

Shulman, I. (1), Kindle, J. C. (1), Paduan, J. D. (2), Ramp, S. R. (2), Rosenfeld, L. K. (2), Haddock, S., H. D. (3), McGillicuddy, D. J. (4), Moline, M. A. (5), Nechaev D. (6), DeRada, S. (7), Anderson, S. C. (7), Phelps, M. W. (7)

(1) Naval Research Laboratory, Stennis Space Center, USA, (2) Naval Postgraduate School, Monterey, USA, (3) Monterey Bay Aquarium Research Institute, Moss Landing, USA, (4) Woods Hole Oceanographic Institution, Woods Hole, USA, (5) California Polytechnic State University, USA, (6) University of Southern Mississippi, USA, (7) Jacobs Sverdrup, Stennis Space Center, USA

I. Introduction

Bioluminescence (BL) short-term predictability experiments are conducted by the assimilation of BL observations into the advection-diffusion-reaction model with velocities and diffusivities from a circulation model.

The approach is being tested with BL observations collected during two Autonomous Ocean Sampling Network (AOSN) experiments in the Monterey Bay Area. In AOSN-I experiment (August 2000), the BL surveys were collected during a strong wind relaxation event. In AOSN-II experiment (August 2003), BL surveys were collected during extended (more than a week) upwelling favorable event. Circulation patterns and results of BL predictability experiments during upwelling and relaxation events are investigated and discussed.

III. Bioluminescence Modeling During Relaxation Event (August 2000)

One of the objectives of the August 2000 Monterey Bay experiment was to study the influence of advective-diffusive processes on bioluminescence variability in the Bay. This experiment was conducted jointly by the Autonomous Ocean Sampling Network (AOSN), MBARI Upper-Water-Column Science Experiment (MUSE), and NOPP ICON projects.

Bioluminescence potential predictability experiments were conducted by using an advection-diffusion-reaction model with velocities and diffusivities from the ICON and frsICON models (Shulman et al. 2003).

The physical conditions in the Bay were representative of a strong extended wind relaxation event (Fig. 2).

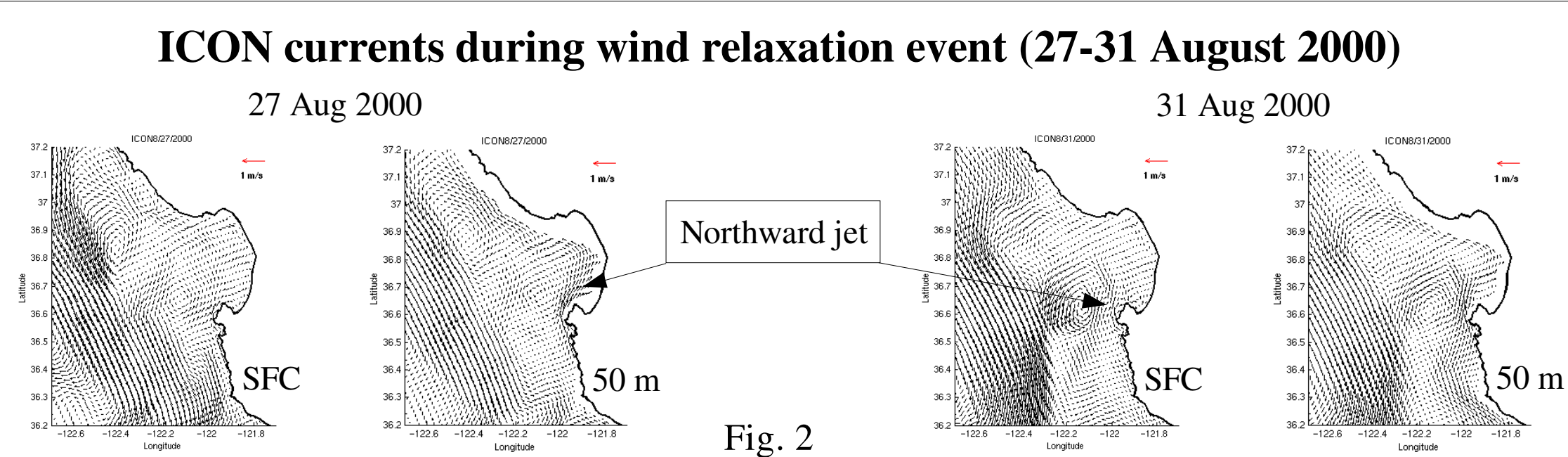


Fig. 2

Analysis of the ICON model currents structure at different depths (Fig. 2) indicates the development of near-shore northward flow, extending down to 100 m depth. This northward flow is connected with the northward flow originating at the southern open boundary of the ICON domain (larger-scale phenomenon generated by the coupling to the Pacific West Coast model). In the Bay, this northward flow develops a cyclonic eddy that is confined between this near-shore northward flow and southward flow offshore.

Two cross-shore surveys of BL were used. The first cross-shore section was taken on calendar day 242 of 2000 in the northern part of the Bay (noted as section AA on Fig. 3, top panel), and the second section was taken inside the Bay on day 245 (noted as section BB). On Fig. 3 (top, panel), the observed BL distribution as a function of depth and distance offshore (in 10^{19} photons/s) is shown for the AA and BB sections.

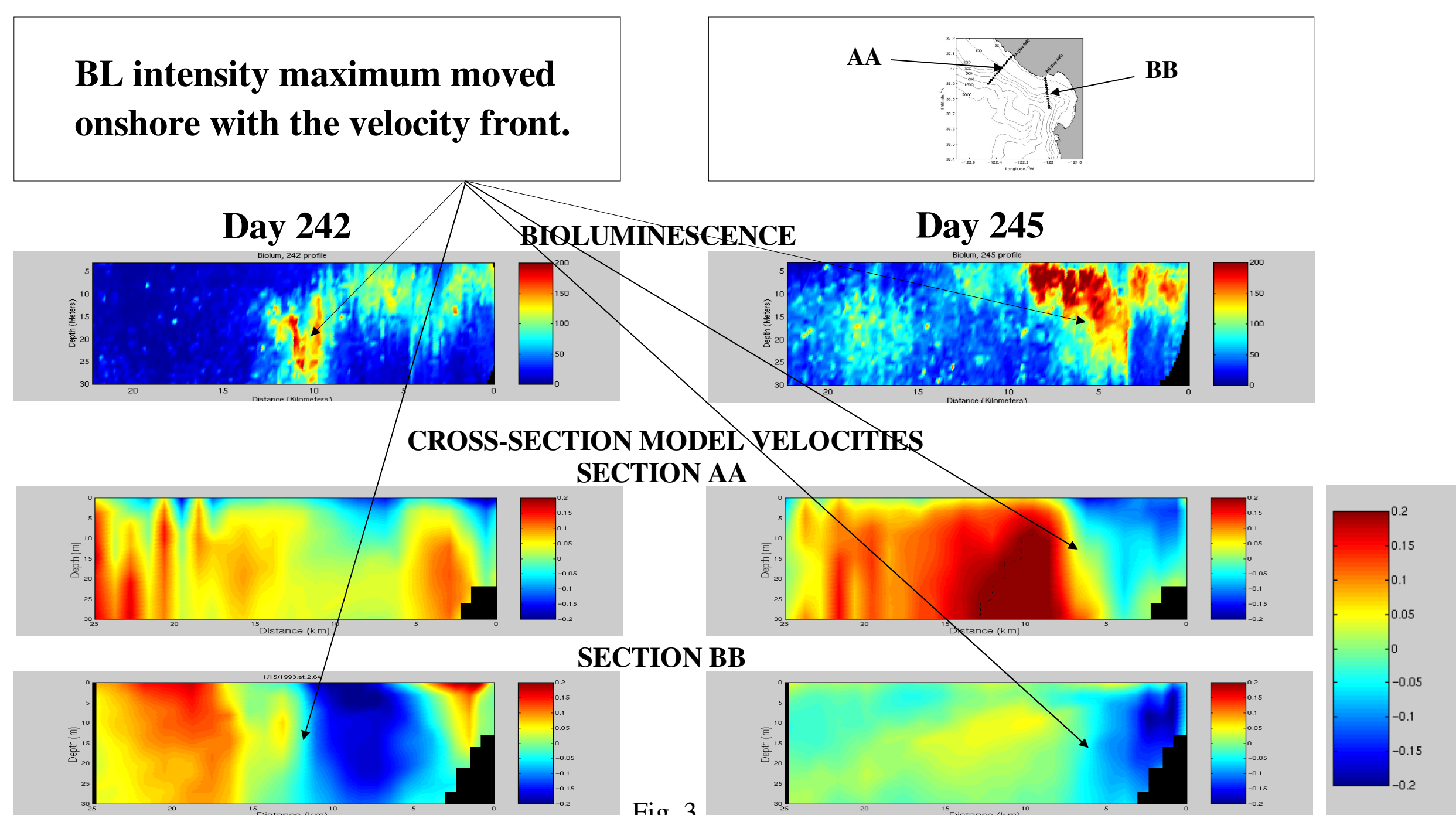


Fig. 3

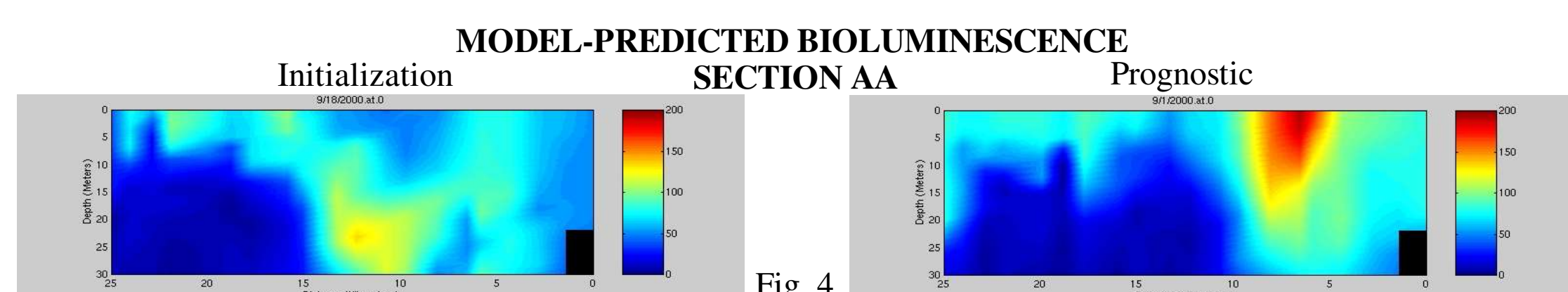


Fig. 4

Transects of bioluminescence data indicate onshore translation, shallowing and intensification of bioluminescence intensity maximum during 3 days. Patterns of cross-section velocities from frsICON model at these sections (Fig. 3 middle and bottom panels) indicate development of sharp fronts moved onshore over three days at both sections.

Due to the development of the northward jet (Fig. 2), numerical BL predictability experiments (Shulman et al., 2003) show that assimilation of BL from inside of the Bay only (BB survey) into the advection-diffusion-reaction model gave a good reconstruction of the observed location of the BL maximum (Fig. 4) outside of the Bay (section AA). The BL distribution at the AA location after three days of prognostic calculations (on 245 day) is shown on Fig. 4, bottom panel, right. After those three days of prognostic calculations, the BL maximum moved closer to shore and became shallower. Also, the intensity of the BL maximum was stronger after three days. This corresponds to observed temporal and spatial tendencies in observed BL.

According to figs. 3 and 4, during the wind relaxation event, the locations of the observed and model-predicted BL maxima coincide with the location of the high horizontal shear frontal area where the flow reverses direction.

II. Models

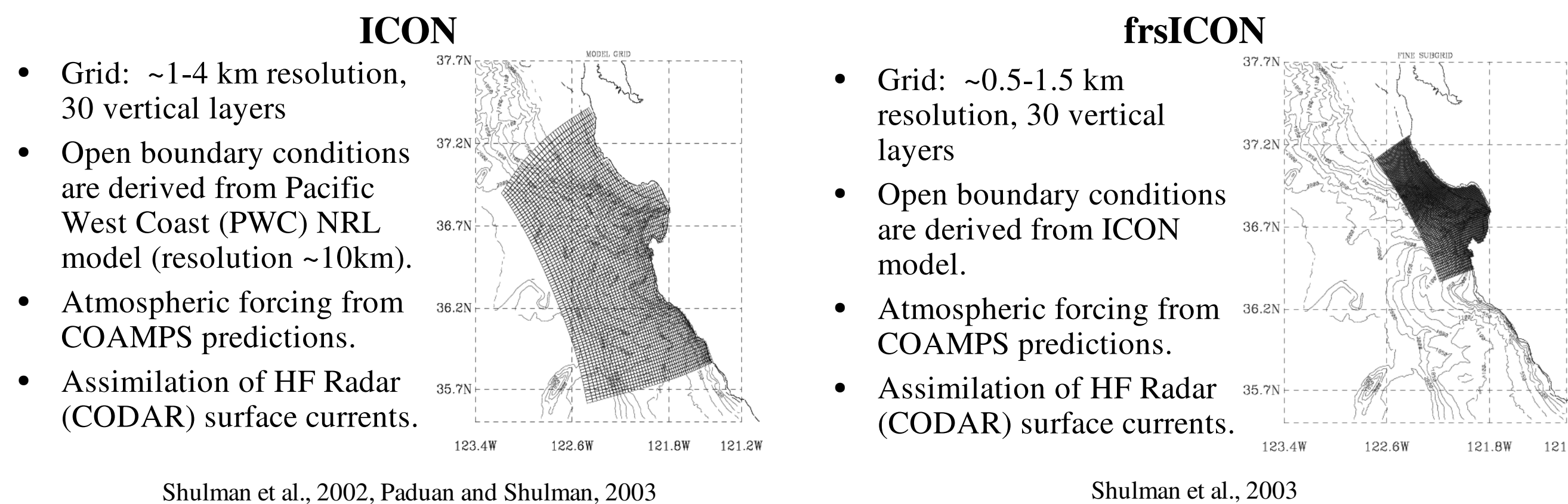


Fig. 1

IV. Bioluminescence Modeling During Upwelling Event (August 2003)

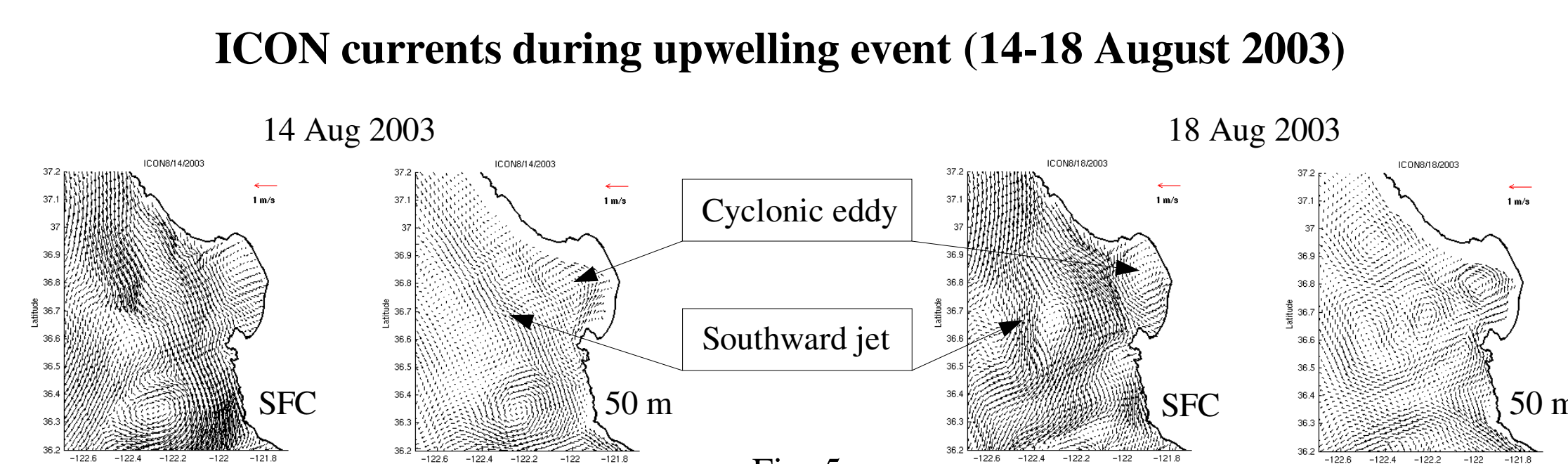


Fig. 5

Analysis of the ICON model currents structure at different depths (Fig. 5) indicates a strong southward offshore jet during the upwelling event. In the Bay, a cyclonic eddy is present.

BL intensity maximum moved offshore with the velocity front.

M14a, M14b, H225, H226

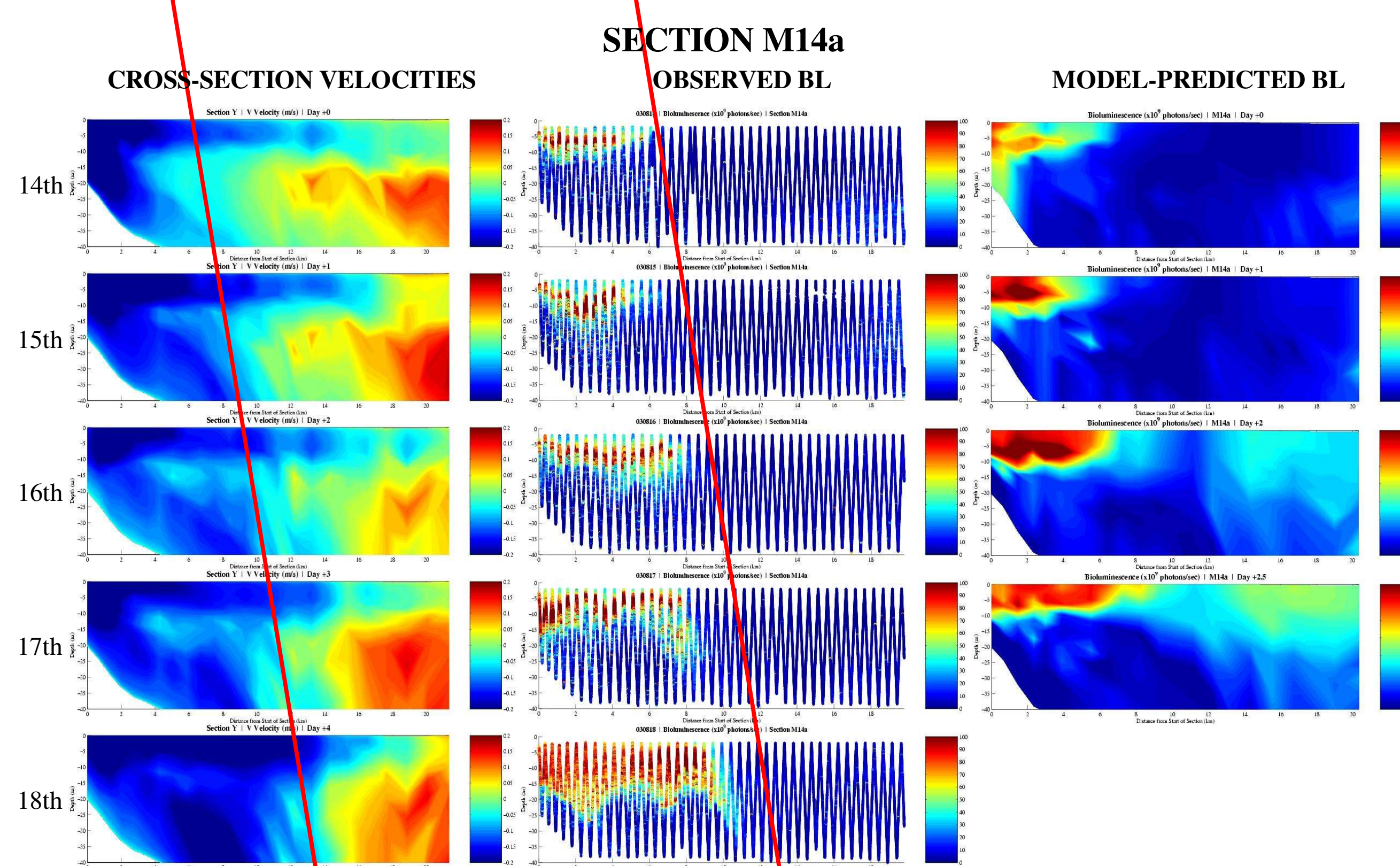


Fig. 6

On 14 August 2003, the advection-diffusion-reaction model was dynamically initialized (according to methodology described in Shulman et al. 2003) by using velocities and diffusivities from the frsICON model and bioluminescence observations from four sections (H225 on 13 August; H226, M14a, and M14b on 14 August). After that, three days of prognostic simulations were conducted. Observations and prognostic model predictions indicate offshore spreading of bioluminescence intensity during upwelling event.

VIII. Acknowledgments

This research has been supported by ONR Biological and Chemical Oceanography and Ocean Modeling and Prediction Programs. We thank Alan Weidemann and Bob Arnone for helpful discussions and support. The authors would also like to thank Shelley Blackwell, Jodi Brewster, Cristina Orrico, and Christy Herren for help with bioluminescence data. Our thanks also goes to the AOSN-II interdisciplinary group for many helpful discussions.

V. Optimization of Bioluminescence Sampling with Adjoint

Adjoint code to the ICON model is being used to study the sensitivity of the modeled bioluminescence distributions to the sampling strategies of BL intensity.

Fig. 7 shows BL sensitivity maps for the section inside the Bay for the two relaxation events that occurred during August 2000 and August 2003. BL sensitivity maps are shown for one and two days prior to the forecasts. Positive values indicate that changes in BL intensity in this area will result in an increase of the flux of BL intensity through the corresponding section, while negative values indicate that increase in BL intensity in this area will result in a reduction of the flux of BL intensity. Both positive and negative areas are critical and should be sampled prior to the forecast.

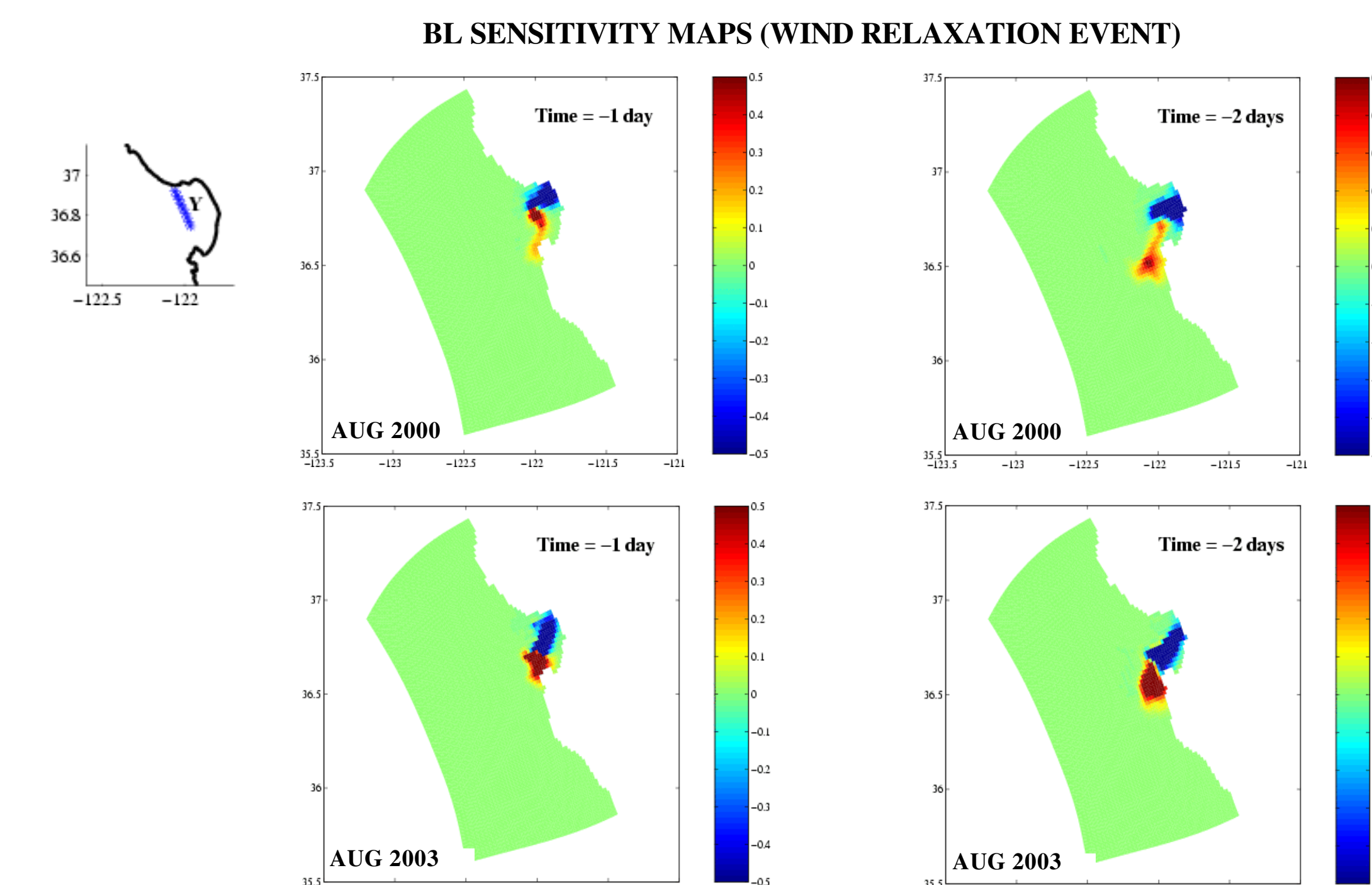


Fig. 7

VI. Conclusions

• It is shown that **short-term changes** in some of the salient features in coastal bioluminescence can be explained and predicted with the assimilation of BL observations into the advection-diffusion-reaction model, with velocities and diffusivities derived from a circulation model.

• There is a strong dependence of BL intensity distribution on flow conditions. During relaxation event, the bioluminescence intensity maximum was moving onshore with the velocity front. During upwelling event, the BL intensity was moving offshore with the velocity front. It is important to make BL observations in particular flow-dependent "sensitive" regions.

• Optimization of locations and times of BL observations prior to the forecast are critical for successful short-term BL predictions. During the wind relaxation event in the Monterey Bay, the assimilation of only one section of observed BL inside of the Bay gave a good reconstruction of the location and the maximum of observed (not assimilated) BL outside of the Bay (Fig. 4). At the same time, it was shown that sampling of BL outside of the Bay will provide little information for short-term BL predictability inside of the Bay (Shulman et al. 2003).

• Sensitivities of short-term BL forecasts are being investigated by using the adjoint to the advection-diffusion-reaction model code. Sensitivity maps of BL forecasts during AOSN-I and AOSN-II experiments show that for short-term BL intensity predictions at the cross-section inside of the Bay, the area to the south of the Bay (around the Pt. Pinos area) should be sampled with priority. Adjoint-based sensitivity maps provide a simple methodology for optimization of BL sampling strategies.

VII. Future Plans

• Continuation of the development of adjoint-based techniques for identifying the optimal deployment of BL observational assets.

• Estimation of sources and sinks of BL intensity in the Monterey Bay.

• Understanding of the relative contributions of advective-diffusive processes versus biological processes to short-term and relatively long-term variability of BL intensity in Monterey Bay.

• Use of the Coupled Physical Bio-Optical Model (<http://www7320.nrlssc.navy.mil/cobiopp/>) for interpretation of BL inversion experiments and for the development of numerical parameterizations of BL sources and sinks.

IX. References

- Paduan, J. D. and I. Shulman, 2003: HF Radar Data Assimilation in the Monterey Bay Area. *JGR Oceans*, to appear.
- Shulman, I., S. H. D. Haddock, D. J. McGillicuddy, J. D. Paduan, and W. P. Bissett, 2003: Numerical Modeling of Bioluminescence Distributions in the Coastal Ocean. *Journal of Atmospheric and Oceanic Technology*, **20**, 1060-1068.
- Shulman, I., C.-R. Wu, J. K. Lewis, J. D. Paduan, L. K. Rosenfeld, J. C. Kindle, S. R. Ramp, C. A. Collins, 2002: High Resolution Modeling and Data Assimilation in the Monterey Bay Area. *Continental Shelf Research*, **22**, 1129-1151.