Cross Validating Ocean Prediction and Monitoring Systems

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With the ongoing development of ocean circulation models and real-time observing systems, routine estimation of the synoptic state of the ocean is becoming feasible for practical and scientific purposes. The models can assist in ocean monitoring and regional dynamics studies, but only after they have been validated.

For the first time, beginning 1 November 2004, independent ocean model estimates of the Florida Current (FC) volume transport are available, in real time, for cross validation with observed transport variations forced by cold front passages, tropical cyclones, and other weather systems. The FC flows poleward through the Straits of Florida and ultimately becomes the Gulf Stream. The FC originates from both the large-scale, wind-driven circulation of the North Atlantic subtropical gyre and the trans-equatorial Atlantic thermohaline overturning circulation (i.e., the "global conveyor belt"). The FC is constrained by Florida to the north and/or west and by Cuba and the Bahamas to the south and east, respectively (Figure 1).

Based on FC transport events that are due to the passage of cold fronts, independent results from a U.S. Navy operational ocean modeling system and a U.S. National Oceanic and Atmospheric Administration (NOAA) research observing system are cross validated in this article. This cross validation leads to new knowledge of regional ocean dynamics and increased confidence in the validity of the Navy modeling and NOAA observing systems for ocean prediction and monitoring, respectively.

The FC regime is known to be responsive to atmospheric forcing, but there are competing notions about whether it responds to local, regional, or large-scale forcing [*Lee and Williams,* 1988]. Because of its importance for both ocean dynamics and climate research, the FC has been studied intensively over the past several decades; e.g., the comprehensive Subtropical Atlantic Climate Studies (STACS) in 1983–1984 [*Johns and Schott,* 1987; *Schott et al.,* 1988].

NOAA initiated long-term monitoring of the FC transport in 1982 using a submarine telephone cable connecting Florida and Grand Bahama Island. This system utilizes the principle that ions in seawater moving through the geomagnetic field induce an electric field perpendicular to the flow. The resulting electric field is measured as a voltage on a submarine cable, and the voltage is proportional to volume transport [*Larsen and Sanford,* 1985].

Presently, as many as a dozen hydrographic sections per year are also sampled across the Straits of Florida near the cable site to obtain independent velocity measurements for use in calibration of the cable transport estimates in units of a Sverdup (Sv) (1 Sv = 10^6 m^3 s^{-1}), with an uncertainity of ± 3 Sv. NOAA distributes the real-time cable transport estimates on the Web (www.aoml.noaa.gov/phod/floridacurrent/). The cable measurements also play a role in an international collaboration to monitor the integrated mass and heat flux across 26ºN in the Atlantic: the U.K. Natural Environment Research Council's Rapid Climate Change Program and the U.S. National Science Foundation's Meridional Overturning Circulation and Heat-flux Array (MOCHA) Program.

The annual mean FC transport has been fairly stable (32 ± 1 Sv) over the past few decades. The cable measurements have a negative correlation with the North Atlantic Oscillation, one of the dominant decadal signals in the ocean-atmosphere system [*Baringer and Larsen,* 2001]. Comparisons of the transport estimates derived from the cable with wind and coastal sea level measurements demonstrate that the FC transport also manifests higher-frequency fluctuations; for example, the passage of a large, strong atmospheric cold front in mid-January 2005 was immediately followed by a large (~10 Sv; 30% of the annual mean), rapid (three-day) decrease in the FC transport that persisted for several days (Figure 2). Furthermore, this decrease in transport was also reflected in the real-time nowcast operational predictions of the Global Navy Coastal Ocean

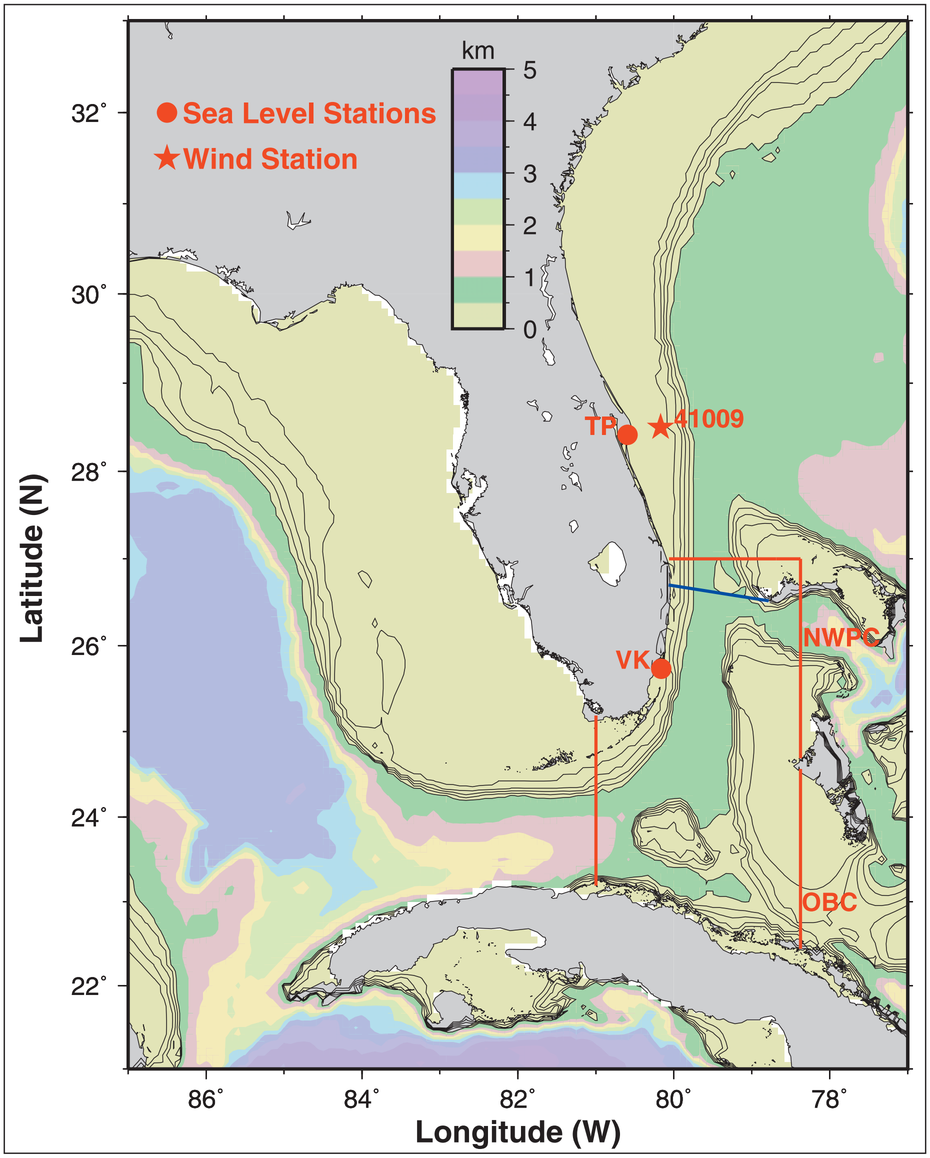

Fig. 1. Straits of Florida locator map. Blue line indicates cable, red lines indicate NCOM control volume. OBC is Old Bahamas Channel, NWPC is the Northwest Providence Channel, meteorological buoy (NDBC 41009), and coastal sea level stations are: TP, Trident Pier; VK, Virginia Key.

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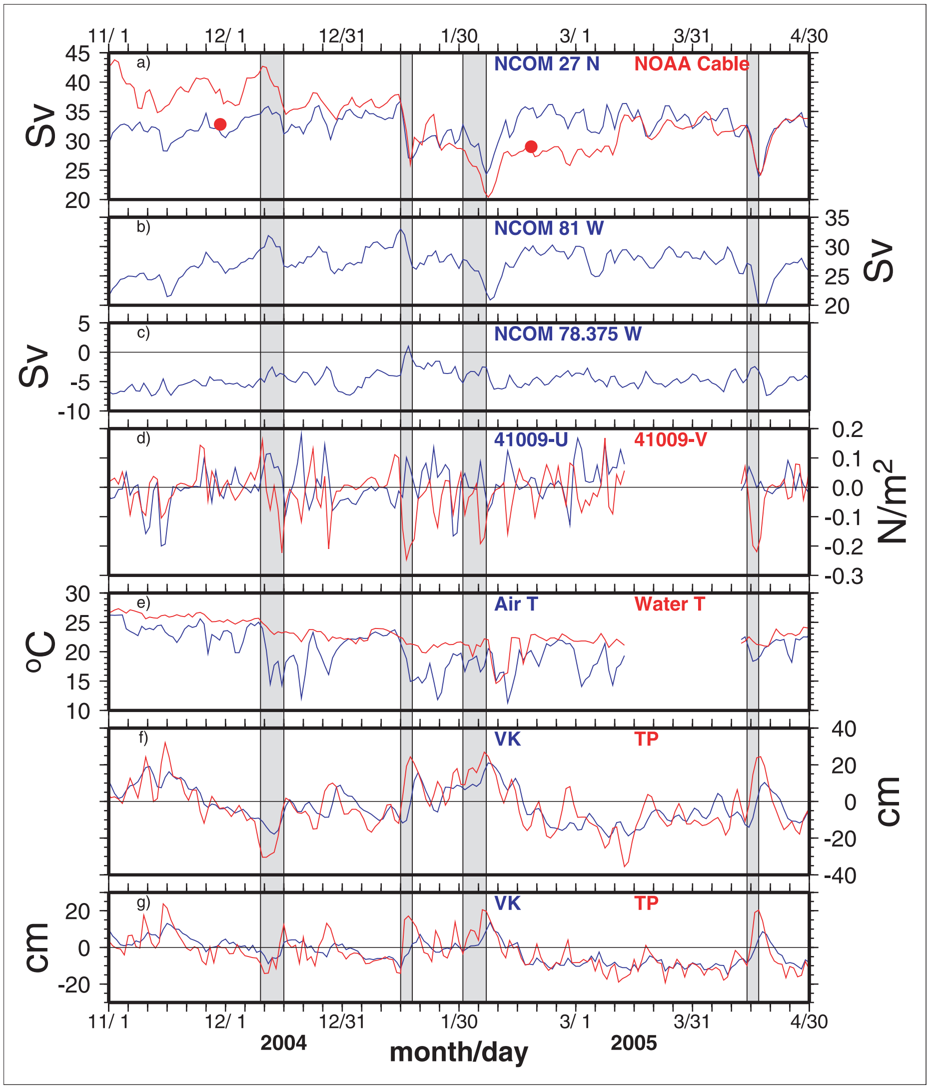

Fig. 2. Transport and related daily time series, 1 November 2004 to 30 April 2005. Shaded time periods are discussed in the article. (a) Cable and G-NCOM transport (27°N) (red circles are dropsonde section transports). (b) G-NCOM transport (81°W). (c) G-NCOM transport (78.375°W). (d) Wind stress components (NDBC 41009). (e) Surface atmospheric and oceanic temperature (NDBC 41009). (f) Subtidal observed coastal sea level (TP, Trident Pier; VK, Virginia Key). (g) Subtidal G-NCOM coastal sea level (interpolated to TP and VK sites). NDBC buoy 41009 has a data gap from 14 March to 11 April.

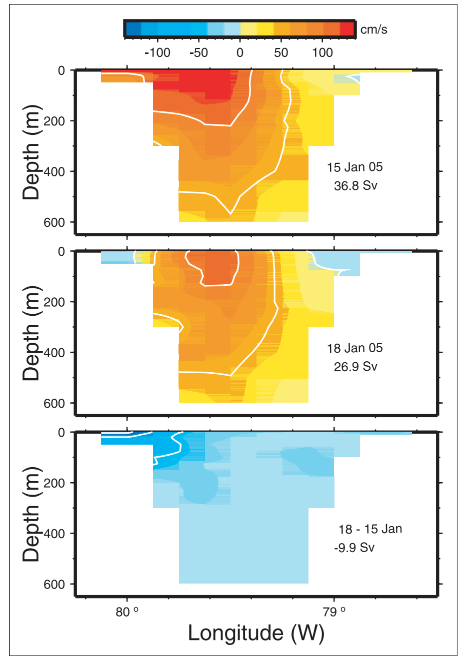

Fig. 3. Transects (27°N) of along-channel velocity from G-NCOM. (top) At local maximum transport (15 January 2005). (middle) At local minimum transport (18 January 2005). (bottom) The 18–15 January difference field. Plotted from the z-level analysis grid provided by NAVOCEANO.

Model (G-NCOM) of the U.S. Naval Oceanographic Office (NAVOCEANO), which suggests that the model reproduced these events.

Using G-NCOM [*Barron et al.*, 2005], NAVOCEANO produces a daily set of global ocean forecasts for Navy applications. With 1/8° horizontal mid-latitude resolution on a global curvilinear grid, G-NCOM forecasts ocean temperature, salinity, current, and surface elevation fields out to 72 hours [*Barron et al.*, 2005].

G-NCOM is a variant of the Princeton Ocean Model that uses hybrid sigma/*z* vertical coordinates; it has 19 sigma levels in the upper 137 m and 21 *z*-levels below, logarithmically stretched from a 1-m surface layer to 5500-m depth. Atmospheric forcing is provided by the Navy Global Atmospheric Prediction System (NOGAPS) forecast data from the Navy's Fleet Numerical Meteorological and Oceanographic Center. G-NCOM initialization is provided by assimilation of daily-averaged sea surface temperature and synthetic temperature and salinity profiles inferred from altimetric sea surface height [*Barron et al.*, 2004] using modeling systems at NAVOCEANO [*Rhodes et al.*, 2002].

Transport and Related Time Series

The observed (modeled) volume transport at 27°N for 1 November 2004 to 30 April 2005 had a mean of 33.2 (32.5) Sv and a standard deviation of 4.9 (2.4) Sv (Figure 2a). On a weekly timescale, fluctuations of 3–10 Sv occurred in both, with a large decrease between 15 and 18 January 2005.

A control volume was formed for the model between 81°W (Key West to Havana), 27°N, and 78.375°W to include flow through the Old Bahamas Channel and the Northwest Providence Channel (Figures 2b and 2c). The mean and standard deviation at 81°W (78.375°W) were 27.2 (4.7) Sv and 2.4 (1.4) Sv, respectively. Hence, the transport was typically ~5.0 Sv greater at 27°N than at 81°W due to inflow through channels in the Bahamas, consistent with an analysis of observations [*Hamilton et al.*, 2005]. The fluctuations at 81°W typically have amplitudes similar to those at 27°N; their correlation was 0.77, with a one-day lag (27°N leading). While the 15–18 January decrease at 27°N was 9.9 Sv, it was only 6.4 Sv at 81°W, which was compensated for by a decrease of 3.5 Sv through the Bahamas channels, including a reversal to slight outflow. (Very similar events occurred 10–16 December 2004, 31 January–6 February 2005, and 14–17 April.)

The transport fluctuations were generally associated with equatorward along-channel wind stress pulses (Figure 2d) and cold-air outbreaks (~10°C decrease, Figure 2e). The observed coastal sea level (Figure 2f) indicated that for major events (~20 cm rise), Virginia Key lags Trident Pier (Figure 1) by a day or two, due either to delays in the forcing or an equatorward free wave response. The modeled (Figure 2g) and the observed (Figure 2f) coastal sea level fluctuations were visually correlated for most wind events and indicative of equatorward propagation.

Interpretations and Implications

From G-NCOM, the 27°N along-channel velocity at the time of local maximum transport (36.8 Sv) on 15 January 2005 is characterized by a strong, near-surface FC jet core over the continental slope off Florida and poleward flow throughout the 27°N transect (Figure 3, top panel). In contrast, at the time of local minimum transport (26.9 Sv) on 18 January

2005, the 27ºN along-channel velocity is characterized by a jet core displaced offshore (~20 km) and reduced in cross-sectional area and strength, and by strong (~30 cm s^{-1}) equatorward countercurrents over the Florida and Bahamas shelves (Figure 3, middle panel). The velocity difference (i.e., 18–15 January) transect reveals a spatial pattern (Figure 3, bottom panel) that is characteristic of a coastally trapped wave [*Wang and Mooers*, 1976], with the vertically sheared perturbation flow of ~100 cm s^{-1} concentrated over the Florida shelf and with an offshore trapping distance of ~25 km. The corresponding along-channel phase speed is ~250 km d^{-1}, consistent with the one-day lag and distance of 310 km between 27ºN and 81ºW. Similar velocity differences occur for the other three cold front responses noted above.

The close comparison between the cable-derived and model transport estimates on the weekly timescale not only validates G-NCOM per se, but also implies that the atmospheric forcing (from NOGAPS) applied to G-NCOM represents the cold front passages adequately. The nature of the observed and modeled responses indicates the importance of regional (synoptic) scale wind-forcing.

Altogether, these results suggest G-NCOM may be a reliable source of lateral open boundary conditions for a regional coastal ocean predictive model; e.g., the East Florida Shelf Information System (http://efsis.rsmas.miami.edu). Further, they indicate that the cable-derived transport estimates can be used for ongoing verification of G-NCOM performance, and thus the cable data have a key role to play in the Integrated Ocean Observing System (IOOS). (IOOS is the U.S. contribution to the Global Ocean Observing System (GOOS), which supports the advancement of "operational oceanography" for improved marine weather and ocean forecasts, climate analyses, marine emergency management, ecosystem-based marine management, etc.) However, the explanation of the discrepancies on the several-month time-scale await longer records and fuller understanding.

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NEWS

In Brief

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Rule would stiffen export controls at universities A U.S. Department of Defense proposed rule on export controlled technology could significantly increase the number of export control clauses that appear in university contracts, according to the American Association of Universities (AAU).

The rule, published in the Federal Register on 12 July, does not recognize the fundamental research exclusion that protects fundamental university research from export control licensing requirements, AAU noted.

The rule also calls for an access control plan that includes "unique badging requirements for foreign nationals and foreign persons and segregated work areas for export-controlled information and technology."

The rule would amend the Defense Federal Acquisition Regulation Supplement, and follows up on recommendations of a 25 March 2004 report by the Defense Department's inspector general, "Export-Controlled Technology and Contractor, University, and Federally Funded Research and Development Center Facilities."

The DOD Federal Register notice is online at: http://a257.g.akamaitech.net/7/257/2422/01jan20051800/edocket.access.gpo.gov/2005/05-13305.htm. Comments on the DOD rule are accepted through 12 September 2005.

NOAA to develop strategy to protect coral and sponge habitat The U.S. National Marine Fisheries Service (NMFS) will develop a strategy to address research, conservation, and management issues regarding deep-ocean coral and sponge habitat, the agency indicated in an 11 July Federal Register notice. The Service, which is a unit of the National Oceanic and Atmospheric Administration, indicated that this strategy "eventually may result in rulemaking for some fisheries" but that "emergency rulemaking is not warranted."

The NMFS announcement is in response to a 24 March 2004 petition to the Commerce Department filed by Oceana, a non-governmental organization. That petition urged the department through NMFS to "initiate immediate rule-making" to protect coral and sponge habitats in the U.S. exclusive economic zone through mapping, monitoring, research, and enforcement measures.

The Oceana petition noted that coral and sponge communities are "especially vulnerable to destructive fishing practices like the use of bottom-tending mobile fishing gear (bottom trawling) that damage and destroy these sensitive biological systems." The Federal Register notice is available online through the Web site: http://www.nmfs.noaa.gov/habitat/habitatconservation/DSC_petition/.

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