



Hermanus, South Africa

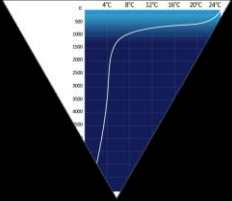
Mapping seasonal variations in tides from tide gauges and satellite altimetry

OPPORTUNITIES AND CHALLENGES

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EGU 2021 – Display material

POSSIBLE DRIVERS SEASONAL VARIATIONS IN TIDES



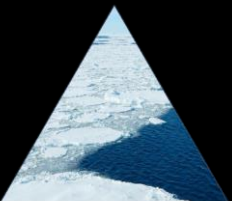
Density differences /stratification

E.g. water column stability affects the amount of tidal energy that is lost into other processes (e.g. turbulence or internal tide generation) (Müller, 2012; Müller et al., 2012).



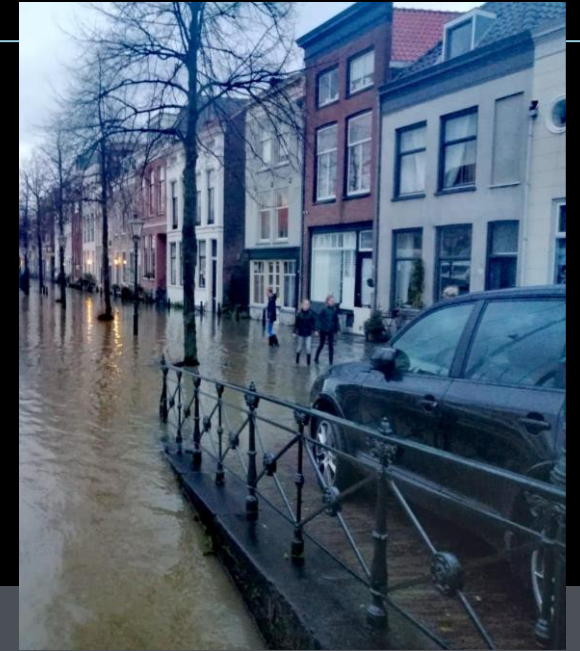
Meteorological forces

Non-linear interactions between tides and surges could alter tidal development (Huess & Andersen, 2001)



Sea ice cover

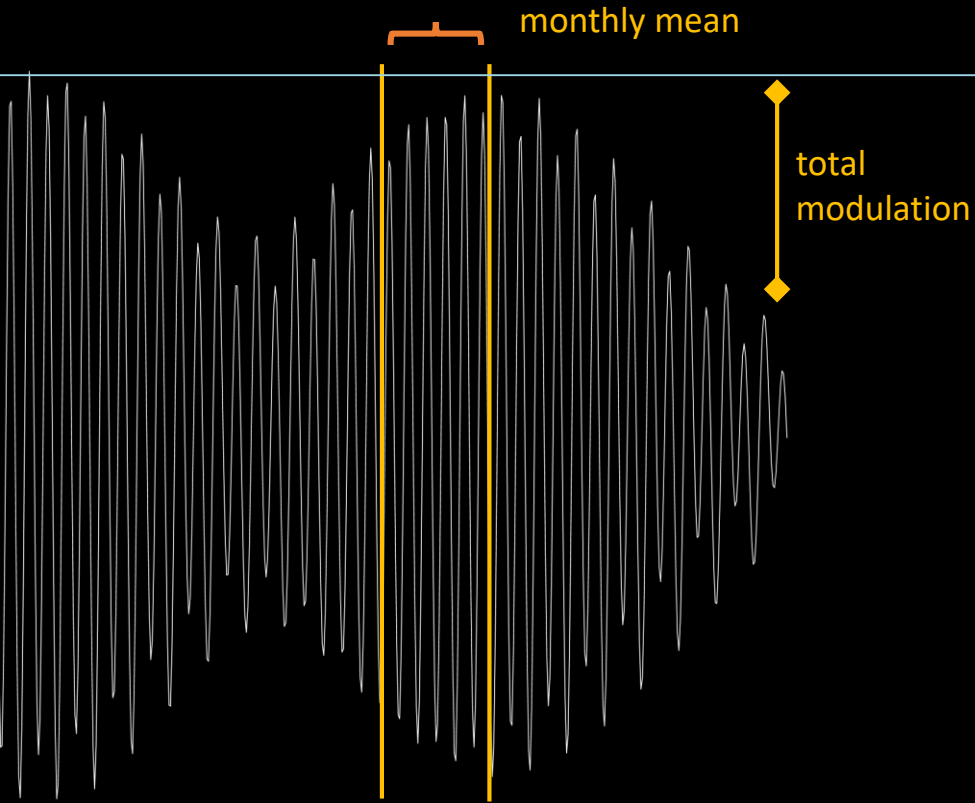
E.g. increased friction dampens local tidal amplitudes and delays the phase (Kowalik, 1984)



WHY CARE?

- Tidal seasonality is often not considered in models used for water level forecasting, nor in products used for correcting altimetry derived water levels.
- Local data suggests seasonal modulation of the M2 tide to be significant (e.g. Kleptsova & Pietrzak, 2018; St-Laurent et al., 2008)
- Understanding seasonal modulation of tides could contribute to understanding and predicting **long-term changes to the tides** and extreme events.

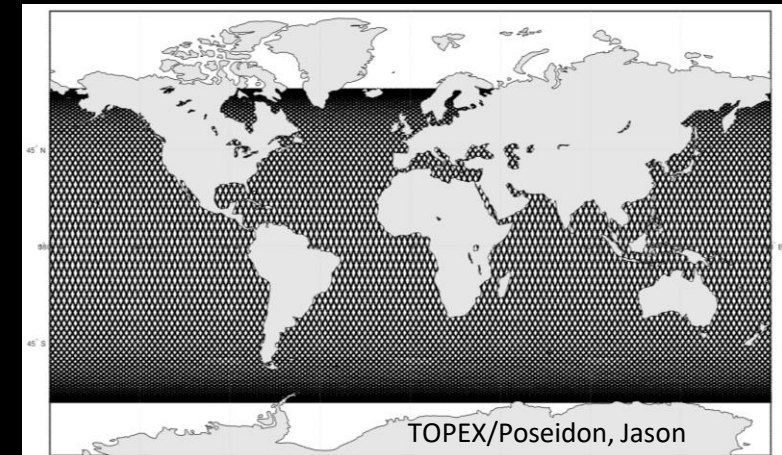
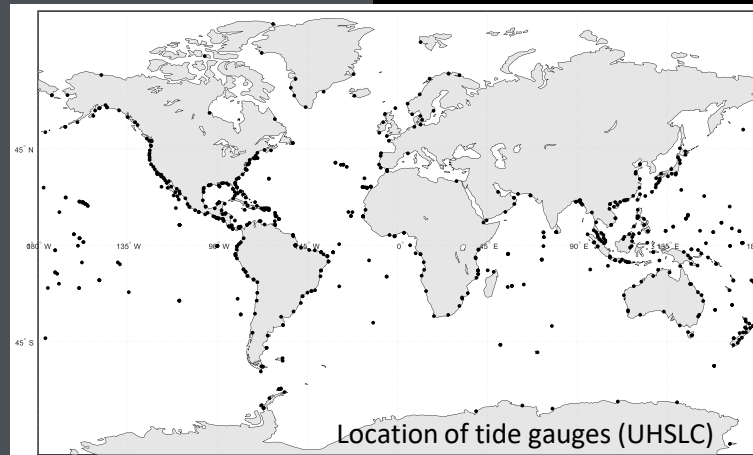
TIDAL ANALYSIS



1. Tidal analysis using **Utide**
Including *satellite constituents* of M2: H1 and H2
that describe annual modulation of M2
2. Reconstruct yearly signal M2 **including H1 and H2**
3. Extract total annual modulation and monthly averages

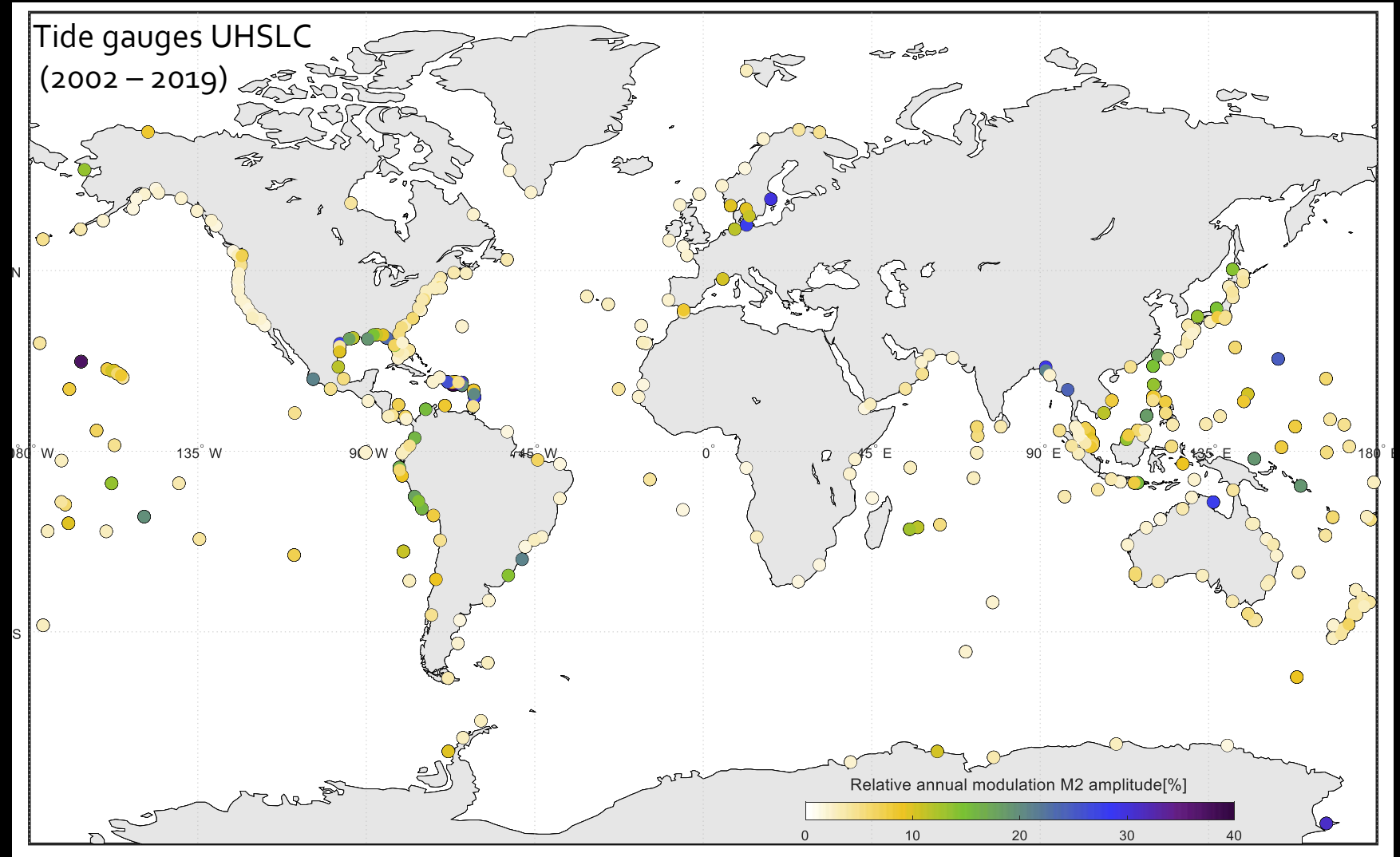
COMMON WATER LEVEL PRODUCTS

1. Tide gauges across globe
sampling interval: ~1h
2. Satellite altimetry:
e.g. TOPEX/Poseidon + Jason (TPJ)
sampling interval: 9.9 days



1. SEASONAL MODULATION FROM TIDE GAUGES

Relative annual modulation:
Total annual modulation as
percentage of yearly average M2
amplitude



2. SEASONAL MODULATION FROM SATELLITE ALTIMETRY

CHALLENGES

Relatively large sampling interval of TPJ causes **aliasing** of tidal components, makes it difficult to resolve and separate non-major tides

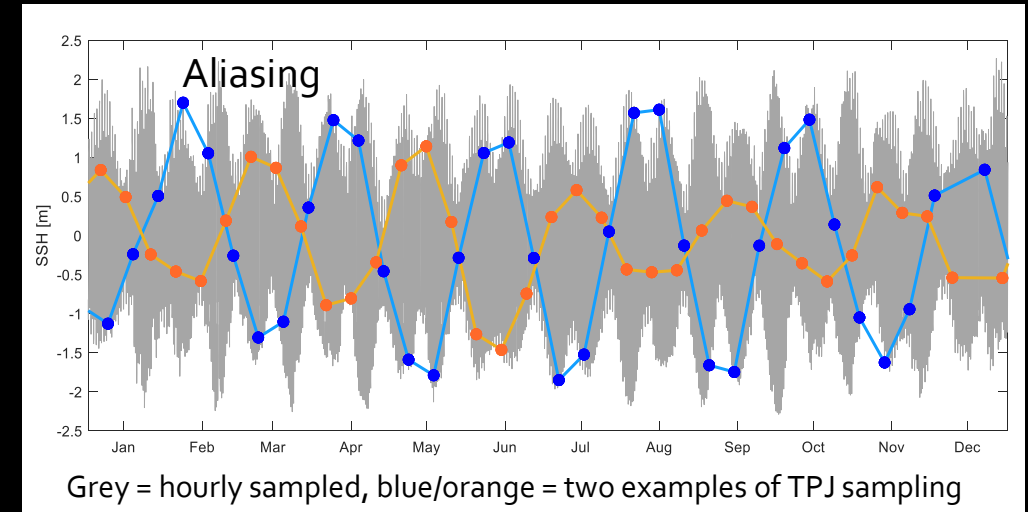
Rayleigh criterium should be applied to alias periods:

$$T = \frac{360}{\Delta\omega * 24} \quad [\text{days}]$$

$\Delta\omega$ = frequency difference of two constituents (or aliases)

T = minimum required timeseries length

Example S1 (diurnal) vs. H1 (semi diurnal)
Hourly sampling $T_{S1H1} = 1 \text{ day}$
TPJ sampling (9.9 days) $T_{S1aH1a} = > 11 \text{ years}$

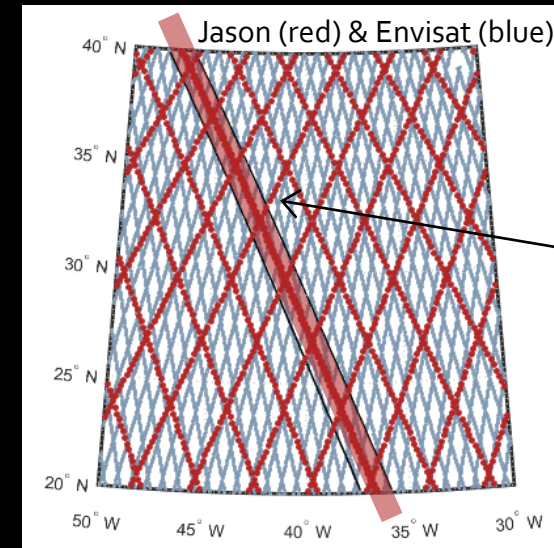


Grey = hourly sampled, blue/orange = two examples of TPJ sampling

Solution?

(inspired by Savchenko & Bosch, 2007)

1. Stack data at **crossover** locations
2. Combine data of **different satellite missions** with different sampling intervals and cross-track spacings →



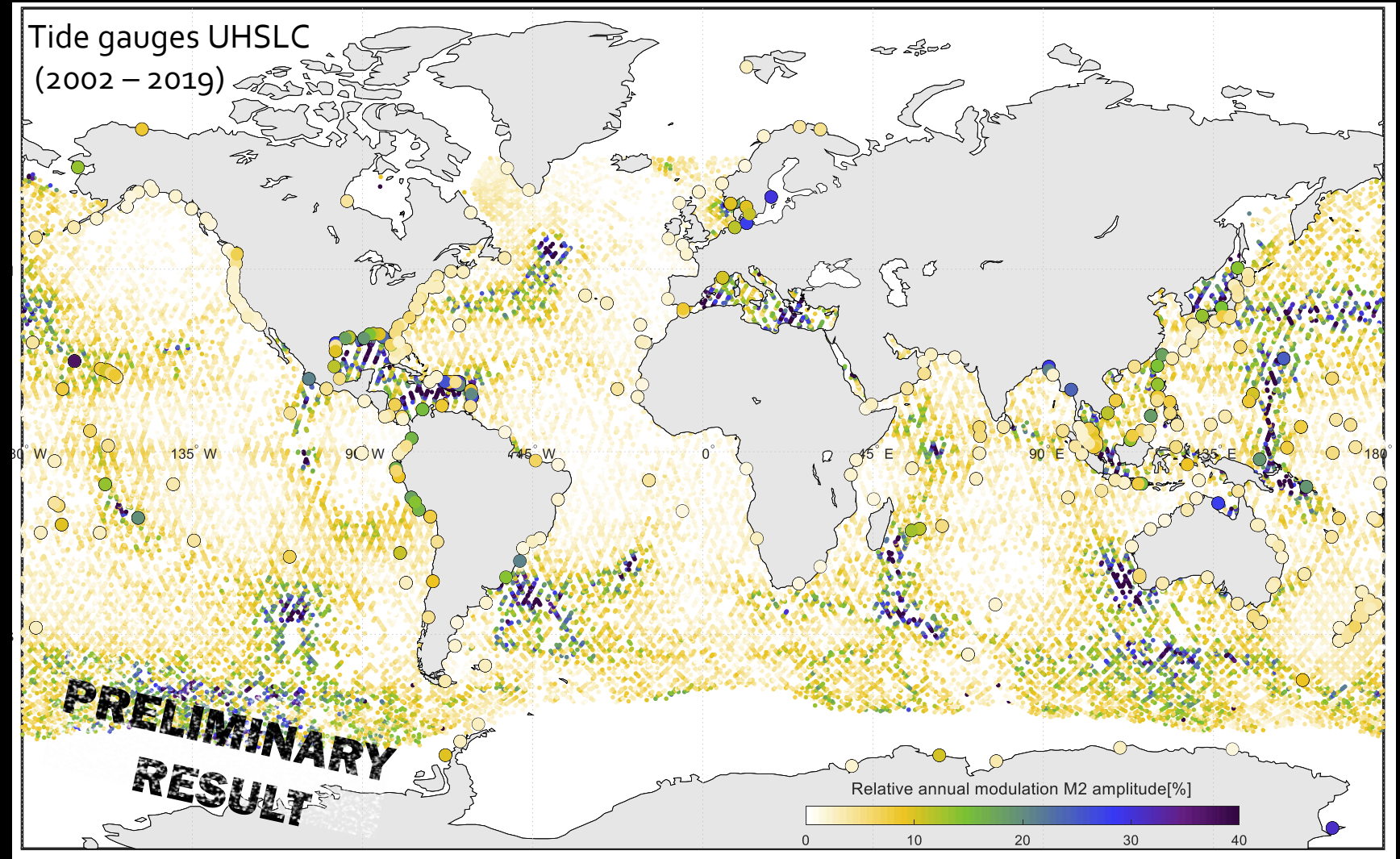
Include nearby data of other missions

2. SEASONAL MODULATION FROM SATELLITE ALTIMETRY

Relative annual modulation:
Total annual modulation as
percentage of yearly average M2
amplitude

→ Similar magnitude compared
to tide gauges in most regions

Background: Jason + Envisat + S₃A + SARAL (2002-2020)



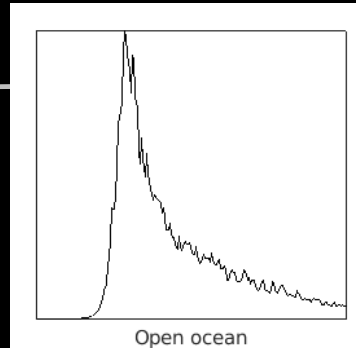
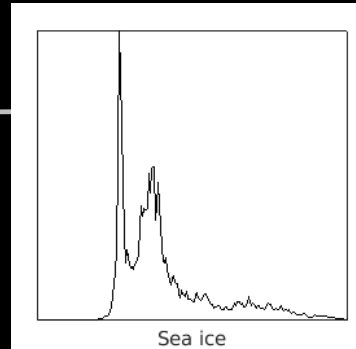
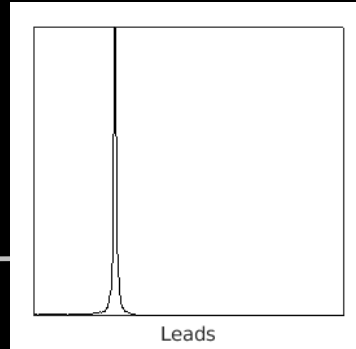
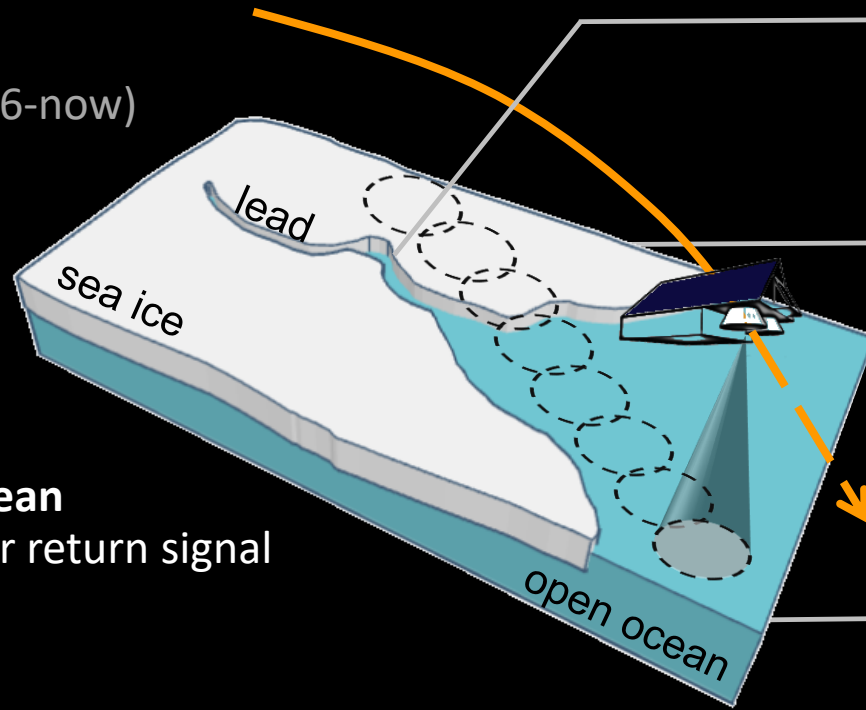
WHAT ABOUT THE ARCTIC?

- Very few tide gauges
- Not covered by TOPEX/Poseidon, Jason
- Largely covered by sea ice

→ Data from CryoSat-2 (2010-now) & Sentinel-3 (2016-now)

SAR altimetry

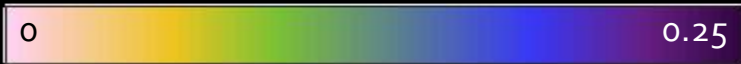
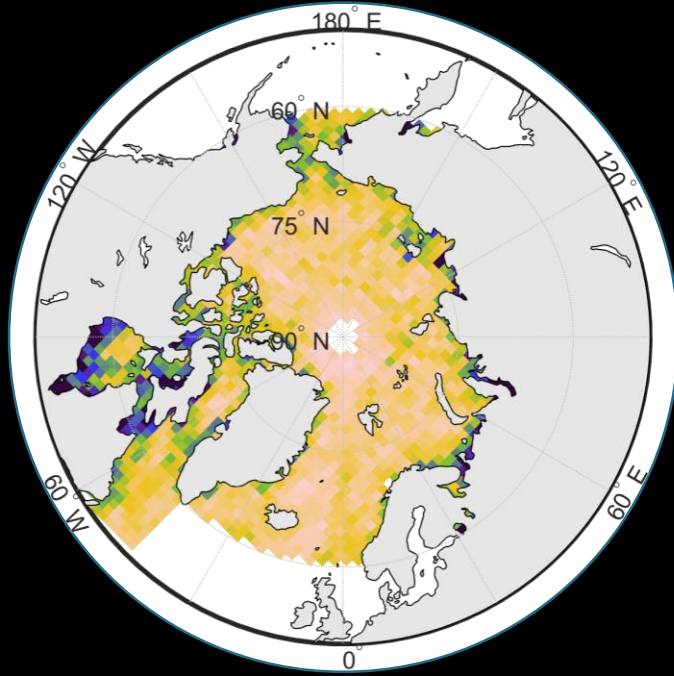
Distinguish measurements from **sea ice**, **leads** and **ocean**
based on radar return signal



Data stacking on 3x1 grid to deal with large sampling interval (~30 days) (following Cancet et al., 2018)

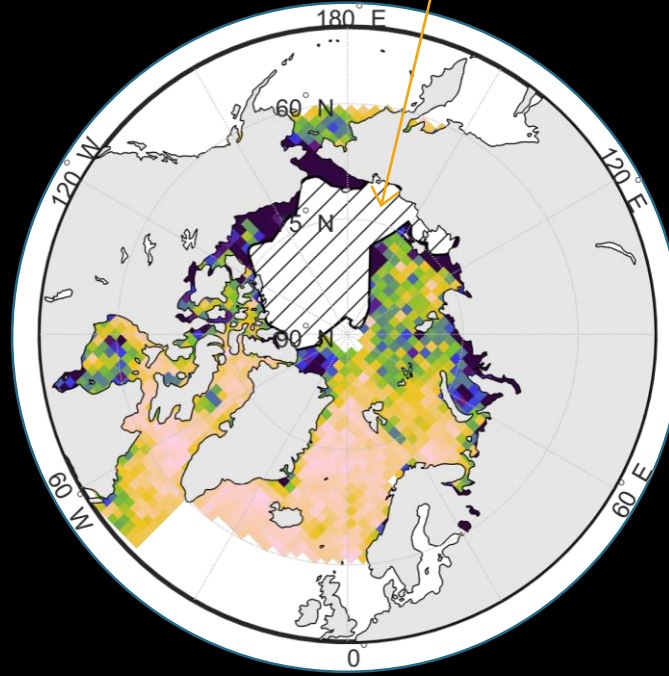
ARCTIC SEASONAL MODULATION M2

M2 = lunar semidiurnal tide , *main tide in Arctic*

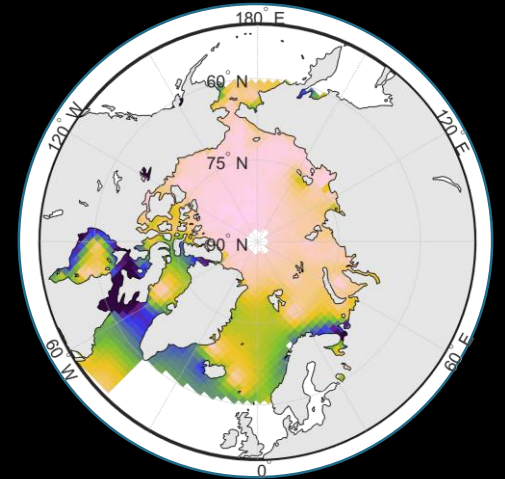


Total annual modulation amplitude (m)

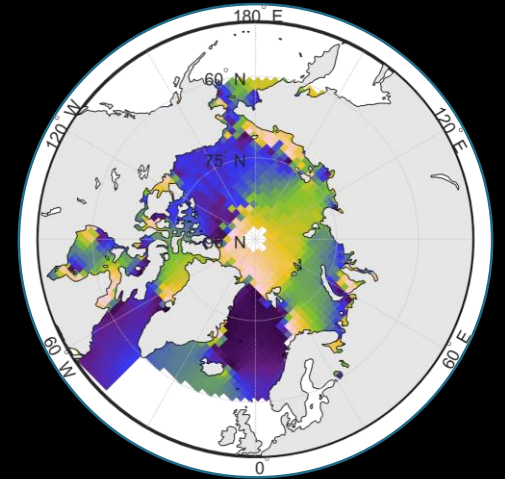
Phase modulation unreliable
because of small amplitude



Total annual modulation phase (deg.)

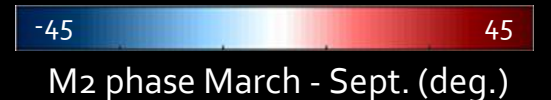
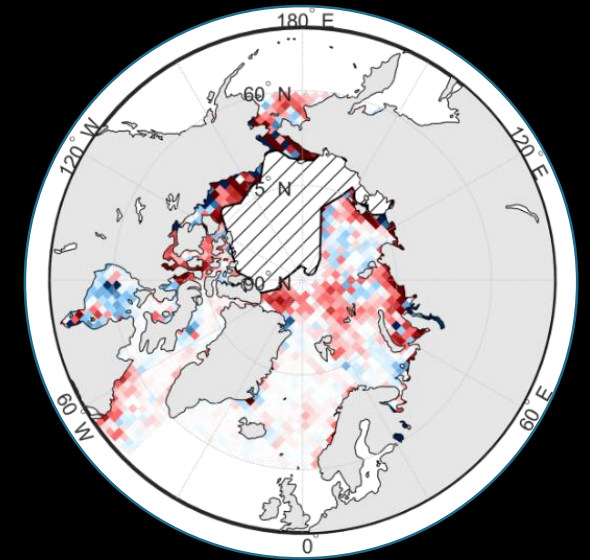
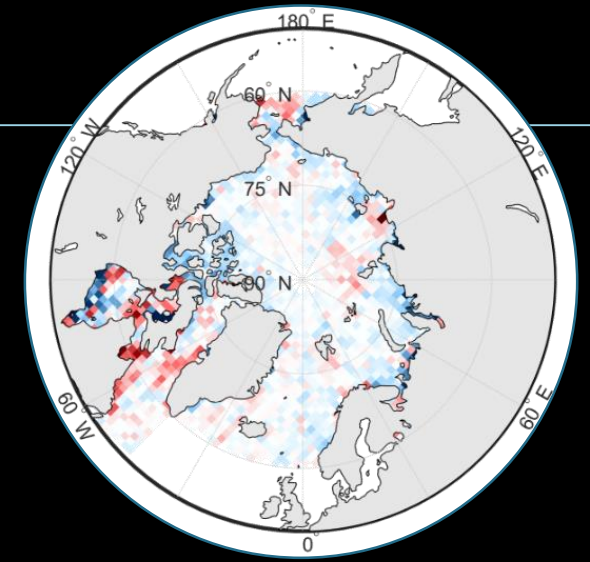
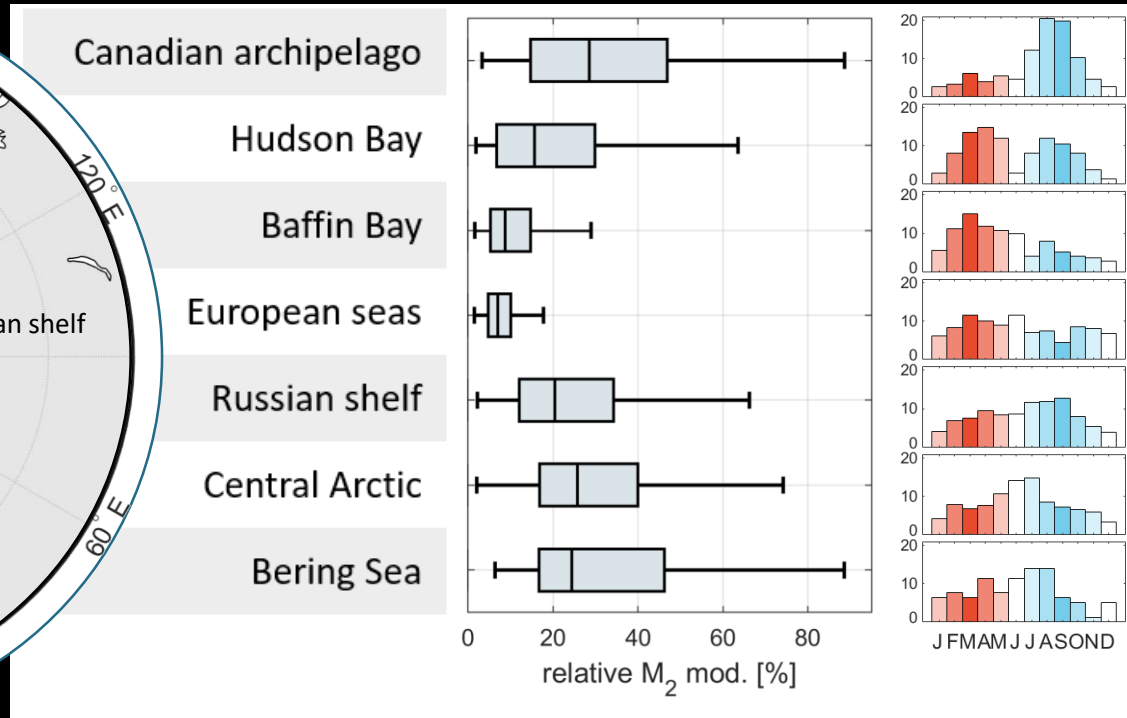
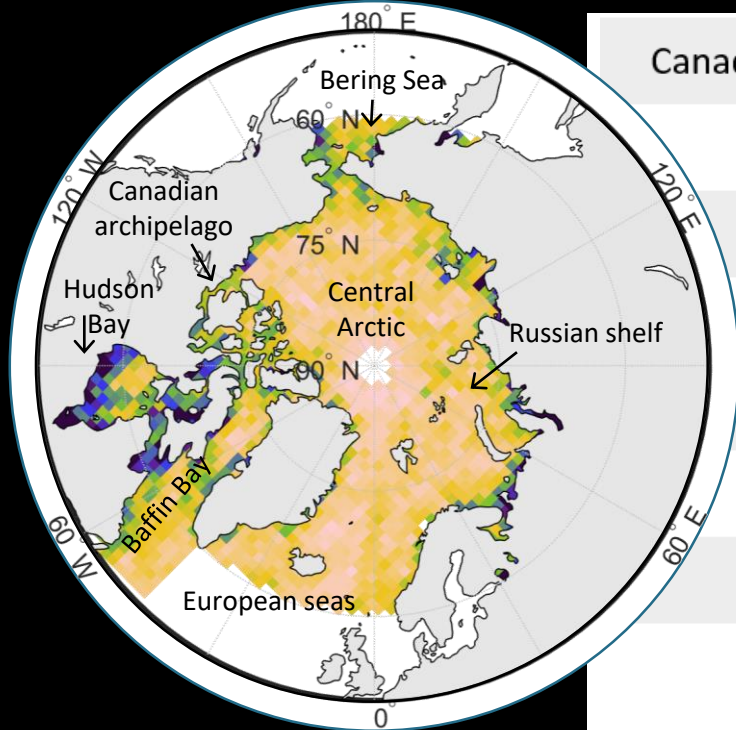


Mean M2 amplitude (m)



Mean M2 phase (deg.)

ARCTIC SEASONAL MODULATION M2



General message maximum ice cover in March relates to:

- Lower amplitudes at locations of ice cover, but increased amplitudes further afield
- Phase delay in most locations, except for Hudson Bay

CONCLUSIONS & OUTLOOK

- Seasonal modulation of M2 observed at tide gauges across the globe; up to 20% of mean amplitude
- First attempt made to derive global seasonal modulation from satellite altimetry
- Larger seasonal modulation observed in Arctic; up to 25 cm / 40% of mean amplitude

→ Continue with global analysis from satellite altimetry

→ Connect observed modulation to seasonal processes by model

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- Cancet, M., Andersen, O., Lyard, F., Cotton, D., & Benveniste, J. (2018). Arctide2017, a high-resolution regional tidal model in the Arctic Ocean. *Advances in space research*, 62 (6), 1324-1343.
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