

Trends and Variability of Extra-Tropical Cyclone Activity in the Ensemble of 20th Century Reanalysis

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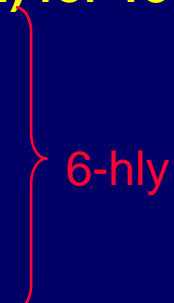
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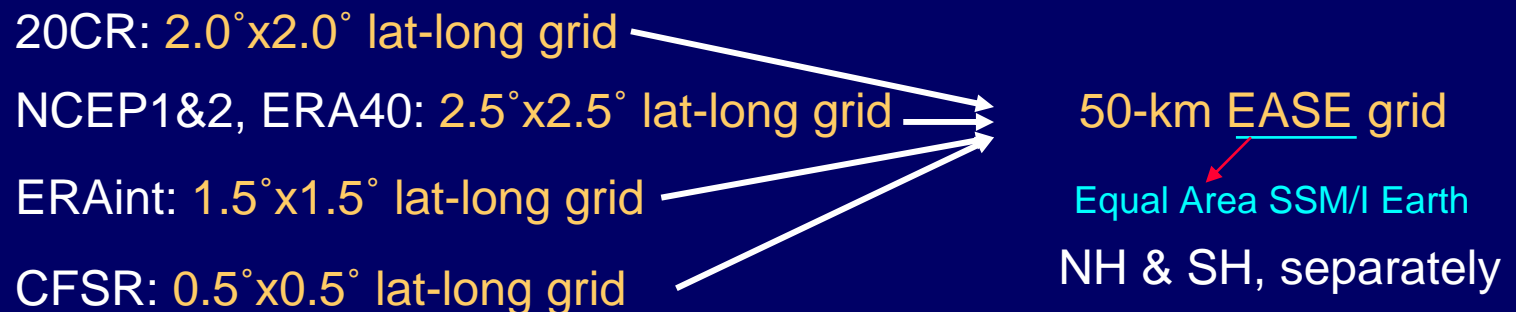
Outline

- Datasets & methodology
- Tracking ensemble mean SLP versus tracking SLP of individual runs
- Brief comparison of 20CR (v2) with five other reanalysis datasets
 - 20CR assimilated only surface pressure data → homogeneous in the NH after 1950
- Long-term trends in ensemble mean seasonal cyclone count and mean intensity
 - discontinuities in the ensemble mean series
- Summary

Datasets: Global 6-hourly MSLP fields

1. **20CR: (v2, each of the 56 runs & ensemble mean) for 1871-2008**
 2. **NCEP1: NCEP/NCAR Reanalysis for 1948-2008**
 3. **NCEP2: NCEP-DOE Reanalysis for 1979-2007**
 4. ERA40: WCMWF Reanalysis for 1958-2001
 5. **ERAint: ERA-Interim Reanalysis for 1989-2009.03.31**
 6. CFSR: NCEP CFS Reanalysis for 1979-2009 – hly (6-hly used)
- 

Different spatial resolutions:

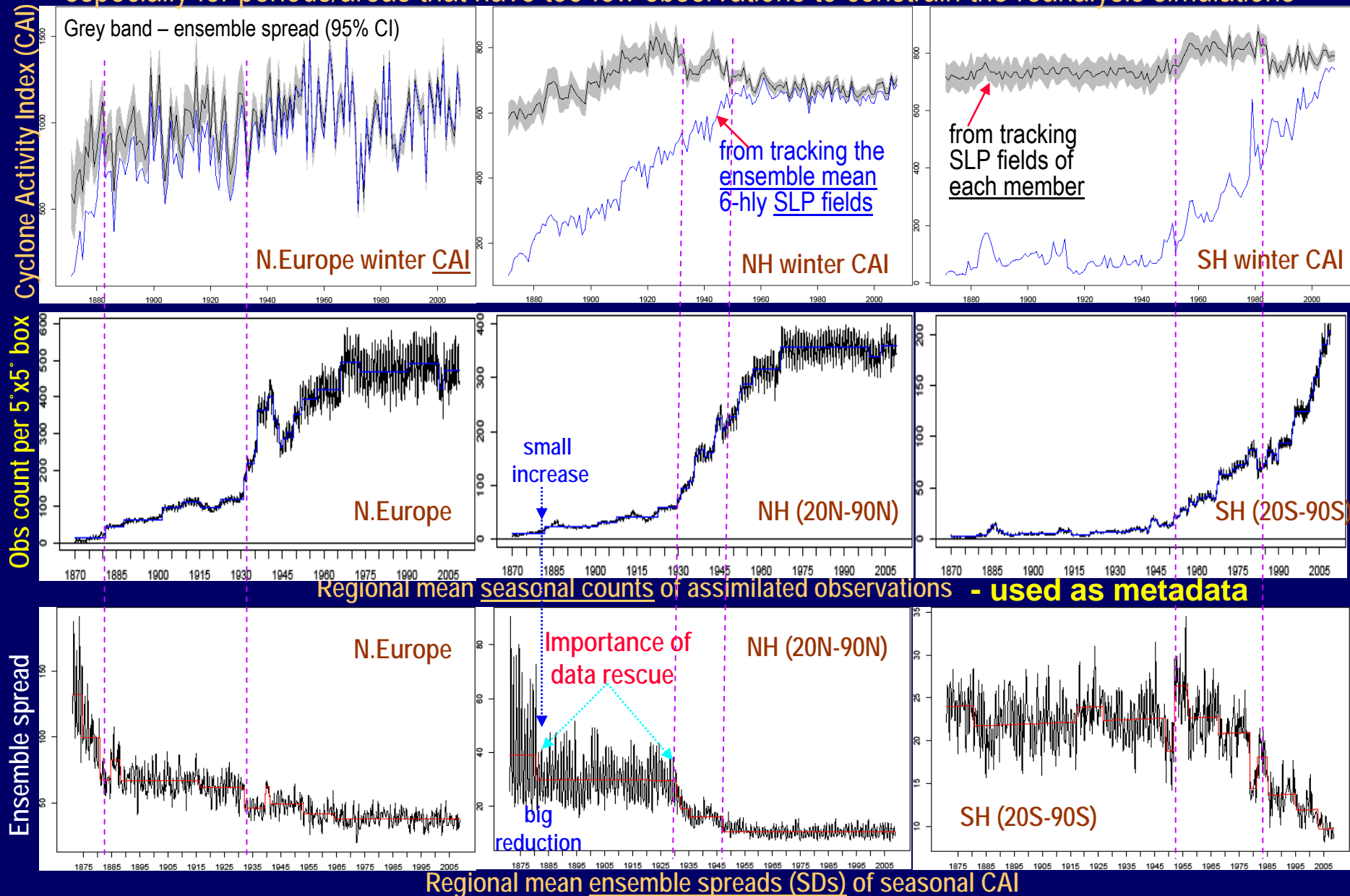


Identification/tracking algorithm: Serreze et al. 1997 (Courtesy of Mark Serreze)

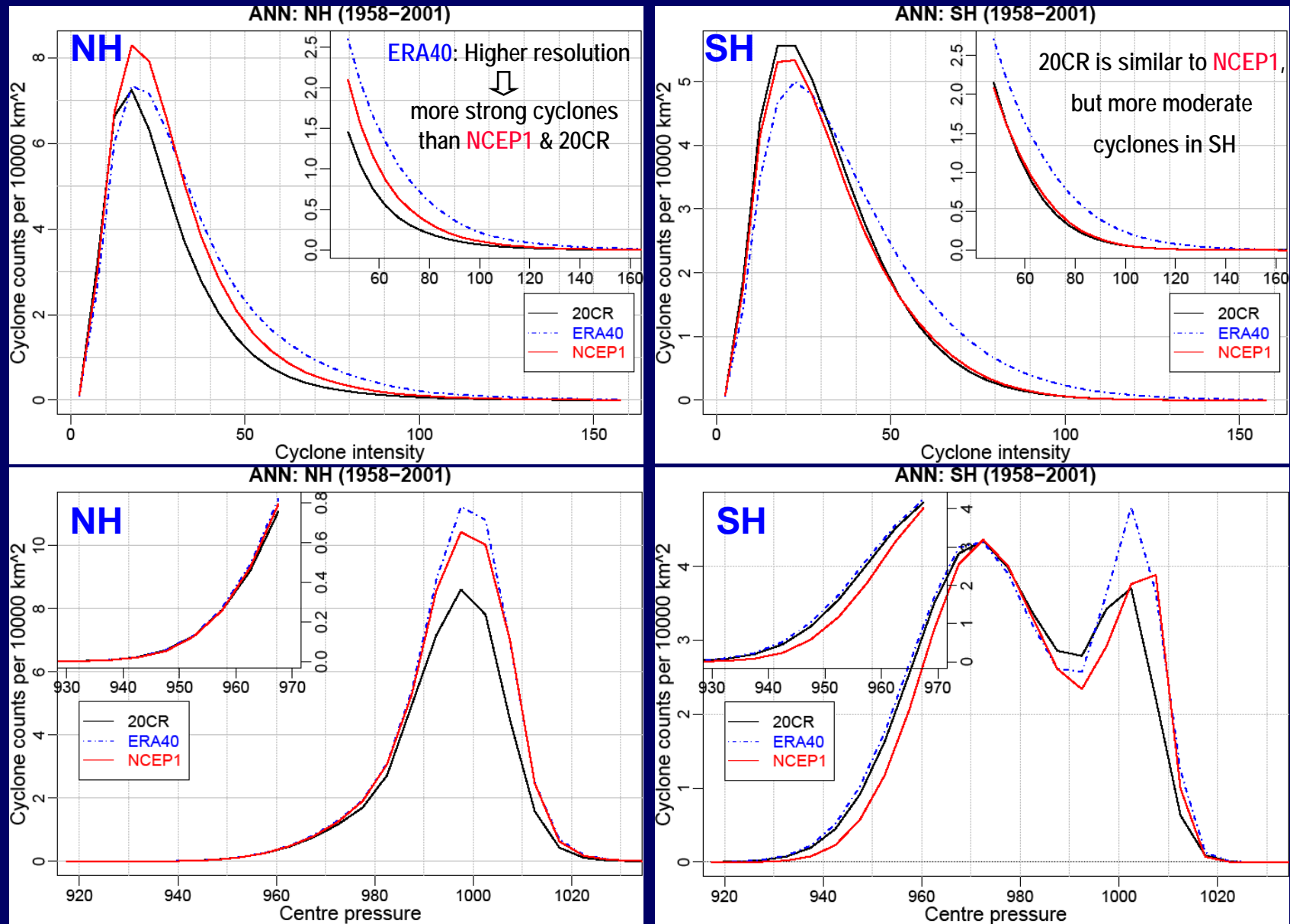
MSLP is an extrapolated field → Exclude areas of elevation > 1000 m; also the 20N-20S zone

Also, we exclude cyclones/tracks of lifespan < 24 hours (4x6-hr), and those traveling < 500 km

Ensemble mean 6-hourly SLP fields are not suitable (too smooth) for analyzing cyclones/extremes, especially for periods/areas that have too few observations to constrain the reanalysis simulations

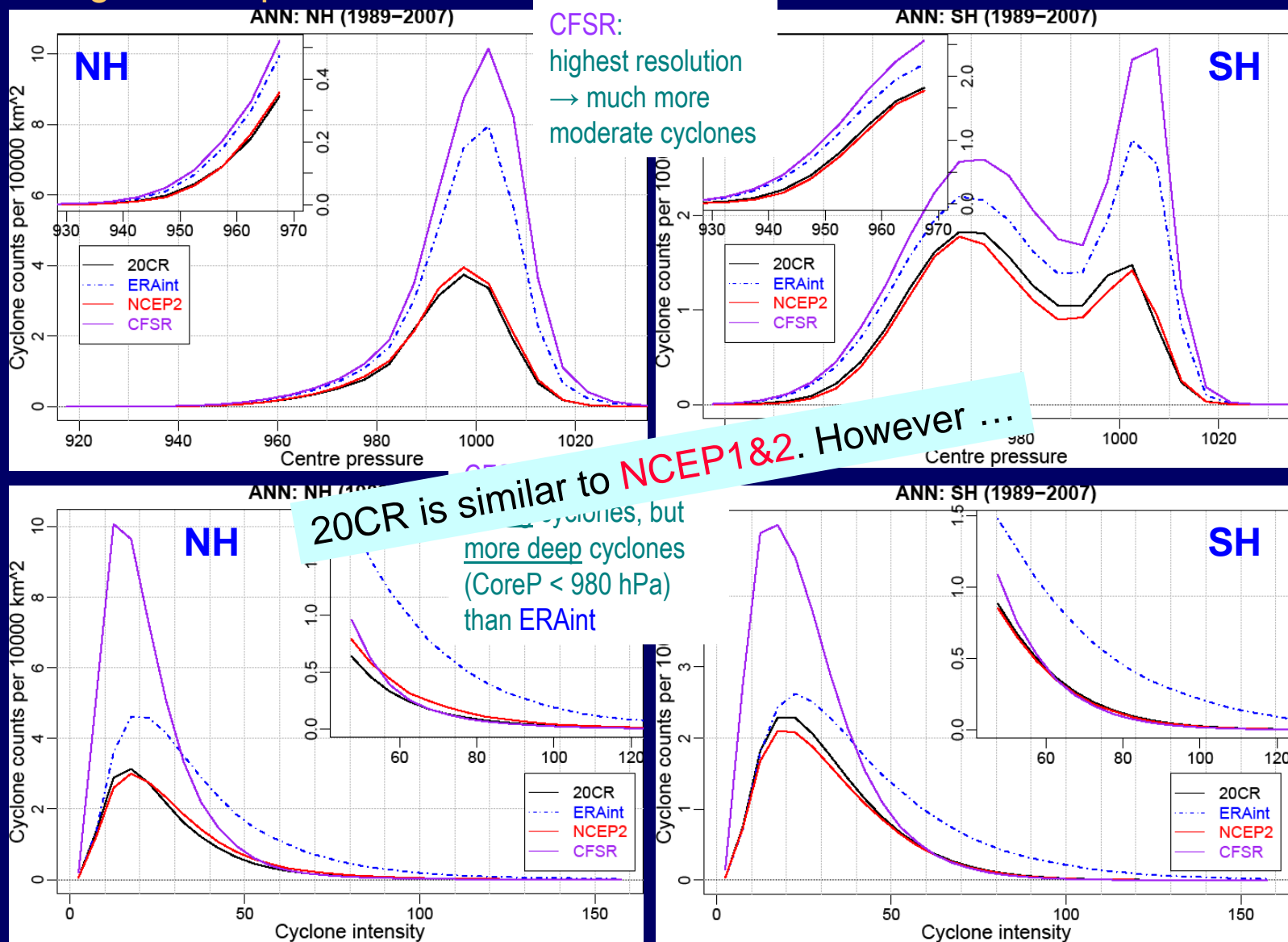


Histogram comparison of reanalyses for 1958-2001:



The differences are smaller for extremes if cyclone intensity is measured by its center pressure

Histogram comparison of reanalyses for 1989-2007:



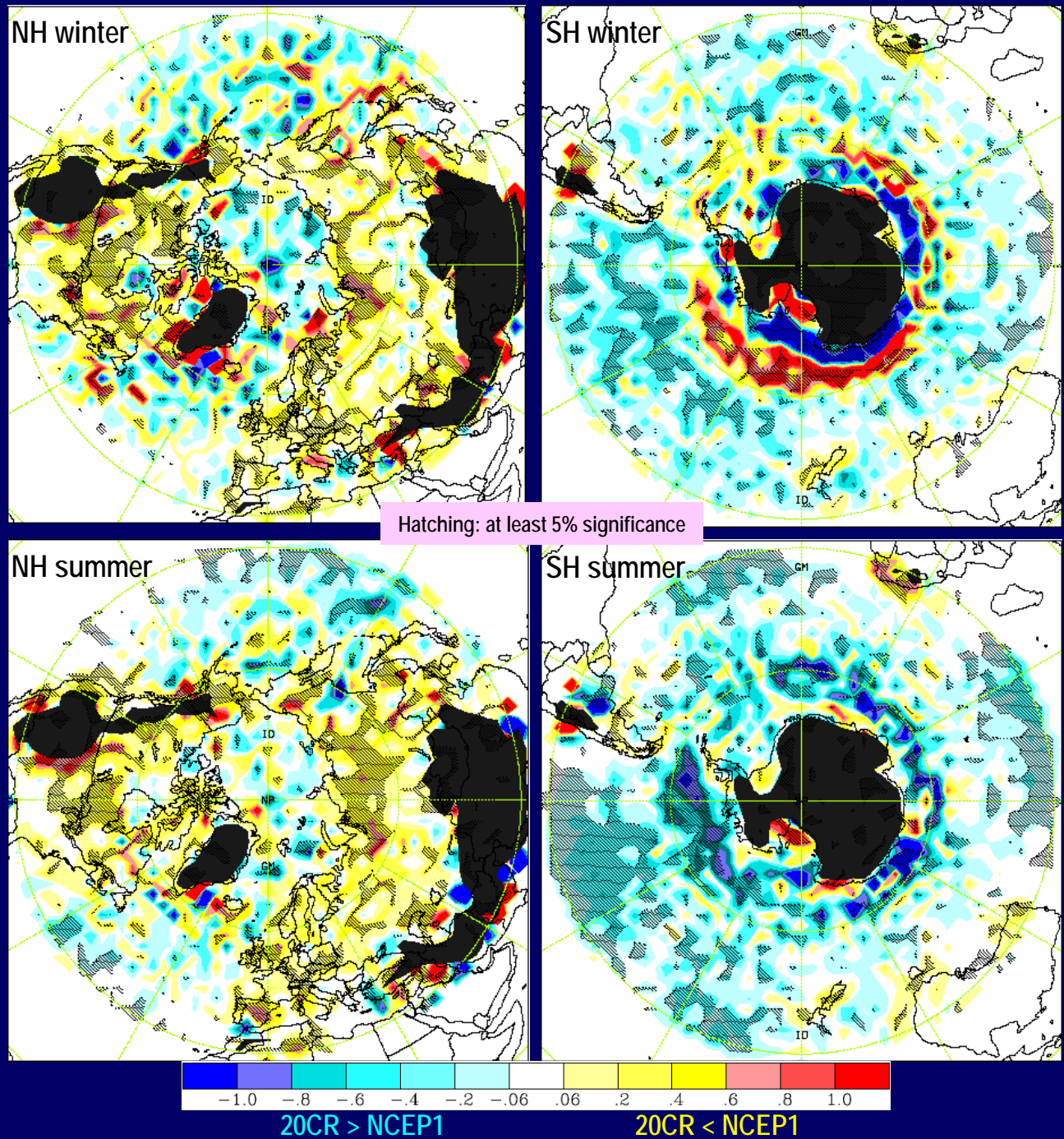
For extremes, the CFSR-ERAint comparison is very dependent on what is used as intensity measure. ERA-Interim (4D-Var assimilation system) appears to show much stronger wind force around the core

20CR versus NCEP1:

Differences in
1958-2001 mean
cyclone activity index
(count * mean intensity)
250-km EASE grid

In general, cyclone activity
is **weaker in 20CR** than in
NCEP1 **over land**, but
stronger over oceans,
especially in SH in summer

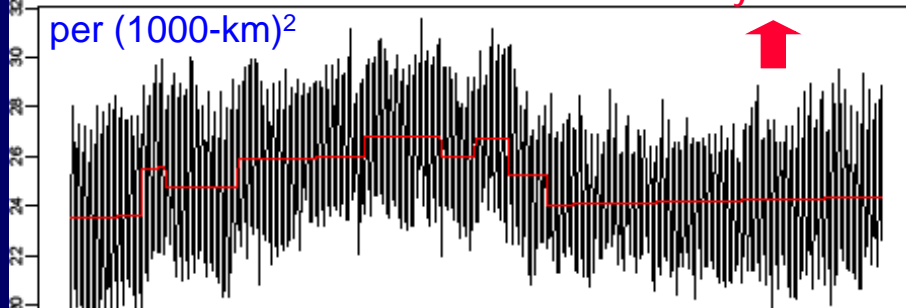
Black areas: elevation > 1000 m



In terms of hemispheric statistics, both cyclone count & intensity seem to have increased significantly in both hemispheres since 1871

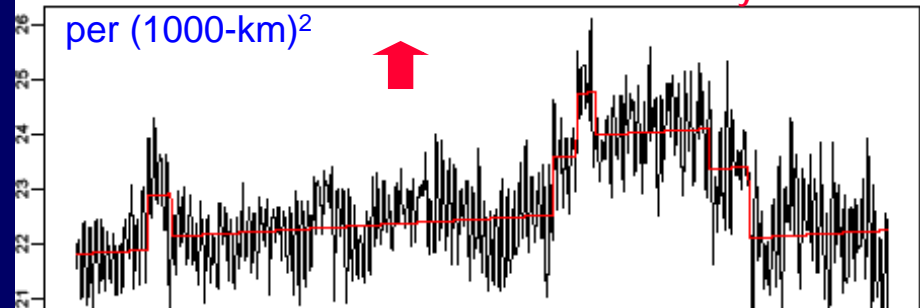
NH (20N-90N)

Seasonal counts per (1000-km)² AllCycloneCnts_NH
TrEnAvg= 0.0058 /yr; p-val= 1 +4.4/yr in the NH

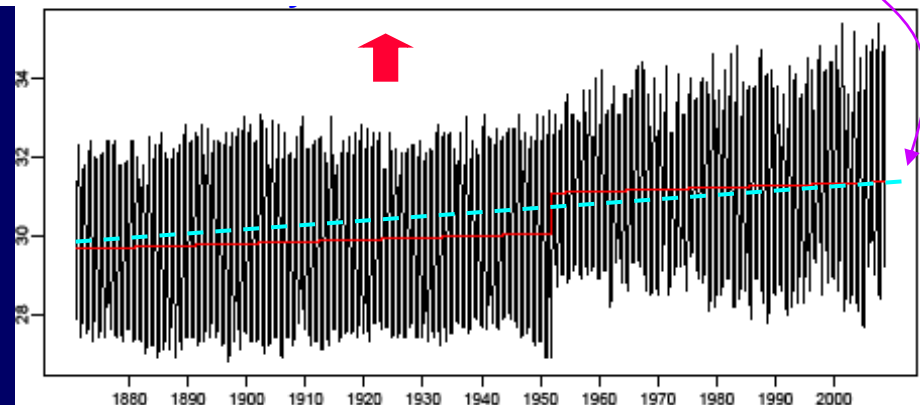
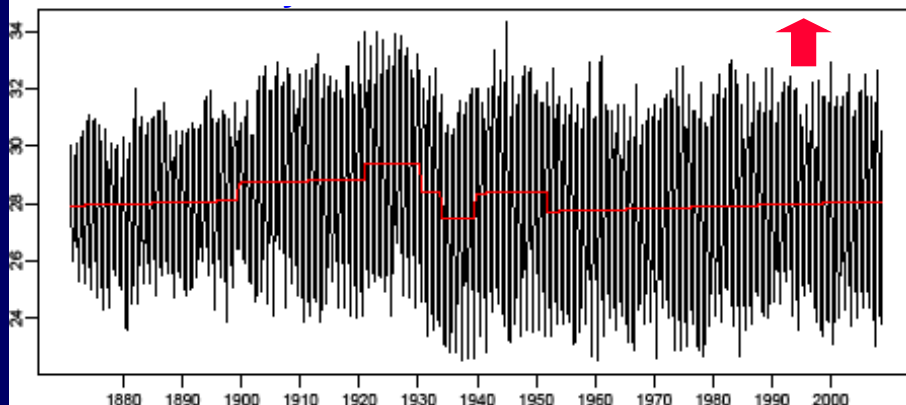


SH (20S-90S)

Seasonal counts per (1000-km)² AllCycloneCnts_SH
TrEnAvg= 0.0061 /yr; p-val= 1 +4.7/yr in the SH



Red lines - common trend multi-phase regression: segments have different means but the same trend, which is the trend estimate I am talking about. Without this,



Similar pictures for strong cyclones

There are notable regional and seasonal differences!

NH – seasonal trends:
(unit per 100-yr)

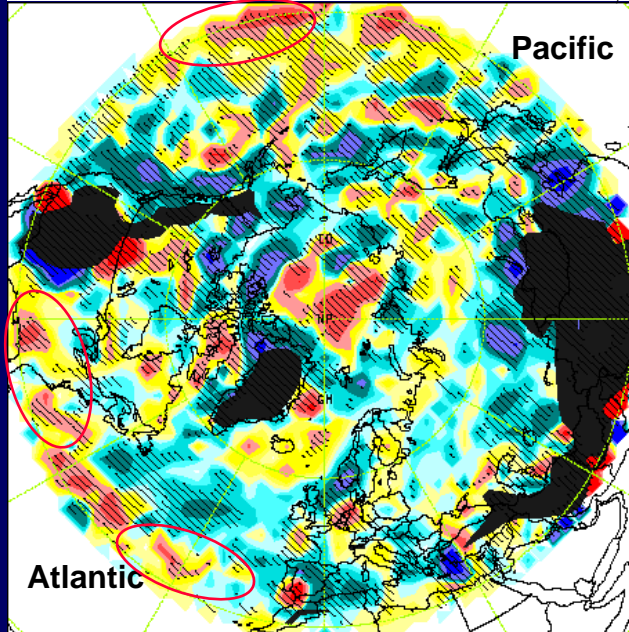
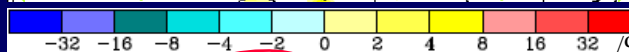
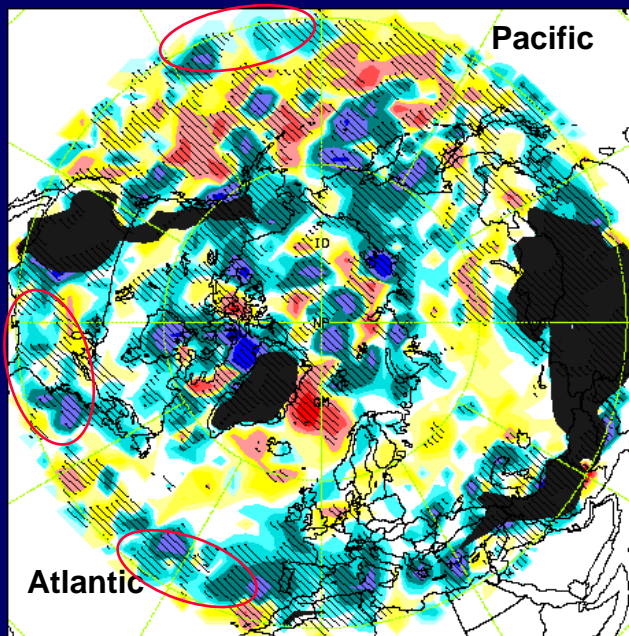
JFM →
Winter

Yellow-Red: ↑
Cyan-Blue: ↓

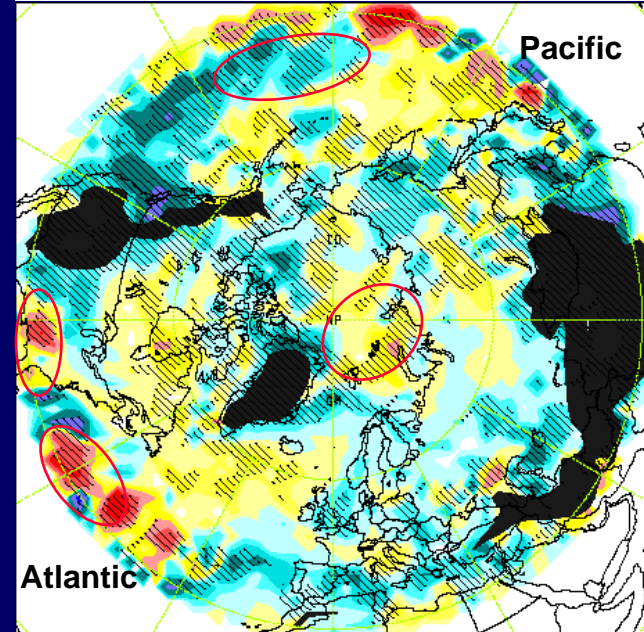
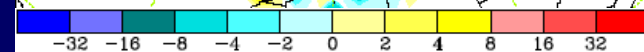
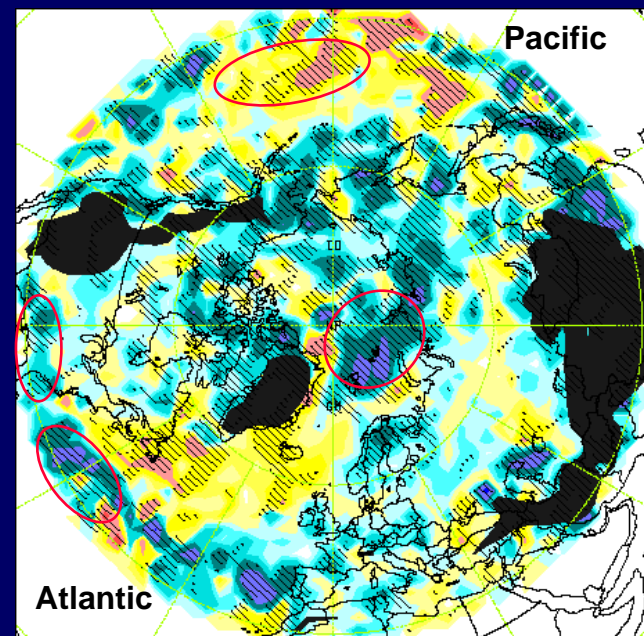
Hatching:
at least 5% significance

JAS →
Summer

Count/(250-km)² of all cyclones



Mean intensity of all cyclones



SH – seasonal trends:
(unit per 100-yr)

JAS →
Winter :

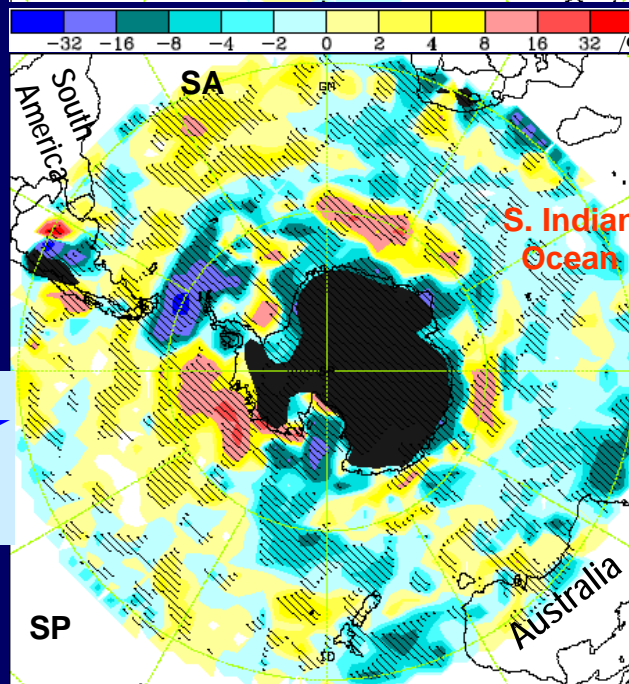
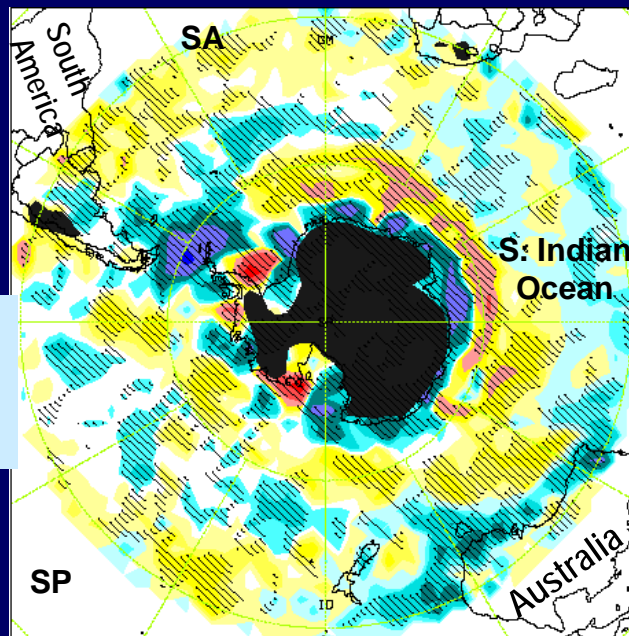
Significant Inten ↑ in
Highlat SA-Indian Ocean
sector, but ↓ in SP

Hatching:
at least 5% significance

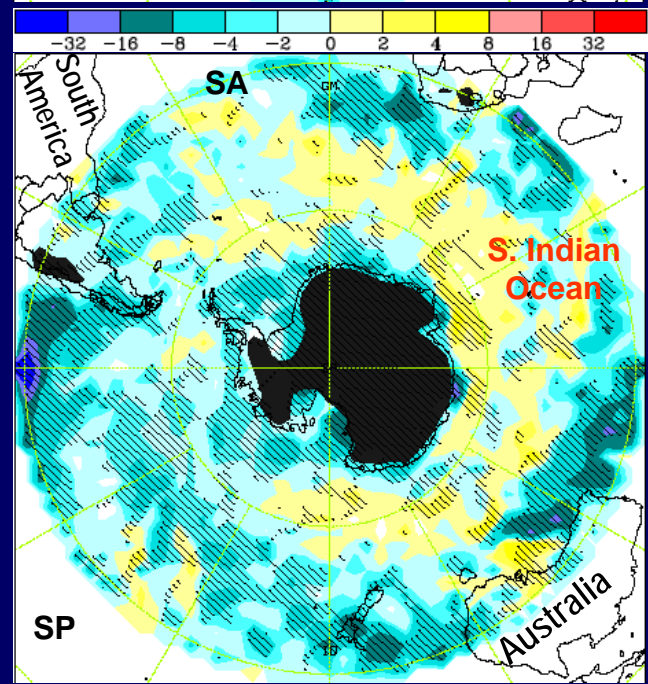
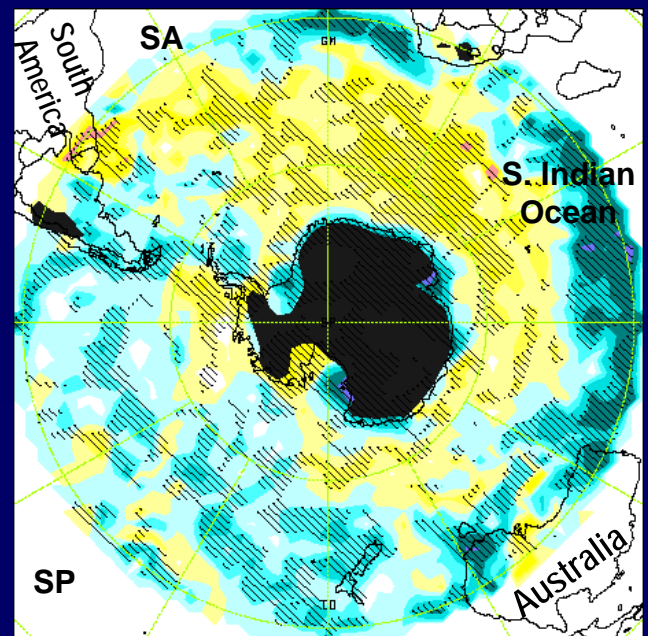
JFM →
Summer :

SA-SP: Count ↑ , Inten ↓
Indian Ocean:
Count ↓ , Inten ↑

Count/(250-km)² of all cyclones

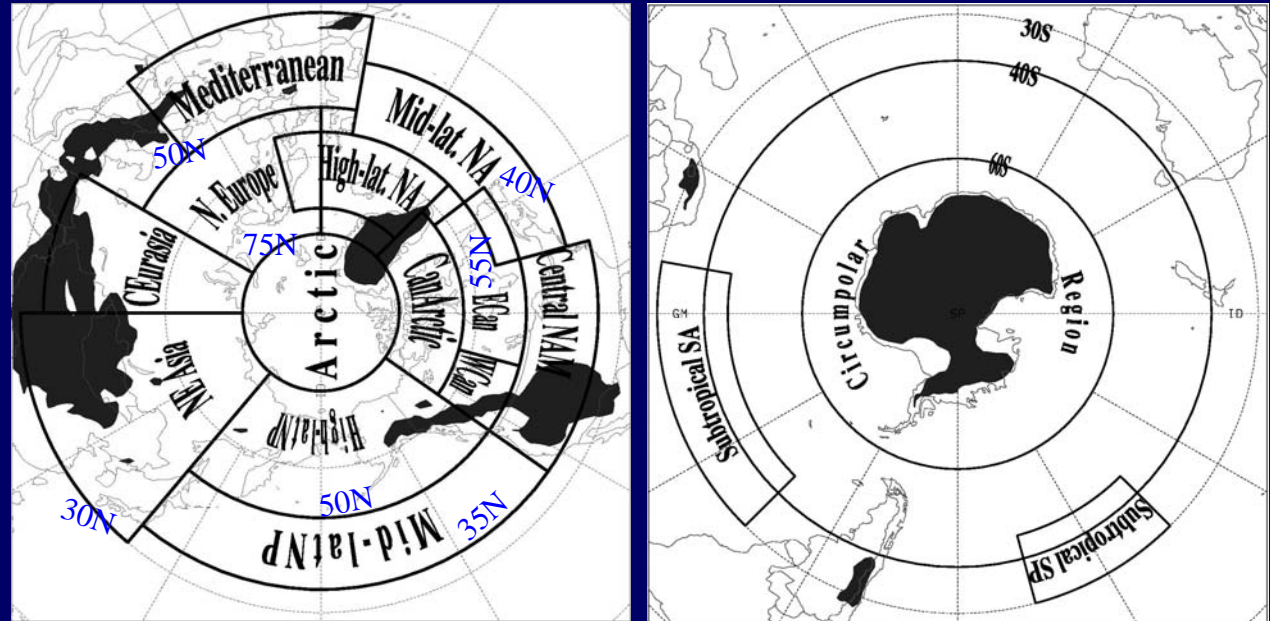


Mean intensity of all cyclones



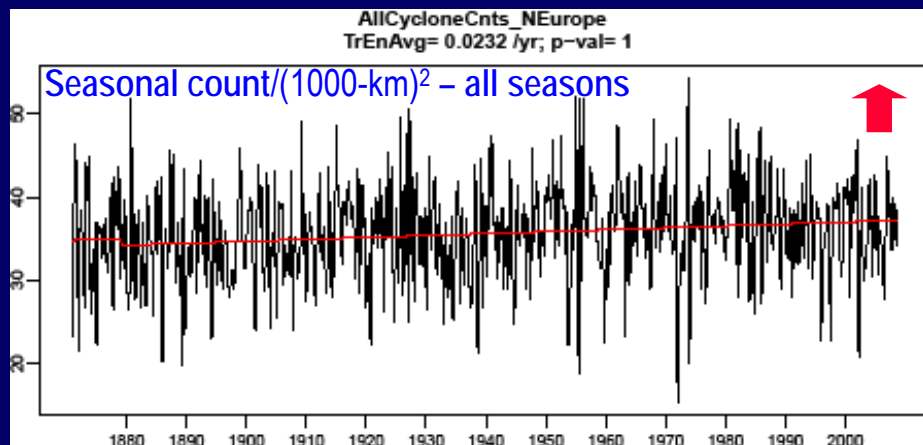
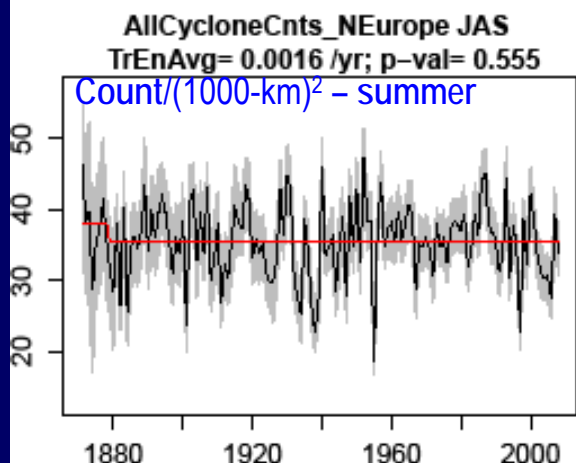
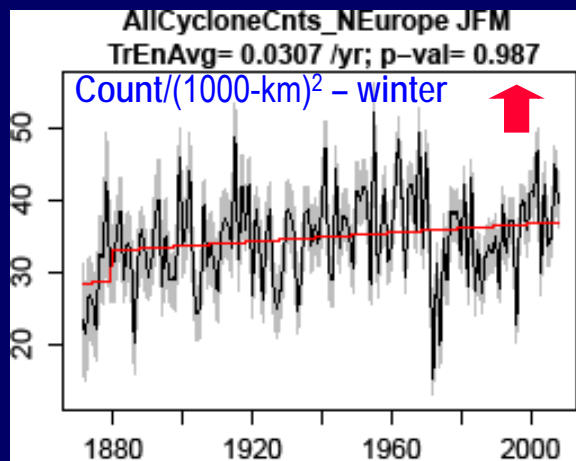
Ensemble mean series of regional means of seasonal cyclone counts and mean intensity

Selected regions:



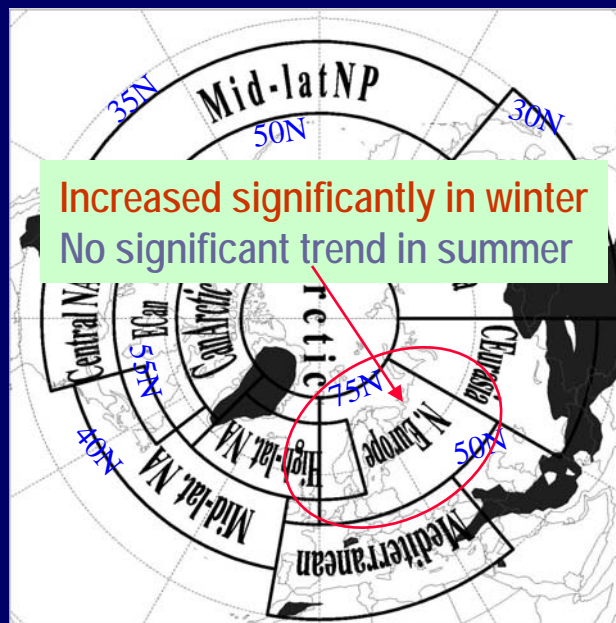
Strong cyclones: cyclones of intensity ≥ 45 units

↓
local Laplacian of pressure; unit: 10^{-5} hPa/km²)

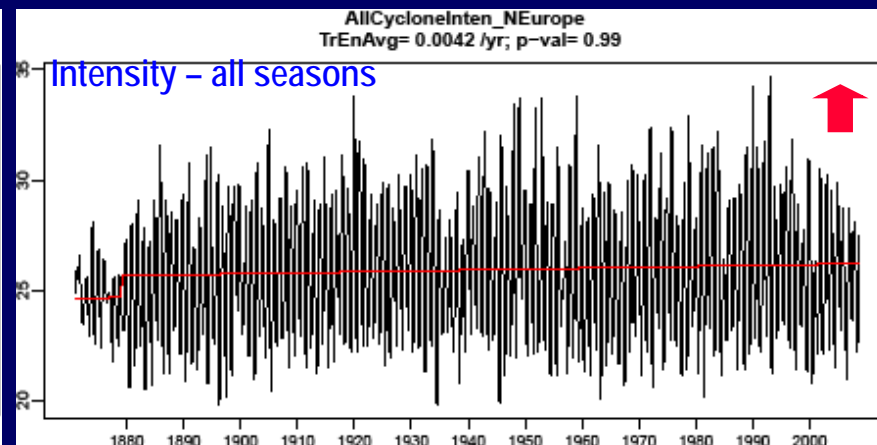
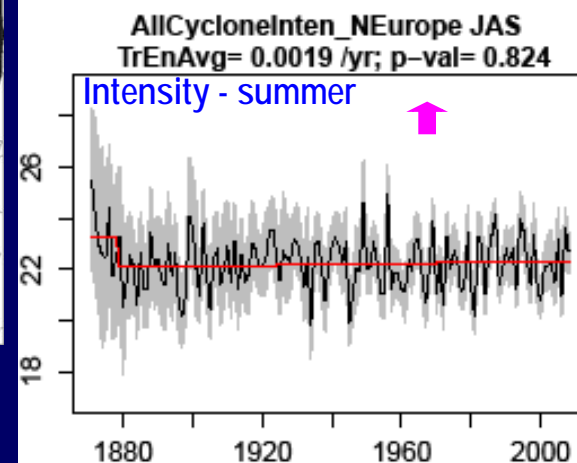
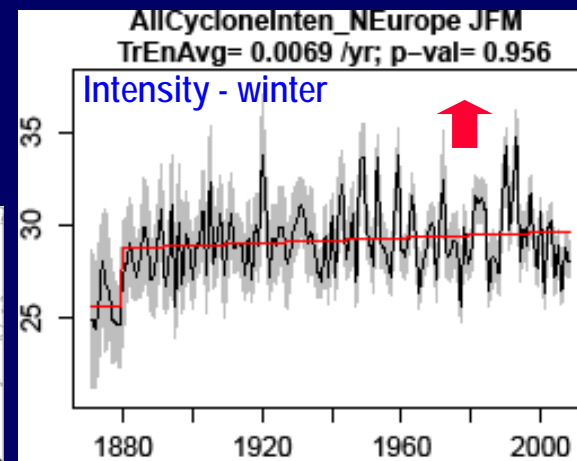


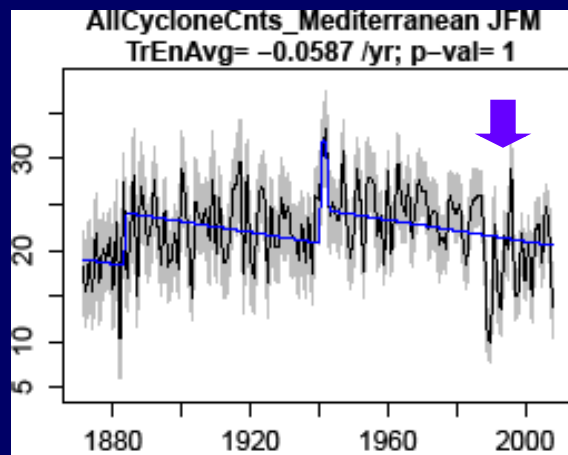
Northern Europe

- basically homogeneous
- small ensemble spread



Similar picture for strong cyclones
Grey band – ensemble spread (95% CI)

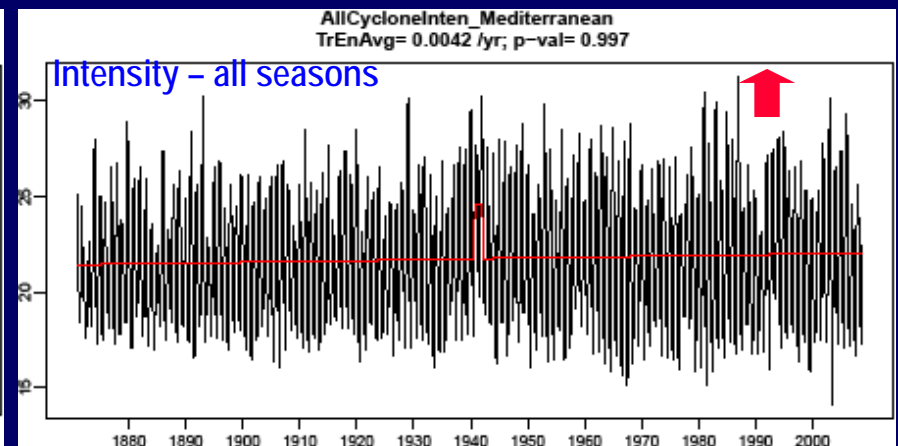
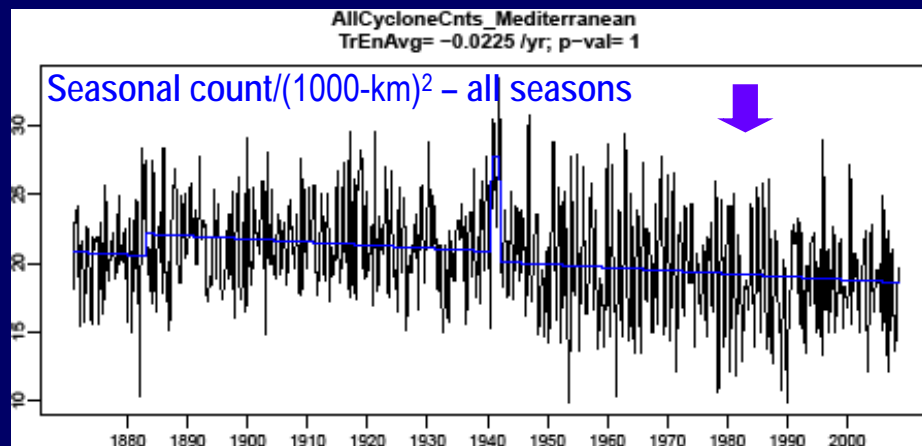
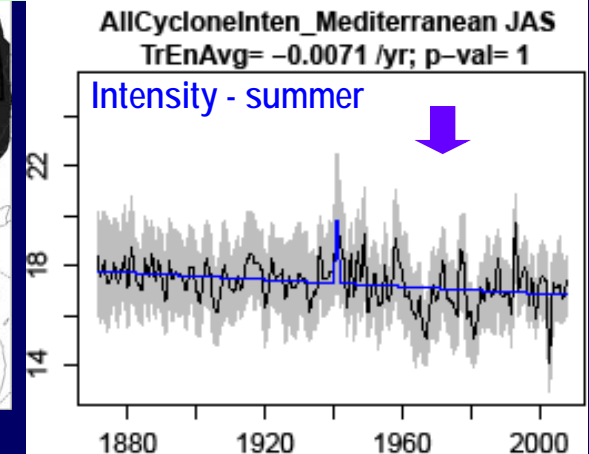
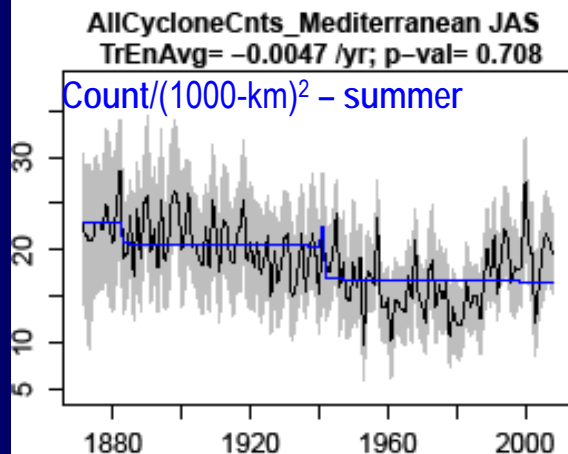
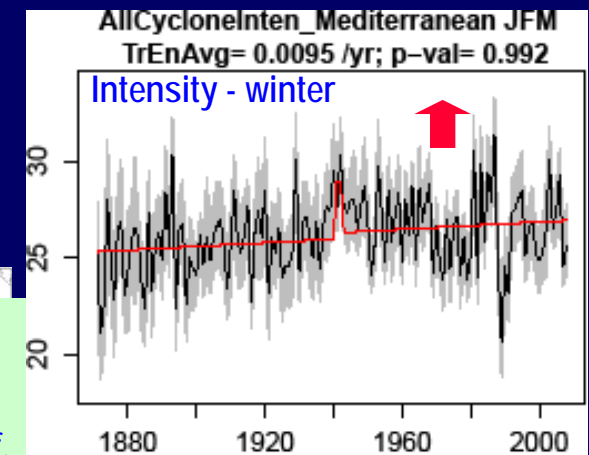
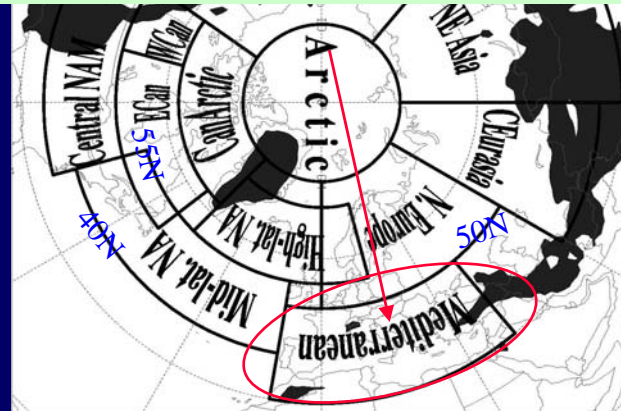


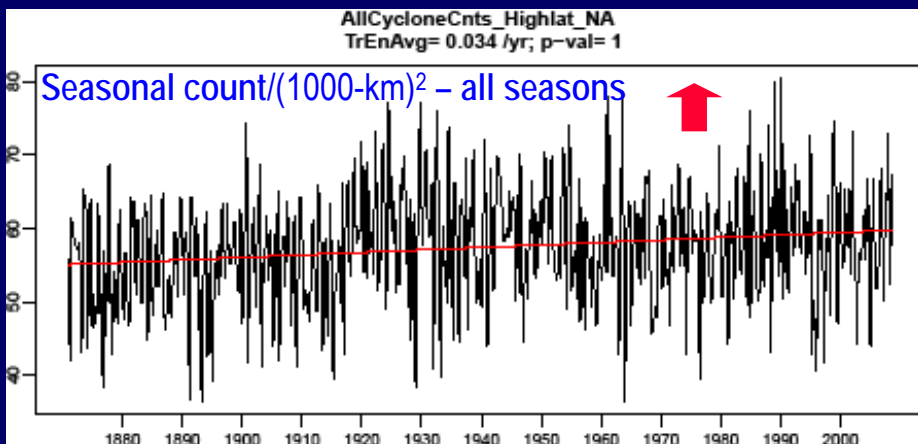
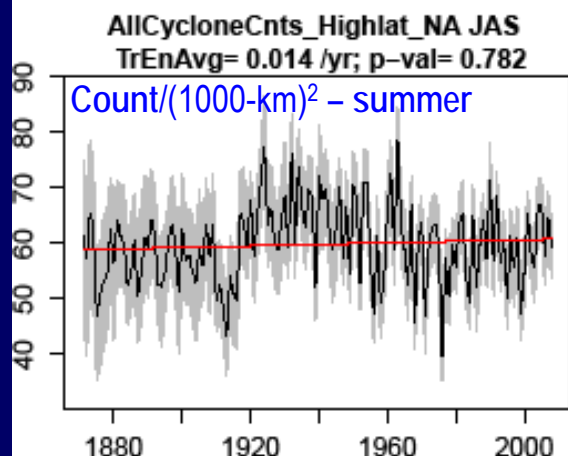
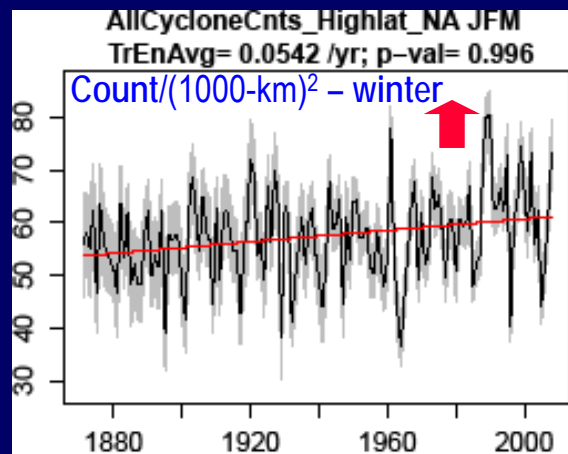


Mediterranean

- not bad in terms of homogeneity
- small ensemble spread in winter

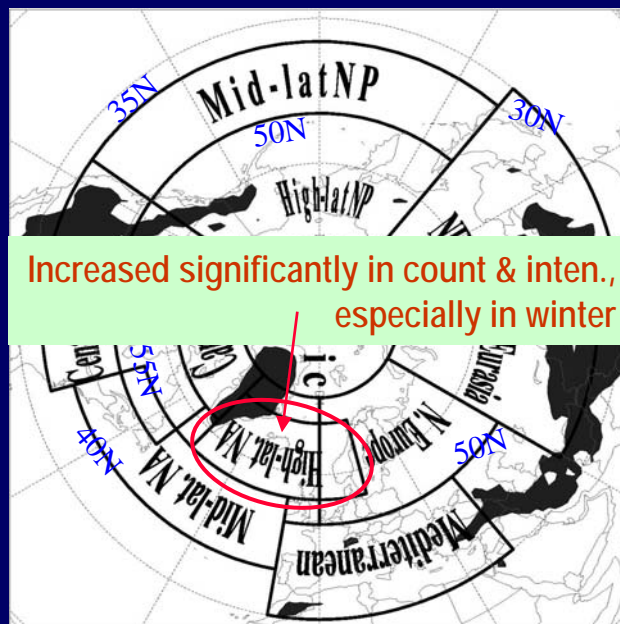
Winter cyclone inten. - increased signif.
but count seems to have decreased
Summer cyclone inten. - decreased signif.



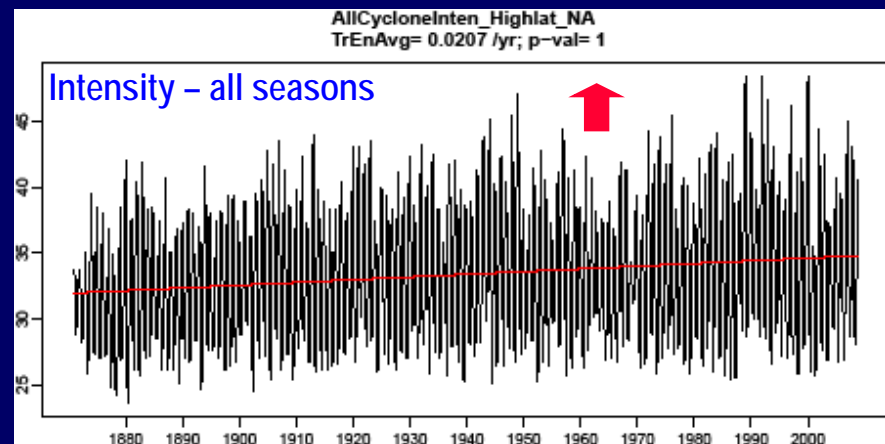
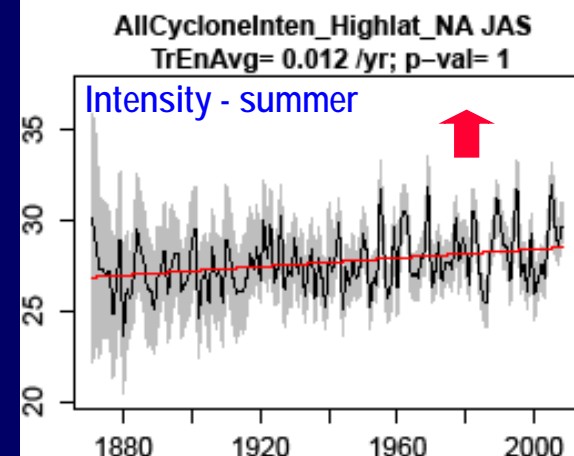
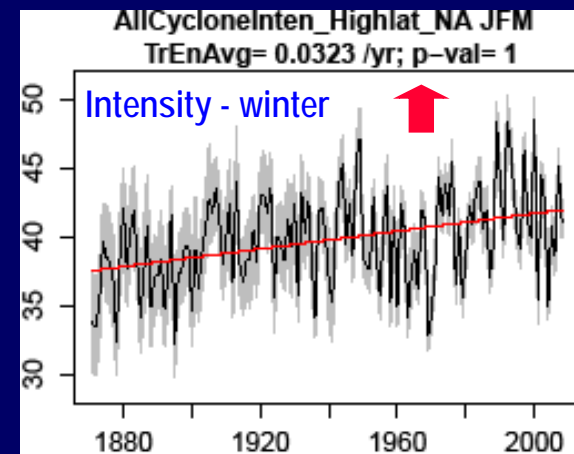


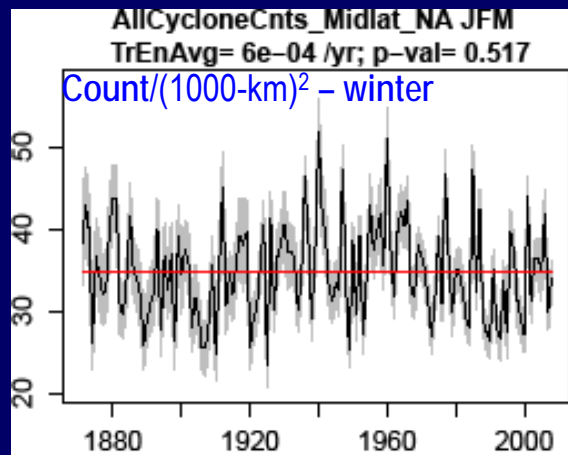
High lat. North Atlantic

- homogeneous
- small ensemble spread



Similar picture for strong cyclones



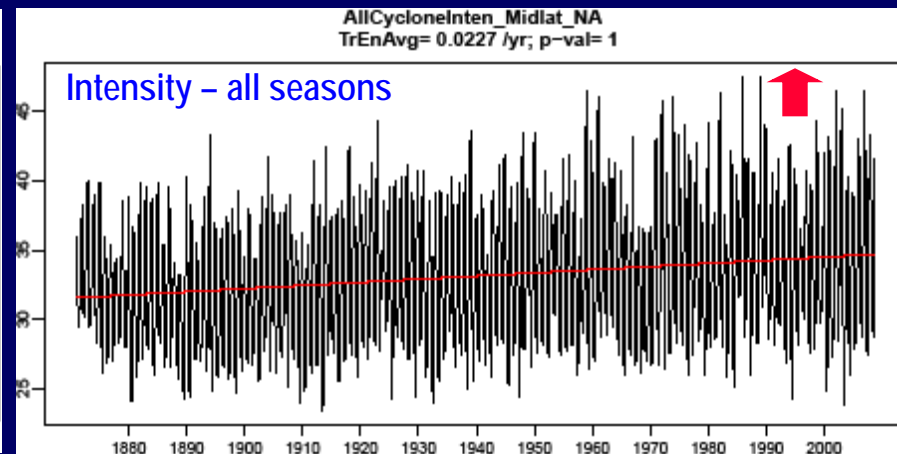
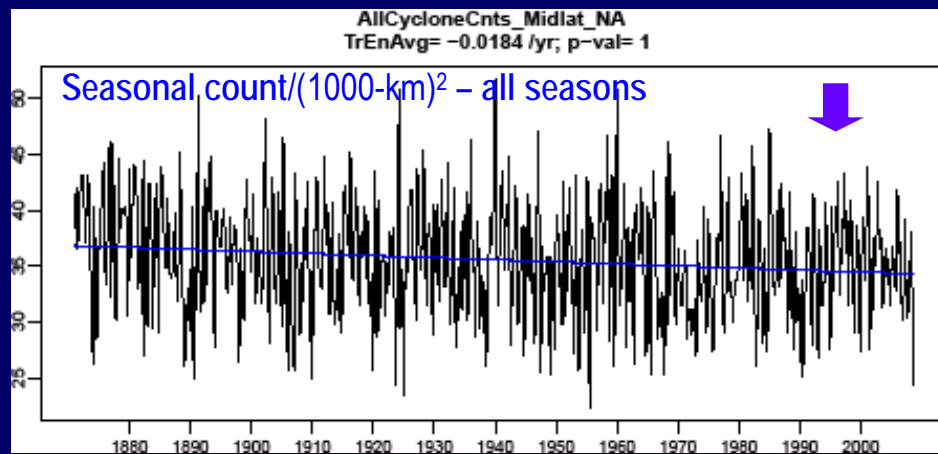
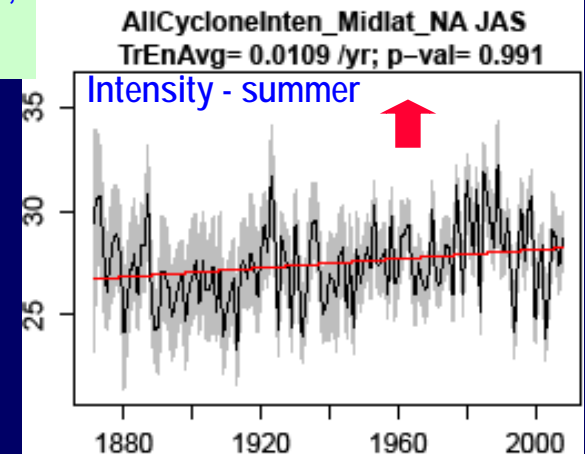
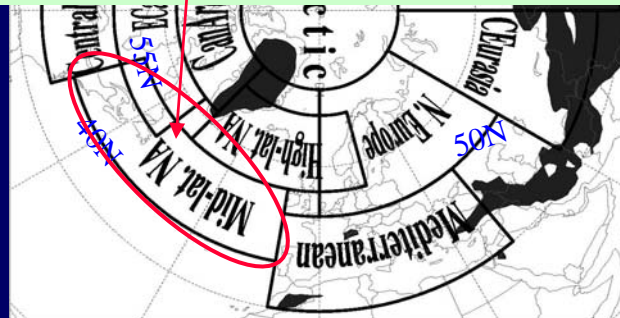
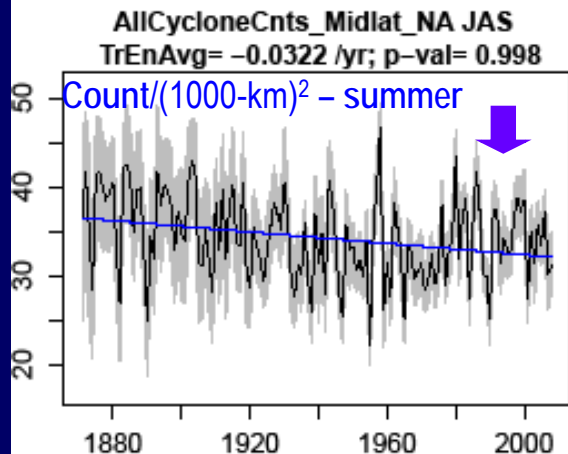
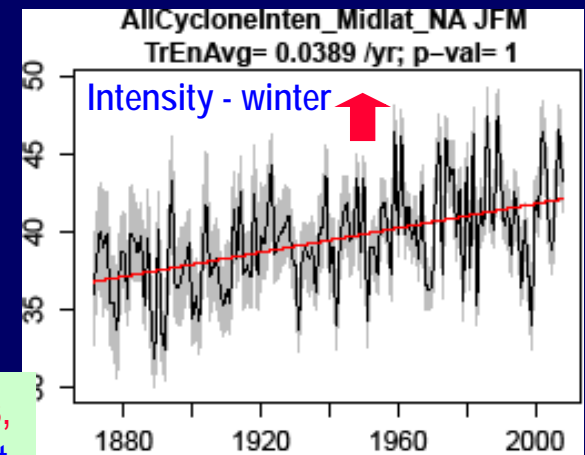


Mid-lat. North Atlantic

- homogeneous
- small ensemble spread

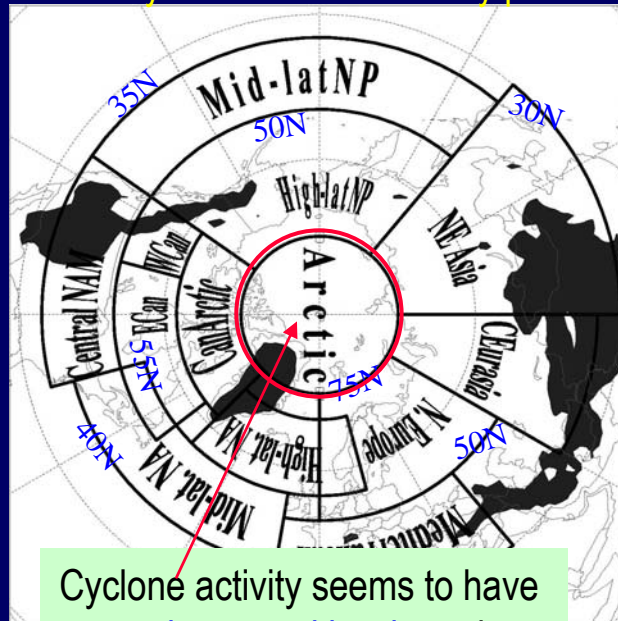


Cyclone **inten** - increased in both seasons,
with a signif. decrease in summer count,
but no signif. change in winter count

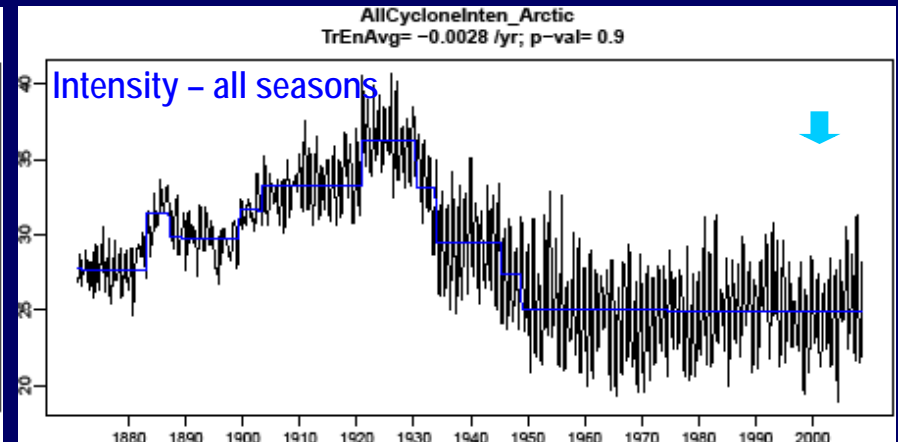
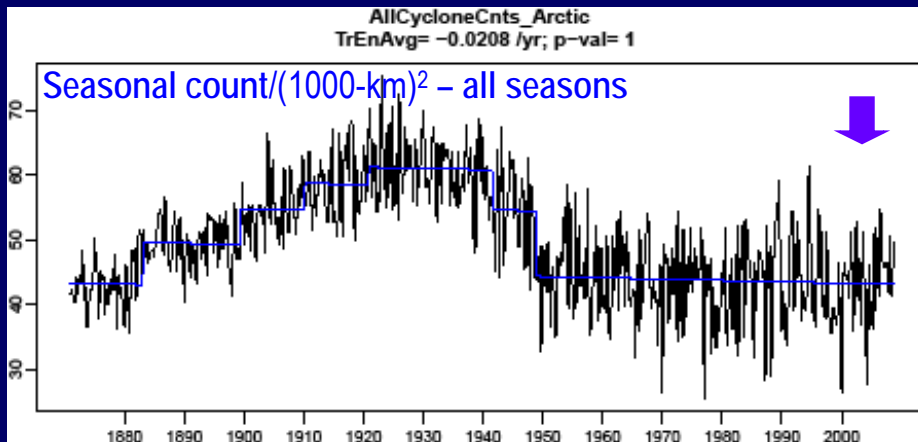
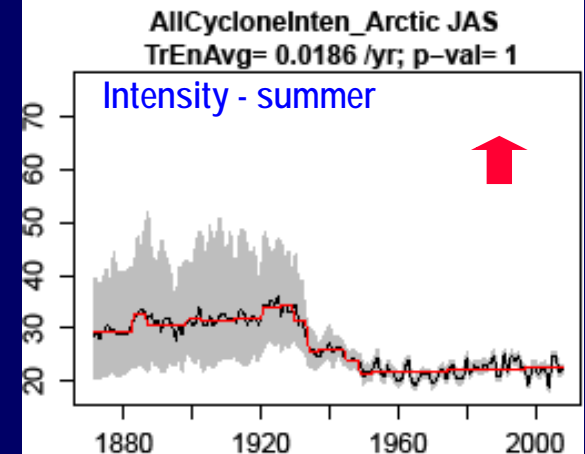
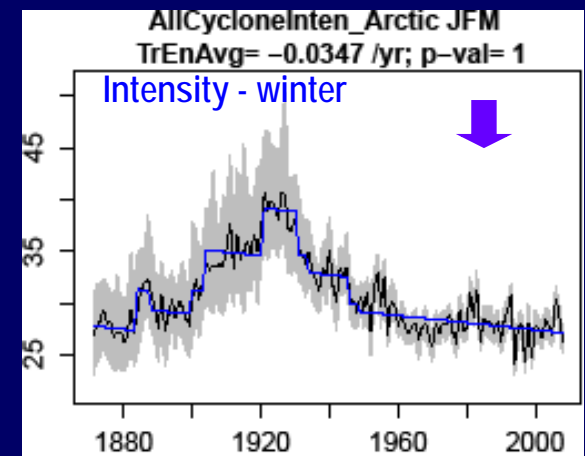
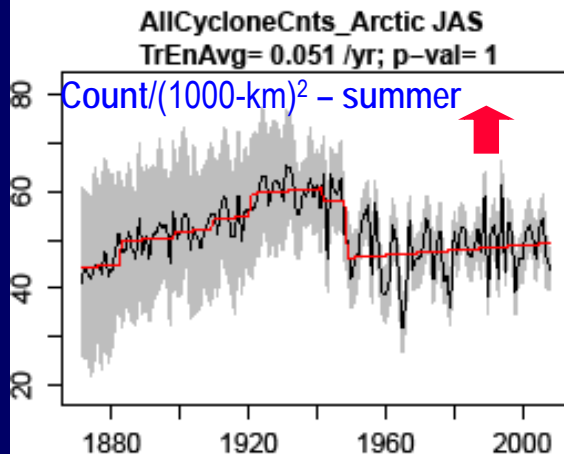
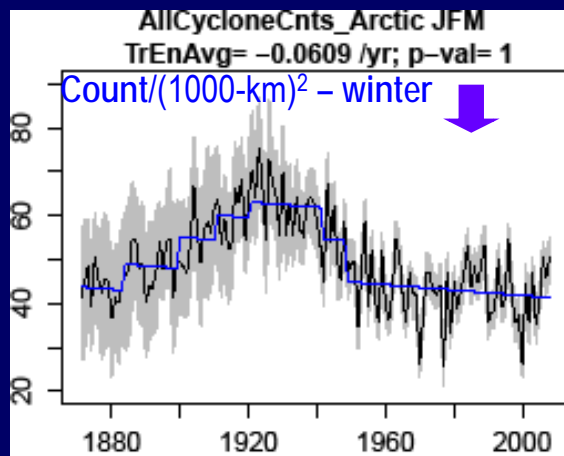


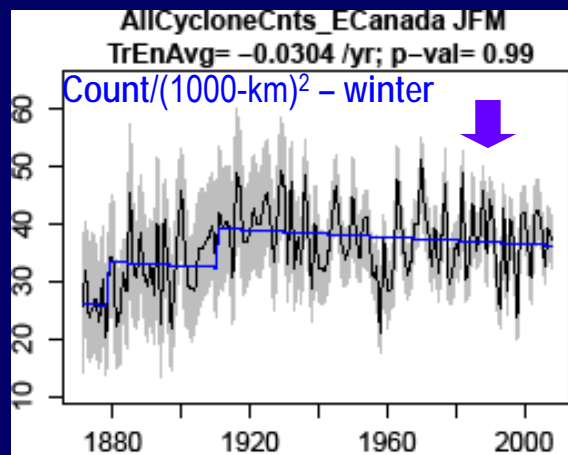
Arctic

- data sparse region
- very uncertain in the early period

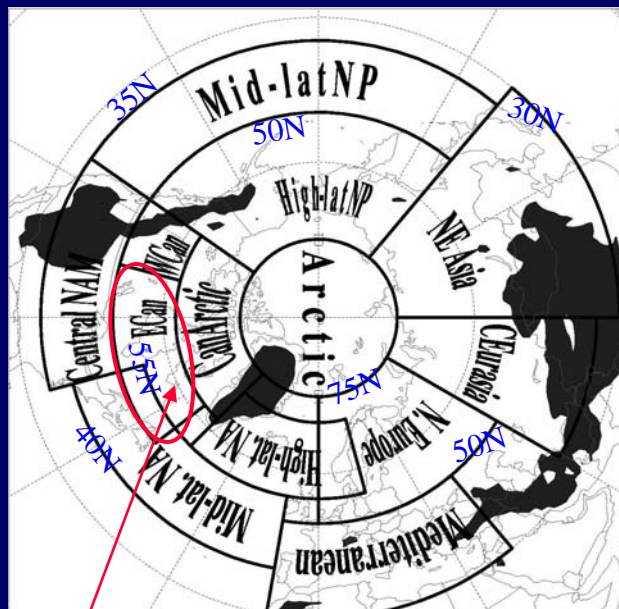


Cyclone activity seems to have
decreased in winter, but
increased in summer

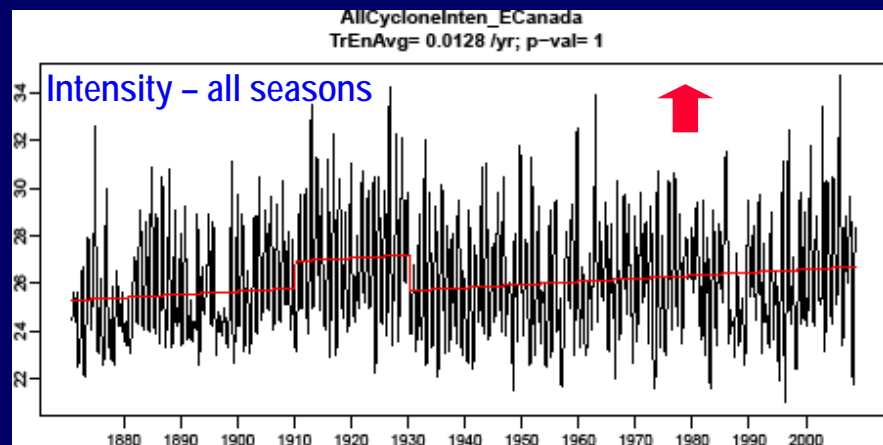
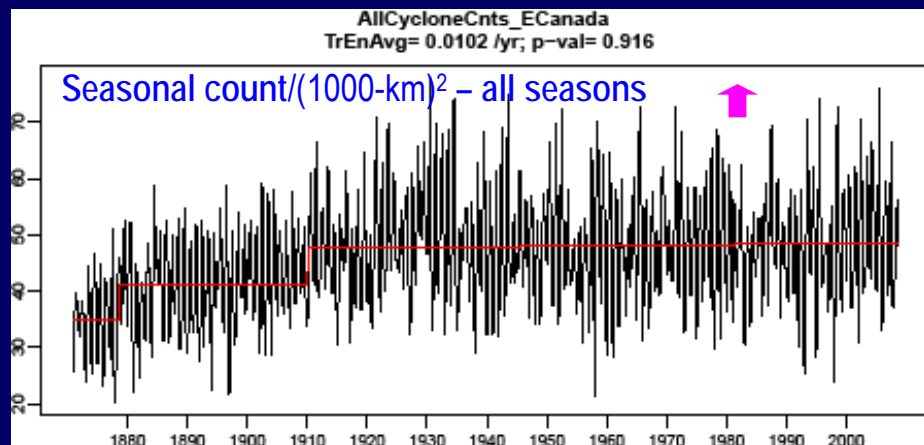
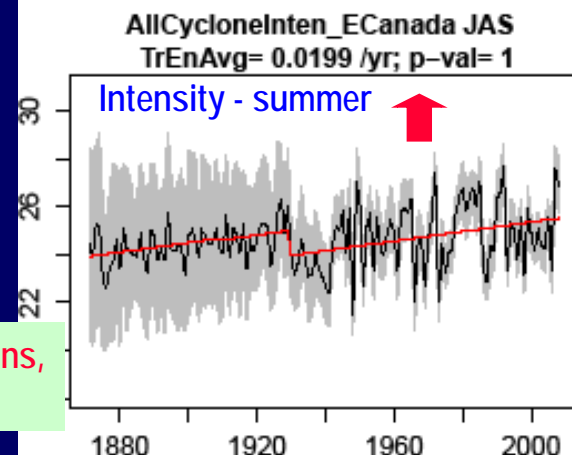
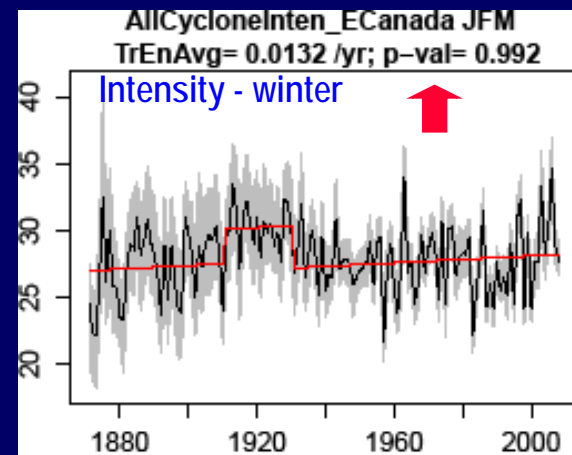
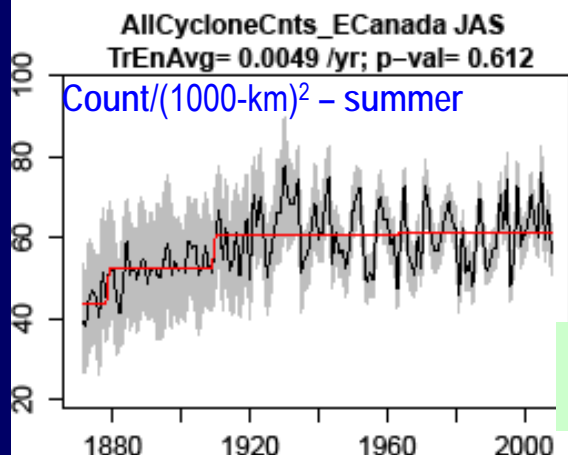




Eastern Canada
- uncertain in the early period

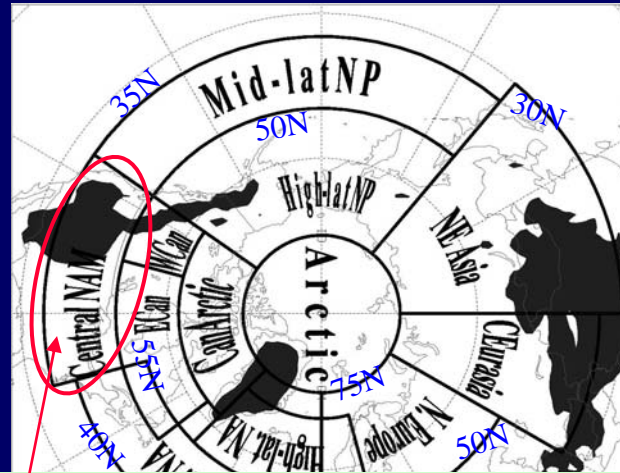


Cyclone **intensity** has increased in both seasons,
but **winter count** seems to have decreased.



Central North America (Central-North USA)

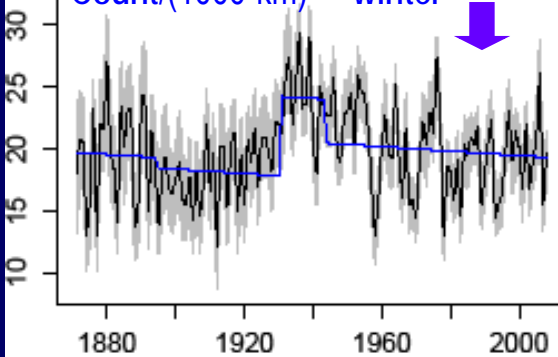
- not too inhomogeneous



Winter cyclone count seems to have decreased.
Cyclone activity in all seasons together seems to have increased significantly

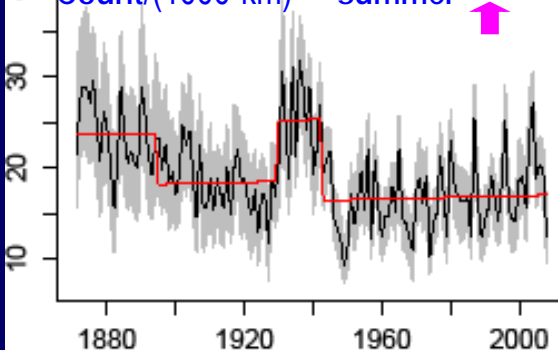
AllCycloneCnts_Central_NAM JFM
TrEnAvg= -0.018 /yr; p-val= 0.99

Count/(1000-km)² - winter



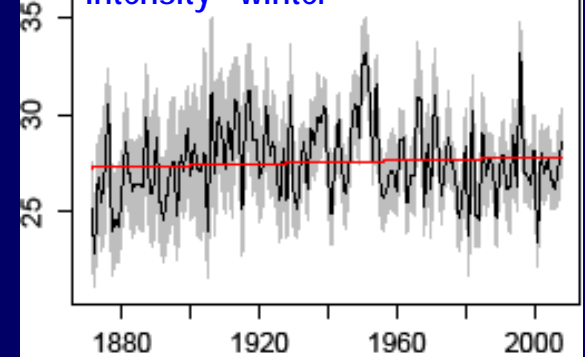
AllCycloneCnts_Central_NAM JAS
TrEnAvg= 0.009 /yr; p-val= 0.838

Count/(1000-km)² - summer



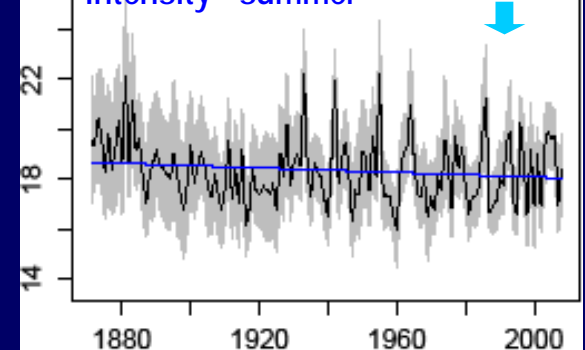
AllCycloneInten_Central_NAM JFM
TrEnAvg= 0.004 /yr; p-val= 0.795

Intensity - winter



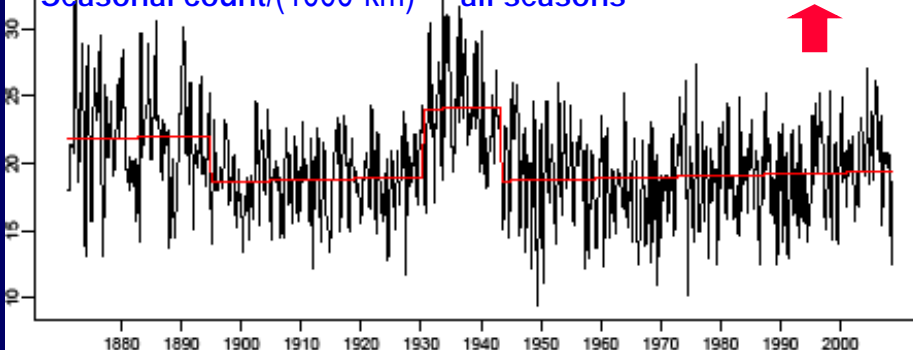
AllCycloneInten_Central_NAM JAS
TrEnAvg= -0.0046 /yr; p-val= 0.927

Intensity - summer



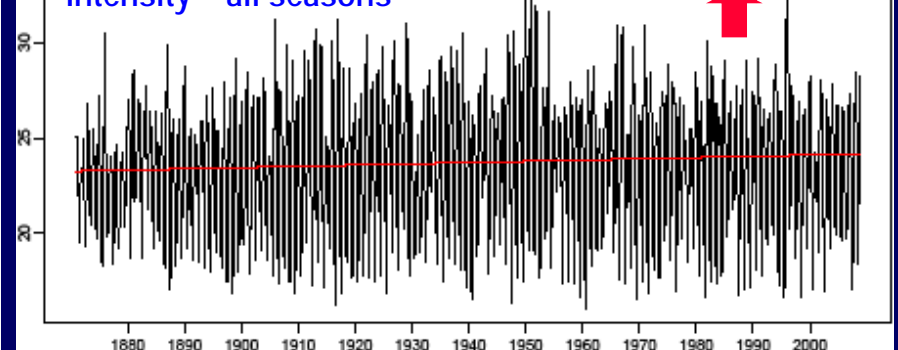
AllCycloneCnts_Central_NAM
TrEnAvg= 0.0109 /yr; p-val= 0.997

Seasonal count/(1000-km)² + all seasons

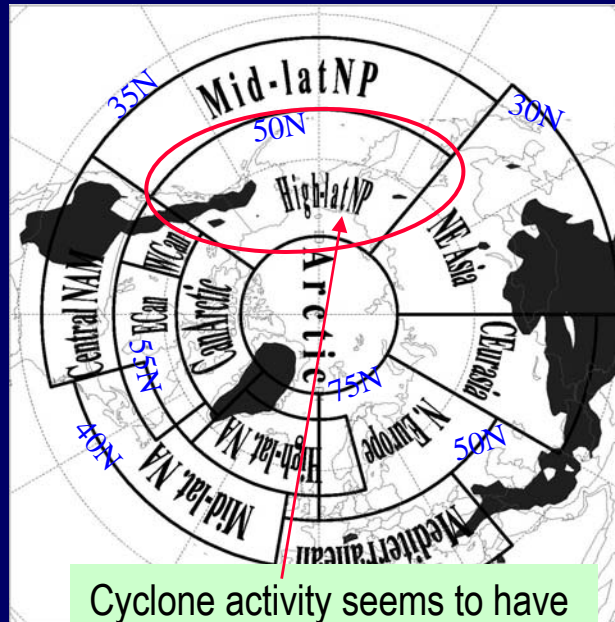


AllCycloneInten_Central_NAM
TrEnAvg= 0.0066 /yr; p-val= 0.999

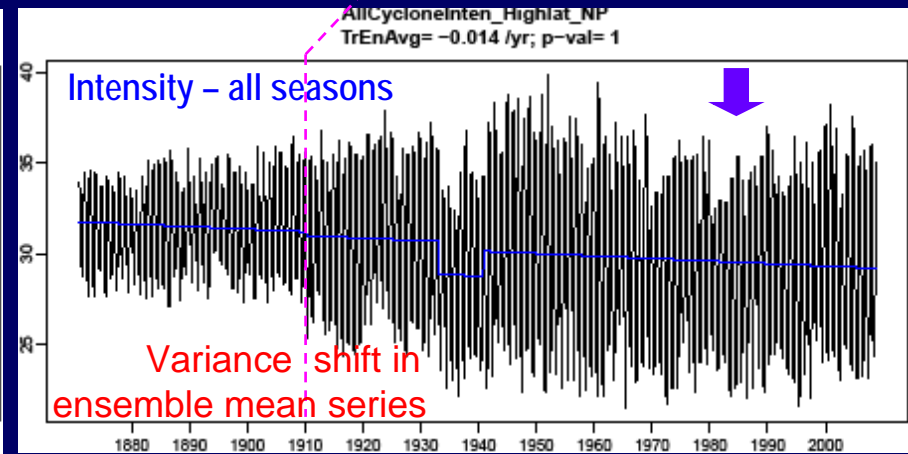
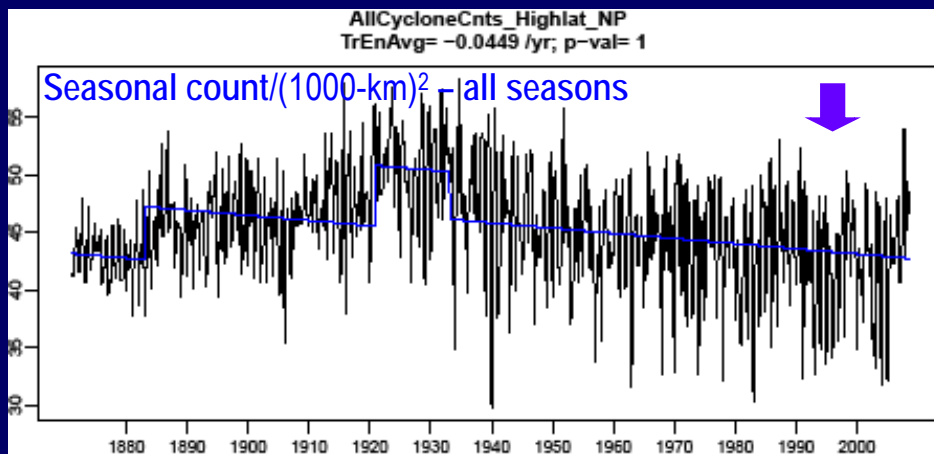
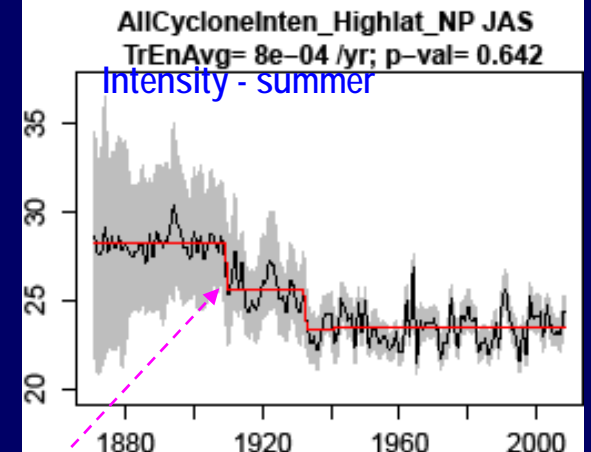
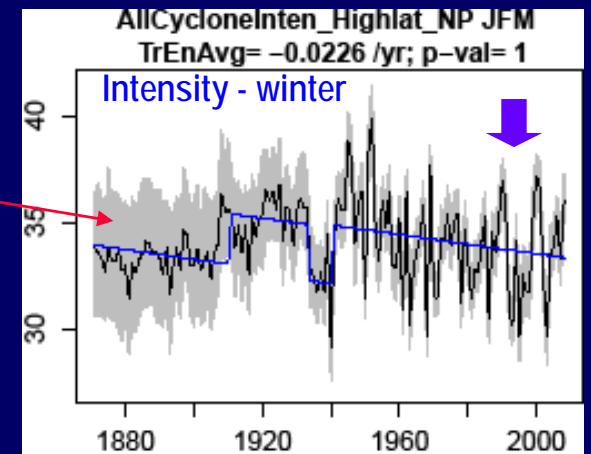
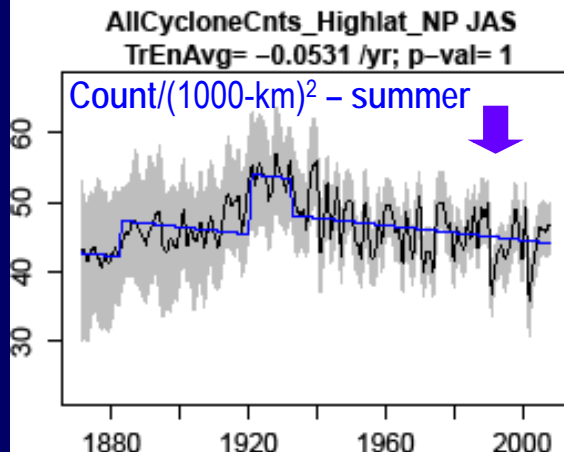
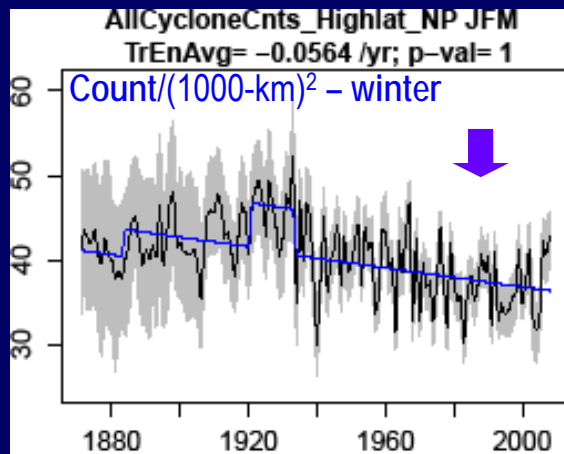
Intensity - all seasons



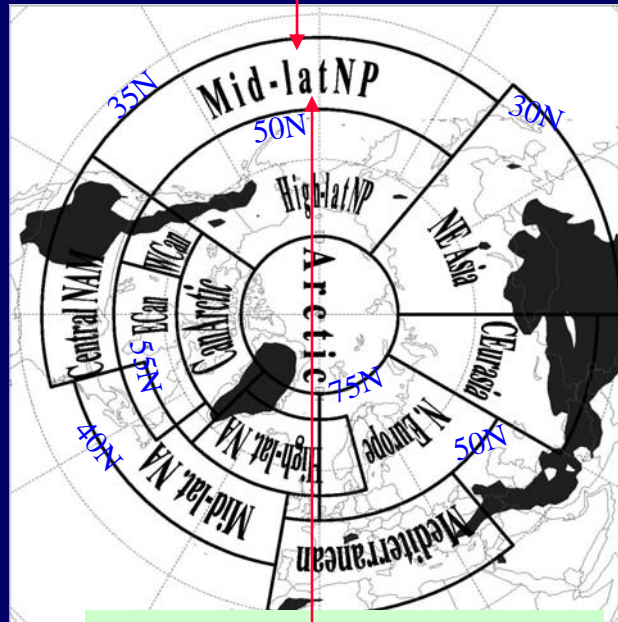
High-lat. North Pacific: (Alaska – Siberia) - very uncertain in the early period



Cyclone activity seems to have decreased, especially in winter



Mid-lat. North Pacific - uncertain in the early period

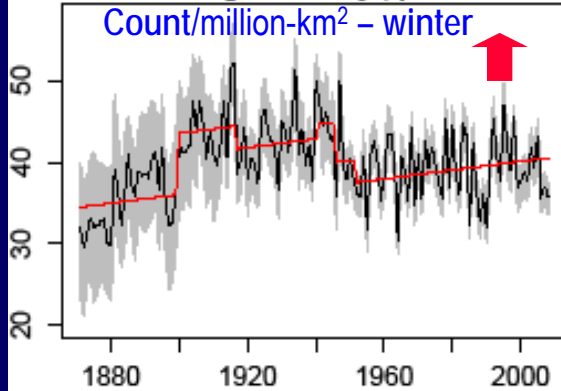


Cyclone activity seems to have
increased in all seasons

AllCycloneCnts_Midlat_NP JFM

TrEnAvg= 0.0534 /yr; p-val= 1

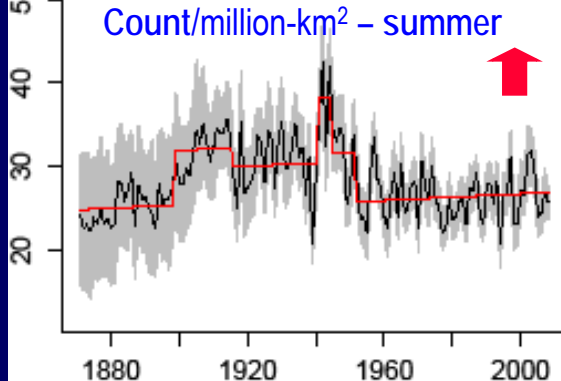
Count/million-km² - winter



AllCycloneCnts_Midlat_NP JAS

TrEnAvg= 0.02 /yr; p-val= 0.998

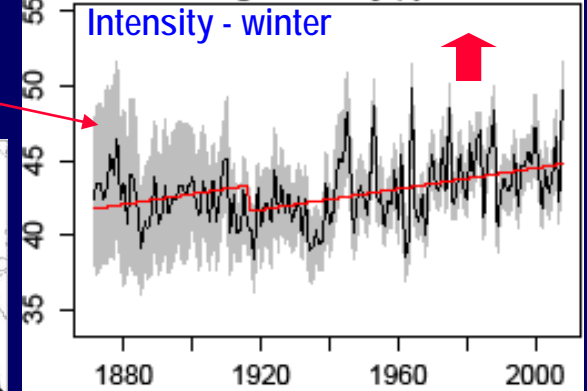
Count/million-km² - summer



AllCycloneInten_Midlat_NP JFM

TrEnAvg= 0.0348 /yr; p-val= 1

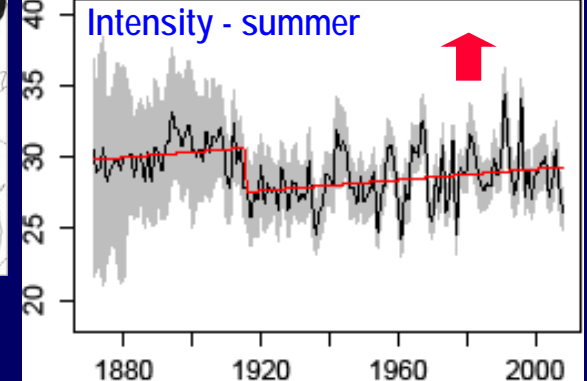
Intensity - winter



AllCycloneInten_Midlat_NP JAS

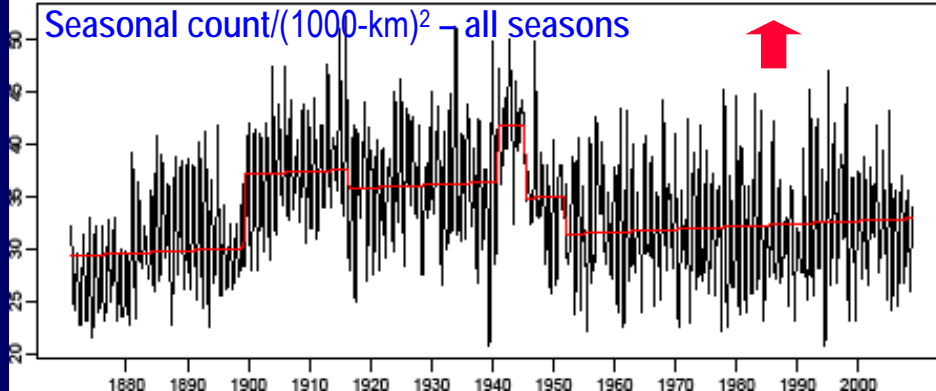
TrEnAvg= 0.019 /yr; p-val= 1

Intensity - summer



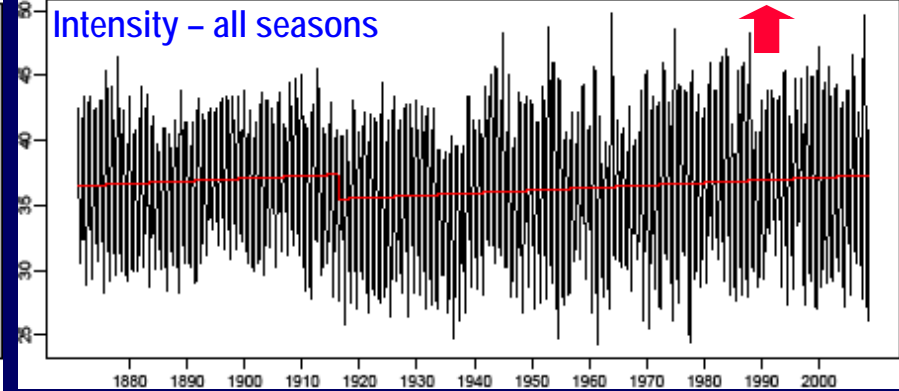
AllCycloneCnts_Midlat_NP
TrEnAvg= 0.0268 /yr; p-val= 1

Seasonal count/(1000-km)² - all seasons

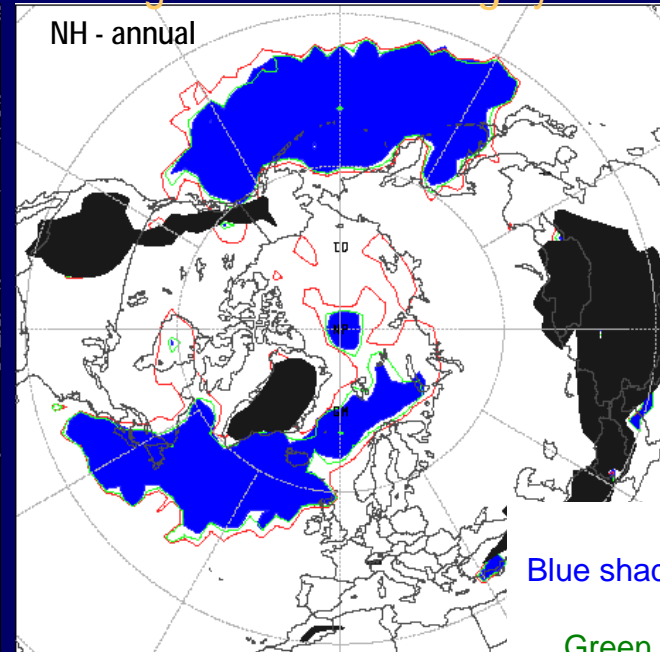
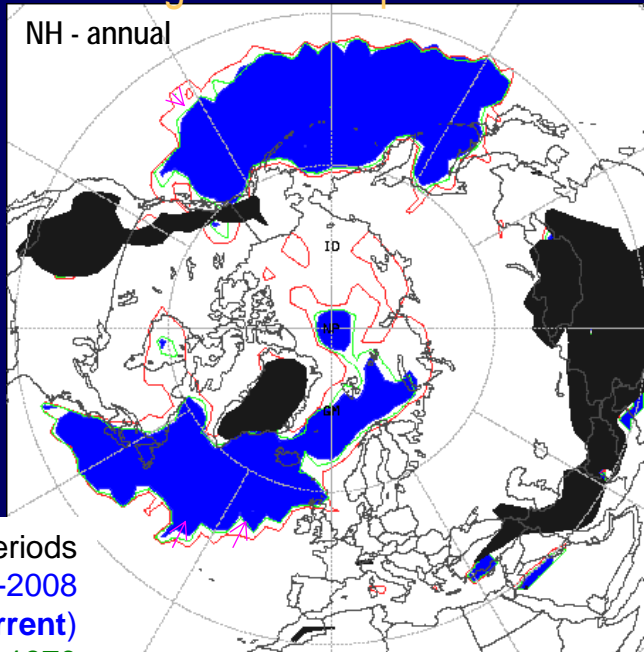


AllCycloneInten_Midlat_NP
TrEnAvg= 0.0197 /yr; p-val= 1

Intensity - all seasons

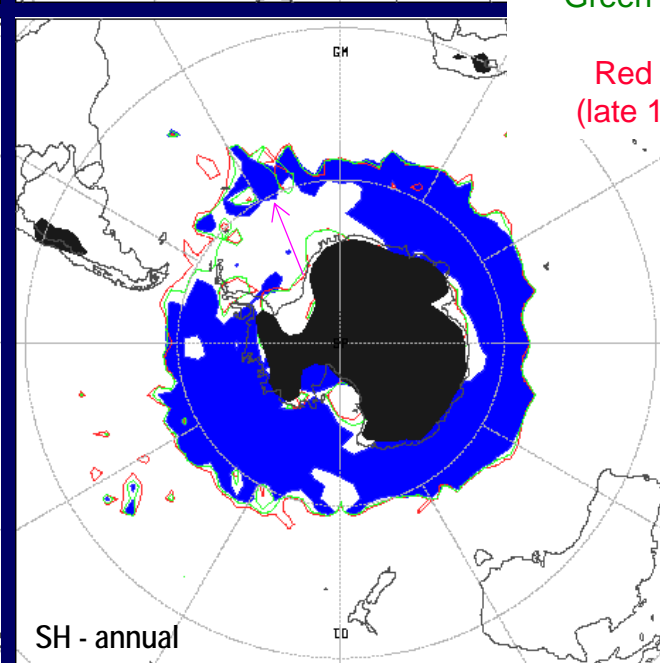
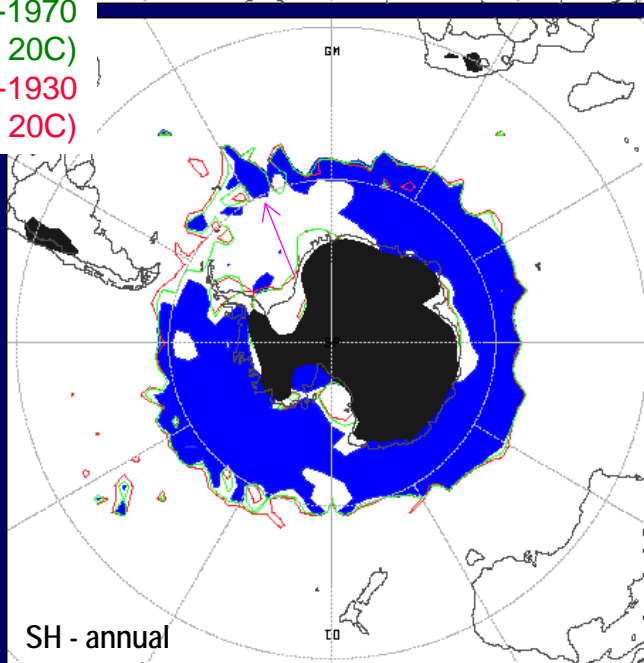


Major storm track regions – 85th percentile contour of long-term mean strong cyclone counts



30-yr periods
Blue shading: 1979-2008
(current)
Green line: 1941-1970
(mid 20C)
Red line: 1901-1930
(early 20C)

20-yr periods
Blue shading: 1989-2008
(current)
Green line: 1939-1958
(mid 20C)
Red line: 1889-1908
(late 19C - early 20C)



Summary

The 20CR ensemble mean 6-hourly SLP fields are not suitable for analyzing extremes such as cyclone activity, especially in data sparse areas/periods.

e.g., the Arctic in the pre-1950 period

Good news: The 20CR shows homogeneous representation of cyclone activity over the N. Atlantic & Europe.

In the SH, it is more homogeneous than NCEP1 (and ERA40) for the last half century.

In general, it is quite comparable to NCEP1&2, especially over oceans.

After the discontinuities being accounted for, the 20CR shows significant

increases in hemispheric cyclone count & mean intensity in both hemispheres, with regional & seasonal differences:

- The NH **increases** are mainly in **High-lat NA, N.Europe, and Mid-lat. NP**, with **decreases** in **High-lat NP**;
- Mediterranean: **winter cyclone intensity has increased** but **count decreased**, with a **decrease in summer intensity**
- Central-North USA: cyclone activity seems to have increased annually, with a **decrease in winter count**.
- Central-Eastern Canada: cyclone intensity has **increased in both winter & summer**, but decreased in winter count

Thank you very much!