Barotropic instability in the West Spitsbergen Current

"Reading the pulse of the Barotropic WSC branch"

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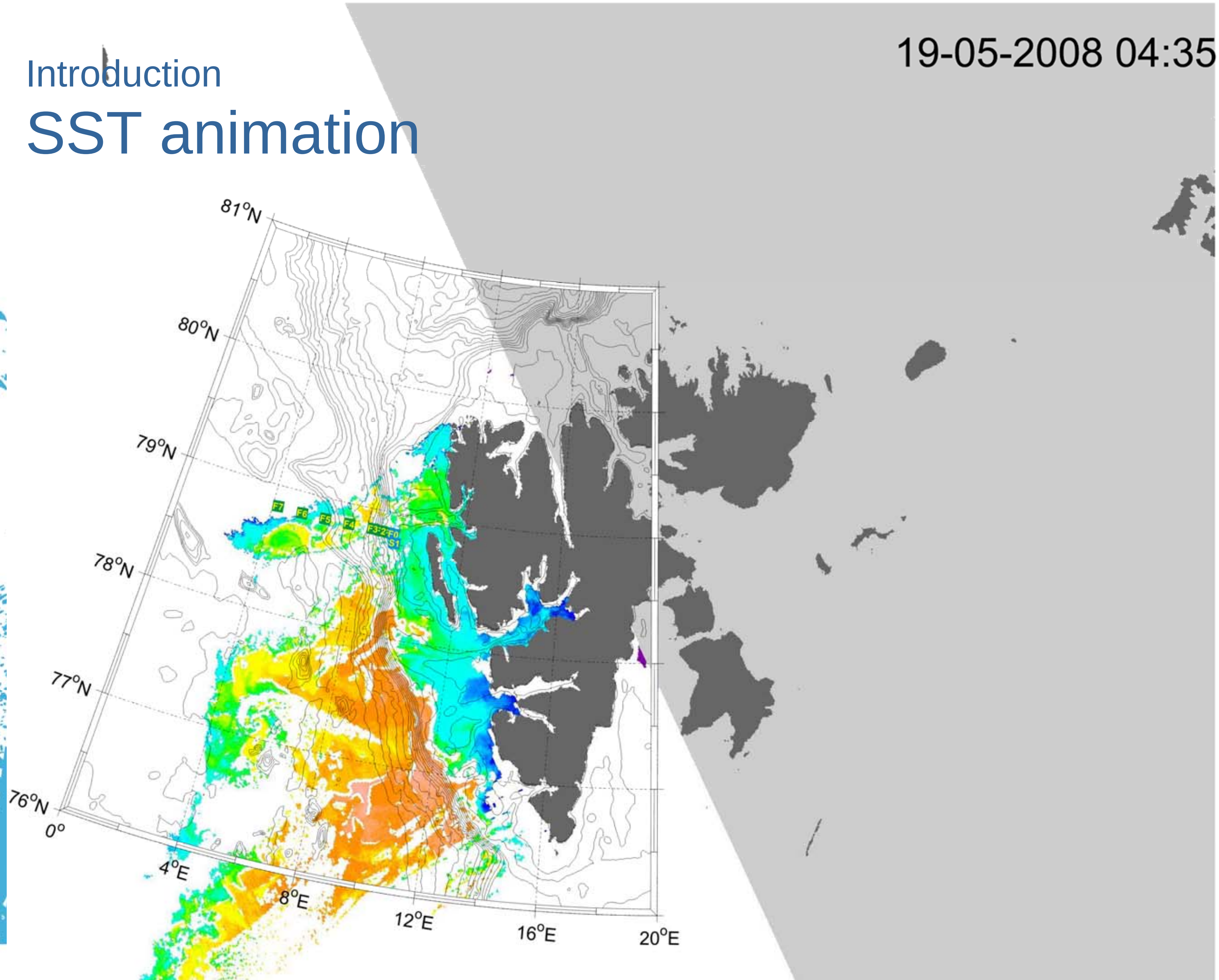
Outline

1. Introduction
2. Data set
3. Linear stability analysis
4. Time series analysis
   - Application of linear stability analysis
   - Wavelet analysis
   - Spatial coherence and complex demodulation
   - Heat flux calculations
5. Summary

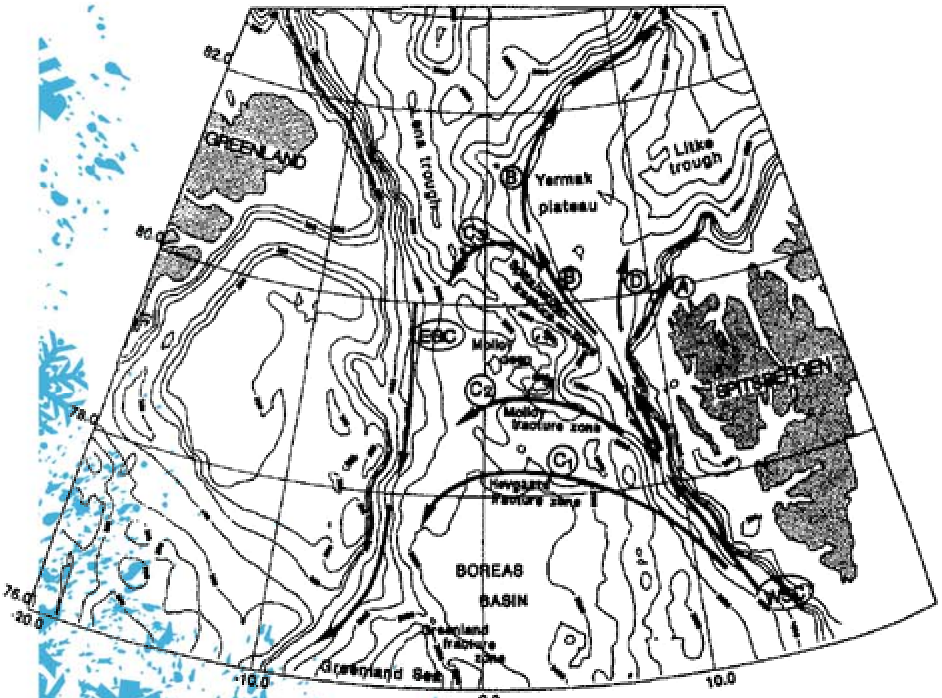
Introduction

SST animation

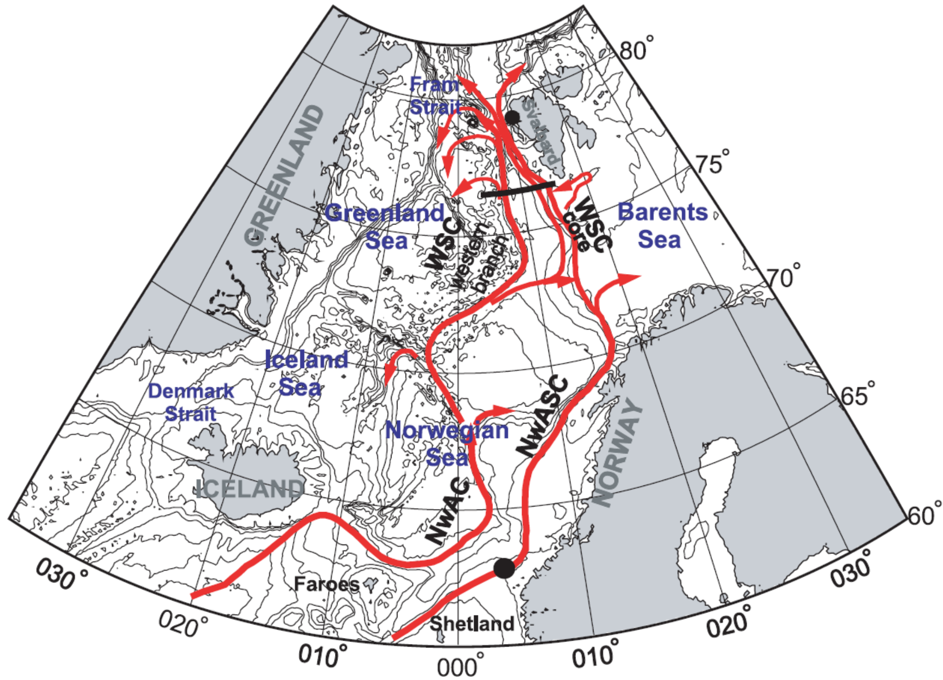


Introduction

Regional setting



Gascard et al. (1995)



Walczowski and Piechura (2007)

Introduction

Cooling of the slope current

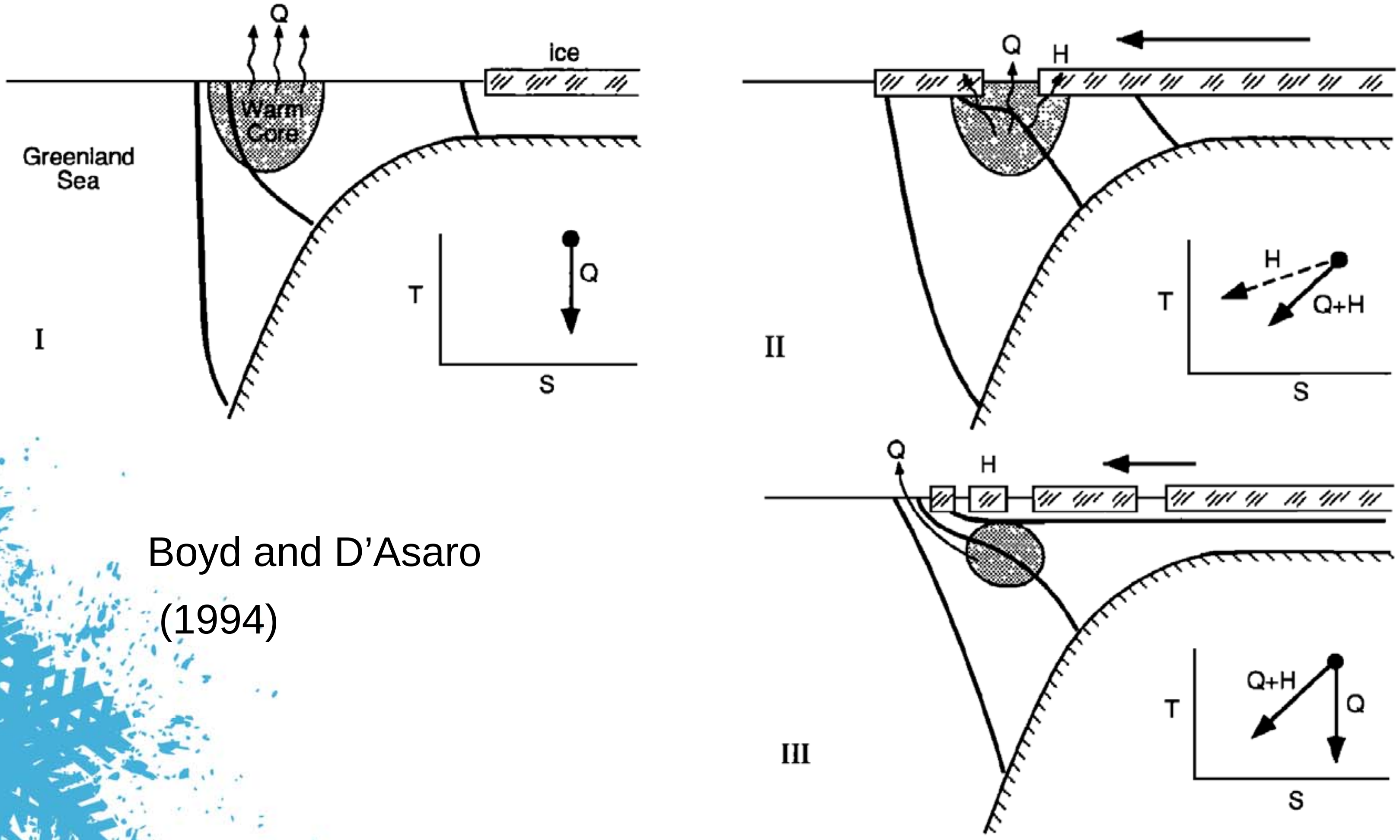
Table 1. Long-term mean northward along-slope gradients in temperature (dT^*/dy) and salinity (dS^*/dy) in the upper-slope domain. A nominal current speed (v) of 0.1 and 0.2 m s^{-1}, based on Fahrbach et al. (2001), are used in summer and winter, respectively, to calculate the depth-integrated mean heat loss rates Q^*_a (Eq. 2) for the water column illustrated in Fig. 6.

	Layer, z_1 - z_2 (m)	dT^*/dy (°C/100 km)	dS^*/dy (psu/100 km)	Q^*_a (W)
Summer	0 - 100	–0.32	–0.028	–130
	100 - 500	–0.20	–0.010	–330
	0 - 500	–0.22	–0.013	–460
Winter	0 - 100	–0.42	–0.025	–350
	0 - 250	–0.40	–0.016	–830
	100 - 500	–0.31	–0.004	–1050
	0 - 500	–0.34	–0.008	–1400

Saloranta and Haugan (2004)

Introduction

Conceptual stages in WSC heat loss



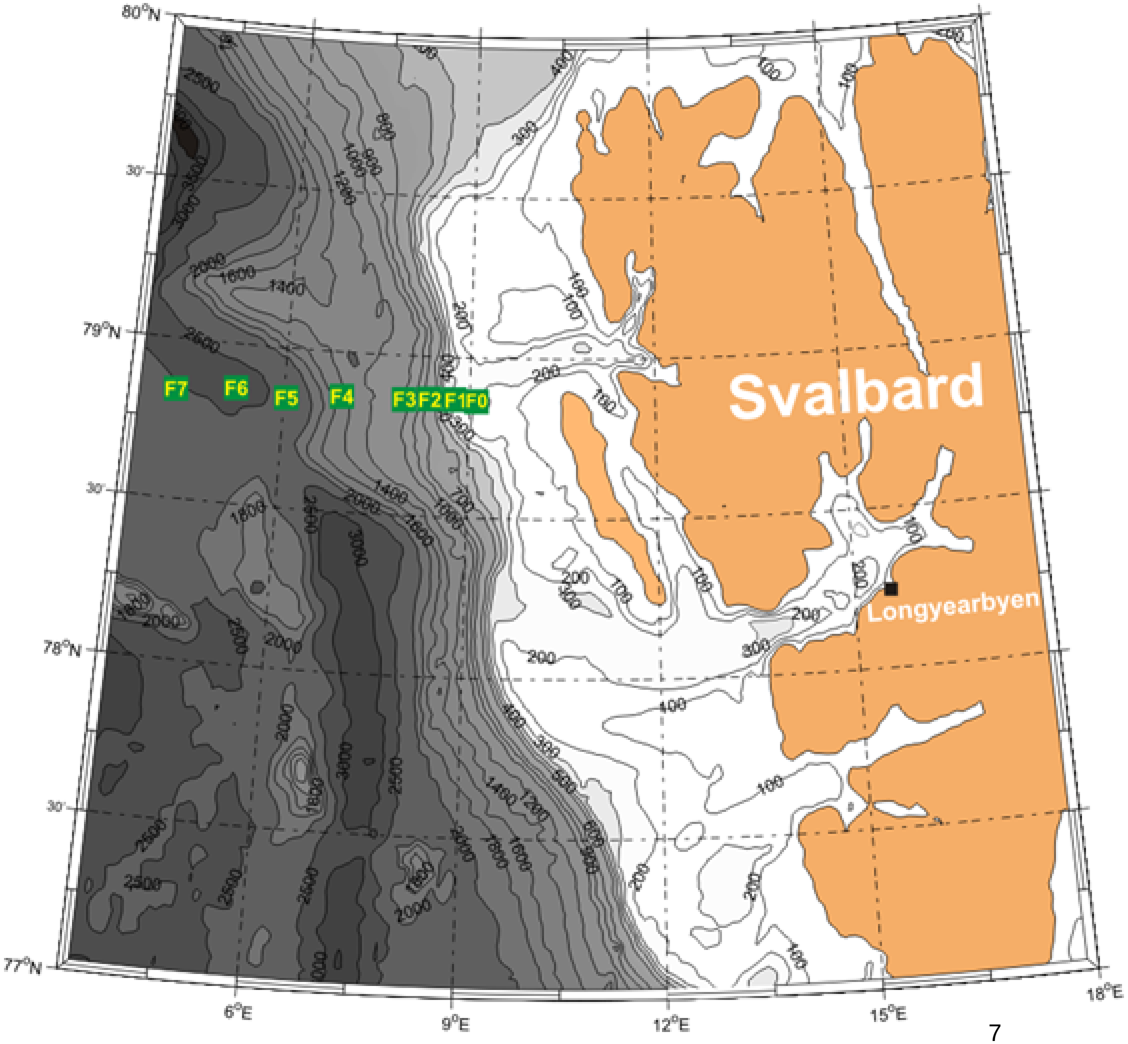
Boyd and D'Asaro

(1994)

Data set

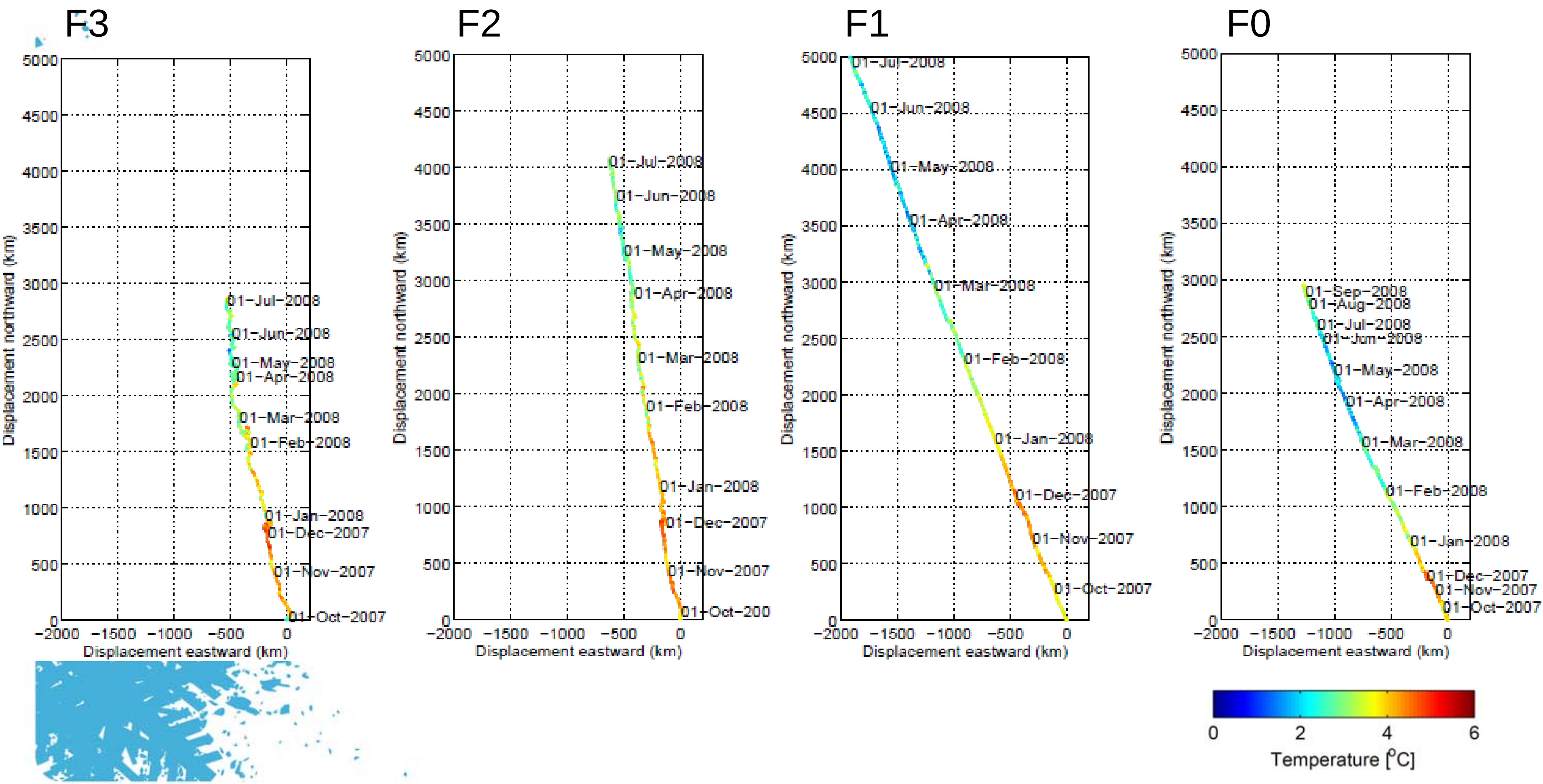
Map of Fram Strait (east) mooring section

- AWI's array of seven current meter moorings (F1 to F7)
- Additional shelf break mooring, F0 2007-2008



Data set

Progressive vector diagrams from 200-250 m depth, 2007-2008



Linear stability analysis

Mathematics

- A necessary condition for instability is that potential vorticity, q, attains a local extremum within the domain

$$\bar{q} = \frac{f - \frac{\mathrm{d}\bar{v}}{\mathrm{d}x}}{h}$$

- Assume small perturbations to a steady, along-shelf current

$$\begin{aligned} u &= u', \\ v &= \bar{v} + v', \\ \eta &= \bar{\eta} + \eta', \end{aligned}$$

Mathematics

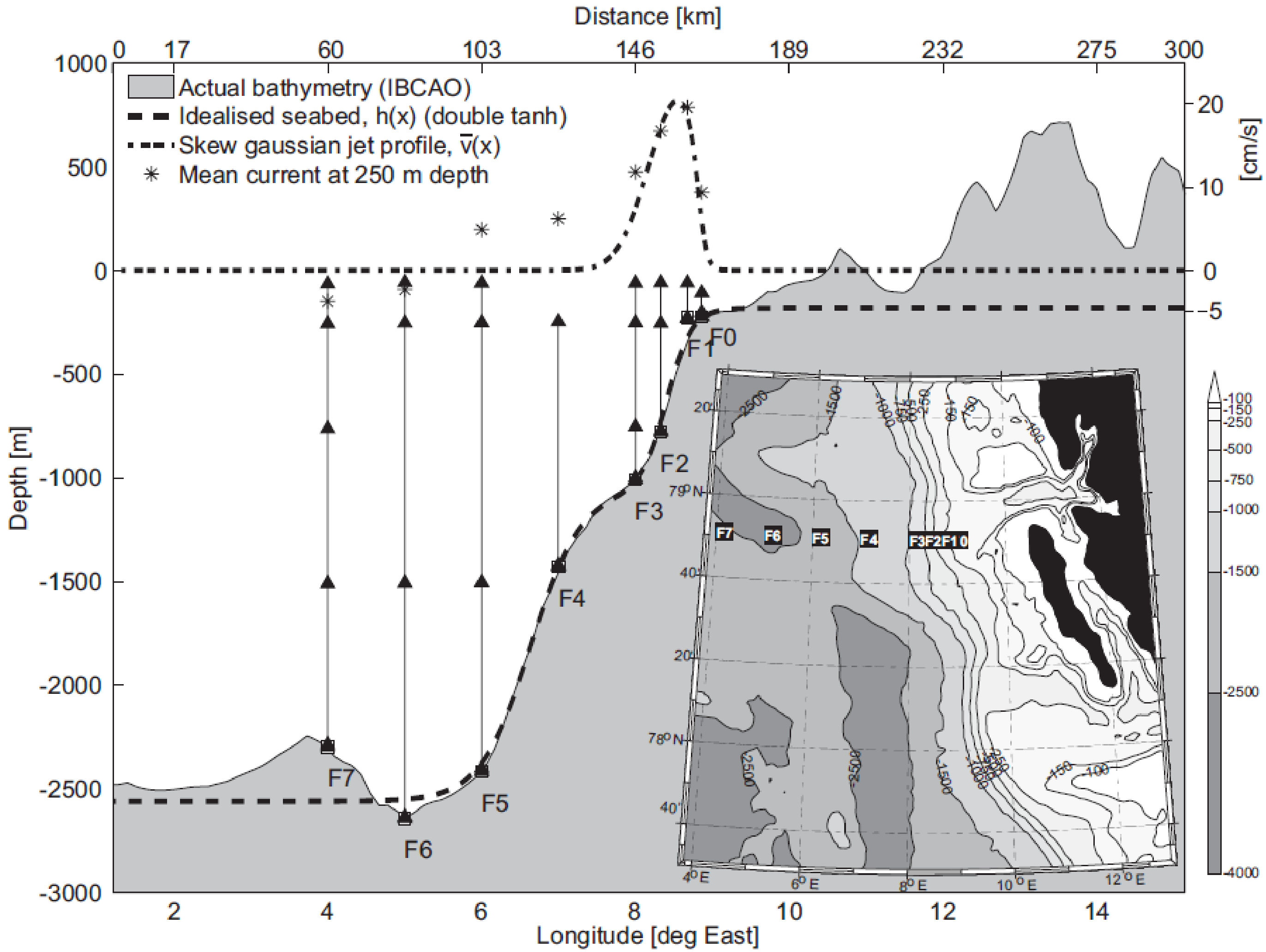
- We search for normal modes on the form

$$
\begin{aligned}
u' &= \hat{u}(y)\cos(kx - \omega t) \\
v' &= \hat{v}(y)\sin(kx - \omega t) \\
\eta' &= \hat{\eta}(y)\cos(kx - \omega t)
\end{aligned}
$$

- Inserted into the shallow water equations, this results in a matrix eigenvalue problem that can be solved numerically for a specified bottom topography and current profile
- For complex ω, the solution is unstable, with growth rate (e-folding time) $\tau = 1/\omega_i$

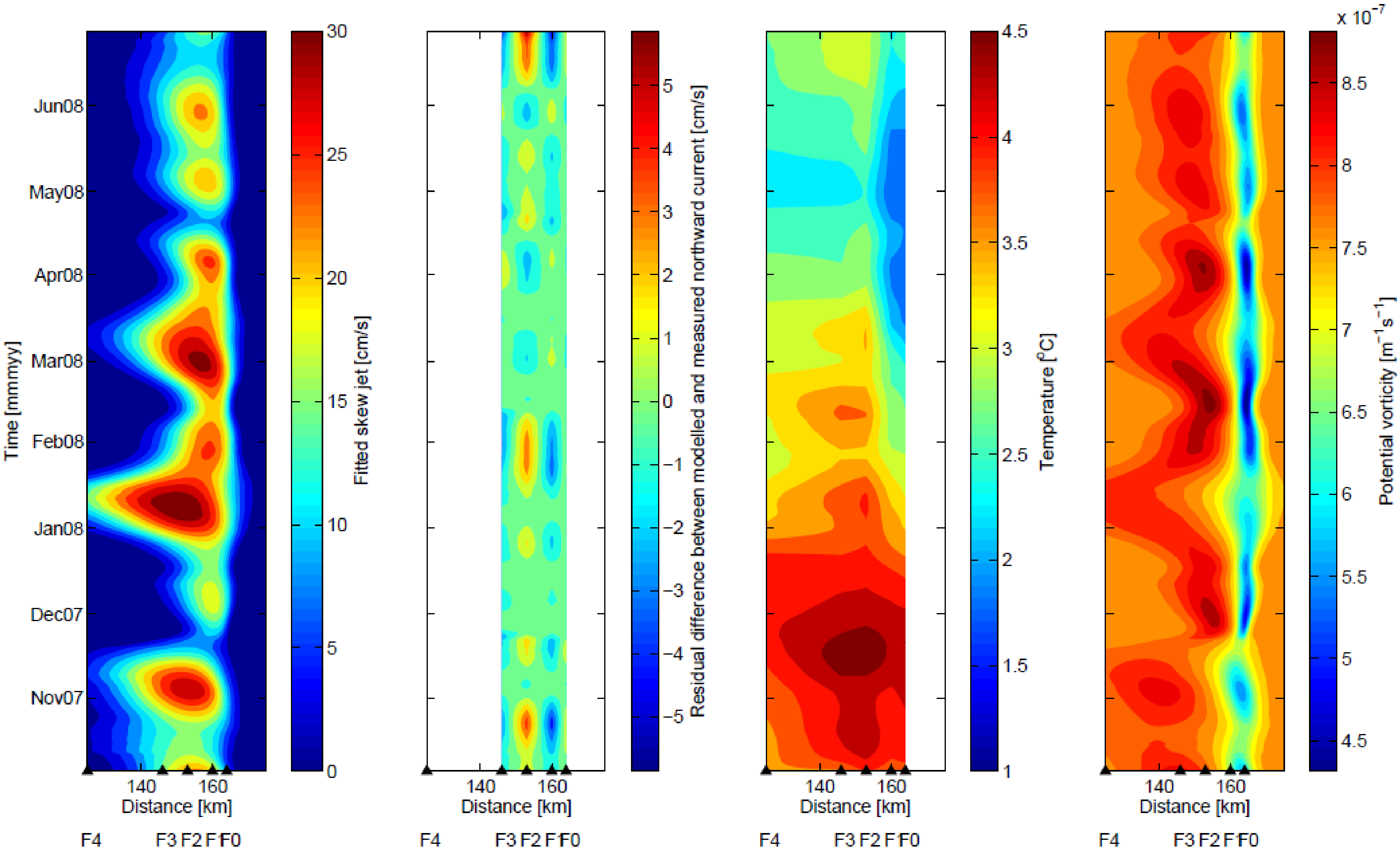
Linear stability analysis

Idealized topography (double tanh) and current profile (skew gaussian jet)



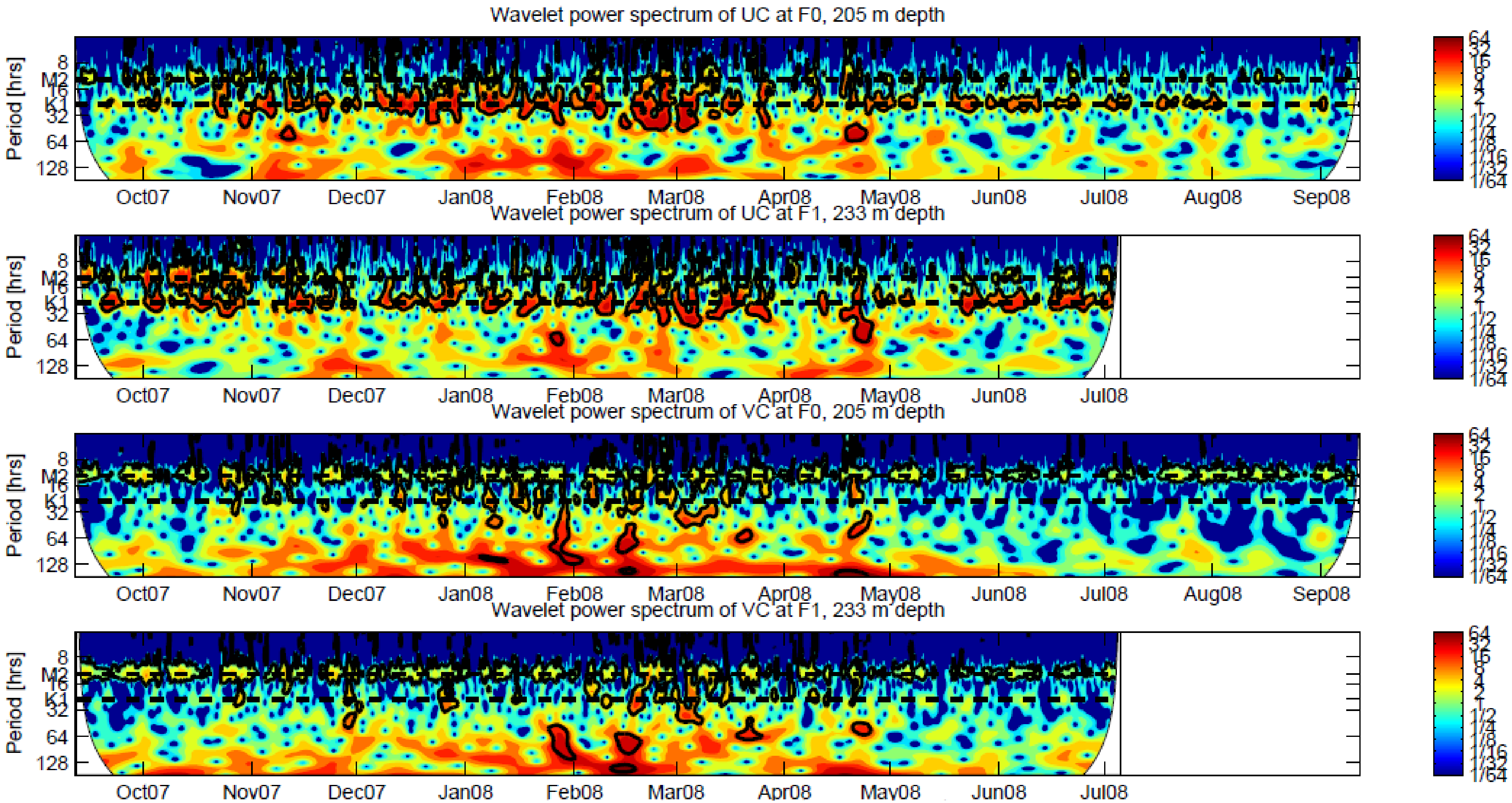
Time series analysis

Diagnostics of fitted skew jet



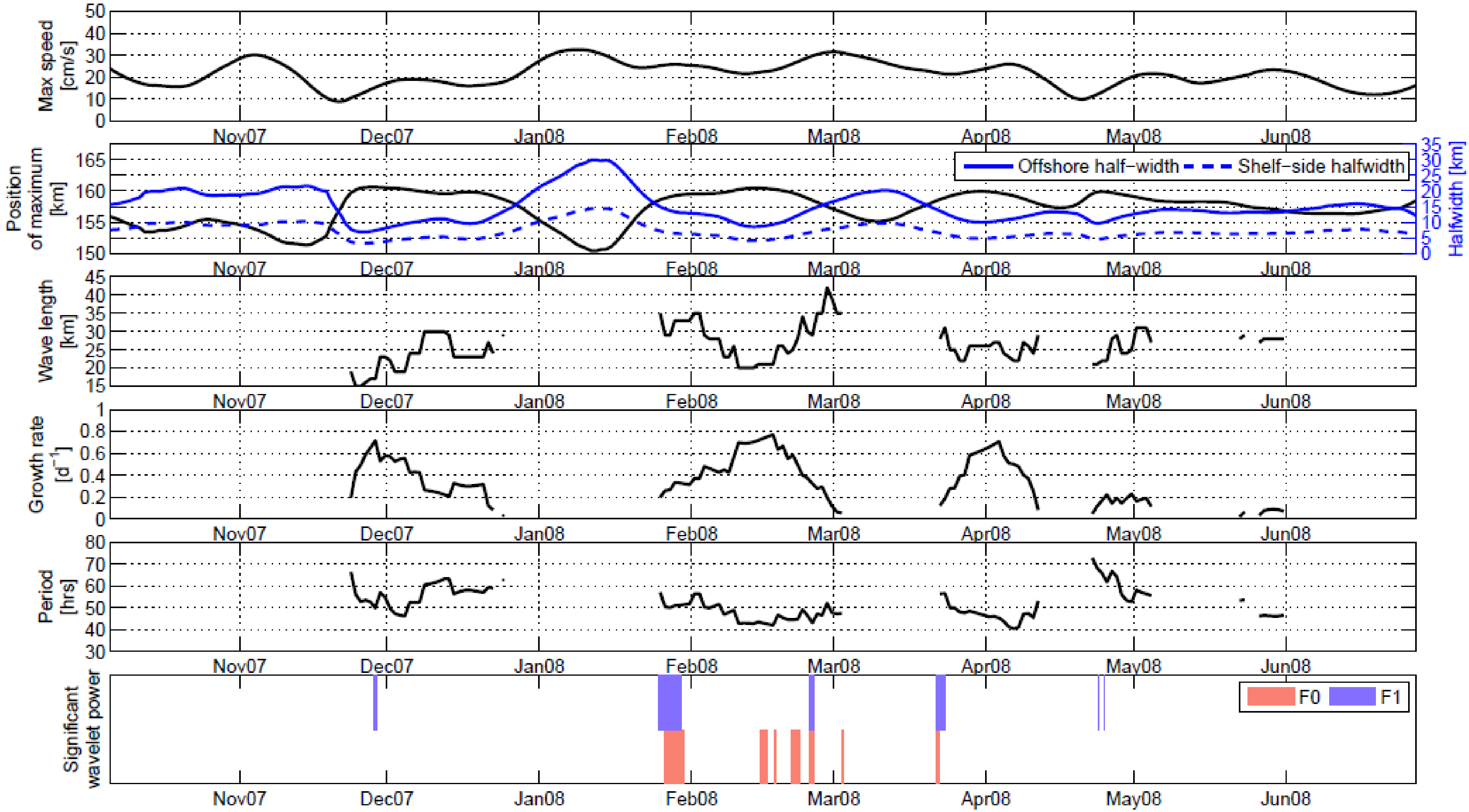
Time series analysis

Wavelet analysis



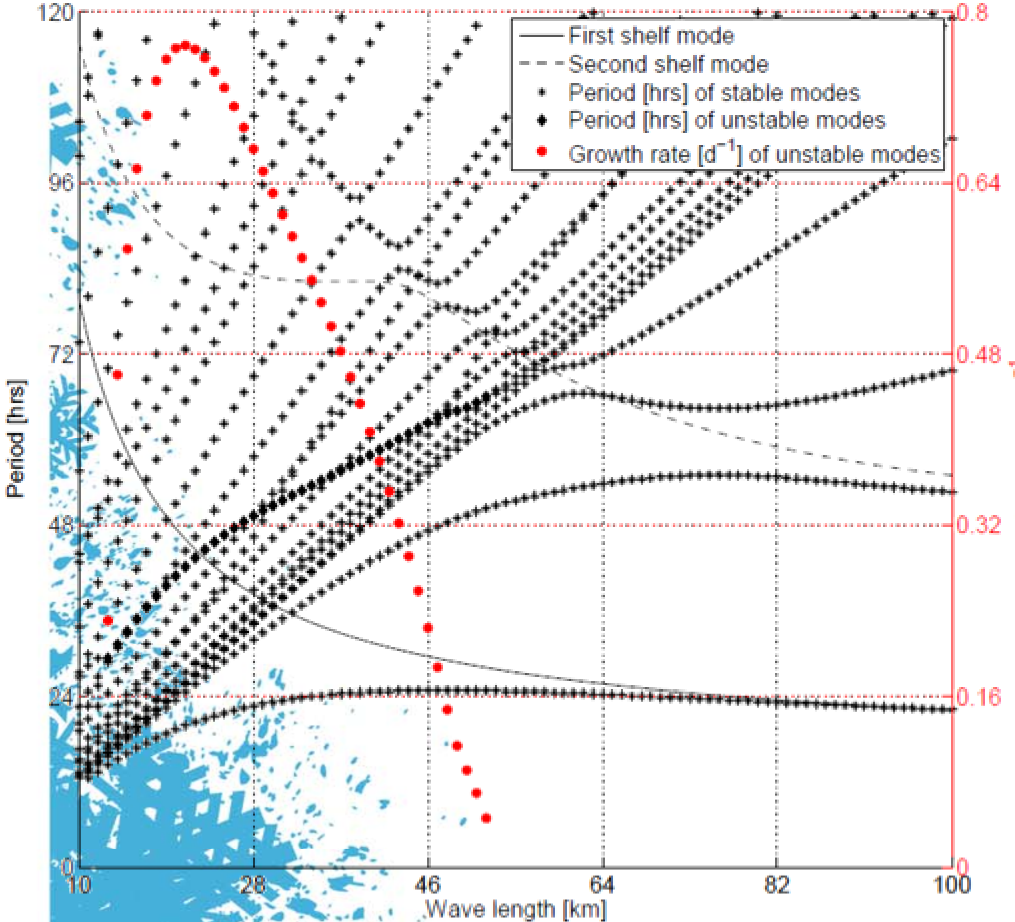
Time series analysis

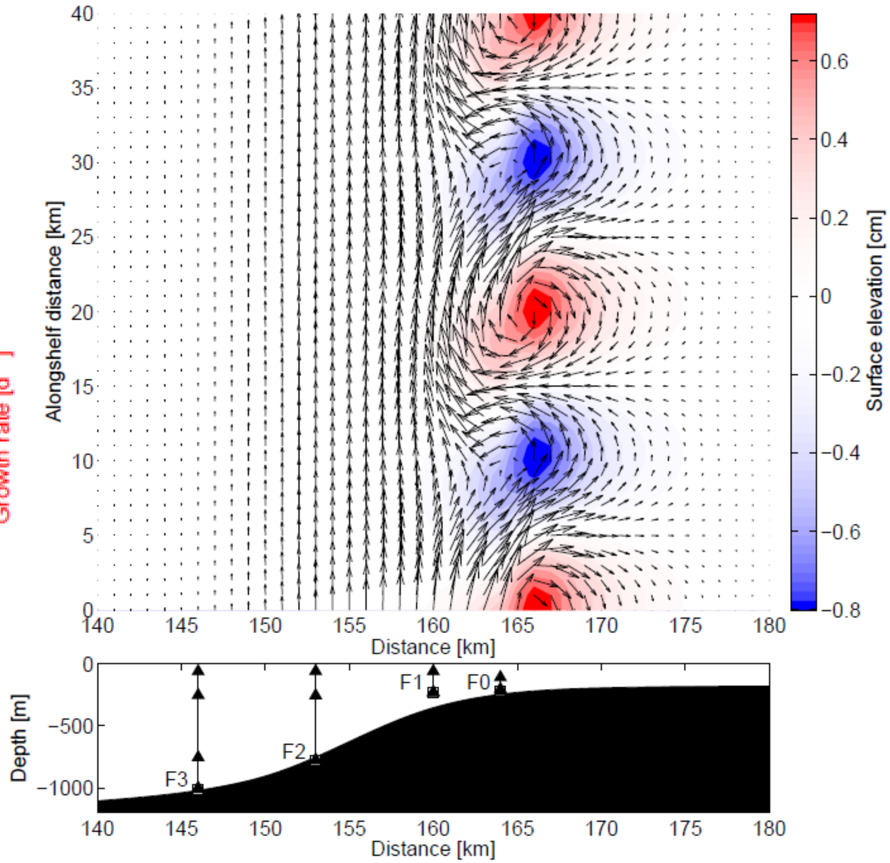
Time series of unstable conditions



Time series analysis

Unstable event, 17-feb-2008



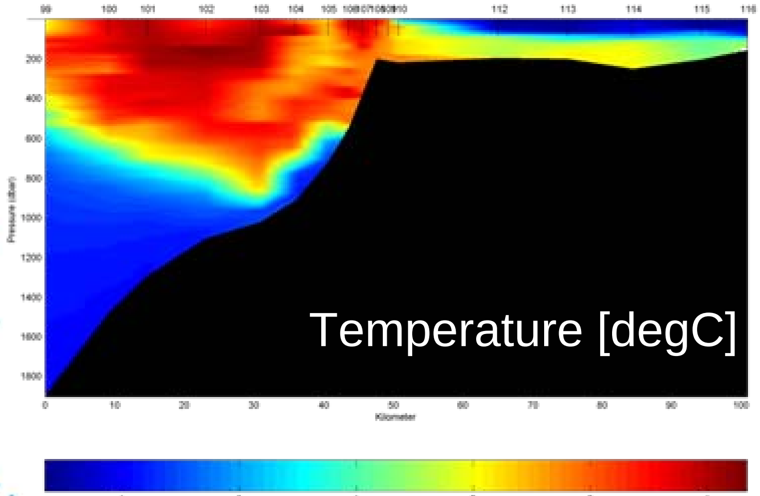


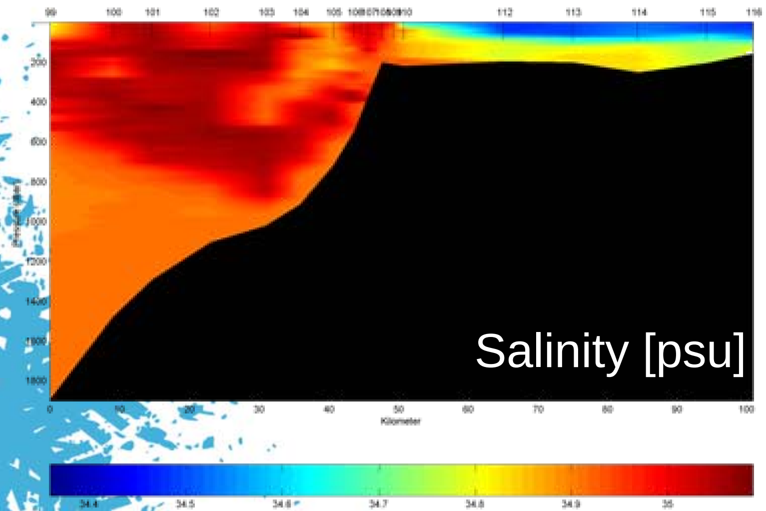
v_{max} = 0.23 m/s, L_B = 160 km, B = 9 km

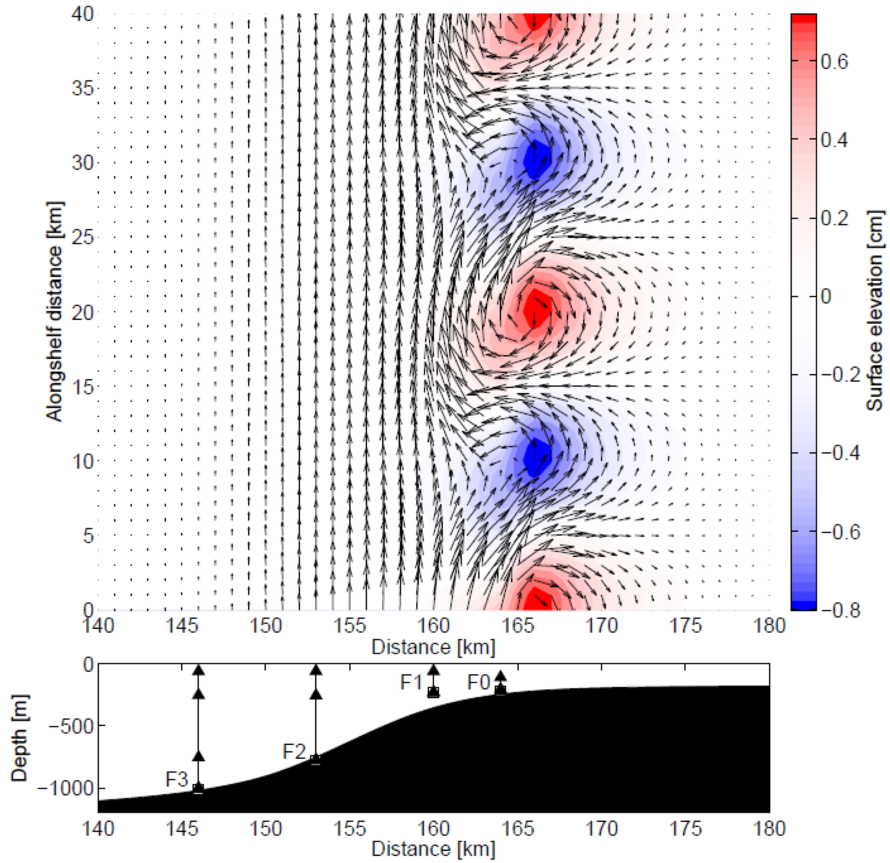
-> λ = 20 km, T = 40 h, τ = 0.77d^{-1}

Time series analysis

Unstable event, 17-feb-2008







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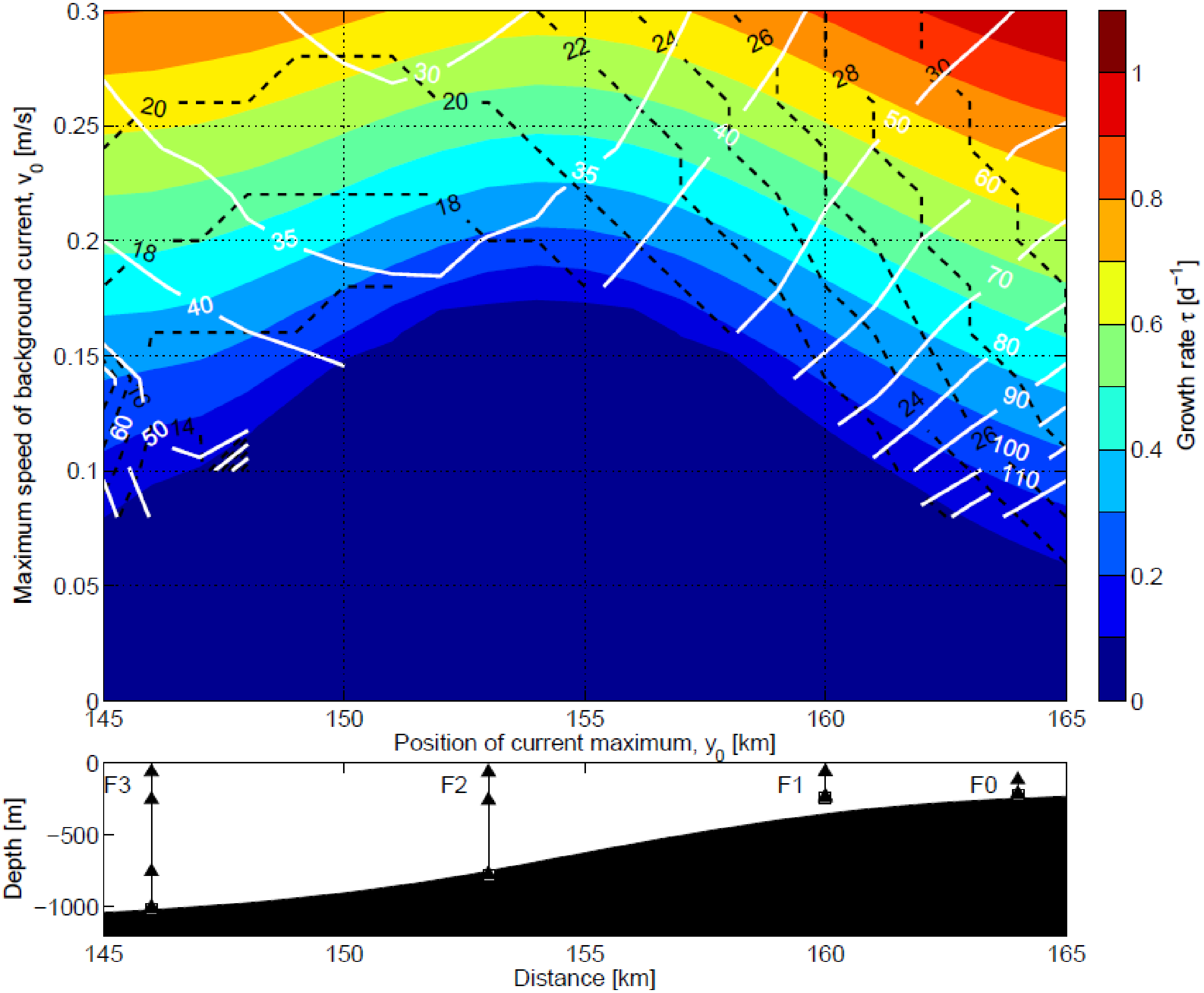
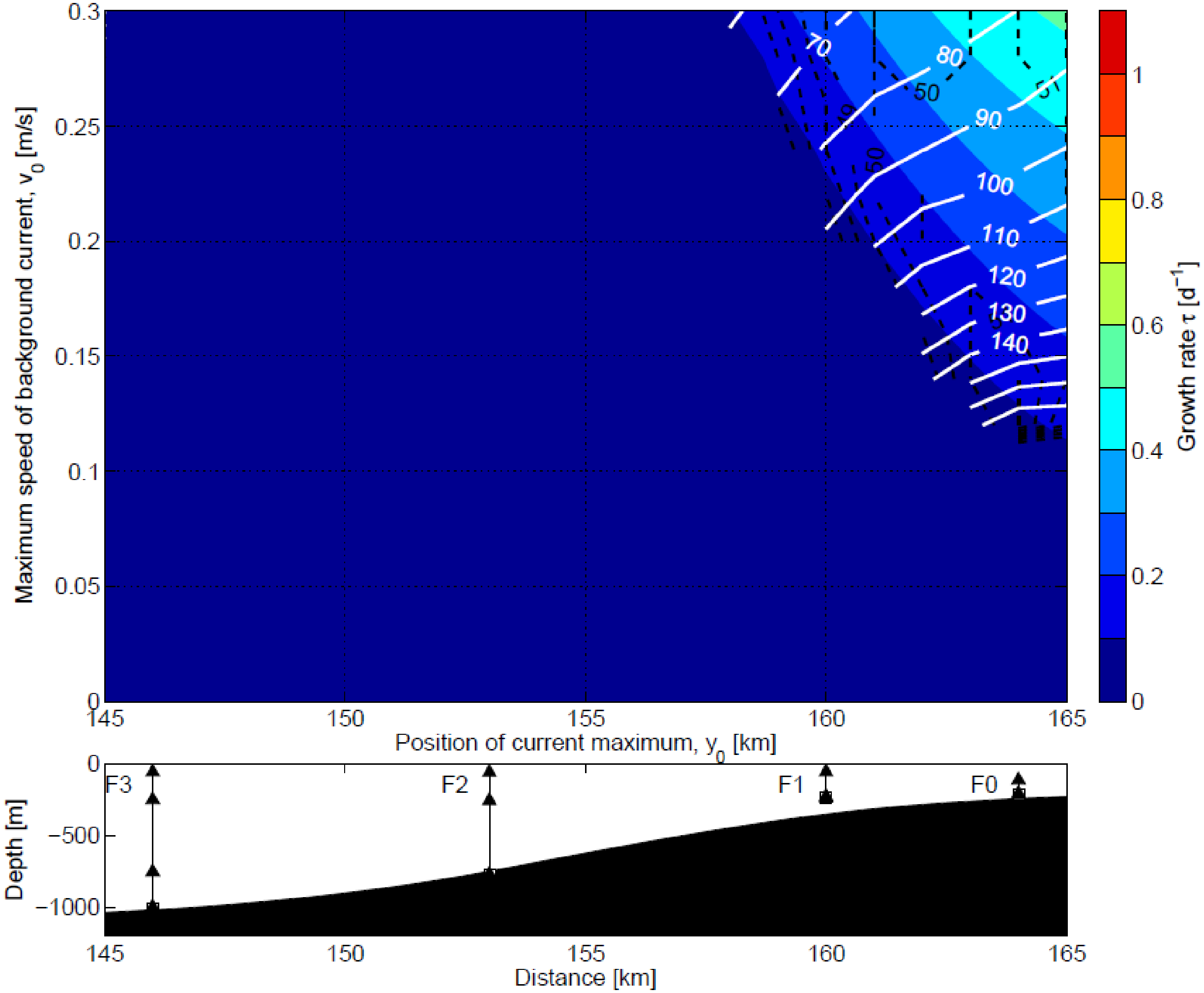
Sensitivity analysis

- Halfwidth B = 10km (const)
- Systematic variation of position (L_B) and amplitude (v_{max}) of skew jet



Time series analysis
Sensitivity analysis

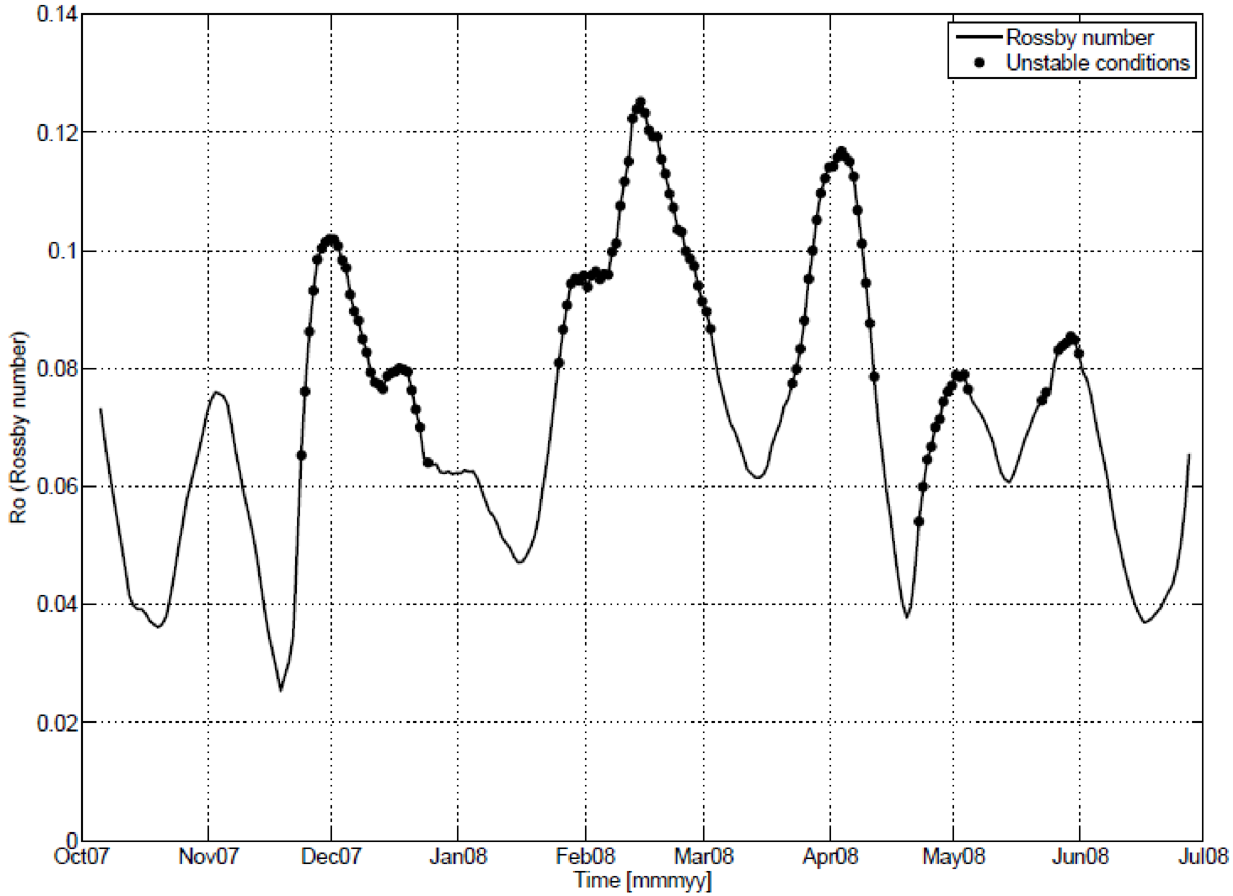
- Halfwidth B = 18 km (const)
- Systematic variation of position (L_B) and amplitude (v_{max}) of skew jet



Time series analysis

Rossby number

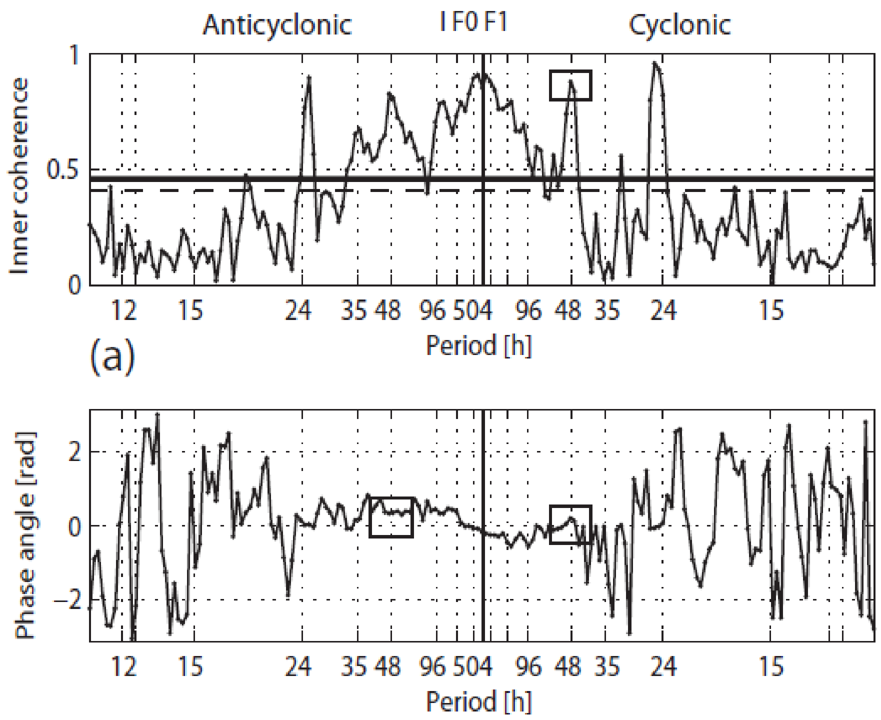
- $Ro = v_{max}/f*B$



Time series analysis

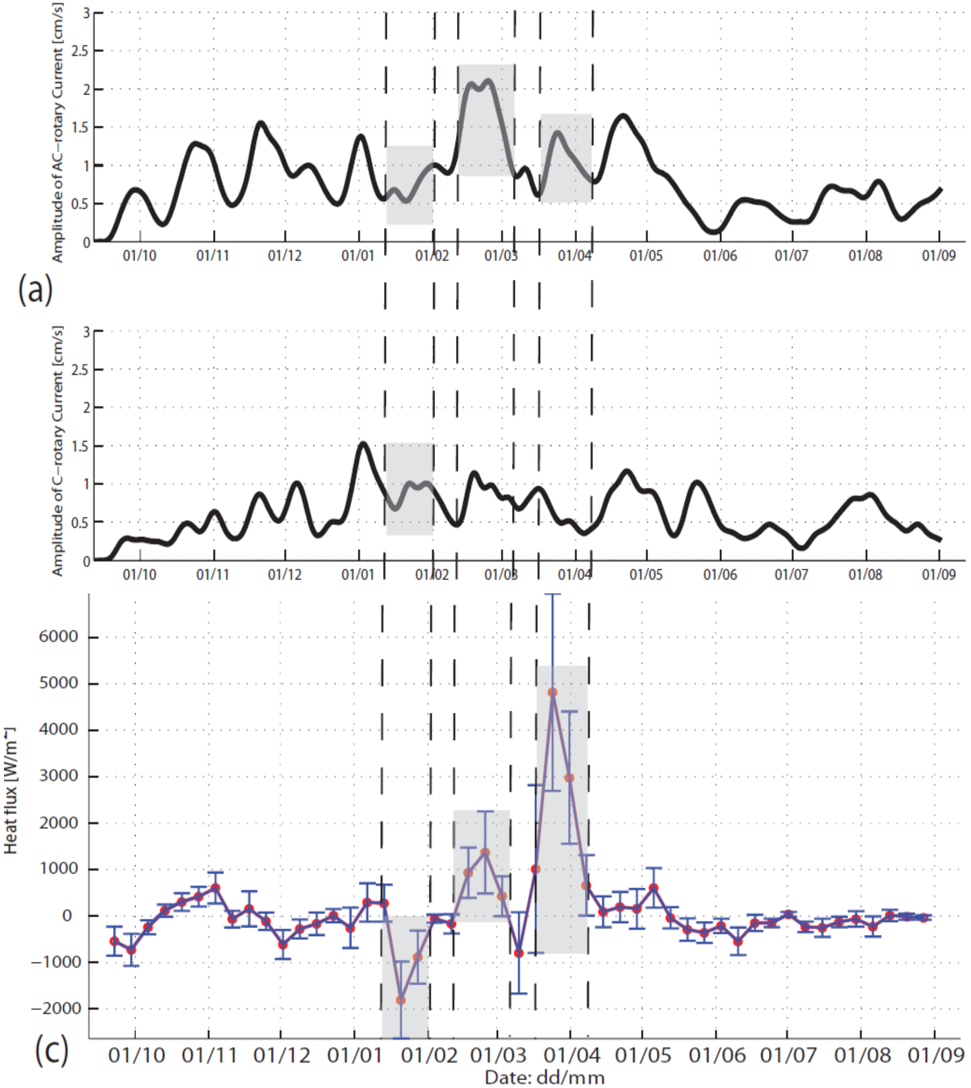
Rotary spectra

- The wave period 48h shows up with a significant response in the inner and outer (not shown) coherence spectra between F0 and F1
- Close to the mean period (52h) of unstable waves estimated from linear stability analysis



Complex demodulation/heat flux estimates

- Based on the demodulated temperature around 48h and the rotating wave field, the across slope eddy heat flux is estimated
- Two episodes, with heat fluxes 1000-2000 W/m^2



Summary and conclusions

- The barotropic WSC branch exhibits an asymmetric current profile, resulting in a sharp shear on the shelf side
- Linear stability analysis of the timeseries at F0-F3 indicates that unstable events are possible, dominantly during the winter months
- Wavelet, rotary spectra and complex demodulation confirm that oscillations matching the wave period preditcted by linear stability analysis are present at significant levels
- The heat loss associated with this process can reach $O(1000 W/m^2)$

Questions? Comments?

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