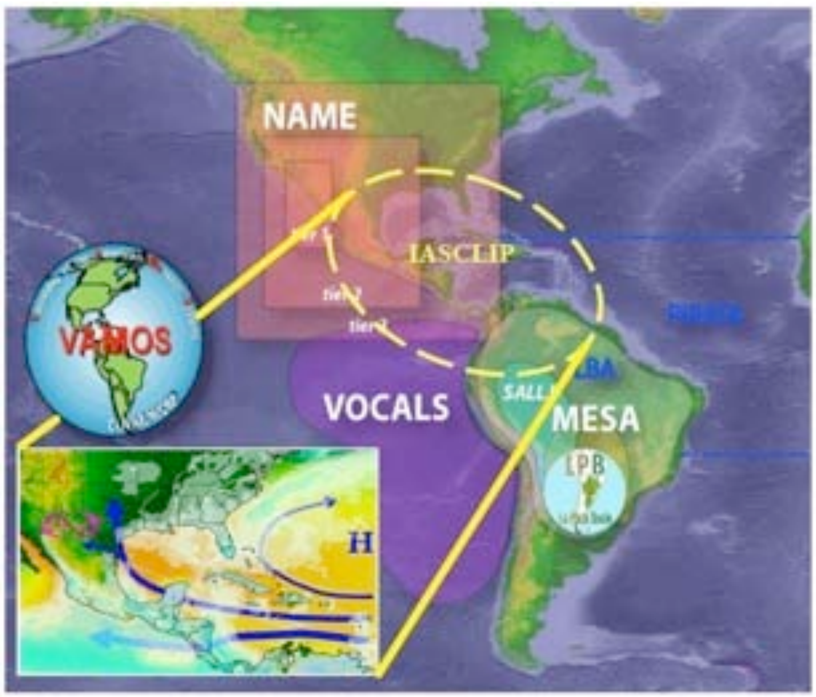
Intra-Americas Study of Climate Processes (IASCLIP)

A white paper for monitoring the Intra-Americas Sea

January 2011



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Executive Summary

Unlike NW Mexico (VAMOS-NAME) where mesoscale orographic uplift is key to understanding monsoon dynamics, or the SE Pacific (VAMOS-VOCALS) where the microphysics of cloud formation dominate the large offshore cloud deck and thus account for model bias, the summer climate of the Intra-Americas Sea and surrounding land areas is dominated by the large-scale SST anomalies of the Atlantic warm pool (AWP) that stretches from Central America to the western tropical Atlantic east of the Lesser Antilles. The AWP anomalies occur in a 3-dimensional response to air-sea interaction forcing over vast areas, the advection of ocean heat into and out of the warm pool by the large-scale circulation, and the diffusion of heat through the thermocline to the colder waters below. Typically, coupled climate models are characterized by a 1-2C negative bias in SST all across the tropical North Atlantic (TNA) to West Africa with a counterpart positive anomaly in the subtropical SE Atlantic. However, in the heart of the AWP, in the Caribbean and Gulf of Mexico, there is a noteworthy dearth of oceanic and atmospheric measurements comparable to what exists elsewhere in the tropics. Especially challenging is the lack of subsurface thermal measurements by buoys, XBTs and Argo floats, without which even the seasonal cycle of the warm pool is difficult to analyze, much less its seasonal-to-interannual changes, while the ability to estimate the hurricane heat potential in real time is limited to indirect satellite altimeter measurements. Hence, model pathologies in the IAS region clearly have to be assessed with a program of improved large-scale monitoring of key parameters on a large scale.

To address these needs we propose a strategy that mainly bootstraps from monitoring programs already in existence or in planning stages, such as the CPO-led US GCOS (Argo, drifters, XBTs), the NDBC-NWS moored array of surface met buoys in the Caribbean, and the NSF-funded COCONet system of GPS ground stations for estimating atmospheric precipitable water and soil moisture in real time. In some cases, as with the moored buoys, new funding is required, e.g., to place thermistors on mooring cables so that the buoys can report temperature with depth in real time to anchor satellite estimates of hurricane heat potential, estimate warm pool heat content and assess warm pool simulations and predictions by models. Other measurements, such as drifters and Argo floats, may only require a re-prioritization of the GCOS deployment strategy. And other existing efforts, such as COCONet, can benefit from IASCLIP's coordination of international cooperation and by providing scientific guidance on deployments in the IAS region. In addition to these, we propose to supplement the existing – but deteriorating – upper air network through an array of strategically distributed sounding stations that acquire atmospheric profiles more economically, on a need-prioritized basis, and at critical sites in the Caribbean where our regional partners can aid with logistics.

The proposed system of enhanced monitoring is designed to build upon capabilities that already exist in the IAS. One such capability is the array of surface meteorological buoys already deployed and maintained by NDBC, to which subsurface temperature sensors and specialized meteorological instrumentation can be added. Another is the network of land stations operated by national met services in the region, which can host additional instrumentation (e.g., COCONet-GPS and supplementary soundings) and can be coordinated through IASCLIP in cooperation with NSF. A third is the under-utilized array of small islands that are manned and logistically supported by several navies in the region. And finally, of course, the US GCOS program that can extend open Atlantic monitoring into the IAS either through re-prioritization (Argo, drifters) or expansion (Argo, drifters, XBTs).

It is anticipated that the additional measurements of subsurface temperature, soundings, rainfall, precipitable water, soil moisture and air-sea fluxes in the IAS region will prove valuable in the assessment and verification of models (c.f. IASCLIP model plan) and will enhance essential climate services such as hurricane and drought predictions.

Introduction

IASCLIP is an international research program focusing on the role of the Intra-Americas Sea (IAS = Gulf of Mexico and Caribbean) as a regulator of summer climate across the Western Hemisphere. Program emphasis is placed on the understanding and prediction of extreme weather events and improved seasonal to interannual climate forecasting. Outreach and focused research collaboration across the region are prime goals of IASCLIP (www.eol.ucar.edu/projects/iasclip). The summer climate of the region is dominated by ENSO and the Atlantic warm pool (AWP), and IASCLIP aims to leverage the AWP as a value-added source of climate predictability by getting climate models to correctly replicate the processes that govern SST evolution in the warm pool region, and the linkages between the AWP and its summer climate impacts.

Research over the last decade suggests that remote climate patterns in winter-spring (e.g. the NAO, ENSO, Amazon convection, etc) can force large AWP anomalies by early summer, which in turn affect regional climate (hurricanes, tornados, floods and droughts). The heat budget of the AWP must play a key role in the seasonal evolution of the climate system in the tropical Americas but so far models have not replicated the buildup of the AWP in the summer. We know that coupled models suffer from a severe negative bias in tropical North Atlantic SST. Most IPCC-class global models underestimate SST in the IAS and do not reproduce the observed AWP or the seasonal cycle of precipitation associated with the AWP. Unfortunately, the oceanic and atmospheric observations in the IAS are very poor, and it's clear that we need to find ways of extending Atlantic Ocean monitoring into the IAS, both to aid in initializing model forecasts and as a means of validating climate forecasts and assessing the model deficiencies.

It is sometimes asked, what kind of intensive observational experiment can be devised for the IAS region, comparable to what has been done in previous monsoon programs, such as NAME (North American Monsoon Experiment) and VOCALS (SE Pacific Regional Experiment). Those experiments were justified by having identified one or more key small-scale climate-ocean processes, unique to a region, that climate models were not replicating correctly and for which there was good reason to believe that correcting those deficiencies would substantially improve climate forecasts. However, in the case of IASCLIP, the model biases extend over the entire tropical North Atlantic and are likely connected with opposite model biases in the South Atlantic, therefore a regional scale experiment is not likely to resolve such issues. What is needed, however, is to develop a judiciously placed real-time monitoring system within the IAS region that is at least comparable to that which we have between Africa and the Lesser Antilles or along the equator in the Pacific (TAO array). Model errors in the IASCLIP region are most pronounced in the area which experiences the greatest surface warming during the summer and this greatly impacts the atmospheric response to the AWP. An improved monitoring program in the IAS will work hand-in-hand with research efforts aimed at solving large scale SST biases in coupled climate models, and improved climate monitoring within the IAS will aid efforts to understand warm pool processes and their relation to summer climate impacts. Improved observations will also aid another very important effort in IASCLIP, namely to expand our current experimental model forecasts for the IAS region (http://coaps.fsu.edu/iasclip), and to verify and assess forecast errors as a key feedback for the process of model improvement. Kirtman and Min (2009) showed that by properly initializing a coupled model like CCSM3.0 (which is well known to have some strong ENSO bias) one can still generate seasonal to interannual forecast skill comparable to or at times even better than the NCEP CFS which is perceived to have a better simulation of ENSO (as seen in multidecadal integrations).

The lack of adequate oceanic monitoring in the IAS is manifested in a number of ways. Although commercial vessels that transit the IAS could be used for deploying XBTs, no VOS routes have yet been implemented across the IAS and as such the IAS lacks the detailed observing that has taken place across the Pacific and open Atlantic for many years. Some near-coastal moorings have been deployed in the Gulf of Mexico to sample currents and/or thermal structure, but these typically do not have long lifetimes and have no long-term support as part of NOAA's ocean observing system. No such moorings with upper ocean vertical sensors exist in the Caribbean Sea. Neither surface drifting buoys nor Argo profiling floats are regularly deployed in the IAS as they are elsewhere. The relative lack of subsurface thermal observations in the IAS can be readily seen in the World Ocean Database and this paucity of subsurface monitoring precludes the detailed type of research focusing on seasonal-to-interannual variability of heat storage and ocean structure that has been possible with ocean monitoring in the Pacific and open Atlantic where drifters, Argo floats, XBT line and T(z) moorings are much more plentiful. More specifically, subsurface observations are grossly inadequate to document seasonal and interannual variations in the 3-dimensional structure and heat content of the AWP. Ocean-atmosphere coupled models lack sufficient real time observations in the IAS to even attempt to assess model reliability in the detailed evolution of the AWP.

The network of atmospheric observations across the IAS is in better shape than that for oceanic observations across much of the IAS region. US-Mexico cooperation that started with NAME has resulted in improvements in the Mexican meteorological network that are ongoing and which we are optimistic can continue during IASCLIP. Weather observations from Central America vary from country to country, as do the observations from northern South America. First-order stations such as airports and weather service observatories are generally the best source for real-time data. However, although many of the second- and third-tier stations are operative, the quality of the data is often poor and the data for the most part are not available internationally, especially in real time, and valuable archived climate data sets do not get into the research databases elsewhere. Representatives from IASCLIP (A. Douglas, M. Douglas and D. Enfield) have visited a number of countries in 2010 to understand the problems and needs for measurements, data quality and availability of data. Of the 7 countries visited for assessment of their possible participation in IASCLIP, almost all of them showed strong interest in improving their shared climate data bases and they all showed a strong desire to increase the flow of real time observations that enter the operational models. The importance of regional data assimilation into the models is now becoming an important focal point of regional weather services who rely on NOAA, Canadian and ECMWF products. Cooperation will continue under IASCLIP to make improvements in the data flow from these countries.

That said, the current availability of surface and upper air data in the Caribbean is not in good shape and the past decade has shown a steep decline in the surface and upper air station network. The upper air database has been variable over time and has numerous gaps throughout the region including Central and South America. It continues to be difficult to maintain due to aging equipment, unsafe hydrogen generators and budgetary constraints. This is likely to become even worse in the future, due in large part to the availability of other sources of data (e.g., satellites) that supplant some of the historical utility of radiosonde data for operational purposes. At most stations launches are generally made only once a day now but many days and weeks are entirely missing observations. Precipitation is poorly sampled and in particular, it is unavailable over ocean areas, especially in the Caribbean where large biases probably exist. The upper air and rainfall data networks are arguably the most important data sets for diagnostic research and for assessing and improving model performance.

For IASCLIP, we propose a gradual ramping up of oceanic and atmospheric monitoring of key variables, taking advantage of existing infrastructures to the extent possible, and enlisting the cooperation of hydrographic and meteorological entities in the region. In the following section we outline proposals for atmospheric and oceanic monitoring.

OBSERVATIONAL STRATEGY FOR IASCLIP

Given the current uncertainties and biases present in operational/research climate forecast models and the limited understanding of what specific information is needed to improve such models, the focus of IASCLIP will be on the development of a baseline climate monitoring system. Such a system should have the following characteristics:

1) Long term sustainability of an ocean-atmosphere monitoring network aimed at enhancing both operational and research modeling. The network should be designed to mesh with new satellite observing systems planned for the future.

2) Close oversight of the observing network from both the scientific and operational sector, similar to that which has provided both insight and added value to the TAO and PIRATA arrays.

3) Leveraging of efforts from other agencies like NDBC (Caribbean moored buoys) and the NSF funded project for the Continuously Operating Caribbean GPS Observational Network (COCONet) which is primarily meant to study solid earth processes, but has the capability to measure precipitable water and soil moisture as well as standard atmospheric observations.

4) Deployment of new aerological systems where needed to supplement failing networks. The best example of this is an adaptive upper air sampling scheme to counter the failing network of radiosonde soundings.

Ocean monitoring

Monitoring the heat content of the IAS warm pool has been described as one clearly defined objective of the IAS science plan. To accomplish this goal IASCLIP will require a strategy for measuring the temperature profile in the mixed layer and across the thermocline. These observations will need to be centered over the Caribbean Sea and eastern Pacific west of Central America where relatively few routine measurements exist today. Initially, we are proposing to attach subsurface thermistor strings to four existing NDBC-NWS surface meteorological buoys in the Caribbean as a highest priority. Doing so will essentially convert these well-maintained buoys into TAO-class measurement platforms. This strategy will provide the vertical ocean temperature distribution required to constrain the AWP heat budget and initialize and assess models for climate purposes, and it will provide direct measurement of the tropical cyclone heat potential (TCHP) along the path of destructive hurricanes that transit the region. The specific requirements for this are set out in Appendix A.

Several other readily implemented ocean monitoring mechanisms are currently being discussed for potential funding requests in the future: but we are not prepared at this time to make specific proposals:

(1) Surface drifters can be shipped to and deployed by the Colombian Navy on their island resupply cruises.

(2) IRIDIUM-equipped Argo floats can be deployed, so that grounding problems can be avoided by controlling the parking depth.

(3) Recruit 2-4 VOS vessels to launch XBTs across the Caribbean and Gulf of Mexico.

Atmospheric monitoring

It is necessary to enhance the real-time transmission of regional rainfall measurements to met service data centers and to improve the quality control of the existing data stream and of historical data. This will require working with the entire region’s data bases to ensure that they are digitized, quality-controlled, and made available in suitable formats. Several enhancements to atmospheric monitoring are suggested for the IAS:

(1) The perception that satellites can replace radiosondes operationally cannot be reversed, and we do not propose to reconstruct the current radiosonde network as it previously existed. Rather than abandon the sounding network entirely we are recommending that the current radiosonde strategy for the region be revamped to include observations at more locations – but less frequently. We recommend establishing more sites, but with lower-cost systems making primarily tropospheric soundings with both less frequent, but regular observations and a component that is adaptive – providing more frequent observations for both high impact weather events and also for research studies of aspects of the circulation whose understanding benefits from more frequent measurements. We also propose to establish GPS-Met observations at each sounding site.

(2) IASCLIP will work closely with NSF on the recently funded COCONet GPS observing system (cost at $6 million). NSF GPS monitoring within the IASCLIP domain affords an opportunity to leverage expanded observing across the IAS region. In October and November 2010 meetings took place with NSF GPS community and IASCLIP representatives in order to strengthen the working relationship between the two programs. NSF PIs are also interested in placing GPS PW instrumentation on the NDBC-NWS buoys in the Caribbean and Gulf of Mexico. IASCLIP will work with this newly proposed project that will allow for the first time GPS PW measurements from buoys. In addition to the recent innovations on soil moisture measurements and PW water measurements from ocean buoys, NSF has also proposed a number of super sites that will be able to measure deeper soil moisture levels and to calculate moisture advection from an enhanced array of GPS stations.

IASCLIP is also working with NSF PIs on the development of a similar GPS network for Mexico (estimated cost at $10 million). It appears that a couple of enhanced arrays will be placed within the COCOnet domain and the Mexican White Paper for the NSF funded GPS observing system will also include a number of enhanced arrays. IASCLIP will work with NSF to ensure the transmittal of the data sets onto the GTS for use in operational models. NSF will help to maintain the archived data sets through funding to UNAVCO in Boulder and all data will be available to researchers.

(3) A third component of the improved monitoring will include improvement in key small-island measurement sites, which will provide high-quality measurements for better monitoring of the surface climate, including precipitation. Small islands have negligible topographic influence with small diurnal effects, and better represent conditions over the surrounding oceanic region than do observations from large island sites. Maintaining more complex instrumentation is also easier on islands than on oceanic buoys, provided transport to and from the islands is assured. Several countries in the region maintain small bases on these islands for purposes of sovereignty, with regular logistical resupply cruises. IASCLIP has already made contact with the most important of these countries – Colombia, with an agreement in principle to conduct a cooperative effort at establishing satellite-transmitted surface met stations at a number of advantageous locations.

IASCLIP has pledged to help COCOnet in the selection of island sites and to work the host countries in instrument setup and data transmission.

(4) The NDBC buoys, in addition to enabling subsurface temperature measurements, provide excellent platforms for adding additional atmospheric instrumentation. One of course, is the GPS capability mentioned above. Another would be a sonic anemometer package (C. Fairall) that can aid in direct measurements of surface fluxes. Such enhancements are best made in the context of project-funded researchers who will have the responsibility for coordinating field operations with NDBC, and who can also manage the data handling requirements.

Summary

In summary, the observational component of IASCLIP seeks to strengthen the routine monitoring of the climate over the region by:

1) Making subsurface temperature and enhanced meteorological measurements part of the current NDBC buoy network in the Caribbean.

2) Consider several additional options for ocean thermal profiling of the IAS in the context of the existing US GCOS system.

3) Establishing surface observation sites on small islands in the western Caribbean Sea and other islands as appropriate.

4) Digitizing and quality-controlling the historical surface observations throughout the region. This could be an effort potentially funded by the CPO ARC program.

5) Establishing an adaptive radiosonde network that satisfies the needs for both climate monitoring and research needs and for high-impact weather events.

6). Work closely with NSF on the development of the GPS system across the IASC region (COCOnet and Mexico) with emphasis on ideal monitoring locations, real time data receipt into NCEP and long term climate monitoring goals for the region (goals of both NOAA and NSF).

Budget

The initial estimate for the cost of each component is:

Thermistor chain for 5 years on four buoys: $420K

Surface sites on 15 Caribbean/Bahamian Cays and islands in E. Pacific: $500K

Digitizing/QC of historical surface data: $300K

Establish 8 adaptive sounding sites ($150K) and 5 years operation[1] ($1500K): $1650K

Establish 8 GPS-Met sites collocated with adaptive radiosonde sites ($200K)

Estimated total cost of the observational enhancements ~ $2.6M. This is ~ $500K/yr.

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[1] High impact (30 events/year), routine monitoring (10 obs's/month) for 8 sites ~1200 obs/yr = $300K/yr

APPENDIX A

NDBC/IASCliP Subsurface Temperature Measurements at NDBC Buoys located in the Caribbean Sea

PROJECT REQUIREMENTS AND SCOPE STATEMENT

Version: *Draft*

Project Name:

Subsurface Temperature Measurements at National Weather Service Caribbean Buoys

Prepared by:

Customer: Intra-American Seas Climate Program (IASCliP)

Date Prepared:

1. References:

a) Proposal to Equip Caribbean Buoys with Thermistor Strings
b) Email from Dave Enfield dated 5/28/2010, Subj: Re: Idea for T(z) on Caribbean buoys

2. Scope

The objective of this project is to augment the existing four stations in the Caribbean Sea operated by NOAA's National Data Buoy Center (NDBC) with subsurface temperature measurements (hereafter referred to as T(z)) with instrumentation and supplied or funded by IASCliP as outlined in reference (a).

NDBC will provide from its existing technology:

a) Hulls suitable for T(z)
b) Transportation to and deployment of the T(z) instrumentation at the sites.
c) Pre-deployment instrument checks and integration with the buoy electronics using existing NDBC procedures and test equipment.
d) Existing Data management and communications support
e) Technical approach and cost proposal based on the requirements set forth herein.

IASCliP will provide:

a) Funding to support the procurement of the sensors and supporting components, the pre-deployment instrument checks, mooring, integration, and costs associated with the deployment of the T(z), but not the costs of the buoy and the buoy deployment itself.
b) Funding for any pre and post-deployment calibrated instrument measurements to determine instrument drift.
c) Funding for the handling and return of the instruments to an IASCliP receipt point at the conclusion of the project.
d) Funding for any instrument repair, service or re-calibration by the vendor.

3. Primary Requirements (reference (a), except as noted)

a) The buoys of interest are 42056, 42057, 42058, and 42059 in the Caribbean Sea.
b) Measure ocean temperature at the approximate depths of 0, 20, 30, 50, 70, 100, 150, 200, 250, 300 meters, assuming 10 thermistors and that the buoys do not already have a hull-mounted thermistor. If there is already one at the (near) surface, 10 could be arranged thusly: 15, 25, 35, 50, 70, 100, 150, 200, 250, 300 meters (reference (b))
c) Measure ocean pressure at 300 m.
d) Upon recovery, NDBC will forward any data stored on instrument data storage devices to a designated IASCliP receipt point.
e) Measurements to commence in 2011 with the deployment of two T(z) moorings and continue or terminate for future years based upon annual review and receipt of funds based on the cost proposals for subsequent years.

4. Ancillary Requirements

a) The project will use existing NDBC technology and will not require any development effort by NDBC.
b) Deployments, service, and recoveries will only be conducted using NDBC's regular service schedule for the buoys of interest (NDBC schedules one trip a year in the spring, early summer).
c) Provide at least one measurement from each sensor per hour in near real-time (within 30 minutes of the actual measurement) at NDBC's level of reporting precision (Table 1) to a designated receipt point for IASCliP using existing NDBC data transfer mechanisms and formats.
d) NDBC will distribute the data in real-time in support of National Weather Service and make the data available on its webpages.
e) IASCliP may fund NDBC to conduct post-deployment calibrations and processing following NDBC's Tropical Atmosphere Ocean (TAO) Refresh processes, or provide funding for the delivery of instrumentation to a third-party.

5. Performance Requirements

NDBC cannot guarantee levels of performance, such as accuracy or data availability, but will treat the instrumentation and data to the same level it would its own.

The instrumentation will be configured to TAO Refresh specifications (Table 1):

Table 1: TAO Refresh Configuration

Measurement	Sample rate	Sample period	Sample time	Data recorded in memory	Transmitted data	Transmission Interval
Near surface and subsurface temperature and pressure	**1 per 10 minutes**	**instantaneous**	**0000, 0010,...**	**10 min**	**10-minute instantan-eous**	**Once per hour**

Subsurface instrumentation will be at depths of 1, 20, 30, 50, 70, 100, 150, 200, 250, 300 meters.

NDBC procure instrumentation compatible with its existing technologies, that is Seabird Electronics.

NDBC will perform real-time quality control in accordance with NDBC Handbook of Automated Data Quality Control Checks and Procedures; Technical Document 09-02 (http://www.ndbc.noaa.gov/NDBCHandbookofAutomatedDataQualityControl2009.pdf)

6. Operational Requirements

The project will use NDBC operational or operational evaluation hulls, electronics, and data management and communications.

The technical approach is predicated on the availability of NDBC's Standard Buoy hull and electronics.

In Fiscal Year 2011, as part of the 2011 Hurricane Service cruise, NDBC intends to deploy two Standard Buoys one each at two of the candidate locations.

Each Standard Buoy will have 10 subsurface instruments, as well, as a standard suite of meteorological sensors.

The subsurface instruments will be replaced annually with each Hurricane Service cruise.

NDBC will employ an inductive mooring and modems for the communication between the subsurface sensors and the buoy's datalogger.

In Fiscal Year 2012, as part of the 2012 Hurricane Service cruise, NDBC will deploy two additional Standard Buoys – one each at the two remaining locations.

7. Scope Assumptions

a) Neither party is held liable for lost or damaged equipment due to acts of nature or normal wear and tear from being deployed for lengthy periods of time in the marine environment.
b) Because the stations are funded by NOAA/NWS, they may be disestablished at the discretion of NOAA/ NWS.

8. Reviews and Timelines

- NDBC and IASCliP will review the requirements and MOU annually by June 15th in order to allow sufficient planning for the schedule service cruise usually in the following spring.
- The decision timelines are as follows:

NDBC normally makes the service cruise for the hurricane buoys in March or April. In order for NDBC to have sufficient time to procure materials, modify contracts, and assembly components, the following timeline is necessary:

For Year 1 for Deployment of two moorings in 2011

01 October 2010:	Funding for sensor procurement ($136,992) and signed Memorandum of Agreement received at NDBC.
01 January 2010:	Engineering and Buoy Production Funds ($37,620) received at NDBC.
01 February 2010:	Deployment and Verification Funding ($54,500) received at NDBC.
March/April 2011:	NDBC deploys two T(z) moorings in the Caribbean.

For Year 2 for two replacement moorings (replace 2011 deployments) and deploy two new moorings for 2012.

15 June 2011:	NDBC receives Requirements Document and request for cost proposal for 2012 deployments from IASCliP.
15 July 2011:	NDBC provides IASCliP with cost proposal for 2012 deployments.
01 October 2011:	Funding for sensor procurement and signed Memorandum of Agreement received at NDBC.
01 January 2011:	Engineering and Buoy Production Funds received at NDBC.

01 February 2011:	Deployment and Verification Funding received at NDBC.
March/April 2012:	NDBC deploys two new T(z) moorings in the Caribbean and replaces the two established moorings.

For Year 3 recovery of 4 moorings:

15 June 2012:	IASCliP notifies NDBC of project termination or provides Requirement Document and request for cost proposal to continue the project.
15 July 2012:	NDBC provides IASCliP with closeout costs and return shipping costs for sensors.
March/April 2013:	NDBC recovers all moorings.
June/July 2013:	Upon receipt of closeout and shipping costs to return sensors, NDBC will return remaining sensors as directed by IASCliP.

NDBC 5-year budget for adding T(z) to Caribbean buoys

Cost Estimate -- IASClip	Materials Unit Price					Closure and
	N/C = No Cost					Recovery
		# Units Materials	# Units	2012	# Units	2013
Engineering						
Power Analysis and Power System Sizing		Labor		$1,800.00	0.00	0.00
Stability	N/C	Labor		$0.00	0.00	0.00
Mooring Design		Labor		$8,700.00	0.00	0.00
Pre-Deployment Testing		Labor		$8,700.00	0.00	0.00
Drafting		Labor		$8,700.00	0.00	0.00
Sub-total:				**$27,900.00**		**$0.00**
Materials:						
Hull	N/C					
Compartment	N/C					
Buoy Internal Structure	N/C					
Bridle	N/C					
Inductive Thermisters	$2,508		44	$110,352.00	0.00	0.00
Inductive Thermistor with Pressure Sensor	$3,520		5	$17,600.00	0.00	0.00
Inductive Modem Cable	$5,130		5	$25,650.00	0.00	0.00
Inductive Coupler Assembly	$1,370		5	$6,850.00	0.00	0.00
Misc. Small Components	$2,280		1	$2,280.00	0.25	570.00
Acoustic Releases	$14,820		5	$74,100.00	0.00	0.00
Sub-total:				**$236,832.00**	**0.25**	**$570.00**
Buoy Production:						
Hull	N/C	Materials & Labor				
Compartment	N/C	Materials & Labor				
Buoy Internal Structure	N/C	Materials & Labor				
Bridle	N/C	Materials & Labor				
Anchors	N/C	Materials & Labor	2	$0.00	0.00	
Power System	N/C	Materials & Labor				
Wireless Communications	N/C	Materials & Labor				
Solar O&I Mounting	N/C	Materials & Labor				
Electrical Components/Wiring (T(z) Buoy connections)		Labor		$8,720.00	0.00	0.00
Sub-total:				**$8,720.00**	**0.00**	**$0.00**
Deployment						
Ship Alterations	N/C	Materials & Labor		$0.00	0.00	0.00
Field Service Costs		Labor		$17,440.00	0.00	0.00
Ship Time (,$/day & # days (0.5 days per mooring))	$37,600	1	2	$75,200.00	1.00	$37,600.00
Sub-total:				**$92,640.00**	**0.00**	**$37,600.00**
Testing and Verification						
End to End		Labor		$14,600.00	0.00	0.00
Field Verification		Labor		$1,760.00	0.00	0.00
Travel	N/C	Labor		$0.00	0.00	0.00
Sub-total:				**$16,360.00**	**0.00**	**$0.00**
Real-time Data Distribution and Quality Control	N/C	Labor		$0.00		0.00
Yearly Subtotals				**$382,452.00**		**$38,170.00**
Five-Year Cost		**$420,622.00**				