



Image credit: NASA Visible Earth

<https://www.visibleearth.nasa.gov/images/58567/low-pressure-system-over-the-bering-sea/58569>

# Understanding Decadal-scale Trends in Altimeter-derived Significant Wave Height in the Bering Sea

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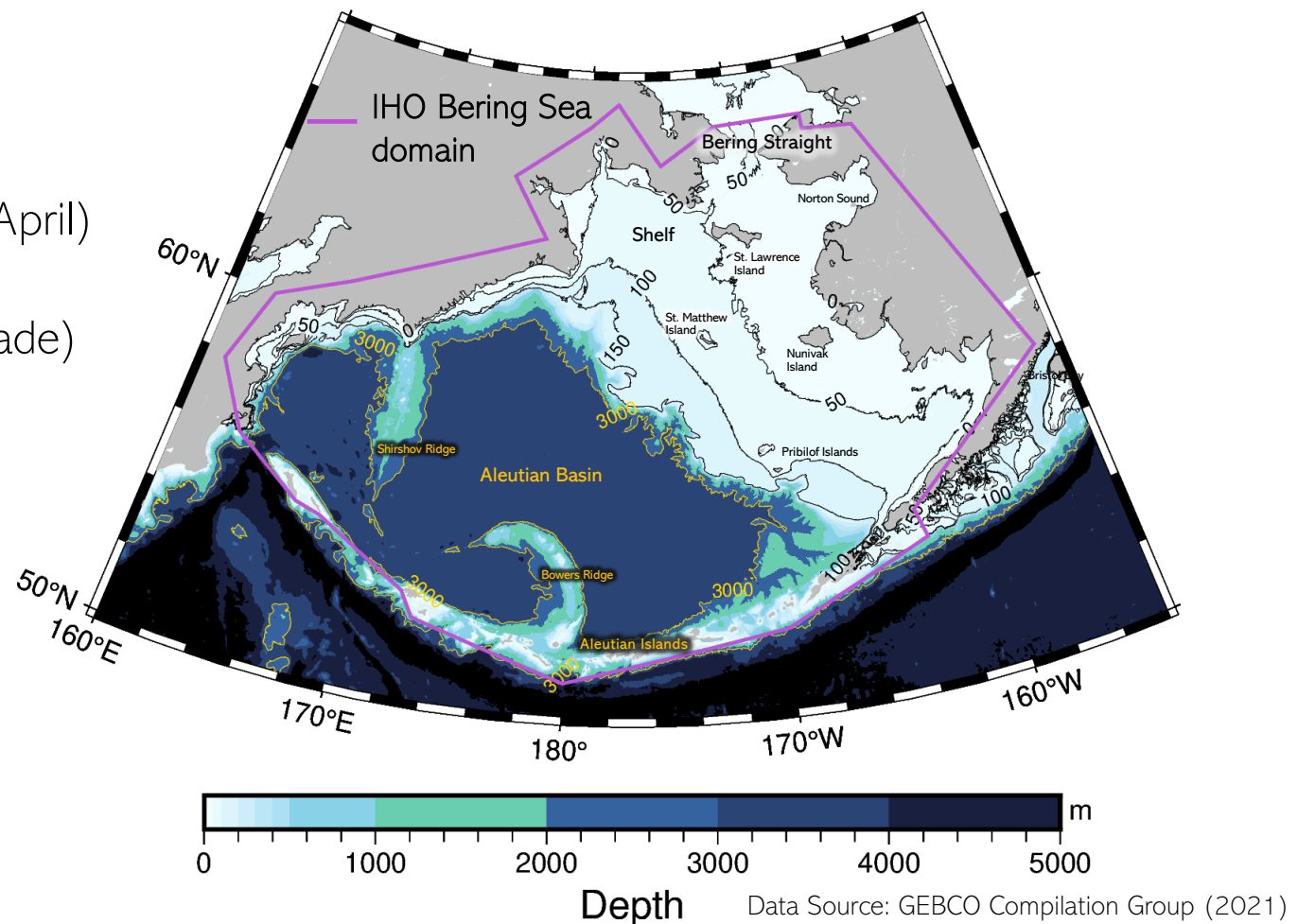
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# The Bering Sea

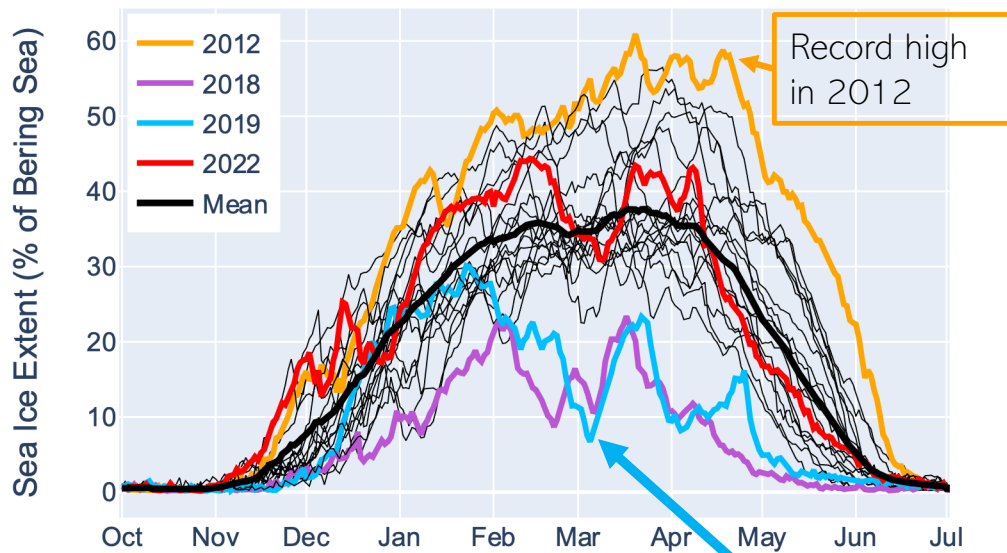
- Stormy winters (October – April)
- Sea ice loss (-13% per decade)
- Vulnerable communities
  - Coastal protection
  - Subsistence living
- Billion-dollar fishing industry



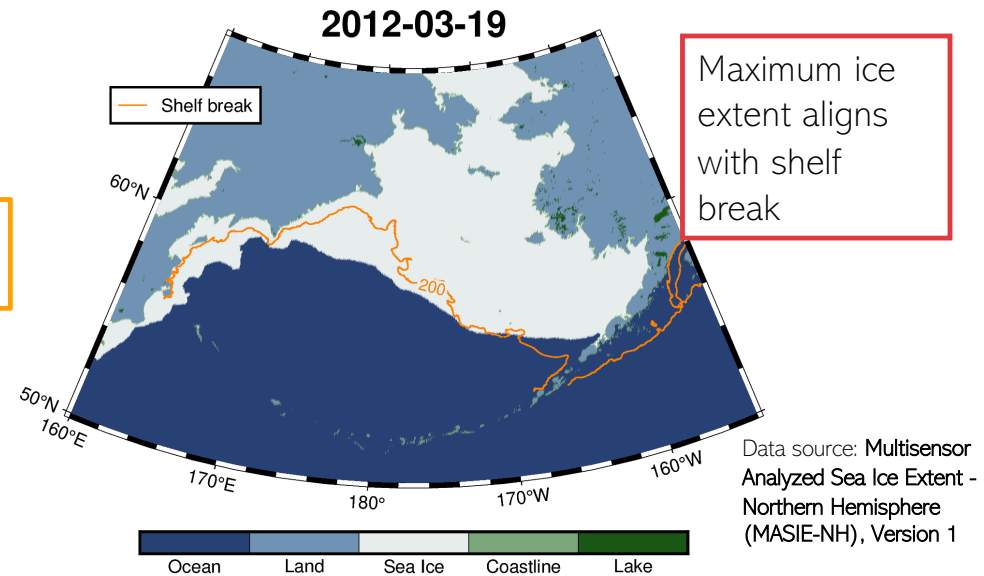
# Vulnerability due to Sea Ice Loss

## Bering Sea Ice extent

Winters 2003 - 2022



Data Source: NOAA/NSIDC CDR Passive Microwave Sea Ice Concentration version 4



September 2022 Ex-TC Merbok

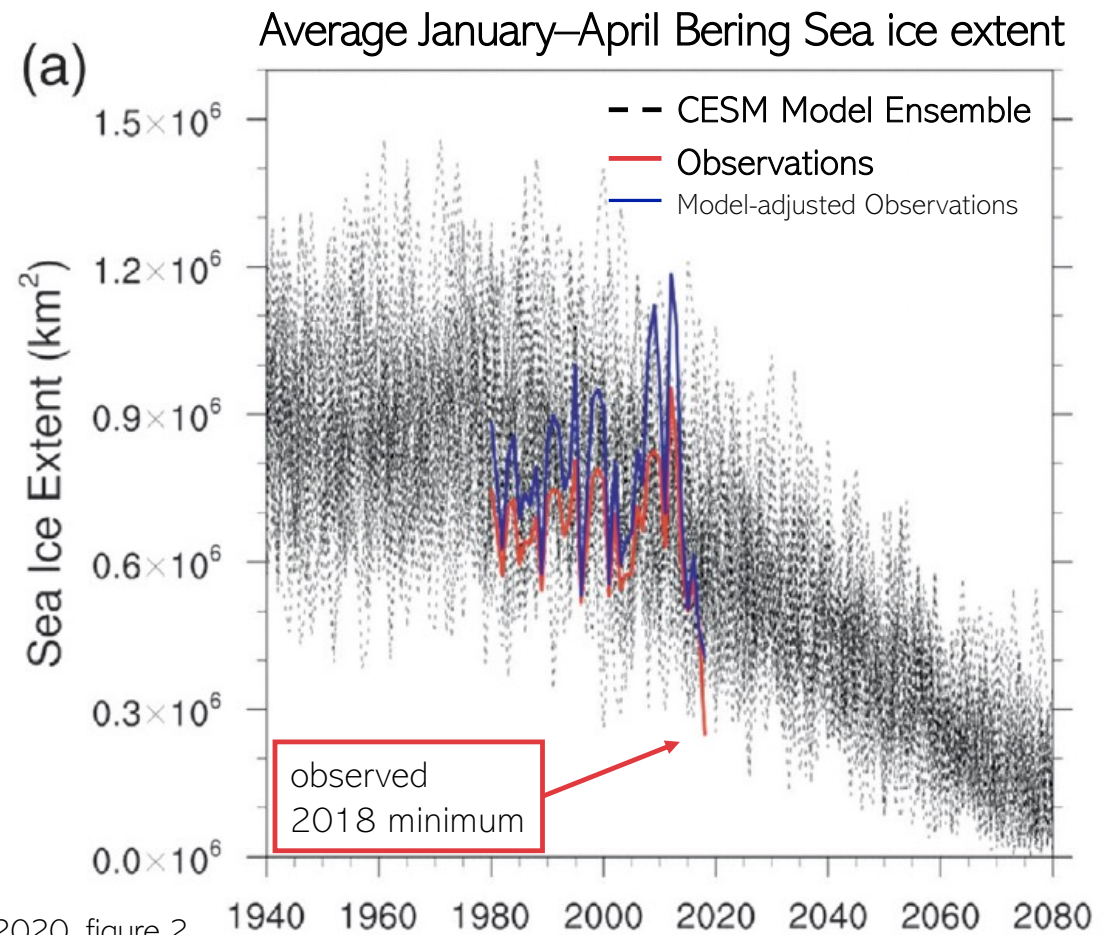


- sea ice protects coastal communities
- loss of sea ice results in bigger impacts due to storm surge

Source: Anchorage Daily News photo by Annette Piscoya [5]

- Record low ice extents in winter in the Bering Sea will become the norm in the future

# Future Sea Ice Conditions



Source: Thoman et al. 2020, figure 2





# Altimeter-Derived Significant Wave Height (SWH)

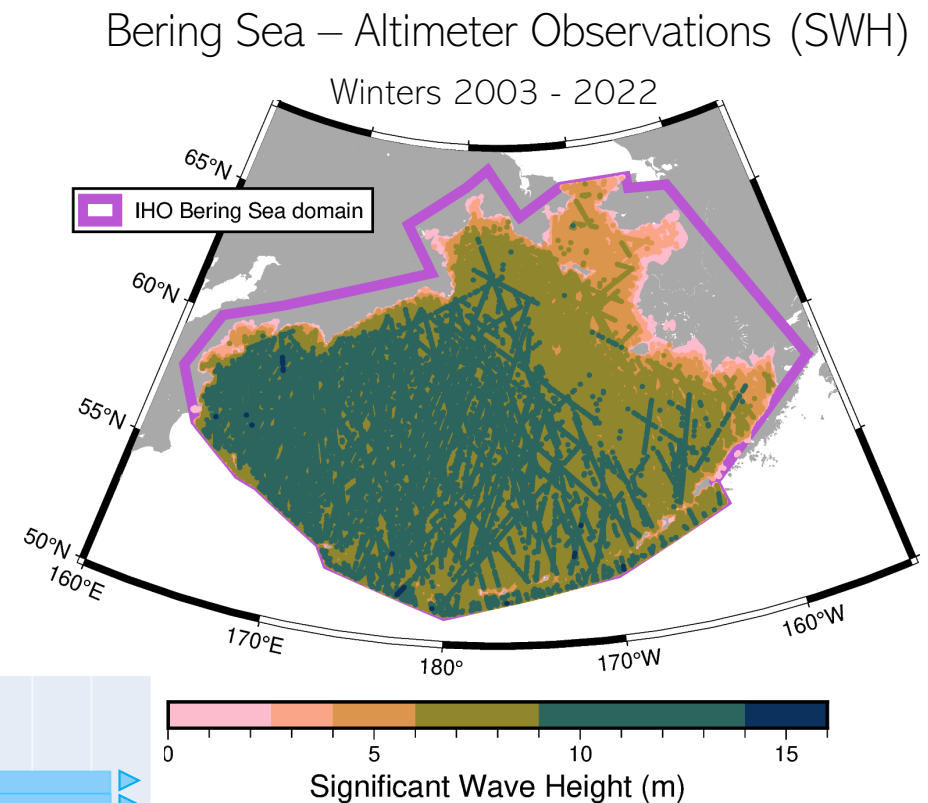
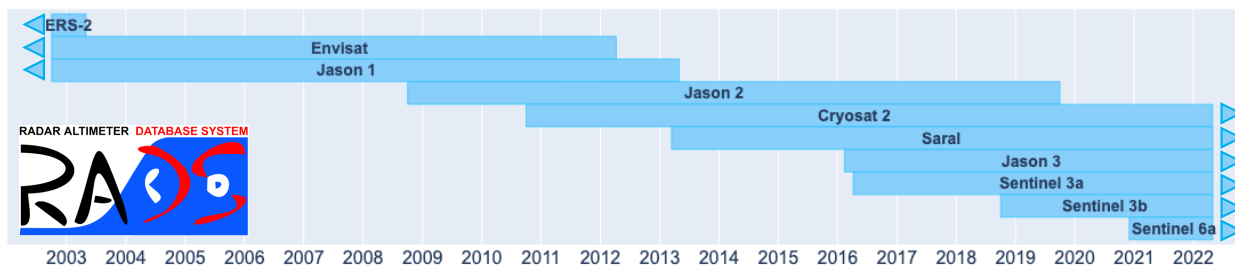
Study period:

Winters 2002/2003 - 2021/2022

Satellite altimeter datasets

- ERS-2
- Envisat
- Jason-1
- Jason-2
- Cryosat-2
- Saral
- Jason-3
- Sentinel-3a
- Sentinel-3b
- Sentinel-6a

TU Delft / EUMETSAT / NOAA Radar Altimeter Database System



Significant Wave Height (m)

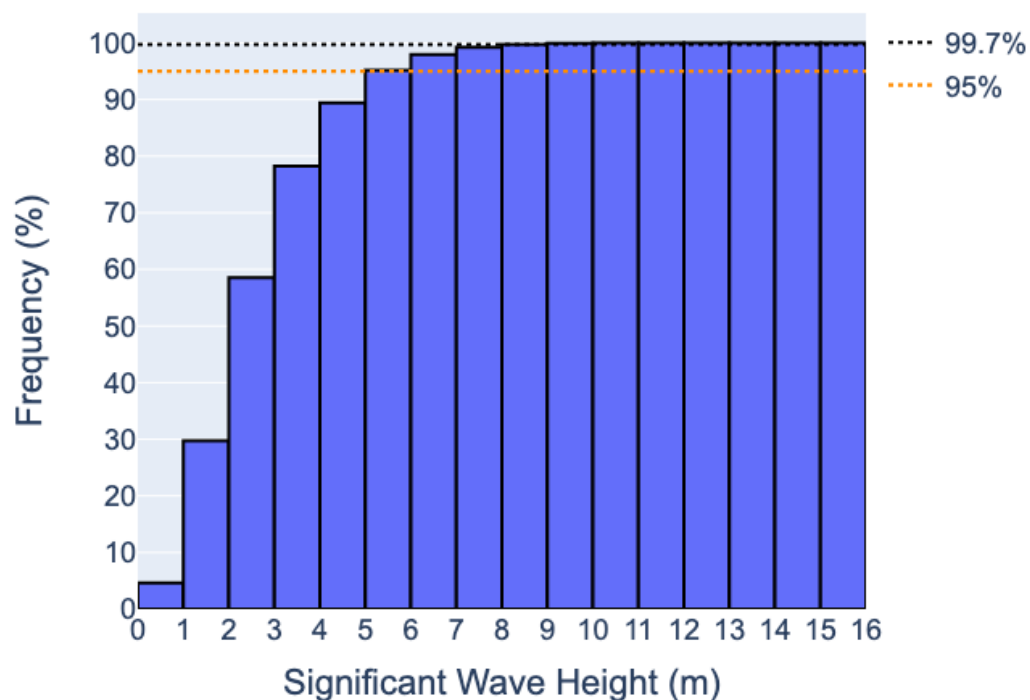
SWH Frequency = 1 Hz

Storm seasons = October - April

# Observing very high seas (SWH > 9m)

Satellite radar altimeter SWH

All winters 2003 - 2022



WMO Sea State Code	Wave height	Characteristics
0	0 metres (0 ft)	Calm (glassy)
1	0 to 0.1 metres (0.00 to 0.33 ft)	Calm (rippled)
2	0.1 to 0.5 metres (3.9 in to 1 ft 7.7 in)	Smooth (wavelets)
3	0.5 to 1.25 metres (1 ft 8 in to 4 ft 1 in)	Slight
4	1.25 to 2.5 metres (4 ft 1 in to 8 ft 2 in)	Moderate
5	2.5 to 4 metres (8 ft 2 in to 13 ft 1 in)	Rough
6	4 to 6 metres (13 to 20 ft)	Very rough
7	6 to 9 metres (20 to 30 ft)	High
8	9 to 14 metres (30 to 46 ft)	Very high
9	Over 14 metres (46 ft)	Phenomenal

Total observations = 6.2 million

Extreme events

- High seas (> 6 m) = 5%
- Very high seas (> 9 m) = 0.3%
- Phenomenal seas (>14 m) = 0.0005% (n=28)

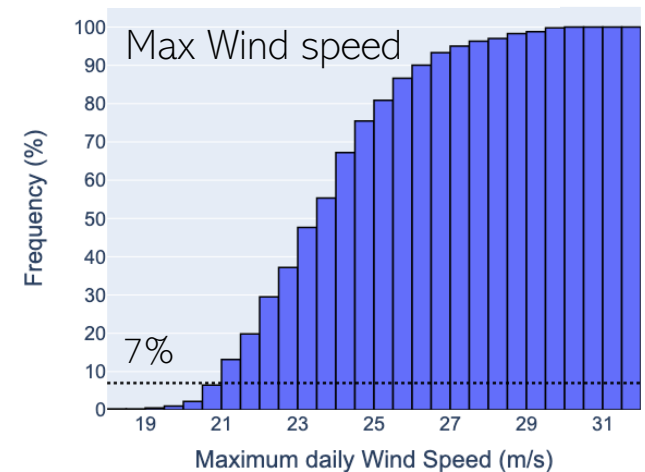
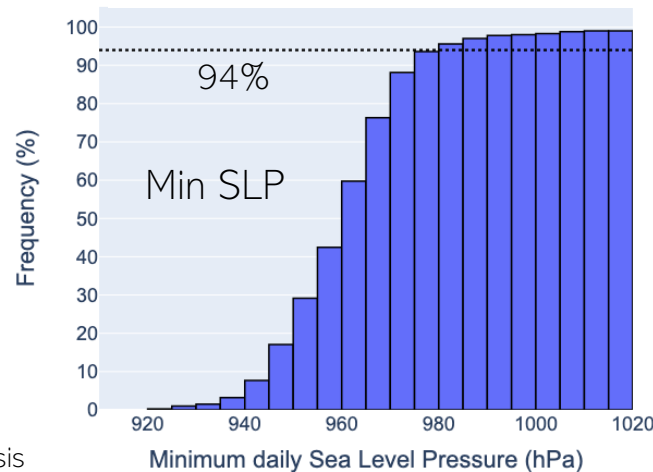
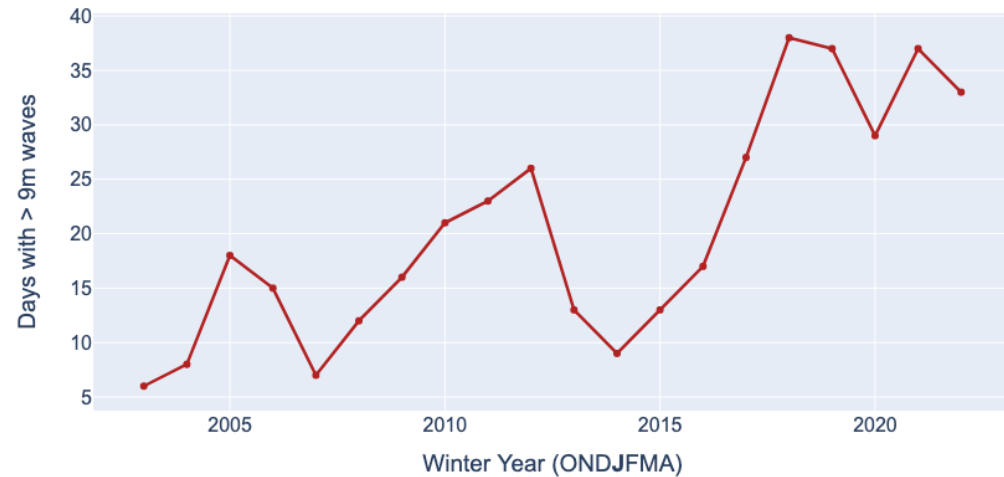


# Atmospheric conditions during storm events

- 405 days with very high seas (> 9 m) observed by altimetry
- On 94% of these days there is a low-pressure system with a minimum Sea Level Pressure < 980 hPa
- 93% of these days have maximum ten-meter wind speeds of Strong Gale force ( $21 \text{ ms}^{-1}$ ) or stronger in the Bering Sea

Data source: ERA5 reanalysis

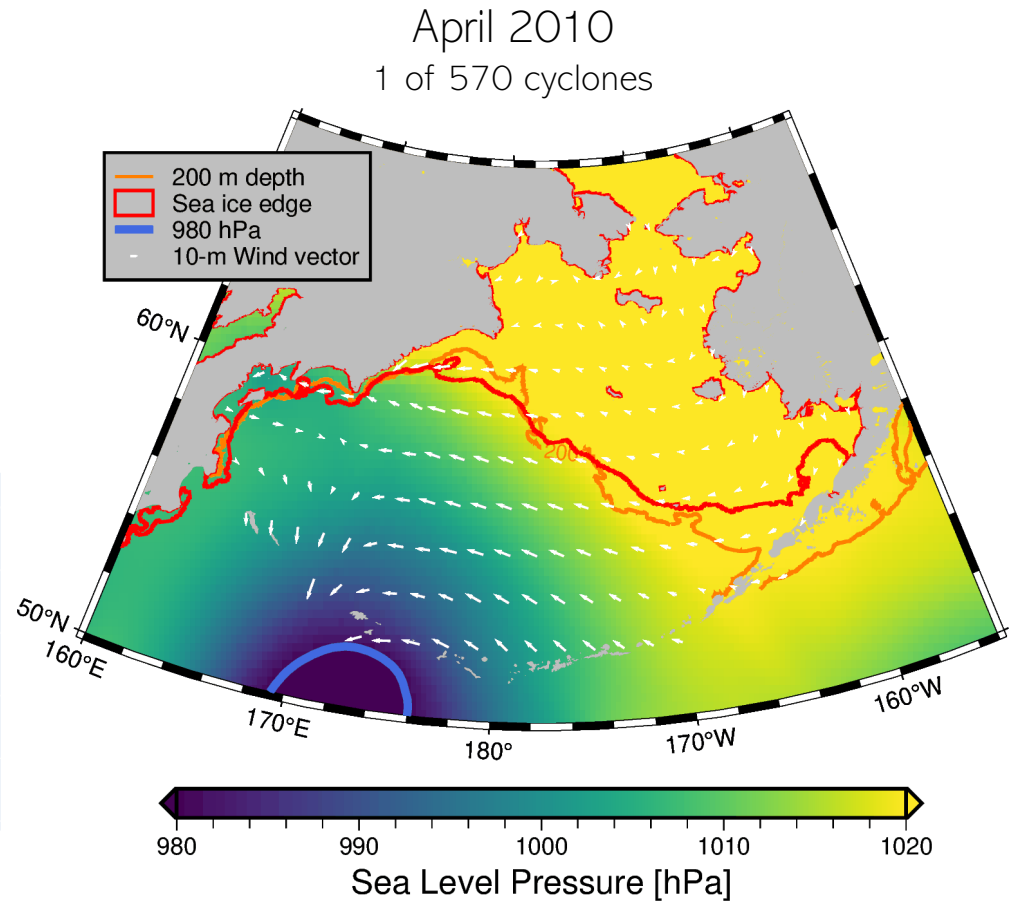
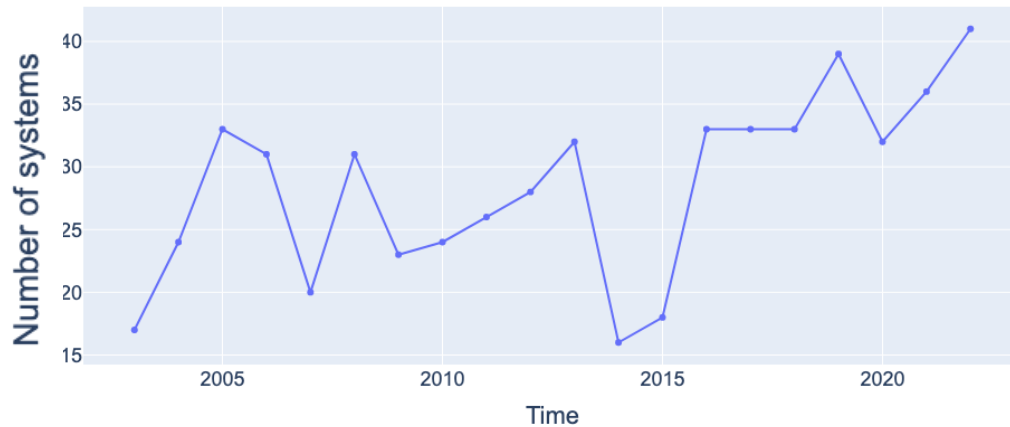
Annual occurrence of SWH > 9 m



# Finding the cyclones

- Track low-pressure systems in ERA5 based on Sea Level Pressure (Crawford et al. 2021)
- Select storms
  - $< 980$  hPa minimum pressure
  - $> 21$  m/s maximum windspeed
- 570 cyclones over 20 years

Storm systems - Winters 2003 - 2022

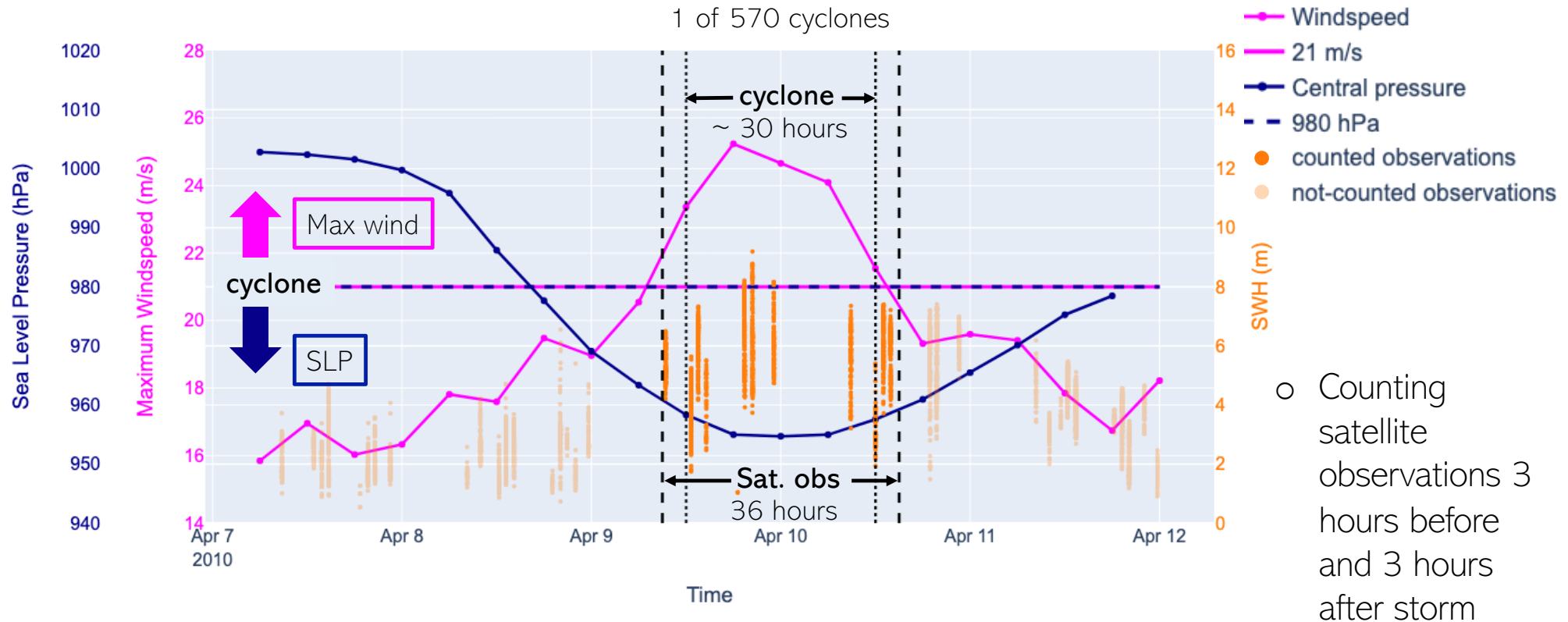




# How good is the satellite coverage?

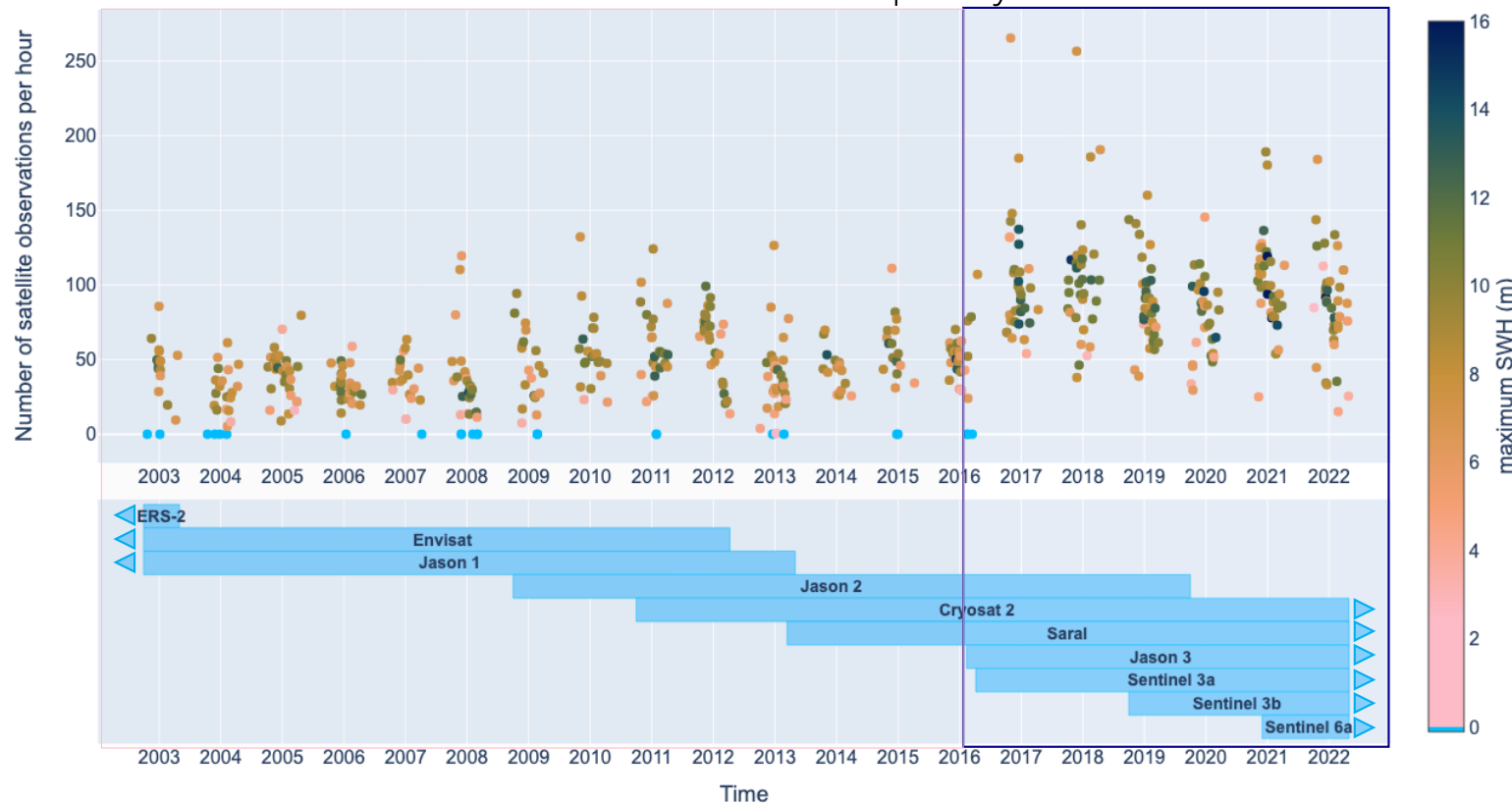
## Illustrative Case Study – April 2010

1 of 570 cyclones



# Satellite SWH during cyclones

Number of Altimeter observations per cyclone

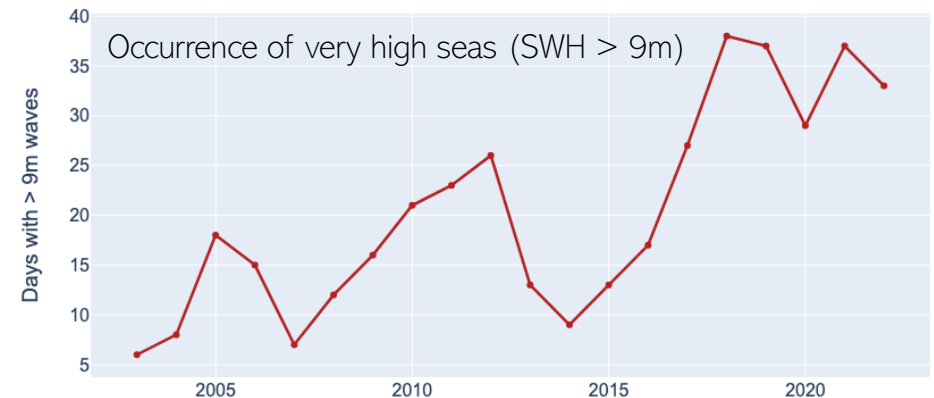
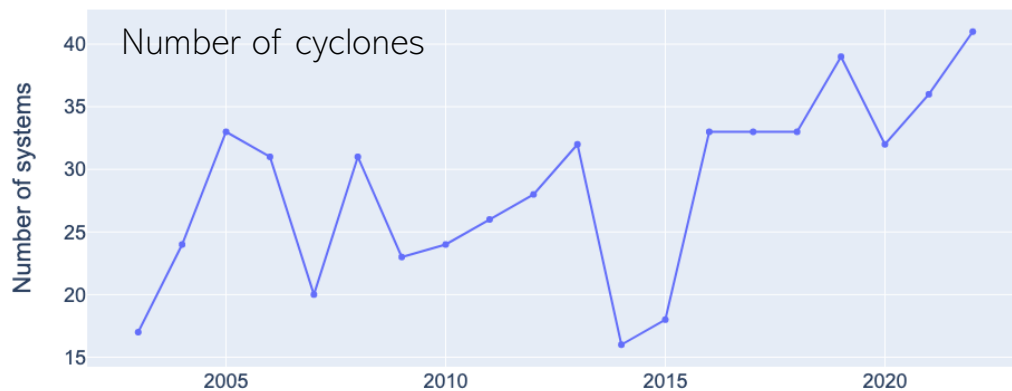


- 1 dot = 1 cyclone  
570 cyclones found in ERA5
- 1. Significantly better coverage since launch Jason-3 + Sentinel-3a (mid-2016)
- 2. Prior to 2016, **24 cyclones** were **not observed** by satellite altimeters (blue dots) (all < 6 hour events)
- 3. More rare events (Phenomenal seas) captured since mid-2016 -> darker dots



# Take-away messages

- Vulnerability of affected **communities** increased by sea-ice loss (-13% per decade DJF)
- Increasing the **number of satellite altimeters** from 3 to 5/6 has allowed us to capture cyclone events – important for fidelity in relevant ocean observations
- 20-year time period too short to verify long-term climate trend, however Bering Sea conditions in **last 5 years** have been significantly **more stormy** than previously





# References

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