# Development of a Rapid Response Prediction System for the Northern Persian Gulf

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# Acknowledgements

NRL Finite Element Modeling Team

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Ocean Optics at NRL, Code 7333

Mr. Bob Arnone

Mr. Sherwin Ladner

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# Outline

Motivation

Criteria for Success

Application to the N. Persian Gulf

- Description of the system
- Fine-scale circulation features
- Linking to remotely sensed optical properties

Upcoming Improvements

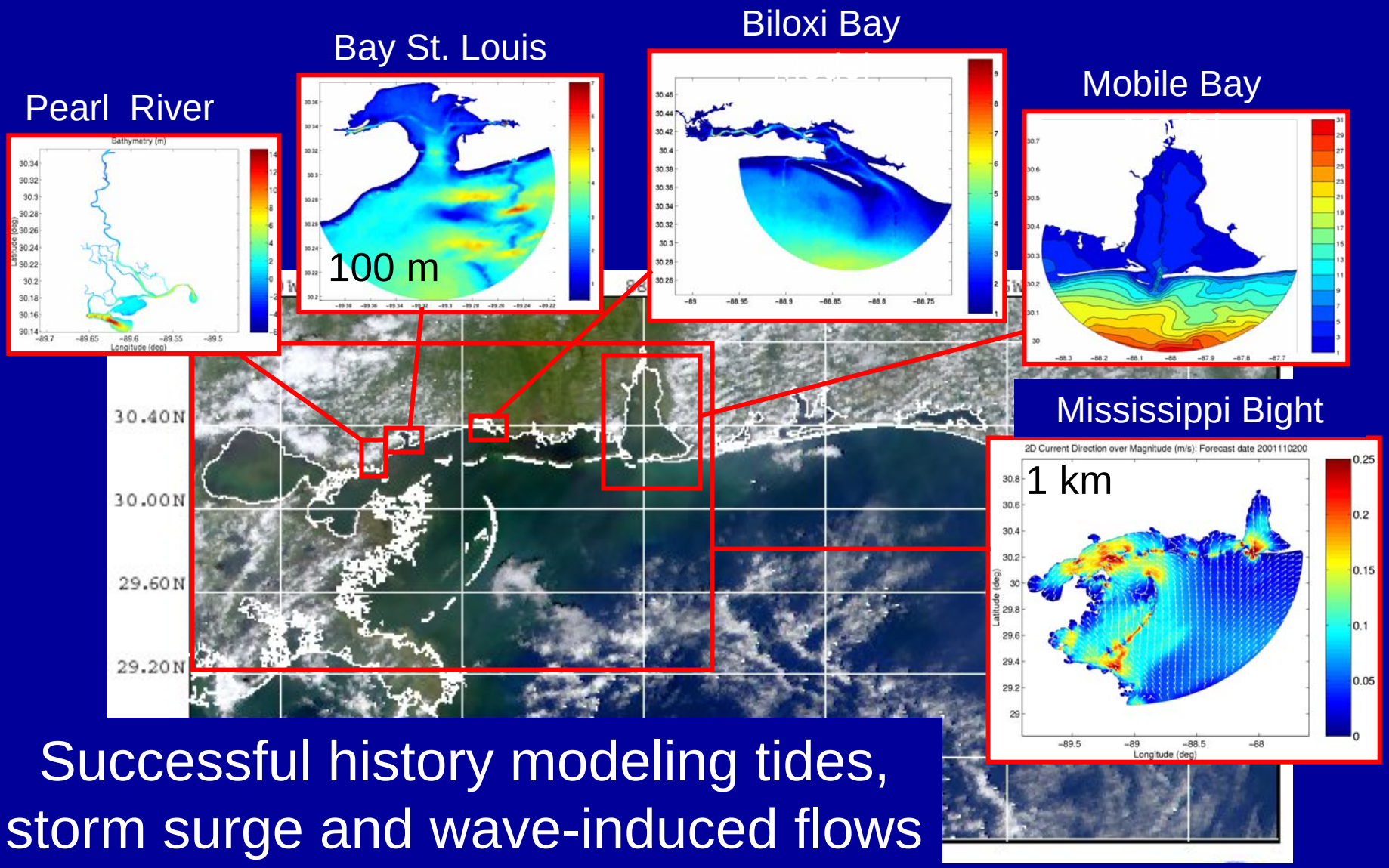
# Motivation for a Prediction System

- Economic advantages over observational networks
- Higher spatial and temporal resolution
- A virtual laboratory for understanding and planning
- Feasible for denied areas

# Criteria for Success

- Accurate and flexible dynamical model
- Ability to meet operational time constraints
- Automated, rapid relocation
- Generation of meaningful operational products
- Quantification of forecast skill

# The Dynamical Model: ADCIRC




Successful history modeling tides, storm surge and wave-induced flows

# The Dynamical Model: ADCIRC

- 2D/3D shallow water hydrodynamics
- Coastal processes associated with tides, wind, waves, rivers
- Shoreline inundation/recession
- Finite element-based discretization

# ADCIRC: Advanced CIRCulation Model for Shelves, Coasts and Estuaries

Originally developed by Luettich (UNC), Westerink (UND), USACE
Recent development partners include NRL, U. Oklahoma, U. Texas

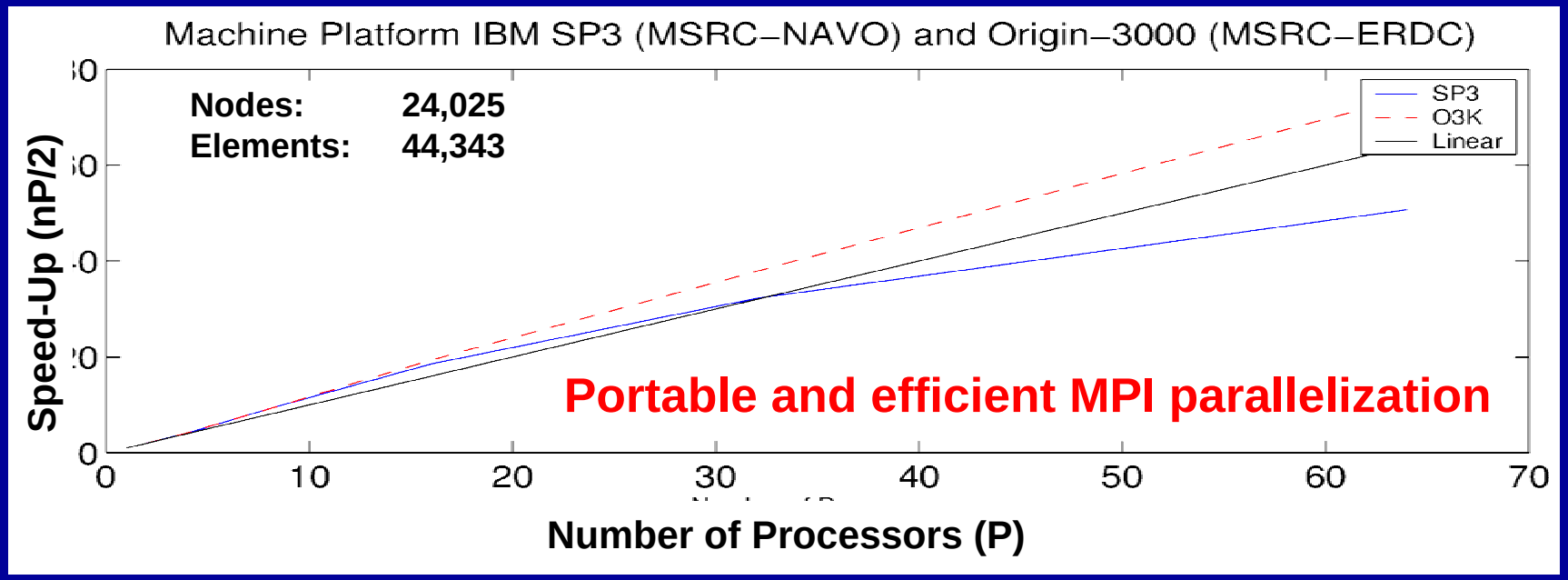
## Dynamics

- Generalized Wave Continuity equation (GWCE)
- 2D or 3D momentum equations
- Forcing from tides, tidal potential, wind, waves, and river flux
- Shoreline inundation/recession
- Vertical mixing: constant, linear, nonlinear, Mellor-Yamada 2.5
- Eddy viscosity horizontal mixing
- Full suite of BCS: barriers, radiation, discharge, elevation specified

## Numerical

- Continuous Galerkin linear finite elements in space
- Generalized sigma vertical coordinate
  - non-uniform spacing, not applied to the horizontal pressure gradient terms
- Split mode solution
  - Solve GWCE for elevation, then momentum equation for velocities
- Time discretization (3-level for GWCE, 2-level for momentum)
- F90, MPI implementation

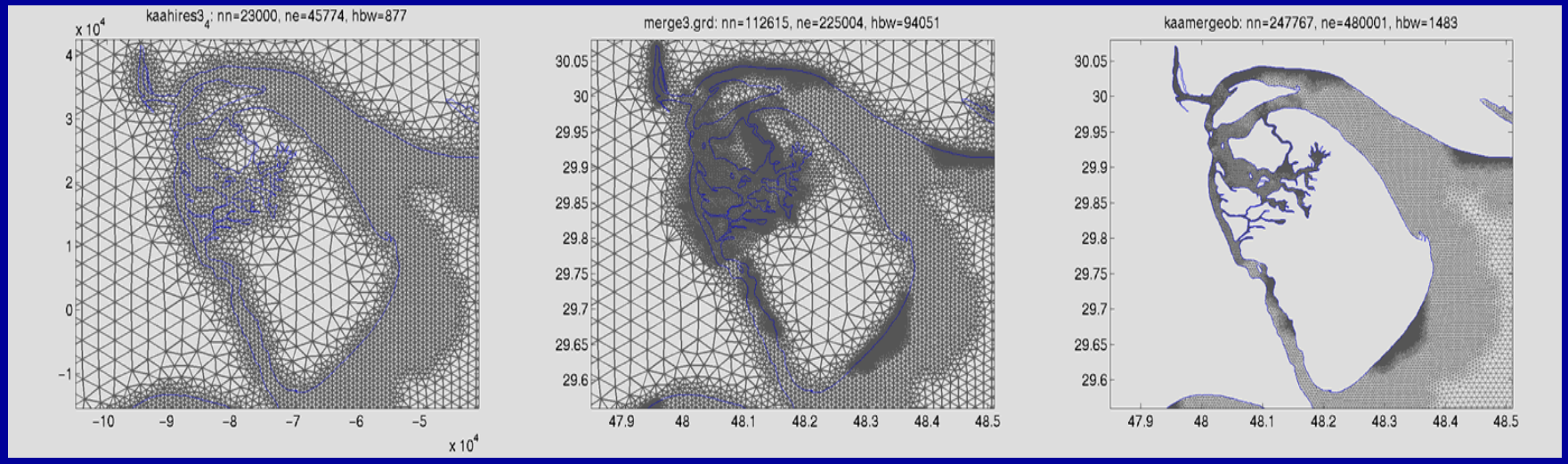
# Efficient Operational Execution



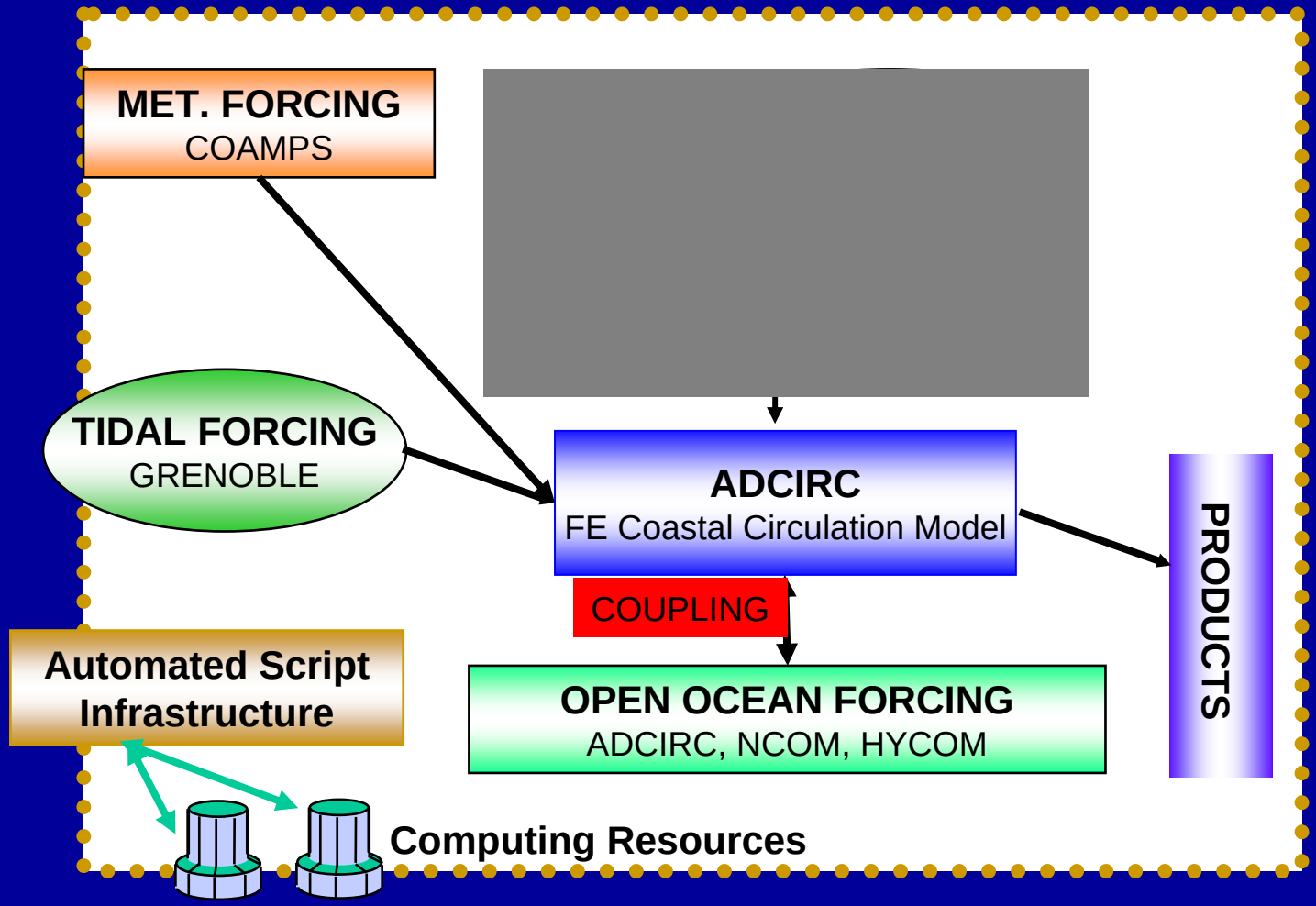

- Linear speedup (with increasing nodes and CPUs)
- Benchmarked for parallel accuracy, portability, speedup

# Automated, Rapid Relocation

- Ordered coastline from segmented data
- Automated mesh generation
  - refinement by depth
  - accommodates narrow deep channels
  - accommodates user specified levels for refinement
  - checks for mesh robustness



# Real-Time Forecast Capability



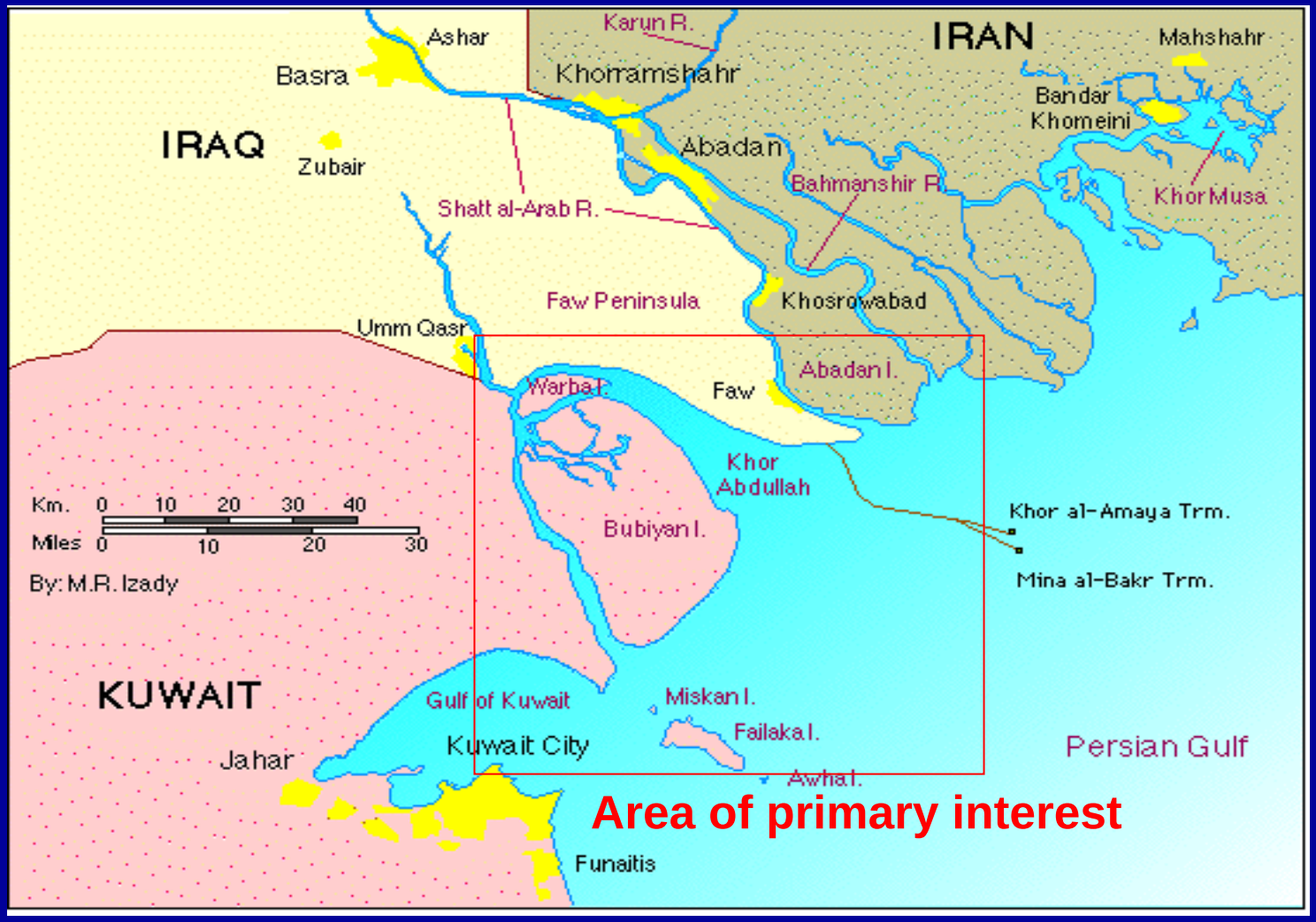

Under Development

## Applications

- AUVFEST
  Oct-Nov, 2001
  Mississippi Sound
- *Prestige* Oil Spill
  Nov-Dec, 2002
  Spanish coast
- Operation *Iraqi Freedom*
  Mar-Apr, 2003
  KAA Persian Gulf

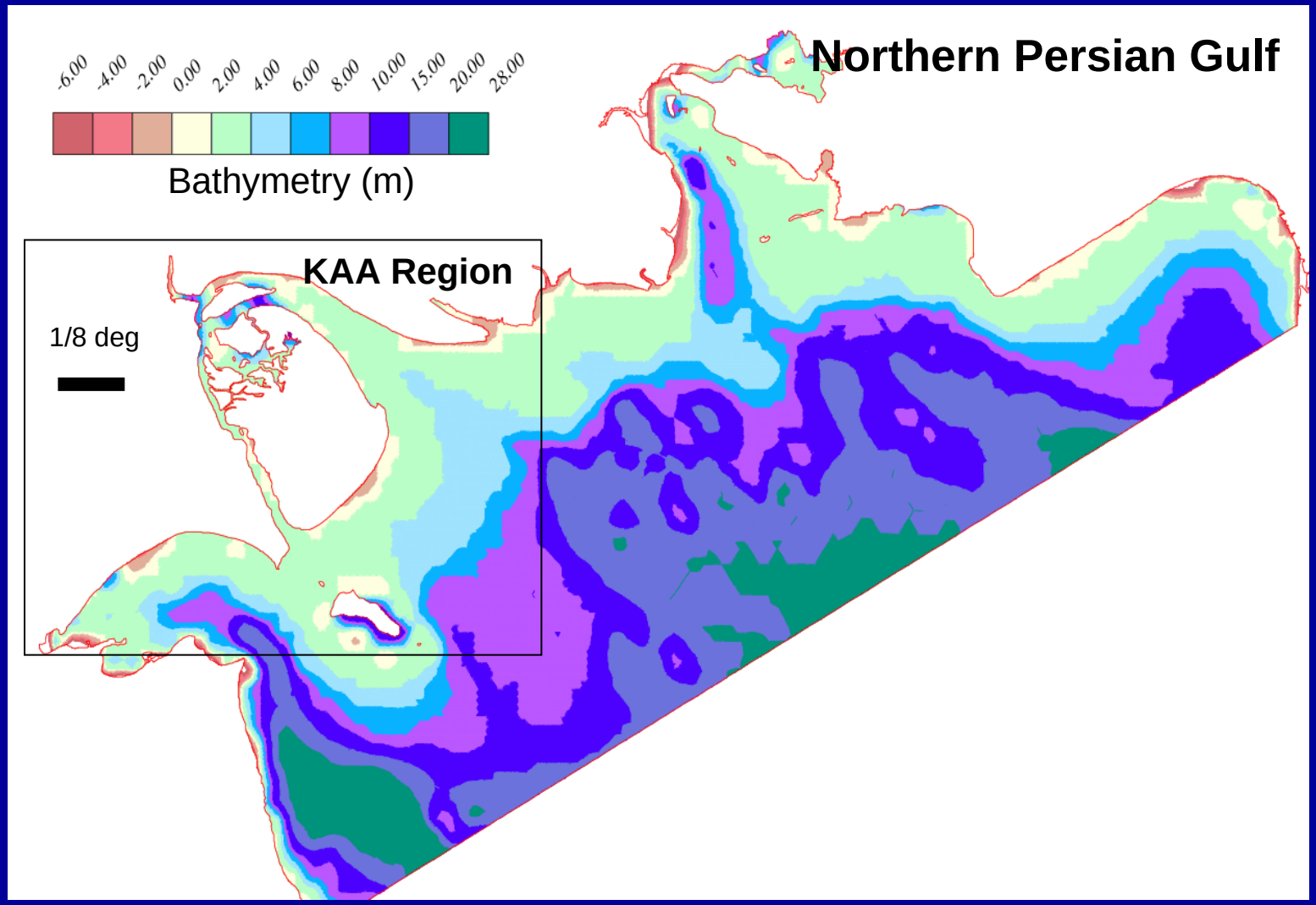
# Pushing the Limits

## *Operation Iraqi Freedom*, March-April 2003



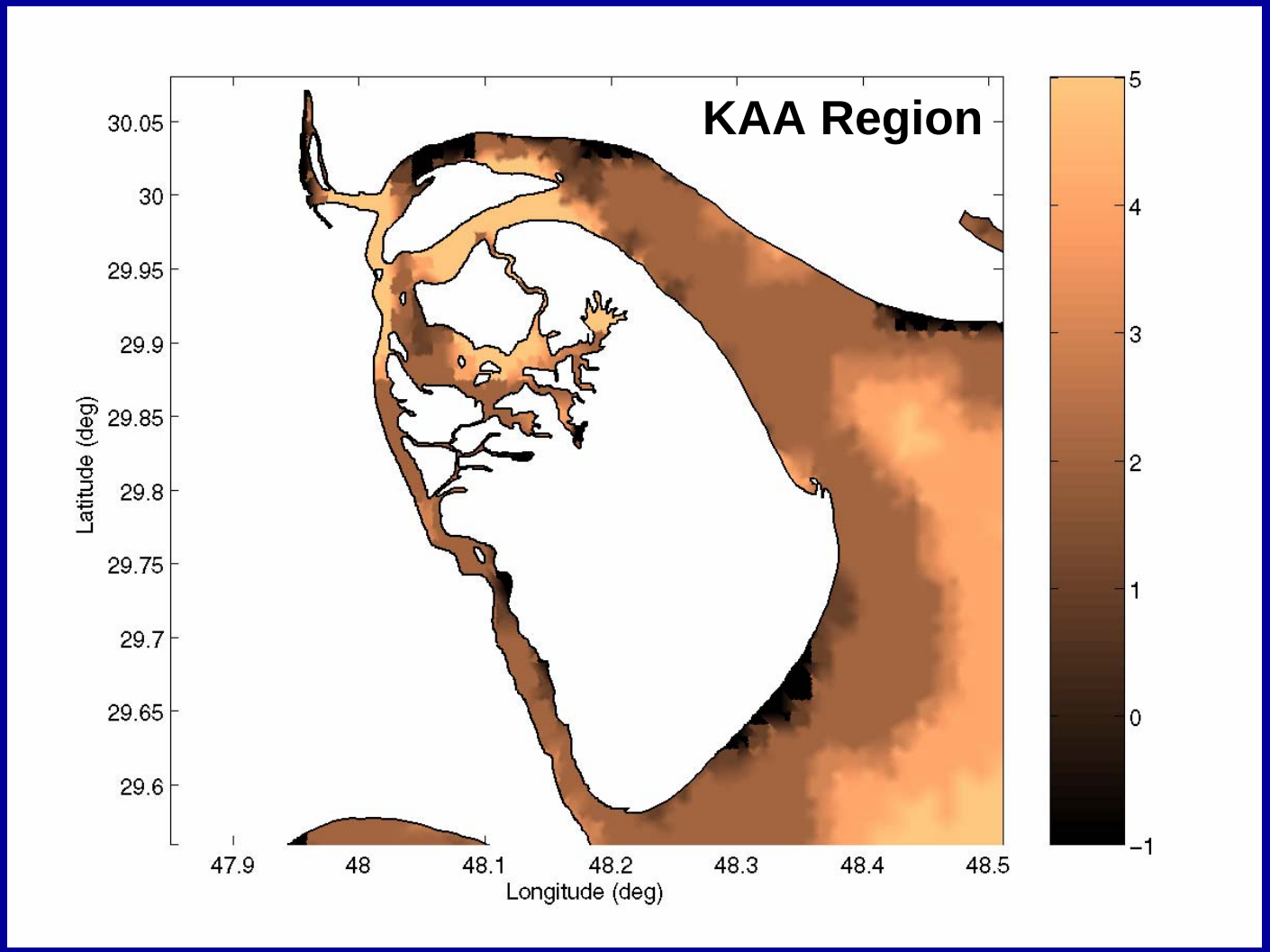
# A Tidal Model of the N. Persian Gulf

## Bathymetry



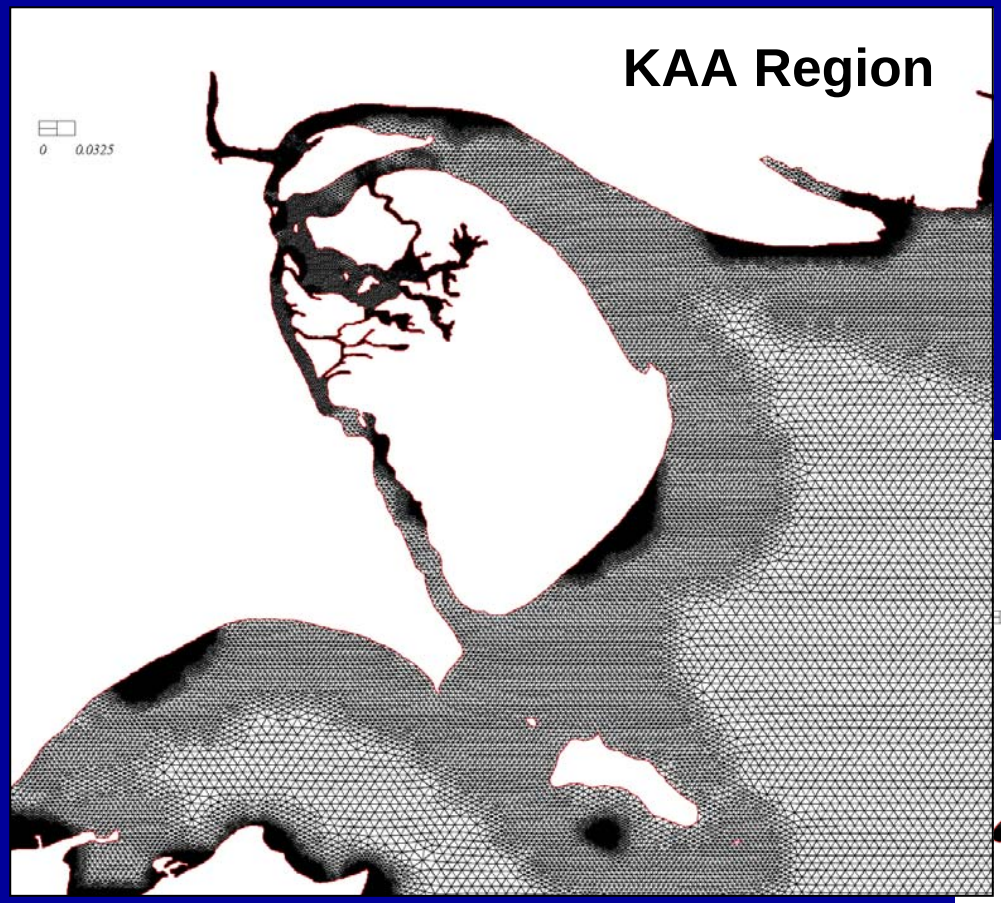
# A Tidal Model of the N. Persian Gulf

Bathymetry from 6 m above MSL to 5 m of water

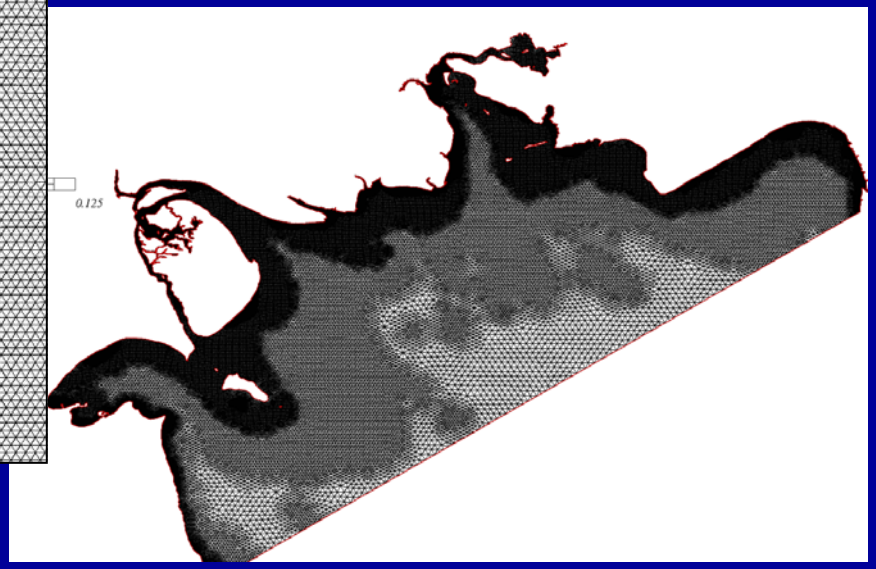


# A Tidal Model of the N. Persian Gulf

## Finite Element Mesh

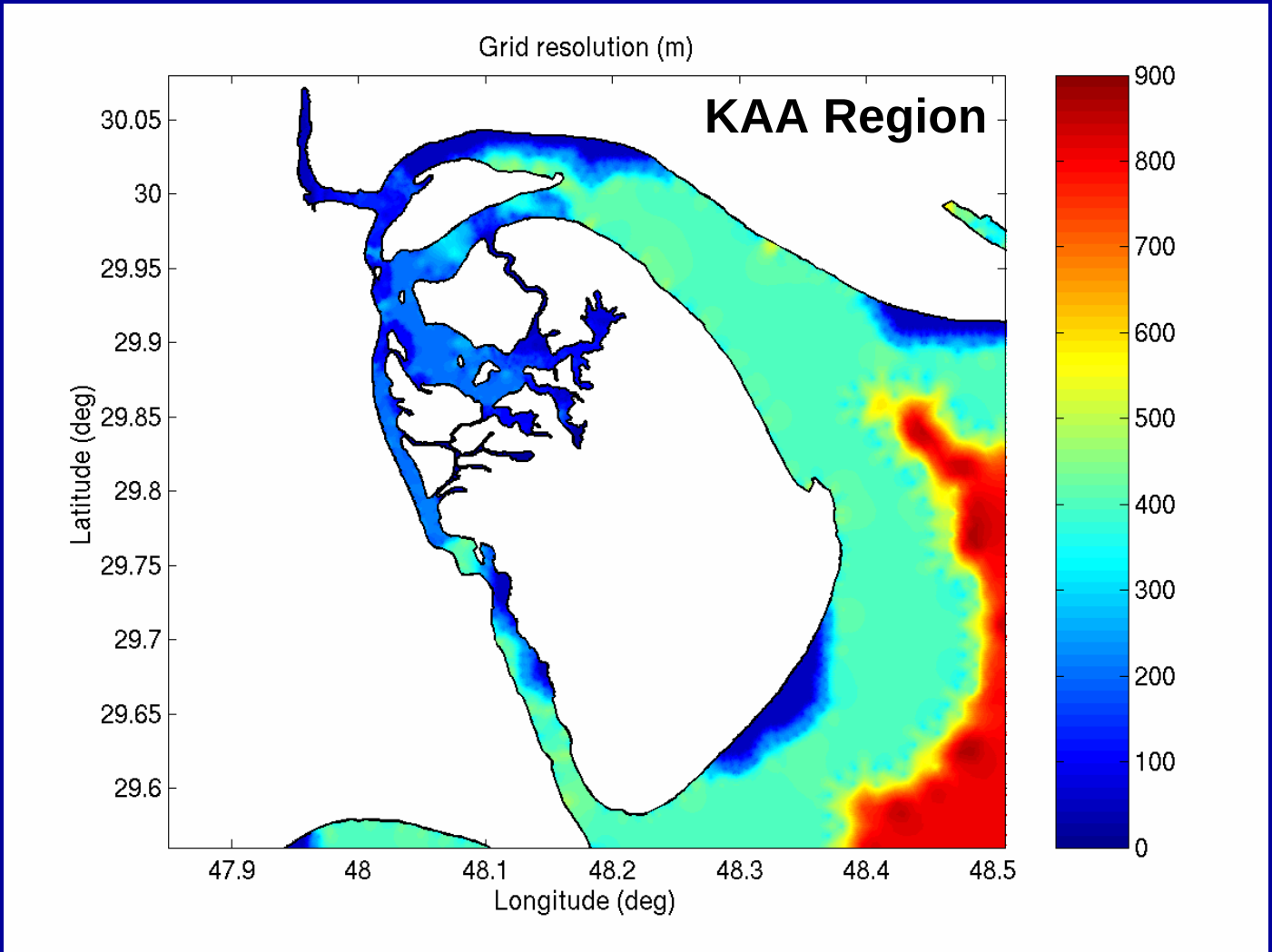



| | |
|---|---|
| No. nodes | 247,767 |
| No. elements | 480,001 |
| Resolution | 2 m – 1 km |



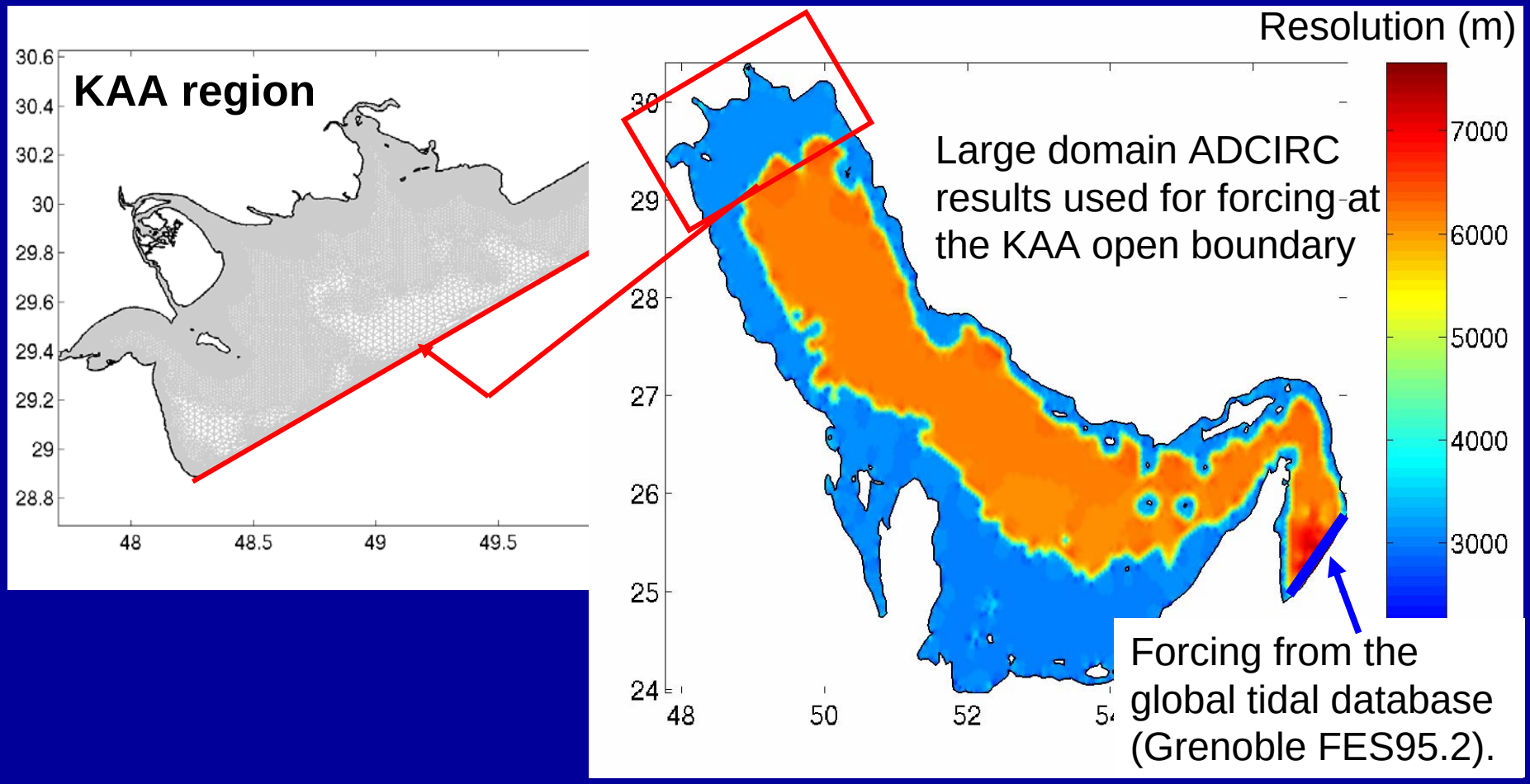
# A Tidal Model of the N. Persian Gulf

Spatial Resolution from 900 m to 2 m

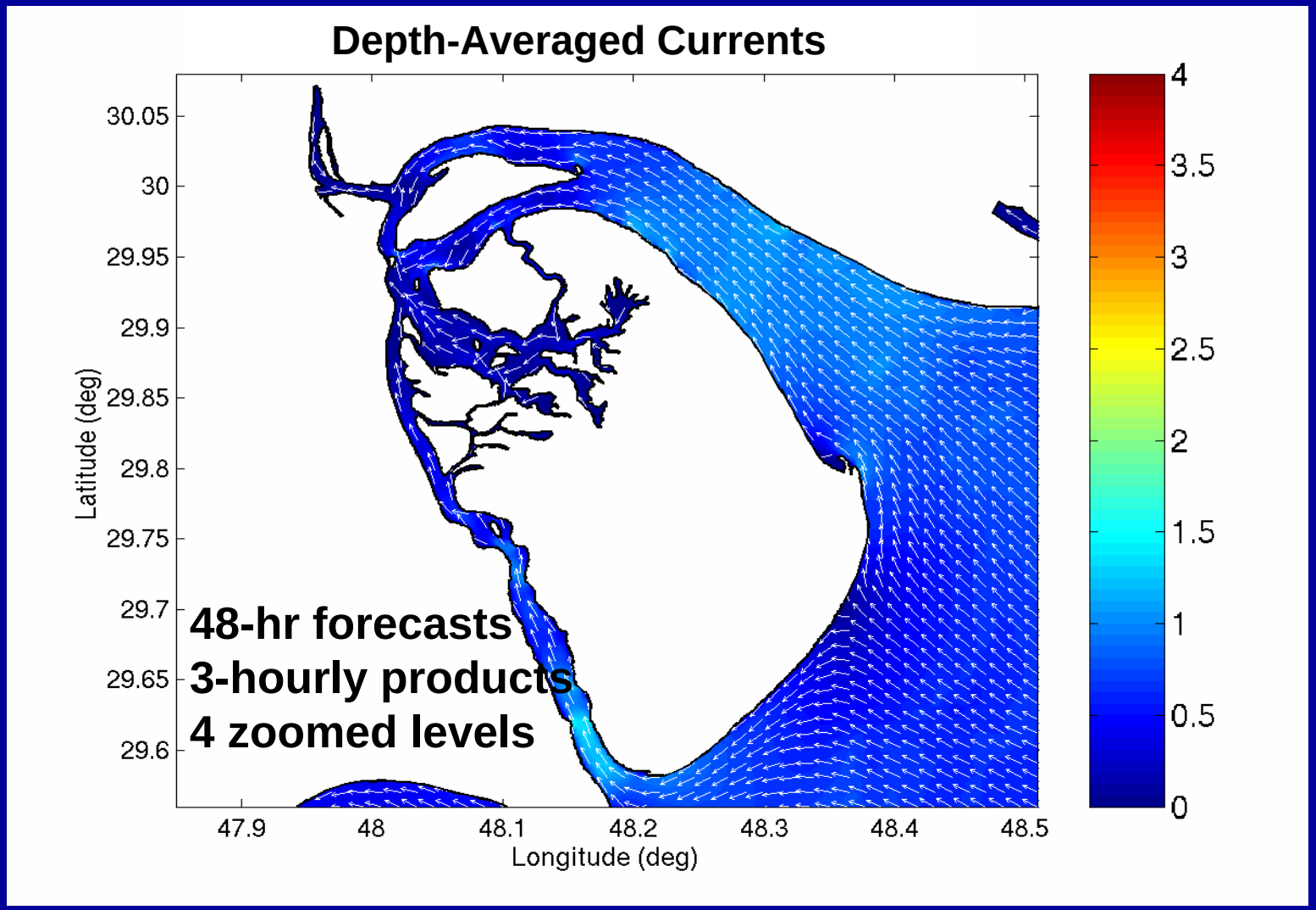


# Open Ocean Tidal Forcing

Taken from large domain ADCIRC tidal database



# Meaningful Operational Products



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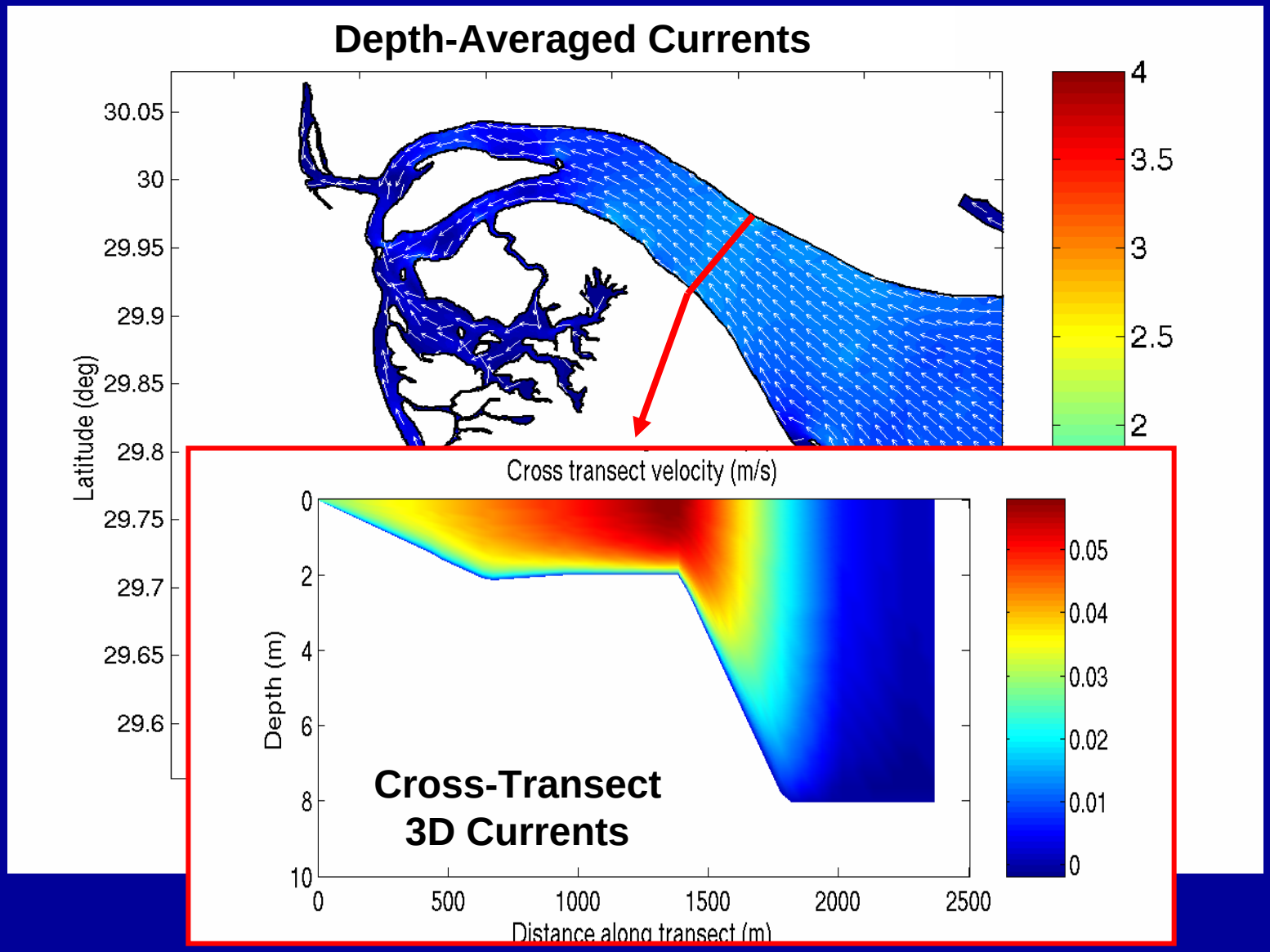

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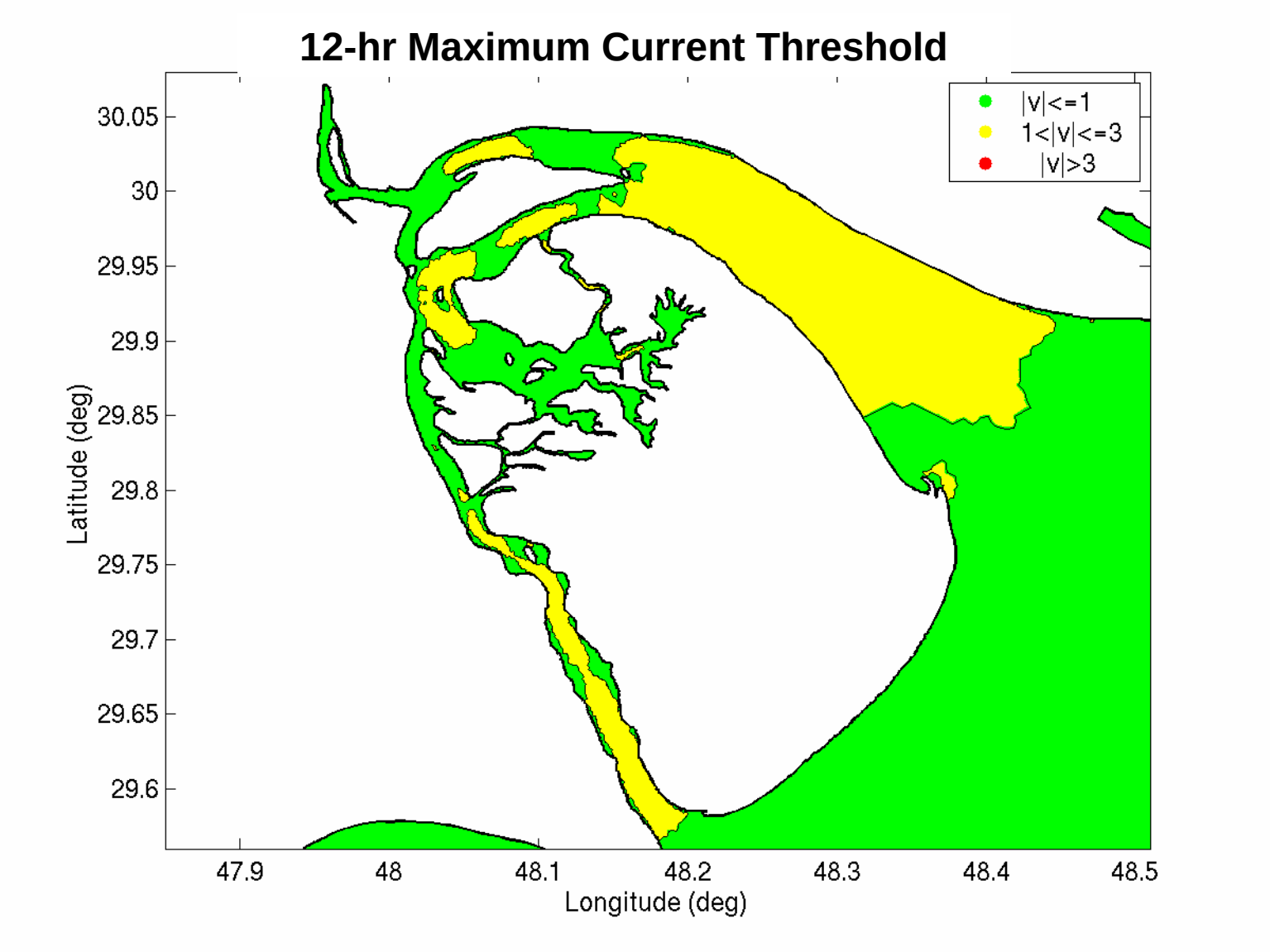
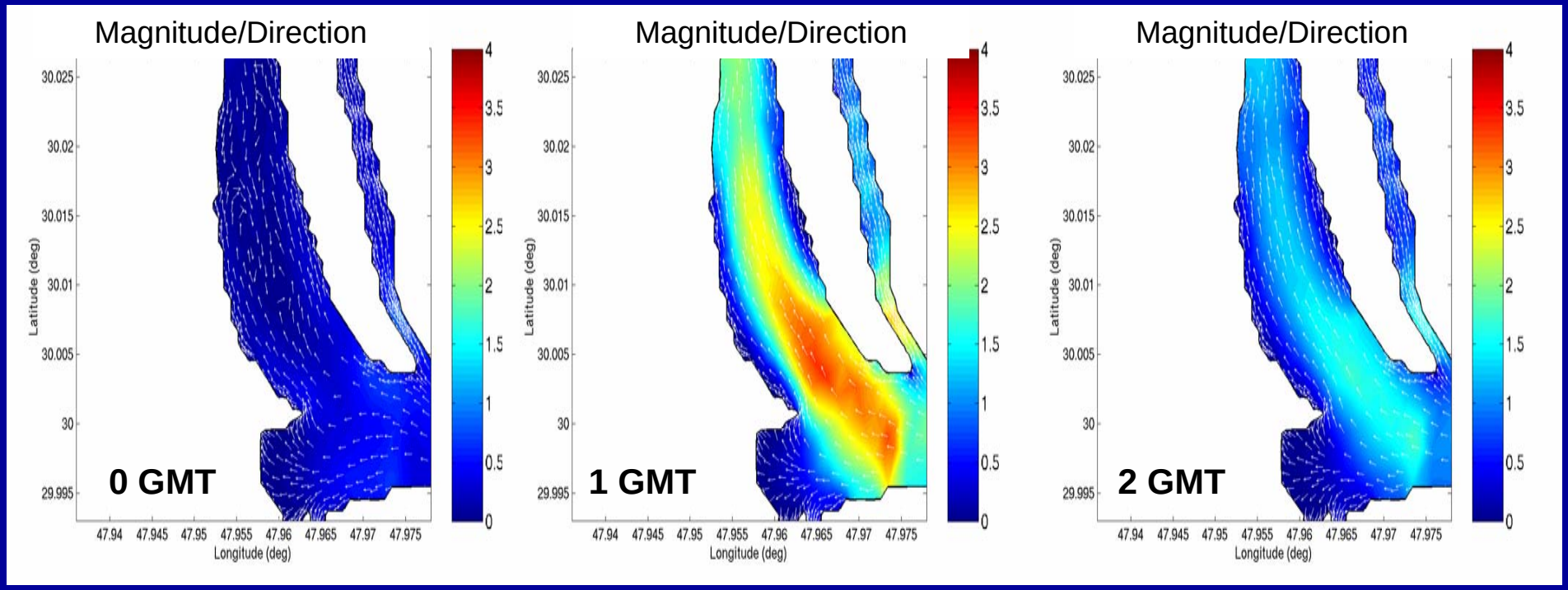


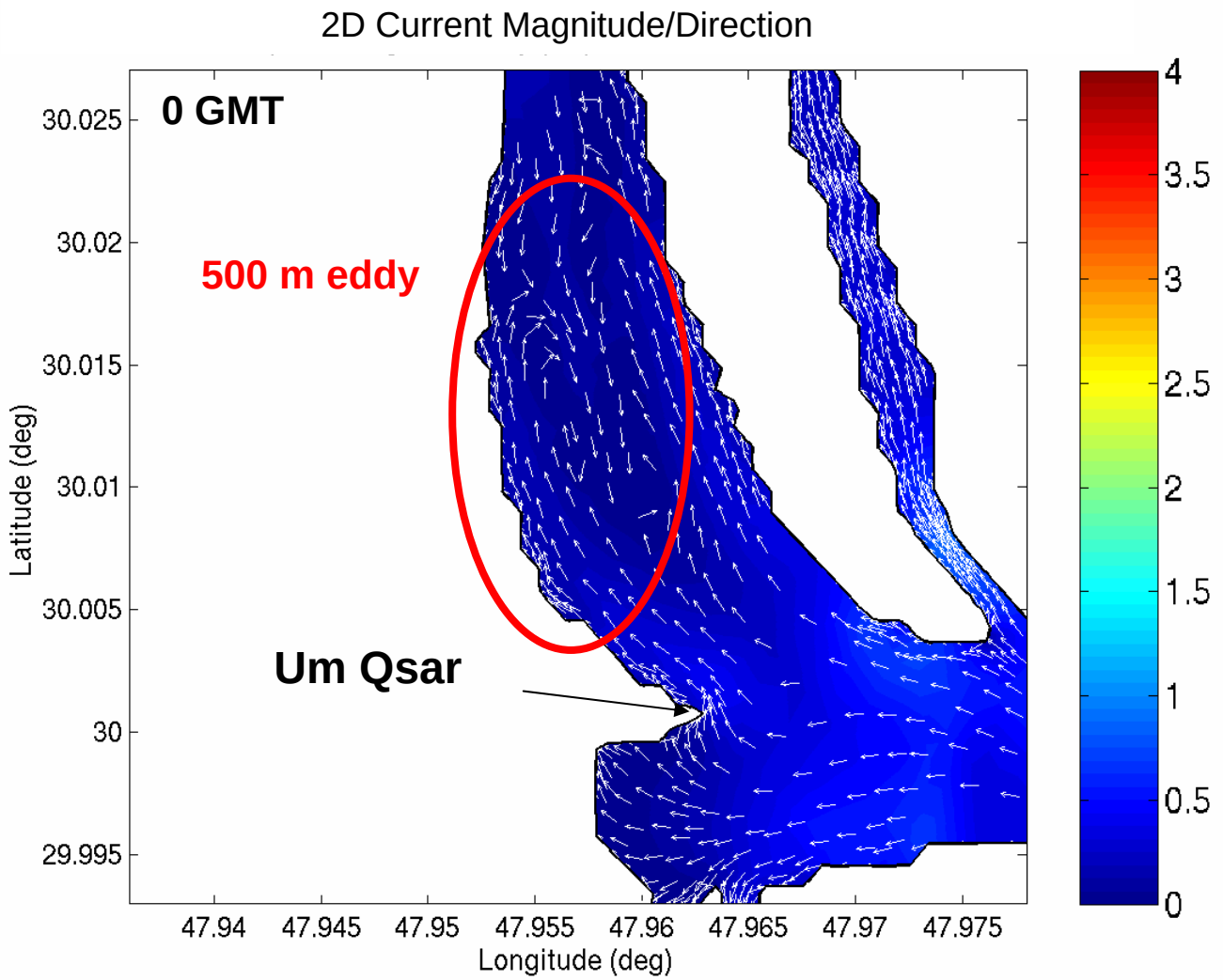
# Fine-Scale Circulation Features

Depth-averaged tidal currents north of Um Qsar



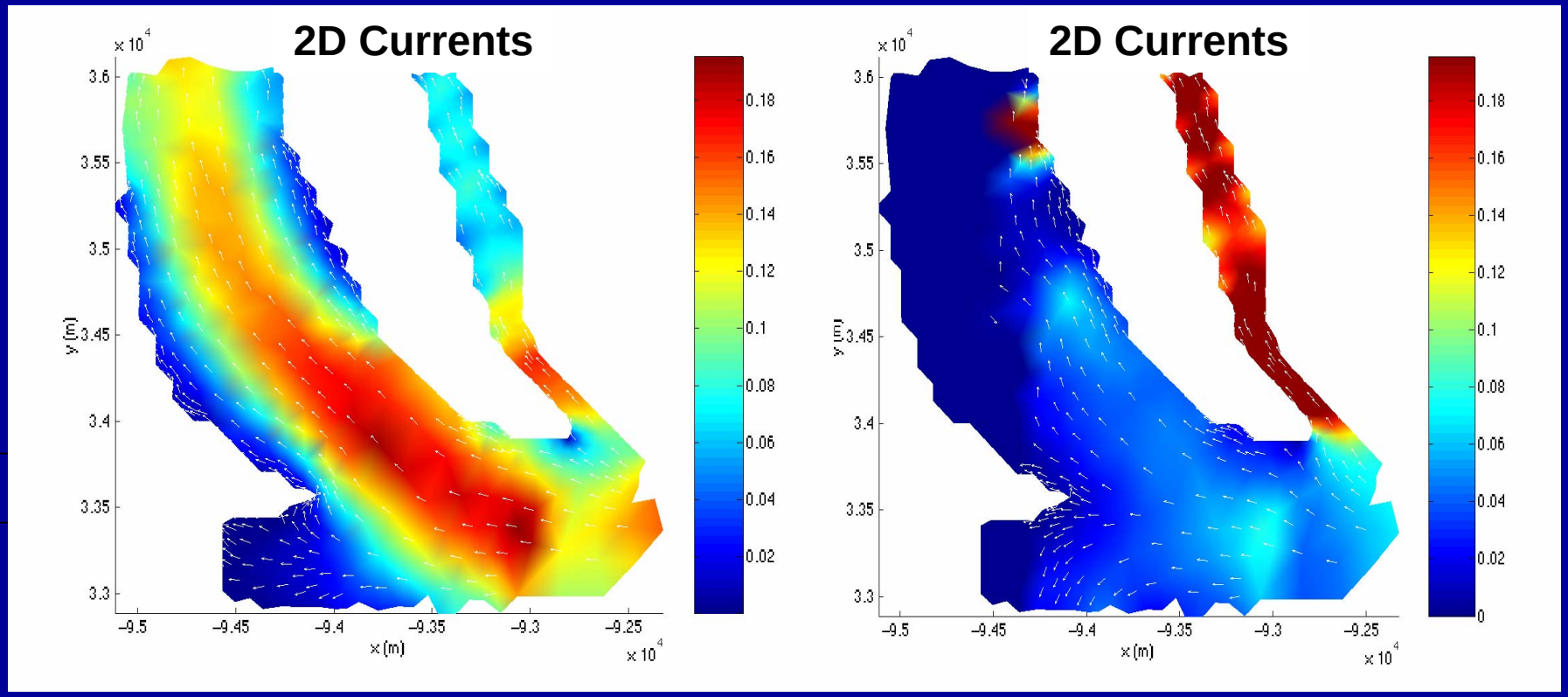

Variability on the scale of hours

# Fine-Scale Circulation Features




High current shear on ebb/flood transitions

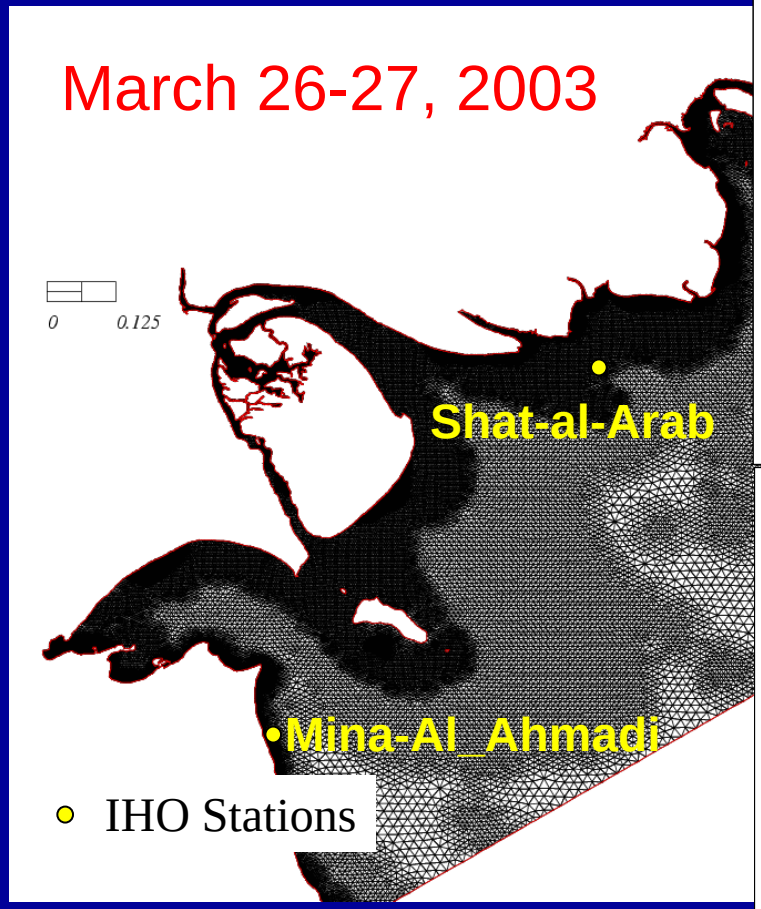
# Importance of Shoreline Inundation

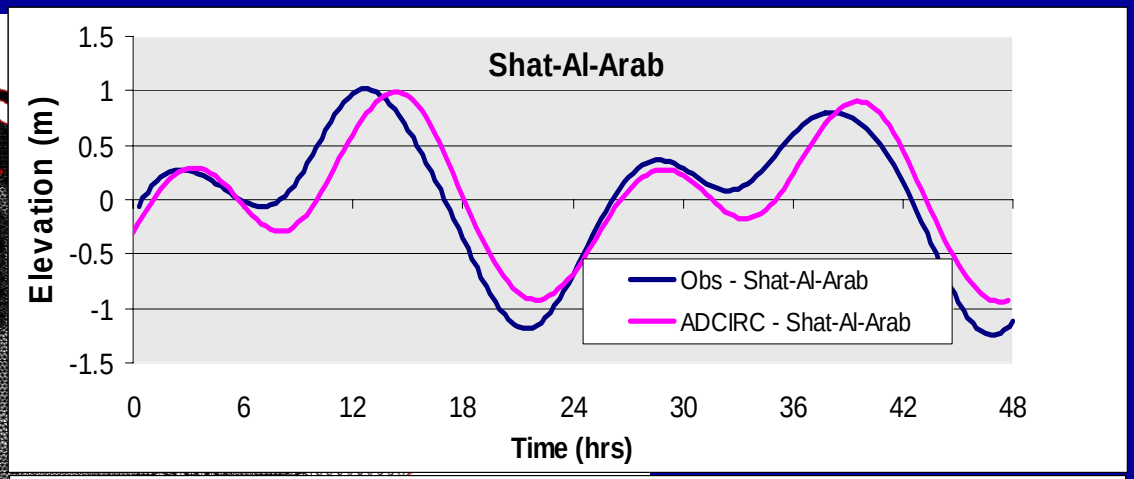


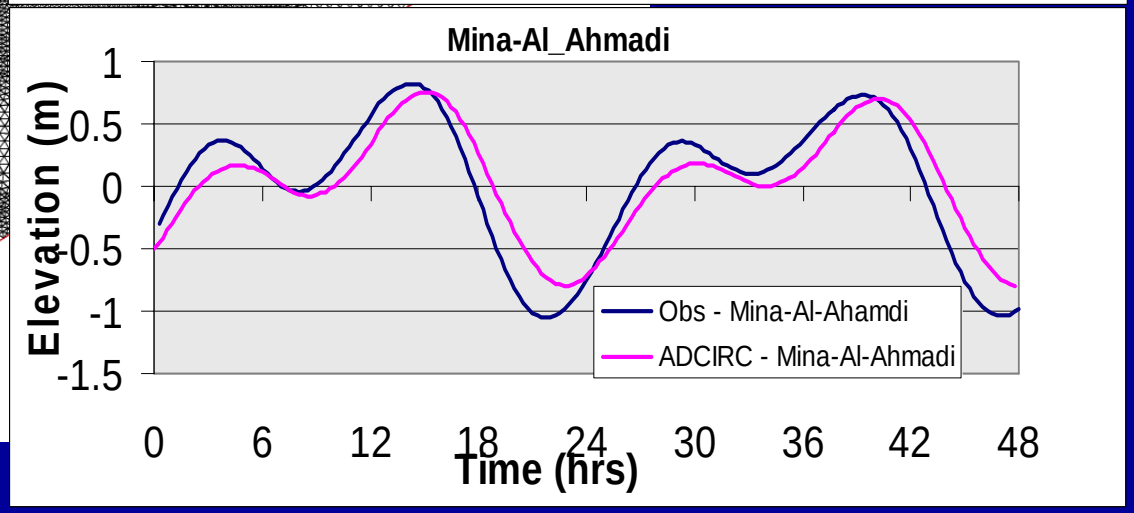

**No Shoreline Inundation/Drying**

Spatial and temporal resolution sufficient to capture shoreline inundation/drying but circulation highly sensitive to bathymetric data.

# Validation of the Forecast Elevations



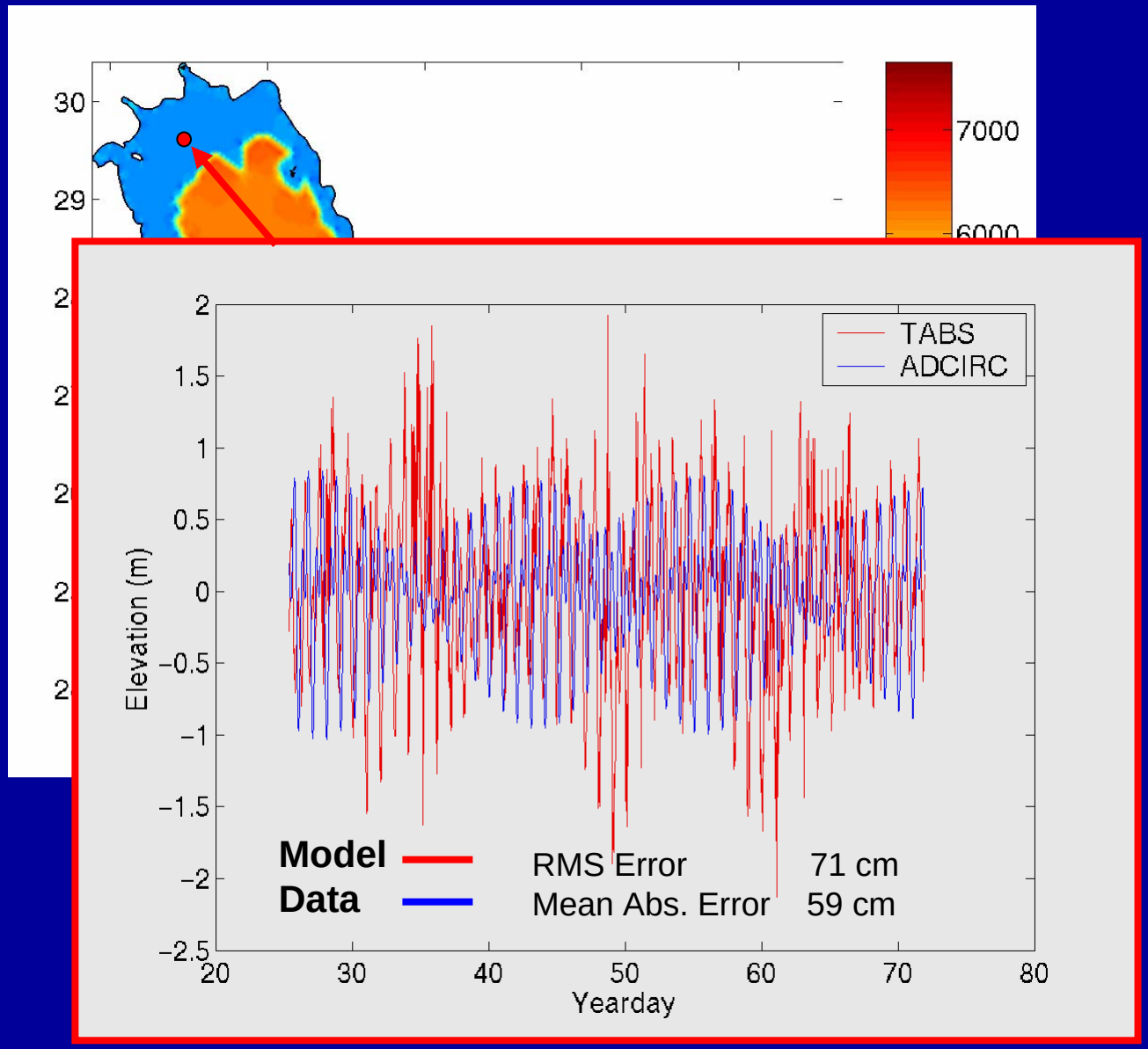




| | |
|---|---|
| RMS Error | 25 cm |
| Mean Absolute Error | 20 cm |
| Phase Lag | 15-30 min |

Time series correlation 0.98

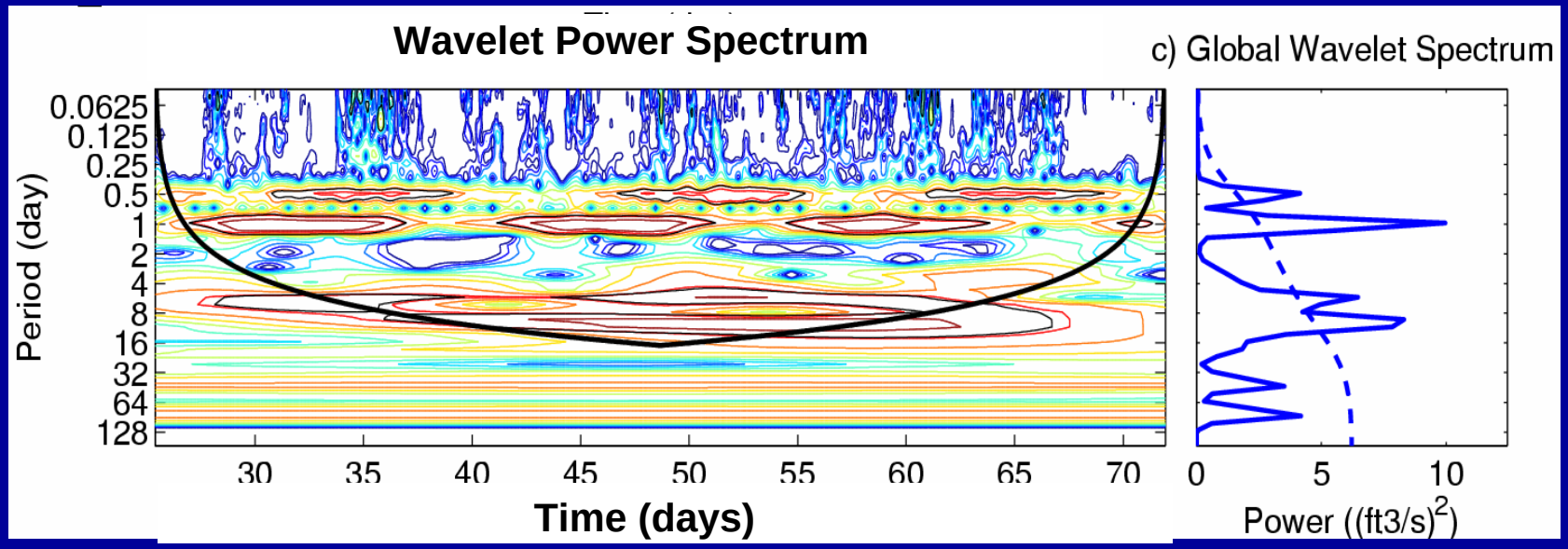
# Validation of the Boundary Forcing




- Comparisons of tidal elevations to IHO data reasonable for the large domain tidal model

- Comparison of KAA SSH to TABS Buoy data January 15 – March 12, 2003

# Validation of the Boundary Forcing



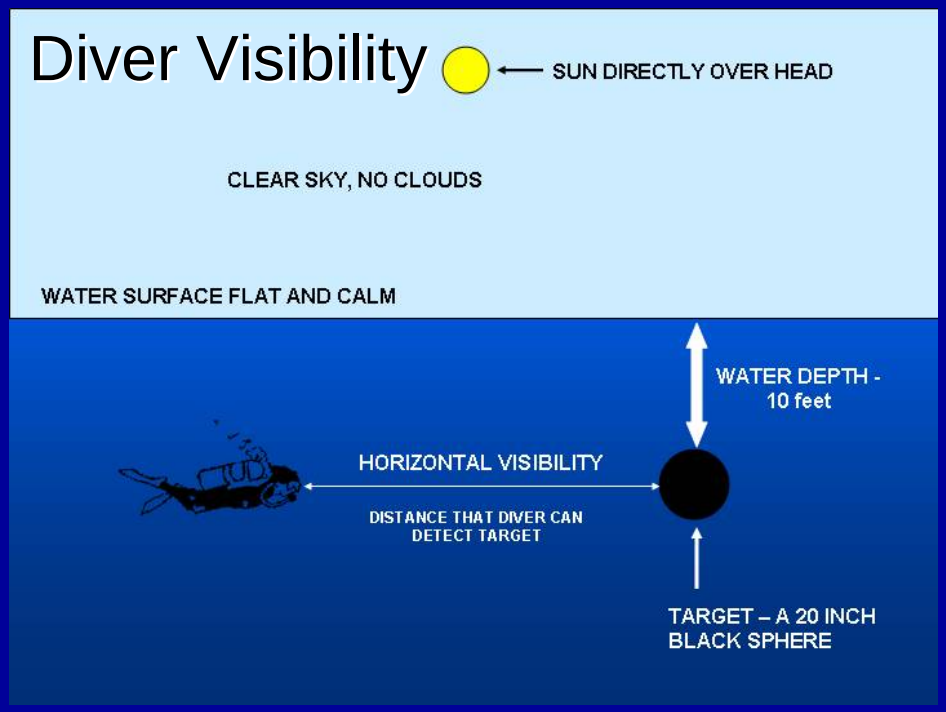

- Wavelet analysis of the TABS buoy data reveals a fortnightly signal likely due to the contribution of the surface winds to the SSH

- Winds were neglected in the extracted BCs

Motivates the need to derive BCs from operational models

# Coupling Circulation and Optical Properties

Immediate need to define underwater targets



## Overall Objectives

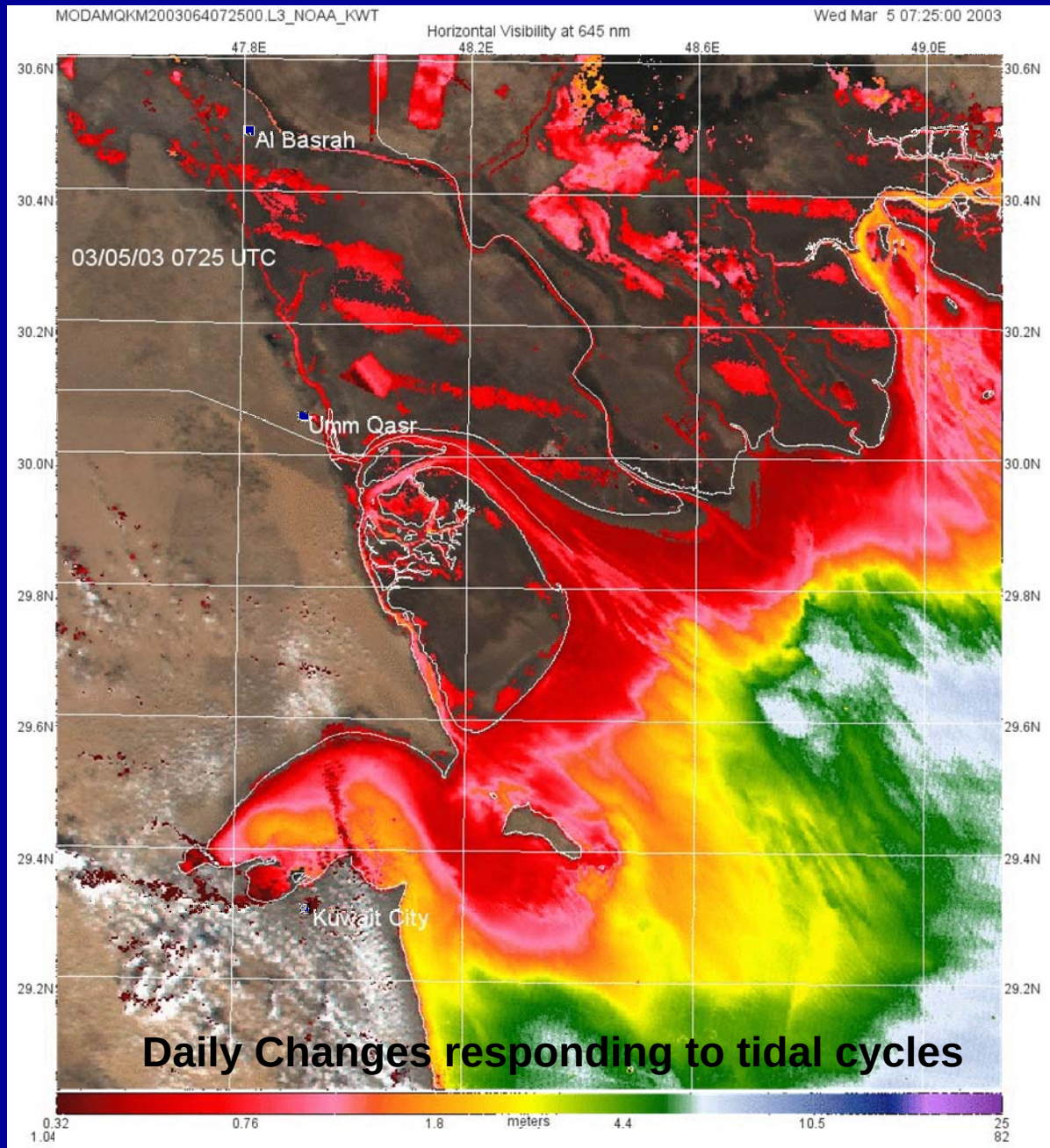
- Predict visibility to fill in temporal gaps
- Assimilate remote sensed information into models
- Validate models including shoreline inundation

# Diver Visibility

Derived using beam attenuation coefficient from the MODIS satellite

- AQUA and Terra 250 m channels

- AM: 7- 9 GMT
- PM: 22-24 GMT

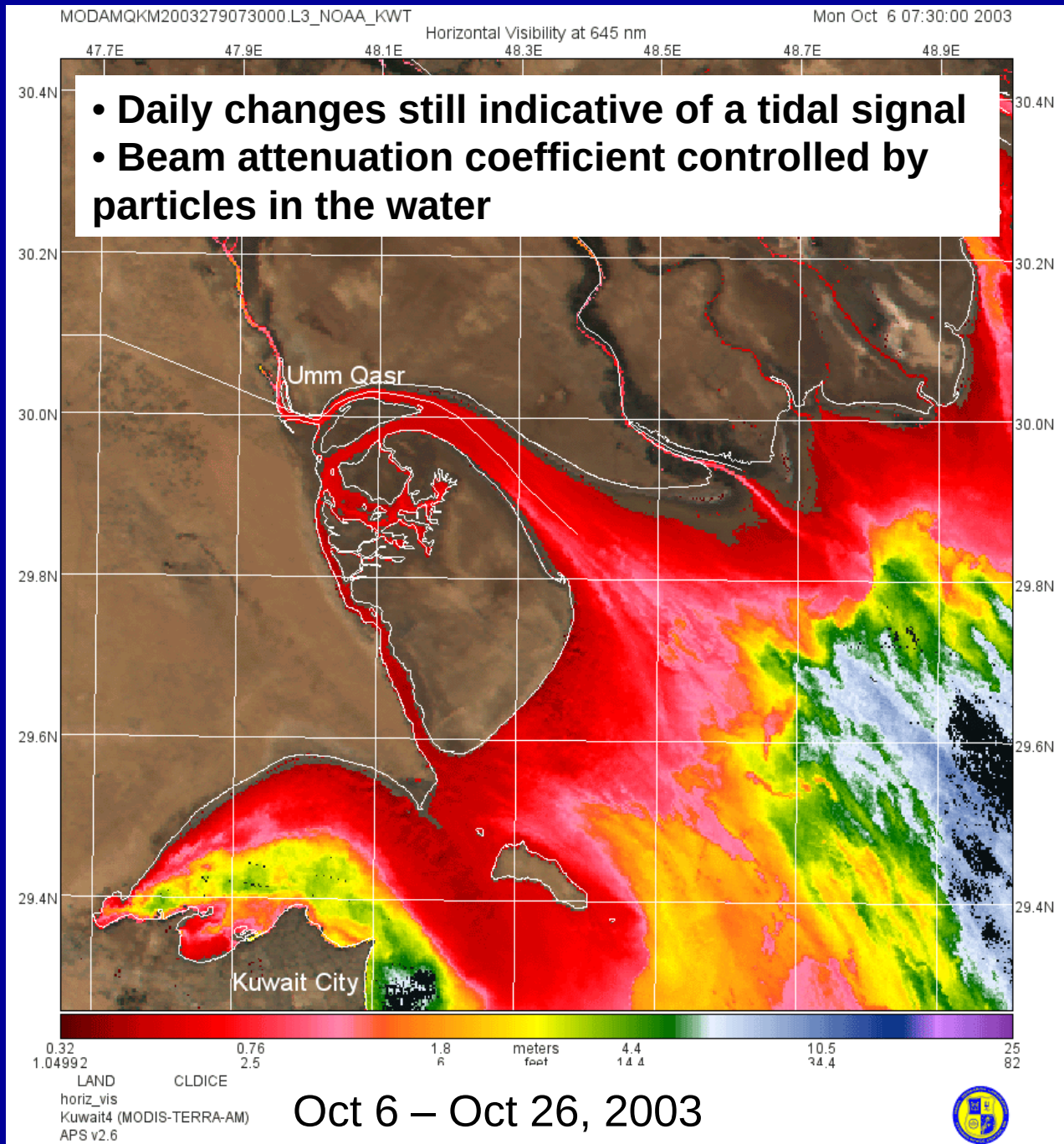



March 5 – May 3, 2003

# Diver Visibility

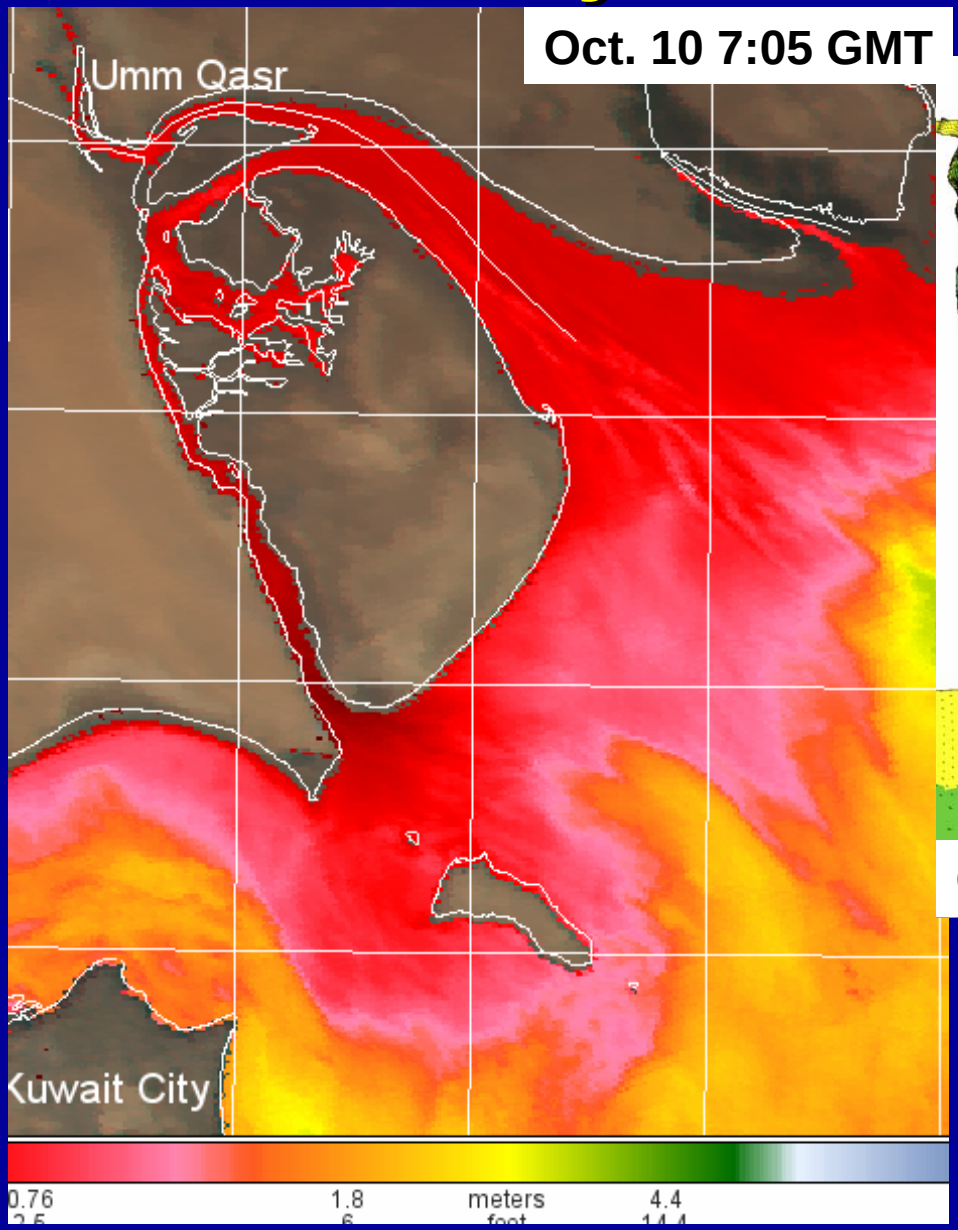
To analyze in more detail, a continuous time series of imagery is identified

- Oct. 6 -26, 2003

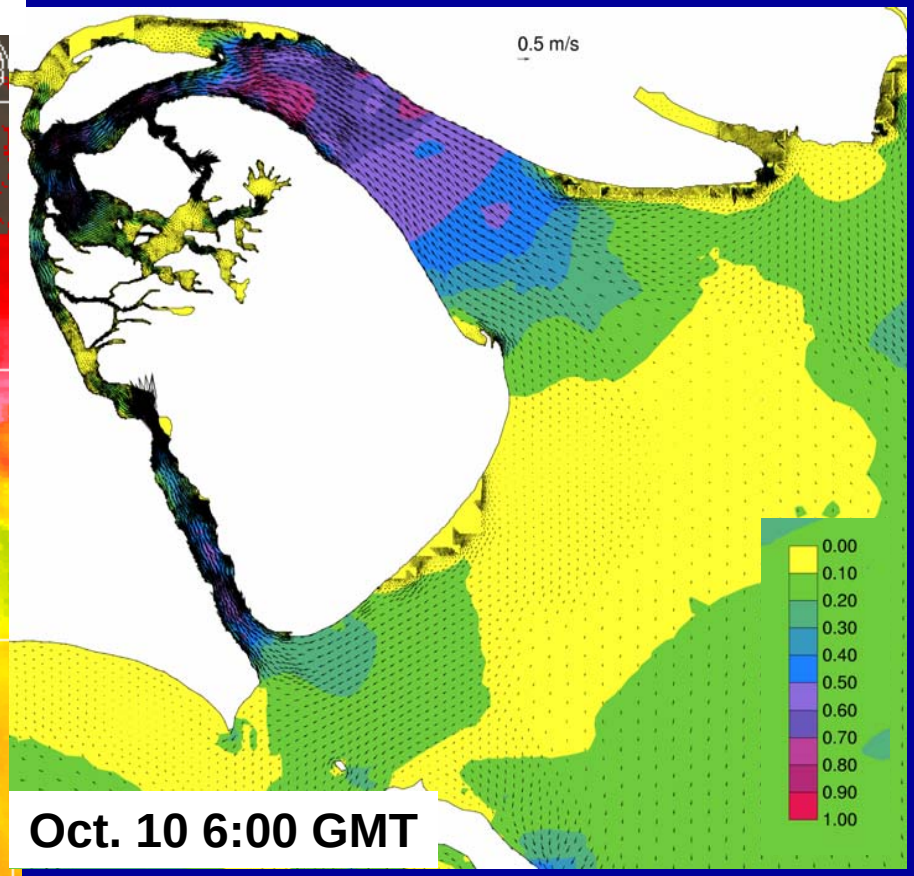



Oct 6 – Oct 26, 2003

# Low Visibility

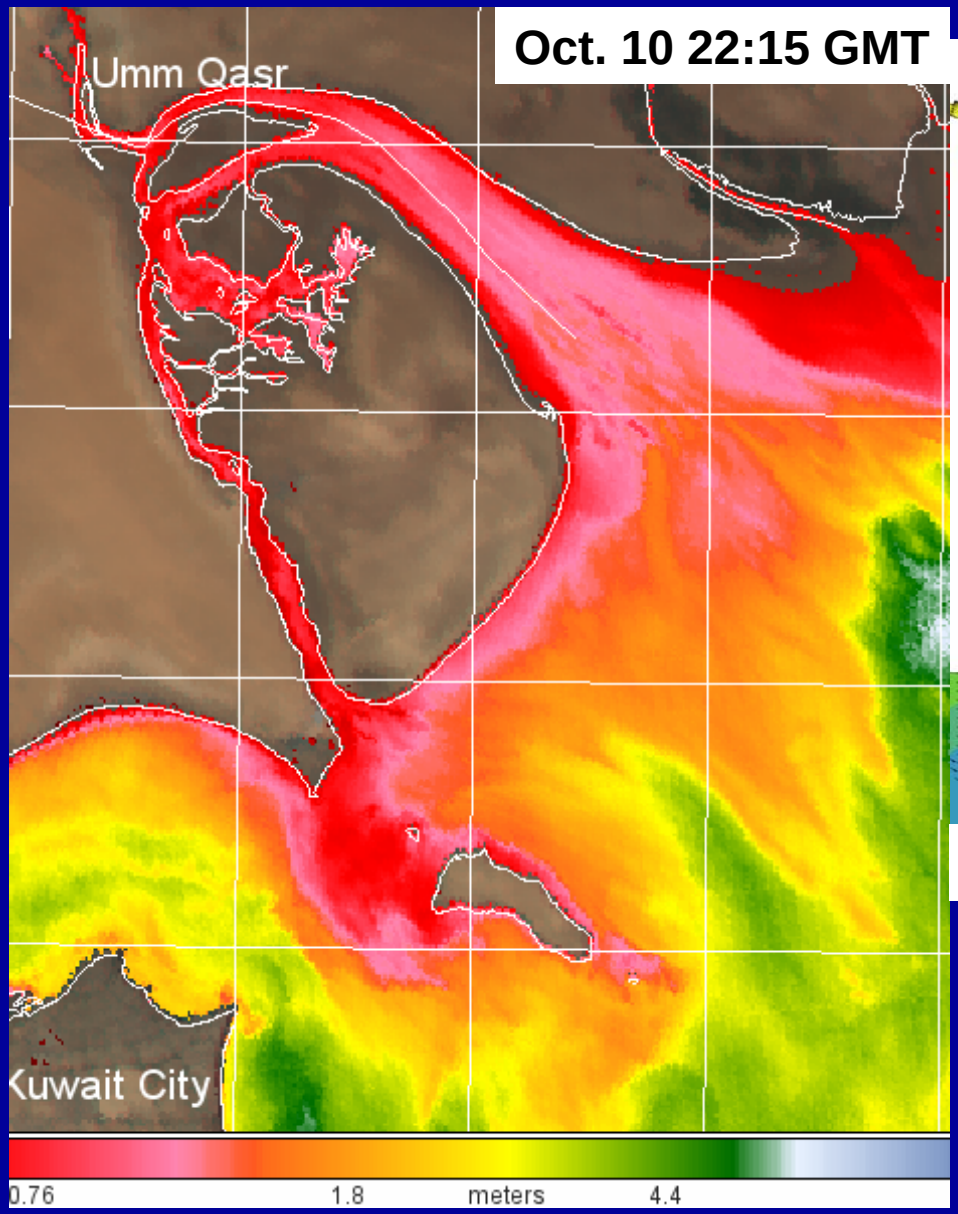



FLOOD TIDE

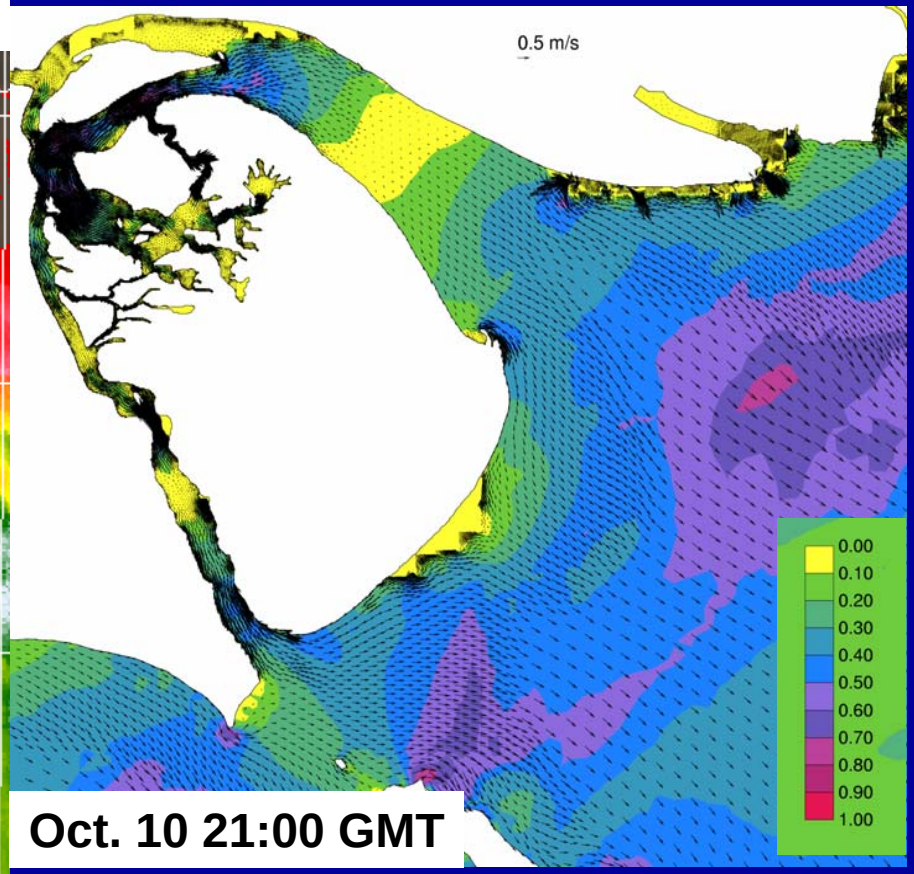



Higher velocities result in more mixing and thus increased turbidity

# Increased Visibility

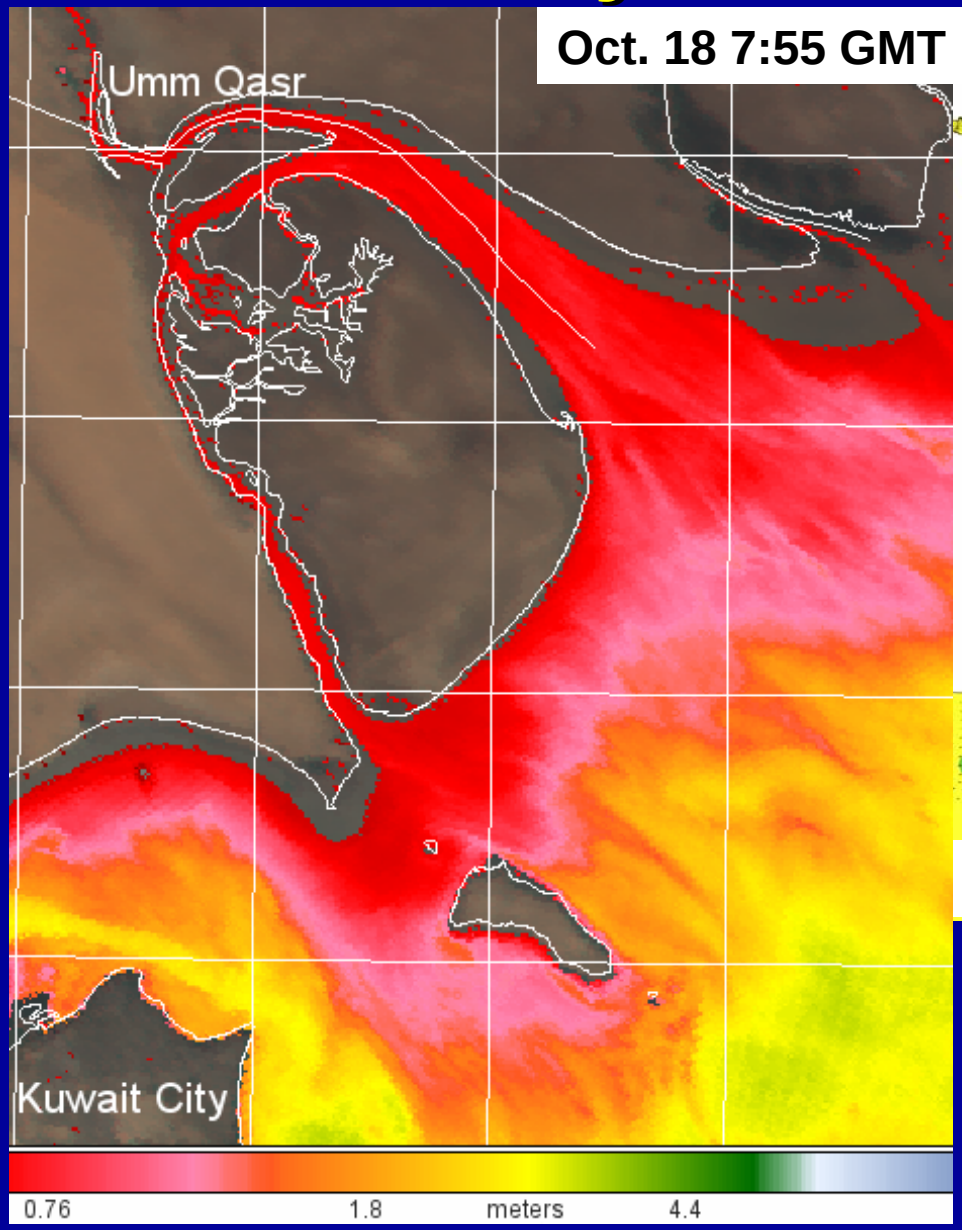



SLACK TIDE

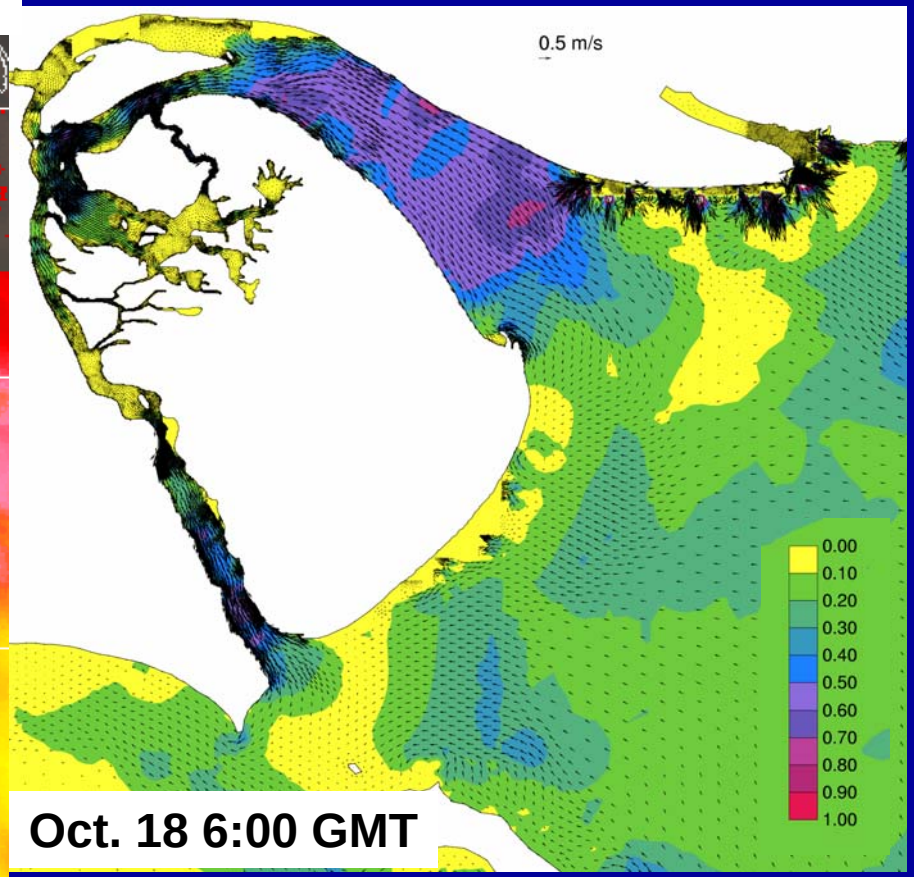



Low velocities allow particle setting and reduce turbidity

# Low Visibility

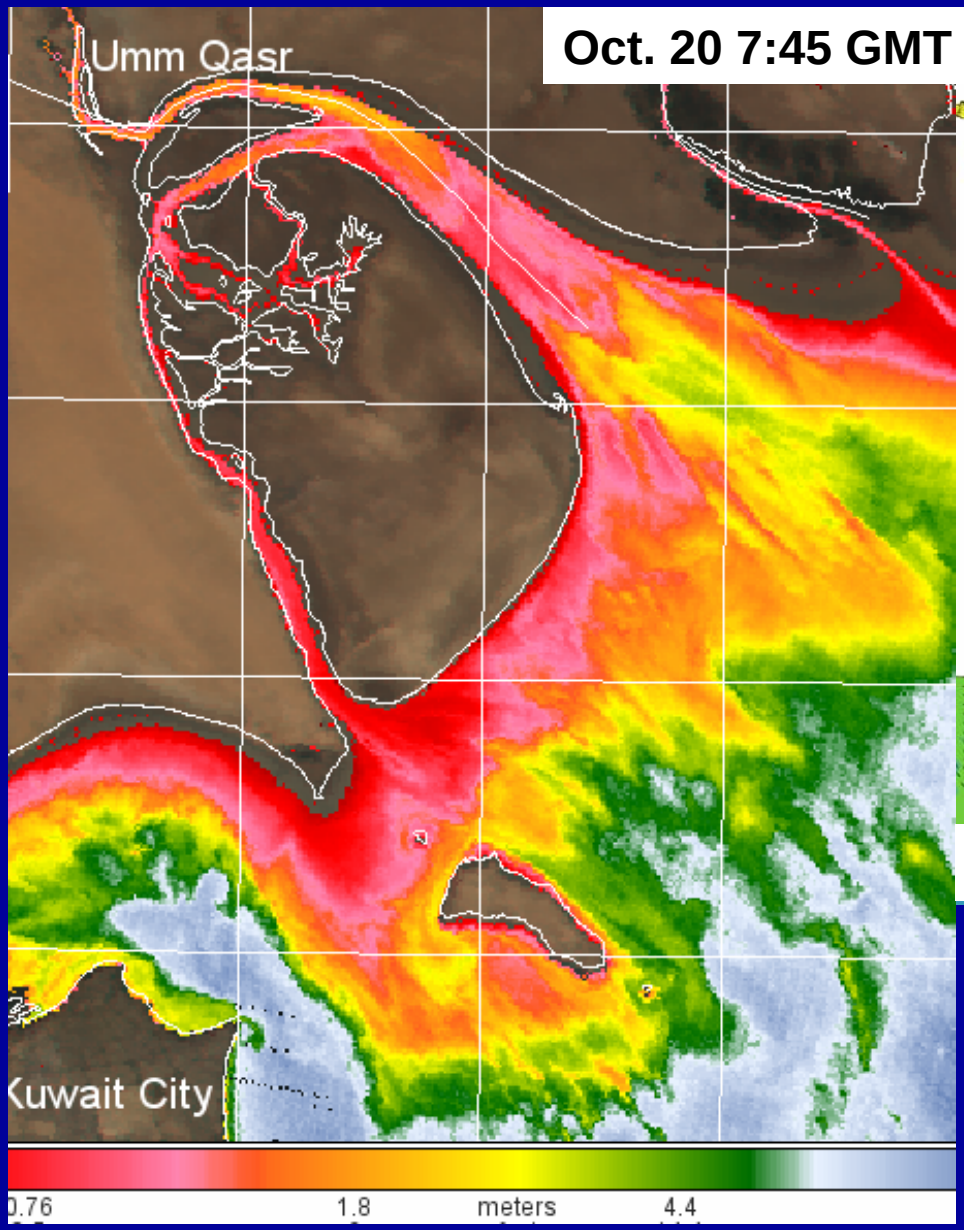



EBB TIDE

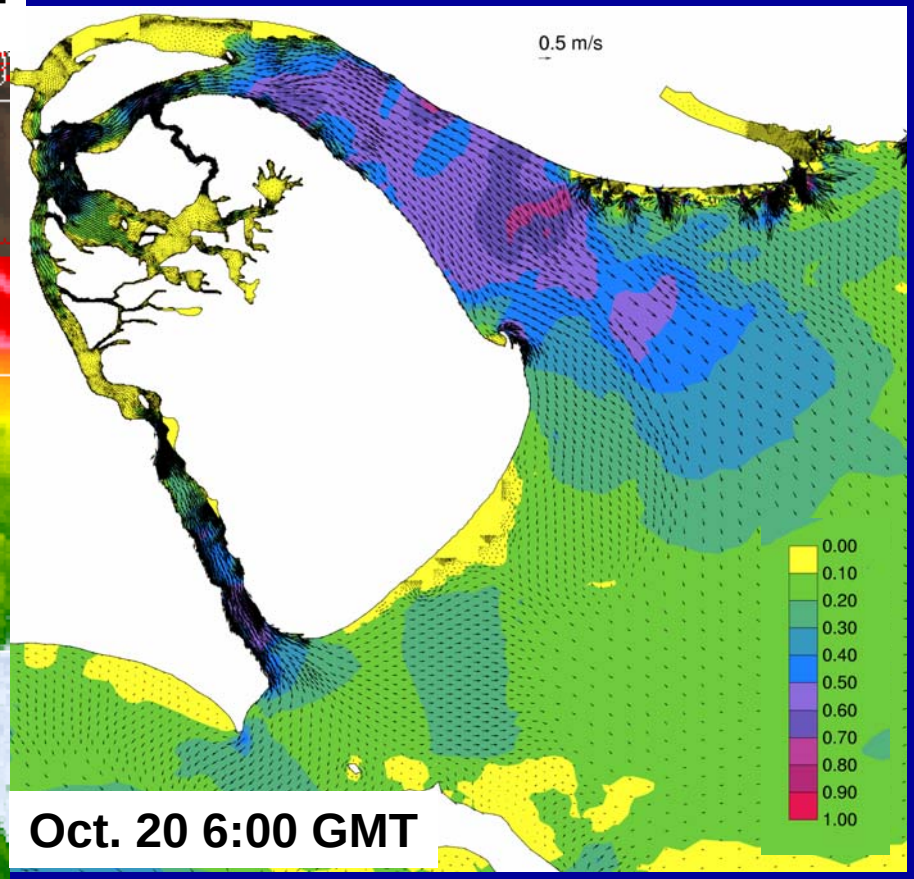



The magnitudes of the ebb tide are not as strong as for flood tide

# Increased Visibility




EBB TIDE




Non-tidal processes likely to be contributing to the increased visibility

# Where to Go From Here

- Develop a quantitative relationship between the currents and the imagery
  - consider surface and bottom currents
  - examine distribution of mixing and dissipation
  - successive addition of modeled physics

- Consider multiple remote-sensed products

Recall our primary objectives:

- To predict optical properties
- To assimilate observed imagery into models

# Upcoming Improvements

- A Mass Conserving FE Algorithm
  - using higher order discontinuous Galerkin (DG) methods
  - will provide accurate transport capability
  - additional baroclinic dynamics

- Strategies for Nesting to Global/Regional Models
  - HYCOM and NCOM

- Data Assimilation
  - Ensemble Kalman Filters (short term/operational)
  - Adjoint 4DVAR (long term)

# ADCIRC: Recent/Upcoming Advances

## Algorithm Development

- Predictor-Corrector Time Stepping
- Conservative form of the momentum equation
- Discontinuous Galerkin (DG) mass conservation
- Coupled DG-GWCE algorithms

## Physics

- Baroclinic dynamics : DG transport model for T and S
- Locally conservative
- DG Sediment transport

## Data Assimilation

- Linear adjoint for 4D-VAR data assimilation
- Ensemble Kalman Filter implementation