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Coupled Ocean/Atmosphere Mesoscale Prediction System – Rapid Environmental Assessment and Data Assimilation for the Systems Integration Facility

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LONG-TERM GOALS

The long-term goals of this project are to (i) develop a robust, generalized COAMPS-OS®[1] capability that optimizes the user's ability to operate forward deployed to minimize network bandwidth limitation to reduce operational impact, and (ii) advance the COAMPS-Rapid Environmental Assessment (REA) capability to assimilate and update locally optimized analysis and forecast of ocean and surface weather conditions based on *in situ* and non-traditional observations. Such observations could include unmanned surface (e.g., Sensor Hosting Autonomous Remote Craft (SHARC) Waveglider, Lagrangian drifter, directional wave spectra buoys), subsurface (e.g., Slocum glider, Remote Environmental Monitoring UnitS (REMUS), Large-Diameter Unmanned Underwater Vehicle (LD-UUV) and remotely sensed (e.g., Synthetic Aperture Radar (SAR), High Frequency (HF) radar) data. The goal is to examine the impact of the assimilation on forecasts, with a goal of reduction in coupled model forecast error, as well as through Observing System Simulation Experiments (OSSEs) for tactical and operational autonomous platform mission planning and execution. The initial target facility is the Unmanned Maritime Vehicle Command and Control (UMVC2) Center laboratory at the SPAWAR Systems Integration Facility (SIF).

OBJECTIVES

The objectives of this project are to: (i) create a coupled model initial (IC) and lateral boundary condition (LBC) service that will provide a web-enabled capability to request and make available "cut-outs" (or reduced area domains) of initial or lateral boundary conditions from the global Navy Global Environmental Model (NAVGEM) for the atmosphere, Hybrid Coordinate Ocean Model (HYCOM) for the ocean, and WAVE WATCH III for the wave models for executing COAMPS-OS forward deployed; (ii) improve COAMPS by assimilating new observing systems that provide simultaneous observations in the oceanic and atmospheric model boundary layers; (iii) establish a common air/ocean data format, as well as expected data types that can be used by the Navy Coupled Ocean Data Assimilation system (NCODA); and (iv) test and validate the new capability using new datasets such as Trident Warrior 13 (TW-13), Coupled Air-Sea Processes and EM Ducting Research (CASPER), and other suitable field datasets.

[1] COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) and COAMPS-OS (COAMPS-On Scene) are registered trademarks of the Naval Research Laboratory.

APPROACH

The technical approach of this project is to: (i) develop a robust, generalized COAMPS-OS capability for a user to easily setup a COAMPS-OS project/domain; (ii) assess the time required for creating and obtaining cut-out initial and boundary condition data from remote sites using available satellite data links; (iii) qualitatively assess the quality of the model predictions based on general "rules of thumb" generated for selected boundary conditions, and to subsequently modify the size and configuration of the COAMPS-OS domains, if necessary, to optimize the time and bandwidth required to obtain IC and LBC data and run COAMPS-OS; (iv) acquire observations from the new observing systems listed above and incorporate the data into the real-time data processing and quality control systems at Fleet Numerical Meteorology and Oceanography Center (FNMOC) for assimilation in COAMPS; (v) develop data processing software, to include data decoders as needed, modification and development of NCODA and NAVDAS system software for quality control of the ocean and atmosphere variables from the new observing systems, and development of software for collocating the data with the various COAMPS domains as well as HYCOM and NAVGEM fields for quality control on regional and global scales; (vi) perform limited assimilation experiments to tune the velocity error covariance model parameters and develop necessary validation and verification software; (vii) perform coupled model runs using test data sets of the new observing systems and evaluate their impacts using adjoint-based methods and data denial experiments; (viii) participate in the CASPER East field experiment off North Carolina where SHARC Wave Gliders are expected to be deployed; and (ix) work with FNMOC on decoding data off the Global Telecommunication System (GTS) and setting up data pulls of the new observing system from the various data providers to support operations.

WORK COMPLETED

Work completed on the technical tasks include (i) New "user-selected boundary" capability: We have developed a prototype for a new user interface called *RunNow!* that allows for quick setup and execution of a COAMPS-OS run (see Figure 1). The interface was described in a PowerPoint presentation distributed to UMVC2 laboratory personnel. We have worked on adding and testing options to the *RunNow!* interface including the client/server connections, input options (center point, forecast length, creating project templates), defining a track XML format to use to import track information, and updating the COAMPS-OS server code that converts all input from the *RunNow!* interface into a COAMPS-OS project. We have installed the COAMPS-OS prerelease of version 2.5.3 to obtain feedback from UMVC2 personnel to improve the *RunNow!* interface. The *RunNow!* interface calculates an optimal domain based on bandwidth and time restrictions, but might require improvements at higher latitudes where longitudes converge and larger data files are required for comparable spatial coverage at lower latitudes. A minimum cutout threshold (31x31) and options to select resolution are available in the *RunNow!* interface. An operator can modify the bandwidth and download time which impacts the user-selected boundary configuration. The software is backward compatible, and a project created with the *RunNow!* interface can still be modified with the COAMPS-OS GUI. A button on the *RunNow!* interface allows users to submit a scheduled forecast. The server side code is able to handle submissions based on a user calendar (active time). In addition a draft of a users guide for the new capability (including *RunNow!*) has been completed;

(ii) Cut-out capabilities: We completed a delivery of COAMPS-OS v2.5.2 that includes the NAVGEM cutout option and provided support to UMVC2 personnel to help set up the Come And Get It Product Services (CAGIPS) subscript. UMVC2 successfully ran a COAMPS domain over the North Carolina coast. We subsequently provided an installation and on-site demo version of version 2.5.3. As part of

the demonstration, UMVC2 set up a CAGIPS download of subset NAVGEM data and a script supporting the NAVGEM conversion of CAGIPS GRIB data into NAVGEM data supporting an area covering the San Francisco Bay. We also provided routine troubleshooting and maintenance, including responding to requests from UMVC2 personnel to: a) help troubleshoot failed runs due to missing NAVGEM data. We determined that data was late to arrive to the data server (USGODAE) and wrote a new script to download NAVGEM data directly from an NRL ftp server as an interim solution; b) review unusual discontinuities in COAMPS upper air data. We discovered the issue to be caused by a limitation in the GRIB-1 specification of level height which did not permit values above 32000 meters and aliased values above this height to lower levels; c) add SST and land surface temperature to the GRIB output for BUILDER. We completed the work and updated code for UMVC2 personnel; d) troubleshoot a failed regional WW3 run and provide information regarding ice observations for a COAMPS domain over the Arctic region. We advised UMVC2 personnel about the limitation of running WW3 at high latitudes; e) review a BUILDER Initial Capabilities Document (ICD). We provided feedback regarding parameters produced from COAMPS; f) troubleshoot issues with running two CAGIPS conversion scripts that overlap. We provided phone support to troubleshoot the CAGIPS data conversion, and on-site support to produce additional CAGIPS/COAMPS-OS documentation based on feedback from UMVC2 personnel.

Regarding HYCOM cutouts, we contacted NAVO regarding their code used to generate NAVO HYCOM cutouts. These cutouts are the same cutouts that have been provided to the UMVC2 lab to support past demonstrations. NAVO provided NRL-MRY sample PERL code. NRL-MRY hosted a meeting with FNMOC and NAVO (C. DeHaan) to discuss potential options to provide global HYCOM cutout data. Numerous options were discussed, each with limitations. A solution in which UMVC2 procures and uses a local server to receive the global ocean data directly was agreed upon. Subsequently, we have demonstrated a 12-h simulation of UMVC2's Pt Judith domain using a global HYCOM cutout. The demonstration requires additional validation against a standard global HYCOM run, but the run completed with no errors and the standard NCOM graphics were generated at depth levels (e.g. 30-m to 300-m). UMVC2 is currently investigating the feasibility of obtaining the internal server and its ability to communicate with the server devoted to run COAMPS-OS. A similar solution was agreed upon for obtaining WW3 data directly from FNMOC; and

(iii) Ocean data and assimilation: a) HF radar: The Integrated Ocean Observing System (IOOS) HF radar data around the continental US are available in real-time from the National Data Buoy Center (NDBC: http://hfradar.ndbc.noaa.gov/) in a 3-day rolling store and from Scripps Institution of Oceanography (ftp://sandbox.ucsd.edu/pub/CORDC/outgoing/HFRNet/) in NetCDF format. The Australian HF radar data are available from the Integrated Marine Observing System (IMOS) website (http://imos.aodn.org.au/webportal). We (J. Cummings, SAIC) have pulled back HF radar data from the NDBC web site and processed the data through NCODA quality control (QC). We have begun coordination with the Naval Postgraduate School (NPS, J. Paduan) to see if they can advise us on the best real-time source for that data. Given a reliable data source, we will coordinate with FNMOC to start ingesting the data in their alpha computing environment; b) surface velocity data: We have begun preliminary work with global drifter data. Figure 2 shows the current status of the global drifter array. A quarter of the array is now equipped with Iridium communication, which provides more continuous and reliable reporting of drifting positions and surface currents than the old Argos communication system. The number of Iridium drifters is expected to increase with time, thereby continually improving the global drifter data set. Surface drifter trajectories can either be assimilated in COAMPS or withheld from assimilation to verify COAMPS model forecasts. In either case, the surface currents from the drifter trajectory data need to be obtained and made available to the COAMPS ocean and

atmosphere assimilation components at the operational center. Surface currents from the global surface drifter trajectory data are available on the GTS as World Meteorological Organization (WMO) buoy and TESAC (TEmperature, Salinity, And Currents) code forms. Global drifter data in these code forms are currently being received at FNMOC but they are not being decoded. We have had discussions with FNMOC and will work with them to get the decoders working for the trajectory data and will ensure that all surface trajectory GTS bulletins are being received at FNMOC. This will be accomplished by comparing the trajectory data decoded from GTS at FNMOC with the drifter trajectory data currently available in real-time from the NOAA web site: http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html. We have begun coordination with P. May (CSC) to add new sources of surface velocity data to the current COAMPS coupled model runs for the Central and Northern California Ocean Observing System (CenCOOS) region. Work is ongoing and the process of setting up the necessary data feeds (e.g., HYCOM boundary conditions, etc) is continuing; and c) glider data: Slocum glider data are routinely received from the Glider Operational Center (GOC) at NAVOCEANO as independent profiles of temperature and salinity. Threaded glider data are not routinely provided by the GOC. We are exploring options to work with the GOC to obtain representative samples of threaded glider to compare impacts of assimilating the data as profiles or continuous time series. SHARC Wave Glider data will be provided when the platforms are deployed in support of Navy exercises and field experiments. Wave Gliders have been deployed for several recent Navy exercises. We are working on the steps necessary to obtain SHARC data from those time periods and develop the necessary infrastructure to be prepared to process newly received SHARC data in real-time. We have had discussions with FNMOC personnel about testing the SPAWAR SHARC data encoder, and they are agreeable to testing out new encoders. We are coordinating with SPAWAR to obtain sample data.

RESULTS

The *RunNow!* interface and associated cutout capability provides a new concept of operations for forward deployed systems. The main results from this new capability is the power for the user to a) define and display optimal COAMPS-OS domains based on expected bandwidth and download time (i.e., compute the sizes of the cut-out fields and, based upon the bandwidth/download time, the optimal size of model domains); b) define minimum cut-out data requirements and provide a qualitative indication of the quality of predictions produced by the defined data domain (this could be as simple as a text message stating that the desired COAMPS-OS domains are not optimal; e.g., the area of interest is too close to the lateral boundaries; the resolution is insufficient to resolve the environmental features of interest, etc.); c) allow the user to override the *RunNow!* configuration and modify the expected bandwidth and download time and/or COAMPS-OS domains to customize their configuration; d) support backward compatibility with the existing COAMPS-OS GUI; the *RunNow!* capability creates project configuration files that can be updated using the existing COAMPS-OS GUI; e) support an option to submit interactive runs using the *RunNow!* web page; f) provide prediction data in the same file formats as previous COAMPS-OS versions to ensure compatibility with interfaces to UMVC2 Center applications that currently use COAMPS-OS outputs.

The main result from the initial work on new ocean data source and data assimilation is establishing collaborations and operational data access of coupled data for future integration, testing, and transition of data assimilation capabilities. Observations from platforms that measure both ocean and atmosphere variables will be processed and kept together to provide coupled data for the coupled model. The preferred format for observational data input into FNMOC systems are the WMO formats. These formats are of two types: Binary Universal Form for the Representation (BUFR) and the alpha-numeric

text code forms. In all cases we are working to meet FNMOC data acquisition and data decoding requirements when acquiring the data. Output formats of the new observing systems in the NCODA system will be tailored to ensure that all variables are saved for assimilation and verification purposes. The output format will be efficient to support routine space/time queries of the observations to select data that match the geographic domain and time period of the forecast model run.

Velocity is an analysis variable in NCODA. The covariance model in NCODA includes the auto- and cross-correlations of the u, v vector velocity components (Fig. 3). Horizontal correlation length scales of velocity observations are specified as the first derivative of the length scales assigned to the temperature and salinity mass variables. Horizontal length scales of mass variables in NCODA are typically set in accordance with the Rossby radius of deformation. The multivariate balance operator in NCODA provides geostrophic adjustments to the mass fields from assimilation of velocity observations through the geopotential. This geostrophic coupling is controlled by a parameter that varies from zero (no geostrophic coupling) to one (complete geostrophic coupling). We are currently evaluating the coupling parameter for adjustments when assimilating surface current measurements from HF Radar and drifters. The balance operator has a second parameter that controls divergence of the flow. It too varies from zero (totally divergent) to one (non-divergent). The ocean is strongly non-divergent at depth but near the surface we will likely have to allow assimilation of surface currents to be divergent, especially in near-shore, coastal areas. Figure 4 shows prototype NCODA assimilation efforts assimilating HF Radar data in the southern California region. The HF Radar data are so dense that surface current mapping directly from the data is possible, without any model data inputs. The covariance model parameterization in this run was set to be 0.95 for both the geostrophic coupling and divergence parameters. New runs will be made with new available datasets.

IMPACT/APPLICATIONS

The impact and applications of a new rapid response, forward deployed system with assimilation of new air/ocean coupled data sources are significant. The major impact from assimilation of the observing systems will be assessed in terms of reducing coupled model forecast error. This objective will be achieved in two ways. First, data impacts will be estimated using NCODA assimilation and COAMPS moist adjoint models. These adjoint-based data impact procedures characterize, for a given forecast error cost function, the impact of every observation assimilated, and allow observation impacts to be partitioned by data type, geographic region, and vertical level. Second, a series of OSSEs, or data denial, experiments will be performed that selectively remove one of the new observing systems from the assimilation at a time. The disadvantage of an OSSE is the expense of multiple runs of the model to determine the impact of the various denied observing systems. In addition, the results can be difficult to interpret since the influence of data that remain in the analysis is altered by removing other data constraints. However, all aspects of forecast error are available in an OSSE, which make them powerful tools for determining observation value. Several numerical weather prediction (NWP) studies have shown that adjoint-based data impact procedures and OSSEs are complementary. We will confirm those results in this study.

RELATED PROJECTS

This project is related to 6.2 projects within PE 0602435N that focus on the development of the atmospheric and air/ocean coupled components (QC, analysis, initialization, and forecast model) of COAMPS. Developments in model post-processing software concerning the diagnosis and analysis of

fields relevant to coupled prediction generated for this work would be transtioned via the SPAWAR-funded “Small-scale atmospheric models (COAMPS)” and “COAMPS-On Scene” projects.

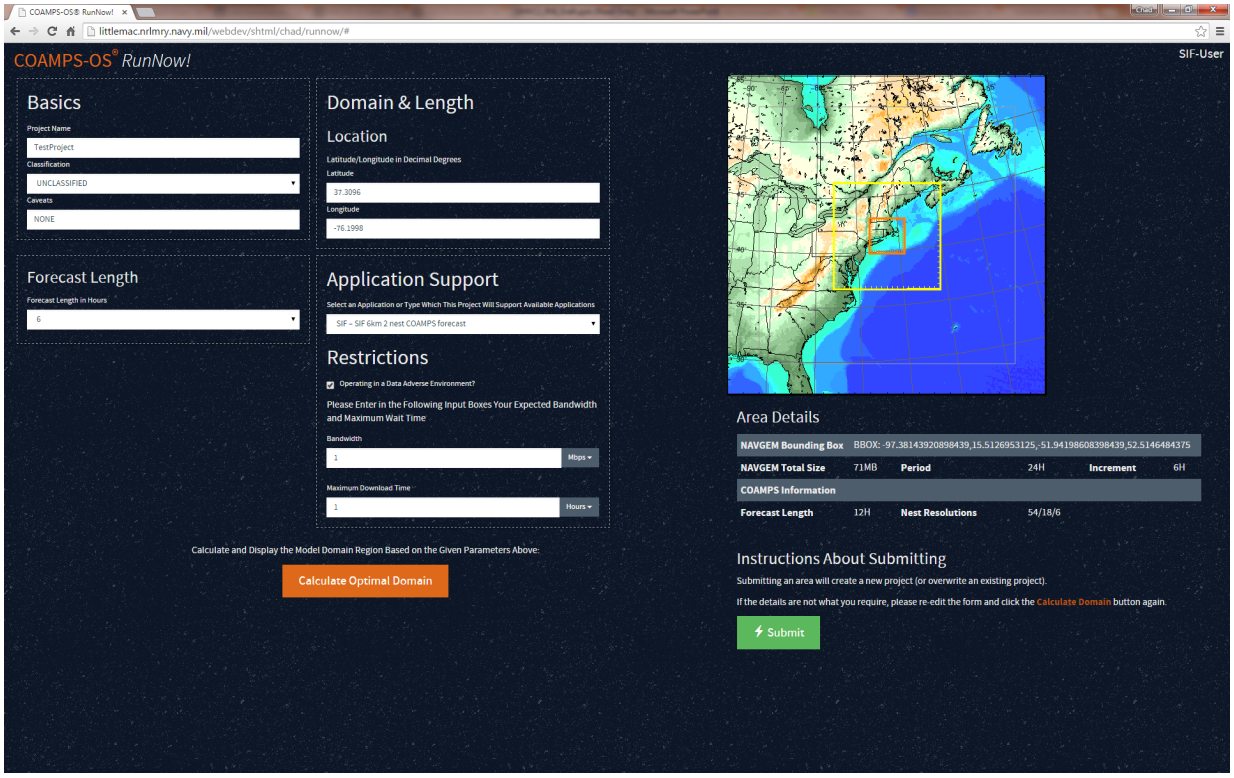

Figure 1. Screen shot of the new COAMPS-OS user interface RunNow!.

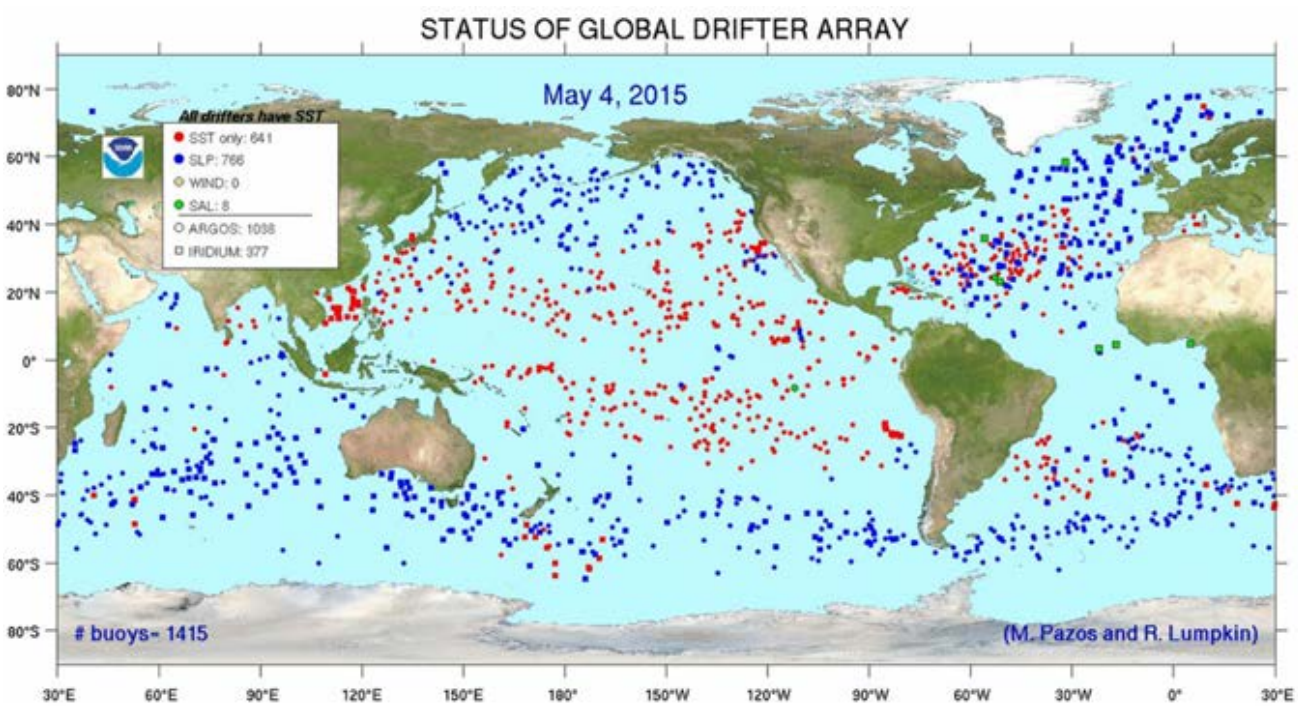

Figure 2. Data coverage of the global drifter array as of May 4, 2015.

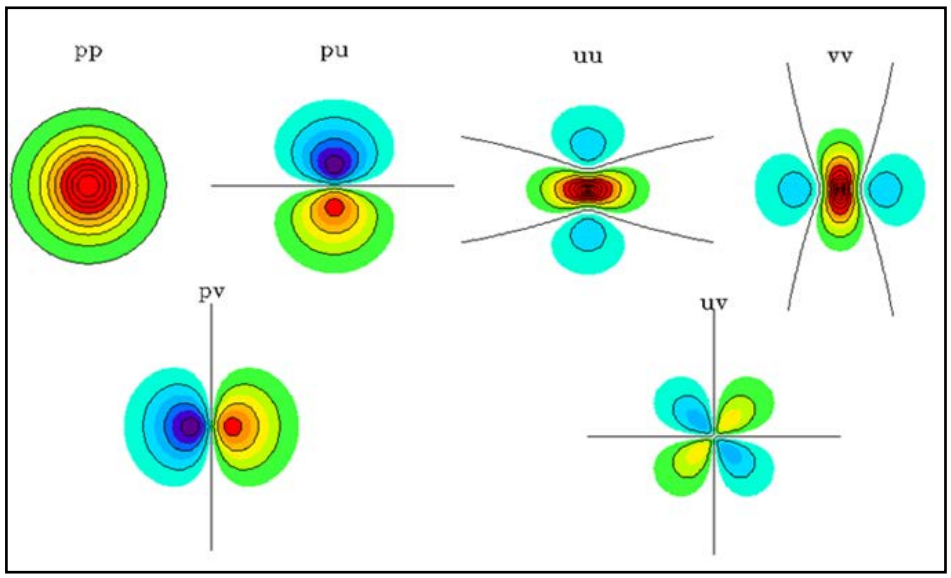

Figure 3. Velocity error covariances in NCODA. Warm colors indicate positive correlations; cool colors indicate negative correlations. The figure on the left shows the cross correlations of the geostrophic coupling of the u,v vector velocity components with the geopotential (p) and the geopotential autocorrelations, modeled here as a second order autoregressive function. The geostrophic and flow divergence parameters were set to 0.95. The shape and strength of the error correlations will change as those parameters are modified. Note the shorter vector velocity length scales relative to the geopotential length scales. The figure on the right shows the auto (uu, vv) and cross (uv) correlations of the velocity vector components.

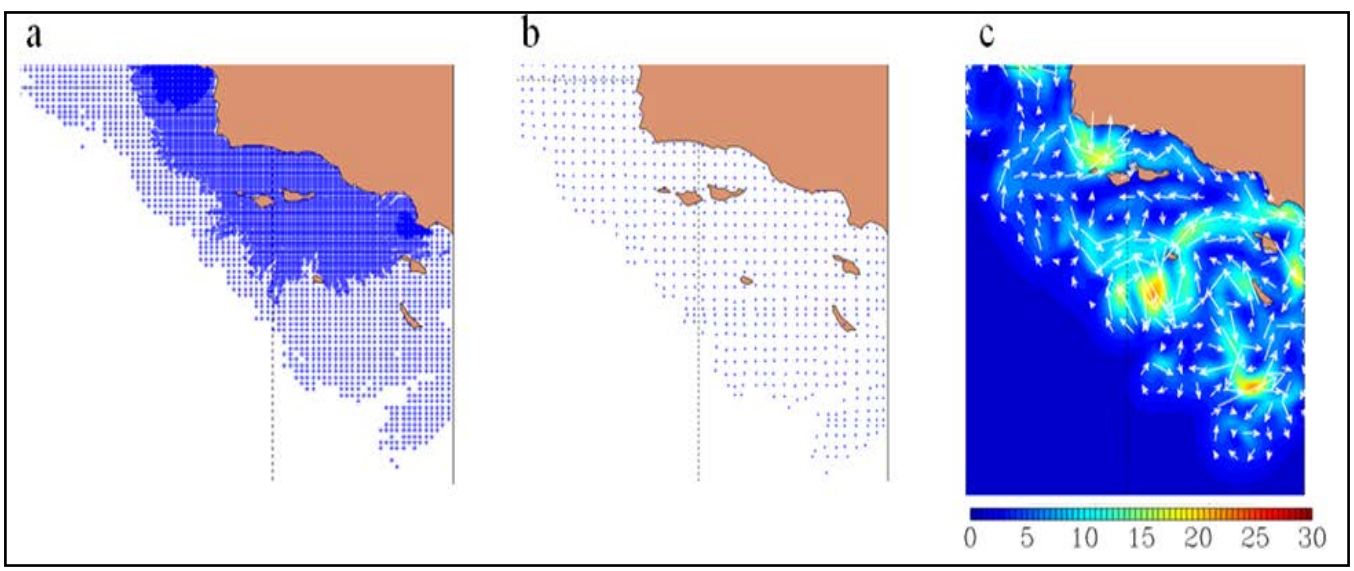

Figure 4. Example of surface current mapping from NCODA assimilation of variable resolution HF Radar observations in the Southern California bight (31 July 2010). (a) raw observations at 500 m, 2 km, and 6 km resolutions; (b) data thinned to the 6 km analysis grid resolution; (c) analyzed velocity field, with velocity vectors plotted over current speed (cm/s^{-1}).