Observed seasonality in internal wave energy in a temperate shelf sea

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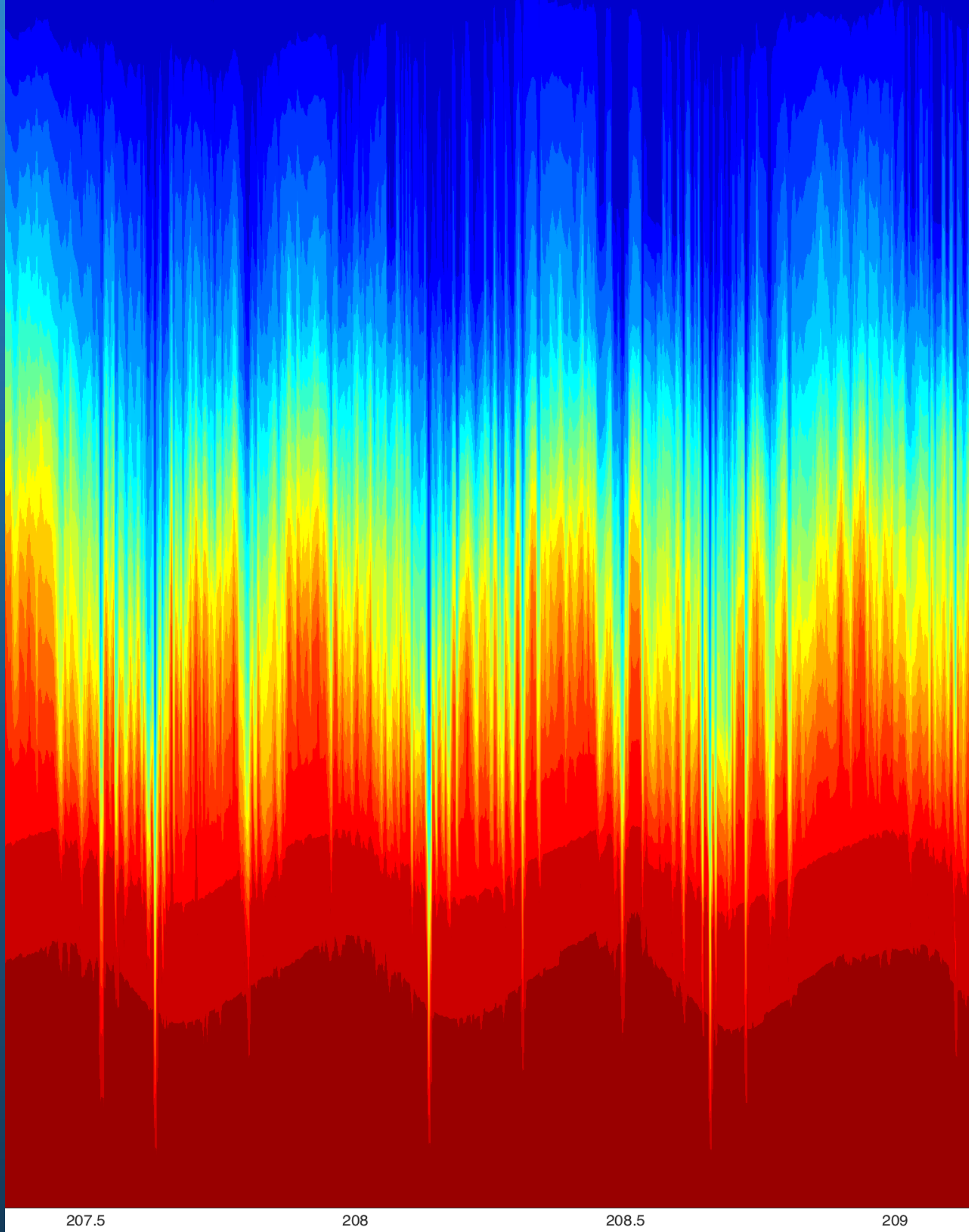
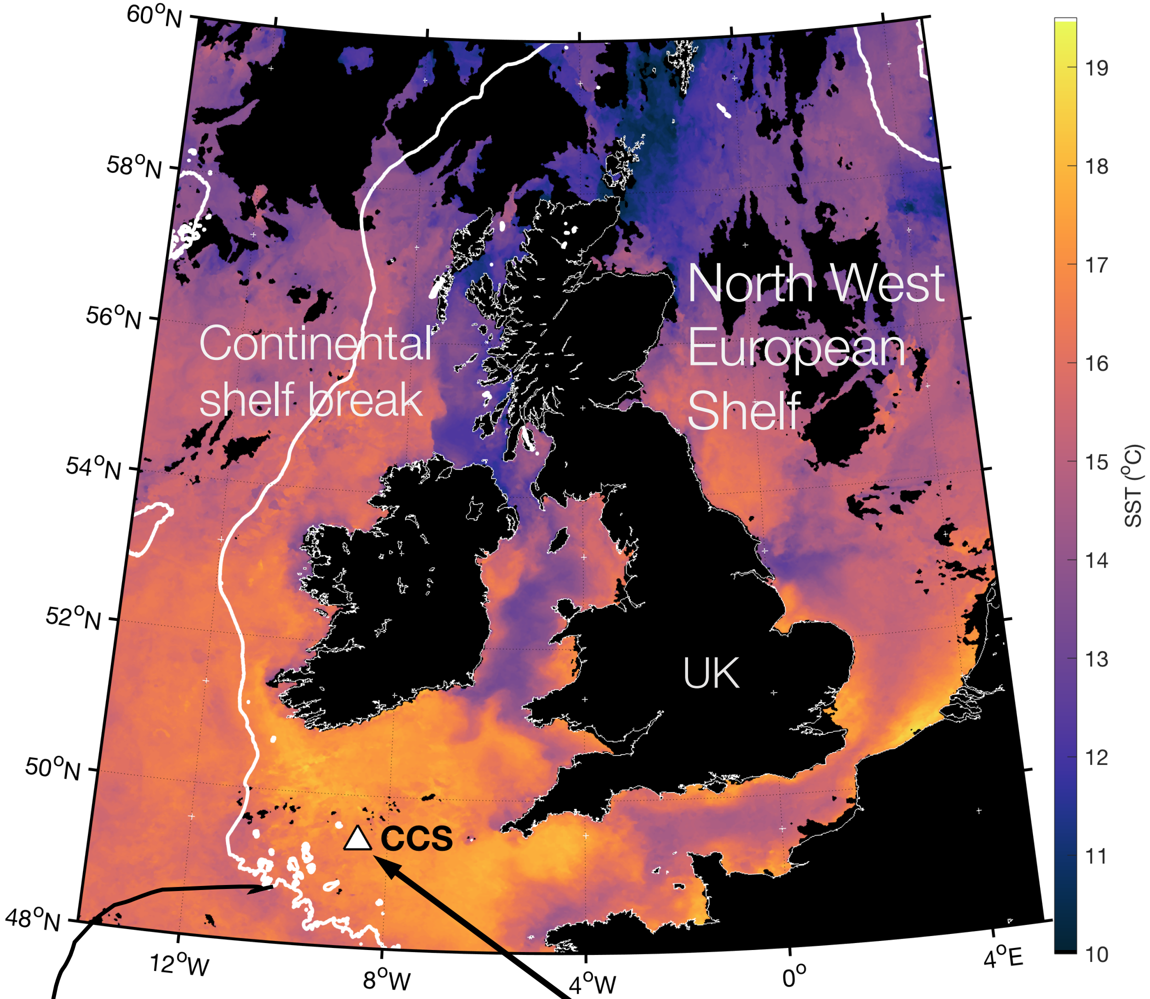


17-month full depth density & current timeseries

- Observations analysed here originate from a 17-month long, continuous deployment of a multivariable moored array spanning March 2014 - July 2015.
- This array was centrally deployed in a temperate, seasonally stratifying shelf sea, in a mean water depth of 145 m.
- A full-depth temperature-salinity chain and an alongside bottom mounted, upward facing 150kHz ADCP provided a near continuous timeseries of full depth density and current structure[1].
- The CCS site was specifically chosen to be away from strong bathymetric features such as the continental shelf break or banks and thus represents the background state of a temperate shelf sea.

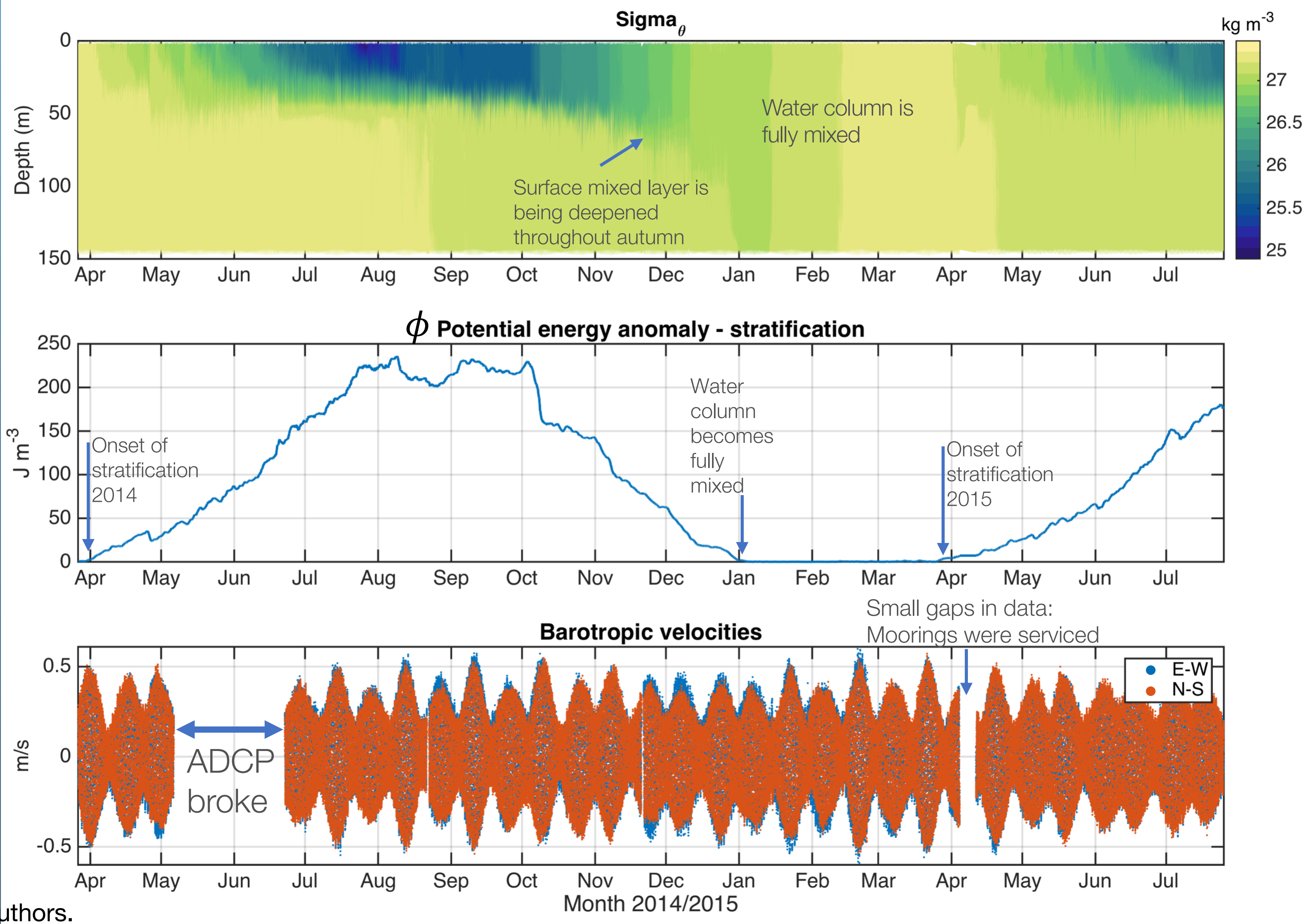


Distance to the shelf break was 120 km.

Location of central Celtic Sea (CCS) mooring site: 49.4°N, 8.6°W.

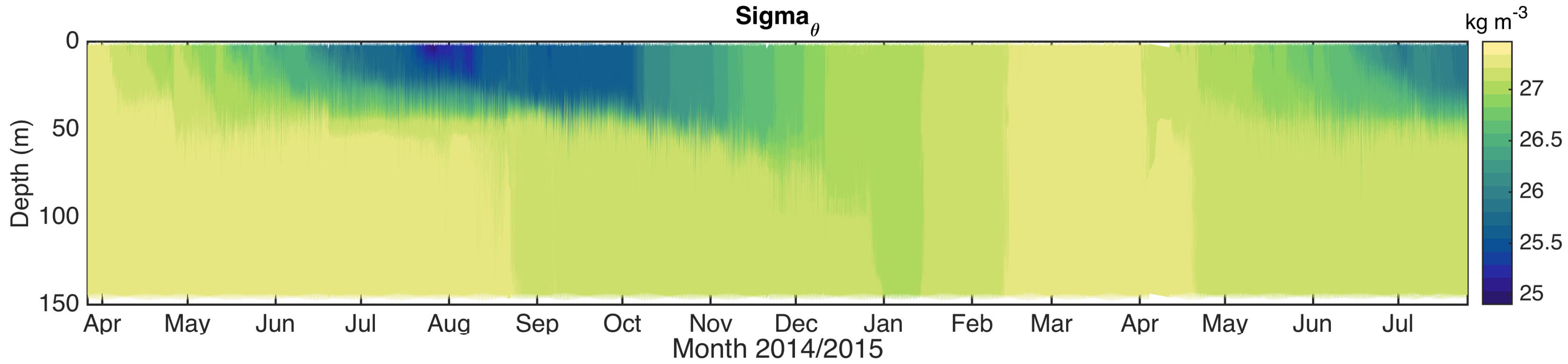
[1]Wihsgott et al. (2019), https://doi.org/10.1016/j.pocean.2019.01.001

Seasonal cycle of stratification

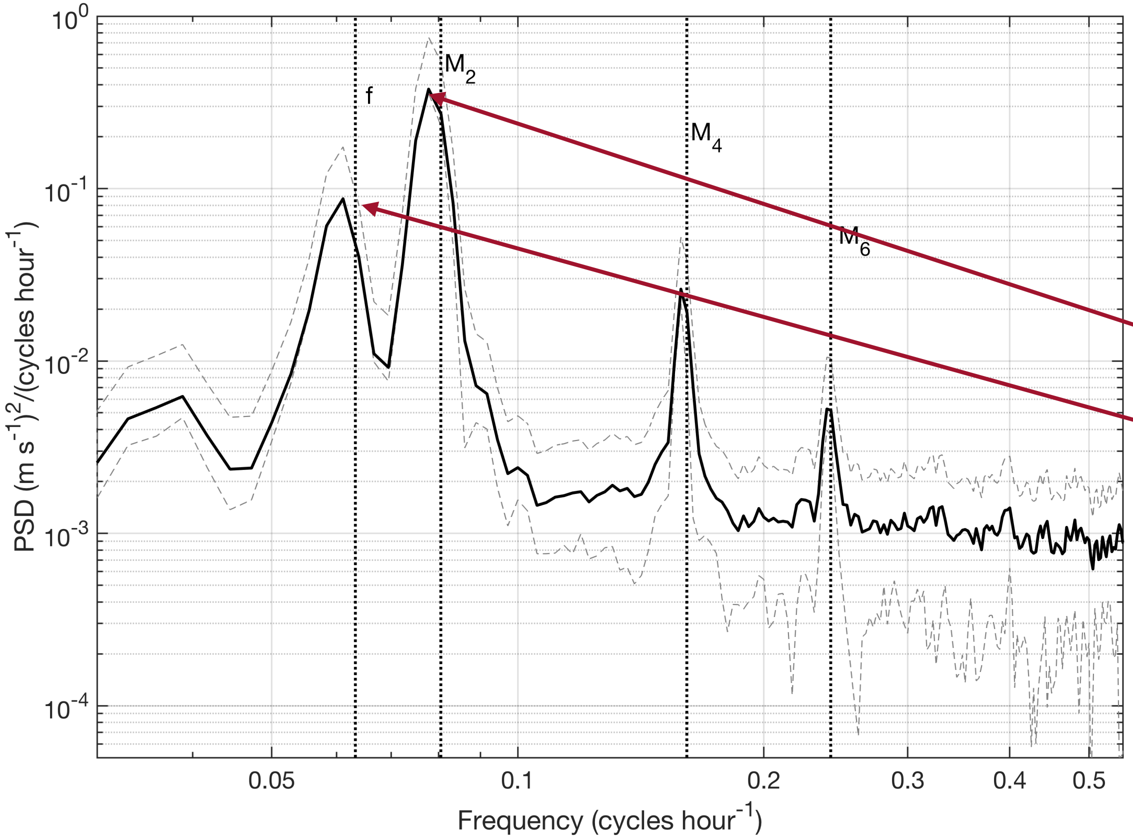


- The overall pattern in density structure observed at CCS showed a typical seasonal cycle of stratification.
- Throughout the winter months, the water column was fully vertically mixed, while the positive net heat flux during spring and summer months resulted in the development of stratified conditions.
- Peak horizontal velocities reaching 0.88 and 0.50 m s^{-1} were observed during spring and neap tides, respectively.
- The dominant tidal constituents are: M_2, S_2, N_2, K_1 and O_1.

Internal waves at CCS

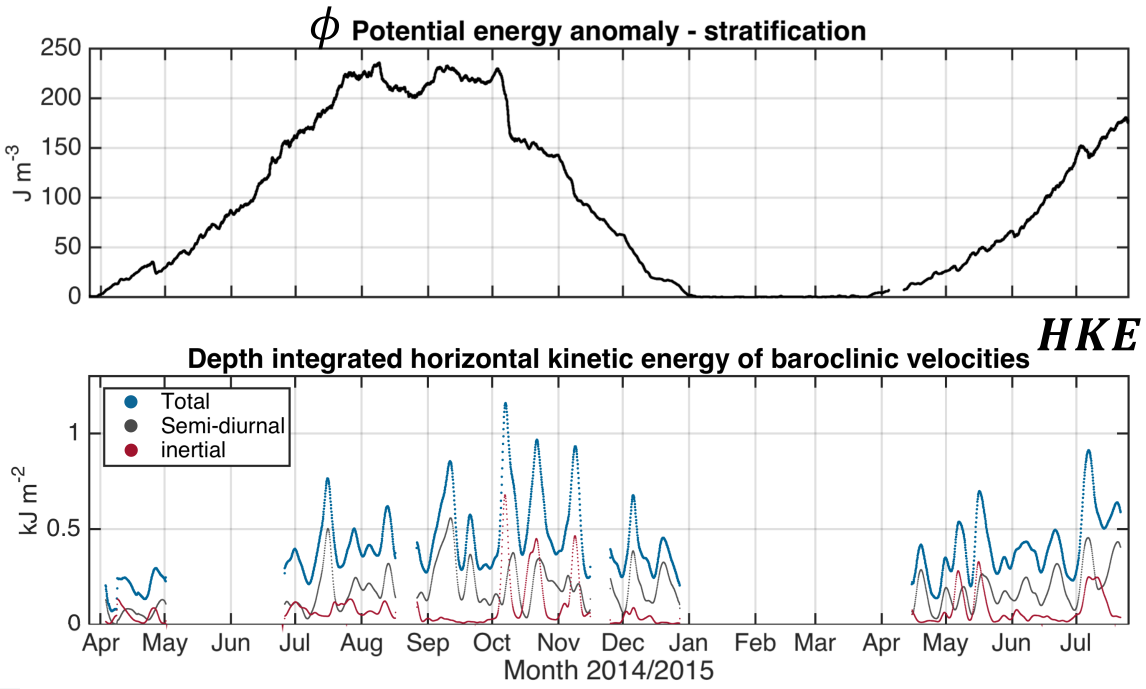


Methodology:
The power spectral density (PSD) was calculated using the complex form u+*i*v of the baroclinic velocities within the bottom boundary layer.
This was done using a Hanning window of 50% of the total data record of 8640 points.



- We observed evidence of internal waves throughout the stratified period.
- The typical wave heights reached 10-20 meters, with a maximum observed wave height of 40 meters.
- The observed internal wave field was dominated by semi-diurnal internal tides and inertial oscillations.
- At CCS the local inertial period is 15.76 hours.

Observed seasonality in internal wave energy

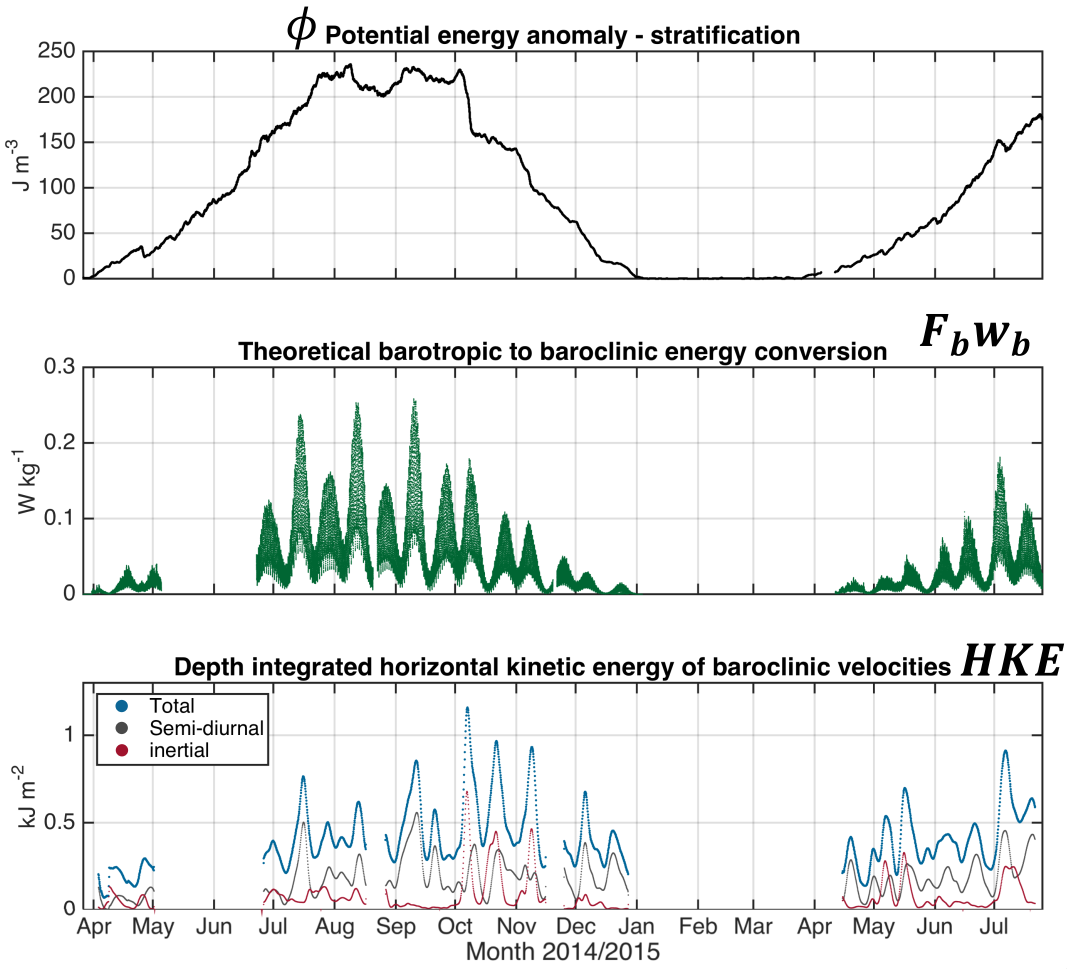


To analyse the seasonality of the internal wave field effectively the total depth integrated kinetic energy of the horizontal baroclinic velocities was calculated: HKE_{Total}.

HKE_{Total} displayed some evidence of a seasonal cycle with an apparent strong spring-neap variability, which includes some evidence of the N_2 modulation.

Weakest energy levels were clearly observed during transitional periods of stratification in spring and late autumn 2014 and spring 2015. Strongest peaks were observed during summer and autumn periods.

Observed seasonality in internal wave energy



The observed seasonality in the internal wave energy is generally consistent with the theory of internal tide generation. Following Nash et al. (2006) the total rate of work of the barotropic tide interacting with topography is given by the product of the Baines (1982) body force (F_b) and the barotropically induced vertical velocity (w_b), which Nash et al. (2006) combines as:

$$F_b w_b = \frac{N^2 w_b^2}{\omega}$$

F_b Baines body force[2]

N^2 Brunt Väilsälä frequency squared

w_b barotropically induced vertical velocity (as barotropic flow interacts/flows over sloping topography it induces a vertical velocity)

ω frequency of oscillation

w_b is a function of the barotropic flow and the slope of the sea bed. While CCS was designed to be away from internal wave generation sites, internal wave energy was present throughout the stratified period, suggesting that a slope somewhere within a suitable propagation distance of CCS must have been sufficient to generate internal tides under the given conditions. Thus for the CCS location it is assumed that:

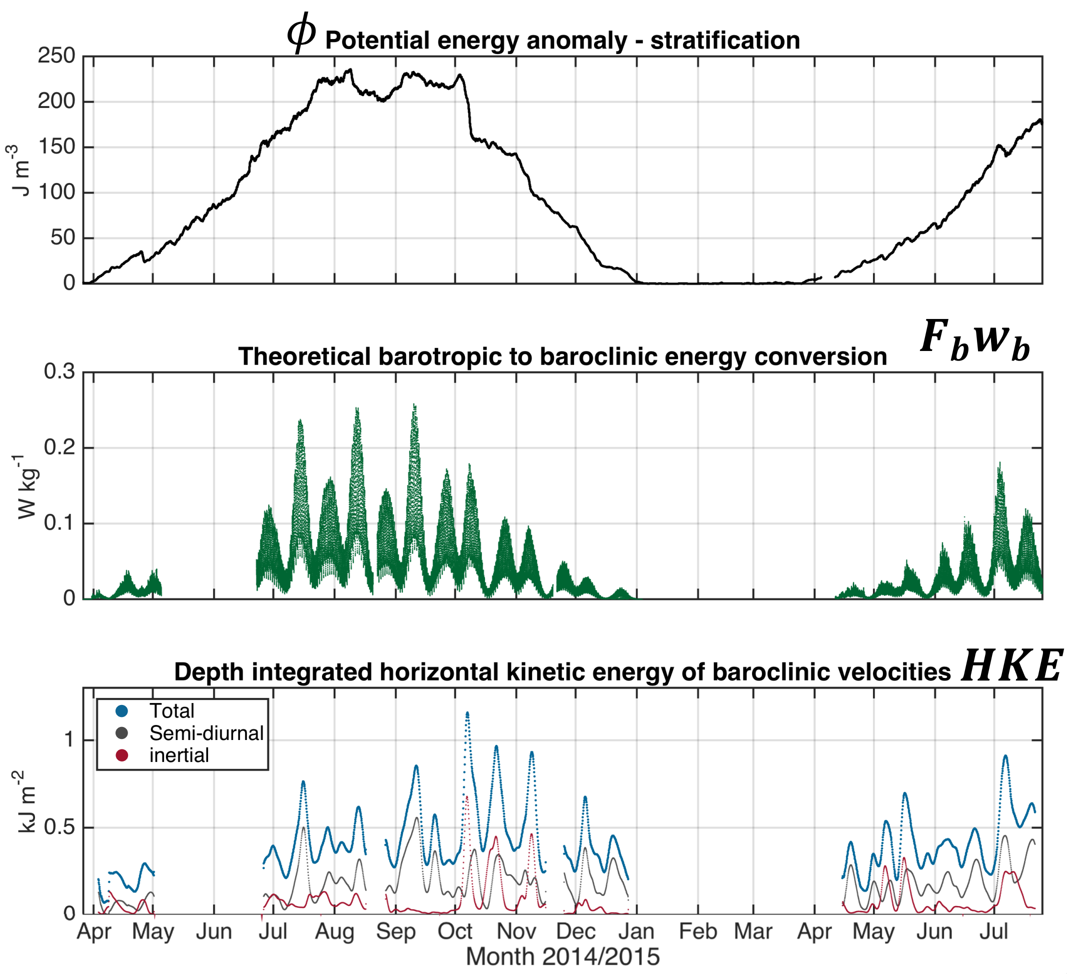
$$w_b \propto |\langle u \rangle|$$

Hence the following approximation is used to indicate the likely relative energy level of the internal tide at CCS

$$\boldsymbol{F_b w_b = \frac{N^2 |\langle u \rangle|^2}{\omega}}$$

[1]Baines, P. G. (1982). On internal tide generation models. Deep Sea Research Part A. 29(3), 307–338.
[2]Nash et al. (2006), Structure of the Baroclinic Tide Generated at Kaena Ridge, Hawaii.

Observed seasonality in internal wave energy

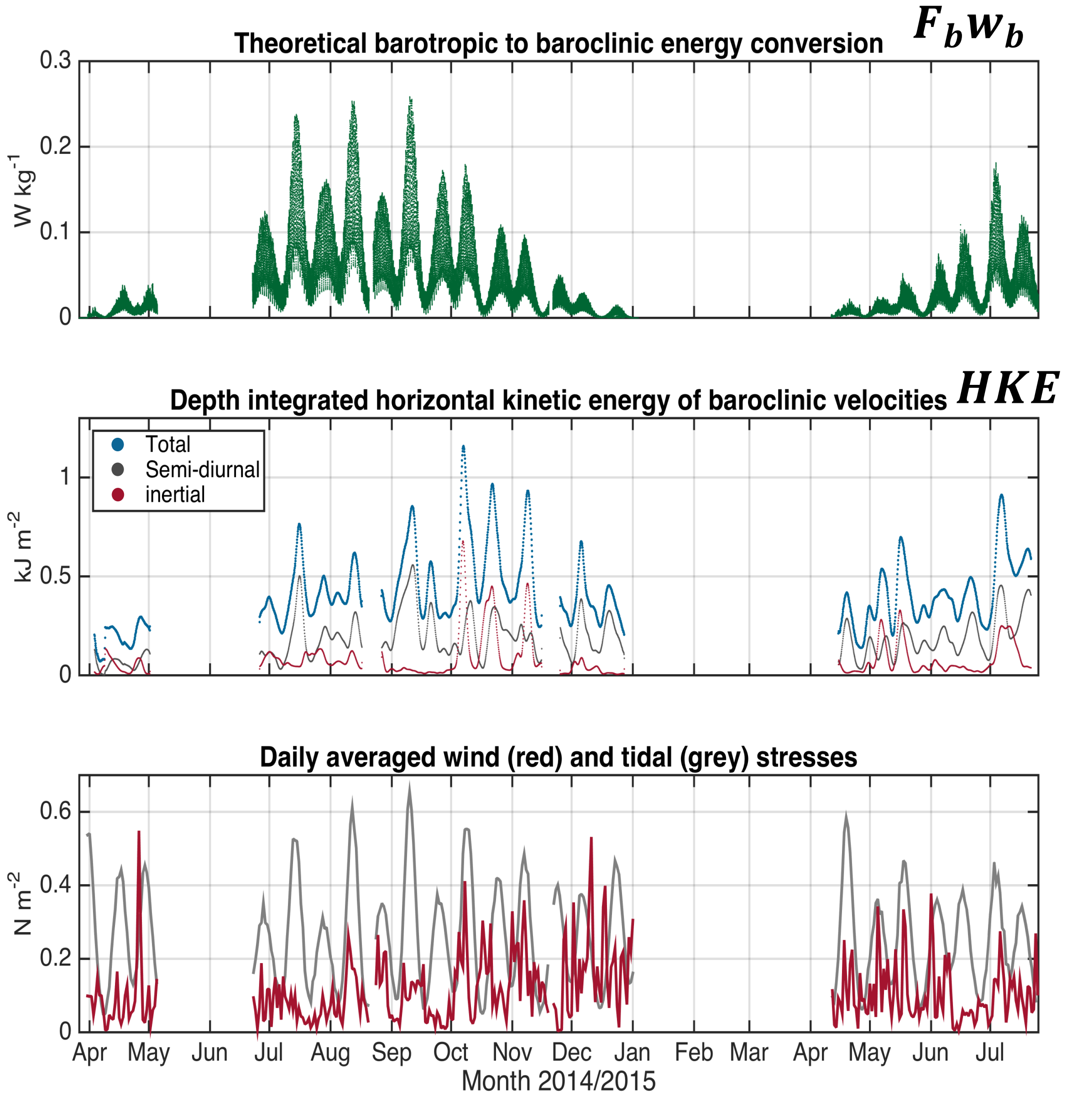


$F_b w_b$ intuitively follows the seasonal cycle of N^2 (or Φ here) and is modulated by the spring neap variability of the barotropic velocity.

Generally, the the behaviour of the observed internal wave energy (HKE_{Total}) compared relatively well to the indicative barotropic to baroclinic energy conversion term, $F_b w_b$.

Interestingly, the highest measured values of HKE_{Total} during 2014 were in autumn, in contrast to the behaviour of $F_b w_b$, which was generally reducing at this time.

Observed seasonality in internal wave energy



While energy contribution from the semi-diurnal internal tide ($HKE_{semi\text{-}diurnal}$) follows the overall pattern predicted by $F_b w_b$, we find that inertial oscillations ($HKE_{interial}$) potentially supplied the extra energy evident in autumn 2014 which is in good agreement with increased wind speeds compared to spring and summer periods.

Conclusions

- An active internal wave field was observed throughout the majority of the stratified periods in a temperate shelf sea. Analysis of the observed baroclinic velocities revealed that the internal wave field was dominated by semi-diurnal internal tides and inertial oscillations.
- By evaluating the total amount of energy within the internal wave field (HKE_{Total}) an apparent seasonality with a super-imposed spring-neap variability was found. Here, peaks in energy were observed during summer and autumn months, while weaker levels occurred during the transitional periods of stratification.
- The observed signal of HKE_{Total} was generally in good agreement to the barotropic forcing term, $F_b w_b$, but showed a number of disparities. While energy contribution from the semi-diurnal internal tide follows the overall pattern predicted by the theory of internal wave generation, inertial oscillations potentially supplied the extra energy evident in autumn 2014 in good agreement with increasing wind speeds reported during this time.

- The apparent seasonality in the total amount of energy within the internal wave field in agreement with the seasonal cycle of stratification and the super-imposed spring-neap modulation of this signal suggests a level of predictability of the internal wave field.

- Our results suggest that mixing due to internal waves could be effectively scaled by the seasonal cycle of N^2.