Essay
Please describe in 300 words or less how the proposed work will foster your growth as an interdisciplinary environmental scholars and/or problem-solver.

This internship would not only foster my growth greatly as an Oceans major, but be an integral step in my career.

As an Oceans Major, this internship will be an excellent academic supplement for several reasons. By learning to model climate change, I will gain a better understanding of the physical oceanographic and atmospheric processes that interact with a globally warming climate. In addition, it will assist me in considering the biological aspects that will be affected by climate change, given the complex interactions that occur between the physical ocean and the organisms in each ecosystem. Furthermore, the internship will increase my exposure to the facets of anthropogenic climate change drivers. Another extremely important academic advantage that I will receive is the experience of working with professionals in a lab setting through hands-on and extremely applicable experience. While the academic benefits that I will receive will be invaluable the internship will also offer me preparation for a career.

My internship will give me great preparation in that I am extremely interested in devoting my future towards coral reef and climate research in the near future and environmental policy in the distant future. Through the internship I will gain valuable networking opportunities and lessons from the wisdom of my more mature and experienced colleagues. Not only will I receive skills in programming and developing models for climate change but working with a team of diverse and experienced environmental academics, approaching scientific inquiries, and effective science communication; these are extremely important for future research and policy positions. Finally, the internship will provide me with future direction for approaching my career path as a scientist and political advocate for oceanic conservation.

Ultimately, not only will this internship be a valuable learning experience, but an integral step towards developing my career in sustainable science.

Emergence of Multiple Ocean Ecosystem Drivers in a Large Ensemble Suite with an Earth System Model Revised

Introduction:

Recent warming, acidification, deoxygenation, and anthropogenic biological changes have increasingly impacted ocean ecosystems. These ocean ecosystem drivers can occur simultaneously, however, so detecting their trends is complicated. One of the main complications is the presence of noise that is associated with natural variability in the climate system. Due to this interference, it is crucial to consider all contributing aspects of climate change drivers when creating models that will represent future change. As a result, I will be adding carbon surface trends as a driver to a pre-established climate model[1] that has been based off of the Pacific Warm pool and Coral triangle data.

Oceanic surface water carbon trends will be a crucial addition because they significantly affect the physical and biological conditions of the ocean and climate in several ways. Physically, ocean surface water absorption of carbon dioxide directly affects its acidification levels, as represented by the chemical equation: $CO_2 + H_2O \rightarrow H^+ + HCO_3^-$. In addition, CO_2 is also released by surface waters, which can further affect climate change. Biologically, increasing acidification of ocean waters prevents countless, calcium-bicarbonate-producing organisms from successfully forming skeletons; without a functional skeleton their chances of survival drop drastically. Coral reef need calcium carbonate to form a skeleton to protect their dinoflagellates, (Symbiodinum); and other coral symbionts. However, ocean acidification produces carbonic acid, which reduces the amount of calcium carbonate available for coral reefs for production of calcium carbonate skeletons. Evidently, by adding CO_2 surface trends to the model, we can better understand the cycles that affect climate change and ocean ecosystem health. Furthermore we will have the ability to improve estimates on human influence through surface water CO_2 uptake and production data.

In order to improve the accuracy of these models in predicting the future climate and physical and biological processes of the Pacific Warm Pool, we will be adding surface water CO_2 trends through collaboration with Professor Sarmiento's colleague, Masao Ishii at MRI in Tsukuba. Through this collaboration we will use the SOCAT and PACIFICA carbon data products. My main job will involve learning and running Matlab to evaluate model output stressor data, considering and presenting methods to connect observations and modeling efforts, and adding those that are considered viable. This will be enhancing the 30-member model between 1950-2100 that the lab has conducted, including stressors/drivers for the tropics such as SST, omega aragonite levels, ocean acidification, and perturbations to the height of the sea surface.

The Addition of Surface Carbon Data: Further Implications:

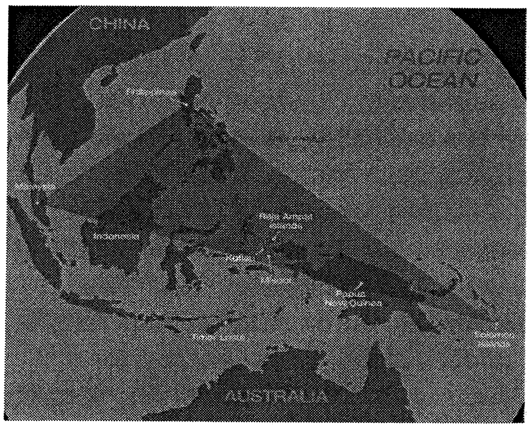
Oceanic surface water carbon trends will be a crucial addition to the current model in that they will improve the accuracy of predicting future trends. Accuracy will be improved in that the model will include a new significant factor that affects the physical conditions of the ocean and its climate. The ocean is not only the world's largest carbon sink, but a significant heat sink. As a result, it plays a crucial role in the regulation of climate due to its interactions with the atmosphere. It is also simultaneously affected by conditions of the atmosphere, creating a complex and typically positive feedback loop. By adding oceanic surface water CO_2 trends, we

1. Rodgers, K.B., Lin, J., Frolicher, T.L. "Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an earth system model". Copernicus Publications. (8 Dec 2013)

can better understand and predict changes in the climate and physical state of the Ocean in the Pacific Warm Pool. In addition it will create a more holistic understanding of anthropogenic affects on climate, considering the immense impact man-made carbon has on the carbon, and water cycle that influence the physical conditions of the atmosphere and water of the Warm Pool.

The current model has already identified ocean acidification as having an early emergence, during the 20th century, which coincides with the steep increases of carbon trends that occur within 1910 until the present. Ocean acidification is directly linked to carbon uptake. By adding the surface water carbon trend to the current model, it will additionally emphasize the directly proportionate relationship between CO_2 concentration trends, ocean acidification trends, and coral reef health. This will help demonstrate the human influence on the physical and biological conditions of ocean through increased production of CO_2, which is absorbed by the surface waters of the ocean.

The Site:



The main focus of this study will be the Western Equatorial Pacific; this is an ideal focus in that it is not only a significant portion of the ocean that plays an essential role in the cycle of climate change, but it also contains the Coral Triangle. The Coral Triangle has already given the study a plethora of data for the previously used drivers, and was also a focus of Masao Ishii's carbon surface trend data. The addition of these data, will greatly improve the models already produced for this region. While the model will include data from surrounding oceans that influence the physical conditions of the Western Equatorial Pacific, the main ensemble and focus of data and modeling will in the Western Equatorial Pacific, namely the Coral Triangle.

Preliminary Hypothesis:

The addition of surface water CO_2 trends will improve the accuracy of the current earth system model by including the intertwined relationships of the carbon cycle and the water cycle, which have critical impacts on the physical conditions of the ocean and atmosphere. Furthermore, it will not only demonstrate a direct relationship between CO_2 uptake by surface water and ocean acidification, but will provide a direct relationship between anthropogenic carbon production and oceanic surface water carbon uptake. The current compilation of data demonstrates that ocean acidification has markedly increased since the 20th century. CO_2 data, which has shown significant increases in global trends, will further demonstrate how increase use of fossil fuels and production of carbon dioxide.

Methods and Analyses:

In this research, I will comprehensively use Large Initial-Condition Ensemble Simulations and the Earth System Model under a historical/RCP8.5 pathway over 1950–2100. This will be used to study emergence characteristics for the four individual and combined drivers previously mentioned with the addition of ocean surface carbon trends; this will improve the thoroughness and accuracy of the model.

As previously mentioned, the pre-established model "Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an earth system model", has shown that ocean acidification emerges much earlier than other drivers, namely during the 20th century, by using a one-standard deviation (67 % confidence) threshold of signal-to-noise to define emergence with a 30-year trend window. This is for the combined multiple-driver field, which reveals emergence patterns that are fairly high over much of the Southern Ocean, North Pacific, and Atlantic Ocean. While these results have implications for the optimization of the ocean observing system, risk assessment and mitigation strategies, they exclude ocean surface water carbon trends.

The 30 ensemble members will be run with the same Earth System Model (ESM2M), which was developed at the Geophysical Fluid Dynamics Laboratory at Princeton University (Dunne et al., 2012, 2013). The physical state model underlying ESM2M is the updated version of the coupled model CM2.125 (Delworth et al., 2006). It consists of the 1-degree version of the MOM4p1 ocean model (Griffies, 2009) coupled to an approximately 2-degree configuration of the AM2 atmospheric model (Anderson et al., 2004). The ocean biogeochemical model is the Tracers of Ocean Phytoplankton and Allometric Zooplankton code version 2; it includes 30 tracers to represent cycles of carbon, oxygen, and the major macronutrients and iron (Dunne et al., 2010). The 30 ensemble members are defined as such: by using model state snapshot for the ends of days 1–29 in January 1950 as the initial model states for 1 January 1950 for each of the ensemble members 2–30, we will correct for this difference. This will be repeated for the time period of 1950-2000. Given that decadal modulations of ENSO are the most pronounced driver of decadal physical variability in this coupled model, decadal variability will be randomized amongst the individual ensemble members.

The four ecosystem drivers that have already been considered in this study are surface sea water saturation state with respect to aragonite, a mineral phase of calcium carbonate, sea surface temperature (SST), subsurface O_2 concentration vertically integrated from 100 to 600 m, net primary production (NPP) vertically integrated over the top 100 m, and carbon dioxide levels integrated from sea level to 20 m. The focus on subsurface O_2 concentrations allows us to characterize regimes ranging from oxygen minimum zones to the main thermocline of polar and circumpolar regions. The process of incorporating surface water carbon uptake as a driver will follow the same methods as the previous 30 member ensembles.

1. Rodgers, K.B., Lin, J., Frolicher, T.L. "Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an earth system model". Copernicus Publications. (8 Dec 2013)

Tentative Work Plan:

This summer I will be working at Princeton University's Professor Jorge Sarmiento's lab as an intern. My internship will begin June 15th and terminate August 20th. I will work 40 hours a week in the lab. My main responsibilities will roughly follow the schedule below:

Week 1-2	• learning and running Matlab to evaluate model output stressor data • Learning the language of the pre-established Model • considering and presenting methods to connect observations and modeling efforts, and adding those that are considered viable
Week 2-10	• running a "journal club" in which other Princeton researchers, postdocs, and will read through a series of papers that pertain to oceanographic and climate research and publish them in a comprehensive manner
Week 3-10	• assisting in adding and evaluating surface water carbon uptake data
Week 5-10	• assisting in refining the scope of the project by focusing on the Line Islands region and evaluating its stressors for future additions to model drivers

Tentative Budget:

Item Description:	Budget Requested:	Duration:	Total Budget Requested:
Student Stipend	$640/40-hour-week	10 weeks	**$6400**

Works Cited:

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Dunne, J. P., Gnanadesikan, A., Sarmiento, J. L., and Slater, R. D.: Technical description of the prototype version (v0) of Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ) ocean biogeochemical model as used in the Princeton IFMIP model, Biogeosciences, 7 (Suppl.), 3593, doi:10.4195/bg-7-3593-2010, 2010.

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1. Rodgers, K.B., Lin, J., Frolicher, T.L. "Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an earth system model". Copernicus Publications. (8 Dec 2013)