AMOC variability and its impacts on the global climate

Yehui Chang, Siegfried Schubert, Max Suarez and Yury Vikhliaev

Global Modeling and Assimilation Office
NASA/GSFC

Email: yehui.chang-1@nasa.gov

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Motivation

- **AMOC is the largest source of decadal/multi-decadal variability**
- **AMOC variability and its impacts on the global climate**
- **Decadal variability arising from ocean internal variability**
- **Atmospheric relevance on oceanic variability**
- **Short climate system records**

GEOS-5 Coupled Model Replay System

AGCM

- Finite-volume dynamical core (S.J. Lin)
- Moist physics (J. Bacmeister, S. Moorthi and M. Suarez)
- Physics integrated under the Earth System Modeling Framework (**ESMF**)
- Generalized vertical coord to 0.01 hPa
- Catchment land surface model (R. Koster)
- Prescribed aerosols (P. Colarco)
- Interactive ozone

OGCM

- GFDL ocean model (MOM4)

Sea Ice

- CICE (The Los Alamos Sea Ice Model)

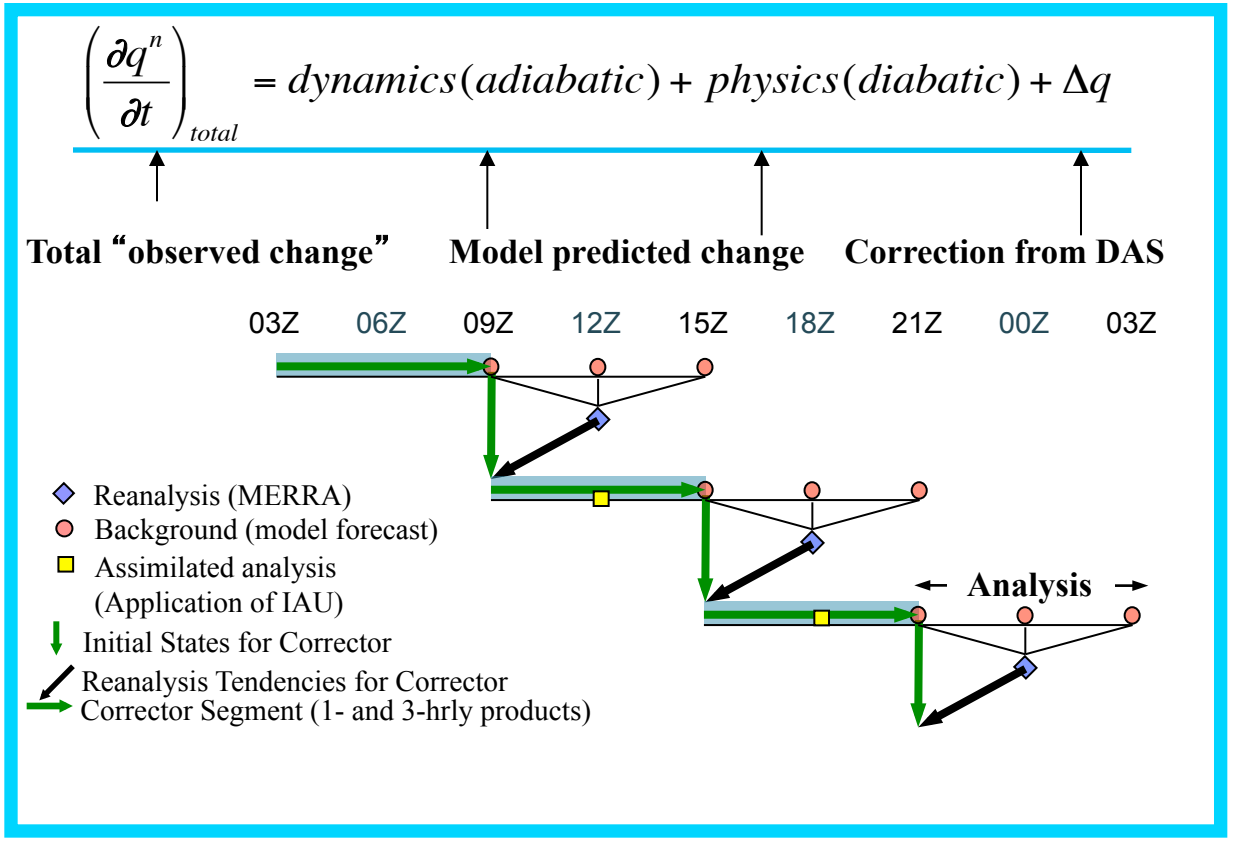
A replay of the atmospheric data analysis in the CGCM.

Replay

- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion (Bloom et al.)
- IAU gradually forces the model integration throughout the 6 hour analysis period

Reanalysis

- MERRA
- NCEP, JRA-25, ERA



GEOS-5 Coupled Model Experiments

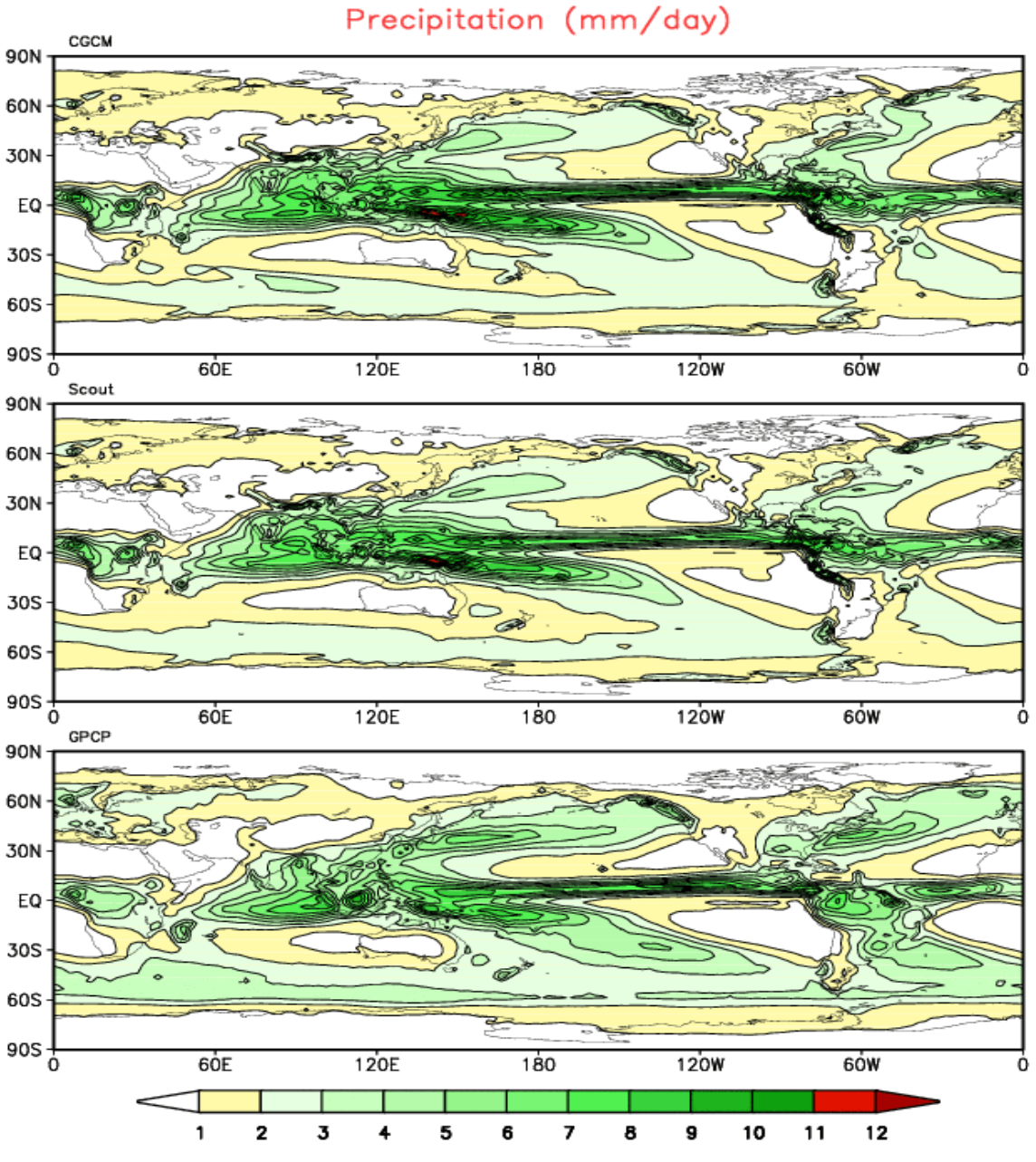
- **Models**

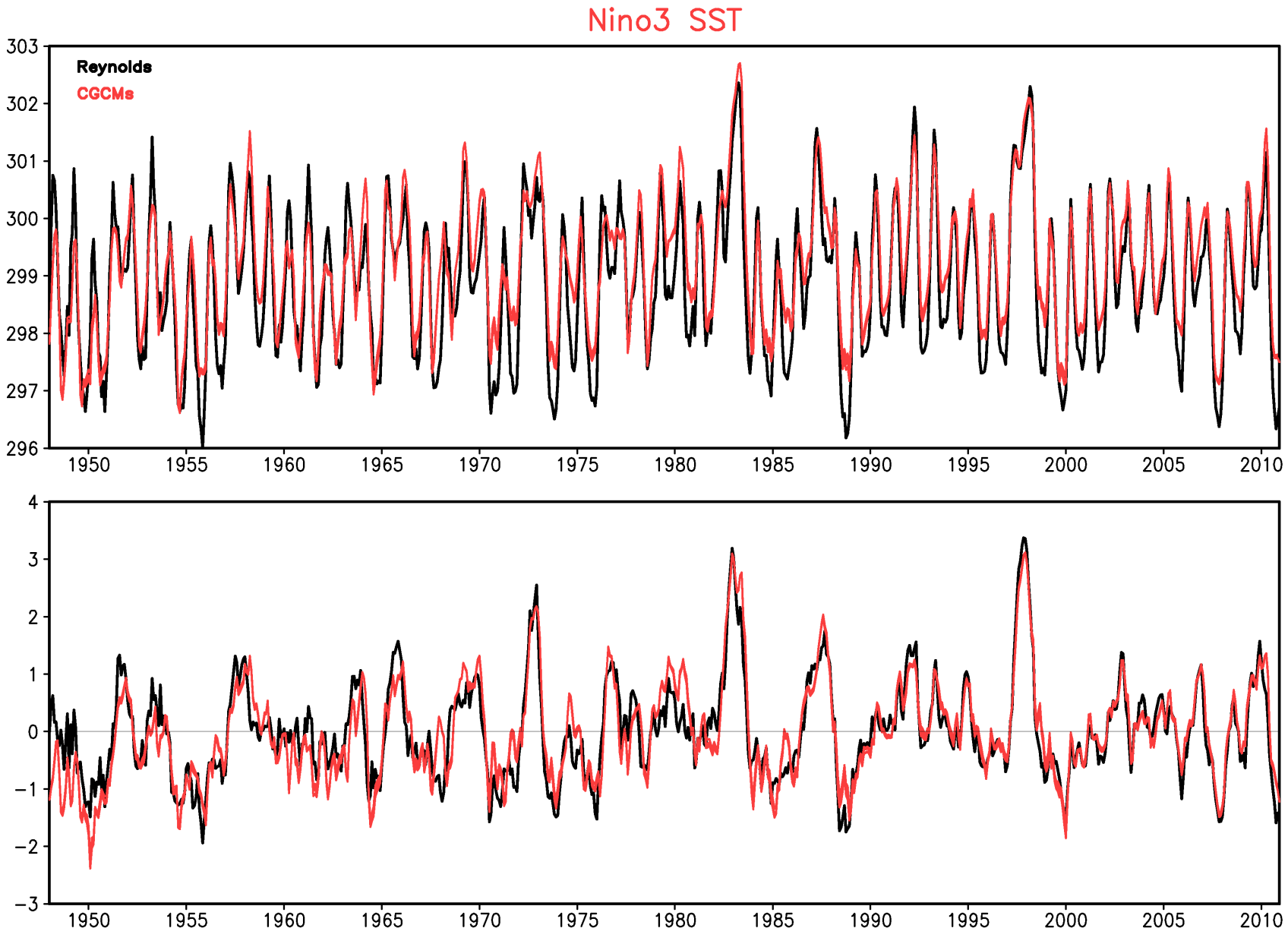
  AGCM: GEOS5 at 2X2.5X72
  OGCM: MOM4 at 1/3x1 in tropics; 1x1 in extratropics; 50 layers
  Sea Ice: CICE (The Los Alamos Sea Ice Model)
  Coupling every 30 minutes

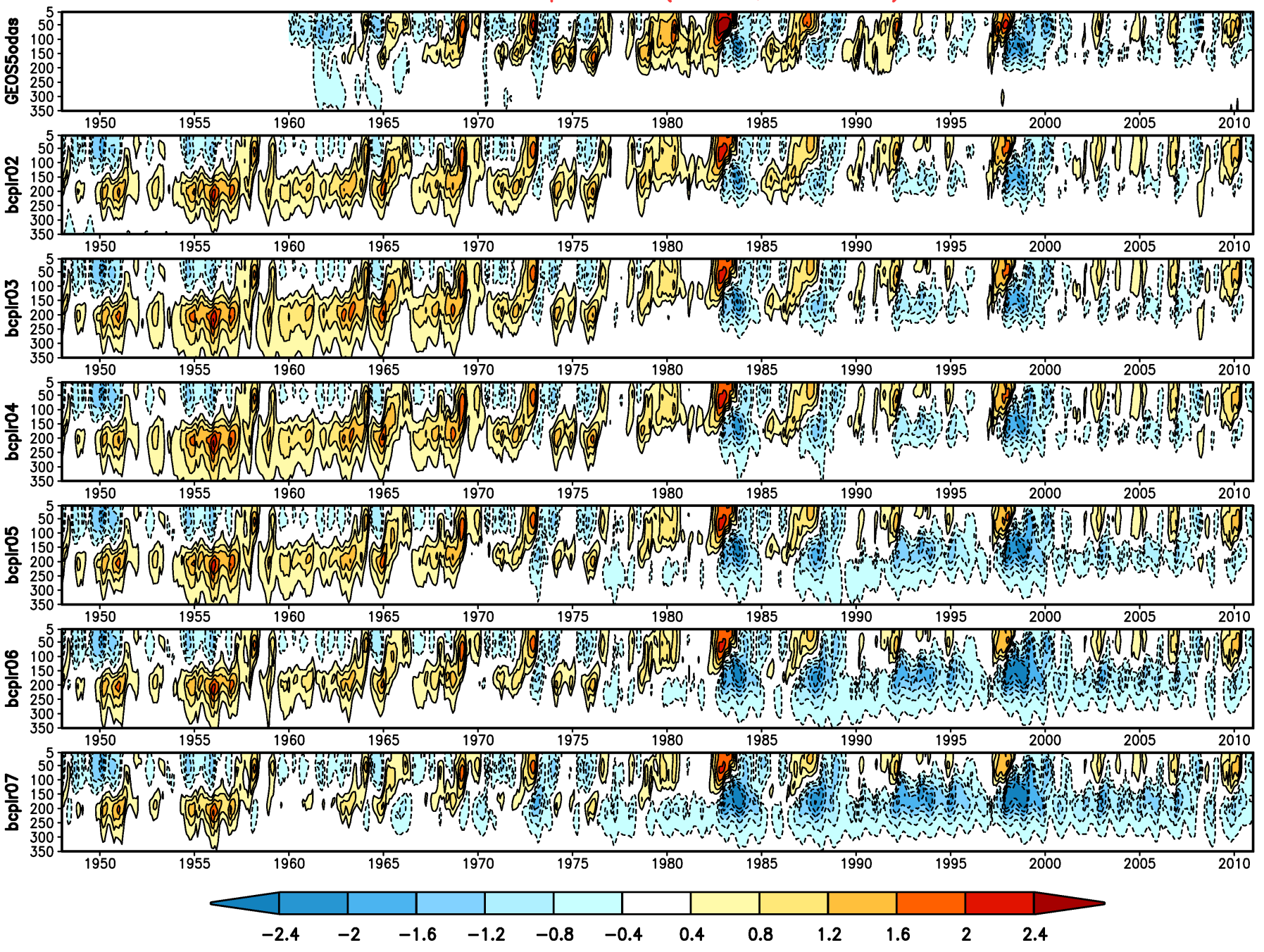
- **Replay runs (MERRA Scout data)**
  CGCM replay run: 1948-2010

- **7-cycle: replay u,v,T,q and ps**
- **1-cycle: replay u,v,T and ps**

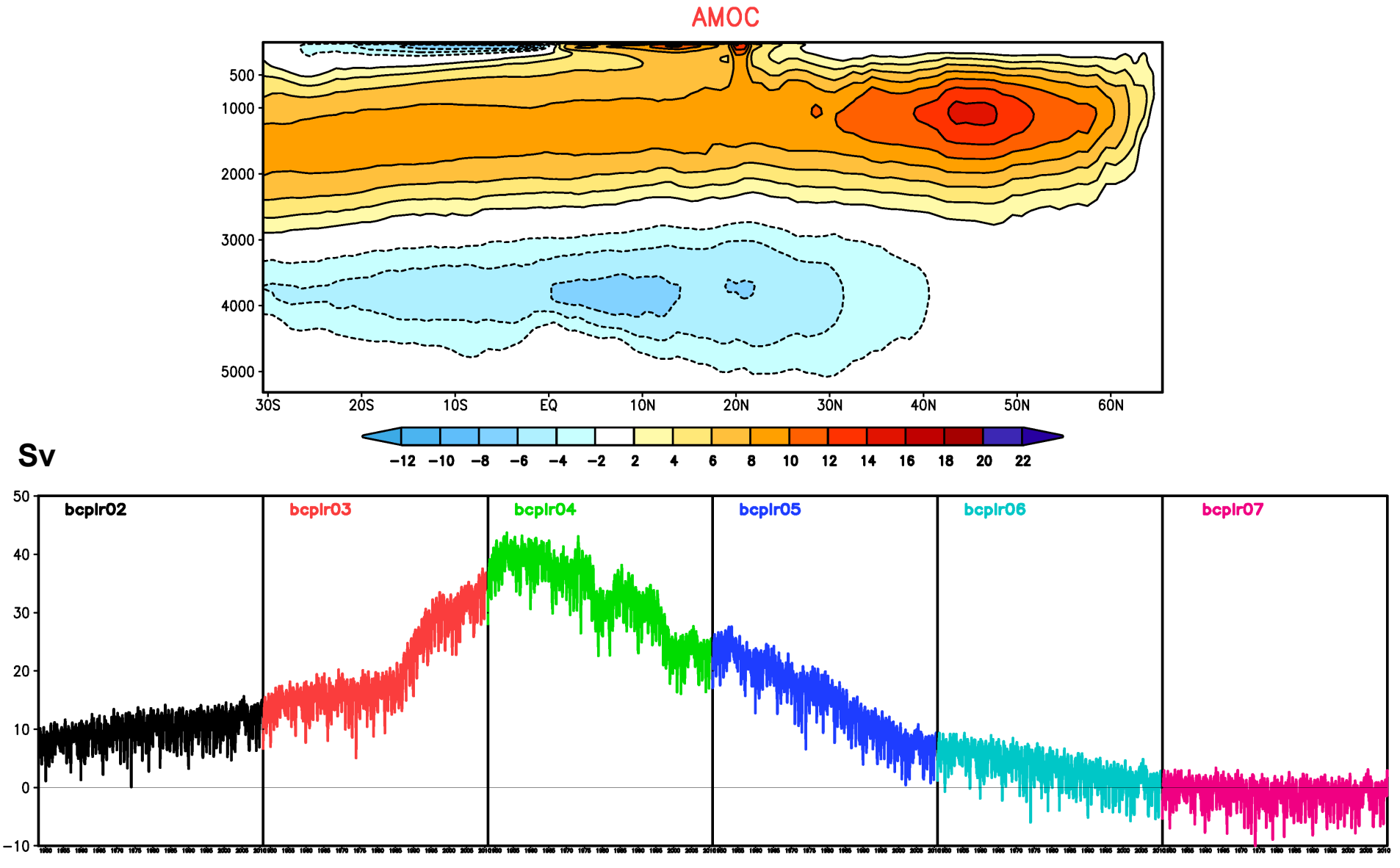
❖ MERRA Scout: coarse resolution, precursor of MERRA system

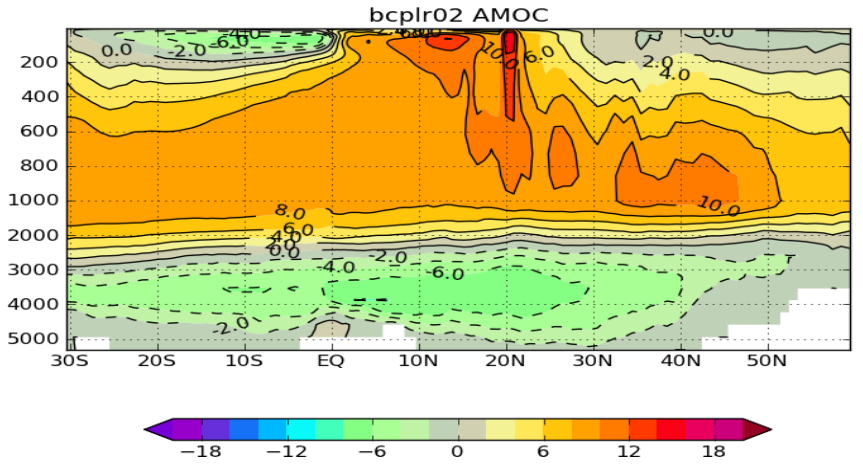

Precipitation (mm/day)
CGCM
Scout
GPCP
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
1
2
3
4
5
6
7
8
9
10
11
12

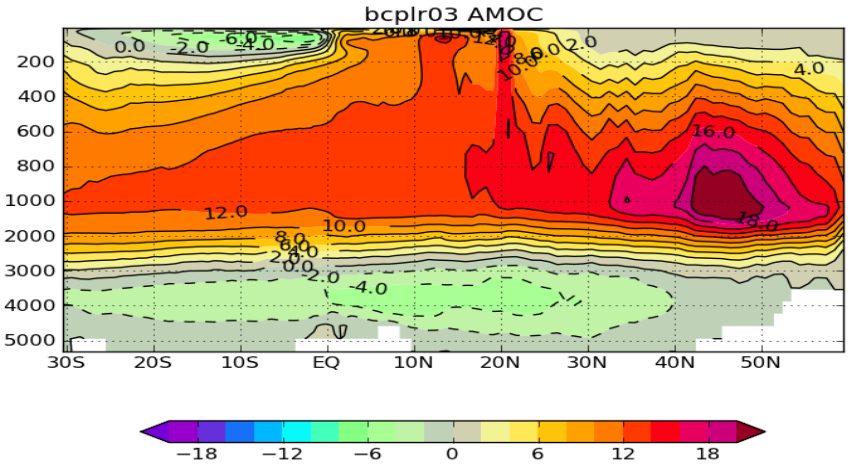

Nino3 SST
Reynolds
CGCMs
303
302
301
300
299
298
297
296
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
4
3
2
1
0
−1
−2
−3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

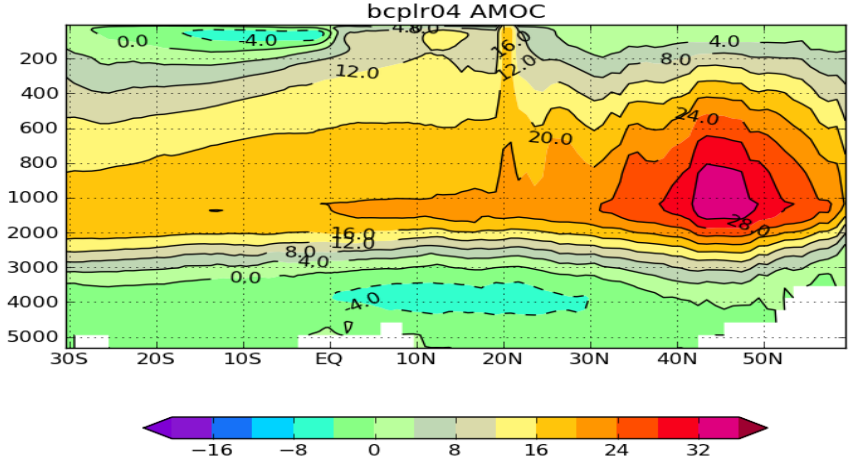

Ocean Temperature (5S–5N,130E–80W)
GEOS5odas
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
5
50
100
150
200
250
300
350
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−2.4
−2
−1.6
−1.2
−0.8
−0.4
0.4
0.8
1.2
1.6
2
2.4

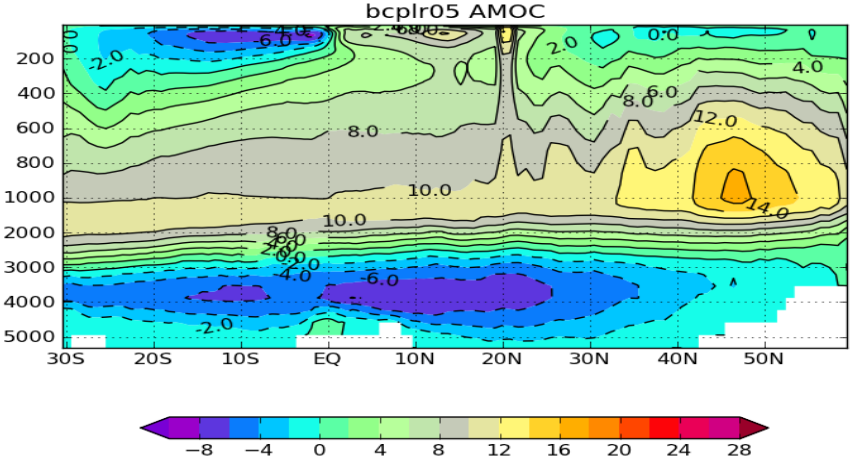
Atlantic Meridional Overturning Circulation

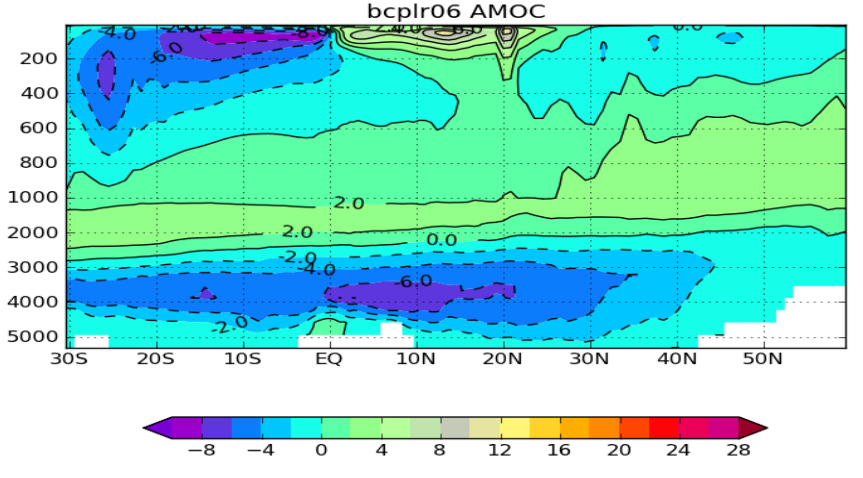

AMOC
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
−12 −10 −8 −6 −4 −2 2 4 6 8 10 12 14 16 18 20 22
Sv
50
40
30
20
10
0
−10
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07

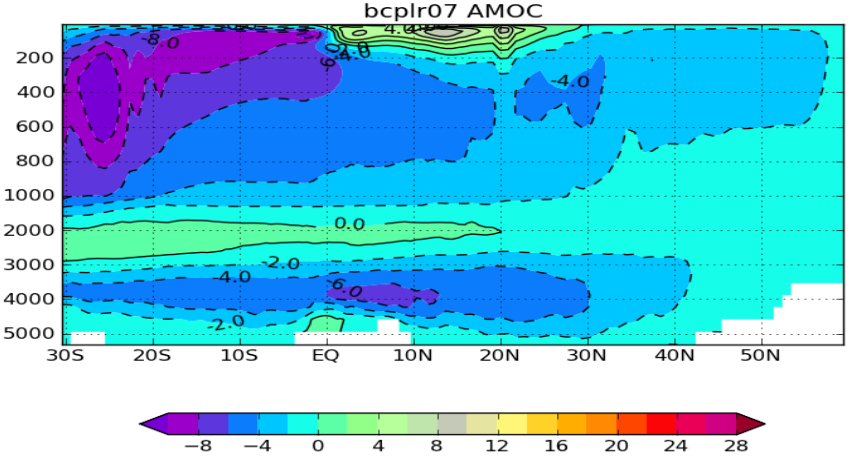

bcplr02 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−18
−12
−6
0
6
12
18


bcplr03 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−18
−12
−6
0
6
12
18

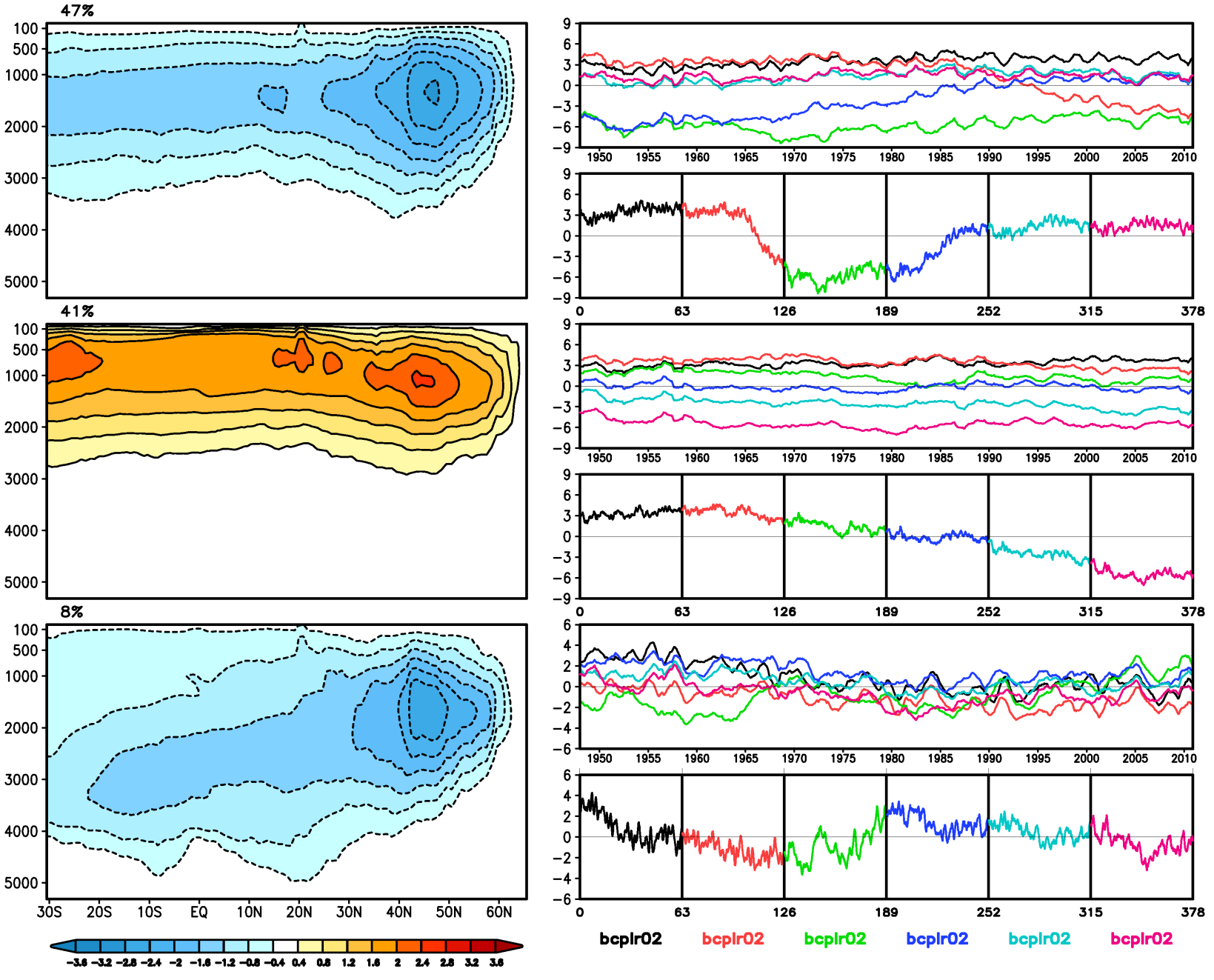

bcplr04 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−16
−8
0
8
16
24
32

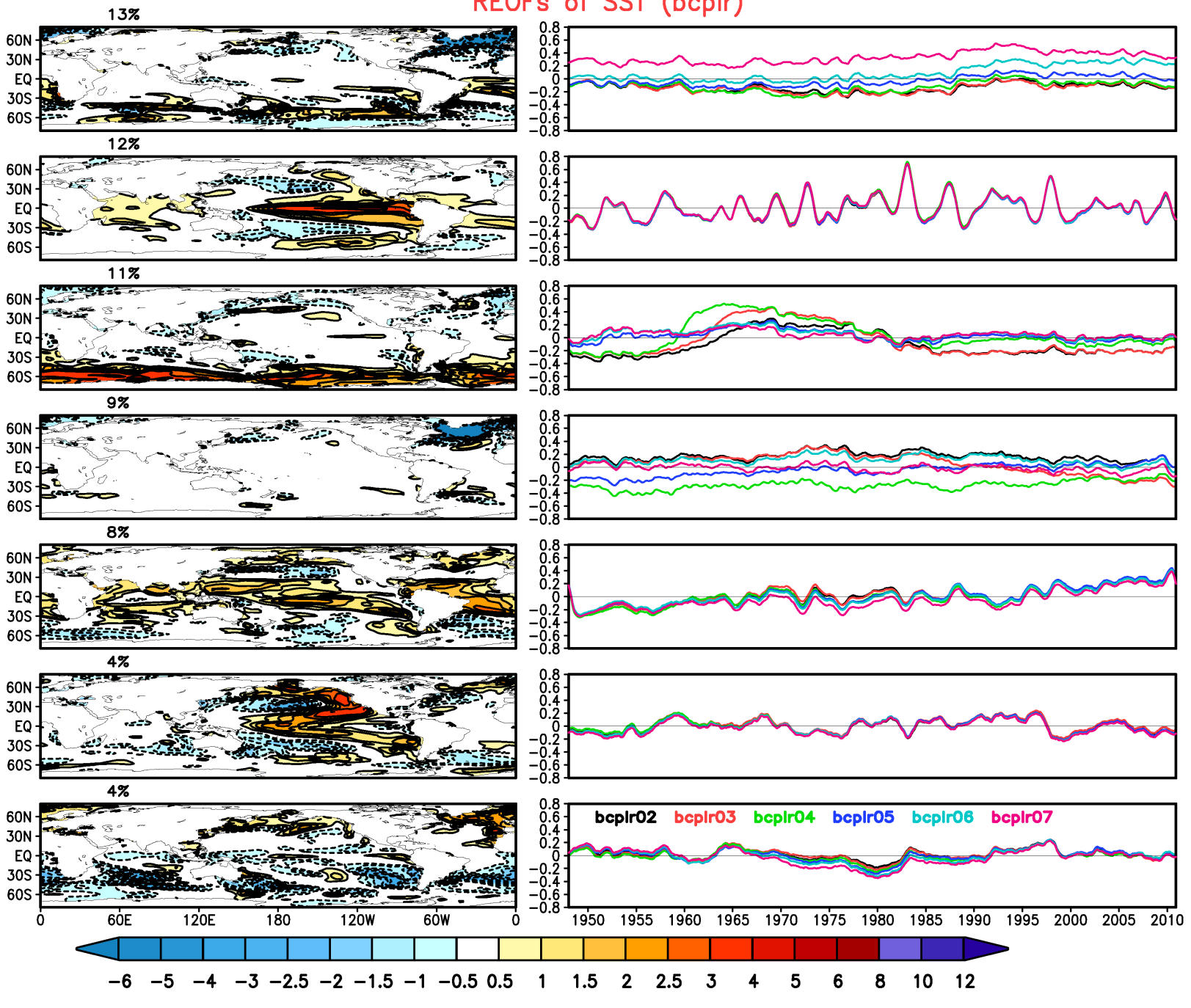

bcplr05 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−8
−4
0
4
8
12
16
20
24
28

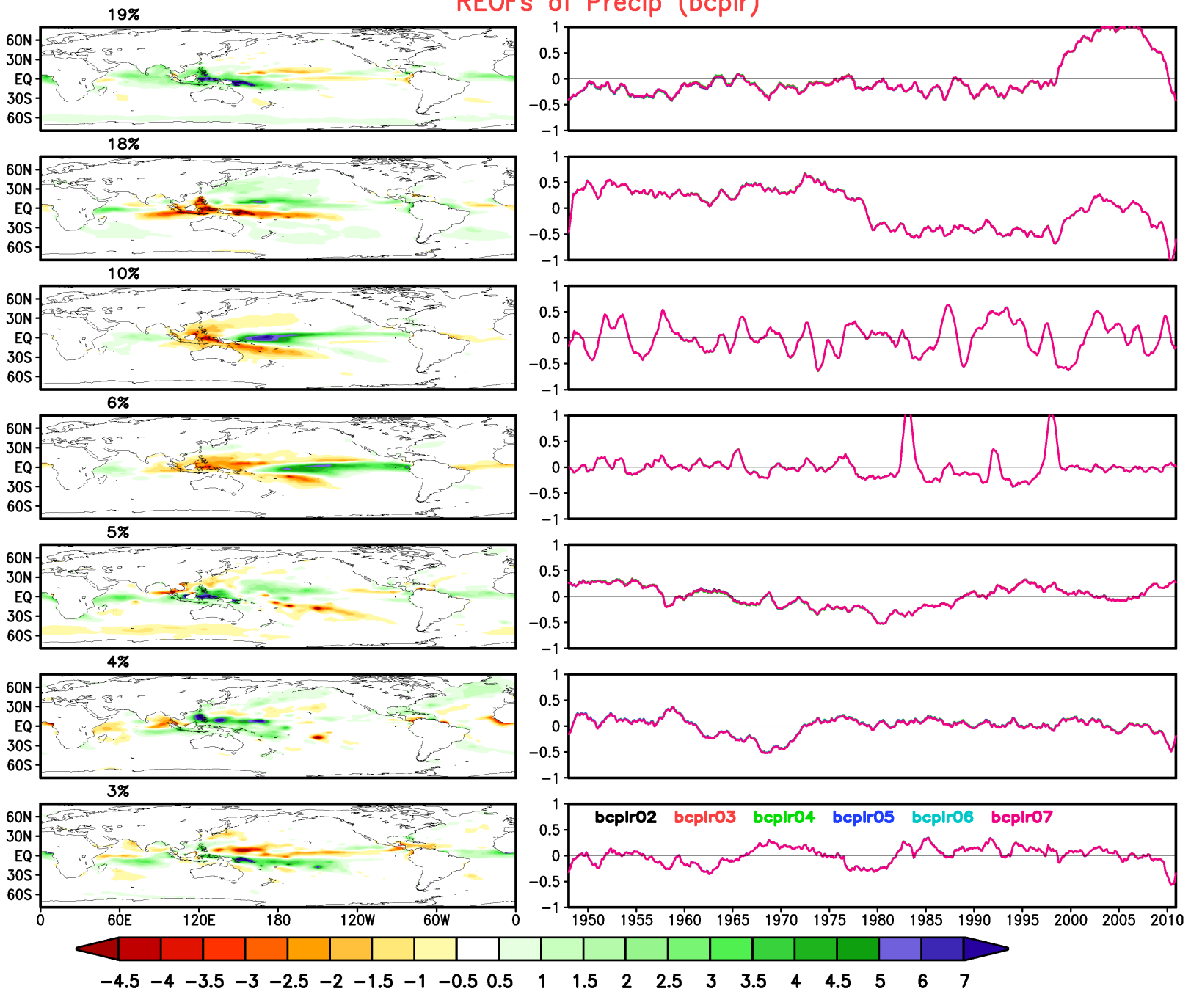

bcplr06 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−8
−4
0
4
8
12
16
20
24
28

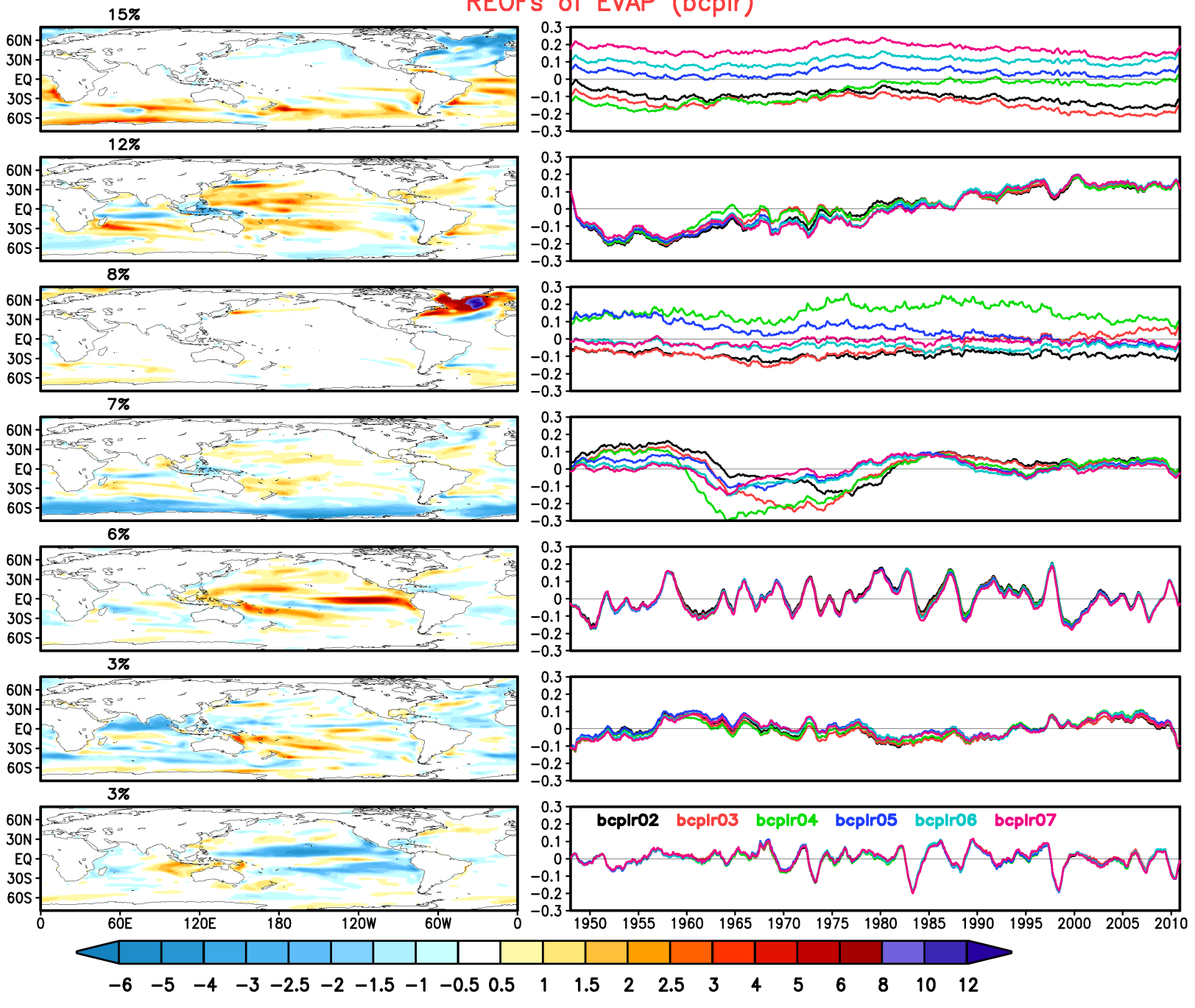

bcplr07 AMOC
200
400
600
800
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
−8
−4
0
4
8
12
16
20
24
28

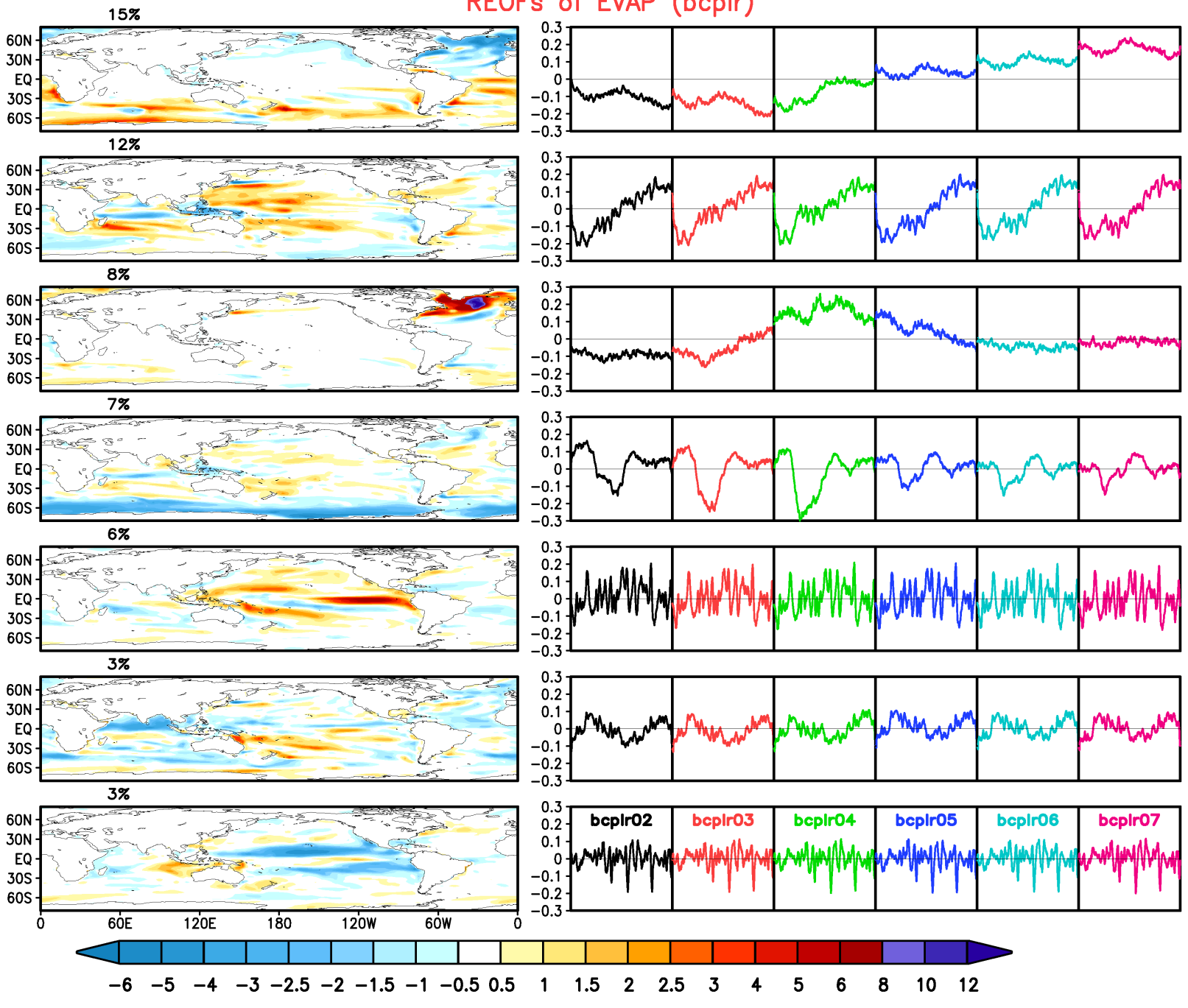
AMOC REOF


47%
41%
8%
100
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
0
63
126
189
252
315
378
bcplr02
bcplr02
bcplr02
bcplr02
bcplr02
bcplr02

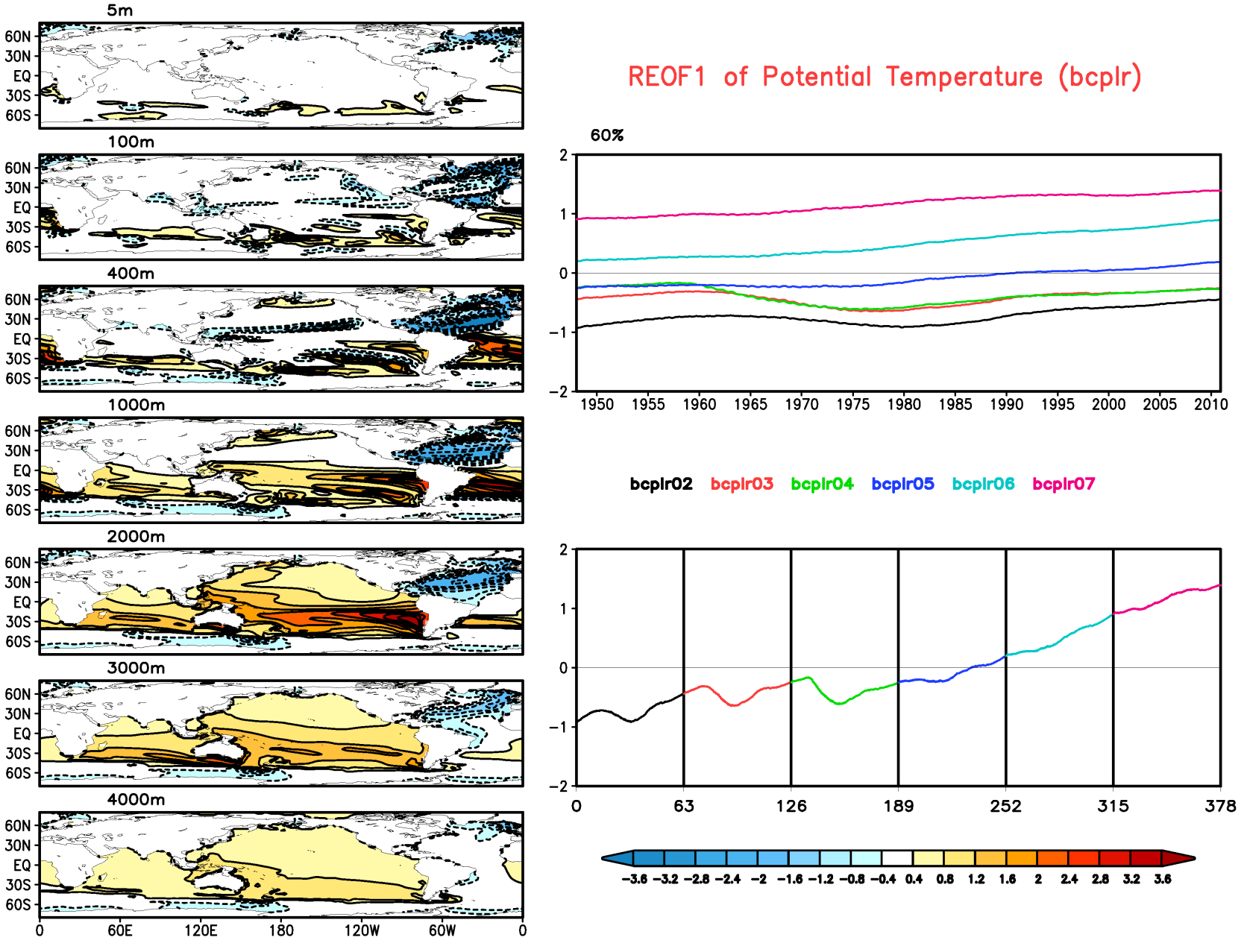

REOFs of SST (bcplr)
13%
12%
11%
9%
8%
4%
4%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
−6
−5
−4
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
4
5
6
8
10
12


REOFs of Precip (bcplr)
19%
18%
10%
6%
5%
4%
3%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
1
0.5
0
−0.5
−1
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 6 7

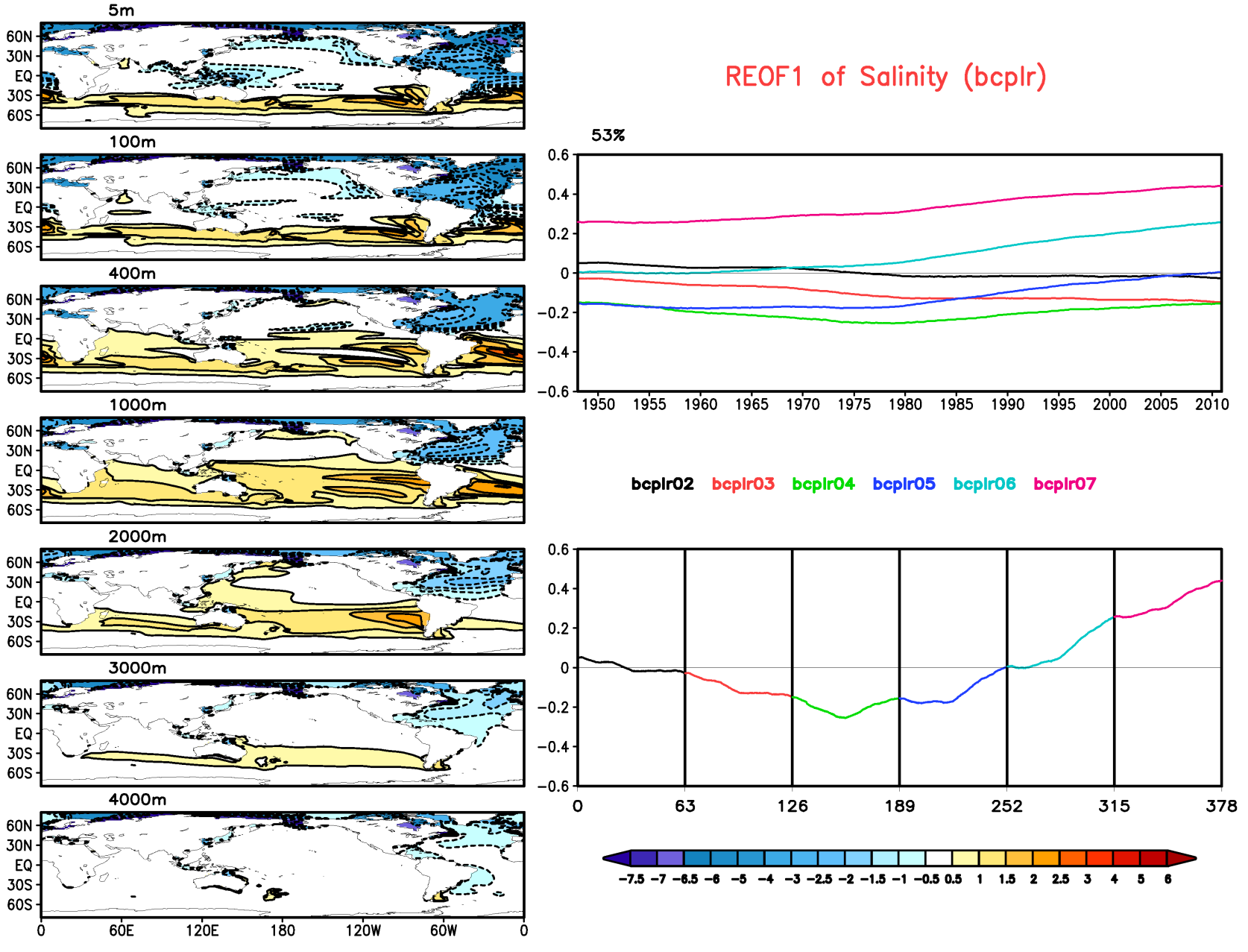

REOFs of EVAP (bcplr)
15%
12%
8%
7%
6%
3%
3%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
−6
−5
−4
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
4
5
6
8
10
12

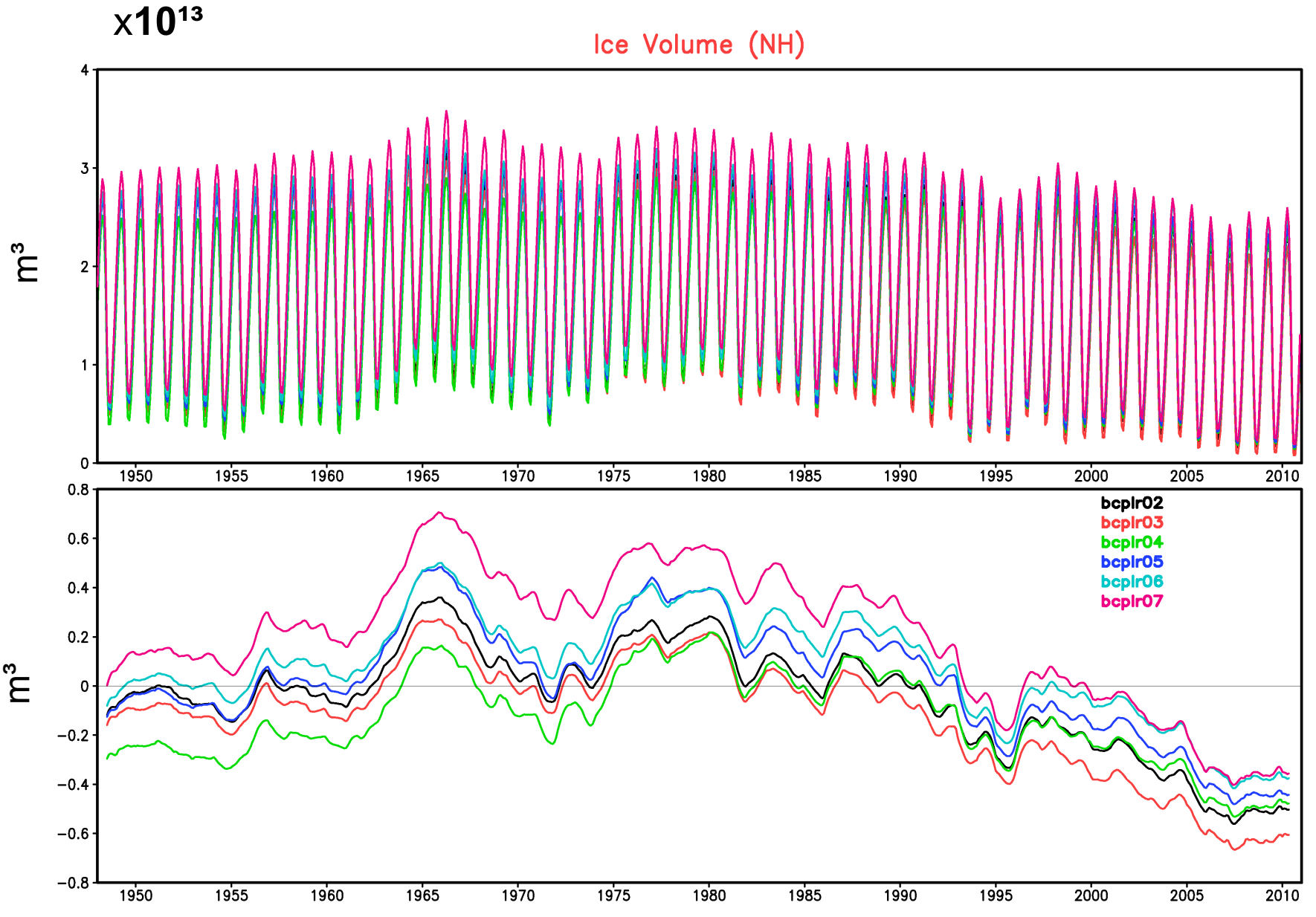

REOFs of EVAP (bcplr)
15%
12%
8%
7%
6%
3%
3%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
−6 −5 −4 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 4 5 6 8 10 12

Ocean Potential Temperature

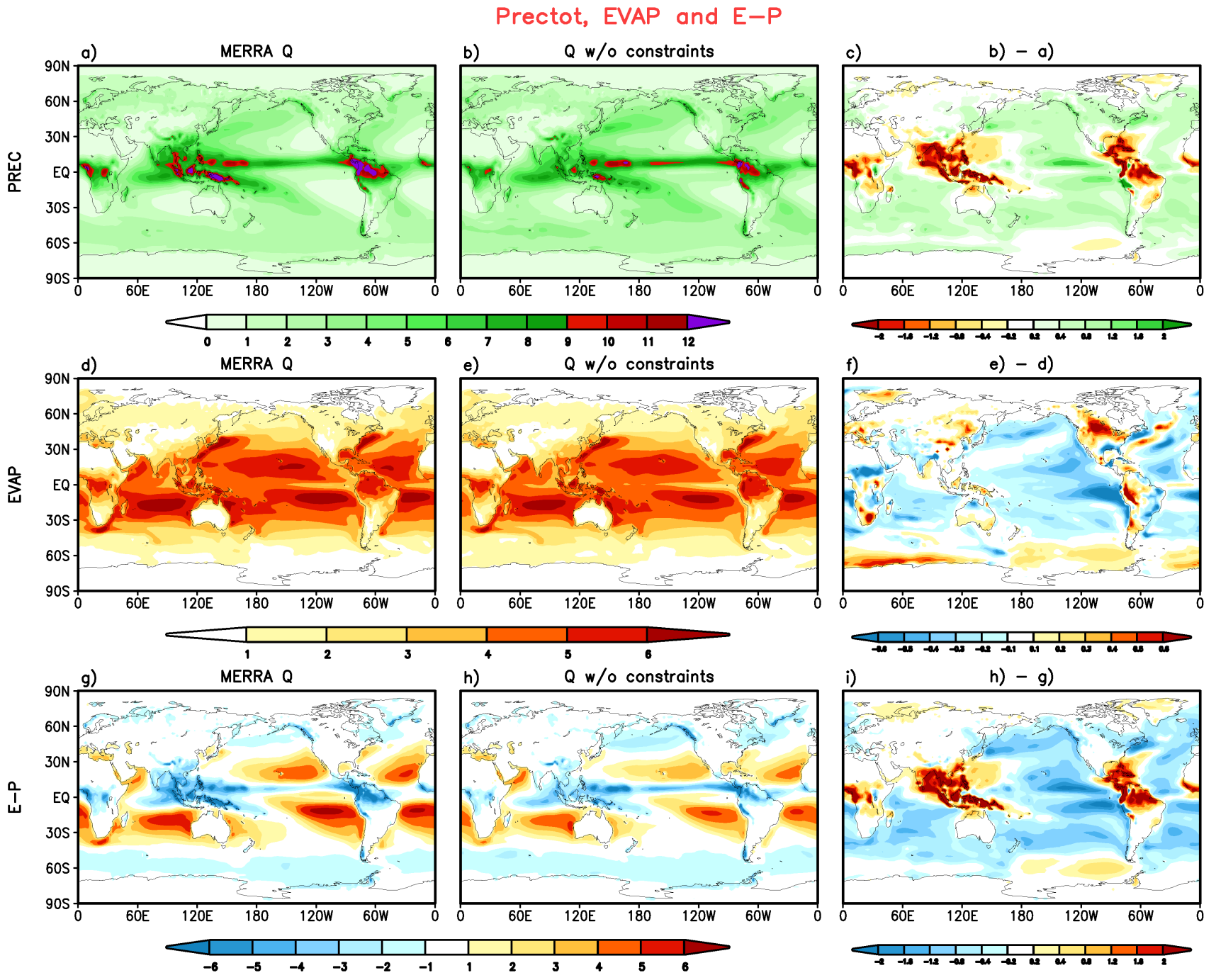

REOF1 of Potential Temperature (bcplr)
5m
100m
400m
1000m
2000m
3000m
4000m
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
60%
2
1
0
−1
−2
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
63
126
189
252
315
378
−3.6 −3.2 −2.8 −2.4 −2 −1.6 −1.2 −0.8 −0.4 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2 3.6

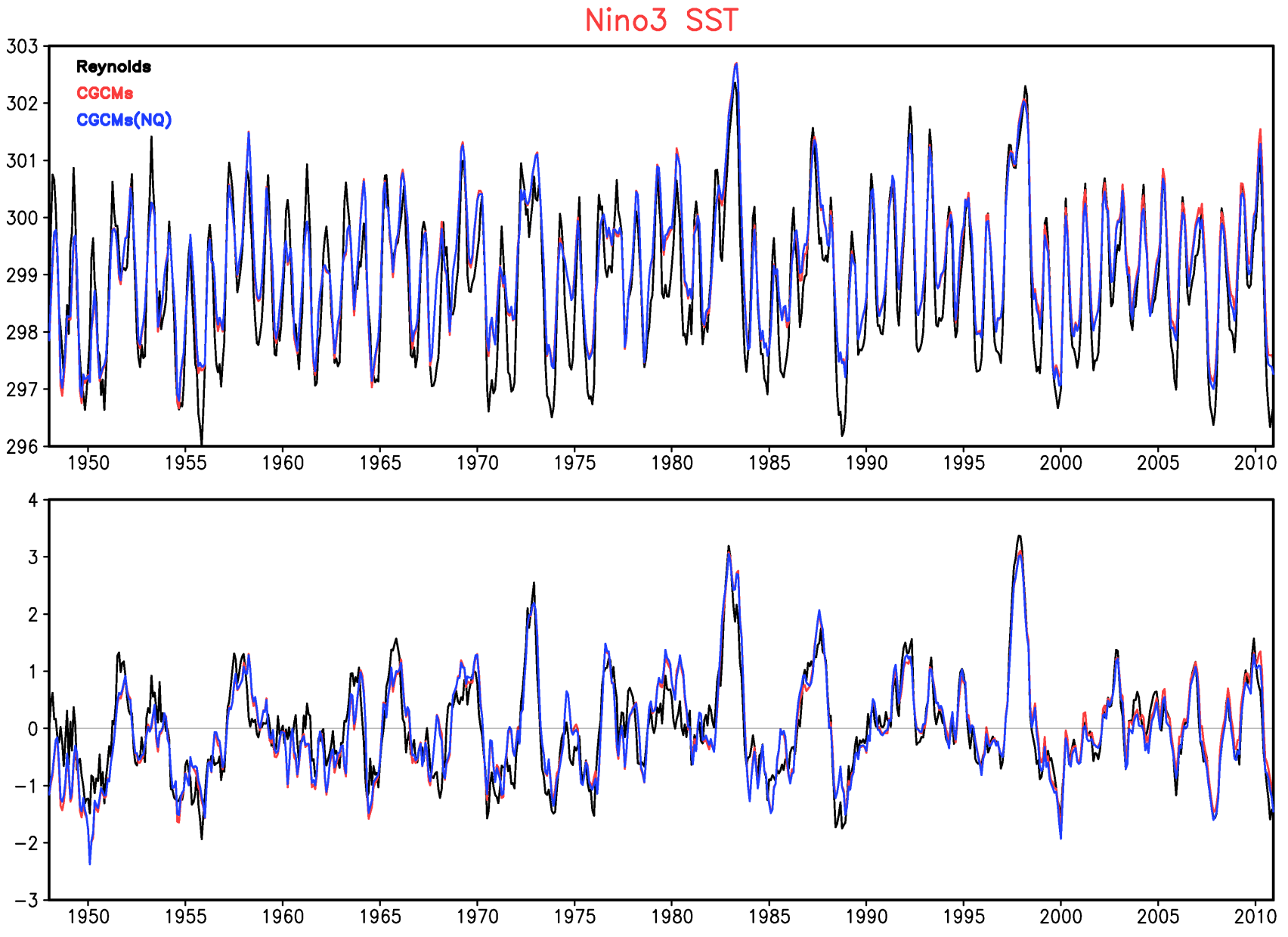
Ocean Salinity

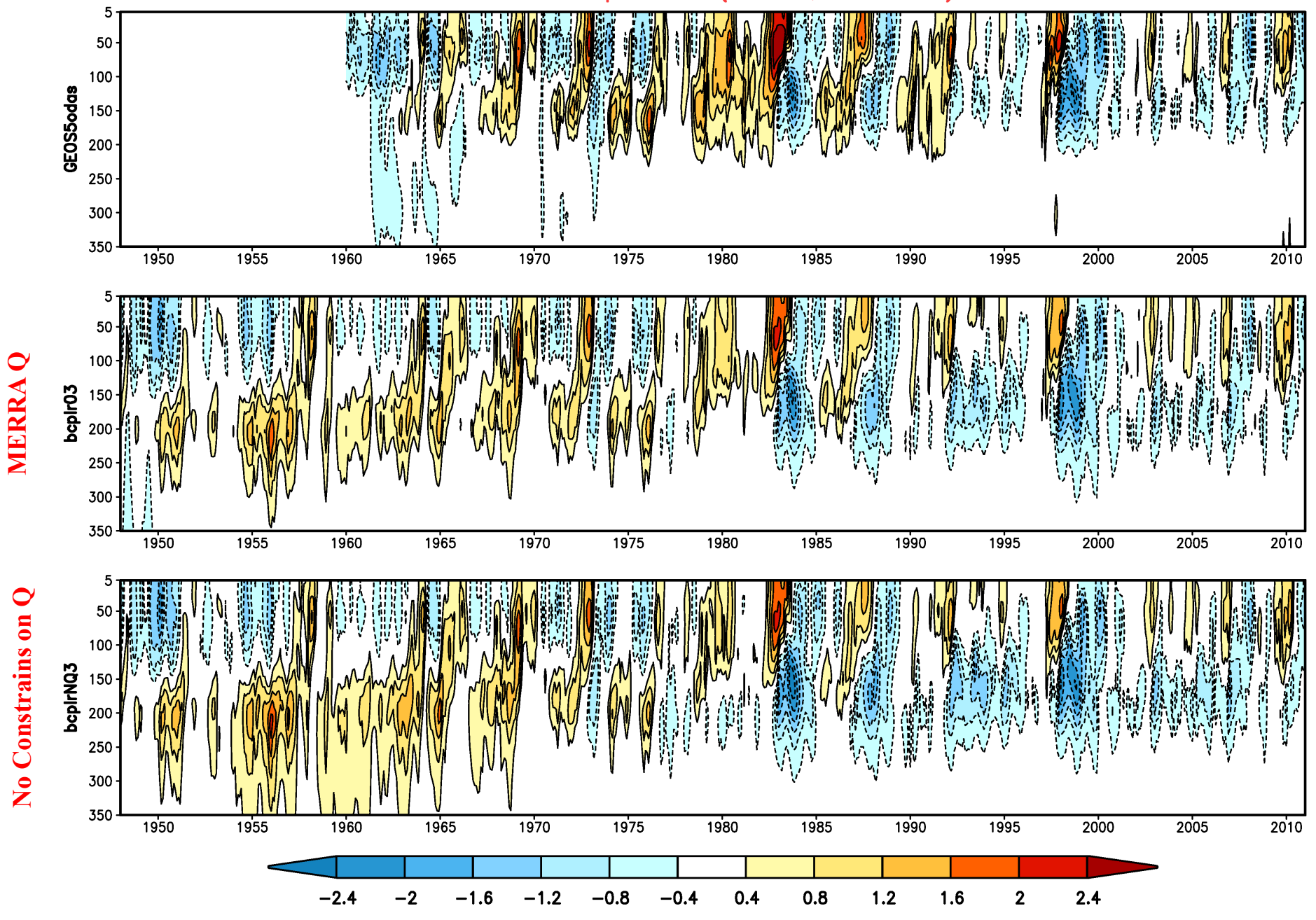

REOF1 of Salinity (bcplr)
5m
100m
400m
1000m
2000m
3000m
4000m
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
53%
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07
0
63
126
189
252
315
378
−7.5 −7 −6.5 −6 −5 −4 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 4 5 6

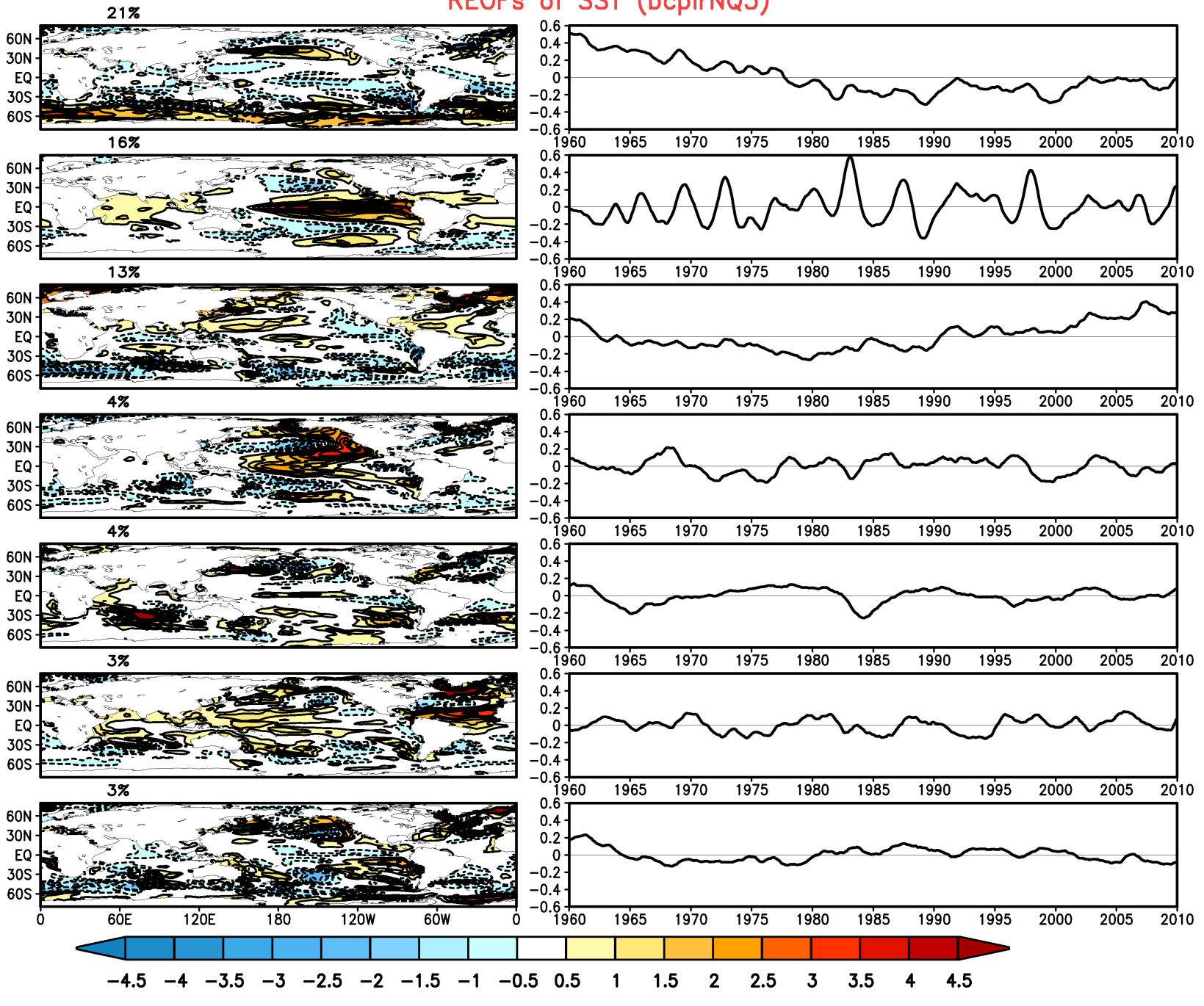

x10^13
Ice Volume (NH)
m^3
4
3
2
1
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
m^3
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
bcplr02
bcplr03
bcplr04
bcplr05
bcplr06
bcplr07

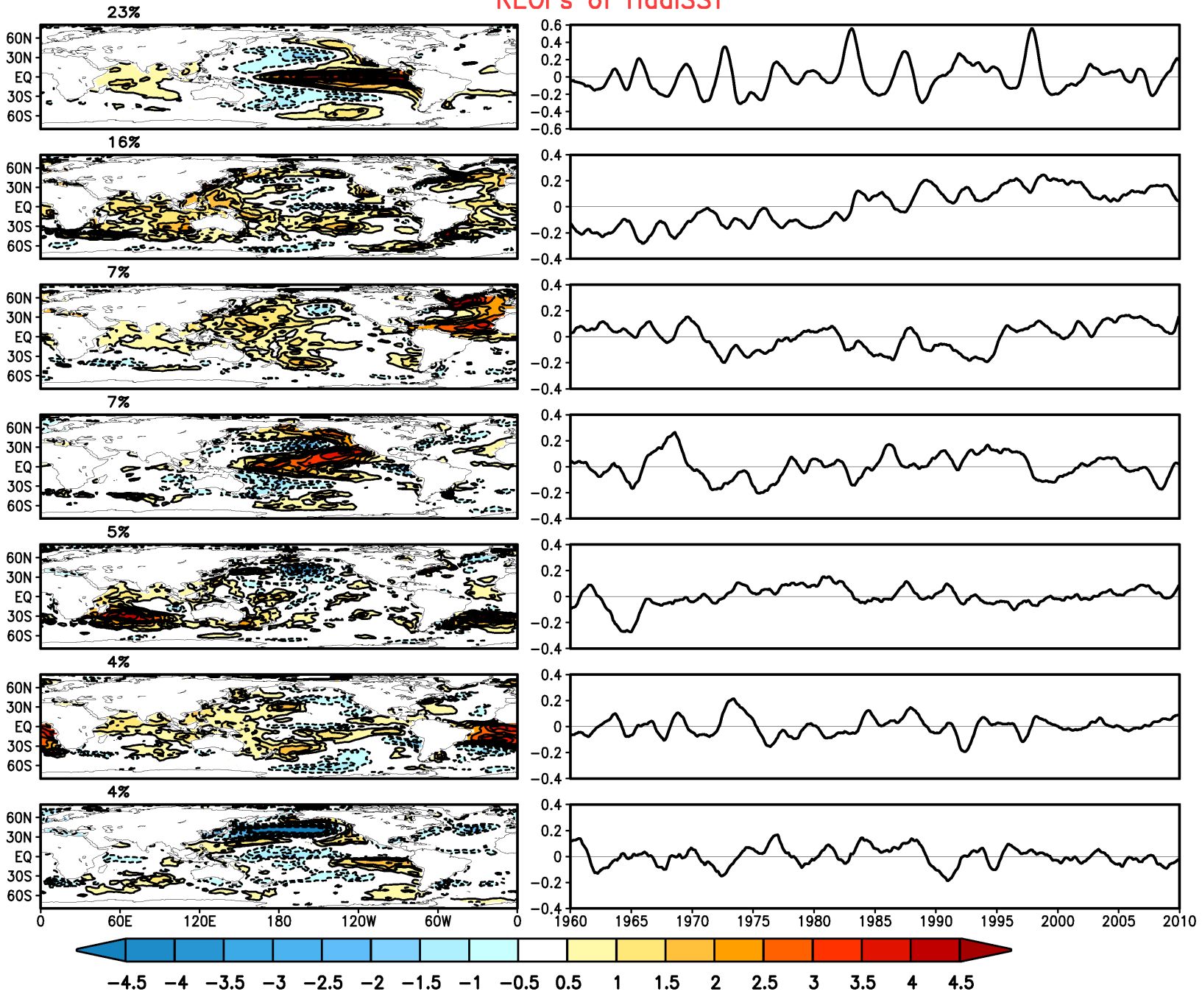
No Constrains On Q


Prectot, EVAP and E−P
a) MERRA Q
b) Q w/o constraints
c) b) − a)
d) MERRA Q
e) Q w/o constraints
f) e) − d)
g) MERRA Q
h) Q w/o constraints
i) h) − g)
PREC
EVAP
E−P
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0 1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6
−6 −5 −4 −3 −2 −1 1 2 3 4 5 6

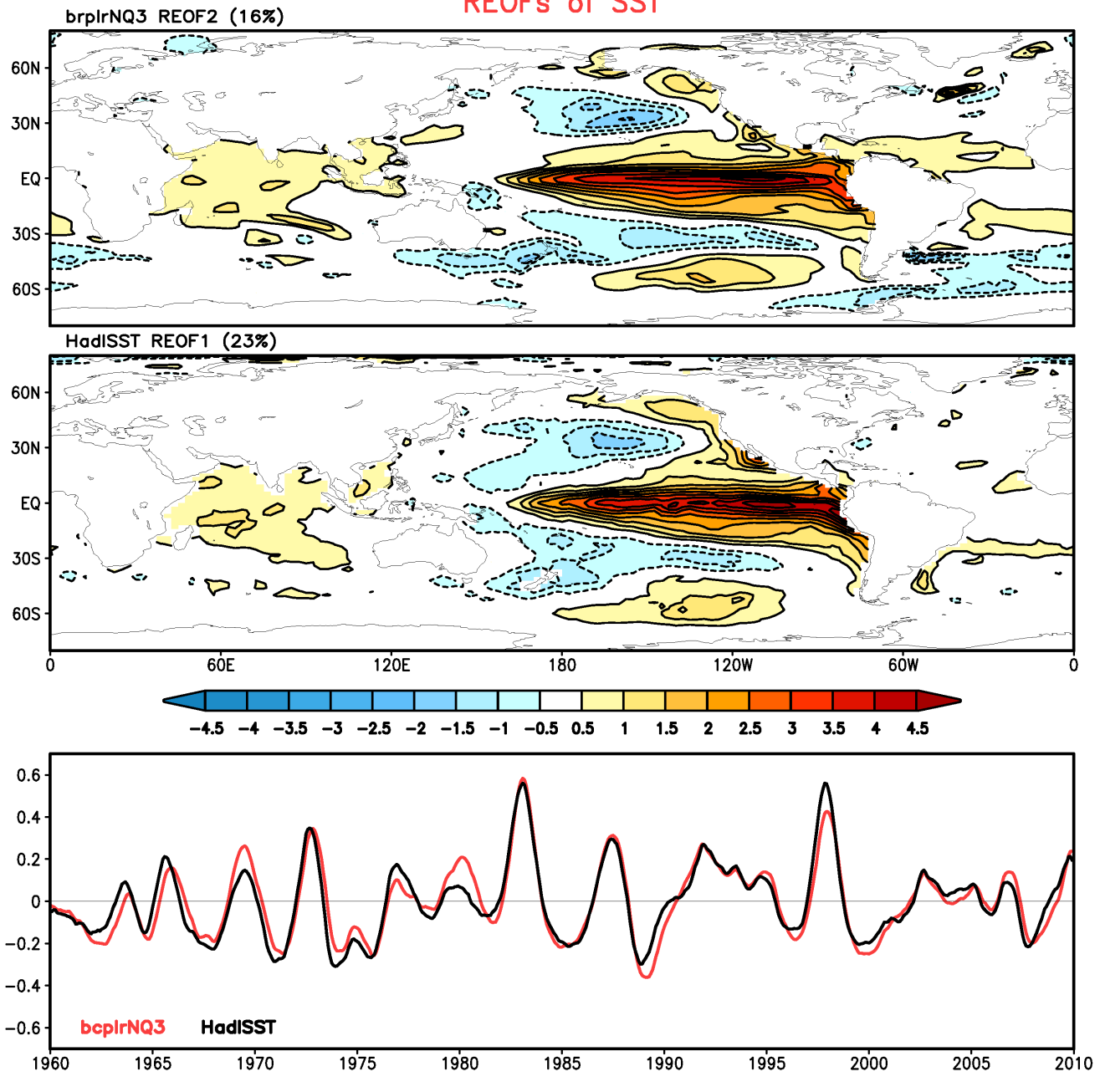

Nino3 SST
Reynolds
CGCMs
CGCMs(NQ)
303
302
301
300
299
298
297
296
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
4
3
2
1
0
−1
−2
−3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Ocean Temperature (5S–5N,130E–80W)
GEOS5odas
bcplr03
bcplrNQ3
MERRA Q
No Constrains on Q
5
50
100
150
200
250
300
350
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−2.4
−2
−1.6
−1.2
−0.8
−0.4
0.4
0.8
1.2
1.6
2
2.4

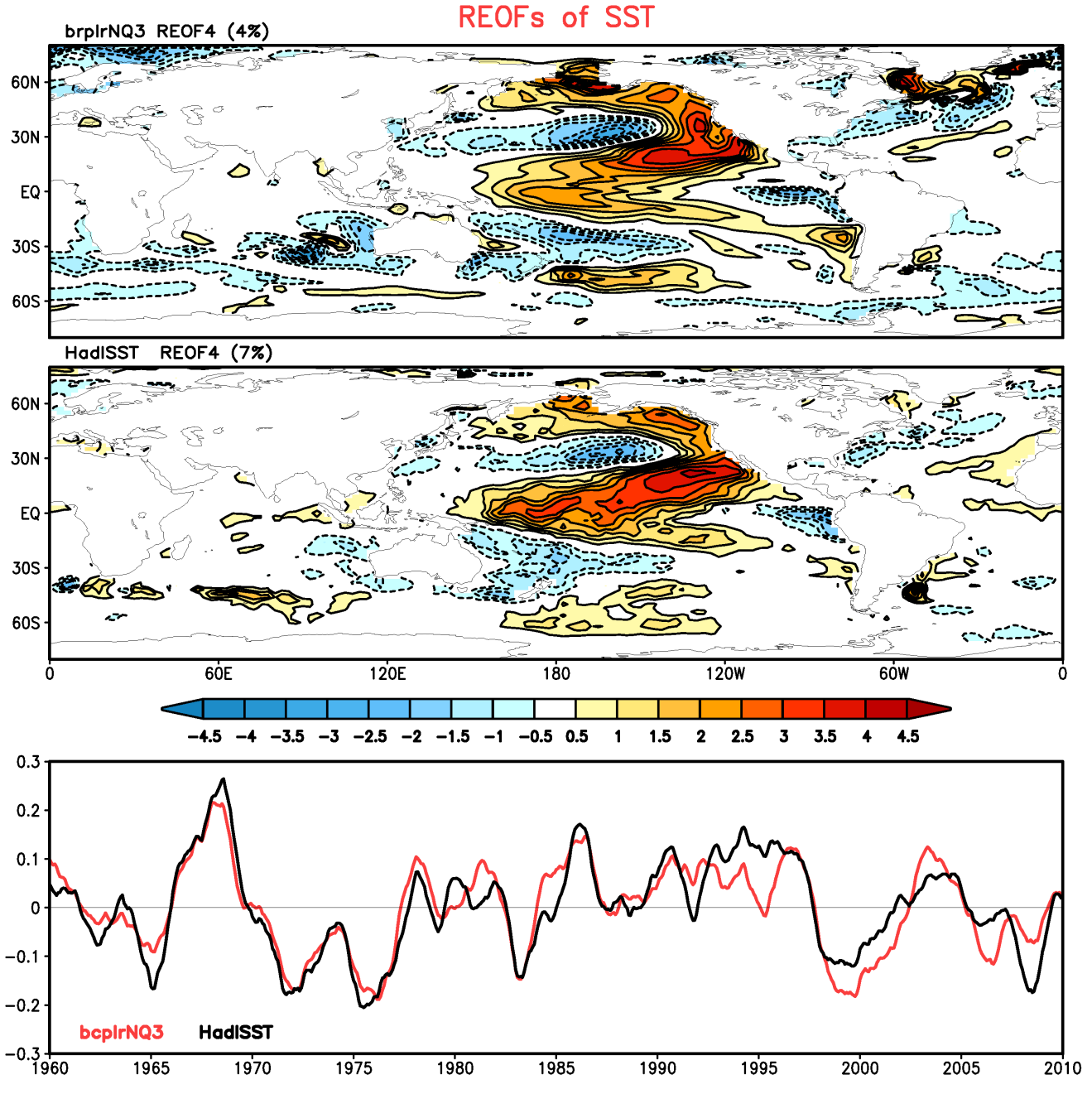

REOFs of SST (bcplrNQ3)
21%
16%
13%
4%
4%
3%
3%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5


REOFs of HadISST
23%
16%
7%
7%
5%
4%
4%
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5

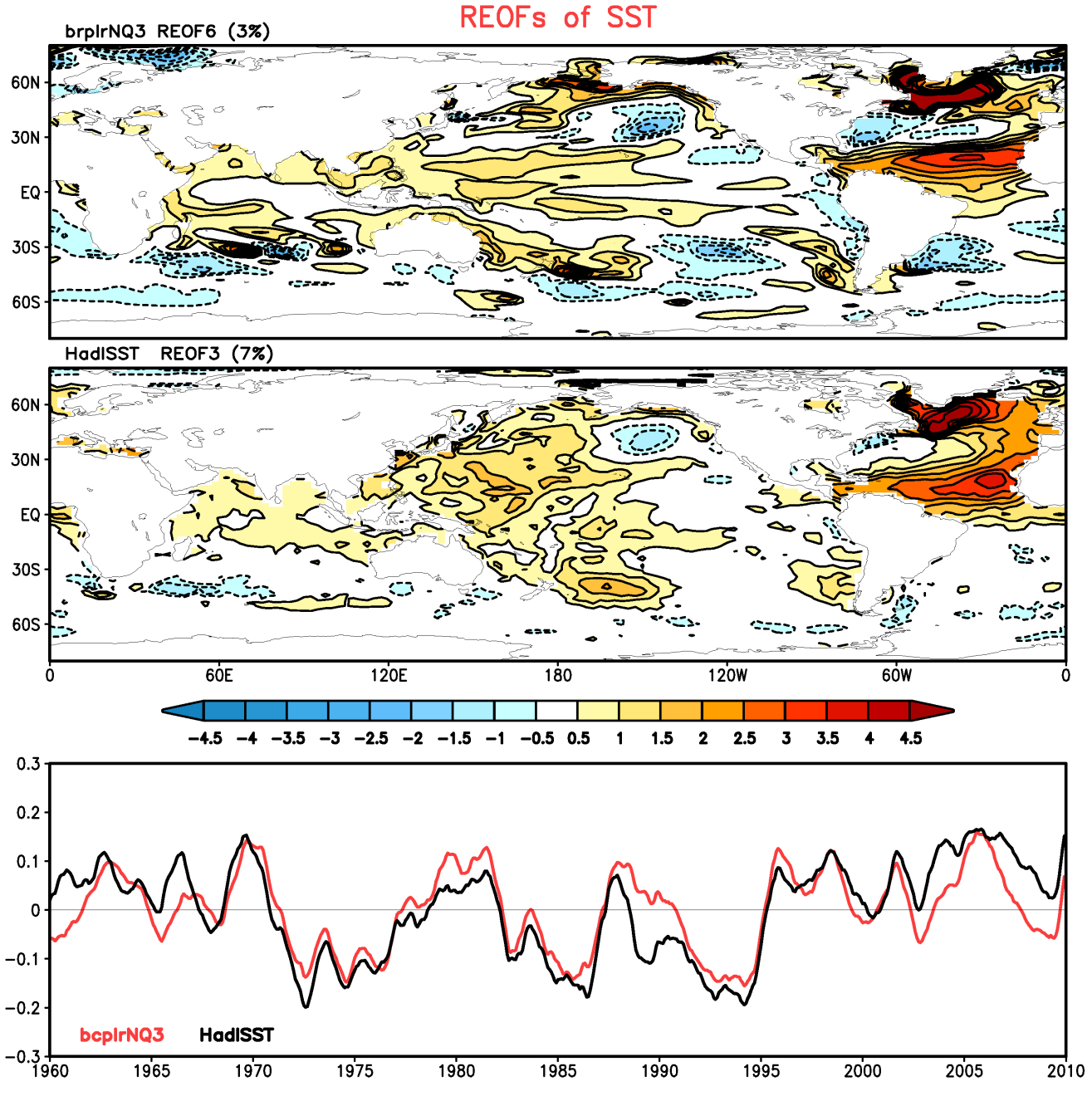
ENSO

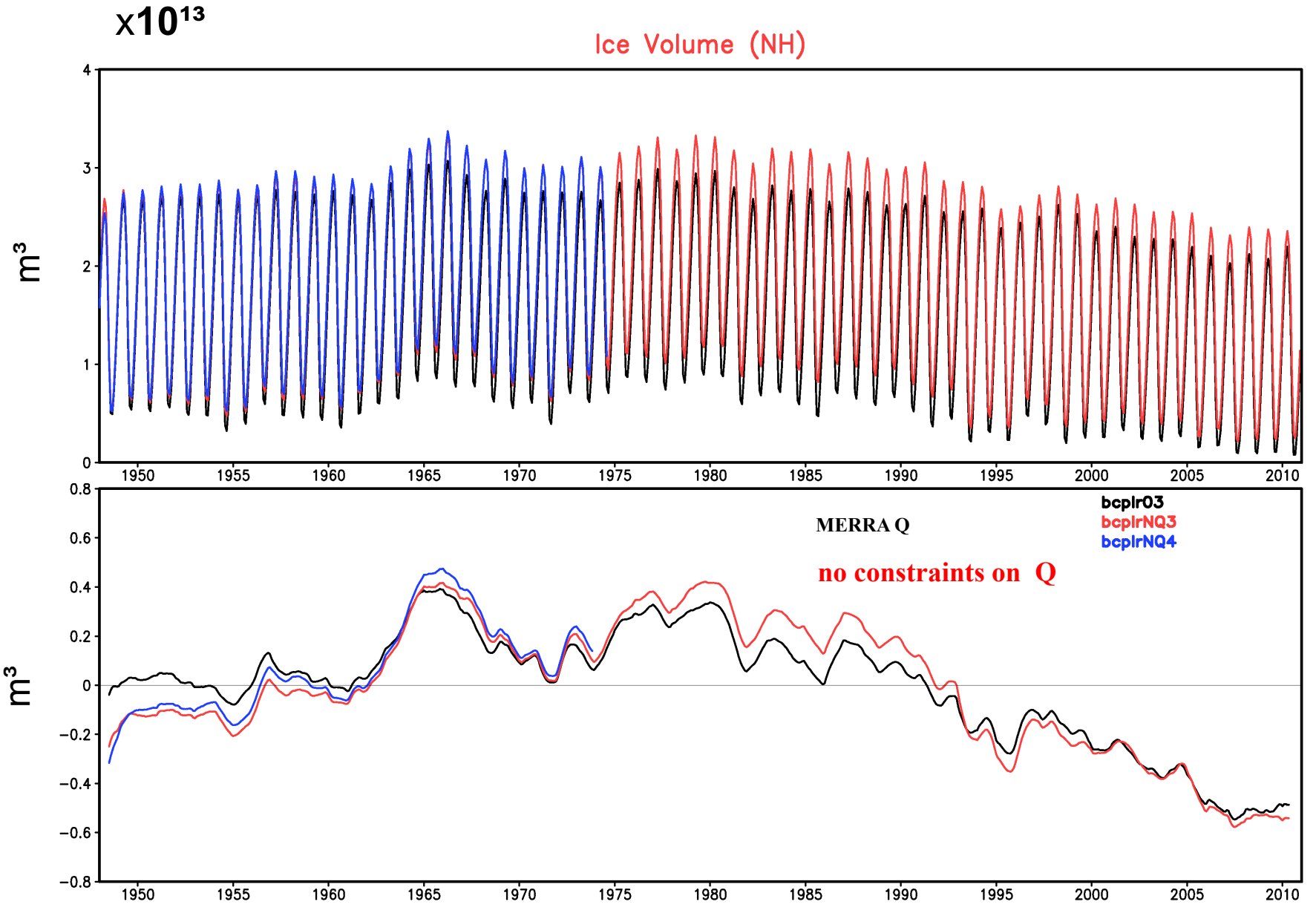

REOFs of SST
brplrNQ3 REOF2 (16%)
60N
30N
EQ
30S
60S
HadISST REOF1 (23%)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
bcplrNQ3
HadISST
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

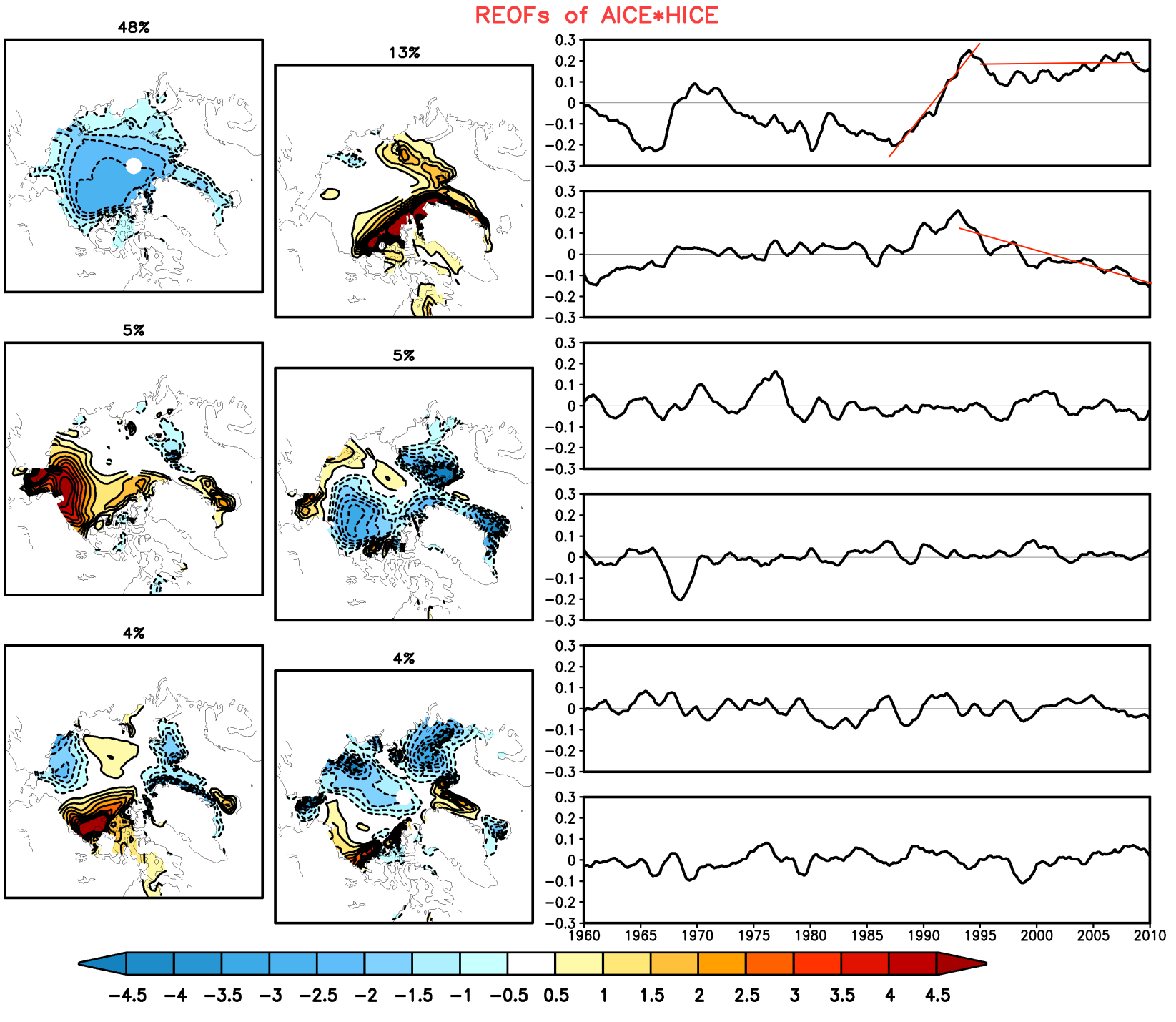
PDO

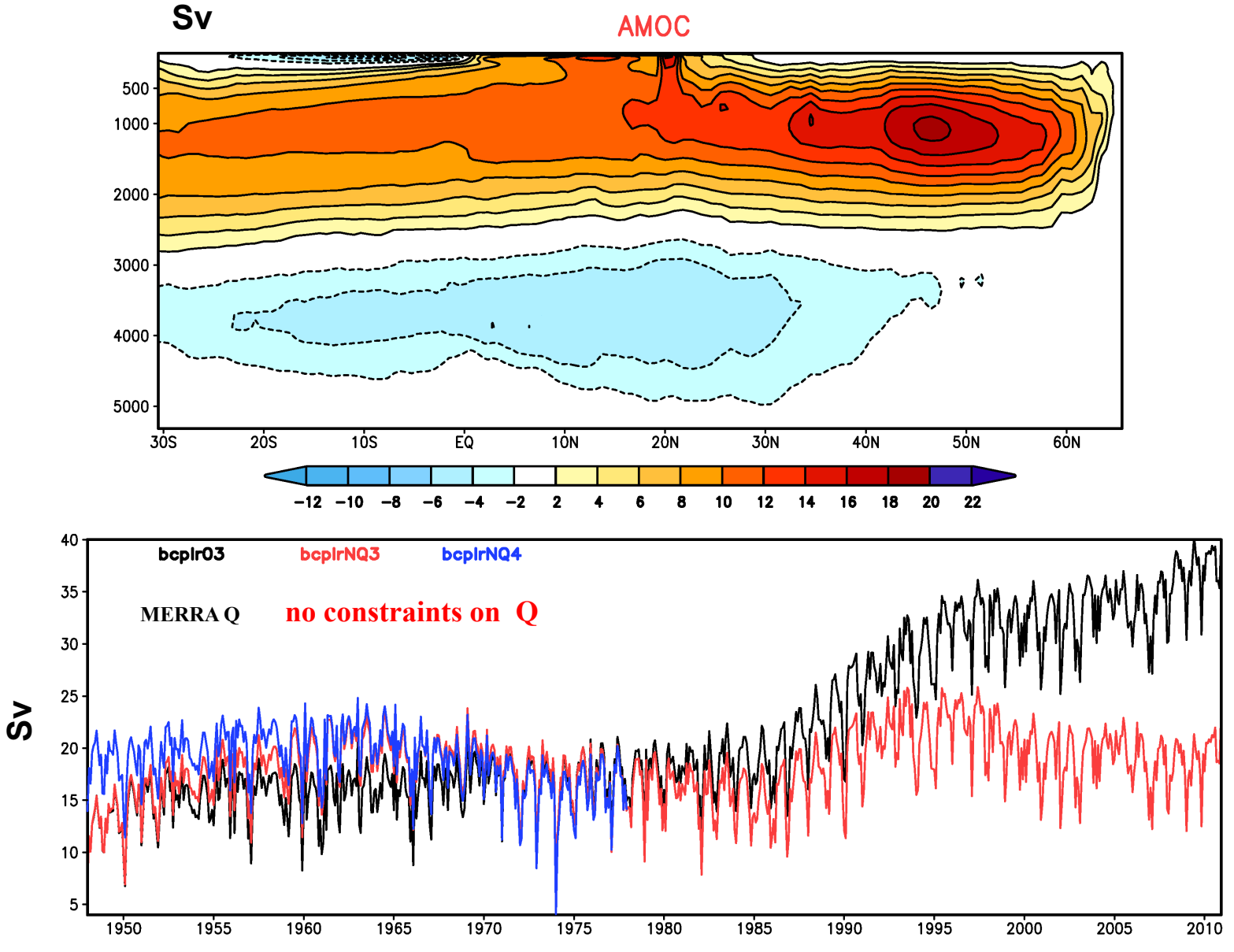

REOFs of SST
brplrNQ3 REOF4 (4%)
HadISST REOF4 (7%)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
bcplrNQ3
HadISST
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

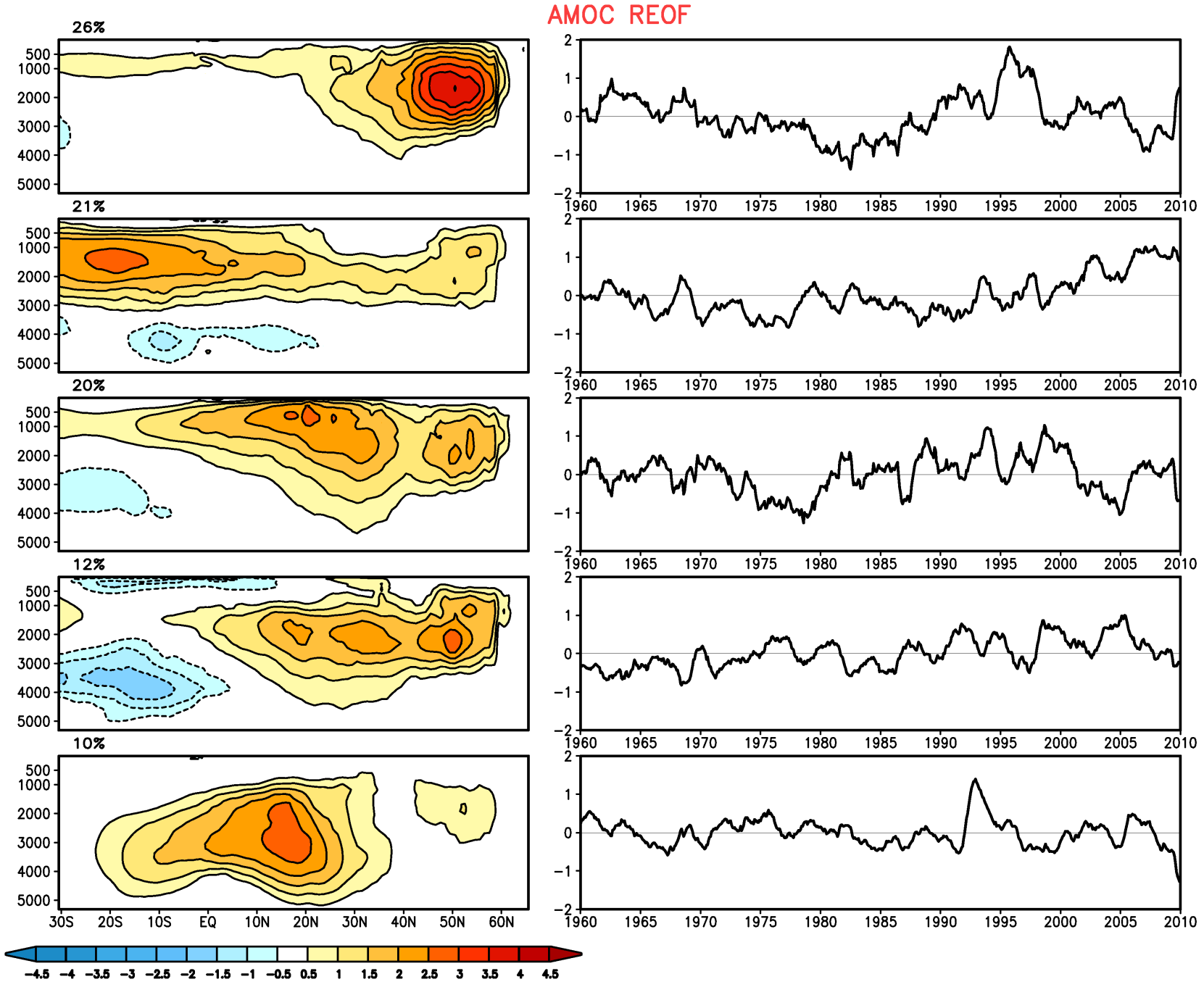
AMO


REOFs of SST
brplrNQ3 REOF6 (3%)
HadISST REOF3 (7%)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
bcplrNQ3
HadISST
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

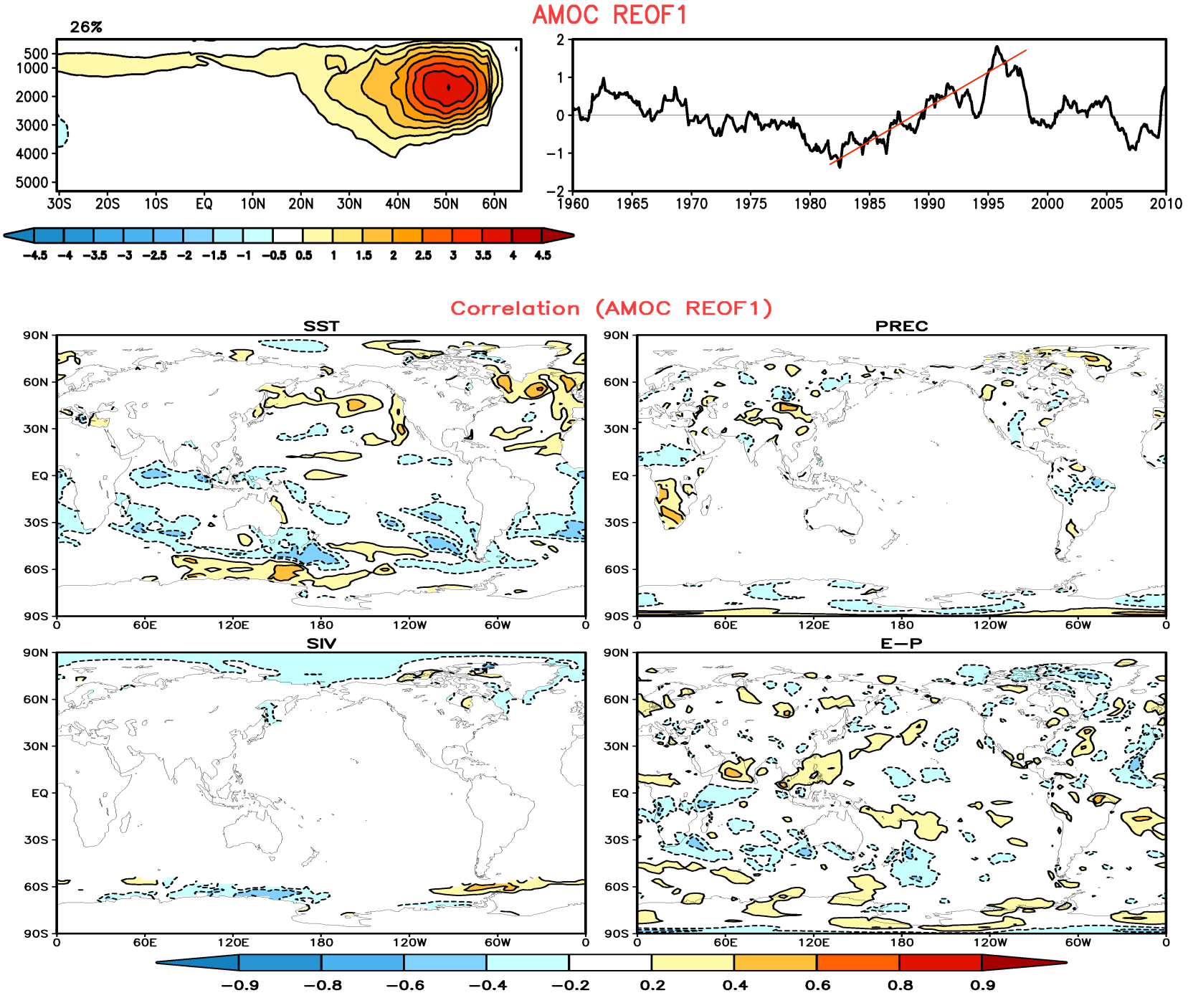

x10^13
Ice Volume (NH)
m^3
4
3
2
1
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
MERRA Q
bcplr03
bcplrNQ3
bcplrNQ4
no constraints on Q
m^3
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8

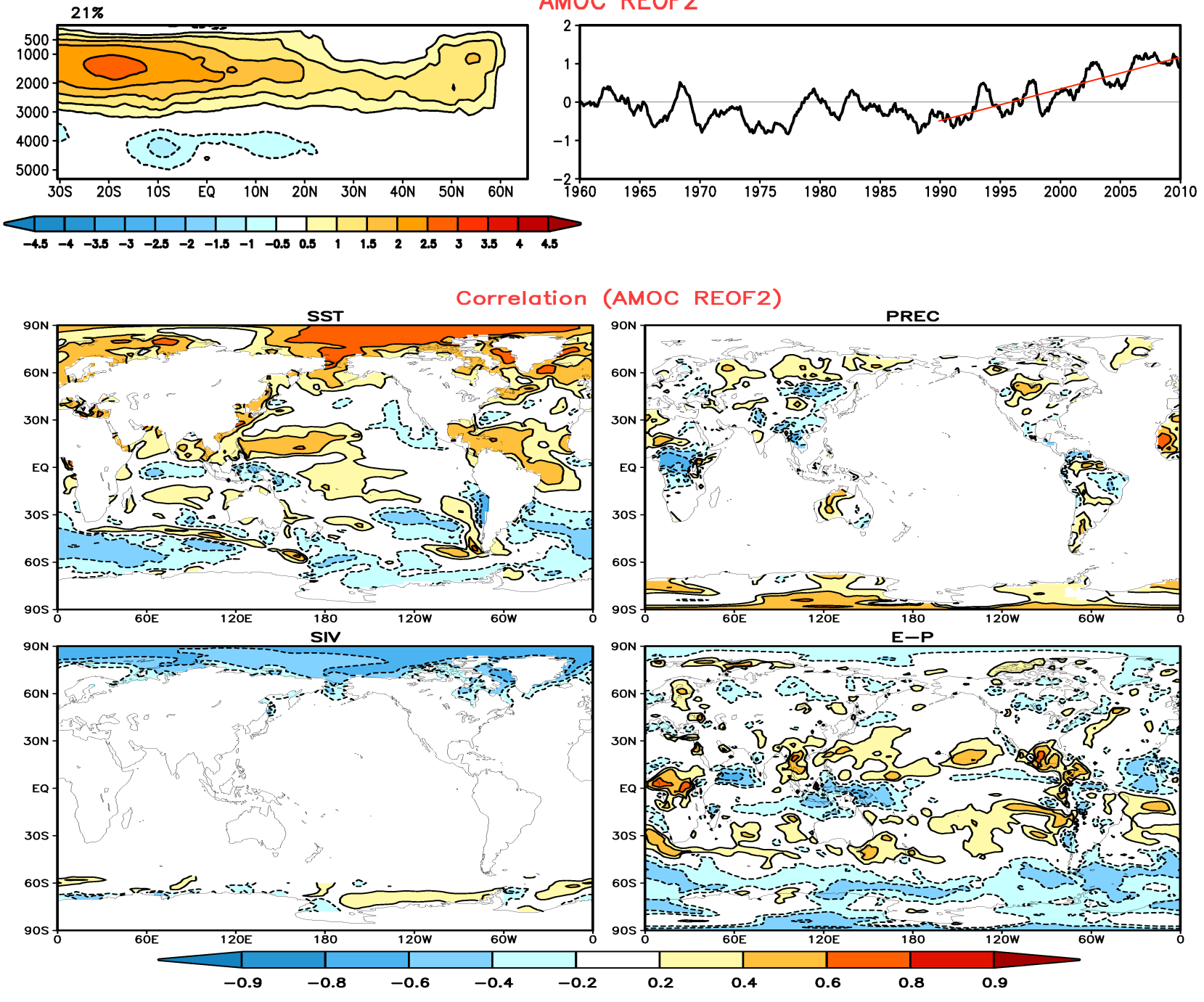

REOFs of AICE*HICE
48%
13%
5%
5%
4%
4%
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5

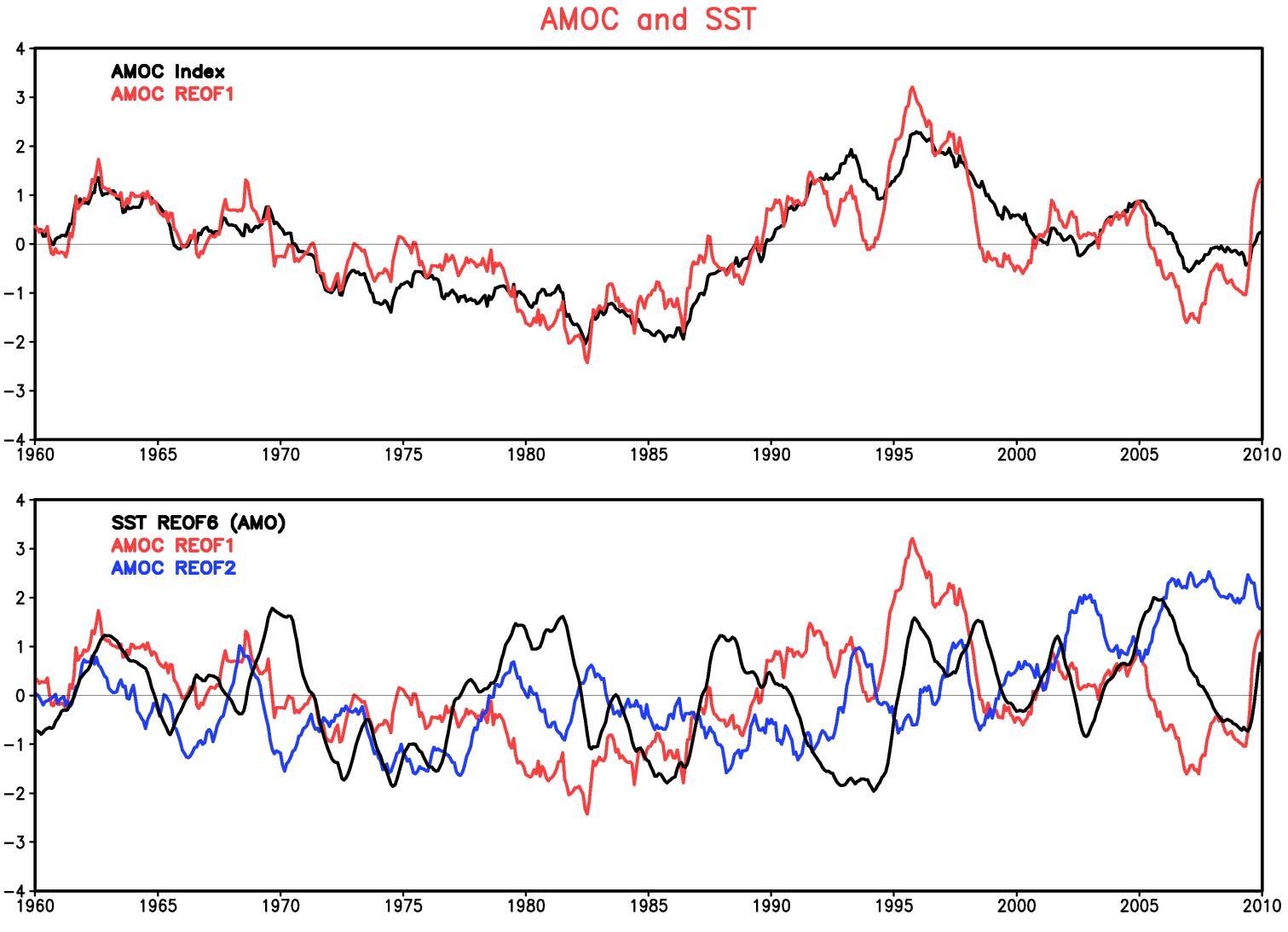

Sv
AMOC
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
−12 −10 −8 −6 −4 −2 2 4 6 8 10 12 14 16 18 20 22
Sv
40
35
30
25
20
15
10
5
bcpIr03
bcpIrNQ3
bcpIrNQ4
MERRA Q
no constraints on Q
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


AMOC REOF
26%
21%
20%
12%
10%
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
2
1
0
−1
−2
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5

Correlations


AMOC REOF1
26%
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
2
1
0
−1
−2
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Correlation (AMOC REOF1)
SST
PREC
SIV
E−P
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
−0.9 −0.8 −0.6 −0.4 −0.2 0.2 0.4 0.6 0.8 0.9


AMOC REOF2
21%
500
1000
2000
3000
4000
5000
30S
20S
10S
EQ
10N
20N
30N
40N
50N
60N
2
1
0
−1
−2
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
−4.5 −4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Correlation (AMOC REOF2)
SST
PREC
SIV
E−P
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
−0.9 −0.8 −0.6 −0.4 −0.2 0.2 0.4 0.6 0.8 0.9


AMOC and SST
AMOC Index
AMOC REOF1
SST REOF6 (AMO)
AMOC REOF1
AMOC REOF2
4
3
2
1
0
−1
−2
−3
−4
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Summary

- **Using the GEOS-5 coupled model, we study the variability of the Atlantic meridional overturning circulation (AMOC) and its impacts on the global climate.**

- **Atlantic-wide variability (AMO) is thought to have important impacts on Atlantic hurricane activities, North American and European climate. But there is no definitively link between AMOC and AMO from this coupled model study.**

- **AMOC REOF1 shows a localized circulation in the northern Atlantic Ocean and its variation is in phase with the AMOC maximum index. But this leading REOF has limited impact on climate.**

- **AMOC REOF2 indicates the role of the south Atlantic Ocean. It is connected to the Southern Ocean and the global ocean circulations (MOC). This REOF2 is found to be significantly anticorrelated with the Arctic sea ice volume anomalies and significantly correlated with the SST in the tropical, and SST in both north Pacific and north Atlantic sectors.**

- **Need To quantify how much AMOC variability being influenced by atmospheric forcing and by ocean internal variability. Repeat the replay cycle (from 1948-2010) many times and use the model states from each cycle at a given date as initial conditions for decadal prediction experiments.**