Changes in extra-tropical storm tracks and cyclone activity as derived from two global reanalyses and the Canadian CGCM2 projections of future climate

by

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- Introduction - Datasets & Methodologies
- Changes “observed” in 1958-2001
- Possible future changes
- Summary

Datasets: Global 6-hourly MSLP fields

"Observations" (on a 2.5x2.5 lat/long grid):

1. ERA-40 reanalysis
2. NCEP reanalysis

→ 1958-2001 (44 yr)

Projections (on a 96x48 Gaussian grid):

3. CGCM2 simulations:

IS92a scenario: 1975-94, 2040-59, 2080-99 (3x20 yr)

Equal Area SSM/I Earth

- Converted to a 250x250 km EASE-grid for detection/tracking of cyclones

Cyclone detection/tracking algorithm: (Courtesy of Mark Serreze; Serreze et al. 1997)

1. Cyclone detection: test whether a grid-point MSLP value is surrounded by grid-point values higher than the central point being tested

2. Cyclone tracking: based on a "nearest neighbor" analysis of the positions of cyclones between time steps with a maximum distance threshold between candidate pairings.

Terminology

Cyclone: A single low pressure center at a specific time & site

Cyclone-track: A cyclone and its trajectory during its lifetime
(may consist of many cyclones, one at each specific time step)

Mean position of extra-tropical storm track: Mean latitude of all cyclones within each 5°-long. band in 30°-70° N (S)

All cyclones
- Strong cyclones: Central SLP < 990 mb
- Weaker cyclones: Central SLP = 990 mb

20-yr periods:

Total # of (log-odds) { all / strong / weaker } cyclones { observed { 1958-77 / 1982-2001 } / simulated { 1975-94 / 2080-99 } }

One-sided two-sample t-tests:

Any significant change in the frequency or areal mean lifespan of cyclone-tracks?

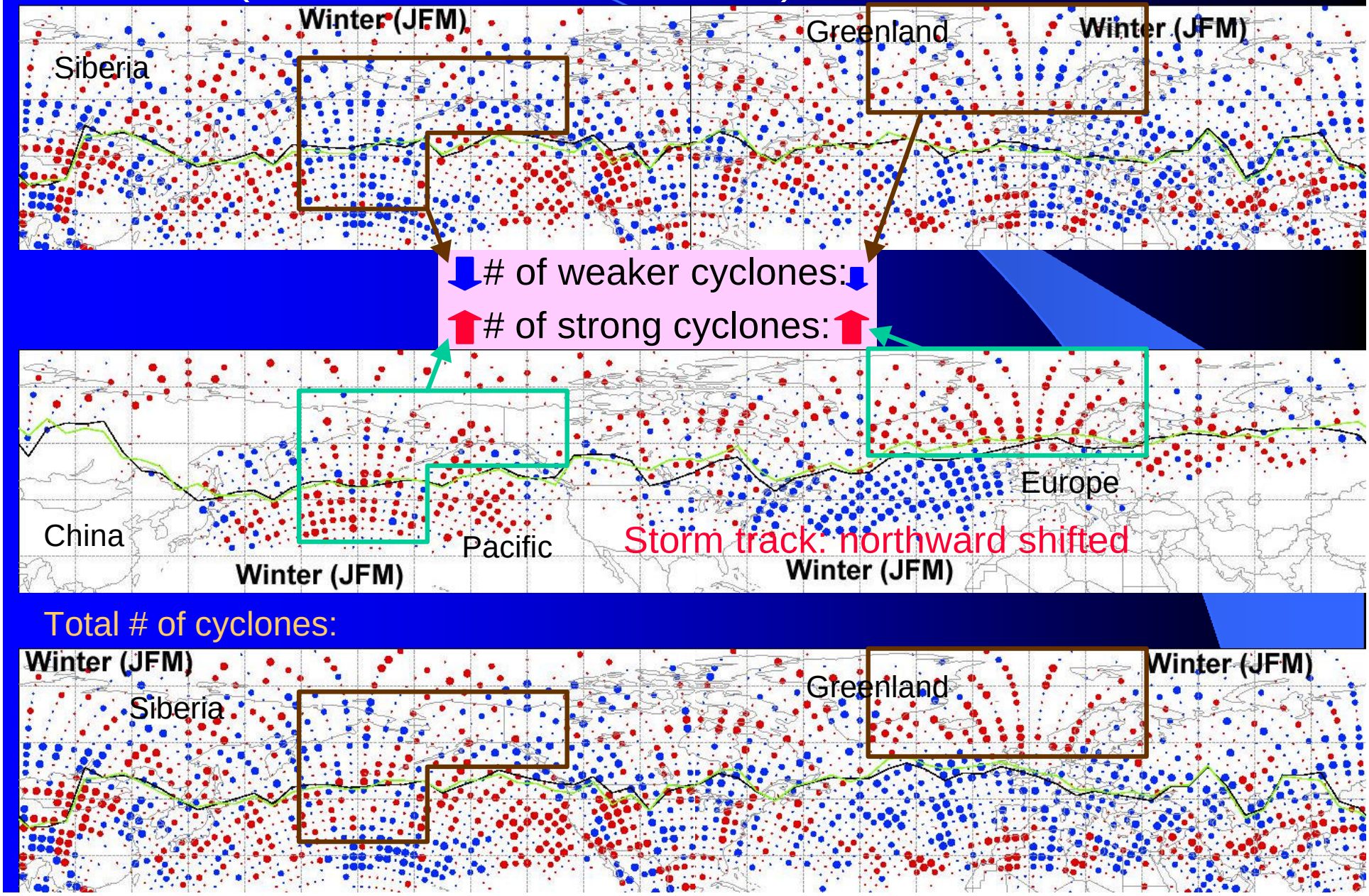
(from the first to the second period)

Observed changes (ERA-40)

(1982-2001 minus 1958-77)

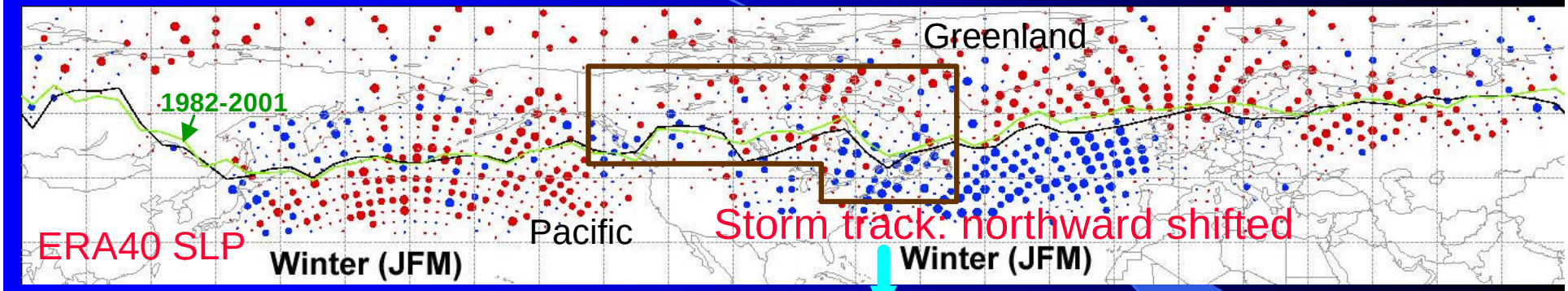
Observed changes – NH winter
(1982-2001 minus 1958-77)

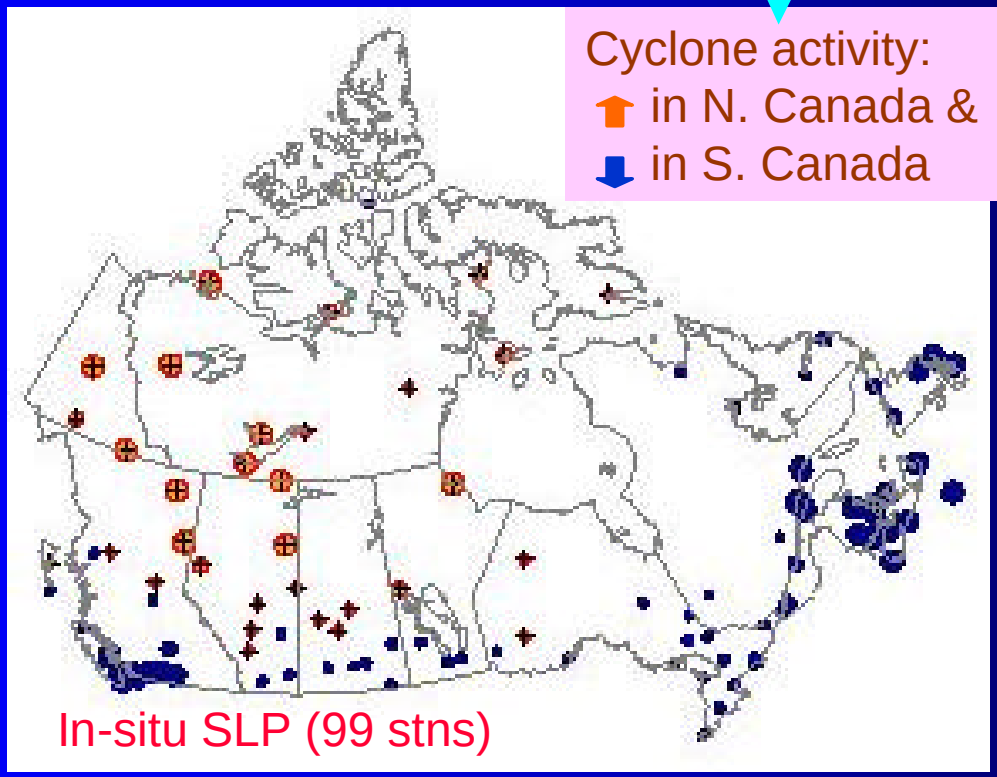
Red: ⬆ Blue: ⬇
Large dots: >= 95% conf.



Observed changes – NH winter

(1982-2001 minus 1958-77)





Cyclone activity:
- ⬆ in N. Canada &
- ⬇ in S. Canada

Consistency between ERA40 & in-situ data

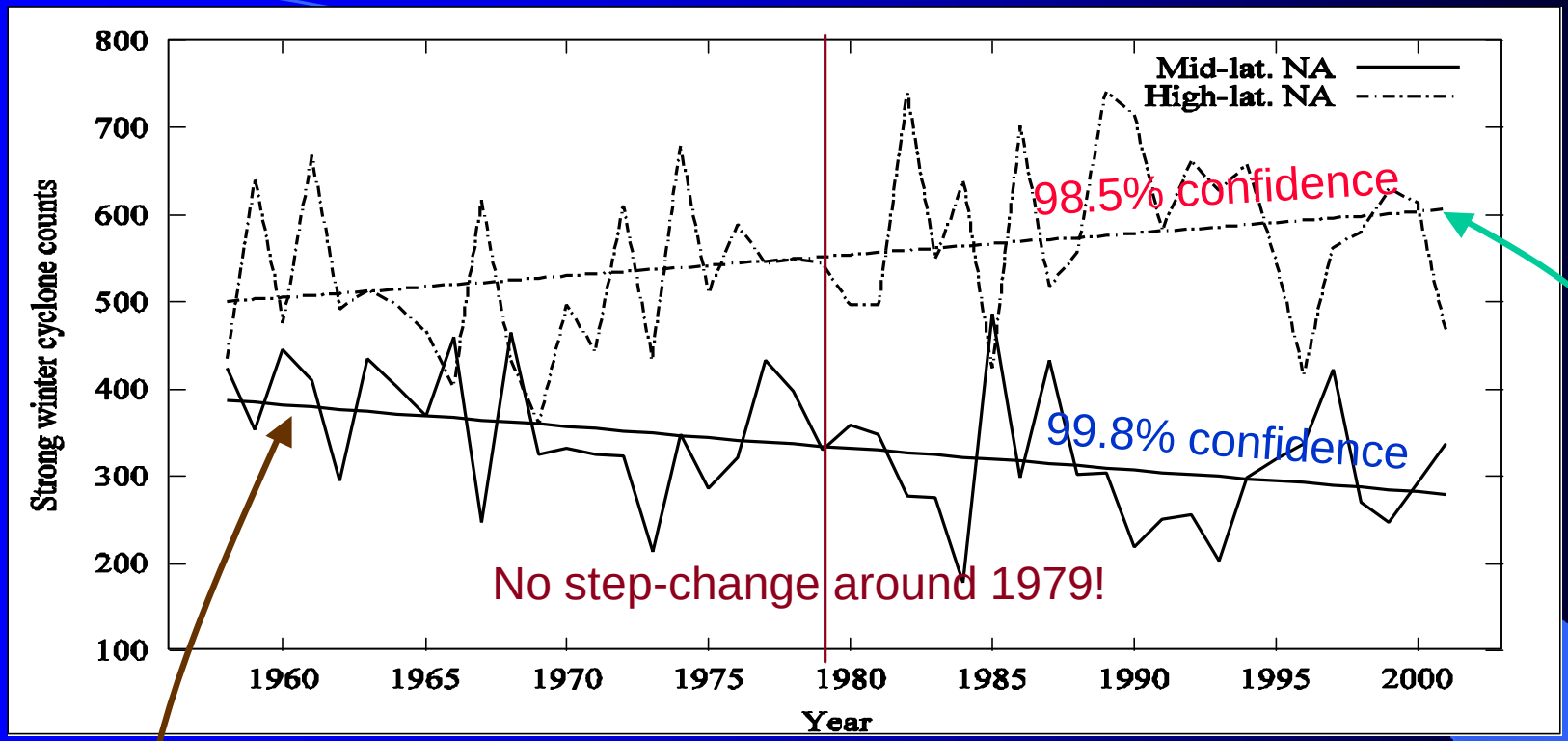
⇩

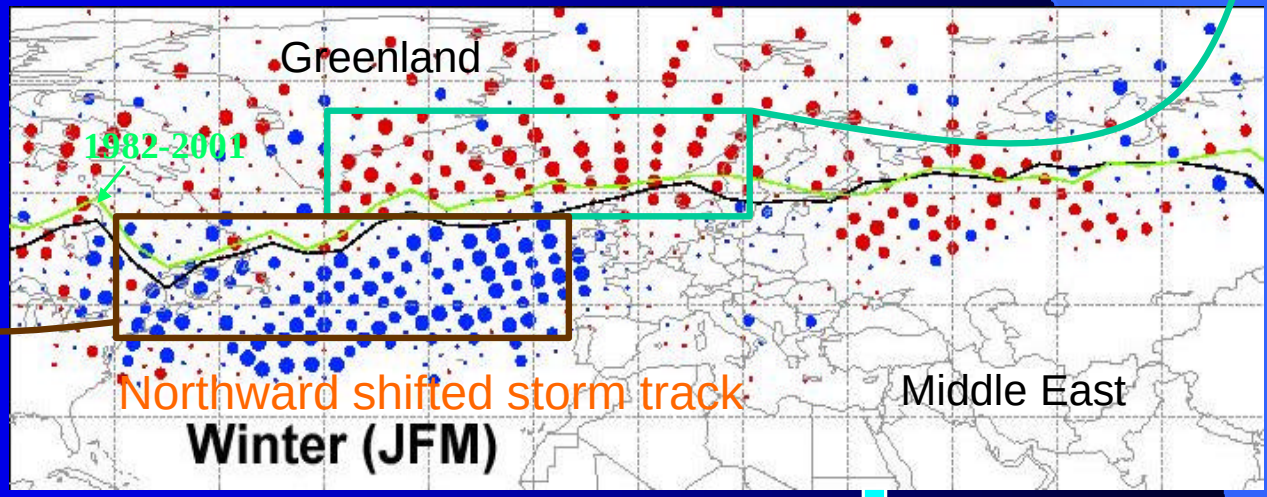
Changes: most likely real, not artifact!

⇩

More evidence

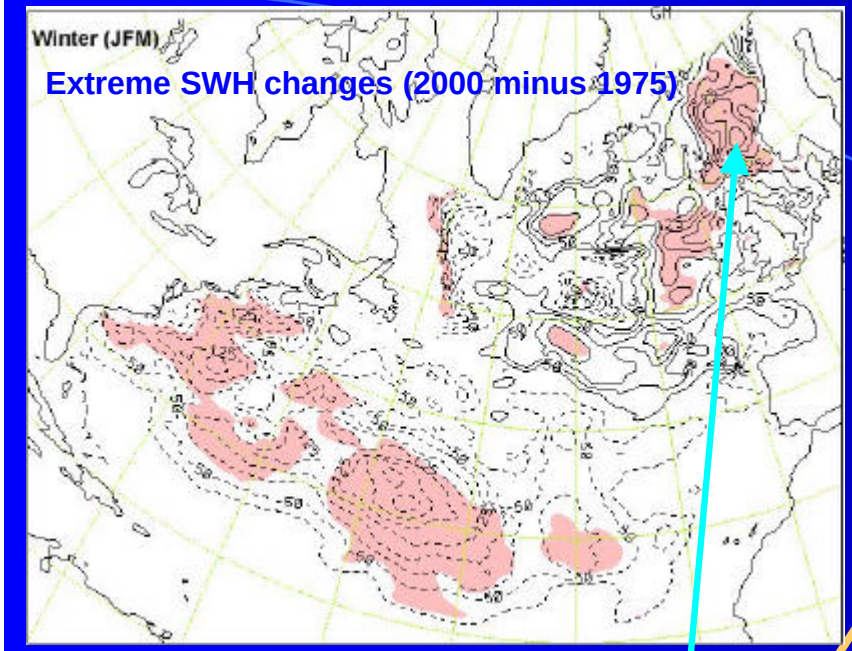
Wang et al. 2004

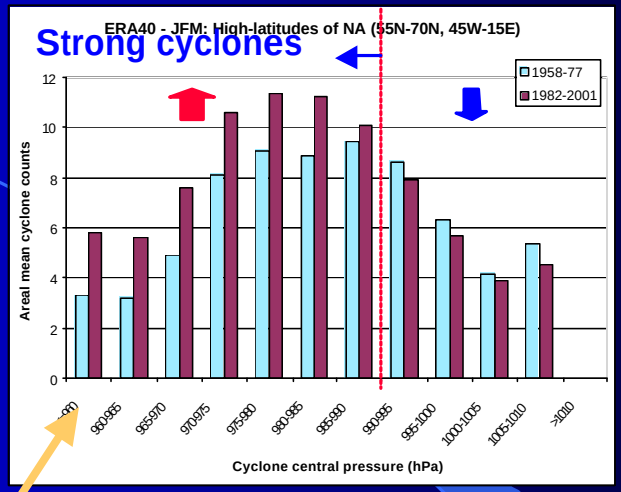




Most likely real!

Wang et al. 2004

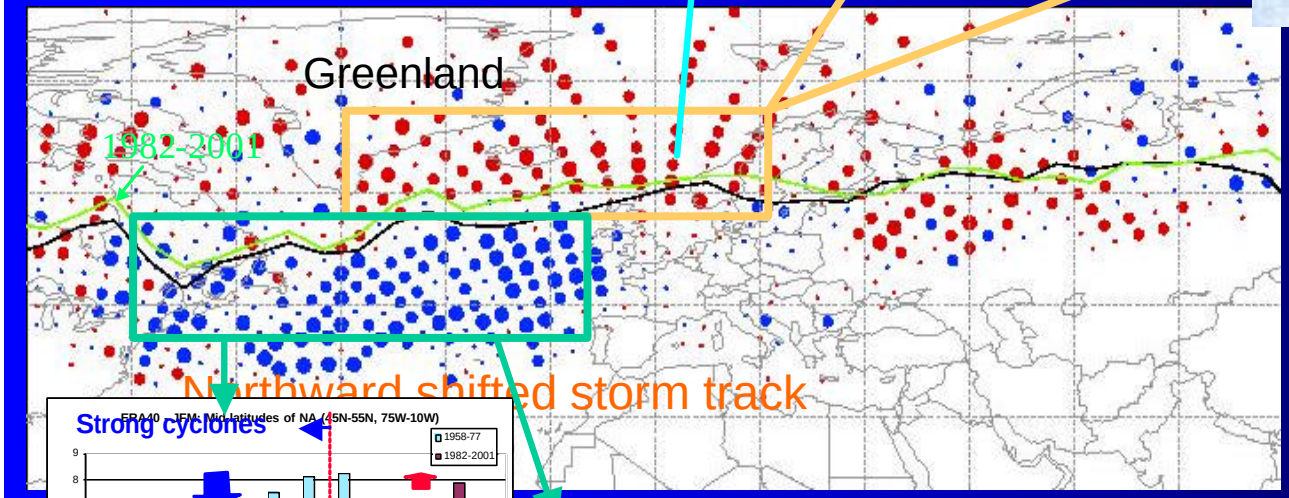




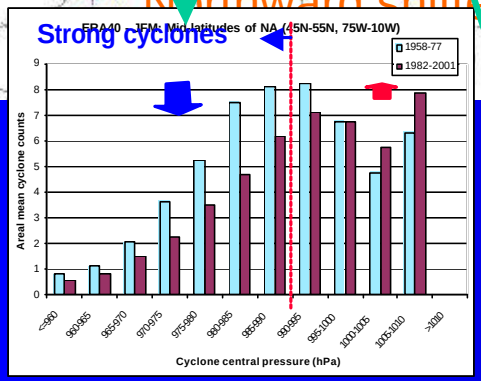
20-yr total:

# of strong tracks: ↑ (+157)
# of weaker tracks: ↓ (-89)
# of all tracks: ↑ (+68)

1982-2001 minus 1958-77



Red: ↑ Blue: ↓
Large dots: >= 95% conf.

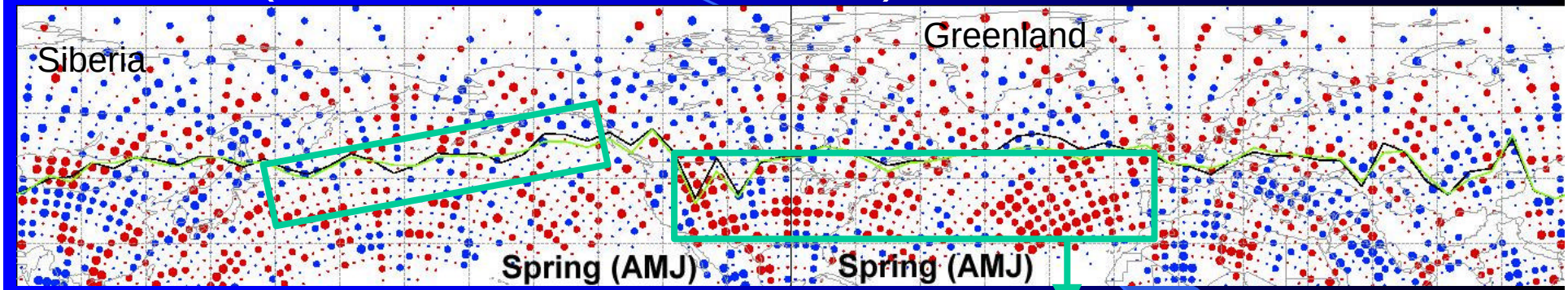


# of strong cyclone-tracks: ↓ (-125)
# of weaker cyclone-tracks: ↑ (+38)
# of all cyclone-tracks: ↓ (-87)

Wang et al. 2004

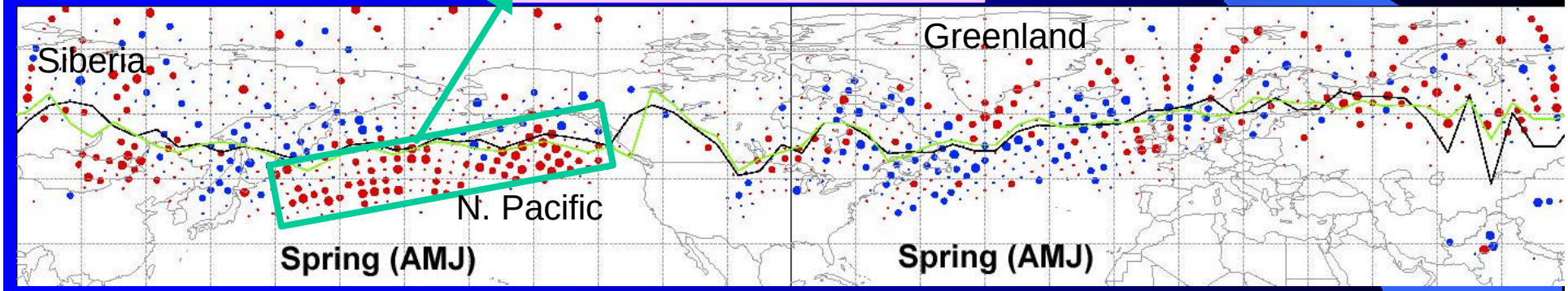
Observed changes – NH spring
(1982-2001 minus 1958-77)

Red: ↑ Blue: ↓
Large dots: >= 95% conf.

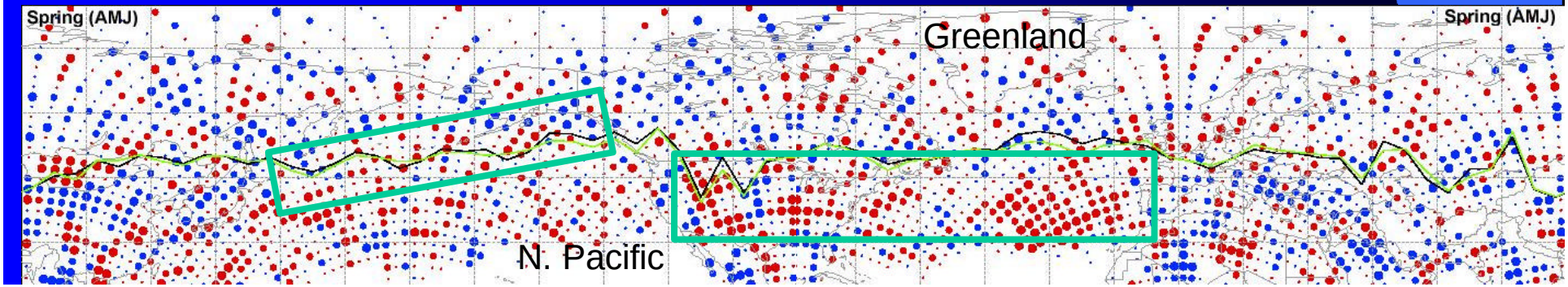


↑ # of weaker cyclones

↑ # of strong cyclones



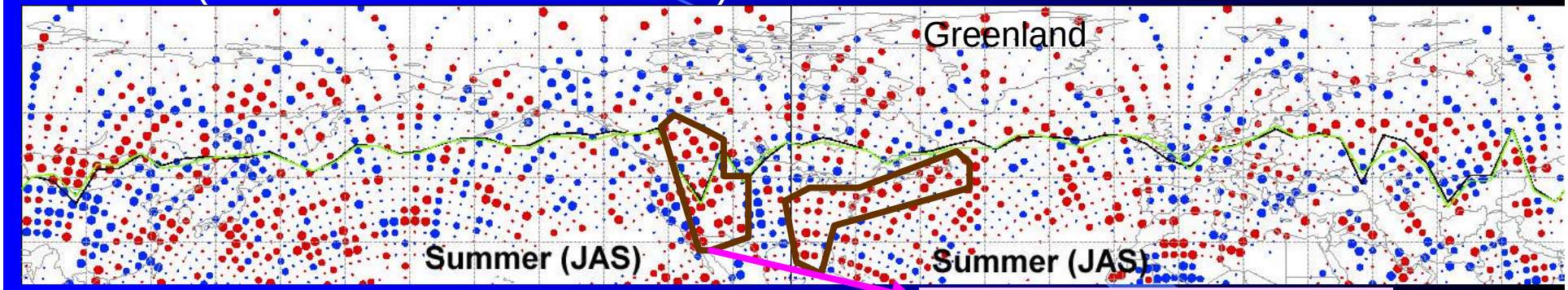
Total # of cyclones:



Observed changes – NH summer

(1982-2001 minus 1958-77)

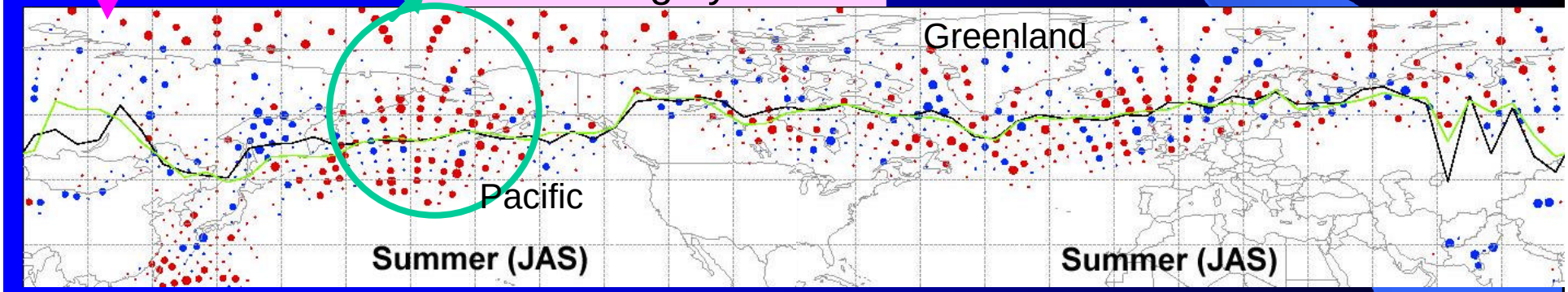
Red: ↑ Blue: ↓
Large dots: >= 95% conf.



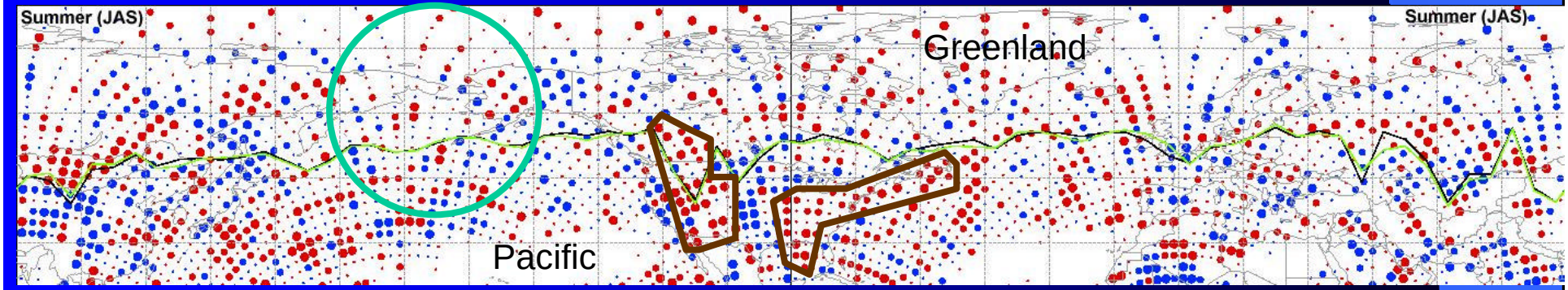
↑ # of weaker cyclones

Weaker changes

↑ # of strong cyclones



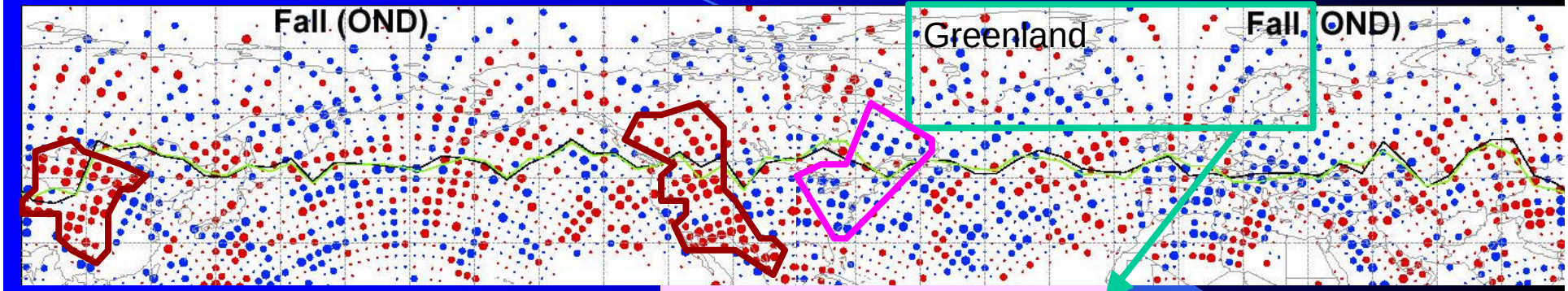
Total # of cyclones:



Observed changes – NH fall

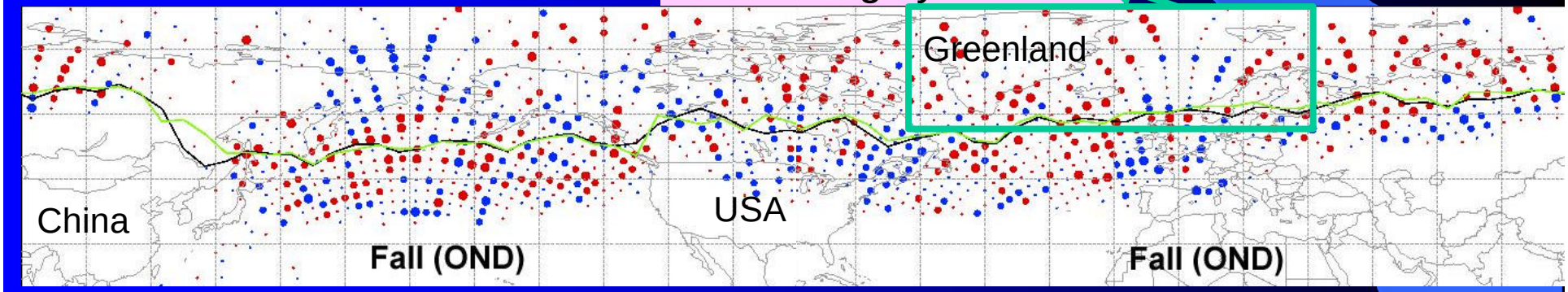
(1982-2001 minus 1958-77)

Red: ⬆ Blue: ⬇
Large dots: >= 95% conf.

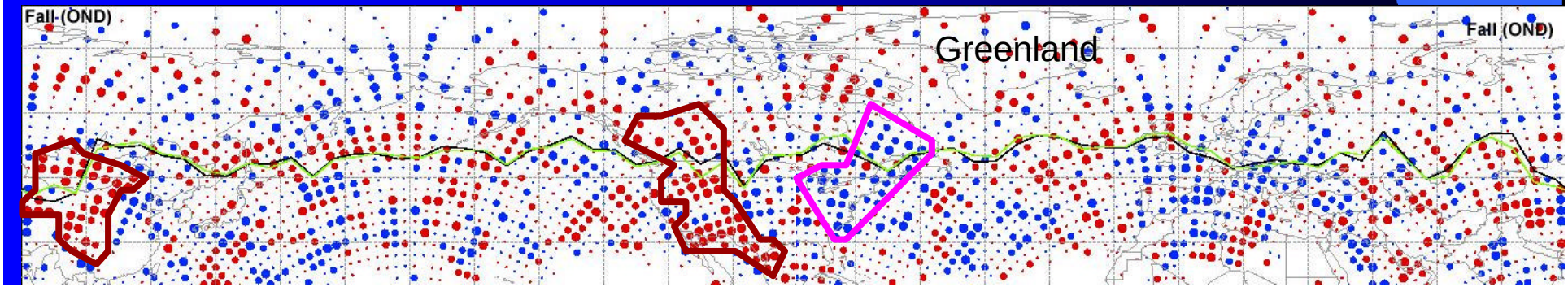


# of weaker cyclones ⬇

# of strong cyclones: ⬆



Total # of cyclones:



Cyclone Lifespan (hr)		High-lat. NA (55°N-70°N, 45°W-15°E)	Mid-lat. NA (45°N-55°N, 75°W-10°W)	Northern Hemisphere Extra-tropics
OND	Strong	2.9 (61.8-58.9)	4.2 (62.9-58.7)	1.9 (47.2-45.3)
	All	1.7 (72.0-70.3)	-0.8 (74.7-75.5)	0.5 (29.8-29.3)
JFM	Strong	-1.2 (57.1-58.3)	0.3 (60.6-60.3)	1.6 (46.0-44.4)
	All	1.1 (66.0-64.9)	-2.1 (68.5-70.6)	0.2 (27.1-26.9)
AMJ	Strong	1.7 (51.6-49.9)	0.3 (50.1-49.8)	3.2 (40.1-36.9)
	All	1.7 (69.6-67.9)	3.0 (75.4-72.4)	0.9 (27.4-26.5)
JAS	Strong	2.4 (53.0-50.6)	-0.2 (56.8-57.0)	5.9 (43.7-37.8)
	All	7.8 (77.6-69.8)	7.2 (79.9-72.7)	1.1 (28.3-27.2)
ANN	Strong	1.3 (57.3-56.0)	1.5 (59.4-57.9)	2.5 (44.7-42.2)
	All	3.0 (70.7-67.7)	1.7 (74.0-72.3)	0.6 (27.5-26.9)

1982-2001 minus 1958-77

Number of Cyclone-tracks		High-lat. NA (55°N-70°N, 45°W-15°E)	Mid-lat. NA (45°N-55°N, 75°W-10°W)	Northern Hemisphere Extra-tropics
OND	Strong	50 (732-682)	-6 (494-488)	155 (3116-3271)
	Weaker	-41 (425-466)	2 (702-704)	-55 (20757-20702)
	All	9 (1157-1148)	-4 (1196-1192)	100 (23873-23973)
JFM	Strong	157 (855-698)	-125 (686-561)	160 (3356-3516)
	Weaker	-89 (368-457)	38 (683-721)	-446 (22517-22071)
	All	68 (1223-1155)	-87 (1369-1282)	-286 (25873-25587)
AMJ	Strong	-29 (225-254)	-38 (228-190)	7 (1475-1482)
	Weaker	26 (860-834)	88 (1004-1092)	-1006 (31618-30612)
	All	-3 (1085-1088)	50 (1232-1282)	-996 (33093-32097)
JAS	Strong	-3 (253-256)	20 (105-125)	-37 (1344-1307)
	Weaker	-45 (816-861)	-39 (1014-975)	-545 (31457-30912)
	All	-48 (1069-1117)	-19 (1119-1100)	-582 (32801-32219)
ANN	Strong	175 (2046-1871)	-152 (1506-1354)	258 (9197-9455)
	Weaker	-142 (2450-2592)	88 (3365-3453)	-2065 (105581-103516)
	All	33 (4496-4463)	-64 (4871-4807)	-1807 (114778-112971)

Generally: No change in lifespan
⇧ # of cyclone-tracks

NA JAS: ⇧ lifespan
⇩ # of cyclone-tracks
(fewer but longer-lived)

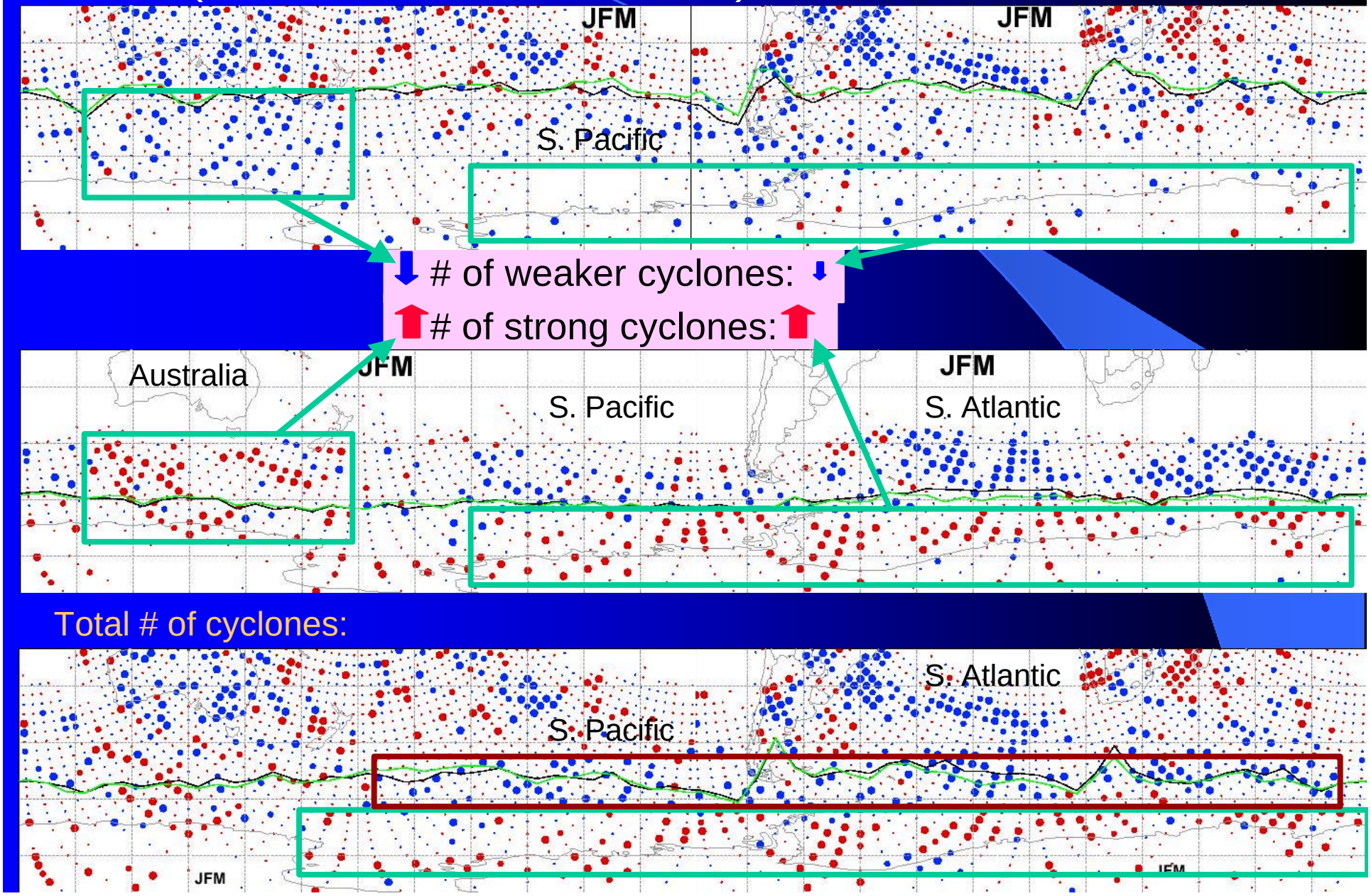
Wang et al. 2004

Observed changes – SH - JFM

(1982-2001 minus 1958-77)

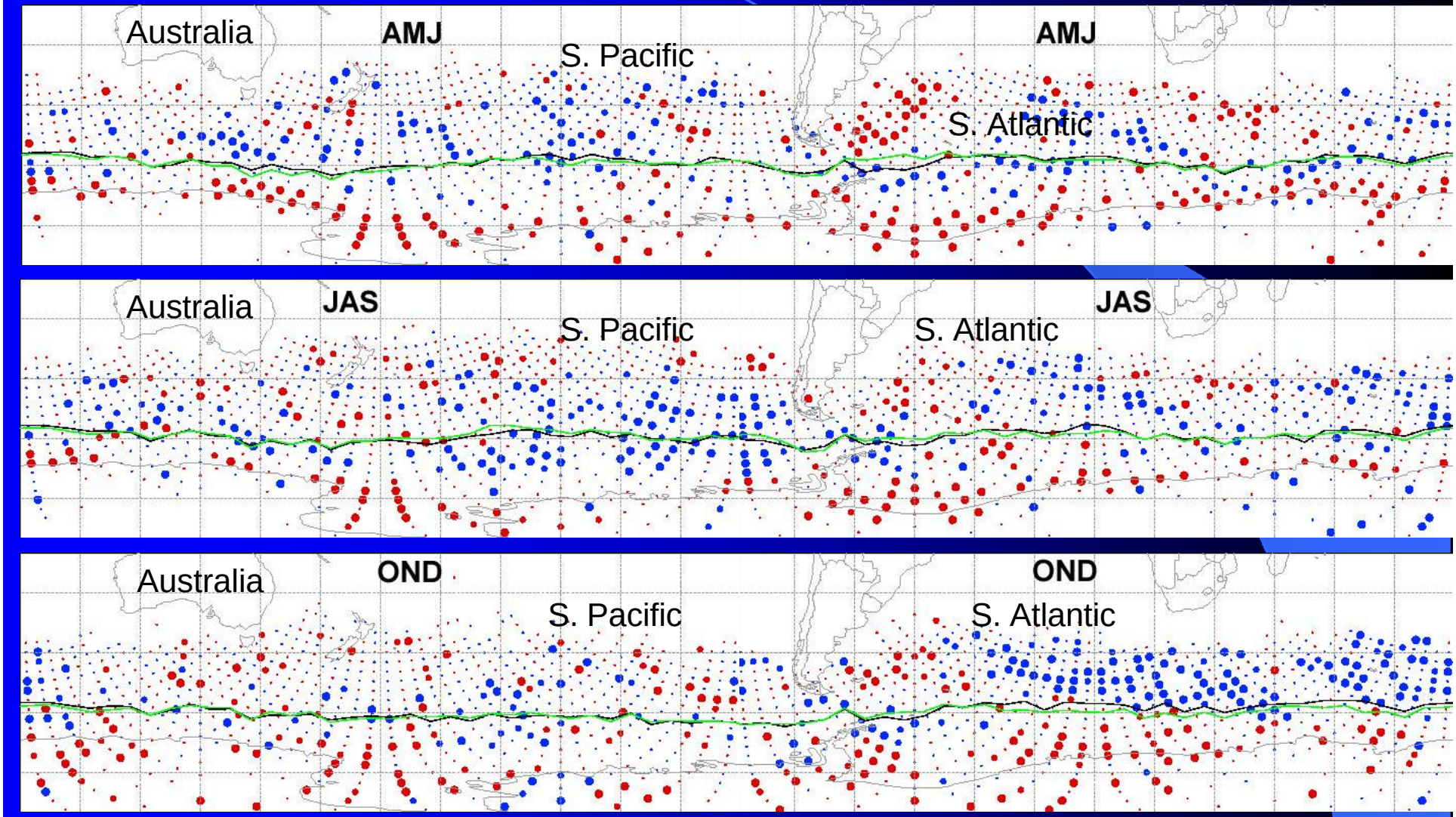
Red: ⬆ Blue: ⬇

Large dots: >= 95% conf.



Observed changes – SH – AMJ, JAS, OND
(Similar to JFM)

# of strong cyclones:

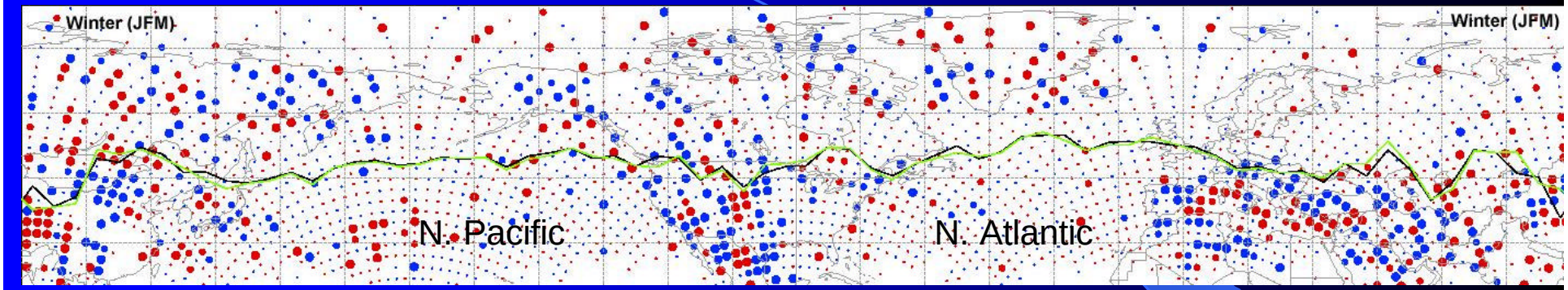


↑ strong cyclone activity in the high latitudes, but ↓ in the mid-latitudes!

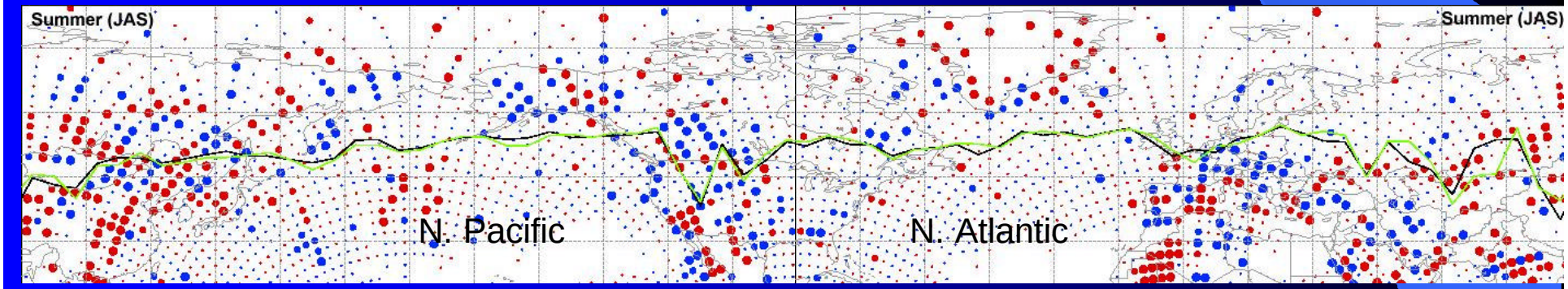
ERA-40 *versus* NRA (NCEP/NCAR):

Any difference in terms of cyclone activity?

Total # of cyclones in the 44 yr:
(ERA-40 minus NRA)

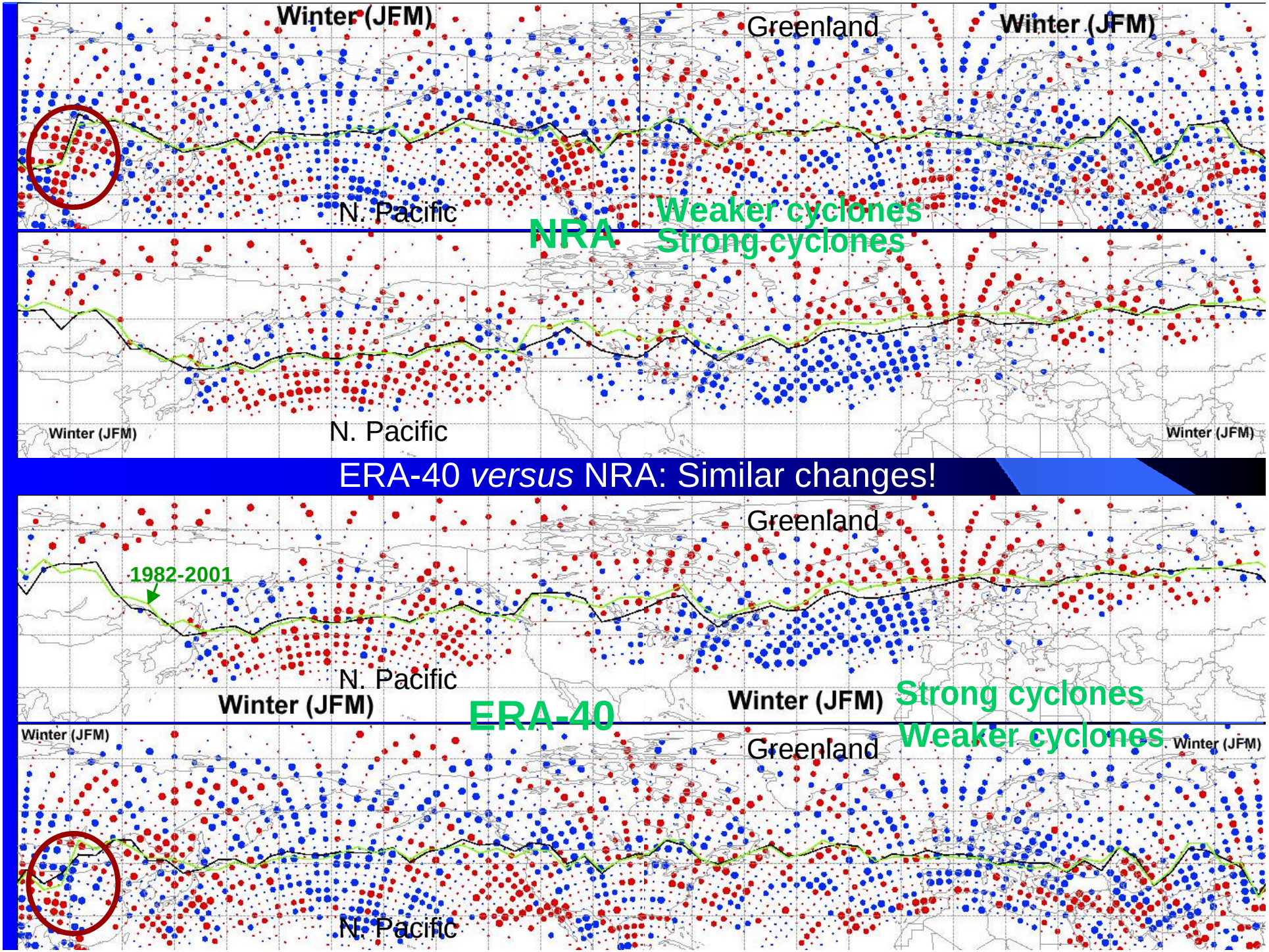


Red: More in ERA-40 Blue: Less in ERA-40
Large dots: >= 95% conf.



Significant differences over some land areas!

But similar in terms of changes!


Winter (JFM)
Greenland
Winter (JFM)
N. Pacific
NRA
Weaker cyclones
Strong cyclones
Winter (JFM)
N. Pacific
Winter (JFM)
ERA-40 versus NRA: Similar changes!
Greenland
1982-2001
N. Pacific
Winter (JFM)
Winter (JFM)
ERA-40
Strong cyclones
Weaker cyclones
Winter (JFM)
Greenland
Winter (JFM)
N. Pacific

CGCM2 Projected Changes
(IS92a forcing scenario)

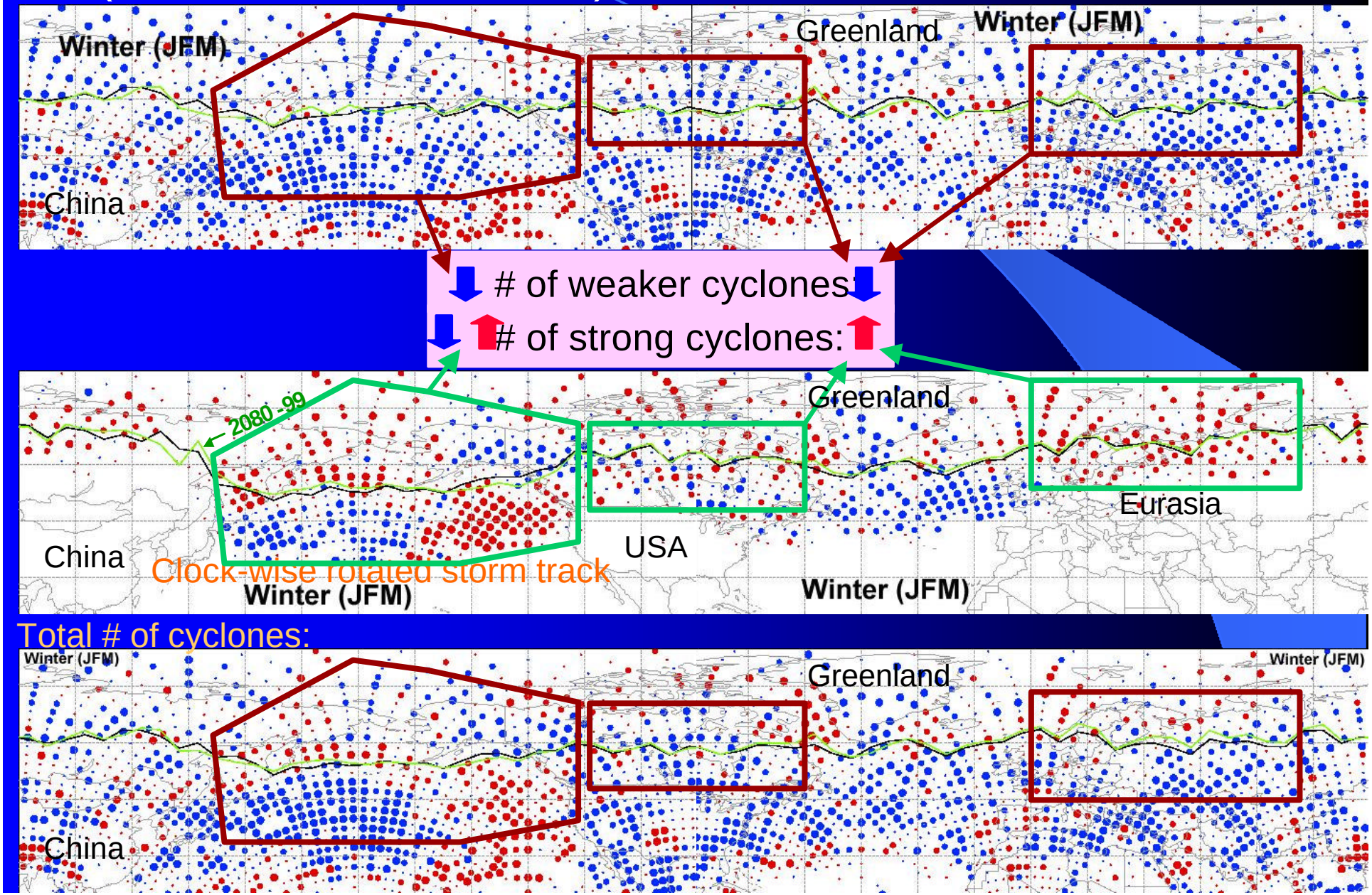
(2080-99 minus 1975-94)

Projected changes – NH winter

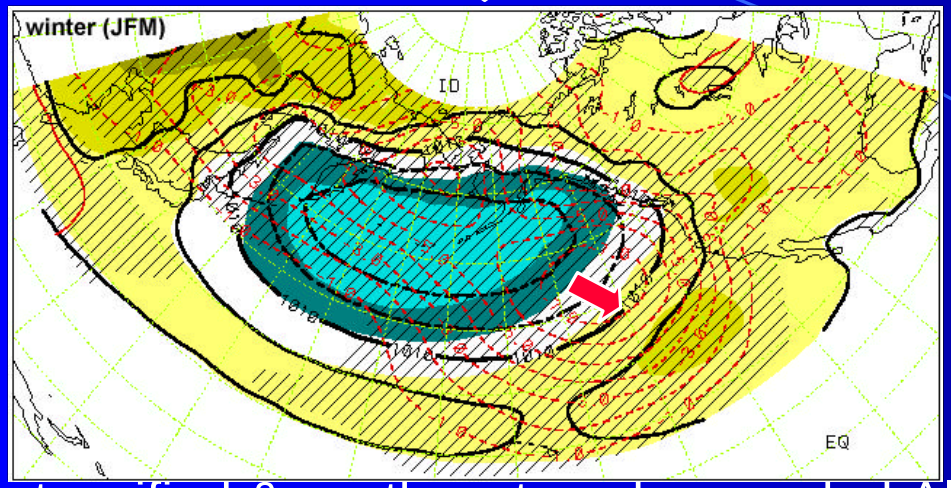
(2080-99 minus 1975-94)

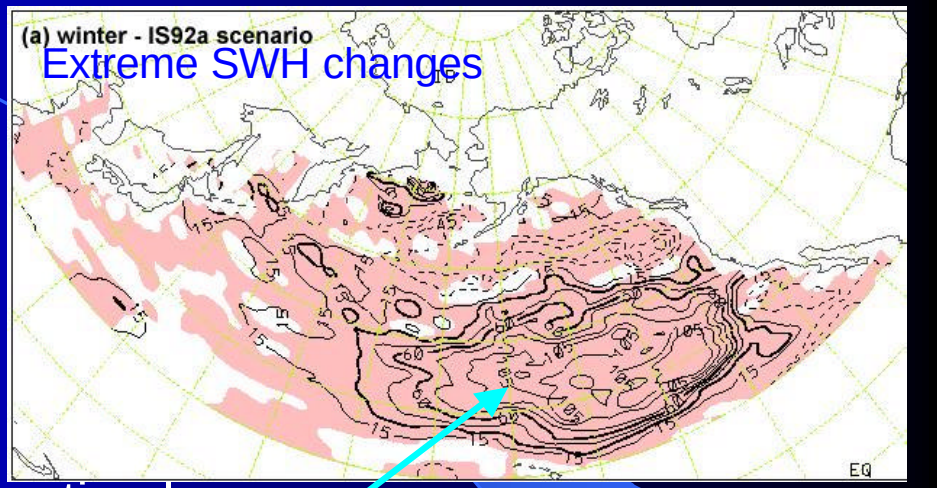
Red: ⬆ Blue: ⬇

Large dots: >= 95% conf.



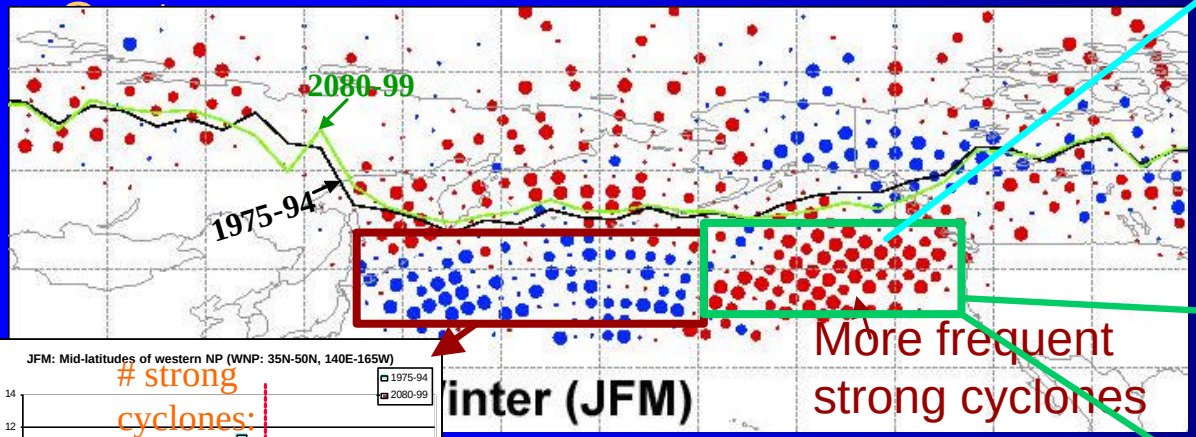
Related climate change – N. Pacific (2080s – 1970s) ⬇ (IS92a scenario)

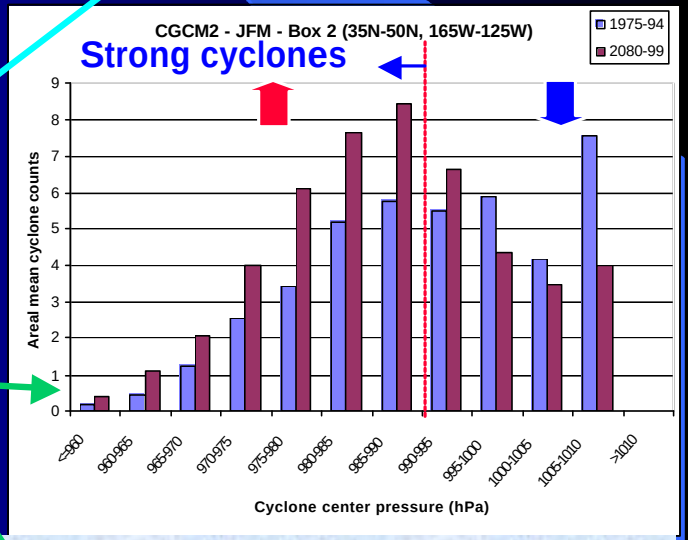


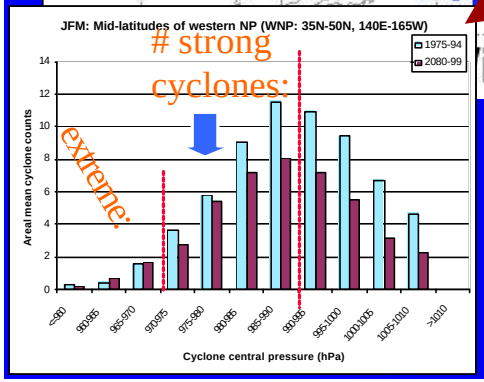


Intensified & southeastward expanded Aleutian low

Clock-wise "rotated" storm track







# of strong cyclone-tracks: ⬆ (+142)

# of weaker cyclone-tracks: ⬇ (-128)

# of all cyclone-tracks: ☛ (+14)

20-yr total:

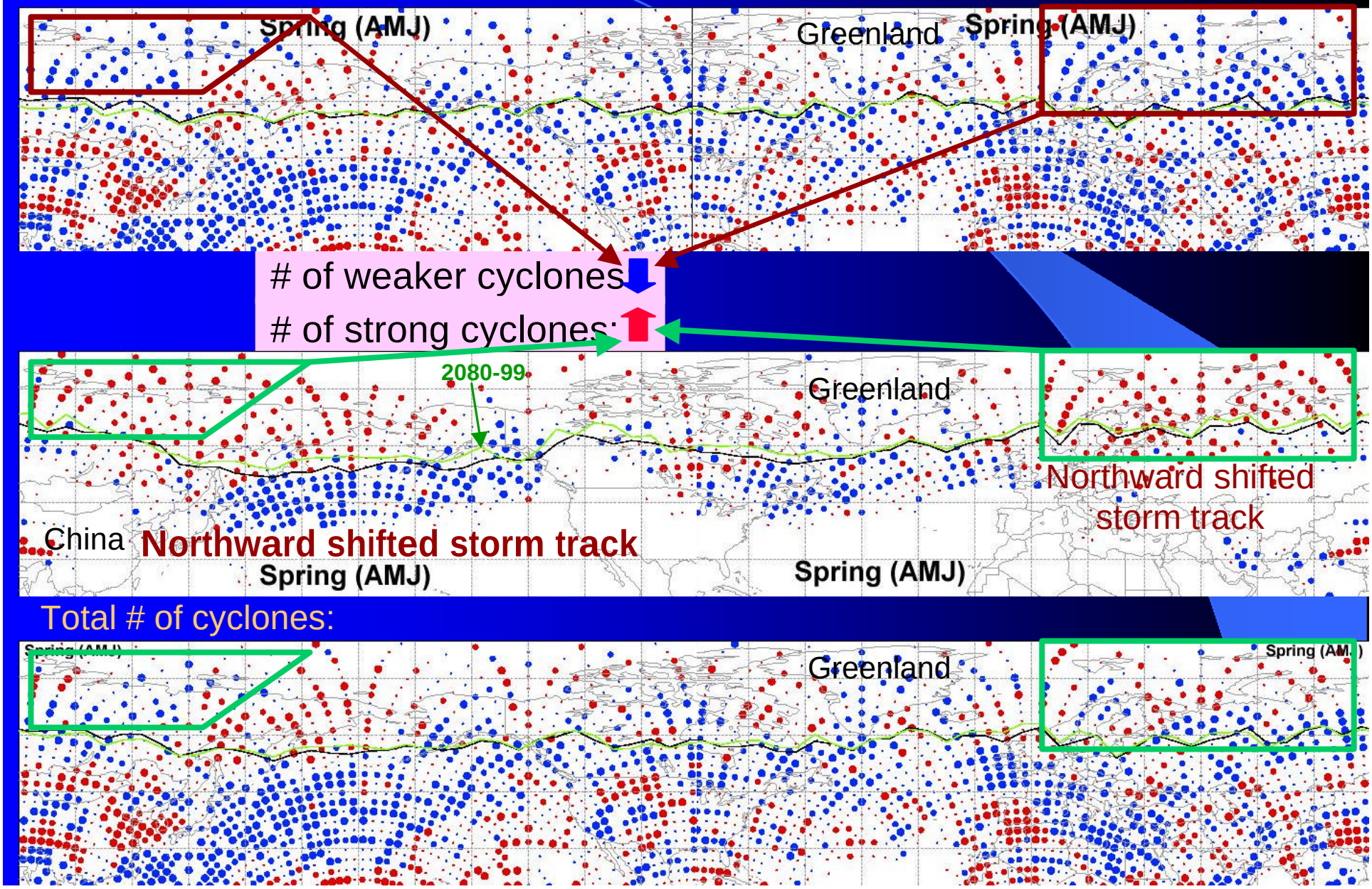
Wang et al. 2004

Projected changes – NH spring

(2080-99 minus 1975-94)

Red: ⬆ Blue: ⬇

Large dots: >= 95% conf.



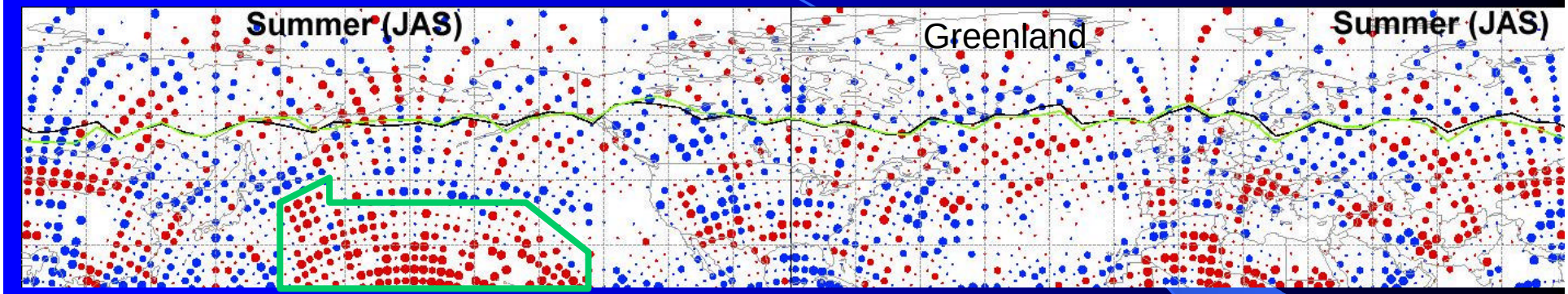
Projected changes – NH summer

(2080-99 minus 1975-94)

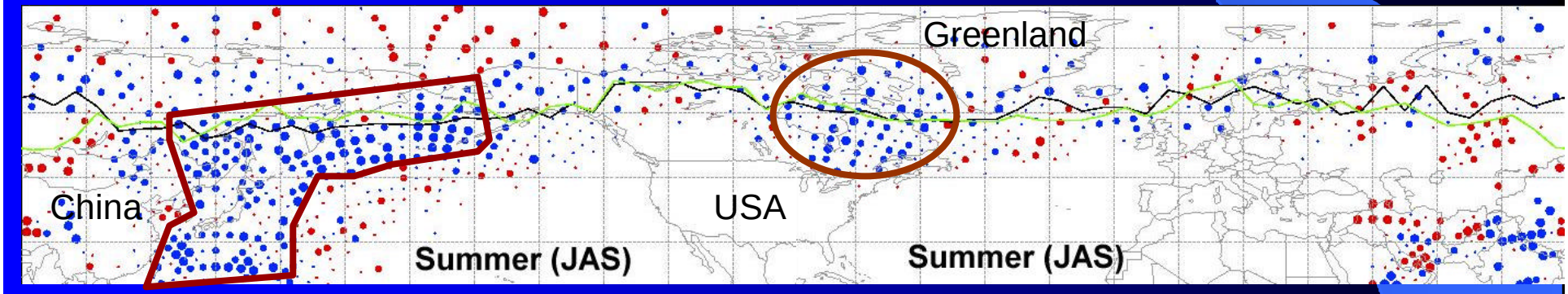
Red: ⬆ Blue: ⬇

Large dots: >= 95% conf.

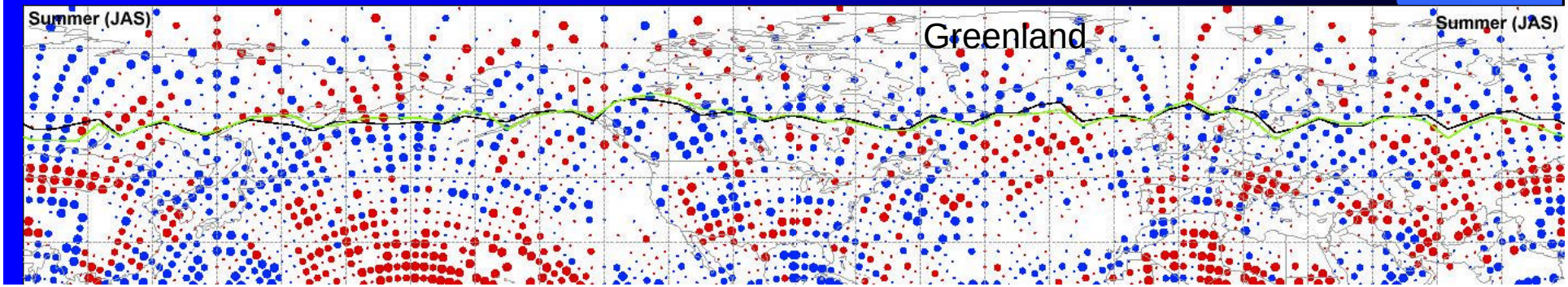
# of weaker cyclones:



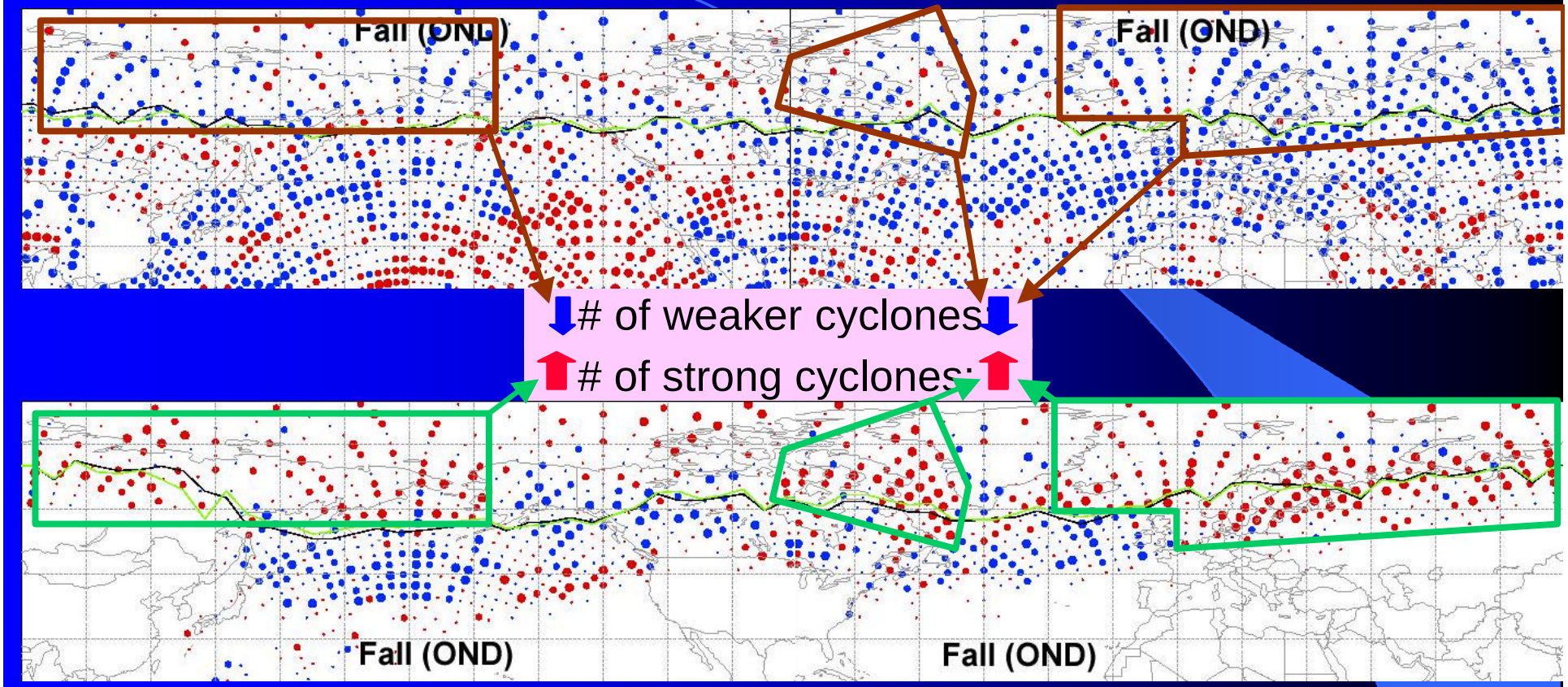
# of strong cyclones:



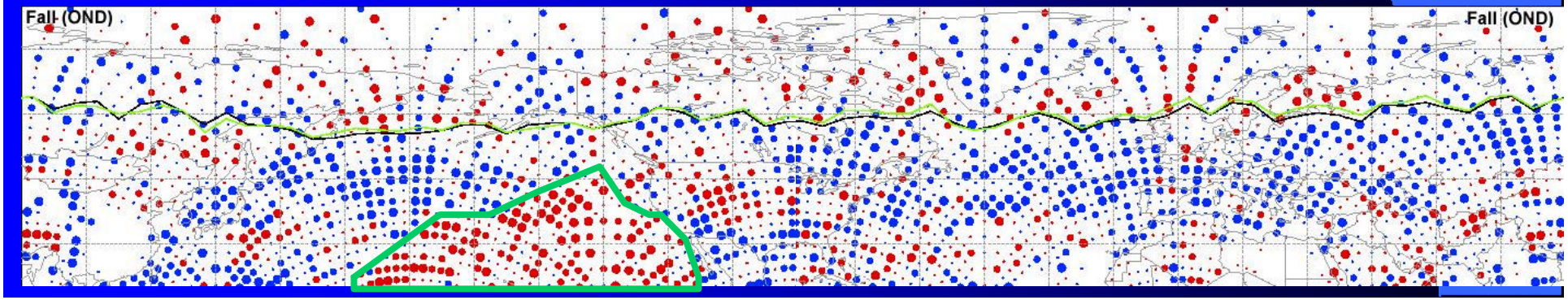
Total # of cyclones:



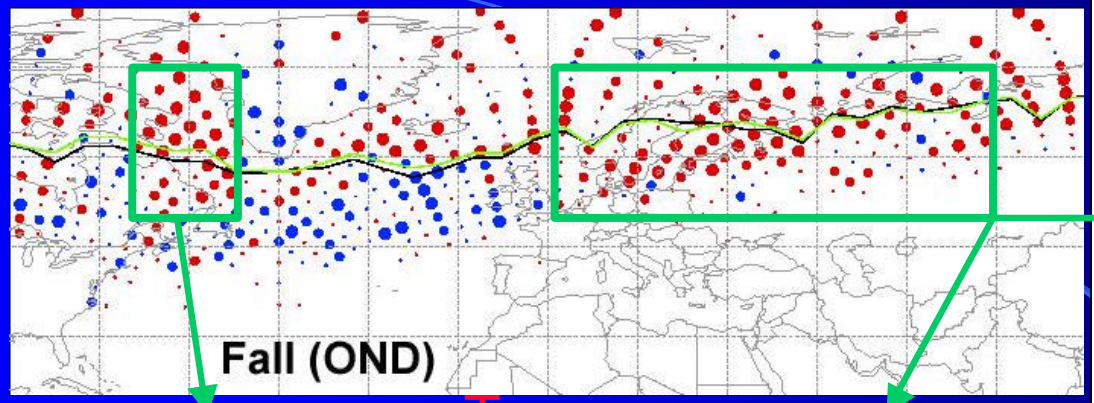
Projected changes – NH fall (similar to NH winter)

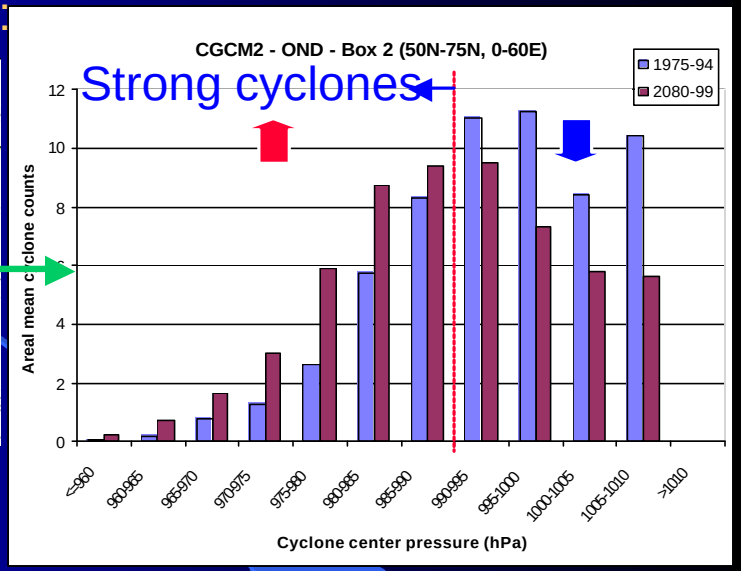


Total # of cyclones:



Distributional shift:



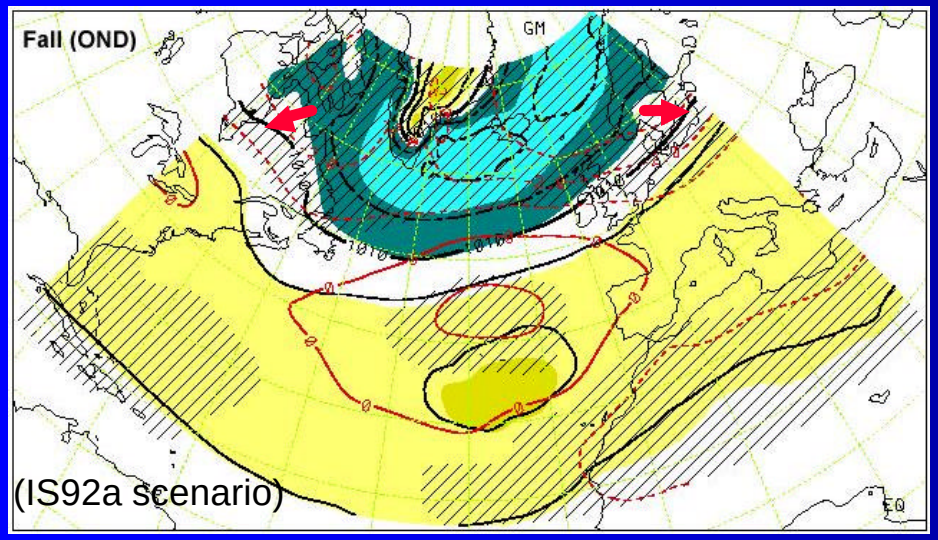


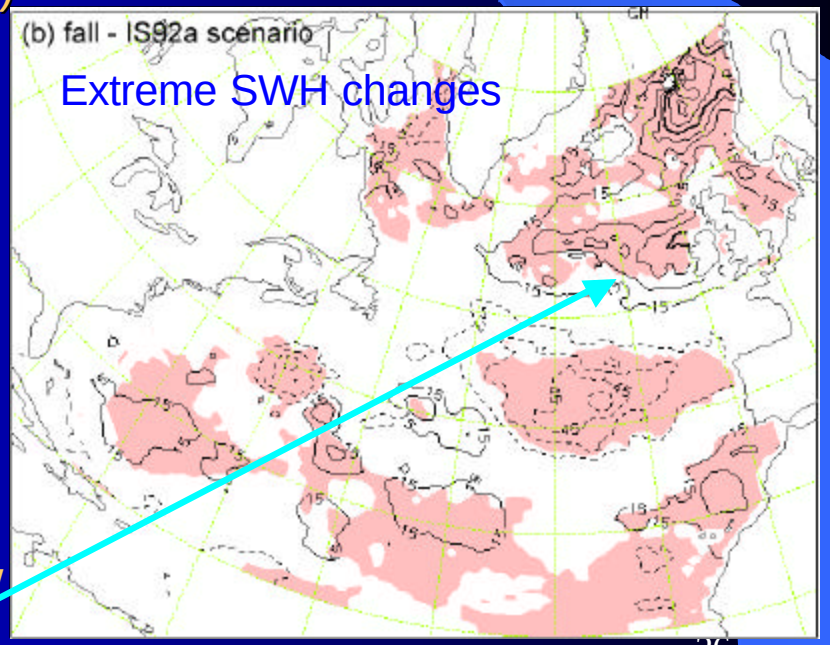
(+94) ← # of strong cyclone-tracks: (+142)

(-69) ← # of weaker cyclone-tracks: (-272)

(+25) ← # of all cyclone-tracks: (-130)

Related climate change – NA (2080s – 1970s)





West- & southeast-ward expanded Icelandic low

- ~ ↑ positive NAO
- ~ ↑ SLP gradient & stronger westerly

Cyclone Lifespan		Northern Europe (50°N-75°N, 0-60°E)	Baffin Bay (50°N-75°N, 70°W-50°W)	Mid-lat. ENP (35°N-50°N, 165°W-125°W)	Mid-lat. WNP (35°N-50°N, 140°E-165°W)	Northern Hemisphere Extra-tropics
OND	Strong	2.0 (72.0-70.0)	2.9 (82.5-79.6)	8.9 (86.4-77.5)	5.8 (90.0-84.2)	2.0 (58.7-56.7)
	All	-0.7 (85.8-86.5)	4.2 (93.8-89.6)	6.2 (88.5-82.3)	8.6 (105.1-96.5)	0.0 (39.4-39.4)
JFM	Strong	3.6 (67.3-63.7)	9.0 (81.2-72.2)	0.6 (71.9-71.3)	6.6 (76.6-70.0)	3.2 (55.6-52.4)
	All	-4.1 (78.7-82.8)	6.2 (85.3-79.1)	2.0 (79.9-77.9)	-2.0 (77.7-79.7)	-1.5 (34.1-35.6)
AMJ	Strong	0.4 (66.0-65.6)	12.2 (85.2-73.0)	11.7 (72.0-60.3)	5.1 (79.5-74.4)	4.5 (55.9-51.4)
	All	-6.2 (91.3-97.5)	-1.6 (87.2-88.8)	-6.4 (82.0-88.4)	-6.8 (104.8-111.6)	0.0 (41.0-41.0)
JAS	Strong	-5.8 (55.4-61.2)	3.1 (64.3-61.2)	-8.3 (81.4-89.7)	-3.3 (89.2-92.5)	0.8 (41.8-41.0)
	All	2.6 (103.4-100.8)	-3.0 (86.5-89.5)	23.4 (108.2-84.8)	9.3 (112.7-103.4)	0.9 (47.7-46.8)
ANN	Strong	2.2 (67.2-65.0)	7.0 (81.0-74.0)	3.9 (76.7-72.8)	4.5 (81.2-76.7)	3.0 (52.8-49.8)
	All	-2.4 (89.2-91.6)	0.9 (87.0-86.1)	3.4 (85.3-81.9)	2.1 (97.6-95.5)	0.0 (39.7-39.7)

Number of Cyclone-tracks		Northern Europe (50°N-75°N, 0-60°E)	Baffin Bay (50°N-75°N, 70°W-50°W)	Mid-lat. ENP (35°N-50°N, 165°W-125°W)	Mid-lat. WNP (35°N-50°N, 140°E-165°W)	Northern Hemisphere Extra-tropics
OND	Strong	142 (533-391)	94 (350-256)	-39 (310-349)	-123 (336-459)	220 (3073-2853)
	Weaker	-272 (550-822)	-69 (403-472)	-15 (394-409)	-82 (387-469)	-1773 (14971-16744)
	All	-130 (1083-1213)	25 (753-728)	-54 (704-758)	-205 (723-928)	-1558 (18039-19597)
JFM	Strong	98 (551-453)	33 (403-370)	142 (609-467)	-150 (557-707)	84 (3433-3349)
	Weaker	-233 (475-708)	11 (403-392)	-128 (344-472)	-192 (382-574)	-1939 (15057-16996)
	All	-135 (1026-1161)	44 (806-762)	14 (953-939)	-342 (939-1281)	-1855 (18490-20345)
AMJ	Strong	144 (344-200)	-5 (252-257)	-48 (43-91)	-102 (171-273)	29 (2003-1974)
	Weaker	-200 (742-942)	6 (544-538)	-27 (370-397)	-100 (512-612)	-1150 (19849-20999)
	All	-56 (1086-1142)	1 (796-795)	-75 (413-488)	-202 (683-885)	-1121 (21852-22973)
JAS	Strong	6 (82-76)	-32 (120-152)	0 (23-23)	-60 (70-130)	-396 (2414-2810)
	Weaker	-9 (1081-1090)	-27 (580-607)	-18 (230-248)	-69 (629-698)	-91 (18833-18924)
	All	-3 (1163-1166)	-59 (700-759)	-18 (253-271)	-129 (699-828)	-487 (21247-21734)
ANN	Strong	373 (1489-1116)	88 (1118-1030)	58 (984-926)	-441 (1125-1566)	-54 (10774-10828)
	Weaker	-714 (2797-3511)	-79 (1916-1995)	-190 (1324-1514)	-444 (1883-2327)	-4931 (67843-72774)
	All	-341 (4286-4627)	9 (3034-3025)	-132 (2308-2440)	-885 (3008-3893)	-4985 (78617-83602)

2080-99 minus 1975-94

Similar to the observed:

↑lifespan

↓# of cyclone-tracks

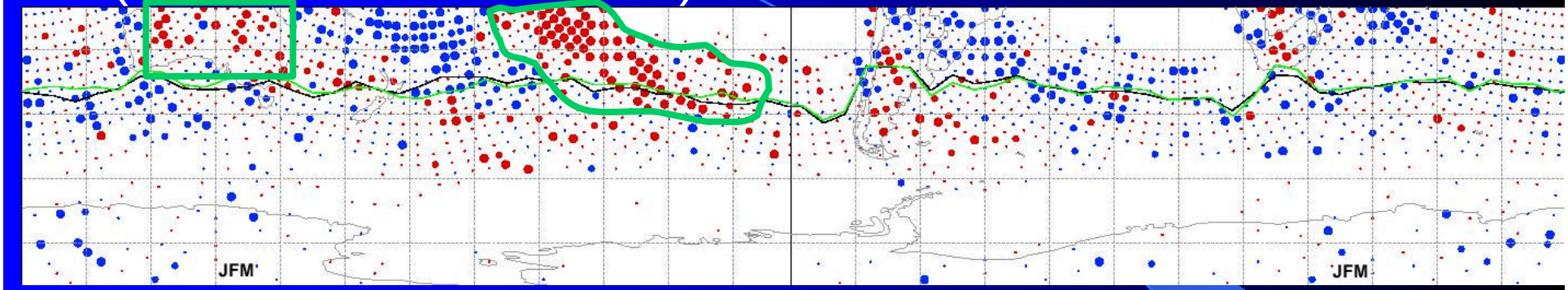
No change in lifespan

↑# of cyclone-tracks

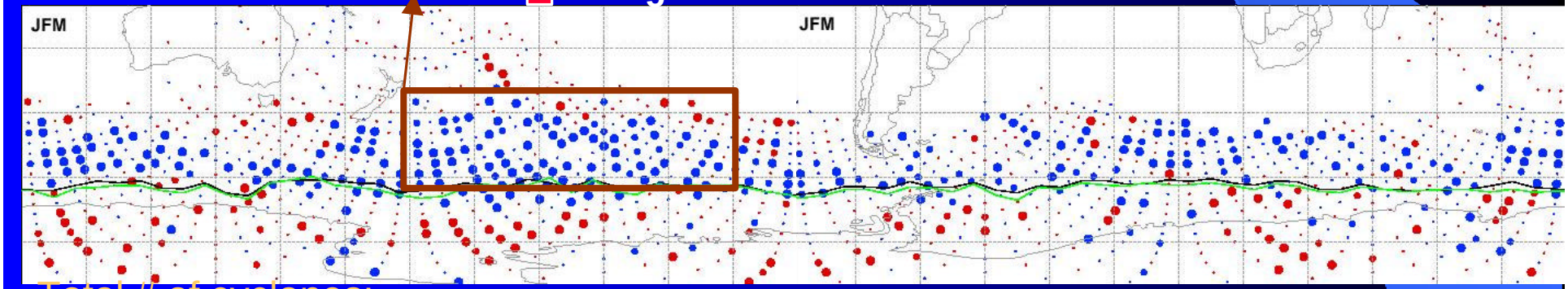
(except N. Europe & Baffin Bay: ↑ # and lifespan)

Projected changes – SH - JFM
(2080-99 minus 1975-94)

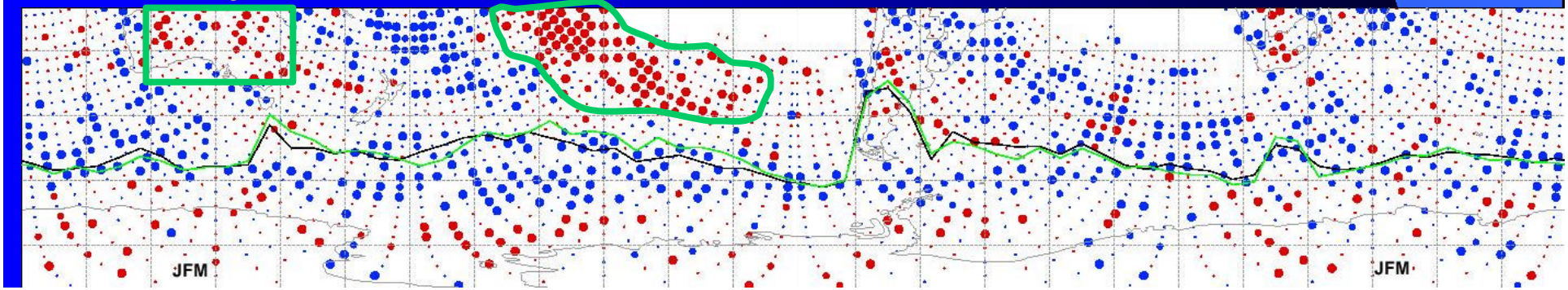
Red: ⬆ Blue: ⬇
Large dots: >= 95% conf.



# of strong cyclones: ⬇ in mid-lat. ⬆ in high-lat.



Total # of cyclones:



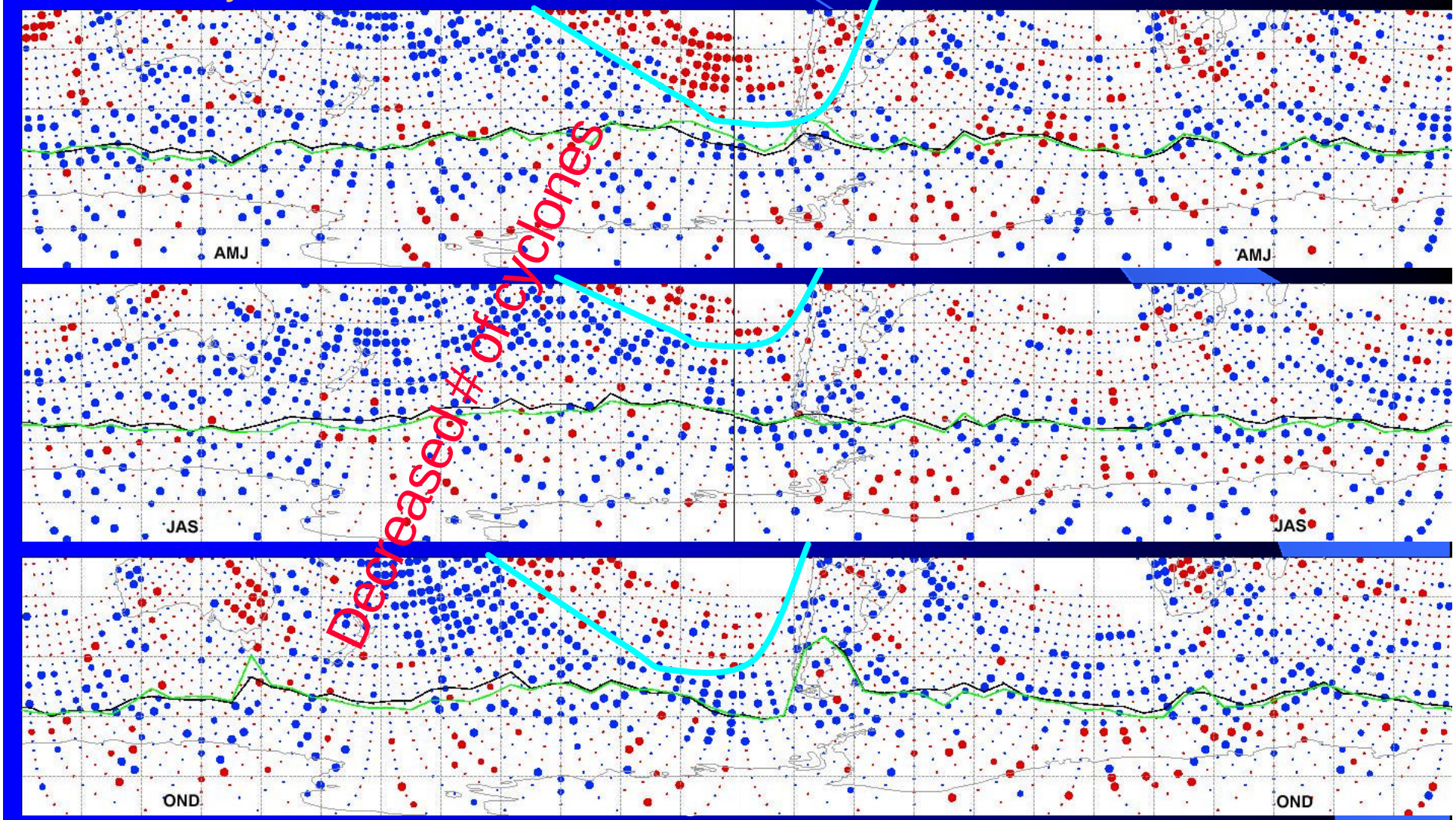
Projected changes – SH – AMJ, JAS, OND

(2080-99 minus 1975-94)

Red: ⬆ Blue: ⬇

Large dots: >= 95% conf.

Total # of cyclones:



Summary

1. Observed or projected climate:

Most substantial changes ~ freq. and track of strong cyclones, especially in NH

2. In the past half century:

> NP: ↑ freq. of strong cyclones in winter & spring

> NA: ↑ freq. of strong autumn & winter cyclones, and winter storm track shifted slightly northward

> freq. of strong cyclones in SH extra-tropics:

↑ poleward of 60S & ↓ in 45S-60S zone, in all seasons

Summary (cont'd)

3. CGCM2 projected changes in the 21st century:

> NP: storm track turns clock-wise in winter
& shifts northward in spring

> NA: more freq. strong cyclones projected
for N. Eurasia in all seasons except summer,
& for Baffin Bay-Labrador in autumn & winter.

> SH: ⬇ freq. of strong cyclones in 45S-60S

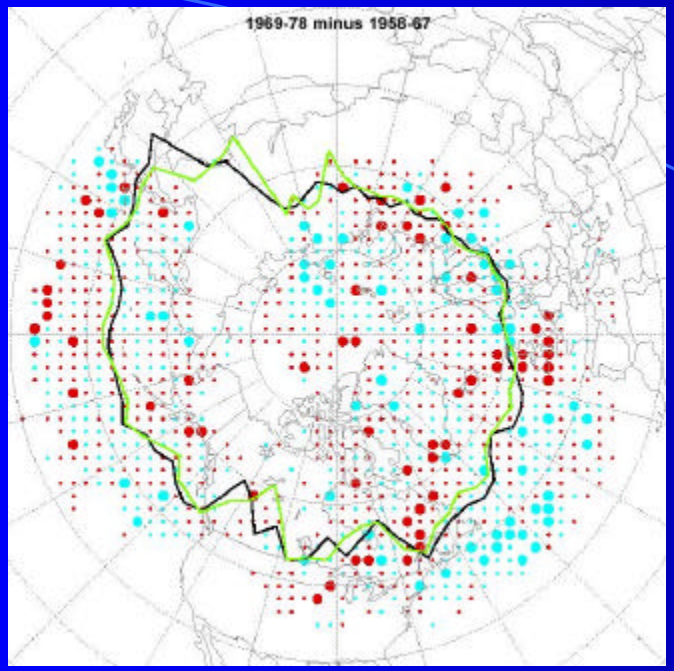
Acknowledgement

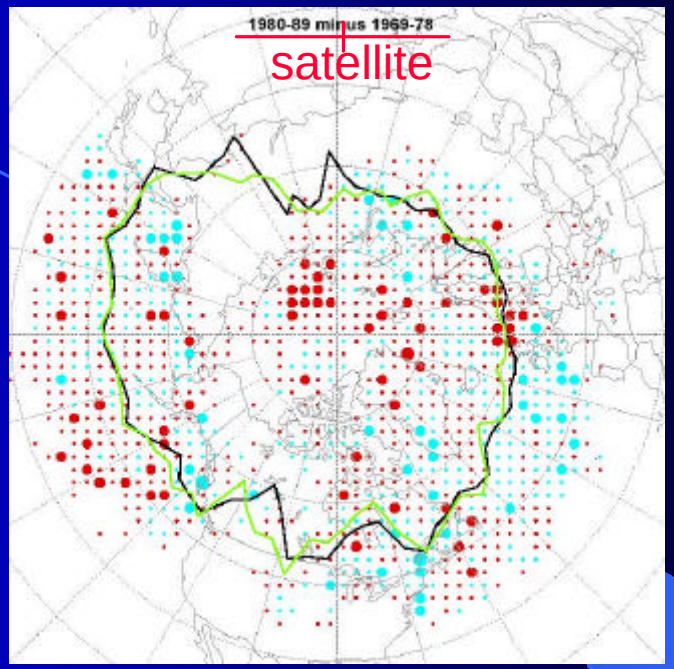
The authors are greatly indebted to Mr. **Yang Feng** for his great computing support.

- The End -

Thank you very much!

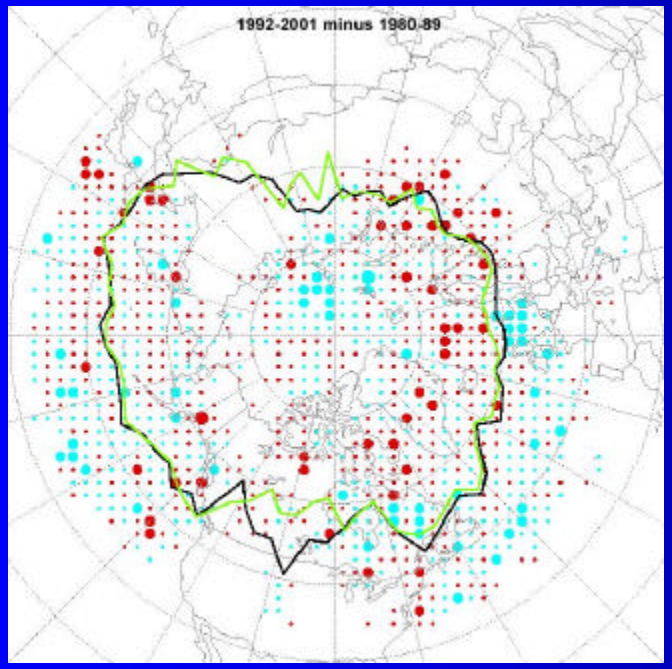
Between 2 decades before 1979

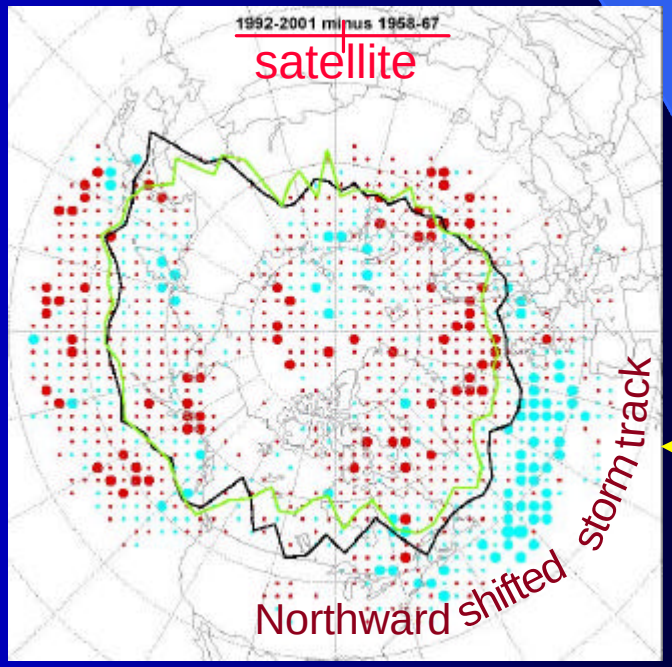




After and before 1979

Between 2 decades after 1979





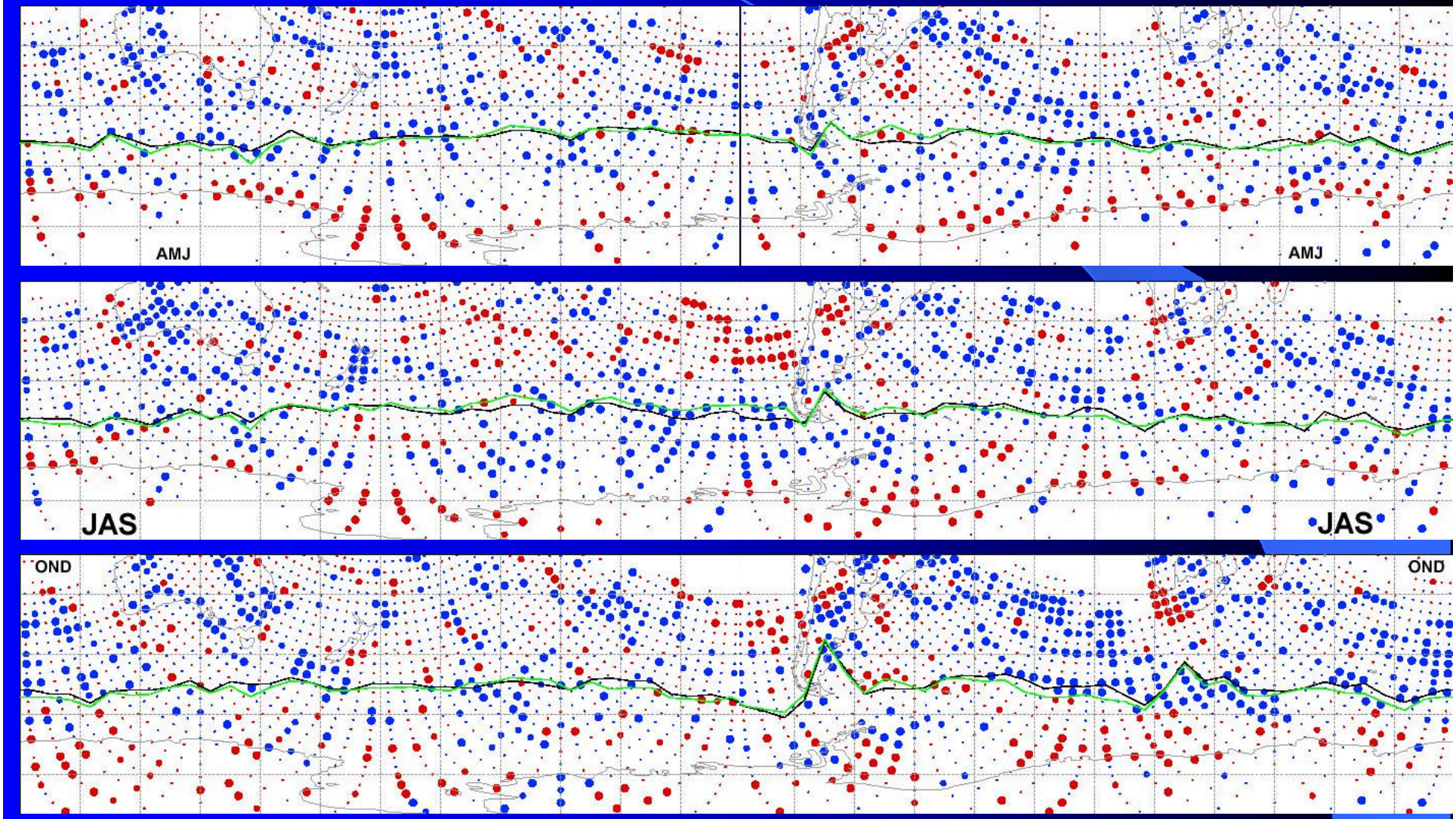
First & last decades in 1958-2001

← Most likely real!

Observed changes – SH – AMJ, JAS, OND

(1982-2001 minus 1958-77)

Total # of cyclones:



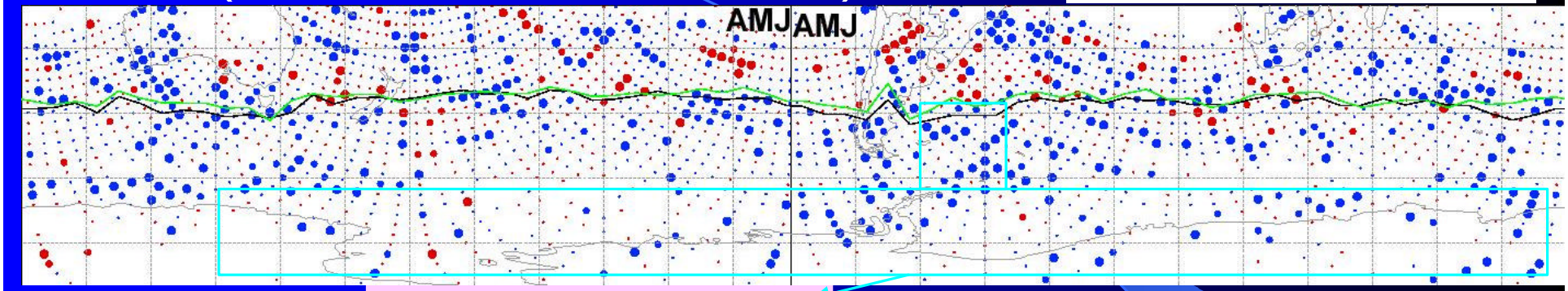
More frequent strong cyclone activity in the high southern latitudes!

Observed changes – SH - AMJ

(1982-2001 minus 1958-77)

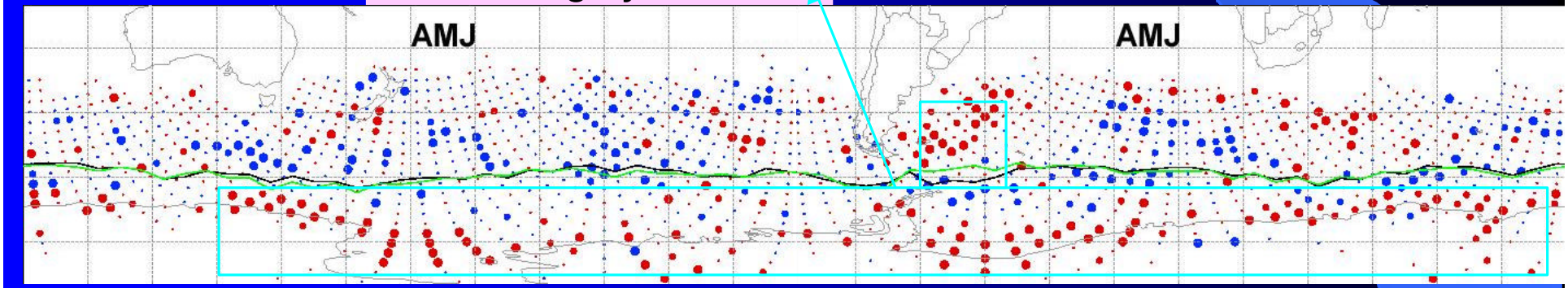
Red: ⬆ Blue: ⬇

Large dots: >= 95% con

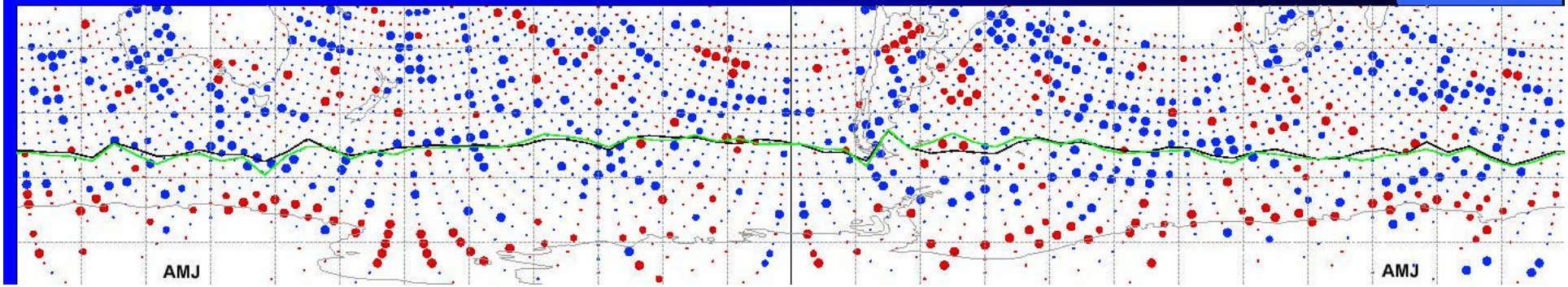


# of weaker cyclones: ⬇

# of strong cyclones: ⬆



Total # of cyclones:

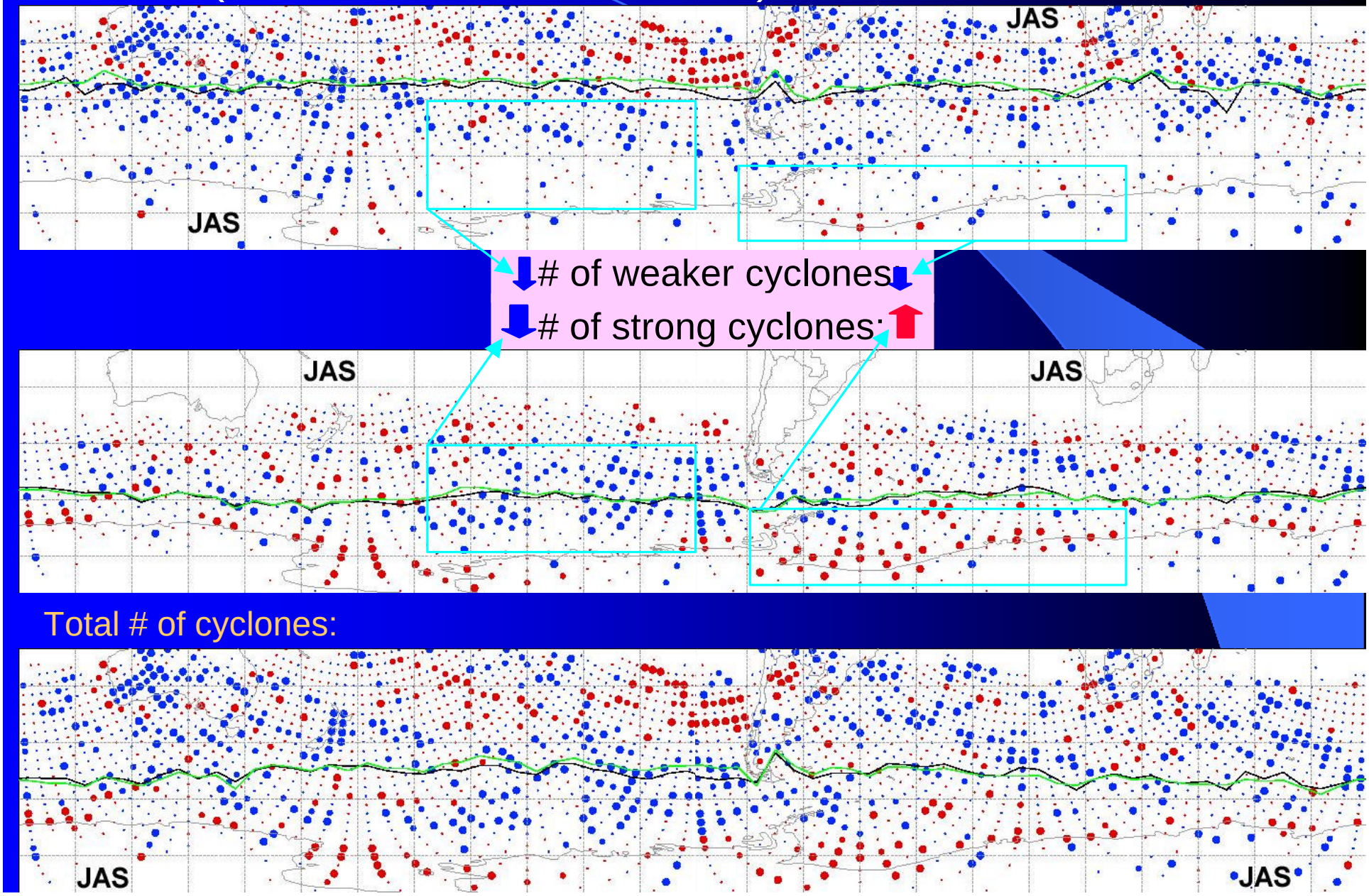


Observed changes – SH - JAS

(1982-2001 minus 1958-77)

Red: ⬆ Blue: ⬇

Large dots: >= 95% con

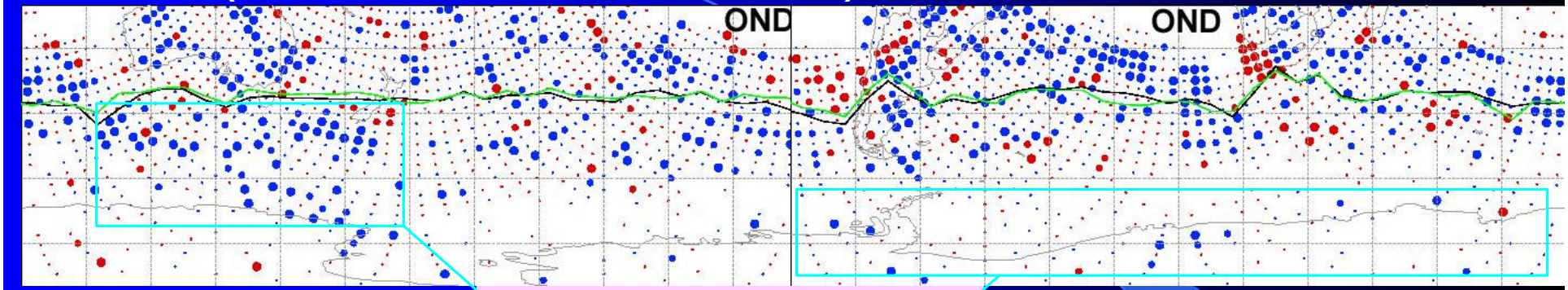


Observed changes – SH - OND

(1982-2001 minus 1958-77)

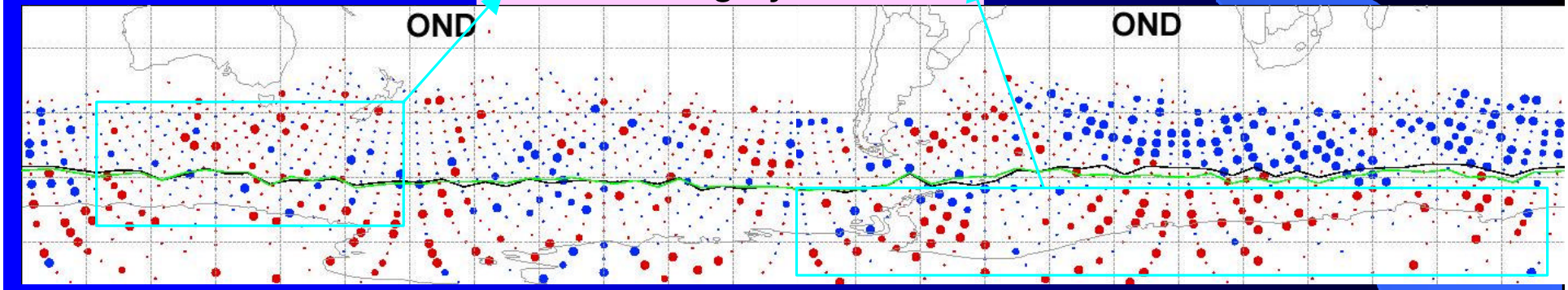
Red: ⬆ Blue: ⬇

Large dots: >= 95% con

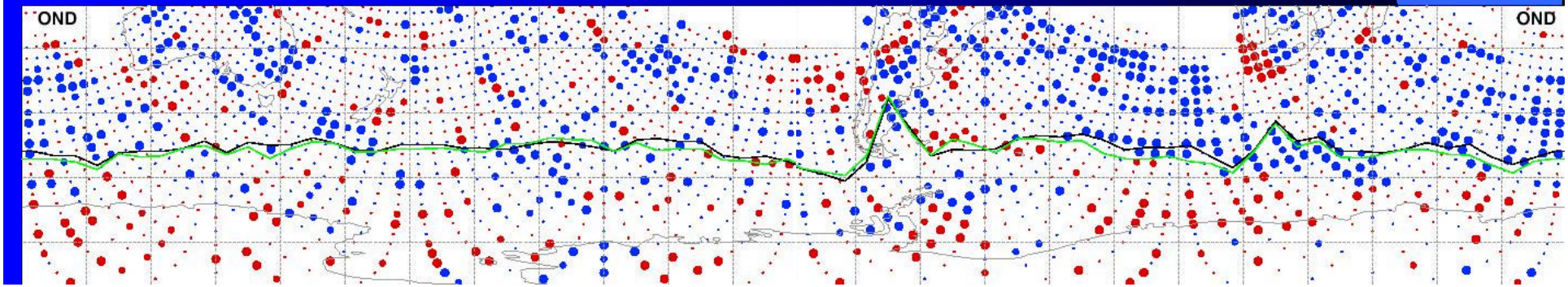


⬇# of weaker cyclones:

⬆# of strong cyclones:



Total # of cyclones:



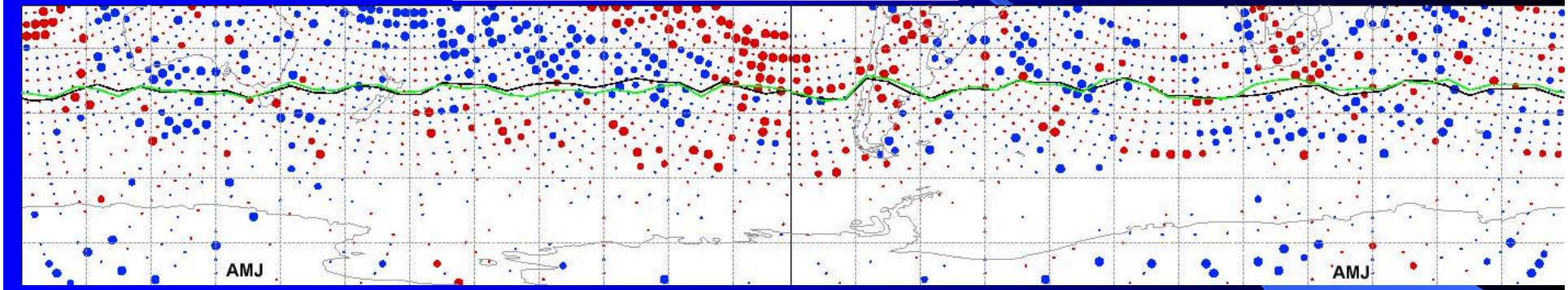
Projected changes – SH - AMJ

(2080-99 minus 1975-94)

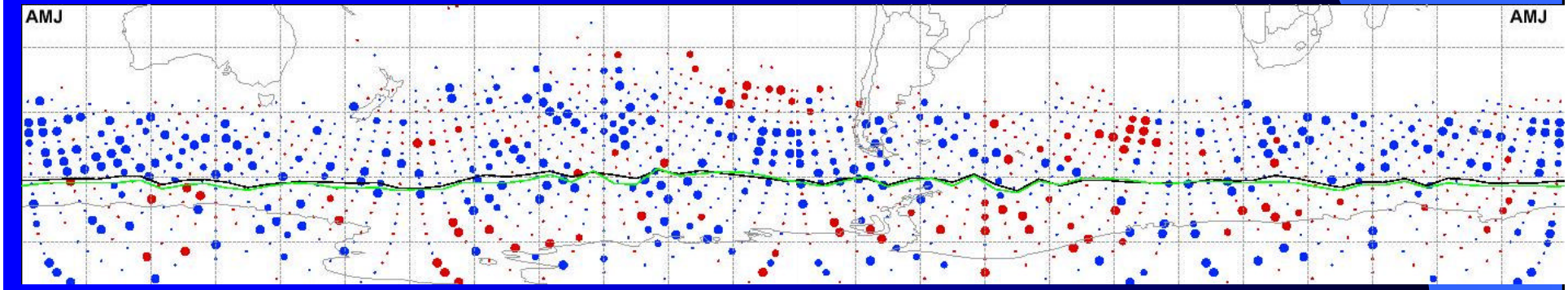
Red: ↑ Blue: ↓

Large dots: >= 95% con

of weaker cyclones:



of strong cyclones:



Wang et al. 2004

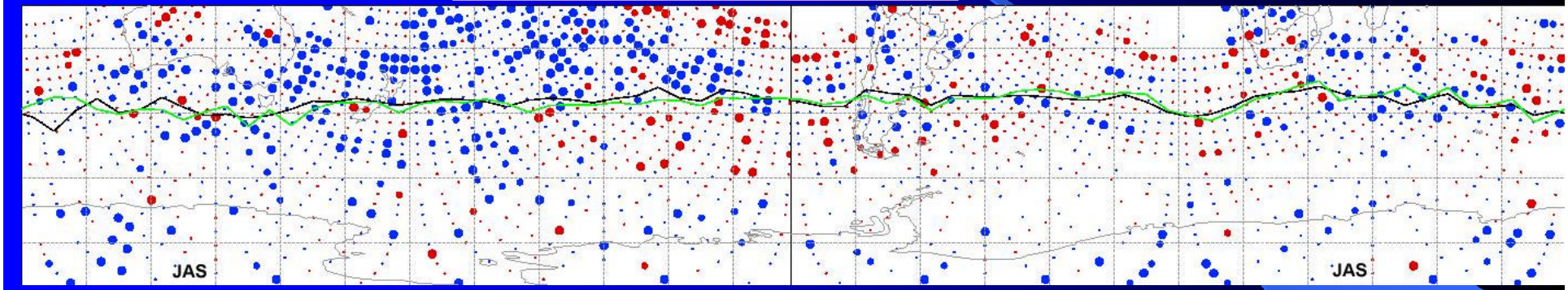
Projected changes – SH - JAS

(2080-99 minus 1975-94)

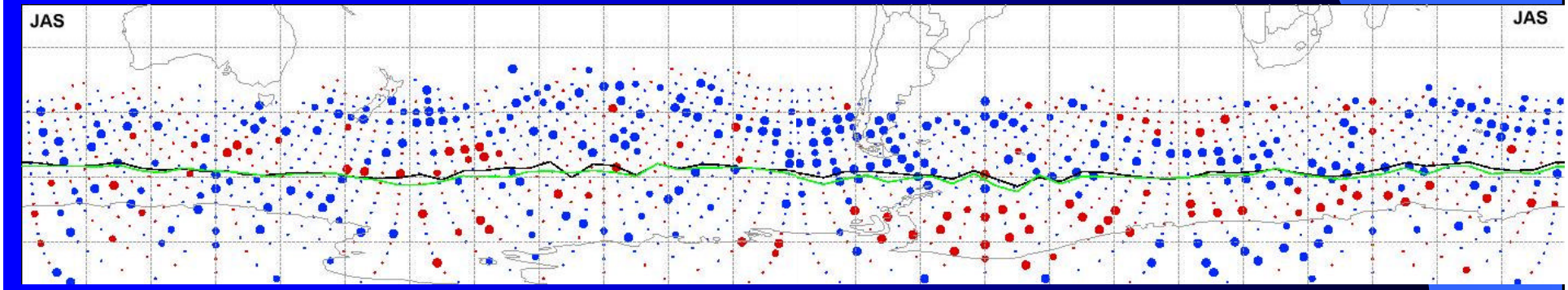
Red: ⬆ Blue: ⬇

Large dots: >= 95% con

# of weaker cyclones:



# of strong cyclones:



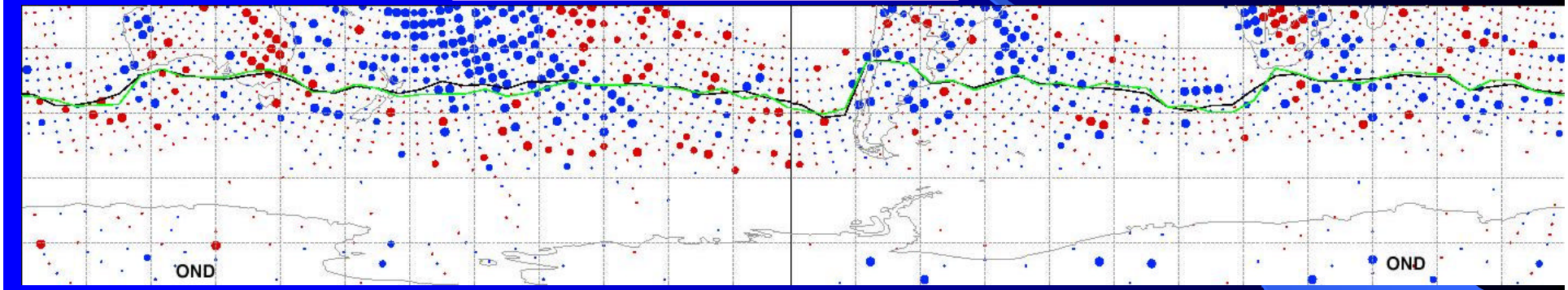
Projected changes – SH - OND

(2080-99 minus 1975-94)

Red: ↑ Blue: ↓

Large dots: >= 95% con

of weaker cyclones:



of strong cyclones: