Climatology and Low Frequency Variability of Extratropical Cyclone Activity

Mark Sinclair

Embry-Riddle Aeronautical University

Prescott, Arizona

Talk outline

- Review/update of the basic climatology
- Describe low-frequency variability in cyclone properties
  - How are cyclone properties modulated by ENSO, PDO, NAO
  - Are there any trends in cyclone properties?
- Underlying theme:

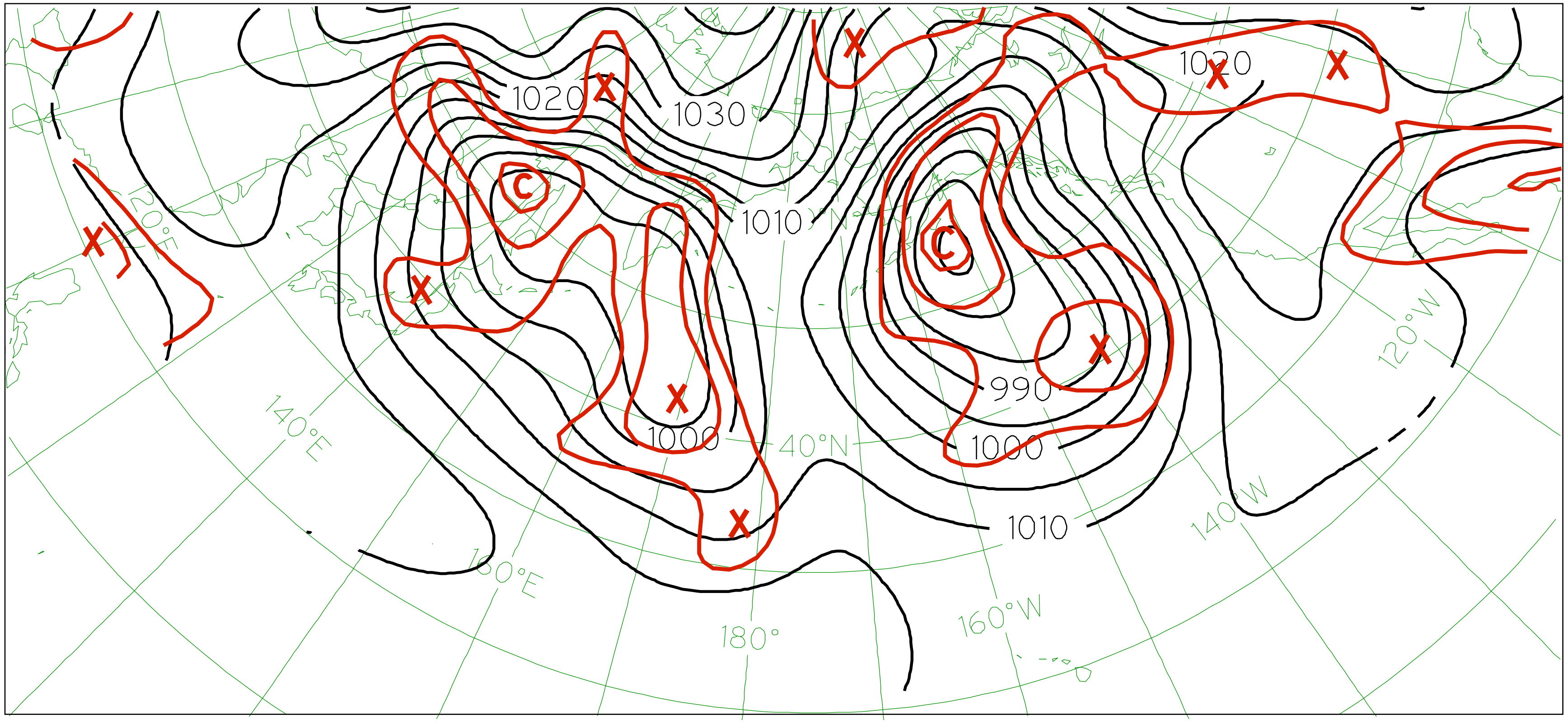
  What is the relationship between cyclones and SST?
- A work in progess …

Cyclone finding and tracking

- NCEP 2.5 x 2.5 reanalyses 1950-2006
- Based on Sinclair (1994, 1997)
- Cyclones identified as max of cyclonic geostrophic vorticity from H 1000 (or 500)
  - Identifies both open and closed centers
  - Spatial filtering to avoid latitude bias
- Tracking uses scheme similar to Murray and Simmonds (1991)
- Identification of cyclones and cyclone domain as in Sinclair (1997) (next slide)

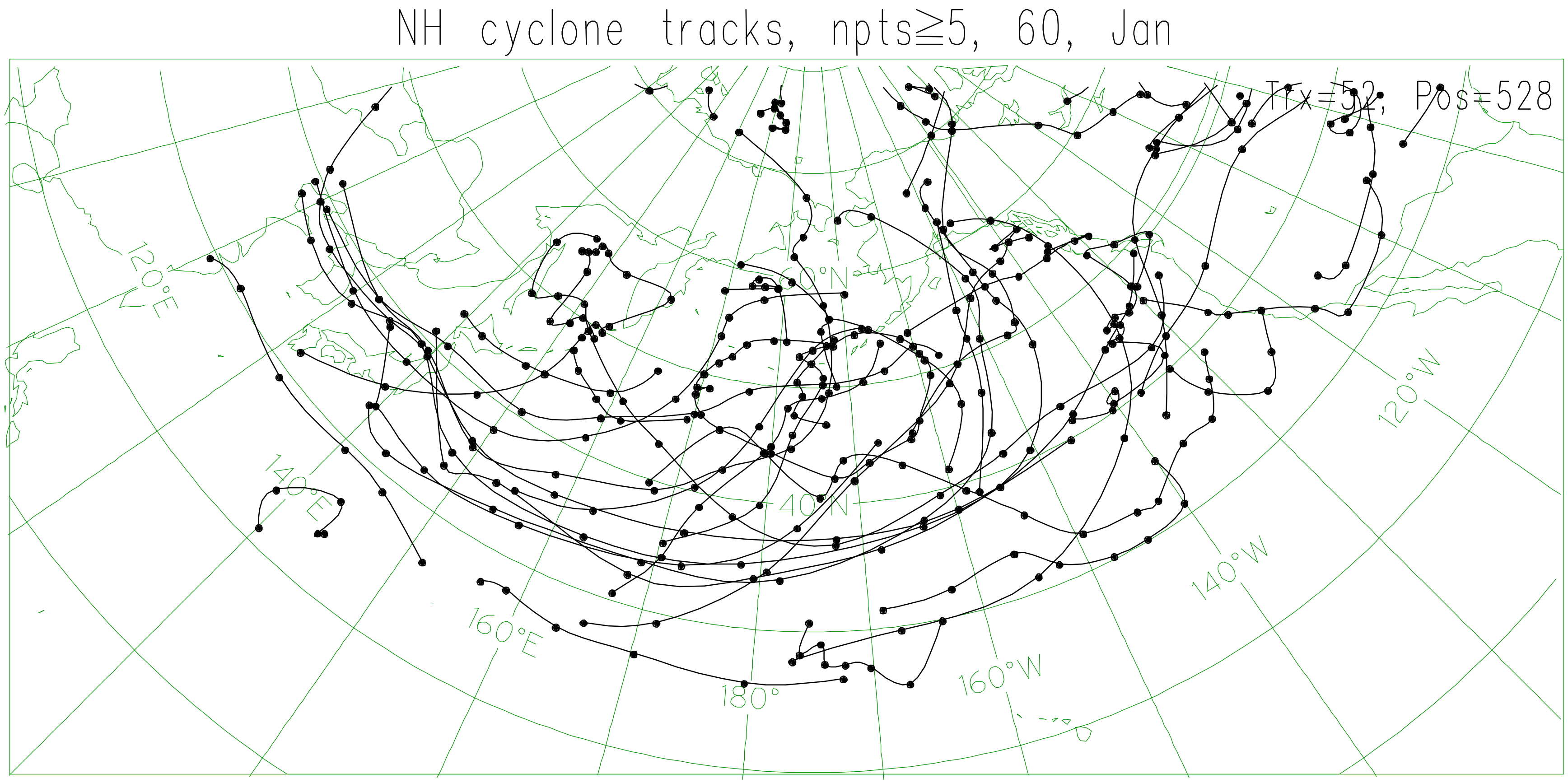
Identification of cyclone centers

Open (x) and closed © centers, for Feb 2, 1980, & MSL press
("Open" means no press min, "closed" means press min)



Both open and closed centers considered

Cyclone tracks lasting more than 2.5 days, January 1960 (dots every 12 h)

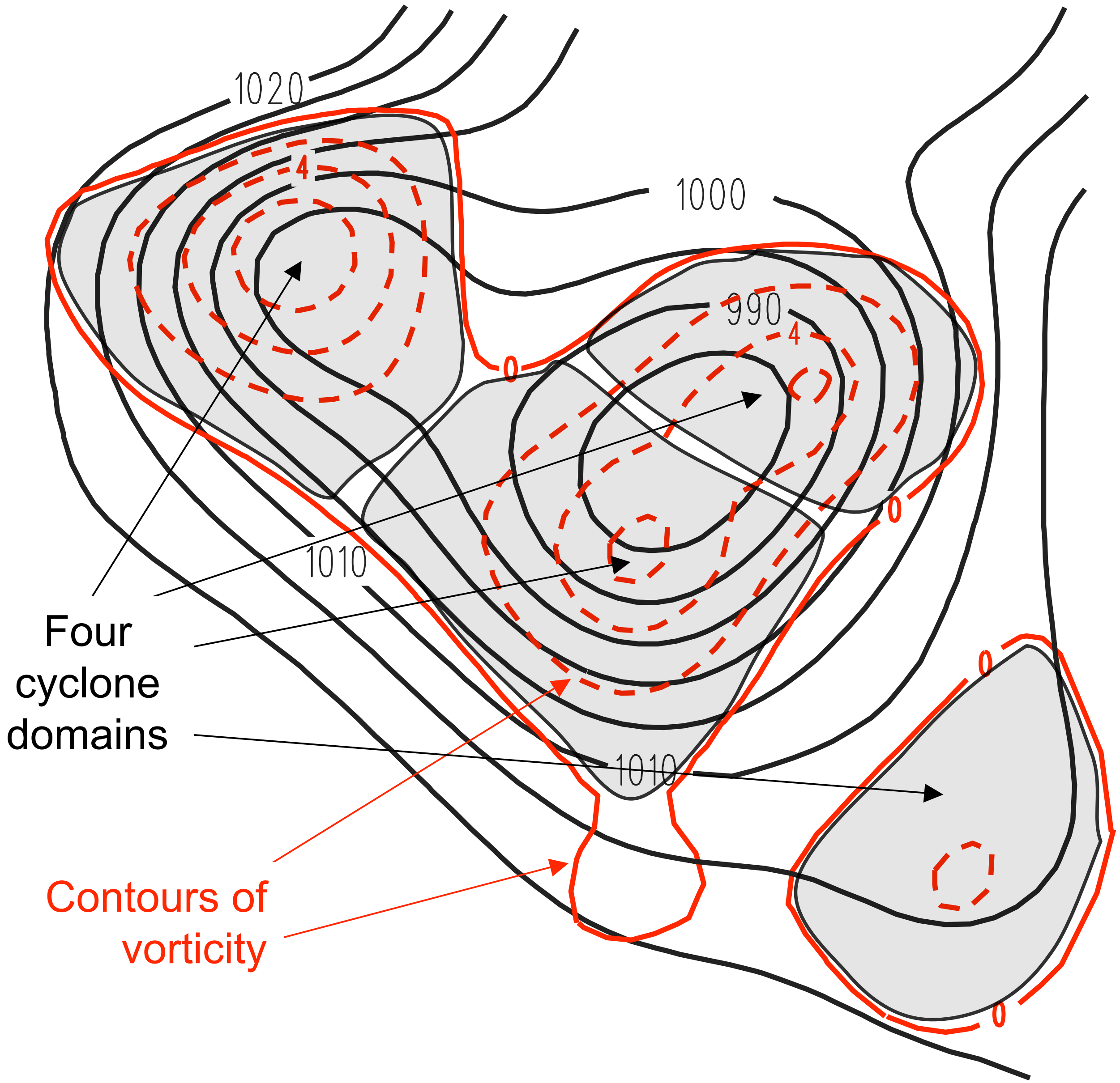


Identification of cyclone domain

Searching radially outward, domain boundary is where ζ_r=0 or $|\nabla\zeta_r|$ changes sign, whichever occurs first

$$Radius = \sqrt{\frac{Area}{\pi}}$$

$$Circ = \iint_A \zeta_G dA$$



Track statistics

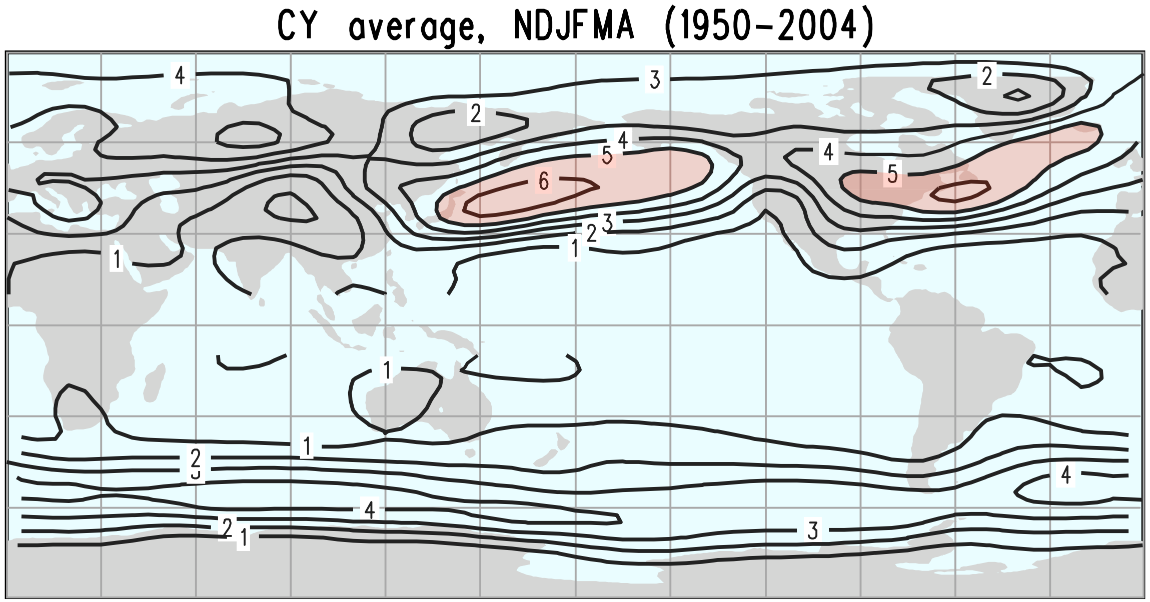
year	*m*	*d*	*h*	*lat*	*long*	*press*	*vort*	*circ*	*rad*	*wspd*	*iddff*
2006	01	01	00	37.6	72.2W	1009.14	3.15	2.71	7.44	11.49	26/17
2006	01	01	12	39.1	62.5W	1007.95	4.47	4.10	7.89	13.29	26/17
2006	01	02	00	40.8	55.3W	1005.42	6.01	5.16	7.61	14.94	25/15
2006	01	02	12	43.8	48.3W	1000.62	6.84	6.48	8.11	17.67	24/14
2006	01	03	00	47.5	43.2W	992.81	7.73	7.59	8.78	21.72	23/12
2006	01	03	12	51.0	38.4W	985.69	7.30	9.44	9.72	27.81	24/09
2006	01	04	00	51.3	32.9W	990.81	5.44	7.92	9.83	27.02	24/09
						Center press (mb)	Center vort (10^{-5} s^{-1})	Circ ($10^7 m^2 s^{-1}$)	Radius (^{o} lat)	Max wind (ms^{-1})	Cyclone motion (ms^{-1})

Results for each month from Jan 1950 to April 2006 interpolated to 5 x10 lat-long grid

Cyclone properties

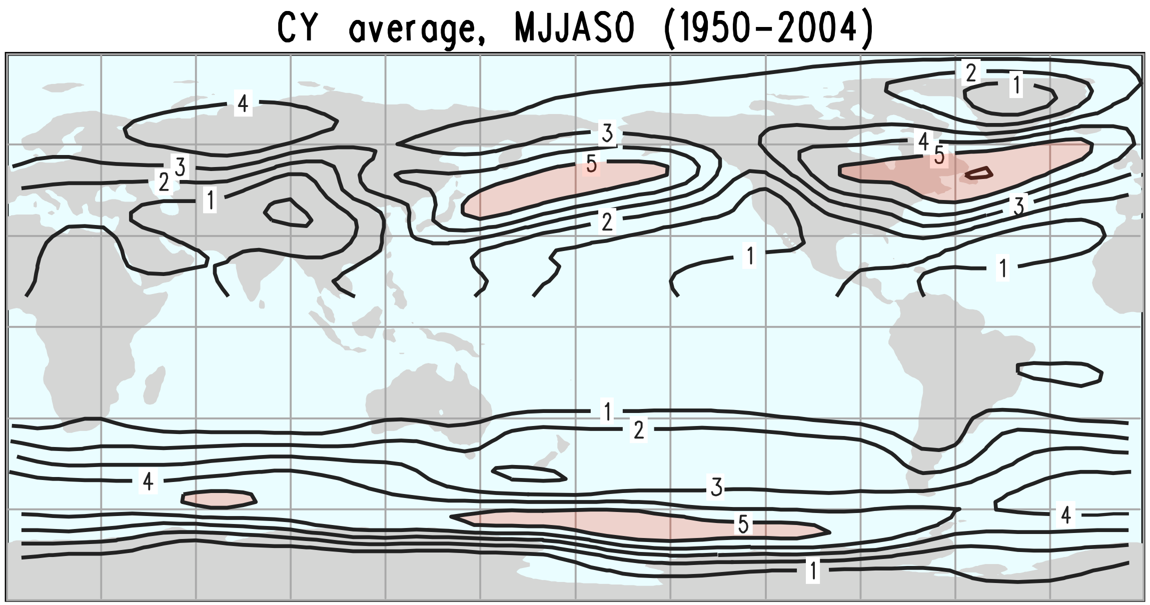
- Center pressure
- Center vorticity
- Circulation over domain
- Cyclone motion vector
- 24 h tendency of vorticity or pressure
  - cyclogenesis or cyclolysis
- Cyclone radius
- Max windspeed within cyclone domain

Average cyclone track density



Nov-Apr

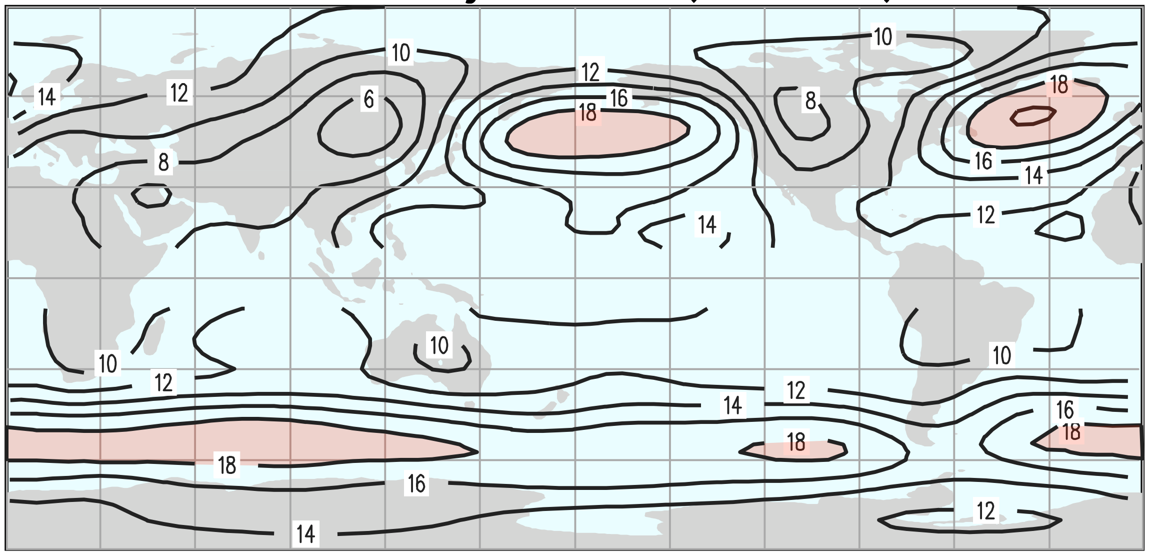
Units are no. of cyclones per 5 degree latitude circle per month



May-Oct

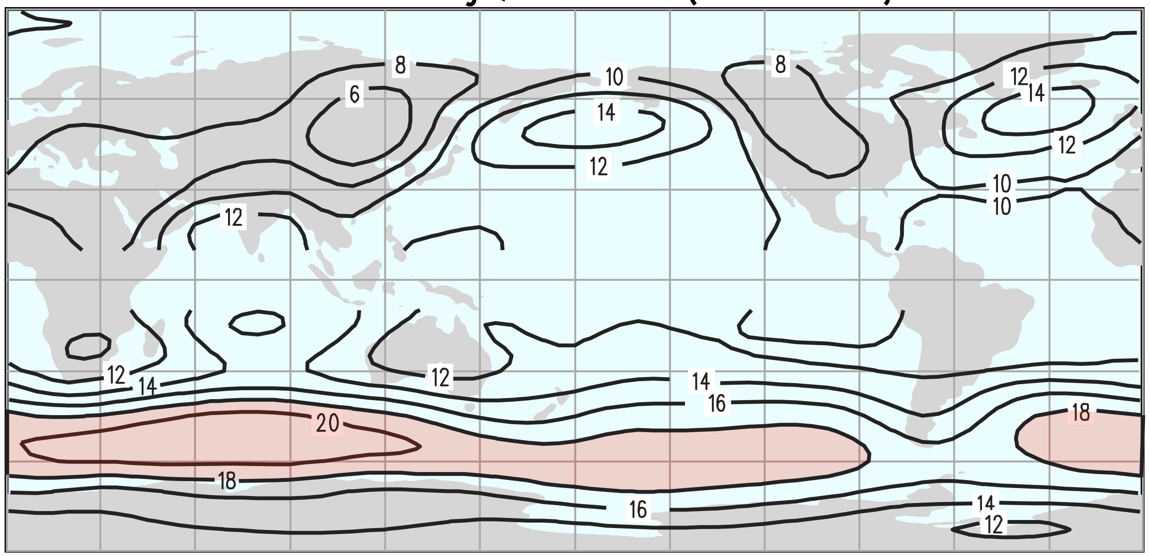
Average max cyclone wind speed (ms^{-1})

WSPD average, NDJFMA (1950-2004)



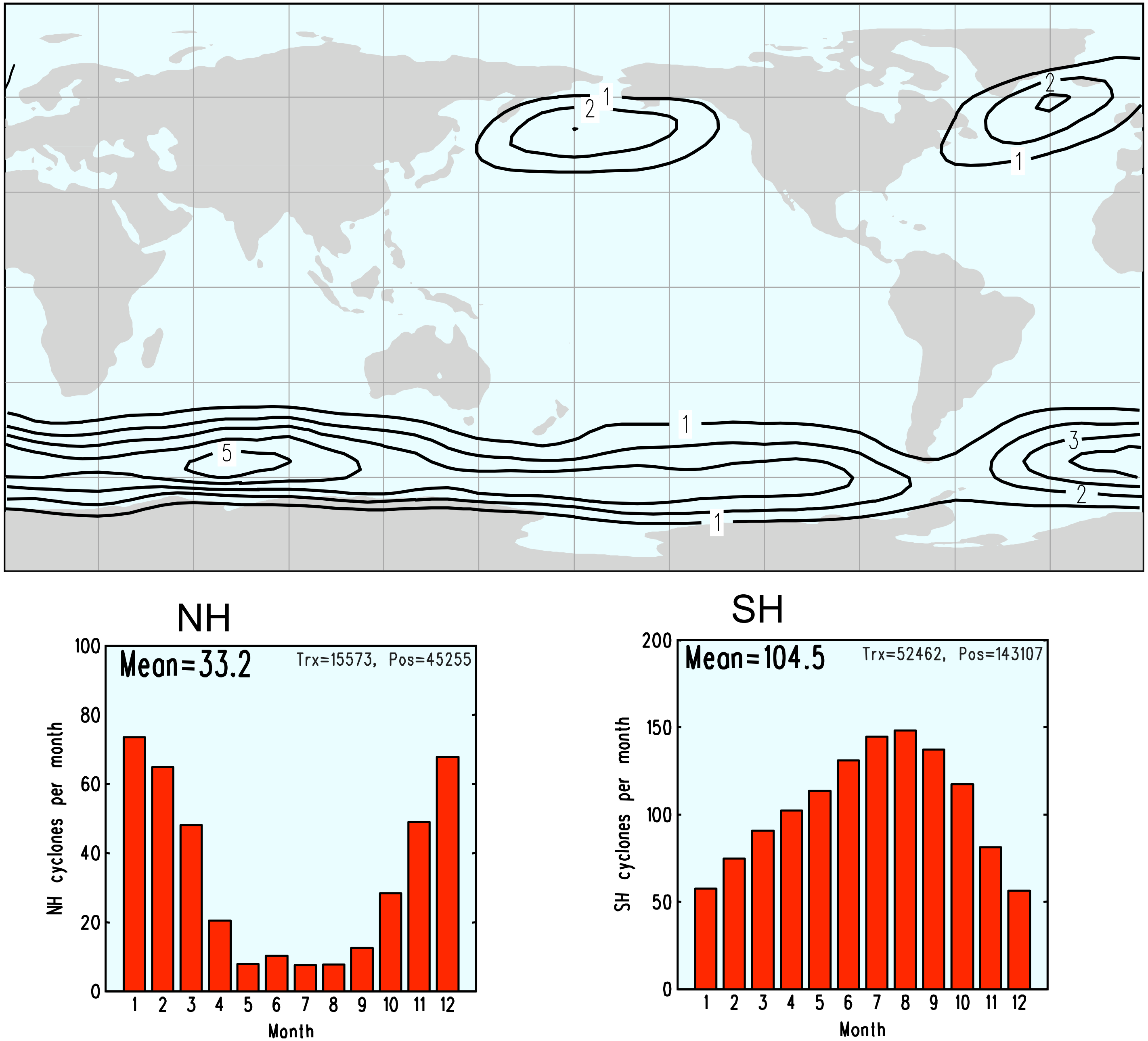
Nov-Apr

WSPD average, MJJASO (1950-2004)

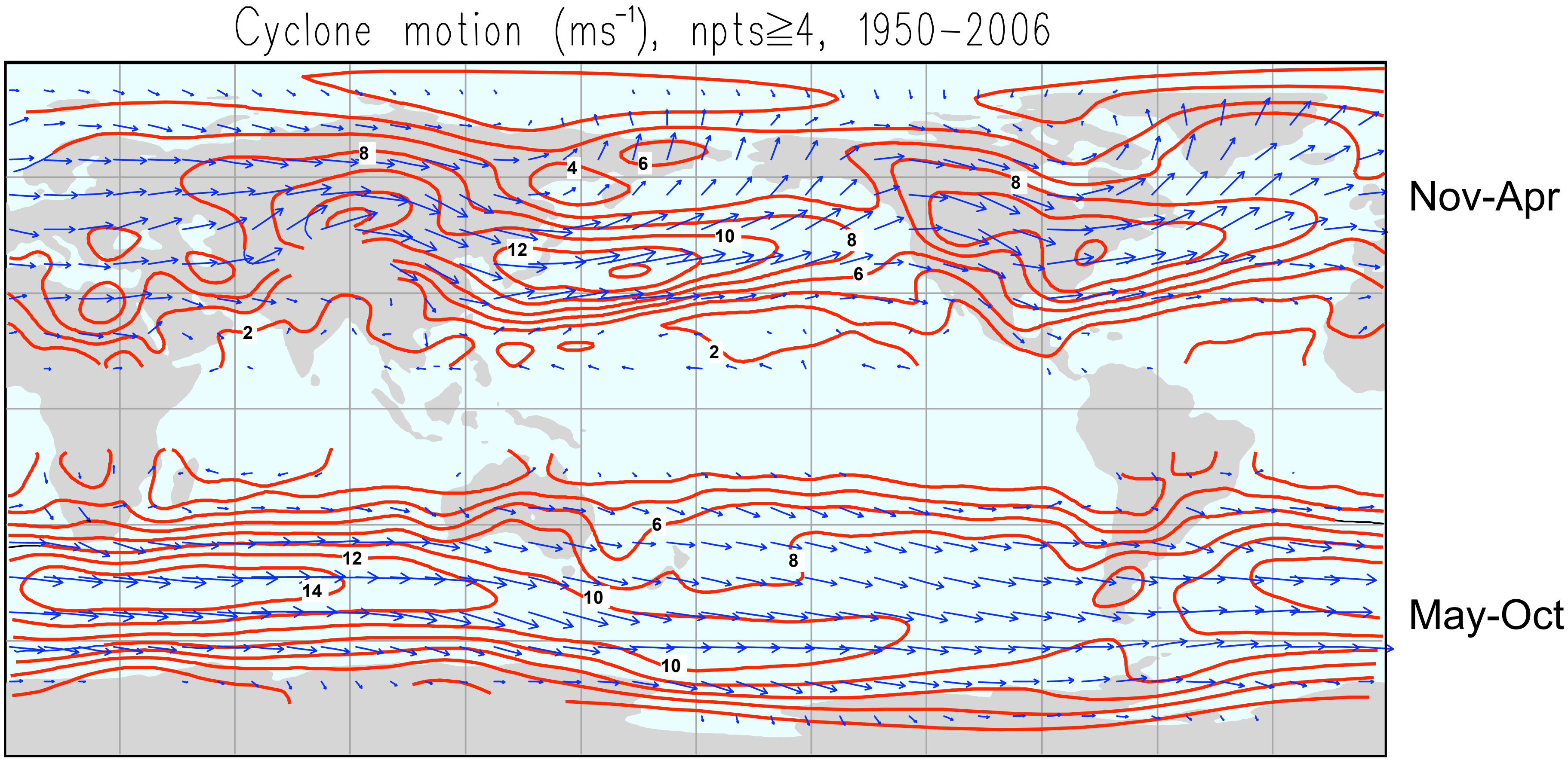


May-Oct

Strong cyclones (wind > 20 ms^{-1})



Average cyclone motion vector (ms^{-1})

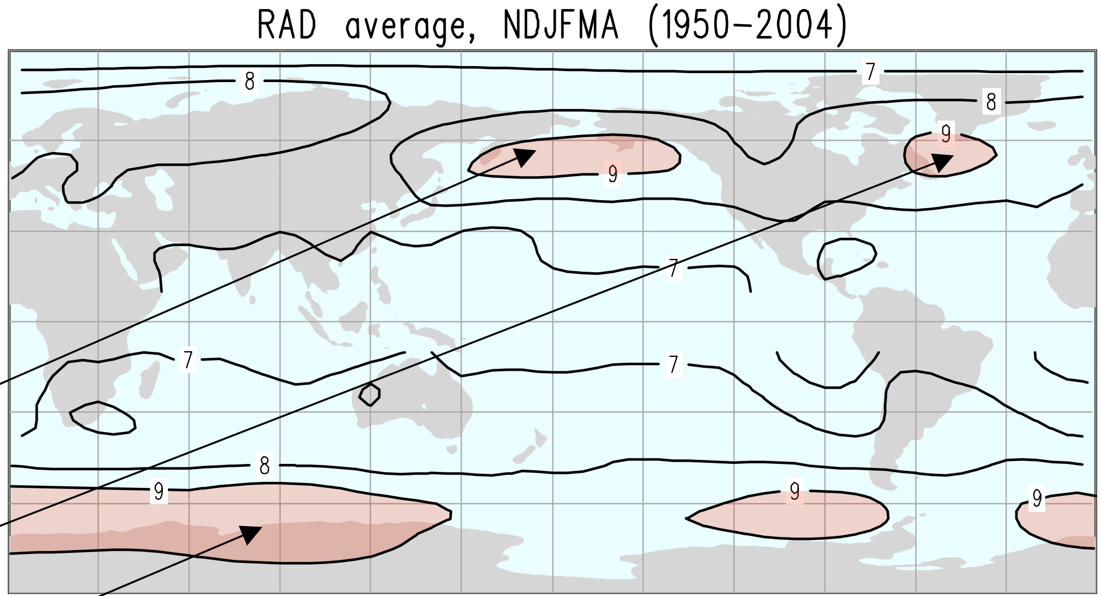


Average cyclone radius (º lat)

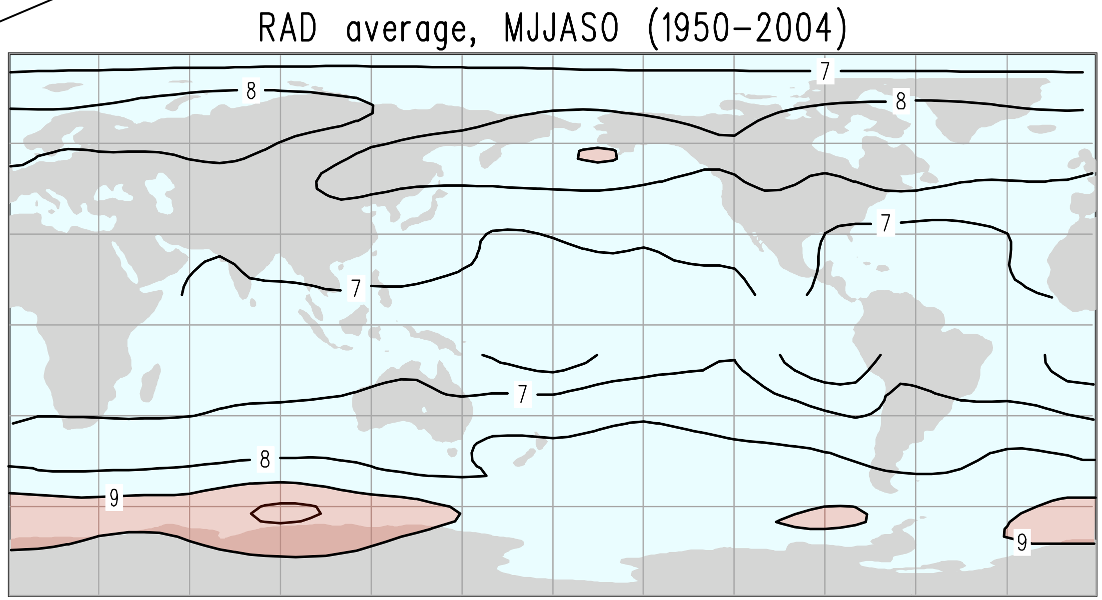
Largest radii at end of life cycle (cyclone graveyards)

Aleutian and Icelandic lows for the NH, circumpolar trough for SH

Radii smaller in tropics and in summer – increased role of latent heating

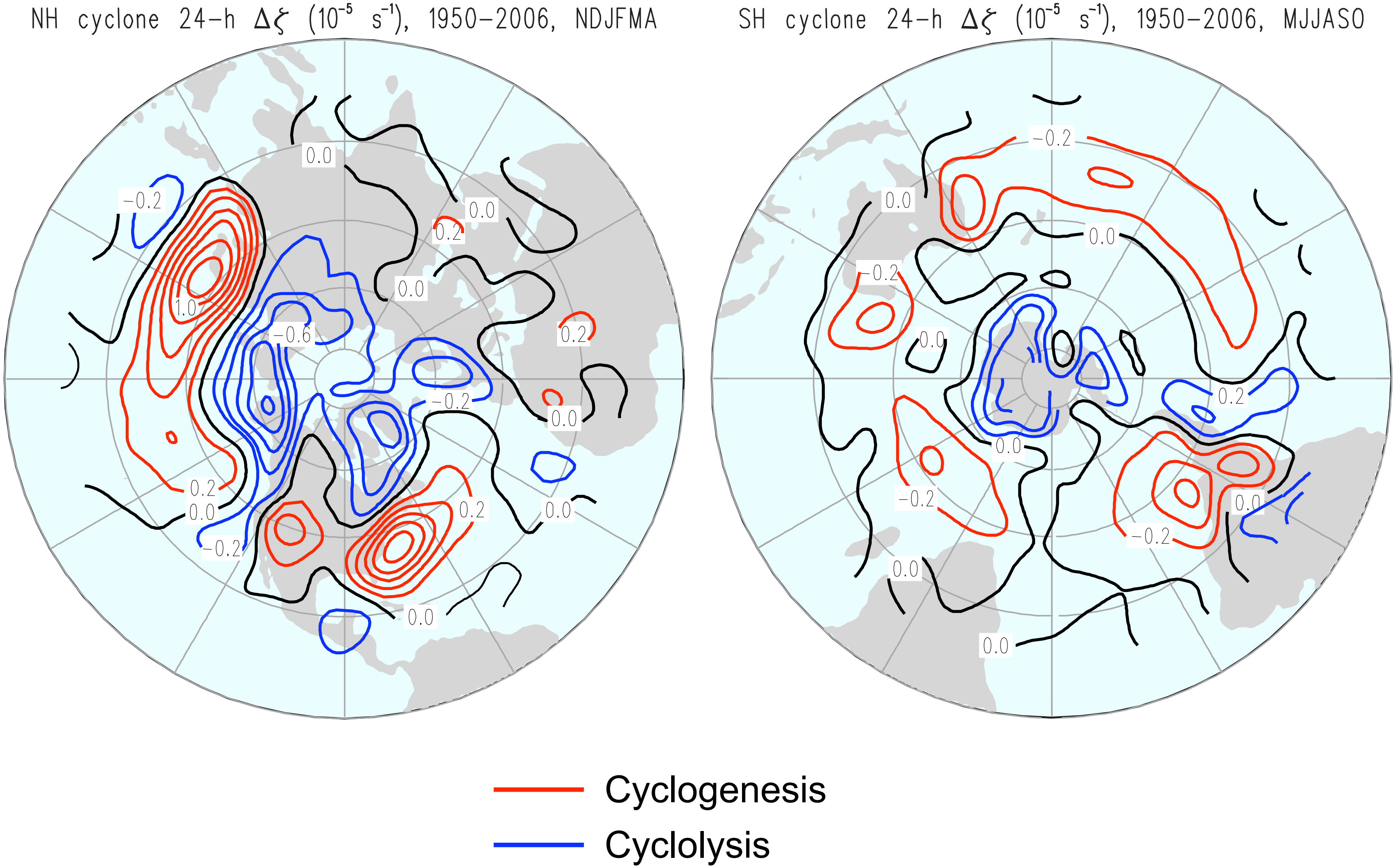


Nov-Apr

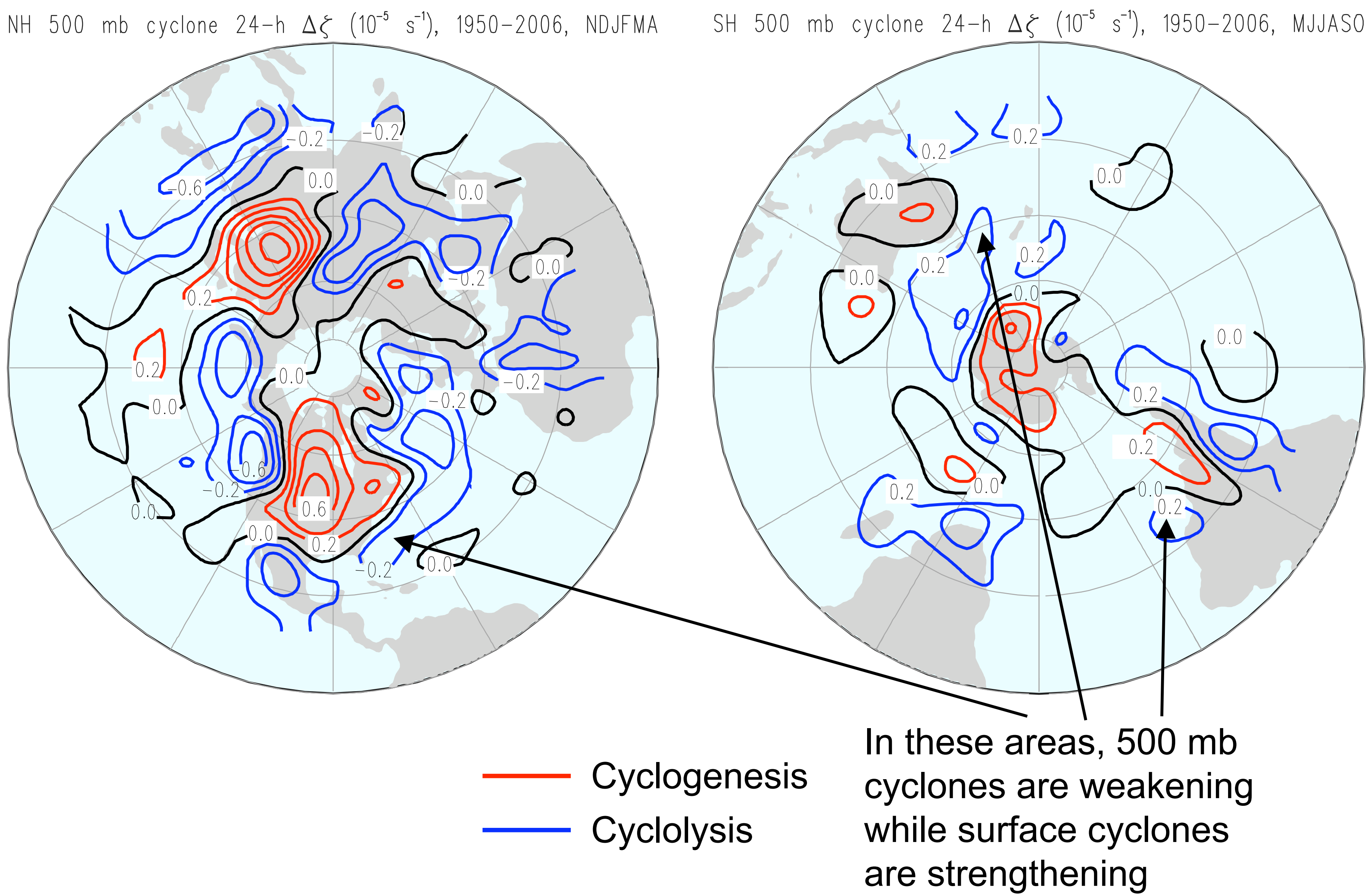


May-Oct

Average winter MSL center 24-h track $\Delta\zeta$



Average center 500 mb 24-h track $\Delta\zeta$



Development rates …

- 500 hPa development rates consistent with simple PV conservation
  - Ascent of barrier is cyclolytic
  - Descent is cyclogenetic
- MSL cyclogenesis favored …
  - Over warm currents, esp near SST gradients
  - Downstream from 500 hPa development
  - Downstream from topographic barriers (Rockies, Andes)
  - Near STJ (south Pacific, N. Africa/Caspian Sea)

Low frequency variability

- Correlations with SOI, PDO, NAO etc
- Do these cyclone responses to common indices of low frequency variability have anything in common?
- Are they in fact “responses” – cause/effect?
- What is the link between cyclones and SST?

Data

- The basic cyclone data set consists of time series of 55 years of monthly anomalies (~660 months) on coarse horizontal grid
  - Cyclone track density at MSL and 500 hPa
  - Center 24-h vorticity tendency, radius, wind speed, circulation, MSLP
- Compared with basic NCEP monthly anomalies of H 500, T 700 etc etc
- Time series of extended, reconstructed SST (ERSST v2) from NCDC

Methodology

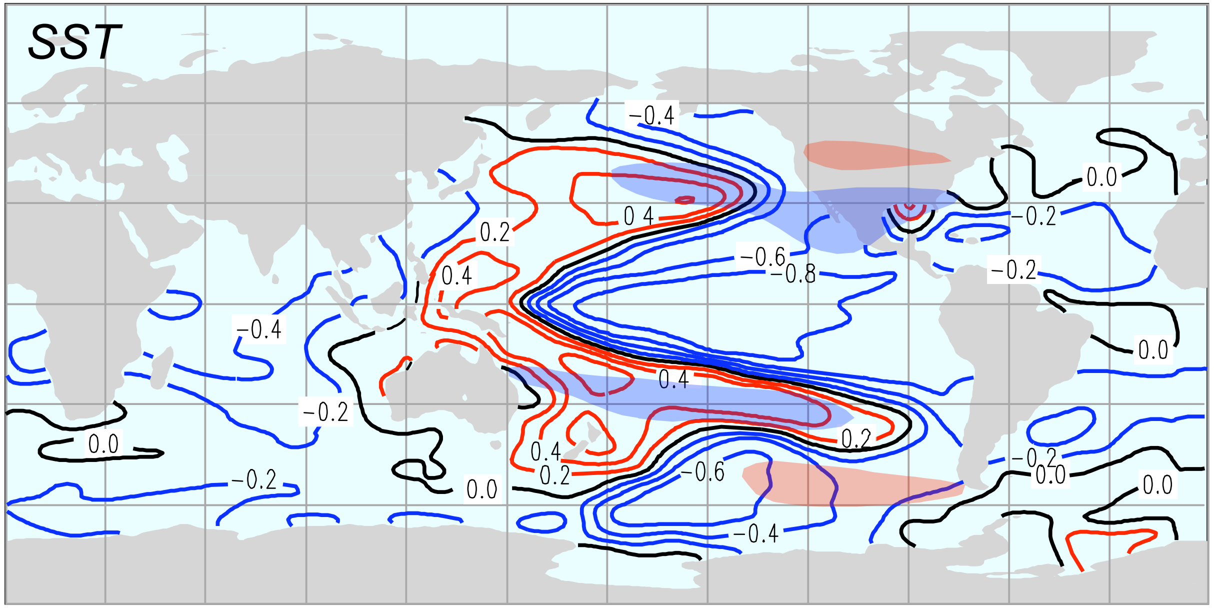
- Mostly correlation analysis between SOI, PDO, NAO monthly index values and monthly anomalies of SST (top panel) and cyclone properties (lower panel)
- Occasionally, temporal filtering is used

SOI

SST anomaly correlation

Blue = warmer during El Nino

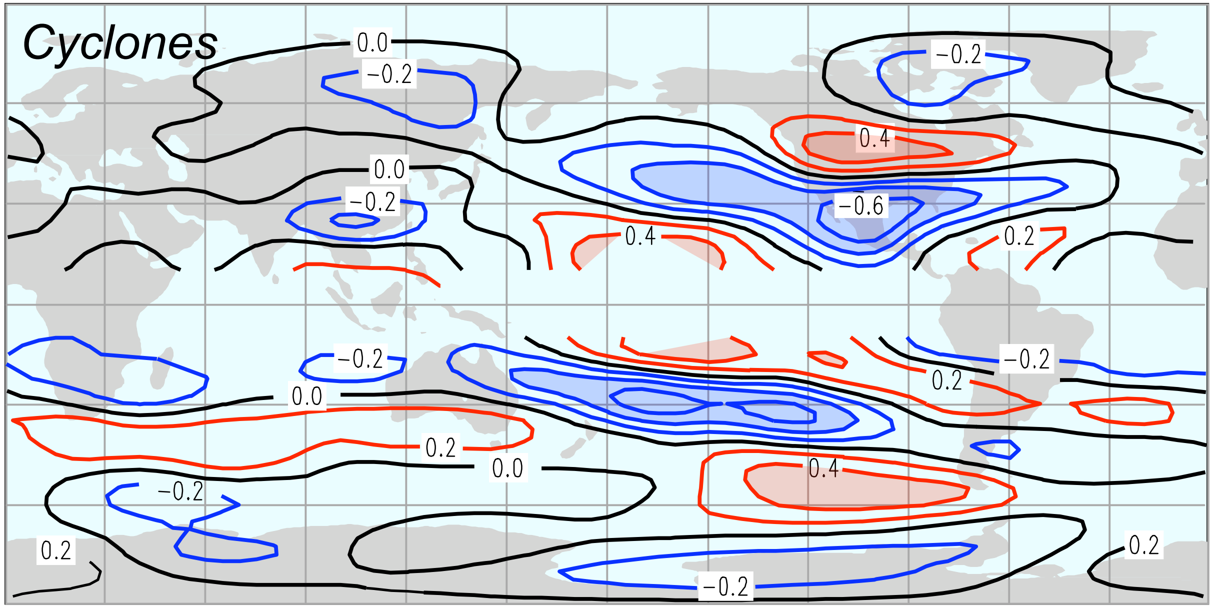
Red = warmer during La Nina



500 mb winter cyclone track density

Blue = enhanced during El Nino

Red = enhanced during La Nina

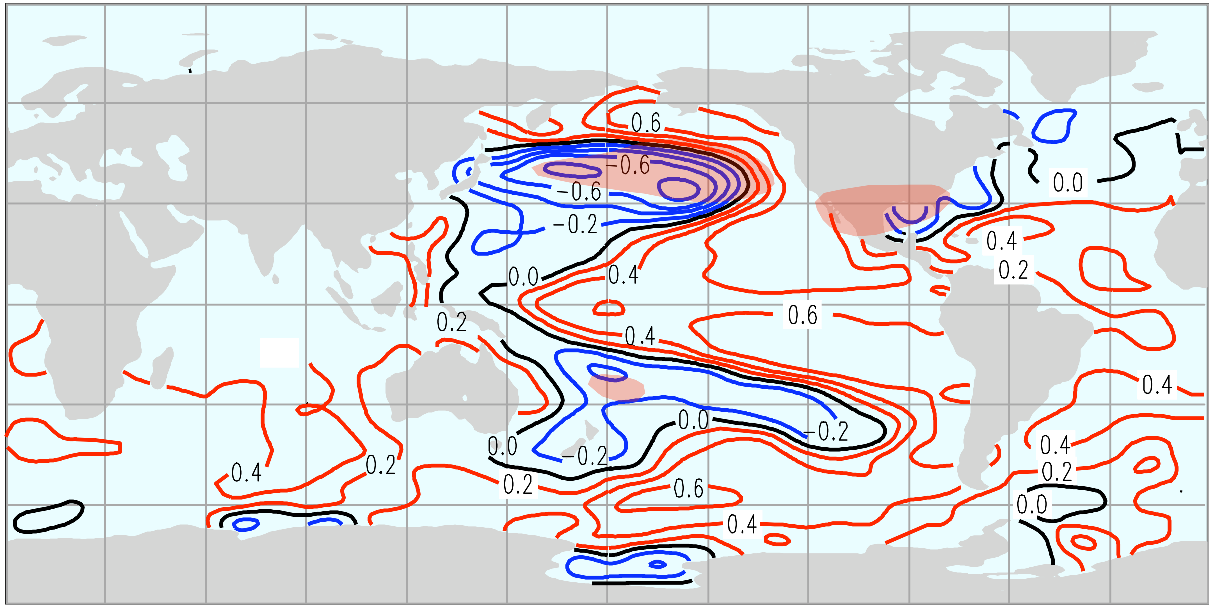


Nov-April

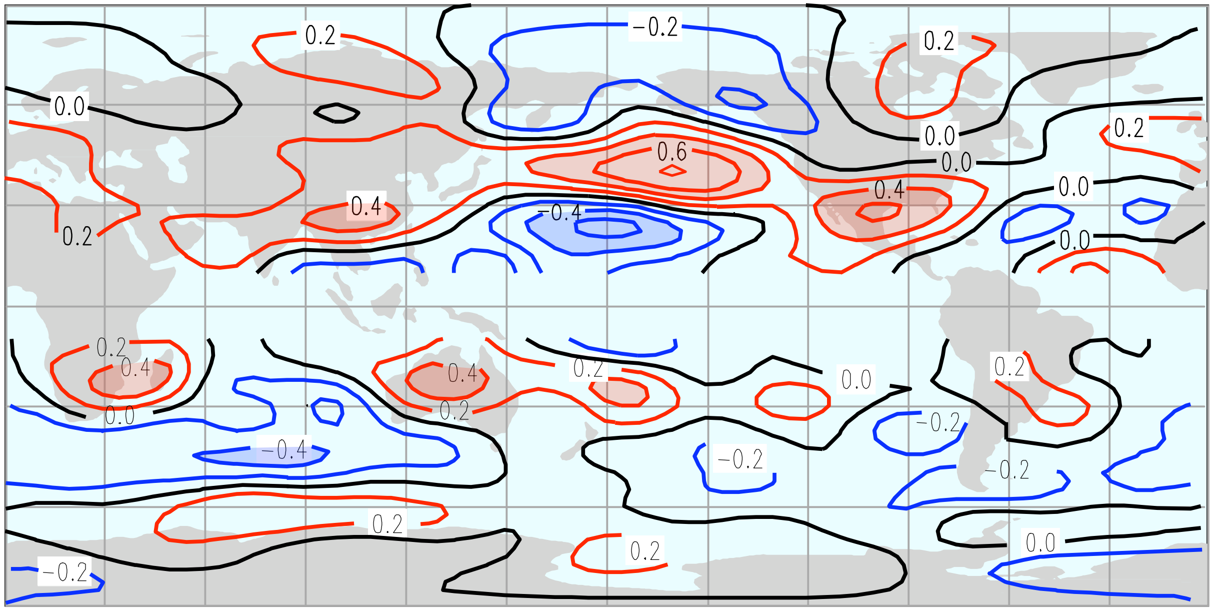
May-Oct

PDO

SST anomaly correlation



500 mb winter cyclone track density



Nov-April

May-Oct

Strong correlation with cold SST

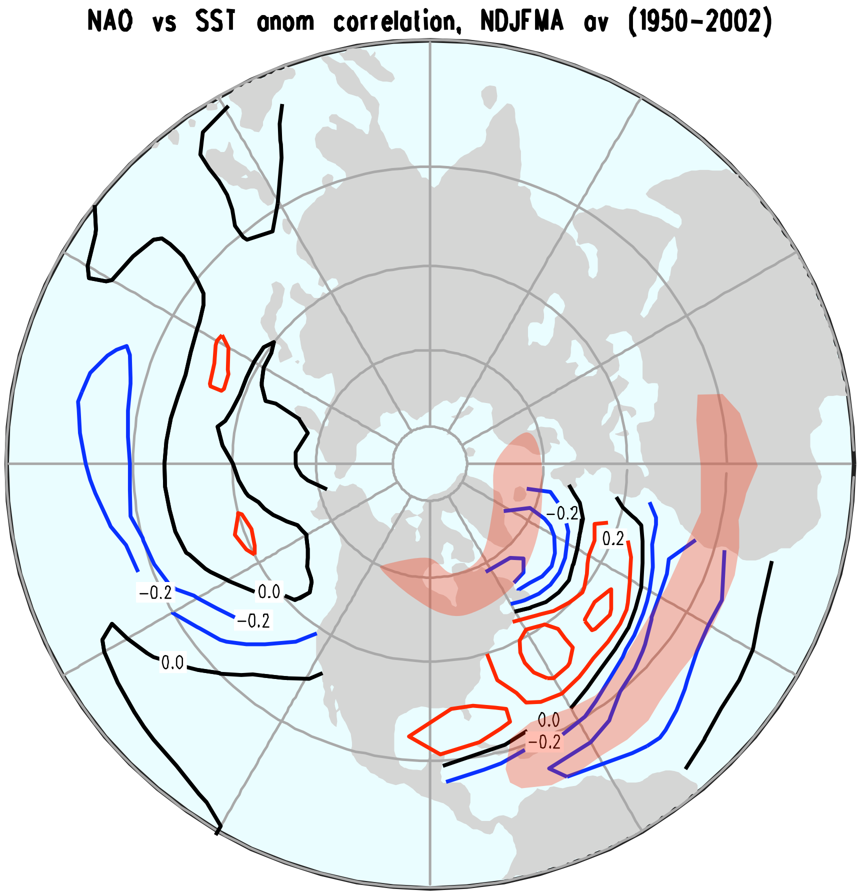
Synergy with Aleutian low?

Response to SOI & PDO

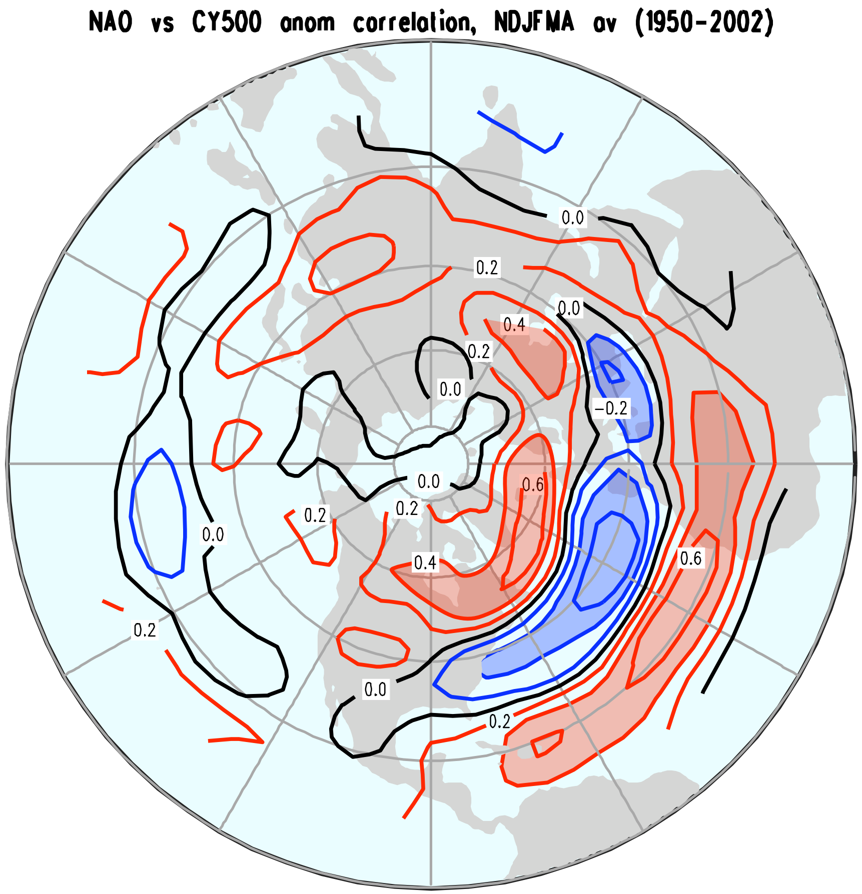
- Enhanced cyclones found downstream of enhanced SST gradients
  - Is part of the midlatitude cyclone (geopotential) response due to upstream baroclinic forcing?
- PDO has in-situ and a downstream response
  - Is there a synergy between the cyclones & cold SST?
  - Do the enhanced cyclones keep the sea cold via Ekman divergence?
- Note some degree of mirror imaging between NH & SH for both PDO and PDO
  - Rossby wave generation?

NAO

SST



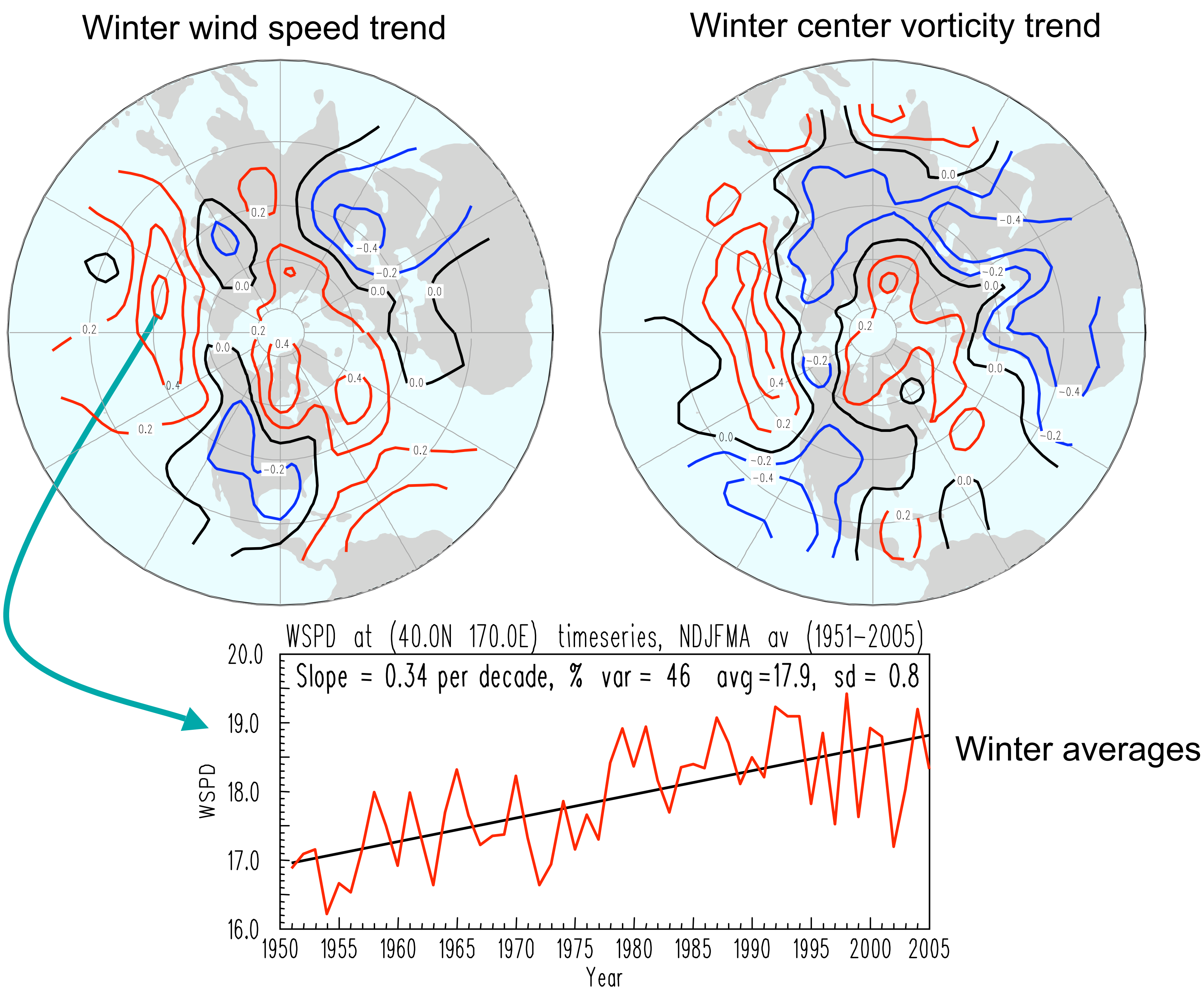
Cyclones



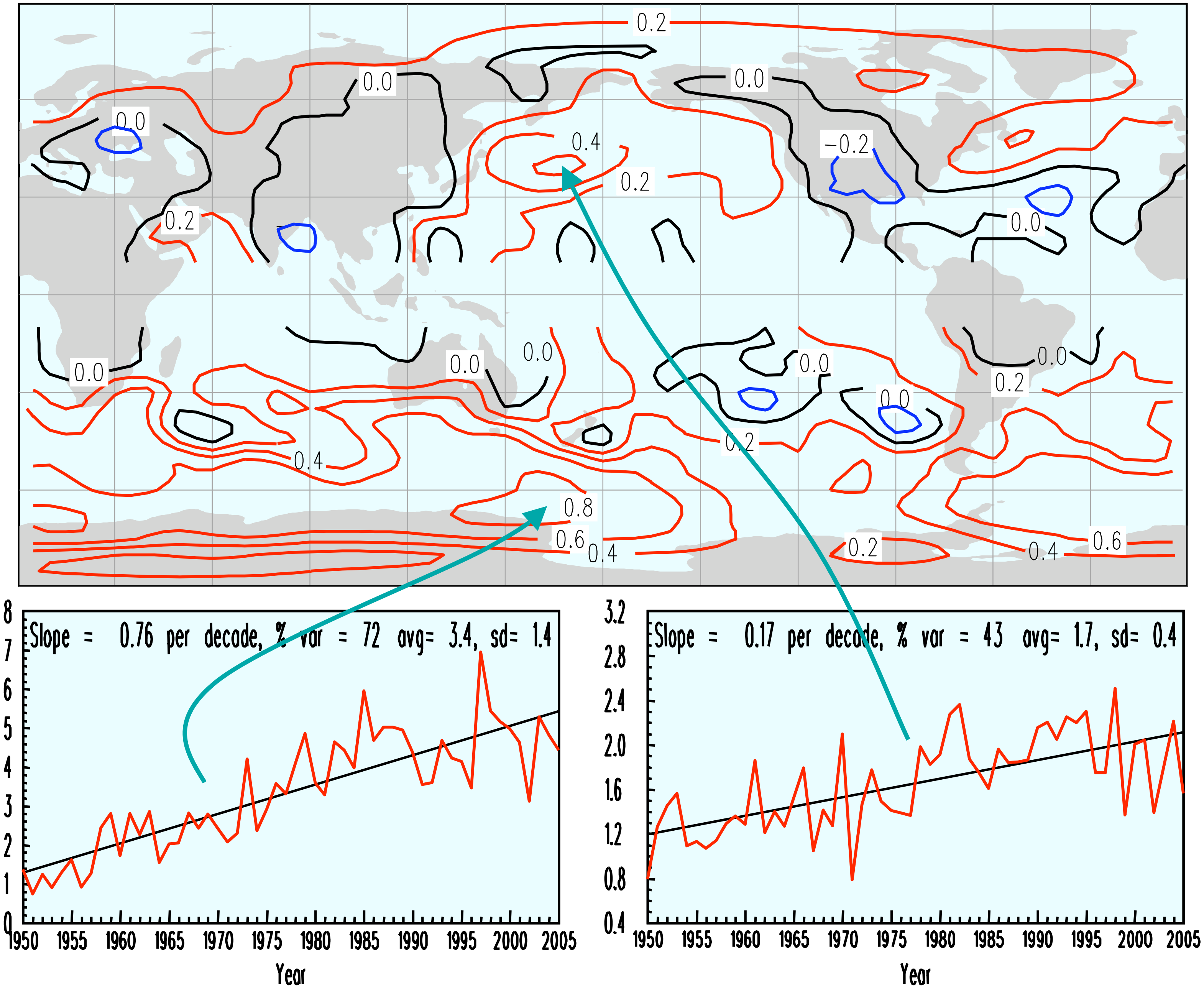
Enhanced cyclone activity correlated with colder SSTs and weaker SST gradients. Thus SST anomalies seem to be a response rather than a contributing cause of enhanced storm activity, as in other studies

Trends

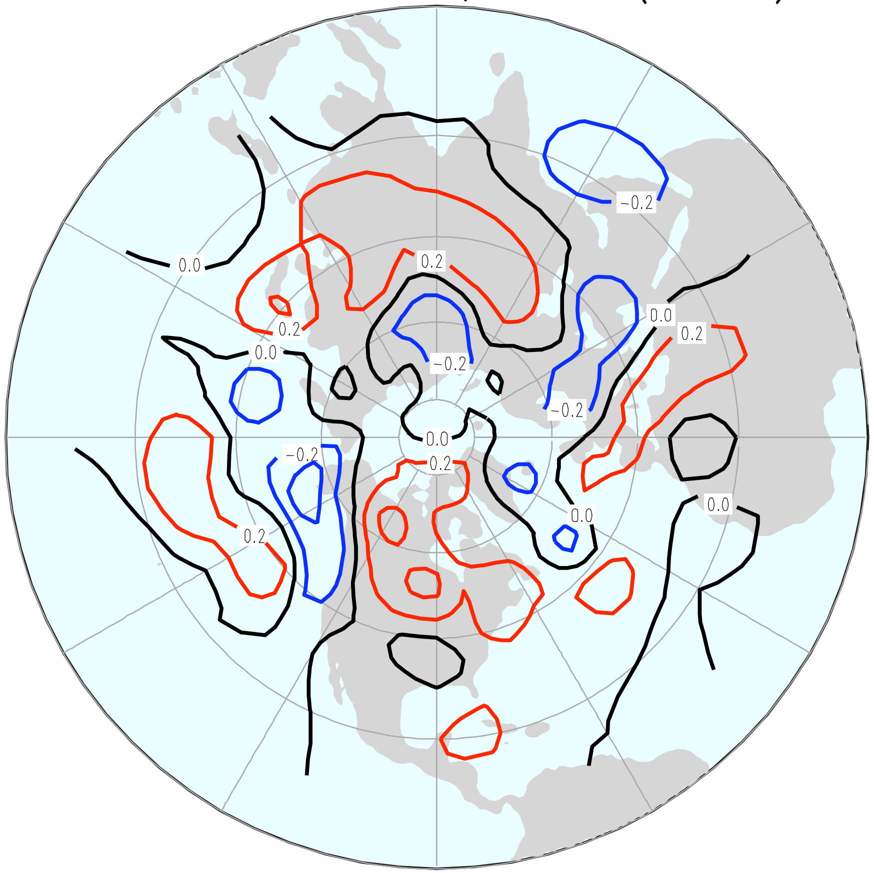
- Evaluated using correlation of series with its own time index
- Data from 1950 to 2005

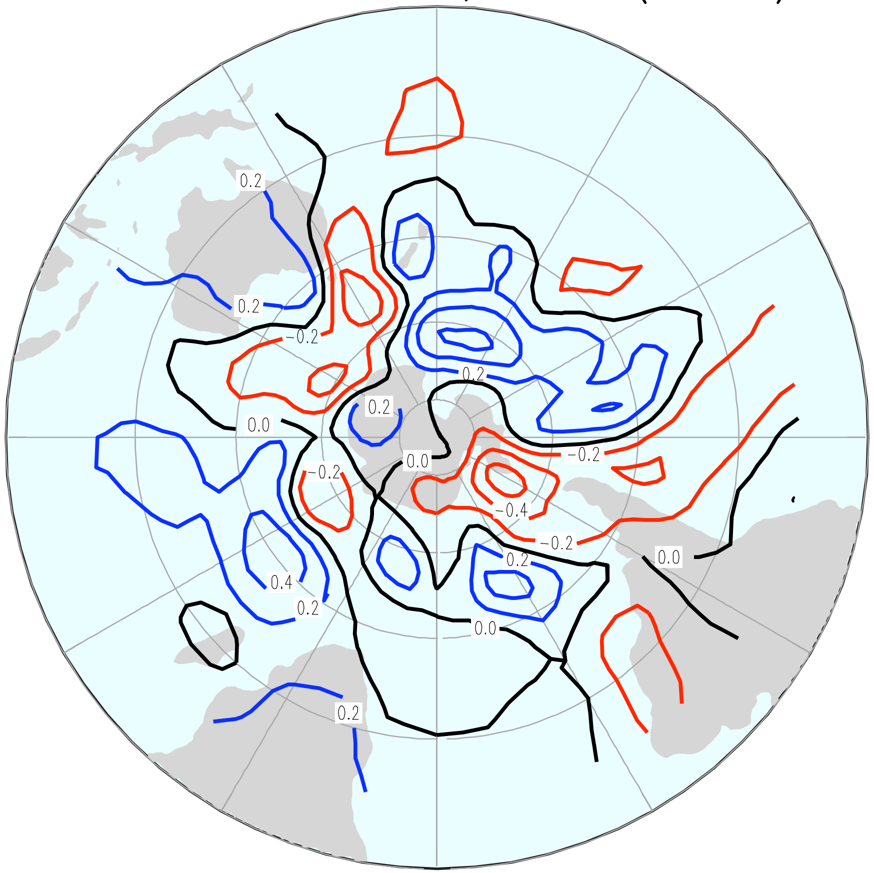

Winter wind speed trend
Winter center vorticity trend
WSPD at (40.0N 170.0E) timeseries, NDJFMA av (1951–2005)
Slope = 0.34 per decade, % var = 46 avg =17.9, sd = 0.8
WSPD
20.0
19.0
18.0
17.0
16.0
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Year
Winter averages

Trend in no. of cyclones with wind > 20 ms^{-1}

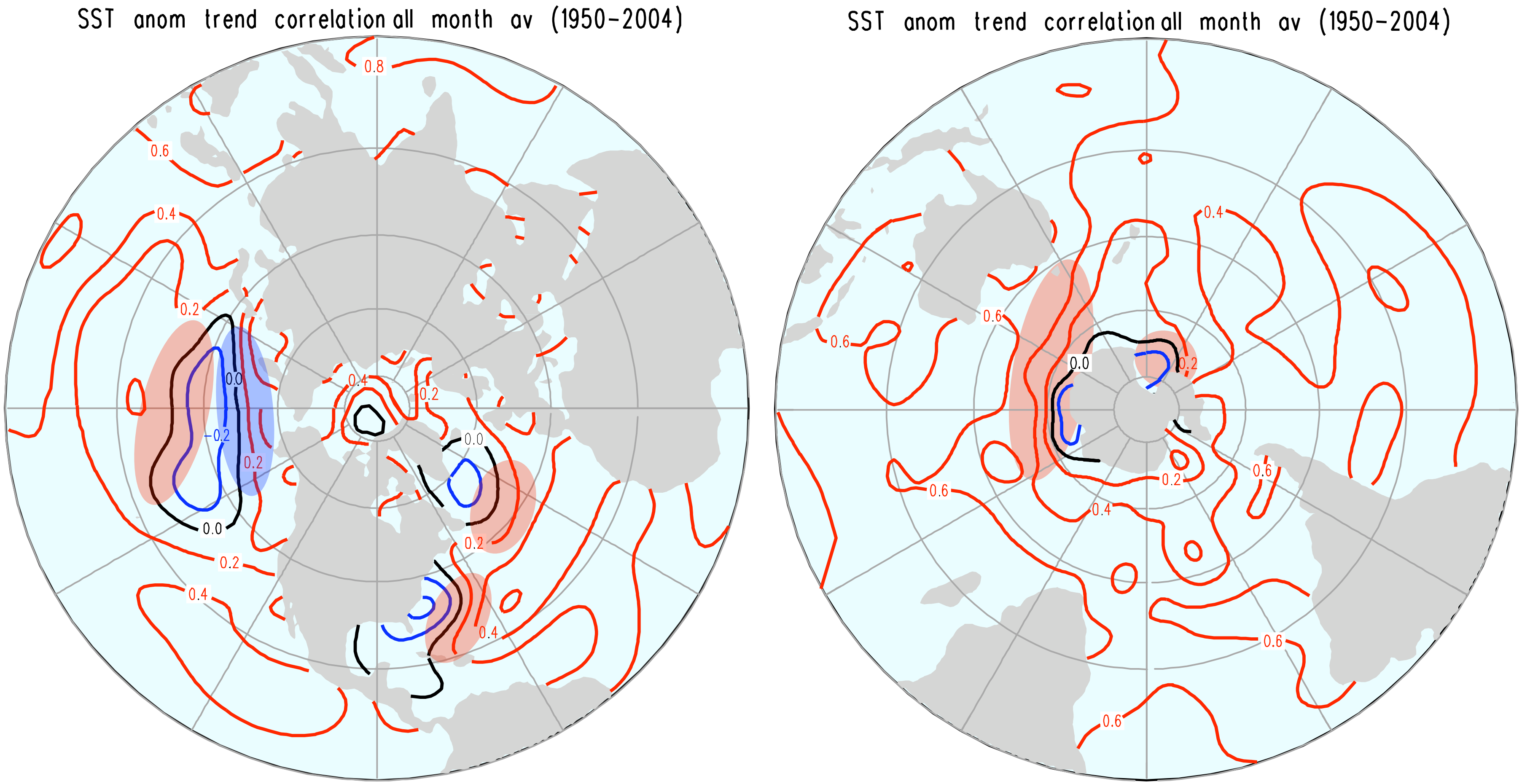


Trend in intensification rate





SST trends

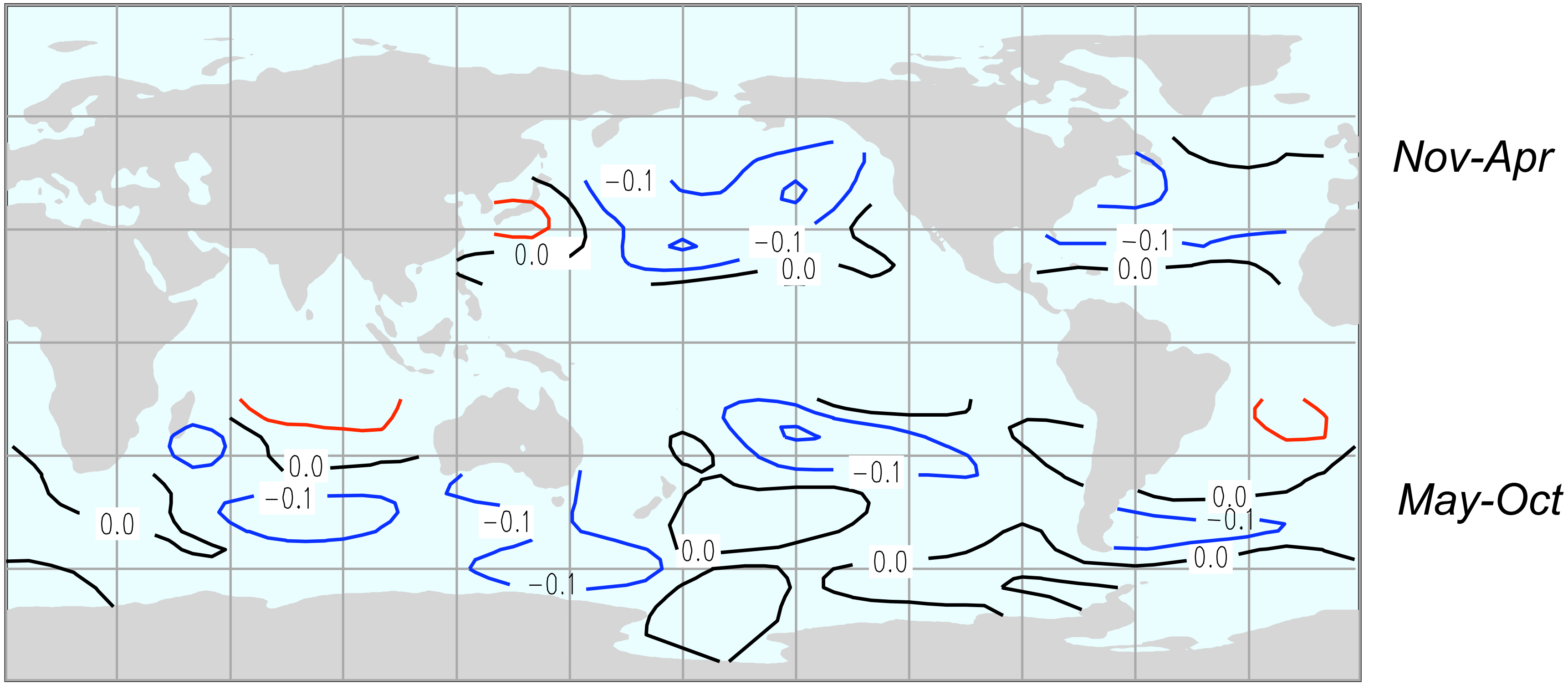


Regions where SST trends could be frontogenetic

Regions where SST trends could be frontolytic

Cyclones vs SST – 3 month highpass

Focus just on month-to-month fluctuations, low-frequency variability removed

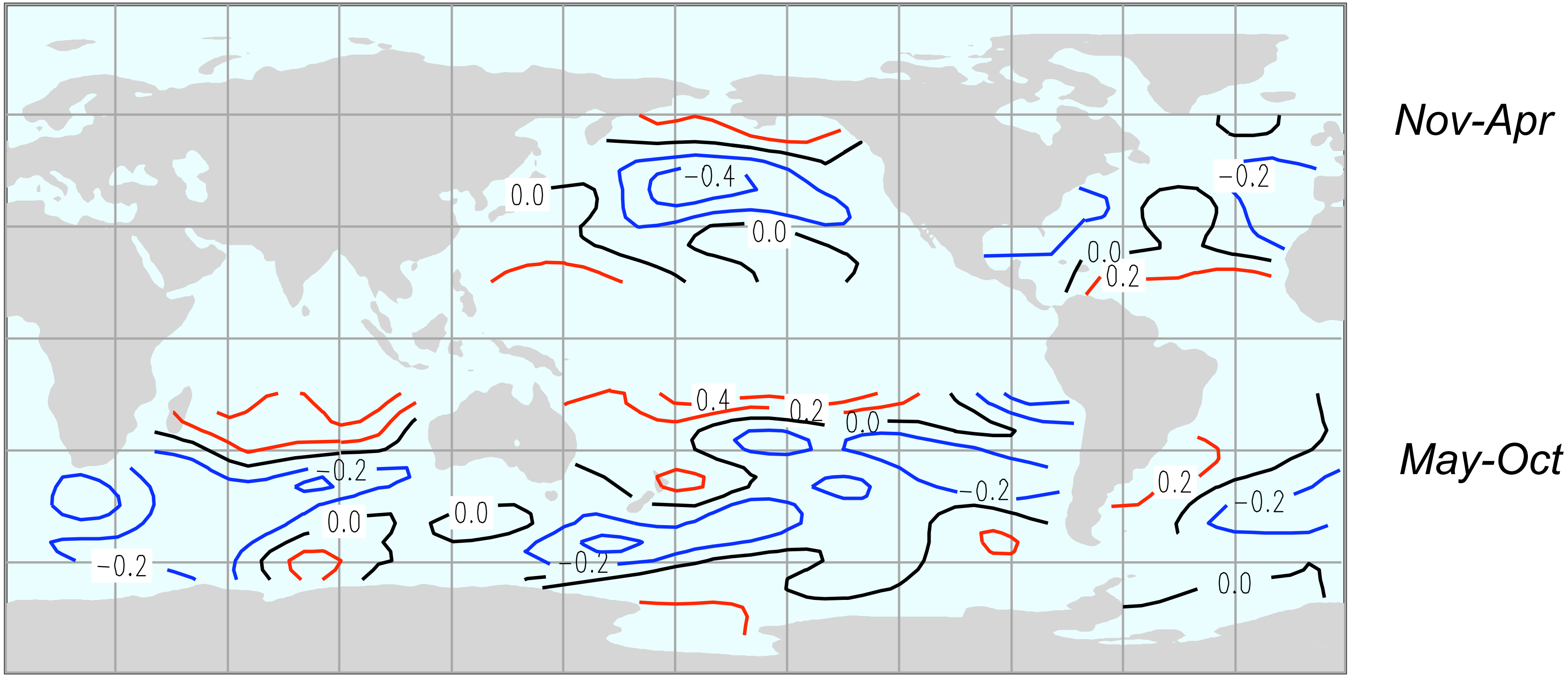


Negative correlation between cyclone frequency and in-situ SST anomalies.

More cyclones typically mean colder SST, except south Japan.

Cyclones vs SST – 1-3 year bandpass

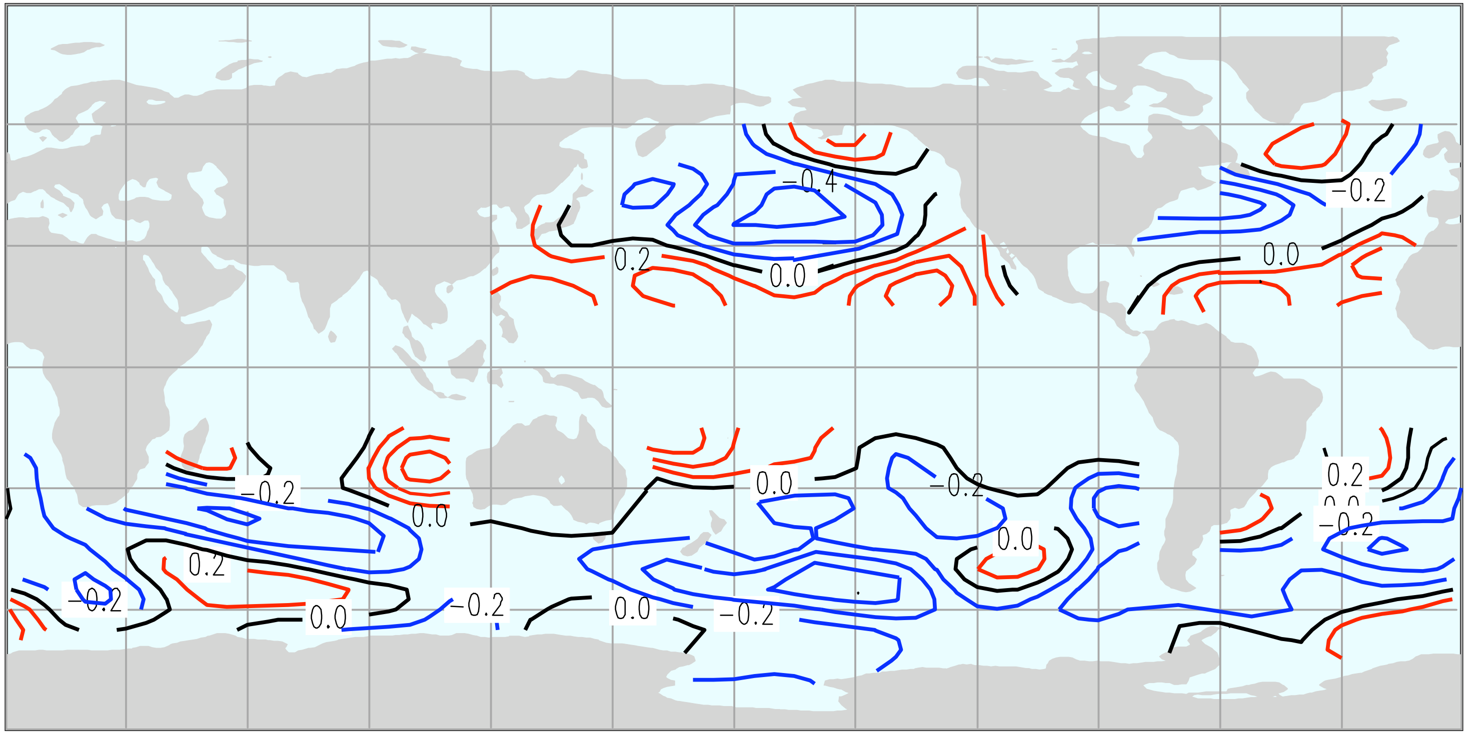
Focus on year-to-year fluctuations with decadal variability removed (leaves mostly ENSO variability)



More cyclones means colder SST, except in tropics.

Cyclones vs SST – 3 year lowpass

Focus on decadal variability



Nov-Apr

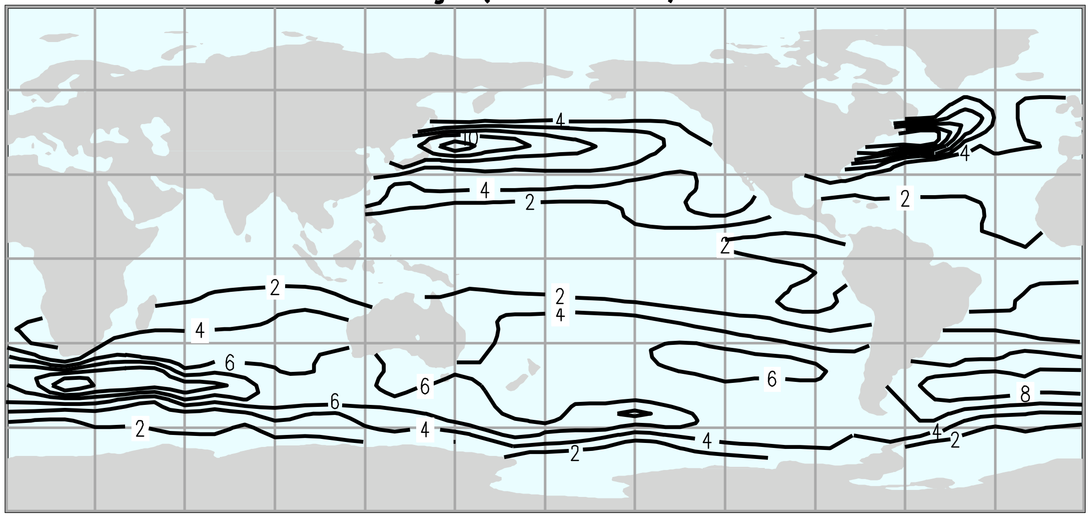
May-Oct

More cyclones means colder SST, except in subtropics.

Cold pool N. Pacific associated with PDO

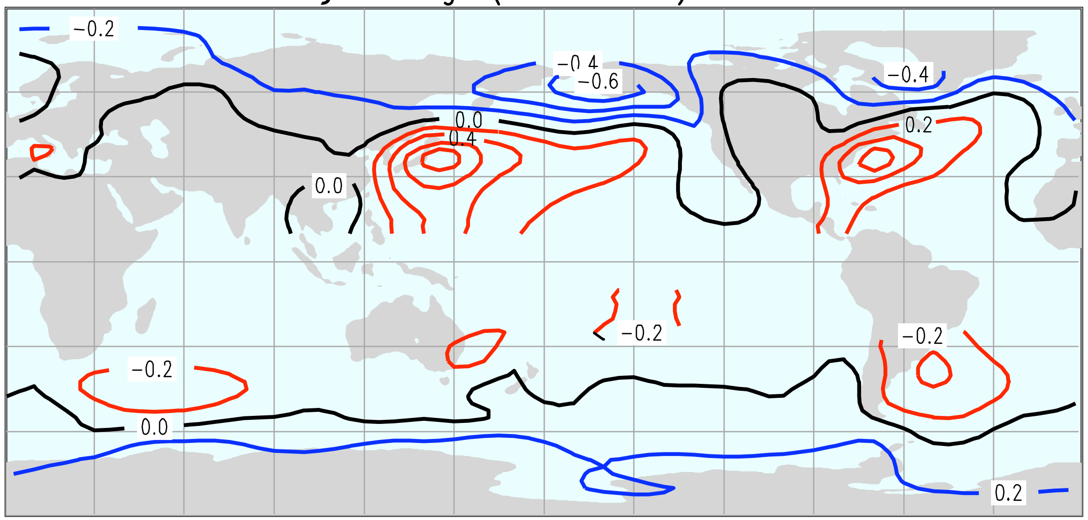
SST gradients

GSST average (1950-2004)



Is there a link between cyclones and SST gradients?

Δζ average (1950-2004)



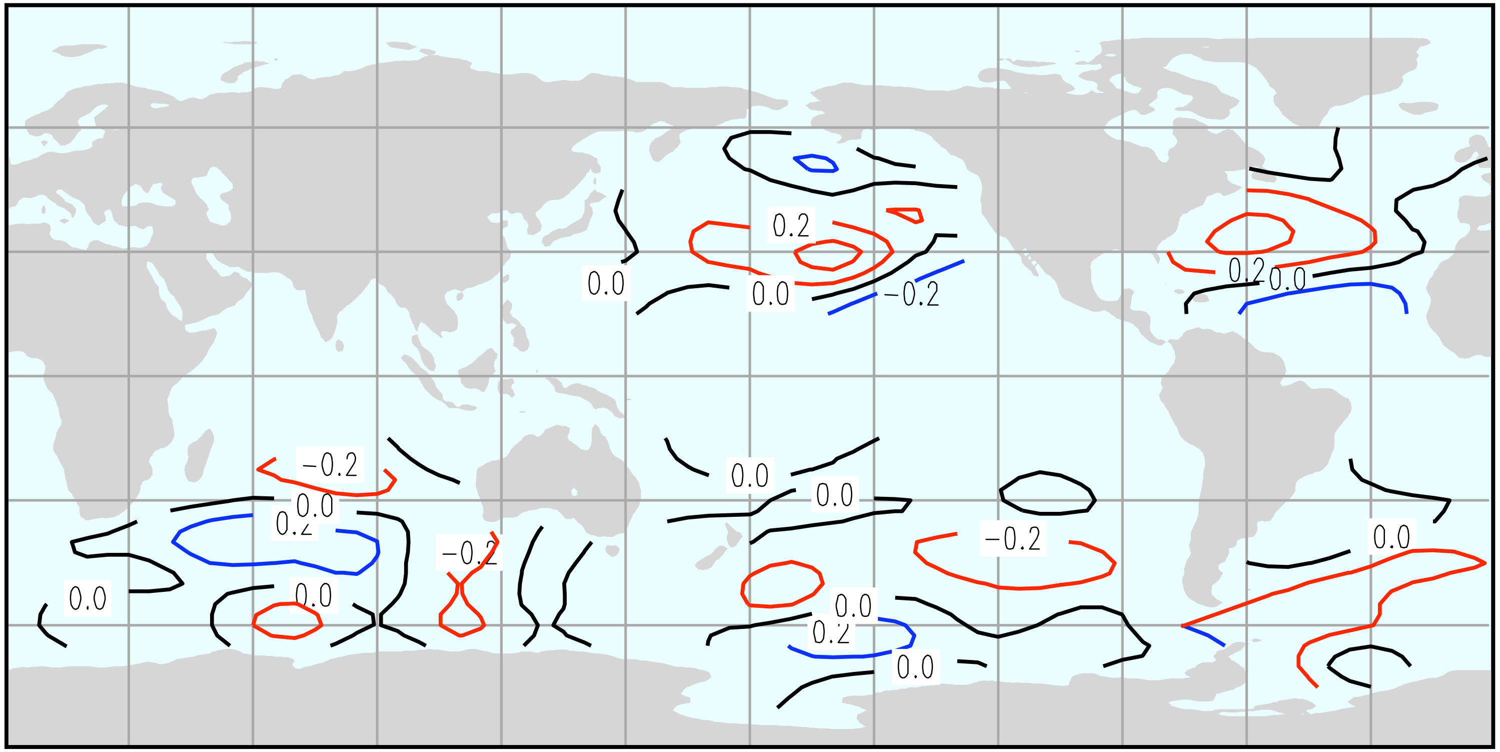
Cyclogenesis

Cyclolysis

All months

Cyclone $\Delta\zeta$ vs SST gradient
(annual av)

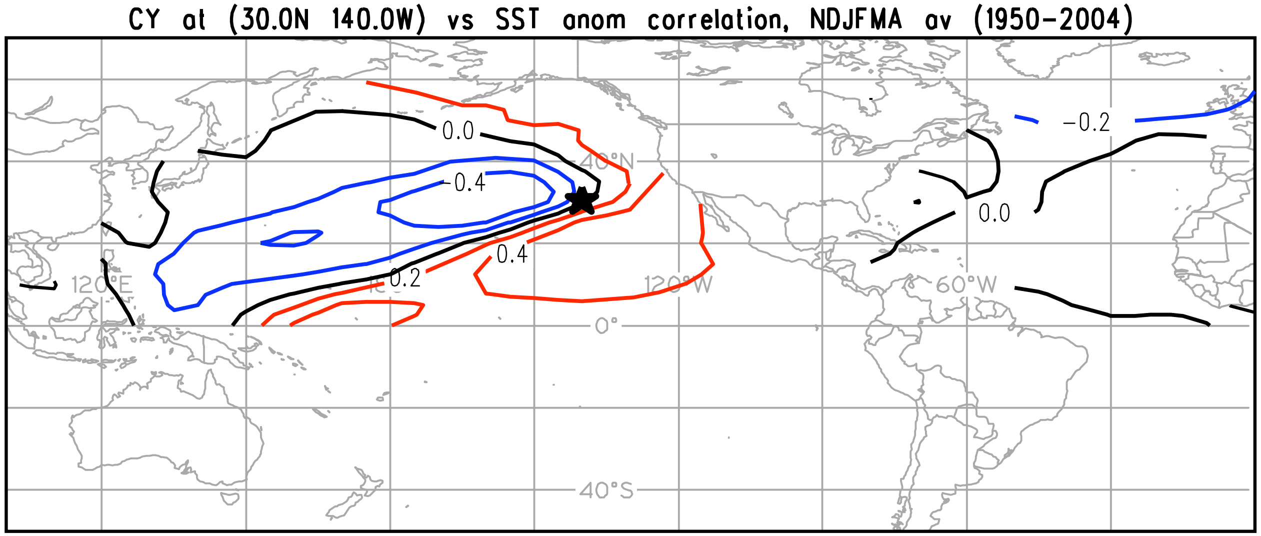
Red means cyclones intensify faster when SST gradients are larger



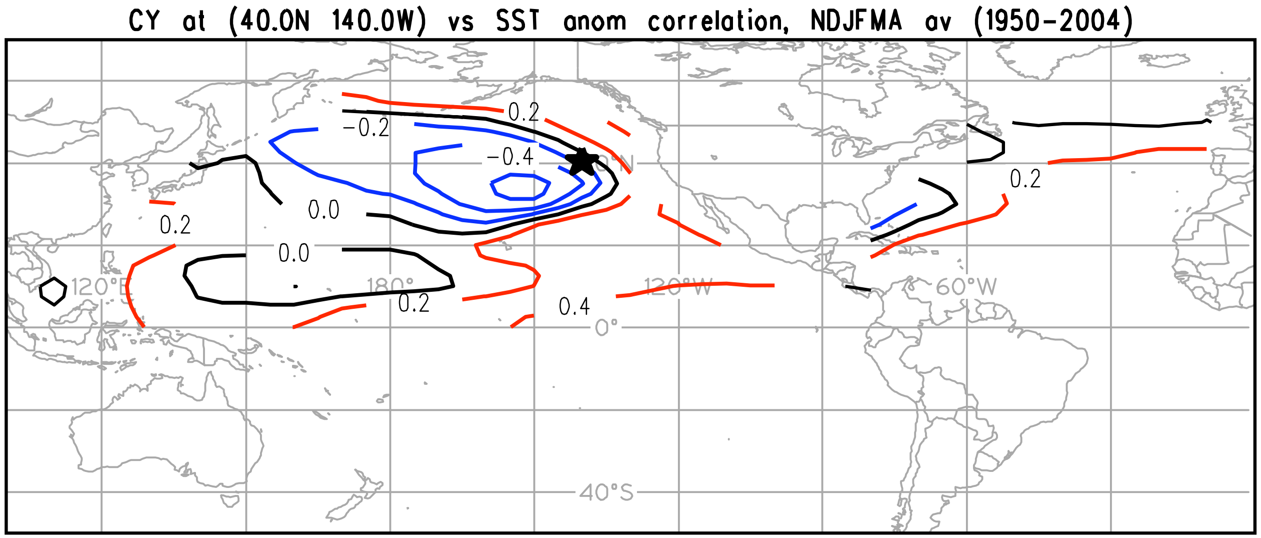
Despite the fact that cyclones intensify near SST gradients, there is little correlation between temporal fluctuations in SST gradients and cyclone intensification rates, except in red areas

Cyclones vs SST

(correlation between cyclone occurrence at the * and SSTs)

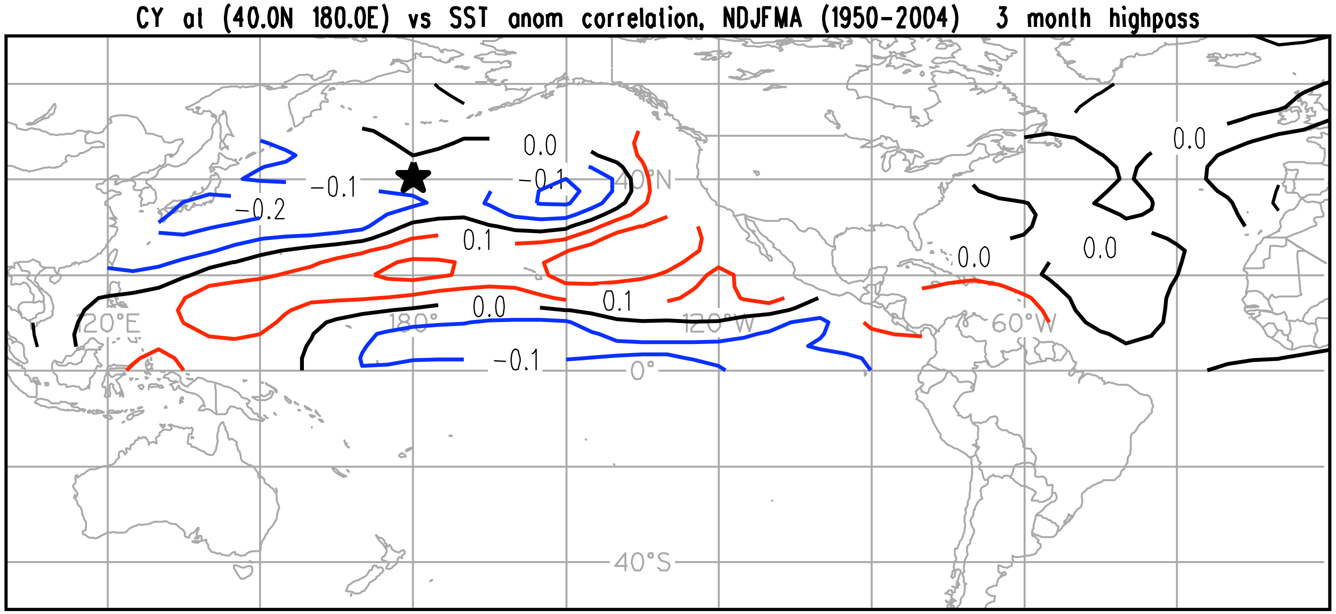


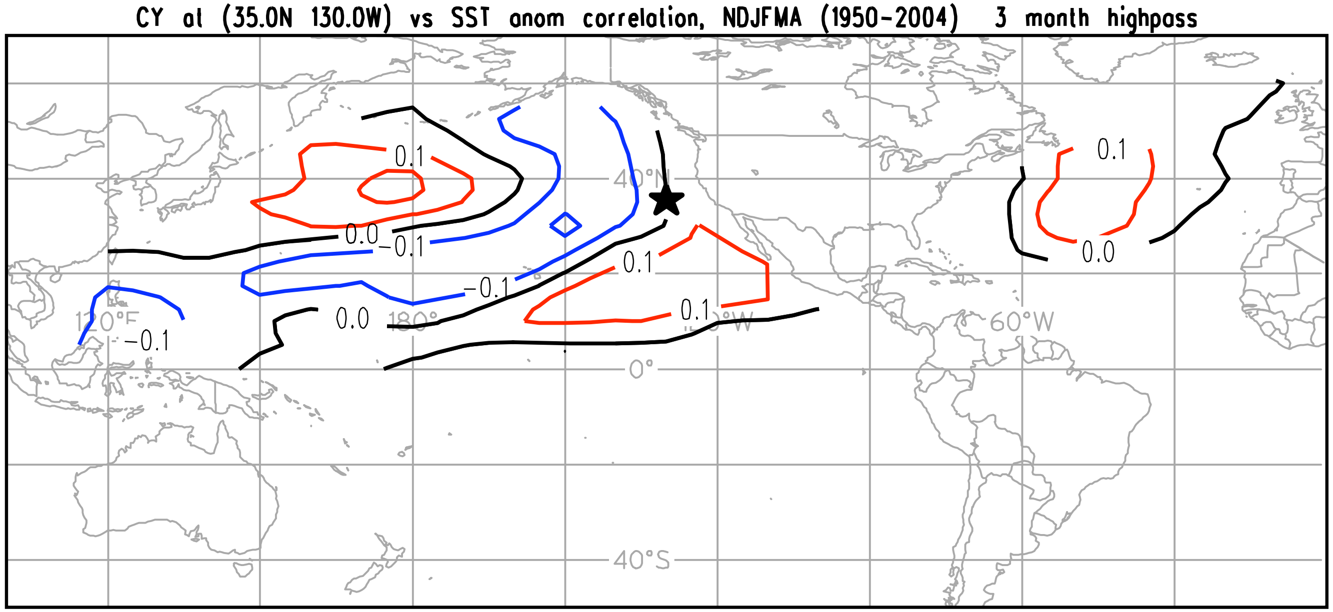
Looks like ENSO



Looks like PDO

Cyclones vs SST
(low freq variability removed)





Upstream SST gradients are important, but less so than ENSO PDO etc

Conclusions

- Correlation with SST mostly negative
  - Cyclones create Ekman divergence and upwelling, along with increased mixing
- Apparent link with upstream SST gradients in certain location is really ENSO/PDO
- There is a residual smaller correlation with upstream SST gradients that is not related to low frequency variability