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Forcing mechanisms of the circulation on the Brazilian Equatorial Shelf

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COSS-TT meeting, Montreal, Canada, 2-4 May 2023

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Forcing mechanisms of the circulation on the Brazilian Equatorial Shelf

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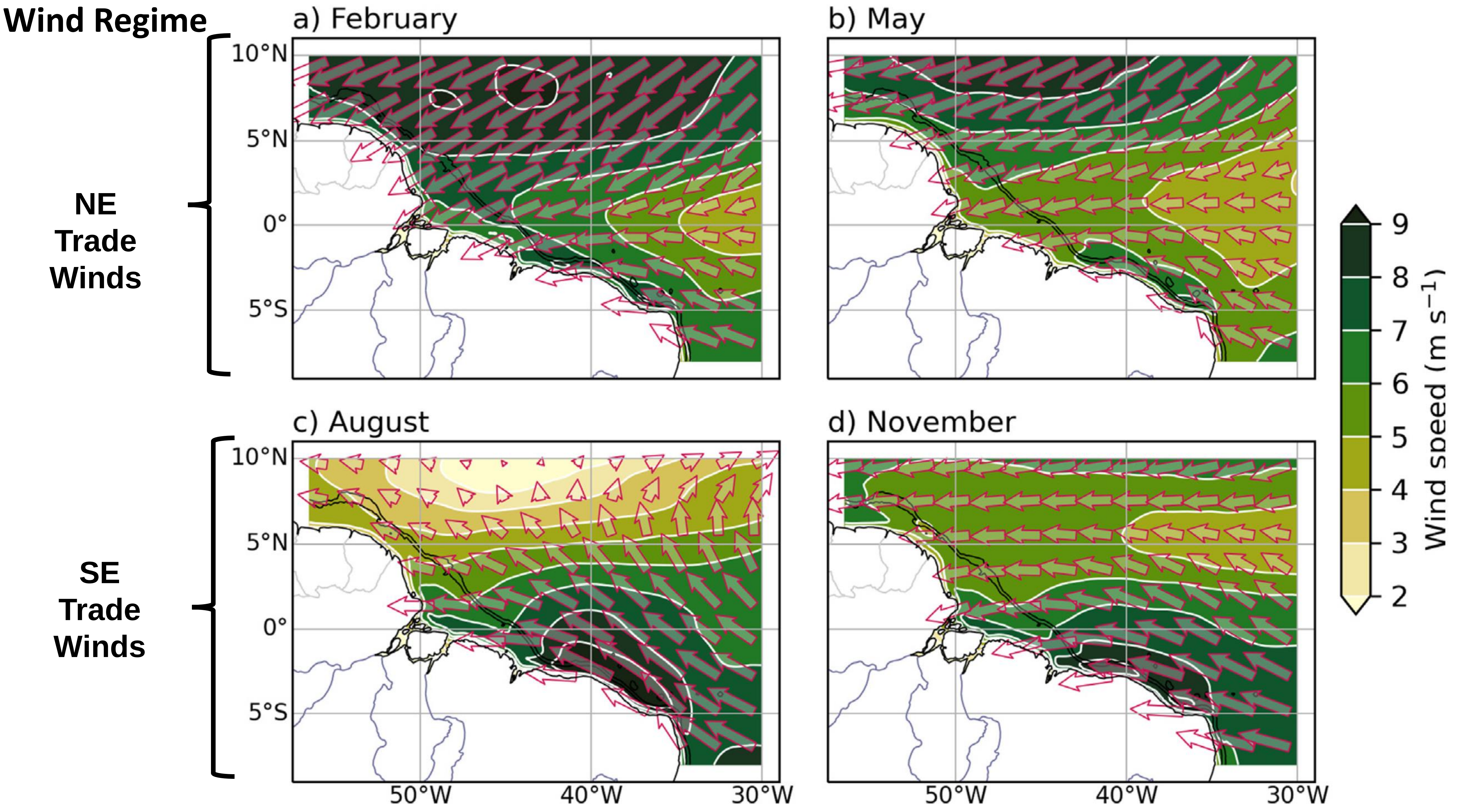
https://doi.org/10.1016/j.csr.2022.104811
Received 3 May 2021; Received in revised form 25 June 2022; Accepted 14 July 2022
Available online 6 August 2022

Introduction

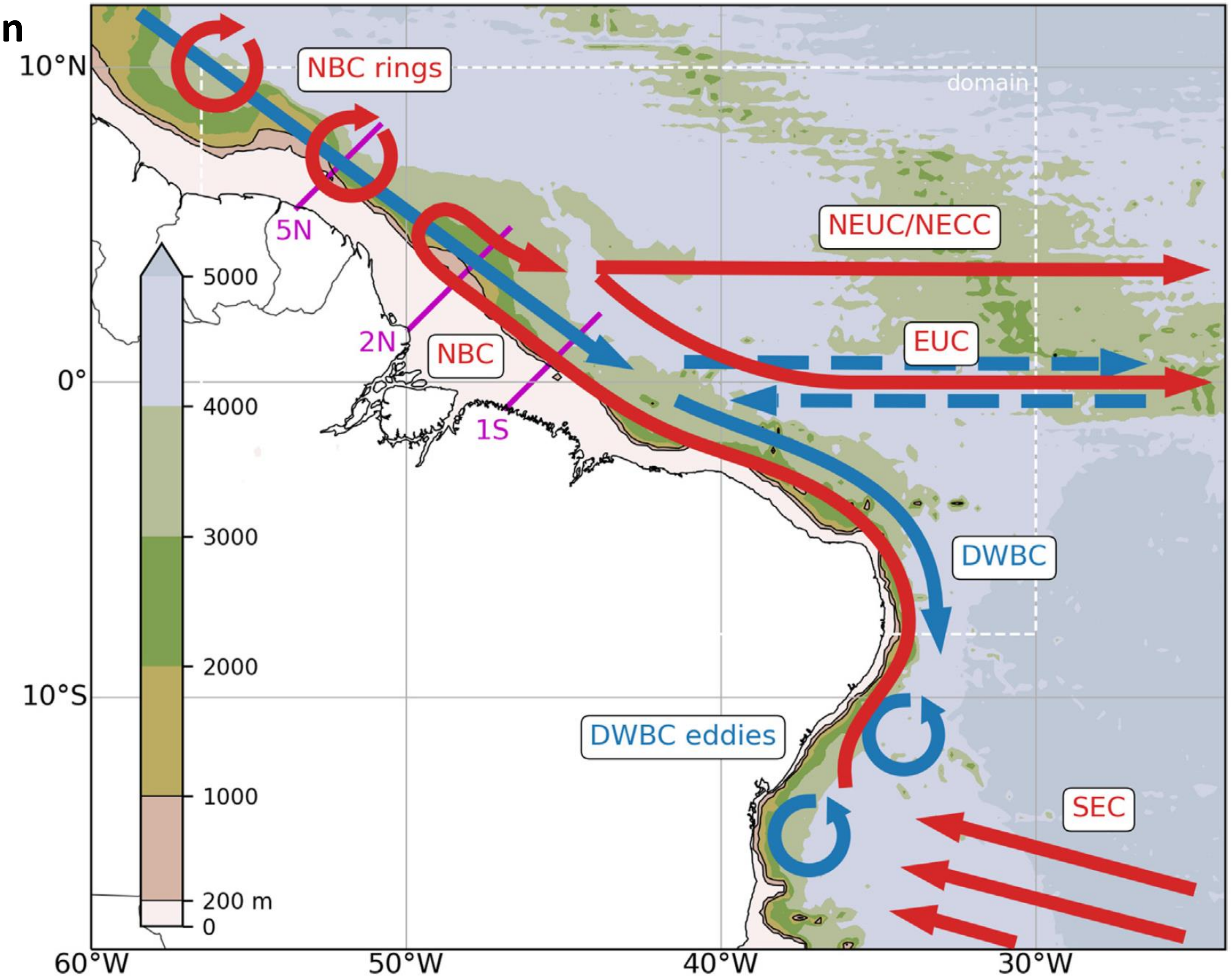
The Brazilian Equatorial Shelf (BES) is a very dynamic region due to the influence of various forcings:

- Trade winds;
- Macrotides (tidal range: > 3 m; tidal currents reaching 2 $m\ s^{-1}$ during spring tides);
- Amazon River;
- North Brazil Current (NBC).



Wind Regime
NE Trade Winds
SE Trade Winds
a) February
b) May
c) August
d) November
10°N
5°N
0°
5°S
50°W
40°W
30°W
Wind speed (m s−1)
2
3
4
5
6
7
8
9

Circulation



Legend:

Surface circulation

Subsurface circulation

Deep circulation

Model setup

The ocean simulations were performed using the Regional Ocean Modeling System (ROMS).

ROMS is a 3D model that solves the free-surface, hydrostatic, primitive equations of the ocean over a variable topography.

The simulations were performed for a five-year period, 2009 to 2013. The simulations started earlier on September 2008, as a 4-month model spin-up.

The grid has horizontal resolution of $1/24^{o}$ ($\sim$4.2 km) and 32 vertical levels.

The domain covers the latitudes 8^{o} S and 10^{o} N and longitudes 56^{o} W and 30^{o} W, extending $\sim$2000 km in north–south direction and $\sim$2900 km in east–west direction.

Model setup

The topography derives from very high resolution bathymetric surveys held by the Brazilian Navy over the Amazon shelf and ETOPO1, with a resolution of an arc-minute (about 1.8 km).

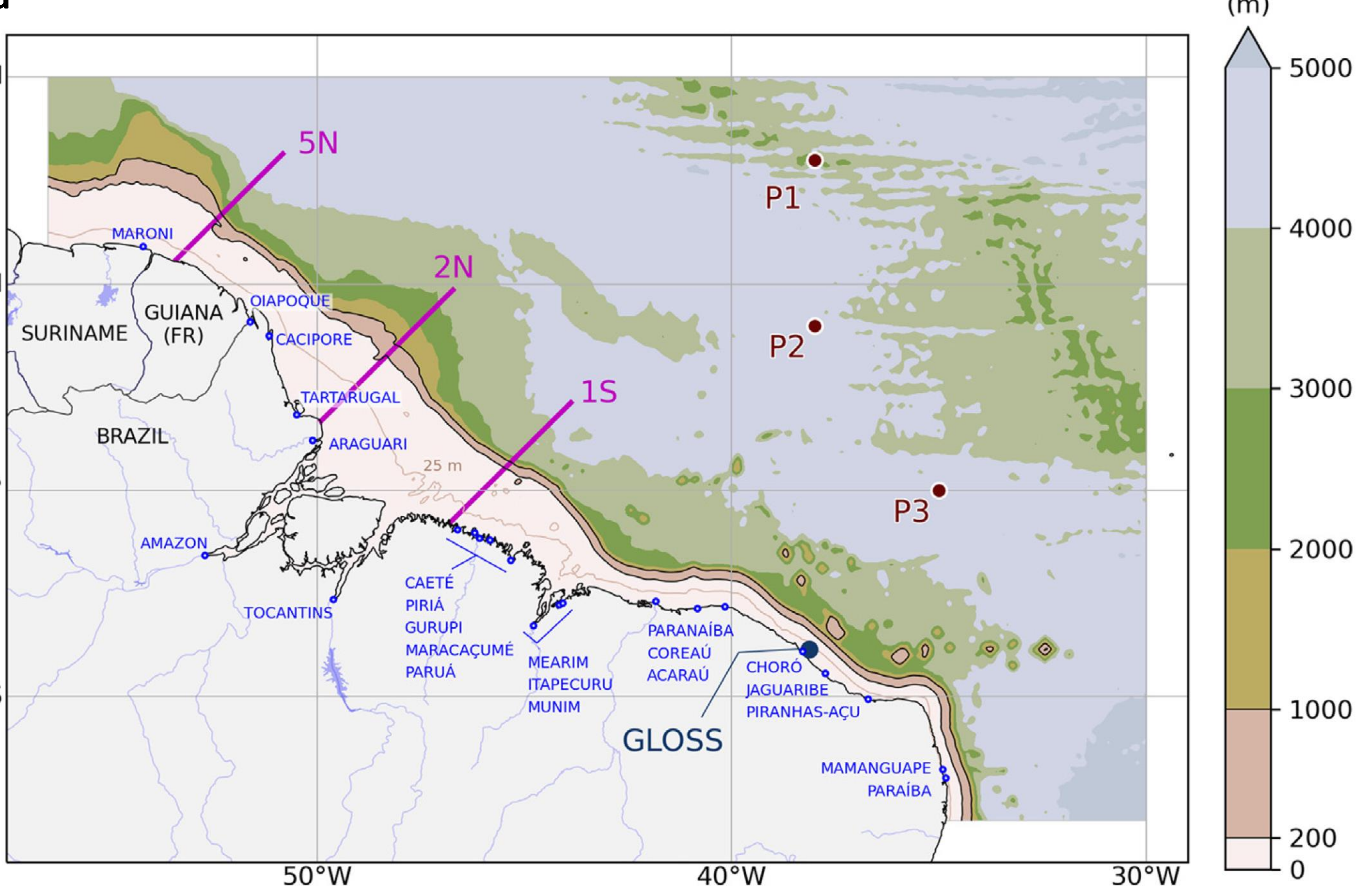
Boundary conditions from HYCOM-NCODA (Version 2.2).

Tidal forcing from TPXO 7.2 global data base.

Atmospheric forcing from CFSR (NCAR/NCEP) with spatial resolution of 0.25º at the surface and temporal resolution of 6 h.

Rivers were included as monthly climatologies which were calculated based on measurements taken by ANA (Portuguese acronym for National Waters Agency).

Study Area



(m)
5000
4000
3000
2000
1000
200
0
10°N
5°N
0°
5°S
50°W
40°W
30°W
5N
2N
1S
P1
P2
P3
25 m
MARONI
OIAPOQUE
CACIPORE
TARTARUGAL
ARAGUARI
AMAZON
TOCANTINS
CAETÉ
PIRIÁ
GURUPI
MARACAÇUMÉ
PARUÁ
MEARIM
ITAPECURU
MUNIM
PARANAÍBA
COREAÚ
ACARAÚ
CHORÓ
JAGUARIBE
PIRANHAS-AÇU
MAMANGUAPE
PARAÍBA
GLOSS
SURINAME
GUIANA
(FR)
BRAZIL

Analysis of the simulations

The analysis was based on the comparison of the surface and vertical structure in terms of monthly means.

May and November were used as reference months:

May represents the month of maximum river discharge, northeasterly winds, and no NBC retroflection;

November represents the month of minimum river discharge, southeasterly winds, and occurrence of NBC retroflection.

Analysis of the simulations

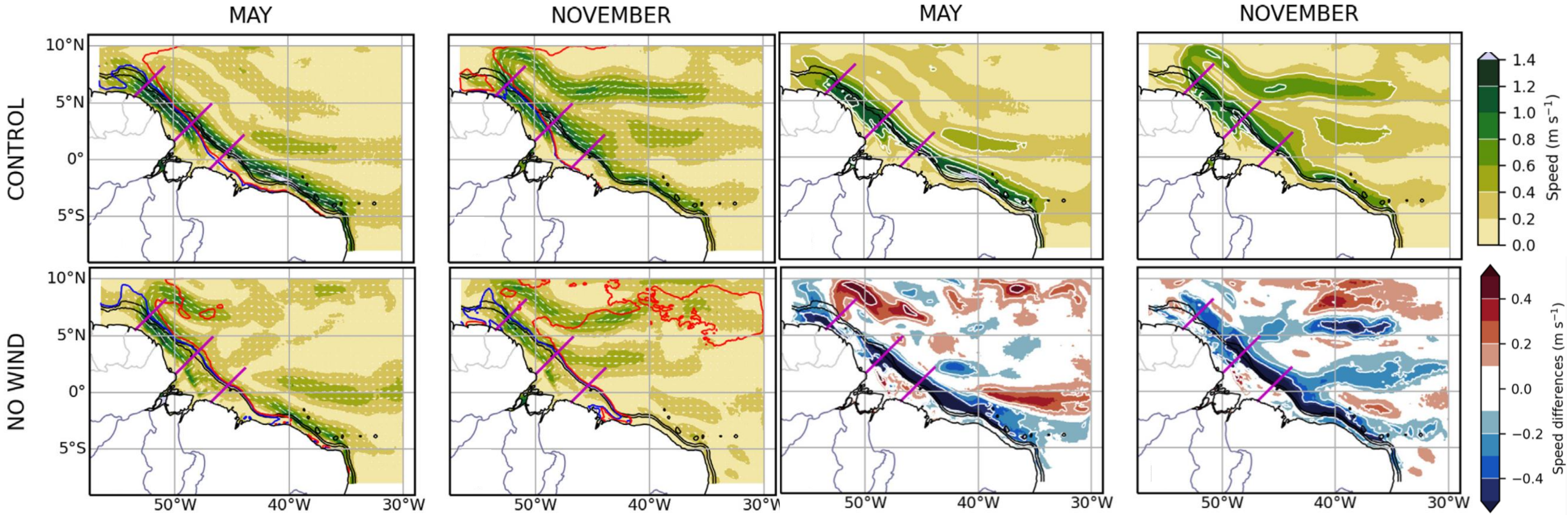
To track the position of the Amazon River plume, the 34 isohaline was adopted as the limit of its extension, following Molleri et al. (2010) who established a threshold of surface salinity less than 34 to map the plume.

The 34 isohaline was also used here as a reference to the plume along the water column.

The 35 isohaline was used to evaluate the waters outside the plume but still less saline than the ocean, hereafter referred to as low-salinity waters.

Molleri, G., Novo, E., Kampel, M., 2010. Space-time variability of the Amazon River plume based on satellite ocean color. Cont. Shelf Res. 30 (3–4), 342–352. http://dx.doi.org/10.1016/j.csr.2009.11.015.

Results



Control – May

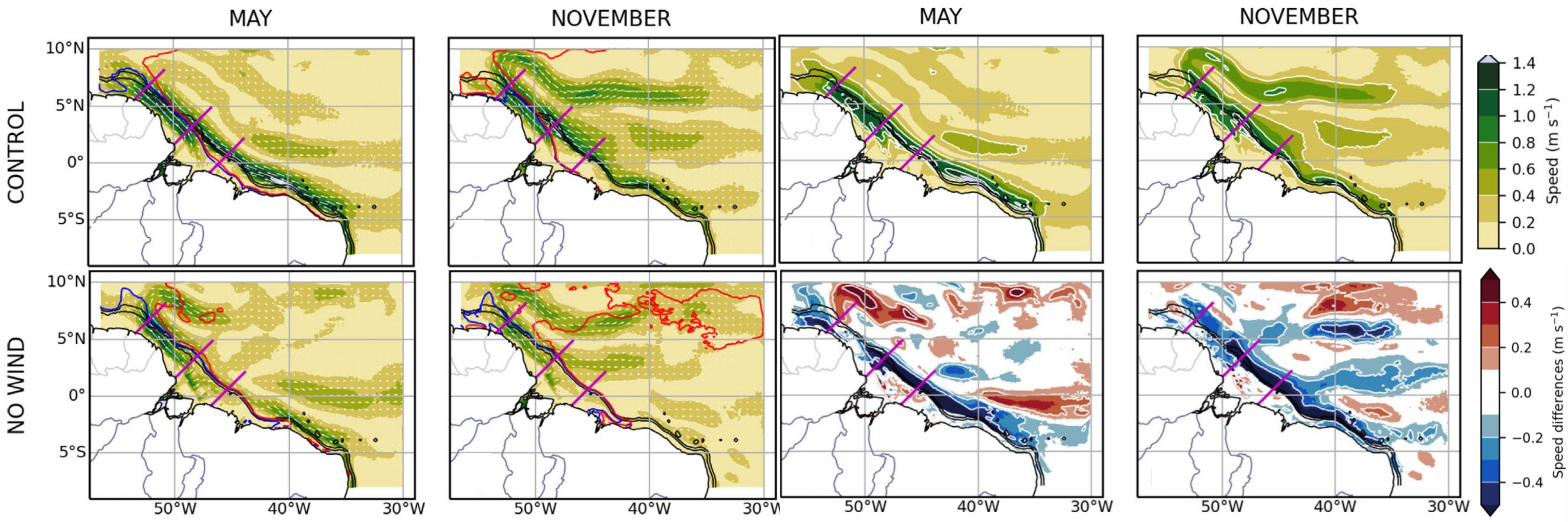
NBC is more intense over the shelf, while its retroflection and NECC are weak.

Amazon River discharge is maximum and the NBC advects the river plume northwestward into the Caribbean Sea.

Control – November

NBC weakens along the shelf, marked retroflection occurs, which feeds the NECC and advects low-salinity waters eastward.

Results



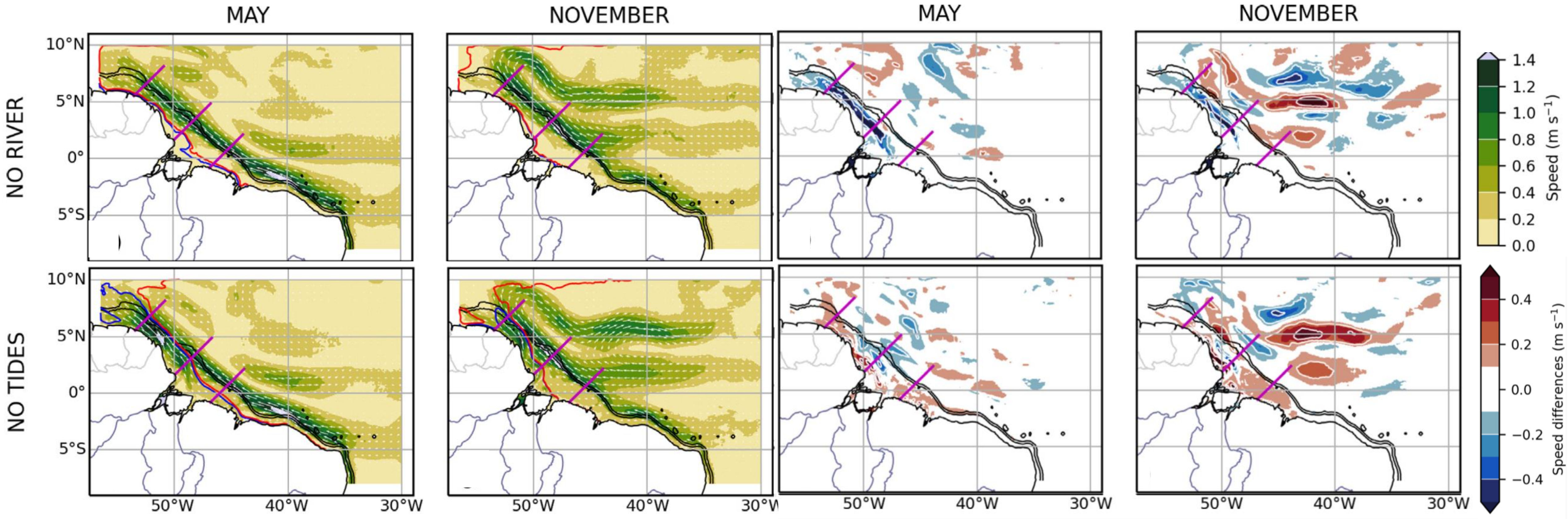
No Wind

The western boundary flow vanished on the surface and only the undercurrents remained in most of BES, i.e., EUC at the Equator and NBUC south of the Equator.

NBC retroflection was enhanced when wind was either disabled during May (southeasterly winds) or included in the simulation during November (northeasterly winds).

Therefore, we can assume southeasterly winds inhibit NBC retroflection system and thus, NECC and EUC intensification.

Results

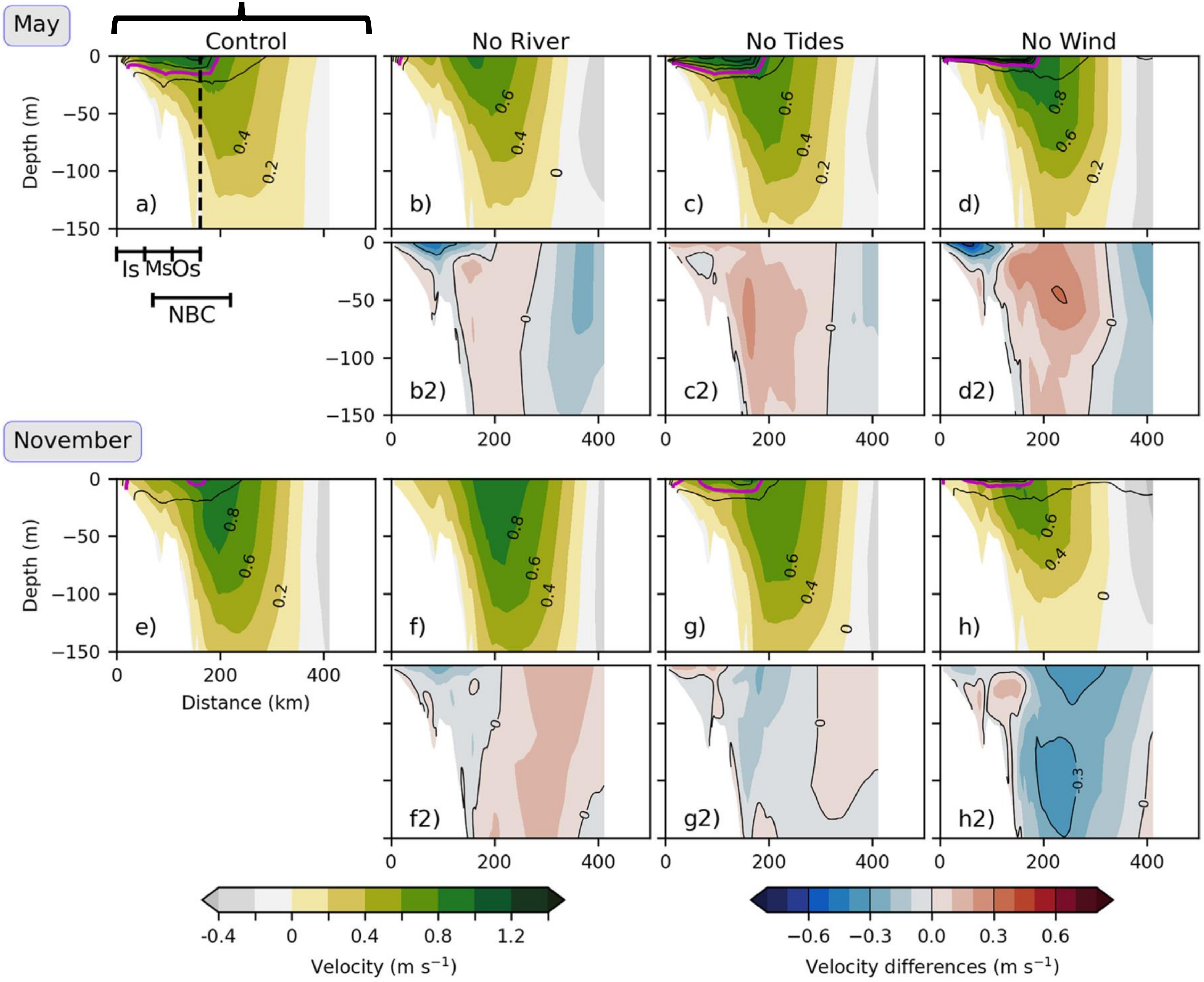


Tides and river discharge worked against the NBC retroflection and, thus against the intensification of the NECC and EUC during both boreal summer and winter.

The lack of riverine forcing greatly reduced the area the plumes spread. The scenario without tides shows a plume more advected by the NBC.

NBC exhibited the strongest flow when all forcings were included in the simulation.

Therefore winds, tides, and river discharge work in concert with NBC dynamics.



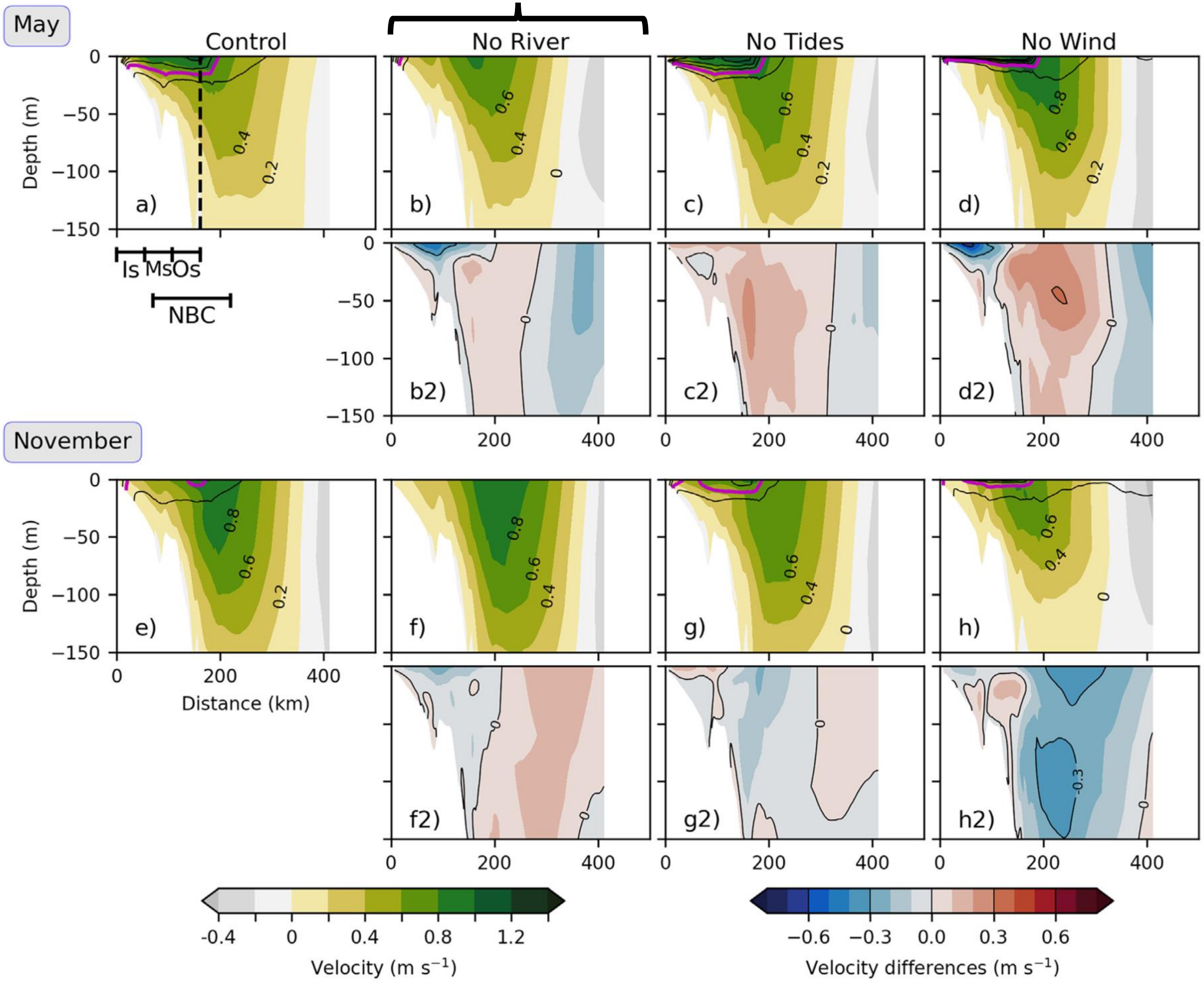
Retroflection region (5N):

Control

The NBC core is shallow (20 m) and found over the shelf in May.

In November, however, the core is observed off the shelf break and becomes deeper (100 m).

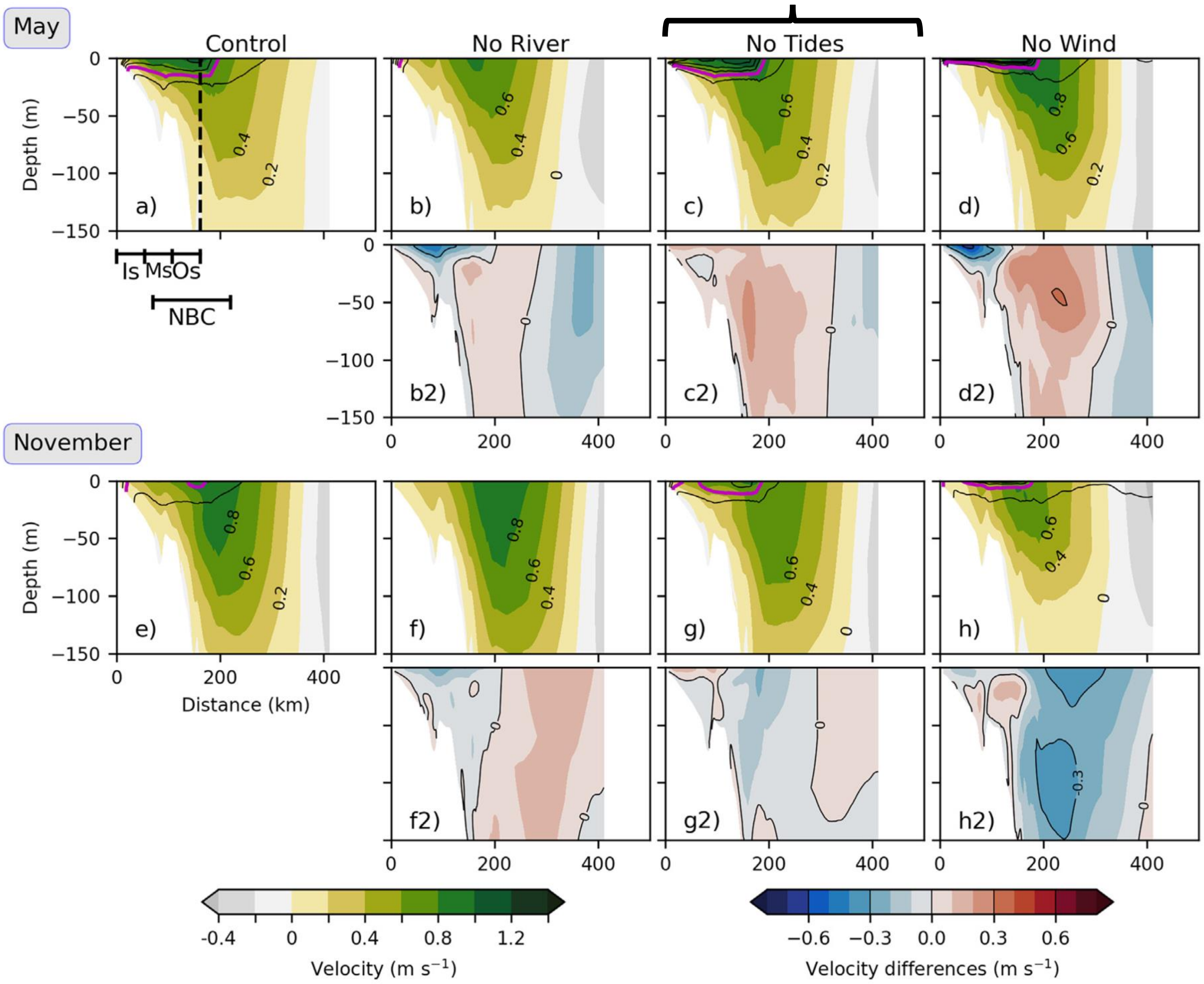
The freshwater core is close to the coast in May, while it is more advected eastward by the NBC retroflection in November.



Retroflection region (5N):

No River

The cross-shore salinity gradient almost disappeared in all sections. The NBC core decreased approximately 0.4 m s^{-1} during May.



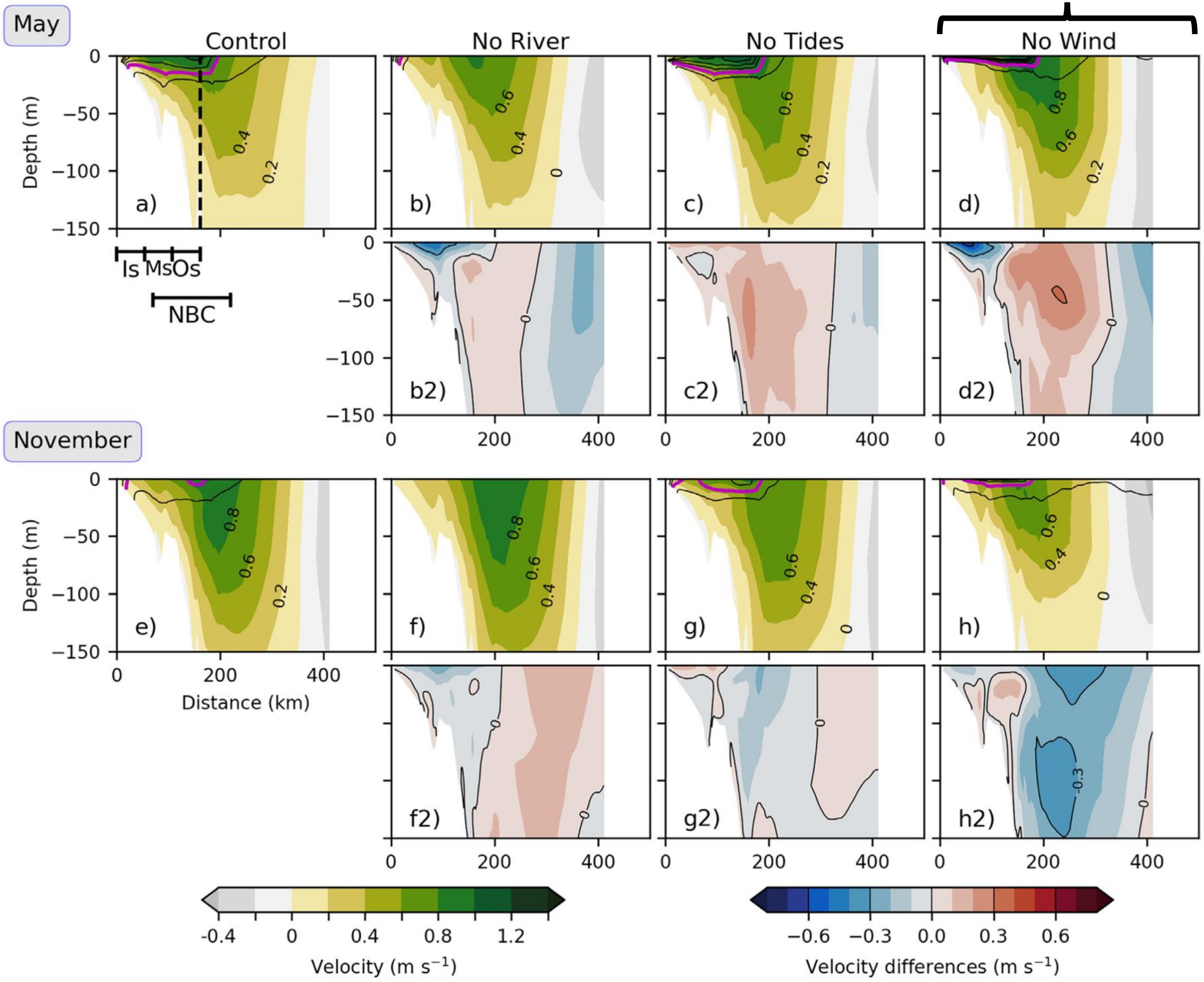
Retroflection region (5N):

No Tides

A vertical salinity gradient tended to form over the inner shelf during May (All Sections).

The plume was constricted to the first 10 m, whereas, in the control simulation, the river plume occupied all the water column over the shelf.

The plume shape was the same either with or without tides as NBC dynamics dominate the circulation.
However, low-salinity waters spread more offshore in the control simulation (i.e., with tides) than in the simulation without tides.



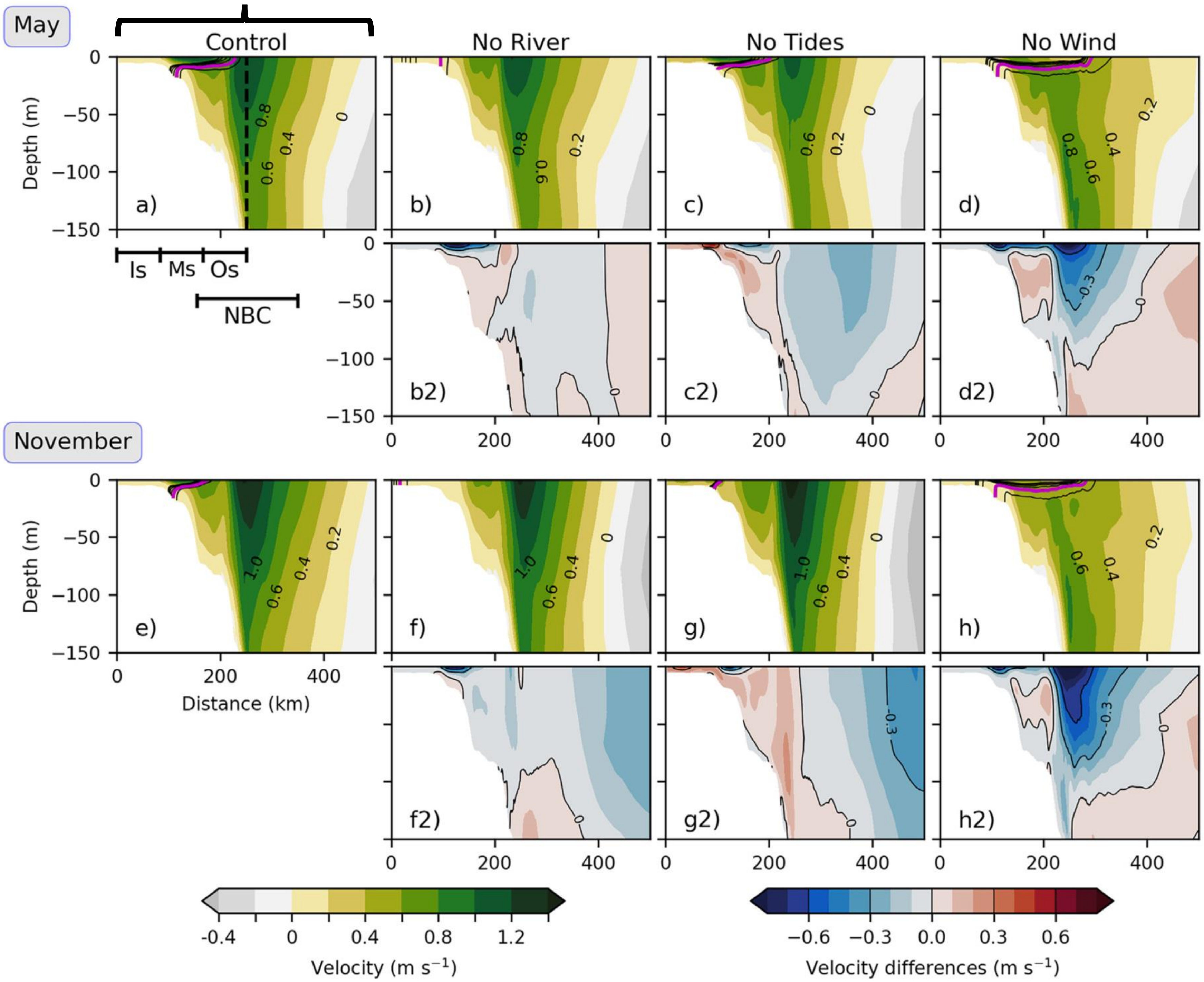
Retroflection region (5N):

No Wind

NBC weakened over the shelf and strengthened from the shelf break to about 300 km offshore in May, while in November the scenario was reversed.

The plume spread about the same distance as in the control simulation.

Possibly, in the simulation without wind, the plume also could spread more offshore compared to the control simulation, but less fresh water was advected to 5N as the NBC weakened.



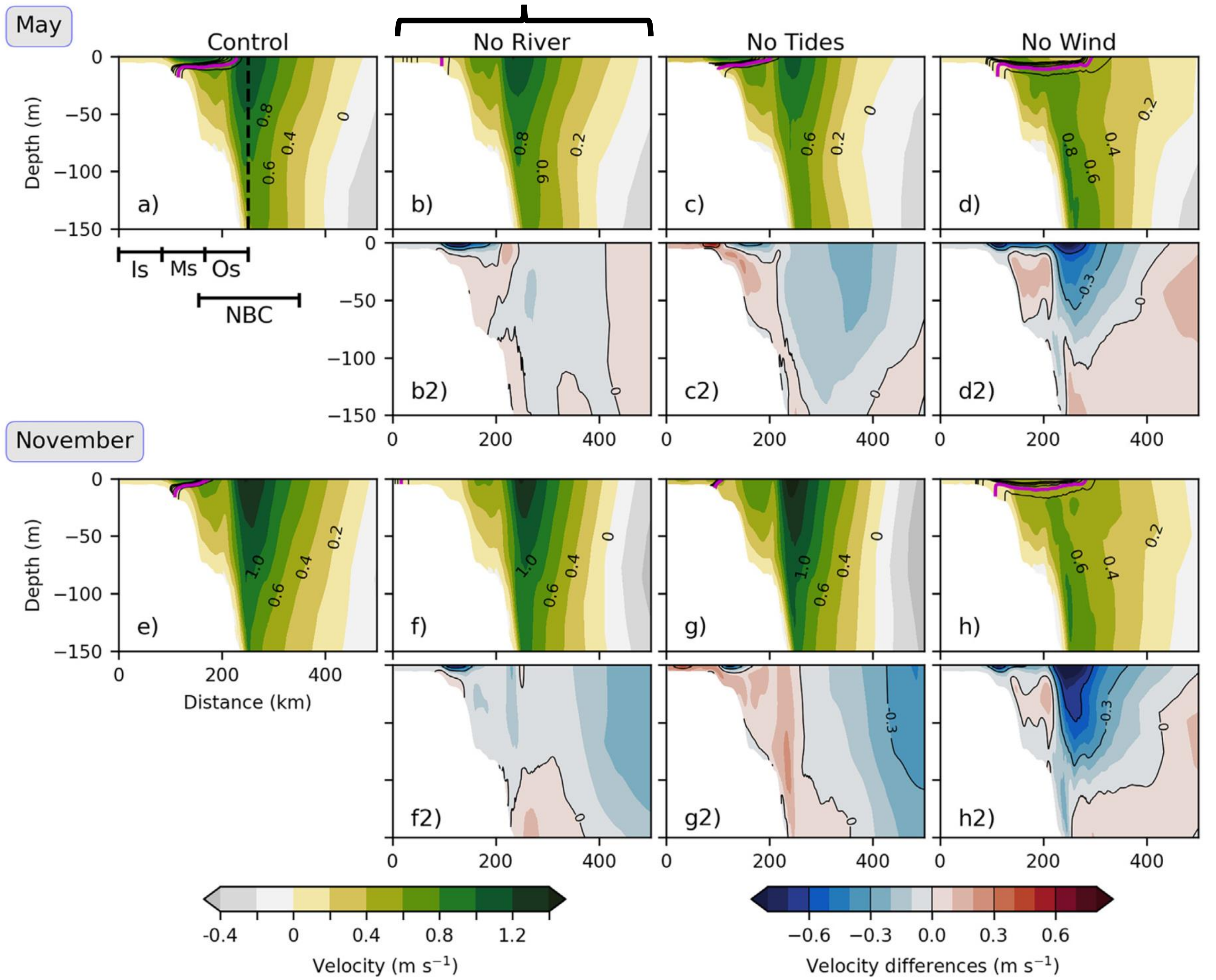
Just north of the Amazon River mouth (2N):

Control

The NBC core is shallow (20-50 m) and found over the shelf in May.

In November, however, the core is observed off the shelf break and becomes deeper (100 m).

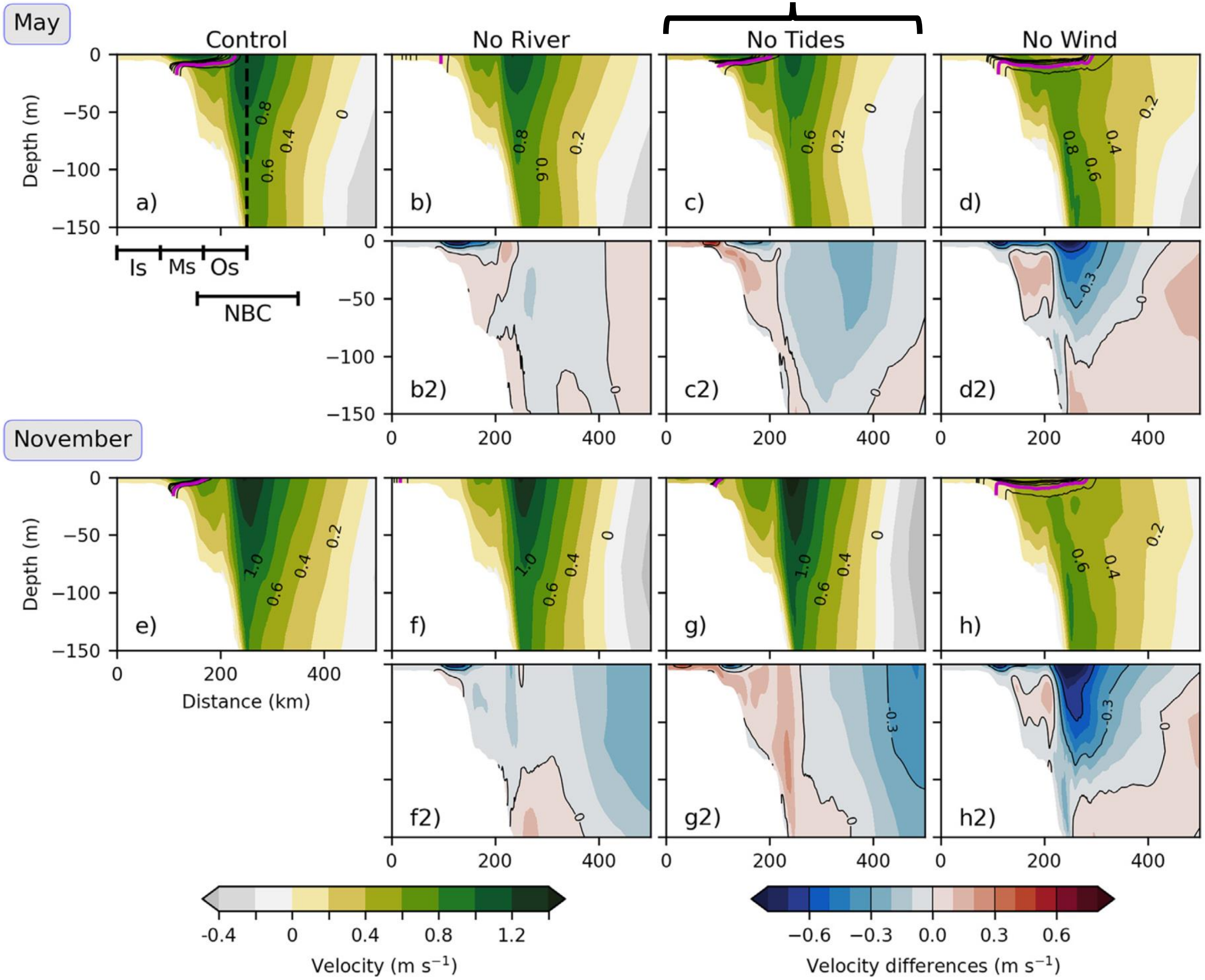
A well-mixed region extends over the shelf to about 120 km (May and November) followed by a 10 m deep plume, which reaches 220 and 200 km in May and November respectively.



Just north of the Amazon River mouth (2N):

No River

The cross-shore salinity gradient almost disappeared in all sections. The NBC core decreased approximately 0.4 m s^{-1} during both May and November.

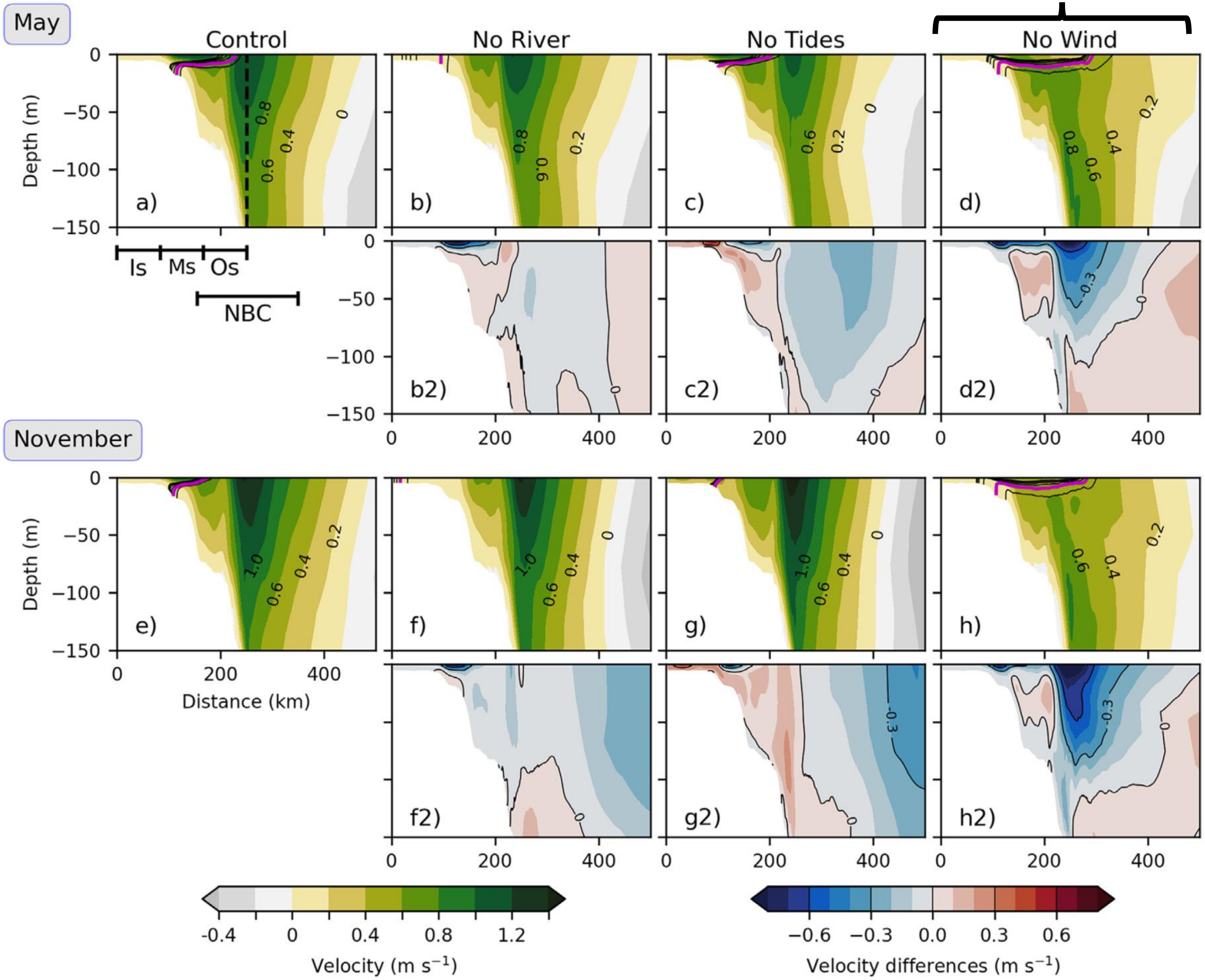


Just north of the Amazon River mouth (2N):

No Tides

In May, the intense river flow dominated the vertical mixing, thus the plume extended to the bottom even without tidal forcing

In November, the plume spread about 70 km less compared to the control simulation.

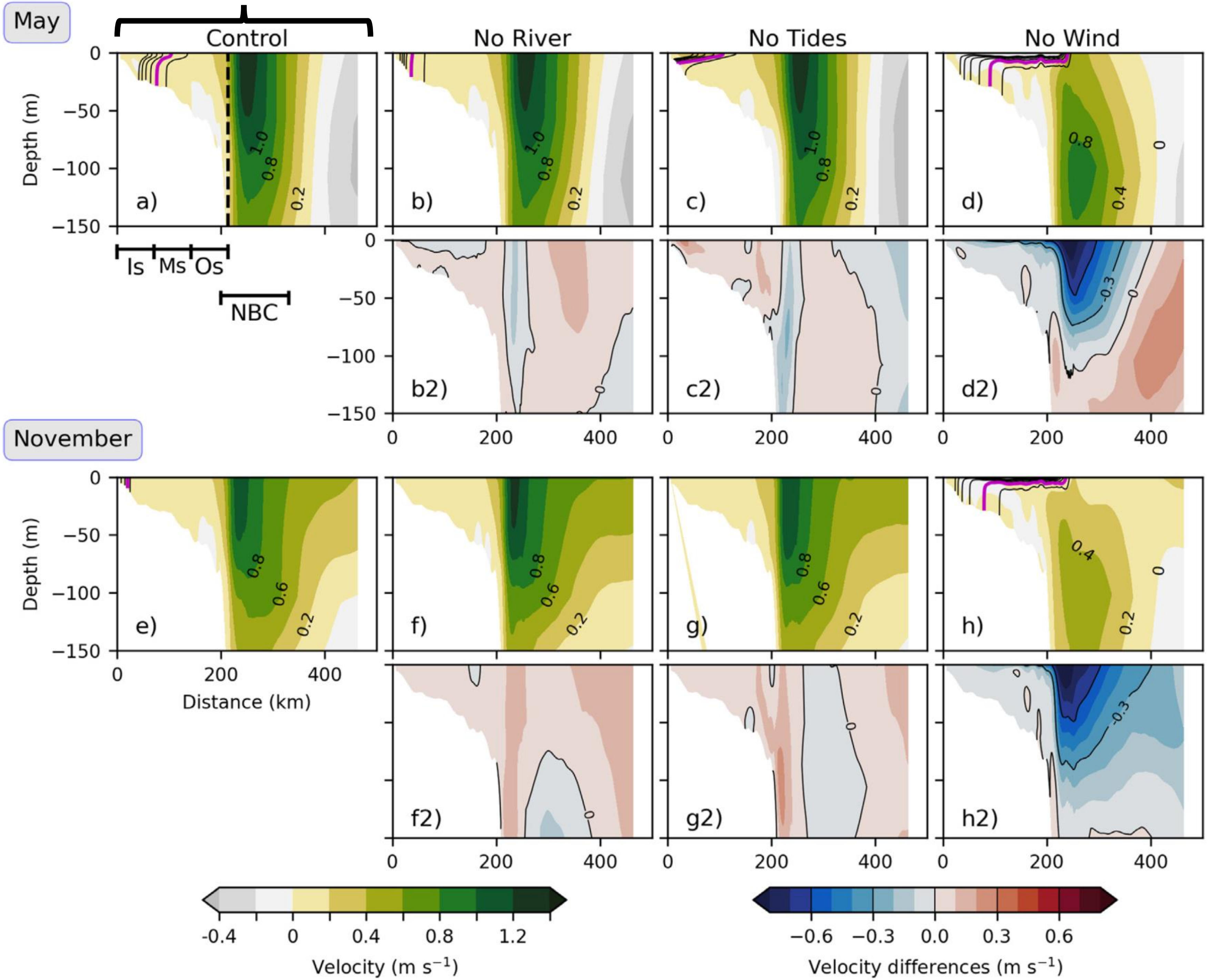


Just north of the Amazon River mouth (2N):

No Wind

NBC drastically weakened in 2N.

The plume extended approximately 100 km farther in both May and November.

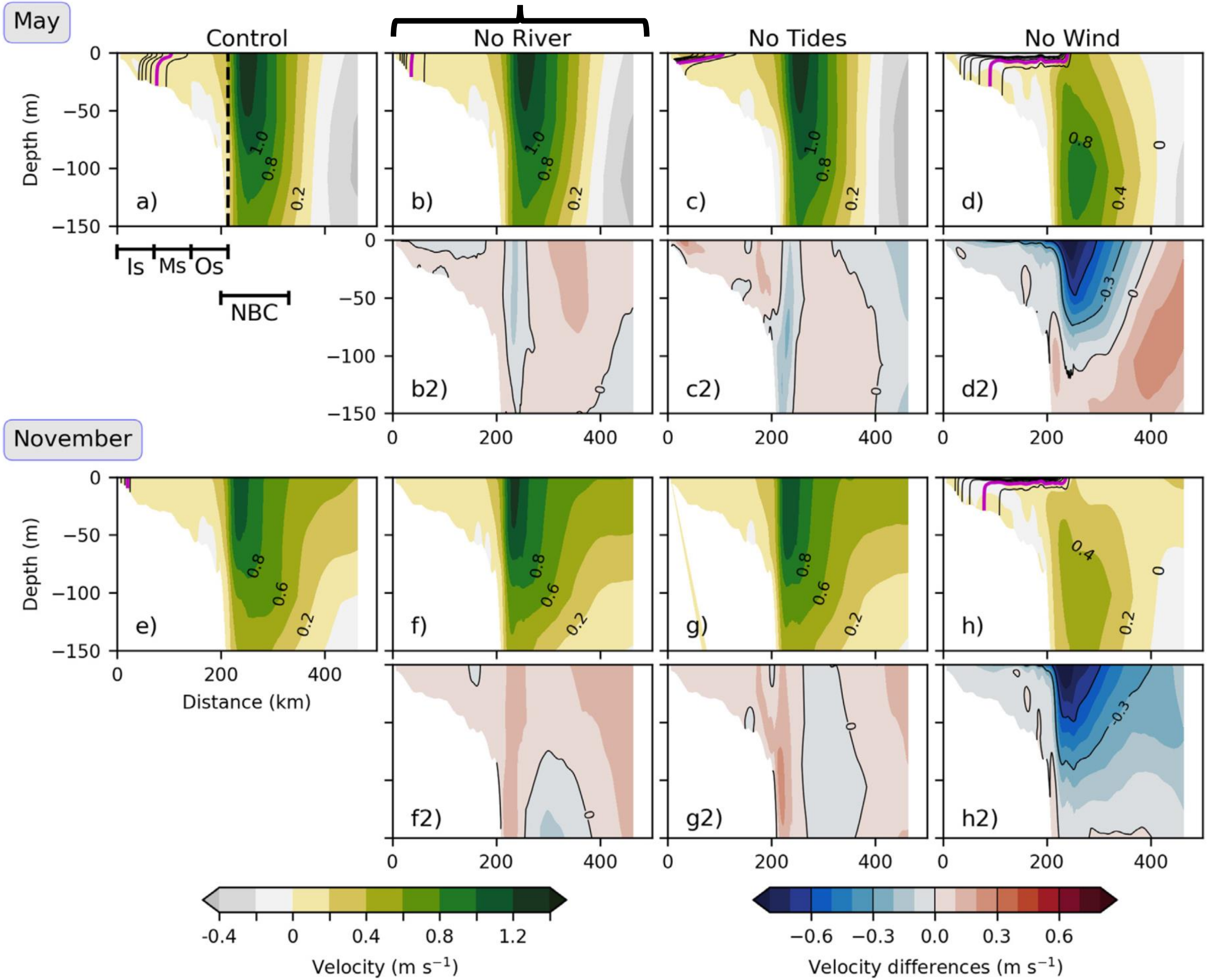


South of the river mouth (1S):

Control

The NBC core is about 50 m deep and found off the shelf break in May and November.

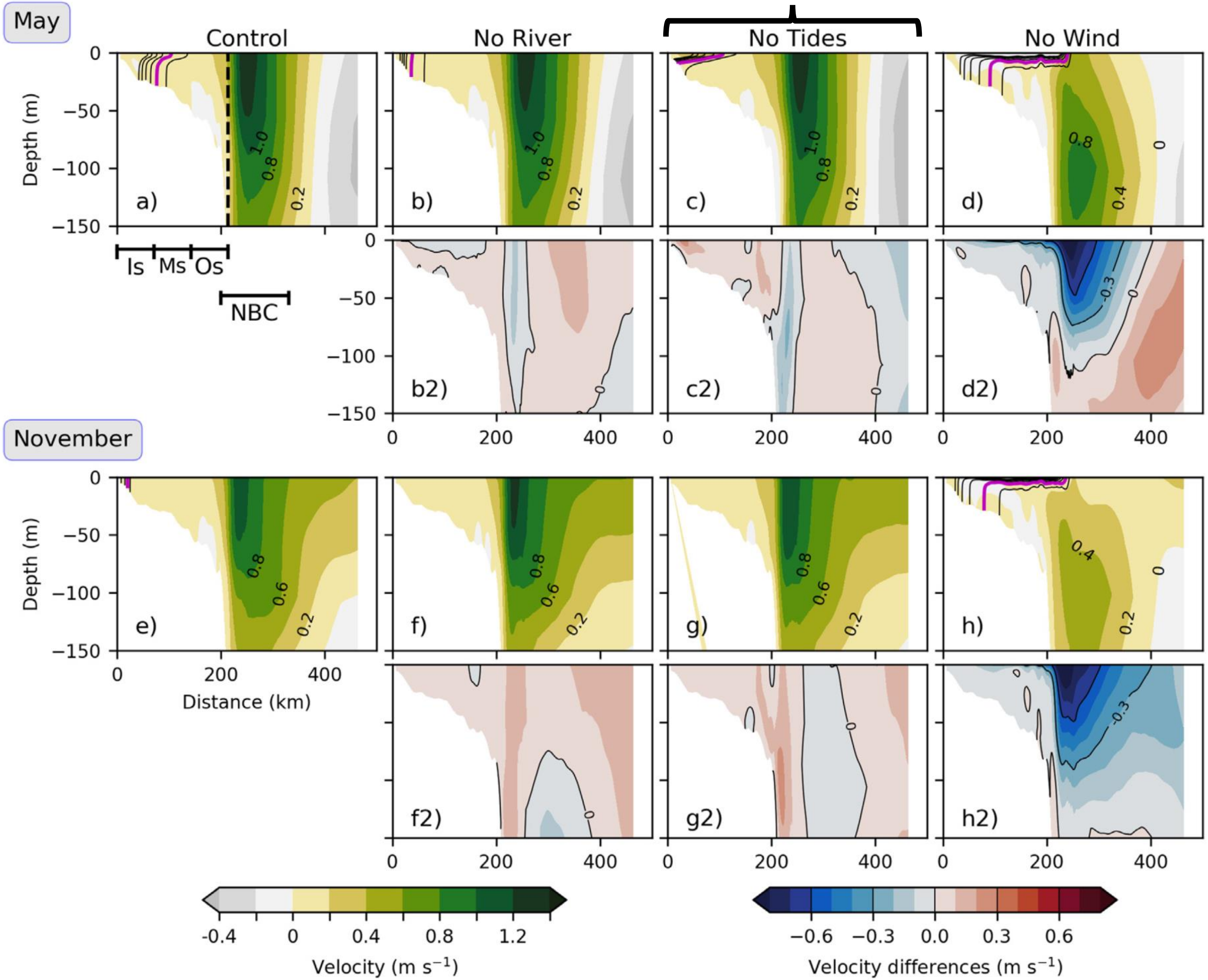
The mixing zone and the plume are noticed only in May.



South of the river mouth (1S):

No River

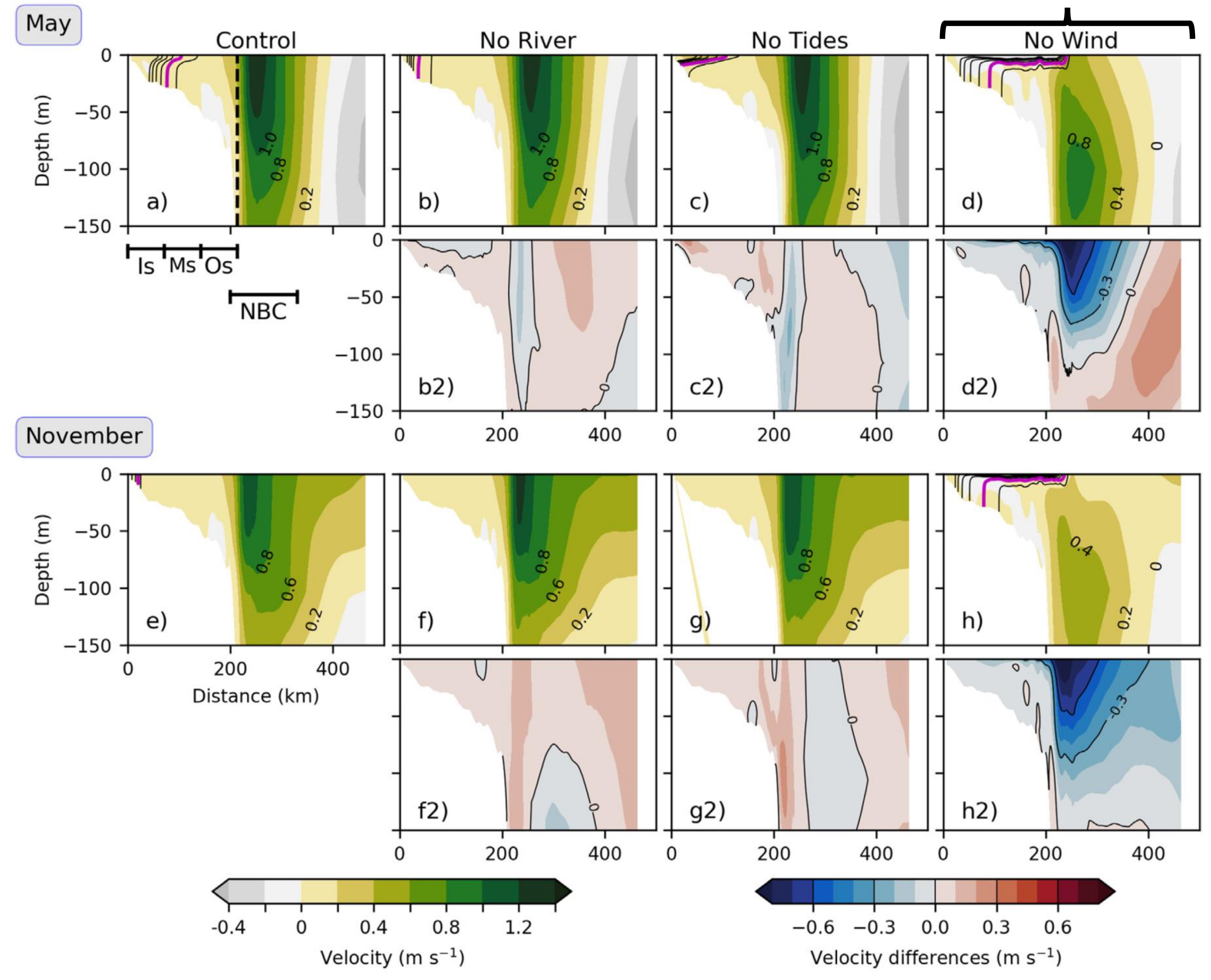
The cross-shore salinity gradient almost disappeared in May and completely disappeared in November.



South of the river mouth (1S):

No Tides

Vertical mixing is reduced and a salt wedge is observed near the coast in May.



South of the river mouth (1S):

No Wind

NBC vanished at the surface and only the NBUC remains.

The plume spread approximately 250 km oceanward in both May and November.

Conclusions

NBC advected low-salinity waters from the Amazon River northwestward to Caribbean Sea and occasionally eastward through the NBC retroflection.

The NBC exhibited the strongest flow when all forcings were included in the simulation.

On the other hand, southeasterly winds inhibited the NBC retroflection system and, thus reducing its contribution to North Equatorial Counter Current (NECC) and Equatorial Undercurrent (EUC).

The simulation without tides showed a plume more advected by the NBC and constricted to the first 10 m of the water column, while in the simulation without wind the plume was less advected northwestward by the weakened NBC and spread more toward the shelf break.

Conclusions

The correlation analysis highlighted the complexity of the system, the complementarity of the forcings and their time-variable interdependence.

The three sensitivity simulations and correlation analysis demonstrated the wind to be the main mechanism of the circulation in the BES.