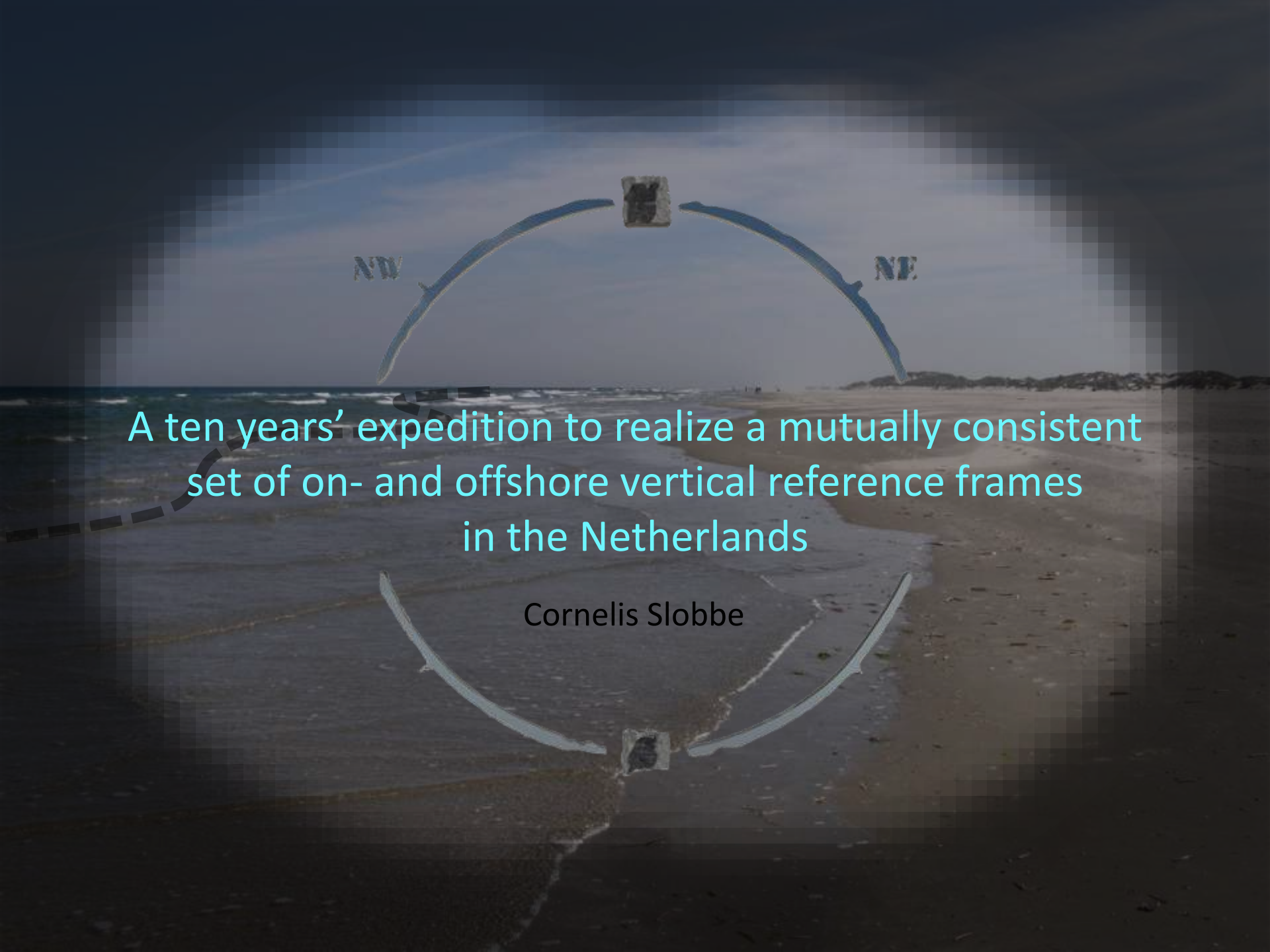
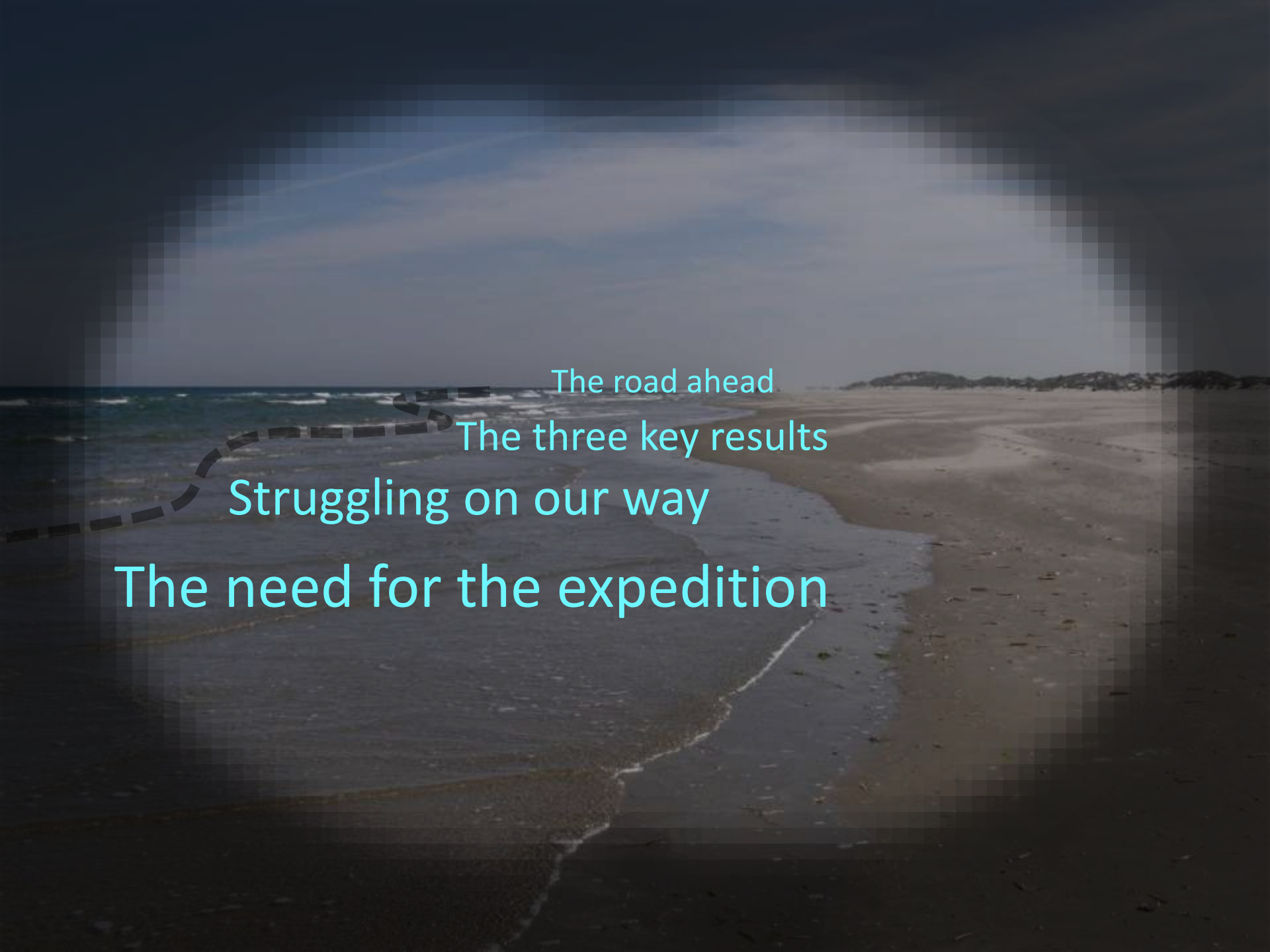
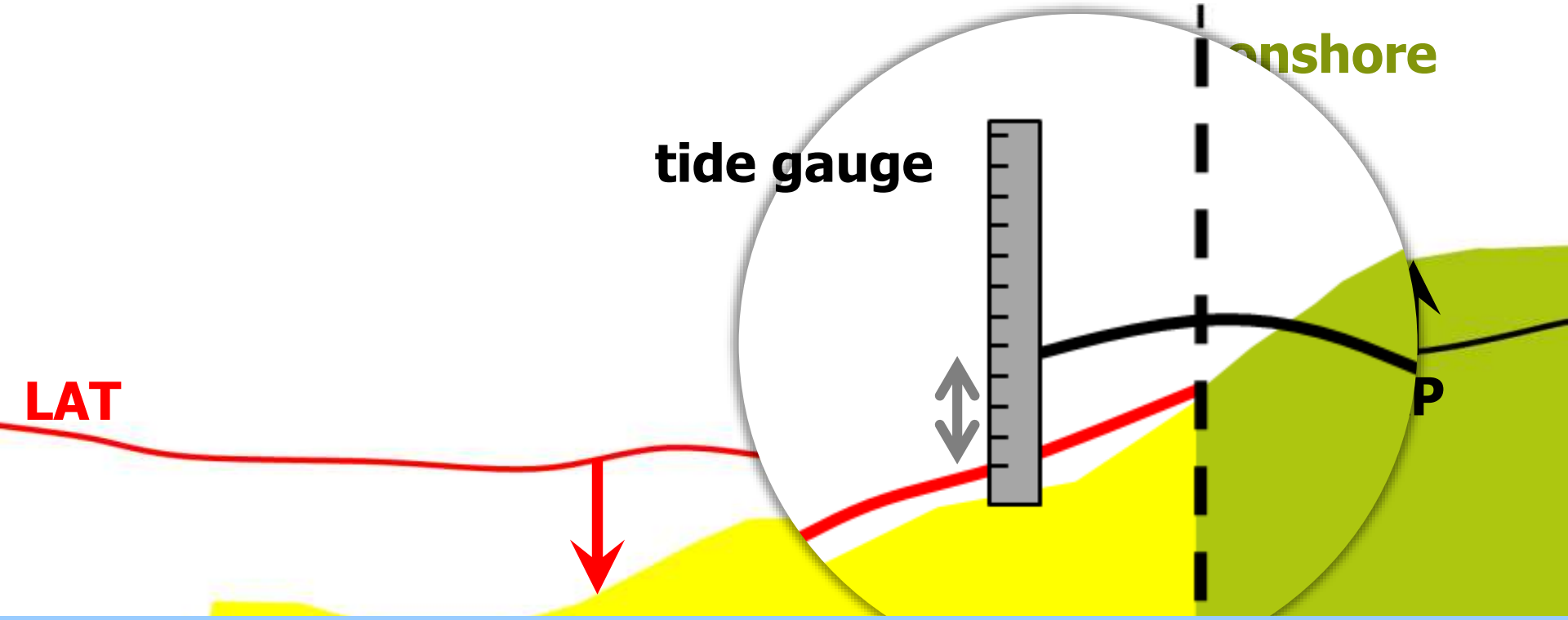


A ten years' expedition to realize a mutually consistent set of on- and offshore vertical reference frames in the Netherlands

Cornelis Slobbe

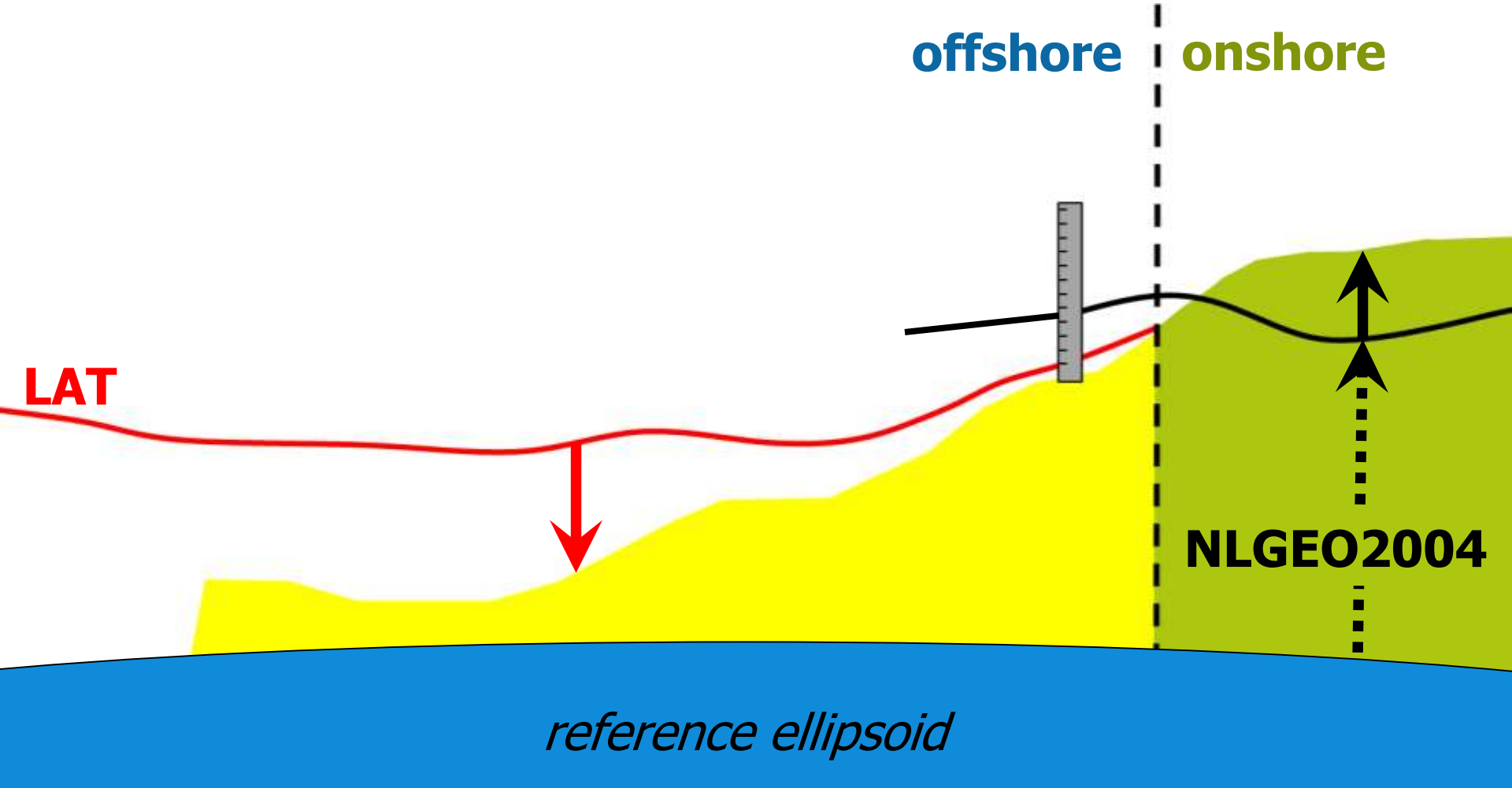

The road ahead
The three key results
Struggling on our way
The need for the expedition

The problem…



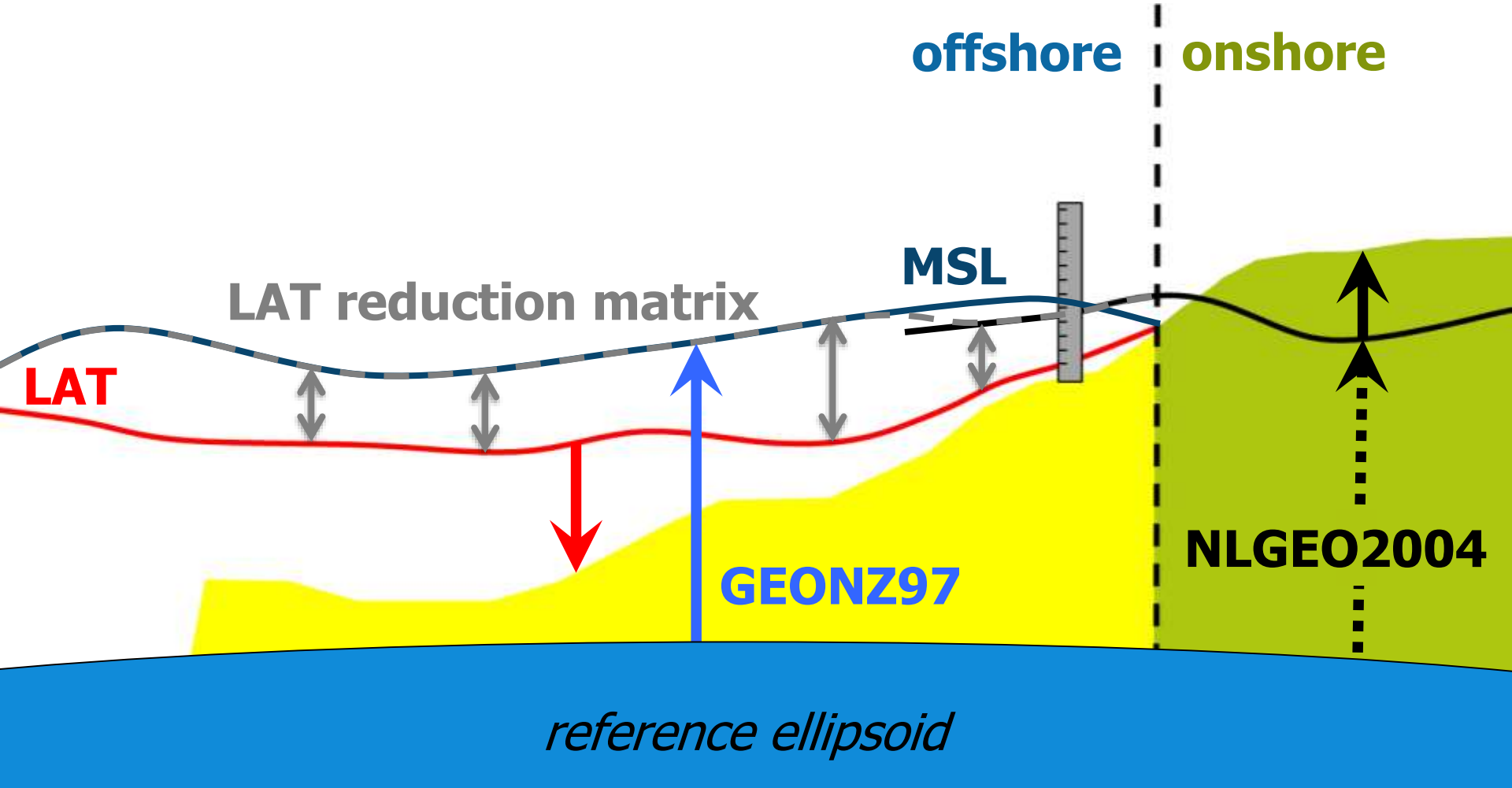
Typically, the separation chart datum/ height reference surface is a *spatially varying* function only known at the tide gauges!

The problem…



The problem…

LAT reduction matrix = difference LAT – "MSL" in open sea and LAT - NAP along the coast (smooth transition)



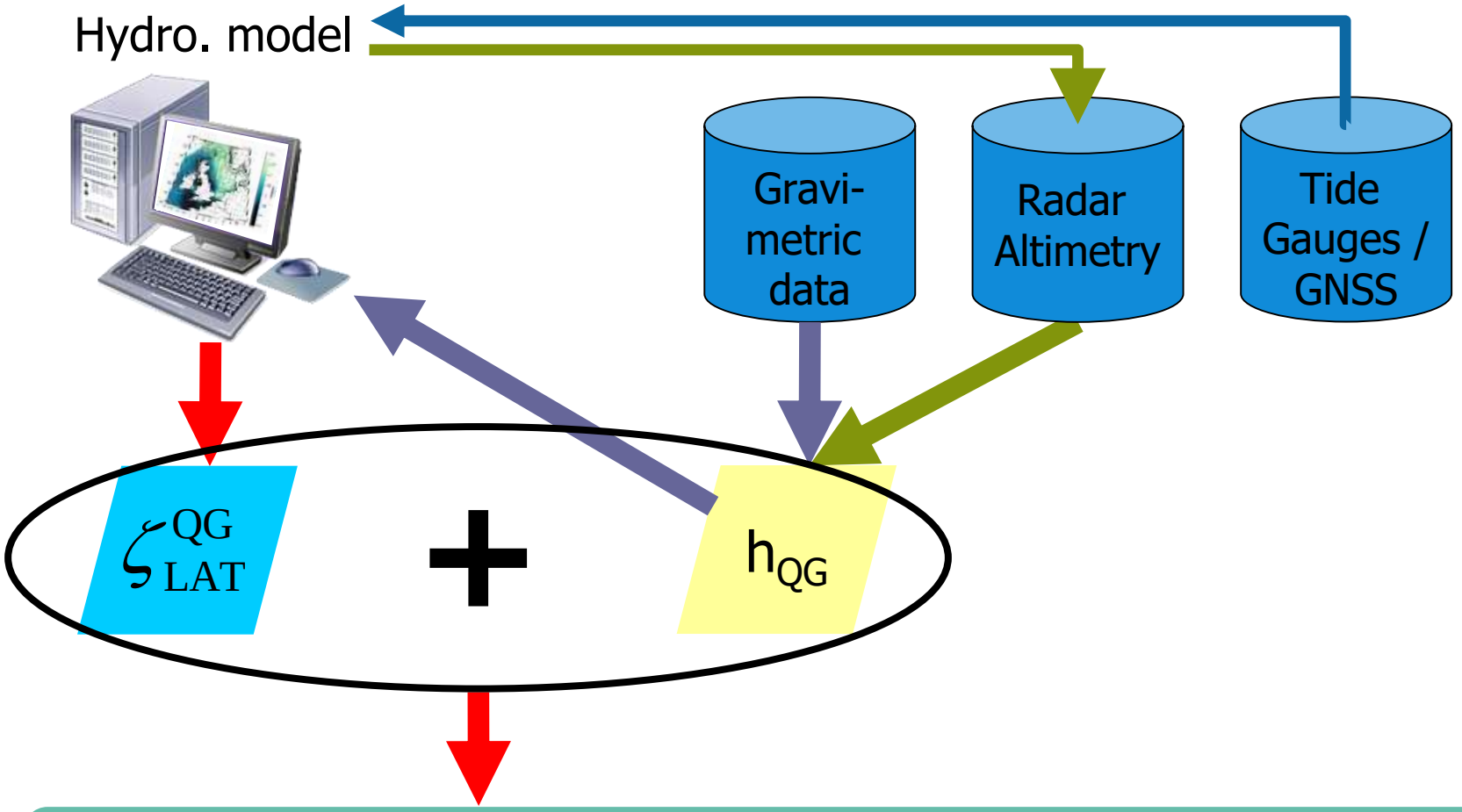
Main objective NEVREF project

Required with cm accuracy …

*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*

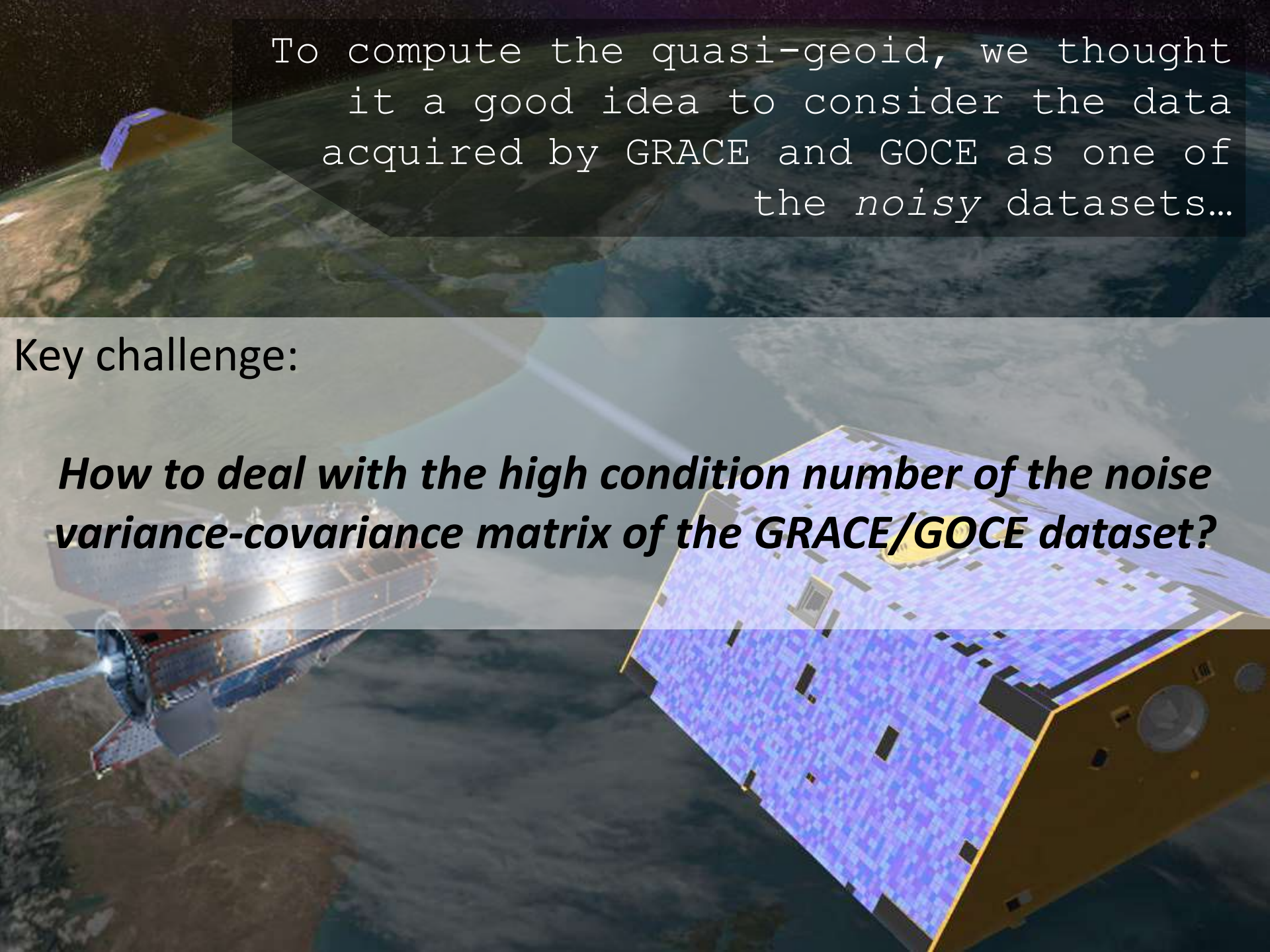
…to obtain this one with accuracy of 1 dm!

Approach



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

Struggling on our way…



To compute the quasi-geoid, we thought it a good idea to consider the data acquired by GRACE and GOCE as one of the *noisy* datasets…

Key challenge:

How to deal with the high condition number of the noise variance-covariance matrix of the GRACE/GOCE dataset?

At first, it went very smoothly (May 2014)…

Data: GRACE/GOCE

- In computing NLGEO
  in a remove-comput
  1. Subtract GRACE/
     observations (e.g.
  2. Model the residua
  3. Restore GR
- In this way, the st
  data are ignored…!

In the following

GRACE/GOCE propagated covariance matrix
(in the form gravity disturbances at satellite altitude)

Variances

North-South covariance function

Geoid comput
+Shipb+Airb+

Note,

ignoring whose distan

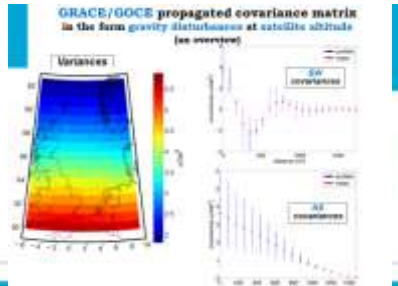
2008
+DoV$_{EGG2008}$)

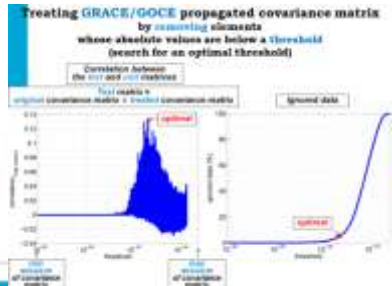
trol GPS/leveling data
Shipb+Airb+SA+DoV$_{EGG2008}$)
t of GRACE/GOCE data)

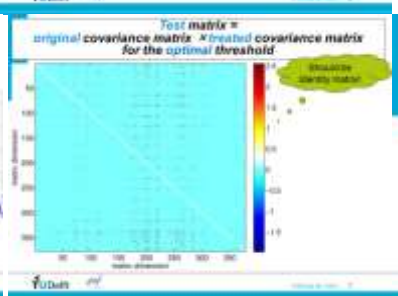
			with GRACE/GOCE data (cm)	
	STD	RMS	STD	RMS
	5.14	12.39	5.11	12.40
	1.65	1.81	1.32	1.70
The Netherlands (RWS-AGI)	1.16	2.66	0.90	2.79
Norway	6.04	7.59	5.85	6.99

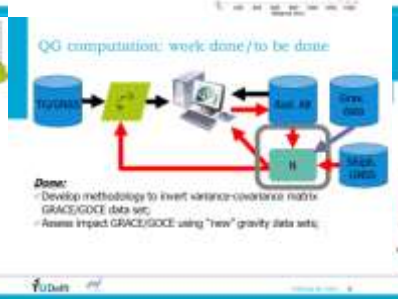
Impact is positive!

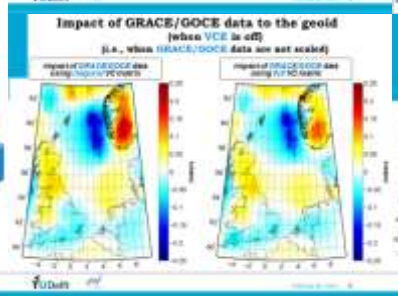
Mar 2015, we confirmed preliminary results…

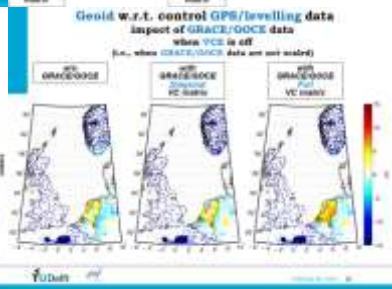


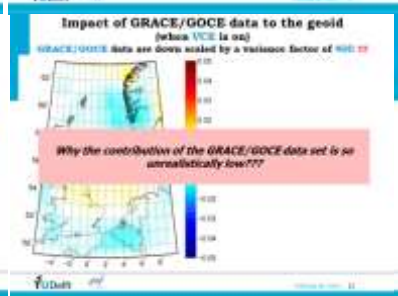


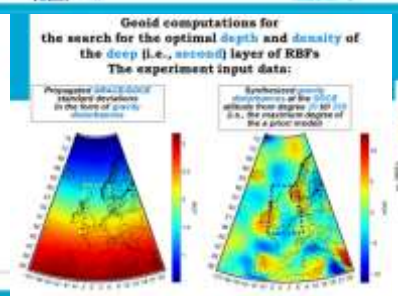


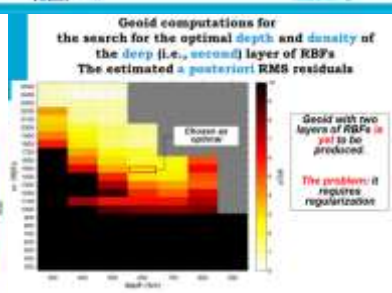


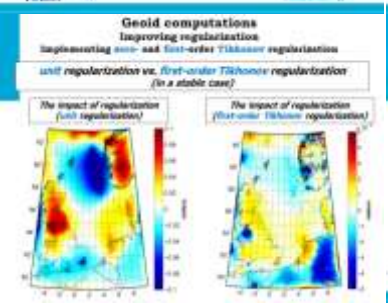


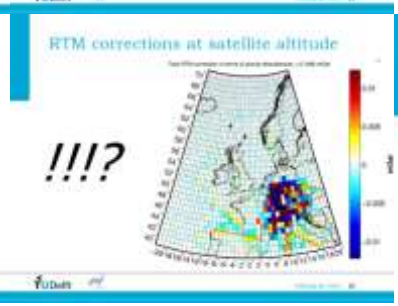




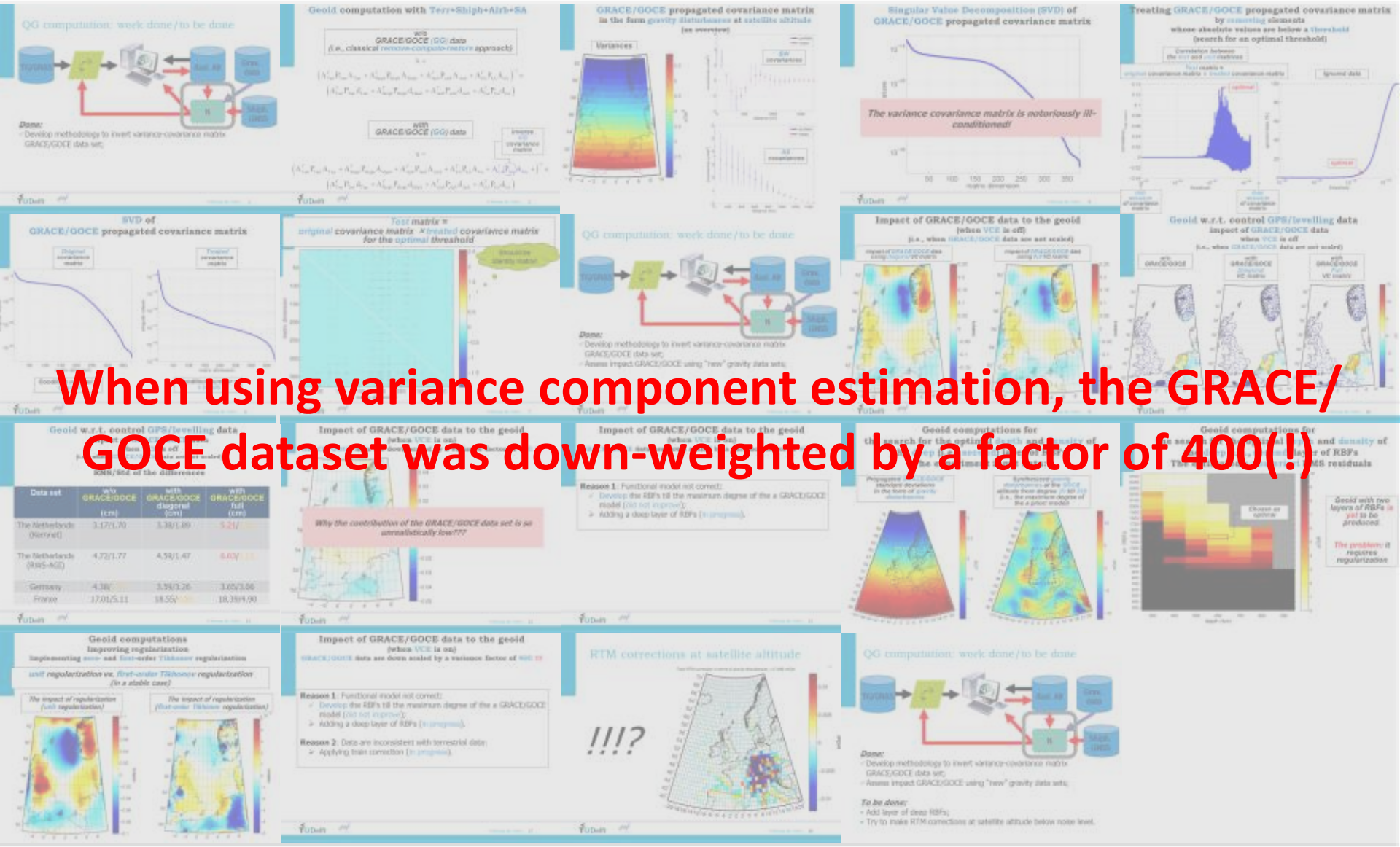








TU Delft



Though there was a "minor", but annoying, issue…

The noise variance covariance matrix of the satellite-only gravity field model is not properly computed!

Error in data pre-processing

Use different regularization method?

Functional model is wrong…?

Still there should be bugs

Apply proper low-pass filter???

RTM corrections @ satellite altitude should be below noise level…

pute inverse using multi-precision toolbox!!!

Parameterization area should be > data area?

Bug in software!!!

Is Cholesky decomposition the proper way to so

system of equations…?

More bugs!?

Oversampling…?

Our data area is too small…?

When the struggle continued (Feb 2015)…

When the struggle continued (Nov 2015)…

When the struggle continued (15 Mar 2016)…

When the struggle continued (16 Mar 2016)…

TU Delft

But, when the result turned out to be not reproducible…

On 17 Mar 2016, I said to myself: OK, the very last thing I will do is to try figuring out how that one good result was obtained…

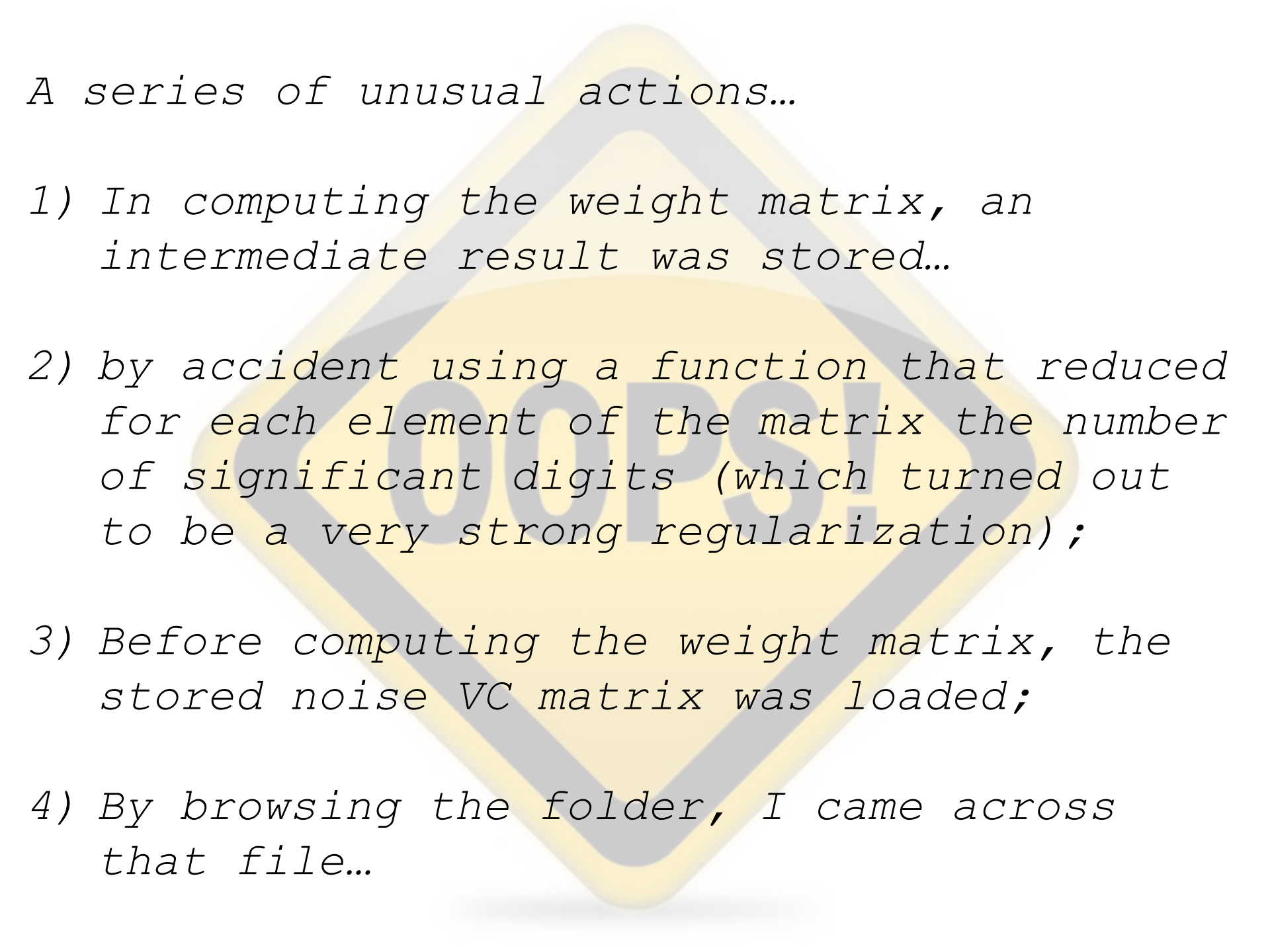
A series of unusual actions…

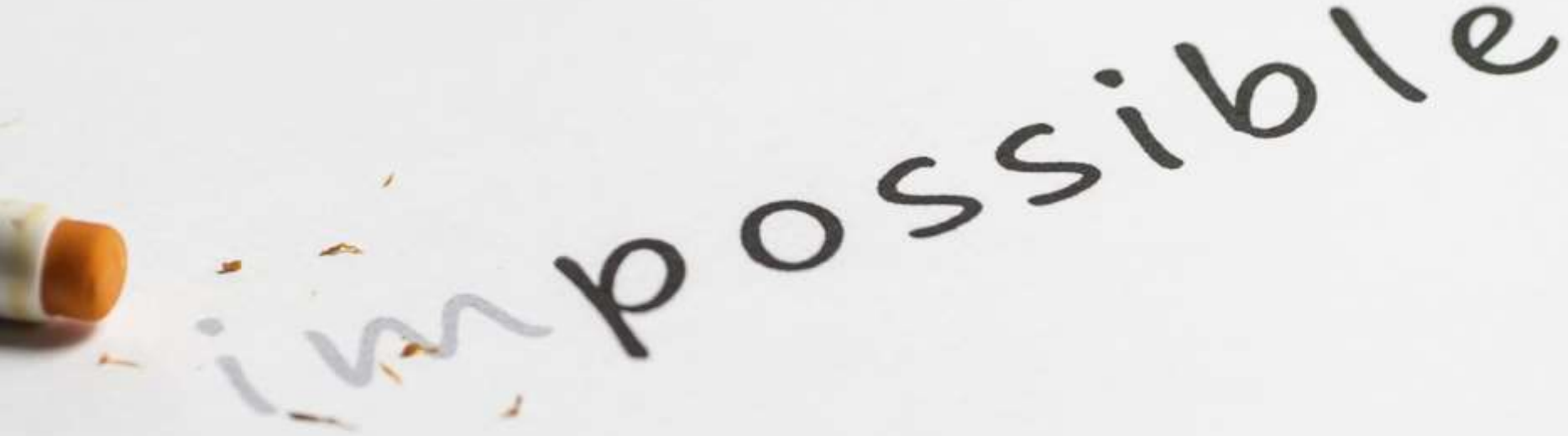
1) In computing the weight matrix, an intermediate result was stored…

2) by accident using a function that reduced for each element of the matrix the number of significant digits (which turned out to be a very strong regularization);

3) Before computing the weight matrix, the stored noise VC matrix was loaded;

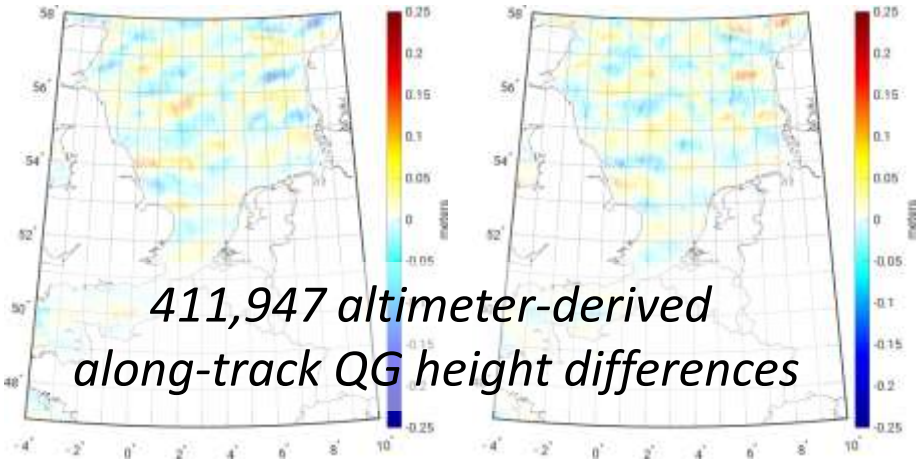
4) By browsing the folder, I came across that file…



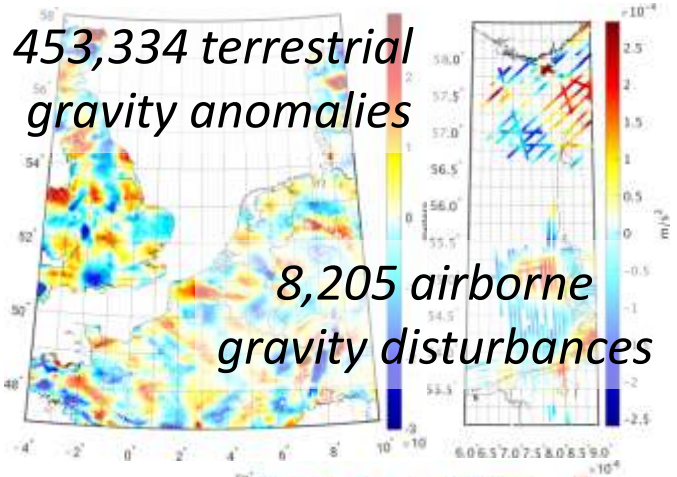


An exceptionally strong regularization of the noise VC matrix was needed, much larger than we expected from the condition number of the noise covariance matrix…

Key result 1: the new Dutch quasi-geoid model NLGEO2018…

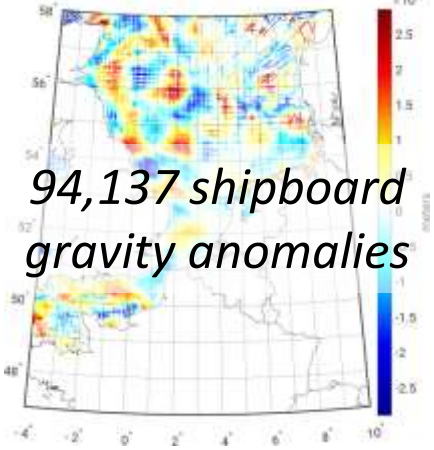


411,947 altimeter-derived along-track QG height differences

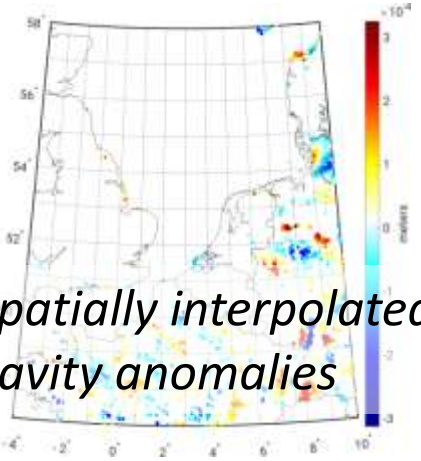


453,334 terrestrial gravity anomalies

8,205 airborne gravity disturbances

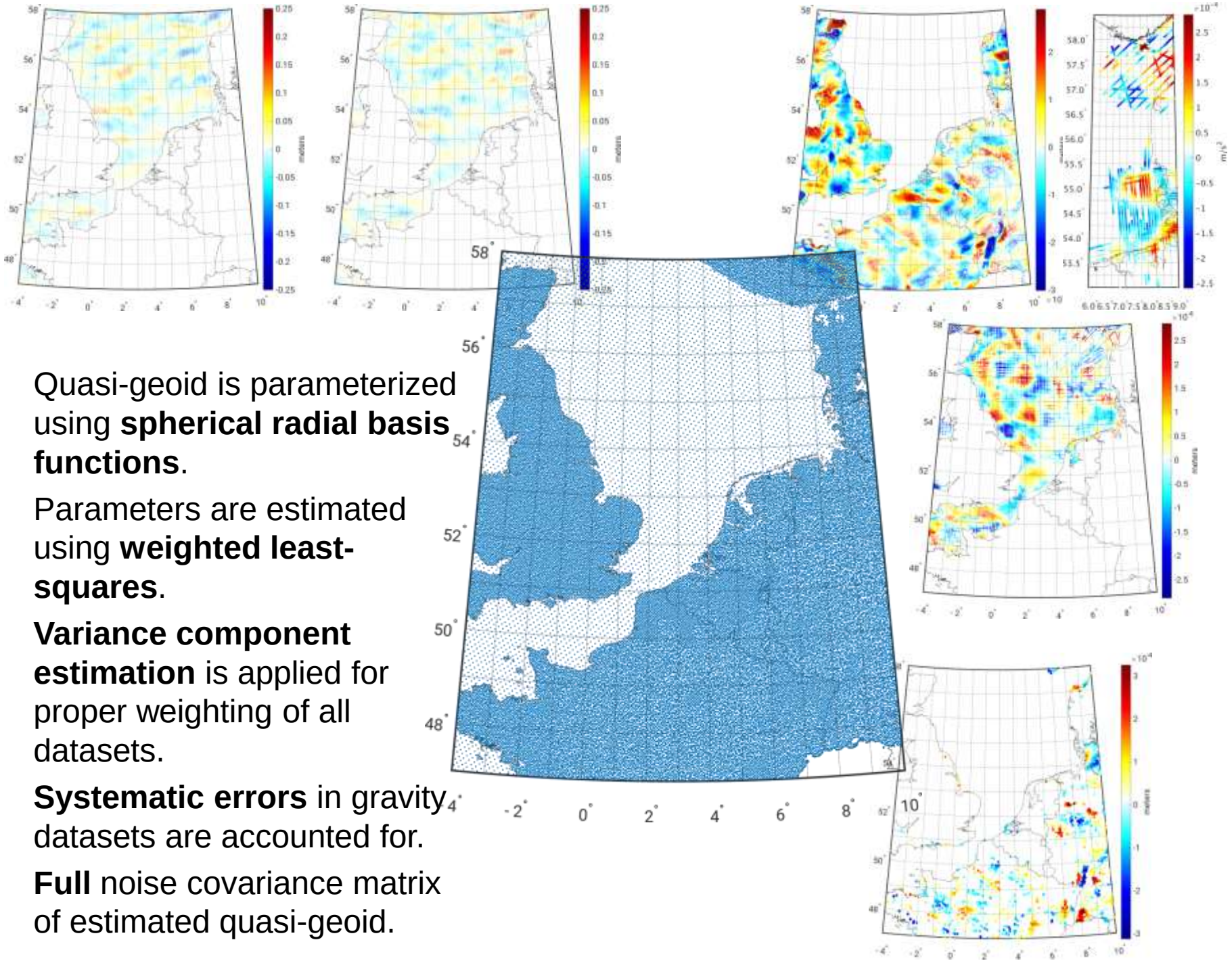


94,137 shipboard gravity anomalies



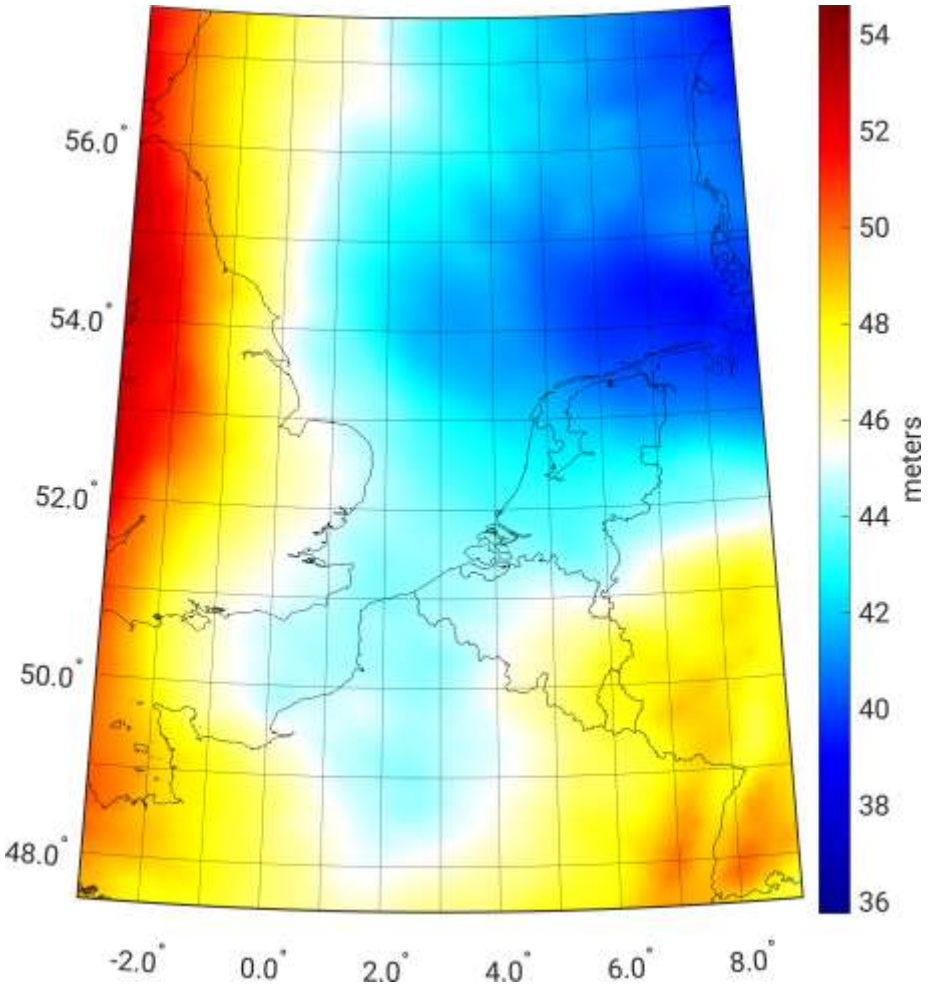
7,179 spatially interpolated gravity anomalies

- Altimeter data corrected for dynamic topography from Dutch operational storm-surge model;
- **Colored noise** in altimeter-derived QG height differences accounted for;
- **New** terrestrial gravity data in Limburg, Germany, Belgium;
- **New** airborne data in German Bight;
- Shipboard data **re-processed**;
- Remove-compute-restore:
  - **GOCO05S** as a-priori gravity field;
  - **RTM** correction applied using the TS (tesseroid) software;



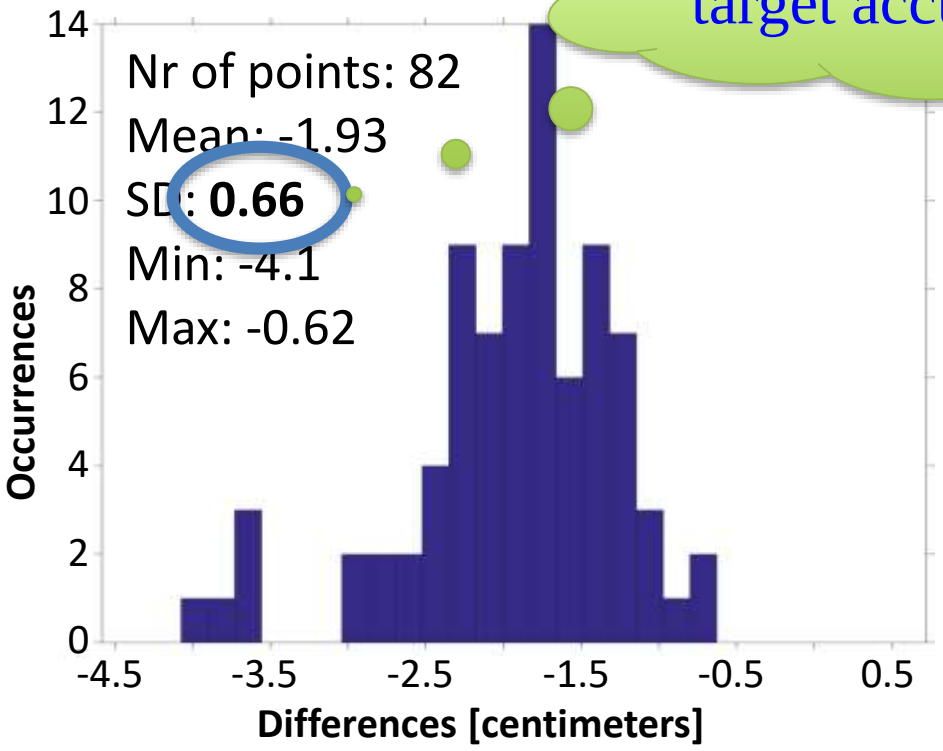
- Quasi-geoid is parameterized using **spherical radial basis functions**.
- Parameters are estimated using **weighted least-squares**.
- **Variance component estimation** is applied for proper weighting of all datasets.
- **Systematic errors** in gravity datasets are accounted for.
- **Full** noise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

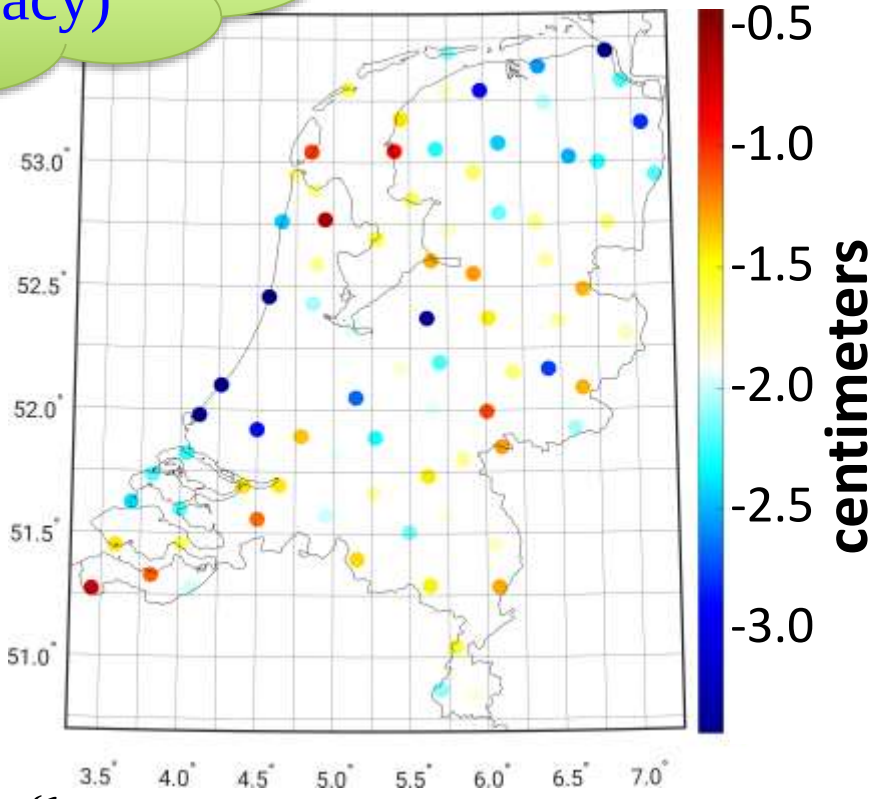
NLGEO2018 - gravimetric quasi-geoid



Validation - Netherlands

< 1 cm (better than target accuracy)





$$\varepsilon = \zeta_{\text{geometric}} - \zeta_{\text{gravimetric}}$$

A brief (historical) review on definitions and applications of the geoid

IX Hotine-Marussi Symposium, Rome, 18-22 June, 2018

prof. Tomislav Bašić, Matej Varga

June 18, 2018

Faculty of Geodesy, University of Zagreb

Accuracy of (quasi-)geoid models (I)

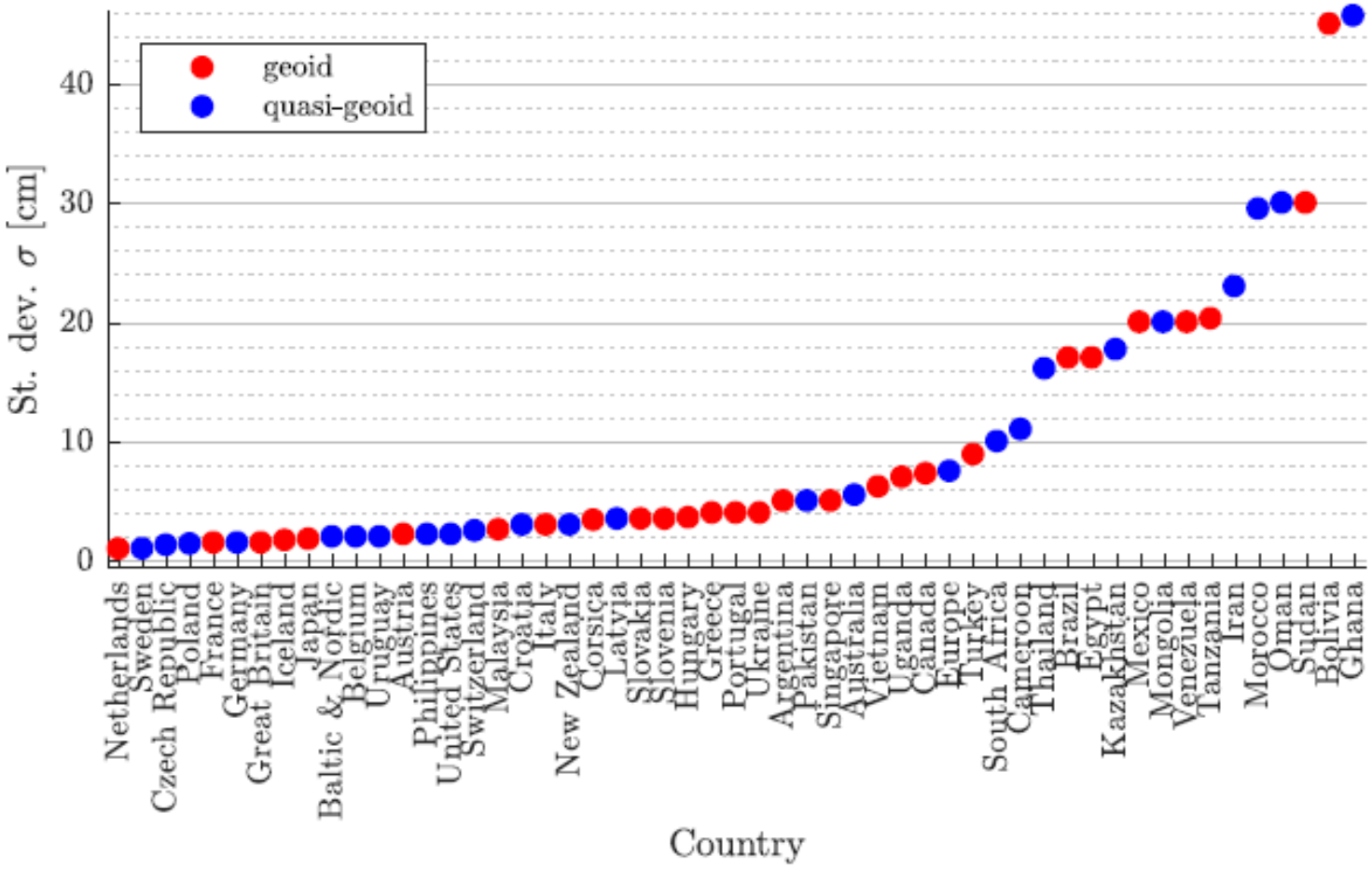


Figure 2: Accuracy of geoid and quasi-geoid models compared to GNSS/levelling for different countries

Accuracy of (quasi)-geoid models (II)

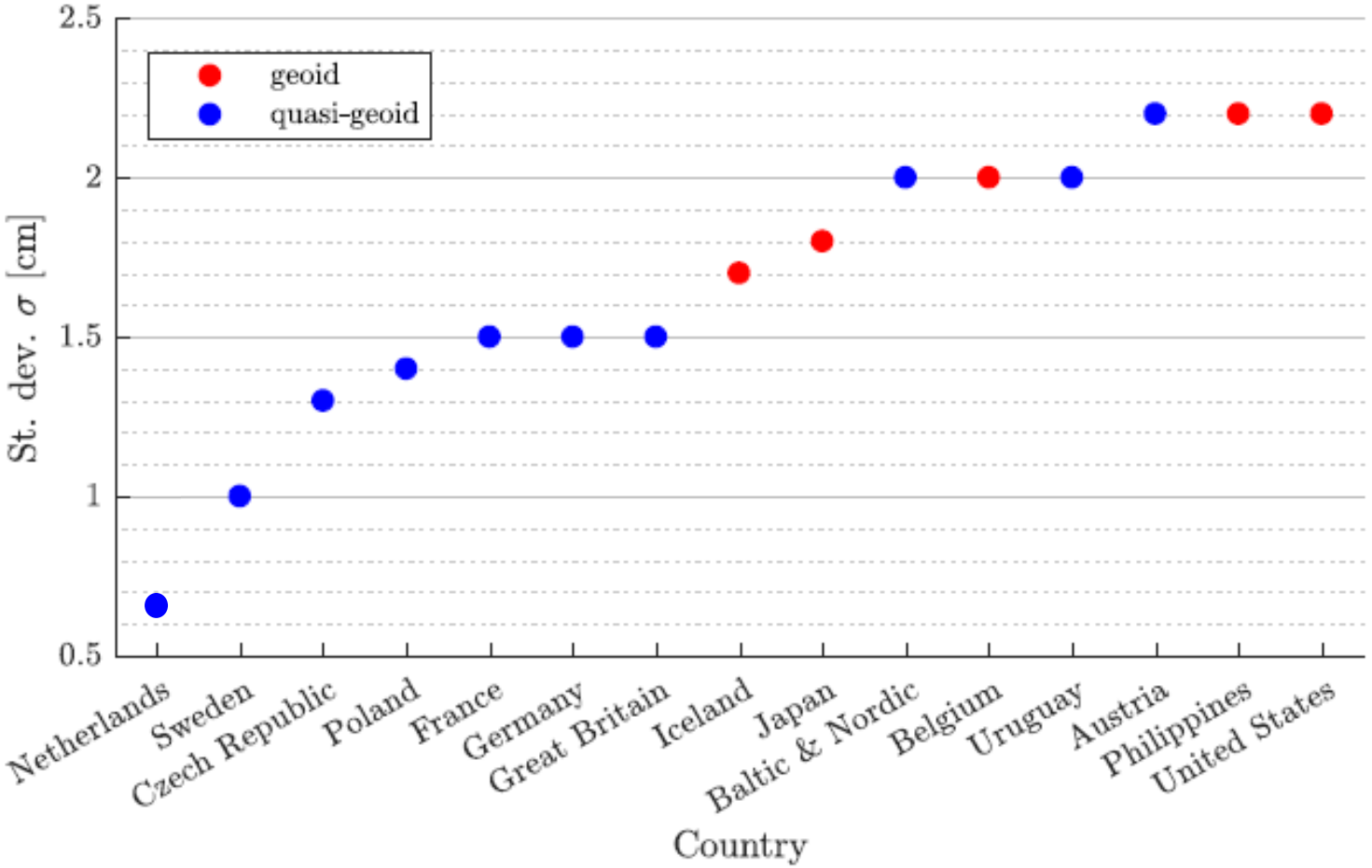
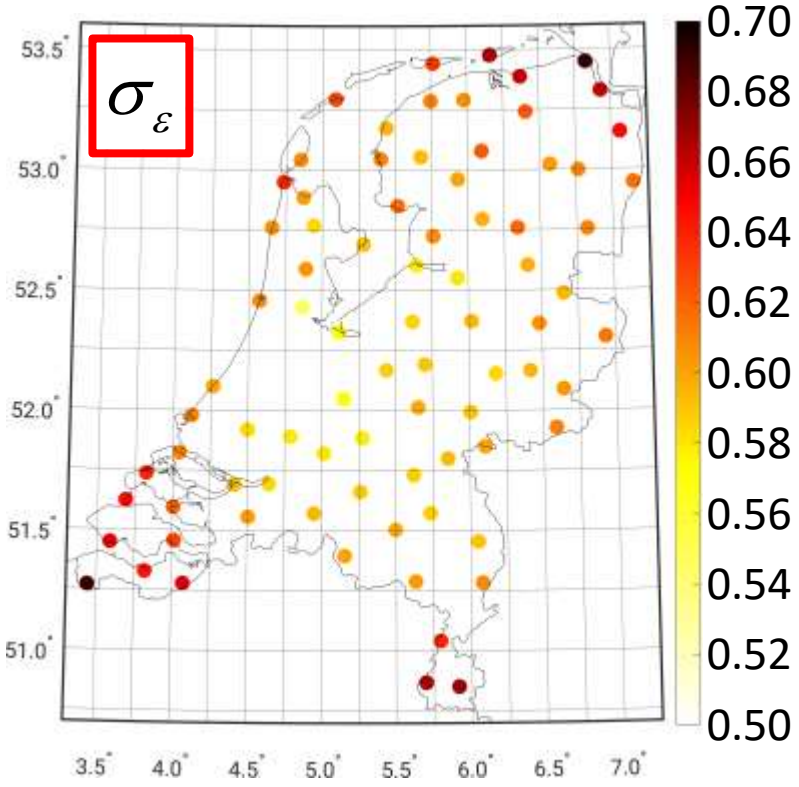
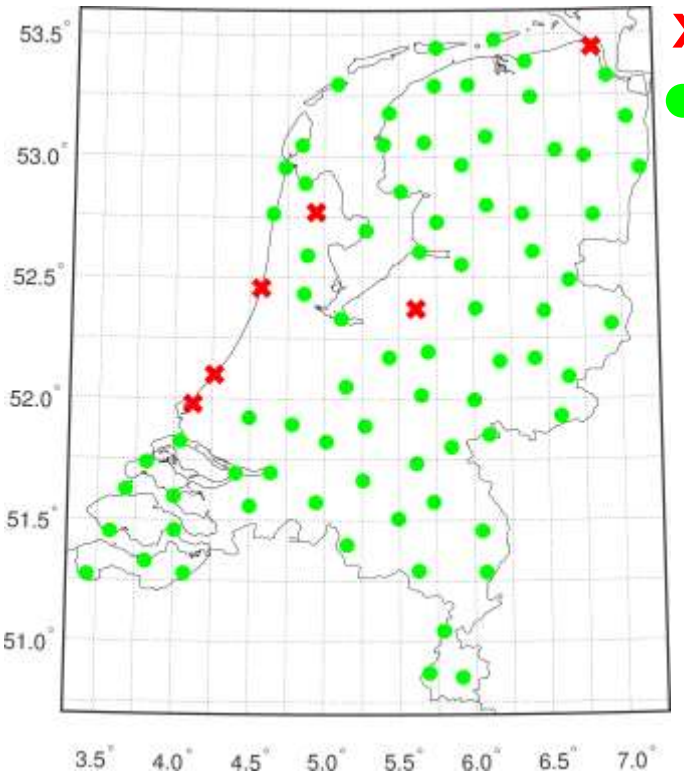


Figure 3: Accuracy of geoid and quasi-geoid models compared to GNSS/levellin

Validation - Netherlands



$$\text{abs}(\varepsilon) > 2\sigma_\varepsilon$$



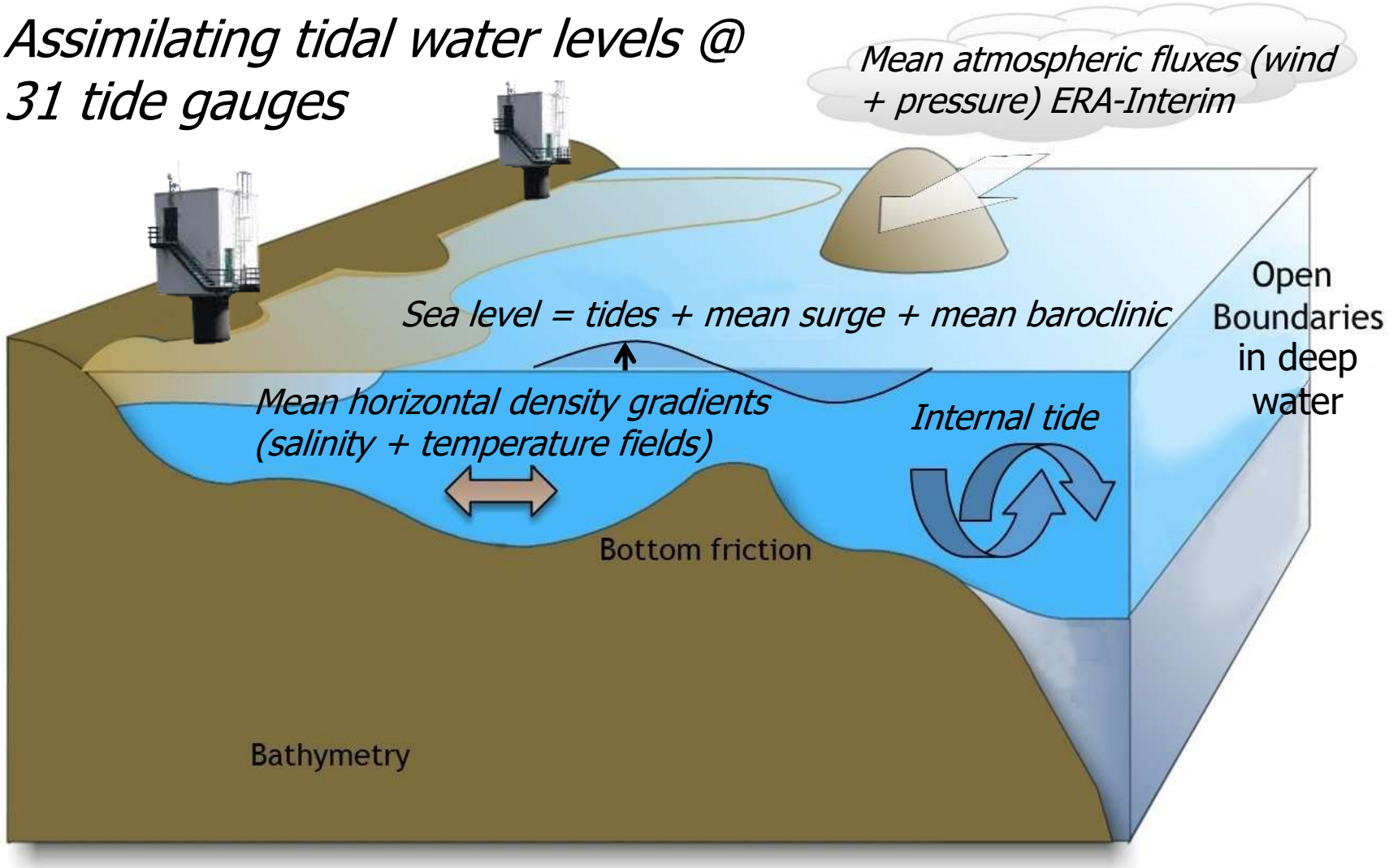
x true
● false

$$\varepsilon = \zeta_{\text{geometric}} - \zeta_{\text{gravimetric}}$$

Key result 2: the new Dutch LAT model NLLAT2018…

LAT computations: setup

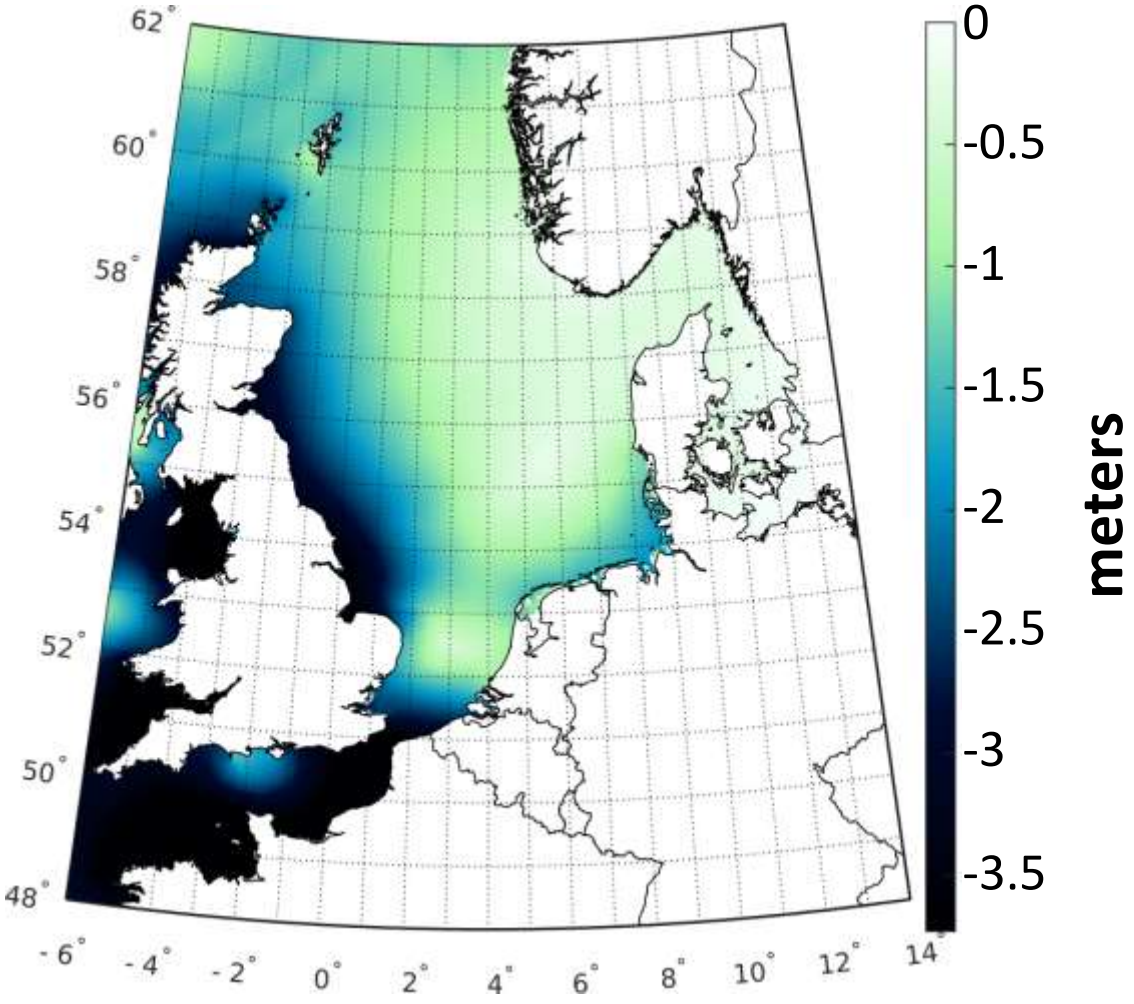
Assimilating tidal water levels @ 31 tide gauges



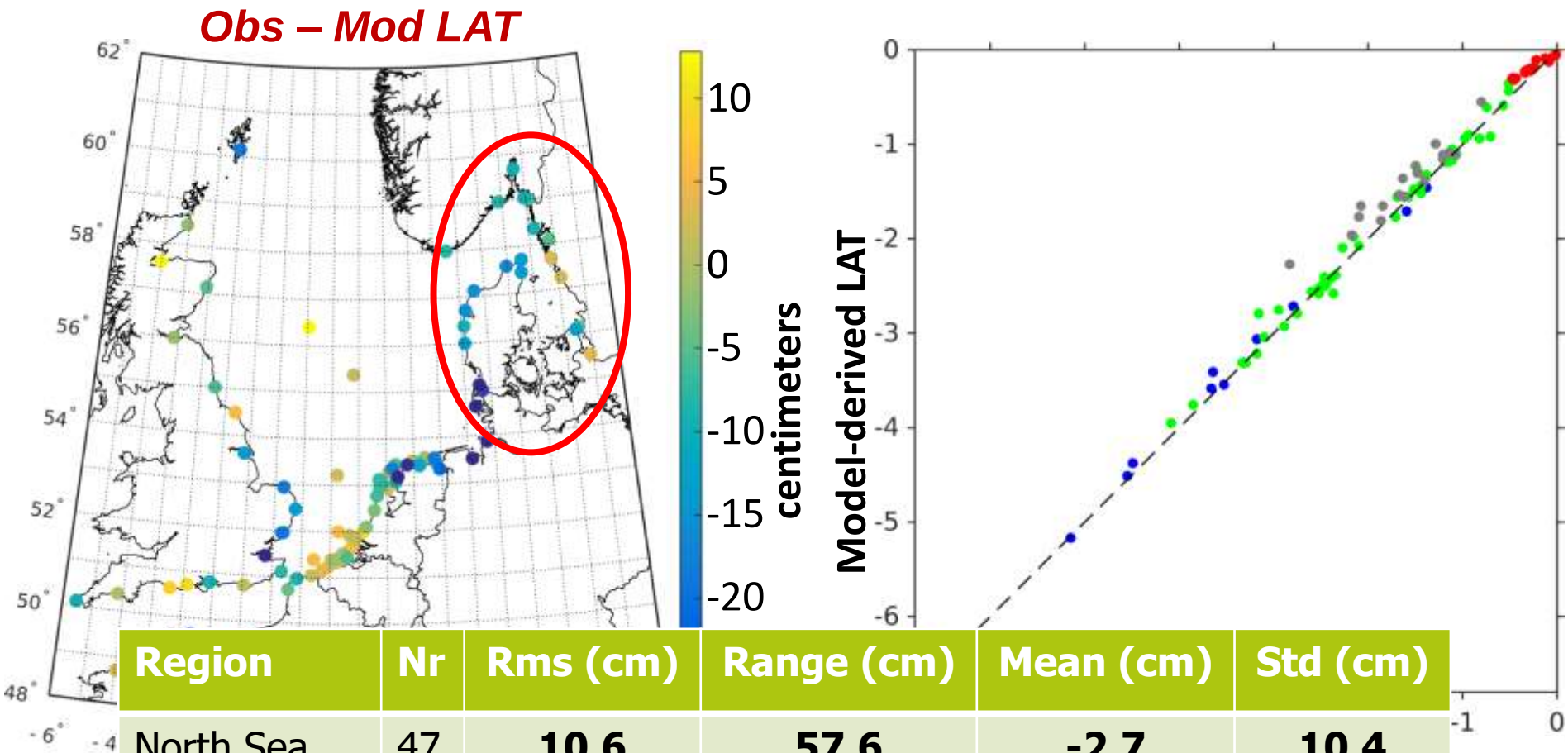
Vertical reference of hydrodynamic model → NAP


CONSISTENCY

LAT w.r.t. quasi-geoid

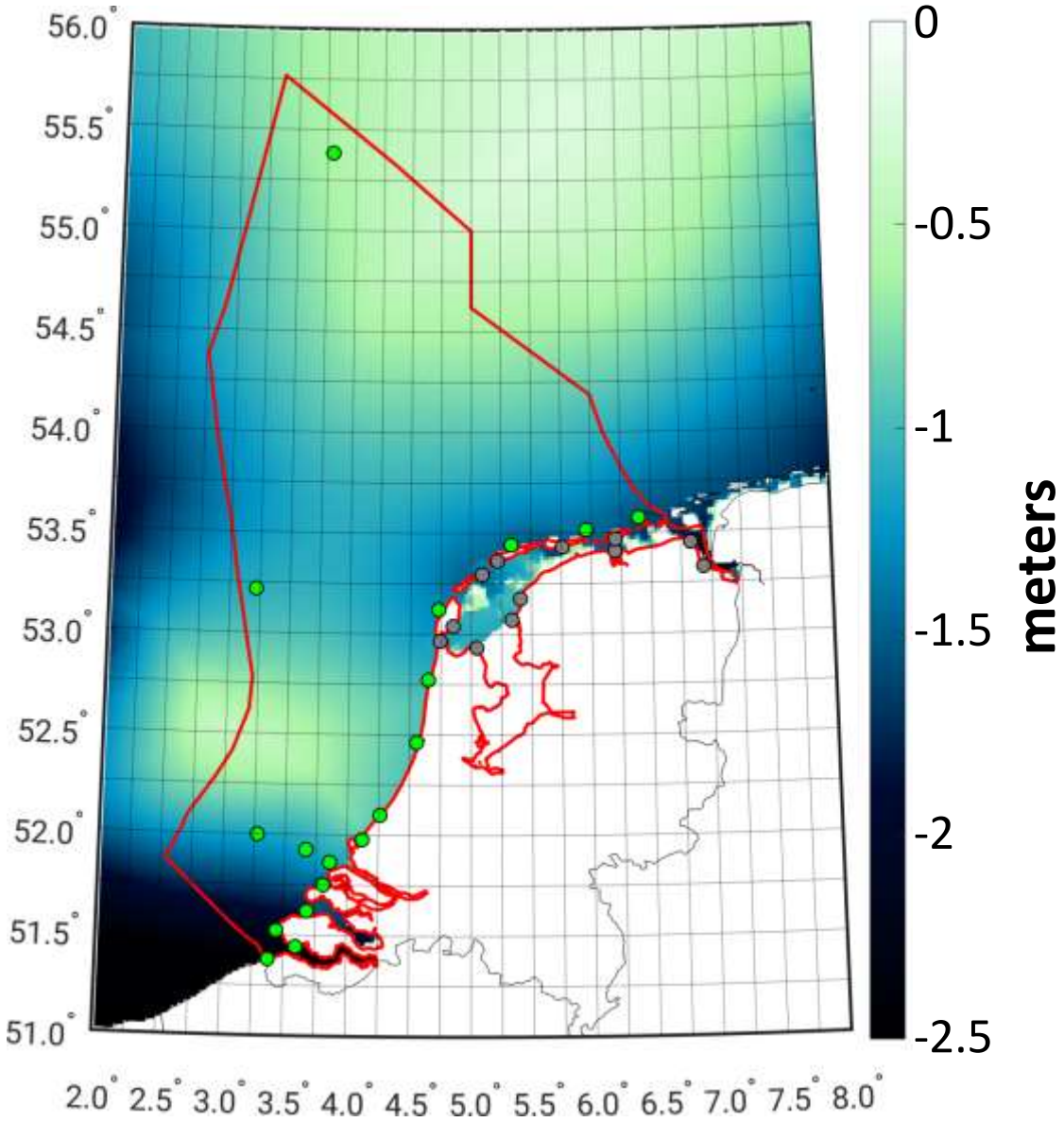


LAT w.r.t. quasi-geoid - validation



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. quasi-geoid – Dutch waters



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

Key result 3: hydrodynamic leveling; a new method to maintain the NAP height system at the Dutch Wadden Islands?

Adieu Niveau

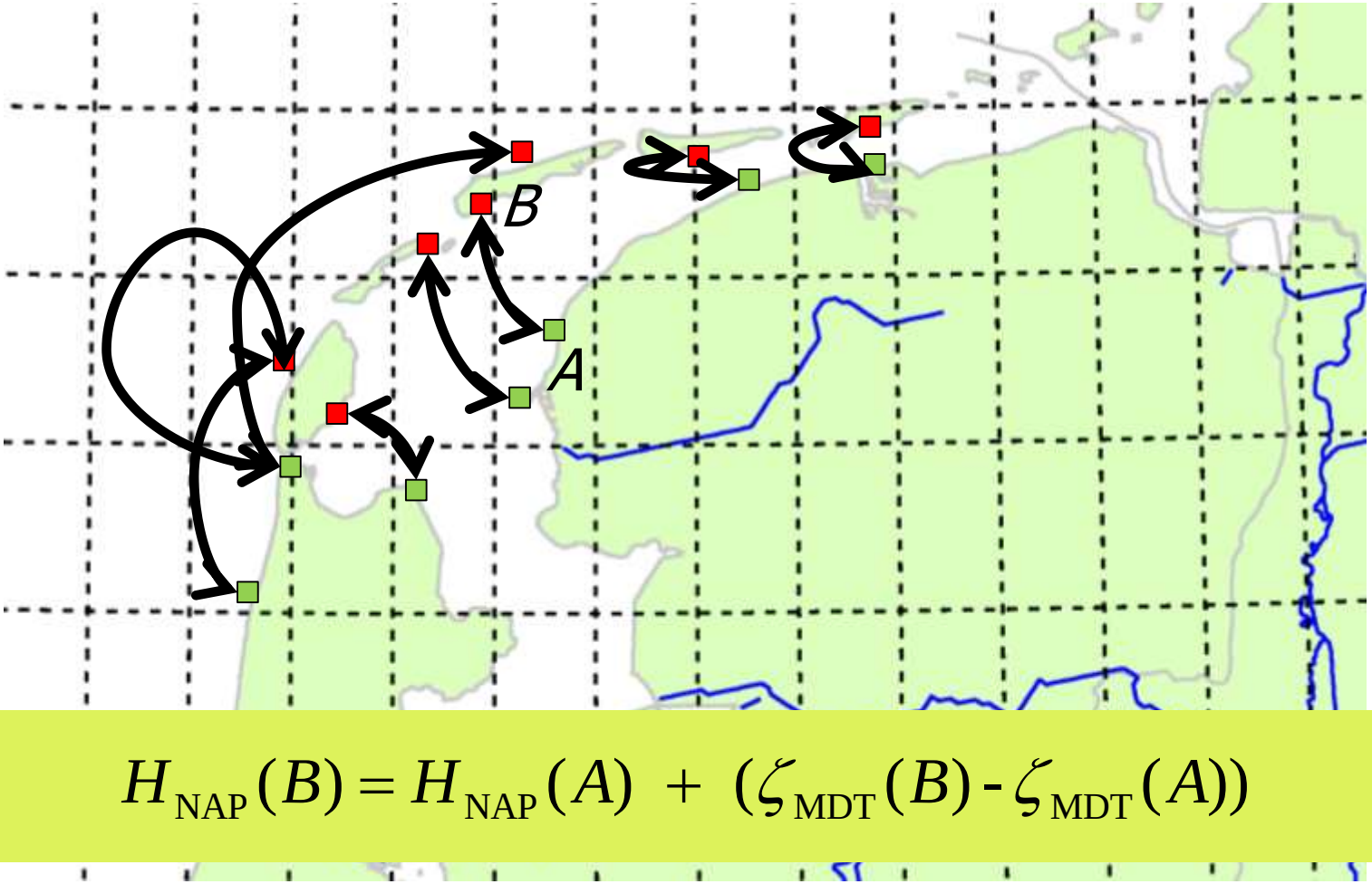
De Niveau loopt de haven van Bommenede binnen.

Het heeft een halve eeuw geduurd, het hydrostatisch waterpassen bij de Meetkundige Dienst van de Rijkswaterstaat (MD). Vijftig jaar lang heeft men met een uit de kluiten gewassen 'flesjeswater-pas' ons land doorkruist (en regelmatig ook een stukje daarbuiten) om met het meest simpele,

Heel precies is niet vast te stellen hoe oud het NAP is, maar zeker is dat Amsterdam al in de 17e eeuw over een Stadspeil beschikte, dat de gemiddelde vloedhoogte bij de Amsterdamse sluizen aangaf. Na de stormvloed van 1675 sprak men voor het eerst over het Amsterdams Peil. Het duurde tot 1800 vooraleer generaal Krayenhoff dit peil uitbreidde rond de Zuiderzee en tot aan de grote rivieren, omdat die ook weleens buiten hun oevers traden. Een geheel landsdekkend systeem werd gerealiseerd door ir. Lely door de uitvoering van de 1e Nauwkeurigheidswaterpassing. Bij het vaststellen van de uitkomsten daarvan (in 1891) ontstond de naam NAP (Normaal Amsterdams Peil). Het onderhoud van dat landsdekkend hoogtemerkensysteem werd opgedragen aan de 'Algemene Dienst van de Rijkswaterstaat', wat tot op heden eigenlijk zo is gebleven, zij het dat de uitvoering nu een zorg is van de MD.

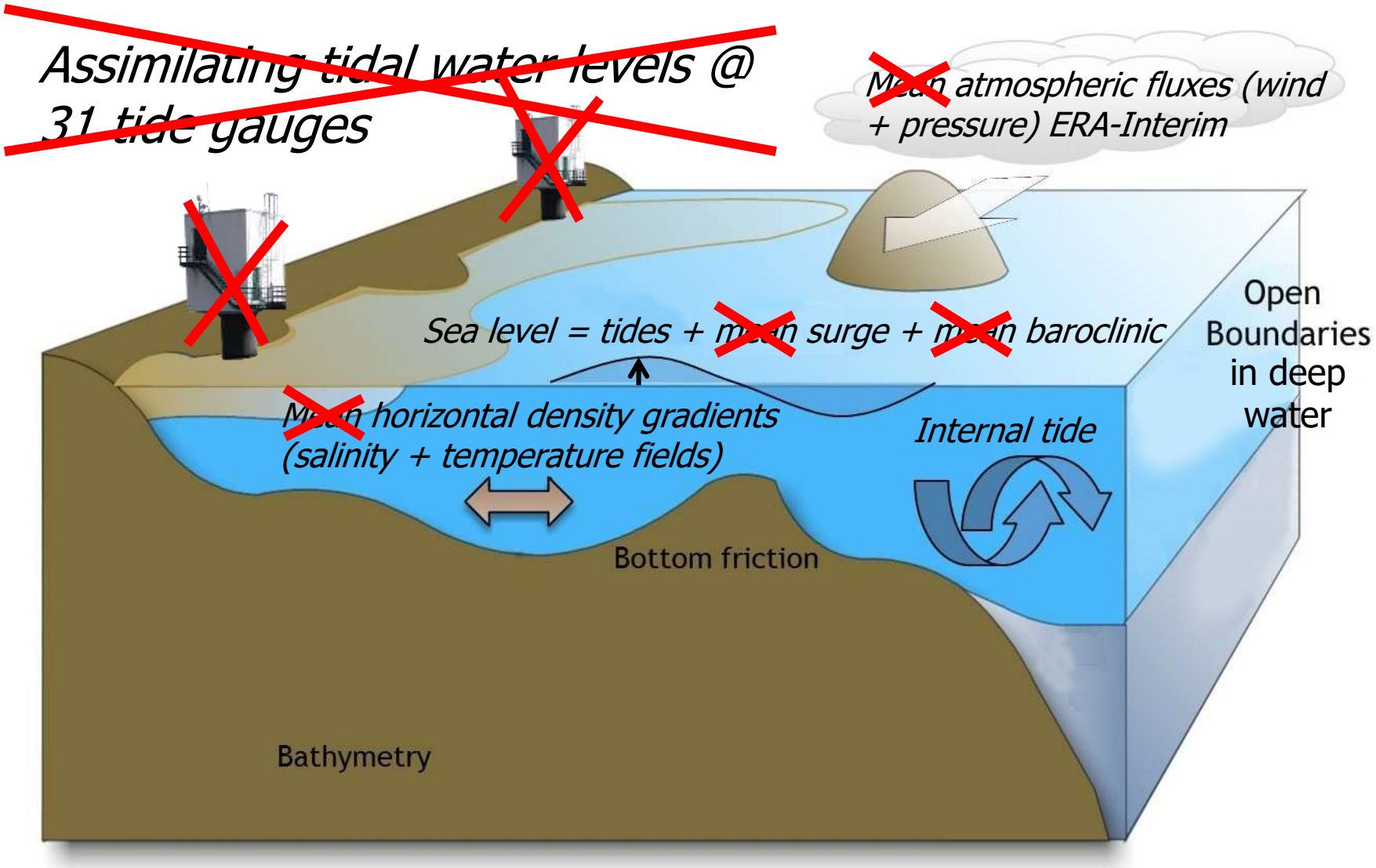
In 2002, we said goodbye to hydrostatic leveling

Model-based hydrodynamic leveling



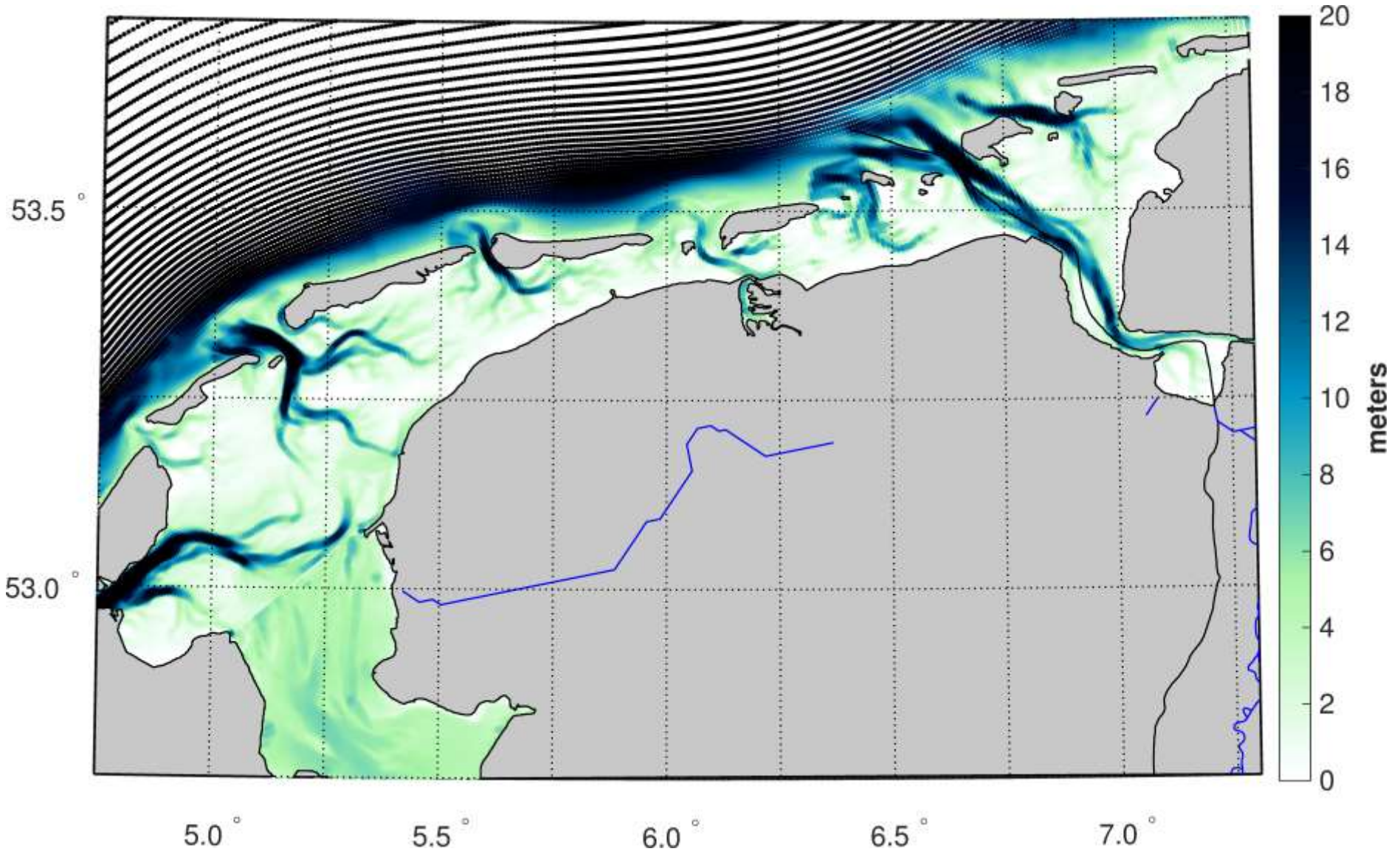
$$H_{\mathrm{NAP}}(B) = H_{\mathrm{NAP}}(A) \; + \; (\zeta_{\mathrm{MDT}}(B) - \zeta_{\mathrm{MDT}}(A))$$

MDT computations: setup

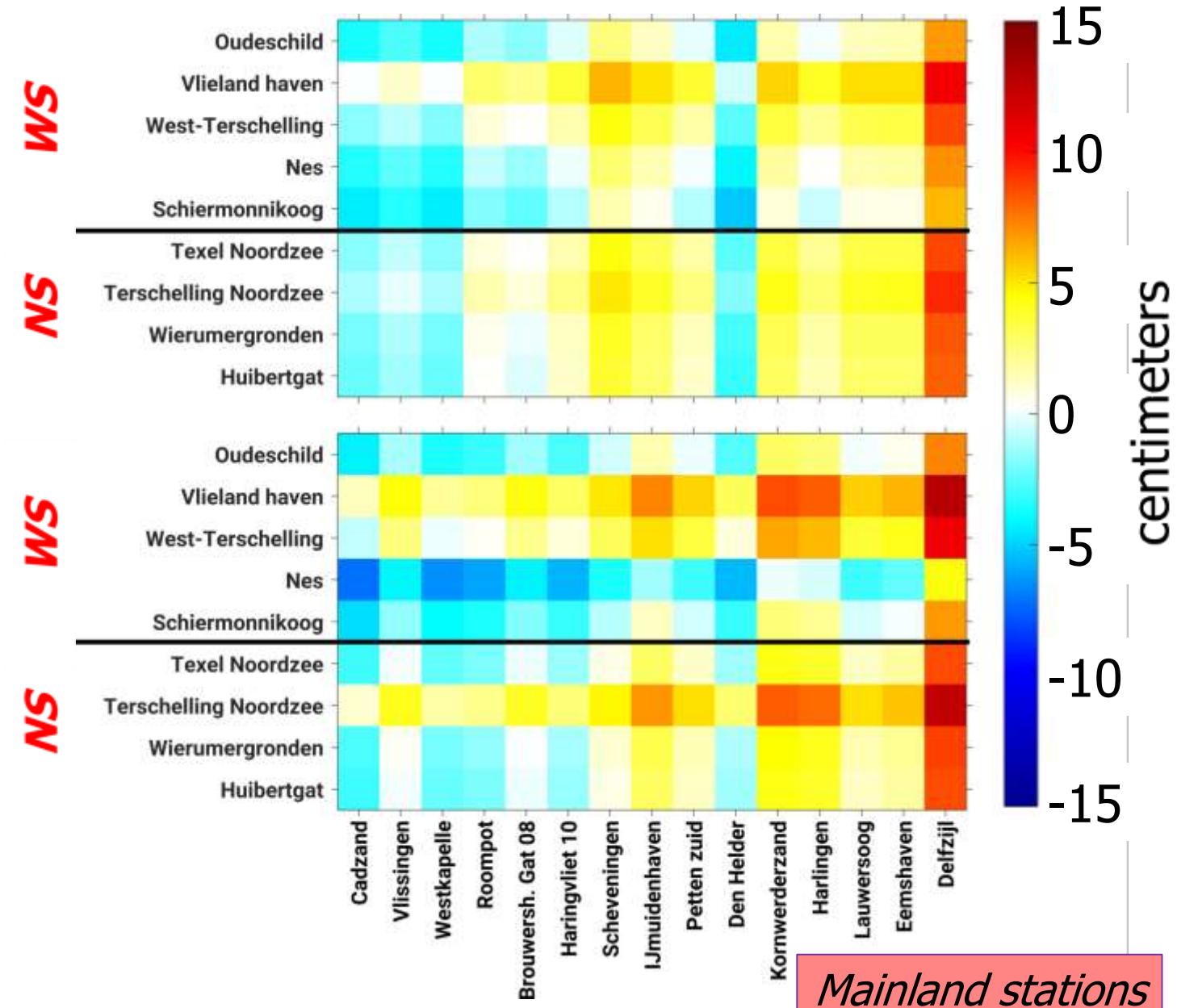


Vertical reference of hydrodynamic model → NAP

High-resolution model



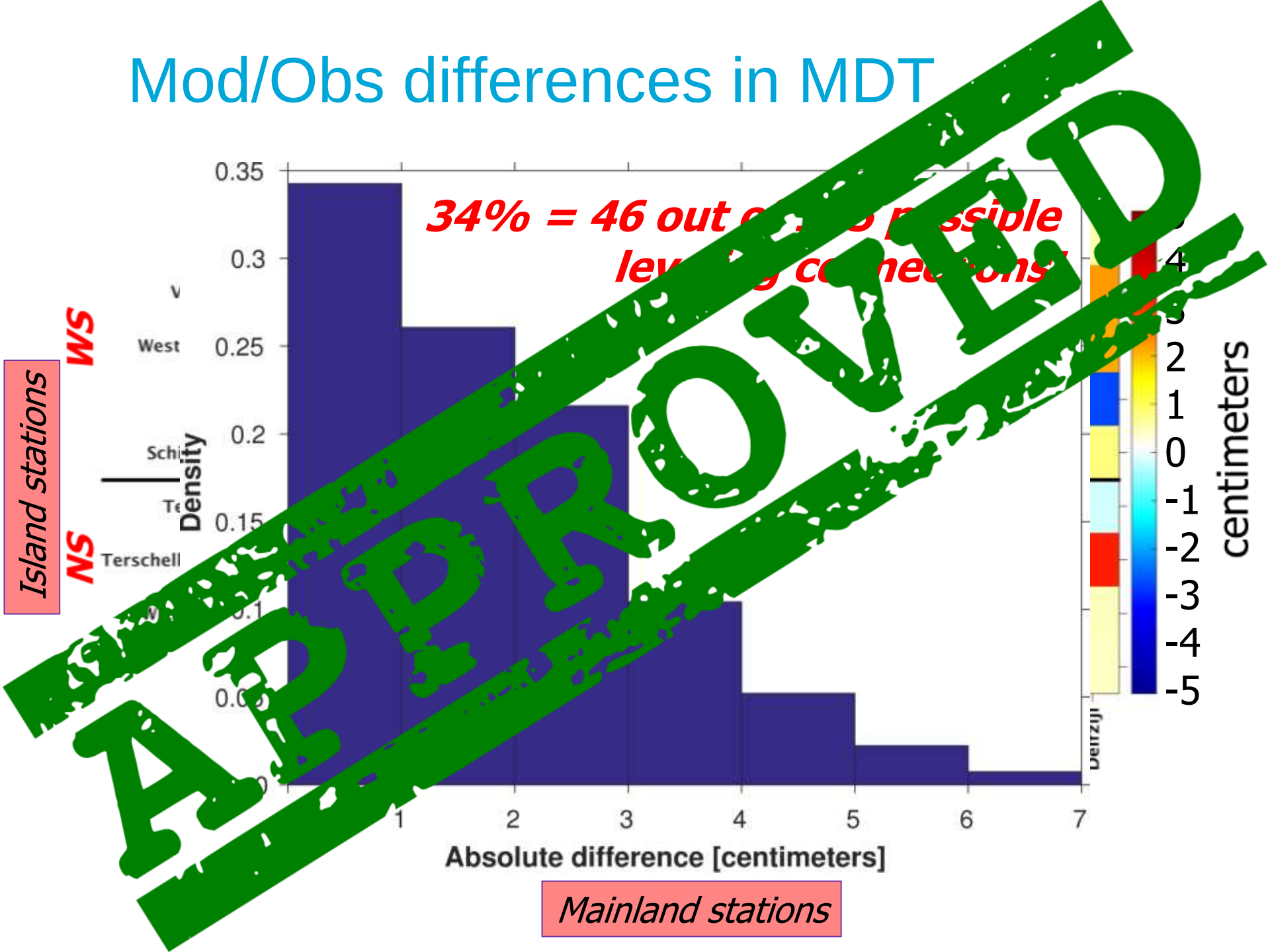
Mod/Obs differences in MDT



Island stations

Mainland stations

Mod/Obs differences in MDT



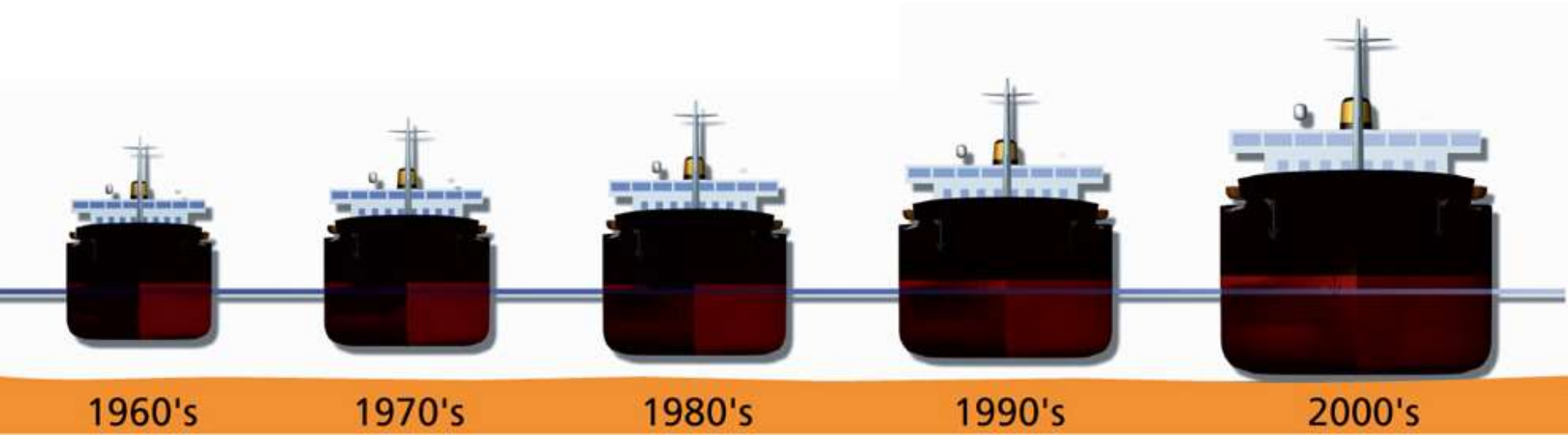
The road ahead…

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
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↓
http://versatile-hydrodynamics.nl/

To combine the knowledge of past, present, and future state of our seas…

Dynamic Bathymetric Chart

Dynamic Nautical Information System

Dynamic Marine Information System

Instantaneous water depths, density + *Waves, currents, meteo* + *Sediment transport, …*

… and feed these systems with altimeter-derived water levels, waves, and currents!

Dynamic Bathymetric Chart

Dynamic Nautical Information System

Dynamic Marine Information System

Currents

Waves

Water levels


NW
NE
Thank you!