Hurricane simulations using a regional climate model:
challenges (and opportunities)

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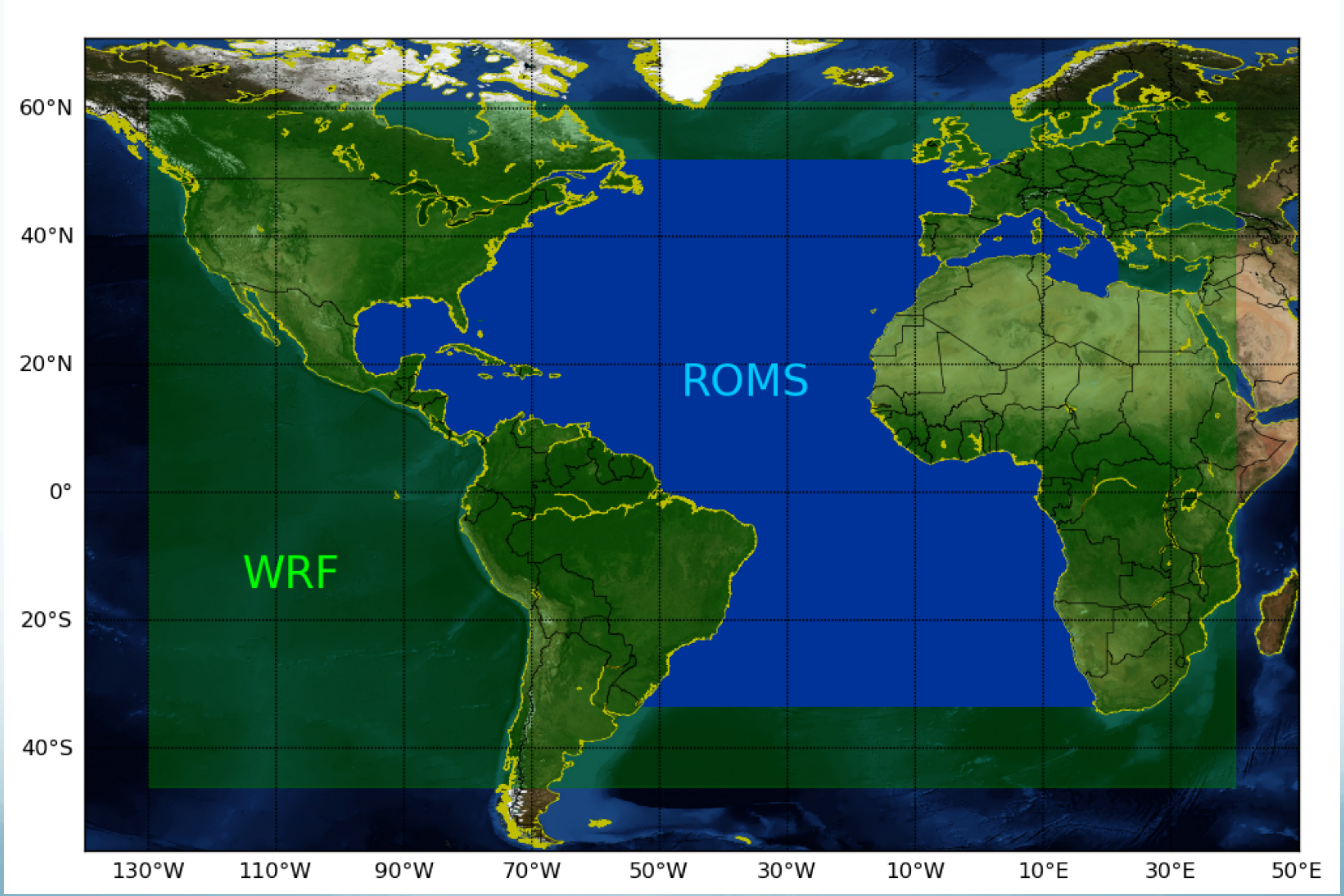
Texas A&M Coupled Regional Climate Model (TAMU-CRCM)



Coupled regional climate model (TAMU-CRCM)

Atmosphere:

- WRF (Weather Research and Forecasting Model)
- 27 km resolution
- 28 vertical levels (up to 50hPa)
- 90 sec time step
- Convection: Kain-Fritsch
- Radiation: Goddard SW, RRTMG LW
- Lin microphysics
- YSU PBL
- Noah LSM

Ocean :

- ROMS (Regional Ocean Modeling System)
- 9 km resolution, 30 vertical levels, 10 min time step

US CLIVAR Hurricane Working Group Simulations

Interannual (1980-2000):

• lateral boundary conditions: 6-hourly NCEP-II Reanalysis 1980-2000

• SST and sea ice: monthly HadISST 1980-2000

• greenhouse gases and aerosols: annually update, following protocol

Climatology (21 years, representative of 1980-2000):

• lateral boundary conditions: 6-hourly NCEP-II Reanalysis 1980-2000, with low-frequency (30 day) anomalies removed

• SST and sea ice: monthly climatology HadISST 1980-2000

• greenhouse gases and aerosols: present average values, following protocol

Double CO_2, +2K SST (21 years, representative of "warming"):

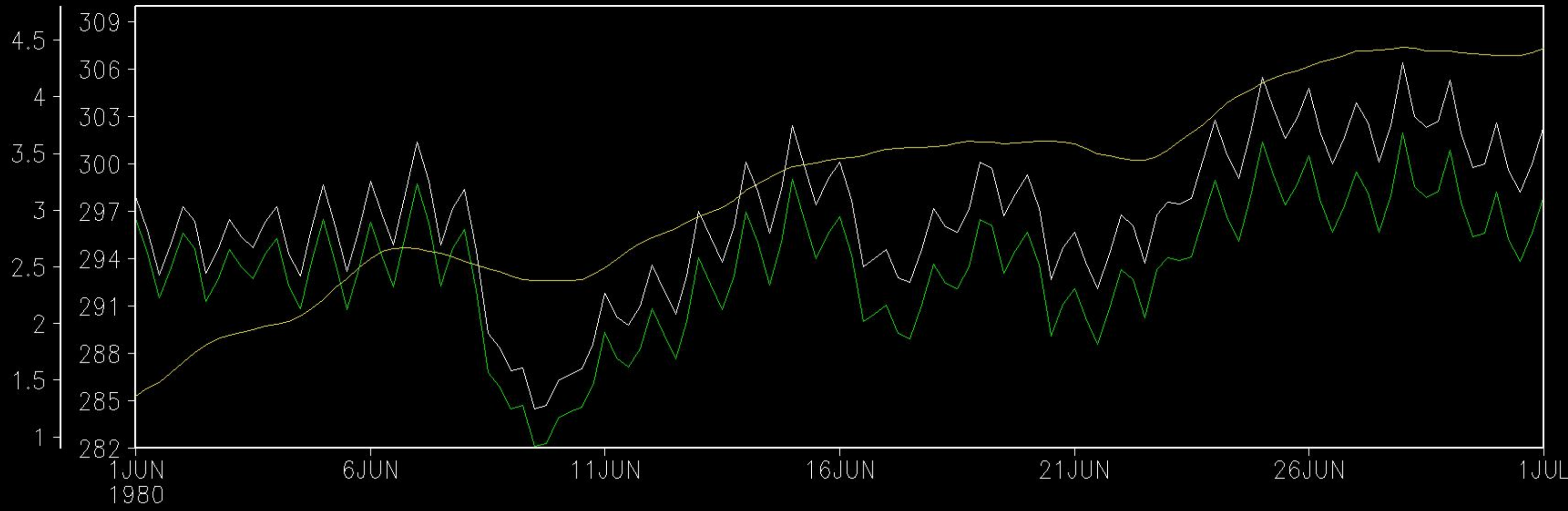
• lateral boundary conditions: *6-hourly from 1-degree double CO_2 and +2K CAM5 simulation, provided by Michael Wehner*

• SST and sea ice: monthly climatology HadISST 1980-2000 plus uniform 2K

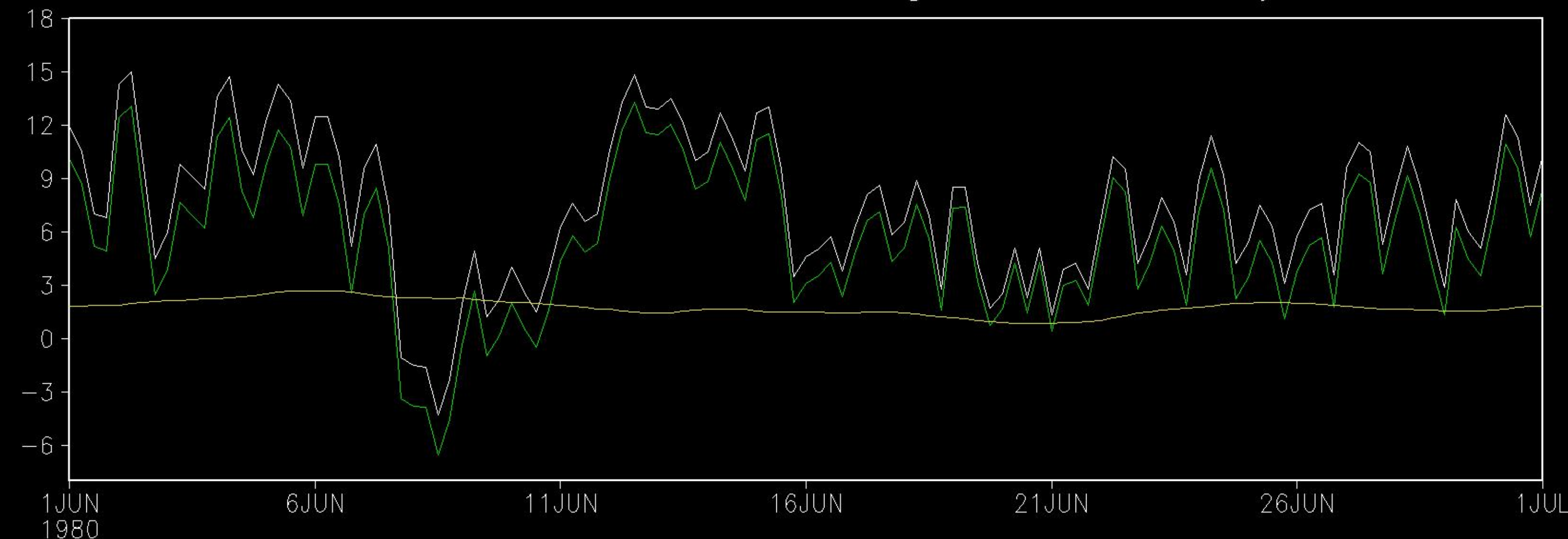
• greenhouse gases and aerosols: double present average values, following protocol

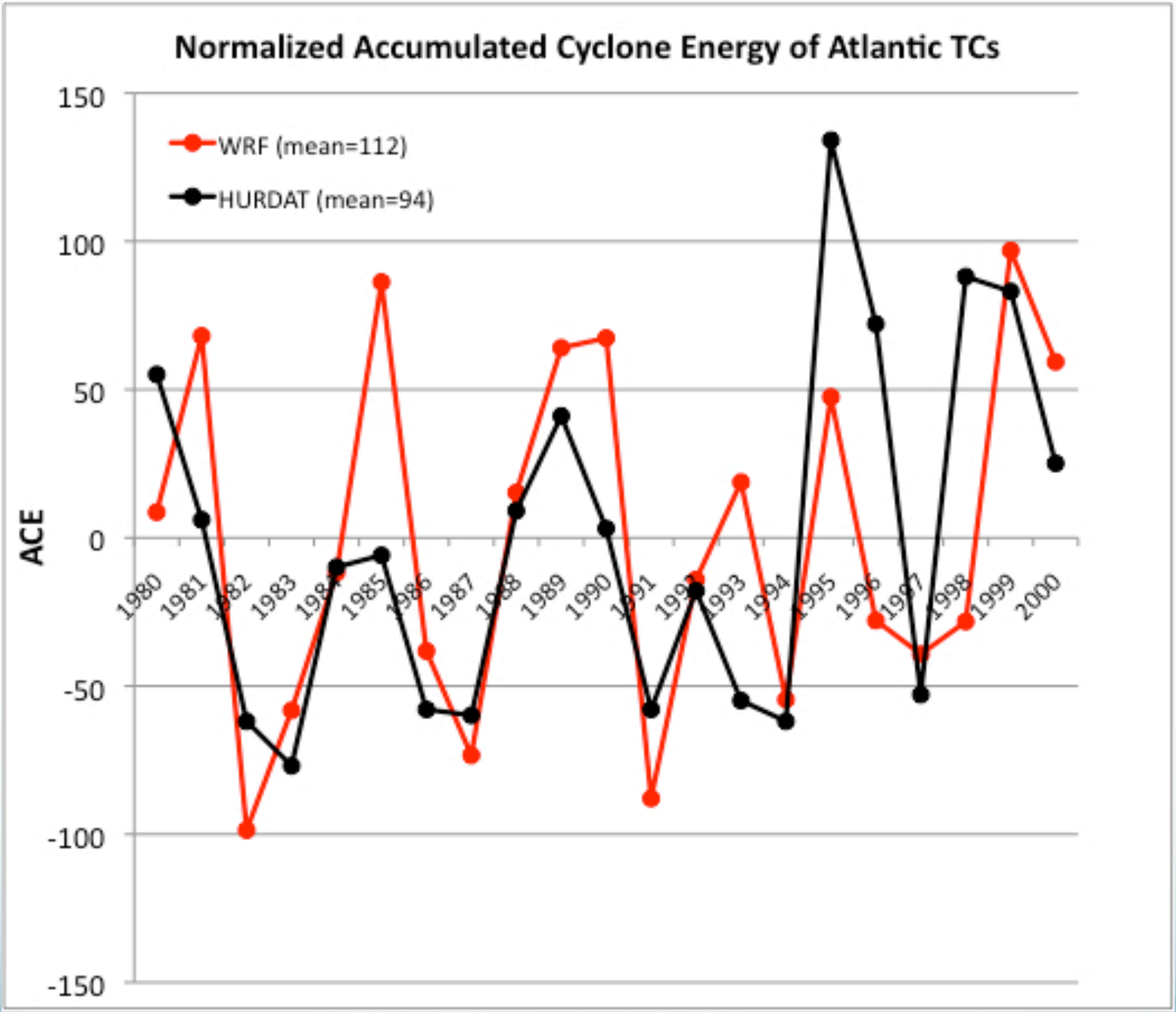
TC tracking: Walsh (1997)

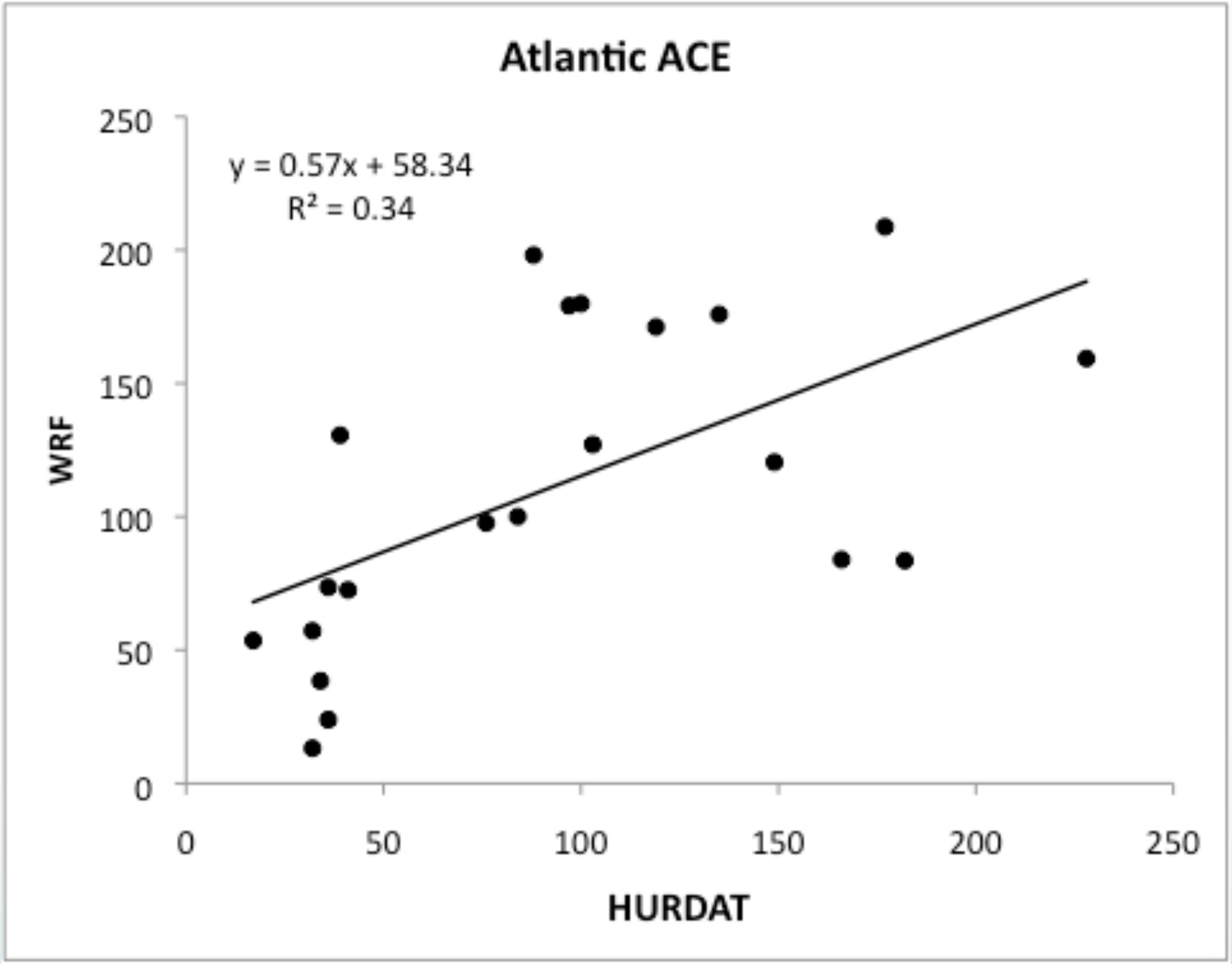
T 850hPa,35N,100W wh−NCEP2; gr−climLBC; yl−NCEP−clim

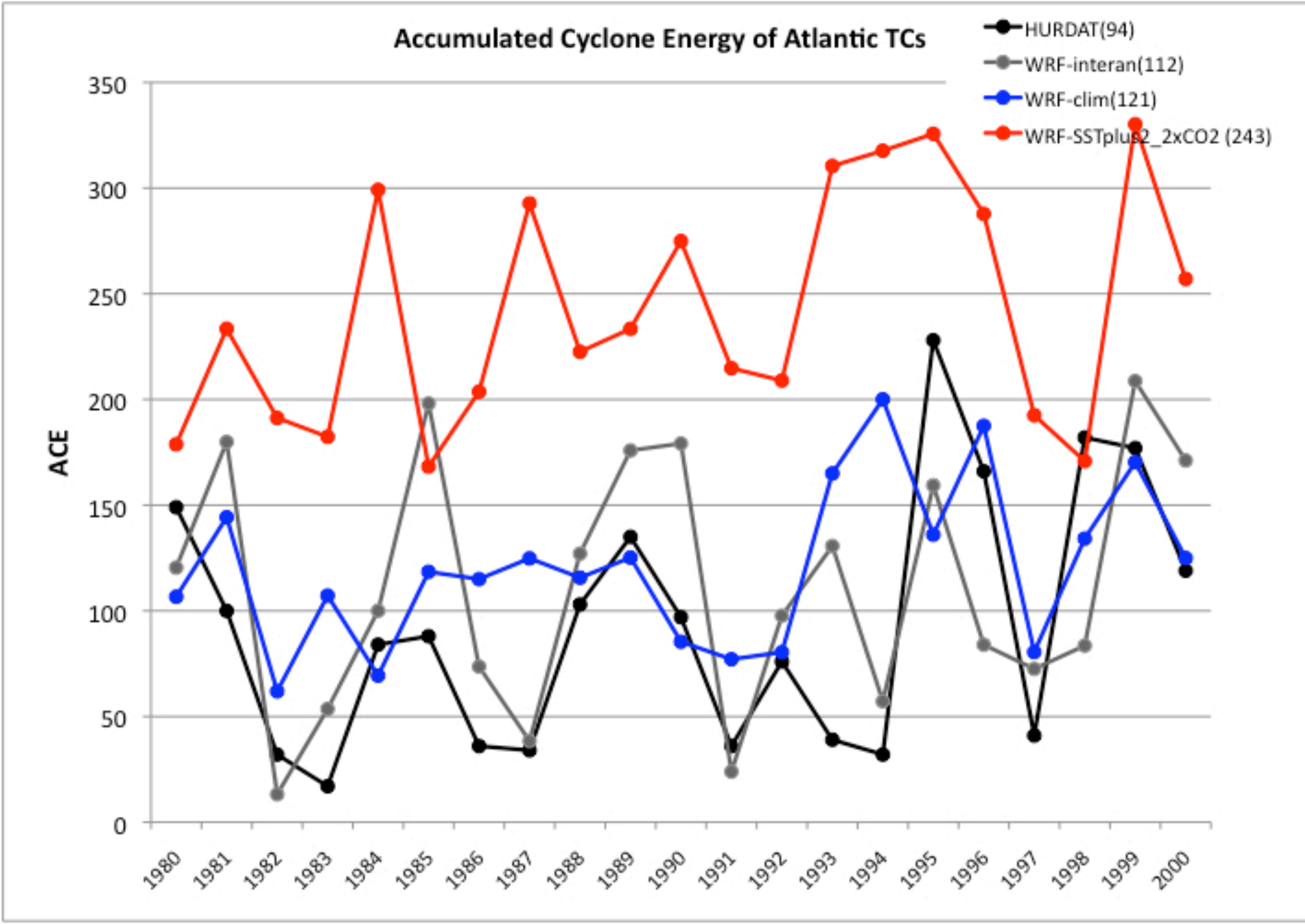


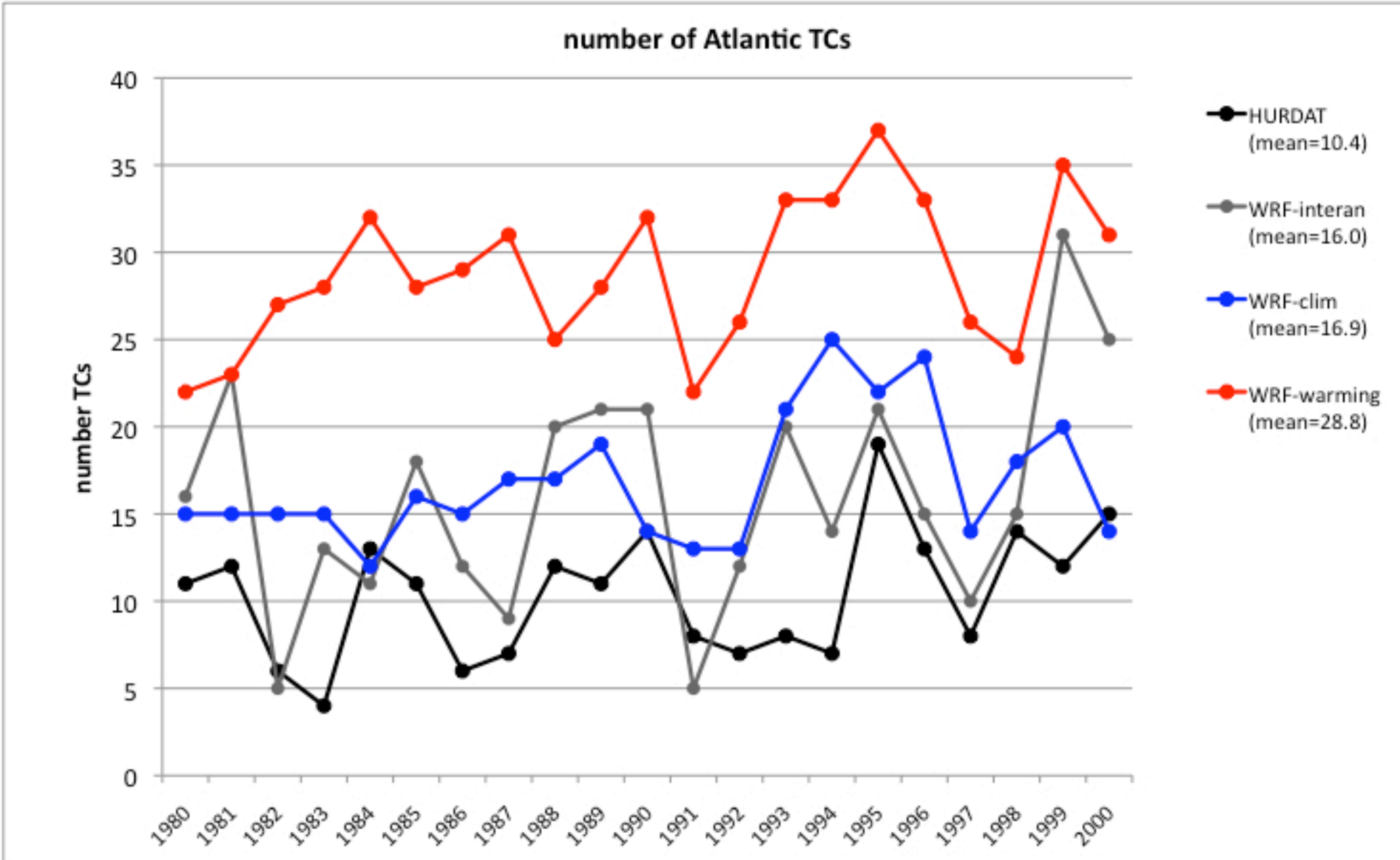
V 850hPa,35N,100W wh−NCEP2; gr−climLBC; yl−NCEP−clim



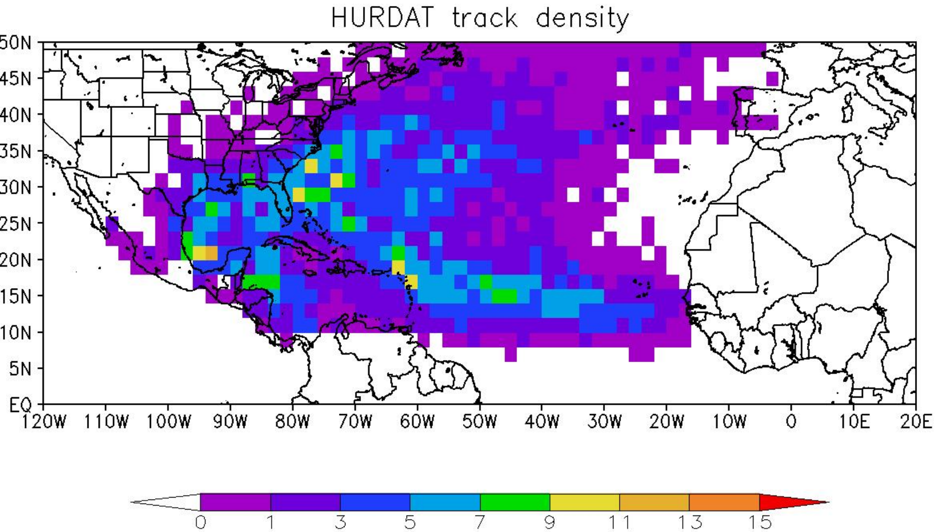

Normalized Accumulated Cyclone Energy of Atlantic TCs
WRF (mean=112)
HURDAT (mean=94)
ACE
150
100
50
0
-50
-100
-150
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

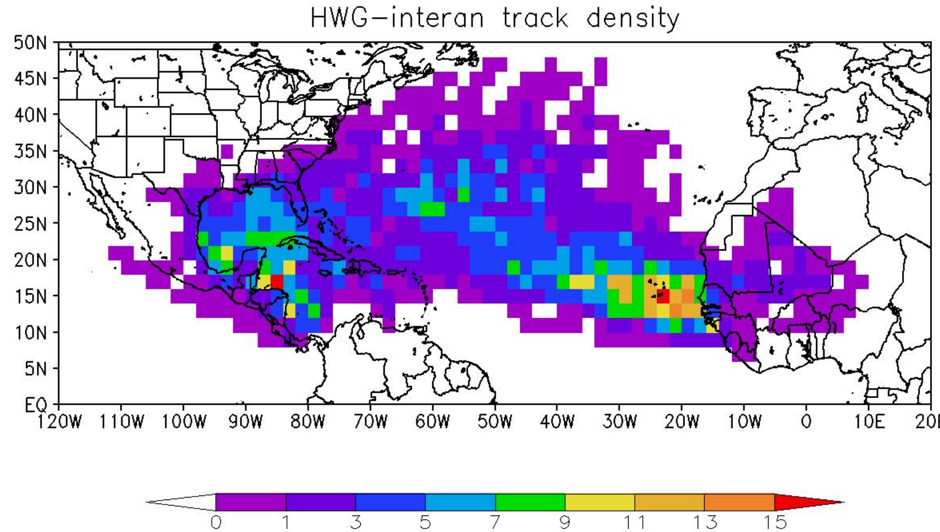

Atlantic ACE
y = 0.57x + 58.34
R² = 0.34
WRF
HURDAT
0
50
100
150
200
250
0
50
100
150
200
250

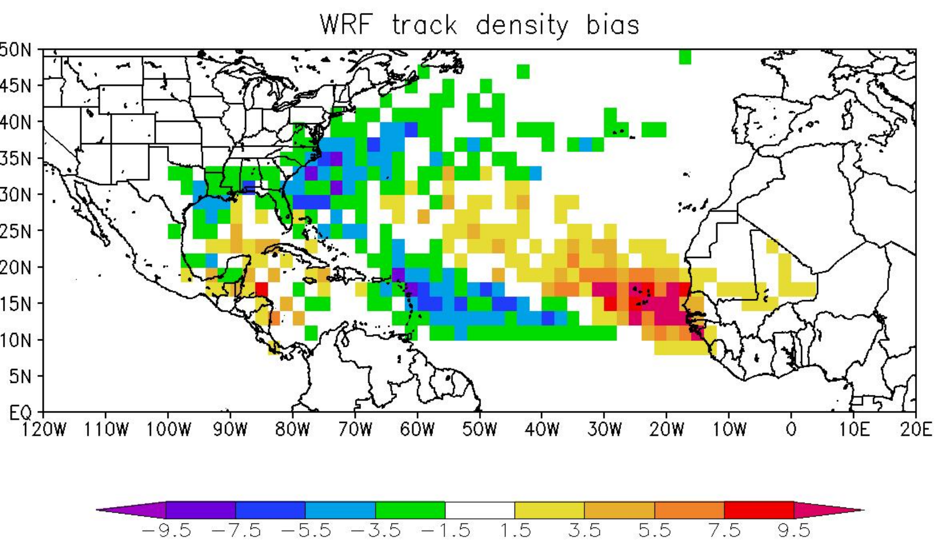

Accumulated Cyclone Energy of Atlantic TCs
HURDAT(94)
WRF-interan(112)
WRF-clim(121)
WRF-SSTplus2_2xCO2 (243)
ACE
0
50
100
150
200
250
300
350
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

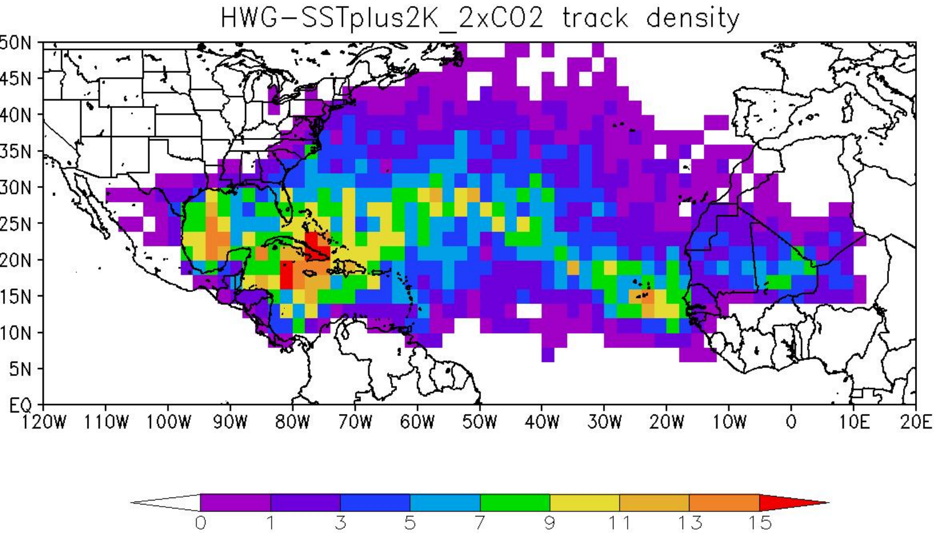


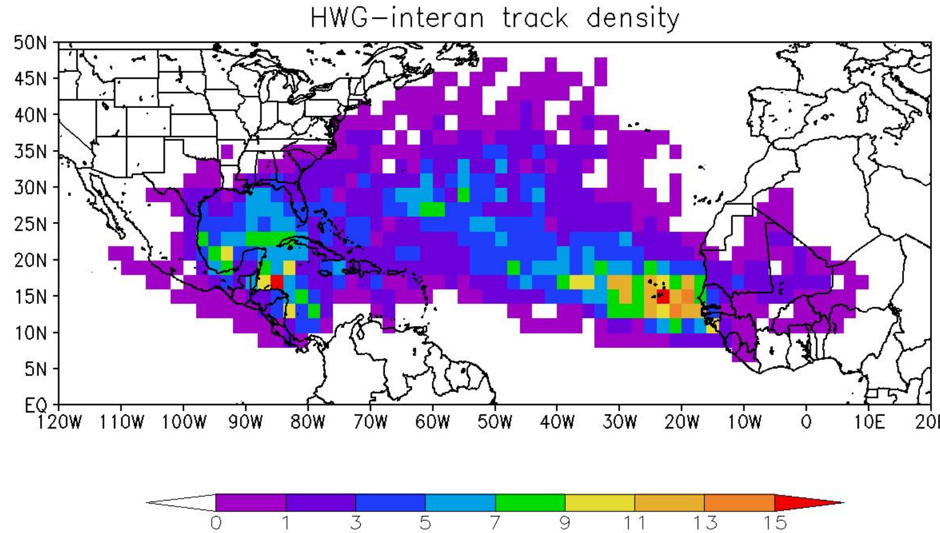
number of Atlantic TCs
number TCs
0
5
10
15
20
25
30
35
40
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
HURDAT (mean=10.4)
WRF-interan (mean=16.0)
WRF-clim (mean=16.9)
WRF-warming (mean=28.8)

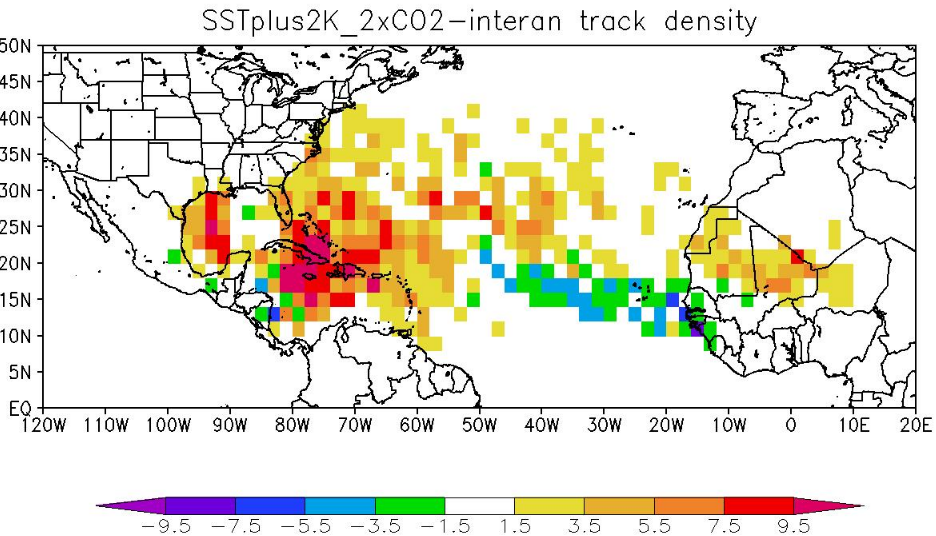

HURDAT track density
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
0 1 3 5 7 9 11 13 15

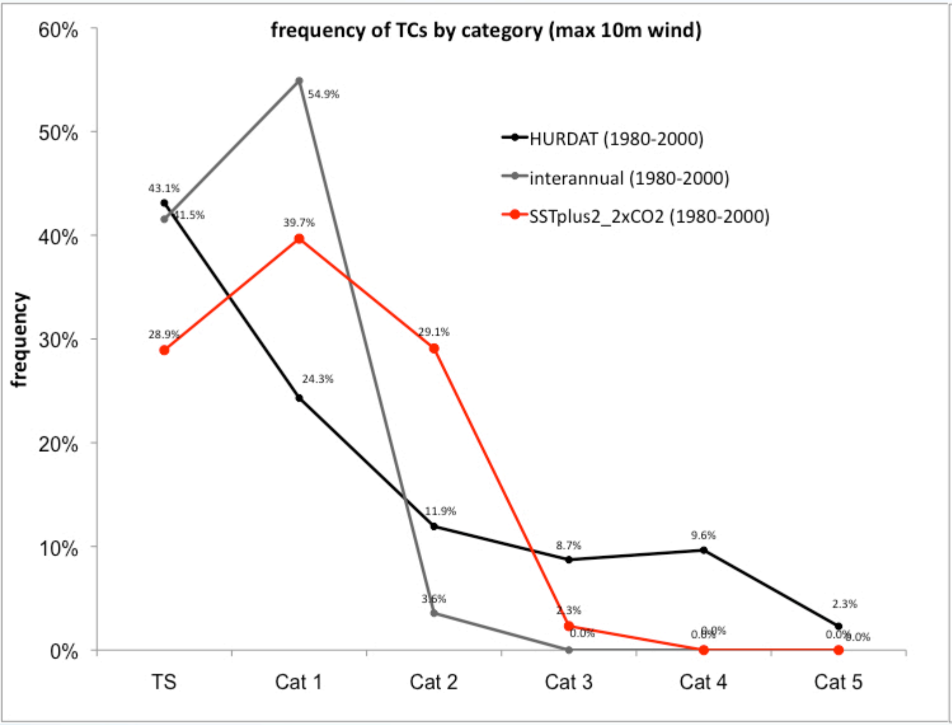

HWG-interan track density
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
0 1 3 5 7 9 11 13 15


WRF track density bias
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
−9.5 −7.5 −5.5 −3.5 −1.5 1.5 3.5 5.5 7.5 9.5

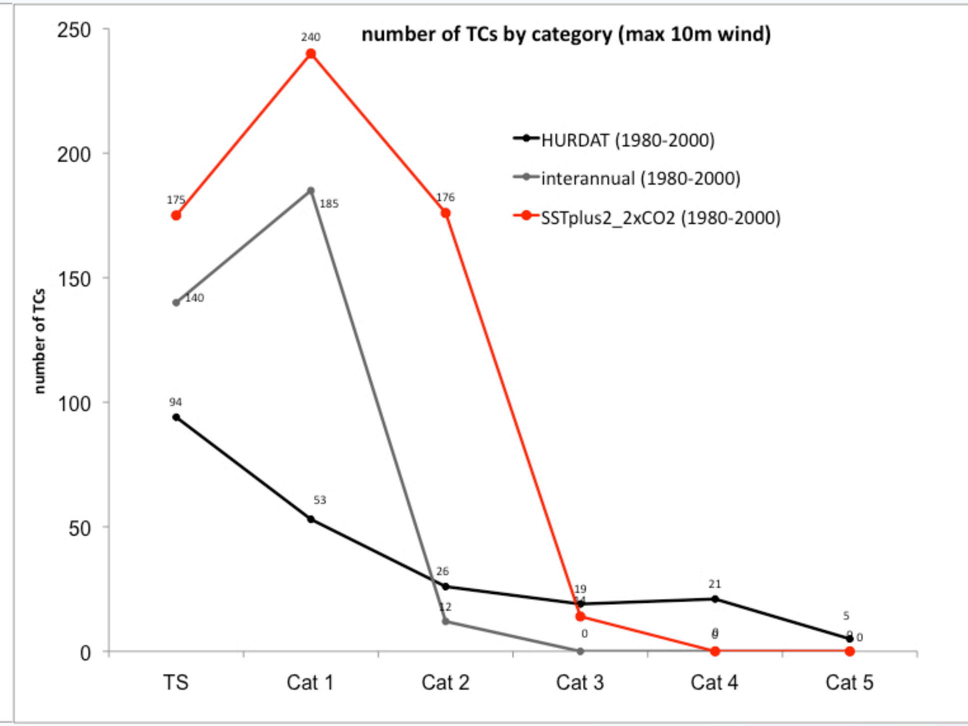

HWG−SSTplus2K_2xCO2 track density
50N 45N 40N 35N 30N 25N 20N 15N 10N 5N EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
0 1 3 5 7 9 11 13 15


HWG−interan track density
50N 45N 40N 35N 30N 25N 20N 15N 10N 5N EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
0 1 3 5 7 9 11 13 15

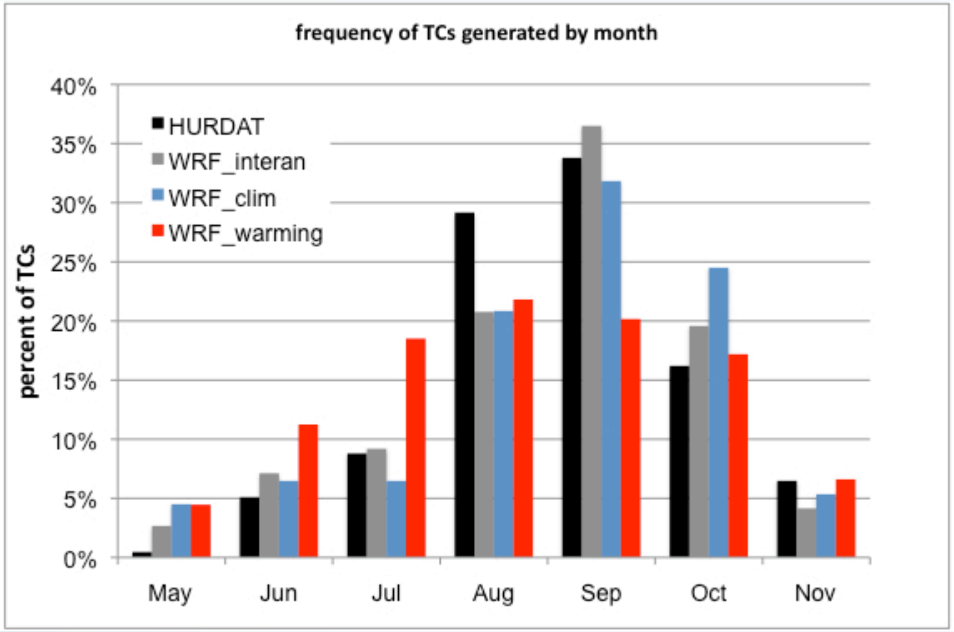

SSTplus2K_2xCO2−interan track density
50N 45N 40N 35N 30N 25N 20N 15N 10N 5N EQ
120W 110W 100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0 10E 20E
−9.5 −7.5 −5.5 −3.5 −1.5 1.5 3.5 5.5 7.5 9.5

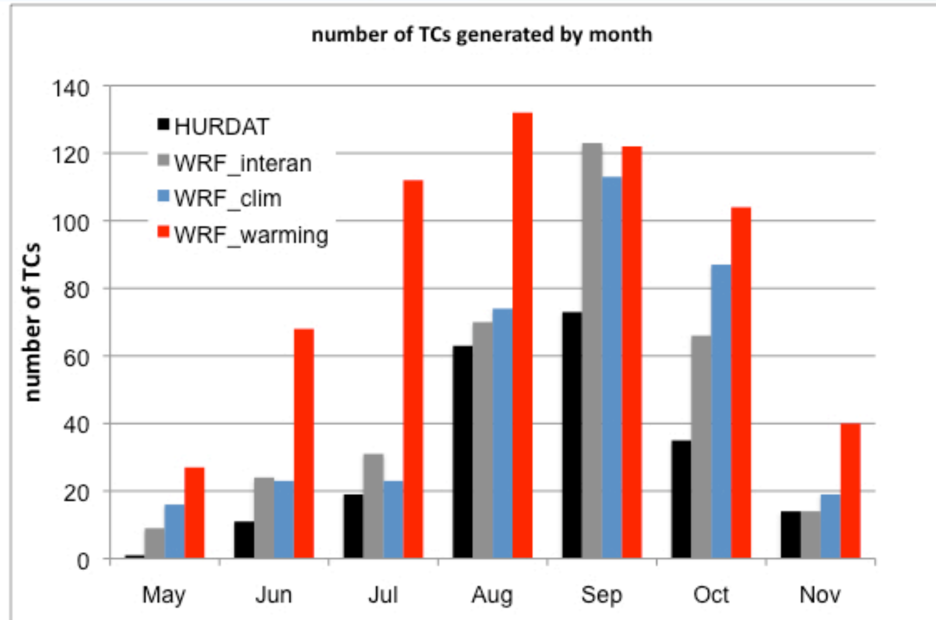


frequency of TCs by category (max 10m wind)
frequency
60%
50%
40%
30%
20%
10%
0%
TS
Cat 1
Cat 2
Cat 3
Cat 4
Cat 5
HURDAT (1980-2000)
interannual (1980-2000)
SSTplus2_2xCO2 (1980-2000)
43.1%
41.5%
28.9%
54.9%
39.7%
24.3%
29.1%
11.9%
3.6%
8.7%
2.3%
0.0%
9.6%
0.0%
0.0%
2.3%
0.0%
0.0%



number of TCs by category (max 10m wind)
number of TCs
250
200
150
100
50
0
TS
Cat 1
Cat 2
Cat 3
Cat 4
Cat 5
HURDAT (1980-2000)
interannual (1980-2000)
SSTplus2_2xCO2 (1980-2000)
175
140
94
240
185
53
176
26
12
19
0
21
5
0


frequency of TCs generated by month
percent of TCs
40%
35%
30%
25%
20%
15%
10%
5%
0%
HURDAT
WRF_interan
WRF_clim
WRF_warming
May
Jun
Jul
Aug
Sep
Oct
Nov


number of TCs generated by month
number of TCs
140
120
100
80
60
40
20
0
HURDAT
WRF_interan
WRF_clim
WRF_warming
May
Jun
Jul
Aug
Sep
Oct
Nov

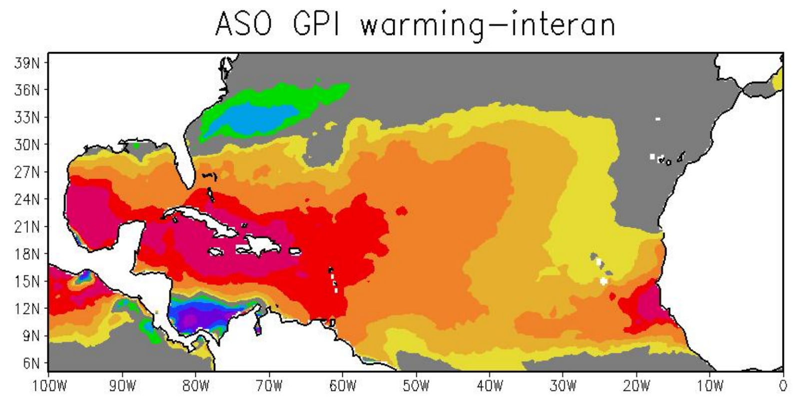
Genesis potential index (GPI)

(Emanuel and Nolan, 2004)

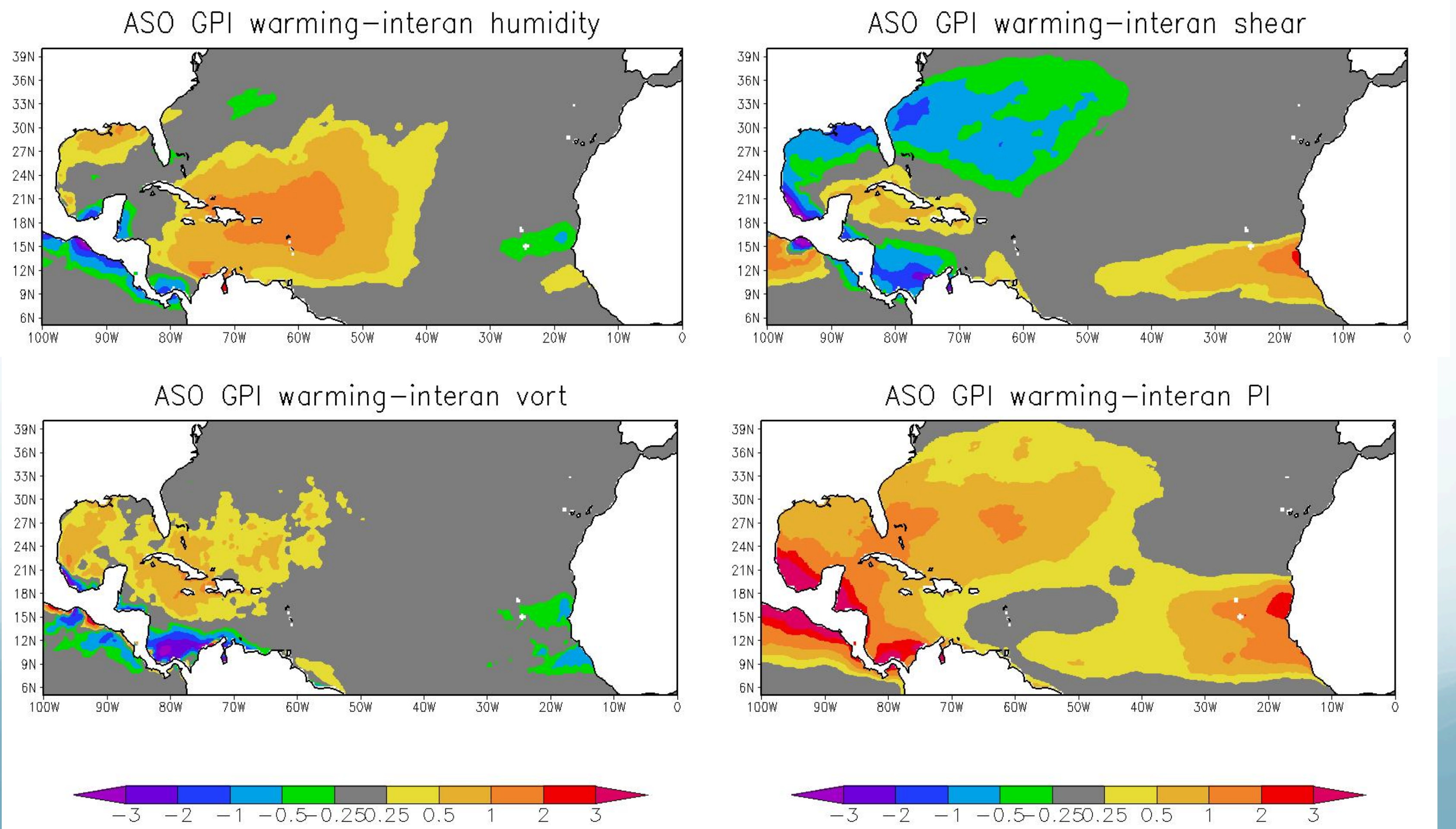
$$GPI = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1V_{shear}\right)^{-2}$$

η = absolute vorticity at 850 hPa
H = relative humidity at 600 hPa
V_{pot} = potential intensity (function of SST and vertical profiles of atmospheric temperature and moisture)
V_{shear} = vertical wind shear between 850 hPa and 200 hPa

ASO GPI

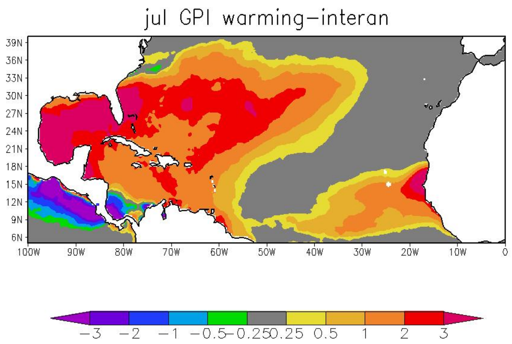


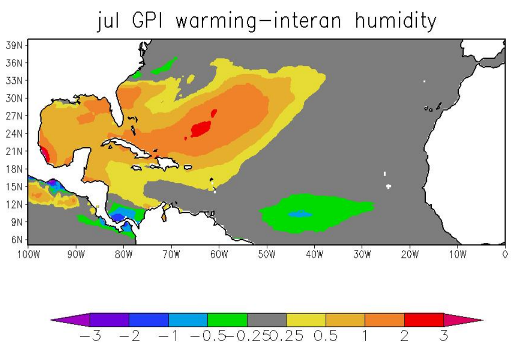
ASO GPI warming−interan
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0

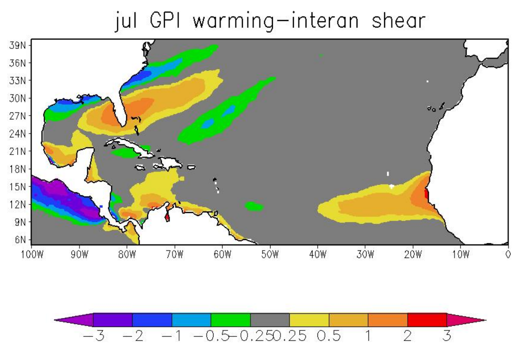


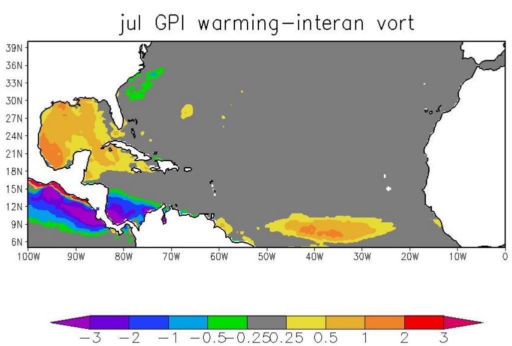
ASO GPI warming−interan humidity
ASO GPI warming−interan shear
ASO GPI warming−interan vort
ASO GPI warming−interan PI
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

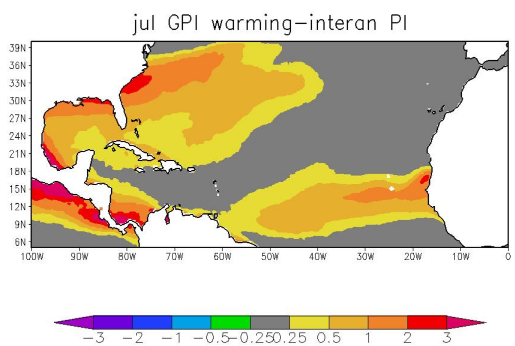
July GPI

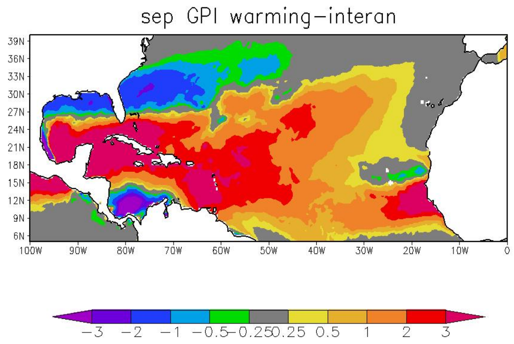

jul GPI warming−interan
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3


jul GPI warming−interan humidity
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

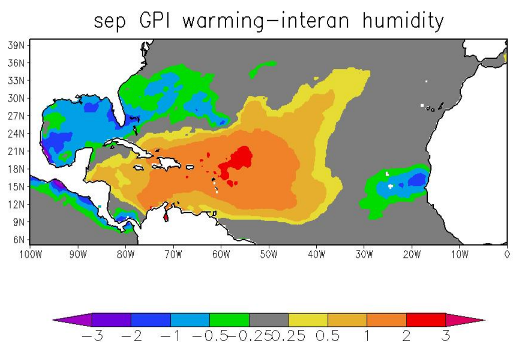

jul GPI warming−interan shear
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

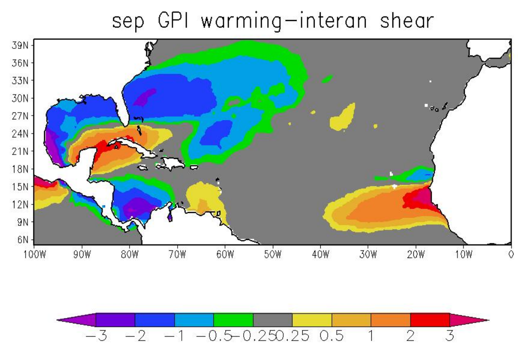

jul GPI warming−interan vort
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

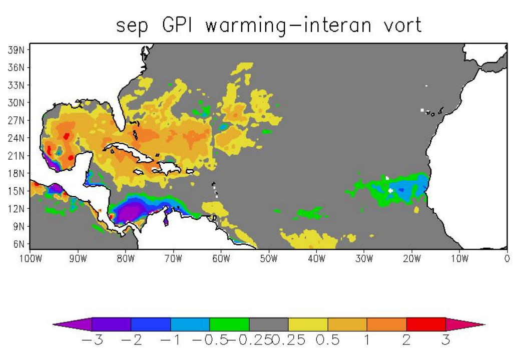

jul GPI warming−interan PI
39N 36N 33N 30N 27N 24N 21N 18N 15N 12N 9N 6N
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W 0
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

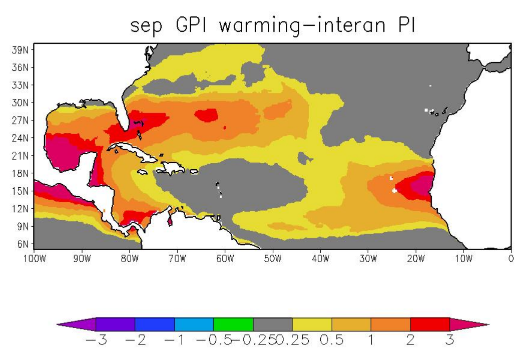

sep GPI warming−interan
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

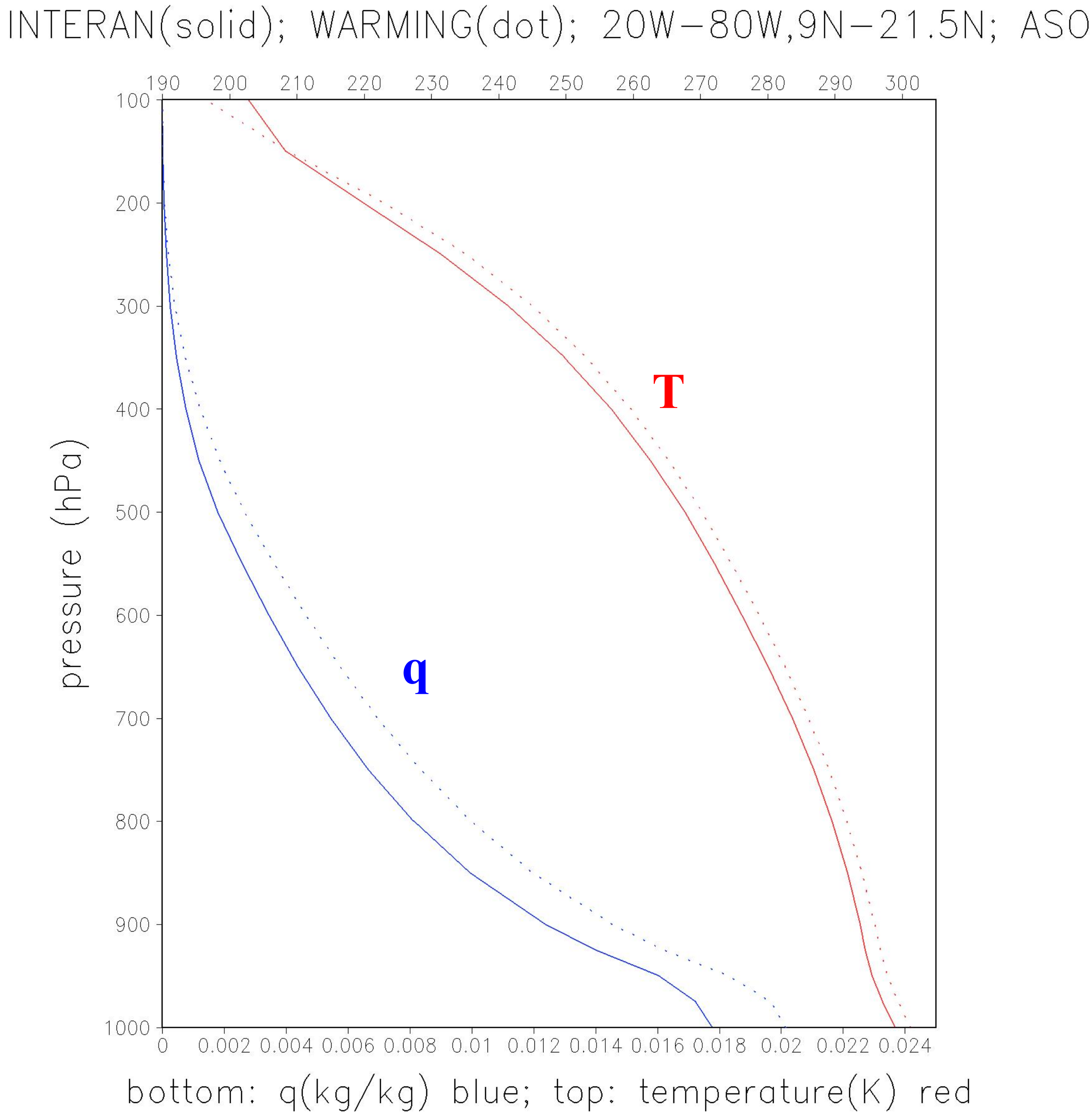
Sep. GPI

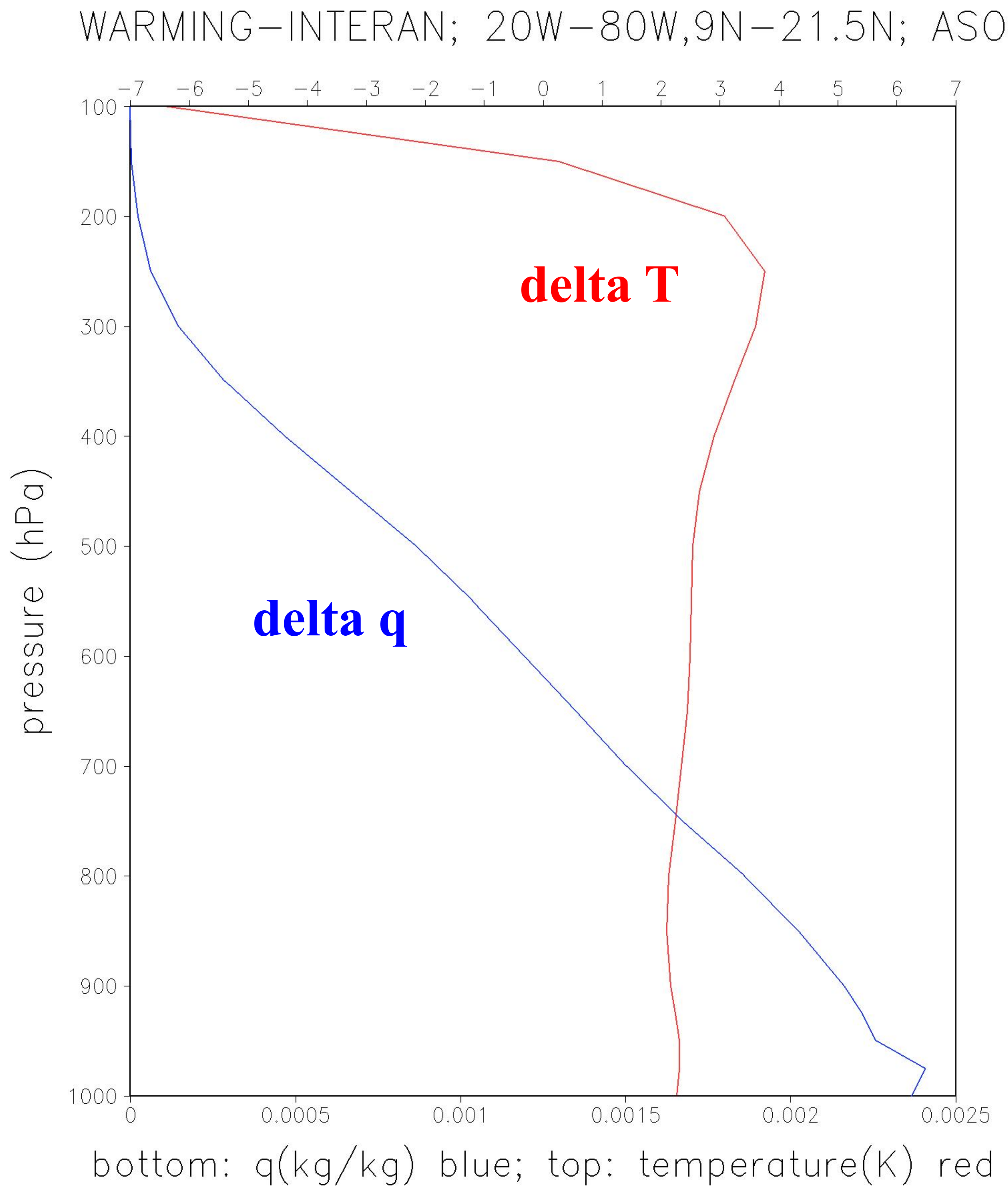

sep GPI warming−interan humidity
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3


sep GPI warming−interan shear
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3


sep GPI warming−interan vort
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3

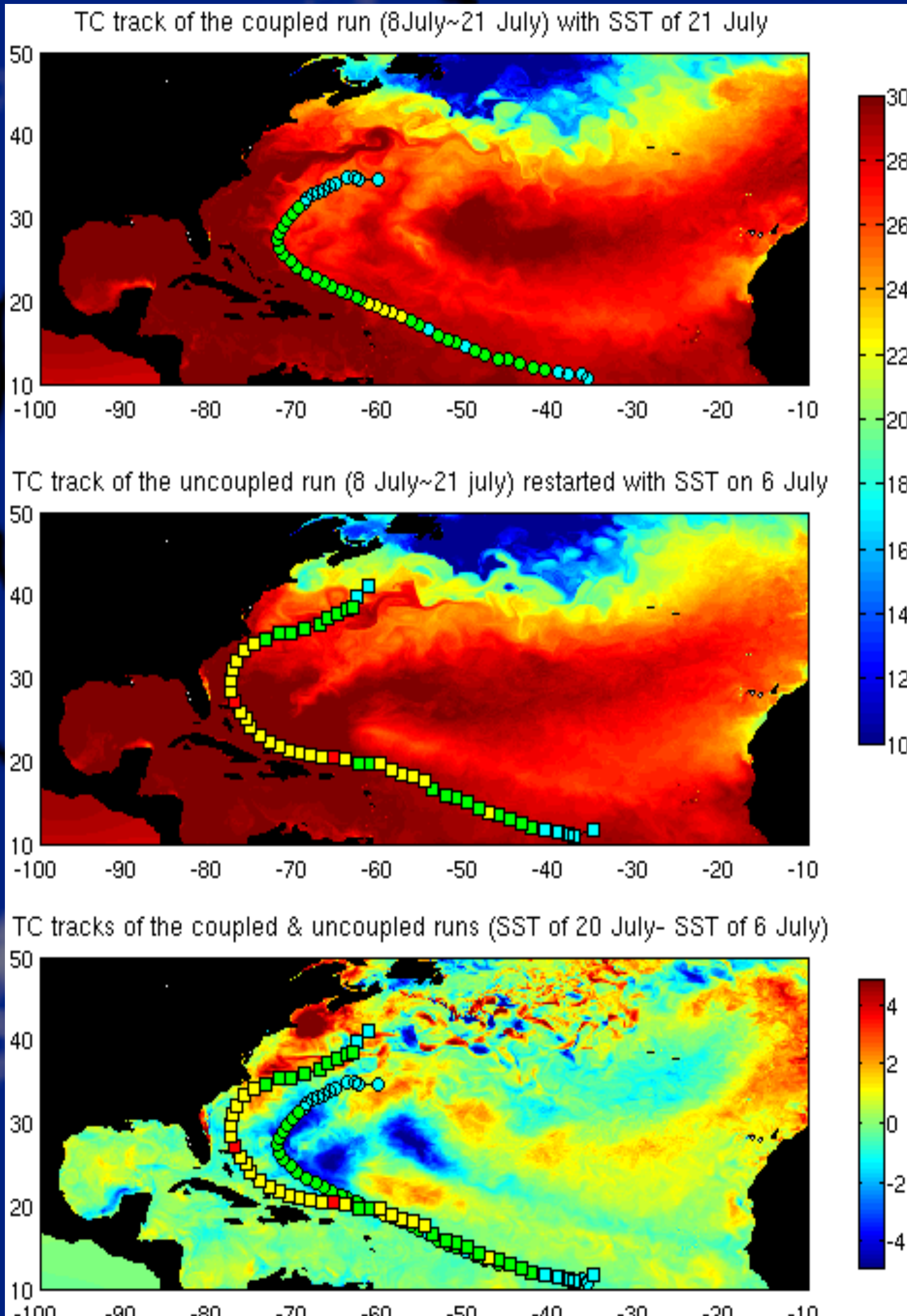

sep GPI warming−interan PI
−3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3


INTERAN(solid); WARMING(dot); 20W-80W,9N-21.5N; ASO
190 200 210 220 230 240 250 260 270 280 290 300
100 200 300 400 500 600 700 800 900 1000
pressure (hPa)
T
q
0 0.002 0.004 0.006 0.008 0.01 0.012 0.014 0.016 0.018 0.02 0.022 0.024
bottom: q(kg/kg) blue; top: temperature(K) red



WARMING–INTERAN; 20W–80W,9N–21.5N; ASO
−7
−6
−5
−4
−3
−2
−1
0
1
2
3
4
5
6
7
100
200
300
400
500
600
700
800
900
1000
pressure (hPa)
delta T
delta q
0
0.0005
0.001
0.0015
0.002
0.0025
bottom: q(kg/kg) blue; top: temperature(K) red

Comparing simulated TCs in CRCM and WRF-only runs

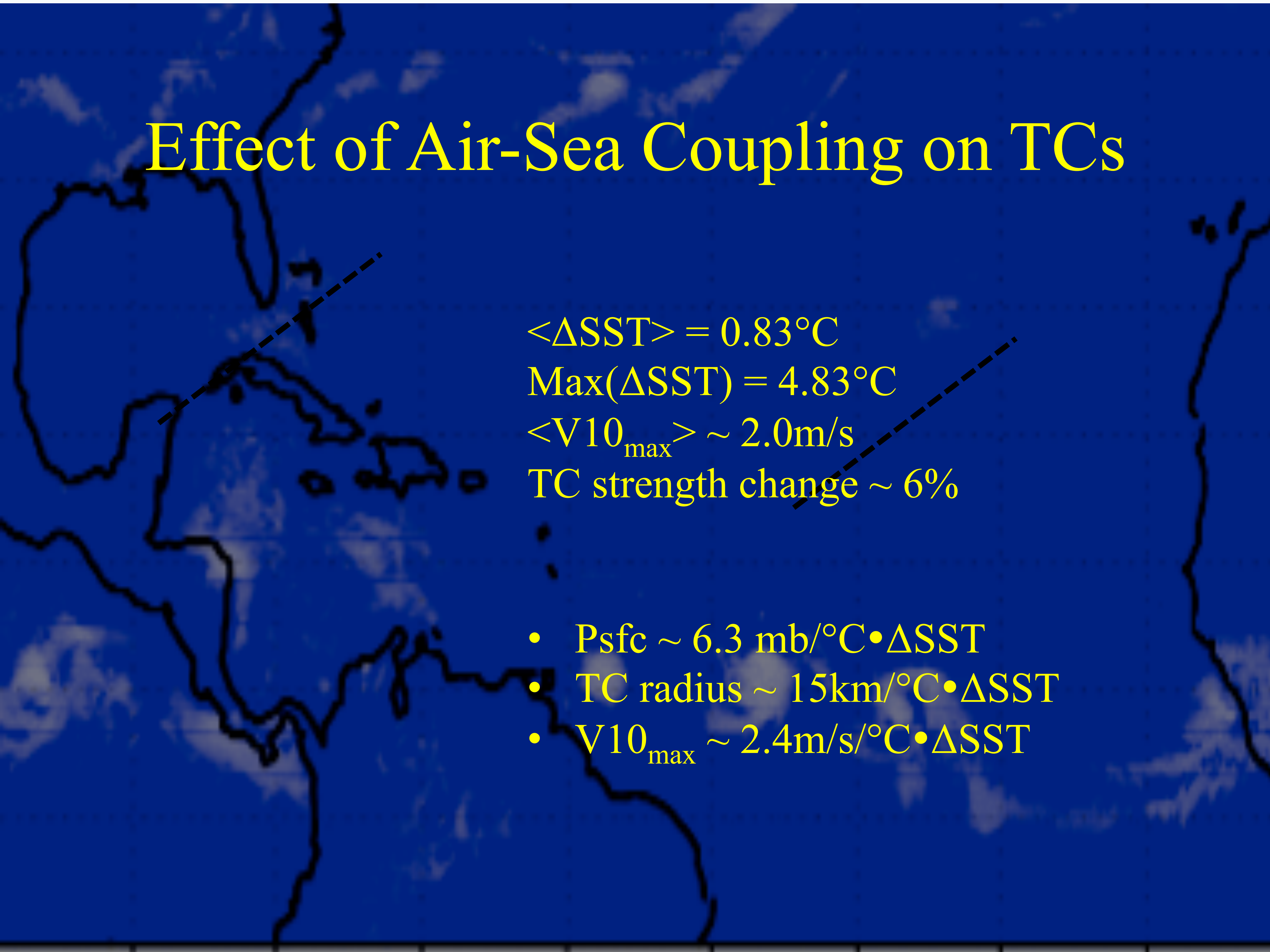


Coupled (atmosphere+ocean)

Atmosphere-only

Surface temperature difference

Effect of Air-Sea Coupling on TCs



$<\Delta SST> = 0.83°C$

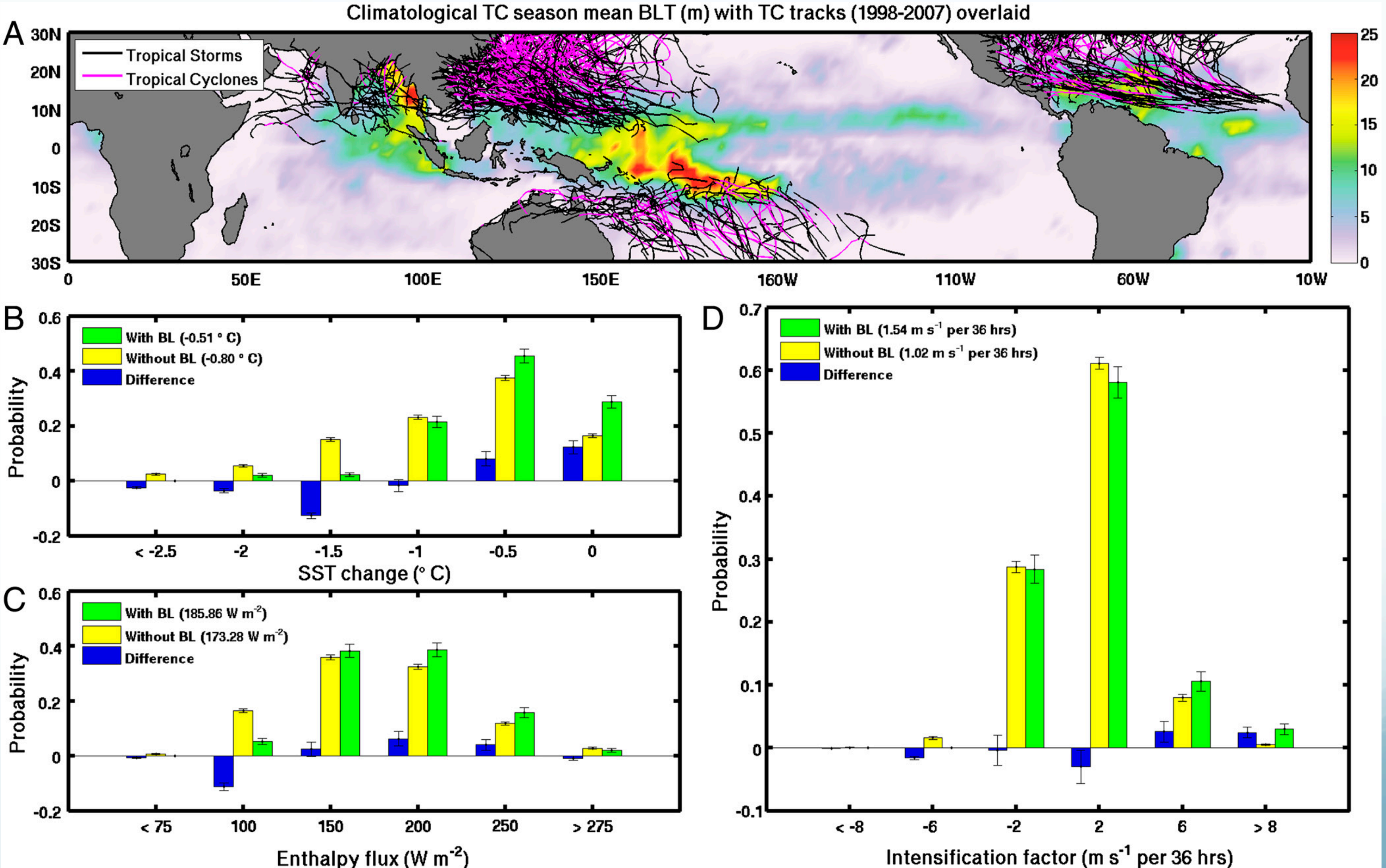
$Max(\Delta SST) = 4.83°C$

$<V10_{max}> \sim 2.0 m/s$

TC strength change ~ 6%

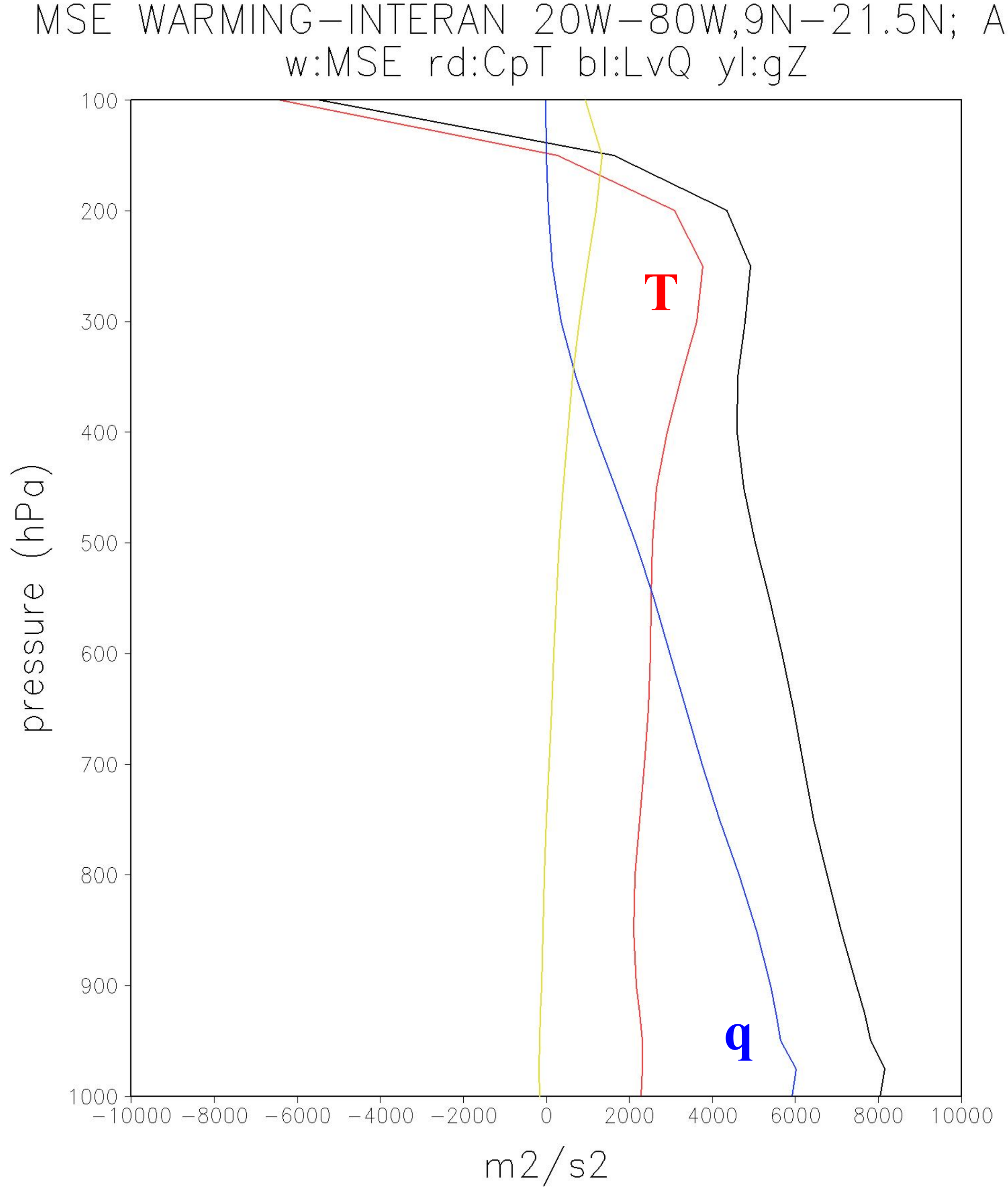
- Psfc ~ 6.3 mb/°C•ΔSST
- TC radius ~ 15km/°C•ΔSST
- $V10_{max}$ ~ 2.4m/s/°C•ΔSST

Balaguru et al., PNAS, 2012: Ocean barrier layers' effect on tropical cyclone intensification



Conclusions

- Challenges of using WRF
  - WRF is not necessarily a good climate model
  - Lateral BC needs to be specified
- Advantages of using WRF
  - WRF is a good weather model
  - Lateral BC can be modified
  - Higher resolution
- Hurricane WG simulations
  - WRF simulates interannual variability quite well
  - $2xCO_2$+2K simulation
    - Increase in stronger storms
    - Also, large increase in weaker storms
    - Increase over the Caribbean region; extended season
    - GPI: Increase in humidity and PI (cooling near the tropopause?)



MSE WARMING-INTERAN 20W-80W,9N-21.5N; ASO
w:MSE rd:CpT bl:LvQ yl:gZ
100
200
300
400
500
600
700
800
900
1000
pressure (hPa)
−10000 −8000 −6000 −4000 −2000 0 2000 4000 6000 8000 10000
m2/s2
T
q