Weather related temporal and spatial variability of high turbidity areas in the North Sea and the English Channel

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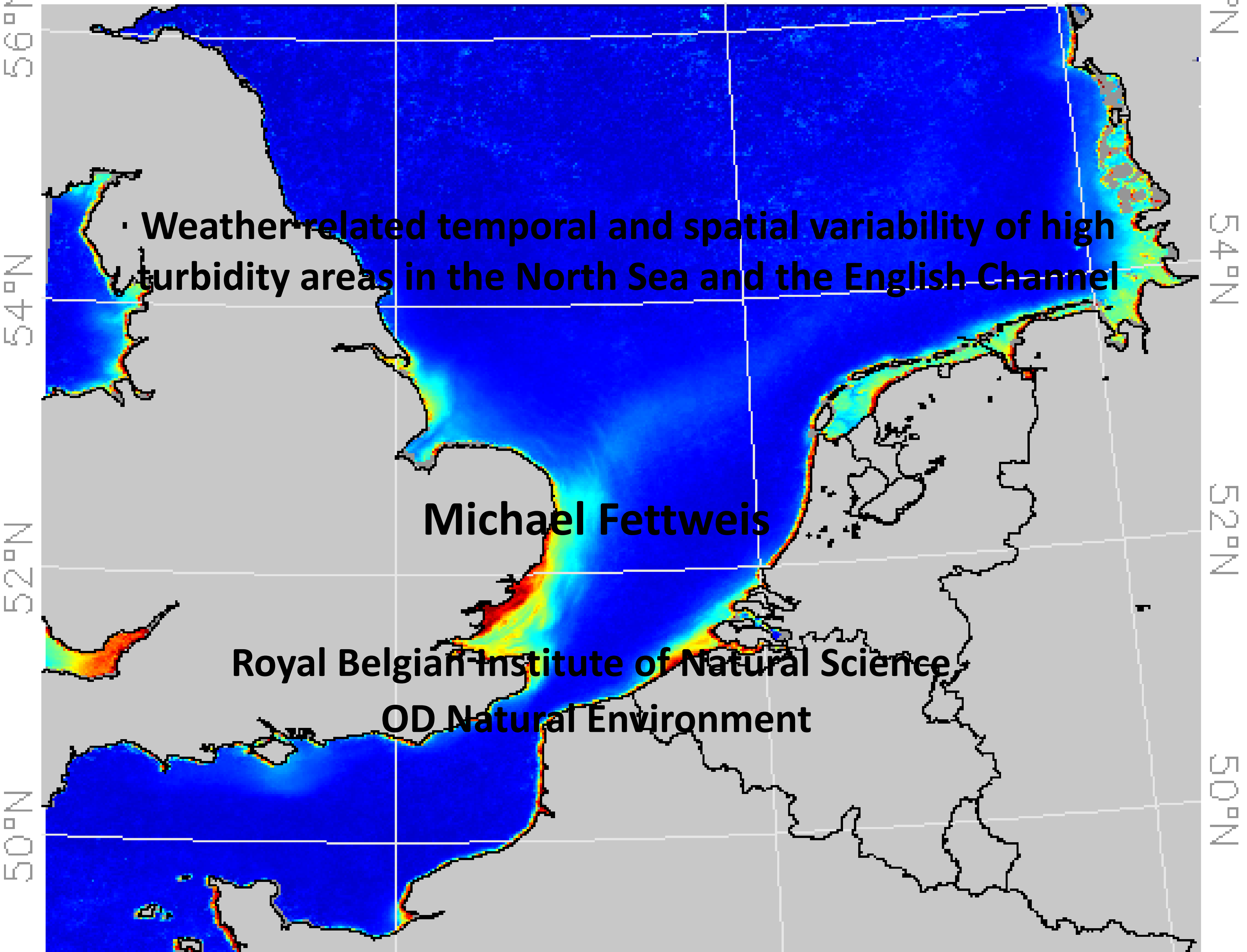


Research Questions: Suspended Particulate Matter

SPM is a key parameter for environmental condition: light condition, bed sediments, pollution:

- What is natural variability (space/time) of SPM concentration?
- What are the effects of large engineering works?

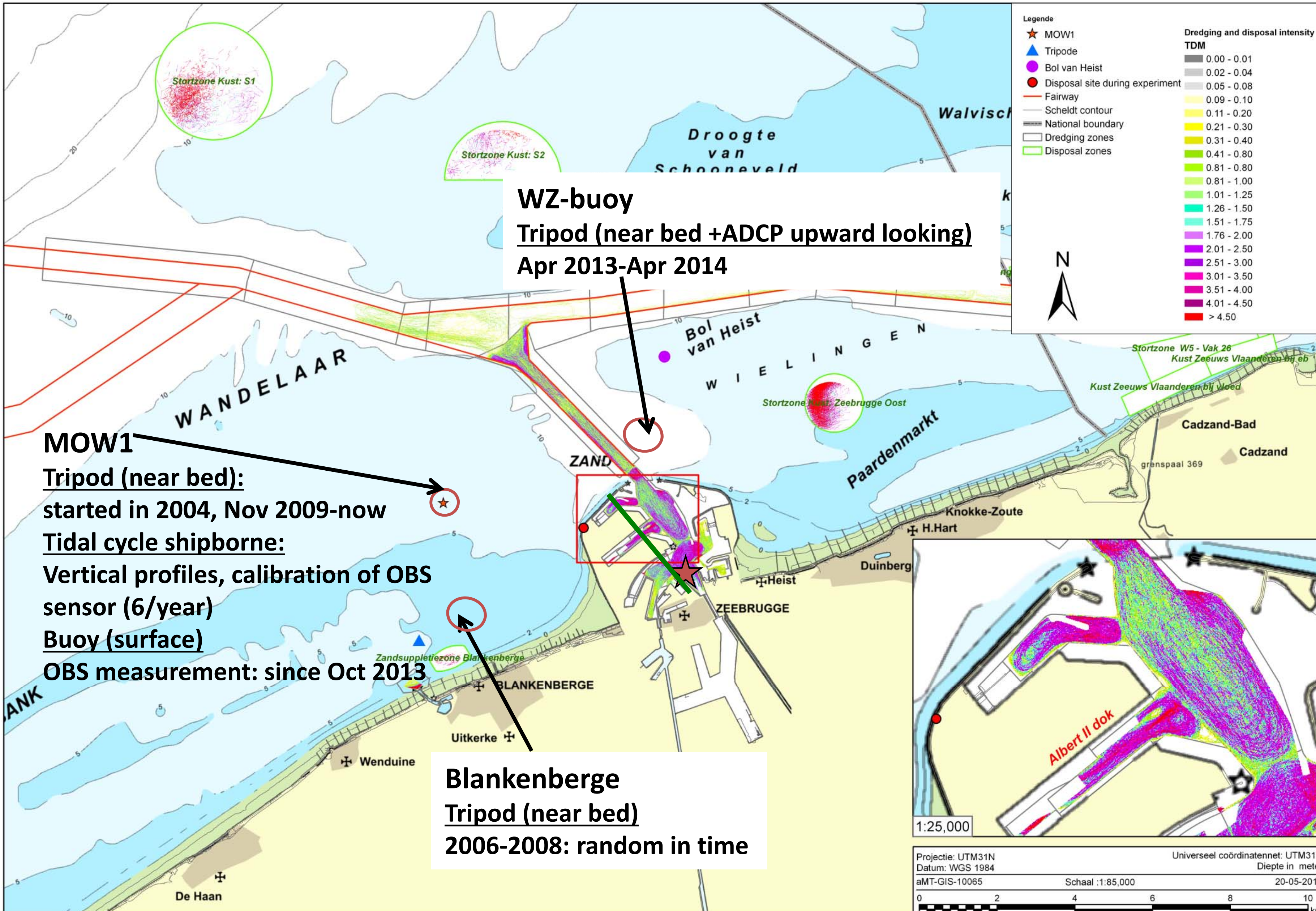
In many coastal areas there is a lack of **long-term in situ data**. However, these data are **necessary to determine the environmental status** of the coastal area.

Often, **monitoring is linked to specific projects** (eg dredging operations, specific construction) and are not aiming to understand the whole system:

- **Shifting baseline :** natural variability is related to specific operations, but the natural background values remain unknown.
- **Monitoring is not process-oriented but project oriented**: the variability cannot be related to the natural processes

RBINS is doing long-term in situ data and using remate sensing data (MODIS, MERIS) to understand natural process and to study long-term processes

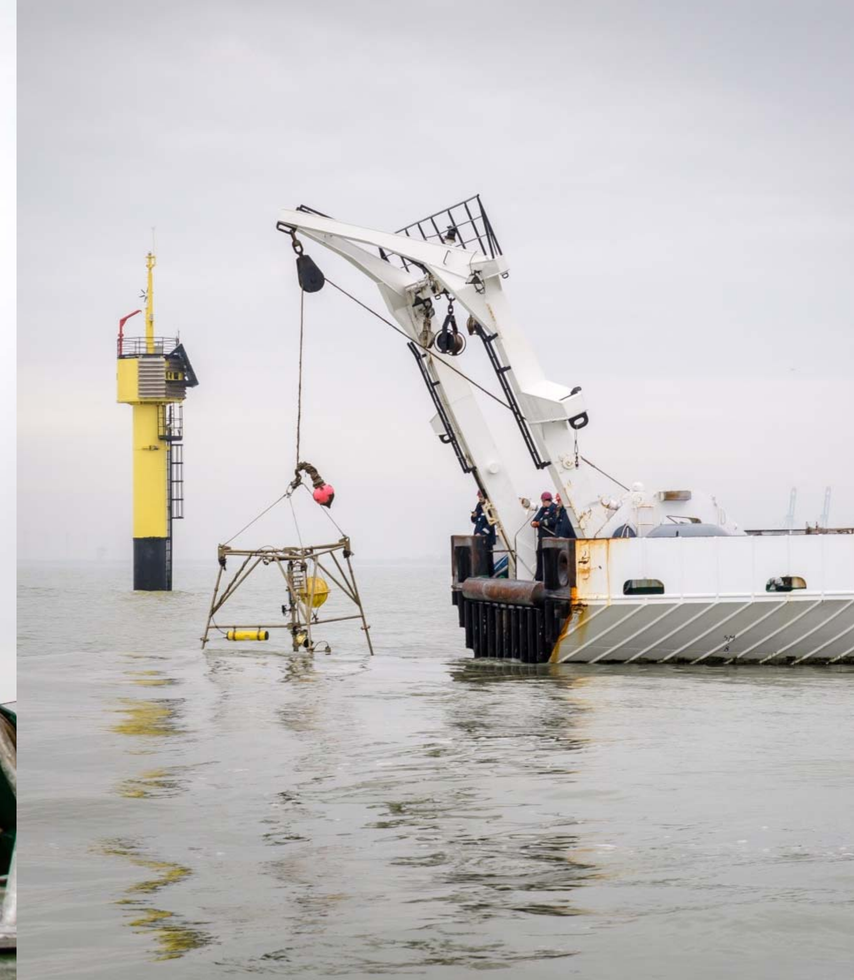
SPM concentration from in situ measurements



SPM concentration from in situ measurements

Tripod MOW1:

OBS: SPM concentration,
ADP: SPM concentration + velocity,
ADV: Turbulence, velocity
LISST 100X: Particle size distribution
<u>CTD, passive sampler (pollution), CPoD (sea mamals)</u>



SPM concentration from in situ measurements

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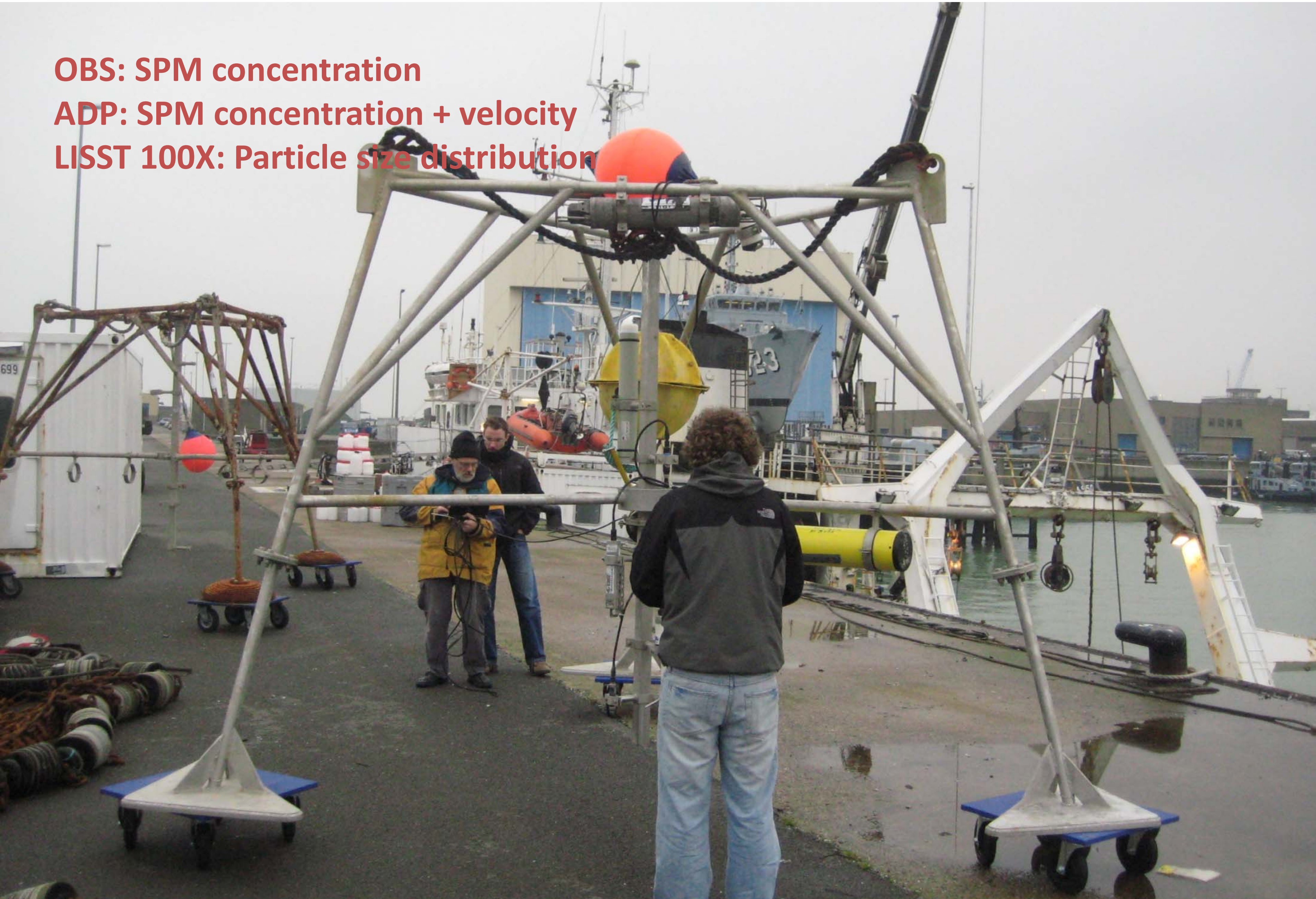
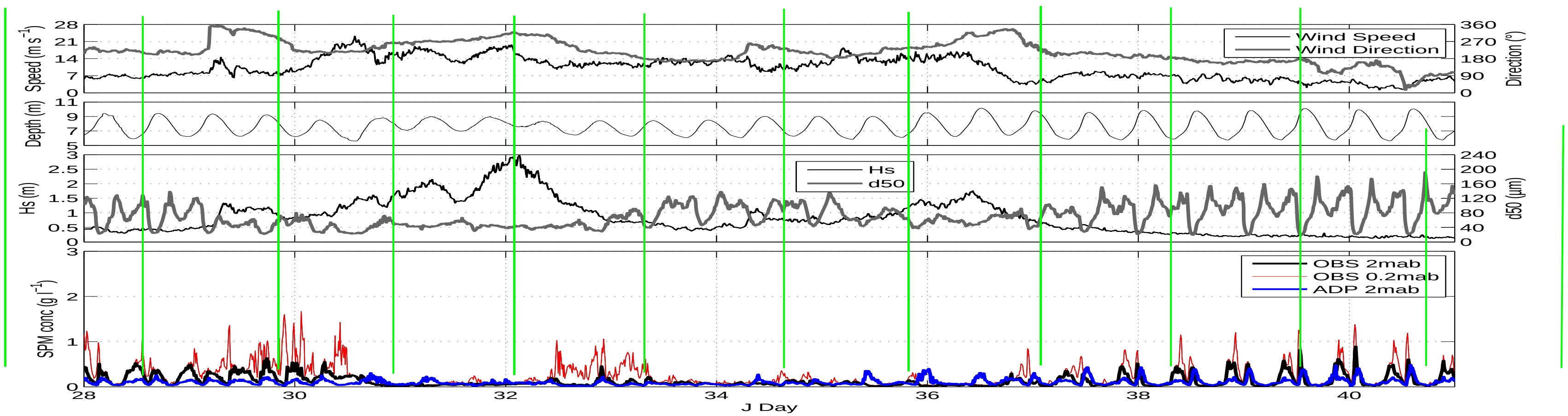


in situ vs. remote sensing SPM concentration



SPM concentration varies on different time scales:

•neap-spring

•**ebb-flood signal (quarter-diurnal)** + higher frequencies

•Meteo related variations

•seasonal

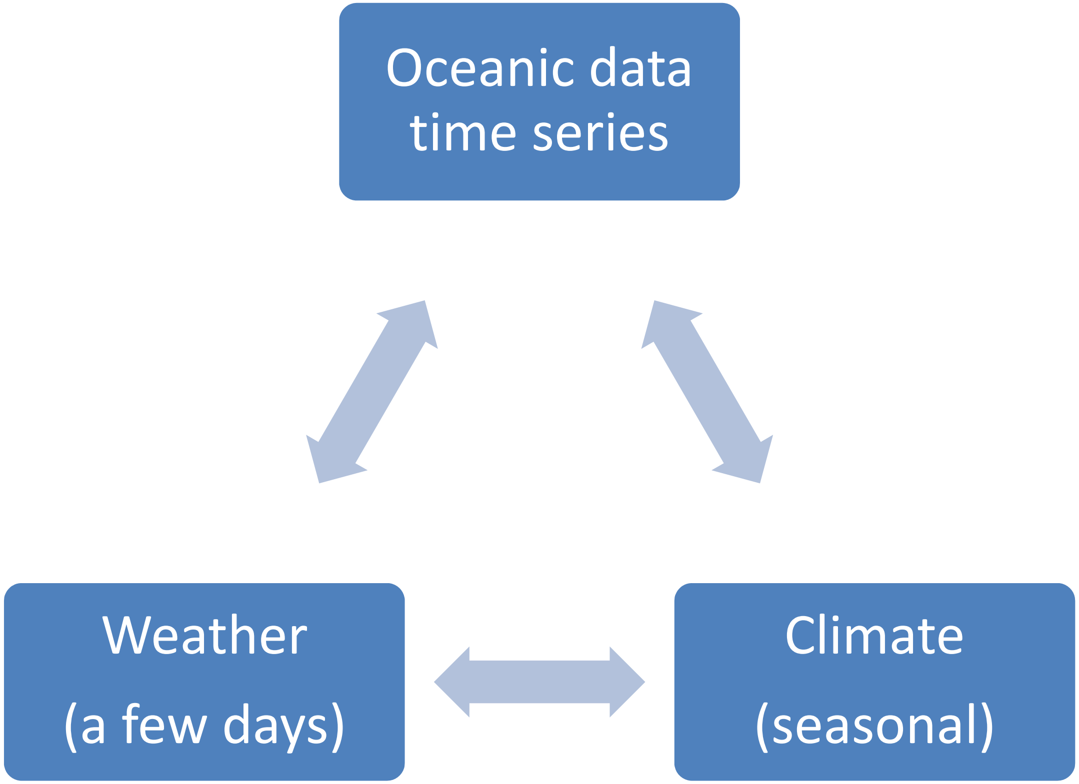
Sampling frequency of MODIS is too low, and many data are missing due to clouds, but long-time series are available (2002-today)

→ grouping and averaging according to some criteria:

•**Season**, **oceanographic data** (currents, waves), see e.g. Dobrynin et al. 2010, Pietrzak et al. 2011

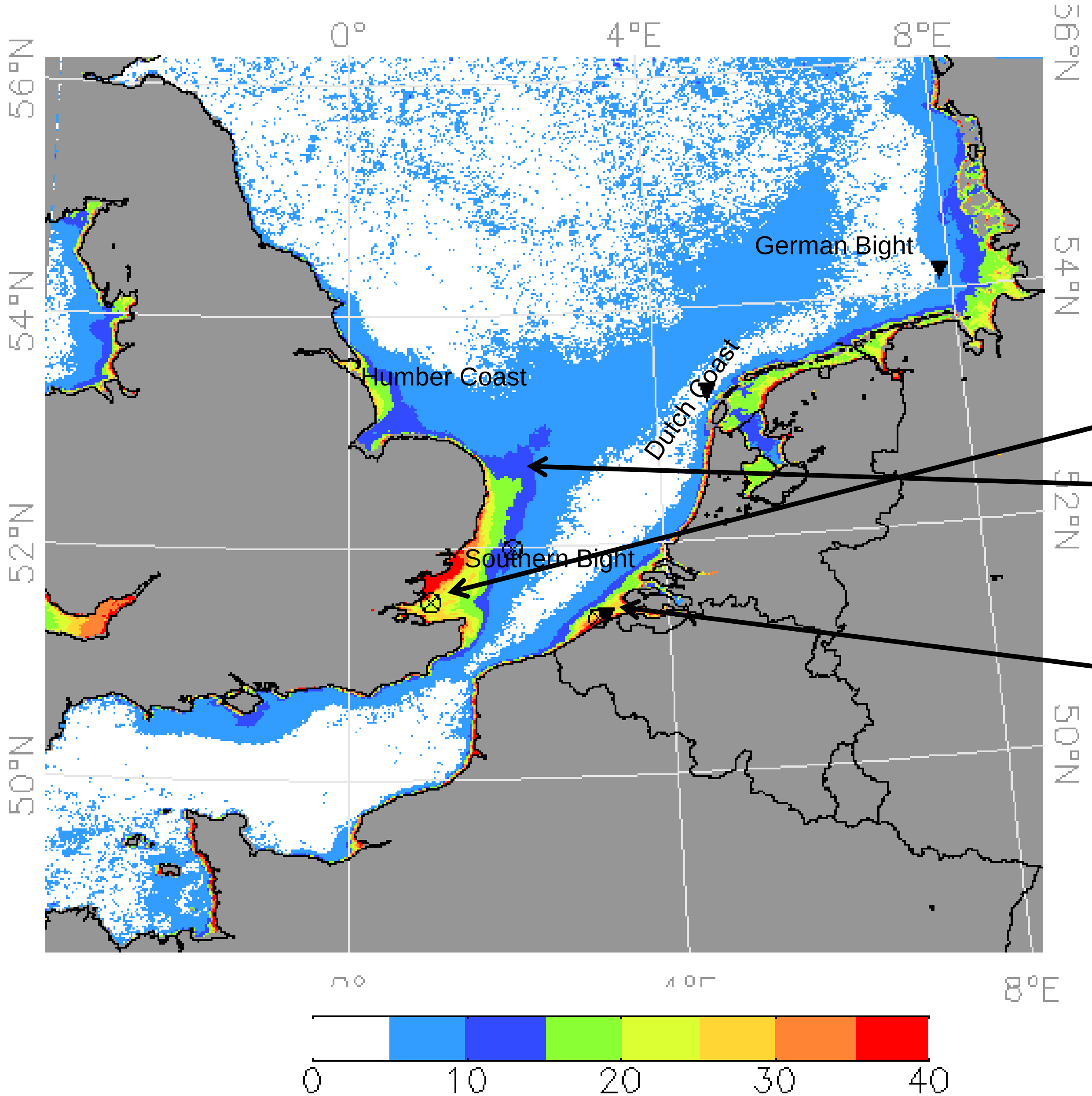
•**Meteorology, climate**

Research Questions: Suspended Particulate Matter



- A method is proposed to produce ensemble averages of Suspended Particulate Matter (SPM) concentrations maps from satellite, in situ data and model data for typical meteorological and climatological conditions
- The approach provides a tool to improve our understanding of coastal and shelf sea processes, especially with respect to variations of SPM concentration distribution forced by weather, climate and climate change.

SPM concentration 2002-2009 from MODIS



High turbidity zones

Humber coast

Thames

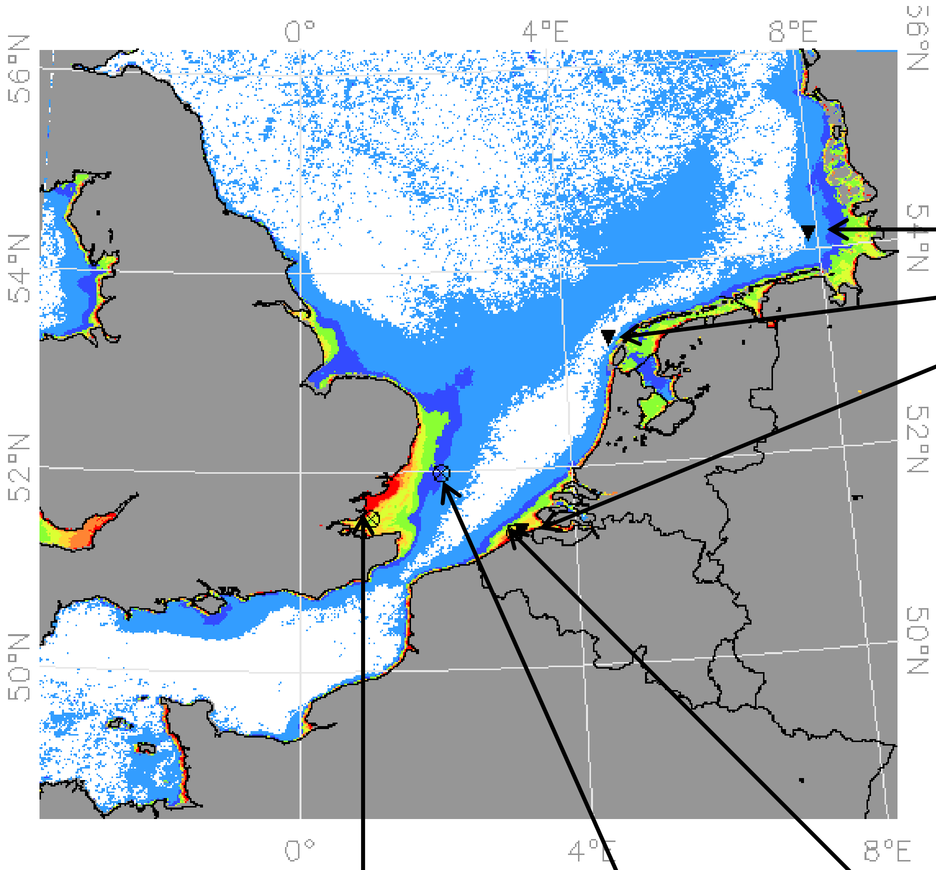
East-Anglain Plume

German Bight

Wadden Sea

Belgian-Dutch coastal area

SPM concentration from in situ measurements



Wave data
Helgoland
Eierlandse Gat
BvH

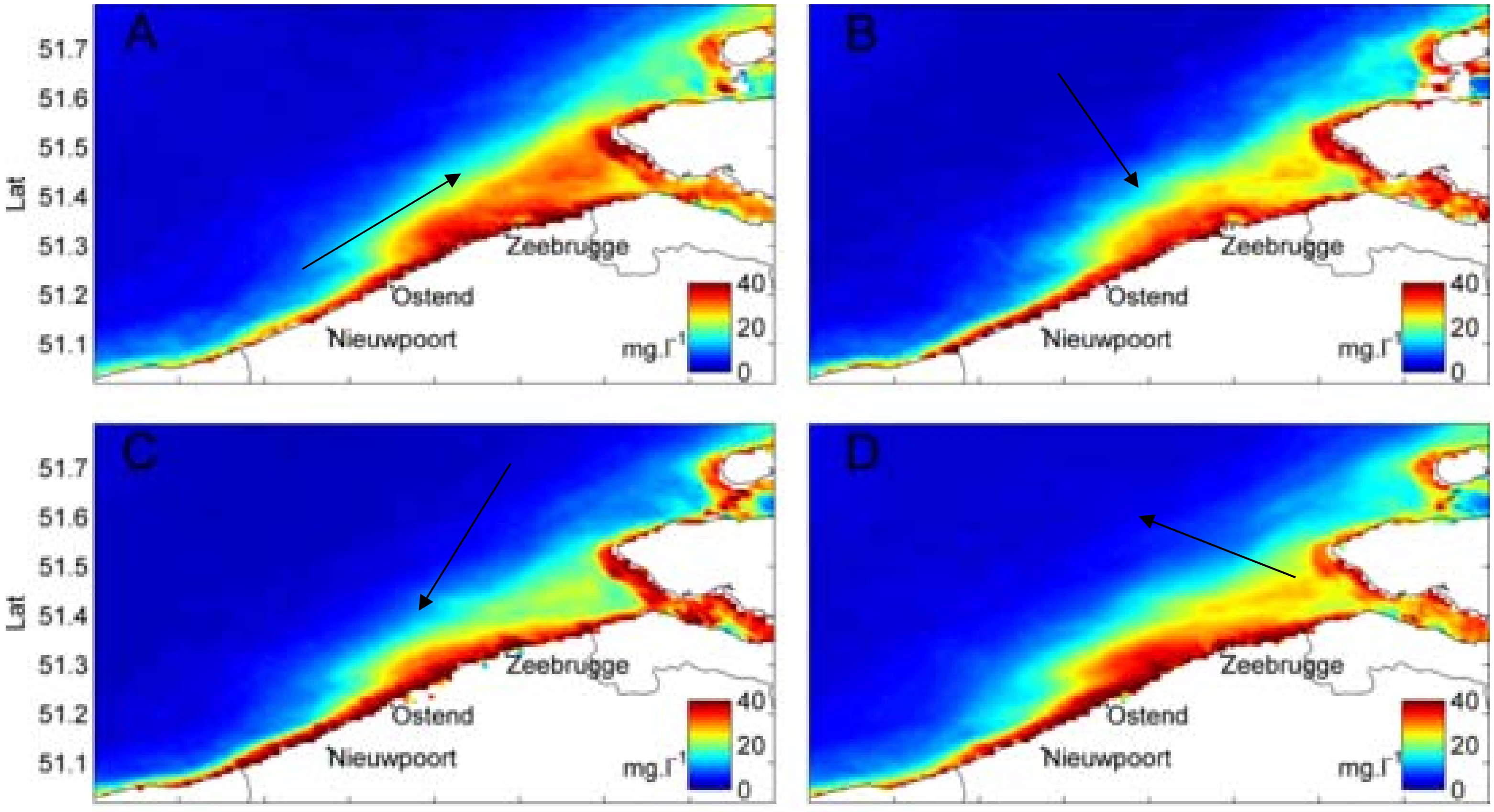
Hydrodynamic information is from 3D Coherens model

SPM concentration

West Anchorage West Gabbard MOW1

Meteorology, climate

Classification according to wind direction for B-Nl coastal zone: local



Larger areas: weather types and climate indices (e.g. NAO)

Meteorology: Weather types

Automated Lamb (1972) classification of 27 weather types centered above the British Isles:

- Weather type is described using the locations of high and low-pressure centres that determines the direction of geostrophic flow
- Classification is based on pressure gradients, geostrophic winds and vorticity indices

Jenkinson & Collison (1977) objectification of the classification

Demuzere et al. (2009) has centered the classification above Belgium → representative for North Sea and has simplified the WT into 11 types

- ***Unclassified**: 'calm' weather*
- ***2 vorticity type**: anticyclonic, cyclonic*
- ***8 directional types**: N, NE, E, SE, S, SW, W, NW*

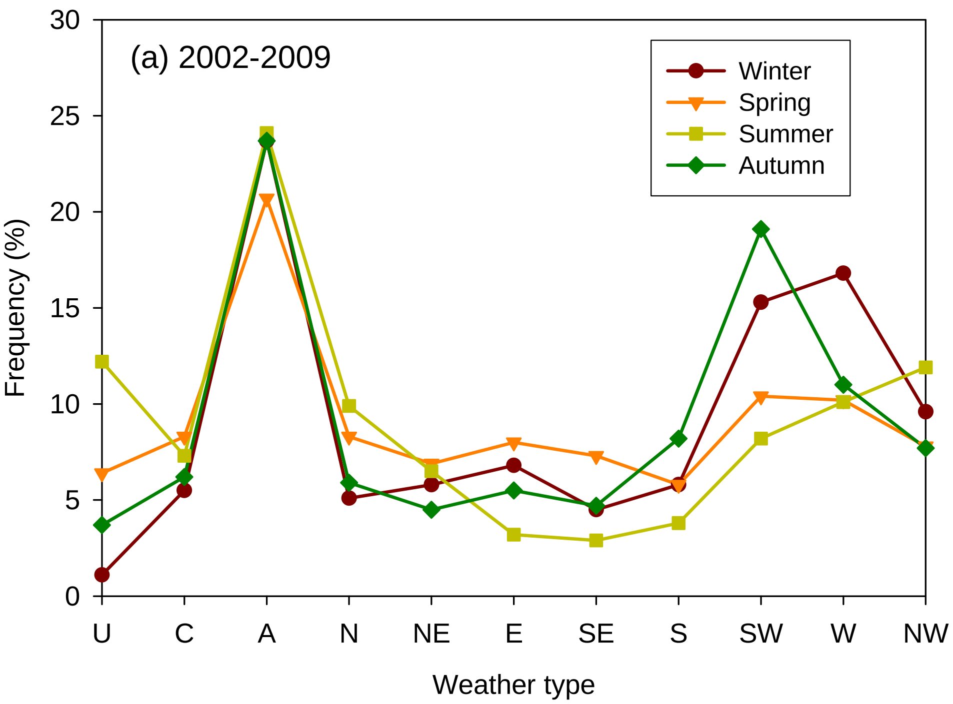
We have used 6h meteo data from UK-MET Office to classify weather for 2002-2009

Frequency of Weather Types

Unclassified *(5%)*

Vorticity types*: C (7%), A (23%)*

Directional types*: N (8%), NE (7%), E (6%), SE (5%), S (6%), SW (13%), W (12%), NW (9%)*



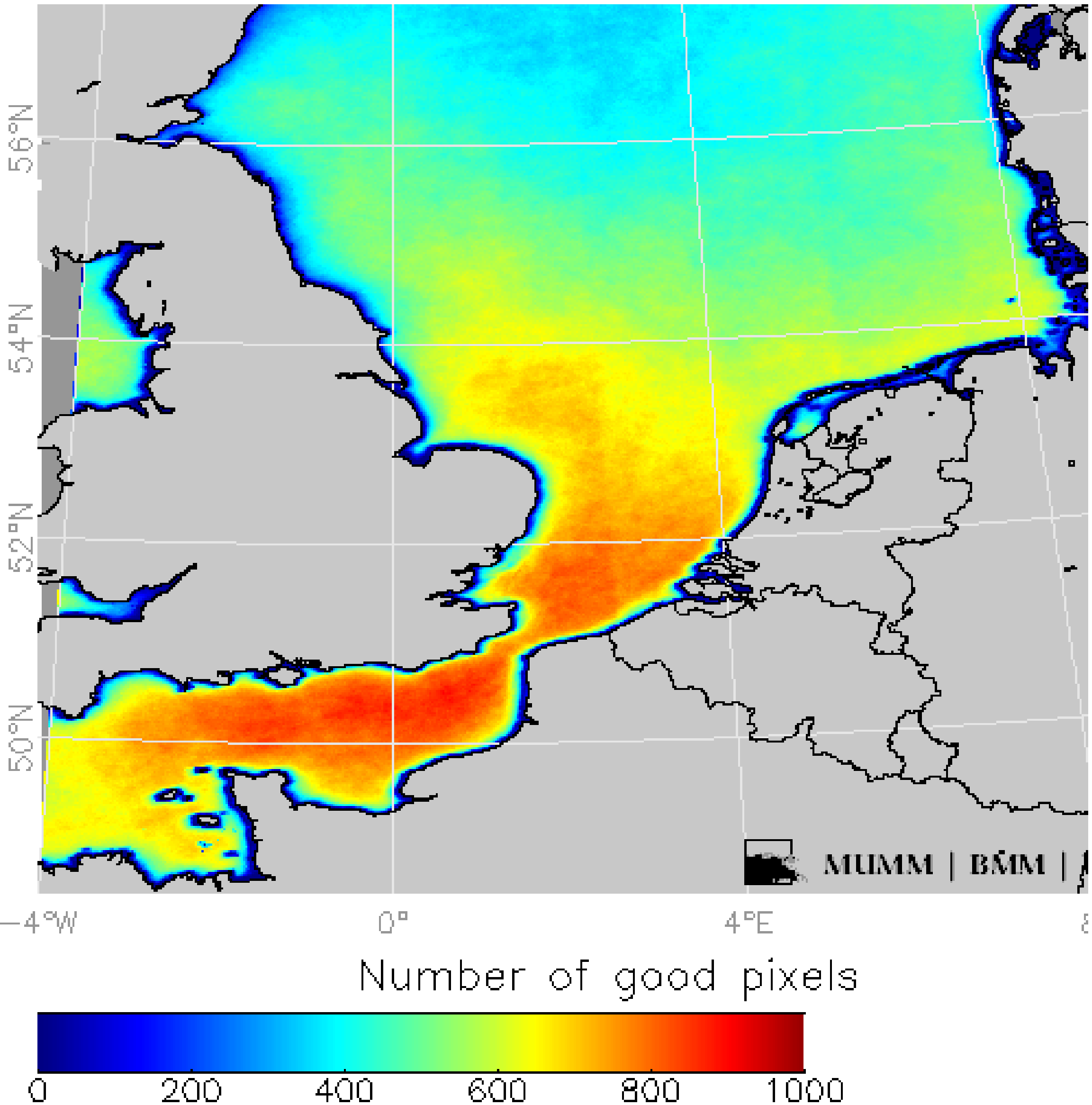
Frequency of satellite image per WT depends on cloud cover (12% of good pixels for all images in southern North Sea):

Unclassified *(17%)*

Vorticity types*: C (10%), A (13%)*

Directional types*: N (12%), NE (17%), E (23%), SE (25%), S (14%), SW (7%), W (8%), NW (9%)*

MODIS DATA 2002-2009



total 3712 images (±1/day)

resolution = 1×1 km²

Number of good pixels = on average 434 in whole North Sea

- decreases toward N
- lower along coastline (reflection from land)

Frequency of cloud free data

Frequency of weather types

Unclassified *(5%)*

Vorticity types*: C (7%), A (23%)*

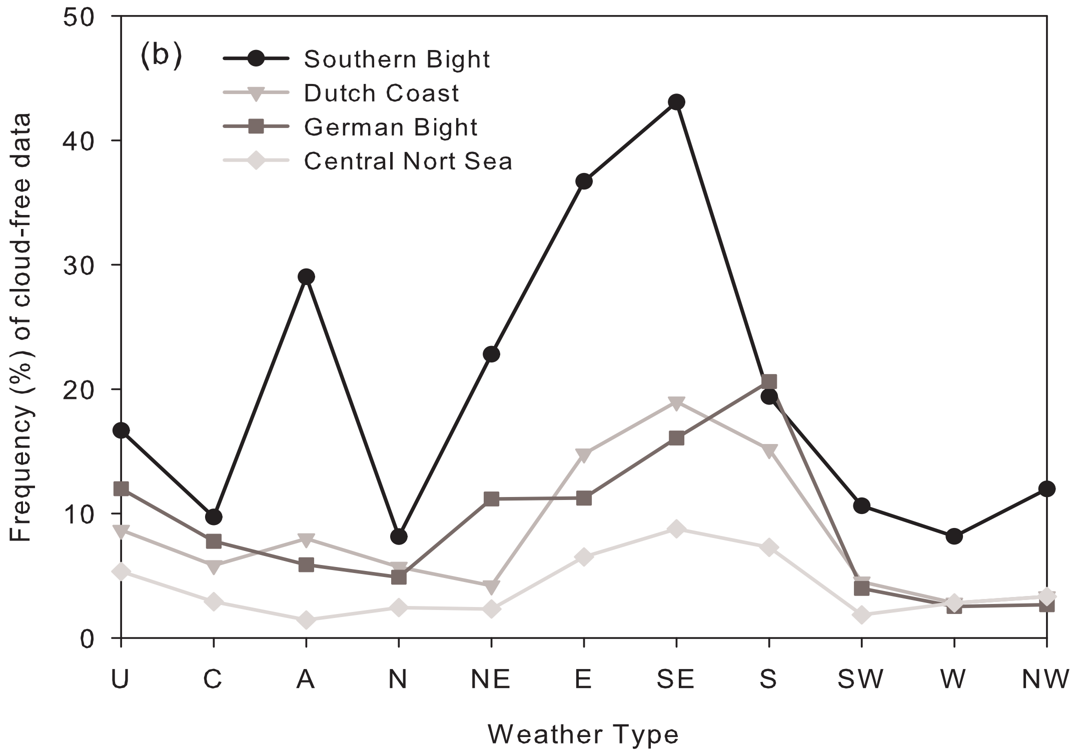
Directional types*: N (8%), NE (7%), E (6%), SE (5%), S (6%), SW (13%), W (12%), NW (9%)*

Frequency of cloud free data (southern Bight)

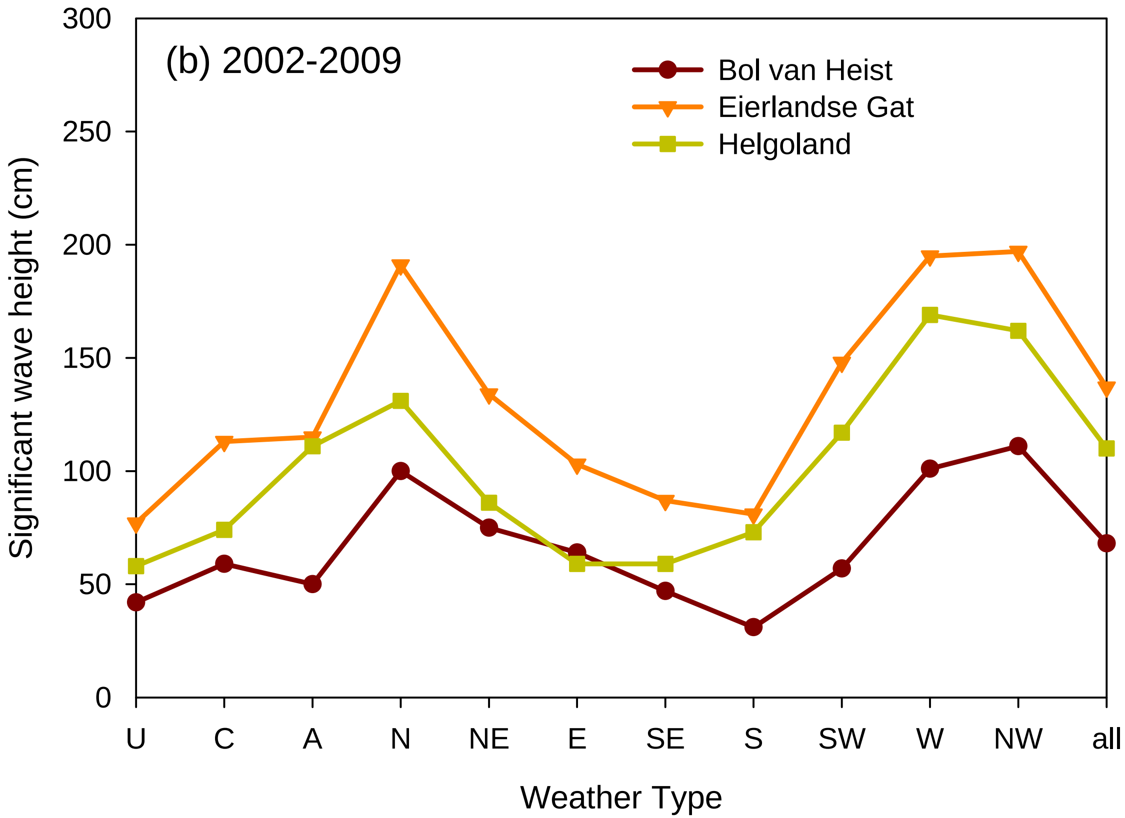
Unclassified *(17%)*

Vorticity types*: C (10%), A (13%)*

Directional types*: N (12%), NE (17%), E (23%), SE (25%), S (14%), SW (7%), W (8%), NW (9%)*



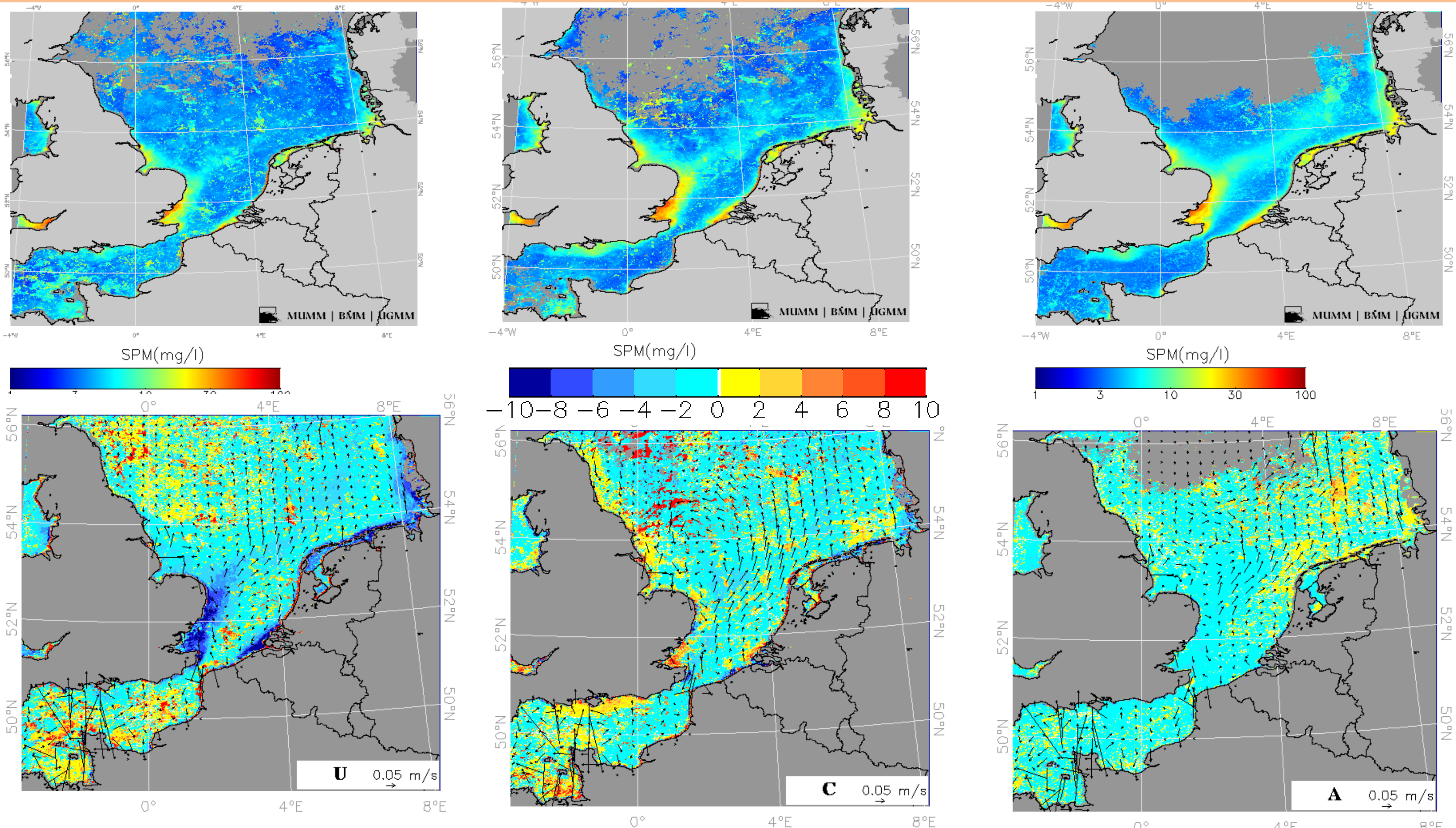
Wave data according to weather type



Wave height depends on weather type and location:

Resuspension-favourable
Southern Bight: N, W, NW
Dutch Coast: A, N, NE, E, SW, W, NW
German Bight: A, N, SW, W, NW

Unclassified	C-vorticity	A-vorticity



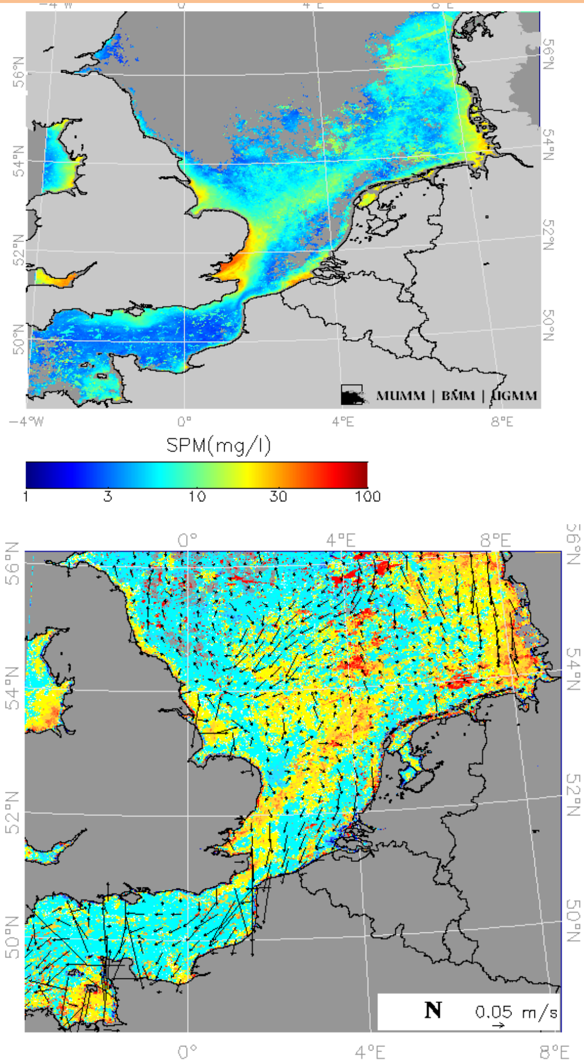
significant wave height (cm)

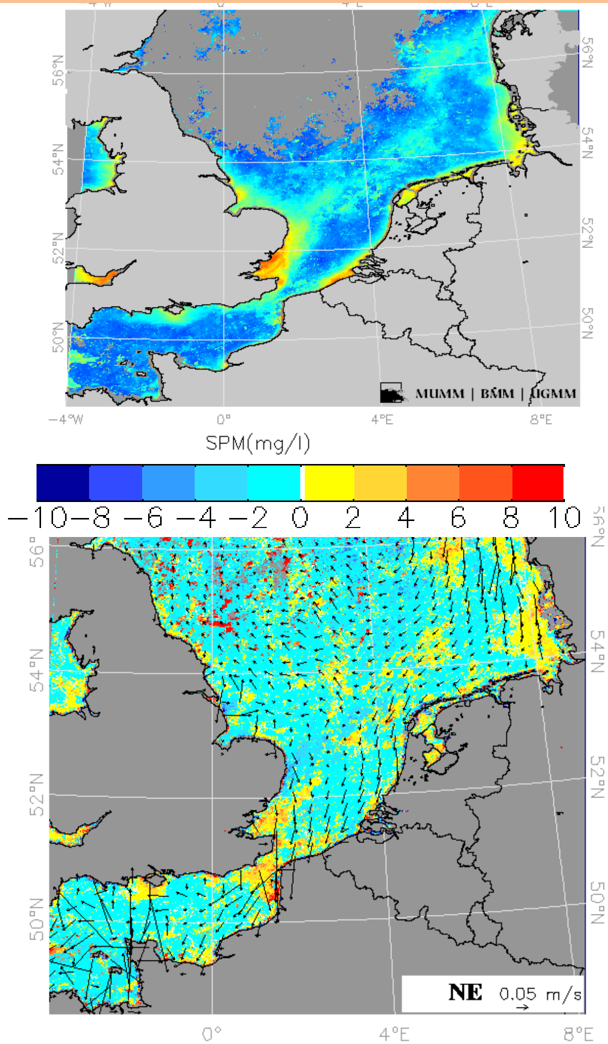
	Unclassified	C-vorticity	A-vorticity
BvH:	42 cm	59 cm	50 cm
Eierl. Gat:	77 cm	113 cm	191 cm
Helgol.	58 cm	74 cm	111 cm

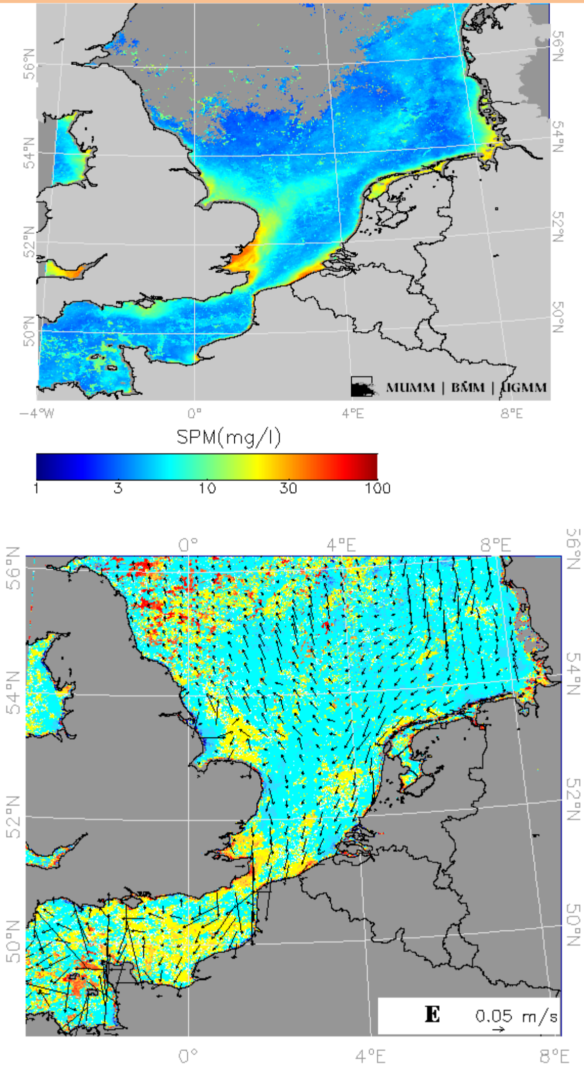
% of images during summer & spring

Unclassified	C-vorticity	A-vorticity
82%	57%	53%

N	NE	E







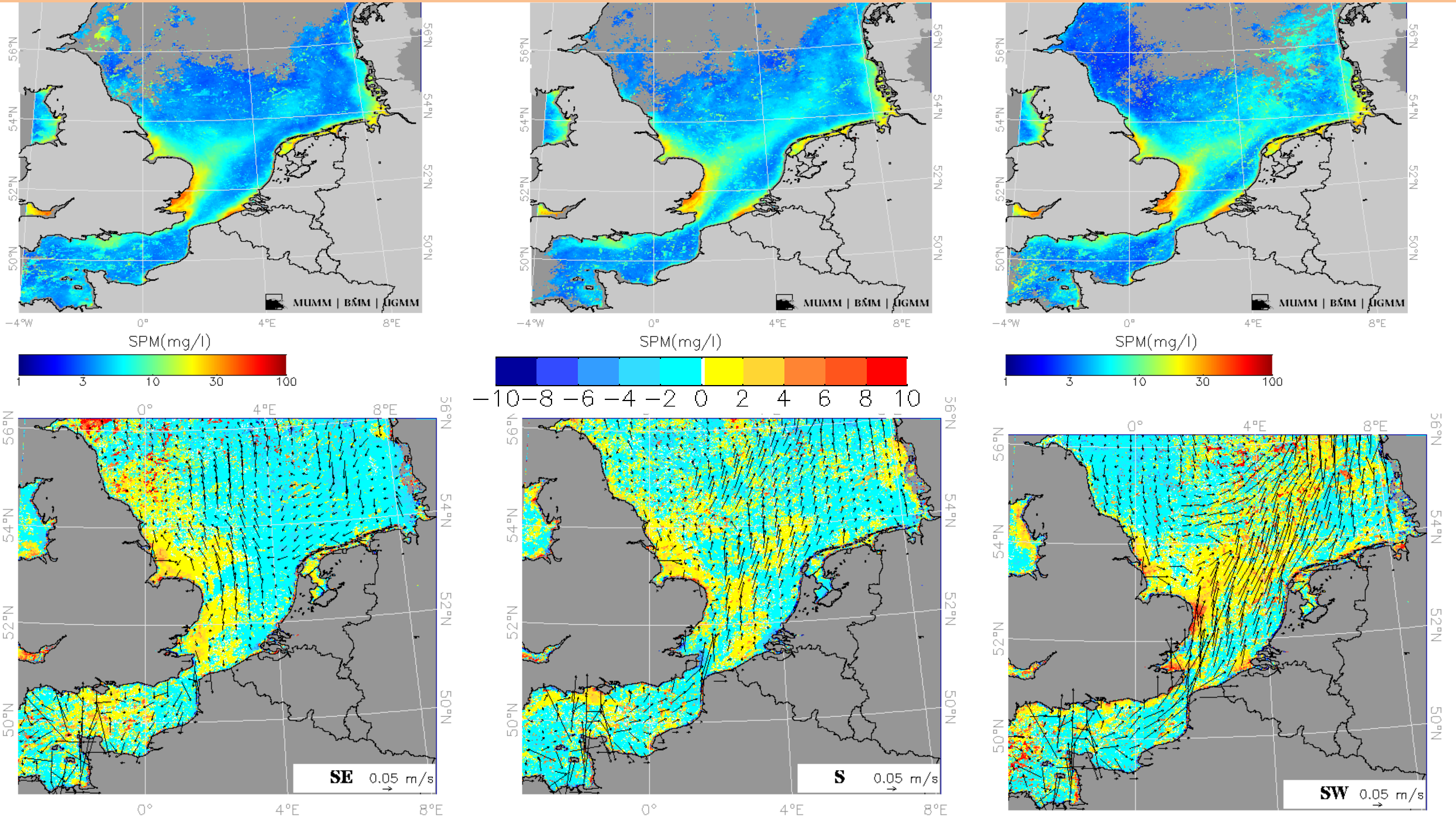
significant wave height (cm)

	N	NE	E
BvH:	100 cm	75 cm	64 cm
Eierl. Gat:	191 cm	134 cm	103 cm
Helgol.	131 cm	86 cm	59 cm

% of images during summer & spring

N	NE	E
57%	65%	52%

SE	S	SW



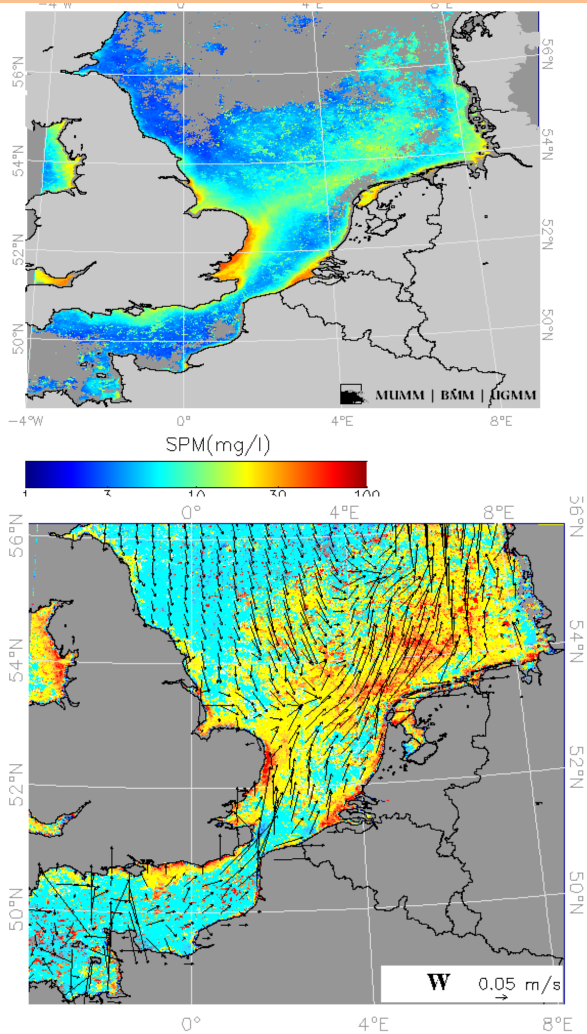
significant wave height (cm)

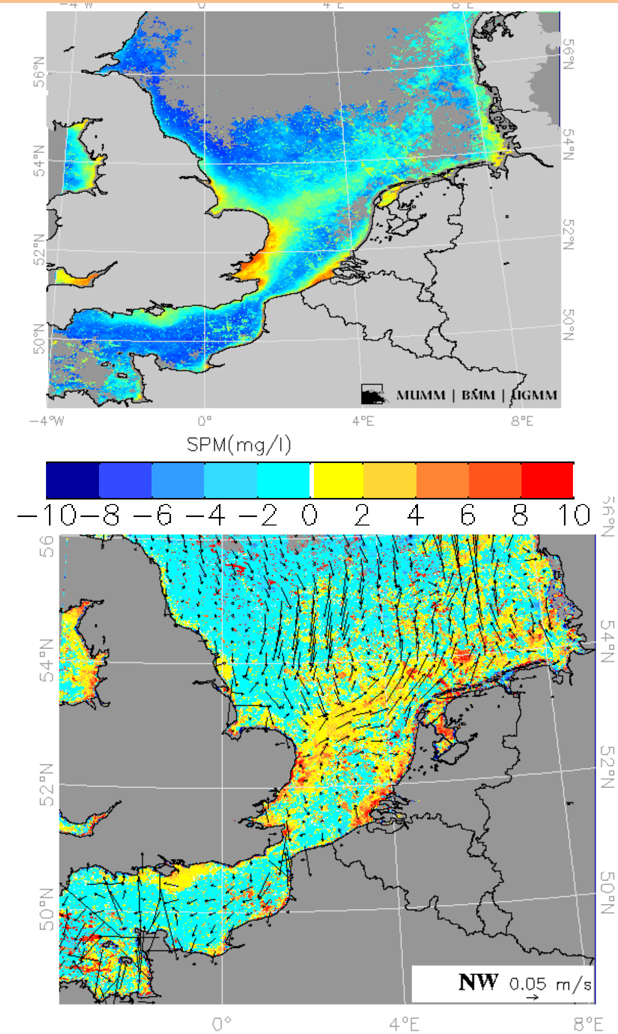
	SE	S	SW
BvH:	47 cm	31 cm	57 cm
Eierl. Gat:	87 cm	81 cm	148 cm
Helgol.	59 cm	73 cm	117 cm

% of images during summer & spring

SE	S	SW
55%	46%	36%

W NW





significant wave height (cm)

	W	NW
BvH:	101 cm	111 cm
Eierl. Gat:	195 cm	197 cm
Helgol.	169 cm	162 cm

% of images during summer & spring

W	NW
39%	51%

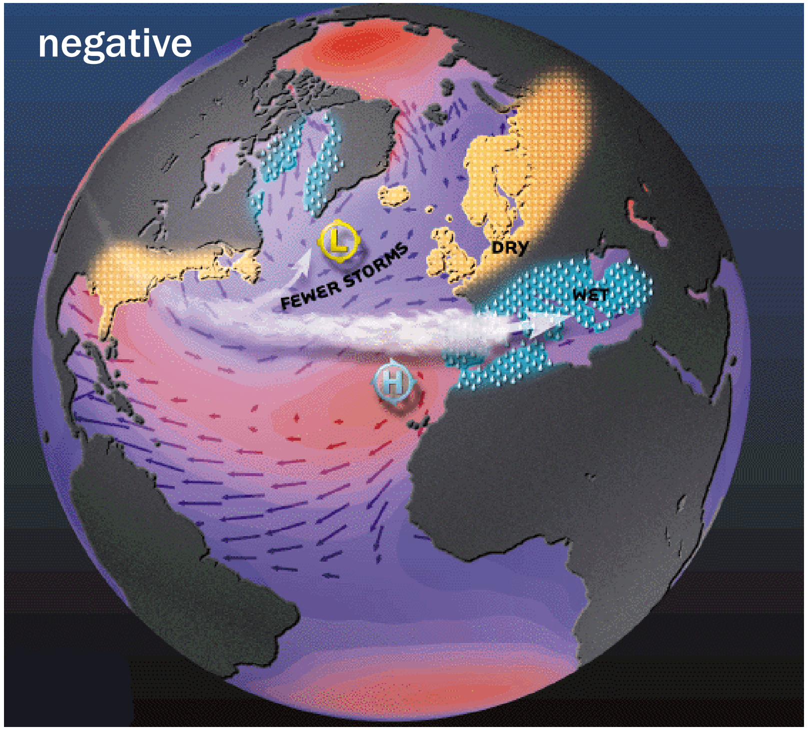
Climate: North Atlantic Oscillation

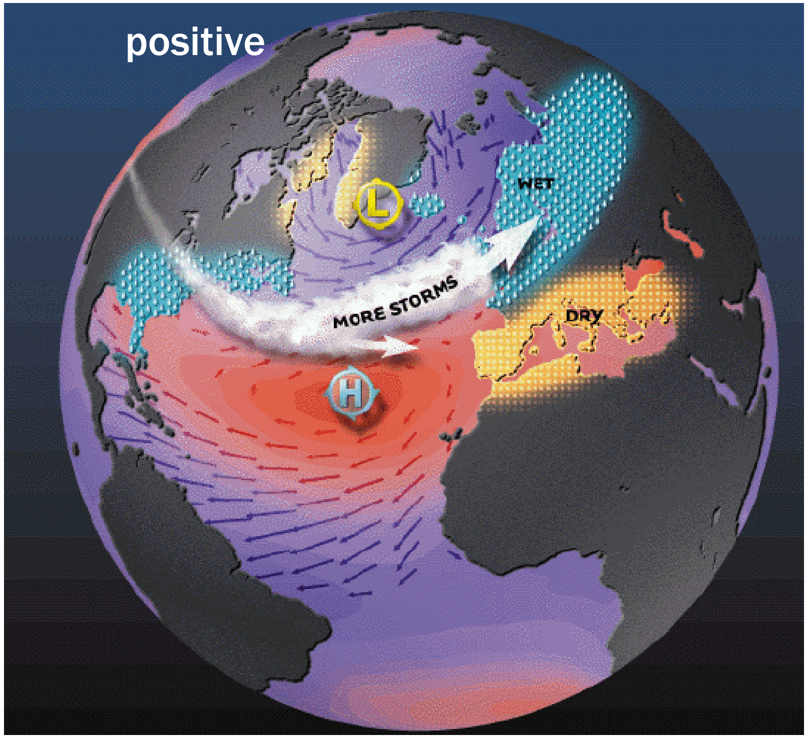
NAO-: weaker Acores high and Icelandic low pressure

Fewer and weaker storms, cold weather in central Europe

NAO+: stronger Acores high and Icelandic low pressure

More and stronger storms (SW), mild temperature





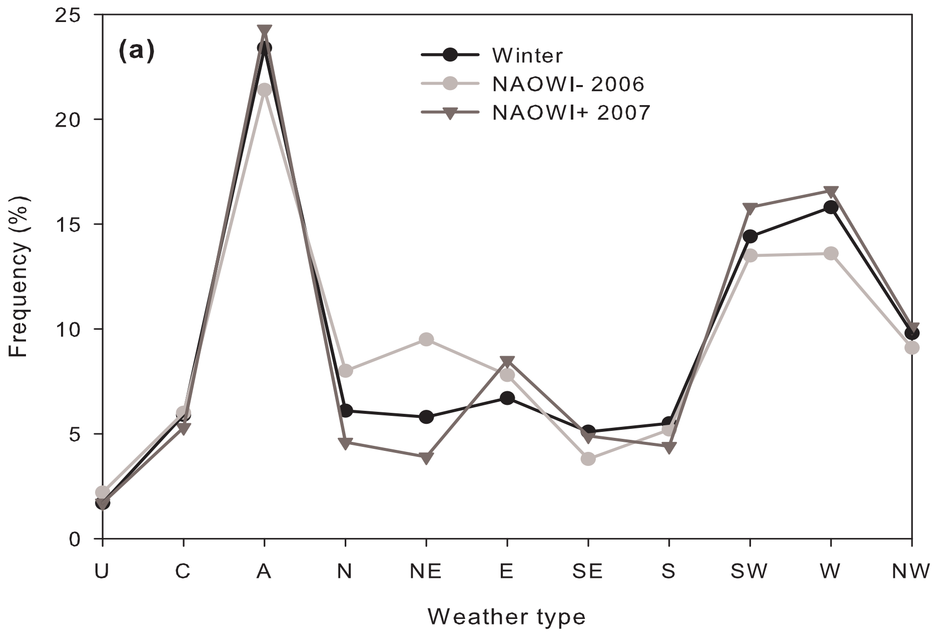
Focus is on winter climate (winter highest SPM concentration)

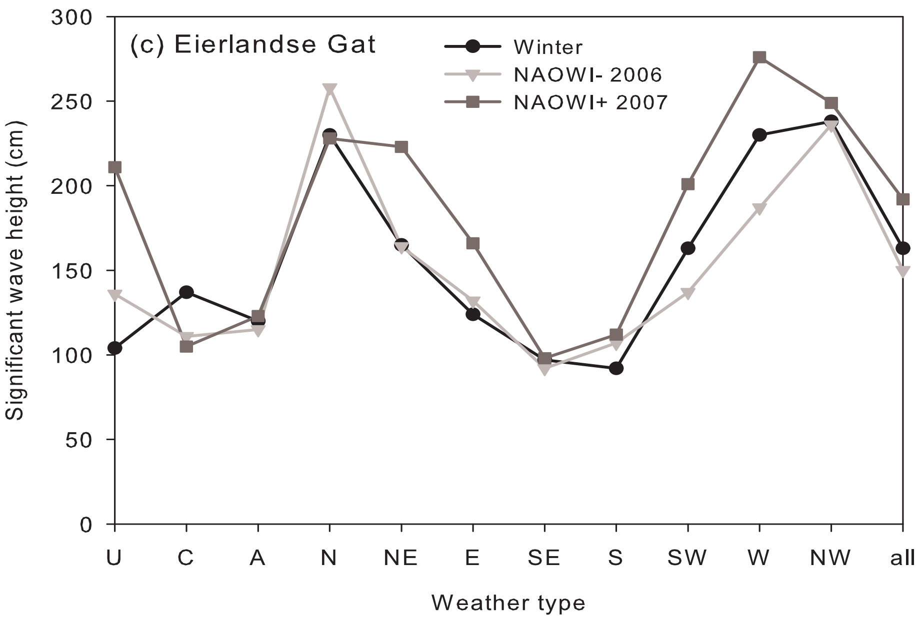
Negative NAO index: more abundant N, NE wind, weak W, SW winds, intrusion of arctic cold air

Positive NAO index: more abundant SW, W winds, more rainfall

Climate

Differences in NAO index are correlated to changes in frequency of WTs during winter



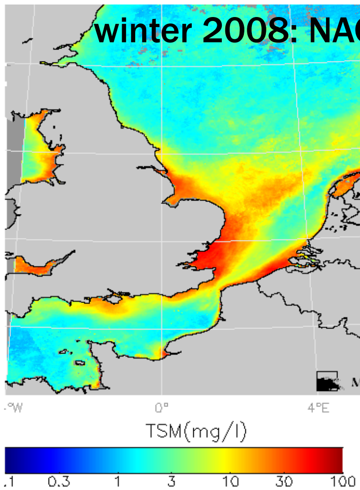


Frequency (%) of WT during winter 2008 (NAOWI- 2008) and 2007 (NAOWI+ 2007)

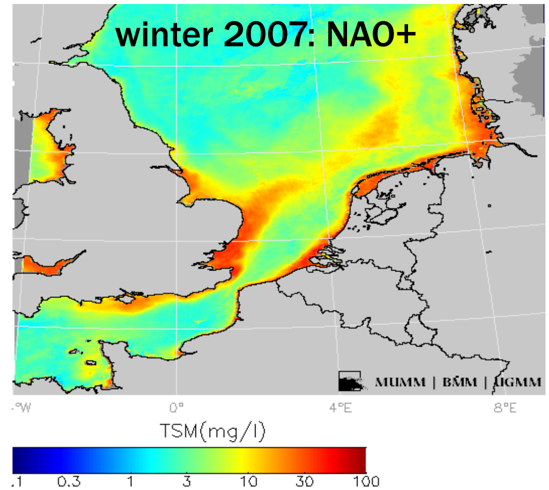
Significant wave height

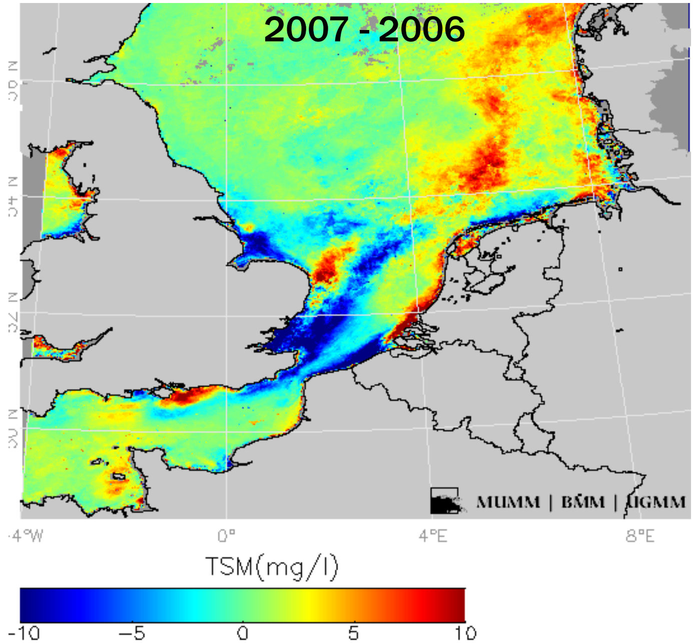
SPM concentration & climate (NAO)

NAO-: less wind, arctic influence (N, NE, E)



NAO+: W, SW winds





neg: NAO- is higher

pos: NAO+ is higher

NAO-

higher turbidity in southern Bight

NAO+

higher turbidity in German Bight

Turbidity plume extend over whole the North Sea

Climate change

1) **Past trend: Increase of WT SW during the last decades** (see Siegismund and Schrum (2001) and Van den Eynde et al. (2012))
   → This implies higher a general increase of SPM concentration in the North Sea and status quo in the Southern Bight and German Bight

2) **Future trend: Increase of WT W, decrease of SE, E, NE** (see Demuzere et al. (2009)) = IPCC 2001 report scenario A1B.
   → Increase of winters with positive NAO index

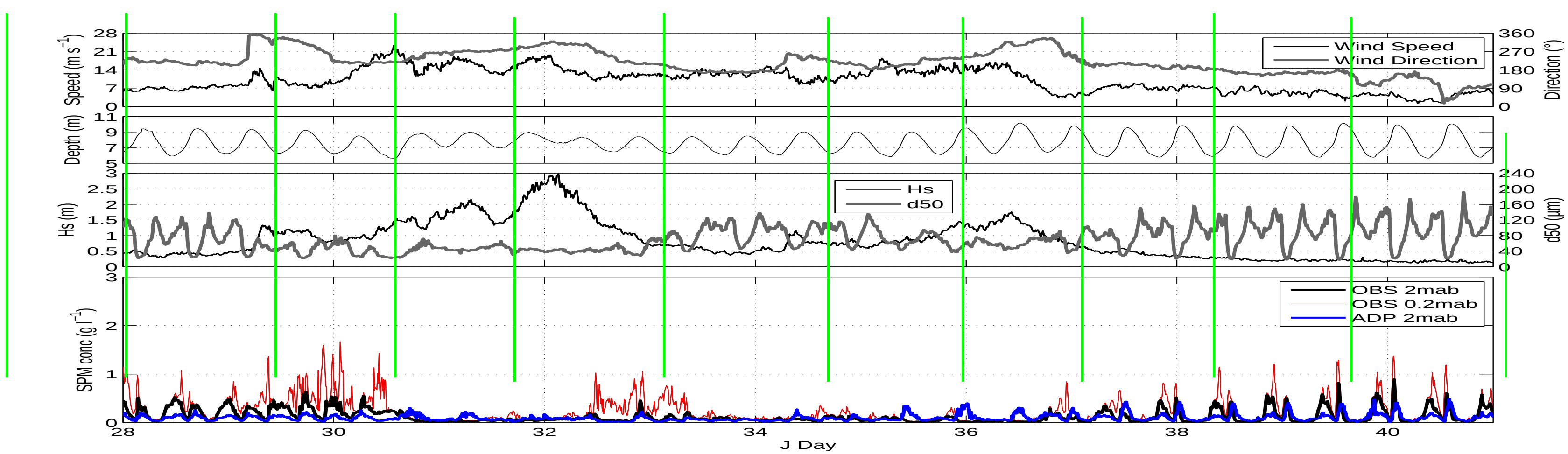
3) **Future trend: Increase of weather type N, NE, decrease of SW, W** (see Petoukhov & Semenov (2010), Jaiser et al. (2012))
   → surface SPM concentration will be higher in the German Bight and the Strait of Dover and lower along the Belgian-Dutch coastal zone.

Discussion: Limitation of satellite imagery

Low sampling frequency: 1xday

Occurrence of clouds.

- frequency of cloud-free data is highest in the Southern Bight and the English Channel and decreases towards the North and East
- not necessarily correlated with WT frequency
  - Weather types SW, W and NW are relatively abundant (>10%), but have only few good data.
  - Weather types NE, E and SE are less abundant (5%) but have more cloud free data



Validation of remote sensing v.s. in situ data

using statistical methods (frequency distribution)

Evaluation of the temporal SPM conc. using a large set of MODIS and in situ data

1. Extrapolation of tripod data (near- bed) towards surface using vertical profiles (in order to compare surface MODIS with in situ)

2. Determine the statistical characteristics of these datasets

3. How do these data set describe the sediment dynamics: What are the sampling schemes applied and how do they alter the results

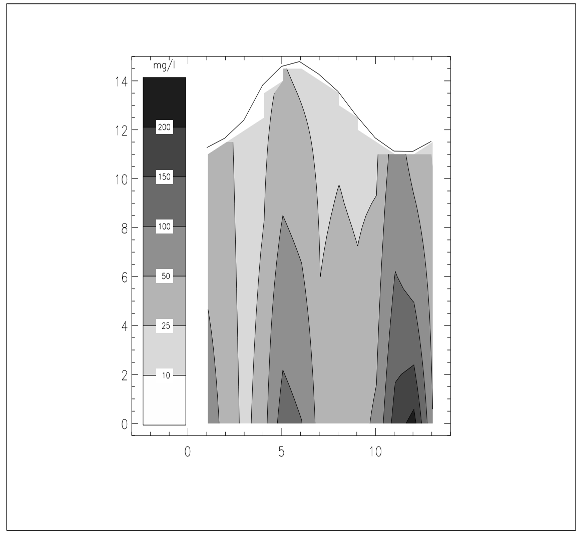
see:

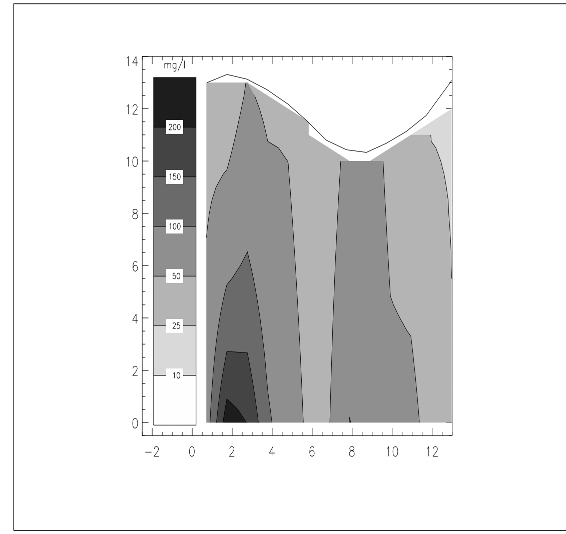
Extrapolation of tripod data towards surface

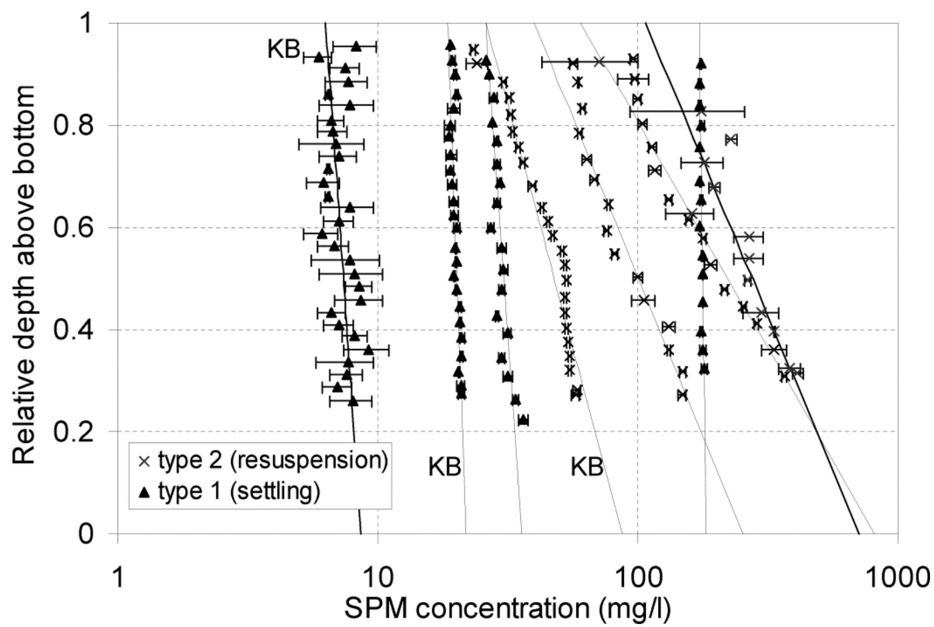
Extrapolation of tripod data towards surface using vertical profiles

Tidal cycle shipborne data:
Link surface-near bed

Derive a 'general' formula to calculate surface SPM conc. from tripod







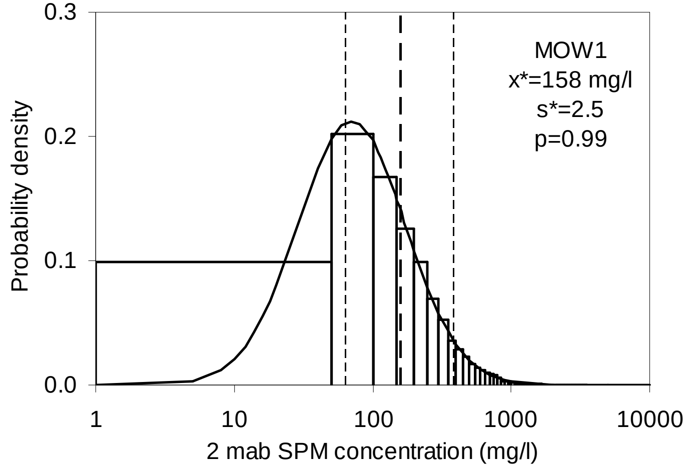
Frequency distribution of SPM concentration

Frequency distribution of surface and bottom SPM concentration

Idea: Frequency distributions of different datasets can be used to determine if two distributions are drawn from the same distribution function by use of standard statistic tests (chi2 test, Kolmogorov–Smirnov test).

If the data collected with different sampling methods have similar distributions, means and standard deviations, then —within the range of uncertainties—the methods provide similar subsamples from the whole population.

SPM concentration has a log-normal distribution



Frequency distribution of SPM concentration

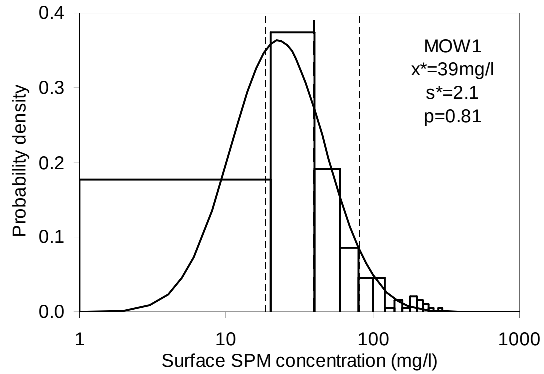
Frequency distribution of surface and bottom SPM concentration

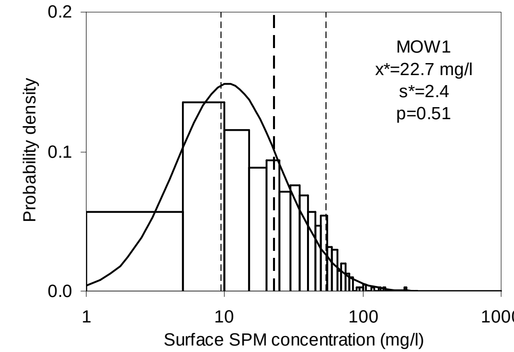
Tripod

Tidal cycle

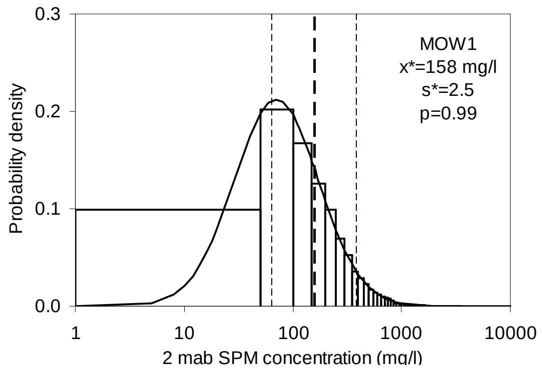
MODIS

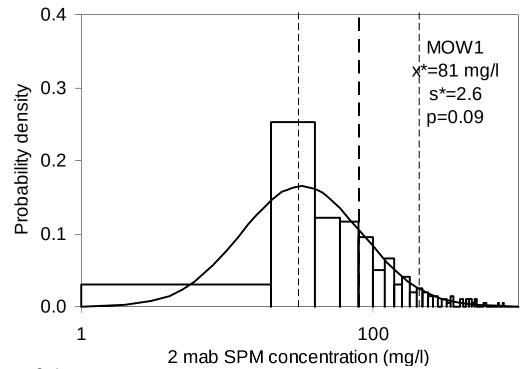
surface



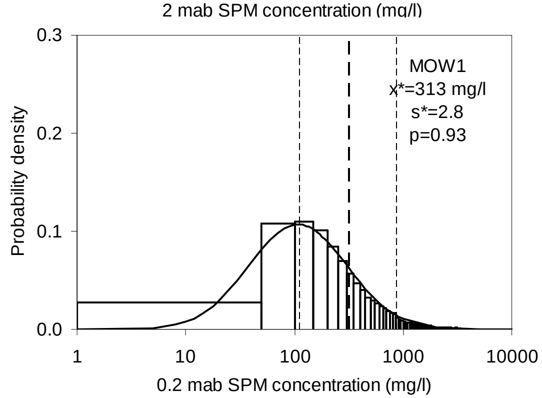


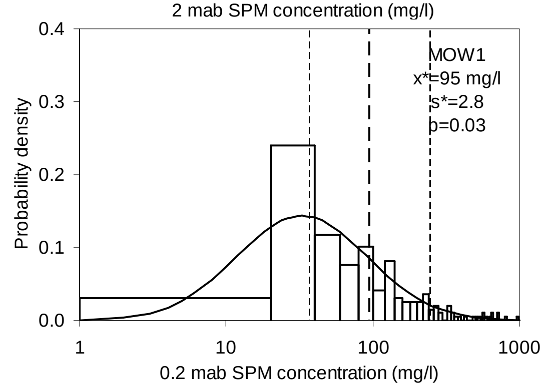
2 mab





0.2 mab

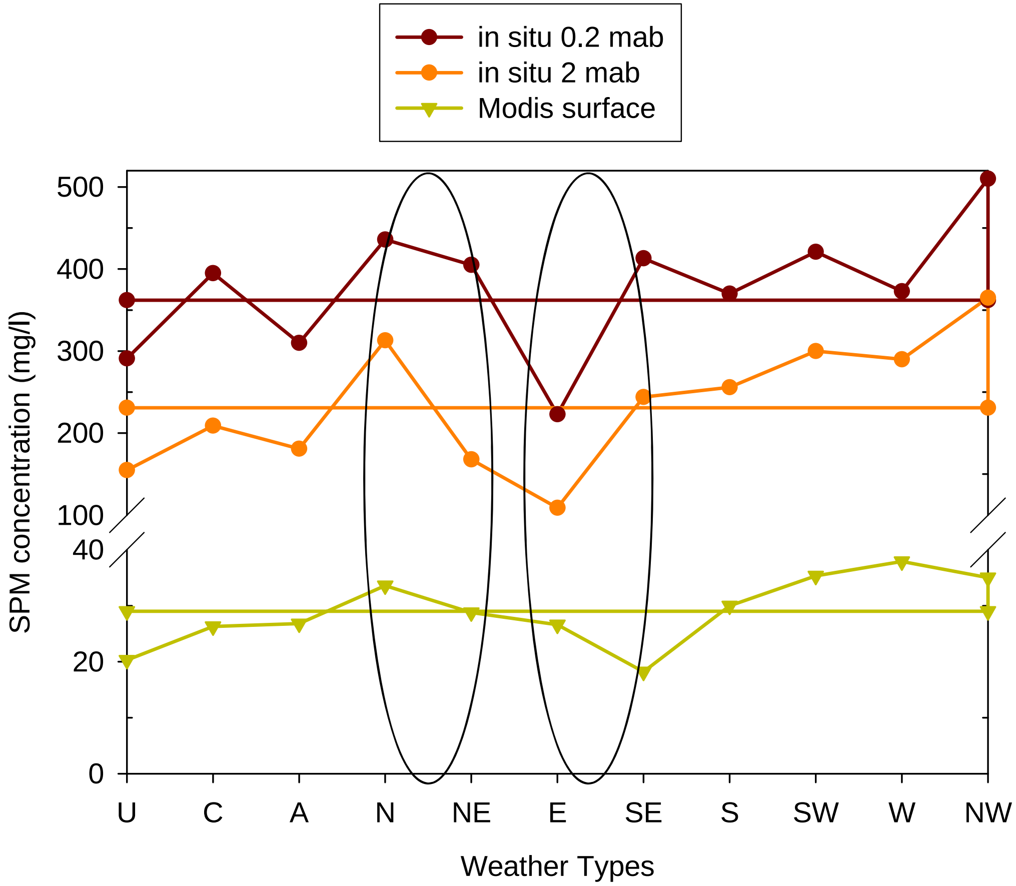




Stratification effects

Thermal and fresh water stratification disables vertical mixing (Pietrzak et al. 2011): surface SPM conc. is not a proxy for sediment transport.

MODIS: SPM conc. decreases along the German coast during WT W and SW and along the Belgian-Dutch coast during WT NE and SE.



High concentrated mud suspensions occur during WT NE (Baeye et al., 2011): reduction of turbulence and resuspension

→stratification due to High Concentrated Mud Suspensions

NE near-bed SPM conc increases while higher in the water column SPM conc. decreases

Limitation of satellite imagery

The results of standard statistic tests show that the tidal cycle, tripod and MODIS datasets have different distributions!

They represent a different subpopulation of the whole SPM concentrations population

1) near-bed processes (<0.2 m) are partially uncoupled from surface (fluid mud)

2) Sampling method is different
   - Tripod continuous : represents whole population of SPM concentration
   - Tidal cycle: 6/cycles per year ‘good’ weather (max 1.5 m wave height)
   - Modis: only cloud free data, not whole the tidal cycle is sampled

Conclusion

Weather type signal is visible in SPM concentration distribution

Geographical distribution of SPM is influenced by weather types

- alternation of higher SPM concentration between Southern Bight and German Bight is a result of local resuspension and advection

Bias of satellite image:

- surface concentration is not always a proxy of sediment dynamics in high turbidity areas
- In coastal high-turbidity areas, greater sampling efforts are necessary as compared to offshore systems with low SPM concentration.
- Satellites or low-frequent (=6/year) tidal cycle measurements cannot replace long-term continuous measurements in high turbidity areas, which include all sea state conditions.
- Satellite data are a subset of the population biased towards good weather condition. Sediment transport based on these data will underestimate reality

Conclusion

Perspectives:

- Climate change scenario's: how will it affect SPM conc. distribution
- Are the changes in SPM concentration due to climate changes and can they explain observed changes in benthic life?

Fettweis M, Nechad B. 2011. Evaluation of in situ and remote sensing sampling methods for SPM concentrations on the Belgian continental shelf (southern North Sea). Ocean Dynamics 61, 157-171.

Fettweis M, Monbaliu J, Baeye M, Nechad B, Van den Eynde D. 2012. Weather and climate induced spatial variability of surface suspended particulate matter concentration in the North Sea and the English Channel

Thank you