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Wave dynamics and hydrodynamics in Potter Cove, King George Island, Antarctica

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Photo: Ulrike Falk

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Where is Potter Cove?

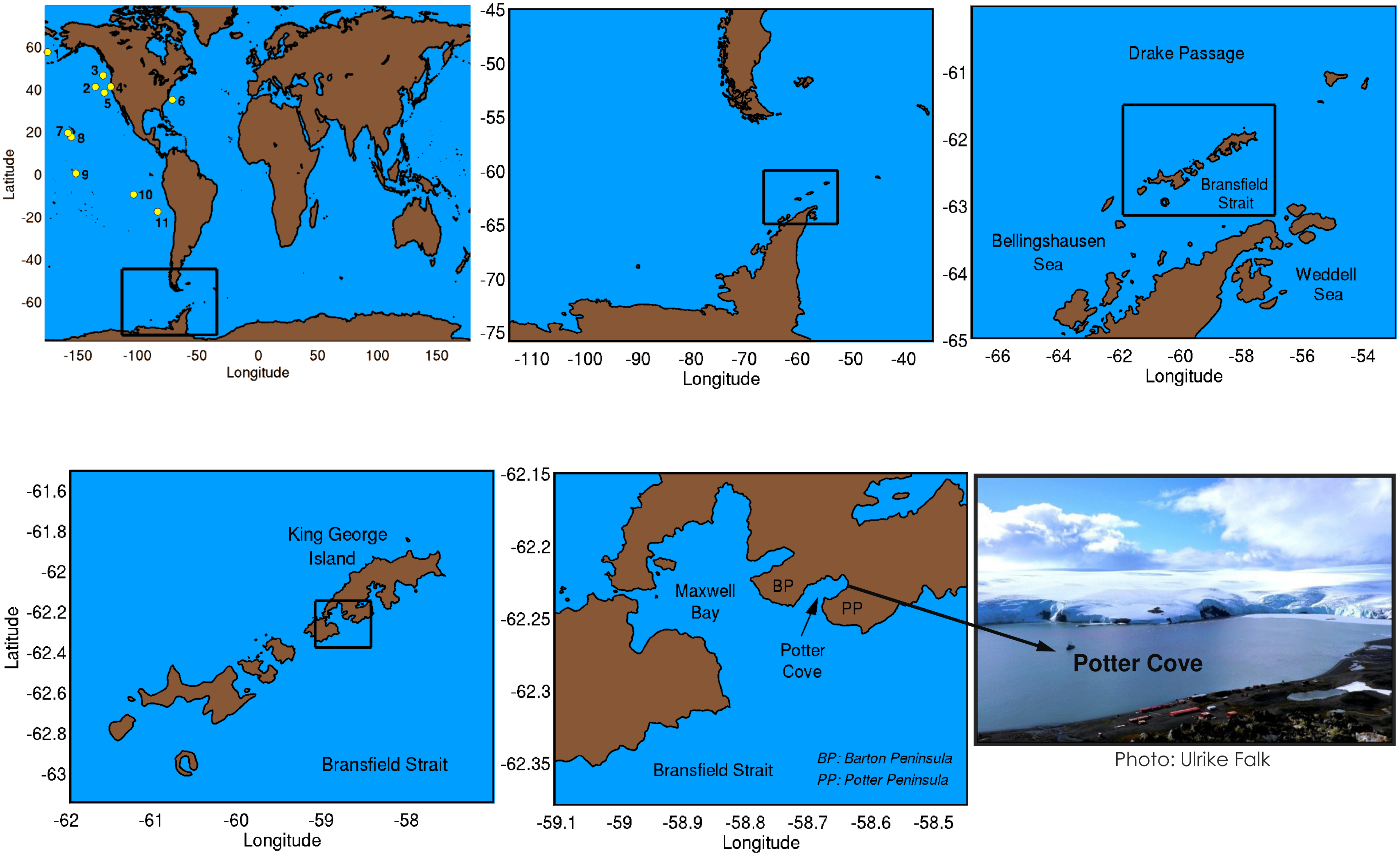
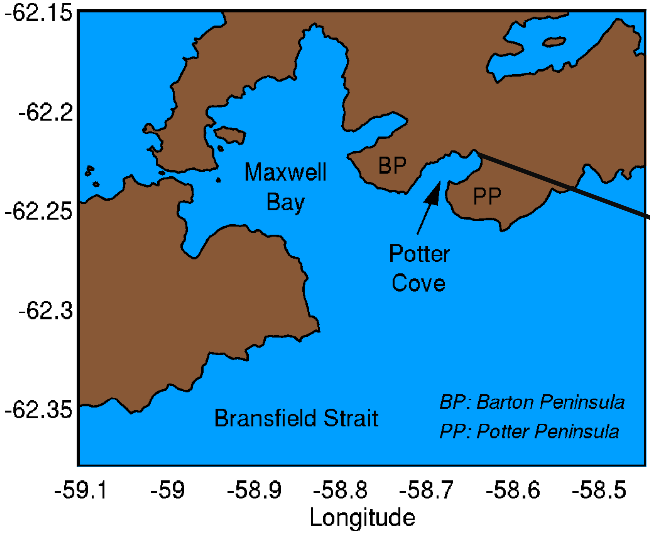
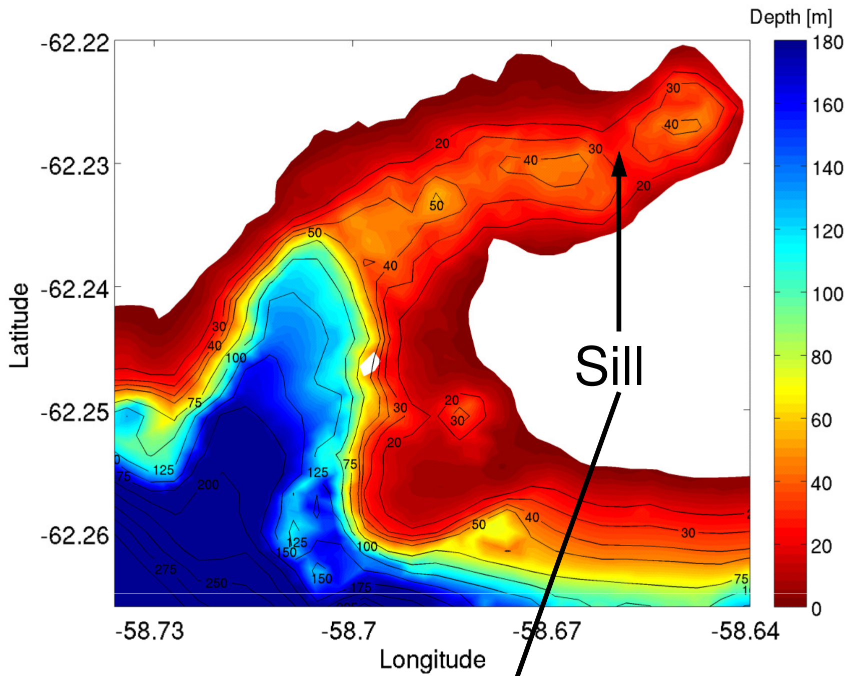


Photo: Ulrike Falk

Potter Cove





Potter Cove - a small inlet:

- 4 km long
- 1 to 2.5 km wide

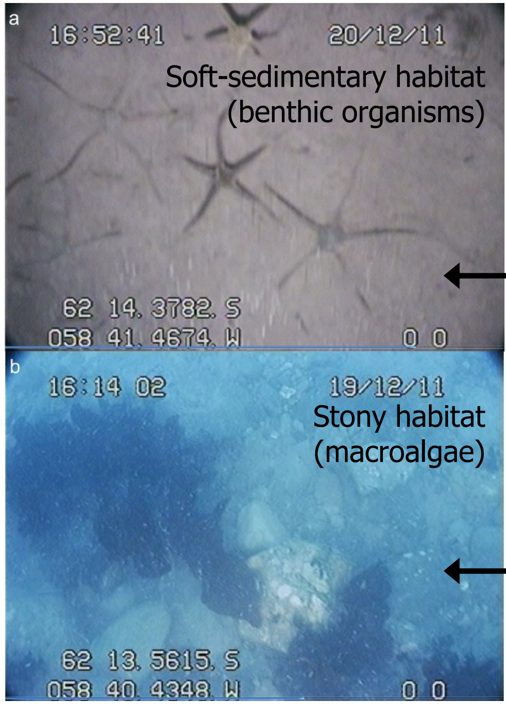
Seafloor topography:

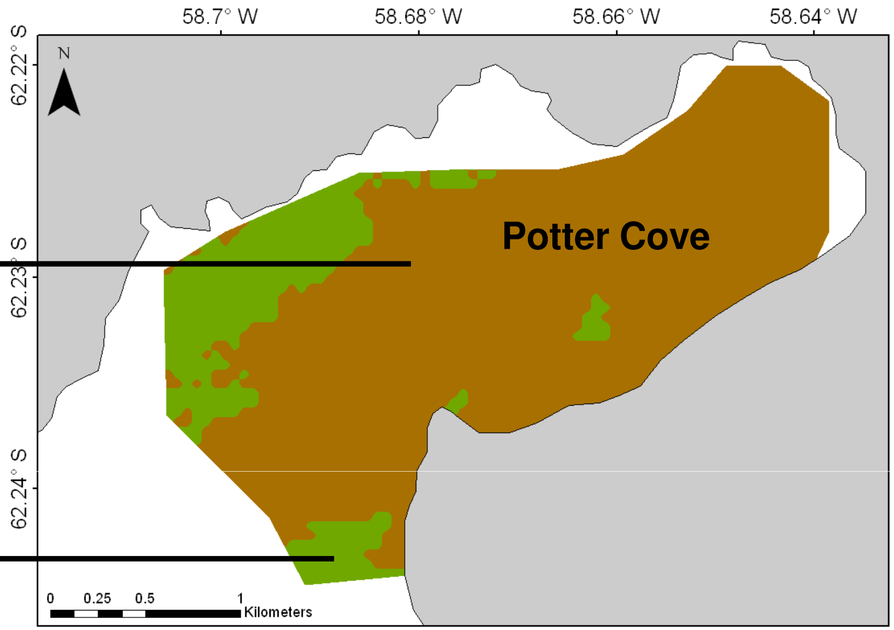
- Inner cove, d = 30-50 m
- Outer cove, d > 100 m

Image removed due to copyright considerations.

Background

1. Recent study (Wölfl et al., 2014): occurrence of different seafloor habitats.





Images: Anne-Cathrin Wölfl

2. To understand
    - the wave dynamics in the study area.
    - the flow circulation patterns under various forcings.
3. Which physical mechanisms (waves/currents) that potentially influence the bottom sediment movement and habitat distributions in Potter Cove?
4. To study water transport and exchange characteristics of the cove.

Wave modelling

SWAN

Structured Grid

Hydrodynamic modelling

FVCOM

Unstructured Grid

Image removed due to copyright considerations.

Ocean

Chen *et al.* (2006)
Oceanography, Vol. 19, No. 1, Mar. 2006

SWAN

...simulating waves

Spectral action balance equation:

$$\frac{\partial N}{\partial t} + \frac{\partial c_\lambda N}{\partial \lambda} + \frac{\partial c_\varphi N}{\partial \varphi} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{tot}}{\sigma}$$

1st term: local change of the energy density in time. Action density, N = E/σ.
2nd and 3rd terms: propagation of wave energy in lon and lat.
4th term: shifting of the relative frequency due to variations in depths.
5th term: depth-induced refraction.
6th term: total sources and sinks of energy:

$$S_{tot} = \underbrace{S_{in}}_{\text{wave growth by wind}} + \underbrace{S_{nl3} + S_{nl4}}_{\text{wave-wave interactions}} + \underbrace{S_{ds,w} + S_{ds,b} + S_{ds,br}}_{\text{wave dissipations}}$$

- Whitecapping
- Bottom friction
- Depth-induced wave breaking

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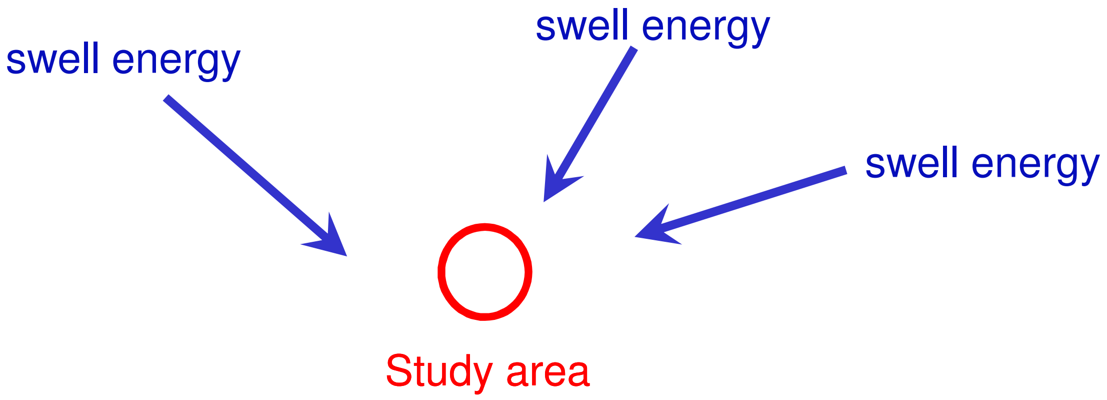
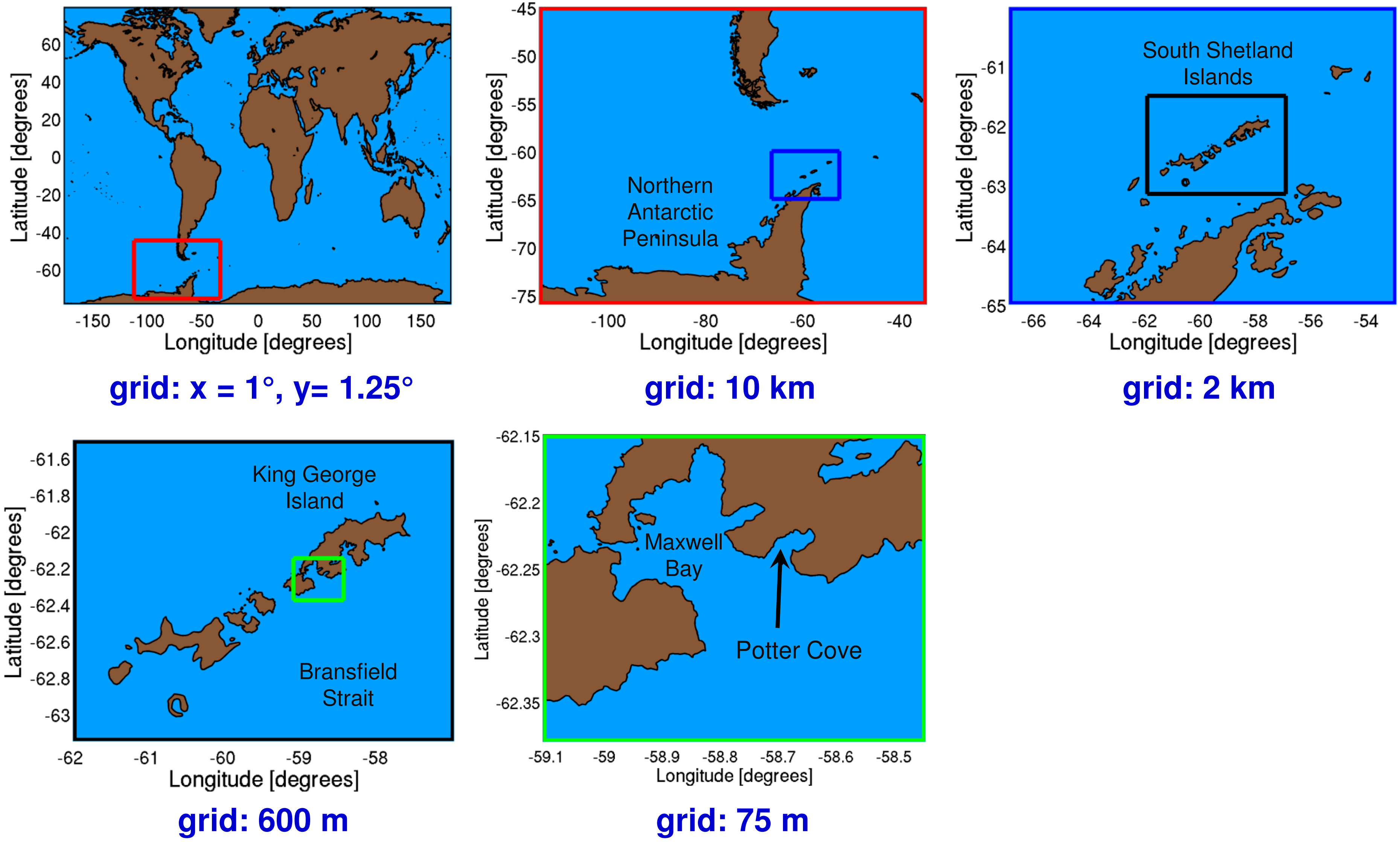


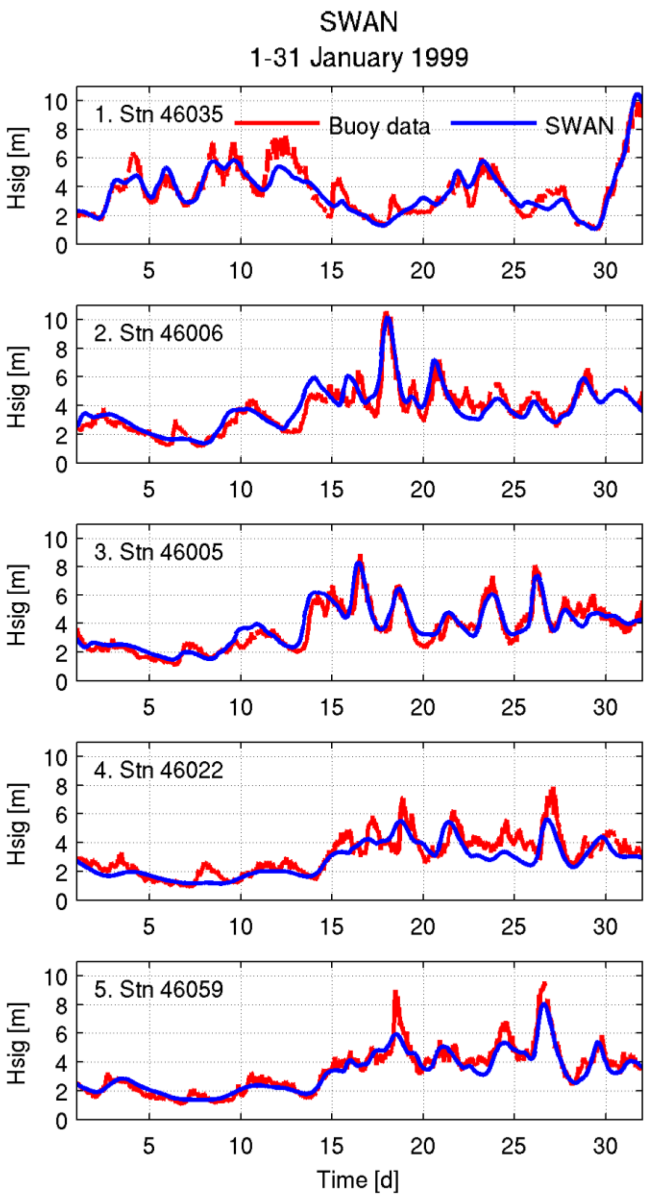
SWAN

one-way nesting

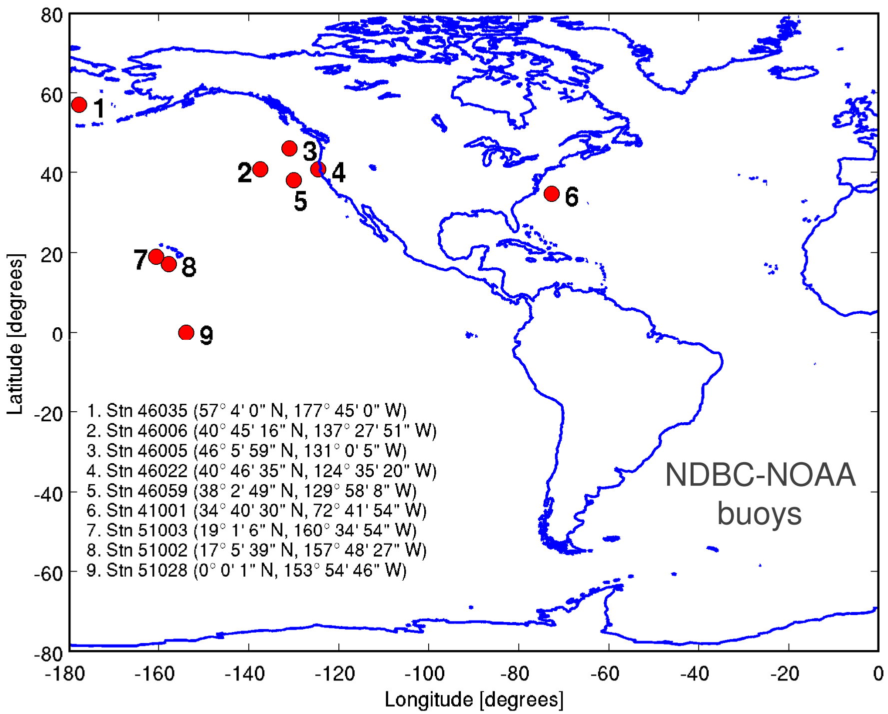


SWAN

...simulating waves

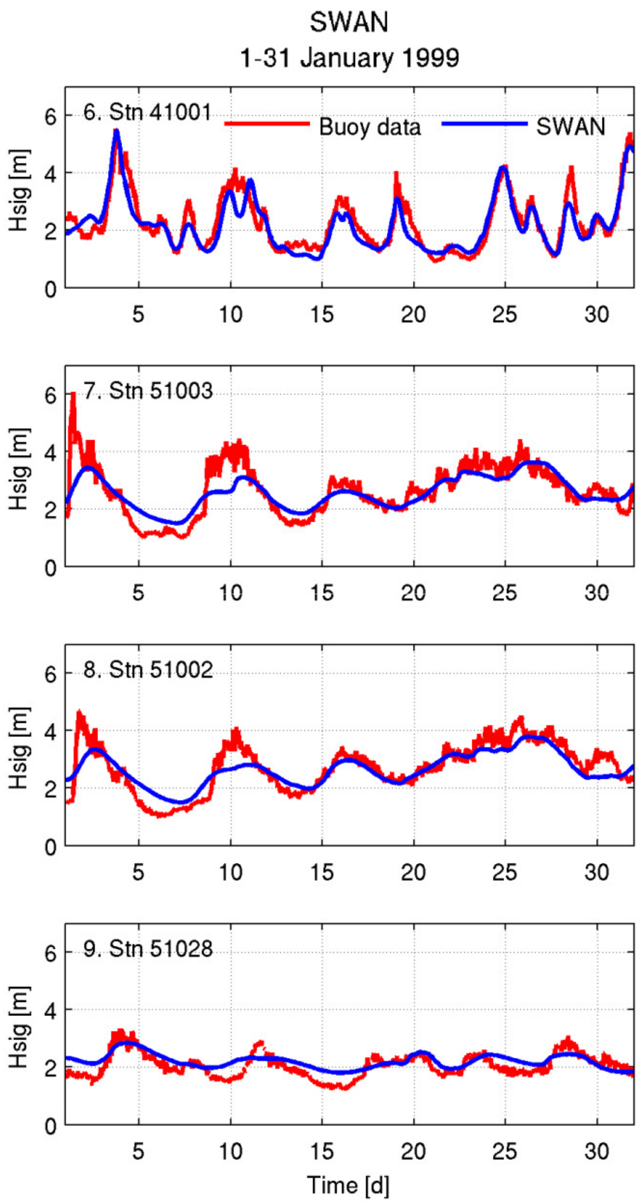


H_s
Buoys 1-5

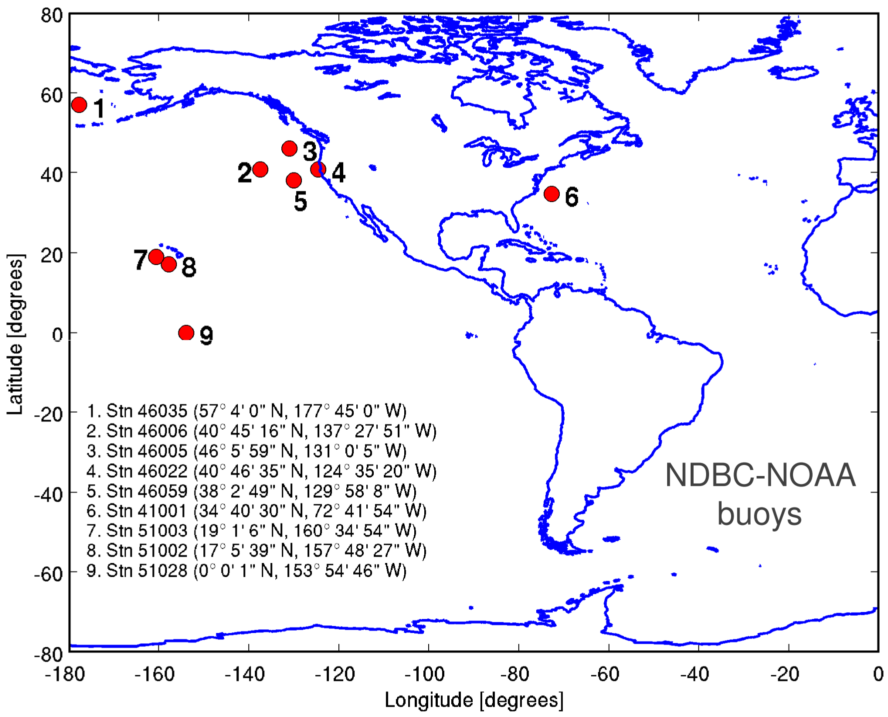


SWAN

...simulating waves



H_s Buoys 6-9



Goodness-of-fit

Willmott's *D* index of goodness-of-fit:

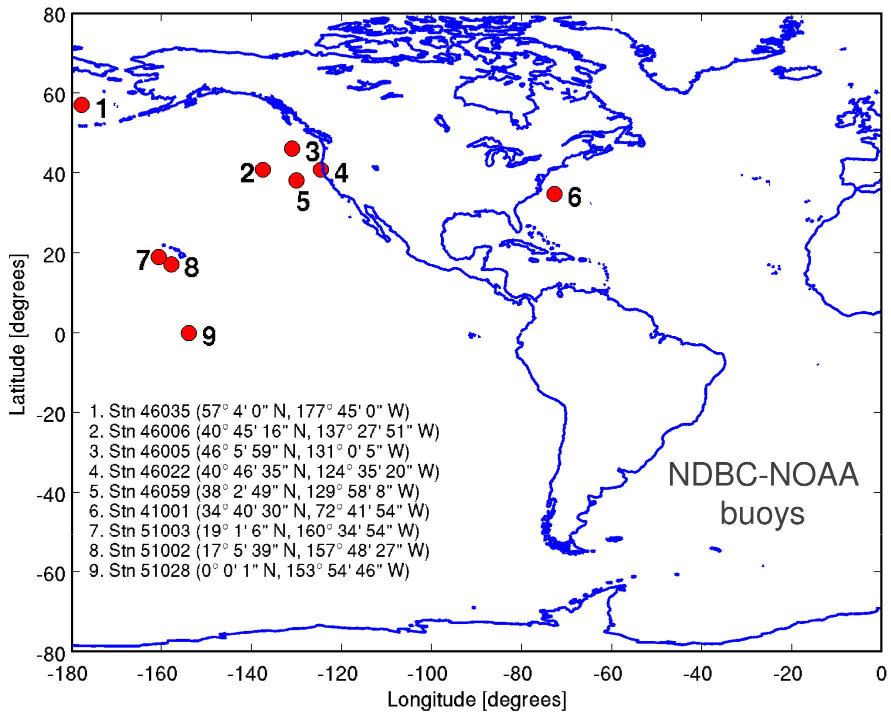
$$D = 1 - \frac{\sum_{n=1}^{N}(P_n - O_n)^2}{\sum_{n=1}^{N}(|P_n - O| + |O_n - O|)^2}$$

D = 0	complete disagreement
D = 1	perfect agreement

Bias index:

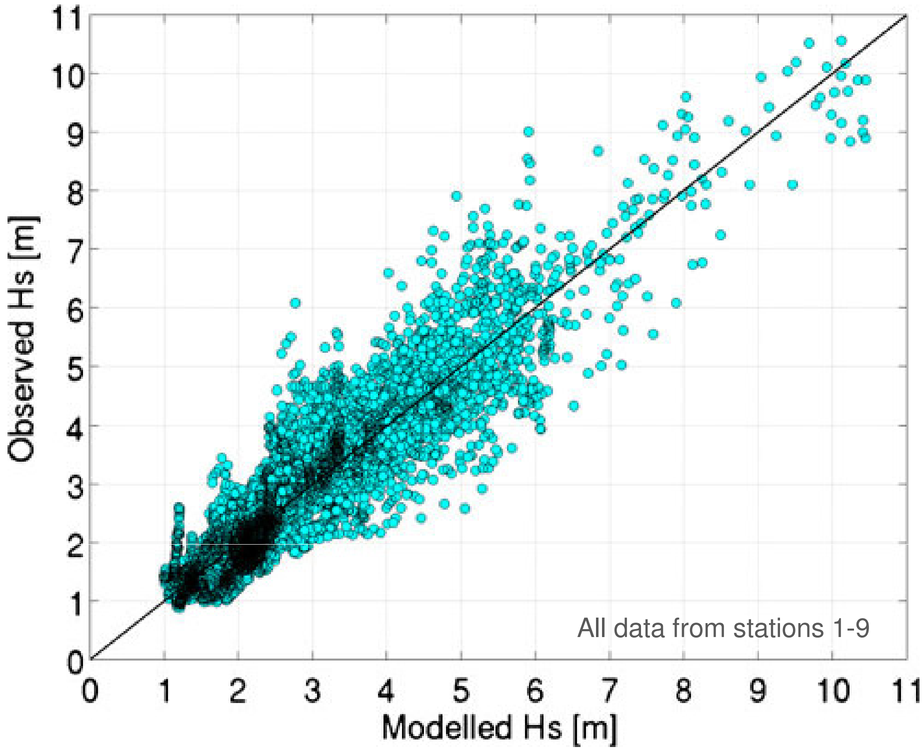
$$bias(P) = \frac{\sum_{n=1}^{N}(P_n - O_n)}{\sum_{n=1}^{N} O_n}$$

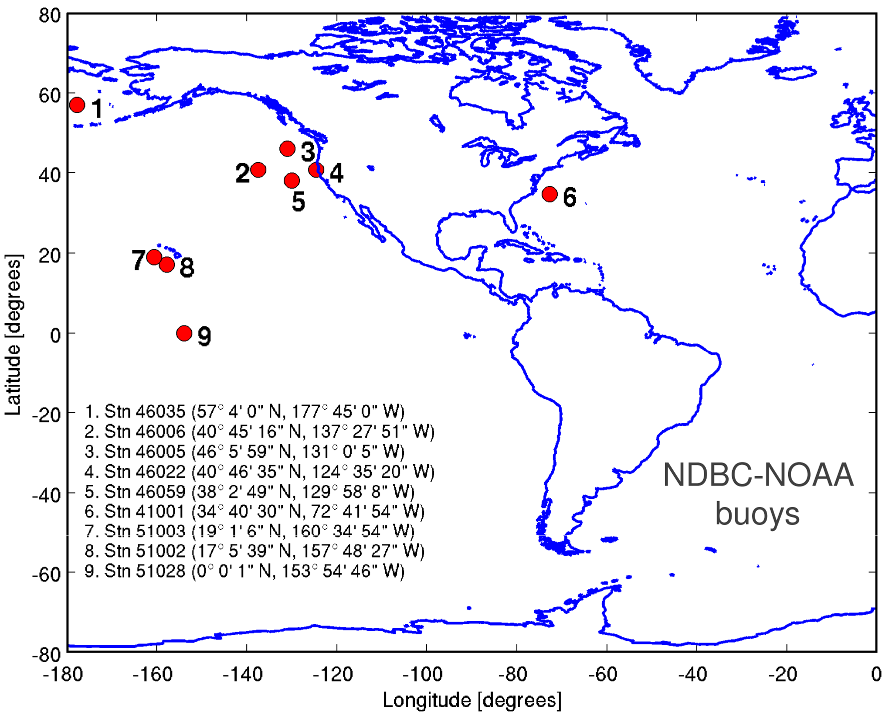
bias (P) = 0	perfect agreement
bias (P) = -0.01	under predicting the observed data by 1% on average

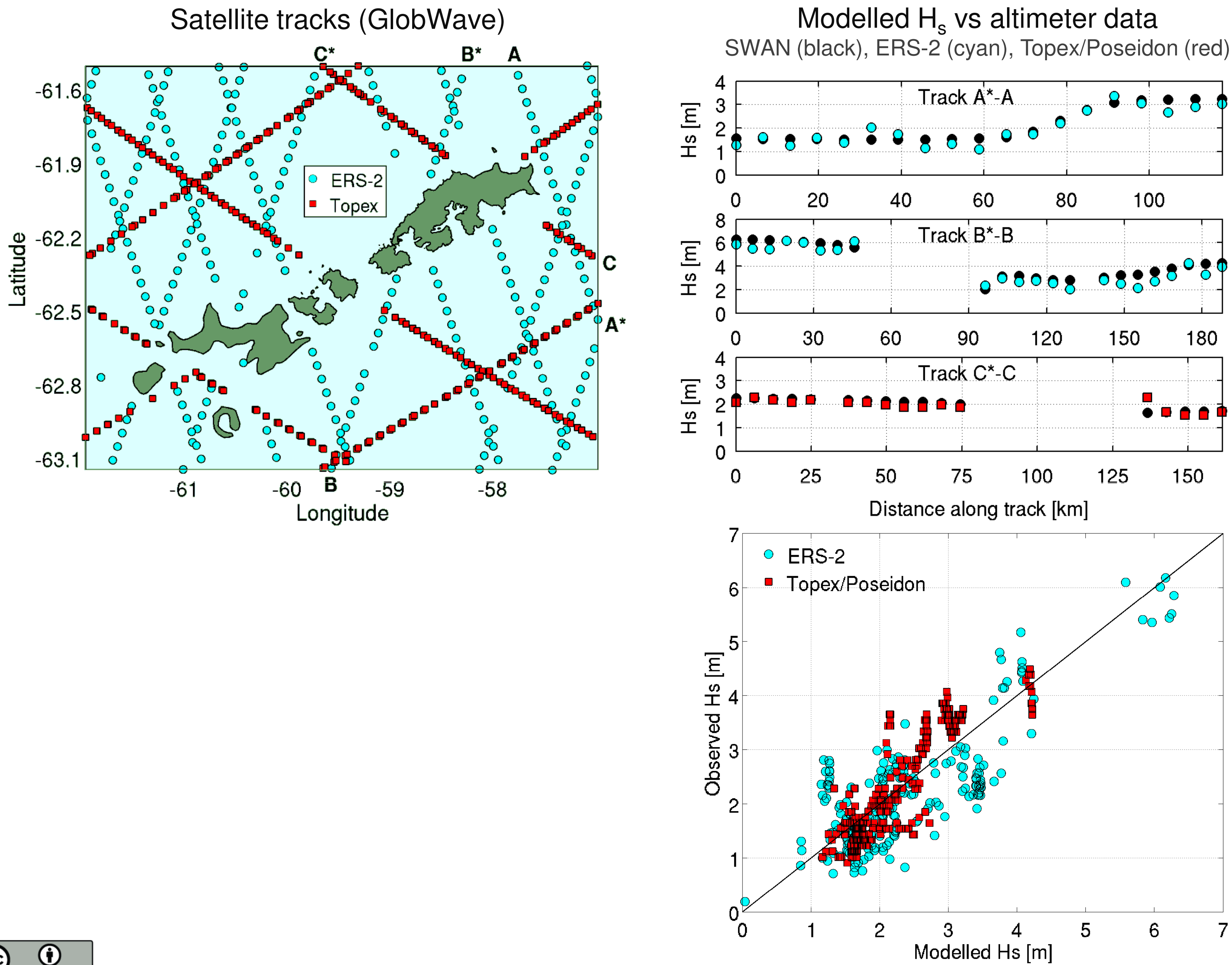


Station	1	2	3	4	5	6	7	8	9
D index	0.95	0.95	0.96	0.90	0.97	0.94	0.85	0.89	0.76
bias index	-0.01	0.02	0.03	-0.12	-0.04	-0.07	-0.02	-0.03	0.07

Goodness-of-fit

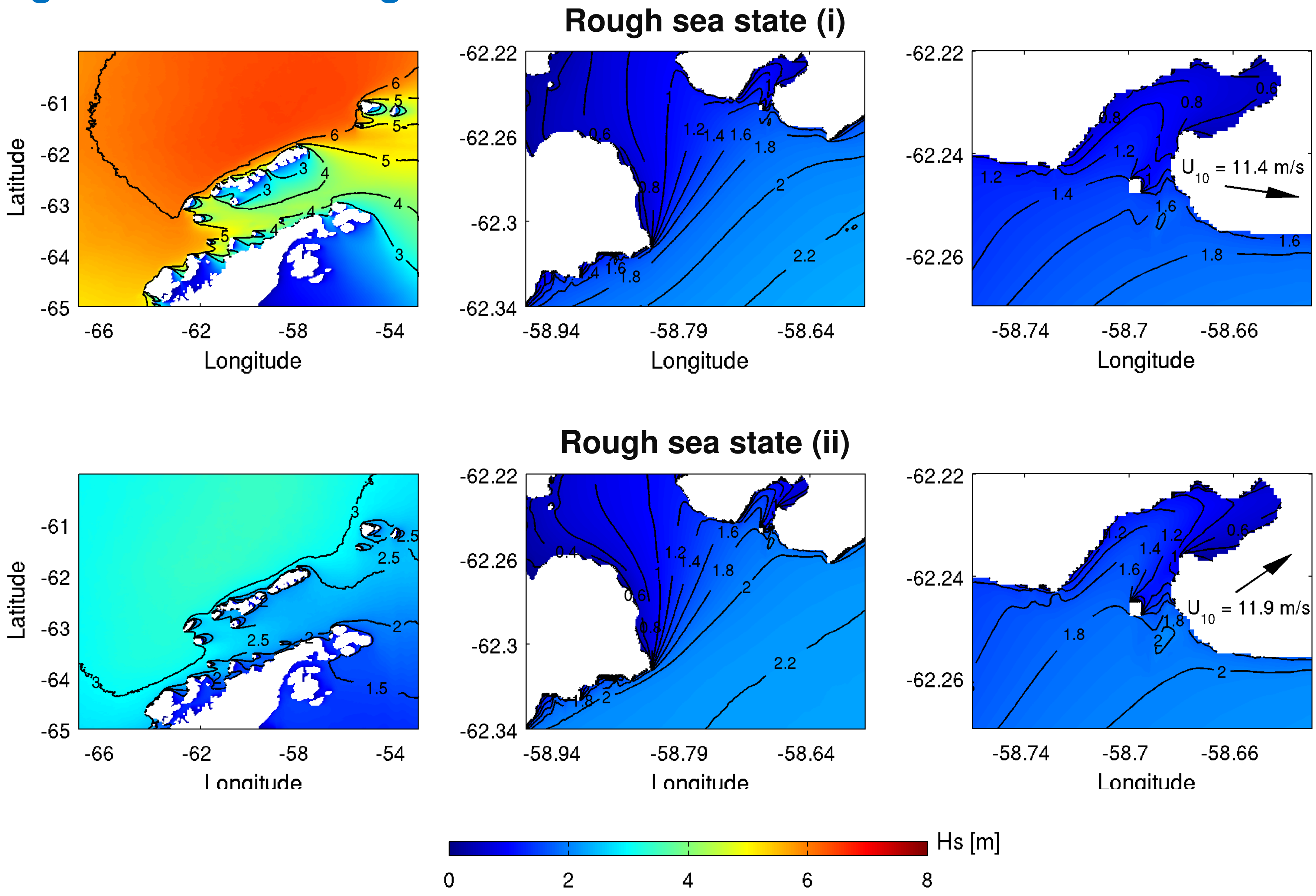






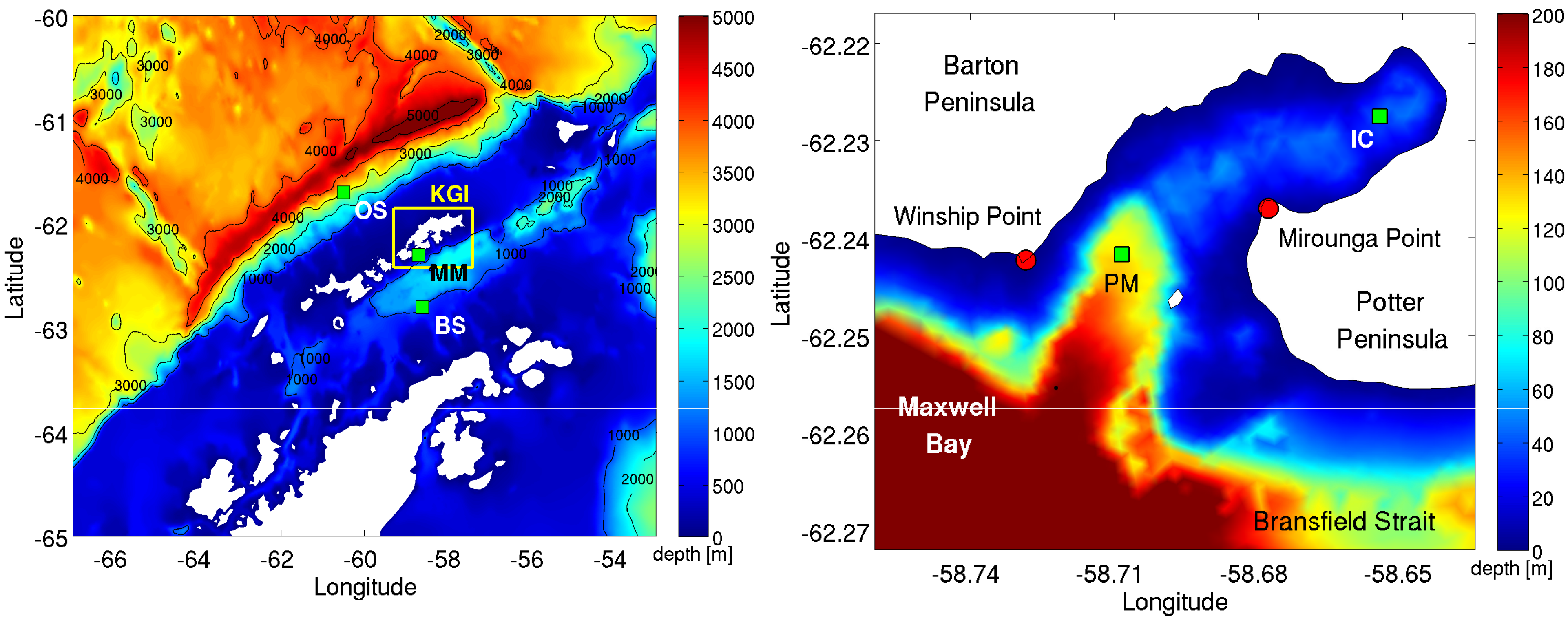
Satellite tracks (GlobWave)
C*
B*
A
C
A*
B
ERS-2
Topex
Latitude
-61.6
-61.9
-62.2
-62.5
-62.8
-63.1
-61
-60
-59
-58
Longitude
Modelled H_s vs altimeter data
SWAN (black), ERS-2 (cyan), Topex/Poseidon (red)
Track A*-A
Track B*-B
Track C*-C
Hs [m]
Distance along track [km]
ERS-2
Topex/Poseidon
Observed Hs [m]
Modelled Hs [m]

Significant Wave Height



Points to extract wave spectra

To identify whether the wave states are swell-generated or locally wind-generated

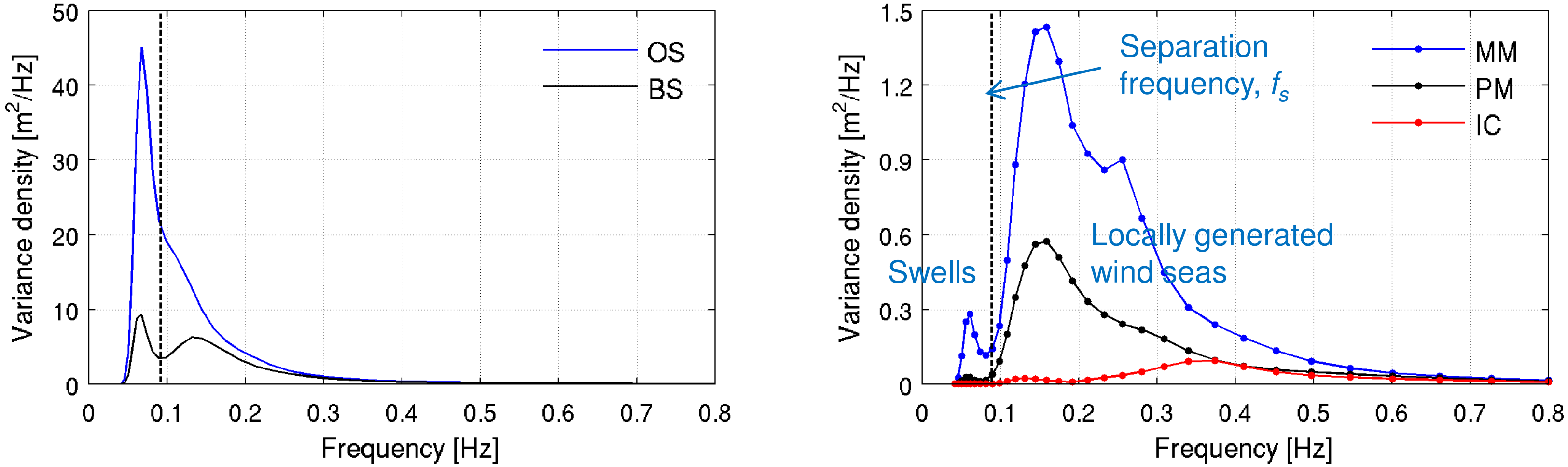


KGI: King George Island

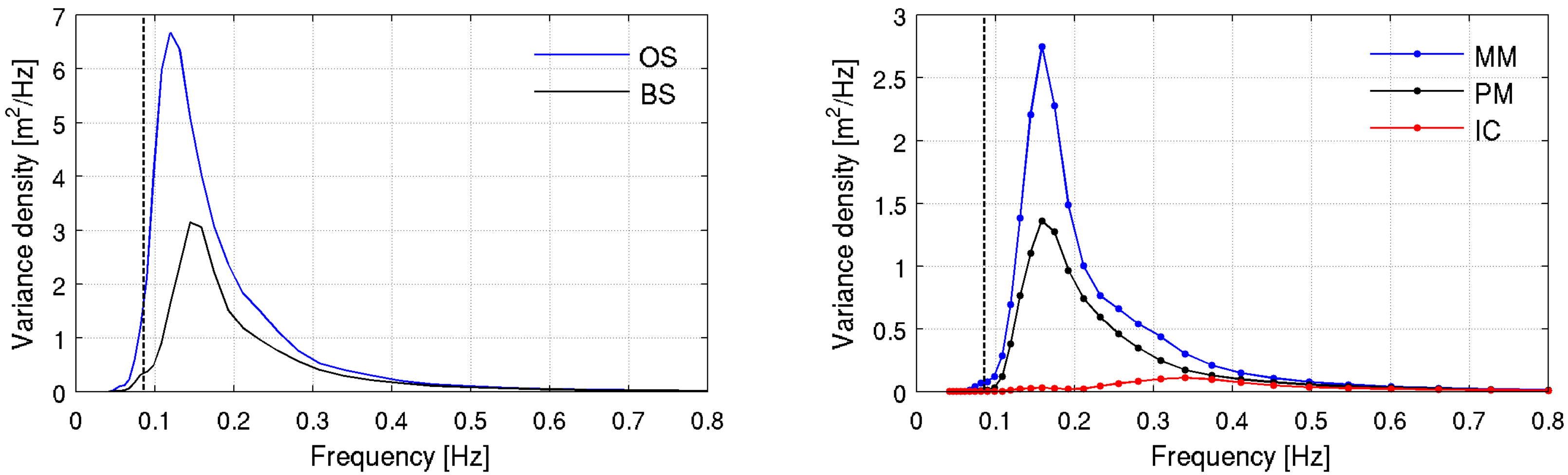
OS: Open sea
BS: Bransfield Strait
MM: Maxwell mouth
PM: Potter mouth
IC: inner cove

Wave Spectra

Rough sea state (i)

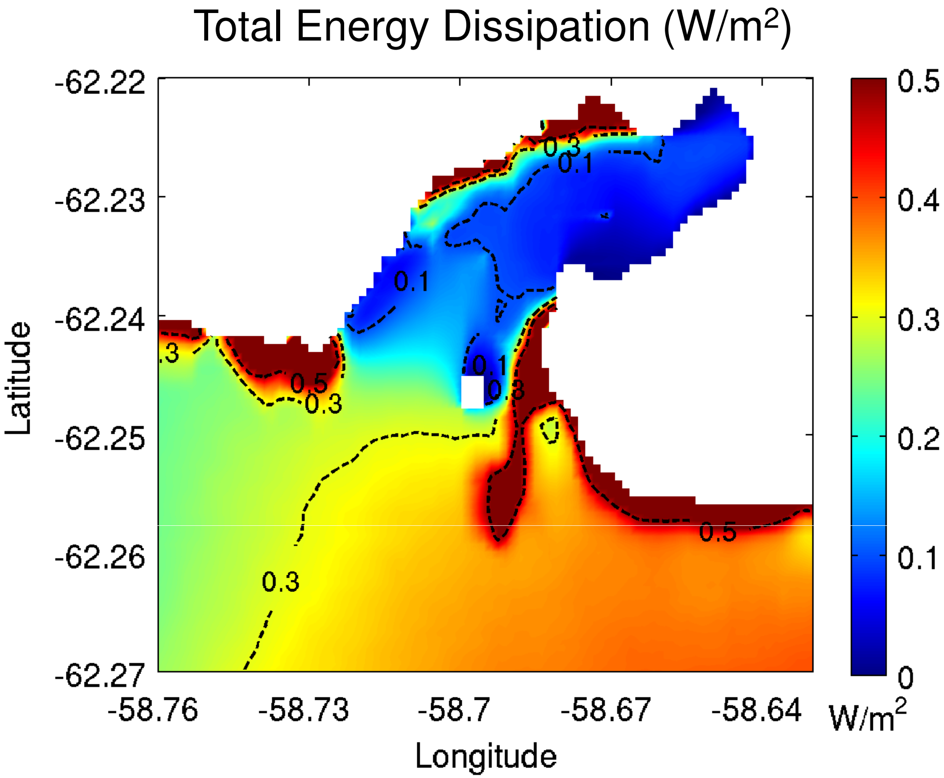


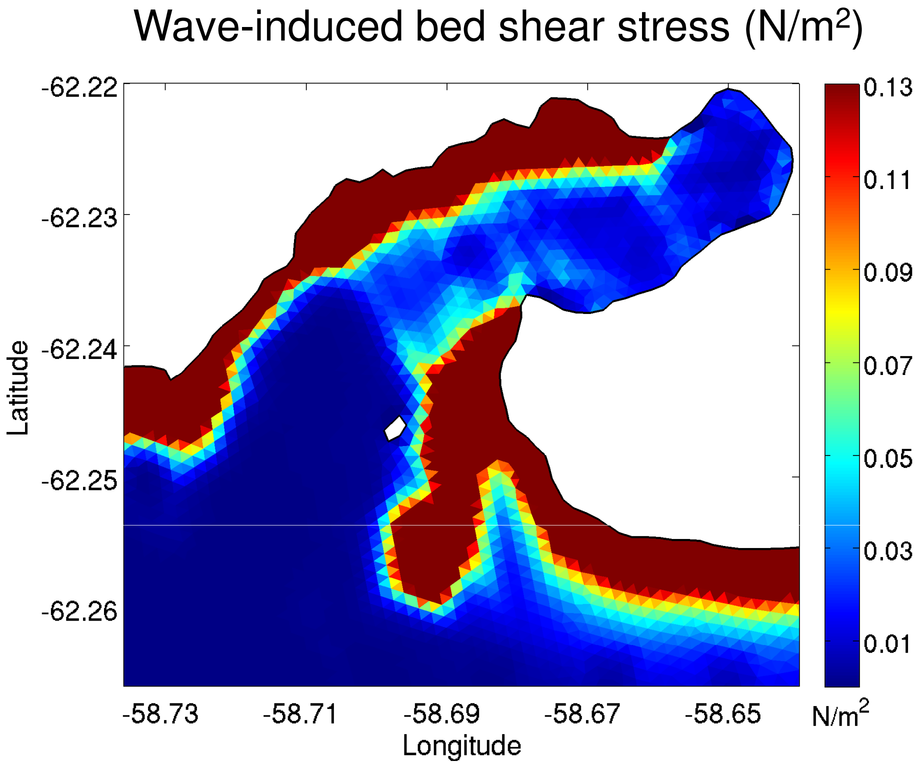
Rough sea state (ii)



OS: Open sea BS: Bransfield Strait MM: Maxwell mouth PM: Potter mouth IC: inner cove

Example: Rough sea state (ii)





Bed shear stress is specified to a maximum of 0.13 N/m² (equal to τ_{cr}) to delineate the bed erosion prone regions.

FVCOM model:

- An unstructured-grid finite volume coastal ocean model.

  (Chen *et al.*, 2006) - an 'open' community model.

- FVCOM computes the governing equations of momentum and continuity:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_o}\frac{\partial P}{\partial x} + \frac{\partial}{\partial z}(K_m\frac{\partial u}{\partial z}) + F_u$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho_o}\frac{\partial P}{\partial y} + \frac{\partial}{\partial z}(K_m\frac{\partial v}{\partial z}) + F_v$$

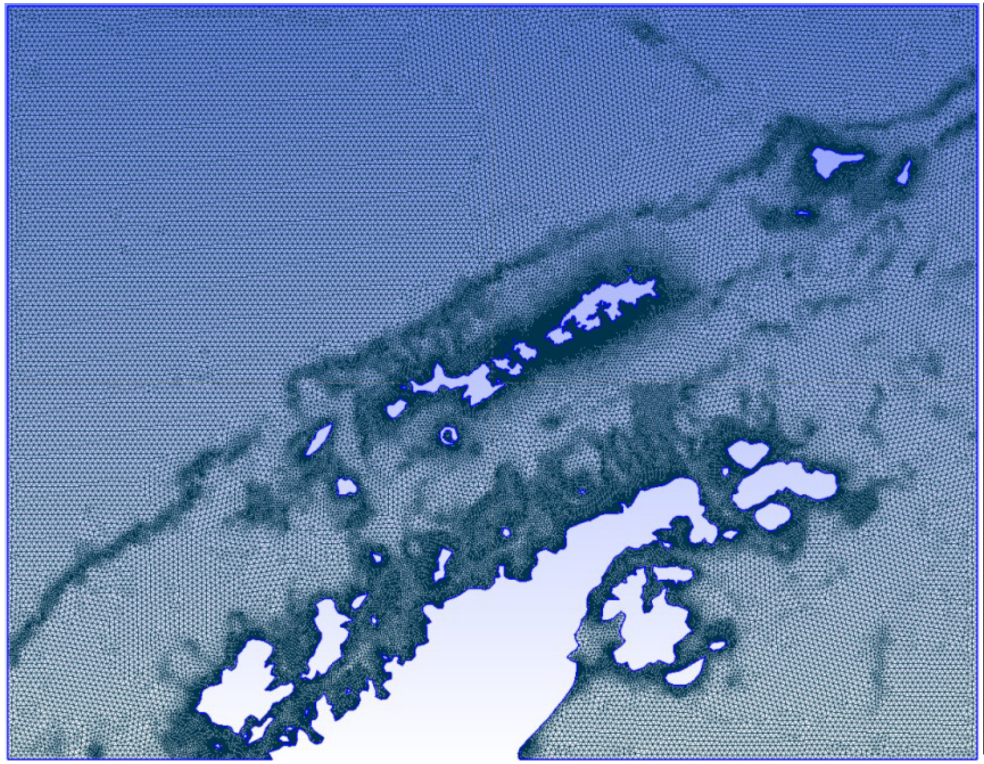
$$\frac{\partial P}{\partial z} = -\rho g$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

f: Coriolis parameter
Km: vertical eddy viscosity coefficient
(Fu,Fv): horizontal momentum diffusivity terms

FVCOM model:

• Horizontal grid: unstructured triangular mesh.
• Vertical grid: uniform σ-coordinate (vertical layers in the water column).



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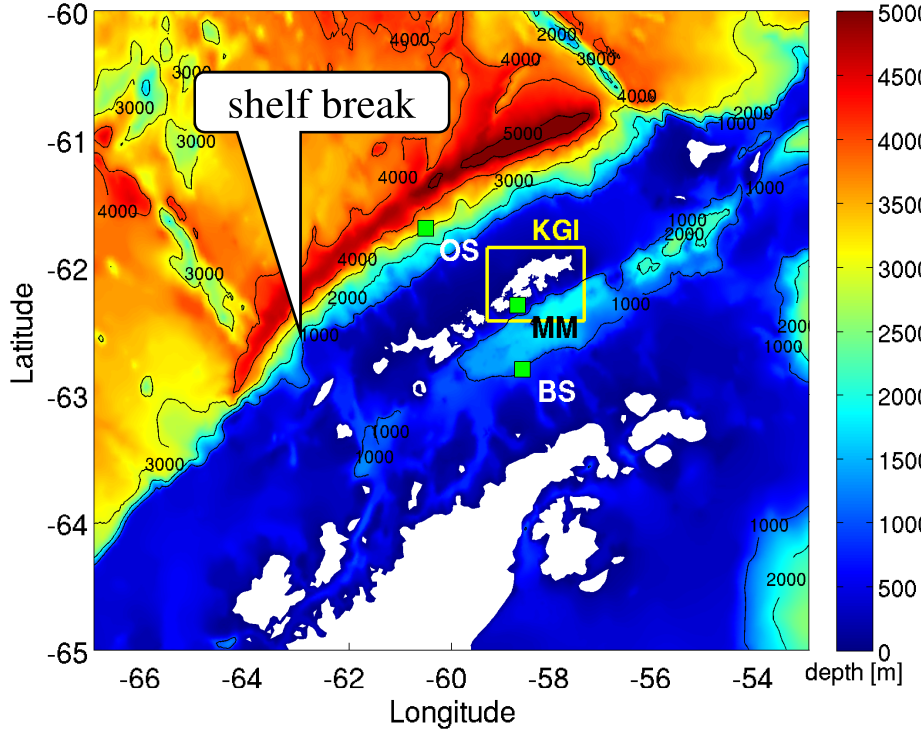
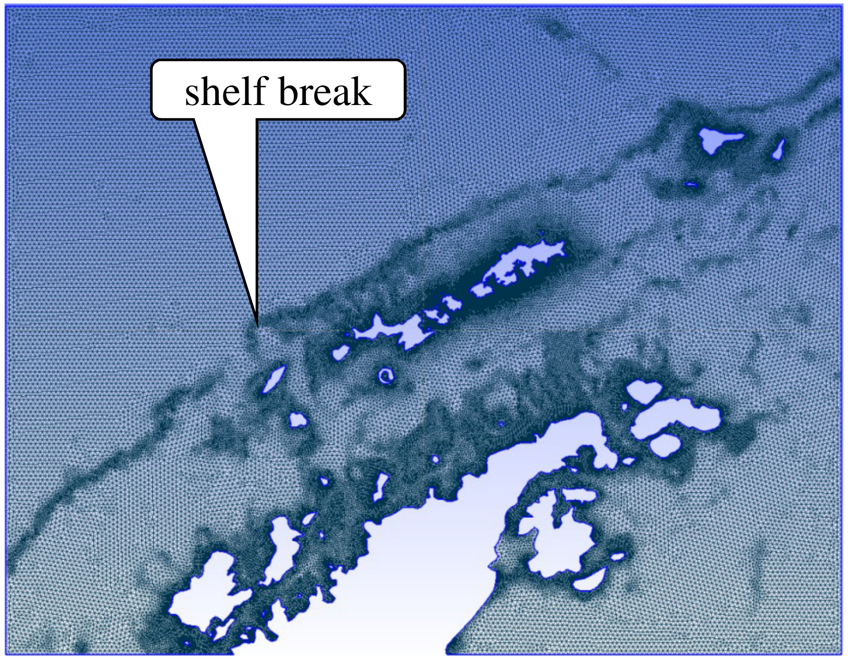




Mesh

- 152 805 elements
- 78 702 nodes

Horizontal resolution

- Min element size: 100 m
- Max element size: 4 km
- Shelf break, ~1.5-2 km

Vertical resolution

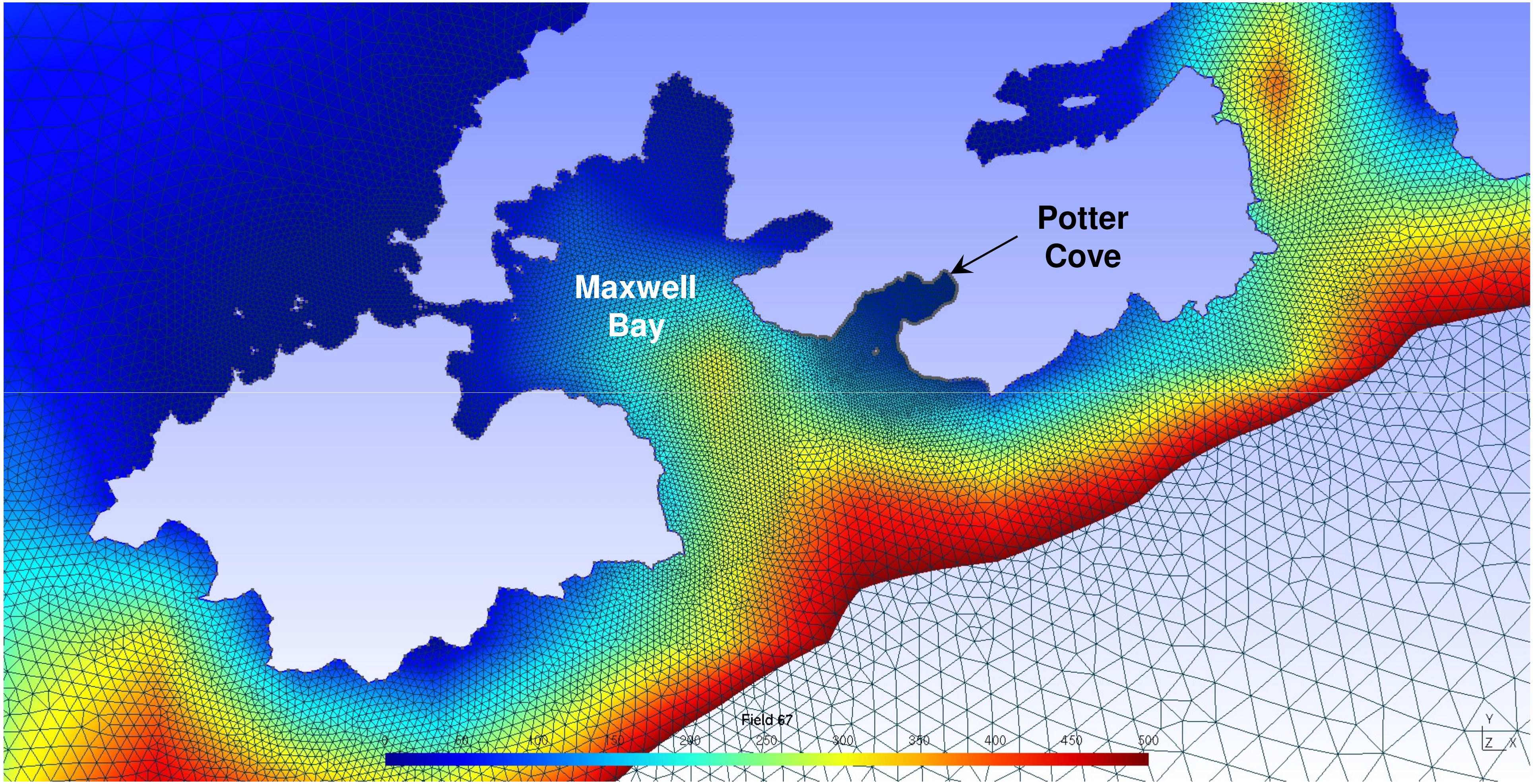
- 41 σ levels (uniform layers)

  ~ 0.16 m to 18.84 m (Potter Cove)

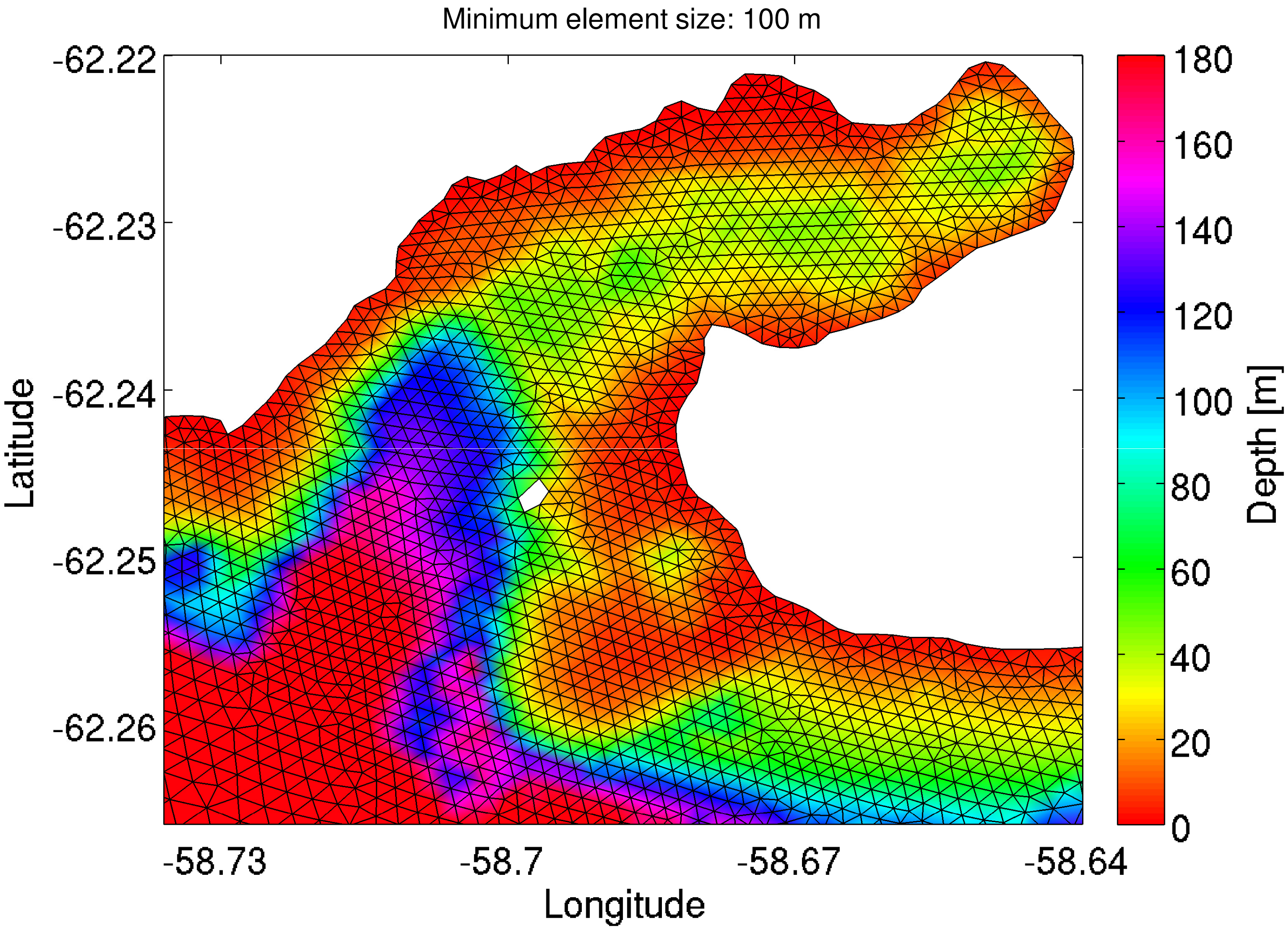
- 3D simulation
- time step = 10 s
- Boundary conditions:

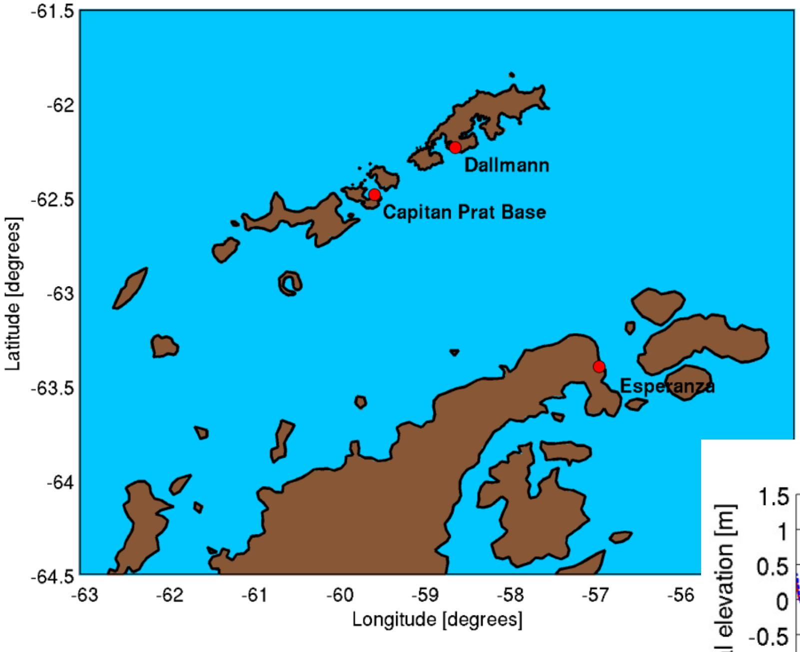
(1) Tidal forcing: Global FES2004 predicted tides
(2) Wind: wind at 10 m, 6-hourly, NOAA-NCEP

Maxwell Bay: The Bathymetry and Mesh



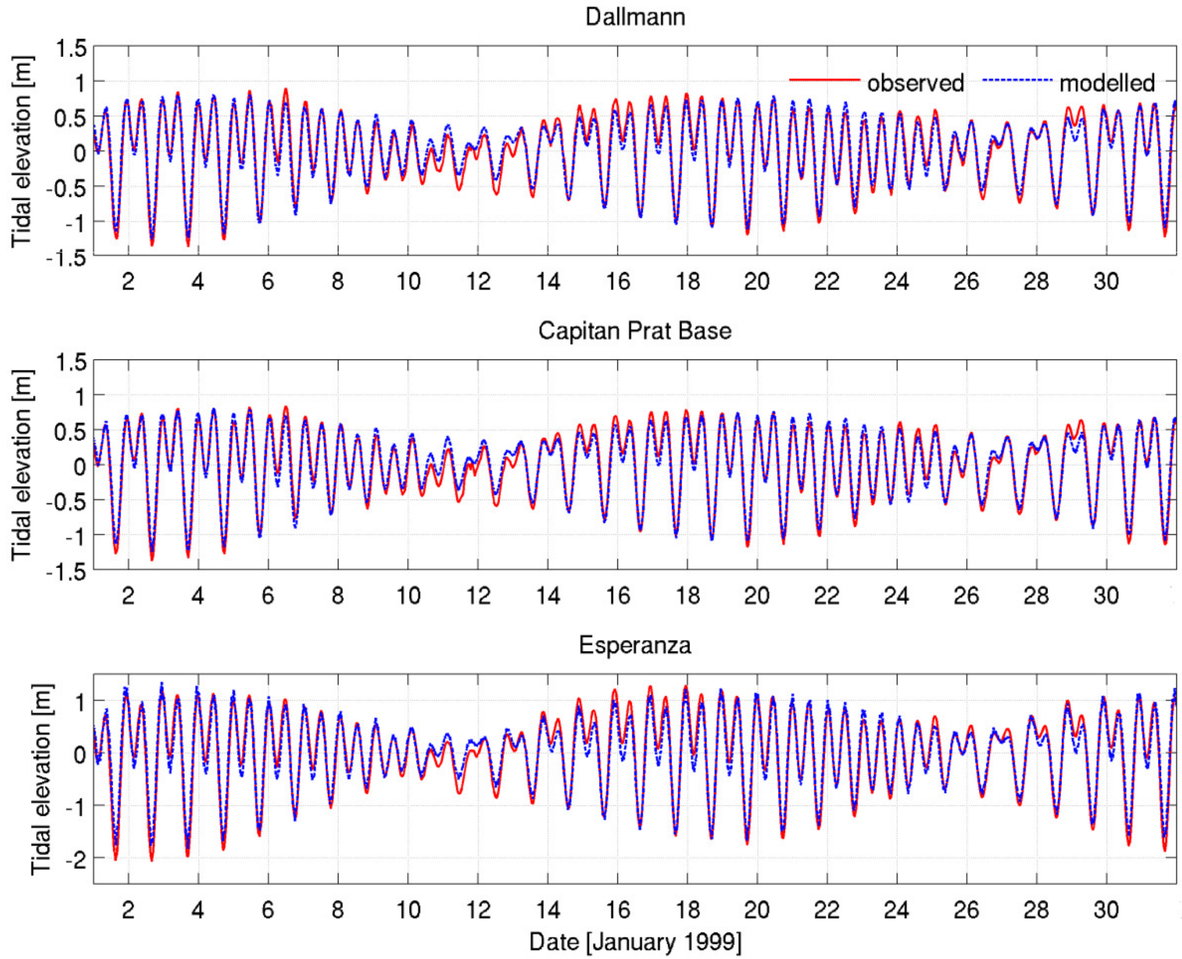
Potter Cove: The Bathymetry and Mesh





Stations	D index	bias index (%)
1. Capitan Prat Base	0.990	0.82
2. Dallmann	0.989	0.53
3. Esperanza	0.986	0.02

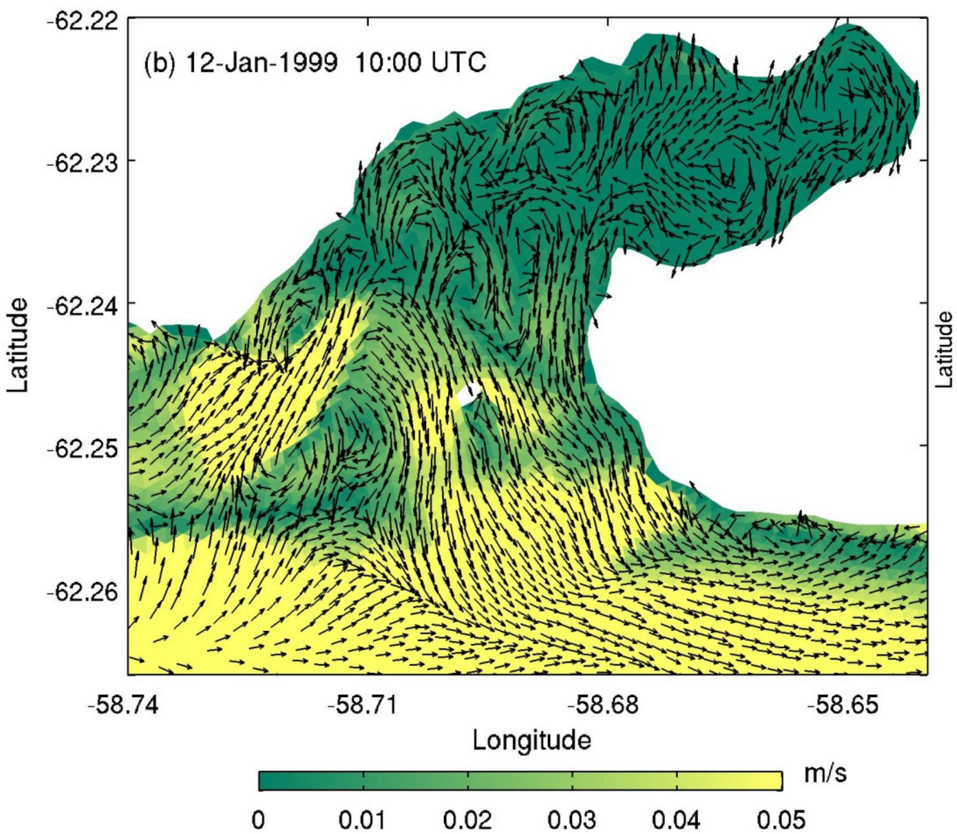
Tidal elevation: modelled vs observed



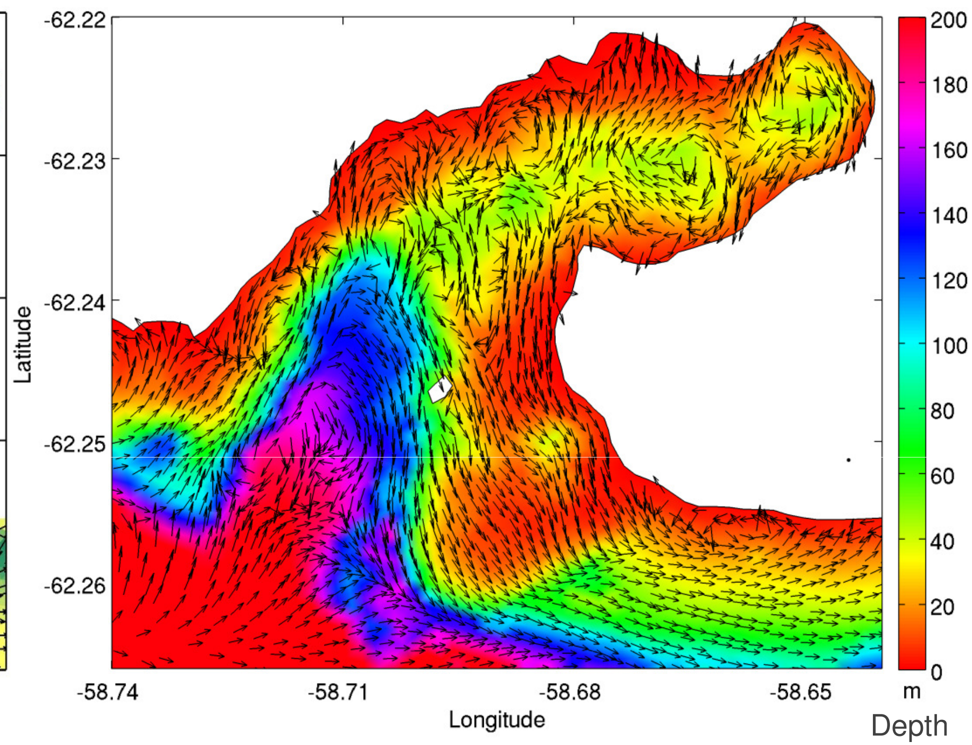
Observed sea level data:

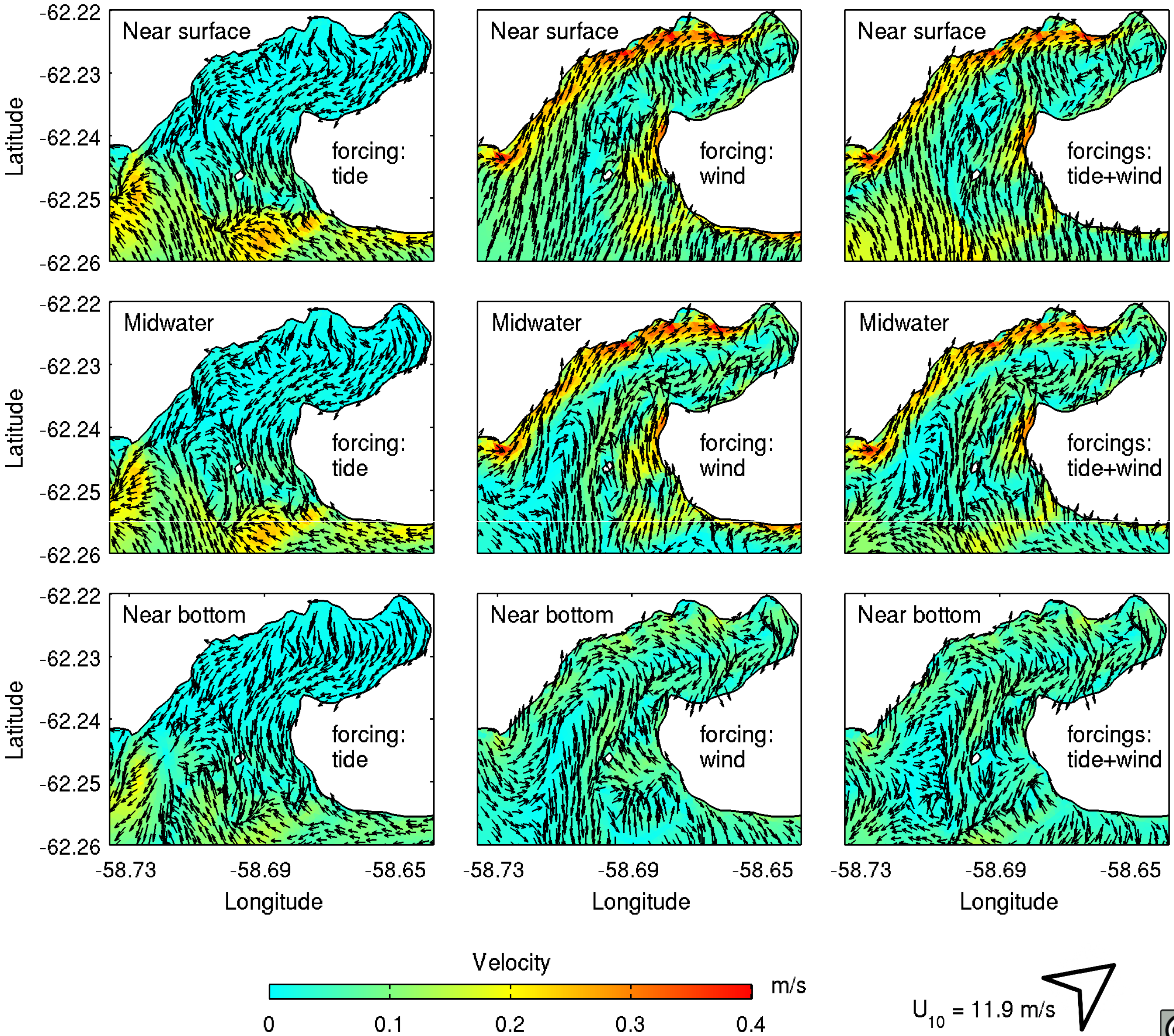
1. **Dallmann**
   UHSLC research quality database
2. **Capitan Prat Base**
   BODC database
3. **Esperanza**
   UHSLC - GLOSS/CLIVAR database

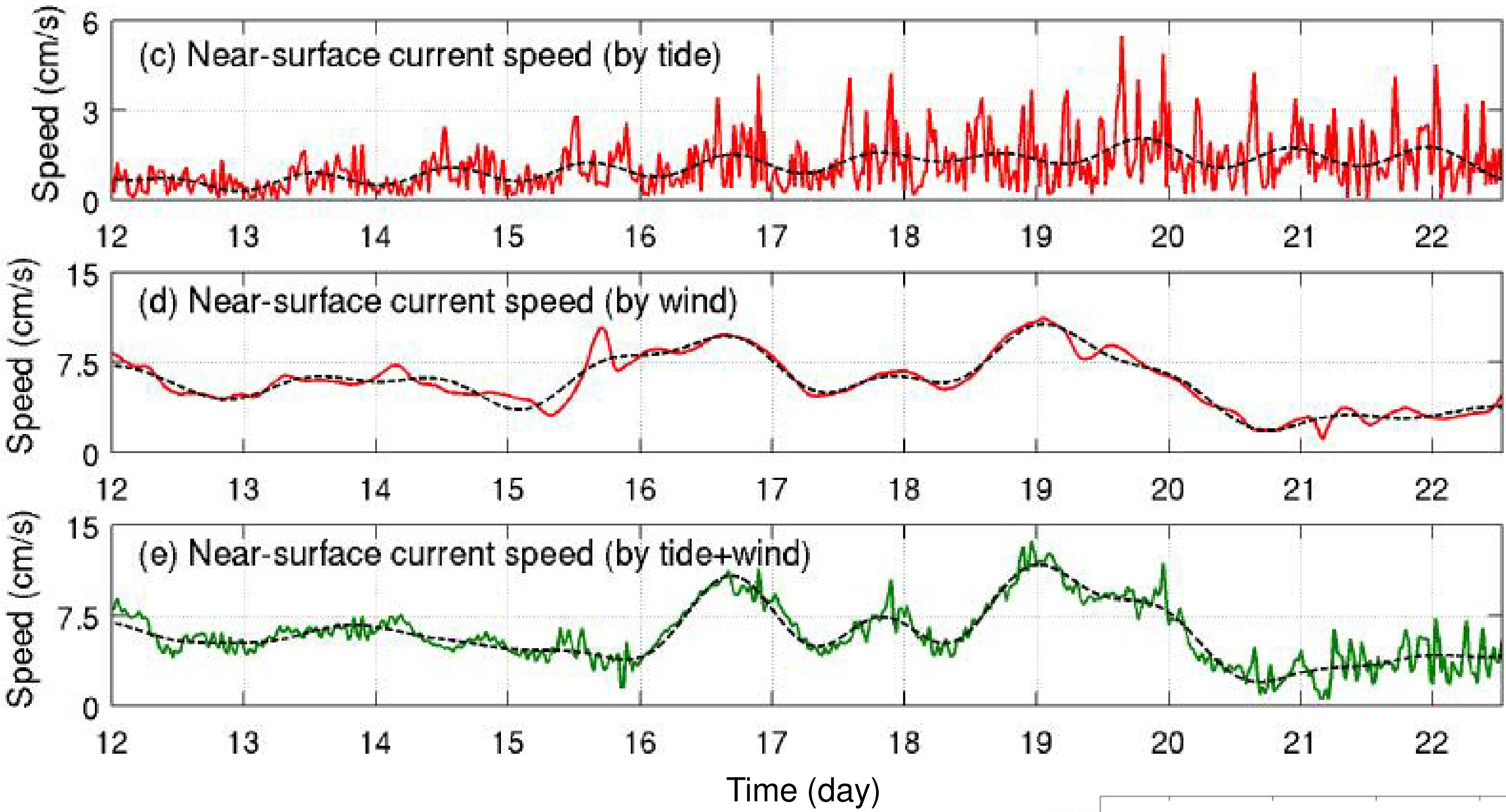
Tidal circulation during neap tide (ebb condition)



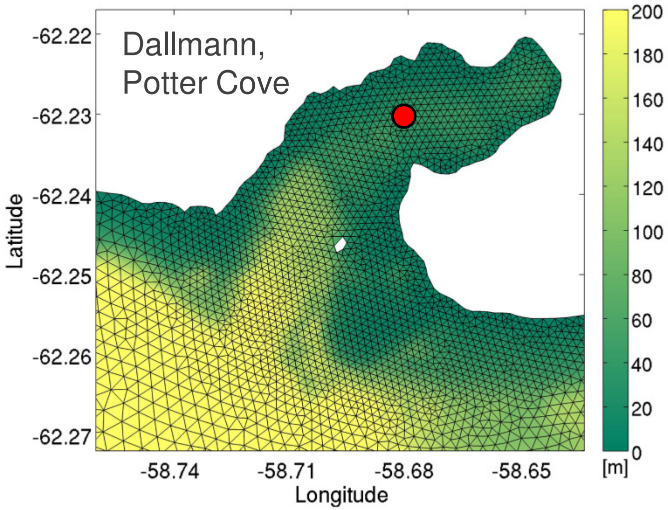
Tidal flow fields follow the seafloor topography

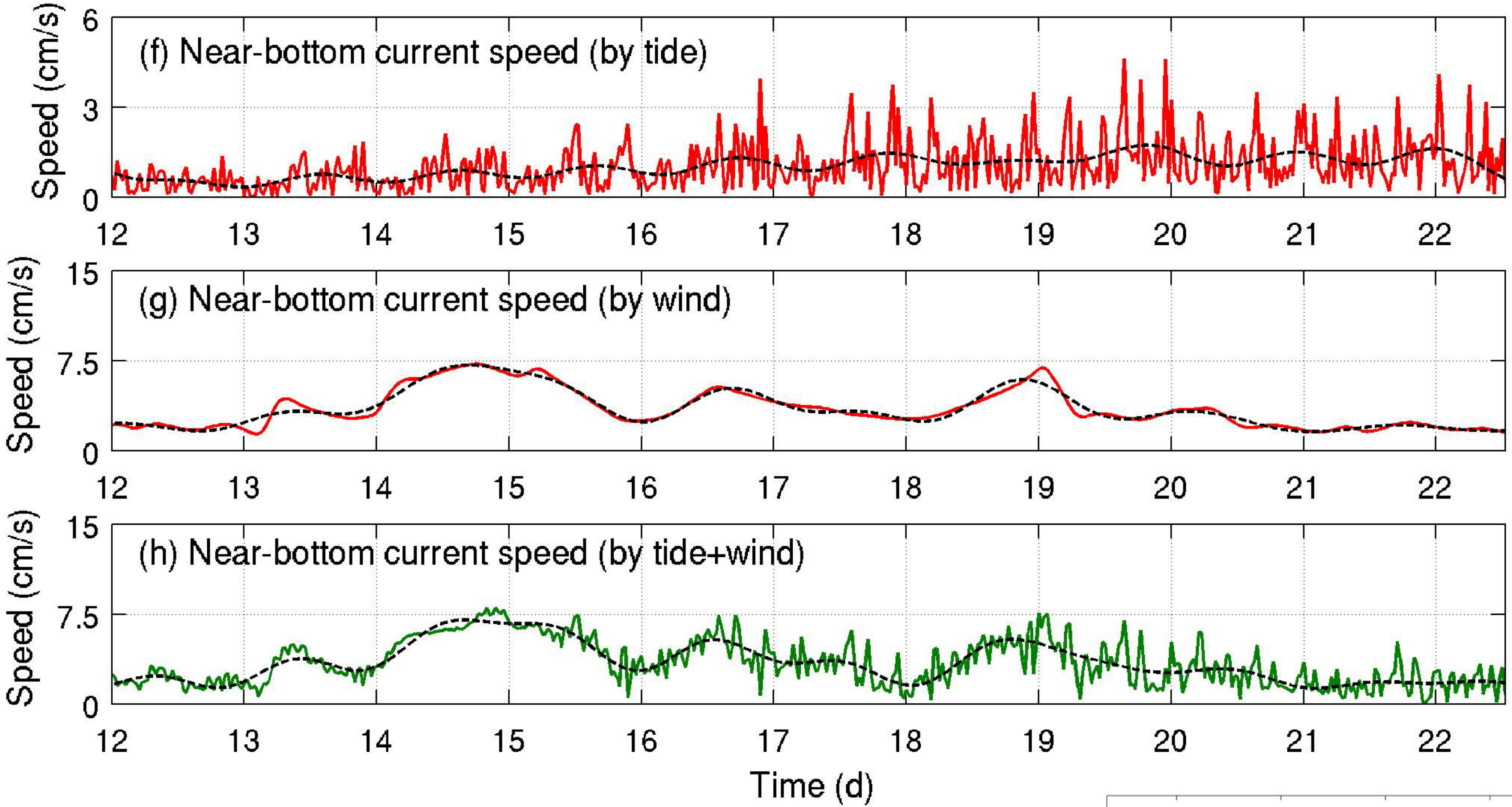



Near surface
forcing: tide
forcing: wind
forcings: tide+wind
Midwater
Near bottom
Latitude
Longitude
-62.22
-62.23
-62.24
-62.25
-62.26
-58.73
-58.69
-58.65
Velocity
m/s
0
0.1
0.2
0.3
0.4
U_{10} = 11.9 m/s



Black dashed lines are signals filtered through FFT low-pass filter with a cutoff frequency of 1 day^{-1}.





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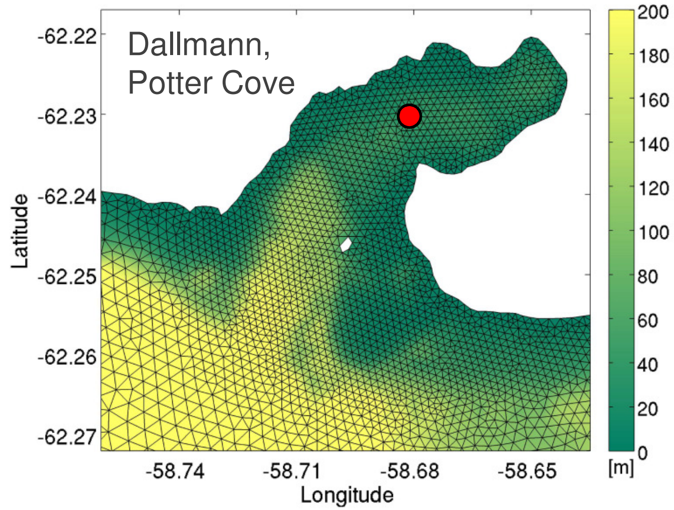
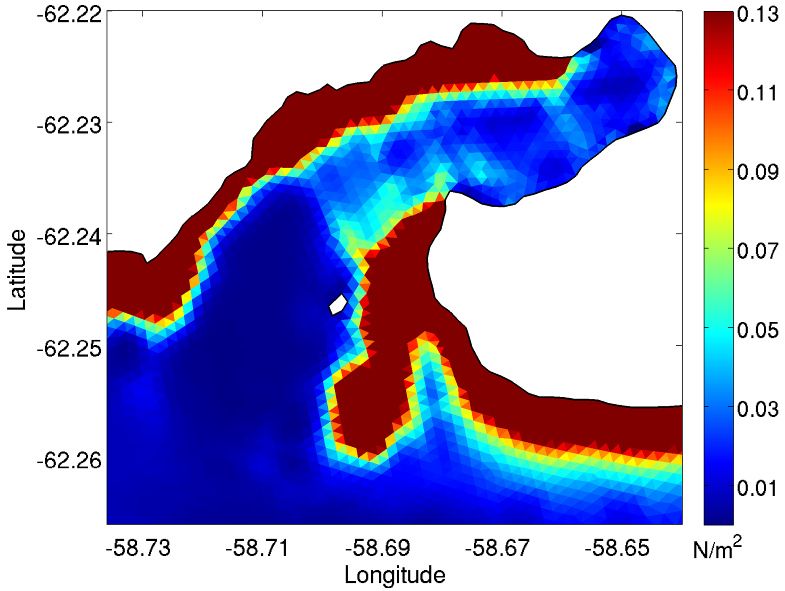


Total bed shear stress



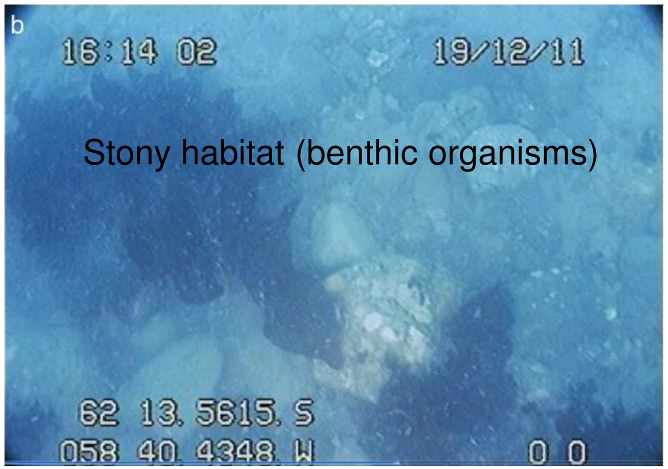
Bed shear stress is specified to a max. of 0.13 N/m^2 (equal to τ_{cr}) to delineate the bed erosion prone regions.

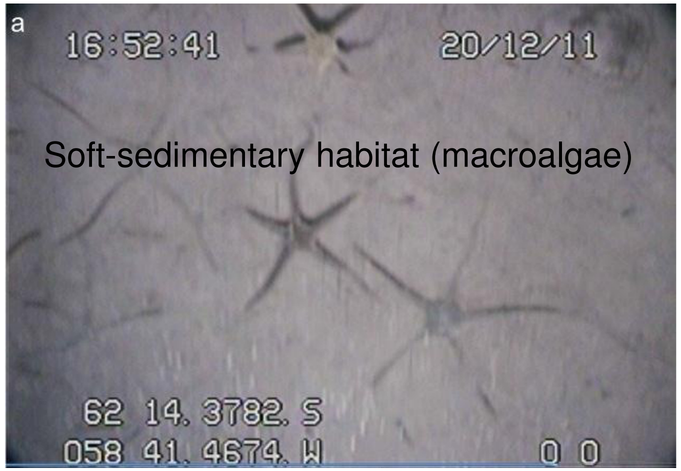
Distribution of habitat type

Image removed due to copyright considerations.

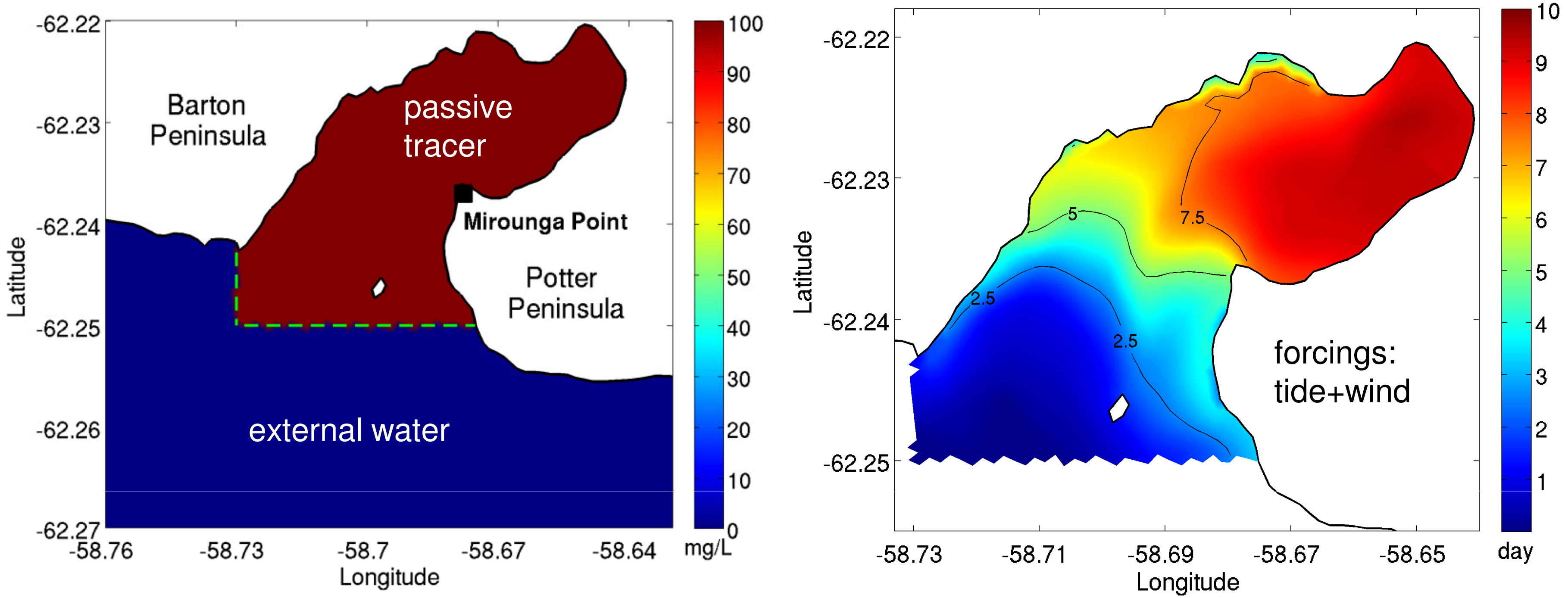
Image: Wölfl et al., 2014

Images: Anne-Cathrin Wölfl





Local residence time (LRT)

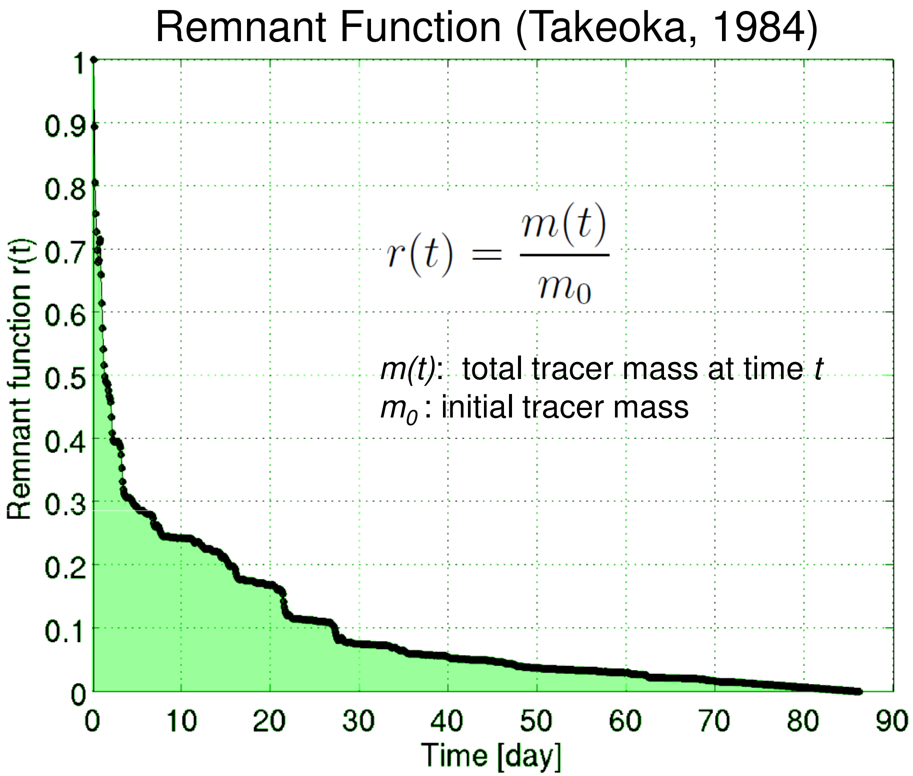


Initial tracer concentration C_0 = 100 g/L

Residence time

The time it takes for a water parcel starting at a specific location within Potter Cove to leave its outlet or boundaries.

Flushing time



$$\text{Flushing time} = \int_0^\infty r(t)\, dt$$

Forcing scenario	Flushing time (day)
Tide	8.5
Tide + realistic wind	3.2
Tide + NW10 wind	4.0
Tide + W10 wind	1.0

Flushing time
The time required for a well-mixed volume of the entire cove to be replaced with external water.

Conclusions

1. Wave condition in Potter Cove is dependent on the local wind condition.
2. Tides have minimal influence on the circulation in Potter Cove.
3. Current regime in Potter Cove is rather wind-dominated.
4. Wave-induced bed shear stress is a potential major driving force for the bed sediment erosion.
5. The flushing time is approximately 3.2 days.

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thank you

terima kasih

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