Process-Oriented Diagnostics

for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction

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Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications

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Abstract

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Western boundary currents (WBCs), such as the Kuroshio-Oyashio Extension in the North Pacific and the Gulf Stream in the North Atlantic, are the regions of largest ocean variability and intense air-sea interaction. In particular at interannual and longer time scales, the WBC variability generates strong ocean-to-atmosphere heat fluxes, resulting in anomalous diabatic heating that can impact the large-scale atmospheric circulation and the poleward heat transport in both the ocean and atmosphere. Therefore, variability in the WBCs and associated air-sea interaction play fundamental roles in regulating our climate. In addition, the WBCs variability have significant impact on extreme weather, coastal ecosystem, and sea-level.

Despite the importance of WBC variability and associated midlatitude air-sea interaction, the WBCs are the regions with some of the largest and longstanding ocean biases in the state-of-the-art coupled climate models. There have been numerous studies on the mean state biases in global climate models, in particular in WBC regions, and on the impact of improved spatial resolution. However, the influence of climate model spatial resolution on the biases of the WBC variability and associated air-sea interaction is yet to be systematically examined, despite their strong climate impacts. Here we propose to investigate the nature and impacts of the main biases of the WBC variability in state-of-the-art climate models based on a set of process-oriented model diagnostics, and establish their dependence on model resolution, as well as their links to main large-scale circulation biases. Our process-oriented diagnostics would lead to: (1) a systematic quantification of the model biases for the oceanic and atmospheric variability in the WBCs and resulting air-sea interaction, (2) identification of the key processes responsible for the model biases, and their sensitivity to the horizontal resolution of the model, and (3) improved understanding of the links between the WBC biases and the simulated large-scale atmospheric and oceanic circulations. The diagnostics will be first developed based on various state-of-the-art observational and reanalysis datasets. Then, they will be applied to the state-of-the-art climate model simulations at standard resolution as well as higher resolution to investigate the role of model resolutions in the biases and the representation of the associated processes.

This proposal targets the FY 2021 NOAA Modeling, Analysis, Predictions, and Projections (MAPP) Program solicitation **Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications** by proposing to better understand and benchmark process-level deficiencies related to the WBC ocean variability and associated air-sea interaction in the CMIP6 and HighResMIP simulations, with additional in-depth analyses of the GFDL and NCAR models using the proposed set of process-oriented diagnostics. Our proposed work is also directly relevant to NOAA's long-term climate goal of *advancing scientific understanding, monitoring, and prediction of climate and its impacts, to enable effective decisions*, especially since the improvement in the climate model processes related to the WBC variability and associated air-sea interaction has significant implications for the prediction of our climate and its impacts.

Results from Prior Research

Results from prior research are organized for each area of expertise required for our proposed research and to emphasize previous work, on which the two PIs have collaborated in the past.

Western boundary currents and their impact on the atmospheric circulation

PIs Kwon and Frankignoul have extensive expertise on the western boundary current (WBC) air-sea interaction and its impact on the atmospheric circulation. They were members of the US CLIVAR Working Group on the Western Boundary Current Ocean-Atmosphere Interaction, which produced two highly cited review papers (Kwon et al. 2010; Kelly et al. 2010). The two PIs have collaborated on multiple projects on this topic over the last 13 years. Estimates of the WBC impacts were based on statistical analyses of observational and reanalysis data sets (Frankignoul et al. 2011a; Révelard et al. 2016, 2018), targeted numerical experiments (Smirnov et al. 2015) for the North Pacific, and global climate model analyses (Frankignoul et al. 2013, 2015) for the North Atlantic. In addition, PI Kwon has studied the impact of WBCs on large-scale atmospheric circulation and climate variability, including the storm track (Kwon and Joyce 2013; Booth et al. 2017; Small et al. 2019a), eddy-driven jet (Kwon et al. 2020; Parfitt and Kwon 2020), blocking (Joyce et al. 2019; Kwon et al. 2020; Yamamoto et al. 2020), and leading modes of variability (Kwon and Deser 2007; Kwon et al. 2011).

Large-scale oceanic and atmospheric circulation, and mid-latitude air-sea interaction

Co-PI Frankignoul is well known for his significant contributions to advancing our knowledge on mid-latitude air-sea interaction, including his seminal papers on the SST response to the stochastic atmosphere (Frankignoul and Hasselmann 1977), review on the mechanisms for the mid-latitude SST anomalies (Frankignoul 1985), conceptual model for the decadal ocean response to the wind forcing (Frankignoul et al. 1997), quantification of the surface heat flux damping (Frankignoul and Kestenare 2002), reemergence of SST (de Coëtlogon and Frankignoul 2003), and statistical methods to detect the atmospheric response to SST anomalies (Czaja and Frankignoul 1999, 2002; Frankignoul et al. 2011b). PIs Kwon and Frankignoul conducted multiple projects to study Atlantic multidecadal overturning circulation (AMOC) variability and its impact on the atmosphere in climate models (Kwon and Frankignoul 2012, 2014; Frankignoul et al. 2013, 2015; Zhang et al. 2019; Li et al. 2019). The most recent project by the two PIs is on the impact of the Arctic sea-ice variability on the large-scale atmospheric circulation, using observations (Simon et al. 2020; Liang et al. 2020b) and coordinated large-ensemble climate model simulations (Liang et al. 2020a, Ghosh et al. 2020). The resulting three sets of 200-member ensemble coupled Community Earth System Model version 2 (CESM2) simulations using the high-top Whole Atmosphere Community Climate Model version 6 (WACCM6) will be made public through the Polar Amplification Model Intercomparison Project (PAMIP).

Climate model diagnostics

Both PIs have worked on assessing climate model performance against the observational and reanalyses data sets, with a particular focus on the WBC variability and its impact on the large-scale circulation. They conducted a twin experiment using an atmospheric model with the horizontal resolution at 0.25° and 1°, respectively, to show that the responses to prescribed SST anomalies in the Kuroshio-Oyashio Extensions are very different in the two cases and the higher resolution model is more realistic (Smirnov et al. 2015). PI Kwon has systematically compared the storm tracks from 12 Coupled Model Intercomparison Project Phase 5 (CMIP5) models to assess the WBCs' impact (Booth et al. 2017), and those simulated by the high- and low-resolution climate models from the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and National Center for Atmospheric Research (NCAR) to study the importance of high-resolution in resolving the impact of WBCs (Small et al. 2019a). Co-PI Frankignoul recently published a review paper on how the oceanic and atmospheric horizontal resolutions in the climate models impact simulated WBC air-sea interaction (Czaja et al. 2019). PI Kwon also studied how the Kuroshio Extension decadal variability is artificially enhanced due to model biases in a low-resolution climate model (Thompson and Kwon 2010), and how the model biases in the atmospheric blocking, eddy-driven jet and North Atlantic Oscillation depend on the model horizontal resolution and the representation of the stratosphere (Kwon et al. 2018).

Collaboration with the NCAR and GFDL modelers

PIs Kwon and Frankignoul have collaborated with scientists from various climate modeling centers around the world. In particular, they have had multiple collaborative projects with current and former NCAR and GFDL scientists on AMOC variability (Gokhan Danabasoglu, Steve Yeager, Alicia Karspeck, Tom Delworth, Rong Zhang, and Rym Masdek), WBC air-sea interaction (Justin Small, Frank Bryan, and Clara Deser), and Arctic – lower latitude interaction (Gokhan Danabasoglu and Steve Yeager).

1. Identification of the Problem

Western boundary currents (WBCs), such as the Kuroshio-Oyashio Extension in the North Pacific and the Gulf Stream in the North Atlantic, are the most energetic features in the ocean and regions of large heat release to the atmosphere, strong cyclogenesis, and intense air-sea interaction due to their co-location with the atmospheric storm track (Kwon et al. 2010; Kelly et al. 2010). Furthermore, the WBCs are the regions with the fastest SST warming trend (Wu et al. 2012), the largest interannual-to-decadal SST variability (Deser et al. 2010), and the largest extratropical cyclone variability (Iwao et al. 2012). The WBC variability is also shown to exert significant impact on the coastal ecosystem (Nye et al. 2011) and sea-level (Minobe et al. 2017; Yin et al. 2009). A significant part of the SST variability in WBCs is driven by the ocean, especially on decadal and longer time scales. This SST variability generates ocean-to-atmosphere heat fluxes, resulting in anomalous diabatic heating that can impact the large-scale atmospheric circulation and the poleward heat transports in both ocean and atmosphere (Frankignoul and Kestenare 2002; Kwon et al. 2010; Kwon and Joyce 2013). Therefore, variability in the WBCs and associated air-sea interaction play fundamental roles in regulating our climate.

Notwithstanding the importance of WBC variability and associated midlatitude air-sea interaction, the WBCs are the regions with some of the largest and longstanding ocean biases in the state-of-the-art coupled climate models (Fig. 1). The primary reason for these large biases in the WBCs is insufficient horizontal resolution of the model. The current generation climate models with the standard resolution of ~1° in ocean and ~1° in atmosphere cannot realistically simulate either the separation of the WBCs from the coast or the narrow and strong WBCs and associated tight SST gradients (e.g. Thompson and Kwon 2010). However, recent studies including those by the PIs of this proposal suggest that higher resolutions both in atmosphere and ocean lead to an improved simulation of the storm tracks and the air-sea interaction in the WBC regions (e.g., Woollings et al. 2009; Smirnov et al. 2015; Ma et al. 2017; Vannière et al. 2019; Small et al. 2019a; Czaja et al. 2019). These studies have largely focused on the influence of model

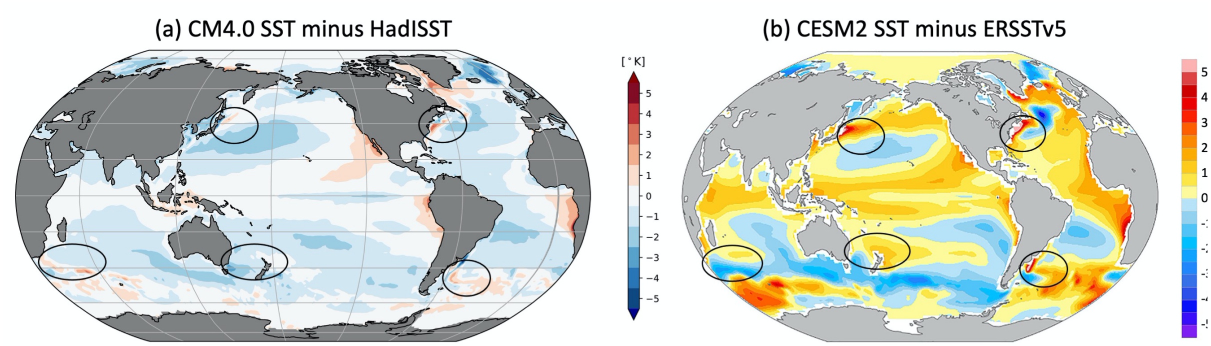

Figure 1: The SST biases in the two state-of-the-art CMIP6 models, (a) the GFDL CM4.0 (~50 km atmosphere, ~0.25° ocean) and (b) the NCAR CESM2 (~1° atmosphere, ~1° ocean). The figures are from Held et al. (2019) and Danabasoglu et al. (2020), respectively. The SST biases in the major western boundary current regions are highlighted with the black circles.

resolution on the mean climate state, but little is known on its influence on WBC variability. Only a few recent studies have begun to show some impacts of increasing oceanic or atmospheric resolution on interannual variability and potential predictability in individual climate models (Siqueira and Kirtman 2016; Haarsma et al. 2019). Therefore, a systematic quantification of WBC model biases along with better understanding of the associated key processes and their sensitivity to the model resolution would be a prerequisite for improving the simulation of the WBC variability and associated midlatitude air-sea interaction.

We propose to develop a set of process-oriented diagnostics to better understand and describe the coupled climate model deficiencies associated with the WBC variability and midlatitude air-sea interaction. Process-oriented diagnostics would lead to: (1) a systematic quantification of the model biases for the oceanic and atmospheric variability in the WBCs and resulting air-sea interaction, (2) identification of the key processes responsible for the model biases, and their sensitivity to the horizontal resolution of the model, and (3) improved understanding of the links between the WBC biases and the simulated large-scale circulations in the atmosphere (e.g. eddy-driven jet) and the ocean (e.g. AMOC). The diagnostics will be first developed based on various observational and reanalysis datasets. Then, they will be applied to both standard resolution climate model simulations and higher resolution simulations to investigate the role of model resolutions in the biases and the representation of the associated processes.

2. Background

Numerous studies have shown that a correct representation of the mean path of the Gulf Stream and the North Atlantic Current requires resolving the oceanic mesoscale eddies as it is unsatisfactory even in eddy-permitting ocean models (e.g., Chassignet and Marshall 2008), and that high resolution improves the representation of the storm tracks (e.g. Small et al. 2019a). However, the resolution impact on WBC low-frequency variability is little documented. The WBC variability can be characterized by many different aspects, which are associated with different oceanic processes and potentially have different implications for the mid-latitude air-sea interaction. In terms of the ocean-to-atmosphere feedback, the changes in the location, strength or transport of the WBC are crucial as they are directly associated with the large gradients of the SST and air-sea heat fluxes across the SST fronts (Parfitt et al. 2016), which in turn influence the atmospheric baroclinicity and the large-scale atmospheric circulation (e.g., Hotta and Nakamura 2011; Révelard et al. 2016). In addition, the representation of mesoscale eddies seems to play a large role in the influence of WBC on the atmosphere (Ma et al. 2015, 2017). Hence, one expects more realistic simulations with higher-resolution models.

The fluctuation in the latitude of the overall path of a WBC, which is associated with the large-scale adjustment of the wind-driven ocean gyres or the overturning circulation (Marshall et al 2001; Qiu et al. 2007), is most often used to quantify the WBC variability, based on SST, sea-surface height (SSH) or subsurface temperature at 200 m. The meridional shifts are linked to shifts of the zone of large heat release to the atmosphere and atmospheric baroclinicity (Hotta and Nakamura 2011; Révelard et al 2016), which control the large-scale atmospheric response to WBC variability (e.g., Révelard et al. 2016). The meridional fluctuation in the latitude of the Gulf Stream was shown to be lagging the North Atlantic Oscillation (NAO) by a few years (Joyce et al. 2000; Frankignoul et al. 2001; Hameed 2004). The Kuroshio Extension variability was shown to be linked to the basin-wide wind forcing modulated by the Pacific Decadal Oscillation (PDO) using the linear Rossby wave model (Schneider and Miller 2001; Qiu and Chen 2005; Kwon and Deser 2007). Similarly, the linear Rossby wave model has been successfully applied to explain the wind-driven WBC variability in the Southern Hemisphere (e.g. Qiu and Chen 2006a; Holbrook et al. 2011). Therefore, the wind-driven baroclinic adjustment is one of the fundamental processes driving the WBC variability and determining their time scales (Frankignoul et al. 1997), although the variability of the deep AMOC also affects the Gulf Stream path (Zhang and Vallis 2007; Joyce and Zhang 2010; Kwon and Frankignoul 2014). Whether the representation of Rossby wave propagation and its impact on the WBC variability improves with model resolution because of more realistic upper ocean stratification has not been previously discussed and should be investigated.

The meandering or the eddy kinetic energy, which is primarily driven by the instability of the strong ocean currents, is another aspect that characterizes the WBC variability. In the Kuroshio Extension, Qiu et al. (2014) showed that the variability of the meandering and eddy kinetic energy is dynamically linked with the variability of the latitude of the Kuroshio Extension and the strength of the southern recirculation gyre, which are primarily driven by the basin-scale wind forcing. This covariability among different aspects of the Kuroshio Extension forms a dynamical constraint, which can be used to assess the realism of the model simulations at a process level. In the Gulf Stream, recent studies reported long-term changes in the meandering and eddy activity (Andres 2016; Gangopadhyay et al. 2019). The cause of these changes is not fully understood, but some studies suggested that the Gulf Stream instability may be modulated by the strength of the equatorward North Atlantic Deep Water transport (Spall et al. 1996a,b; Koelling et al. 2020), which should be further investigated in high-resolution climate model simulations. The variability of WBC frontal strength is influenced by oceanic current instability, nonlinearities and eddy-mean flow interaction (Hogg et al. 2005; Berloff et al. 2007), and remote wind forcing, but it can also be affected by the local heat fluxes. As remote wind forcing and oceanic instability affect the thermocline depth and upper ocean stratification, thus the mixed layer depth, the relative contribution of the heat flux and mixed layer depth variations on determining the frontal strength can form a process-based metric for the WBC frontal strength (Tozuka et al. 2018), which can be used for model validation.

The SST and SSH fronts in WBCs generally coincide. However, the North Pacific is a special case as the SSH front in the Kuroshio Extension and the SST front in the Oyashio Extension are separated by the so-called mixed water region (Yasuda 2003). The interannual to decadal variability of the two fronts are dynamically linked with a time lag of a few years (Frankignoul et al. 2011a; Qiu et al. 2017). Qiu et al. (2017) used an upper ocean heat budget to show that the western Oyashio Extension variability is coupled with the Kuroshio Extension eddy variability, while the eastern Oyashio Extension variability is dictated by the meridional shift of the Kuroshio Extension. Inability to separate these two frontal systems is one of the inherent limitations of the coarse resolution climate models, which often results in an excessively strong decadal WBC variability in the North Pacific (Thompson and Kwon 2010).

As the WBC variability is both driven by and impacting the atmosphere, the complex interaction between the WBCs and the atmosphere along with associated processes are often disentangled by considering the lead-lag relationship between the two (e.g., Frankignoul et al. 1998; Fig. 2). For example, the strength of the ocean-to-atmosphere feedback is often quantified by the surface heat flux feedback coefficient (Frankignoul and Kestenare 2002), a measure of how much air-sea heat flux changes when the SST warms by 1°C, which can be estimated when the SST leads the air-sea heat flux by one or two months. In addition, the dominant processes defining this two-way interaction depend on the temporal and spatial scales; e.g. the ocean-to-atmosphere feedback increases with time scale (Figs. 2c-d) but decreases with spatial scale. Bishop et al. (2017) showed from observational analyses that the surface heat flux variability is dominated by the oceanic variability at time scales of longer than a few months and spatial scales smaller than ~500 km. This scale-dependent surface heat flux feedback can be a measure of how realistic the WBC air-sea interaction is in climate models (Small et al. 2019b).

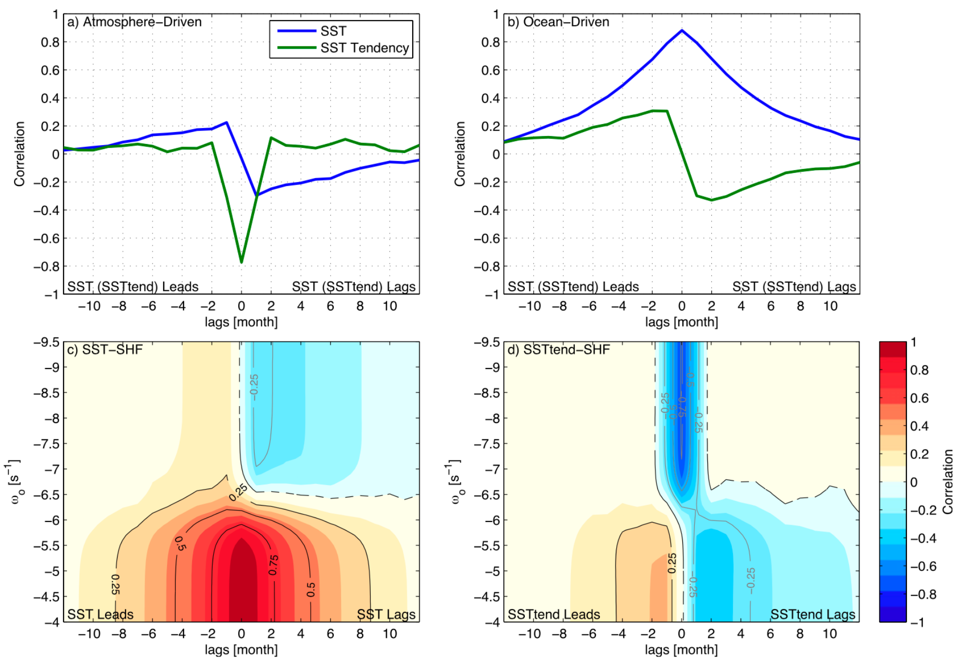

Figure 2: Lagged correlations based on a local air-sea coupled stochastic theoretical model. (a) Lagged correlation between SST and turbulent surface heat flux (SHF) (blue) and between SST tendency and SHF (green) with variability driven by atmospheric noise. (b) As in (a), but with variability driven by oceanic noise. Lagged correlation between (c) SST and SHF and (d) SST tendency and SHF as a function of the forcing frequency (ω_0) of the stochastic ocean forcing on a logarithmic scale. Black and gray contours are positive and negative correlations respectively [contour interval=0.25] and the black dashed contour is the zero correlation contour. From Bishop et al. (2017).

The SST-surface wind coupling in WBCs is also scale dependent (Chelton et al. 2004; Small et al. 2008; Bryan et al. 2010; Schneider and Qiu 2015; Schneider 2000), with stronger wind corresponding to warmer SST due to the marine boundary layer response to the oceanic heating at spatial scales smaller than atmospheric baroclinic Rossby radius of deformation. Therefore, scale dependence of the SST-wind stress coupling strength can be used to assess the realism of WBC air-sea interaction in climate models (e.g. Bryan et al. 2010). For time scales longer than monthly, the SST feedback on the local wind generates a surface wind convergence over the WBCs (Chelton et al. 2004; Minobe et al. 2008). The two widely discussed mechanisms are the downward momentum mixing induced by warming from the ocean (Wallace et al. 1989) and the pressure adjustment, in which SST gradient generates the atmospheric pressure gradient across the SST gradient (Lindzen and Nigam 1987). The relative contribution of these two processes in WBCs can be another metric for the climate models (Takatama et al. 2011). At synoptic weather time scale, the surface wind convergence is associated with the traveling weather systems, e.g. extratropical storms and embedded atmospheric fronts (O'Neill et al. 2017; Parfitt and Seo 2018).

The variability of the oceanic WBCs not only affects the local atmospheric boundary layer, but also the large-scale atmospheric circulation (Kwon et al. 2010; Frankignoul et al. 2011a; Qiu et al. 2007, 2014), through the modulations of the storm track (Kwon and Joyce 2013; O'Reilly and Czaja 2015; Révelard et al. 2016), eddy-driven jet (Révelard et al. 2016; O'Reilly et al. 2017; Kwon et al. 2020), and blocking (O'Reilly et al. 2016; Joyce et al. 2019; Kwon et al. 2020). Also, the WBC variability is closely linked to the large-scale oceanic variability including the AMOC (Joyce and Zhang 2010), subtropical gyre circulation and water masses (Qiu and Chen 2006b; Dong et al. 2007), and sea-level (Yin et al. 2009; Minobe et al. 2017). Therefore, the model biases in the WBC variability and associated air-sea interaction are not only affected by the biases in the large-scale ocean and atmospheric circulation, but also affect the large-scale biases. The relationship between the WBC and large-scale biases should provide precious information on these two-way interactions, although cause and effect may not always be easy to disentangle, but is yet to be quantified in the climate models.

Recent studies clearly show that the climate model simulation of the WBC variability and the associated air-sea interactions reviewed in the previous paragraphs are highly sensitive to the horizontal resolution in both ocean and atmosphere (Thompson and Kwon 2010; Smirnov et al. 2015; Small et al. 2014, 2019a,b, 2020; O'Reilly et al. 2016, 2017; Czaja et al. 2019), which is not surprising given the scale dependence of many key processes. For example, the PIs of this proposal showed in twin atmospheric model simulations that the atmospheric responses to WBC SST anomalies are fundamentally different in high (0.25°) and low (1°) resolution models (Smirnov et al. 2015). In the high-resolution simulations, we found that the SST anomaly forced a robust atmospheric response dominated by a balance between local changes in the eddy heat and moisture transports and diabatic heating, while the low-resolution simulations were dominated by low-level mean horizontal advection (Fig. 3). As most of these resolution sensitivity studies analyzed one or two particular models, it is particularly important to systematically assess the resolution sensitivity of the WBC processes in a multi-model framework based on process-oriented diagnostics.

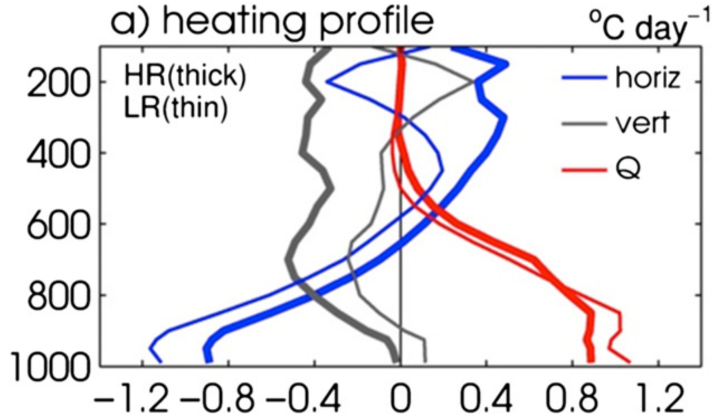

Figure 3: Atmospheric responses to warm SST anomalies due to a northward shift in the Oyashio Extension SST front from the high-resolution (0.25°; thick lines) and low-resolution (1°; thin lines) twin atmospheric model simulations by Smirnov et al. (2015). The local thermodynamic budget is used to diagnose the vertical profiles of the heating rate response (K day^{-1}) arising from horizontal (blue) and vertical (gray) transport, and diabatic processes (red). From Smirnov et al. (2015).

3. Scientific Objectives

The overall goal of our proposal is ***to develop a set of process-oriented diagnostics to better understand and describe the coupled climate model's performance on the WBC variability and associated midlatitude air-sea interaction to guide future model development***. Specific scientific objectives are:

I. To develop process-oriented diagnostics for systematic quantification of the model biases for the oceanic and atmospheric variability in the WBC regions and resulting air-sea interaction.

II. To identify the key processes responsible for the model biases using process-oriented diagnostics, and their sensitivity to the horizontal resolution.

III. To improve our understanding on the role of the WBC biases in the simulated large-scale circulations in atmosphere and ocean.

4. Data and Models

4.1. Observational and reanalysis data sets

To quantify the mean and variability associated with strong WBC ocean fronts and atmospheric storms, high oceanic and atmospheric horizontal resolutions are required. To quantify the WBC ocean frontal variability, we will primarily use the ¼° NOAA Optimum Interpolation SST (OISST;

Reynolds et al. 2007) since 1982 and the ¼° satellite sea-surface height and surface geostrophic velocity since October 1992 from Copernicus Marine Environment Monitoring Service. In addition, the soon-to-be released 0.25° WHOI OAFlux heat flux and surface wind (Lisan Yu, *personal communication*) as well as the Cross-Calibrated Multi-Platform Ocean Surface Wind at 0.25° will also be used.

For the atmospheric and oceanic variables, the NOAA/NCEP CSFR reanalysis available since 1979 will be the primary data set; its horizontal resolution for the atmosphere is T382 (~38 km) and 0.25-0.5° for the ocean (Saha et al. 2010). In addition, we will also consider the European Centre for Medium-range Weather Forecasting (ECMWF) ERA5 starting in 1979 (~31 km horizontal resolution and 137 vertical levels; Hersbach et al. 2019) for the atmosphere, the GLORYS12v1 global ocean reanalysis from Mercator Ocean for 1993-2018 at 1/12° horizontal resolution (Lellouche et al. 2018) and the new ECCO v5 ocean state estimate at 1/3° for the ocean. Three ocean reanalysis products are chosen because of their complementary strengths. The CFSR is a coupled assimilation product and is thus well suited to examine air-sea interaction processes. The GLORYS12v1 is eddy-resolving and thus could be useful in resolving some of the WBC variability. However, many aspects of WBC variability proposed in Section 5.2 may be sufficiently detected in the other two eddy-permitting products. The ECCO v5 will be particularly useful for the budget calculations, as it is based on the adjoint method.

4.2. Climate model simulations

We aim to apply the proposed process-oriented diagnostics to the CMIP6 multi-model ensemble to systematically investigate the state-of-the-art climate models. The first step will be to apply the proposed process-oriented diagnostics to GFDL CM and NCAR CESM simulations. Given their successful application, we will expand the application to the additional CMIP6 models.

GFDL CM

The CM4 (Held et al. 2019), GFDL's state-of-the-art model, has adopted much higher horizontal resolutions than their previous model versions. The ocean component, MOM6, has a nominal horizontal grid spacing of 0.25°, which is generally considered as eddy-permitting. The atmosphere component, AM4, has C96 resolution (roughly 100 km spacing). The historical simulations will be primarily analyzed.

In addition, previous versions with different horizontal resolutions in the atmosphere and ocean (Saba et al. 2015) will be analyzed to assess the resolution sensitivity. These simulations include the CM2.1 (1° ocean, 2° atmosphere), CM2.5 FLOR (1° ocean, 0.5° atmosphere), CM2.5 (0.25° ocean, 0.5° atmosphere), and CM2.6 (0.1° ocean, 0.5° atmosphere). The 1990 control simulation from these four models will be compared.

NCAR CESM

The CESM2 (Danabasoglu et al. 2020), the current state-of-the-art model from NCAR, uses nominal resolution of 1° both in ocean and atmosphere. We will primarily use the 100-member

CESM2 Large Ensemble (LENS) historical simulations, which combines macro (ocean) and micro (atmosphere) initial condition perturbation to generate the ensemble. The LENS will be particularly useful in quantifying the role of internal variability (Deser et al. 2020) when comparing to the observational and reanalysis data sets, while providing close conditions to the observations.

As for the GFDL models, the parallel simulations using the high (0.1° ocean, 0.25° atmosphere)- and low (1° ocean and atmosphere)-resolution CESM1.3 will be used to systematically assess the resolution sensitivity. The 1980-2015 period from both the 1850-2100 and 1950-2100 transient simulations will be primarily analyzed.

CMIP6

The historical simulations from the CMIP6 will be used to place the analyses of the CM4 and CESM2 into the multi-model ensemble context. In addition, the simulations from the High-Resolution Model Intercomparison Project (HighResMIP; Haarsma et al. 2016) will be used to further analyze the resolution sensitivity. Note that the both the CMIP and HighResMIP have the daily winds, geopotential heights, air temperature, humidity at multiple levels and surface heat flux components available for the atmospheric analyses describe below. For the oceanic analyses, the monthly mean SSH, SST, barotropic streamfunction, and mixed layer depth, which are available from both the CMIP and HighResMIP, will be primarily used.

5. Proposed Methodology

5.1. Overall strategy

We propose to first develop a set of process-oriented diagnostics based on the various observational and reanalysis data sets described in Section 4.1. In addition to formulating the process-oriented diagnostics based on existing understanding of the processes, we anticipate to gain further process-level insights on the WBC variability and its impacts through development of the diagnostics from the observational and reanalysis data sets. Then, the set of process-oriented diagnostics will be applied to the various climate model simulations (Section 4.2) to identify the key processes responsible for the model biases. To be consistent with the observational period, the 1980-2015 period from the historical simulations will be primarily analyzed. The Kuroshio-Oyashio Extensions region in the North Pacific and the Gulf Stream region in the North Atlantic will be our primary regions of interest, but we will also consider expanding our analyses to the WBCs in the Southern Hemisphere, if time and resources allow. The detail description for the process-oriented diagnostics for various aspects of the WBC variability and its impacts are provided in Sections 5.2-5.4.

Our particular interest is to compare the standard resolution climate model simulations with the higher resolution simulations (Section 4.2) to investigate the role of model resolutions in the representation of the key processes. The primary emphasis is to systematically assess the model performance at process-level in a multi-model framework, using the CMIP6 and HighResMIP simulations. However, the GFDL and NCAR models will be used to perform in-depth analyses to gain deeper understanding on the resolution-sensitivity of the processes and insights on how to improve the models. In addition to developing the process-oriented diagnostics and applying them to the state-of-the-art climate models, we will actively communicate with the scientists in the modeling centers, in particular through our existing collaborators at GFDL and NCAR, so that our findings can guide their future model development. In addition to the email and virtual discussions, we will visit GFDL and NCAR to give presentations and discuss our findings (the visits to GFDL and NCAR are included in the budget). We also plan to develop and make the diagnostic package available through GitHub according to the standard recommended by the MAPP Marine Diagnostics Task Force.

5.2. WBC ocean variability

The first task will be to define set of indices for the WBC variability at interannual and decadal time scales. The simple observation-model comparisons at fixed geographical locations (e.g. Fig. 1) exhibit large model biases in the WBC regions, because the climate models with non-eddy-resolving ocean component struggles to simulate the mean path of the strong WBCs. Despite the incorrect mean position, it is not clear how well the characteristics of the WBC variability are reproduced in these models. For a more physically meaningful assessment, we propose to define and examine indices for various aspects of the WBC variability based on physical characteristic of the WBCs, instead of simply their exact geographical locations.

The variability in the WBC paths will be defined based on strong gradient in SSH (Qiu and Chen 2005; Peña-Molino and Joyce 2008; Andres 2016) or SST (Frankignoul et al. 2011a; Seo et al. 2014). The indices for the ***meridional fluctuation in the WBC paths*** will be defined either based on the zonal mean or the leading empirical orthogonal function (EOF) mode of the WBC path variability. The indices for the ***degree of WBC instability*** will be defined by the meandering based on the path length as well as the eddy-kinetic energy around the WBCs. The ***WBC strengths*** will be defined based on the meridional SSH and SST gradient (difference) across the WBC paths. Once the indices are defined and applied to both observations and models, the dominant time scale and associated spatial pattern (i.e. the footprint of the WBC variability) will be characterized (e.g., using the auto-correlation/power spectrum of individual index and regression of SST, SSH, and mixed layer depths), and compared between observations and models, as well as between the standard and high resolution models. In addition, the lead-lag relationship between the different aspects of the WBC variability will be examined, e.g. using the cross-correlation/coherence among different indices. In the North Pacific, the SSH front in the Kuroshio Extension (KE) and SST front in the Oyashio Extension (OE) will be separately defined (c.f. Frankignoul et al. 2011a; Qiu et al. 2017) in the observations and high-resolution models and the relationship between the two will be examined. Furthermore, we will examine whether the single North Pacific WBC in the standard resolution models (due to their inability to separately simulate the KE and OE) exhibits characteristics of the KE or OE or some combination of the two. In the Gulf Stream, the SSH and SST fronts are not distinct features. However, there is a separate secondary SST front nearby the shelf break, which often fails to be simulated separately in the standard resolution models. We will also investigate how this limitation of the standard resolution models in the Gulf Stream region affects the simulated Gulf Stream variability.

The next step will be to examine the relationship of the various WBC variability (represented by the indices) with remote and local drivers. The ***role of the mid-latitude wind forcing*** will be diagnosed based on the linear Rossby wave model (Frankignoul et al. 1997; Schneider and Miller 2001; Qiu 2002; Kwon and Deser 2007). The large-scale, baroclinic ocean response to wind stress curl forcing can be approximated using a 1½-layer reduced gravity model. Under the long-wave approximation, the linear vorticity equation of the model is

$$\frac{\partial h}{\partial t} - C_{RW}\frac{\partial h}{\partial x} = -\frac{g'}{\rho_0 g f}\,\boldsymbol{k}\cdot\nabla\times\tau - \varepsilon h$$

where h is the SSH, C_{RW} is the speed of the long baroclinic Rossby waves, g' is the reduced gravity, ρ_0 is the reference density of sea water, f is the Coriolis parameter, **k** is the unit vector in the vertical direction, $\nabla\times\boldsymbol{\tau}$ is the wind stress curl, and ε is the Newtonian dissipation rate. By integrating the above equation from the eastern boundary (x_e) along the baroclinic Rossby wave characteristics, the following solution can be obtained

$$h(x,t) = \frac{g'}{\rho_0 g f C_{RW}}\int_{x_e}^{x}\boldsymbol{k}\cdot\nabla\times\tau\left(x', t + \frac{x - x'}{C_{RW}}\right) exp\left[\varepsilon\frac{x - x'}{C_{RW}}\right]dx'$$

The boundary condition at the eastern boundary can be assumed to be $h(x_e, t) = 0$, which is reasonable for our purposes (Fu and Qiu, 2002). The wind forcing associated with individual leading mode of climate variability, e.g. NAO or Pacific-North American teleconnection (PNA), can be separately examined in this framework. We will also consider the role of high-latitude wind forcing impacting along the topographic wave guide (Andres et al. 2011; Minobe et al. 2017).

The ***mixed layer or upper ocean heat budget analysis*** (Dong and Kelly 2004; Kwon and Deser 2007; Buckley et al. 2014; Qiu et al. 2017; Small et al. 2020) will be the primary framework to diagnose the role of the local heat flux forcing and oceanic conditions (e.g. mixed layer depth variability) in the WBC variability. The mixed layer heat budget can be expressed in the following form (e.g. Alexander et al. 2000):

$$\frac{\partial T}{\partial t} = -\frac{1}{\rho_0 C_p H}Q_{net} - \left(u_{Ekman}\frac{\partial T}{\partial x} + v_{Ekman}\frac{\partial T}{\partial y}\right) - \left(u_{geo}\frac{\partial T}{\partial x} + v_{geo}\frac{\partial T}{\partial y}\right) - w_e\frac{\Delta T}{H} + Residual$$

where T is the mixed layer temperature, ΔT is the vertical temperature difference across the bottom of the mixed layer, Q_{net} is the net air-sea surface heat flux, H is the mixed layer depth, u_{Ekman} (v_{Ekman}) is the zonal (meridional) Ekman velocity, and u_{geo} (v_{geo}) is the zonal (meridional) geostrophic velocity. The w_e is the vertical entrainment velocity, which is defined as $w_e = \frac{\partial H}{\partial t}$ when the mixed layer is deepening and set to zero otherwise. All the terms not explicitly listed, including diffusion, make up the $Residual$. In particular, our focus will be to diagnose which terms play the dominant role in various aspects of the WBC variability. As the WBC is dynamically coupled with the recirculation gyres to the south and north, we will consider the heat budget separately for the southern and northern recirculation gyres, and investigate how the variability in the two regions, distinctly or collectively, affects (and is affected by) the WBC variability. For example, our preliminary analysis suggest the Gulf Stream frontal strength variability is dominated by the variability in the northern recirculation gyre, while the southern recirculation gyre exhibits somewhat distinct low-frequency variability (Fig. 4). The heat budget analyses will be complemented by the ***frontogenesis metric*** proposed by Tozuka et al. (2018), which is based on the mixed layer heat budget. Their metric quantifies the relative contribution of the mixed layer depth and surface heat flux to the reinforcement or relaxation of the frontal strength. While Tozuka et al. (2018) applied this metric to the mean state, we will adopt it to examine the contributions to the WBC variability. As reviewed in Section 2, relative contributions from the atmosphere and ocean are scale-dependent. Therefore, we will examine the ***scale-dependence*** by repeating the above analyses with different degrees of spatial smoothing (Bishop et al. 2017; Small et al. 2020).

Note that our primary focus is on the natural variability of the WBCs, as opposed to the climate change signal. Therefore, the internal variability and externally forced signal needs to be properly separated. For the model simulations, we will define the externally forced signal based on the multi-model or single model ensemble mean. For the observations or reanalyses, we will apply advanced statistical methods such as the optimal filter using the linear inverse model (Frankignoul et al. 2017) or the low-frequency pattern analysis (Wills et al. 2020).

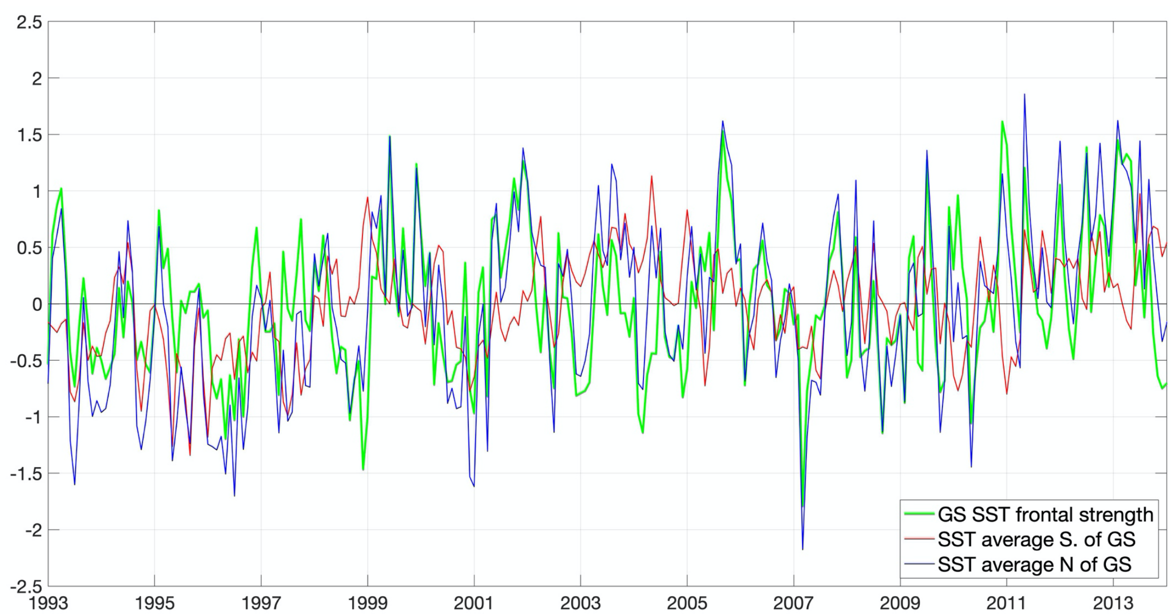

Figure 4: Preliminary monthly GS SST frontal strength index (green curve) for 1993-2014 based on the satellite SSH and NOAA OI SST. The GS path at each monthly time step is detected based on 25 cm SSH isoline. Subsequently, the SST anomalies are averaged over the regions within 3 degrees north (blue curve) and south (red curve) of the time varying GS path. The GS frontal strength is defined as the northern SST minus southern SST at each time step.

5.3. WBC impact on local atmosphere

In this section, we focus on the processes that drive the local atmospheric responses to WBC variability, including surface heat flux damping, surface wind, and local transient eddy activity (i.e. storm track activity). The ***surface heat flux damping*** is one of the most direct process that acts upon the SST anomalies, controlling the time scale the SST variability driven by the atmosphere as well as driving anomalous diabatic heating of the atmosphere (Frankignoul and Hasselmann 1977; Barsugli and Battisti 1998). More importantly, the WBC regions are where the ocean largely drives the SST anomalies especially in interannual and longer time scales (Kwon et al. 2010; Smirnov et al. 2014) and the heat flux damping is particularly large (Frankignoul and Kastenare 2002; Park et al. 2005; Li et al. 2020). We will examine how realistically the heat flux damping is simulated and whether the high-resolution models are more realistic, and if so, why. The heat flux damping (or heat flux feedback, λ) process can be quantified based on the covariance between the surface heat fluxes (Q') and the SST (T') anomalies with a lag (τ) longer than a few weeks, which is an intrinsic atmospheric decorrelation time scale. Following Frankignoul et al. (1998), we will use the following definition.

$$\lambda = -\frac{< Q' \cdot T' >_{\tau}}{< T' \cdot T' >_{\tau}}$$

where the denominator is the lagged auto-covariance of SST anomalies. Our preliminary calculation of the heat flux damping in the 1° CESM1 Large Ensemble (Kay et al. 2015) shows that the values near the Gulf Stream are much lower than in the observations (Fig. 5). It needs to be diagnosed whether the latest generation and/or higher resolution models perform better, and if so why. To answer the latter, we will further decompose the heat flux variability into the contributions due to the variability in the air temperature, humidity, wind, SST, and mixed layer depth, and their respective contribution to the heat flux damping (Li et al. 2020; Small et al. 2019b). We will also examine the scale dependence of the heat flux damping and the respective contributions from ocean and atmospheric variability by applying different spatial and temporal filtering (Bishop et al. 2017; Small et al. 2019b).

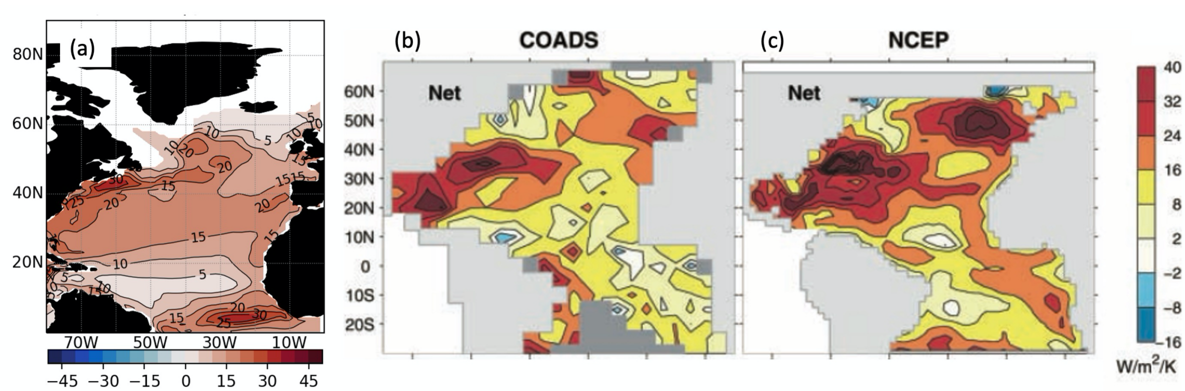

Figure 5: Annual mean net surface heat flux damping coefficients (W/m^2/°C) in (a) the CESM1 Large Ensemble, (b) Comprehensive Ocean-Atmosphere Data Set (COADS), and (c) NCEP-NCAR Reanalysis (NCEP). The positive value indicates increased ocean-to-atmosphere heat flux associated with warm SST anomalies. (b-c) are from Frankignoul and Kestenare (2002).

Next, we propose to investigate the ***SST-surface wind coupling*** (Chelton et al. 2004; Bryan et al. 2010; Schneider 2020) in the WBCs. We will use the regression slope between SST and surface wind speed or wind stress as a measure of the coupling strength (Chelton et al. 2004), and systematically assess the model performance in standard and high-resolution models. We will also examine the scale dependence in observation and models by applying various filtering. Furthermore, we will adopt the approach by Takatama et al. (2011) to diagnose the relative contributions from the vertical momentum mixing and pressure adjustment on ***the surface wind convergence in WBCs***. They applied the diagnostic to examine the mean surface wind convergence. We will use the framework to investigate the modulations in the surface wind convergence associated with the low-frequency WBC variability.

Upstream ***transient eddy heat flux variability*** (i.e. storm track activity) over the WBCs are shown to drive the downstream changes in the eddy-driven jet latitudes in theoretical and observational studies (Rivière 2009; Novak et al. 2015). In addition, the WBC variability are shown to drive changes in the local transient eddy heat flux variability, thus the storm track variability is a key process linking the WBC variability to the large-scale atmospheric circulation response (Smirnov et al. 2015; Révelard et al. 2016; O'Reilly et al. 2016, 2017). Hence, we propose to diagnose how the local submonthly transient eddy heat fluxes vary in response to the WBC variability (represented by the WBC indices; Section 5.2). First, we will compare the footprint of the storm track anomalies at different levels associated the WBC indices. Booth et al. (2017) used the spatial correlation and maximum amplitude at different levels as the metrics to assess the CMIP5 models for the mean storm track. We will adopt this approach and use it for the variability associated with the WBCs. In addition, we will use the thermodynamic budget at selected levels (e.g. near-surface, 850 and 500 hPa) to diagnose the relative contributions from the horizontal and vertical terms as well as mean and eddy terms (Smirnov et al. 2015) on the local atmospheric response to the WBC variability.

5.4. Large-scale implication

Since the model biases in the WBC variability and associated air-sea interaction affect and are affected by the biases of the large-scale ocean and atmospheric circulations, we propose to establish the main relationships between biases in the WBC variability, including the associated surface heat flux release into atmosphere, and the large-scale biases based on the multi-model ensemble of climate models available in CMIP6 and HighResMIP. Investigating this inter-model diversity should provide a broader view on model biases associated with WBC variability and may provide a further insight on how to improve them.

For the large-scale biases in the atmosphere, we will consider for example the North Atlantic and North Pacific storm tracks, the eddy-driven jet position and the blocking distribution. The storm track will be defined based on the variance of meridional winds (e.g., Booth et al. 2017) or the covariance between wind and temperature/humidity (eddy heat flux, e.g. Kwon and Joyce 2013) for the submonthly transients at different levels. We may further separately consider the synoptic (2-8 days) and intraseasonal (8-30 days) storm tracks (e.g., Kwon and Joyce 2013). For the eddy-driven jet, both the monthly mean and daily positions at 850 hPa (e.g., Woollings et al. 2010; Kwon et al. 2018) will be considered. For blocking, the 2-dimensional blocking definition using the daily 500 hPa geopotential height (Scherrer et al. 2006; Kwon et al. 2020) will be used. For the ocean we will consider the biases in the AMOC, gyre intensity, mixed-layer depth in the WBC regions, and sea-level in particular along the coast near the WBC regions.

To establish the links between the WBC and large-scale biases, we will use the EOF analysis of model WBC biases and then regress the large-scale biases on the principal component time series of the WBC biases (e.g., Mohino et al. 2019). We will also consider the maximum covariance analysis (Czaja and Frankignoul 2002) between the WBC and large-scale biases. These analyses will provide useful information on the two-way coupling between WBC and large-scale circulations in climate models. Note that we will consider the biases in both the mean state and the interannual to decadal variability of the large-scale circulations against the biases in the WBC variability, as not only the variability but also the mean state biases in the large-scale may be linked to the WBC variability. We will investigate these bias relationships in each season separately, considering strong seasonality in most of the large-scale fields, especially in the atmosphere. The comparison between the standard and high-resolution simulations will be once again used to evaluate the impacts of higher model resolution on these links. We will further investigate whether the bias relationships between the WBC variability and large-scale circulation are consistent with the interannual variability relationships existing in observation/reanalyses or single model large ensemble (e.g., CESM2 LENS), to gain physical insights on the reason for the bias relationships.

6. Work Plan

The PI Kwon will be responsible for the overall project coordination and also advising the graduate student Glenn Liu. He will lead the analyses on the WBC ocean variability (Section 5.2, Year 1) and WBC impact on local atmosphere (Section 5.3, Year 2). The Co-PI Frankignoul will lead the analyses on the large-scale implication (Section 5.4, Year 3). Mr. Glenn Liu is a second-year graduate student in the MIT-WHOI Joint Program, and currently advised by the PI Kwon. He will participate in all the aspects of the proposed work. The project team will have regular virtual meeting every month during the non-summer months, when the Co-PI Frankignoul resides in Paris. We will have more frequent weekly in-person meetings during July-September when Co-PI Frankignoul visits WHOI. In addition, Kwon and Liu will meet at least weekly throughout the year to discuss the project progress. Our project will host undergraduate student(s) from groups that are historically underrepresented in the sciences through the UCAR SOARS (Significant Opportunities in Atmospheric Research and Science) program and/or the Woods Hole Partnership in Education Program to work on a subtopic of our proposed research (see the Diversity and Inclusion Statement).

7. Relevance to the Competition

Our proposal directly addresses the focus of the *MAPP 2021 Competition for the Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications* by proposing to better understand and benchmark process-level deficiencies related to the WBC variability and associated air-sea interaction in the state-of-the-art climate model simulations (specifically the CMIP6 and HighResMIP simulations) with additional in-depth analyses of the GFDL and NCAR models. This will be based on comparisons with state-of-the-art observational and reanalysis data sets using the proposed set of process-oriented diagnostics. Our focus on the WBC ocean variability and its climate impacts addresses one of the gap areas in the existing MAPP Model Diagnostic Task Force software package identified in the proposal call. Our proposed analyses of the relationship with the large-scale biases including coastal sea-level, storm track, and blocking would connect our climate model diagnostics effort with model applications relevant to high-priority climate risk areas addressed in Climate Program Office's new Climate Risk Areas Initiative. Our proposed work is also directly relevant to NOAA's long-term climate goal of advancing scientific understanding, monitoring, and prediction of climate and its impacts, to enable effective decisions, especially since the improvement in the climate model processes related to the WBC variability and associated air-sea interaction has significant implication on the prediction of climate and its impacts (e.g. Siqueira and Kirtman 2016).

8. Benefit to the General Public and the Scientific Community

Our proposed research will benefit the general public and the scientific community at various levels. The WBC variability and associated air-sea interaction play fundamental roles in regulating our climate, as the WBCs transports huge amount of heat from lower latitude to high latitudes and the intense air-sea heat exchanges in the WBC regions enable communication between the poleward heat transports by the ocean and the atmosphere. Despite their scientific importance, the WBCs are the regions of large, longstanding biases in the state-of-the-art climate models. Therefore, diagnosing, understanding, and potentially improving the model biases in the WBC variability and associated air-sea interaction would allow more reliable simulation, prediction, and projection of our climate. Robust simulation of the WBC variability by the climate models is a prerequisite for addressing many outstanding scientific questions regarding climate change. For example, the recent observational studies suggested that the Gulf Stream became more unstable in recent decades especially near the coast (Andres 2016; Gangopadhyay et al. 2019). However, the reason is not clear, in particular whether it is a part of natural variability or driven by climate change. The current generation climate models cannot address this important question reliably due to the large biases in WBCs. In addition to the inherent scientific merits and benefit to the scientific community, improved simulations and process-level understanding of the WBC variability and its impacts have significant broader implications for the general public, as the WBC variability is shown to impact the extreme weather (storms and blocking), marine heat waves, fish abundance and distribution, and coastal sea-level. Furthermore, recent studies suggested that reliably simulating the WBCs has significant implications for the near-term climate prediction (e.g. Siqueira and Kirtman 2016).

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WHOI Budget Information

The Woods Hole Oceanographic Institution (WHOI) is a non-profit [501(c)(3)] research and education organization subject to the cost principles of 2 CFR 200. WHOI Principal Investigators are responsible for conceiving, funding and carrying out their research programs. Senior Personnel are expected to raise 12 months of support per calendar year for themselves and their staff by writing proposals and obtaining sponsored research grants and contracts from a variety of sources. Some teach voluntarily in WHOI's Joint Program, but support for this is limited. NSF has confirmed to WHOI that salary support from grants beyond 2 months per calendar year can be justifiable for these Principal Investigators.

The rates included in the proposal are negotiated with our cognizant government agency.

WHOI has an annually negotiated rate agreement with the Office of Naval Research and uses the method of allocation of indirect costs to Modified Total Direct Costs (MTDC). The normal exclusions contained in 2 CFR 200.68 (MTDC) apply, as well as the following cost categories: ship use, submersible use, vessel charters and ship fuel.

A proposed labor month is equal to 152 hours or 1824 hours annually versus 2080 hours (40 hours/week for 52 weeks). The difference is for vacations, holidays, sick time, and other paid absences, which are included in the Paid Absences calculation. WHOI cannot "waive" or reduce overhead rates on any sponsored research project due to the structure of our negotiated rates with our cognizant government agency (Office of Naval Research). When a program sets limits on overhead, WHOI must use Institution unrestricted funds to pay the unfunded portion of the overhead costs.

Employee benefits have been proposed using composite weighted average rates that are the total assignable to salaries of regular employees including paid absences, excluding Graduate Research Assistants, overtime salaries & allotted paid leave benefits. The period composite rates are weighted averages of the specific rates for each fiscal year in accordance with WHOI's 2020 provisional rate agreement (dated 12/31/2019) and 2019 Provisional Forward Pricing Letter (dated 2/12/2019) with the Office of Naval Research.

Budget Justification

Senior Personnel: Y.-O. Kwon, PI (1.0 month per year), will be responsible for the coordination of the overall project. He will also advise the graduate student Glenn Liu. He will lead the analyses on the WBC ocean variability and its impact on local atmosphere.

Other Personnel: A graduate student (G. Liu) will contribute to the project in all three years (12 months the first two years, 9.5 months in the third year). He will participate in all the aspects of the project.

J. D. Taft, Administrative Professional (0.25 months per year), will support the team in all project-related activities such as making travel arrangements, monitoring budgets, copyediting manuscripts, and other associated project-related administrative tasks.

Travel: International and domestic travel has been budgeted in all years. PI Kwon or the Graduate Student Liu will attend the Fall AGU Meeting each year to share findings. The details of these meetings may be found below. While salary is not requested for Co-PI Frankignoul, he will spend one summer month working at WHOI during each year of the proposed work. He will lead the analyses on the large-scale implication. In addition, PI Kwon will visit the NOAA GFDL and the NCAR to give presentations and discuss our findings in Year 3.

Co-PI's Annual Summer Month at WHOI (travelling from Paris, France)			
Year	**1**	**2**	**3**
Destination	WHOI	WHOI	WHOI
Number of days/nights	31	31	31
Number travelling	1	1	1
Airfare	$1,150	$1,250	$1,400
Ground Transportation	$500	$500	$500
Per Diem *lodging*	$8,060 ($260/night)	$8,215 ($265/night)	$9,455 ($305/night)
meals	$1,767 ($57/day)	$1,860 ($60/day)	$1,953 ($63/day)
Total Estimated Cost	**$11,477**	**$11,825**	**$13,308**

Domestic Travel					
Year | Meeting	**1 | AGU**	**2 | AGU**	**3 | AGU**	**3 | NCAR**	**3 | NOAA GFDL**
Destination	New Orleans	Chicago	San Francisco	Boulder	Princeton
Number travelling	1 (PI)	1 (PI)	1 (PI)	1 (PI)	1 (PI)
Number of days/nights	6 days/ 5 nights	6 days/ 5 nights	6 days/ 5 nights	4 days/ 3 nights	3 days/ 2 nights
Airfare	$475	$419	$649	$400	$635
Ground Transportation	$600	$600	$600	$400	$400
Per Diem *lodging*	$865 ($173/night)	$755 ($151/night)	$1,625 ($325/night)	$480 ($160/night)	$274 ($137/night)
Per Diem *meals*	$468 ($78/day)	$552 ($92/day)	$606 ($101/day)	$264 ($66/day)	$183 ($61/day)
Registration	$314	$330	$346	$0	$0
Total Est. Cost	**$2,722**	**$2,656**	**$3,826**	**$1,544**	**$1,492**

Basis of estimate for airfare is based on rates currently available on Expedia/American Express for refundable tickets and includes an allowance for baggage and agent fees. Ground transportation costs include rental car(s) and transportation to/from the airports. Meeting registration fees are based on previous meetings. Per Diem expenses are based on rates currently available via the GSA website for domestic travel or via the State Department for foreign per diem. All rates are increased in subsequent years to account for rate hikes.

Other Direct Costs

Materials and Supplies: *Computer Supplies* have been budgeted in each year ($500/year) to cover the cost of purchasing annual licenses of the software, e.g. Adobe Acrobat Creative Cloud, and supplies, e.g. memory stick. A *GRA Laptop* ($4,200) will be purchased in Year 1 for the graduate student to present the results in the conferences or write manuscript. The basis of estimate is set from previous experience.

Publications: *Page Charges* have been included in each year ($2,000 in Years 1 and 2; $2,200 in Year 3) for the publishing of open-access journal manuscripts to share the project findings with others. Possible journals that will be chosen for publication include *Journal of Climate* and *Journal of Geophysical Research*. The basis of estimate: https://publications.agu.org/author-resource-center/publication-fees/.

Other: *Communications* have been budgeted in each year ($100/year) to allow for the seamless sharing of files among the collaborators, e.g. annual subscription of Dropbox. The basis of estimate is set from previous experience. *Tuition costs* for the Graduate Student (G. Liu) have been budgeted in all three years (Year 1: $32,022; Year 2: $33,624; Year 3: $35,405).

Indirect Costs: Beginning January 1, 2021 and for outyears, the indirect cost rate (Modified Total Direct Cost) for WHOI will be **65.00%** (Year 1: $58,292; Year 2: $57,624; Year 3: $56,847).

WHOI Budget for AER & NOAA | **Title: Process-Oriented Diagnostics for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction**

PI: Young-Oh Kwon

	Year 1		**Year 2**		**Year 3**		**Total**	
a. Personnel:	Labor Months	Amount	Labor Months	Amount	Labor Months	Amount	Months	Amount
Kwon, Y-O, PI	1.00	$15,859	1.00	$16,434	1.00	$17,015	3.00	$49,308
Frankignoul, C, Co-PI	1.00	$0	1.00	$0	1.00	$0	3.00	$0
Liu, G, Graduate Student	12.00	$42,575	12.00	$44,279	9.50	$36,172	33.50	$123,026
Taft, J. D., Admin	0.25	$1,308	0.25	$1,356	0.25	$1,404	0.75	$4,068
b. Fringe Benefits		$8,937		$9,501		$9,894		$28,332
TOTAL SALARY, WAGES & BENEFITS		**$68,679**		**$71,570**		**$64,485**		**$204,734**
c. Travel								
International	Co-PI to WHOI		Co-PI to WHOI		Co-PI to WHOI			
Airfare	from Paris	$1,150	from Paris	$1,250	from Paris	$1,400		$3,800
Ground transportation		$500		$500		$500		$1,500
Lodging		$8,060		$8,215		$9,455		$25,730
Per diem		$1,767		$1,860		$1,953		$5,580
International Travel Total		**$11,477**		**$11,825**		**$13,308**		**$36,610**
Domestic								
Period / Meeting	1 / AGU		2 / AGU		3 /AGU	3/NCAR	3/NOAA-GFDL	
Location	New Orleans		Chicago		San Franciso	Boulder	Princeton	
Airfare	$475		$419		$649	$400	$635	$2,578
Ground transportation	$600		$600		$600	$400	$400	$2,600
Lodging	$865		$755		$1,625	$480	$274	$3,999
Per diem	$468		$552		$606	$264	$183	$2,073
Meeting Registration	$314		$330		$346	$0	$0	$990
Domestic Travel Total	**$2,722**		**$2,656**		**$3,826**	**$1,544**	**$1,492**	**$12,240**
d. Equipment								
e. Supplies								
	Computer Supplies	$500		$500		$500		$1,500
	GRA Laptop	$4,200		$0		$0		$4,200
f. Contractual								
g. Construction								
h. Other Direct Costs								
	Publications	$2,000		$2,000		$2,200		$6,200
	Communications	$100		$100		$100		$300
	Tuition GRA	$32,022		$33,624		$35,305		$100,951
i. Total Direct Charges		$121,700		$122,275		$122,760		$366,735
j. Indirect Costs		$58,292		$57,624		$56,847		$172,763
k. TOTALS		**$179,992**		**$179,899**		**$179,607**		**$539,498**

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Education

B.Sc. (1996) & M.Sc. (1998) Oceanography, Seoul National University, Seoul, Korea
Ph.D. (2003) Physical Oceanography, University of Washington, Seattle, WA, USA

Professional Experience

2006-Present: Assistant, Associate, Associate w/tenure, and Senior Scientist, WHOI
2003-2006: Postdoctoral and Visiting Scientist, NCAR

All Publications in the Last 3 Years

Woollings, T., E. Barnes, B. Hoskins, Y.-O. Kwon, R.W. Lee, C. Li, E. Madonna, M. McGraw, T. Parker, R. Rodrigues, C. Spensberger, and K. Williams, 2018: Daily to decadal modulation of jet variability. *J. Clim*, **31**, 1297-1314.

Révelard, A., C. Frankignoul, and Y.-O. Kwon, 2018: A multivariate estimate of the cold season atmospheric response to North Pacific SST variability. *J. Clim*, **31**, 2271-2796.

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Chen, Z., Y.-O. Kwon, K. Chen, P. Fratantoni, G. Gawarkiewicz, and T.M. Joyce, 2020: Long-term SST Variability on the Northwest Atlantic Continental Shelf and Slope. *Geophys. Res. Lett.*, **47**, https://doi.org/10.1029/2019GL085455.

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Simon, A., C. Frankignoul, G. Gastineau, and Y.-O. Kwon, 2020: An observational estimate of the direct response of the cold season atmospheric circulation to the Arctic sea ice loss. *J. Climate*, **33**, 3863-3882.

Parfitt, R., and Y.-O. Kwon, 2020: The modulation of Gulf Stream influence on the troposphere by the eddy-driven jet. *J. Climate*, **33**, 4109-4120.

Jacox, M. G., M. A. Alexander, S. Siedlecki, K. Chen, Y.-O. Kwon, et al., 2020: Seasonal-to-interannual prediction of U.S. coastal marine ecosystems: Forecast methods, mechanisms of predictability, and priority developments. *Progress in Oceanography*, **183**. https://doi.org/10.1016/j.pocean.2020.102307.

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CLAUDE FRANKIGNOUL

Education

Physician Engineer, University of Liège, Belgium 1967
Engineer in Applied Mathematics, University of Liège, Belgium 1968
Doctorate in Applied Sciences, University of Liège, Belgium 1972

Appointments

1982-2013	Professor, University Pierre et Marie Curie, France
2013-	Emeritus professor, Sorbonne University
2002-	Adjunct Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA
1977-1981	Research Associate, Massachusetts Institute of Technology, Cambridge, MA
1982-1996	Visiting Professor, Massachusetts Institute of Technology, Cambridge, MA
1974-1976	Wissenschaftlicher Angestellte, University of Hamburg and Max-Planck Institut für Meteorologie, Germany
1973, 1974	Visiting Investigator (6 months/year), Woods Hole Oceanographic Institution
1968-1974	Aspirant FNRS, University of Liège, Belgium

Publications 2018-2020

Révelard, A., C. Frankignoul, and Y.-O. Kwon: A multivariate estimate of the cold season atmospheric response to North Pacific SST variability. *J. Climate*, 2018, 31, 2771-2796.

Czaja, A., C. Frankignoul, S. Minobe, B. Vannière : Simulating the Midlatitude Atmospheric Circulation: What Might We Gain From High-Resolution Modeling of Air-Sea Interactions? *Current Climate Change reports*, 2019, 10.1007/s40641-019-00148-5

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Related publications

Frankignoul, C, A. Czaja and B. L'Heveder: Air-sea feedback in the North Atlantic and surface boundary conditions for ocean models. *J. Climate*, 1998, 11, 2310-2324.

Frankignoul, C., G. de Coëtlogon, T.M. Joyce and S. Dong: Gulf Stream variability and ocean-atmosphere interactions. *J. Phys. Oceanogr.*, 2001, 31, 3516-3529.

Frankignoul, C. and E. Kestenare: The surface heat flux feedback. Part 1: Estimates from observations in the Atlantic and the North Pacific. *Clim. Dyn.*, 2002, 19, 633-64

YOUNG-OH KWON - Current and Pending Support

Principal Investigator(s) And Project Title	Supporting Agency	Period Covered	1	2	3	4	5	Award Amount
			Person-Months/Project Year Periods shown reflect Individual Project Years					
Current Support								
Y. KWON, K. CHEN, T. JOYCE, G. GAWARKIEWICZ - Development and evaluation of a seasonal-to-interannual statistical forecasting system for oceanographic conditions and living marine resources on the Northeast U.S. Shelf *POC:Daniel Barrie 301-734-1256 daniel.barrie@noaa.gov*	National Oceanic & Atmospheric Admin.(NOAA) NA17OAR4310111	9/1/2017 to 8/31/2021	0.34	0.48	0.49	0.00	0.00	$231,024
Y. KWON, K. CHEN, G. GAWARKIEWICZ, T. JOYCE - Development and Evaluation of a Seasonal-to-interannual Statistical Forecasting System for Oceanographic Conditions on the Northeast U.S. Shelf *POC:Sarah Pike 508-495-2289 sarah.pike@noaa.gov*	NOAA Cooperative Institutes NA19OAR4320074	5/1/2020 to 8/31/2021	0.00	0.00	0.00	0.00	0.00	$151,496
Y. KWON, C. FRANKIGNOUL - Collaborative Research: The Influence of Arctic-Lower-Latitude Interactions on Weather and Climate Variability: Mechanisms, Predictability, and Prediction *POC:Anjuli S. Bamzai 703-292-8688 abamzai@nsf.gov*	National Science Foundation (NSF) OPP-1736738	9/15/2017 to 8/31/2021	1.20	1.10	1.10	0.00	0.00	$540,000
Y. KWON, C. FRANKIGNOUL - The Atlantic Multidecadal Oscillation: Key Drivers and Climate Impacts [Target program: Regional and Global Model Analysis (RGMA)] *POC:Renu R. Joseph 301-903-9237 renu.joseph@science.doe.gov*	DOE - Dept. of Energy DE-SC0019492	9/15/2018 to 9/14/2021	3.03	3.03	3.03	0.00	0.00	$880,885
Y. KWON, H. SEO, K. CHEN - Regional multi-year prediction for the Northeast U.S. Continental Shelf *POC:Sandy Lucas sandy.lucas@noaa.gov*	National Oceanic & Atmospheric Admin.(NOAA) NA20OAR4310482	9/1/2020 to 8/31/2023	0.75	0.75	0.75	0.00	0.00	$354,339

Principal Investigator(s) And Project Title	Supporting Agency	Period Covered	1	2	3	4	5	Requested Amount
			Person-Months/Project Year Periods shown reflect Individual Project Years					
Pending Support								
Y. KWON, C. FRANKIGNOUL - NSFGEO-NERC: Large-Scale Atmospheric Circulation Response to Oyashio Extension Frontal Variability *POC:Dr. Eric T. DeWeaver 703 292 8527 edeweave@nsf.gov*	National Science Foundation (NSF)	1/1/2021 to 12/31/2023	1.00	1.00	1.00	0.00	0.00	$860,286
S. WIJFFELS, Y. KWON - The Oceanic Fingerprint of the Forced Response to Anthropogenic Aerosols *POC:Baris Mete Uz 703-292-4557 bmuz@nsf.gov*	National Science Foundation (NSF)	3/1/2021 to 2/29/2024	1.00	1.00	1.00	0.00	0.00	$885,726
Y. KWON - Collaborative Research: Quantifying the role of the ocean circulation in climate variability *POC:Dr. Eric DeWeaver 703-292-9-8527 edeweave@nsf.gov*	National Science Foundation (NSF)	4/1/2021 to 3/31/2024	1.00	1.00	1.00	0.00	0.00	$165,918
Z. CHEN, K. CHEN, Y. KWON - Dynamical Processes Linking the Interannual and Decadal Variability of the Mid-Atlantic Bight Cold Pool to the Gulf Stream *POC:Dr. B. Mete Uz 703-292-4557 bmuz@nsf.gov*	National Science Foundation (NSF)	6/1/2021 to 5/31/2024	1.00	1.00	1.00	0.00	0.00	$782,338

YOUNG-OH KWON - Current and Pending Support

Principal Investigator(s) And Project Title	Supporting Agency	Period Covered	1	2	3	4	5	Requested Amount
			Person-Months/Project Year Periods shown reflect Individual Project Years					
Pending Support								
Y. KWON, C. FRANKIGNOUL - Process-Oriented Diagnostics for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction	National Oceanic & Atmospheric Admin.(NOAA)	9/1/2021 to 8/31/2024	1.00	1.00	1.00	0.00	0.00	$539,498
POC:Dr. Daniel Barrie, Program Manager 301-734-1256 daniel.barrie@noaa.gov								
N. FOUKAL, Y. KWON, C. PIECUCH - Dynamics and impacts of the North Atlantic eastern subpolar gyre circulation	NASA Grants	4/1/2021 to 3/31/2025	1.00	1.00	1.00	1.00	0.00	$998,335
POC:Nadya Vinogradova Shiffer 202-658-0976 nadya@nasa.gov								
Y. KWON, C. FRANKIGNOUL - Collaborative Research: Constraining Uncertainty in Arctic Climate Variability, Change, and Impacts Through Process-Based Understanding	National Science Foundation (NSF)	9/1/2021 to 8/31/2025	1.00	1.00	1.00	1.00	0.00	$773,931
POC:Dr. Marc Stieglitz 703-292-4354 MSTIEGLI@nsf.gov								

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CLAUDE FRANKIGNOUL - Current and Pending Support

Principal Investigator(s) And Project Title	Supporting Agency	Period Covered	1	2	3	4	5	Award Amount
			Person-Months/Project Year Periods shown reflect Individual Project Years					
Current Support								
Y. KWON, C. FRANKIGNOUL - Collaborative Research: The Influence of Arctic-Lower-Latitude Interactions on Weather and Climate Variability: Mechanisms, Predictability, and Prediction	National Science Foundation (NSF) OPP-1736738	9/15/2017 to 8/31/2021	1.00	1.00	1.00	0.00	0.00	$540,000
POC:Anjuli S. Bamzai 703-292-8688 abamzai@nsf.gov								
Y. KWON, C. FRANKIGNOUL - The Atlantic Multidecadal Oscillation: Key Drivers and Climate Impacts [Target program: Regional and Global Model Analysis (RGMA)]	DOE - Dept. of Energy DE-SC0019492	9/15/2018 to 9/14/2021	1.01	1.01	1.01	0.00	0.00	$880,885
POC:Renu R. Joseph 301-903-9237 renu.joseph@science.doe.gov								

Principal Investigator(s) And Project Title	Supporting Agency	Period Covered	1	2	3	4	5	Requested Amount
			Person-Months/Project Year Periods shown reflect Individual Project Years					
Pending Support								
Y. KWON, C. FRANKIGNOUL - NSFGEO-NERC: Large-Scale Atmospheric Circulation Response to Oyashio Extension Frontal Variability	National Science Foundation (NSF)	1/1/2021 to 12/31/2023	0.00	0.00	0.00	0.00	0.00	$860,286
POC:Dr. Eric T. DeWeaver 703 292 8527 edeweave@nsf.gov								
Y. KWON, C. FRANKIGNOUL - Process-Oriented Diagnostics for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction	National Oceanic & Atmospheric Admin.(NOAA)	9/1/2021 to 8/31/2024	0.00	0.00	0.00	0.00	0.00	$539,498
POC:Dr. Daniel Barrie, Program Manager 301-734-1256 daniel.barrie@noaa.gov								
Y. KWON, C. FRANKIGNOUL - Collaborative Research: Constraining Uncertainty in Arctic Climate Variability, Change, and Impacts Through Process-Based Understanding	National Science Foundation (NSF)	9/1/2021 to 8/31/2025	0.00	0.00	0.00	0.00	0.00	$773,931
POC:Dr. Marc Stieglitz 703-292-4354 MSTIEGLI@nsf.gov								

Data/Information Sharing Plan

We recognize the benefits of freely sharing the data and information produced during this project with the scientific community and general public via open access/open source domain, and preserving data in a format that provides maximum interoperability among our collaboration efforts, as well as support to the users' community to ease their interpretation and analysis of the data. We propose to manage the data and information resulting from our proposed research according to the NOAA Data Management Guidance, in particular the MAPP Program's guideline specified in the solicitation.

Our proposed research includes the analyses of already publicly available observational, reanalysis and climate model data sets, and production of new index time series and process-oriented diagnostics, as detailed below. All the research data displayed in our publications resulting from our proposed research will be made publicly available at the time of publication either from the data servers as detailed below for the row data files or through the PI's webpage (https://www2.whoi.edu/staff/ykwon/data) or MAPP Model Diagnostics Task Force GitHub page (https://github.com/NOAA-GFDL/MDTF-diagnostics) for the derived data, e.g. index time series. Detailed data sharing plans for various data files in this proposed research are as follows.

Observational and reanalysis datasets: All the observational and reanalysis datasets that we propose to utilize in this proposal (Section 4.1 of the Project Narrative) are already available to the public through various data archives maintained and updated by the dataset providers. These datasets are already downloaded on PI's server at WHOI, and regularly updated for newly available files.

Climate model simulations: All the global climate model simulations (Section 4.2 of the Project Narrative) are generated as a part of each modeling center's activities, including their participation to CMIP6. Therefore, these simulations, including those at NCAR and GFDL, are maintained and made available to the public through the CMIP6 Earth System Grid Federation and/or individual modeling center's data server.

Process-oriented diagnostics: We are proposing to develop a process-oriented diagnostic package for the WBC variability and associated air-sea interaction (Section 5 of the Project Narrative). The diagnostic package will be made available through the GitHub page (https://github.com/NOAA-GFDL/MDTF-diagnostics) according to the standard recommended by the MAPP Marine Diagnostics Task Force.

New WBC index time series: The various index time series for WBC variability will be produced from the observational and reanalysis data sets as proposed in Section 5.2 of the Project Narrative. These index time series will be disseminated through peer-reviewed publications and further made available to the community through the GitHub page as well as PI Kwon's research webpage (https://www2.whoi.edu/staff/ykwon/data).

Data and Metadata Standards: All metadata will be in NetCDF format, which is self-describing and platform independent. It is supported by almost all plotting and analysis packages (e.g., Ferret, IDL, MATLAB, Python, GrADS), which can directly read the files for the analysis and graphics.

Statement of Diversity and Inclusion

We highly value diversity and inclusion. We will invest and engage in every opportunity to expand the diversity and inclusion in this project team, our institution, the broader science community, and the science, technology, engineering, and mathematics (STEM) education. The research groups led by the both PIs have been highly diverse and inclusive. PI Kwon have advised total of 23 postdocs, graduate students, and visiting students (including REU students) in the past 14 years at WHOI. Among them, 14 are female scientists and 9 are male. Ethnic or racial backgrounds consist of 4 Latinos, 10 Asians, and 9 Whites. Among 16 Ph.D. students whom Co-PI Frankignoul advised at Pierre and Marie Curie university (now Sorbonne University), 12 are female and 4 are male.

PI Kwon have been actively involved in UCAR's SOARS (Significant Opportunities in Atmospheric Research and Science; http://www.soars.ucar.edu) program, which is an undergraduate-to-graduate bridge program designed to broaden participation in the atmospheric and related sciences. The program is built around research, mentoring, and community for students from groups that are historically underrepresented in the sciences. Kwon has mentored three SOARS students in the last five years. In addition, Kwon engaged in K-12 STEM education by serving as mentors and judges for the local public school annual science fairs (e.g., www.falmouthsciencefair.com) in the past several years. We will continue to engage in these activities to broaden the diversity and inclusion in the STEM community. We will also engage where possible with existing programs aimed at increasing diversity in the Woods Hole science community, including the well-established Woods Hole Partnership in Education Program (PEP; https://www.woodsholediversity.org/pep/). In particular, the PIs will host and mentor SOARS and/or PEP students to work on a subtopic of our proposed research (at no cost to this proposal).

At the institution level, WHOI is committed to support and advance a diverse and inclusive environment and strives to be an equal opportunity employer. WHOI is one of the six Woods Hole science institutions, which established the Woods Hole Scientific Community Diversity Initiative and the Woods Hole Diversity Advisory Committee (DAC) to make recommendations as to how the institutions can make Woods Hole a more diverse, more inclusive community (https://www.woodsholediversity.org/). One of the products from the Initiative is the recently released *Diversity and Inclusion Report and Recommendations on Behalf of the Woods Hole Diversity Initiative* by Dr. R. Livingston (Harvard), an independent researcher commissioned by the DAC. WHOI has been actively implementing the recommendations from the report, for example in hiring (e.g. https://careers.whoi.edu/opportunities/diversity-inclusion/). Latest efforts include the new Diversity, Equity, and Inclusion Committee established in each department with an initial charge to proactively conduct a "talent search" for scientists from underrepresented groups in the geosciences. WHOI also has multiple employee-led committees whose goals are to increase awareness and engagement in various efforts related to diversity and inclusion, e.g. the WHOI Committee for Diversity and Inclusion and WHOI Workplace Climate Committee.

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON, VA 22203-1995

IN REPLY REFER TO

Agreement Date: December 31, 2019

NEGOTIATION AGREEMENT

INSTITUTION: **WOODS HOLE OCEANOGRAPHIC INSTITUTION (WHOI)**
WOODS HOLE, MASSACHUSETTS 02543

The Indirect Cost and Fringe Benefits rates contained herein are for use on grants, contracts, and other agreements issued or awarded to Woods Hole Oceanographic Institution by all Federal Agencies of the United States of America, in accordance with the provisions and cost principles mandated by 2 CFR Part 200. These rates shall be used for forward pricing and billing purposes for Woods Hole Oceanographic Institute Fiscal Year 2020. This rate agreement supersedes all previous rate agreements/determinations for Fiscal Year 2020.

Section I: RATES - TYPE: PROVISIONAL (PROV)

TYPE	FROM	TO	RATE	BASE	APPLICABLE TO	LOCATION
Indirect Rates:						
PROV	01/01/20	12/31/20	61.50%	(a)	Research[1]	ALL
PROV	01/01/20	12/31/20	36.13%	(a)	Marine Operations[2]	ALL
Fringe Benefit Rates:						
PROV	01/01/20	12/31/20	44.86%	(b)	Fringe (Reg)	ALL
PROV	01/01/20	12/31/20	39.85%	(c)	Fringe (Reg OT)	ALL
PROV	01/01/20	12/31/20	9.02%	(d)	Fringe (Casual)	ALL
PROV	01/01/20	12/31/20	6.94%	(e)	Fringe (Casual OT)	ALL
PROV	01/01/20	12/31/20	4.25%	(f)	Cruise Leave	ALL
PROV	01/01/20	12/31/20	17.71%	(g)	Paid Absences	ALL

[1]Research: Contracts and awards (projects) that include all sponsored and internally sponsored research activities carried out by the Institution other than those defined as Marine Operations.

[2]Marine Operations: Contracts and awards (projects) that deploy marine related facilities (example: docks), vessels, equipment and department administration solely supporting the Marine Operations Facilities and Operations group that directly or indirectly benefit or provide support to the University Oceanographic Laboratory System (UNOLS).

DISTRIBUTION BASES

(a) Modified Total Direct Costs (MTDC) means all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel, and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). MTDC excludes equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs, the portion of each subaward in excess of $25,000, ship and submersible use, ships fuel, vessel charges, and maintenance and stabilization agreements for ship overhauls.

(b) Total assignable salaries of regular employees (direct and indirect) including paid absences, excluding Graduate Research Assistants and overtime salaries and allocated paid leave benefits.

(c) Total assignable overtime salaries of regular employees.

(d) Total assignable salaries of casual employees (direct and indirect) excluding Graduate Research Assistants and overtime salaries.

(e) Total assignable overtime salaries of casual employees.

(f) Total assignable cruise leave salaries of regular employees.

(g) Total assignable salaries of regular employees (direct and indirect) excluding Graduate Research Assistants and overtime salaries.

SECTION II - GENERAL TERMS AND CONDITIONS

A. **LIMITATIONS:** Use of the rates set forth under Section I is subject to any statutory or administrative limitations and is applicable to a given grant, contract, or other agreement only to the extent that funds are available. Acceptance of the rates agreed to herein is predicated upon the following conditions: (1) that no costs other than those incurred by the recipient/contractor were included in this indirect cost pool as finally accepted and that such costs are legal obligations of the recipient/contractor and allowable under governing cost principles; (2) that the same costs that have been treated as indirect costs are not claimed as direct costs; (3) that similar types of costs have been accorded consistent accounting treatment; and (4) that the information provided by the recipient/contractor which was used as a basis for acceptance of the rates agreed to herein, and expressly relied upon by the Government in negotiating and accepting the said rates is not subsequently found to be materially incomplete or inaccurate.

B. **ACCOUNTING CHANGES**: The rates contained in Section I of this agreement are based on the accounting system in effect at the time the agreement was negotiated. Changes to the method(s) of accounting for costs, which affect the amount of reimbursement resulting from the use of these rates require the prior approval of the authorized representative of the cognizant negotiation agency. Such changes include but are not limited to changes in the charging of a particular type of cost from indirect to direct. Failure to obtain such approval may result in subsequent cost disallowances.

C. **PROVISIONAL RATES:** The provisional rates contained in this agreement are subject to unilateral amendment by the Government or bilateral amendment by the contracting parties at any time.

D. **USE BY OTHER FEDERAL AGENCIES**: The rates set forth in Section I are negotiated in accordance with and under the authority set forth in 2 CFR Part 200. Accordingly, such rates shall be applied to the extent provided in such regulations to grants, contracts, and other agreements to which 2 CFR Part 200 applies, subject to any limitations in part A of this section. Copies of this document may be provided by either party to other federal agencies to provide such agencies with documentary notice of this agreement and its terms and conditions.

E. **SPECIAL REMARKS**: The Government's agreement with the rates set forth in Section I is not an acceptance of WHOI accounting practices or methodologies. Any reliance by the Government on cost data or methodologies submitted by WHOI is on a non-precedence-setting basis and does not imply Government acceptance.

Accepted:

FOR WOODS HOLE OCEANOGRAPHIC INSTITUTION:	FOR THE U.S. GOVERNMENT:
	TINGLE.BETTY.JOHNSON.1204289359 Digitally signed by TINGLE.BETTY.JOHNSON.1204289359 Date: 2019.12.31 11:49:33 -05'00'
Jeffrey Fernandez Vice President for Finance and Administration and CFO	Betty J. Tingle Contracting Officer
12/31/19 Date	Date

For information concerning this agreement contact:
Betty Tingle, Contract Specialist
Office of Naval Research
Phone: (703) 696-7422
E-mail: betty.tingle@navy.mil

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON, VA 22203-1995

IN REPLY REFER TO:

BD0242
February 12, 2019

Via email

Mr. Jeffrey Fernandez
Vice President for Finance & Administration
and Chief Financial Officer
Woods Hole Oceanographic Institution
569 Woods Hole Road
Woods Hole, MA 02543

RE: Woods Hole Oceanographic Institution (WHOI) – FY 2020 through 2023 Forward Pricing

Dear Mr. Fernandez:

Enclosed are the government-approved provisional forward pricing rates for FYs 2020 through 2023, which are based on your submission of December 7, 2017, and incorporates the results of DCAA's analyses. The fringe benefit and indirect rates are shown in Enclosure 1. These rates are to be used for forward pricing purposes (FY 2020 – 2023) on all grants, contracts, and/or other agreements issued or awarded to WHOI by all Federal agencies, and in all proposals submitted by WHOI, subject to the following conditions:

- These rates are subject to unilateral amendment by the Government or bilateral amendment by the contracting parties at anytime. The government's agreement to these rates does not represent an agreement or approval of WHOI's accounting systems and allocation methods.
- Use of the rates is subject to any statutory or administrative limitations and is applicable to a given grant, contract, or other agreement only to the extent that funds are available and consistent with any and all limitations of cost clauses or provisions, if any, contained therein.
- Final rates will be submitted within six months of the year's end for each year.

If you have any questions regarding this matter, please contact me at (703) 696-7742, or email at betty.tingle@navy.mil.

Sincerely,

TINGLE.BETTY.JOHNSON.1204289359

Digitally signed by TINGLE.BETTY.JOHNSON.1204289359
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=TINGLE.BETTY.JOHNSON.1204289359
Date: 2019.02.12 15:21:59 -05'00'

Betty J. Tingle
Contracting Officer

Enclosure 1
WHOI
Forward Pricing Rates for FYs 2020 through 2023
INDIRECT RATES

	2020	2021	2022	2023	
Indirect Rates					
Research[1]	65.00%	65.00%	65.00%	65.00%	(a)
Marine Operations[2]	41.50%	41.50%	41.50%	41.50%	(a)
Employee Benefits					
Regular	47.44%	50.63%	52.78%	53.72%	(b)
Regular Overtime	31.62%	34.47%	36.26%	36.85%	(c)
Casual	8.38%	8.55%	8.72%	8.78%	(d)
Casual Overtime	6.53%	6.72%	6.92%	7.01%	(e)
Cruise Leave	10.47%	10.99%	11.54%	11.92%	(f)
Paid Absences	18.75%	18.89%	19.05%	19.18%	(g)

[1]Research: Contracts and awards (projects) that include all sponsored and internally sponsored research activities carried out by the Institution other than those defined as Marine Operations.

[2]Marine Operations: Contracts and awards (projects) that deploy marine related facilities (example: docks), vessels, equipment and department administration solely supporting the Marine Operations Facilities and Operations group that directly or indirectly benefit or provide support to the University Oceanographic Laboratory System (UNOLS).

DISTRIBUTION BASES

(a) Modified Total Direct Costs (MTDC) means all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel, and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). MTDC excludes equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs, the portion of each subaward in excess of $25,000, ship and submersible use, ships fuel, vessel charges, and maintenance and stabilization agreements for ship overhauls.

(b) Total assignable salaries of regular employees (direct and indirect) including paid absences, excluding Graduate Research Assistants and overtime salaries and allocated paid leave benefits.

(c) Total assignable overtime salaries of regular employees.

(d) Total assignable salaries of casual employees (direct and indirect) excluding Graduate Research Assistants and overtime salaries.

(e) Total assignable overtime salaries of casual employees.

(f) Total assignable cruise leave salaries of regular employees.

(g) Total assignable salaries of regular employees (direct and indirect) excluding Graduate Research Assistants and overtime salaries.

OMB Number: 4040-0004
Expiration Date: 12/31/2022

Application for Federal Assistance SF-424

* 1. Type of Submission:	* 2. Type of Application:	* If Revision, select appropriate letter(s):
☐ Preapplication	☒ New	
☒ Application	☐ Continuation	* Other (Specify):
☐ Changed/Corrected Application	☐ Revision	

* 3. Date Received: 11/24/2020	4. Applicant Identifier: PO27270.01_Kwon
5a. Federal Entity Identifier: NOAA-OAR-CPO-2021-2006389	5b. Federal Award Identifier:

State Use Only:

6. Date Received by State:	7. State Application Identifier:

8. APPLICANT INFORMATION:

* a. Legal Name: Woods Hole Oceanographic Institution

* b. Employer/Taxpayer Identification Number (EIN/TIN): 042105850	* c. Organizational DUNS: 0017666820000

d. Address:

* Street1:	266 Woods Hole Road
Street2:	Fenno MS #39
* City:	Woods Hole
County/Parish:	Barnstable
* State:	MA: Massachusetts
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	02543-1535

e. Organizational Unit:

Department Name: Physical Oceanography	Division Name:

f. Name and contact information of person to be contacted on matters involving this application:

Prefix:	Ms.	* First Name:	Theresa
Middle Name:			
* Last Name:	Gordon		
Suffix:			

Title: Pre-Award Manager, Grant & Contract Services

Organizational Affiliation:
Grant & Contract Services

* Telephone Number: 508-289-2619	Fax Number: 508-457-2189

* Email: awards-noaa@whoi.edu

Application for Federal Assistance SF-424

*** 9. Type of Applicant 1: Select Applicant Type:**

M: Nonprofit with 501C3 IRS Status (Other than Institution of Higher Education)

Type of Applicant 2: Select Applicant Type:

Type of Applicant 3: Select Applicant Type:

* Other (specify):

*** 10. Name of Federal Agency:**

Department of Commerce

11. Catalog of Federal Domestic Assistance Number:

11.431

CFDA Title:

Climate and Atmospheric Research

*** 12. Funding Opportunity Number:**

NOAA-OAR-CPO-2021-2006389

* Title:

Climate Program Office FY2021

13. Competition Identification Number:

2864458

Title:

MAPP: Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications

14. Areas Affected by Project (Cities, Counties, States, etc.):

Add Attachment | Delete Attachment | View Attachment

*** 15. Descriptive Title of Applicant's Project:**

Process-Oriented Diagnostics for the Western Boundary Current Variability and Midlatitude Air-Sea Interaction

Attach supporting documents as specified in agency instructions.

Add Attachments | Delete Attachments | View Attachments

Application for Federal Assistance SF-424

16. Congressional Districts Of:

* a. Applicant: MA-09
* b. Program/Project: MA-09

Attach an additional list of Program/Project Congressional Districts if needed.

[ ] Add Attachment | Delete Attachment | View Attachment

17. Proposed Project:

* a. Start Date: 09/01/2021
* b. End Date: 08/31/2024

18. Estimated Funding ($):

* a. Federal	539,498.00
* b. Applicant	0.00
* c. State	0.00
* d. Local	0.00
* e. Other	0.00
* f. Program Income	0.00
* g. TOTAL	539,498.00

*** 19. Is Application Subject to Review By State Under Executive Order 12372 Process?**

[ ] a. This application was made available to the State under the Executive Order 12372 Process for review on ______ .

[ ] b. Program is subject to E.O. 12372 but has not been selected by the State for review.

[X] c. Program is not covered by E.O. 12372.

*** 20. Is the Applicant Delinquent On Any Federal Debt? (If "Yes," provide explanation in attachment.)**

[ ] Yes [X] No

If "Yes", provide explanation and attach

Add Attachment | Delete Attachment | View Attachment

21. *By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)**

[X] ** I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency specific instructions.

Authorized Representative:

Prefix: Ms.
* First Name: Theresa
Middle Name:
* Last Name: Gordon
Suffix:

* Title: Pre-Award Manager, Grant & Contract Services

* Telephone Number: 508-289-2619
Fax Number: 508-457-2189

* Email: awards-noaa@whoi.edu

* Signature of Authorized Representative: Theresa Gordon
* Date Signed: 11/24/2020

BUDGET INFORMATION - Non-Construction Programs

OMB Number: 4040-0006
Expiration Date: 02/28/2022

SECTION A - BUDGET SUMMARY

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. Climate Program Office FY2021 NOAA-OAR-CPO-2021-2006389	11.431	$	$	$ 539,498.00	$	$ 539,498.00
2.						
3.						
4.						
5. Totals		$	$	$ 539,498.00	$	$ 539,498.00

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SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1)	(2)	(3)	(4)	(5)
	Climate Program Office FY2021 NOAA-OAR-CPO-2021-2006389	N/A	N/A		
a. Personnel	$ 59,742.00	$ 62,069.00	$ 54,591.00	$	$ 176,402.00
b. Fringe Benefits	8,937.00	9,501.00	9,894.00		28,332.00
c. Travel	14,199.00	14,481.00	20,170.00		48,850.00
d. Equipment					
e. Supplies	4,700.00	500.00	500.00		5,700.00
f. Contractual					
g. Construction					
h. Other	34,122.00	35,724.00	37,605.00		107,451.00
i. Total Direct Charges (sum of 6a-6h)	121,700.00	122,275.00	122,760.00		$ 366,735.00
j. Indirect Charges	58,292.00	57,624.00	56,847.00		$ 172,763.00
k. TOTALS (sum of 6i and 6j)	$ 179,992.00	$ 179,899.00	$ 179,607.00	$	$ 539,498.00
7. Program Income	$	$	$	$	$

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SECTION C - NON-FEDERAL RESOURCES					
	(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e)TOTALS
8.	Climate Program Office FY2021 NOAA-OAR-CPO-2021-2006389	$	$	$	$
9.					
10.					
11.					
12. TOTAL (sum of lines 8-11)		$	$	$	$

SECTION D - FORECASTED CASH NEEDS					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 179,992.00	$ 44,998.00	$ 44,998.00	$ 44,998.00	$ 44,998.00
14. Non-Federal	$ 0.00	0.00	0.00	0.00	0.00
15. TOTAL (sum of lines 13 and 14)	$ 179,992.00	$ 44,998.00	$ 44,998.00	$ 44,998.00	$ 44,998.00

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT					
(a) Grant Program		FUTURE FUNDING PERIODS (YEARS)			
		(b)First	(c) Second	(d) Third	(e) Fourth
16.	Climate Program Office FY2021 NOAA-OAR-CPO-2021-2006389	$ 179,899.00	$ 179,607.00	$	$
17.					
18.					
19.					
20. TOTAL (sum of lines 16 - 19)		$ 179,899.00	$ 179,607.00	$	$

SECTION F - OTHER BUDGET INFORMATION

21. Direct Charges: $366,735

22. Indirect Charges: $172,763

23. Remarks: Indirect Charges: Modified Total Direct Cost 65.00% of base total of $89,678 for Y1; $88,651 for Y2; $87,455 for Y3. Representative: Ms. Michel Marshall, michele.marshall@navy.mil, 617-753-4404.

ASSURANCES - NON-CONSTRUCTION PROGRAMS

Public reporting burden for this collection of information is estimated to average 15 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Office of Management and Budget, Paperwork Reduction Project (0348-0040), Washington, DC 20503.

PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE OFFICE OF MANAGEMENT AND BUDGET. SEND IT TO THE ADDRESS PROVIDED BY THE SPONSORING AGENCY.

NOTE: Certain of these assurances may not be applicable to your project or program. If you have questions, please contact the awarding agency. Further, certain Federal awarding agencies may require applicants to certify to additional assurances. If such is the case, you will be notified.

As the duly authorized representative of the applicant, I certify that the applicant:

1. Has the legal authority to apply for Federal assistance and the institutional, managerial and financial capability (including funds sufficient to pay the non-Federal share of project cost) to ensure proper planning, management and completion of the project described in this application.

2. Will give the awarding agency, the Comptroller General of the United States and, if appropriate, the State, through any authorized representative, access to and the right to examine all records, books, papers, or documents related to the award; and will establish a proper accounting system in accordance with generally accepted accounting standards or agency directives.

3. Will establish safeguards to prohibit employees from using their positions for a purpose that constitutes or presents the appearance of personal or organizational conflict of interest, or personal gain.

4. Will initiate and complete the work within the applicable time frame after receipt of approval of the awarding agency.

5. Will comply with the Intergovernmental Personnel Act of 1970 (42 U.S.C. §§4728-4763) relating to prescribed standards for merit systems for programs funded under one of the 19 statutes or regulations specified in Appendix A of OPM's Standards for a Merit System of Personnel Administration (5 C.F.R. 900, Subpart F).

6. Will comply with all Federal statutes relating to nondiscrimination. These include but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352) which prohibits discrimination on the basis of race, color or national origin; (b) Title IX of the Education Amendments of 1972, as amended (20 U.S.C.§§1681-1683, and 1685-1686), which prohibits discrimination on the basis of sex; (c) Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. §794), which prohibits discrimination on the basis of handicaps; (d) the Age Discrimination Act of 1975, as amended (42 U.S.C. §§6101-6107), which prohibits discrimination on the basis of age; (e) the Drug Abuse Office and Treatment Act of 1972 (P.L. 92-255), as amended, relating to nondiscrimination on the basis of drug abuse; (f) the Comprehensive Alcohol Abuse and Alcoholism Prevention, Treatment and Rehabilitation Act of 1970 (P.L. 91-616), as amended, relating to nondiscrimination on the basis of alcohol abuse or alcoholism; (g) §§523 and 527 of the Public Health Service Act of 1912 (42 U.S.C. §§290 dd-3 and 290 ee- 3), as amended, relating to confidentiality of alcohol and drug abuse patient records; (h) Title VIII of the Civil Rights Act of 1968 (42 U.S.C. §§3601 et seq.), as amended, relating to nondiscrimination in the sale, rental or financing of housing; (i) any other nondiscrimination provisions in the specific statute(s) under which application for Federal assistance is being made; and, (j) the requirements of any other nondiscrimination statute(s) which may apply to the application.

7. Will comply, or has already complied, with the requirements of Titles II and III of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (P.L. 91-646) which provide for fair and equitable treatment of persons displaced or whose property is acquired as a result of Federal or federally-assisted programs. These requirements apply to all interests in real property acquired for project purposes regardless of Federal participation in purchases.

8. Will comply, as applicable, with provisions of the Hatch Act (5 U.S.C. §§1501-1508 and 7324-7328) which limit the political activities of employees whose principal employment activities are funded in whole or in part with Federal funds.

9. Will comply, as applicable, with the provisions of the Davis-Bacon Act (40 U.S.C. §§276a to 276a-7), the Copeland Act (40 U.S.C. §276c and 18 U.S.C. §874), and the Contract Work Hours and Safety Standards Act (40 U.S.C. §§327-333), regarding labor standards for federally-assisted construction subagreements.

10. Will comply, if applicable, with flood insurance purchase requirements of Section 102(a) of the Flood Disaster Protection Act of 1973 (P.L. 93-234) which requires recipients in a special flood hazard area to participate in the program and to purchase flood insurance if the total cost of insurable construction and acquisition is $10,000 or more.

11. Will comply with environmental standards which may be prescribed pursuant to the following: (a) institution of environmental quality control measures under the National Environmental Policy Act of 1969 (P.L. 91-190) and Executive Order (EO) 11514; (b) notification of violating facilities pursuant to EO 11738; (c) protection of wetlands pursuant to EO 11990; (d) evaluation of flood hazards in floodplains in accordance with EO 11988; (e) assurance of project consistency with the approved State management program developed under the Coastal Zone Management Act of 1972 (16 U.S.C. §§1451 et seq.); (f) conformity of Federal actions to State (Clean Air) Implementation Plans under Section 176(c) of the Clean Air Act of 1955, as amended (42 U.S.C. §§7401 et seq.); (g) protection of underground sources of drinking water under the Safe Drinking Water Act of 1974, as amended (P.L. 93-523); and, (h) protection of endangered species under the Endangered Species Act of 1973, as amended (P.L. 93-205).

12. Will comply with the Wild and Scenic Rivers Act of 1968 (16 U.S.C. §§1271 et seq.) related to protecting components or potential components of the national wild and scenic rivers system.

13. Will assist the awarding agency in assuring compliance with Section 106 of the National Historic Preservation Act of 1966, as amended (16 U.S.C. §470), EO 11593(identification and protection of historic properties), and the Archaeological and Historic Preservation Act of 1974 (16 U.S.C. §§469a-1 et seq.).

14. Will comply with P.L. 93-348 regarding the protection of human subjects involved in research, development, and related activities supported by this award of assistance.

15. Will comply with the Laboratory Animal Welfare Act of 1966 (P.L. 89-544, as amended, 7 U.S.C. §§2131 et seq.) pertaining to the care, handling, and treatment of warm blooded animals held for research, teaching, or other activities supported by this award of assistance.

16. Will comply with the Lead-Based Paint Poisoning Prevention Act (42 U.S.C. §§4801 et seq.) which prohibits the use of lead-based paint in construction or rehabilitation of residence structures.

17. Will cause to be performed the required financial and compliance audits in accordance with the Single Audit Act Amendments of 1996 and OMB Circular No. A-133, "Audits of States, Local Governments, and Non-Profit Organizations."

18. Will comply with all applicable requirements of all other Federal laws, executive orders, regulations, and policies governing this program.

19. Will comply with the requirements of Section 106(g) of the Trafficking Victims Protection Act (TVPA) of 2000, as amended (22 U.S.C. 7104) which prohibits grant award recipients or a sub-recipient from (1) Engaging in severe forms of trafficking in persons during the period of time that the award is in effect (2) Procuring a commercial sex act during the period of time that the award is in effect or (3) Using forced labor in the performance of the award or subawards under the award.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL	TITLE
Theresa Gordon	Pre-Award Manager, Grant & Contract Services
APPLICANT ORGANIZATION	DATE SUBMITTED
Woods Hole Oceanographic Institution	11/24/2020

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FORM **CD-511**
(REV 1-05)

U.S. DEPARTMENT OF COMMERCE

CERTIFICATION REGARDING LOBBYING

Applicants should also review the instructions for certification included in the regulations before completing this form. Signature on this form provides for compliance with certification requirements under 15 CFR Part 28, 'New Restrictions on Lobbying.' The certifications shall be treated as a material representation of fact upon which reliance will be placed when the Department of Commerce determines to award the covered transaction, grant, or cooperative agreement.

LOBBYING

As required by Section 1352, Title 31 of the U.S. Code, and implemented at 15 CFR Part 28, for persons entering into a grant, cooperative agreement or contract over $100,000 or a loan or loan guarantee over $150,000 as defined at 15 CFR Part 28, Sections 28.105 and 28.110, the applicant certifies that to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, 'Disclosure Form to Report Lobbying.' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure occurring on or before October 23, 1996, and of not less than $11,000 and not more than $110,000 for each such failure occurring after October 23, 1996.

Statement for Loan Guarantees and Loan Insurance

The undersigned states, to the best of his or her knowledge and belief, that:

In any funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this commitment providing for the United States to insure or guarantee a loan, the undersigned shall complete and submit Standard Form-LLL, 'Disclosure Form to Report Lobbying,' in accordance with its instructions.

Submission of this statement is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required statement shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure occurring on or before October 23, 1996, and of not less than $11,000 and not more than $110,000 for each such failure occurring after October 23, 1996.

As the duly authorized representative of the applicant, I hereby certify that the applicant will comply with the above applicable certification.

* NAME OF APPLICANT: Woods Hole Oceanographic Institution

* AWARD NUMBER:

* PROJECT NAME: Process-Oriented Diagnostics for the WBC ....

Prefix: Ms.

* First Name: Theresa

Middle Name:

* Last Name: Gordon

Suffix:

* Title: Pre-Award Manager, Grant & Contract Services

* SIGNATURE: Theresa Gordon

* DATE: 11/24/2020