Hydrodynamics and Remote Sensing of Far Wakes of Ships

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Introduction

The problem of remote ship detection attracts much attention due to its importance for fishing and pollution control, global security, marine navigation safety, and other applications.

SAR images of ship wakes is a source of data for the ship monitoring.

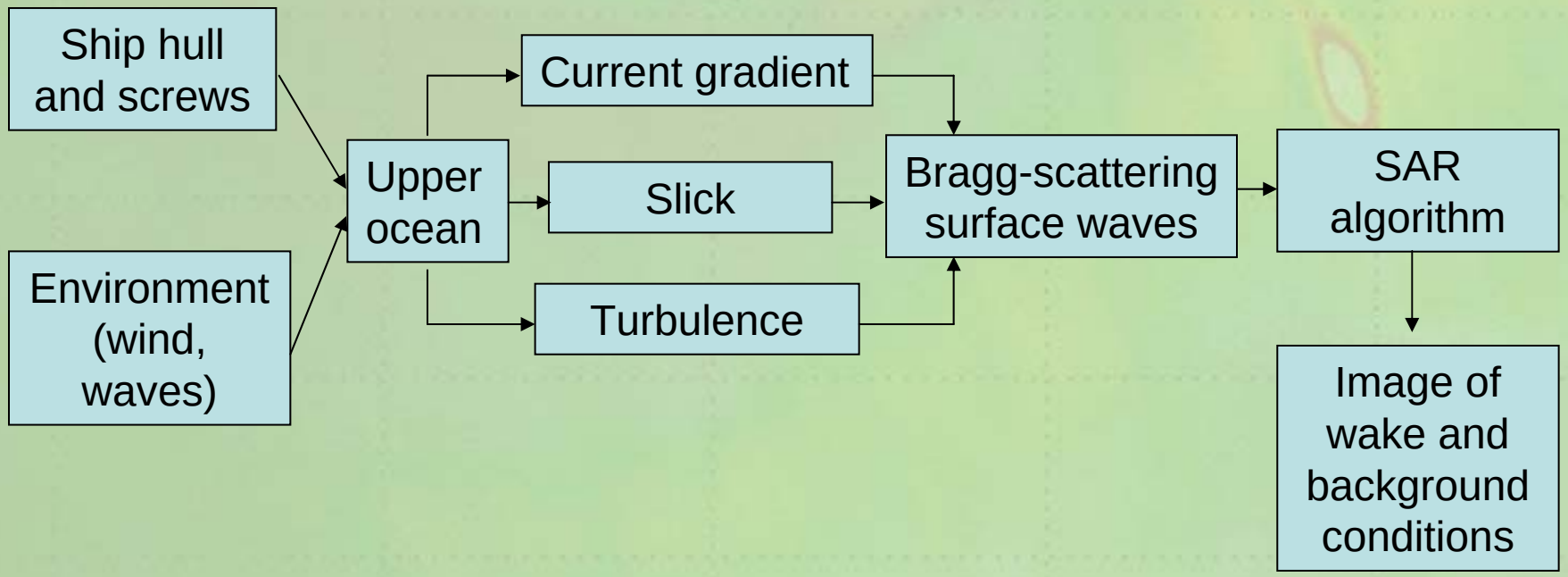
A big uncertainty of wakes visibility, size, and features complicates the operational utilization for ship identification.

Ship Wake Structure

Ship wakes have a complex structure and may have one or more of the following elements:

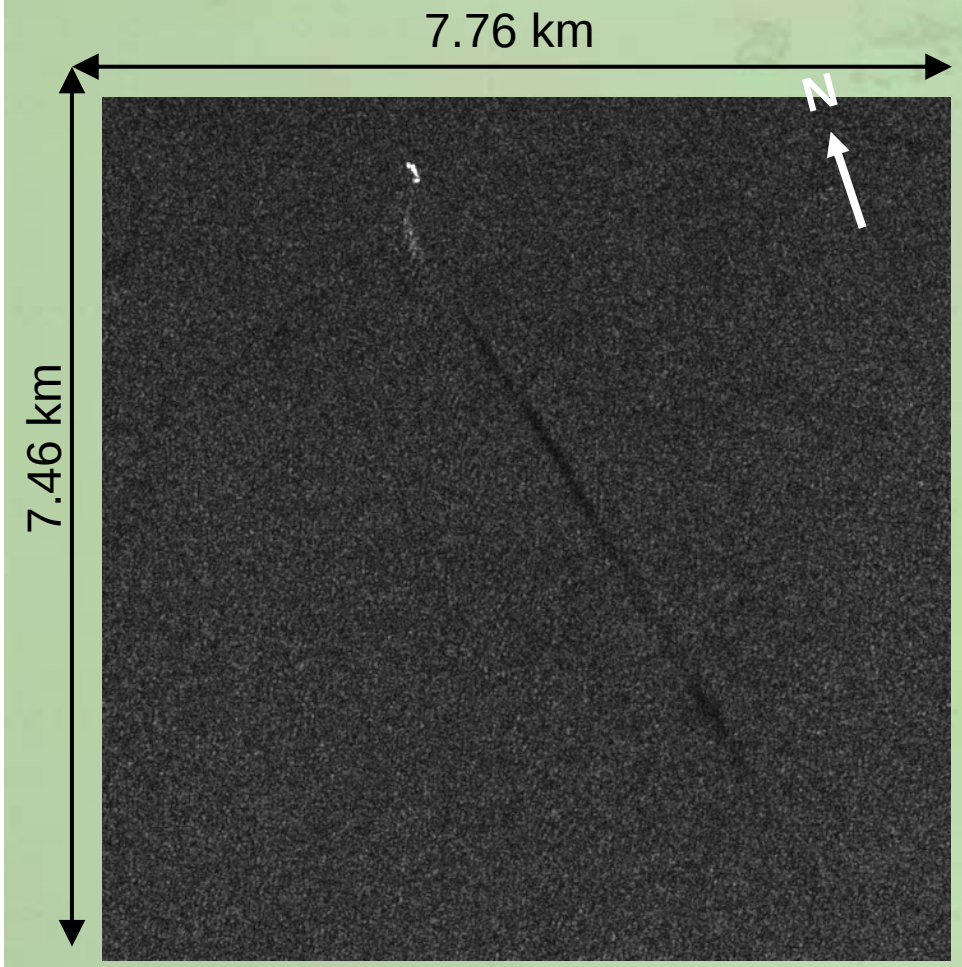
- Centerline wake
- Kelvin arms, and Kelvin wake area
- V-like structures
- Internal wave features generated by the ship

SAR Imaging of Ship Wake



Effects of stratification, long/short wave modulation, coherent structures add more complexity.

Ferry *Le Méditerranée and its wake in SAR*



- **Date: October 30, 2006**
- **Time: 10:21:27 GMT**
- **Satellite: ERS-2**
- **Image Mode: SAR**
- **Polarization: VV**
- **Latitude: 43.008 °**
- **Longitude: 5.462 °**
- **Ship Course: 339.17°**
- **Ship Speed: 11.6 m/s**
- **Wind Speed: 3.2 m/s**
- **Wind Direction: 61.17°**

Inverse problem would benefit from proper physical models of ship wake, sea surface, and selecting adequate radar imaging modes

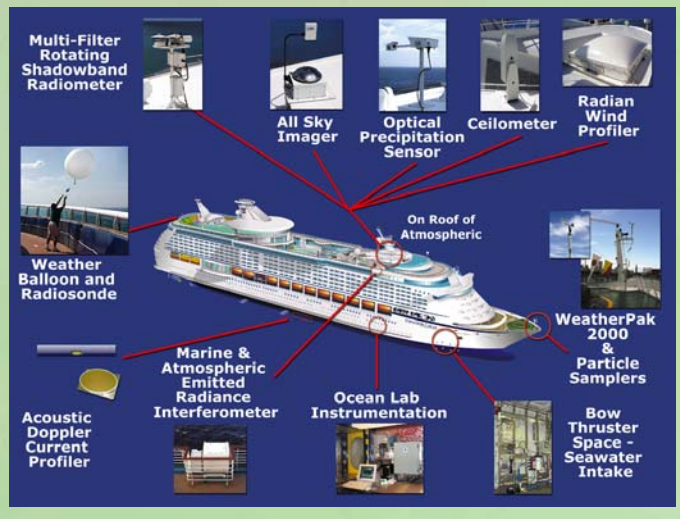
Recent status of the problem:

- No comprehensive hydrodynamic theory of far wakes of ships exists
- Ship-wake dependence on ship parameters and the effects of environmental conditions are not well understood
- Optimal parameters for SAR imaging of ship wakes (angle, band, polarization) have not been finally determined
- **Satellite SAR images found in literature typically refer to unidentified ships and unknown hydrometeorological conditions**

Our Experimental Approach

Ships equipped with hydro-meteorological sensors can provide ground truth information:

1) UM RSMAS: Royal Caribbean *Explorer of the Seas*



2) ISKS: Ferry *Le Méditerranée*, Container Ship *Polk*, Carnival Cruises Ship *Spirit,* Holland America *Amsterdam*

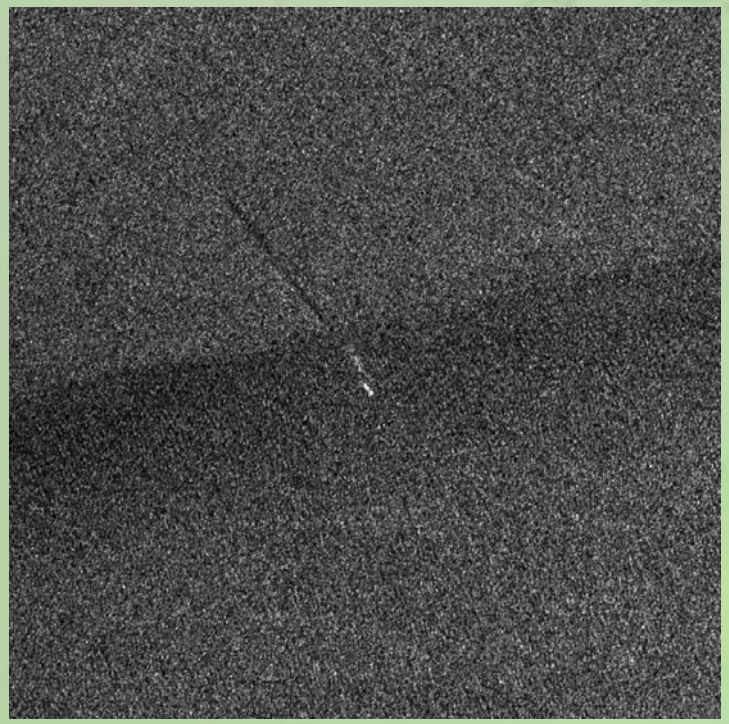
Camera Installation on the *Explorer*

Camera Locations on *Explorer*

A Caribbean Track of *Explorer of the Seas*

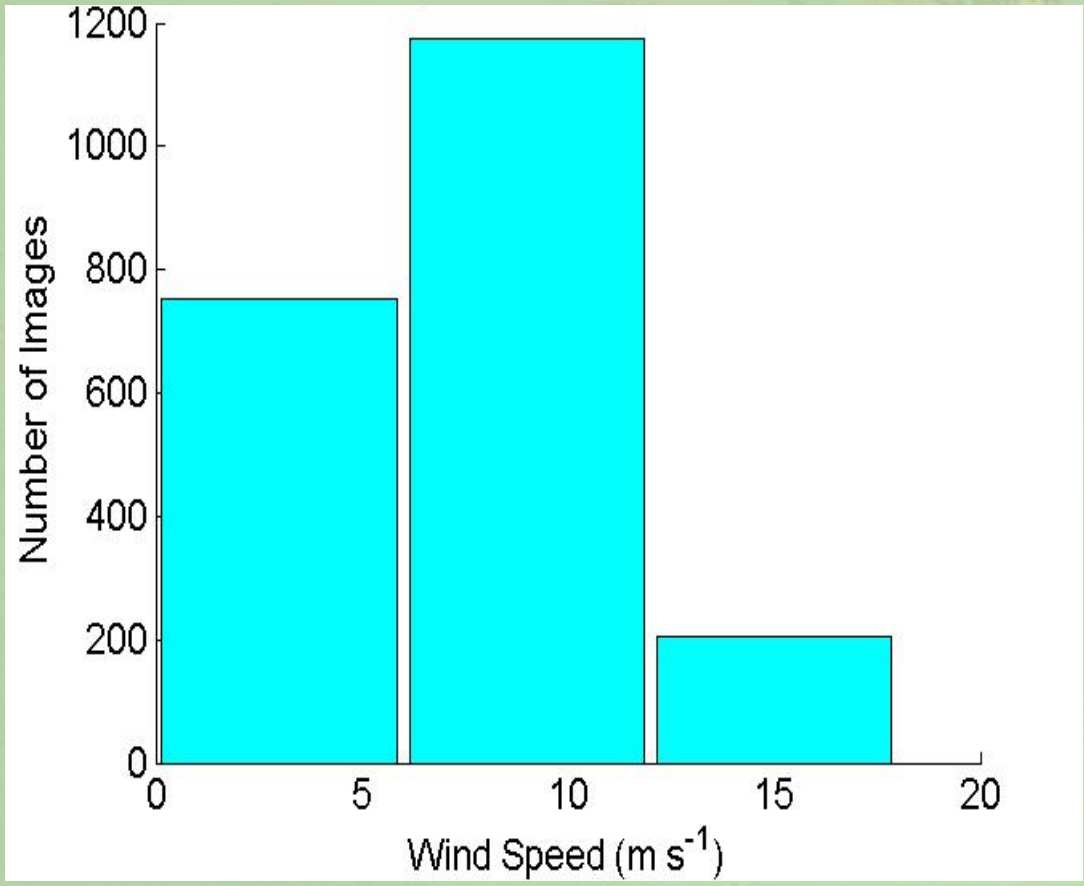
SAR and Photo Imaging of *Explorer*'s Wake

RADARSAT-1



05/21/2007, 10:51 UTC, 37.6°N, 70.3°W
Wind: 8 m/s, 314°, ship: 11 m/s, 133.2°

One Year Image Collection Statistics



Examples of wake photo-images at different wind speeds

4.4 ms^{-1}

9.5 ms^{-1}

13.1 ms^{-1}

Explorer's Wake at a Low Wind

Wake Asymmetry: Wind from Right to Left

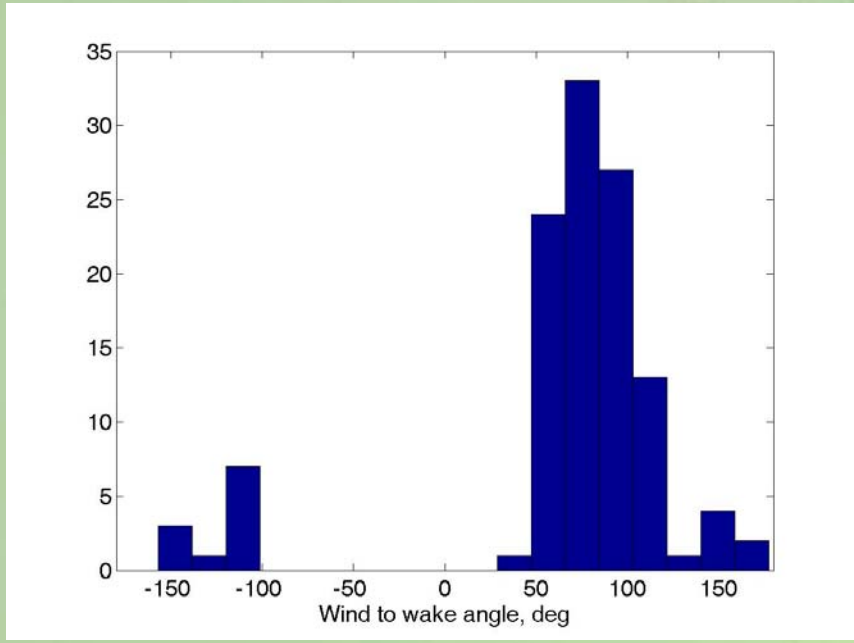
Jul 23, 2007
18:30 UTC
25.3ºN 64:06ºW
Ship:
22.8kt
177deg
Wind:
18.5kt
82deg

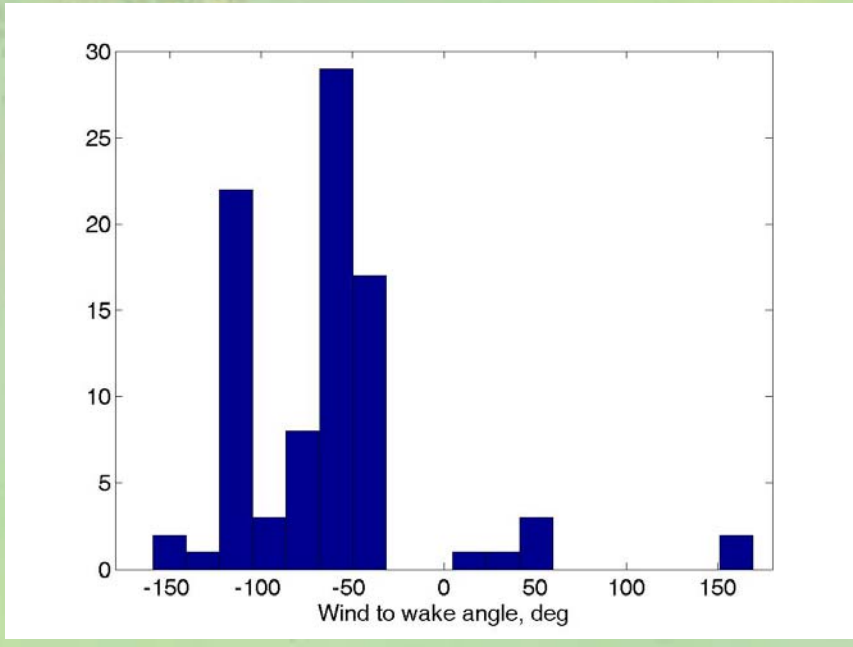
Wake Asymmetry: Wind from Left to Right

12-Jul-07
19:56 UTC
18.949°N -
66.2726°W
Ship:
21.8kt
345.4°
Wind:
22.9kt
96.7°

EX0728B0146

Ship Wake Asymmetry



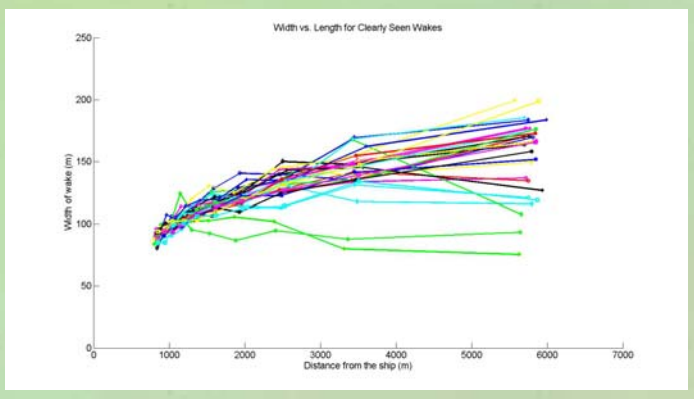


Explorer of the Seas wake asymmetry statistics: number of images where only the starboard (port) wake boundary is sharp (left and right plate, respectively). Horizontal axis: ship course relative to wind direction, degs, 0 is upwind course, positive values correspond to the wind from port side. Winds > 5 m s-1

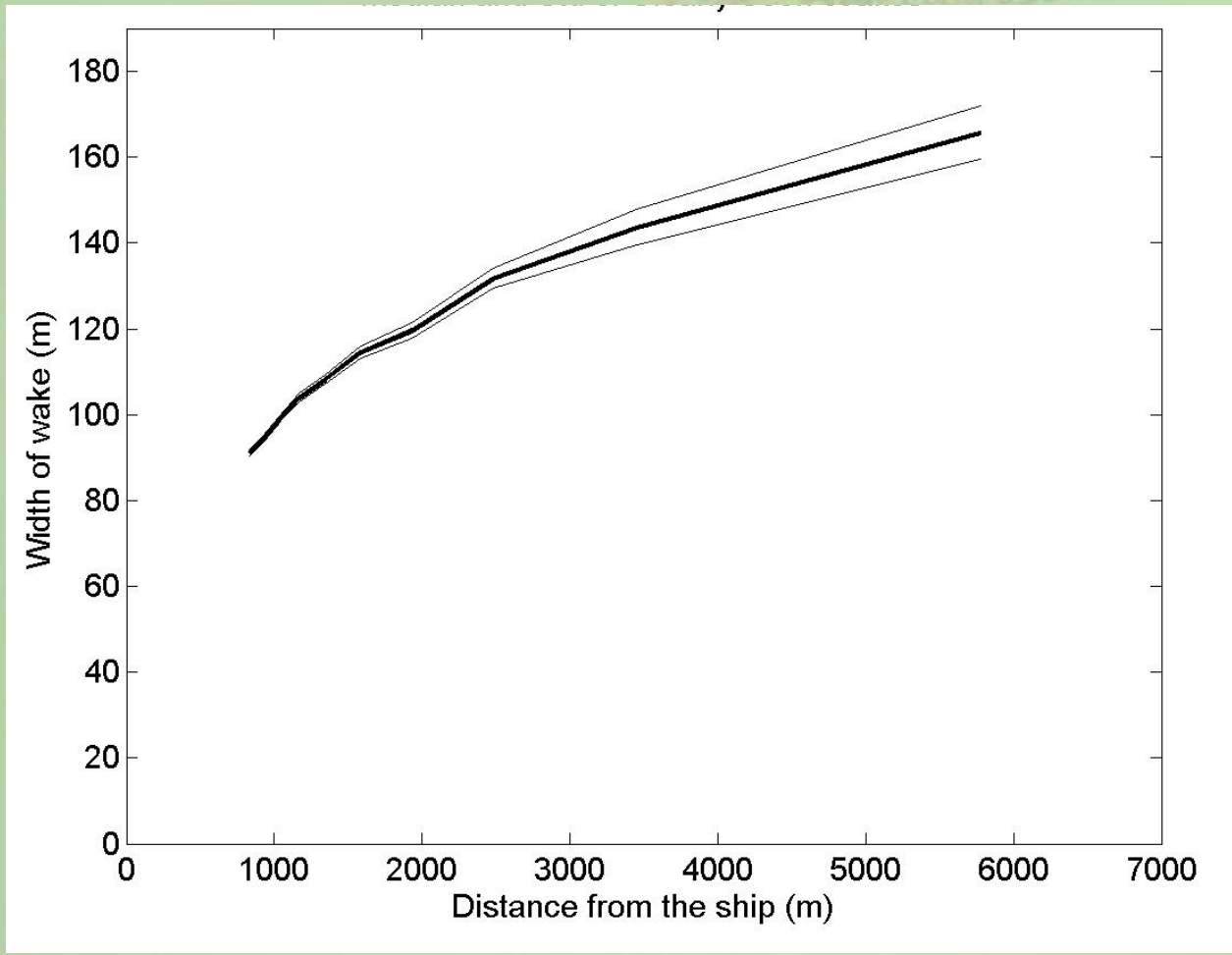
Image Processing

Contrasting

Digitizing, correction for Earth's curvature, correction for refraction



Wake width versus distance from the ship



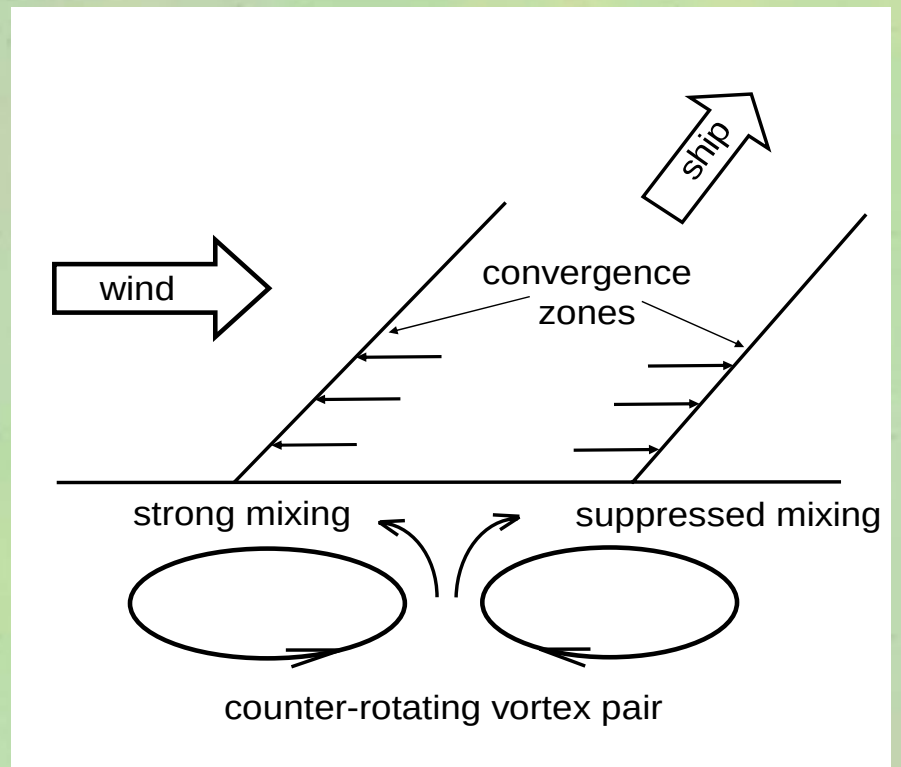
Quite Unusual Wake: Internal Waves?

Date:	01/23/2007
Time (UTC):	14:20
Lat:	19.38°N
Lon:	67.28°W
Ship speed:	21.5 kt
Ship course:	127.3°
Wind speed:	9.8 kt
Wind dir:	69.6°

Hydrodynamics of Far Wakes of Ships

Working Hypothesis:

Far wakes of ships are controlled by coherent structures developing due to contribution from the hull and, probably, depend on the number of screws



Scaling law for the dependence of wake width *W* on the distance *x*:

$$W \sim x^{1/5}$$

An attempt to include ship beam width *B*:

$$W(x) = (AxB^{(\alpha-1)})^{1/\alpha}$$

A is dimensionless proportionality constant, α varies from 4 to 7.

A model of the far wake with a point source

$$W = function(P, \rho, x, U, g)$$

where: *W* - ship wake width

P - propulsion power of the ship

ρ - water density

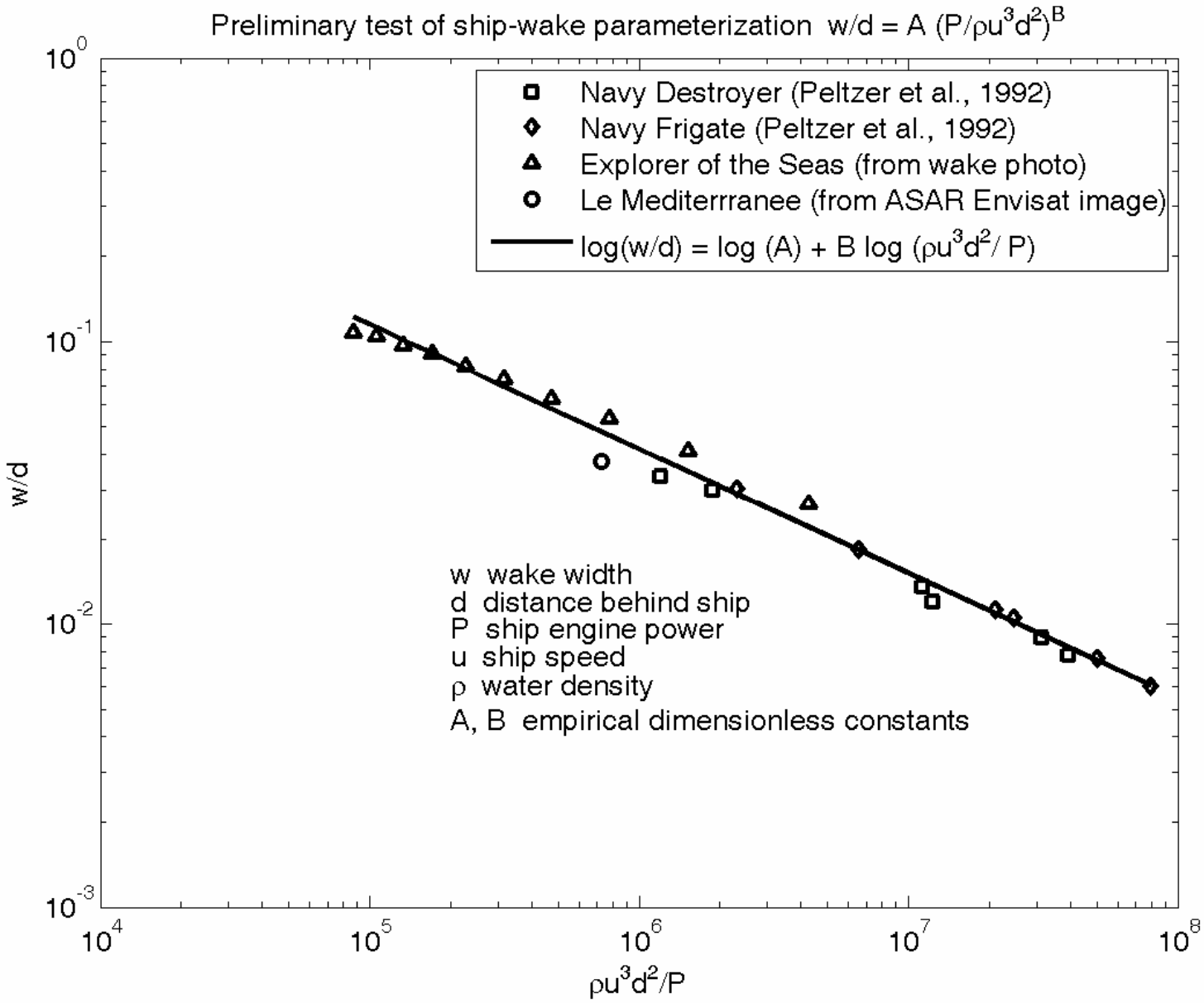
x - distance form the ship

U – ship speed

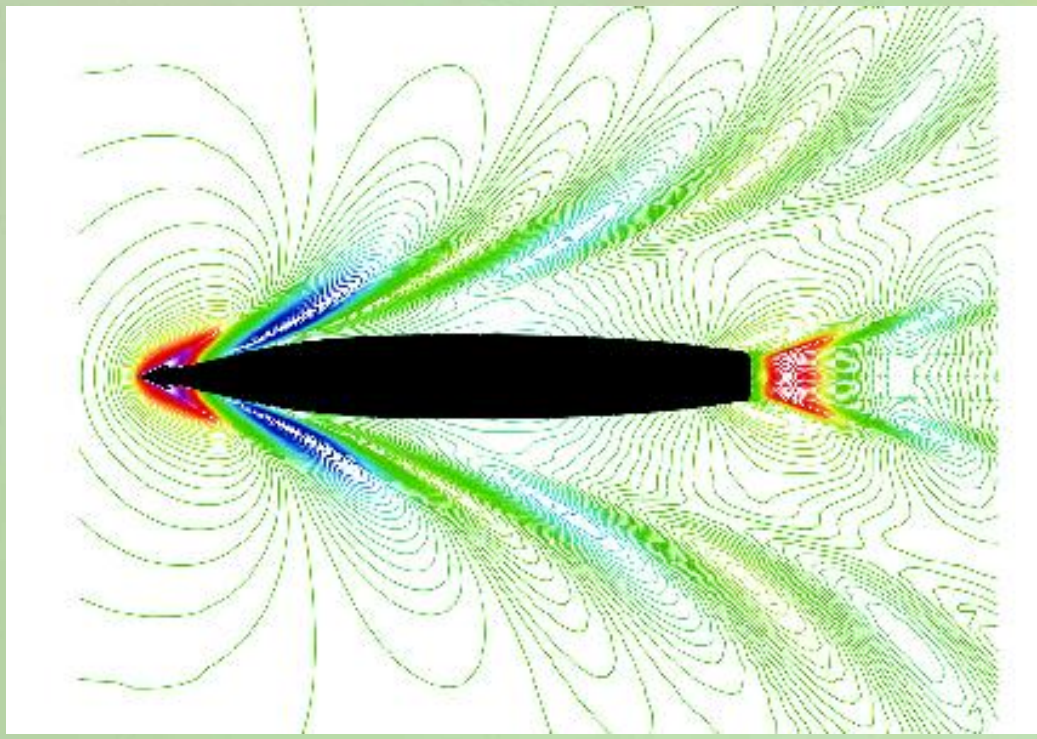
g – acceleration due to gravity

Ignoring Froude number dependence:

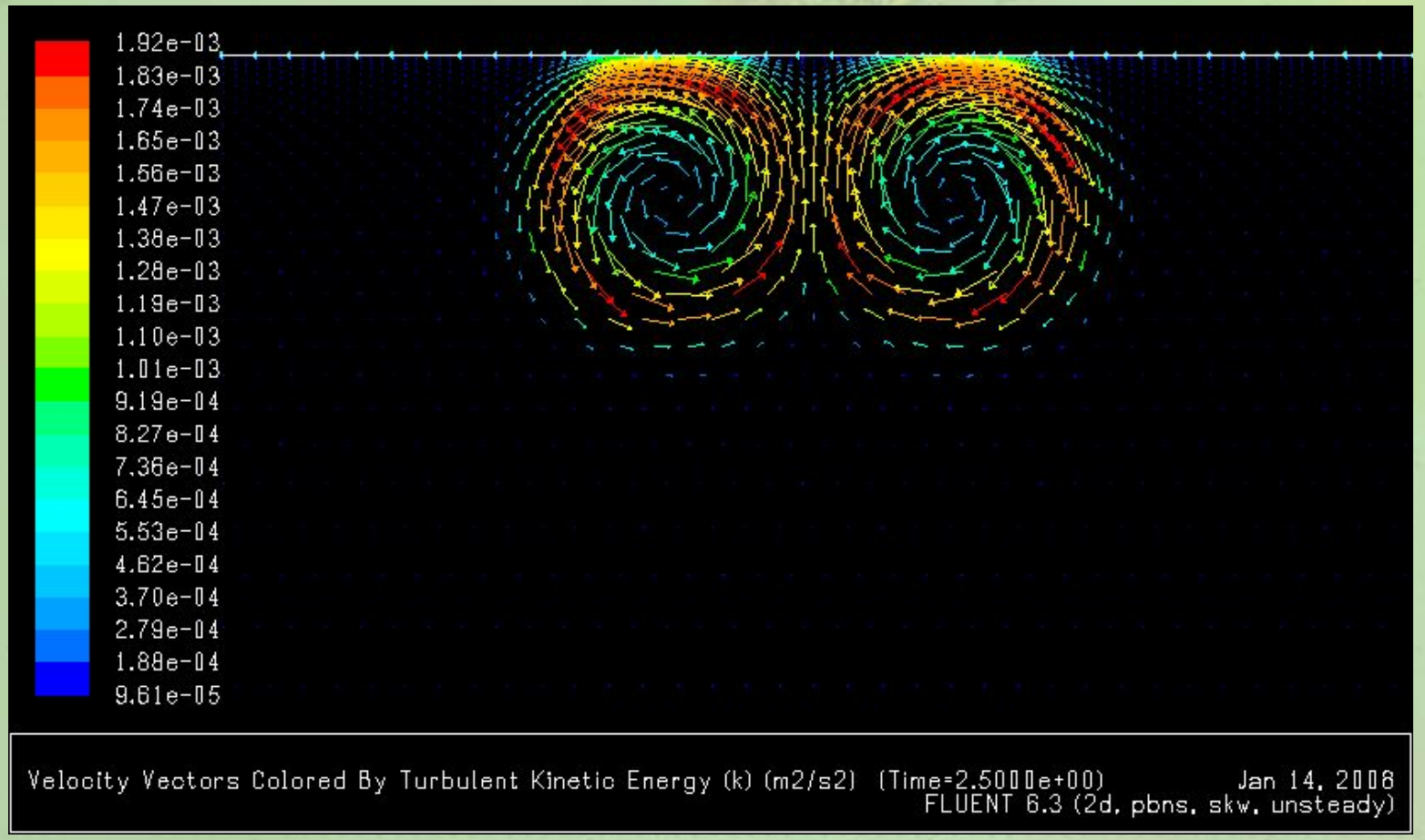
$$\frac{W}{x} \approx C\left(\frac{P}{\rho U^3 x^2}\right)^{2/5}$$


Preliminary test of ship-wake parameterization w/d = A (P/ρu³d²)^B
Navy Destroyer (Peltzer et al., 1992)
Navy Frigate (Peltzer et al., 1992)
Explorer of the Seas (from wake photo)
Le Mediterranee (from ASAR Envisat image)
log(w/d) = log (A) + B log (ρu³d²/ P)
w wake width
d distance behind ship
P ship engine power
u ship speed
ρ water density
A, B empirical dimensionless constants
w/d
ρu³d²/P
10⁰
10⁻¹
10⁻²
10⁻³
10⁴
10⁵
10⁶
10⁷
10⁸

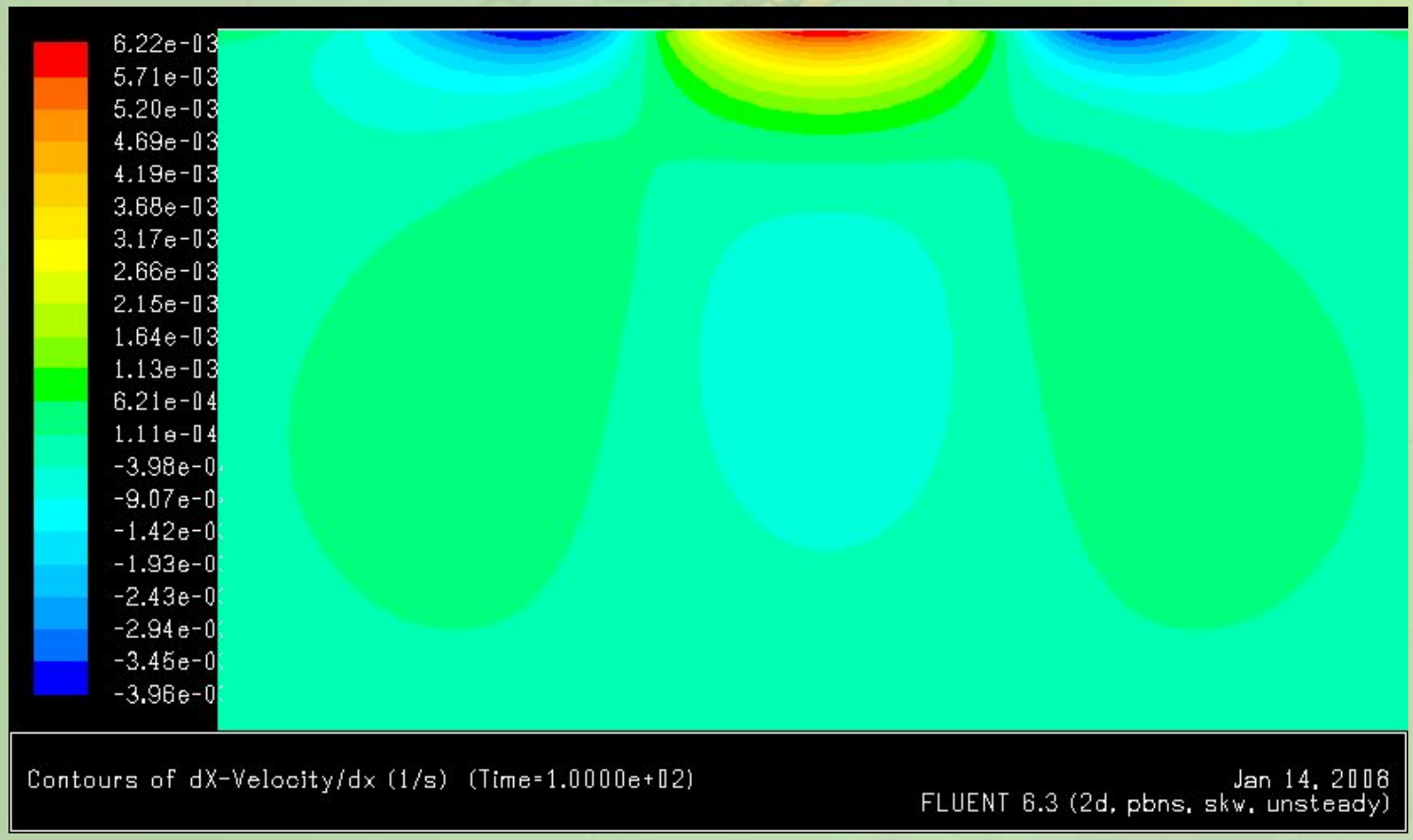
CFD *Fluent*



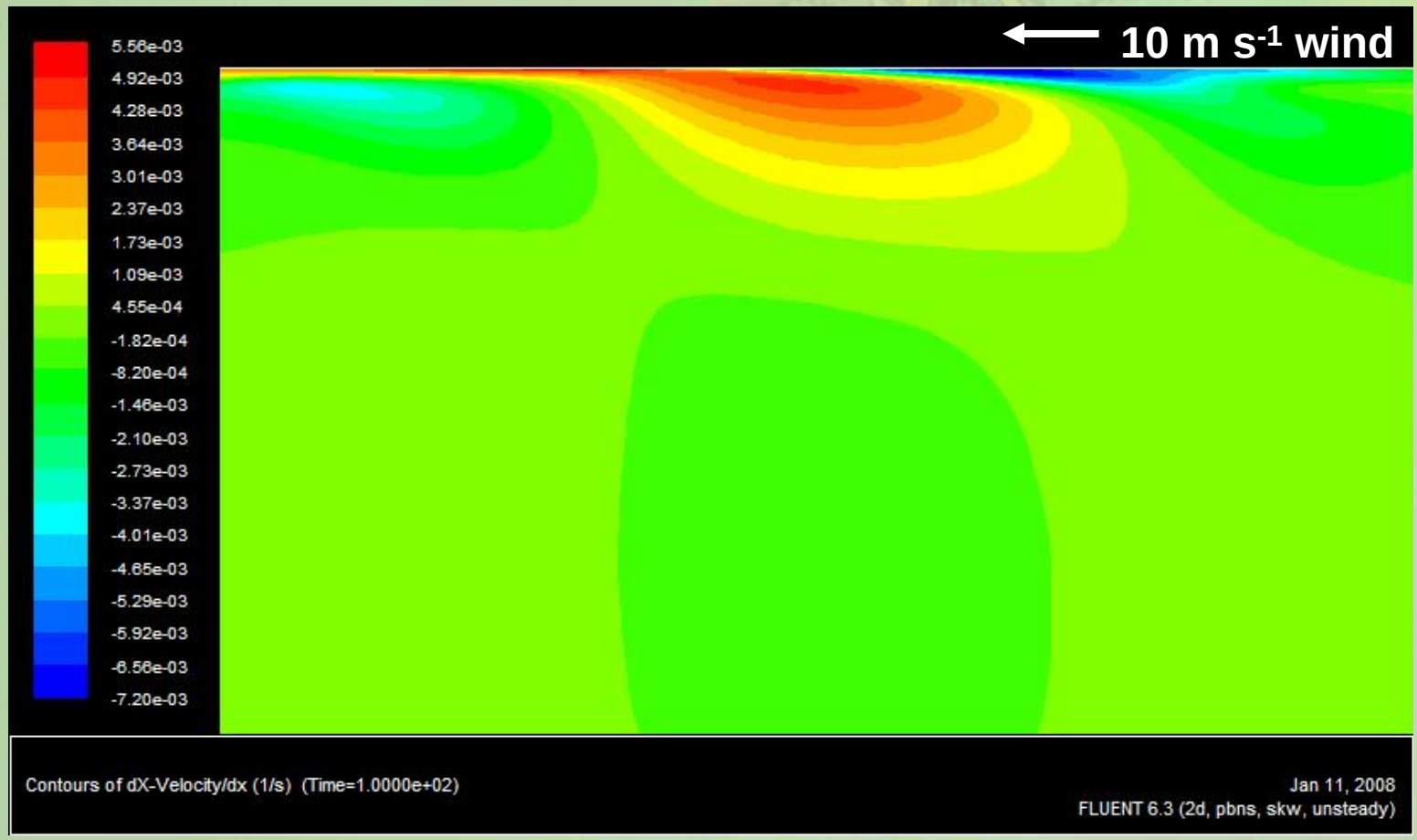
Velocity Field: Initial Conditions



Convergence (blue) and divergence zones (red) after 100 s of simulation



Wind from right to left



Conclusions

- Introduction of a new generation of SAR satellites (TerraX, COSMO-Skymed, Radarsat-2, Sentinel-1) opens an opportunity to investigate fine features of ship wakes and, thus, in combination with in-situ measurements and numeric simulations, allow the development of improved inverse algorithms aimed at ship identification
- Using ground truth data is greatly facilitated by ship-borne hydro-meteorological laboratories.
- An early result of this project is ship wake asymmetry due to wind-wake interaction, which may appear on high resolution SAR images.

Next Steps

- Planning future acquisitions of SAR images of ships with hydro-met labs including new SAE satellites
- Numerical modeling and conducting field observations in the wake

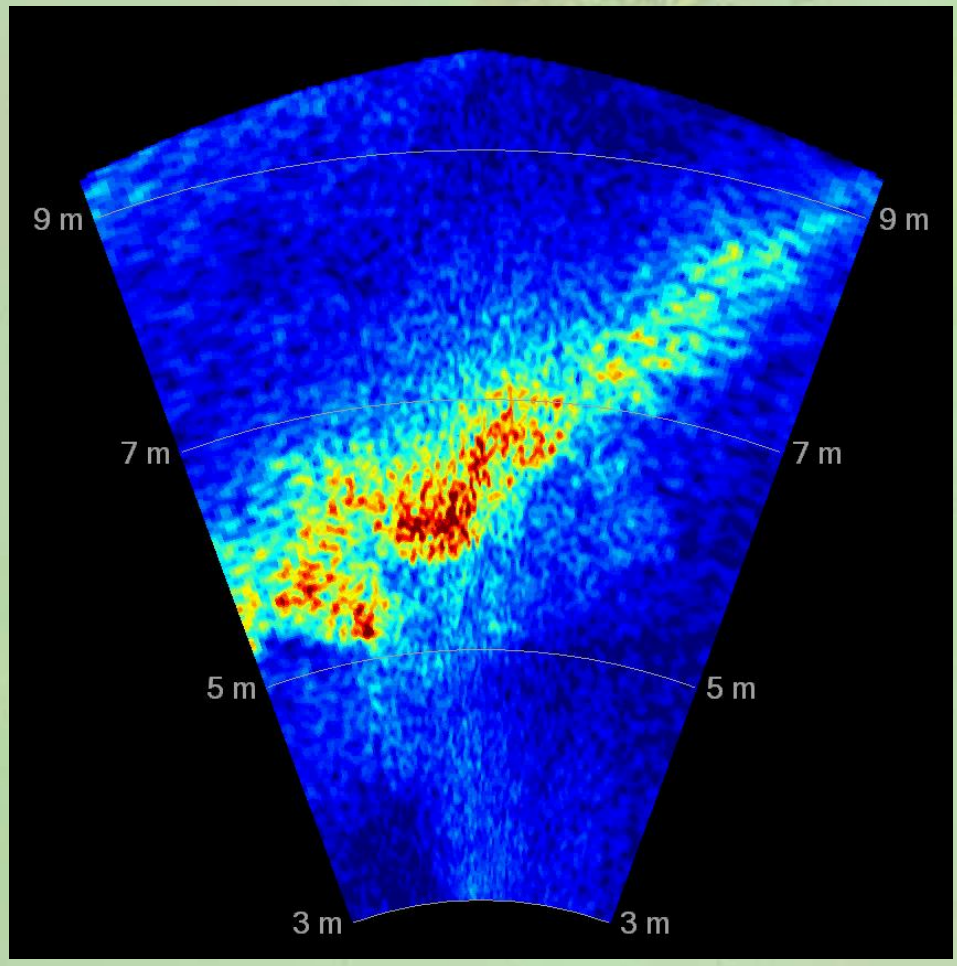
Acoustic Imaging of Ship Wakes

VideoRay MicroROV with *BlueView* acoustic Imager

Test with a Multibeam Sonar

Key Largo, FL, November 7, 2007

with the help of Don Draper (UI Technologies), Steve Van Meter (VideoRay Inc.), and BlueView Inc.



Thank you!