Using bottom pressure sensors to measure form drag on topography

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November 10, 2011
CERF Conference
Form drag and mixing

Form drag causes:
- internal wave generation
- eddy generation
- local mixing and dissipation

\[ D_{\text{form}} = - \int_{A_0} p_B \frac{\partial h}{\partial x} \, dA_0 \]

Tidal energy conversion \( = D_{\text{form}} U \)
Previous work
> Measured the internal form drag
  Edwards et al., 2004
> Measured the external form drag
  McCabe et al., 2006

Our goal
> Measure the total form drag with bottom pressure sensors
Why measure form drag?

Find better parameterizations for form drag that can be implemented into larger scale models.

Imagine some topography with tides

Fine grid resolution resolves form drag >> Drag coefficients well parameterized

Coarse grid resolution does not resolve form drag >> Drag coefficients unknown

Build model
New method: PPODs

Use bottom pressure sensors (PPODs) to directly measure form drag.

Bottom pressure sensors: PPODs

Also ship transect measurements: ADCP, CTD
Bottom pressure at max flood

- High pressure anomaly on the upstream side
- Low pressure anomaly on the downstream side

Total PPOD pressure
- Resting pressure
- Tidal height

= Pressure anomaly
Density at max flood

- Internal lee wave visible in density section
- Bottom pressure anomaly from the density section

\[
\text{internal pressure} + \text{external pressure} = \text{PPOD pressure}
\]
Eddy currents at max flood

As of now, form drag due to the eddy and other surface perturbations is unquantified.
Eddy pressure from model

- **External pressure**
  - [± 1 cm]

- **Internal pressure**
  - [± 1 cm]

- **Total bottom pressure**
  - [± 1 cm]

- **Surface vorticity**
  - [$10^{-3}$ 1/s]

- **Negative surface pressure anomaly**
- **Positive internal pressure anomaly**
- **External and internal pressures counteract each other**

**Legend**:
- **Surface eddy**
- **Internal lee waves**
- **Bottom pressure**
Time series of form drag

Spatial integral of pressure anomalies at every time step gives a time series of form drag

\[ D_{\text{form}} = - \int_{A_0} p_B \frac{\partial h}{\partial x} \ dA_0 \]
Time series of form drag

Tidal velocity (m/s)

Form drag (N x 10⁷)

Power (W x 10⁶)

Large peaks of dissipation during strong flood tides
Drag coefficients in models

In a 5-km grid cell:
> without Three Tree Point, just frictional drag
  \[ C_D = 3 \times 10^{-3} \]

> with Three Tree Point, frictional and form drag
  \[ C_D = 3 \times 10^{-2} \]

>>> Drag is 10x higher with form drag than just with frictional drag
Conclusions

• Bottom pressure sensors (PPODs) can be used to directly measure form drag on under-sea topography.

• At Three Tree Point, the internal fluctuations of density surfaces make up about half of the total form drag.

• The form drag at Three Tree Point is significant enough to raise the frictional drag coefficient in a model by 10 times its original value.

Using bottom pressure measurements, we have made a step towards better form drag parameterizations.