NOTES AND CORRESPONDENCE

Sea Surface Flow Estimation with Infrared and Visible Imagery

ANDREW C. VASTANO

Department of Oceanography, Texas A&M University, College Station, TX 77843

STEPHEN E. BORDERS

SIO/Satellite Oceanography Facility, University of California, San Diego, La Jolla, CA 92093

RUTH E. WITTENBERG

Visibility Laboratory, University of California, San Diego, La Jolla, CA 92093

26 October 1984 and 11 January 1985

ABSTRACT

Sequential Nimbus-7 CZCS infrared and visible images obtained on orbits 3157 and 3171 during 9–10 June 1979 have been used to derive sea surface flow from advective sea surface pattern displacements and elapsed time. Individual analyses with infrared (11 microns) and visible blue/yellow ratio (0.443 and 0.550 microns) pairs of images yielded coherent velocity distributions over an oceanic region near Georges Bank. A composite of eighty flow vectors illustrates a seaward diversion of cold surface water off Northeast Channel, Gulf of Maine by a northeastward intrusion of Gulf Stream water along the continental slope. These results demonstrate that instances arise when infrared and visible surface pattern changes can be used jointly to compose flow regimes. A sea surface topography map derived from the composite vector distribution has a range of 20 cm and an expected repeatability of 0.39 cm.

1. Introduction

Satellite observations can yield quantitative measurements pertinent to mesoscale dynamics and studies of the total time rate of change of scalar properties of the oceanic surface layer. Surface flow estimates can be extracted from data gathered by a number of sensors and are a topic of current research. Radar altimetric sensings of the surface result in surface topographic measurements adequate for flow computations. However, the narrow sensor footprint and orbital characteristics have heretofore produced inadequate areal coverage and aliasing of moving mesoscale features. The NOAA (AVHRR)[1] and Nimbus (CZCS) satellite sensors can provide the necessary spatial and temporal resolution to define mesoscale features. The pattern displacements apparent in sequential AVHRR and CZCS scenes have revealed motion and led to simple measures of flow (e.g., Vastano and Bernstein, 1984). Image processing algorithms that provide quantitative sea surface motion estimates are a recent development (Kelly, 1983; Vastano and Borders, 1984). Kelly has used temperature fields computed from AVHRR data to derive both cross- and along-isotherm components of motion and compose a total vector field. This method is an automated one after small feature displacements in sequential images are used to evaluate a free parameter in an analytic model of the velocity field. A uniformly computed vector field can be produced over the image by this method. Vastano and Borders have applied an interactive algorithm that requires sequential images and objectively identifies small feature displacements in the direction of the temperature gradient. The result is a nonuniform field of vector estimates. Both techniques have been applied to NOAA-7 AVHRR images with successful production of sea surface vector fields that represent horizontal motion.

Infrared or visible image analyses can be hampered by the presence of atmospheric interference. Clouds over a target area often partially or completely obscure views of the sea surface and mesoscale features. However, observations by more than one polar-orbiting satellite can take advantage of atmospheric motion that may clear clouds during the interval between satellite pass times. Whether in order to alleviate interference problems or to increase the temporal resolution within a given day, the use of multiple satellites can produce a greater number of sequential sea surface patterns. In such instances, the patterns from different satellites may be related to different scalar quantities. This note reports an application of the interactive method of flow vector computation to pairs of coincident CZCS in-

[1] Advanced Very High Resolution Radiometer.

frared and visible images and presents the resulting composite flow estimate. The objective is to show the relation between infrared and visible vector flow estimates.

2. Sequential image analyses

Nimbus-7 CZCS scenes of the region immediately east of the Gulf of Maine and south of Nova Scotia were taken on orbits 3157 and 3171 during 9–10 June 1979. The 11-micron infrared channel and two visible channel [0.443 (blue) and 0.550 (yellow) microns] images for each scene were registered to within 0.6 km, yielding 512 × 512 pixel images (423 × 423 km) for flow analyses. Sequential pairs were formed by the infrared images and computed, visible ratio images (blue/yellow). The patterns exhibited in the images correspond to the sea surface temperature distribution (infrared) and an uncorrected approximation to the pig-

FIG. 1. Flow vectors and dynamic topography overlayed on the infrared image for 9 June 1979.

ment concentration or chlorophyll distribution (blue/yellow). Similar pattern shapes, structures and displacements were apparent in these four images. The algorithm for flow vectors (Vastano and Borders, 1984) was applied to the infrared and visible pairs and produced a total of eighty estimates. In order to provide independent assessments of pattern displacement and vector estimates, each pair was treated separately by different investigators. Figure 1 presents the results of the flow computations overlayed on the infrared image for 9 June 1981. The vector estimates from the infrared image pair (red) and the visible image pair (yellow) can be visually compared and jointly form a coherent set that indicates the intrusion of Gulf Stream water along the continental shelf east of Georges Bank. Immediately east of the intrusion, cooler waters move west-southwest and southwest over the one-day interval between scenes. The composite set of infrared and visible images has been used to compute the associated streamfunction representation (Vastano and Reid, 1985). This method assumes a nondivergent flow approximation and trigonometric streamfunction expansion basis functions. The contours shown in Fig. 1 are sea surface topography derived from the streamfunction by taking a geostrophic approximation. The range of topography is approximately 20 cm and the expected repeatability is 0.39 cm.

The similarity of the vector estimates from the infrared and visible image pairs and the coherent field they portray demonstrates that instances arise when flow estimates based on different types of sensors may be combined. These results infer that separate flow fields derived from different sensors can be used together to examine the evolution of mesoscale features in a region. Experimental verifications of these methods are in progress.

Acknowledgments. The image processing and analyses were carried out at the Scripps Satellite Oceanography Facility, Scripps Institution of Oceanography, La Jolla, California. Andrew C. Vastano was supported by Grant OCE 80-26037 of the National Science Foundation and the Office of Naval Research under Contract N00014-75-0537.

REFERENCES

Kelly, K. A., 1983: Swirl and plume or application of statistical methods to satellite-derived sea surface temperature. CODE Tech. Rep. No. 18, SIO Ref. No. 83-15, 210 pp.

Vastano, A. C., and R. L. Bernstein, 1984: Mesoscale features along the First Oyashio Intrusion. *J. Geophys. Res.*, **89,** 587–596.

——, and S. E. Borders, 1984: Sea surface motion over an anticyclonic eddy on the Oyashio Front. *Remote Sens. Environ.*, **16,** 87–90.

——, and R. O. Reid, 1985: Sea surface topography estimation with infrared satellite imagery. *J. Atmos. Ocean. Tech.*, **2,** 393–400.