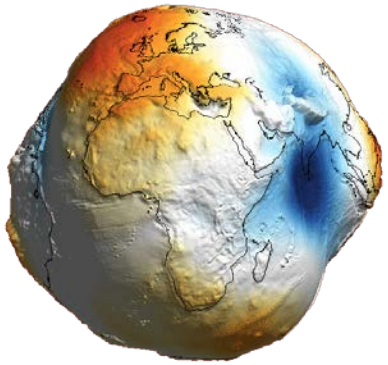
Realisation of a mutually consistent set of on- and offshore vertical reference surfaces in the Netherlands

R. Klees, D.C. Slobbe, H.H. Farahani, M. Verlaan, F. Zijl, and J. Sumihar

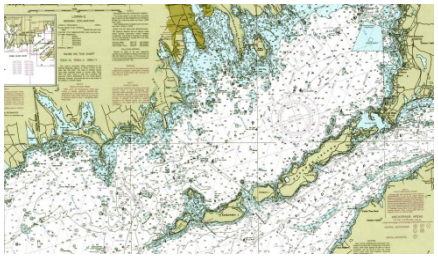
Outline

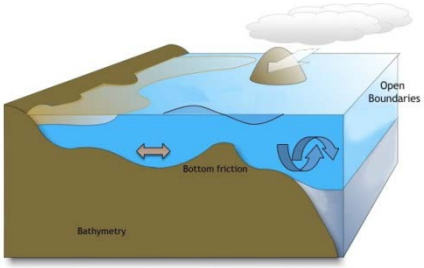

Tomorrow's opportunities
Results for the Netherlands
The Dutch approach
The problem at hand



***Geoid**: a level surface close to mean sea level; no flow of water on the geoid ("horizontal" surface). Ideal reference surface for heights.*

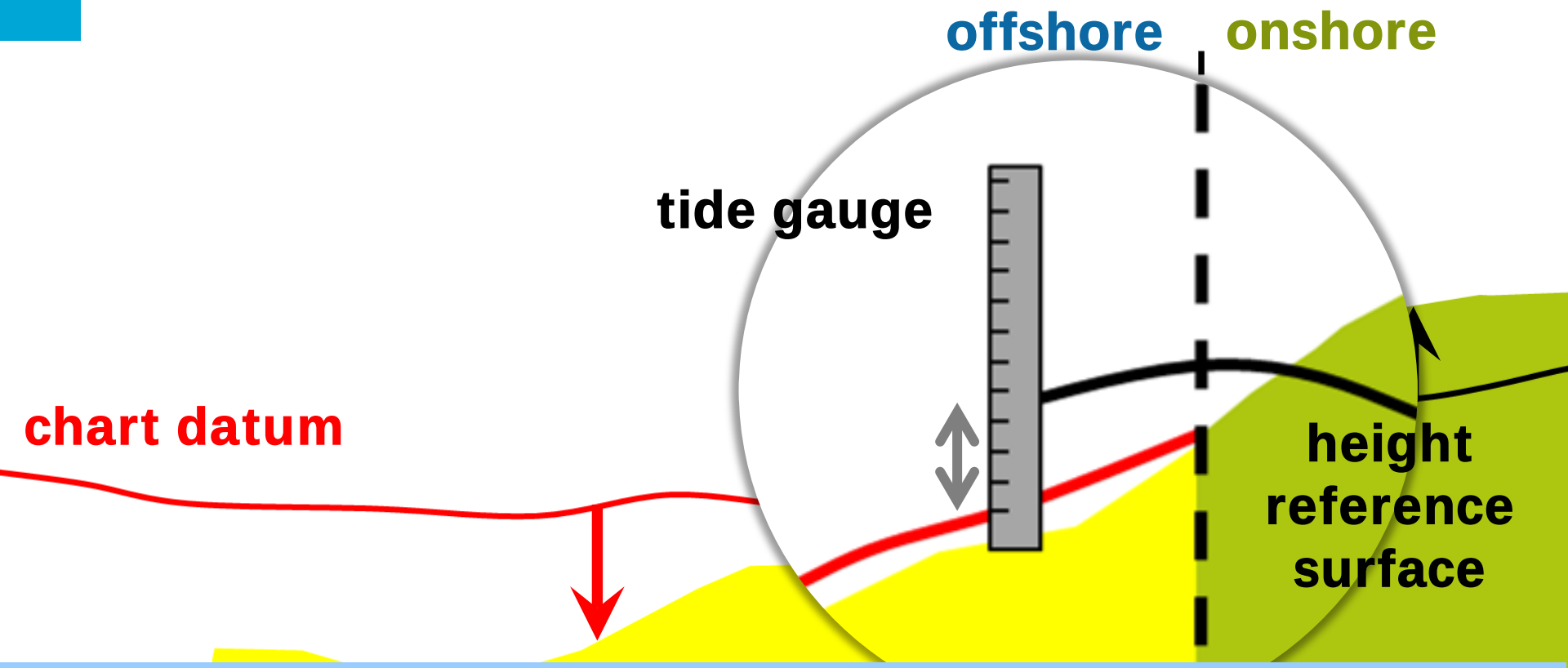
***Chart Datum**: level of water that charted depths are measured from; usually a tidal surface, e.g., Lowest Astronomical Tide.*





***Hydrodynamic model**: numerical model that, among others, allows to hindcast/ forecast water levels.*

The problem…



Separation between chart datum and height reference surface is a *spatially varying* function, which is only known at tide gauges!

Bathymetric and topographic datasets cannot be merged without introducing inconsistencies ("jumps").

Causes a lot of problems with coastal zone management!

So what...?

How to make reliable simulations of flood events?

Gerwin de Haan, 2011, graphics.tudelft.nl

So what…?

How to assess the impact of rising sea levels on the coastal morphology?

http://www.sectionz.nl/

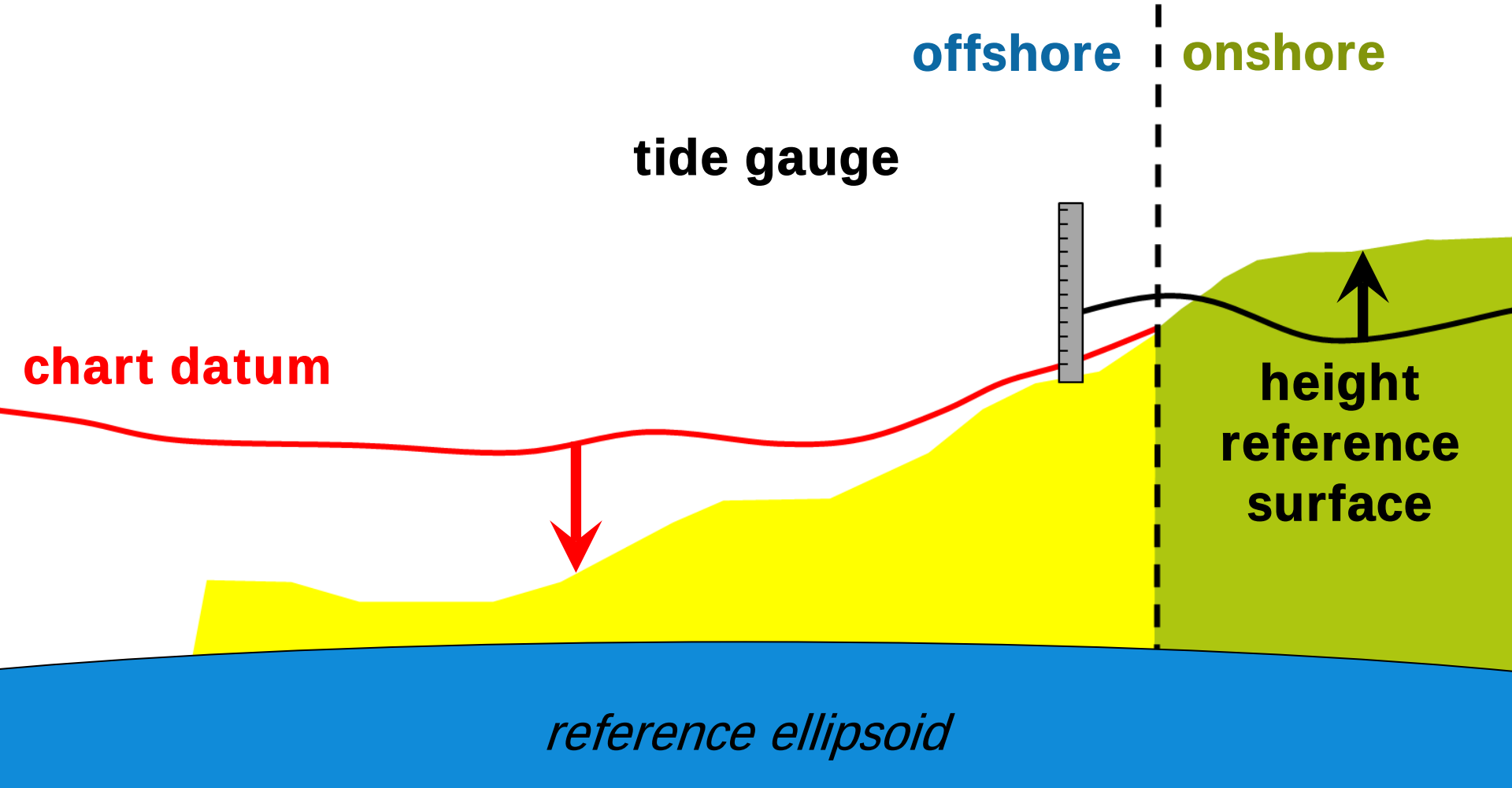
The separation between height and depth reference surfaces is a spatially varying function, which is only known at tide gauge locations (if at all).

This separation must be known everywhere for coastal zone management in a changing climate!

*Take home message #1

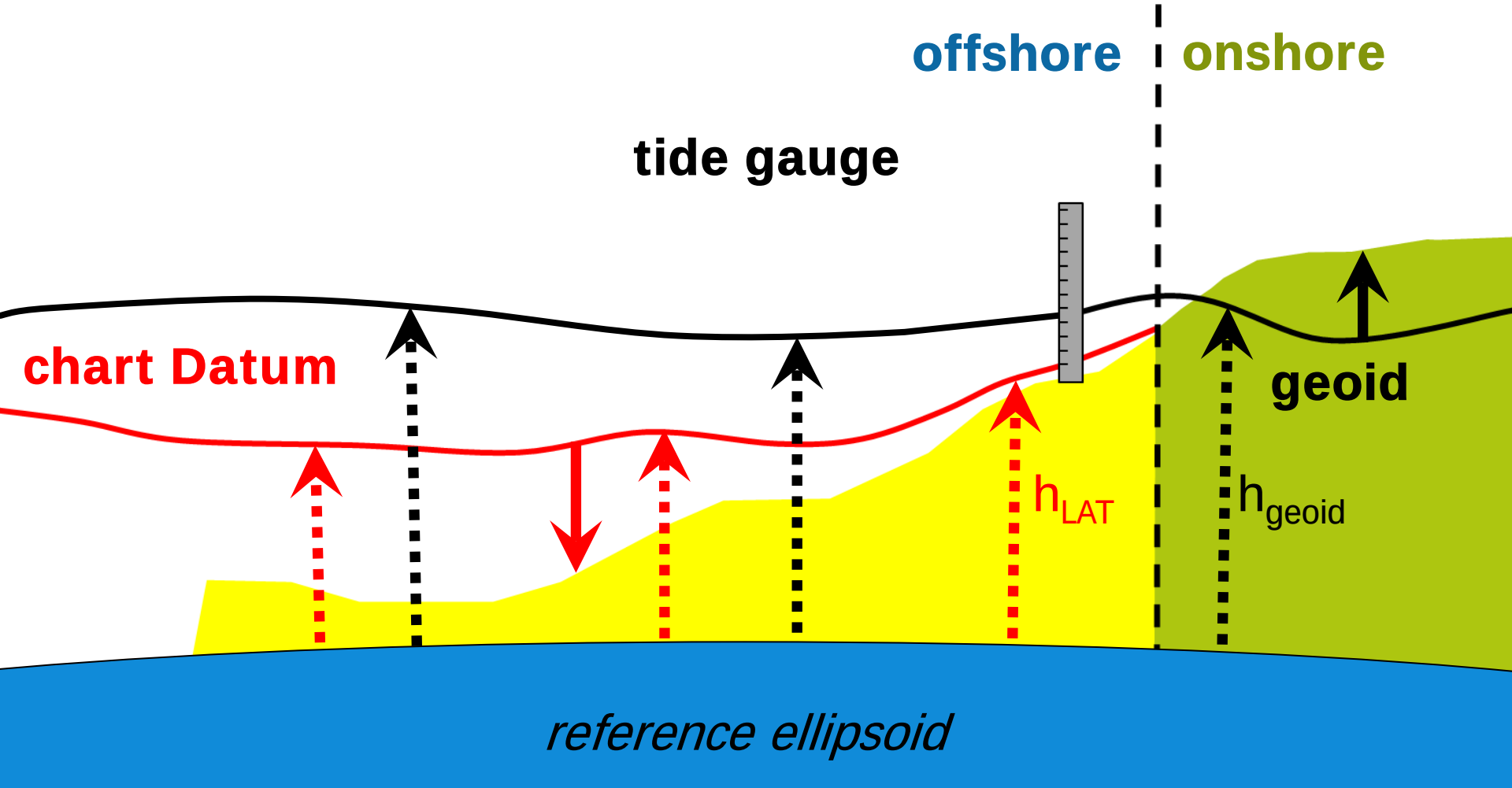
The solution…

Refer chart datum and height reference surface to a common reference surface!



The solution…

Refer chart datum and height reference surface to a common reference surface!

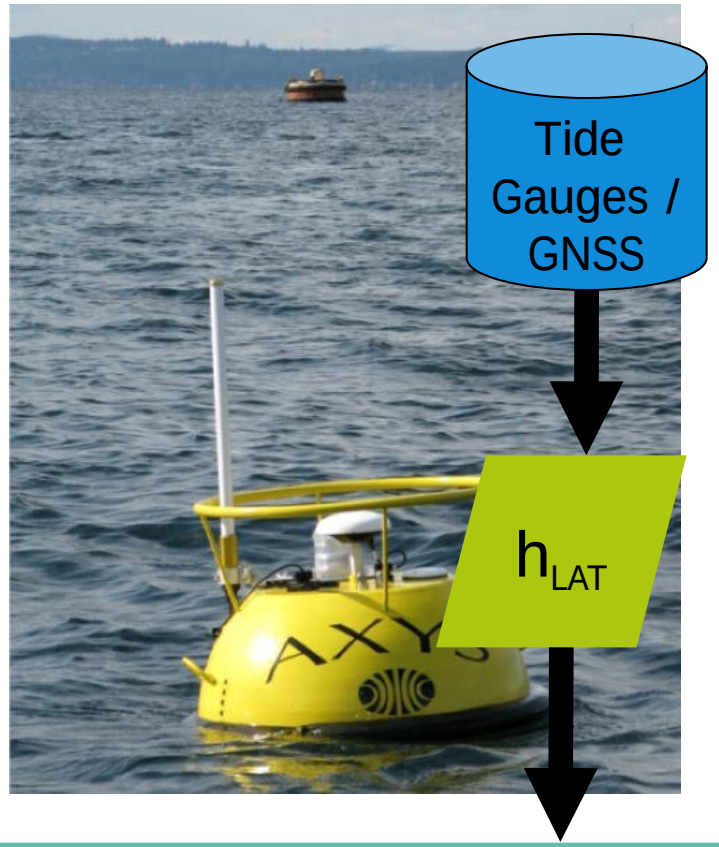


How to achieve this? Note that we have a special interest in the coastal waters!

Task 1: determine ellipsoidal heights of the geoid (h_{geoid}).

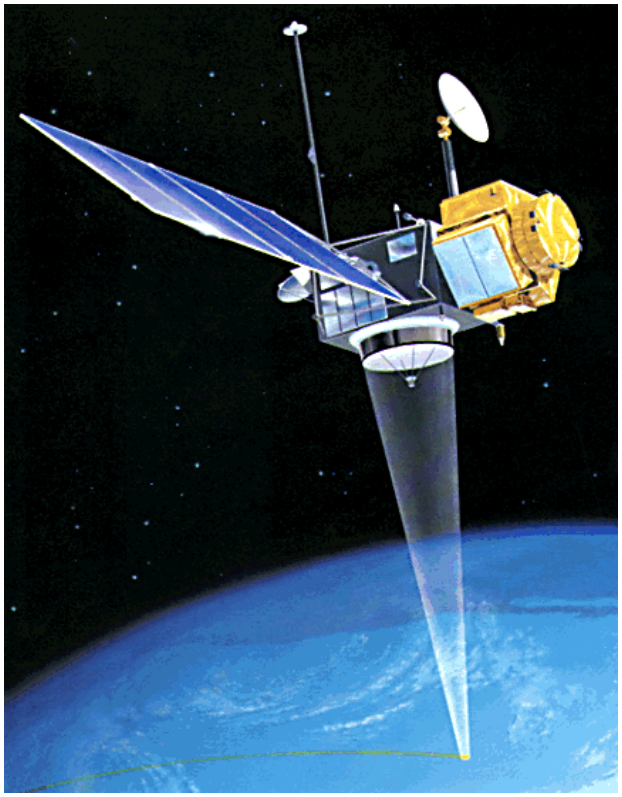
Task 2: determine ellipsoidal heights of chart datum (here: h_{LAT}).

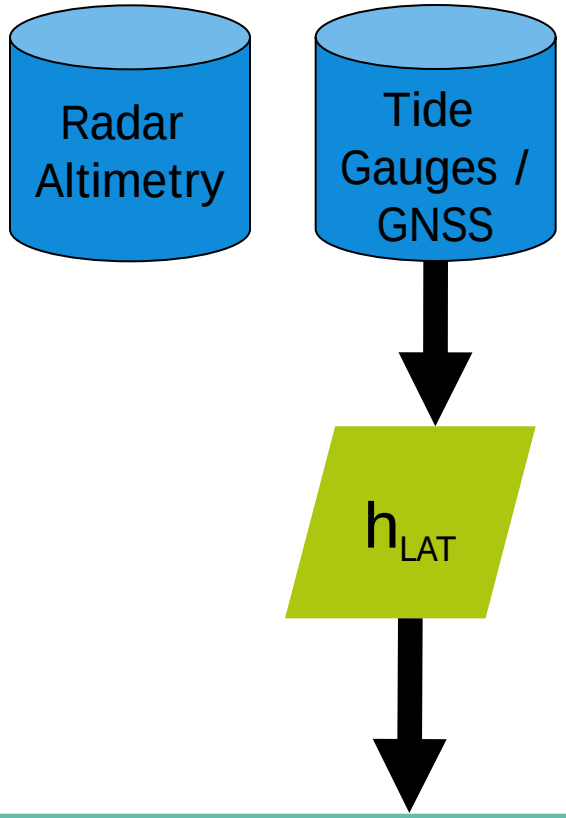
State-of-the-art: h_{LAT} in shallow water



Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

State-of-the-art: h_{LAT} in shallow water

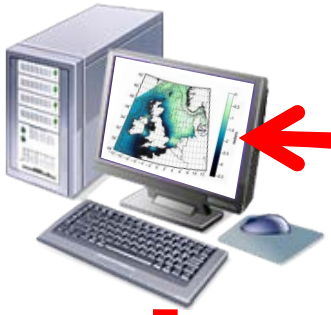




Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

State-of-the-art: h_{LAT} in shallow water

Ocean tide model



calibration

Radar Altimetry

Tide Gauges / GNSS

ζ_{LAT}^{MSL}

h_{LAT}

Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

State-of-the-art: h_{LAT} in shallow water

Ocean tide model

Radar Altimetry

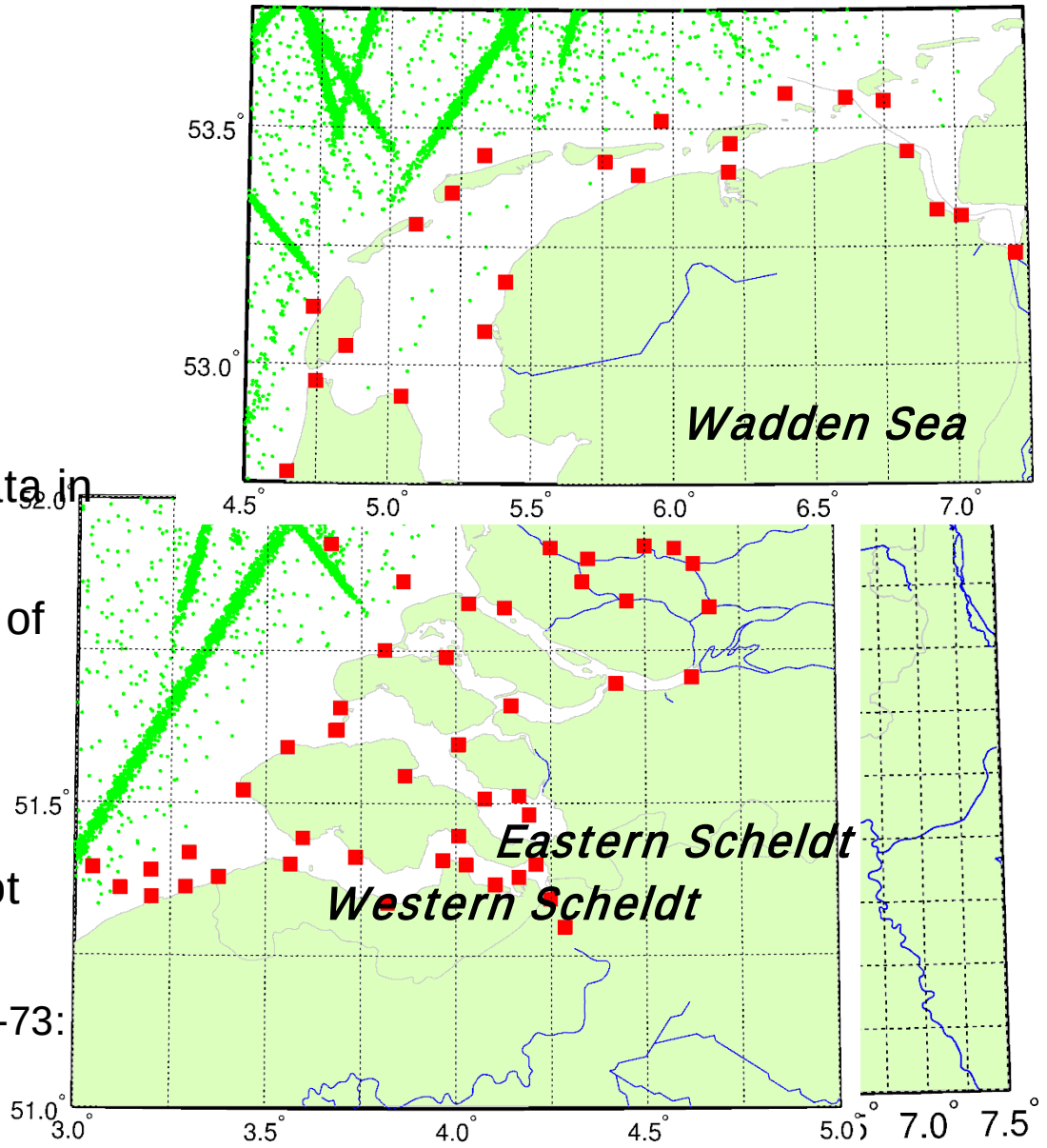
Tide Gauges / GNSS

ζ_{LAT}^{MSL} + h_{MSL} h_{LAT}

Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

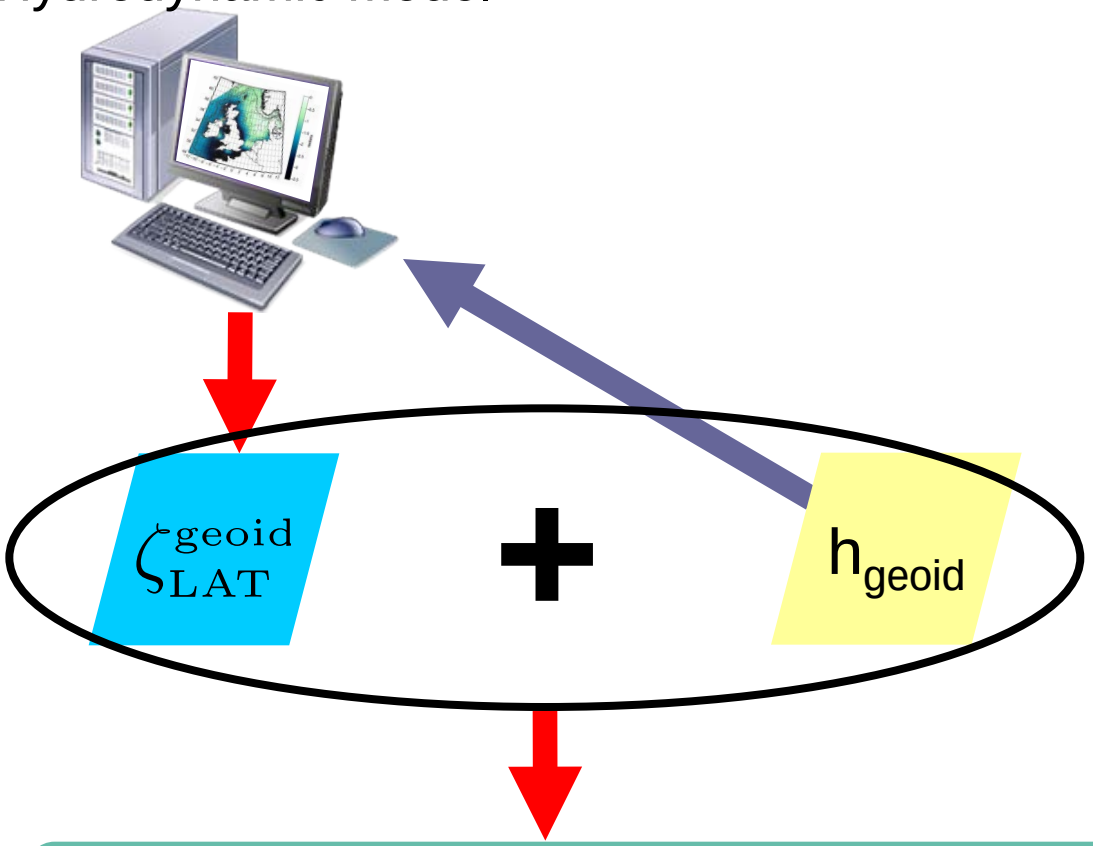
However …

- (Conceptual) problems
  - No accurate radar altimeter data in coastal waters
  - MSL not the reference surface of an ocean tide model
  - Tides contribute to MSL
  - Tide-surge interaction ignored
  - MSL over long periods does not fulfil all practical needs
    - Thompson, JGI 63 (1980): 57-73: annual amplitudes ~ 7 cm



Dutch approach to realize h_{LAT} and h_{geoid}

Hydrodynamic model



Radar Altimetry

Tide Gauges / GNSS

Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

Dutch approach to realize h_{LAT} and h_{geoid}

Airborne gravimetry

Gravi-metric data

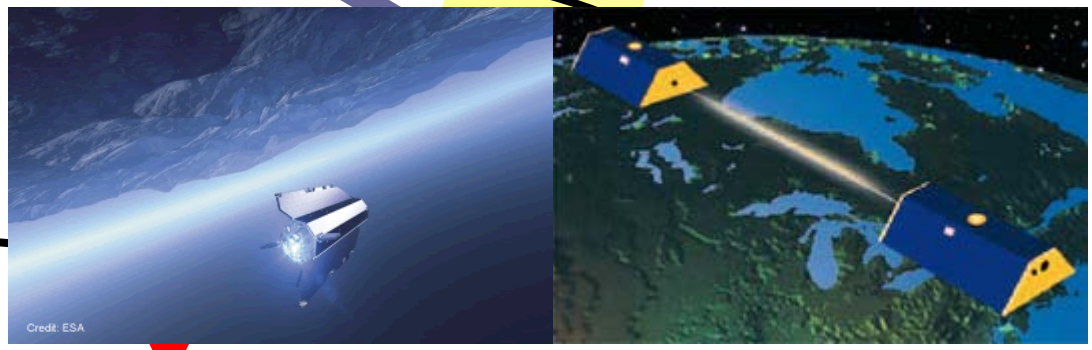
Radar Altimetry

Terrestrial + ard etry

Tid Gaug GNSS

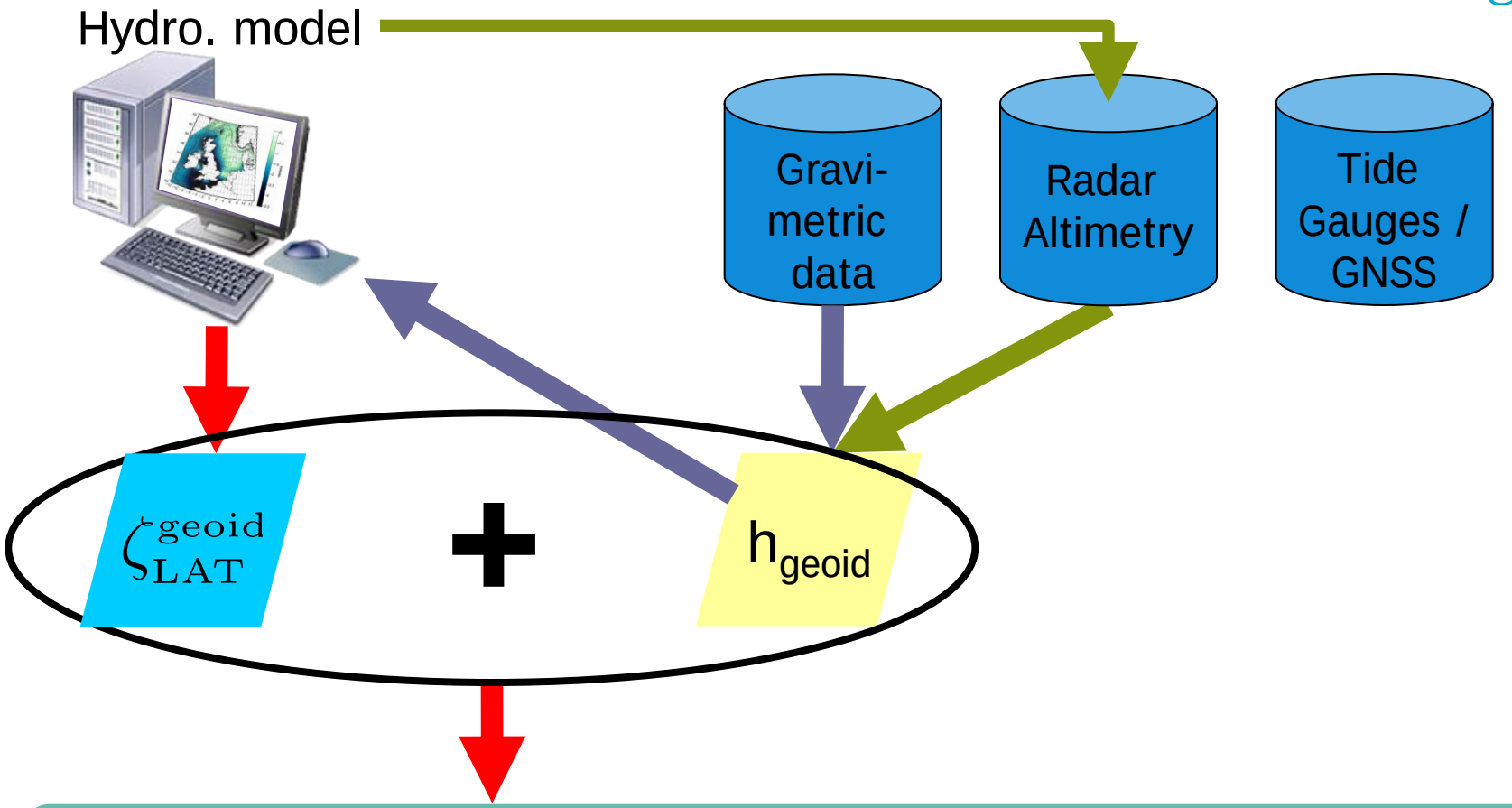
Satellite gravimetry

ζ^{geoid}_{LAT}



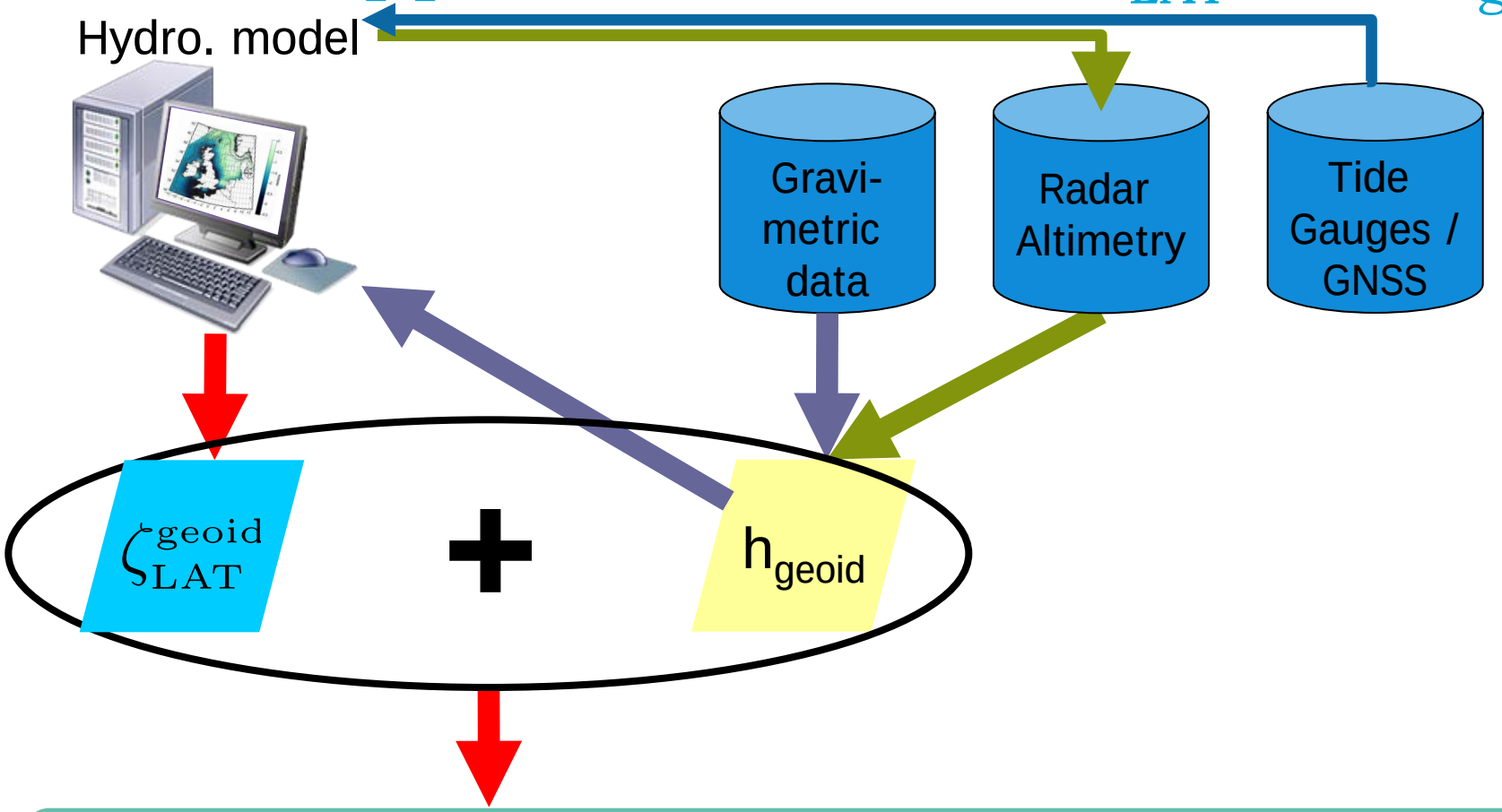
Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

Dutch approach to realize h_{LAT} and h_{geoid}



Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

Dutch approach to realize h_{LAT} and h_{geoid}



Coastal-waters-inclusive continuous (CWIC) 3D description of LAT

The Dutch approach to realize chart datum with respect to a reference ellipsoid uses the geoid rather than the MSL as the intermediate surface!

*Take home message #2

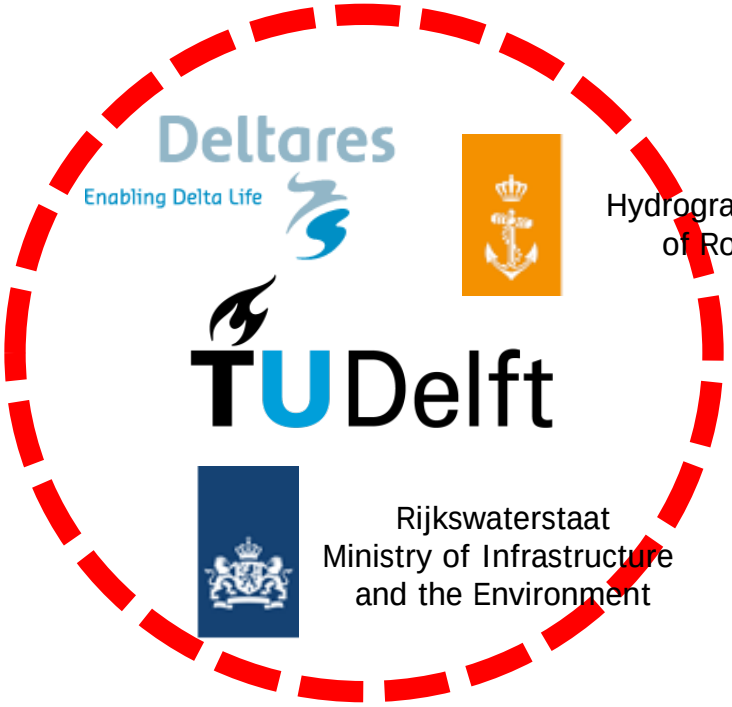
Main objective NEVREF project

1 cm standard deviation

*To obtain accurate realizations of the **quasi-geoid** and **lowest astronomical tide** surface, including the necessary **transformations** from/to all common land and marine vertical reference surfaces*

10 cm standard deviation

Research team



Hydrographic service
of Royal Navy

Rijkswaterstaat
Ministry of Infrastructure
and the Environment

Research team & user committee

Boskalis

World leading dredging contractor and marine services provider

kadaster

Netherlands Cadastre, Land Registry and Mapping Agency

Deltares
Enabling Delta Life

Hydrographic service of Royal Navy

Van Oord
Marine ingenuity

International contractor in dredging, marine engineering and offshore oil, gas, and wind energy activities

TU Delft

Allseas

Global leader in offshore pipeline installation and subsea construction

Rijkswaterstaat
Ministry of Infrastructure and the Environment

QPS

Quality positioning services for hydrography, sea-floor mapping, portable pilots, and electronic nautical charts

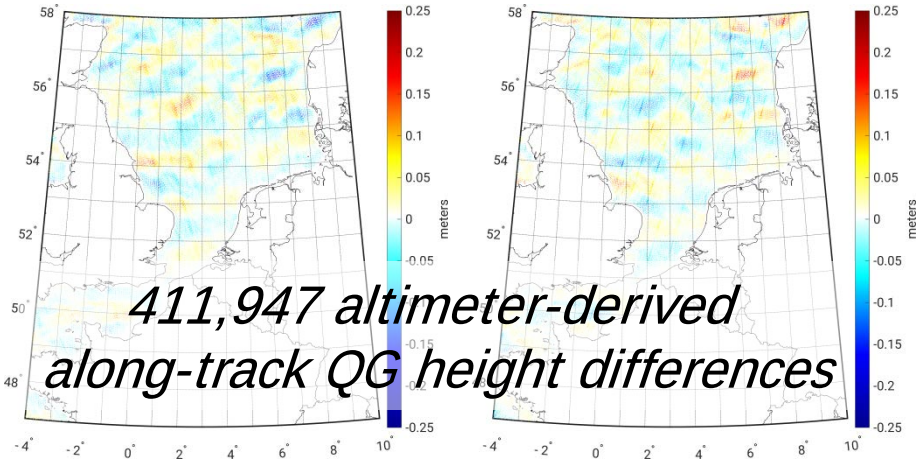
FUGRO

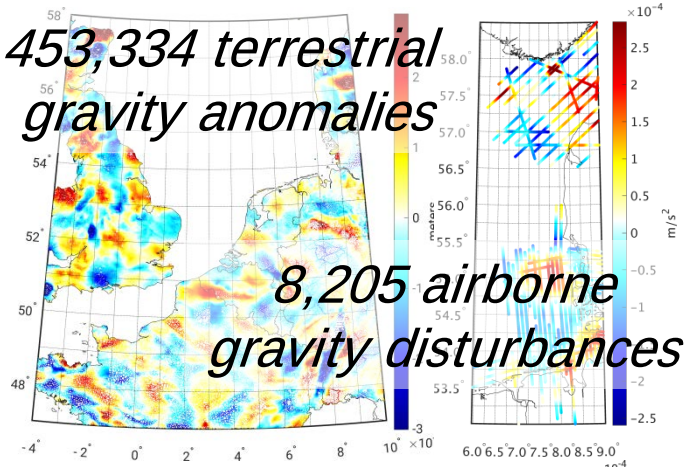
One of the biggest survey companies in the world

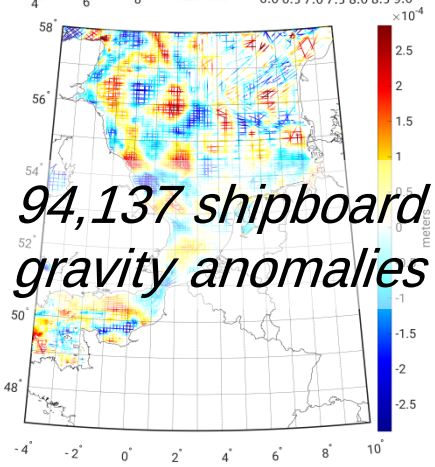
NAM

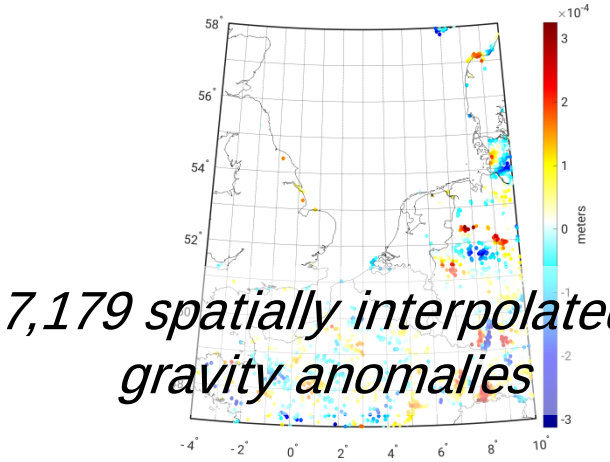
Joint Shell & BP enterprise, which exploits the oil and gas fields in NL

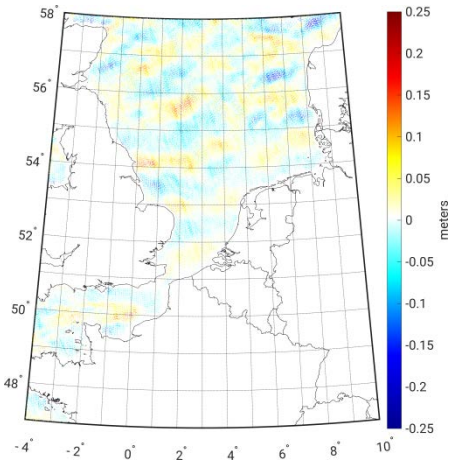
NLGEO2018, the new Dutch quasi-geoid model…

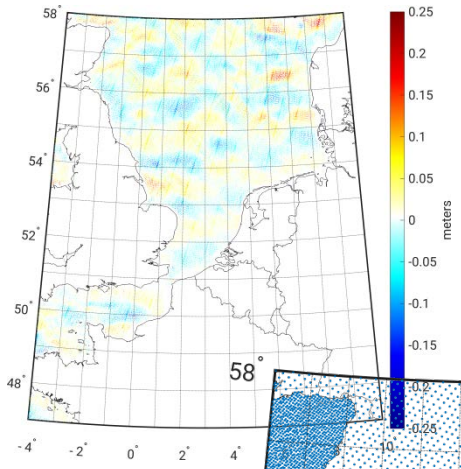

411,947 altimeter-derived
along-track QG height differences

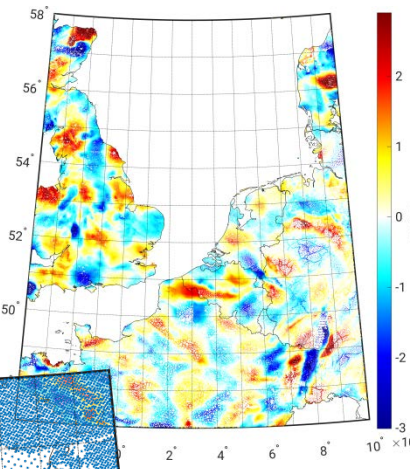

453,334 terrestrial
gravity anomalies
8,205 airborne
gravity disturbances

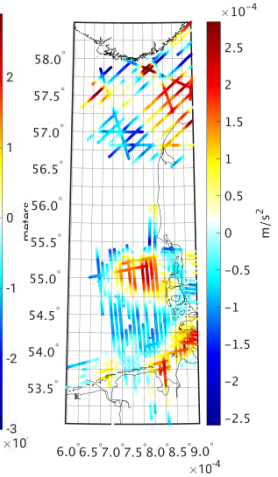

94,137 shipboard
gravity anomalies

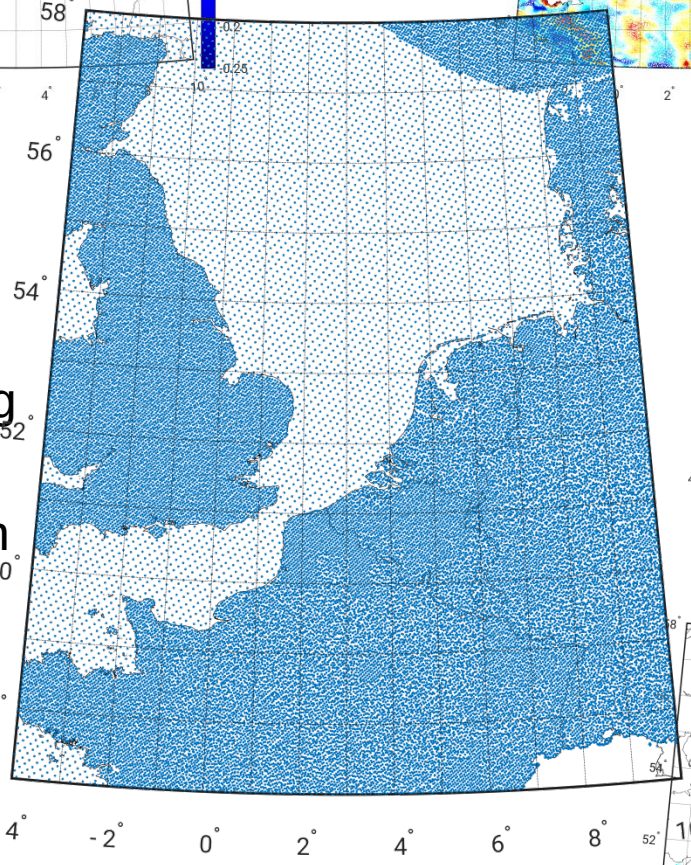

7,179 spatially interpolated
gravity anomalies

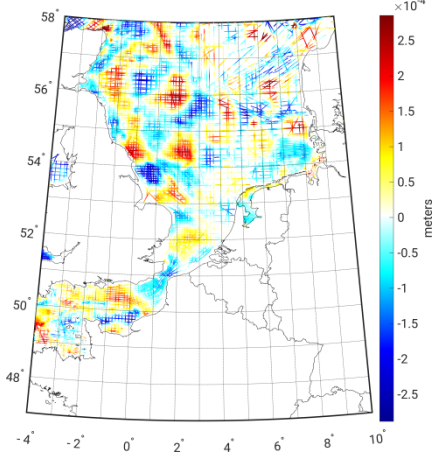


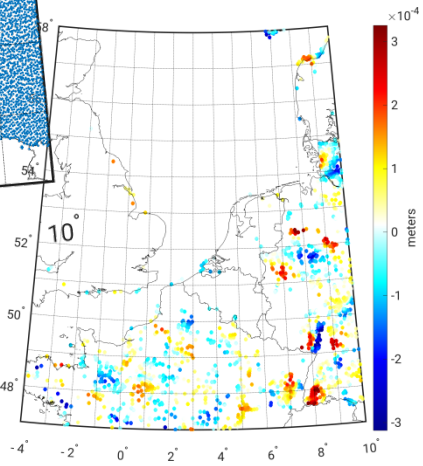






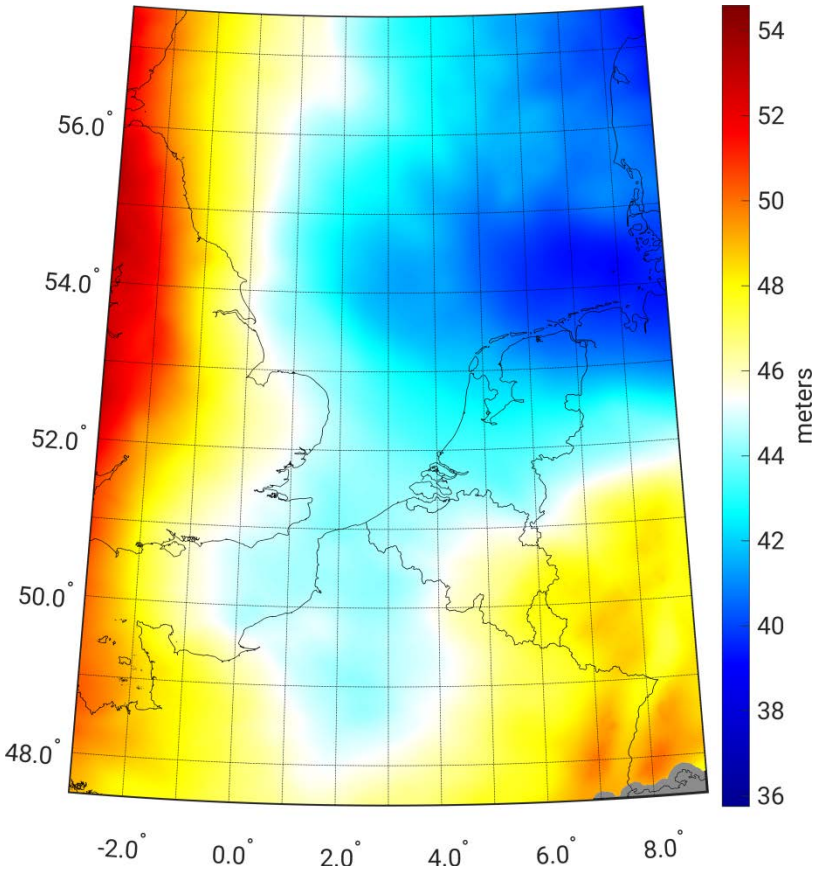






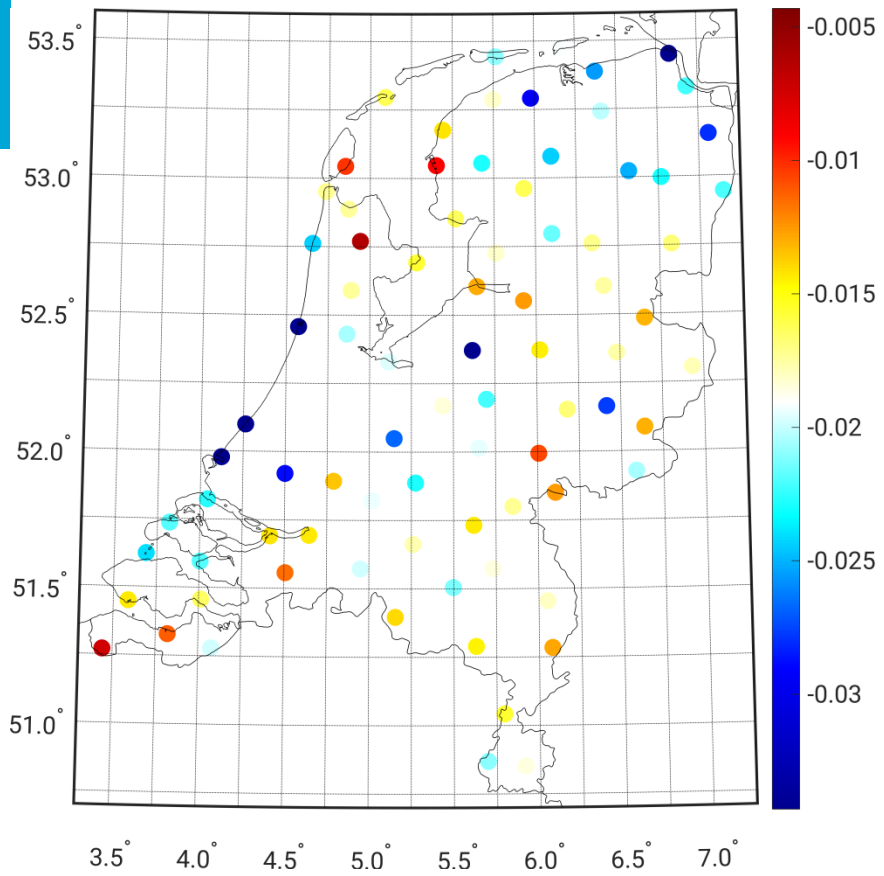
- Quasi-geoid is parameterized using spherical radial basis functions.
- Parameters are estimated using weighted least-squares.
- Variance component estimation is applied for proper weighting of all datasets.
- Systematic errors in gravity datasets are accounted for.
- Full noise covariance matrix of estimated quasi-geoid.

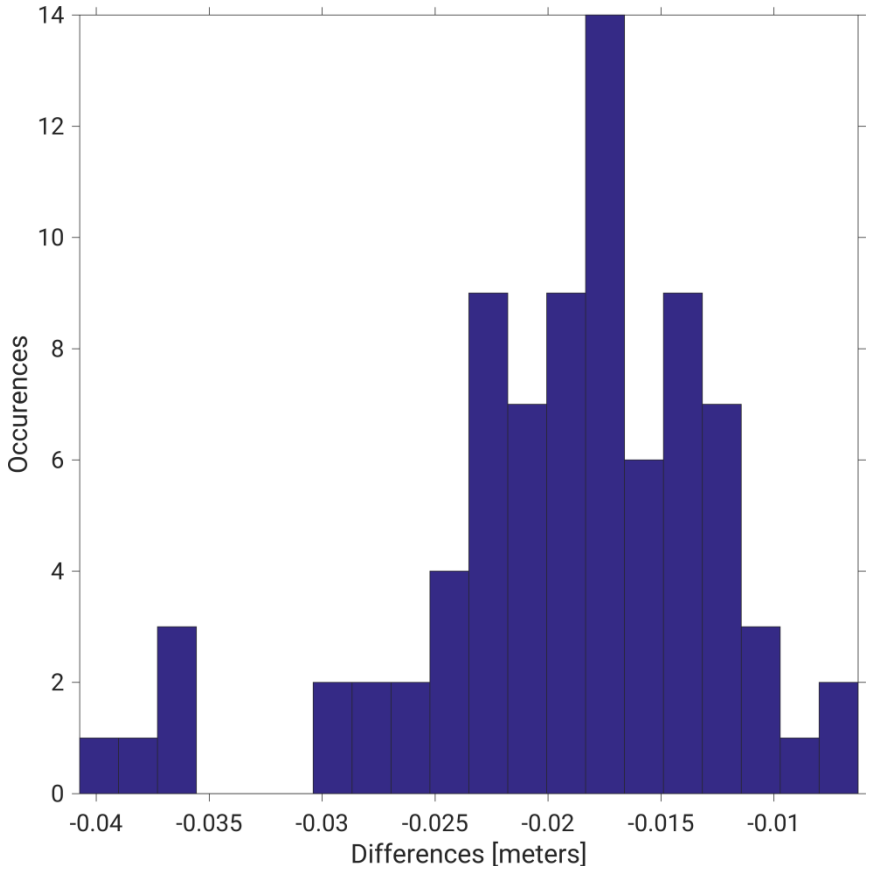
NLGEO2018 - gravimetric quasi-geoid



NLGEO2018 - validation

NLGEO2018-GNSS/leveling



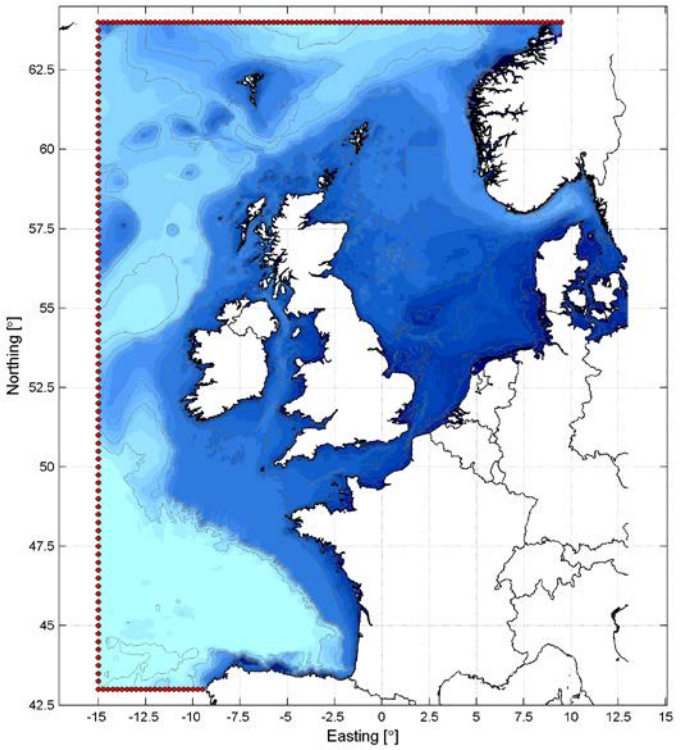


Region	Nr	Rms (cm)	Range (cm)	Mean (cm)	Std (cm)
Netherlands	82	2.0	**3.5**	-1.9	**0.66**

NLLAT2018, the new Dutch LAT model…

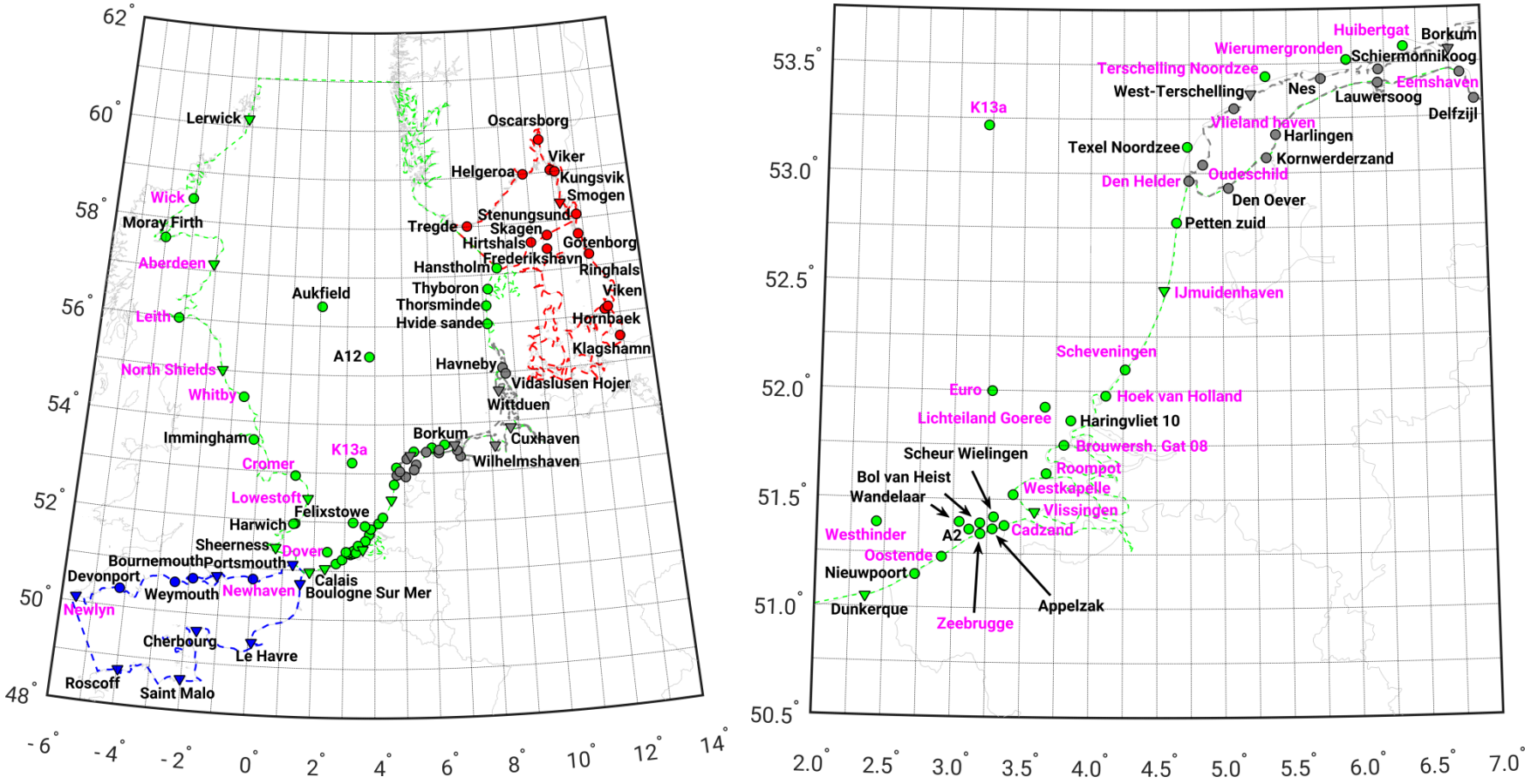
LAT computations: model setup

- Hydrodynamic model = Dutch operational storm surge model;
- Simulation period: Jan 1993 - Jan 2012;
- Multi-year average monthly mean wind/ atmospheric pressure + baroclinic forcing included;
- Open boundary conditions:
  1. Tide, defined in frequency domain
     - ✓ 8 main + 5 long-term constituents taken from global ocean tide models;
     - ✓ 13 smaller (semi-)diurnal const.;
  2. Multi-year average monthly mean surge;
  3. Multi-year average monthly mean baroclinic contr.



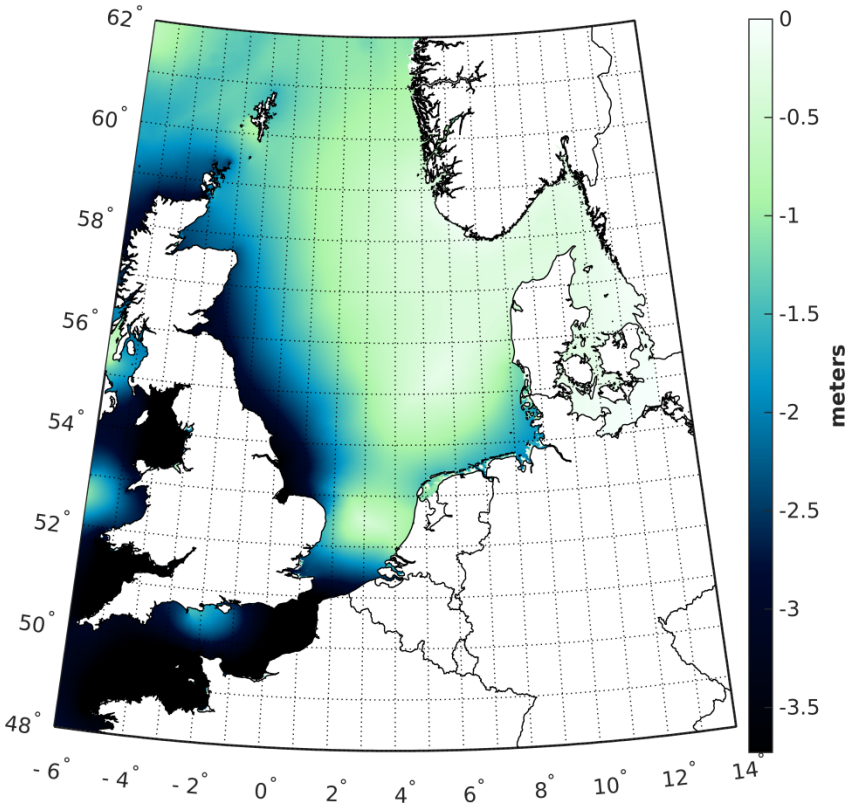
Data assimilation

- LAT solution obtained by assimilating *tidal* water levels @ 31 tide gauges;

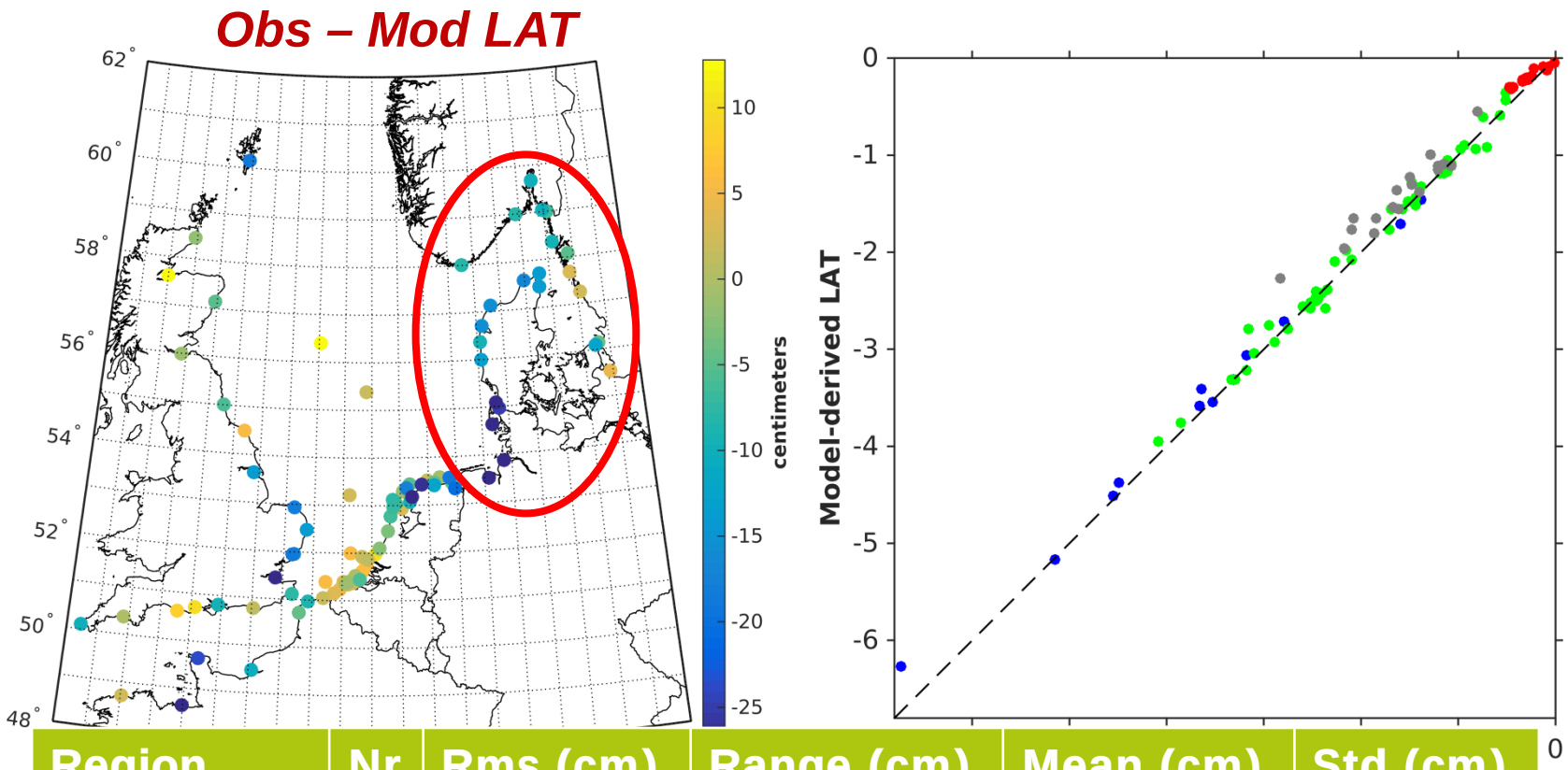



CONSISTENCY

LAT w.r.t. geoid

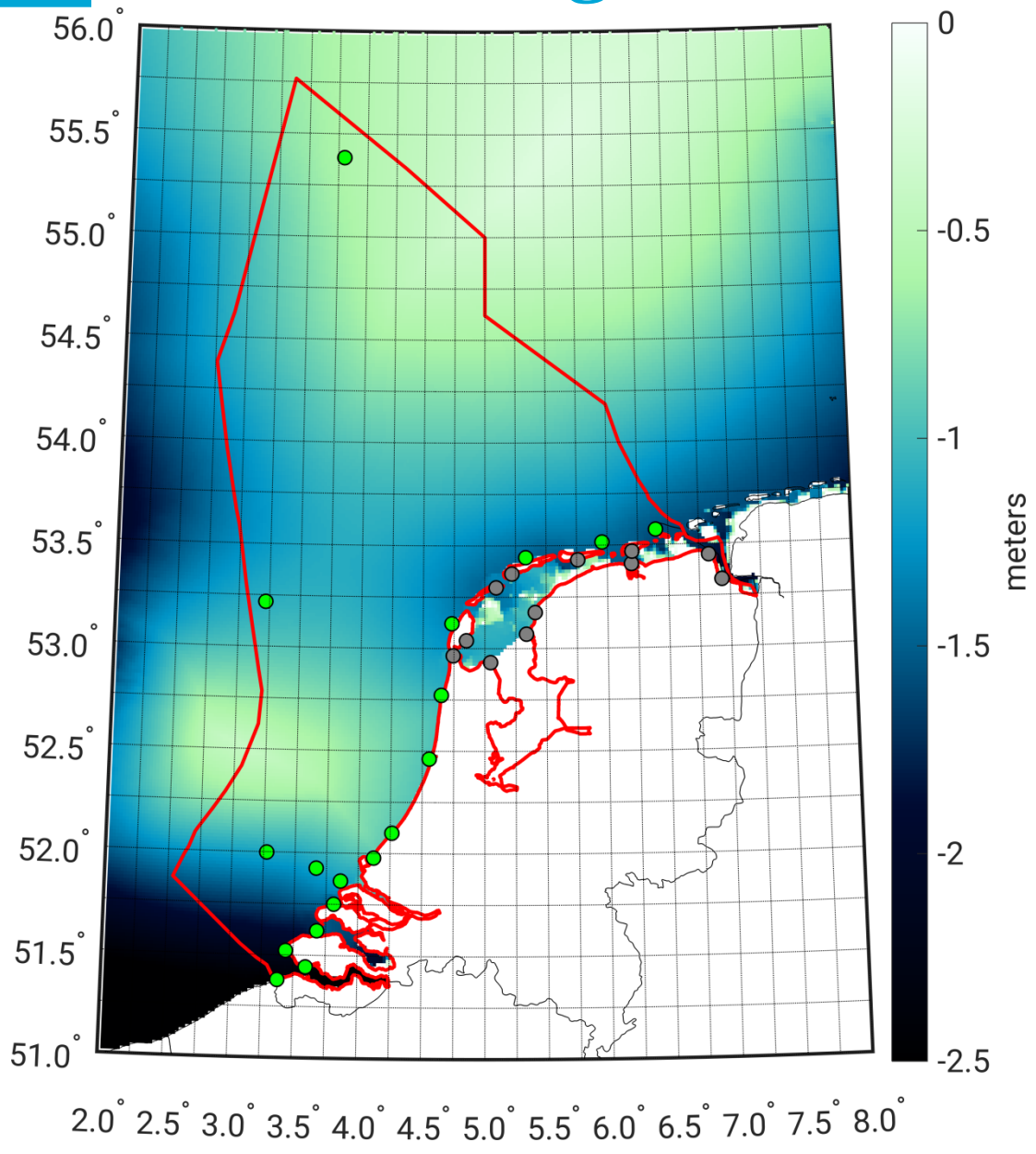


LAT w.r.t. geoid - validation



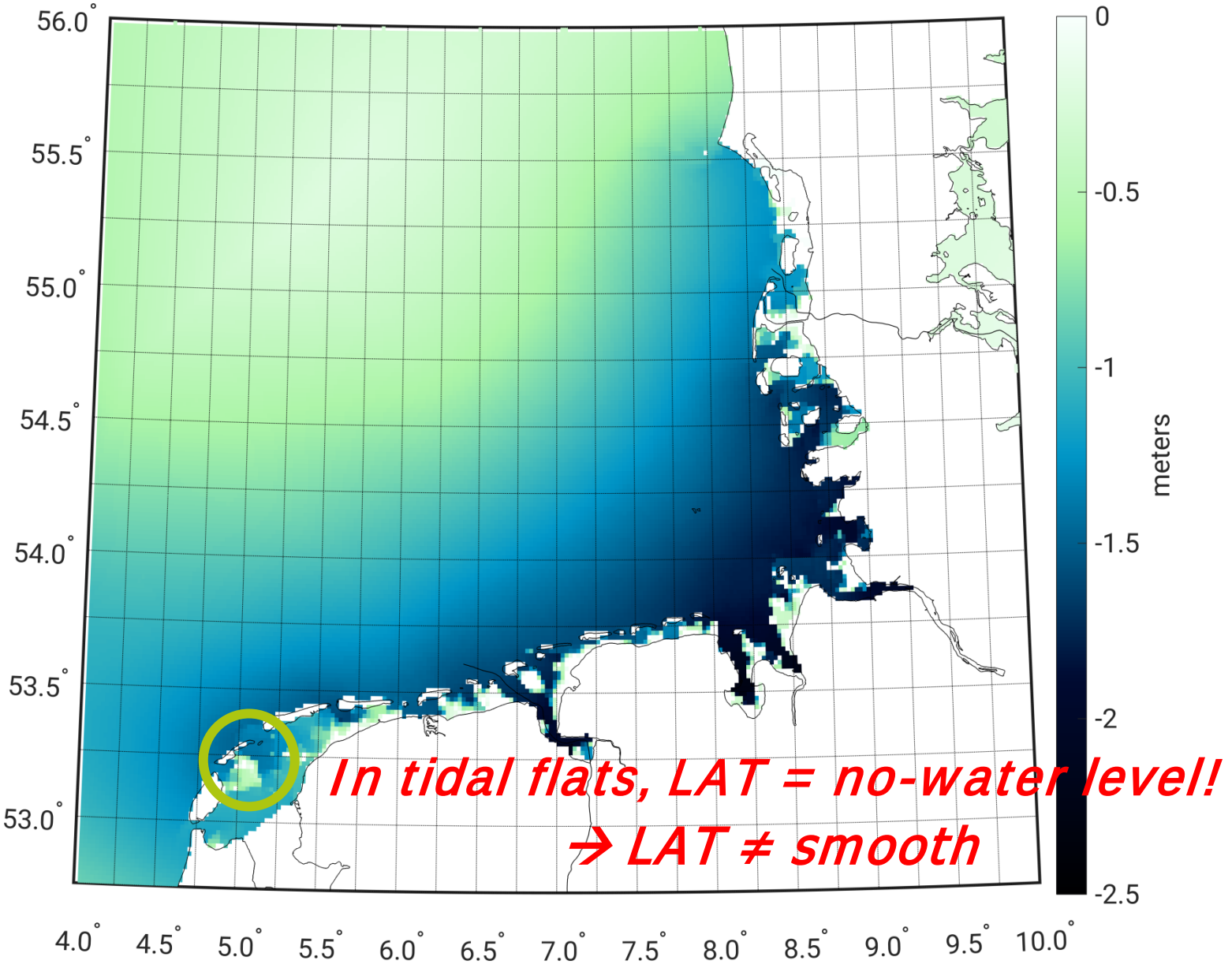
Region	Nr	Rms (cm)	Range (cm)	Mean (cm)	Std (cm)
North Sea	47	**10.6**	**57.6**	**-2.7**	**10.4**
Wadden Sea	18	**24.0**	**59.5**	**-18.7**	**15.4**
All	92	**14.9**	**77.6**	**-7.2**	**13.1**

LAT w.r.t. geoid – Dutch waters

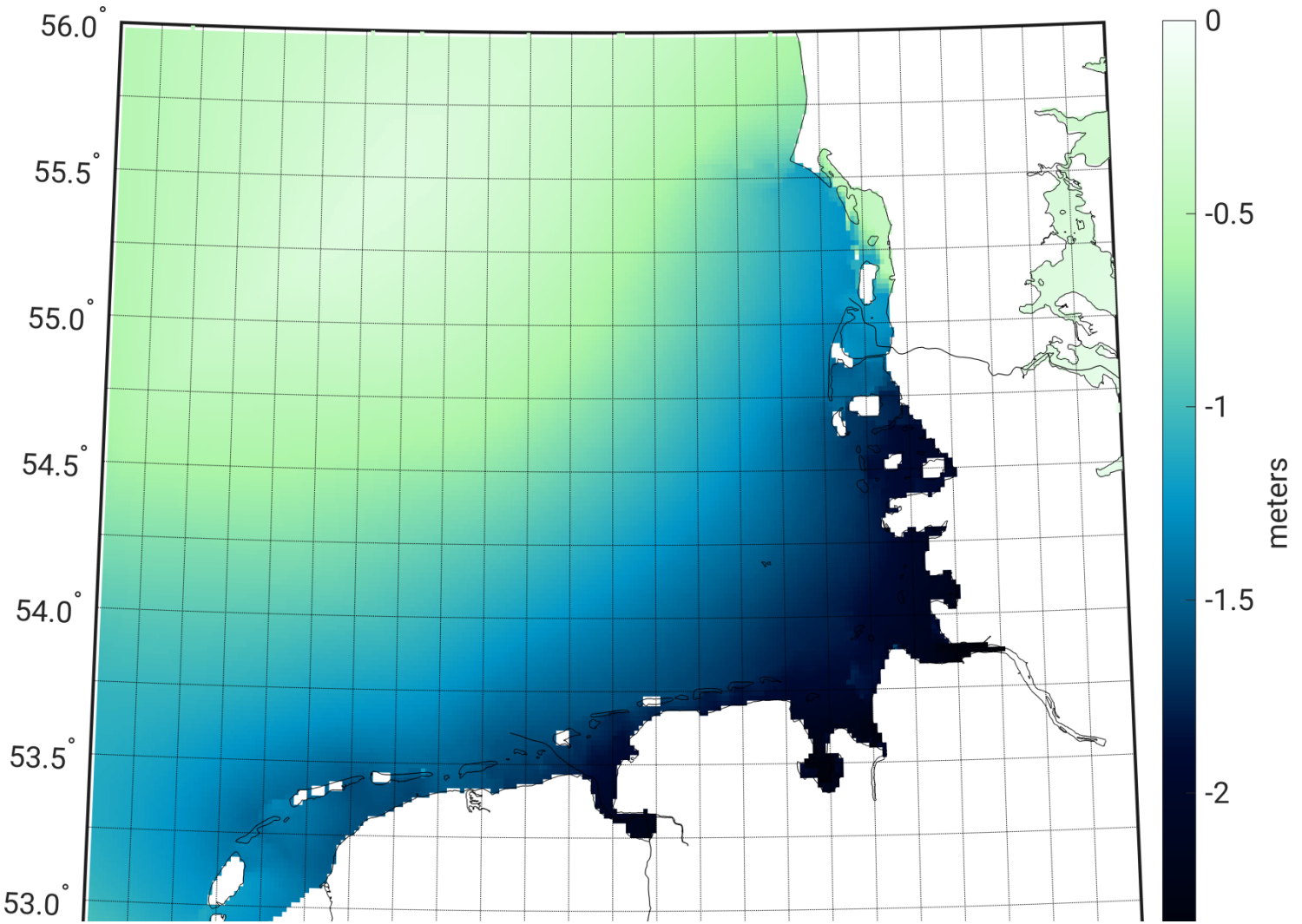


Region	Nr	rms (cm)
North Sea	19	**6.6**
Wadden Sea	12	**14.8**
All	31	**10.5**

LAT in the Wadden Sea?



In the Wadden Sea LAT → pseudo LAT



To obtain pseudo-LAT, we added 2 m of water to open boundary conditions & assimilated tidal water levels

The Dutch approach has been used successfully to compute a new quasi-geoid and LAT model for the Netherlands.

*Take home message

#3

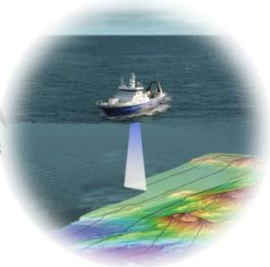

OPPORTUNITIES
AHEAD

Application domain

Vertical reference for dredging activities

Vertical reference for offshore engineering activities

Vertical reference for coastal zone management

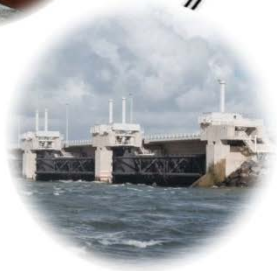


Improved bathymetric surveys

Improved absolute vertical positioning of ROVs

Nautical charts and support to nautical safety

Improved storm surge forecasting



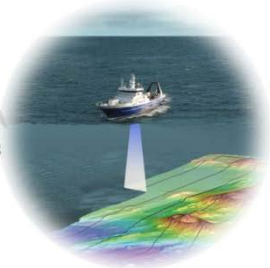
Vertical reference for building wind farms

Application domain

Vertical reference for dredging activities

Vertical reference for offshore engineering activities

Vertical reference for coastal zone management



Improved bathymetric surveys

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Nautical charts and support to nautical safety

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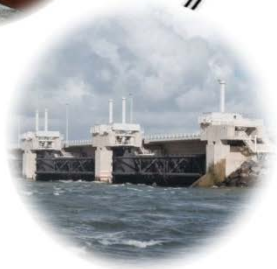
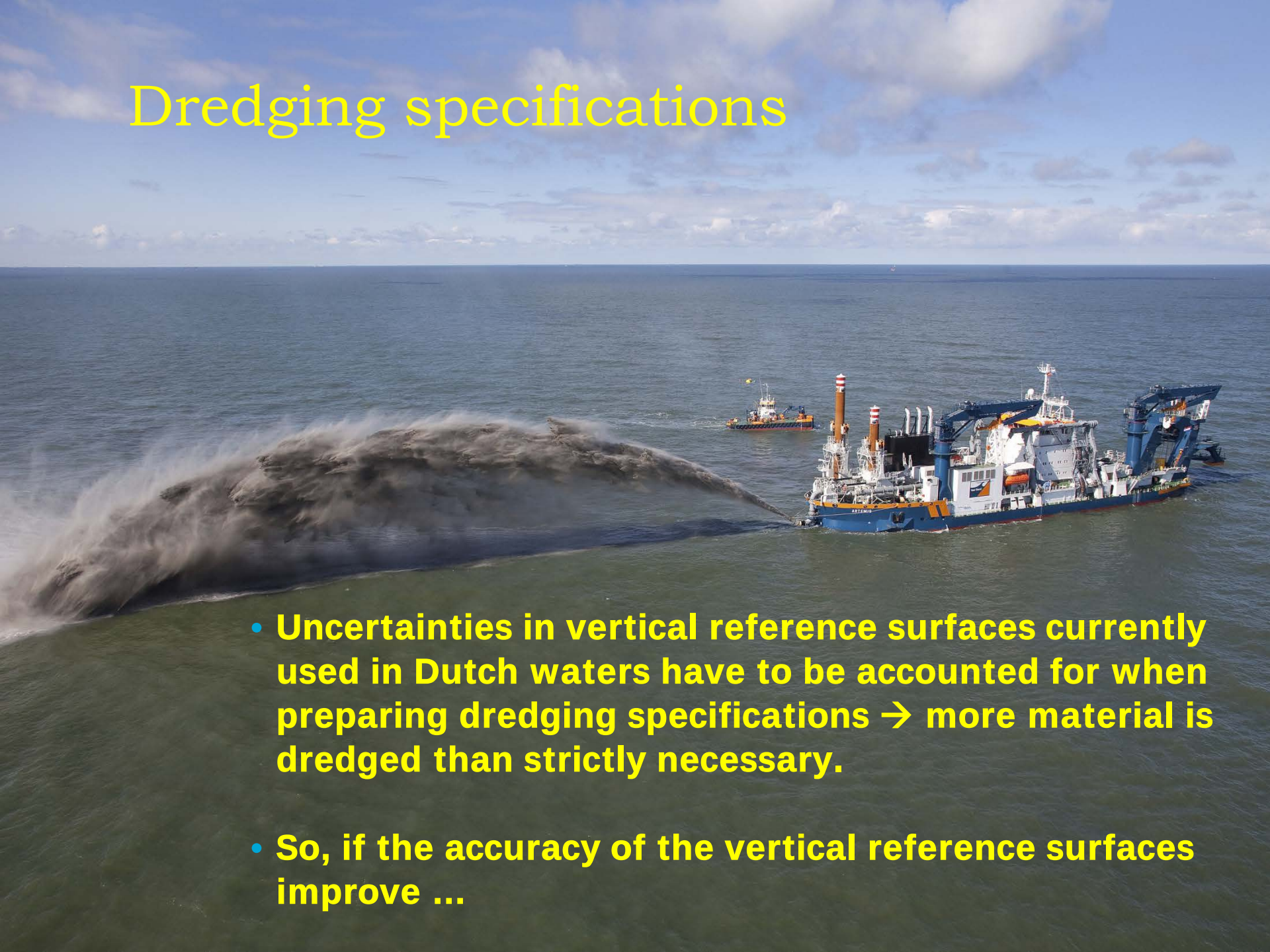


Vertical reference for building wind farms

Dredging specifications



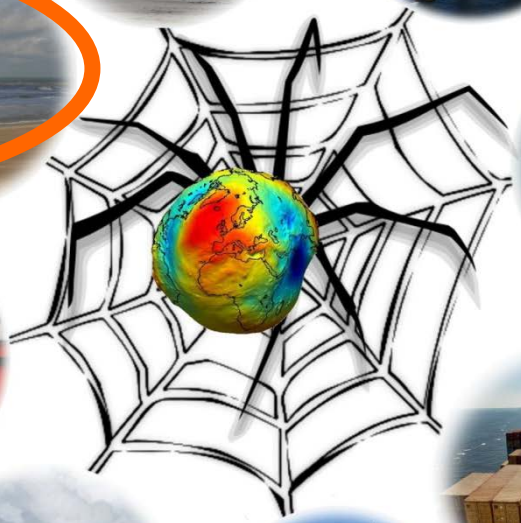
- **Uncertainties in vertical reference surfaces currently used in Dutch waters have to be accounted for when preparing dredging specifications → more material is dredged than strictly necessary.**
- **So, if the accuracy of the vertical reference surfaces improve …**

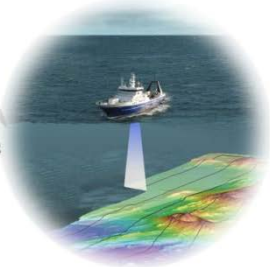
Application domain

Vertical reference for dredging activities

Vertical reference for offshore engineering activities

Vertical reference for coastal zone management



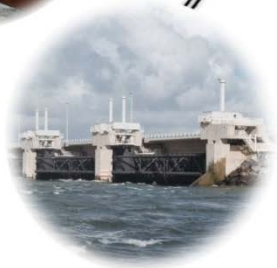


Improved bathymetric surveys

Improved absolute vertical positioning of ROVs

Nautical charts and support to nautical safety

Improved storm surge forecasting



Vertical reference for building wind farms

Coastal Zone Management

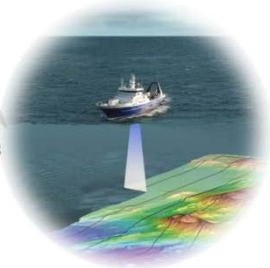
Integration of marine and land-based datasets

Application domain

Vertical reference for dredging activities

Vertical reference for offshore engineering activities

Vertical reference for coastal zone management

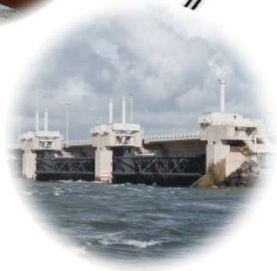


Improved bathymetric surveys

Improved absolute vertical positioning of ROVs

Nautical charts and support to nautical safety

Improved storm surge forecasting



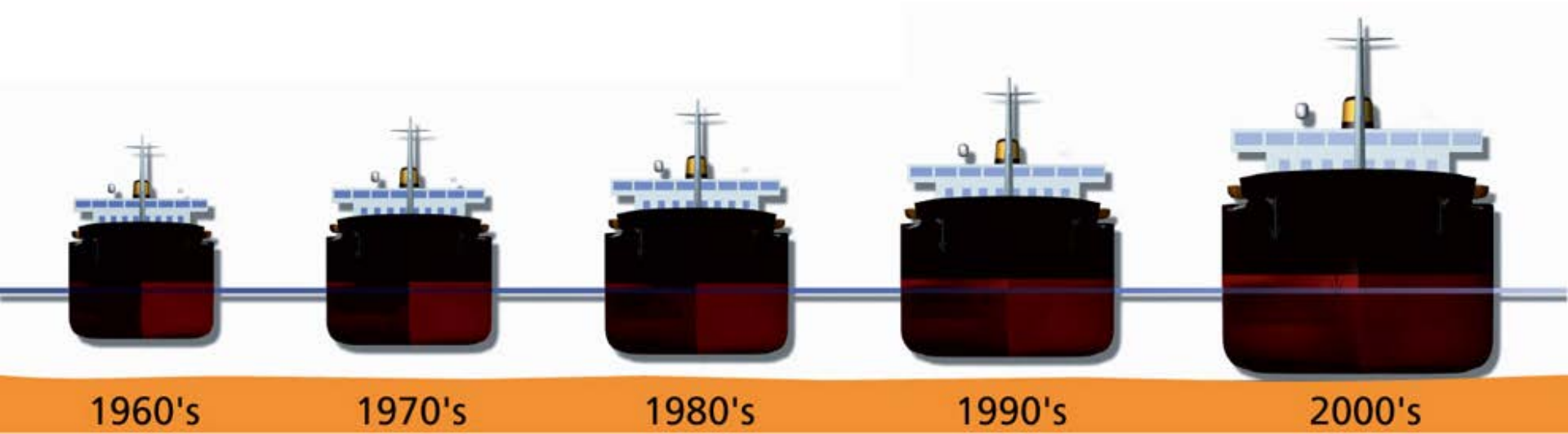
Vertical reference for building wind farms

The challenge ahead…

Access to the main Dutch harbors and their approach routes is for the bigger ships already **restricted** to certain stages of the tide...

...ships are still getting bigger & ship drafts deeper!

How informative are depths w.r.t. LAT?



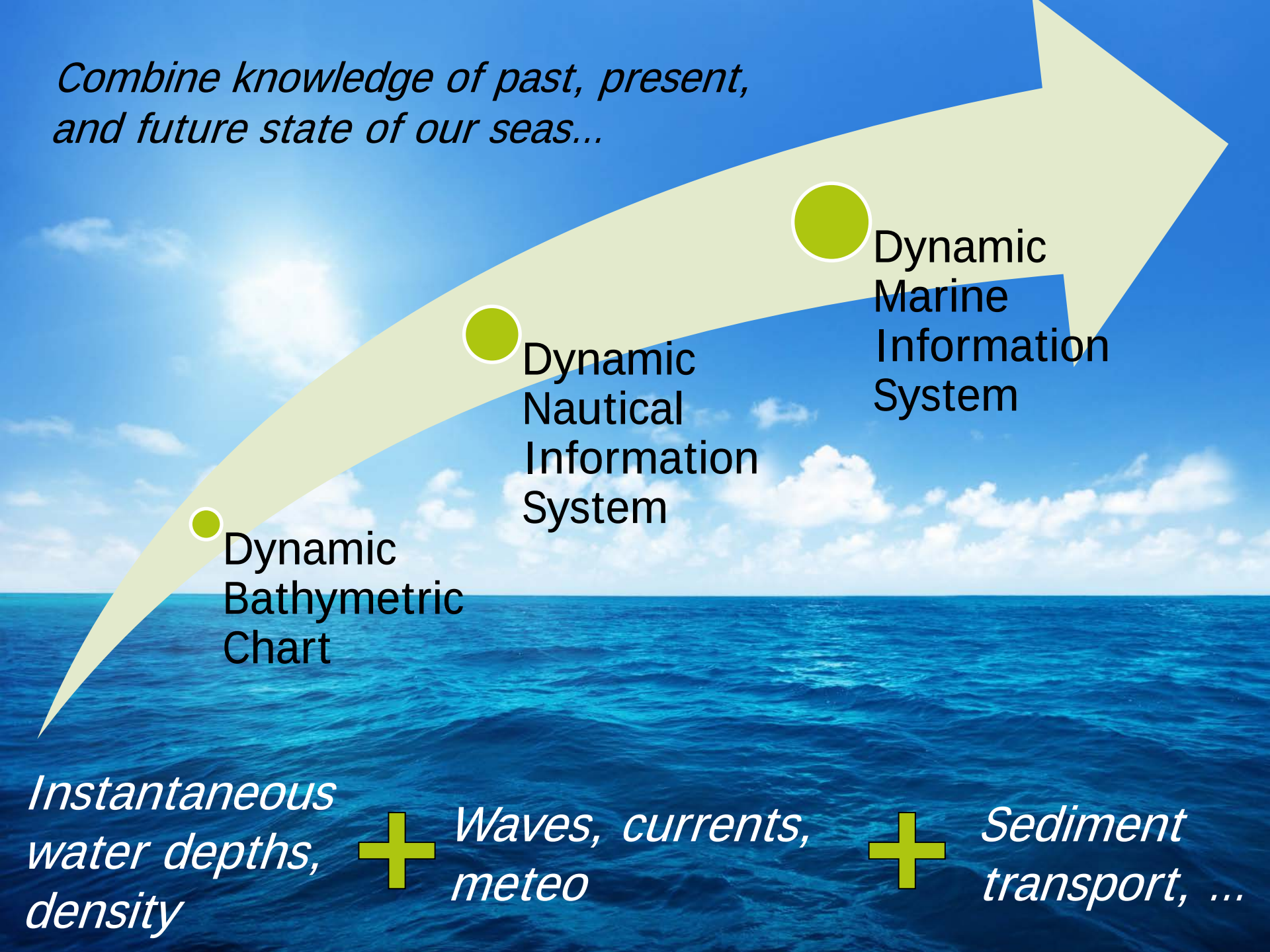
The next 5 years:

VERSATILE HYDRODYNAMICS

A SYNERGYSTIC DEVELOPMENT OF TOMORROW'S MARINE NAVIGATION PRODUCTS

To develop a hydrodynamic model properly embedded in the observational network that allows accurate, seamless forecasting of total water depths in the Dutch North Sea.


The next 5 years:
VERSATILE HYDRODYNAMICS
A SYNERGYSTIC DEVELOPMENT OF TOMORROW'S MARINE NAVIGATION PRODUCTS
LEARN MORE
↓
http://versatile-hydrodynamics.nl/


Combine knowledge of past, present, and future state of our seas…
Dynamic Marine Information System
Dynamic Nautical Information System
Dynamic Bathymetric Chart
Instantaneous water depths, density
+
Waves, currents, meteo
+
Sediment transport, …

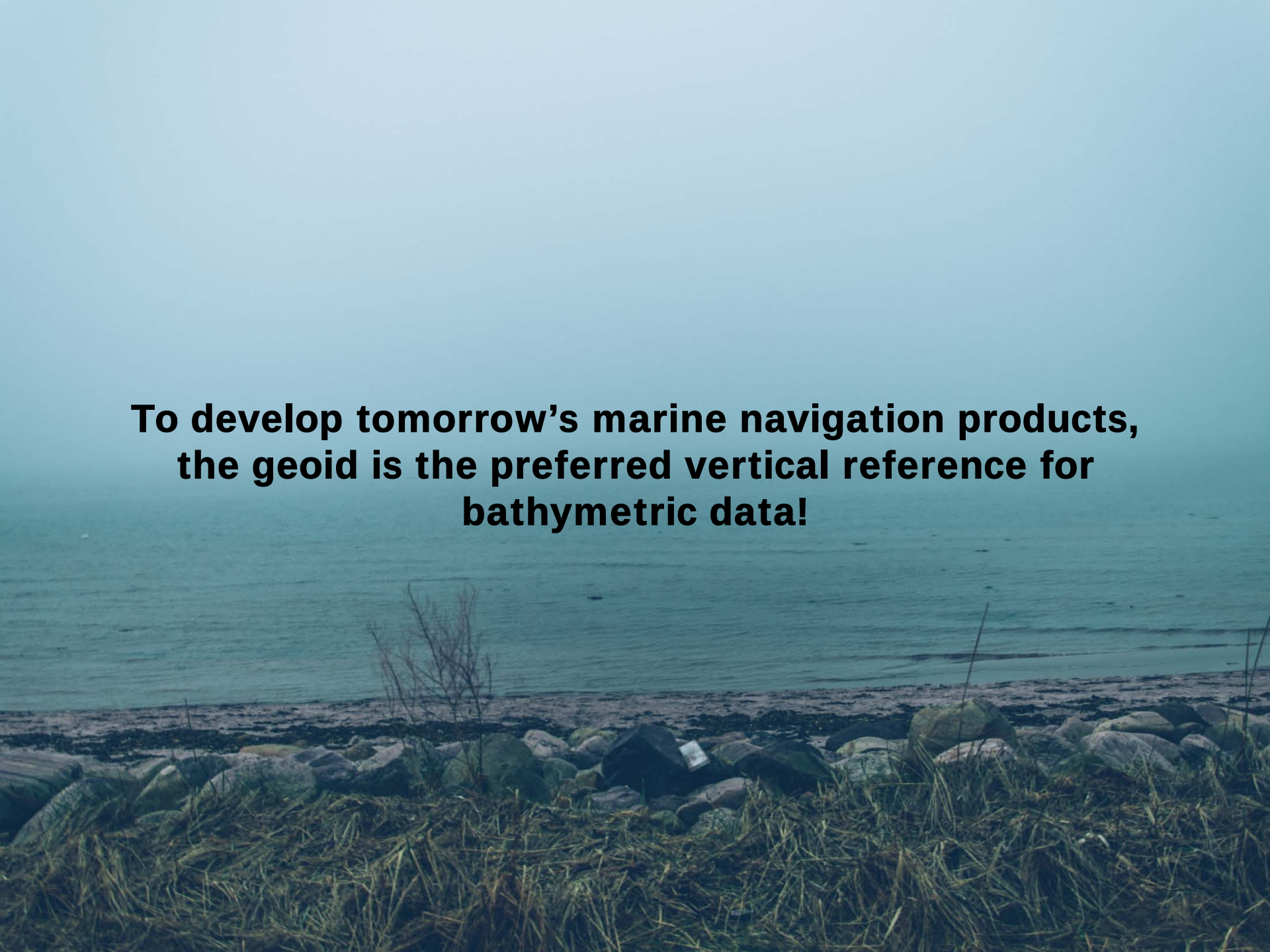
The Dutch approach to solve the problem of the unknown relationship between height / depth vertical reference surfaces provides great opportunities for the public & private sectors!

Required infrastructure forms the basis for a dynamic marine information system!

*Take home message #4

LAT as Chart Datum?

- Has a poor idealization precision;
- Lacks an operational definition;
- Is hard to validate;
- Is not defined in intertidal waters;
- Might be often fallen below by wind-driven water level variations;
- Does not provide the information actually needed.
- Is of no use in case we switch to dynamic bathymetry!

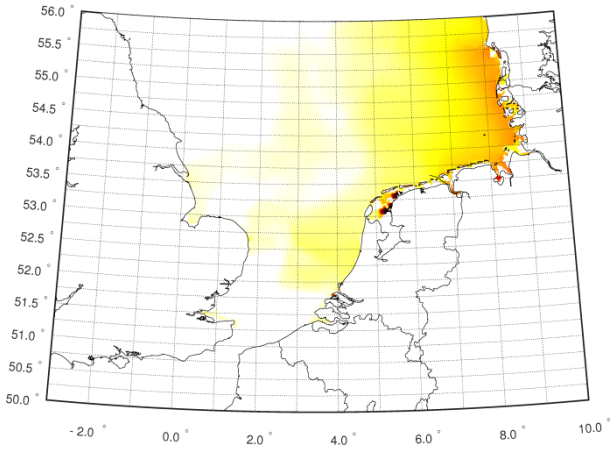

To develop tomorrow’s marine navigation products, the geoid is the preferred vertical reference for bathymetric data!

Thank you!

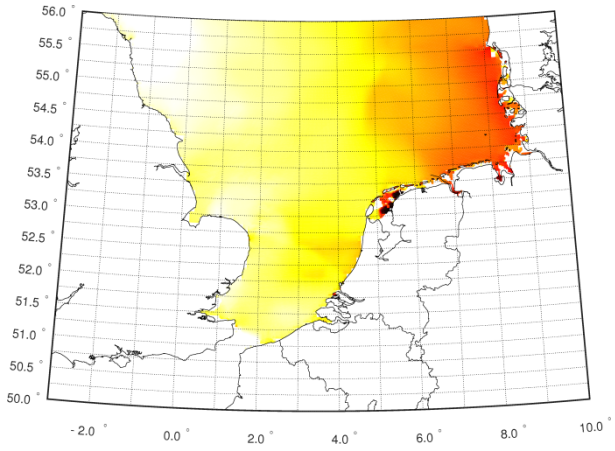
Spare slides

Probability that minimum instantaneous water level (DCSMv6) in periods of tidal minima drops below:

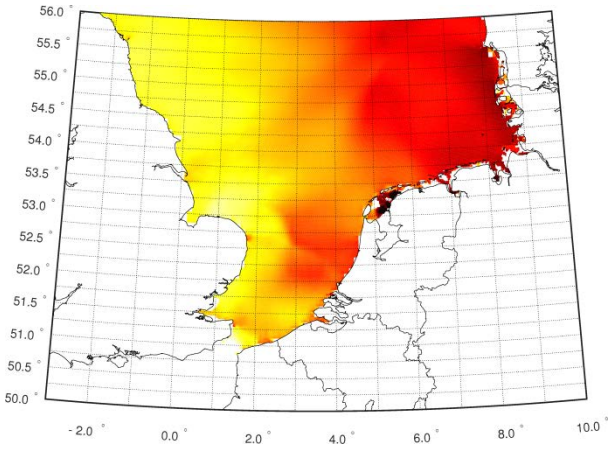
LAT-0.5m

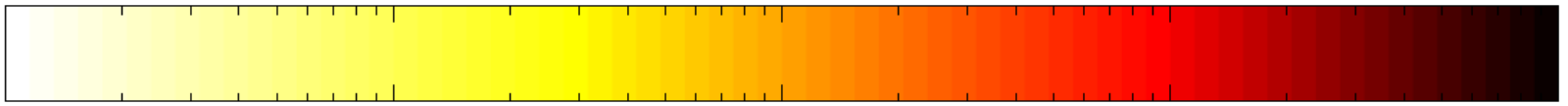


LAT-0.25m



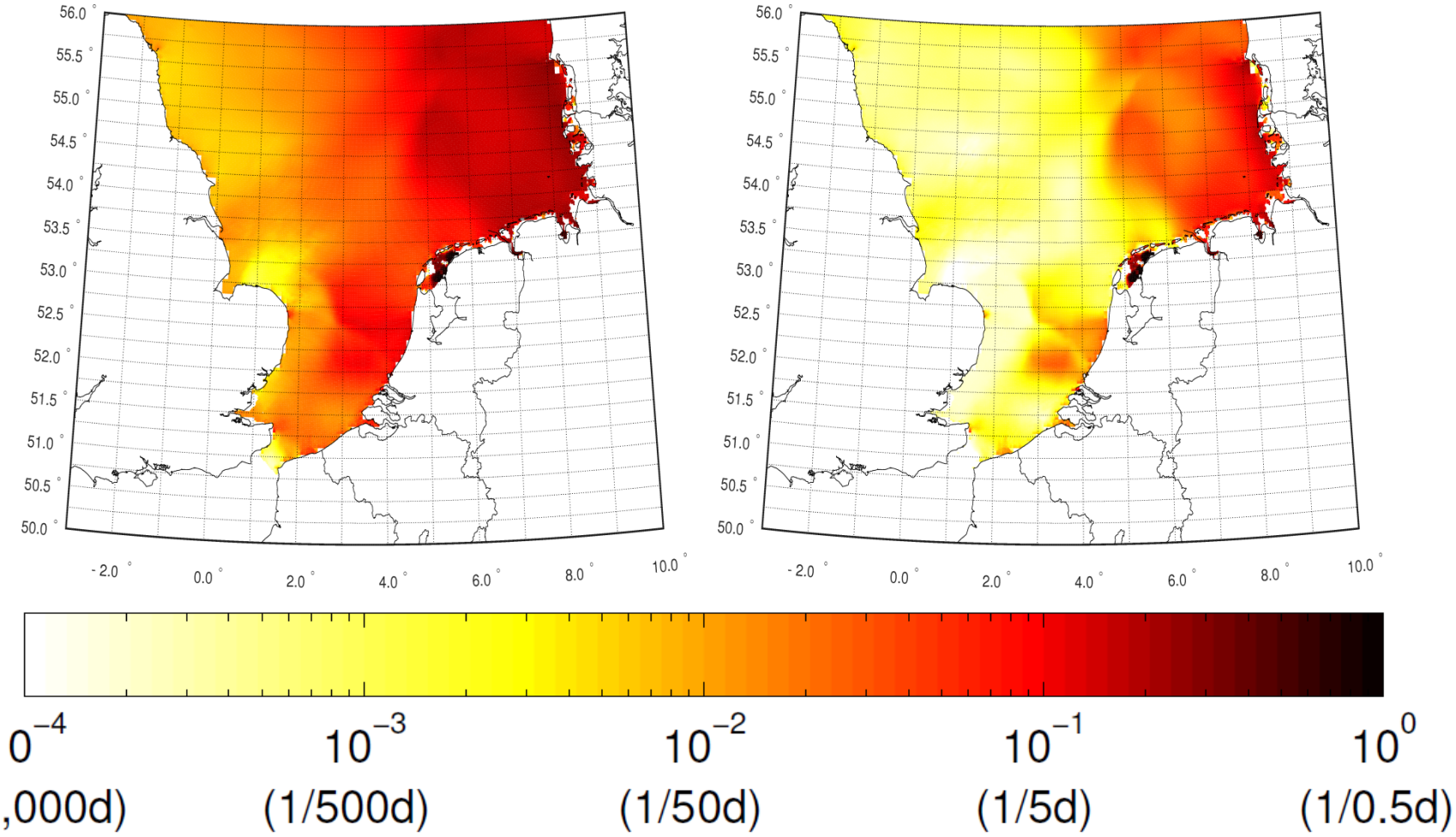
LAT





10^{-4} (1/5,000d) 10^{-3} (1/500d) 10^{-2} (1/50d) 10^{-1} (1/5d) 10^{0} (1/0.5d)

Probability that minimum instantaneous water level (DCSMv6) in periods of tidal minima drops below LAT in winter and summer:

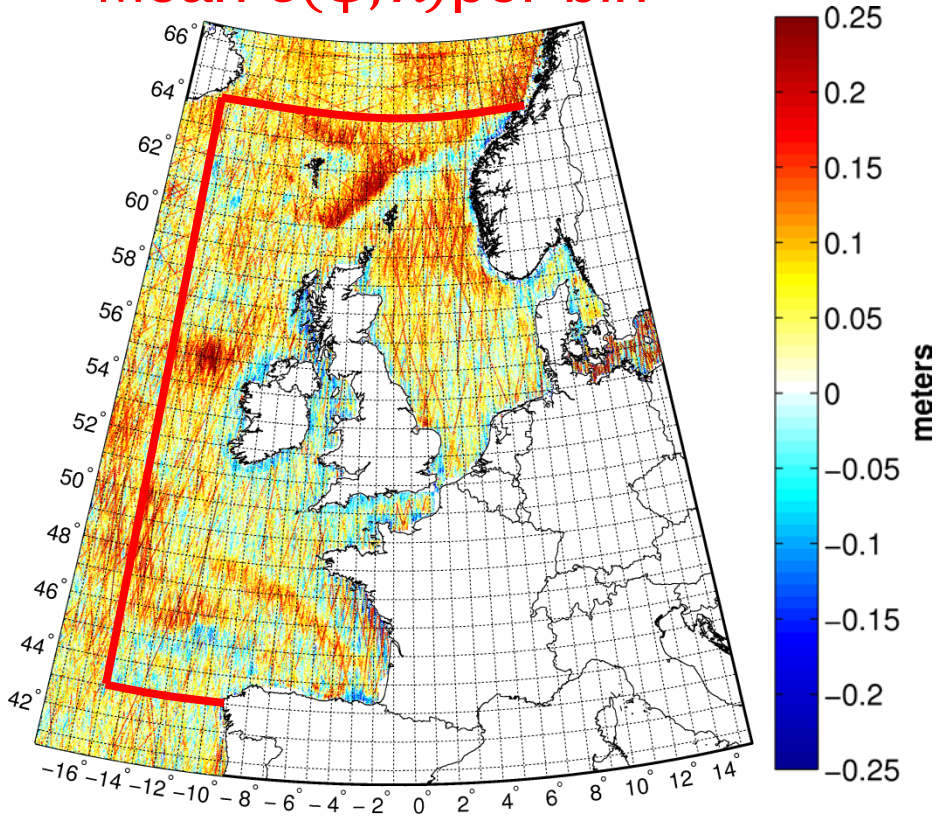


DT corrections DC

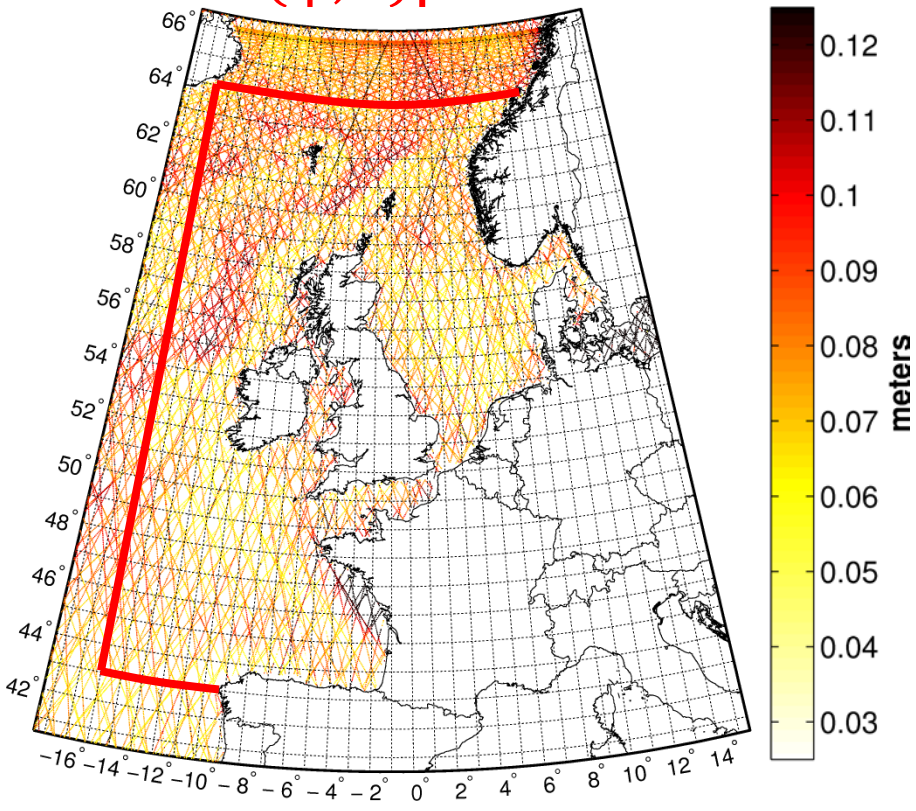
Noise level altimetry ~ 5 cm,
size footprint 2-10 km

$$\varepsilon(\varphi,\lambda) = h - \xi_{\mathrm{DCSMv6}} - \xi_{\mathrm{steric}}(t) - N_{\mathrm{EGG2015}}$$

Mean $\varepsilon(\varphi,\lambda)$ per bin



Std $\varepsilon(\varphi,\lambda)$ per bin



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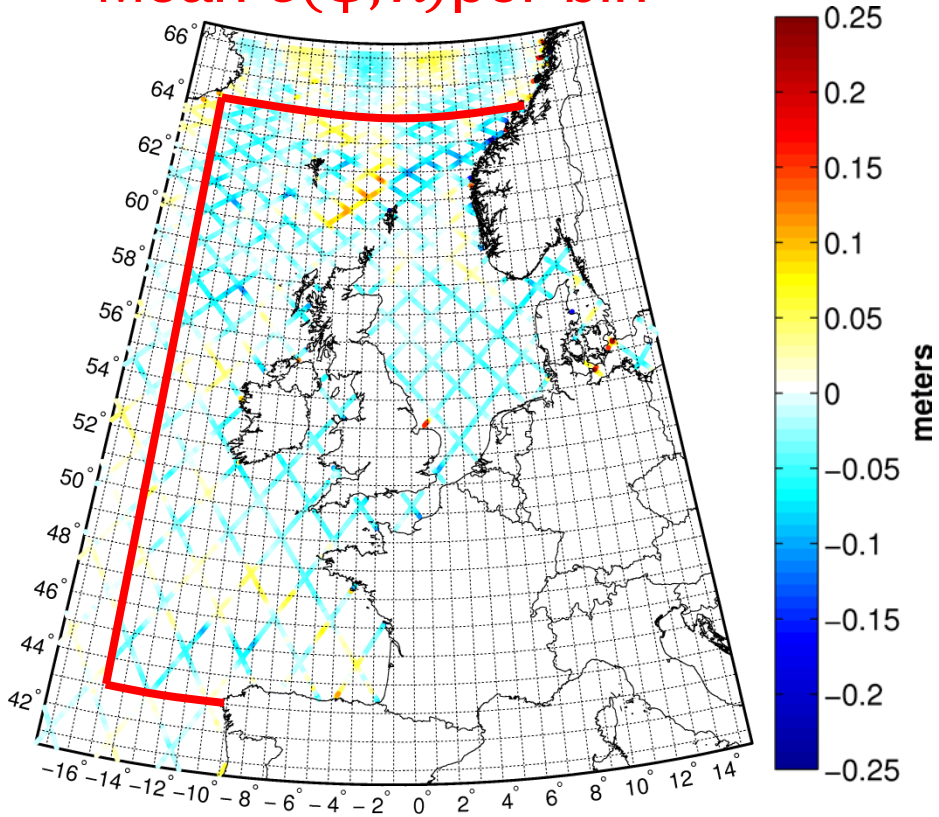

Std $\varepsilon(\varphi,\lambda)$ per bin