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Introduction to special section: Recent Advances in Oceanography and Marine Meteorology of the Adriatic Sea

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[1] Owing to its strategic location, rich fisheries and natural resources, the Adriatic Sea possesses a long history of scientific exploration (*Cushman-Roisin et al.* [2001] provides a comprehensive review). The two volumes of this Adriatic Sea special section contribute to this rich literature by collecting results from a recent period of intense research activity. During 2002–2003, the combined efforts of several large, multi-disciplinary international programs brought an exceptional array of observational and numerical resources to bear on contemporary questions in Adriatic research. Supported by the U.S. Office of Naval Research, NATO, the Croatian Ministry of Science and Technology and the Italian Ministry of the Environment and Ministry of Universities and Research, scientists from several countries pursued interrelated collaborative research programs. Broad-ranging studies included investigations of circulation at kilometer to basin scales, physical and biological response to bora wind forcing, sediment transport and mucilage formation. Extensive numerical efforts contributed to the success of many of these programs, providing interpretation and understanding and, in some cases, extensions into short-term forecasting.

[2] The Dynamics of Localized Currents and Eddy Variability in the Adriatic (DOLCEVITA) program investigated mesoscale and submesocale response to strong atmospheric and riverine forcing [*Lee et al.*, 2005]. DOLCEVITA efforts employed Lagrangian drifters, high-frequency radar, a towed, undulating profiler, conventional hydrography, microstructure measurements, remote sensing and numerical models to characterize and understand the physical and biological response of the northern and central subbasins at scales ranging from ones to tens of kilometers. This project conducted intensive measurement programs during winter 2003, under strong bora forcing [*Dorman et al.*, 2006], and provided a novel, synoptic, three dimensional characterization of northern Adriatic small-scale response to strong forcing. Simultaneously, the European Margin Strata Formation (EUROSTRATAFORM) program conducted investigations directed at understanding how nearshore sediment transport processes act to create deposition patterns observed offshore of the Po and Apennine river outflows [*Nittrouer et al.*, 2004]. These studies involved extensive ship-based measurements, moored tripods and numerical simulations. DOLCEVITA and EUROSTRATAFORM were nested within the domains of a collection of large-scale circulation studies that employed moorings and repeated hydrographic sections to characterize the region's general circulation. The Adriatic Circulation Experiment (ACE) quantified the northern Adriatic's large-scale circulation and basin-scale response to bora and tidal forcing [*Martin et al.*, 2006], while the East Adriatic Coastal Experiment (EACE) examined seasonality of circulation off the Croatian coast, near Veli Rat [*Orlić et al.*, 2006], and the Western Istria Coastal Experiment (WISE) focused on wind-driven flow offshore of the Istrian peninsula [*Kuzmić et al.*, 2006].

[3] Additional programs addressed potentially harmful biological activity. These efforts included the Mucilages in the Adriatic and Tyrrhenian Seas (MAT) project, which investigated widespread formation of mucilaginous aggregates using monthly physical and biological measurements along three northern Adriatic sections, and studies focused on bottom layer hypoxia [*Giani et al.*, 2005]. The Adriatic Sea Integrated Coastal Area and River Basin Management System Pilot Project (ADRICOSM) represented the confluence of these diverse efforts, combining measurements with extensive modeling to produce a near real-time forecast system [*Castellari et al.*, 2006].

[4] Volume one of the Adriatic special section begins with a climatological analysis and bora meteorology, followed by a series of papers examining physical and biogeochemical processes on a variety of scales. Bora wind and its impact on the northern Adriatic provide a common theme connecting many of these investigations. In an analysis of historical data, *Jeffries and Lee* [2007] find a narrow, fresh filament that extends from the Po delta toward the Istria peninsula during periods of bora forcing. The climatology reveals two separate dense water pools, beneath the Trieste and Senj bora pathways, and the paired cyclonic/anticyclonic gyre system seen in observations [*Orlić et al.*, 1994; *Supić and Orlić*, 1999] and models [*Pullen et al.*, 2003; *Paklar et al.*, 2001; *Orlić et al.*, 1994]. *Dorman et al.* [2006] reveal an additional bora pathway, the

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Novalja jet, which is largely confined to the Adriatic eastern margin. In contrast, the Trieste jet extends across the entire basin but exhibits fine-scale structure, breaking into two smaller features. *Pullen et al.* [2007] demonstrate that different bora episodes differ in their cross-basin reach and diurnal variability, while *Kuzmić et al.* [2006] find that the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) tends to overpredict bora wind strength. Microstructure measurements performed during bora episodes in a frontal zone off Senj reveal that turbulence is generated predominantly by wind stress and, to a lesser extent, by surface buoyancy flux and bottom stress, while vertical velocities in the energy-containing and inertial ranges point to narrower and more intense downdrafts and weaker and wider updrafts [*Peters et al.*, 2007]. Off Trieste, moored measurements show that summertime bora promptly induce mixing and upwelling, producing a considerable temperature drop in the coastal area [*Querin et al.*, 2006].

[5] Numerical simulations show that, due to considerable along-basin bora variability, three cyclonic and two anticyclonic cells are produced in the northern Adriatic, with the East Adriatic Current (EAC) sometimes meandering rather than overturning into the cells [*Martin et al.*, 2006]. In a more limited domain, *Kuzmić et al.* [2006] find a cyclonic bora-driven gyre positioned north of the Po-Rovinj line, with a related anticyclonic gyre close to the Istrian coast – between Rovinj and Pula. *Lyons et al.* [2007] find evidence of this paired anticyclonic/cyclonic circulation pattern in a set of three frequently occupied hydrographic sections radiating from the Croatian coast between Poreč and Pula. These data also suggest a strengthening of eastward (upwind) transport during bora events. Experiments employing two-way coupling of atmospheric (COAMPS) and oceanic (Navy Coastal Ocean Model, NCOM) models reveal that the coupling improves surface flux and current predictions, with different bora episodes producing somewhat different velocity fields, but consistently inducing double-gyre response in the northernmost Adriatic [*Pullen et al.*, 2007]. *Ursella et al.* [2006] employ surface drifter data to examine the influence of other wind patterns, finding that sirocco enhances the EAC and weakens the West Adriatic Current (WAC), while maestro reinforces the WAC and weakens the EAC. Whereas there are some earlier studies of sirocco-driven variability [e.g., *Orlić et al.*, 1994], response to maestro forcing has received little previous attention.

[6] This volume also includes investigations of Adriatic mesoscale variability and general circulation. *Cushman-Roisin et al.* [2007] show that Dietrich Center for Air Sea Technology (DieCAST) model is successful at simulating the jets and cold filaments that occur off the Croatian coast and the meanders and eddies that appear off Italian coast, the latter being the result of baroclinic instability of the WAC. The only previous modeling study of the Adriatic mesoscale variability concentrated on a west coast research polygon [*Masina and Pinardi*, 1994]. *Querin et al.* [2006] find that the MIT General Circulation Model (MITgcm) can reproduce the advective plume generated in Trieste Bay by strong Isonzo outflow, complete with downwelling at the edge of the front and shear instabilities at the river mouth. Po River forcing supports maximum of the kinetic energy of mean flow in autumn [*Ursella et al.*, 2006]. Shallow stratification produced by Po outflow, along with strong shears associated with the WAC, may also impact tide generation and propagation, causing significant phase differences between modeled tides and those observed using an array of high frequency radars [*Chavanne et al.*, 2007]. The EAC was found to peak in January/February and in May 2003, with the first maximum being related to the haline circulation developing inside the Adriatic, the second maximum to the thermal circulation developing between the Adriatic and East Mediterranean [*Orlić et al.*, 2006]. Study of the two circulation systems was pioneered by *Hendershott and Rizzoli* [1976] and by *Nielsen* [1912], respectively, and it is now established that they coexist in the Adriatic albeit on different spatial and therefore different temporal scales. By using Princeton Ocean Model (POM) driven by ECMWF products, *Wang et al.* [2006] show that springtime occurrence of the Gargano density plume depends on adequate cooling of the northern Adriatic during the previous autumn and winter and on low Po River outflow during previous summer. This numerical study also suggests that the northern Adriatic experiences more surface heat loss during winter than can be accounted for by heat gain through advection.

[7] Several papers demonstrate the impact of physical phenomena on Adriatic biogeochemical processes. *Bignami et al.* [2007] use remote sensing to demonstrate that both bora and strong Po discharge events can produce offshore export of turbid coastal waters in front of the Po River mouth and off Ancona. The remote sensing suggests that neither sirocco nor maestro produce offshore transport, and that Po discharge strength can drive large changes in WAC width. *Mauri et al.* [2007] successfully decomposed satellite-derived chlorophyll concentrations into EOF modes. The first three modes explain 61% of variability, with the first mode capturing a strong seasonal signal and the second reflecting separation of coastal waters from the open sea. *Polimene et al.* [2006] employ an ECMWF-driven POM coupled to European Sea Ecosystem Model (ERSEM) to produce the first attempt at coupling high-resolution physical and biological models for the Adriatic Sea. The model associates a region of large phytoplankton and small bacterial biomass with the WAC, with oligotrophic conditions found farther offshore. Model results are encouraging, but also reveal the complexity of biological processes under temporal variability and regional heterogeneity. *Polimene et al.* [2007] find that the same coupled models tend to underestimate observed wintertime dissolved organic carbon, though agreement is better in summer and autumn. Summertime simulations also show that dissolved organic carbon produced in Po-influenced coastal waters is carried toward the oligotrophic midbasin, where slower turnover times allow greater accumulation.

[8] This collection represents the first of two volumes. A second collection will follow, expanding on physical and biogeochemical processes in the northern and central Adriatic.

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