

Marine Heatwaves in Fjord system: Combining In Situ and Satellite Data for Better Understanding

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MARINE HEATWAVES (MHW)

Anomalously warm water events

Formed due to
processes

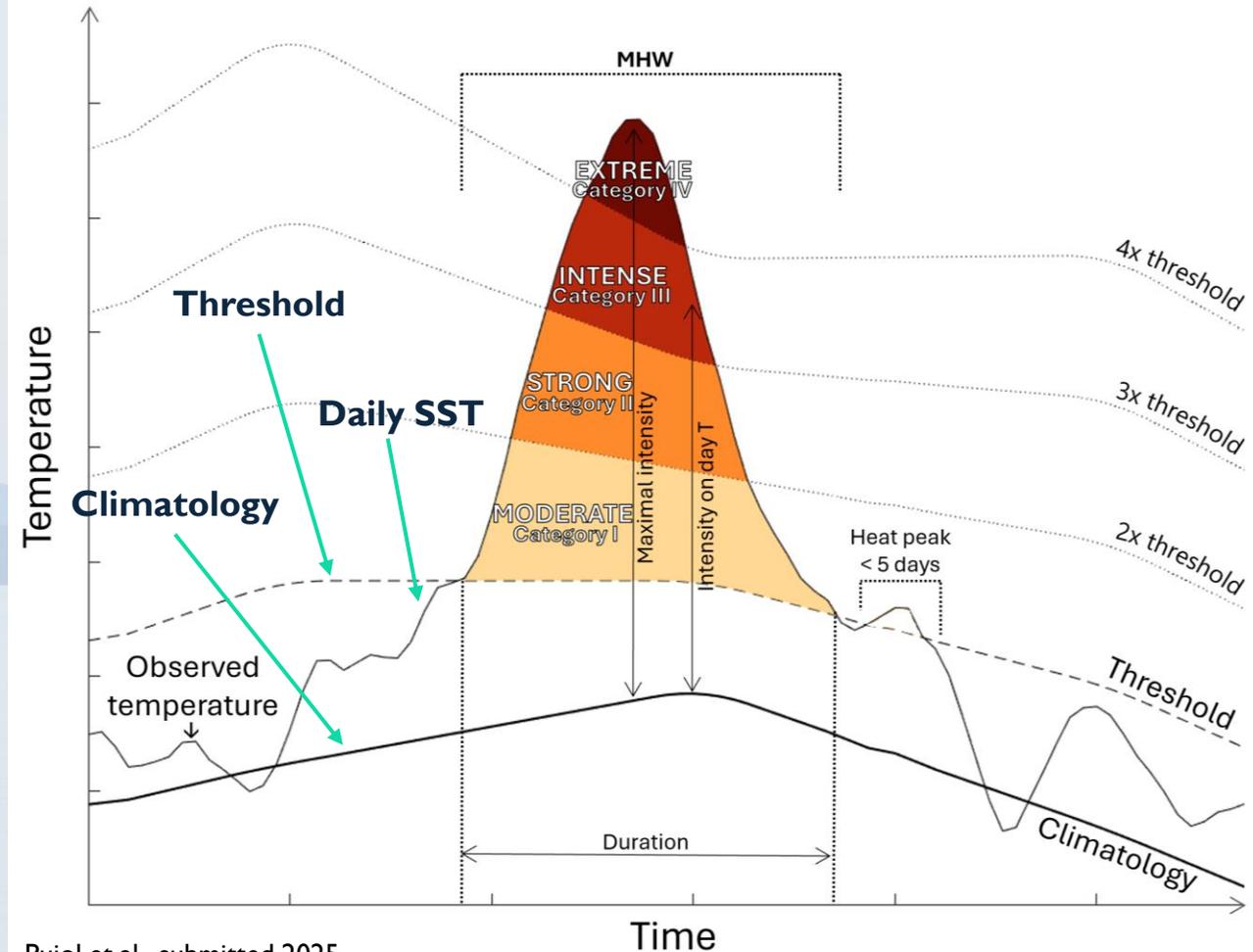
Atmospheric

Oceanic

Increasing frequency and intensity

Amplification due to global warming

MHWs definition from Hobday et al. (2016)



Pujol et al., submitted 2025

MARINE HEATWAVES (MHW)

Anomalously warm water events

Formed due to processes

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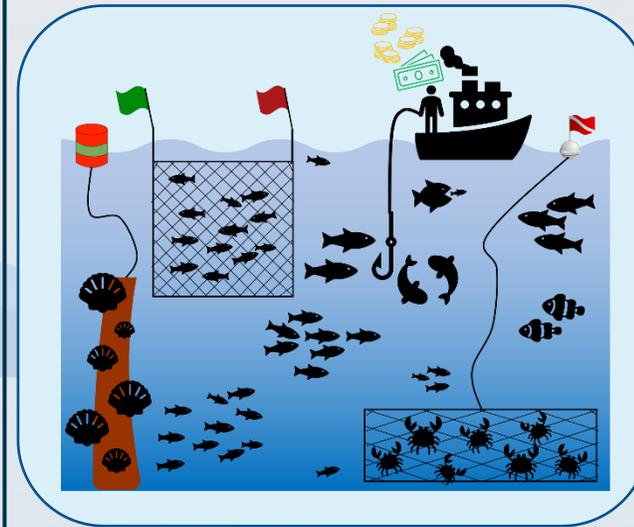
Increasing frequency and intensity



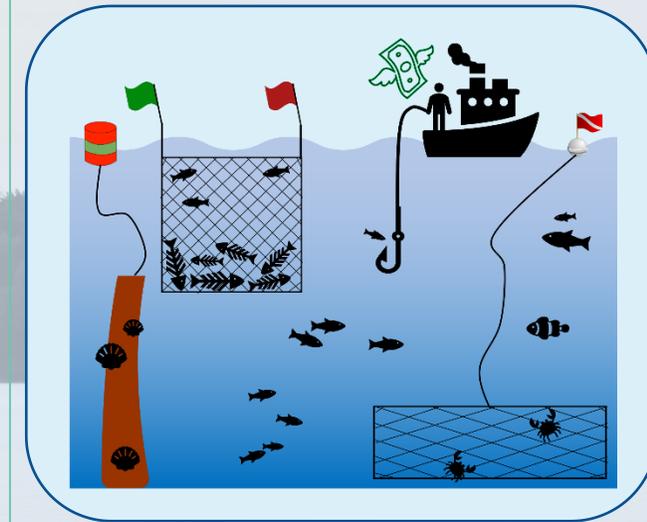
Amplification due to global warming

Devastating consequences

Before a MHW



During a MHW



WHAT DO WE NEED FOR MHW DETECTION ?

Climatology

Needs to be based on long-term data >30 years

Should be a robust and representative baseline

**Threshold
90th
percentile**

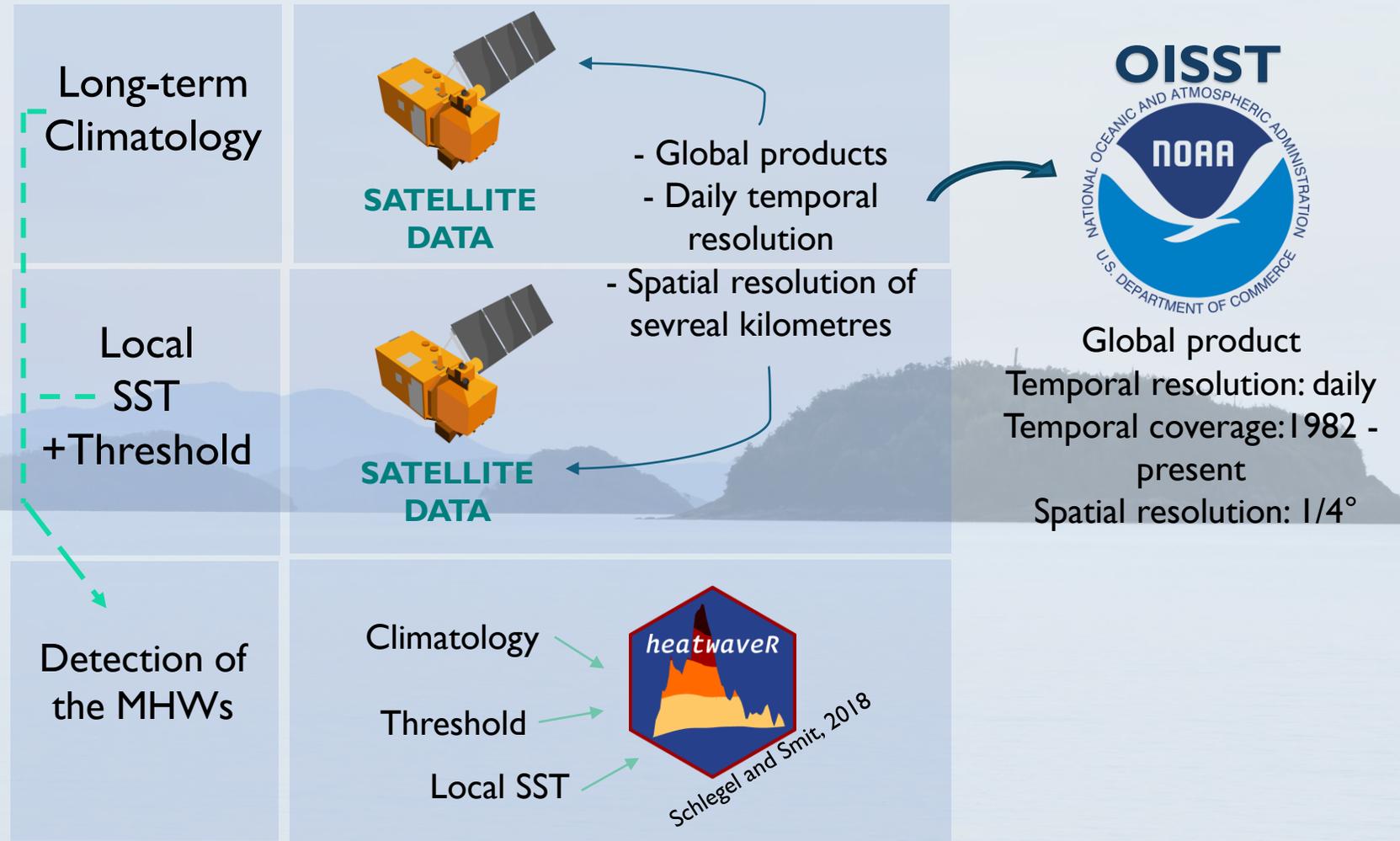
**SST for
MHW
detection**

Needs daily temporal resolution

Needs spatial homogeneity

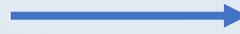
MHW TRADITIONAL DETECTION

In an open ocean-like environment

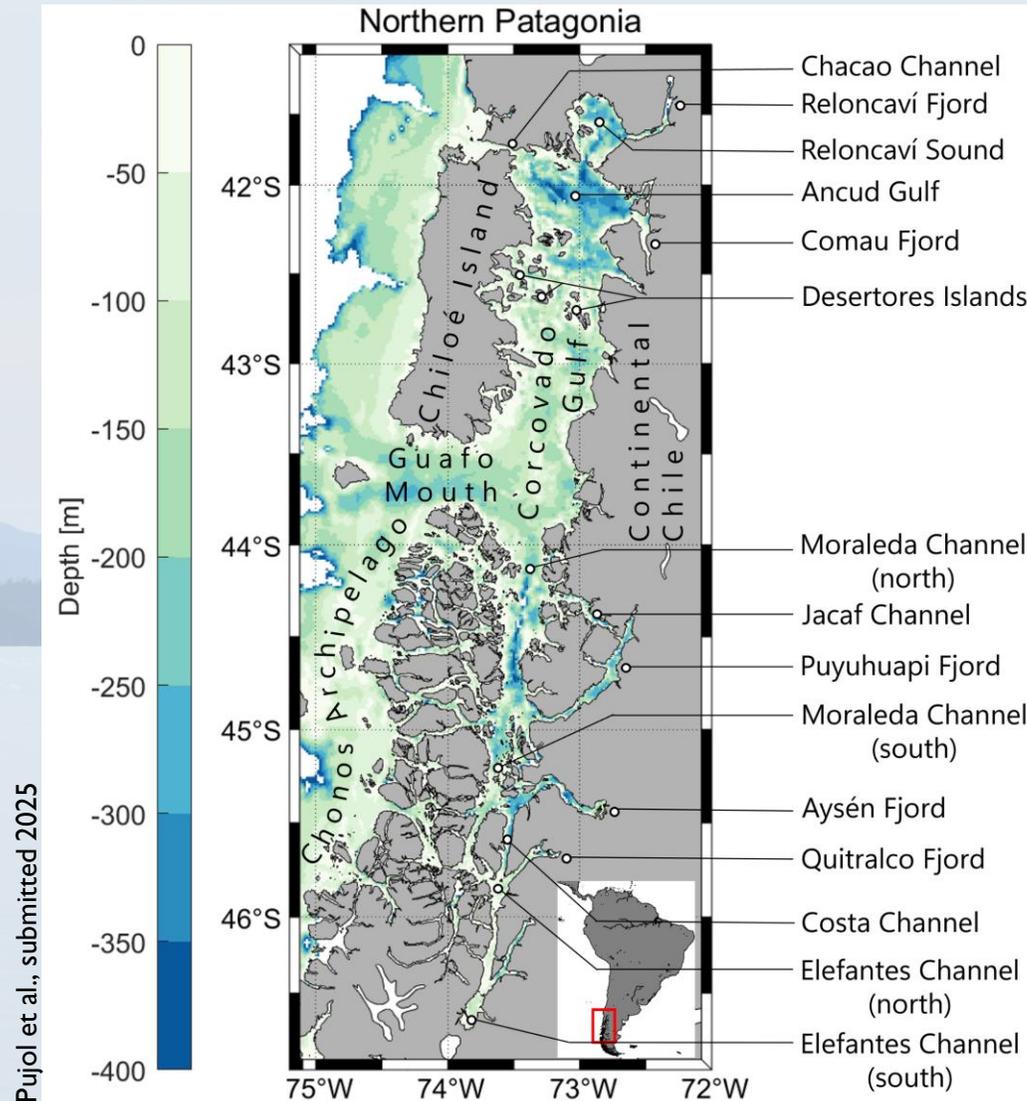


MHW TRADITIONAL DETECTION: LIMITS

In an open ocean-like environment

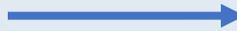


Complex coastal environment such as fjords ?

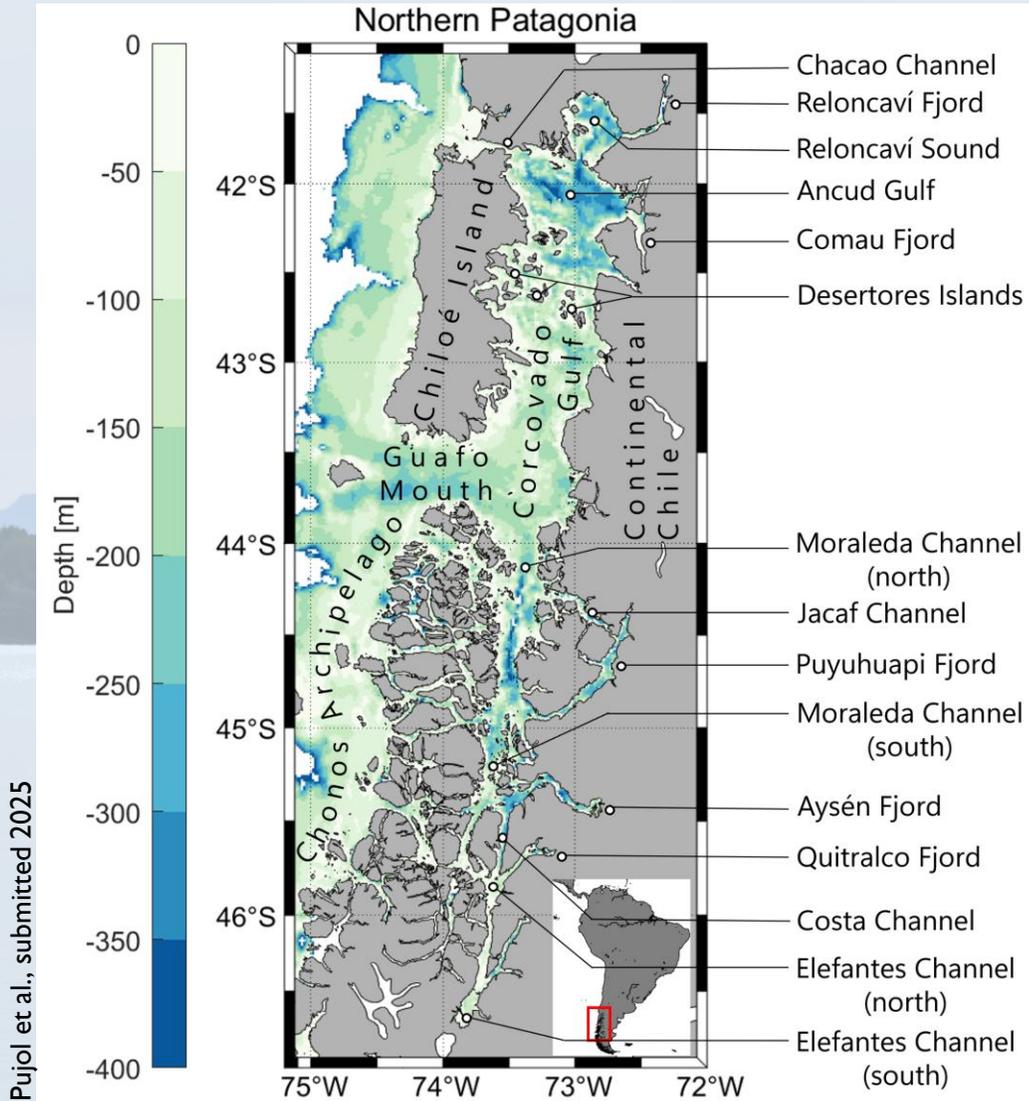


MHW TRADITIONAL DETECTION: LIMITS

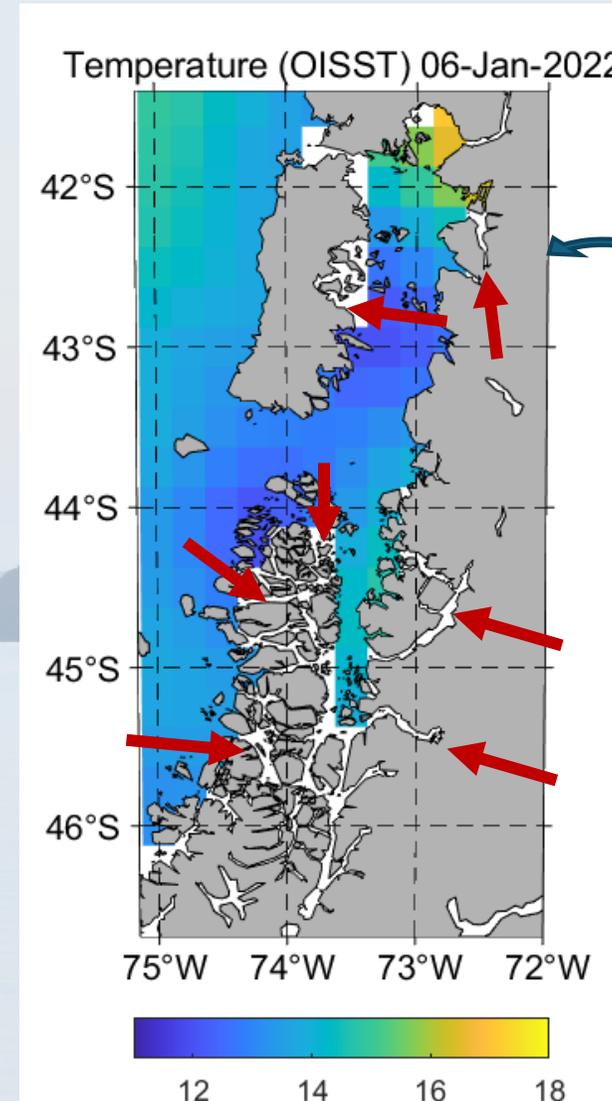
In an open ocean-like environment



Complex coastal environment such as fjords ?



Pujol et al., submitted 2025

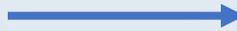


Global product
 Temporal resolution: daily
 Temporal coverage: 1982 - present
 Spatial resolution: 1/4°

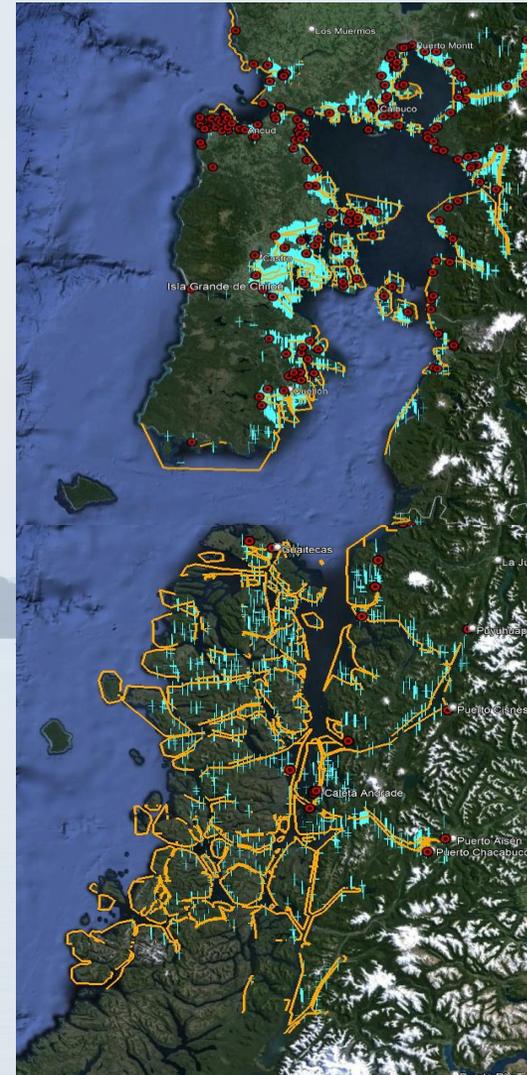
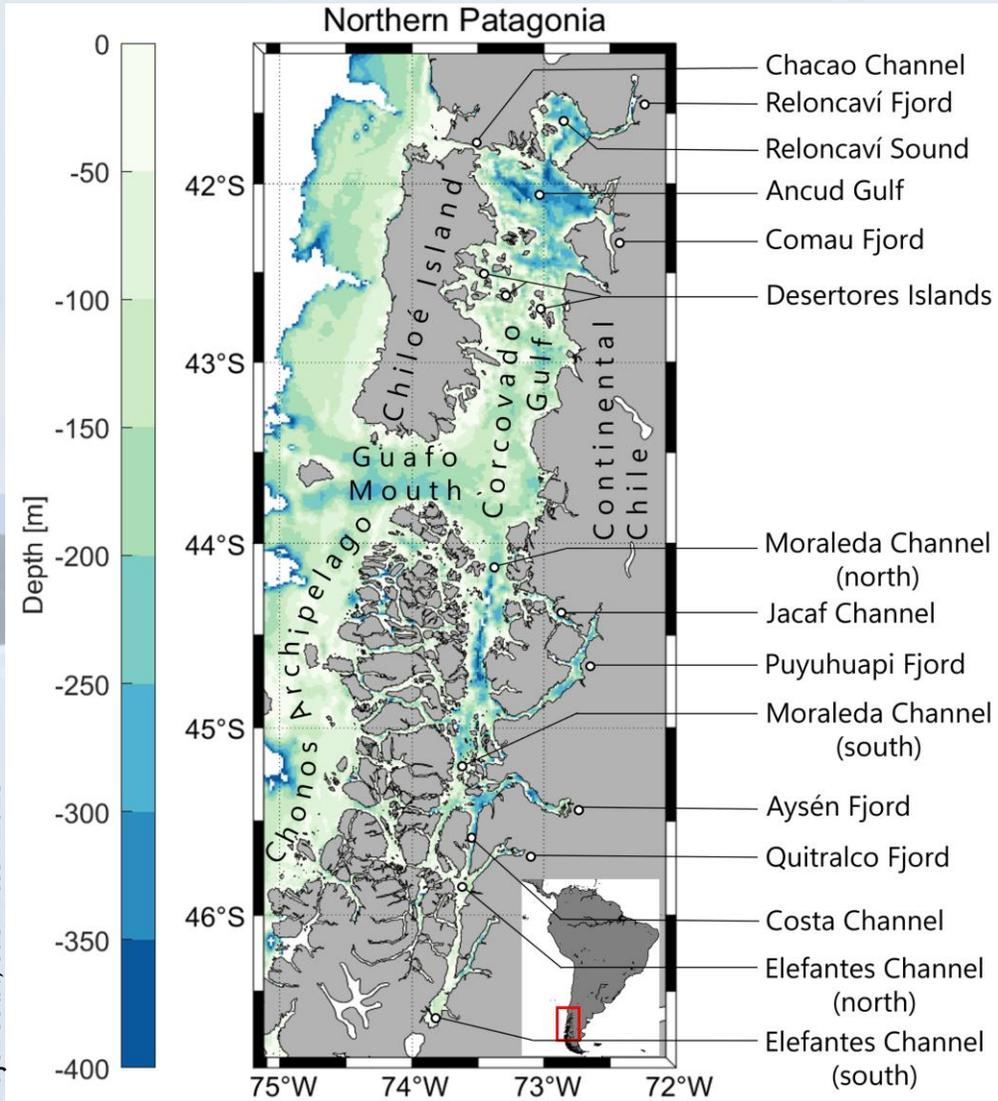
Problem:
 1/4°
 Fjords and channels not resolved

MHW TRADITIONAL DETECTION: LIMITS

In an open ocean-like environment



Complex coastal environment such as fjords ?

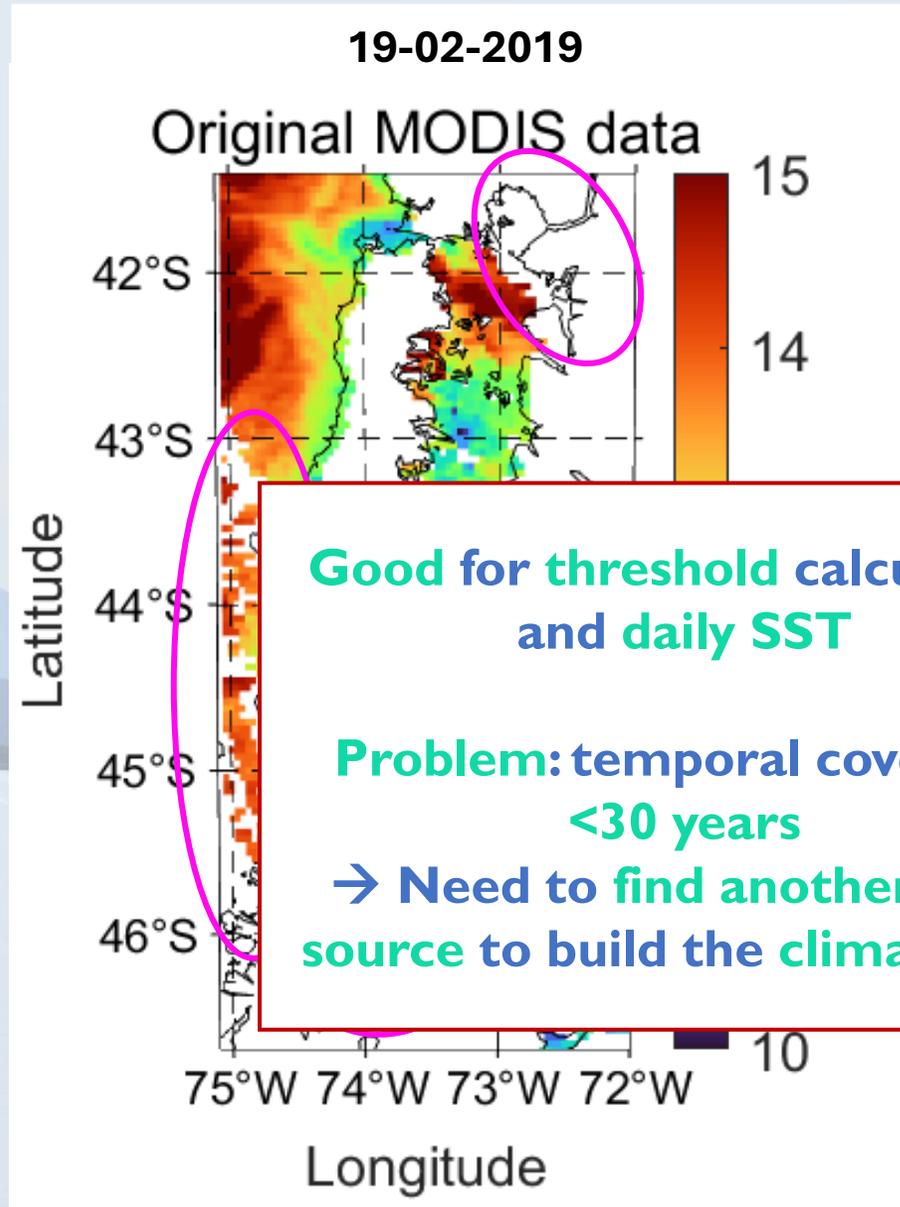


Need of good coastal, channels and fjords representation for aquaculture industry

-  Artisanal fishing cove
-  Area suitable for aquaculture
-  Aquaculture centre

Data from subpesca.ci

SATELLITE DATA



Satellite data

MODIS AQUA:

Spatial resolution: 4km

Temporal resolution: daily

Temporal coverage: 2003-2023



Advantages:

Spatial and temporal homogeneity

Daily resolution

Solves most of the fjords and channels

Disadvantages:

Land interferences

Clouds/rain interferences

Temporal coverage <30 years

IN SITU DATA

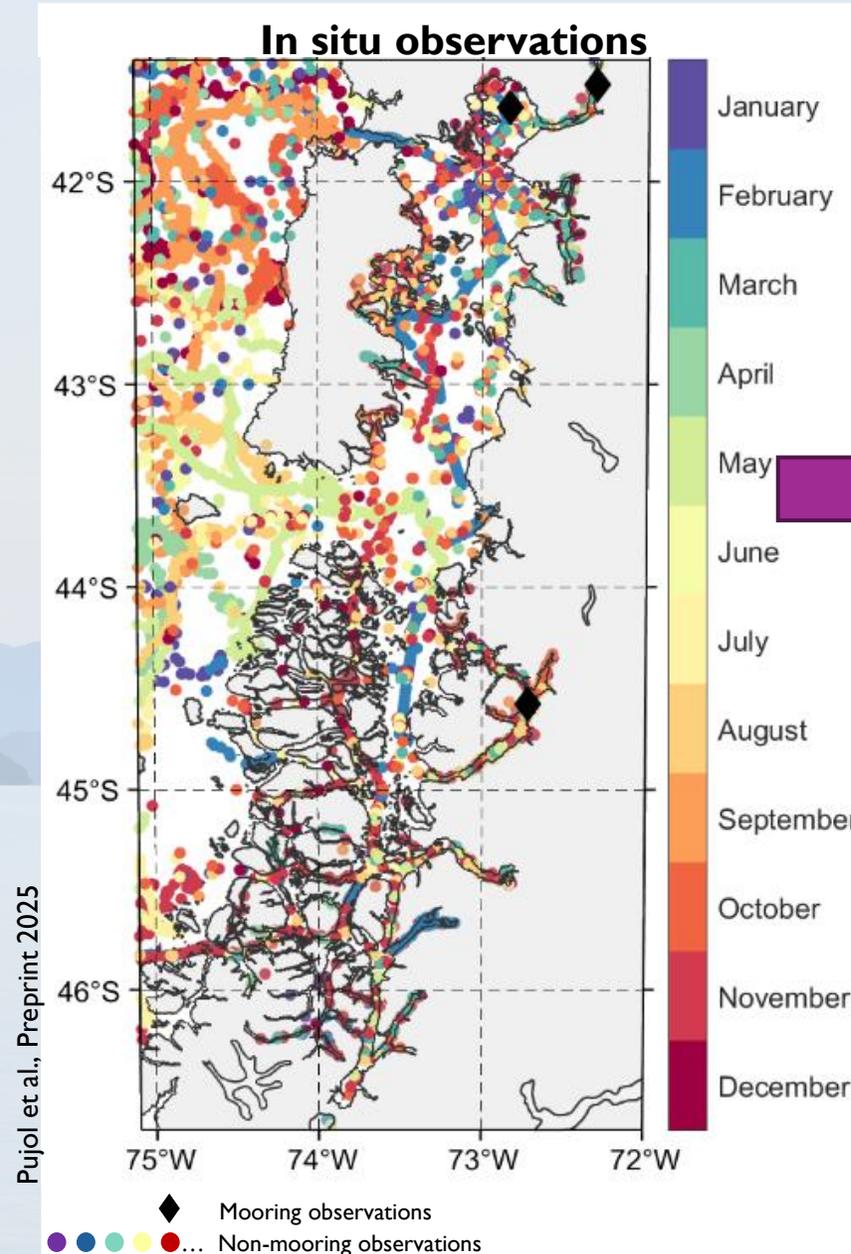
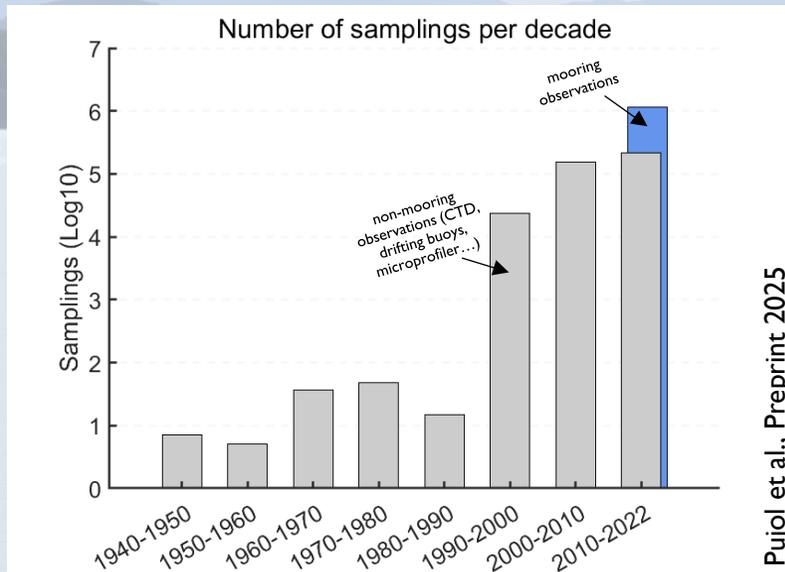
In situ data

Advantages:

Fjords and channels highly sampled
Temporal coverage >30 years

Disadvantages:

Spatial and temporal heterogeneity

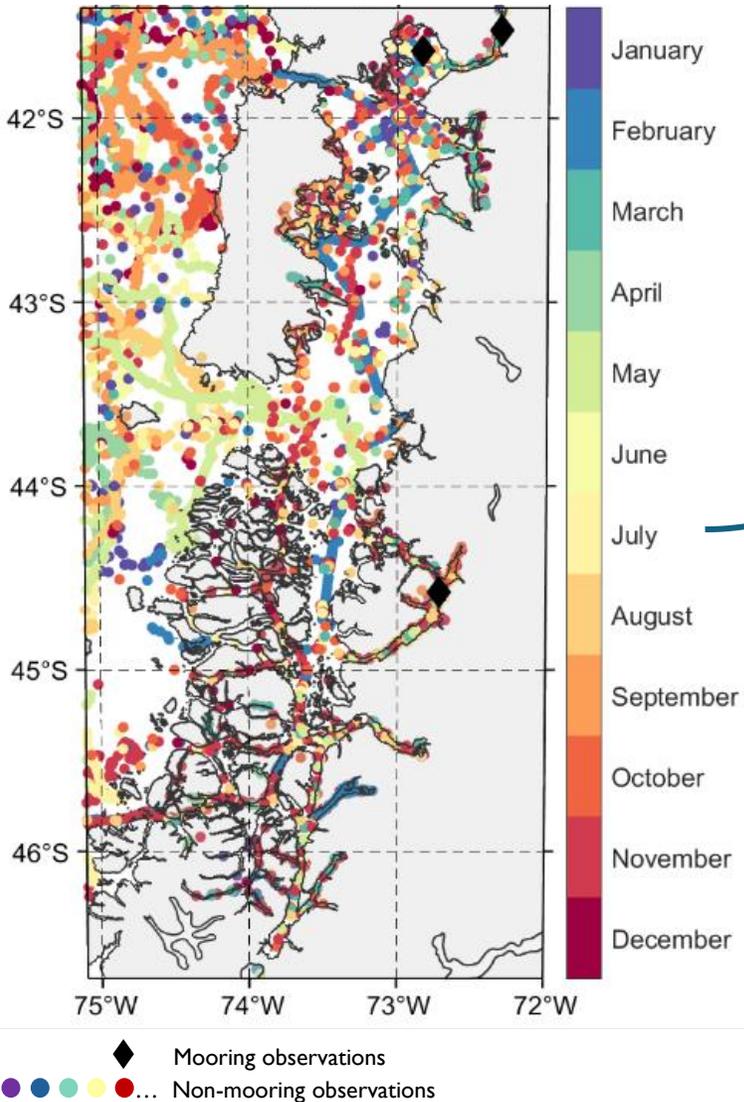


Build the climatology from in situ data

In situ data
Total: 3 million observations

CLIMATOLOGY FROM IN SITU DATA

In situ observations



Data-Interpolating Variational Analysis

(Troupin et al., 2014)

DIVA

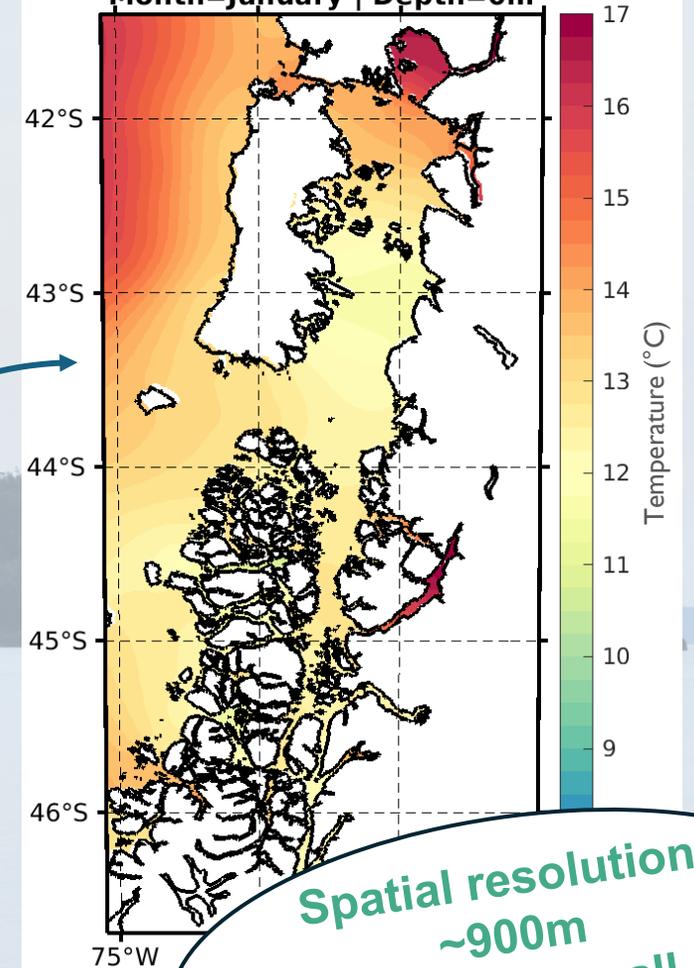
Uses scattered in situ points to generate a continuous field

3D Monthly climatology

Horizontal correlation length: 50km
Lower weight attributed to data clusters

DIVA reconstruction

SST reconstruction with DIVA
Month=January | Depth=0m



Spatial resolution:
~900m
→ resolves all fjords and channels

WHAT DO WE NEED FOR MHW DETECTION ?

Climatology

Needs to be based on long-term data >30 years

Should be a robust and representative baseline

Based on in situ data

Threshold
90th
percentile

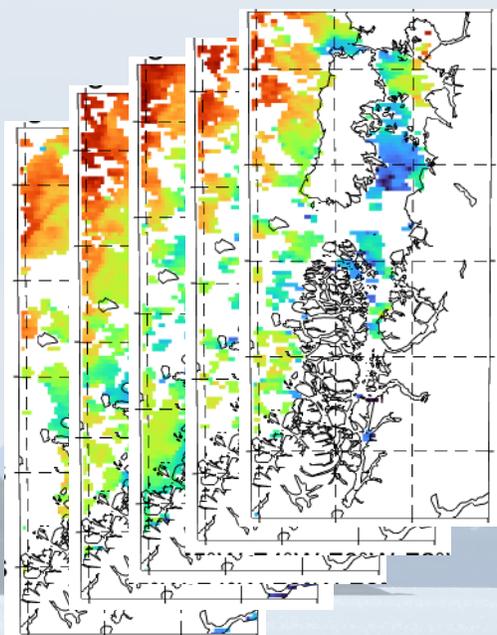
SST for
MHW
detection

Needs daily temporal resolution

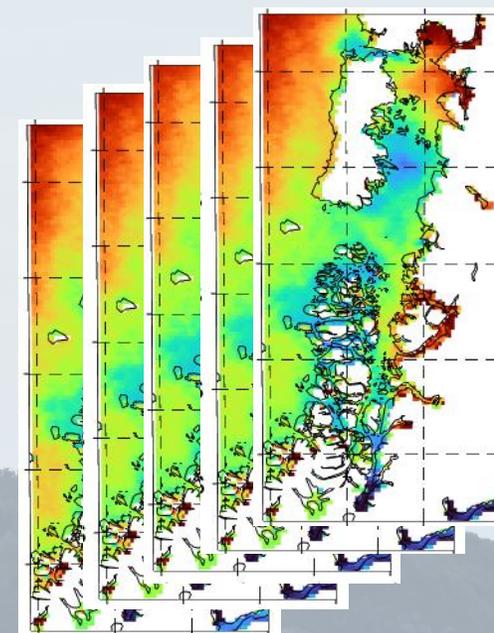
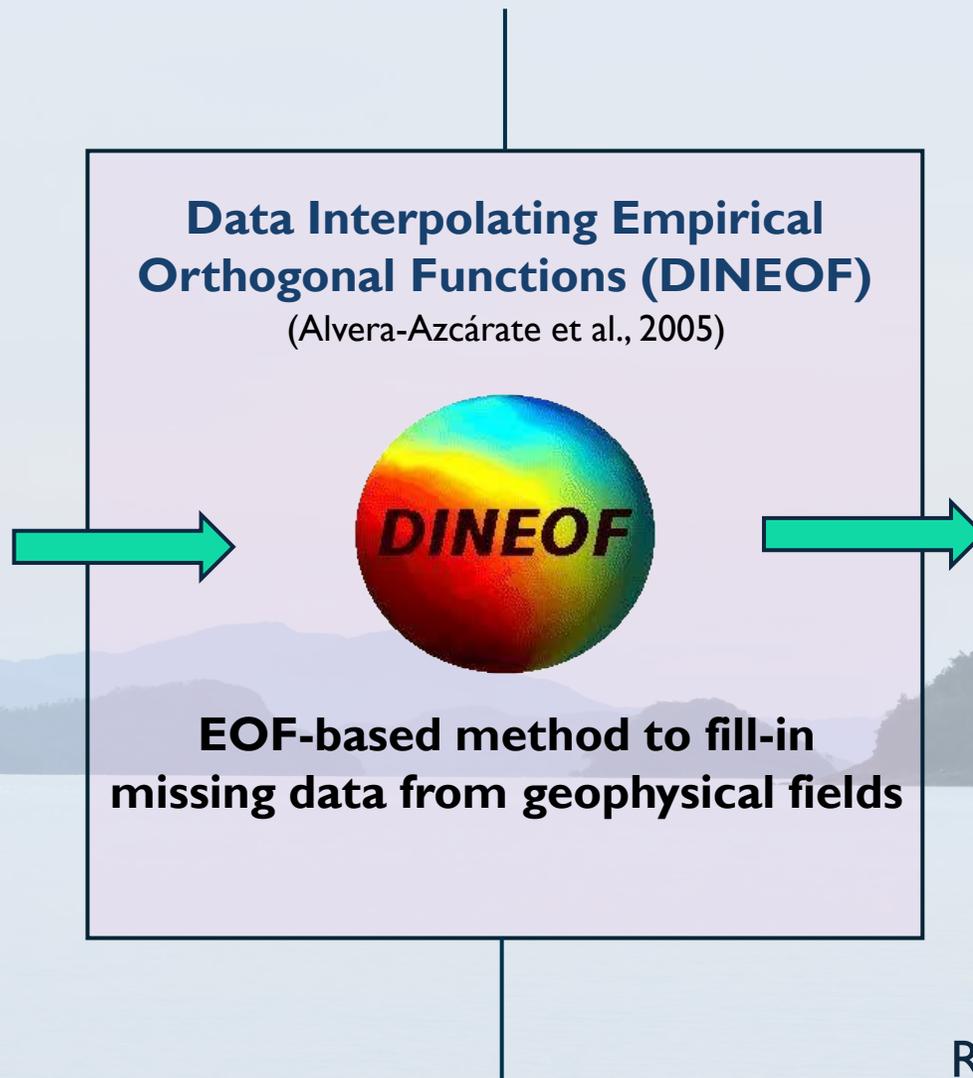
Needs spatial homogeneity

Need to fill the cloud-gaps in the satellite dataset

THRESHOLD FROM SATELLITE DATA

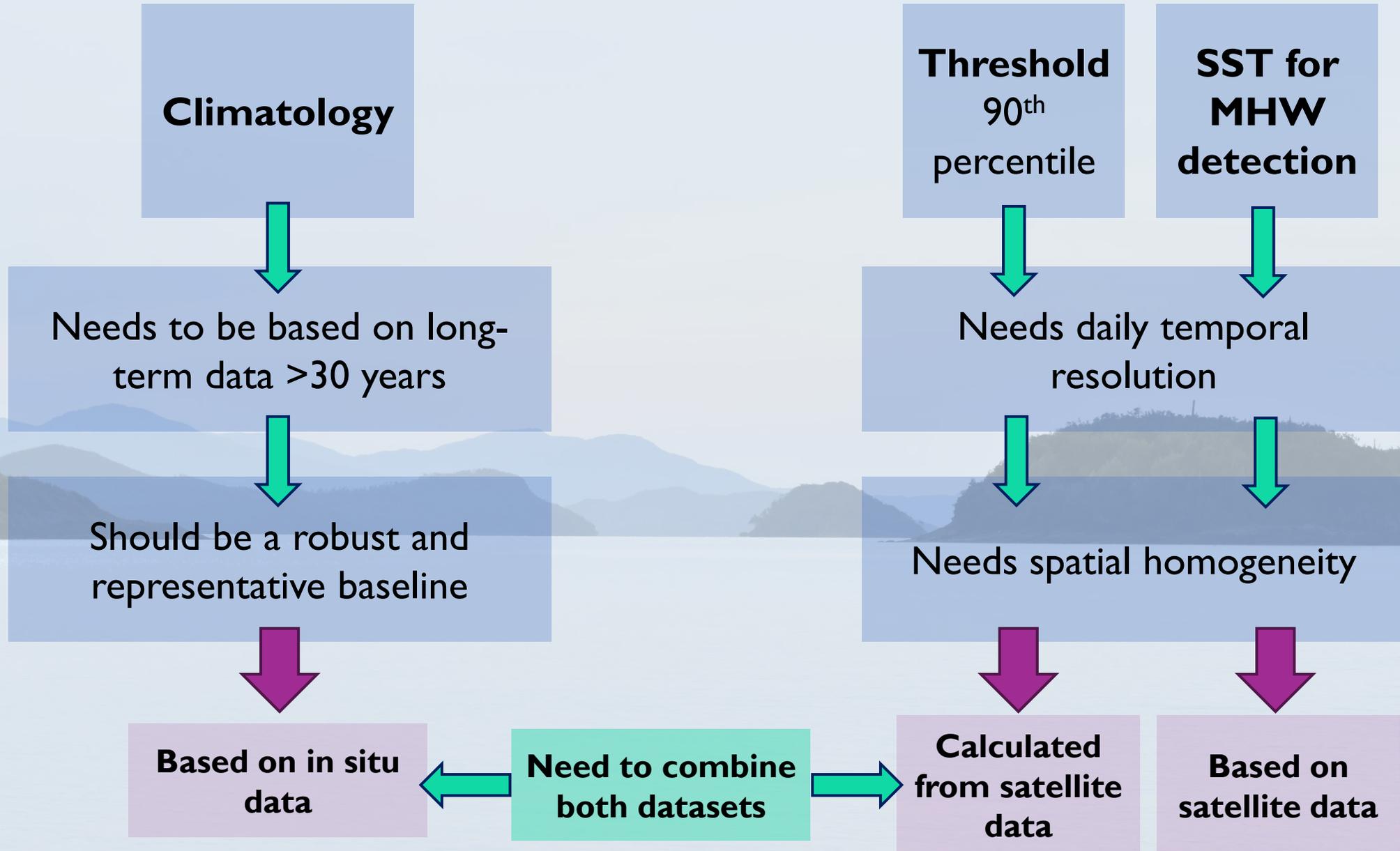


**MODIS AQUA
L3 SST**
Daily (2003-2023)
Gaps



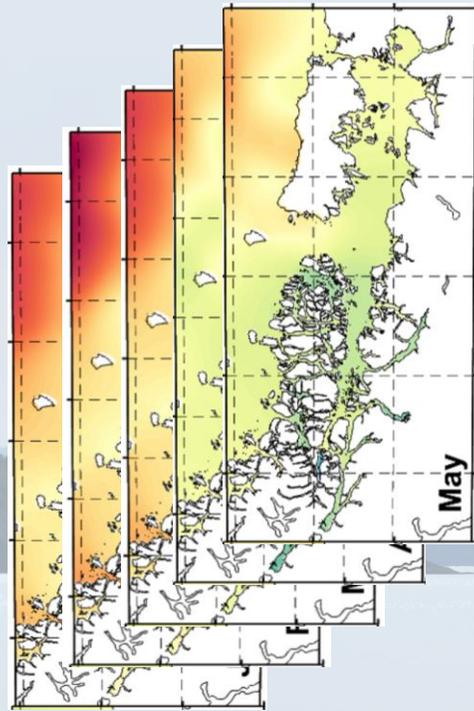
L4 SST
Daily SST (2003-2023)
Gap-free
Resolving most fjords and channels

WHAT DO WE NEED FOR MHW DETECTION ?

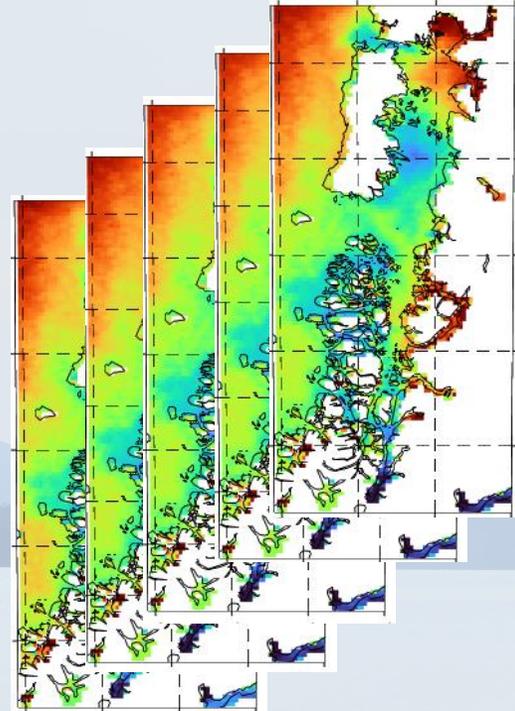


COMBINATION OF IN SITU AND SATELLITE DATASETS

Bias calculation

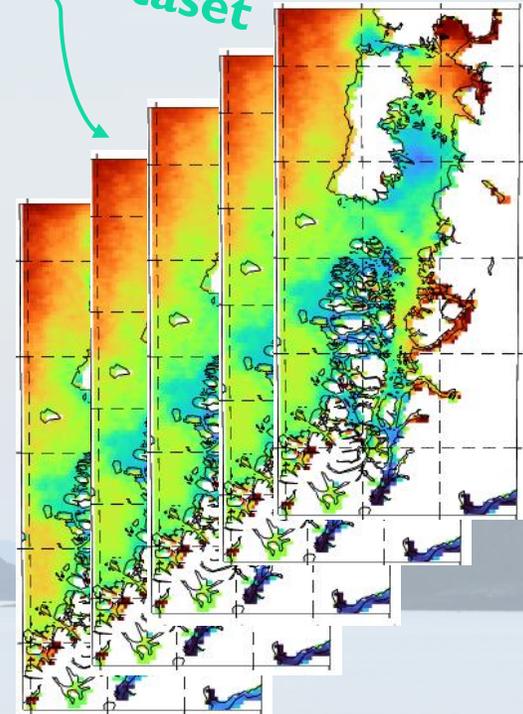


In situ-based climatology



SST Satellite dataset

Removing the bias from the satellite dataset

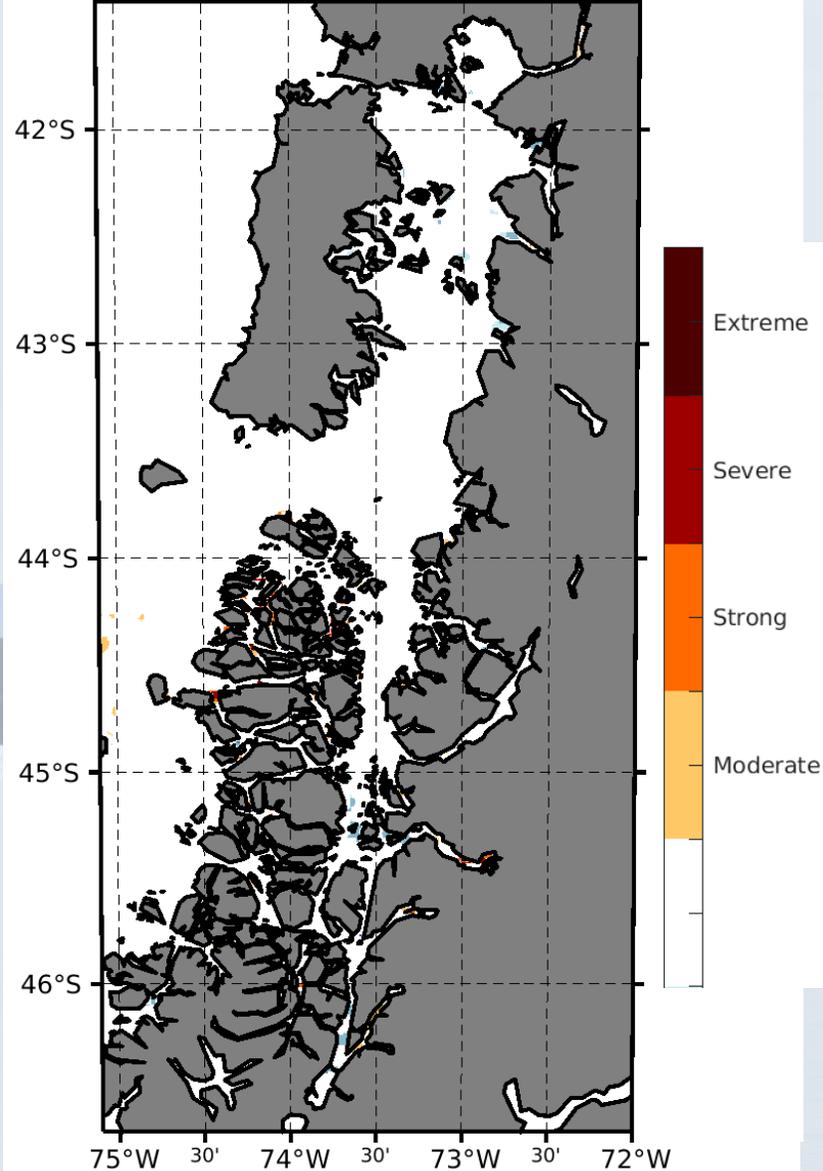


SST Satellite dataset

Align the satellite dataset on the in situ dataset

RESULTS

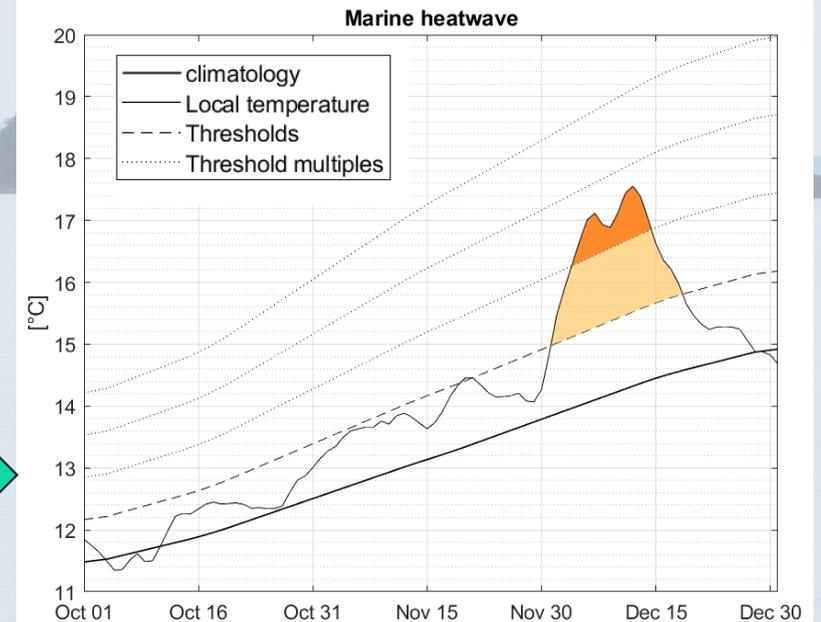
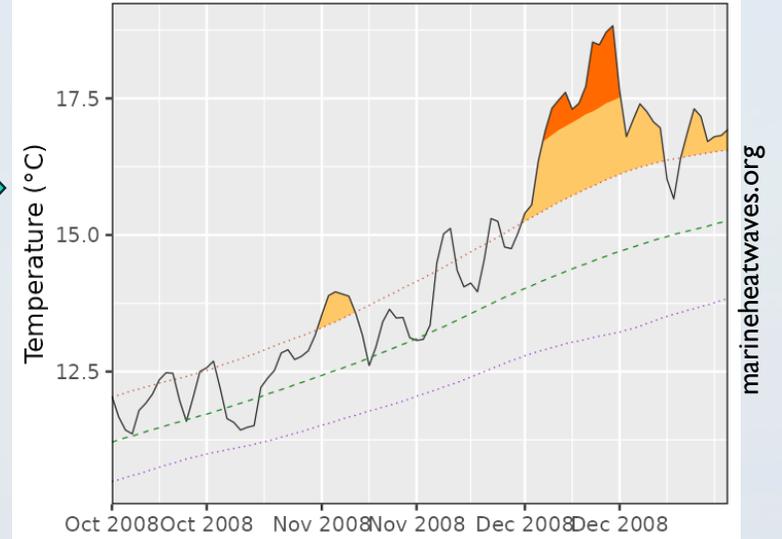
Category reached by the MHW on 2008-9-17



Development of the
MHW with NOAA
OISST product
(spatial resolution 1/4°)

Development of the
MHW with our
method
(spatial resolution
~900m)

Lon: 72.875°W Lat: 41.625°S



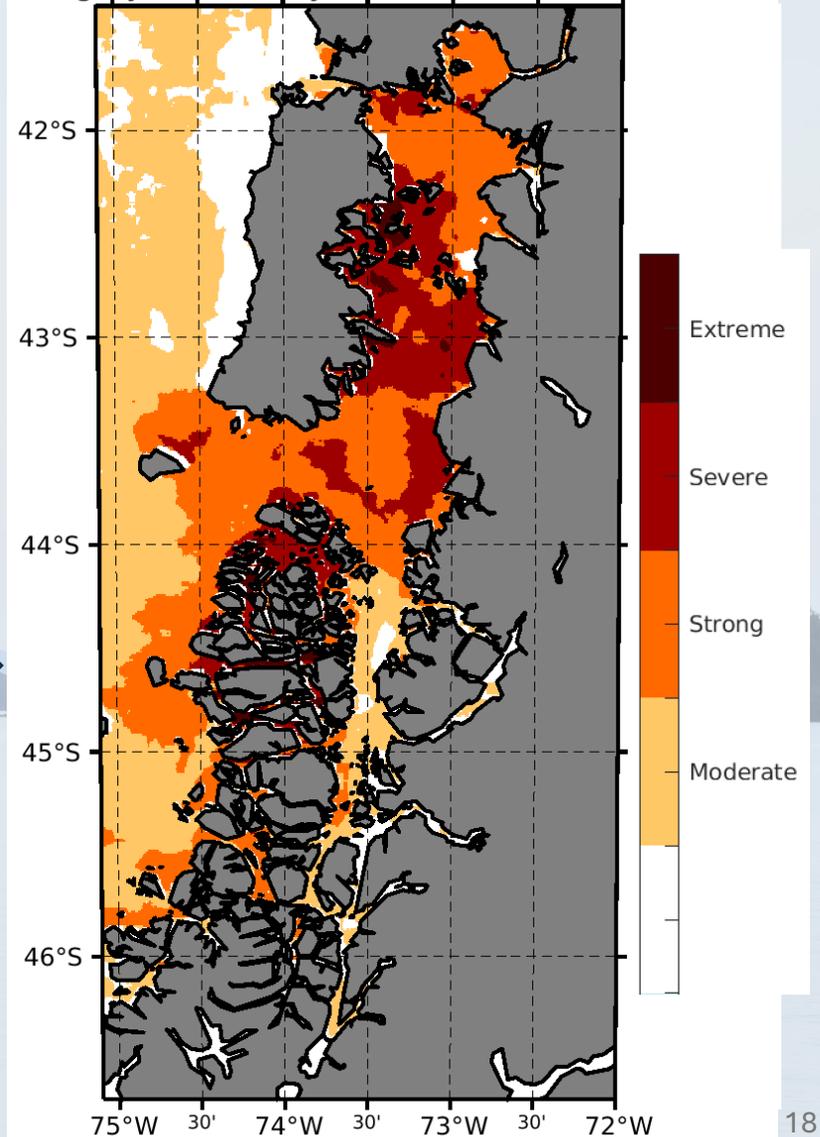
RESULTS



MHW on 2008-12-12
with **NOAA OISST**
product
(spatial resolution $1/4^\circ$)

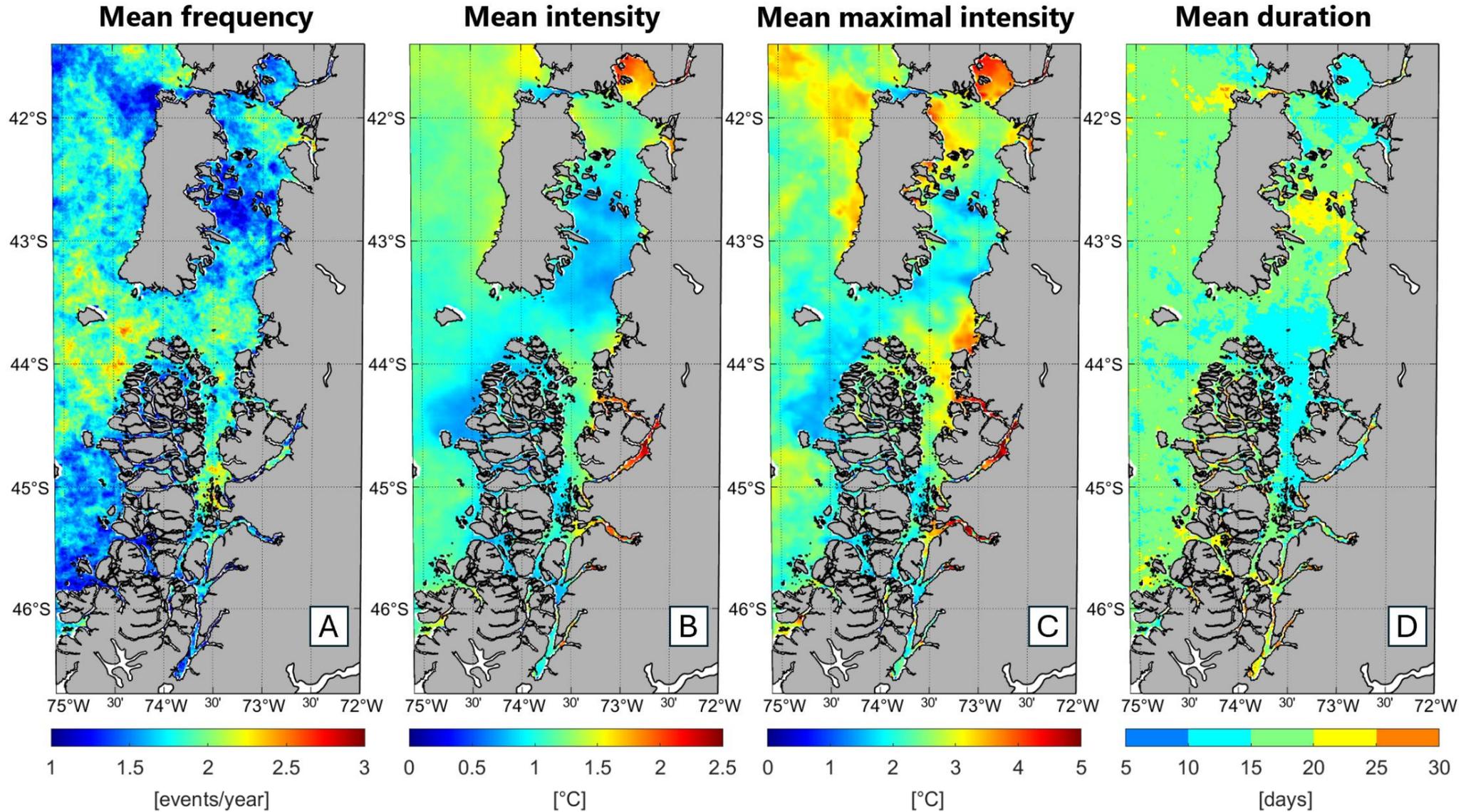
MHW on 2008-12-12
with **our methodology**
(spatial resolution
 $\sim 900\text{m}$)

Category reached by the MHW on 2008-12-12



THE NEED FOR APPROPRIATE RESOLUTION

MHWs average metrics (2003-2023)



High spatial variability

- Freshwater inputs
- Enclosed basins
- Local circulation

MHW

Pujol et al., Preprint 2025

CONCLUSIONS

Alternative for MHW detection

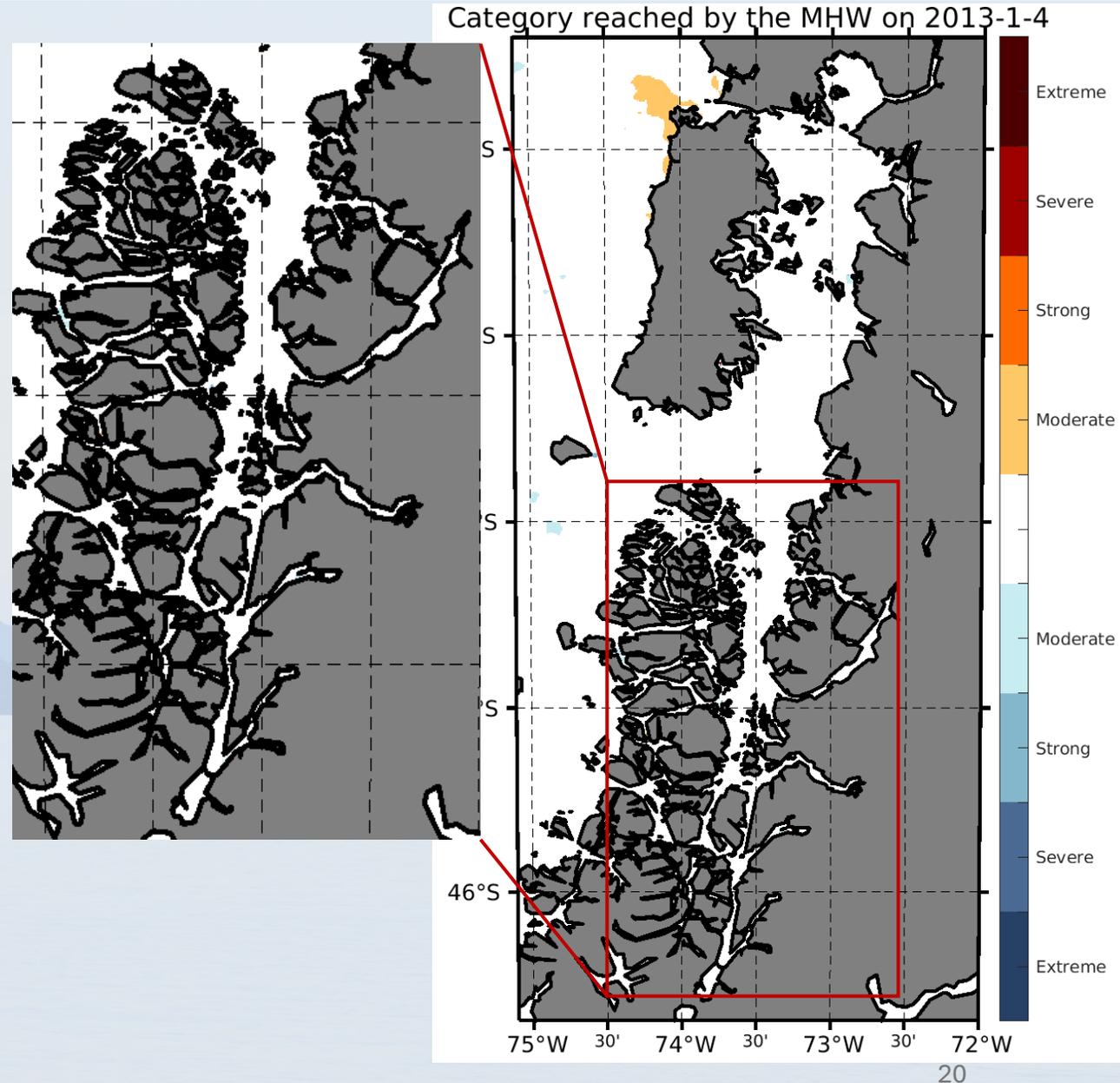
Combination of *in situ* and satellite data

Detection of MHWs at high-resolution (~900m)

MHWs do not develop uniformly and each basin shows different characteristics

MHWs associated to harmful algal blooms

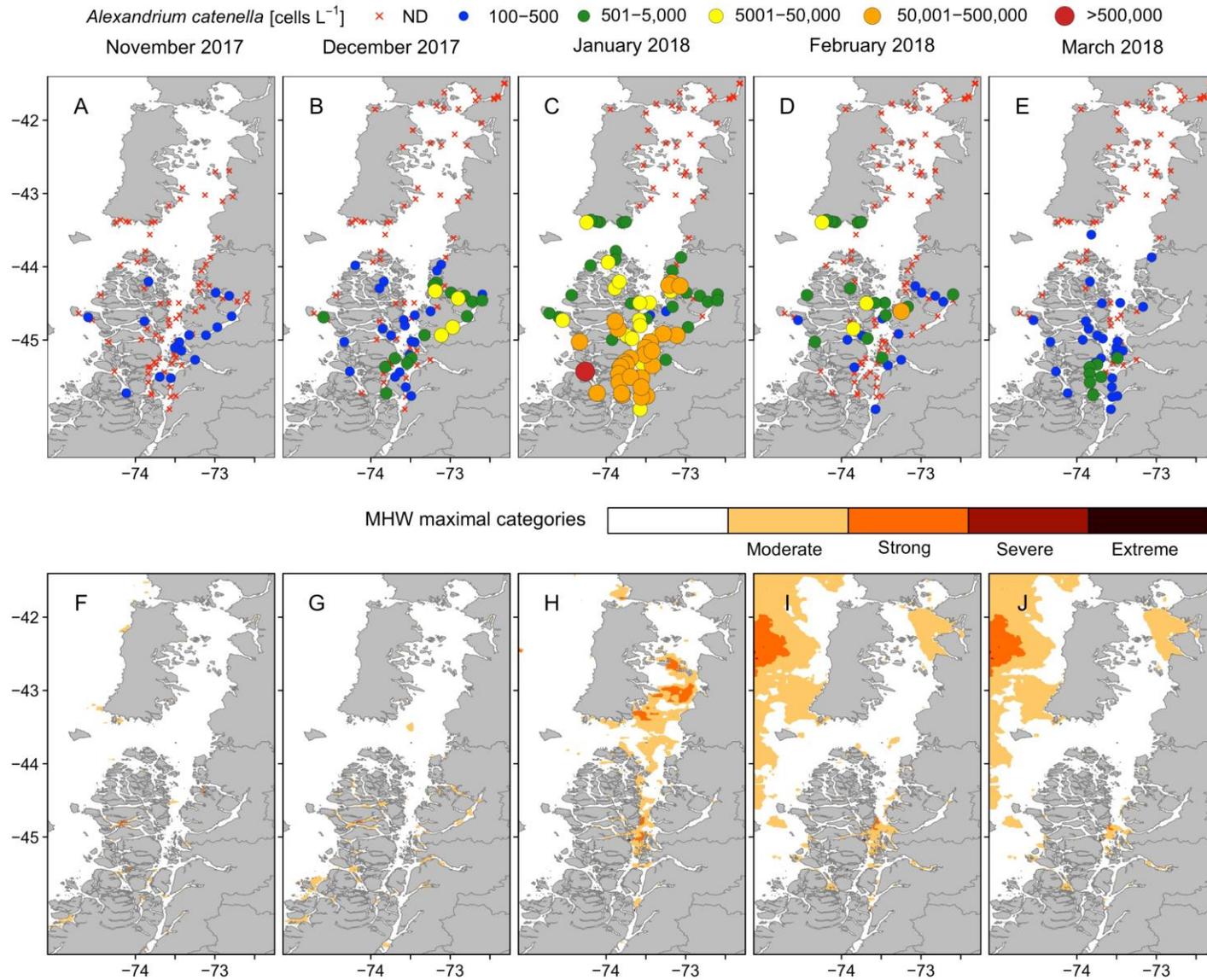
Important for aquaculture industry to monitor the different fjords and channels



SUPPLEMENTARY



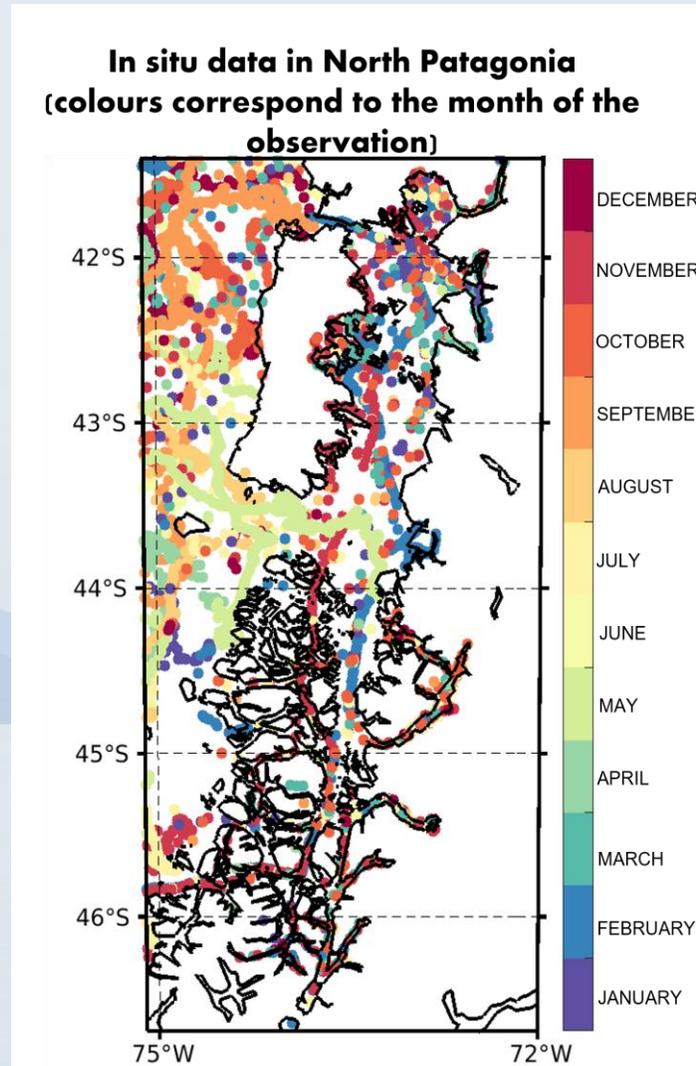
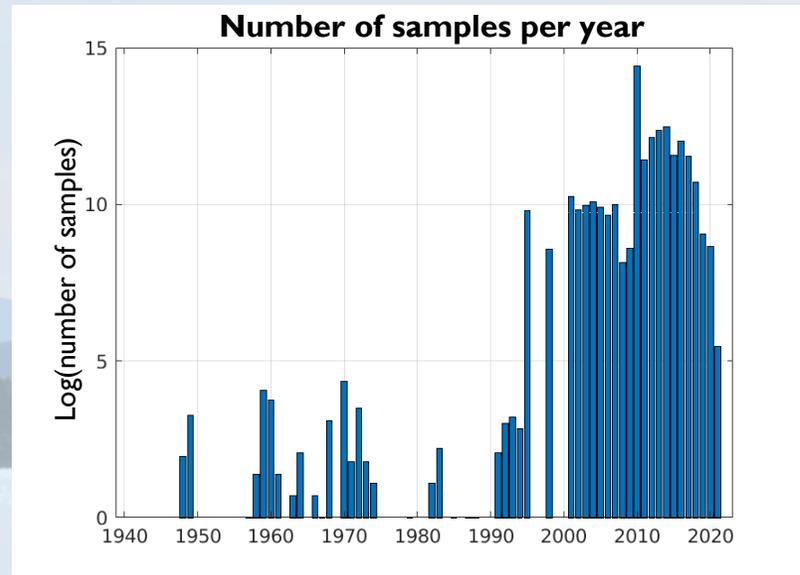
MHW CONSEQUENCES



**Toxic
phytoplanktonic
bloom**

MHWs

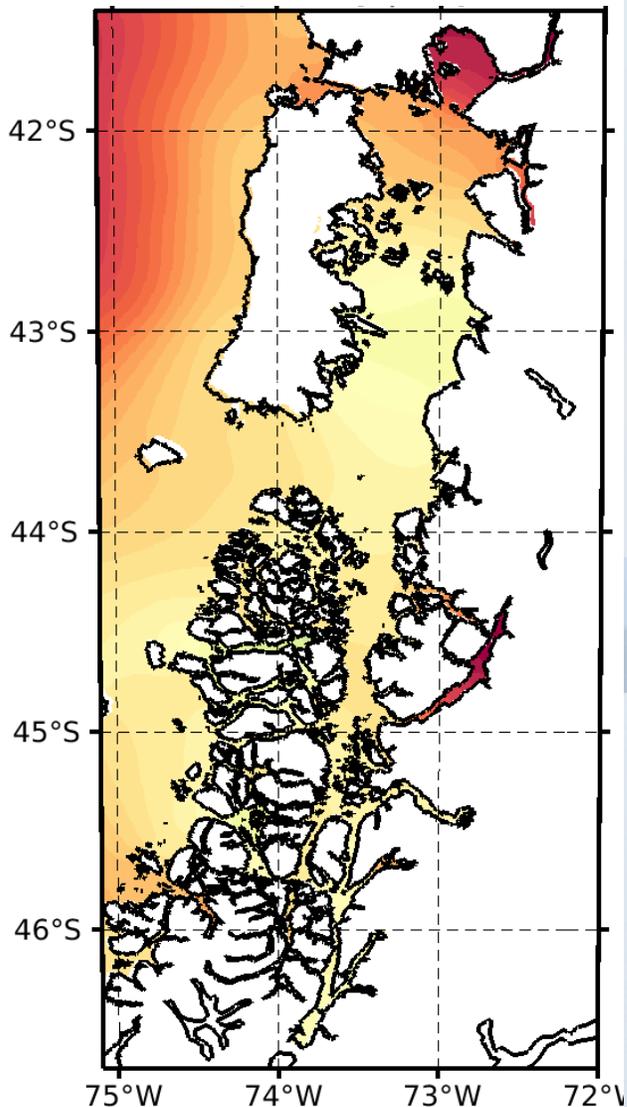
IN SITU DATA AVAILABLE



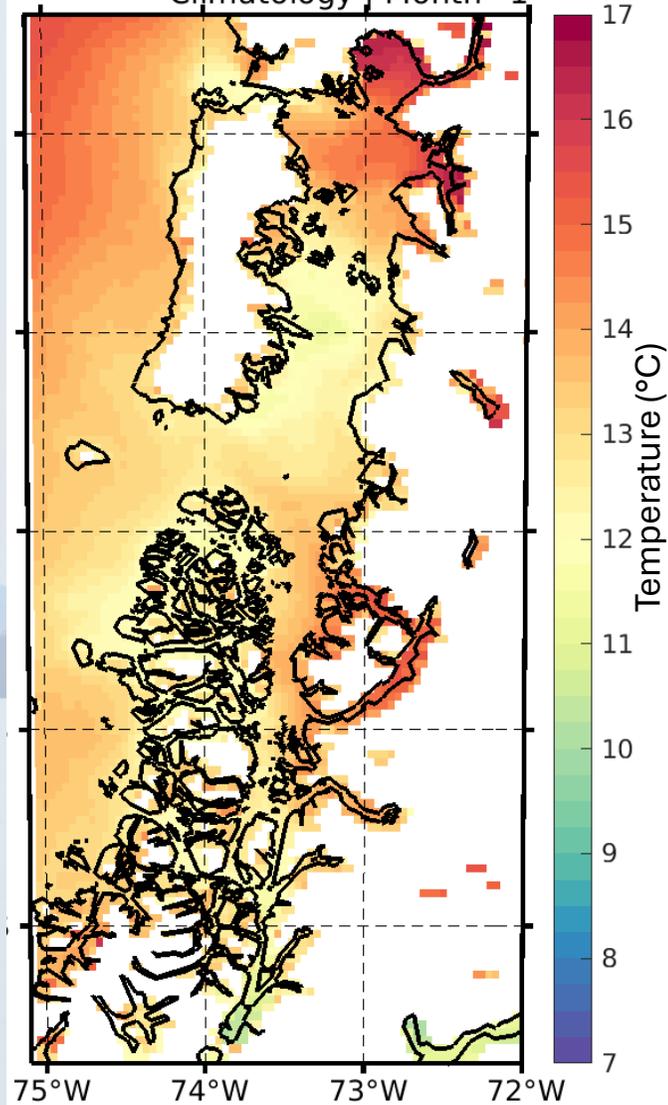
Total number of samples
~ 3 millions

CLIMATOLOGY VALIDATION

DIVA reconstruction
Climatology | Month=1

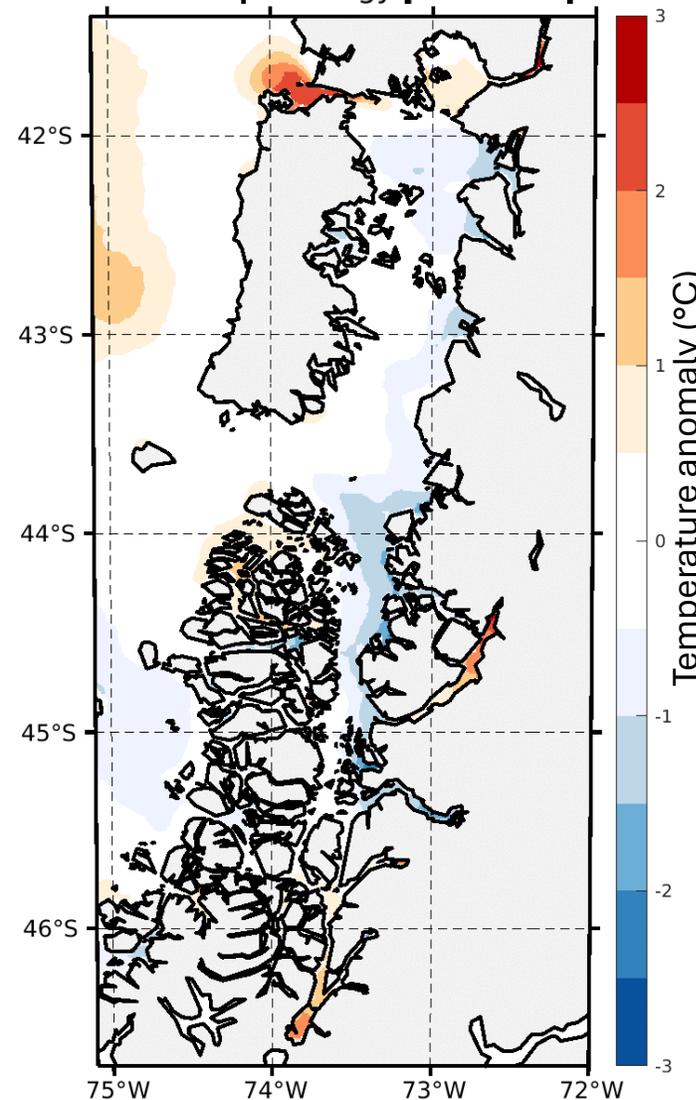


MODIS AQUA temperature
Climatology | Month=1



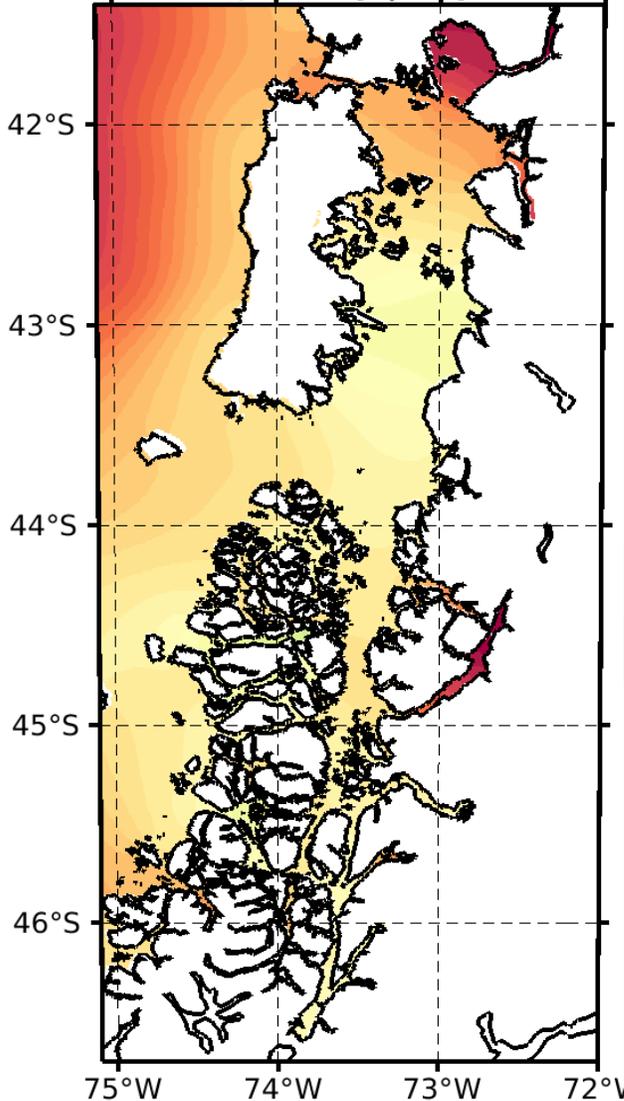
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Difference between DIVA and MODIS AQUA
Climatology | Month=1



VALIDATION OF THE CLIMATOLOGY

DIVA reconstruction
Climatology | Month=1.



5% of the in situ data kept apart for validation

	Bias between DIVA and in situ (°C)	rms	crms	Standard deviation in situ data
Jan	0,21	1,85	1,83	1,97
Feb	0,04	1,43	1,43	2,05
Mar	0,11	1,14	1,14	1,68
Apr	-0,07	1,01	1,00	0,83
May	-0,08	0,78	0,78	0,77
Jun	-0,08	0,71	0,70	0,46
Jul	0,06	0,87	0,87	0,59
Aug	-0,14	0,71	0,69	0,58
Sep	0,01	0,73	0,73	0,51
Oct	0,20	0,95	0,93	0,82
Nov	0,09	1,23	1,23	1,23
Dec	0,10	1,42	1,42	2,18

FILLING GAPS IN SATELLITE DATA

