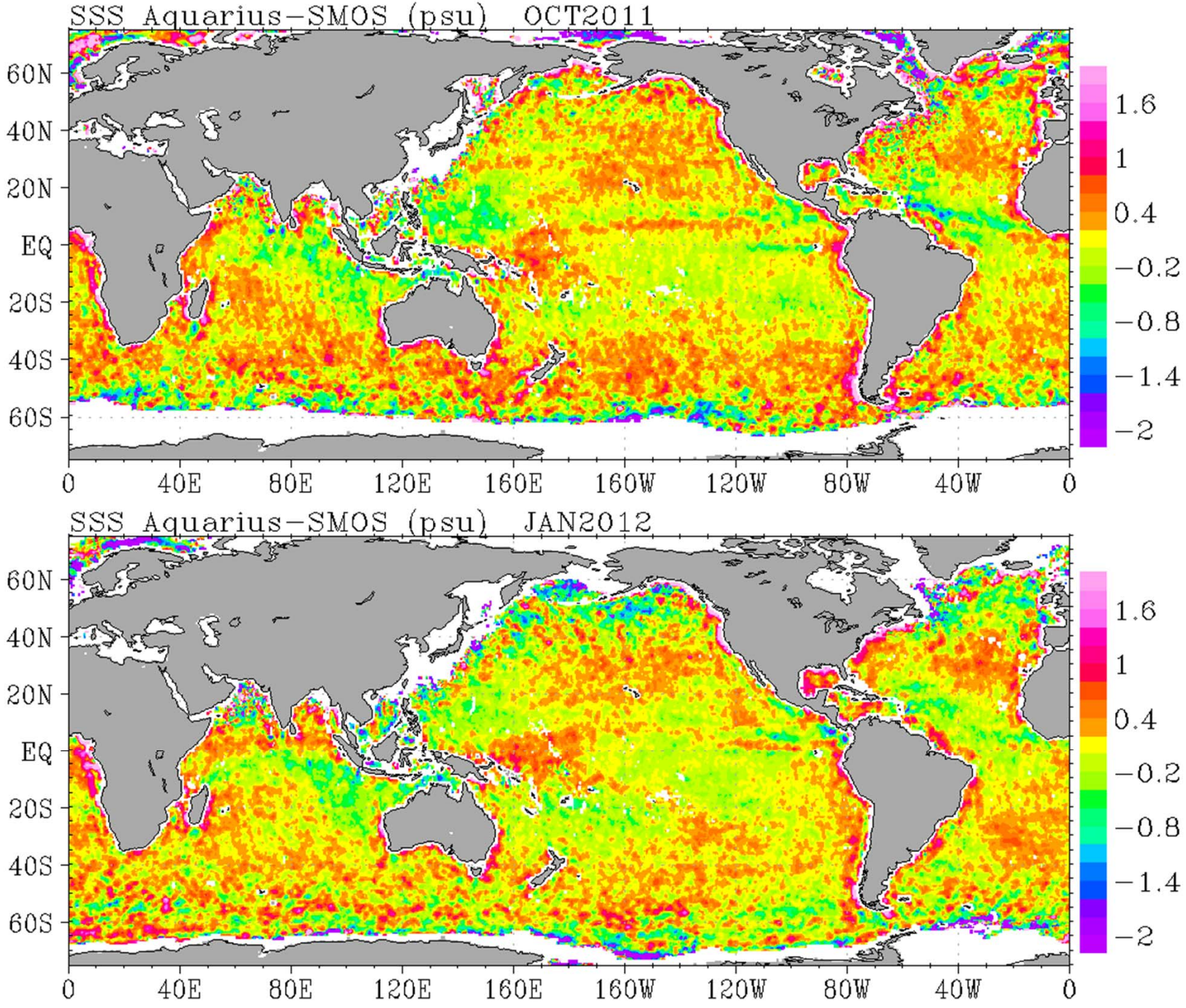
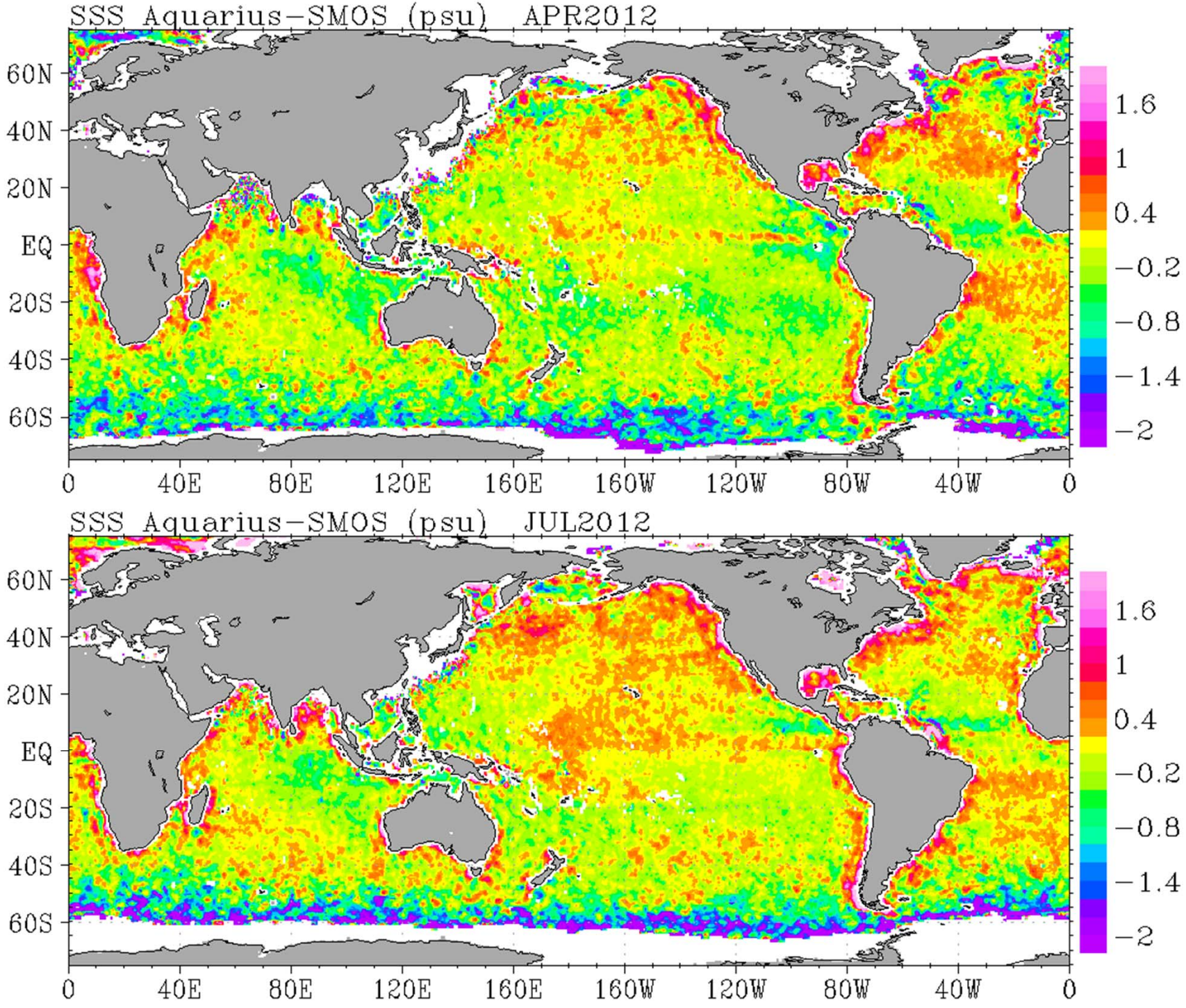
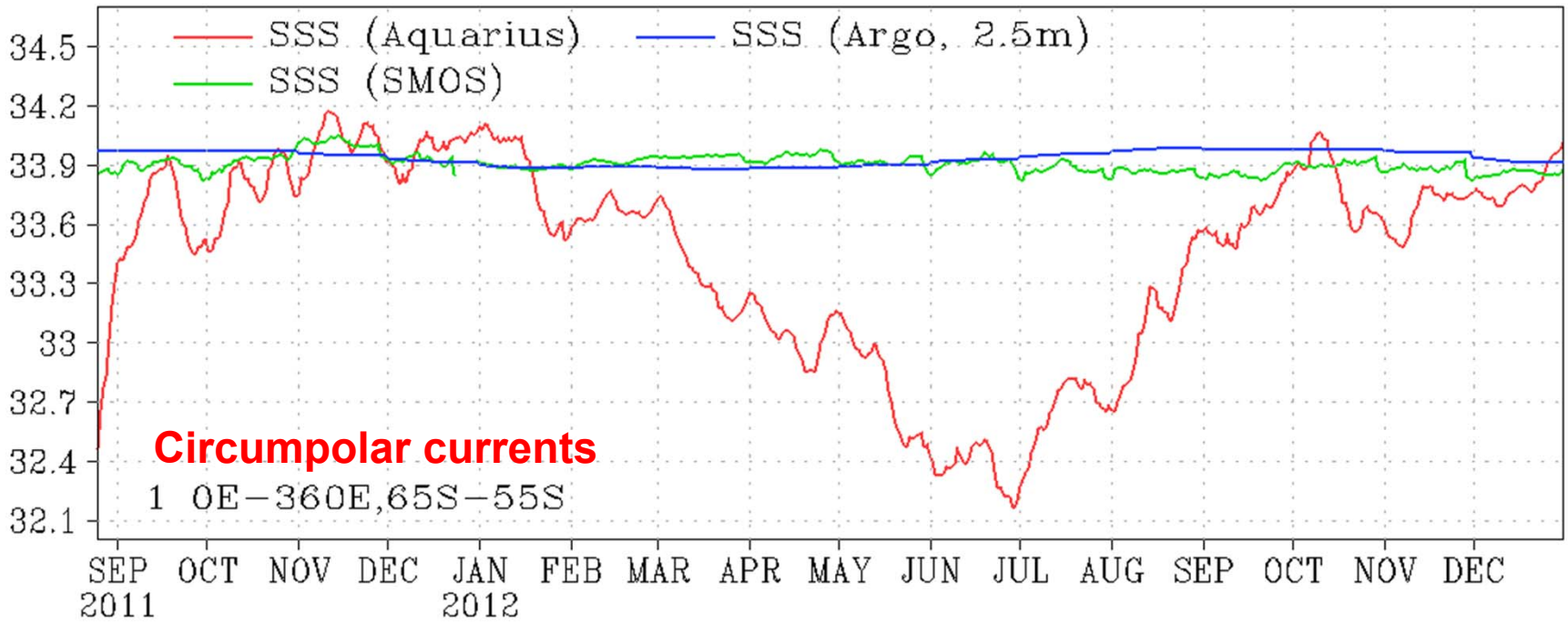
Ocean Surface Salinity Features as Observed by SMOS and Aquarius

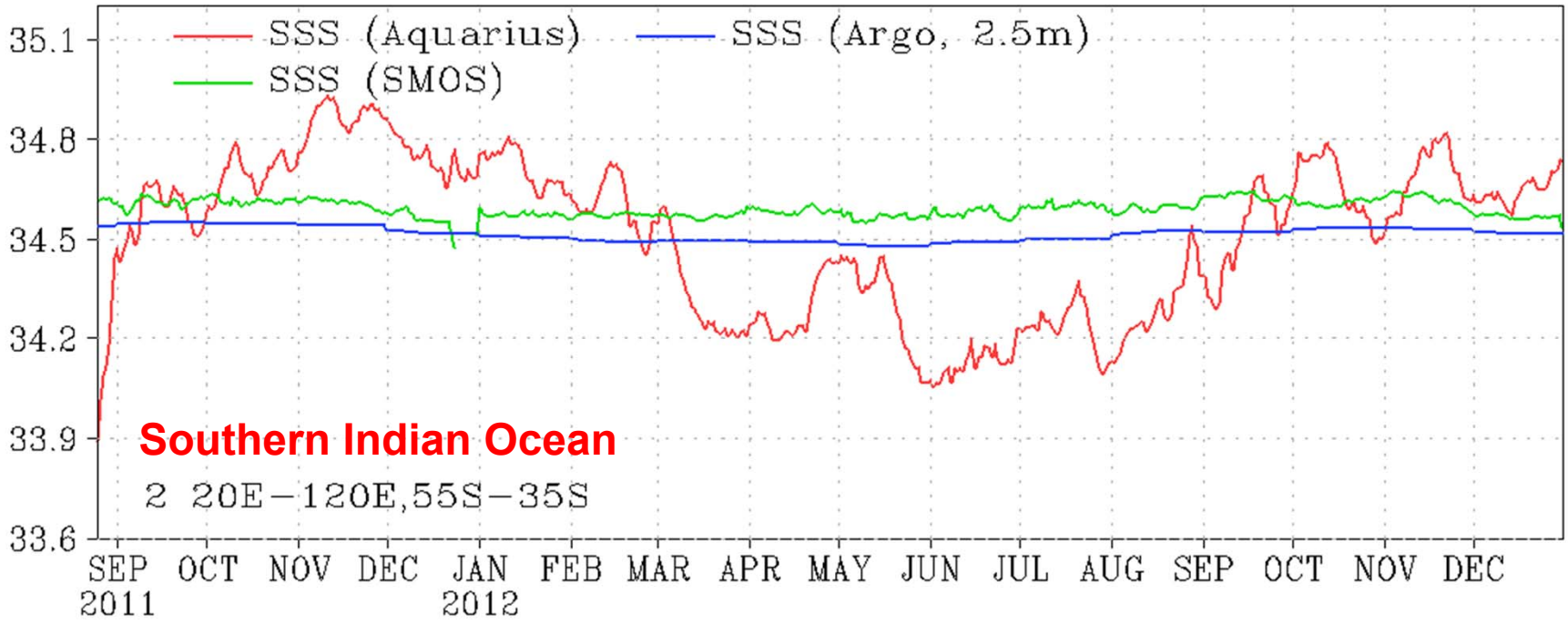
W. Timothy Liu and Xiaosu Xie
Jet Propulsion Laboratory

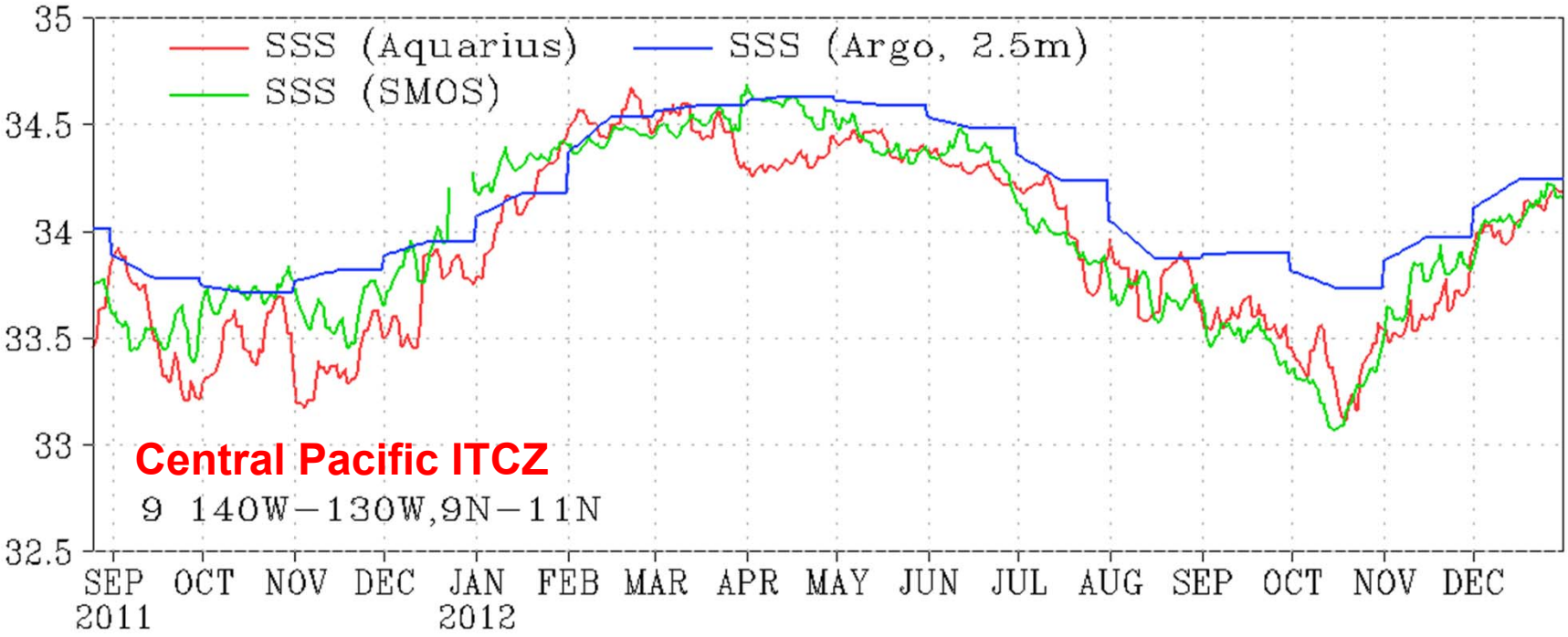
- picking the low lying fruits

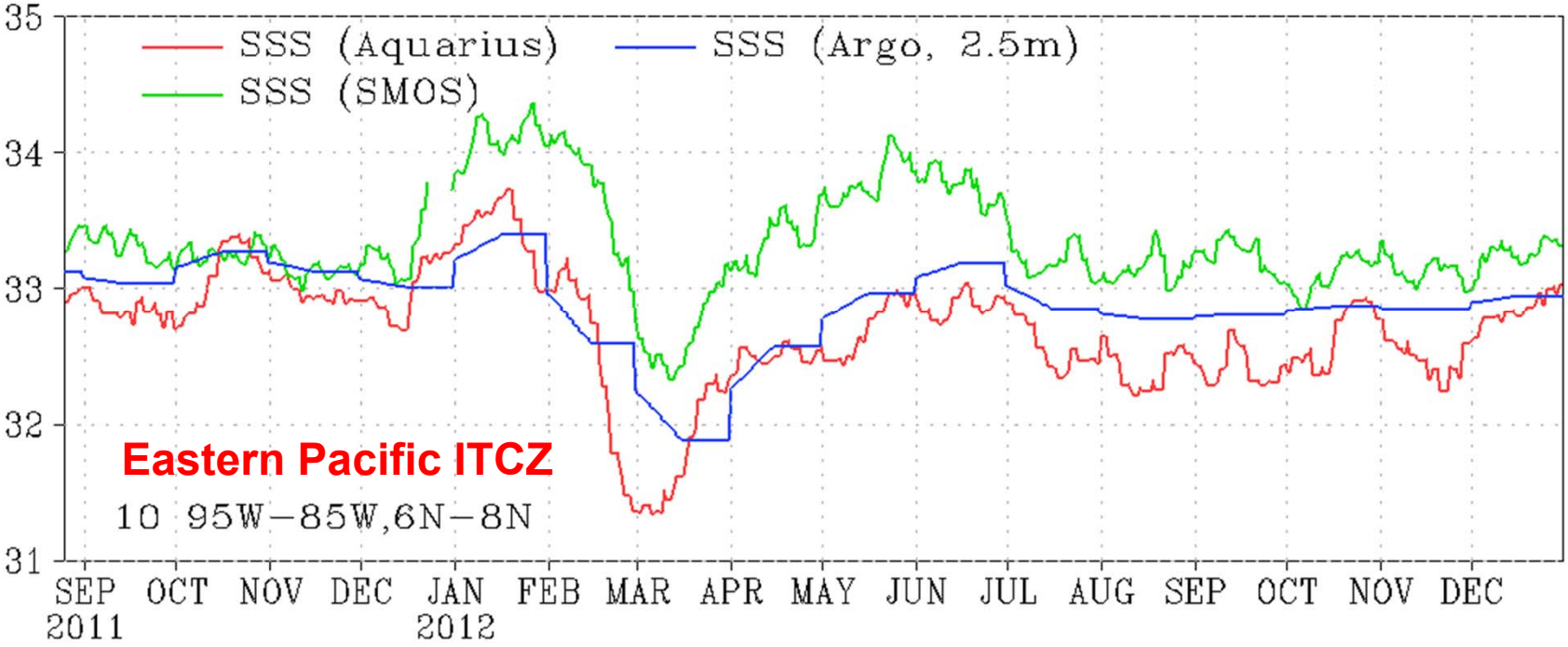

SSS Aquarius−SMOS (psu) OCT2011
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1
0.4
−0.2
−0.8
−1.4
−2
SSS Aquarius−SMOS (psu) JAN2012
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1
0.4
−0.2
−0.8
−1.4
−2

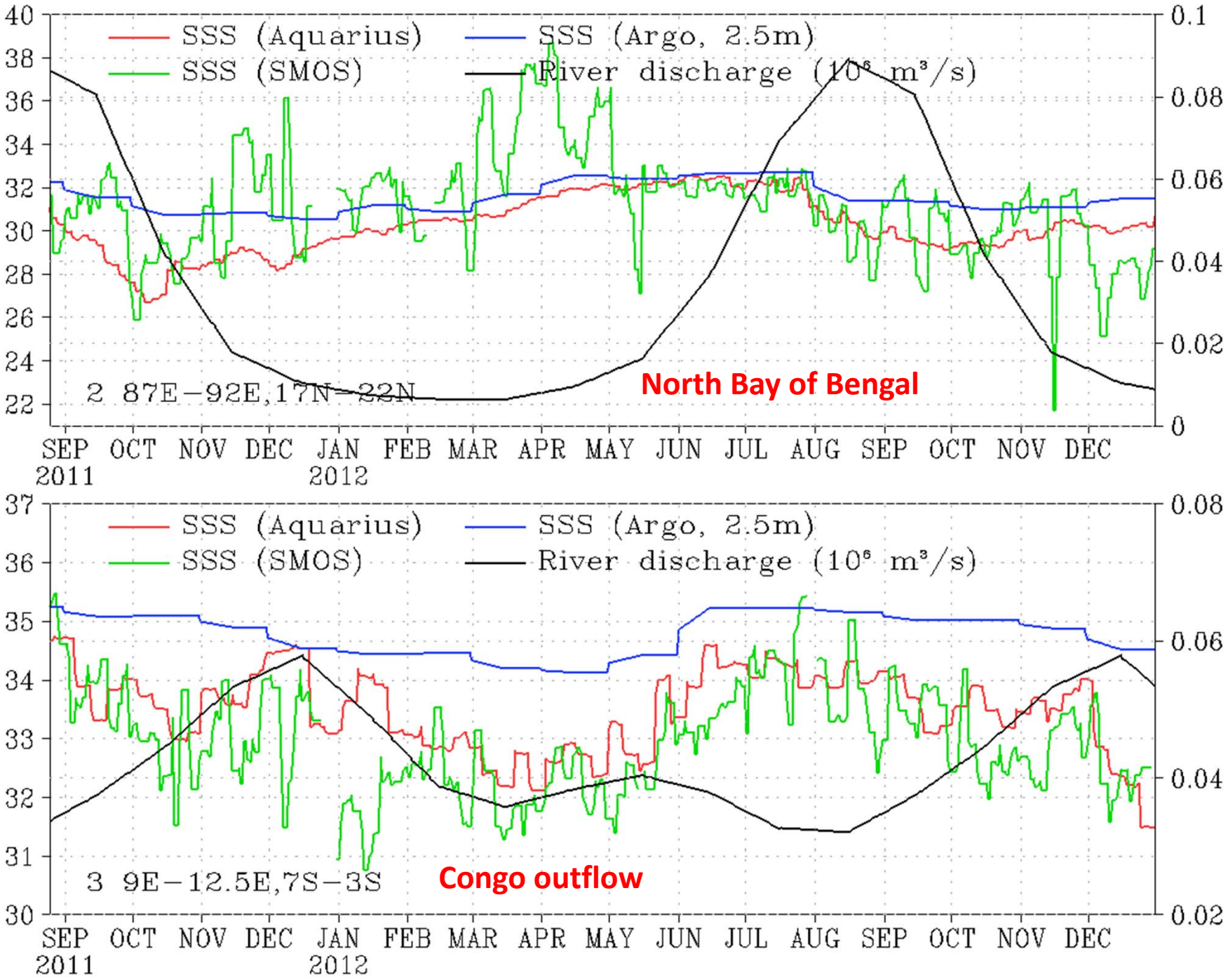

SSS Aquarius−SMOS (psu) APR2012
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1
0.4
−0.2
−0.8
−1.4
−2
SSS Aquarius−SMOS (psu) JUL2012
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1
0.4
−0.2
−0.8
−1.4
−2

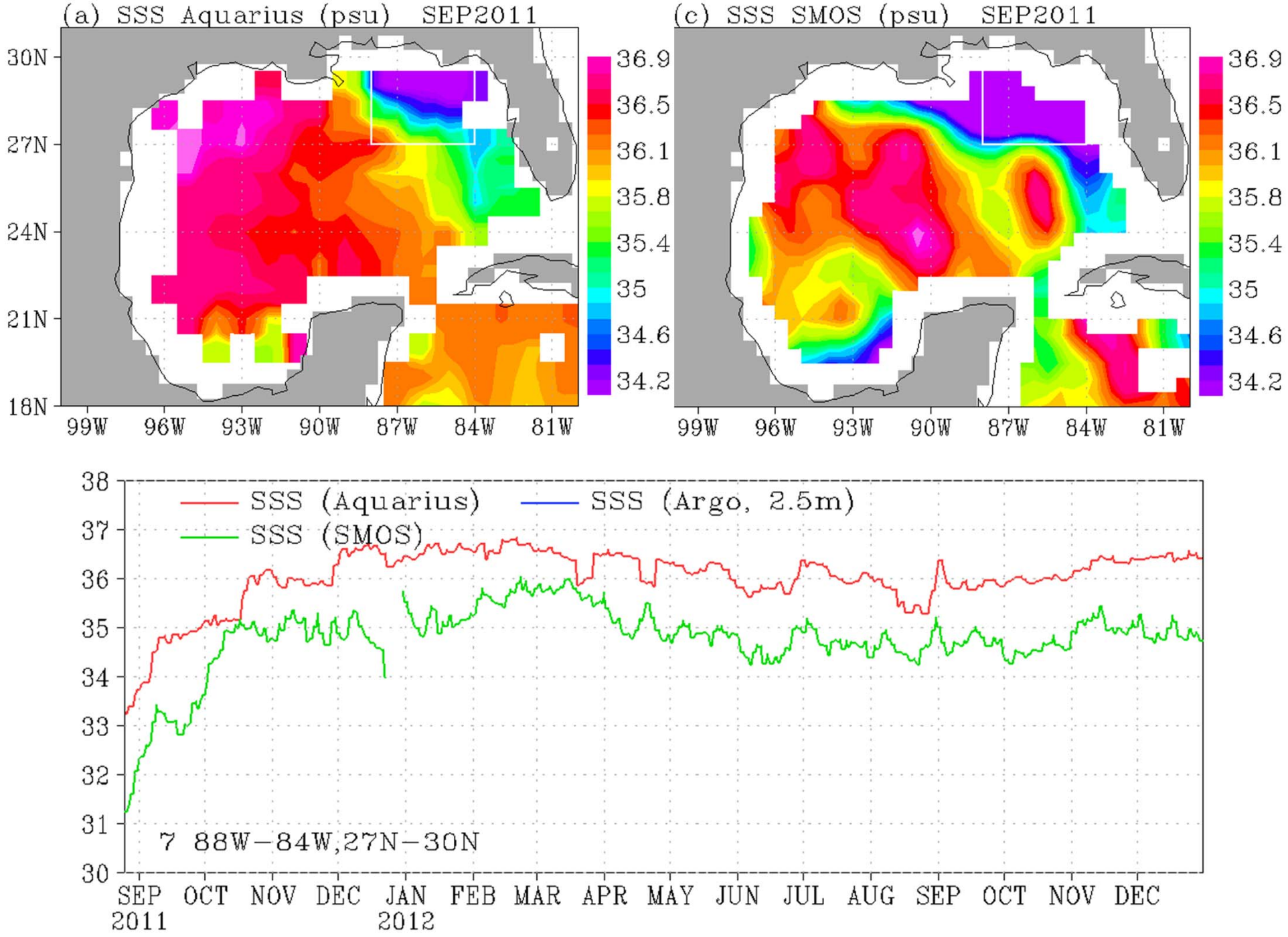

SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
34.5
34.2
33.9
33.6
33.3
33
32.7
32.4
32.1
Circumpolar currents
1 0E-360E,65S-55S
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012


SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
35.1
34.8
34.5
34.2
33.9
33.6
Southern Indian Ocean
2 20E-120E,55S-35S
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012


SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
Central Pacific ITCZ
9 140W-130W,9N-11N
35
34.5
34
33.5
33
32.5
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012


SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
Eastern Pacific ITCZ
10 95W-85W,6N-8N
35
34
33
32
31
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012

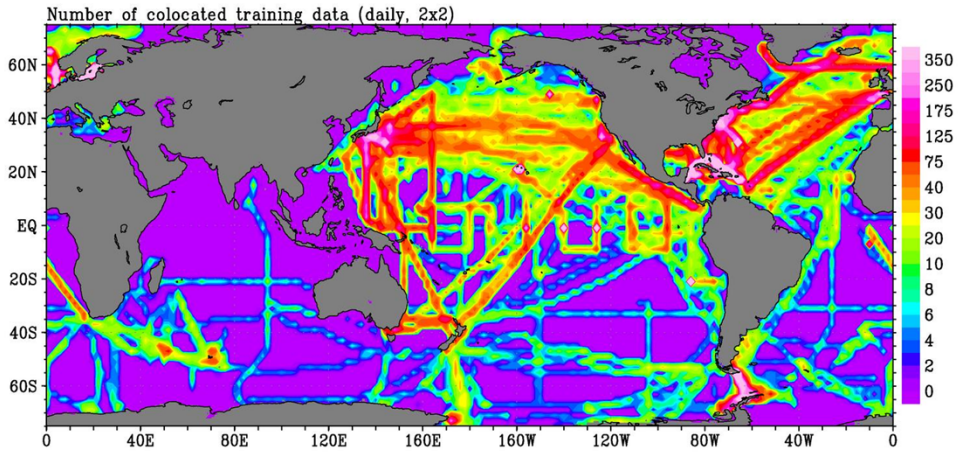

SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
River discharge (10⁶ m³/s)
2 87E−92E,17N−22N
North Bay of Bengal
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012
3 9E−12.5E,7S−3S
Congo outflow


(a) SSS Aquarius (psu) SEP2011
(c) SSS SMOS (psu) SEP2011
30N
27N
24N
21N
18N
99W
96W
93W
90W
87W
84W
81W
36.9
36.5
36.1
35.8
35.4
35
34.6
34.2
SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
7 88W-84W,27N-30N
38
37
36
35
34
33
32
31
30
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2011
2012

Milestones Completed

- Acquire in situ data
- Identify spacebased measurement
- Collocate data and train statistical model
- Produce 9-year data
- Validate data and examine deficiencies

Compiled from SOCAT+all other sources through CDIAC, with collocation with satellite data



❑Statistical model was developed using support vector regression

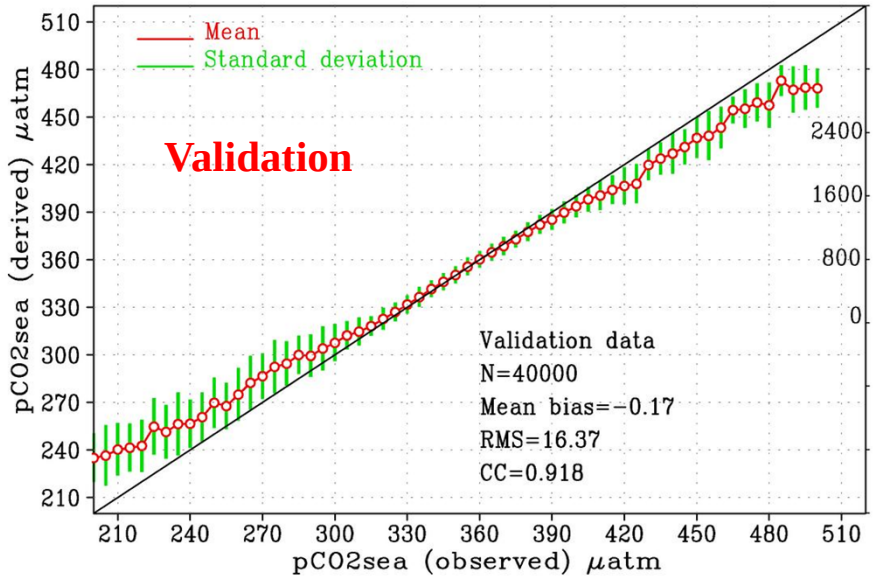
❑Input (daily): sin(day), cos(day), lat, sin(lon), cos(lon), SST (AMSR-E) , Chl-a (SeaWiFS+MODIS TERRA+MODIS Aqua), SSS (Levitus climatology), Mixed layer depth (GODAS).

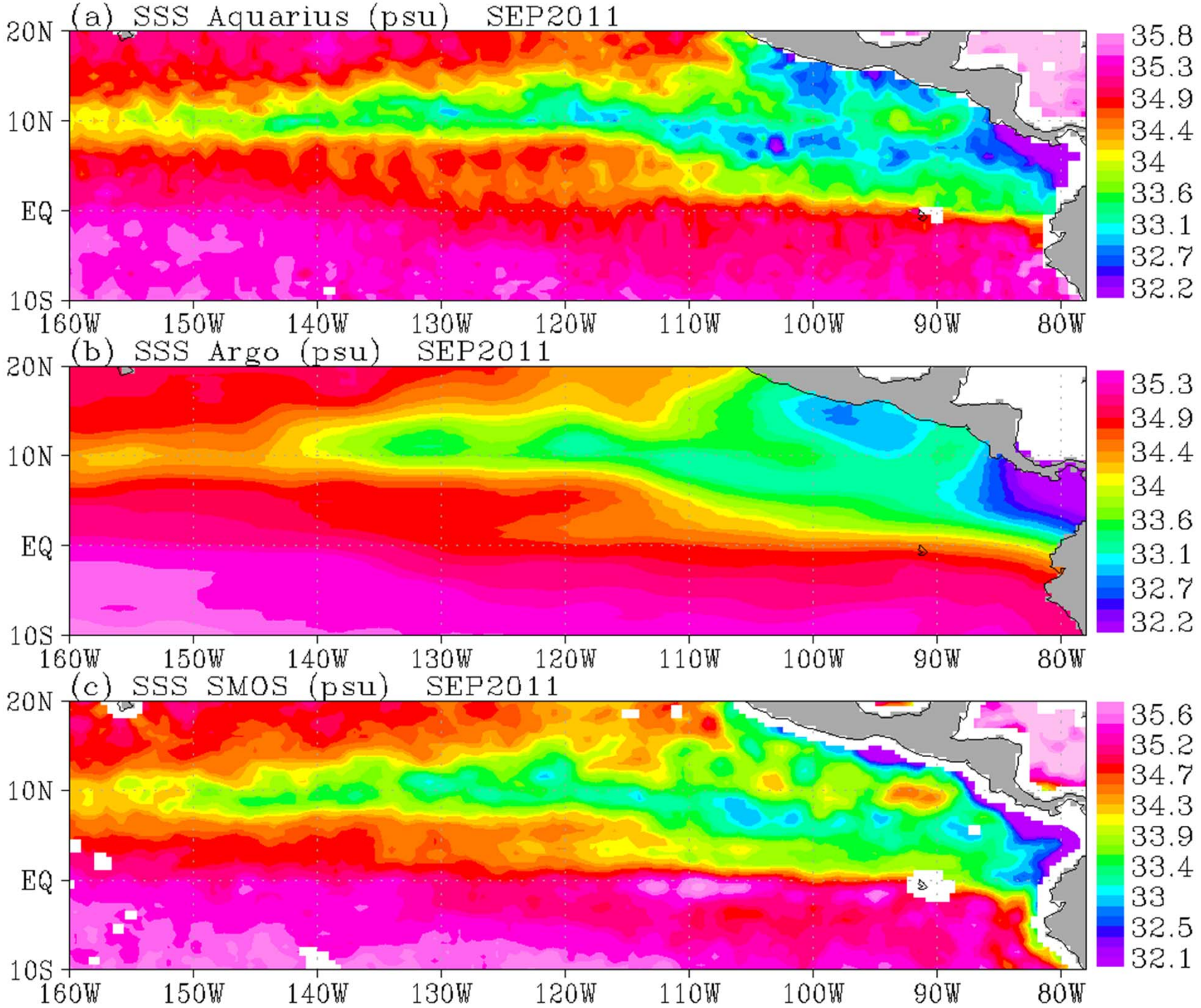
❑206265 data groups found 2002-2010

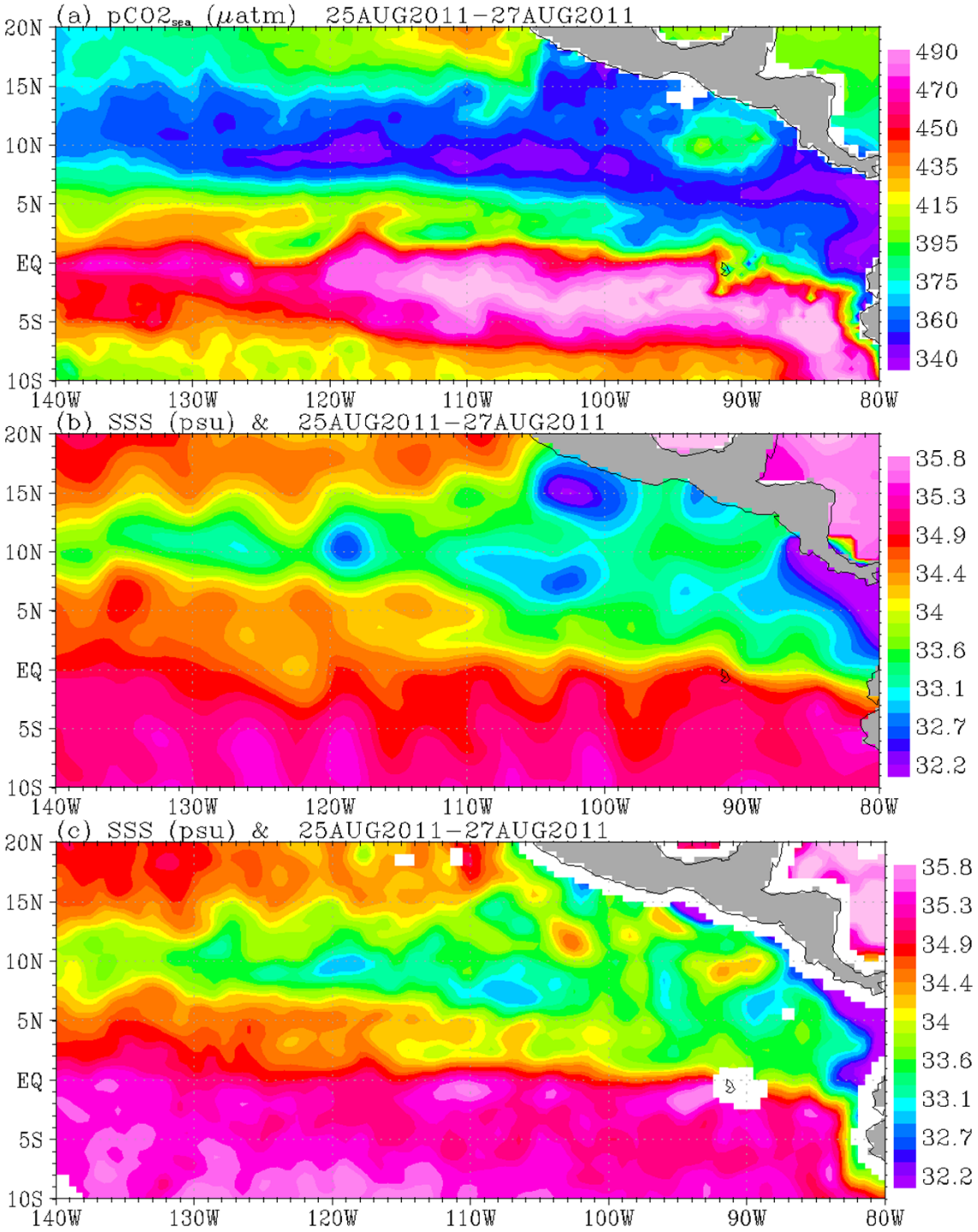
40,000 randomly selected for training and 40,000 for validation

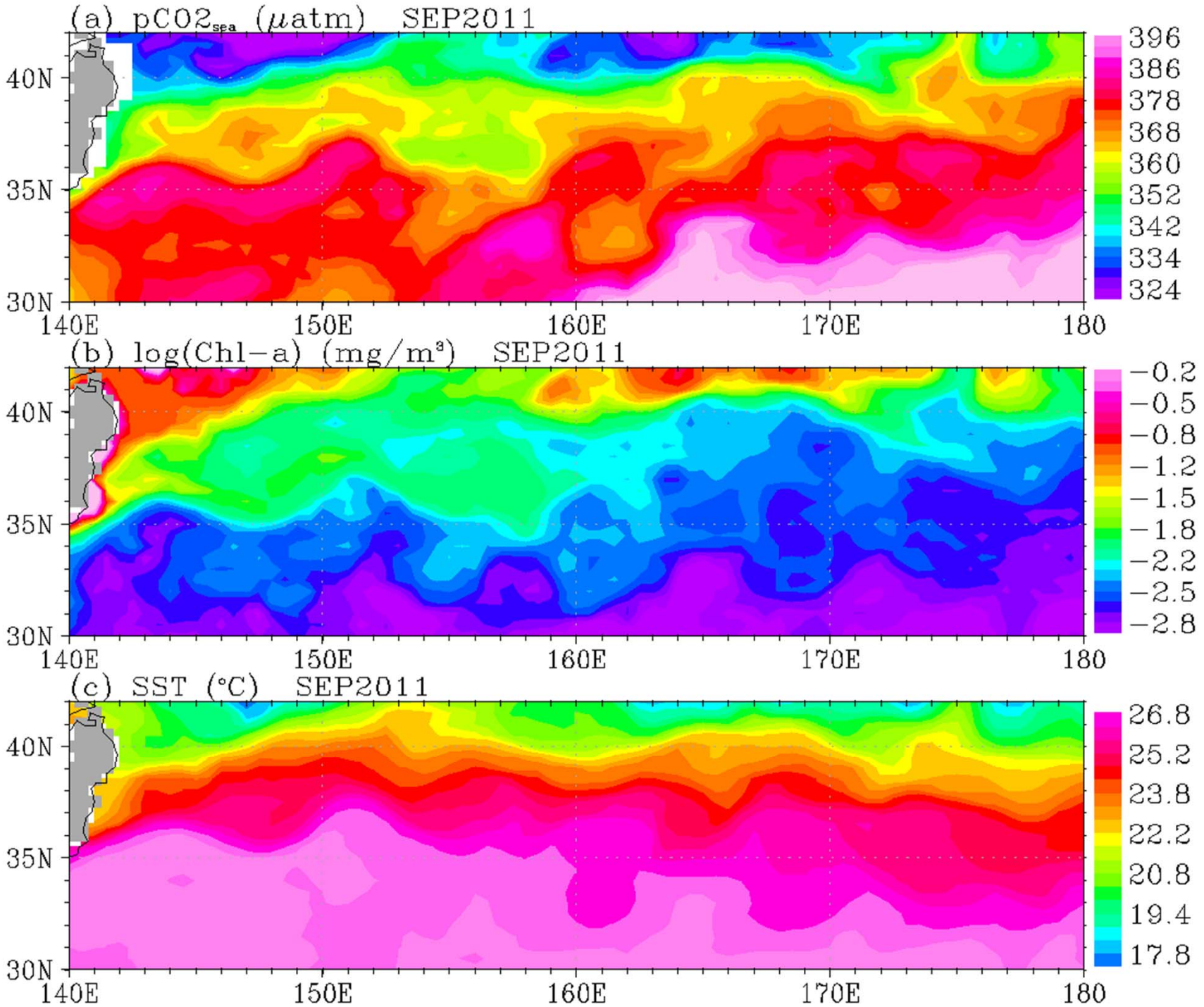
❑Output: 9 year $pCO2_{sea}$ at 0.5°, daily resolution

❑RMS (16.4) is 6% of range (270)

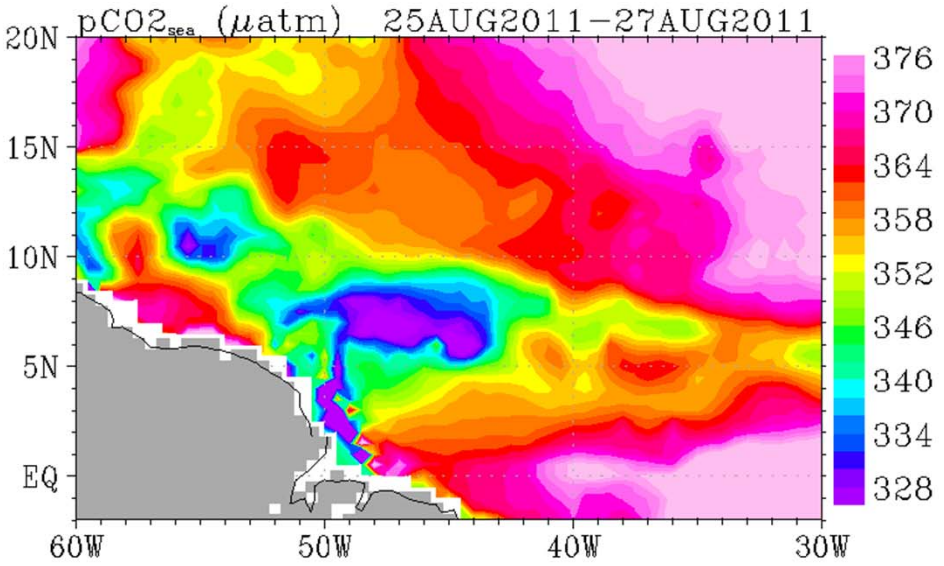



(a) SSS Aquarius (psu) SEP2011
20N
10N
EQ
10S
160W
150W
140W
130W
120W
110W
100W
90W
80W
35.8
35.3
34.9
34.4
34
33.6
33.1
32.7
32.2
(b) SSS Argo (psu) SEP2011
20N
10N
EQ
10S
160W
150W
140W
130W
120W
110W
100W
90W
80W
35.3
34.9
34.4
34
33.6
33.1
32.7
32.2
(c) SSS SMOS (psu) SEP2011
20N
10N
EQ
10S
160W
150W
140W
130W
120W
110W
100W
90W
80W
35.6
35.2
34.7
34.3
33.9
33.4
33
32.5
32.1

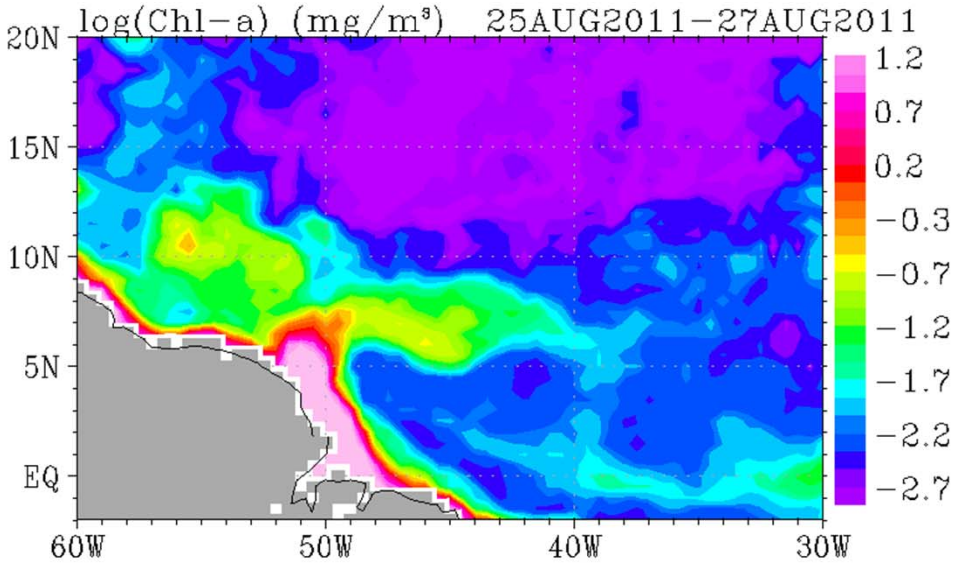

(a) pCO2sea (μatm) 25AUG2011-27AUG2011
20N
15N
10N
5N
EQ
5S
10S
140W
130W
120W
110W
100W
90W
80W
490
470
450
435
415
395
375
360
340
(b) SSS (psu) & 25AUG2011-27AUG2011
35.8
35.3
34.9
34.4
34
33.6
33.1
32.7
32.2
(c) SSS (psu) & 25AUG2011-27AUG2011

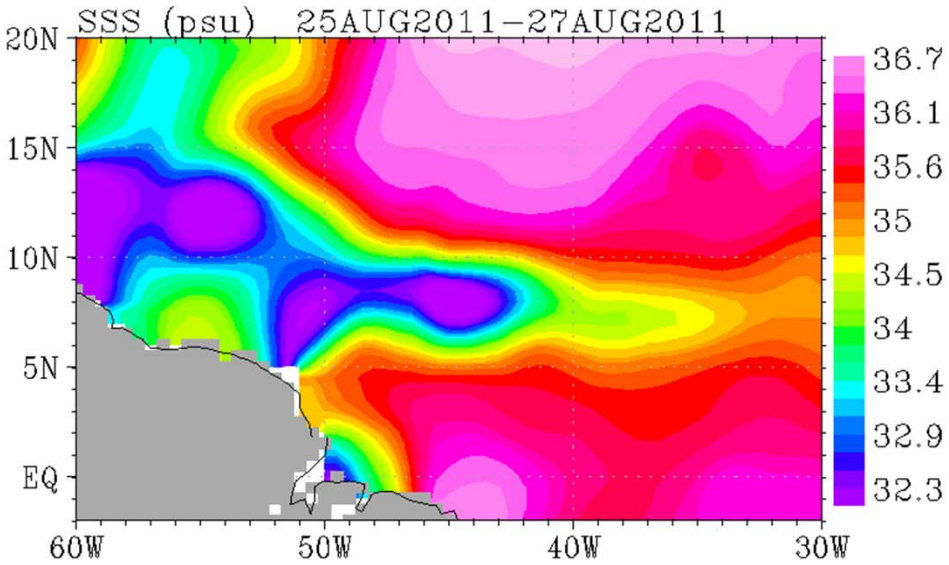

(a) pCO2sea (μatm) SEP2011
396
386
378
368
360
352
342
334
324
(b) log(Chl-a) (mg/m³) SEP2011
−0.2
−0.5
−0.8
−1.2
−1.5
−1.8
−2.2
−2.5
−2.8
(c) SST (°C) SEP2011
26.8
25.2
23.8
22.2
20.8
19.4
17.8
40N
35N
30N
140E
150E
160E
170E
180

pCO2sea

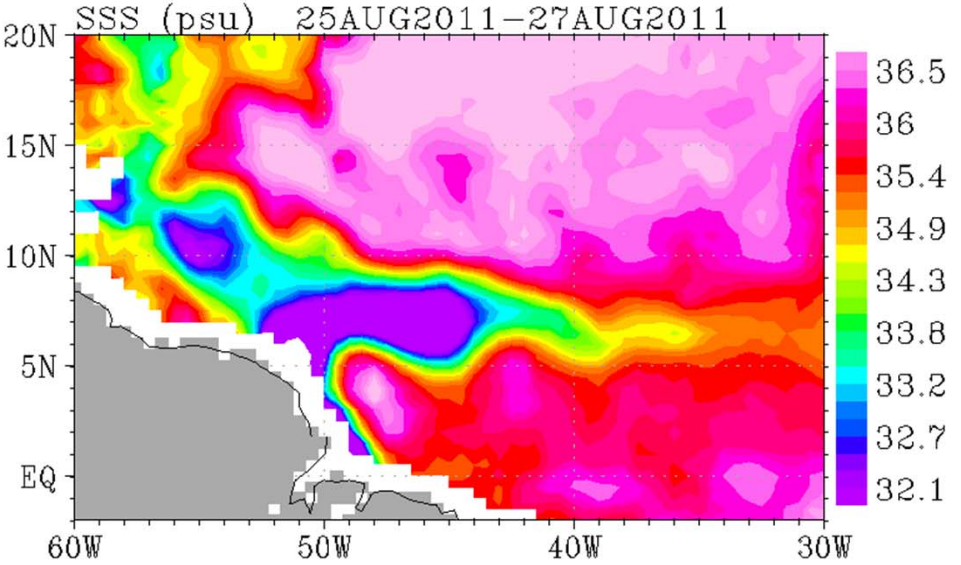


log(Chl-a)



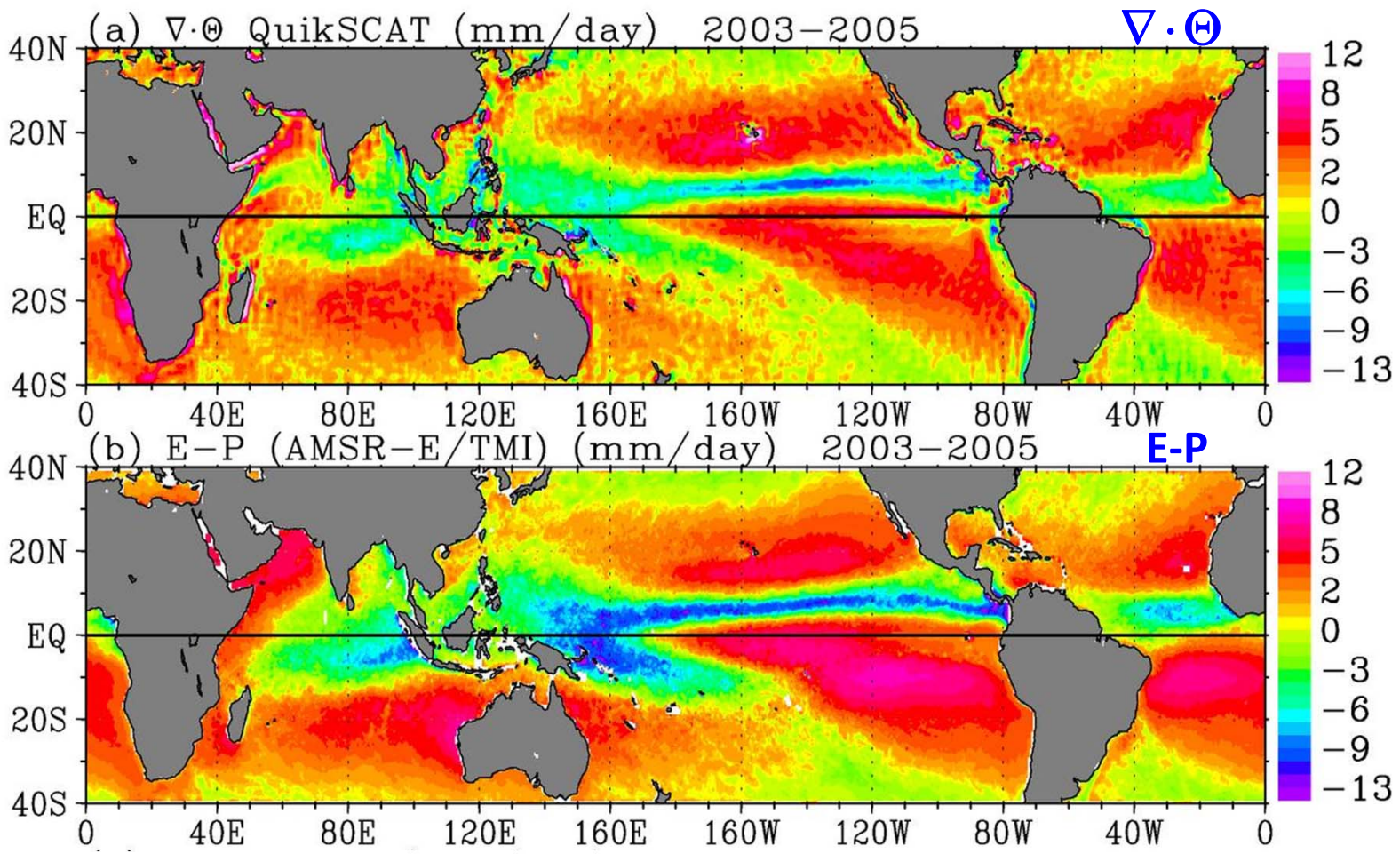


SSS (Aquarius)



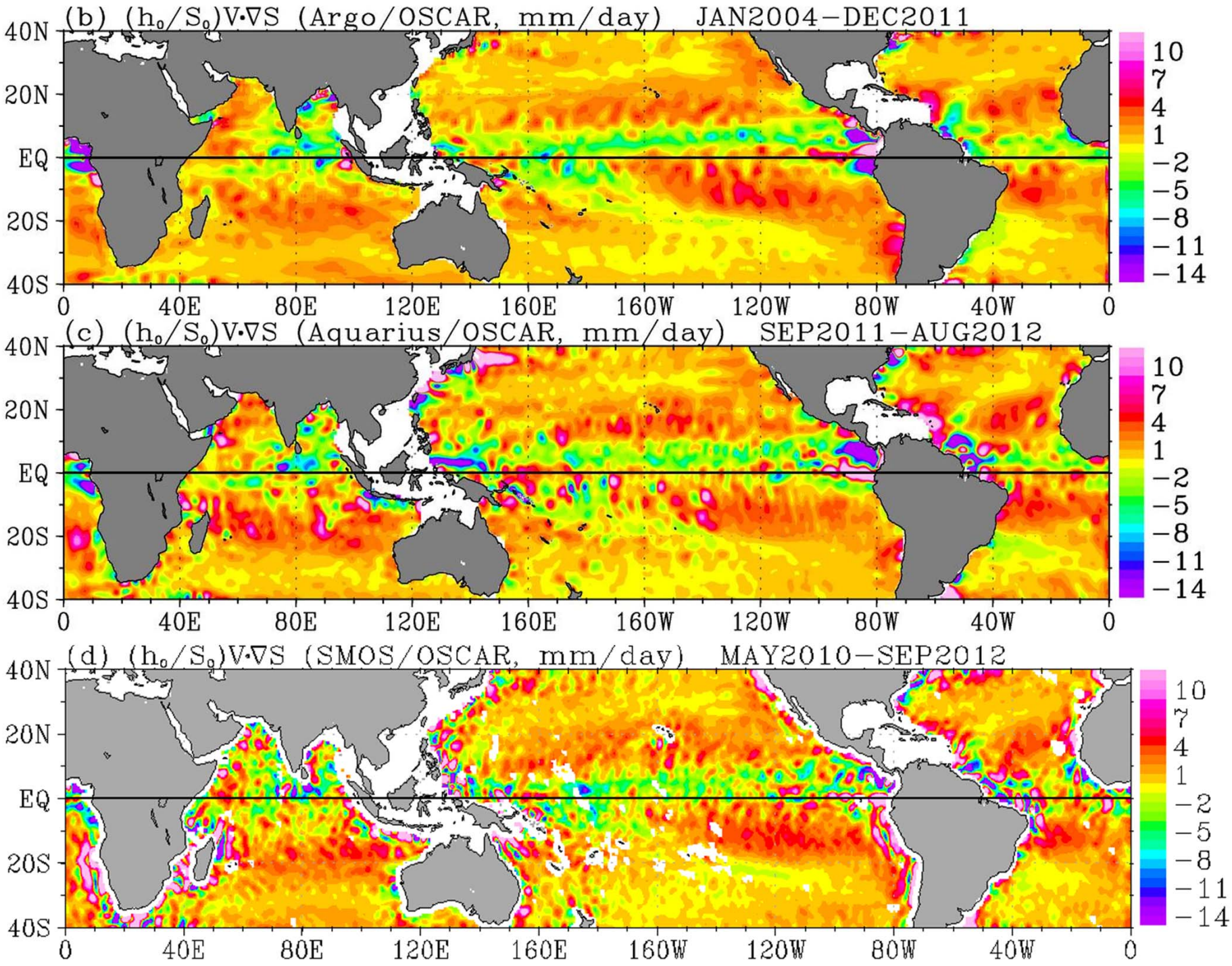
SSS (SMOS)

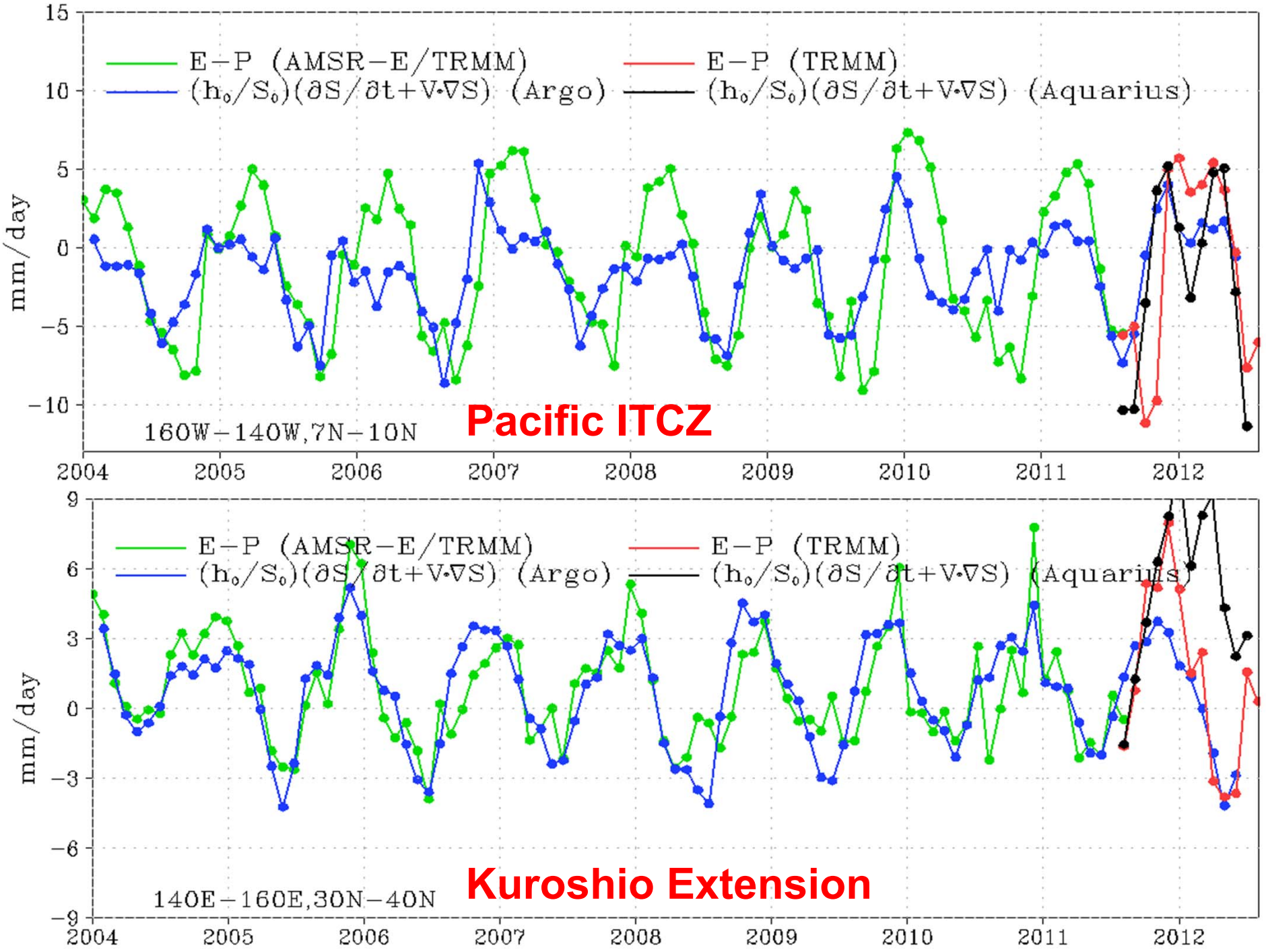
$$E - P = \frac{h_0}{S_0}\left(\frac{\partial S}{\partial t} + V \cdot \nabla S\right)$$

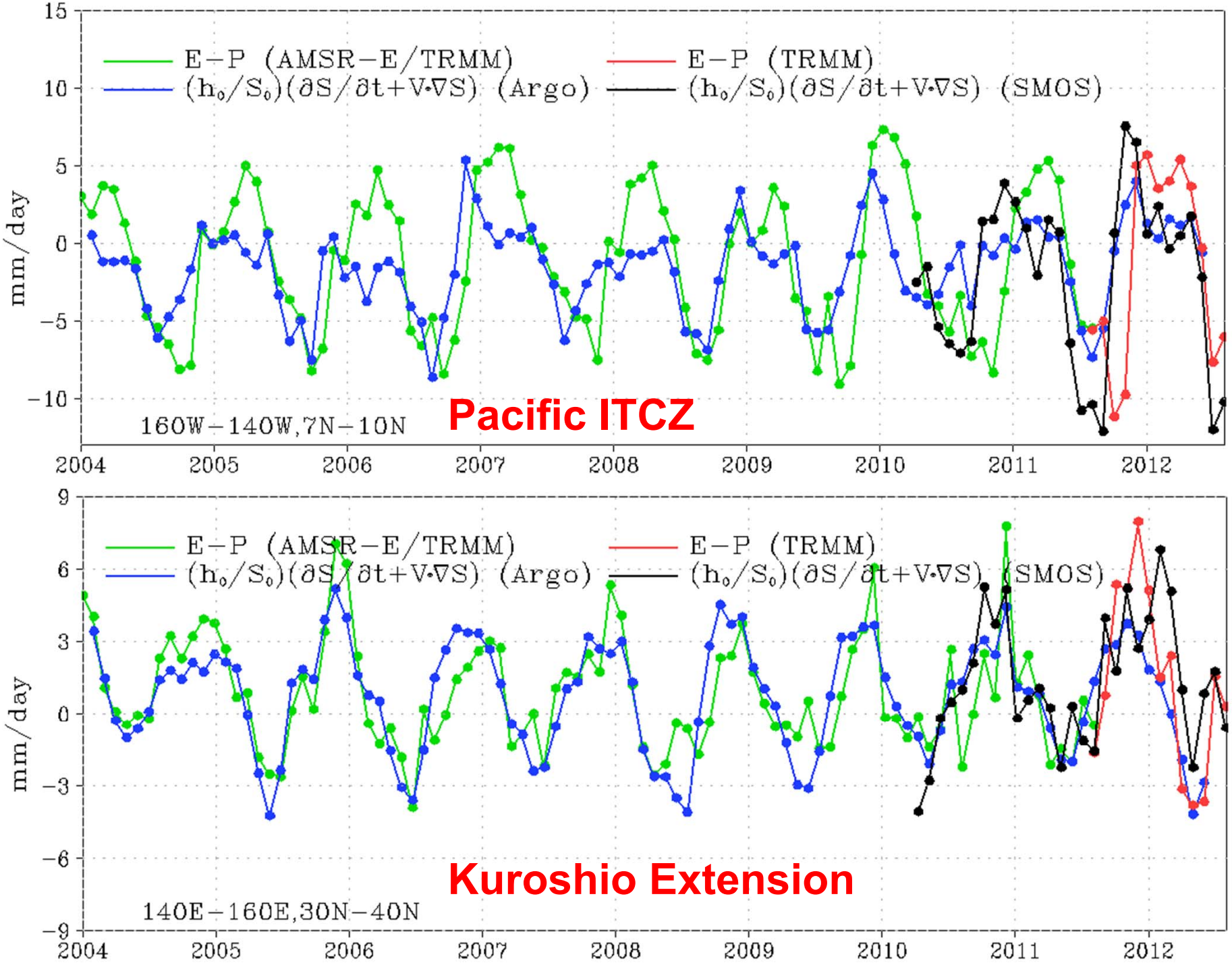


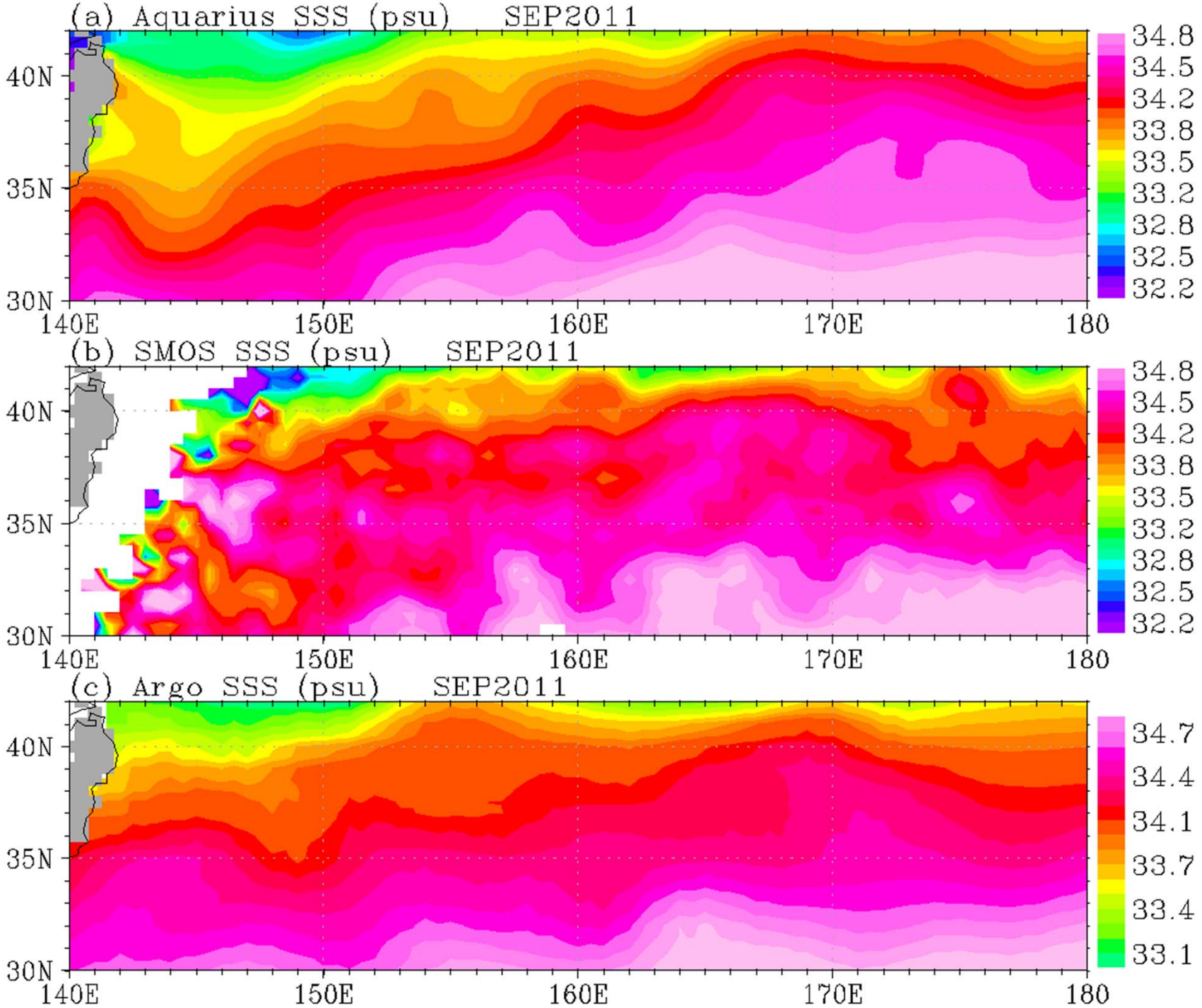
$$\frac{\partial W}{\partial t} + \nabla \bullet \Theta = E - P$$

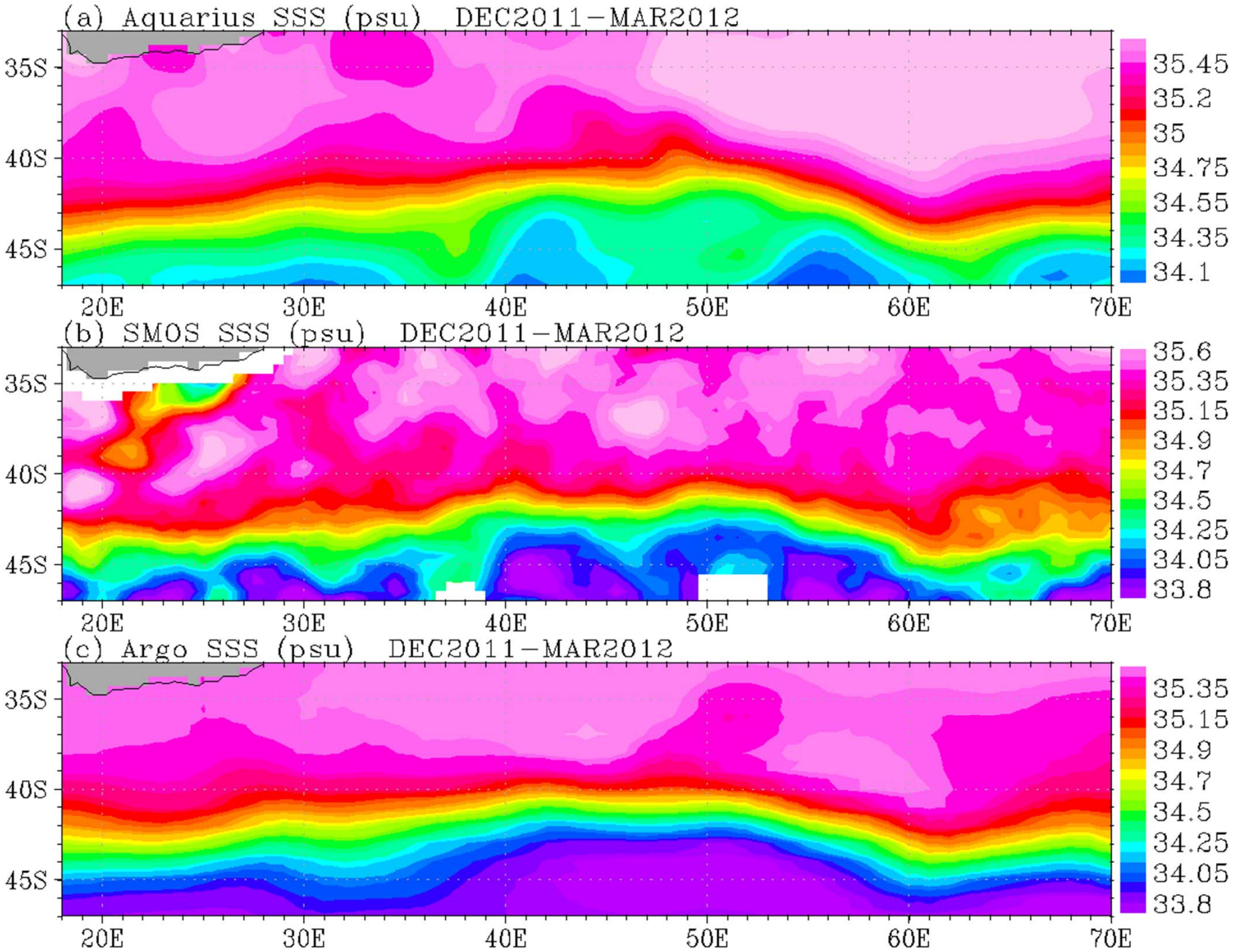
$$\Theta = \frac{1}{g}\int_0^{p_0} qU\,dp \qquad W = \frac{1}{g}\int_0^{p_0} q\,dp$$

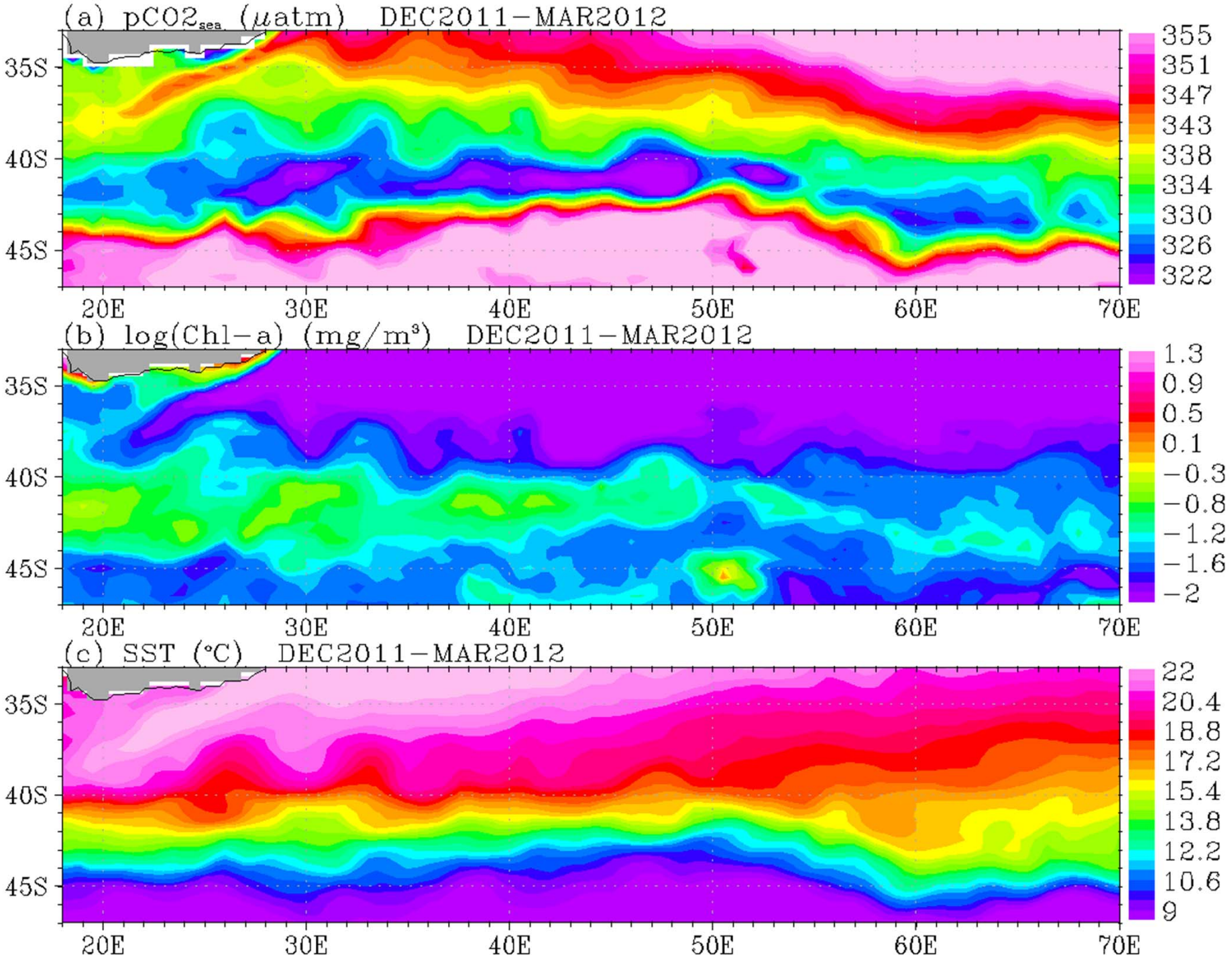

(b) (h₀/S₀)V·∇S (Argo/OSCAR, mm/day) JAN2004−DEC2011
(c) (h₀/S₀)V·∇S (Aquarius/OSCAR, mm/day) SEP2011−AUG2012
(d) (h₀/S₀)V·∇S (SMOS/OSCAR, mm/day) MAY2010−SEP2012
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
10
7
4
1
−2
−5
−8
−11
−14

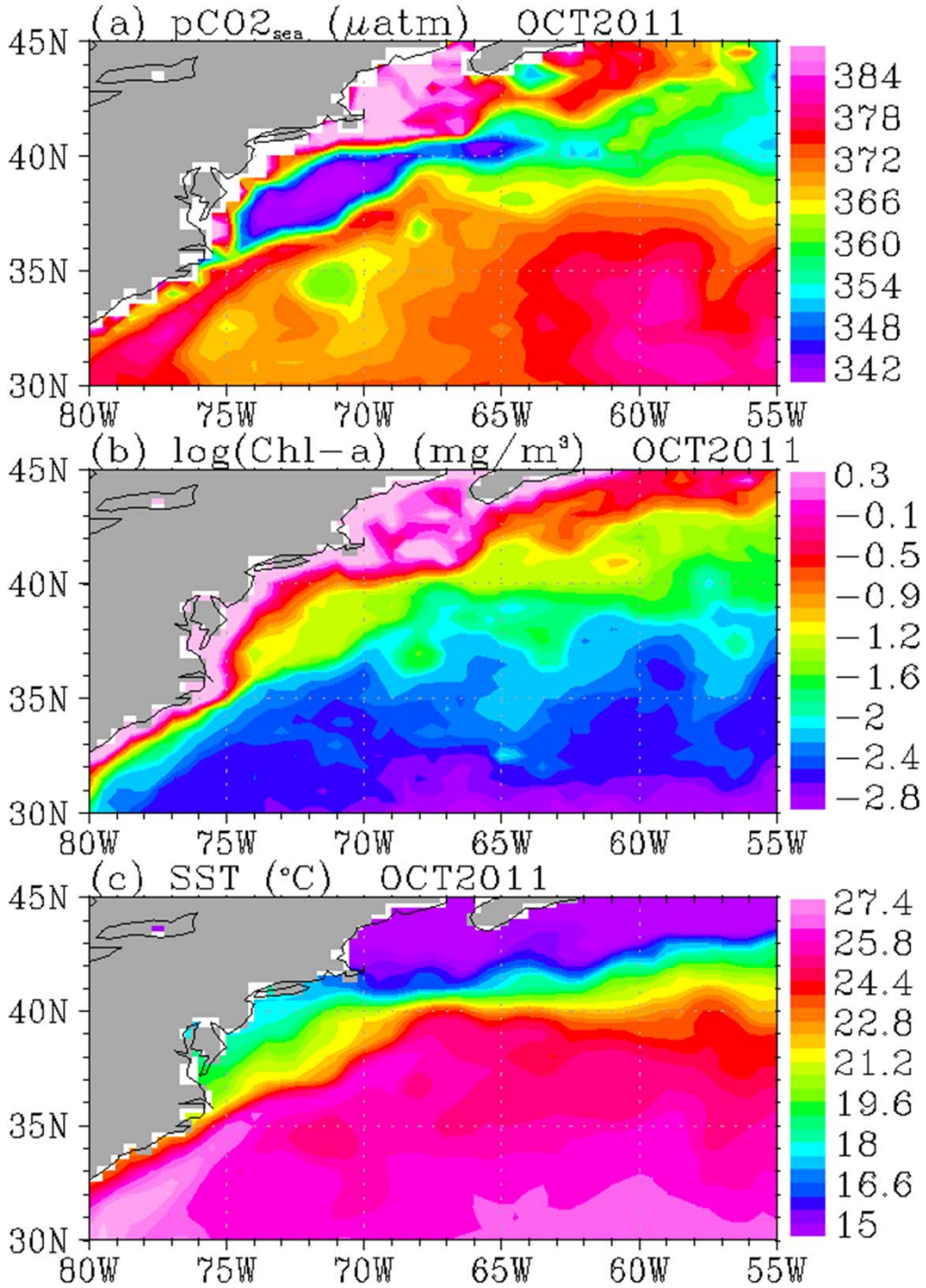

E−P (AMSR−E/TRMM)
(h₀/S₀)(∂S/∂t+V·∇S) (Argo)
E−P (TRMM)
(h₀/S₀)(∂S/∂t+V·∇S) (Aquarius)
mm/day
160W−140W,7N−10N
Pacific ITCZ
140E−160E,30N−40N
Kuroshio Extension
2004
2005
2006
2007
2008
2009
2010
2011
2012

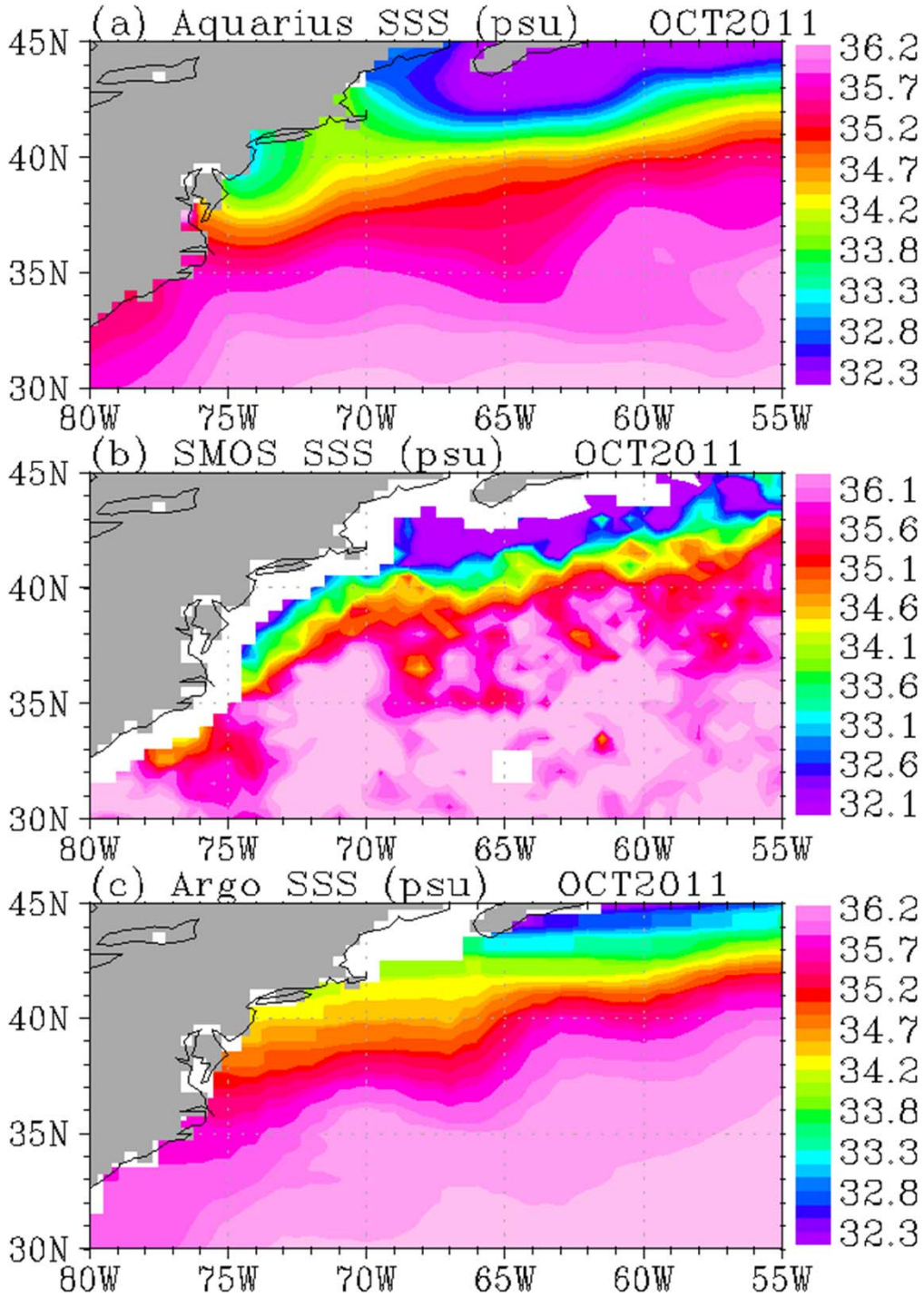

E−P (AMSR−E/TRMM)
E−P (TRMM)
(h₀/S₀)(∂S/∂t+V·∇S) (Argo)
(h₀/S₀)(∂S/∂t+V·∇S) (SMOS)
mm/day
160W−140W,7N−10N
Pacific ITCZ
140E−160E,30N−40N
Kuroshio Extension
2004
2005
2006
2007
2008
2009
2010
2011
2012

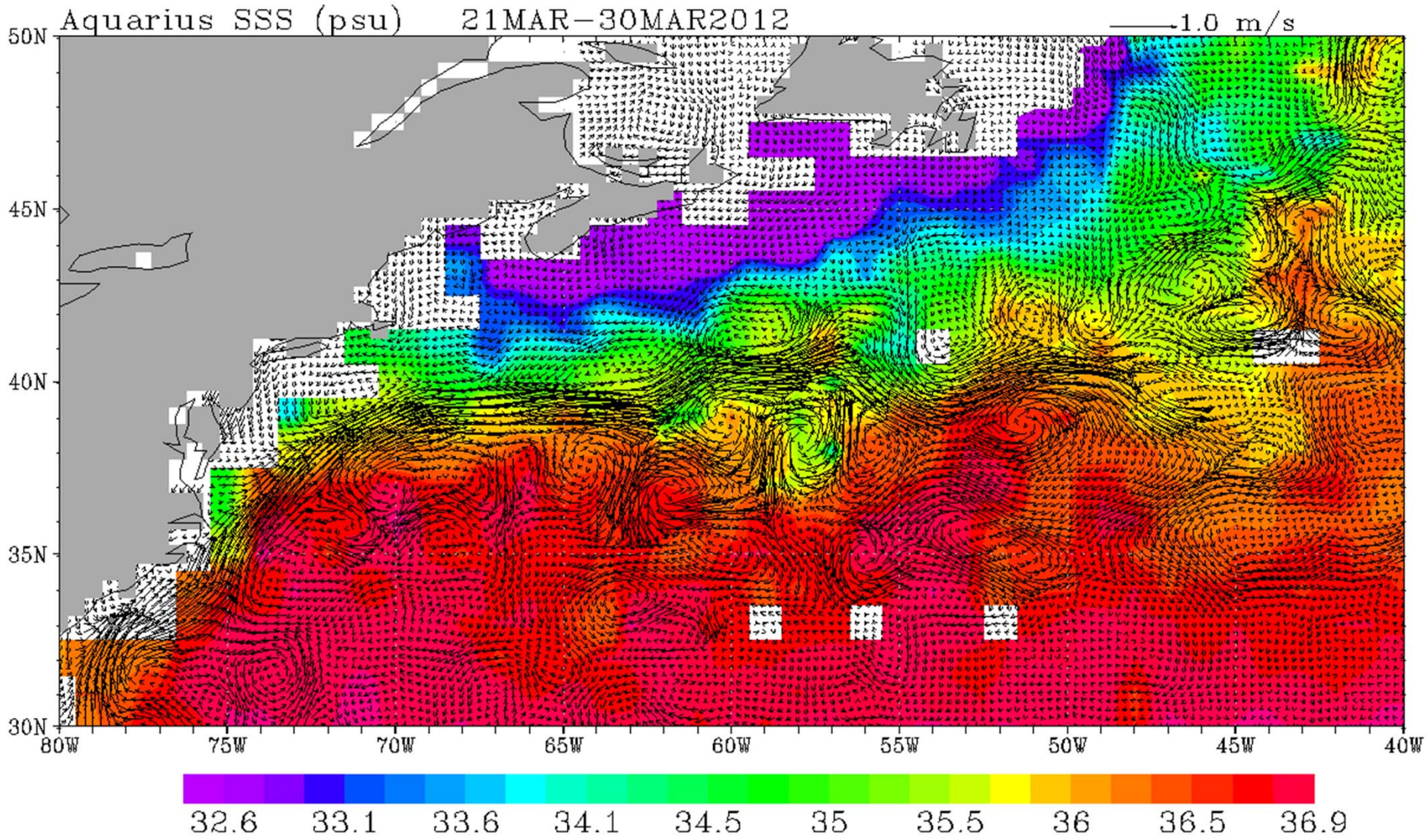

(a) Aquarius SSS (psu) SEP2011
34.8
34.5
34.2
33.8
33.5
33.2
32.8
32.5
32.2
40N
35N
30N
140E
150E
160E
170E
180
(b) SMOS SSS (psu) SEP2011
34.8
34.5
34.2
33.8
33.5
33.2
32.8
32.5
32.2
40N
35N
30N
140E
150E
160E
170E
180
(c) Argo SSS (psu) SEP2011
34.7
34.4
34.1
33.7
33.4
33.1
40N
35N
30N
140E
150E
160E
170E
180

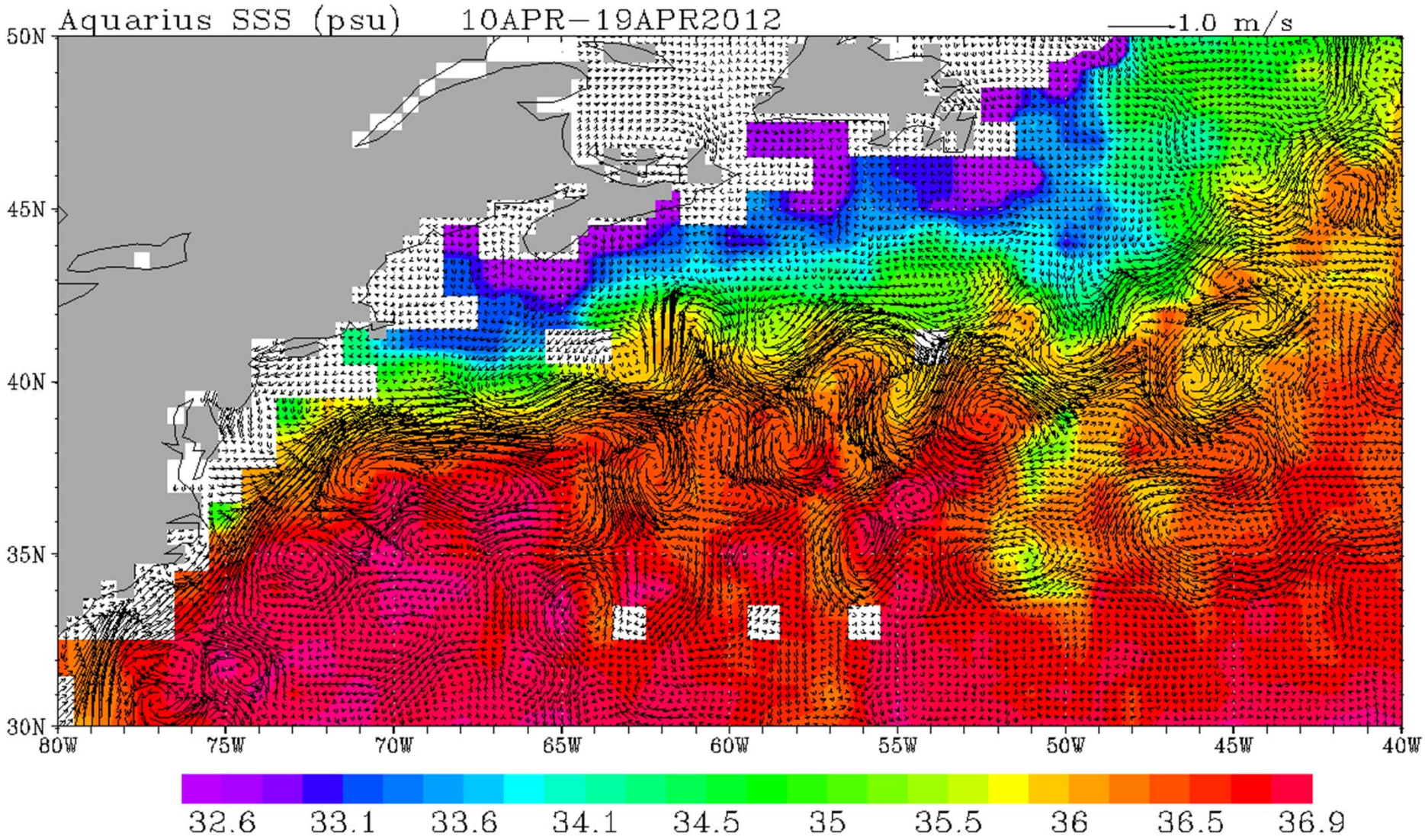

(a) Aquarius SSS (psu) DEC2011−MAR2012
35S
40S
45S
20E
30E
40E
50E
60E
70E
35.45
35.2
35
34.75
34.55
34.35
34.1
(b) SMOS SSS (psu) DEC2011−MAR2012
35S
40S
45S
20E
30E
40E
50E
60E
70E
35.6
35.35
35.15
34.9
34.7
34.5
34.25
34.05
33.8
(c) Argo SSS (psu) DEC2011−MAR2012
35S
40S
45S
20E
30E
40E
50E
60E
70E
35.35
35.15
34.9
34.7
34.5
34.25
34.05
33.8

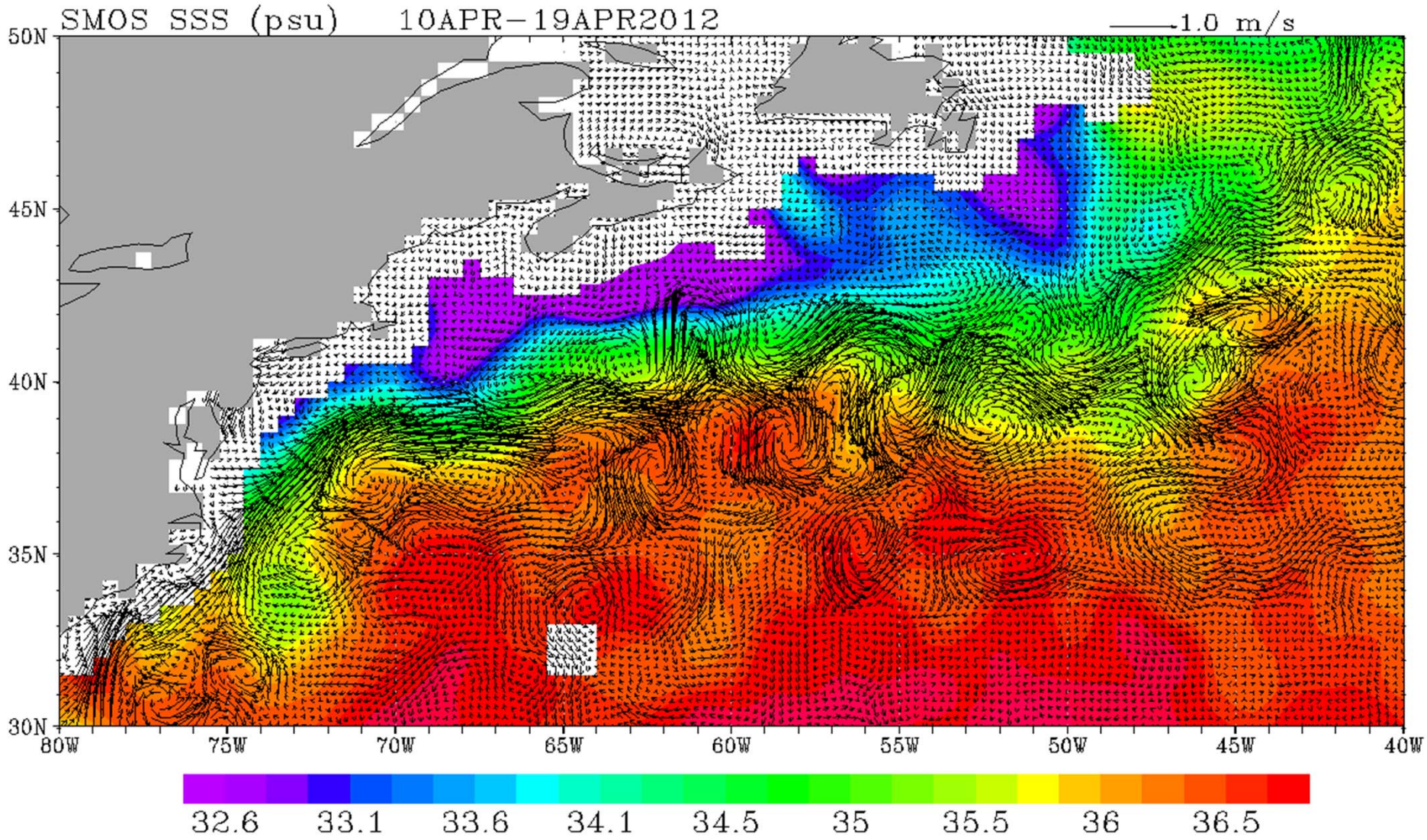

(a) pCO2sea (μatm) DEC2011−MAR2012
355
351
347
343
338
334
330
326
322
(b) log(Chl−a) (mg/m³) DEC2011−MAR2012
1.3
0.9
0.5
0.1
−0.3
−0.8
−1.2
−1.6
−2
(c) SST (°C) DEC2011−MAR2012
22
20.4
18.8
17.2
15.4
13.8
12.2
10.6
9
35S
40S
45S
20E
30E
40E
50E
60E
70E

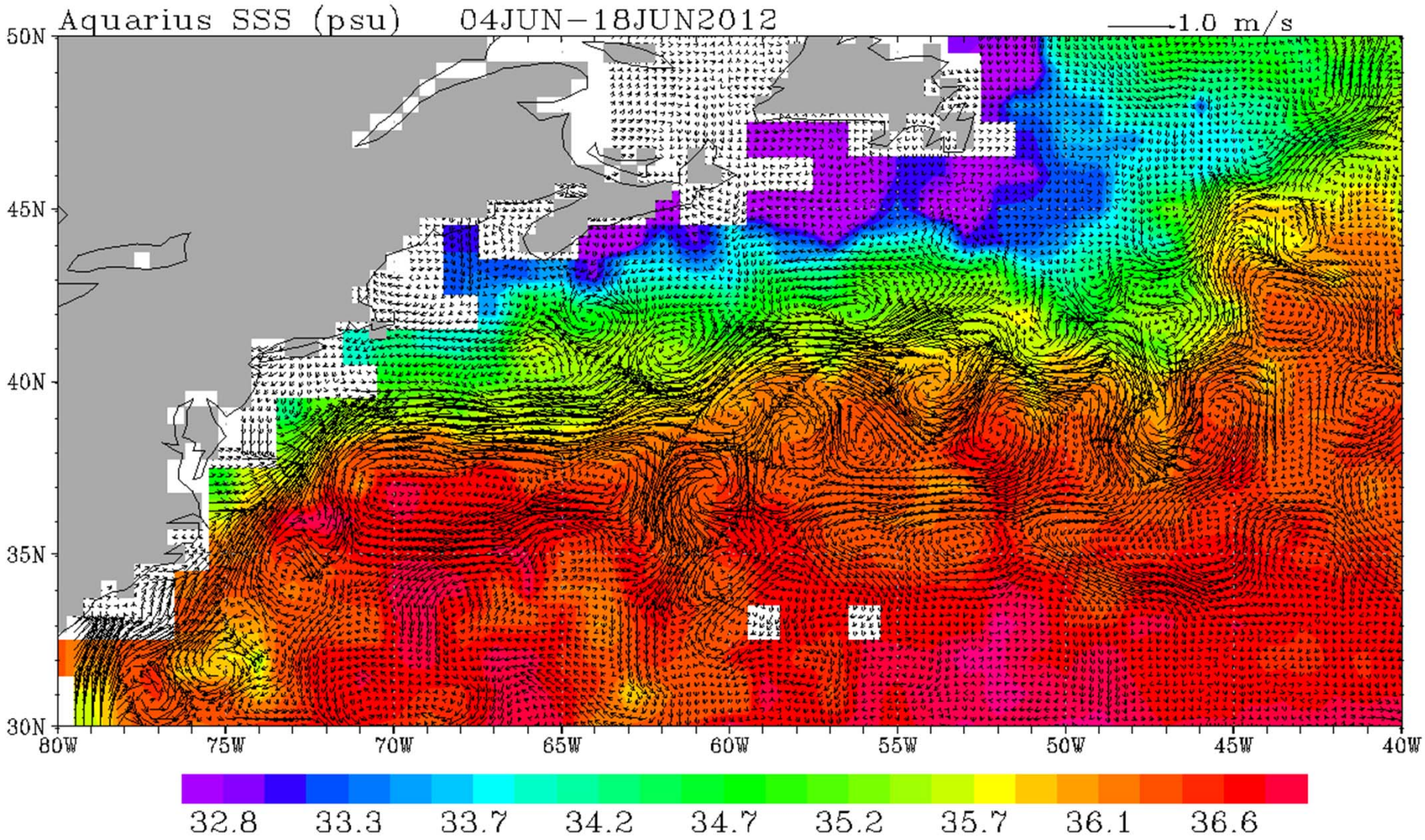

(a) pCO2sea (μatm) OCT2011
384
378
372
366
360
354
348
342
(b) log(Chl−a) (mg/m³) OCT2011
0.3
−0.1
−0.5
−0.9
−1.2
−1.6
−2
−2.4
−2.8
(c) SST (°C) OCT2011
27.4
25.8
24.4
22.8
21.2
19.6
18
16.6
15
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W

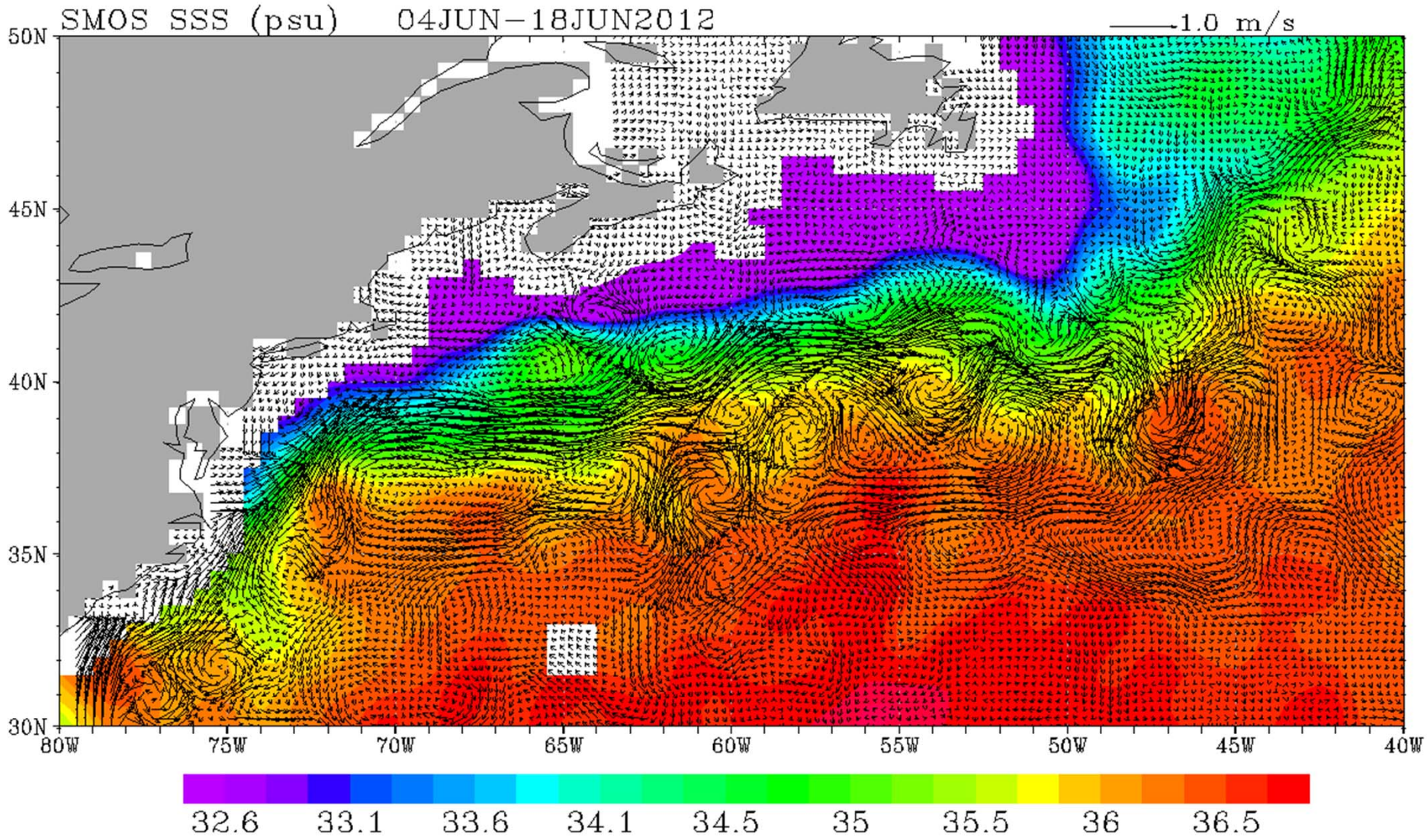

(a) Aquarius SSS (psu) OCT2011
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
36.2
35.7
35.2
34.7
34.2
33.8
33.3
32.8
32.3
(b) SMOS SSS (psu) OCT2011
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
36.1
35.6
35.1
34.6
34.1
33.6
33.1
32.6
32.1
(c) Argo SSS (psu) OCT2011
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
36.2
35.7
35.2
34.7
34.2
33.8
33.3
32.8
32.3

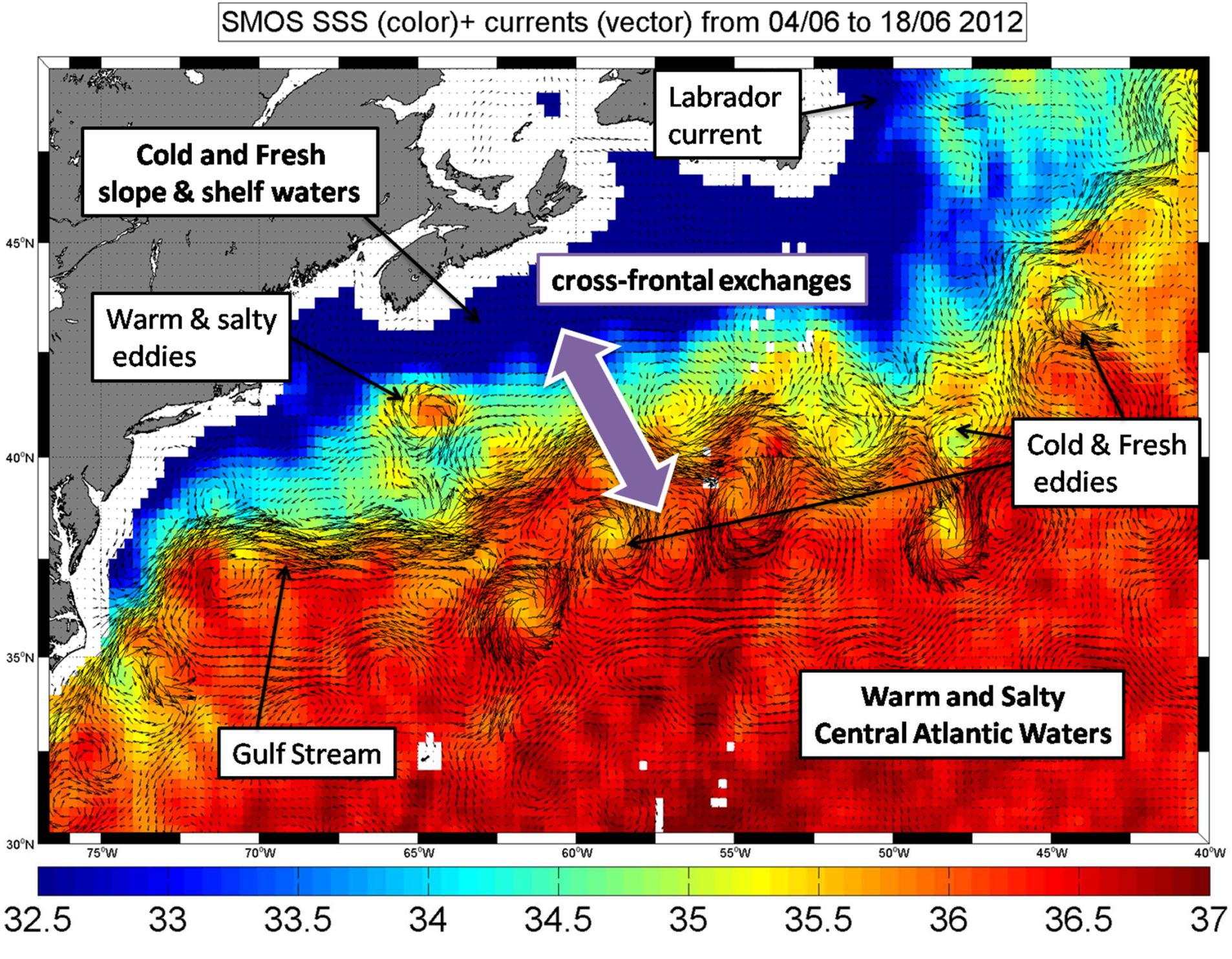

Aquarius SSS (psu) 21MAR-30MAR2012
1.0 m/s
50N
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
50W
45W
40W
32.6
33.1
33.6
34.1
34.5
35
35.5
36
36.5
36.9


Aquarius SSS (psu) 10APR−19APR2012
1.0 m/s
50N
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
50W
45W
40W
32.6
33.1
33.6
34.1
34.5
35
35.5
36
36.5
36.9


SMOS SSS (psu) 10APR−19APR2012
1.0 m/s
50N
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
50W
45W
40W
32.6
33.1
33.6
34.1
34.5
35
35.5
36
36.5


Aquarius SSS (psu) 04JUN–18JUN2012
1.0 m/s
50N
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
50W
45W
40W
32.8
33.3
33.7
34.2
34.7
35.2
35.7
36.1
36.6

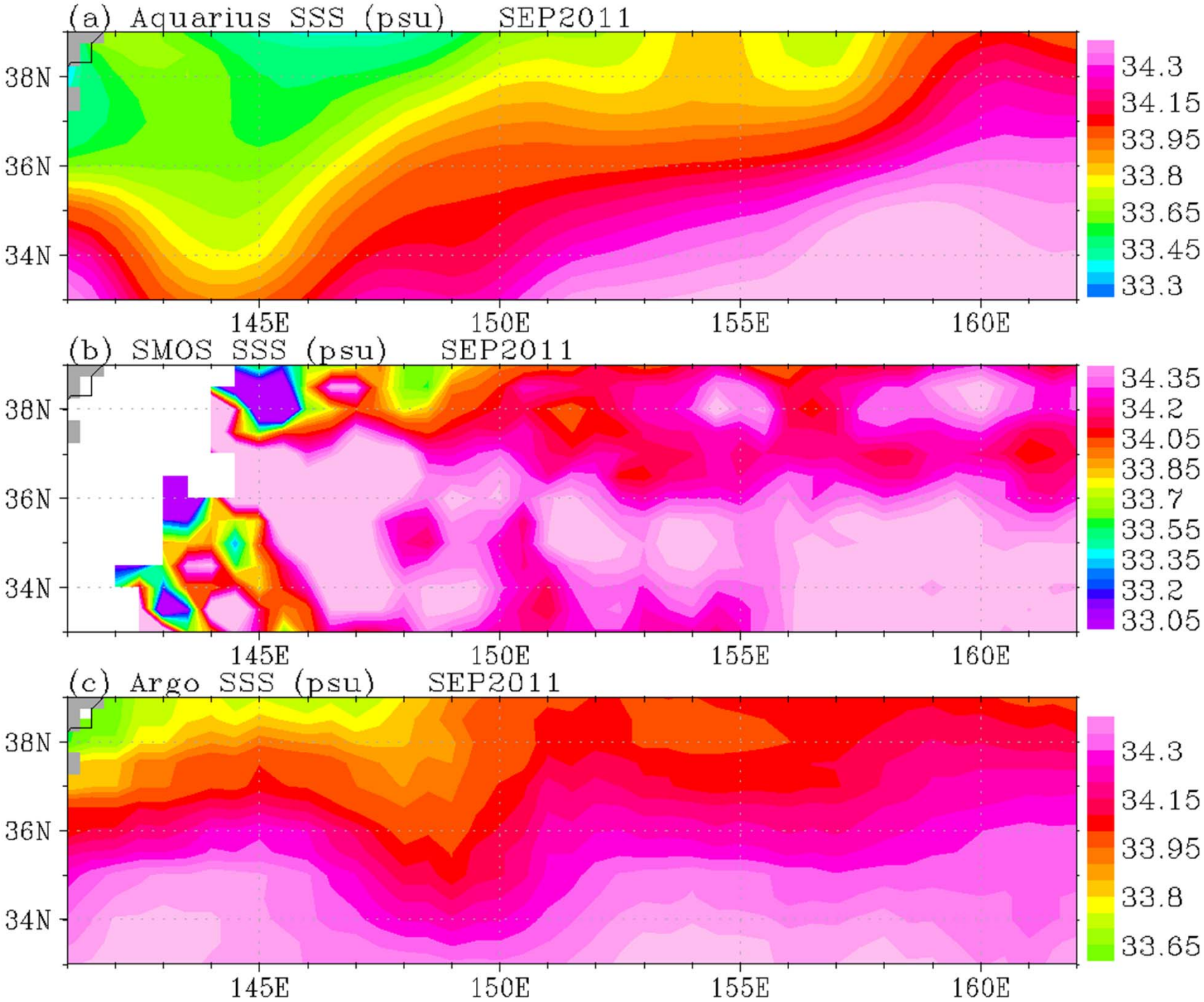

SMOS SSS (psu) 04JUN−18JUN2012
1.0 m/s
50N
45N
40N
35N
30N
80W
75W
70W
65W
60W
55W
50W
45W
40W
32.6
33.1
33.6
34.1
34.5
35
35.5
36
36.5

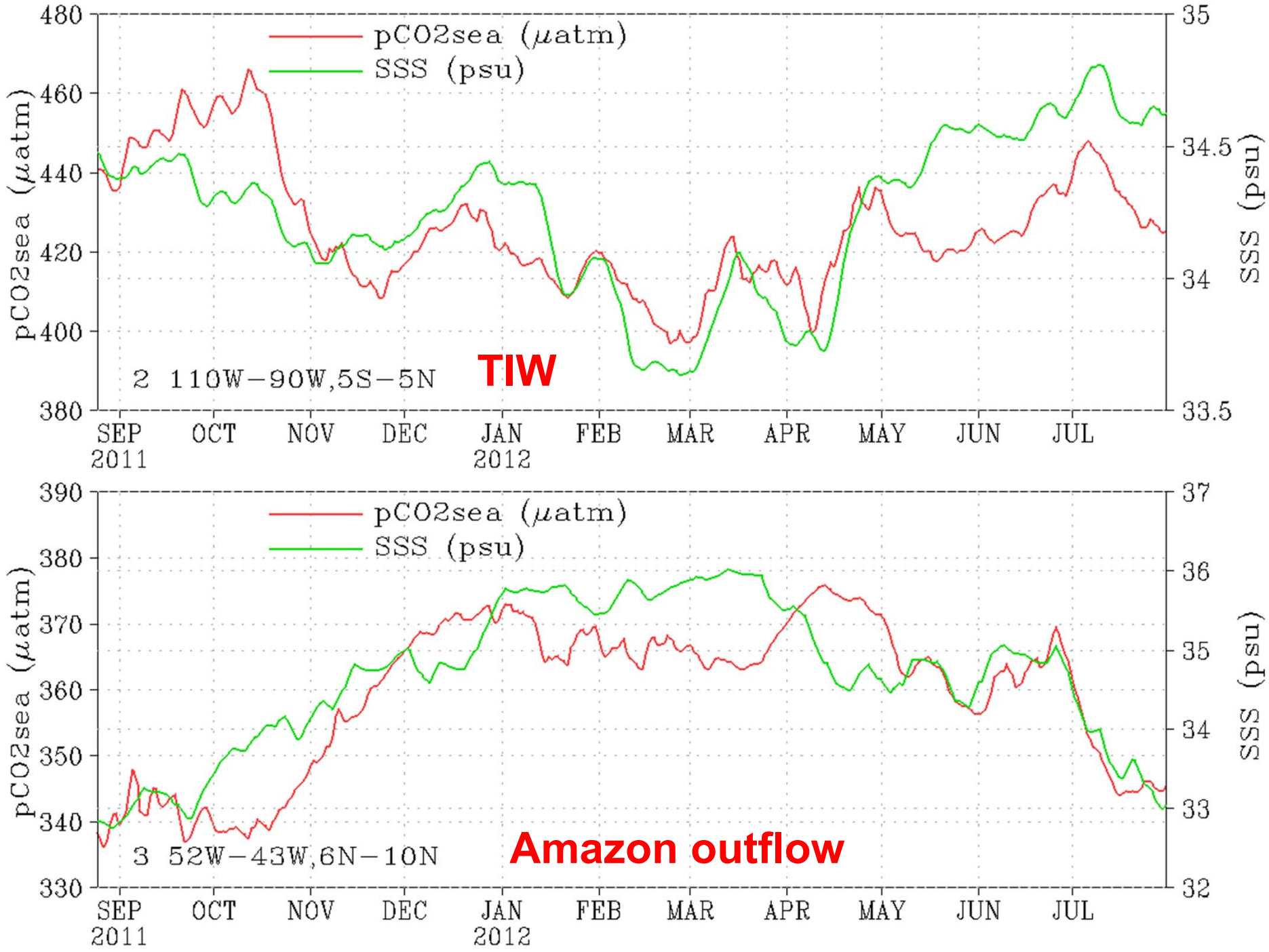

SMOS SSS (color)+ currents (vector) from 04/06 to 18/06 2012
Labrador current
Cold and Fresh slope & shelf waters
cross-frontal exchanges
Warm & salty eddies
Cold & Fresh eddies
Gulf Stream
Warm and Salty Central Atlantic Waters
45°N
40°N
35°N
30°N
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
32.5
33
33.5
34
34.5
35
35.5
36
36.5
37

Aquarius reveasl salinity and density fiend

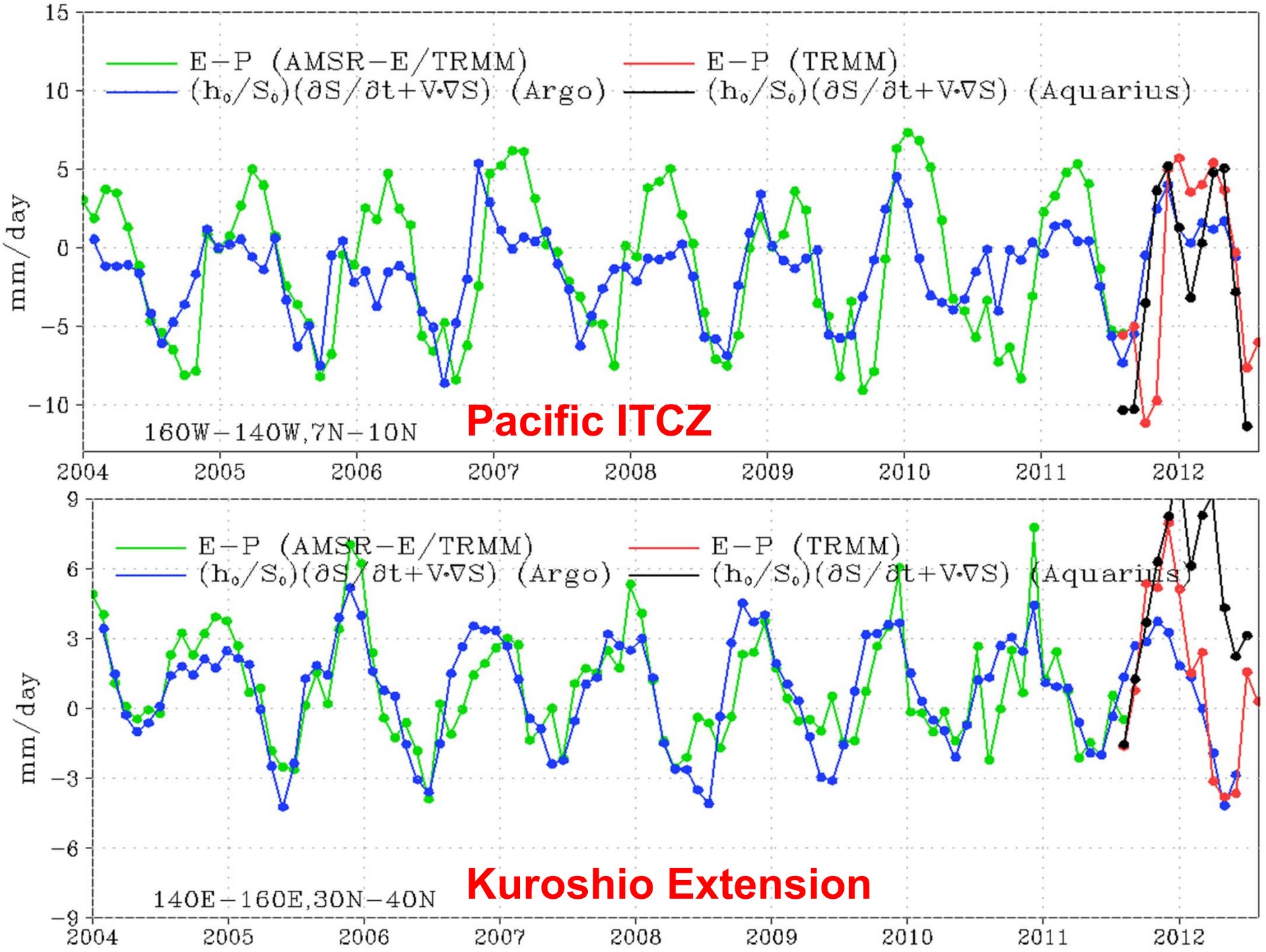
Aquarius links water with carbon cycle through salinity

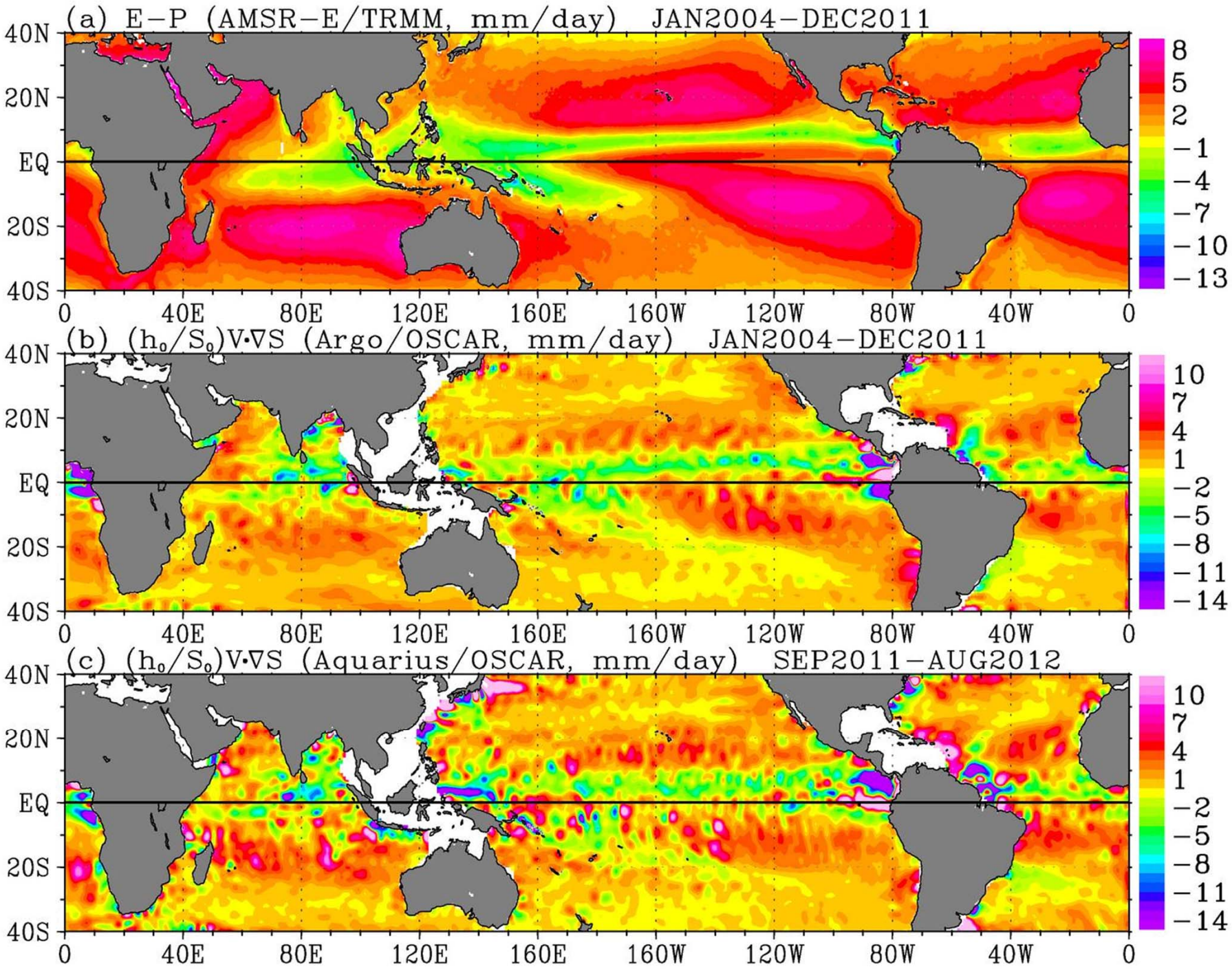
Aquarius helpto resolve hypothesis of ampliciton
Of water cycle

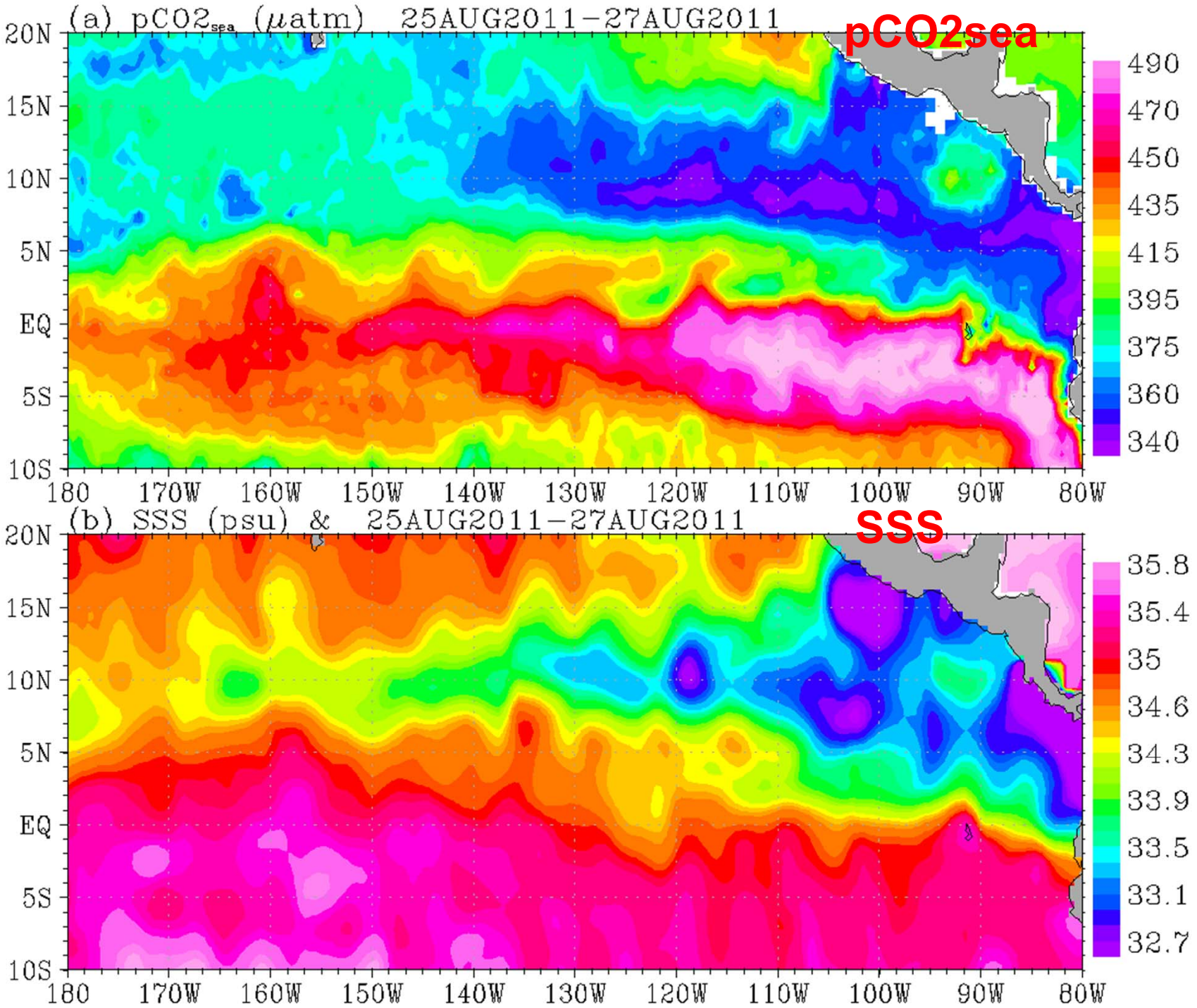

(a) Aquarius SSS (psu) SEP2011
38N
36N
34N
145E
150E
155E
160E
34.3
34.15
33.95
33.8
33.65
33.45
33.3
(b) SMOS SSS (psu) SEP2011
38N
36N
34N
145E
150E
155E
160E
34.35
34.2
34.05
33.85
33.7
33.55
33.35
33.2
33.05
(c) Argo SSS (psu) SEP2011
38N
36N
34N
145E
150E
155E
160E
34.3
34.15
33.95
33.8
33.65


pCO2sea (μatm)
SSS (psu)
2 110W−90W,5S−5N
TIW
SEP
2011
OCT
NOV
DEC
JAN
2012
FEB
MAR
APR
MAY
JUN
JUL
480
460
440
420
400
380
35
34.5
34
33.5
pCO2sea (μatm)
SSS (psu)
3 52W−43W,6N−10N
Amazon outflow
390
380
370
360
350
340
330
37
36
35
34
33
32

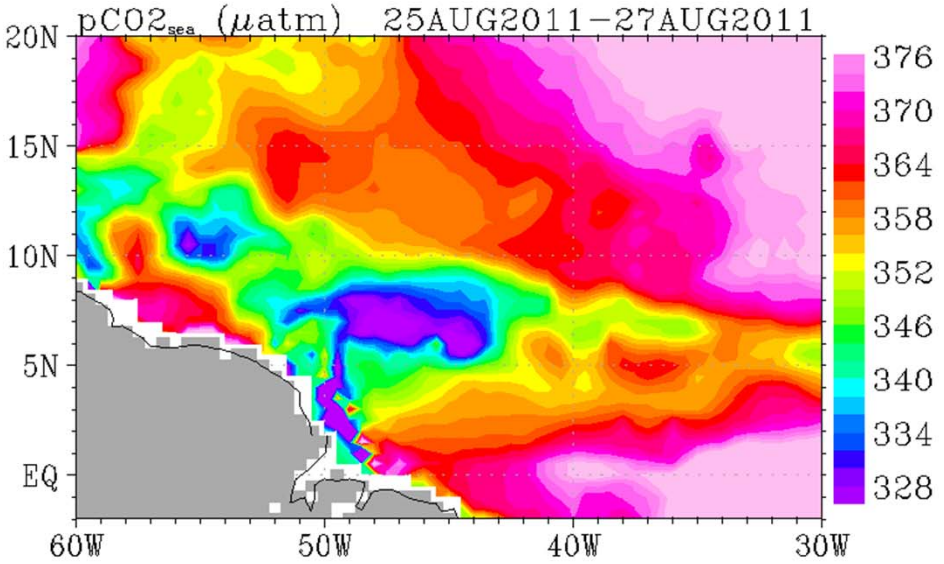
$$E - P = \frac{h_0}{S_0}\left(\frac{\partial S}{\partial t} + V \cdot \nabla S\right)$$


E−P (AMSR−E/TRMM)
(h₀/S₀)(∂S/∂t+V·∇S) (Argo)
E−P (TRMM)
(h₀/S₀)(∂S/∂t+V·∇S) (Aquarius)
mm/day
160W−140W,7N−10N
Pacific ITCZ
140E−160E,30N−40N
Kuroshio Extension
2004
2005
2006
2007
2008
2009
2010
2011
2012

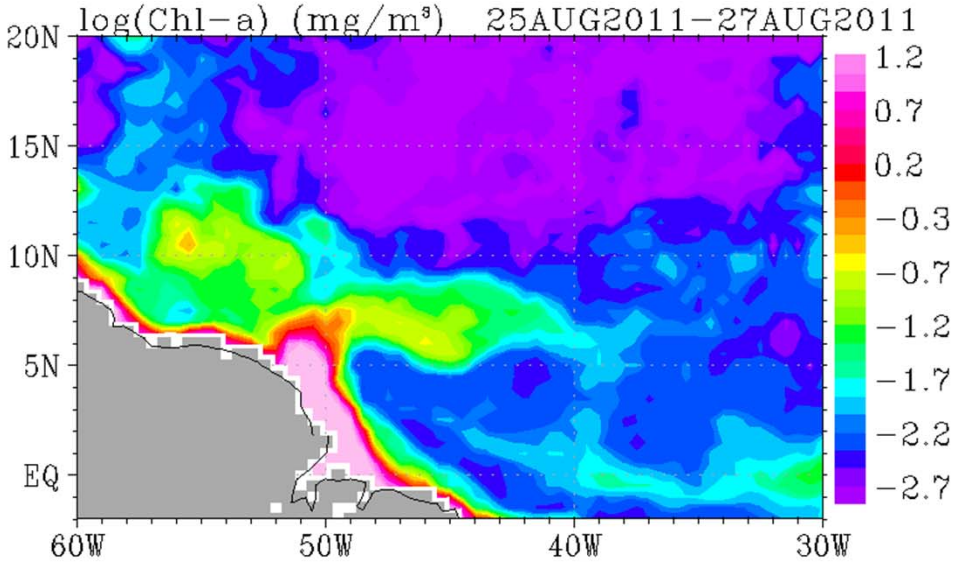

(a) E−P (AMSR−E/TRMM, mm/day) JAN2004−DEC2011
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
8
5
2
−1
−4
−7
−10
−13
(b) (h₀/S₀)V·∇S (Argo/OSCAR, mm/day) JAN2004−DEC2011
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
10
7
4
1
−2
−5
−8
−11
−14
(c) (h₀/S₀)V·∇S (Aquarius/OSCAR, mm/day) SEP2011−AUG2012
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
10
7
4
1
−2
−5
−8
−11
−14


(a) pCO2sea (μatm) 25AUG2011–27AUG2011
pCO2sea
20N
15N
10N
5N
EQ
5S
10S
180
170W
160W
150W
140W
130W
120W
110W
100W
90W
80W
490
470
450
435
415
395
375
360
340
(b) SSS (psu) & 25AUG2011–27AUG2011
SSS
35.8
35.4
35
34.6
34.3
33.9
33.5
33.1
32.7

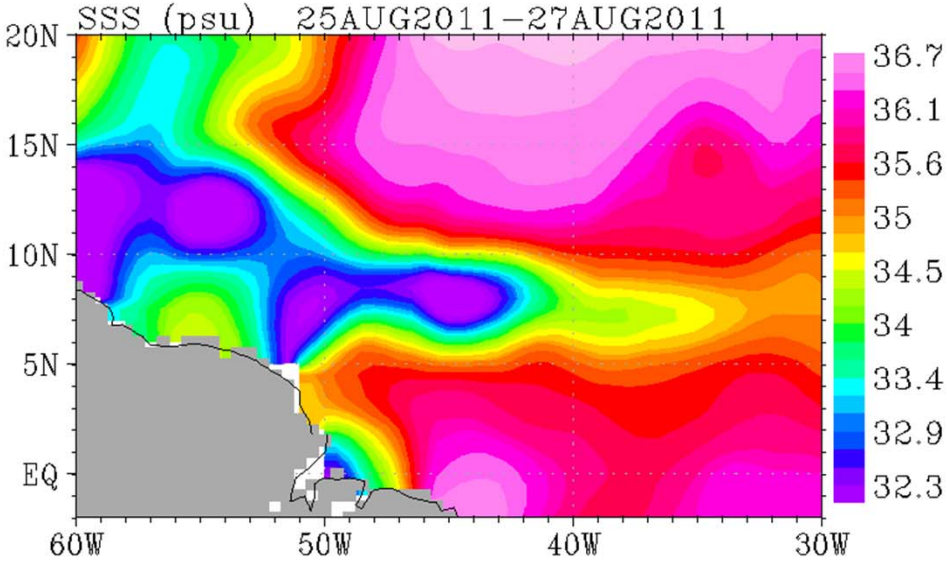
pCO2sea



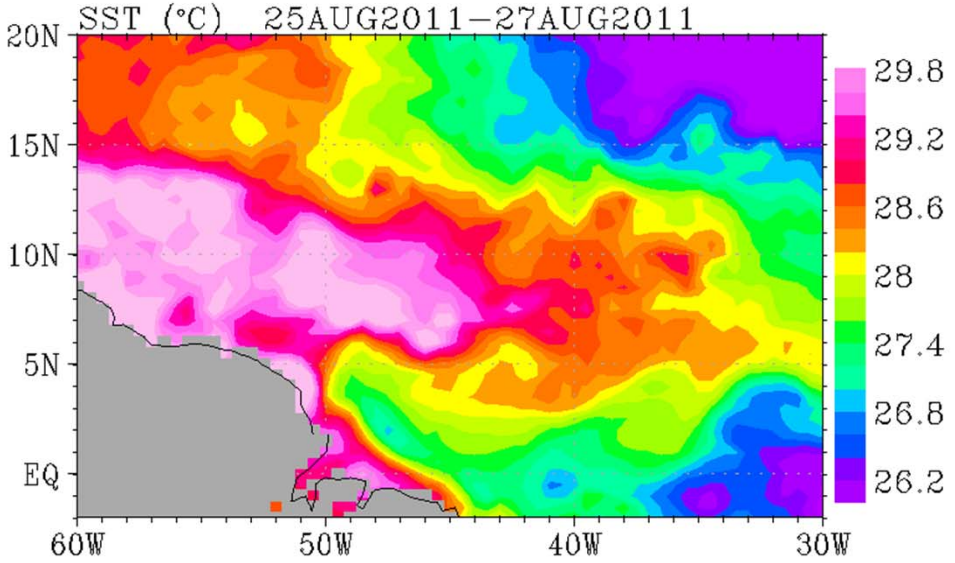
Chl-a

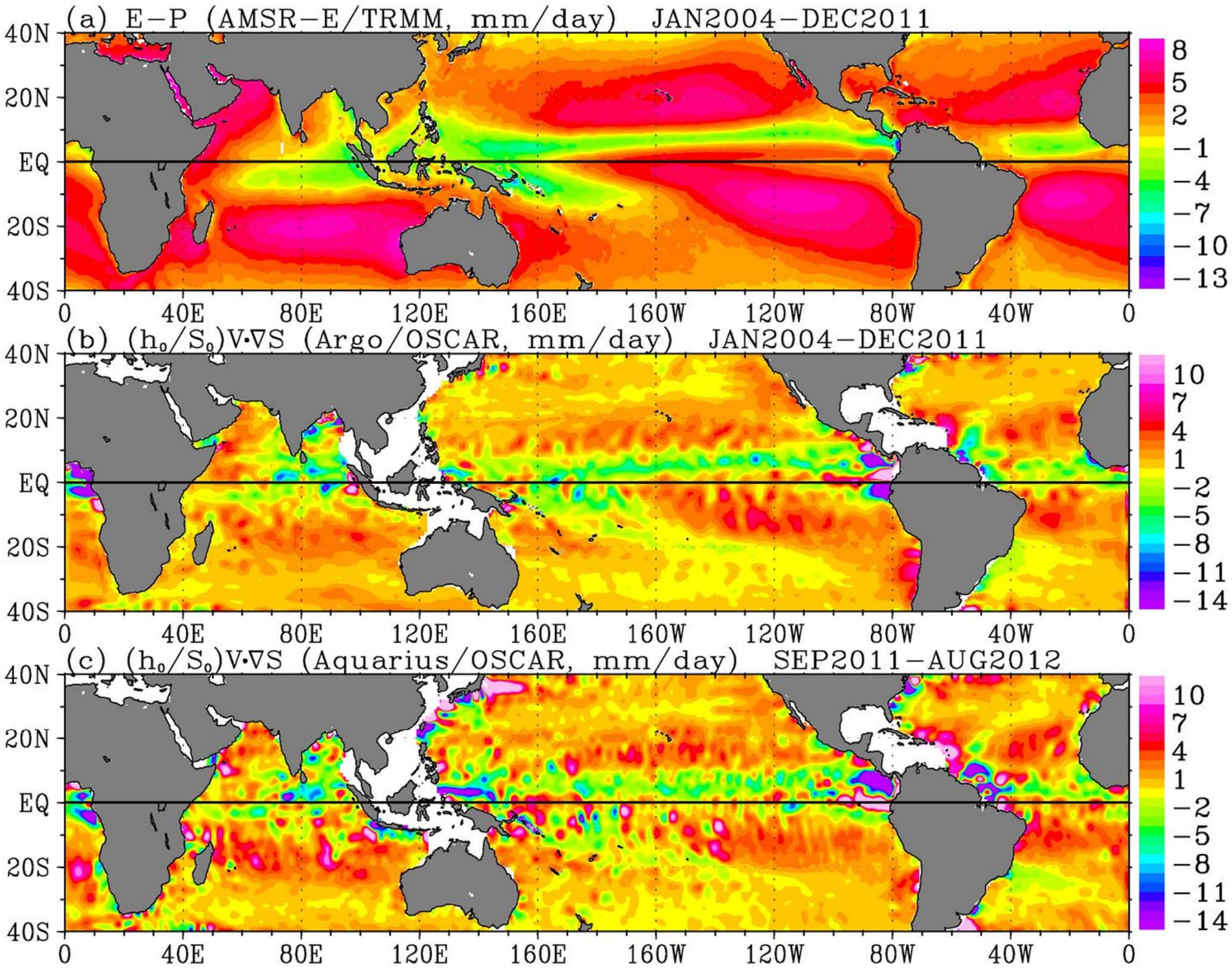


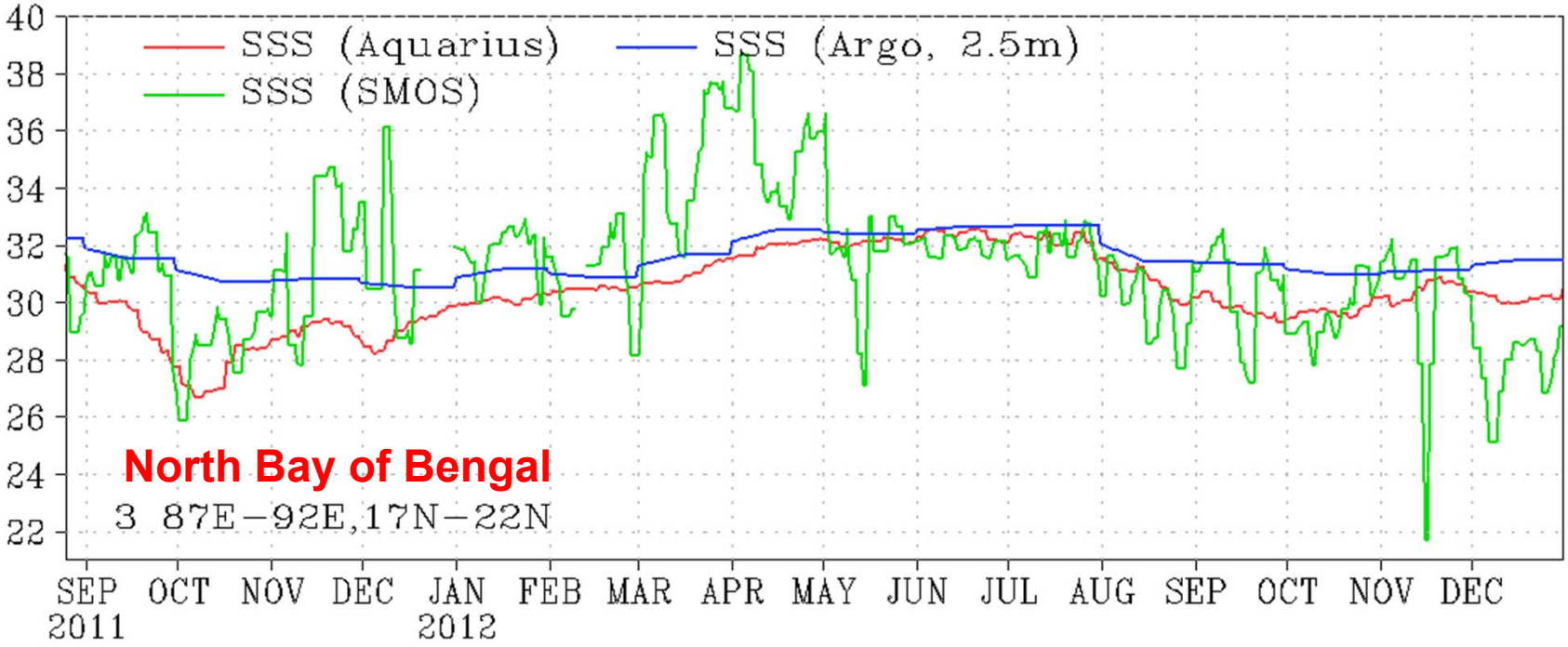
SSS

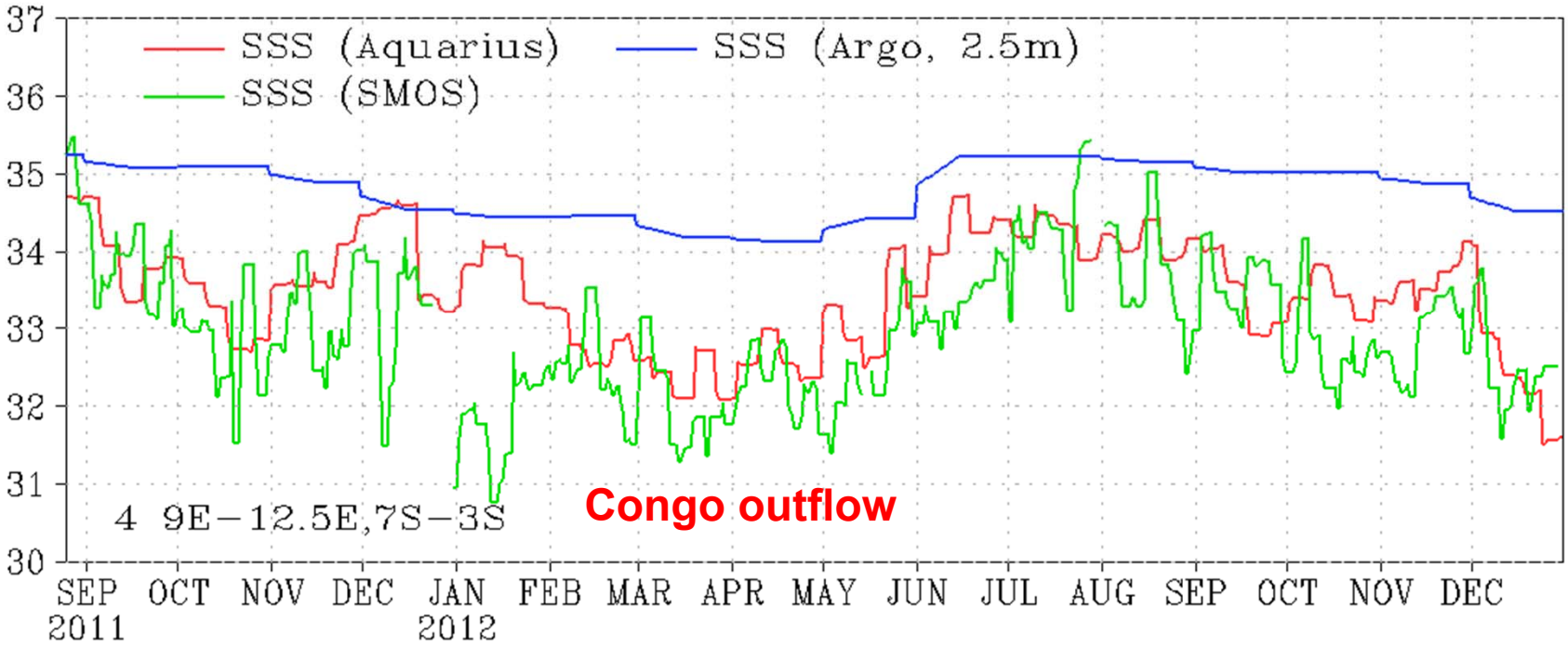


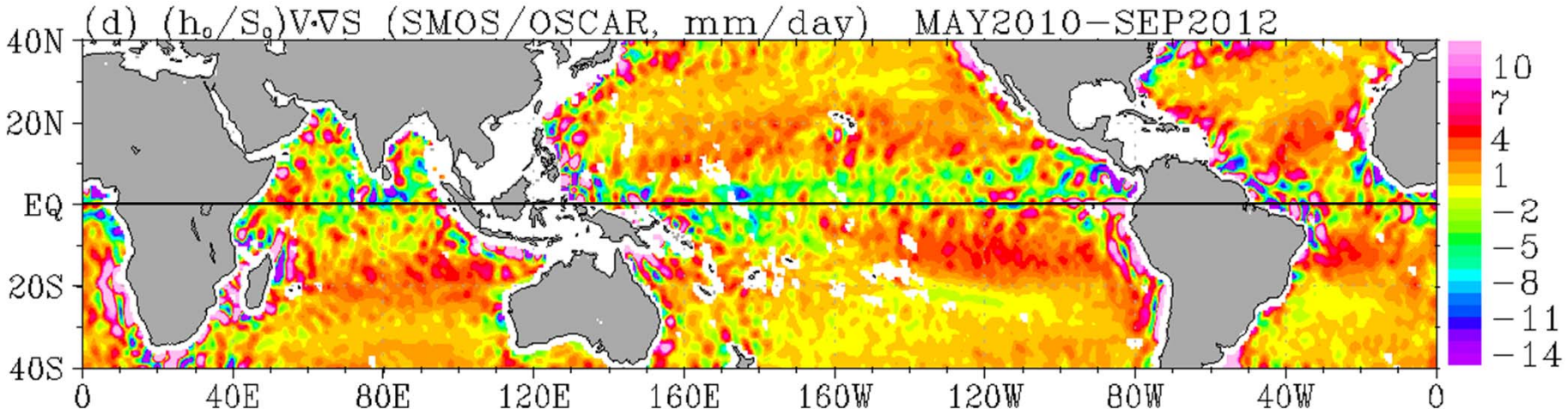
SST




(a) E−P (AMSR−E/TRMM, mm/day) JAN2004−DEC2011
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
8
5
2
−1
−4
−7
−10
−13
(b) (h₀/S₀)V·∇S (Argo/OSCAR, mm/day) JAN2004−DEC2011
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
10
7
4
1
−2
−5
−8
−11
−14
(c) (h₀/S₀)V·∇S (Aquarius/OSCAR, mm/day) SEP2011−AUG2012
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
10
7
4
1
−2
−5
−8
−11
−14


SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
North Bay of Bengal
3 87E-92E,17N-22N
40
38
36
34
32
30
28
26
24
22
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012


SSS (Aquarius)
SSS (Argo, 2.5m)
SSS (SMOS)
4 9E-12.5E,7S-3S
Congo outflow
37
36
35
34
33
32
31
30
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2011
2012


(d) (h₀/S₀)V·∇S (SMOS/OSCAR, mm/day) MAY2010−SEP2012
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
10
7
4
1
−2
−5
−8
−11
−14