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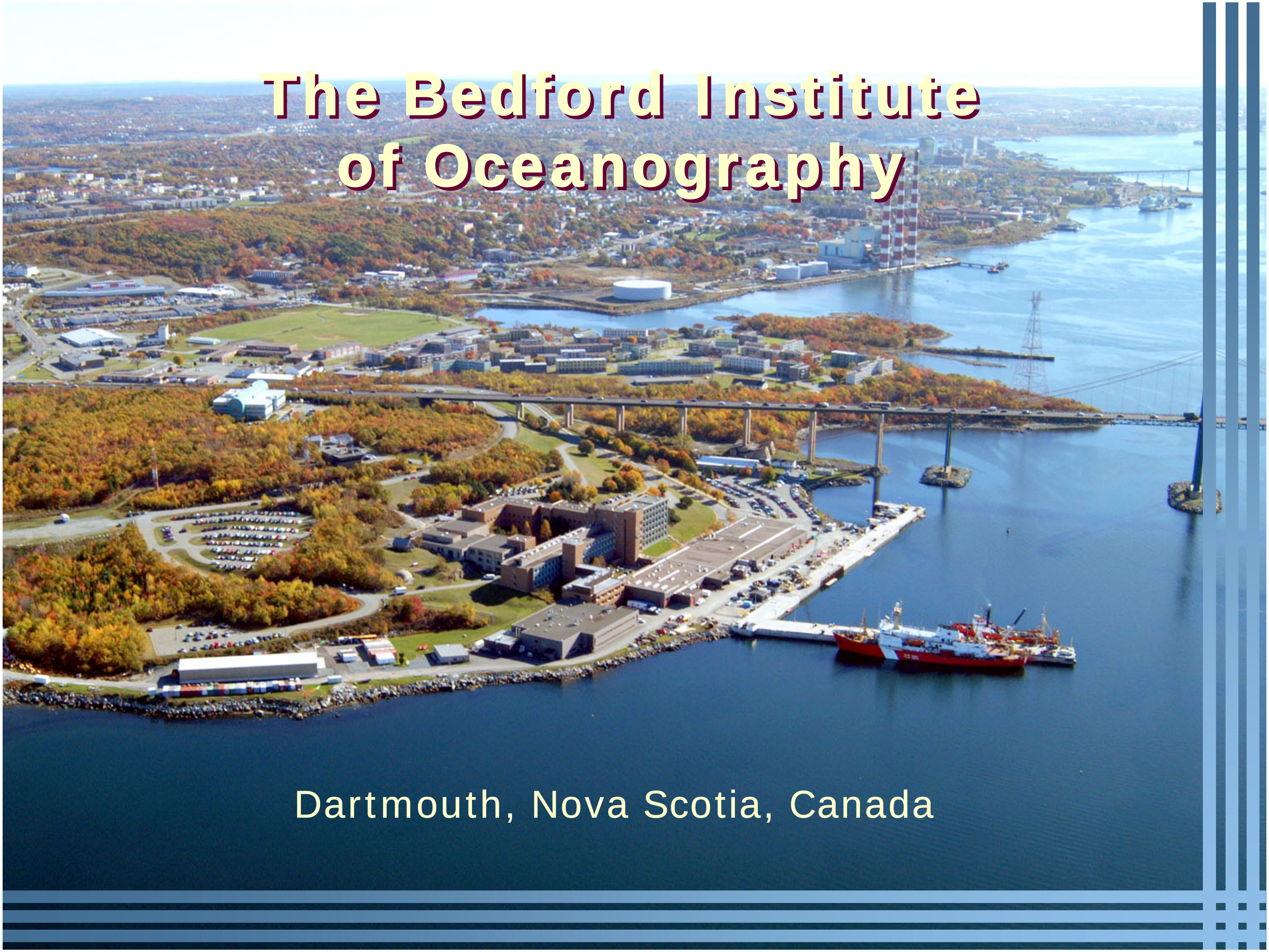

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Wave induced surface currents on the Grand Banks

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Outline

- Introduction to surface currents
- Theoretical basis
- Wave and ocean models
- Surface drifter data and model simulations
- Statistical analysis of model results
- Conclusion

Surface currents

Why

Surface currents are important for search and rescue operations, oil spill, dispersion of pollutant, ice movement and marine transportation.

Role of waves

Waves play an important role in the generation of surface currents, and transfer of momentum between wind and ocean.

Scales

The wind driven and wave induced surface currents have temporal and spatial scales similar to those of wind and wave fields.

Objectives

- Investigate the role of waves in the dynamics of surface currents
- Simulate surface currents on the Grand Banks using a coupled ocean-wave model

Dynamics of ocean currents

- Permanent/mean current – topography, density, large-scale circulation

- Tidal currents – astronomical forces

- Wind driven current
  - direct wind forcing (Ekman current)
  - surface slope

- Wave induced current: wave-current coupling
  - Stokes drift
  - Wave-ocean momentum transfer

Wave-current coupling

One-way coupling

1. Wave fields modified by mean currents (Gulf Stream, Labrador Current, ..)

$$T_{current} >> T_{wave/wind}$$

2. Short-term surface currents generated by wind and wave forcing

$$T_{current} \sim T_{wave/wind}$$

Formulation of Jenkins (1989)

$U = u + u_s + u_{tide}$

u : Eulerian current (mean current, wind driven current modified by wave effects)

u_s : Stokes drift

u_{tide} : tidal current

$$\frac{\partial E(f,\theta)}{\partial t} + \mathbf{C_g} \cdot \nabla E(f,\theta) = S_{in} + S_{ds} + S_{nl}$$

$$\mathbf{u_s} = 4\pi \iint f\mathbf{k} e^{2kz} E(f,\theta)\, df\, d\theta$$

Momentum equation and boundary condition for Eulerian current

$$\frac{d\mathbf{u}}{dt} + \mathbf{f} \times (\mathbf{u} + \mathbf{u}_s) = -\frac{1}{\rho_o}\nabla p + \frac{\partial}{\partial z}(K_m \frac{\partial \mathbf{u}}{\partial z}) + \mathbf{F}_{ds}$$

$$\mathbf{F}_{ds} = -4\pi \iint f\hat{\mathbf{k}} S_{ds} k e^{2kz} df d\theta$$

Wave dissipation

$$K_m \frac{\partial \mathbf{u}}{\partial z}\Big|_{z=0} = \frac{1}{\rho_o}(\mathbf{T}_a - \mathbf{T}_{in})$$

Boundary condition

$$\mathbf{T}_{in} = 2\pi\rho_o \iint f\hat{\mathbf{k}} S_{in} df d\theta$$

Wave generation

Methodology

- Use a wave model to compute the wave spectrum, the Stokes drift, F_{ds} and F_{in}
- Use a 3-d circulation model and the modified momentum equation to compute the Eulerian currents
- Add the Stokes drift and tidal currents to the current fields from the circulation model
- Use a simple drifter model to correct for wind drag
- Analyze model output and surface drifter data

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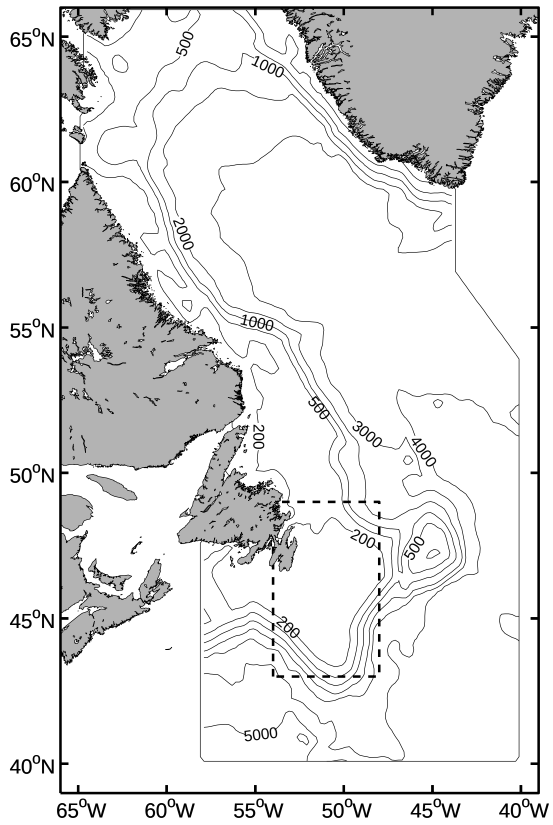
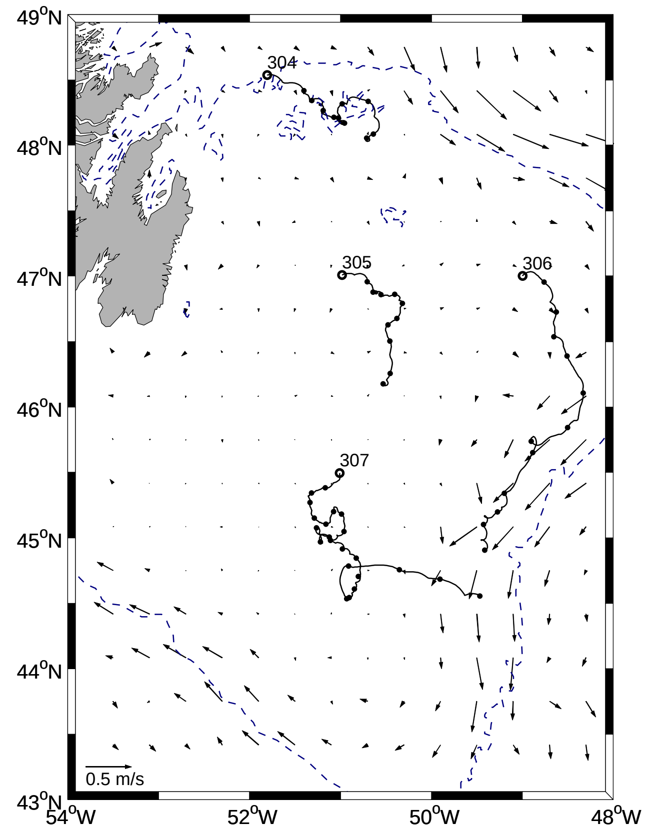
Models, forcing, data

- Ocean circulation model: Princeton Ocean Model
- Wave model: WaveWatch 3
- Atmospheric forcing: 6 hourly winds from EC
- Surface drifter data: 4 surface drifters deployed over the Grand Banks in October 2002.

Domain of ocean model



Drifter trajectories



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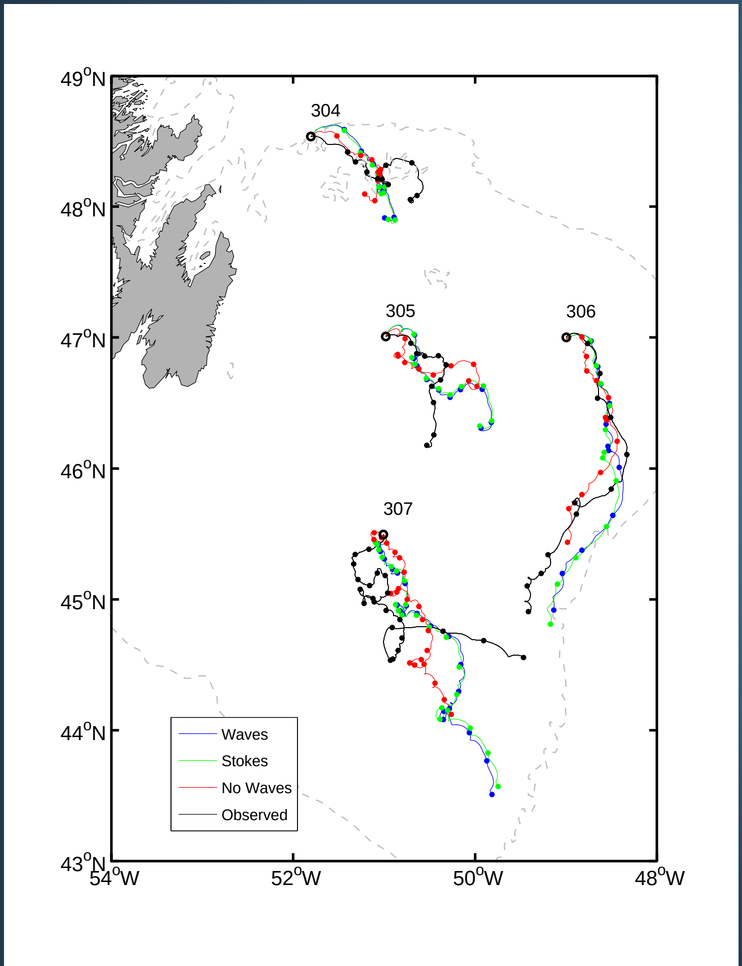
Over-all model-data comparison



Black: data

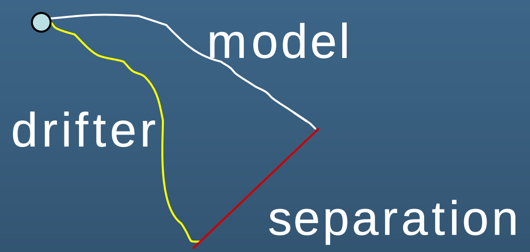
Red: no waves

Blue: with waves effects including Stokes drift

Green: Stokes drift only

Statistical analyses

1. Separation as a function of time computed for different start positions of the trajectories.

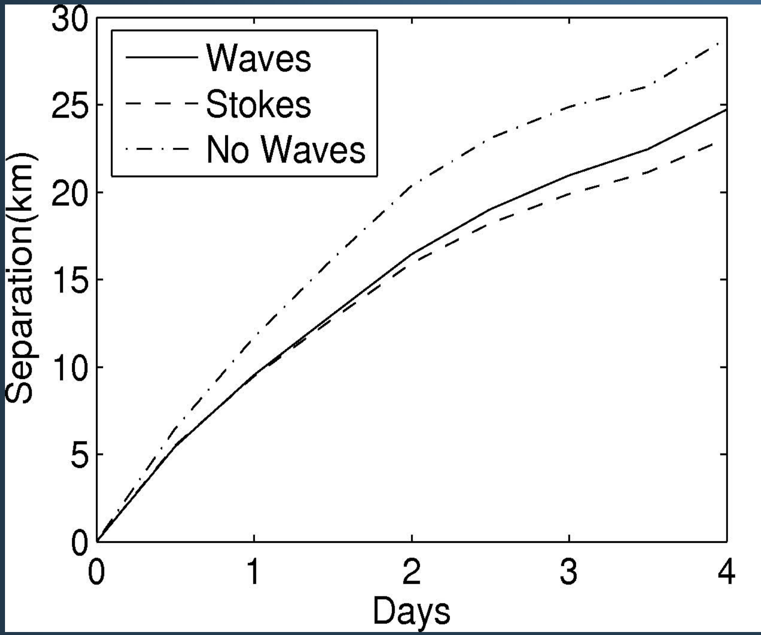


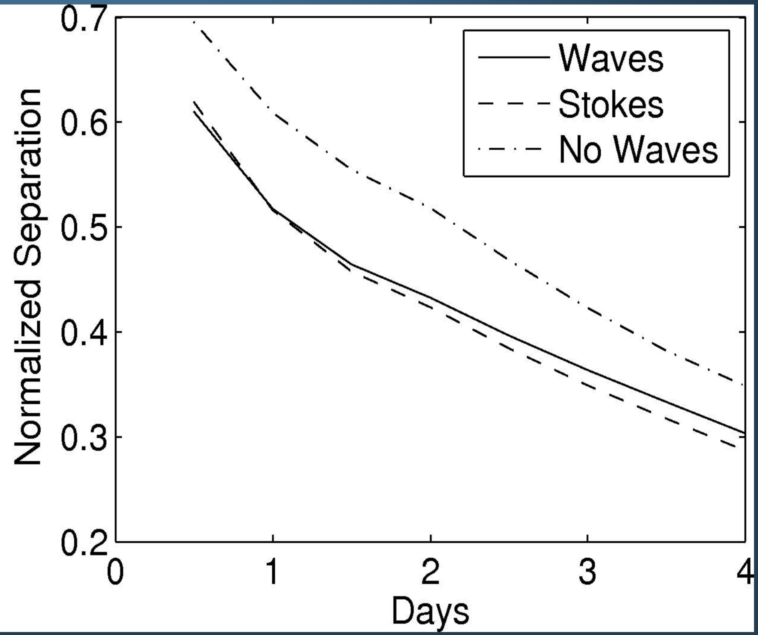
2. Linear regression of surface current velocities along the trajectories against winds

Separation analysis

Separation

Normalized separation





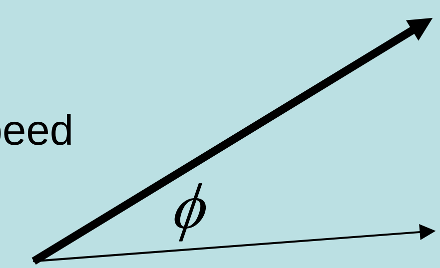
Vector regression analysis for velocity

	Observation	Model		
		(a) No wave	(b) Full wave effects	(c) Stokes drift
R **(%)**	2.06	1.54	2.07	2.08
ϕ **(º)**	30.2	58.0	33.9	35.3
Correlation coefficient (0 – 2)	0.97	0.71	0.99	0.95

$$U_b = R \cdot W \exp(i\phi)$$

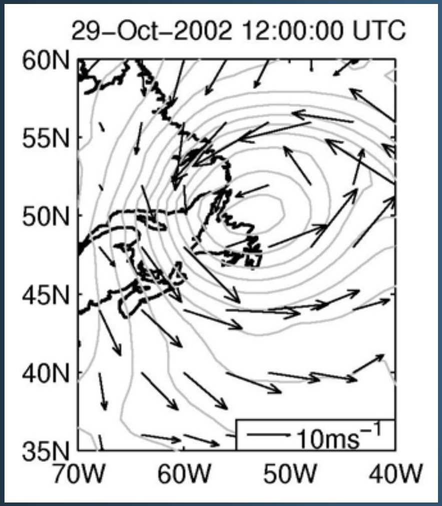
R : ratio of current speed to wind speed
ϕ : turning angle

Complex variables
U_b : surface current
W : surface wind



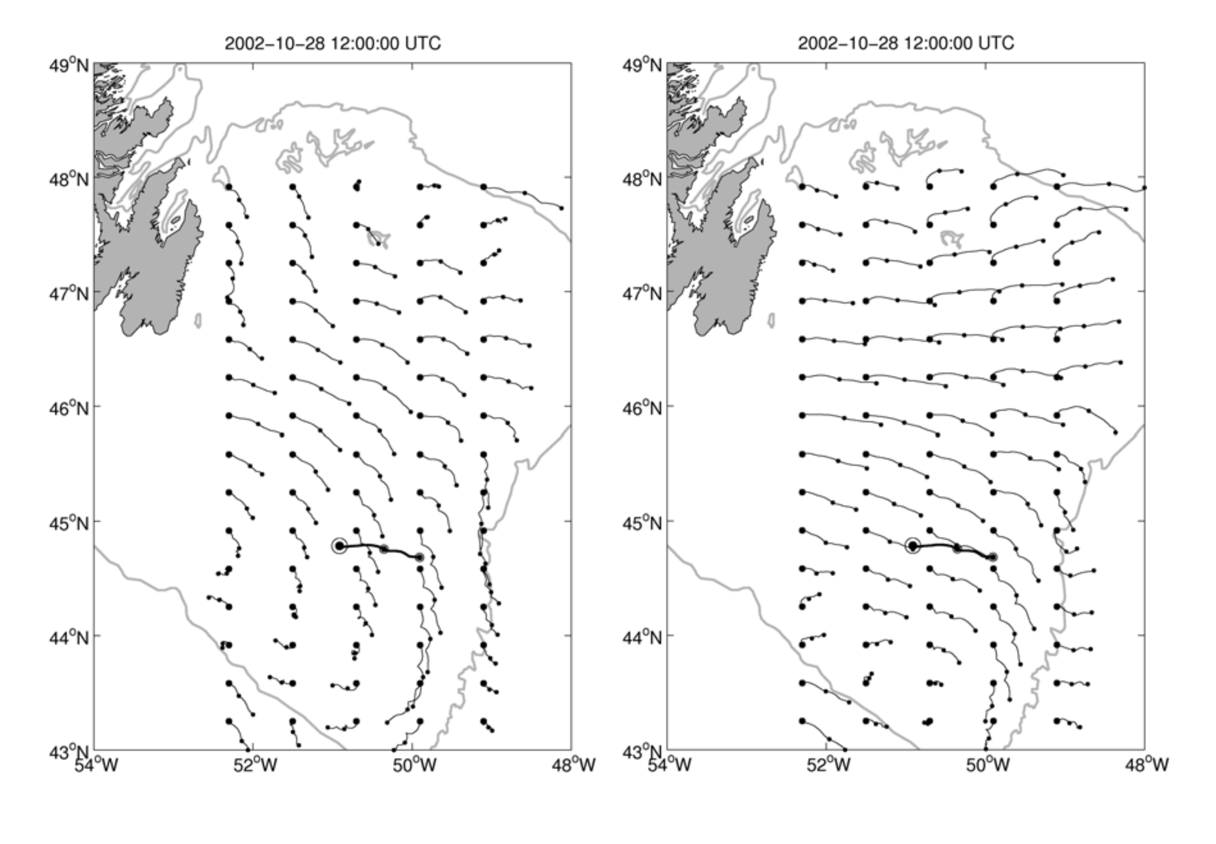
2-day surface trajectories (model and data)

Surface wind



No wave effects

With waves



Parameter values in the base experiments.

Model	**Symbol**	**Value in base runs**	***Parameters***
Ocean model	β	4×10^{-5}	Mixing length parameter in eddy viscosity
	z_{oa}	0.1 m	Apparent bottom roughness
Drifter model	r^2	0.18×10^{-4}	Drag parmeter ratio of drifter
Wave model	WAM	S_{in} and S_{ds} parameterizations from WAMDI Group	

Sensitivity experiments

Parameter	**Value**	**R (%)**	**ϕ (deg)**	**Correlation Coefficient (0-2)**
Base set	Table	2.07	33.9	0.99
β	2×10^{-5}	2.32	33.6	1.10
z_{oa}	0.5 m	2.06	33.7	1.00
r^2	0.4×10^{-4}	2.13	32.3	1.00
S_{in},, S_{ds}	WW3	1.99	35.9	0.94

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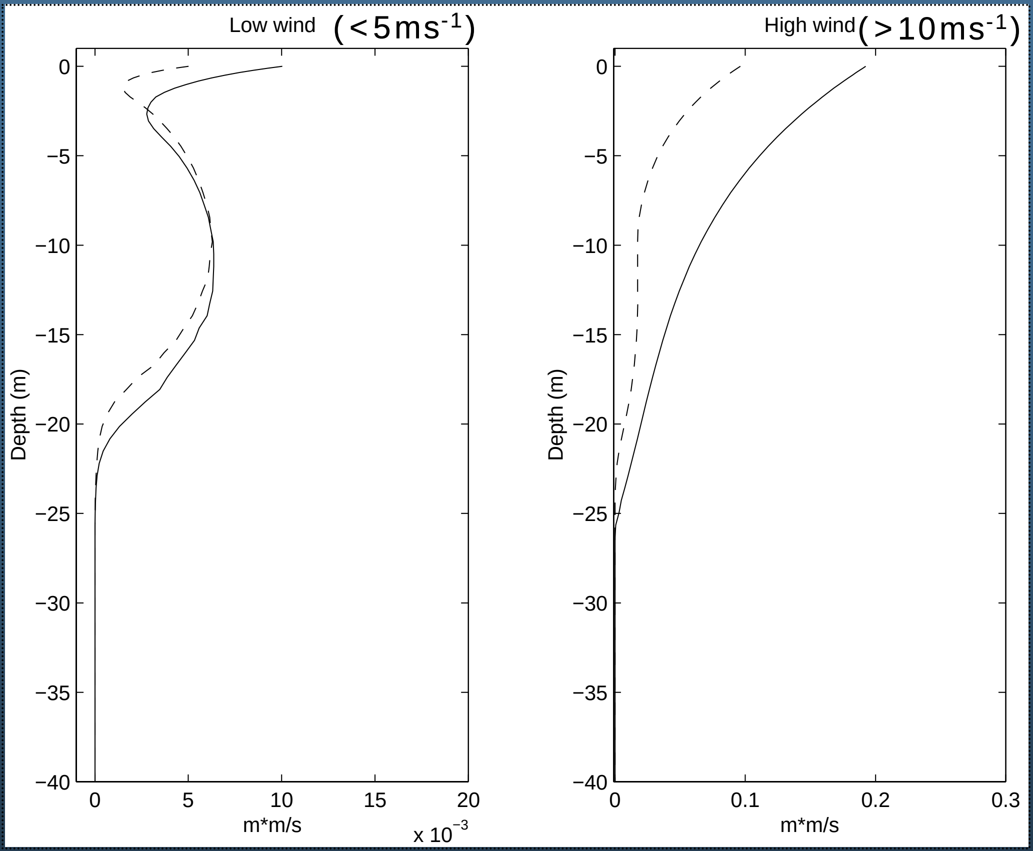
Profiles of eddy viscosity



$\beta = 4 \times 10^{-5}$ (solid line), 2×10^{-5} (dotted line)

Conclusions

- The inclusion of the wave effects in ocean models can improve the simulation of surface currents significantly;
- The dominant wave effect on wind-driven surface currents is the Stokes drift;
- The effect of the Stokes drift can increase the speed by 35% and turn the currents toward the wind directions;
- The model parameters that can influence surface currents include eddy viscosity, wave spectrum parameterization and bottom friction.

The end

Thank you

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