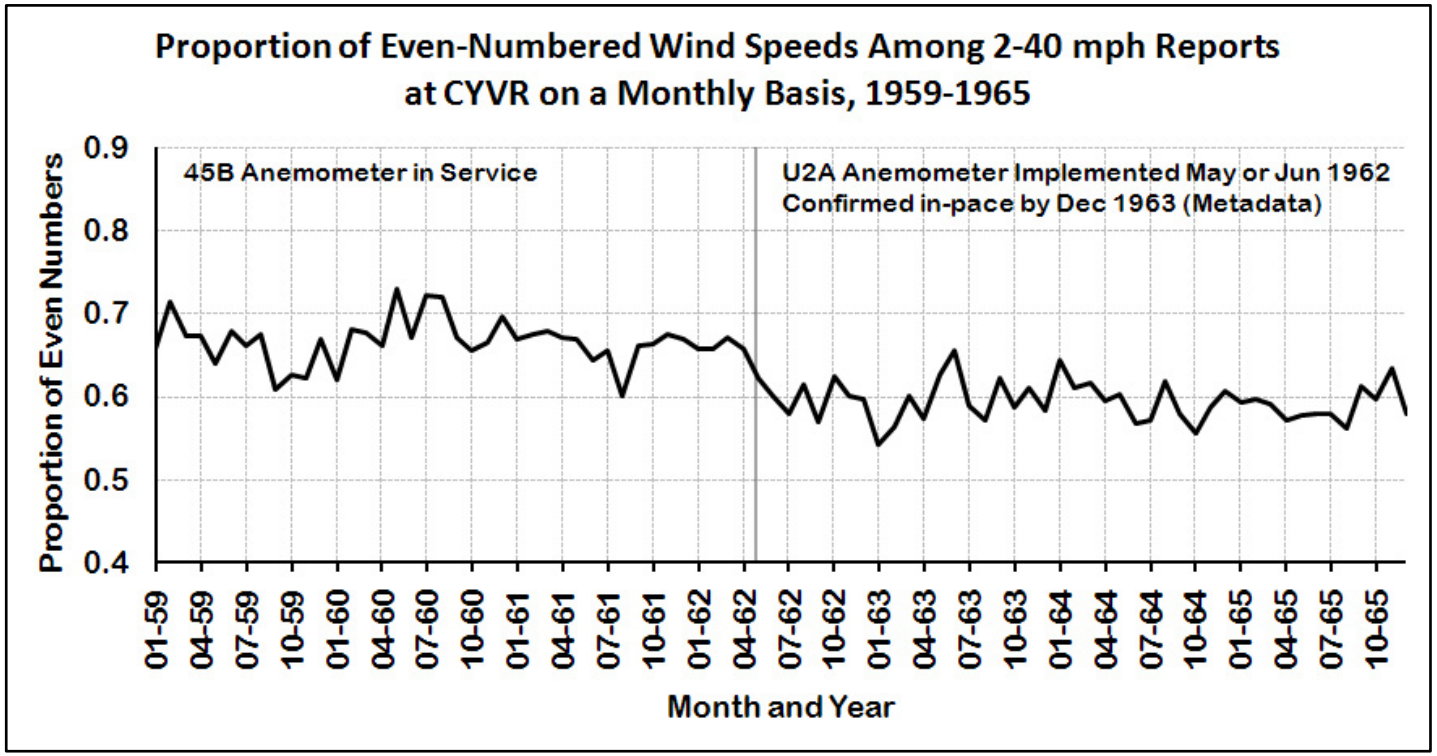
Wind Record Time-Series



- Even-wind proportion is the frequency that even numbers appear in the wind record: 0.7 = 70% of the time

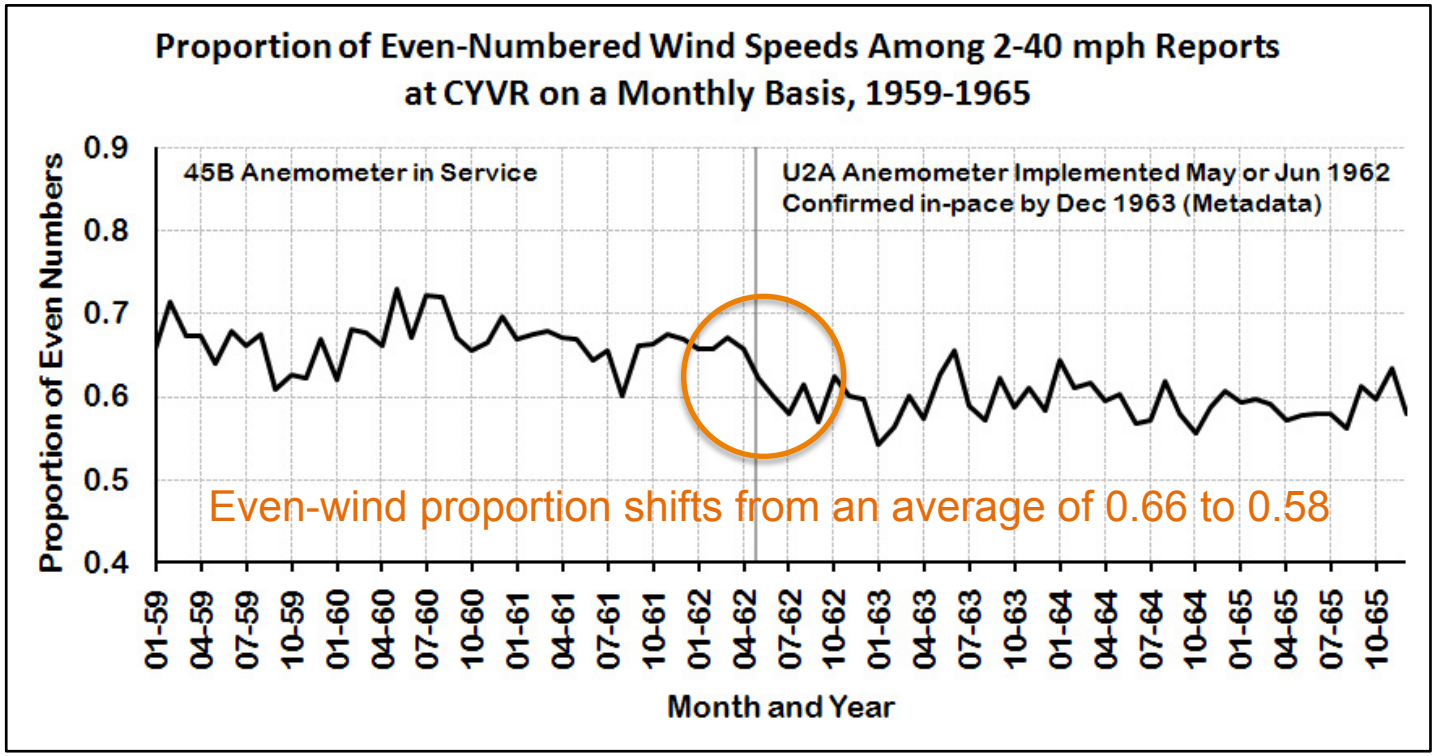
- An inflection in even-wind proportion points to a methodological, and likely, an instrumental change

Wind Record Time-Series



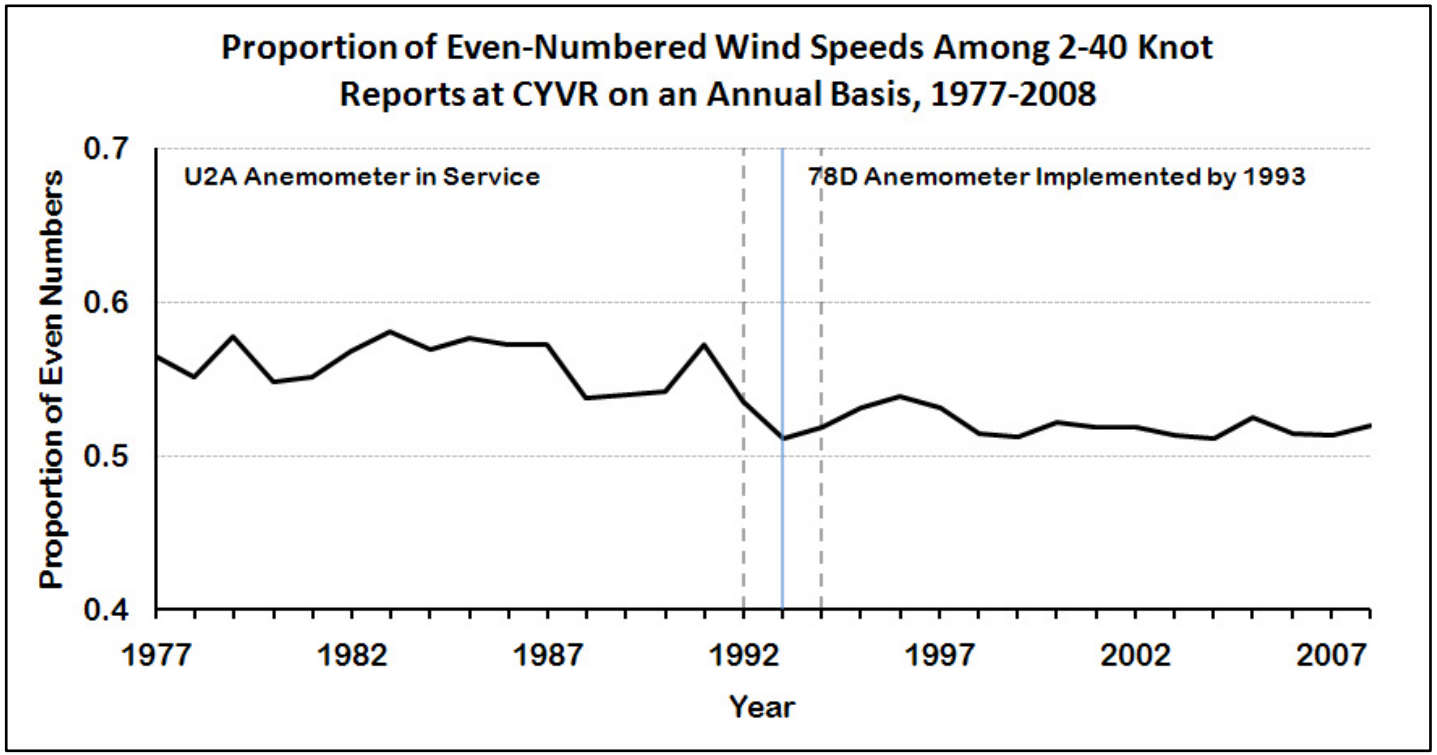
- This method can sometimes be used on monthly counts

Wind Record Time-Series



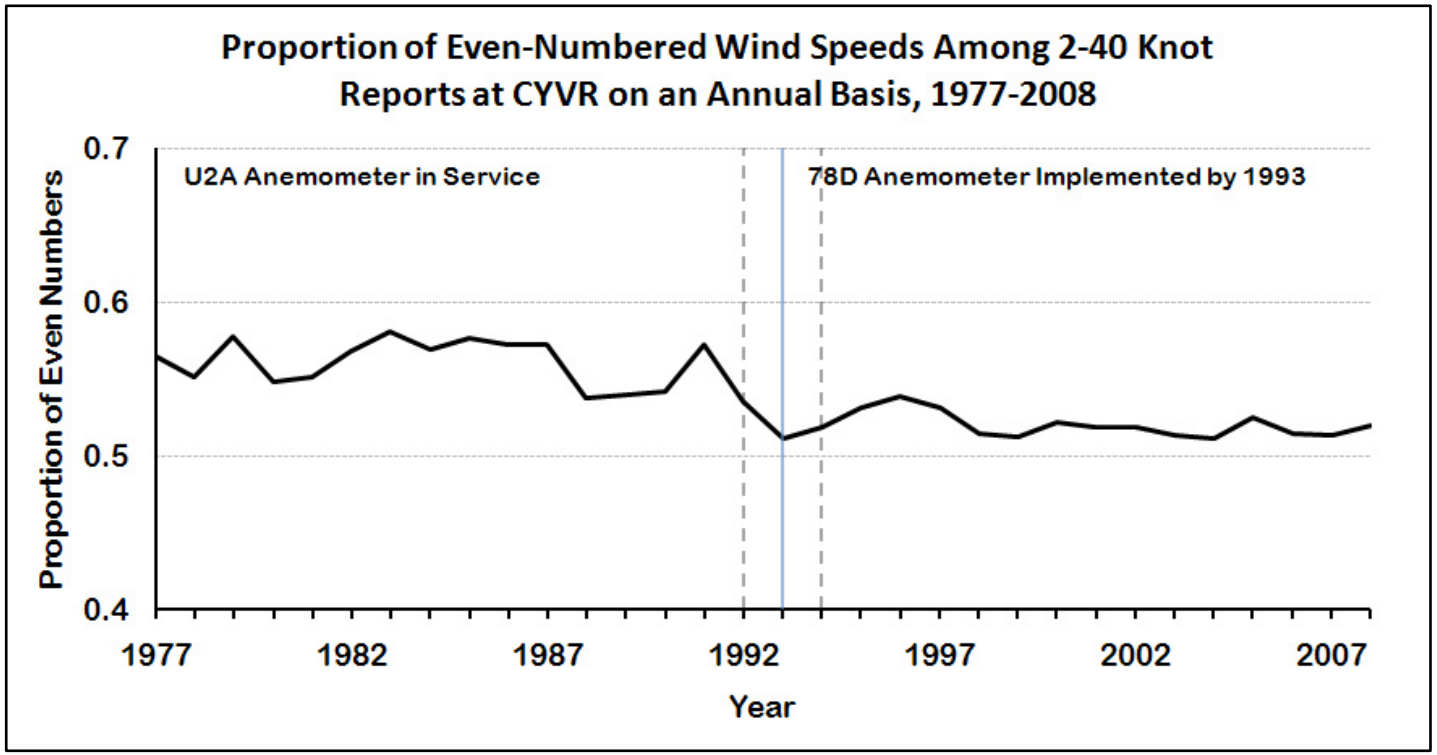
- This method can sometimes be used on monthly counts
- A step change in even-wind proportion suggests that the U2A became dominant during the summer of 1962

Wind Record Time-Series



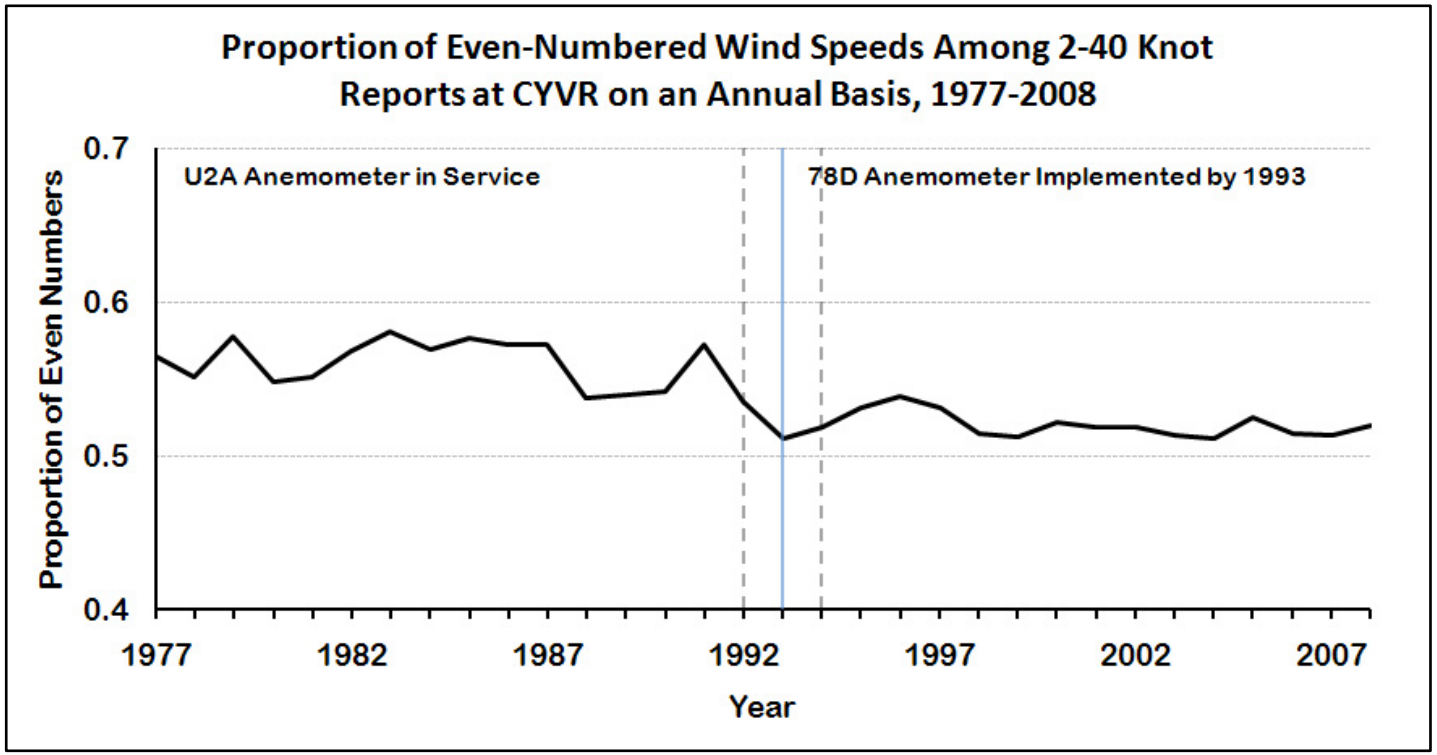
- Here is the change from U2A to 78D

Wind Record Time-Series



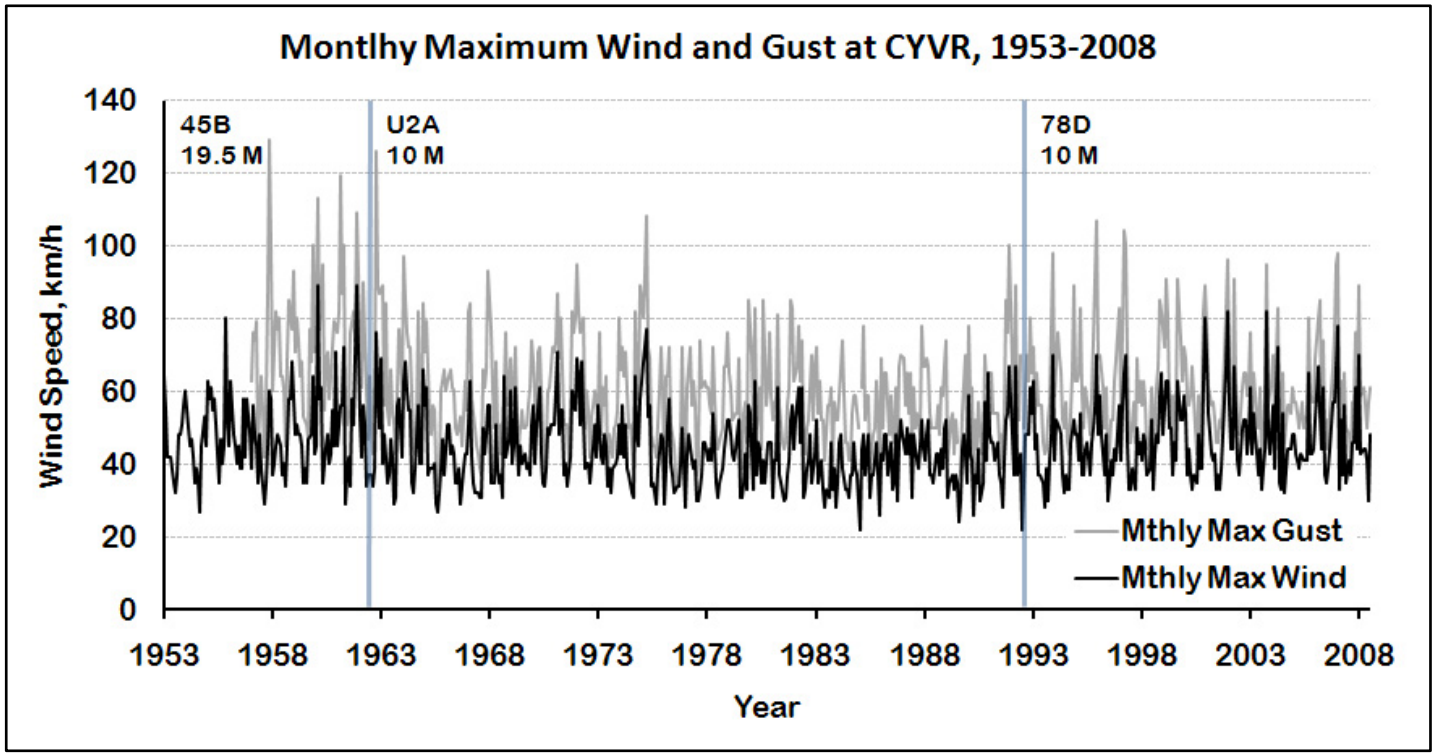
- Here is the change from U2A to 78D
- There is still a slight bias in favor of even numbers for the 78D
- Why?

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

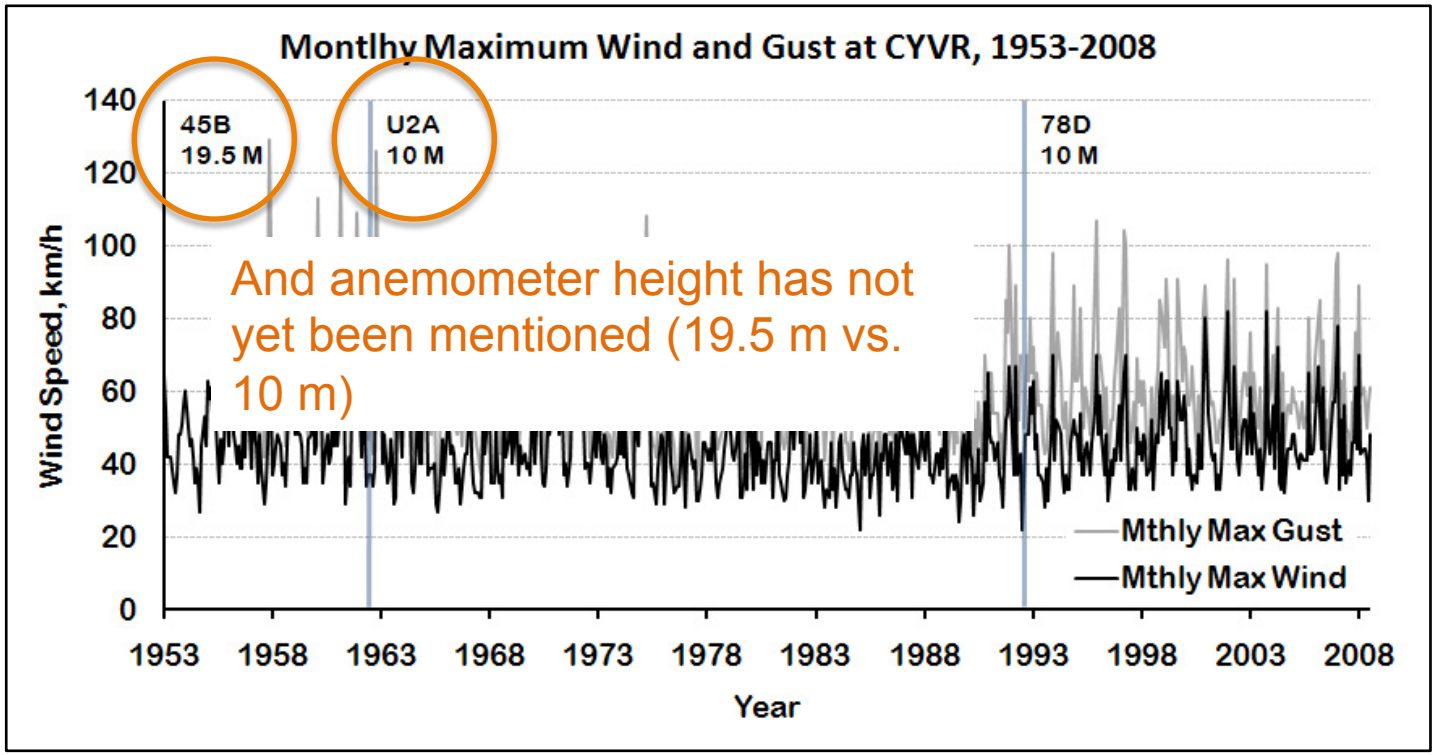
Wind Record Time-Series



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

Wind Record Time-Series



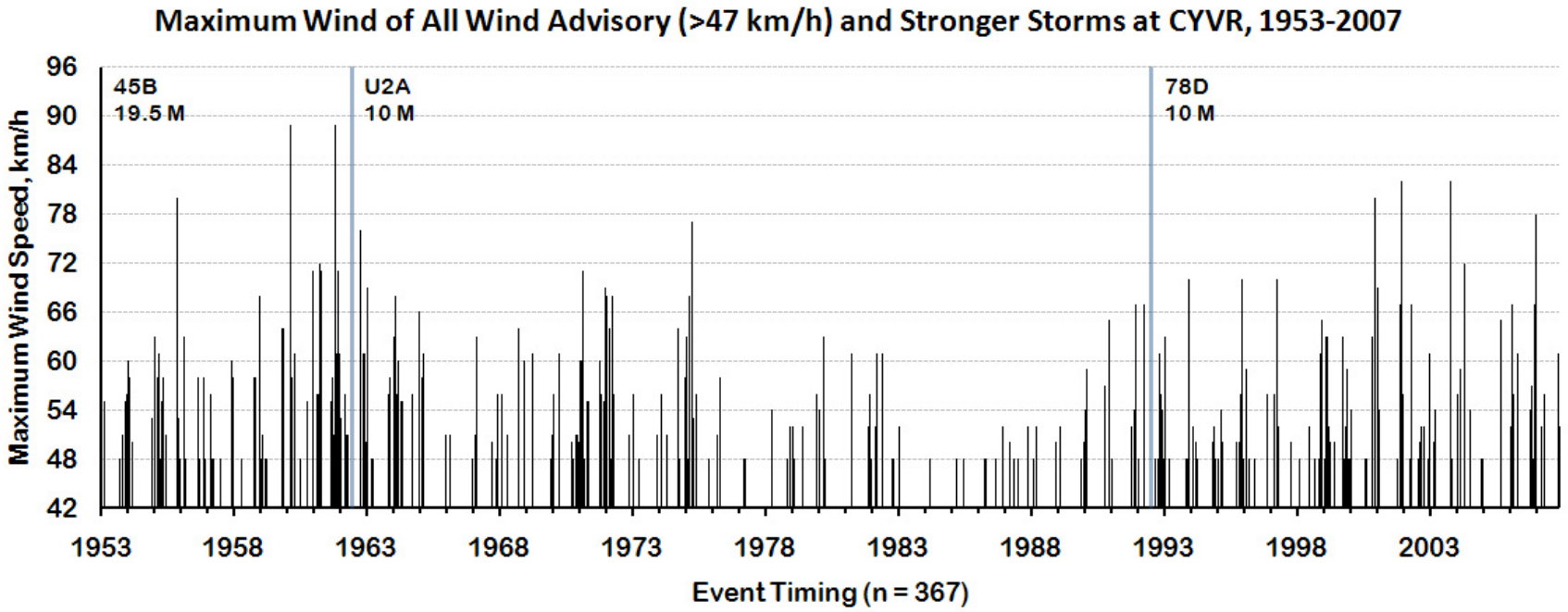
Key ideas to keep in mind when considering the next part of this presentation:

- 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

Windstorm Climatology at CYVR

Vancouver International (CYVR) Windstorms 1953-2008

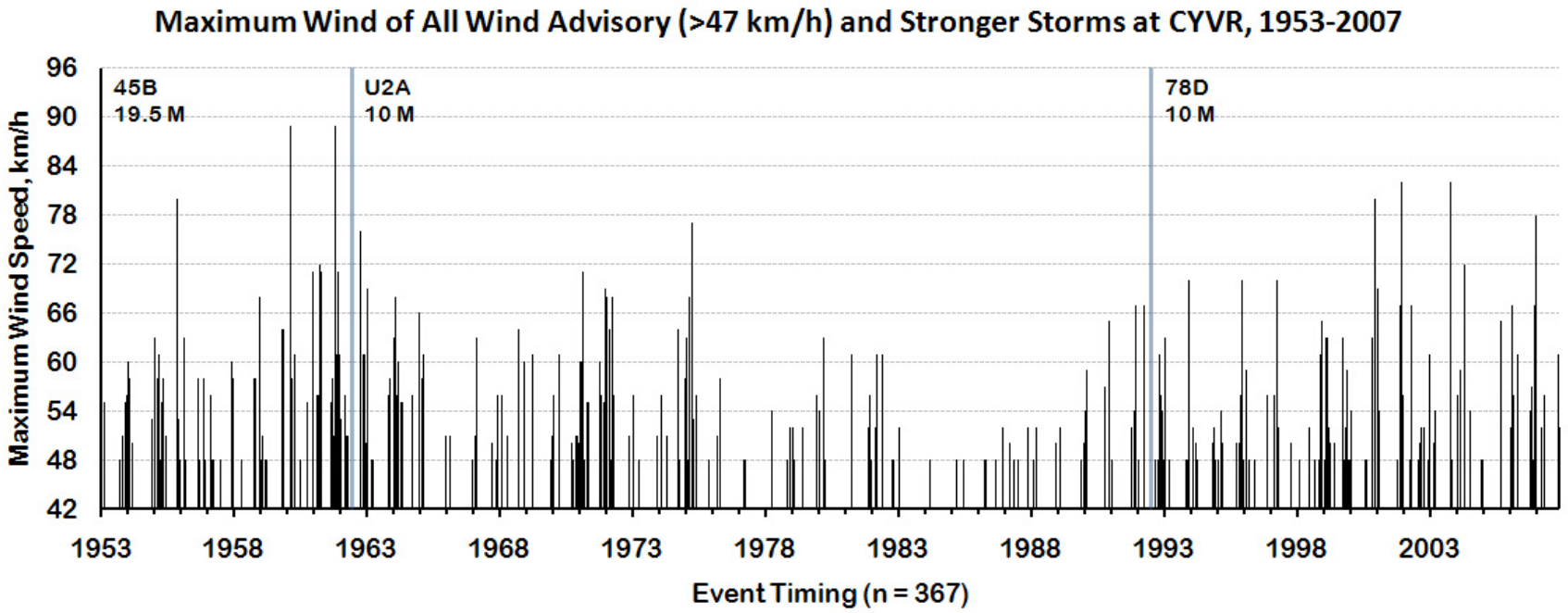
Discrete Storm Events



- These are discrete windstorm events, not daily, weekly, monthly or some other arbitrary time-length

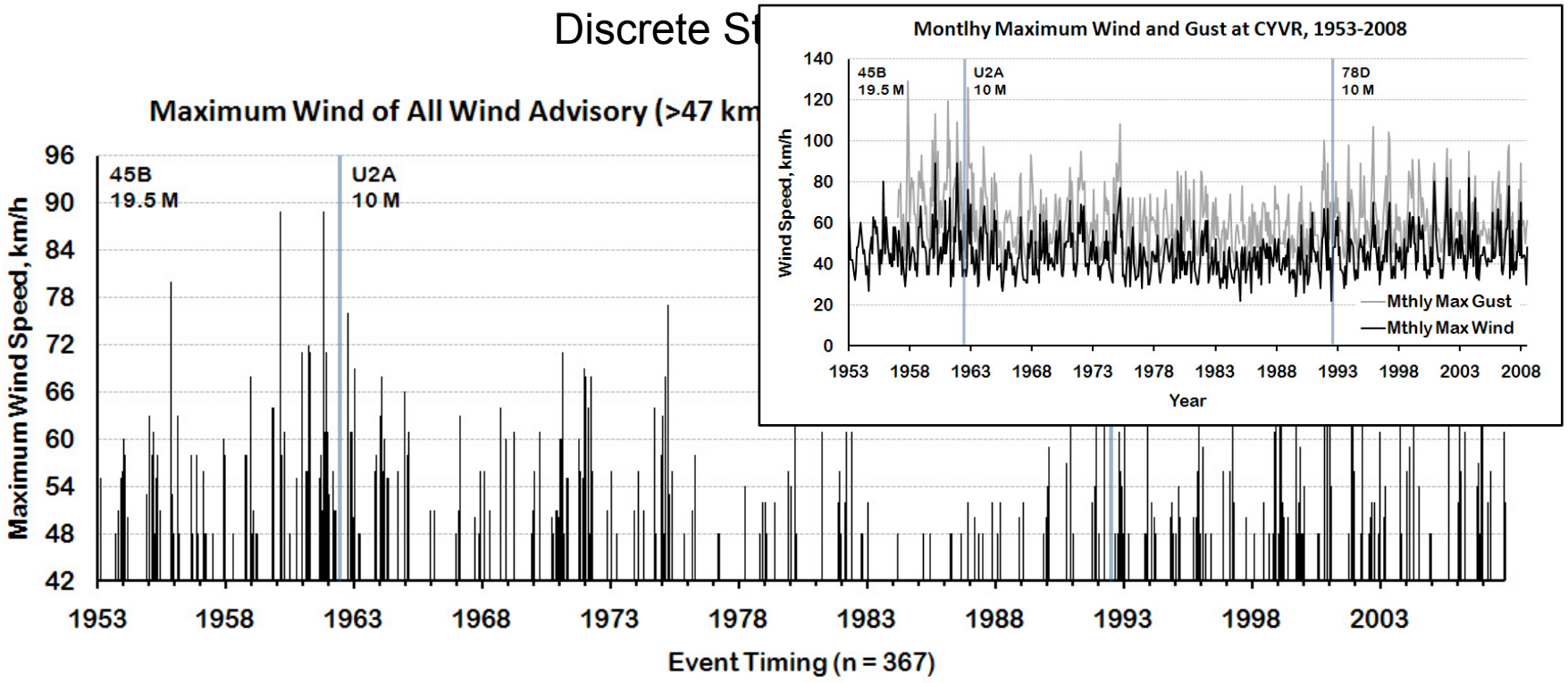
Vancouver International (CYVR) Windstorms 1953-2008

Discrete Storm Events



- These are discrete windstorm events, not daily, weekly, monthly or some other arbitrary time-length
- Used hourly and special observations, supplied from Environment Canada

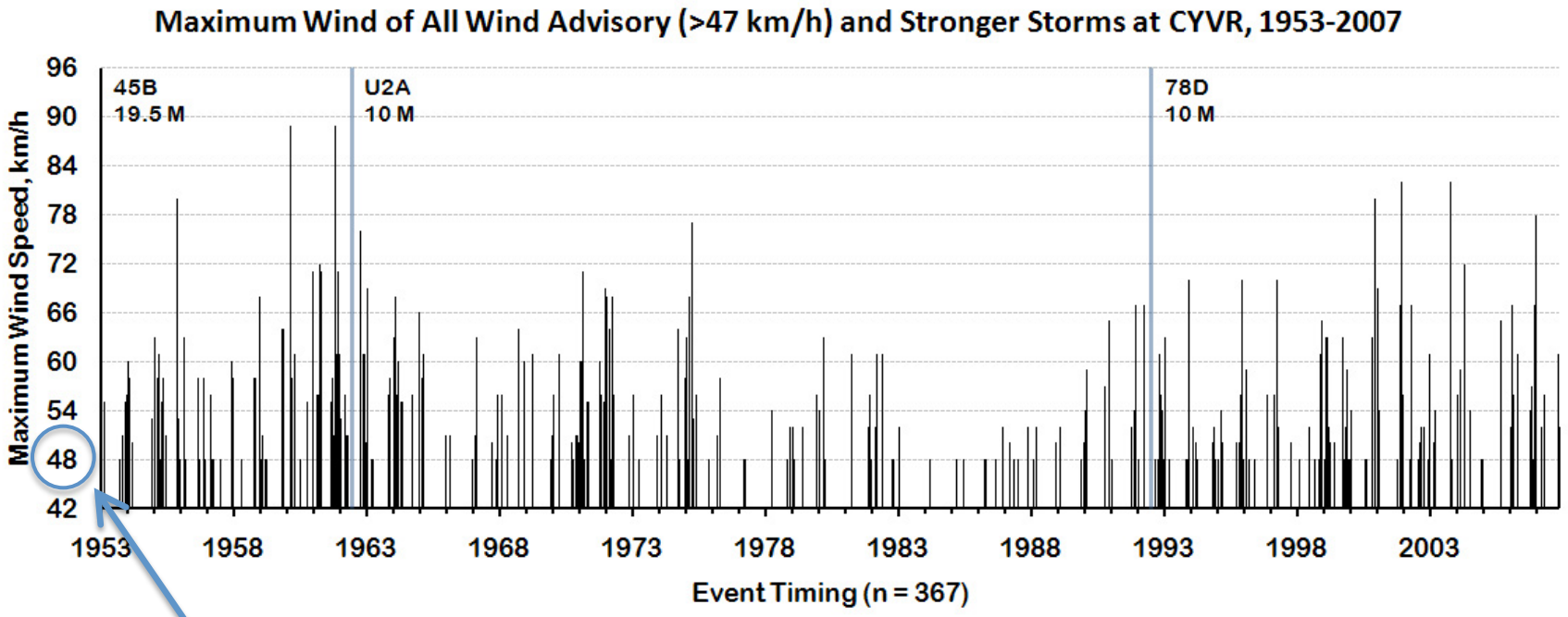
Vancouver International (CYVR) Windstorms 1953-2008



- This is entirely different data compared to what was used in the previous sections (monthly maximums)

Vancouver International (CYVR) Windstorms 1953-2008

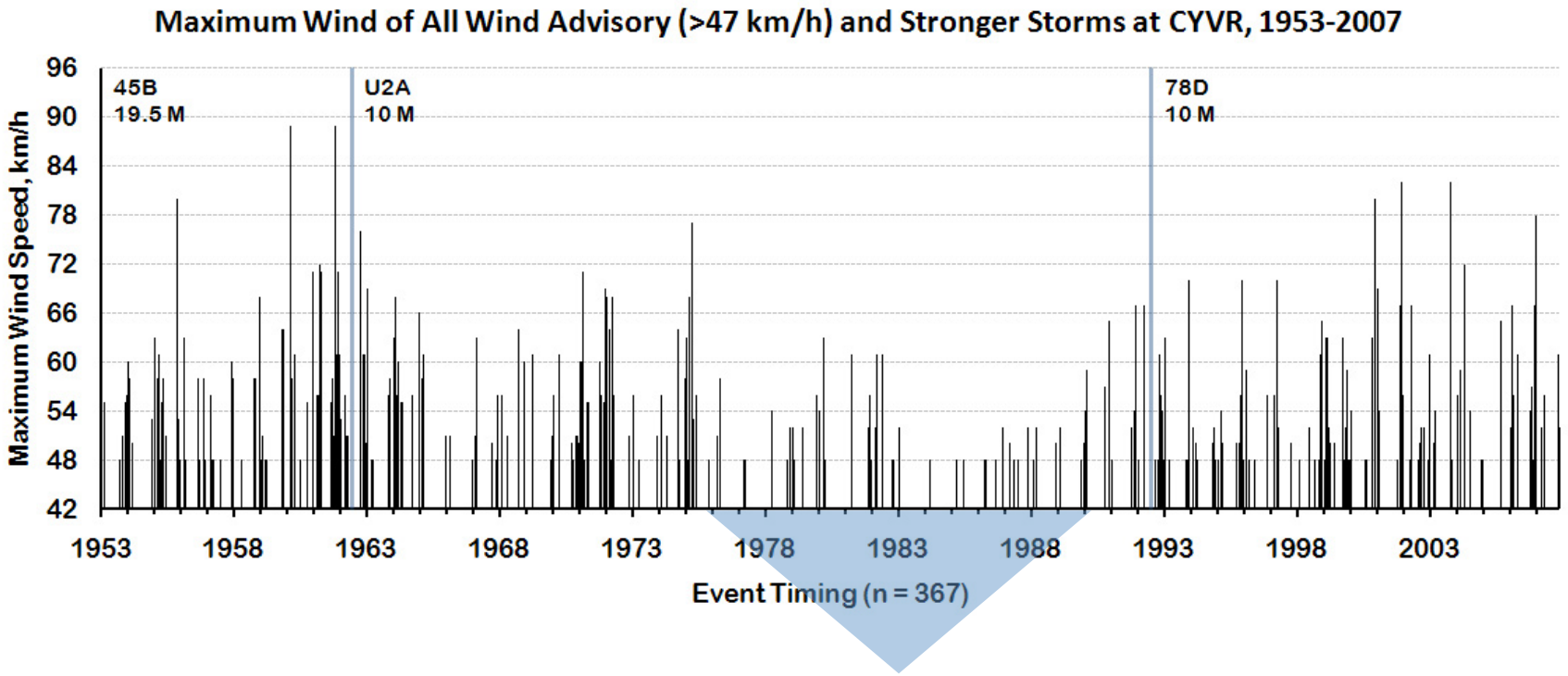
Discrete Storm Events



48 km/h (>25 kt) cutoff for “windstorm” (arbitrary)

Vancouver International (CYVR) Windstorms 1953-2008

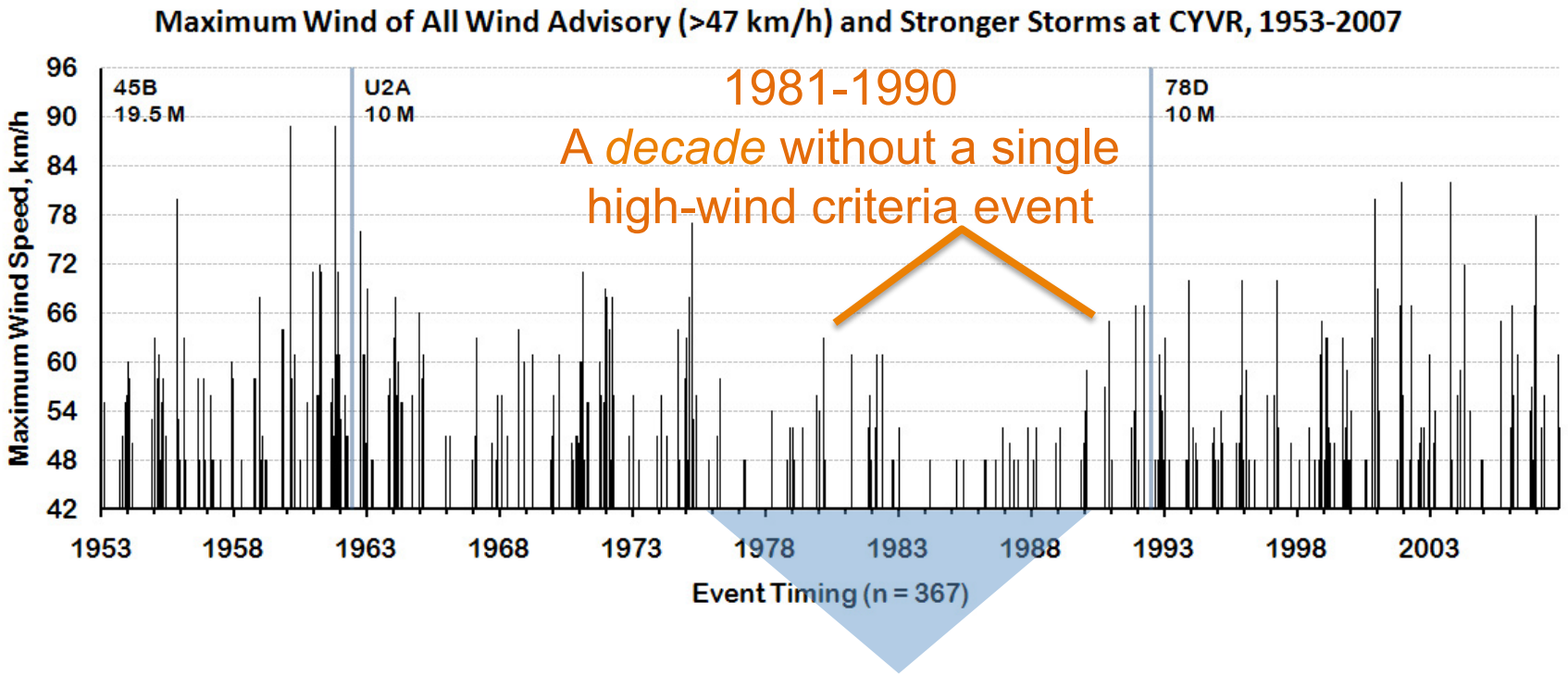
Discrete Storm Events



The "Great Calm"
1976-1990

Vancouver International (CYVR) Windstorms 1953-2008

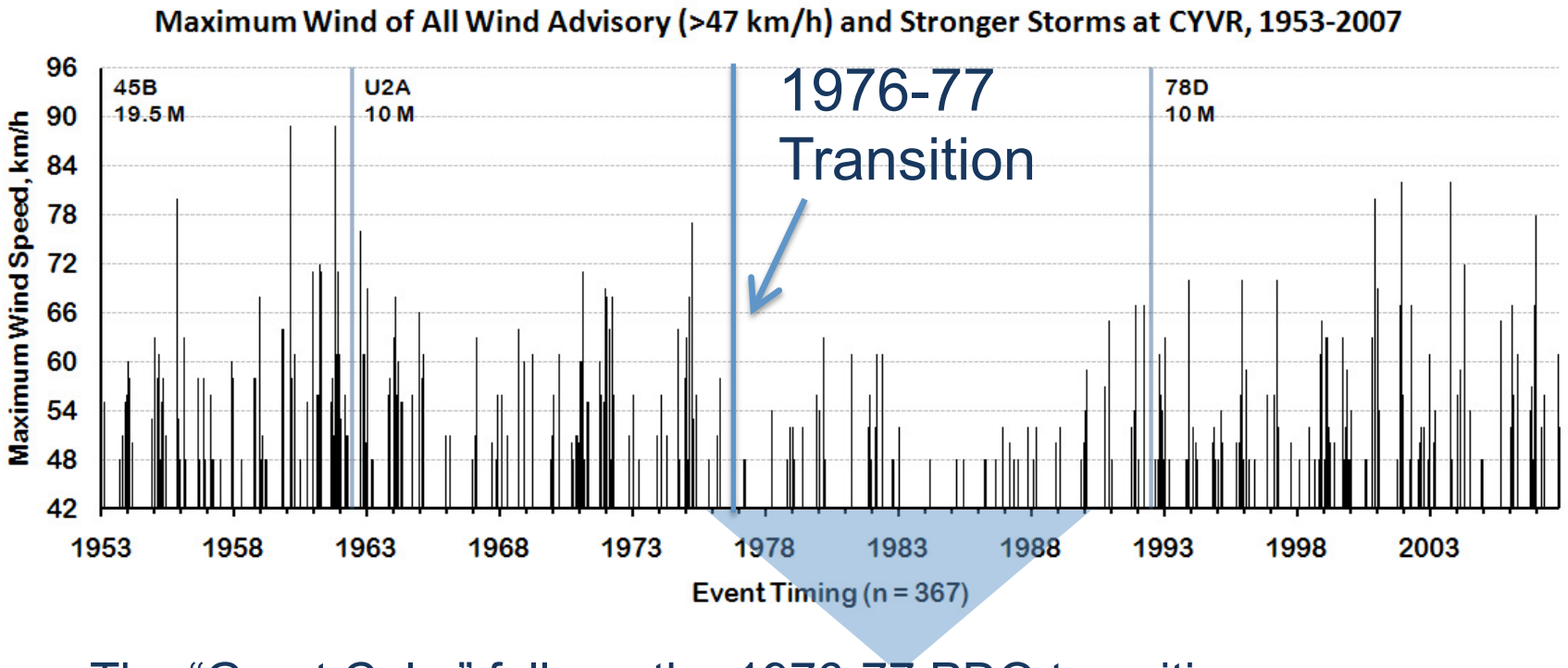
Discrete Storm Events



The "Great Calm"
1976-1990

Vancouver International (CYVR) Windstorms 1953-2008

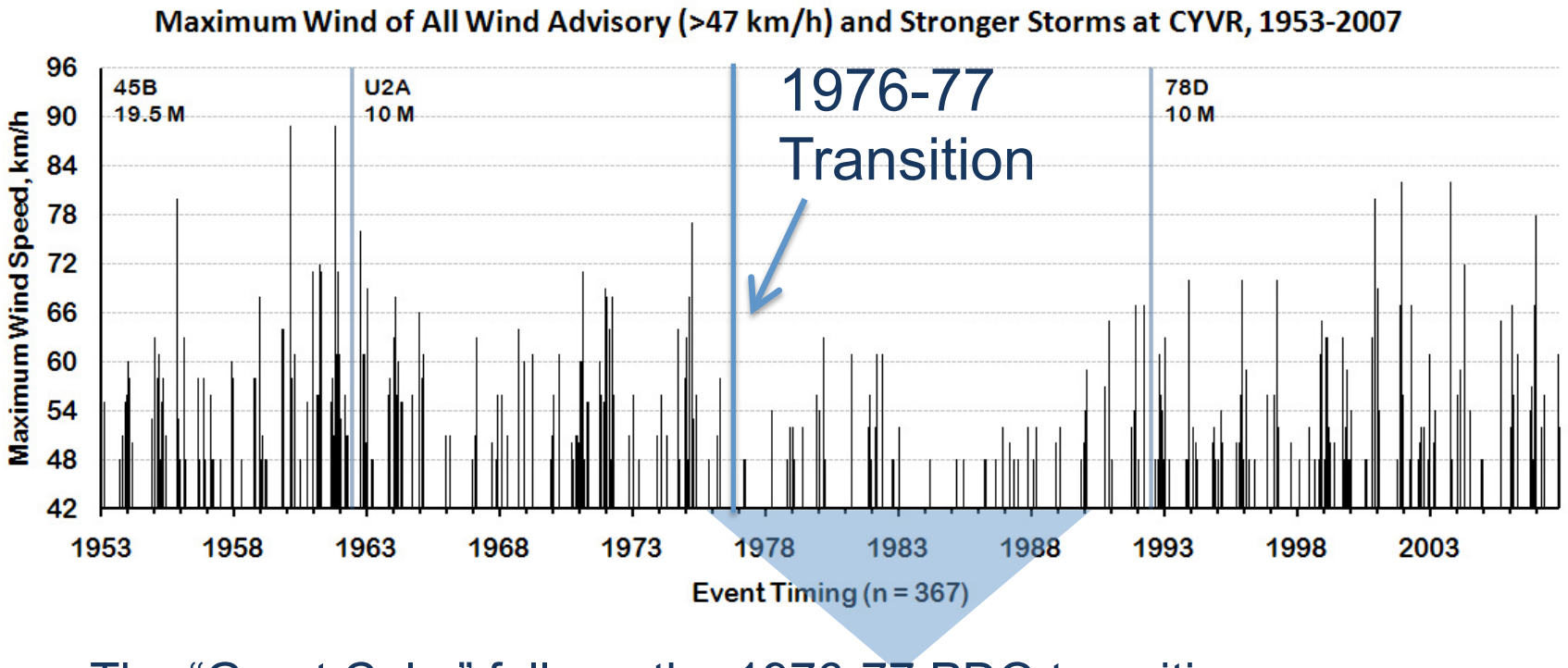
Discrete Storm Events



- The “Great Calm” follows the 1976-77 PDO transition

Vancouver International (CYVR) Windstorms 1953-2008

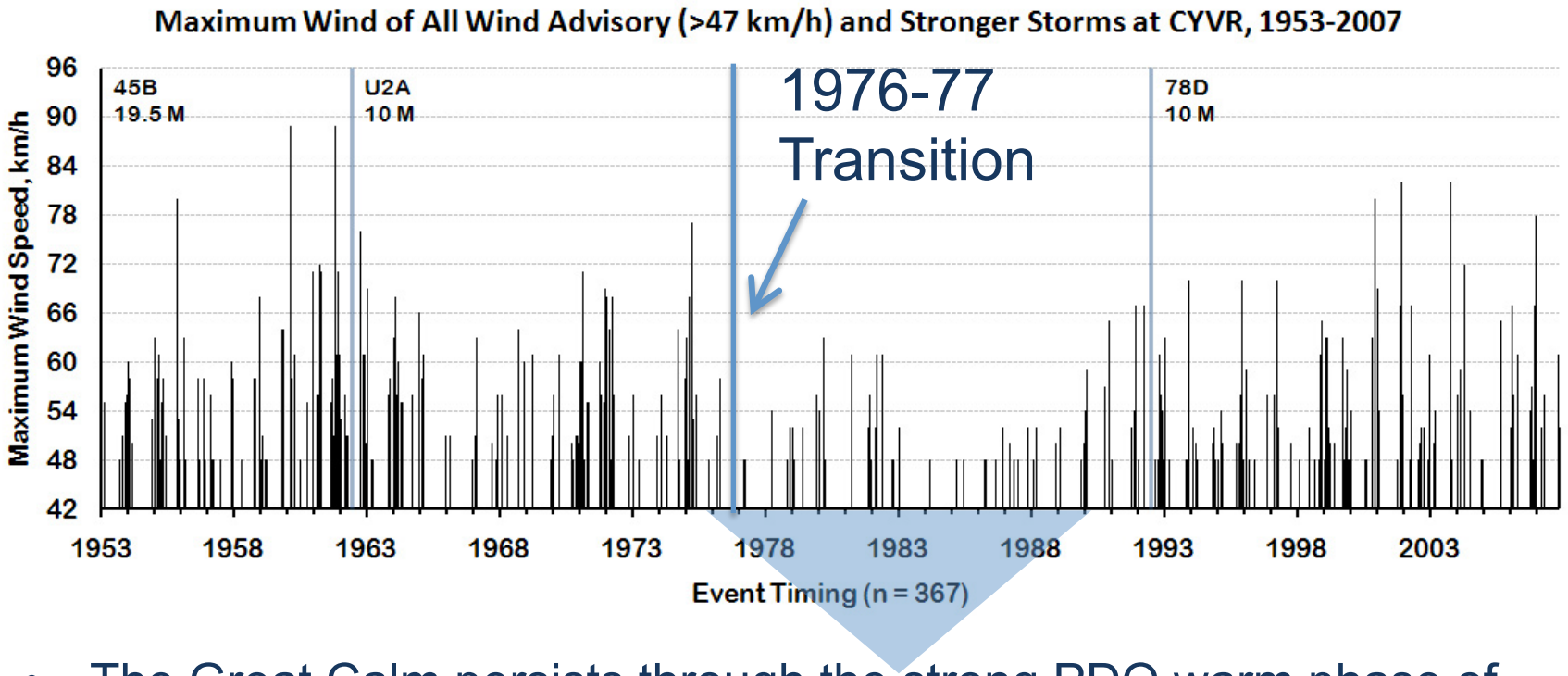
Discrete Storm Events



- 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)

Vancouver International (CYVR) Windstorms 1953-2008

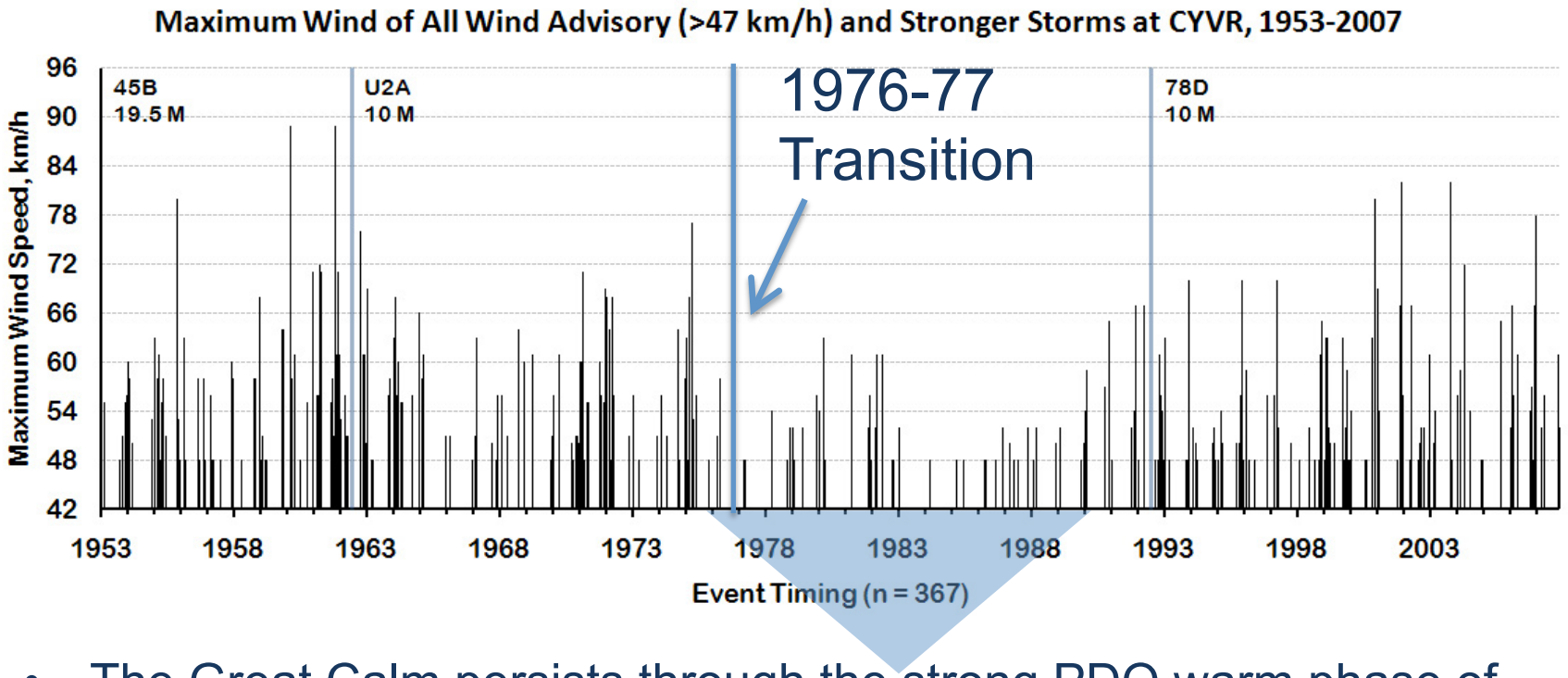
Discrete Storm Events



- The Great Calm persists through the strong PDO warm phase of the 1980s

Vancouver International (CYVR) Windstorms 1953-2008

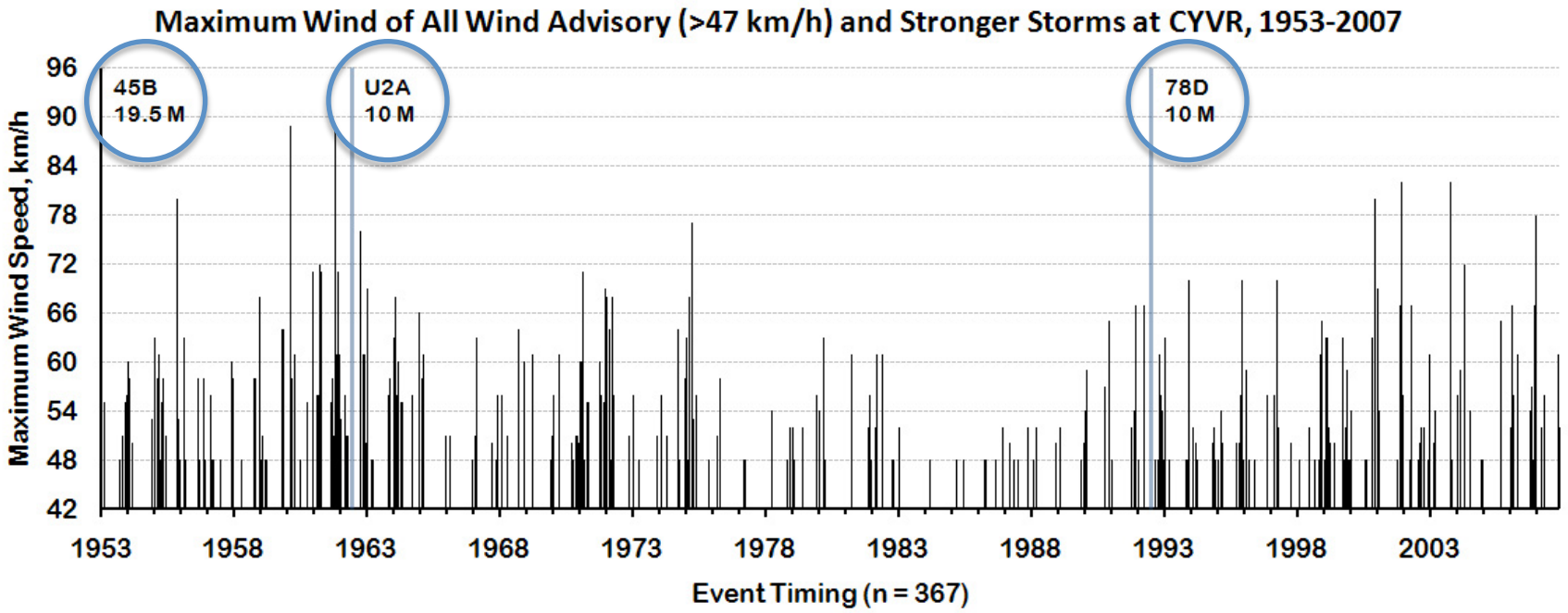
Discrete Storm Events



- 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

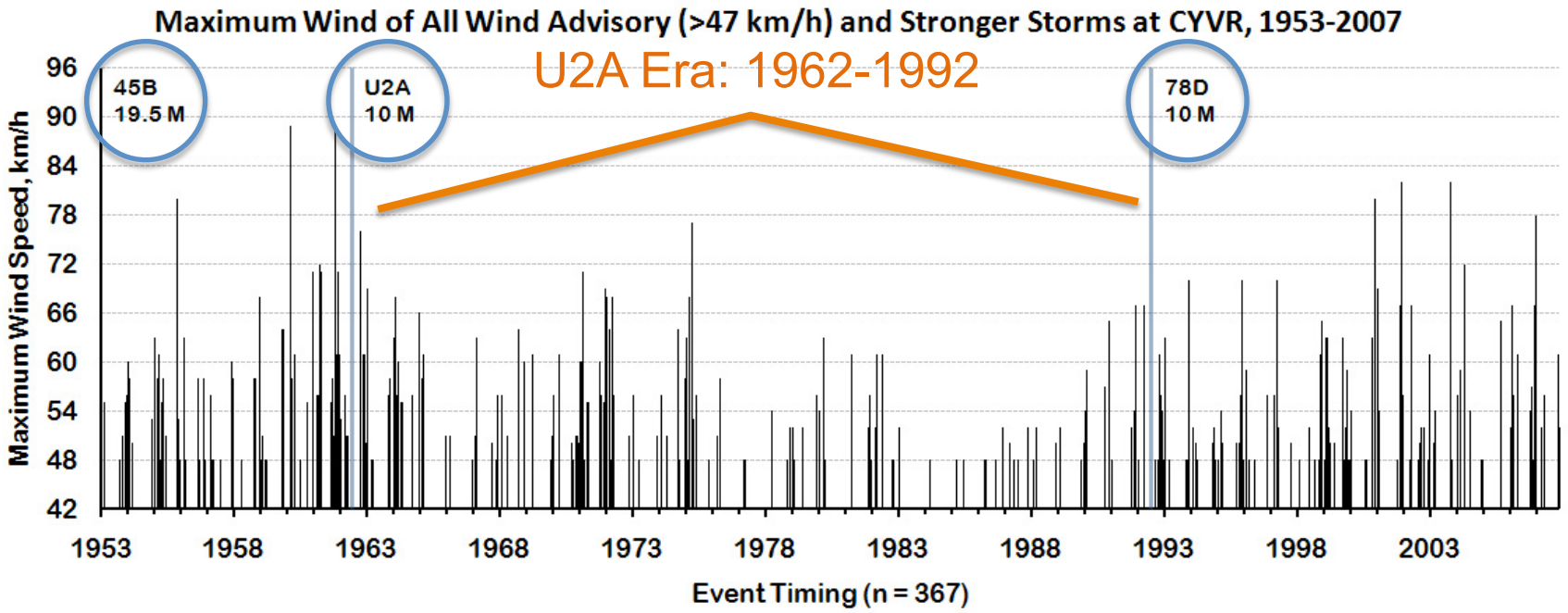
Discrete Storm Events



- Significant anemometer changes as described earlier

Vancouver International (CYVR) Windstorms 1953-2008

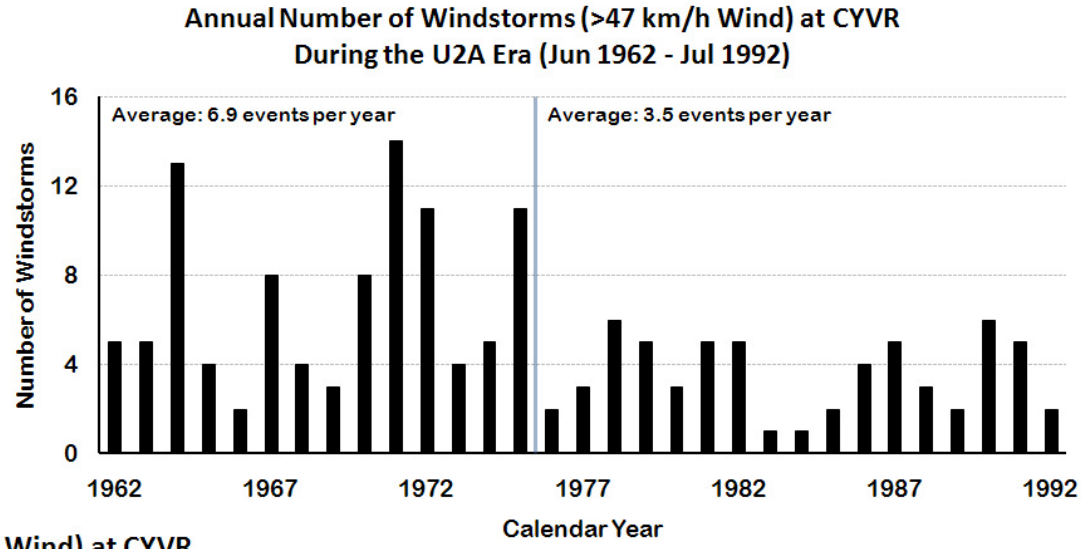
Discrete Storm Events

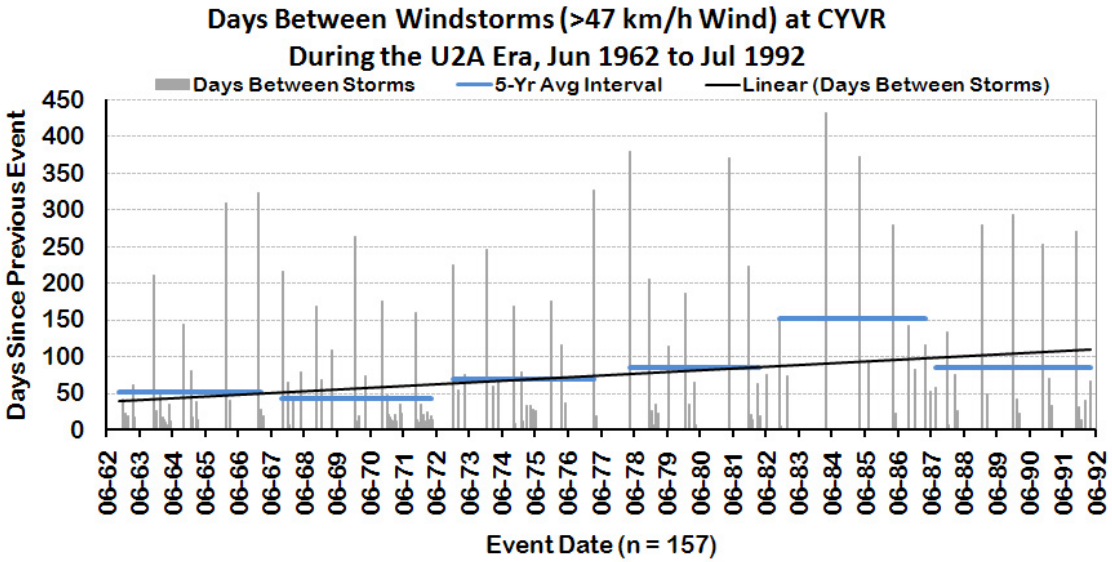


- Significant anemometer changes as described earlier
- However, era of U2A operation (1962-1992) contains much of the signal

Vancouver International (CYVR) Windstorms U2A Era: 1962-1992

Different ways of characterizing the "Great Calm" at CYVR

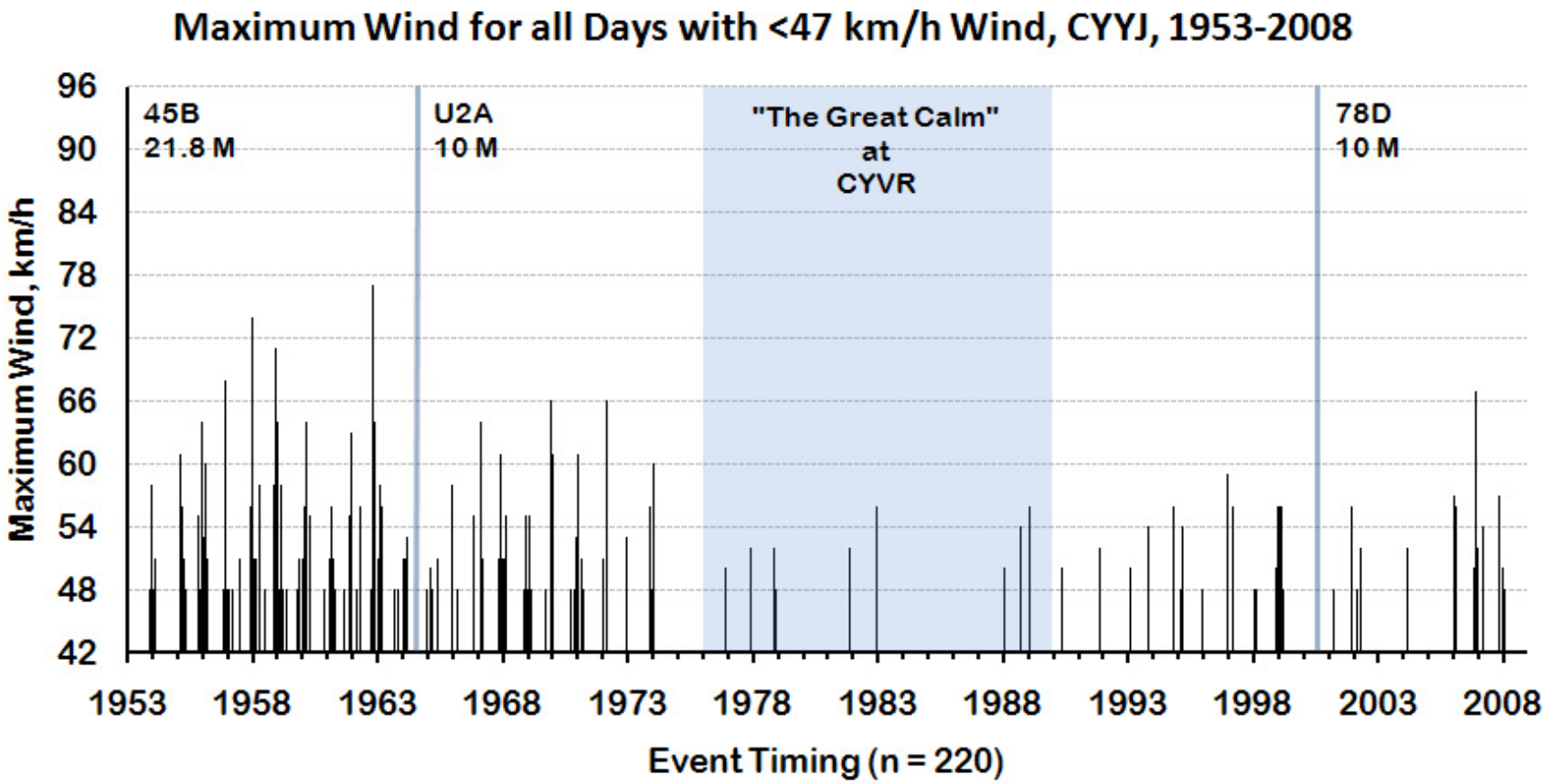




Events Per Year
1962-1975: 6.9
1976-1992: 3.5
Ratio: 2.0

Preliminary Multi-Station Analysis

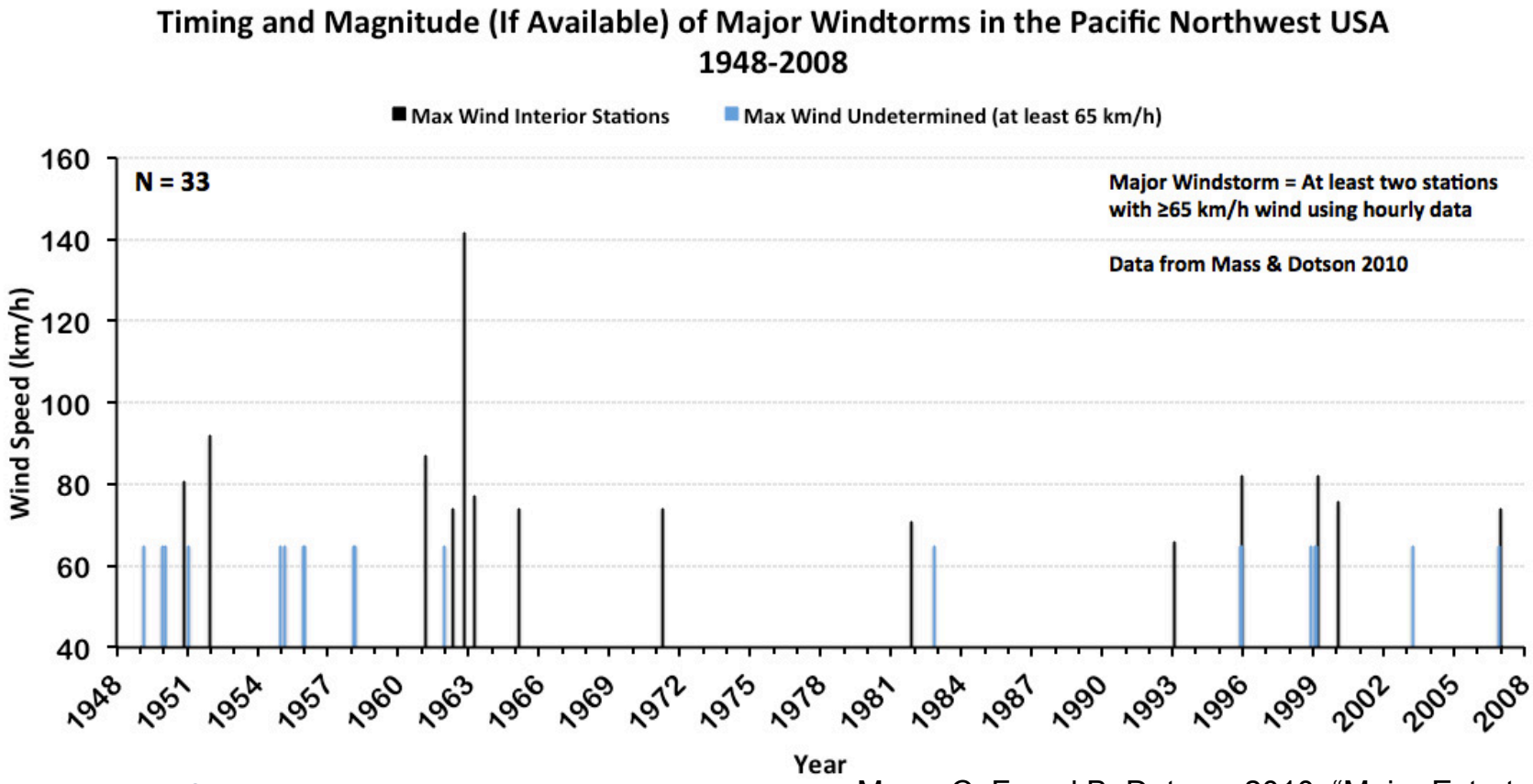
Victoria International Airport



- 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

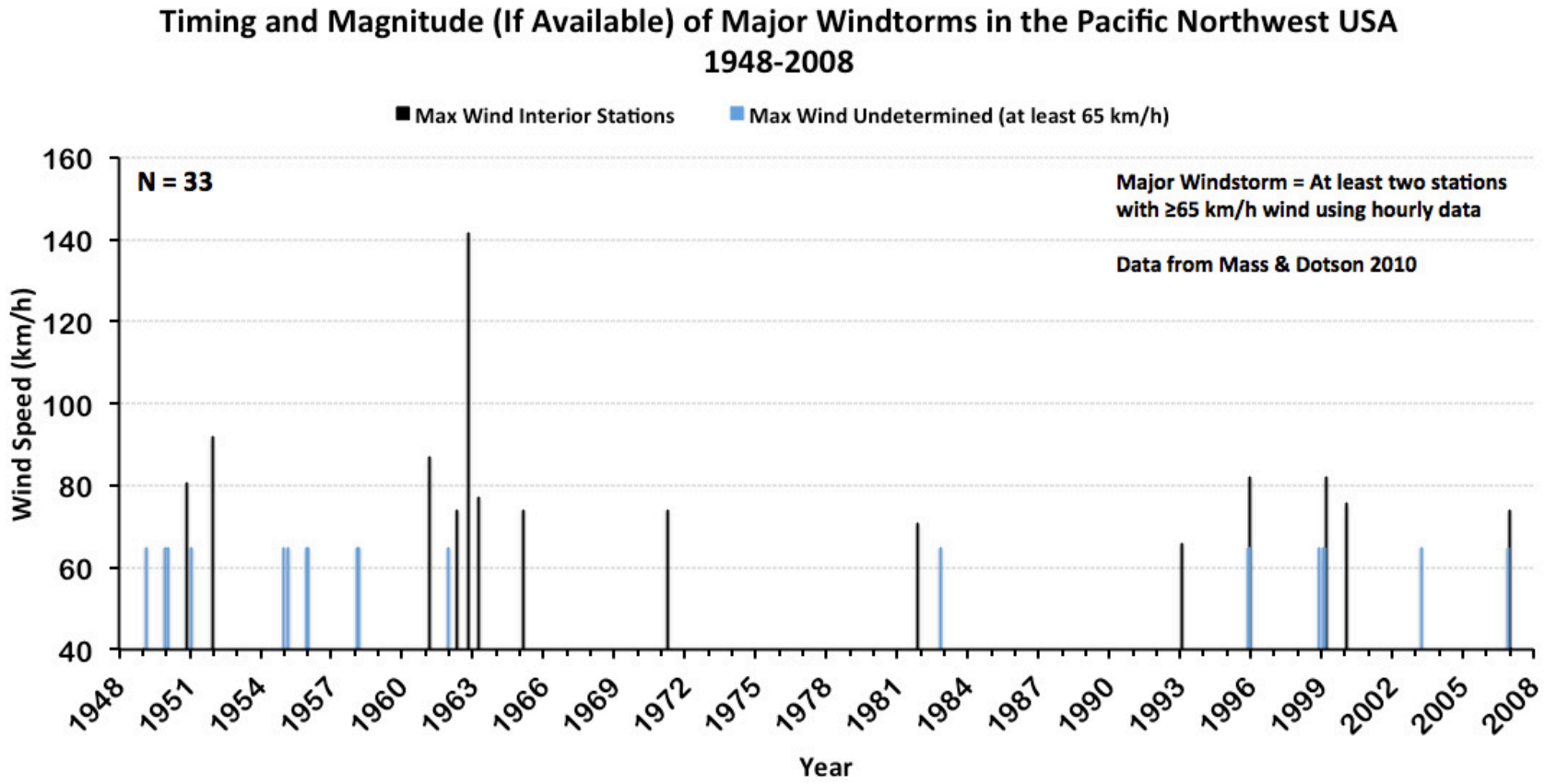


- Mass & Dotson (2010) used hourly observations only; some major events missed (e.g. 02 Oct 1967)

Mass, C. F. and B. Dotson. 2010. "Major Extratropical Cyclones of the Northwest United States: Historical Review, Climatology, and Synoptic Environment." *Monthly Weather Review*, vol 138, p 2499-2527.

Washington and Oregon Data

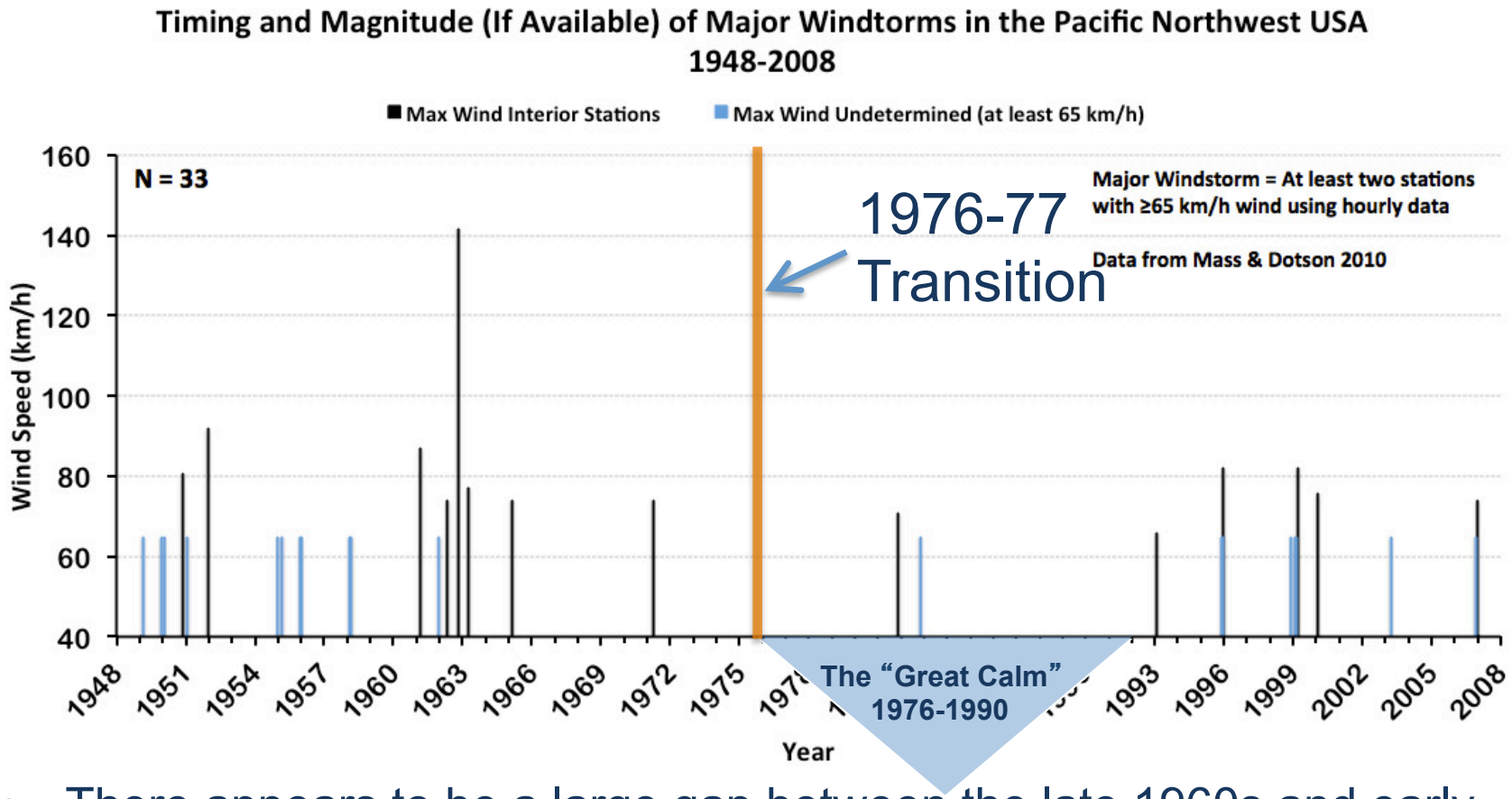
Interior Stations KMFR to KBLI



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

Washington and Oregon Data

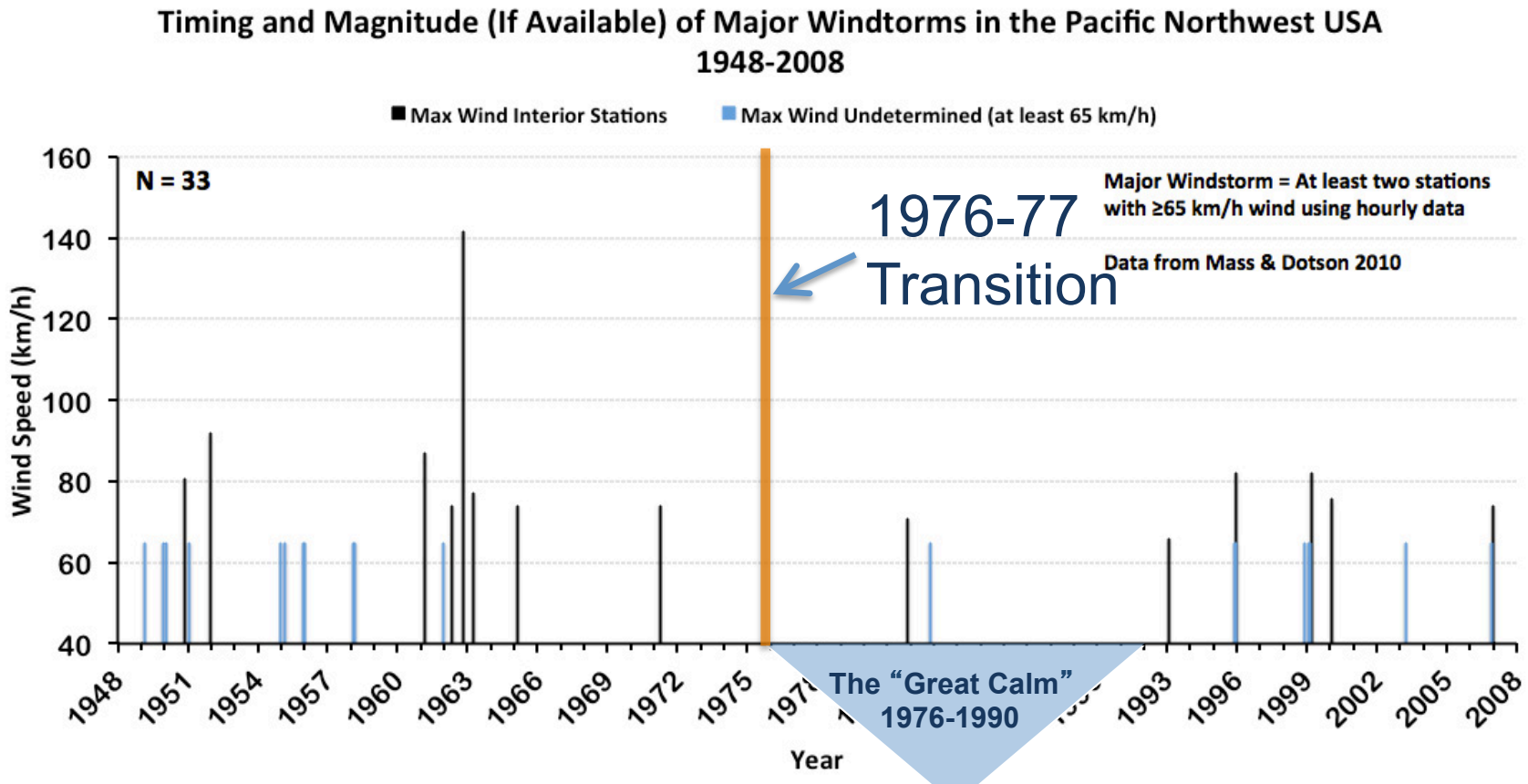
Interior Stations KMFR to KBLI



- There appears to be a large gap between the late 1960s and early 1990s, a suggestion of the pattern

Washington and Oregon Data

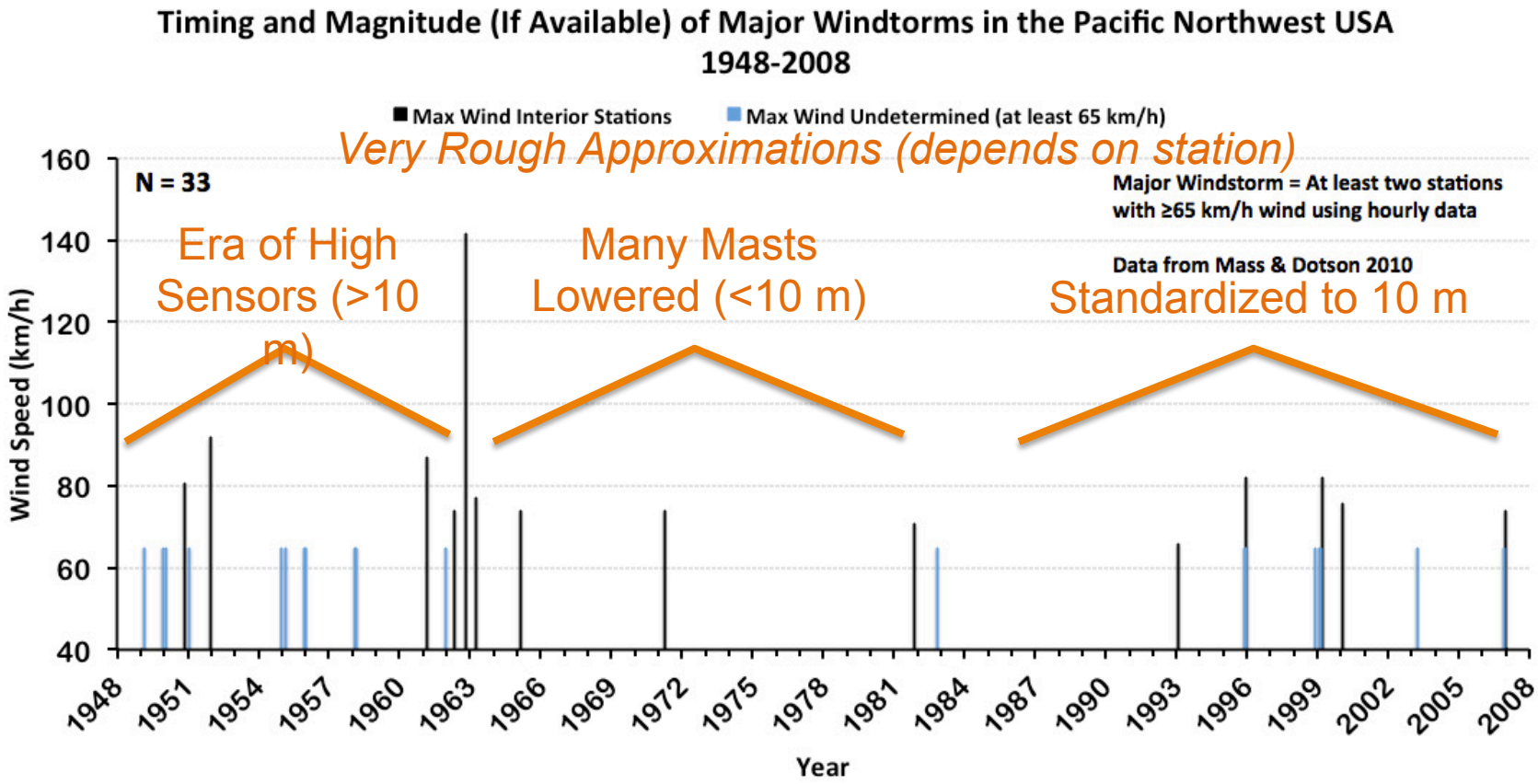
Interior Stations KMFR to KBLI



- 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



- 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:

Measure Compared to PNA	Correlation Coefficient
Frequency of southerly (102°-258°) wind speeds	-0.98
Frequency of wind speed >5.7 m/s	-0.98
Frequency of wind speed >8.7 m/s	-0.96

Ebbesmeyer, C. E. and C. Coombs. 1989. "Strong, Low-Frequency (Decadal) Environmental Fluctuations During the 20th Century." *Oceans '89 Proceedings*, vol 1, p 242-246.

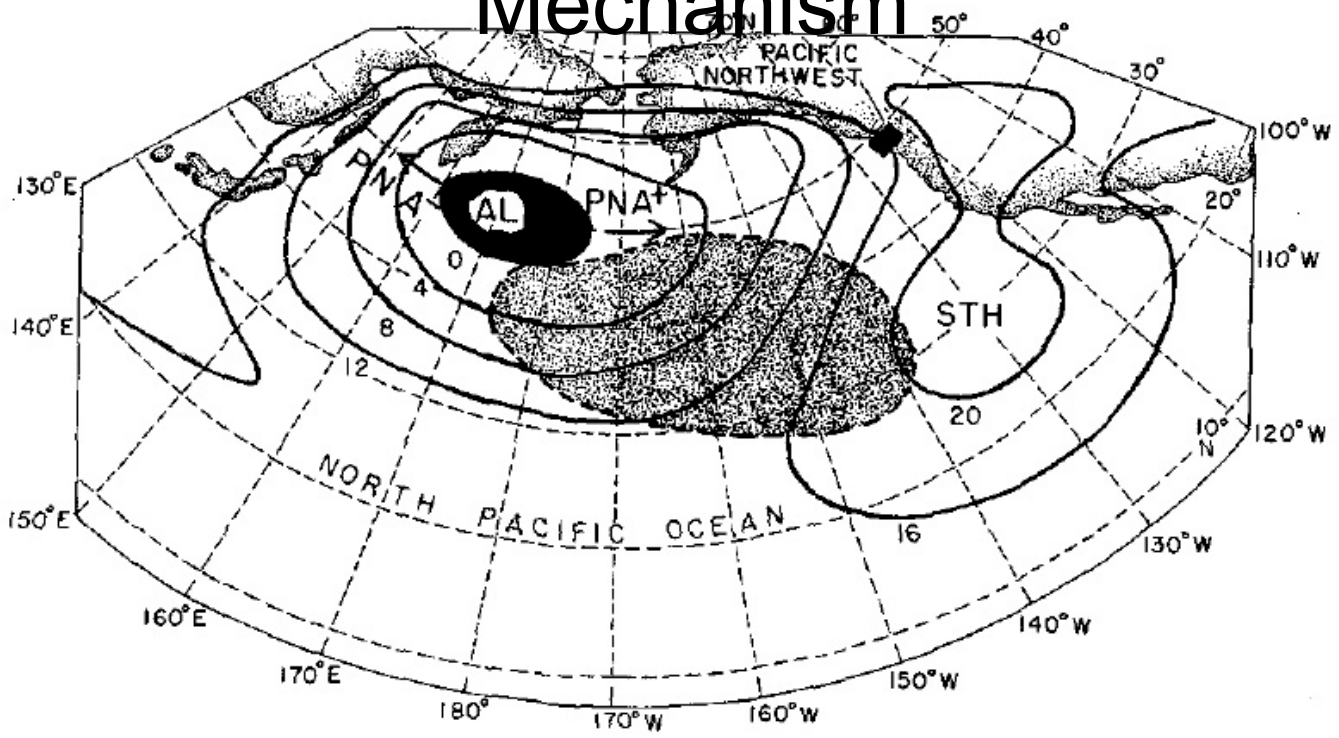
Further Evidence From American Stations

- 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:

Measure Compared to PNA	Correlation Coefficient
Frequency of southerly (102°-258°) wind speeds	-0.98
Frequency of wind speed >5.7 m/s	-0.98
Frequency of wind speed >8.7 m/s	-0.96

- Given the narrow span of years with the 1976-77 transition right in the middle, such high correlations are perhaps not that surprising

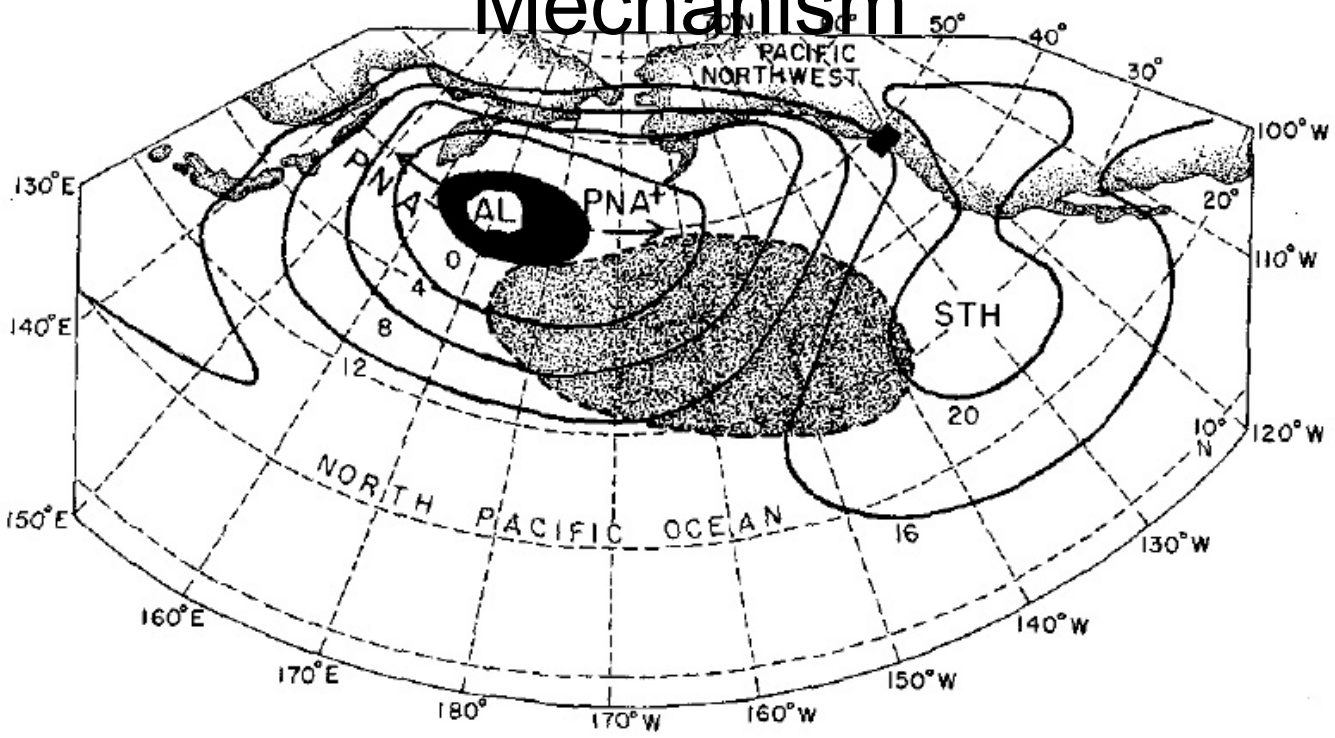
Digression: The PNA & a Possible Mechanism



- Negative PNA reflects an Aleutian low further west, and a zonal upper-air pattern conducive to winter-storminess in the Puget Lowlands (Ebbesmeyer 1989)

Ebbesmeyer, C. E. and C. Coombs. 1989. "Strong, Low-Frequency (Decadal) Environmental Fluctuations During the 20th Century." *Oceans '89 Proceedings*, vol 1, p 242-246.

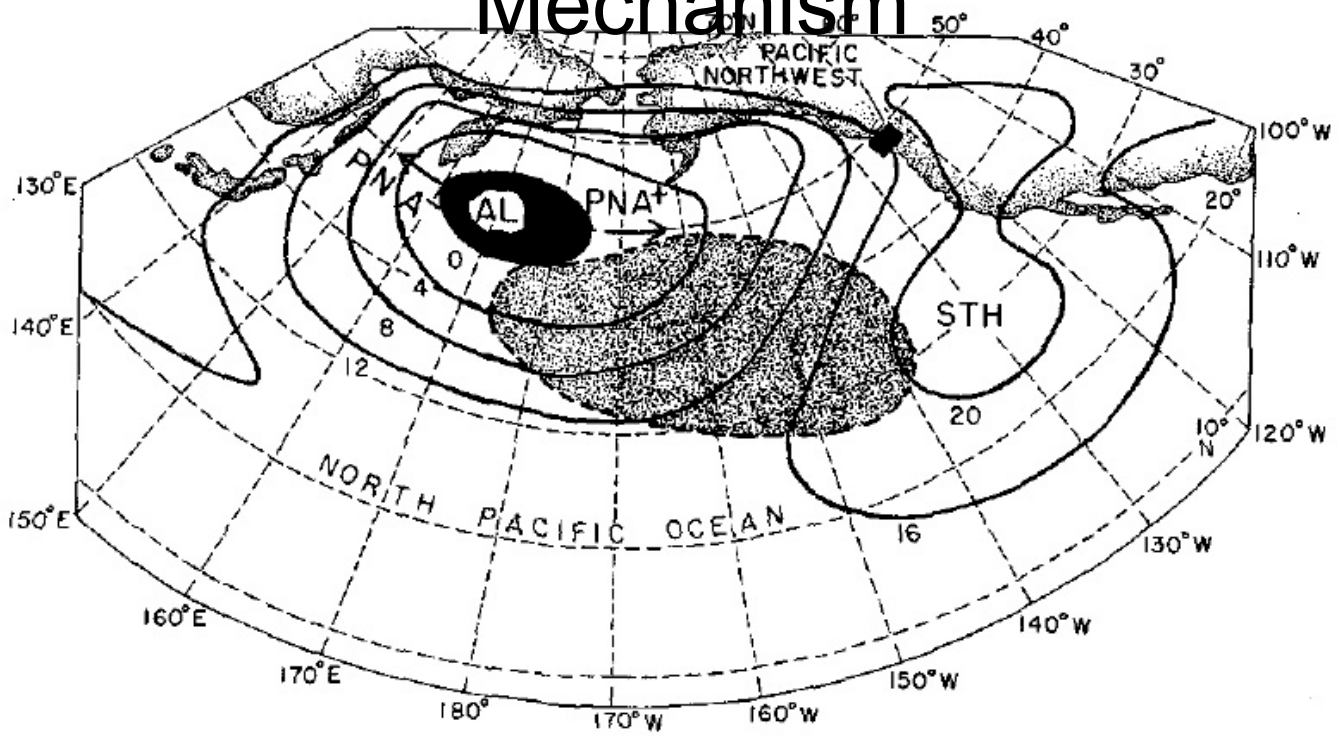
Digression: The PNA & a Possible Mechanism



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

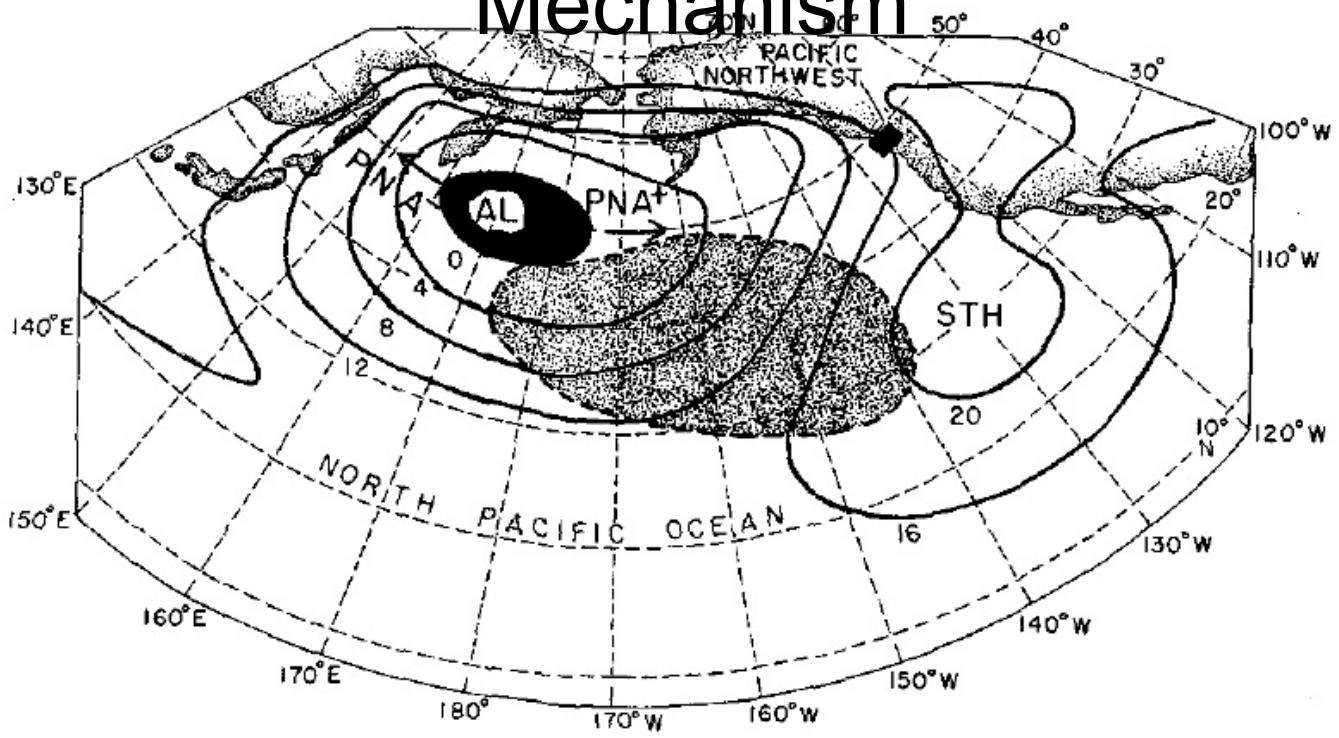
Tuller, S. E. 2004. “Measured wind speed trends on the West Coast of Canada.” *International Journal of Climatology*, vol 24, p 1359-1374.

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

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

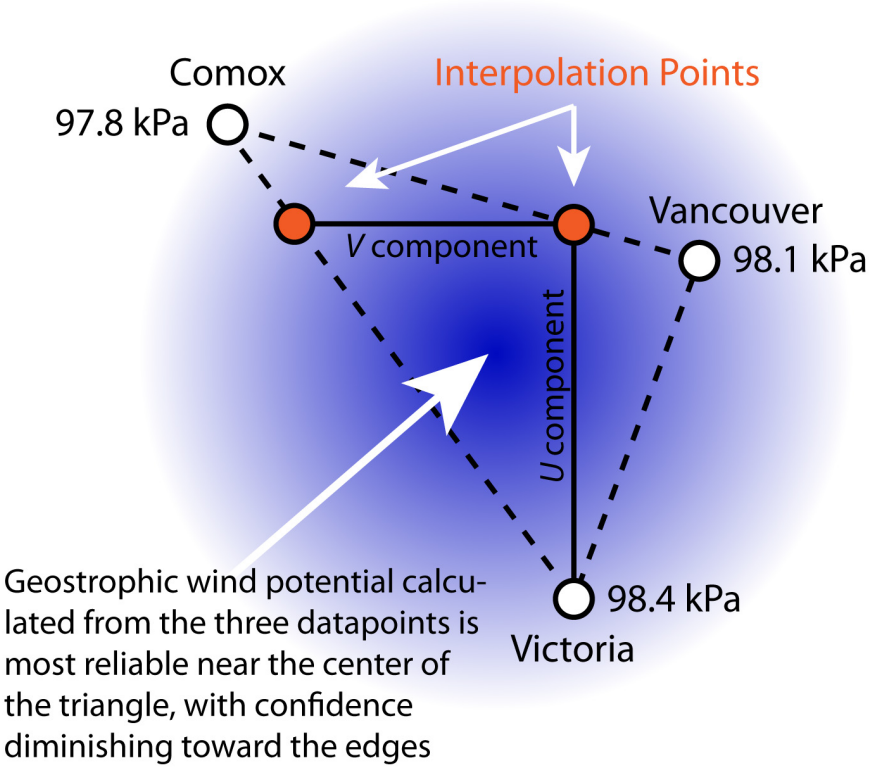
Proxy Data For Wind

- 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

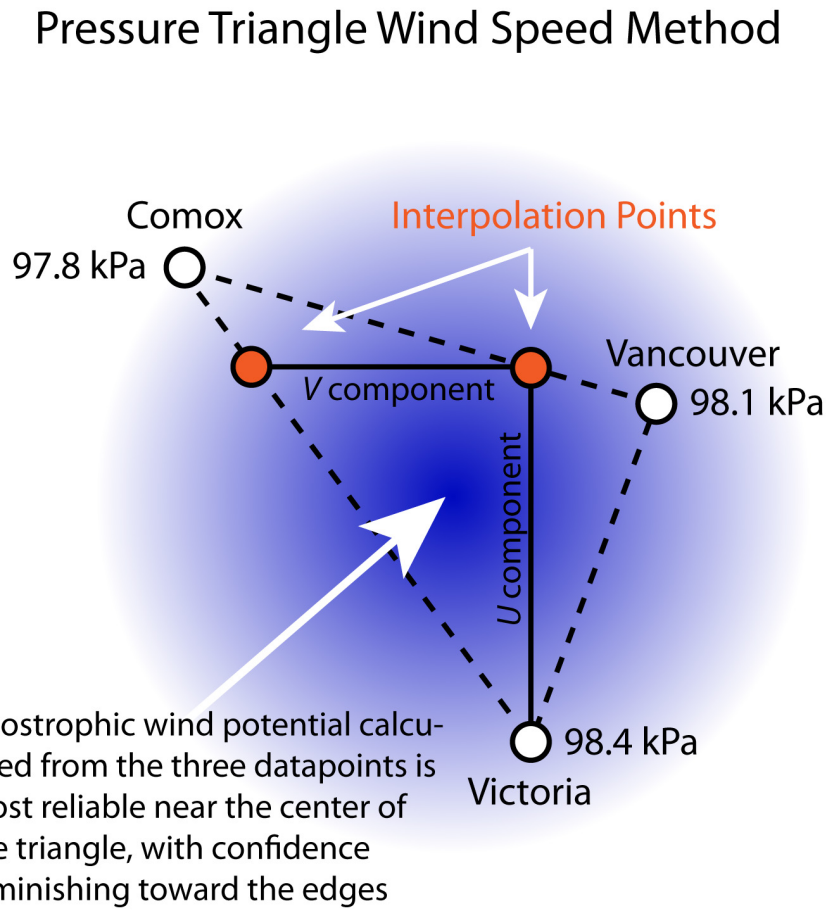
Pressure Triangle Wind Speed Method



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 speeds" (Tuller 2004)



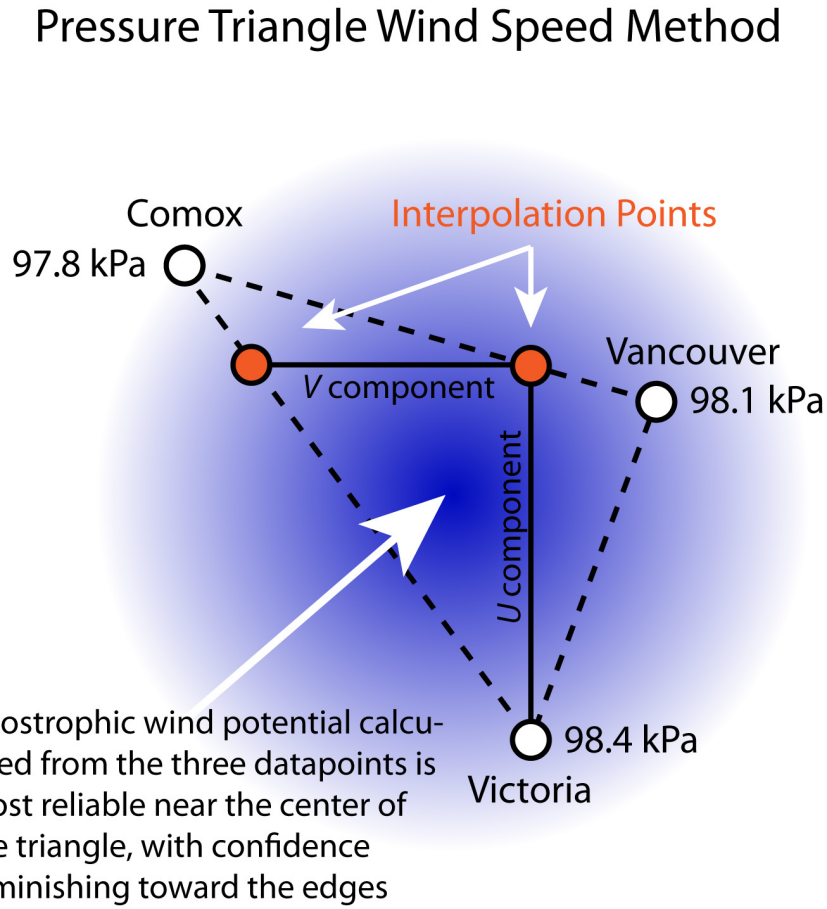
Tuller, S. E. 2004. "Measured wind speed trends on the West Coast of Canada." *International Journal of Climatology*, vol 24, p 1359-1374.

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 speeds" (Tuller 2004)

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



Tuller, S. E. 2004. "Measured wind speed trends on the West Coast of Canada." *International Journal of Climatology*, vol 24, p 1359-1374.

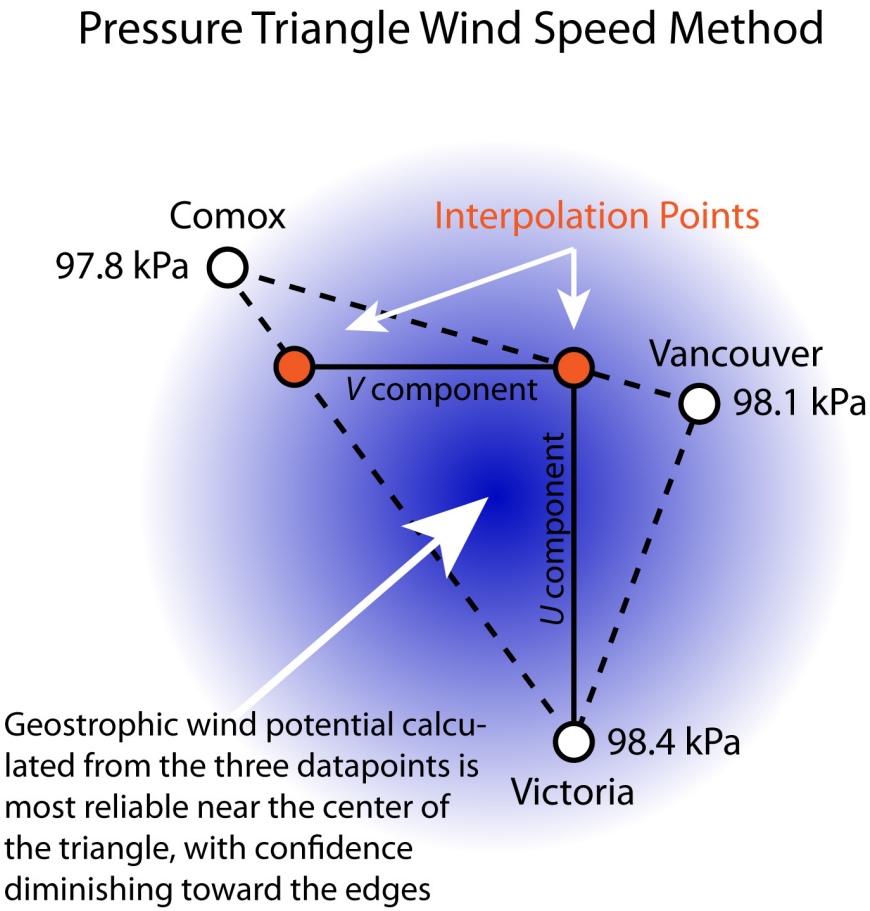
Proxy Data For Wind

- 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 speeds" (Tuller 2004)

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

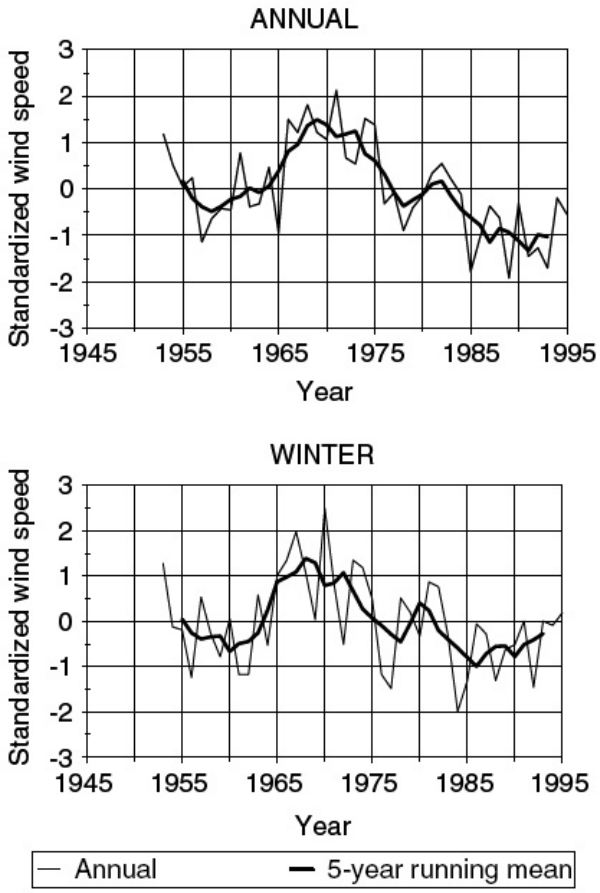
- Barometers do not have the same issues as anemometers



Tuller, S. E. 2004. "Measured wind speed trends on the West Coast of Canada." *International Journal of Climatology*, vol 24, p 1359-1374.

Proxy Data For Wind

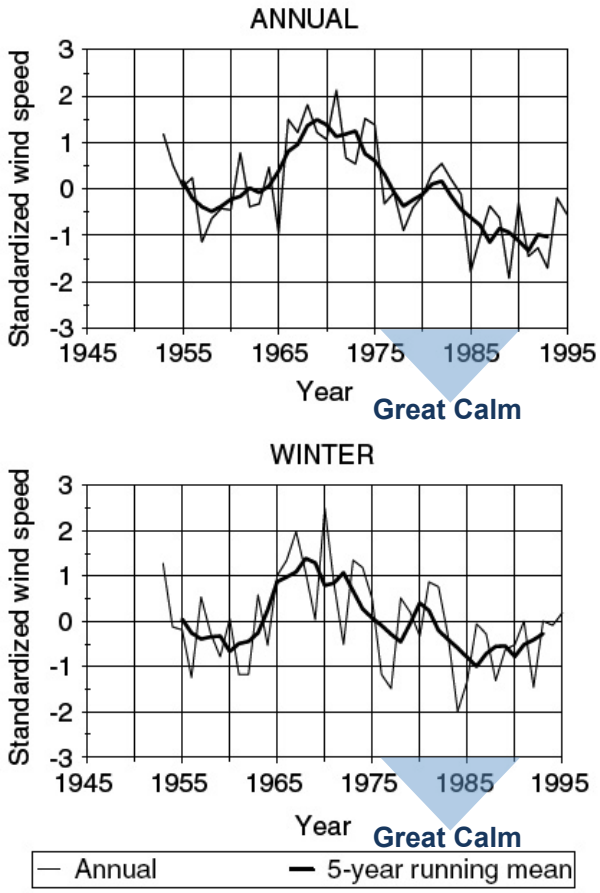
- Tuller used the geostrophic wind potential based on hourly pressure data from Vancouver, Victoria and Comox



Proxy Data For Wind

- Tuller used the geostrophic wind potential based on hourly pressure data from Vancouver, Victoria and Comox

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

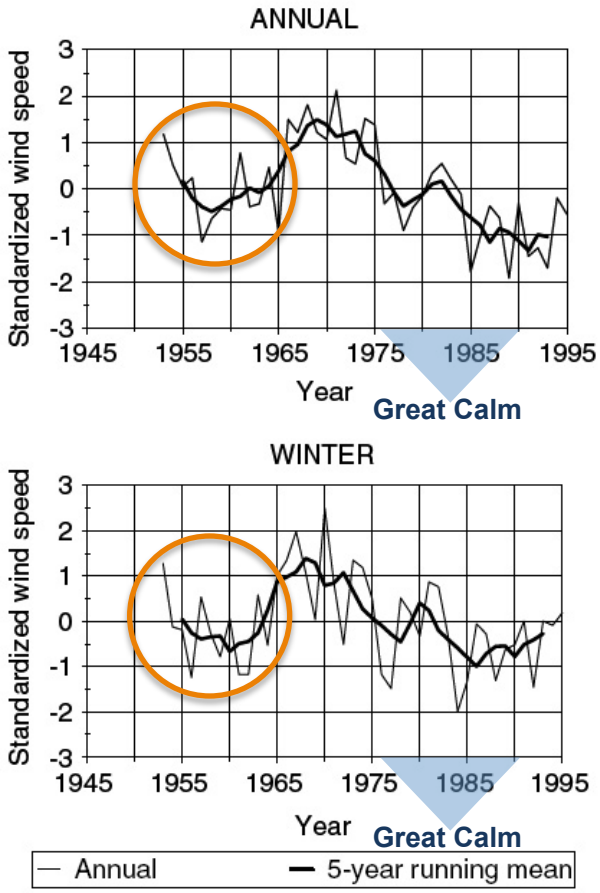


Proxy Data For Wind

- Tuller used the geostrophic wind potential based on hourly pressure data from Vancouver, Victoria and Comox

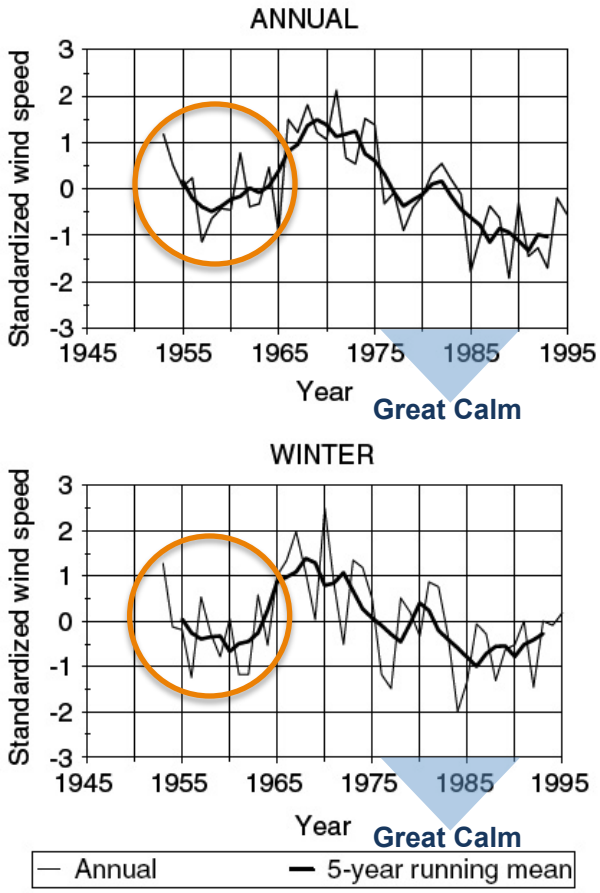
- Trends in wind speed based on geostrophic wind potential also point to a decrease during the Great Calm

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



Proxy Data For Wind

- Tuller used the geostrophic wind potential based on hourly pressure data from Vancouver, Victoria and Comox
- 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

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

- Calculated the geostrophic wind potential (M_g) via a right triangle interpolated between stations

Proxy Data For Wind

- Used hourly sea-level pressure data for CYYJ, CYVR and CYXX Jan 1953-Jul 2008 (Supplied by Environment Canada)
- Calculated the geostrophic wind potential (M_g) via a right triangle interpolated between stations
- Surface wind speeds during windstorms tend to fall between 0.25 and 0.40 of M_g

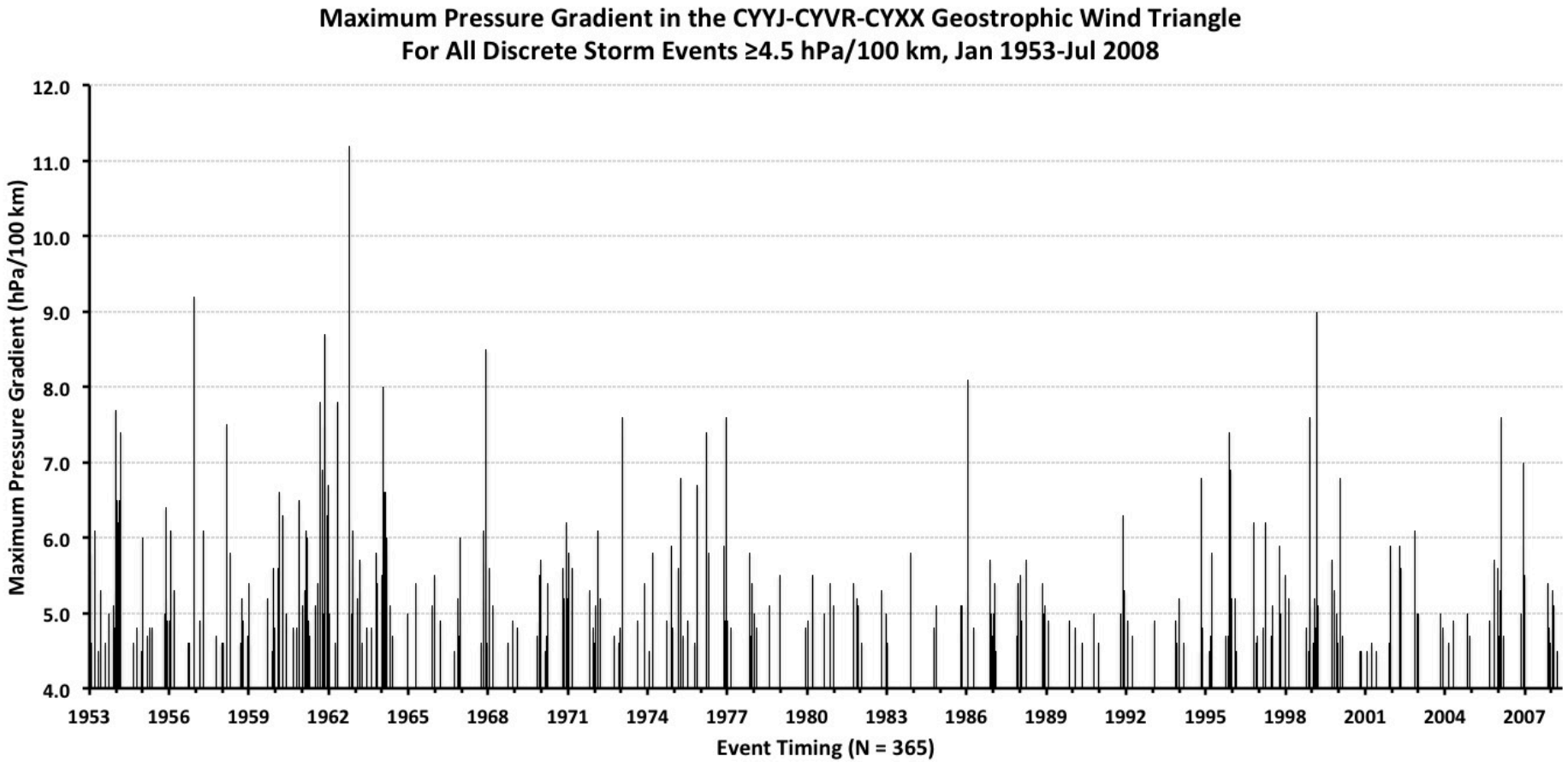
Proxy Data For Wind

- Used hourly sea-level pressure data for CYYJ, CYVR and CYXX Jan 1953-Jul 2008 (Supplied by Environment Canada)
- Calculated the geostrophic wind potential (M_g) via a right triangle interpolated between stations
- Surface wind speeds during windstorms tend to fall between 0.25 and 0.40 of M_g
- Sorted out all events with 0.40 M_g >47 km/h

Proxy Data For Wind

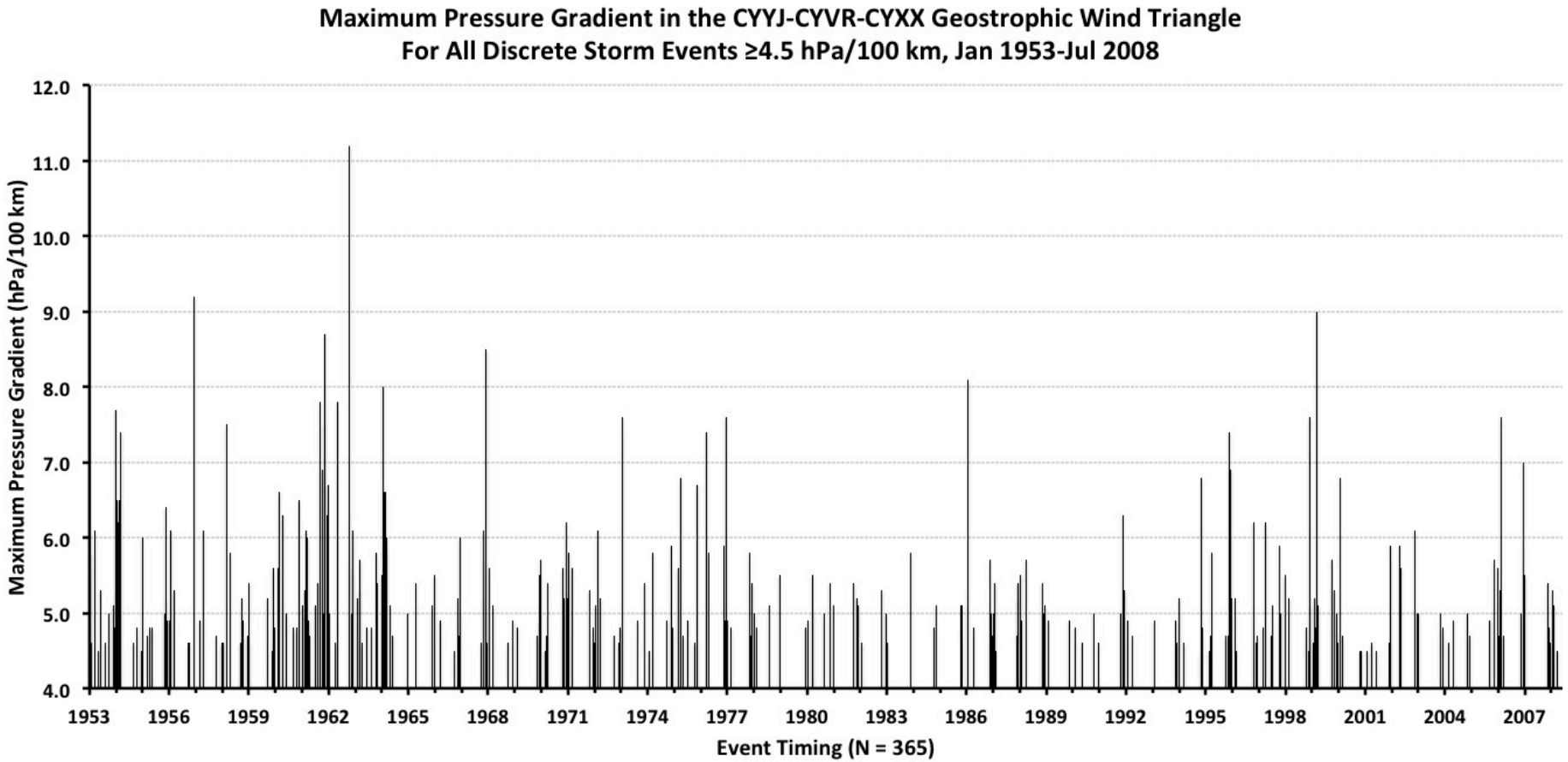
- Used hourly sea-level pressure data for CYYJ, CYVR and CYXX Jan 1953-Jul 2008 (Supplied by Environment Canada)
- Calculated the geostrophic wind potential (M_g) via a right triangle interpolated between stations
- Surface wind speeds during windstorms tend to fall between 0.25 and 0.40 of M_g
- Sorted 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

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



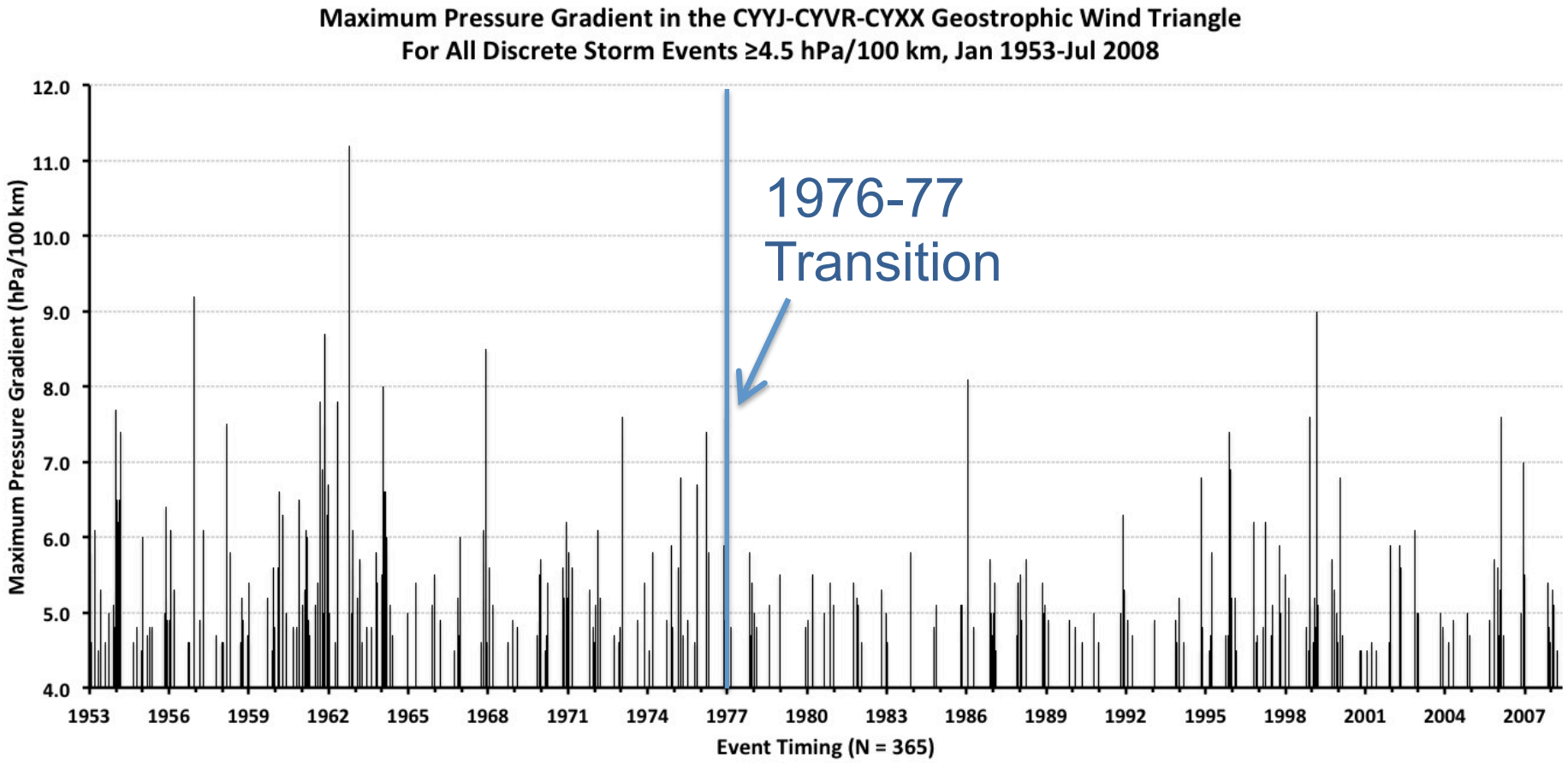
- For 1953-2007, the total number (358) is in approximate agreement with total from surface wind data (367)

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



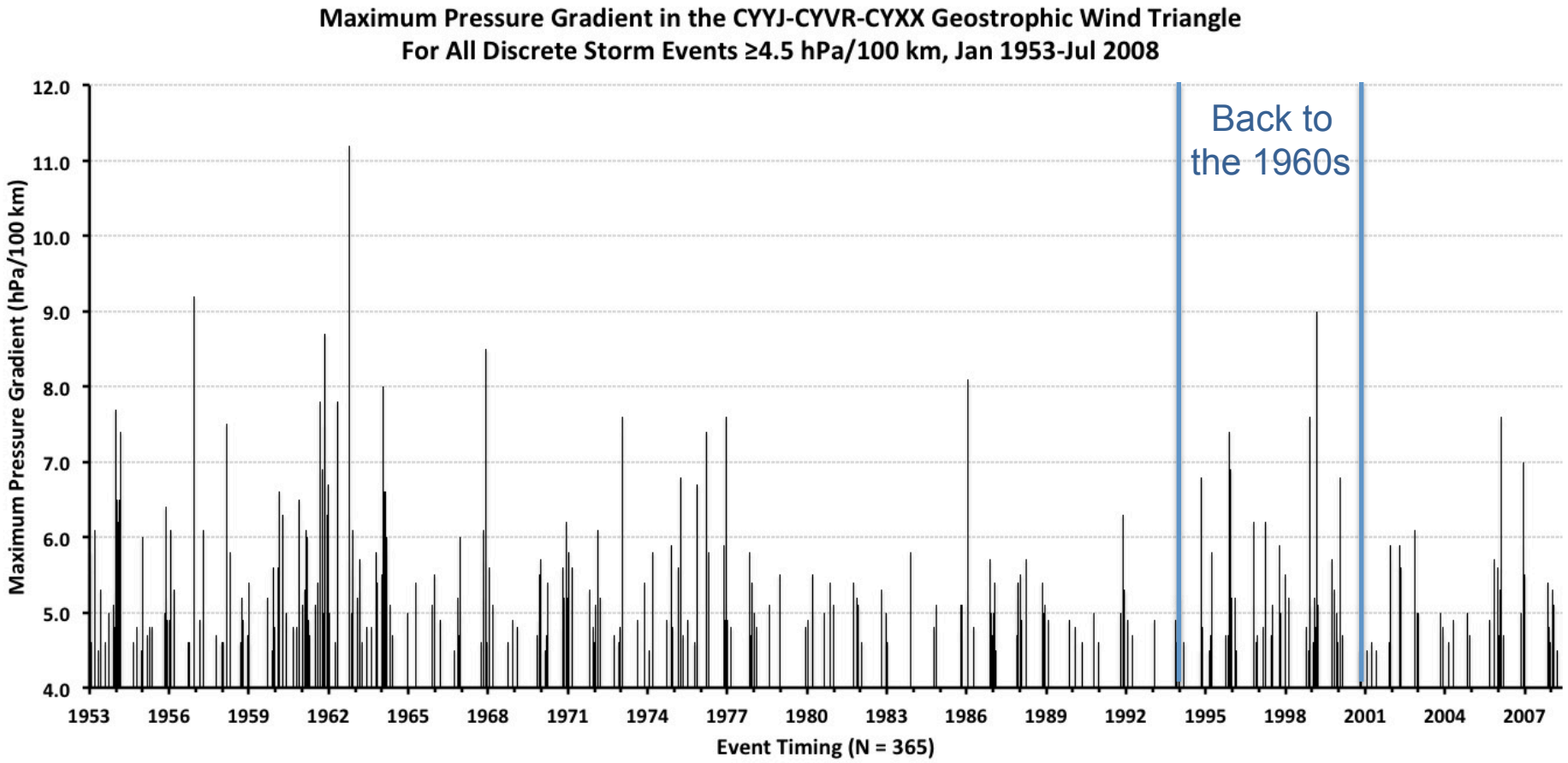
- For 1953-2007, the total number (358) is in agreement with total from surface wind data (367)
- However, only 28.1% of events match up exactly date-wise (probably would be higher if ±1 day is allowed for)

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



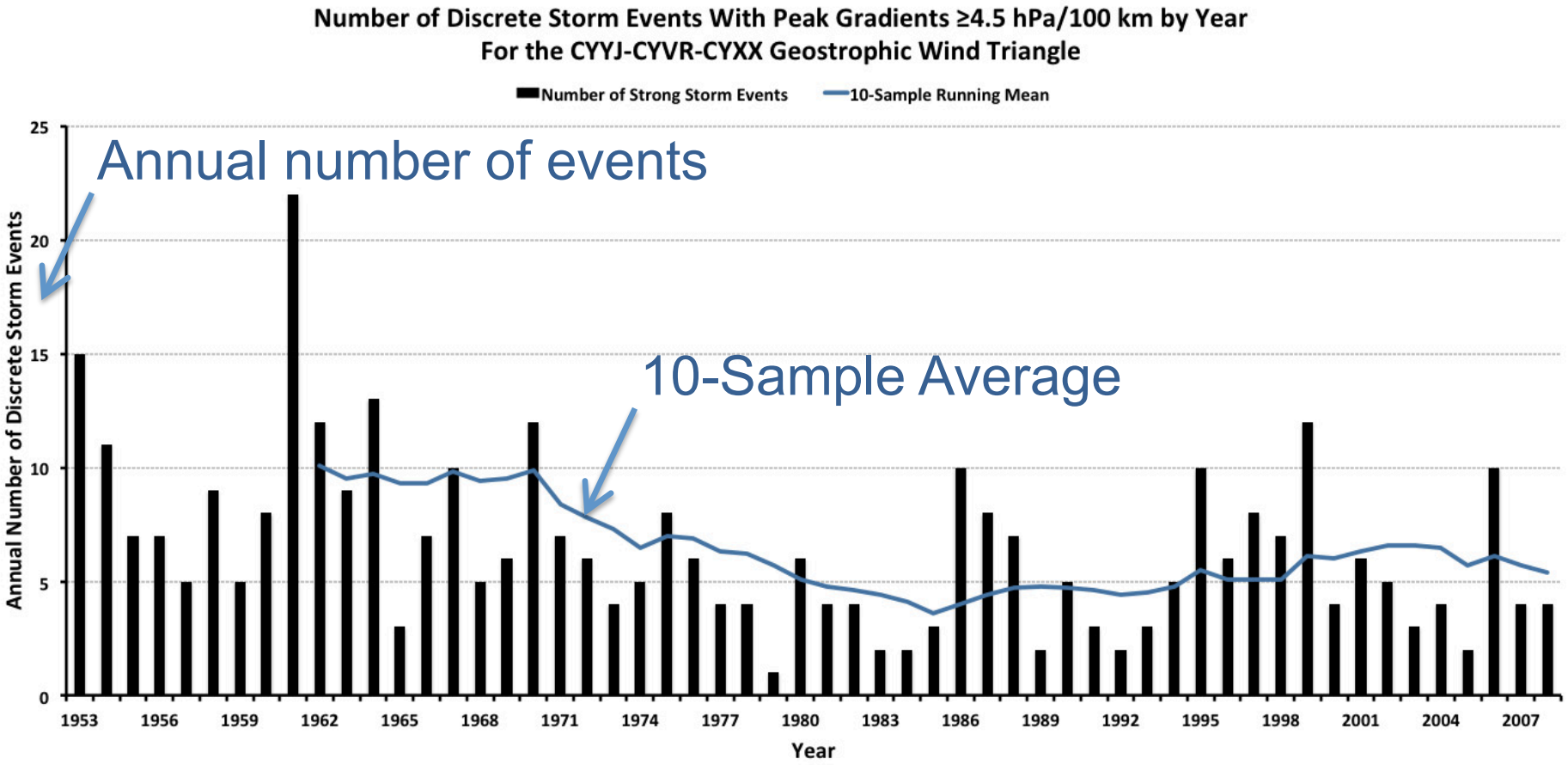
- Reduced frequency and magnitude of events appears to occur at least weakly post-1976-77

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



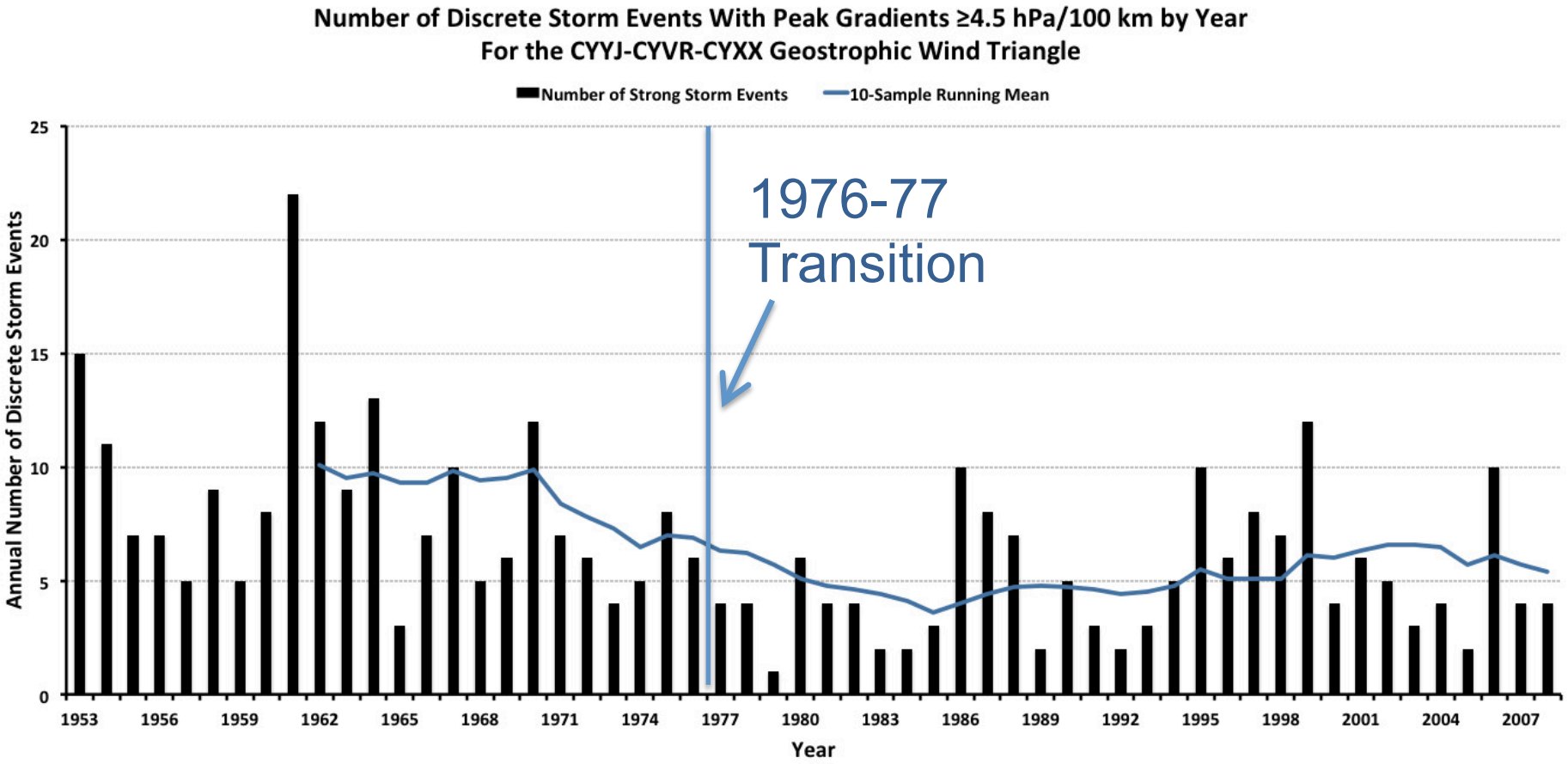
- Storm frequency appears to return to pre-1976-77 levels between 1994 and 2001, then falls off again

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



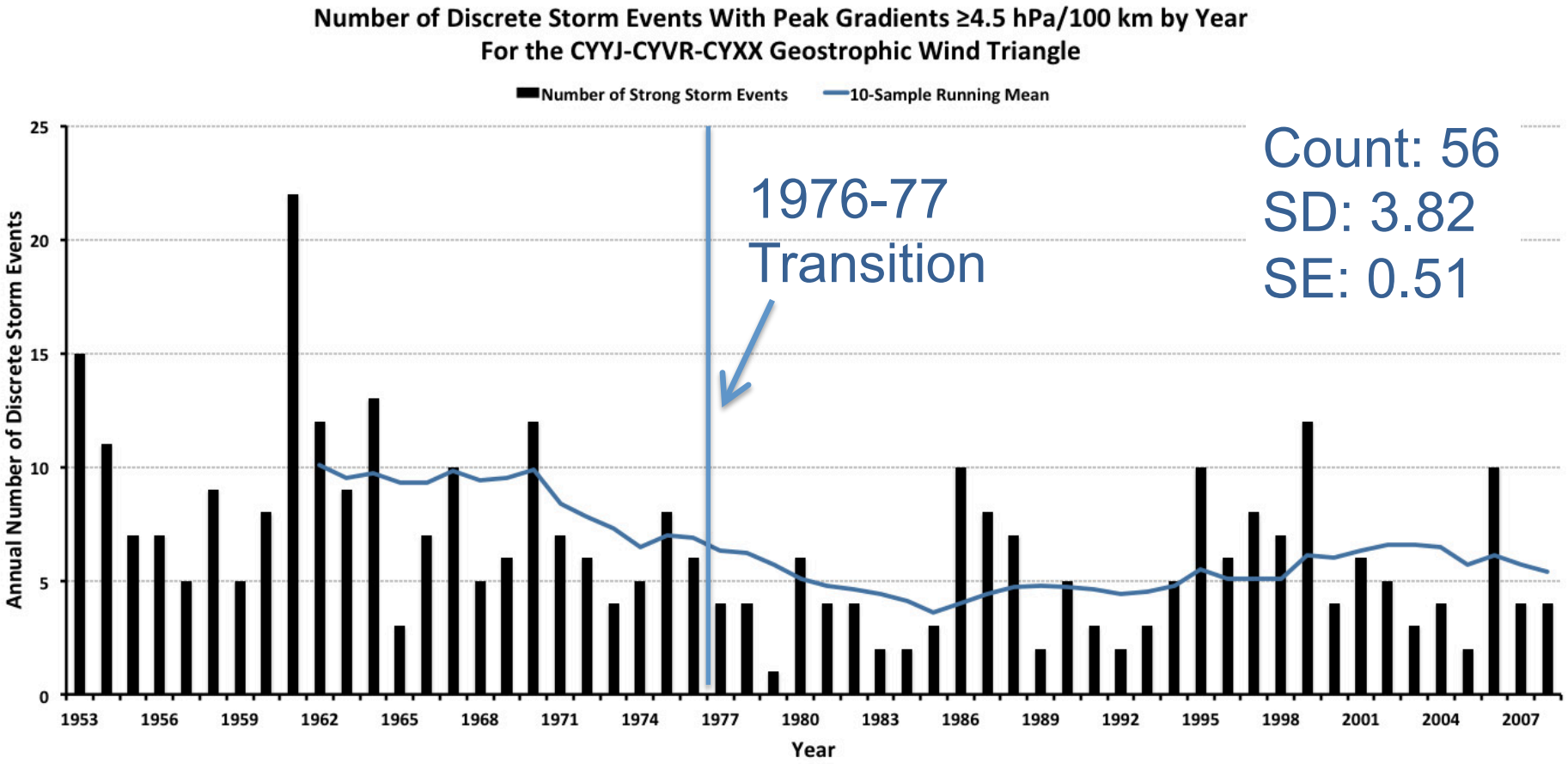
- A different way of looking at some of the data
- Does not account for magnitude

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



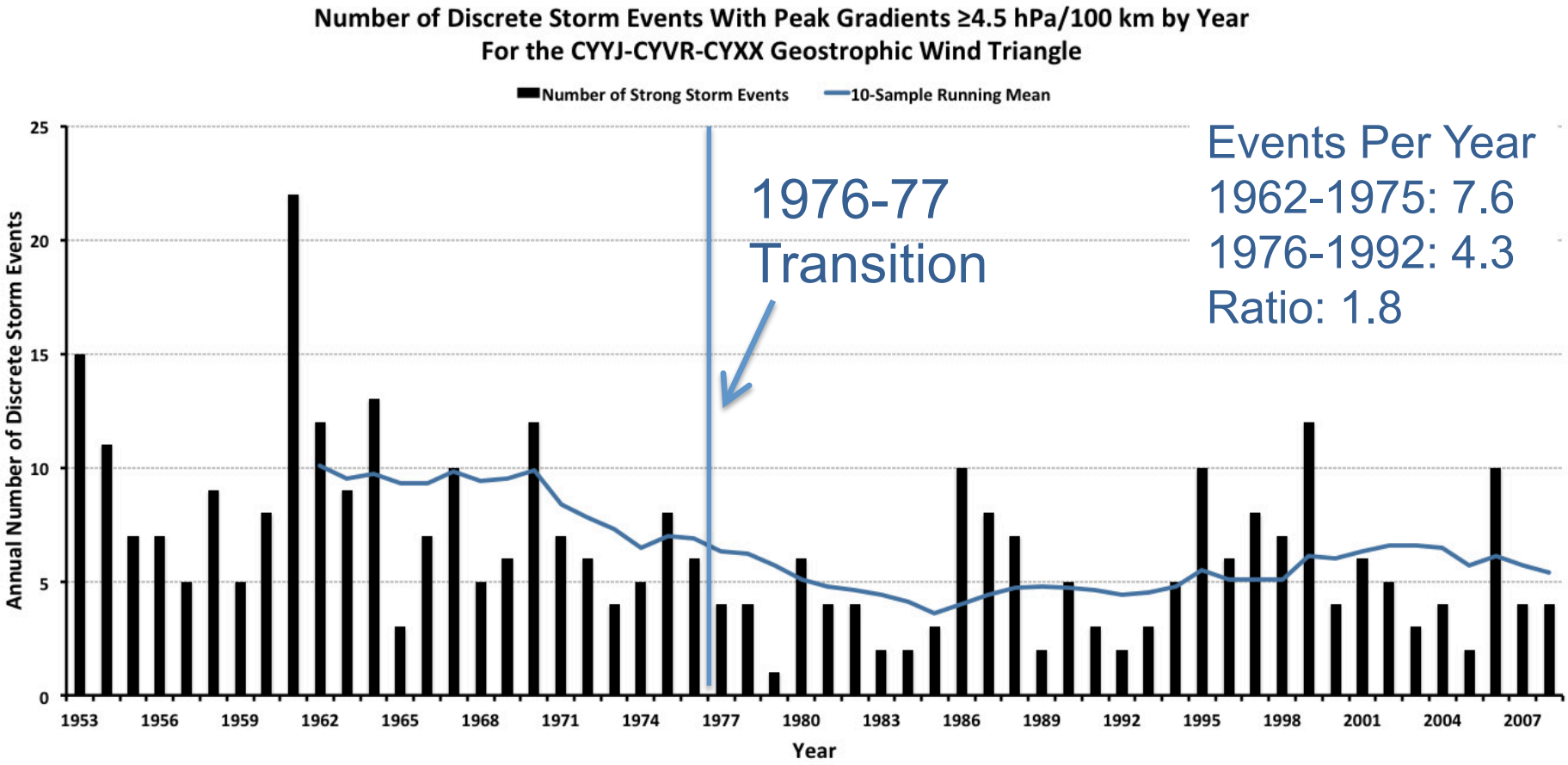
- The 10-Year average number of events ≥4.5 hPa/ 100 km appears to drop from 10 to less than 5

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



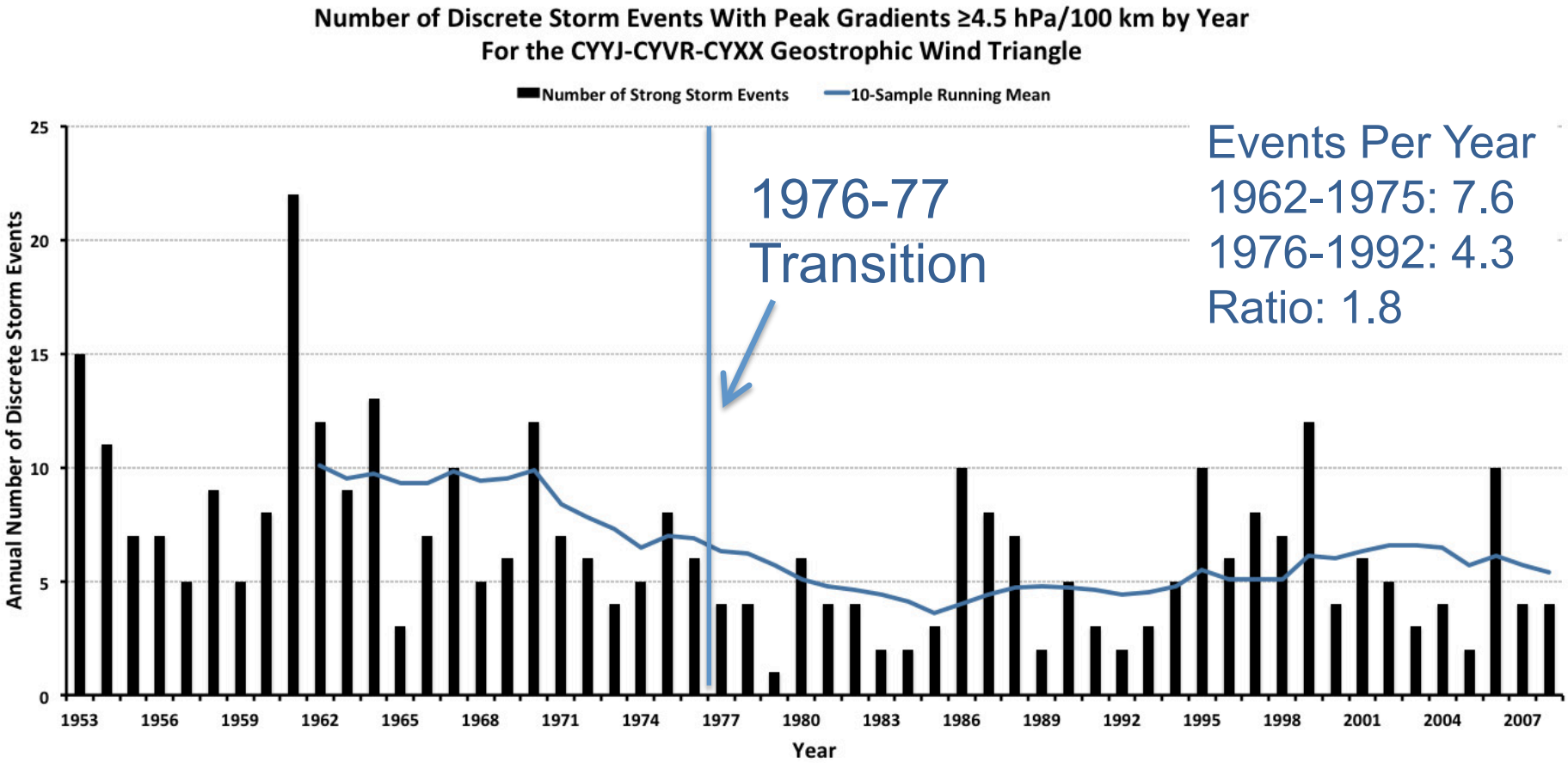
- However, the reduction appears to begin ahead of the 1976-77 transition by many years (like the Mass & Dotson data)
- And, the SD is fairly high, reducing confidence in the mean

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



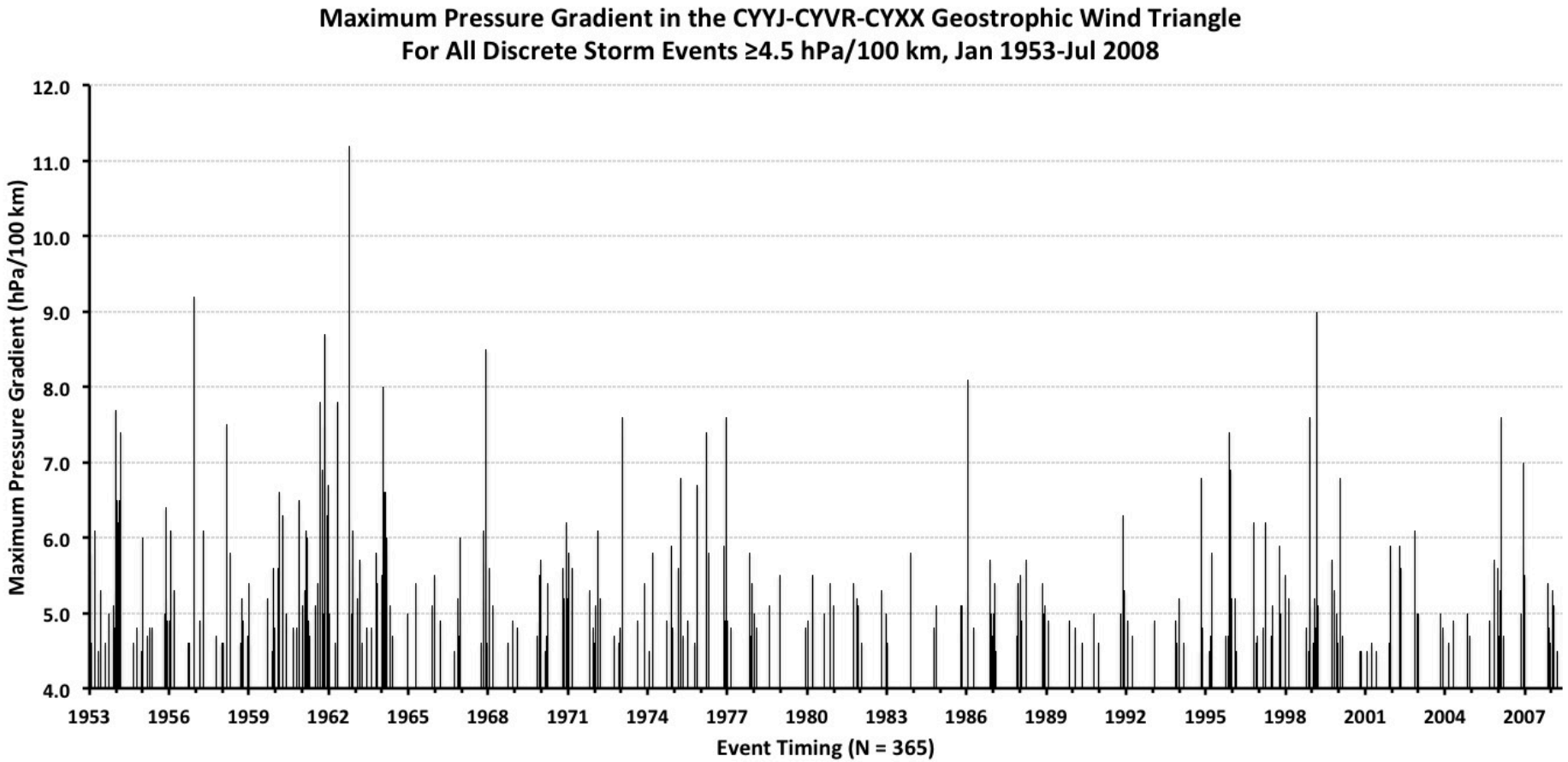
- Ratio between the two eras is similar to that for the surface wind data: 1.8 vs. 2.0

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



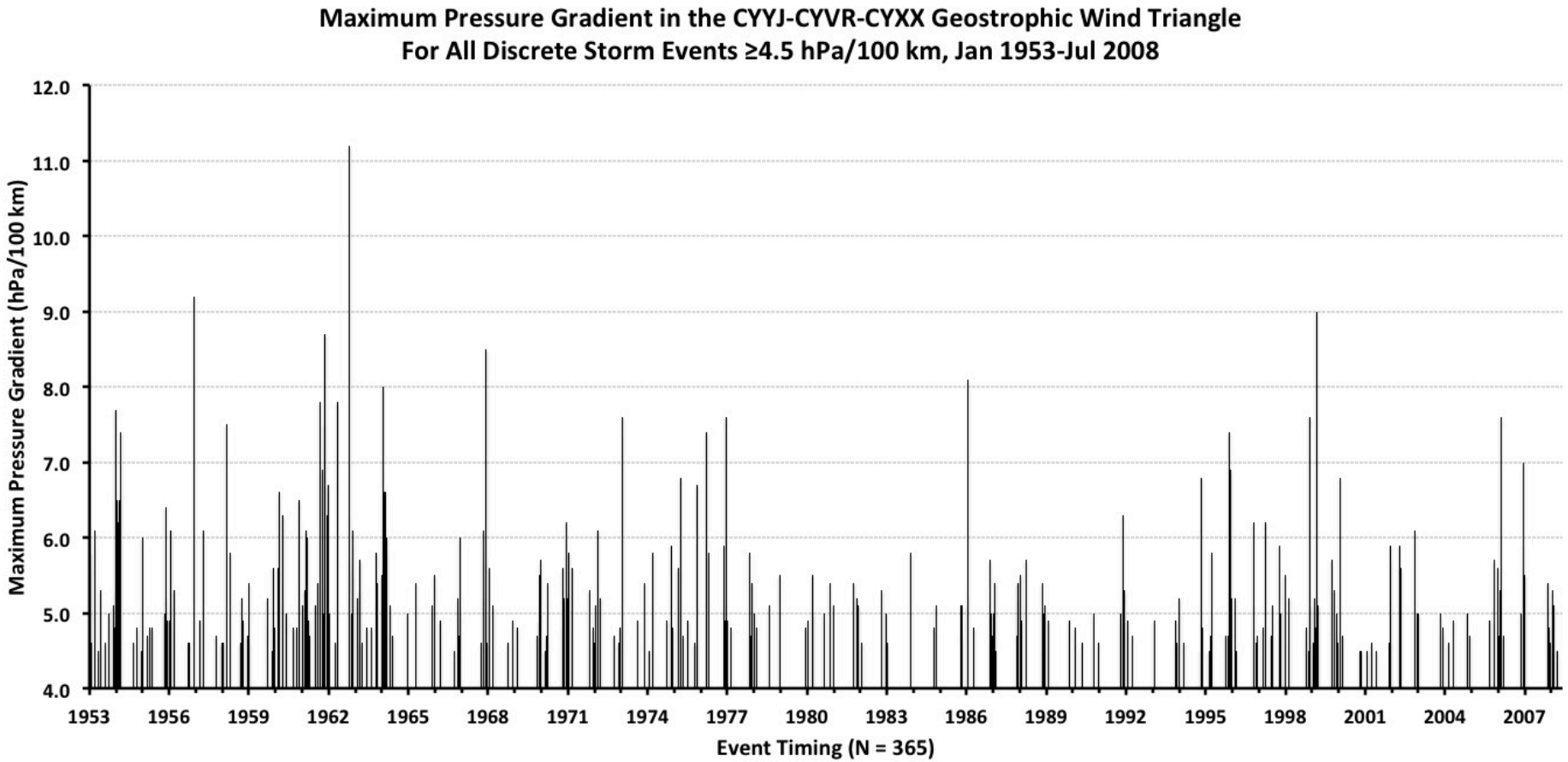
- Ratio between the two eras is similar to that for the surface wind data: 1.8 vs. 2.0
- To “test the waters”: F-test for 1953-76 vs. 1977-00: *p* 0.044 (1-tail), 0.087 (2-tail)

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



- In any event, the proxy data do not *disagree* with the surface observations, and do show some correlation

CYYJ-CYVR-CYXX Pressure Triangle Preliminary Results



- 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

References

Devine, K. A. 2008. "John Patterson and the three-cup anemometer." *CMOS Bulletin*, vol 36, no 2, p 51-56.

Ebbesmeyer, C. E. and C. Coombs. 1989. "Strong, Low-Frequency (Decadal) Environmental Fluctuations During the 20th Century." *Oceans '89 Proceedings*, vol 1, p 242-246.

Gates, E.M. and W.C. Thompson. 1986. "Simulated atmospheric rime icing of some wind speed sensors." *Journal of Atmospheric and Oceanic Technology*, vol 3, p 273-282.

Hare, S. R. and N. J. Mantua. 2000. "Empirical evidence for North Pacific regime shifts in 1977 and 1989." *Progress in Oceanography*, 47, 103-145.

Mantua, N. J. 2000. "The pacific decadal oscillation (PDO)." January 2000. *Joint Institute for the Study of the Atmosphere and Ocean*, University of Washington. Accessed 25 Oct 2011 at http://www.jisao.washington.edu/pdo/

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace and R. C. Francis. 1997. "A Pacific interdecadal climate oscillation with impacts on salmon production." *Bulletin of the American Meteorological Society*, 78, 1069-1079.

Mass, C. F. and B. Dotson. 2010. "Major Extratropical Cyclones of the Northwest United States: Historical Review, Climatology, and Synoptic Environment." *Monthly Weather Review*, vol 138, p 2499-2527.

Overland, J., S. Rodionov, S. Minobe, N. Bond. 2008. "North Pacific regime shifts: Definitions, issues and recent transitions." *Progress in Oceanography*, 77, 92-102.

Tuller, S.E. 1980. "The even wind speeds on the British Columbia coast." *Atmosphere-Ocean*, vol 18, no 4, p 322-328.

Tuller, S. E. 2004. "Measured wind speed trends on the West Coast of Canada." *International Journal of Climatology*, vol 24, p 1359-1374.

Wolf Read
wolfread@me.com

Project funding: UBC, BC Hydro, NSERC