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THE STOKES DRIFT IN OCEAN SURFACE DRIFT PREDICTION

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Why are we interested by surface drift prediction ?

Ocean surface drift forecasts are essential for numerous applications :

- Search and rescue and oil spill response operations.
- Predict the transport of pelagic eggs, larvae and detritus or other organisms and solutes.
- Track plastic debris and predict their accumulation zones .
- Environmental planning and management.

What does the drift of a floating object at the sea surface depend on ?

- Geophysical forcings such as wind, waves and surface currents which interact together.
- The drift velocity of a floating object depends on how it responds to these geophysical forcing (Daniel et al. 2002 ; Breivik et Allen. 2008).
- The drift of a floating object depends of it size, shape and nature.

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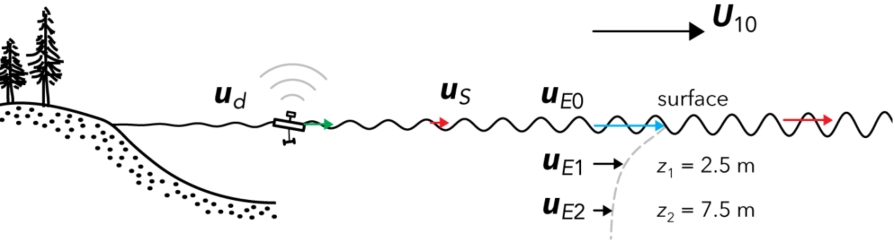
Canadian Operational Drift Model (Model A) : $\mathbf{u}_d = \mathbf{u}_{E1} + \alpha \mathbf{U}_{10} \quad \alpha \in [1\ ;\ 6\%]$



The wind correction term $\alpha \mathbf{U}_{10}$ accounts for windage and unresolved processes such as :

- Current shear
- Stokes drift
- Submesoscales processes and so on

Tamtare et al. 2019 (published in JOO) extrapolated Eulerian current and reduced the bias induce by current shear. Model D $\mathbf{u}_d = \mathbf{u}_{E0} + \alpha_D \mathbf{U}_{10}$

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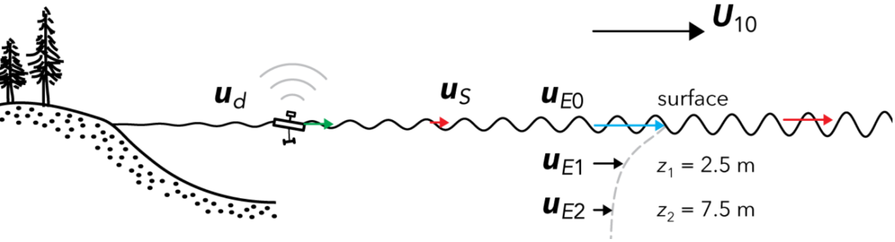

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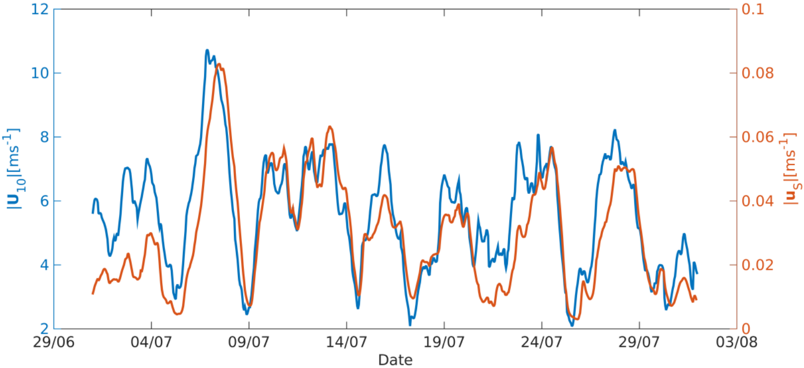
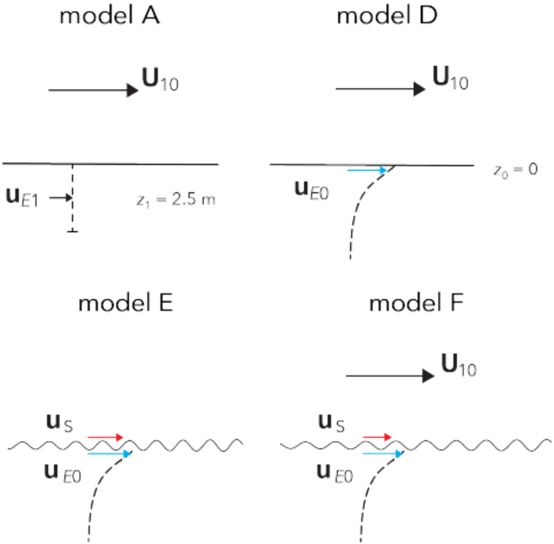
Wind and Stokes drift

Here, we suppose that because of the evolution of the sea state, winds and waves are not always correlated, which does not allow representing the Stokes drift using a wind correction.



Wind intensification and wind-generated waves are not instantaneous.
$\Longrightarrow$ **We can not parametrized Stokes drift using a local wind.**

Schematic of drift models



Drift models

1. Model A [Stantard]

$$\mathbf{u}_d = \mathbf{u}_{E1}^{A} + \alpha_A \mathbf{U}_{10} \qquad \alpha_A = 0.023 + i0.0020$$

2. Model D [Ekman response to a variable wind $(K_z = f(z))$]

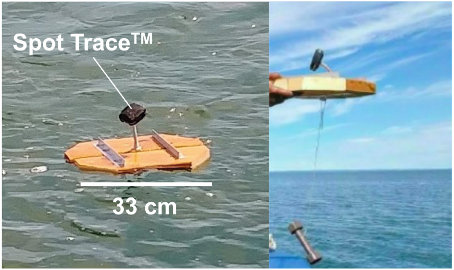
$$\mathbf{u}_d = \mathbf{u}_{E0}^{D} + \alpha_D \mathbf{U}_{10} \qquad \alpha_D = 0.013 + i0.0001$$

3. Model E [Extrapolation and Stokes drift]

$$\mathbf{u}_d = \mathbf{u}_{E0}^{D} + \mathbf{U}_s \qquad \alpha_E = 0.000 + i0.0000$$

4. Model F [Extrapolation, windage and Stokes drift]

$$\mathbf{u}_d = \mathbf{u}_{E0}^{D} + \alpha_F \mathbf{U}_{10} + \mathbf{U}_s \qquad \alpha_F = 0.011 + i0.0007$$



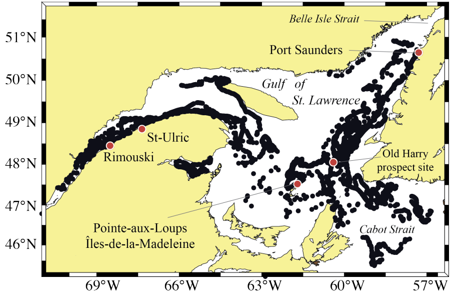
A drifting buoy designed and built at Institut des sciences de la mer de Rimouski. The Spot Trace TM device is attached to the 33 cm-wide and 4 cm-thick wooden platform with a springing metal coil. A weigth hanging 20 cm below the buoy is attached to prevent capsizing.

Models

1-GSL model $\Longrightarrow$ surface current
Horizontal resolution 5km
Vertical resolution 5m

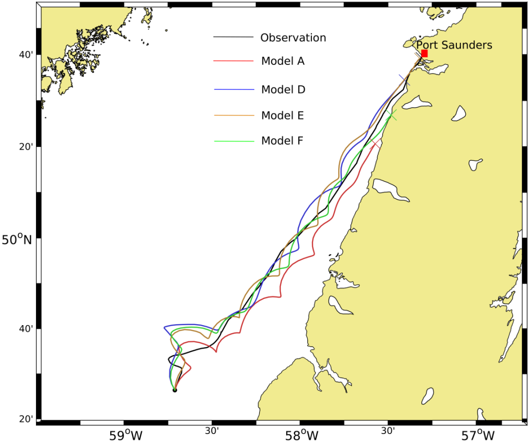
2-WAVEWATCH III (5km) $\Longrightarrow$ Stokes drift

3-RDPS (35km) $\Longrightarrow$ wind



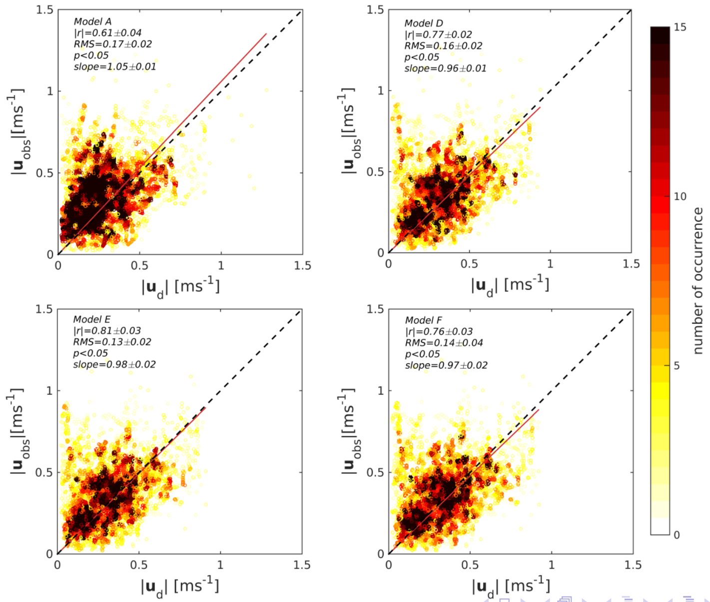
2014-2015

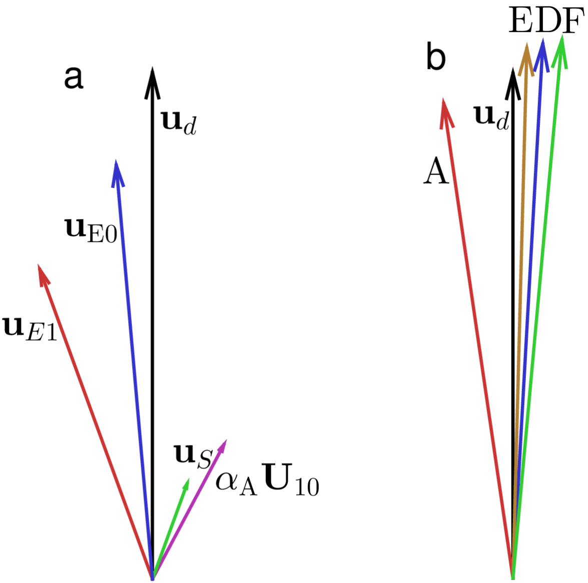
Results : examples of observed trajectory (black line) and simulated trajectories



Trajectory predicted by model E is closer to the observed trajectory.

$$r = \frac{\langle \mathbf{u}^*_{\mathbf{obs}}(t).\mathbf{u}_d(t)\rangle}{\langle \mathbf{u}^*_{\mathbf{obs}}(t).\mathbf{u}_{\mathbf{obs}}(t)\rangle^{1/2}\langle \mathbf{u}^*_d(t).\mathbf{u}_d(t)\rangle^{1/2}} \quad (1)$$





Model A

$u_{E1} + \alpha_A U_{10}$

Model D

$u_{E0} + \alpha_D U_{10}$

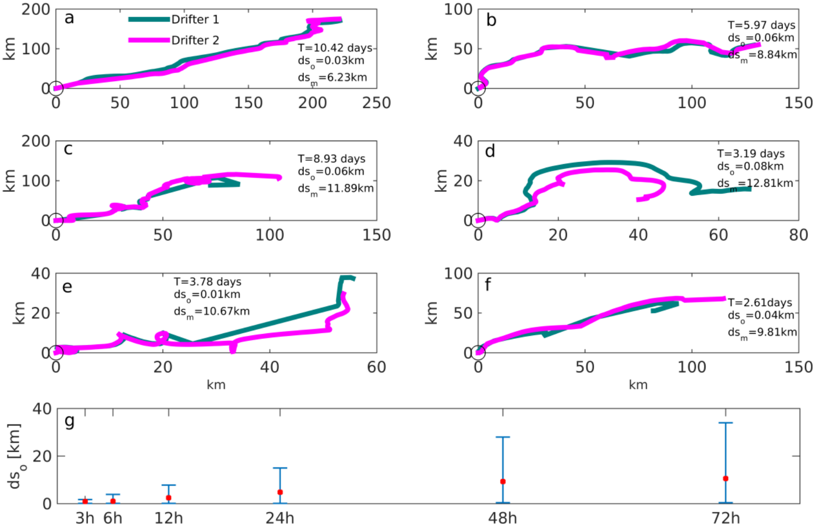
Model E

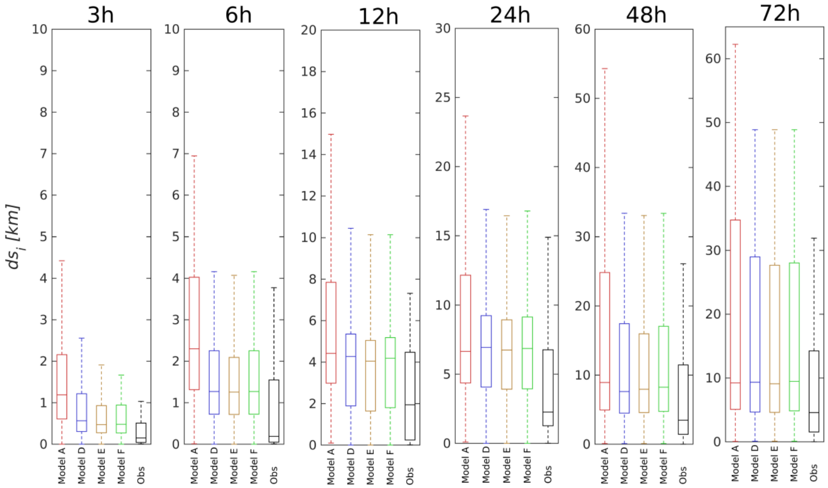
$u_{E0} + u_s$

Model F

$u_{E0} + u_s + \alpha_F U_{10}$

Adding explicitly Stokes drift to the extrapolated surface current improves both the direction and the amplitude of surface drift velocity.


a
Drifter 1
Drifter 2
T=10.42 days
ds_o=0.03km
ds_m=6.23km
b
T=5.97 days
ds_o=0.06km
ds_m=8.84km
c
T=8.93 days
ds_o=0.06km
ds_m=11.89km
d
T=3.19 days
ds_o=0.08km
ds_m=12.81km
e
T=3.78 days
ds_o=0.01km
ds_m=10.67km
f
T=2.61days
ds_o=0.04km
ds_m=9.81km
g
km
ds_o [km]
3h 6h 12h 24h 48h 72h



Separation distances between the observed drifters pairs also increase with time.

Lagrangian cumulative separation (Liu et al., 2011)

$$s = \frac{\sum dl_i}{\sum_{i=0}^{N} \sum_{j=0}^{i} dl_j} \qquad (2)$$

N number of observations ; dl_i are the distances between the observed and simulated positions and dl_j are the distances between two consecutive positions on the observed trajectory.

Skill scores (Röhrs et al., 2012)

$$ssc = \begin{cases} 1 - s & \text{si s} \leqslant 1 \\ 0 & \text{si s} > 1 \end{cases} \qquad (3)$$

Models D-F improve the separation distance compared to model A

$$\Delta_{\mathsf{A}i} = \langle (ds_{\mathsf{A}} - ds_i)/ds_{\mathsf{A}} \rangle \times 100\%, i = \text{D,E,F} \qquad (4)$$

		Model A	Model D	Model E	Model F
Metric	Lead time				
ssc					
	3 h	0.70	0.89	**0.93**	0.91
	6 h	0.66	0.86	**0.90**	0.86
	12 h	0.65	0.87	**0.88**	0.85
	24 h	0.63	0.84	**0.85**	0.84
	48 h	0.62	0.83	**0.86**	0.81
	72 h	0.61	0.79	**0.81**	0.78
Δ_{Ai} (%)					
	3 h	-	41	**50**	46
	6 h	-	38	**43**	38
	12 h	-	33	**40**	32
	24 h	-	35	**37**	34
	48 h	-	31	**35**	30
	72 h	-	24	**26**	24

A skill of 1 means a perfect agreement between simulation and observation all along the trajectory.

- Taking into account explicitly Stokes drift modifies amplitude and direction of drift speed and improve surface drift forecasts.
- No empirical wind correction term is required for surface drift forecasting when the wind-induced vertical shear and the Stokes drift are explicitly accounted for.
- The chaotic nature of oceanic and atmospheric motions sets an inevitable limit on surface drift forecasting skills as illustrated here by the increasing separation distance with time of drifter pairs.
- We share our data with ECCC (Environment and Climate Change Canada).
- The mobile application is developed in collaboration with SLGO to help users to display the surface drift in real-time.

Tamtare T., D. Dumont, C. Chavanne (in review) : The Stokes drift in ocean surface drift prediction. J Oper Oceanogr.

THANK YOU

[1]

F. Ardhuin, F. R. Martin-Lauzer, B. Chapron, P. Craneguy, F. Girard-Ardhuin, and T. Elfouhaily.
Dérive à la surface de l'océan sous l'effet des vagues.
Comptes Rendus - Geoscience, 336(12) :1121–1130, 2004.