Gulf Hypoxia Modeling 2006-2012: Progress, Challenges and Prospects

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Forecasting Gulf's Hypoxia: The Next 50 Years?

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ABSTRACT: This review discusses the use of hypoxia models in synthesizing the knowledge about the causes of Gulf of Mexico hypoxia, predicting the probable consequences of management actions, and building a consensus about the management of hypoxia. It also offers suggestions for future efforts related to simulating and forecasting Gulf hypoxia. The existing hypoxia models for the northern Gulf of Mexico range from simple regression models to complex three-dimensional simulation models, and they capture very different aspects of the physics, chemistry, and biology of this region. Several of these models were successfully calibrated to observations relevant for their process formulations and spatial-temporal scales. Available model results are compared to reach the consensus that large-scale hypoxia probably did not begin in the Gulf of Mexico until the mid 1970s, and that the 30% nitrogen load reduction that is called for by the Action Plan may not be sufficient to achieve its goal. The present models results suggest that a 40–45% reduction in riverine nitrogen load may be necessary to achieve the desired reduction in the areal extent of hypoxia. These model results underscore the importance of setting this goal as a running average because of significant interannual variability. Caution is raised for setting resource management goals without considering the long-term consequences of climate variability and change.

Introduction

Large-scale hypoxia (< 2 mg O_2 l^{-1}) in the northern Gulf of Mexico, up to 22,000 km^2, overlaps with habitat and fishing grounds of commercially important fish and shrimp. Hypoxia typically occurs from March through October in waters below the pycnocline, and extends between 5 and 60 m depth offshore (Rabalais and Turner 2001; Rabalais et al.

production in the northern Gulf of Mexico (Lohrenz et al. 1990, 1997, 1999; Rabalais et al. 2002).

Hypoxia develops from a suite of biological and physical factors, two of which are most important: nutrient-enhanced surface primary productivity, which is also manifested in a high carbon flux to sediments (Justić et al. 1996; Lohrenz et al. 1997; Rabalais and Turner 2001), and high stability of the

Objective

- Overview of advances in Gulf hypoxia modeling 2006 - 2012
- Uncertainties and new paradigms
- Future hypoxia models

Gulf Hypoxia Models (2006)

- Bierman et al. (1994) - Simulation
- Chen et al. (1997) – Simulation
- Wiseman et al. (1997) - Statistical
- Justic et al. (1996, 1997, 2002) – Simulation
- Rowe (2001) - Simulation
- Scavia et al. (2003, 2004) – Simulation
- Stow et al. (2005) - Statistical
- Turner et al. (2005, 2006) - Statistical

“There is an apparent need for model development along two fronts: refinement of relatively simple models that can provide forecast rigor at the expense of detailed mechanistic insight, and enhancement of more complex 3-D models that can help describe and dissect controls and consequences at the expense of forecast rigor…”

Justic et al. (2007)

Gulf Hypoxia Models (2012)

- Bierman et al. (1994) - Simulation
- Chen et al. (1997) – Simulation
- Wiseman et al. (1997) - Statistical
- Justic et al. (1996, 1997, 2002) – Simulation
- Rowe (2001) - Simulation
- Scavia et al. (2003, 2004); Scavia and Donnelly (2007); Evans and Scavia (2012) – Simulation
- Stow et al. (2005) - Statistical
- Turner et al. (2005, 2006, 2008, 2012) – Statistical
- Morse and Eldridge (2007); Eldridge and Morse (2008) – Simulation
- Hetland et al. (2008, 2012); Fennel et al. (2011) – Simulation
- Green et al. (2008) – Simulation
- Ko et al. (2008) – Simulation
- Greene et al. (2009) – Statistical
- Wang et al. (2009); Justic et al. (2009) – Simulation
- Eldridge and Roelke (2010) – Simulation
- Forrest et al. (2011) – Statistical

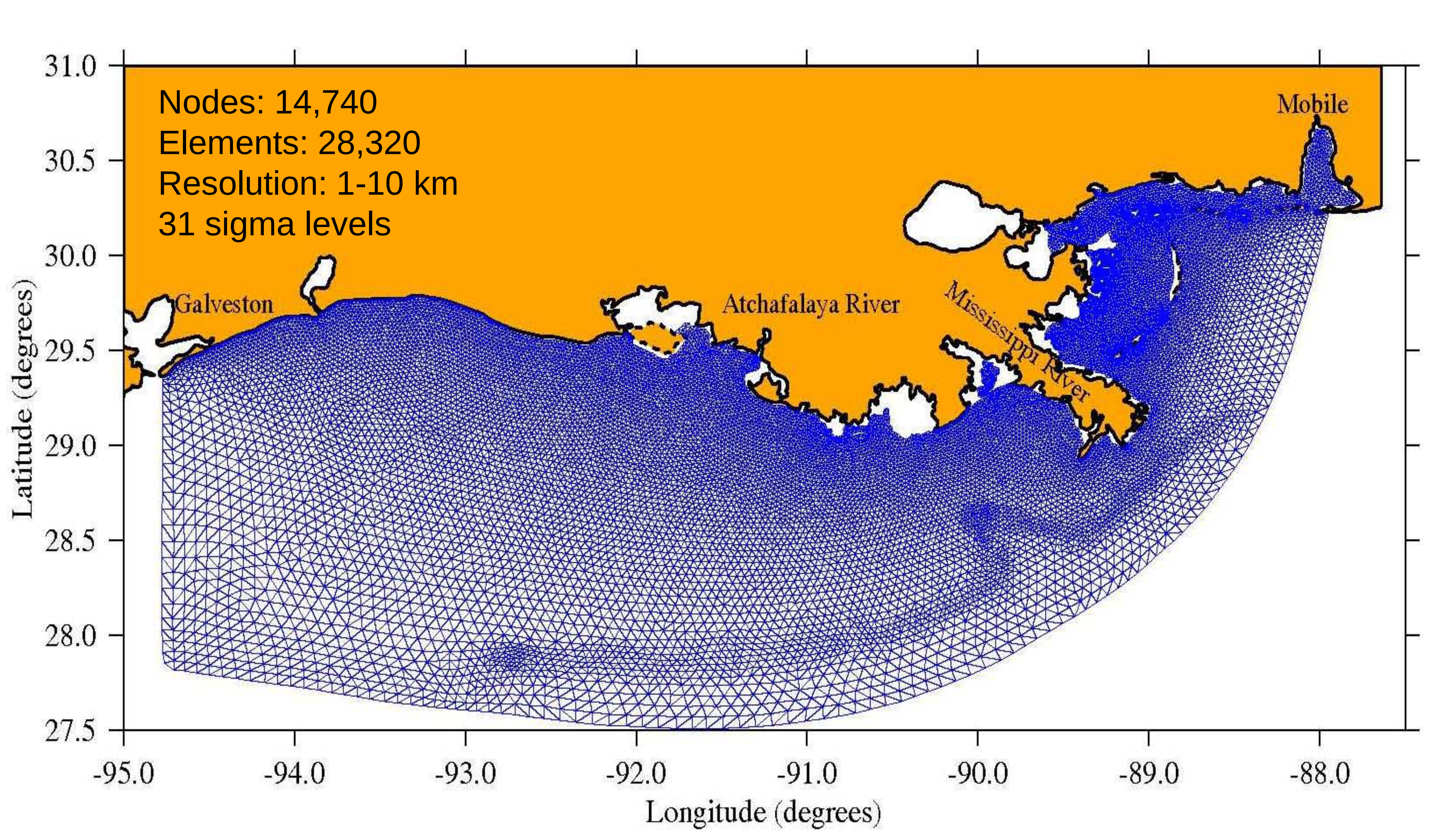
Gulf Hypoxia Models (2012)

3-D coupled hydrodynamic-biological models

- **ROMS/NPZ (TAMU/Dalhousie) - Hetland et al. (2008, 2012); Fennel et al. (2011)**
- **IASNFS/NPZD (EPA/NRL) - Ko et al. (2008); Eldridge and Roelke (2010)**
- **FVCOM/WASP (LSU) - Wang et al. (2009); Justic et al. (2009)**
- **NGOM/FVCOM/ WASP (CSDL) – Xu et al. (in preparation)**

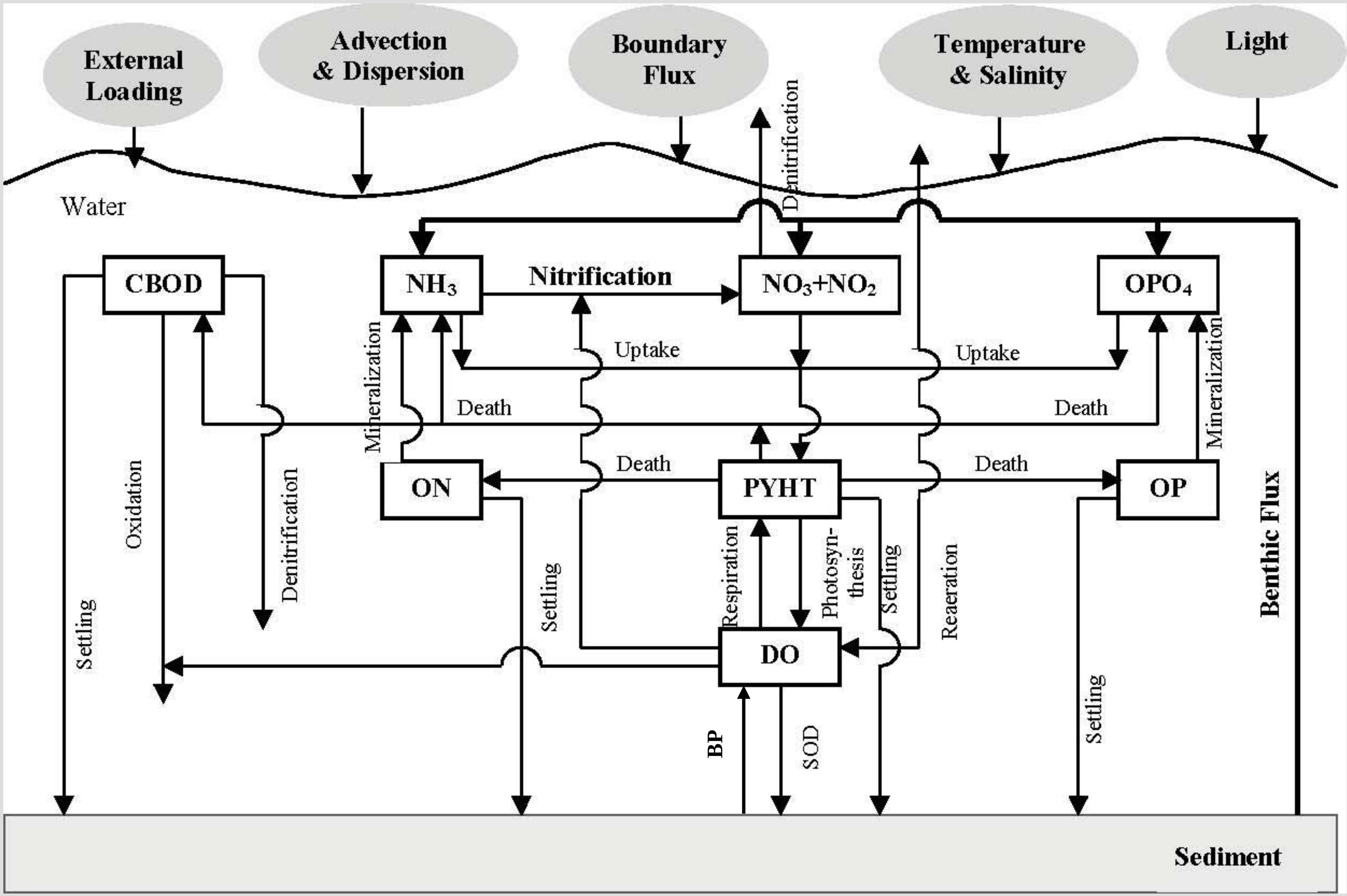
FVCOM-LaTex

Computational Domain and Grid



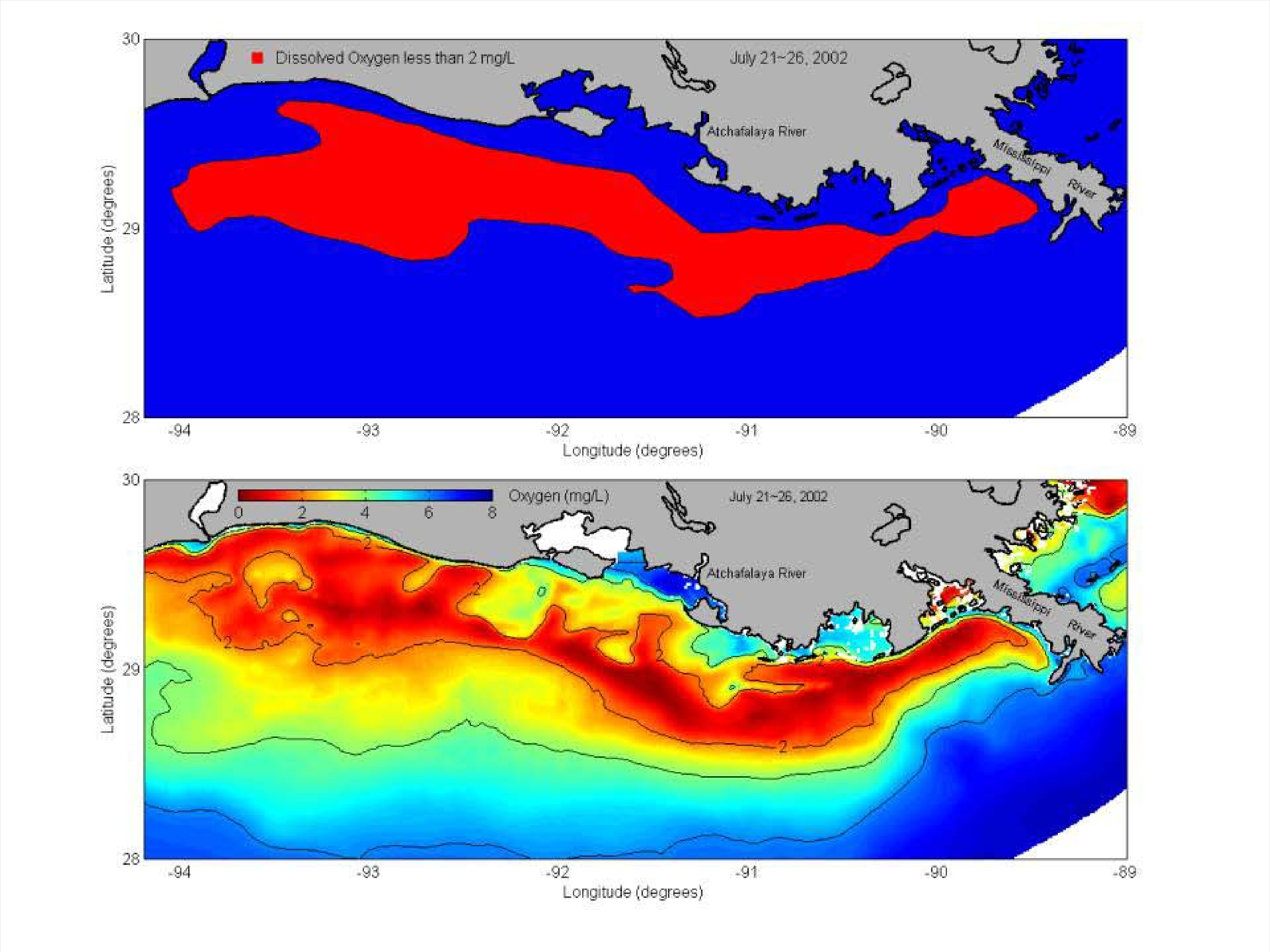
Wang and Justic (2009); Justic and Wang (2009)

WASP



Justic and Wang (in preparation)

Coupled FVCOM-WASP



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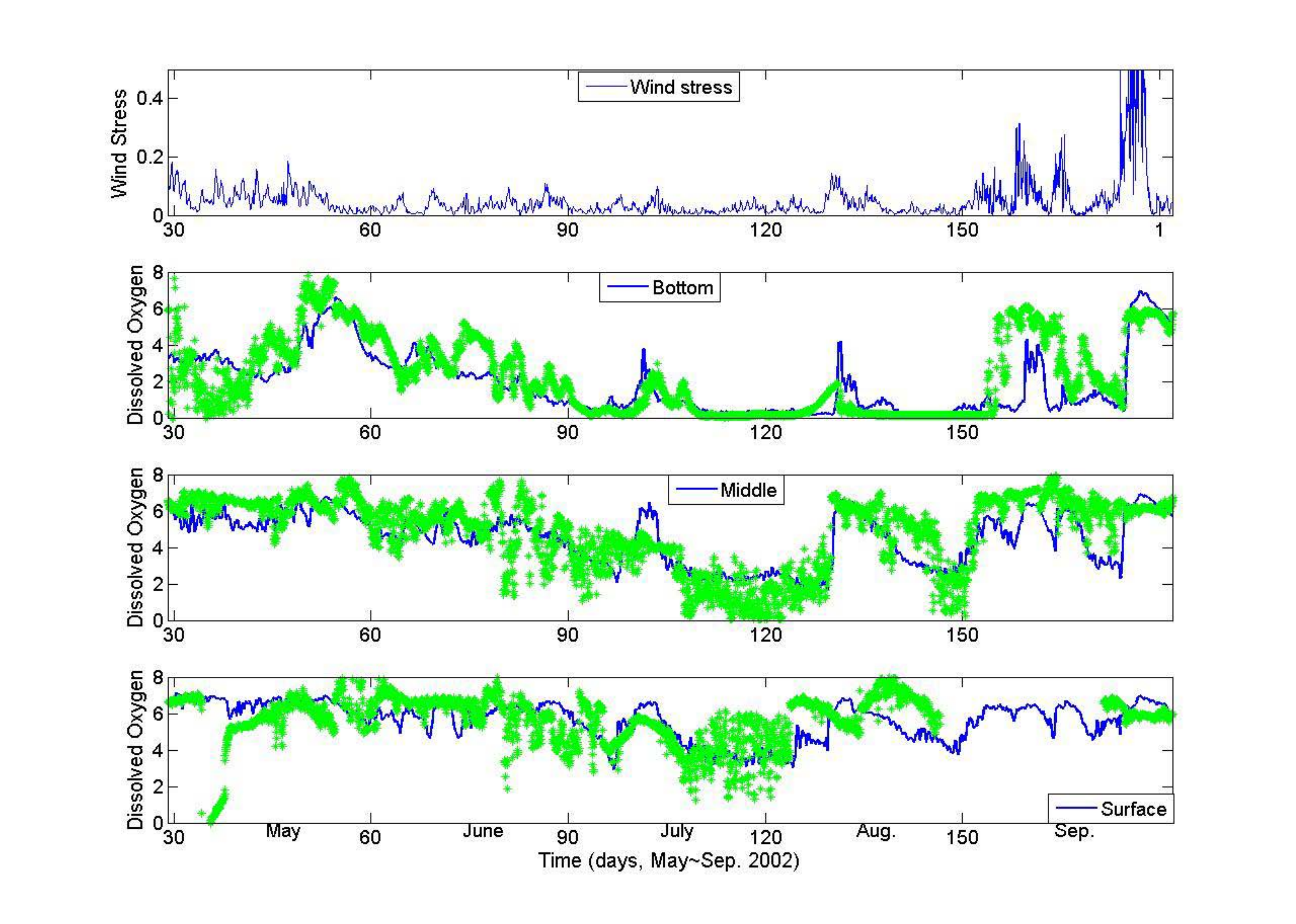

Justic and Wang (in preparation)

N versus P limitation

- Model generated 3-D nutrient limitation patterns
- < 25 psu; N, P or Light
- > 25 psu; mostly N
- Caveat - “Stoichiometric” versus “Probable” limitation (Dortch and Whitledge, 1992; Justic et al. 1995)

Challenges

<u>New Paradigms</u>

- “Wetland Hypothesis”
- “Benthic Photosynthesis”
- “Benthic Versus Water Column Respiration”
- “Missing Carbon”
- “River Diversions”

Challenges

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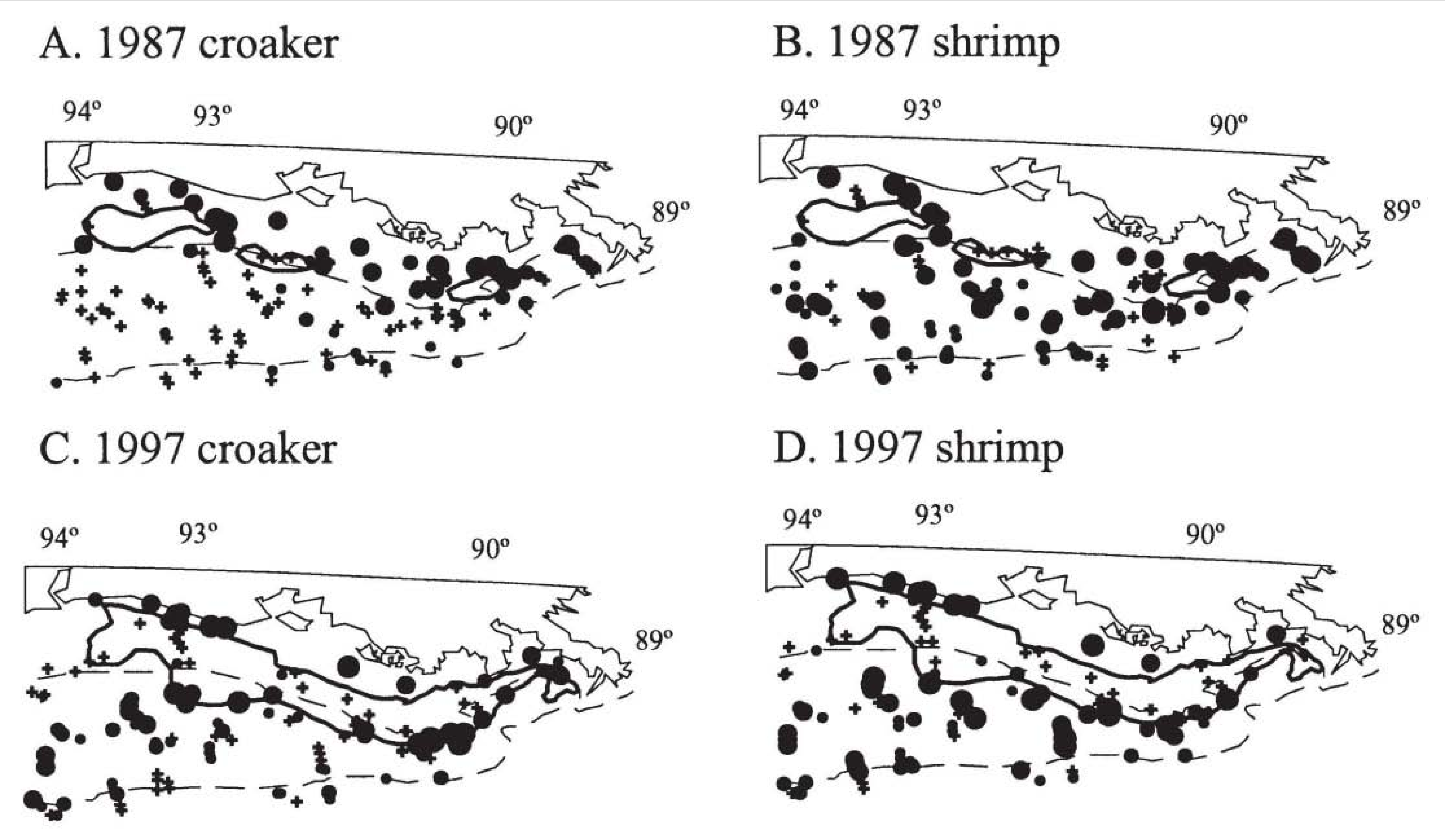
<u>“Next Generation” Hypoxia Models</u>

- Impact of hypoxia on living resources

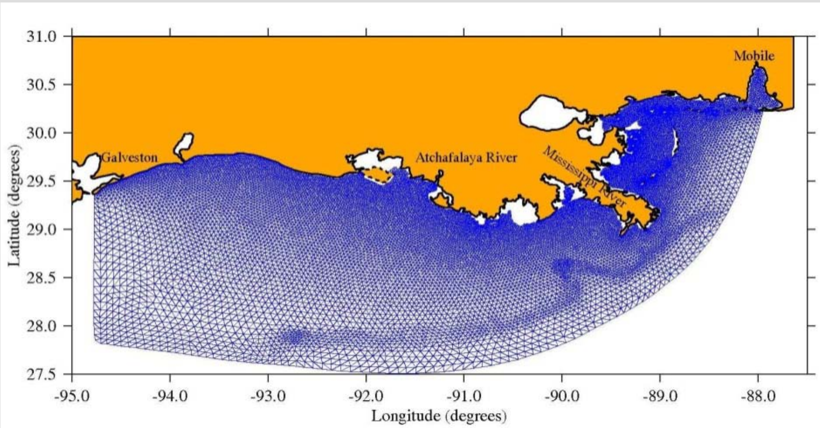
Population Displacements



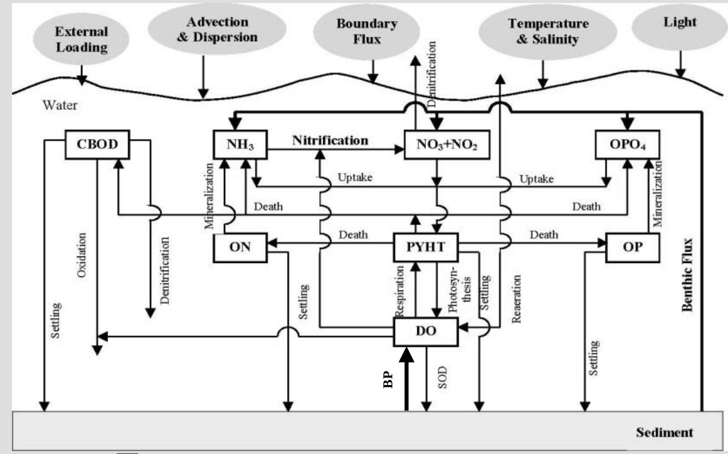
(Craig and Crowder, 2005)

“Next Generation” Hypoxia Models

FVCOM-LaTex



WASP



IBM

Individual Processes

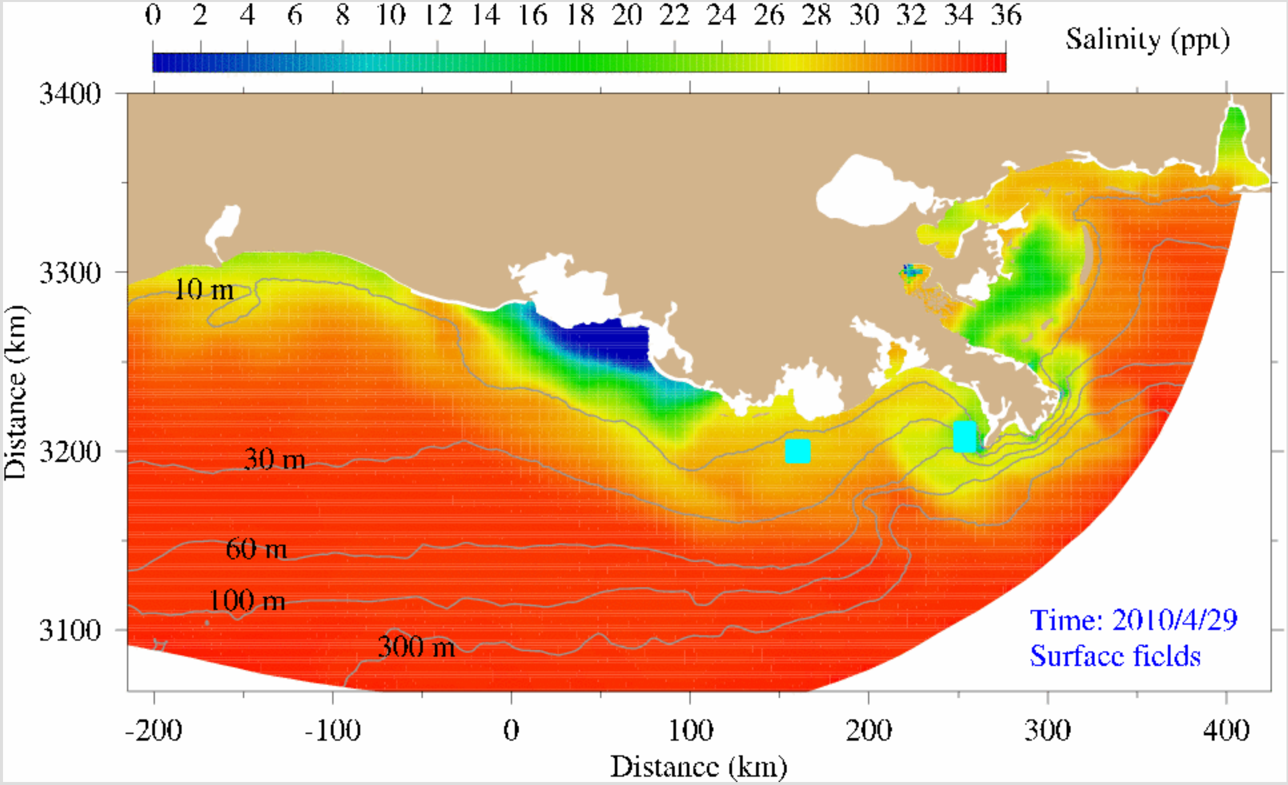
Movement
Growth
Mortality
Spawning

Conditions

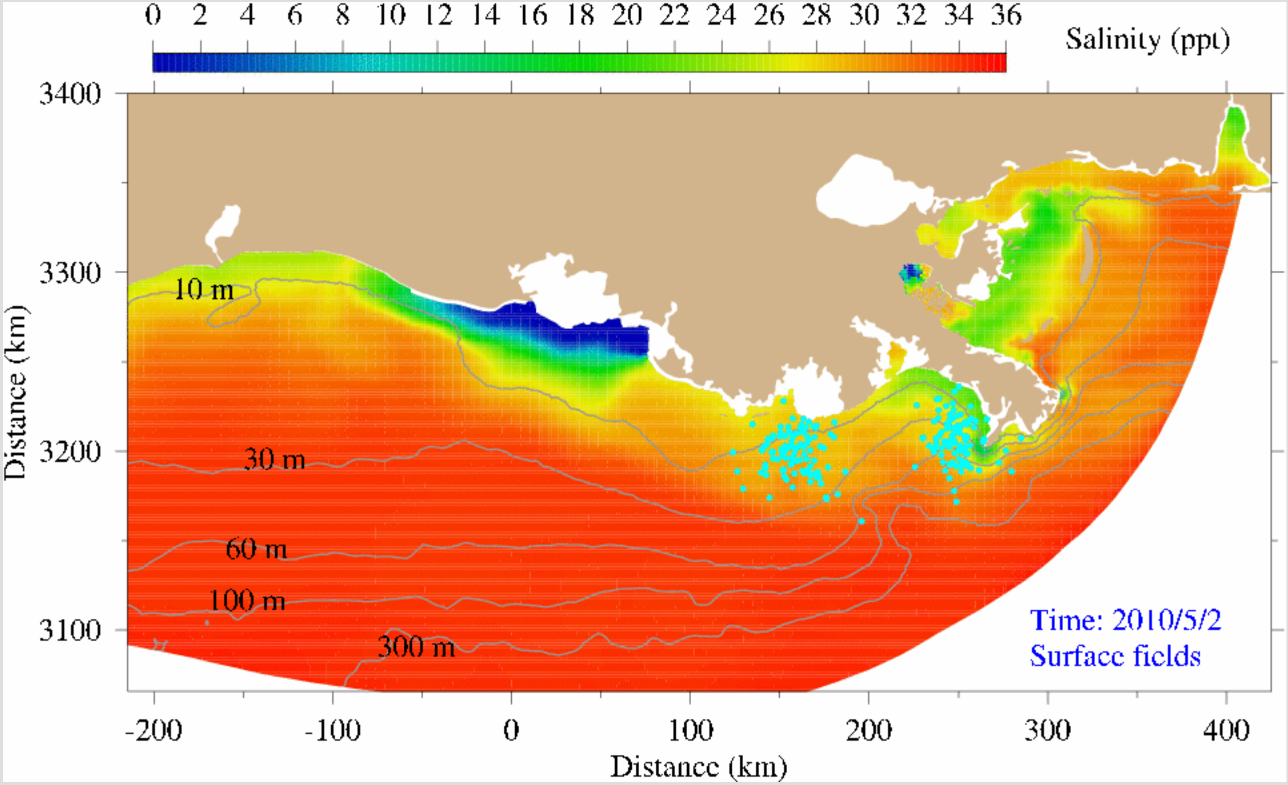
Dissolved O_2
Temperature
Salinity
Food density
Predator Density
Individual Size

Justic et al. (in preparation); Rose et al. (in preparation)

Kinesis; S_{Opt} = 27 psu; simulation interval = 60 days



Justic et al. (in preparation)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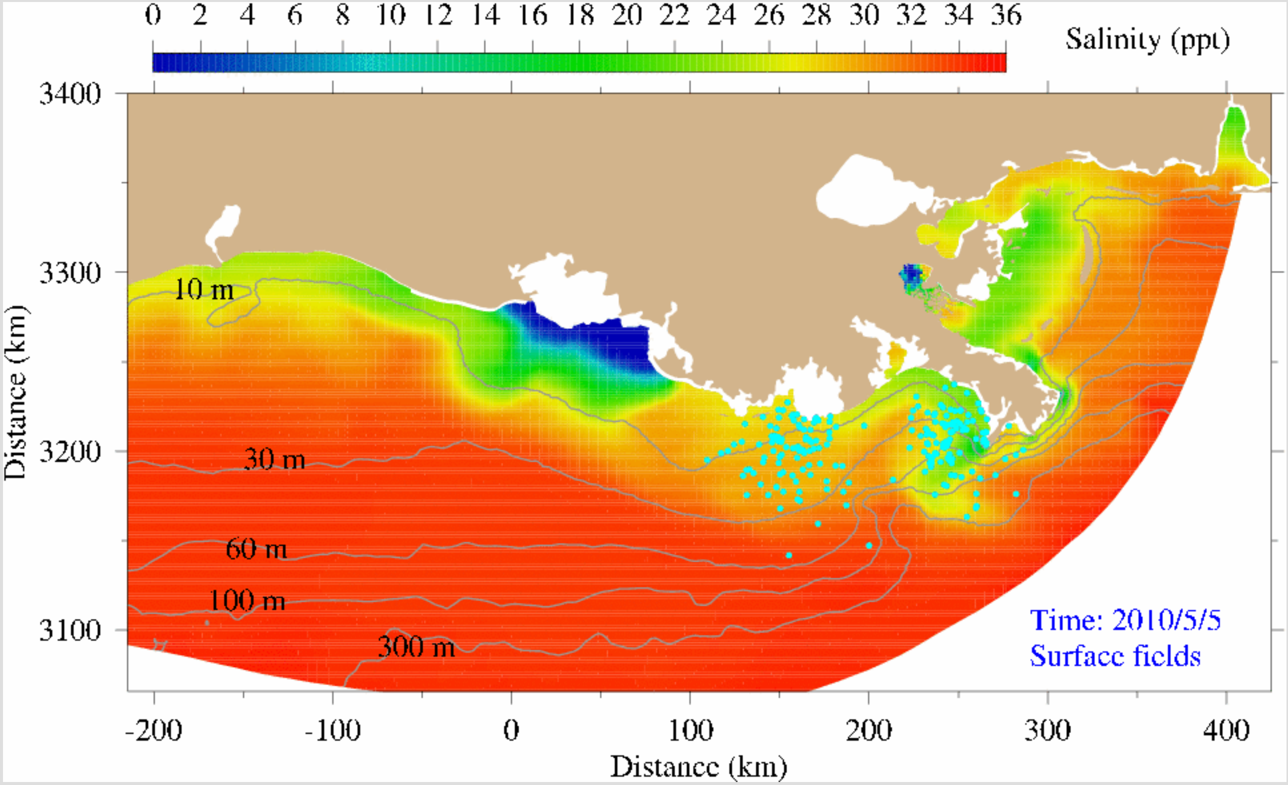

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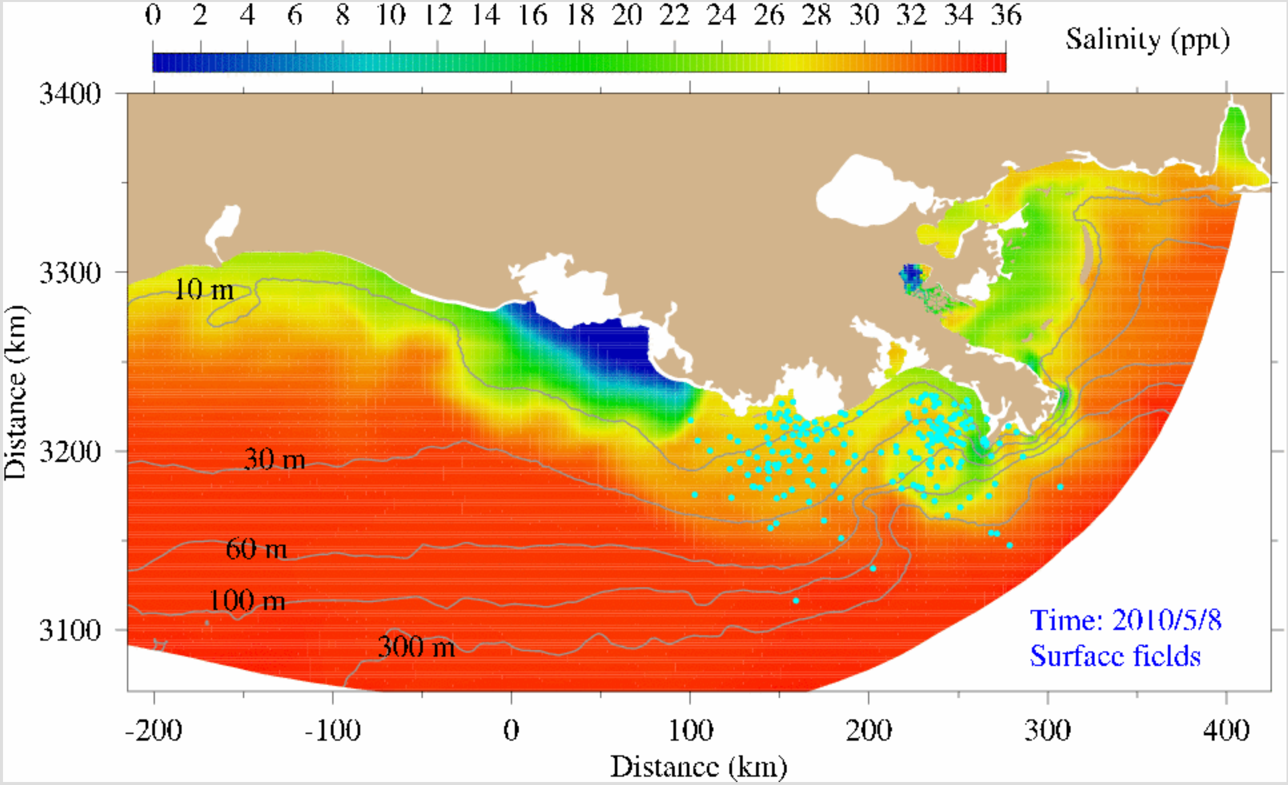

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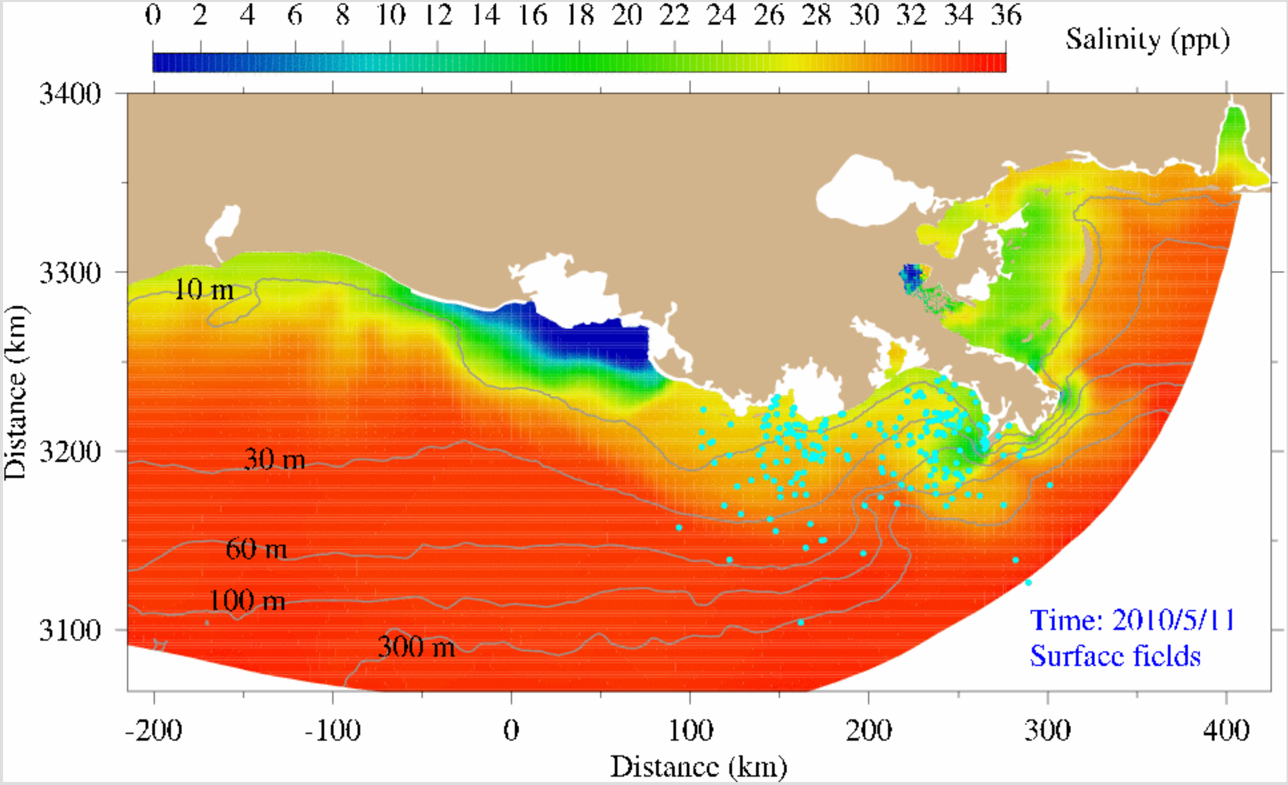

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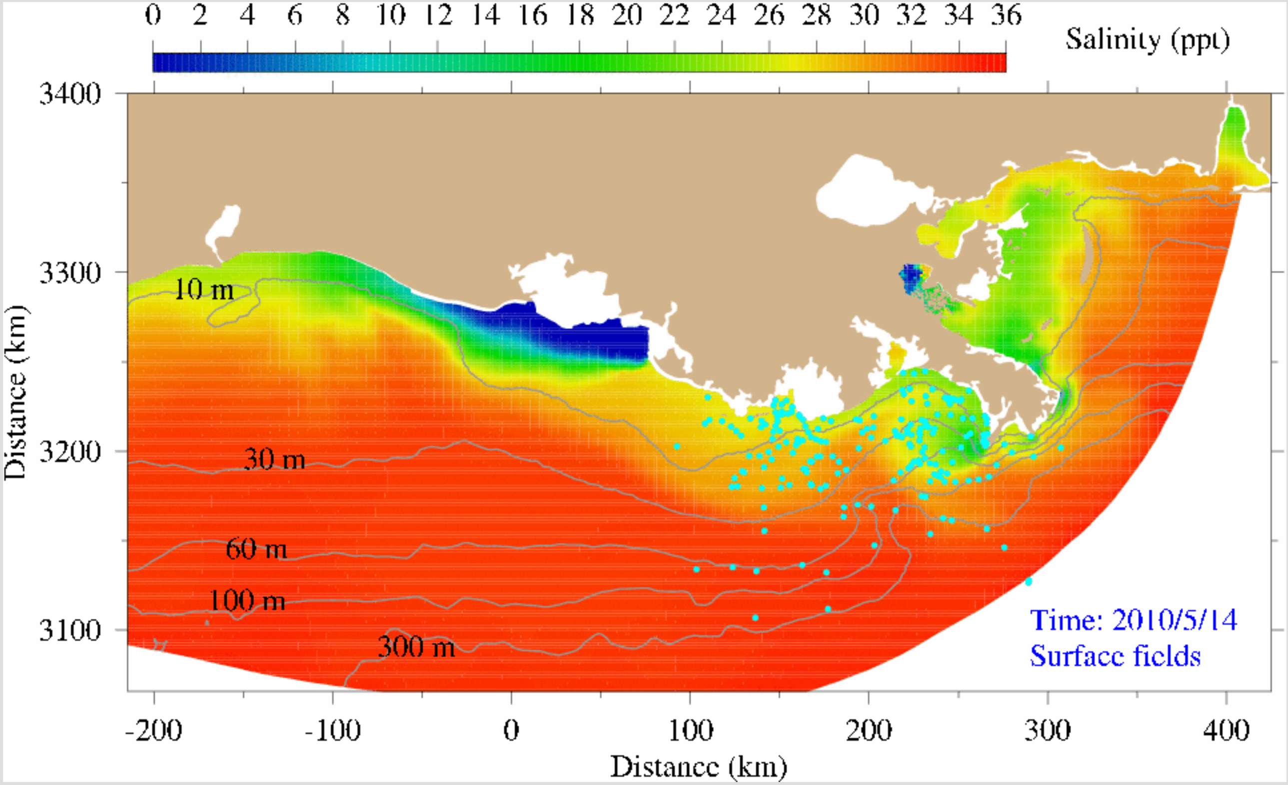

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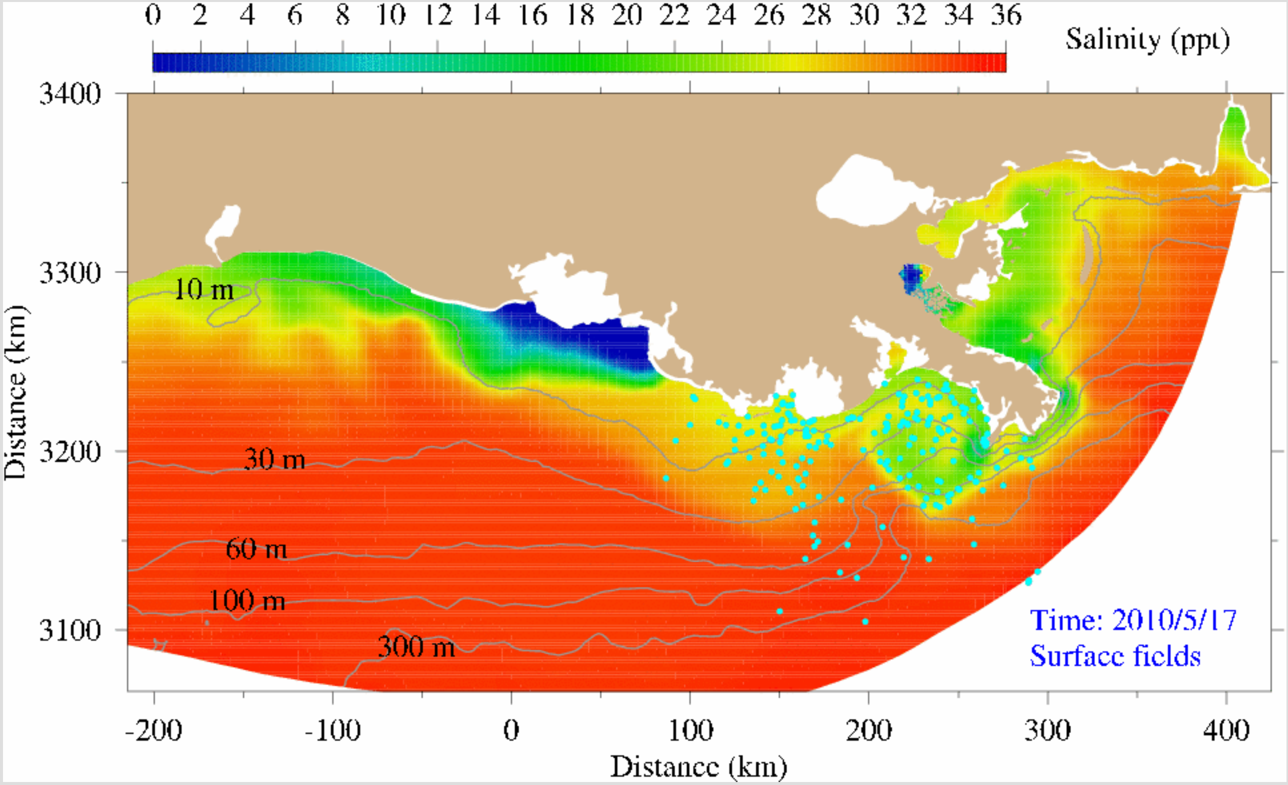

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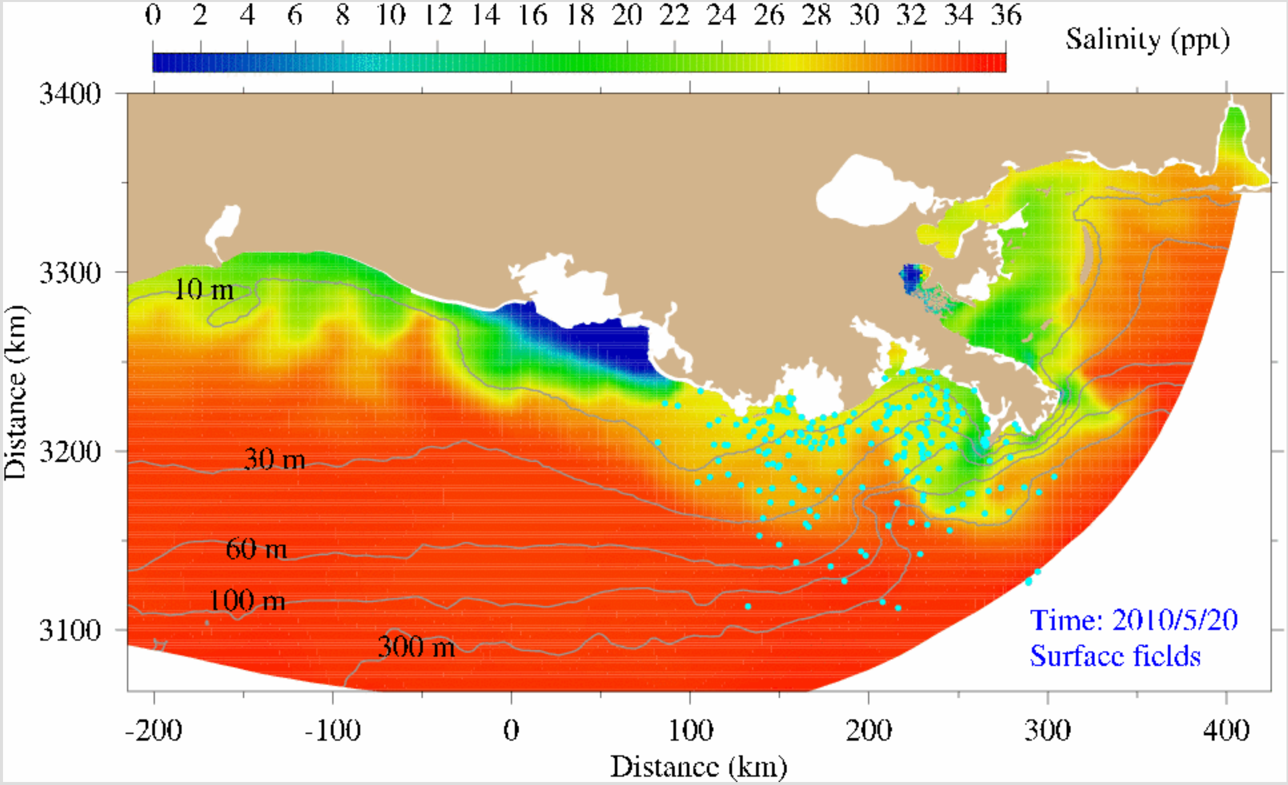
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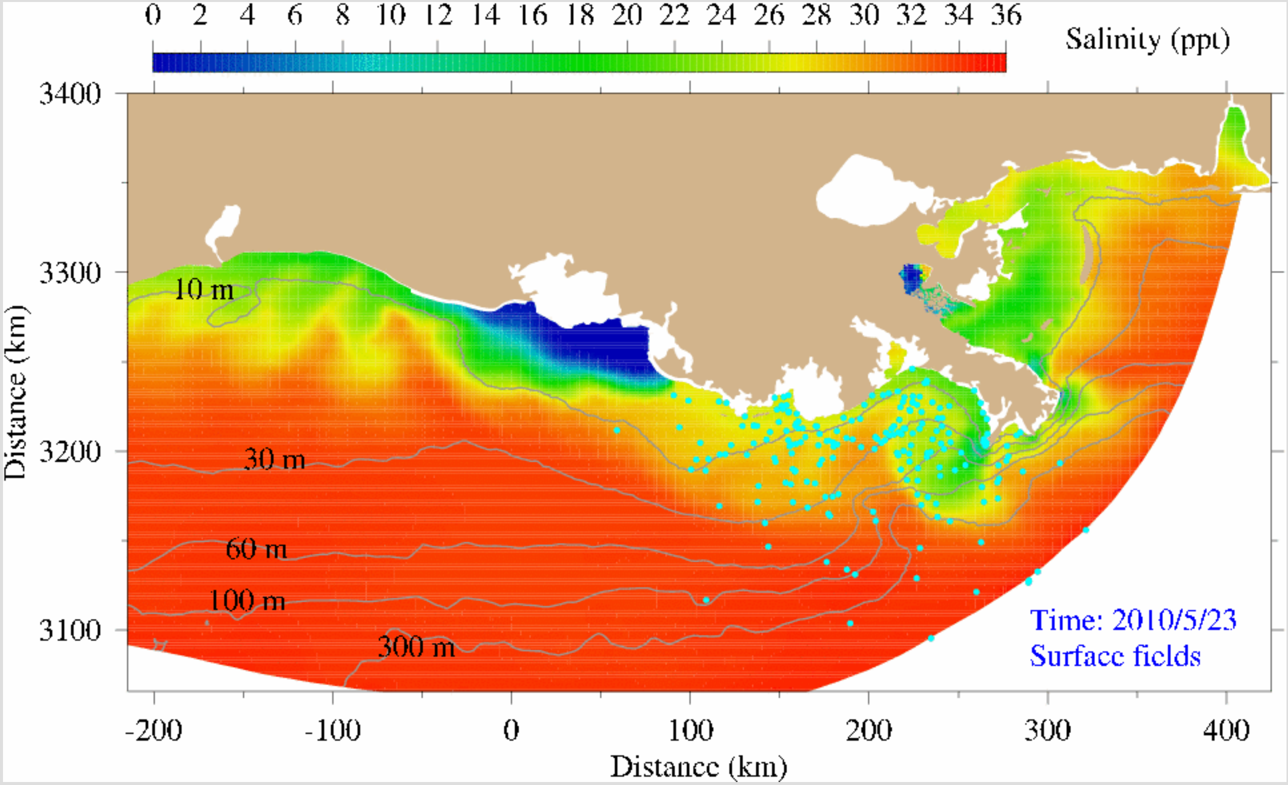

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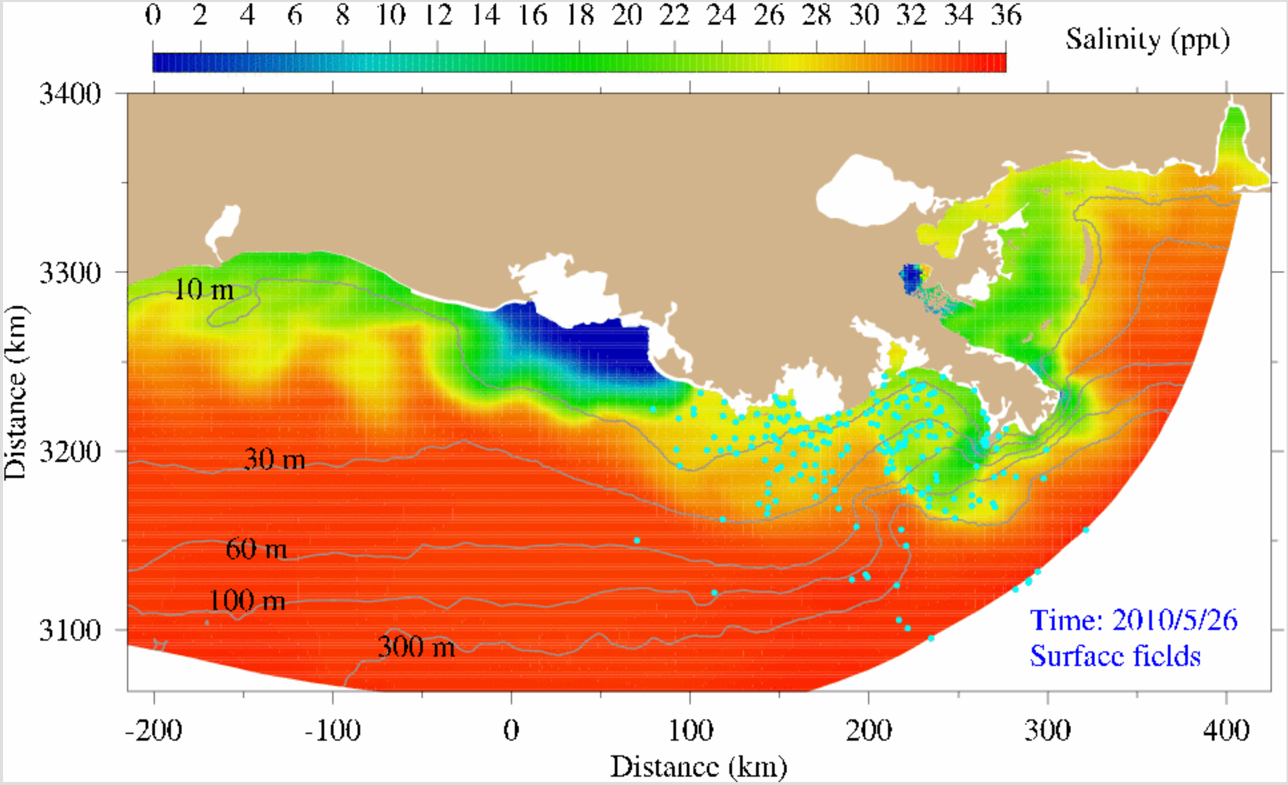

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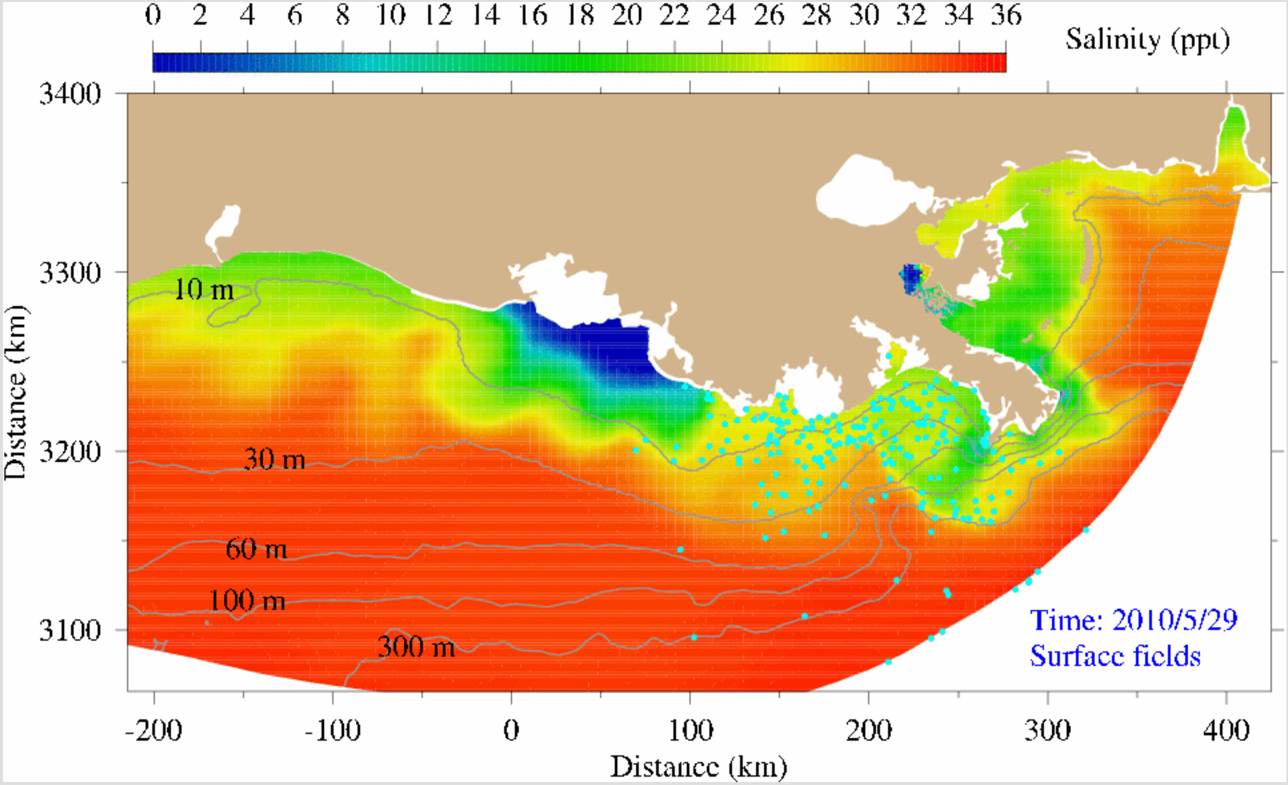

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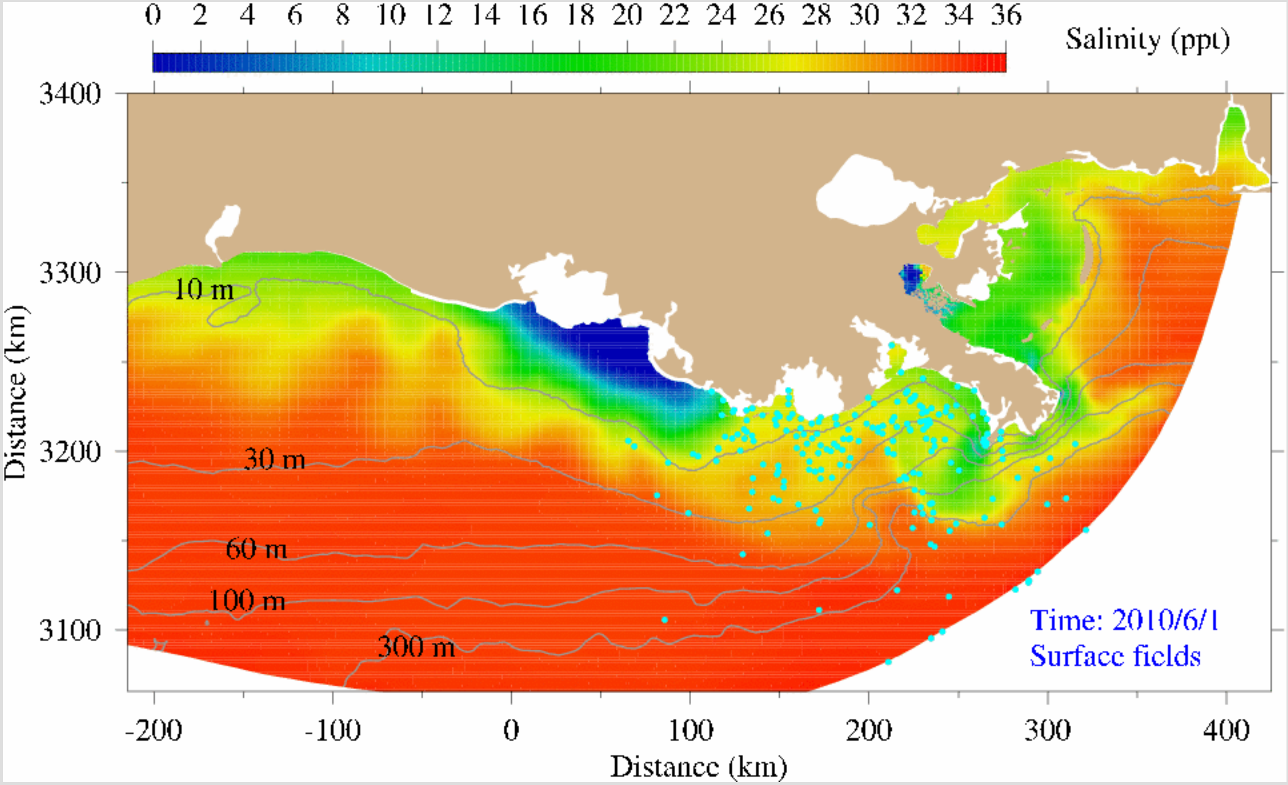

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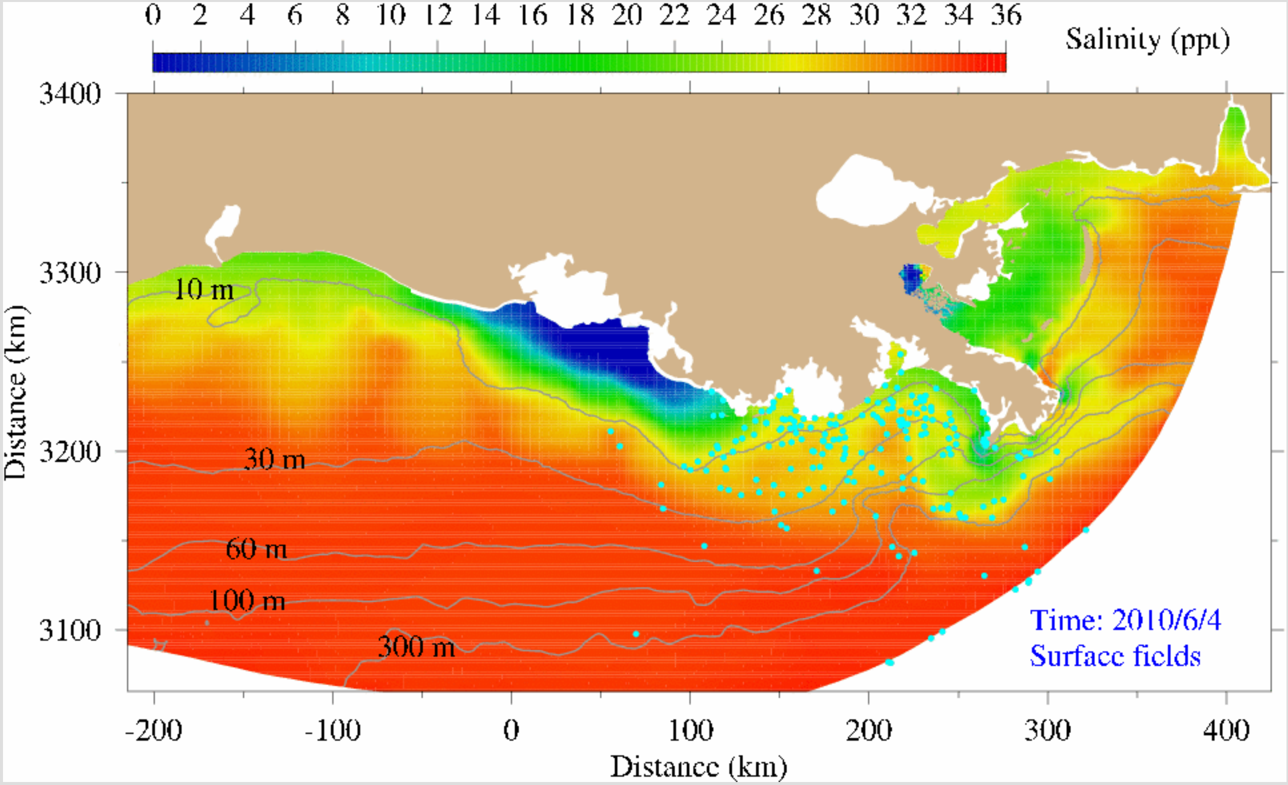

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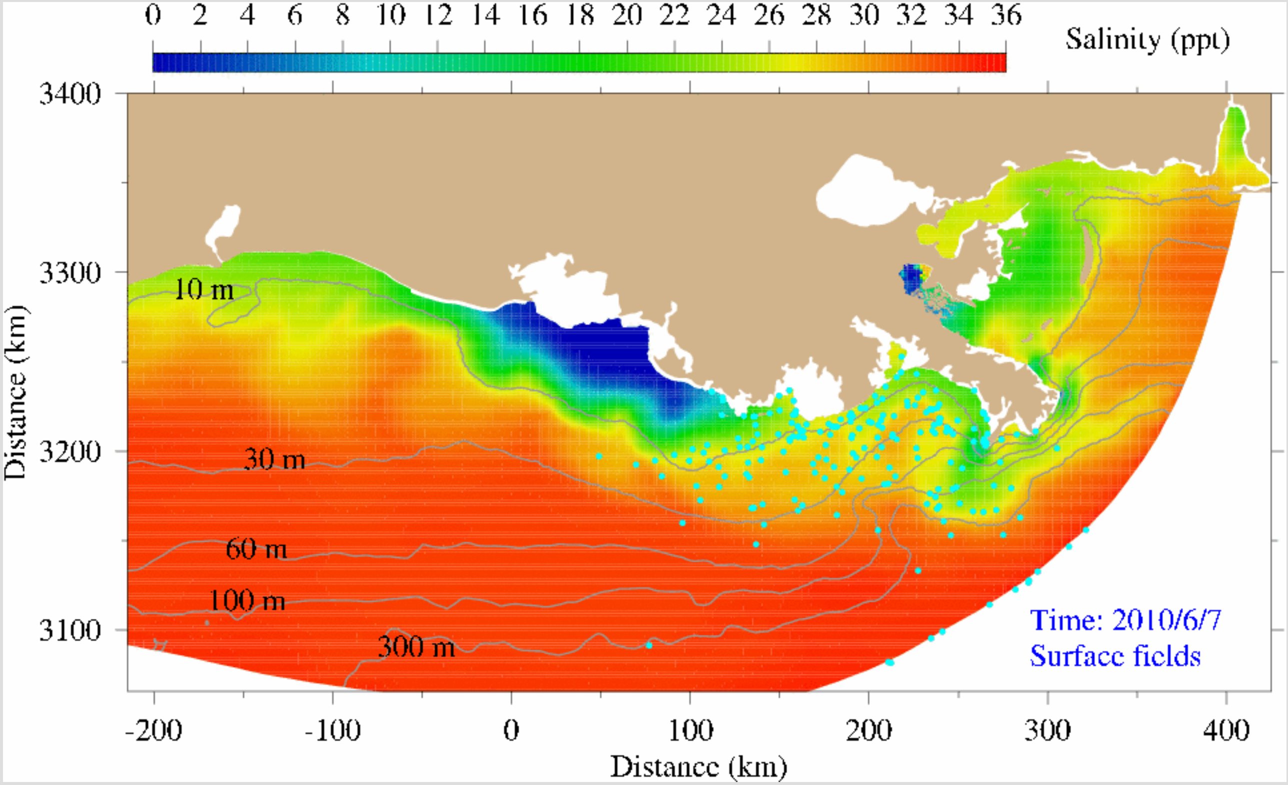

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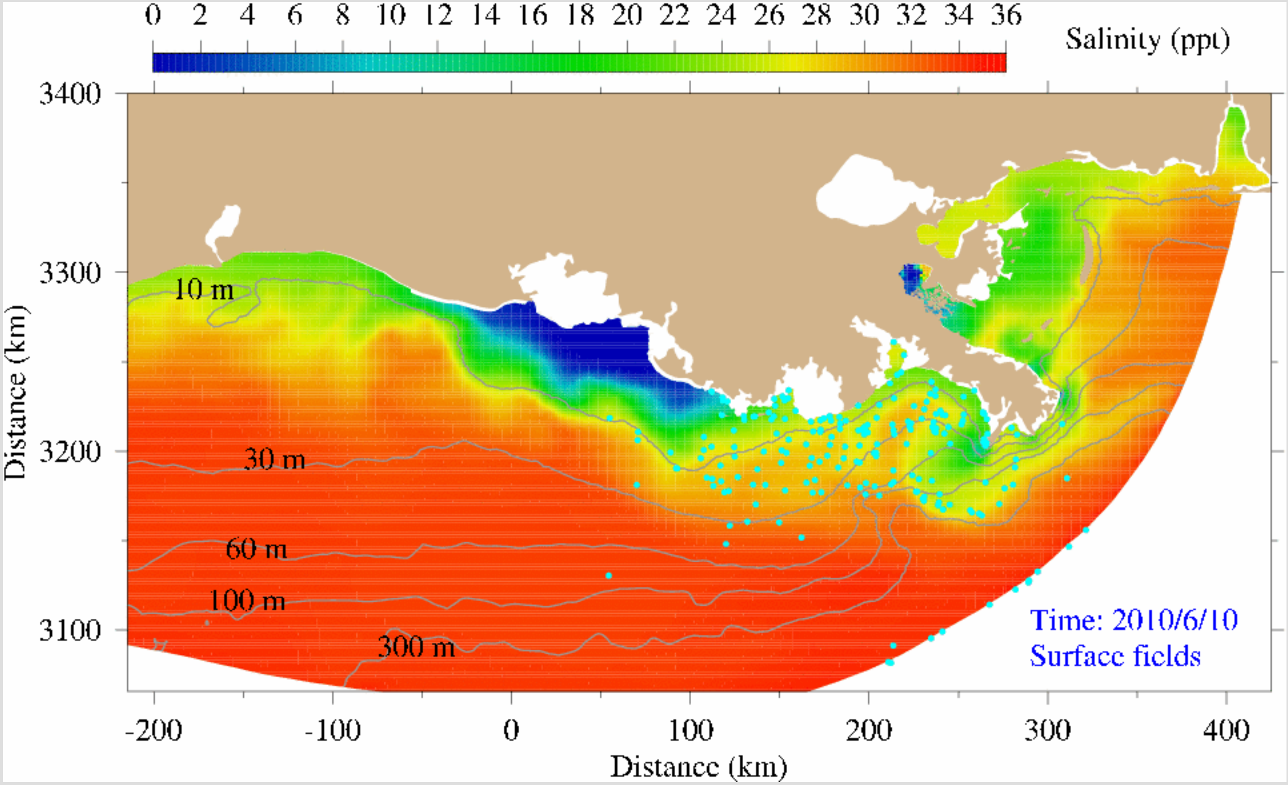

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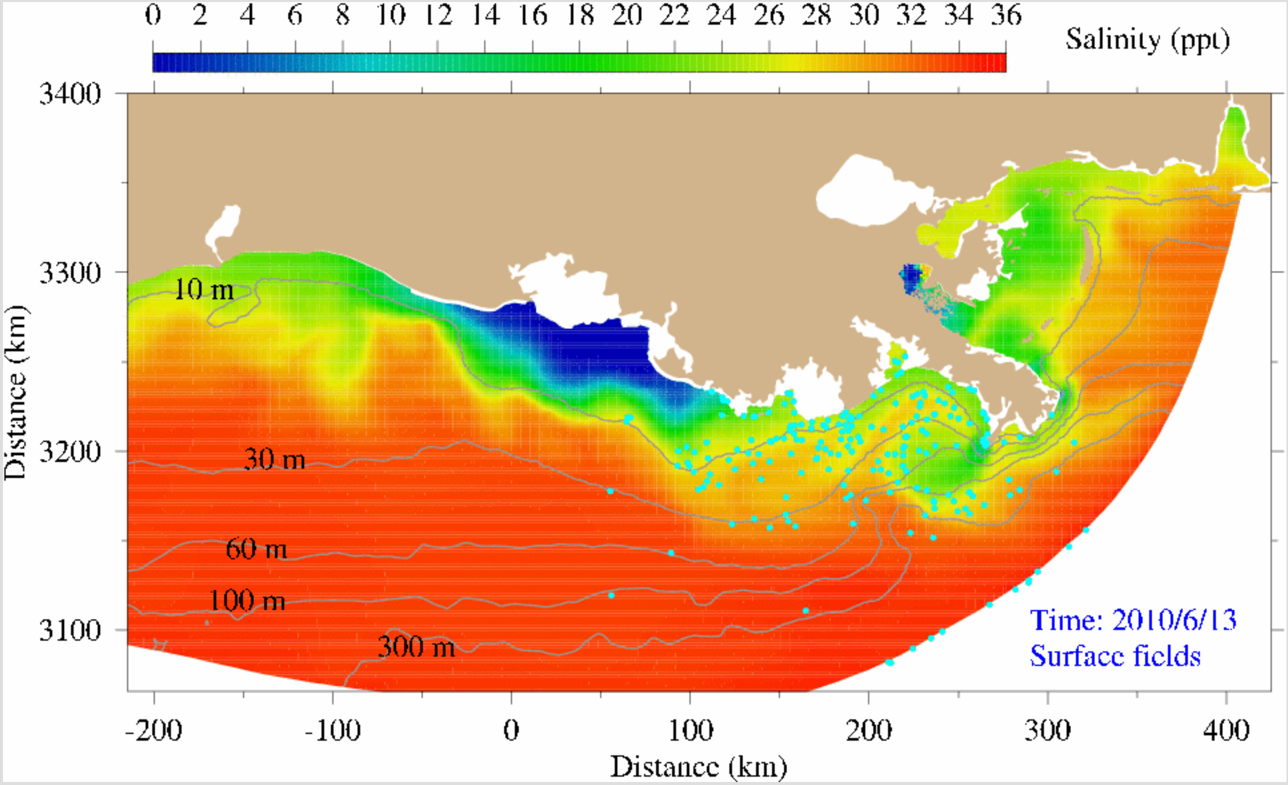
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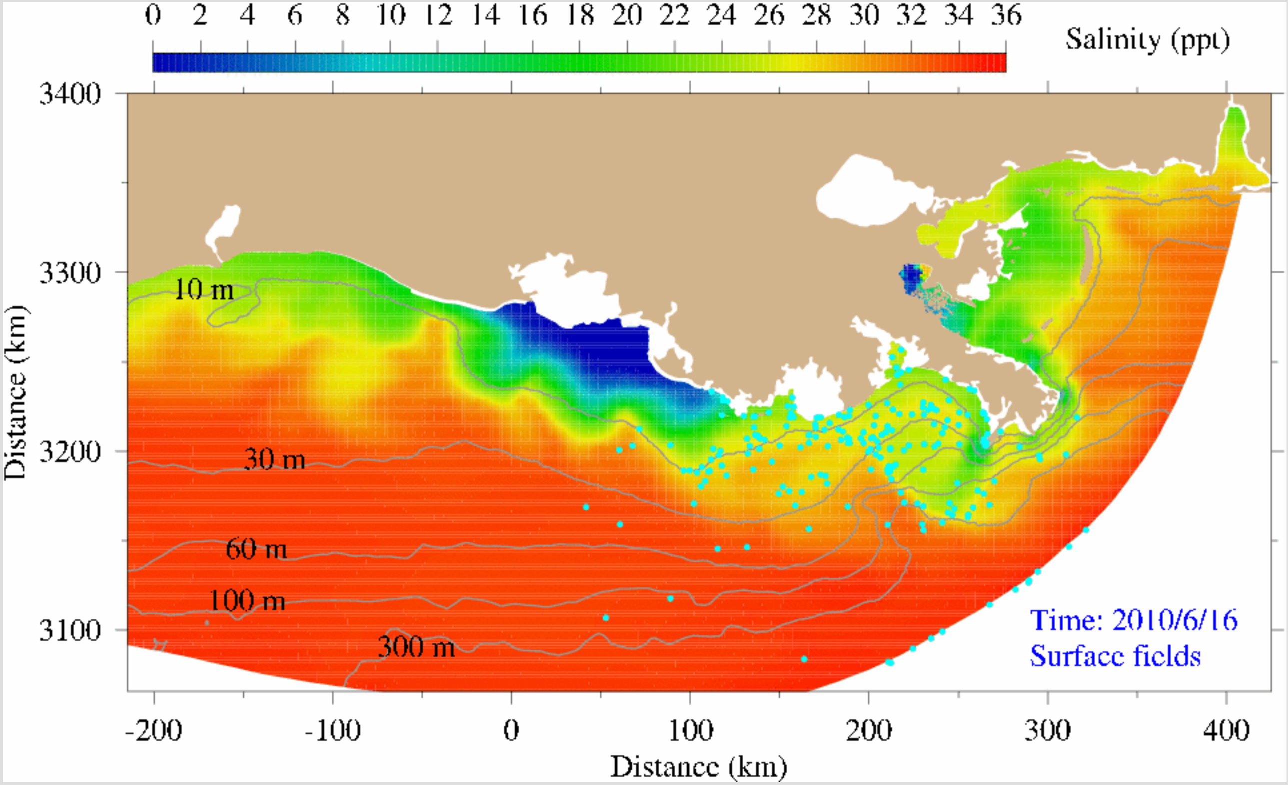

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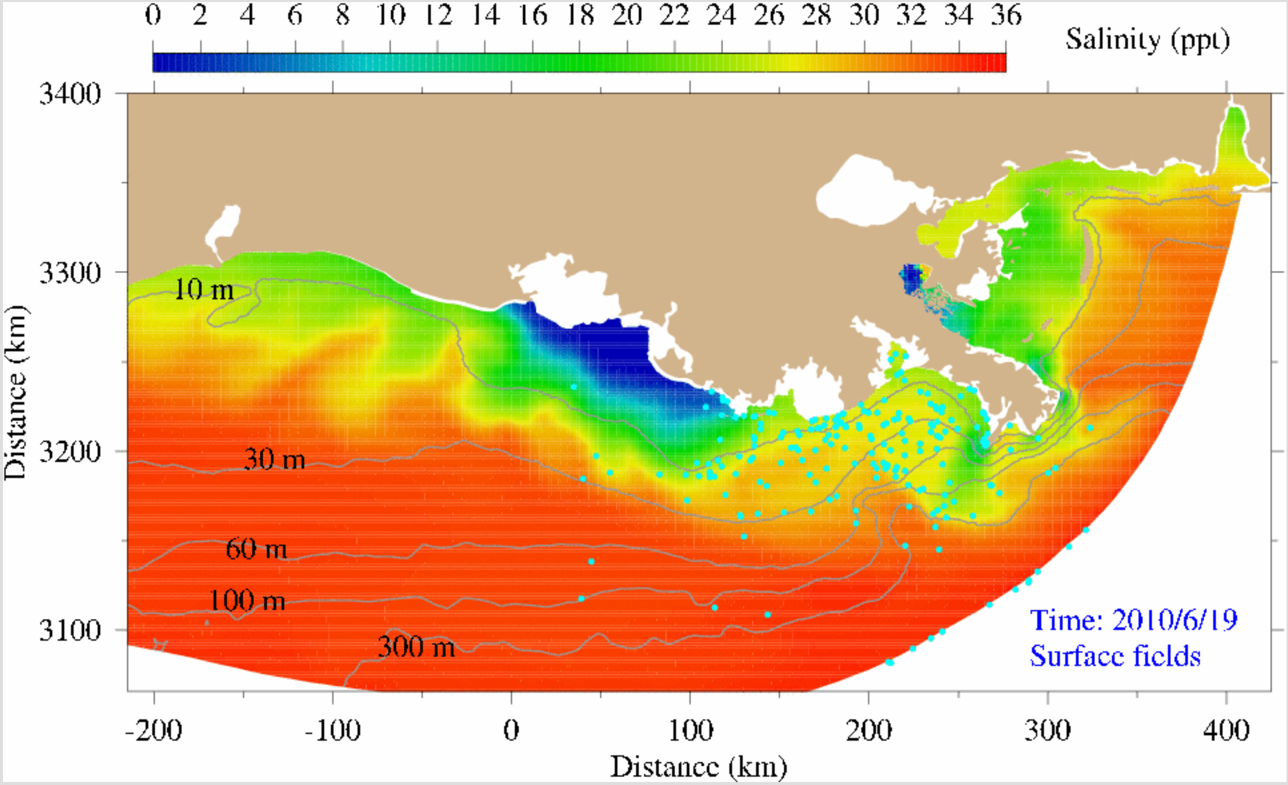
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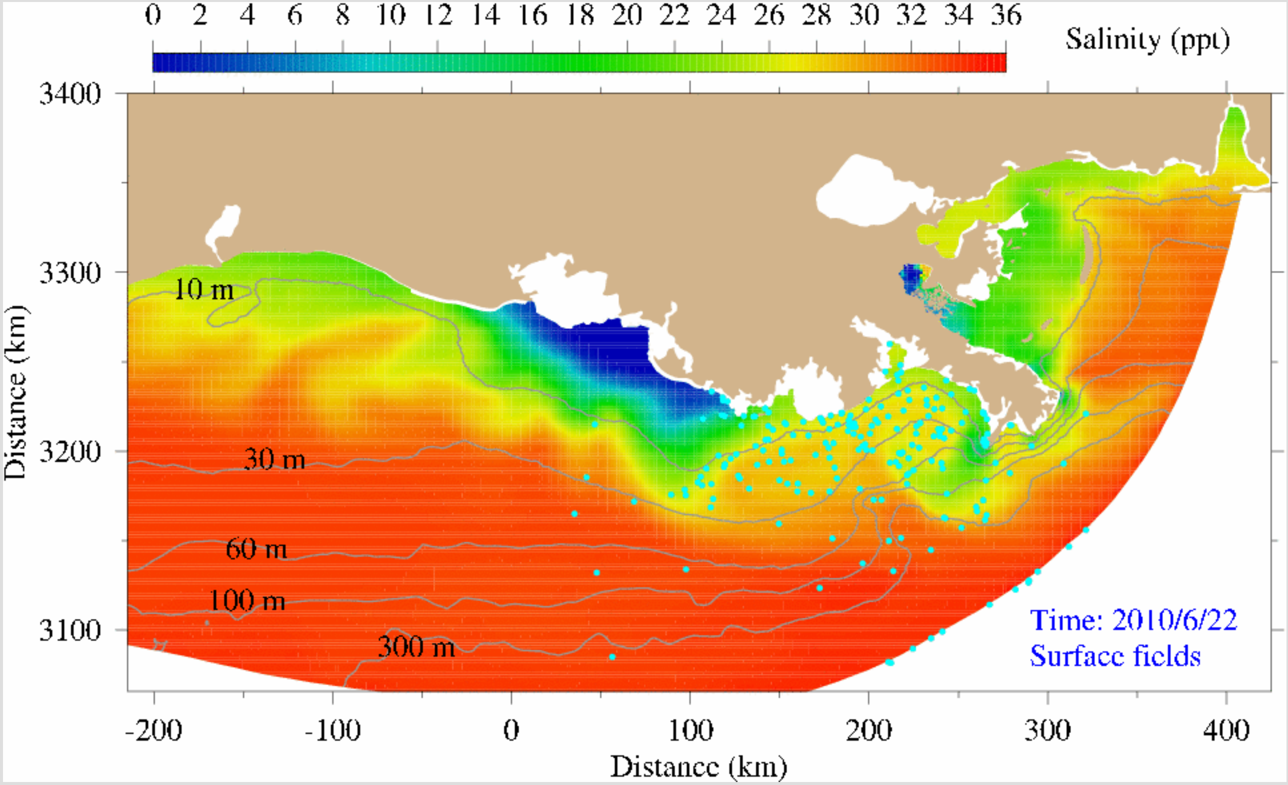

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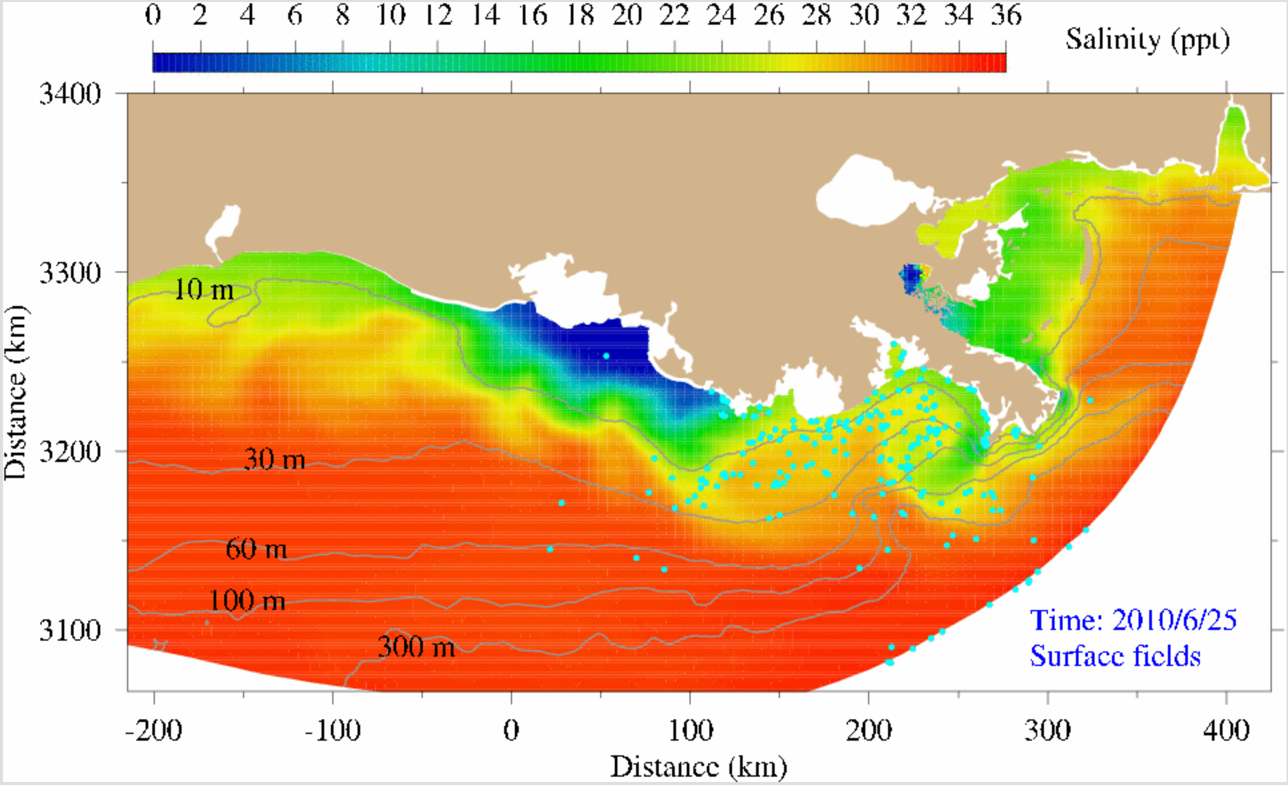

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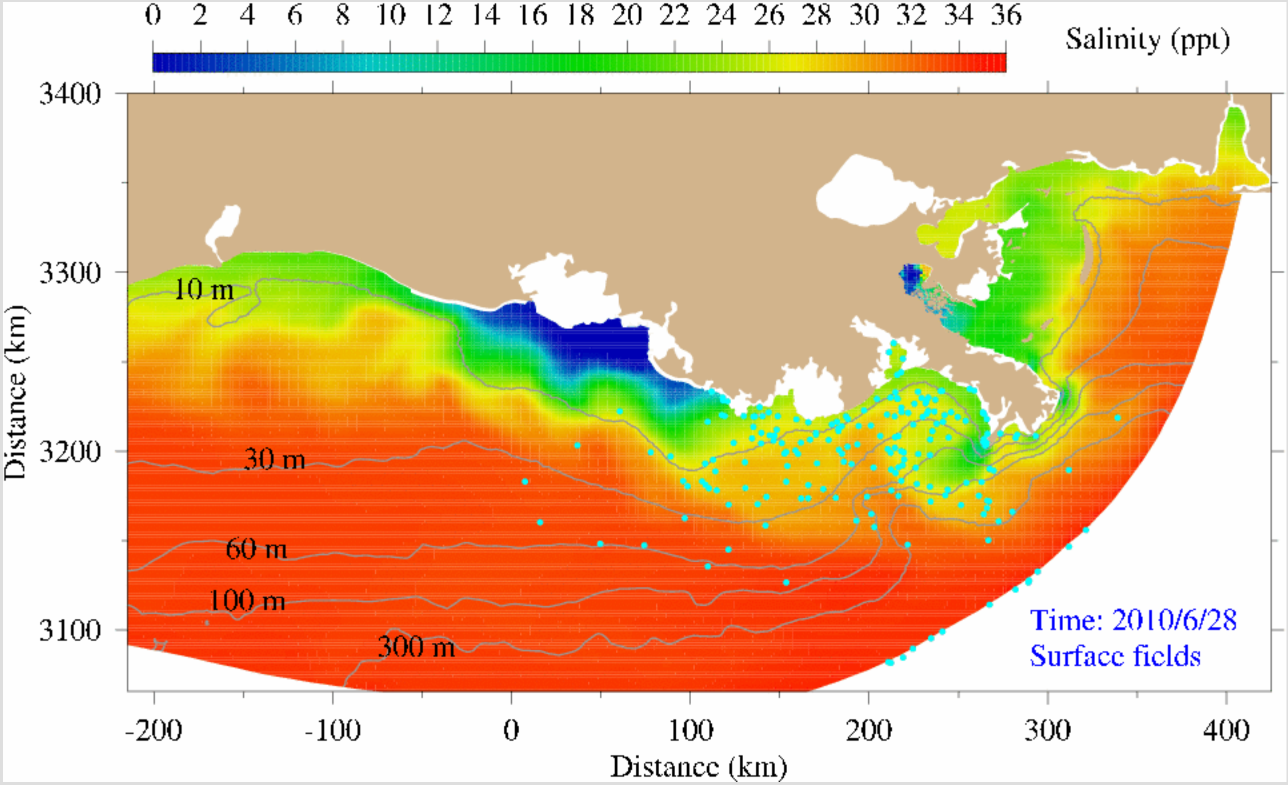

Justic et al. (in preparation)

Acknowledgements:

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G. Müller-Niklas, 1997.