Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number

12-PO12-0034

NASA PROCEDURE FOR HANDLING PROPOSALS

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SECTION I - Proposal Information

Principal Investigator **Marlos Goes**	E-mail Address **mgoes@rsmas.miami.edu**	Phone Number **305-361-4533**

Street Address (1) **4301 Rickenbacker Cswy**	Street Address (2) **225/2**

City **Miami**	State / Province **FL**	Postal Code **33149-1026**	Country Code **US**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget
02 / 01 / 2013	**01 / 31 / 2016**	**498,448.00**	**97,108.00**	**200,249.00**	**201,091.00**

SECTION II - Application Information

NASA Program Announcement Number **NNH12ZDA001N-PO**	NASA Program Announcement Title **Physical Oceanography**

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*
NASA , Headquarters , Science Mission Directorate , Earth Science

Date Submitted **06 / 29 / 2012**	Submission Method **Electronic Submission Only**	Grants.gov Application Identifier	Applicant Proposal Identifier

Type of Application **New**	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted

International Participation **No**	Type of International Participation

SECTION III - Submitting Organization Information

DUNS Number **152764007**	CAGE Code **1NV47**	Employer Identification Number (EIN or TIN) **590624458**	Organization Type **8H**

Organization Name (Standard/Legal Name) **University Of Miami, Key Biscayne**	Company Division **SPONSORED PROGRAMS - RSMAS**
Organization DBA Name **UNIVERSITY OF MIAMI ROSENSTIEL MARINE**	Division Number

Street Address (1) **4600 RICKENBACKER CSWY**	Street Address (2)

City **KEY BISCAYNE**	State / Province **FL**	Postal Code **33149-1031**	Country Code **USA**

SECTION IV - Proposal Point of Contact Information

Name **Bonnie Townsend**	Email Address **btownsend@rsmas.miami.edu**	Phone Number **3054214084**

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in the two Certifications and one Assurance contained in this NRA (namely, (i) the Assurance of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, and Assurances Regarding Lobbying and Debarment and Suspension.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name **Bonnie Townsend**	AOR E-mail Address **btownsend@rsmas.miami.edu**	Phone Number **305-421-4084**

AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)* **Date**

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION VI - Team Members

Team Member Role **PI**	Team Member Name **Marlos Goes**	Contact Phone **305-361-4533**	E-mail Address **mgoes@rsmas.miami.edu**
Organization/Business Relationship **University Of Miami, Key Biscayne**		Cage Code **1NV47**	DUNS# **152764007**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Co-I/Institutional PI**	Team Member Name **Ryan Sriver**	Contact Phone **574-514-0848**	E-mail Address **rsriver@psu.edu**
Organization/Business Relationship **University Of Illinois, Urbana-Champaign**		Cage Code **4B808**	DUNS# **041544081**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **Gregory Foltz**	Contact Phone **305-361-4430**	E-mail Address **gregory.foltz@noaa.gov**
Organization/Business Relationship **National Environmental Satellite, Data And Information Service, Miami**		Cage Code **1DJC8**	DUNS# **039261847**
International Participation **No**	U.S. Government Agency **National Oceanic and Atmospheric Administration (NOAA)**		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **Gustavo Goni**	Contact Phone **305-361-4339**	E-mail Address **gustavo.goni@noaa.gov**
Organization/Business Relationship **National Environmental Satellite, Data And Information Service, Miami**		Cage Code **1DJC8**	DUNS# **039261847**
International Participation **No**	U.S. Government Agency **National Oceanic and Atmospheric Administration (NOAA)**		Total Funds Requested **0.00**

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION VII - Project Summary

Tropical cyclones (TCs) are extreme weather events that adversely affect coastal populations worldwide. Their frequency, distribution, and intensities are closely linked to tropical ocean variability through atmospheric and oceanic interactions on intra-seasonal to inter-decadal timescales. The full extent of the impact of TCs on the upper tropical ocean, and the potential for feedbacks, remain poorly understood, due in part to our inability to resolve TC processes in both observations and Earth system models.

Recent modeling studies show TCs can impact upper ocean heat and mixing budgets, circulation patterns, and transports. Our preliminary results suggest strong connections may also exist between these processes and equatorial dynamics, with possible links to tropical modes of variability (e.g. ENSO in the Pacific and the equatorial and meridional modes in the Atlantic). While TC connections have been examined for subtropical dynamics, equatorial connections remain largely unexplored. These subtropical/tropical interactions, and the associated feedbacks, may be important for understanding the dynamical behavior of the global oceans, and how the behavior may change in the future.

Our goal is to investigate the impact of TCs in the tropical and subtropical global oceans with a special focus on the transient ocean response to TC forcing. Our research plan centers around 3 questions:

1. How does transient TC-induced surface forcing affect upper ocean dynamics of the tropical and subtropical oceans?
2. What are potential feedbacks between TC activity and tropical modes of variability that can influence the dynamics of the tropical and subtropical oceans?
3. Does the inclusion of realistic TC forcing in a state-of-the-art global ocean general circulation model improve hindcast skill?

To confront these questions, we will combine observational analyses from NASA remote sensing and CLIVAR data products with a high-resolution global ocean model to investigate TC-ocean interactions at the surface and the dynamical implications. We will conduct multi-decadal global hindcast model experiments and examine the sensitivity of a high-resolution ocean model to TC forcing against control runs without TC forcing fields. The TC runs will feature global TC fields from NASA satellite-derived rain rates (e.g. TRMM) and high-resolution wind fields (e.g. CCMP), with additional scaling from Best Track wind estimates as necessary.

Analysis and comparisons will be made on various spatial and temporal scales: from daily time scales examining local storm responses, to interannual scales focusing on basin-wide variability and possible teleconnections with tropical modes of variability. We will diagnose model sensitivity to TC forcing and hindcast improvement by comparison with available observational NASA and U.S. CLIVAR in situ products. Relevant quantities include: responses in SST (e.g. GHRSST) and salinity (e.g. AQUARIUS) to TC forcing, and the evolution of changes in ocean heat content and transport using altimetry and moorings (e.g. TOPEX/POSEIDON, Jason-1,2, TAO, PIRATA).

This project will promote new and novel applications of pre-existing NASA satellite missions and build on the previous research that use idealized observational and modeling techniques, which have demonstrated viable connections between TCs and upper ocean dynamics, heat and freshwater budgets, and transports. We will provide a rigorous examination of the ocean's dynamical response to TC forcing on multiple spatial and temporal scales and explore possible connections and interactions with tropical modes of variability and larger-scale ocean circulations. Because TC activity is closely linked to oscillatory climate patterns and variability, understanding dynamical relationships between TCs and the upper ocean, and reliably capturing these processes in Earth system models, will ultimately result in better climate predictions.

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SECTION VIII - Other Project Information

Proprietary Information

Is proprietary/privileged information included in this application?
Yes

International Collaboration

Does this project involve activities outside the U.S. or partnership with International Collaborators?
No

Principal Investigator	Co-Investigator	Collaborator	Equipment	Facilities
No	**No**	**No**	**No**	**No**

Explanation :

NASA Civil Servant Project Personnel

Are NASA civil servant personnel participating as team members on this project (include funded and unfunded)?
No

Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year
Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
Organization Name : **University Of Miami, Key Biscayne**	

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION VIII - Other Project Information

Environmental Impact

Does this project have an actual or potential impact on the environment? **No**	Has an exemption been authorized or an environmental assessment (EA) or an environmental impact statement (EIS) been performed? **No**

Environmental Impact Explanation:

Exemption/EA/EIS Explanation:

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SECTION VIII - Other Project Information

Historical Site/Object Impact

Does this project have the potential to affect historic, archeological, or traditional cultural sites (such as Native American burial or ceremonial grounds) or historic objects (such as an historic aircraft or spacecraft)?

No

Explanation:

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

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SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: Tropical Cyclones and Modes of Variability

Question 2 : Type of institution:

Answer: Educational Organization

Question 3 : Will any funding be provided to a federal government organization including NASA Centers, JPL, other Federal agencies, government laboratories, or Federally Funded Research and Development Centers (FFRDCs)?

Answer: No

Question 4 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: N/A

Question 5 : Does this proposal include the use of NASA-provided high end computing?

Answer: No

Question 6 : Research Category:

Answer: 2) Data analysis/data restoration/data assimilation/Earth System modeling (including Guest Observer Activities)

Question 7 : Team Members Missing From Cover Page:

Answer:

NA

Question 8 : This proposal contains information and/or data that are subject to U.S. export control laws and regulations including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR).

Answer: No

Question 9 : I have identified the export-controlled material in this proposal.

Answer: N/A

Question 10 : I acknowledge that the inclusion of such material in this proposal may complicate the government's ability to evaluate the proposal.

Answer: N/A

Question 11 : Does the proposed work include any involvement with collaborators in China or with Chinese organizations, or does the proposed work include activities in China?

Answer: No

Question 12 : Are you planning for undergraduate students to be involved in the conduct of the proposed investigation?

Answer: No

Question 13 : If yes, how many different undergraduate students?

Answer: N/A

Question 14 : What is the total number of student-months of involvement for all undergraduate students over the life of the proposed investigation?

Answer: NA

Question 15 : Provide the names and current year (1,2,3,4) for any undergraduate students that have already been identified.

Answer:

NA

Question 16 : Are you planning for graduate students to be involved in the conduct of the proposed investigation?

Answer: No

Question 17 : If yes, how many different graduate students?

Answer: N/A

Question 18 : What is the total number of student-months of involvement for all graduate students over the life of the proposed investigation?

Answer: NA

Question 19 : Provide the names and current year (1,2,3,4, etc.) for any graduate students that have already been identified.

Answer:

NA

PI Name : **Marlos Goes**	**NASA Proposal Number**
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Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Cumulative Budget

Budget Cost Category	Funds Requested ($)			
	Year 1 ($)	Year 2 ($)	Year 3 ($)	Total Project ($)
A. Direct Labor - Key Personnel	39,772.00	41,761.00	43,849.00	125,382.00
B. Direct Labor - Other Personnel	0.00	0.00	0.00	0.00
Total Number Other Personnel	0	0	0	0
Total Direct Labor Costs (A+B)	39,772.00	41,761.00	43,849.00	125,382.00
C. Direct Costs - Equipment	5,000.00	0.00	0.00	5,000.00
D. Direct Costs - Travel	4,000.00	4,000.00	4,000.00	12,000.00
Domestic Travel	4,000.00	4,000.00	4,000.00	12,000.00
Foreign Travel	0.00	0.00	0.00	0.00
E. Direct Costs - Participant/Trainee Support Costs	0.00	0.00	0.00	0.00
Tuition/Fees/Health Insurance	0.00	0.00	0.00	0.00
Stipends	0.00	0.00	0.00	0.00
Travel	0.00	0.00	0.00	0.00
Subsistence	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00
Number of Participants/Trainees				0
F. Other Direct Costs	16,233.00	123,176.00	126,573.00	265,982.00
Materials and Supplies	0.00	0.00	0.00	0.00
Publication Costs	2,000.00	2,000.00	2,000.00	6,000.00
Consultant Services	0.00	0.00	0.00	0.00
ADP/Computer Services	0.00	0.00	0.00	0.00
Subawards/Consortium/Contractual Costs	14,233.00	121,176.00	124,573.00	259,982.00
Equipment or Facility Rental/User Fees	0.00	0.00	0.00	0.00
Alterations and Renovations	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00
G. Total Direct Costs (A+B+C+D+E+F)	65,005.00	168,937.00	174,422.00	408,364.00
H. Indirect Costs	32,103.00	31,312.00	26,669.00	90,084.00
I. Total Direct and Indirect Costs (G+H)	97,108.00	200,249.00	201,091.00	498,448.00
J. Fee	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	97,108.00	200,249.00	201,091.00	498,448.00
Total Cumulative Budget				498,448.00

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2013**	End Date : **01 / 31 / 2014**	Budget Type : **Project**	Budget Period : **1**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Goes, Marlos	PI	0.00	5			29,374.00	10,398.00	39,772.00
							Total Key Personnel Costs	39,772.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	39,772.00

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2013**	End Date : **01 / 31 / 2014**	Budget Type : **Project**	Budget Period : **1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Computer**	5,000.00
	Total Equipment Costs	5,000.00

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	4,000.00
2. Foreign Travel	0.00
Total Travel Costs	4,000.00

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		0.00
2. Stipends		0.00
3. Travel		0.00
4. Subsistence		0.00
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	0.00

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2013**	End Date : **01 / 31 / 2014**	Budget Type : **Project**	Budget Period : **1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**14,233.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**16,233.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**65,005.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	**Funds Requested ($)**
MTDC	**53.50**	**60,005.00**	**32,103.00**
Cognizant Federal Agency: **DHHS, Darryl Mayes, 202/401-2808**		**Total Indirect Costs**	**32,103.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**97,108.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**97,108.00**

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
Organization Name : **University Of Miami, Key Biscayne**	
Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**	

SECTION X - Budget

Start Date : **02 / 01 / 2014**	End Date : **01 / 31 / 2015**	Budget Type : **Project**	Budget Period : **2**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Goes, Marlos	PI	0.00	5			30,843.00	10,918.00	41,761.00
							Total Key Personnel Costs	41,761.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	41,761.00

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
Organization Name : **University Of Miami, Key Biscayne**	

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2014**	End Date : **01 / 31 / 2015**	Budget Type : **Project**	Budget Period : **2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**4,000.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**4,000.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Marlos Goes**	**NASA Proposal Number**
Organization Name : **University Of Miami, Key Biscayne**	**12-PO12-0034**

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2014	**01 / 31 / 2015**	**Project**	**2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**121,176.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**123,176.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**168,937.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	**Funds Requested ($)**
MTDC	**53.50**	**58,528.00**	**31,312.00**
Cognizant Federal Agency: **DHHS, Darryl Mayes, 202/401-2808**		**Total Indirect Costs**	**31,312.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**200,249.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**200,249.00**

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
Organization Name : **University Of Miami, Key Biscayne**	

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2015**	End Date : **01 / 31 / 2016**	Budget Type : **Project**	Budget Period : **3**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Goes, Marlos	PI	0.00	5			32,385.00	11,464.00	43,849.00
							Total Key Personnel Costs	43,849.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	43,849.00

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
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Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2015**	End Date : **01 / 31 / 2016**	Budget Type : **Project**	Budget Period : **3**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	0.00

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	4,000.00
2. Foreign Travel	0.00
Total Travel Costs	4,000.00

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		0.00
2. Stipends		0.00
3. Travel		0.00
4. Subsistence		0.00
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	0.00

PI Name : **Marlos Goes**	**NASA Proposal Number** **12-PO12-0034**
Organization Name : **University Of Miami, Key Biscayne**	

Proposal Title : **Transient response of the upper ocean to tropical cyclones and relationship with tropical modes of variability**

SECTION X - Budget

Start Date : **02 / 01 / 2015**	End Date : **01 / 31 / 2016**	Budget Type : **Project**	Budget Period : **3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	0.00
2. Publication Costs	2,000.00
3. Consultant Services	0.00
4. ADP/Computer Services	0.00
5. Subawards/Consortium/Contractual Costs	124,573.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
Total Other Direct Costs	126,573.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	174,422.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC	53.50	49,849.00	26,669.00
Cognizant Federal Agency: DHHS, Darryl Mayes, 202/401-2808		**Total Indirect Costs**	26,669.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	201,091.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	201,091.00

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ABSTRACT

Our goal is to investigate the impact of tropical cyclones (TCs) on the tropical and subtropical oceans with a special focus on the dynamic response to transient TC forcing. Our research plan centers around three fundamental questions: (1) How does transient TC-induced surface forcing affect upper ocean dynamics of the tropical and subtropical oceans? (2) What are potential interactions between TC activity and tropical modes of variability that can influence climatic variability on inter-seasonal to decadal scales? (3) Does the inclusion of realistic TC forcing in a state-of-the-art global ocean general circulation model improve hindcast skill?

To confront these questions, we will combine observational analyses from NASA remote sensing and CLIVAR data products with a high-resolution global ocean model to investigate near-surface TC-ocean interactions, in order to examine how TCs influence upper ocean energy/mixing budgets and explore dynamical implications. We will diagnose the ocean response to TC forcings on various spatial and temporal scales: from daily time scales examining local storm responses, to interannual scales focusing on basin-wide variability and possible teleconnections with tropical modes of variability.

The project will highlight novel utilization of various observational platforms, including: local and global SST (e.g. GHRSST) and salinity (e.g. AQUARIUS) responses to TC forcing, and the evolution of changes in ocean heat content and transport using altimetry and moorings (e.g. TOPEX/POSEIDON, Jason-1,2, TAO, PIRATA). In addition, the modeling component will feature analyzed TC fields of NASA satellite-derived rain rates (e.g. TRMM) and high-resolution wind fields (e.g. CCMP). We will compare and contrast analyzed fields of TC-impacts with the modeled responses using well-studied and validated techniques. The end result will be a better mechanistic understanding of how TCs contribute to upper-ocean dynamics and variability, with implications for improving inter-seasonal to inter-decadal climate predictability.

1. Background

1.1 Tropical Cyclones as Ocean Mixers

Ocean mixing is an important physical process for the maintenance of the large-scale ocean transports of volume and heat (Stommel, 1961; Munk and Wunsch, 1998, Talley, 2003; Wunsch and Ferrari, 2004), and biogeochemical cycles (Sabine et al., 2004, Doney et al., 2004). The current generation of climate models lacks a realistic representation of oceanic mixing due to the inability of models to resolve mechanistic processes responsible for the mixing. Due to its non-linear characteristic, uncertainty in diffusivity parameters can lead to considerably divergent climate hindcasts, projections, and mechanistic interpretations (Forest et al., 2002, Goes et al., 2010, Olson et al., 2012). Transient wind forcing and weather events, such as tropical cyclones, have been shown to increase microstructure mixing estimates by an order of magnitude (Oakey et al., 2004), with potential to impact global mixing budgets (Sriver and Huber, 2007; Sriver et al., 2008).

The tropical oceans maintain strong stratification in the upper regions, and model simulations show low latitude diapycnal mixing is important in maintaining the ocean heat transport (OHT) (Scott and Marotzke, 2003). Furthermore, modeling results suggest transient mixing localized in space and time may influence large-scale circulation patterns (Boos et al., 2004). Tropical cyclones are transient events, but their high wind speeds, coupled with the high fraction of wind energy that results in turbulent mixing, make them efficient upper ocean mixers (Leipper, 1967; Chang and Anthes, 1978; D’Asaro, 2001), as is observed by the cold wakes associated with these storms (See Figure 1). The frequency, intensity, and distribution of TCs may be directly linked to the mean climate state by the potential relationship between TC activity and sea surface temperatures (SST) (Emanuel, 2005; Trenberth, 2005; Webster et al., 2005; Sriver and Huber, 2006), the El Niño-Southern Oscillation (ENSO) (Chan, 1985), and widespread changes in vertical wind shear (Vecchi and Soden, 2007b). Thus, they may provide a climate-sensitive source of ocean mixing that is not captured in the state-of-the-art climate models (e.g. IPCC FAR; Meehl et al, 2007).

Modeling (Bender and Ginis, 1993; Wada, 2005) and observational (Black and Dickey, 2008; Huang et al., 2009) studies have sought to constrain the importance of the mechanisms responsible for TC-induced cooling of the upper ocean. TCs cool the upper ocean through multiple mechanisms such as geostrophic and near-inertial advection, surface fluxes, and entrainment across the base of the mixed layer (Dickey et al., 1998; Jacob et al., 2000). Research has shown the dominant factor for TC-induced upper-ocean cooling is entrainment at the base of the mixed layer caused by the excitation of the near-inertial wave field (Shay et al., 1992; Shay et al., 1998; Jacob et al., 2000; Black and Dickey, 2008). Shear between the inertial currents and the background velocity within the thermocline induces vertical velocities, which propagate wave energy to significant depths and small scales necessary for diapycnal mixing. An additional important component of the vertical redistribution of seawater is Ekman pumping (upwelling), or the geostrophic response to cyclonic wind forcing. The relative contribution of the inertial versus the geostrophic response to the vertical mixing budget depends on multiple factors, including TC size, intensity, and translation speed (Mei et al., 2012). For example, a slow-moving large storm will likely lead to more upwelling via Ekman pumping compared to a fast-moving small storm, which will likely yield a larger inertial wave response. In this instance, the former storm has a larger aspect ratio, thus enabling more geostrophic response compared to the fast moving small storm (Ginis, 2002). However, the ocean response depends on the background regional and seasonal conditions.

Transient ocean response to tropical cyclones

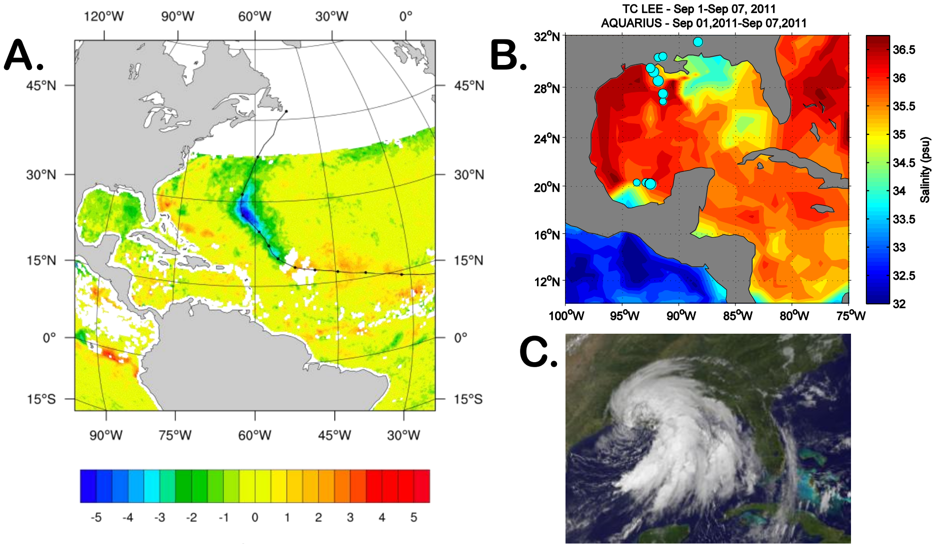


Figure 1: (A) (Adapted from Done et al., 2009). Sea surface temperature anomaly (in deg C) following Hurricane Gert, 1999. The figure highlights the impact of a single tropical cyclone on the upper ocean. Mixing area is equivalent in size to the US eastern seaboard, and surface cooling reflects upwelling depths of more than 100 meters. (B) Aquarius salinity (contour) and the tropical storm Lee track (Sep 2011) in the Gulf of Mexico. (C) Satellite image of storm Lee.

The extent of TC-induced mixing is apparent in the depressed SST occurring in the wakes of the storms (Price, 1981) and in phytoplankton blooms observed after storm passage (Lin et al., 2003; Babin et al., 2005). Observed phytoplankton blooms indicate upwelling from within the euphotic zone (Lin et al., 2003) (50 - 150 meters), and mixing-induced temperature anomalies may penetrate to depths of 100-200 meters (Price et al., 1994) and even up to 300-400 meters (Ginis, 2002). Interestingly, ocean-atmosphere surface fluxes account for approximately 10 to 20% of the overall upper ocean cooling (Jacob et al., 2000; Ginis, 2002), while the inertial and geostrophic ocean responses are the main factors. Therefore, though it is true that TCs extract heat from the upper ocean to warm the atmosphere through latent heating, the contribution of this cooling on the upper ocean heat content is small in terms of the total heat budgets. In addition, recent satellite observations of sea surface salinity also show a measurable imprint of TC rainfall over the ocean surface (Figure 1b). Increased salinity stratification and stability of the mixed layer has the potential to reduce the efficiency of the TC mixing and consequently the ocean surface cooling (Balanguru et al., 2012). Even though both the thermal and haline structures of the mixed layer affect the mixed layer heat budget (Maes et al., 2002, Foltz and McPhaden, 2009), the salinity effect has not generally been taken into account in previous studies.

1.2 Equilibrium Ocean Response to Tropical Cyclones and Climate Impacts

TC-induced upwelling cools and deepens the mixed layer, thus depressing SSTs and decreasing the mixed layer heat content, as observed via altimeter-derived surface height anomalies (Shay et al., 2000). This near-surface cooling is accompanied by downward pumping of heat into the upper-thermocline (Huang et al., 2009). SSTs are usually restored to climatologically normal values on the timescale of days to weeks through surface fluxes and seasonal thermocline adjustment, leaving a pronounced warm anomaly beneath the mixed layer (Price et al., 1994; Zedler et al., 2002).

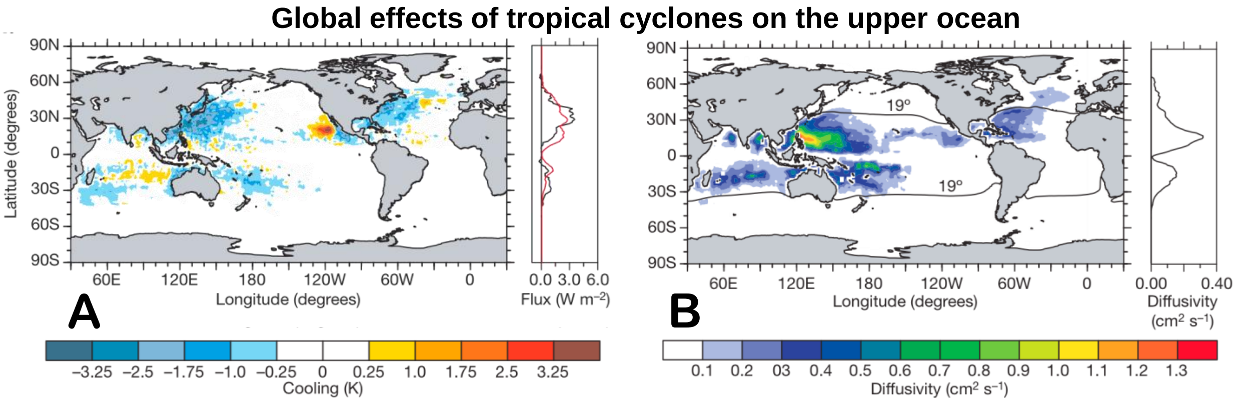


Figure 2. (Adapted From Sriver and Huber, 2007). A. Annual surface temperature anomalies by tropical cyclone mixing. The panel to the right represents the zonal average of surface flux required to restore surface anomalies to pre-storm conditions, assuming anomaly depth of 30 m. B. Estimated annual mixing by tropical cyclones represented as a vertical diffusivity. The panel to the right shows the zonal average of the diffusivity. These diffusivity values are consistent with typical background diffusivities parameterized in climate models.

It has been hypothesized that this process of storm-induced cooling and post-storm warming within the upper ocean represents a net column-integrated heating in the regions affected by the storms, which must be balanced by the equivalent amount of heat transferred poleward on time scales long enough such that the total heat content anomalies are assumed to be zero (Emanuel, 2001). In this steady state scenario, TCs—although transient—may be critically important for driving the meridional overturning circulation and ocean heat transport. Using a simple model/data approach, Emanuel (2001) concluded that TC-induced mixing may be responsible for about 1.4 PetaWatts (PW) of global annual OHT, which would explain the majority of peak observed OHT in the subtropics.

Several studies have refined this estimate using observation-based analysis. Results using reanalysis (Sriver and Huber, 2007) and satellite (Sriver et al., 2008) estimates of sea surface temperature suggest that heat pumping by TCs is more likely on the order of ~0.3 to 0.5 PW. Subsequent analysis that also accounted for seasonal variations in thermocline depth is consistent with these lower estimates (Jansen et al., 2010). The interesting picture of the annual contribution of TCs to tropical ocean mixing budgets (see Figure 2), which emerged from the results of Sriver and Huber (2007), indicate that these events significantly cool the upper ocean and are major sources of mixing on a global scale. The mixing patterns exhibit large spatial variability that is not captured in modeled representations of parameterized mixing budgets. Furthermore, mixing by TCs is on the same order of magnitude as background mixing parameter applied in climate models, suggesting that TCs may be at least partially responsible for the missing mixing in current state-of-the-art climate models.

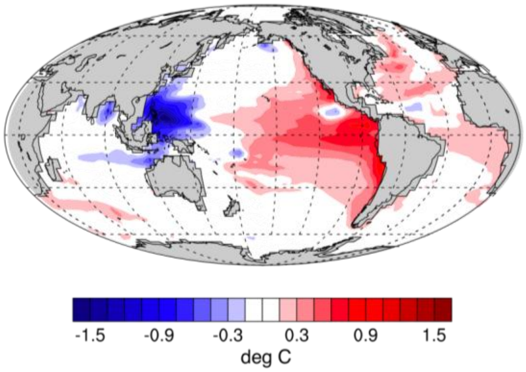


Figure 3. (Adapted from Sriver et al., 2010) Effect of tropical cyclones on near-surface ocean temperature in an ocean general circulation model. The model's background vertical diffusivity scheme has been adjusted to include an idealized representation of mixing by tropical cyclones. Spatial variability in the mixing is a key factor in the modeled response.

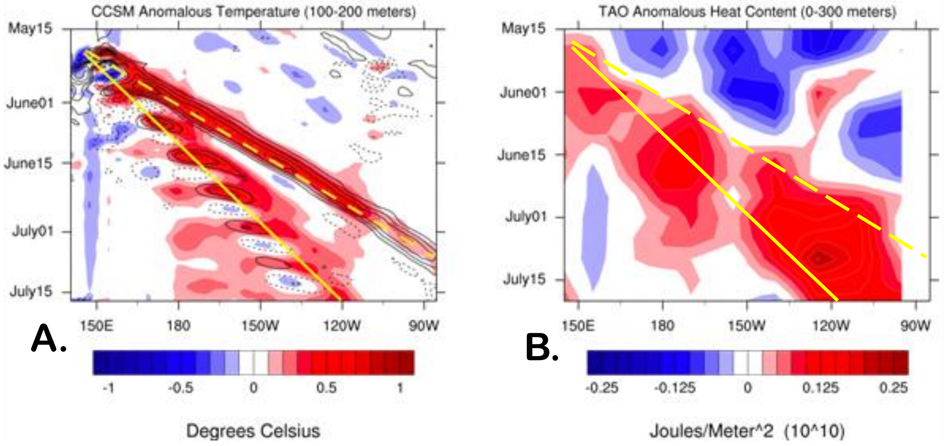
These preliminary large-scale observational studies were limited by the inability to observe the processes beneath the surface on a global scale. Thus, any impacts of TCs on subsurface circulation, heat transport, and other dynamical features could only be inferred. In other words, the fate of the converged ocean heat after being pumped beneath the mixed layer was still unclear. Recently, several idealized modeling studies have sought to answer these questions, by attempting to simulate the effects of TCs on the ocean using idealized techniques that do not resolve the complexity of these events. Notably, Korty et al., (2008) include an interactive mixing parameterization into an intermediate complexity model based on TC maximum potential intensity, and they find TCs enhance poleward ocean heat transport in equilibrated climate conditions under increased atmospheric CO_2 levels. Mixing from TCs may therefore explain past warm climate periods with weaker equator-to-pole temperature gradients by maintaining large ocean heat transport, and thus buffering the tropics to warming while increasing temperatures at high latitudes. Other studies examined the time evolution of tropical heat anomalies associated with mixed layer deepening (Pasquero and Emanuel, 2008) and the impact of increased precipitation during storm events on poleward freshwater transport (Hu and Meehl, 2009). Both studies found a diminished role of tropical cyclones for poleward heat transport either through anomalous tropical heat convergence (Pasquero and Emanuel, 2008) or partial compensation by poleward freshwater fluxes associated with enhanced precipitation during TC events (Hu and Meehl, 2009). Conversely, findings from an idealized coupled modeling study show that TC mixing can substantially contribute to poleward heat fluxes (Liu et al., 2009). The contrasting nature of these preliminary findings and interpretations points to the underlying complexity of the problem. Subsequent studies incorporating more realistic representations of TC mixing based on observed climatologies (Figure 2) into Earth system models (e.g., Sriver et al., 2010; Sriver and Huber, 2010) indicate that TC mixing may significantly influence the thermal structure of the upper ocean, with important consequences on surface energy budgets in the tropics (Figure 3). Interestingly, the modeled response is extremely sensitive to the spatial and temporal variability in the mixing, consistent with independent modeling studies (Scoccimarro et al. 2011; Manucharyan et al., 2011).

The importance of spatial variability is highlighted in the tropical Pacific (Figure 3). TC-induced mixing in the western Pacific injects warm water into the return branch of the subtropical overturning cell, which feeds this anomalously warm water into the equatorial undercurrent where it is upwelled in the eastern equatorial Pacific. The end result, in steady-state conditions, is an anomalously warm eastern equatorial cold tongue, similar to a permanent El Niño-like temperature pattern, though the physical mechanisms at play are fundamentally different from those involved in ENSO dynamics (e.g., Wyrtki, 1975; Battisti and Hirst, 1989). Independent research using more idealized representations of TC mixing supports the importance of mixing in the subtropical latitudes for determining thermal structure of the upper equatorial ocean (Jansen and Ferrari, 2009; Fedorov et al., 2010). Thus, variability in these mixing patterns, associated with changes in TC frequency, intensity and regional distributions, can impact surface energy and mixing budgets in the tropics. It is not yet clear on what timescales these changes are important, as these preliminary studies do not examine temporal variability (e.g. interannual) in the mixing.

1.3 Tropical Variability and Transient Ocean Response to Tropical Cyclones

1.3.1 Tropical Pacific Variability

The El Niño Southern Oscillation (ENSO) is a strong feature in the Equatorial Pacific (Neelin et al., 1998). Changes in tropical convection associated with ENSO influence the atmospheric circulation globally (e.g., Alexander et al., 2002 and references therein). An ENSO observing system in the Pacific Ocean (TOGA) comprises in large extent the TAO array of moored buoys and satellite altimetry (McPhaden, 1999). El Niños have been associated with the buildup of heat in the western Pacific a few months before the event, and strong intraseasonal SST, westerly wind anomalies and east-west slope of the equatorial thermocline nearly in phase with El Niño events (Wyrtki, 1975; Meinen and McPhaden, 2000; Kessler and McPhaden, 1995; Luther et al., 1983; Verbickas, 1998). These wind anomalies have been associated with Madden-Julian Oscillations and TCs (McPhaden, 1999). The relationship of TC genesis and ENSO is variable with time, and strong in some periods (Camargo and Sobel, 2005), what suggests that there is predictability between the two mechanisms (Lander, 1994).



Modeled (A) and observed (B) tropical ocean waves excited by tropical cyclones

Figure 4. A. Time-latitude plot of modeled equatorial Kelvin and Yanai waves in the equatorial Pacific. The waves were excited by tropical cyclone wind forcing and correspond to 3 real near-simultaneous events occurring in May 2003. Yellow lines denote the model's internal Kelvin wave phase/group speed (dashed), and Yanai wave group speed for the 1st baroclinic mode (solid). B. Observed passage of a Kelvin wave by the TAO buoy array in the equatorial Pacific. The timing and characteristics of the observed wave event are consistent with the simulated wave. Figure 4 provides evidence that TCs are capable of influencing the equatorial wave guide, which are well-represented in the CCSM ocean model (A) and observations (B).

Other observational (Keen, 1982; Nitta, 1989) and modeling (Sriver and Huber, 2010; Sriver et al., 2010) studies have hypothesized that TCs may be important for triggering the onset of El Niño events through generation of equatorial Kelvin waves. Our preliminary results (Figure 4) show how TC winds can influence the equatorial wave guide in and Earth system model (CCSM3) through generation of Kelvin and Yanai waves in the Pacific basin, which are also recorded by the Tropical Atmosphere Ocean (TAO) buoy array. These preliminary model results point to potentially strong connections between interseasonal to interdecadal climate variability and changes in spatial and temporal distributions of TCs, through linkages to tropical Pacific modes of variability.

1.3.2 Tropical Atlantic Variability

The Tropical Atlantic is characterized by two main modes of coupled ocean-atmosphere variability: the Equatorial Mode, which is similar to the Pacific El-Niño (Zebiak, 1993), and the Atlantic Meridional Mode (AMM)(Servain et al., 1999; Xie and Carton, 2004). The equatorial mode mechanism is known to be similar to its Pacific counterpart, but the width of the Atlantic basin restricts the formation of an equatorial warm pool, thus SST anomalies in the eastern equatorial Atlantic are smaller (Zebiak, 1993). The equatorial mode is strongly tied to the ocean dynamics, in that reduced southeasterly trade winds decrease the equatorial thermocline tilt, and therefore the equatorial upwelling through ocean dynamic mechanisms (Goes and Wainer, 2003; Hormann et al., 2008). The AMM is characterized by an anomalous interhemispheric SST gradient, which displaces the Intertropical Convergence Zone (ITCZ) towards the warm hemisphere. It is mainly generated by the WES feedback, which is the thermodynamic air-sea feedback among surface Wind speed, Evaporation, and SST (Chang et al., 1997; Xie 1999), but there is also indication that off-equatorial heat content anomalies are forced by the changes in the wind stress curl associated to the AMM (Huang and Shukla, 1997; Doi at al., 2010).

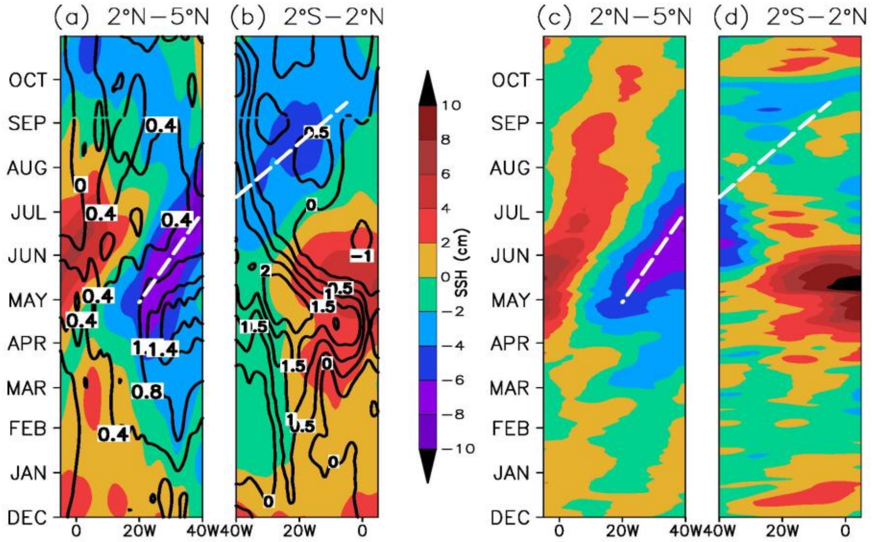


Figure 5: Observed sea level anomalies (shaded) during Dec 2008–Oct 2009 averaged between (a) 2°N–5°N and (b) 2°S–2°N. Contours in (a) are Ekman pumping velocity in m day−1, with positive values indicating upward velocity, calculated at a depth of 20 m by assuming a linear momentum balance as done by Lagerloef et al. [1999]. (b) Contours are zonal wind stress in 10^−2 N m^−2. (c and d) Same as (a) and (b) except sea level anomalies are from the linear wave model. The longitude axes in (a) and (c) have been reversed to show reflection at the western boundary. Dashed white lines represent propagation speeds of observed negative sea level anomalies.

Some studies suggest that ocean heat content changes can propagate equatorward into the equatorial waveguide and trigger the equatorial mode (Huang et al., 1995; Huang and Shukla, 1997). However, the impact of heat content anomalies on the TAV is still an open question.

Some studies also find that the two Tropical Atlantic modes are not independent (e.g., Servain 1999, 2000). Their relationship could be related to a delayed negative feedback in which Rossby waves generated by wind stress anomalies induced by the meridional mode are reflected at the western boundary, triggering the equatorial mode (Foltz and McPhaden, 2010). Wave mechanisms associated with the equatorial and meridional modes have been observed using satellite altimetry, SST and in situ measurements of thermocline depth (Figure 5). Both modes of variability have been suggested to be related to the TC formation. For example, the AMM is associated with dynamical mechanisms that cooperate with the seasonal variability of the hurricane activity (Vimont and Kossin, 2007). The positive phase of the AMM causes warming in the north Atlantic basin and therefore more TC activity. Related wave mechanisms can trigger the equatorial mode (Zhu et al., 2012).

1.3.3 Transient Response to TCs in the Tropics

Climate models show a strong equatorial response to the turbulent mixing caused by hurricanes (Sriver et al., 2010). However, past studies are inconclusive about the ocean mechanisms that govern the advection of heat anomalies in the tropics, and the importance of a dynamical ocean response on intra-seasonal to annual timescales is unclear. The TC influence on the tropical variability is likely to be triggered by oceanic waves, but there is also a pathway through the shallow subtropical cells. As discussed in Section 1.2, several studies show consistent effects of TC mixing on the subtropical-tropical regions: equatorial warming and deepening of the thermocline, cooling of the subtropical bands, and strengthening of the shallow overturning circulation (STC) in the ocean and Hadley circulation in the atmosphere. Other effects such as the Ekman response to cyclonic winds (Manucharyan et al., 2011) and the dynamical links between the subtropical and global (AMOC) overturnings and equatorial currents are still to be investigated.

In this context, the western boundary currents are of extreme importance. They form the main link between the equator, tropics and subtropics, and concentrate a large part of the STCs and the upper branch of the AMOC flow (Fratantoni et al., 2000, Zhang et al., 2003, Goes et al., 2005). Major western boundaries such as the Kuroshio and Gulf Stream are also likely to play an important role in TC intensification when tracks cross these warm currents (Bright et al., 2002), and for carrying heat anomalies from the tropics poleward during TC events (Sriver and Huber,2010). As part of this work, we will investigate how a passage of a TC could affect the dynamics of the Kuroshio and Gulf Stream in a seasonal to annual basis, which might impact the northward heat transport and weather in the northern latitudes.

Temporal changes in the mixed layer can alter subduction rates and produce anomalies in the subtropical cells (Valdivieso da Costa et al., 2005). Tropical cyclones bring a large cooling effect into the mixed layer, mostly through entrainment (Bender et al., 1993), a warming in the layer below, with an overall deepening of the thermocline through strong mixing. Air-sea fluxes restore the stratification of the mixed layer after the passage of the TC (Price et al., 2008), promoting the uplift of the thermocline. The heat stored below the thermocline will likely follow a path in the subtropical cells around the subtropical gyre and toward the equator, into the equatorial upwelling region (Schott et al 2004; Liu and McCreary 2002). Subduction processes are strongly tied to the winter season, when the mixed layer is deeper (Stommel, 1979; Williams et al., 1995). Mixing induced by tropical cyclones can produce a second seasonal peak of effective detrainment, and change the seasonality of the subduction rates (Liu et al., 2011). The deepening of the mixed layer in the following winter can bring back the warm anomalies caused by TCs to the mixed layer, and release them back to the atmosphere (Jansen et al., 2010). In the outcropping regions of the mixed layer, Ekman pumping and lateral advection through a tilted mixed layer are the main players to originate subduction in the subtropics. In the tropical and subtropical regions, the Ekman pumping component most likely dominates subduction processes away from the boundaries (Goes et al., 2008). So far, the Ekman response to a TC vortex has been mostly ignored (Liu et al., 2011). Accounting for this component could potentially increase the effect of TC on the subtropical cells, and on the upwelling zones along the equatorial and eastern basins.

2. Project Objectives

Our goal is to investigate the impact of TCs on the tropical and subtropical global oceans with a special focus on the transient (intraseasonal to decadal) ocean response to TC forcing. Our research plan centers around 3 questions:

1. How does transient TC-induced surface forcing affect upper ocean dynamics of the tropical and subtropical oceans?
2. What are the interactions between TC activity and the tropical modes of variability that can influence climatic variability on inter-seasonal to decadal scales?
3. Does the inclusion of realistic TC forcing in a state-of-the-art global ocean general circulation model improve hindcast skill?

To confront these questions, we will combine observational analyses from NASA remote sensing and CLIVAR data products with decadal-scale hindcast simulations using a high-resolution global ocean model, the ocean component of the Community Earth System Model v1 (CESM). We hypothesize that TCs are important contributors to the dynamics of the tropical and subtropical oceans, with implications for climate variability on inter-seasonal to inter-decadal time scales. To address the three questions above, we propose to: (i) examine the upper oceanic response to tropical cyclones on multiple spatial and temporal scales using observed fields from NASA and CLIVAR products, (ii) diagnose the capability of a state-of-the-art ocean general circulation model to simulate the observed responses, and (iii) synthesize the model/observational findings to examine the importance of TCs within the climate system and explore implications for improving predictability on inter-seasonal to inter-decadal time scales.

3. Research Plan

3.1 Overview

The proposed work will highlight novel syntheses of NASA/CLIVAR data products with an ocean general circulation model to examine how tropical cyclones contribute to dynamic variability of the global tropical and subtropical oceans on inter-seasonal to inter-decadal time scales. The fundamental goal of these analyses is to build a better understanding of how the cumulative effects of transient, yet extreme, events like tropical cyclones can affect climate variability, ultimately leading to improved predictability of climate variability on decision-relevant timescales.

The project will rely heavily on novel use of NASA remote sensing and CLIVAR in situ data products to: (1) develop improved data sets of TC surface fields (such as winds and precipitation) to be blended into surface input data sets used to force ocean general circulation model hindcasts (using the ocean component of CESM); (2) create new global climatologies of the oceanic response to TCs (such as surface temperature, salinity, and ocean heat content anomalies), which could have important climate implications via redistribution of upper ocean properties, freshwater forcing, and equatorial wave dynamics; and (3) diagnose the sensitivity of the ocean model to the inclusion of TC forcing fields on multiple spatial (local to global) and temporal (daily to interdecadal) scales.

While each of these components will provide important insight into general connections between the effects of tropical cyclones (winds and freshwater forcing) and the response of the upper ocean, the combination of these three components will enable a deeper understanding of the overall contribution of TCs to variability of Earth's climate system through exploration of non-local effects and possible oceanic teleconnections (such as equatorial wave excitation shown in Figure 4). The connections between TC-induced tropical and subtropical responses have yet to be explored, though previous observational analyses have pointed to important connections for explaining the main modes of variability, such as ENSO, and preliminary model results using CCSM3 provides strong mechanistic support for those early observational findings.

3.2 Observational exploration of oceanic TC impacts

The proposed research will rely strongly on in situ and remotely sensed data analysis in the tropical oceans. The data will be used to support and validate the model findings, and to infer observed physical properties of the ocean. We will examine the interactions between TCs and ENSO in the Pacific and the zonal and AMM modes in the Atlantic through analysis of wave mechanisms, mixed layer budgets and upper ocean heat anomalies, barrier layer formation, subtropical cells and western boundary currents variability. The main data products we will use are:

i) **Rainfall**: The Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) is available at (http://mirador.gfsc.nasa.gov) in different temporal resolutions (3-hourly, daily, monthly) since 1998 and at 0.25 degree horizontal resolution (Huffman et al., 2007).

ii) **Satellite altimetry**: Satellite altimetry provides optimally interpolated, cross-calibrated global coverage of the sea level anomaly (SLA). Here we use the Archiving, Validation, and Interpretation of Satellite Oceanographic Data (AVISO) delayed mode product (http://www.aviso.oceanobs.com), which consists of gridded weekly SLA relative to the 1993-1999 period mean, obtained from a multi-satellite mission (Le Traon et al., 1998), available continuously since October 1992, on a 1/3° horizontal grid.

iii) **Winds**: The pseudo-wind stress data are obtained from the cross-calibrated, multi-platform (CCMP), multi-instrument ocean surface wind velocity data set. This product combines data derived from SSM/I, AMSRE, TRMM TMI, Quikscat, and other missions using a variational analysis method to produce a consistent record of global ocean surface vector winds at a 25 km resolution and is available since July 1987 (Atlas et al., 2011). Best Track data (IBTrACS) merges best track and maximum wind speed data of tropical cyclones from individual agencies in one worldwide database, and is distributed at www.ncdc.noaa.gov. The latest version of the data comprises storms from 1842 -2011. We are interested in the best track data after 1950, which discards known data mismatches before that period.

iv) **Sea surface Temperature (SST) and Salinity (SSS)**: Satellite SST data from the multi-agency GHRSST project (www.ghrsst.org) are available in daily composites This product exploit the synergy from using SST derived from in situ, satellite microwave, and satellite infrared sensors, daily and in a high resolution (≤25 km) format (Donlon et al., 2007), and is available since 1981 in different resolutions. Satellite SSS data from Aquarius are now available for evaluation and validation. SSS has a resolution of 1° x 1° with daily images starting in 2011.

v) **In situ data**: As part of CLIVAR, TAO (McPhaden 1995) and PIRATA (Bourlés et al., 2008) moored arrays provide a high temporal resolution velocity, temperature and surface fluxes data in the equatorial Pacific and Atlantic basins. These data have been used successfully as validation for satellite measurements and models, and to study wave mechanisms in the equatorial area.

3.2.1 Observed Mechanistic Exploration of Oceanic Response to Tropical Cyclone Forcing

As part of our main goal, the observational analysis will focus on understanding relationships between TCs and El Niño and the Atlantic zonal mode, and related tropical-subtropical interactions. The cold wakes left after the TC will be monitored using SST data from the GRHSST dataset. After the SST recovery following the TC passage, the buildup of heat in the western basins will be investigated using weekly merged satellite altimetry data. A regression between satellite altimetry combined with historical temperature profile relationships and SST will give an estimation of the global upper-ocean heat content anomalies, i.e., the tropical cyclone heat potential (TCHP), using a 2-layer reduced gravity scheme (Goni et al., 1996). With this methodology, the local Ekman pumping (entrainment) into the mixed layer will be estimated from the vertical displacement of the synthetically-derived 20°C isotherm from before and after the passage of a storm (Shay et al., 2000). Using this information, mixing can then be estimated using a 1D mixing-advection balance, similar to what has been applied in previous studies (e.g., Sriver and Huber, 2007; Korty et al., 2008; Pasquero and Emmanuel, 2008), but also accounting for entrainment directly.

The statistical relationship for TCHP does not take into account salinity variations. As we stated in the introduction, TC-induced freshwater fluxes influence the mixed layer both locally and globally. Locally, the freshwater input by TCs can have a large impact on the stability of the mixed layer and in the formation of barrier layers, especially in the western basins. The barrier layers in the tropical oceans, which are regions where the bottom of the mixed layer is shifted with respect to the bottom of the isothermal layer, inhibits the entrainment of cold water from below into the mixed layer, and therefore can prevent TC heat pumping into the thermocline (Maes et al., 2005; Foltz and McPhaden 2009). We will test the ability of data from the novel NASA satellite mission Aquarius to diagnose how TC-induced freshwater fluxes and the climatological background salinity stratification affect vertical mixing and entrainment. This will be an update for the current TCHP methodology of Goni et al. (1996) by including SSS as an additional constraint in the regression. To aid in this analysis, locations and seasonality of ocean barrier layers in the TC affected regions will be retrieved from the global Argo data. The global Argo array has recently been proven to be a useful tool for the study of effects of TCs in the upper ocean (Park et al., 2011).

To examine how TCs impact the equatorial regions, we will use three techniques: (1) Heat content anomalies will be tracked from the TC affected region, tracking anomalies of the thermocline depth in time and space; (2) Correlations between equatorial SST anomalies and TC events will be assessed to investigate causal relationships (with TC leading) between these processes. We will also examine annual composites of the events which the time lag between the TC and equatorial SSTs converge to the wave speed mechanisms in a given region. The background ocean state previous to the storm will provide information on the triggering mechanisms for ENSO, and in the Atlantic the AMM relationship with the equatorial mode; (3) High resolution timeseries of CLIVAR in situ data, the TAO and PIRATA moorings in the tropical Pacific and Atlantic, respectively, will provide information on the impact of the TC anomalies in the equatorial regions, in terms of heat content and velocity anomalies. Wave propagation speeds will be retrieved and compared to the linear wave theory. Several studies have shown, for example, that the TAO array (e.g., Kessler and McPhaden, 1995; Yu and McPhaden, 1999) and satellite altimetry (Chelton and Schlax, 1996; Boulanger and Fu, 1996) are able to capture propagation of equatorial waves.

The effects of the wave mechanisms in the equatorial region will be contrasted with the subtropical cells variability, which is the mechanism described to be responsible for the equilibrium El Niño response to TCs in several modeling studies (e.g., Fedorov et al., 2010, Sriver et al., 2010). An analysis of the subduction of warm anomalies across the mixed layer and subsequent pathway along the subtropical cells will be performed. We will investigate the seasonal to decadal variability of subduction processes and heat uptake related to TCs, and the effect of these anomalies in the equatorial regions. Seasonality and reentrainment of heat anomalies into the mixed layer in the following winter, which is the time of maximum deepening (Jansen et al., 2010), will be taken into account. Additionally in this calculation, we will take into account interannual variability of the mixed layer depth using, for example, mixed layer estimates from the TCHP method, which was not included in Jansen et al. (2010).

Complementary to these observational analyses, we will produce a new wind dataset (see next section) that will include transient TC features. Since observations have known problems of lack of temporal and spatial resolution, this new wind product will be used to perform model hindcast runs, which will be analyzed and compared with the observations.

3.3 Model Experiments

The PI Sriver has recently conducted exploratory research into the equilibrium and transient response of the ocean to TC surface wind forcing using the low resolution CCSM3 (Collins et al., 2006) ocean component model (Smith and Gent, 2004; Danabasoglu et al., 2006), based on the Parallel Ocean Program (POP v 1.4.3) (Smith et al., 1992). Results indicated transient surface wind forcing by TCs significantly affect upper ocean mixing budgets, subtropical circulations, energetics of the equatorial ocean, and even ENSO dynamics (Sriver and Huber, 2010; Sriver, 2011). While promising, these findings represent only the first step in understanding the influence of TCs on the upper ocean and the potential for atmosphere-ocean feedbacks. Limitations included: (i) use of the coarse resolution (nominal 3 degree grid) ocean model, (ii) highly idealized forcing input and TC winds, and (iii) a small sample of years from which TCs were drawn.

Building on these previous results, we propose to use the higher resolution, and most recent version, of the ocean component of the Community Earth System Model (CESM), which is based on the Parallel Ocean Program version 2 (POP2) (Danabasoglu et al., 2011). In comparison to previous versions of the model, this state-of-art version produces a more realistic El-Niño variability (Gent et al., 2012; Sriver et al, 2012a) and an improved representation of the Gulf Stream and meridional overturning circulation due to a new overflow parameterization. Additionally, changes in the mixing parameterization produce more realistic tropical instability waves off the equator. The meridional model resolution is 0.27° at the equator, gradually increasing to 0.54° at 33°N/S, and is constant at high latitudes. The zonal resolution is constant at 1.1°, and it has 60 vertical levels.

Our initial findings and other related studies will serve as a base to build a more sophisticated methodology that utilizes the new CESM ocean component in a higher resolution configuration, as well as an updated forcing configuration that combines global TC winds from the Best Track data set with the bulk forcing atmospheric state variables of Large and Yeager (2004), as part of the Coordinated Ocean-ice Reference Experiments (CORE; Griffies et al., 2008). A shortcoming of the interannual bulk forcing data sets is that the surface wind fields are filtered to remove large-magnitude wind vectors as a quality control check for reducing processing errors (Milliff et al., 1999). A consequence of this processing correction is the removal of extreme transient wind events such as TCs, albeit many wind data sources cannot preserve the extreme nature of such events, even for high-resolution satellite measurements (e.g. Brennan et al., 2005). Our method will combine the historical, interannual atmospheric fields with 2-dimensional surface TC wind fields from CCMP dataset (Atlas et al., 2011) for the past ~25 years.

Preliminary analysis shows that TC wind fields from CCMP are, on average, improved compared to the standard CORE forcings. However, this data product cannot reproduce the most intense magnitude winds, although it robustly captures the circulation dynamics. This limitation is typical for satellite-based winds, for example QuikScat winds are only reliable up to 50 meters per second (Brennan et al., 2005), which represents wind conditions within a category 3 storm. To circumvent this problem, we will include maximum wind speeds from the Best Track fields (IBTRaCS), which offers merged best track and maximum wind speed data of tropical cyclones from individual agencies in one worldwide database. When necessary, we will employ well-studied scaling techniques to relate maximum wind speed estimates to 2-dimensional surface wind fields (e.g. Holland, 2008; Holland et al., 2010). The final TC wind product will capture the 2-dimensional circulation of the CCMP with additional scaling from IBTRaCS. We will blend this new TC wind field product into the interannual Bulk Forcing input data sets (e.g. COREII and/or Large and Yeager, 2004). If we find 25 years is not a sufficiently long period to examine inter-annual to inter-decadal variability, we can include as an earlier portion of the record, idealized closed TC circulations by blending the maximum sustained wind speeds from the IBTRaCS data base with previously considered methodologies, such as assuming idealized closed circulations with Rankine vortex structure (Holland, 1980).

We will also include TC rainfall using satellite–based information (TRMM; Huffman et al., 2007) for available years. By definition, rain and wind stress will follow similar structures, axisymmetric and with maximum values at the radius of maximum winds (Robertson and Ginis, 2002), thus we can employ these relationships to extrapolate (to first-order) TC rainfall rates prior to the launch of TRMM, to match the time period of the wind forcing fields. When employing these techniques, special consideration will be paid towards conserving the model's freshwater budget, by including a salinity restoring term in the ocean or a large scale freshwater compensation (Hu and Meehl, 2009).

We will use this new blended data set, featuring TC wind and precipitation fields, as input to CESM ocean-only model simulations, building on the idealized modeling framework of Sriver and Huber (2010). We will augment the standard input forcings with the blended TC wind and precipitation fields as described above, corresponding to global historic TC conditions during the past 50-60 years. Control simulations (without the augmented inputs fields) will be performed to test the sensitivity of the model to the forcings. Additional runs featuring scaled wind/precip fields will be performed to diagnose and test the sensitivity of the modeled response compared to TC fields derived from the observational products (e.g. Rankine vortex versus rescaled CCMP).

This methodology will enable diagnostic analysis of the model's response to TC surface forcings in a realistic manner using multi-decadal inter-annual forcing that features realistic TC conditions corresponding to the forcing years (which was not possible in earlier efforts). We can also assess any scale-dependent response between low- and high-resolution ocean model configurations, via comparison with previous low-resolution simulations and additional scaling sensitivity analysis. This methodology is well-suited for examining the potential impact of TC activity on observed upper-ocean dynamics and processes over the past 60 years within the context of ocean hindcast experiments.

Complementing the global eddy-resolving simulations, we will apply a process oriented, idealized high resolution model to simulate TC-forced dynamic features in the tropical ocean. This will be performed with a 3 ½ layer, reduced gravity model described in Goes et al. (2009). The idealized model is suitable, for example, to study how the intensity, translation speed and fetch produced by a single idealized storm would affect the upper layer thickness and equatorial dynamics.

The proposed modeling component will build on previous results by: (i) utilizing a multi-decadal time series of global TC activity with improved representation of TC wind and precipitation estimates, (ii) performing hindcasts based on historical TC fields combined with atmospheric forcing that is directly comparable to observations (using remote sensing and in situ records of climate events such and El Niño), and (iii) enabling a global representation of the oceanic response on multiple spatial and temporal scales, thus enabling direct assessment of model hindcast skill by contrasting and comparing model results with the observation-based analyses described in section 3.2. Ultimately, these assessments will be used to explore the potential for important climate linkages and feedbacks that could improve predictability on inter-seasonal, inter-annual, and inter-decadal time scales.

4. Relevance to the NASA Announcement

TCs are transient phenomena that affects directly coastal regions and indirectly by affecting modes of variability and heat storage in the ocean. An improved understanding of the TC effects in the ocean will consequently improve climate predictions and reduce their adverse economic and societal impacts. Our proposal aims to develop a better understanding of how TCs interact with the upper ocean on multiple temporal and spatial scales, using novel NASA/CLIVAR data and modeling approaches. Fundamentally, this study will advance NASA's goals to understand the ocean's role in climate variability and prediction, by providing a better mechanistic understanding of how the ocean responds to TCs: from transient dynamic effects associated with single events to cumulative impacts and climatic interactions between interannual variability in TC frequencies and regional distributions, tropical modes of variability in the Pacific and

Atlantic basins, and coastal circulation patterns. This study will highlight a rich collection of data products distributed by NASA and CLIVAR, including satellite altimetry, mooring data, surface wind stress, high-resolution sea surface temperature (GHRSST) and sea surface salinity (Aquarius).

5. Qualifications of the Project Team

This multi-disciplinary collaborative project combines novel utilization of state-of-the-art observations systems with cutting edge climate model development, to analyze the role of TC impacts on tropical to subtropical oceanic processes and variability on multiple spatial and temporal scales, ultimately leading to improved climate projections on inter-seasonal to inter-decadal timescales. The PIs possess extensive experience in data analysis and large-scale climate modeling (and data-model fusion and synthesis), as evidenced in the peer-reviewed literature (e.g., Sriver and Huber, 2007; Sriver et al., 2008; Goes et al., 2008; Goes at al., 2009; Warnaar et al, 2009; Goes et al., 2010; Sriver and Huber, 2010; Sriver et al., 2010; Irvine et al., 2012; Woodruff et al., 2012; Olson et al., 2012; Sriver et al, In Review; Goes et al., In Review). The PIs have been involved in projects using NCAR’s CCSM3, collaborating with members of NCAR’s CESM ocean model working groups (G. Danabasoglu, S. Yeager and P. Gent). PI Sriver has successfully ported/optimized the most recent version of CESM (1.0.3) to multiple computing platforms and architectures. He is currently involved in several different projects centered on the coupled version of CESM, including examining the skill of CESM interannual variability in the tropical Pacific (Sriver et al., 2012a), and quantifying the effect of initial conditions uncertainty on predictability of trends in key climate indicators regional scales (Sriver et al., 2012b). PI Goes has published several papers in ocean dynamics and has extensive experience in investigating subduction processes, and circulation and variability of the tropical Atlantic. Both PI’s possess extensive experience analyzing NASA and CLIVAR products (see references earlier in section). The PIs have been collaborating closely for more than 4 years and have jointly published several key papers synthesizing models and observations, such as developing an observation-based TC-ocean mixing parameterization (Sriver et al., 2010) and Bayesian data-model fusion using timeseries of ocean observations (Olson et al., 2012).

Collaborators Goni and Foltz are recognized ocean observationalists, offering expertise in TC heat potential observed via satellite altimetry (Goni), and mixed layer budget analysis from TAO and Pirata (Foltz). Goni and Foltz will provide their expertise and mentorship on a no-cost, since their interests are strongly tied to the ones from this research (e.g., Foltz is a PI of the PIRATA project and Goni is a PI on the Tropical Cyclone Heat Potential project and other altimetry related projects). They will interact with PI Goes on a daily basis for discussion of results, advices and data sharing.

6. Management Plan and Data-Sharing Policy

The project will be led by PI Goes, in close collaboration with Co-PI Sriver. Goes will lead the overall project management, reporting, budgeting, as well as communication and outreach. Goes will also lead the subprojects (see section 7) related primarily to the data processes: (1) assessing observation-based TC-ocean interactions and (5) data-model synthesis. Co-PI Sriver will lead the subprojects related primarily to the modeling components: (3) design and perform CESM simulations and (4) model diagnostics and sensitivity analysis. The PIs will collaborate on subproject (2) development and implementation of TC wind and precipitation fields. Both

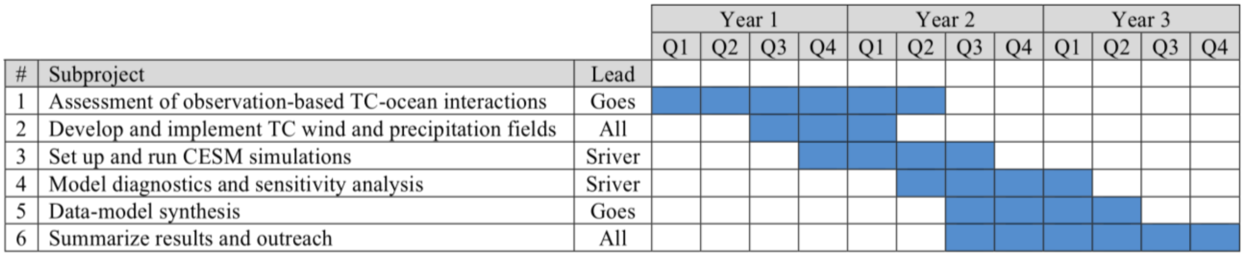
PIs will also collaborate on subproject (6) to summarize the results in form of manuscripts for submission to peer reviewed publications and to reach out to the Earth system modeling community, as well as the general public, via a project web-page.

The PIs request a postdoctoral researcher for years 2 and 3 of the project (to be selected later), who will collaborate with both institutions but will work primarily with Co-PI Sriver. He/She will be responsible for the day-to-day operations of the modeling subprojects, which will be performed at the University of Illinois. We will utilize computational resources already made available to Co-PI Sriver as part of his startup package (dedicated time on institutional computing clusters and funds for an additional 8 cluster nodes featuring 12 cores per node plus 2x hyperthreading). At no additional cost to the project, Co-PI Sriver will incorporate part-time graduate student involvement during the first 1.5 years of the project, funded through research support as part of Cop-PI Sriver's startup negotiations. The student will participate in the development of the ocean model input data set and preliminary model testing, with additional coordination and mentorship from PI Goes and the requested postdoctoral researcher during year 2. Travel funds are budgeted to allow for the postdoctoral researcher to visit the University of Miami and NOAA AOML for 1-2 weeks/ year, working with PI Goes and NOAA colleagues on analyzing observational products and data-model syntheses. PI Goes budgeted a personal computer for data storage. The PIs will coordinate project meetings at annual national conferences and also conduct bi-weekly project meetings via videoconference.

We will provide the data necessary to recreate our results (e.g., model codes, input files, value-added data sets, and the specific model simulations results and data/model diagnostics) on a project web-page for at least five years after the project end. Co-PI Sriver has been involved with previous efforts to document CCSM modification and setup using an editable web page (Wiki) intended as a learning tool for new users. This endeavor was highly successful and served as a valuable resource where new users could reference useful setup descriptions and techniques. We will use this previous experience as a tool for documenting our modeling and data analysis so that they are easily accessible and interpretable to the public. Data providers will be invited to contribute to the research effort, and we will leverage expertise from several multiple observationalists with strong ties to NASA, NOAA and CLIVAR programs and products.

7. Sequence of Project Activities

The sequence of project activities is as follows:



			Year 1				Year 2				Year 3			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
#	Subproject	Lead												
1	Assessment of observation-based TC-ocean interactions	Goes	■	■	■	■	■	■						
2	Develop and implement TC wind and precipitation fields	All			■	■	■							
3	Set up and run CESM simulations	Sriver				■	■	■	■					
4	Model diagnostics and sensitivity analysis	Sriver						■	■	■	■			
5	Data-model synthesis	Goes							■	■	■	■		
6	Summarize results and outreach	All							■	■	■	■	■	■

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Biographical Sketch

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(a) Professional Preparations:

Educational Institution	*Major*	*Degree*	*Degree Year*
University of Campinas, Brazil	Physics	B.Sc / Licenciate	1999
University of Sao Paulo, Brazil	Oceanography	M.Sc.	2001
University of Reading, UK	Oceanography	Doctorate fellow	2005
University of Sao Paulo, Brazil	Oceanography	Ph.D.	2006
Penn State University, USA	Climate studies	Post-doc.	2009

(b) Appointments:

2010 - present	Assistant Research Scientist, Cooperative Institute for Marine and Atmospheric Studies, University of Miami
2007-2009	Post-doctoral fellow, The Pennsylvania State University
2007	Visitor Scientist, POGO-SCOR scholarship, University of Maryland
2004-2005	Visitor research Assistant, CAPES scholarship, University of Reading, UK
2002-2006	Graduate Research Assistant, University of Sao Paulo, Brazil
2000-2001	Graduate Research Assistant, University of Sao Paulo, Brazil

(c) Publications

Five publications related to the proposed research:

Goes, M., G. Goni, V. Hormann, R. Perez: Variability of eastward currents in the equatorial Atlantic during 1993-2010, in review at J. Geophys. Res.-Oceans.

Goes, M., Urban, N. M., Tonkonojenkov, R., Haran, M., Schmittner, A., and Keller, K. (2010), What is the skill of ocean tracers in reducing uncertainties about ocean diapycnal mixing and projections of the Atlantic Meridional Overturning Circulation?, J. Geophys. Res., doi:10.1029/2010JC006407.

Sriver, R. L., M. Goes, M. E. Mann, and K. Keller (2010), Climate response to realistic tropical cyclone-induced ocean mixing in an Earth system model of intermediate complexity, J. Geophys. Res.-Oceans, doi:10.1029/2010JC006106.

Goes, M., Marshall, D. P., and Wainer, I. (2009), Eddy Formation in the Tropical Atlantic Induced by Abrupt Changes in the Meridional Overturning Circulation. J. Phys. Oceanogr., 39, 3021–3031.

Goes, M., Wainer, I., Gent, P. R., and Bryan, F. O. (2008), Changes in subduction in the South Atlantic Ocean during the 21st century in the CCSM3, Geophys. Res. Lett., 35, L06701, doi:10.1029/2007GL032762.

Five additional publications:

I. Wainer, M. Goes, L.N.Murphy, and E. Brady (2012): Changes in the Water Mass Formation Rates in the Global Ocean for the Last Glacial Maximum, Mid-Holocene and Pre-Industrial Climates, in review at Paleoceanography.

Olson, R., R. Sriver, M. Goes, N. M. Urban, H. D. Matthews, M. Haran, and K. Keller (2012), A climate sensitivity estimate using Bayesian fusion of instrumental observations and an Earth System model, *J. Geophys. Res.*, 117, D04103, doi:10.1029/2011JD016620.

Bhat, K.S., Haran, M., and Goes, M. (2010), Computer model calibration with multivariate spatial output, in "Frontiers of Statistical Decision Making and Bayesian Analysis", eds. M-H. Chen et al., New York: Springer-Verlag, 2010.

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Góes, M., and Wainer, I. (2003), Equatorial currents transport changes for extreme warm and cold events in the Atlantic Ocean, Geophys. Res. Lett., 30(5), 8006,doi:10.1029/2002GL015707.

(d) Synergistic activities

Referee in the state finals of the 2009 Pennsylvania Junior Sciences and Humanities Symposium.
Reviewer for: Research proposals (NOAA, FACEPE/Brazil), and research articles (*Journal Of Geophysical Research*, *Climatic Change, Earth System Dynamics*)

(e) Collaborators & Other Affiliations

Collaborators:
Gustavo Goni (NOAA/AOML), Molly Baringer (NOAA/AOML), Renellys Perez (U. Miami), Verena Hormann (U. Miami), Klaus Keller (Penn State), Nancy Tuana (Penn State), Ryan Sriver (Penn State), Nathan M. Urban (Princeton), Roman Olson (Penn State), Michael E. Mann (Penn State), Murali Haran (Penn State), Andreas Schmittner (Oregon State U.), Ilana Wainer (U. Sao Paulo).

Graduate Advisor: Ilana Wainer (U. Sao Paulo)

Graduate scholarship advisor: David P. Marshall (Oxford University)

Visitor Scientist advisor: James Carton (U. Maryland)

Postdoctoral Advisor: Klaus Keller (Penn State)

Biographical Sketch

Ryan L. Sriver

University of Illinois Department of Atmospheric Sciences, 105 South Gregory Street, Urbana, IL 61801
Email -rsriver@illinois.edu; Website -http://www.met.psu.edu/people/rls66

Education

Purdue University, Earth and Atmospheric Sciences Ph.D., 2008 Purdue University, Physics M.S., 2003 Purdue University, Physics B.S., 2001

Professional Experience

August 2012 – present Assistant Professor Department of Atmospheric Sciences, University of Illinois

June 2010 – July 2012 Research Associate Department of Geosciences, Pennsylvania State University

June 2008 – May 2010 NOAA Climate and Global Change (C&GC) Postdoctoral Research Fellow Department of Meteorology, Pennsylvania State University

Relevant Publications

Sriver, R. L., Urban, N. M., Olson, R., and Keller, K. (Submitted), Towards a physically plausible upper bound of sea-level projections, Prepared for *Proceedings of the National Academy of Sciences*.

Wang, J.-W., Han, W., and **Sriver, R. L.** (In Review), Impact of tropical cyclones on the ocean heat budget in the Bay of Bengal during 1999, Prepared for *Journal of Geophysical Research-Oceans*.

Olson, R., **Sriver, R. L.**, Goes, M., Urban, N. M., Matthews, H. D., Haran, M., and Keller, K. (2012), A climate sensitivity estimate using Bayesian fusion of instrumental observations and an Earth System model, Journal *of Geophysical Research-Atmospheres, 117*, D04103, doi:10.1029/2011JD016620.

Irvine, P., **Sriver, R. L.**, and Keller, K. (2012), Tension between reducing sea-level rise and global warming through solar radiation management, *Nature Climate Change*, *2*, 97-100, doi:10.1038/nclimate1351.

Sriver, R. L. (2011), Climate Change: Man-made cyclones (News & Views), *Nature*, *479*, 50-51, doi:10.1038/479050a.

Woodruff, J. D., **Sriver, R. L.**, and Lund, D. C. (2011), Tropical cyclone activity and western North Atlantic stratification over the last millennium: A comparative review with viable connections, *Journal of Quaternary Science*, doi:10.1002/jqs.1551.

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Warnaar, J., Bijl, P. K., Huber, M., Sloan, L., Brinkhuis, H., Rohl, U., **Sriver, R. L.**, and Visscher,
H. (2009), Orbitally forced climate changes in the Tasman sector during the Middle Eocene, *Palaeogeography, Palaeoclimatology, Palaeoecol*ogy, *280*, 361-370, doi:10.1016/j.palaeo.2009.06.023.

Sriver, R. L., Huber, M., and Nusbaumer, J. (2008), Investigating tropical cyclone-climate feedbacks using the TRMM Microwave Imager and the Quick Scatterometer, *Geochemistry, Geophysics, Geosystems, 9,* Q09V11, doi:10.1029/2007GC001842.

Sriver, R. L., and Huber, M. (2007), Observational evidence for an ocean heat pump induced by tropical cyclones, *Nature*, *447,* 577-580, doi:10.1038/nature05785.

Sriver, R. L., and Huber, M. (2006), Low frequency variability in globally integrated tropical cyclone power dissipation, *Geophysical Research Letters, 33,* L11705 doi:10.1029/2006GL026167.

Prior Research Efforts (based on C&P file)

Project: State-level climate change scenarios for the United StatesFunding Agency: EPA (11/11/2011-06/30/2012)

This project aims to quantify uncertainty surrounding temperature and precipitation projections at the state-level, focusing primarily on decadal-scale (and decision-relevant) time scales. The methodology consists of performing a ~20 member fully-coupled climate model ensemble of hindcasts and projections using the Community Earth System Model (CESM), which we combine with dynamically downscaled climate results based on results from the CMIP3 initiative (as part of the IPCC Fourth Assessment). The goal of the project is to provide probabilistic projections of temperature and precipitation fields, in which we quantify the uncertainties associated with internal model variability combined with the effects of spatial aggregation. Co-PI Sriver's role in the project focuses primarily on the CESM model development and implementation, including: porting the model to various computational architectures, benchmarking and code optimization, and designing, executing, and analyzing ensembles of historic hindcasts and projections for different model configurations, forcings, and resolutions.

Current and Pending Support

1) PI: Marlos Goes

Marlos Goes has no Pending or Current Support.

2) PI: Ryan L. Sriver

Current

Agency: Environmental Protection Agency (EPA) Title: State-level climate change scenarios for the United States Investigator Months/yr: 6 Total Award Amount: $70,431 Duration: 11/11/2011 – 6/30/2012 Role in project: Co-PI Location of research: Penn State

Pending

Ryan Sriver has no Pending Support.

Title: Transient response of the upper ocean to Tropical Cyclones and relationship with tropical modes of variability.

Dr. Ryan Sriver

Statement of work to be done at University of Illinois

As discussed in section 6 of the main text, co-PI Sriver will lead all the subprojects related to the modeling components. This includes designing and executing the CESM simulations (subproject 3) and performing the model diagnostics and sensitivity analysis (subproject 4). For these subprojects, we will utilize computational resources at the Univerisity of Illinois already made available to Co-PI Sriver as part of his startup package (dedicated time on institutional computing clusters and funds for an additional 8 cluster nodes featuring 12 cores per node plus 2x hyperthreading). Co-PI Sriver will also contribute to the development of new wind and precipitation fields (subproject 2) to be implemented in the modeling tasks. This subproject will be performed in coordination with PI Goes and NOAA collaborators Goni and Foltz.

The requested postdoctoral research will be under the supervision of co-PI Sriver at the University of Illinois during project years 2 and 3. He/She will be responsible for the day-to-day operations of the modeling subprojects, and he/she will contribute to the diagnostics and data-model synthesis and analysis. At no additional cost to the project, Co-PI Sriver will incorporate part-time graduate student support during the first 1.5 years of the project, funded through existing research support as part of Cop-PI Sriver's startup negotiations. The student will work closely with co-PI Sriver, and also the postdoctoral researcher during year 2, on the development of the input data sets for the modeling subprojects and on the preliminary model testing and sensitivity analysis.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Causeway Miami FL 33149

29 June 2012

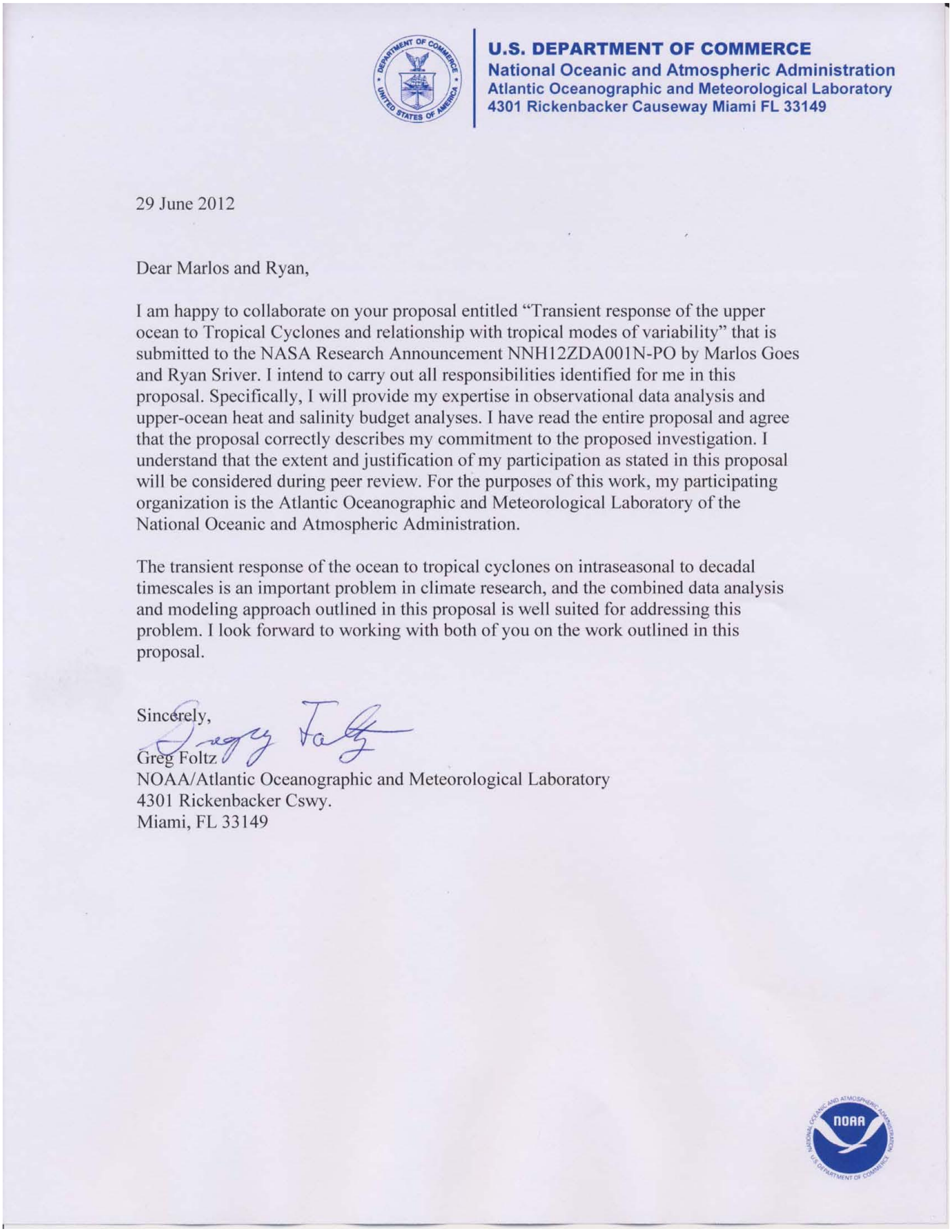
Dear Program Manager:

I acknowledge that I have been identified as a collaborator to the proposed investigation entitled "Transient response of the upper ocean to Tropical Cyclones and relationship with tropical modes of variability" that is submitted by Marlos Goes and Ryan Sriver to the NASA Research Announcement NNH12ZDA001N-PO. I intend to carry out all responsibilities outlined for me in this proposal with no cost. I have read the entire proposal and I agree that the proposal correctly describes the nature of my collaboration to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is the Atlantic Oceanographic and Meteorological Laboratory of the National Oceanic and Atmospheric Administration.

I will be glad happy to provide Marlos and Ryan my expertise in Tropical Cyclones Heat Potential analyses, and provide advices in the area of tropical cyclones interactions with the ocean and observational data analysis. I believe this work will provide valuable and much needed enhanced understanding of air-sea ocean dynamics, and predictability of the tropical modes of variability during these strong events.

Sincerely,

Gustavo Goni
NOAA/Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Cswy.
Miami, FL 33149



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Causeway Miami FL 33149

29 June 2012

Dear Marlos and Ryan,

I am happy to collaborate on your proposal entitled "Transient response of the upper ocean to Tropical Cyclones and relationship with tropical modes of variability" that is submitted to the NASA Research Announcement NNH12ZDA001N-PO by Marlos Goes and Ryan Sriver. I intend to carry out all responsibilities identified for me in this proposal. Specifically, I will provide my expertise in observational data analysis and upper-ocean heat and salinity budget analyses. I have read the entire proposal and agree that the proposal correctly describes my commitment to the proposed investigation. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review. For the purposes of this work, my participating organization is the Atlantic Oceanographic and Meteorological Laboratory of the National Oceanic and Atmospheric Administration.

The transient response of the ocean to tropical cyclones on intraseasonal to decadal timescales is an important problem in climate research, and the combined data analysis and modeling approach outlined in this proposal is well suited for addressing this problem. I look forward to working with both of you on the work outlined in this proposal.

Sincerely,

Greg Foltz
NOAA/Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Cswy.
Miami, FL 33149

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

School of Earth, Society, and Environment
173B Computing Applications Building, MC-235 605 E. Springfield Avenue Champaign, IL 61820 USA

Phone: (217) 333-3440 Fax: (217) 244-6323

June 25, 2012

Bonnie Townsend Sponsored Programs University of Miami 4600 Rickenbacker Causeway Miami, FL 33149

Dear Ms. Townsend:

The University of Illinois at Urbana-Champaign is pleased to submit a proposal entitled, "*Transient response of the upper ocean to Tropical Cyclones and relationship with tropical modes of variability*" in support of your project of the same name with the National Aeronautics and Space Administration (NASA). This proposal was prepared by Dr. Ryan Sriver in the Department of Atmospheric Sciences.

For information relating to the technical portions of this project, please contact Dr. Ryan Sriver, University of Illinois at Urbana-Champaign, Department of Atmospheric Sciences, 105 South Gregory Street, Urbana, IL, 61801, (217) 333-2046.

Negotiations concerning fiscal aspects of this project or any other official correspondence should be addressed to the Office of Sponsored Programs and Research Administration, 1901 South First Street, Suite A, Champaign, IL, 61820, (217) 333-2187.

Scott Morris

Scott Morris
Associate Director of Operations
School of Earth, Society and Environment

Debasish Dutta
Chair, Research Board

Sincerely,

UNIVERSITY OF ILLINOIS
AT URBANA - CHAMPAIGN

Office of Sponsored Programs
and Research Administration
1901 South First Street, Suite A
Research Park
Champaign, IL 61820

June 27, 2012

Bonnie Townsend
University of Miami

U of I REF. NO. 2012-06852
TITLE: Transient Response of the Upper Ocean to Tropical Cyclones and Relationship with Tropical Modes of Variability
AMOUNT : $ 259,981.00
PERIOD: 2/1/13-1/31/16
PRINCIPAL INVESTIGATOR(s): Ryan Sriver
DEPARTMENT: Atmospheric Sciences
TYPE OF REQUEST: New Request

Enclosed are copies of the above referenced proposal. This proposal has been approved for submission by the proper University administrative official(s).

Your consideration will be appreciated. Any contract or grant supporting the above described project must be issued in the University's corporate name, The Board of Trustees of the University of Illinois, Urbana, Illinois 61801.

Any questions of a non-technical nature regarding this proposal should be addressed to the individual below at (217) 333-2187:

Kim Darnell

Sincerely,

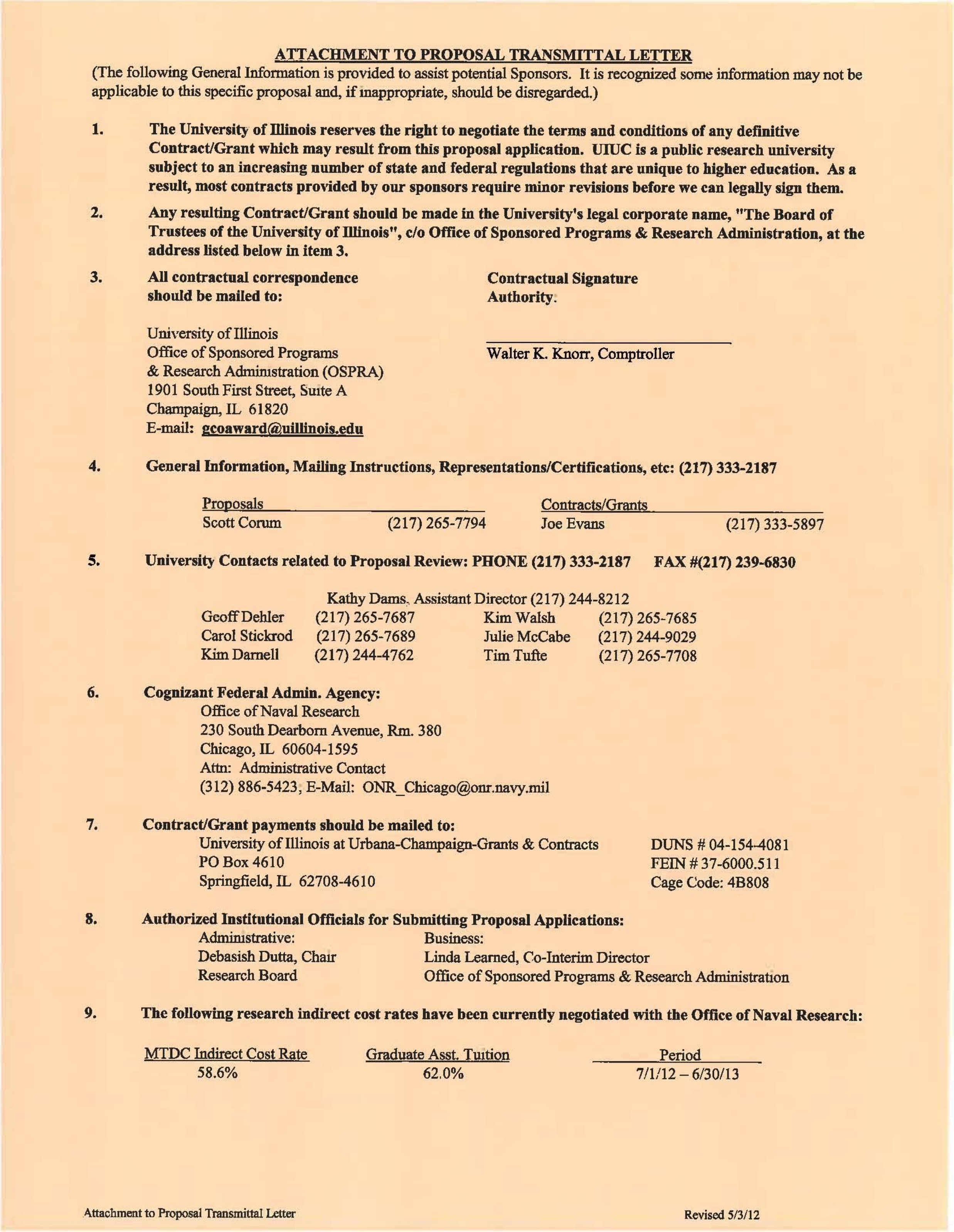
Linda Learned /jm

Linda Learned, Co-Interim Director
Office of Sponsored Programs and Research Administration

LL: JM

Enclosure

cc: Stephanie Cresap



ATTACHMENT TO PROPOSAL TRANSMITTAL LETTER

(The following General Information is provided to assist potential Sponsors. It is recognized some information may not be applicable to this specific proposal and, if inappropriate, should be disregarded.)

1. **The University of Illinois reserves the right to negotiate the terms and conditions of any definitive Contract/Grant which may result from this proposal application. UIUC is a public research university subject to an increasing number of state and federal regulations that are unique to higher education. As a result, most contracts provided by our sponsors require minor revisions before we can legally sign them.**
2. **Any resulting Contract/Grant should be made in the University's legal corporate name, "The Board of Trustees of the University of Illinois", c/o Office of Sponsored Programs & Research Administration, at the address listed below in item 3.**
3. **All contractual correspondence should be mailed to:**

   University of Illinois
   Office of Sponsored Programs
   & Research Administration (OSPRA)
   1901 South First Street, Suite A
   Champaign, IL 61820
   E-mail: **gcoaward@uillinois.edu**

   Contractual Signature Authority:

   Walter K. Knorr, Comptroller

4. **General Information, Mailing Instructions, Representations/Certifications, etc: (217) 333-2187**

Proposals		Contracts/Grants	
Scott Corum	(217) 265-7794	Joe Evans	(217) 333-5897

5. **University Contacts related to Proposal Review: PHONE (217) 333-2187 FAX #(217) 239-6830**

Kathy Dams, Assistant Director (217) 244-8212

Geoff Dehler	(217) 265-7687	Kim Walsh	(217) 265-7685
Carol Stickrod	(217) 265-7689	Julie McCabe	(217) 244-9029
Kim Darnell	(217) 244-4762	Tim Tufte	(217) 265-7708

6. **Cognizant Federal Admin. Agency:**

   Office of Naval Research
   230 South Dearborn Avenue, Rm. 380
   Chicago, IL 60604-1595
   Attn: Administrative Contact
   (312) 886-5423, E-Mail: ONR_Chicago@onr.navy.mil

7. **Contract/Grant payments should be mailed to:**

   University of Illinois at Urbana-Champaign-Grants & Contracts
   PO Box 4610
   Springfield, IL 62708-4610

   DUNS # 04-154-4081
   FEIN # 37-6000.511
   Cage Code: 4B808

8. **Authorized Institutional Officials for Submitting Proposal Applications:**

Administrative:	Business:
Debasish Dutta, Chair	Linda Learned, Co-Interim Director
Research Board	Office of Sponsored Programs & Research Administration

9. **The following research indirect cost rates have been currently negotiated with the Office of Naval Research:**

MTDC Indirect Cost Rate	Graduate Asst. Tuition	Period
58.6%	62.0%	7/1/12 – 6/30/13

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

School of Earth, Society, and Environment
173B Computing Applications Building, MC-235
605 E. Springfield Avenue
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June 25, 2012

Bonnie Townsend
Sponsored Programs
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Dear Ms. Townsend:

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Sincerely,

Scott Morris — D. Dutta

Scott Morris
Associate Director of Operations
School of Earth, Society and Environment

Debasish Dutta
Chair, Research Board

UNIVERSITY OF MIAMI
BUDGET JUSTIFICATION
Principal Investigator: Marlos Goes
Period: Feb 01, 2013 – Jan 31, 2015

A. Senior Personnel

Salary support is requested for the PI M. Goes, for 5 months each year of the project. The collaborators G. Goni and G. Foltz will work on this project for two months per year at no additional salary cost.

B. Fringe Benefits

Fringe benefits are charged at a rate of 35.4% on senior salary. Benefits include retirement, worker's compensation, health, life and dental insurance, termination, and Medicare

C. Travel

Support of $4000/year for domestic travel throughout the course of the project is requested for meetings with collaborators as necessary. This also includes travel and registration fees for attending an annual scientific meeting to present results. At the US GSA (www.gsa.gov) rate for a 5-day AGU fall meeting estimate is US$2030:

Fixed: Airfare ($450); Land Transp. ($150); Registration ($300)

Daily: Accommodation ($155/day=$775); Per diem ($71/day=$355)

D. Other Direct Costs

Publication Costs: The budget includes $2,000 each year as the estimated cost of preparing and publishing project results.

Computer Costs: One personal computer for Marlos Goes to be used for data storage and analysis associated with this project is budgeted as $5000 in the first year.

E. Indirect Costs

The University of Miami's negotiated IDC rate is 53.5% with DHHS.

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN BUDGET JUSTIFICATION

Principal Investigator: Ryan Sriver Period: 02/01/13-01/31/16

A. Senior Personnel

Salary support is requested for the PI, Ryan Sriver, for 1/2 month each year of the project. Salaries are based on actual UIUC AY2012 rates and are incremented at a rate of 3.0% each year.

B. **Other Personnel** Funding is requested for one post-doc for 12 months each for Years 2 and 3 of the project. This salary is estimated based on similar appointments in the Department and School, and the rate is incremented at a rate of 3.0% each for Year 3.

C. **Fringe Benefits** Fringe benefits are charged at a rate of 45.0% on senior and the post-doc salaries. Benefits include retirement, worker's compensation, health, life and dental insurance, termination, and Medicare

D. **Travel** Support for domestic travel throughout the course of the project is requested for meetings with NASA personnel and/or collaborators as necessary. This also includes travel to attend an annual scientific conference to present research.

E. **Other Direct Costs** Publication Costs: The budget includes $2,000 in Years 2 and 3 as the estimated cost of preparing and publishing project results.

F. **Indirect Costs** Indirect costs are assessed at a rate of 58.6% of Modified Total Direct Costs (MTDC), the rate for which was negotiated with the Office of Naval Research, and approved on March 1, 2012. MTDC is direct costs less capital equipment, tuition remission, and subawards in excess of $25,000.