Canadian Prairie Drought, Climate Change and impact on future grain yield

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Synopsis

1. A historical survey of Prairie drought
2. Prairie droughts during the dust bowl years
3. Linkage with Pacific SSTs and ENSO
4. Brief overview of climate change debate
5. Solar variability, earth’s climate & drought
6. New emerging view of Prairie drought
7. Future grain yield & concluding remarks

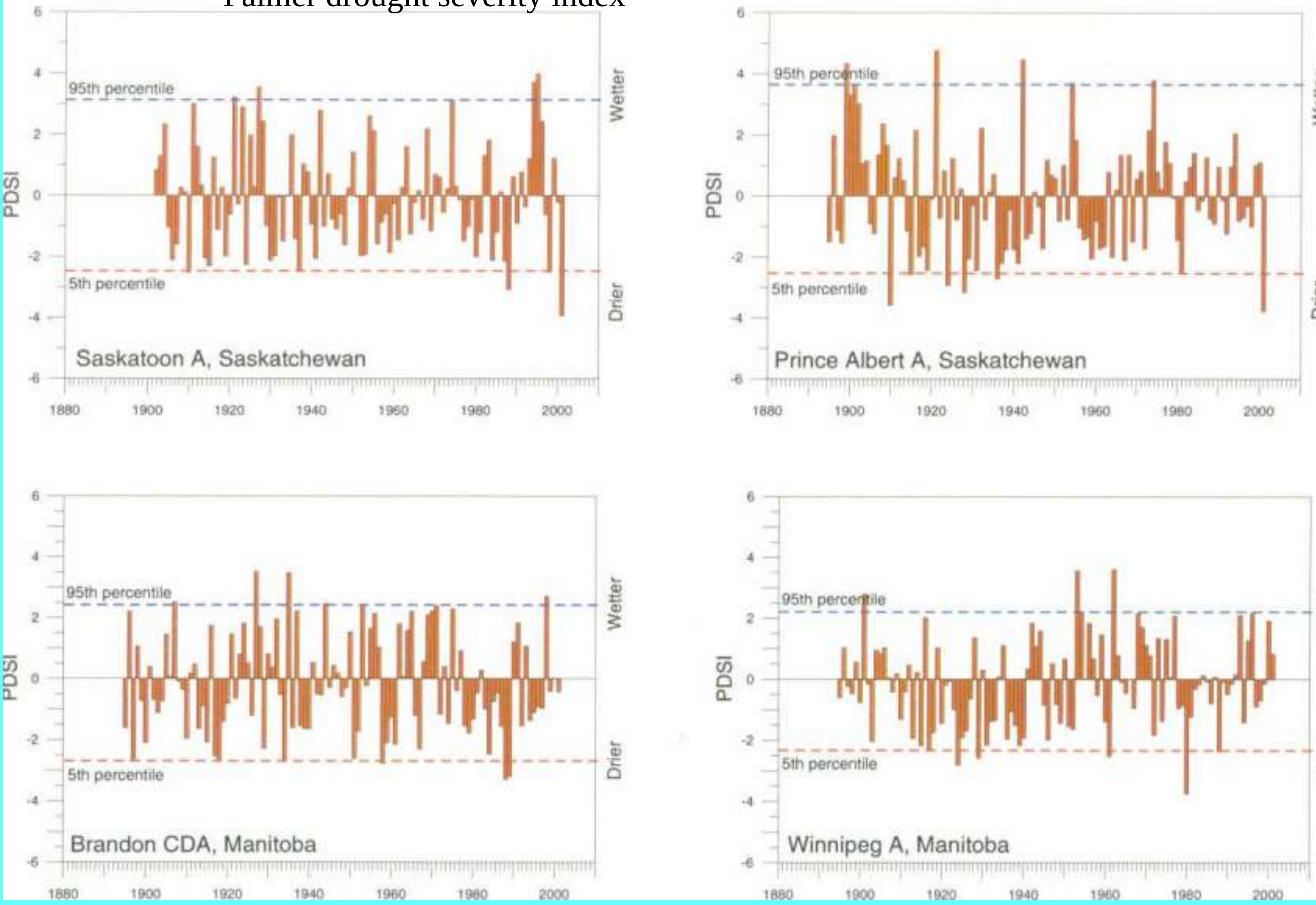
Drought on the Canadian/US Prairies

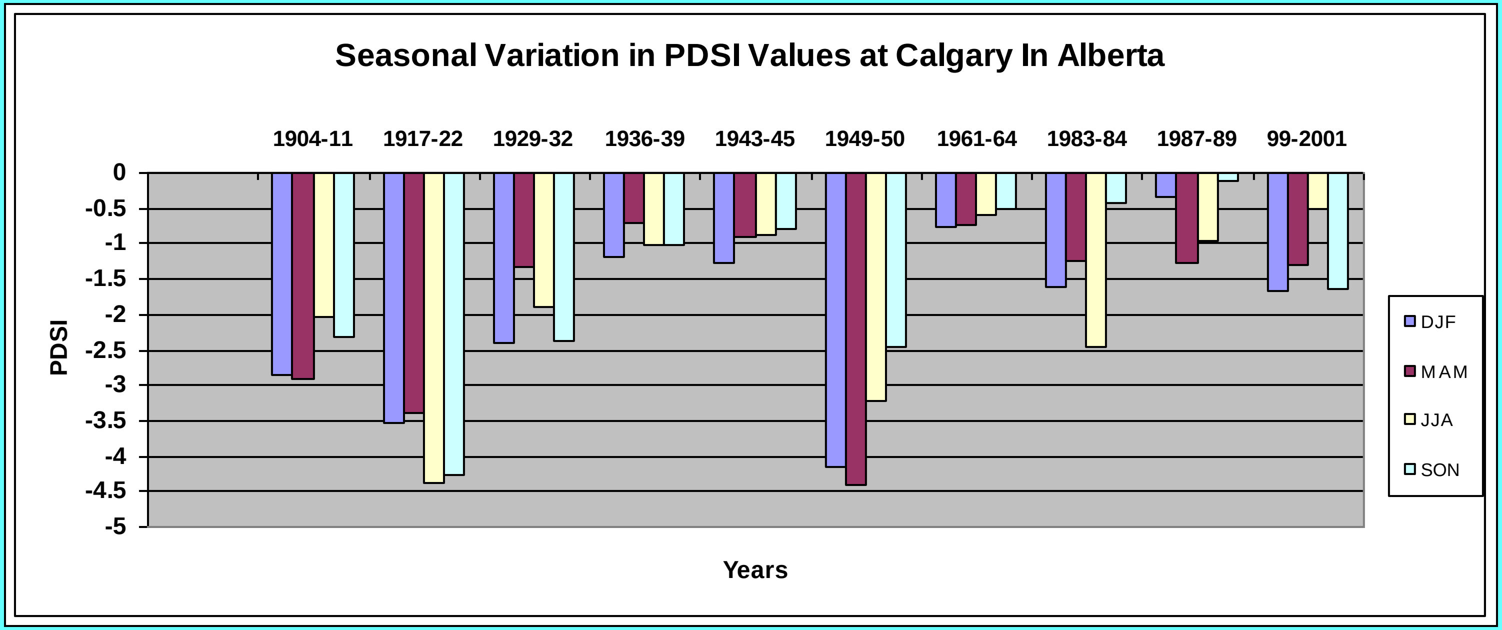
- Prairie drought is a challenging problem in climate science today
- Droughts of varying intensity & duration have been occurring on the Prairies for hundreds of years.
- Tree-ring analysis suggests some of the severest droughts in the 13th,16th and 17^{th} century; Nebraska droughts 1276-1313; 1512-1529;1688-1707
- 20^{th} century recurring droughts of 1920s and 1930s, these years known as Dust Bowl years.
- Recent droughts of 1987-89 and 1999-2001 appear to be part of the drought cycle
- Drought driving mechanism not fully understood yet

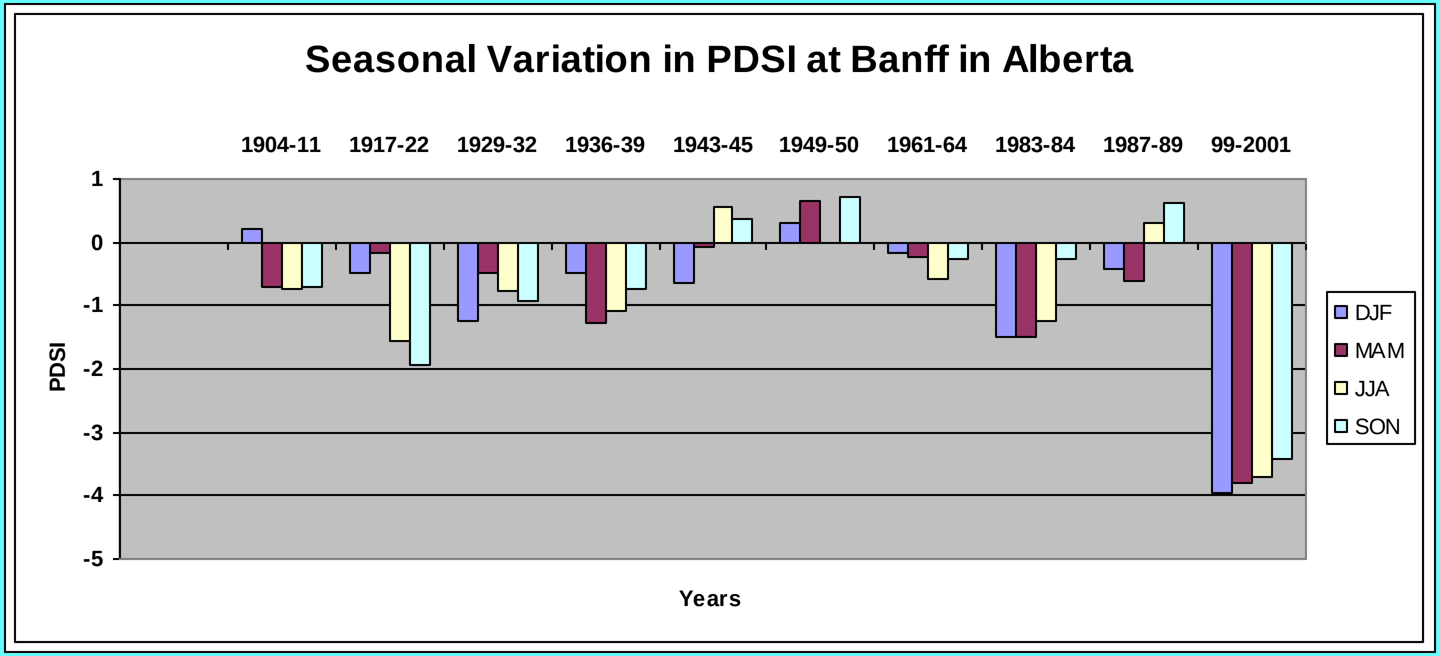
20th century droughts on Canadian Prairies

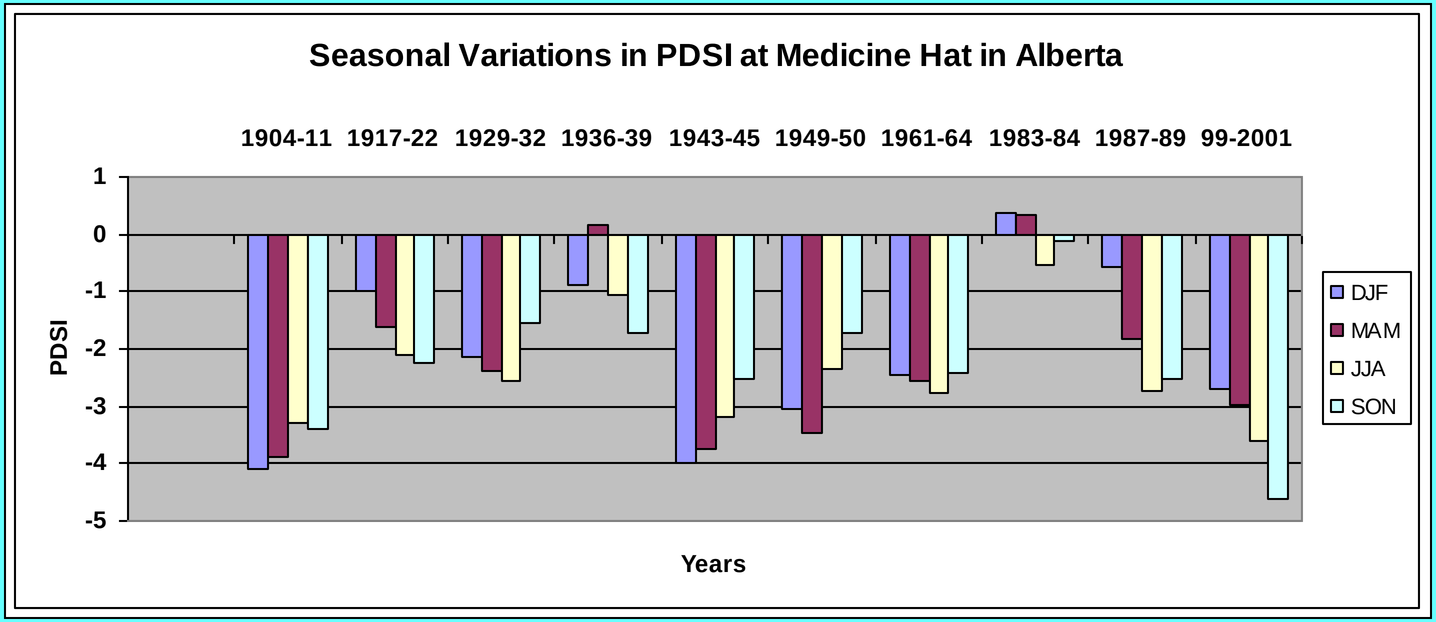
Summer (June, July, August) PDSI to 2001

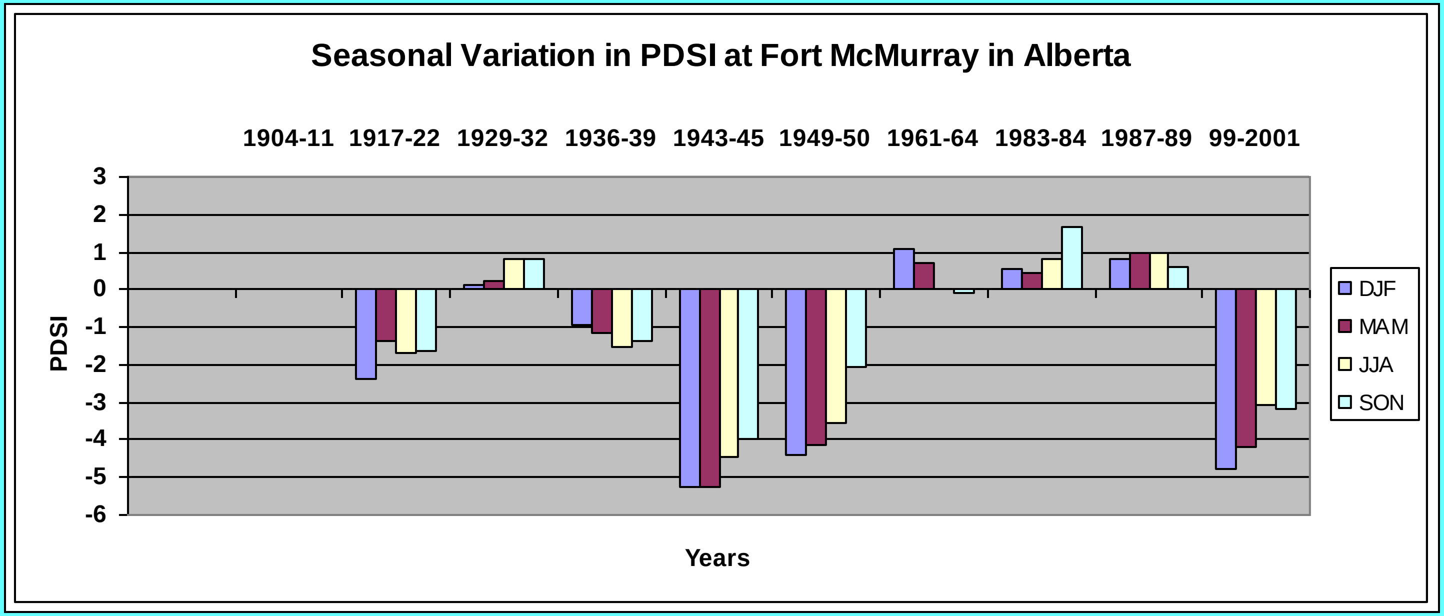
Palmer drought severity index

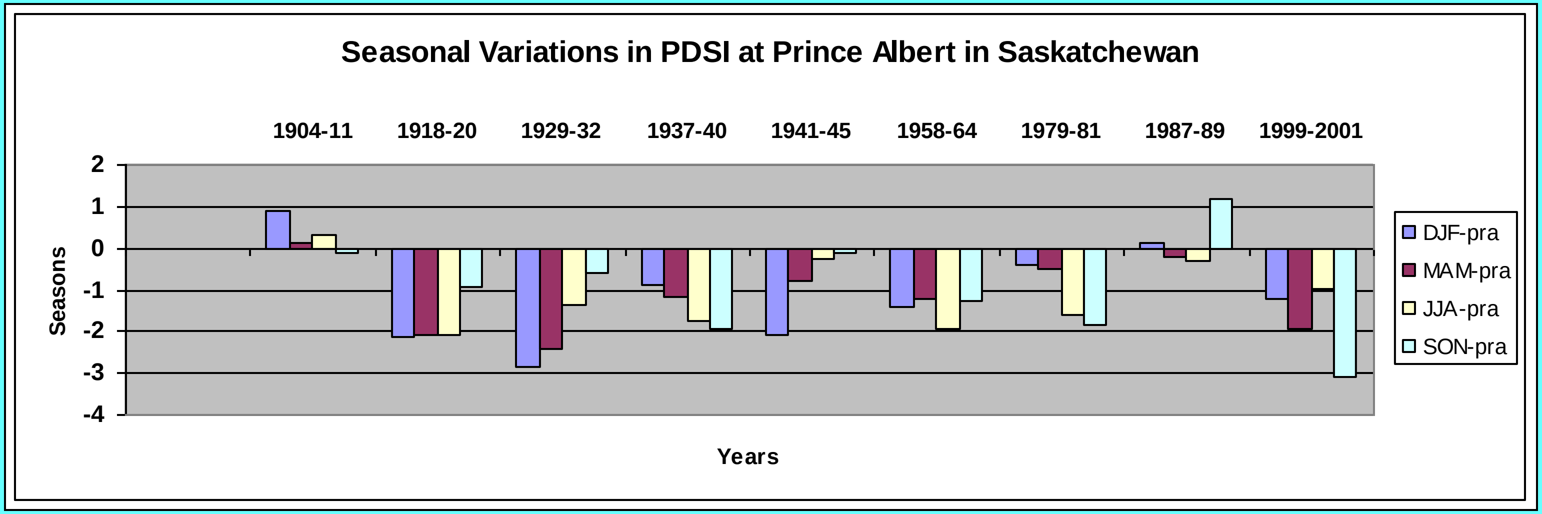


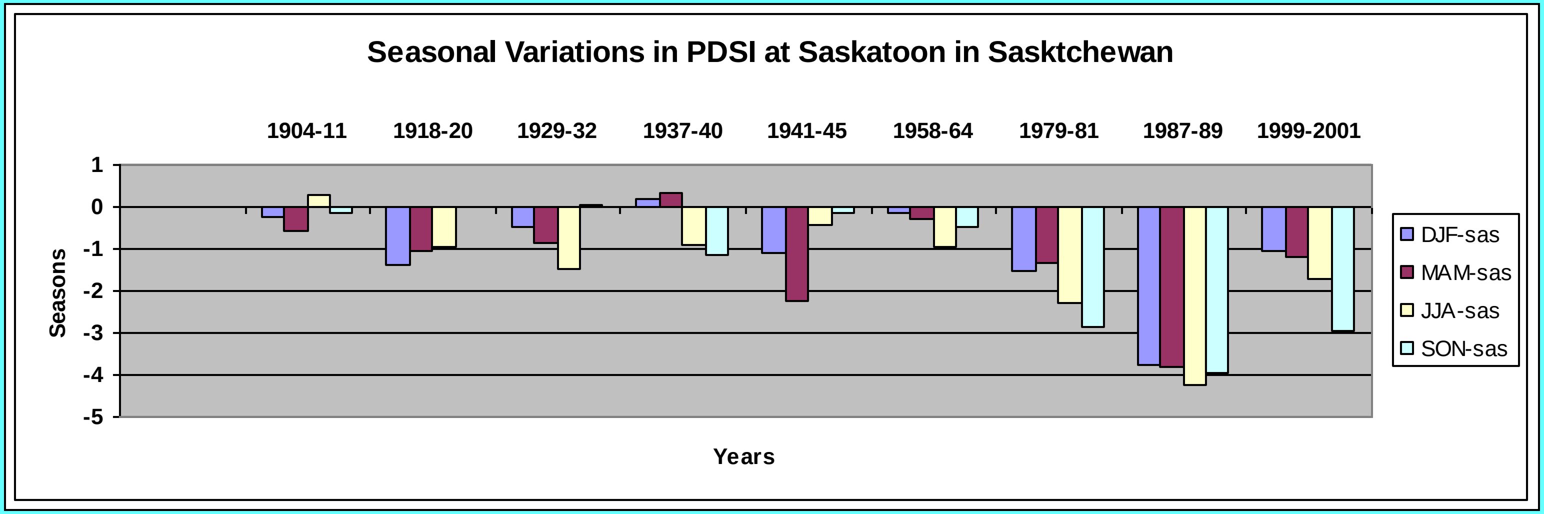

Seasonal Variation in PDSI Values at Calgary In Alberta
1904-11
1917-22
1929-32
1936-39
1943-45
1949-50
1961-64
1983-84
1987-89
99-2001
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
PDSI
Years
DJF
MAM
JJA
SON

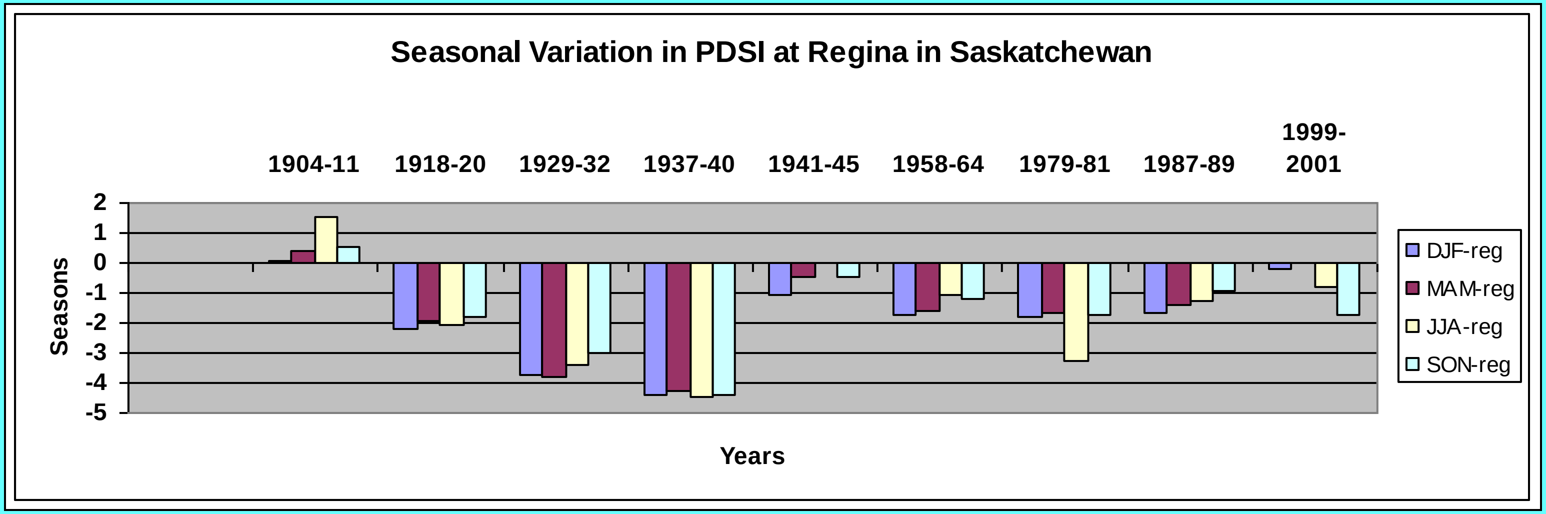

Seasonal Variation in PDSI at Banff in Alberta
1904-11
1917-22
1929-32
1936-39
1943-45
1949-50
1961-64
1983-84
1987-89
99-2001
1
0
-1
-2
-3
-4
-5
PDSI
Years
DJF
MAM
JJA
SON

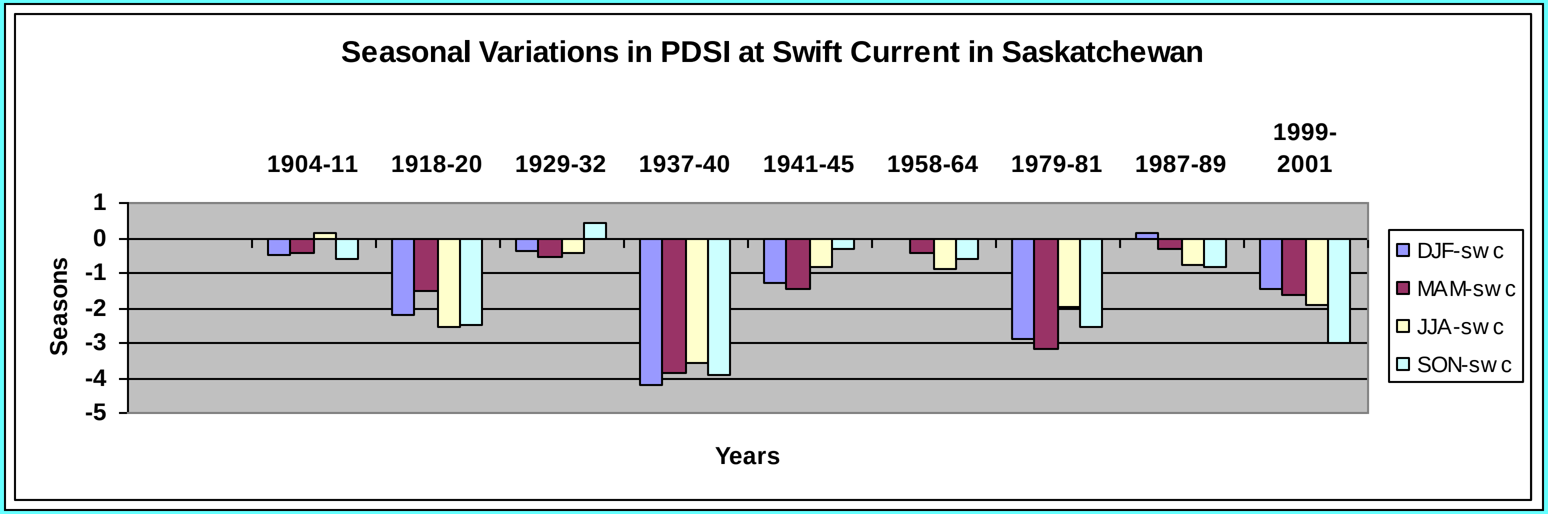

Seasonal Variations in PDSI at Medicine Hat in Alberta
1904-11
1917-22
1929-32
1936-39
1943-45
1949-50
1961-64
1983-84
1987-89
99-2001
PDSI
1
0
-1
-2
-3
-4
-5
Years
DJF
MAM
JJA
SON

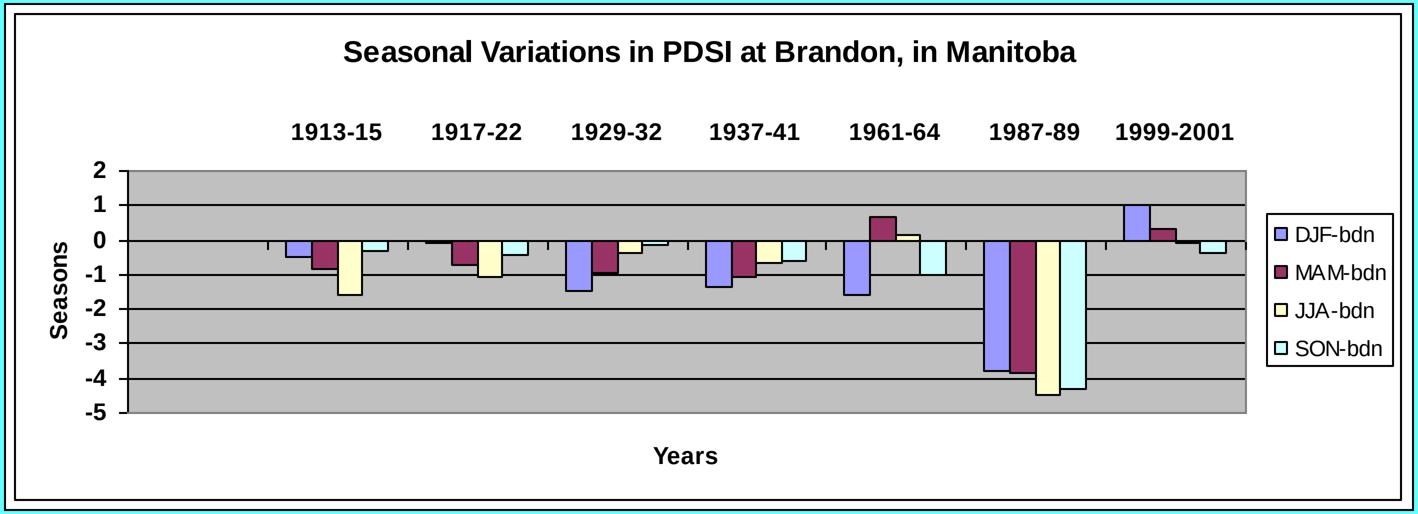

Seasonal Variation in PDSI at Fort McMurray in Alberta
1904-11
1917-22
1929-32
1936-39
1943-45
1949-50
1961-64
1983-84
1987-89
99-2001
PDSI
3
2
1
0
-1
-2
-3
-4
-5
-6
Years
DJF
MAM
JJA
SON

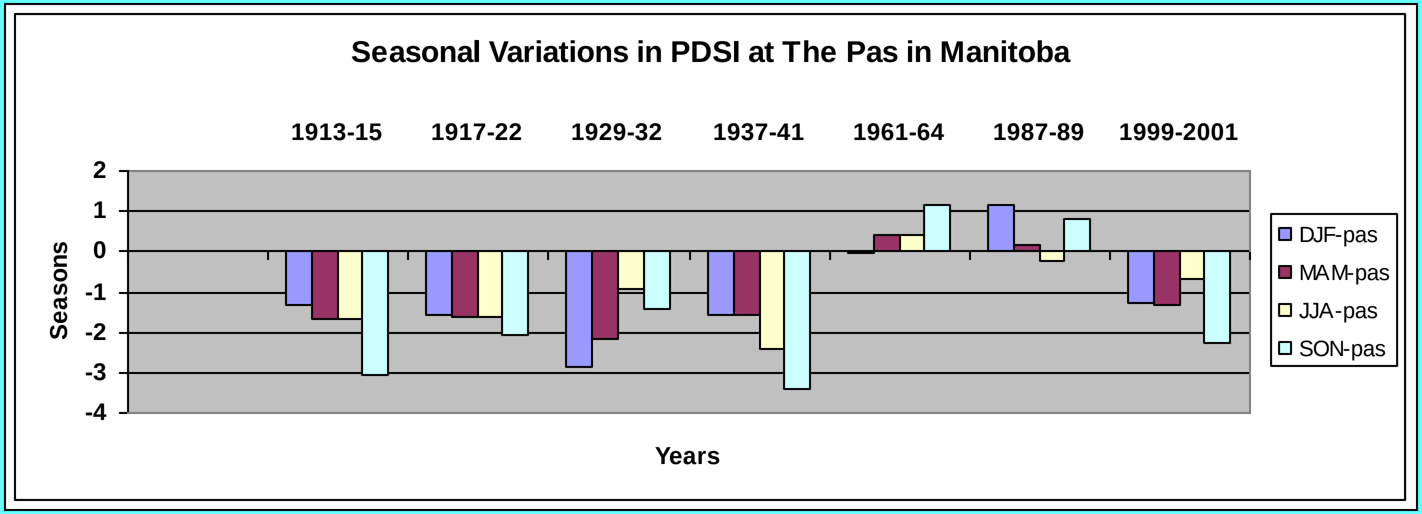

Seasonal Variations in PDSI at Prince Albert in Saskatchewan
1904-11
1918-20
1929-32
1937-40
1941-45
1958-64
1979-81
1987-89
1999-2001
2
1
0
-1
-2
-3
-4
Seasons
Years
DJF-pra
MAM-pra
JJA-pra
SON-pra

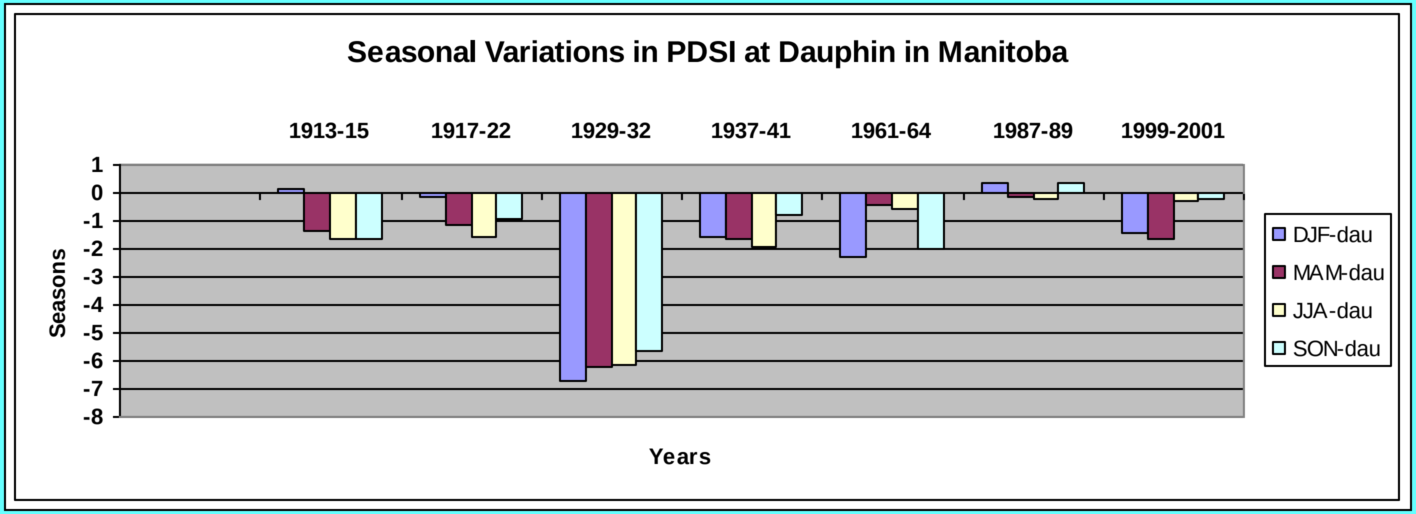

Seasonal Variations in PDSI at Saskatoon in Sasktchewan
1904-11
1918-20
1929-32
1937-40
1941-45
1958-64
1979-81
1987-89
1999-2001
1
0
-1
-2
-3
-4
-5
Seasons
Years
DJF-sas
MAM-sas
JJA-sas
SON-sas

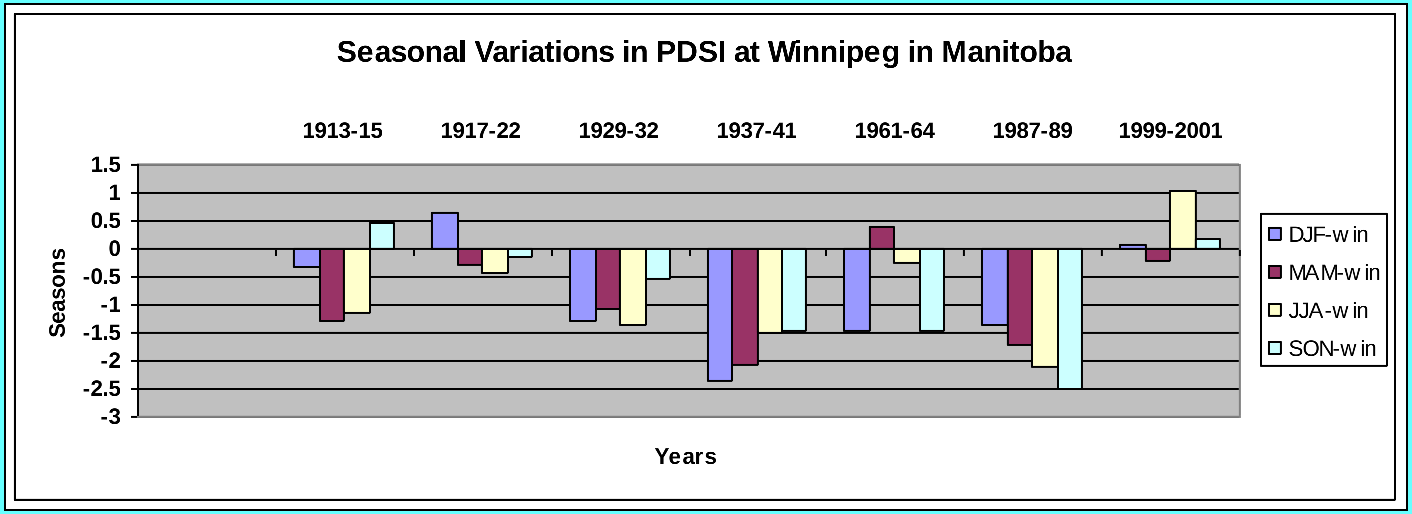

Seasonal Variation in PDSI at Regina in Saskatchewan
1904-11
1918-20
1929-32
1937-40
1941-45
1958-64
1979-81
1987-89
1999-2001
2
1
0
-1
-2
-3
-4
-5
Seasons
Years
DJF-reg
MAM-reg
JJA-reg
SON-reg


Seasonal Variations in PDSI at Swift Current in Saskatchewan
1904-11
1918-20
1929-32
1937-40
1941-45
1958-64
1979-81
1987-89
1999-2001
1
0
-1
-2
-3
-4
-5
Seasons
Years
DJF-sw c
MAM-sw c
JJA-sw c
SON-sw c

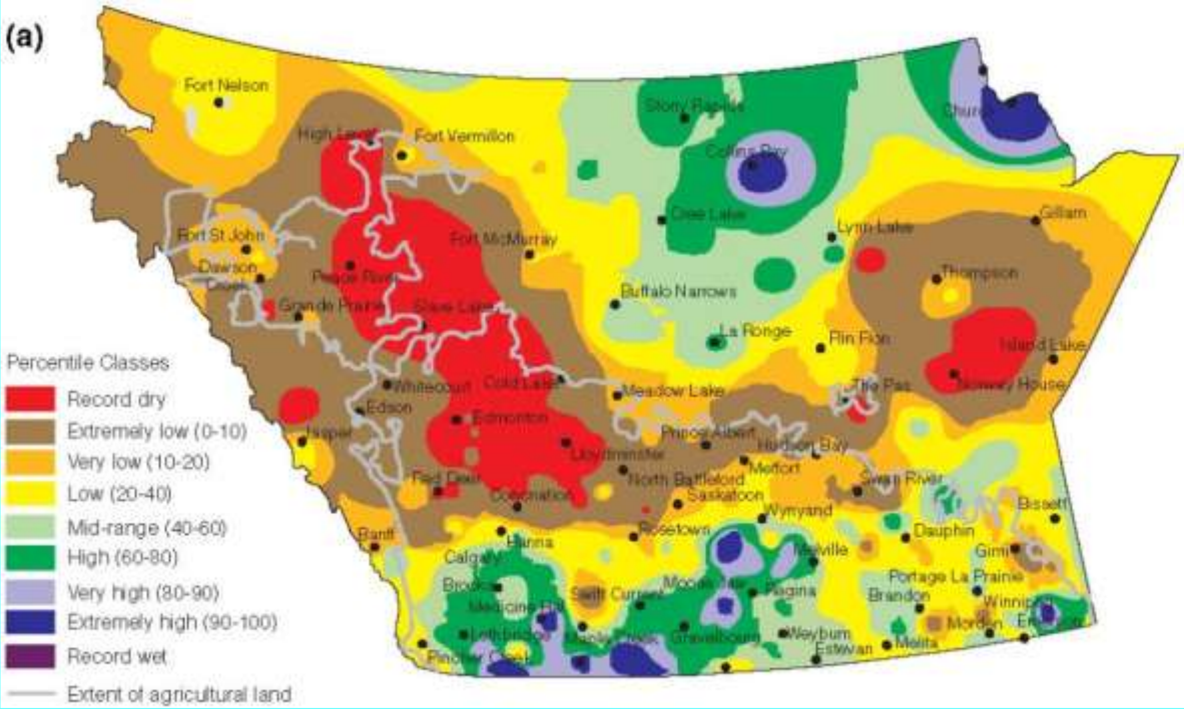

Seasonal Variations in PDSI at Brandon, in Manitoba
1913-15
1917-22
1929-32
1937-41
1961-64
1987-89
1999-2001
2
1
0
-1
-2
-3
-4
-5
Seasons
Years
DJF-bdn
MAM-bdn
JJA-bdn
SON-bdn

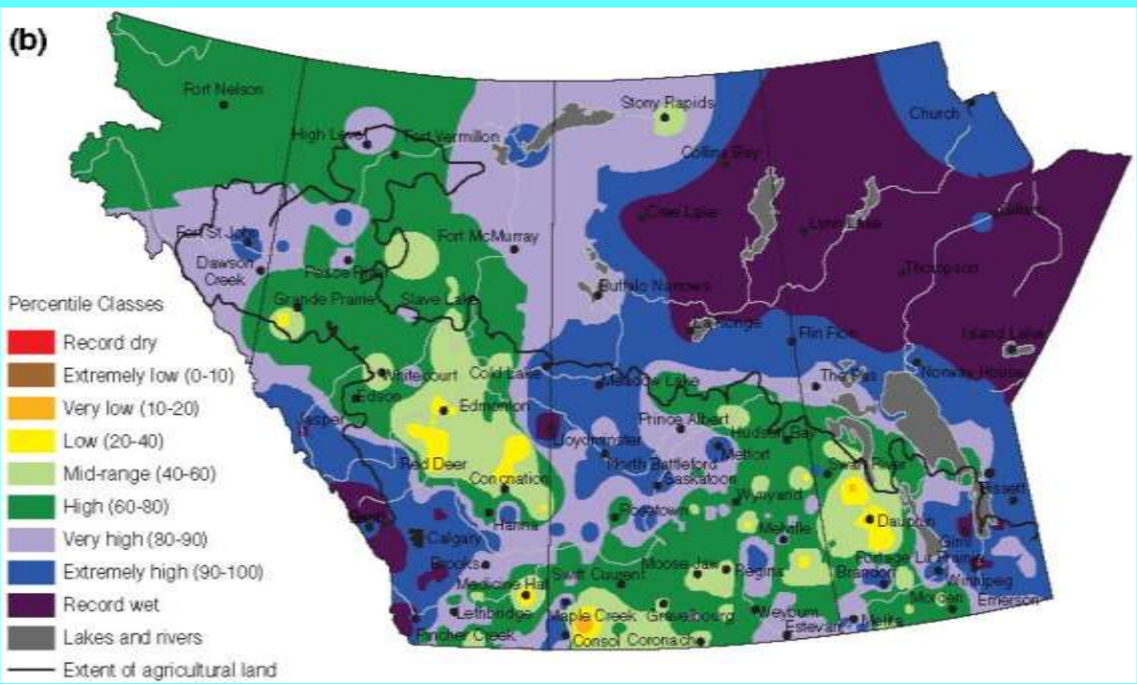

Seasonal Variations in PDSI at The Pas in Manitoba
1913-15
1917-22
1929-32
1937-41
1961-64
1987-89
1999-2001
2
1
0
-1
-2
-3
-4
Seasons
Years
DJF-pas
MAM-pas
JJA-pas
SON-pas


Seasonal Variations in PDSI at Dauphin in Manitoba
1913-15
1917-22
1929-32
1937-41
1961-64
1987-89
1999-2001
1
0
-1
-2
-3
-4
-5
-6
-7
-8
Seasons
Years
DJF-dau
MAM-dau
JJA-dau
SON-dau


Seasonal Variations in PDSI at Winnipeg in Manitoba
1913-15
1917-22
1929-32
1937-41
1961-64
1987-89
1999-2001
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
Seasons
Years
DJF-w in
MAM-w in
JJA-w in
SON-w in

ought





Meteorological drought conditions for September 2001- August 2002 (a). Areas in red are record dry conditions. Contrast with conditions observed September 2005 – August 2006 (b).

Drought & ENSO

- It is now generally accepted that a warm event (El Nino) in the equatorial pacific brings summer rains on the Prairies.
- A cold event (La Nina) is linked with drier summer on the Prairies.
- El Nino is a ‘friend’ to Canadian farmers.
- Besides ENSO, the PDO-Pacific Decadal Oscillation also impacts dry/wet conditions on Prairies.

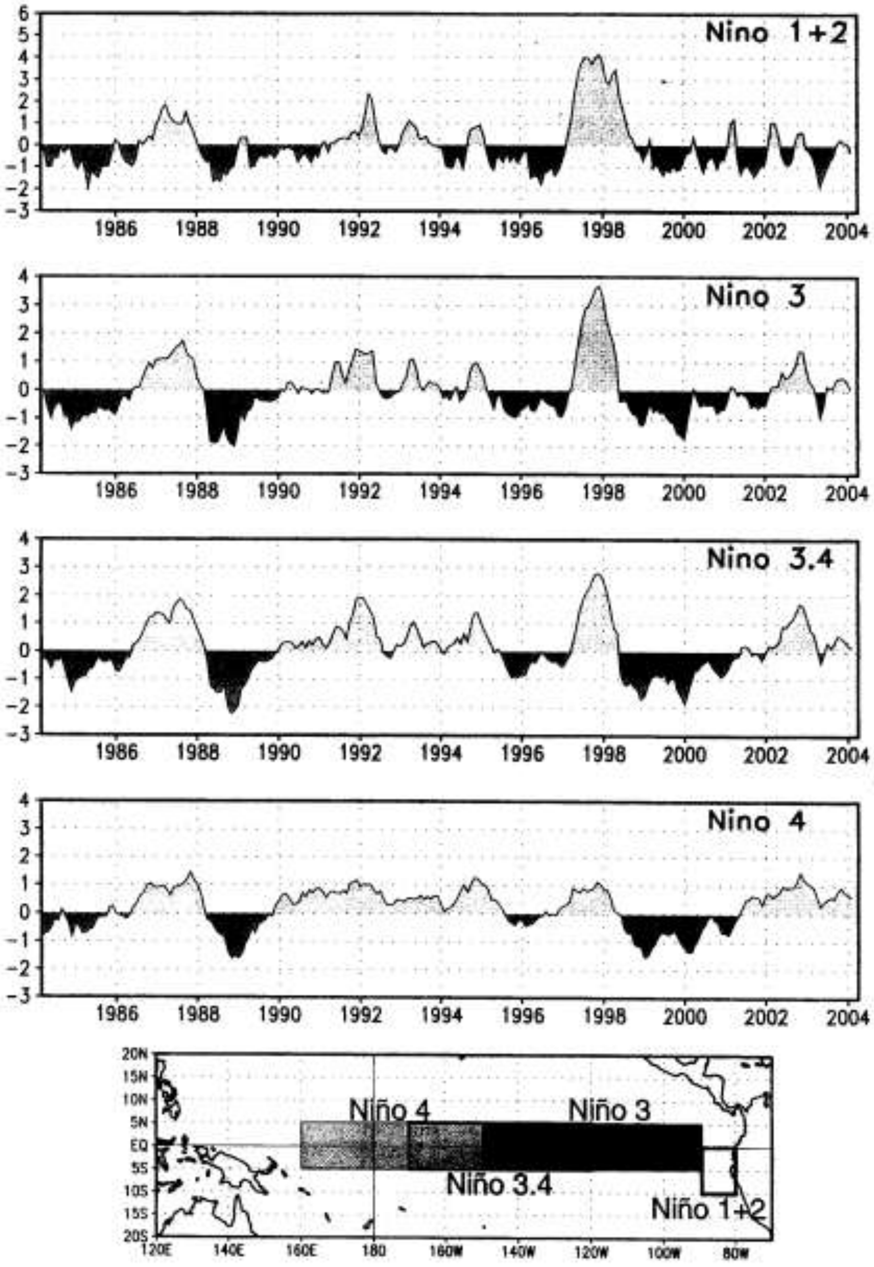
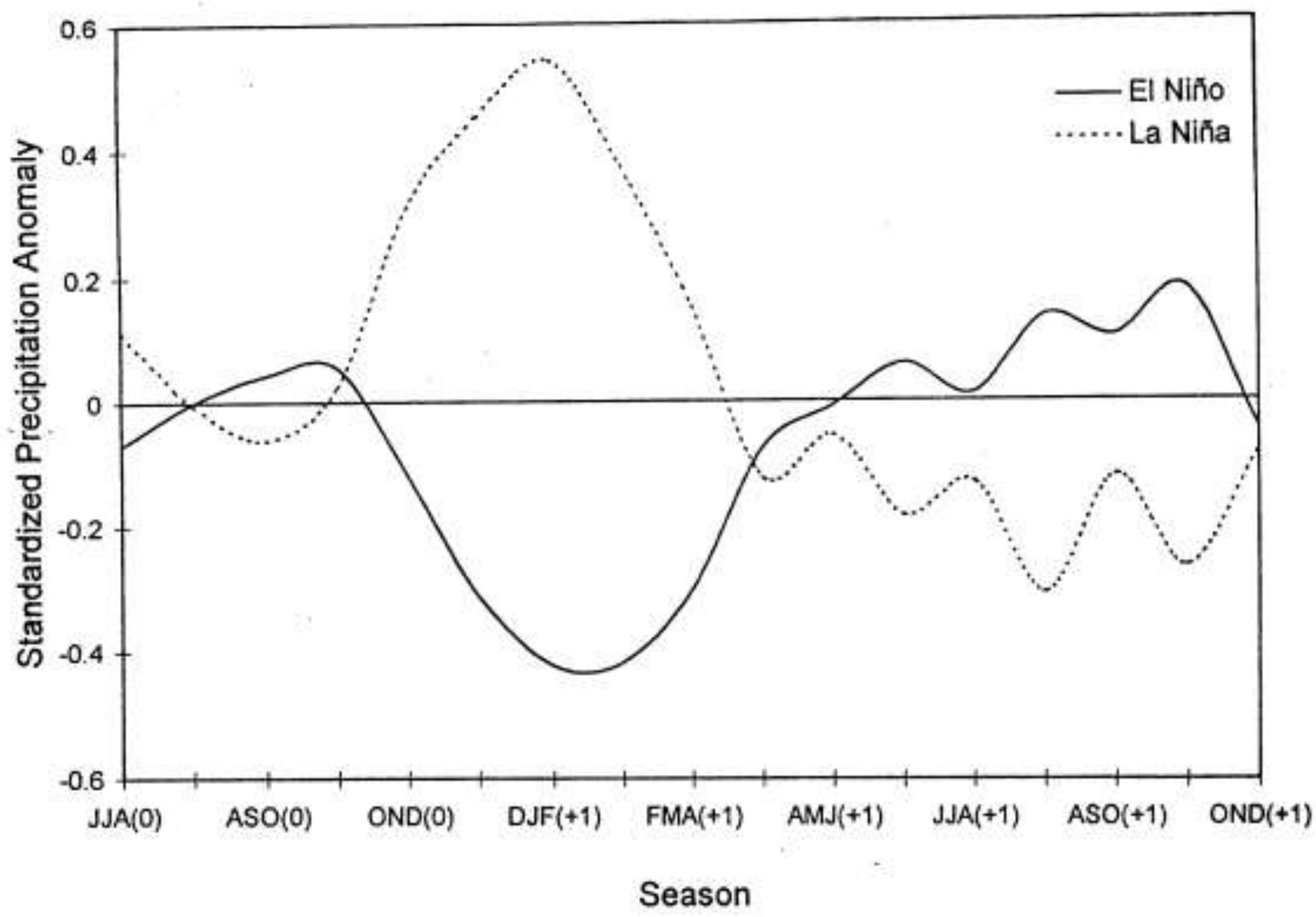


Figure 4.2: SST distribution over four Nino regions for the past 20 years together with

Composite standardized precipitation anomalies: El Nino/La Nina onset year JJA(0) to OND(1) of following year

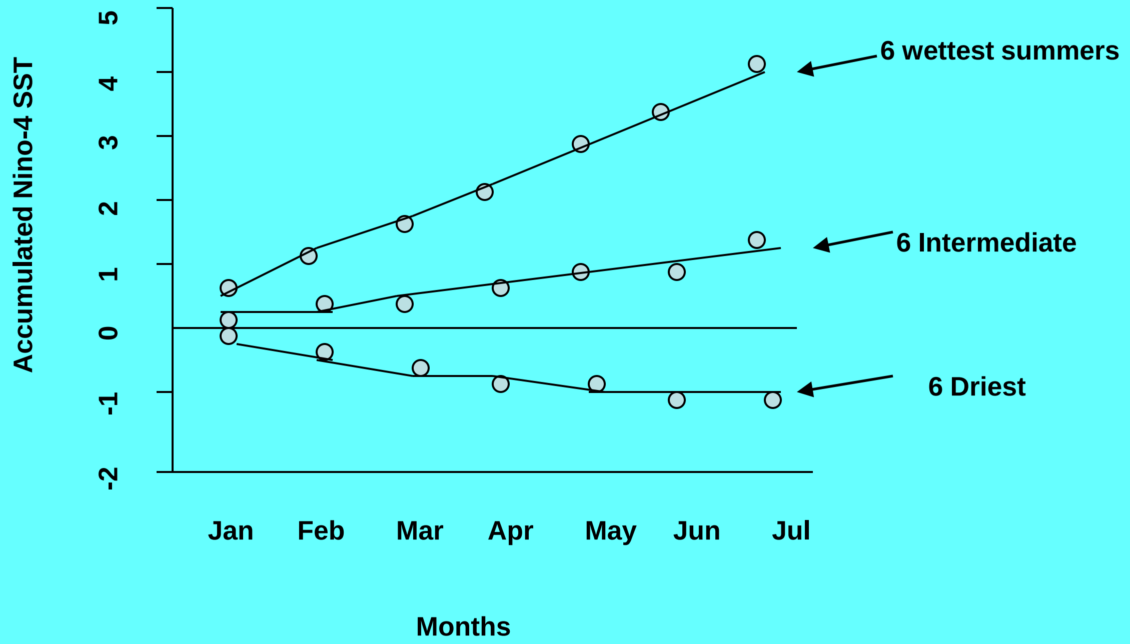


Values of Nino-3 anomalies together with values of PDO index for intervals of drought years .								
Season -->	***DJF***		***MAM***		***JJA***		***SON***	
Interval	***Nino-3***	***PDO***	***Nino-3***	***PDO***	***Nino-3***	***PDO***	***Nino-3***	***PDO***
1904-1911	-0.37	0.25	-0.43	0.15	-0.23	-0.04	-0.24	0.15
1917-1922	-0.31	-0.25	-0.16	-0.35	0.02	-0.46	-0.09	-0.31
1936-1939	-0.30	0.83	-0.32	0.57	-0.55	0.62	-0.06	0.27
1987-1989	0.05	0.72	-0.18	1.00	-0.21	0.94	-0.20	0.47
1999-2001	-1.01	-0.50	-0.26	-0.11	-0.48	-0.86	-0.79	-1.43

Note: DJF: December January February etc.

Values of NP index for intervals of drought and wet years.				
***Interval* ↓ *Season* →**	***DJF***	***MAM***	***JJA***	***SON***
1978-80 wet	1.34	1.15	0.91	0.55
1987-1989 drought	-0.36	0.14	-1.53	-0.24
1992-1994 wet	1.77	2.14	1.44	1.84
1999-2001drought	-2.78	-3.21	-1.64	-1.65

NP Index based on Castro/Mckee/Pielke paper 2001



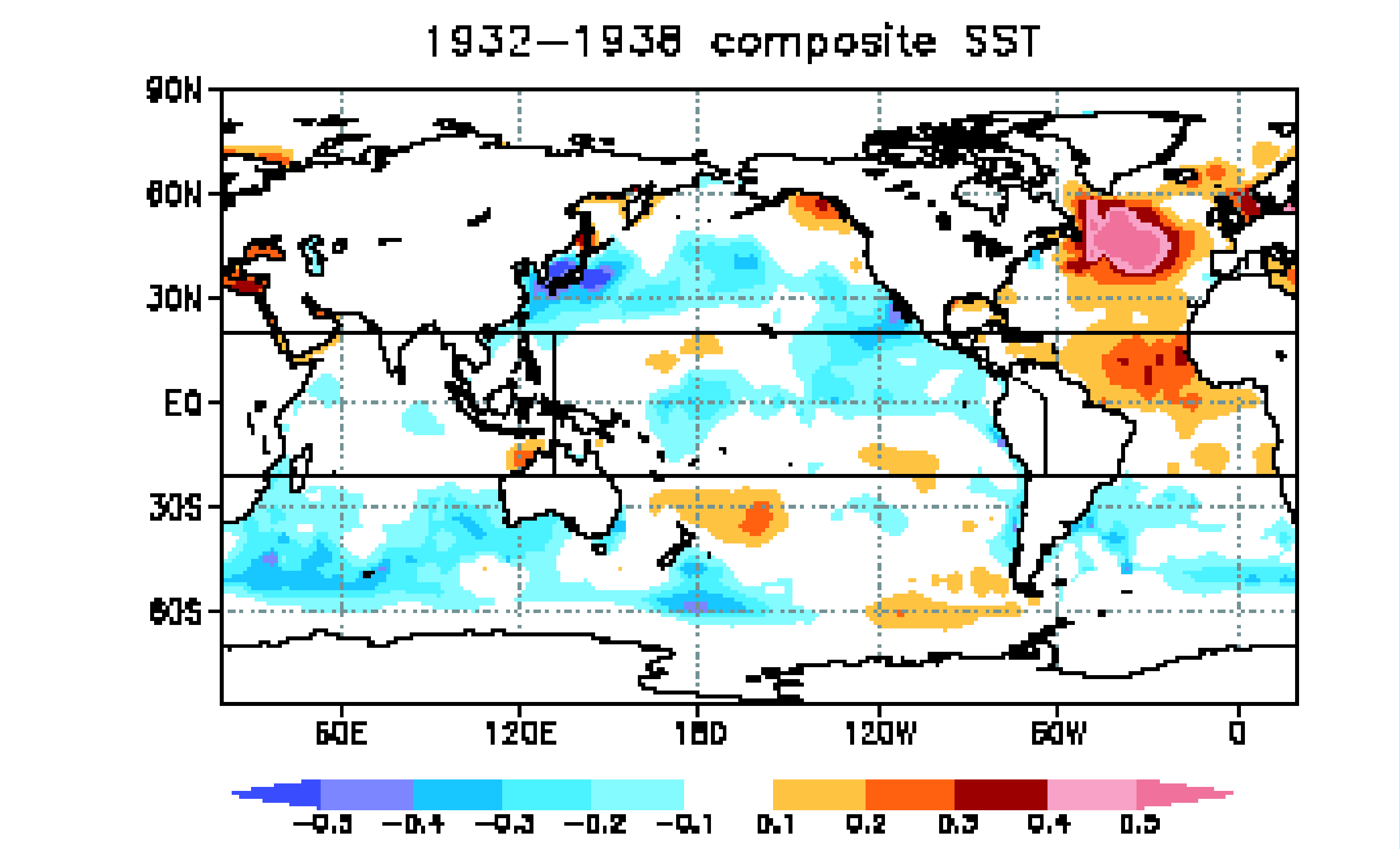
Accumulated Nino-4 SST anomalies before and during the wettest, intermediate and driest Julys over Saskatchewan for the period 1950-1998

From Garnett et al 2006

On the Cause of the 1930s Dust Bowl

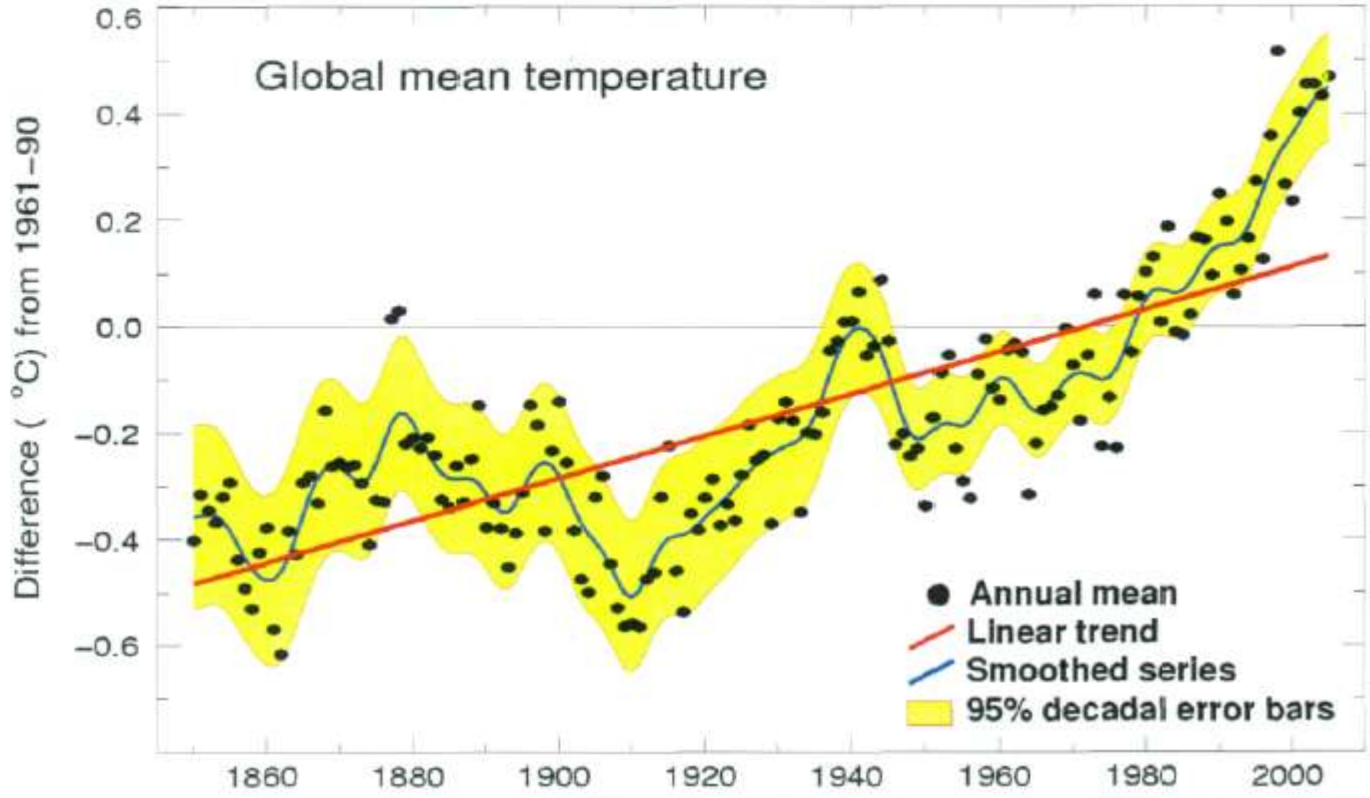
Siegfried D. Schubert,1* Max J. Suarez,1 Philip J. Pegion,1,2
Randal D. Koster,1 Julio T. Bacmeister1,3

SCIENCE VOL 303 19 MARCH 2004

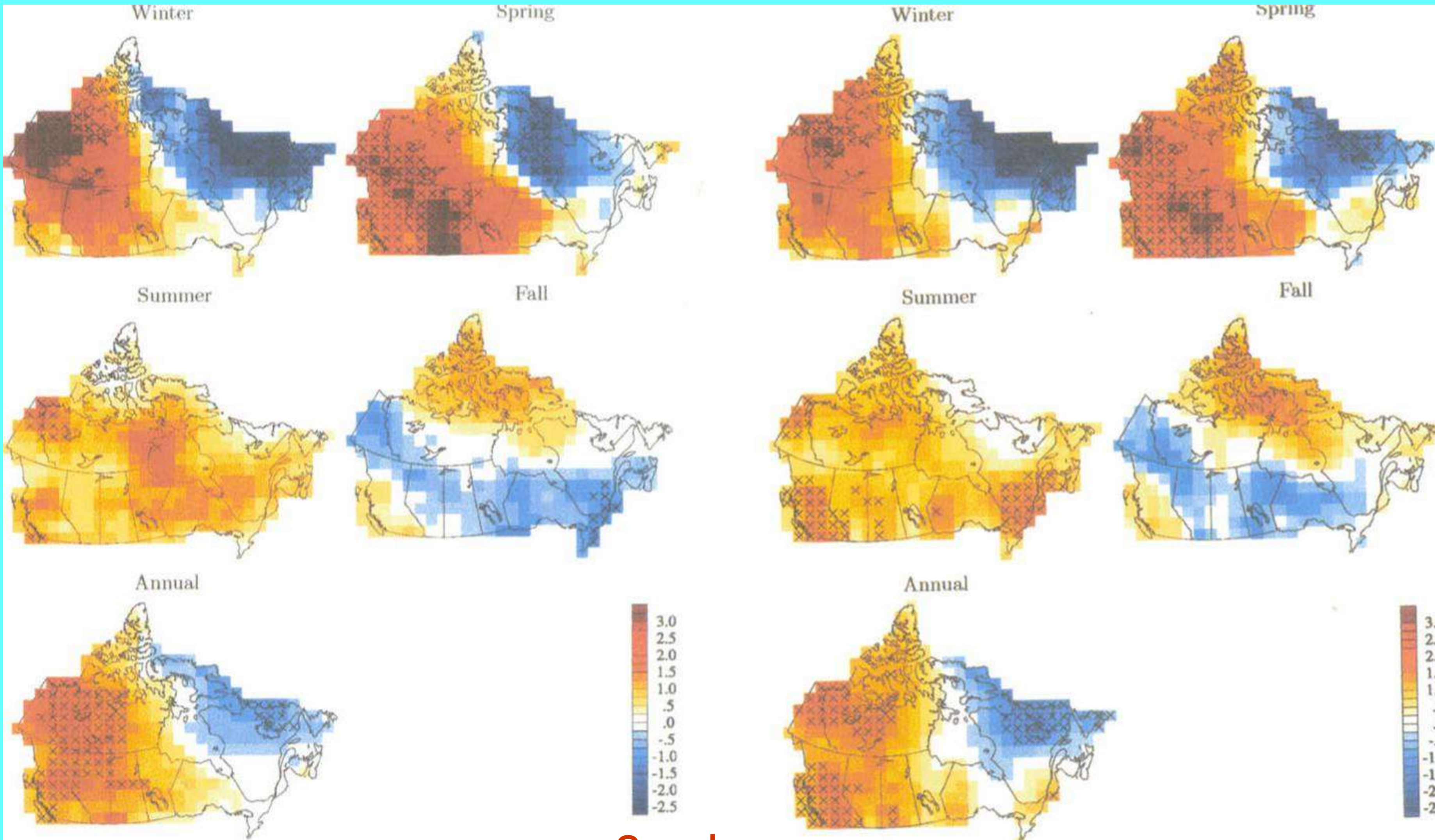


Brief Overview of Climate Change Debate

- Temperature trends, global & regional
- EW & Droughts
- Climate change & solar variability
- Solar variability linkage to drought
- New emerging view of Prairie drought

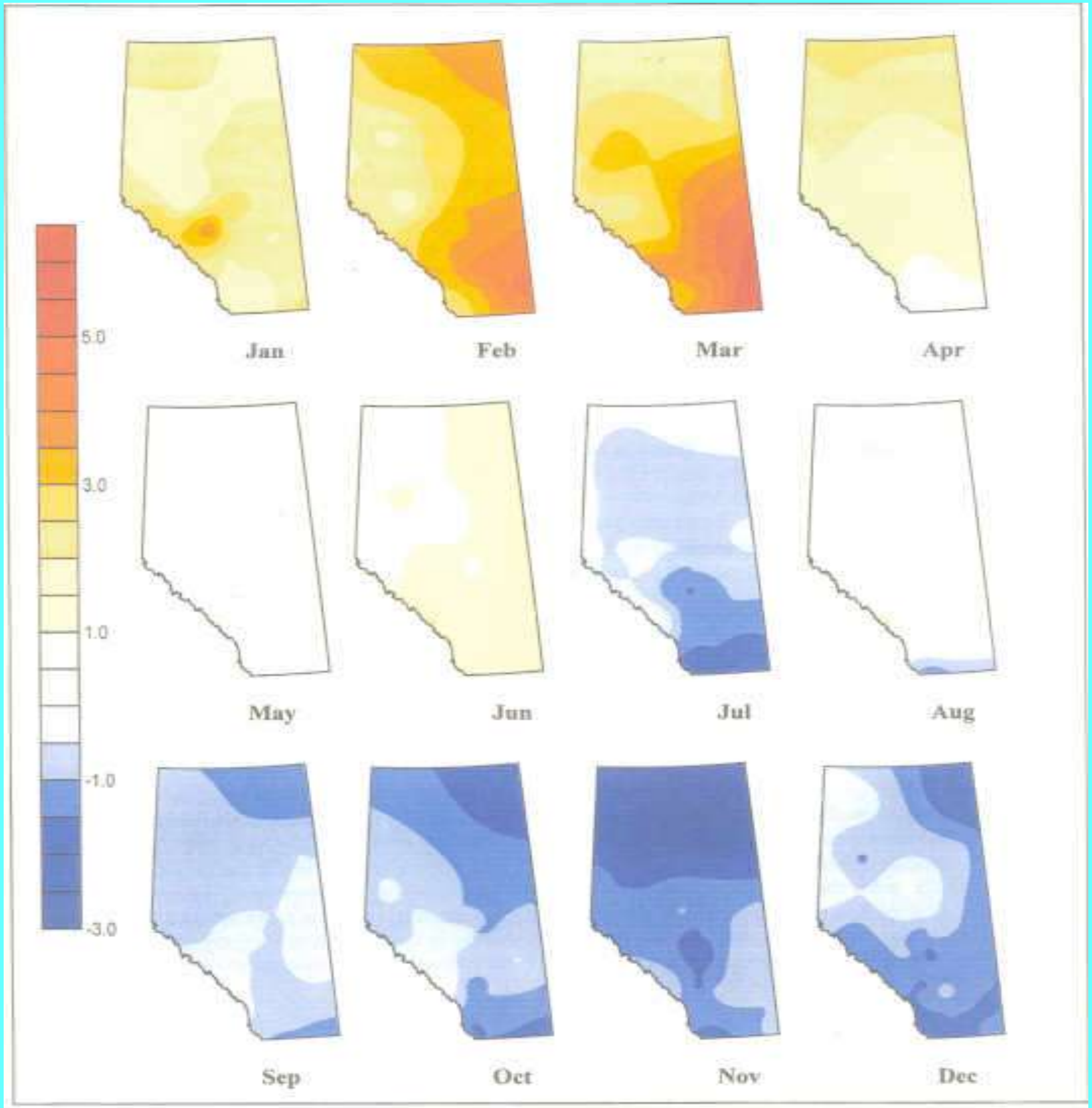

Global mean temperature
Difference (°C) from 1961–90
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
1860
1880
1900
1920
1940
1960
1980
2000
Annual mean
Linear trend
Smoothed series
95% decadal error bars

IPCC 2007

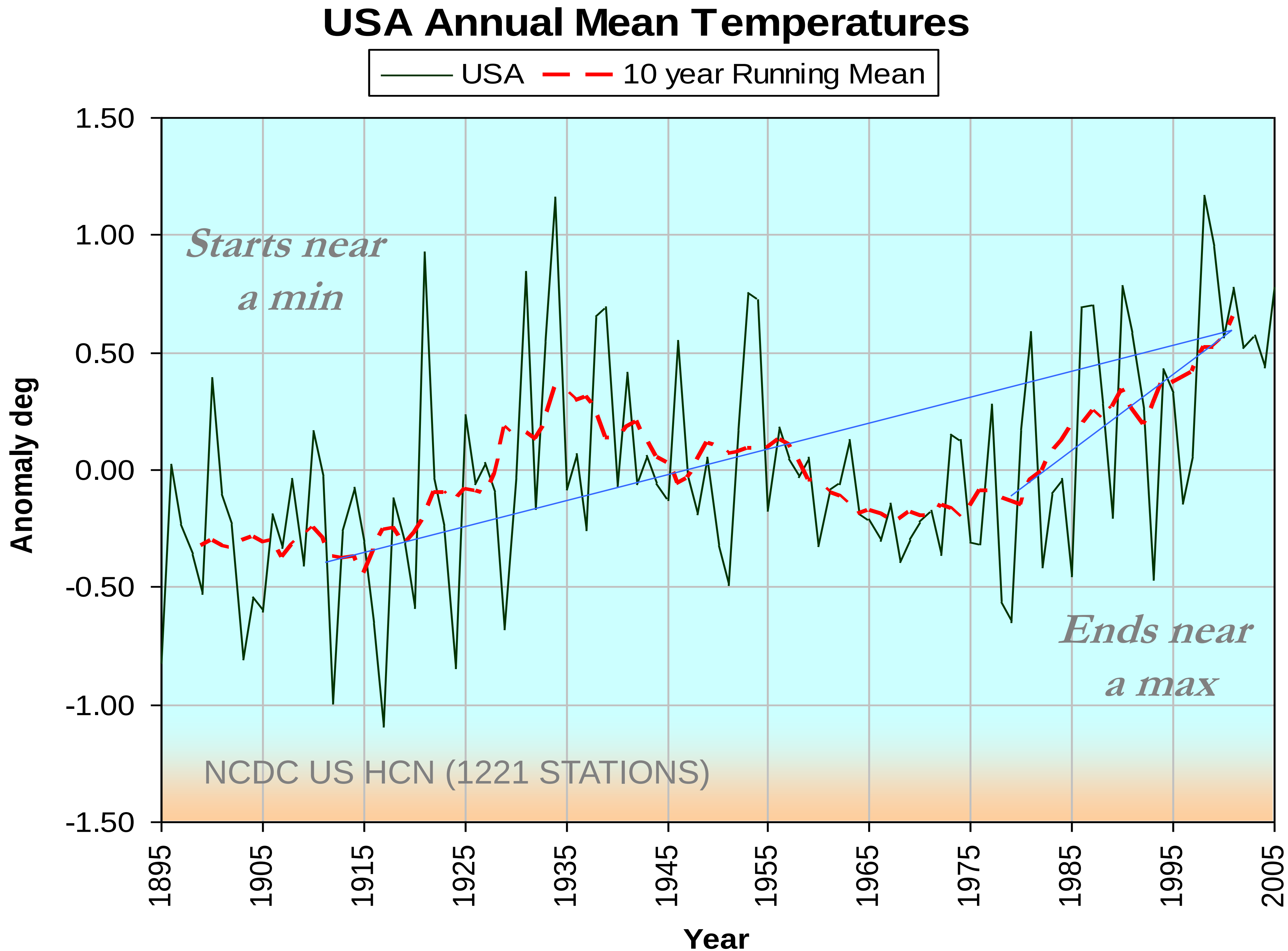


Canada

Trends in Maximum Temp. 1950-1998	Trends in Minimum Temp. 1950-1998



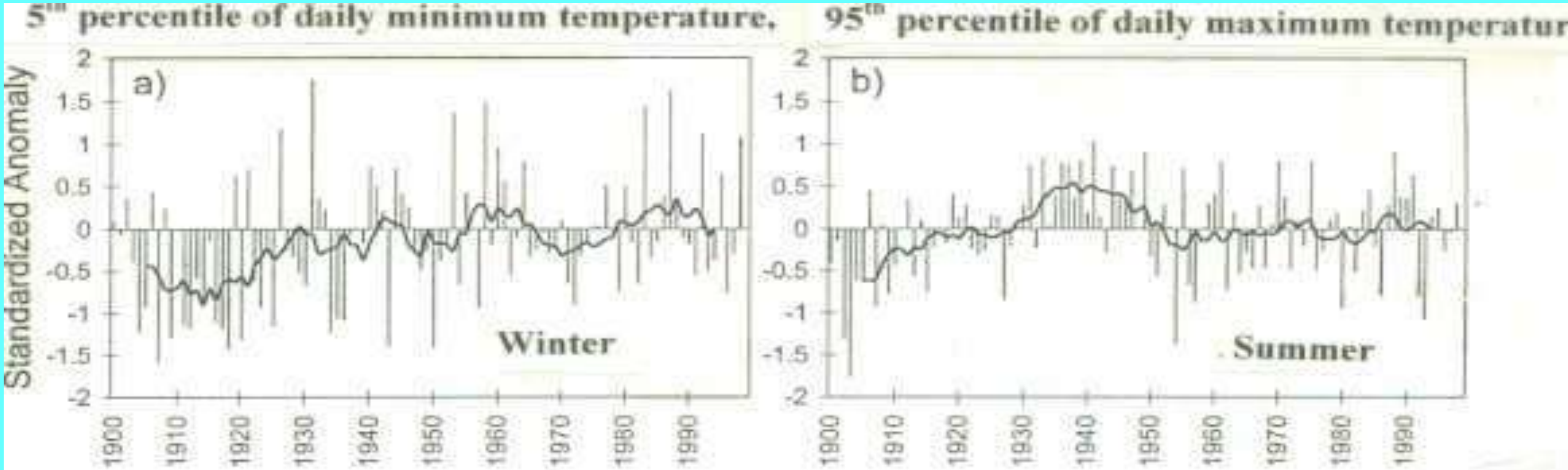
Monthly mean temperature change in Alberta, 1938-1995



USA Annual Mean Temperatures
USA
10 year Running Mean
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
Anomaly deg
Starts near a min
Ends near a max
NCDC US HCN (1221 STATIONS)
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
Year

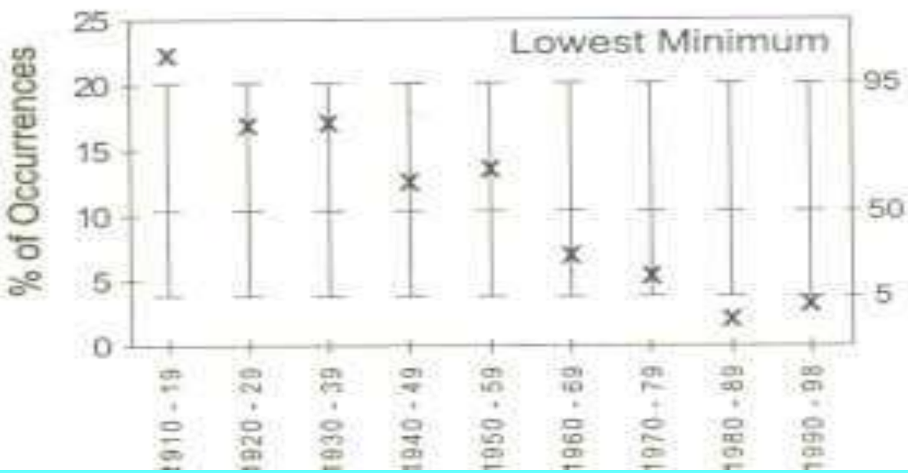
Phenomenon	*Likelihood that trend occurred in late 20th century (typically post 1960)*	*Likelihood that observed trend is due to human influence*	*Confidence[a] in trend predicted for 21st century*
Cool days / cool nights / frosts: decrease over mid- and high-latitude land areas	Very likely	Likely	High
Warm days / warm nights: increase over mid- and high-latitude land areas	Very likely	Likely (warm nights)	High
Warm spells / heat waves: increase	Likely	*More likely than not*	High
Proportion of heavy precipitation events: increase over many areas	Likely	*More likely than not*	High (but a few areas with projected decreases in absolute number of heavy events)
Droughts: increase over low-latitudes (and mid-latitudes in summer)	Likely	More likely than not	Moderate – mid-latitude continental interiors in summer (but sensitive to model land-surface formulation)
Tropical cyclones: increase in intensity	More likely than not since 1970	*More likely than not (but with low confidence)*	Moderate (few high-resolution models)
Mid- and high-latitude cyclones: increase in most intense storms; storm tracks move polewards	More likely than not	*Not assessed*	Moderate (intensity not explicitly analysed for all models)
High sea level events: increase (excludes tsunamis)	More likely than not	*Not assessed*	Moderate (most mid-latitude oceans)

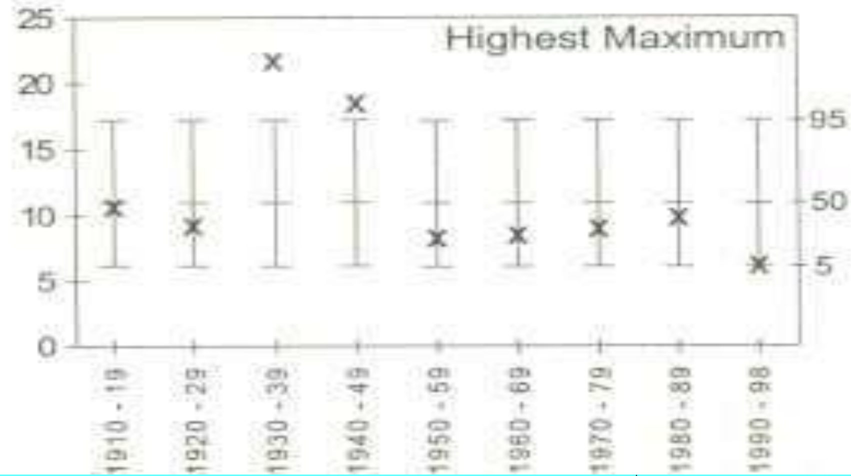
IPCC 2007 Table of Extreme Weather Events



The highest maximum in summer for each decade

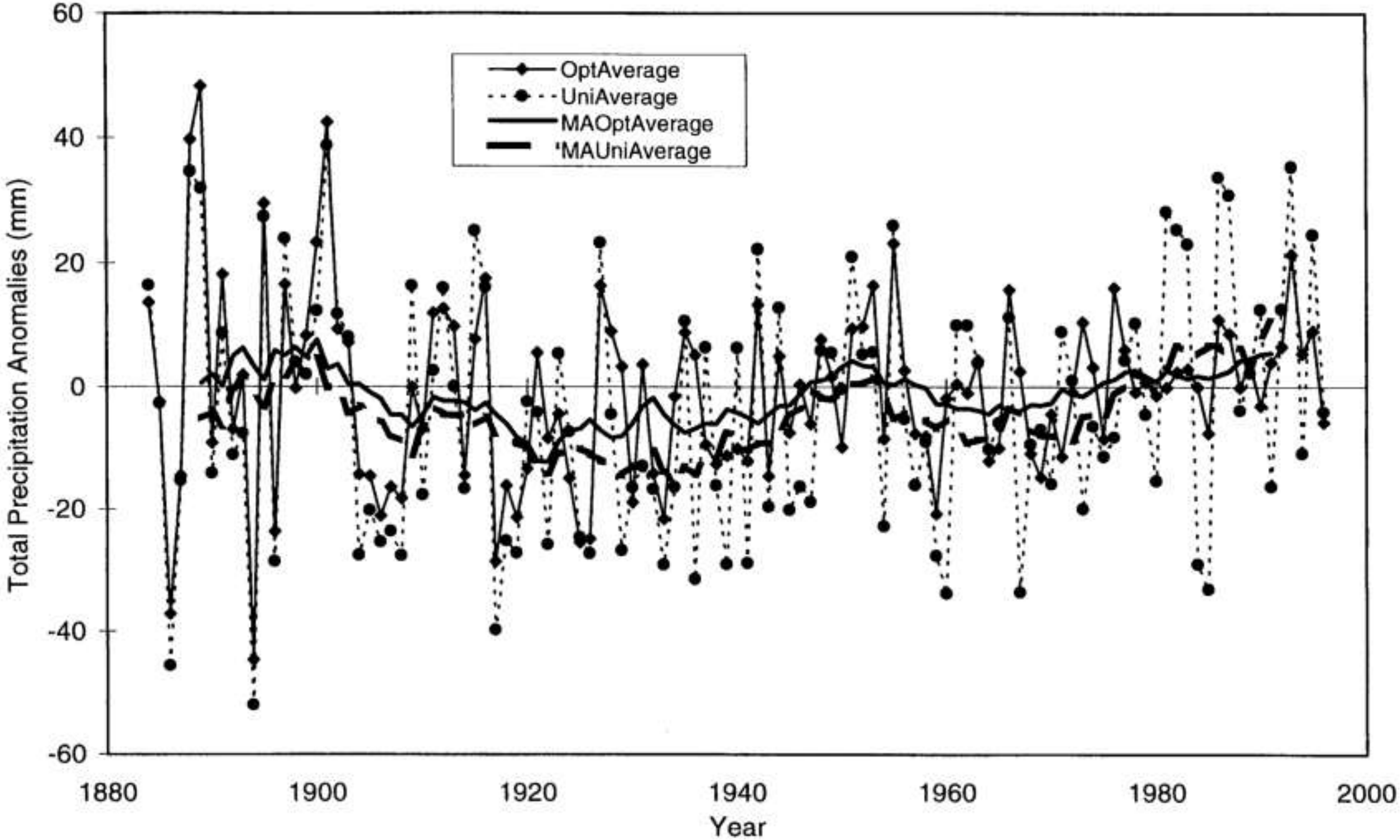
The lowest minimum in Winter for each decade





Each decade's highest maximum temperature

Each decade's lowest minimum temperature



July Precipitation Anomalies for Alberta

Decadal mean maximum Jun - Aug temperature values

at selected locations on the prairies

		Past decades			Recent decades	
Province	**Location**	**1910-1919**	**1920-1929**	**1930-1939**	**1980-1989**	**1990-1999**
Alberta	Calgary	22.0	22.4	23.2	22.1	21.4
	Fort McMurray	21.5	21.9	23.0	22.3	22.5
	Lethbridge	23.9	23.9	24.6	24.3	23.7
	Medicine Hat	26.0	26.1	26.7	26.1	25.3
Sasktchewan	Estevan	24.7	25.1	27.2	26.3	24.6
	Prince Albert	22.6	23.0	23.6	23.4	22.9
	Regina	23.8	24.3	25.9	25.3	24.2
	Saskatoon	23.2	24.0	24.9	24.5	23.7
Manitoba	Brandon	24.7	24.3	25.9	25.5	24.5
	Dauphine	23.4	23.9	24.9	24.3	23.5
	The Pas	21.2	21.6	22.6	22.4	21.3
	Winnipeg	24.5	24.8	25.6	25.1	24.5
Average over the Prairies		**23.5**	**23.8**	**24.8**	**24.3**	**23.5**

The decades 1910 through 1940 were the hottest summer months

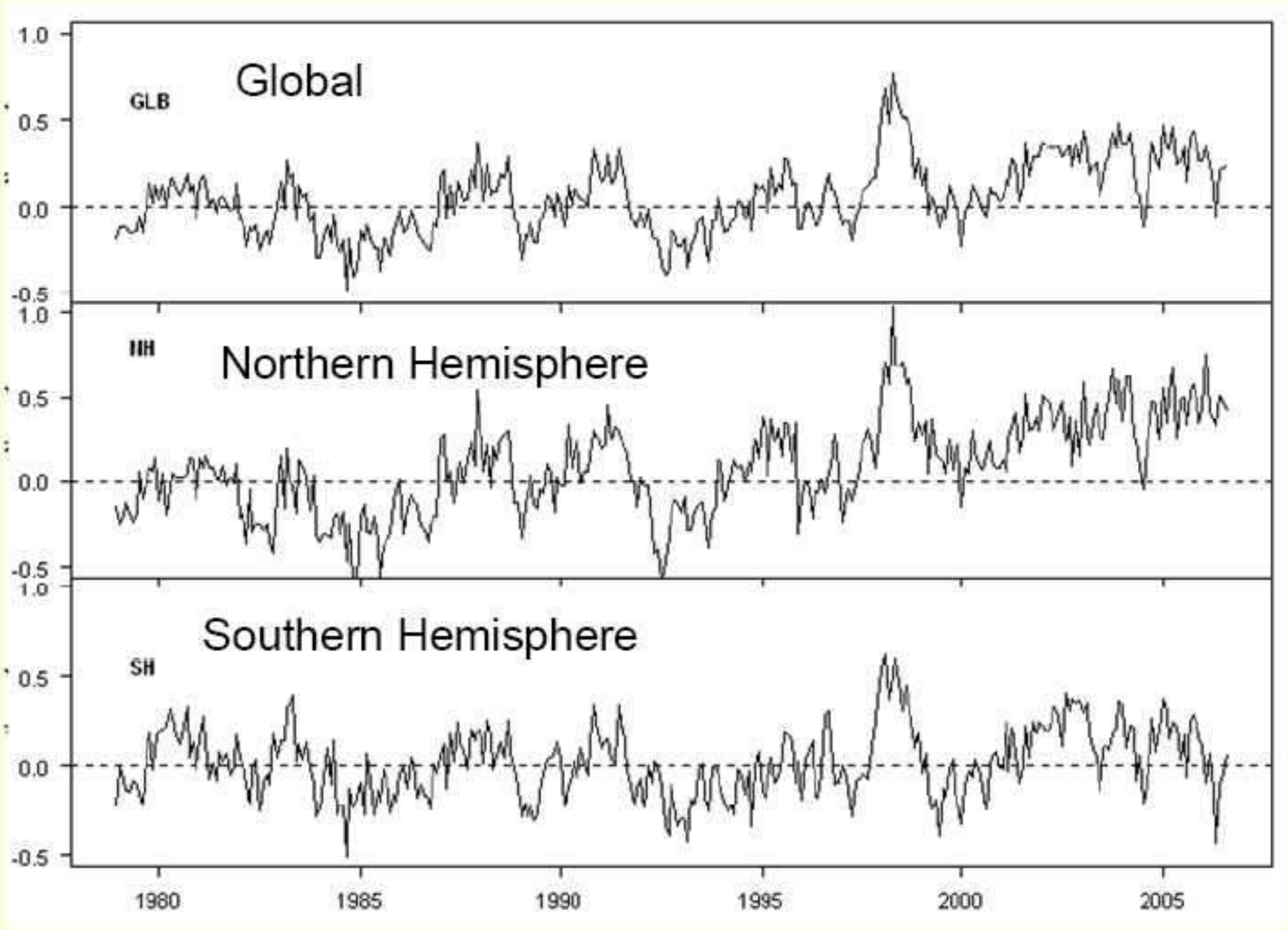
of the century. The decade 1990 - 2000 was relatively cooler

Current status on mean temperature trends

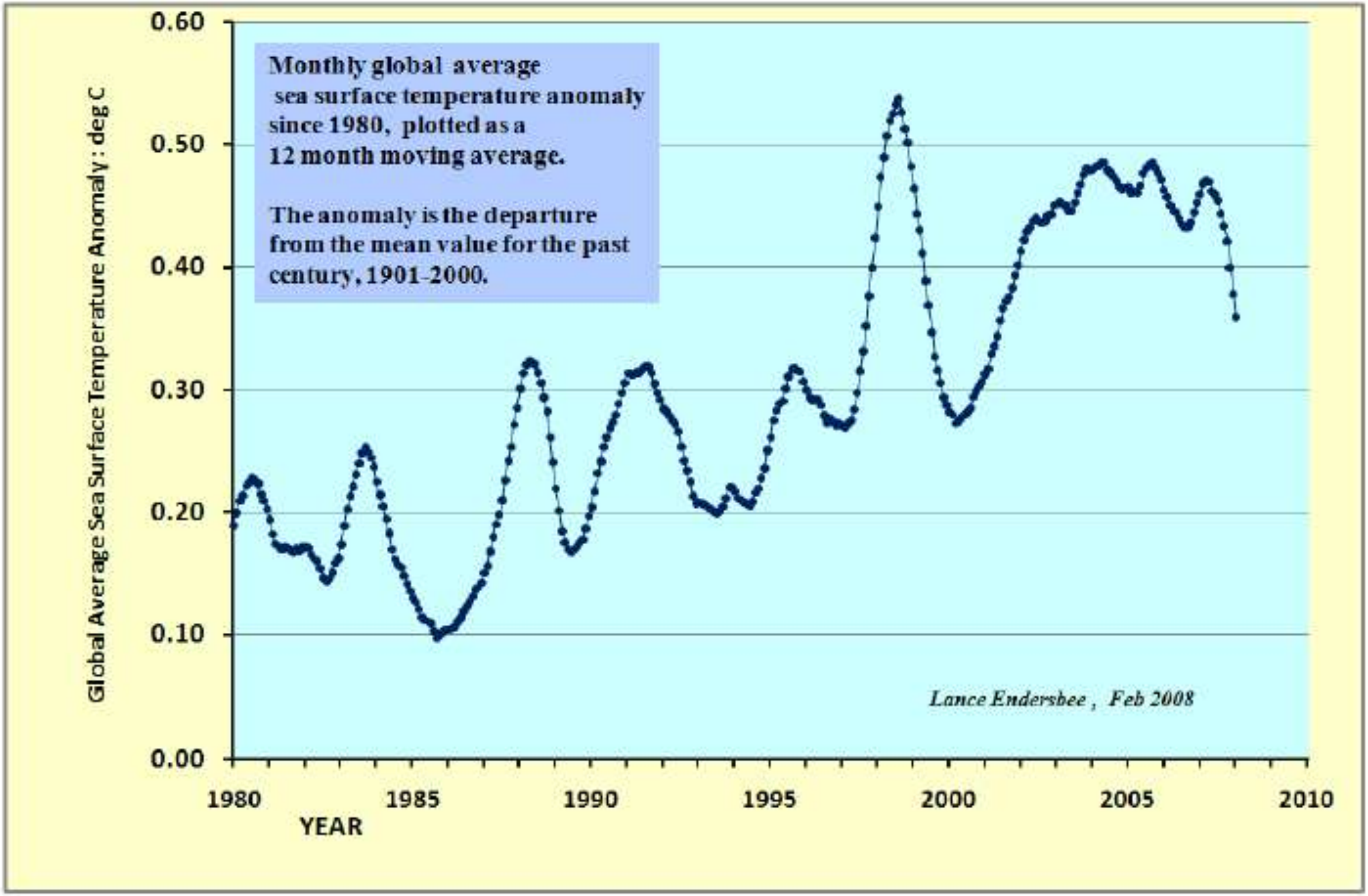
Satellite data

SST trends

The 29 years of High Quality Satellite Data



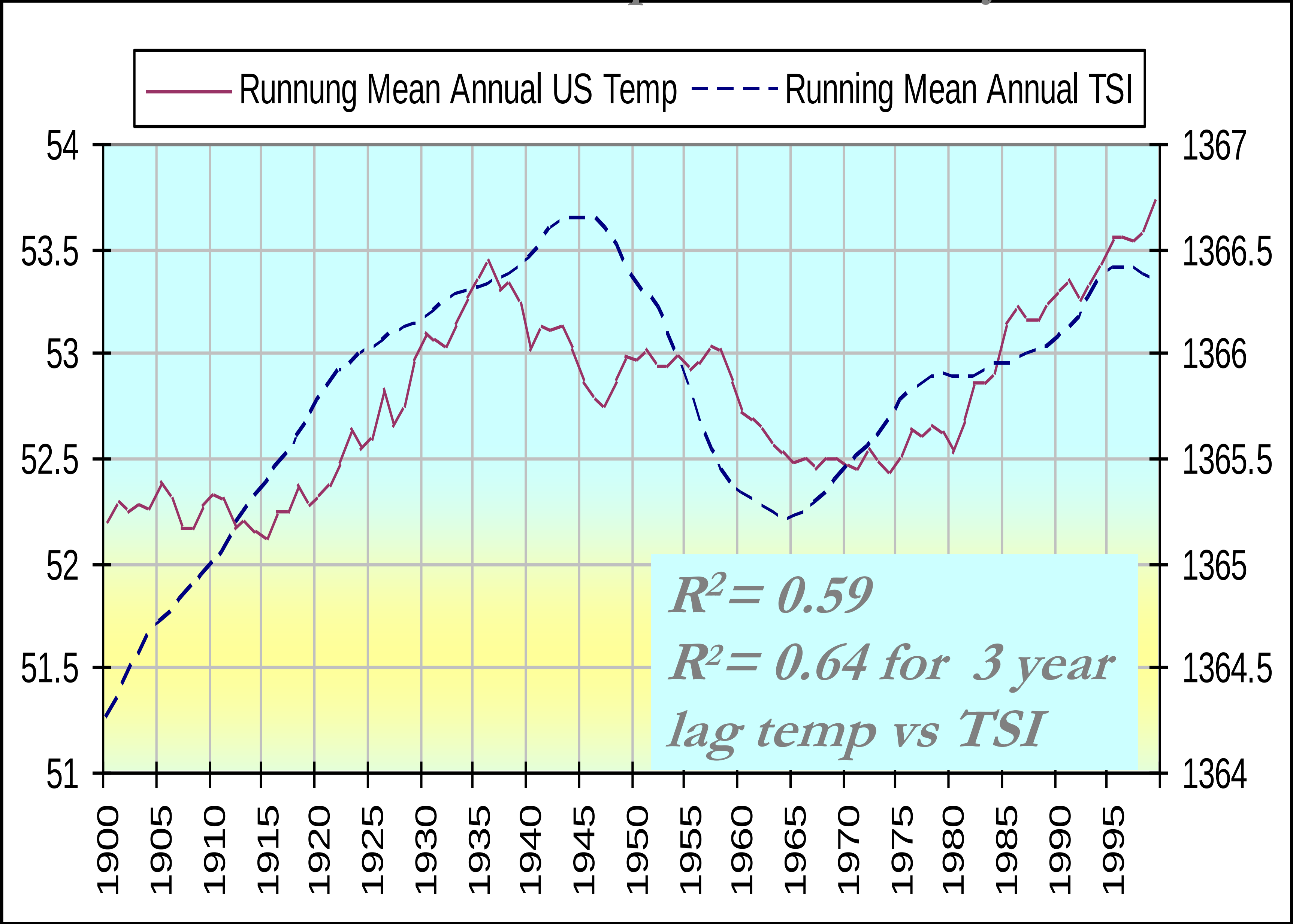
The Southern Hemisphere is the same temperature it was 28 years ago, the Northern Hemisphere has warmed slightly.



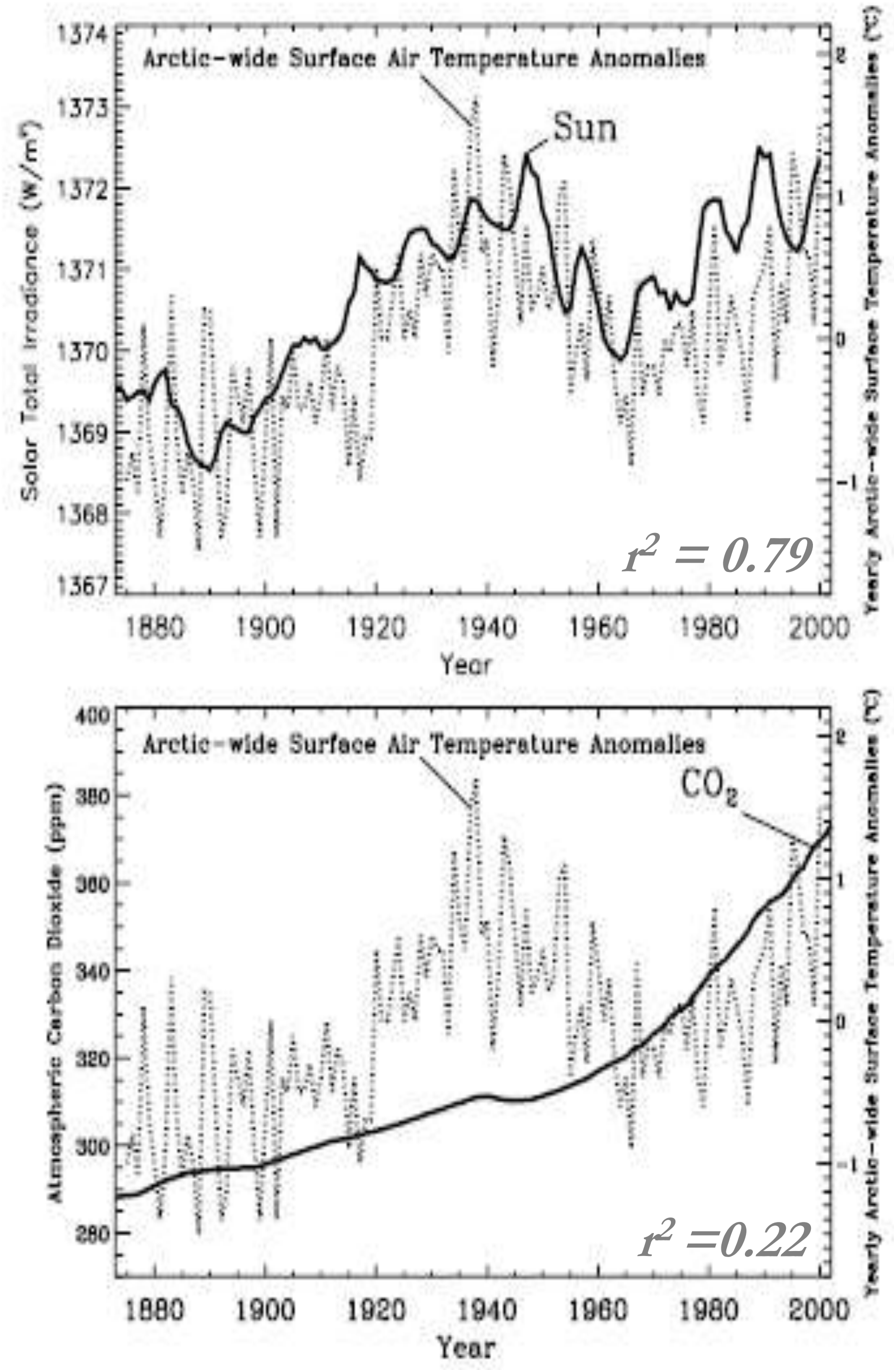
Monthly global average
sea surface temperature anomaly
since 1980, plotted as a
12 month moving average.
The anomaly is the departure
from the mean value for the past
century, 1901-2000.
Global Average Sea Surface Temperature Anomaly : deg C
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1980
1985
1990
1995
2000
2005
2010
YEAR
Lance Endersbee , Feb 2008

Drought (Climate change) & Solar Variability

NCDC Annual Mean US Temperature vs Hoyt Schatten TSI



Gleissberg Cycle

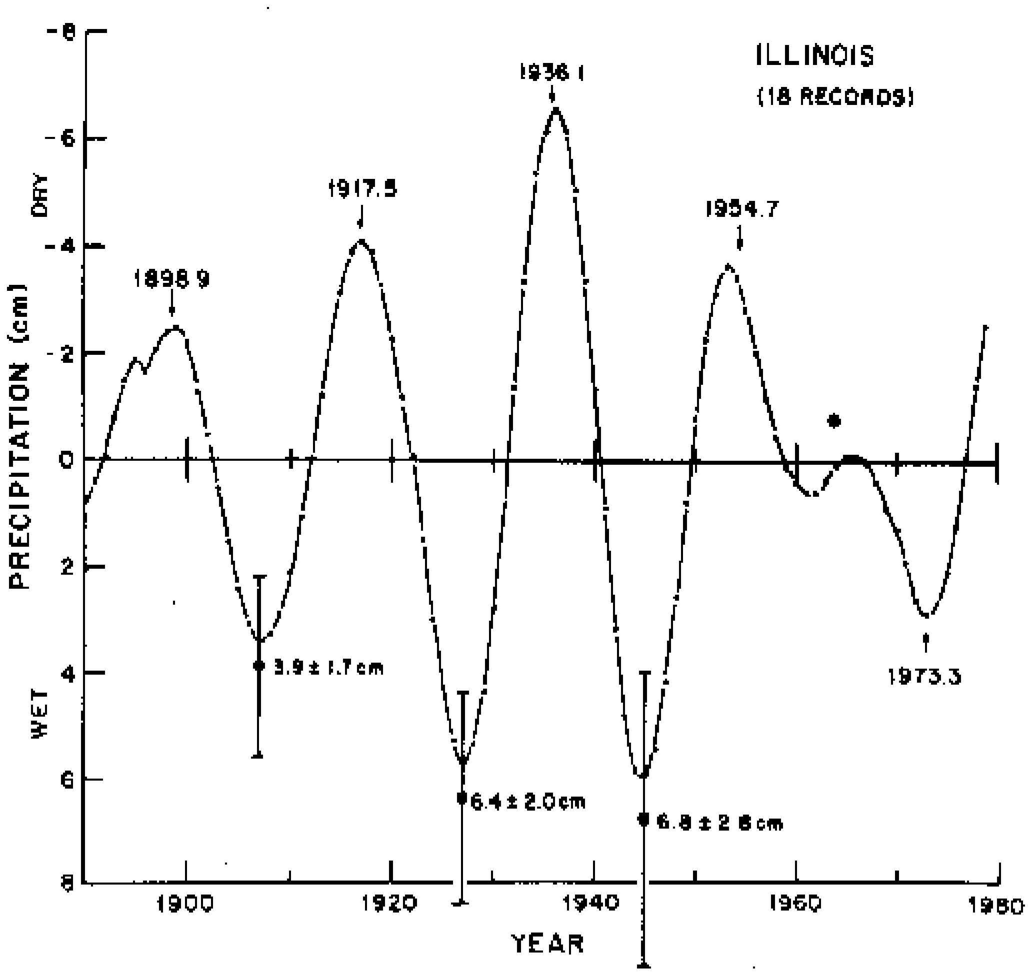


Arctic Annual Mean Temperatures vs Solar Irradiance

(Soon GRL 2005)

Fit is much better of solar irradiance with arctic temperatures (Polyokov) than with CO^2

Cyclic variation of precipitation in response to epochs of maximum tidal forcing of the atmosphere



Selected Prairie Drought/Wet Years with Sunspots

Year	Summer Weather	Sunspot No. (Annual Mean)
1917	Severe Drought	56
1933	Wet Summer	11
1936	Moderate Drought	38
1937	Severe Drought	77

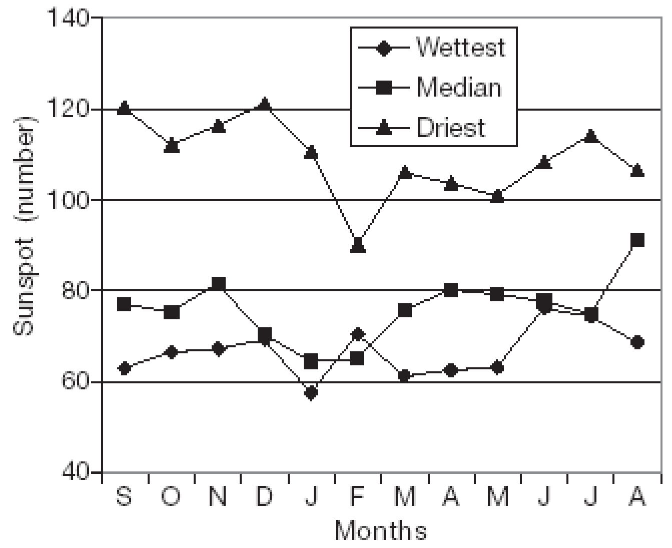
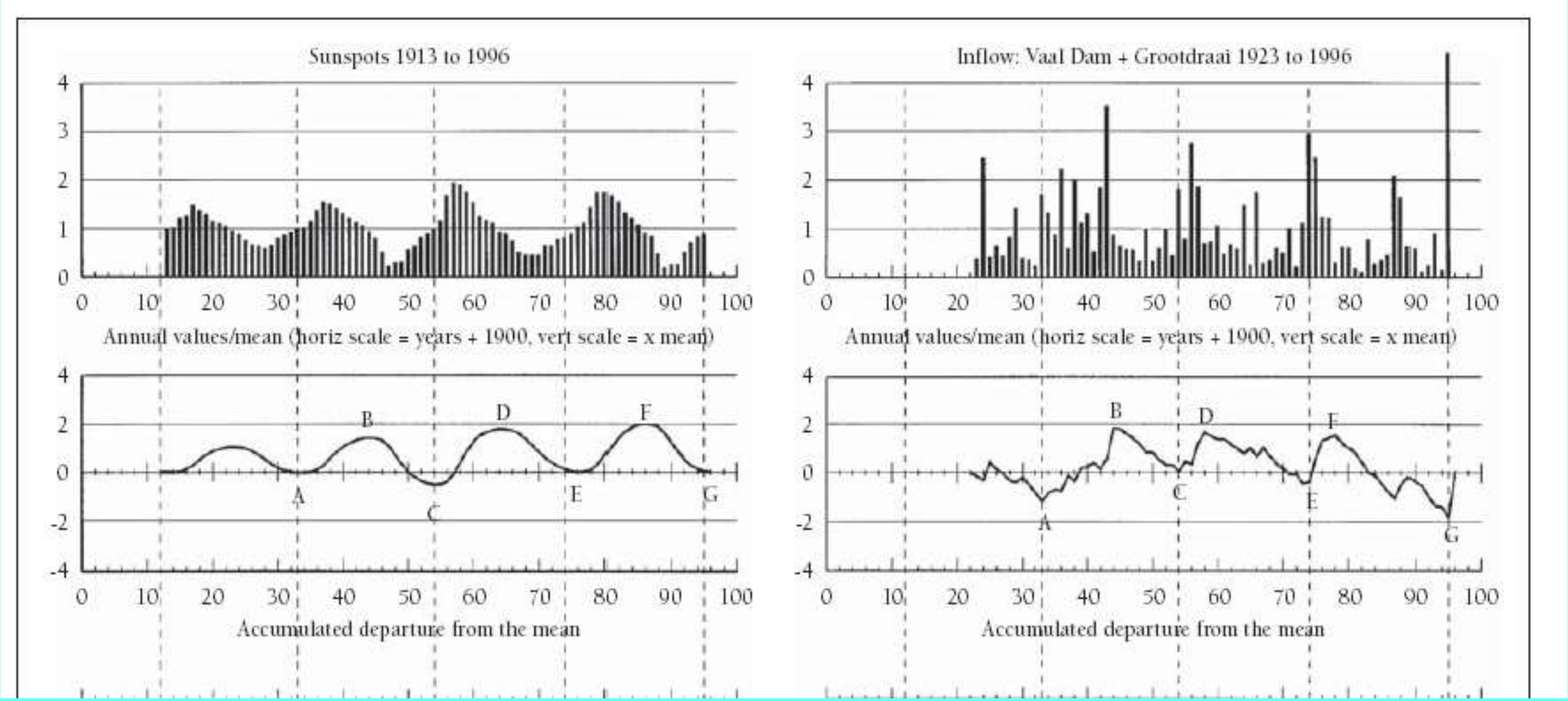


Fig. 4. Number of sunspots before, during and after the 5 driest, 5 near-median and 5 wettest May–July periods

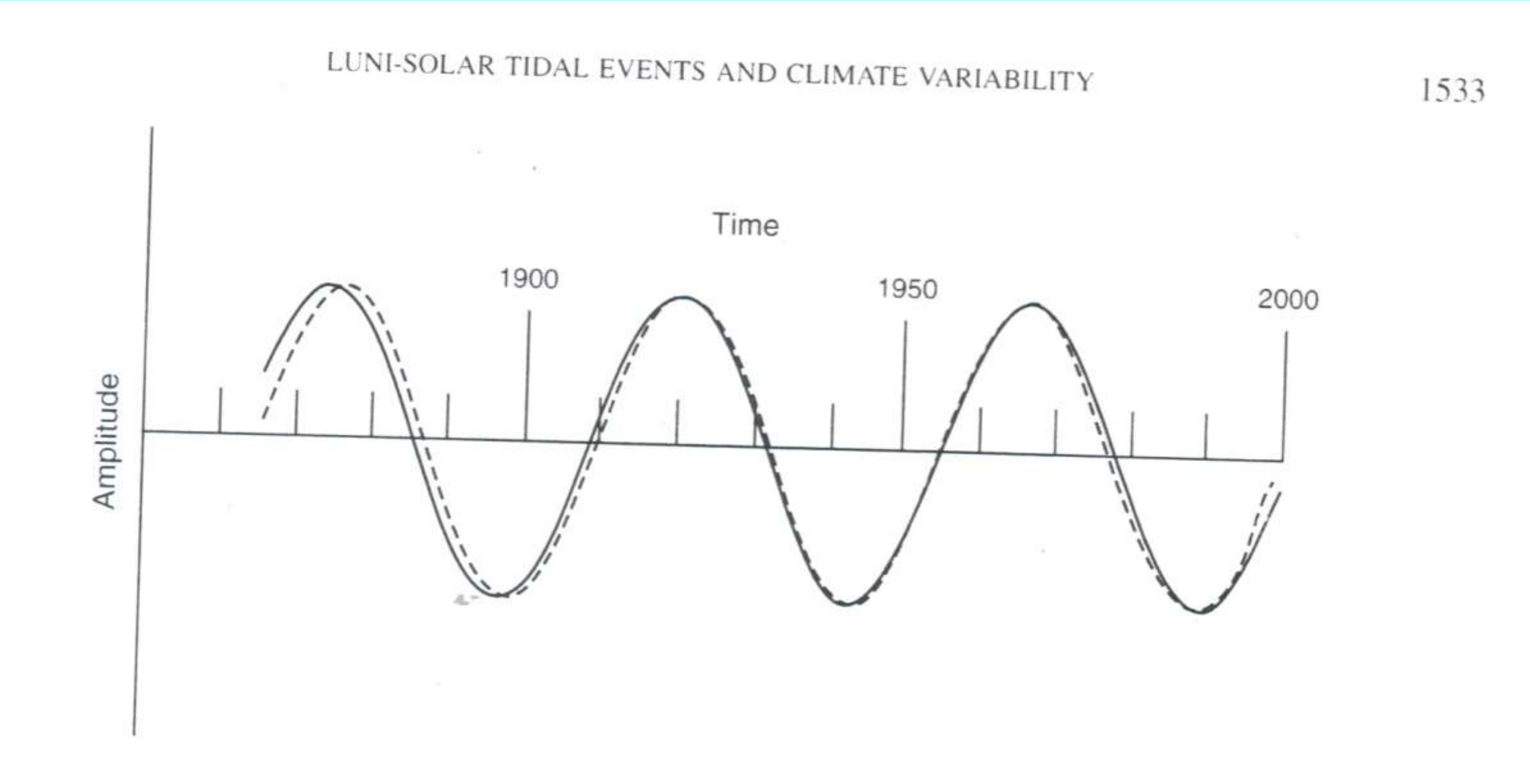
Sunspots linked to dry/wet summers on the Can Prairies (Garnett et al 2006)



Sunspots and reservoir flow departure for S Africa (Alexander 2007)

Maximum Rain and Sunspots

Rank	South African rainfall		Sunspot minima	
	Month	mm	Year	Lag (years)
1	Mar 1925	211	1923	+2
2	Jan 1974	149	1976	-2
3	Feb 1939	148	1933	+6
4	Feb 1988	145	1986	+2
5	Jan 1923	138	1923	0
6	Jan 1976	136	1976	0
7	Feb 1955	132	1954	+1
8	Jan 1958	130	1954	+4



'Comparison of 46-yr tidal (solid) and SOI (dotted) cycles. SOI cycles has maximum at 1876.25, 1921.25 and 1966.25. Major tidal events occur at 1874, 1920 and 1966. (from Treloar 2002)

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The Terrestrial Cosmic Ray Flux: Its Importance for Climate

There has been prolonged debate in the scientific community as to whether or not changes in solar activity significantly affect Earth's climate. One of the main arguments against solar influence is that because the intensity of solar radiation changes by too little (~0.1%) during the course of a solar cycle (or on longer time scales) to have a significant impact on changes in Earth's climate, an amplifying mechanism must be at work if solar influence is to be taken seriously. *Ney* [1959] proposed that the solar-modulated terrestrial cosmic ray flux (CRF) is another solar influence that must be considered as possibly affecting climate. The CRF affects the electrical conductivity of the atmosphere through ion production and is the meteorological variable subject to the largest solar cycle modulation that penetrates into the denser layers of the atmosphere.

The need to consider the effects of the CRF is even more pertinent because *Bond et al.* [2001] have shown strong correlations between variations in carbon-14 and beryllium-10 (^{10}Be) accumulation rates (CRF proxies) with ice-rafted glacial debris in the North Atlantic. The detailed variations found by Bond et al. also correlate with worldwide

peak corresponds to a single year of snow accumulation, the peaks were instrumental in dating the ice core with great precision in tree ring–like manner. The changes in dust concentration are attributed to changes in precipitation and soil moisture.

It has been found [*Ram et al.*, 1998; *Ram and Stolz*, 1999] that the dust concentration in the top 2.8 kilometers of GISP2 ice, spanning more than about 100,000 years, is strongly modulated at regular periods close to 11, 22, 80, and 200 years, all of which are well-known periods of solar activity. Typical 11-year modulations are shown in Figure 1c. Twenty-two-year Hale (magnetic) periods are generated from two adjacent 11-year periods in a very special manner (Figure 1d). For example, 11-year cycles 1 and 2, 3 and 4, 5 and 6, and 7 and 8 combine to generate 22-year cycles. Eleven-year cycles 2 and 3, 4 and 5, and 6 and 7 do not. This pattern is reminiscent of the neutron monitor records of the CRF, where alternate 11-year modulations with sharp peaks are separated by flat-topped 11-year maxima [*Jokipii*, 1991] (Figure 2). This effectively produces a 22-year-period terrestrial cosmic ray cycle. The striking similarity of

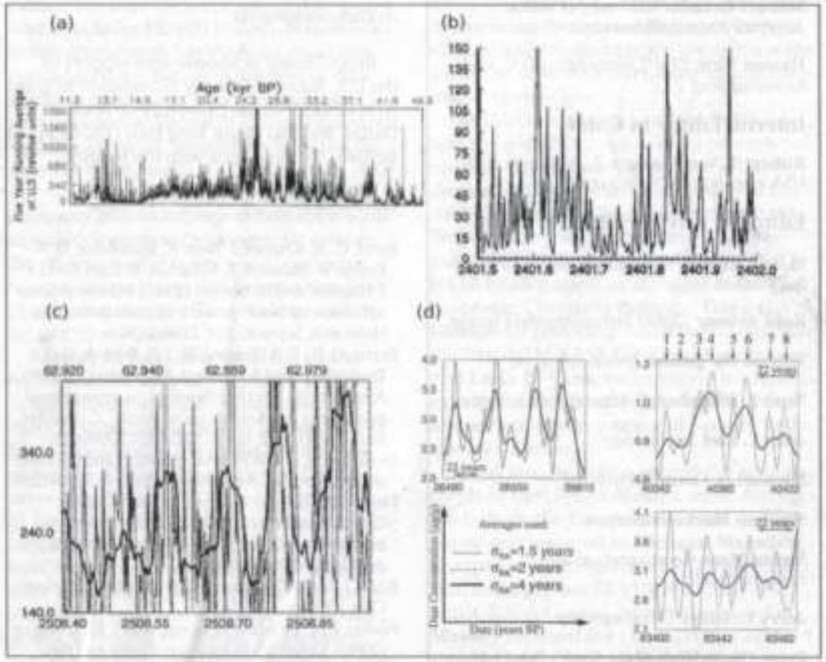

Fig. 1. (a) Dust profile of glacial ice from the Greenland Ice Sheet Project 2 (GISP2) ice core [Ram and Koenig, 1997]. LLS means laser light scattering. (b) Dust profile of a short section of GISP2 glacial ice, illustrating the sharpness of the dust peaks. (c) The rapidly oscillating thin curve is the raw dust data. The bold curve is the 4-year running average (RA) of the raw data showing the very large 11-year dust modulations. (d) The generation of 22-year cycles from two adjacent 11-year cycles [Ram and Stolz, 1999].

SUMMARY

- Droughts of varying intensity & duration have occurred on North American Prairies for many centuries. Some of the worst droughts have occurred in the 13^{th} and 16^{th} centuries.
- In the 20^{th} century, severe and recurring droughts occurred during the Dust Bowl years of 1920s and 1930s. Recent droughts of the 1980s and late 1990s are comparable to Dust Bowl year droughts.
- In general, eastern Prairies have suffered less sever droughts than western Prairies.

SUMMARY (Contd.)

- Large-scale atmospheric circulation patterns, driven by SST distribution in the equatorial & central Pacific appear to be the primary drought-driving mechanism.
- Solar influence as measured by sunspot numbers and associated magnetic field and cosmic ray flux (CRF) at earth's surface level appear to be linked to the drought severity & drought cycle.

CONCLUSIONS

- Prairie droughts are primarily governed by circulation patterns induced by SST distribution in the equatorial & central Pacific.
- Solar variability is now identified as playing an important role on drought.
- Recent droughts (1987-89; 1999-2001) appear to be driven by Pacific SSTs as well as solar forcing.
- If low sunspot trend continues, Canadian Prairies could experience cooler summers over the next decade. This cooling could adversely impact grain yield.
- More research is needed to develop solar forcing mechanism on drought cycle.