Projected sea surface temperature and salinity changes over the Northwest Atlantic shelf and slope in the 21st century from regional downscaling models

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A North Atlantic Ocean-ice Downscaling System (NAODS) was used to downscale global climate model (GCM) output for ocean conditions over the northwest Atlantic shelf and slope off Canada in the 21st century. Three downscaling runs were completed. One was for the Climate Change System Model Version 4 (CCSM4) under a high emission scenario Representative Concentration Pathway (RCP) 8.5. The two others were for Hadley Centre Global Environmental Model Version 2 with an Earth-System component (HadGEM2-ES) under RCP 8.5 and a median emission scenario RCP 4.5 respectively. The annual-mean sea surface temperature (SST) over the Northwest Atlantic shelf and slope downscaled from CCSM4 under RCP 8.5 is projected to increase, more significantly in the southern part of domain (3 to 4 °C) than over the Labrador Shelf and Slope (about 2 °C). Under RCP 8.5 the SST increase downscaled from HadGEM2-ES is approximately two times of that downscaled from CCSM4. The SST increase downscaled from HadGEM2-ES under RCP 4.5 varies from half to two thirds of that under RCP 8.5. The annual-mean sea surface salinity (SSS) over the Canadian Atlantic shelf and slope under RCP 8.5 is projected to decrease except in the Gulf of Maine (including Georges Bank) where the projected SSS change is smaller and less certain. The SSS decrease is more substantial over the Labrador and Newfoundland Shelf and Slope (up to 2) than over the Scotian Shelf and Slope (up to 0.55). The projected SSS decrease over the Labrador and Newfoundland Shelf and Slope downscaled from the HadGEM2-ES is about three times of that downscaled from the CCSM4.

RÉSUMÉ

Han, G., Chassé, J., Lambert, N., Zhang, M., and Perrie, W. 2025. Projected sea surface temperature and salinity changes over the Northwest Atlantic shelf and slope in the 21st century from regional downscaling models. Can. Data Rep. Hydrogr. Ocean Sci. 222: vi + 9 p.

Un système de Régionalisation Océan-Glace pour l'Atlantique Nord (ROGAN) a été utilisé pour réduire l'échelle des sorties des modèles climatiques globaux (GCM) afin de simuler les conditions océaniques sur le plateau et le talus de l'Atlantique nord-ouest au large du Canada au 21e siècle. Trois simulations de réduction d'échelle ont été réalisées. L'une était basée sur le Climate Change System Model Version 4 (CCSM4) sous un scénario à fortes émissions, le Representative Concentration Pathway (RCP) 8.5. Les deux autres ont été réalisées à partir du modèle Hadley Centre Global Environmental Model Version 2 possédant un module du système terrestre (HadGEM2-ES), sous les scénarios RCP 8.5 et RCP 4.5 (scénario médian) respectivement. La température de surface de la mer (SST) annuelle moyenne sur le plateau et le talus nord-ouest de l'Atlantique, réduite d'échelle à partir de CCSM4 sous RCP 8.5, devrait augmenter, de manière plus significative au sud (3 à 4 °C) que sur le plateau et le talus du Labrador (environ 2 °C). Sous RCP 8.5, l'augmentation de la SST obtenues de HadGEM2-ES est environ deux fois supérieure à celle obtenue avec CCSM4. L'augmentation de la SST obtenue de HadGEM2-ES sous RCP 4.5 varie de la moitié aux deux tiers de celle sous RCP 8.5. La salinité de surface de la mer (SSS) annuelle moyenne sur le plateau et le talus atlantique canadien sous RCP 8.5 devrait diminuer, sauf dans le golfe du Maine (y compris le banc de Georges) où les changements projetés de la SSS sont plus faibles et moins certains. La diminution de la SSS est plus importante sur le plateau et le talus du Labrador et de Terre-Neuve (jusqu'à 2) que sur le plateau et le talus néo-écossais (jusqu'à 0.55). La diminution projetée de la SSS sur le plateau et le talus du Labrador et de Terre-Neuve, obtenue à partir de HadGEM2-ES, est environ trois fois supérieure à celle obtenue avec CCSM4.

1. INTRODUCTION

There have been more and more evidences that climate change impacts ocean and ice conditions. Information on the future state of the oceans is needed in order to adapt to climate change. So far, climate models have been developed to simulate likely changes of ocean conditions under different emission scenarios. On the global and basin scales, global climate models (GCMs) have projected useful information on ocean conditions for the 21st century and beyond. Nevertheless, the spatial resolutions of GCMs remain too coarse so that they are unable to account for small scale processes important to climate variability. On the other hand, high-resolution regional models have been used to downscale from the global climate models (Fagundes et al., 2019; Long et al., 2019; Han et al., 2019).

The northwest Atlantic continental shelf and slope off Eastern Canada extends from the Labrador Shelf in the north to the Gulf of Maine in the South. It is a confluence zone for the poleward flowing and equatorward flowing western boundary currents of the North Atlantic, as well as the Arctic outflow through the Canadian Arctic Archipelago. The region has complex coastline and bottom topography, coastal-shelf exchanges and shelf-slope interactions, which are insufficiently represented in present GCMs. To address this issue, we developed a North Atlantic Ocean-ice Downscaling System (NAODS), with a 1/12^{o} model for the northwest Atlantic region nested in a 1/4^{o} model for the North Atlantic. The system was used to downscale the results for selected GCMs under different emission scenarios.

In this report, we present the results on the projected sea surface temperature and salinity changes in the Northwest Atlantic in the 21st Century from the North Atlantic Ocean-ice Downscaling System (NAODS).

2. METHOD

2.1 THE COUPLED OCEAN-ICE MODEL

We used version 3.6 of the Nucleus for European Modelling of the Ocean (NEMO) (Madec, 2016) and version 2 of the Louvain-la-Neuve Ice model (LIM2) in the present study. NEMO 3.6 is a primitive-equation, finite-difference ocean circulation model with a free sea surface. The model with a z-coordinate has 50 vertical layers, with a minimum grid spacing of about 3 m at the sea surface. There are two grid domains. The North Atlantic domain is from 7^{o}N in the south to 66^{o}N in the north, with a horizontal resolution of 1/4^{o} (Fig. 1) The Northwest Atlantic nested domain is from 35^{o}N to 64^{o}N in the north, and west of 35^{o}W, with a horizontal resolution of 1/12^{o}.

2.2 ATMOSPHERE FORCING AND OPEN BOUNDARY CONDITIONS

The atmospheric forcing was downscaled by the Weather and Research Forecast (WRF) model (Zhang et al., 2019) implemented over the North Atlantic, from the Climate Change System Model Version 4 (CCSM4; Gent et al., 2011) output under a high emission scenario Representative Concentration Pathway (RCP) 8.5 and the Hadley Centre Global Environmental Model Version 2 with an Earth-System component (HadGEM2-ES; The HADGEM Development Team, 2011) output under RCP 8.5 and a median emission scenario RCP 4.5 used in the Intergovernmental Panel for Climate Change (IPCC) Fifth Assessment Report (AR5). At the open boundaries of the North Atlantic model domain sea level and vertically averaged velocity were applied for the barotropic mode, while three-dimensional temperature, salinity and velocity were specified to account for baroclinicity. Sea ice concentration and thickness were also specified at the northern open boundary based on the CCSM4 and HadGEM2-ES output. Climatological monthly river runoffs were used (Bordeau et al., 2010) for the North Atlantic model, while monthly river runoffs calculated from the downscaled atmospheric fields (Lambert et al., 2013) were used for the Northwest Atlantic model.

3. RESULTS

3.1. MODEL EVALUATION AT STATION 27 AND STATION 2

The modelled temperature and salinity are compared with observations at Station 27 over the inner Newfoundland Shelf and Station 2 over the inner Scotian Shelf (See Fig. 1 for their locations) for the period from 1996 to 2015. The temperature and salinity observations are collected by the Atlantic Zone Monitoring Program.

Both models are able to represent the observed sea surface temperature (SST) change (about 0.6ºC) at Station 2 from 1996-2005 (the last decade of hindcast before projection) to 2006-2015 (the first decade for projection) (Table 1). CCSM4 is also able to well represent the observed SST change (0.4 ºC) at Station 27 between the two decades, though HadGEM2-ES is not (the model shows a cooling). The observed sea surface salinity (SSS) change between the two decades shows small increases (<0.05) at Station 2 and Station 27. CCSM4 is able to reproduce the observed SSS change at Station 2, but shows a small decrease at Station 27. HadGEM2-ES shows decreases at both stations.

3.2. SEA SURAFCE TEMPERATURE

All model simulations and scenarios show SST increase over the Canadian Atlantic shelf from 1986-2005 to 2080-2099, but with substantial differences between models and between scenarios (Fig. 2). The annual-mean SST from the two HadGEM2-ES downscaling runs indicates larger increase under RCP 8.5 (5.5ºC) than RCP4.5 (3.6ºC) emission scenarios. Under RCP 8.5, the SST increase downscaled from HadGEM2-ES is much larger than that from CCSM4 (2.9ºC).

The annual-mean SST changes from 1986-2005 to 2080-2099 are calculated for five regions (Fig. 3, Table 2). They are the Labrador Shelf and Slope, the Newfoundland Shelf and Slope, the Scotian Shelf and Slope, the Gulf of Maine (including Georges Bank and Slope), and the Gulf of St. Lawrence. The annual-mean SST downscaled from CCSM4 under RCP 8.5 is projected to increase by 3 to 4 °C over the Scotian Shelf and Slope, in the Gulf of Maine (including Georges Bank and Slope), and in the Gulf of St. Lawrence, and by about 2 °C on the Labrador Shelf and Slope. Under RCP 8.5 the SST increase downscaled from the HadGEM2-ES is about two times of that downscaled from CCSM4, except over the Labrador Shelf and Slope where the SST increases from the two models are comparable.

The SST increase downscaled from HadGEM2-ES under RCP 4.5 is about two thirds of that under RCP8.5 over the Scotian Shelf and Slope, in the Gulf of Maine (including Georges Bank and Slope) and the Gulf of St. Lawrence. Over the Labrador Shelf and Slope, the SST increase downscaled from HadGEM2-ES under RCP 4.5 is about half of that under RCP 8.5.

3.3. SEA SURAFCE SALINITY

All model and scenarios show overall SSS decrease over the northern continental shelves from 1986-2005 to 2080-2099, but with substantial differences between models and between scenarios (Fig. 2). In the southern shelf regions, the SSS change is less certain.

The annual-mean SSS over the Labrador Shelf and Slope, the Newfoundland Shelf and Slope and the Scotian Shelf and Slope, as well as in the Gulf of St. Lawrence is projected to decrease substantially under RCP 8.5 in the 21st century (Fig. 4, Table 2). The SSS decrease is up to 2.03 over the Labrador and Newfoundland Shelf and Slope and up to 0.55 over the Scotian Shelf and Slope. The projected SSS decrease over the Labrador and Newfoundland Shelf and Slope downscaled from the HadGEM2-ES is much larger than that downscaled from the CCSM4.

The SSS decrease downscaled from HadGEM2-ES under RCP 4.5 is about half of that under RCP 8.5 over the Labrador Shelf and Slope, the Newfoundland Shelf and Slope and in the Gulf of St. Lawrence. In the Gulf of Maine (including Georges Bank and Slope), the projected SSS change varies from -0.38 to 0.7, depending on models and scenarios.

4. CONCLUSIONS

We have developed a North Atlantic ocean-ice downscaling system to refine the projections of oceanographic conditions in the Northwest Atlantic from the CCSM4 under RCP 8.5 and HadGEM2-ES output under RCP 8.5 and RCP 4.5. While the downscaled CCSM4 results are more consistent with observed changes at Station 2 and 27 from 1996-2005 (the last decade of hindcast) to 2006-2015 (the first decade of projection), the downscaled HadGEM2-ES results provide informative perspectives on the sensitivity of projected changes to global climate models used, and to emission scenarios considered.

The annual-mean SST over the Northwest Atlantic Shelf and Slope off Canada downscaled from HadGEM2-ES under RCP 8.5 is projected to increase significantly, more so over the Scotian Shelf and Slope, in the Gulf of Maine (including Georges Bank and Slope), and in the Gulf of St. Lawrence (3 to 4 °C) than over the Labrador Shelf and Slope (about 2°C). Under RCP 8.5 the projected SST increase downscaled from HadGEM2-ES is about twice of that from CCSM4 except over the Labrador Shelf and Slope. The SST increase downscaled from HadGEM2-ES under RCP 4.5 is about two thirds of that under RCP 8.5 over the Scotian Shelf and Slope, in the Gulf of Maine (including Georges Bank and Slope), and in the Gulf of St. Lawrence, and about half over the Labrador Shelf and Slope.

The annual-mean SSS over the Labrador Shelf and Slope, the Newfoundland Shelf and Slope and the Scotian Shelf and Slope under RCP 8.5 is projected to decrease substantially, more so over the Labrador and Newfoundland Shelf and Slope than over the Scotian Shelf and Slope. The projected SSS decrease over the Labrador and Newfoundland Shelf and Slope downscaled from the HadGEM2-ES is about three times of that downscaled from the CCSM4. In the Gulf of Maine (including Georges Bank and Slope), the projected SSS increase or decrease is less certain.

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TABLES

Table 1: Changes in the sea surface temperature (SST) and salinity (SSS) between 2006-2015 and 1996-2005 at Station 2 and Station 27.

		SST Change (ºC)	SSS Change
Station 2	Observed	0.58	0.04
	CCSM4	0.58	0.05
	HadGEM2-ES	0.46	-0.18
Station 27	Observed	0.38	0.03
	CCSM4	0.37	-0.08
	HadGEM2-ES	-0.14	-0.20

Table 2: Projected changes in the sea surface temperature (T, ºC) and salinity (S) between 2080-2099 and 1986-2005, downscaled from CCSM4 and HadGEM2-ES under RCP 8.5 and/or RCP 4.5.

Region name	Variable	CCSM4, RCP 8.5	HadGEM2-ES, RCP 8.5	HadGEM2-ES, RCP 4.5
Labrador Shelf and Slope	T	2.01	2.27	1.21
	S	-0.33	-2.00	-1.08
Newfoundland Shelf and Slope	T	2.60	4.91	2.60
	S	-0.47	-2.03	-1.23
Scotian Shelf and Slope	T	3.15	8.05	5.39
	S	-0.55	-0.48	-0.00
Gulf of Maine (including Georges Bank and Slope)	T	3.41	7.45	4.94
	S	-0.38	0.41	0.70
Gulf of St. Lawrence	T	3.71	6.78	4.03
	S	-1.06	-0.88	-0.41

FIGURES

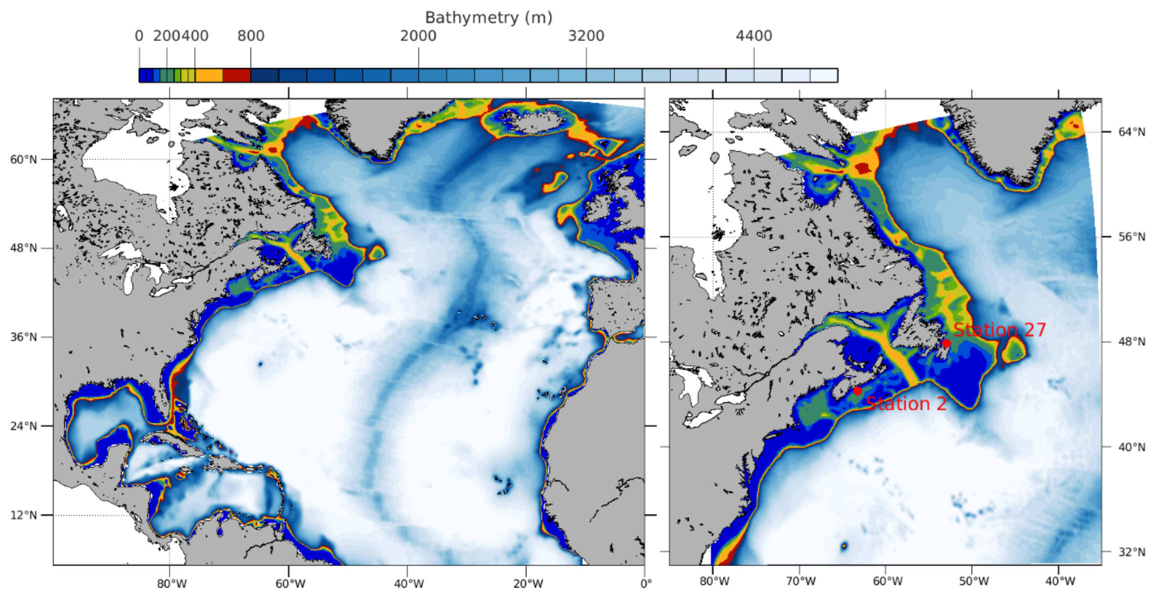

Figure 1: The North Atlantic model (left, 1/4o) domain and the northwest Atlantic model (right, 1/12o) domain with bathymetry, respectively. Station 2 over the Scotian Shelf and Station 27 over the Newfoundland Shelf are depicted.

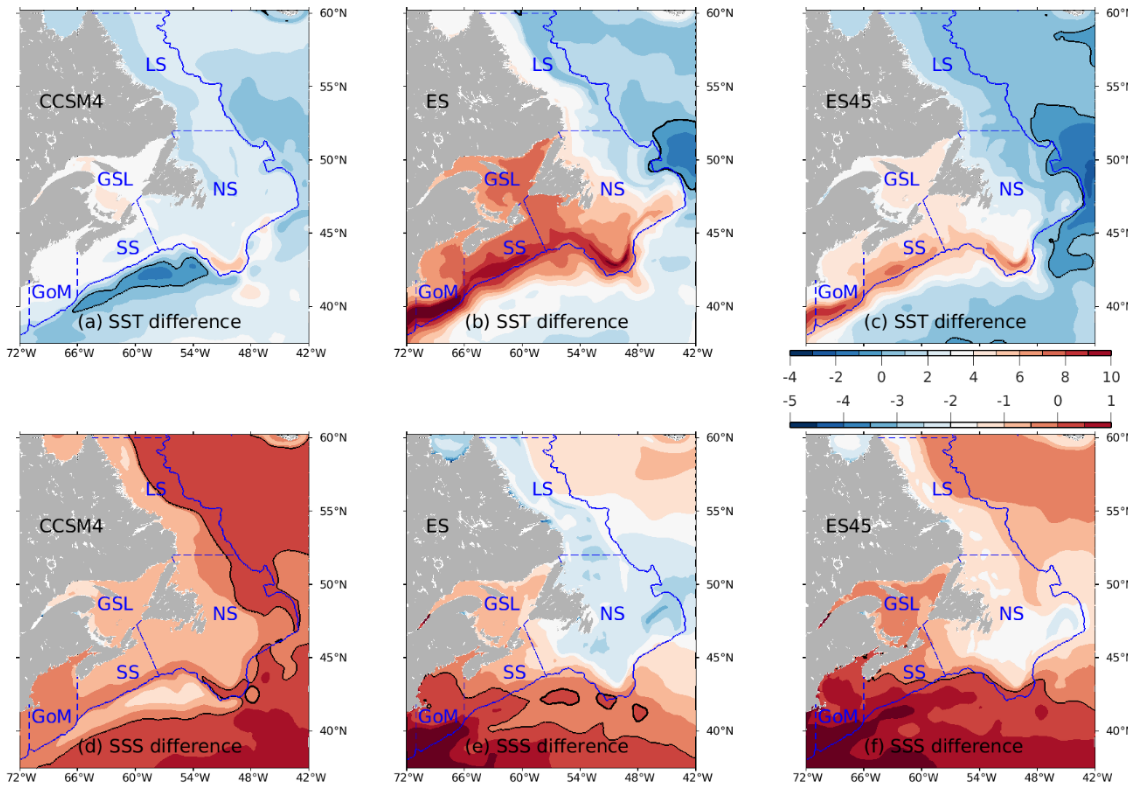

Figure 2: Projected changes in the sea surface temperature (oC) and salinity by 2080-2099 relative to 1986-2005. ES and ES45 are for HadGEM2-ES under RCP 8.5 and RCP 4.5 respectively. LS: Labrador Shelf and Slope; NS: Newfoundland Shelf and Slope; SS: Scotian Shelf and Slope; GoM: Gulf of Maine (including Georges Bank and Slope); GSL: Gulf of St. Lawrence. Their geographical extents are defined by the blue dashed lines and 3000-m isobath (blue solid curve). The black curve depicts zero contour line.

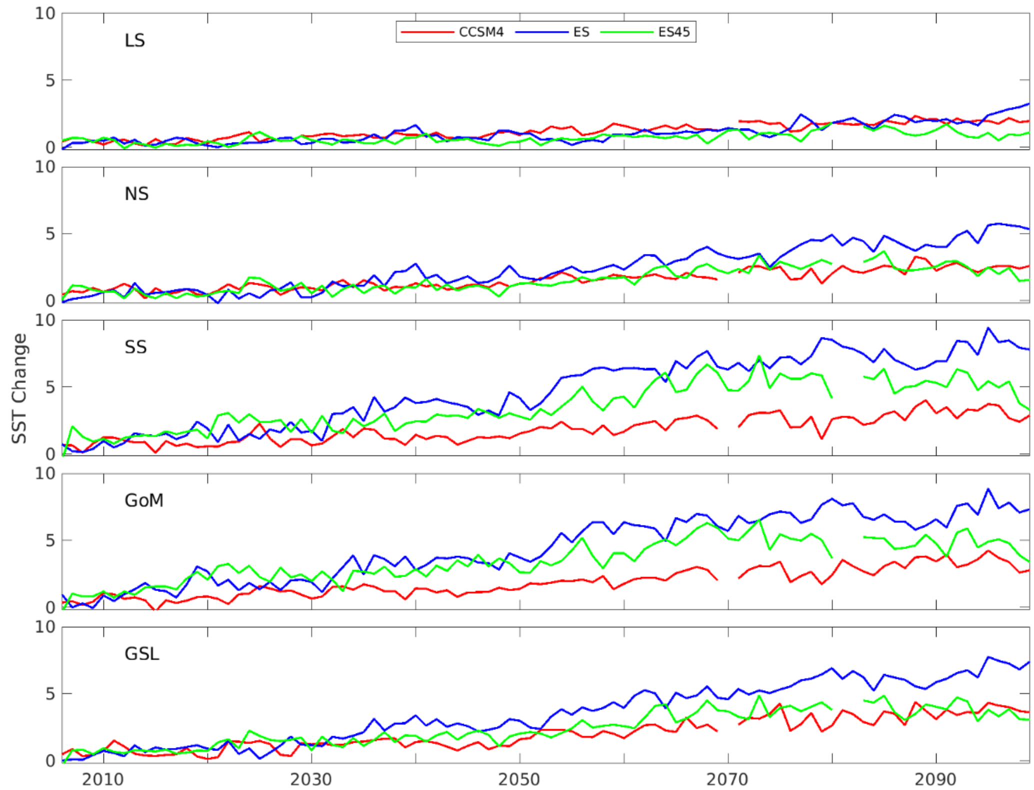

Figure 3: Projected changes in the annual-mean sea surface temperature (SST, ºC) in the five regions over the Northwest Atlantic from 2006 to 2099, relative to the mean over 1986-2005. ES and ES45 are for HadGEM2-ES under RCP 8.5 and RCP 4.5 respectively. LS: Labrador Shelf and Slope; NS: Newfoundland Shelf and Slope; SS: Scotian Shelf and Slope; GoM: Gulf of Maine (including Georges Bank and Slope); GSL: Gulf of St. Lawrence.

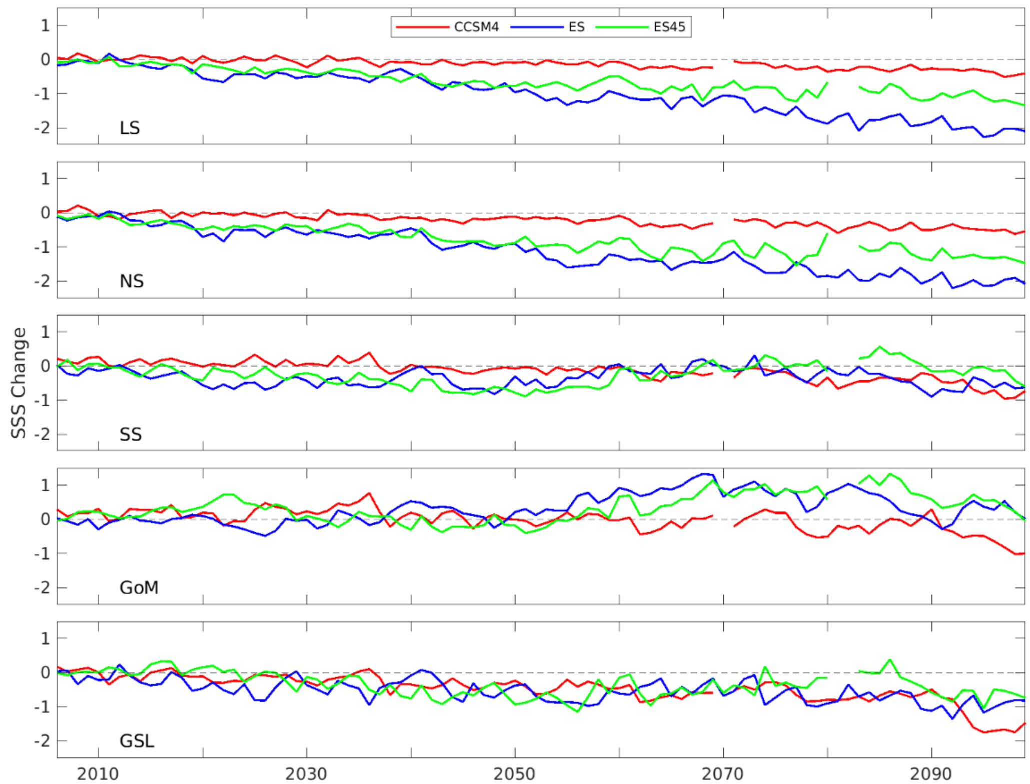

Figure 4: Projected changes on the annual-mean sea surface salinity (SSS) in the five regions over the Northwest Atlantic from 2006 to 2099, relative to the mean over 1986-2005. ES and ES45 are for HadGEM2-ES under RCP 8.5 and RCP 4.5 respectively. LS: Labrador Shelf and Slope; NS: Newfoundland Shelf and Slope; SS: Scotian Shelf and Slope; GoM: Gulf of Maine (including Georges Bank and Slope); GSL: Gulf of St. Lawrence.