Tide gauges and height systems

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Connections

1. Height datum definition from tide gauges
2. Vertical land motion determined from tide gauge records
3. Sea surface topography from levelling and tide gauges
4. Height system differences from tide gauges and oceanography
5. Control of levelling using tide gauges and oceanography

Discussion in terms of annual means

Height datum definition from tide gauges I

European examples

- **Amsterdam (NAP): NL, DE, SE, AT; EVRF2000**
- **Kronstadt (Baltic H.S.): EE, LV, LT, PL, CZ, SK, HU, BG, RU**
- **Other TGs (12 different): The rest of the countries**

Height datum definition from tide gauges II

Examples from Nordic and Baltic countries

Country	Denmark	Finland	Norway	Sweden	Baltic
System	DVS90	N60	NN1954	RH2000	Baltic H.S.
Tide gauge	10 TGs	Helsinki	4 TGs	Amsterdam (NAP)	Kronstadt
Obs period	1890-1990	1935-1954		1684 MHT	1833
MSL epoch	1990.0	1944.0	1952		

Height datum definition from tide gauges III

Strategies applied

- **MSL, or high/low water**
- **single TG or average sea level around the coasts of the country**
- **short records (often only one year)**

Determination of land motion using tide gauges

- Was first method to determine contemporary postglacial rebound (PGR) in Fennoscandia
- Provides rates relative to mean sea level (MSL) which itself is moving, both relative to the geoid and to the Earth's center of mass
- Terminology introduced by Martin Ekman:
  - apparent uplift: vertical motion relative to MSL
  - levelled uplift: motion relative to the geoid
  - absolute uplift: motion relative to the Earth's center of mass

Vertical motion from TGs

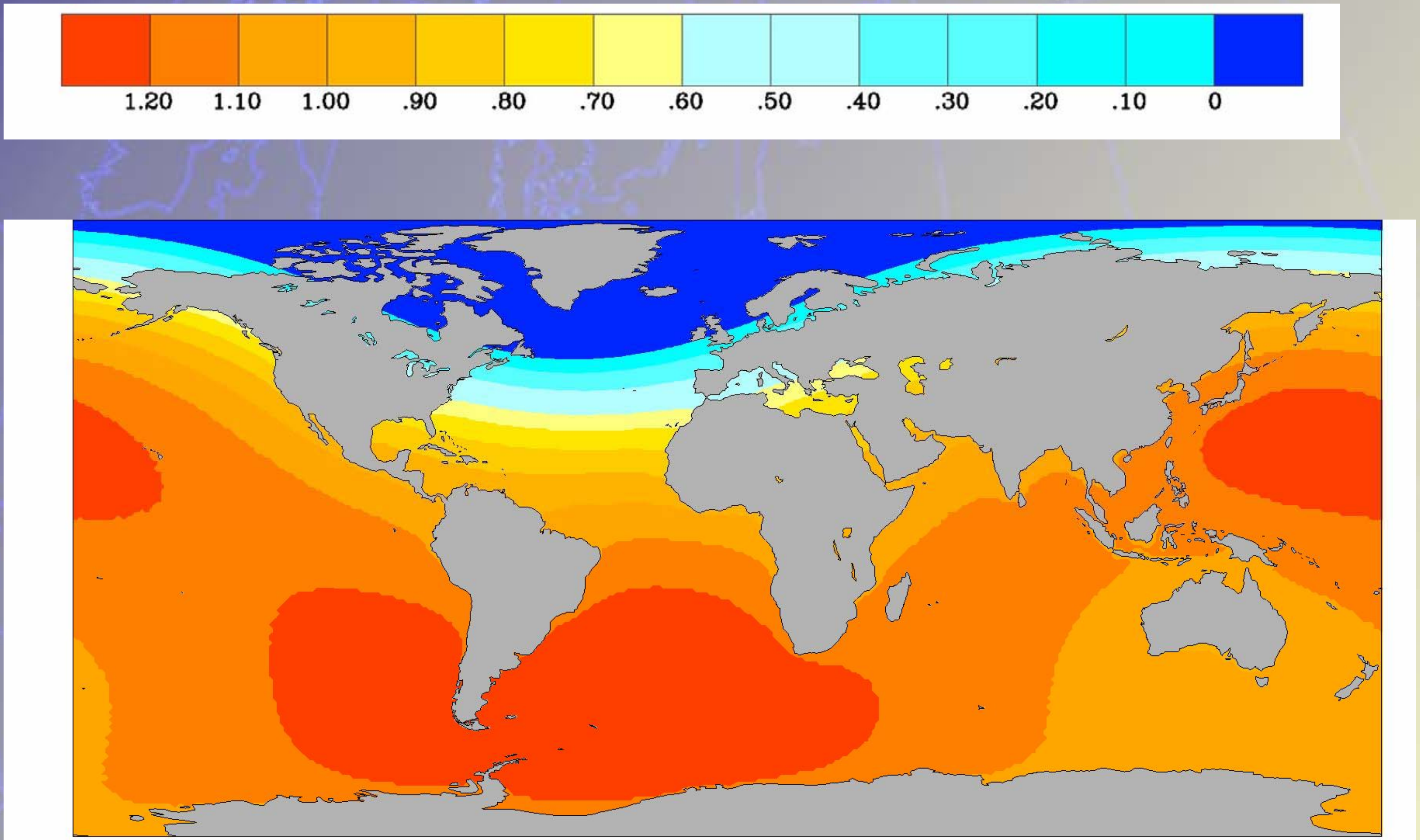
absolute uplift = uplift relative to MSL

+ uplift of the geoid

+ ”eustatic” rise in MSL

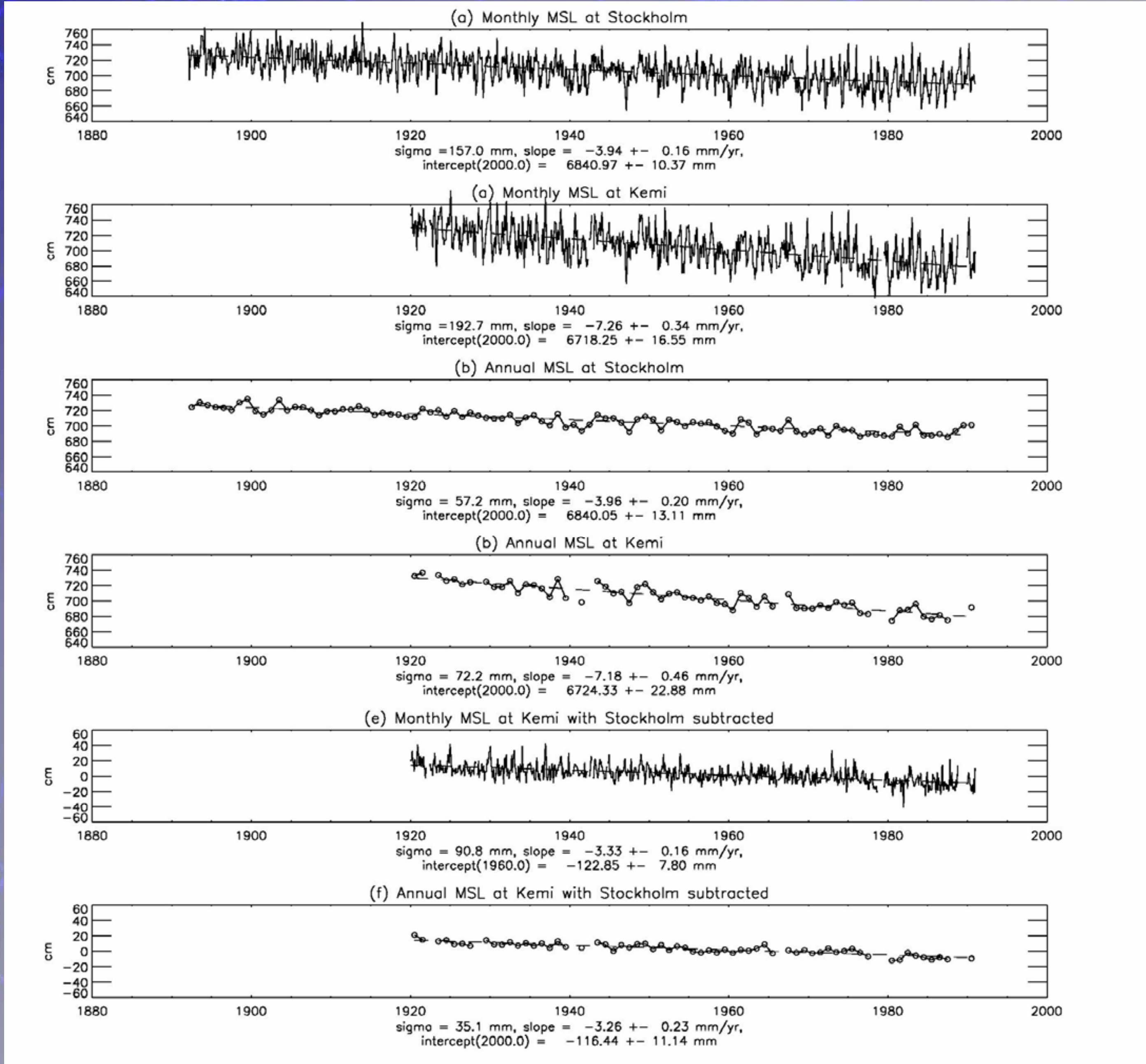
separation may involve tricky issues

Example: sea level rise (in mm) relative to land, resulting from the addition of 1 mm of water to the world ocean from Greenland glaciers (Mitrovica et al., 2001)



Vertical motion from TGs

- long series are needed due to the decadal and longer-period variation in sea level
- equal time spans at TGs help to get consistent differential motion estimates
- the Baltic Sea is a special case due to the highly coherent sea level variation throughout the sea (save for scale)



Differencing approach in the Baltic

Formal precision of linear trend from TG assuming white noise

$$m_b = m_0 \sqrt{\frac{12}{N(N-1)(N+1)}}$$

where

m_b is the precision of the trend estimate

m_0 is the standard deviation of the annual MSL

N is a the number of consecutive years

Leads to very high ***formal*** precision

e.g.

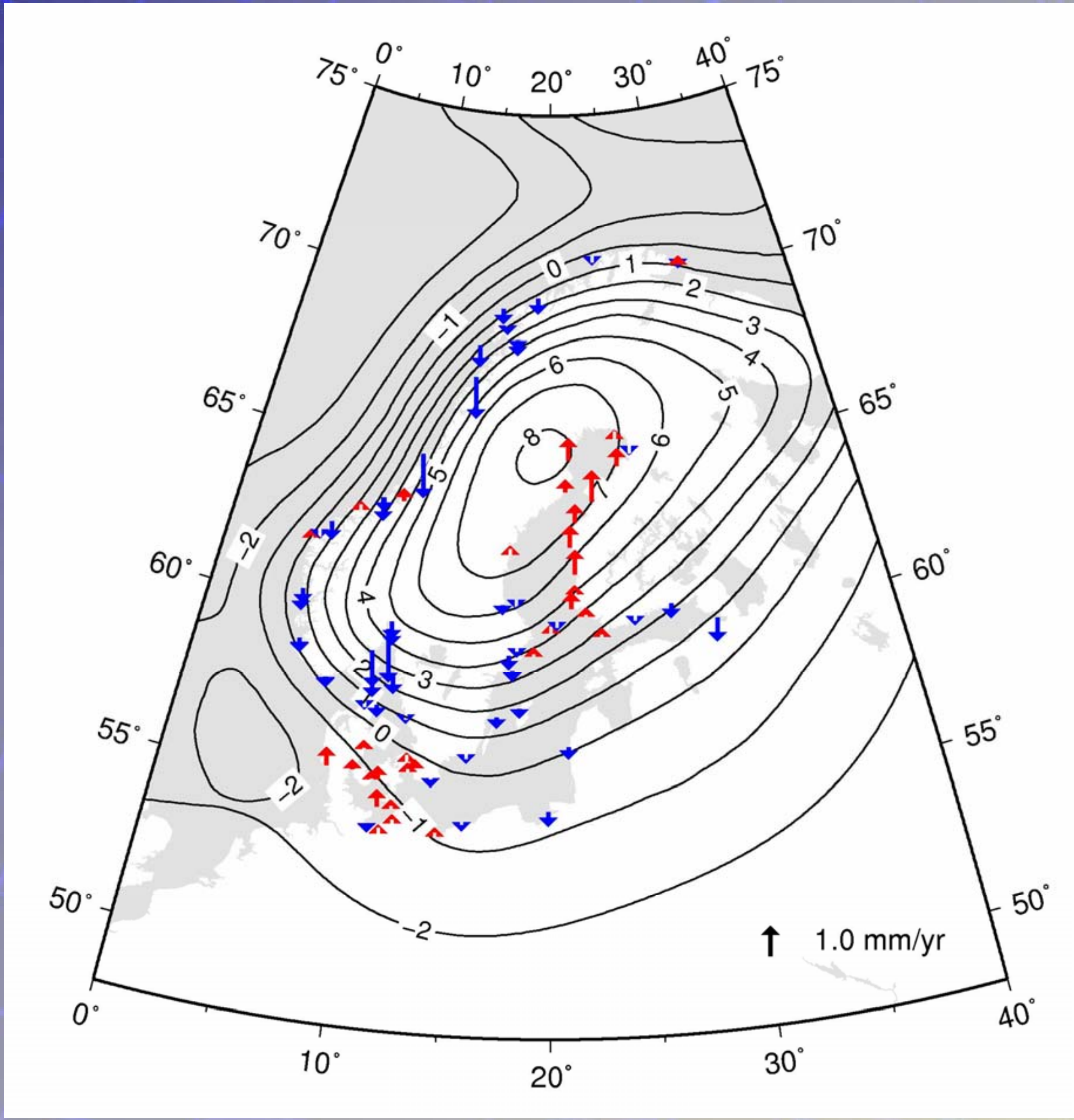
N = 100 years, m_0 = 20...80 mm $\Rightarrow$

m_b = 0.07...0.28 mm/yr

N = 50 years, m_0 = 20...80 mm $\Rightarrow$

m_b = 0.20...0.80 mm/yr

Some comparisons made for the Baltic Levelling Ring

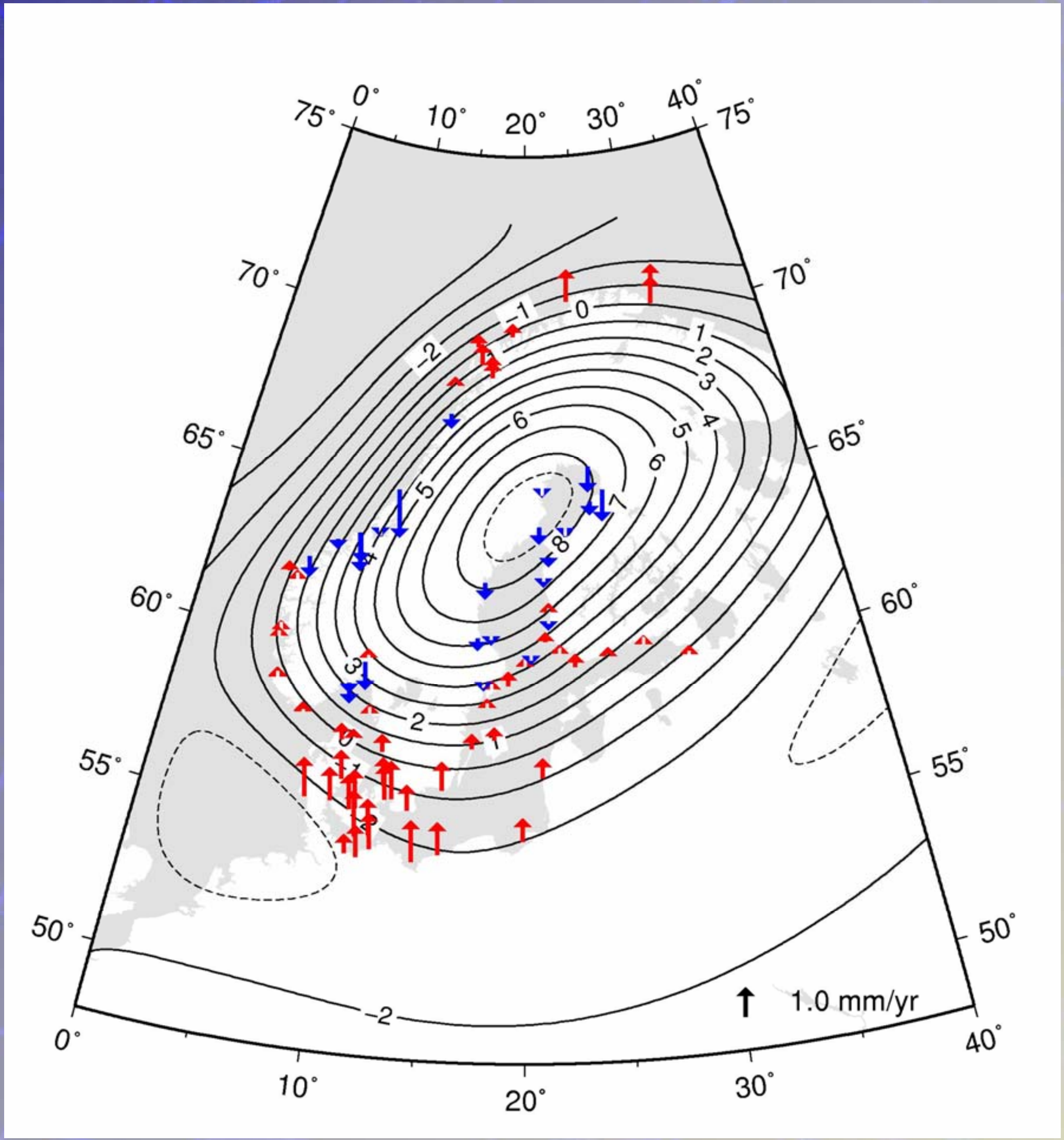


TG rates (Ekman & Norway)

minus

Lambeck geophysical model

(from map)

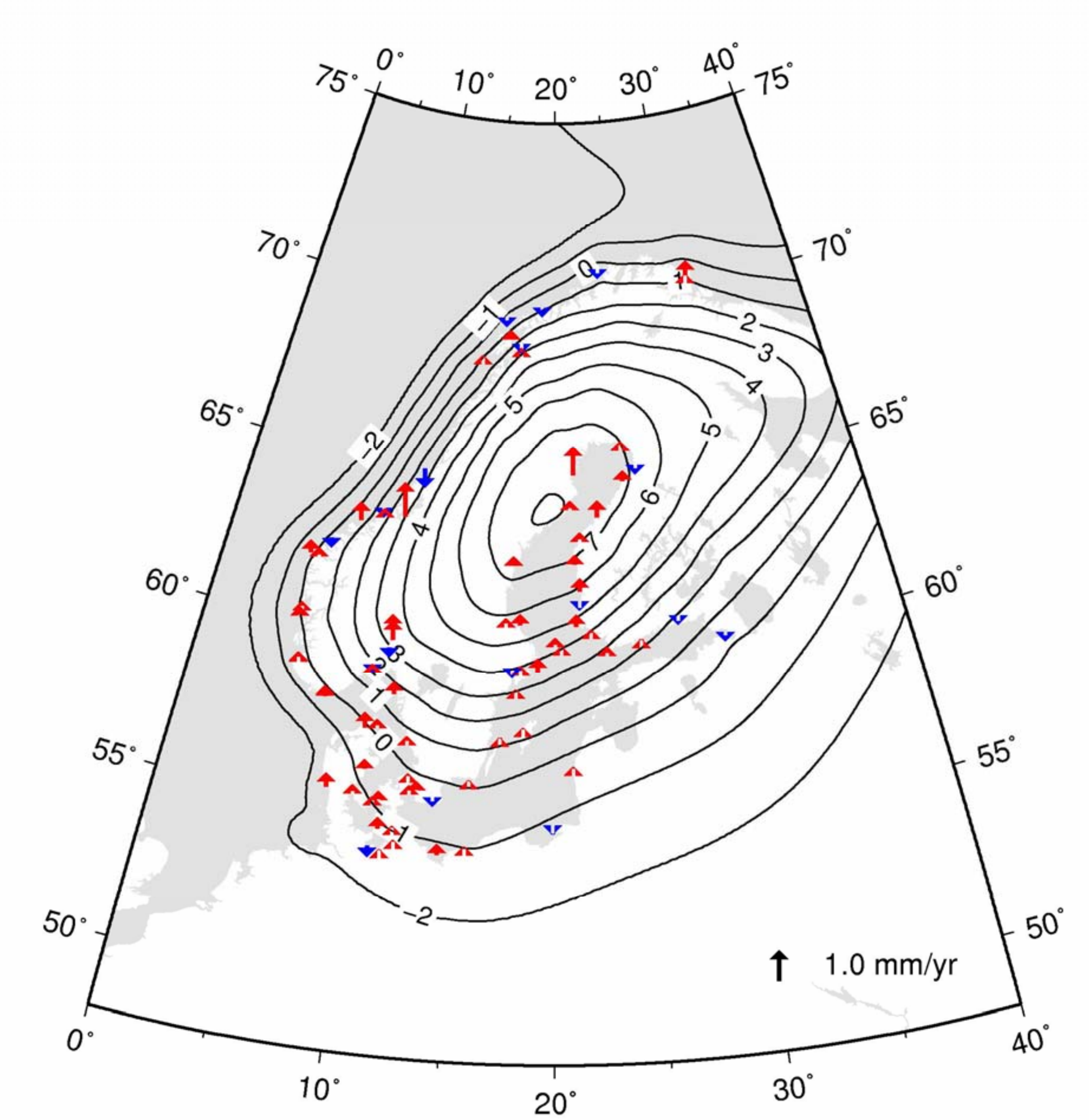


TG rates (Ekman & Norway)

minus

Bifrost geophysical model

assuming eustatic rise = 1.5 mm/yr



TG rates (Ekman & Norway)

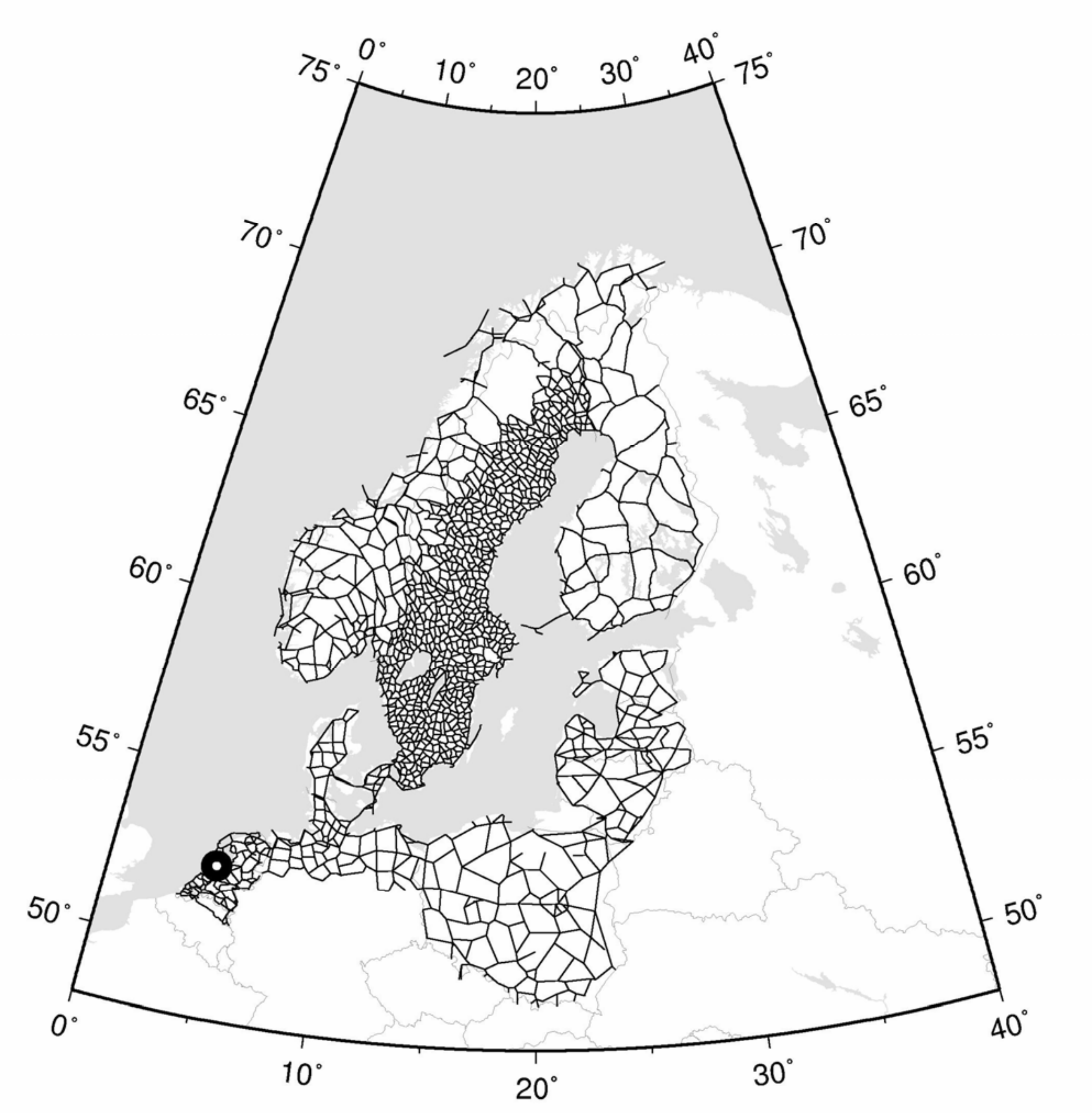
minus

Vestöl-Lambeck-Ågren hybrid model

Height system differences from tide gauges and oceanography

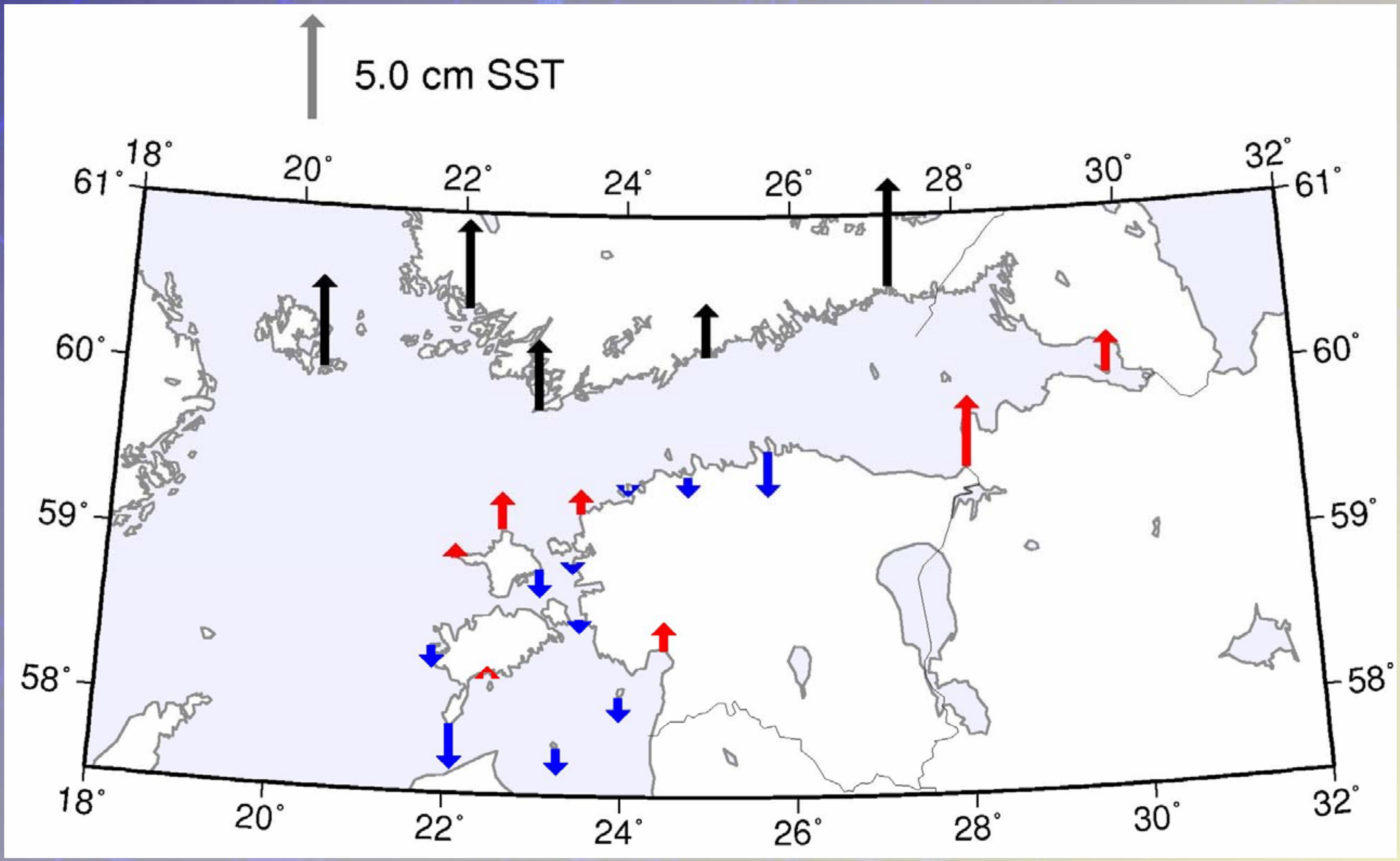
Estimating the difference

between Finnish N60 and Estonian BK77

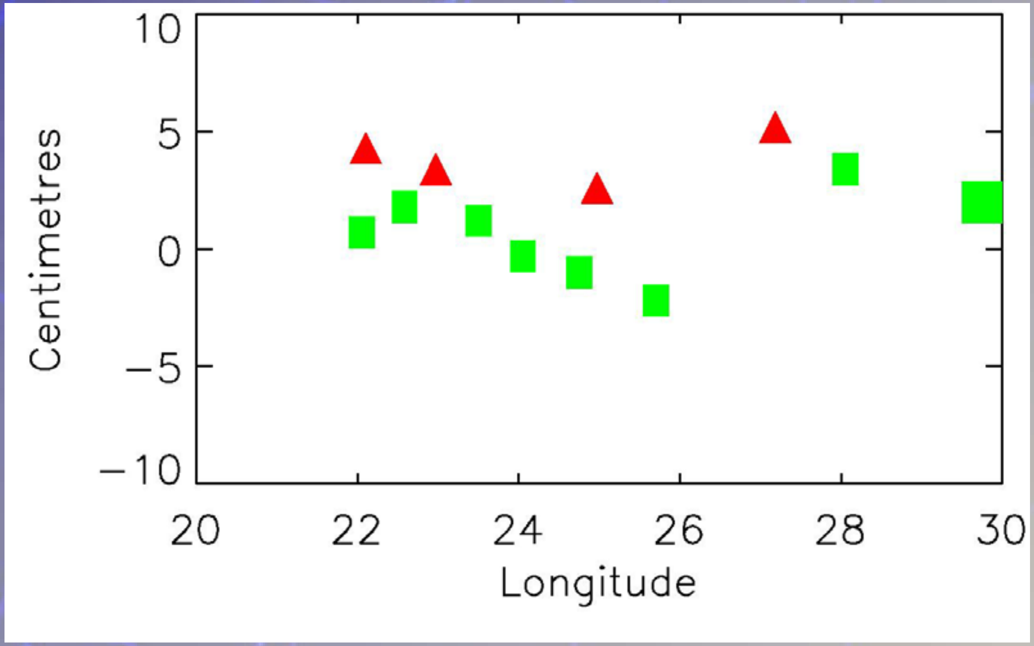


Baltic Levelling Ring.
No connection around the Gulf of Finland

MSL 1960.0 in Finnish N60 (black) and Estonian BK77 (red/blue) height systems



MSL at tide gauges along the Gulf of Finland



Red = North side, Finnish N60 system

Green = South side, BK77 system

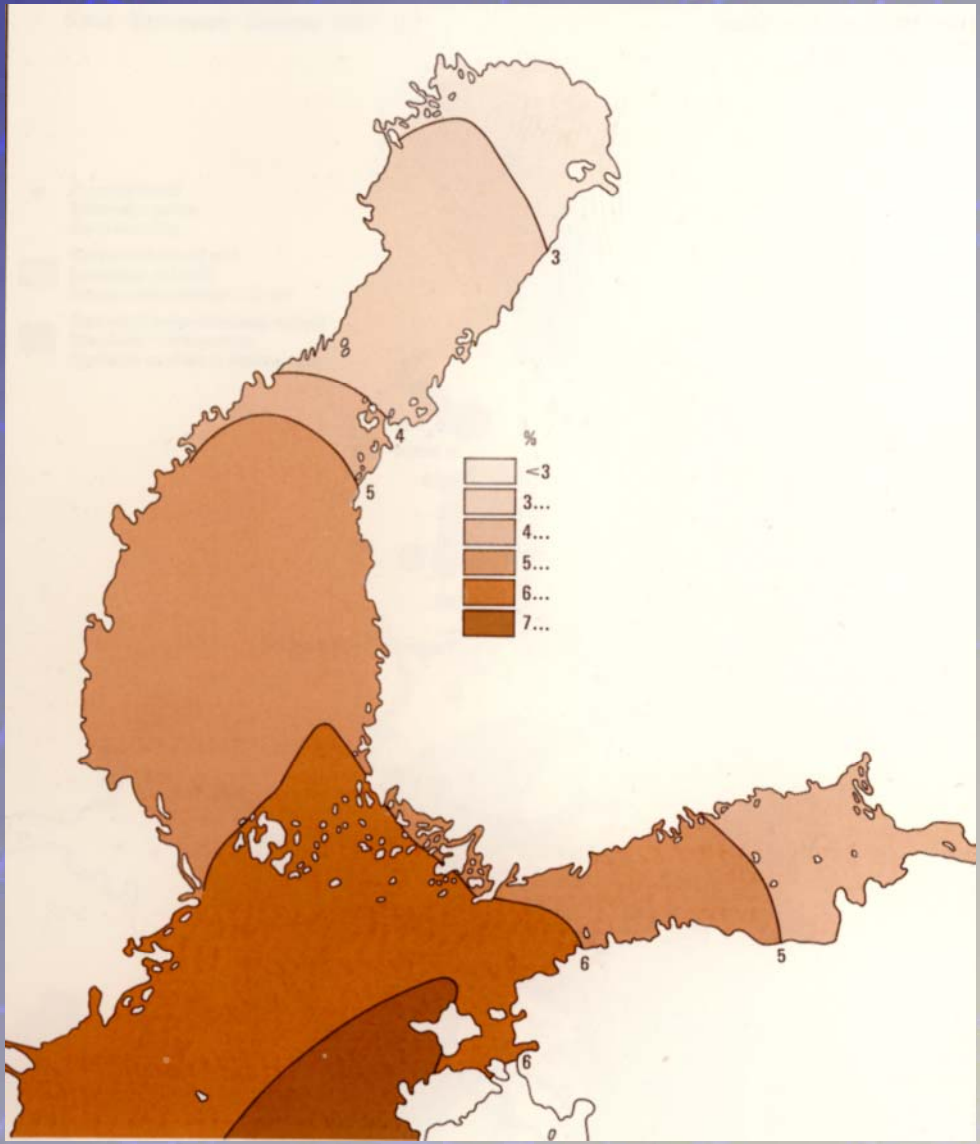
The red triangles are 1...4 cm ≈ 3 ± 2 cm higher

What comes from the difference in height systems, what comes from the SST?

Answer:

- oceanographically it can be expected that the SST difference N-S across the Gulf of Finland is about zero
- therefore the system difference between N60 and BK77 is about 3 ± 2 cm (BK77 zero is higher); need not be constant

Salinity in the Baltic (down to the halocline)

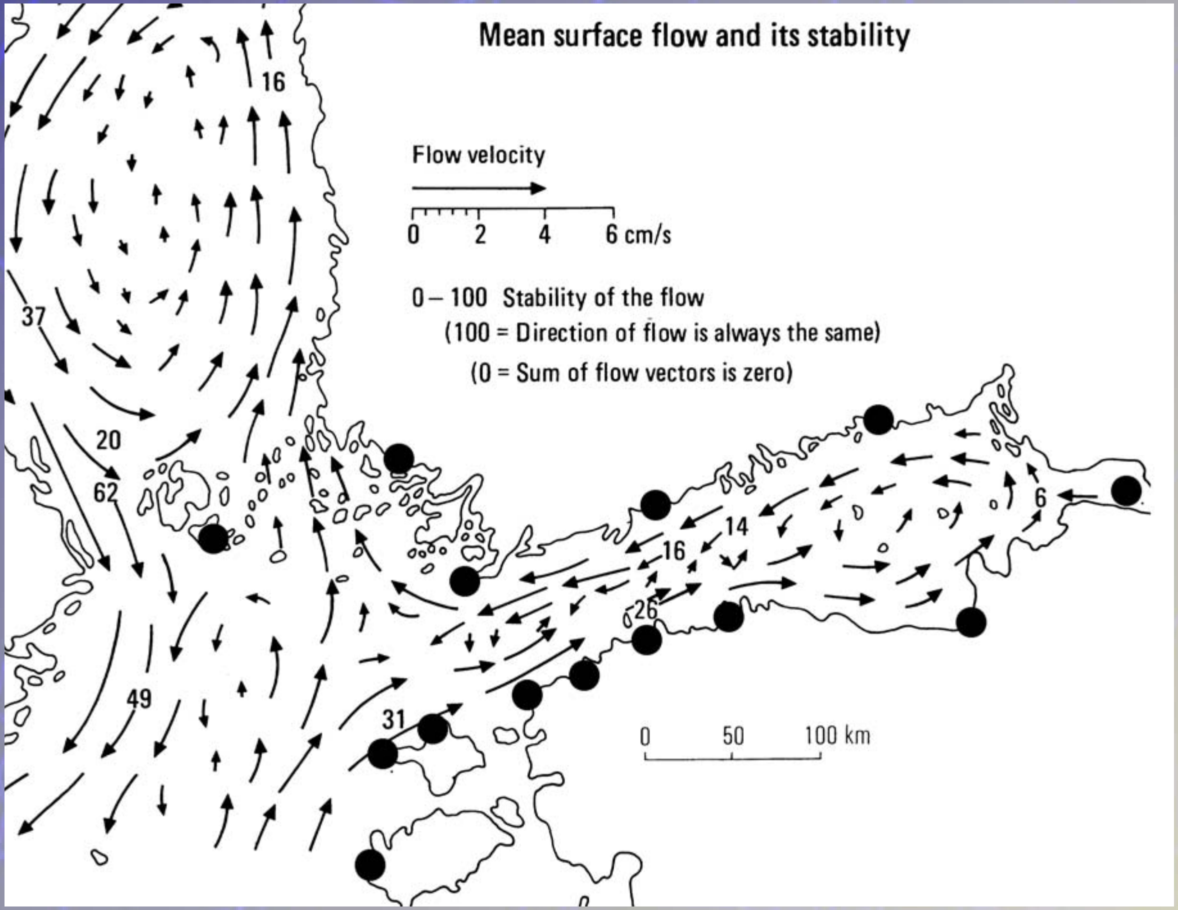


1 color zone = 1 ‰

1 ‰ ≈ 1 cm SST

Modified from Atlas of Finland (1986)

Surface currents (Atlas of Finland, 1986; Palmen, 1930)



$$\Delta H = \frac{2 v \omega \sin\phi}{g} \Delta d$$

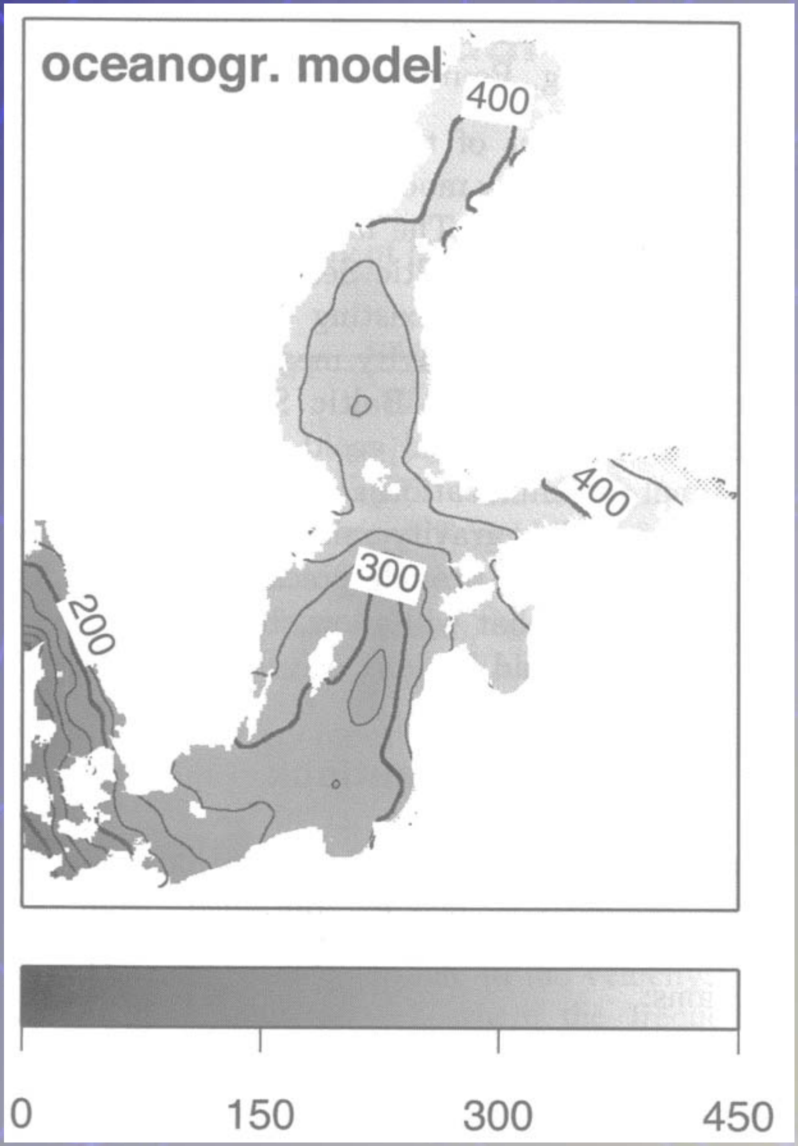
max values:

$$\Delta d = 40 \text{ km}$$

$$v = 4 \text{ cm/s}$$

$$\Rightarrow \Delta H = 20 \text{ mm}$$

right-hand side of current is higher $\Rightarrow$ Finnish and Estonian coasts are about equally high

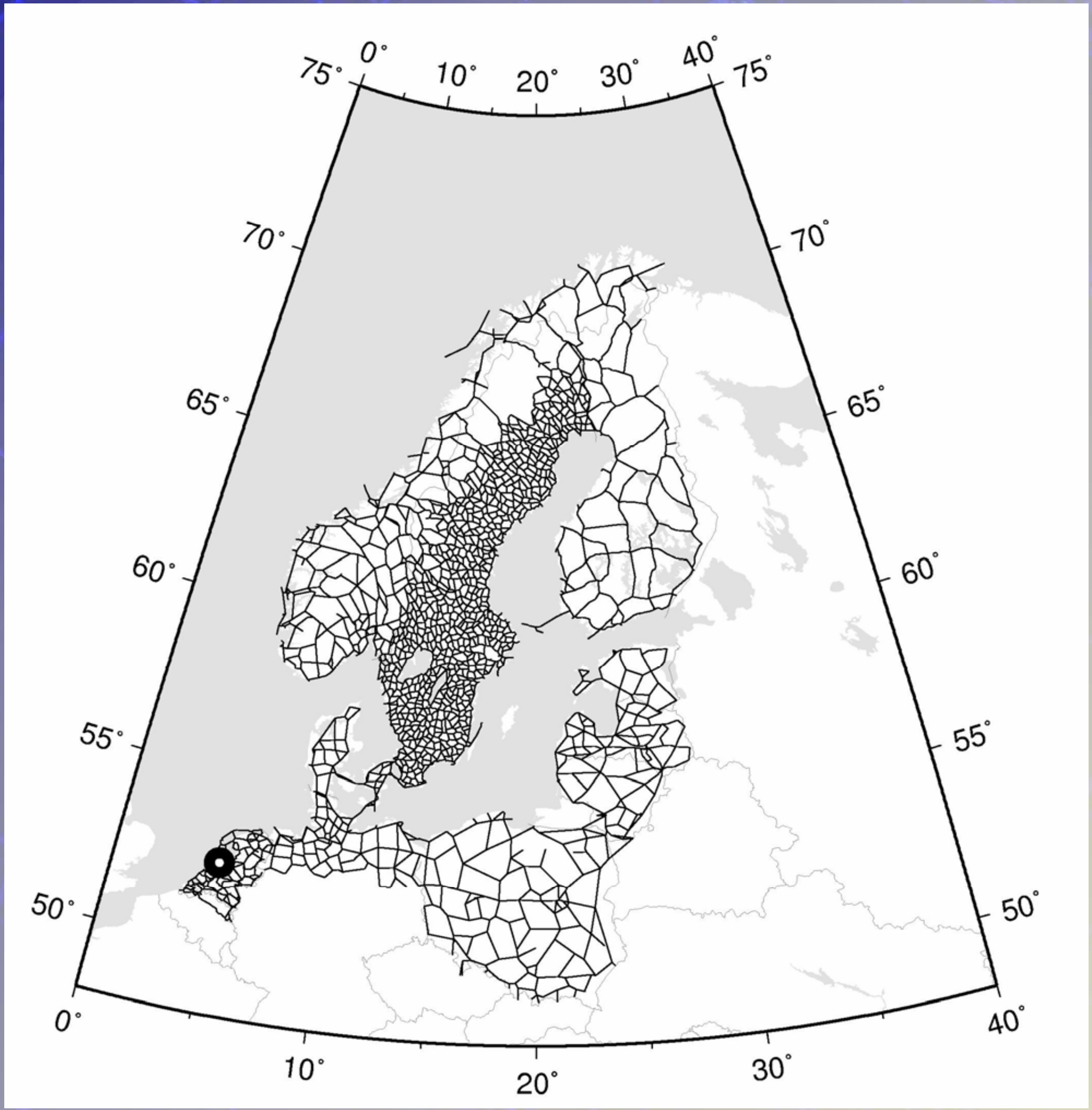


Baltic mean SST modelled in mm

from a dynamical model, 5-year run by Novotny et al. (2002)

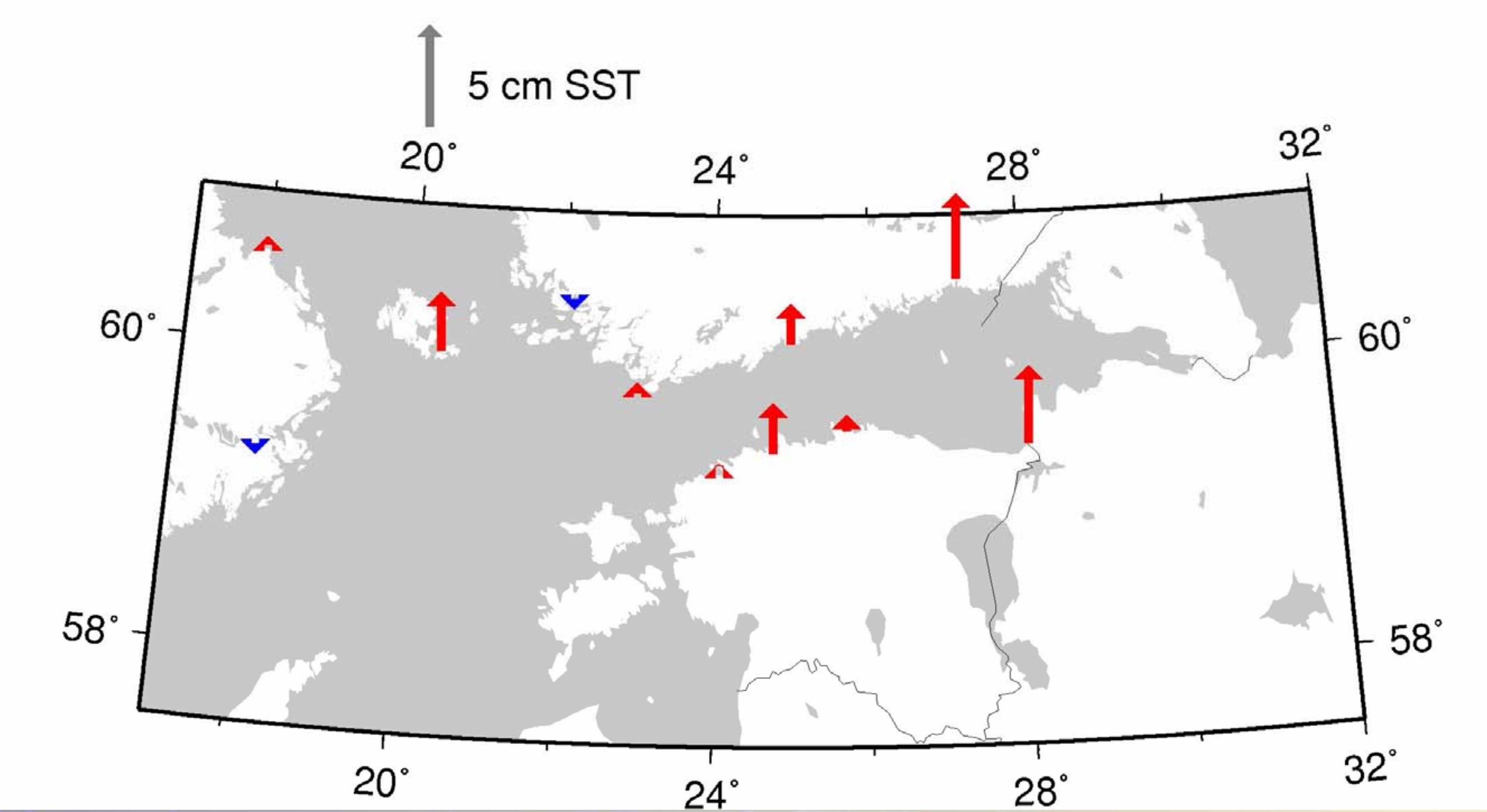
“Levelling observation” from tide gauges and oceanography

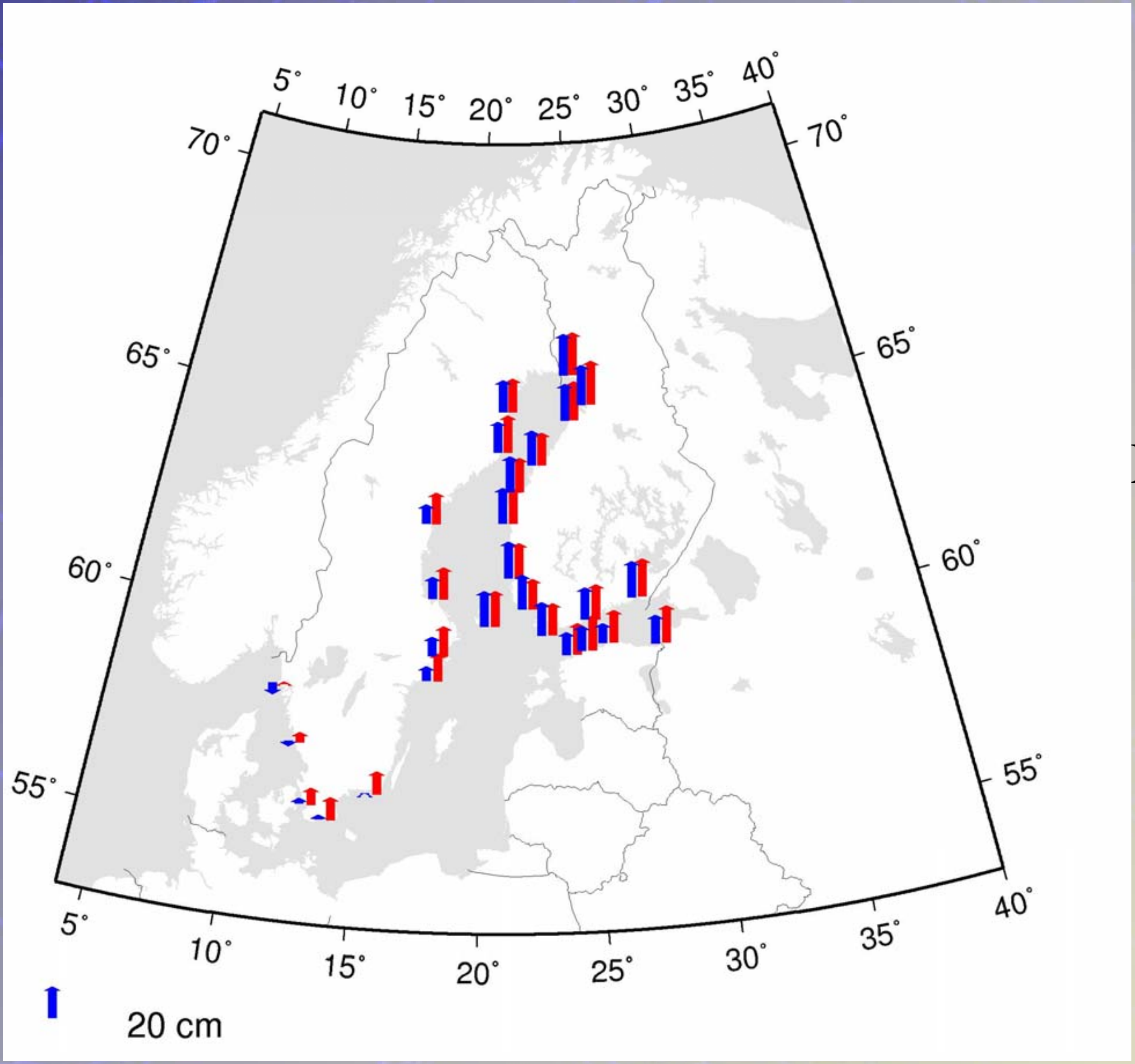
Estimating the misclosure of the Baltic Levelling Ring over the Gulf of Finland



Baltic Levelling Ring. No connection around the Gulf of Finland

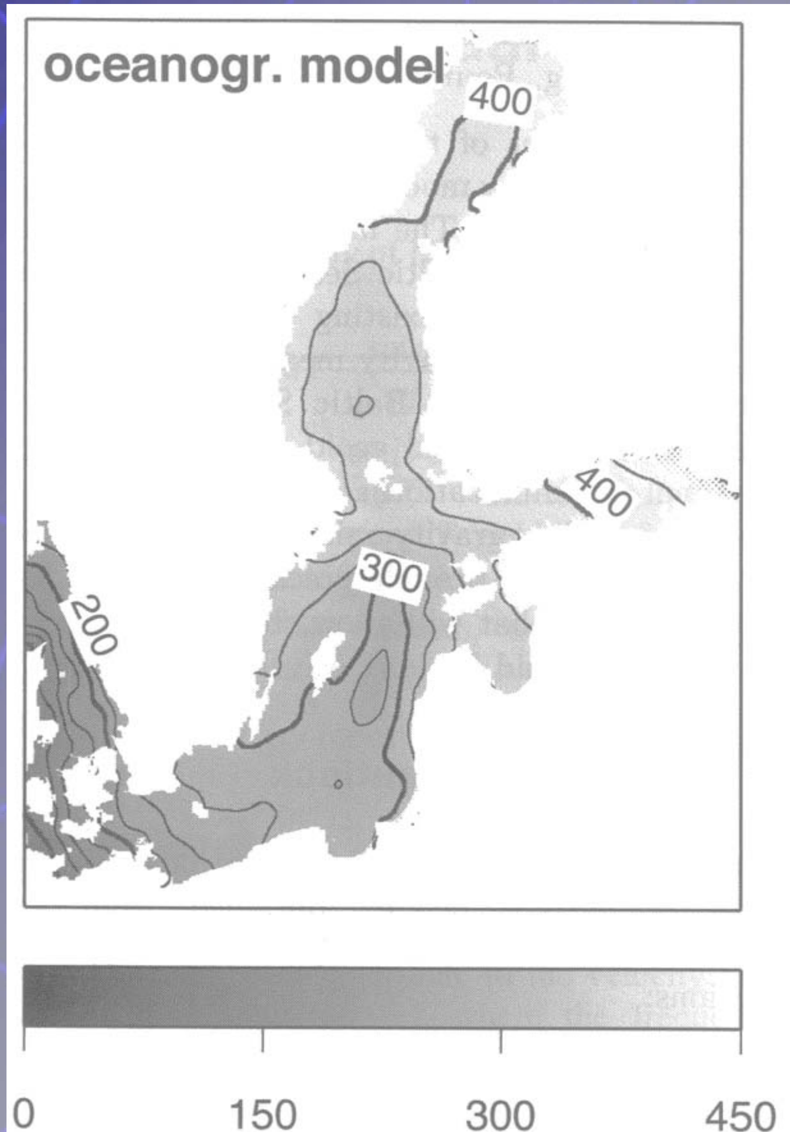
MSL 2000.0 relative to NAP according to the adjustment of the Nordic Height block. 20 cm subtracted





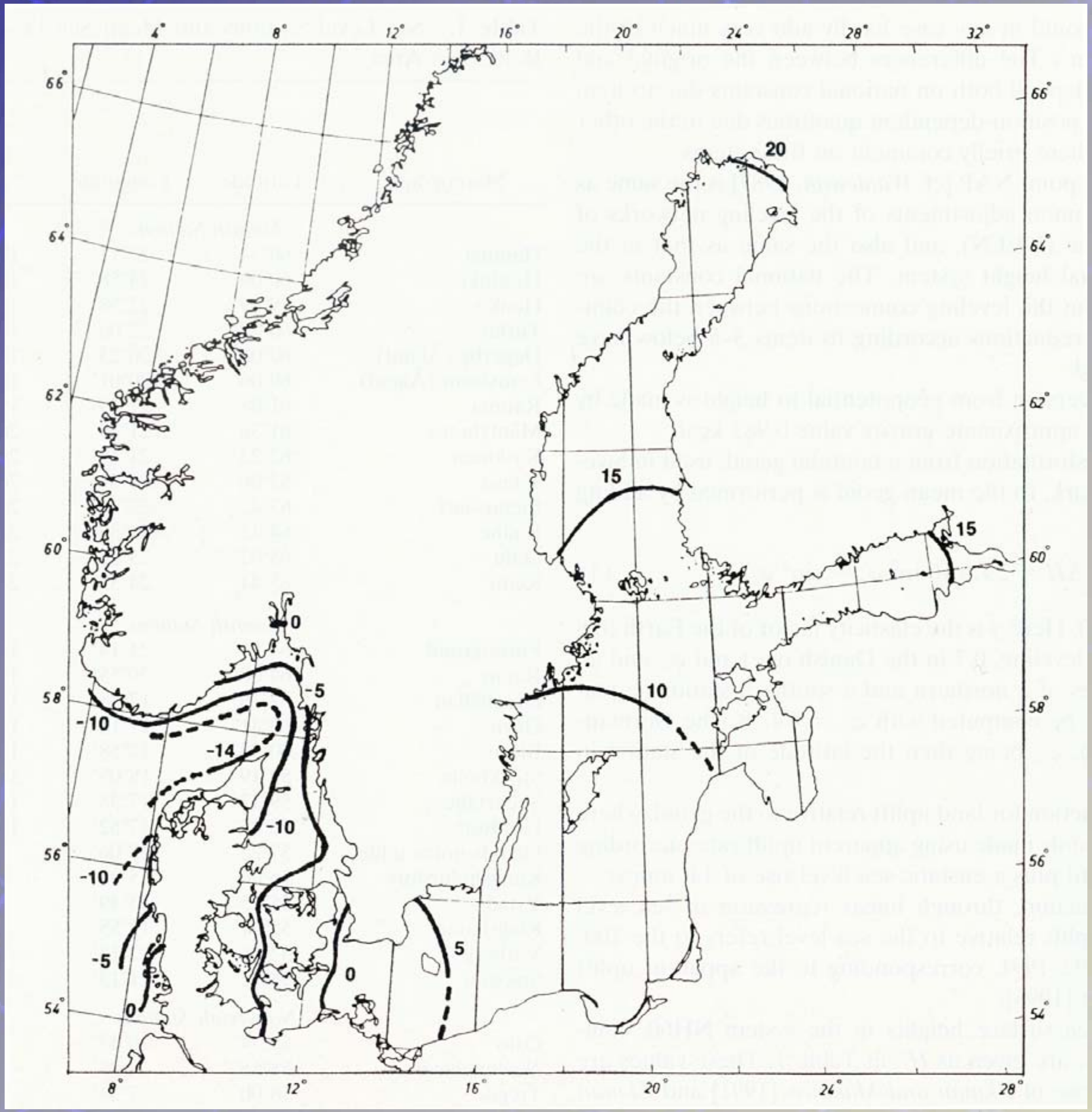
Baltic SST from EVRF2000 (blue) and BLR2000 (red)

Baltic mean SST modelled in mm



from a dynamical model, 5-year run by Novotny et al. (2002)

Mean SST in the Baltic from SECOND levellings and tide gauges in Denmark, Norway, Sweden, Finland.



Contour interval 5 cm, referred to NAP in the NH60 height system (Ekman and Mäkinen 1996).

Corrrection to heights, from mean tide to zero tide system