Dissertation Outline /Notes

# **Introduction**

## Main Goals / Hypothesis:

* Identify internal wave signals and prove that the observed waves are lee waves
  + Characterize wave properties (frequency and wavenumbers)
  + Calculate rotary components (**DO THIS SOON)** to show upward or downward propagation (important for sign of m)
  + Ray tracing backwards to see if path hits topography
* Test whether lee waves play a significant role in energy dissipation and drag on mean flow
  + Calculate internal wave energies of observations and compare with other work?
  + Use ray tracing to track energy and momentum as lee waves propagate.
  + **How do you show they are causing drag?**

# **Methods**

This study utilizes a 100 km towyo transect over a region of complex topography by the Shag Rocks islands. The data was collected as part of the JC69 DIMES cruise in 2012. The primary goal of this study is to characterize direct observations of lee waves and assess their role in the region.

## Linear Wave Theory & Diagnostic Equations

Linear internal wave theory allows for construction of polarization relations which are critical to understanding internal waves in observations. Eq. 1 relates the ratio of internal wave kinetic and potential energies to the frequency.

(1)

This observed frequency has been Doppler shifted by the mean flow and must therefore by modified by Eq. 2 to obtain an intrinsic frequency.

(2)

U is the mean flow and represents the wavenumber vector. The intrinsic frequency can be utilized, along with the local buoyancy frequency, to estimate the horizontal wavenumber with Eq. 3:

(3)

where *m* is the vertical wavenumber, estimated from observations (see following section). For ray tracing, the horizontal wavenumber must be decomposed into its meridional and zonal components *k* and *l*.

## Internal Wave Parametrizations

This section details the use of the diagnostic equations shown above for estimating observed wave properties, following much of the methodology used by Waterman et al. 2013. Integrated variance spectra of velocity and density anomalies are used for estimation internal wave energies. For each quantity of interest, the anomaly component is estimated by subtracting a sliding 2nd order polynomial fit to each vertical profile, where the polynomial fit represents the mean value (Eq. 4):

(4)

where *X* represents an observed quantity of interest, is the mean value, and is the quantity anomaly. The sliding polynomial fit was constructed by fitting to overlapping 100 dB segments which increase in size by 8 dB every 8 dB. The polynomial fits are combined and linearly regressed back into single vertical profiles which can subtracted from observed profiles. The resulting anomaly profiles are binned into half overlapping 1500 dB bins. Bin size was chosen to fully capture the clearly observable wave features in *figure velocity anomalies.* The power spectral density is then calculated in each bin using Welch’s method and Hanning windowing to reduce loss of variance. Finally, spectral power is integrated between target vertical wavelengths corresponding to the vertical size of velocity anomaly features. Rather than use constant integration limits, they are adjusted for each bin to properly capture the wave features. Kinetic energy is estimated using Eq. 5, where denotes integrated variance spectra. Potential energy is estimated from isopycnal displacements (Eq. 6), where Γ is neutral density. Neutral densities are calculated using the CSIRO neutral density code. is calculated by differencing Γ over 400 dB windows.

## Ray Tracing

The second aspect of this study deals with understanding the role lee waves play in the Southern Ocean’s eddy field through ray tracing. **Add Ray Tracing Background (where equations come from and previous studies which used it)**  Several key studies have utilized this approach to better understand internal gravity waves in a variety of scenarios. However, due to limitations in observational data, these studies simplified local physical conditions. **Add examples**. This study utilizes the satGEM product to simulate lee wave propogation in realistic conditions, varying in 4 dimensions (x,y, z, and t). The satGEM product is an estimation of the four dimensional structure of the Southern Ocean’s temperature, salinity, and velocities using Argo float data and sea surface height altimetry (Meijers, Bindoff, and Rintoul 2010).

### Ray tracing equations

#### Group Speeds:

#### Wave Property Changes:

#### Plane Wave Fitting:

For all relevant parameters (), a plane wave solution is assumed in the form:

#### Wave Action and Momentum Fluxes:

Wave Action and Momentum Fluxes Wave action is the ratio of energy density to frequency which remains constant along the ray path. Consequently, changes in local frequency must result in directly proportional changes in energy density. The changes in energy density represent momentum fluxes between a ray *tube* and the mean flow.

### Interpolating satGEM

* Gradients are all pre-calculated and saved with original satGEM data (i.e. dudx, dvdx, dNdx, etc…)
* Interpolate through a subsection of the satGEM field using linear interpolation (scipy linearNDinterpolator) by generating interpolation function that can take the ray’s current coordinates as inputs ( f(x,y,z,t) ).
* If point is below lowest data point of nearest satGEM grid point, switch to nearest neighbor interpolation
* Use linear interpolation for bathymetry data.

### Wave Action:

Wave action is the ratio of energy density to relative frequency (Constant). In regions where frequency decreases, energy decreases proportionally and is fed into the mean flow. In regions where frequency increases, energy density increases proportionally, removing energy (momentum?) from the mean flow. **The wave-flow momentum flux (Reynolds stress) is equal to the wavenumber vector times the wave action flux (also a vector?).**

* How do you convert changes in wave action to momentum loss or gain for mean flow?

### Reverse Runs:

Show results of running ray tracing backwards in time to support the argument that the observed velocity/density anomalies are in fact lee wave observations

### Forward Runs:

Use forward runs to test the hypothesis: **lee waves play a significant role in energy dissipation and drag on the mean flow.**

* Calculate energy and momentum flux along ray path
* Track wave action along ray path.
  + What kind of signals in energy/momentum/action along ray path would confirm/refute the hypothesis.

# **Results**

## Observations

## Ray Tracing

# **Discussion**