INTEGRATING DATA FROM NASA MISSIONS INTO NOAA's PACIFIC REGION INTEGRATED CLIMATOLOGY INFORMATION PRODUCTS (PRICIP)

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ABSTRACT

The Pacific Region Integrated Climatology Information Products (PRICIP) Project is developing a number of products that will successfully promote awareness and understanding of the patterns and effects of "storminess" in the Pacific Rim. The National Oceanic and Atmospheric Administration's (NOAA) Integrated Data and Environmental Applications (IDEA) Center initiated the PRICIP Project to improve our understanding of such storm processes by creating a web portal containing both scientific and socioeconomic information about Pacific storms. Working in conjunction with partners at NOAA, students from the NASA Ames DEVELOP internship program integrated select NASA satellite imagery into the PRICIP web portal by animating eight storm systems that took place in the South Pacific Ocean between 1992 and 2005, four other anomalous high water events in the Hawaiian Islands, and several annual storm tracks. The primary intended audience for these products includes coastal disaster management decision-makers and other similarly concerned agencies. The broad access of these web-based products is also expected to reach scientists, the National Weather Service (NWS), the Federal Emergency Management Agency (FEMA), and media broadcasting consumers. The newly integrated and animated hindcast data will also help educate laypersons about past storms and help them prepare for the future.

INTRODUCTION

Few people realize the number of storms that occur in the Pacific Ocean, relative to the number in the Atlantic Ocean. A greater number of high intensity storms occur in the Pacific than the Atlantic, though fewer heavily-populated landmasses are in the path of such events, which may lend lesser discussion to the Pacific storms. Significant destruction and numbers of people are still affected, however. The National Oceanic and Atmospheric Administration (NOAA) Integrated Data and Environmental Applications (IDEA) Center, the Pacific Region Integrated Climatology Information Products (PRICIP) Project, and NASA Ames DEVELOP have joined to create an interactive decision support tool intended to reduce coastal vulnerability. Annual tropical storm tracks from 1992, 2002, and 2004 were created by the 2007 DEVELOP PRICIP Team, as well as animated geovisualizations for Typhoon Chata'an, Super Typhoon Pongsona, and Cyclone Heta. The 2008 team has built upon these foundations and created animated geovisualizations for five tropical storms which occurred within a five week period in and around the Cook Islands in 2005 – Namely, Cyclones Meena, Nancy, Olaf, and Percy, and Tropical Storm Rae. The team has added to the collection of annual storm tracks, as well as developed geovisualizations for four other anomalous high water events in the Hawaiian Islands. In addition to a broader scope of events, the 2008 team has updated the user interface of the visualizations to now allow frame-by-frame control of the animations.

PROJECT DESCRIPTIONS

2007 DEVELOP PRICIP Project

The previously analyzed and/or animated projects from the Pacific Ocean include: Hurricane Iniki, Typhoon Chata'an, Super Typhoon Pongsona, and Cyclone Heta (Teske *et al*., 2008). Hurricane Iniki, a Category 4 storm, was the United States' sixth most damaging and deadly hurricane of the 1990s, with maximum wind speeds of 155 mph. In addition to the damage caused, Iniki was interesting for its relatively unusual location for a Pacific hurricane. Formed as a tropical depression over warm waters southwest of Baja California on September 5, 1992, it intensified as it crossed the Pacific Ocean, eventually upgrading to a hurricane on September 8, southeast of Hilo, Hawaii. Iniki's center ravaged the island of Kauai for forty minutes. In addition to six deaths and over one hundred injuries, Iniki's monetary damage is reported to have reached US $1.8 billion (PRICIP Event Home webpage). Due to a lack of satellite data generally available at the time of the storm, however, Hurricane Iniki was not included in the 1992 geovisualizations for PRICIP years 2007 or 2008. Specifically, rainfall (TRMM) data was unavailable before 1998, and sea surface height data (Jason-1) wasn't available before 2001. Sea surface temperature data (AMSR-E) comes from the Aqua satellite, which was not launched until 2002.

Typhoon Chata'an lasted from June 28 through July 11, 2002 and passed over the island of Guam. Data collected on Guam indicated wind speeds of 85 to 90 mph and storm rainfall totals exceeding 21 inches. Classified as a Category 4 typhoon, damages amounted to several tens of millions of dollars (Fontaine, 2003).

Category 4 Super Typhoon Pongsona also hit Guam later that same year, in December of 2002. This storm ran from December 2 through December 11. Damage was also sustained on nearby islands Rota and Tinian. Maximum sustained wind speeds were recorded at 150 mph (Earth Observatory webpage).

Cyclone Heta's course covered mostly unpopulated areas in the Pacific Ocean, and blew from December 28, 2003 to January 8, 2004, eventually achieving Category 5 status. It threatened the Tokalua Islands and Western Samoa before gaining strength and passing the island of Niue. After causing massive damage to the area, it continued over open water where it eventually lost strength and dissipated (Cyclone Heta wepage).

Severity ratings for storm systems are often based on the Saffir-Simpson Scale (see below, Table: 1).

Table 1. The Saffir-Simpson Scale

SAFFIR-SIMPSON HURRICANE SCALE
Tropical Depression: < 38 mph
Tropical Storm: 39 – 73 mph
Category 1 Hurricane: 74 – 95 mph
Category 2 Hurricane: 96 – 110 mph
Category 3 Hurricane: 111 – 130 mph
Category 4 Hurricane: 131 – 155 mph
Category 5 Hurricane: >156 mph
(http://www.nhc.noaa.gov)

2008 DEVELOP PRICIP Project

The goal for the 2008 DEVELOP PRICIP Team was to modify the 2007 team's animations and homogenize these presentation and user interface upgrades with the newer geovisualizations requested by NOAA. All animations are consistent in look and feel and contain the user-friendly feature upgrades, such as enhanced timeline controls, rolling date/time stamps, and storm name labels. Per the specific request of our project partners at NOAA, there is the addition of an interactive scrubber-bar and single frame forward and backward buttons, now allowing the user greater control of the geovisualization, with frame-by-frame precision.

The PRICIP Project's primarily aim is toward enhanced decision support. The more severe a storm, the steeper the exponential curve for sustained economic, environmental and safety costs to coastal communities. While several models referenced by the Intergovernmental Panel on Climate Change, Fourth Assessment (IPCC) do not currently predict that global warming will significantly alter the *frequency* of tropical storms in general, it is predicted that the *intensity* of these storms will increase. These are the storms that quickly cost the most, and the record-breaking hurricane seasons of 2004 and 2005 suggest that we may already be witnessing this amplification in severity. It is for these reasons of obvious economic and safety concern, as well as the scientific intrigue these extreme events conjure, that the 2008 DEVELOP Team was asked to focus on these events of anomalous severity.

Organizations partnering with NOAA and NASA DEVELOP include the Federal Emergency Management Agency (FEMA), the National Weather Service (NWS), and the Coastal Service Center (CSC). By offering visual and other data contributing to a more thorough understanding of storm patterns, trends, intensities, and frequencies, the creation of integrated information products will assist emergency managers, planners, and decision-makers in reducing vulnerabilities associated with extreme storm events (PRICIP Project Work Plan 2007).

Cook Islands Addition

Added to the list adopted above, was a new geovisualization for 2008 depicting a specific series of cyclones, which took place within one five-week period near the Cook Islands, in the early weeks of 2005. Nicknamed “the Cook Islands Five,” these storms ravaged the area, reaching extreme wind speeds and causing massive destruction.

Cyclone Meena developed first, moving over the South Pacific Ocean between February 2 and February 8, 2005. By February 6, Meena had already reached super-cyclone status and maximum wind speeds of 144 mph. It made contact with the Cook Islands on February 7, though caused less damage than had been expected. Meena was classified as a Category 4 storm (Earth Observatory webpage).

Cyclone Nancy hit the Cook Islands only ten days after Cyclone Meena (smh.com.au). Nancy ran from February 10 through February 18, 2005, also reaching Category 4 status. As Nancy began to weaken, Cyclone Olaf was already picking up strength not far behind. As Olaf approached Samoa’s Manu’a Islands, winds over 99 mph were recorded. Storm surges produced waves that were 30 to 40 feet high along all shores of Manu’a. The main islands of Samoa and American Samoa declared states of emergency, but were spared full destruction as the cyclone changed course (smh.com.au). Olaf moved over the South Pacific from February 10 through February 23, 2005, reaching a Category 5 classification.

When two cyclones approach one another and their circulations begin to intermingle, as was the case with Cyclones Nancy and Olaf, two interactions are possible. One phenomenon is referred to as the Fujiwara effect, wherein the cyclones begin circling one other, and can influence the other’s speed and direction. Another possibility is when the outflow from one storm impedes the outflow of the other, thereby weakening it (Earth Observatory webpage). Cyclone Olaf exhibited some minor Fujiwhara effect while crossing Cyclone Nancy's lingering path, before continuing on its southeasterly course.

Just one day after Olaf's demise, Cyclone Percy began on February 24 and dissipated by March 5, 2005. On March 2, it was upgraded to Category 5. From wind speeds reaching 161 mph, Percy began to weaken as it moved southward. Earlier that week, it had already destroyed most structures on the two northern Cook Islands of Pukapuka and Nassau (Earth Observatory webpage).

Offering some relief to the battered Cook Islands, the next storm in the series, Rae, was not expected to reach hurricane strength, topping out at the Tropical Storm category. That system brought flooding to parts of Fiji and Samoa in the earlier stages of its February 27 to March 8, 2005 track. Unsurprisingly, of the five cyclones to hit the area in such short succession, Rae was the least destructive.

Data Elements

Oceans play a complex role in extreme weather conditions globally. Therefore, severe weather phenomena such as tropical cyclones have the most direct potential to threaten coastal communities, sea-faring vessels, and ocean species (Easterling *et al.* 2000, Woolf *et al.* 2003). Typhoons, hurricanes, and cyclones (all regionalized names for the same weather phenomena, and often collectively referred to as cyclones) typically occur between early June and late November, for the Eastern Pacific and Northern Atlantic regions. Meteorological factors requisite in the development of tropical cyclones include: sea surface temperatures at or greater than 78.8^{o} F, vertical shear, or unstable air mass, and mid-tropospheric moisture (Goldenburg *et al.* 2001, Webster *et al.* 2005).

The purpose of this project was to integrate relevant weather data acquired by NASA missions into georeferenced visualizations, or geovisualizations, of tropical storm and anomalous high water events. Applying georeferenced storm tracks, sea surface height (SSH), sea surface temperature (SST), precipitation accumulation, and sea surface wind speed and direction, the 2008 DEVELOP Team implemented existing NASA satellite technologies to aid in creating multifaceted depictions of past storm events. This combined application of satellite data and web presentation technologies may one day assist in accurate and accessible damage predictions, with the goal of minimizing the costly effects of these events.

METHODS

NOAA provided the PRICIP team with a list of several significant storms occurring since 1980 and in the Pacific regions in which they were most interested. These storm events were chosen based on their intensities and severe impact on various pacific basin communities. The 2008 DEVELOP Team created geovisualizations by combining multiple sources of remotely sensed imagery for the requested dates and geographic extents of the storms or high water events. Once downloaded, data sets were processed using one or more of the following tools: ERDAS Imagine, ESRI Suite, Microsoft Access, Adobe CS3 Flash & Photoshop, IDL, etc. An image was produced for each available data timeframe within the event, and was layered and animated sequentially, within Adobe Flash.

NOAA gave the 2008 DEVELOP PRICIP Team two primary tasks:

(1) Create a Regional Scale Tropical Cyclone Viewer/Dashboard to support animations/visualizations of the five tropical events, displaying:

Sea Surface Temperature
Sea Surface Height
Rain
Wind speed/vector
Track Position, Intensity, Translation Speed, etc.

(2) Create a High Seas Viewer/Dashboard to support animation/visualization of four extreme tide events (two of which include extra-tropical storms and require a Regional Scale view requiring):

Rain
Wind
Wave Watch III wave height and period

These would also require a "Local" Scale Viewer/Dashboard using:

Tides (predicted from model)
Sea Surface Height (plus currents and eddy tracks)
Wave Watch III wave height and period
SWAN wave heights

Along with these tasks, the 2008 team was also assigned the responsibility of modifying the 2007 animation design, to enhance user experience. This was done by adding timeline control and date/time information.

Data characteristics and acquisition methods differ between satellites. Therefore, it was important to choose sensors for the project capable of capturing data for the team's specific variables, as well as at the appropriate spatial and temporal resolutions. Satellites were chosen based on their ability to acquire sea surface wind speeds and directions, rates of precipitation, sea surface height, and sea surface temperature. All datasets for each of the aforementioned variables were captured by NASA missions, but were acquired from a variety of online NASA downloadable sources.

Jason-1

From an altitude of 1336 km, the latest launch of the Jason is capable of measuring the altimetry of the hydrosphere (sea surface height) to an accuracy of <2.5 cm (1.0 inch). Sea surface height is used not just to find out where waters may be anomalously high or low, but where they are also warm, to significant depths. Other remote sensors, such as AMSR-E, can measure only the relative skin surface temperature of water, collecting data no deeper than a few inches. Due to thermal expansion, water expands measurably with increases in its temperature (1 cm per 50 meters per 1^{o} C). The water body area bulges upward, as deep slabs become warmer. This leaves Jason data uniquely qualified for assisting in the study of deeper ocean temperatures, as they may relate to global warming, as well as monitoring deeper warm water bodies, which are one of the crucial components necessary in the incubation of tropical cyclones. Jason does not measure water temperatures directly, but can be used to directly infer this information, and to significantly greater depths than any other sensors currently available.

Launched in 2001, Jason-1's objective is to increase the understanding of ocean circulation on seasonal climate changes (Earth Science Reference Handbook, 2006). Aspects of the main objective include measuring global sea-level change, improving open ocean tide models, and the improved forecasting of climate events like El Niño. Jason-1 also provides estimates of significant wave height and wind speeds over the ocean, while mapping ocean surface topography (Earth Science Reference Handbook, 2006).

Covering 95% of ice-free oceans between 66^{o}N and 66^{o}S every 9.9 days, Jason-1 has ±1 km accuracy. The NASA Jason Microwave Radiometer (JMR) is a three-frequency microwave radiometer that measures water vapor along the altimeter path to correct for pulse delay. The satellite has a circular orbit at an altitude of 1336 km, and a 66^o inclination. Jason-1 made contact with TOPEX/Poseidon (a joint U.S.-French orbital mission, launched in 1992 to track changes in sea-level height with radar altimeters) in 2002 (Earth Science Reference Handbook, 2006).

Sea surface height data from the Jason-1 satellite were obtained from the Oceanwatch Live Action Server. Files were downloaded in ASCII format and then imported in ArcMap as raster layers. However, these layers did not have correct longitudinal coordinates when crossing the date line, as was the case with several project areas of interest. To correct for this, the layers were split at 180^o, and the parts from the western hemisphere were imported into ERDAS Imagine. Using a tool for changing layer properties, the coordinates were corrected, and the layers were re-imported into ArcMap. From here, the process became very similar to other datasets. The same coordinate system was applied as well as an appropriate color scheme. Each time slice was exported as a separate PNG file, modified in Photoshop, and imported into Flash.

AMSR-E

NASA's Earth Observing System (EOS) Aqua satellite was launched in 2002. Its goal is to gather information about Earth's water by collecting data on global precipitation, evaporation, and the cycling of water. The Advanced Microwave Scanning Radiometer Earth Observing System (AMSR-E) is one of six sensors on Aqua. It is a passive microwave radiometer that collects data at six microwave frequencies in two polarizations (Lobl, 2001; NSIDC, 2007), and observes atmospheric, land, oceanic, and cryospheric parameters. This includes precipitation, sea surface temperatures, ice concentrations, snow water equivalent, (terrestrial) surface wetness, wind speed, atmospheric cloud water, and water vapor. AMSR-E also extends the spatial coverage of the TRMM satellite (Earth Science Reference Handbook, 2006). At a 705 km orbital altitude (NSIDC, 2007; Spencer, 2000), AMSR-E passes over the earth twice each day and collects 1445 km swaths. At 89.0 GHz, AMSR-E's spatial resolution is 5 km, while at 6.9 GHz, it's spatial resolution is 56 km (Spencer, 2000; NSIDC, 2007).

AMSR-E sea surface temperature data was obtained from the National Snow and Ice Data Center (NSIDC) online Distributed Active Archive Center (DAAC) in the form of hierarchical data format (HDF) files. These were then processed using a free program called HEGTools. This tool extracted the desired dataset and converted it to the more GIS-friendly GeoTIFF format. The files underwent this conversion and then were ready for import into ESRI's ArcMap. Once in this program, the datasets were "clipped" to the desired extent. That is, a bounding box of Latitude/Longitude coordinates was established for each event, and used to extract the relevant data from each world-wide extent. Then a standard coordinate system, which was applied to all data layers, was implemented. This was somewhat complicated because most of the spatial extents for the events crossed the International Date Line. Therefore, a custom coordinate system was developed using Mercator, WGS-84, and customized with a central meridian of 180^o longitude. A standard color scheme was also applied to each piece of AMSR-E data. A color ramp with fixed high and low end values was used to ensure accurate representation across all of the data. Once clipped, colored, and projected, each time-slice of data was exported as a separate portable network graphics (PNG) file. These files were modified in Adobe Photoshop to have a transparent background (rather than white, where there might be a registration of no data, over land masses, etc.) the files were then imported into the Adobe Flash movie libraries, for animation.

TRMM

The Tropical Rainfall Measuring Mission (TRMM) was created in order to acquire accurate measurements of the spatial and temporal variation of tropical rainfall around the world. TRMM monitors the release of energy that helps power global atmospheric circulation, which shapes global weather and climate (Earth Science Reference Handbook, 2006). As it measures between the latitudes of 35^{o}N and 35^{o}S, TRMM is providing scientists with rainfall and latent heating data from oceanic and tropical continental regimes. An oceanic surface event called the Pacific Kuroshio current transports heat away from the tropics, and influences climate at the mid-latitudes. Oceans absorb and store heat during summer, and transport and release it during the rest of the year. Therefore, the oceanic thermal mass acts as a buffer, moderating land temperatures, especially at mid-latitudes. When ocean surface currents fluctuate, the potentially devastating climatic effects can be extensive (TRMM Home webpage).

TRMM has already helped scientists better understand rainfall properties and their variation. These include: (1) frequency distributions of rainfall intensity and areal coverage; (2) partitioning of rainfall into convective and stratiform categories; (3) vertical distribution of hydrometers (including the structure and intensity of the stratiform region bright band); and (4) variation of the timing of heaviest rainfall, particularly night-time intensification of convective systems over the oceans, and day-time intensification of mountain and sea-breeze forced systems over land (TRMM Home webpage).

The TRMM archive data are stored within the Goddard Earth Science Data and Information Services Center's Giovanni data download system. The Giovanni system allows the end user to easily access numerous datasets, using both visual and numerical data selection processes. With the bounding box set, the user can proceed down the Giovanni page to select a dataset based on date and time. The user also has the option to change the plot type, color options, and end resolution. For the purposes of this project, the previously mentioned options were left in their default positions, and only the bounding box, dates, and time values were selected. American Standard Code for Information Interchange (ASCII) tables were downloaded for the spatial and temporal ranges needed to depict an event. With the tables created, a model can be used to convert the table to points and then convert these points to a raster layer. While the model is running, it assigns the WGS 84 projection to the final dataset, and defines the final raster's cell size as 0.25 decimal degrees. The final operation of the model is to shift the raster image -0.125 decimal degrees to avoid complications with the International Date Line. The model built and used for this project processes an entire day's worth of data with each iteration. The raster datasets are then ready for symbology manipulation (Rainfall Archives).

QuikSCAT

In an effort to improve storm monitoring and warning, NASA's Earth Science Enterprise (now the Science Mission Directorate) launched the Quick Scatterometer (QuikSCAT) into space in 1999. The SeaWinds instrument on the QuikSCAT satellite measures near-surface wind speed and direction under all weather and cloud conditions over the oceans with a specialized microwave radar. This apparatus uses a rotating dish antenna with two spot beams that sweep in a circular pattern, radiating microwave pulses at a frequency of 13.4 gigahertz. SeaWinds collects data in a continuous, 1,800-kilometer-wide band, making about 400,000 measurements and covering approximately 90% of the Earth's surface each day with ascending and descending passes (JPL Missions website). QuikSCAT's orbit is sun-synchronous, at an altitude of 803 kilometers above the Earth's surface and has a 98.6^{o} inclination orbit. Its wind vector resolution is 12.5 km (JPL Missions website).

The objectives of the QuikSCAT mission include several factors of interaction between air and sea. QuikSCAT provides acquisition of all-weather, high-resolution measurements of near-surface winds over global oceans. Atmospheric forcing, ocean response, and air-sea interaction mechanisms are also to be determined on several spatial and temporal scales. QuikSCAT also works in conjunction with other scientific instruments to enable a better understanding of the mechanisms of global climate change and weather patterns (JPL Missions website).

QuikSCAT data collection began with the acquisition of Level 2B datasets from NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) website in the form of hierarchical data format (HDF) files. Each dataset is representative of one full orbital revolution (at a 12.5 km spatial resolution). Variables of interest (wind velocity and wind vector) were extracted using Interactive Data Language (IDL) script. Once the data were downloaded and processed using IDL, the next step was to further process the data using both Microsoft Access and ESRI ArcGIS. The IDL process produced files that contained a higher data field resolution than were needed or useful for this project. Utilizing Access, the team imported the files, renamed the appropriate fields, and deleted the unwanted fields. These steps can be saved, which makes the several step process for each dataset take as few as three mouse clicks. Once the data were processed through Access, the resulting ASCII files could then be run through a model within ArcGIS, which output thinned point data with the values needed to display wind speeds and vectors. The first step of the created model involved using one table to create two intermediate tables, which were converted to point layers. During this step, the data were projected (WGS 84). The points were then converted into raster images using the Mean Cell Assignment Method, with a cell size of 1.75 decimal degrees. This was necessary because of the fine resolution of points, which were far too many for meaningful representation. Using the 1.75 decimal degree cell size allowed for the data to be thinned enough to be easily viewed in the final product. With the raster images created, the model runs a raster to point conversion, which creates points at the centroids of each raster cell. The points in both layers are in the exact same location due to identical inputs. However, one layer will have a VALUE field with wind speeds, while the other layer will have a VALUE field with wind vectors. Since the data needed to be in one shapefile in order to visualize the speeds and vectors efficiently, and the point layers were in identical locations, an Intersect was used to combine the data. The QuikSCAT data uses a wind vector convention in which zero degrees represents winds flowing to the south. In order to display the vectors correctly, a new field was calculated to correctly orient the arrow symbols.

Final Animation and Interface

All storm tracks and data were compiled into one viewer using Adobe Flash CS3. One keyframe was created for every three hours throughout a storm's entire life cycle. This temporal building unit for each movie was based on the storm track coordinates, which were provided at three hour time intervals. TRMM data was also available and collected for every three hours. So (apart form the animated storm tracks themselves) TRMM were the smallest visible data layer collection interval depicted. Even for future data layers, this interval was also decided upon for the purposes of manageable download size and speed. Each data image was added to it's correspondingly dated and timed keyframe, dependent upon the temporal resolution of that particular satellite's sensor. A progressing storm track was created, as well as a storm icon, which was made to spin counterclockwise in the Northern Hemisphere, or clockwise in the Southern Hemisphere, just as the actual storms do, because of the Coriolis Effect. Clearly labeled buttons were provided for the user, for turning each data layer on and off. This was accomplished by engaging a Flash layer masking function. This method ensured that all layers would always be loaded, available and moving along the same critically important timeline. Only their visibility state would change with button selection. By embedding each geovisualization timeline into its own customized external viewing frame of a second Flash .swf movie, a "grabbable" scrubber bar and one-frame-change-at-a-time buttons were added, allowing for large scale as well as precise control of the event's total timeline.

When creating the entire season's serialized storm track animations, no additional data layers were requested to be added, beyond the storm tracks. Similarly, when creating the high water event animations, no tropical storm tracks were added, even when available.

RESULTS/PRODUCTS

New animations have successfully been completed for the 2007 list of Pacific storms, including the new requests for the Cook Islands Storm Cluster as well as the basin-wide extents for the North Shore and South Shore Hawaii High Water Events for which appropriate data were available. The 2003-2004 Pacific storm season was also completed, based on the storm track coordinates provided.

In retrospect, and from a visual communication standpoint, one aspect of the data layer display might have been rendered more legible, especially to the less trained eye, which may be part of the broadly defined audience. A design decision was made to distinguish each dataset with its own distinctive and globally applied color scheme and range. This was done to avoid confusion while switching from and comparing one available data layer to another, consistent throughout all regions and geovisualizations (e.g. Sea Surface Height data was presented in an orange-yellow-blues range, while Sea Surface Temperature data was shown in light yellow-green-blues). These between-dataset distinctions were a reasonable success. However, further advanced experimentation with the narrower output that resulted from the relatively homogenous equatorial and mid-altitude global regions of tropical cyclone study left room for yet further refinement, perhaps toward a broader color range that could have spanned a richer spectrum within those regions, thus enhancing legibility and more detailed data steps and transpositions.

Another chosen adaptation for such a predictably broad web audience was to automate the Flash movie output dimensions as "full-screen," dynamic to all browser window sizes, thus rendering the resolution limitations of nearly any monitoring device practically irrelevant.

Examples of the resulting geovisualizations, with samples of both the serial storm track animations and the interactive data layers, are shown in the Cook Islands Storm Cluster (Figures 1 through 4).

Figure 1. All data layers turned off.

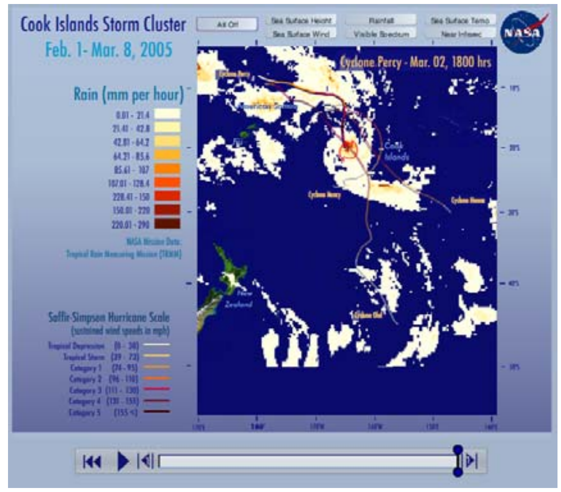

Figure 2. Rainfall (TRMM) data turned on.

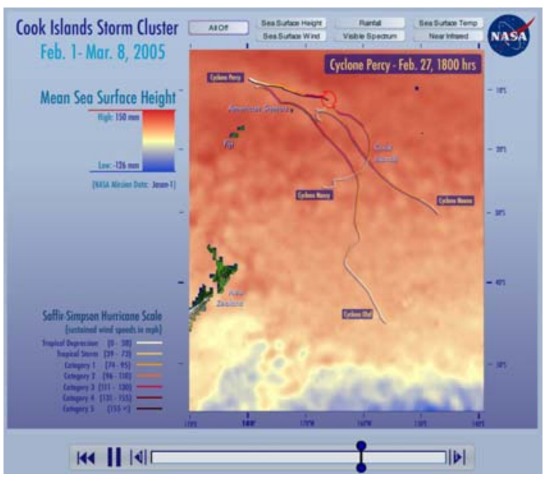

Figure 3. SSH (Jason-1) data turned on.

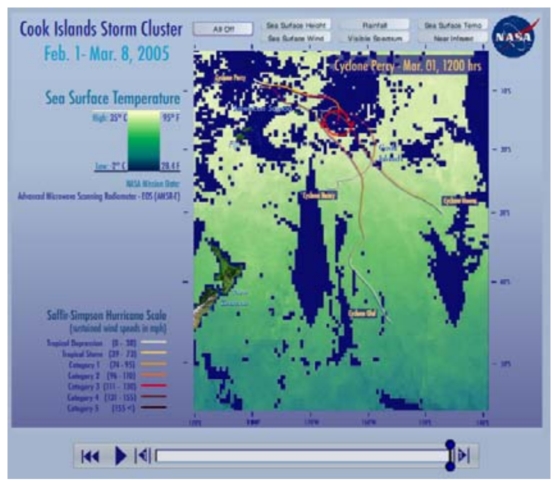

Figure 4. SST (AMSR-E) data turned on.

With all layers turned off (Figure 1), a clean image of the Pacific Basin can be seen, with only the Cook Islands storm tracks animated. This background image, courtesy of NASA's Blue Marble imagery, offers cleaner and greater spatial detail of the Earth's surface than the 2007 background (Teske *et al.* 2008). New Zealand is shown in the viewer, for a sense of scale and orientation.

In Figure 2, the "Rainfall" button is on, showing the viewer the data acquired from the TRMM sensor. For this layer, a new weather layer appears at three hour intervals as the storm tracks move along the surface.

With the "Sea Surface Height" button clicked, as in Figure 3, the blue color is representative of low sea surface heights, while the red is representative of high sea surface heights, with the established mean being the middle of the color ramp. It is interesting to note that, as the storm track moves along, the storm intensity often grows correspondingly over the highest (and, therefore, warmest, deepest) ocean waters. The Jason-1 sensor data changes here every 9.9 days, as this is the rate at which it is collected and available.

Figure 4's AMSR-E data changes once daily. The darker blue-green color shows colder sea surface temperatures, with the yellow-green color representing higher sea surface temperatures. Although the layers change daily, it is frustrating to note that gaps in the data often coincide with the storm's current location.

Rolling dates and time stamp with current storm names, as well as the names of nearby land masses are clearly labeled, for temporal and geographical reference and context.

As for complications and technical difficulties, the team ran into several problems with the download and processing of the QuikSCAT data, which were eventually resolved. The PO.DAAC site had been experiencing internal technical difficulties, resulting in all downloaded data extending as far south as approximately 20^o, while our requirements extended to 70^o. The selection and gathering of manageable data set sizes for visible and near-infrared data layers, which was suggested during earlier conceptualization and development of the 2008 project, also proved too problematic, within the ten weeks allotted for the project and the resources available to us.

FUTURE NASA DATA MISSIONS OF RELEVANCE

Aquarius, with a planned launch date in May of 2010, is expected to measure changes in global sea surface salinity (SSS) with highly accurate radiometers. The goal of this mission is to analyze the oceans' response to climate change and the water cycle. Aquarius data will be used to track the formation and movement of the large water masses that regulate Earth's climate and ocean circulation. Aquarius will have a temporal resolution of seven days, and within two months, will collect as many sea surface salinity measurements as the entire 125-year historical record from ships and buoys, while providing measurements over the 25% of the ocean where no previous observations have been made (Decadal Survey Missions: Aquarius).

Global Precipitation Measurement (GPM) Constellation, proposed to launch in June of 2013, will build upon the success of the Tropical Rainfall Measuring Mission (TRMM) by measuring global precipitation. Its objectives include improving "ongoing efforts to predict climate by providing near-global measurement of precipitation, its distribution, and physical processes; to improve the accuracy of weather and precipitation forecasts through more accurate measurement of rain rates and latent heating; and to provide more frequent and complete sampling of the Earth's precipitation." (Decadal Survey Missions: GPM).

The Ocean Surface Topography Mission (OSTM), mounted on a low-Earth orbiting satellite, Jason-2, was launched on June 20, 2008. This radar altimetry mission provides sea surface heights for determining ocean circulation, sea-level rise, and climate change. The Jason-2 satellite follows the TOPEX/Poseidon and Jason-1 satellite objectives, which provides sea surface height measurements necessary for ocean modeling and the forecasting of storm events (Decadal Survey Missions: OSTM).

CONCLUSION

Severe storms and high water events have been devastating to coastal communities in the Pacific Basin Region. Easy access to this sort of information should be valuable, as the severity of these storms increases and mean sea levels rise, in response to global climate change. These planetary responses deliver corresponding risks to these communities. PRICIP geovisualization products will be integrated and publicly distributed via NOAA's existing PRICIP web portal, as highly visual and interactive additions to available decision support tools.

All completed geovisualizations have a new and consistent look, feel, and user interface, complimenting and advancing the 2007 DEVELOP Team's highly valuable groundwork and successes.

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