What we can learn about the ocean in a 60 x 60 x 60 cm^3 tank

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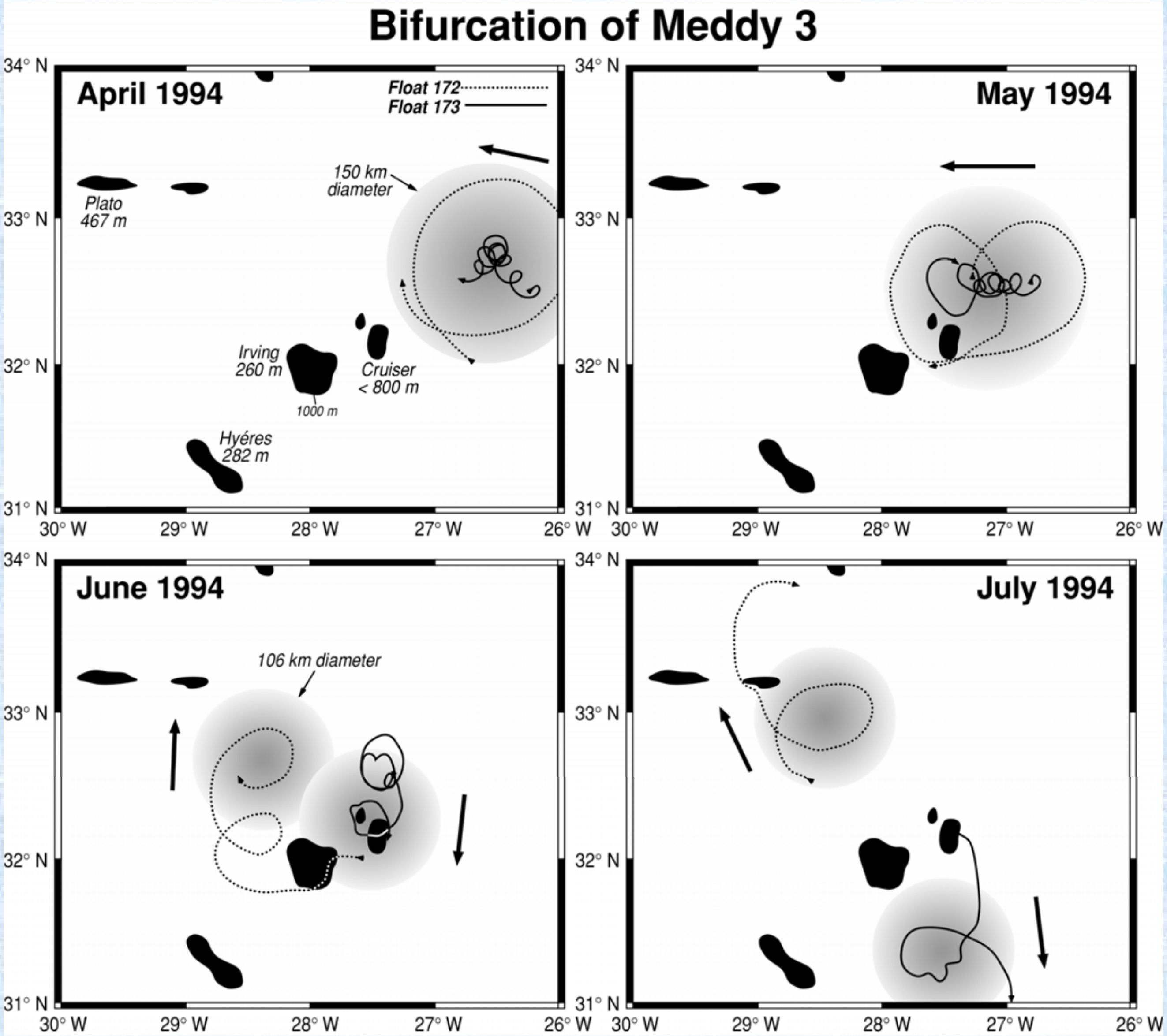
Outline

- **Oceanic vortices**
- **Laboratory vortices:**

  - Self propagating

  - Advected by a background flow
- **Vortex collision with a seamount**
- **Comparison of laboratory results with oceanic observations**

Meddy collision with one island



Richardson and Tychensky (1998)

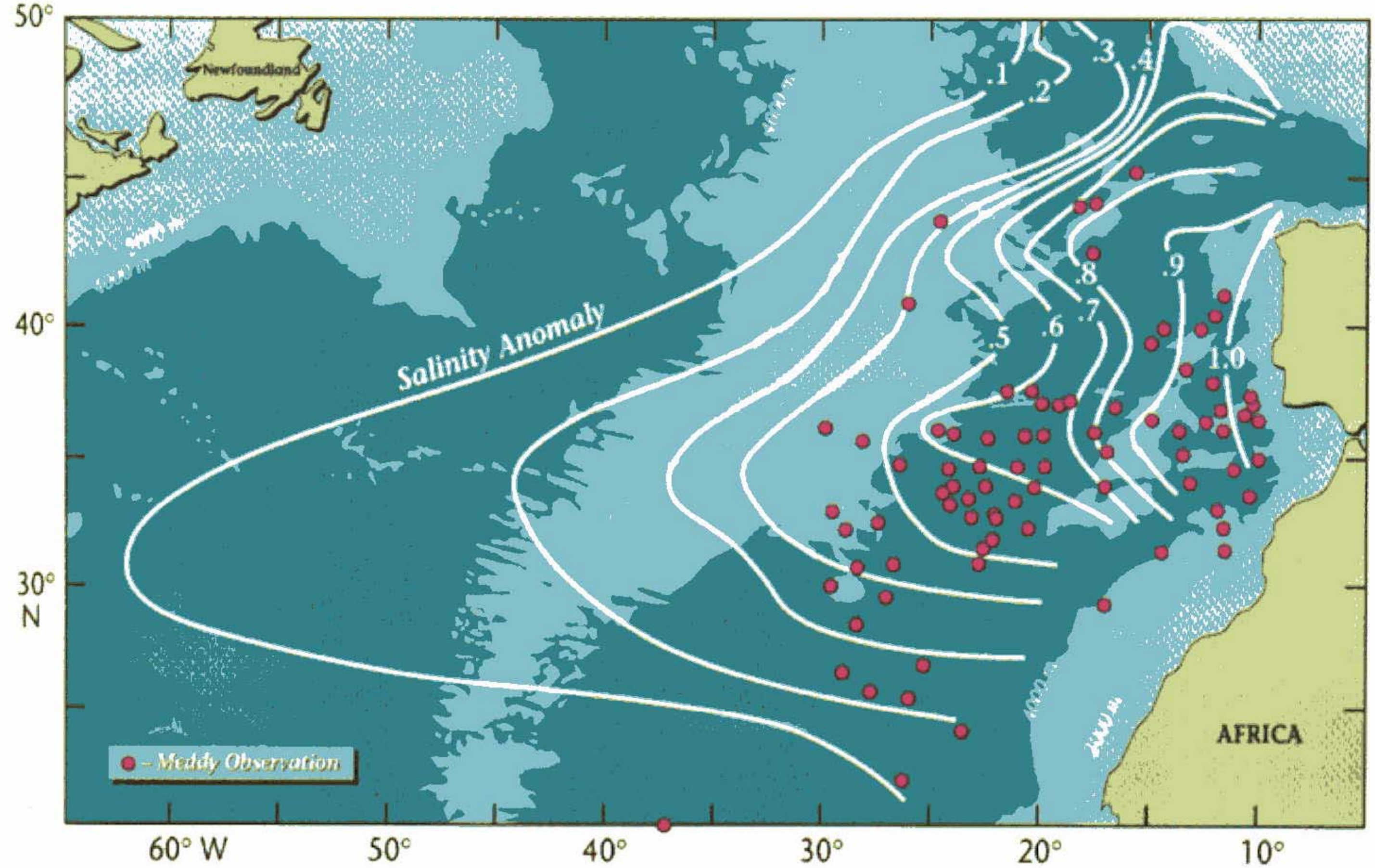


Fig. 2. Summary of historical Meddy observations listed by Richardson et al. (1991) and Shapiro and Meschanov (1996) and shown by Richardson and Tychensky (1998). The diameter of the dots in this figure is approximately 50 km, somewhat smaller than the diameter of a typical Meddy which is around 100 km. Contours of the salinity anomaly of the Mediterranean Water relative to 35.01 psu near a depth of 1100 m are based on a figure by Needler and Heath (1995) and shown by Joyce (1981).

Atmospheric Cyclone colliding with Greenland

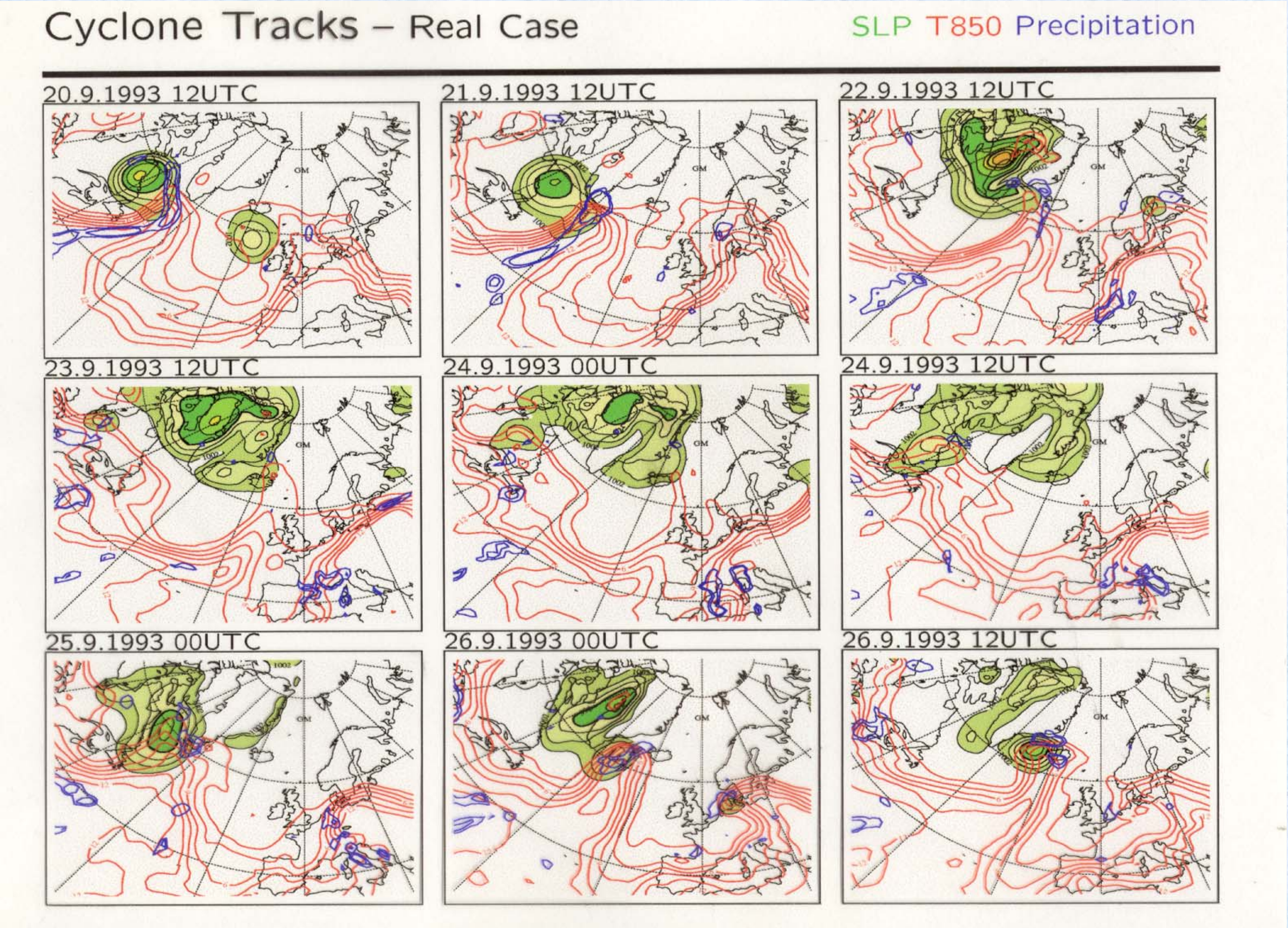
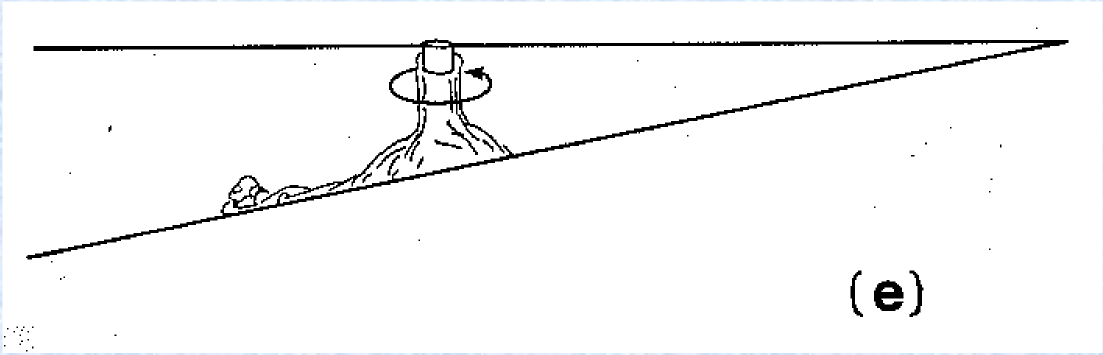
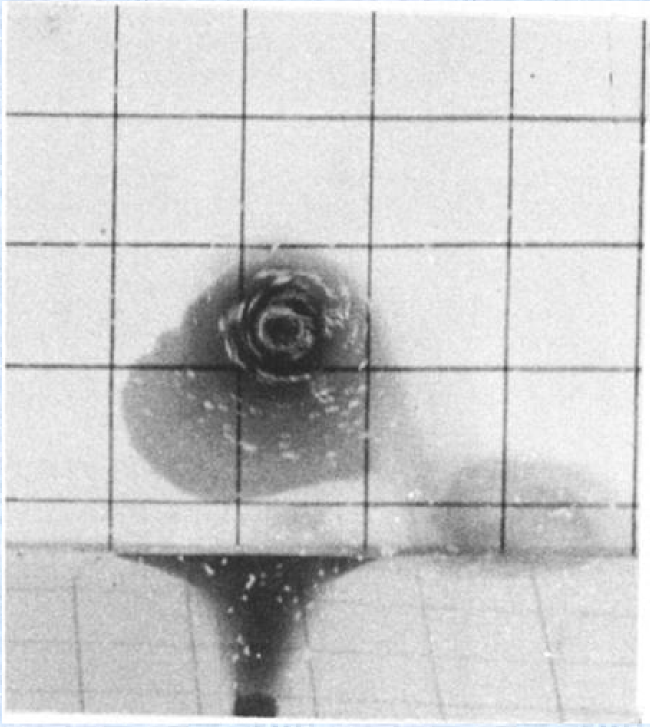


Fig. 12. Time sequence (20.9.1993 12UTC to 26.9.1993 12UTC) of ECMWF analysis fields. SLP (shaded, interval 4 hPa; max: 1002 hPa; 980 and 990 hPa bold) and temperature on 850 hPa (contour interval 4 K, from 0 to 12 °C.).

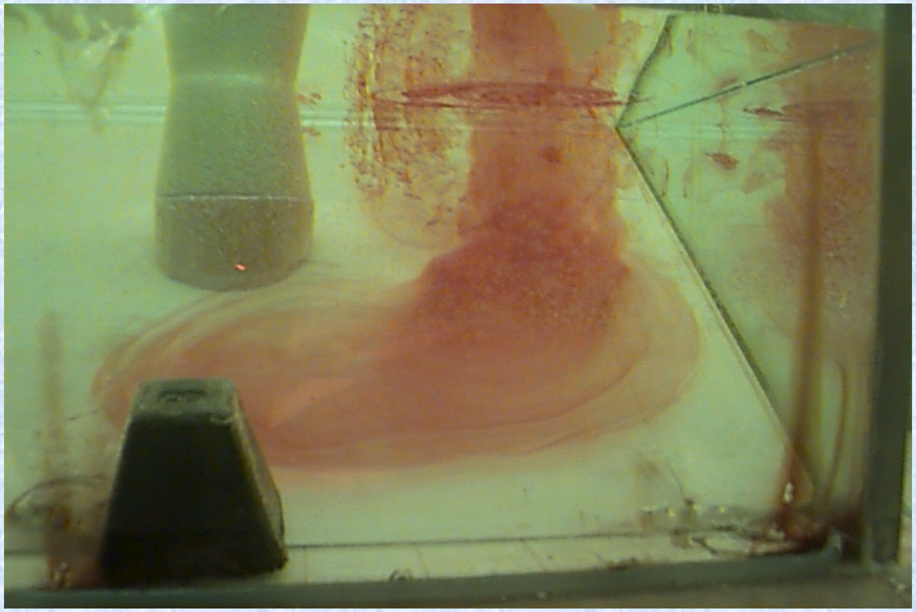
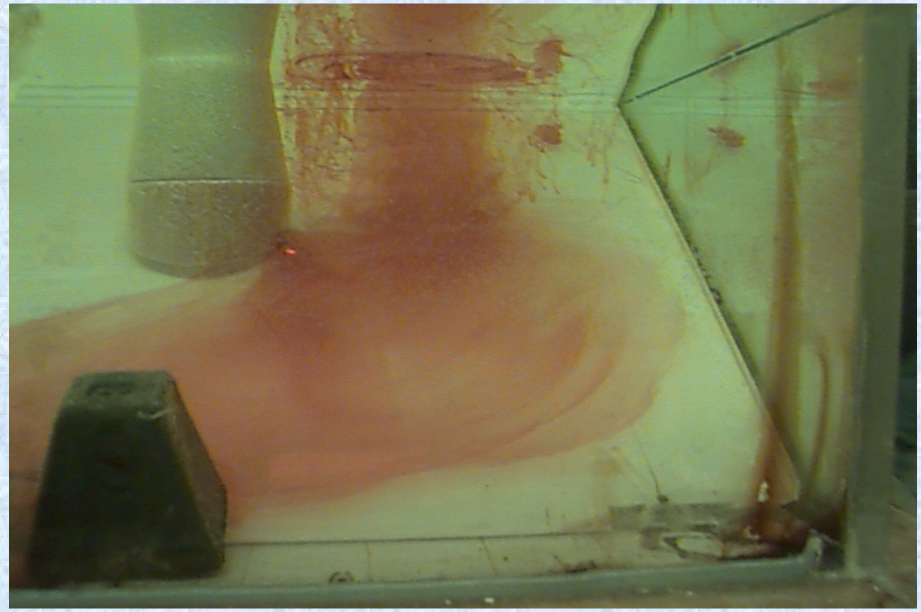
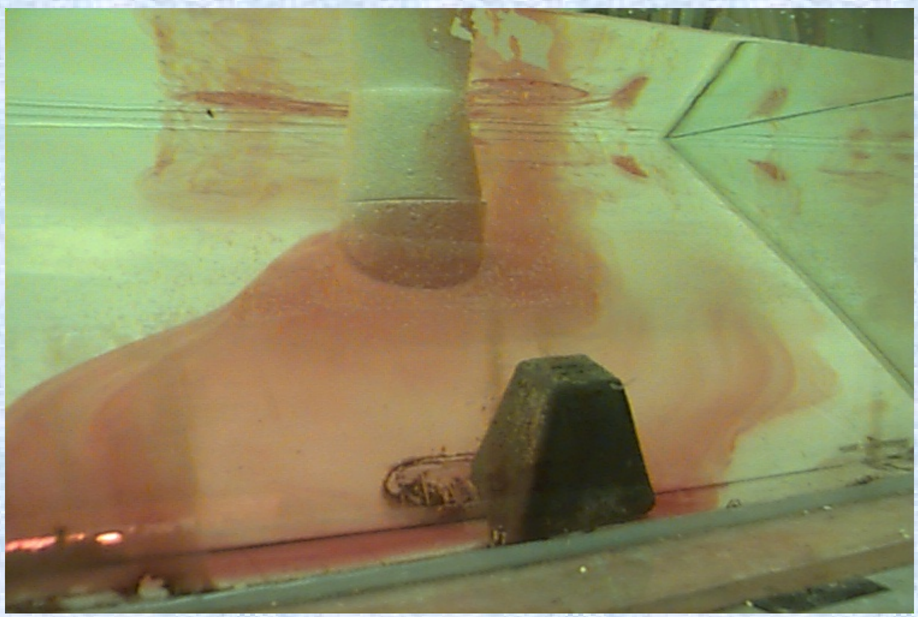
Schwierz & Davies (2003)

Vortex generation: the "ice cube" technique

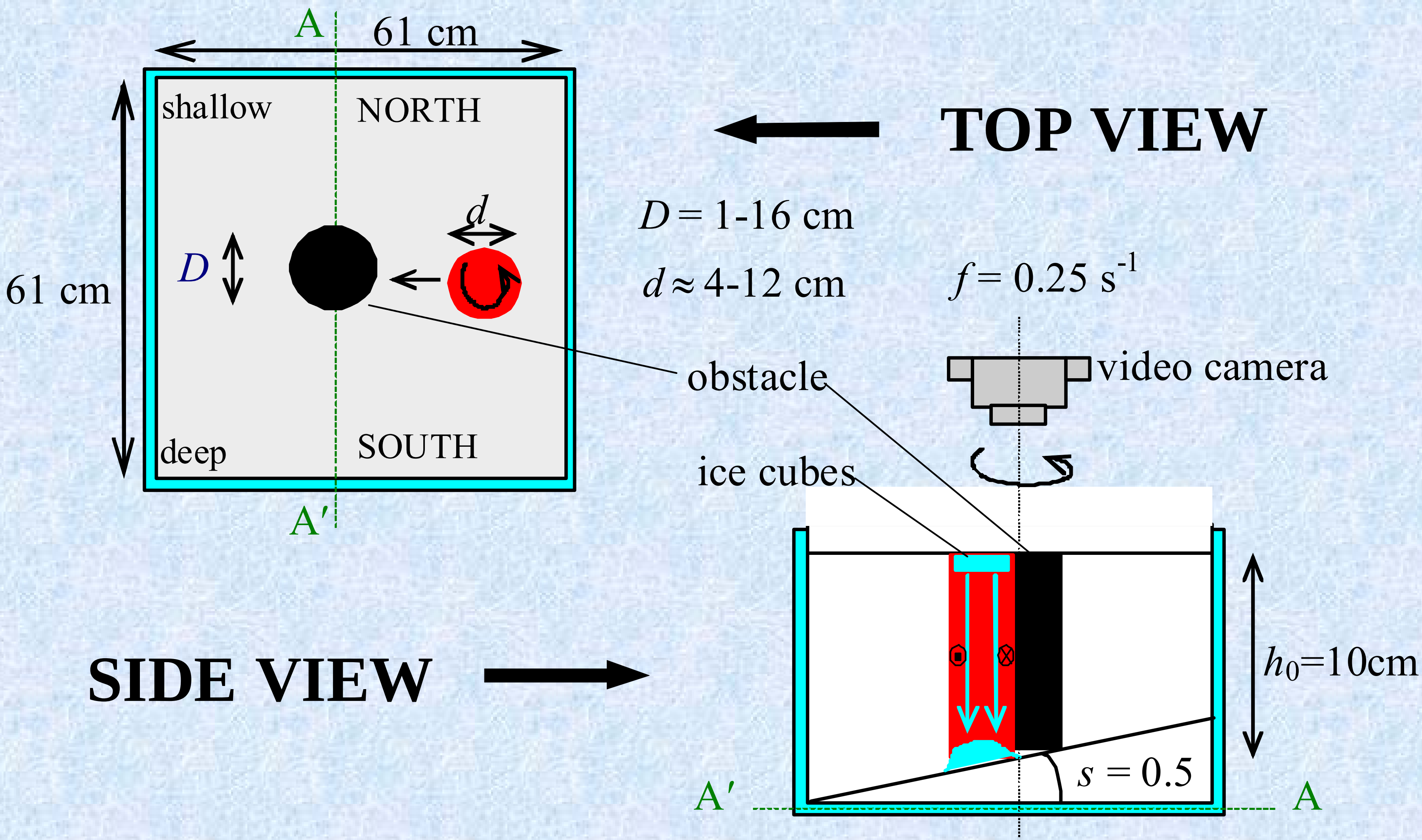




Whitehead et al. (1990)

Experimental apparatus: self-propagating



Self propagating vortex

$$f = f_0 + \beta y, \quad \text{where } f_0 = 2\Omega \sin\lambda_0 \text{ and } \beta = \tfrac{2\Omega\cos\lambda_0}{R}$$

$$PV = \frac{f+\zeta}{H+\eta} \quad \text{in absence of motion} \Rightarrow$$

$$PV_\beta = \frac{f_0 + \beta y}{H_0}$$

$$PV_s = \frac{f_0}{H_0\left(1 - \frac{sy}{H_0}\right)} \simeq \frac{f_0\left(1 + \frac{sy}{H_0}\right)}{H_0} \quad \text{when } s \ll 1$$

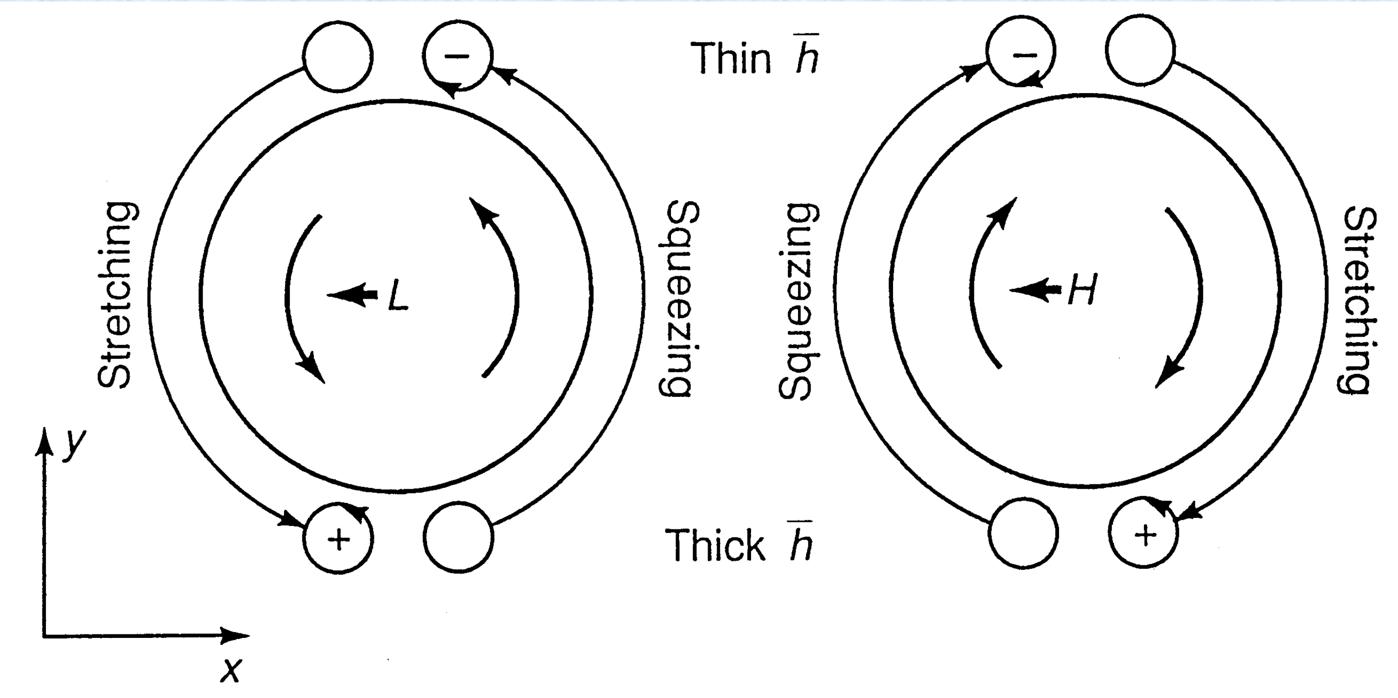
$$\beta = \frac{f_0 s}{H_0}$$

Exact dynamical equivalence between the variation of the Coriolis parameter with latitude, the β-effect, and variation of topography in the presence of a constant f

N.B.: for Meddies a $\beta = 1.57\ 10^{-13}\ \mathrm{cm^{-1}s^{-1}}$ is equivalent in the lab to $s = 0.05$

Vortex westward drift

SHALLOW

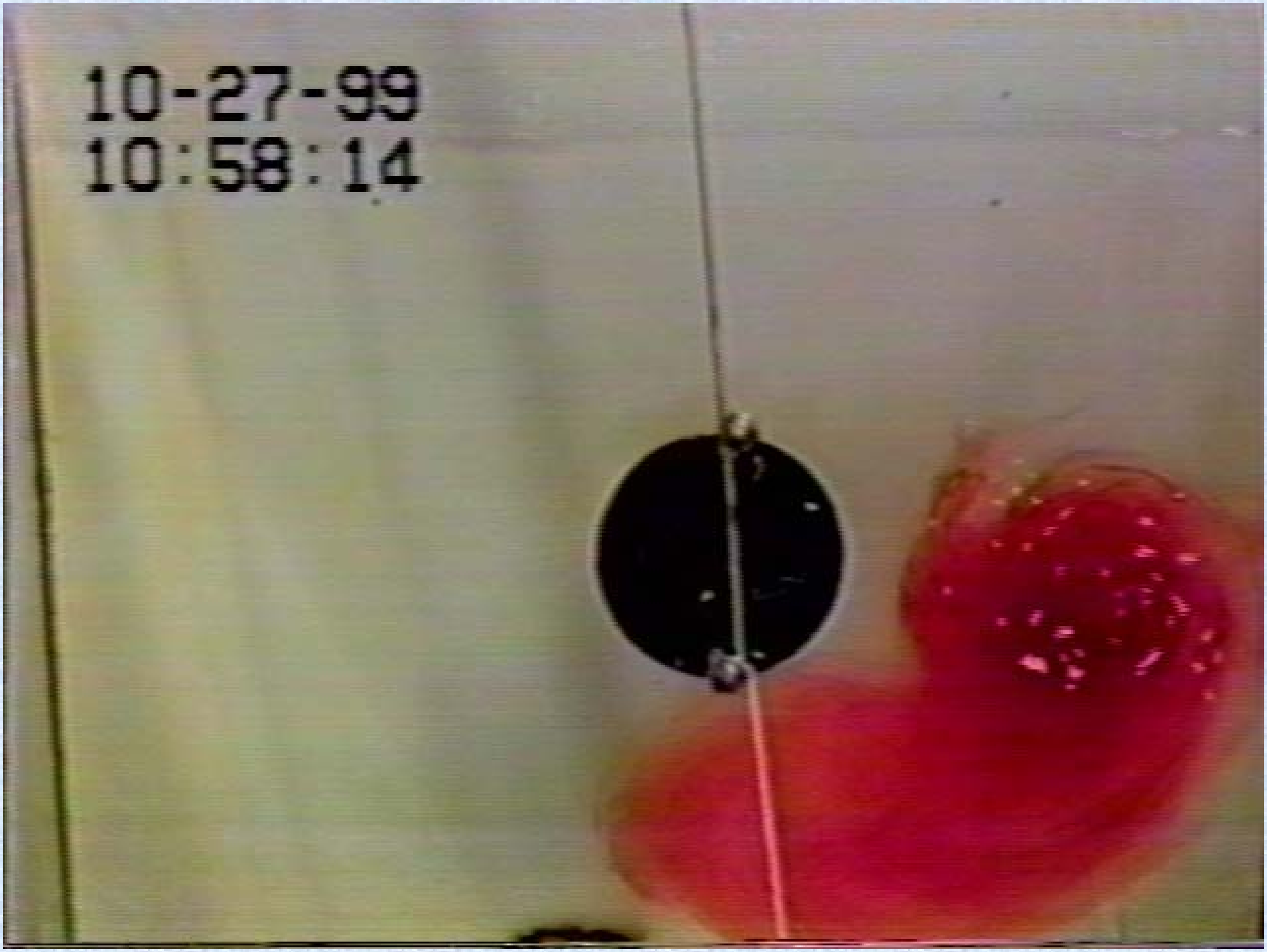


DEEP

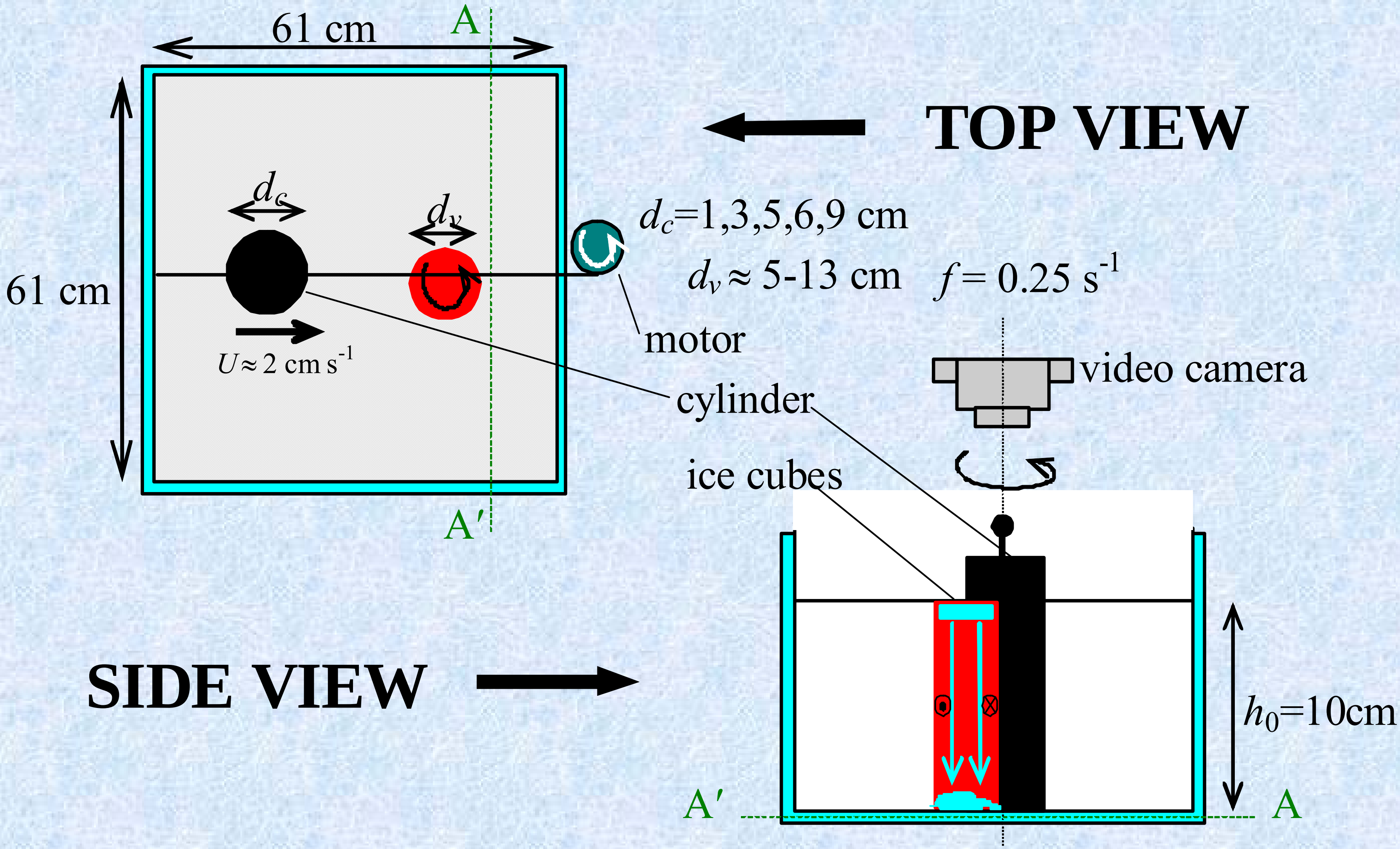
$$PV = \frac{f + \zeta}{H + \eta}$$

Cushman-Roisin (1994)

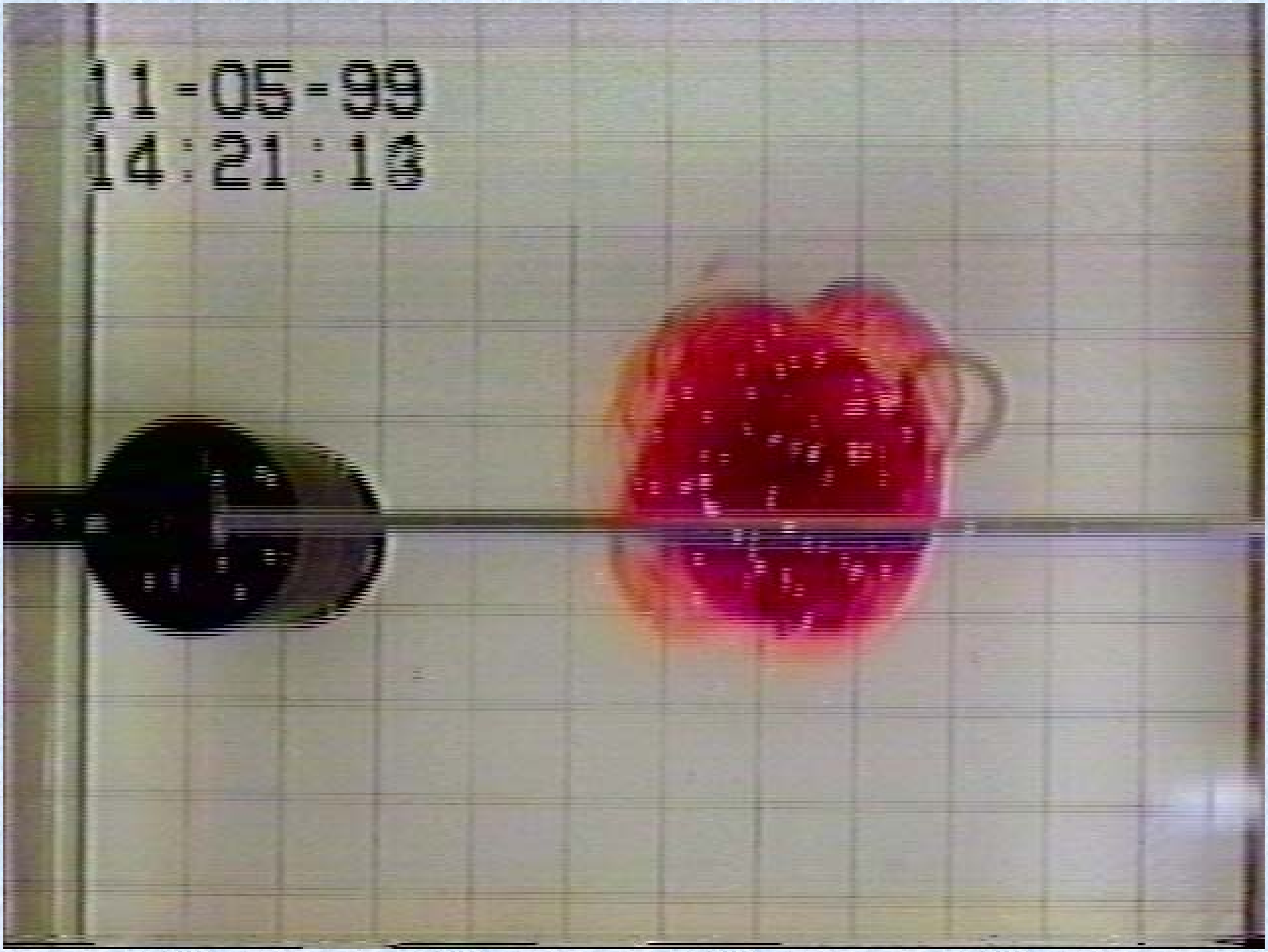
Self propagating: Barotropic flow



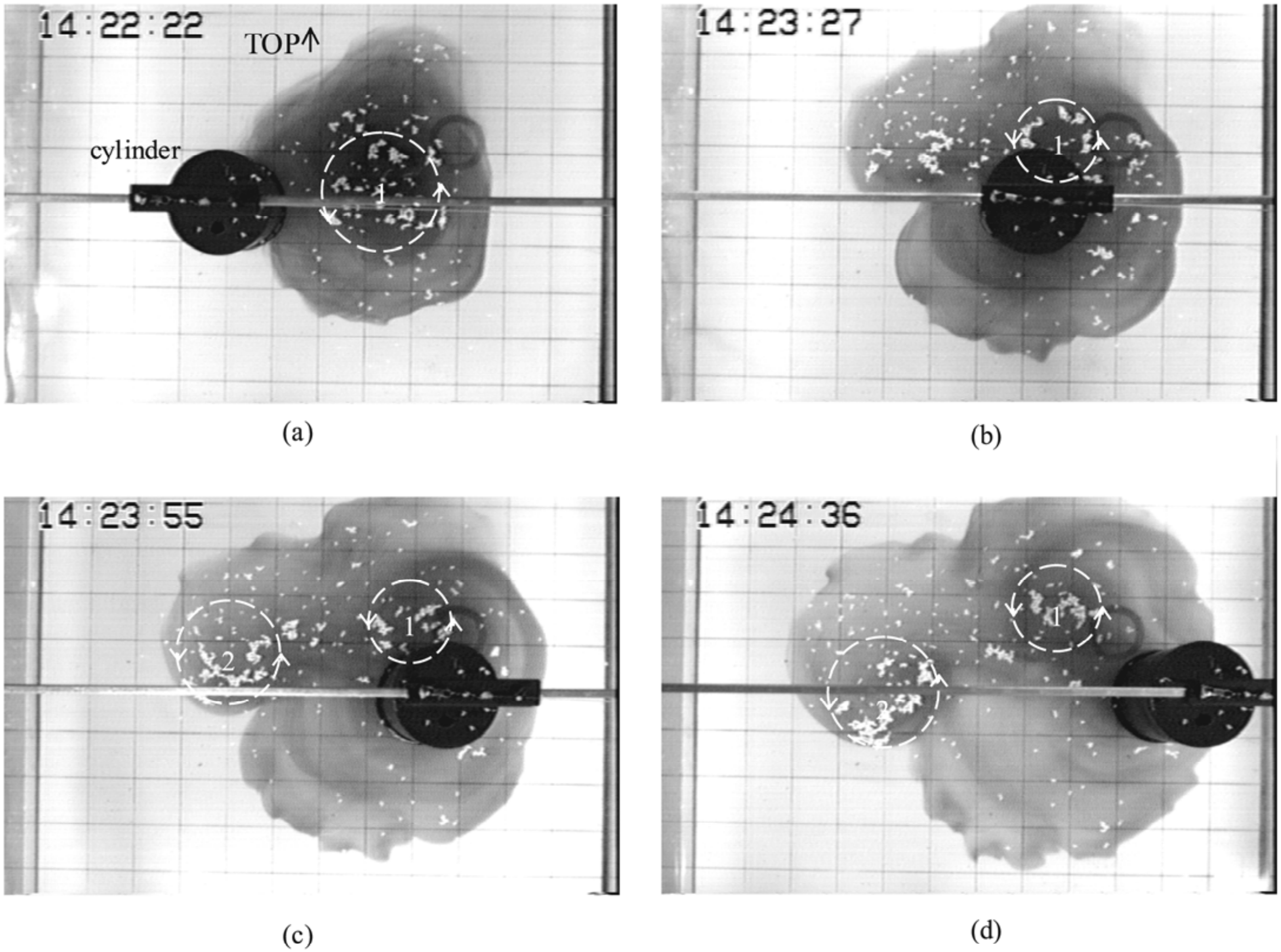
Experimental apparatus: background flow



Background flow

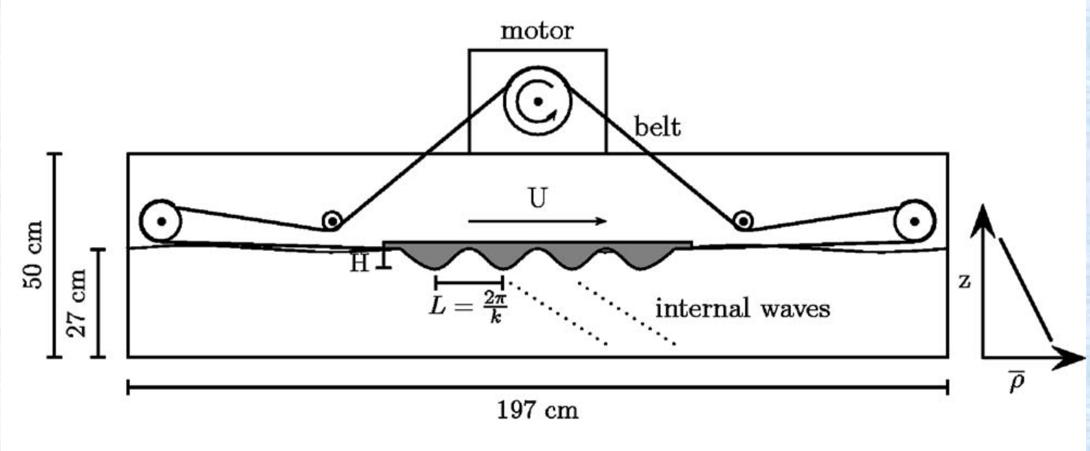


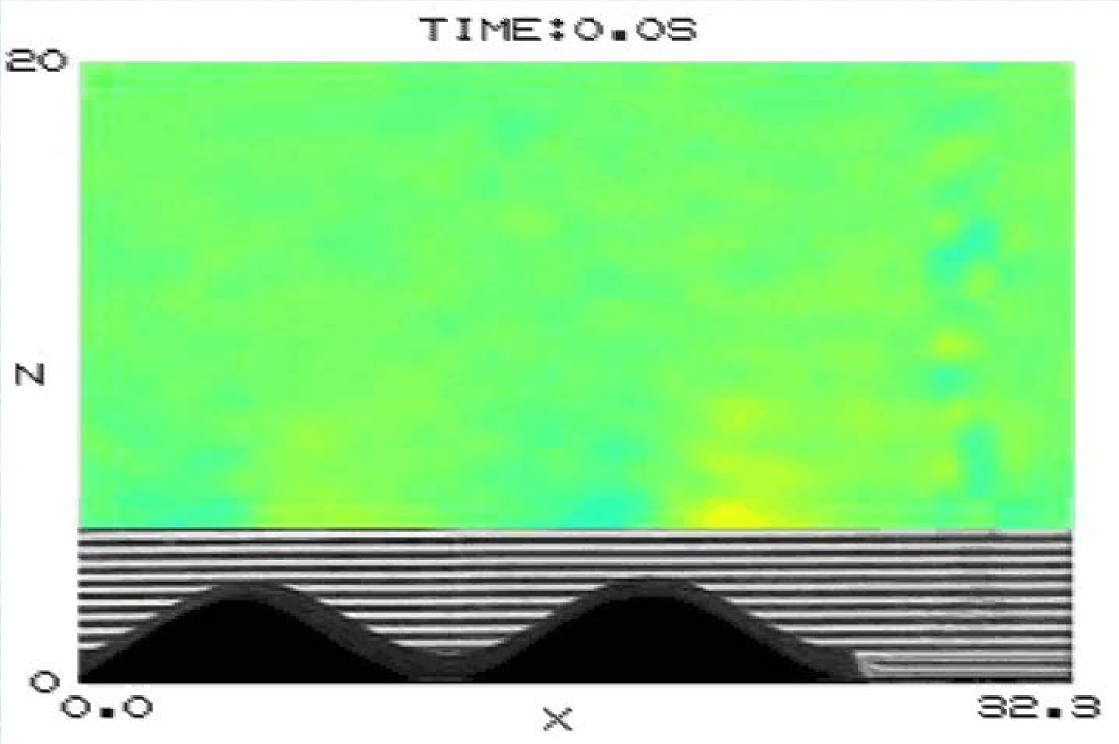
Background flow



(a) (b) (c) (d)

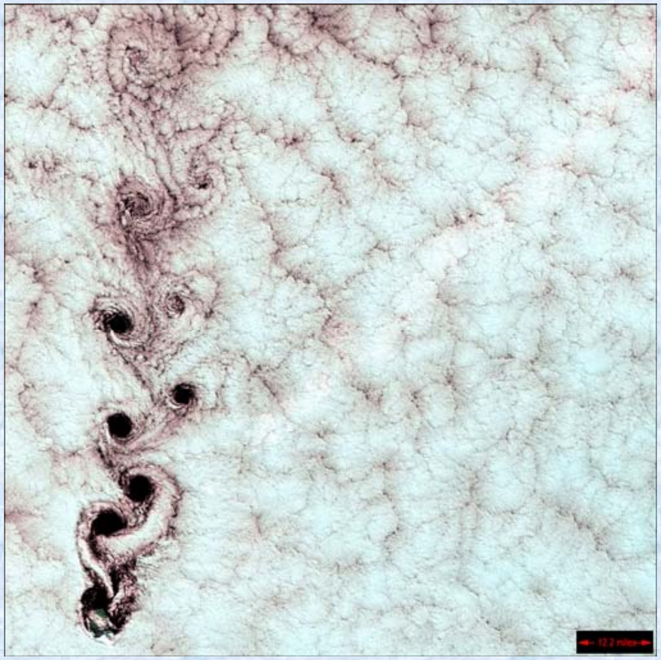
Other applications of a background flow





Aguilar and Sutherland (2006)

The "Reynolds number issue"



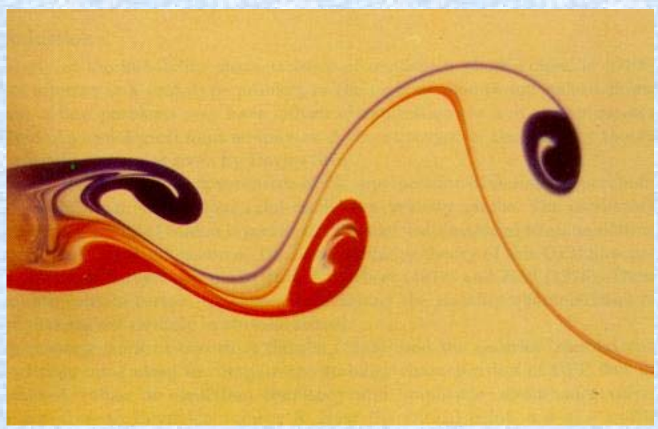
http://www.earthasart.gsfc.nasa.gov

$Re \sim 10^7$

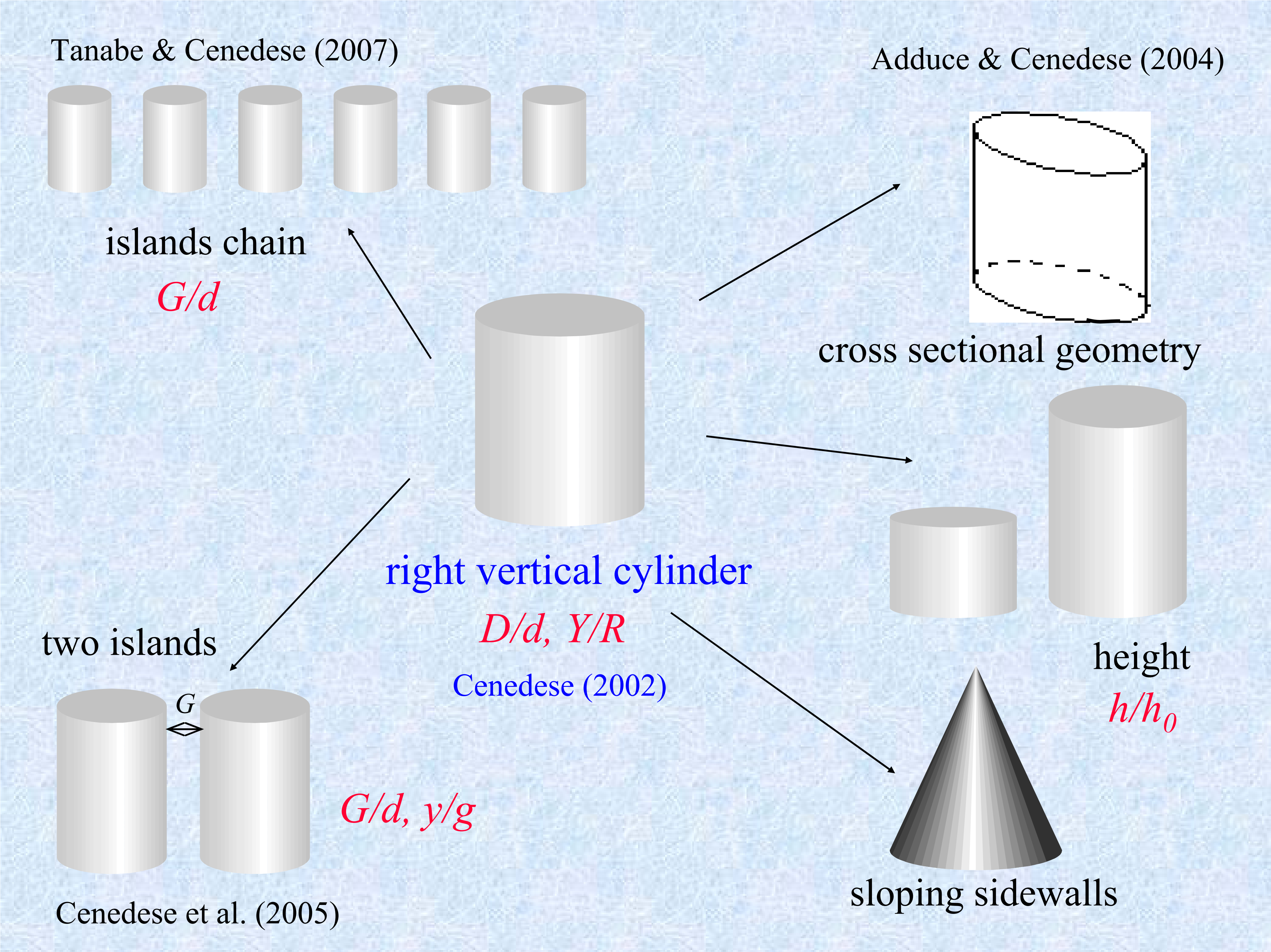
Sorrocco Island

"Lab" Island

$Re \sim 100$



http://www.engineering.uiowa.edu/~cfd/gallery/vortex.html


Tanabe & Cenedese (2007)
islands chain
G/d
Adduce & Cenedese (2004)
cross sectional geometry
right vertical cylinder
D/d, Y/R
Cenedese (2002)
height
h/h0
two islands
G
G/d, y/g
Cenedese et al. (2005)
sloping sidewalls

Influence of sloping side walls: motivations

Conservation of the ratio of relative vorticity gradient and planetary vorticity gradient

$$\frac{U_{lab}}{\beta_{lab} R_{lab}^2} = \frac{U_{oce}}{\beta_{oce} R_{oce}^2}$$

Topographic beta

$$\beta = \frac{sf}{h_0}$$

$U_{lab} \approx 0.2 \text{ cm s}^{-1}$

$R_{lab} \approx 5 \text{ cm}$

$f_{lab} \approx 0.25 \text{ s}^{-1}$

$h_{0lab} \approx 10 \text{ cm}$

$U_{oce} \approx 5 \text{ cm s}^{-1}$

$R_{oce} \approx 100 \text{ km}$

$f \approx 10^{-4} \text{ s}^{-1}$

$h_{0oce} \approx 1000 \text{ cm}$

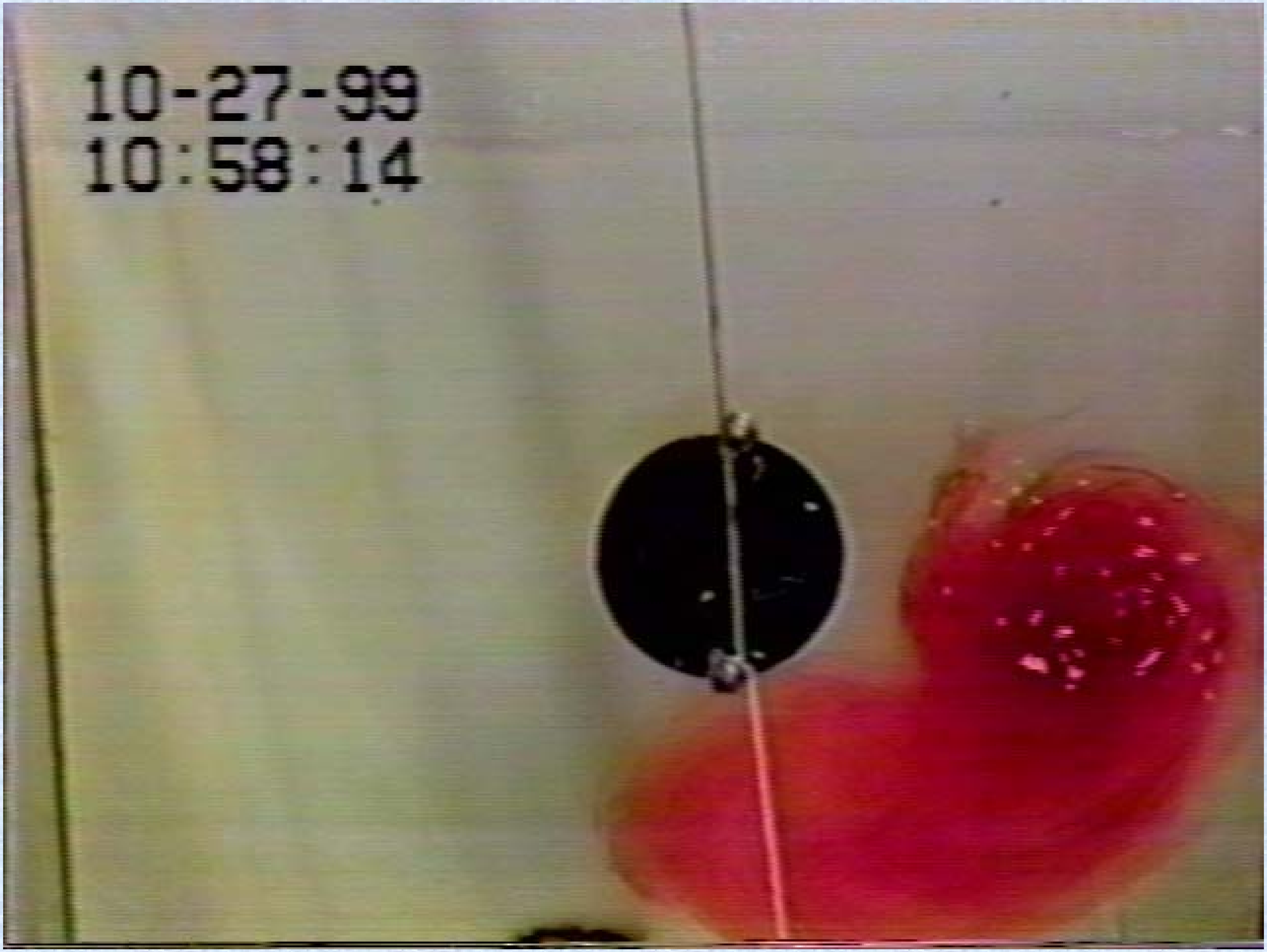
$\alpha_{lab} = 83^\circ \quad \Rightarrow \quad s_{oce} = 5.0 \cdot 10^{-3}$

$\alpha_{lab} = 70^\circ \quad \Rightarrow \quad s_{oce} = 1.7 \cdot 10^{-3}$

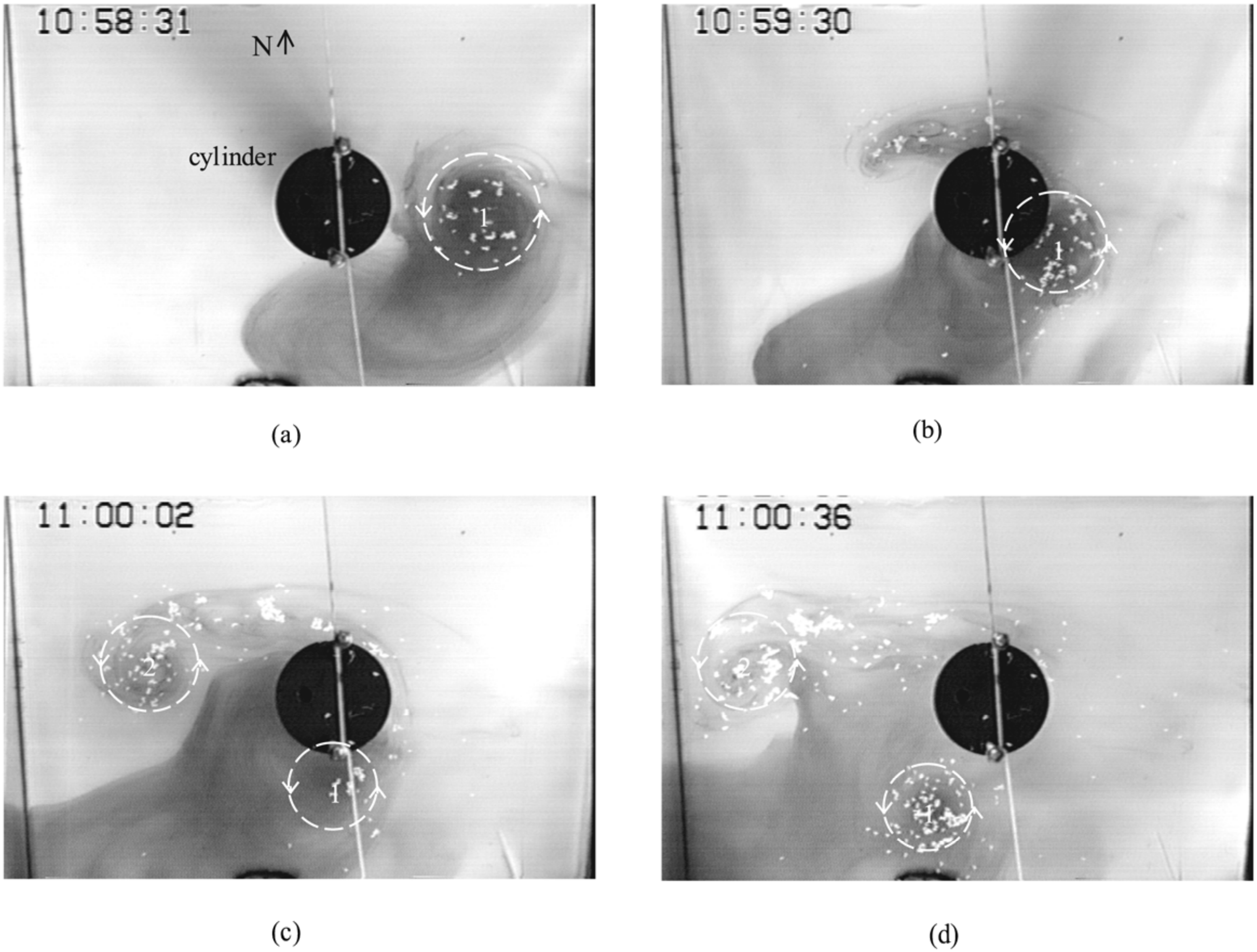
$s_{lab} = 64 \quad \Leftarrow \quad s_{oce} = 0.04$

$\alpha_{lab} = 89.1^\circ$

South and Central collisions: $Y/R \leq 0$



South and Central collisions: $Y/R \leq 0$



Circulation around a circular cylinder

$$\frac{\partial \mathbf{u}}{\partial t} + (\zeta + f)\,\hat{k} \times \mathbf{u} = -\nabla\left(\frac{p}{\rho} + \frac{|\mathbf{u}|^2}{2}\right) + Diss(\mathbf{u})$$

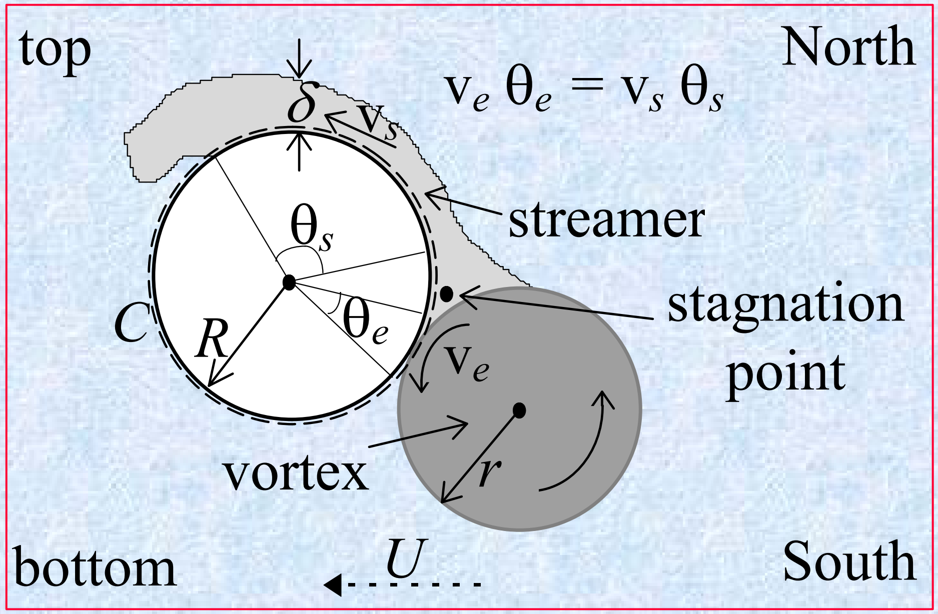
$$\frac{\partial}{\partial t}\oint_C \mathbf{u}\cdot\hat{t}ds = \oint_C Diss(\mathbf{u})\cdot\hat{t}ds$$

$$\oint_C Diss(\mathbf{u})\cdot\hat{t}ds = \oint_C \nu\nabla^2\mathbf{u}\cdot\hat{t}ds = 0$$

$$\oint_C \nu\nabla^2\mathbf{u}\cdot\hat{t}ds = \oint_C \nu\frac{\mathrm{v}}{\delta^2}R\,d\theta = 0$$

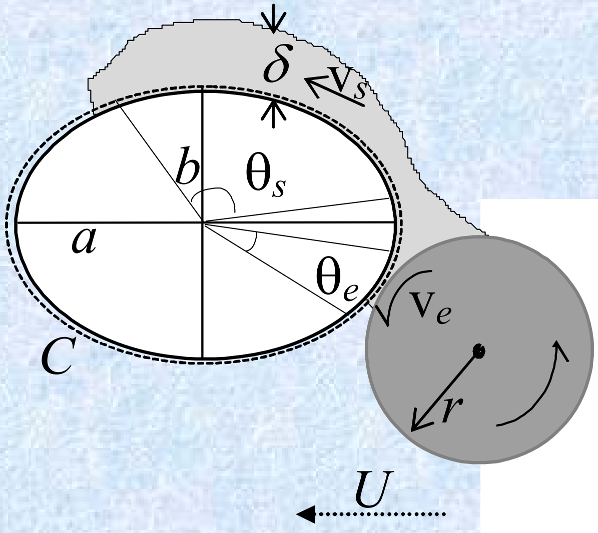
$$\oint_C \mathrm{v}\,d\theta = 0$$

$$\mathrm{v}_e\ \theta_e = \mathrm{v}_s\ \theta_s$$

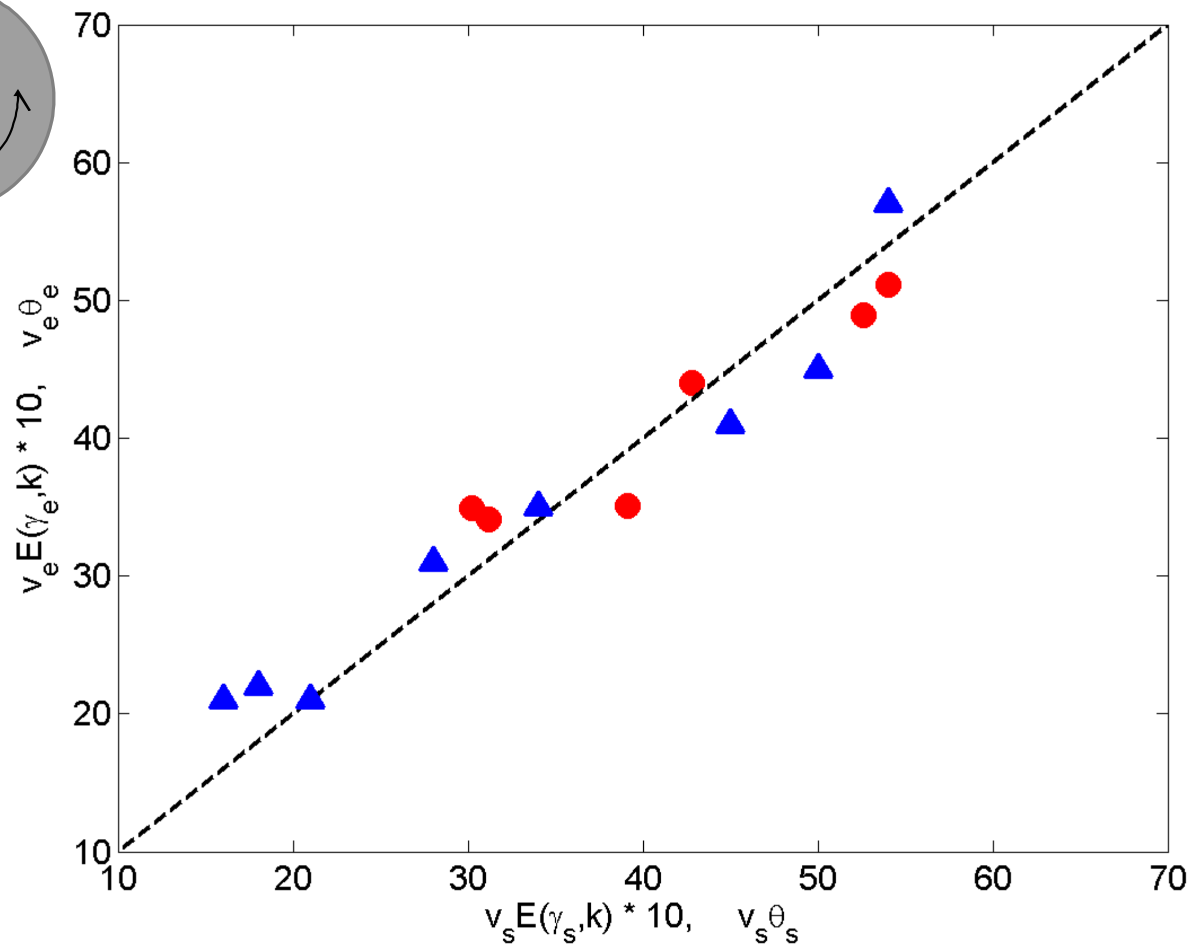


(Godfrey, 1989; Pedlosky et al., 1997; Cenedese, 2002)

Circulation around a circular and elliptical cylinder

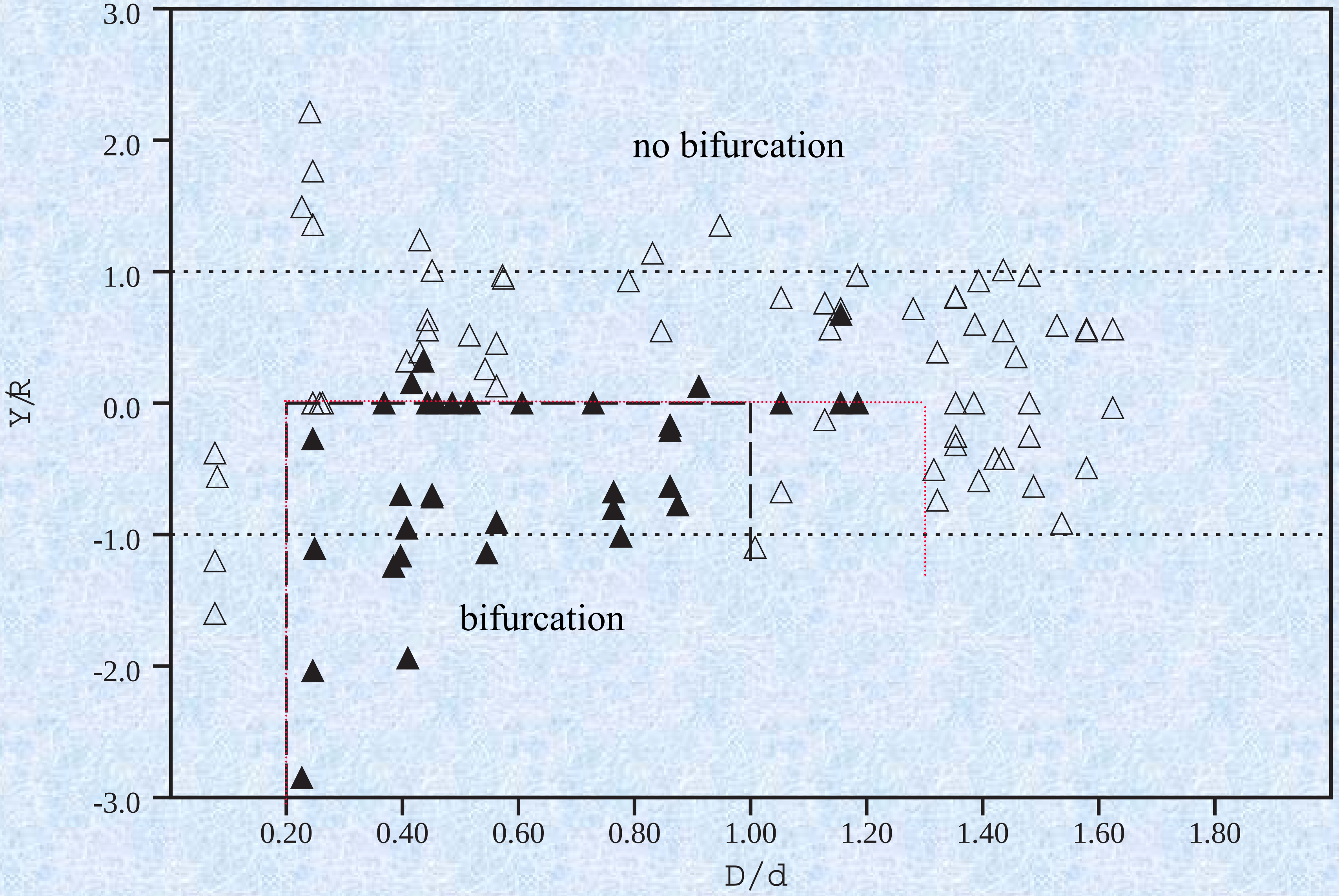


$$v_s E(\gamma_s, k) + v_e E(\gamma_e, k) = 0$$



$$v_e \theta_e = v_s \theta_s$$

Bifurcation occurs for: $0.2 \le \frac{D}{d} \le 1.0 \quad \frac{Y}{R} \le 0$



Bifurcation occurs for: $400 \le Re \le 1100$

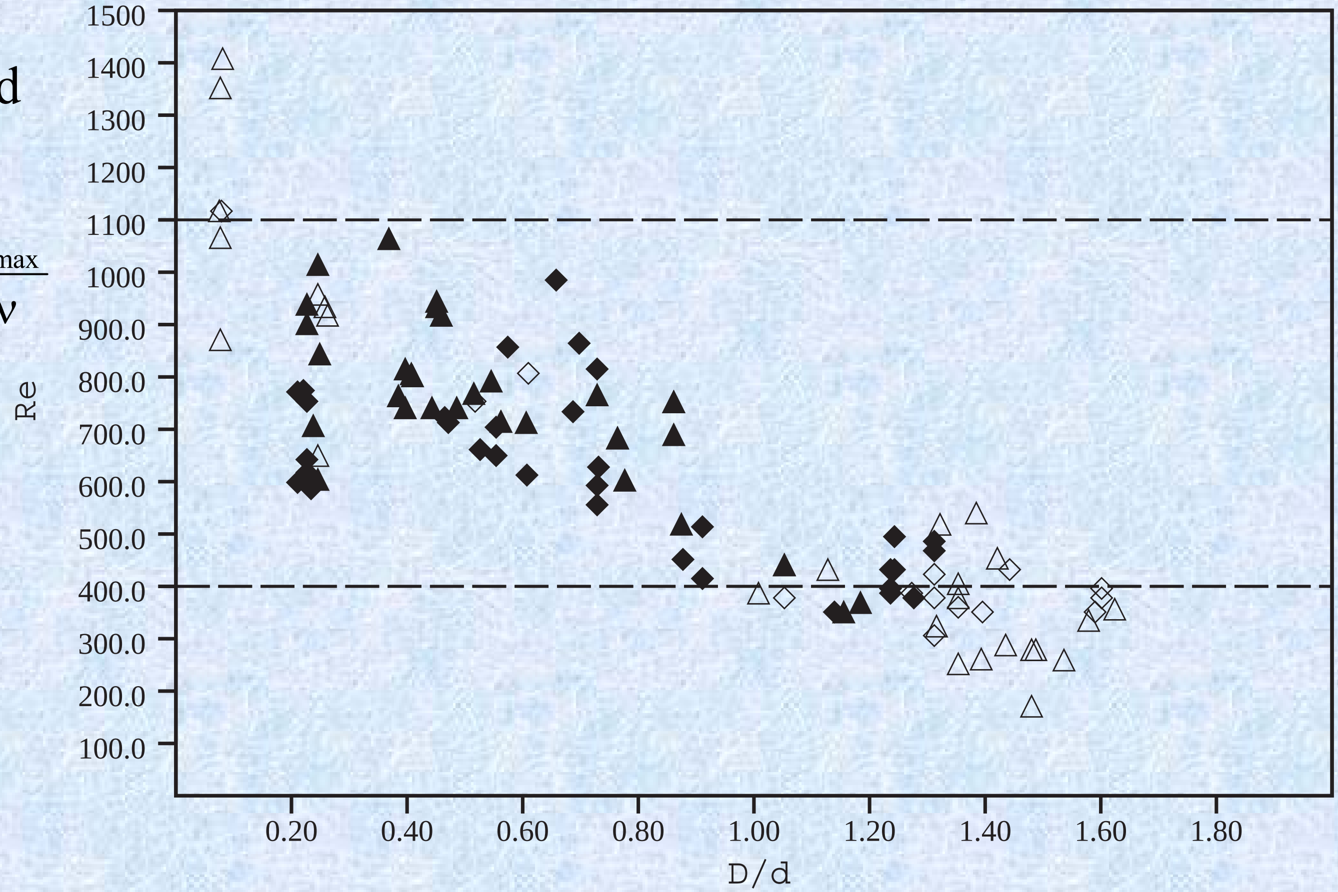
$$Re = \frac{v_s \, L_{max}}{\nu}$$

Self-Propagating (triangles):

$$Re = \Omega_e \frac{\theta_e}{\theta_s} \frac{r L_{max}}{\nu} = \Omega_e \frac{\theta_e}{\theta_s} \frac{r}{R} \frac{R L_{max}}{\nu}$$

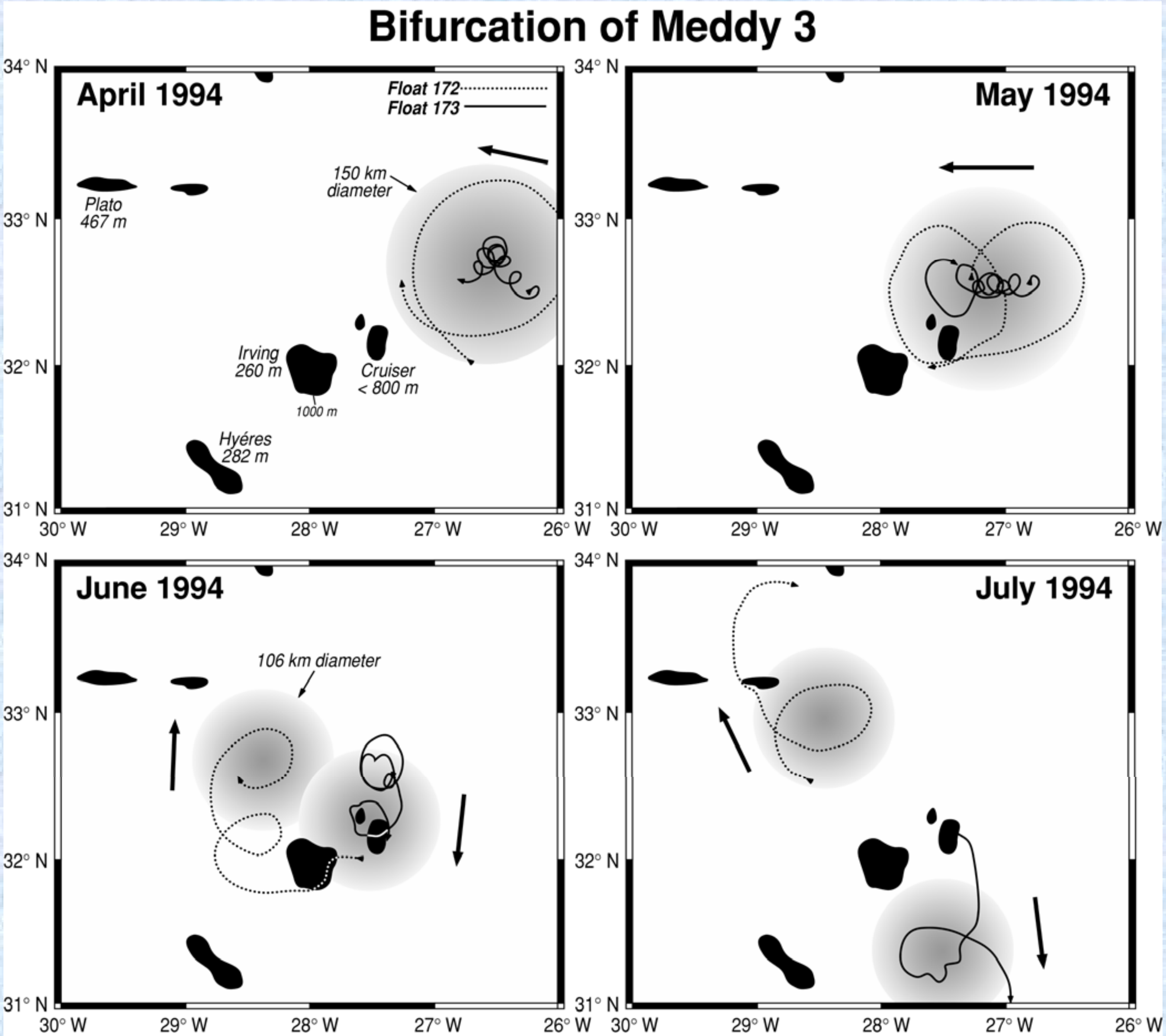
Advected by background flow (diamonds):

$$Re = \left(\left(\Omega_e \frac{\theta_e}{\theta_s} \frac{r}{R} R \right) + U \right) \frac{L_{max}}{\nu}$$



(Cenedese, 2002)

Comparison with observations



$$0.2 \le \frac{D}{d} \le 1.0$$

$d = 150$ km

$Dcr = 18$ km

$Di = 36$km

Cruiser

$D/d = 0.12$

$h/h_0 = 0.82$

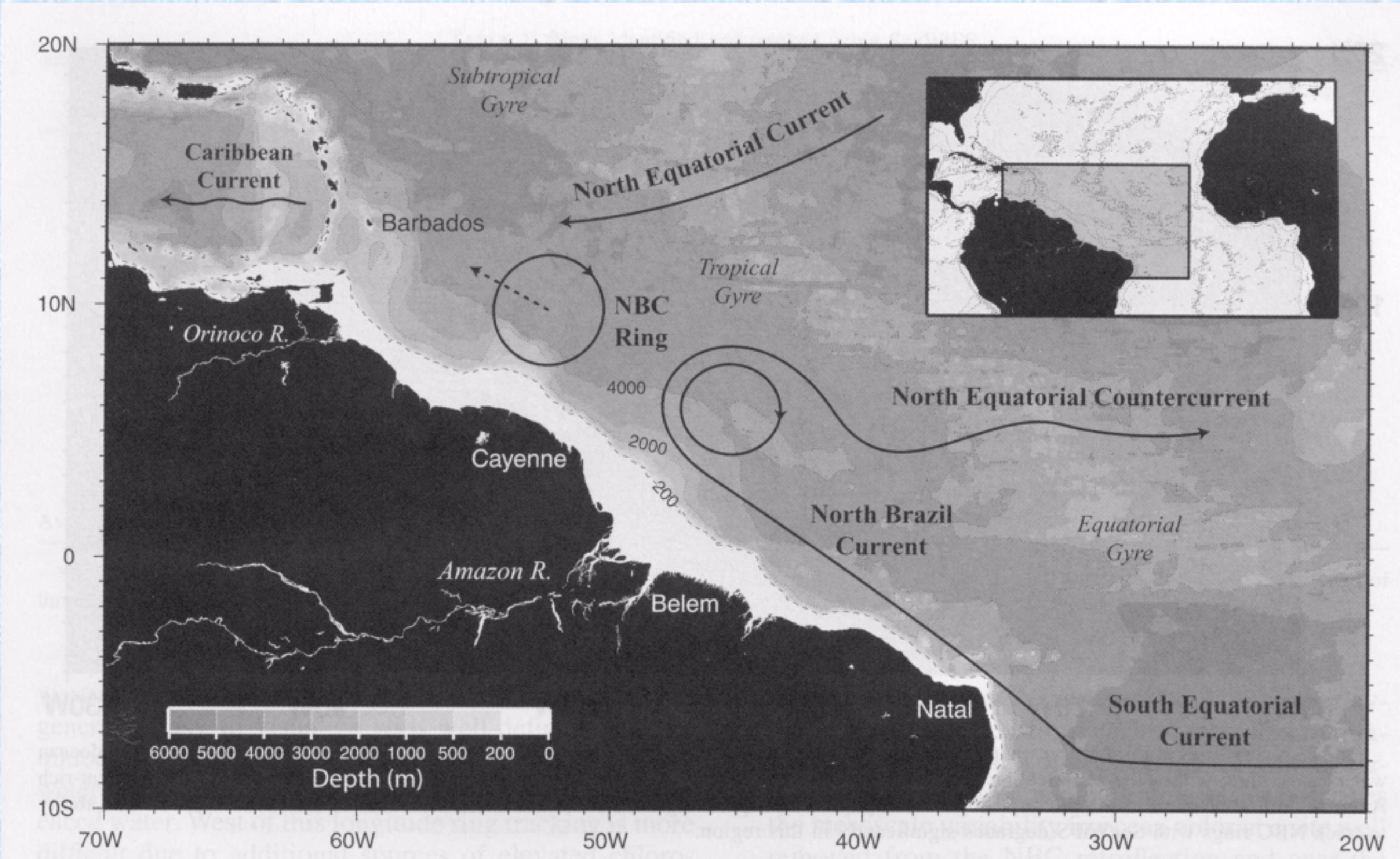
Irving Seamount

$D/d = 0.24$

$h/h_0 > 1.0$

Richardson and Tychensky (1998)

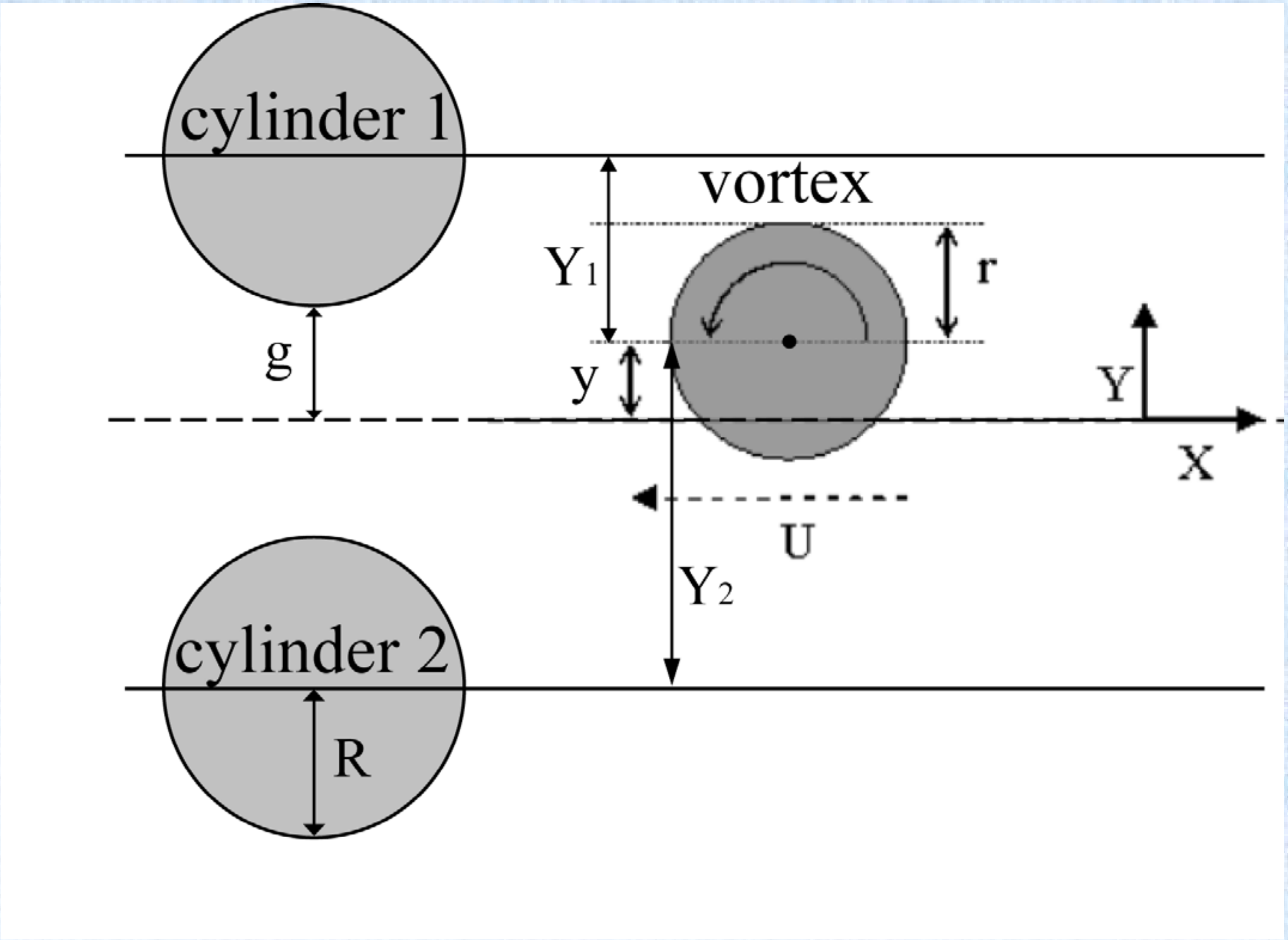
North Brazil Current ring collision with multiple islands



Fratantoni and Glickson (2002)

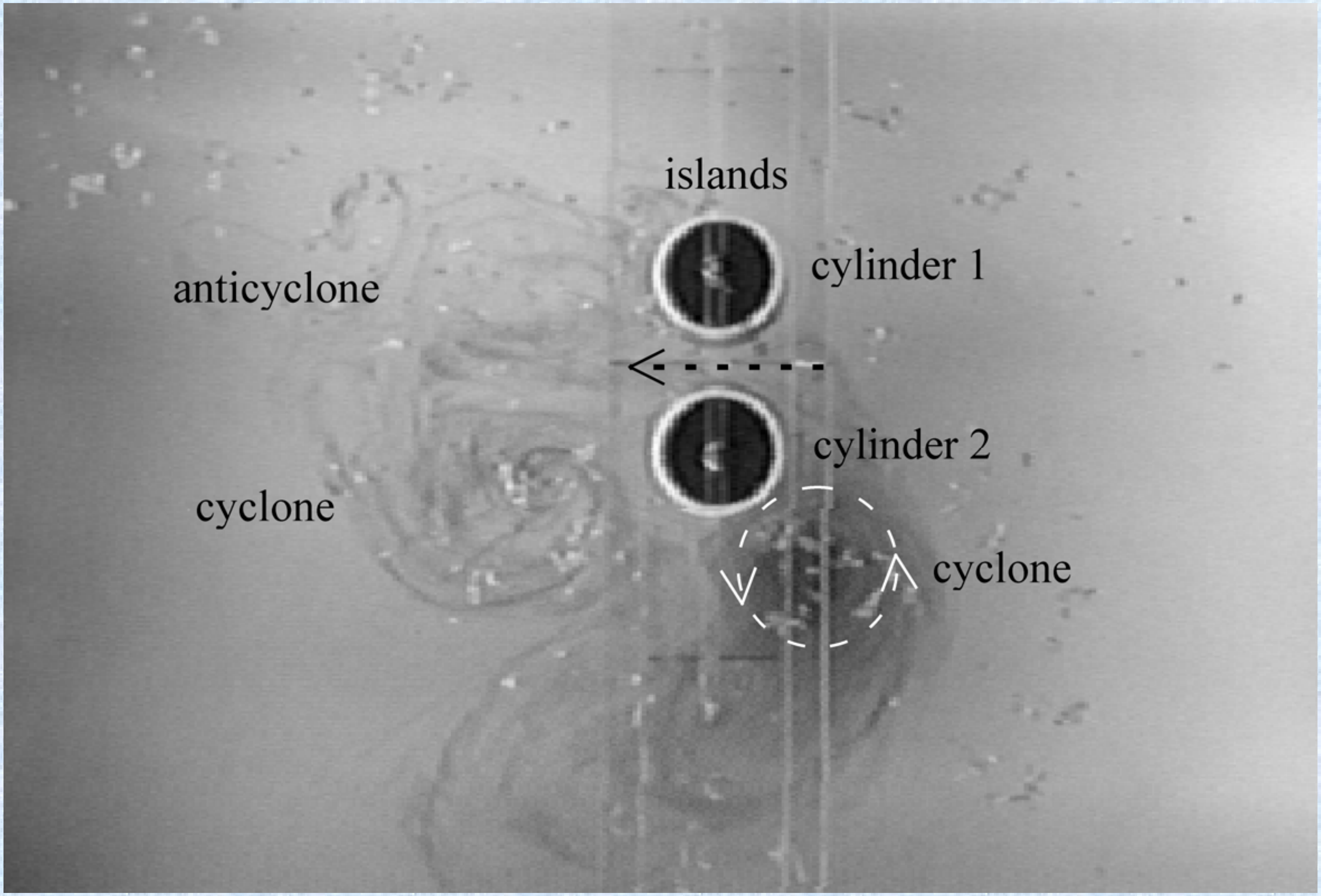
Vortex collision with two islands:

Geometry of the interaction

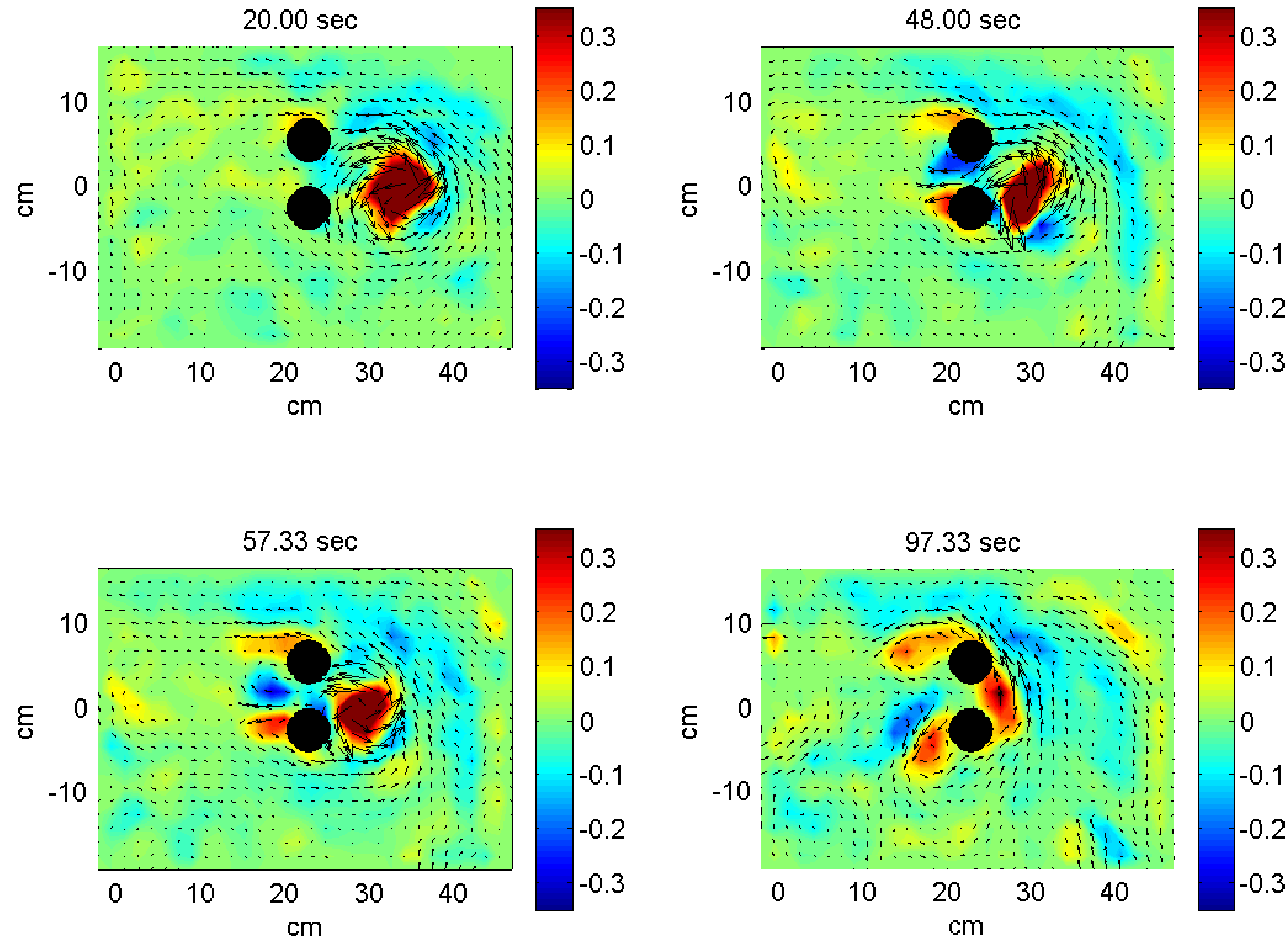


(Cenedese et al, 2005)

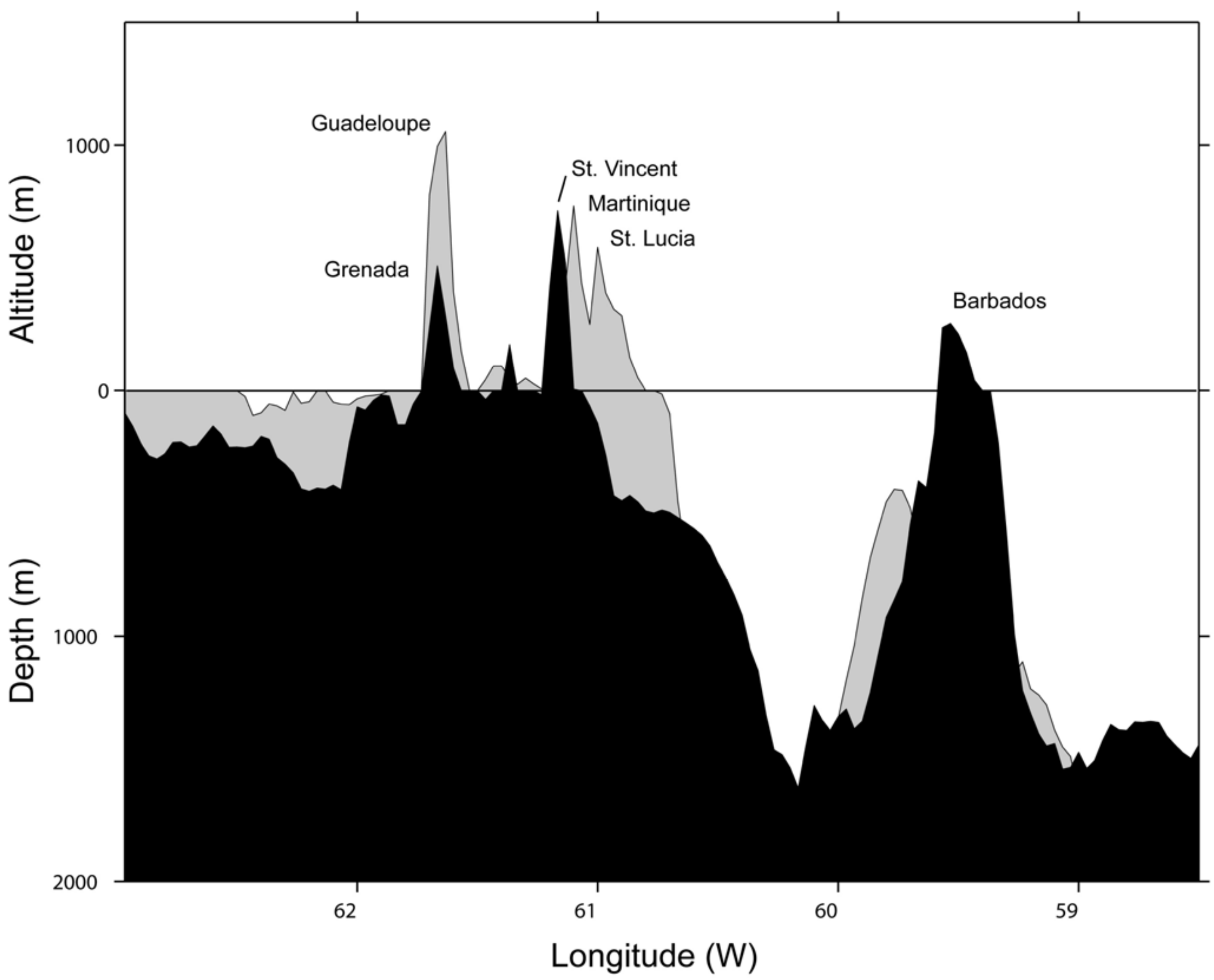
Dipole formation



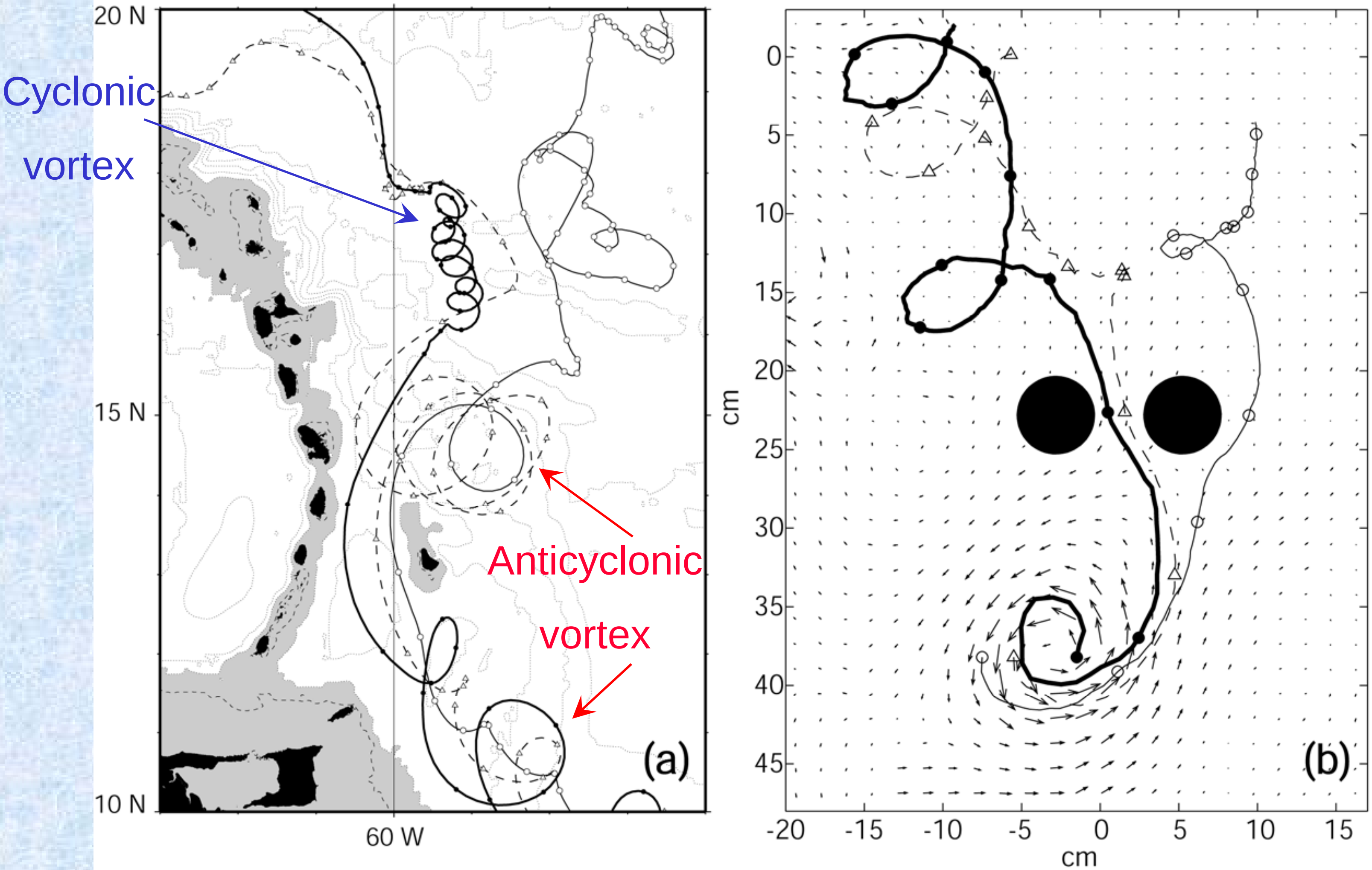
Dipole formation



Comparison with observations



Comparison with observations



$$\frac{G}{d} = \frac{120\ km}{200\ km} = 0.4$$

(Cenedese et al, 2005)

Conclusions

Throw an ice cube in a rotating tank…..it is fun!

… and … you can learn something about the ocean….

THANK YOU!