Ekman drift and vortical structures

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(Ocean Modelling 2008)

Conclusion

Wind stress interacts with vortical structures and modifies Ekman drift

Decelerates surface vortices / Accelerates subsurface ones

Additional along wind propagation

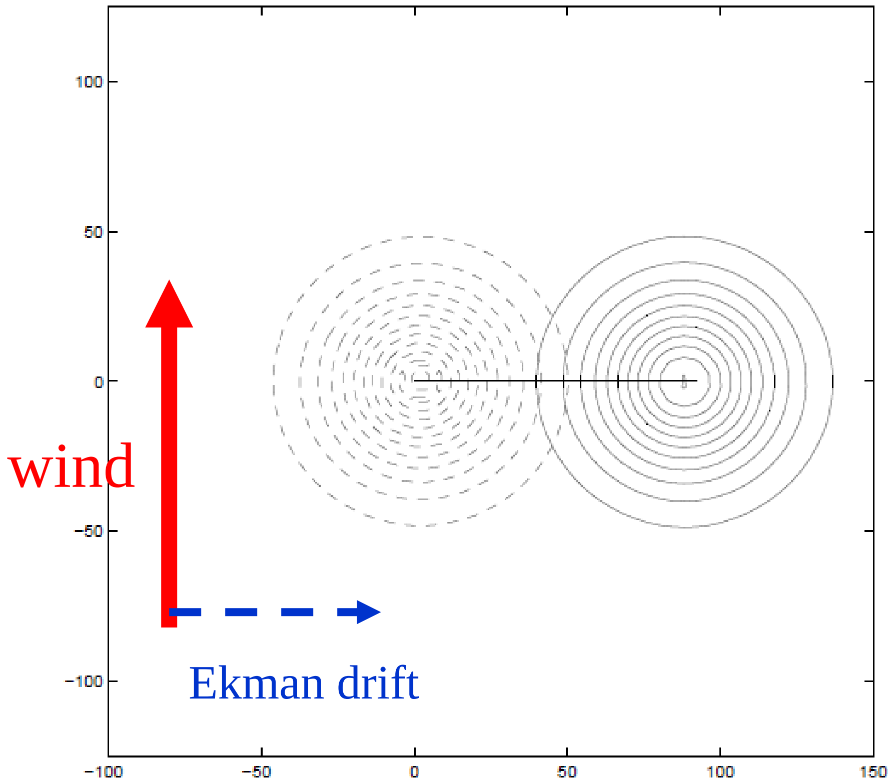
Analytical solutions can be calculated but no simple rules/parameterization (depends on details of vortex structures in a non trivial way)
Not a problem if you have enough resolution, but

⇒ In OGCMs with coarse resolution water mass distribution may be difficult to reproduce accurately if mainly trapped in vortices in reality

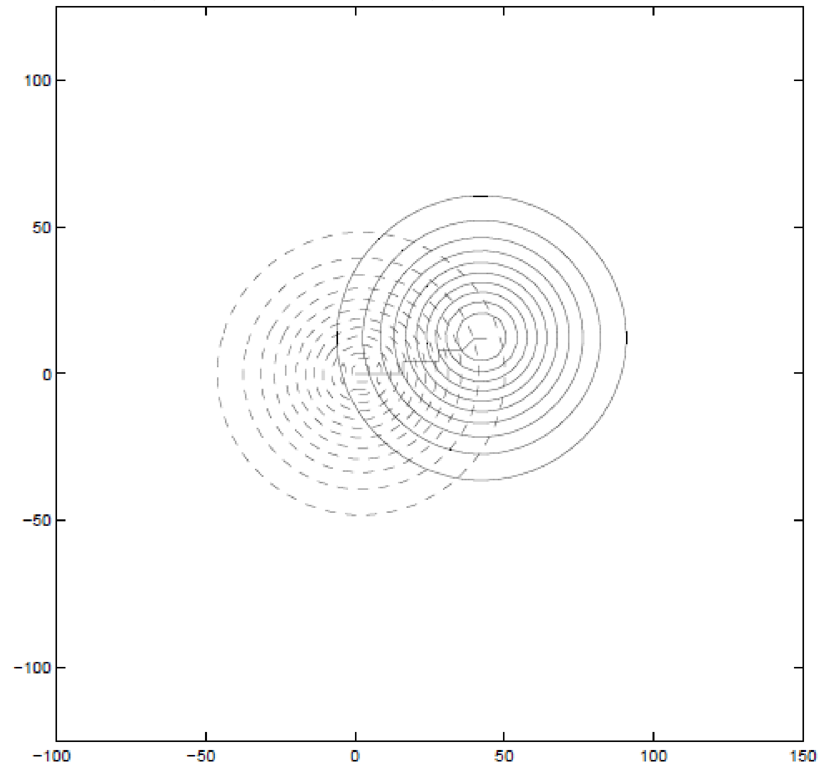
Potential problem for climate studies

Numerical experiment 2 layers, 100 days, wind, micom code

Advection of a tracer



advection of (tracers in) a vortex (subsurface)



Preliminary principles 1
POTENTIAL VORTICITY "thinking"

ζ= rot (U)   important quantity

BUT NOT CONSERVED

$$PV = (\zeta+f)\,.\vec{\nabla}\rho \quad (= (\zeta+f)/h\ )$$

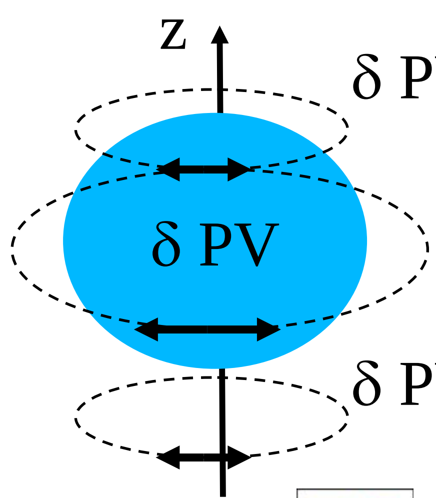
is conserved for each particles if adiabatic motion

PV = TRACER

The velocity field can be reconstructed from the knowledge of PV (if geostrophic balance is assumed)

INVERSION PRINCIPLE

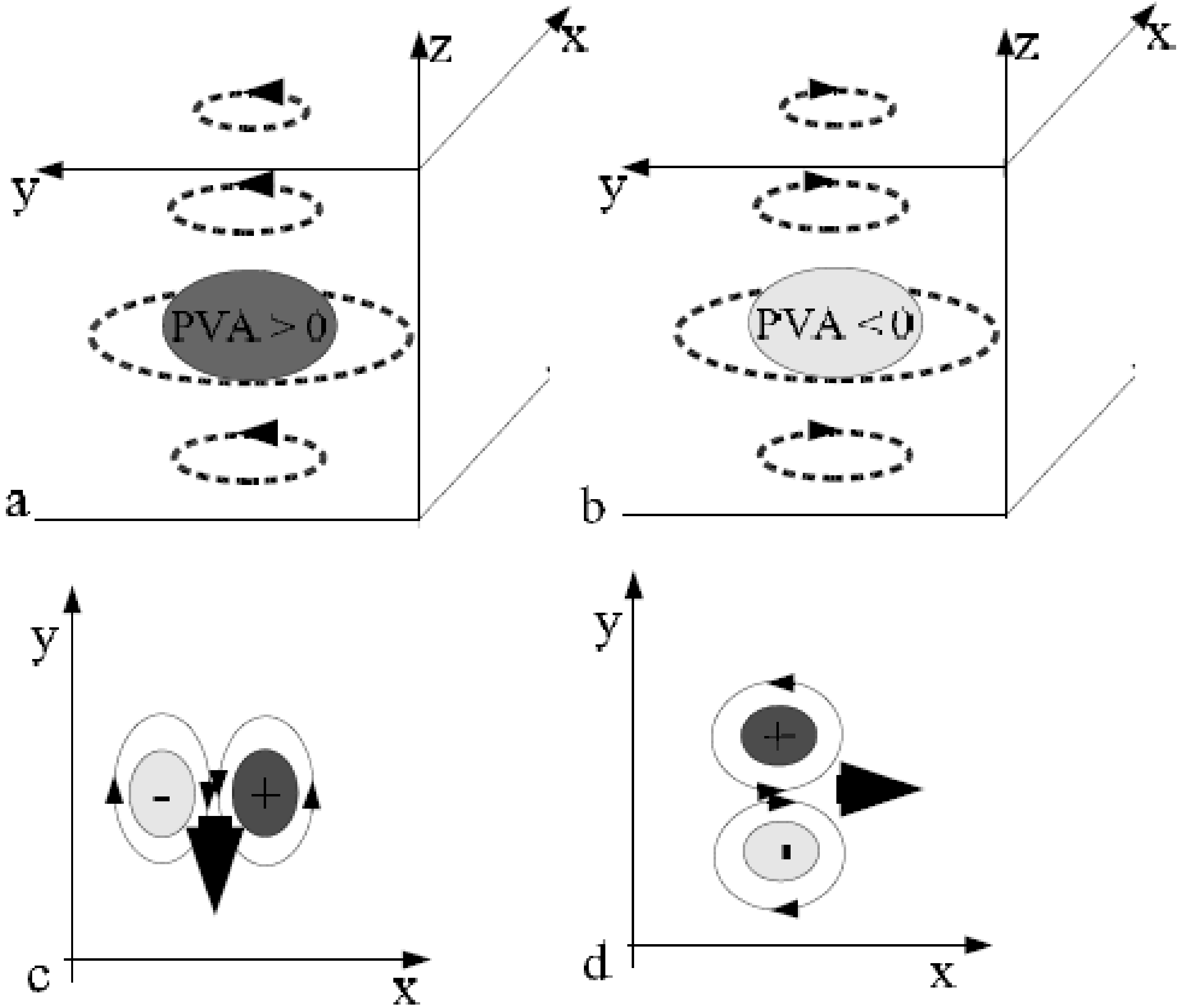
δ PV > 0 => cyclonic



δ PV < 0 => anticyclonic

Preliminary principles 1

Dipolar structures and vortex propagation



Preliminary principles 2

Wind Stress effects

Thomas 2005, Morel et al 2006
… and Stern 1965

$$\frac{d\,\Delta Q}{dt} = \frac{\mathrm{rot}\ F_w}{h}$$

rot F_w?

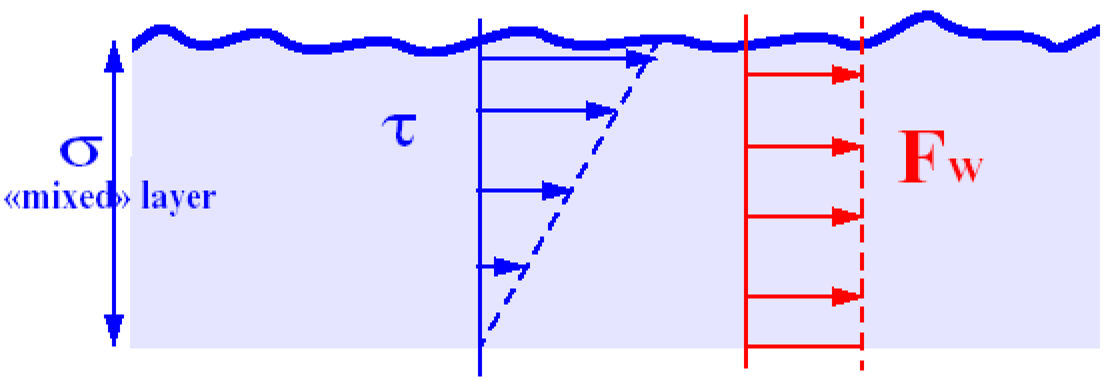
$F_w = d\tau/d_z$

$\tau_w = C_D\,\rho_a\,|W|\,W$

F_w = cstt if W = cstt

$$\frac{d\,\Delta Q}{dt} = 0$$

need rot(W)



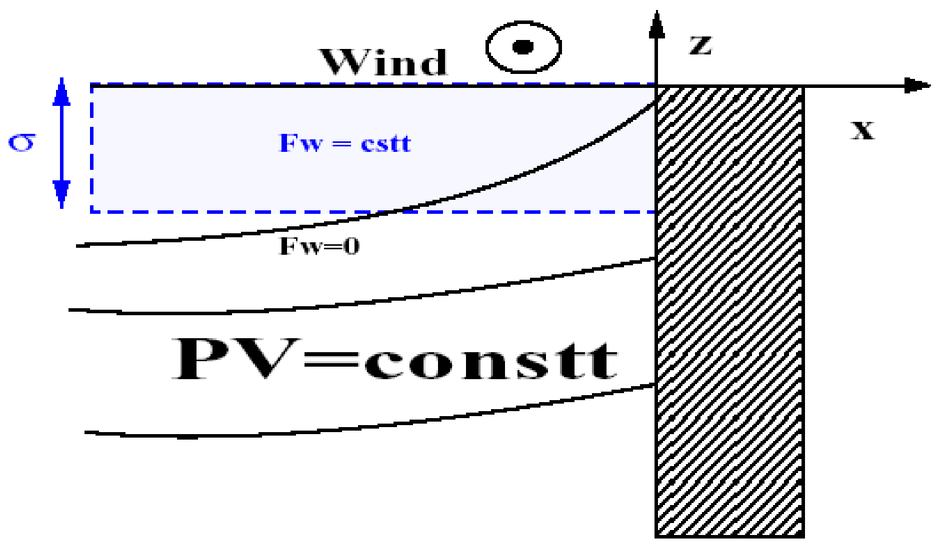
Preliminary principles 2

Upwellings: $\tau w < 0 \Rightarrow Fw < 0 \Rightarrow rot(Fw) = dx(Fw) < 0$

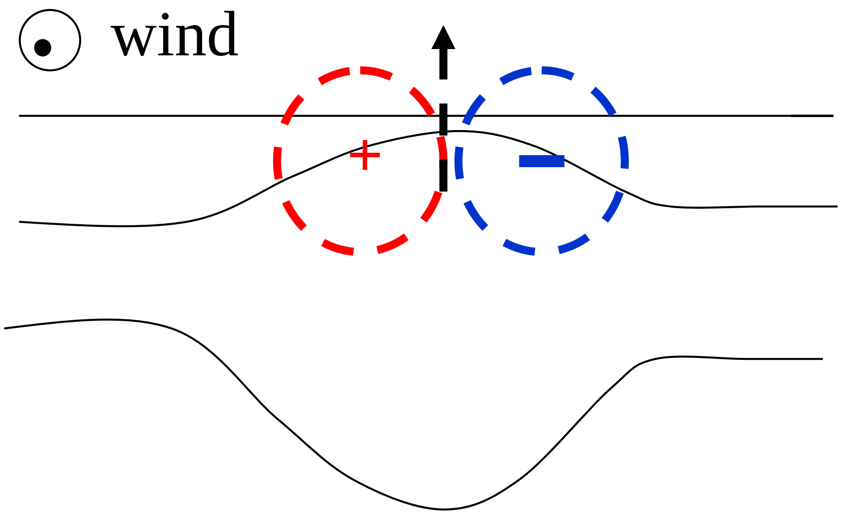
$$\frac{dQ}{dt} < 0$$

Downwellings: $\tau w > 0 \Rightarrow Fw > 0 \Rightarrow rot(Fw) = dx(Fw) < 0$

$$\frac{dQ}{dt} < 0$$



Application to vortex



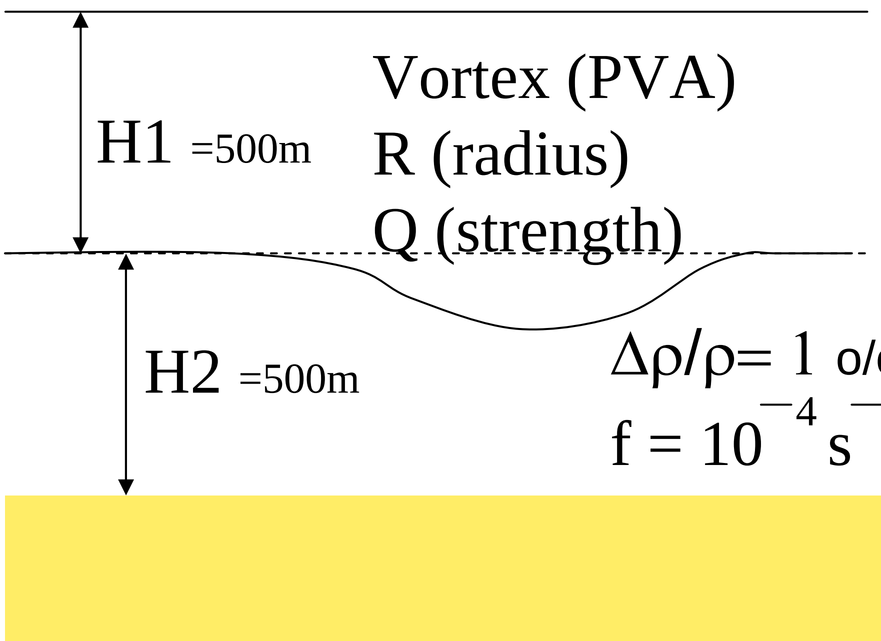
Analytical and numerical calculations

Configuration for numerical tests

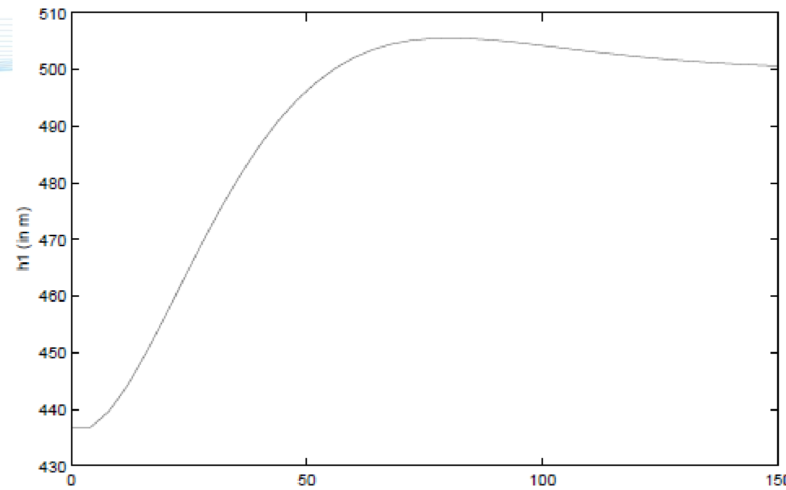
2 layers MICOM

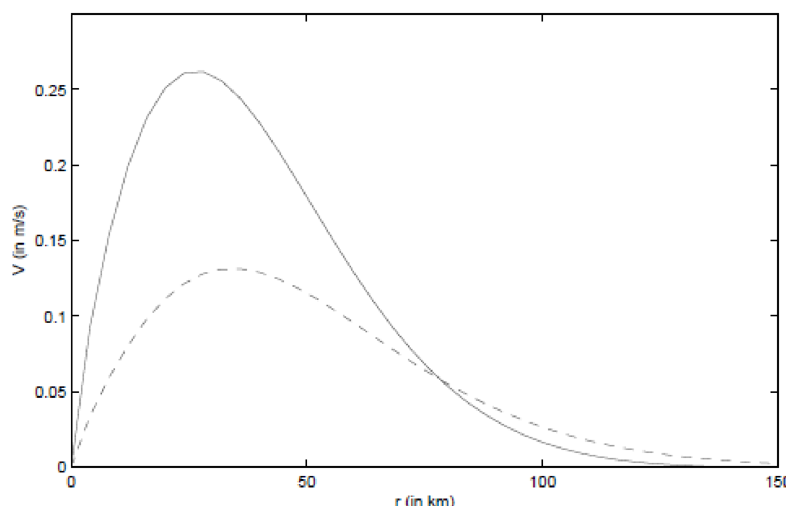
Biperiodic

$\tau = 0.5\ N.m^{-2}$



$$\Delta Q_1^o = 0.5\ f,\ \Delta Q_2^o = 0,\ R = 40\ km$$





Problem

can we predict and parameterize the effect in coarse resolution models?

Stern (long linear waves)

$$C = U_{Ek}\frac{F_2}{F_1+F_2}, \quad = U_{Ek}\frac{H_1}{H_1+H_2},$$

= barotropic part of Ekman drift

$$U_{Ek} = \frac{\tau_o}{f\ \rho_1\ H_1}$$

Present study

$$q_1 = \frac{f\ \tau_o}{\rho_1\ g'\ H_1^2}\ \frac{\partial_r(\overline{\psi}_1 - \overline{\psi}_2)}{\partial_r\overline{\psi}_1}\ r\ [sin(\theta - \overline{\Omega}_1\ t) - sin\theta],$$
$$= \frac{f\ \tau_o}{\rho_1\ g'\ H_1^2}\ \frac{\overline{V}_1 - \overline{V}_2}{\overline{V}_1}\ r\ [sin(\theta - \overline{\Omega}_1\ t) - sin\theta],$$
$$= \frac{f\ \tau_o}{\rho_1\ g'\ H_1^2}\ \frac{\overline{\Omega}_1 - \overline{\Omega}_2}{\overline{\Omega}_1}\ r\ [sin(\theta - \overline{\Omega}_1\ t) - sin\theta],$$

Much more complicated
Depends on vortex structure
(sign, strength, radial shape)
+ exists along wind drift

Some basic principles can however be found (4 cases)

(1) In the case of a cyclonic vortex intensified in the upper layer, $-\partial_r \overline{h}_1/\overline{\Omega}_1$ is negative and the cross wind displacement associated with the beta-gyre is at the left of the wind, compensating the Ekman drift. This is indeed what is observed for the reference experiment.

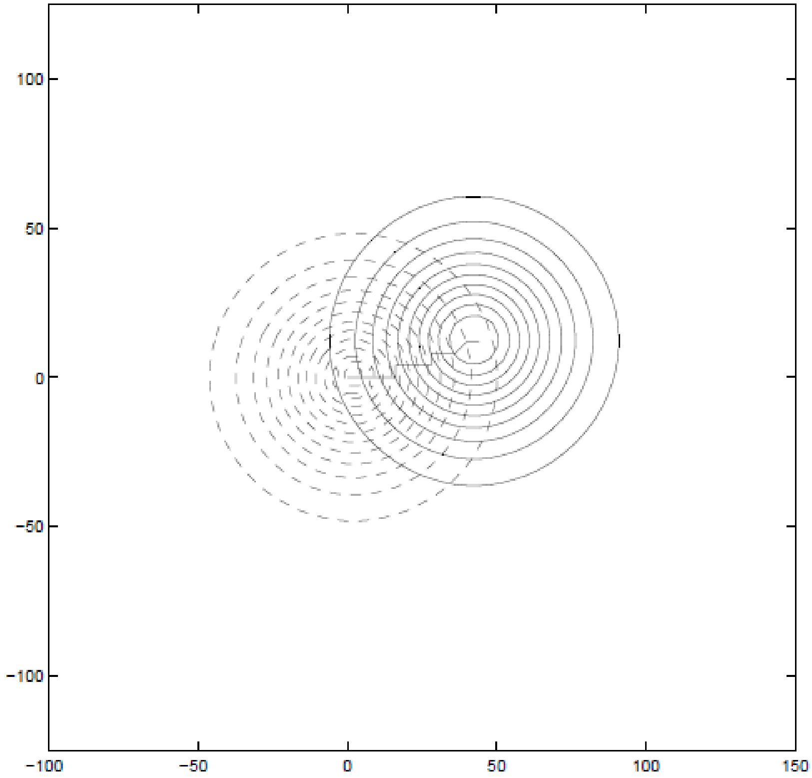
(2) In the case of an anticyclonic vortex intensified in the upper layer, $-\partial_r \overline{h}_1/\overline{\Omega}_1$ is also negative, again leading to a compensation of the Ekman drift.

(3) In the case of a cyclonic vortex intensified in the lower layer, $-\partial_r \overline{h}_1/\overline{\Omega}_1$ is positive, which yields a propagation to the right of the wind reinforcing the Ekman drift (normally playing no advection role in the lower layer).

(4) In the case of an anticyclonic vortex intensified in the lower layer, $-\partial_r \overline{h}_1/\overline{\Omega}_1$ is positive, yielding again a propagation to the right of the wind reinforcing the Ekman drift (normally playing no advection role in the lower layer).

Simple rules for vortex sign and surface/subsurface, illustrated further

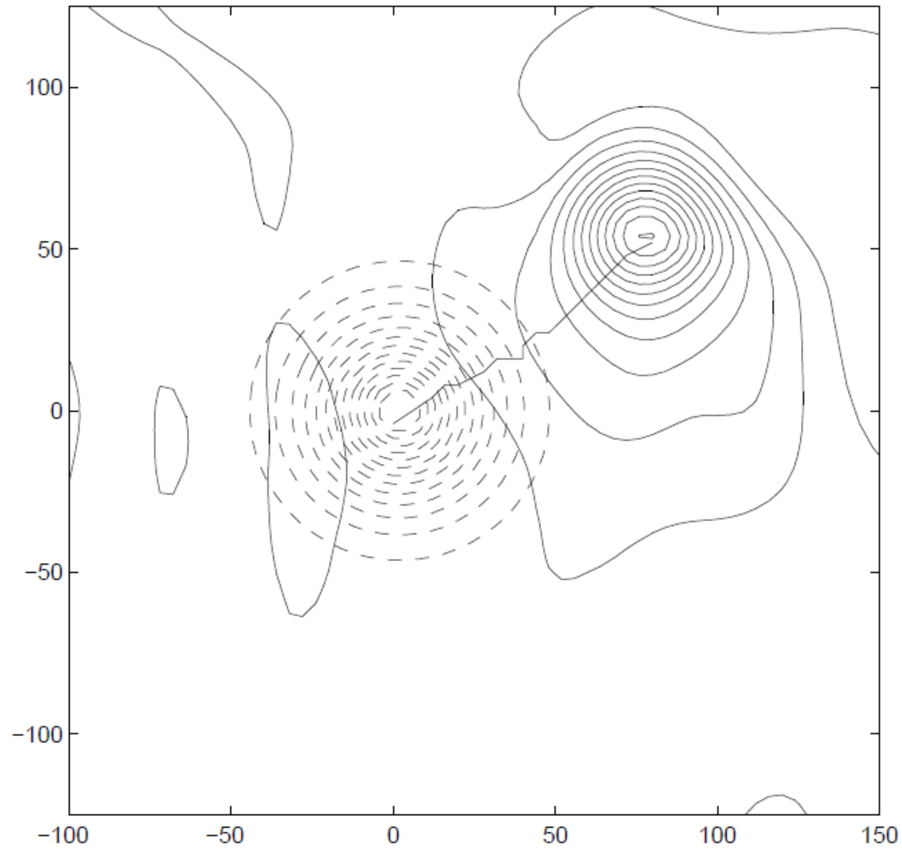
H1 = 100 m
H2 = 900 m



Reference experiment

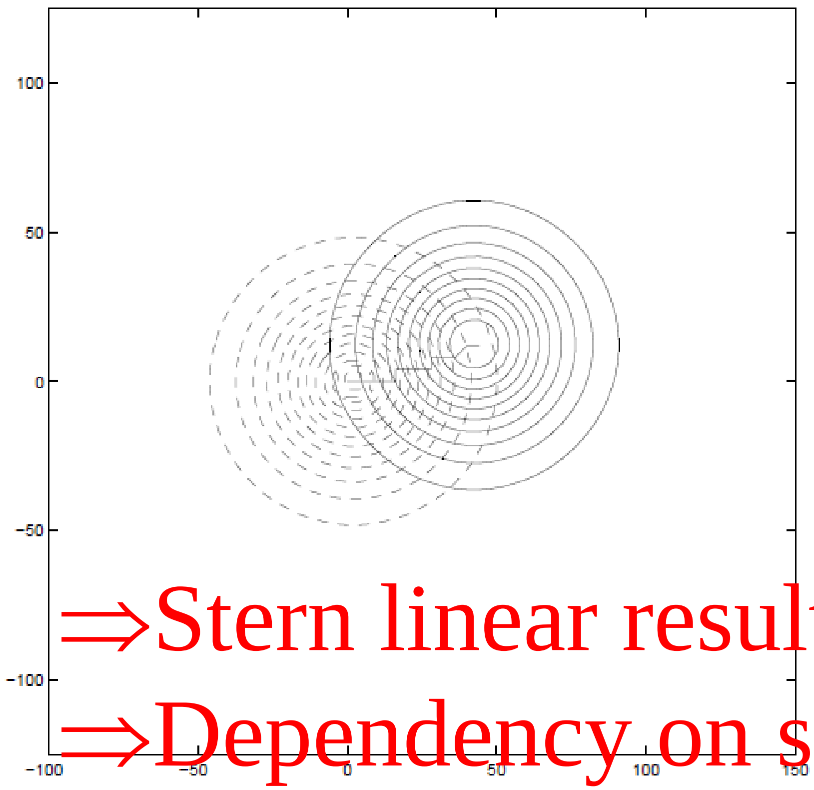
U_{Ek} = 1 cm/s
C_{Stern} = 0.5 cm/s

U_{Ek} = 5 cm/s
C_{Stern} = 0.5 cm/s



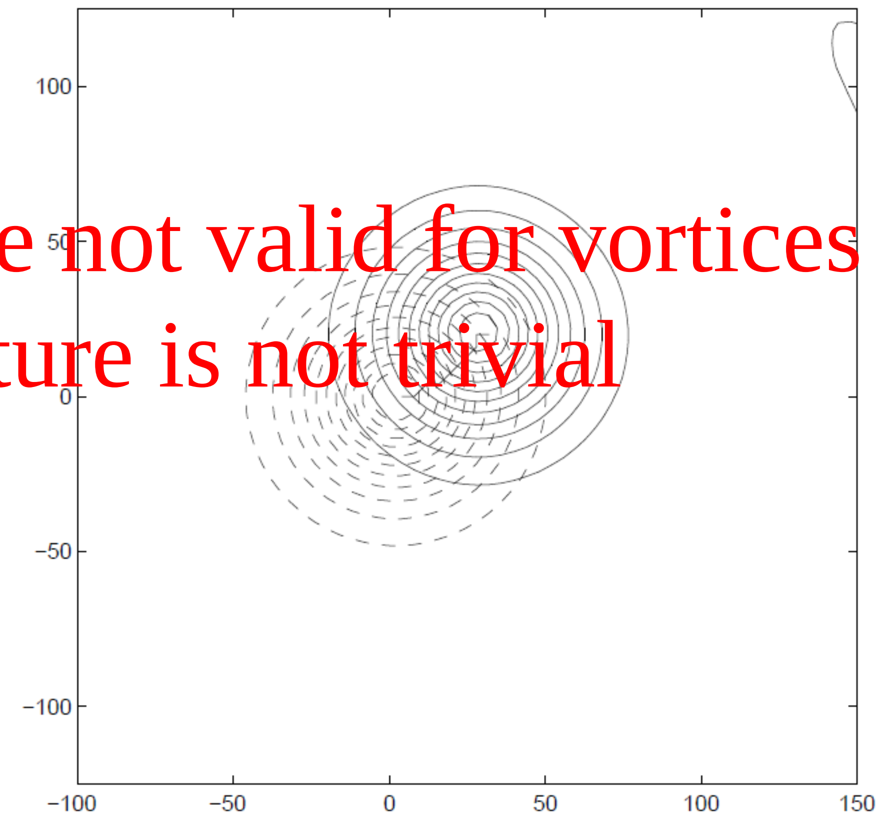
H1 = 500 m
H2 = 1500 m

U_{Ek} = 1 cm/s
C_{Stern} = 0.25 cm/s



Reference experiment

U_{Ek} = 1 cm/s
C_{Stern} = 0.5 cm/s

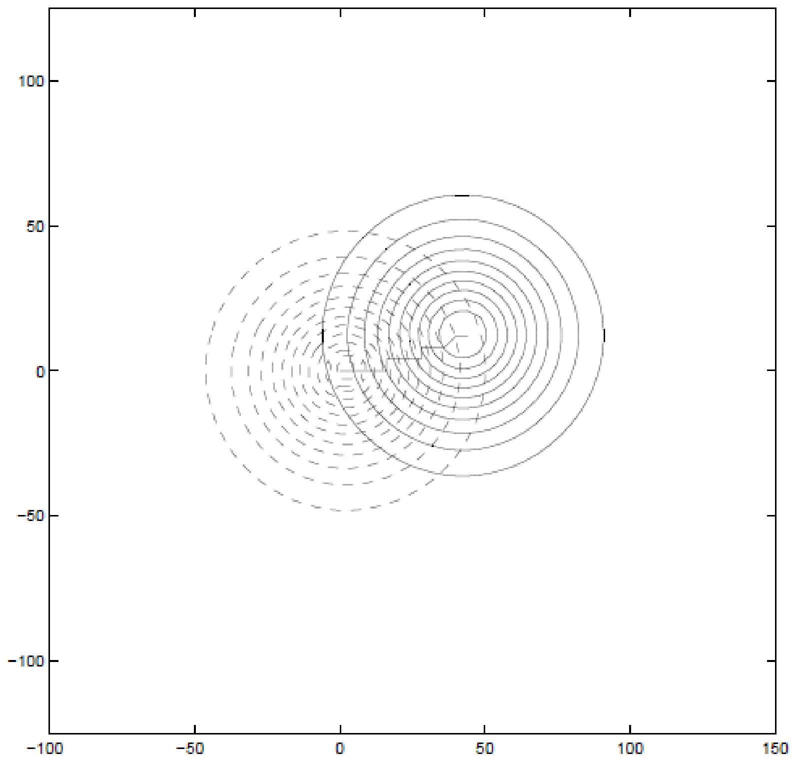


⇒Stern linear results are not valid for vortices

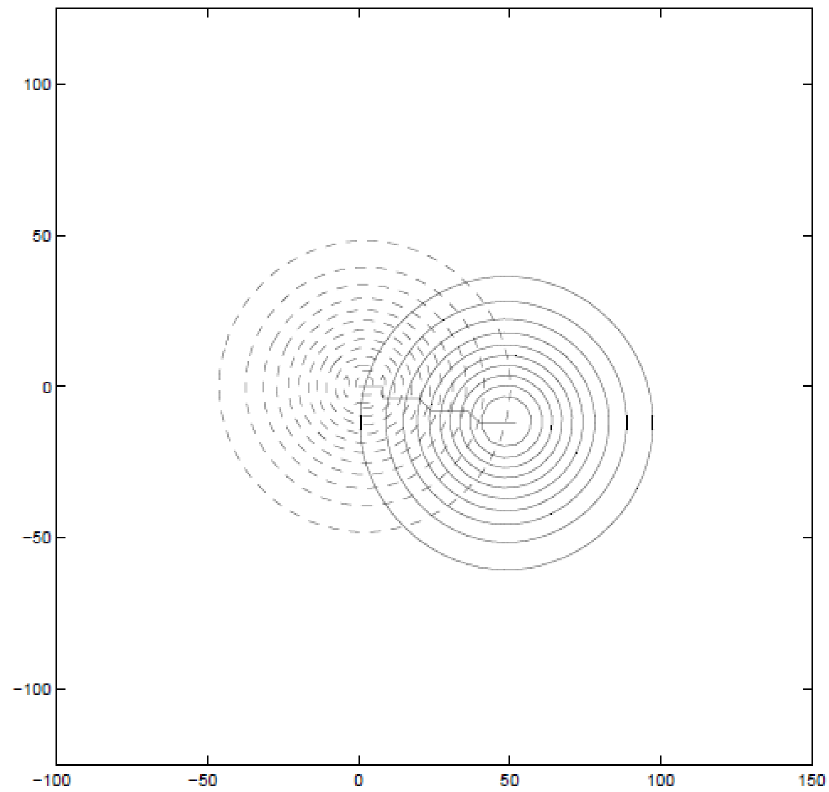
⇒Dependency on structure is not trivial

Effect of vortex sign

$\Delta Q_1^o = -0.5\ f,\ \Delta Q_2^o = 0,\ R = 40\ km.$

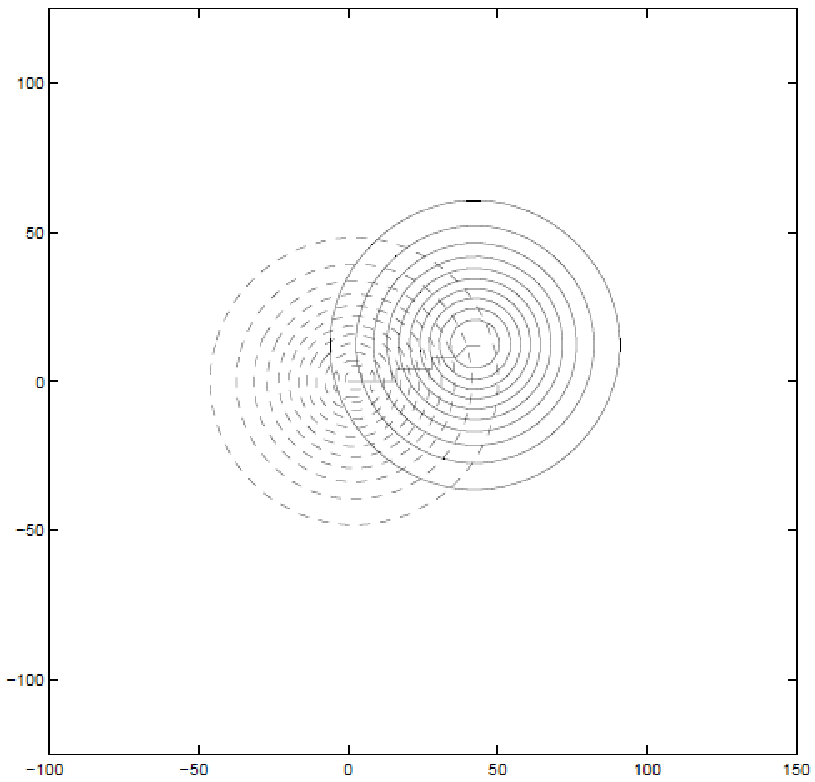


Reference experiment



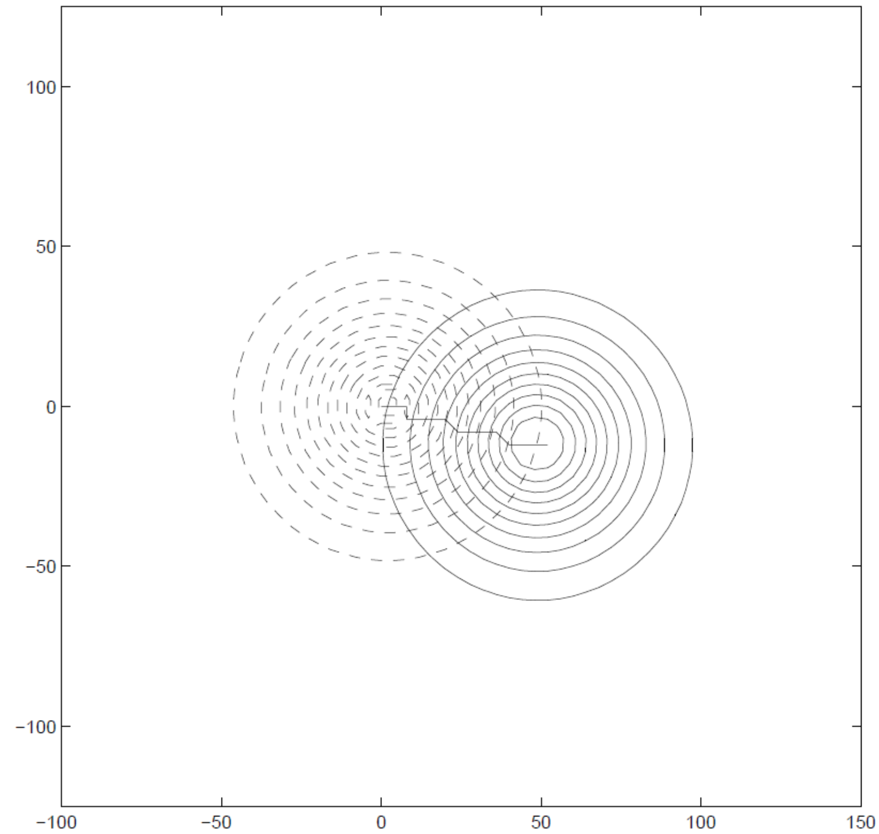
$U_{Ek} = 1$ cm/s

$C_{Stern} = 0.5$ cm/s



Effect of vortex vertical structure

Bottom intensified

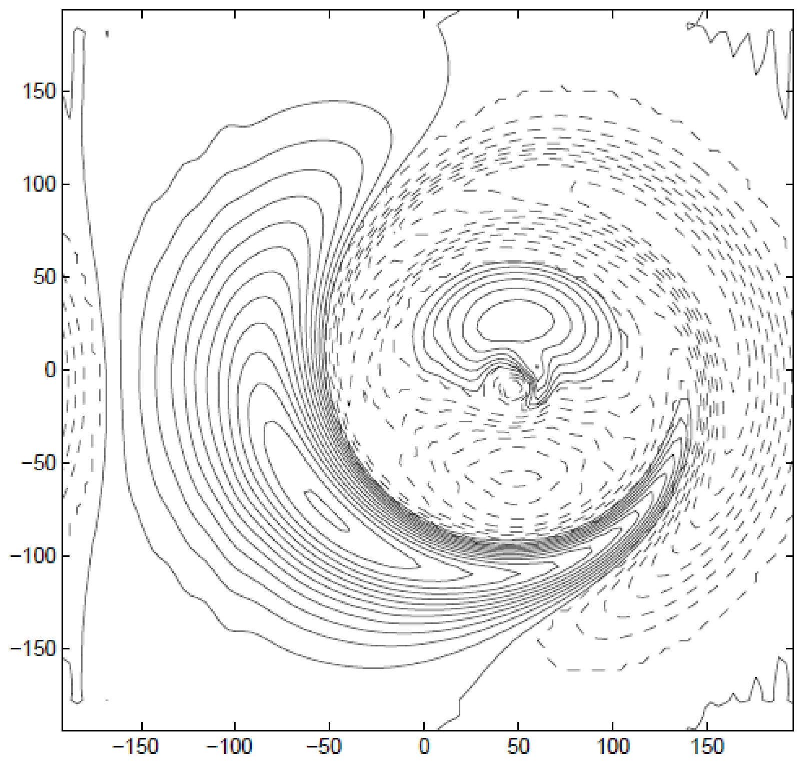


Reference experiment

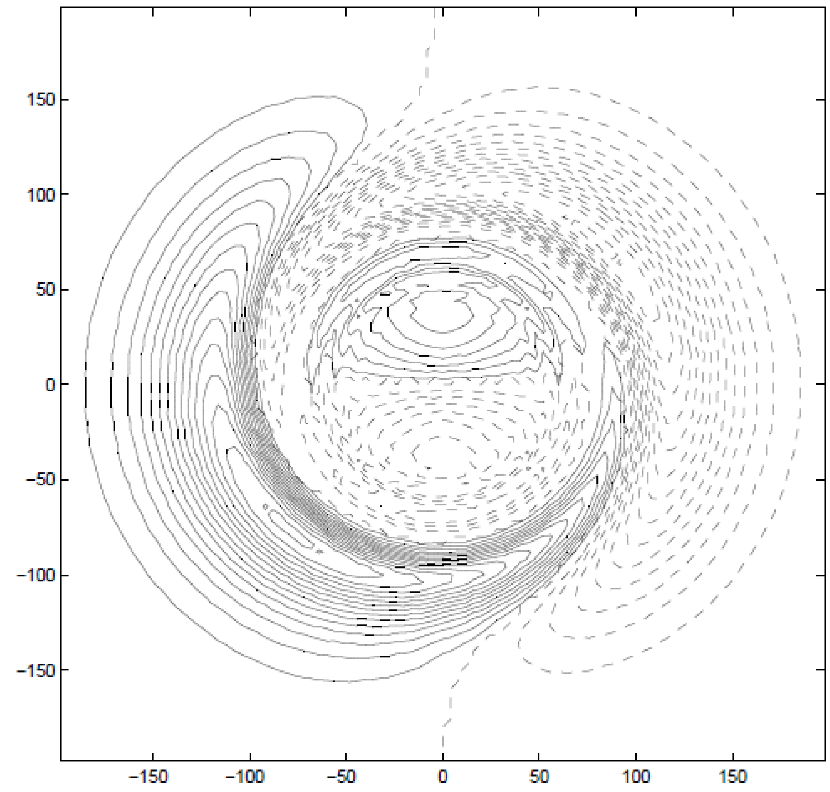
U_{Ek} = 1 cm/s
C_{Stern} = 0.5 cm/s

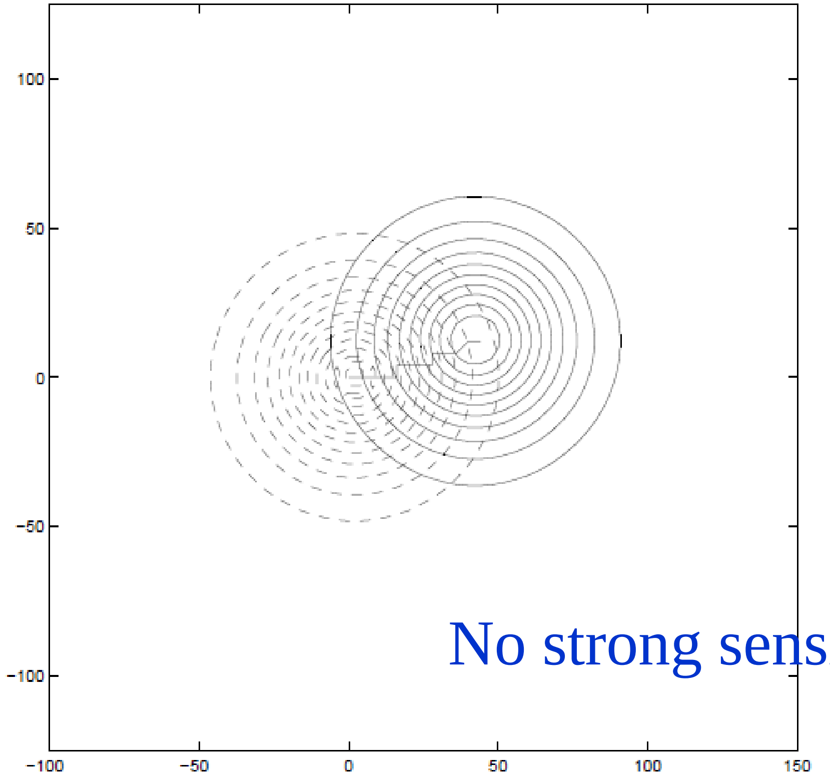
Dipolar structure for bottom intensified vortex

Numerical results



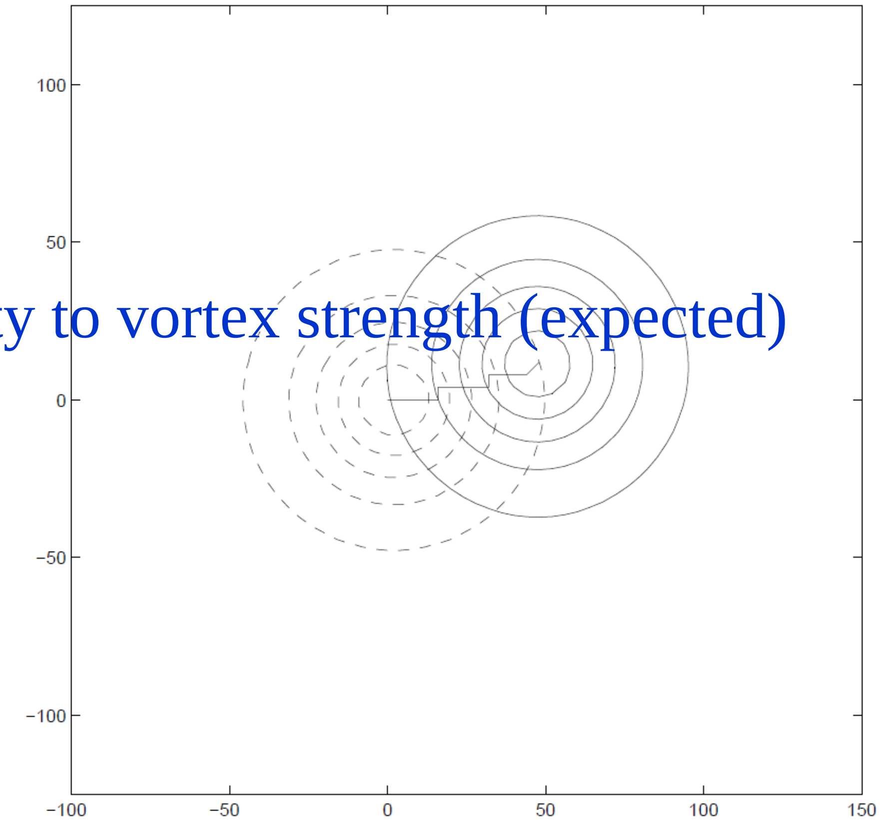
Analytical results





Effect of vortex strength

Q1 = 0.25 f (half ref.)

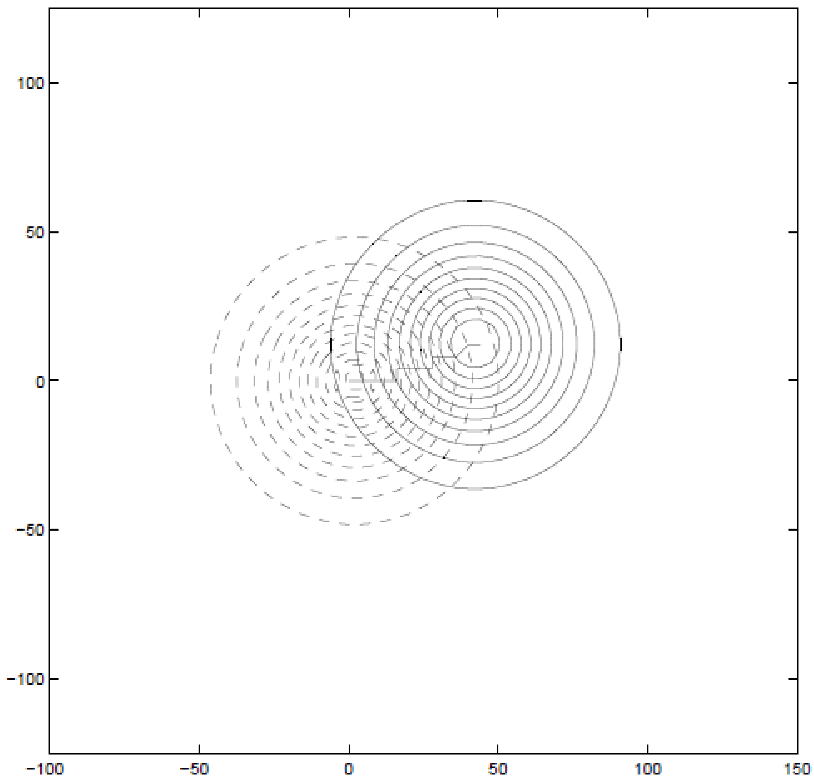


No strong sensitivity to vortex strength (expected)

Reference experiment

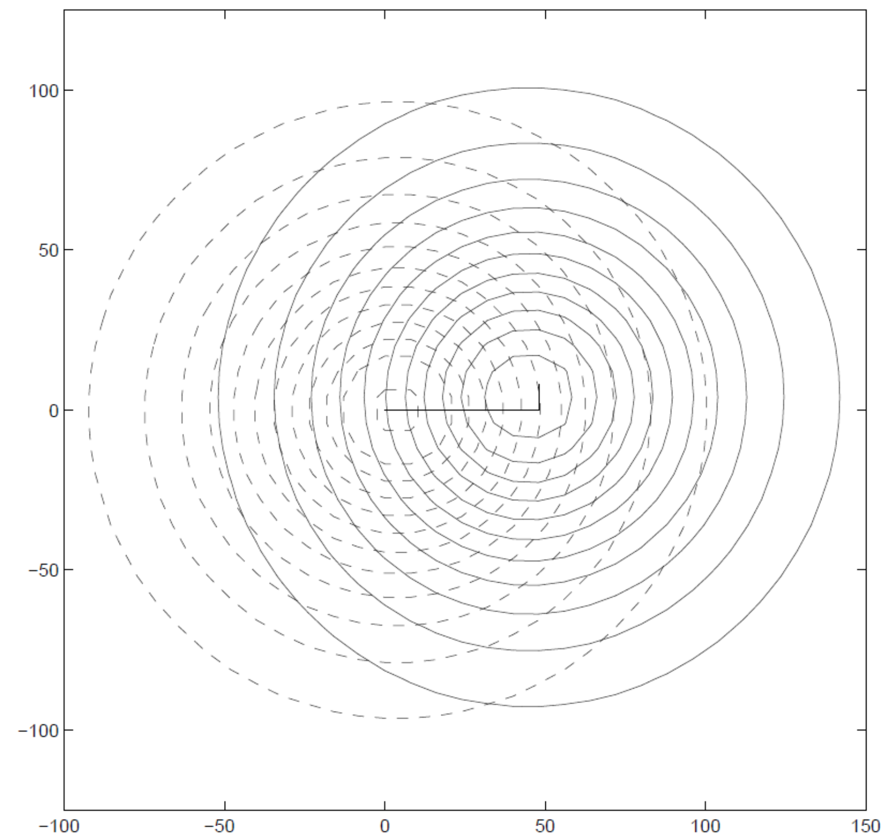
U_{Ek} = 1 cm/s

C_{Stern} = 0.5 cm/s



Effect of vortex radius

R = 80 km (twice ref.)



Reference experiment

U_{Ek} = 1 cm/s

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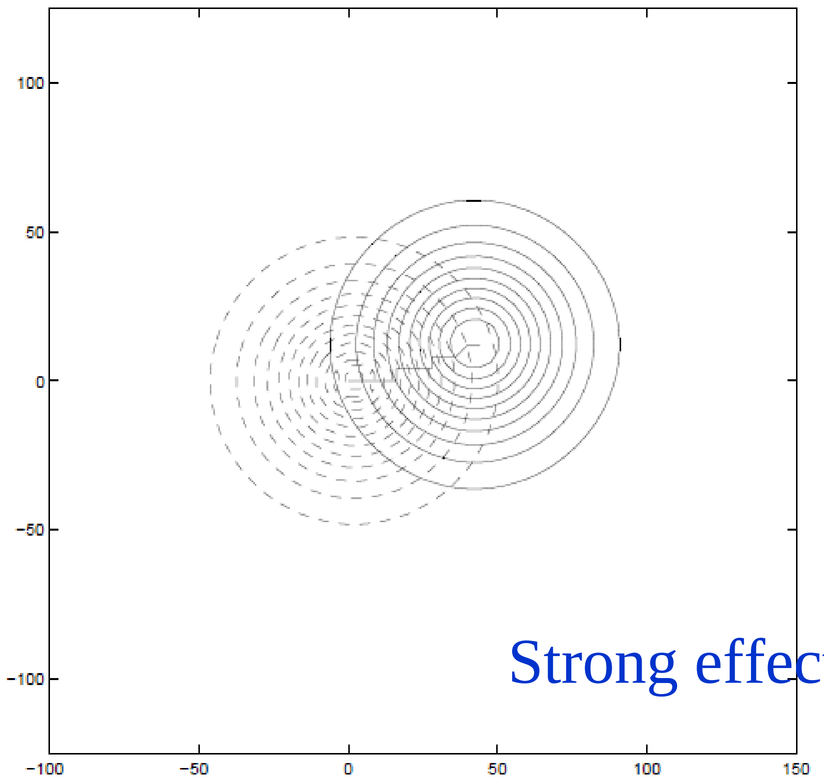
Effect of vortex radius

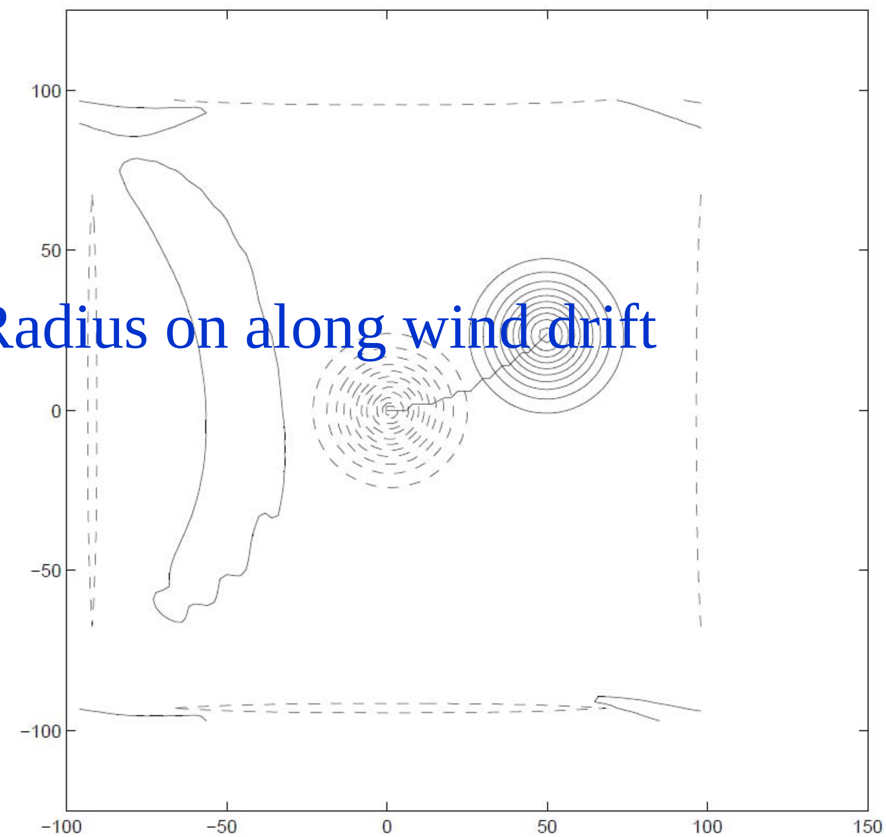


Reference experiment

$U_{Ek} = 1$ cm/s

$C_{Stern} = 0.5$ cm/s

R = 20 km (half ref.)



Strong effect of Radius on along wind drift

Conclusion

Wind stress interacts with vortical structures and modifies Ekman drift

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Additional along wind propagation

Analytical solutions can be calculated but no simple rules/parameterization (depends on details of vortex structures in a non trivial way)

⇒ In OGCMs with coarse resolution water mass distribution may be difficult to reproduce accurately if associated with vortices

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