Title: Modelling Surface Driven Flows in the Ocean

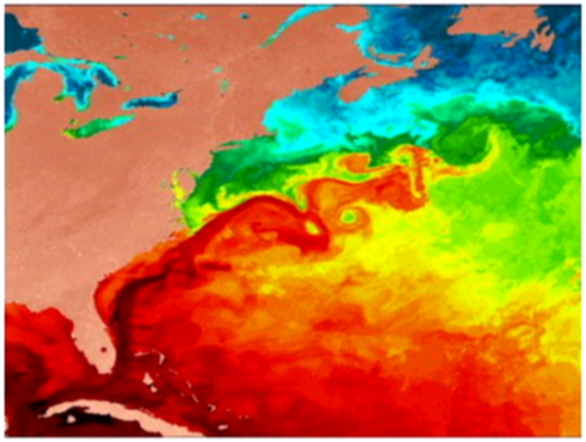
Date: May 07, 2014 11:55 AM

URL: http://pirsa.org/14050047

Abstract: Buoyancy driven flows at the top of the ocean or bottom of the atmosphere are inherently different from their interior dynamics. Oneidealized model that has recently become very popular to idealizethese surface flows with strong rotation is Surface Quasi-Geostrophic (SQG) dynamics. This model is appropriate for large-scale dynamics and assumes the motion is in near geostrophic and hydrostatic balance. Many of the numerical simulations of SQG have shown thatvortices are frequently generated at very small scales scales thatare well beyond the SQG limits.In this talk we examine the dynamics of a rotating three-dimensionalelliptic vortex in both the SQG model and a more general and muchmore complicated primitive equation model. In order to compute highresolution solutions to the three dimensional primitive equations we make use of Sharcnet resources. We find that in the case of strongrotation (small Rossby number) we confirm the predictions from SQG.With weaker rotation (moderate Rossby number) we see the non-SQG effects that arise and find that the regime where SQG can beappropriate can be very limited. We conclude that some of thepredictions that arise from the SQG model might not be very accuratein idealizing geophysical flows at the surface.

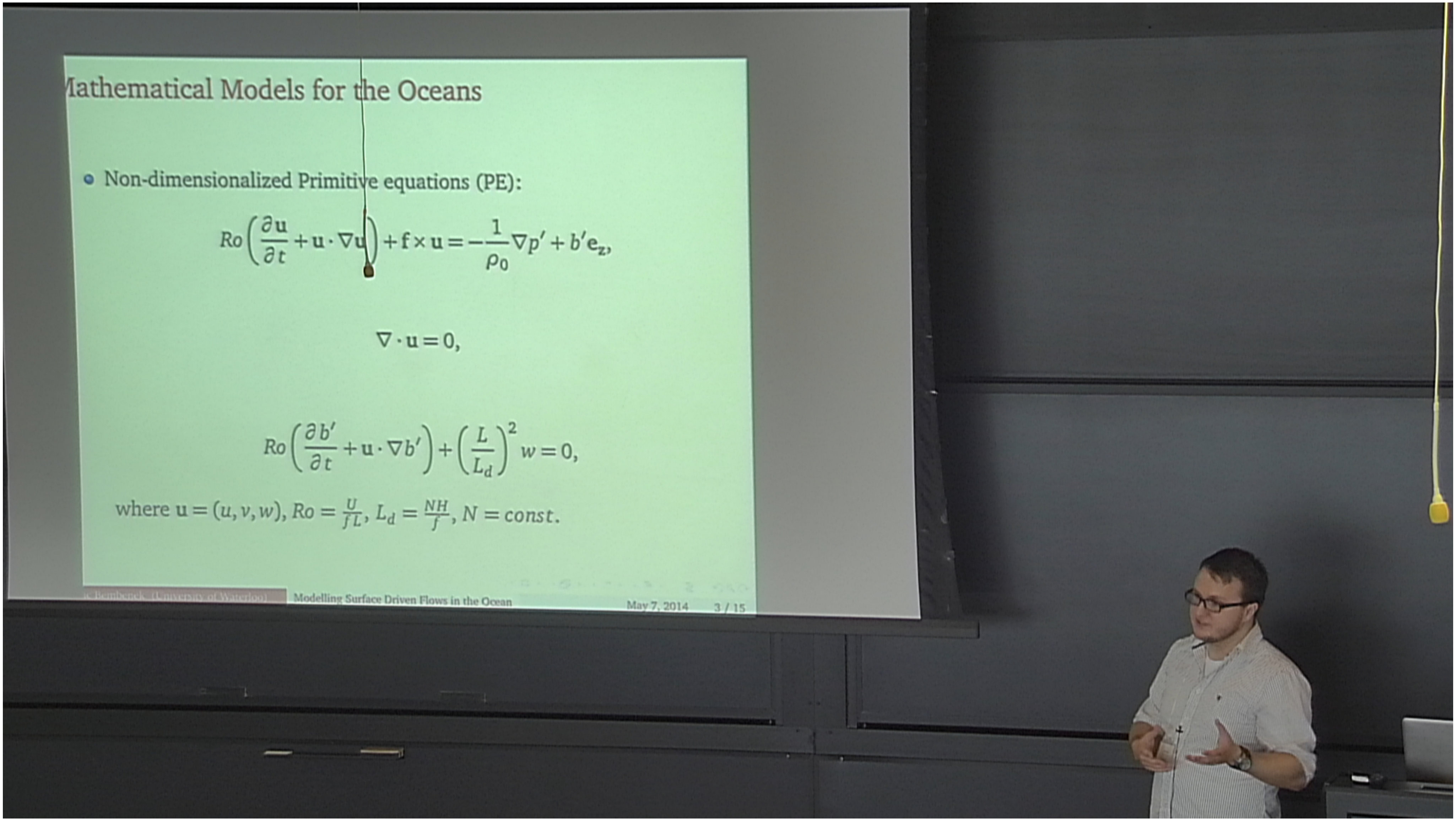

ntroduction
igure : Left: Jupiter's Red Spot (Image from universetoday.com). Right: Sea
urface Temperatue of Gulf Steam (Image from the NC State Climate Office)
Modelling Surface Driven Flows in the Ocean
May 7, 2014
2 / 15

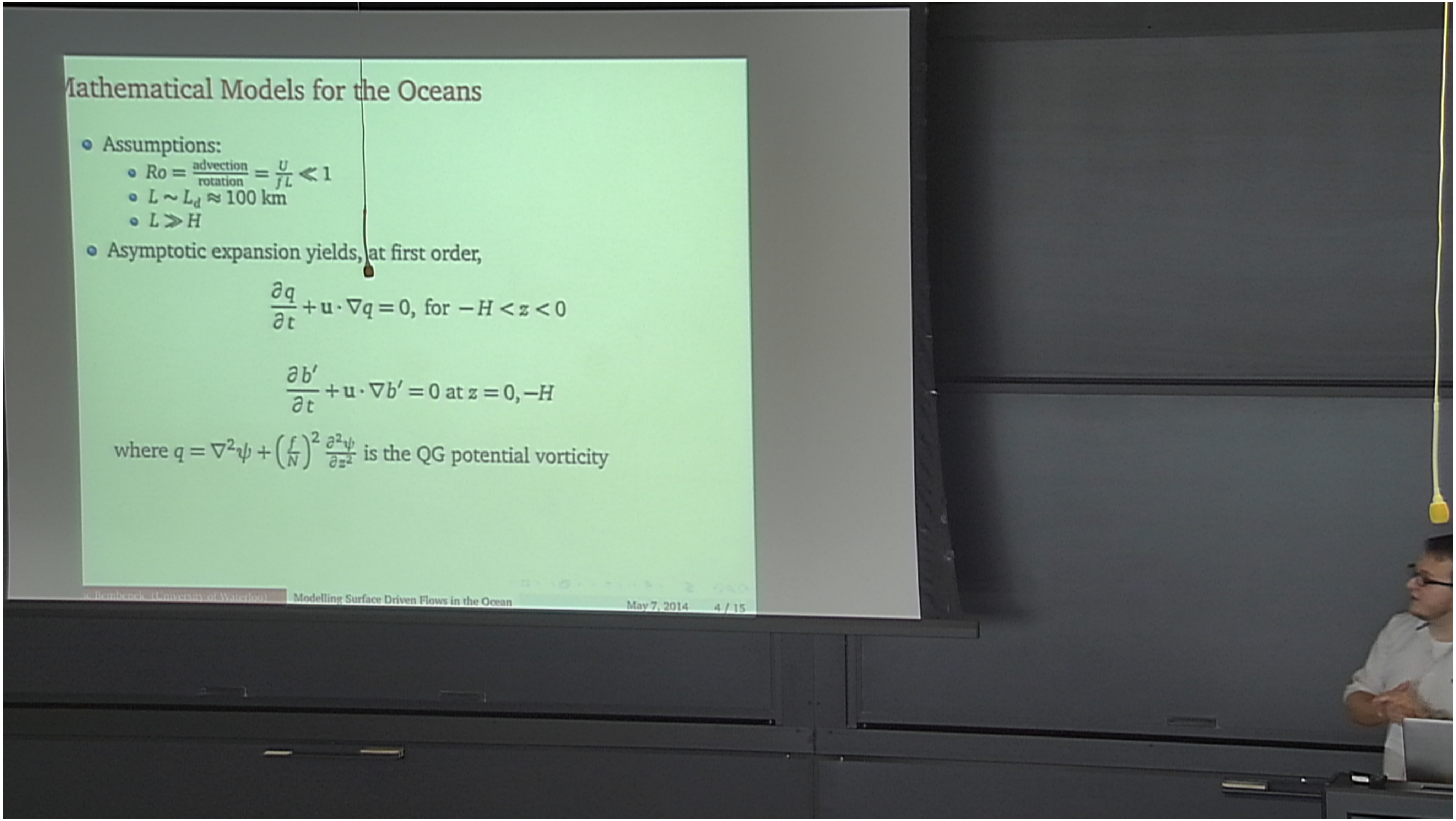
ntroduction

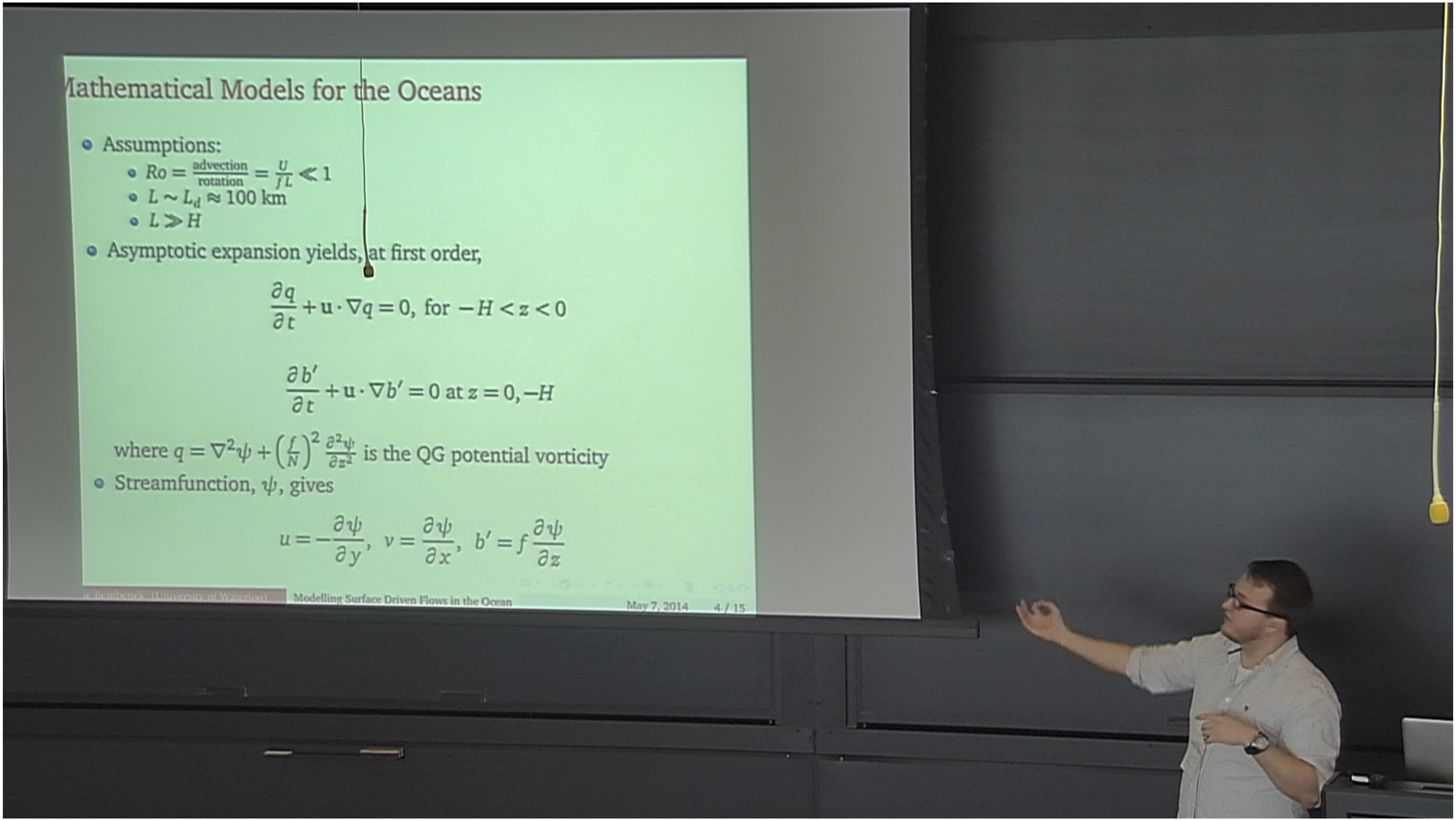


'igure : Left: Jupiter's Red Spot (Image from universetoday.com). Right: Sea ;urface Temperatue of Gulf Steam (Image from the NC State Climate Office)

- Large scale oceanic flows are rather slow
- Rotation of the Earth is important (Coriolis force)
- Quasi-Geostrophy (QG) can describe large scale motions very well
- Surface Quasi-Geostrophy (SQG) considers a scenario where all motion is driven by surface temperature


athematical Models for the Oceans
Non-dimensionalized Primitive equations (PE):
$Ro\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) + \mathbf{f}\times\mathbf{u} = -\frac{1}{\rho_0}\nabla p' + b'\mathbf{e_z},$
$\nabla\cdot\mathbf{u} = 0,$
$Ro\left(\frac{\partial b'}{\partial t} + \mathbf{u}\cdot\nabla b'\right) + \left(\frac{L}{L_d}\right)^2 w = 0,$
where $\mathbf{u} = (u, v, w)$, $Ro = \frac{U}{fL}$, $L_d = \frac{NH}{f}$, $N = const.$
Modelling Surface Driven Flows in the Ocean
May 7, 2014
3 / 15


athematical Models for the Oceans
Assumptions:
$Ro = \frac{\text{advection}}{\text{rotation}} = \frac{U}{fL} \ll 1$
$L \sim L_d \approx 100$ km
$L \gg H$
Asymptotic expansion yields, at first order,
$\frac{\partial q}{\partial t} + \mathbf{u} \cdot \nabla q = 0$, for $-H < z < 0$
$\frac{\partial b'}{\partial t} + \mathbf{u} \cdot \nabla b' = 0$ at $z = 0, -H$
where $q = \nabla^2 \psi + \left(\frac{f}{N}\right)^2 \frac{\partial^2 \psi}{\partial z^2}$ is the QG potential vorticity
Modelling Surface Driven Flows in the Ocean
May 7, 2014
4 / 15


athematical Models for the Oceans
Assumptions:
$Ro = \frac{\text{advection}}{\text{rotation}} = \frac{U}{fL} \ll 1$
$L \sim L_d \approx 100$ km
$L \gg H$
Asymptotic expansion yields, at first order,
$\frac{\partial q}{\partial t} + \mathbf{u} \cdot \nabla q = 0,$ for $-H < z < 0$
$\frac{\partial b'}{\partial t} + \mathbf{u} \cdot \nabla b' = 0$ at $z = 0, -H$
where $q = \nabla^2 \psi + \left(\frac{f}{N}\right)^2 \frac{\partial^2 \psi}{\partial z^2}$ is the QG potential vorticity
Streamfunction, ψ, gives
$u = -\frac{\partial \psi}{\partial y},\ v = \frac{\partial \psi}{\partial x},\ b' = f \frac{\partial \psi}{\partial z}$
(University of Waterloo)
Modelling Surface Driven Flows in the Ocean
May 7, 2014
4 / 15

Mathematical Models for the Oceans

- For SQG, set $q = \nabla^2\psi + \left(\frac{f}{N}\right)^2 \frac{\partial^2\psi}{\partial z^2} = 0$
- At $z = 0$, take $b' = b^t$ as given
- Find analytic solution in Fourier space,

$$\boxed{\hat{\psi} = \frac{1}{NK} \frac{\cosh\left(\frac{NK}{f}(z+H)\right)}{\sinh\left(\frac{NKH}{f}\right)} \hat{b}^t,}$$

where $K = \sqrt{k^2 + l^2}$, (k, l) are horizontal wavenumbers

Numerical Methods

- Two numerical models
  - QG3 (G.R. Flierl, priv. comm.) for SQG dynamics

Iumerical Methods

- Two numerical models
  - QG3 (G.R. Flierl, priv. comm.) for SQG dynamics
  - SPINS (Spectral Parallel Incompressible Navier-Stokes Solver) for the primitive equations (Subich et al 2013)

Numerical Methods

	QG3	SPINS
Grid Size	512^2	512^3
Filter	Radially in spectral space	Applied in each direction
Parallel?	No	Yes (64 CPUs on Sharcnet)
Runtime	~ 10 minutes	$\sim 3-5$ days!