El Niño Phenomenon in SODA Data

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数学使世界变得简单

Math makes the world simple

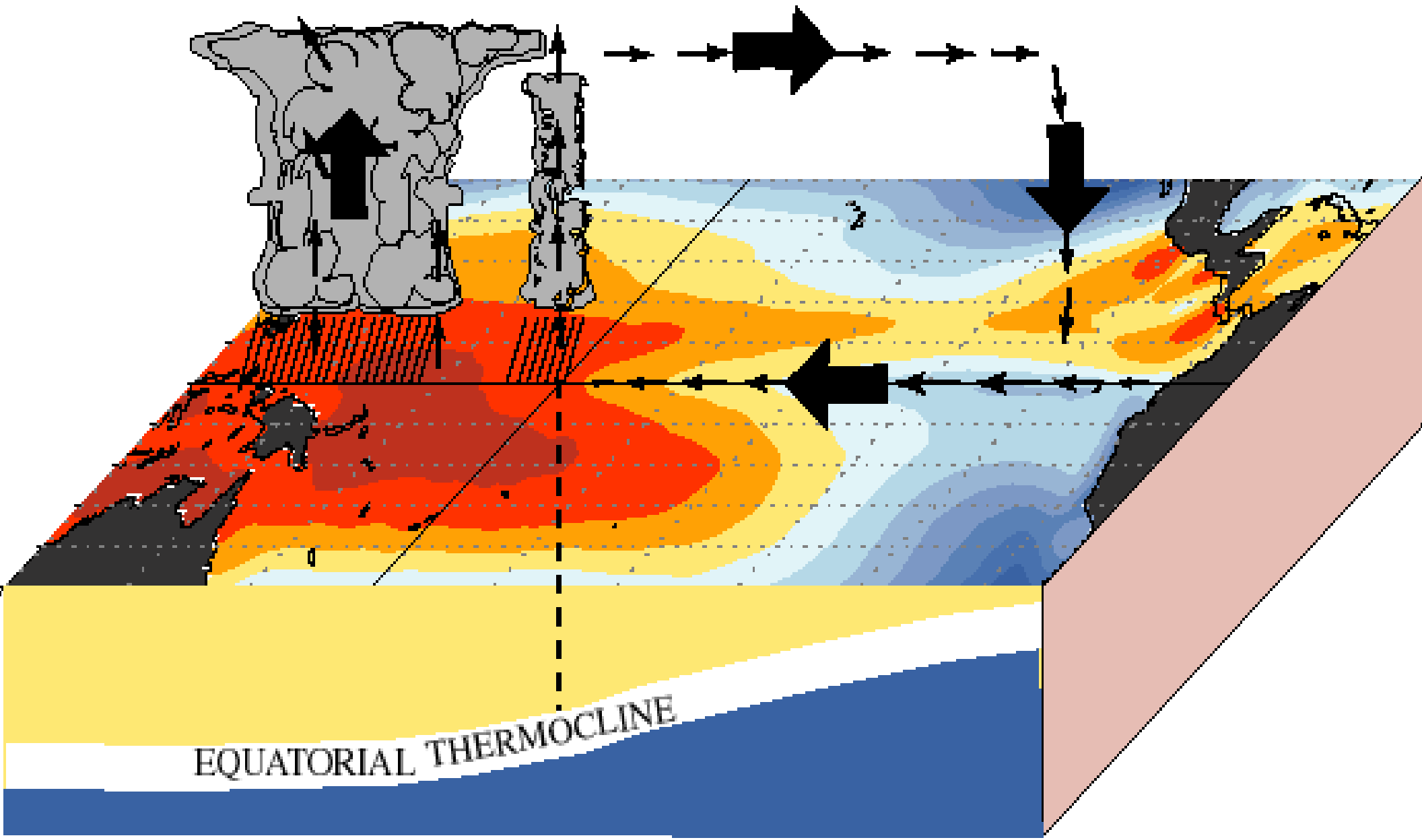
—— 陈省身

S S Chen

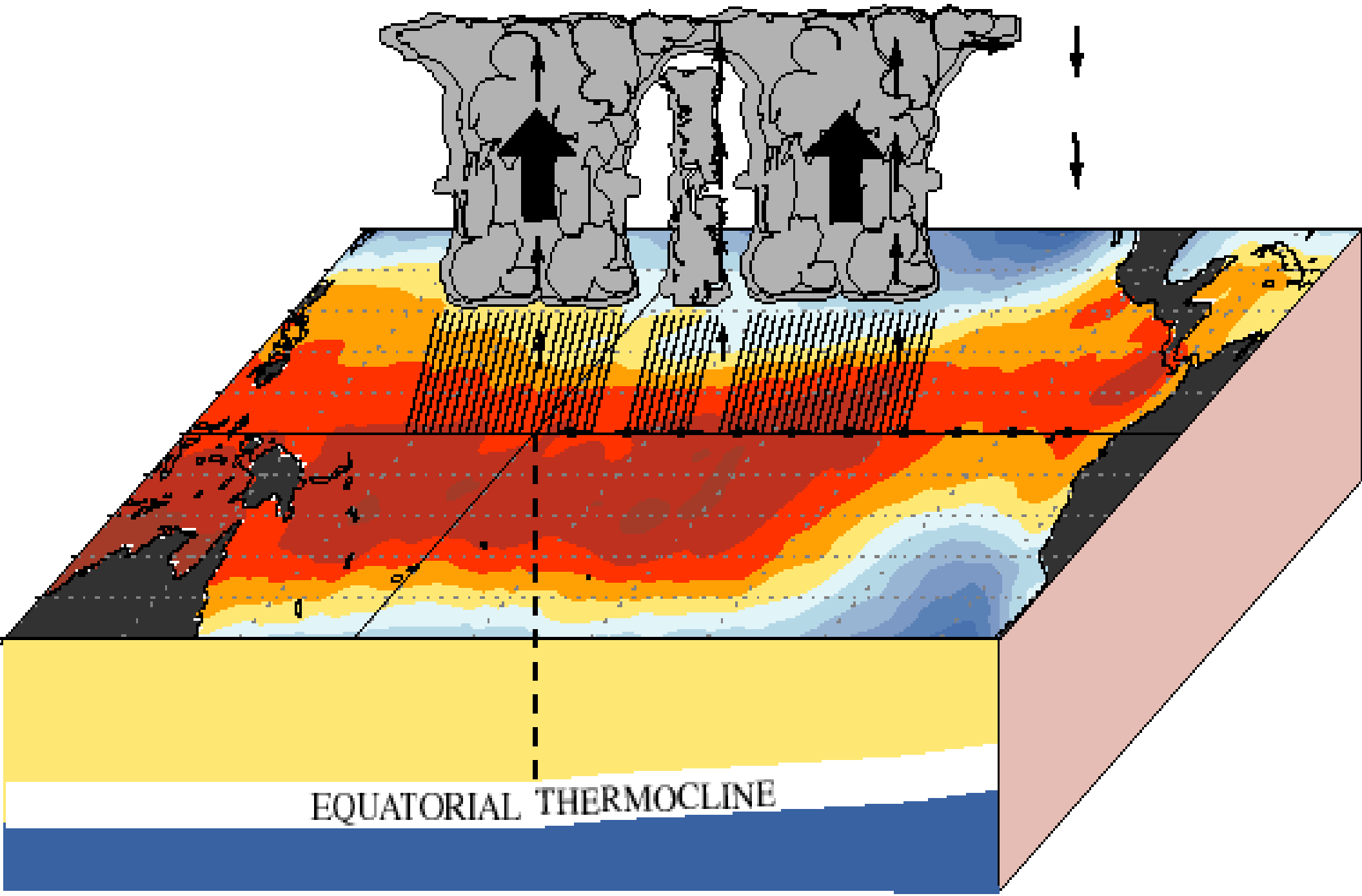
厄尔尼诺现象

El Nino Phenomenon

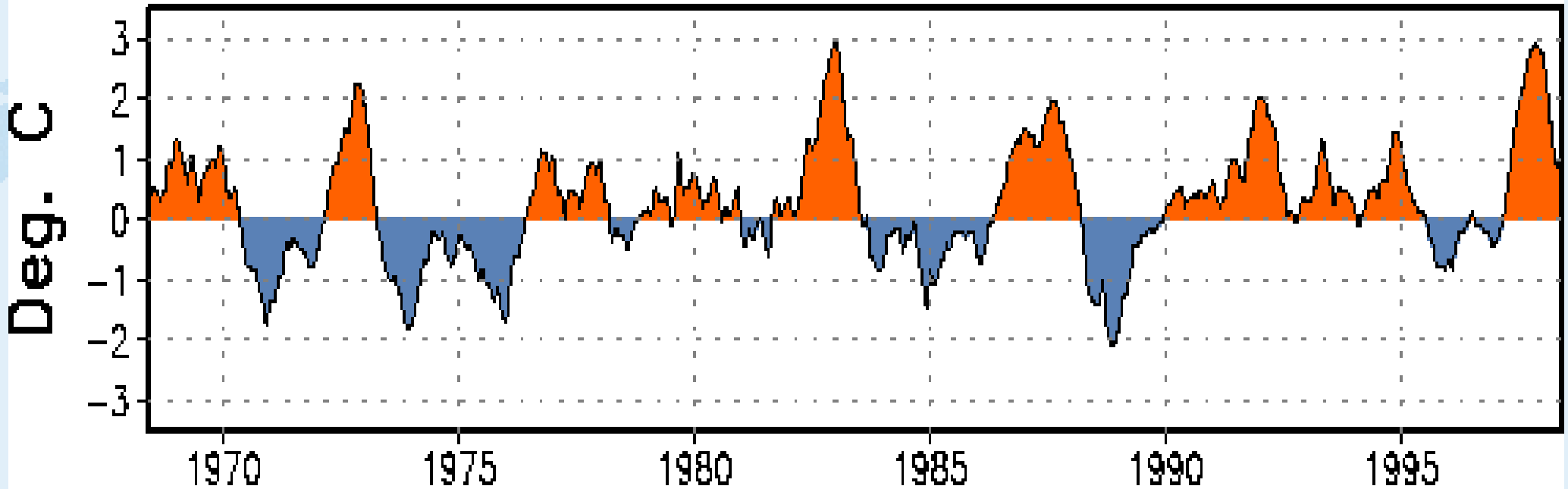
December - February Normal Conditions



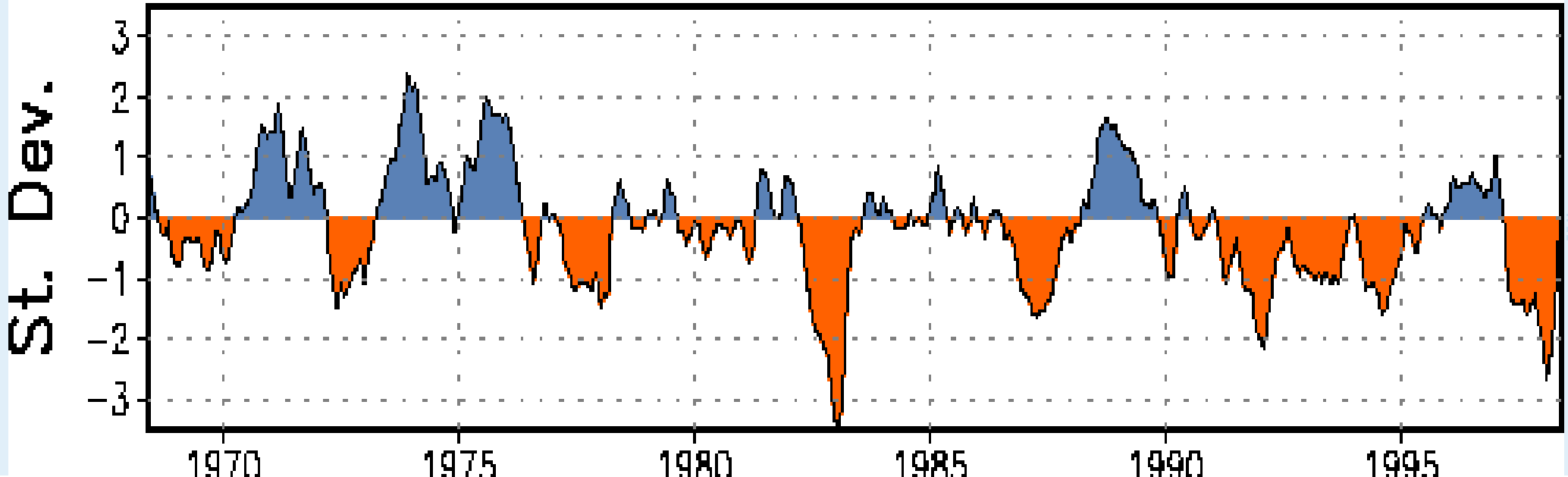
December - February El Niño Conditions



Ocean Temperature Departures (°C) for Niño 3.4
(5°N-5°S, 170°W-120°W)



Tahiti - Darwin SOI (3 month-running mean)



ENSO Physics

Interaction between the tropical ocean and atmosphere produces the largest interannual climate signal ENSO (Charney,1969).

Self-sustained Hypothesis (Bjerknes, 1969)

Relaxation Theory (K. Wyrtki, 1982)

Delayed oscillator (Suarez, 1988; Battisti et al. 1989)

Recharge and Discharge oscillator (F. Jin, 1997）

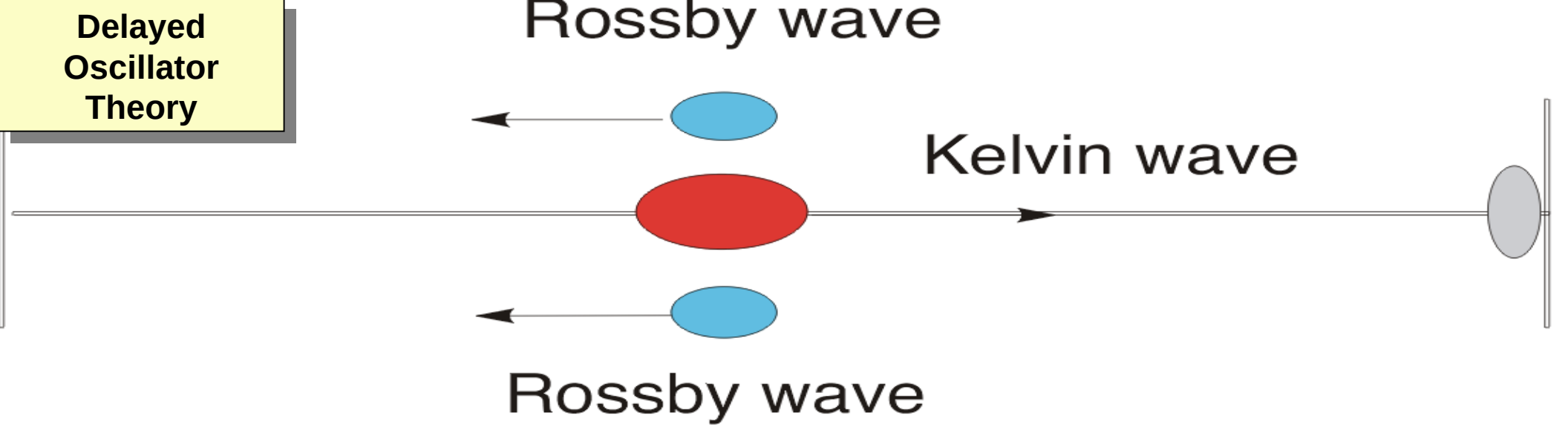
Two air circulation gearing (G. Wu&W. Men, 1998)

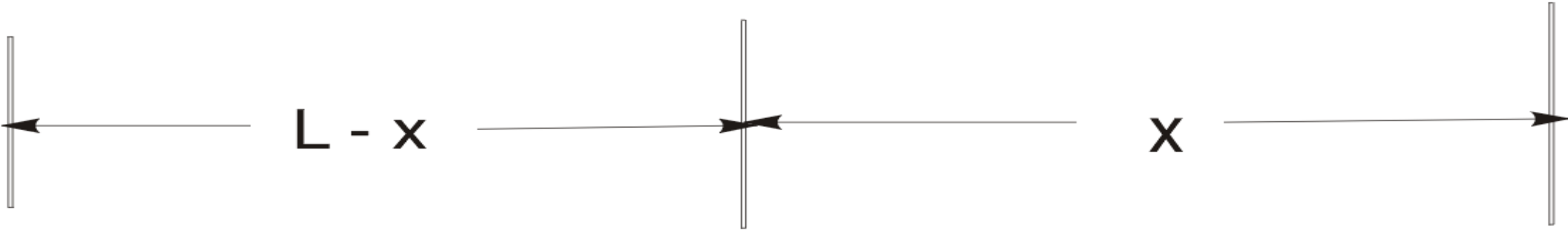
Variation source in WP thermocline (J. Cao, 1999)

EAWM triggering (C. Li, 1988)

Formation mechanism of three factors (Cui at al., 2001)

Delayed Oscillator Theory





t = 0 westerly anomaly

$t1 = x / Ck$ $t2 = (L-x) / Cr + L / Ck$

$T = t2 - t1 = (L-x) * (1/Cr + 1/Ck)$

thus: $x \downarrow$ $T \uparrow$

Prospectus for a Pacific Basinwide Extended Climate Study

R. Lukas, R. Davis, W. Kessler, et al.

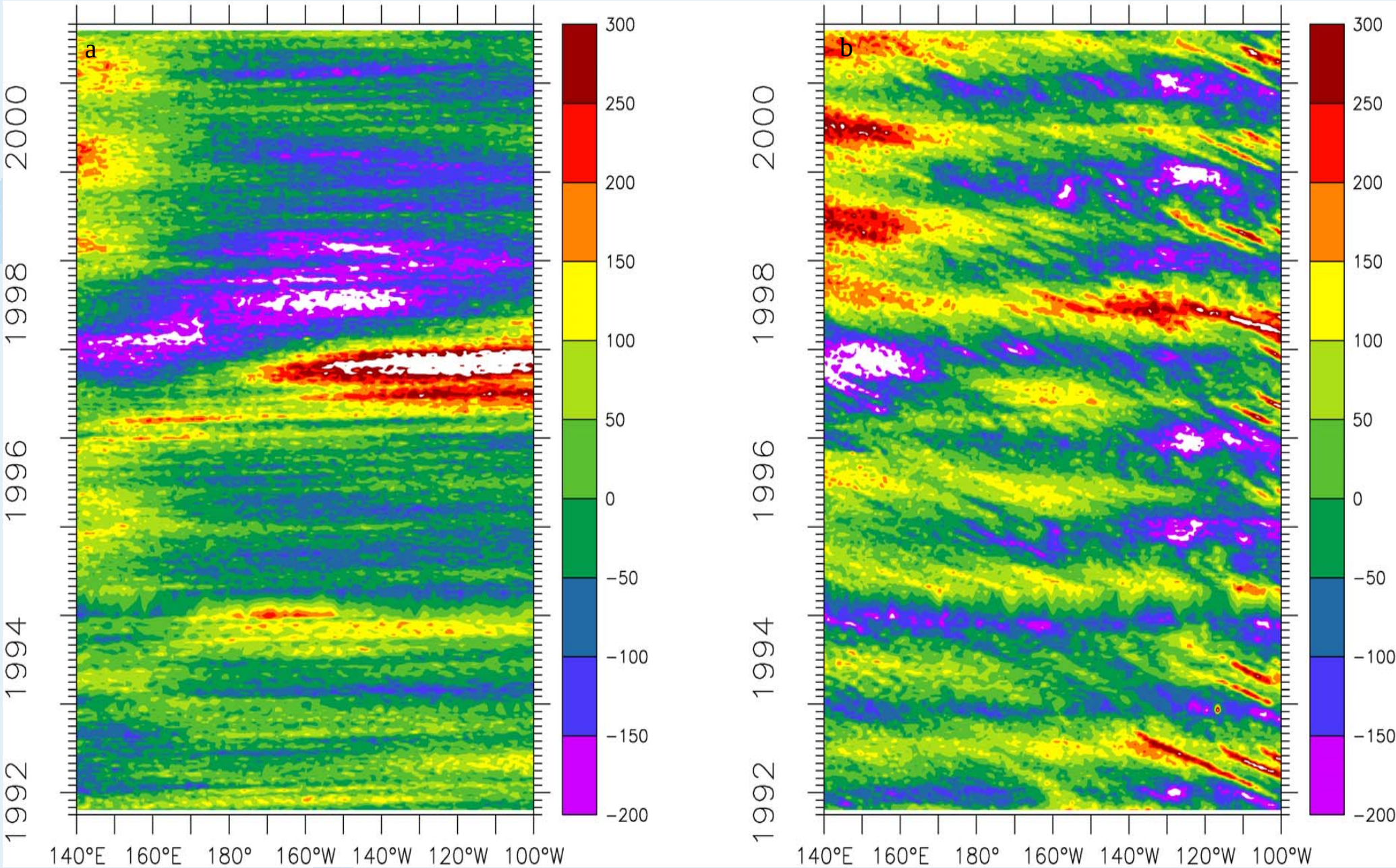
Version 3.1

September 1998

Electronic version available.

http://www.soest.hawaii.edu/~rlukas/PBECS/pbecs.htm

The delayed oscillator models had important successes in predicting the 1986-87 and 1991-1992 El Niño events almost a year in advance, but have largely failed to explain the unusual behavior of the ENSO cycle since then. In particular there has been little evidence that Rossby wave reflection played a major part in the initiation of the mid-1990's warm events, and this absence probably contributed to the lack of forecast success by delayed oscillator models. The focus of attention on ENSO cycle is shifting from wave dynamics towards the more difficult problems of the heat balance in the upper tropical Pacific and how it interacts with the overlying atmosphere.



Remote sensed tentad sea level anomaly transport
a. equator; b. 10ºN
(cited from Dr. Qiao's thesis)

Extended Associate Pattern Analysis

Three Key Points of EAPA

Associate pattern (or regression distribution) has been popularly used in climate studies.

However, it can not tell how much itself is correlated to the given time series. So associate pattern analysis may not be efficient to extract useful information for statistical analyses, especially for larger time lag analyses. In present paper, the EAPA method is adopted again with two more climate datasets to further study ENSO events, in which the ocean and atmosphere of middle and lower latitudes, instead of just tropical regions, are treated as a whole climate system.

Given time series X and variable field Y

$$X = \{ x(j) \mid j = 1, \ldots\ldots, n \}$$

$$Y = \{ y(i, j) \mid i = 1, \ldots\ldots, m;\ j = 1, \ldots\ldots, n \}$$

with zero mean (<X> = <Y> = 0). A space vector A

$$A = \{ a(i) \mid i = 1, \ldots\ldots, m \}$$

can always calculated by the least square method to suit the condition：

$$\sum_j \left[y(i, j) - a(i) \cdot x(j) \right]^2 = \min \qquad (1)$$

It physically means that the information given by X can be explained by its regression value a (I) at any space point i of variable field Y, therefore space vector A can used for the study on formation mechanism of time series X . A is called as X ‘s associate pattern in field Y.

1 Correlation between Given and Associate Time Series

If field Y is projected onto the direction of A, a new time series X' can be obtained, which is usually well correlated to the time series X, defined as X 's associate time series in field Y, so that the former can be used for the latter's simulation and forecast. The r (X, X') represents the precision of the simulation and forecast.

2 Explained Variance by Associate Pattern

The matrix product Y' of the column vector X'^T and unified row vector of A is defined as the associate field separated from the field Y by the time series X. At any space point i in the fields Y and Y', the standard deviation $\sigma_y(i)$、$\sigma_{y'}(i)$ can be easily calculated, The variance explained by associate pattern A can be written as

$$\mathrm{var}(i) = \frac{\sigma_{Y'}(i)}{\sigma_Y(i)} \cdot r(X, X') \cdot 100\%$$

3 Statistical Meaning of Associate Pattern

Taken Nino3 index as X and monthly SST (1950.01~2000.12) as Y , in which just 3 space points (a. 2.5ºN, 97.5ºW; b. 22.5ºN, 157.5ºW; c. 42.5ºN, 177.5ºW) are considered. Fig. 1 shows that the 14 El Niño and 9 La Niña extrema are extremely important for linear regression, no matter X and Y are positively (at point a.), negatively (at point c.) nor weakly (at point b.) correlated to each other. If fig. 4 is turned left or right side down, just like the top center of a fire work radiating strong rays of light, these extremum points (noted as j_k , k=1,…, 23) contribute the most part (about 95%) of linear regression value but others weakly shine below the center and their contributions to change this value are almost balanced to each other.

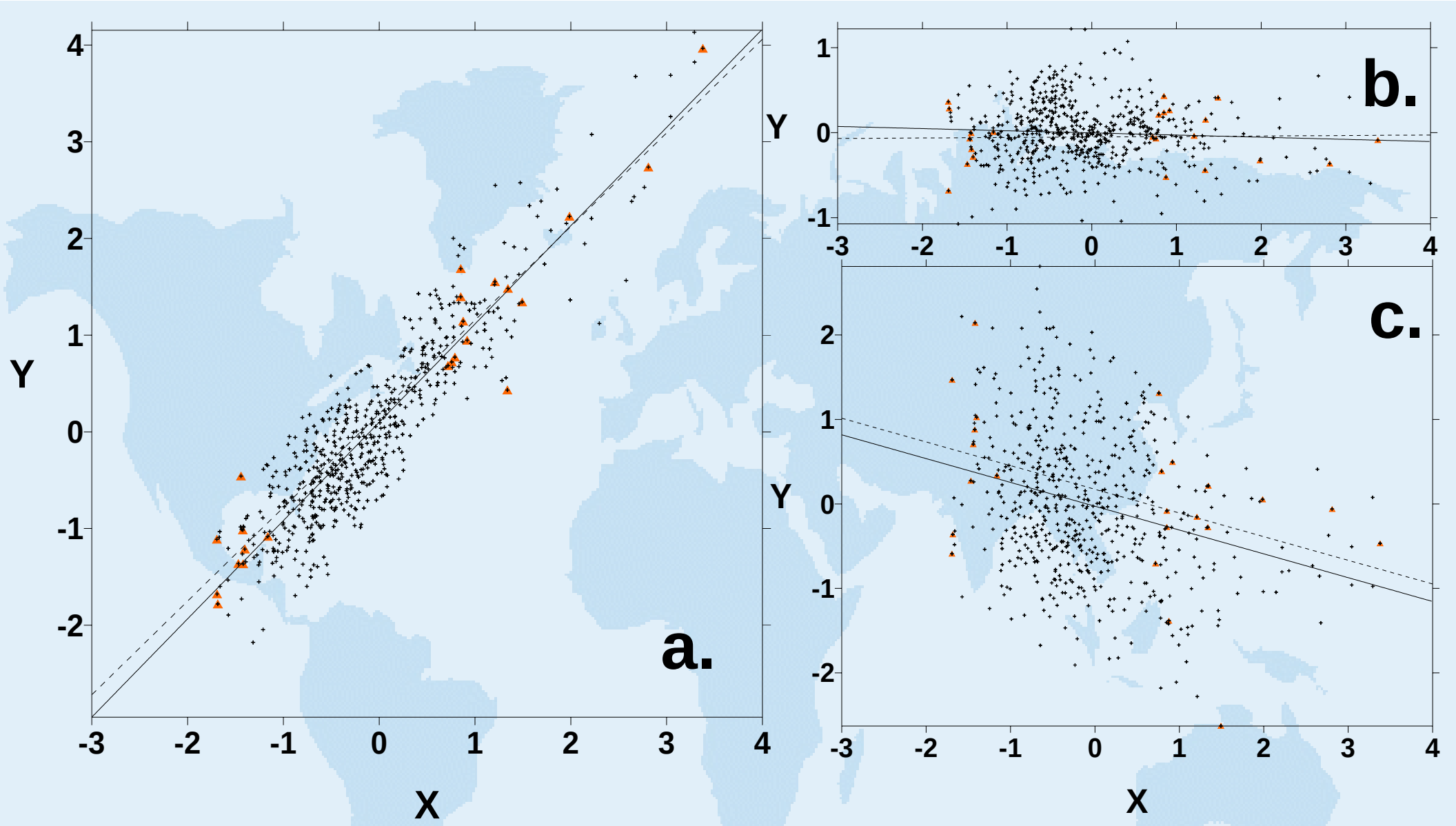


Fig. 1 Linear regressions between Nino3 index and SST at 3 points (small black + represents for all of points and bigger red ▲ for the 14 El Niño and 9 La Niña extrema; real line is the regression line for all points and dashed line for the extremum points).

The condition (1) indicates:

$$y(i, j) = a(i) \cdot x(j)$$

for any space *i* and time *j* under least squares meaning. As the reason mentioned above, specially,

$$y(i, j_k) = a(i) \cdot x(j_k),$$

so that

$$\langle\langle y(i, j_k)\rangle\rangle_k = a(i) \cdot \langle\langle x(j_k)\rangle\rangle_k$$

in which $\langle y(i, j_k)\rangle_k = \langle x(j_k)\rangle_k = 0$, if not remove the mean and

$$\langle\langle x(j_k)\rangle\rangle_k = \frac{\sum_k \mathrm{sgn}(x(j_k)) \cdot x(j_k)}{23}$$

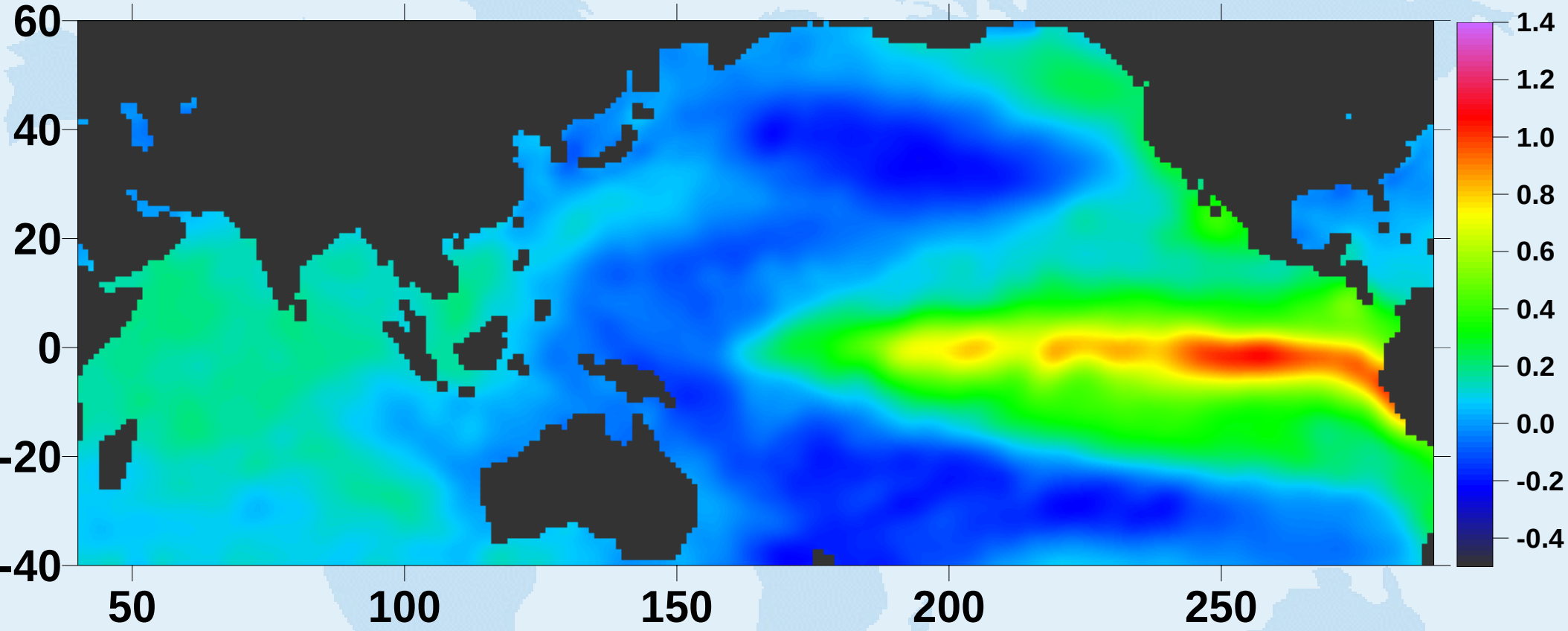
$$\langle\langle y(i, j_k)\rangle\rangle_k = \frac{\sum_k \mathrm{sgn}(x(j_k)) \cdot y(i, j_k)}{23}$$

defined as 'absolute mean' for any space *i* under the same meaning. In return, associate pattern *A* suits the similar condition)

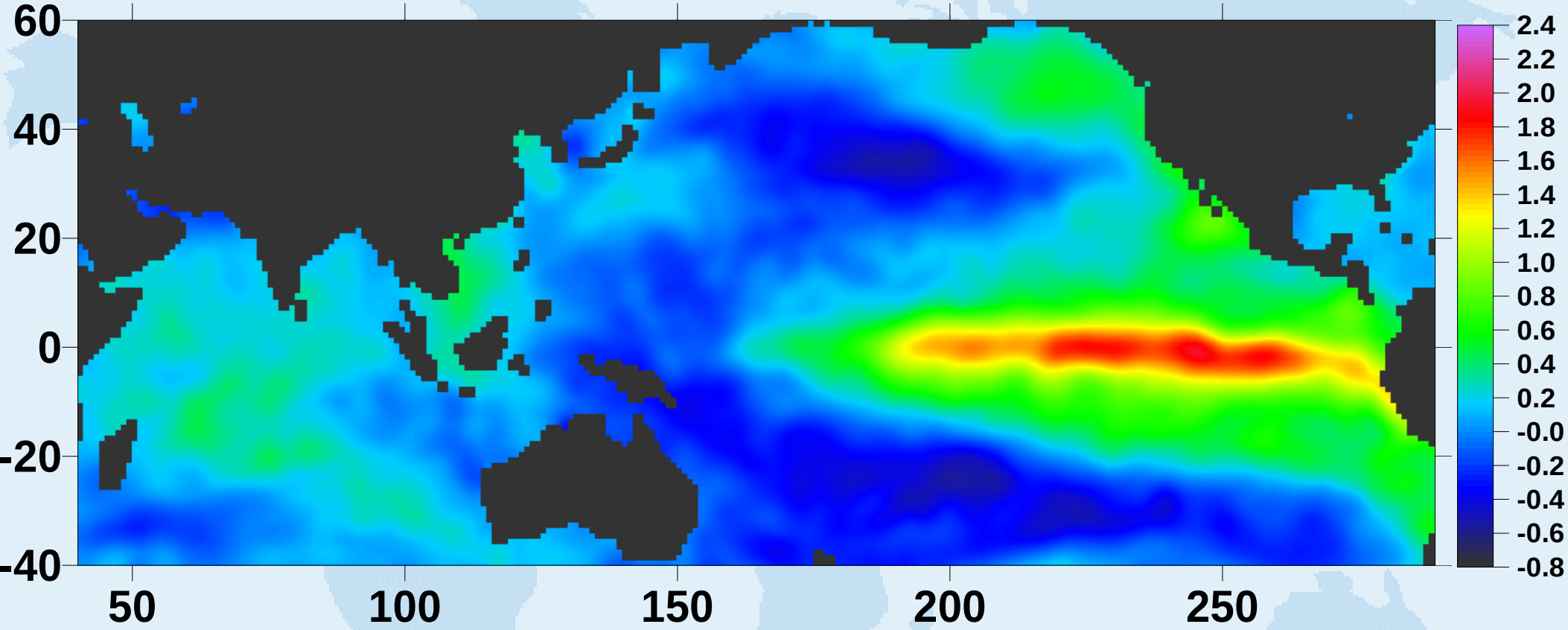
$$\sum_i \left[\langle\langle y(i, j_k)\rangle\rangle_k - a(i) \cdot \langle\langle x(j_k)\rangle\rangle_k\right]^2 = \min. \quad \textbf{(3)}$$

It means that associate pattern *A* is actually the 'absolute' mean state of field *Y* with a constant ratio when *X* reaches all of its El Niño and La Niña extrema. Therefore, it is skillfully equivalent to composite analysis of statistical climatology.

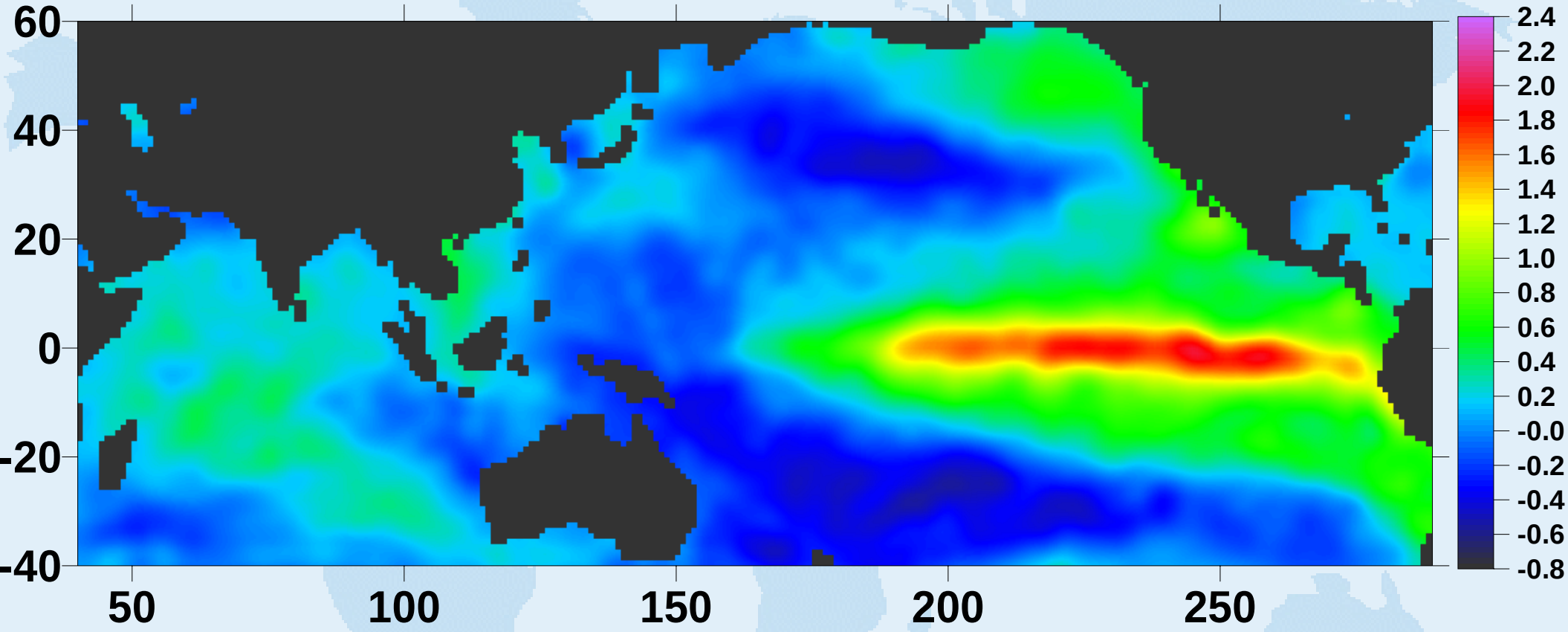
This method is a natural extension of Associate Pattern Analysis and should be called as Extended Associate Pattern Analysis.



a. SST associate pattern (ºC) for all of Nino3 index



b. SST associate pattern (ºC) for 23 of Nino3 extrema



c. Ration between means of 23 Nino3 extrema and SST (ºC)

简易海洋同化数据

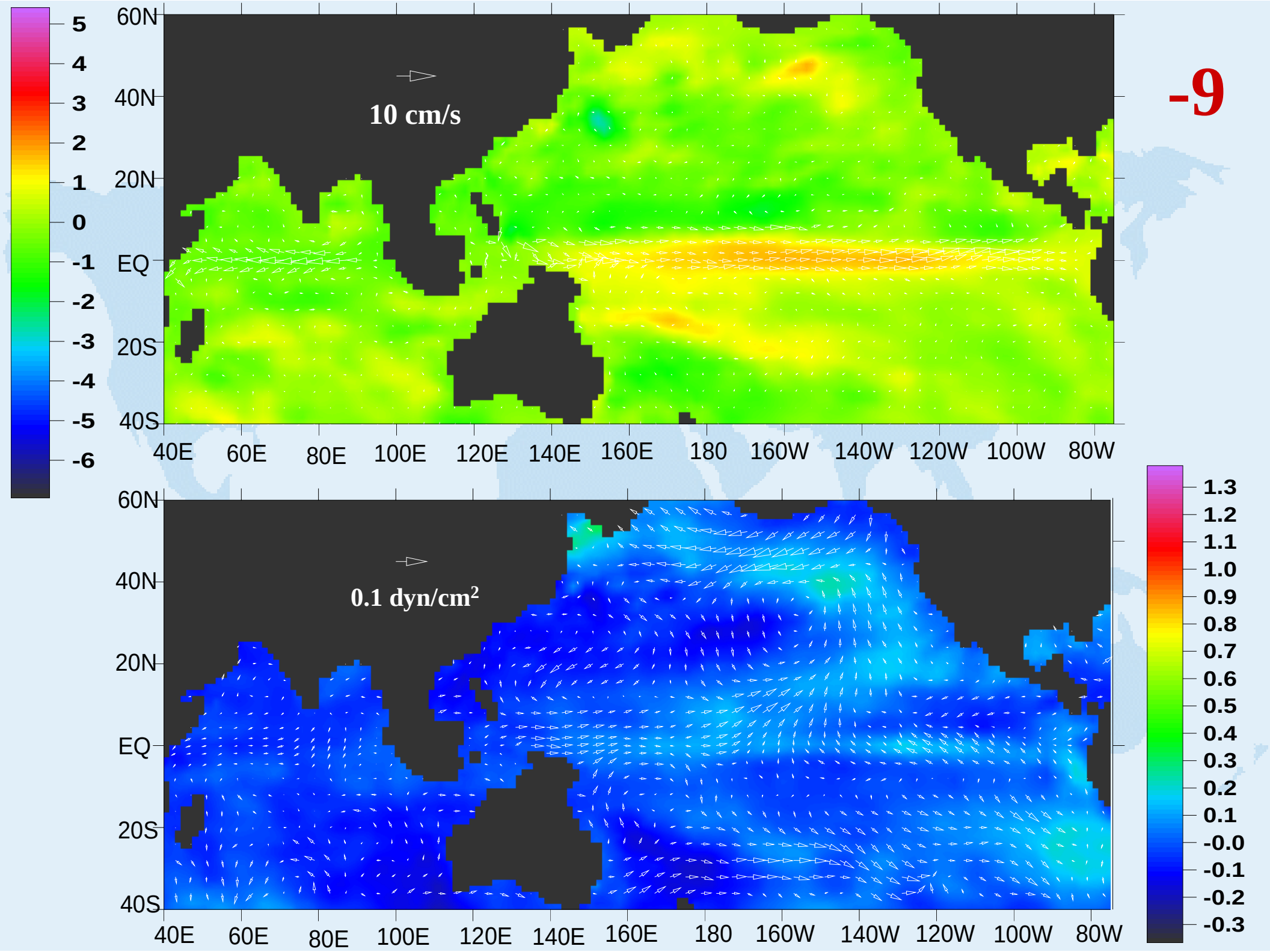
Simple Ocean Data Assimilation Data

The monthly SODA（Simple Ocean Data Assimilation）is based on data assimilation in which the numerical forecast is provided by some form of the Geophysical Fluid Dynamics Laboratory Modular Ocean Model driven by historical winds. The domain of this analysis is global with 1.0x1.0 lat-lon horizontal resolution in midlatitude reducing to 0.45x1.0 resolution in the tropics for a total 362x130 horizontal grid points (Carton at al, JPO)。

Comparisons are made to altimeter sea level, WOCE global hydrographic sections, and to moored and surface drifter velocity, which are quite encouraging. Part of the variance that is not explained is due to unresolved mesoscale phenomena. Another part is due to errors in the rate of water mass formation and errors in salinity estimates. The differences are generally smaller in the Tropics, although the major equatorial currents are too broad and weak. Therefore, the strongest basin-scale signal at interannual periods associated with El Niño should be well reproduced.

海气变异性态特征

Major Behaviors of Air and Sea Variations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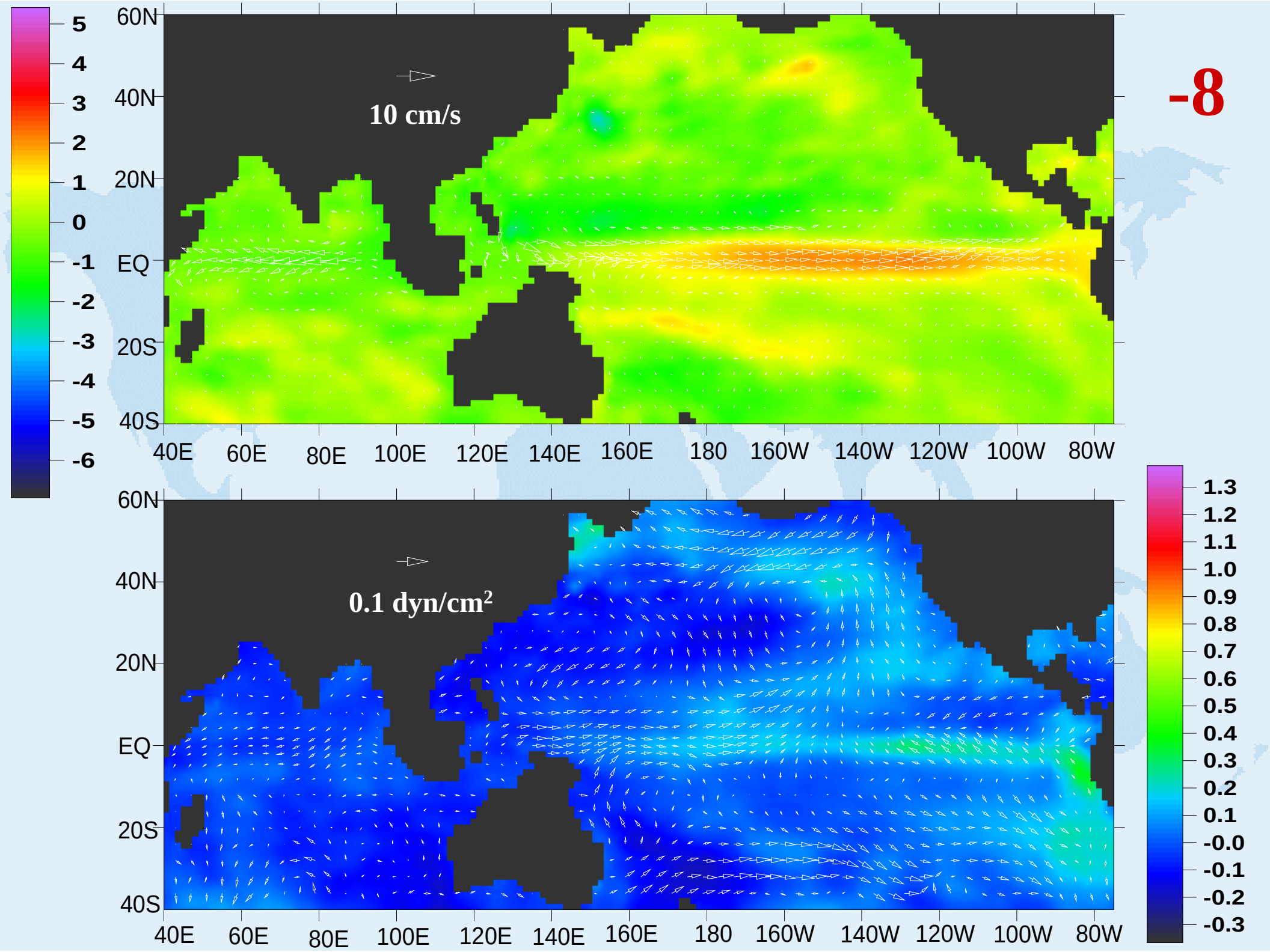
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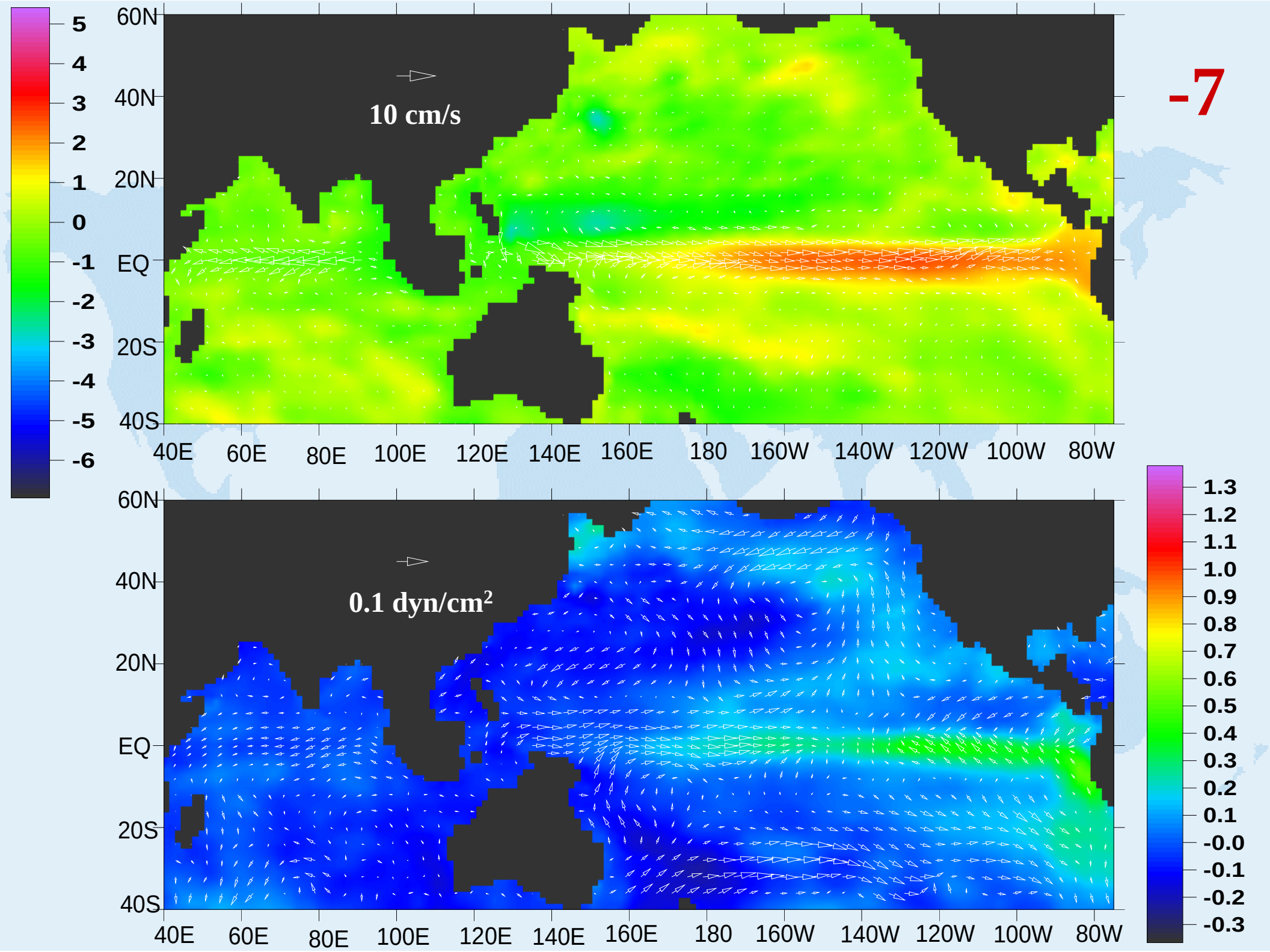
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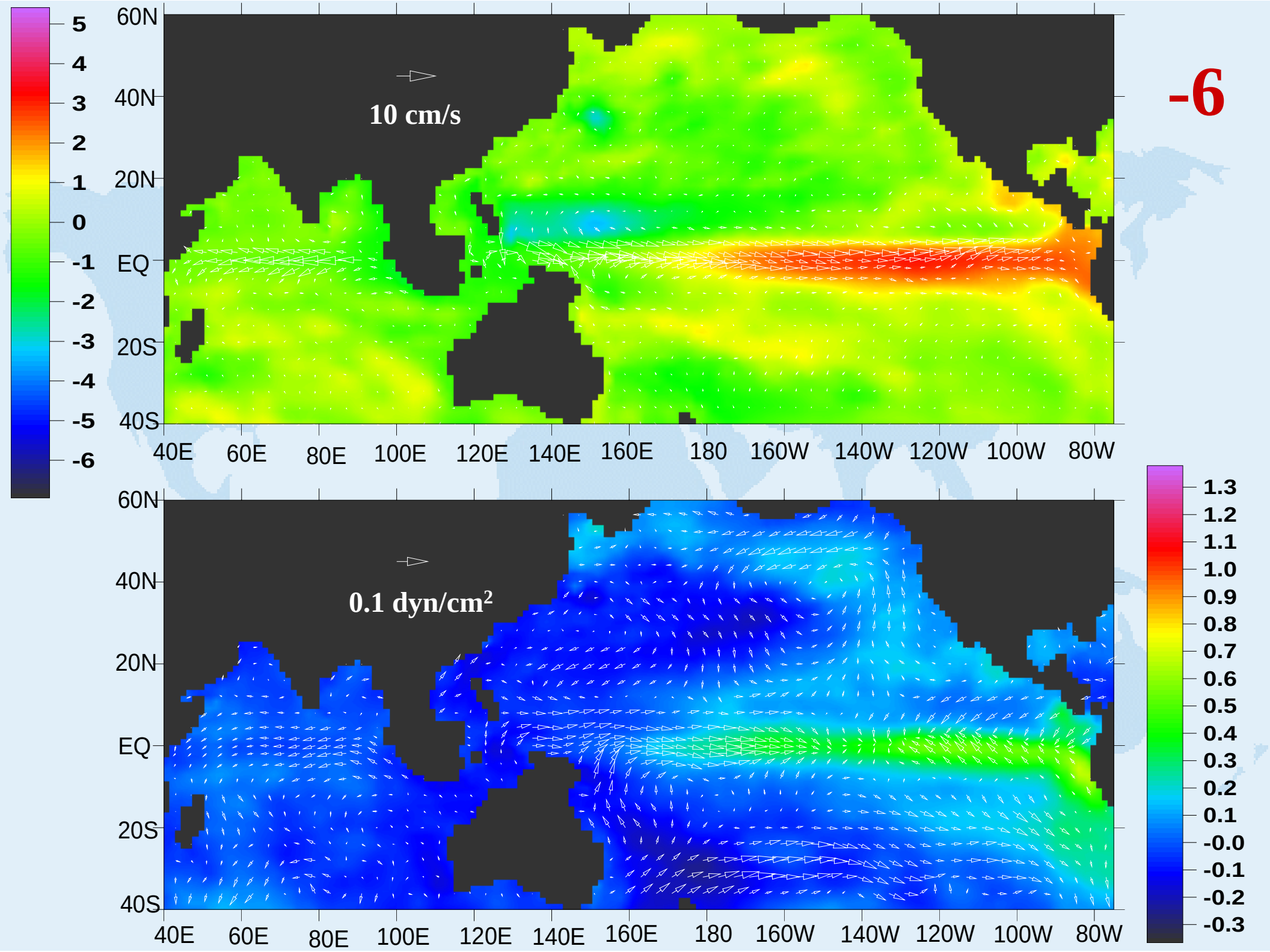
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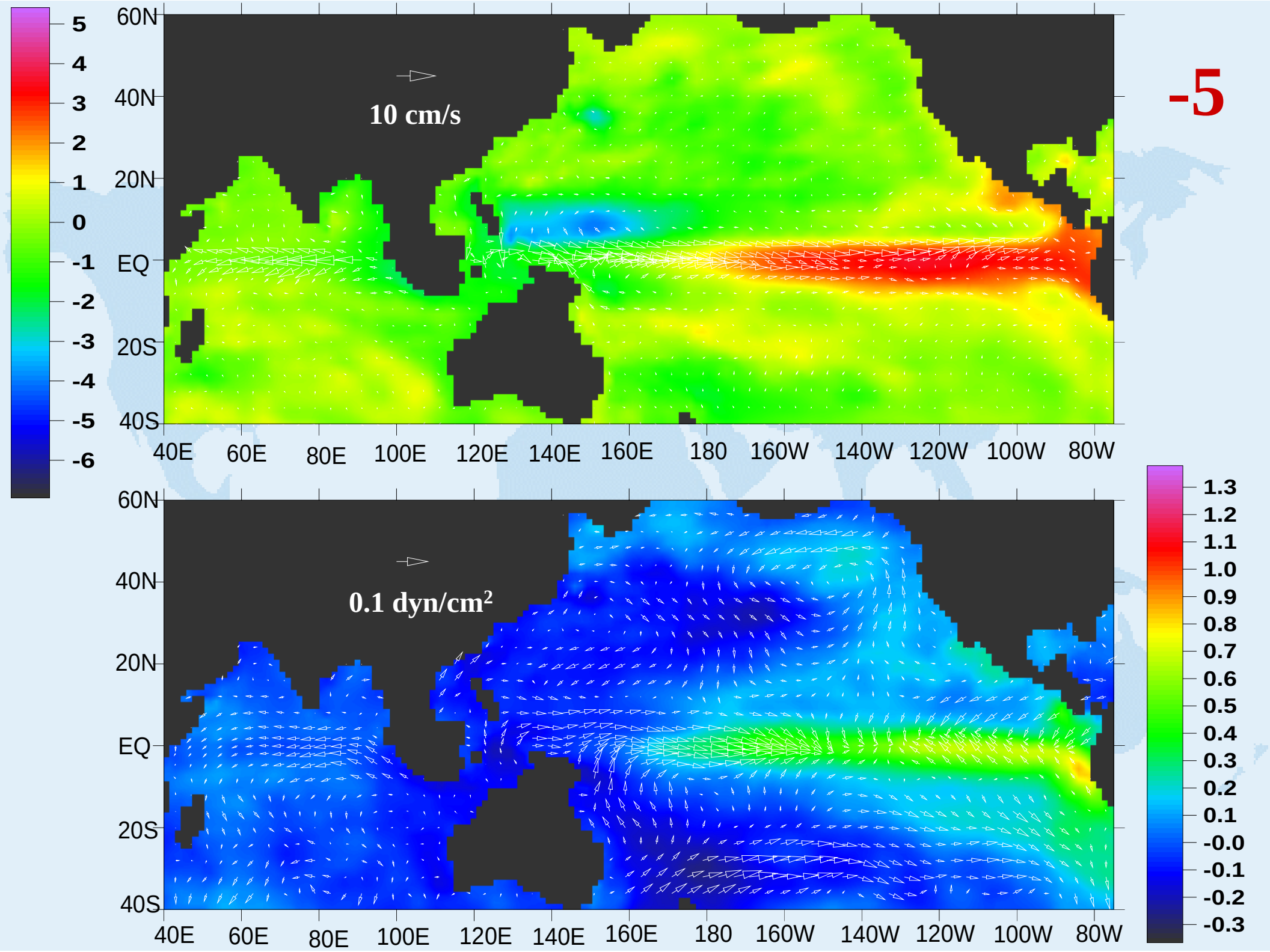
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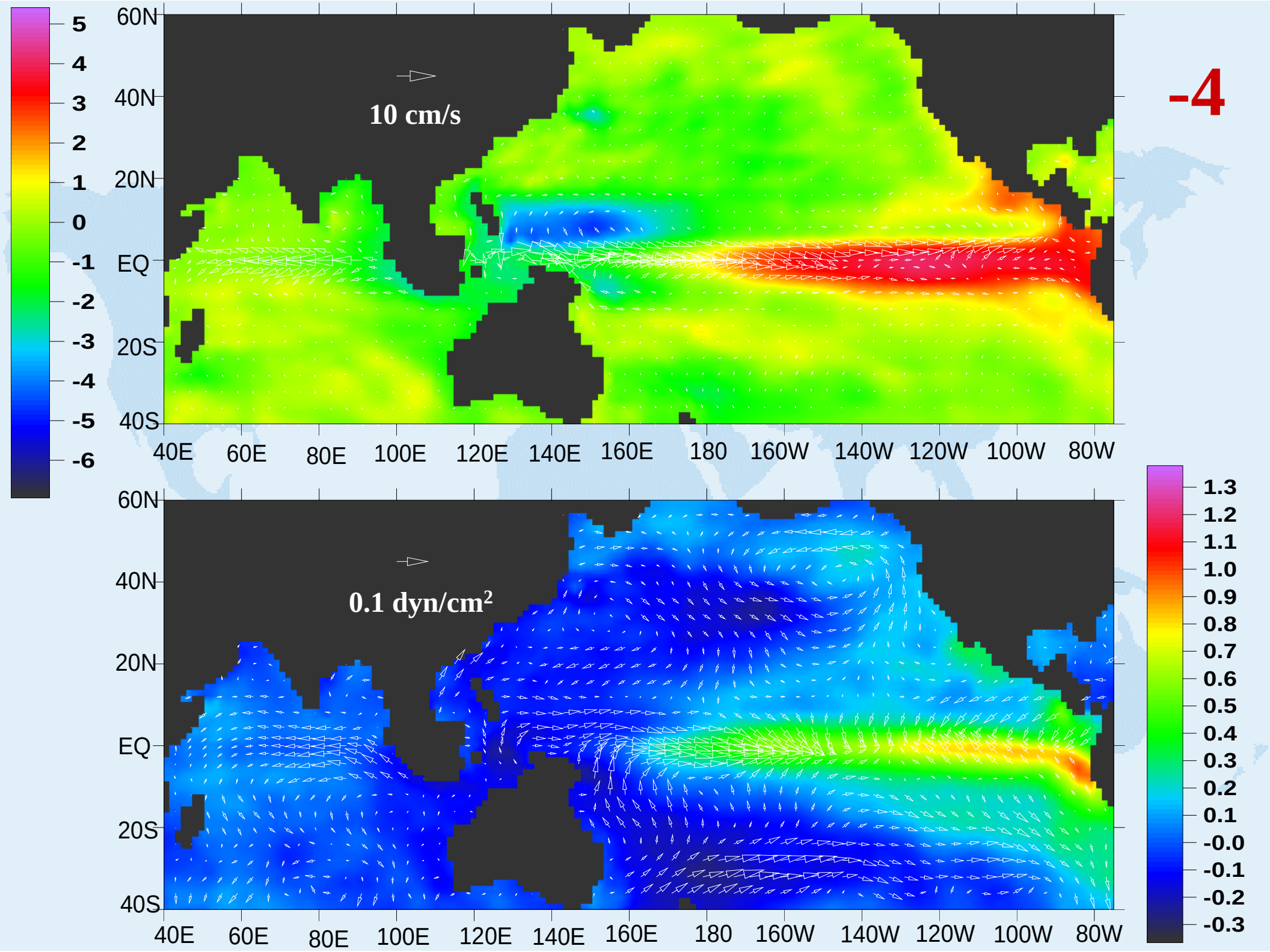
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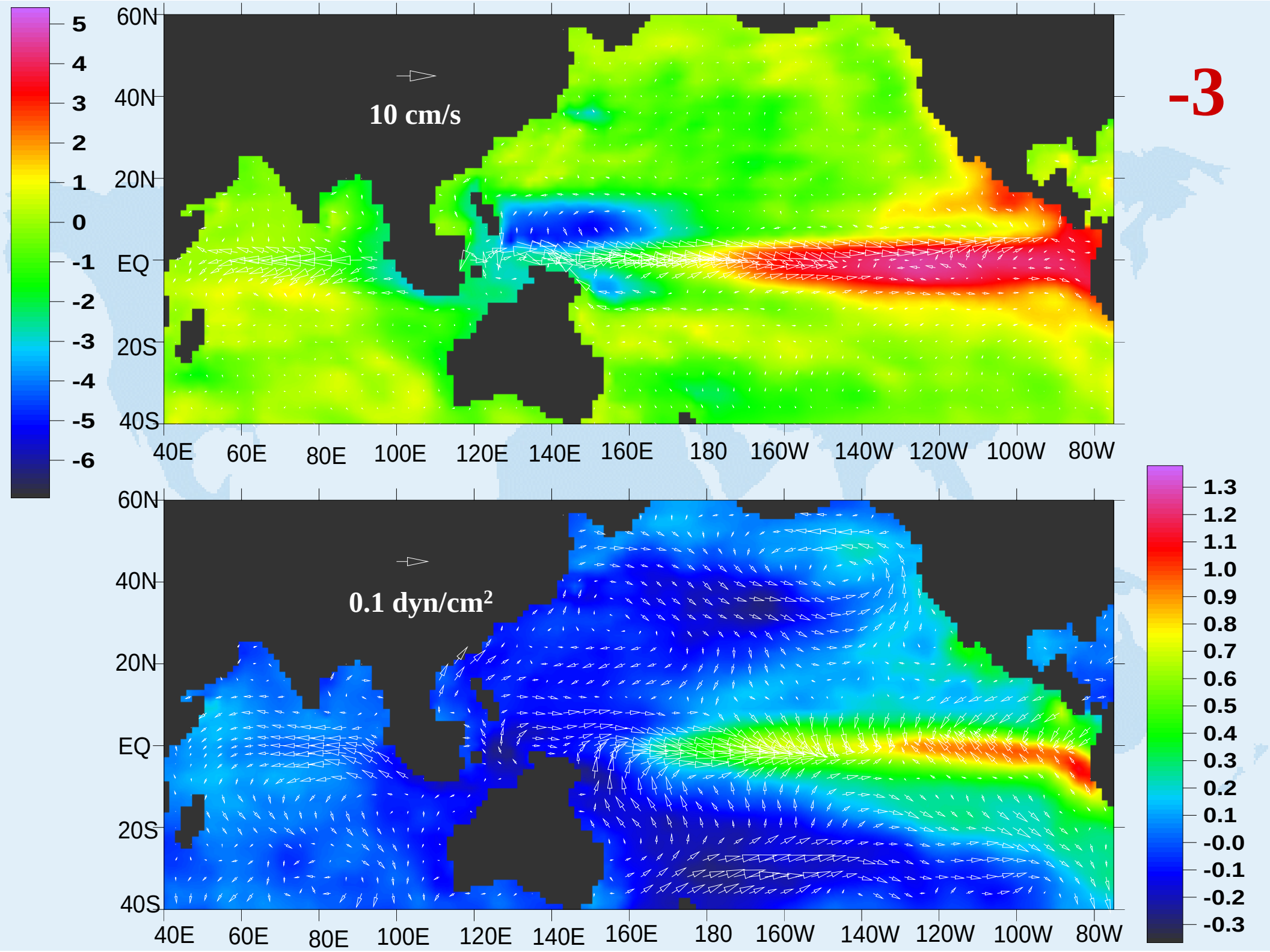
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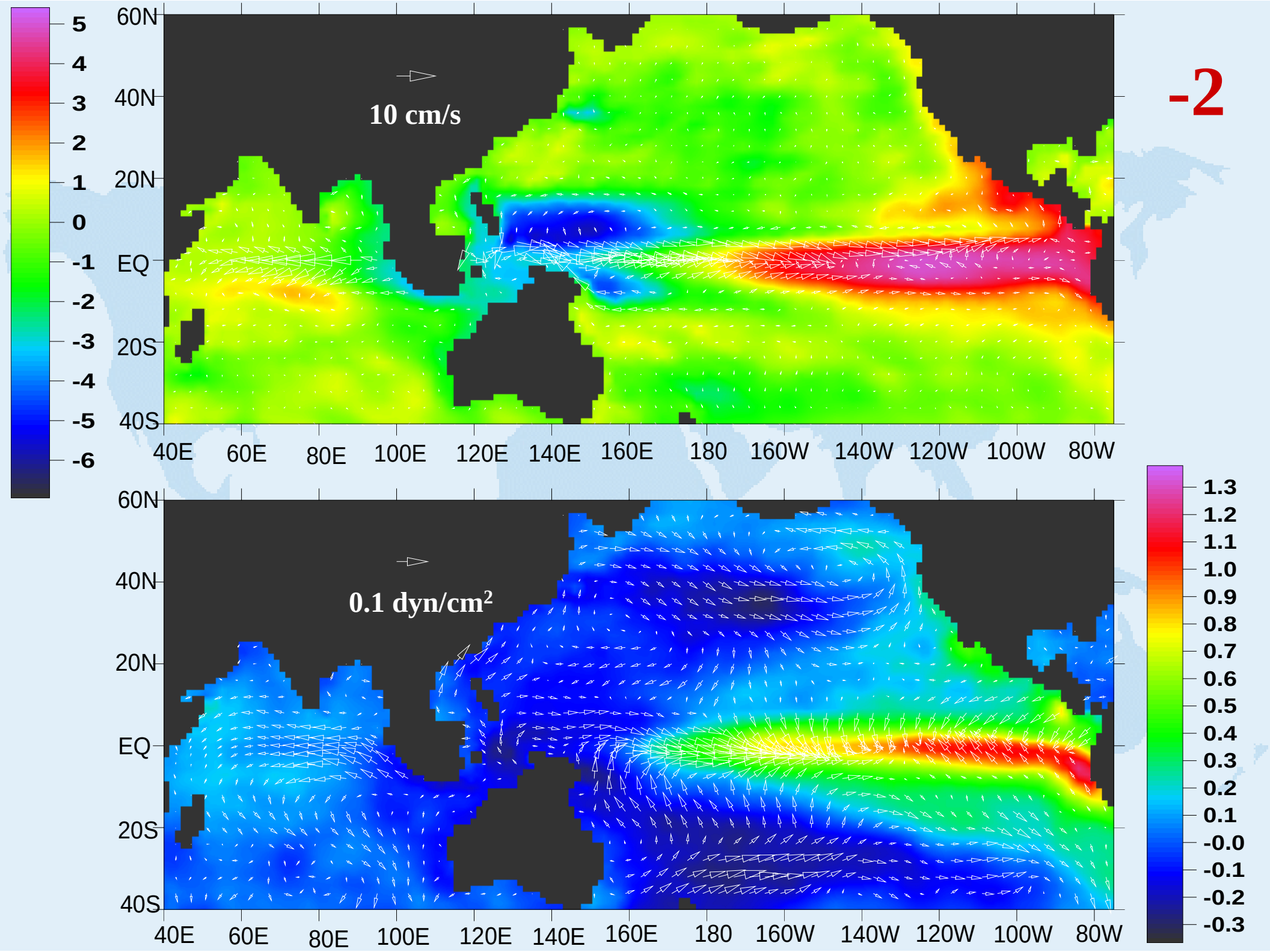
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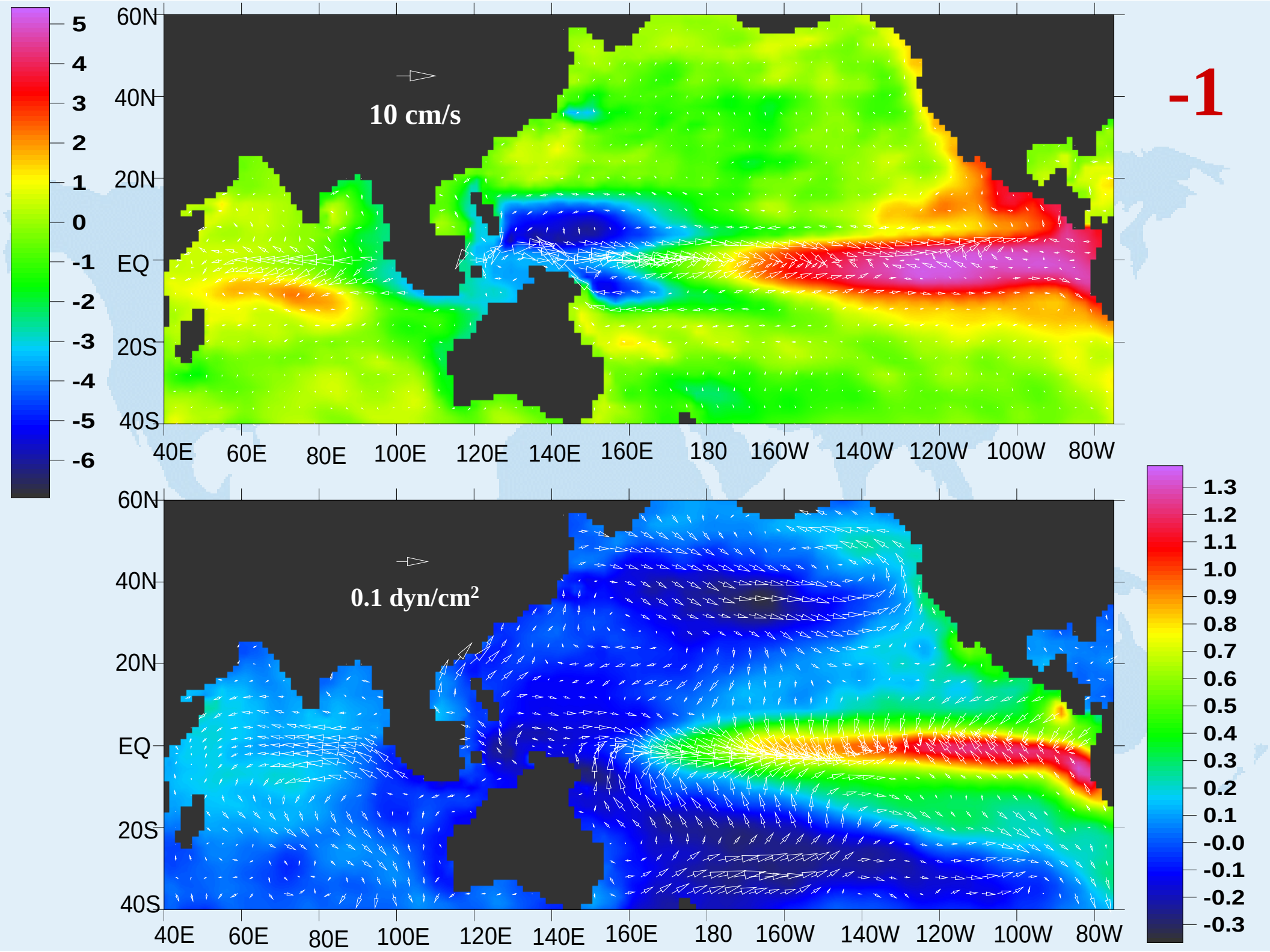
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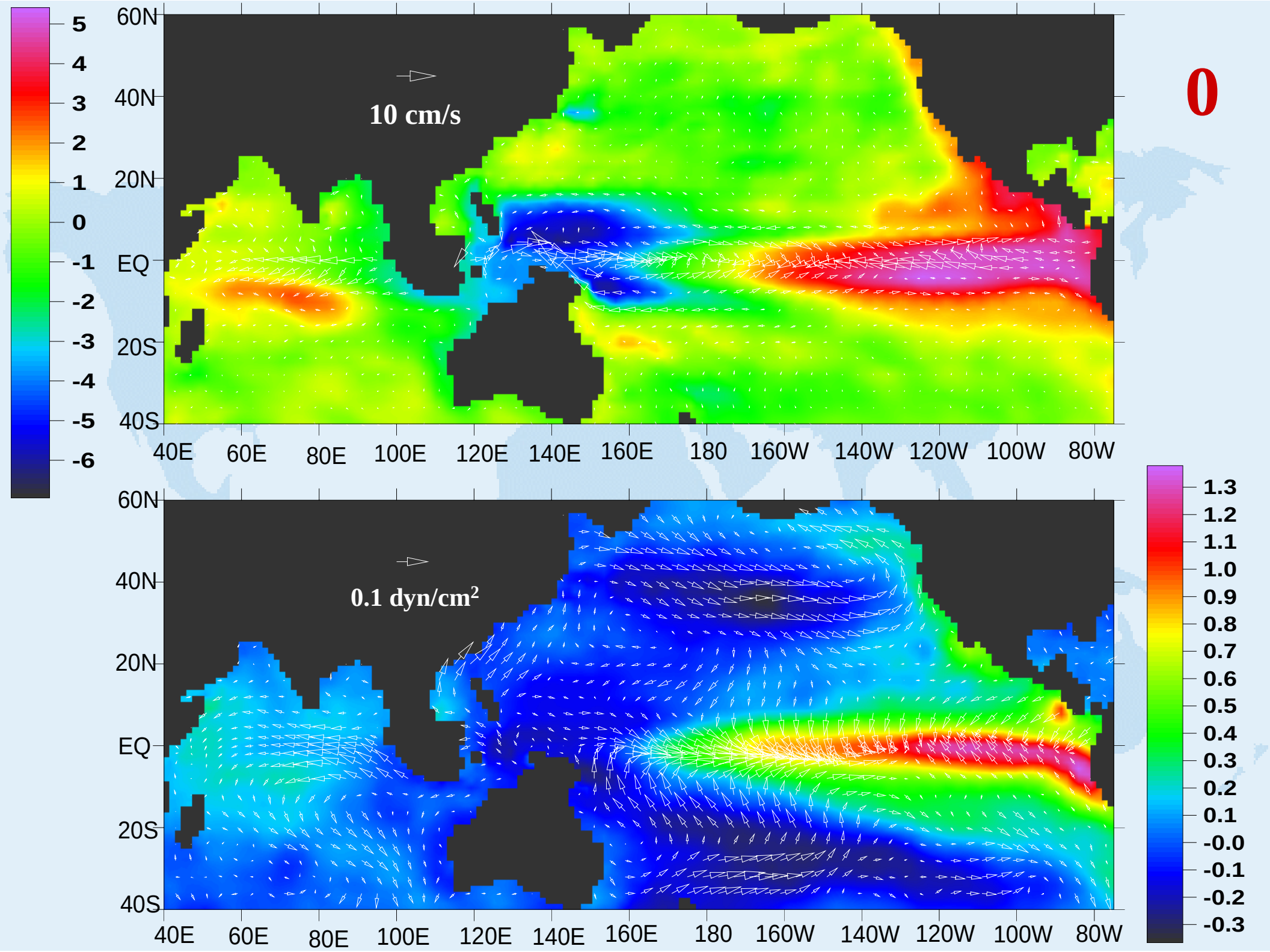
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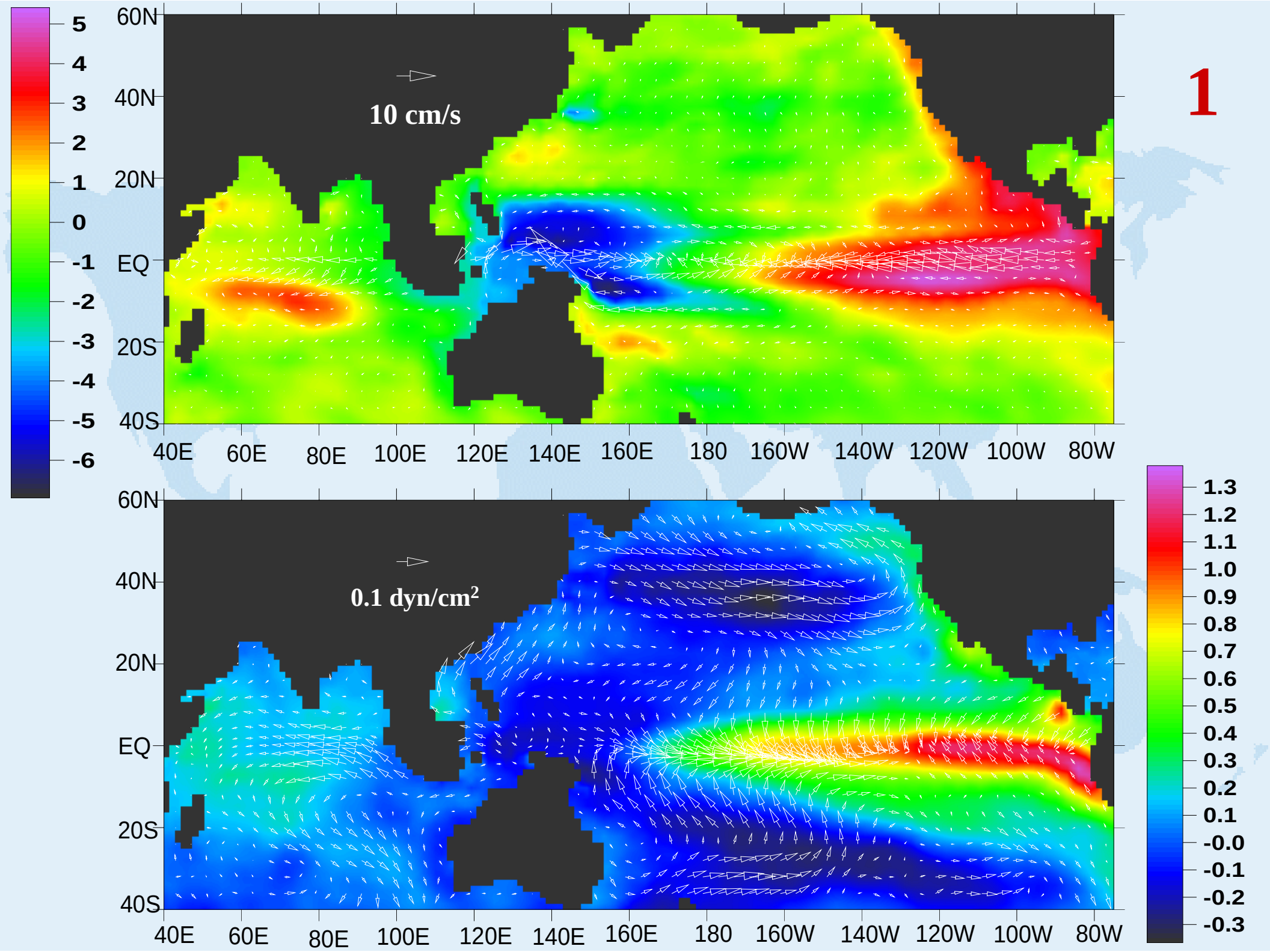
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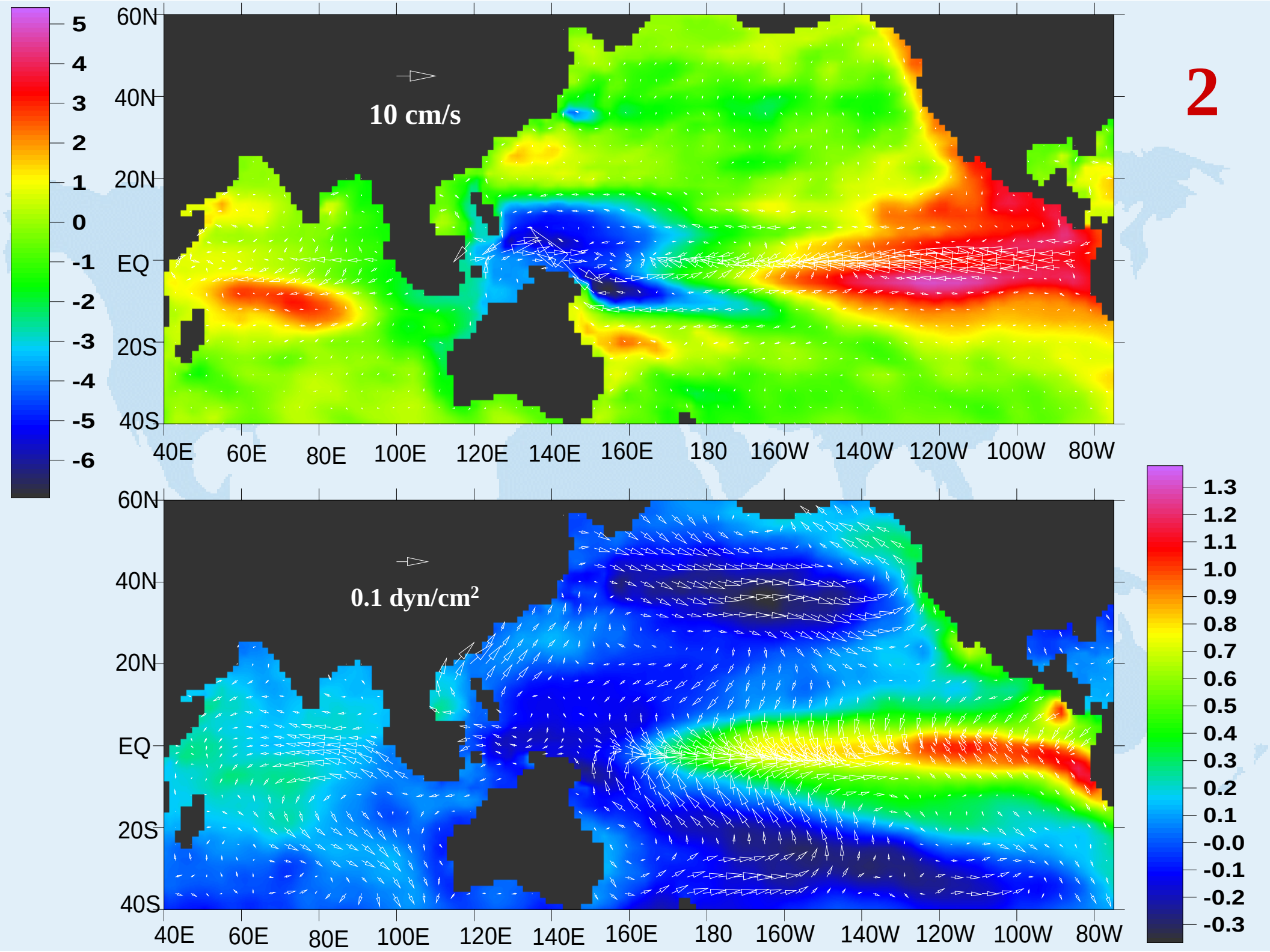
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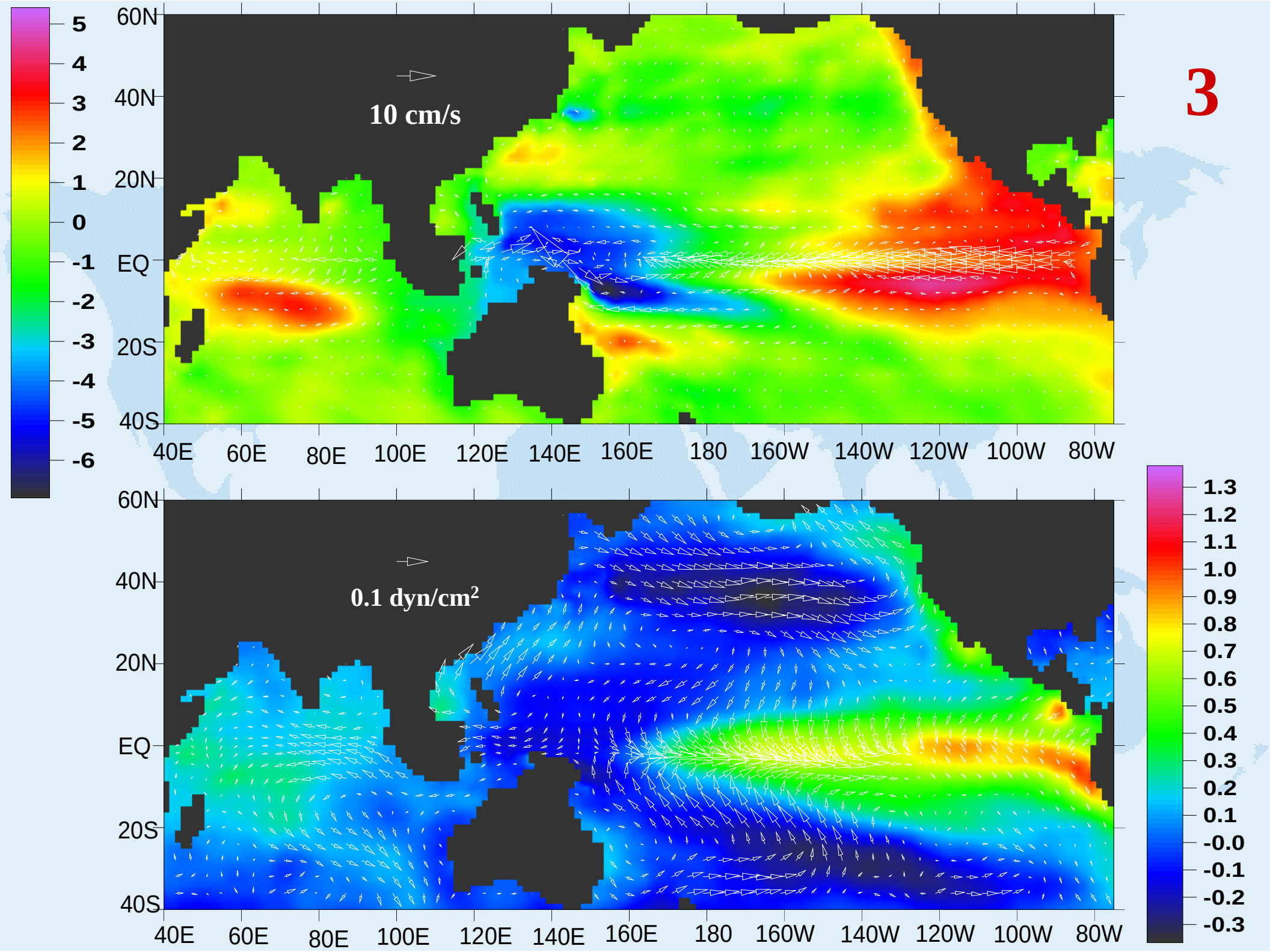
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120W
100W
80W
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4
3
2
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0
-1
-2
-3
-4
-5
-6
1.3
1.2
1.1
1.0
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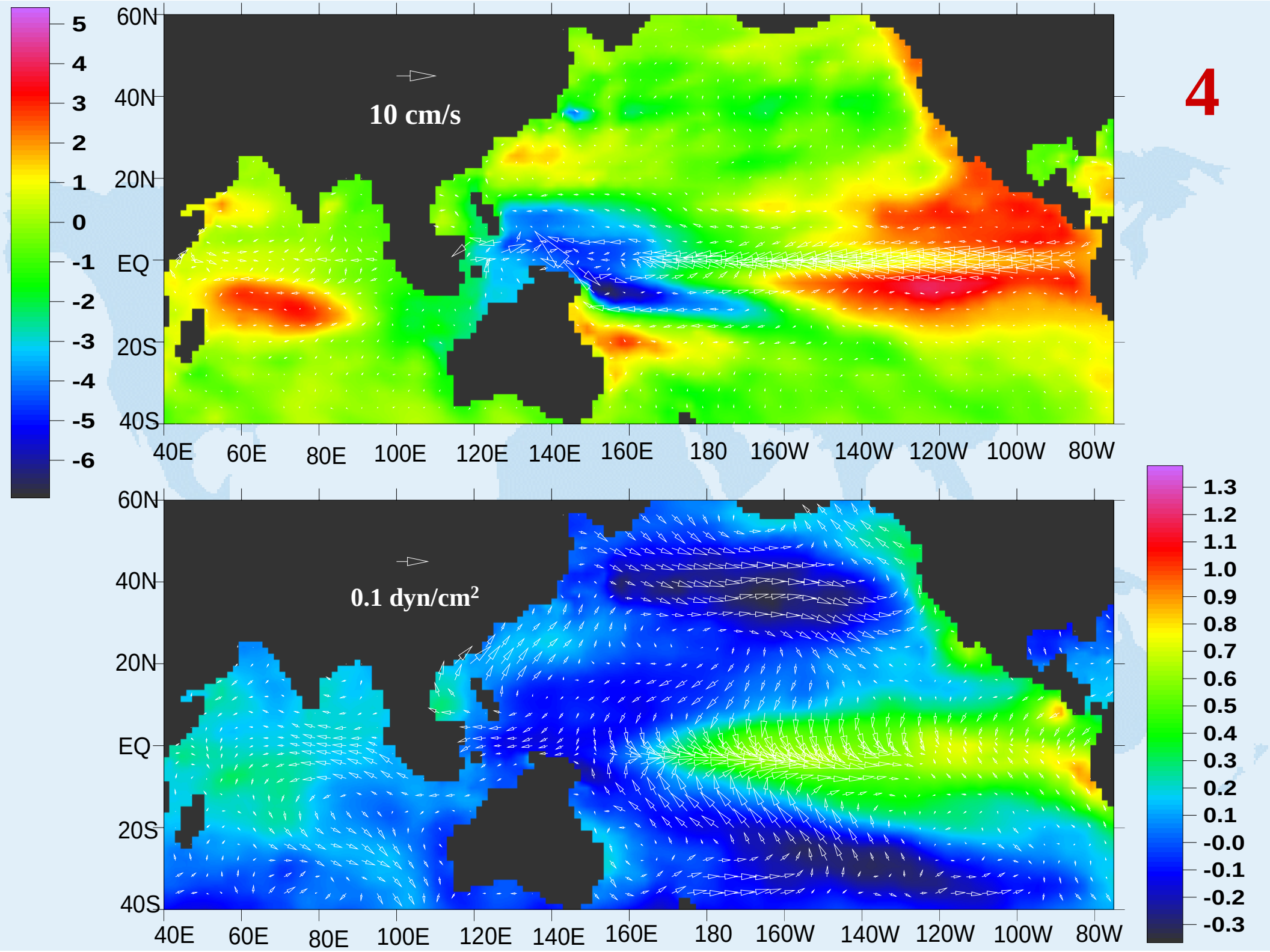
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40N
20N
EQ
20S
40S
40E
60E
80E
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1.3
1.2
1.1
1.0
0.9
0.8
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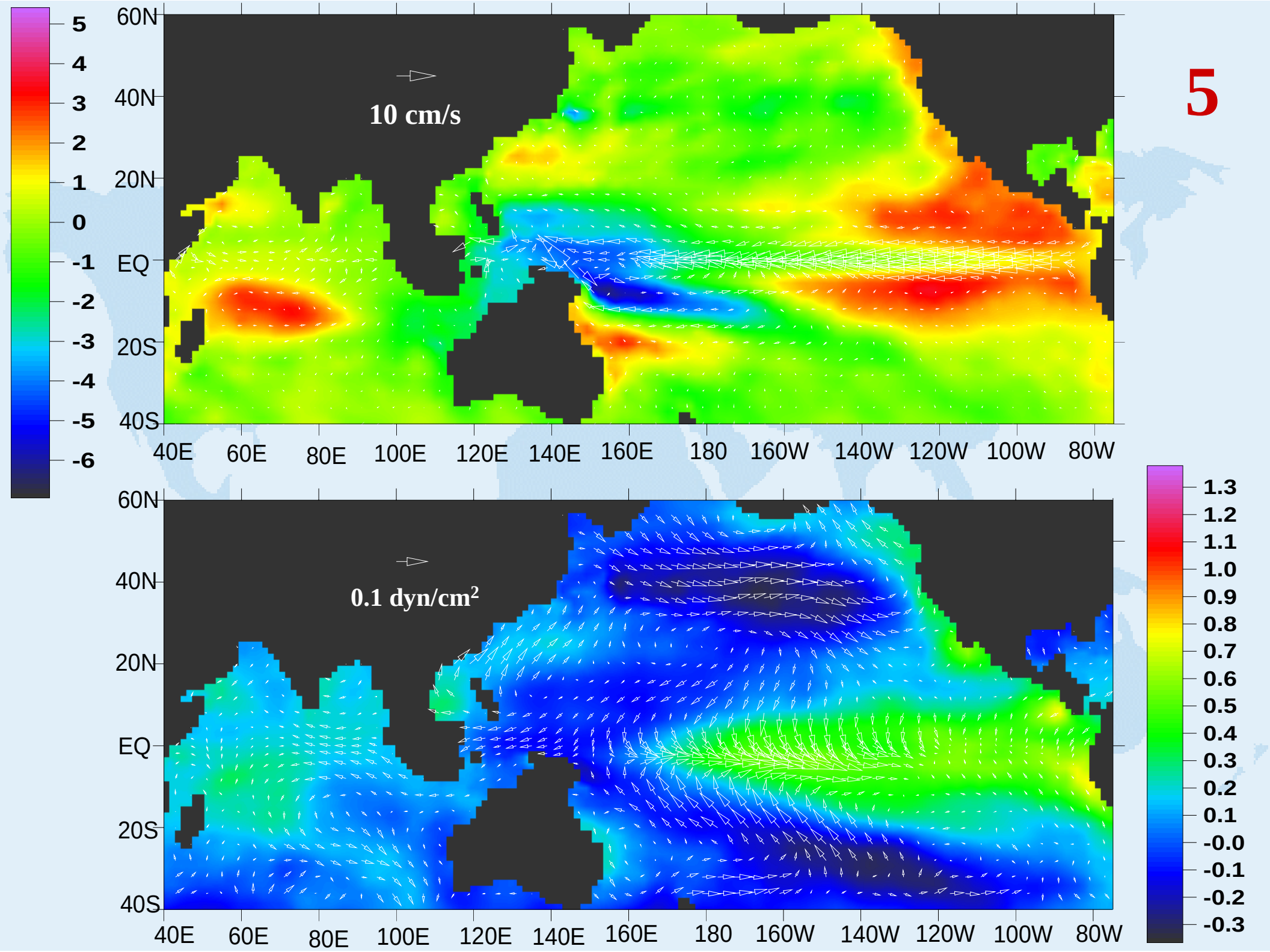
-0.2
-0.3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0.1 dyn/cm2
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40N
20N
EQ
20S
40S
40E
60E
80E
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
5
4
3
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1
0
-1
-2
-3
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-5
-6
1.3
1.2
1.1
1.0
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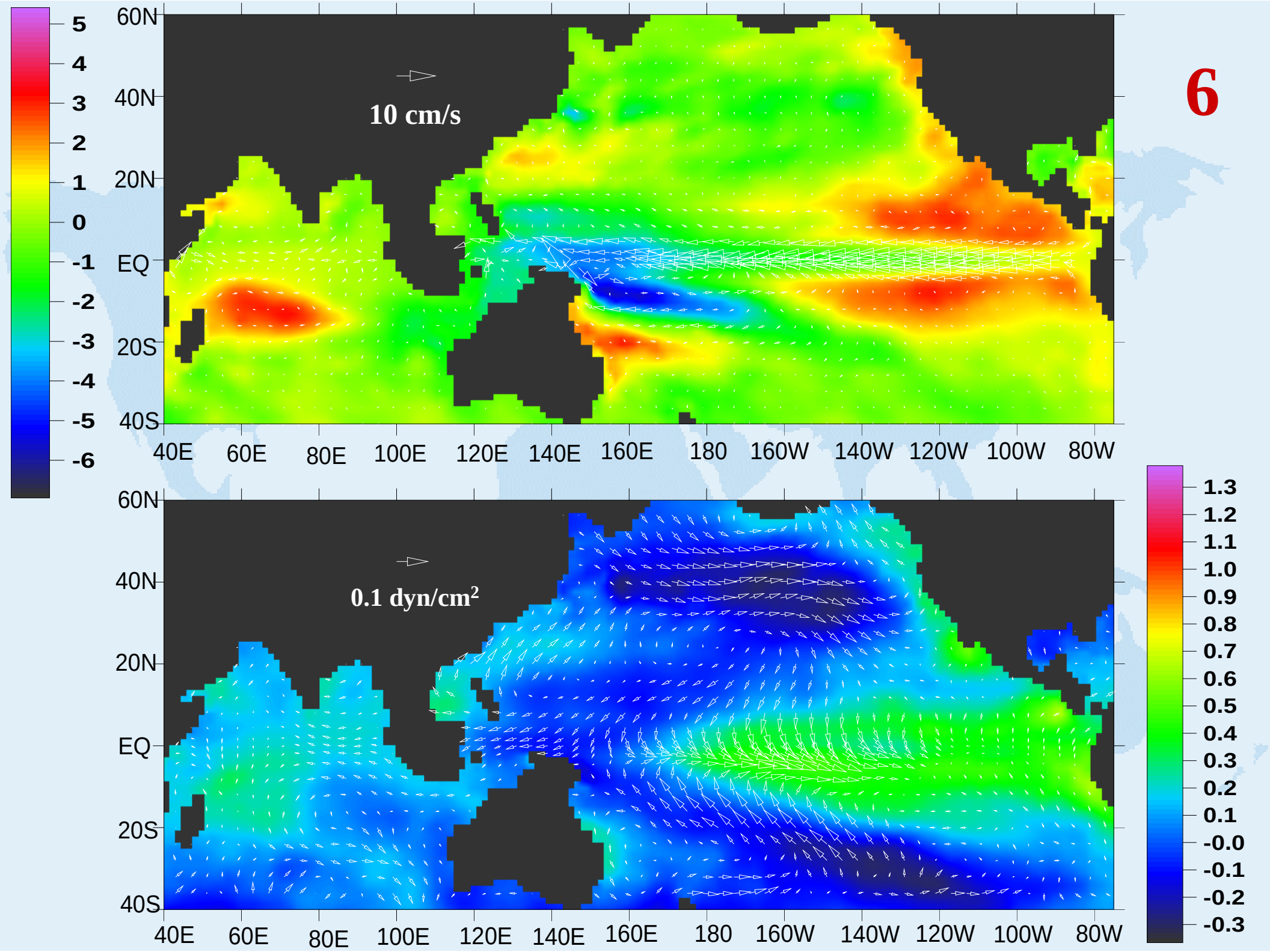
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0.1 dyn/cm2
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EQ
20S
40S
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60E
80E
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
5
4
3
2
1
0
-1
-2
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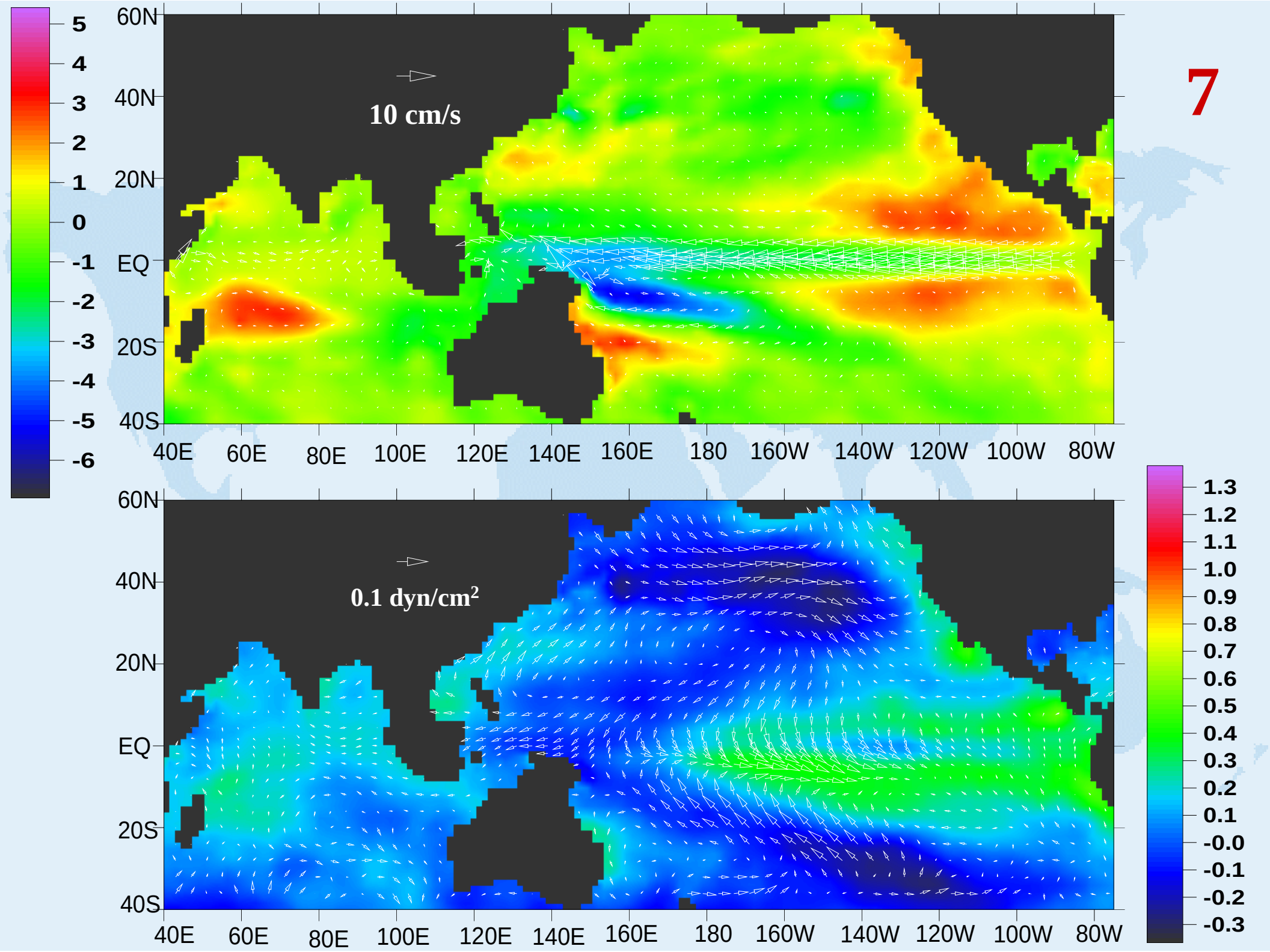
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EQ
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100E
120E
140E
160E
180
160W
140W
120W
100W
80W
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1.3
1.2
1.1
1.0
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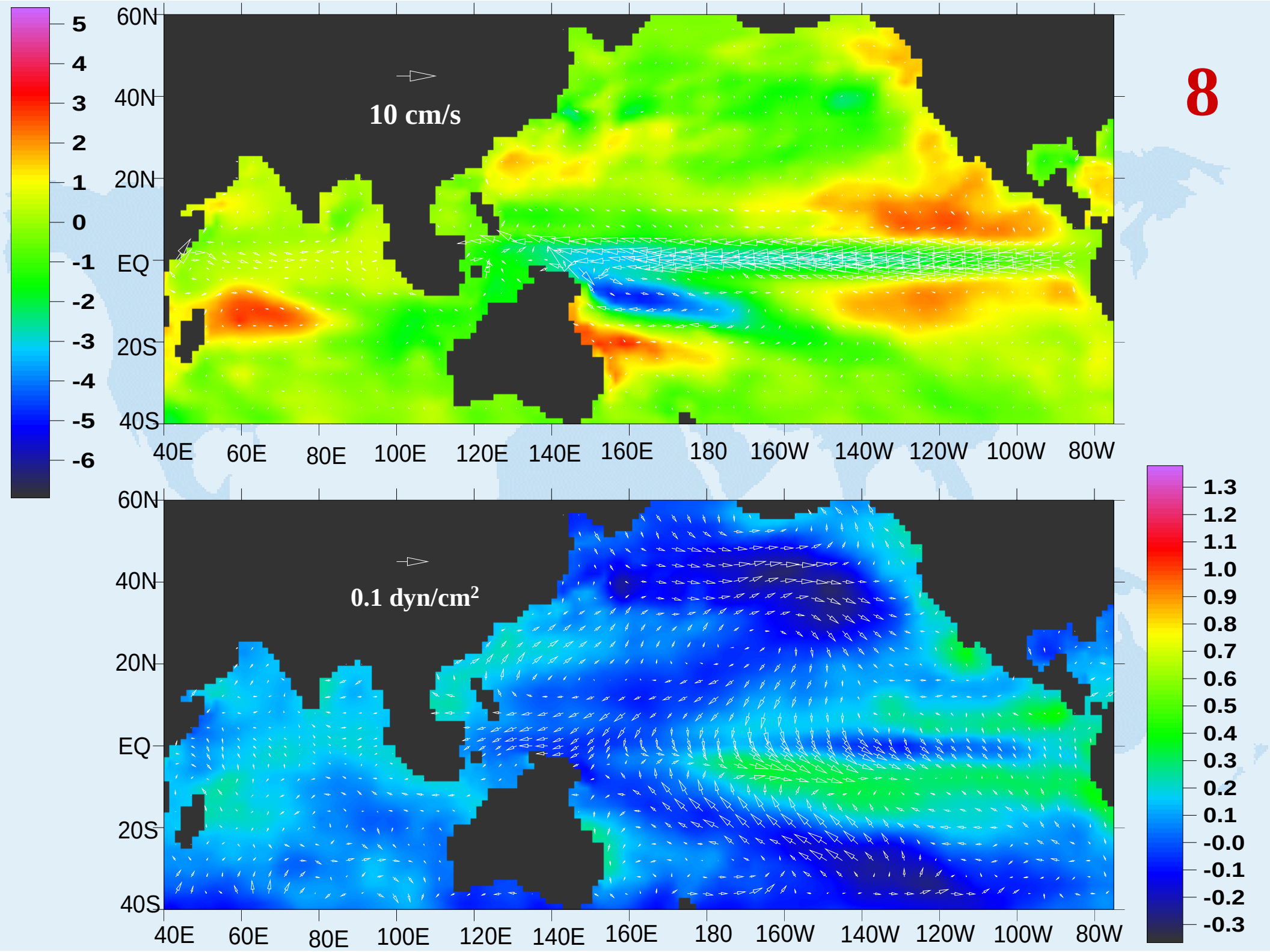
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EQ
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80E
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
5
4
3
2
1
0
-1
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-4
-5
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1.3
1.2
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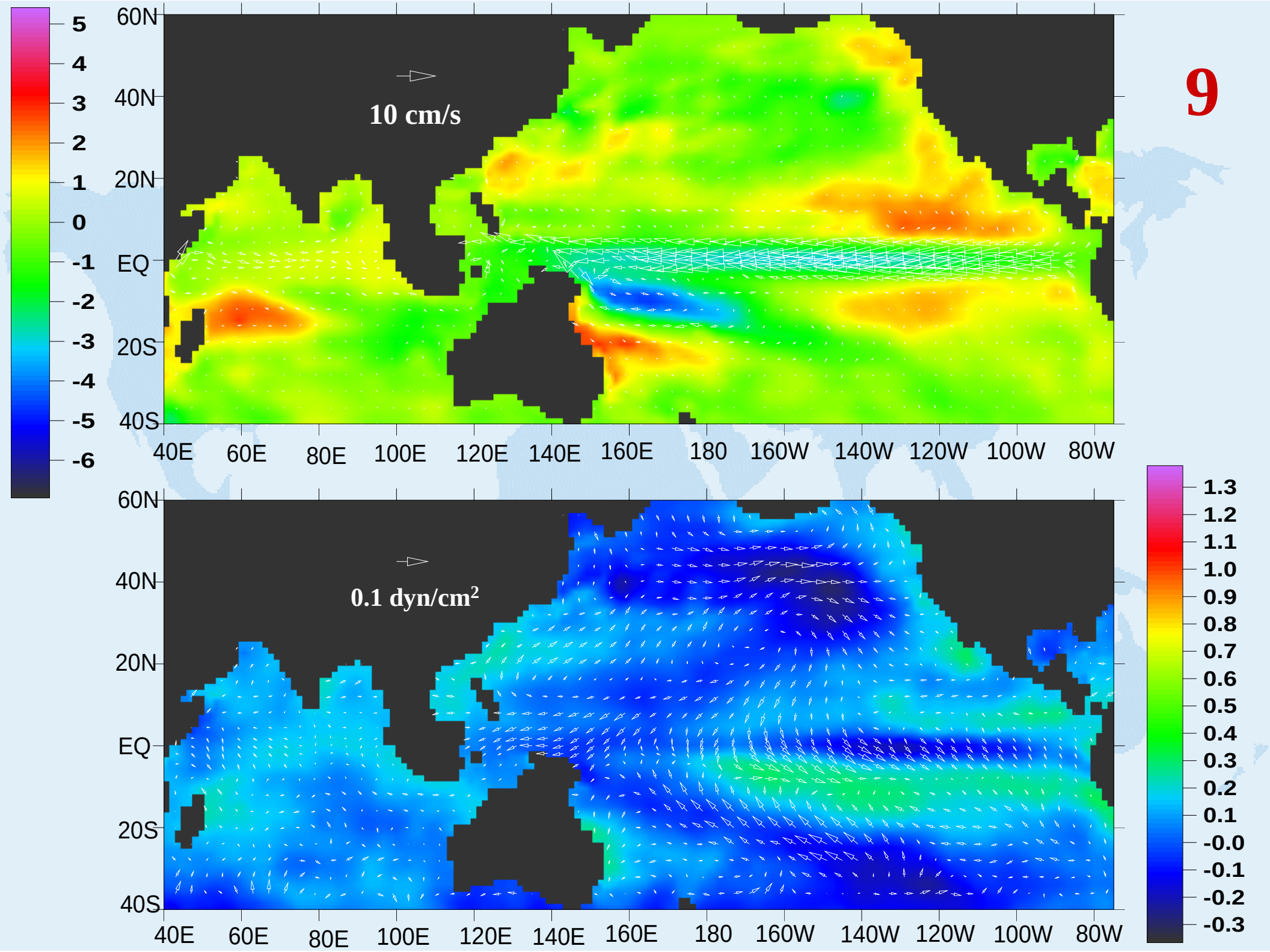
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160E
180
160W
140W
120W
100W
80W
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4
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2
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-1
-2
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1.2
1.1
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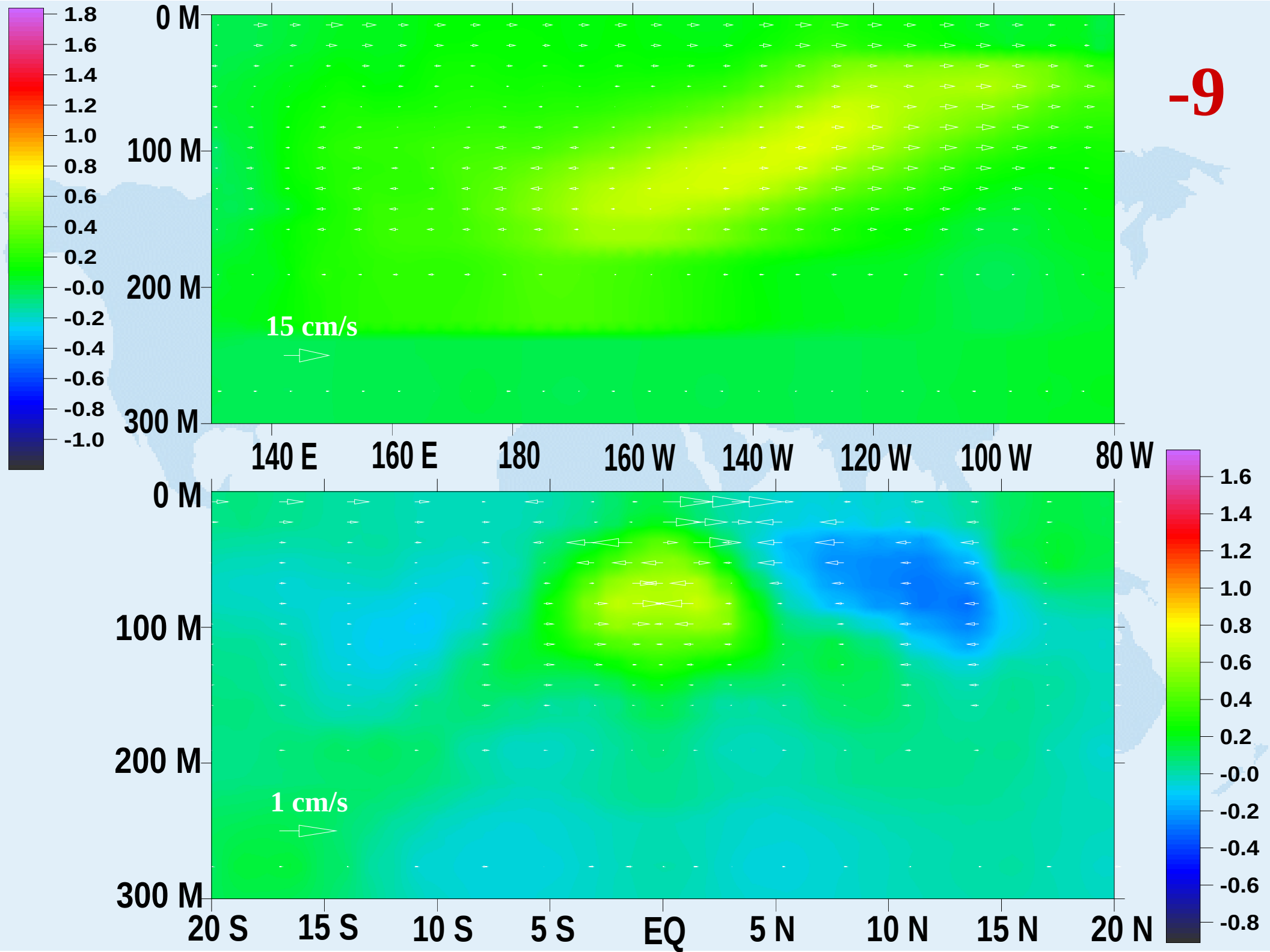
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0.6
0.4
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-0.6
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
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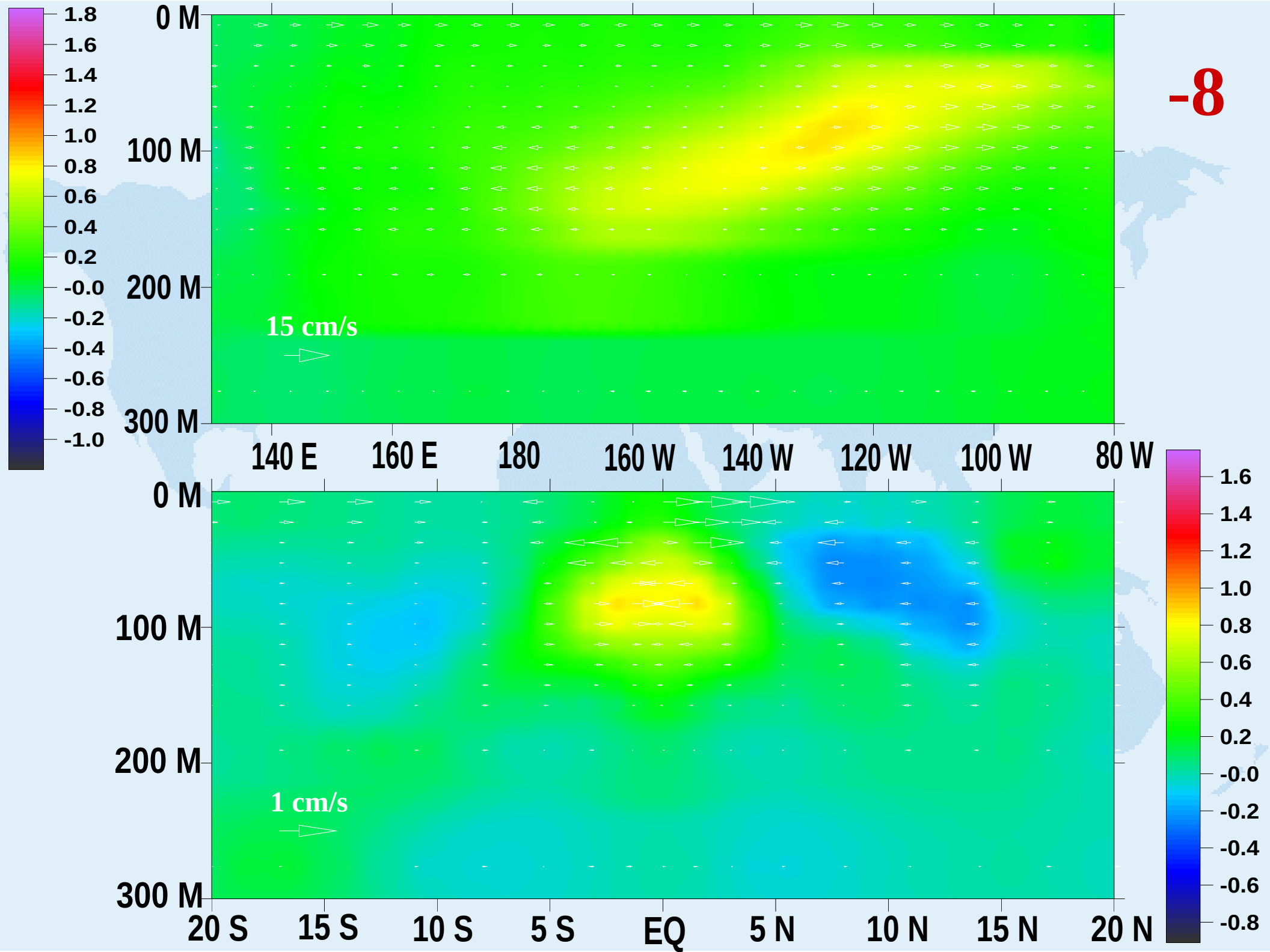
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
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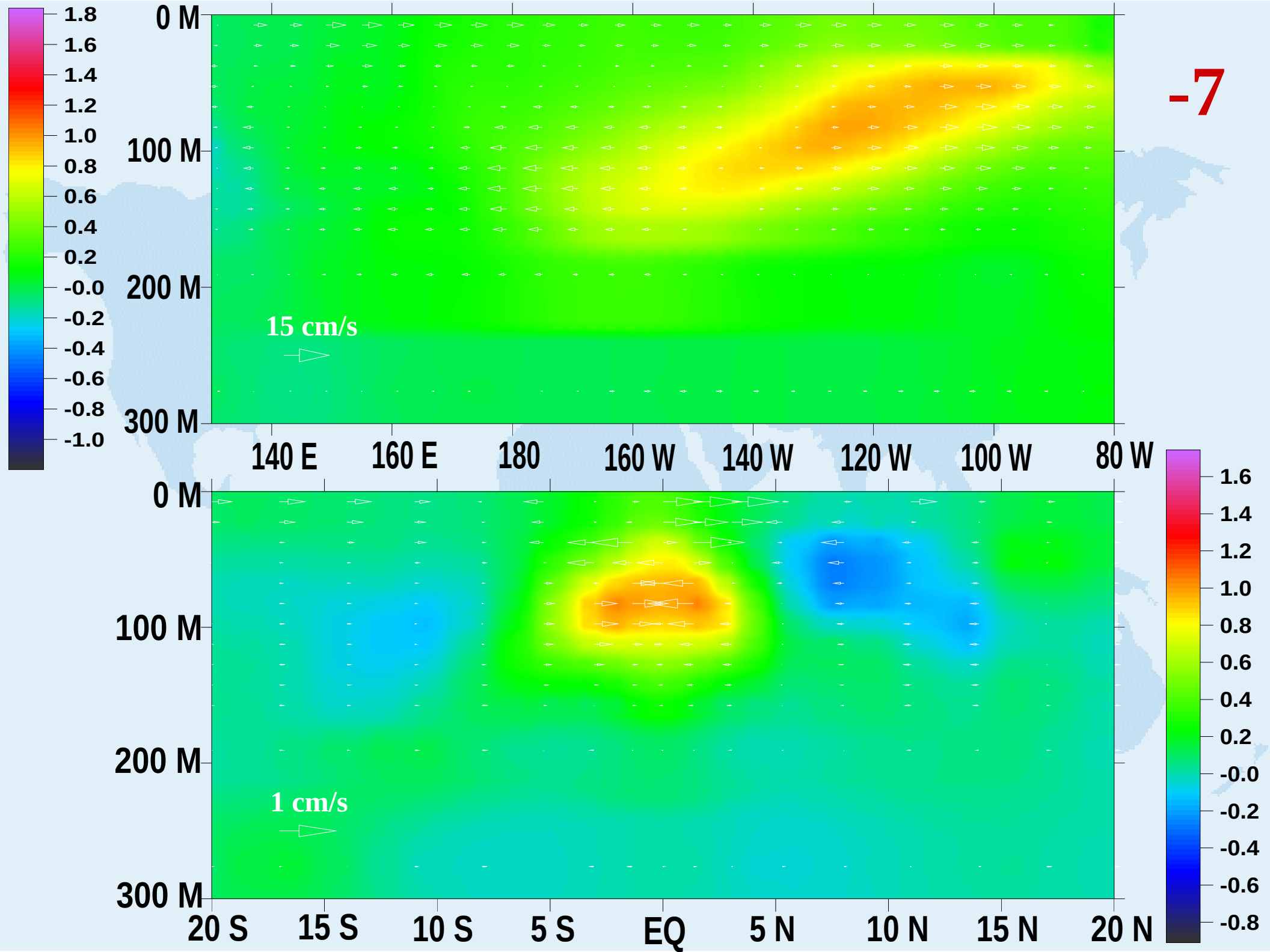
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-0.6
-0.8
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
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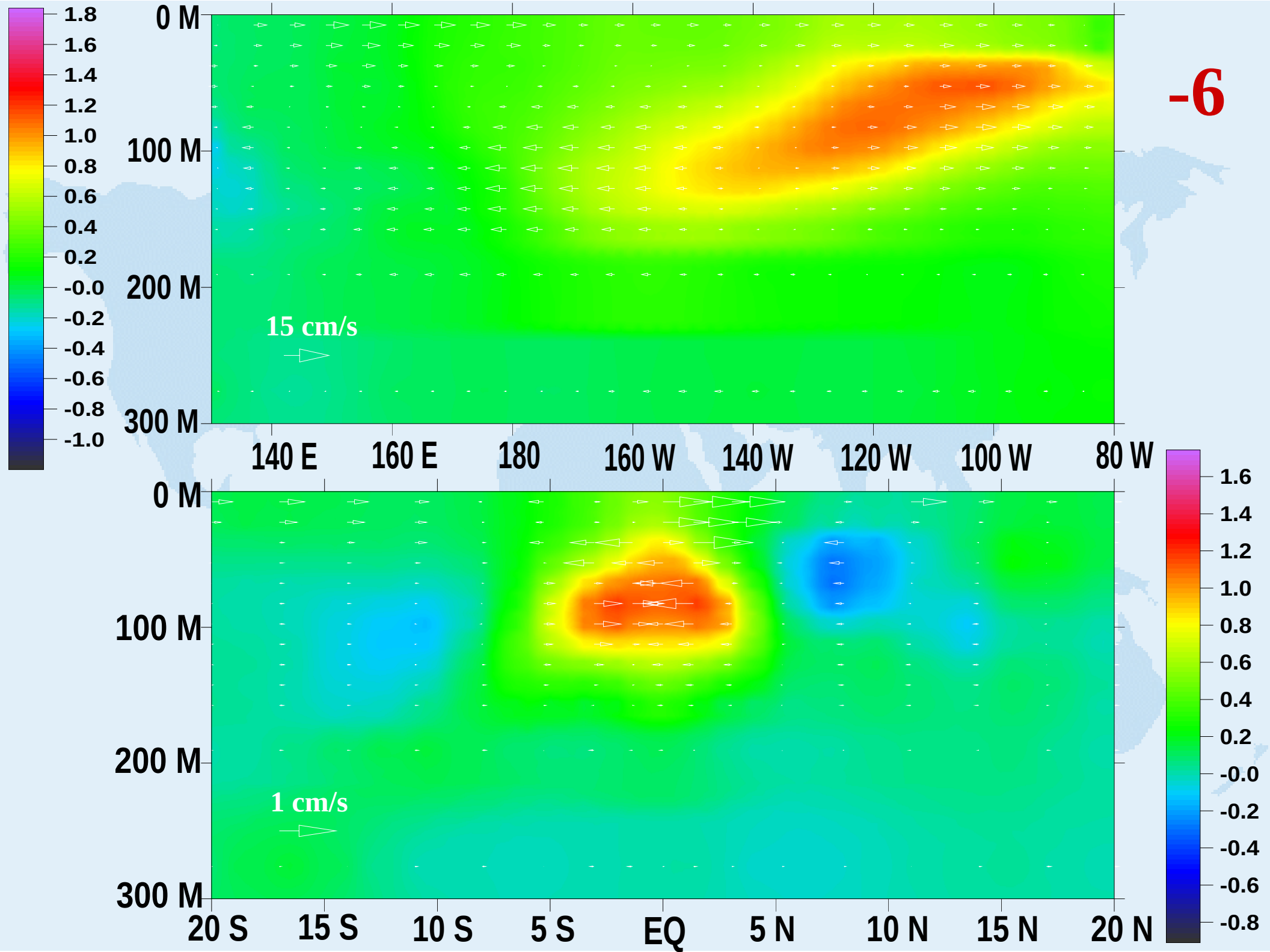
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
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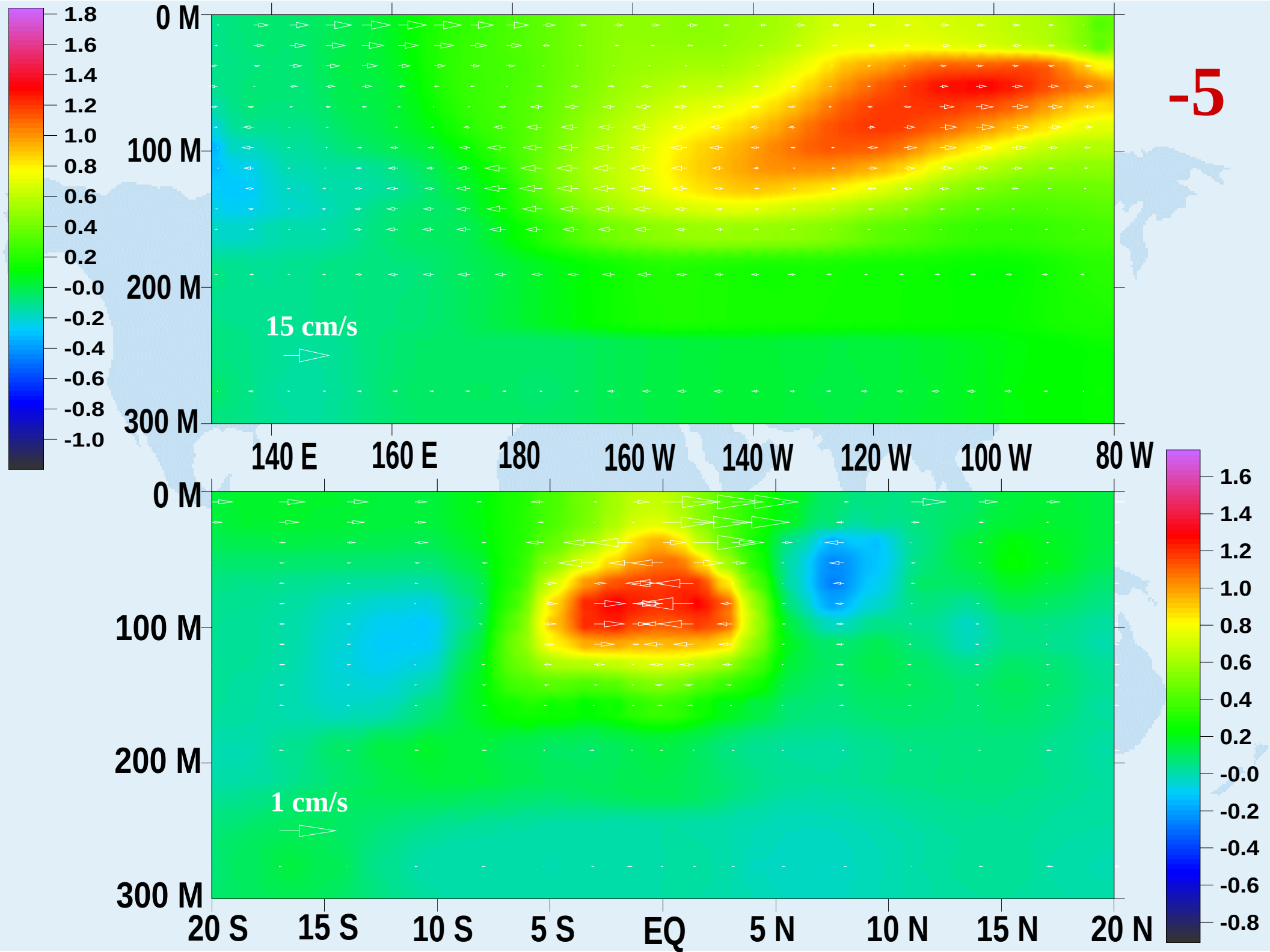
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-0.8
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
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140 W
120 W
100 W
80 W
1 cm/s
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15 S
10 S
5 S
EQ
5 N
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1.4
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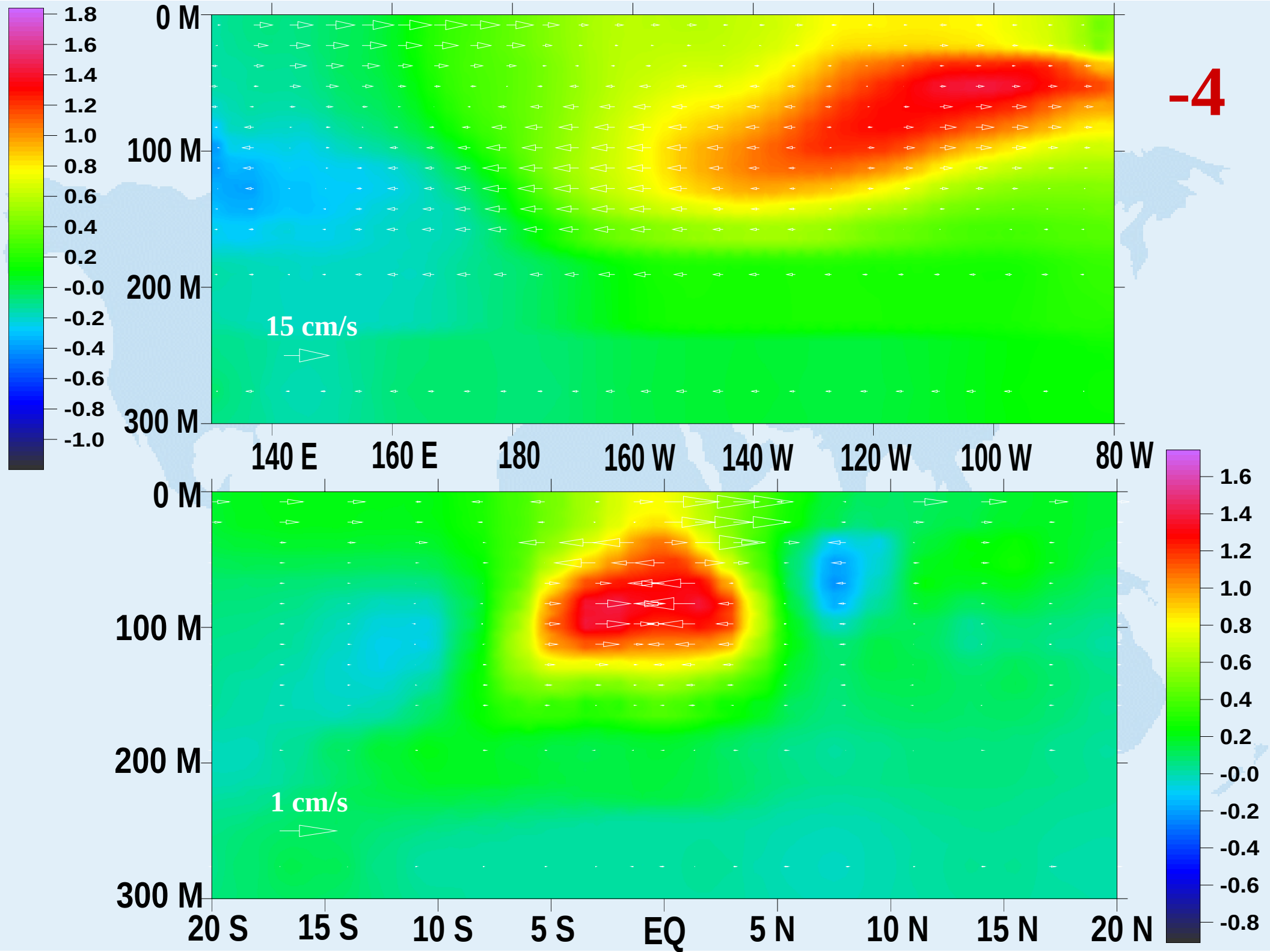
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-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
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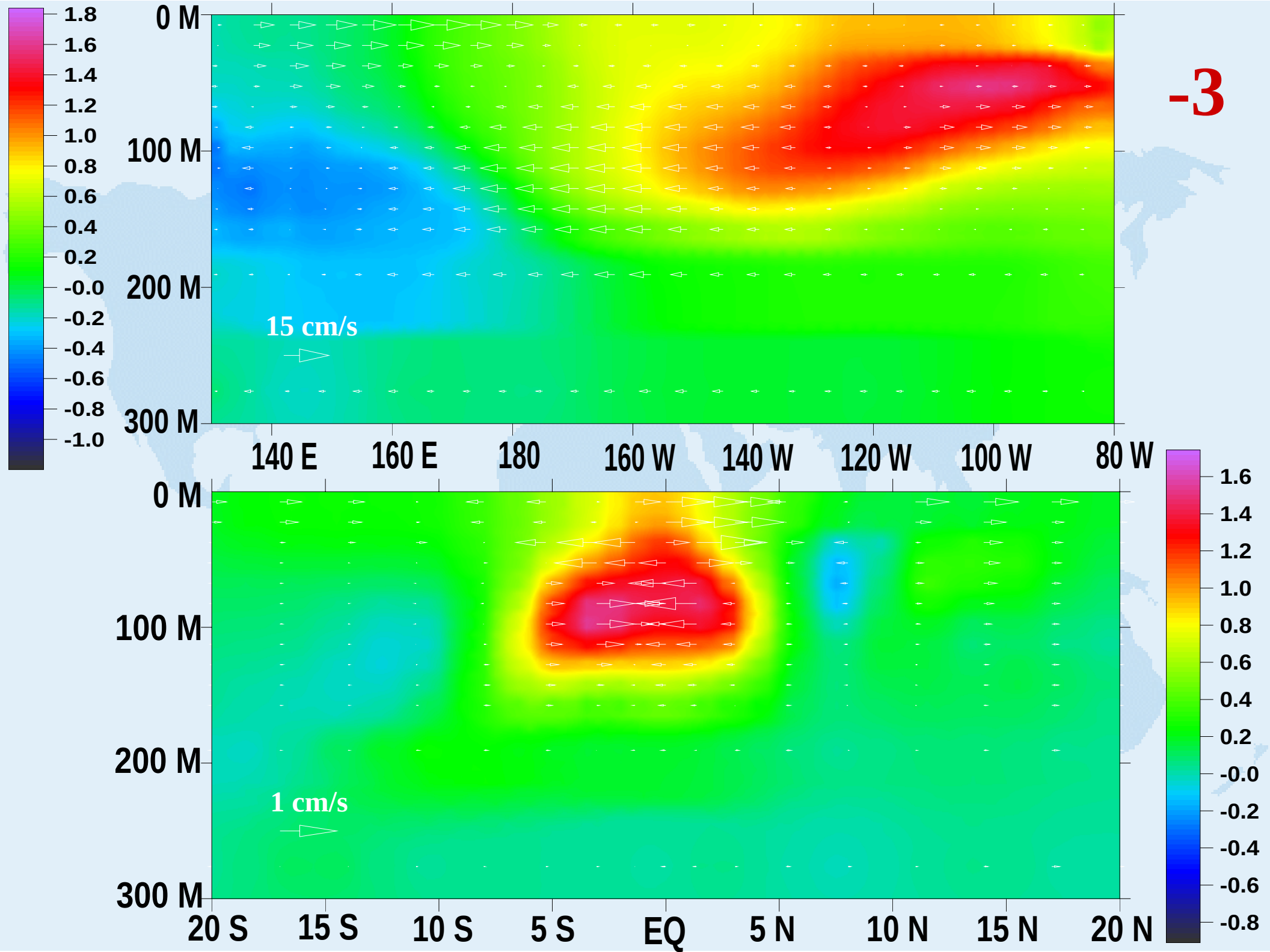
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-0.8
-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
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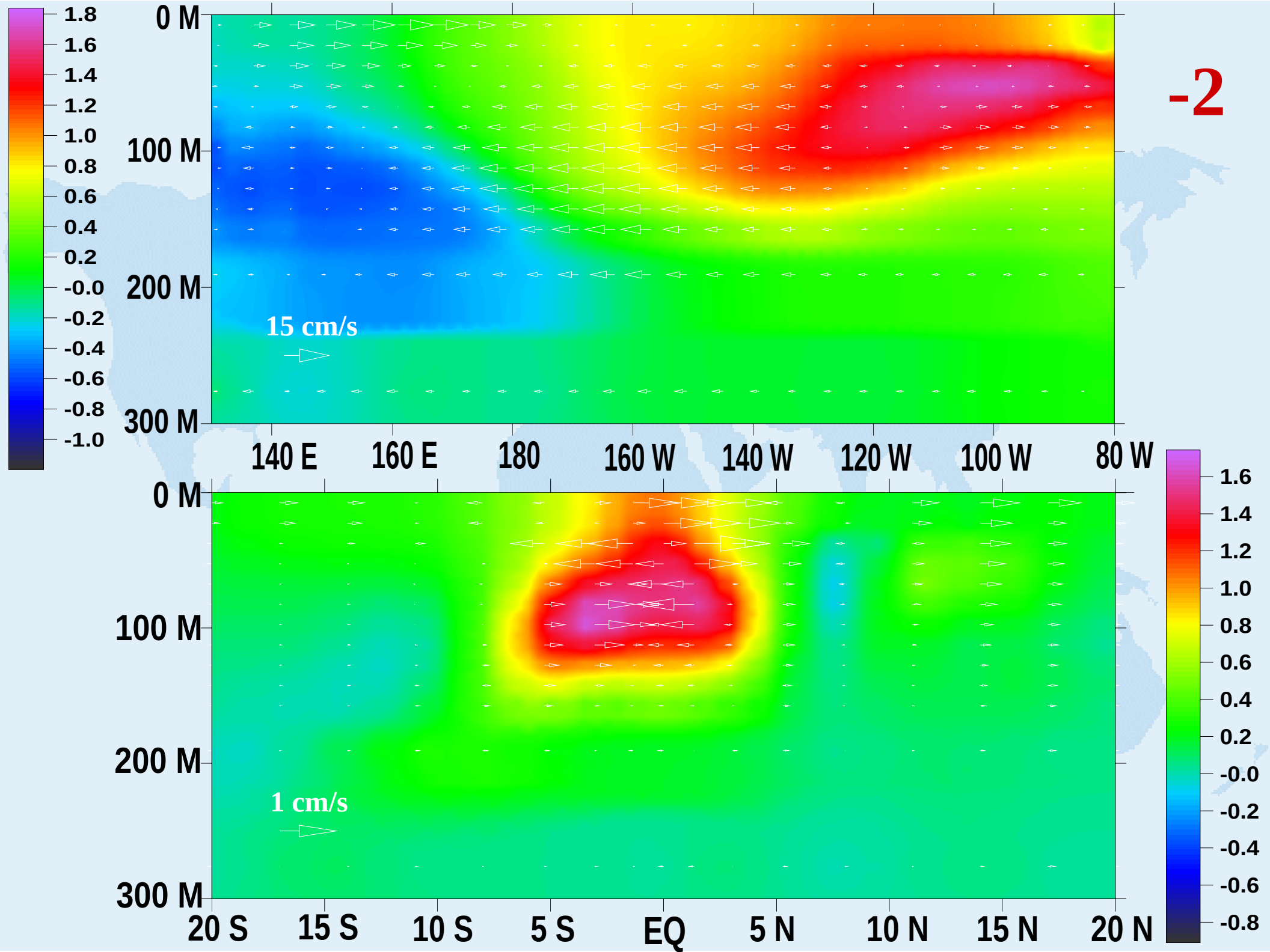
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N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-0.4
-0.6
-0.8
-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
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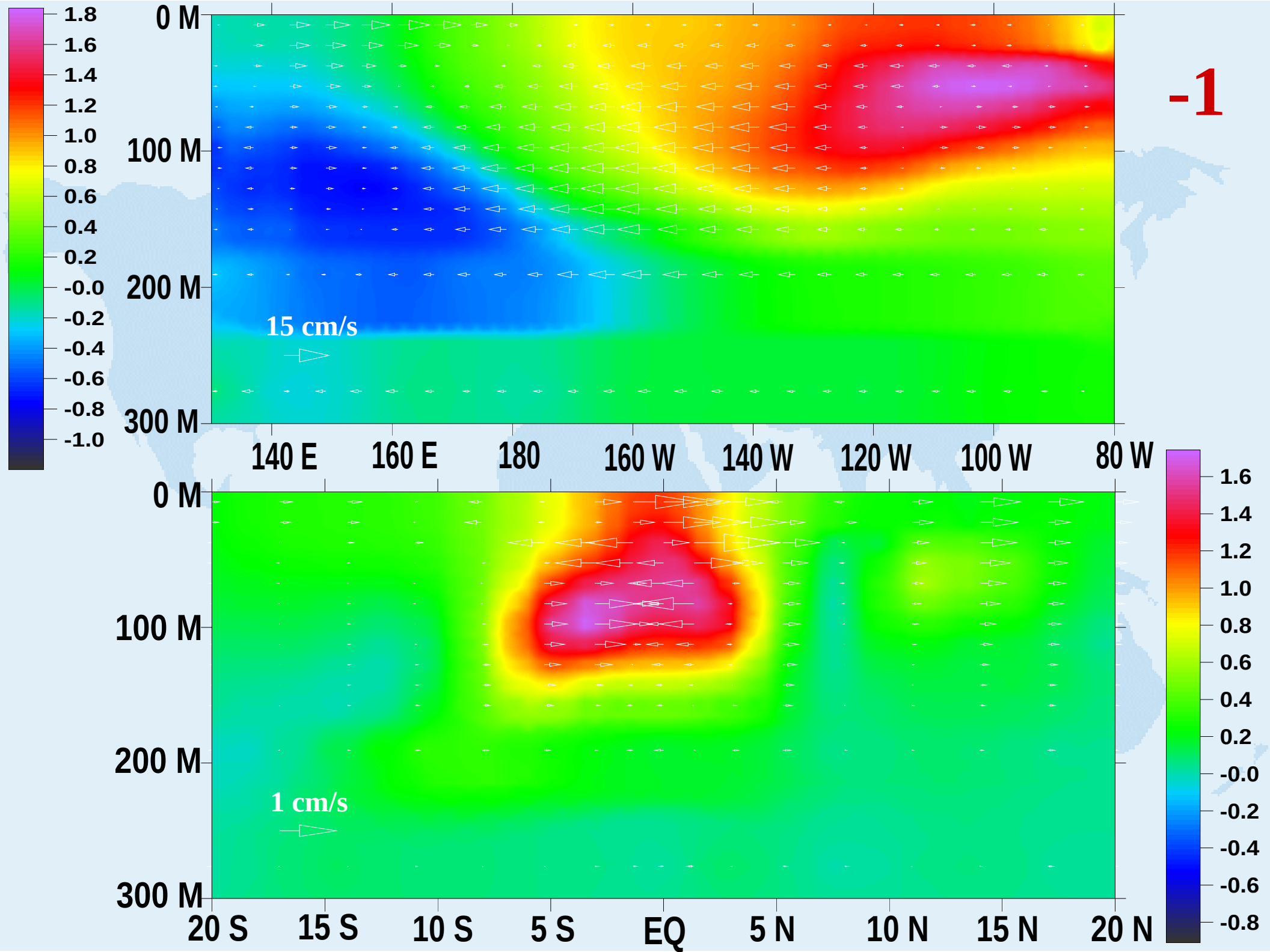
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100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
1 cm/s
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15 S
10 S
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EQ
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10 N
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20 N
1.6
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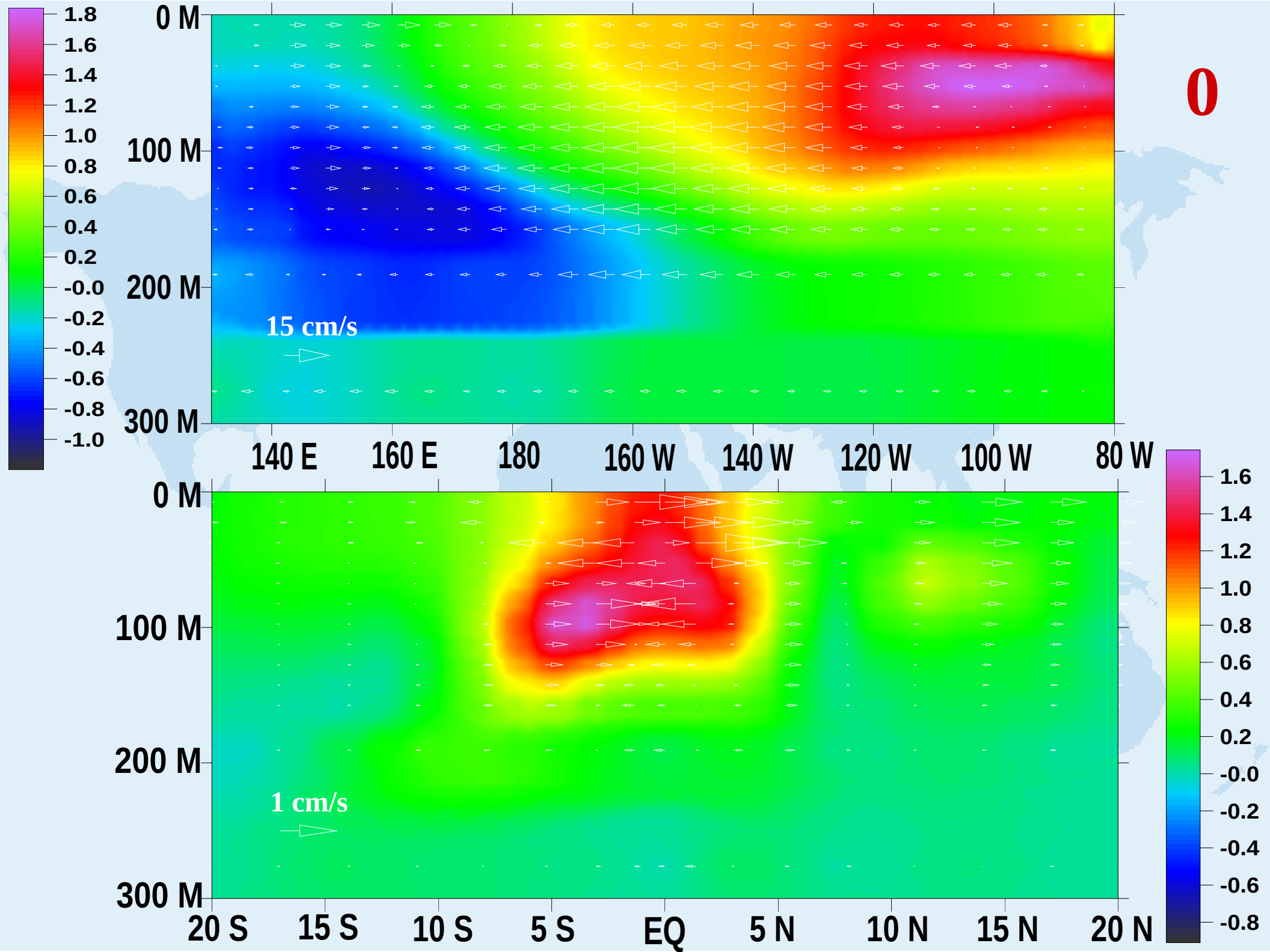
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
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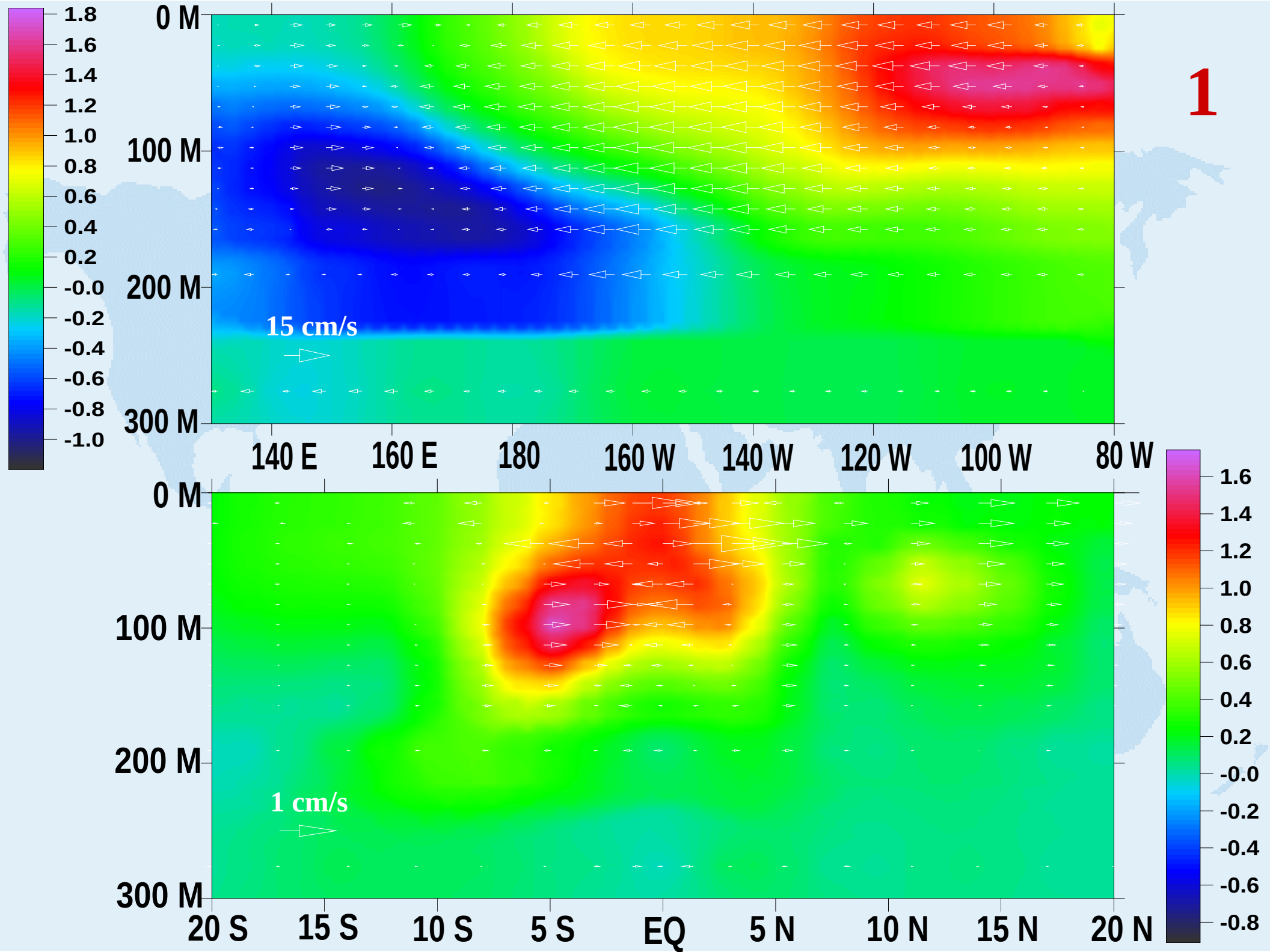
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-0.0
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
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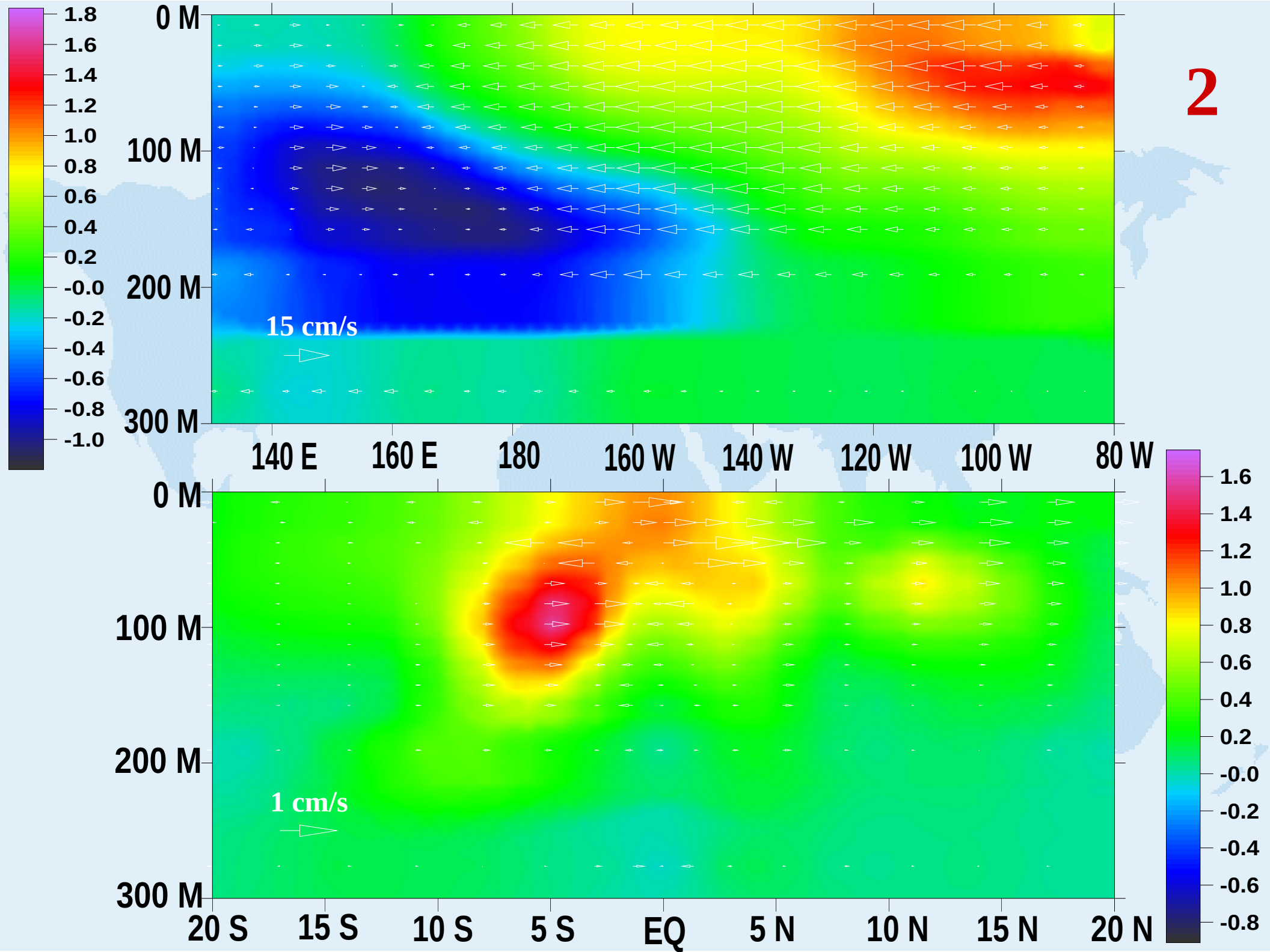
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
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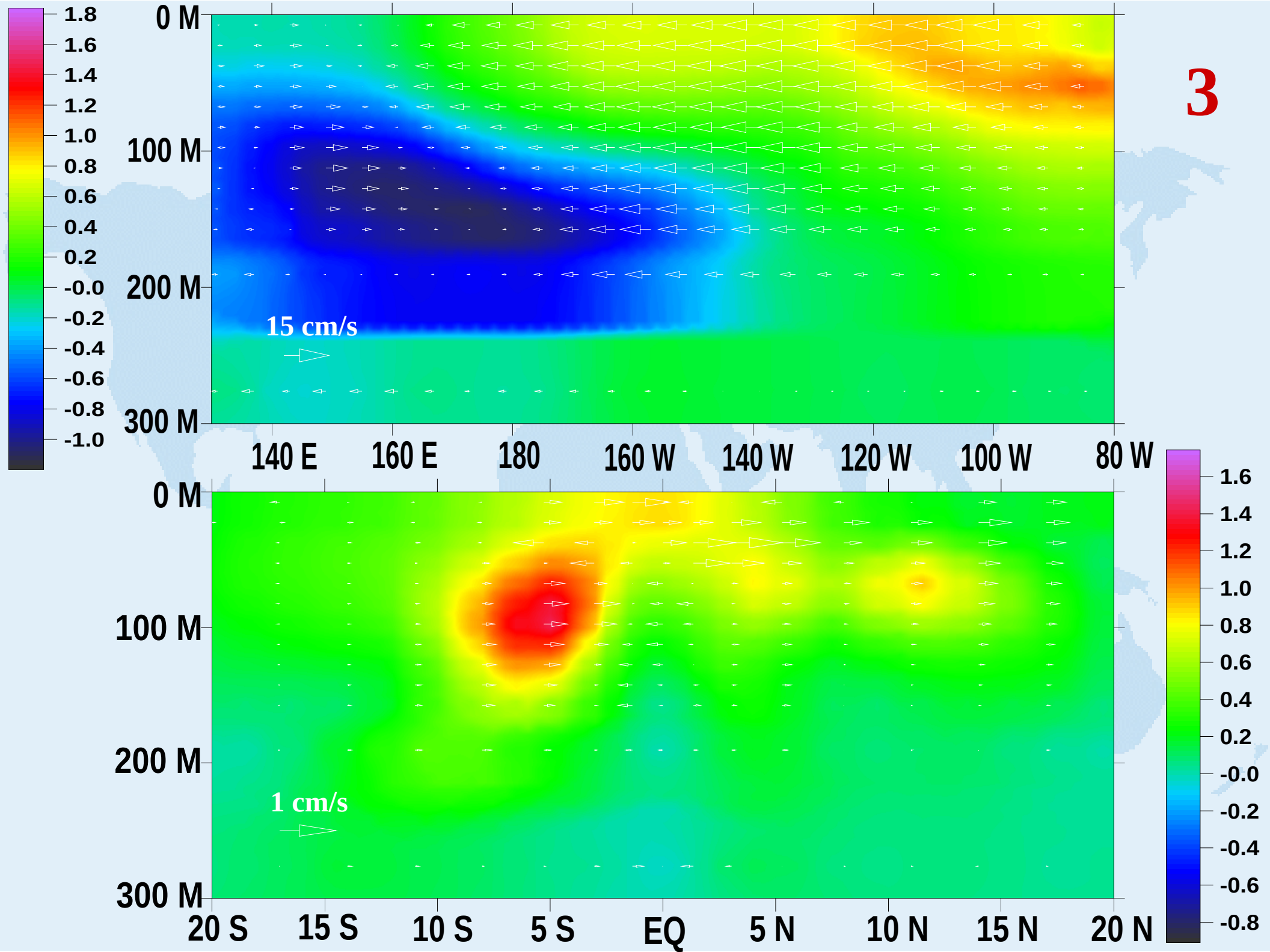
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
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160 W
140 W
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100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
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1.4
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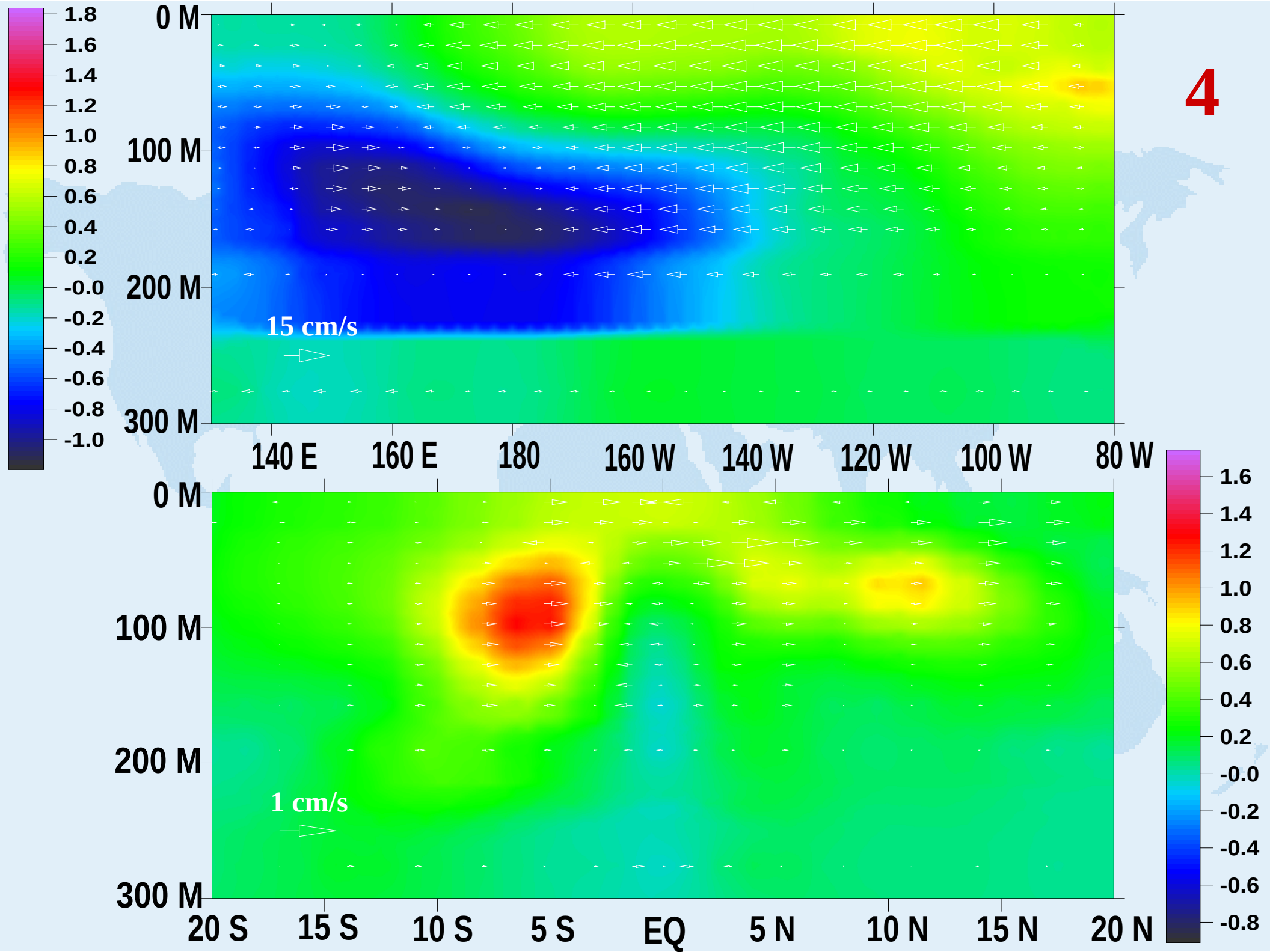
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0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
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160 W
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100 W
80 W
0 M
100 M
200 M
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1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
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20 N
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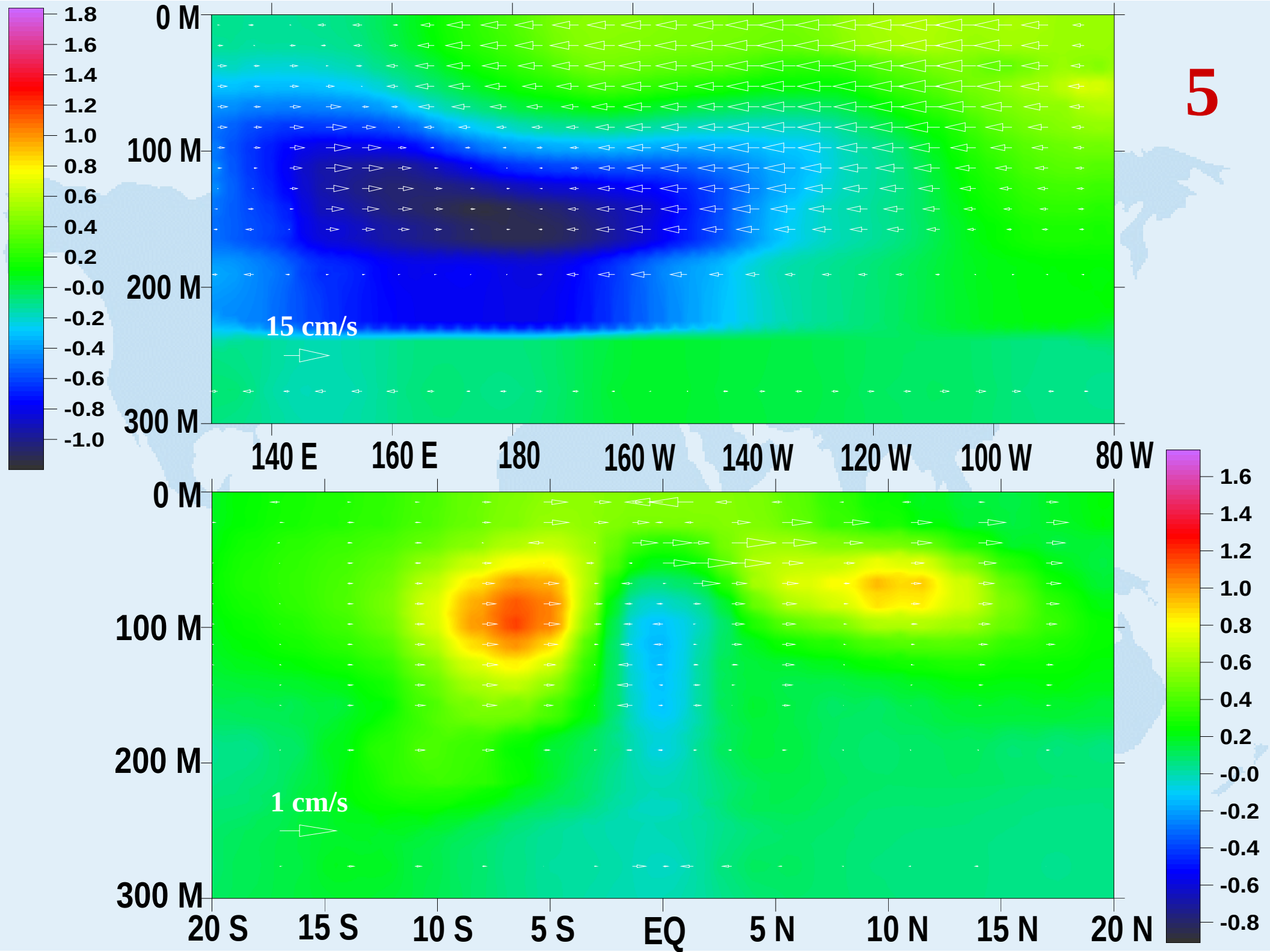
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100 M
200 M
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15 cm/s
140 E
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0 M
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200 M
300 M
1 cm/s
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15 S
10 S
5 S
EQ
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20 N
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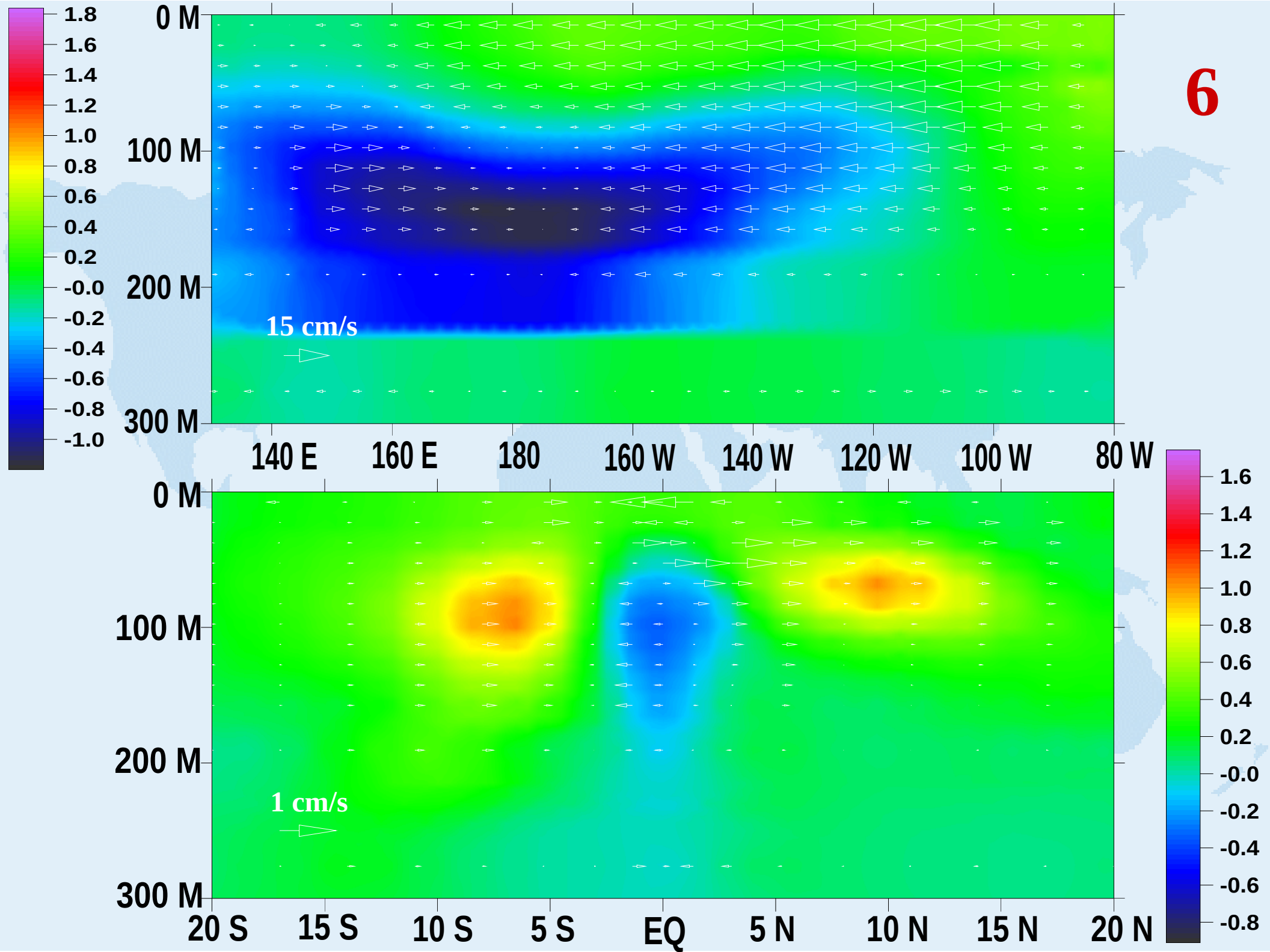
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1 cm/s
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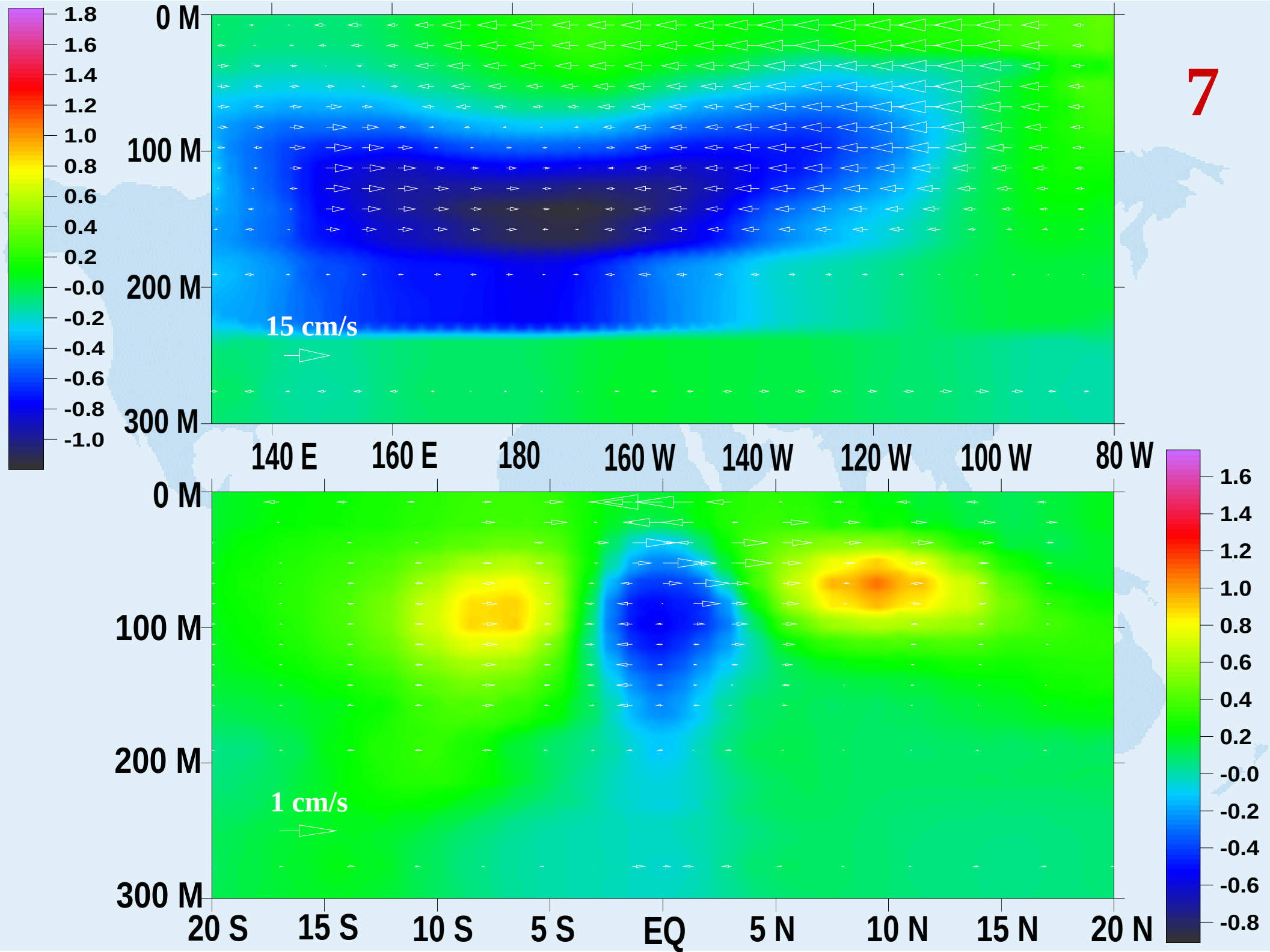
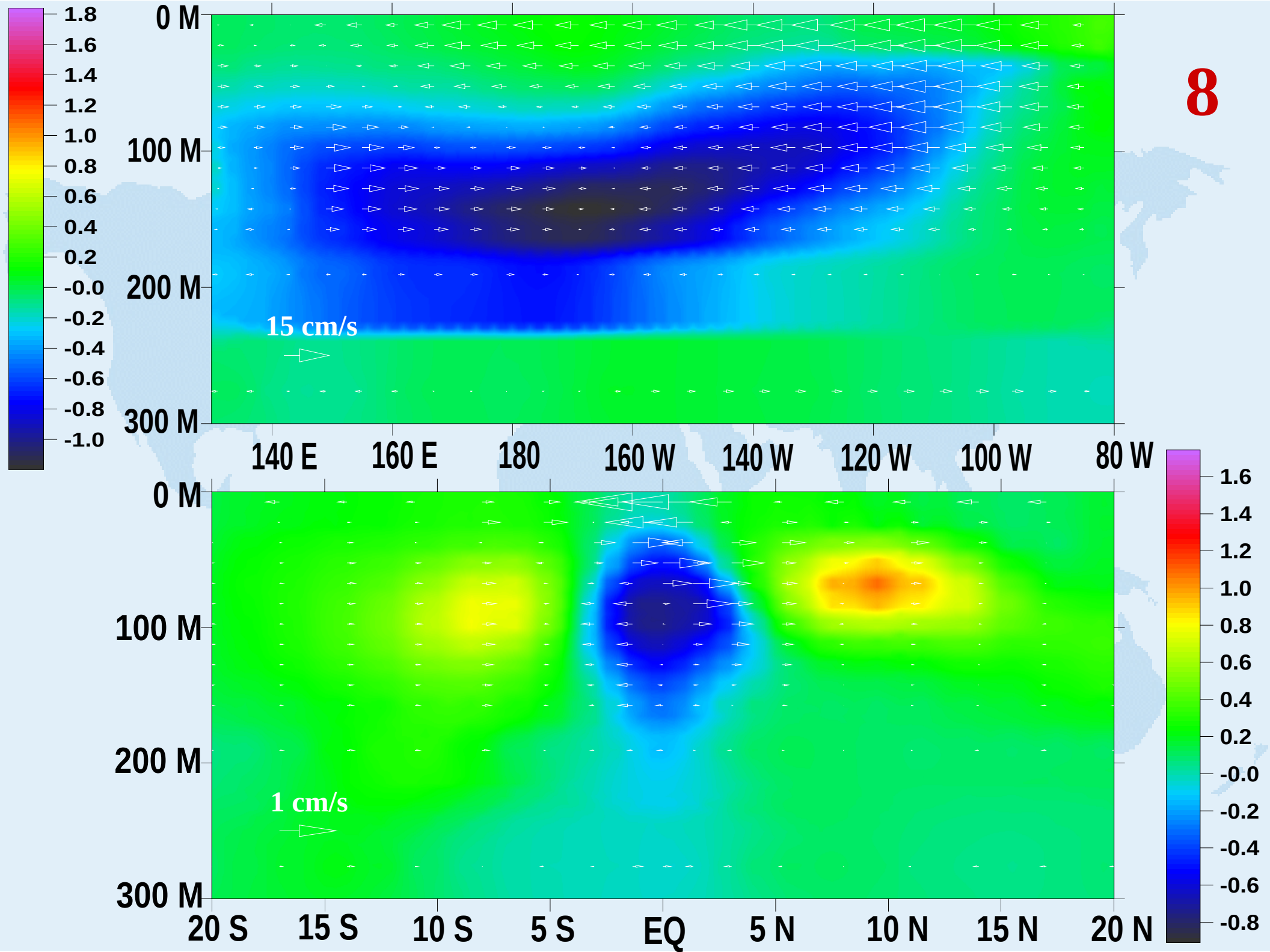
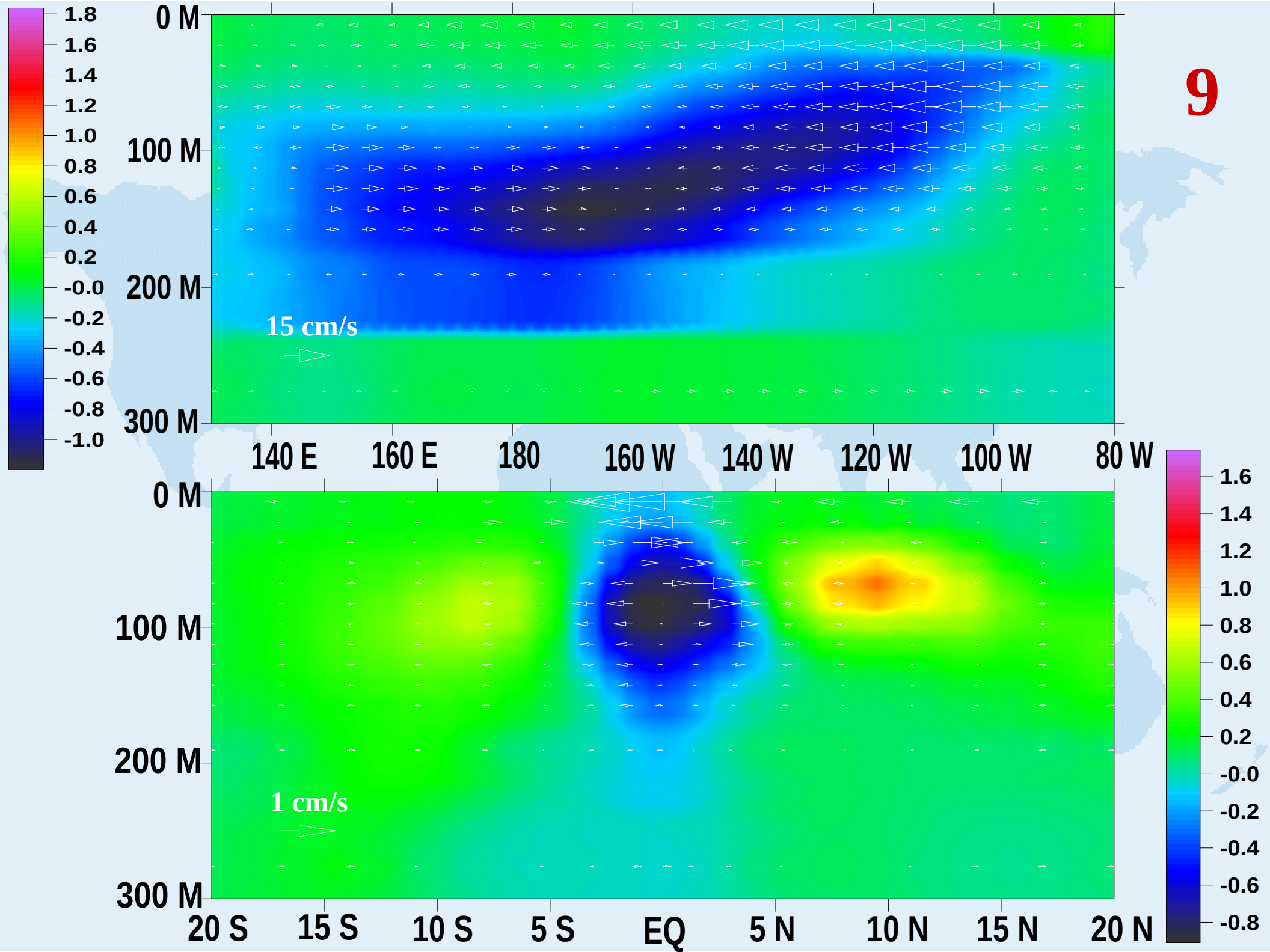
10 N
15 N
20 N
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8


7
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8


8
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8

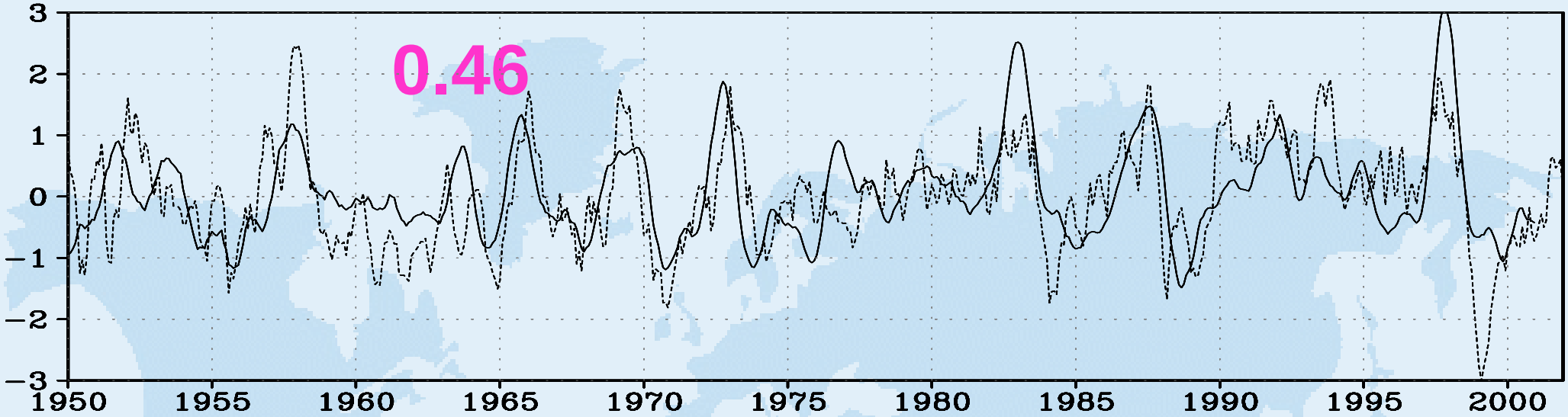

9
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0 M
100 M
200 M
300 M
15 cm/s
140 E
160 E
180
160 W
140 W
120 W
100 W
80 W
0 M
100 M
200 M
300 M
1 cm/s
20 S
15 S
10 S
5 S
EQ
5 N
10 N
15 N
20 N
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8

The results are quite similar to the ones gotten in previous work indicating that the SODA data are really qualified for large scale climate study. Although the major equatorial currents are too broad and weak, errors are generally smaller in the Tropics and the strongest basin and interannual-scale signal with El Niño phenomenon can be well reproduced.

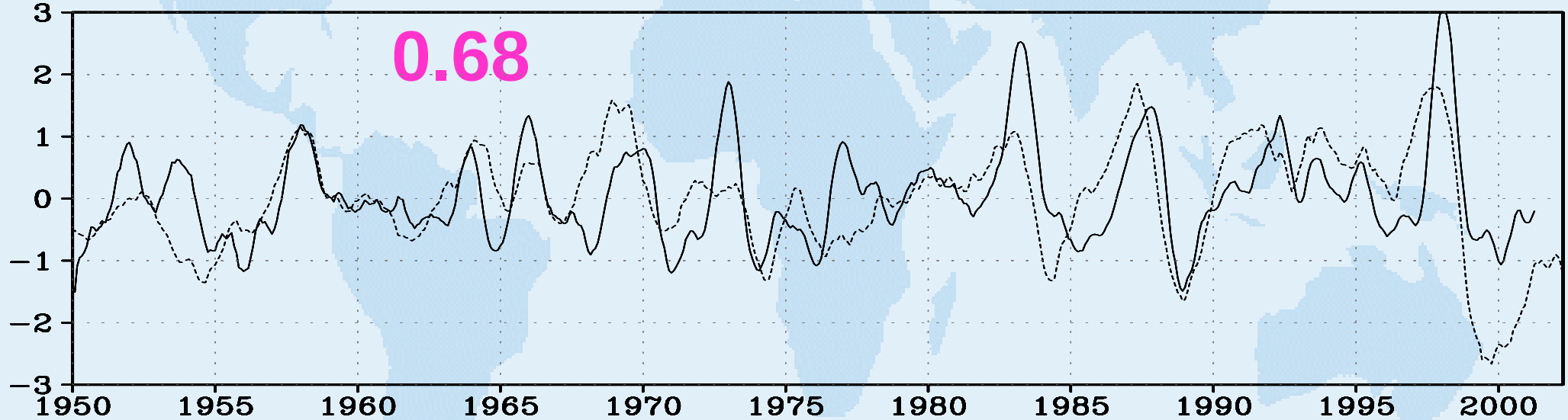
In the tropical Pacific surface SWUA changes about one month before and in subsurface layers of middle Pacific equator westward SWUA takes place 6 months earlier than trade wind reversal, which is somehow consistent with Wyrtki‘s relaxation theory. However, this fact also indicates that during El Niño later stage the ocean may force the atmosphere

- As El Niño's parents their behaviors are quite different, there does not exist a relatively independent tropical atmosphere but does exist a relatively independent tropical Pacific because the air is heated from bottom instead of surface and of much stronger baroclinic instability than the sea and has a very large inter-tropical convergence zone covering the most tropical Pacific;

- it is the wester burst and wind convergence, coming from meddle latitudes directly, instead of Kelvin waves that produce the seawater eastward movement and meridional convergence in the upper levels and result in the typical El Niño sea surface temperature warm signal in nino regions



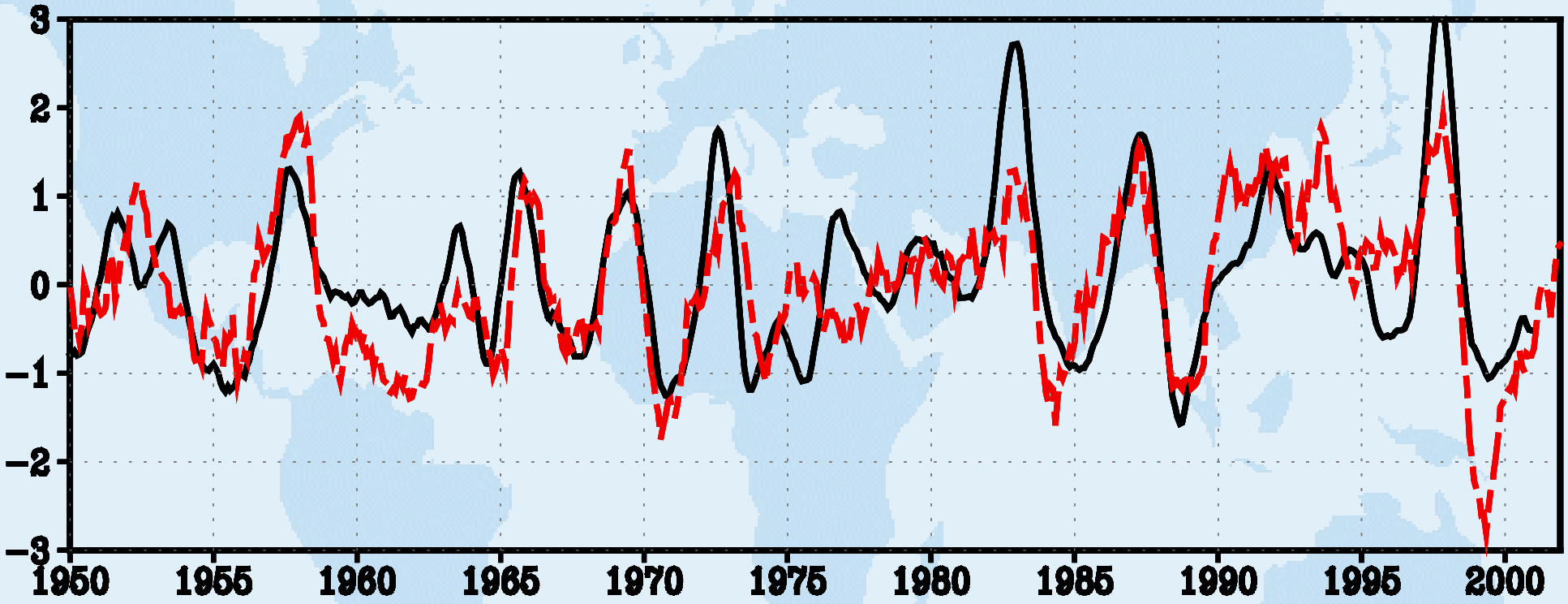
a. By 12 months lead SLP associate pattern



b. By 12 months lead SST associate pattern

The simulated and predicted Nino3 index

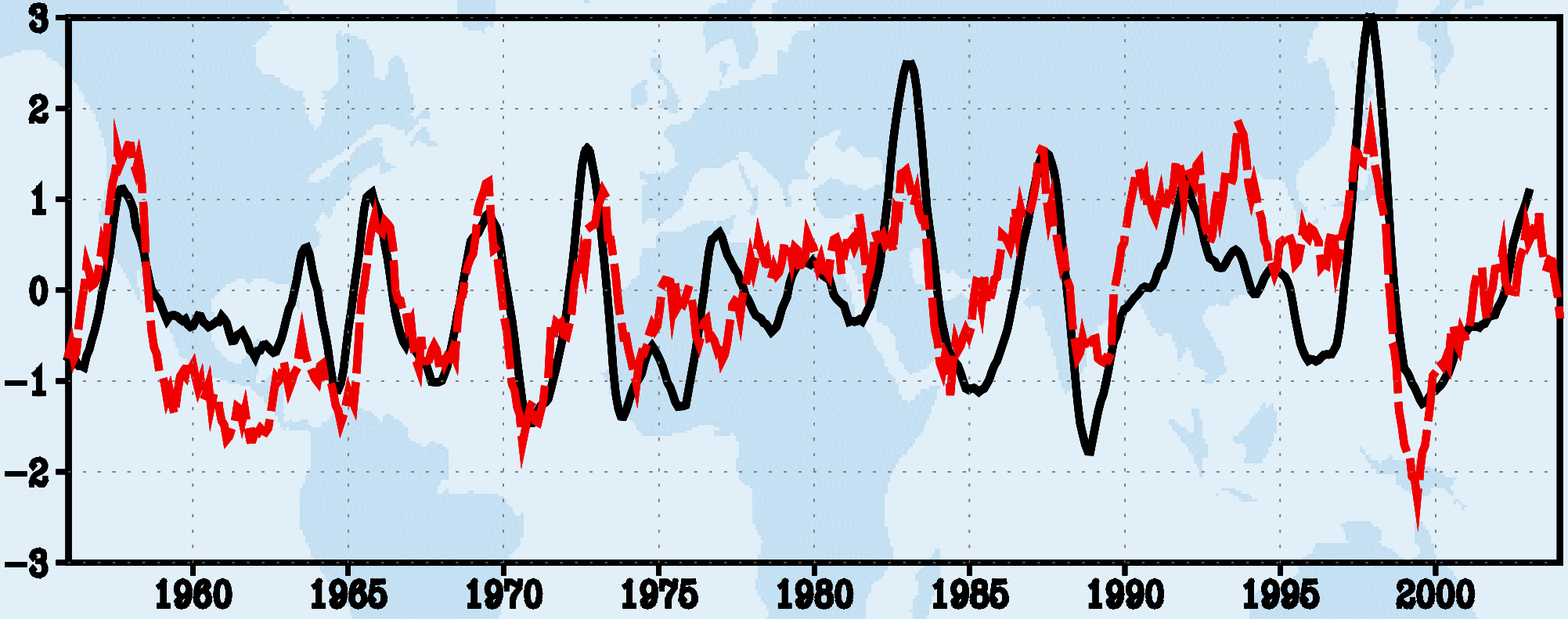
0.70



c. By 12 months lead SLP&SST associate pattern

The simulated and predicted Nino3 index

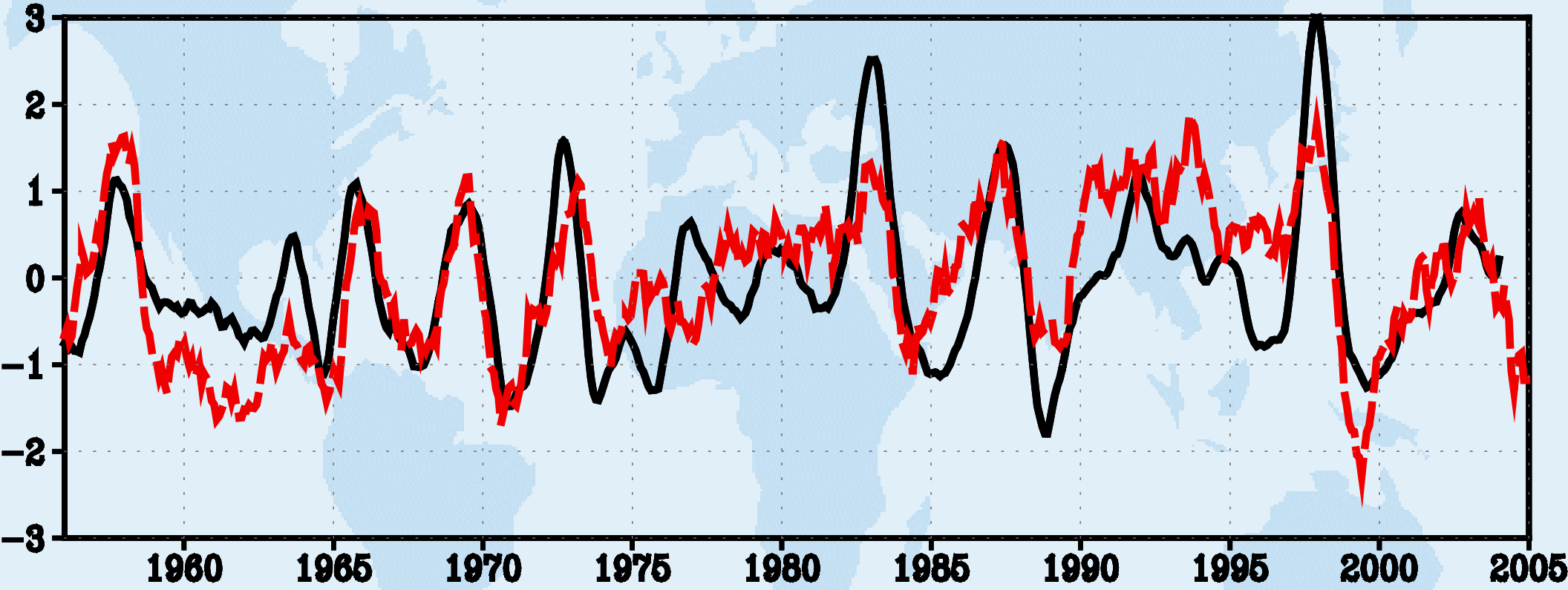
Correlation 0.67; significant level 99.9%



b. By 12 month leading GH-SST associate pattern(1955.1~2002.12)

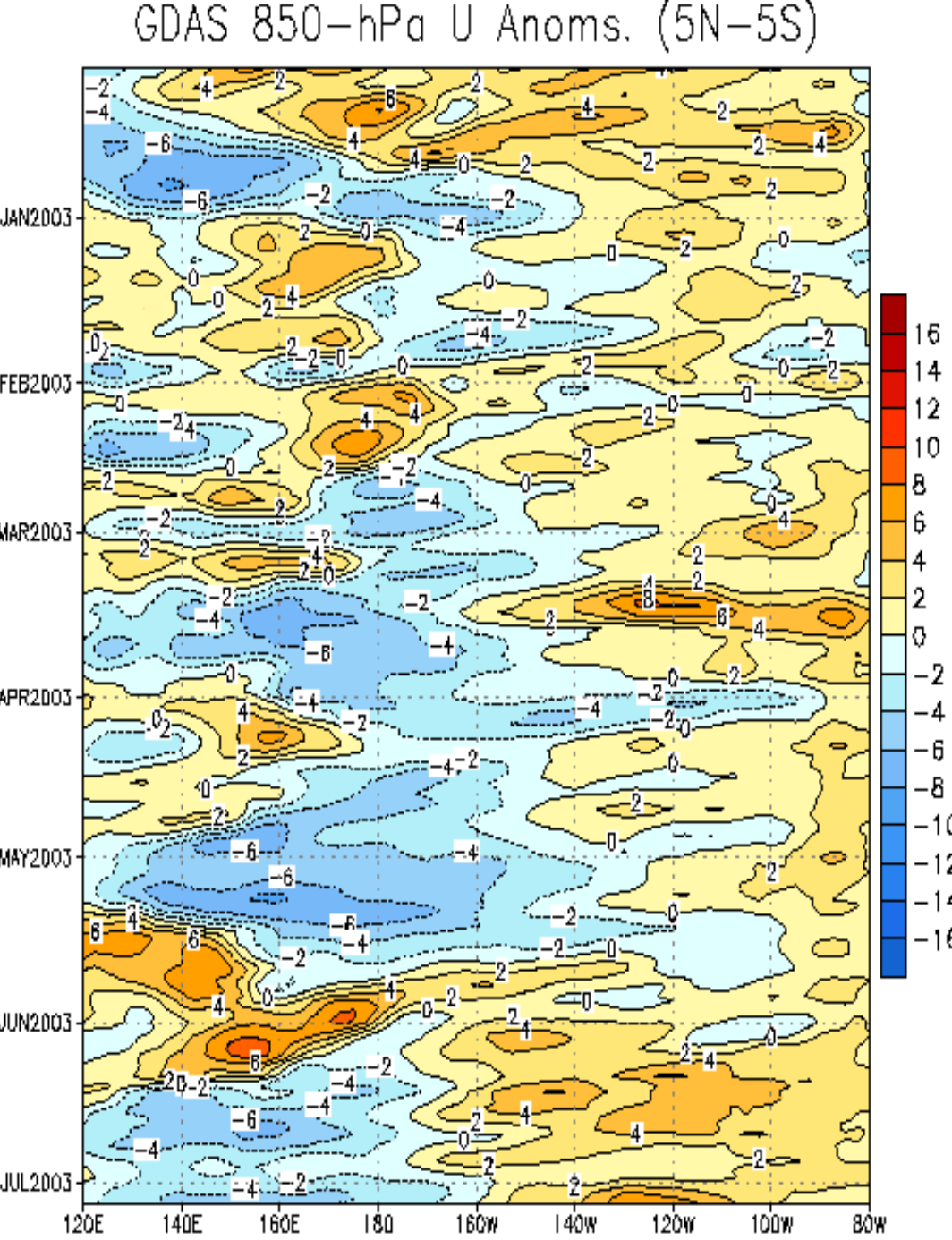
Simulation and forecast of standardized Nino3 index

Correlation 0.67; significant level 99.9%

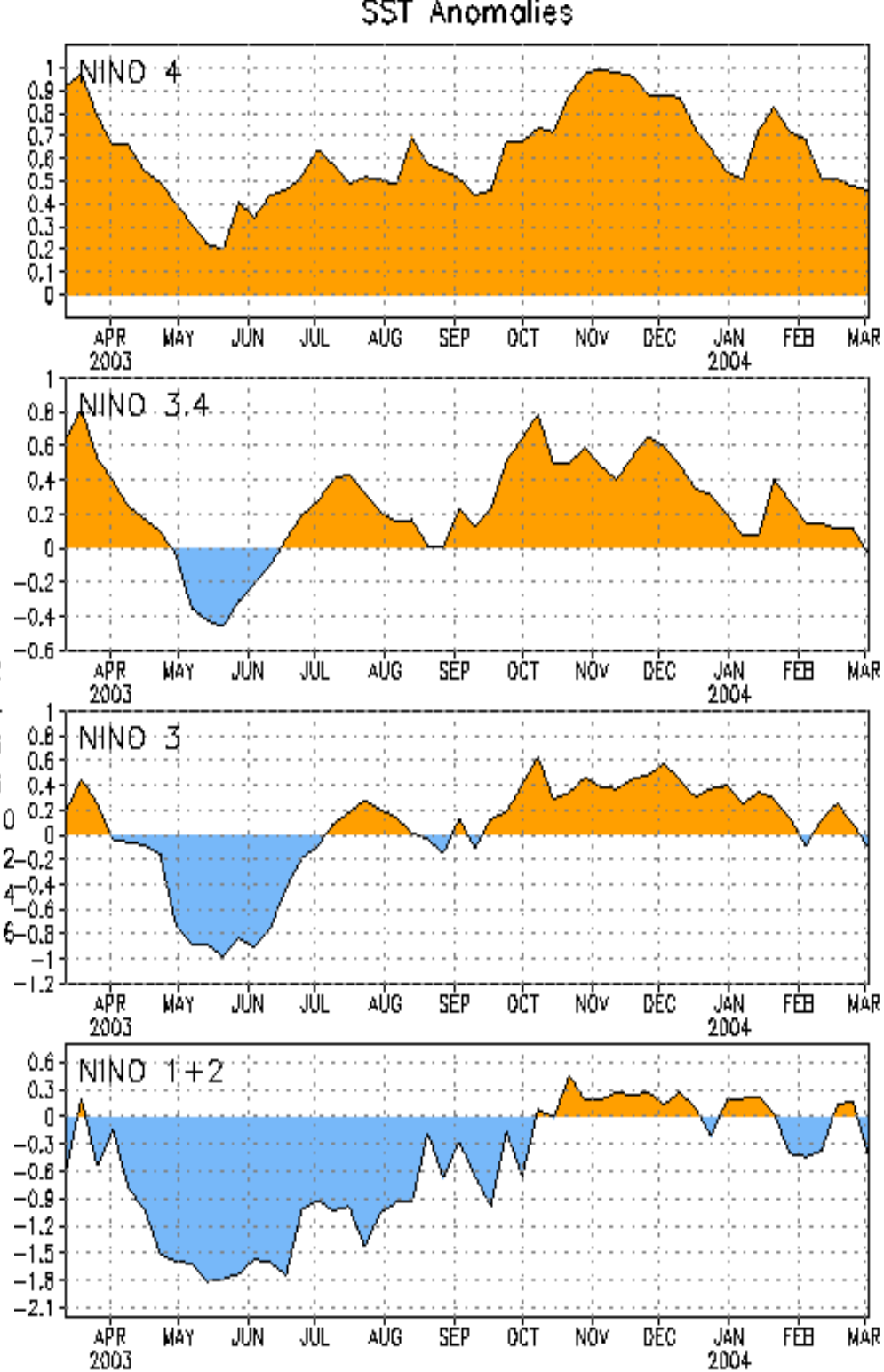


b. By 12 month leading GH-SST associate pattern(1955.1~2003.12)

Simulation and forecast of standardized Nino3 index

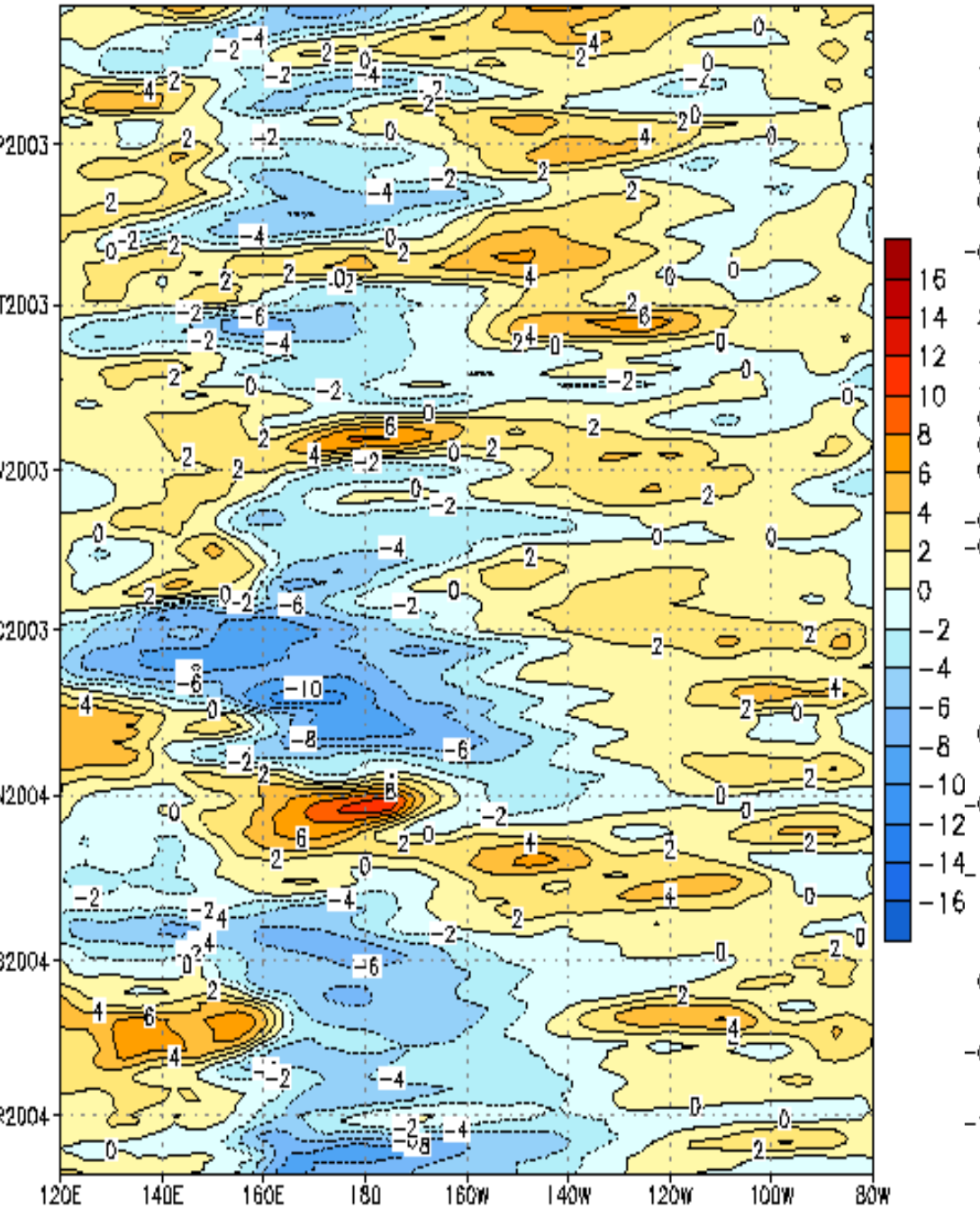


Data updated through 05 JUL 2003



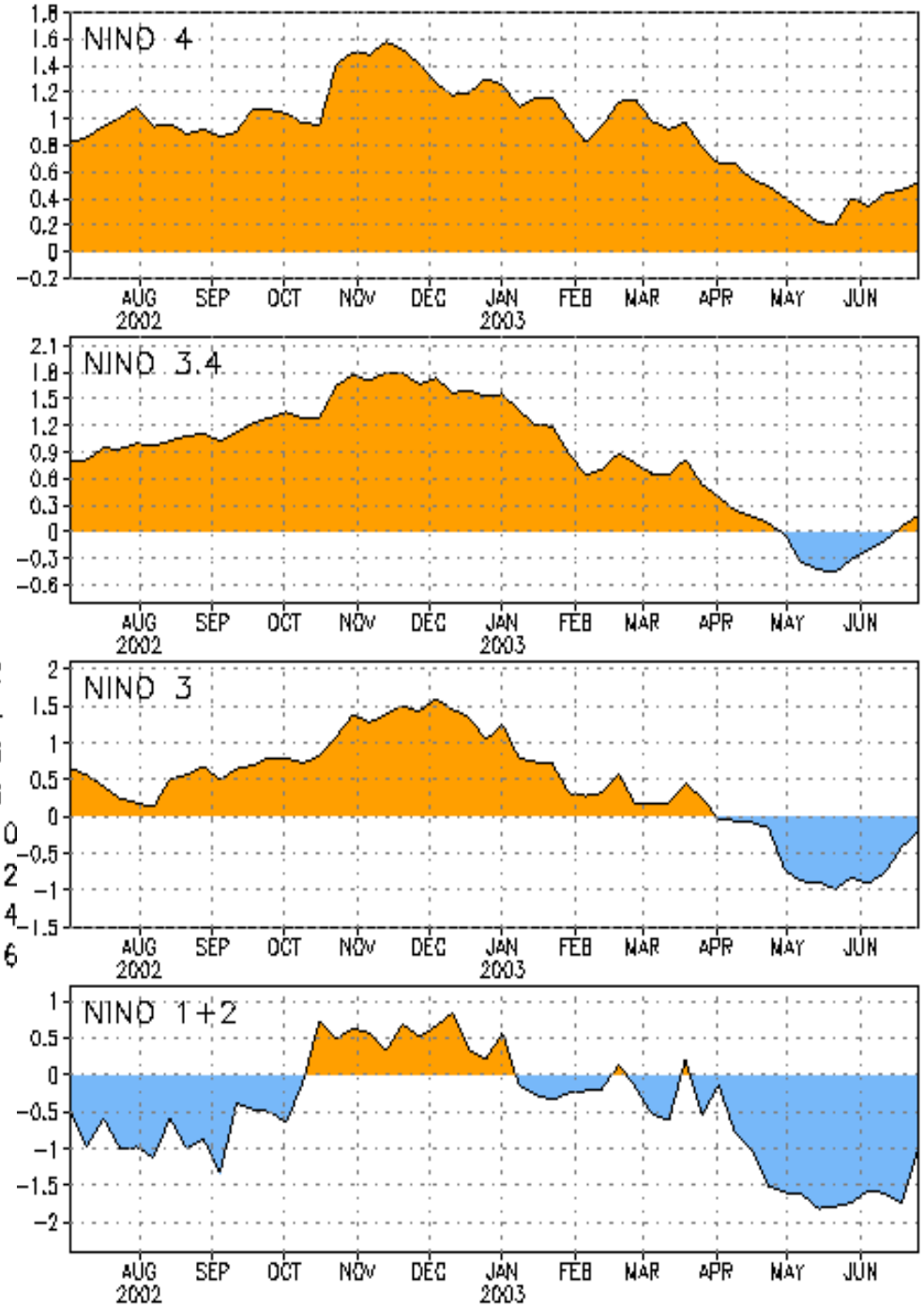
Data updated through 03 MAR 2004

GDAS 850-hPa U Anoms. (5N-5S)



Data updated through 12 MAR 2004

SST Anomalies



Data updated through 25 JUN 2003

CLIMATE PREDICTION CENTER/NCEP

The more and more evidences have shown that the climate system is of semi-dynamic and semi-chaotic properties. Because the climate chaotic theory is still underdeveloped, an exact quasi-dynamic and quasi-chaotic climate model could just be imagined but not be reached today. However, its solution really exists that is the climate observation. Being compared with the exact model, there is always some disadvantage caused by unknown reasons in the present dynamic climate models, so that the climate observation has to be used by statistical methods to improve the initial conditions and outputs of dynamical models. That is the reason why up to now statistical methods are still important tools for climate study after computer technique and dynamic modeling have been well developed. Our results show that the EAPA could extract more information from climate observation and is more effective for ENSO formation mechanism and prediction study.

路漫漫其修远兮
吾将上下而求索

The road is far-forth away,
I walk up-down to seek.

Chinese ancient poem

Thank you very much

for listening to me!

mccui@ms.qdio.ac.cn