Nearshore sandbar response at single-barred embayed beaches

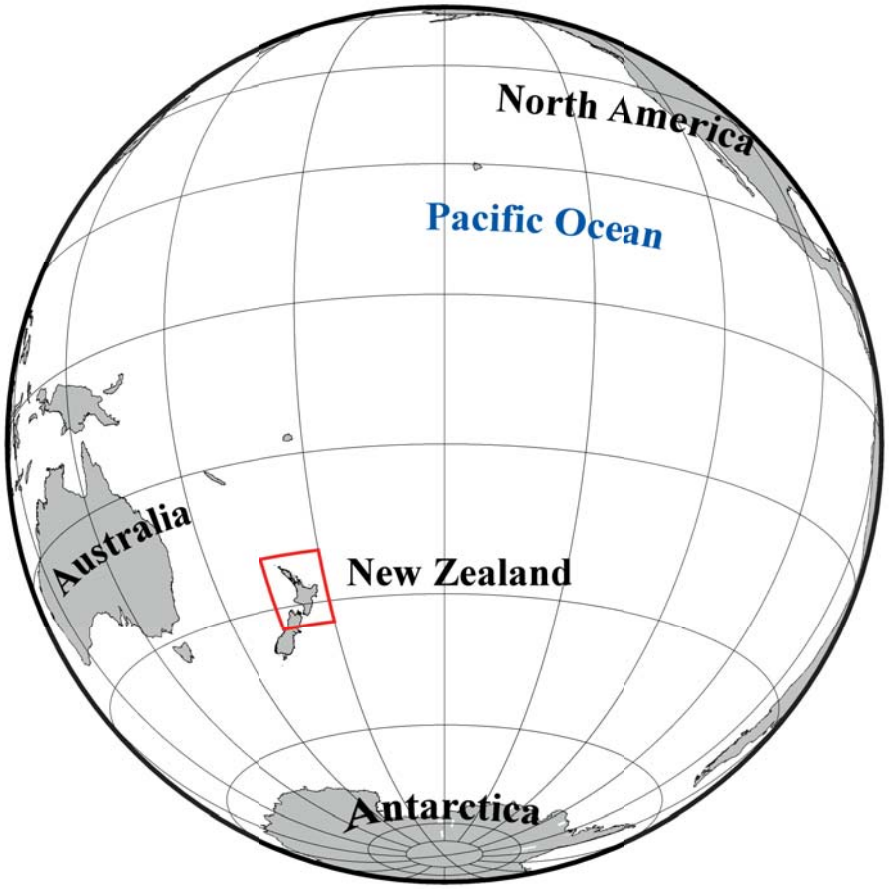
Brice Blossier[1]
Karin R. Bryan[2]
Christopher J. Daly[3]
Christian Winter[1]

25th February 2016
FZK Kolloquium, Hannover, Germany

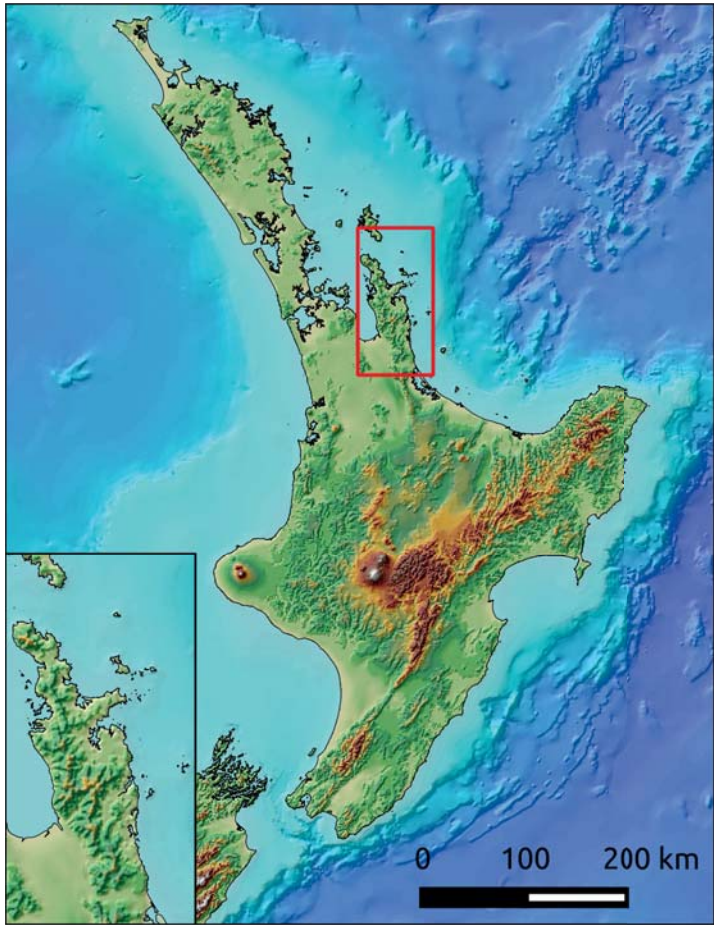
[1] : MARUM, Center for Marine Environmental Sciences, University of Bremen, Germany
[2] : Coastal Marine Group, University of Waikato, New Zealand
[3] : University of the West Indies, St. Augustine, Trinidad, Tobago W.I

Contents

Field site : Tairua Beach



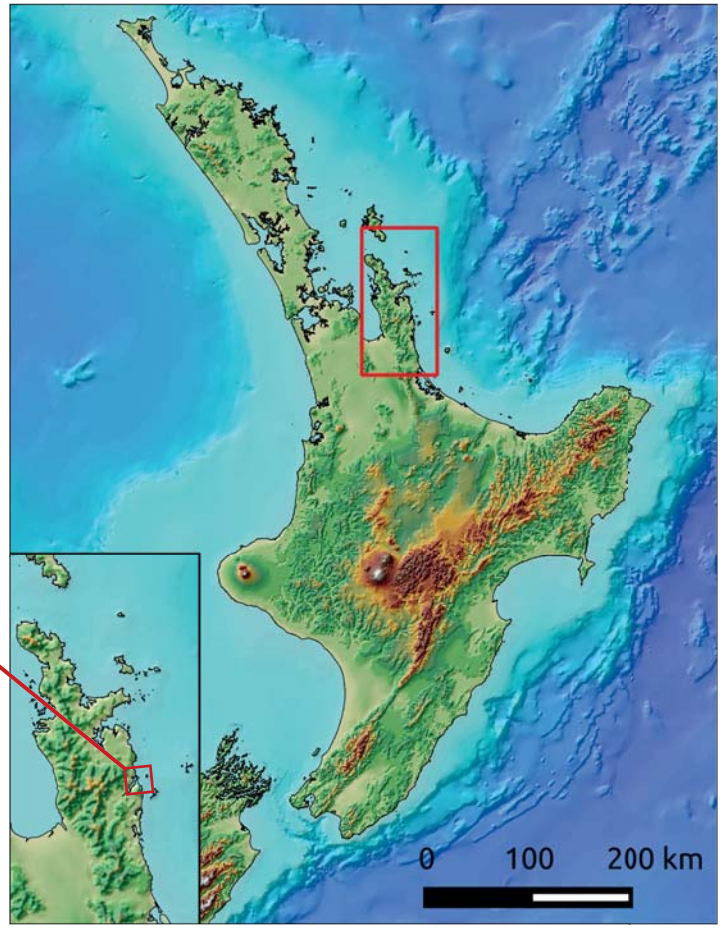
North Island of New Zealand in the southwestern Pacific.



North Island of New Zealand.
Inset : Coromandel Peninsula.
(GIS data from LINZ).

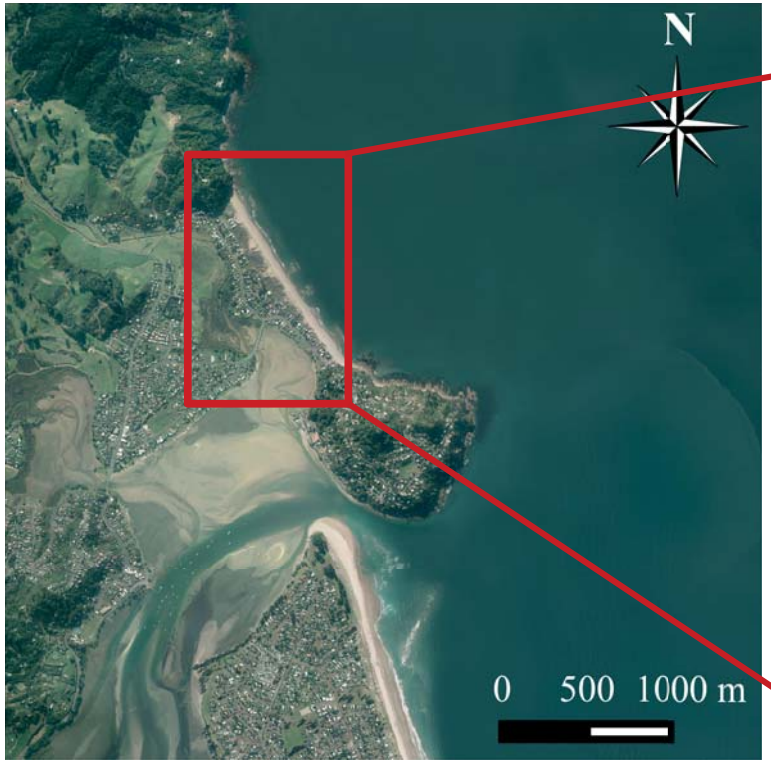
Field site : Tairua Beach

Tairua Beach area,
(Waikato Regional Aerial Photography Service, LINZ)

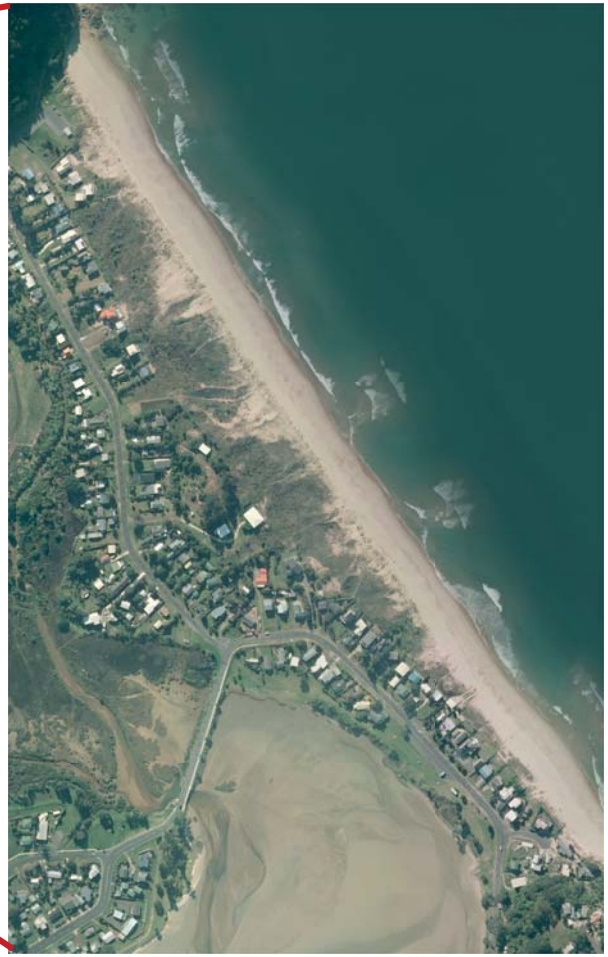


North Island of New Zealand.
Inset : Coromandel Peninsula.
(GIS data from LINZ).

Field site : Tairua Beach

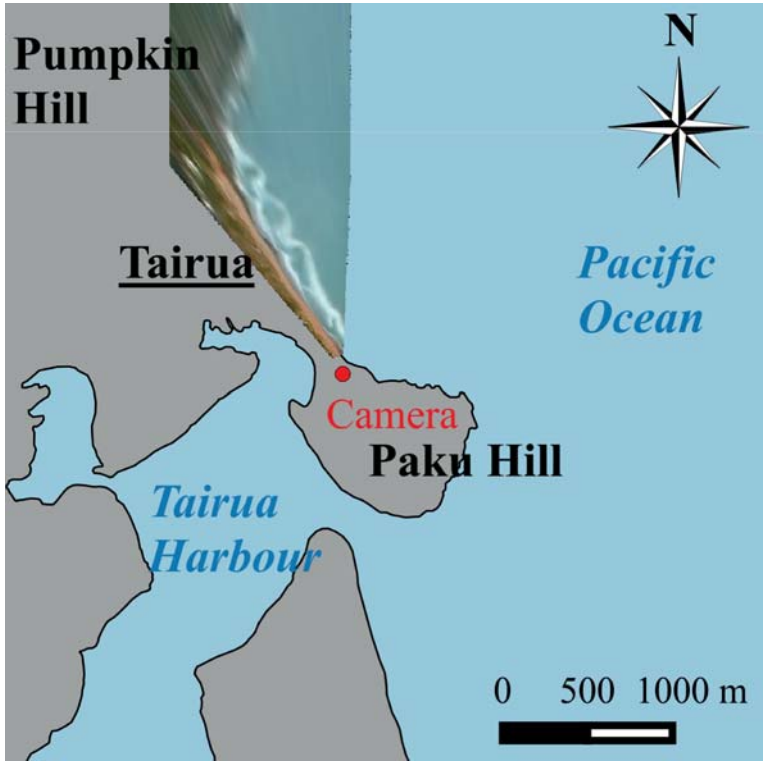


Tairua Beach area,
(Waikato Regional Aerial Photography Service, LINZ)



Aerial view of Tairua Beach

Acquisition of video images

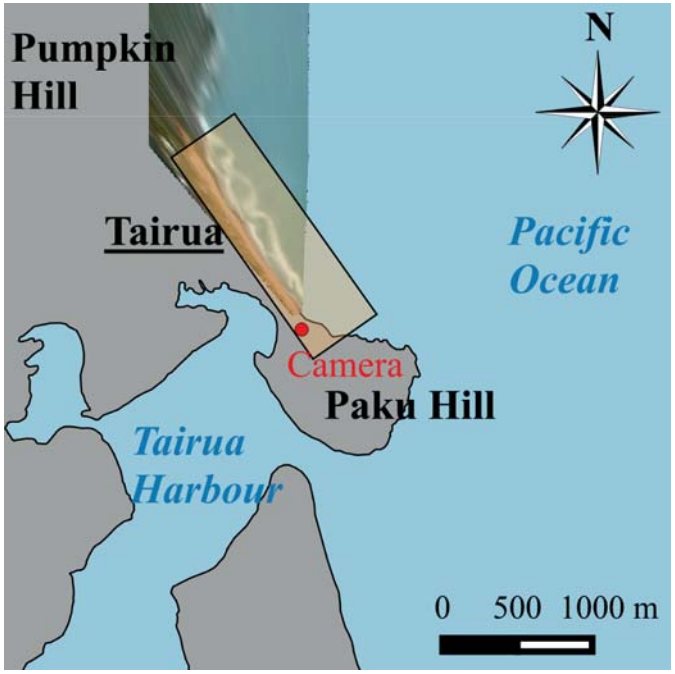


Tairua Beach area

Camera location on Paku Hill, Tairua Beach

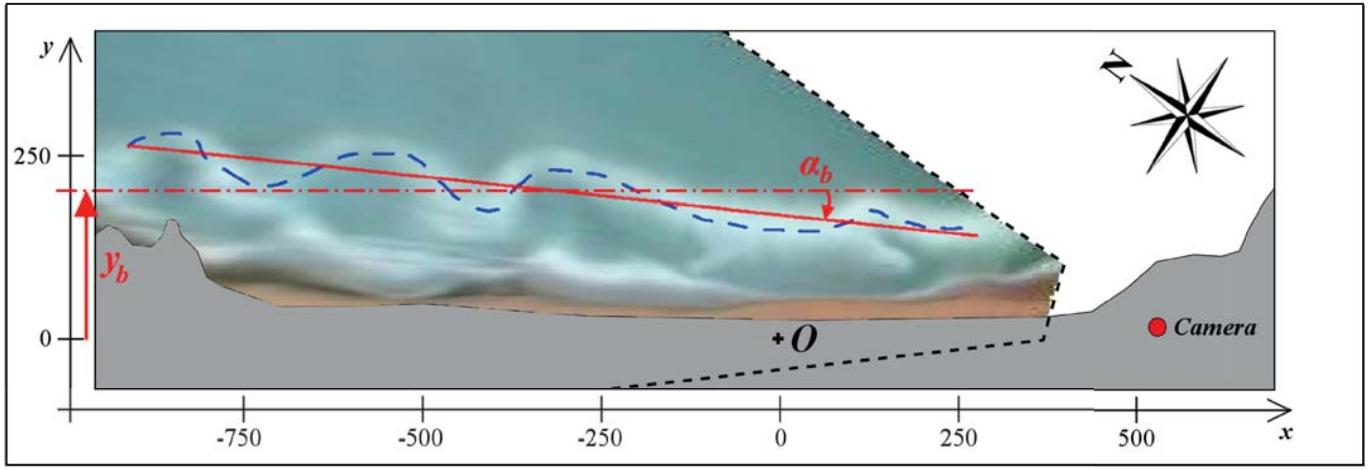
15 minutes averaged camera image

Acquisition of video images



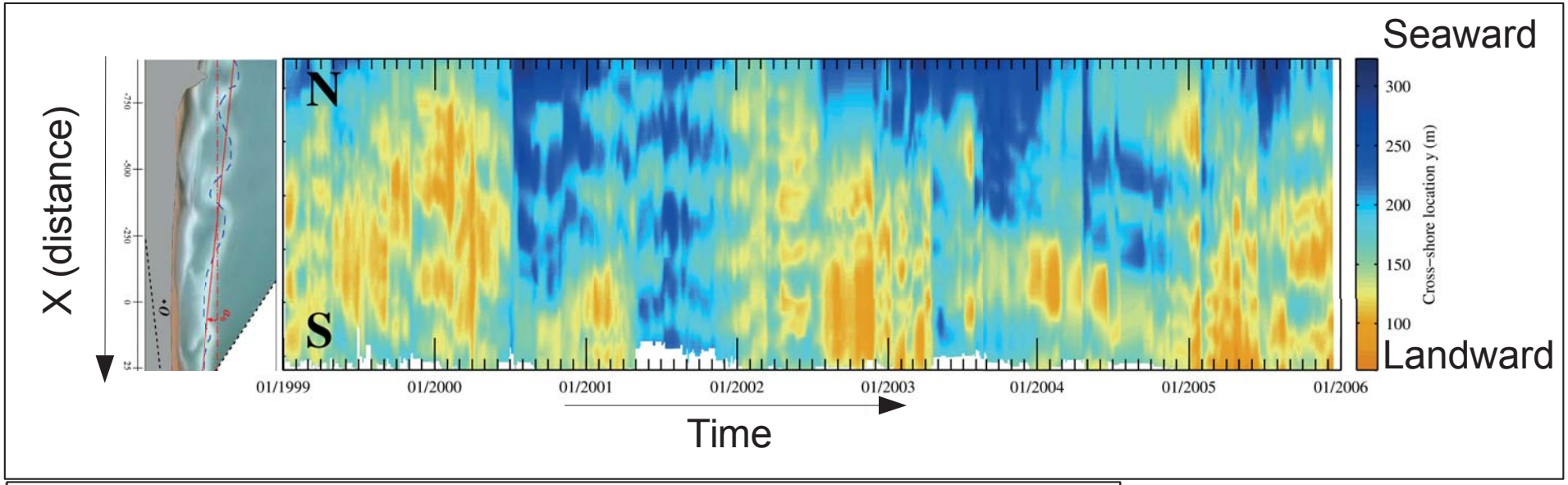
Tairua Beach area

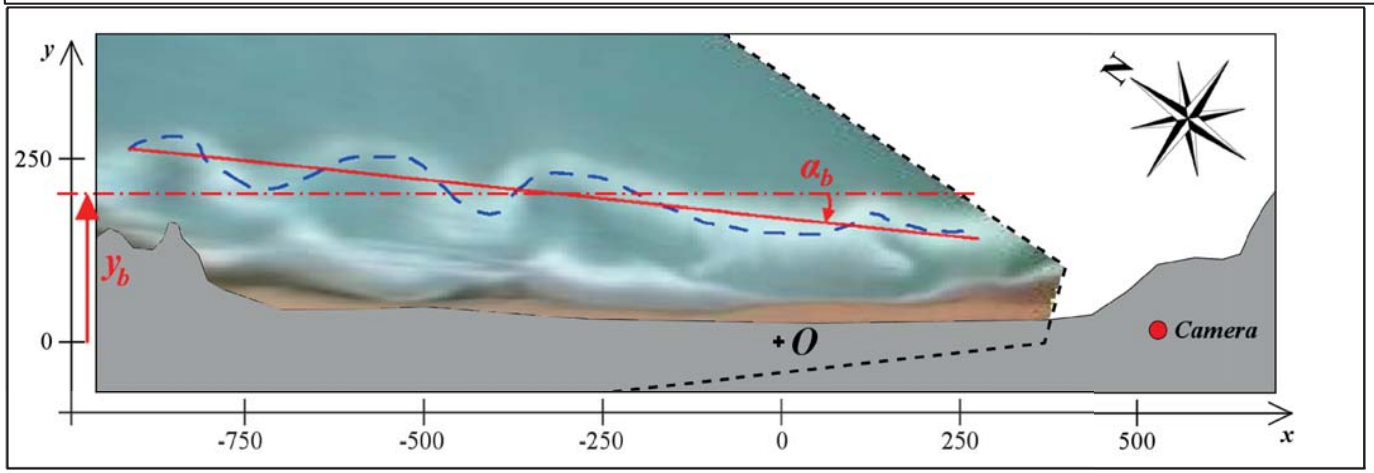
Camera location on Paku Hill, Tairua Beach



Constituting the barline dataset

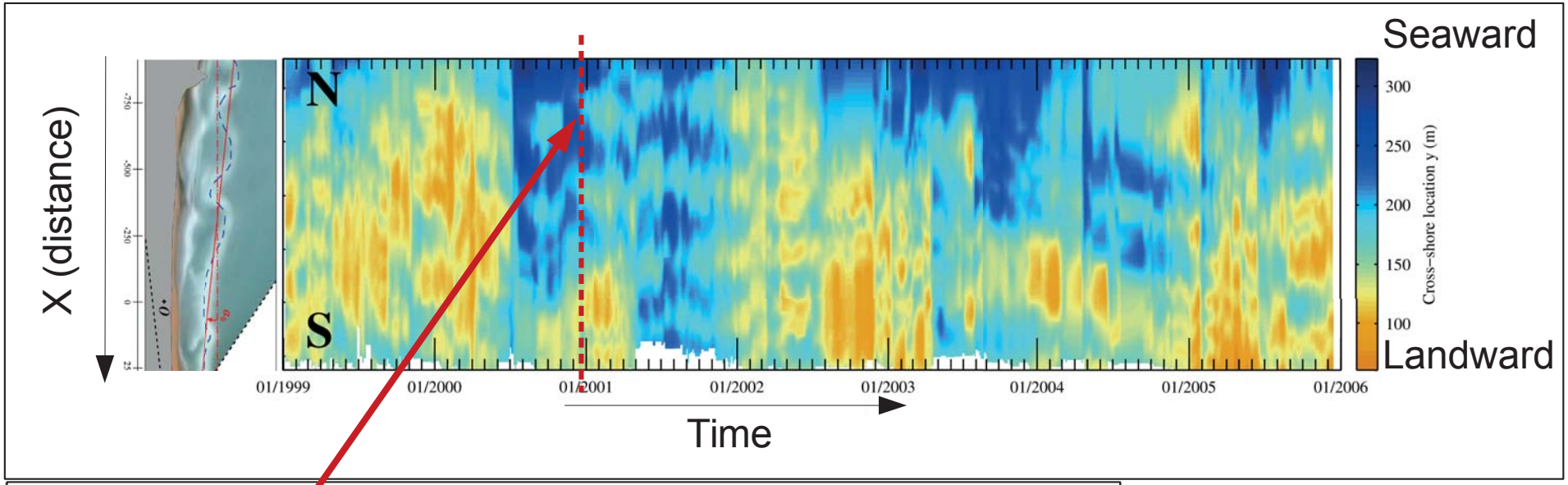
Collection of 7 years of barline position data (Lageweg et al., 2013)

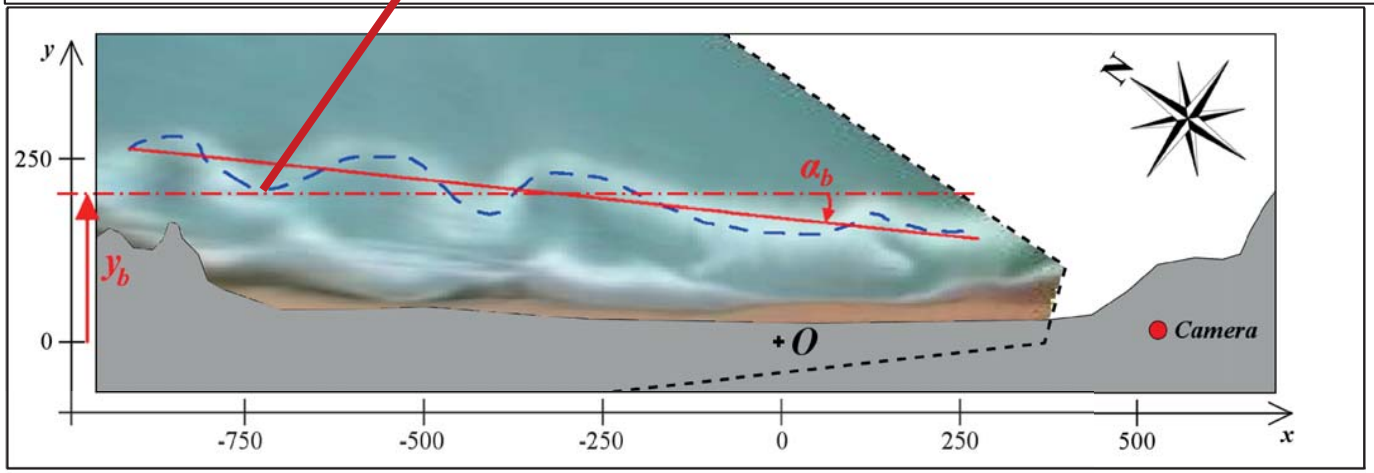




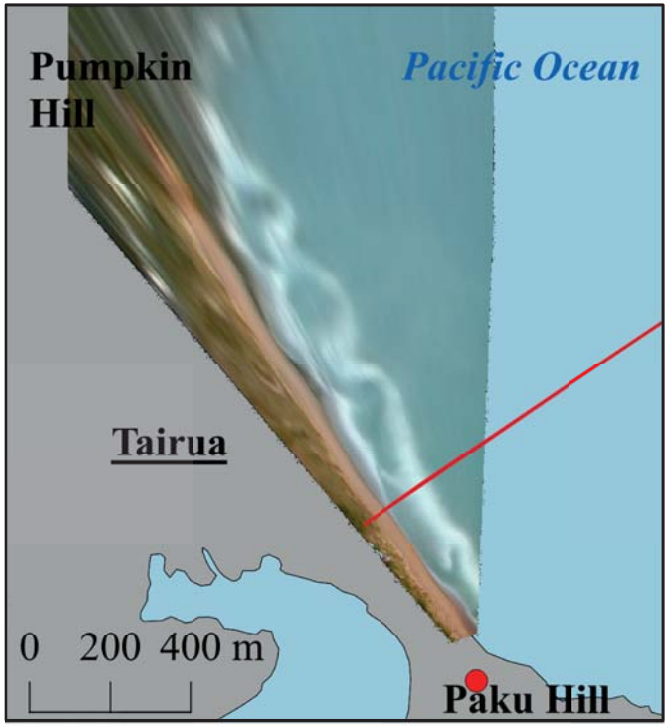
Constituting the barline dataset

Collection of 7 years of barline position data (Lageweg et al., 2013)



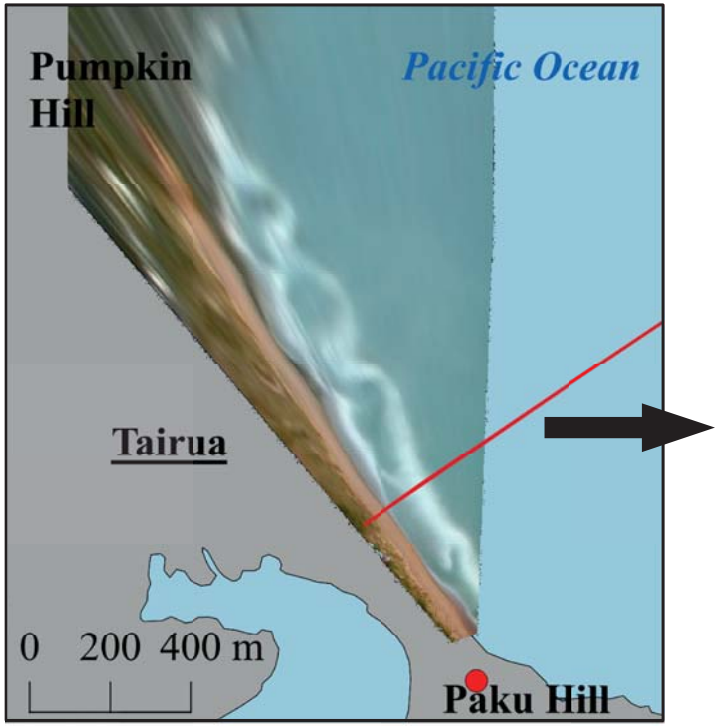


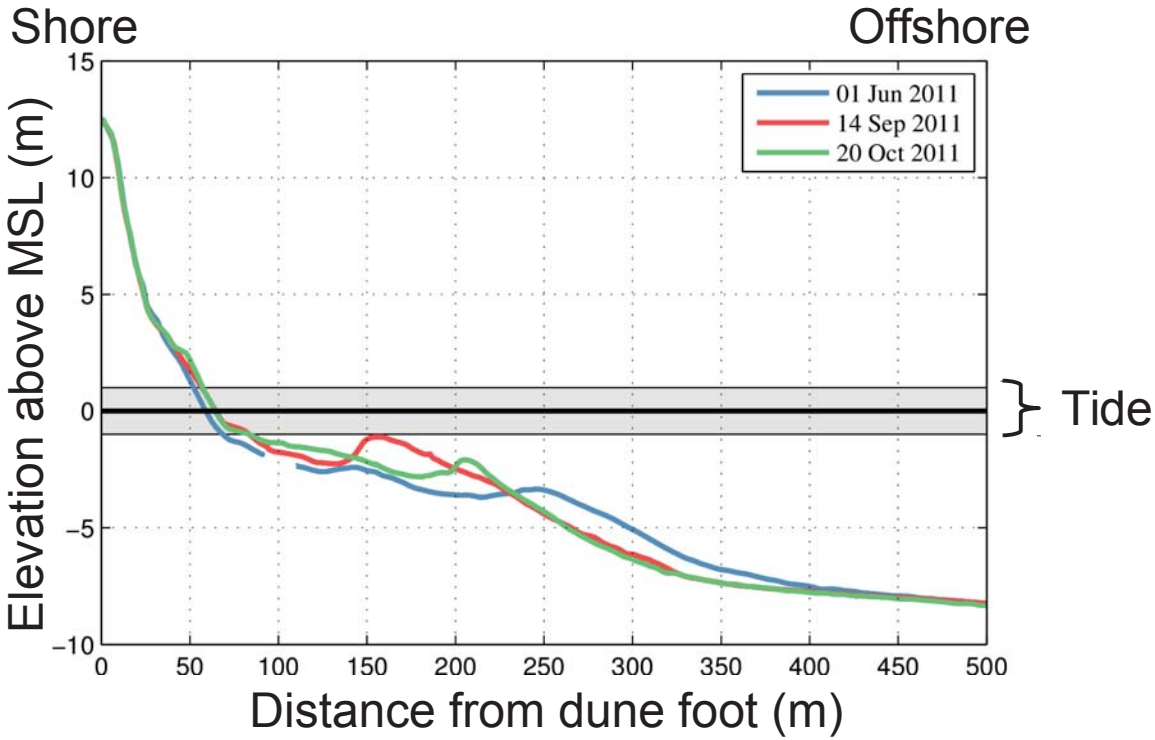
Nearshore sandbar migration



Chris Daly collecting bathymetric data, Tairua Beach.

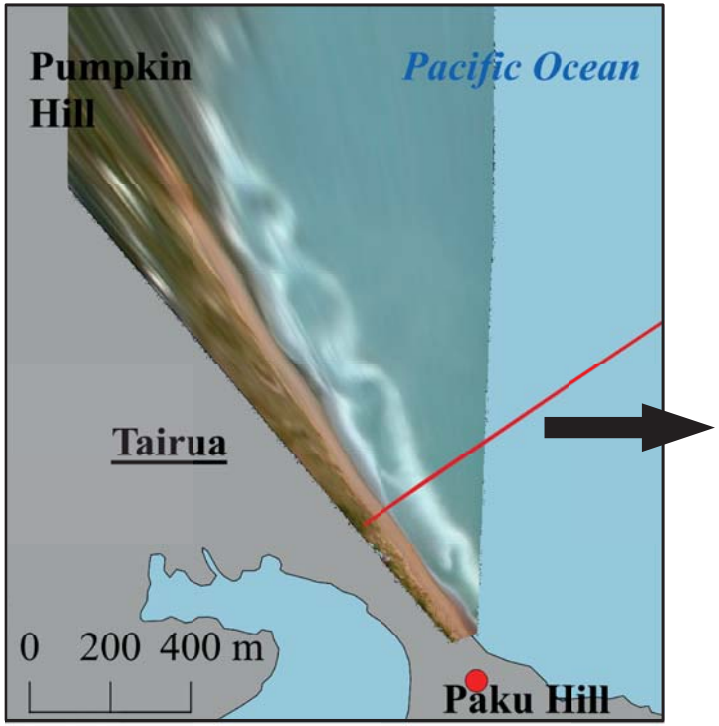
Nearshore sandbar migration



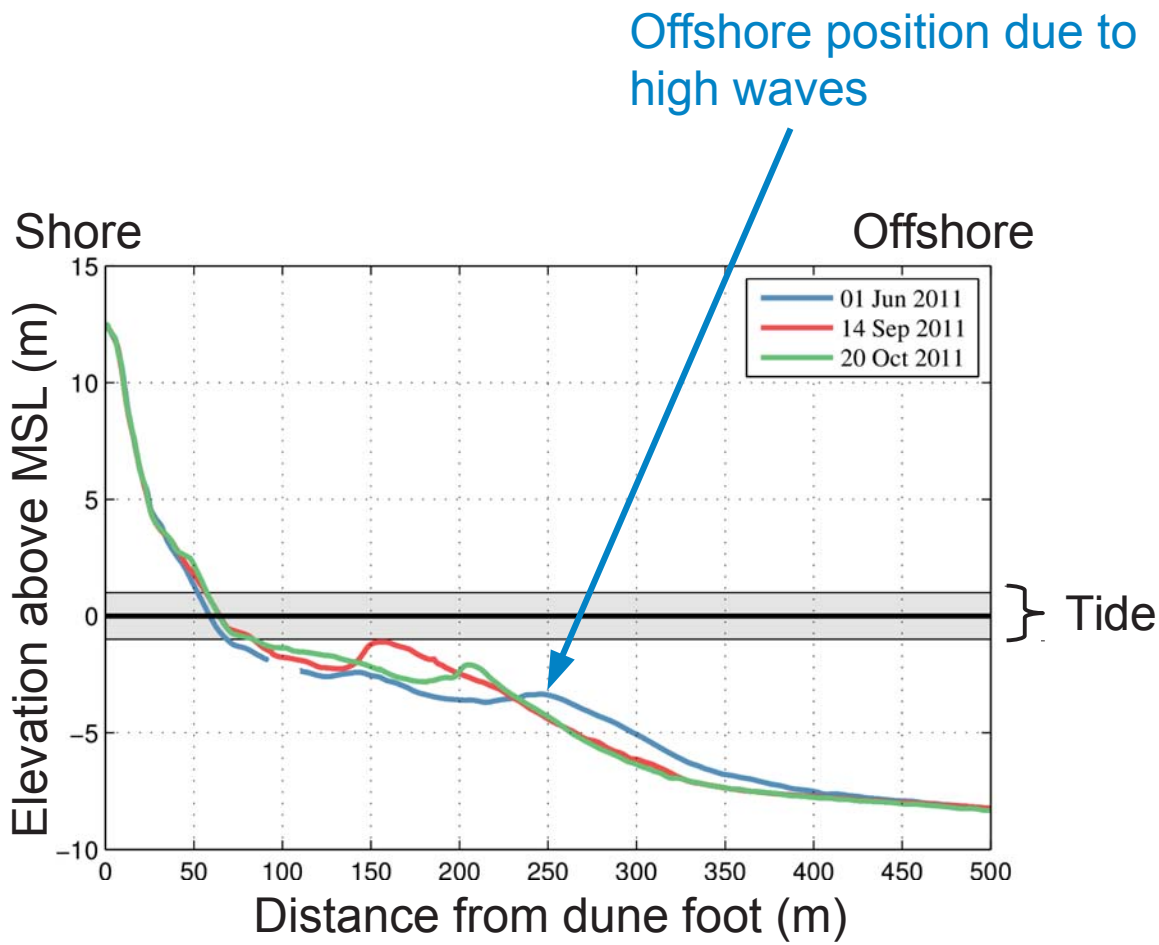


Chris Daly collecting bathymetric data, Tairua Beach.

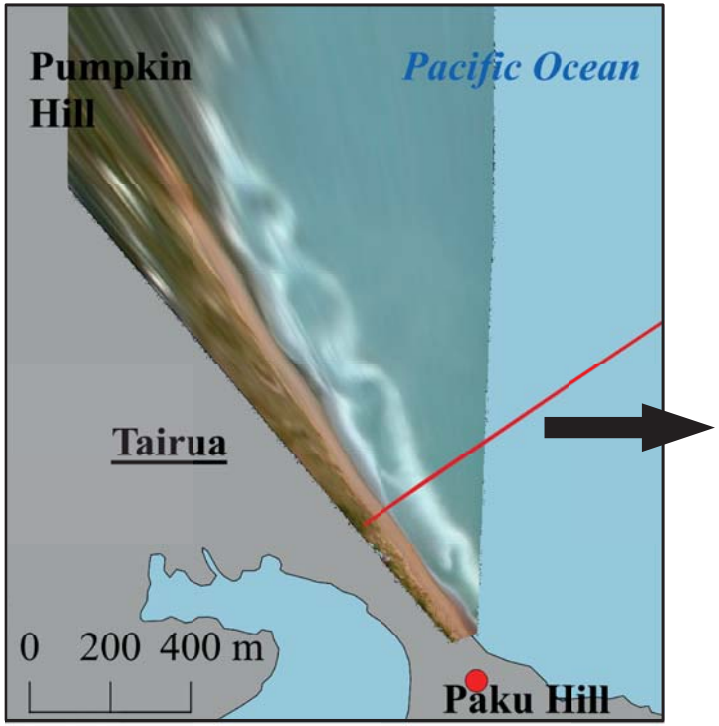
Nearshore sandbar migration



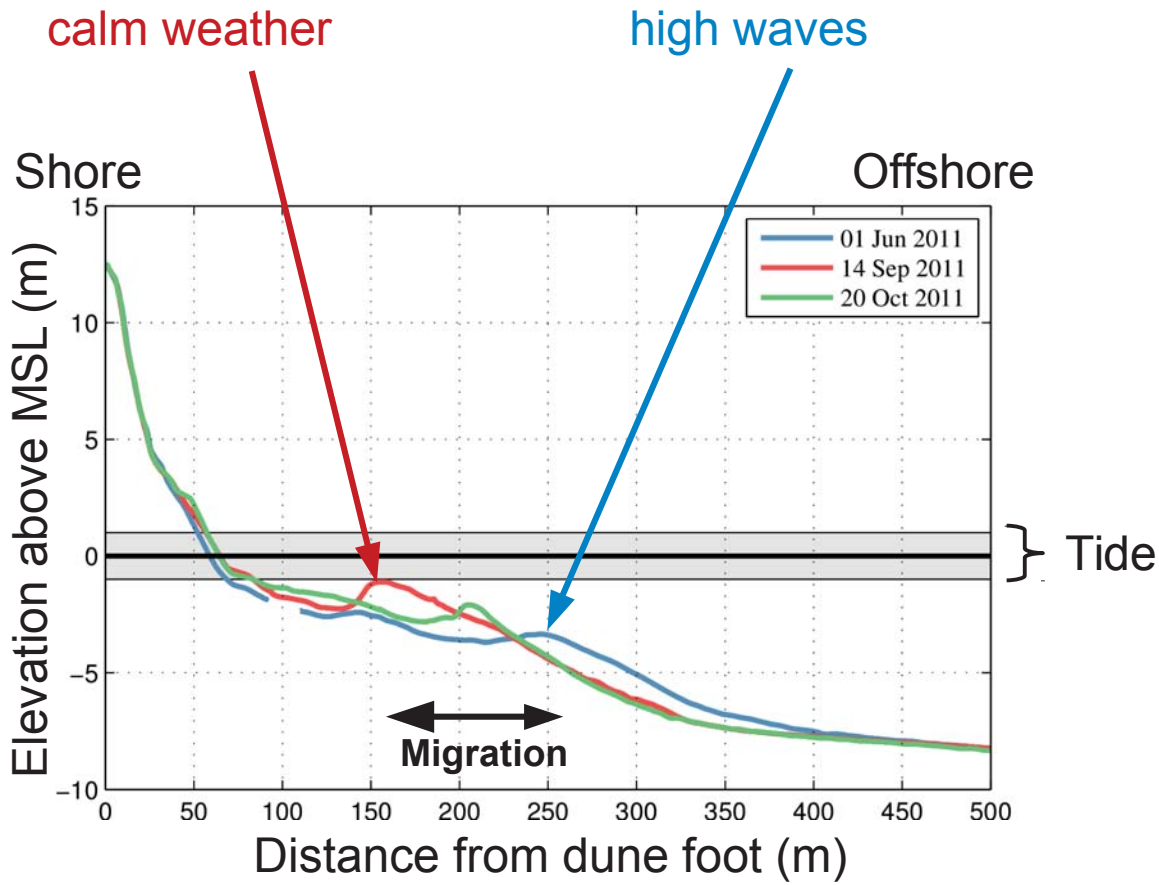
Chris Daly collecting bathymetric data, Tairua Beach.



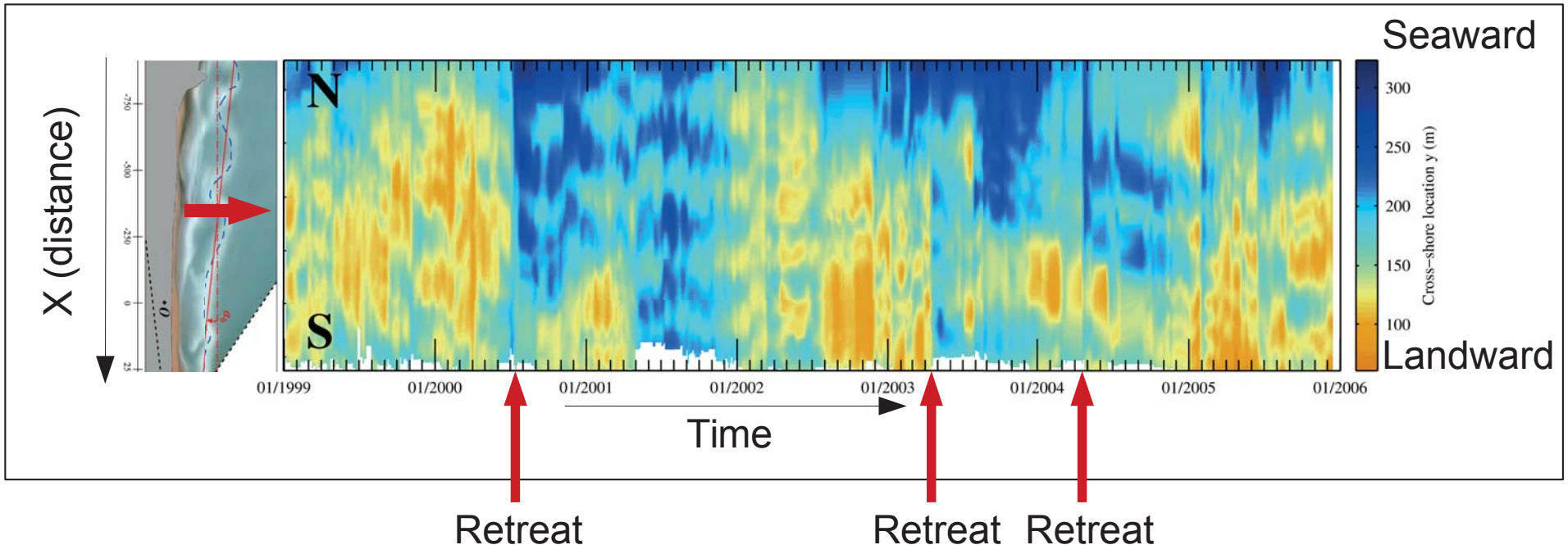
Nearshore sandbar migration



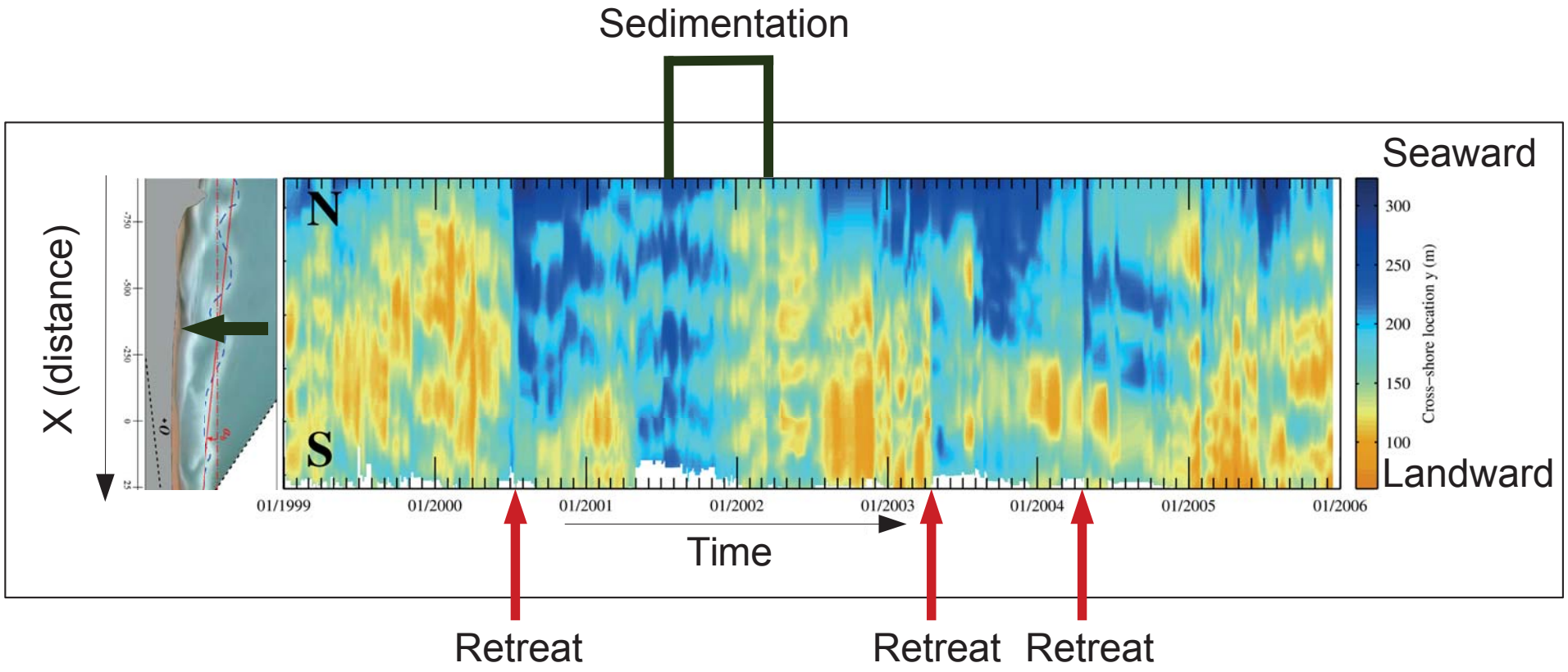
Chris Daly collecting bathymetric data, Tairua Beach.



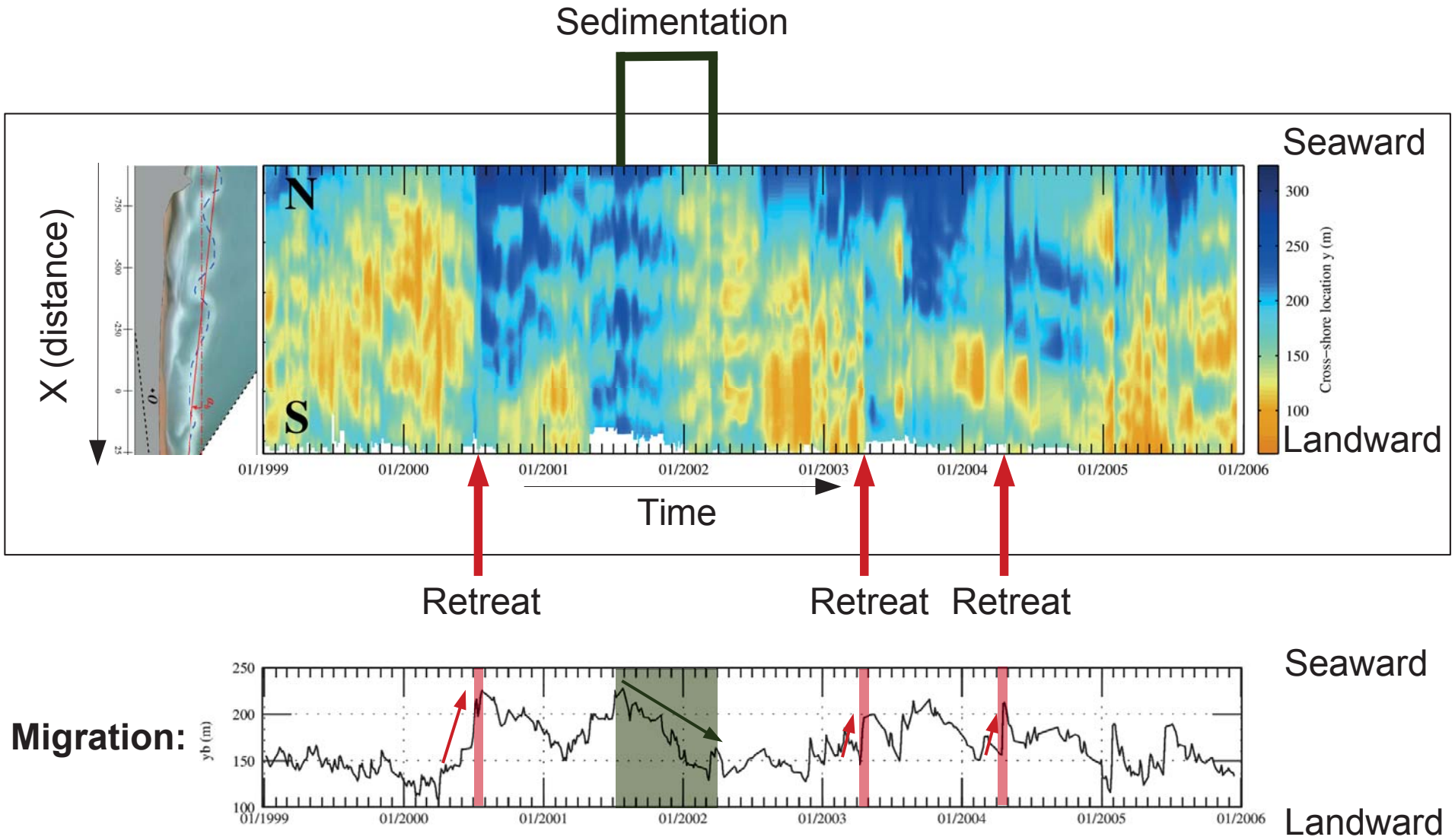
Nearshore sandbar migration



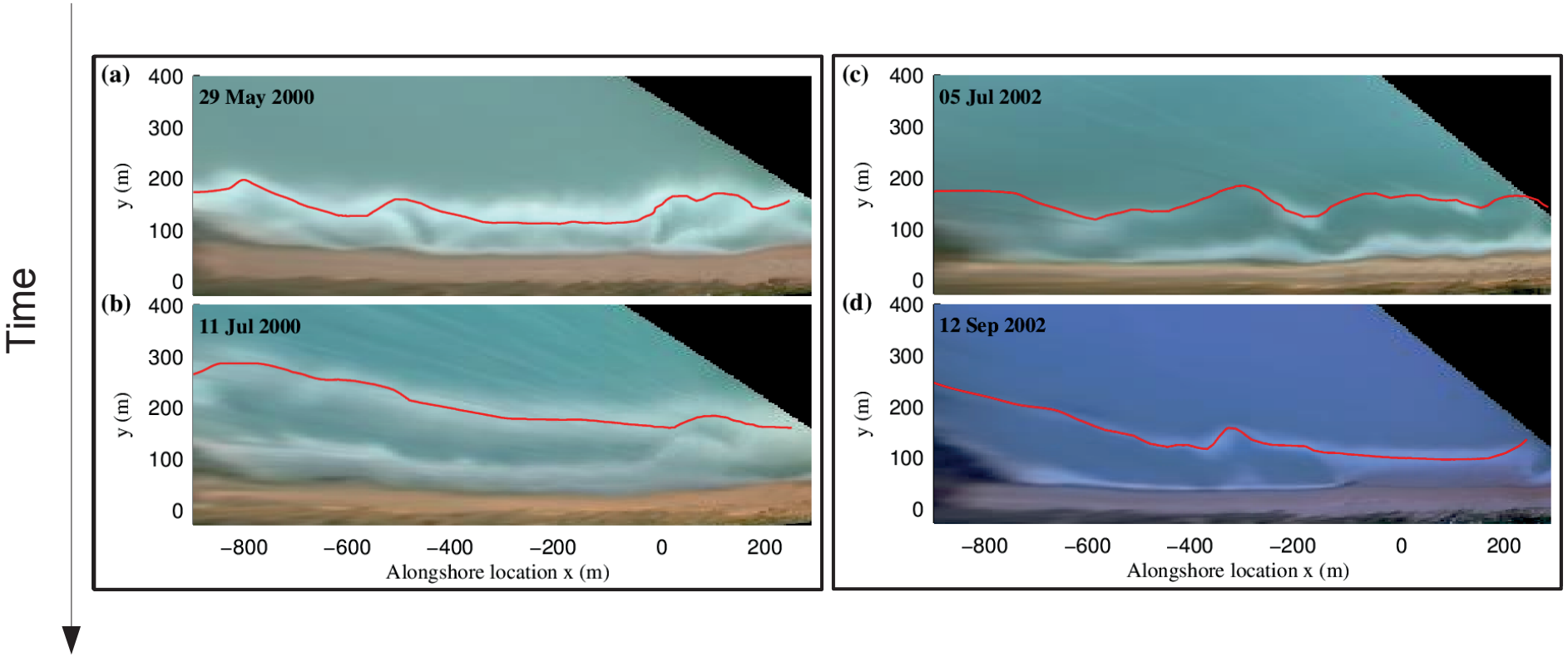
Nearshore sandbar migration



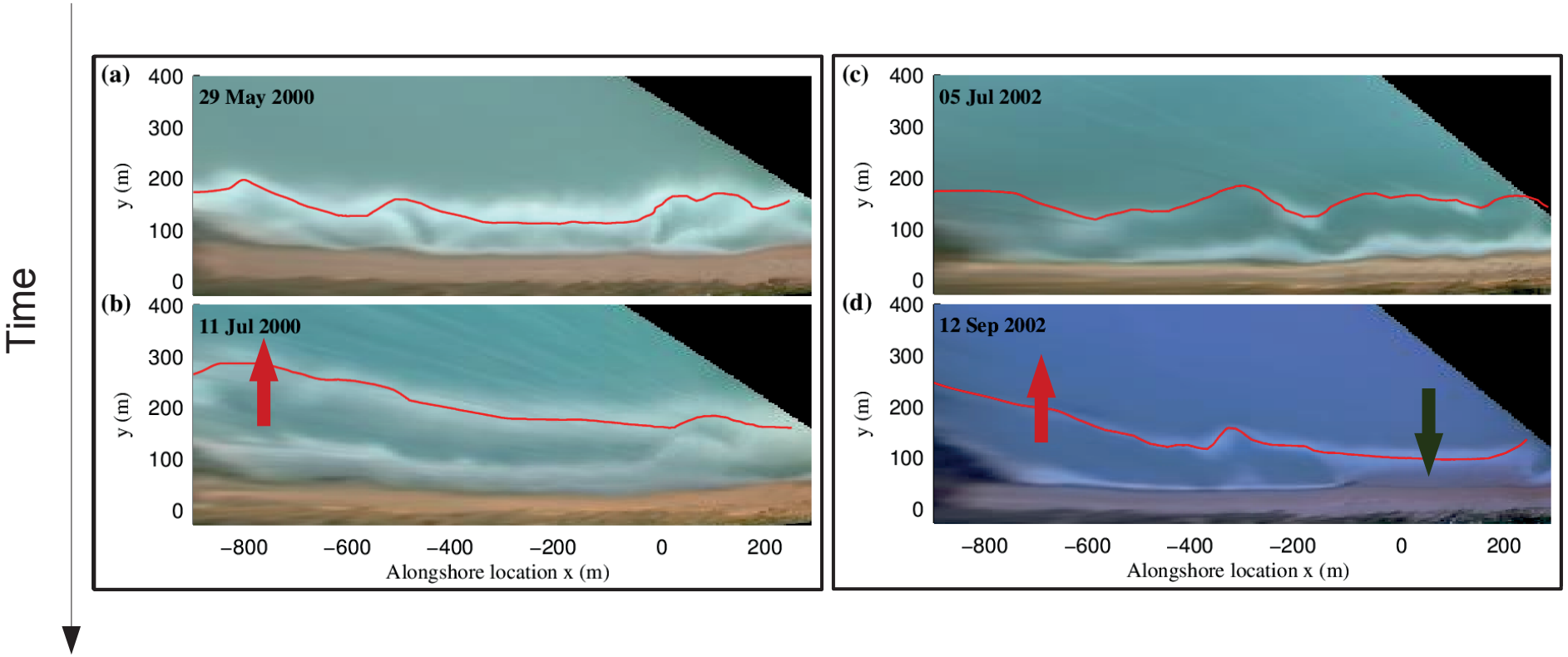
Nearshore sandbar migration



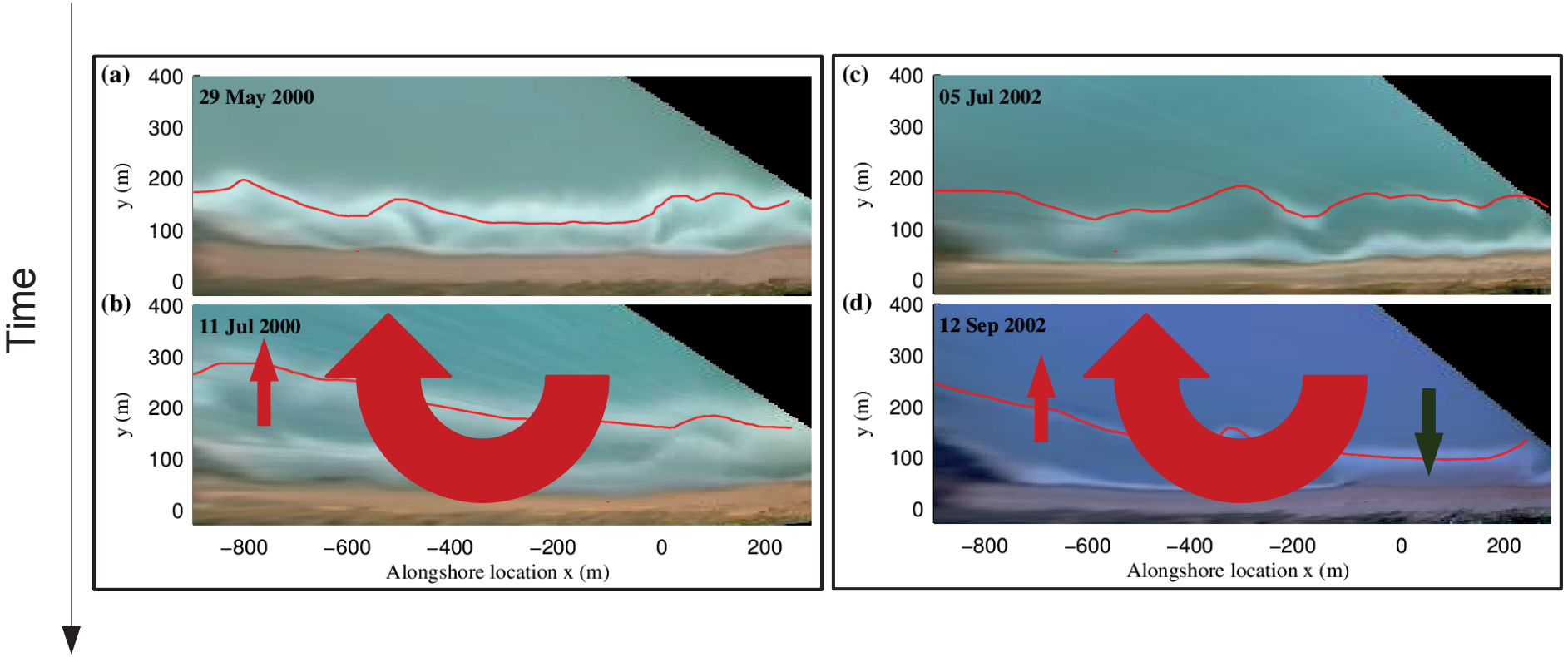
Nearshore sandbar rotation



Nearshore sandbar rotation

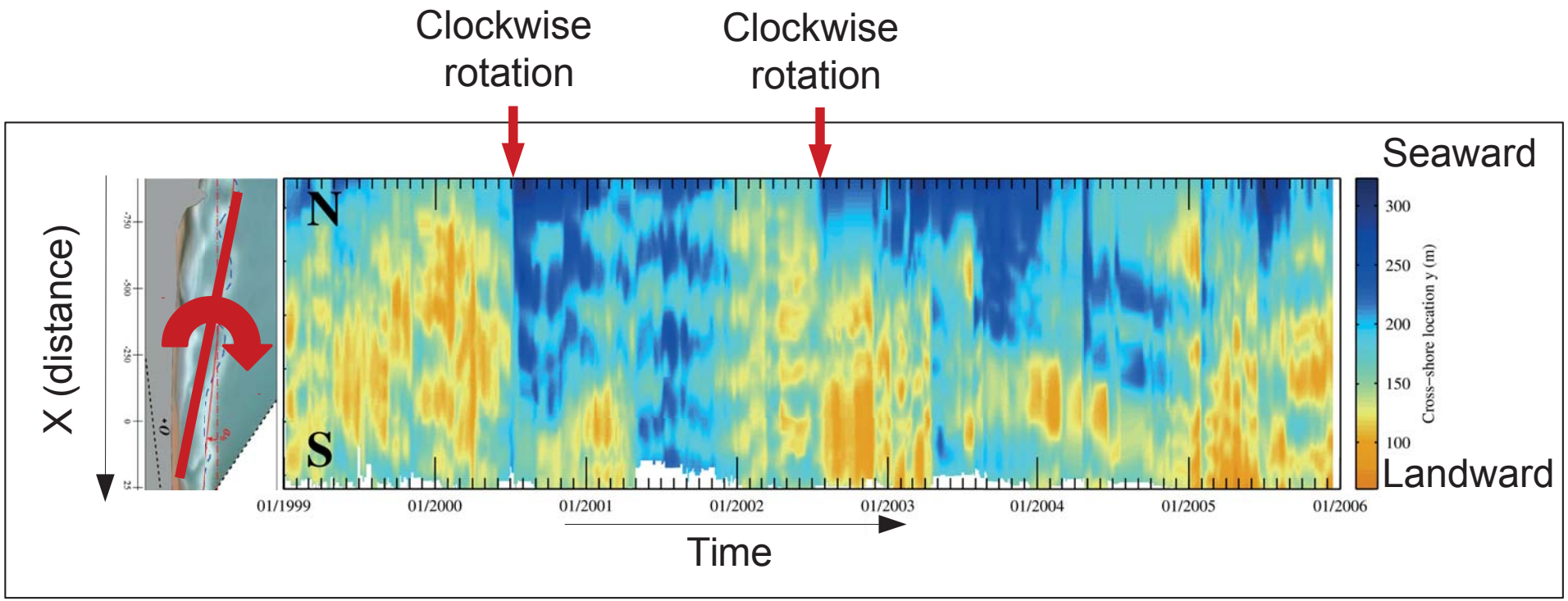


Nearshore sandbar rotation

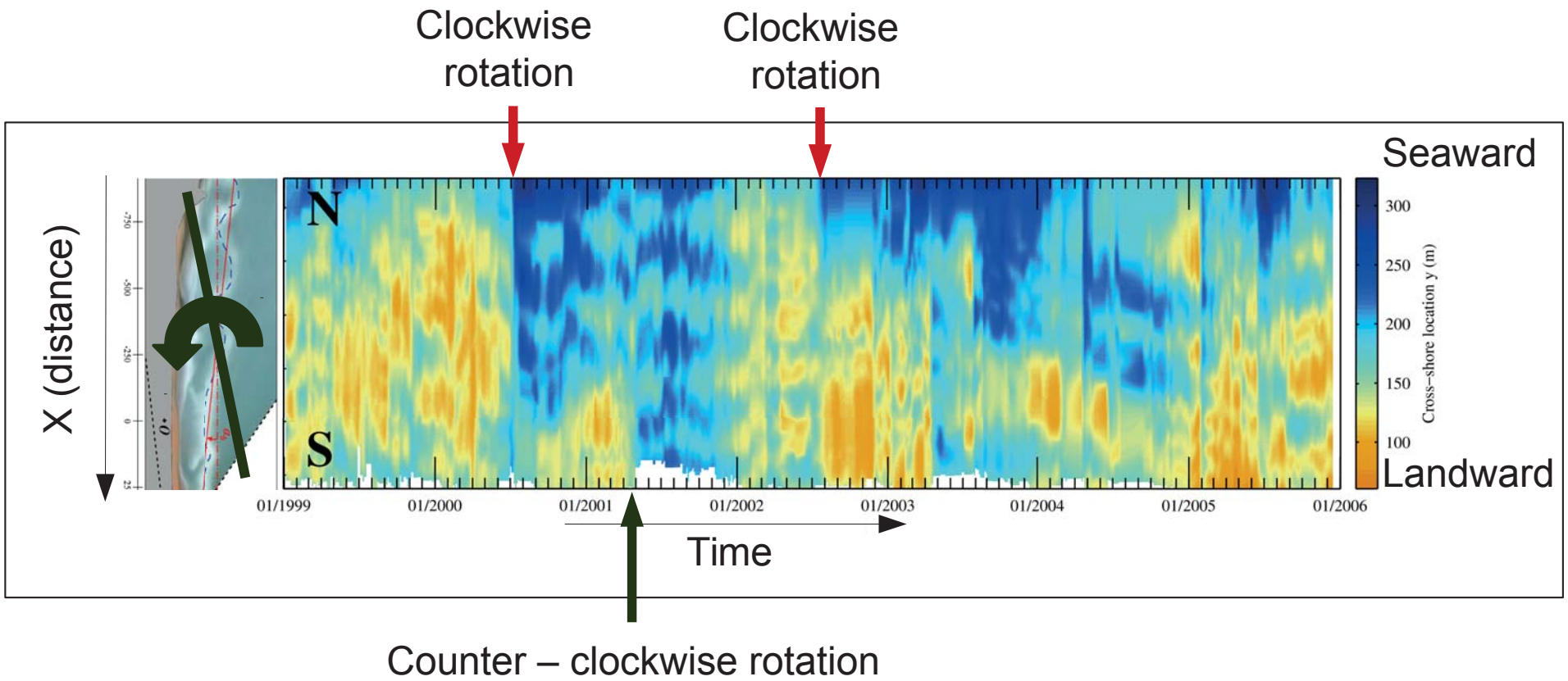


→ Clockwise rotation

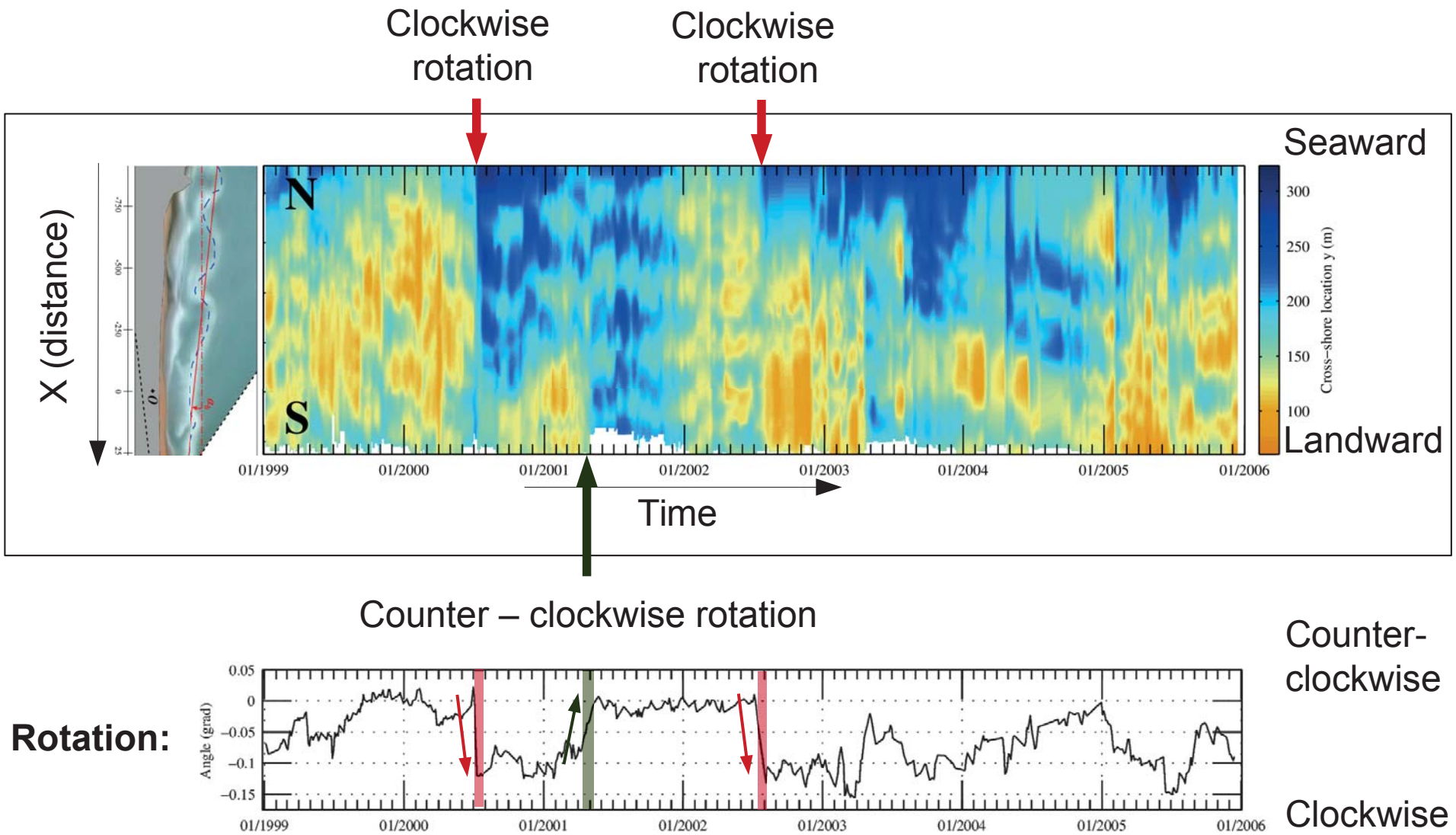
Nearshore sandbar migration



Nearshore sandbar rotation

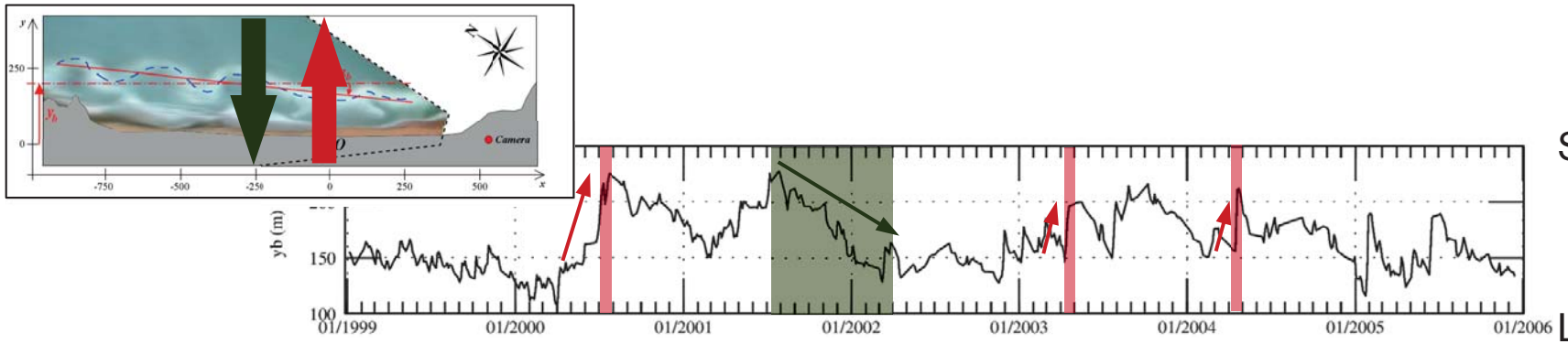


Nearshore sandbar rotation



Quantified barline migration and rotation

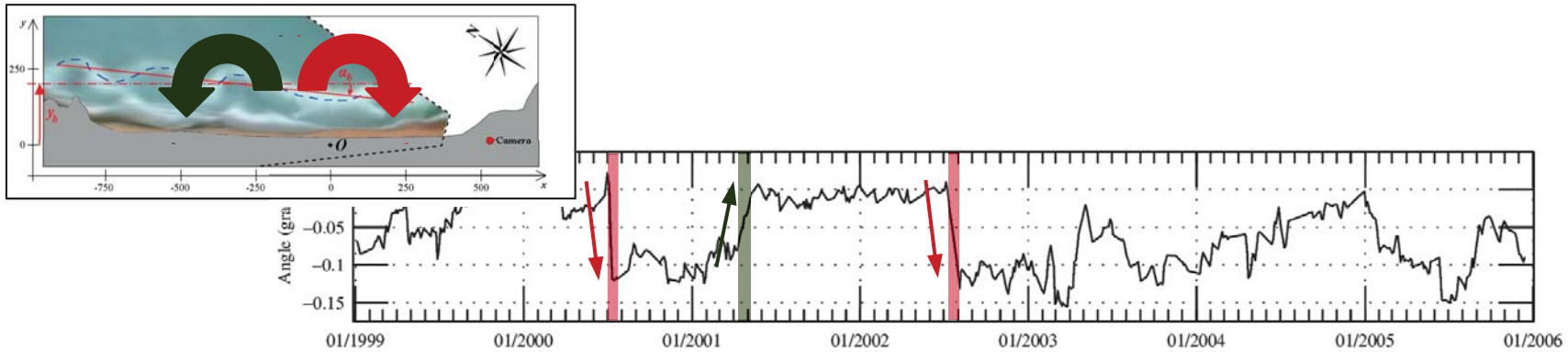
Migration:



Seaward

Landward

Rotation:



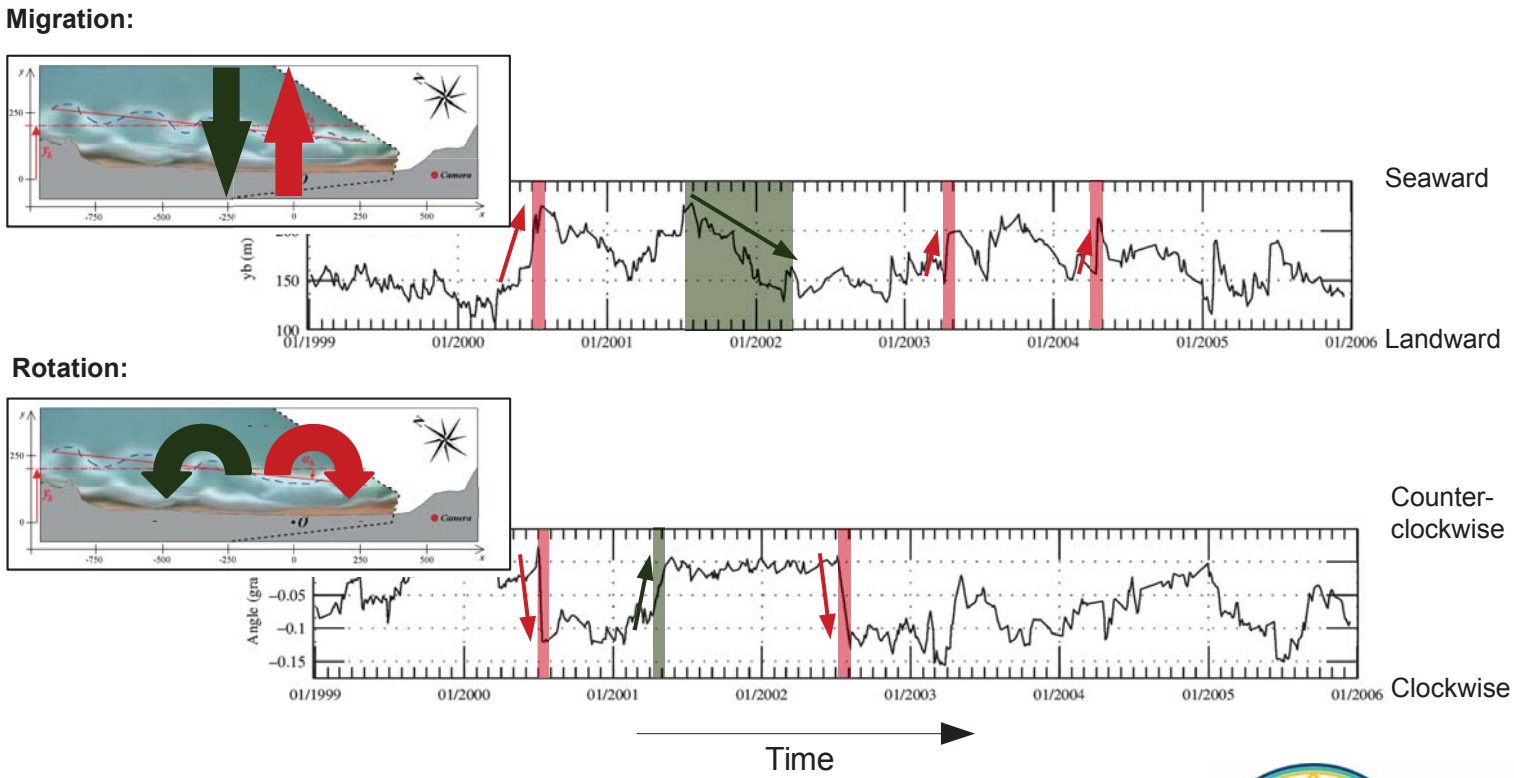
Counter-clockwise

Clockwise

Time

Research question

What hydrodynamic conditions are controlling the migration and rotation of the nearshore sandbar of a single-barred embayed sandy beach ?

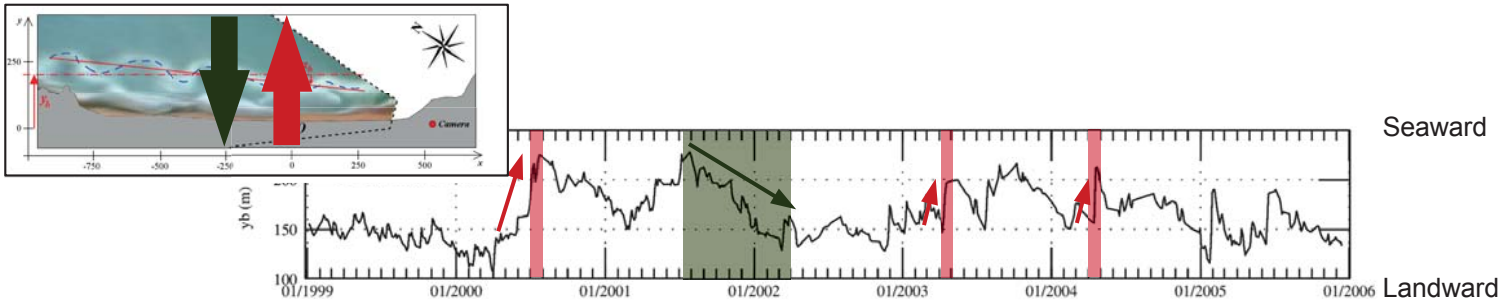


Research question

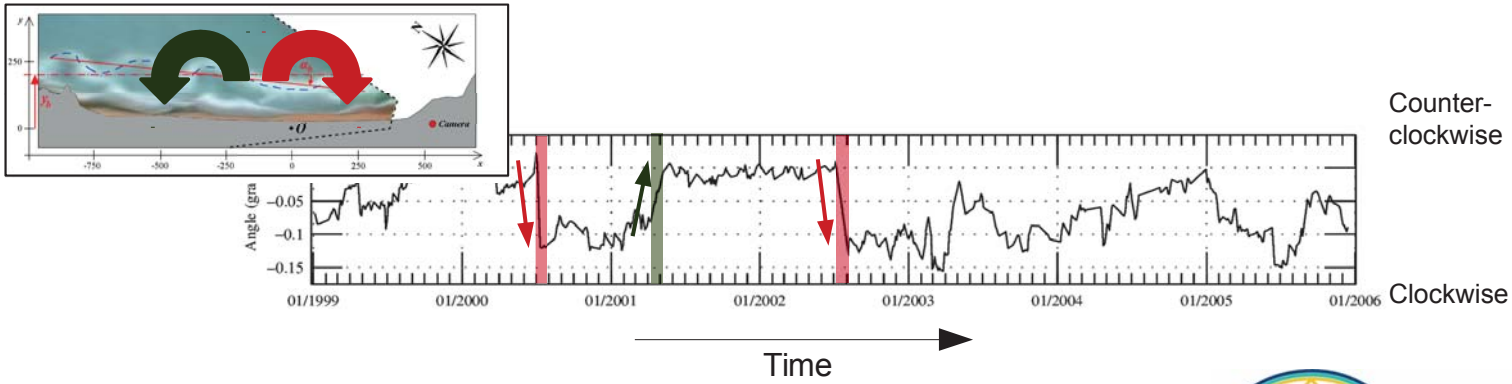
What hydrodynamic conditions are controlling the migration and rotation of the nearshore sandbar of a single-barred embayed sandy beach ?

Hydrodynamic conditions → Waves (micro-tidal environment)

Migration:

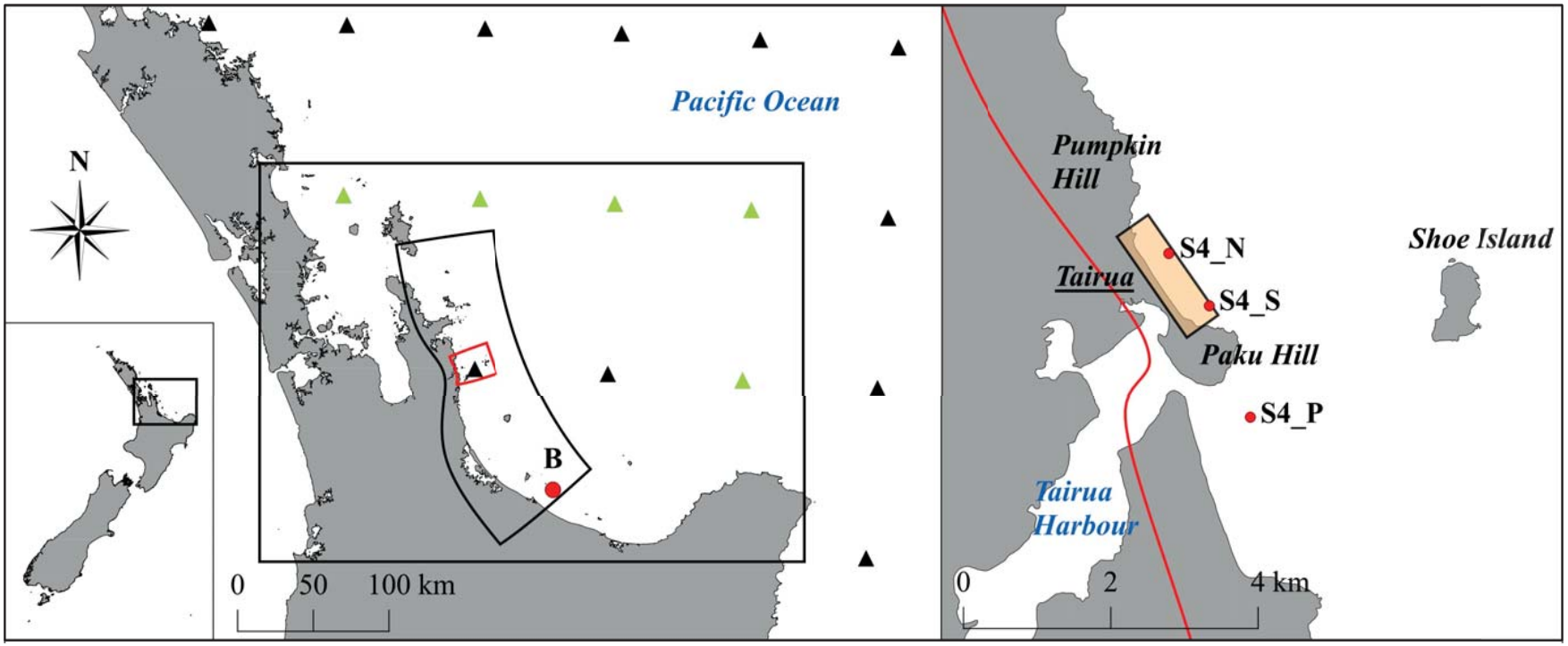


Rotation:



Wave modelling

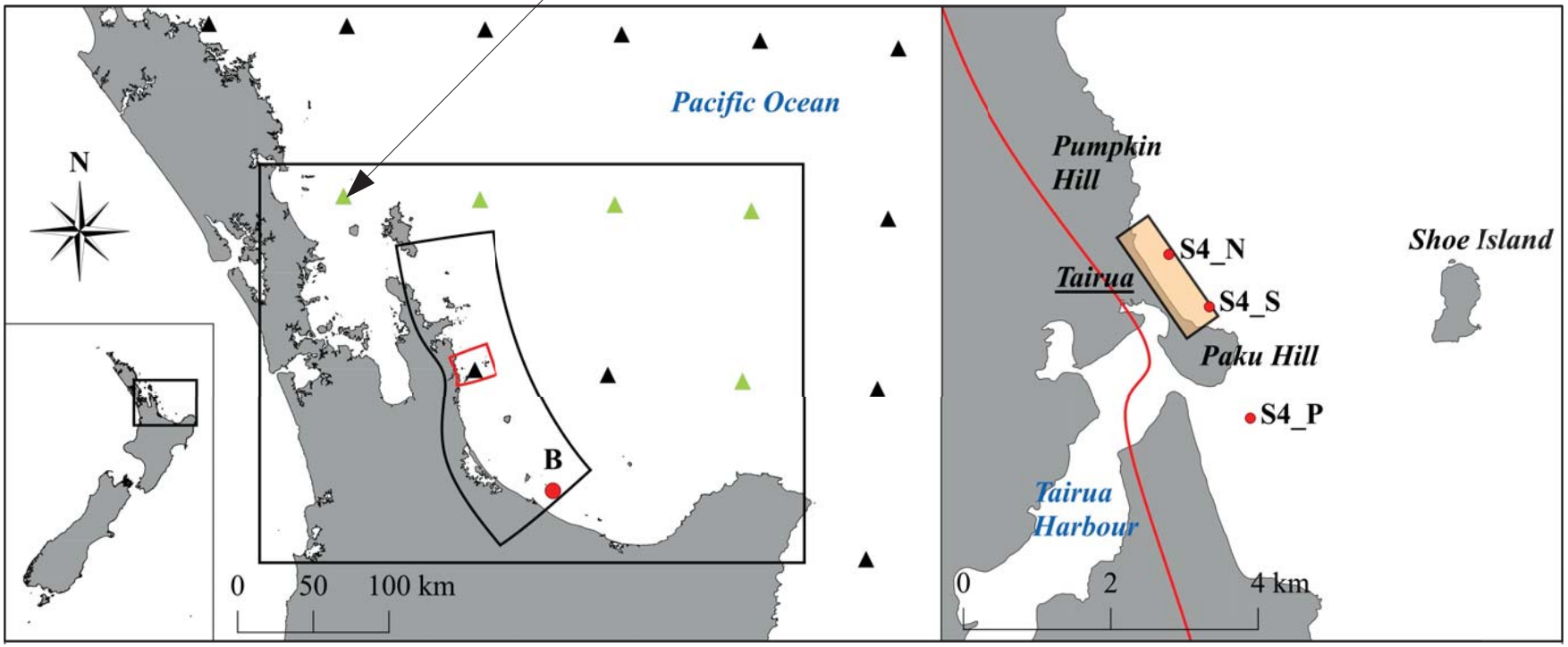
Hydrodynamic conditions → Waves (micro-tidal environment)



Wave modelling

Hydrodynamic conditions → Waves (micro-tidal environment)

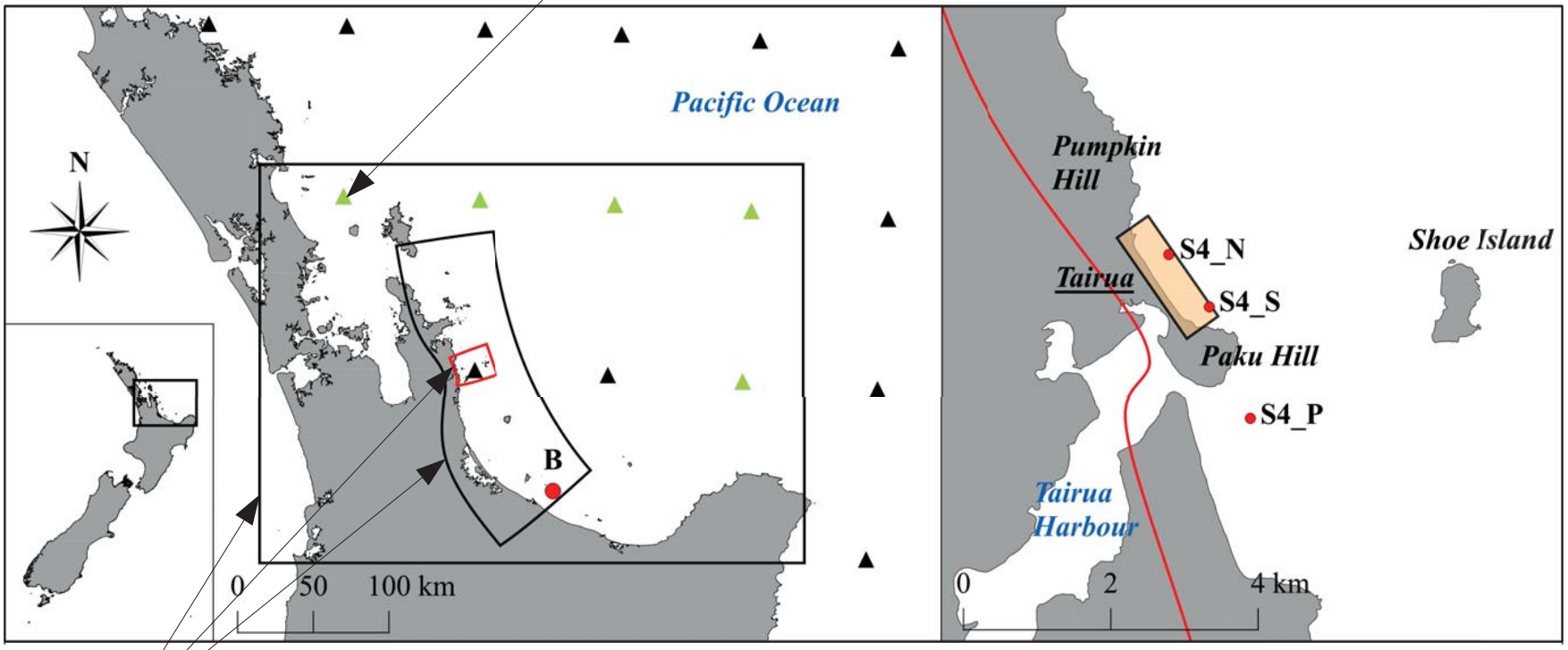
Global wave hindcasts NOAA
→ Green = used in the model



Wave modelling

Hydrodynamic conditions → Waves (micro-tidal environment)

Global wave hindcasts NOAA
→ Green = used in the model

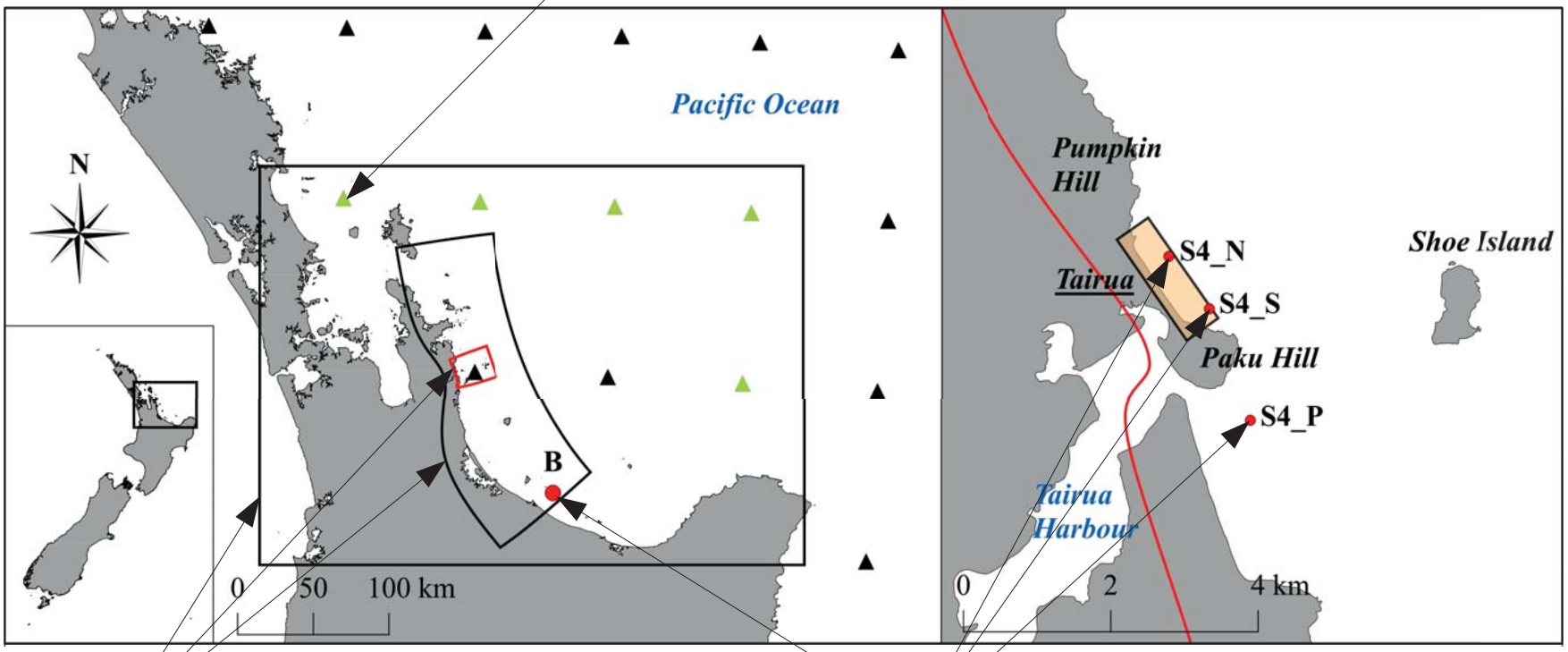


Three nested grids

Wave modelling

Hydrodynamic conditions → Waves (micro-tidal environment)

Global wave hindcasts NOAA
→ Green = used in the model

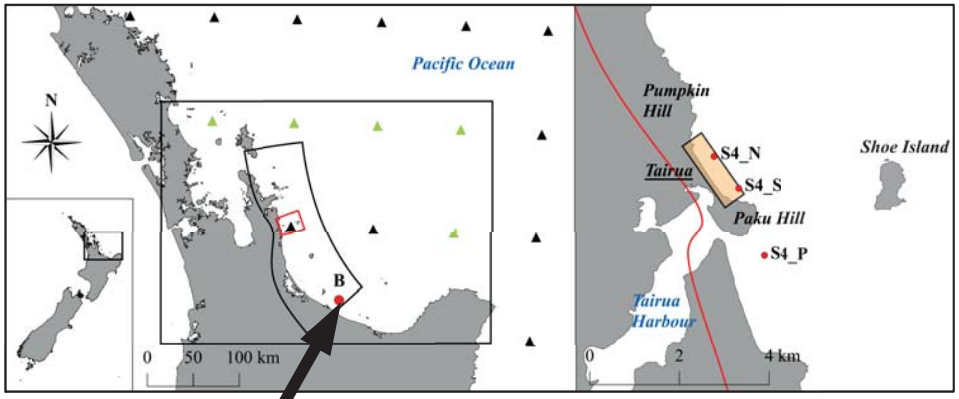


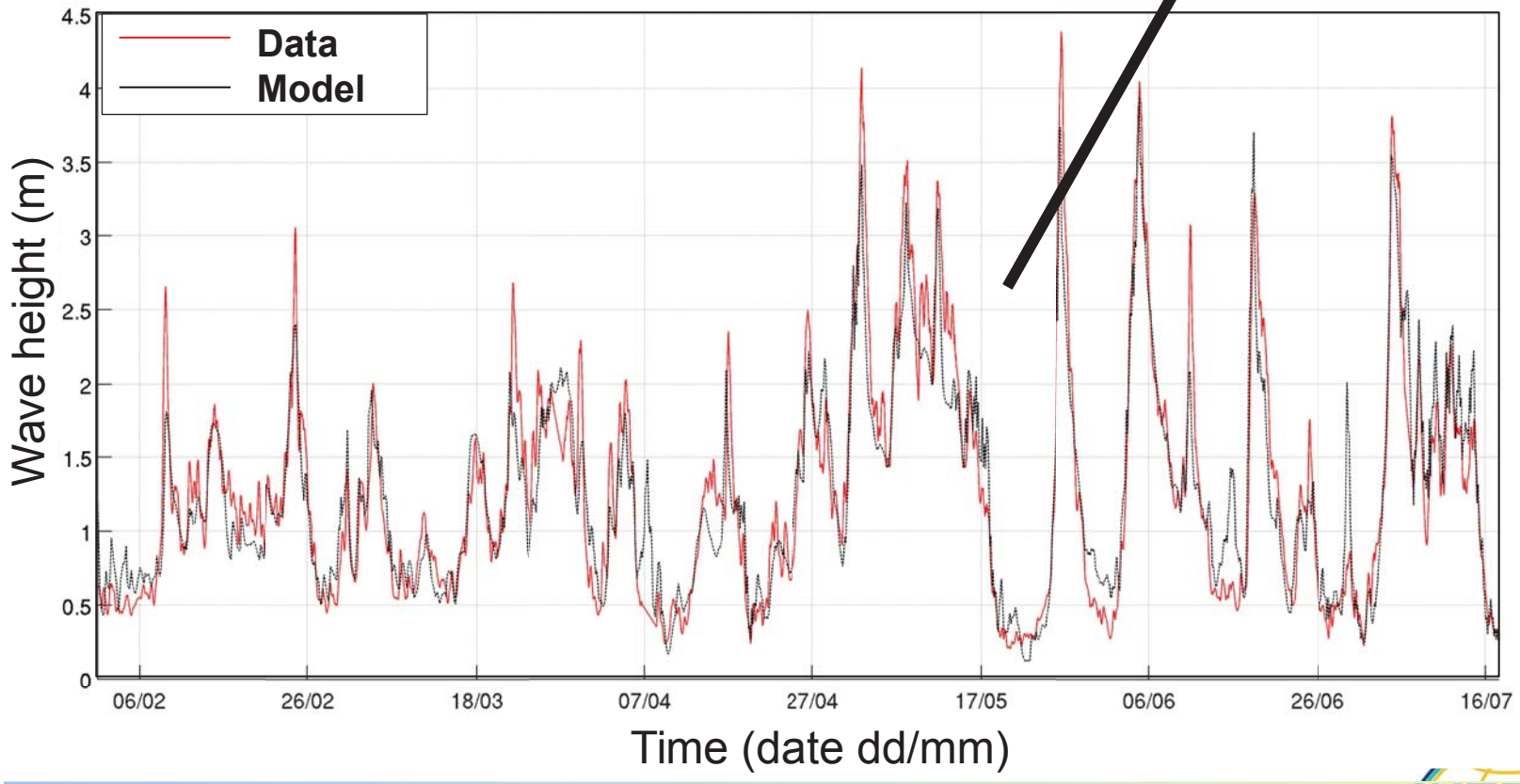
Three nested grids

Measurements

Wave modelling: deep water

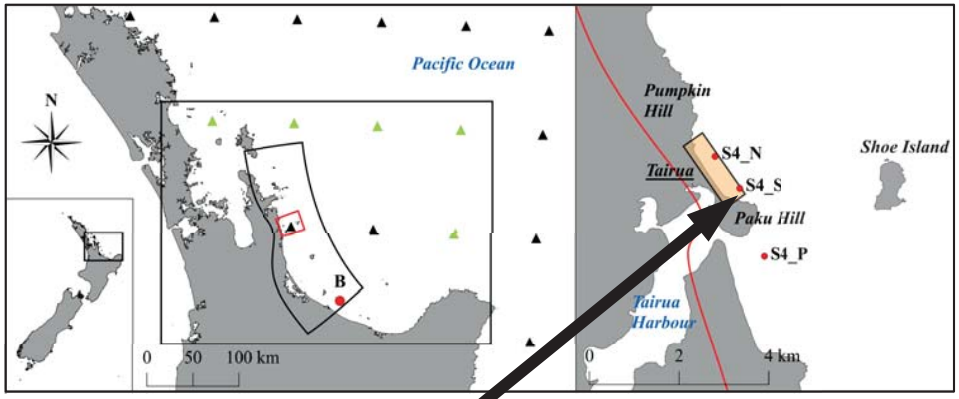
Comparison of significant wave height 13 km offshore Pukehina Beach (Data from Bay of Plenty Regional Council).

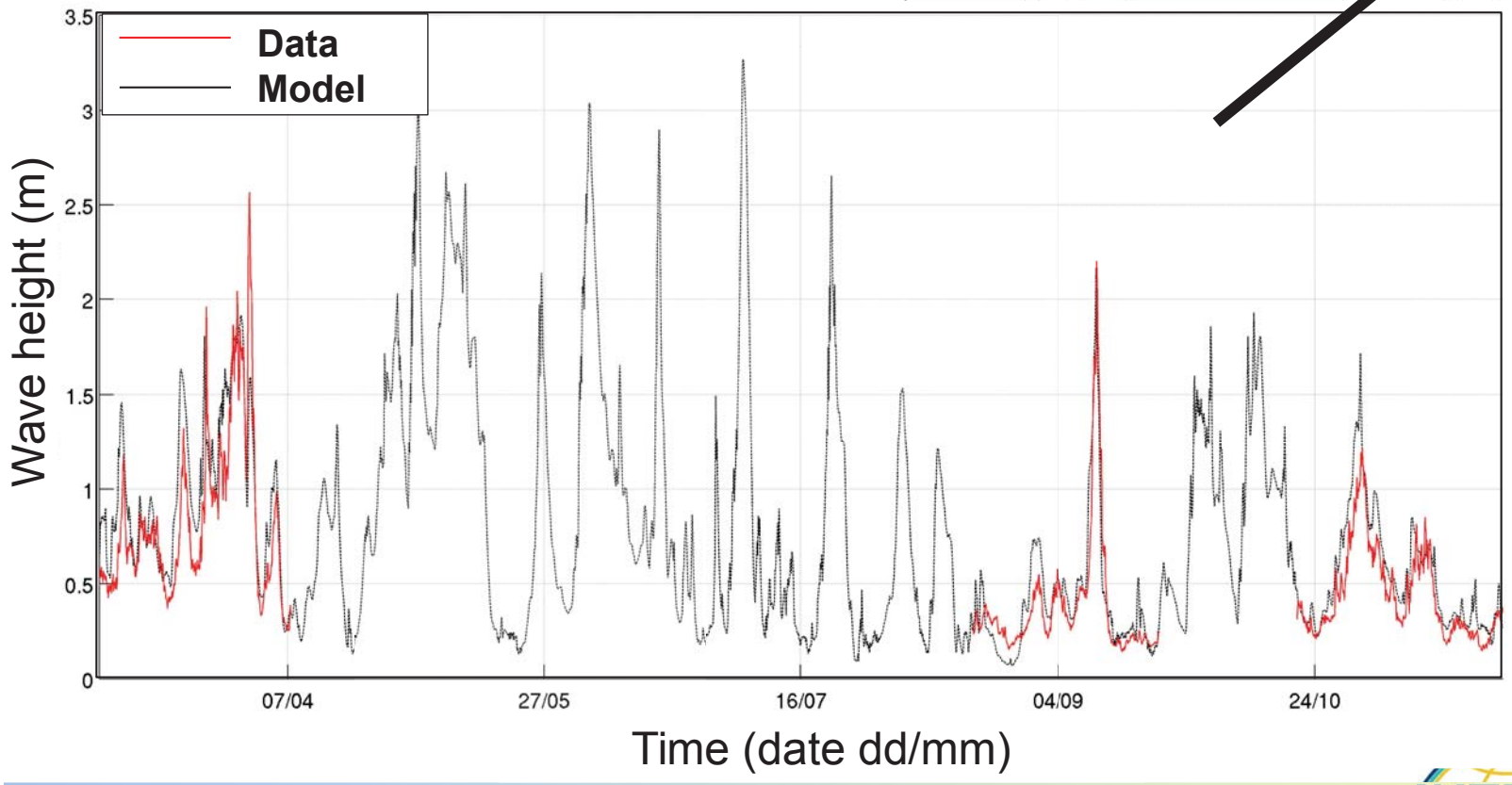




Wave modelling: shallow water

Comparison of significant wave height at Tairua (data from Christopher Daly, IC1_I).





Equilibrium wave energy

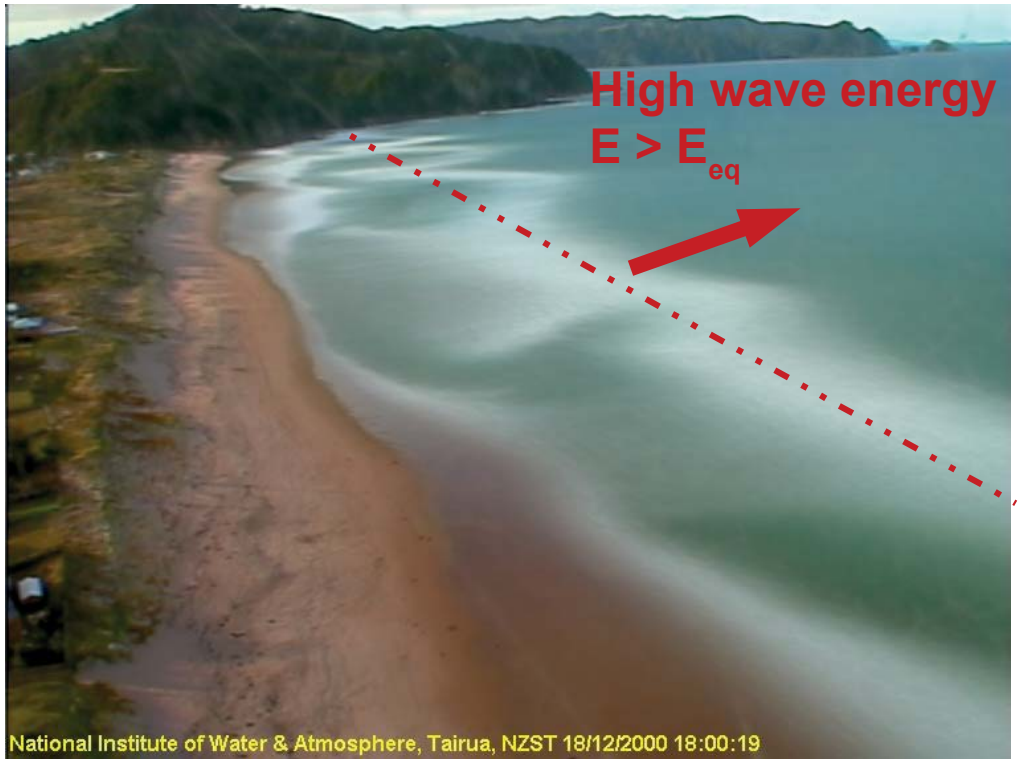
Concept of equilibrium energy validated for shoreline.

Equilibrium energy E_{eq}

If $E = E_{eq}$, stable barline position

Equilibrium wave energy

Concept of equilibrium energy validated for shoreline.

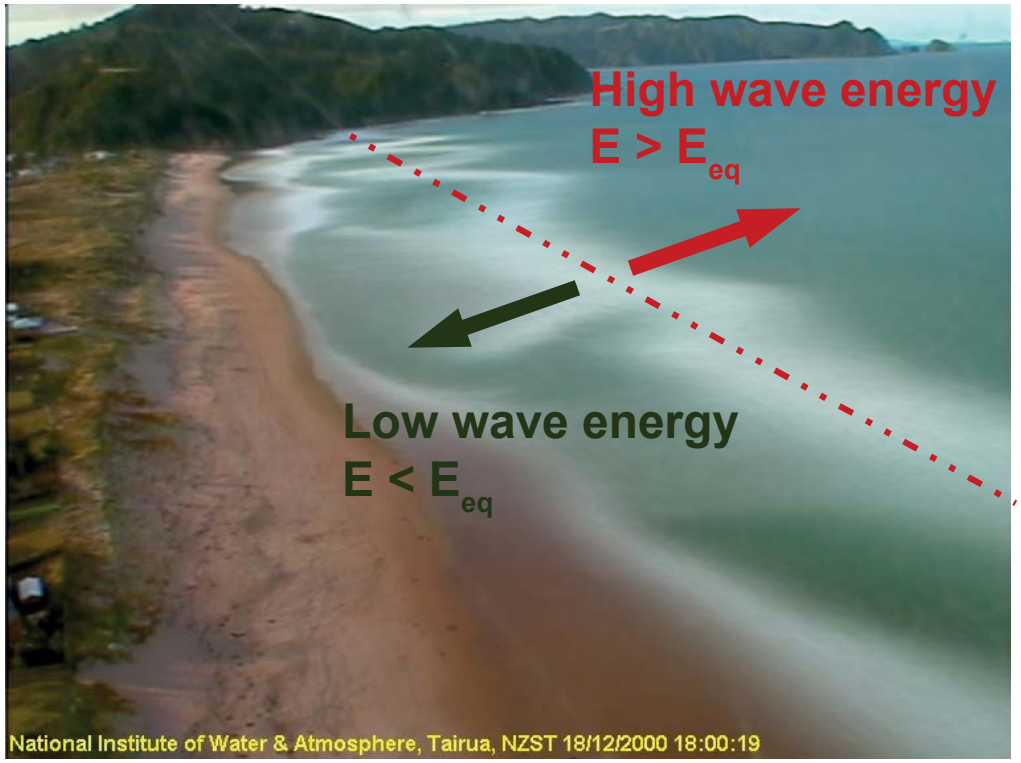


Equilibrium energy E_{eq}

If $E = E_{eq}$, stable barline position

Equilibrium wave energy

Concept of equilibrium energy validated for shoreline.

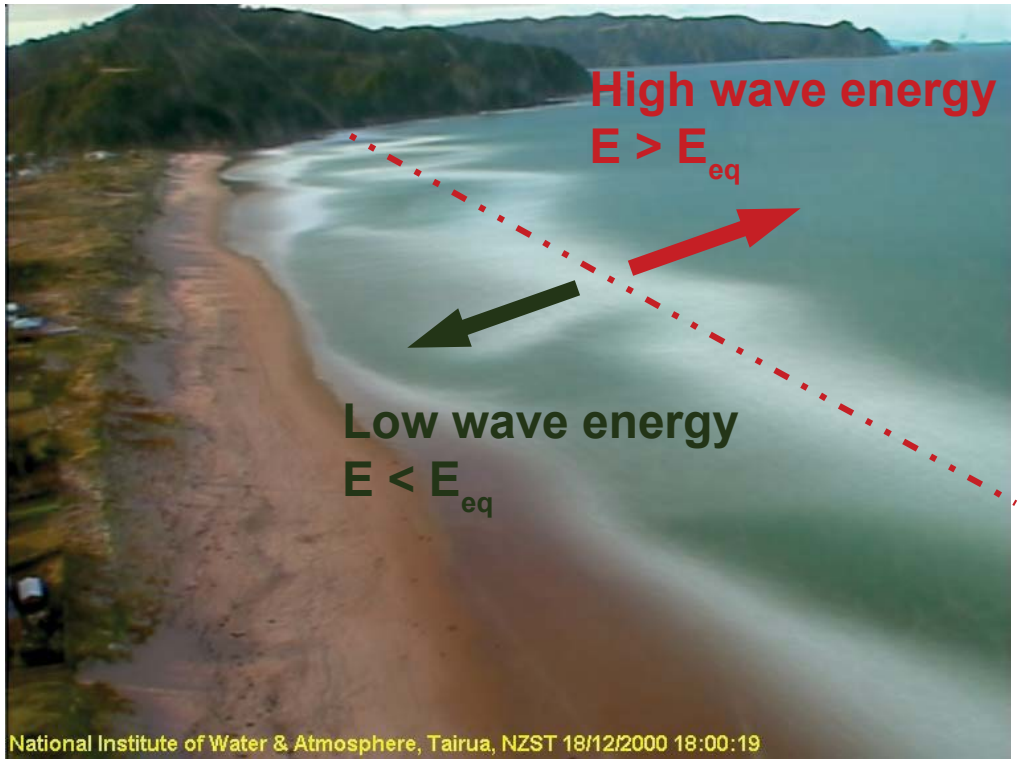


Equilibrium energy E_{eq}

If $E = E_{eq}$, stable barline position

Equilibrium wave energy

Concept of equilibrium energy validated for shoreline.



Equilibrium energy E_{eq}

If $E = E_{eq}$, stable barline position

In case of the barline, *morphodynamic factor* required

→ Activation of the barline when waves break over its crest

Sandbar migration modelling

Model:

Equilibrium energy = **A** x barline cross-shore position + **B**

$$E_{eq} = Ay_b + B$$

Sandbar migration modelling

Model:

Equilibrium energy = **A** x barline cross-shore position + **B**

Bar migration rate = **C** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} E_{eq} = A y_b + B \\ \dfrac{\partial y_b}{\partial t} = C\,(E - E_{eq})\,\sqrt{E} \end{cases}$$

Sandbar migration modelling

Model:

Equilibrium energy = **A** x barline cross-shore position + **B**

Bar migration rate = **C** x (distance to equilibrium) x morphodynamic factor

Bar activation

$$\begin{cases} E_{eq} = a y_b + b \\ \dfrac{\partial y_b}{\partial t} = C\,(E - E_{eq})\,\sqrt{E}\,\boxed{f_b(H_s, H_b)} \end{cases}$$

$$\rightarrow \quad f_b(H_s, H_b) = \min\left(\left[\frac{H_s}{H_b}\right]^p, 1\right)$$

Sandbar migration modelling

Model:

Equilibrium energy = **A** x barline cross-shore position + **B**

Bar migration rate = **C** x (distance to equilibrium) x morphodynamic factor

Calibration using the full dataset

Sandbar migration modelling

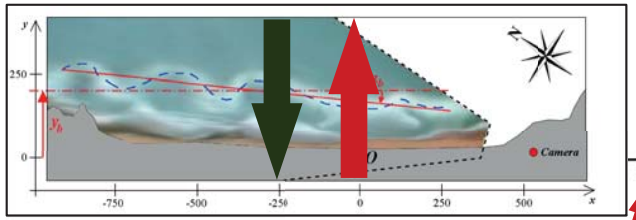
Model:

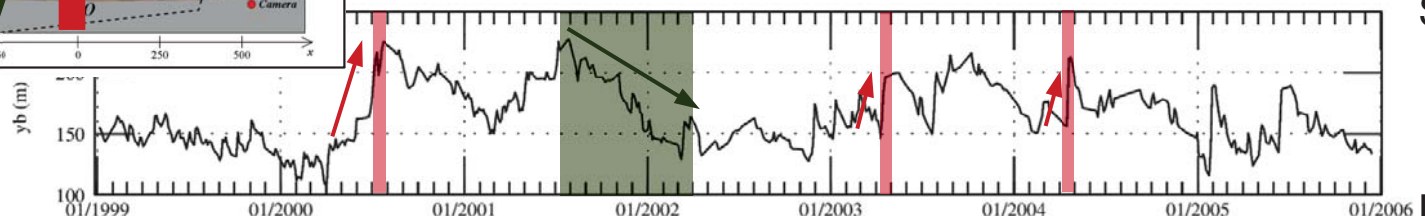
Equilibrium energy = **A** x barline cross-shore position + **B**

Bar migration rate = **C** x (distance to equilibrium) x morphodynamic factor

Calibration using the full dataset

Migration data:

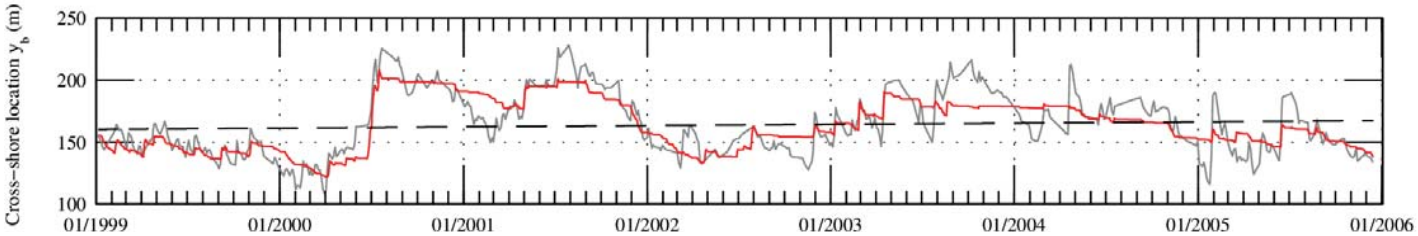




Seaward

Landward

Model hindcast:



Sandbar rotation modelling

How to model the barline rotation ? How to find the involved drivers ?

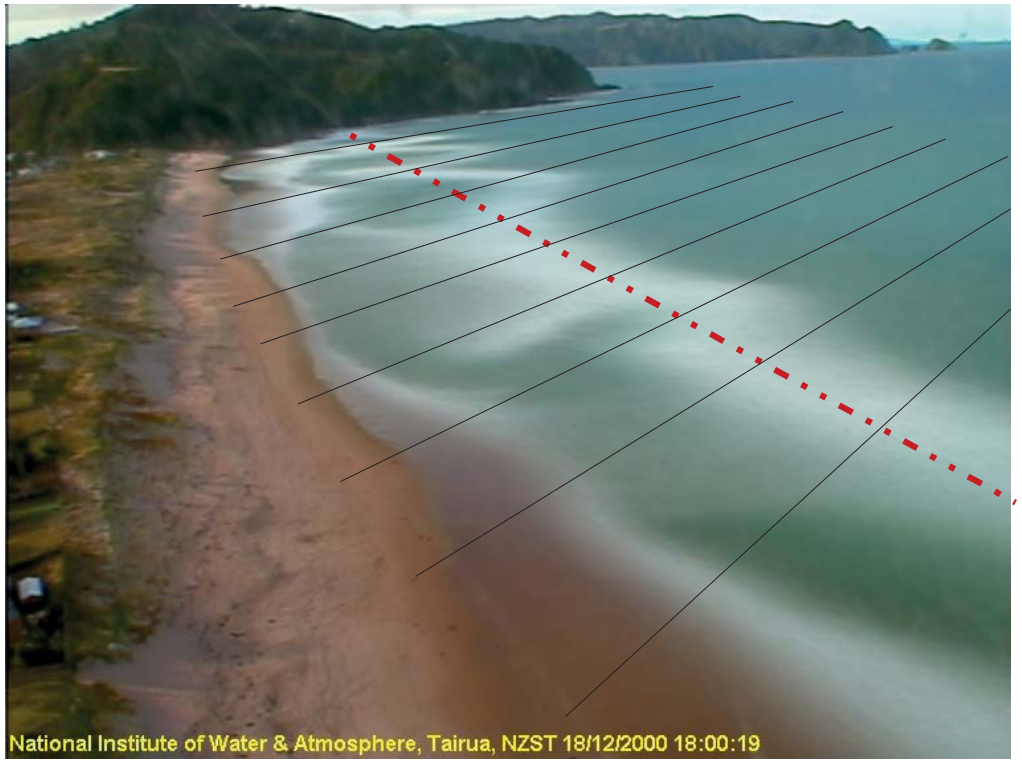
Sandbar rotation modelling

How to model the barline rotation ? How to find the involved drivers ?

1: Separate the beach in sections and apply the migration model

Sandbar rotation modelling

How to model the barline rotation ? How to find the involved drivers ?



1: Separate the beach in sections and apply the migration model

OR

2: Evaluate the difference in migration when traveling alongshore

Sandbar rotation modelling

How to model the barline rotation ? How to find the involved drivers ?

1: Separate the beach in sections and apply the migration model

OR

2: Evaluate the difference in migration when traveling alongshore

→ Does the migration rate increase or decrease while moving along the shore ?

Sandbar rotation modelling

How to model the barline rotation ? How to find the involved drivers ?

1: Separate the beach in sections and apply the migration model

OR

2: Evaluate the difference in migration when traveling alongshore

→ Does the migration rate increase or decrease while moving along the shore ?

Mathematically: differentiation along the alongshore dimension.

Sandbar rotation modelling

Model:

Equilibrium energy **gradient** = **A'** x barline orientation + **B'**

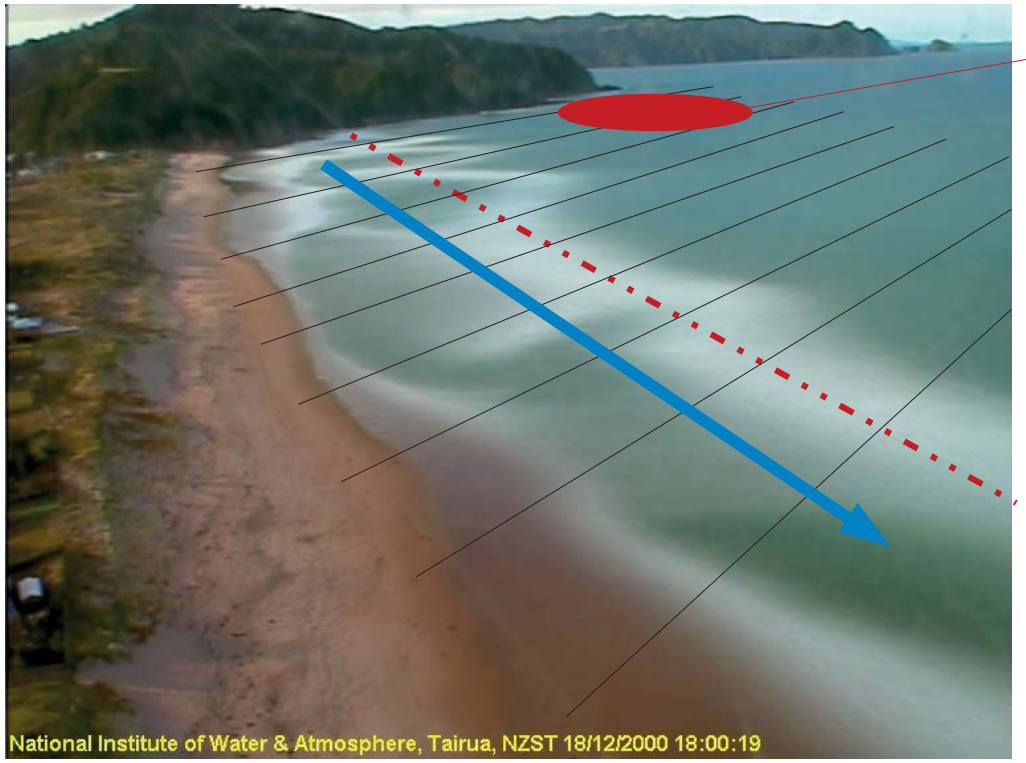
Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

Sandbar rotation modelling

Model:

Equilibrium energy **gradient** = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor



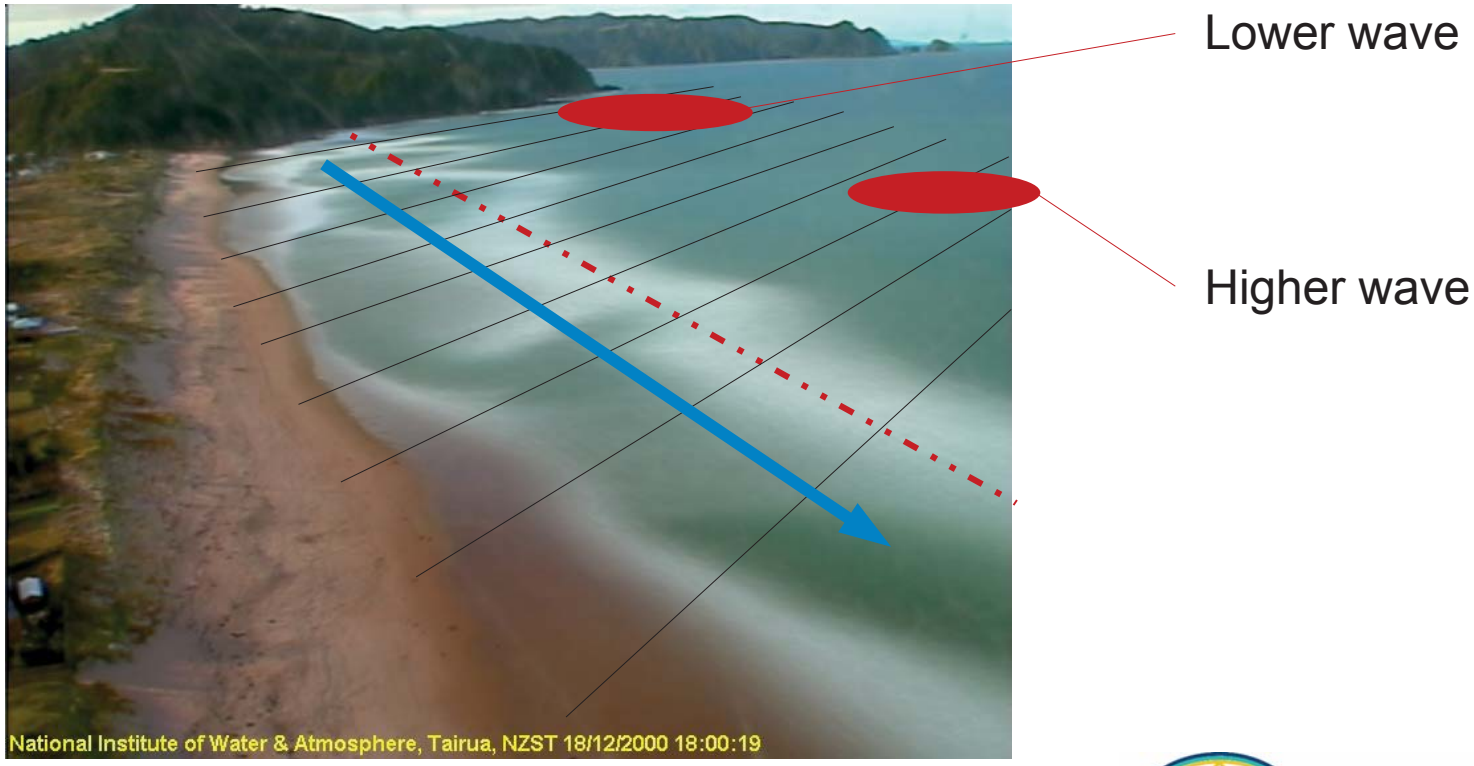
Lower wave

Sandbar rotation modelling

Model:

Equilibrium energy **gradient** = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

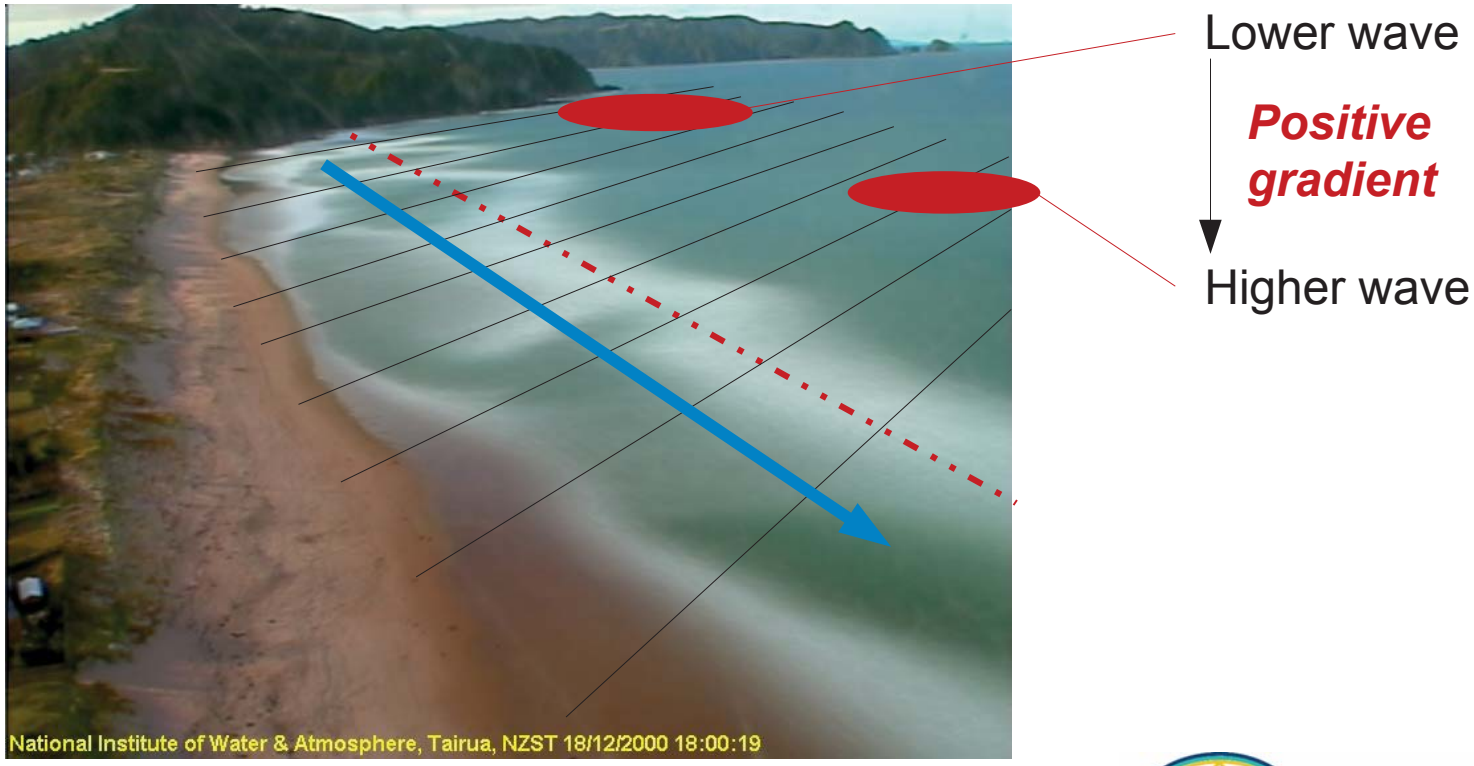


Sandbar rotation modelling

Model:

Equilibrium energy **gradient** = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

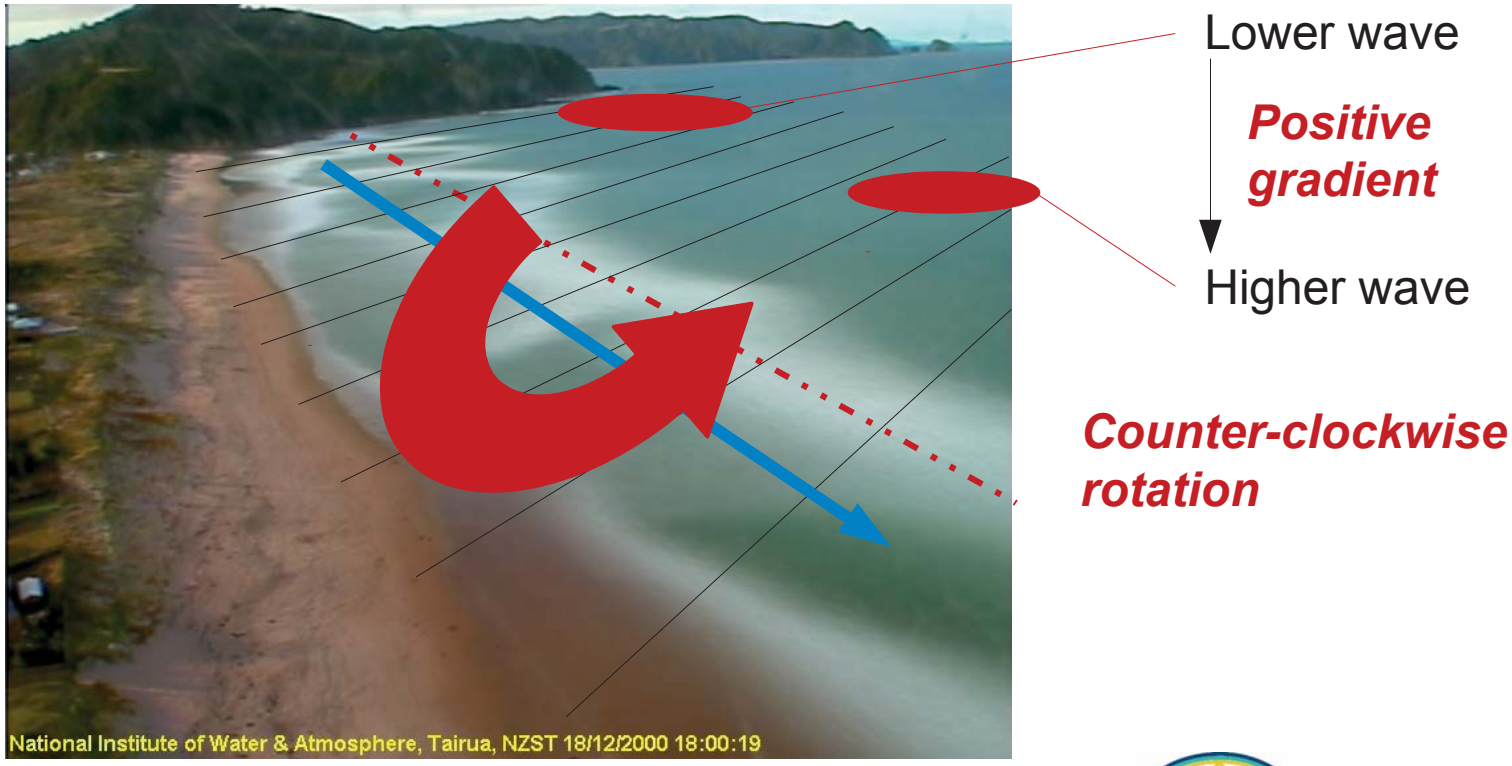


Sandbar rotation modelling

Model:

Equilibrium energy **gradient** = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor



Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} \alpha_{b,eq} = \alpha_0 + \dfrac{1}{\delta A}\dfrac{\partial E}{\partial x}\left[1 + \dfrac{1}{2}\left(1 - \dfrac{E_{eq}}{E}\right)\right] \\ \dfrac{d\alpha_b}{dt} = C'\left[\sqrt{E}\left(\dfrac{\partial E}{\partial x} - \delta A(\alpha_b - \alpha_0)\right) + \dfrac{1}{2\sqrt{E}}\dfrac{\partial E}{\partial x}(E - E_{eq})\right] f_b(H_s, H_b) \end{cases}$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} \alpha_{b,eq} = \alpha_0 + \dfrac{1}{\delta A}\dfrac{\partial E}{\partial x}\left[1 + \dfrac{1}{2}\left(1 - \dfrac{E_{eq}}{E}\right)\right] \\ \dfrac{d\alpha_b}{dt} = C'\left[\sqrt{E}\left(\dfrac{\partial E}{\partial x} - \delta A(\alpha_b - \alpha_0)\right)\right. \\ \qquad \left. + \dfrac{1}{2\sqrt{E}}\dfrac{\partial E}{\partial x}(E - E_{eq})\right] f_b(H_s, H_b) \end{cases}$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} \alpha_{b,eq} = \alpha_0 + \dfrac{1}{\delta A}\dfrac{\partial E}{\partial x} \\ \dfrac{d\alpha_b}{dt} = C'\left[\sqrt{E}\left(\dfrac{\partial E}{\partial x} - \delta A(\alpha_b - \alpha_0)\right) + \cancel{\dfrac{1}{2\sqrt{E}}\dfrac{\partial E}{\partial x}(E - E_{eq})}\right] f_b(H_s, H_b) \end{cases}$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\alpha_{b,eq} = \alpha_0 + \frac{1}{\delta A}\frac{\partial E}{\partial x} \longrightarrow \left.\frac{\partial E}{\partial x}\right|_{eq} = \delta A(\alpha_b - \alpha_0)$$

$$\frac{d\alpha_b}{dt} = C'\left[\sqrt{E}\left(\frac{\partial E}{\partial x} - \delta A(\alpha_b - \alpha_0)\right) + \cancel{\frac{1}{2\sqrt{E}}\frac{\partial E}{\partial x}(E - E_{eq})}\right] f_b(H_s, H_b)$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\left\{\begin{array}{l} \left.\dfrac{\partial E}{\partial x}\right|_{eq} = A'\alpha_b + B' \\[2ex] \dfrac{d\alpha_b}{dt} = C'\left[\sqrt{E}\left(\dfrac{\partial E}{\partial x} - \delta A(\alpha_b - \alpha_0)\right) + \cancel{\dfrac{1}{2\sqrt{E}}\dfrac{\partial E}{\partial x}(E - E_{eq})}\right] f_b(H_s, H_b) \end{array}\right.$$

$$\left.\frac{\partial E}{\partial x}\right|_{eq} = \delta A(\alpha_b - \alpha_0)$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} \left.\dfrac{\partial E}{\partial x}\right|_{eq} = A'\alpha_b + B' \\ \dfrac{d\alpha_b}{dt} = C'\left(\dfrac{\partial E}{\partial x} - \left.\dfrac{\partial E}{\partial x}\right|_{eq}\right)\sqrt{E}\, f_b(H_s, H_b) \end{cases}$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

$$\begin{cases} \left.\dfrac{\partial E}{\partial x}\right|_{eq} = A'\alpha_b + B' \\ \dfrac{d\alpha_b}{dt} = C'\left(\dfrac{\partial E}{\partial x} - \left.\dfrac{\partial E}{\partial x}\right|_{eq}\right)\sqrt{E}\, f_b(H_s, H_b) \end{cases}$$

Sandbar rotation modelling

Model:

Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

Calibration using the full dataset

Sandbar rotation modelling

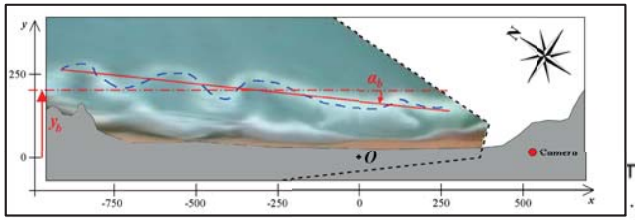
Model:

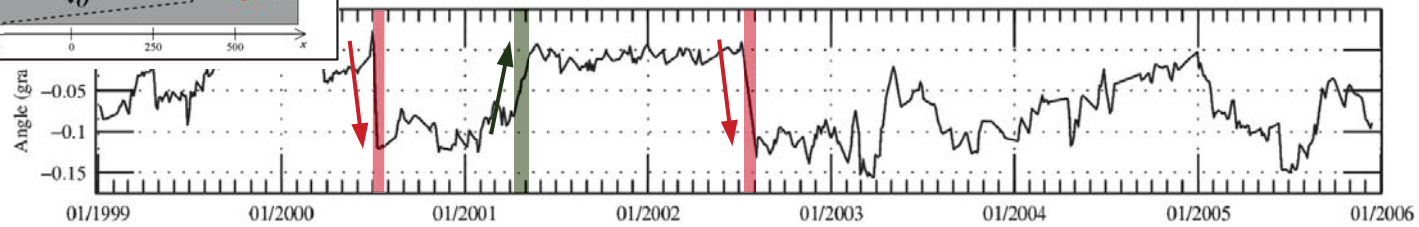
Equilibrium energy gradient = **A'** x barline orientation + **B'**

Bar rotation rate = **C'** x (distance to equilibrium) x morphodynamic factor

Calibration using the full dataset

Rotation:

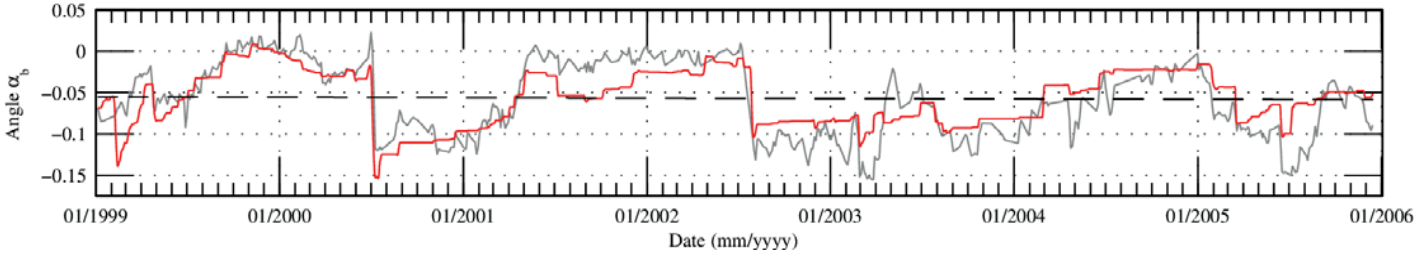




Counter-clockwise

Clockwise

Model hindcast:



Research questions

What hydrodynamic conditions are controlling the migration and rotation of the nearshore sandbar of a single-barred embayed sandy beach ?

Migration ↔ Incident wave energy
Rotation ↔ Alongshore wave energy gradient
Morphodynamic factor necessary

Research questions

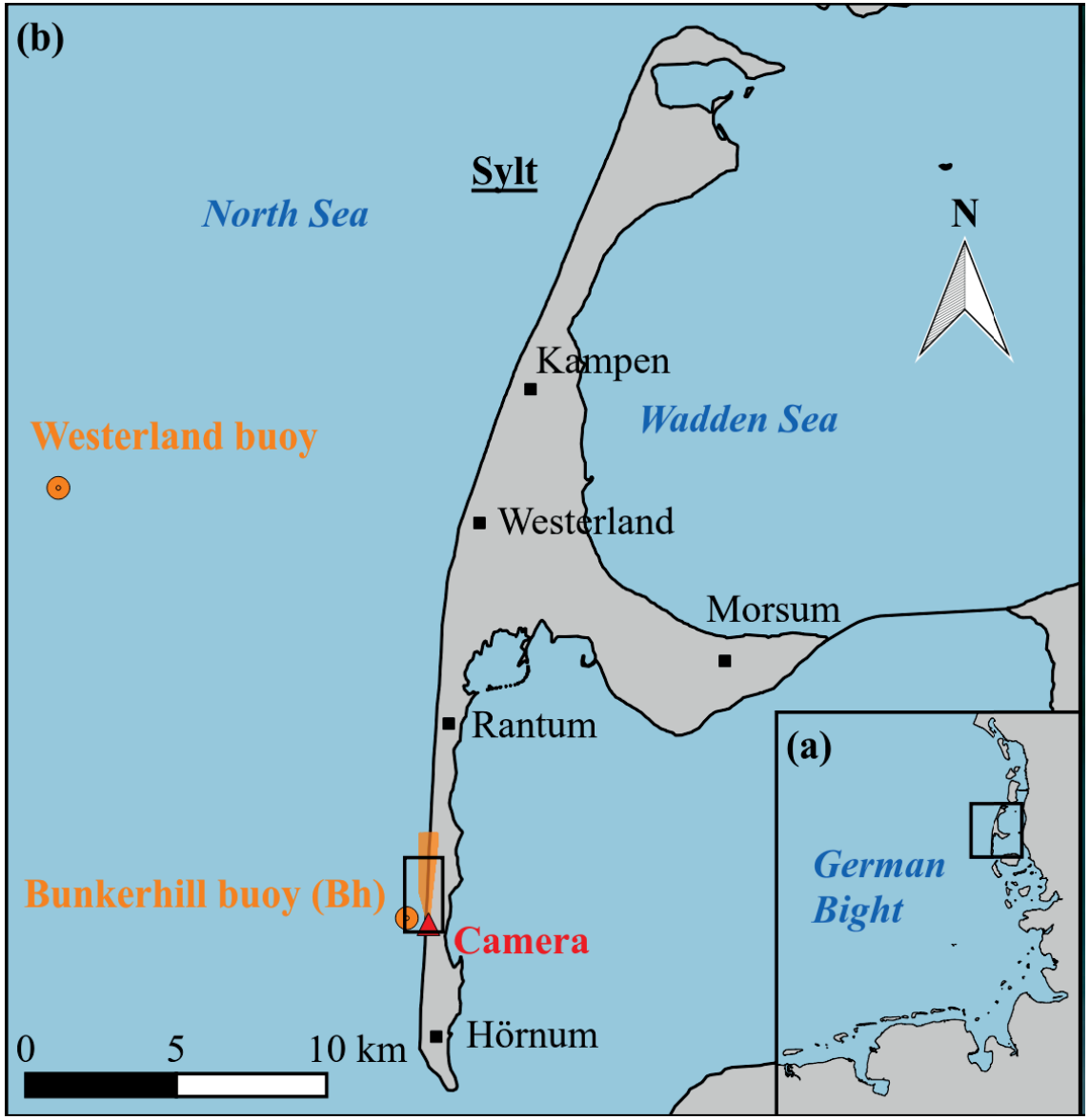
What hydrodynamic conditions are controlling the migration and rotation of the nearshore sandbar of a single-barred embayed sandy beach ?

Migration ↔ Incident wave energy
Rotation ↔ Alongshore wave energy gradient
Morphodynamic factor necessary

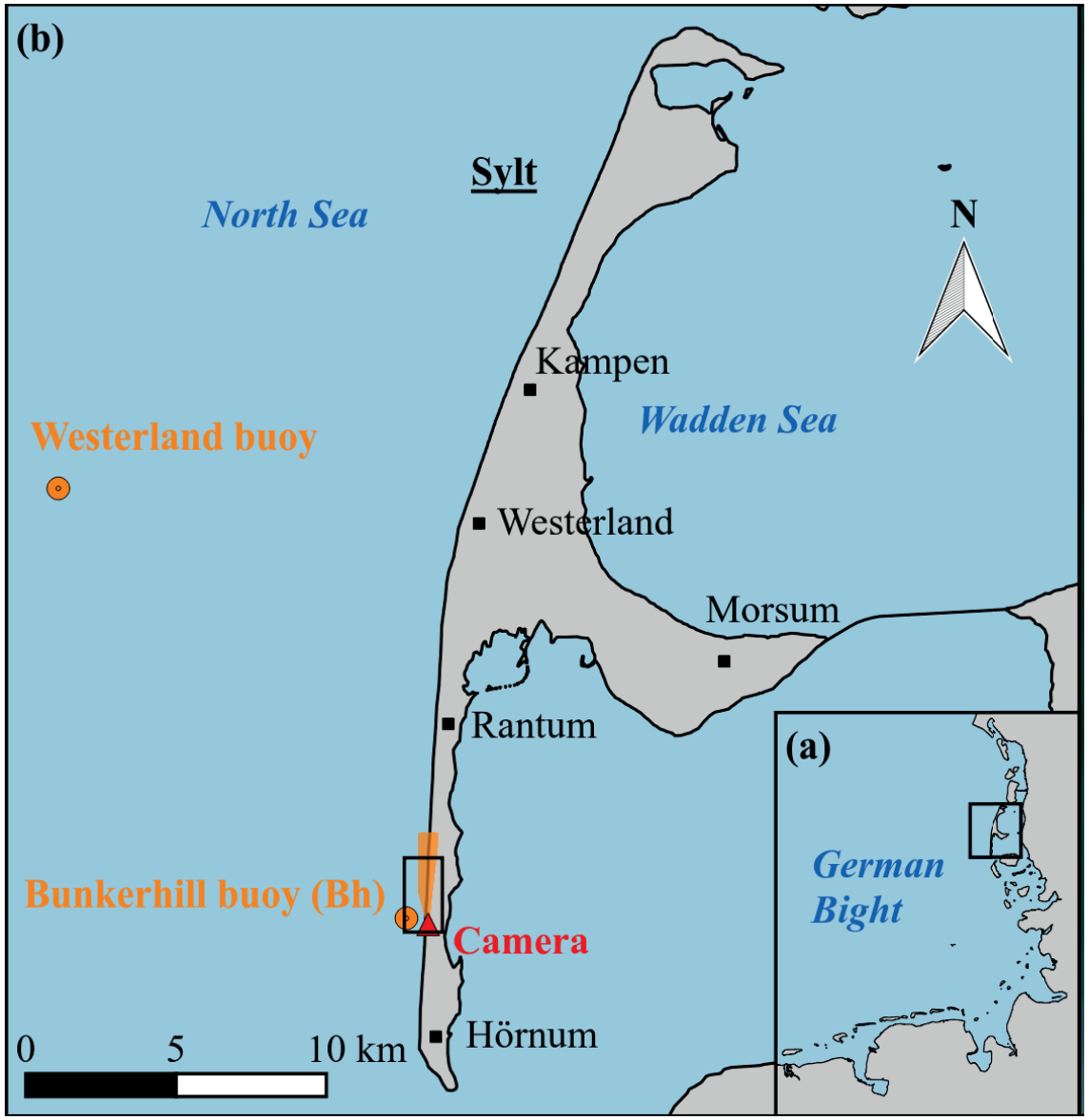
Models also allow to study nearshore sandbars response time:

→ Blossier, B., K. Bryan, C. Daly, and C. Winter (2016), Nearshore sandbar rotation at single-barred embayed beaches, *Journal of Geophysical Research: Oceans*, in press, doi:10.1002/2015JC011031.

Outlook: Sylt case



Outlook: Sylt case



Sediment loss:

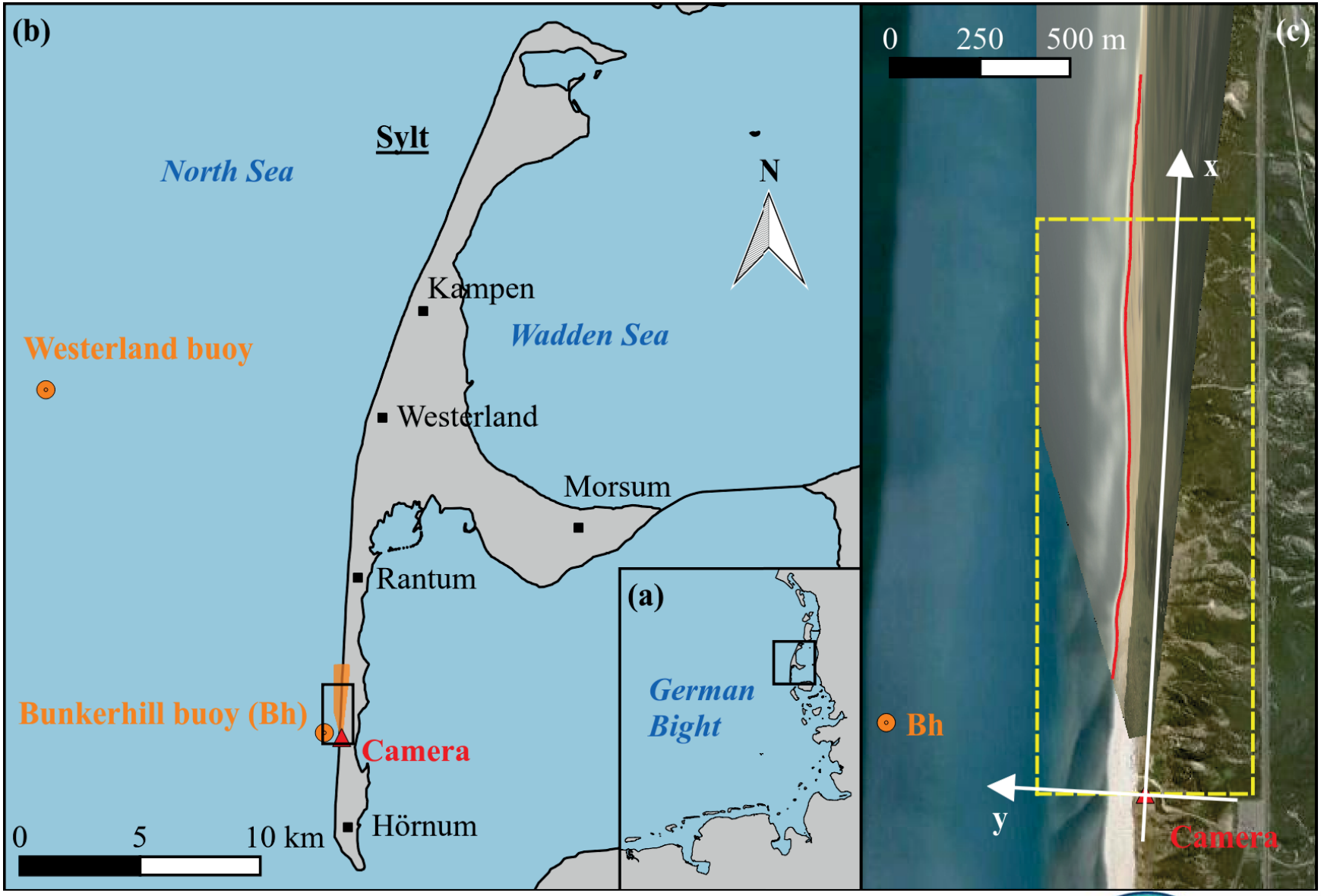
~ 1.2 x 10^6 m^3 yr^{-1}

Retreat:

~ 1.5 m yr^{-1} over the last 7000 years

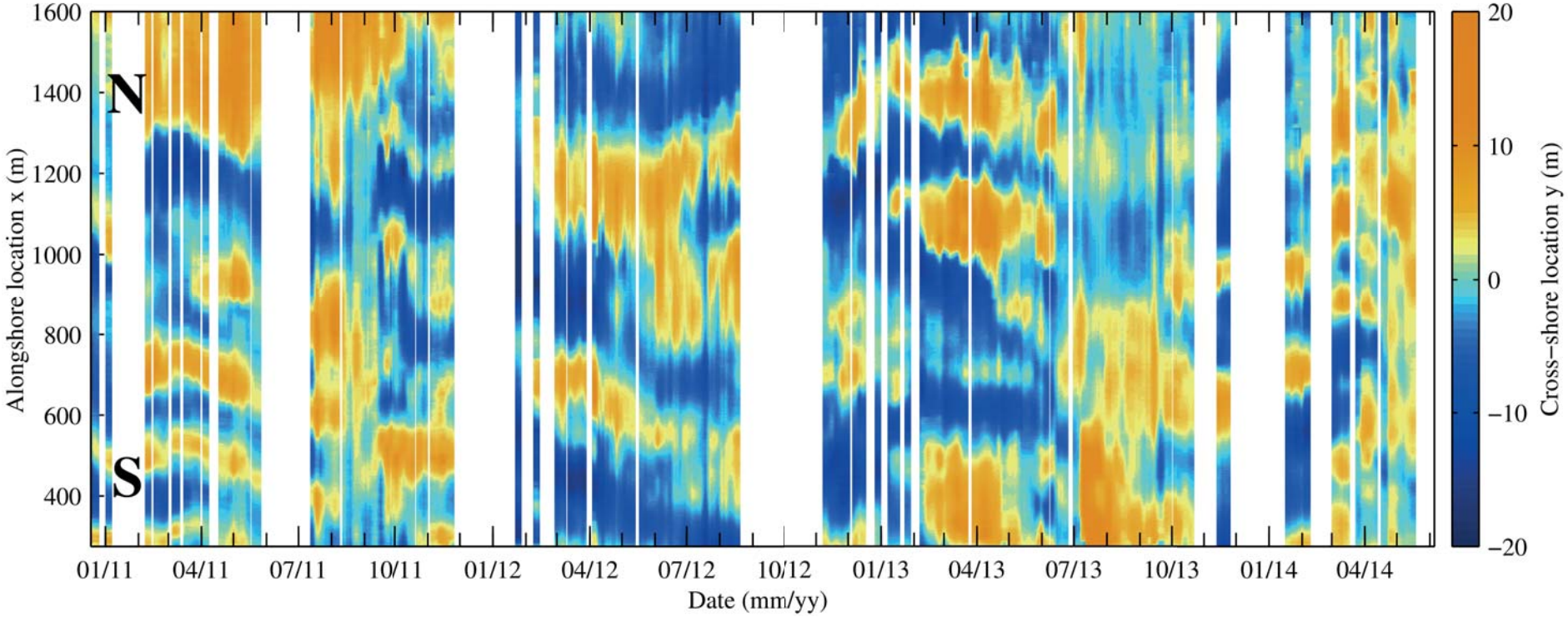
(From *Ahrendt, 2001*)

Outlook: Sylt case



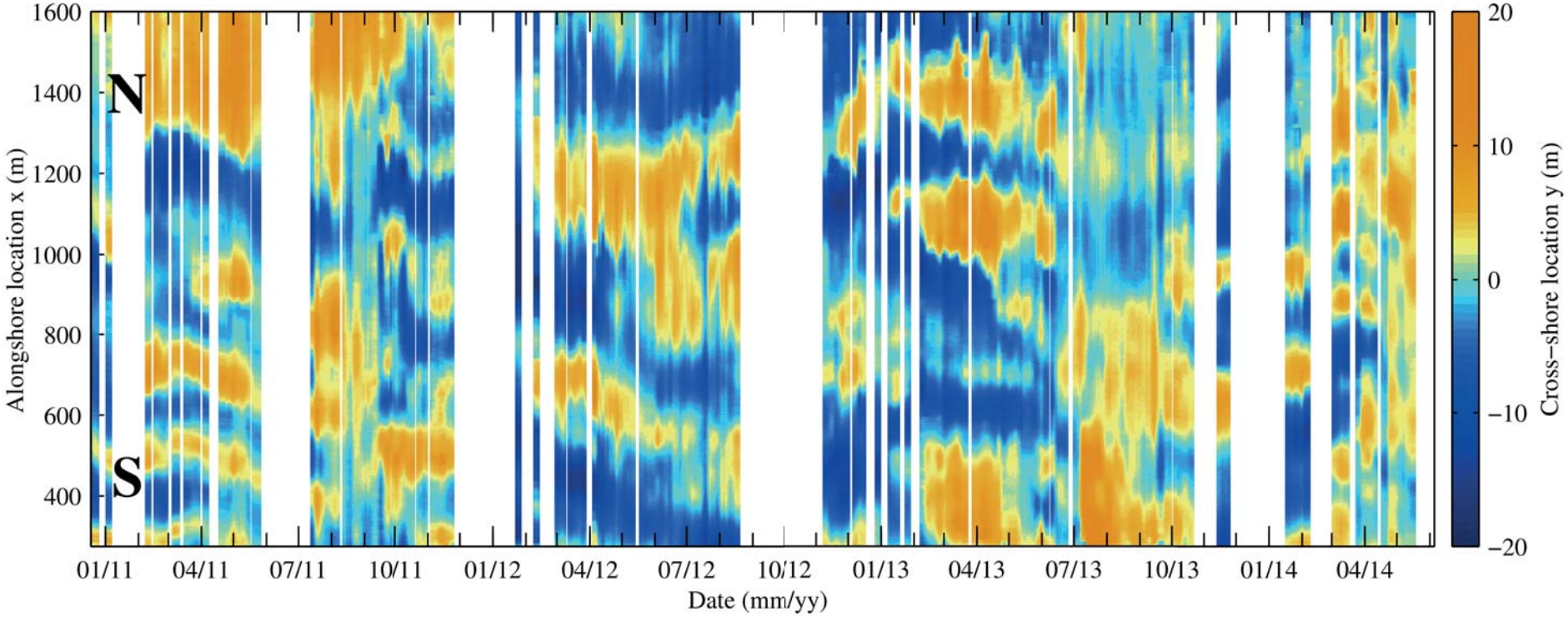
Outlook: Sylt case

- Extraction of the upper shoreline (HAT water level)



Outlook: Sylt case

- Extraction of the upper shoreline (HAT water level)
- Evaluation of temporal and spatial scales (coming soon!)



Thank you !

The Deutsche Forschungs-Gemeinschaft (DFG) funded this research through the International Research Training School InterCoast.

The Waikato Regional Council funded the Tairua CamEra system. George Payne (NIWA) provided the images and maintained the system.

Wietse van de Lageweg digitized the dataset.

The members of the Coastal Marine Group (UoW), the Coastal Dynamics Group (Marum) and InterCoast assisted throughout the present research.