Adriatic Circulation Experiment- Mesoscale Dynamics and Response to Strong Atmospheric Forcing

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LONG-TERM GOALS

This study contributes to our long-term efforts toward understanding:

- Processes governing exchanges between the shelf and deep ocean.
- Strongly forced mesoscale dynamics.
- Processes that communicate atmospheric forcing to the ocean interior.
- Use of dynamical understanding to improve performance of shallow water analysis products.

OBJECTIVES

We seek to understand the role played by three primary driving forces: (1) wintertime Bora winds, (2) weaker, along-basin Sirocco winds and (3) seasonal buoyancy input from the Po River and other sources, in governing the evolution of coastal filaments, eddies and fronts in the northern Adriatic. Additional efforts will focus on the dynamics of watermass formation and subduction in a shallow sea regime.

APPROACH

Winter and spring cruises studied the evolution of selected fronts and filaments under two distinctly different regimes of background stratification, riverine input and wind forcing. During February 2003 the northern basin (with the exception of the Po-influenced region along the Italian coast) was largely unstratified. Po discharge was weak (Fig. 1a) and strong Bora wind events (Fig. 1b) provided the dominant forcing. These cold air outbreaks typically had lateral scales of O(10 km) and durations of 1-2 days, driving the northern and central basin through intense, laterally sheared wind stress and large net surface heat loss. Although the May cruise was timed to sample the spring freshette, when Po outflow reaches its annual peak, discharge rates were anomalously weak (over one standard deviation below the 12-year mean) and provided only weak buoyancy forcing to the northern basin (Fig. 1a).

(a) (b)

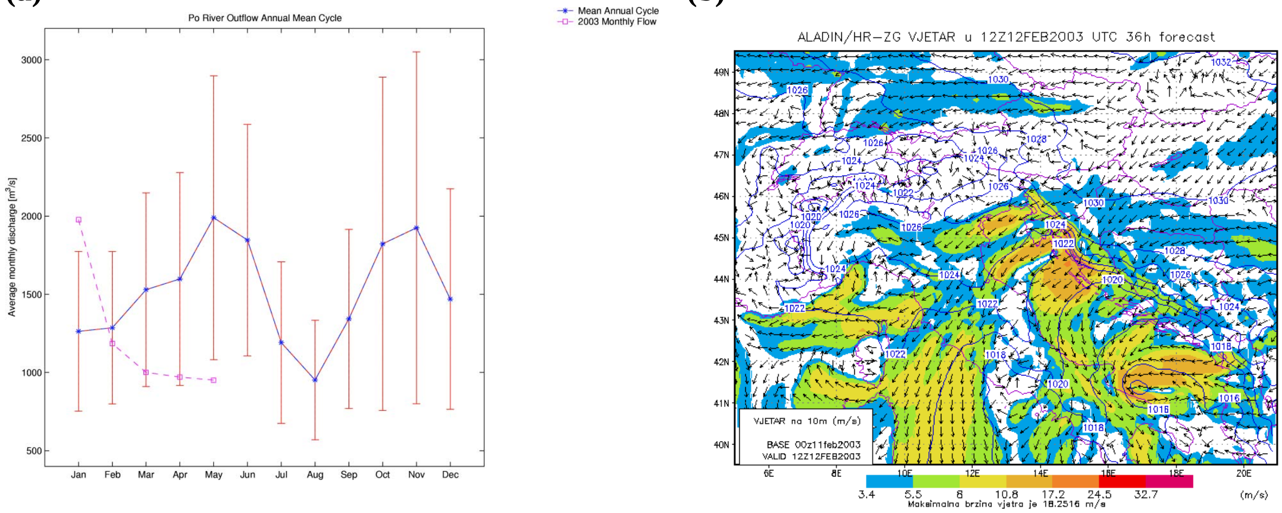

Figure 1. (a) Po River discharge rates. Blue lines mark the monthly average discharge with bars indicating one standard deviation. The magenta line indicates monthly average discharge for the first half of 2003.
(b) Aladin mesoscale model winds for 12 Feb. 2003 (courtesy of V. Tutis, Croatian Meteorological Service). Note the narrow jets characteristic of strong Bora events.

Both cruises followed an adaptive sampling strategy, using remotely sensed sea surface temperature (SST) and ocean color images to select energetic fronts and filaments. We used dedicated short-term meteorological forecasts to coordinate survey timing with atmospheric events, ensuring that target features were sampled during the periods of strong forcing. The observational program employed a towed, undulating sensor platform (TriSoarus, a hybrid SeaSoar vehicle) to conduct high-resolution, three-dimensional surveys of physical and optical variability. Measurements conducted during the two cruises included:

- Continuous underway measurements of ocean currents (150 KHz Broadband Acoustic Doppler Current Profiler (ADCP)) and meteorological variables.
- Towed, undulating profiler measurements of temperature, salinity, chlorophyll and DOM Fluorescence, 660 nm beam attenuation, dissolved oxygen, nine-channel absorption and attenuation (AC-9) and currents (1200 KHz Broadband ADCP). TriSoarus typically profiled from 1-2 m depth to within 5 m of the bottom at tow speeds of 7-8 knots. Typical along track resolution was approximately 150 m (1500 m) at minimum (maximum) profiling depths of 15 m (200 m), with cross-track distances of 3-5 km.
- Optical profiling sampling temperature, salinity, chlorophyll and DOM fluorescence, 660 nm beam attenuation, spectral optical backscatter (Hydroscat), nine-channel absorption and attenuation (AC-9) and upwelling and downwelling irradiance. (B. Jones, USC)
- CTD/rosette casts sampling temperature, salinity, dissolved oxygen, chlorophyll fluorescence, 660 nm beam attenuation, nutrients and pigments. (B. Jones, USC, M. Marini, IRPEM)
- Plankton sampling using vertical net tows and rosette water samples. (D. Vilicic, U. Zagreb)
- Surface drifter deployments coordinated with the intensive towed surveys. (P. Poulain, OGS-Trieste)

- Microstructure profiles and time series of velocity profiles (5-beam bottom-moored ADCP). (H. Peters, U. Miami)
- Real time access to AVHRR and ocean color remote sensing (R. Arnone, NRL-SSC)
- Customized synoptic meteorological forecasts (D. Thaler, Austrian Military Weather Service and V. Tutis, Croatian Meteorological Service)

Efforts to develop a new Adriatic climatology complement the measurement program and provide opportunities to explore new techniques for characterizing regions dominated by short time- and space-scale variability. This alternative climatology organizes archived data by dynamical regime rather than the more typical time (e.g. monthly or seasonal) averaging. Because strong wind outbreaks and Po River discharge govern the dynamics of the northern and central Adriatic, we pursue canonical descriptions of Bora, Sirocco and 'low-wind' regimes under both weak and strong Po outflow. These descriptions will be further refined to account for seasonal variability in background stratification. The resulting dynamics-based climatological fields can be evaluated against both the measurements collected during our field program and individual 'snapshots' taken from the historical data. We also plan to evaluate these techniques using the extensive synthetic data sets generated by the NRL (Pullen) and Dartmouth (Cushman-Roisin) numerical efforts.

WORK COMPLETED

Two cruises (winter and spring 2003) investigated strongly forced small- and meso-scale dynamics in the Northern and Central Adriatic Sea. In addition to our extensive towed profiling surveys, a team of U.S., Croatian and Italian investigators conducted measurements which included optical and microstructure profiling and a suite of chemical and biological sampling. Preliminary data were distributed to participants at the conclusion of each cruise and a comprehensive cruise report is being prepared. We are currently implementing calibration and lag corrections to the towed profiler measurements and hope to release a fully processed data set before the end of 2003.

The winter (February 2003) field program sampled the response to small-scale Bora wind forcing in the absence of significant riverine buoyancy input. Northeasterly (Bora) winds were present throughout the entire cruise, with a mean wind speed of 7 m/s punctuated by strong events of up to 18 m/s lasting 1-3 days. At the start and end of the cruise, we executed broadscale surveys spanning the region north of the Jabuka Pits (Fig. 2a). These were designed to identify dense water formation regions, characterize wintertime variability and provide length scale statistics to aid other analysis. To investigate the relative roles of bathymetric steering and wind forcing, we executed a set of intensive surveys at the northern end of the Jabuka Pit, where the East Adriatic Current (EAC) bifurcates, part flowing westward to follow the bathymetry (forming the Mid-Adriatic Filament (MAF)), with the remainder continuing north along the Croatian coast. A set of nested surveys occupied after a strong Bora event captured the counter-rotating gyres and upwind extension of the Po River plume (Fig. 3) anticipated from numerical results Orlic et al., 1994. These features dominate the northern basin and are hypothesized to be the response to intense, small-scale (O(10 km)) wind stress curl associated with Bora jets passing though the Gulf of Trieste and Kvarner Bay.

In sharp contrast to wintertime conditions, the May/June cruise occurred during a period of extremely weak wind and riverine forcing. In the absence of significant wind-induced mixing, intense surface warming produced very shallow (0-5 m) mixed layers with significant stratification extending

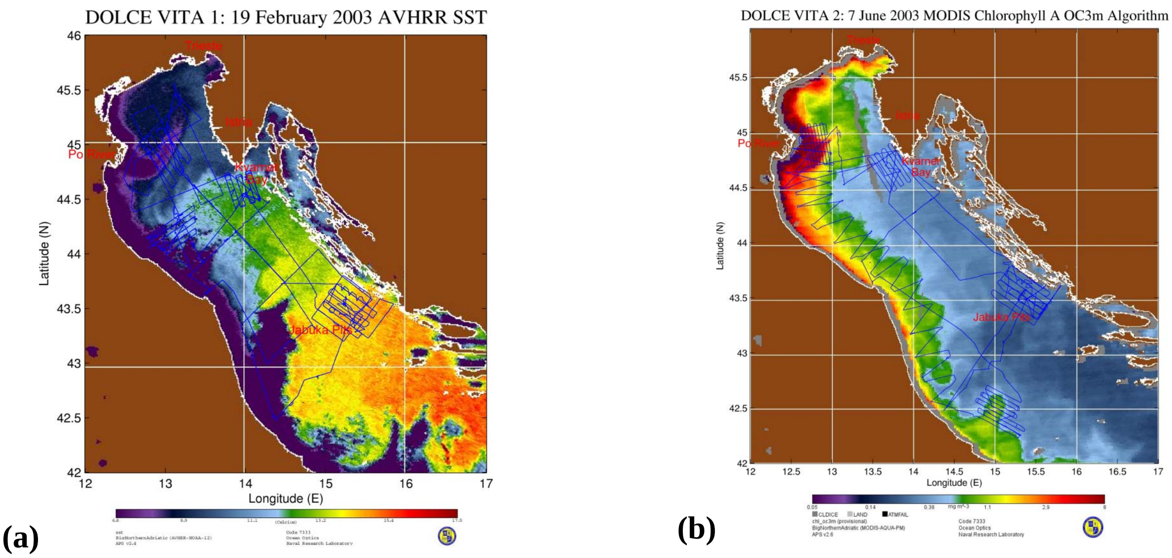

Figure 2. Remotely sensed (a) AVHRR sea surface temperature (23 February) and (b) SeaWiFS ocean color (7 June) with blue lines marking the survey track.

throughout the water column. Intensive surveys focused on the Mid-Adriatic Filament, the Istria front, the Po plume bulge and a Po plume instability located well downstream of the inflow region (Fig. 2b). A series of cross-shelf sections extending from the Po delta to the Jabuka Pit documented downstream physical and optical evolution of the Po plume. All surveys exhibited energetic small-scale velocity and T-S variability, with both TriSoarus and drifter measurements suggesting a significant near-inertial component. Even weak winds may have been enough to set the thin surface layer in motion.

The Adriatic field program also marks the first use of our hybrid SeaSoar system (TriSoarus). This vehicle combines components from out Triaxus towed profiler with oversize wings and ailerons designed by CSIRO (Tasmania). A fiber optic MUX allows easy integration of new sensors and provides ample bandwidth for expansion. TriSoarus can be used in shallow environments (we profiled in waters as shallow as 15 m in the Northern Adriatic), and (in deeper waters) is capable of undulating between the surface and 200 m at tow speeds up to 8 knots. Significantly, TriSoarus uses an unfaired tow cable, easing at-sea operations and decreasing deployment costs.

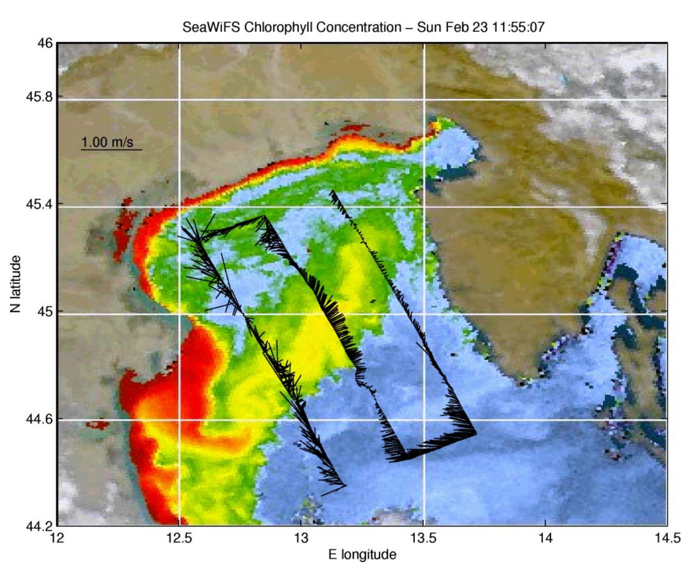

Figure 3. Velocity vectors at 7 m (from the 150 KHz shipboard ADCP) plotted over remotely sensed ocean color illustrate the paired cyclonic/anticyclonic circulation associated with the Bora forced plume in the Northern Adriatic.

RESULTS

Although we have only just begun scientific analysis, a particularly interesting sequence of surveys provides an example of the investigation’s focus. A strong shallow-water front that extended westward from the tip of the Istrian peninsula marked a transition between the northern and central basins, separating two hypothesized dense water formation sites. Guided by real-time SST images and dedicated meteorological forecasts, we executed a sequence of four surveys to document the front's evolution through a strong Bora event. Frontal temperature and salinity contrasts were largely compensating and occurred over extremely small scales (1 ºC in less than 100 m). The interface remained nearly vertical during the period of strong wind forcing, but began to tilt as the winds subsided (Fig. 4a). This could be driven by slumping, distortion by shear in the upper layer flow or distortion by the deep offshore-moving return flow that balances wind-driven downwelling off the tip of Istria. A narrow band of anomalously dense water occupied the frontal interface (Fig. 4b). Elevated levels of chlorophyll fluorescence and beam attenuation were also associated with the dense-water regions. Although cabelling can produce density anomalies across sharp temperature-salinity interfaces, the observed density contrasts are too large to be explained by this mechanism. The associated optical signal and strong westward flow along the front hint that advection may play a role in establishing the observed density structure.

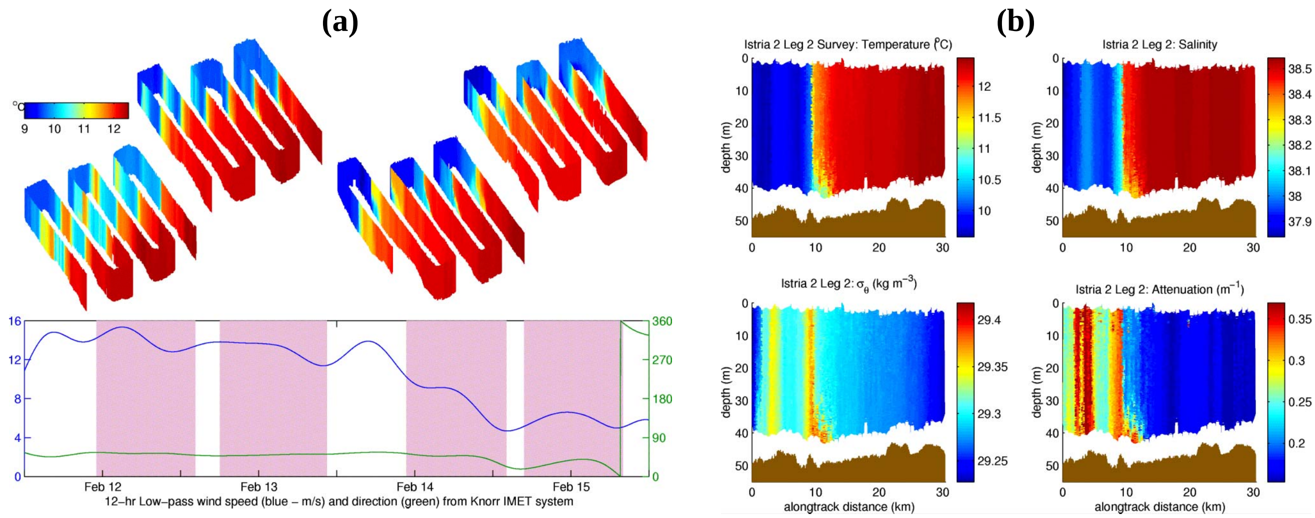

Figure 4. (a) Temperature sections from four successive occupations of the Istria front survey, with time series of wind speed and direction summarized below. Shaded bars in the wind plot mark the times of each survey. The first two occupations coincided with peak Bora winds. The third survey took place during the transition period, while the fourth occurred under weak, post-Bora forcing. (b) Sections of temperature, salinity, potential density and beam attentuation from the second occupation of the Istria Front survey (plotted north to south).

IMPACT/APPLICATION

The new hybrid SeaSoar system provides a flexible new platform for making synoptic measurements in both nearshore and open-ocean environments. TriSoarus complements our Triaxus system, with each platform providing distinct capabilities while also acting as a drop-in backup vehicles for each other.

TRANSITIONS

None.

RELATED PROJECTS

Shallow Water Climatology and Analysis with Application to the Adriatic Sea, C. Lee (APL-UW)

Optical Dynamics in the Adriatic Sea: The Role of River Plumes, Filaments and Fronts in the Distribution, Advection and Transformation of Inherent and Apparent Optical Properties, B. Jones (USC).

Adriatic Mesoscale Experiment, P. Poulain (OGS- Trieste).

East Adriatic Coastal Experiment (EACE), M. Orlic (Univ. of Zagreb).

Mesoscale Dynamics of the Adriatic Sea, B. Cushman-Roisin (Dartmouth).

Surface Current Maps from High Frequency Radar, P. Flament (U.H.) and P. Poulain (OGS-Trieste)

The Adriatic Circulation Experiment, H, Perkins (NRL-Stennis), J. Miller (NRL- STennis) and R. Signell (SACLANTCEN).

REFERENCES

Orlic, M., M. Kuzmic, and Z. Pasaric, 1994: Response of the Adriatic Sea to the bora and sirocco forcing. *Continental Shelf Research*, **14,** 91-116.

PUBLICATIONS

None.