Quantifying how observations inform our models

Brian Powell
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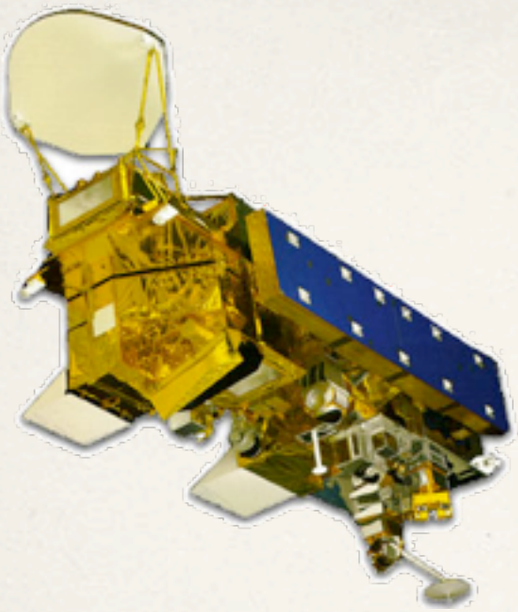
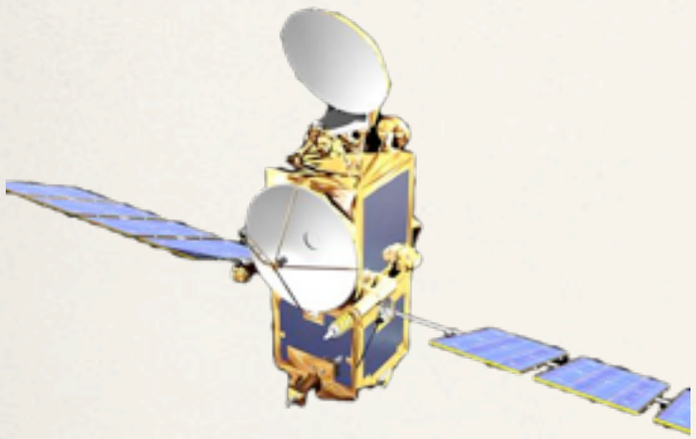
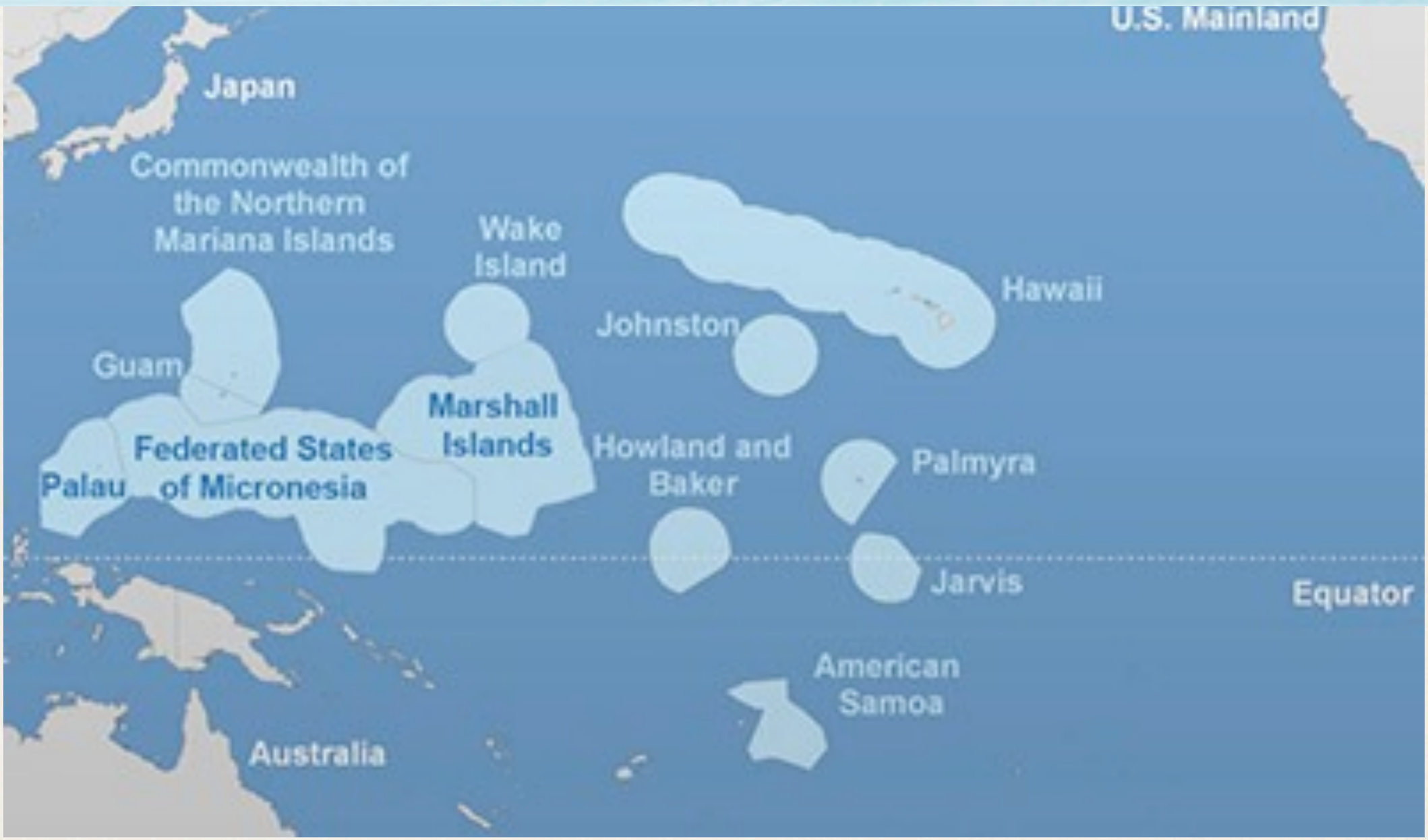


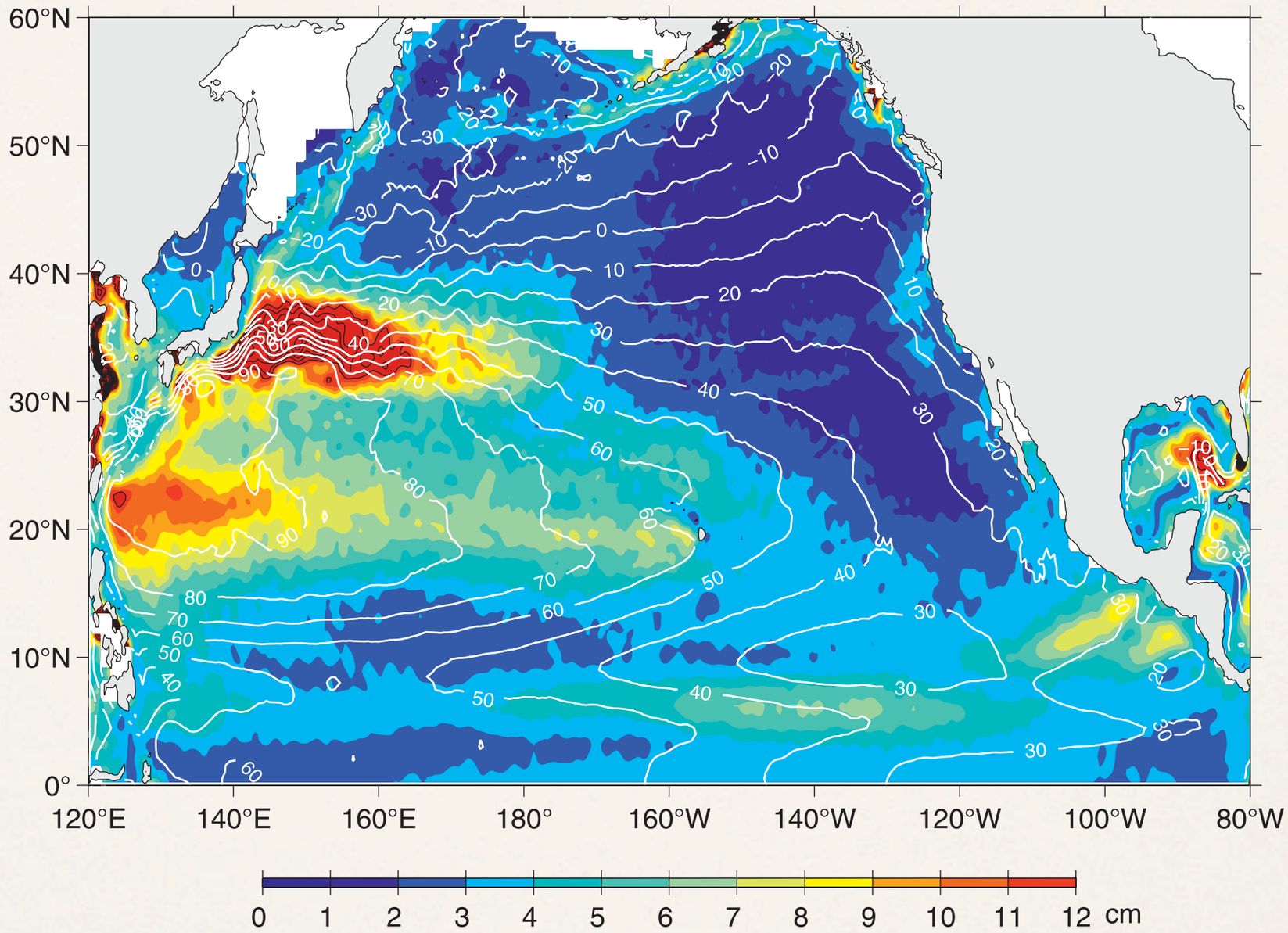

ARGO



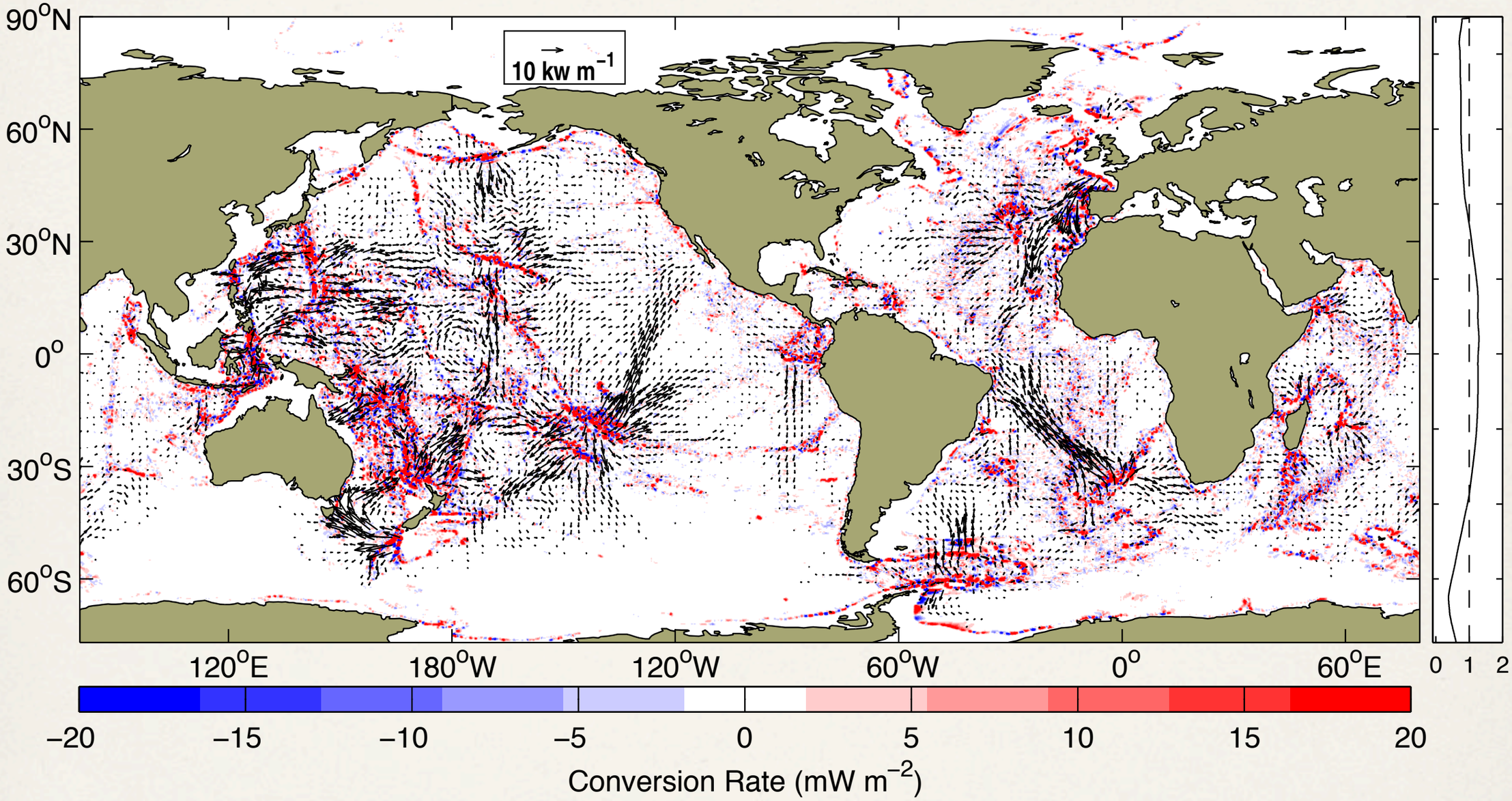
PacIOOS Pacific Islands Ocean Observing System

IN THE SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY AT THE UNIVERSITY OF HAWAI'I AT MĀNOA

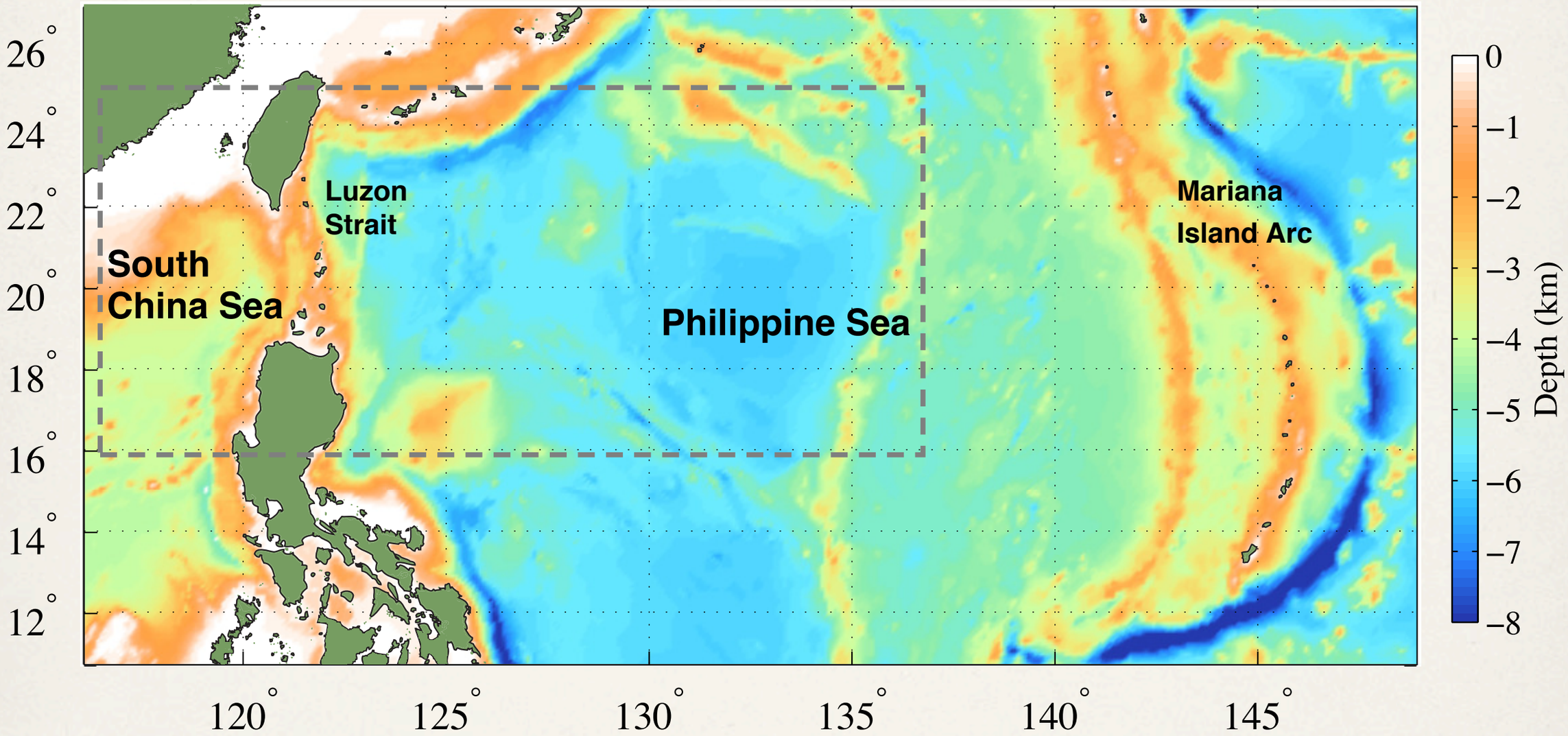


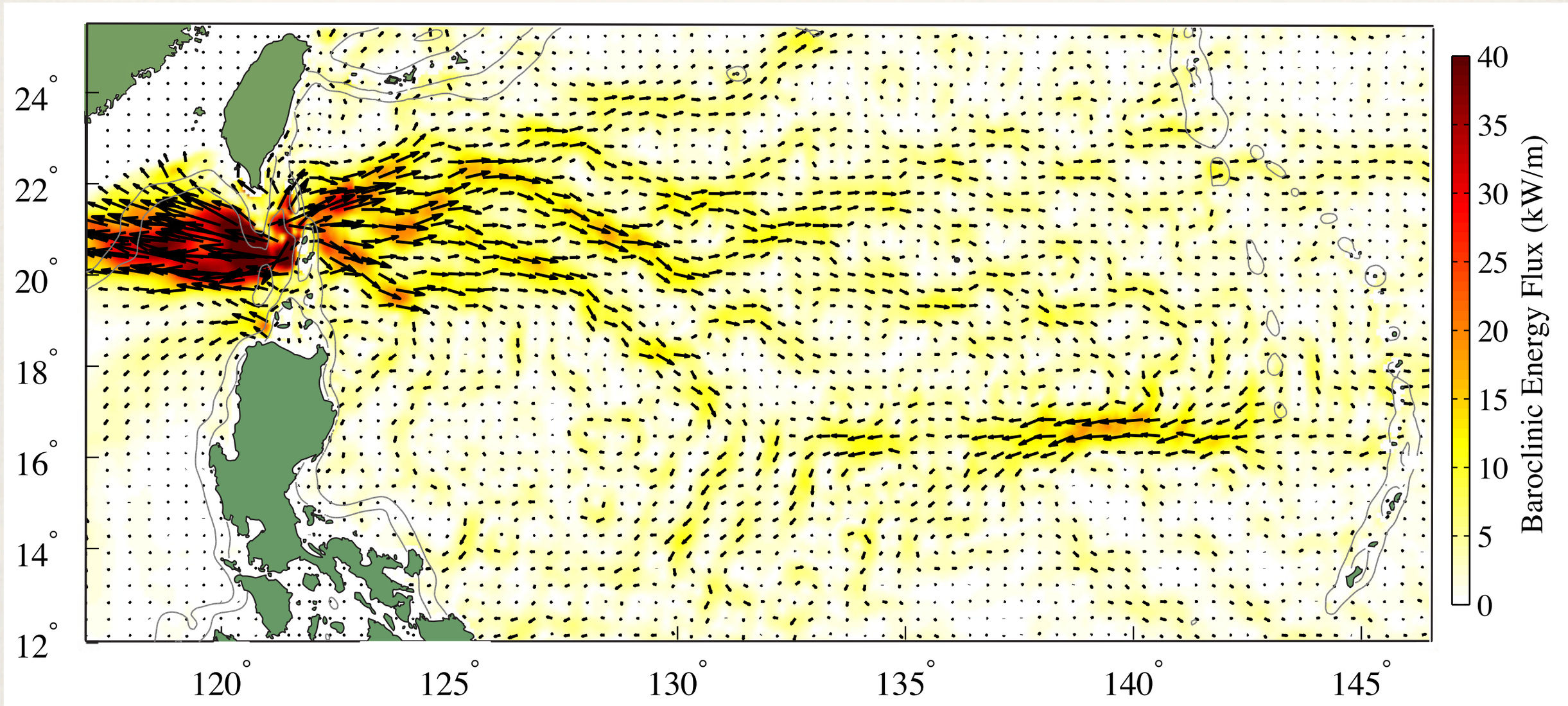


B. Qiu and S. Chen. Interannual Variability of the North Pacific Subtropical Countercurrent and Its Associated Mesoscale Eddy Field. J. Phys. Oceanogr., 40:213–225, 2010.

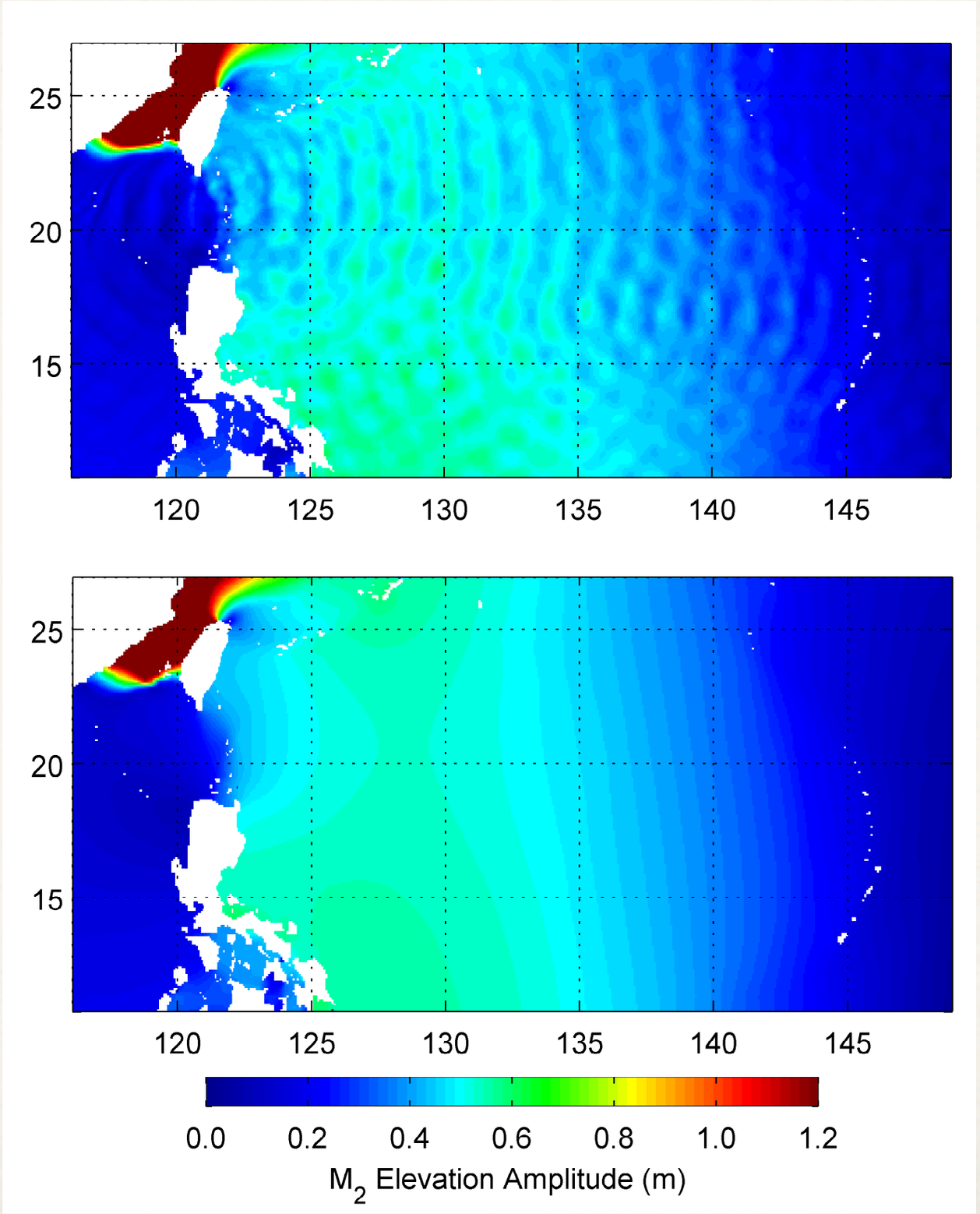


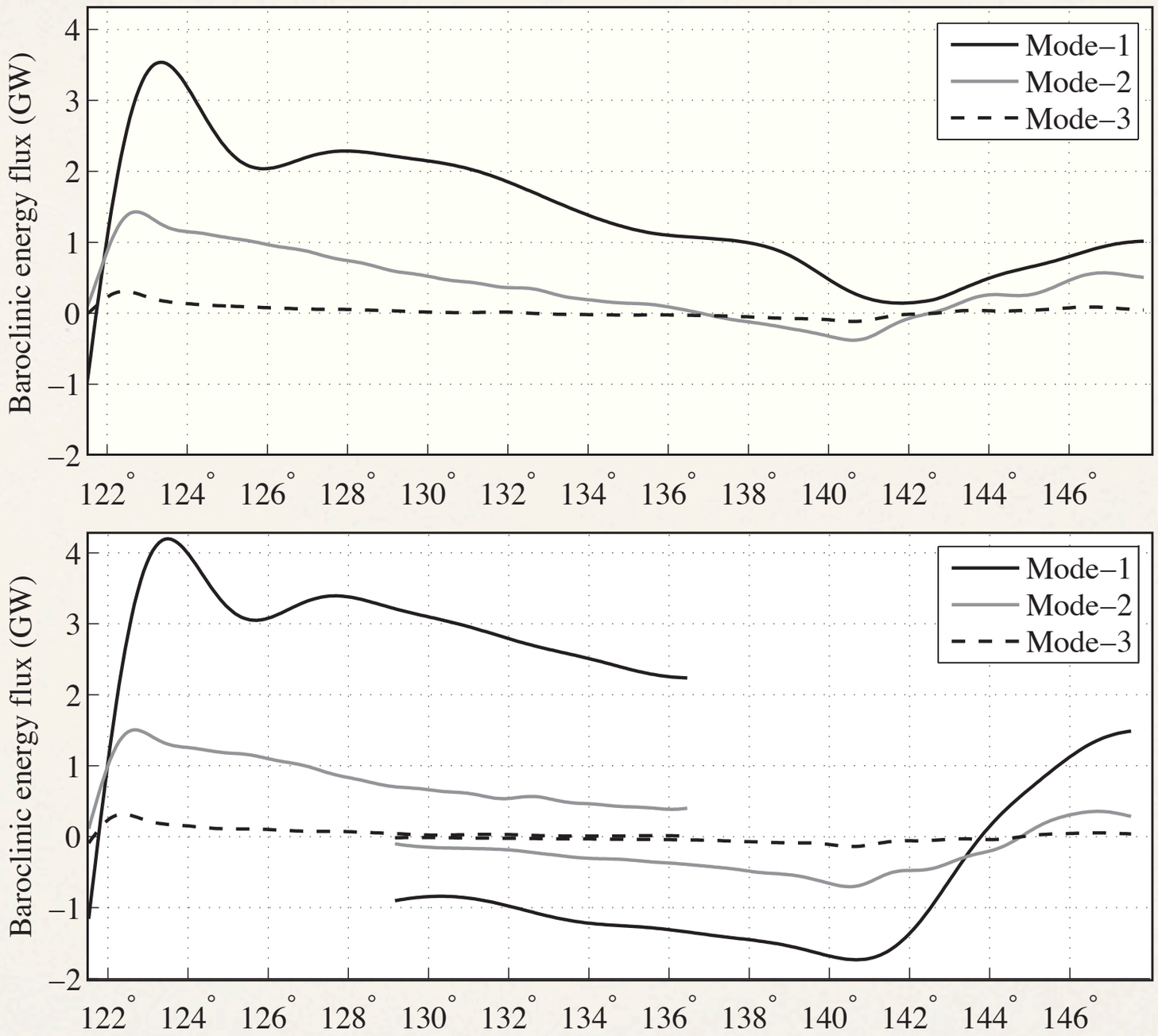
H. L. Simmons, R. W. Hallberg, and B. K. Arbic. Internal wave generation in a global baroclinic tide model. Deep-Sea Res. II, June 2004.


South
China Sea
Luzon
Strait
Philippine Sea
Mariana
Island Arc
26°
24°
22°
20°
18°
16°
14°
12°
120°
125°
130°
135°
140°
145°
0
−1
−2
−3
−4
−5
−6
−7
−8
Depth (km)

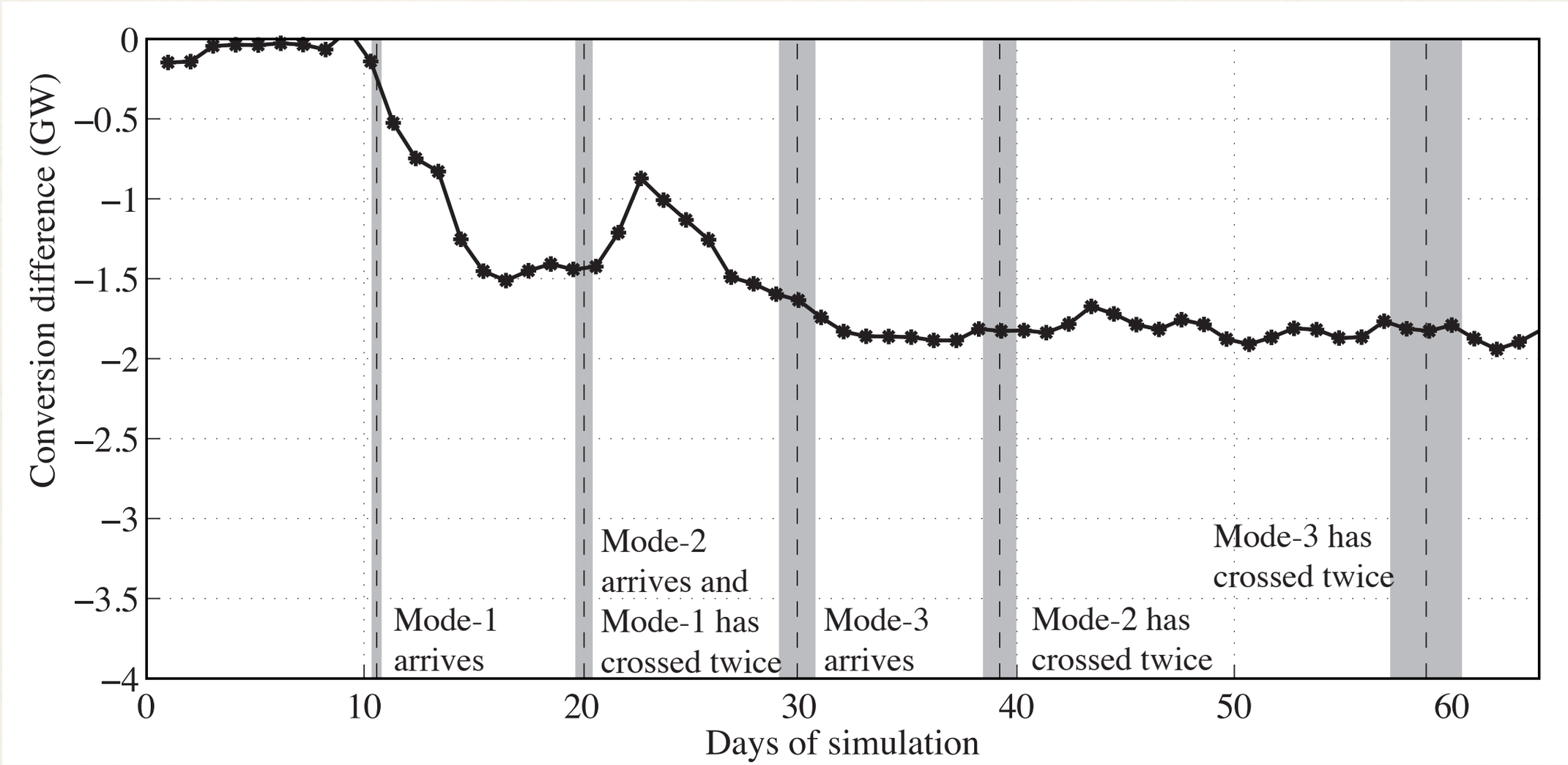


C. G. Kerry, B. S. Powell, and G. S. Carter. Effects of remote generation sites on model estimates of M2 internal tides in the Philippine Sea. J. Phys. Oceanogr., in press, 2012.


25
20
15
120
125
130
135
140
145
0.0
0.2
0.4
0.6
0.8
1.0
1.2
M2 Elevation Amplitude (m)



C. G. Kerry, B. S. Powell, and G. S. Carter. Effects of remote generation sites on model estimates of M2 internal tides in the Philippine Sea. J. Phys. Oceanogr., in press, 2012.



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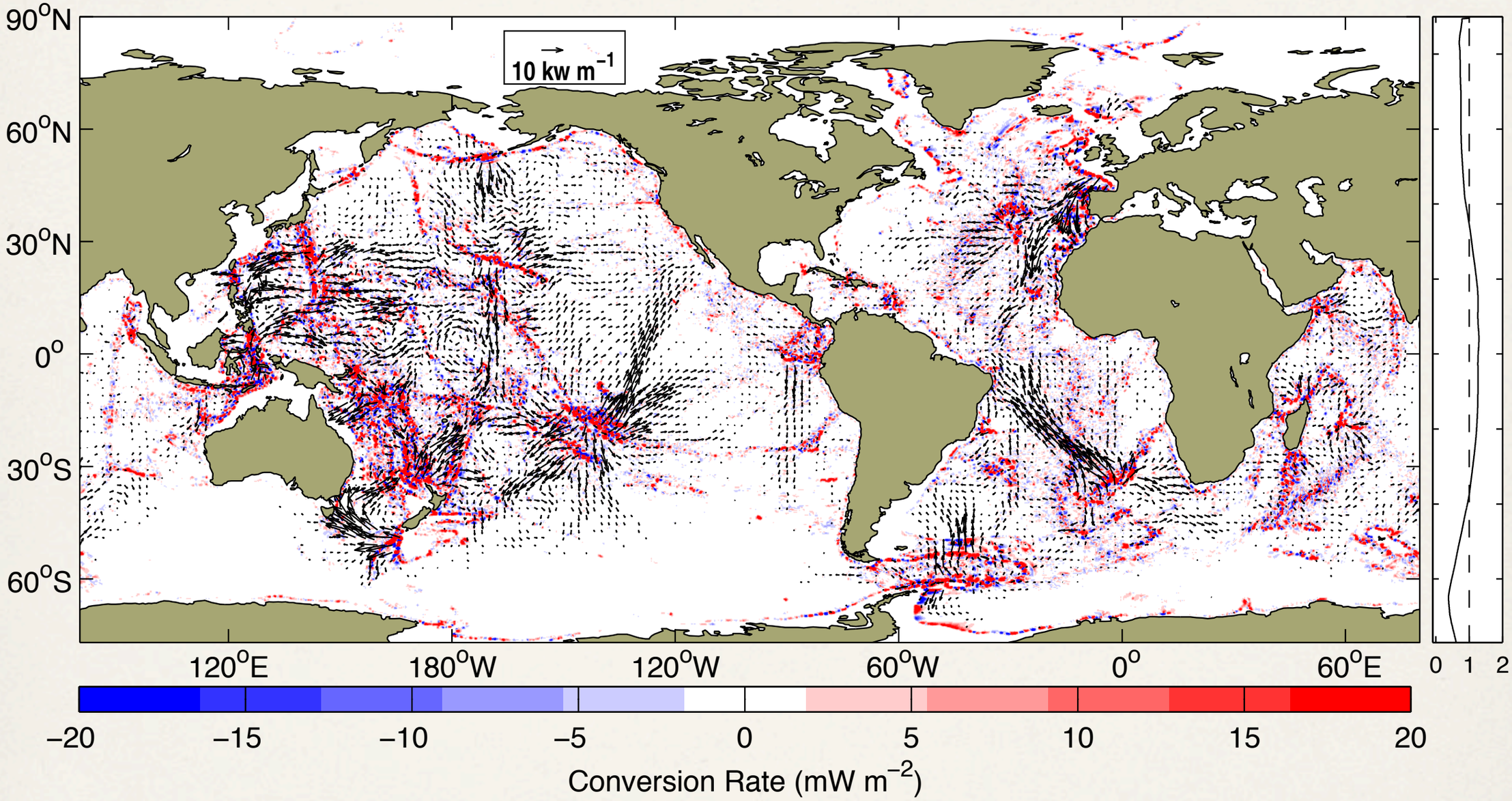

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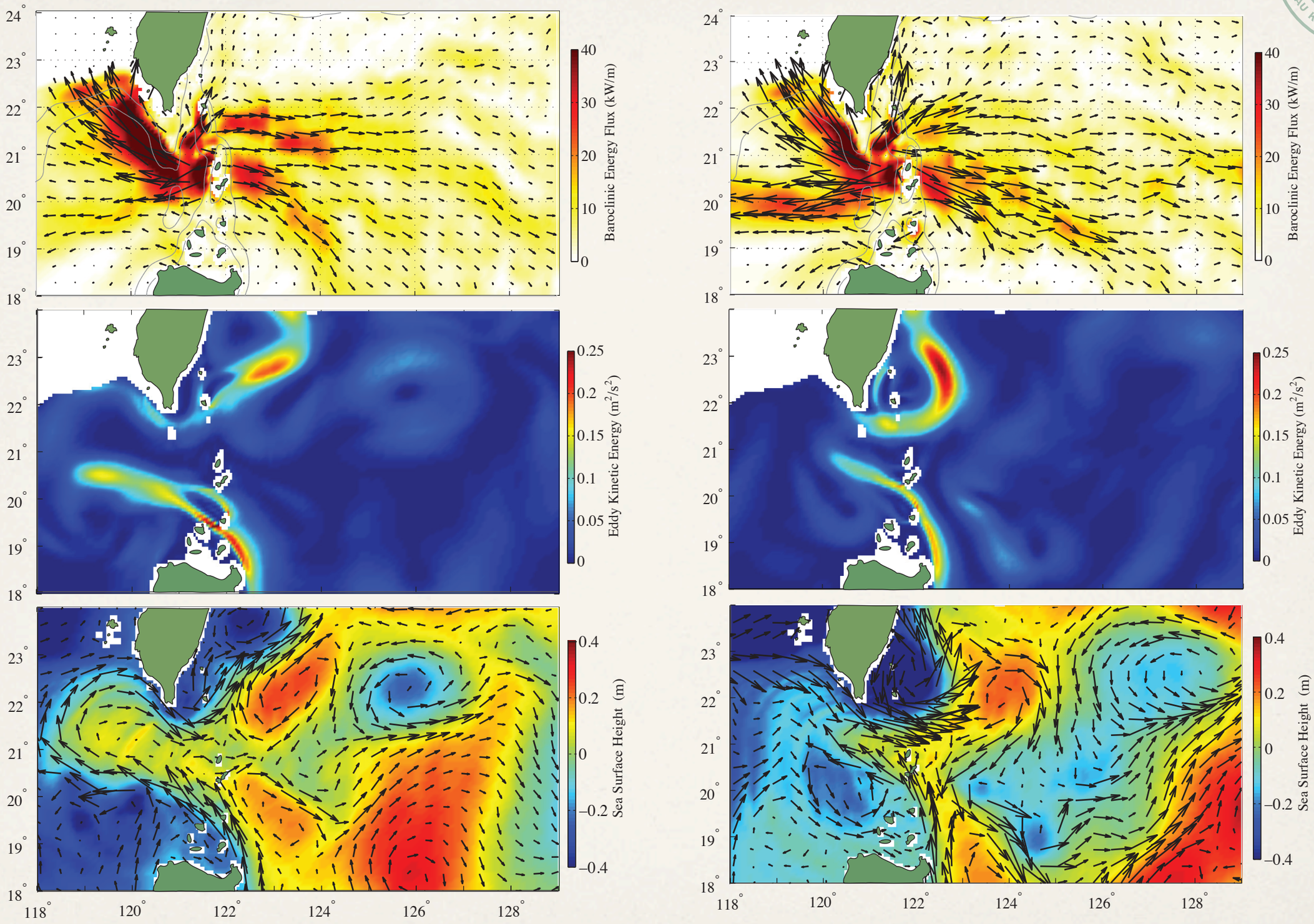
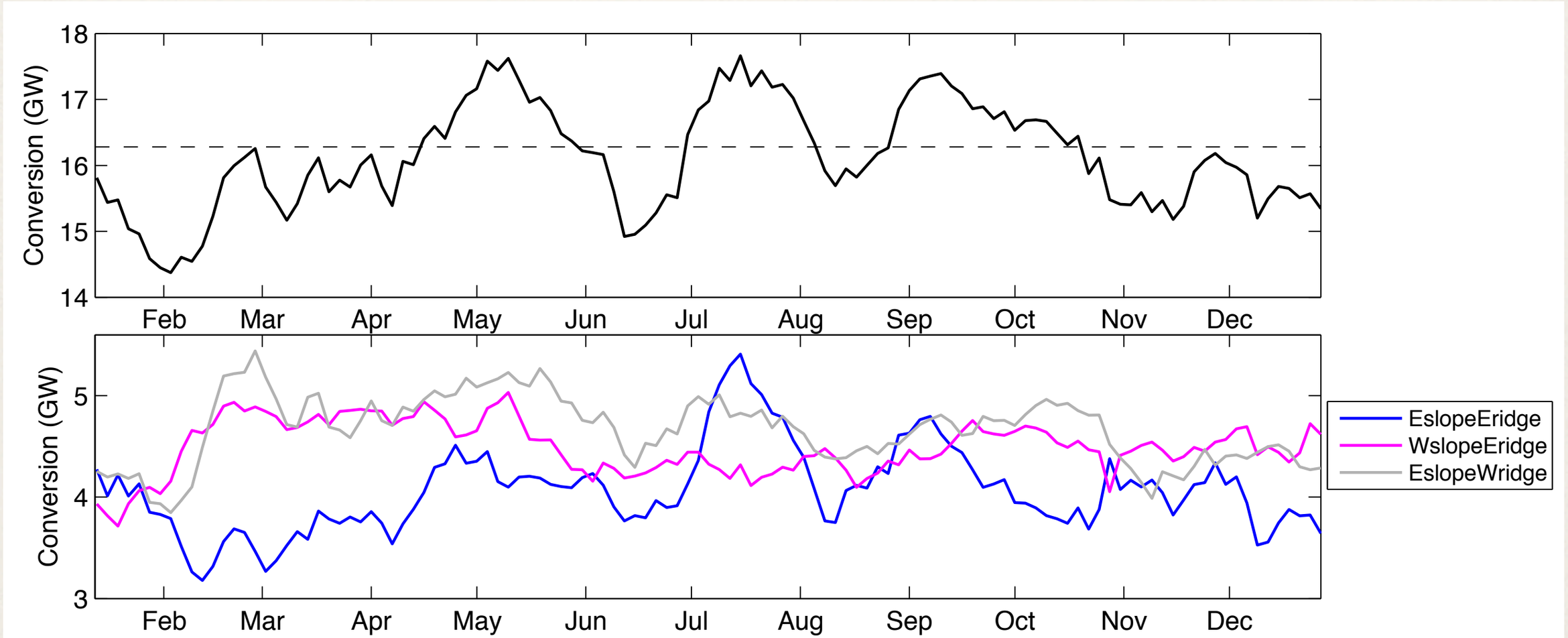
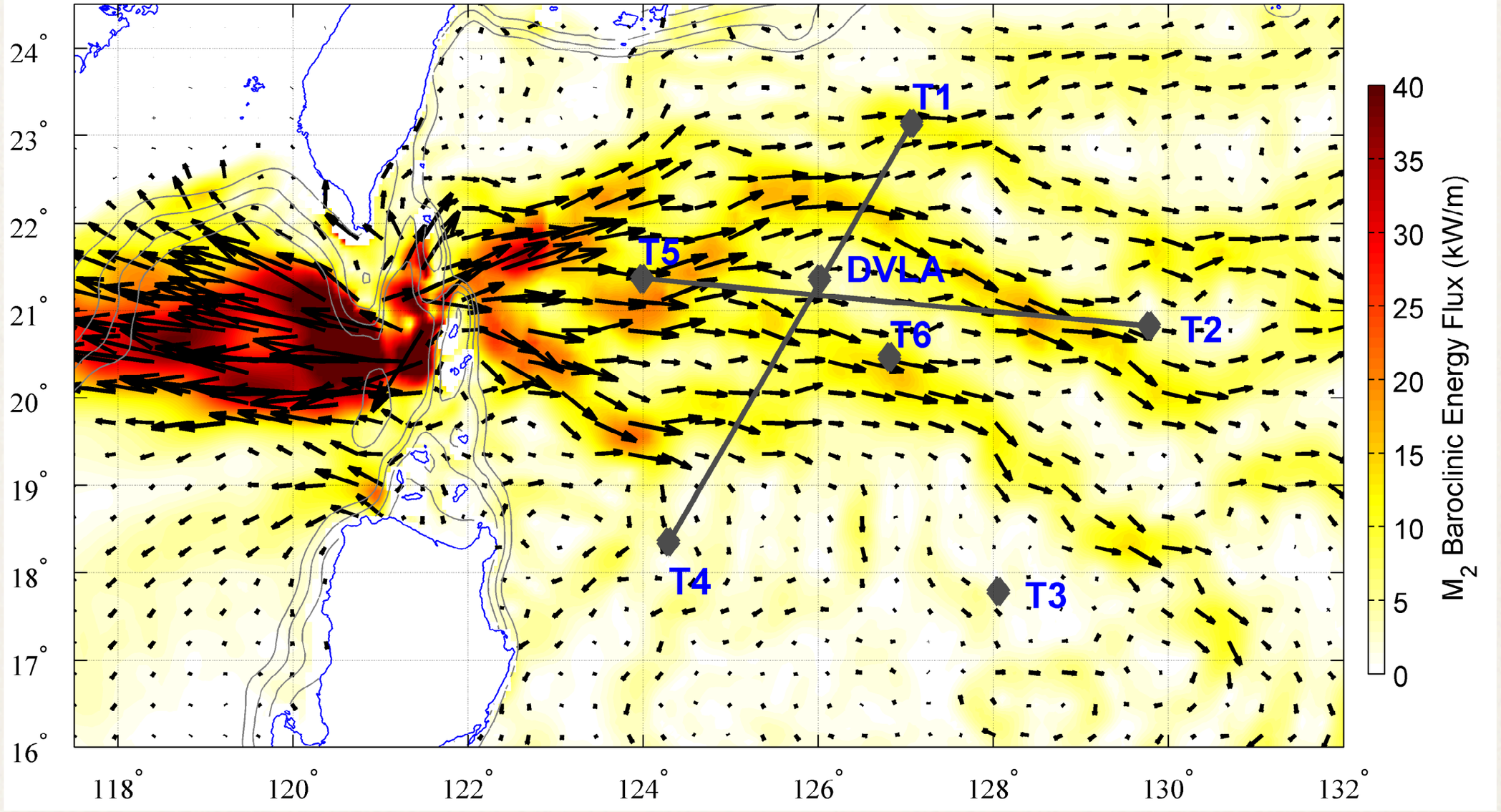
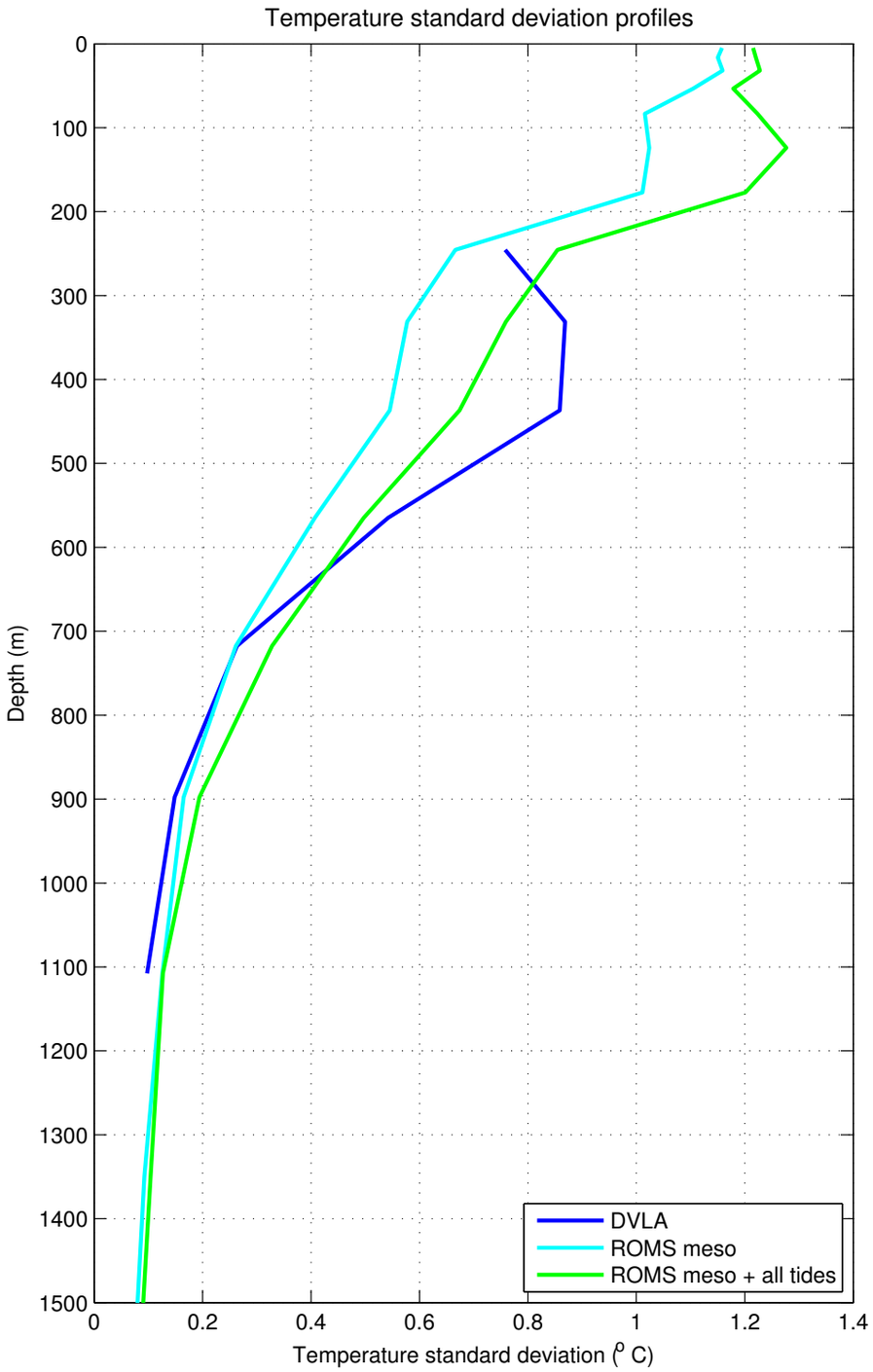
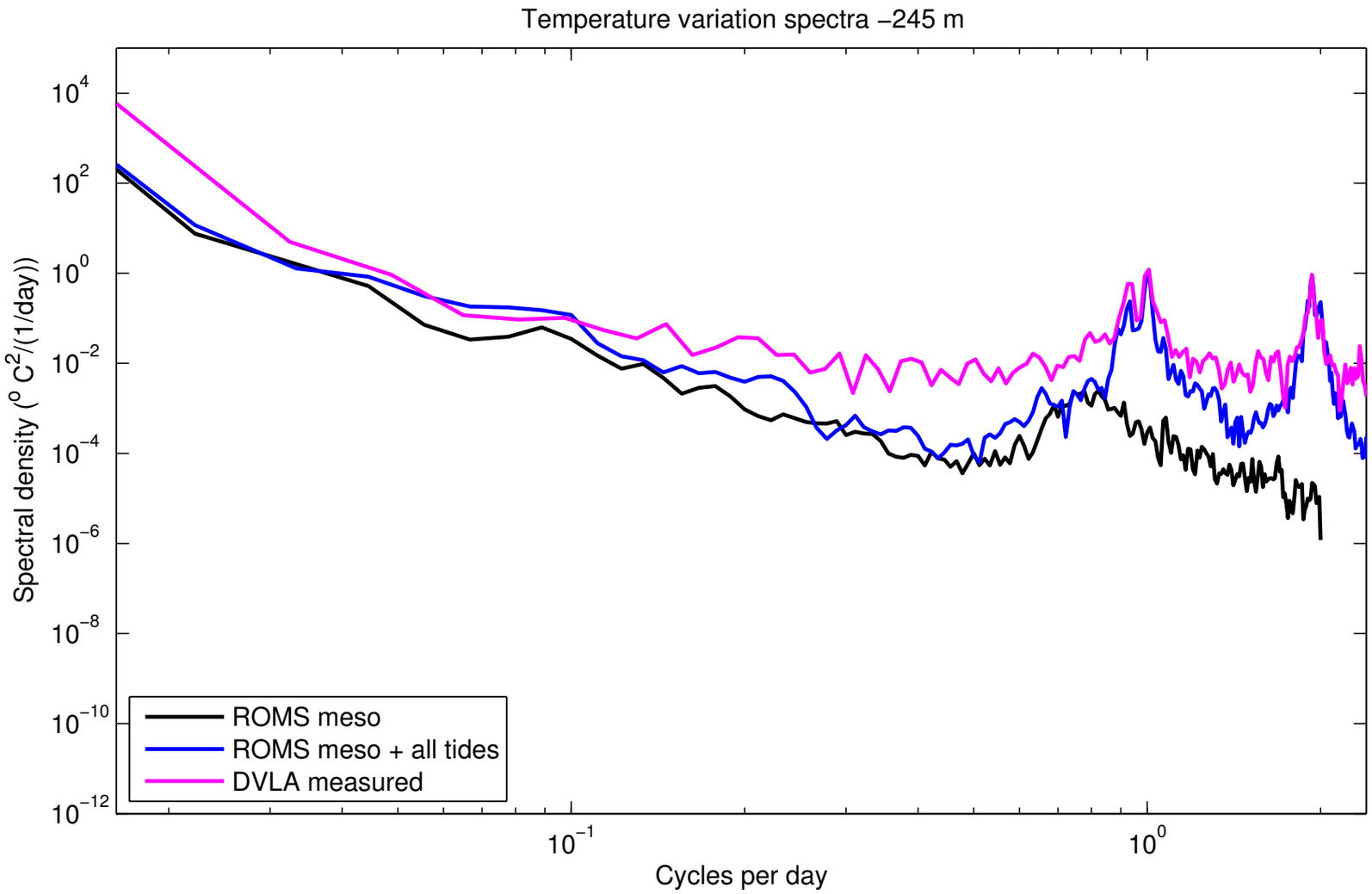

Baroclinic Energy Flux (kW/m)
40
30
20
10
0
Eddy Kinetic Energy (m^2/s^2)
0.25
0.2
0.15
0.1
0.05
0
Sea Surface Height (m)
0.4
0.2
0
−0.2
−0.4
24°
23°
22°
21°
20°
19°
18°
118°
120°
122°
124°
126°
128°

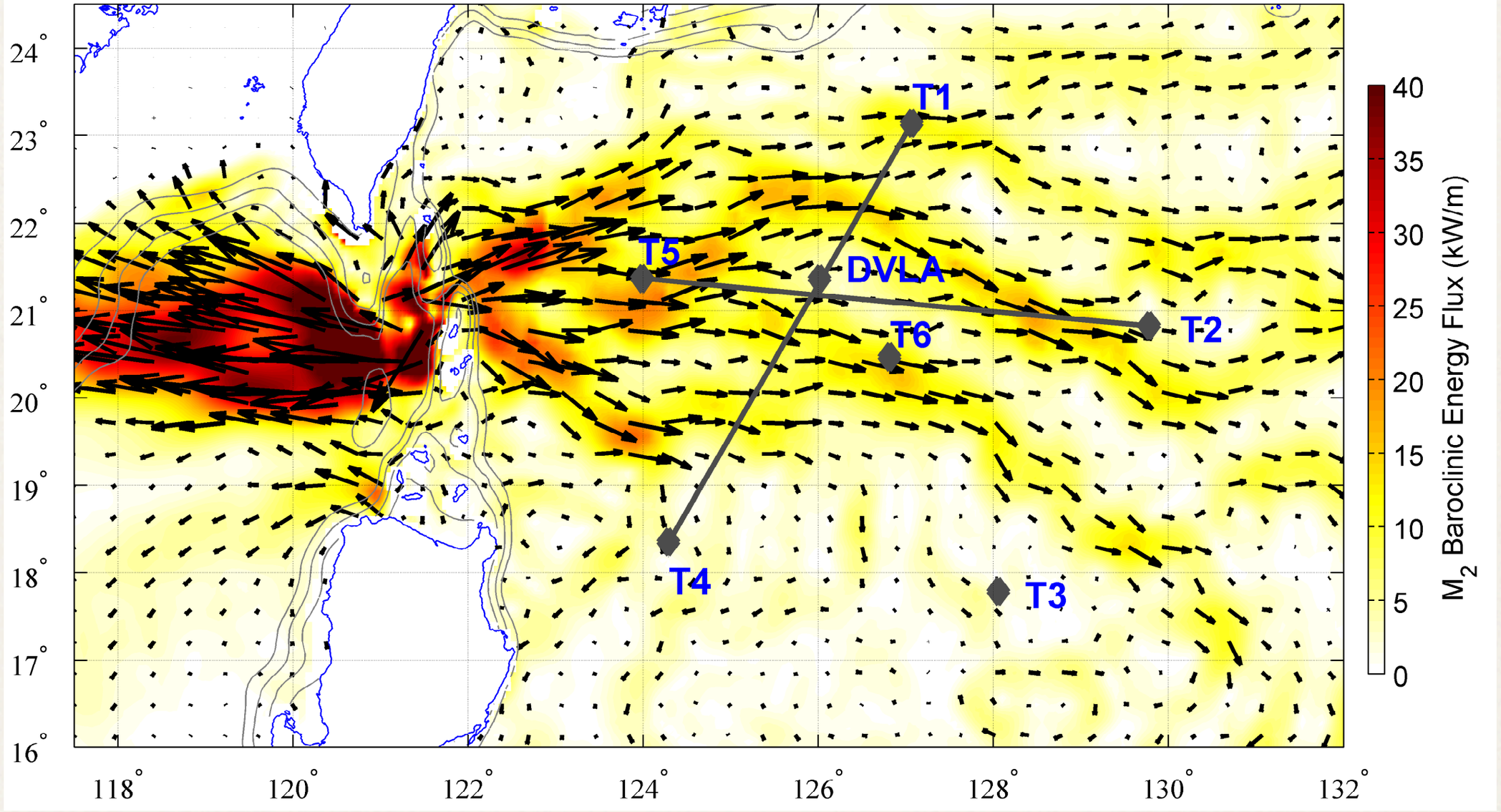

Conversion (GW)
18
17
16
15
14
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Conversion (GW)
5
4
3
EslopeEridge
WslopeEridge
EslopeWridge



B. S. Powell, B. D. Cornuelle, and C. Kerry. Using a numerical model to understand the connection between the ocean and acoustic travel-time measurements. J. Acoust. Soc. Am., revision in review, 2012.


Temperature standard deviation profiles
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Temperature standard deviation (° C)
DVLA
ROMS meso
ROMS meso + all tides


Temperature variation spectra –245 m
Spectral density (° C²/(1/day))
Cycles per day
ROMS meso
ROMS meso + all tides
DVLA measured



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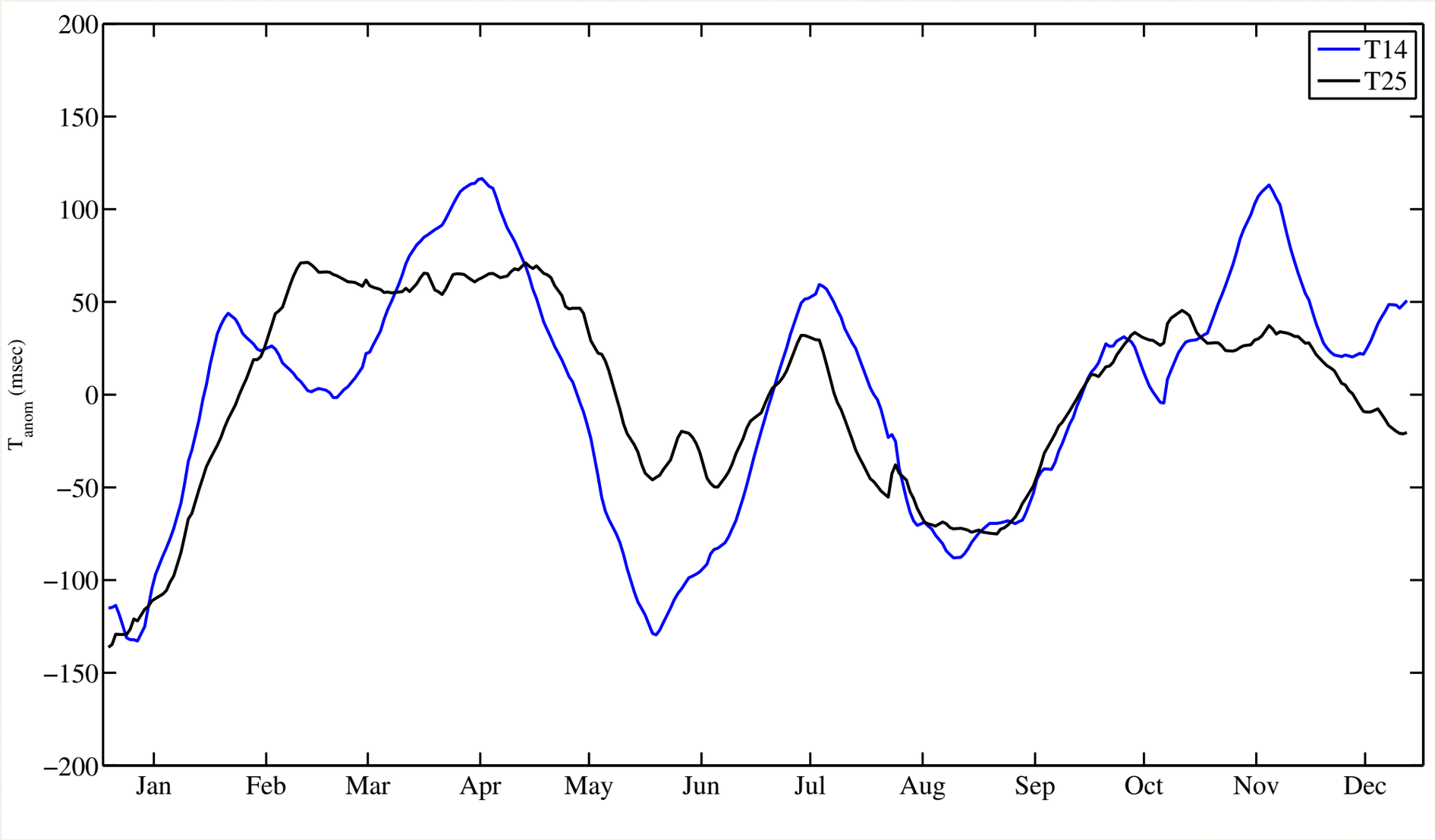

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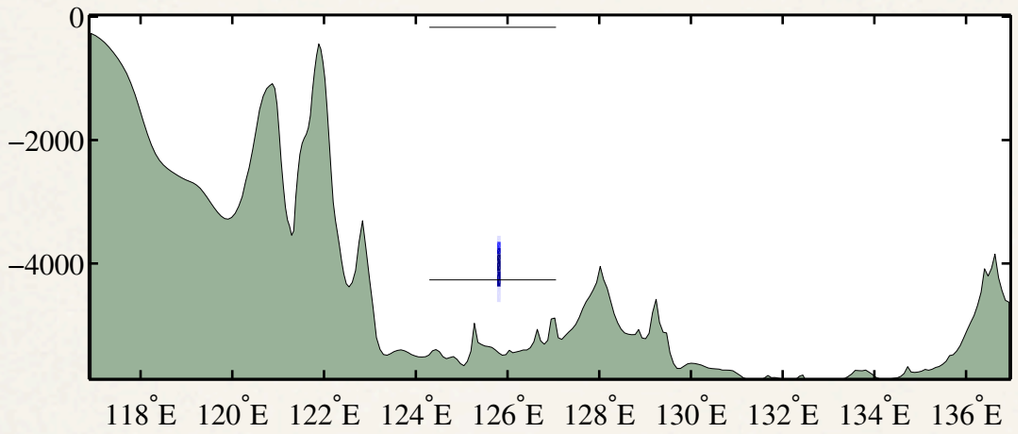
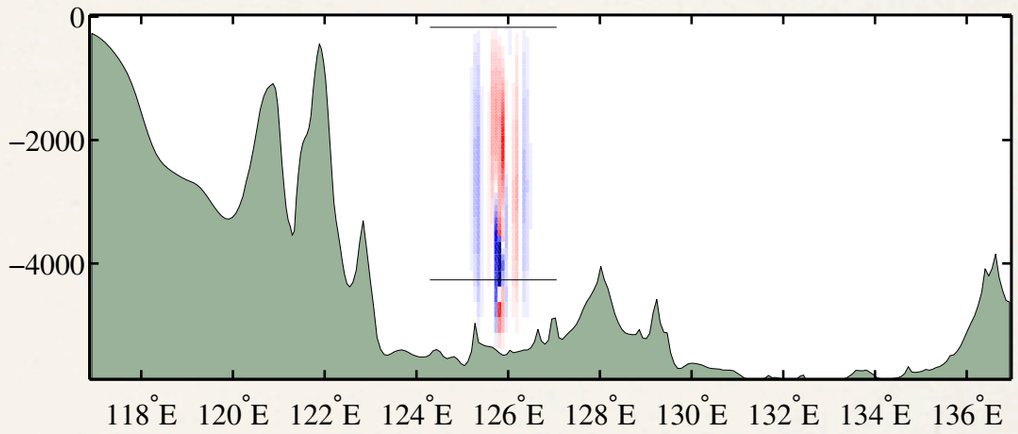
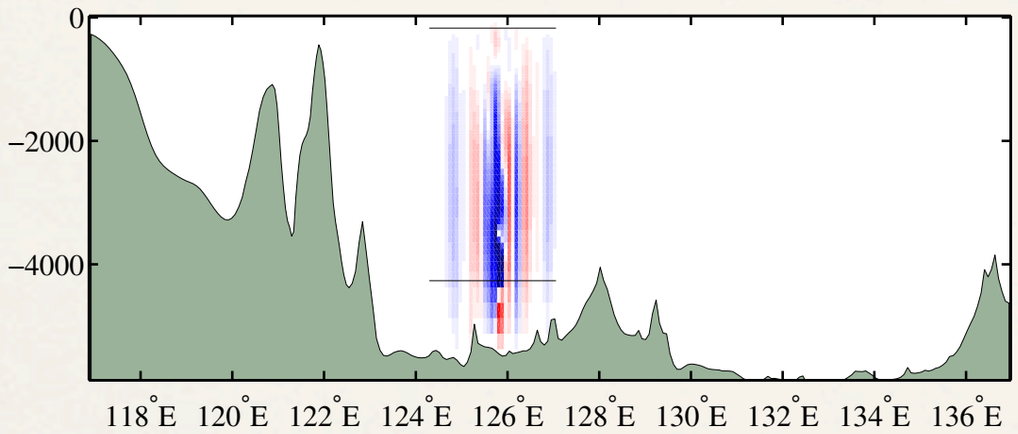


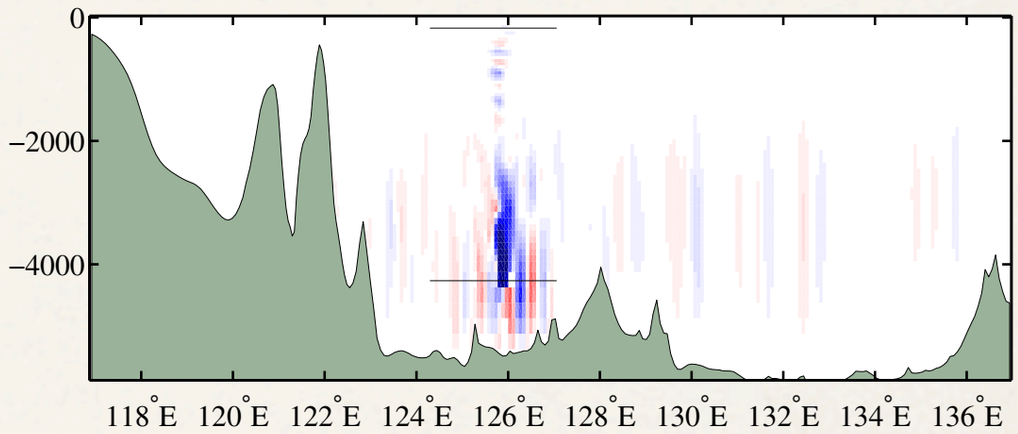
0 hours



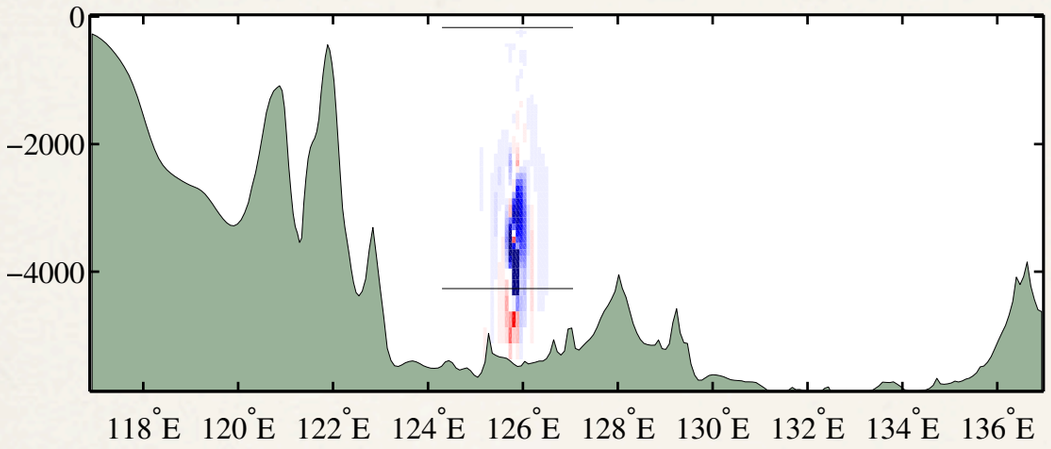
-4 hours



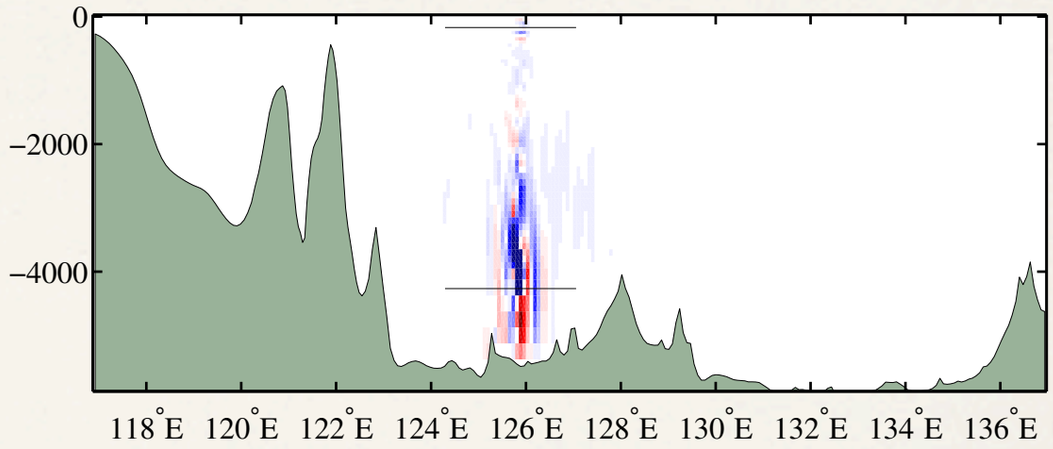
-8 hours



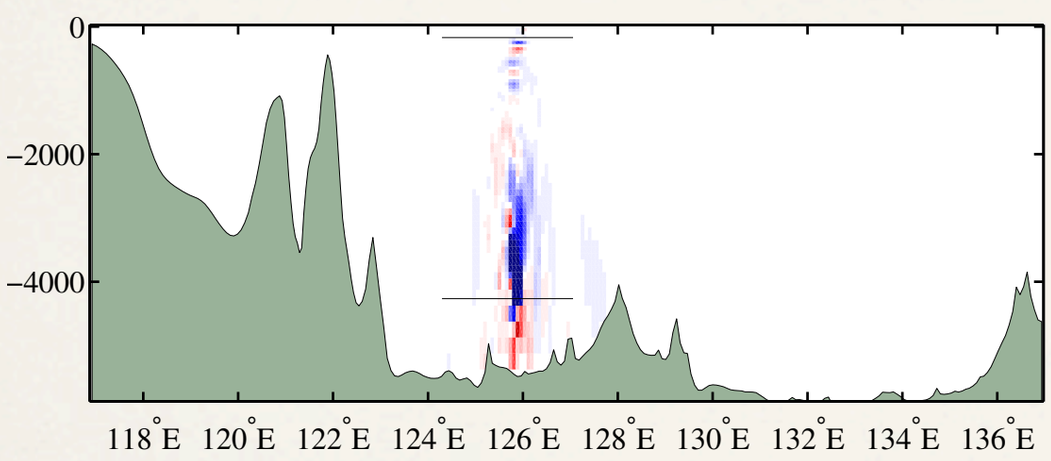
-120 hours



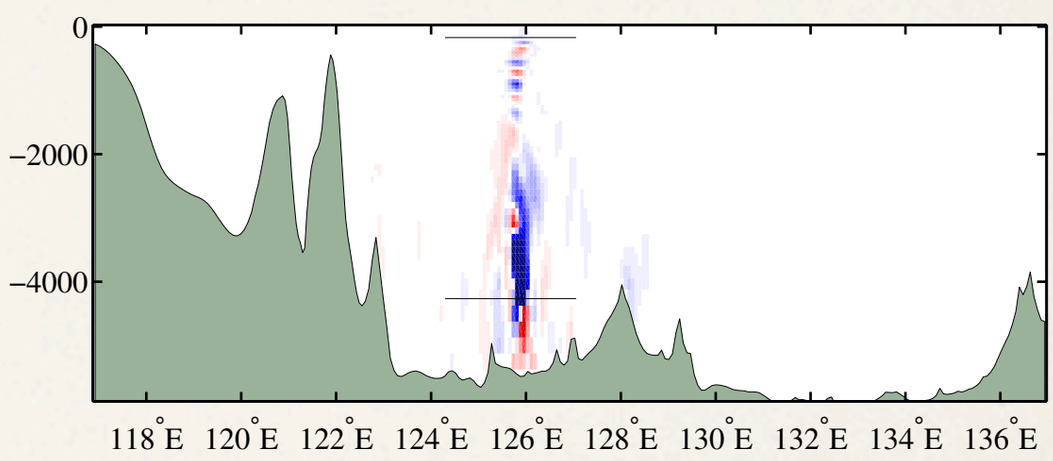
-1 day



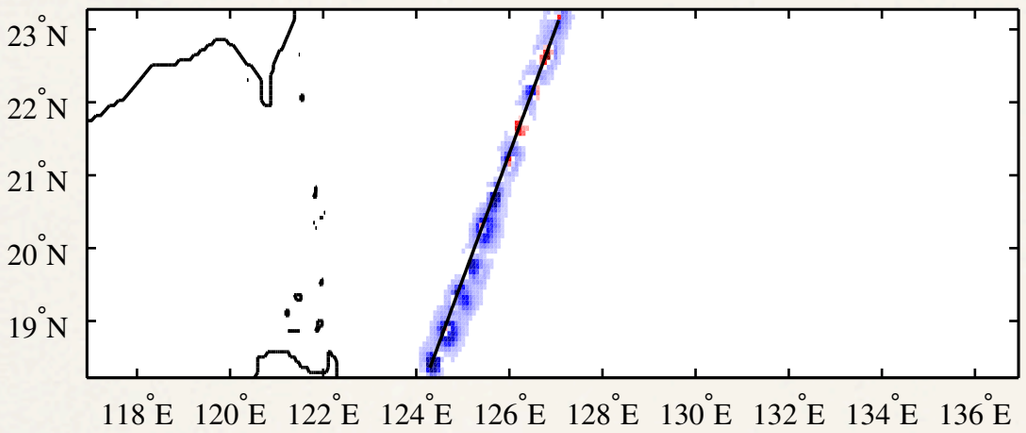
-2 days



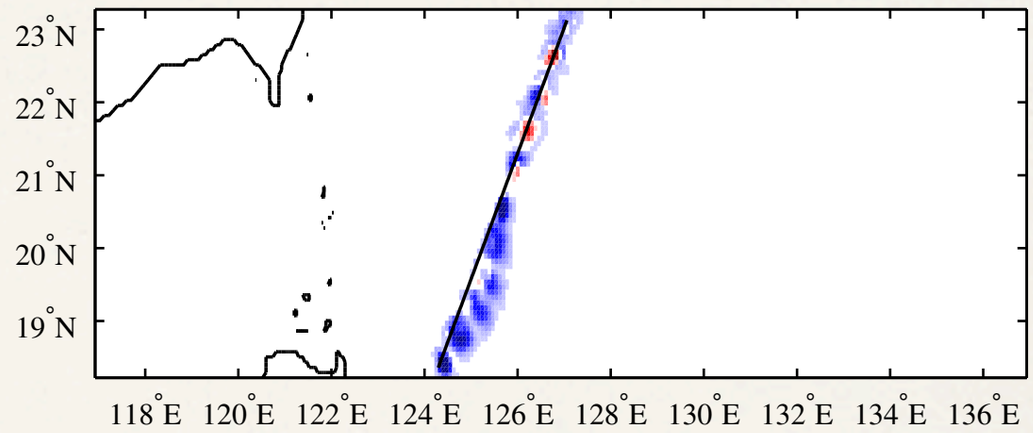
-3 days



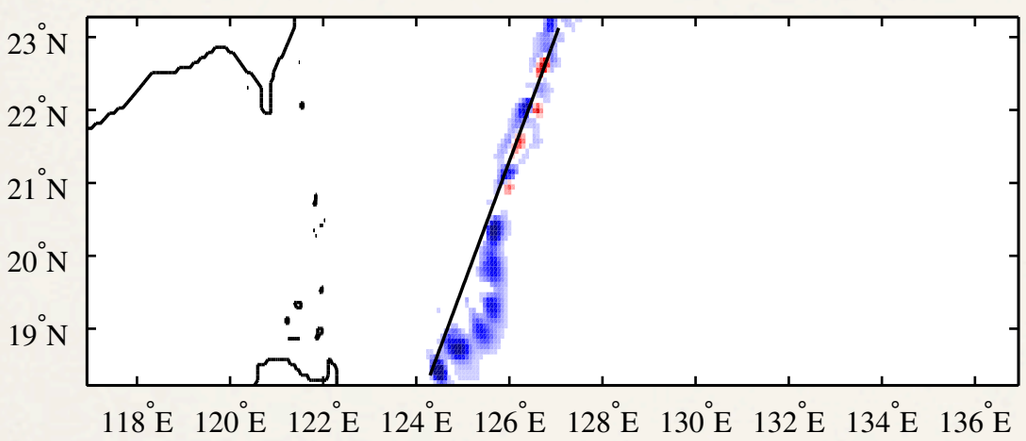
-5 days



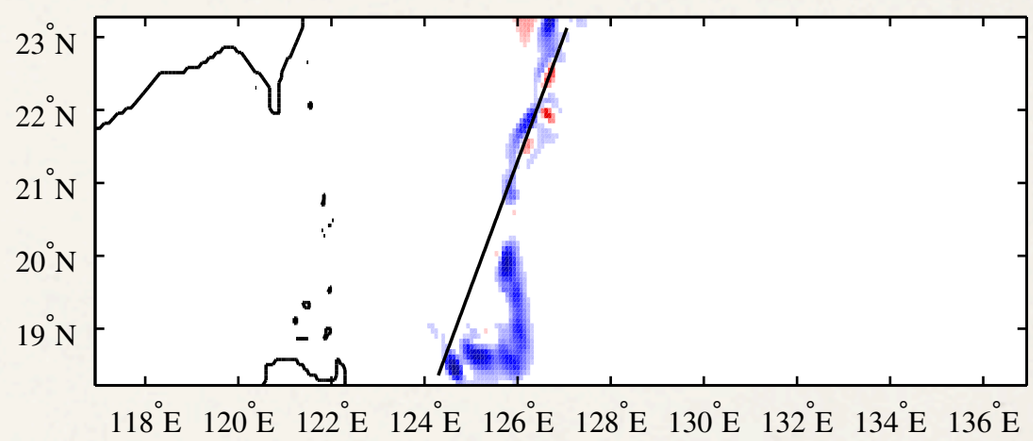
-1 day



-2 days



-3 days

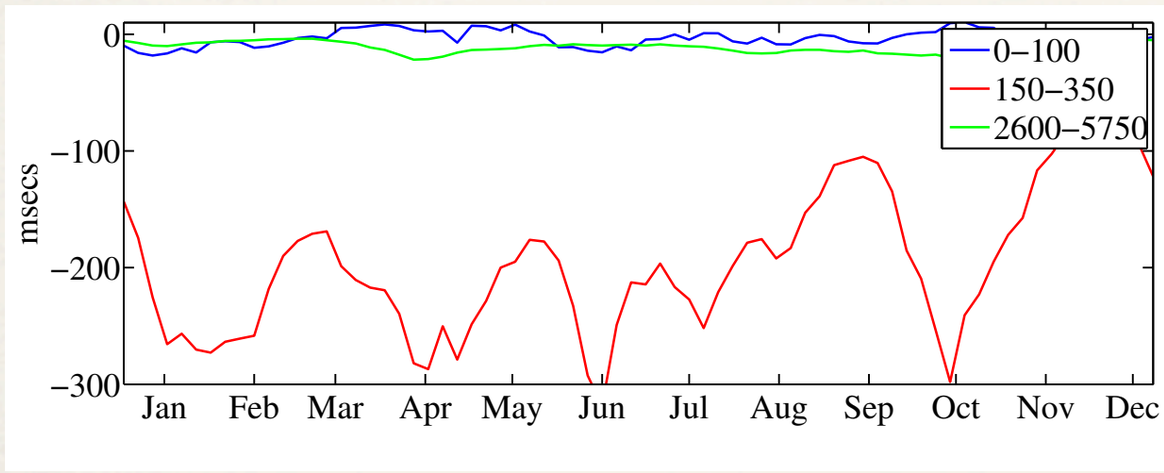


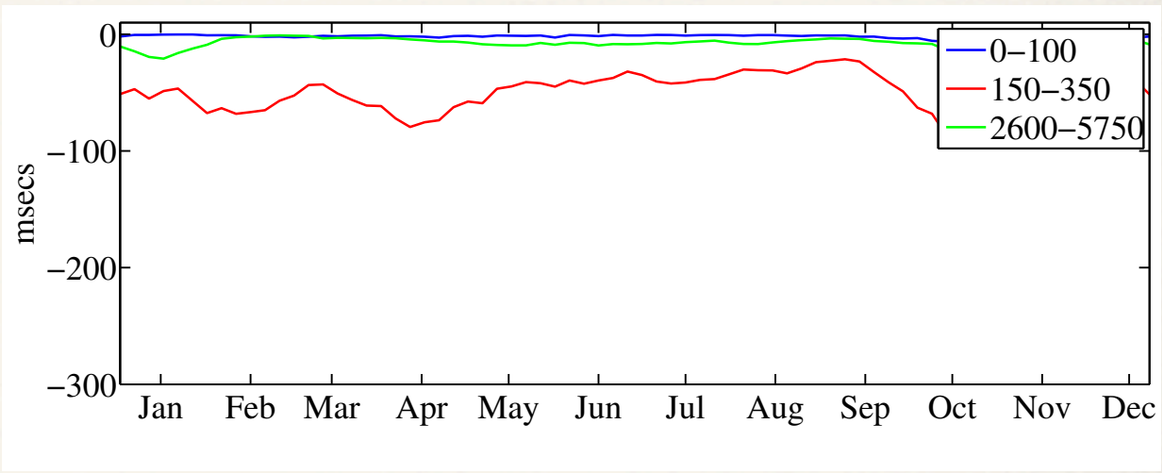
-5 days

Temperature ($\Delta\mathcal{J}_T$)

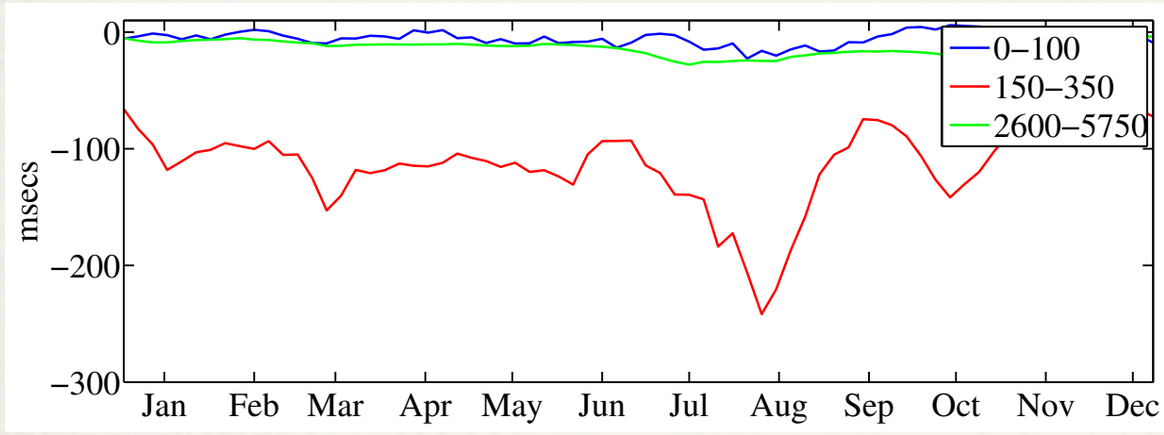
Salt ($\Delta\mathcal{J}_S$)

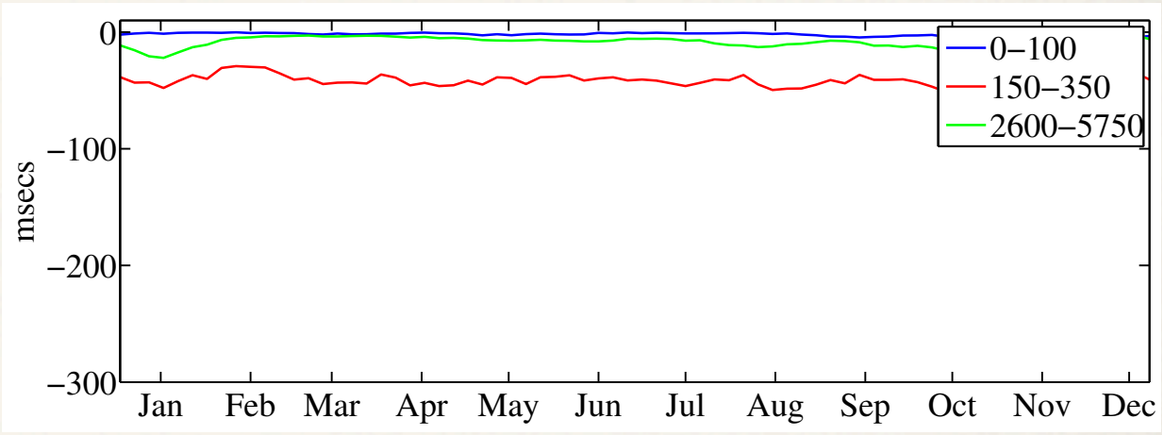
T14





T25





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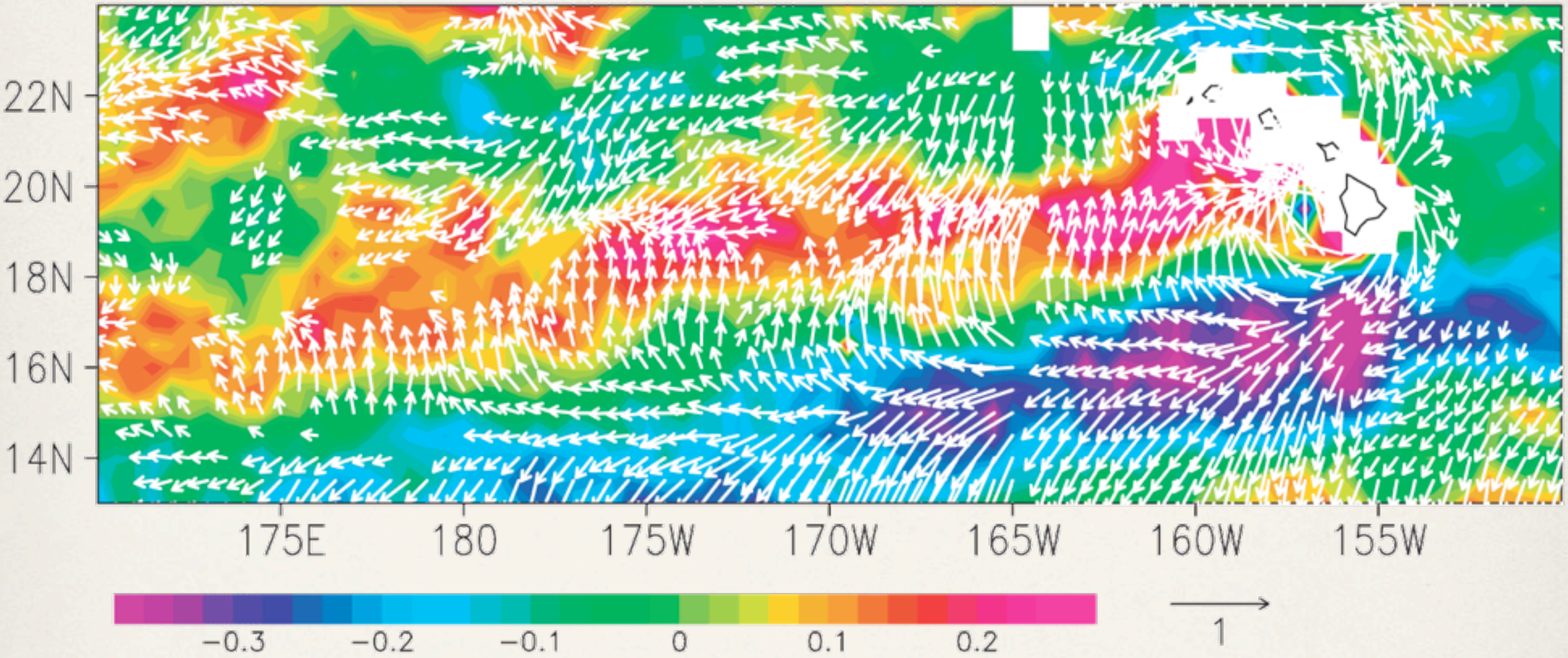
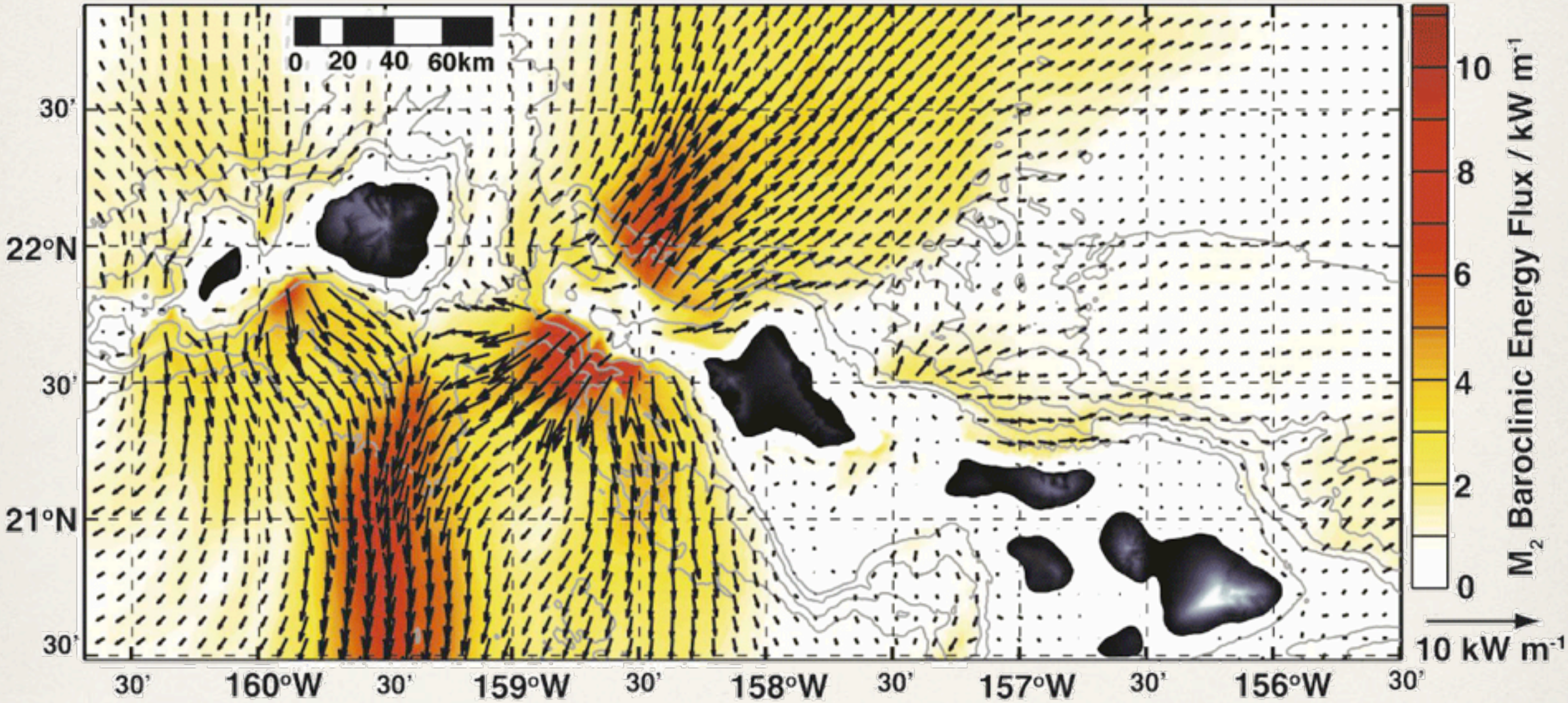
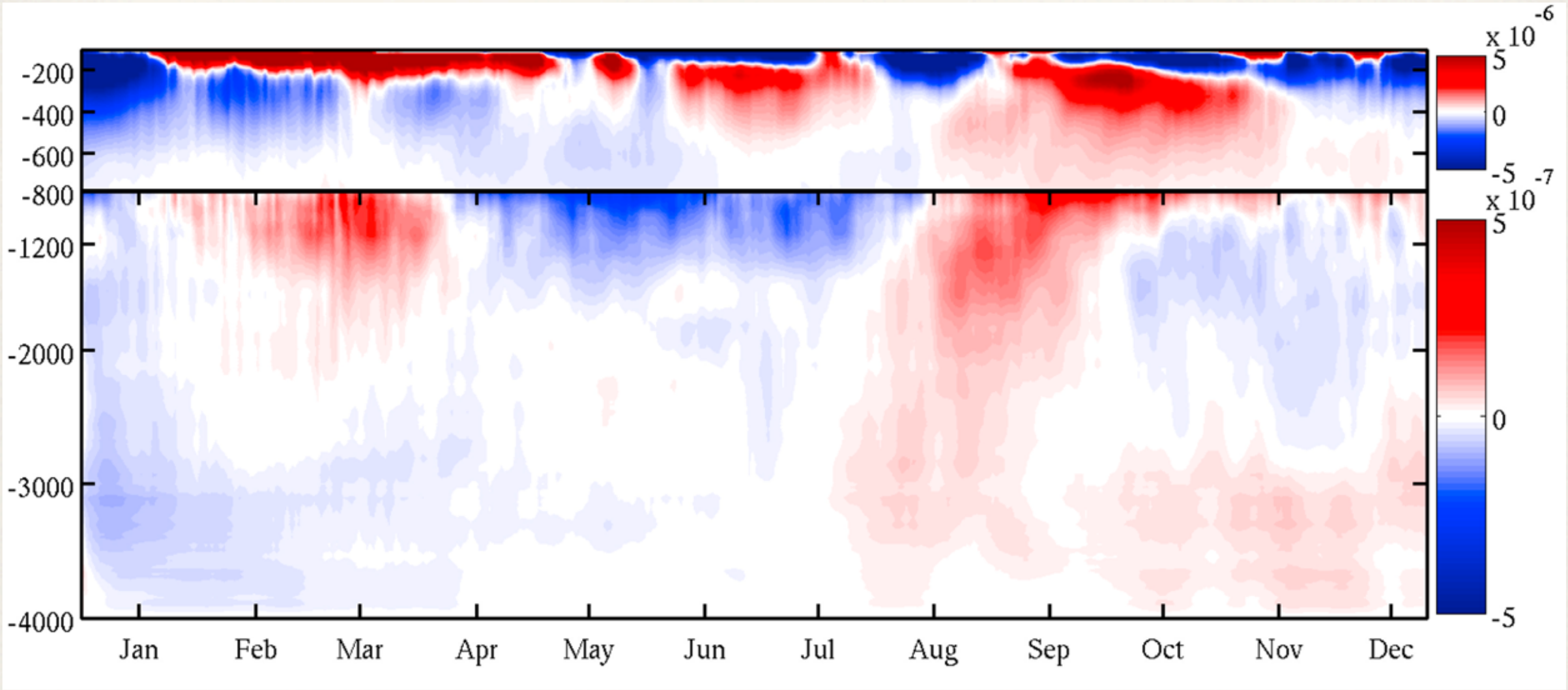


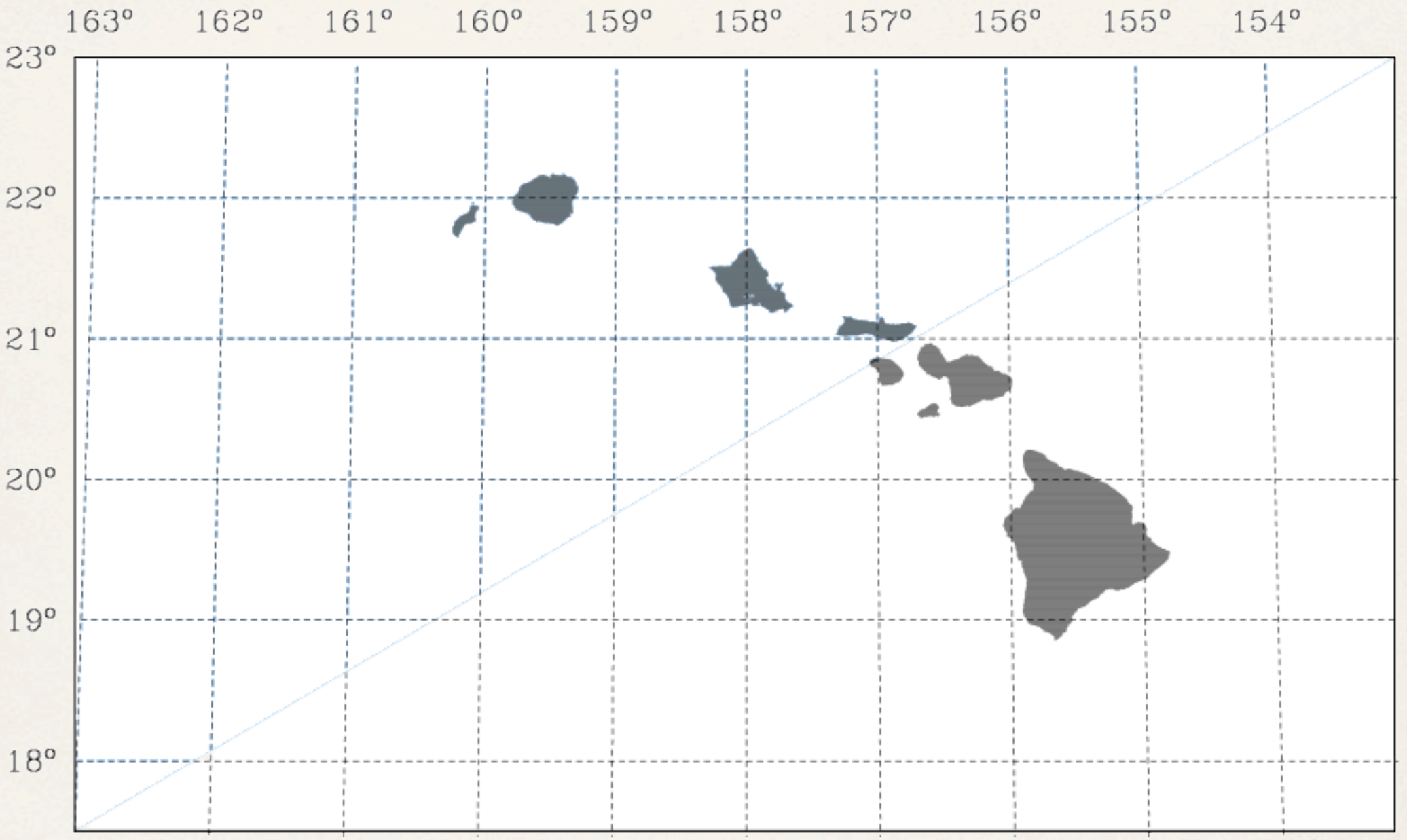
S.-P. Xie, W. Liu, Q. Liu, and M. Nonaka. Far-Reaching Effects of the Hawaiian Islands on the Pacific Ocean-Atmosphere System. Science, 292(5524):2057–2060, 2001.



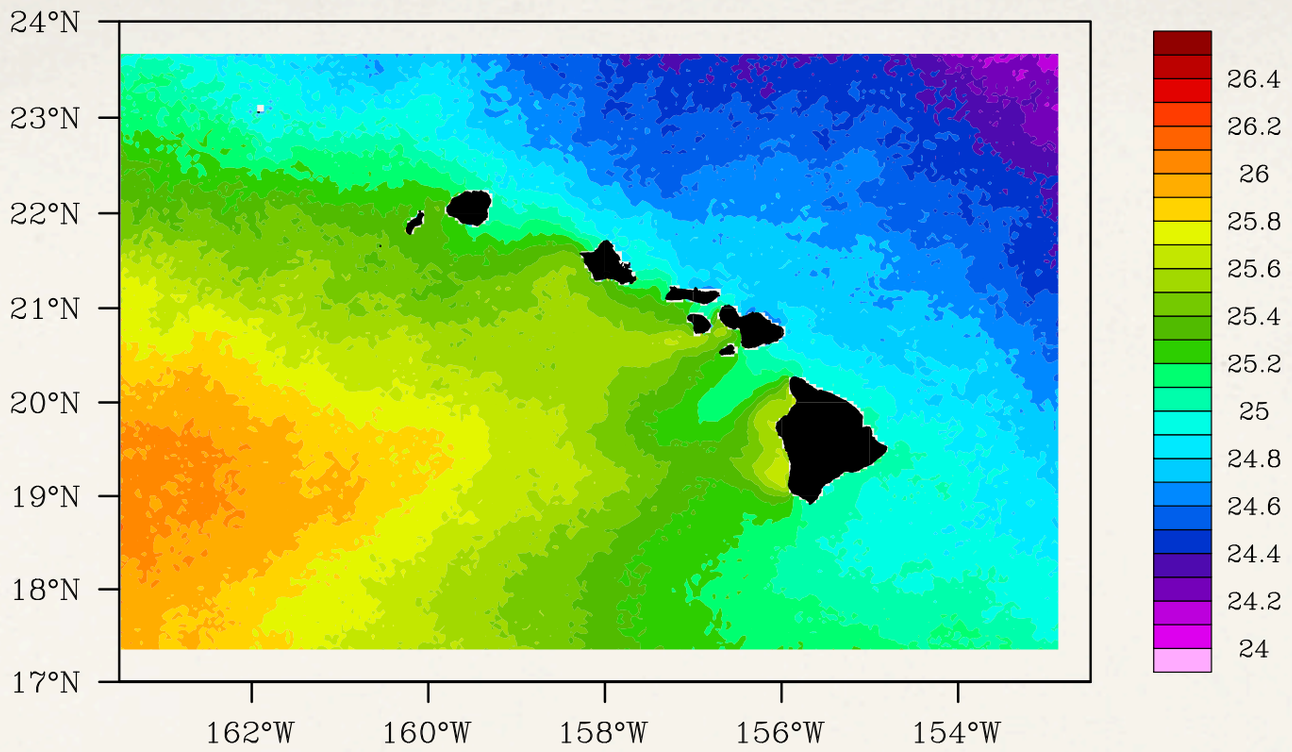
G. S. Carter, M. A. Merrifield, J. M. Becker, K. Katsumata, M. C. Gregg, D. S. Luther, M. D. Levine, T. J. Boyd, and Y. L. Firing. Energetics of M2 Barotropic-to-Baroclinic Tidal Conversion at the Hawaiian Islands. J. Phys. Oceanogr., 38:2,205–2,223, 2008.

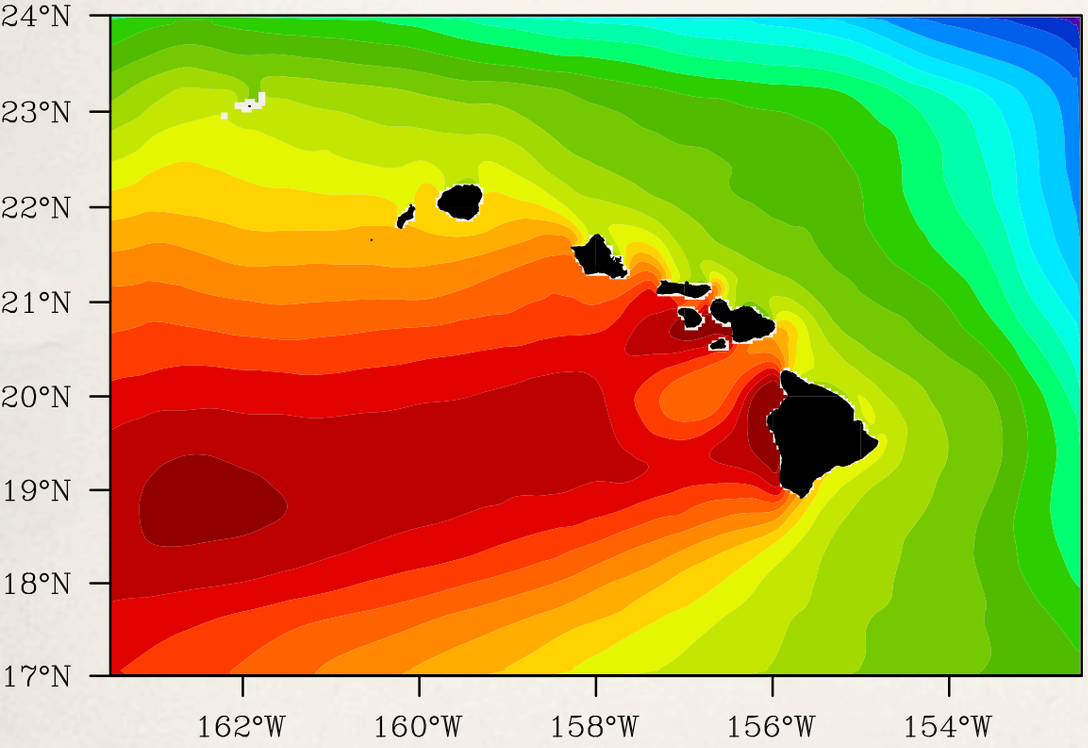


B. S. Powell, I. Janekovic, G. S. Carter, and M. A. Merrifield. Sensitivity of Internal Tide Generation in Hawaii. Geophys. Res. Let., 39(L10606):1–6, 2012.


163°
162°
161°
160°
159°
158°
157°
156°
155°
154°
23°
22°
21°
20°
19°
18°

Observation	Count	Percent
HOT Temperature	4,982	0.02%
HOT Salt	4,982	0.02%
Argo Temp	15,212	0.06%
Argo Salt	15,212	0.06%
Seaglider Temperature	220,266	0.83%
Seaglider Salt	220,266	0.83%
SST	25,201,519	94.50%
SSH	985,731	3.70%
Total	26,668,170	


24°N
23°N
22°N
21°N
20°N
19°N
18°N
17°N
162°W
160°W
158°W
156°W
154°W
26.4
26.2
26
25.8
25.6
25.4
25.2
25
24.8
24.6
24.4
24.2
24


24°N
23°N
22°N
21°N
20°N
19°N
18°N
17°N
162°W
160°W
158°W
156°W
154°W
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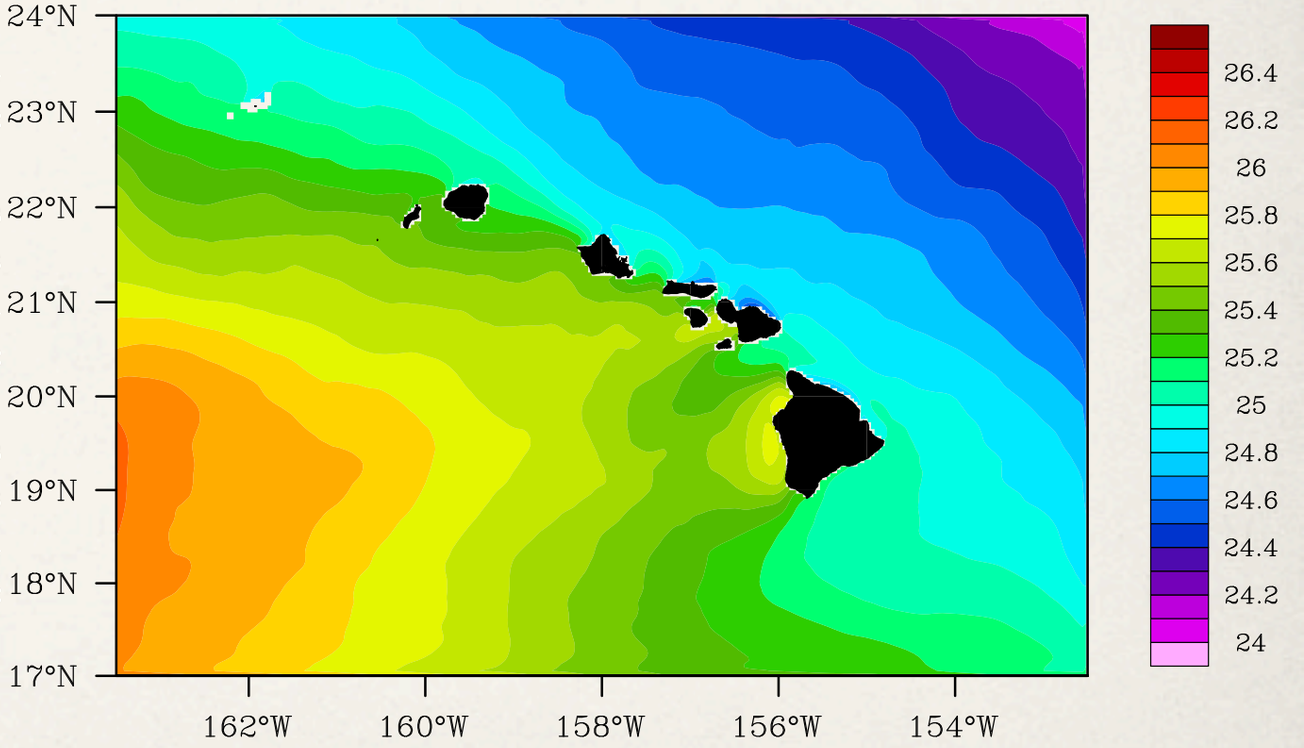
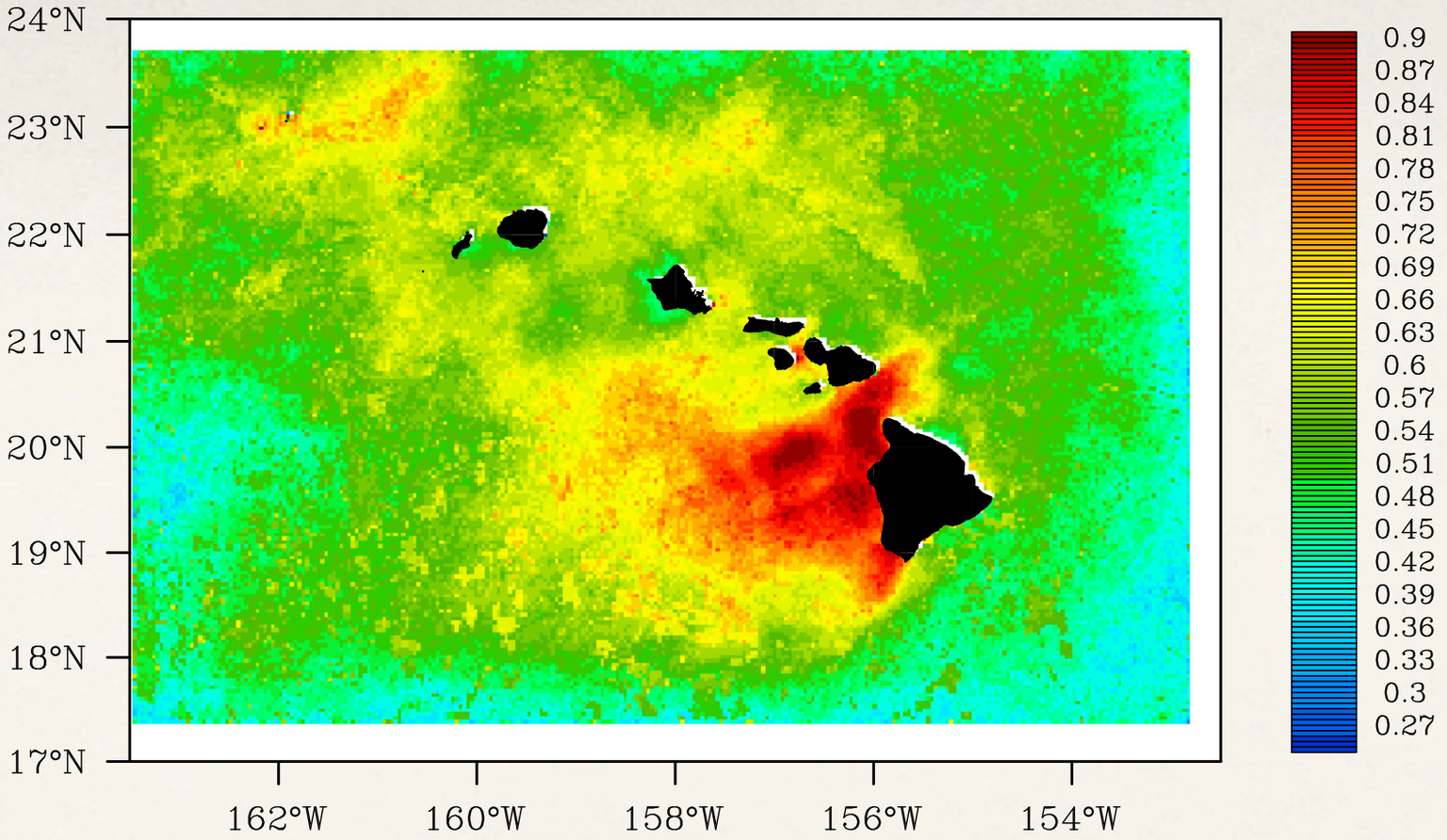
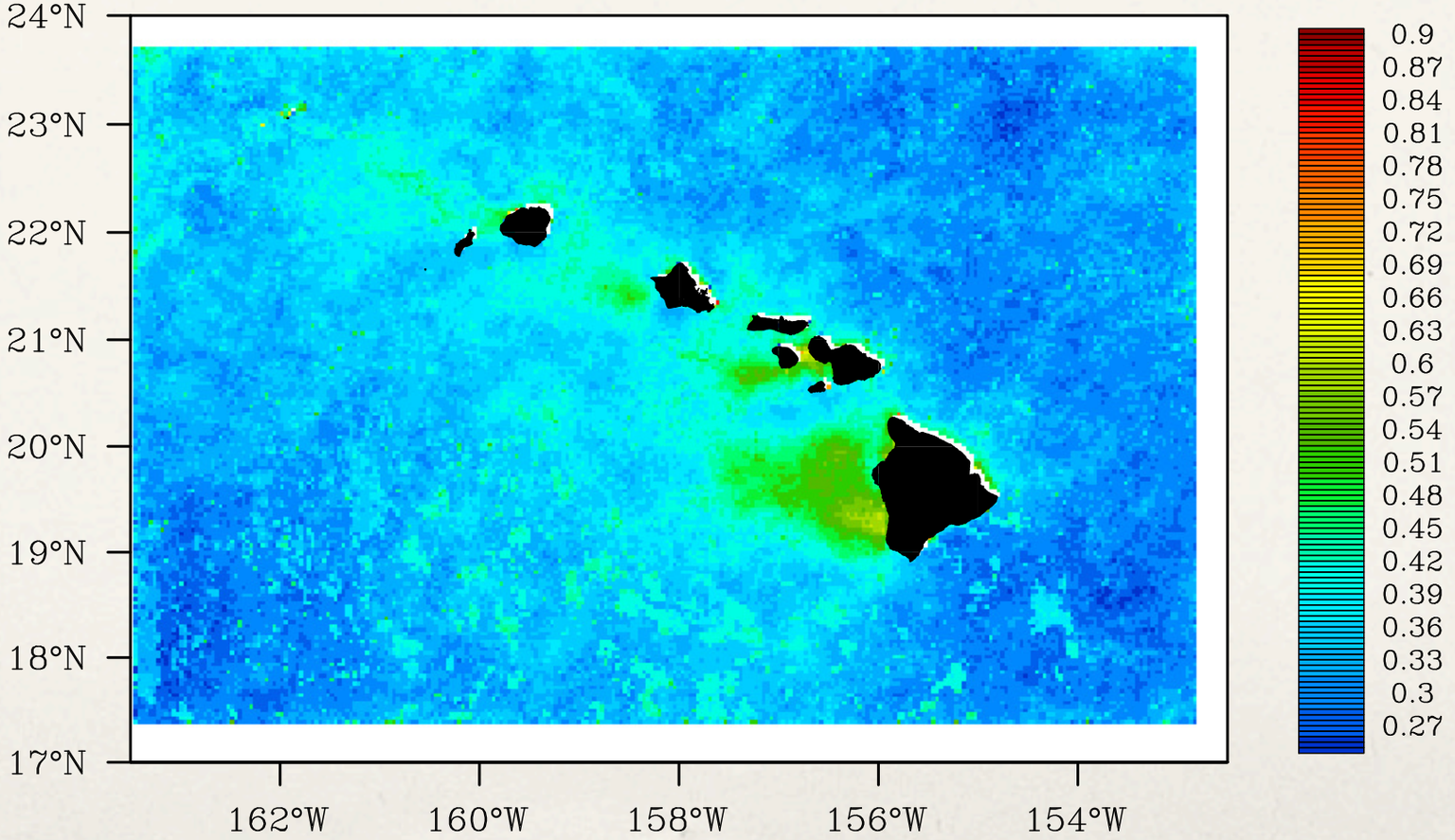
25.2
25
24.8
24.6
24.4
24.2
24


24°N
23°N
22°N
21°N
20°N
19°N
18°N
17°N
162°W
160°W
158°W
156°W
154°W
26.4
26.2
26
25.8
25.6
25.4
25.2
25
24.8
24.6
24.4
24.2
24

Forward



Assimilated



- Recall,

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}\left(\mathbf{y} - \mathbf{H}\mathbf{x}_b\right)$$

- We have some measure of the ocean, $\mathcal{Q}\left(\mathbf{x}\right)$

- Between the analysis and background, we have:

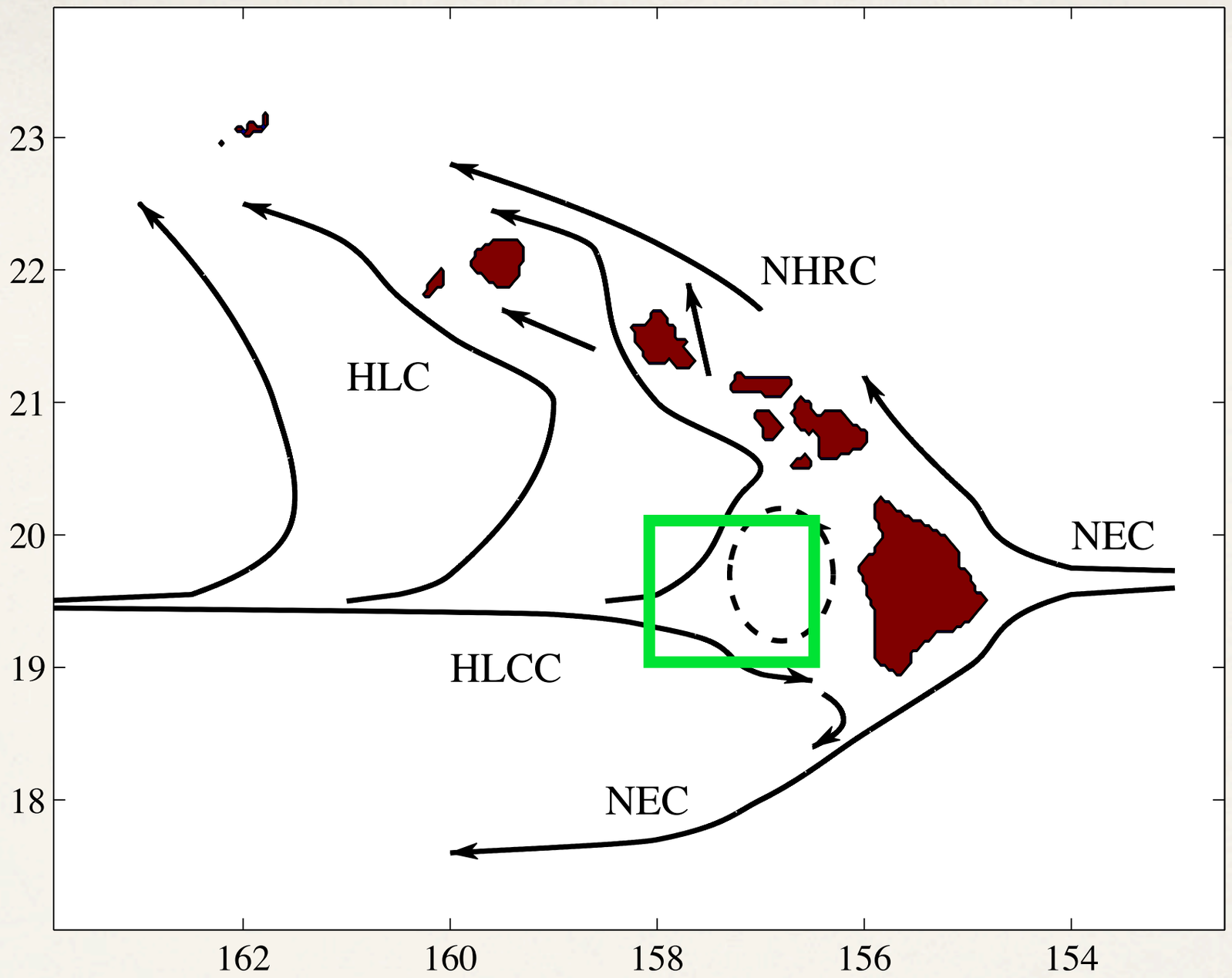
$$\Delta\mathcal{Q} = \mathcal{Q}\left(\mathbf{x}_b + \mathbf{K}\left(\mathbf{y} - \mathbf{H}\mathbf{x}_b\right)\right) - \mathcal{Q}\left(\mathbf{x}_b\right)$$

- Following Langland and Baker (2004), Errico (2007), second-order Taylor Expansion:

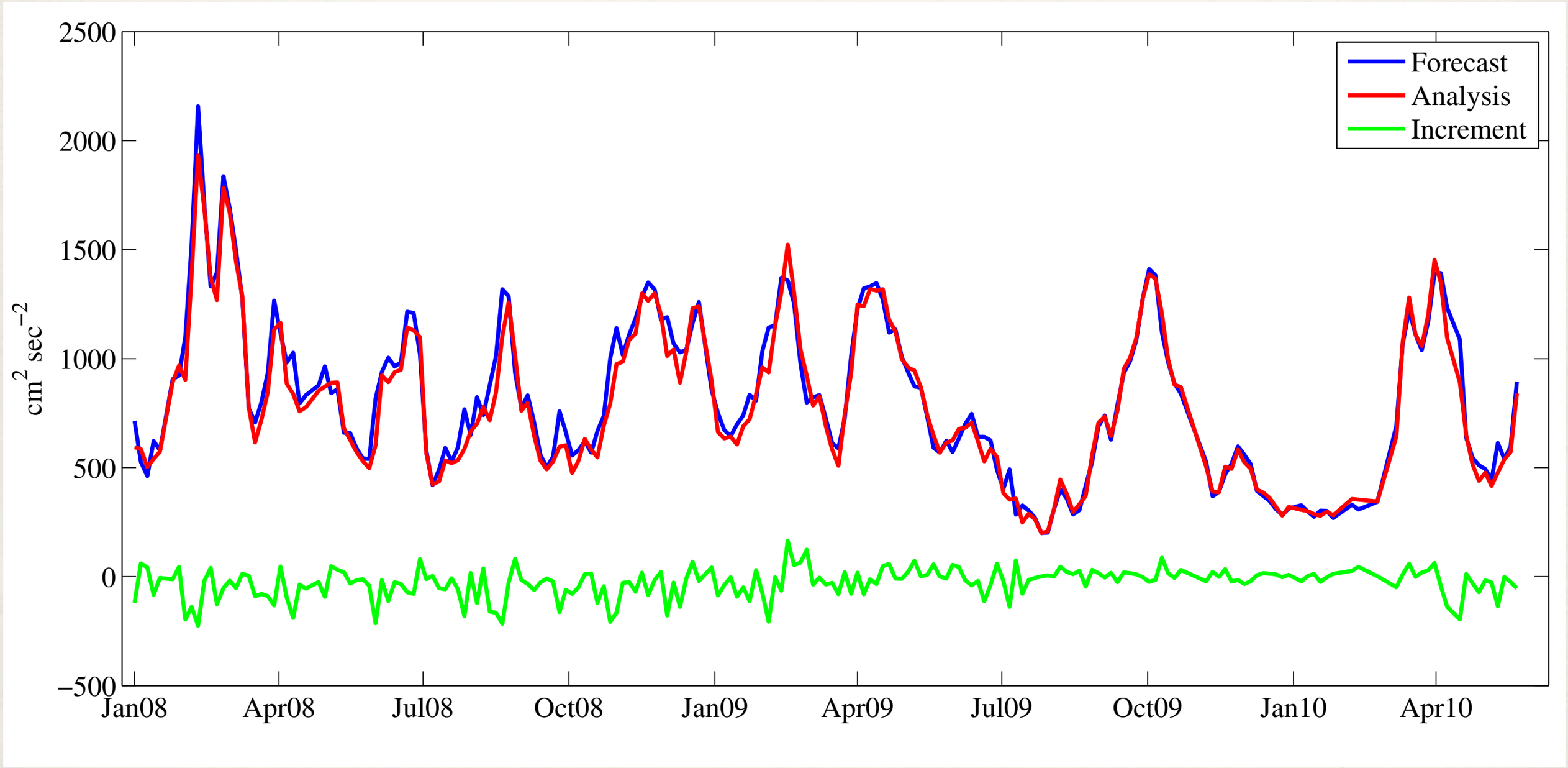
$$\Delta\mathcal{Q} = 2\left(\mathbf{y} - \mathbf{H}\mathbf{x}_b\right)^T \mathbf{K}^T \left(\mathbf{M}_b^T \frac{\partial \mathcal{Q}}{\partial \mathbf{x}_a} + \mathbf{M}_a^T \frac{\partial \mathcal{Q}}{\partial \mathbf{x}_b}\right)$$

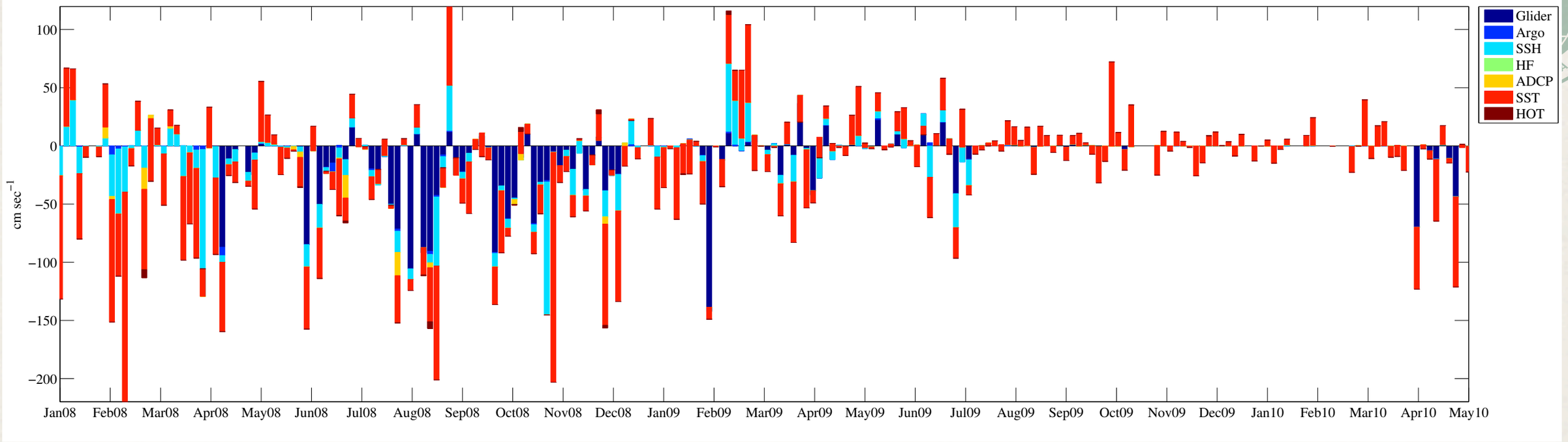
- How is the analysis sensitive to the observations/ background?

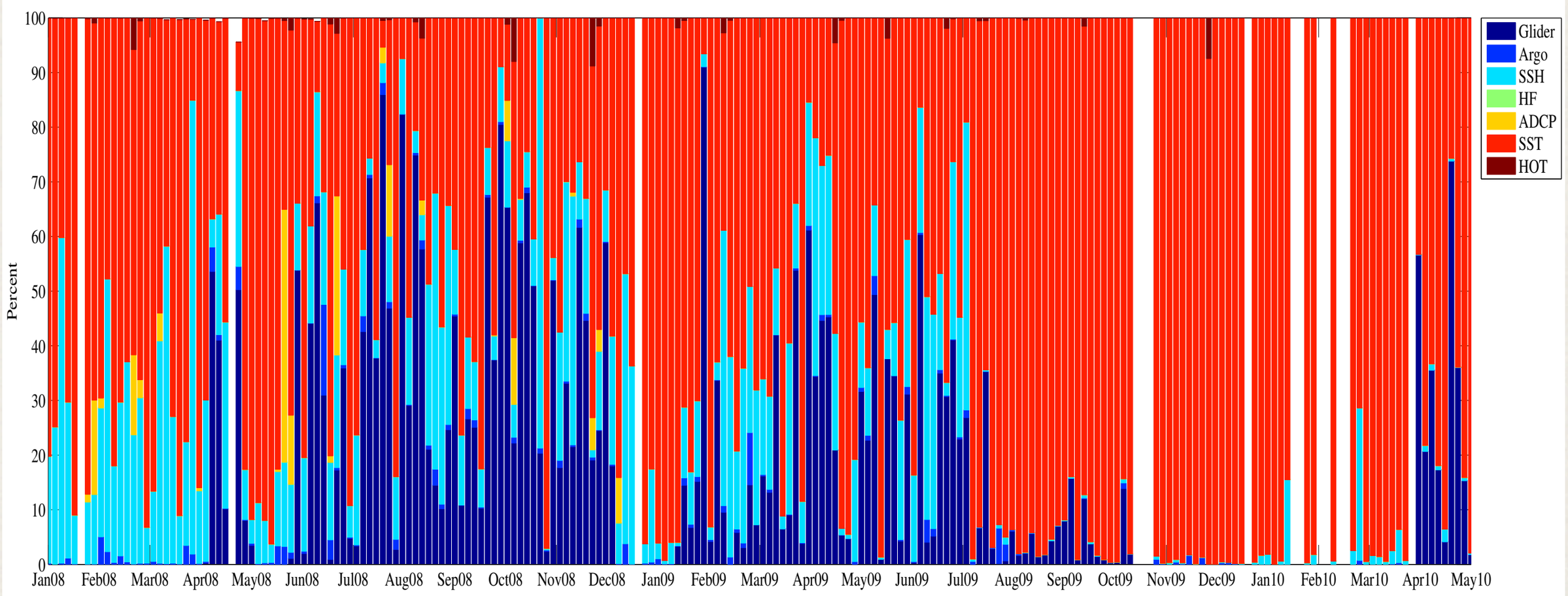
$$\frac{\partial x_a}{\partial y} = \mathbf{K}^T$$



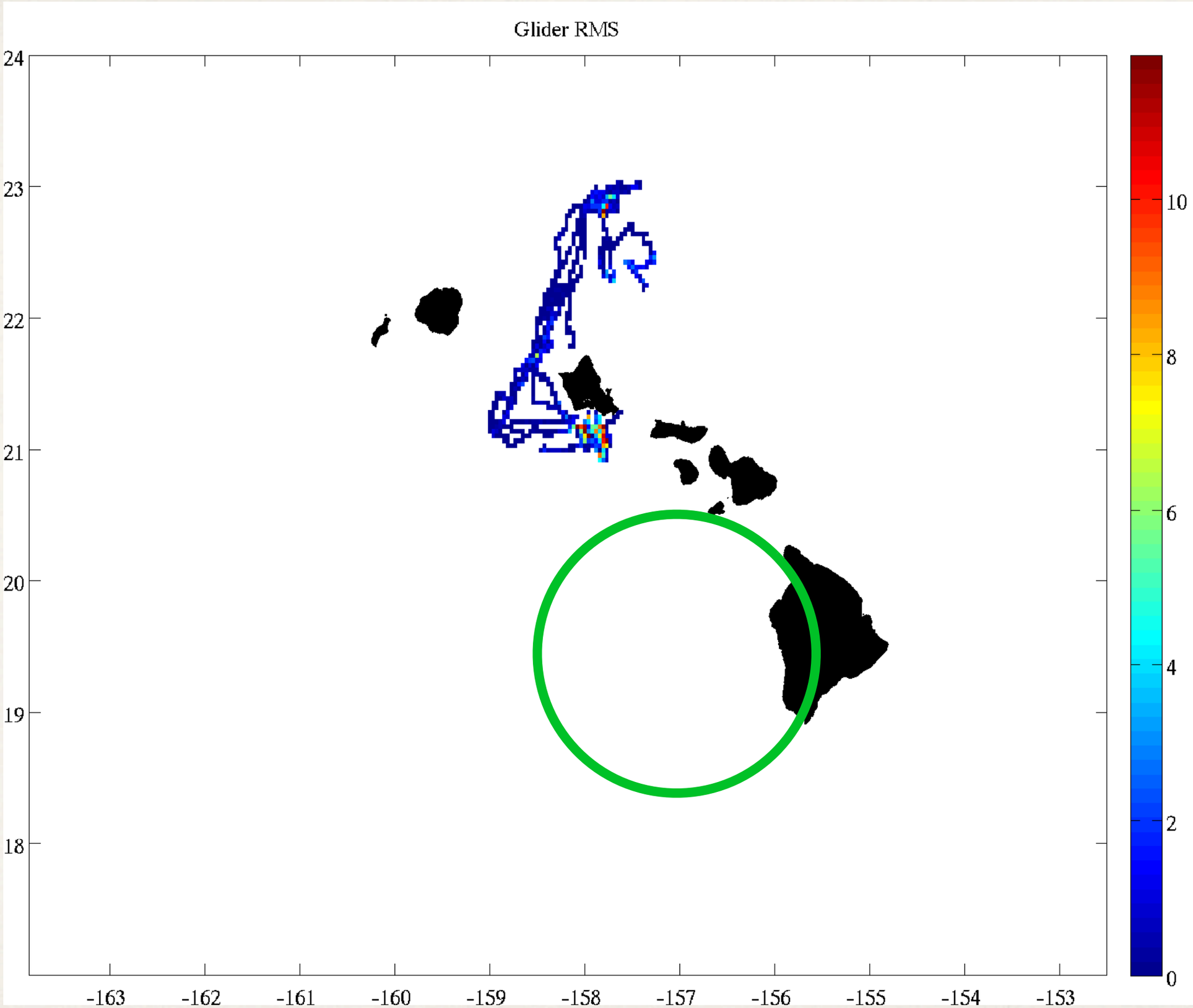
$$\mathcal{Q} = \frac{1}{TZS} \int_T \int_S \int_{-z}^{0} \left(u^2 + v^2\right) \mathrm{d}z\mathrm{d}s\mathrm{d}t$$

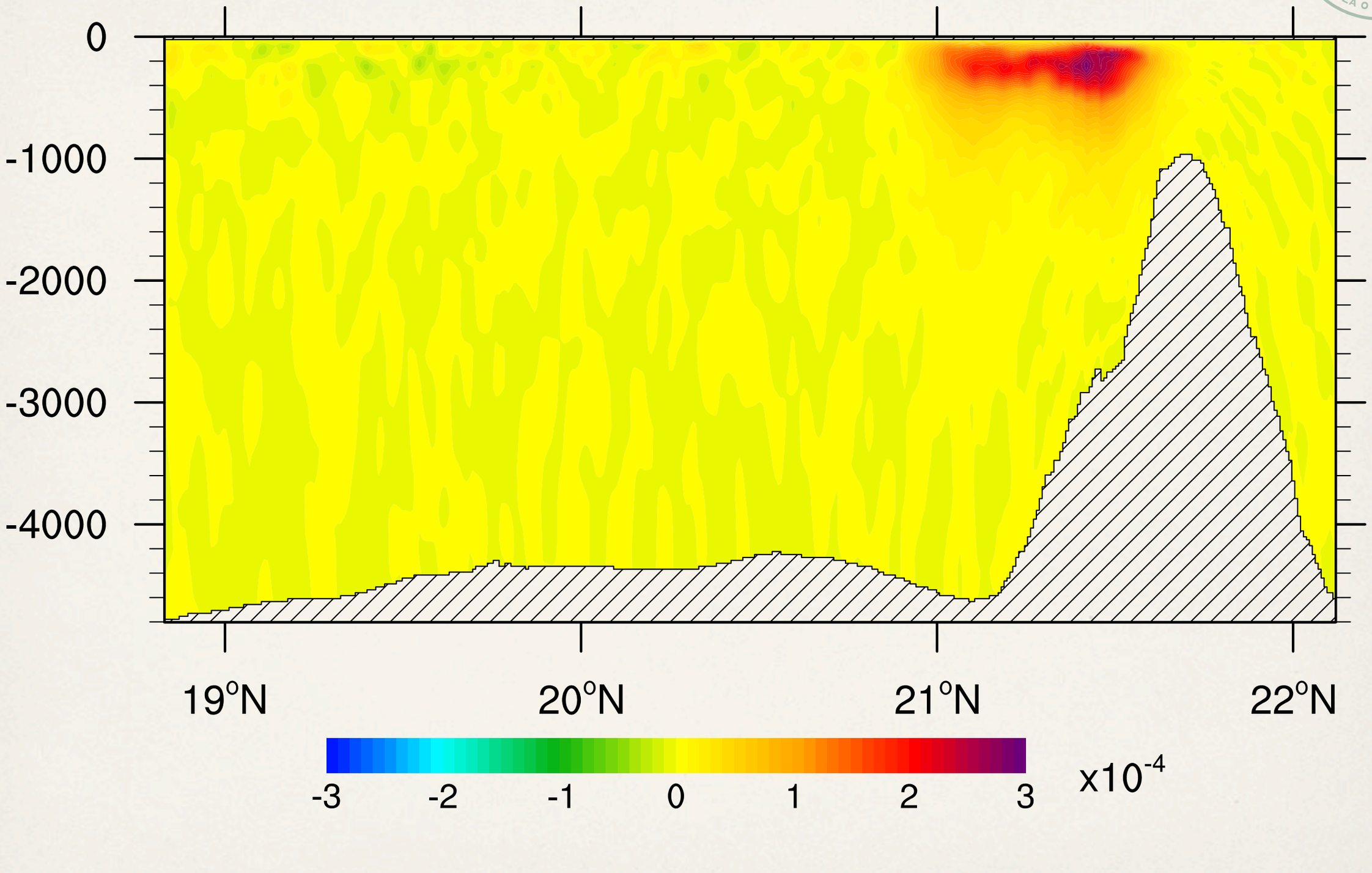

2500
2000
1500
1000
500
0
−500
cm^2 sec^{-2}
Forecast
Analysis
Increment
Jan08
Apr08
Jul08
Oct08
Jan09
Apr09
Jul09
Oct09
Jan10
Apr10

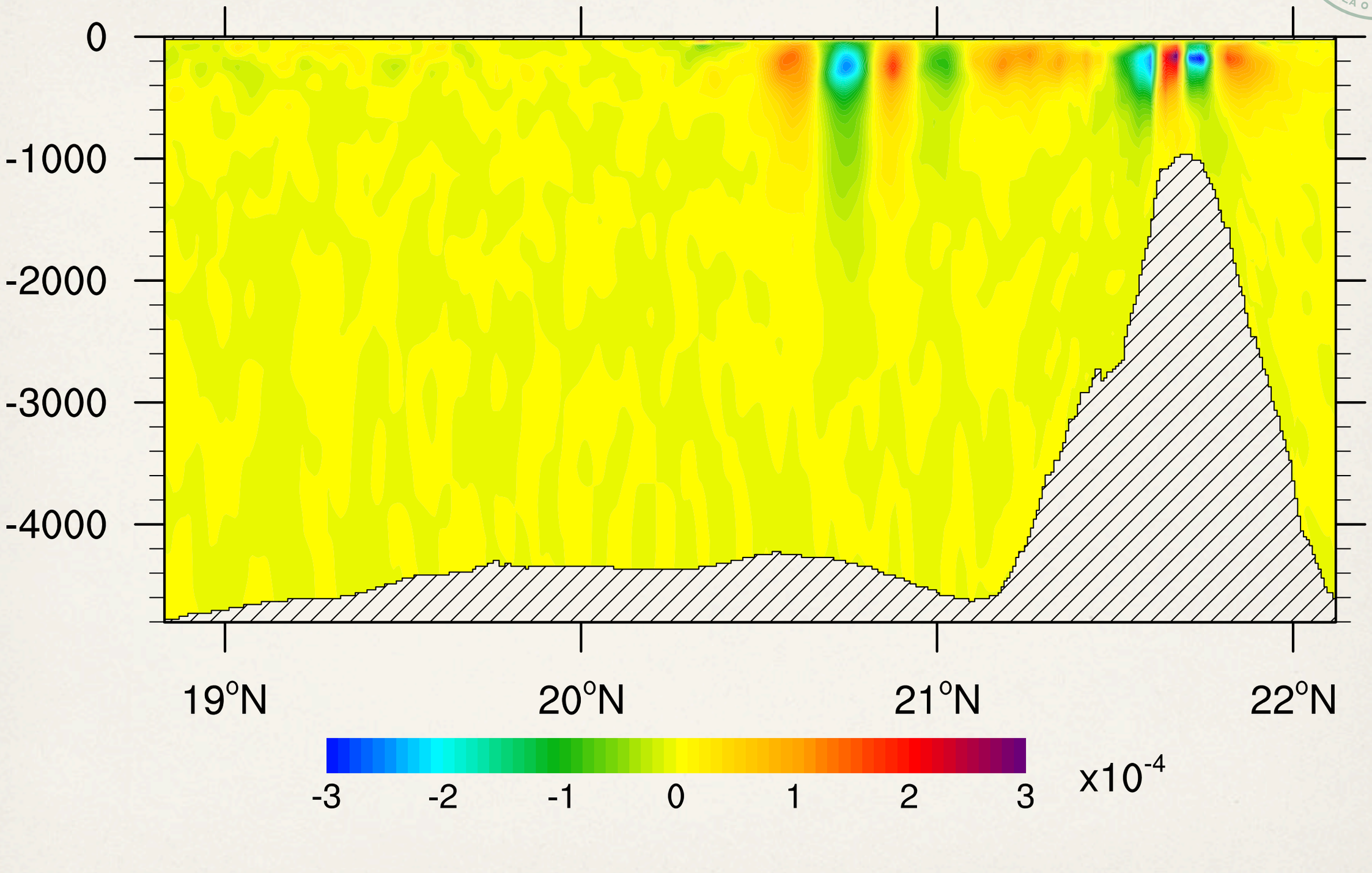

cm sec^{-1}
100
50
0
−50
−100
−150
−200
Jan08 Feb08 Mar08 Apr08 May08 Jun08 Jul08 Aug08 Sep08 Oct08 Nov08 Dec08 Jan09 Feb09 Mar09 Apr09 May09 Jun09 Jul09 Aug09 Sep09 Oct09 Nov09 Dec09 Jan10 Feb10 Mar10 Apr10 May10
Glider
Argo
SSH
HF
ADCP
SST
HOT

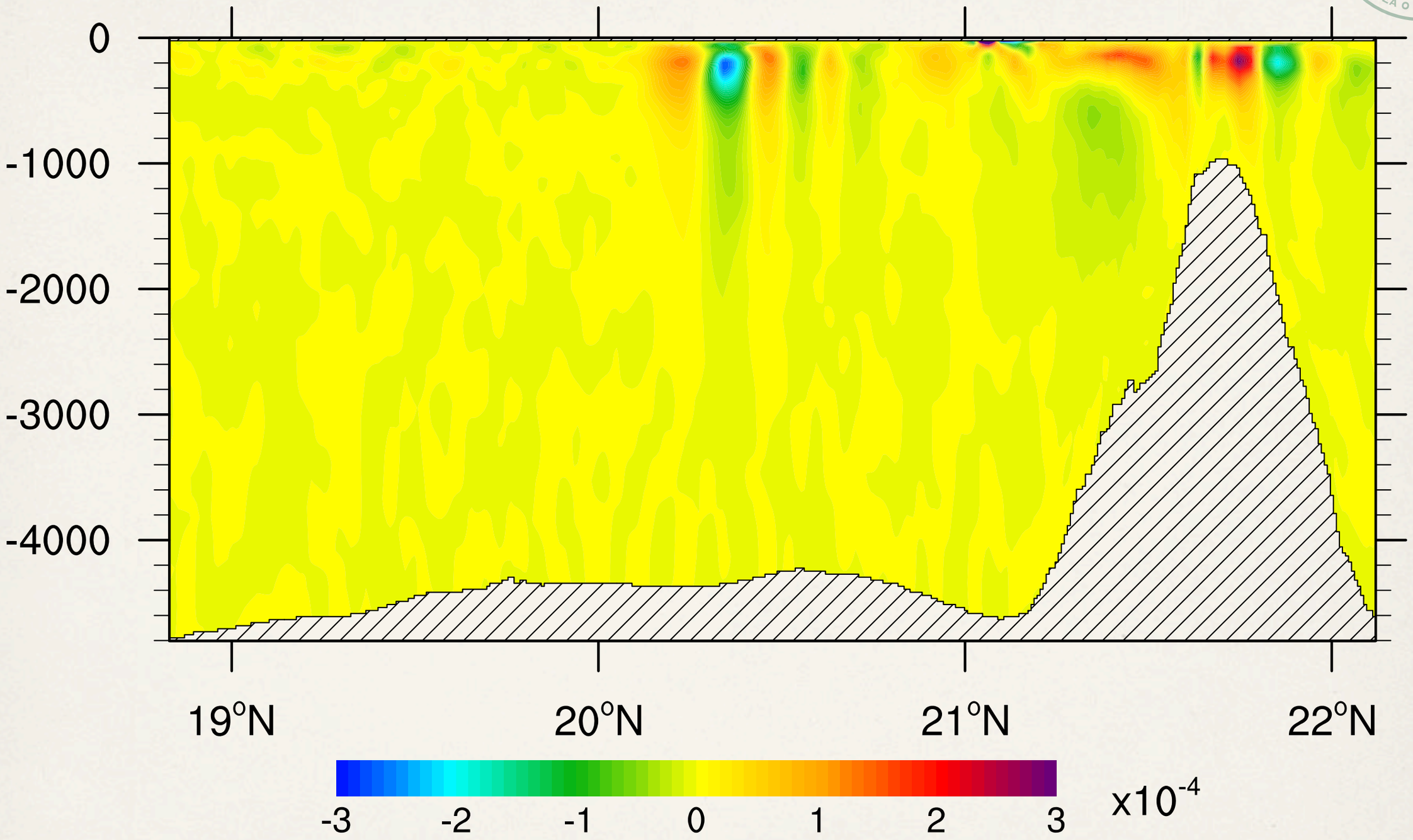

Percent
100
90
80
70
60
50
40
30
20
10
0
Jan08 Feb08 Mar08 Apr08 May08 Jun08 Jul08 Aug08 Sep08 Oct08 Nov08 Dec08 Jan09 Feb09 Mar09 Apr09 May09 Jun09 Jul09 Aug09 Sep09 Oct09 Nov09 Dec09 Jan10 Feb10 Mar10 Apr10 May10
Glider
Argo
SSH
HF
ADCP
SST
HOT

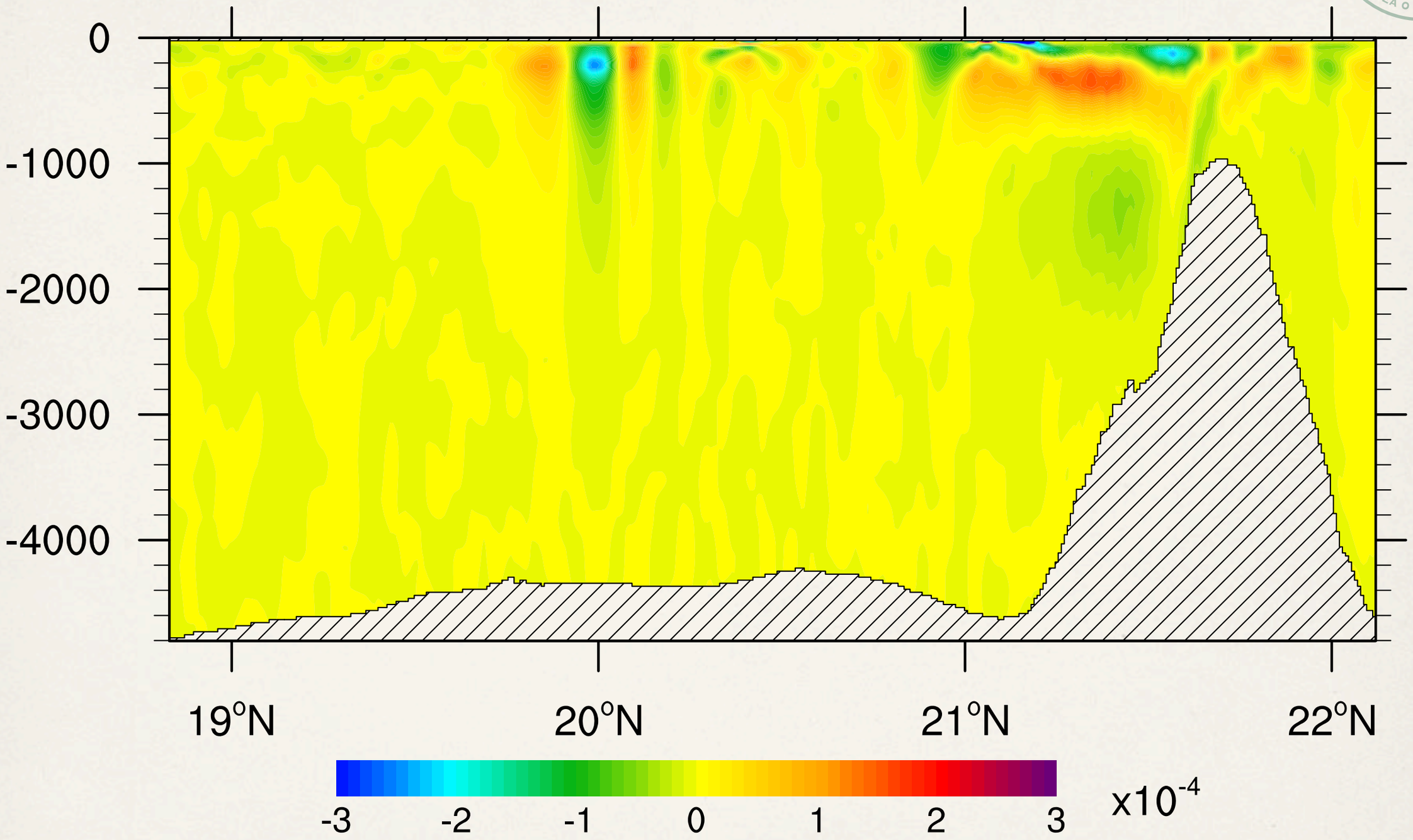
	Temp	Salt	Depth
Glider	9%	5%	0-150m
	32%	42%	150-500m
Profiles	27%	7%	0-150m
	50%	15%	150-500m
		Velocity	
ADCP		21%	0-150m
		59%	150-500m

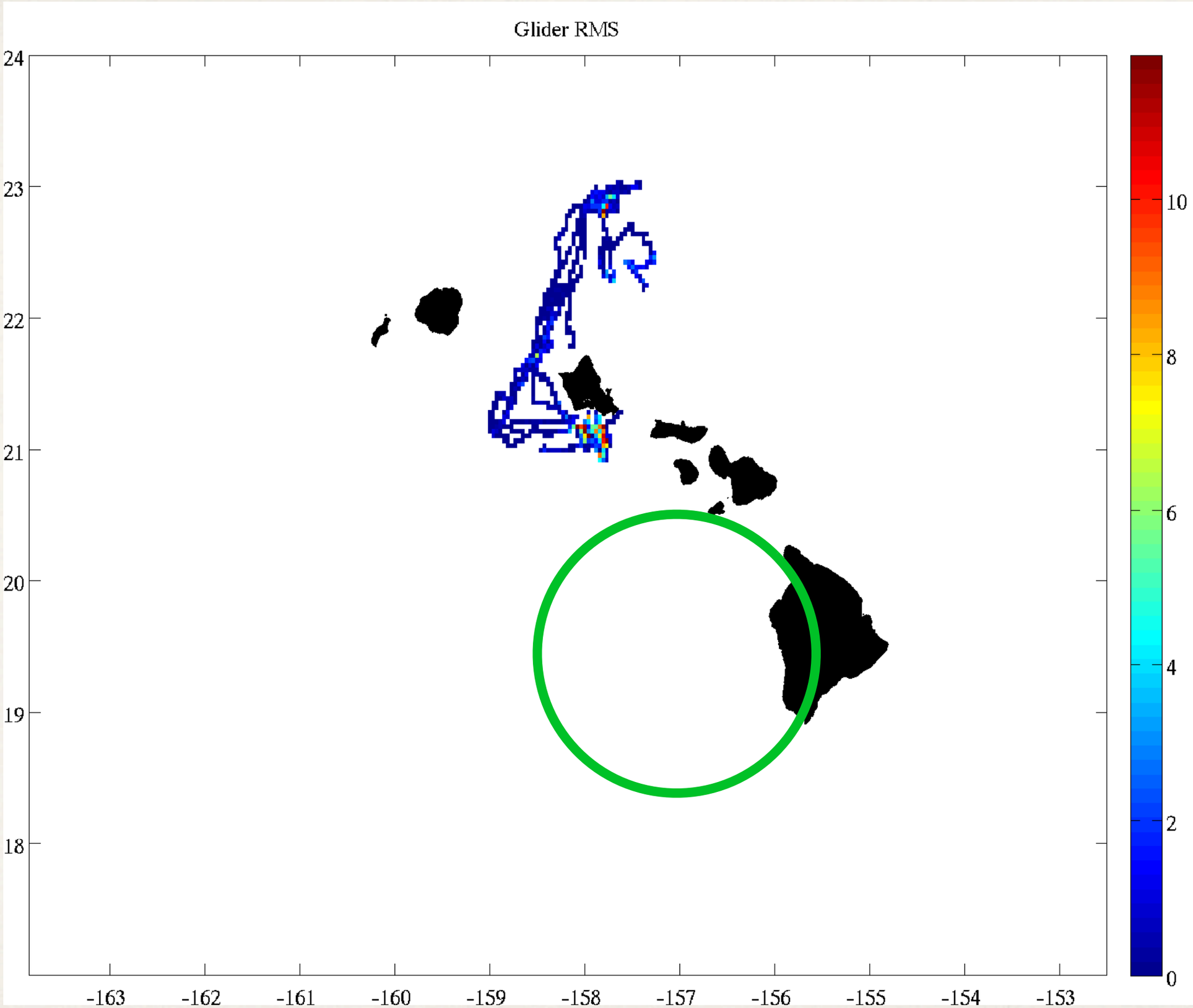

Glider RMS
24
23
22
21
20
19
18
-163
-162
-161
-160
-159
-158
-157
-156
-155
-154
-153
10
8
6
4
2
0

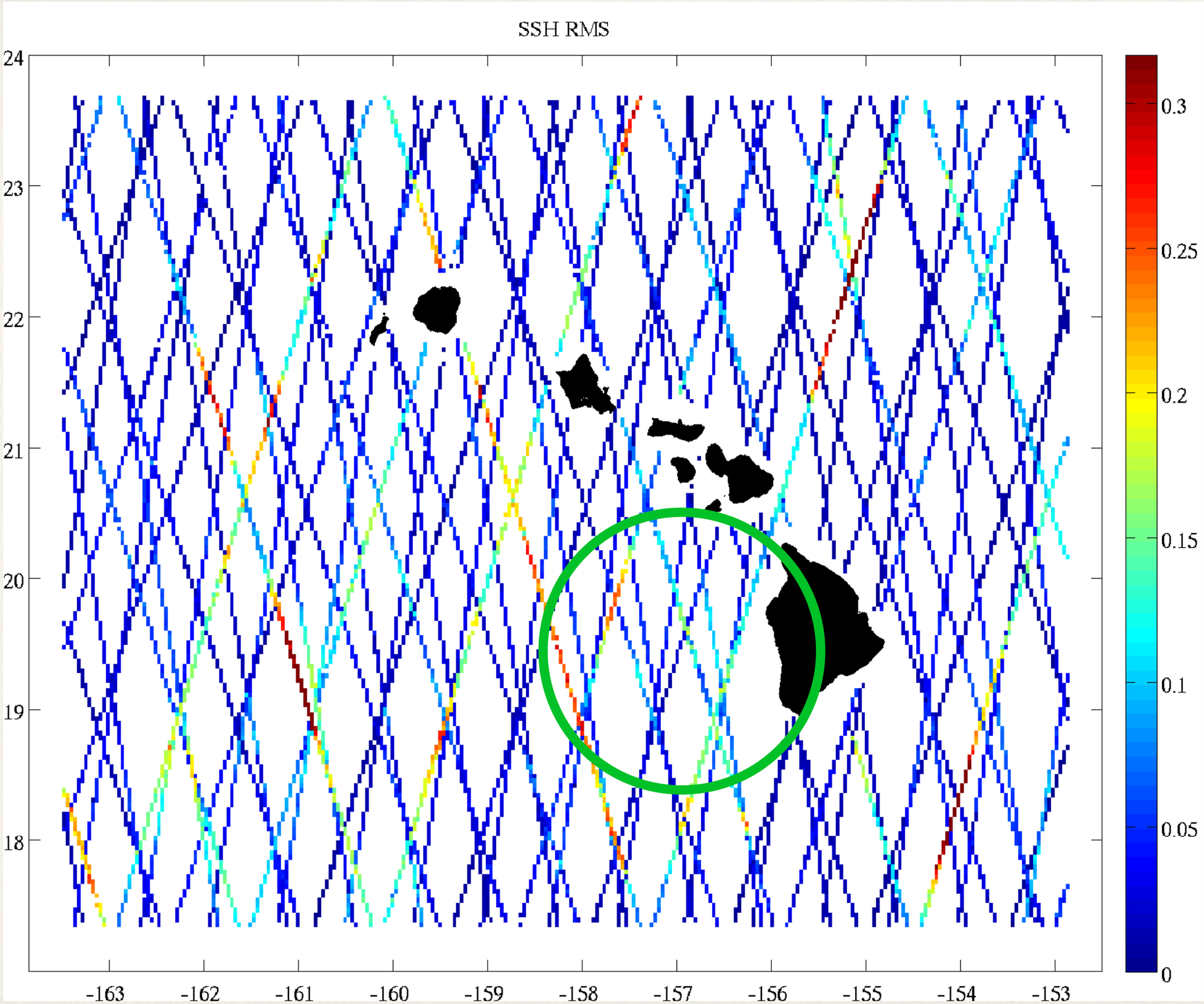

0
-1000
-2000
-3000
-4000
19°N
20°N
21°N
22°N
-3
-2
-1
0
1
2
3
x10-4

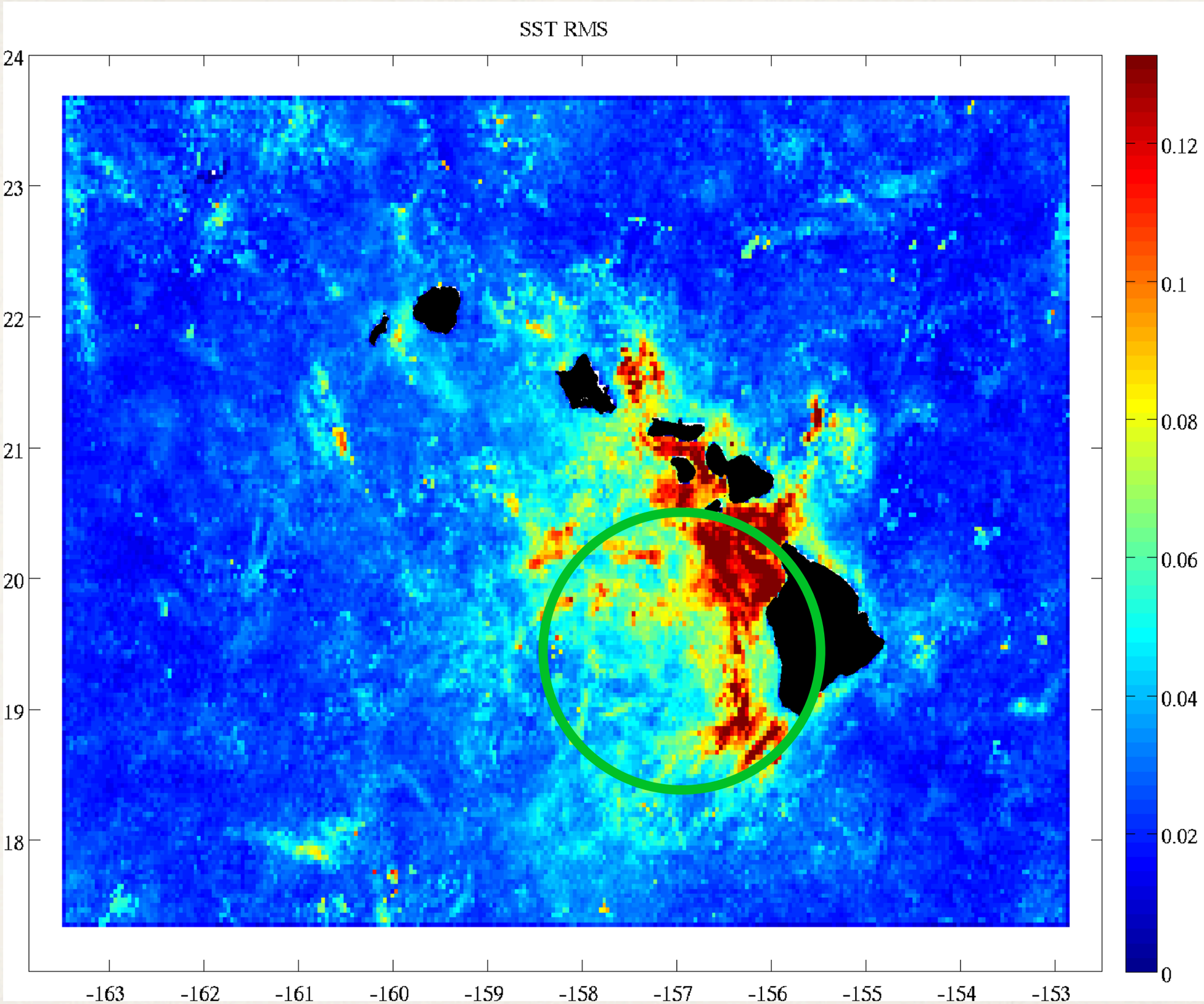

0
-1000
-2000
-3000
-4000
19°N
20°N
21°N
22°N
-3
-2
-1
0
1
2
3
x10-4


0
-1000
-2000
-3000
-4000
19°N
20°N
21°N
22°N
-3
-2
-1
0
1
2
3
x10-4


0
-1000
-2000
-3000
-4000
19°N
20°N
21°N
22°N
-3
-2
-1
0
1
2
3
x10-4


Glider RMS
24
23
22
21
20
19
18
-163
-162
-161
-160
-159
-158
-157
-156
-155
-154
-153
10
8
6
4
2
0


SSH RMS
24
23
22
21
20
19
18
-163
-162
-161
-160
-159
-158
-157
-156
-155
-154
-153
0.3
0.25
0.2
0.15
0.1
0.05
0


SST RMS
24
23
22
21
20
19
18
-163
-162
-161
-160
-159
-158
-157
-156
-155
-154
-153
0.12
0.1
0.08
0.06
0.04
0.02
0

Obs—Model Covariance

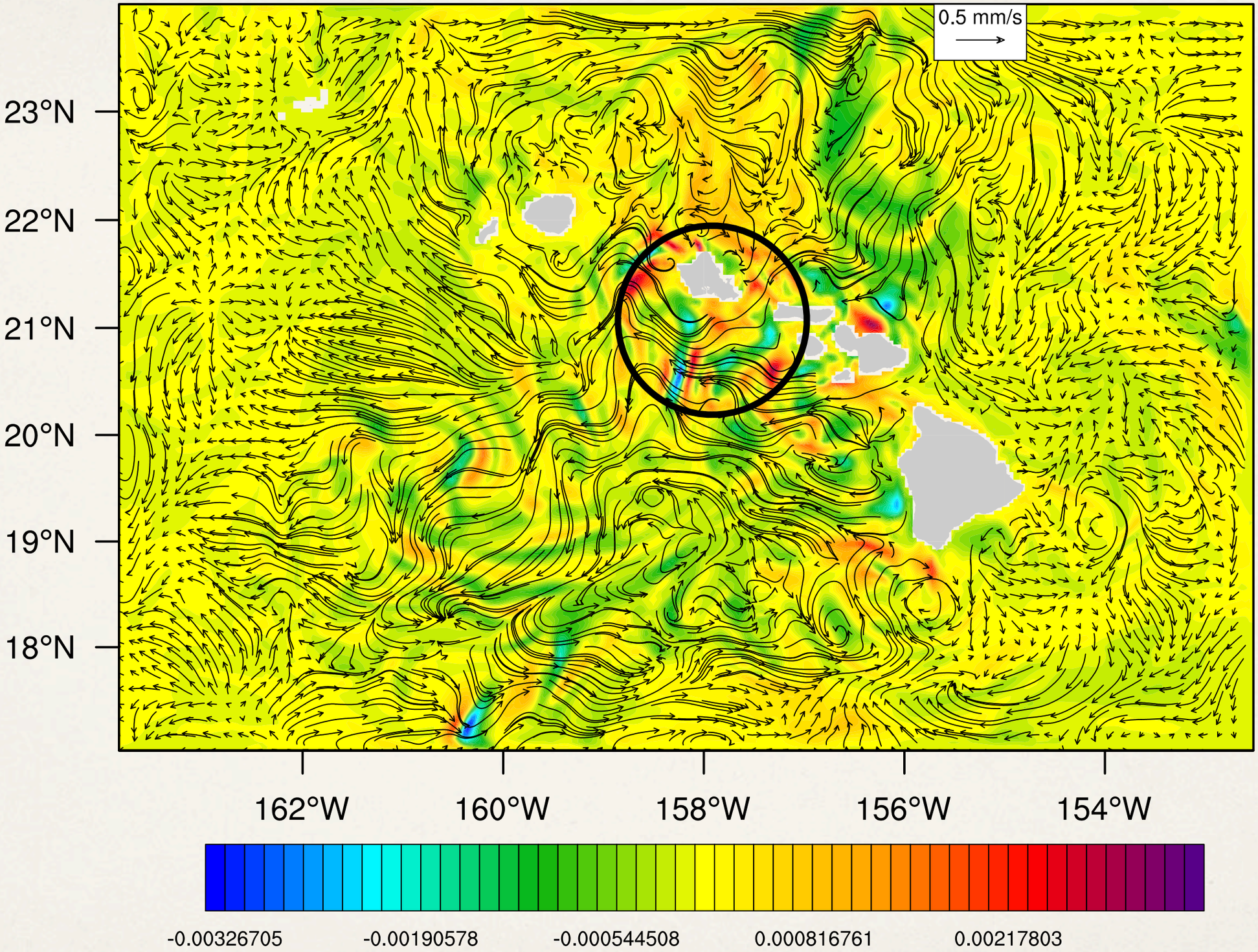
- Recall from the data assimilation,

$$\mathbf{x}_a - \mathbf{x}_b = \mathbf{B}\mathbf{G}^T \left(\mathbf{G}\mathbf{B}\mathbf{G}^T + \mathbf{R} \right)^{-1} \mathbf{d}$$

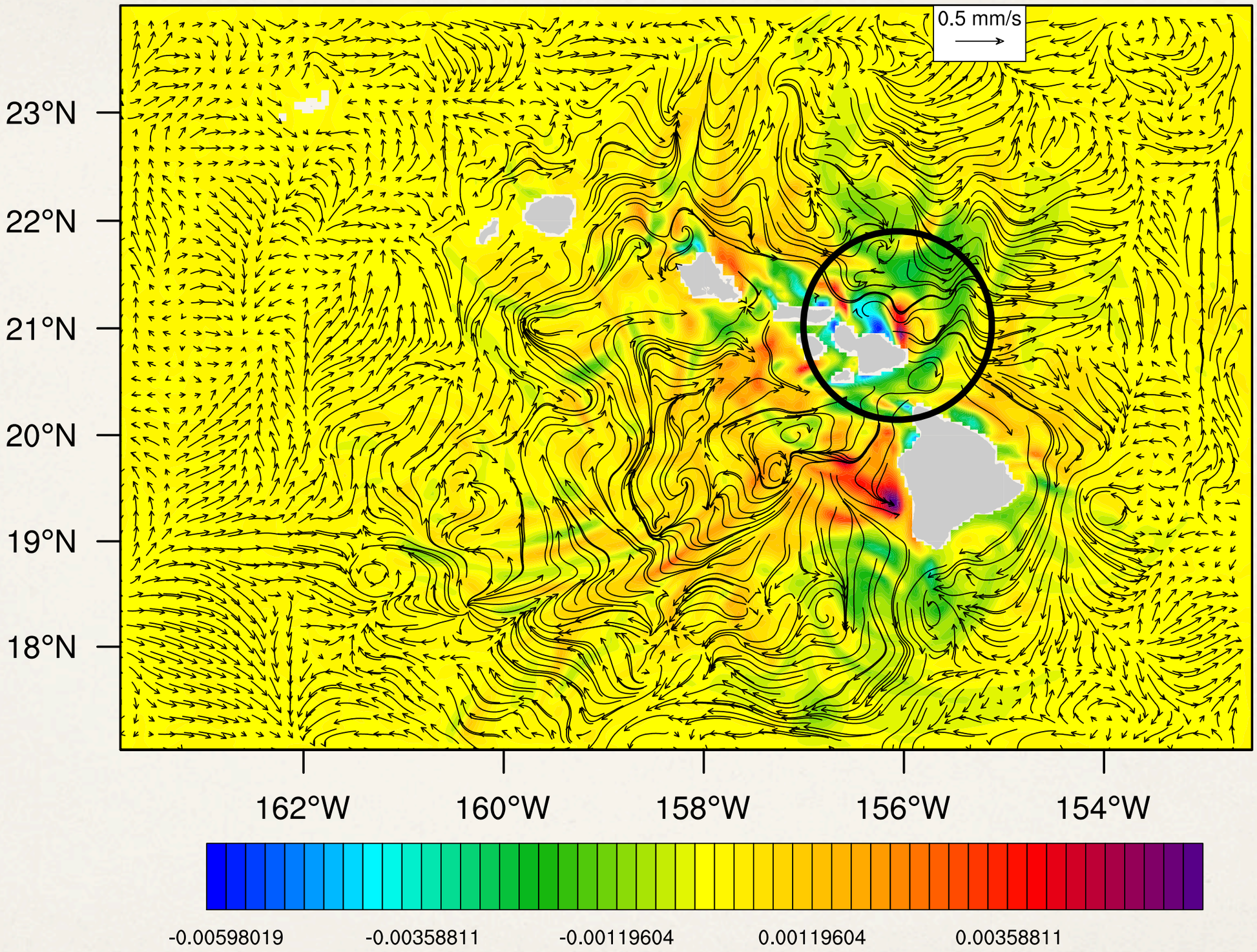
- The covariance between the observation and the ocean is propagted by the dynamics via:

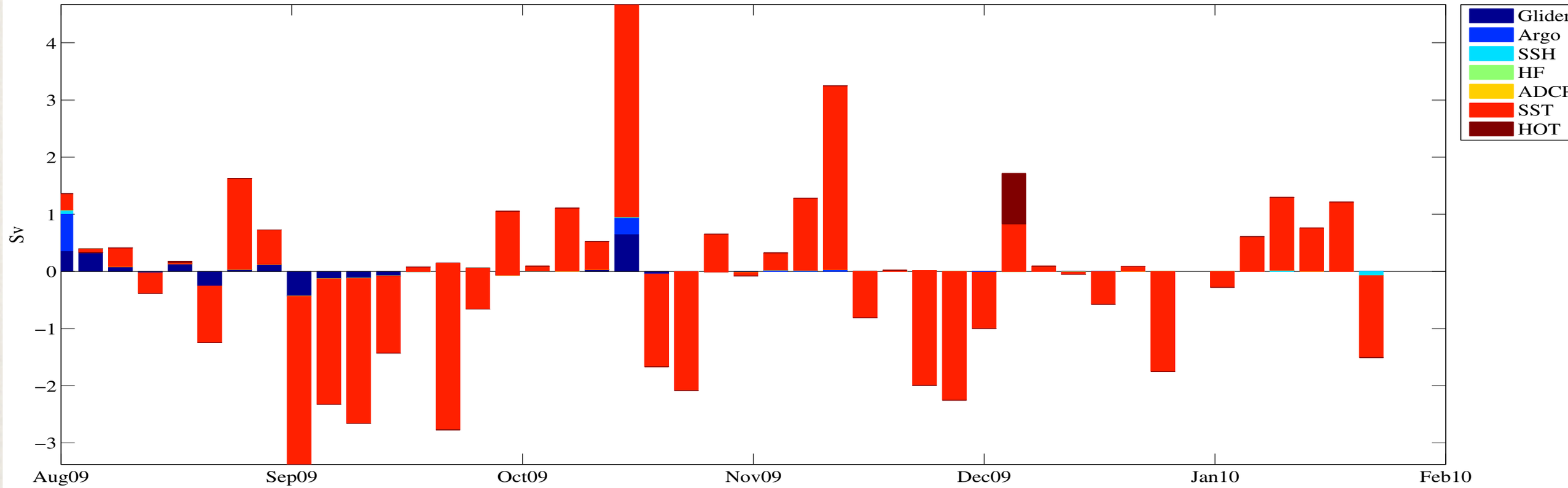
$$\left(\mathbf{G}\mathbf{B}\mathbf{G}^T + \mathbf{R} \right) \delta$$

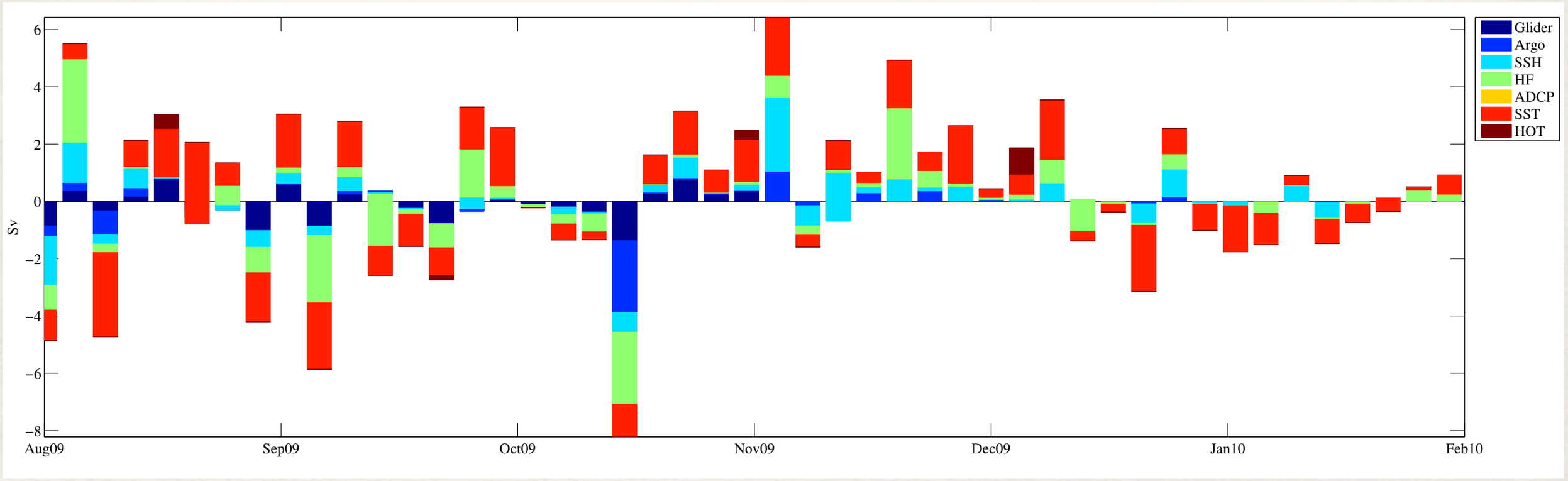
Glider

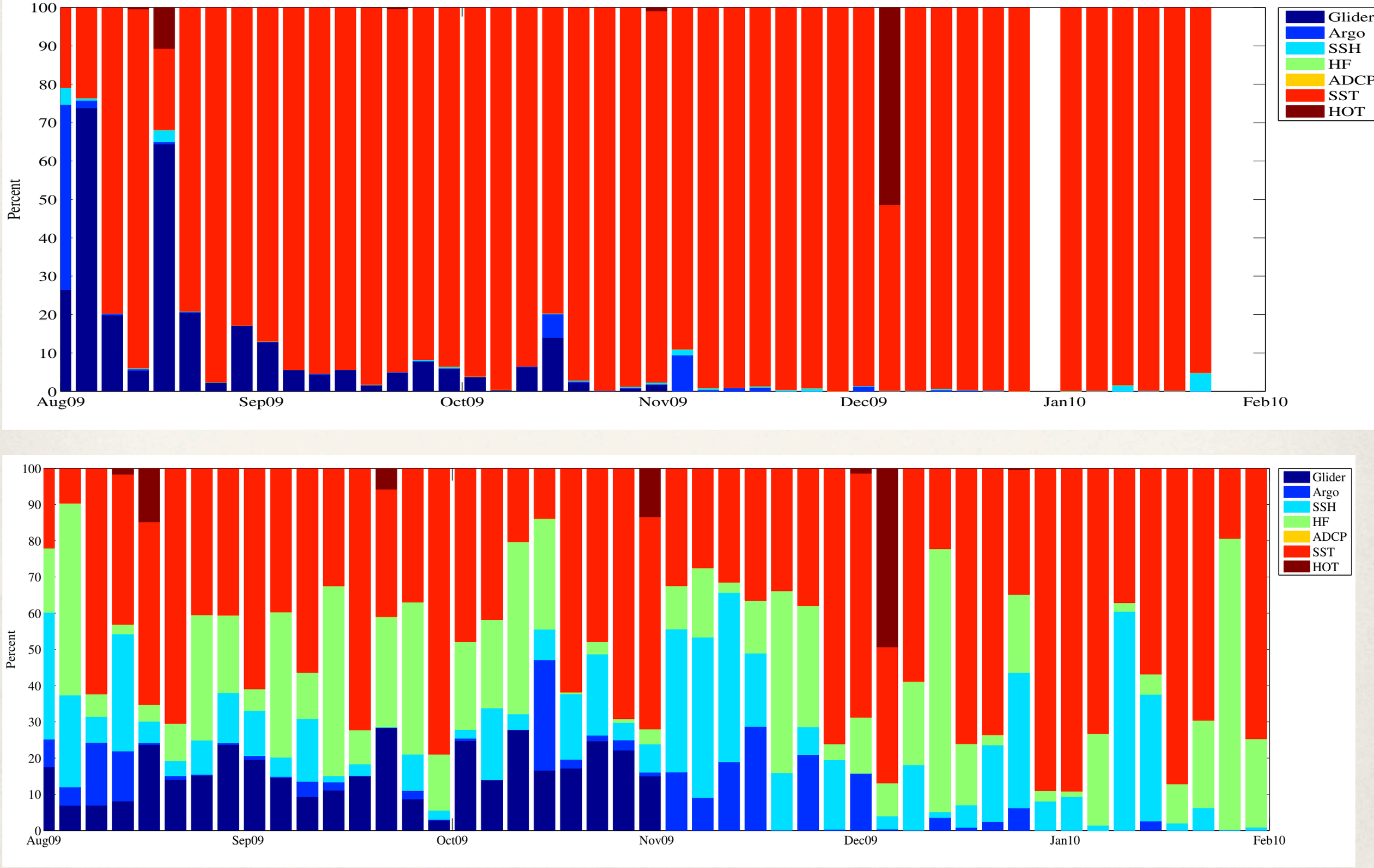

0.5 mm/s
23°N
22°N
21°N
20°N
19°N
18°N
162°W
160°W
158°W
156°W
154°W
-0.00326705
-0.00190578
-0.000544508
0.000816761
0.00217803

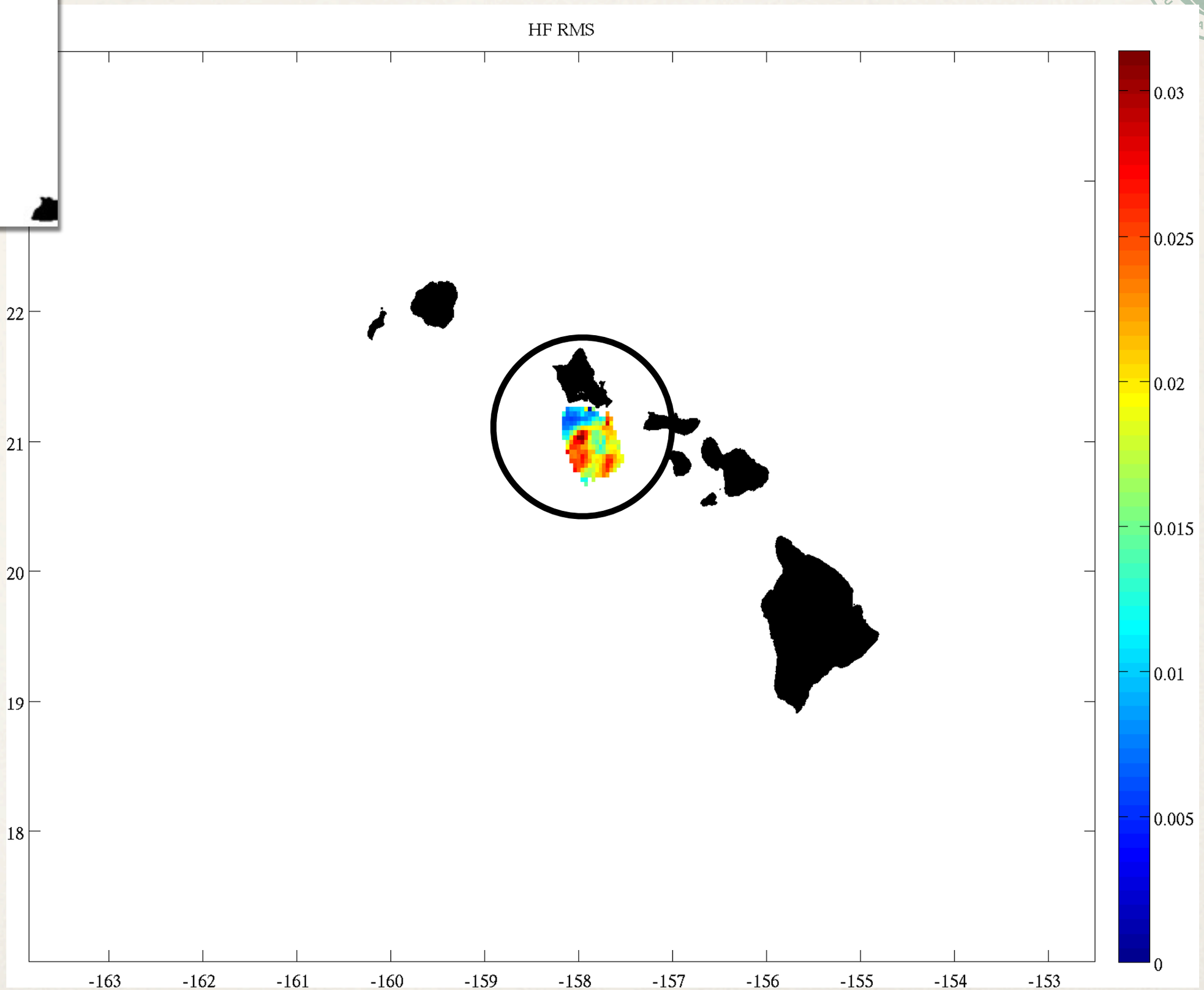
SST


0.5 mm/s
23°N
22°N
21°N
20°N
19°N
18°N
162°W
160°W
158°W
156°W
154°W
-0.00598019
-0.00358811
-0.00119604
0.00119604
0.00358811

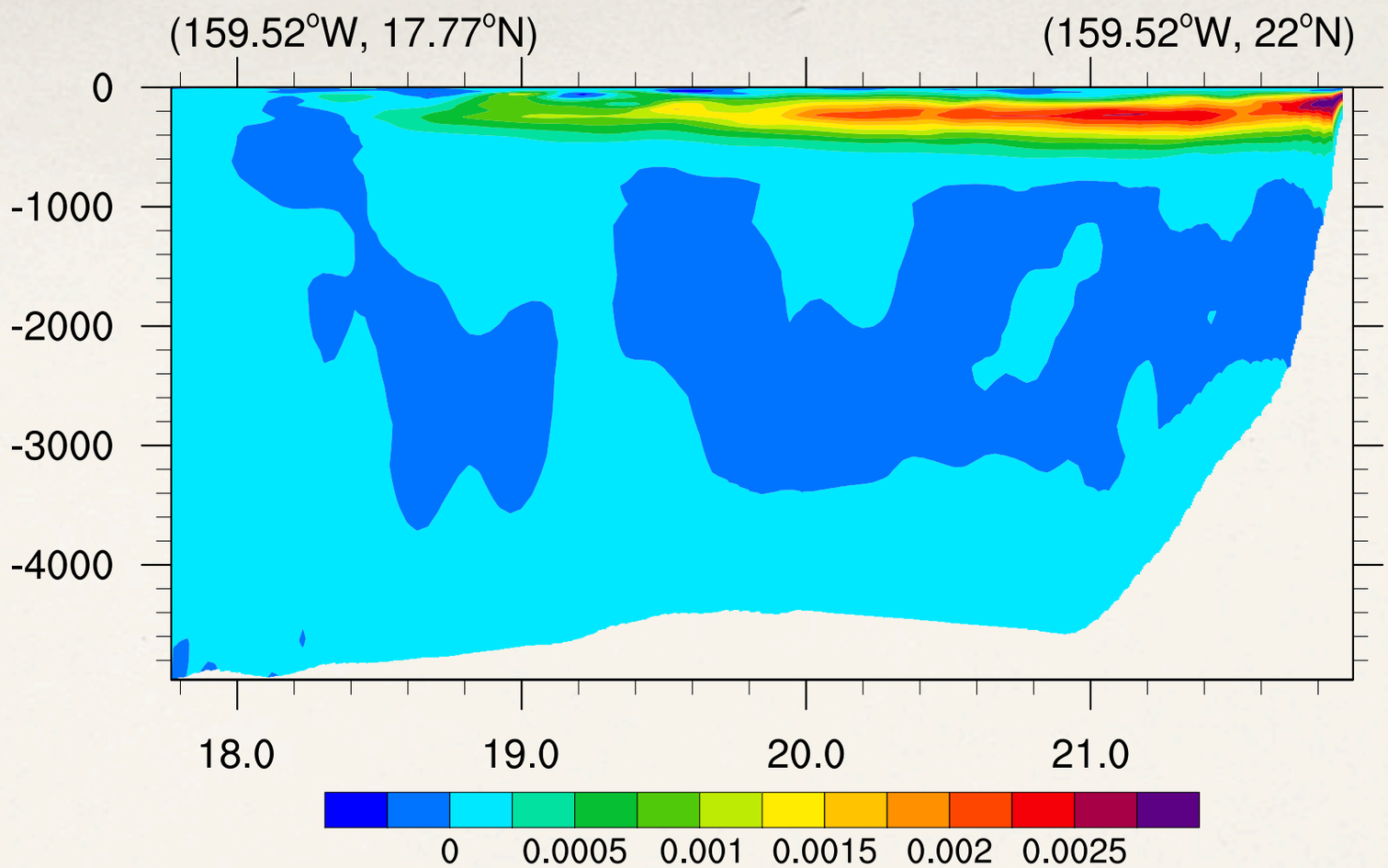

Sv
4
3
2
1
0
−1
−2
−3
Aug09
Sep09
Oct09
Nov09
Dec09
Jan10
Feb10
Glider
Argo
SSH
HF
ADCP
SST
HOT


Sv
6
4
2
0
−2
−4
−6
−8
Aug09
Sep09
Oct09
Nov09
Dec09
Jan10
Feb10
Glider
Argo
SSH
HF
ADCP
SST
HOT

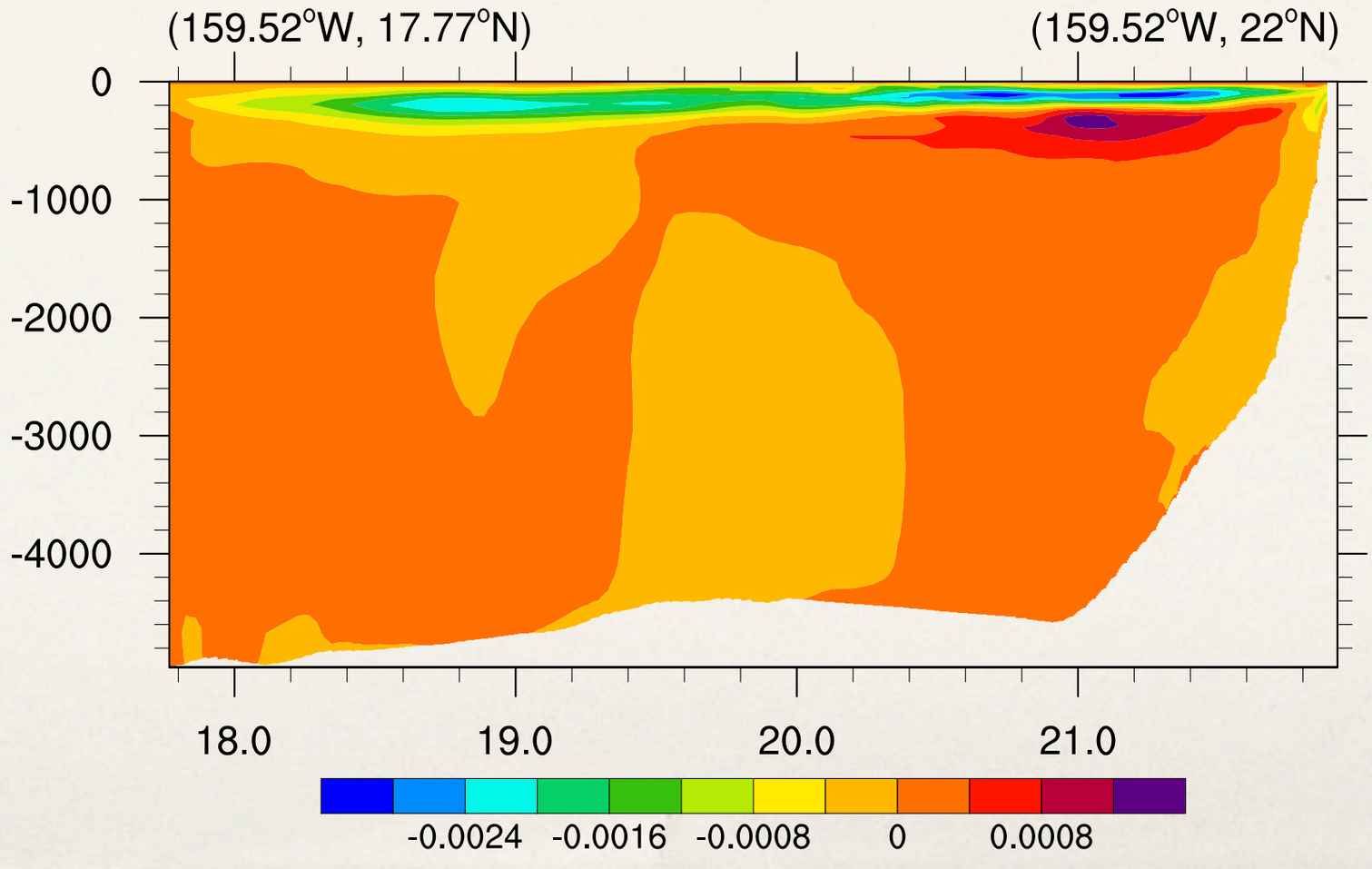

Percent
100
90
80
70
60
50
40
30
20
10
0
Aug09
Sep09
Oct09
Nov09
Dec09
Jan10
Feb10
Glider
Argo
SSH
HF
ADCP
SST
HOT

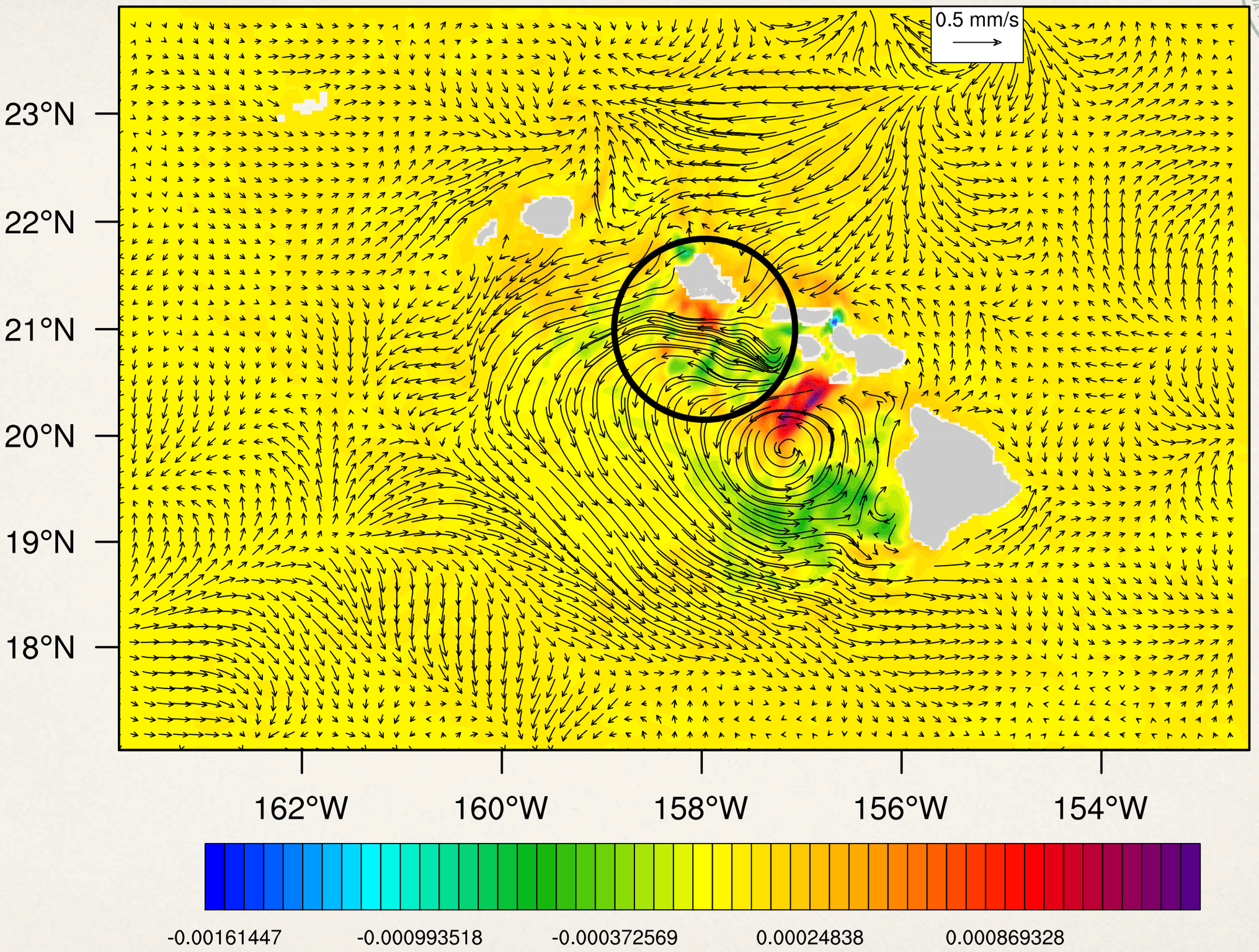

HF RMS
22
21
20
19
18
-163
-162
-161
-160
-159
-158
-157
-156
-155
-154
-153
0.03
0.025
0.02
0.015
0.01
0.005
0

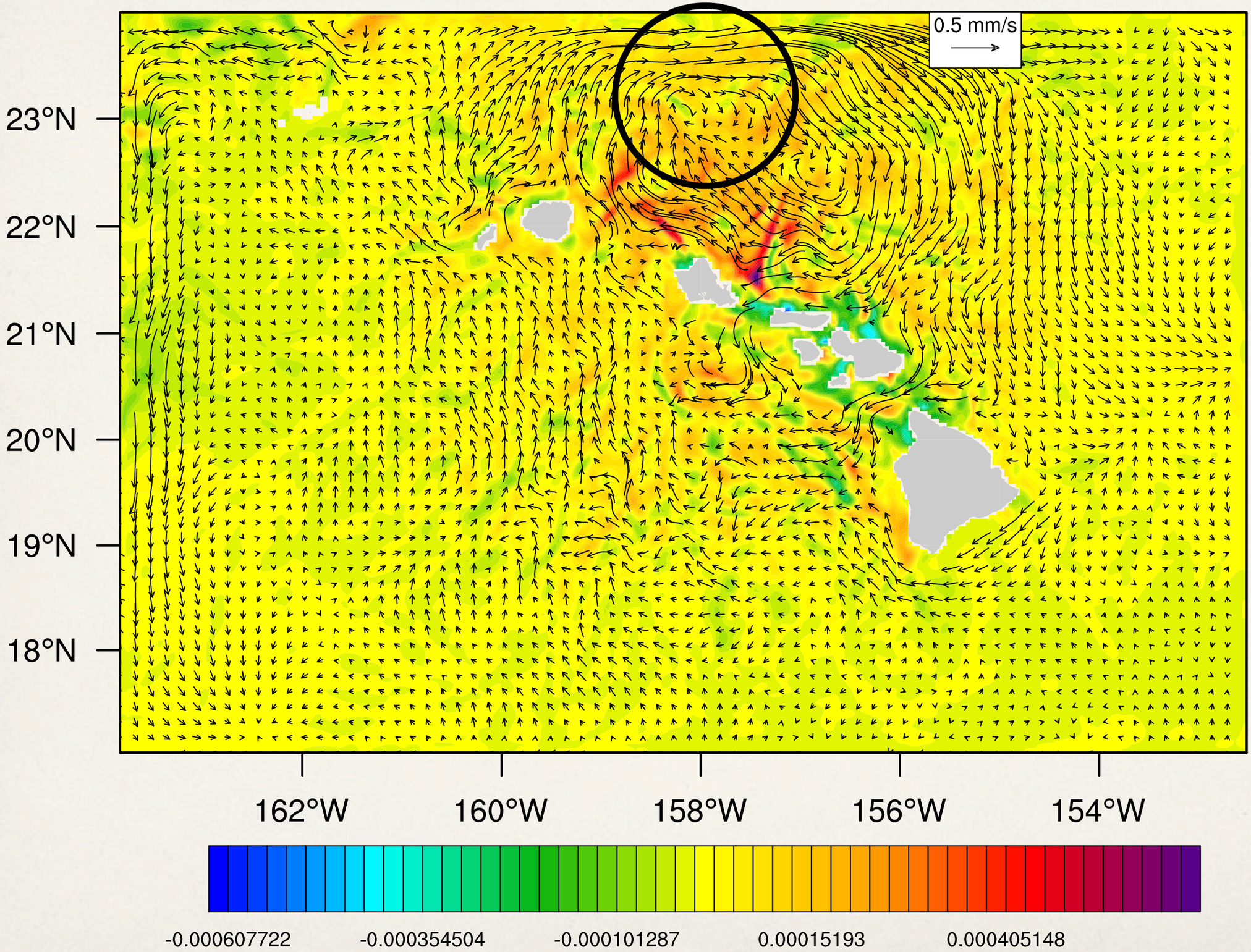
HOT


(159.52°W, 17.77°N)
(159.52°W, 22°N)
0
-1000
-2000
-3000
-4000
18.0
19.0
20.0
21.0
0
0.0005
0.001
0.0015
0.002
0.0025

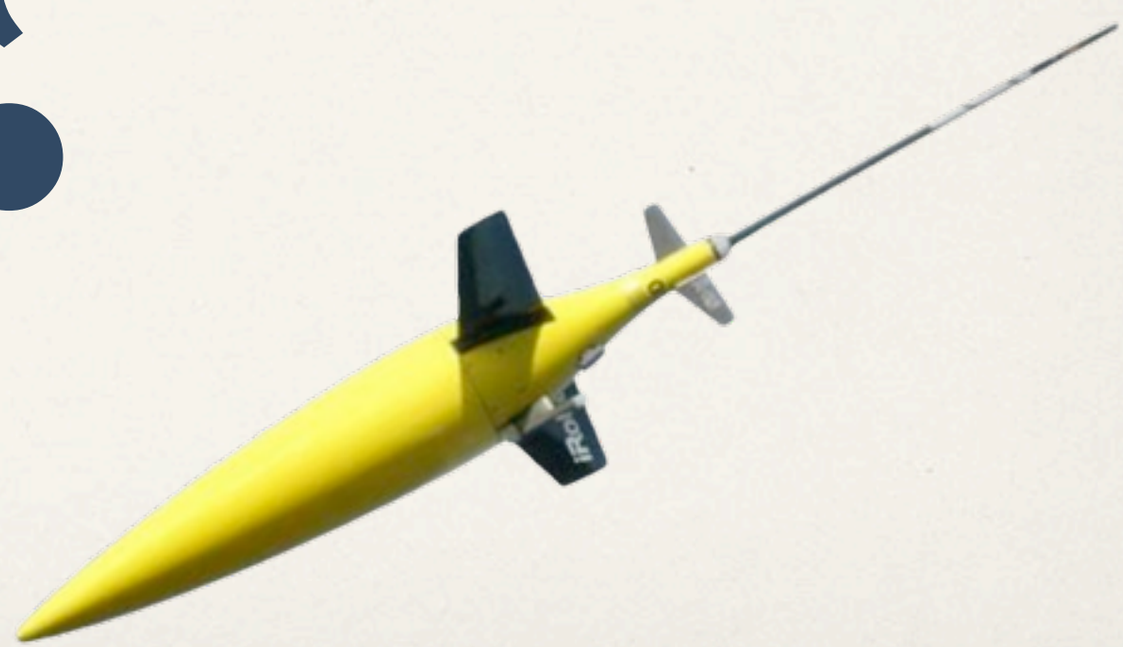
HF


(159.52°W, 17.77°N)
(159.52°W, 22°N)
0
-1000
-2000
-3000
-4000
18.0
19.0
20.0
21.0
-0.0024
-0.0016
-0.0008
0
0.0008


0.5 mm/s
23°N
22°N
21°N
20°N
19°N
18°N
162°W
160°W
158°W
156°W
154°W
-0.00161447
-0.000993518
-0.000372569
0.00024838
0.000869328


0.5 mm/s
23°N
22°N
21°N
20°N
19°N
18°N
162°W
160°W
158°W
156°W
154°W
-0.000607722
-0.000354504
-0.000101287
0.00015193
0.000405148

?

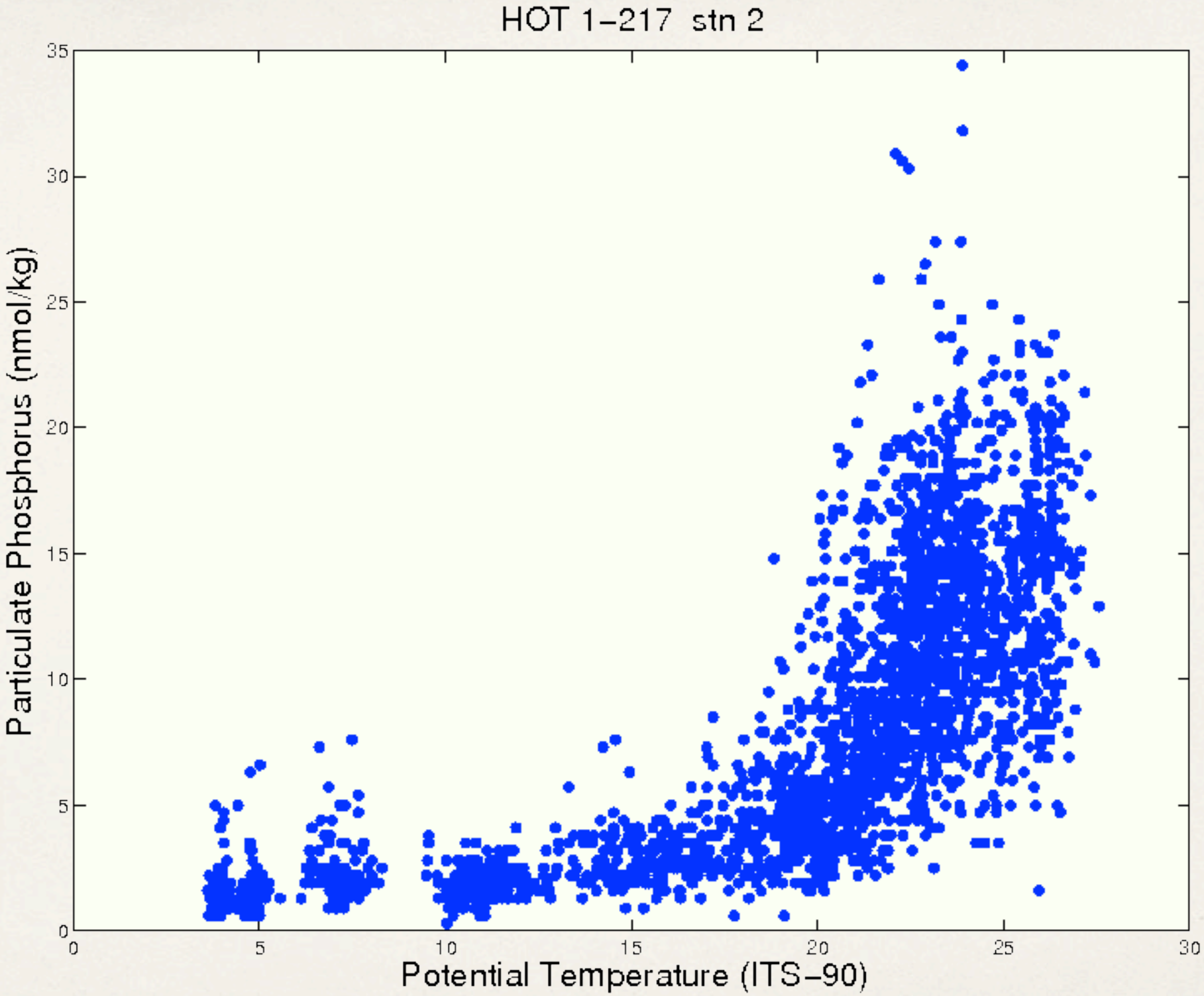


BAD WEATHER? THEN SUE THE WEATHERMAN!

PART I: LEGAL LIABILITY FOR PUBLIC SECTOR FORECASTS

By Roberta Klein and Roger A. Pielke Jr.

How liable is the federal or state government for inaccurate or inadequate weather forecasts?


HOT 1–217 stn 2
Particulate Phosphorus (nmol/kg)
Potential Temperature (ITS–90)
0
5
10
15
20
25
30
35