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The attached proposal is being submitted to you for your consideration by a NOAA Cooperative Institute. Should you recommend funding for this proposal, we request that the funding be transferred through our current NOAA cooperative agreement, #NA19OAR4320073 or a TBD award number. The NOAA contact (described below) for this cooperative agreement should be contacted immediately if this proposal is accepted for funding.

Title of Proposal: Process-oriented evaluation of oceanic equatorial waves in the Indian and west Pacific Ocean forced by intraseasonal westerly wind events

Principal Investigator(s): Emily Riley Dellaripa

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FMC for BOPS:

1) Is there a former DOC employee working for the CI host institution who represented or will represent the host institution before DOC or another Federal agency regarding this proposal? No
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4) Is PGROGRAM INCOME anticipated being earned during performance of this project? No
5) Will a VIDEO be created for public viewing as part of this project? No
6) Will DOC/NOAA owned equipment be provided to any investigator for use outside of a Federal location for this project? No
7) Are any permits required to conduct this project? (If yes, please provide the name of the issuing agency and the permit number.) No

Title Page

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Funding Opportunity: NOAA-OAR-CPO-2021-2006389
Competition ID: Competition 4 (2864458): MAPP - Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications

Title: Process-oriented evaluation of oceanic equatorial waves in the Indian and west Pacific Ocean forced by intraseasonal westerly wind events (NOAA-OAR-CPO-2021-2006389; Competition #4 (2864458): MAPP - Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications)

Abstract

Equatorial shallow water ocean wave modes (OWMs), such as eastward-propagating Kelvin waves and westward-propagating equatorial Rossby (ER) waves, help regulate the depth of the thermocline, ocean heat content (OHC), ocean currents, sea surface height (SSH), and sea surface temperature (SST). Their modification of upper-ocean thermal characteristics influences the evolution of important coupled air-sea phenomena including the Madden-Julian oscillation (MJO), the Indian Ocean dipole (IOD), and the El Niño Southern Oscillation (ENSO). In the tropical Indian and Pacific Oceans, OWMs are frequently forced by strong, but short lived intraseasonal westerly wind events (WWEs; occurring every 30-70 days and lasting 3-21 days) acting on the ocean surface. The strength and meridional structure of the WWE forcing and the ocean mean state (including the depth of the thermocline and the stability of the upper ocean) help determine the amplitude and propagation characteristics of the OWMs.

For the first time, diagnosis of intraseasonal WWE-forced OWMs in CMIP models is possible with daily output of the depth of the thermocline in several CMIP6-member models, which was not available in previous CMIP archives. Our main goal is to diagnose the fidelity of intraseasonal WWE-forced OWMs in CMIP6 and other model databases relative to observations and link OWM biases to biases in the WWE forcing, or to biases in the ocean mean state. We will also examine changes to WWEs, tropical OWMs, and the ocean mean state under climate change. Our work plan is to:

1. Diagnose the fidelity of tropical OWM spectra and spatial variance patterns in CMIP6 models and other climate model databases relative to observations.
2. Characterize the frequency, intensity, and meridional structure of intraseasonal WWEs in models and observations.
3. Assess the realism of intraseasonal WWE-forced OWMs as a function of WWE intensity and meridional structure in models relative to observations.
4. Evaluate the stability of the ocean mean state in models relative to observations and its relationship to OWM amplitude and phase speed.
5. Quantify changes in OWM climatology, WWE statistics, and ocean stability under climate change and relate OWM changes to changes in WWE characteristics and ocean stability.

This work will result in a tropical OWM process-oriented diagnostic (POD) with several diagnostic components that will be added to the Model Diagnostic Task Force software package. The OWM POD fills “clearly-identified gaps in the existing MDTF software package” including “open- and coastal ocean systems'' and advances the evaluation of coupled processes in climate models. Our objectives are highly relevant to one of the main goals of the MAPP Process-Oriented Diagnostics call to “better understand and benchmark process-level deficiencies that result in model performance biases for simulated Earth system and climate phenomena.” More broadly, this work advances NOAA’s long-term goal to “advance [the] understanding of the Earth’s climate system.” Ultimately, understanding the processes that lead to OWM biases is needed to improve OWM representation in models and obtain better predictions of climate modes influenced by OWMs, such as the MJO, the IOD, and ENSO.

Results from Prior Research

1) MAPP Projects: ***Development of a Framework for Process-Oriented Diagnosis of Global Models.*** *08/01/15 - 07/31/18 (NA15OAR4310099). Eric Maloney (lead PI), Yi Ming (co-PI), Andrew Gettelman (co-PI), J. David Neelin (co-PI).*

An Open Framework for Process-Oriented Diagnostics of Global Models. *08/18-07/21 (NA18OAR4310268) David Neelin (lead PI), Eric Maloney (co-PI), Yi Ming (co-PI), Andrew Gettelman (co-PI), Peter Gleckler (co-PI)*

Skillfully Predicting Atmospheric Rivers and Their Impacts in Weeks 2-5 Based on the State of the MJO and QBO. *08/18-07/20 (NA18OAR4310296) Elizabeth Barnes (PI), Eric Maloney (co-PI).*

In the first two projects, Maloney provided leadership on the development of the NOAA MAPP process-oriented diagnostics framework. Early developments of the framework and scientific motivation are detailed in a BAMS article (*Maloney et al. 2019b*). Maloney is currently co-lead of the NOAA MAPP MDTF, and was the lead from 2015-2018. An AMS special collection that describes the scientific development of diagnostics in the package was developed by the MDTF (https://journals. ametsoc.org/collection/114/Process-Oriented-Model-Diagnostics). Diagnostics we helped develop include tropical convective transition statistics (Kuo et al. 2020), diagnosis of MJO teleconnections (Tseng et al. 2020; Wang et al. 2020a,b, Toms et al. 2020a), and development of weak temperature gradient diagnostics to understand MJO change under global warming (Bui and Maloney 2019a,b). Over 40 publications resulted from these projects.

Assessing oceanic predictability sources for MJO propagation. *7/2015-12/2020 (NA16OAR4310094) Charlotte DeMott (lead PI) and Nicholas Klingaman (Co-PI).* Assessing influences of 1) ocean model bias and drift and 2) ocean initial state and evolution on MJO prediction skill in S2S Prediction Project models. Two papers (one accepted, one in final preparation) supported by this work. Creation of the S2S-ocean mailing list to facilitate ocean-relevant collaboration among researchers, forecasters, and model developers.

Understanding Bulk Surface Flux Algorithm Contributions to Climate Projection Uncertainties. *9/2020-8/2023 (NA20OAR4310389) Charlotte DeMott (lead PI), Carol Anne Clayson (Co-PI).* Assessing the role of bulk surface flux algorithm on climate projections through model diagnostics and sensitivity experiments.

2) NOAA CVP Project: ***Understanding the role of diurnal cycle and the mean state on the propagation of the instraseasonal variability over the Maritime Continent.*** *09/18-08/21 (NA18OAR4310299) Daehyun Kim (PI), Eric Maloney (co-PI).* This project is using a hierarchy of models and observations to understand MJO propagation through the Maritime Continent (MC) and its interactions with the diurnal cycle during both boreal summer and winter. At least 17 publications have resulted from this work, including regional observational and modeling work to understand boreal summer interactions between the northward-propagating BSISO and the diurnal cycle near the Philippines (Riley Dellaripa et al 2020a; Natoli et al. 2019), fundamental work to understand the dynamics of the MJO (Jiang et al. 2020a,b), and an analysis of convective morphology in the MC region and how it affects MJO behavior (Toms et al. 2020b).

Improved Understanding of air-sea interaction processes and biases in the Tropical Western Pacific using observation sensitivity experiments and global forecast models*. 9/2018-8/2020 (NA18OAR4310405) Aneesh Subramanian (lead PI), Kris Karnauskas (Co-PI), Matt Mazloff (Co-PI), Charlotte DeMott (Co-PI).* Analysis of climatological upper ocean stratification in the

western Pacific Ocean in CESM2; observing system sensitivity experiments focused on Warm Pool eastward extension event forecasts. One paper under revision; one in preparation.
Understanding the role of mesoscale organization in air-sea interactions. *9/2020-8/2023 (NA20OAR4310374) Juliana Dias (lead PI), Robert Pincus (Co-PI), Charlotte DeMott (Co-PI).* Large eddy simulations to diagnose the effects of ocean-atmosphere coupled feedbacks on the organization of mesoscale shallow convection.

3) NOAA OWAQ Project: *MJO and QBO Contributions to U.S. Precipitation Skills at S2S Leads.* 09/19-08/22 (*NA19OAR4590151) Elizabeth Barnes (PI), Eric Maloney (co-PI).* The goals of the project are to understand the role of the MJO and QBO in driving skillful precipitation forecasts, determine how well the UFS predicts precipitation on S2S timescales, and relate possible low skill in UFS to biases in simulating the MJO and QBO. Early work has included development of an all-season S2S prediction model for U.S. precipitation using the MJO and QBO as predictors (Nardi et al. 2020), and an analysis using reanalysis data showing that MJO wind variability has been decreasing in amplitude relative to precipitation variability over the last century, with consequences for MJO teleconnections and air-sea interactions (Hsiao et al. 2020).

4) ONR project: *Coupled ocean-atmosphere regional model simulations of diurnal Maritime Continent and its synergy with MJO propagation.* *08/16-10/21 (N00014-16-1-3087) Eric Maloney (PI), Emily Riley Dellaripa (Co-I)***.** This project is looking at multiscale air-sea and land-air interactions to the MJO/BSISO in the MC. Riley Dellaripa et al (2020a) examined the effect of topography on the diurnal cycle (DC) of convection over the Philippines during the BSISO. Eight other publications came from this work. The regional model, RAMS, has been coupled to a 1-dimensional ocean mixed layer model to study air-sea feedbacks to the MC DC and the MJO.

5) NASA ROSES project: *Evaluation of Climate Model Precipitation Processes Using a TRMM/GPM Radar Simulator.* *03/17-3/20 (NNX17AH45G) Courtney Schumacher (PI), Emily Riley Dellaripa (Co-I).* This project improved the evaluation of GCM precipitation relative to observations. The radar simulator Quickbeam in the Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package (COSP) was adapted to the GPM precipitation radar and several improvements to the COSP sub-grid algorithm were made (Riley Dellaripa et al. 2020b). We plan to put our modifications onto the COSP GitHub webpage.

6) DOE RGMA: *Collaborative Research: Understanding air-sea feedbacks to the MJO through process evaluation of observations and E3SM experiments.* *9/2019-8/2022 (DE-SC0020092) Charlotte DeMott (lead PI), Nicholas Klingaman (Co-PI).* Applying air-sea interaction diagnostics to E3SM coupled simulations; E3SM upper ocean heat budgets and lower atmosphere moisture budgets; model simulations to assess effects of ocean feedbacks to simulated rainfall variability. Contributing to BAMS article on rainfall exploratory metrics.

7) NSF Physical Oceanography: *Formation of rain layers in the Warm Pool and their feedbacks to atmospheric convection in an idealized modeling framework.* *10/2019-9/2022 (OCE1924659) Charlotte DeMott (lead PI), Peter Jan van Leeuwen (Co-PI).* Investigating the frequency and persistence of shallow oceanic rain layers and their potential for regulating initiation of tropical convection using a regional atmospheric model coupled to many columns of a 1-dimensional ocean mixed layer model.

Project Narrative

1. Identification of the Problem

1.1 Oceanic equatorial waves and their sources

Equatorial shallow water wave modes in the atmosphere, such as eastward-propagating Kelvin waves and westward-propagating equatorial Rossby (ER) waves, play important roles in the vertical and poleward redistribution of heat, moisture, and momentum (Matsuno 1966, Kiladis et al. 2009). The same shallow water wave solutions are also observed in the ocean (e.g., Delcroix et al. 1991; Wakata 2007; Farrar 2008) where they play similar roles in the vertical and horizontal redistribution of heat, fresh water, momentum, and biogeochemical constituents.

In the Indian and Pacific Oceans, oceanic Kelvin and ER waves help regulate the depth of the thermocline, ocean heat content (OHC), ocean currents, sea surface height (SSH), and sea surface temperature (SST). Through their modification of upper-ocean thermal characteristics they influence the evolution of important coupled atmosphere-ocean phenomena including tropical cyclones (Boucharel et al. 2016), intraseasonal (30-90 day) Madden-Julian oscillation (MJO; Madden and Jullian 1972) events (Webber et al. 2010; Rydbeck and Jensen 2017; West et al. 2020), the Indian Ocean dipole (IOD; e.g., Rao and Yamagata 2004; Han et al 2006; Yuan and Liu 2009), and the El Niño Southern Oscillation (ENSO; e.g., Kirtman et al. 1997, Puy et al. 2019).

In the tropics, shallow water ocean wave modes (OWMs) are often excited by equatorial low-level wind stress anomalies (e.g., Battisti 1988; Delcroix et al. 1991; Kessler et al. 1995; Webber et al. 2012). Strong, but short-lived (3-21 day) anomalous westerly wind events (WWEs; e.g., Hartten 1996; Harrison and Vecchi 1997) are particularly capable of producing OWMs (e.g., Seiki and Takayabu 2007). WWEs can result from a variety of sources including the Indian monsoon (e.g., Seik and Takayabu 2007), extratropical intrusions (e.g., Kiladis et al. 1994), single or twin cyclones (e.g., Keen 1982; Harrison and Vecchi 1997), and the MJO. Puy et al (2016) analyzed the zonal surface stress over the western Pacific Ocean and found that 41% of all WWEs were associated with the MJO. MJO-linked WWEs had significantly larger amplitudes, zonal extents, durations, and ocean impacts than non-MJO-linked WWEs.

Intraseasonal WWEs (occurring every 30-70 days and lasting 3-21 days) acting on the equatorial ocean surface can force oceanic intraseasonal downwelling Kelvin waves. These Kelvin waves have maximum amplitude on the equator, a characteristic period of about 70 days, and a phase speed proportional to the depth of the fluid layer through which they propagate, i.e. $c \sim h^{1/2}$ where h is the thermocline depth, yielding a phase speed of about 2.5 ms^{-1} (e.g., Kessler et al. 1995; Shinoda et al. 2008). Phase speed is also affected by background currents and stratification near the thermocline (e.g., Benestad et al. 2002; Roundy and Kiladis 2006). The Kelvin phase speed yields ocean basin transit times of about 35 days and 90 days for the Indian and Pacific Oceans, respectively.

Intraseasonal WWEs can also excite equatorially symmetric upwelling ER waves with maximum amplitude off the equator. Their phase speed is proportional to h and to the inverse of the square of planetary vorticity, i.e., $c \sim hf^{-2}$, (e.g., Meyers 1979). This implies a phase speed dependence on the meridional scale of the ER wave, which is linked to the latitude of maximum curl of the surface stress, and hence the meridional extent of the zonal wind stress forcing (e.g., Kirtman 1997; Capotondi et al. 2006; Capotondi 2008). As a result, ER wave phase speeds range from ~1 ms^{-1} for waves with maximum amplitudes at 5° latitude to ~0.1 ms^{-1} at 13° latitude. The meridional structure of WWEs in climate models, and hence the preferred latitude of oceanic ER waves, can be sensitive to the parameterized physics in the atmosphere, particularly the treatment of convective momentum transport (CMT; Neale et al. 2008; Deser et al. 2012).

Kelvin and ER waves can also be initiated through boundary reflection as shown in Fig. 1 with observed SSH analysis from our collaborator Adam Rydbeck (i.e., Rydbeck and Jensen 2017). The contours are lag composites of SSH anomalies and SSTs over the lifecycle of ER waves. Downwelling coastal Kelvin waves centered along Sumatra at day -60 reflect off the land masses at day -40 as downwelling Rossby waves at ±5° latitude that reach the west-central Indian Ocean by day zero. Upwelling Kelvin waves may be initiated by the reflection of westward propagating upwelling ER waves at the western boundaries of the oceans (e.g., Battisti 1988, Kirtman 1997). Implications of western boundary wave reflection processes for interannual modes of variability, such as ENSO, are discussed in Section 1.2.

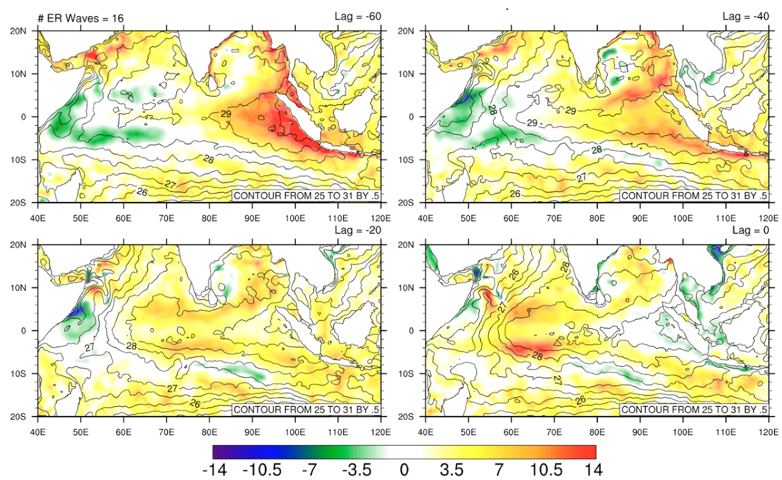


Figure 1 - Fig. 3 of Rydbeck and Jensen (2017). Composites of SSH anomalies (shading; cm) and SST (contours; °C) at indicated lag days. Lag day 0 is the time ER waves were identified in filtered SSH anomalies averaged between 6°S-6°N, 59°-69°E.

1.2 Importance of Intraseasonally-forced OWMs

OWMs are an important link for coupled atmosphere-ocean processes (e.g., DeMott et al. 2015). They alter SST and surface fluxes, which feed back to atmospheric convection (Gribble-Verhagen and Roundy 2010; Maloney and Sobel 2004; Riley Dellaripa and Maloney 2015; DeMott et al. 2016). Increased SSTs and surface fluxes in the western Indian Ocean associated with downwelling ER waves can destabilize the lower atmosphere and trigger an MJO event (Webber et al. 2010, 2012; Rydbeck and Jensen 2017; West 2020). These downwelling ER waves also increase the OHC of the central and western Indian Ocean (Rydbeck et al. 2019) and help sustain warm SSTs in the western Pacific against the cooling effects of intraseasonal convection (Rydbeck et al. 2017).

Indian Ocean Kelvin waves influence coastal mixing and sea level in the Maritime Continent and Bay of Bengal. When eastward-propagating downwelling Kelvin waves reach Sumatra, a portion of their wave energy propagates northward and southward as a coastal Kelvin wave (Fig. 1 lag-day -60; e.g., Vilard et al 2009). The northward component can propagate into the Bay of Bengal and the west coast of India as coastally trapped Kelvin waves and impact local coastal currents and sea levels. The southward component follows the Java coast where it interacts with the Indonesian Throughflow (e.g., Drushka et al. 2010; Shinoda et al. 2016; Pujana and McPhaden 2020).

Indian Ocean Kelvin and ER waves can influence the IOD (Saji et al. 1999), which affects regional weather, such as east African floods (Black et al. 2003) and east Asian and Australian drought (Cai et al. 2009). The IOD is an interannual variation in the east-west equatorial SST dipole structure. The positive IOD has warm anomalies in the western part of the basin and cold anomalies in the eastern part (Saji et al. 1999); the pattern is reversed for the negative IOD. Downwelling Kelvin waves forced by intraseasonal WWEs may delay the onset or initiate the termination of positive IOD events by warming the eastern Indian Ocean (Rao and Yamagata 2004; Han et al 2006; Yuan and Liu 2009).

In the Pacific Ocean, WWE-forced Kelvin waves are thought to be important to the evolution of ENSO (e.g., Kessler et al. 1995; McPhaden and Yu 1999; Zhang and Gottschalck 2002; Puy et al. 2019; Yu and Fedorov 2020). El Niño onset is often preceded by a series of west Pacific WWEs that can initiate new downwelling Kelvin waves, reinforce pre-existing downwelling Kelvin waves (Lybarger and Stan 2018, 2019), and help sustain suppression of the east Pacific thermocline through multiplicative WWE-Kelvin wave feedbacks (e.g., Lopez et al. 2013). These mechanisms may be favored by the WWE-driven eastward extension of the Warm Pool (Drushka et al. 2015), which supports an eastward-shift of the Walker circulation, and a longer fetch for WWE-upper ocean interaction. Understanding of the mechanisms through which WWE-forced OWMs interact with ENSO remains incomplete. Although intraseasonal Kelvin wave activity precedes El Niño onset, lower-frequency eastward-propagating SSH anomalies may be more important for El Nino development (Capotondi et al. 2018). Sensitivities to the frequency, strength, and timing of the WWEs may also be important (e.g., Yu and Fedorov 2020; Zhang and Gottschalck 2002; Hendon et al. 2007; Chiodi and Harrison 2017; Puy et al. 2019).

Termination of El Niño events may also be influenced by westerly wind-ocean wave feedbacks under the delayed-oscillator paradigm (Suarez and Schopf 1988) wherein WWEs in the west Pacific force an upwelling Rossby wave, which is reflected at the western boundary as an El Niño-terminating upwelling Kelvin wave upon reaching the eastern Pacific (e.g., Battisti and Hirst 1989; Kirtman 1997). The periodicity of this process is regulated by the meridional structure of the wind stress forcing, which sets the phase speed of the Rossby wave (e.g., Kirtman 1997), and the longitude of upwelling Rossby wave initiation, which impacts the time the Rossby wave takes to reach the western boundary. During El Niño conditions, the longitude of ER wave initiation may shift eastward as the west Pacific warm pool, Walker circulation, and MJO convection extend eastward (Drushka et al. 2015; DeMott et al. 2018; Wei et al. 2020).

1.3 OWMs in climate models

Misrepresentations of OWMs in earth system models (ESMs) that form the basis of IPCC Assessment Reports likely contribute to biases in mean state SST (e.g., Li and Xie 2012), which may inflate biases in the representation of the MJO (e.g., Klingaman and DeMott 2020), ENSO (e.g., Capotondi et al. 2006; Deser et al. 2012), and the IOD (e.g., McKenna et al. 2020). Through tropical-extratropical teleconnections (e.g., Stan et al. 2017; Alexander et al. 2002; Chen et al. 2020), biases in each of these modes impose biases in the representation of global weather, such as tropical cyclone genesis (e.g., Shaman and Maloney 2012; Wang et al. 2014), atmospheric rivers (e.g., Zhou and Kim 2018), and coastal flooding (e.g., Muis et al. 2018).

Biases in OWMs in ESMs are likely rooted in WWE characteristics and ocean background state. Misrepresentation of the meridional structure of intraseasonal WWEs in the Pacific can lead to biases in the preferred latitude and phase speed of westward-propagating oceanic ER waves, which impacts the period of ENSO (Capotondi et al. 2006; Neale et al. 2008; Deser et al. 2012). The inclusion of CMT in the CCSM cumulus parameterization led to weaker and broader off-equatorial wind responses, which extended El Niño events to more realistic timescales (Neale et al. 2008). ESMs have historically struggled to adequately simulate MJO propagation beyond the Maritime Continent into the western Pacific (Hung et al. 2013; Ahn et al. 2020), suggesting that they also under-represent the frequency and intensity of MJO-linked WWEs. OWM biases are likely further exacerbated by tropical ocean mean state biases (Li and Xie 2012), which affect OWM propagation speed.

Historically, diagnosis of WWE-OWM interactions in Coupled Model Intercomparison Project (CMIP) models and their relationship to low-frequency modes of variability has been hindered by the lack of daily ocean output needed to diagnose the full spectrum of OWMs. While daily surface stress can be empirically estimated from daily low-level wind (e.g., Yu and Federov 2020), intraseasonal OWM diagnosis requires daily SSH or thermocline depth output, which is not available in previous CMIP archives. The addition of daily 20°C isotherm depth (t20d) output from several CMIP phase 6 (CMIP6; Eyring et al. 2016) member models effectively removes this barrier, enabling needed diagnosis of intraseasonal WWE-OWM interactions.

1.4 Future changes to WWEs, stability, and OWMs

In a warmer climate, elevated surface temperatures are associated with increased dry static stability due to a preferential warming of the upper troposphere under moist adiabatic adjustment. This increased dry static stability implies weaker circulations per unit convective heating given the dominant thermodynamic scaling of the tropical atmosphere (e.g. Maloney and Xie 2013). For example, many ESMs show decreased circulations associated with the MJO despite increases in MJO precipitation (Maloney et al. 2019a, Bui and Maloney 2018 and 2019a, b). Even models that show an increase in MJO circulation strength with climate change have a relatively weaker increase in circulation strength compared to MJO precipitation. We hypothesize that expected increases in atmospheric static stability will lead to decreases in intraseasonal WWE intensity per unit intraseasonal precipitation, which will rectify onto the OWM response to WWE forcing. Further, the expected eastward shift in MJO convection (Maloney et al. 2019a) may shift the location of WWEs and OWM initiation eastward.

Also under climate change, the stratification of the ocean is expected to increase (e.g., DiNezio et al. 2009; Collins et al. 2010; Capotondi et al. 2012; Ying and Huang 2016). Anticipated changes in stratification are especially acute in the tropics where changes in SST impact density more so than the higher latitudes (e.g., Capotondi et al. 2012). Warming and freshening of the upper ocean inhibit mixing of surface momentum fluxes to the deeper ocean (Li et al. 2020), confining them more strongly to the upper ocean and driving stronger surface currents (Yoshida 1959; Moum et al. 2014). This suggests that a more stably stratified upper ocean will yield a stronger surface current response to a given eastward momentum flux than a less stably stratified ocean, which may impact Ekman convergence on the Equator and OWM characteristics. Also, stability-related changes to vertical shear and viscous damping with warming may temper OWM damping (e.g., Benestad et al. 2002). How these changes to OWMs might affect ENSO or the IOD remain unclear. For example, an analysis of several CMIP5 models reveals both strengthening and weakening of ENSO (e.g., Chen et al. 2015 and references therein) and the IOD (Zheng et al. 2013).

2. Scientific Objectives

The ubiquity of OWMs, their regulation of upper-ocean thermal characteristics, and their interactions with the MJO, ENSO, and the IOD motivate the need to diagnose how well OWMs are simulated in modern ESMs. The dearth of daily ocean output variables in the previous phases of CMIP and the seasonal-to-subseasonal (S2S) prediction project (Vitart et al. 2017) databases imposed a long-standing blind spot in our ability to diagnose tropical ocean dynamics on intraseasonal timescales. New diagnostics are needed to harness information contained in recently available daily ocean output and to bridge the spectral diagnostic gap between atmospheric synoptic-through-intraseasonal activity, which is diagnosed with daily or greater frequency atmospheric output, and seasonal-to-interannual ocean variability, which is diagnosed with monthly ocean output. Our new diagnostics will evaluate the fidelity of OWMs forced by intraseasonal WWEs in CMIP6 and other ESM datasets and assess how the biases relate to the WWE forcing and the background state of the ocean. Our diagnostics are designed to reveal areas in need of model improvement by identifying sources of OWM biases linked to either WWE biases, which are rooted in atmospheric parameterized physics, or to ocean mean state biases, which can be affected by the OWMs themselves or by biases in the ocean model physics. Our hypotheses and associated scientific objectives are outlined in Table 1.

Table 1 - List of hypotheses (H1, H2, etc.) and scientific objectives (S1, S2, etc.).

Hypothesis:	**Scientific objective to test hypothesis:**
H1: Models exhibit a range of biases in their representations of tropical OWMs	**S1.** Diagnose tropical OWM spectra and spatial variance patterns in observations and ESMs.
H2: Models misrepresent intraseasonal WWE characteristics including frequency, intensity, and meridional structure.	**S2.** Characterize the frequency, intensity, and meridional structure of intraseasonal WWEs in observations and CMIP6 and other ESM databases, such as the S2S prediction project (Vitart et al. 2017).
H3: Biases in modeled intraseasonal OWMs vary as a function of intraseasonal WWE forcing.	**S3.** Assess the fidelity of tropical intraseasonal WWE-forced OWMs as a function of WWE intensity and meridional structure in CMIP6 and other ESMs relative to observations.
H4: Biases in oceanic mean state temperature and salinity profiles affect the amplitude and phase speed of WWE-forced OWMs.	**S4.** Evaluate the stability of the ocean mean state in models relative to observations and its relationship to OWM amplitude and phase speed.
H5: Expected increases in atmospheric and oceanic stability with climate change will result in decreases in WWE frequency and intensity per unit precipitation, and changes to OWM characteristics.	**S5.** Quantify changes in OWM climatology, WWE statistics, and ocean stability under climate change and relate OWM changes to changes in WWE characteristics and ocean stability.

Our objectives will form the basis of a tropical OWM process-oriented diagnostic (POD) with several diagnostic components (DCs) that will be added to the Model Diagnostics Task Force (MDTF) software package (Maloney et al. 2019b). The OWM POD will pinpoint processes in the atmospheric wind forcing and ocean mean state that lead to biases in OWM climatology. These processes are important for regulating low-frequency climate variability and in setting the tropical ocean mean state, but are not yet diagnosed in the MDTF diagnostics package.

This study will help advance the understanding of the link between intraseasonal WWEs, the ocean mean state, and OWMs. Our diagnostics will provide a solid bridge for synthesizing findings of studies focused on improving the parameterization of atmospheric convection with findings of studies focused on diagnosing biases in ENSO, the mean atmospheric and ocean state, and SST pattern effects on estimated equilibrium climate sensitivity.

3. Proposed Methodology

3.1. Data

3.1.1 Models

Our analysis will focus on diagnosing biases in CMIP6 simulations (Eyring et al. 2016) in representing intraseasonal WWE-forced OWMs where the biases will be related to errors in the intraseasonal WWEs and the ocean mean state. These diagnostics are contingent upon the availability of daily near-surface winds and variables pertinent to ocean dynamics, such as SSH or t20d, a common proxy for thermocline depth (e.g., McPhaden and Yu 1999). OWMs can be identified with SSH (**O**(10^{-1} m)) or t20d (**O**(10 m)) perturbations, as the two are highly correlated (e.g., Kutsuwada and McPhaden 2002). Such a relationship can also be inferred from simplified models of upper ocean equatorial dynamics (e.g. Zebiak and Cane 1987). The CMIP6 archive currently includes daily t20d from the historical simulations of five CMIP6 member models: HADGEM3, IPSL-CM6A, MPI-ESM1, NorESM2, UKESM1.

Results from the CMIP6 historical simulations will be augmented using ocean output from global forecast models involved in the S2S prediction project (Vitart et al. 2017). The S2S database includes hindcasts from eleven modeling centers. The hindcast period ranges between 14 and 19 years with leads of 30-60 days. In addition to daily SST and atmospheric variables, three modeling centers (i.e., ECMWF, CMA, and ECCC) now provide daily ocean SSH, t20d, surface currents, mixed layer depth, and 0-300m integrated heat and salinity content. Additionally, our group has 35 years (1980-2015) of historical simulation output from NCAR's Community Earth System Model version 2 (CESM2) at the daily time resolution for both the atmosphere and ocean. We have used this CESM2 output in preliminary analysis of intraseasonal WWE-forced OWMs (discussed below). Co-PI C. DeMott will also provide, under a DOE-supported project, daily ocean output from a historical simulation using the Department of Energy Energy Exascale Earth System Model (E3SM).

Daily output from CMIP6 shared socioeconomic pathway 5 with 8.5 Wm^{-2} radiative forcing (ssp585) future warming simulations (O'Neill et al. 2016) will also be evaluated relative to their historical simulations to determine changes in intraseasonal WWE-forced OWMs and ocean mean state with warming. Two modeling centers (MPI-ESM1 and NorESM2) have provided daily variables needed for our study. Diagnosis of OWMs in additional CMIP6 historical and future climate simulations will be done as more daily output becomes available. The daily ssp585 output will be supplemented with CESM2 simulations that we will perform as part of a NOAA

MAPP-supported project (NA20OAR4310389) and, possibly, E3SM climate change simulations.

3.1.2 Observations

The fidelity of intraseasonal WWEs, intraseasonal WWE-forced OWMs, and the ocean's mean state in models will be evaluated relative to observations. Our initial WWE-OWM diagnostics were developed using previously-acquired data, including ocean reanalysis products. The proposed work will be performed with products more weighted to observations and satellite retrievals. Below, we briefly summarize datasets that will be considered for these purposes.

Observed intraseasonal WWEs will be analyzed with daily zonal wind stress data from TropFlux (Praveen Kumar et al. 2013), SeaFlux (Clayson and Brown 2016; Roberts et al. 2020), and OAFlux (Yu and Weller 2007). Each of these wind stress products are, or will soon be (for OAFlux), available at 0.25° x 0.25° resolution throughout the tropics from roughly 1980-2016. Our current diagnostics use TropFlux wind stresses, which are computed with the COARE 3.0 flux algorithm using ERA-I surface meteorological variables that have been corrected with long-term bias estimates from the TAO/TRITON, PIRATA, and RAMA buoy arrays. The SeaFlux and OAFlux products rely more heavily on satellite and in situ observations. Dr. Carol Anne Clayson, one of the developers of the SeaFlux dataset, is a collaborator with Co-PI DeMott on another NOAA project and will provide guidance for our use of the SeaFlux dataset.

Observed OWMs will be diagnosed using SSH satellite-borne altimeter observations from the Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO; Pascual et al., 2006) product and the Hybrid Coordinate Ocean Model (HYCOM; Metzger et al. 2014) reanalysis. AVISO blends altimeter measurements from multiple satellite missions to produce a global 0.25° gridded product of SSH. Data are available at the daily timescale from 1993 to within 6-12 months of real time. HYCOM reanalysis provides daily SSH and t20d from 1994-2015 at 3-hourly, 1/12° resolution and will provide an essential basis for comparing AVISO SSH and model t20d. Surface forcing fields in HYCOM are from the National Centers for Environmental Prediction Climate Forecast System Reanalysis (Saha et al. 2010). HYCOM uses the Navy Coupled Data Assimilation system (Cummings 2006) to assimilate ocean observations from satellite altimeters and in-situ measurements (Cummings and Smedstad 2013).

Finally, the background state of the ocean will be examined with vertical profiles of temperature and salinity from Argo floats and the HYCOM reanalysis. Monthly 1° x 1° gridded Argo measurements are available from 2005 to within a few months of real time from the Asia Pacific Data-Research Center (APDRC), which is a part of the International Pacific Research Center at the University of Hawaiʻi and funded in part by NOAA. The monthly resolution of the ARGO products is sufficient for this assessment since we are interested in the slowly varying background state of these variables and their effects on ocean stability profiles.

3.2 Methods

3.2.1 OWM climatology (S1, H1)

Biases in the modeled tropical OWM climatology will be diagnosed using (1) wavenumber-frequency power spectra and (2) spatial maps of OWM variance. Wavenumber-frequency power spectrum analysis is a common diagnostic for identifying and isolating the structure of convectively-coupled equatorial waves in the atmosphere (e.g., CLIVAR MJO Working Group 2009). Previous works have applied the Wheeler and Kiladis (1999) wavenumber-frequency analysis to oceanic equatorial waves using SSH observations and model output (e.g., Wakata 2007; Farrar 2008; Shinoda et al. 2008 and 2009). For example, Fig. 2 shows wavenumber-frequency analysis from Shinoda et al. (2009) using observed SSH anomalies in the Pacific Ocean. The red background spectrum has been removed following Wheeler and Kiladis (1999) to highlight detailed features of the spectrum. Notable in the eastward (positive) domain is the peak in power along the dispersion line of the first baroclinic Kelvin wave, which corresponds to a phase speed of ~2.8 ms^{-1}. Similarly, in the westward (negative) domain there's a prominent peak along the dispersion curve of the first meridional mode ER wave.

We will make similar wavenumber-frequency spectra for near-Equator (i.e., 0°-5° degrees latitude) and two off-Equator (i.e., 5°-7° and 7°-13° degrees latitude) bands in both the Indian and Pacific Oceans. Assessing different latitude bands separately ensures the full spectrum of Rossby waves are captured, especially the slower, lower-frequency, off-Equator Rossby waves that are important to the ENSO delayed oscillator mechanism (e.g., Kirtman 1997). The model-based wavenumber-frequency spectra will be from SSH or t20d depending on model output.

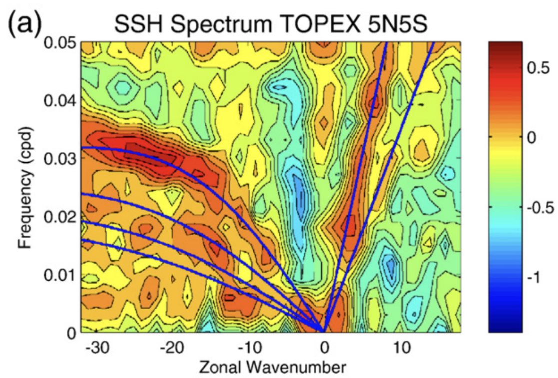


Figure 2 - Fig. 3a of Shinoda et al. (2009). Zonal wavenumber-frequency power spectrum of SSH anomalies from TOPEX between 5°S-5°N in the Pacific Ocean from 1993-2002 divided by the background spectrum. The straight and curved lines are the Kelvin and ER wave dispersion curves, respectively. Color bar represents base-10 logarithm.

Spatial maps comparing modeled and observed oceanic Kelvin and ER wave variance reveal biases in each model's ability to represent the amplitude and spatial structure of OWMs. Each wave is isolated by setting SSH over land points to zero and then filtering SSH anomalies in wavenumber-frequency space (e.g., Fig. 1). This approach follows methods of our collaborator, Adam Rydbeck (Rydbeck et al. 2019; Rydbeck and Jensen 2017; Rydbeck et al. 2017), and yields comparable results to time-only filtering approaches used elsewhere (e.g., Roundy and Kiladis 2006). For Kelvin waves, a 20-180 day bandpass filter is applied to eastward propagating (i.e., wave numbers > 1) SSH anomalies at each latitude between 15°S - 15°N, which is essentially the positive domain of Fig. 1. ER waves are identified in a similar manner but using a 30-180 day bandpass filter for westward (i.e., wavenumbers < -1) propagating SSH anomalies, which corresponds to the negative portion of Fig. 1 between ~0.007 and 0.03 cpd.

Figure 3 compares maps of Kelvin and ER wave variability using CESM2 and version 2 reanalysis from the Estimating the Circulation and Climate of the Ocean (ECCO2) consortium for 1992 - 2013 (Menemenlis et al. 2008). In CESM2, the Kelvin and ER waves are weaker than in ECCO2, and variability of both wave types is shifted somewhat northward from that of the ECCO2 reanalysis. We will extend this analysis to CMIP6 and other models and compare the results to more observationally-weighted data products, such as AVISO observations and HYCOM reanalysis. Also, Kelvin waves will be more clearly identified with empirical orthogonal function (EOF) analysis to remove signals poleward of ±5° latitude, as in Rydbeck et al. (2019).

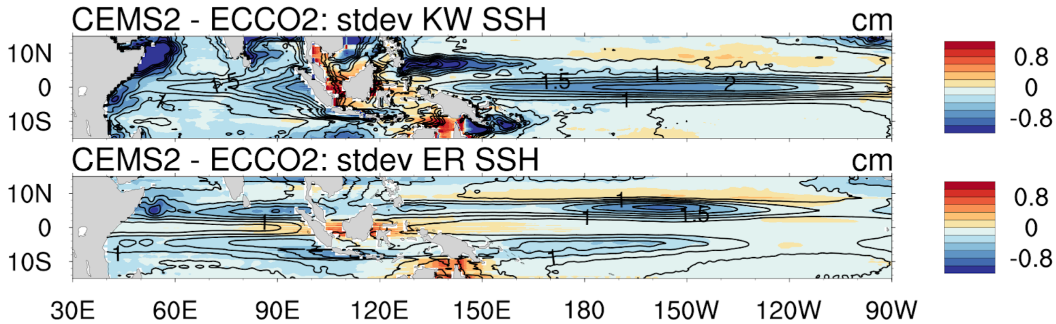


Figure 3 - SSH standard deviation from ECCO2 reanalysis (contours) and CEMS2 biases (shading) for Kelvin waves (20-180 day filtered eastward power; top) and intraseasonal ER waves (30-180 day filtered westward power; bottom).

3.2.2 WWE statistics (S2, H2)

The above diagnostics are useful for pinpointing model biases in OWM climatology, but further analysis is necessary to illuminate the fidelity of processes that determine OWM characteristics, namely the wind stress forcing and ocean mean state. Therefore, we will diagnose biases in WWE wind stress forcing (τ_x). Our approach closely follows Puy et al. (2016): intraseasonal τ_x anomalies are isolated with a 20-100 day bandpass filter. We then compute the standard deviation (σ) of 2°S-2°N averaged τ_x anomalies at each longitude. The WWE threshold is set to 1.5σ averaged from 40°E-95°E for the Indian Ocean and 130°E-150°W for the Pacific Ocean. These thresholds are applied to longitude-time plots of the 2°S-2°N averaged τ_x anomaly series to identify periods with WWE events that are sufficiently strong to disrupt the wind-SSH equilibrium and force an OWM response. The duration and zonal extent of each WWE is recorded (allowing for short temporal or zonal gaps), as are the maximum 2°S-2°N averaged τ_x for each WWE, the integrated wind work (IWW; i.e., the sum of all τ_x within a WWE longitude-time feature), the meridional extent of each WWE, defined as the latitude range where $\tau_x \geq 1.5\sigma$, and the latitude of maximum surface stress curl. Note that this approach only identifies WWEs with an equatorial component. Harrison and Vecchi (1997) reported that many observed WWEs are off-Equator events, which may project more strongly onto the ocean ER wave response. We will explore applying the TempestExtremes feature tracking algorithm (Ullrich and Zarzycki 2017) to meridionally resolved τ_x anomalies to capture these off-Equator WWEs, and to characterize the meridional structure of all WWEs.

A sample diagnostic based on these statistics is shown in Fig. 4 for TropFlux (orange) and 25 years of output from CESM2 (cyan). For clarity, we limit our analysis to WWEs centered between 130°-150°E. Compared to TropFlux, intraseasonal WWEs in CESM2 are generally weaker and shorter lived, and exert less total force on the ocean surface, suggesting that biases in CESM2 OWMs may be at least partially due to biases in WWEs. We will interpret our WWE diagnostics in the context of MJO simulation skill as revealed by MJO PODs already included in the MDTF diagnostic package.

3.2.3 OWM response to intraseasonal WWEs (S3, H3)

Composites of Kelvin or ER wave responses averaged over all WWE events occurring at a single location convolute the effects of WWE diversity (Fig. 4) and the ocean response to WWE forcing. A more targeted approach is required to understand the ocean response to wind forcing, which may reveal biases in the ocean mean state as a source of OWM bias. Ultimately, we want to disentangle the effects of WWE biases from ocean mean state biases in order to understand if ESMs realistically simulate the OWM response to a given WWE forcing.

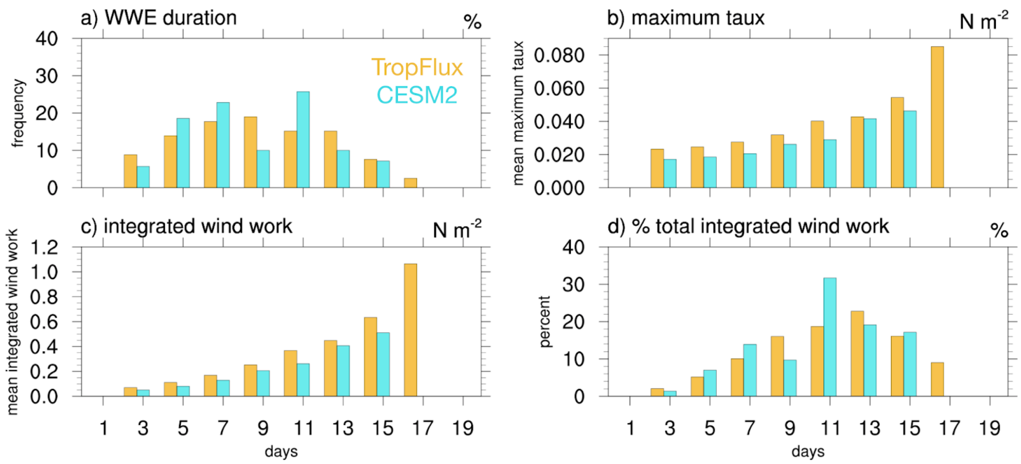


Figure 4 - WWE statistics for TropFlux (orange) and CESM2 (cyan) WWE events within 2°S-2°N and 130°-150°E by WWE duration. a) WWE duration frequency, b) mean maximum zonal surface stress, c) integrated wind work, and d) fraction of total IWW summed over all WWEs.

We are developing diagnostics to quantify the OWM response to WWE forcing by compositing the OWM response to a given IWW threshold, as demonstrated in Fig. 5 for the Kelvin wave response to the western Pacific WWEs summarized in Fig. 4. Plotted in the top row is the mean ECCO2 (left) and CESM2 (right) SSH response averaged over all TropFlux and CESM2 WWEs, respectively. While these all-event composites are clearly different from one another, the larger Kelvin wave amplitude in ECCO2 could simply be the result of longer lasting and higher-amplitude WWEs. Differences in the overall Kelvin wave response are better understood by constraining the composited events to a narrow range of IWW for an "apples to apples" comparison. The middle row of Fig. 5 composites SSH anomalies only for WWEs with IWW between 0-2 N m^{-2} (weak events); the bottom row is the composite for moderate IWW events (4-5 N m^{-2}). This conditional sampling strategy reveals that, compared to ECCO2, the CESM2 ocean response for weak WWEs is too weak, whereas the CESM2 ocean response to stronger WWEs is in better agreement. This exercise will be repeated for WWEs and Kelvin waves in the Indian Ocean. We aim to reduce the OWM response diagnostic in Fig. 5 to a single metric per IWW bin, such as the Kelvin wave SSH anomaly averaged over the entire basin (black rhombuses Fig. 5). This will let us explore whether a scaling relationship between IWW and wave amplitude can be developed for each model and whether such scaling relationships can be related to biases in ENSO, the IOD, and the ocean mean state.

Diagnosis of the ER wave response to wind forcing is more complex due to the latitude dependence of the propagation speed, which can be affected by ocean stability, meridional width of the wind stress, and period of wind forcing. The relationship of ER waves to WWEs will be analyzed by constructing composite ER wave responses that span a range of values for a given forcing criteria, as was done in Fig. 5 for the Kelvin wave. In addition to IWW-binned ER wave composites, ER waves will be composited by binned WWE meridional width and latitude of maximum wind stress curl. We expect the Rossby wave response to be largest for off-Equator Rossby waves with increasing meridional width of wind forcing and increasing latitude of maximum wind stress curl.

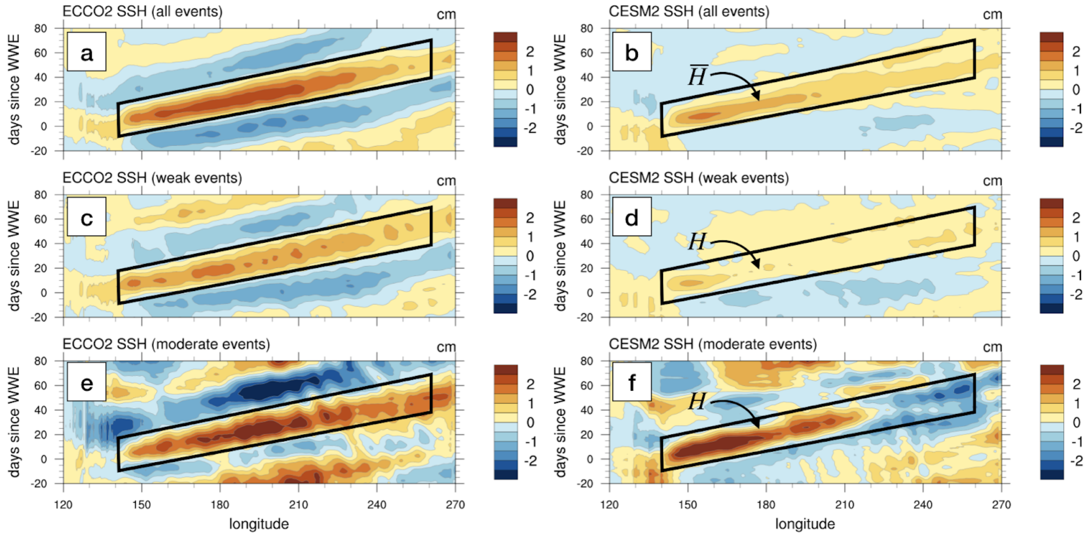


Figure 5 - Composite evolution of left) ECCO2 and right) CESM2 2°S-2°N averaged SSH anomalies as a function of longitude and time following WWEs identified in Fig. 4. Composites are shown for a, b) all WWEs; c, d) WWEs with IWW ≤ 2 N m^{-2}, and e, f) WWEs with 4 ≤ N m^{-2} ≤ 5. Black rhombuses indicate region for computing mean wave amplitude (see text). In b, $\overline{H}$ denotes the all-event mean SSH anomaly averaged across all longitudes and lags within the rhombus. H in d and f is the mean SSH anomaly conditioned by IWW sampling.

3.2.4 OWM dependence on the ocean mean state (S4, H4)

OWM amplitude and phase speed may also depend on biases in tropical mean state salinity and temperature profiles. For example, the too-shallow multi-model ensemble t20d in CMIP5 models (Li et al. 2015) suggests that OWMs are likely to exhibit too-slow propagation speeds (Long and Chang 1990; Benestad et al. 2002; Roundy and Kiladis 2006; Shinoda et al. 2008).

We will assess the ocean mean state using a combination of traditional and new diagnostics. Traditional diagnostics include mean state longitude-depth profiles of observed and simulated temperature and salinity for the Indian and Pacific Oceans, separately. For example, the mean Pacific basin equatorial temperature bias from CESM2 (Fig. 6) indicates that, compared to the ORAS5 reanalysis product, the CESM2 thermocline is too shallow in the west Pacific, and the upper ocean is too stable (i.e., too warm). These biases are consistent with the CESM2 slower-than-observed Kelvin wave propagation speed (due to the shallower thermocline) seen in Fig. 5. Ocean stability will also be assessed by computing temperature- and salinity-dependent Brunt-Vaisala (N^2) stability parameters (e.g., Thompson et al. 2019; Li et al. 2020) to clarify the extent to which temperature and salinity biases influence ocean stability biases. Biases in salinity profiles can also affect ocean stability (Murtugudde and Busalacchi, 1998; Maes and O'Kane 2014) and regulate the eastward extension of the Warm Pool following WWEs (Drushka et al. 2015).

We anticipate that WWE and ocean mean state biases may be linked. For instance, the upper ocean may be under-mixed by wind stirring and OWM mixing for models with insufficient

WWE activity, leading to an erroneously stable ocean that will affect the OWM response. We will investigate this potential relationship by comparing changes to low-frequency equatorial temperature and salinity anomaly profiles following periods of high WWE activity. Envelopes of high WWE activity will be identified with a time series of the 121-day running variance of anomalous WWE activity that will be long enough to capture multiple, successive intraseasonal WWE events. This method of identifying envelopes of activity with the square of the activity index is commonly used to study modulation of one scale by another (e.g., Roundy and Kiladis 2006; DeMott et al. 2011).

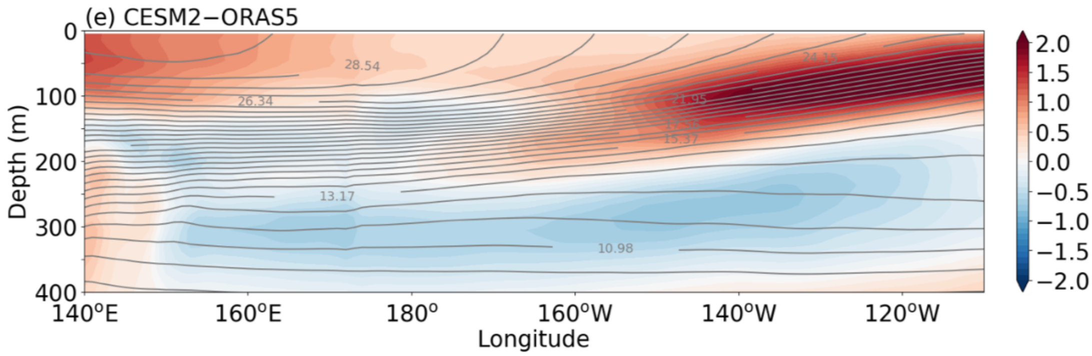


Figure 6 - Fig. 3 of Wei et al. (2020, submitted). Differences in temperature (°C) between CESM2 and ORAS5 (shading) averaged over 1980-2014 in the Pacific Ocean. Absolute ORAS5 temperatures are shown in grey contours.

3.2.5 Summary of diagnostics

Our example diagnostics above have mostly focused on Pacific ocean Kelvin waves, but we will apply these methods to the Indian Ocean and Pacific ocean, and to Kelvin and ER waves. A summary of the diagnostics we expect to add to the MDTF are summarized in Table 2.

Table 2 - List of diagnostic components (i.e, DC1, DC2, etc.) in the OWM POD and their purpose.

Diagnostic component:	**Purpose:**
DC1: Wavenumber-frequency diagrams of OWMs	Diagnose biases in OWM climatology
DC2: Spatial maps of OWM variance	
DC3: WWE statistics: amplitude, duration, integrated wind work (IWW), meridional width, latitude of maximum wind stress curl	Characterize WWE forcing to OWMs
DC4: Composites of Kelvin and ER wave response by IWW, plus composites of ER wave response by meridional width of wind stress anomaly and latitude of maximum wind stress curl for	Assess OWM response to WWE forcing
DC5: Mean state longitude-depth profiles of temperature and salinity	Evaluate the stability of the ocean mean state
DC6: Partition longitude-depth profiles of N^2 biases by temperature and salinity	Identify relative contributions of salinity and temperature to ocean stability biases

3.2.6 Changes to OWMs, their forcing, and feedbacks, in future climate simulations (S5, H5)

Changes to atmospheric and oceanic stability with warming are expected to alter the frequency and intensity of atmospheric WWEs and OWMs. Changes to OWM characteristics between historical and ssp585 CMIP6 simulations will first be assessed by computing the differences in SSH or t20d wave number-frequency spectra (DC1), spatial variance maps for Kelvin and ER waves (DC2), WWE statistics (DC3), and composite OWM responses (DC4). Changes to mean state temperature, salinity, and stability (N^2) profiles will also be assessed (DC5, DC6). We will also relate the changes in WWE wind stress per unit precipitation to changes in atmospheric dry static stability to determine if WWE intensity per unit precipitation is indeed weakening, as suggested by Bui and Maloney (2018, 2019a).

Finally, the relative effects of changes in atmosphere vs. ocean stability with warming on changes to OWM climatology will be synthesized using our diagnoses of WWE characteristics and OWM responses. For example, changes in atmospheric dry static stability is one factor that will affect IWW to the ocean surface, while changes in ocean stability will affect the SSH (and t20d) response to a given IWW. The relative importance of each effect on OWM climatology can be assessed through a linear decomposition of the total OWM change, as measured by SSH or t20d, following Bony et al. (2004) and illustrated in Fig. 7. The left panel is a hypothetical frequency distribution (F) of IWW for all WWEs and the mean Kelvin wave SSH anomaly (H) for each IWW bin from a single model; the right panel shows their respective changes under climate change (i.e., δF and δH). Following Bony et al. (2004), the inset equation details how changes to the IWW frequency distribution and SSH response with warming each contribute to the change in average H across all WWEs (i.e., $\overline{H}$ in Fig. 5b). The first term to the right of the equal sign is the change in $\overline{H}$ due to IWW frequency changes, which reflects changes in atmospheric dry static stability among other factors. The second term is changes in $\overline{H}$ due to the SSH response for a given IWW forcing, which reflects changes in ocean mean state (e.g., stability, currents). The third term is the covariance of both changes. Summation symbols denote integration over all IWW bins.

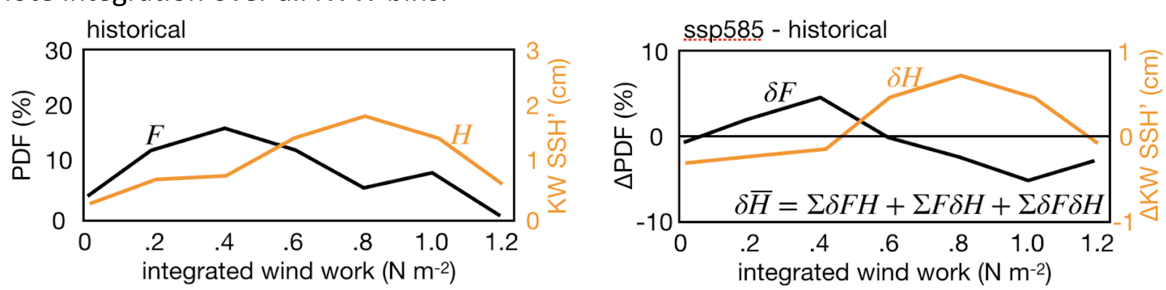


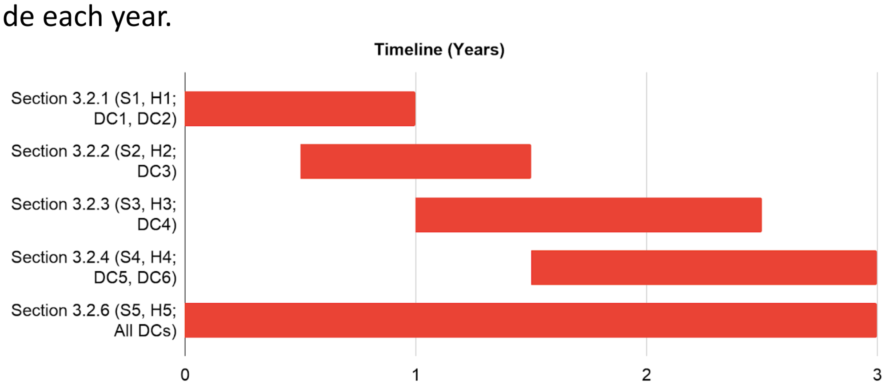
Figure 7 - Left) hypothetical frequency distribution (F; black) of IWW for all identified WWEs, and the mean Kelvin wave SSH anomaly for each IWW bin (H; orange) averaged within the rhombus shown in Fig. 5. Right) changes to the distribution of IWW and to the average SSH anomaly between ssp585 and historical simulations. Inset equation is described in the text.

A similar approach can be applied to ER wave changes with warming. For ER waves, additional conditioning variables (i.e., IWW in Fig. 7) will include WWE meridional width and latitude of maximum WWE wind stress curl. Since ER wave phase speeds are expected to be sensitive to each of these WWE characteristics, we will consider expanding our method of single-variable conditional sampling shown in Fig. 7 to two-variable conditional sampling by binning ER wave characteristics (e.g., SSH, phase speed) as a function of two variables, such as IWW and WWE meridional width, or IWW and latitude of maximum wind stress curl. Preliminary analysis suggests that our WWE selection criteria will identify roughly 100 WWEs for a ~35-year model output record. To avoid introducing climate change signals to our analysis of present day conditions in historical simulations, sampling the same 35-year period from additional ensemble members may be required to obtain statistically significant results using this approach.

4. Experience of PIs and Work Plan

Dr. Riley Dellaripa has extensive experience modeling intraseasonal air-sea interactions, working with satellite observations and reanalysis products, and developing new diagnostics for observations and models (Riley Dellaripa et al. 2018; Riley Dellaripa and Maloney 2015; Riley et al. 2011). She will oversee the project, help develop and apply the diagnostics, analyze the results for publications, and integrate the diagnostics into the MDTF software package. Her role as PI will promote the development of an early career female scientist. Dr. DeMott and Prof. Maloney are both experts and leaders in the field at diagnosing air-sea coupled feedbacks with climate models, especially related to the MJO. Both have served as co-chairs of the WGNE MJO Task Force as well as multiple other leadership roles. Most notably, Prof. Maloney is currently co-chair of the MDTF, a founding contributor to the MDTF diagnostics framework (Maloney et al. 2019b), and is also involved in a new Type II team proposal. His current and past task force leadership will aid in integration of our POD into the MDTF framework. Dr. DeMott and Prof. Maloney will provide expert advice to this project and assist in publications. Dr. DeMott will also assist with development and application of the diagnostics and data analysis. Prof. Maloney will advise the graduate student, while Drs. Riley Dellaripa and DeMott will help mentor the student. The graduate student will conduct original research to improve the understanding of how WWE and OWM characteristics may change with warming. Unfunded collaborator Dr. Adam Rydbeck is an oceanographer at the US Naval Research Laboratory and is an expert in ocean wave dynamics (e.g. Rydbeck et al. 2017, 2019 and Rydbeck and Jensen 2017). He will provide regular feedback on the techniques and analysis for this work (see support letter).

Below is the timeline for completing this work. Code developed for the preliminary analysis will be applied to the proposed work. Several publications will result from this work as sufficient progress is made each year.



5. Relevance to Competition and NOAA's Long-term Climate Research Goals

This work meets NOAA's long-term climate research goal outlined in the CPO-FY21_NOFO.pdf to “advance [the] understanding of the Earth’s climate system and to foster the application and use of this knowledge to improve the resilience of our Nation and its partners.” We also contribute the MAPP program objectives of: “2) supporting an integrated Earth System analysis capability and 3) improving methodologies for global to regional scale climate analysis, predictions, and projections.” This work improves understanding of atmosphere-ocean processes that directly influence major modes of climate variability such as the MJO, the IOD, and ENSO through our analysis of WWEs-forced OWMs. The diagnostics produced from this work (i.e., Table 2) will improve the analysis of climate models and their projections and provide “a clear set of pathways for model improvement” by pinpointing specific model deficiencies that produce OWM biases. These diagnostics can also lead to “potential downstream model improvements...to high-priority climate risk areas the Climate Program Office is organizing” specifically related to coastal inundation. For example, flooding is enhanced along north American coasts during El Niño events (e.g., Muis et al. 2018) making diagnosis of processes such as WWE-forced OWMs that lead to ENSO biases in models key to improving ENSO prediction and planning for possible El Niño induced flooding.

Our scientific objectives are highly relevant to one of the main goals of the MAPP Process-Oriented Diagnostics call to “better understand and benchmark process-level deficiencies that result in model performance biases for simulated Earth system and climate phenomena.” As specified in the call, the diagnosis of the CMIP6 models and other ESMs used in this study will “have a very strong grounding in observational data” by using a mixture of satellite, in situ, and reanalysis based products for model-observation comparisons.

The development of the tropical OWM POD with several diagnostic components (Table 2) builds upon current MJO-focused PODs and “focus[es] on clearly-identified gaps in the existing MDTF software package” including “open- and coastal ocean systems.” Our focus on both the Pacific and Indian Ocean basins is especially relevant to gaps in the existing MDTF software package, since the latter basin is not the focus of any current PODs.

6. Benefits of Proposed Project to the General Public and the Scientific Community

Our work will contribute a tropical OWM POD with several diagnostic components (Table 2) to the MDTF software package, which means the wider scientific community will have access to it for their own model evaluation. These diagnostics will determine biases in the climatology of OWMs in ESMs and help differentiate whether improvements to the representation of WWEs or the ocean mean state are more important for simulating OWMs. The utility of our diagnostics will provide motivation for a larger array of daily ocean output to diagnose modes of ocean variability in a wider set of models. This study will also advance the understanding of the link between intraseasonal WWEs, the ocean mean state, and OWMs.

The isolation of processes that lead to OWM biases and how those processes are deficient is a step toward improving OWM representation in models. Improving the simulation of OWMs potentially leads to better prediction of climate modes such as the MJO, the IOD, and ENSO given that OWMs can play a critical role in the development of each of those phenomena. Such model improvements ultimately benefit the general public as improved predictions of major climate modes such as ENSO will reduce uncertainty in future climate change and allow decision makers to make more informed decisions preparing for future climate changes.

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Data/Information Sharing Plan

Most data for this project, including the observations and CMIP6 simulation output, are archived and available online. Output from and documentation explaining the CESM2and E3SM simulations will be stored in the Mountain Scholar (https://mountainscholar.org/) data repository that is hosted and managed by the Colorado State University Libraries and is available for use by faculty, staff, and students. Mountain Scholar provides free and open access to data via the web through a permanent URL link that is discoverable by any search engines.

The data will be stored as netCDF files, which is a standard and widely used data format for global model output that includes metadata. We anticipate storing no more than 1 TB of data. Data and supplementary documentation from our simulations will be uploaded to Mountain Scholar upon publication of the works that used them. Our group has used Mountain Scholar for previous projects. The PI Dr. Riley Dellaripa will ensure the data and documents are uploaded to Mountain Scholar in a timely manner. Also, code to reproduce the diagnostics developed for this project will be made available through the MDTF software package.

Accepted versions of peer-reviewed publications and their supporting information from this work will be uploaded to Mountain Scholar and to NOAA's Institutional Repository when the work is published. A data availability statement will appear In all the publications.

Statement of Diversity and Inclusion

We fully support NOAA's commitment to diversity and inclusion. Through the inclusion of two female PIs, this project improves the participation of women in STEM. In particular, this proposal supports the development and STEM leadership of an early career female scientist through the participation of Dr. Riley Dellaripa as the lead PI.

The CSU Atmospheric Science Department recently joined the AGU Bridge Program to increase representation of underrepresented students in geosciences graduate programs. Through this program and with guidance from our department's own Diversity, Equity and Inclusion (DEI) committee, we will make every effort to support a student from an underrepresented background with this project. Our DEI committee recently drafted a series of internal actions in response to the call for "No Time for Silence"[1] in the geoscience community that includes a call for cultural competency training for faculty, staff, and students, including the student who will be recruited to work on this project. Co-PI DeMott is a member of our department's DEI committee.

Co-PI DeMott serves as the Assistant Director for the NSF-funded CSU Research Experience for Undergraduates (REU) program. Each summer, the REU site hosts roughly twelve undergraduate students from throughout the US for a 10-week paid internship focused on Earth system science research. Our REU aims to train a cohort of interns that reflect the diversity of genders, ethnicities, religions, orientations, and life-experiences of our nation's populace. Interns will be offered research projects directly related to this proposal. Professional development sessions are held on recognizing implicit biases and increasing cultural competencies in geosciences. The PI and Co-PIs have all mentored past participants in this program. Any graduate or undergraduate student involved in this project will participate in meetings and conferences with the broader and diverse science community.

[1] https://notimeforsilence.org

Emily M. Riley Dellaripa
Department of Atmospheric Science
Colorado State University
1371 Campus Delivery, Fort Collins, CO 80523
Emily.Riley@colostate.edu

EDUCATION

2013 Ph.D., Meteorology and Physical Oceanography, University of Miami, Miami, FL
2009 M.S., Meteorology and Physical Oceanography, University of Miami, Miami, FL
2006 B.S., Meteorology, *cum laude*, Texas A&M University, College Station, TX

PROFESSIONAL EXPERIENCE

November 2016 – Present	Research Scientist (I-II)	Colorado State University
November 2013 – October 2016	Postdoctoral Fellow	Colorado State University
August 2013 – October 2013	Postdoctoral Associate	University of Miami

RELEVANT PUBLICATIONS (*full list: https://emilymriley.weebly.com*)

Riley Dellaripa, E. M., A. Funk, C. Schumacher, H. Bai, and T. Spangehl, 2020: Adapting the COSP Radar Simulator to Compare GCM Output and GPM Precipitation Radar Observations. *J. Atmos. Ocean Tech.*, conditionally accepted.

Bui, H. X., E. D. Maloney, **E. M. Riley Dellaripa**, and B. Singh, 2020: Wind speed, surface flux, and intraseasonal convection coupling from CYGNSS data. *Geophys. Res. Lett.*, **47**, e2020GL090376.

Toms, B. A., S. C. van den Heever, **E. M. Riley Dellaripa**, S. M. Saleeby, E. D. Maloney, 2020: The Relationship Between the Boreal Summertime Madden-Julian Oscillation and Tropical Moist Convective Morphology. *J. Atmos. Sci.* **77**, 647-667.

Riley Dellaripa, E. M., E. D. Maloney, B. A. Toms, S. M. Saleeby, and S. C. van den Heever, 2020: Topographic Effects on the Luzon Diurnal Cycle During the BSISO**,** *J. Atmos. Sci.* **77**, 3-30.

Riley Dellaripa, E. M., E. D. Maloney, and S. C. van den Heever, 2018: Wind-Flux Feedbacks and Convective Organization During the November 2011 MJO Event in a High-Resolution Model. *J. Atmos. Sci.,* **75**, 57-84.

Riley Dellaripa, E. M., and E. D. Maloney, 2015: Analysis of MJO Wind-Flux Feedbacks in the Indian Ocean Using RAMA Observations. *J. Meteor. Soc. Japan*, **93A**, 1-20.

Riley, E. M., B. E. Mapes, and S. N. Tulich, 2011: Clouds Associated with the Madden-Julian Oscillation: A New Perspective from *CloudSat*. *J. Atmos. Sci.*, **68**, 3032-3051.

Riley, E. M., and B. E. Mapes, 2009: Unexpected Peak Near -15°C in *CloudSat* Echo Top Climatology. *Geophys. Res. Lett.*, **36**, L09819.

RELEVANT WORKSHOPS ATTENDED

- CLIVAR workshop: Atmospheric Convection and Air-Sea Interaction Over Tropical Oceans. Boulder, CO. May 2019.
- The Future of Cumulus Parametrization. Delft, Netherlands. July 2017.
- Workshop on Tropical Dynamics and the MJO. Honolulu, HI. January 2014.
- Workshop on Modeling Monsoon Intraseasonal Variability. Busan, South Korea. June 2010.

Eric D. Maloney

Current/recent Positions

Assoc. Department Head, Atmospheric Science, Colorado State University, 2019-present
Professor, Atmospheric Science, Colorado State University, 2015-present
Associate Professor, Atmospheric Science, Colorado State University, 2008-2015
Assistant Professor, Oceanic and Atmospheric Sciences, Oregon State University, 2002-2008

Doctorate: Atmospheric Sciences, University of Washington, 2000

Selected Recent Publications (selected from over 120, full list: ***https://tropical-dynamics.atmos.colostate.edu/publications***)

Maloney, E. D., A. Gettelman, Y. Ming, J. D. Neelin, D. Barrie, A. Mariotti, C.-C. Chen, D. R. B. Coleman, Y.-H. Kuo, B. Singh, H. Annamalai, A. Berg, J. F. Booth, S. J. Camargo, A. Dai, A. Gonzalez, J. Hafner, X. Jiang, X. Jing, D. Kim, A. Kumar, Y. Moon, C. M. Naud, A. H. Sobel, K. Suzuki, F. Wang, J. Wang, A. A. Wing, X. Xu, and Ming Zhao. Process-oriented evaluation of climate and weather forecasting models. *Bull. Amer. Meteor. Soc.* (2019).

Eyring, V., and others: Taking model evaluation to the next level. *Nature Climate Change* (2019).

Wolding, B. O., J. Dias, G. Kiladis, F. Ahmed, **E. Maloney**, and M. Branson. Interactions Between Moisture and Tropical Convection. Part I: Convective Lifecycle and Spatiotemporal Dependence. *J. Atmos. Sci.*, (2020).

Kuo, Y.-H., J. D. Neelin, C.-C. Chen, W.-T. Chen, L. Donner, A. Gettelman, X. Jiang, K.-T. Kuo, **E. Maloney**, C. Mechoso, Y. Ming, K. Schiro, C. Seman, C.-M. Wu, and M. Zhao: Convective transition statistics over tropical oceans for climate model diagnostics: GCM evaluation. *J. Atmos. Sci.* (2020).

Wolding, B. O, **E. D. Maloney**, and M. Branson. Vertically Resolved Weak Temperature Gradient Analysis of the Madden-Julian Oscillation in SP-CESM. *J. Adv. Modeling. Earth. Sys.* (2016).

Maloney, E. D., A. F. Adames, and H. X. Bui. Madden-Julian Oscillation Changes under Anthropogenic Warming. Nature Clim. Change, (2019).

Bui, H. X., and **E. D. Maloney**. Mechanisms for global warming impacts on Madden-Julian Oscillation precipitation amplitude. *J. Climate*. (2019).

Henderson, S. A., **E. D. Maloney**, and S.-W. Son. Madden-Julian oscillation teleconnections: The impact of the basic state and MJO representation in general circulation models. *J. Climate* (2017).

Selected Awards

2016: AGU Atmospheric Sciences Section Ascent Award; ***2010, 2014:*** Dept. of Atmospheric Science, Colorado State University, Professor of the Year; and College of Engineering, George T. Abell Outstanding Mid-Career Faculty Award (**2010**) and Outstanding Research Faculty Award (**2018)**, Colorado State University;

Selected Service/Affiliations

NOAA MAPP Task Force: *S2S* 2016- present, *Model Diagnostics* 2015- present (lead and co-lead), and *CMIP5* 2011- 2014 (co-lead); Editor, Journal of Climate, 2011-2014; and WMO Working Group on Numerical Experimentation (WGNE) MJO Task Force (co-chair with Steve Woolnough up until 2016), 2009-2019.

Charlotte A. DeMott
http://hogback.atmos.colostate.edu/demott

Department of Atmospheric Science
Colorado State University
Fort Collins CO 80523

Telephone: (970) 492-4201
Fax: (970) 491-8693
E-mail: Charlotte.DeMott@ColoState.edu

Education and Training
BS Meteorology, Texas A&M University, College Station, Texas 1987.
MS Atmospheric Science, Colorado State University, Fort Collins, Colorado, 1990.
PhD Atmospheric Science, Colorado State University, Fort Collins, Colorado, 1996.
Post-Doctoral, Department of Atmospheric Science, Colorado State University, 1996-1998.

Research and Professional Experience
2020: Senior Research Scientist, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado
1998-2020: Research Scientist (I—III), Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

Full publication list: http://hogback.atmos.colostate.edu/demott

Five most relevant publications
Wei, H.-H., A. Subramanian, K. Karnauskas, and **C. A. DeMott**, 2020: Tropical Pacific Air-sea Interaction Processes and Biases in CESM2 and their Relation to El Niño Development. *Submitted to J. Phys. Ocean.*

DeMott, C. A., and N. P. Klingaman, 2021: Air-sea interactions in the Madden-Julian oscillation. *The Multi-scale Global Monsoon*. C.-P. Cheng, editor, https://doi.org/10.1142/11723.

Klingaman, N. P., and **C. A. DeMott**, 2020: Mean-state biases and interannual variability affect perceived sensitivities of the Madden-Julian oscillation to air-sea coupling. *J. Adv. Model. Earth Syst.,* **12**, https://doi.org/10.1029/2019MS001799

DeMott, C. A., N. P. Klingaman, W.-L. Tseng, M. Burt, and D. A. Randall, 2019. The convection connection: How ocean feedbacks affect tropical mean moisture and MJO propagation. *J. Geophys. Res. Atmos*., **124**, 11,910-11,931.

Subramanian, A. C., and **co-authors**, 2019: Ocean observations to improve our understanding, modeling, and forecasting of subseasonal-to-seasonal variability. *Frontiers, accepted.*

DeMott, C. A., B. O. Wolding, E. D. Maloney, and D. A. Randall, 2018: Atmospheric contributions to MJO decay over the Maritime Continent. J. Geophys. Res., **123,** doi:10.1029/2017JD026979.

Synergistic Activities and Service
- Co-chair, Scientific Organizing Committee for US CLIVAR Workshop on Tropical Pacific Observing Needs, May 24-26, 2020, Boulder, Colorado.
- Co-chair US CLIVAR Process Study and Model Improvement Panel (2020-; member 2019-).
- Co-chair, WGNE MJO Task Force (2019-present; member since 2012).
- Ocean Liaison to US National Earth System Prediction Capability Interagency Weather Research Coordination Committee/Weather Research Science Working Group, Fall 2020.
- Associate Editor, Monthly Weather Review (2018-present).

Current and Pending Support

EMILY RILEY DELLARIPA: CURRENT & PENDING SUPPORT

CURRENT SUPPORT:

Title of project: Coupled ocean-atmosphere regional model simulations of diurnal Maritime Continent and its synergy with MJO propagation; Sponsor: ONR Award #: N00014-16-1-3087; Duration: 08/16-10/21; Award Amount: $544,056; Commitment/Role: 8 PM/YR (Co-I)

PENDING SUPPORT

Title of project: MJO teleconnections in the current and future climate and their implications for S2S predictability; Sponsor: NASA; Duration: 01/21-12/24; Amount requested: $688,606; Commitment/Role: 5 PM/YR (PI)

Title of project: Latent heat flux-convection coupling on mesoscale through intraseasonal scales using CYGNSS; Sponsor: NASA; Duration: 05/21-05/24; Amount Requested: $423,986; Commitment/Role: 4.75 PM/YR (Co-I)

ERIC MALONEY: CURRENT & PENDING SUPPORT

CURRENT SUPPORT:

Title of project: Coupled ocean-atmosphere regional model simulations of diurnal Maritime Continent and its synergy with MJO propagation; Sponsor: ONR Award #: N00014-16-1-3087; Duration: 08/16-10/21; Award Amount: $544,056; Commitment/Role: 0.12 PM, NCE (PI)

Title of project: A Modeling Study of Easterly Waves and Their Intraseasonal Variability in the East Pacific; Sponsor: NSF Award #: AGS-1735978; Duration: 11/17-10/21; Award Amount: $431,851; Commitment/Role: 0.12 PM, NCE (PI)

Title of project: Understanding tropical convective dynamics and the MJO using CYGNSS observations; Sponsor: NASA Award # NNX17AH77G; Duration: 03/17-03/21; Award Amount: $339,230; Commitment/Role: 0.12 PM, NCE (PI)

Title of project: An Open Framework for Process-Oriented Diagnostics of Global Models; Sponsor: NOAA Award # NA18OAR4310268; Duration: 08/18-07/21; Award Amount: $167,096; Commitment/Role: 1.0 PM/YR (PI)

Title of project: Understanding the role of diurnal cycle and the mean state on the propagation of the instraseasonal variability over the Maritime Continent; Sponsor: NOAA Award # NA18OAR4310299; Duration: 09/18-08/21; Award Amount: $182,240. Commitment/Role: 1.0 PM/YR (PI)

Title of project: Changes to Madden-Julian Oscillation Winds and Convection in a Future Warmer Climate; Sponsor: NSF Award # AGS-1841754; Duration: 06/19-05/22; Award Amount: $538,058; Commitment/Role: 1.0 PM/YR (PI)

Title of project: MJO and QBO Contributions to U.S. Precipitation Skills at S2S Leads; Sponsor: NOAA Award #: NA19OAR4590151; Duration: 09/19-08/22; Award Amount: $524,196; Commitment/Role: 1.0 PM/YR (Co-PI)

Title of project: Untangling Changes in the West Pacific Water Cycle; Sponsor: NASA Award #: 80NSSC20K1105; Duration: 06/20-06/23; Award Amount: $1,949,272; Commitment/Role: 0.5 PM/YR (Co-I)

PENDING SUPPORT

Title of project: Dynamics-Carbon Cycle Coupling by the Madden-Julian Oscillation; Sponsor: DOE; Duration: 07/20-06/23; Amount requested: $694,135; Commitment/Role: 0.5 PM/YR (Co-PI)

Title of project: MJO teleconnections in the current and future climate and their implications for S2S predictability; Sponsor: NASA; Duration: 01/21-12/24; Amount requested: $688,606; Commitment/Role: 0.5 PM/YR (Co-I)

Title of project: Collaborative Research: The relationship between the MJO and midlatitude subseasonal-to-seasonal oscillatory modes; Sponsor: NSF; Duration: 05/21-04/24; Amount requested: $280,475; Commitment/Role: 0.12 PM/YR (Co-PI)

Title of project: Latent heat flux-convection coupling on mesoscale through intraseasonal scales using CYGNSS; Sponsor: NASA; Duration: 05/21-05/24; Amount Requested: $423,986; Commitment/Role: 1 PM/YR (PI)

CHARLOTTE DEMOTT: CURRENT & PENDING SUPPORT

CURRENT SUPPORT:

Title of project: Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation; Sponsor: NOAA Award # NA16OAR4310094; Duration: 07/16-12/20; Award Amount: $404,291; Commitment/Role: No support remaining (PI)

Title of project: Improved Understanding of air-sea interaction processes and biases in the Tropical Western Pacific using observation sensitivity experiments and global forecast models; Sponsor: NOAA Award # NA18OAR4310407; Duration: 09/18-08/21; Award Amount: $35,170; Commitment/Role: No support remaining (PI)

Title of project: Collaborative Research: Understanding air-sea feedbacks to the MJO through process evaluation of observations and E3SM experiments; Sponsor: DOE Award #: DE-SC0020092; Duration: 09/19-08/22; Award Amount: $465,073; Commitment/Role: 3.0 PM/YR (PI)

Title of project: Formation of rain layers in the Warm Pool and their feedbacks to atmospheric convection in an idealized modeling framework; Sponsor: NSF Award #: 1924659; Duration: 10/19-09/22; Award Amount: $612,538; Commitment/Role: 3.6 PM/YR (PI)

Title of project: REU Site: Research Experiences for Undergraduates in Earth System Science at Colorado State University; Sponsor: NSF Award #: 1950172; Duration: 04/20-03/25; Award Amount: $675,000; Commitment/Role: 0.75 PM/YR (Co-PI)

Title of project: Understanding Bulk Surface Flux Algorithm Contributions to Climate Projection Uncertainties; Sponsor: NOAA Award #: NA20OAR4310389; Duration: 09/20-08/23; Award Amount: $175,884; Commitment/Role: 1.8 PM/YR (PI)

Title of project: Understanding the role of mesoscale organization in air-sea interactions; Sponsor: NOAA Award #: NA20OAR4310374; Duration: 09/20-08/23; Award Amount: $96,311; Commitment/Role: 1.8 PM/YR (PI)

PENDING SUPPORT

Title of project: Dynamics-Carbon Cycle Coupling by the Madden-Julian Oscillation; Sponsor: DOE; Duration: 07/20-06/23; Amount requested: $694,135; Commitment/Role: 2.0 PM/YR (PI)

U.S. NAVAL RESEARCH LABORATORY

November 16, 2020

Emily Riley Dellaripa, Charlotte DeMott, and Eric Maloney
Department of Atmospheric Science
Colorado State University
1371 Campus Delivery
Fort Collins, CO, 80523-1371

Dear Dr. Riley Dellaripa, Dr. DeMott and Prof. Maloney:

Thank you for sharing the details of your proposal "*Process-oriented evaluation of oceanic equatorial waves in the Indian and west Pacific Ocean forced by intraseasonal westerly wind events*" being submitted to the NOAA MAPP program competition "Process-Oriented Diagnostics for NOAA Climate Model Improvement and Applications." I am happy to serve as an unfunded collaborator on the proposal. This project aligns with my expertise in feedbacks between intraseasonal atmospheric variability and ocean wave modes and uses techniques developed in my prior work related to the identification of tropical ocean waves (e.g., Rydbeck and Jensen 2017, Rydbeck et al. 2019), which I will provide guidance on. I will additionally give feedback on the use of HYCOM reanalysis and AVISO observations for this work, as I have extensive experience in using them. Finally, I will offer my expert input as an oceanographer as needed to the project. I am excited that this project expands my prior work and I look forward to collaborating with you all on this project.

Sincerely,

Adam Rydbeck

NRL Ocean Sciences Division
Ocean Dynamics and Prediction Branch
Code 7320
U.S. Naval Research Laboratory
Stennis Space Center, MS 39571

COLLEGES AND UNIVERSITIES RATE AGREEMENT

EIN: 846000545

DATE:06/04/2020

ORGANIZATION:

Colorado State University
Business and Financial Services
202 Johnson Hall
Fort Collins, CO 80523

FILING REF.: The preceding agreement was dated 06/14/2019

The rates approved in this agreement are for use on grants, contracts and other agreements with the Federal Government, subject to the conditions in Section III.

SECTION I: INDIRECT COST RATES

RATE TYPES: FIXED FINAL PROV. (PROVISIONAL) PRED. (PREDETERMINED)

	EFFECTIVE PERIOD				
TYPE	**FROM**	**TO**	**RATE(%)**	**LOCATION**	**APPLICABLE TO**
PRED.	07/01/2014	06/30/2015	48.70	On-Campus	Organized Research
PRED.	07/01/2015	06/30/2016	50.00	On-Campus	Organized Research
PRED.	07/01/2016	06/30/2017	51.00	On-Campus	Organized Research
PRED.	07/01/2017	06/30/2019	52.00	On-Campus	Organized Research
PRED.	07/01/2014	06/30/2019	26.00	Off-Campus	Organized Research
PRED.	07/01/2014	06/30/2019	56.00	On-Campus	Instruction
PRED.	07/01/2014	06/30/2019	26.00	Off-Campus	Instruction
PRED.	07/01/2014	06/30/2019	34.00	On-Campus	Other Sponsored Activities
PRED.	07/01/2014	06/30/2019	26.00	Off-Campus	Other Sponsored Activities
PRED.	07/01/2014	06/30/2019	8.00	Off-Campus	(A)
PROV.	07/01/2019	Until Amended		(B)	

*BASE

Modified total direct costs, consisting of 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). Modified total direct costs shall exclude equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000. Other items may only be excluded when necessary to avoid a serious inequity in the distribution of indirect costs, and with the approval of the cognizant agency for indirect costs.

ORGANIZATION: Colorado State University Business and Financial Services

AGREEMENT DATE: 6/4/2020

SECTION I: FRINGE BENEFIT RATES**

TYPE	FROM	TO	RATE(%)	LOCATION		APPLICABLE TO
FIXED	7/1/2020	6/30/2021	27.10	All	(A)	Fac. & Prof. (1)
FIXED	7/1/2020	6/30/2021	45.90	All	(A)	State Classified
FIXED	7/1/2020	6/30/2021	0.90	All	(A)	Student Hourly
FIXED	7/1/2020	6/30/2021	27.40	All	(A)	Temporary (2)
FIXED	7/1/2020	6/30/2021	9.50	All	(A)	All Graduate Students
FIXED	7/1/2020	6/30/2021	13.60	All	(A)	First Year Post Docs (3)
FIXED	7/1/2020	6/30/2021	13.50	All	(A)	Temporary (4)
FIXED	7/1/2020	6/30/2021	23.50	(5)	(B)	All Employees (5)
PROV.	7/1/2021	6/30/2024		(C)		

** DESCRIPTION OF FRINGE BENEFITS RATE BASE:

(A) Salaries and wages including vacation, holiday, sick leave pay and other paid absences.

(B) The total of salaries and wages plus appropriate fringe benefits excluding vacation, holiday, sick leave pay and other paid absences.

(C) Use same rates and conditions as those cited for fiscal year ending June 30, 2021.

(1) Faculty, administrative professionals and second-year plus post docs and interns

(2) Temporary non-student hourly

(3) First-year post docs and interns

(4) Temporary first-year faculty, administrative professionals, including continuing temporary faculty and administrative professionals at less than 50% time.

(5) Leave benefit rate for Center for Environmental Management of Military Lands (CEMML) & Colorado National Heritage Program (CNHP)

SECTION II: SPECIAL REMARKS

TREATMENT OF FRINGE BENEFITS:

The fringe benefits are charged using the rate(s) listed in the Fringe Benefits Section of this Agreement. The fringe benefits included in the rate (s) are:

WORKERS COMPENSATION, MEDICAL/LIFE INSURANCE, DISABILITY INSURANCE, UNEMPLOYMENT INSURANCE, MEDICARE, RETIREMENT PERA/DCP, RETIREMENT TERMINATION PAY, EXCESS LEAVE, RETIREE HEALTH INSURANCE, AND EMPLOYEES' TUITION (DOES NOT INCLUDE GRADUATE STUDENTS).

TREATMENT OF PAID ABSENCES

Except for CEMML & CHNP employees, vacation, holiday, sick leave pay and other paid absences are included in salaries and wages and are charged to Federal projects as part of the normal charge for salaries and wages. Separate charges for the cost of these absences are not made.

For CEMML & CHNP employees, the cost of vacation, holiday, sick leave pay, and other paid absences are included in a leave benefit rate which is applied to the total of salaries and wages plus appropriate fringe benefits for budgeting and charging purposes for Federal projects, and are not included in direct charges for salaries and wages. Charges for salaries and wages must exclude those paid to CEMML & CNHP employees for periods when they are on vacation, holiday, or sick leave, or are otherwise absent from work.

DEFINITION OF OFF-CAMPUS
For projects which include activities conducted at both on- and off-campus sites, the following criteria will determine costs to be allocated as off-campus: Must extend over a period of more than 120 consecutive days (or the duration of the project, if less than 120 days) at the off-campus site.

DEFINITION OF EQUIPMENT
Equipment means tangible personal property (including information technology systems) having a useful life of more than one year and a per-unit acquisition cost which equals or exceeds $5,000.

NEXT PROPOSAL DUE DATES
A fringe benefit rates proposal based on actual costs for fiscal year ended 06/30/20, will be due by 12/31/20.

This rate agreement updates fringe benefits rates only.

SECTION III: GENERAL

A. LIMITATIONS:

The rates in this Agreement are subject to any statutory or administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the organization were included in its facilities and administrative cost pools as finally accepted: such costs are legal obligations of the organization and are allowable under the governing cost principles; (2) The same costs that have been treated as facilities and administrative costs are not claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the organization which was used to establish the rates is not later found to be materially incomplete or inaccurate by the Federal Government. In such situations the rate(s) would be subject to renegotiation at the discretion of the Federal Government.

B. ACCOUNTING CHANGES:

This Agreement is based on the accounting system purported by the organization to be in effect during the Agreement period. Changes to the method of accounting for costs which affect the amount of reimbursement resulting from the use of this Agreement require prior approval of the authorized representative of the cognizant agency. Such changes include, but are not limited to, changes in the charging of a particular type of cost from facilities and administrative to direct. Failure to obtain approval may result in cost disallowances.

C. FIXED RATES:

If a fixed rate is in this Agreement, it is based on an estimate of the costs for the period covered by the rate. When the actual costs for this period are determined, an adjustment will be made to a rate of a future year(s) to compensate for the difference between the costs used to establish the fixed rate and actual costs.

D. USE BY OTHER FEDERAL AGENCIES:

The rates in this Agreement were approved in accordance with the authority in Title 2 of the Code of Federal Regulations, Part 200 (2 CFR 200), and should be applied to grants, contracts and other agreements covered by 2 CFR 200, subject to any limitations in A above. The organization may provide copies of the Agreement to other Federal Agencies to give them early notification of the Agreement.

E. OTHER:

If any Federal contract, grant or other agreement is reimbursing facilities and administrative costs by a means other than the approved rate(s) in this Agreement, the organization should (1) credit such costs to the affected programs, and (2) apply the approved rate(s) to the appropriate base to identify the proper amount of facilities and administrative costs allocable to these programs.

BY THE INSTITUTION:

Colorado State University Business and Financial Services
(INSTITUTION)

[signature]
(SIGNATURE)

David Ryan
(NAME)

Controller
(TITLE)

June 15, 2020
(DATE)

ON BEHALF OF THE FEDERAL GOVERNMENT:

DEPARTMENT OF HEALTH AND HUMAN SERVICES
(AGENCY)

[signature]
(SIGNATURE)

Arif Karim
(NAME)

Director, Cost Allocation Services
(TITLE)

6/4/2020
(DATE) 2341

HHS REPRESENTATIVE: Jeffrey Warren

Telephone: (415) 437-7820

Budget Table: Colorado State University

	YR 1	*YR 2*	*YR 3*	*Totals*
Personnel				
Salary	$91,247	$93,985	$93,934	**$279,166**
Fringe	$18,667	$19,227	$19,058	**$56,952**
Personnel Subtotal	**$109,914**	**$113,212**	**$112,992**	**$336,118**
Non-Personnel				
Travel	$2,912	$2,999	$3,089	**$9,000**
Other Direct	$21,222	$19,394	$20,638	**$61,254**
Non-Personnel subtotal	**$24,134**	**$22,393**	**$23,727**	**$70,254**
Totals				
Total Direct Cost	$134,048	$135,605	$136,719	**$406,372**
Total F&A (35%)	$42,542	$42,737	$42,749	**$128,028**
TOTAL	**$176,590**	**$178,342**	**$179,468**	**$534,400**
MTDC Base	*$121,548*	*$122,105*	*$122,139*	*$365,792*

Budget Narrative: Colorado State University

I. PERSONNEL – $279,166

Base salary included in this proposal reflects the salaries to be approved by the Governing Board of Colorado State University for the period July 1, 2020 through June 30, 2021. **Any salary beyond this period is budgeted at a 3% increase over the prior year's annual base.**

Role, Name & FY21 Base	*Year 1*	*Year 2*	*Year 3*	*Total*
PI, Emily Riley Dellaripa, $69,575	$30,011	$30,911	$31,680	$92,602
Co-PI, Eric Maloney, $152,000	$8,748	$9,010	$9,235	$26,993
Co-PI, Charlotte DeMott, $104,600	$18,050	$18,592	$16,665	$53,307
GRA, TBN, $33,269	$34,438	$35,472	$36,354	$106,264

FRINGE – $56,952

The following approved FY2021 (July 1, 2020 – June 30, 2021) fringe rates were applied to the salaries based on the individual's payroll classification:

- Faculty/Administrative Professional/2nd Year PostDoc: 27.1%
- Graduate Research Assistants: 9.5%

Role, Name & Fringe Rate	*Year 1*	*Year 2*	*Year 3*	*Total*
PI, Emily Riley Dellaripa, 27.1%	$8,133	$8,377	$8,585	$25,095
Co-PI, Eric Maloney 27.1%	$2,371	$2,442	$2,503	$7,316
Co-PI, Charlotte DeMott 27.1%	$4892	$5038	$4516	$14,446
GRA, TBN 9.5%	$3,271	$3,370	$3,454	$10,095

Justification and description of each position (related specifically to project objectives):

Emily Riley Dellaripa, *PI* (5.0 person months (PM)/year), will oversee the project and help develop and apply the proposed diagnostics to observations and models and analyze results for multiple publications. She will ensure the diagnostics are integrated into the MDTF software package.

Eric D. Maloney, *Co-PI* (0.5 PM/year), will provide expert advice to the project and assist in integrating the diagnostics into the MDTF software package. He will also help with publications and advise the graduate student entrained into the project.

Charlotte DeMott, *Co-PI* (2.0 PM/Y1-2, 1.75 PM/Y3), will assist with the development of the proposed diagnostics and help analyze and write up results for publications.
TBN, *GRA* (6.75 person months/year), will partake in all aspects of the proposed work including developing model diagnostics, model and observation analysis, and publications. A full-time GRA in the Department of Atmospheric Science equates to 6.75 PM (56.25% FTE). They are paid at 50% FTE during the academic period and 75% FTE during the summer months.

II. TRAVEL – $9,000

This proposal includes one trip each year for the PI to one scientific meeting to present project-related science and results. The Annual Meeting of the American Geophysical Union (AGU) held in San Francisco, CA is used for budgeting purposes. Lodging and per diem rates based on federal guidelines found at gsa.gov. Other costs based on recent similar travel. A 3% inflation factor is included in each additional year.

1 person, 5 days/4 nights, San Francisco, CA (AGU)	***Year 1***	***Year 2***	***Year 3***	***Cumulative***
Airfare: $500/flight	500	515	530	$1,545
Lodging: $288/night @ 4 nights	1,152	1,187	1,222	$3,561
Per Diem: $76/day @ 5 days	380	391	403	$1,174
Ground Transportation	100	103	106	$309
Checked bags: $60/person (roundtrip)	120	124	127	$371
Conference Registration/abstract	660	680	700	$2,040
Total	**2,912**	**2,999**	**3,089**	**9,000**

III. OTHER DIRECT – $61,254

1. ***Computer Services ($8,710)***: ***ATS Network Use ($2,058)*** - In order to perform the proposed research, it is necessary to use the Atmospheric Science Ethernet to connect to the Internet (this is a specialized network used by employees). The Department charges a fee for such connections. The current approved rate is $47 per month, per person. ***ATS Computer Systems Specialist ($6,652)*** - The systems specialist will provide computing support for the project including the procurement, installation, and maintenance of needed hardware and software. The current approved rate for this service is $8,609/month and this budget includes 0.25 month of support. *The Computer Service charges are rates developed using Section 200.468 (Specialized Service Facilities) of the OMB Uniform Guidance and Colorado State University's internal policy for computing, charging and auditing such Service Facilities.* Each additional year includes a 3% inflation factor.

	Year 1			***Year 2***			***Year 3***			
ATS Network Use	Rate	PM	Total	Rate	PM	Total	Rate	PM	Total	Total
E. Riley		5.0			5.0			5.0		
E. Maloney		0.5			0.5			0.5		
C. DeMott		2.0			2.0			1.75		
TBN, GRA		6.75			6.75			6.75		
Totals	$47	14.25	**$670**	$48.41	14.25	**$690**	$49.86	14.00	**$698**	**$2,058**
ATS ComSys	8,609	0.25	**$2,152**	$8867	0.25	**$2,217**	$9,133	0.25	**$2,283**	**$6,652**

2. ***Materials/Supply ($3,000):*** Funding is requested to purchase a workstation for the GRA. The computer is required to complete the project tasks, which will include generation of

publications and a graduate thesis, presentation of results at conferences and defenses, conducting data analysis, communicating with scientific colleagues, and doing research of the scientific literature. Cost is based on recent similar purchases.

3. ***Publications ($8,964)***: Funding is requested for one publication per year in a peer-reviewed scientific journal. The breakdown of costs is estimated: $145/page x 20 pages. Charges are based on the current American Meteorological Society (AMS) prices and include a 3% inflation factor in years 2 and 3.
4. ***In-State Tuition ($40,580):*** Funding is requested to pay 2 semesters of tuition for the graduate student per year. The current tuition rate is $6250 per semester. Each additional year includes an 8% inflation factor.

Other Direct Costs	***Year 1***	***Year 2***	***Year 3***	***Total***
1. *Computer Services:*	$2,822	$2,907	$2,981	$8,710
2. Materials/Supply	$3000			$3,000
3. Publications	$2,900	$2,987	$3,077	$8,964
4. In-State Tuition	$12,500	$13,500	$14,580	$40,580
Total Other Direct Costs:	**$21,222**	**$19,394**	**$20,638**	**$61,254**

IV. INDIRECT COSTS – $128,028

An Indirect Rate of 35% is charged on this proposal. This is the negotiated rates for CIRA/Colorado State University for the period effective 1 July 2019 and running through June 30, 2024. This is reduced from the NICRA of 52%. The rate is applied to Modified Total Direct Costs (MTDC). MTDC is defined as Total Direct Costs less Equipment, GRA Tuition, and Subcontracts > $25,000. This rate was approved in amendment#0 of award# NA19OAR4320073.

OMB Number: 4040-0007
Expiration Date: 02/28/2022

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
Linda Loing	Research Administrator
APPLICANT ORGANIZATION	DATE SUBMITTED
Colorado State University	11/19/2020

Standard Form 424B (Rev. 7-97) Back

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: Colorado State University

* AWARD NUMBER: NA19OAR4320073

* PROJECT NAME: Process-oriented evaluation of oceanic equatorial waves in t

Prefix: Ms.

* First Name: Linda

Middle Name:

* Last Name: Loing

Suffix:

* Title: Research Administrator

* SIGNATURE: Linda Loing

* DATE: 11/19/2020

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		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. NOAA-OAR-CPO-2021-2006389	11.431	$	$	$ 534,400.00	$	$ 534,400.00
2.						
3.						
4.						
5. Totals		$	$	$ 534,400.00	$	$ 534,400.00

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Prescribed by OMB (Circular A -102) Page 1

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) NOAA-OAR-CPO-2021-2006389	(2) N/A	(3) N/A	(4)	(5)
a. Personnel	$ 91,247.00	$ 93,985.00	$ 93,934.00	$	$ 279,166.00
b. Fringe Benefits	18,667.00	19,227.00	19,058.00		56,952.00
c. Travel	2,912.00	2,999.00	3,089.00		9,000.00
d. Equipment					
e. Supplies	3,000.00				3,000.00
f. Contractual					
g. Construction					
h. Other	18,222.00	19,394.00	20,638.00		58,254.00
i. Total Direct Charges (sum of 6a-6h)	134,048.00	135,605.00	136,719.00		$ 406,372.00
j. Indirect Charges	42,542.00	42,737.00	42,749.00		$ 128,028.00
k. TOTALS (sum of 6i and 6j)	$ 176,590.00	$ 178,342.00	$ 179,468.00	$	$ 534,400.00
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. 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	$ 176,590.00	$ 58,864.00	$ 58,863.00	$ 58,863.00	$
14. Non-Federal	$				
15. TOTAL (sum of lines 13 and 14)	$ 176,590.00	$ 58,864.00	$ 58,863.00	$ 58,863.00	$

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. NOAA-OAR-CPO-2021-2006389	$ 178,342.00	$ 179,468.00	$	$
17.				
18.				
19.				
20. TOTAL (sum of lines 16 - 19)	$ 178,342.00	$ 179,468.00	$	$

SECTION F - OTHER BUDGET INFORMATION	
21. Direct Charges:	22. Indirect Charges: Predetermined; Base - $365,792; Total - $128,028
23. Remarks:	

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

Application for Federal Assistance SF-424

* 1. Type of Submission:	☐ Preapplication ☒ Application ☐ Changed/Corrected Application
* 2. Type of Application:	☒ New ☐ Continuation ☐ Revision
* If Revision, select appropriate letter(s):	
* Other (Specify):	
* 3. Date Received:	11/19/2020
4. Applicant Identifier:	147195
5a. Federal Entity Identifier:	
5b. Federal Award Identifier:	

State Use Only:

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

8. APPLICANT INFORMATION:

* a. Legal Name:	Colorado State University
* b. Employer/Taxpayer Identification Number (EIN/TIN):	84-6000545
* c. Organizational DUNS:	7859796180000

d. Address:

* Street1:	2002 Campus Delivery
Street2:	601 S. Howes St.
* City:	Fort Collins
County/Parish:	
* State:	CO: Colorado
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	80523-2002

e. Organizational Unit:

Department Name:	Sponsored Programs
Division Name:	VP for Research

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

Prefix:	Mr.
* First Name:	William
Middle Name:	
* Last Name:	Moseley
Suffix:	
Title:	Senior Research Administrator
Organizational Affiliation:	
* Telephone Number:	970-491-1541
Fax Number:	970-491-6147
* Email:	bill.moseley@colostate.edu

Application for Federal Assistance SF-424

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

H: Public/State Controlled 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 evaluation of oceanic equatorial waves in the Indian and west Pacific Ocean forced by intraseasonal westerly wind events

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: CO-002
* b. Program/Project: CO-002

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	534,400.00
* b. Applicant	0.00
* c. State	0.00
* d. Local	0.00
* e. Other	0.00
* f. Program Income	0.00
* g. TOTAL	534,400.00

*** 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: Linda
Middle Name:
* Last Name: Loing
Suffix:

* Title: Research Administrator

* Telephone Number: 970-491-6586
Fax Number: 970-491-6147

* Email: Linda.Loing@colostate.edu

* Signature of Authorized Representative: Linda Loing
* Date Signed: 11/19/2020