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Dynamic Loss of the Arctic's Oldest Ice Triggered a Sea-ice Tipping Point

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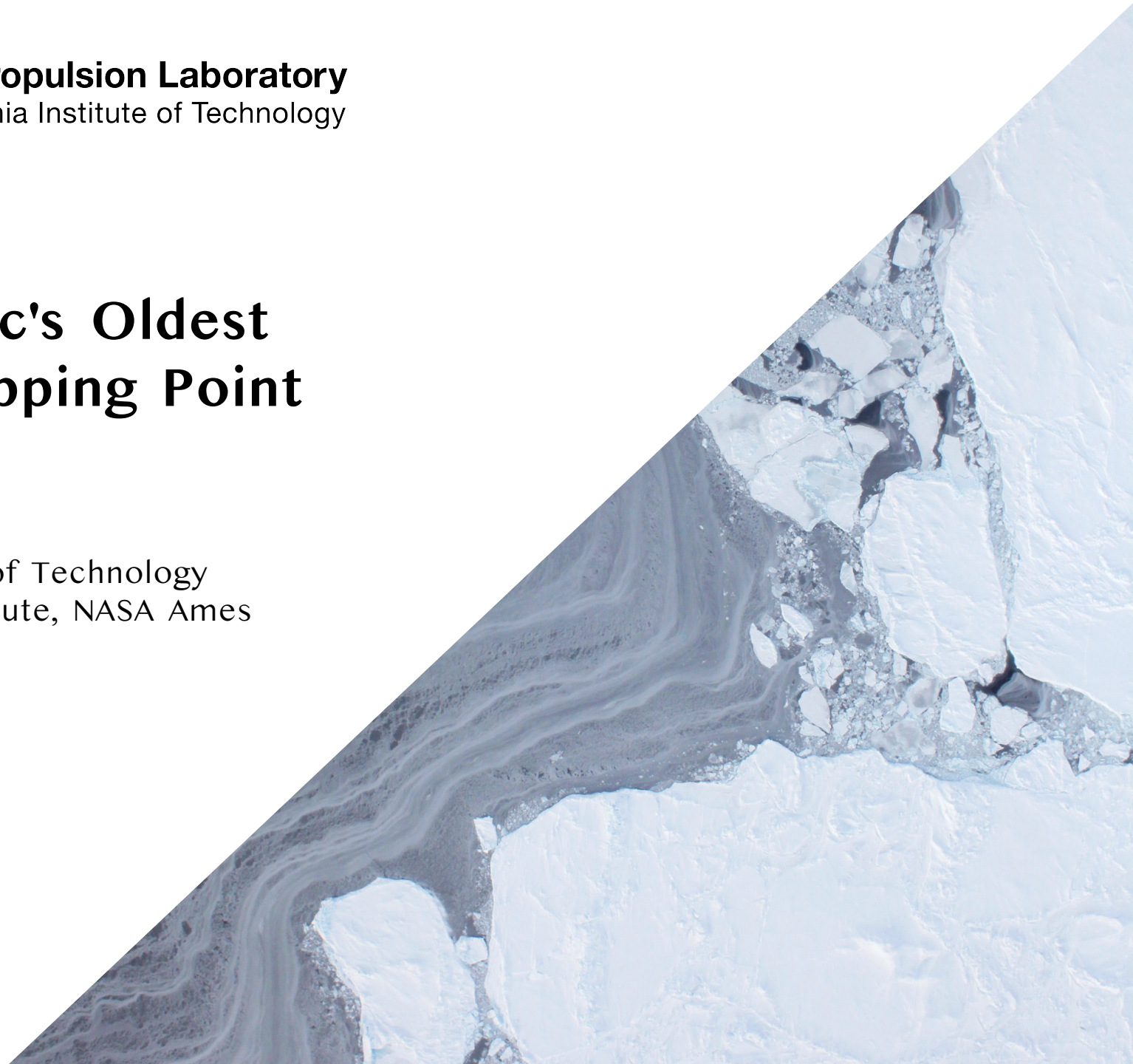


THE DEBATE ON ARCTIC SEA ICE TIPPING POINT

✦ **Arctic sea ice** has been **decreasing** at a rate of **10%** (March) **to 43%** (September) **per year**

✦ Regime shift observed in 2007:
- **September sea ice extent** (SIE) [Livina 2013; Stern 2025]
- **Sea ice thickness** (SIT) [Sumata 2023]
- **Multi-year ice** (MYI) [Babb et 2023]

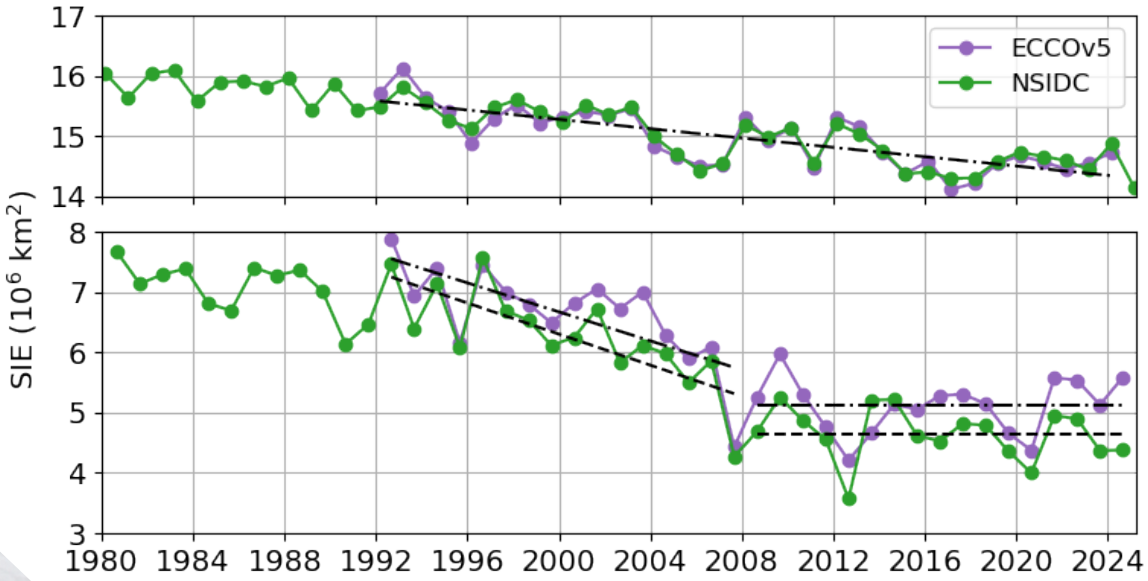
✦ Ongoing **debate** whether Arctic sea-ice is a **tipping element**: Earth system feature for which a **tipping point** might exist

✦ **Definitions:**

- **Tipping point** = "a **critical threshold** beyond which a system reorganizes, often **abruptly** and/or **irreversibly**."
- In the context of **climate change** = non-linear response of the system to increasing temperatures.

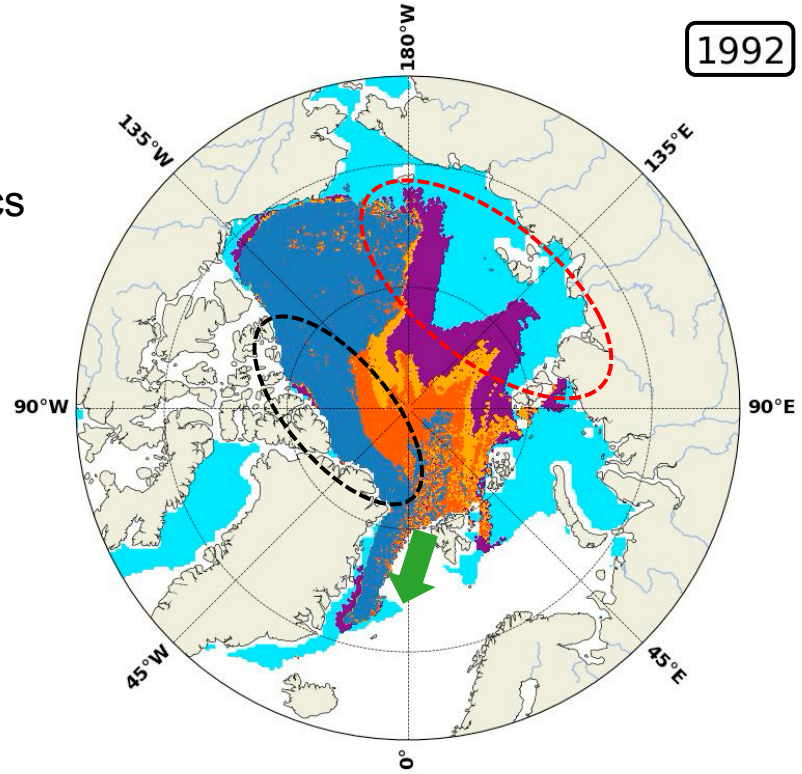
✦ **Problematic:**

- Arctic SIE mirror a state change but doesn't represent the full complexity of the sea-ice system



THE ARCTIC SEA ICE SYSTEM

- **Arctic sea-ice state**:
  - Characterized by sea ice **concentration** and **thickness** (SIC & SIT).
  - **Summer** and **winter** states are intricately related
  - **melting**, **replenishment**, and **export** parameterize the internal dynamics of the system.

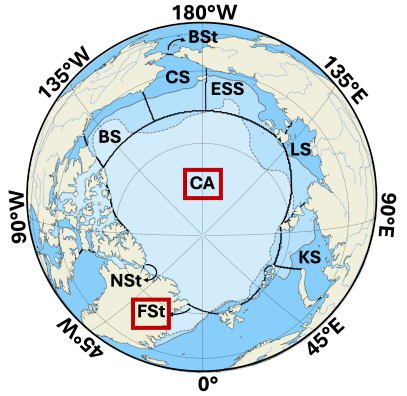


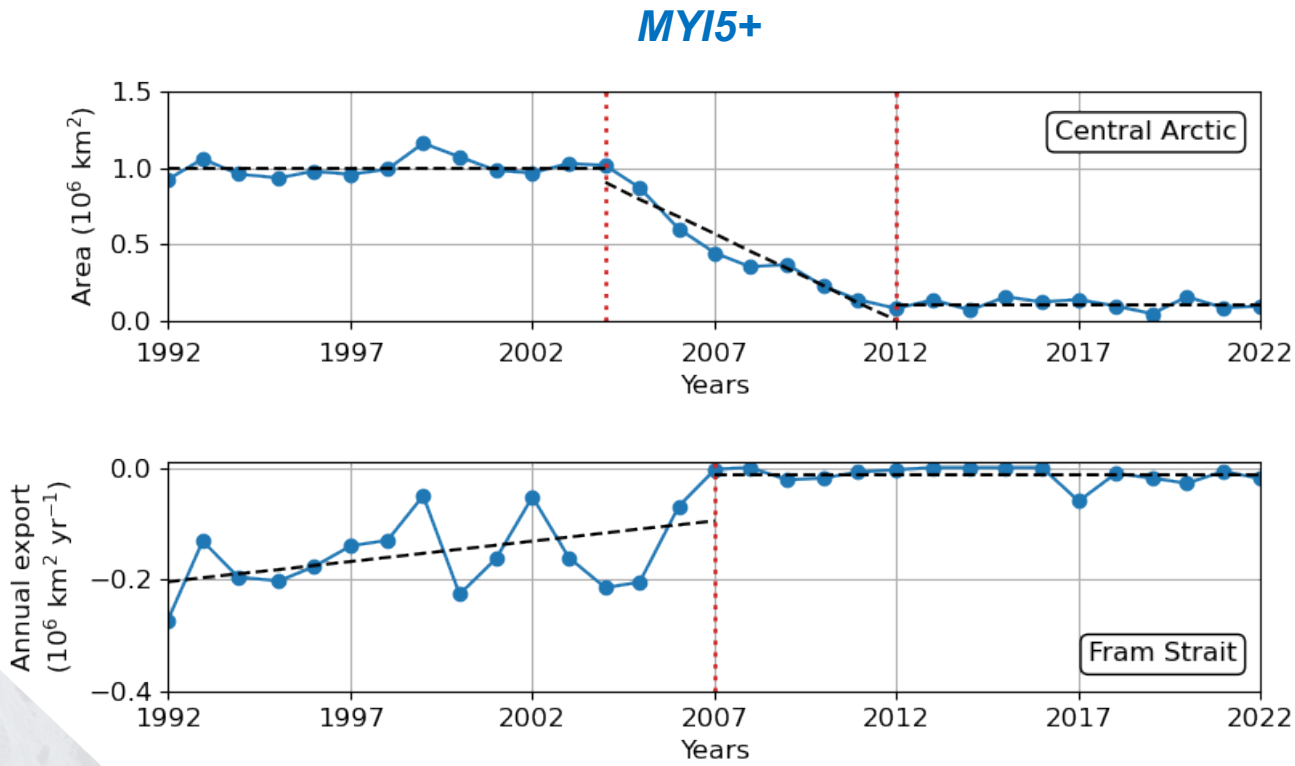
- Complex definition of the Arctic sea ice system.
  - **Hard to test** the tipping point **mathematically** (no single signal)
  - **SIT observations** are **limited in space and time**

- Multi-year ice (MYI) represent a good indicator of the Arctic sea ice system including:
  - **Melting, Replenishment**, **Export** consideration
  - Accounting for the thermodynamic resilience of the ice pack

EVIDENCE OF A TIPPING POINT IN MYI

- Before 2004, MYI older than. 5 yo (MYI5+) represented **42% of MYI pack**
- Central Arctic **lost 96%** of its oldest/thickest ice between 2004 and 2008
- *Concurrently, export of MYI5+ through Fram Strait stopped in 2007.*





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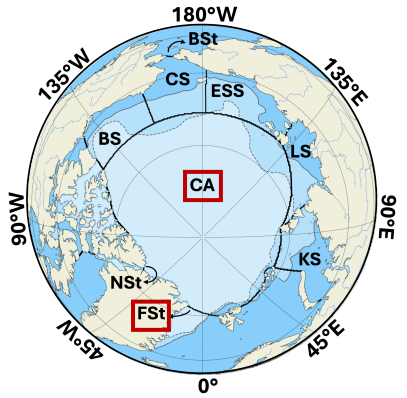

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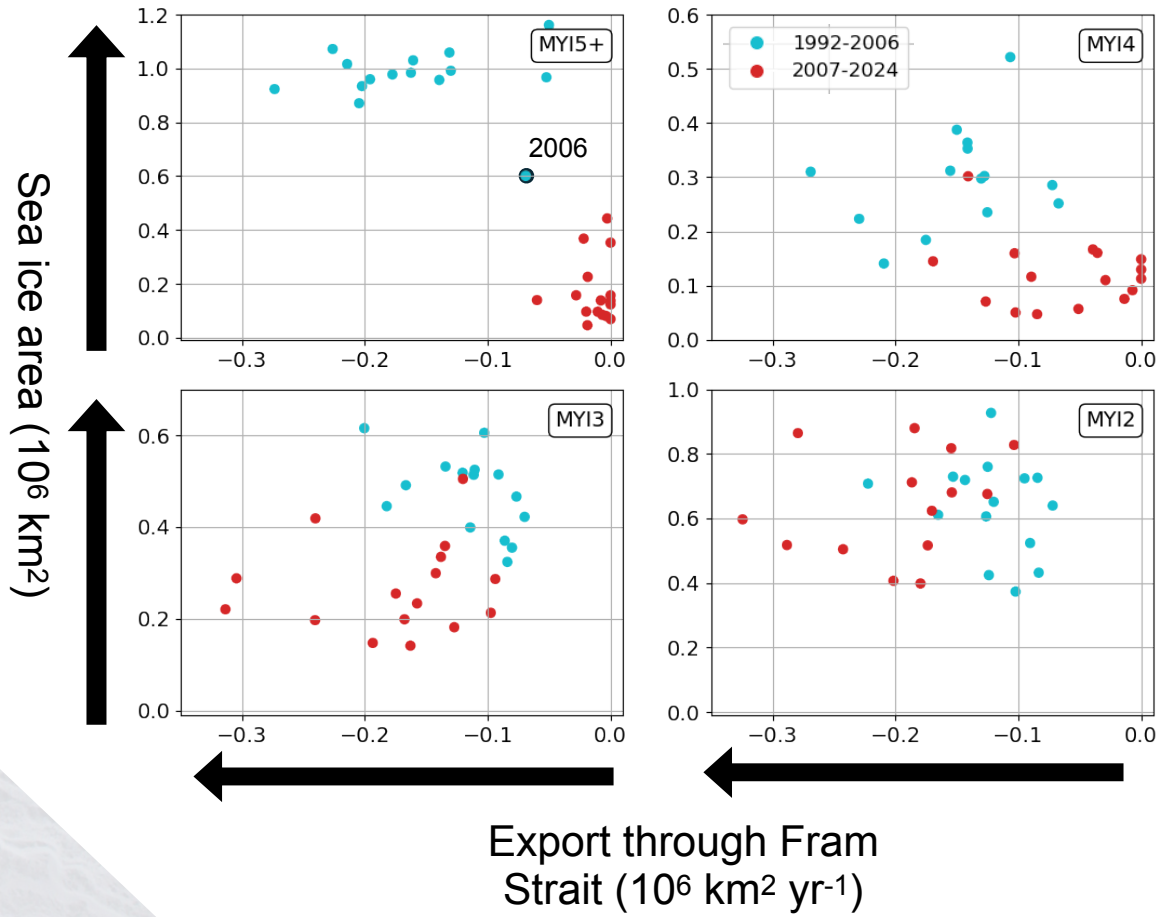
- **Two clear** distinct **states** MYI5+ separated by 2007:
  - Not observed in the other MYI fractions
  - Indicates that **rapid loss of MYI5+** was **caused by exports** through Fram Strait



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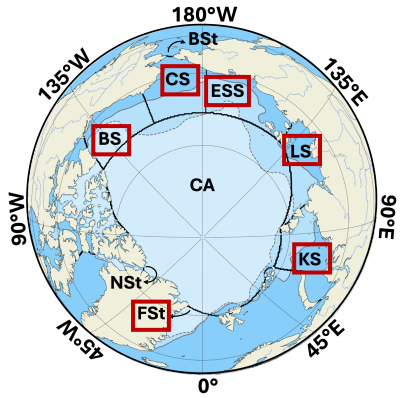

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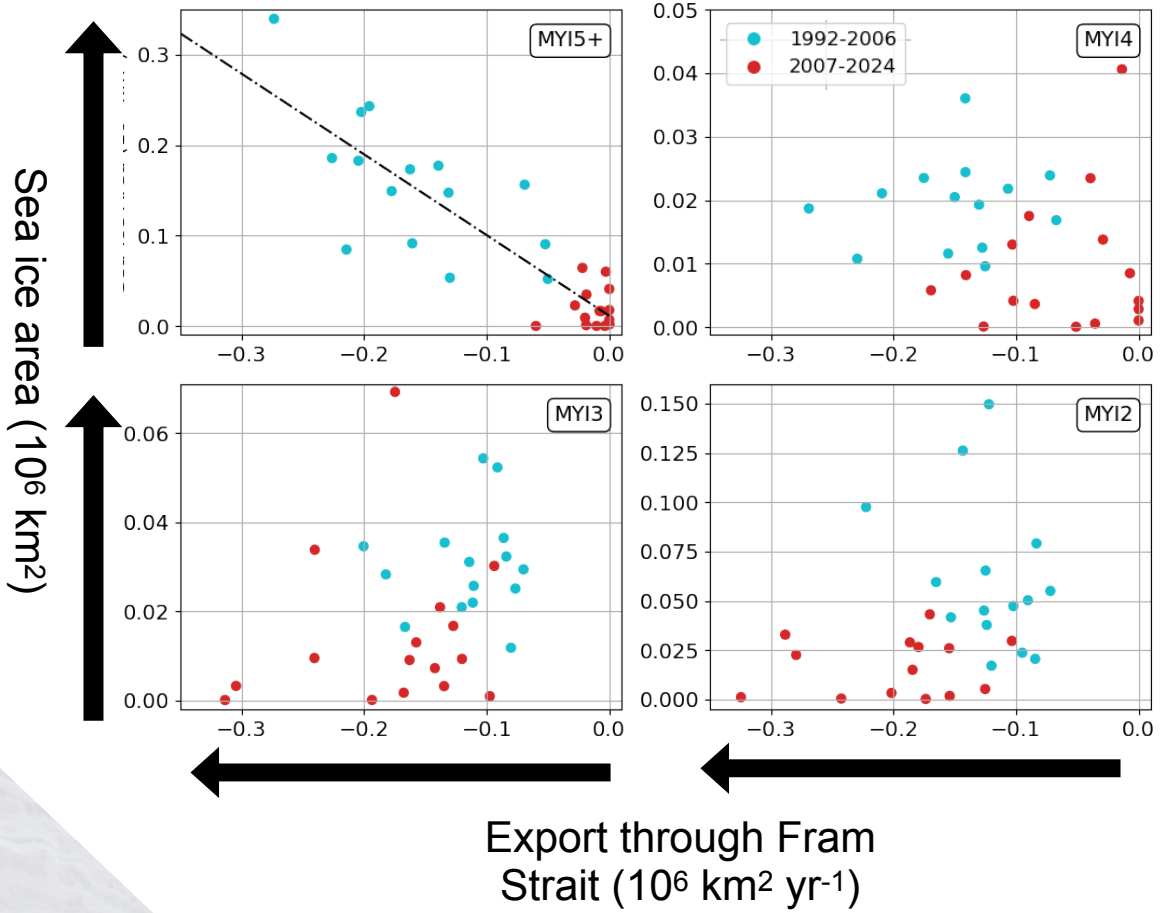
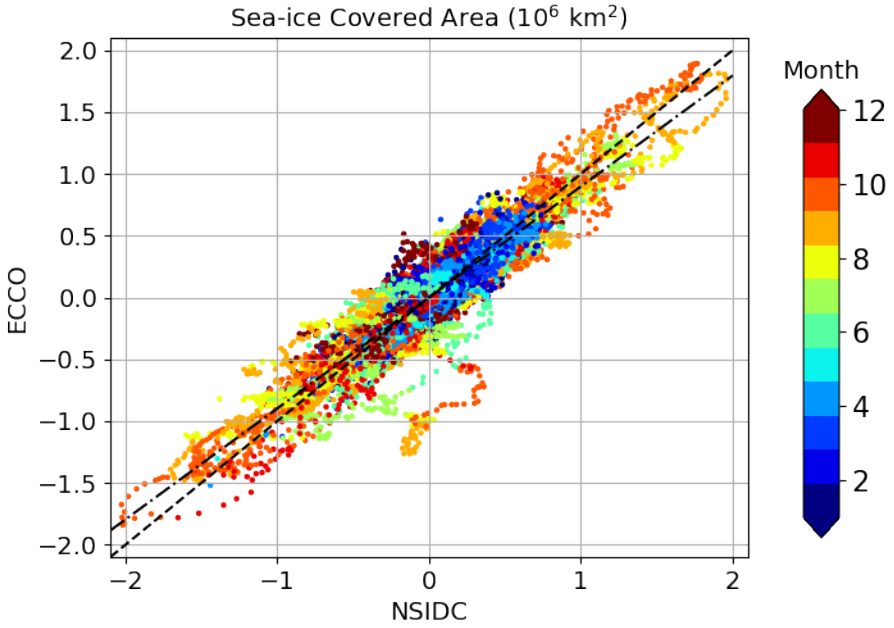
- In the **marginal seas**, a **linear correlation** exist between MYI5+ area and export through Fram Strait
- The dynamic loss of the oldest Arctic sea ice triggered a tipping point:
  - **Abrupt** > fast considering the time scales of the system
  - **Irreversible** > Requires cold conditions, unlikely with the ongoing climate change



REGIONAL RESPONSES TO THE DYNAMIC LOSS

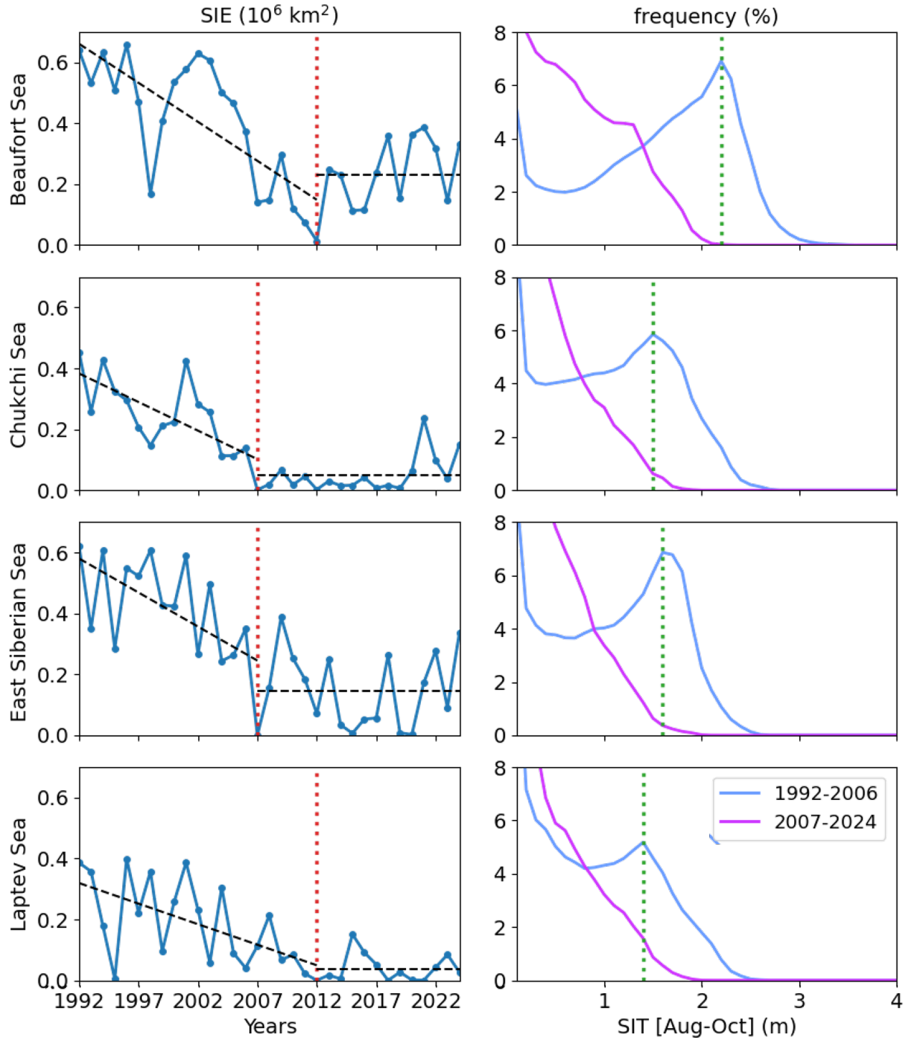
- New **ECCOv5** developments allow for an **accurate representation** of the Arctic sea-ice



REGIONAL RESPONSES TO THE DYNAMIC LOSS

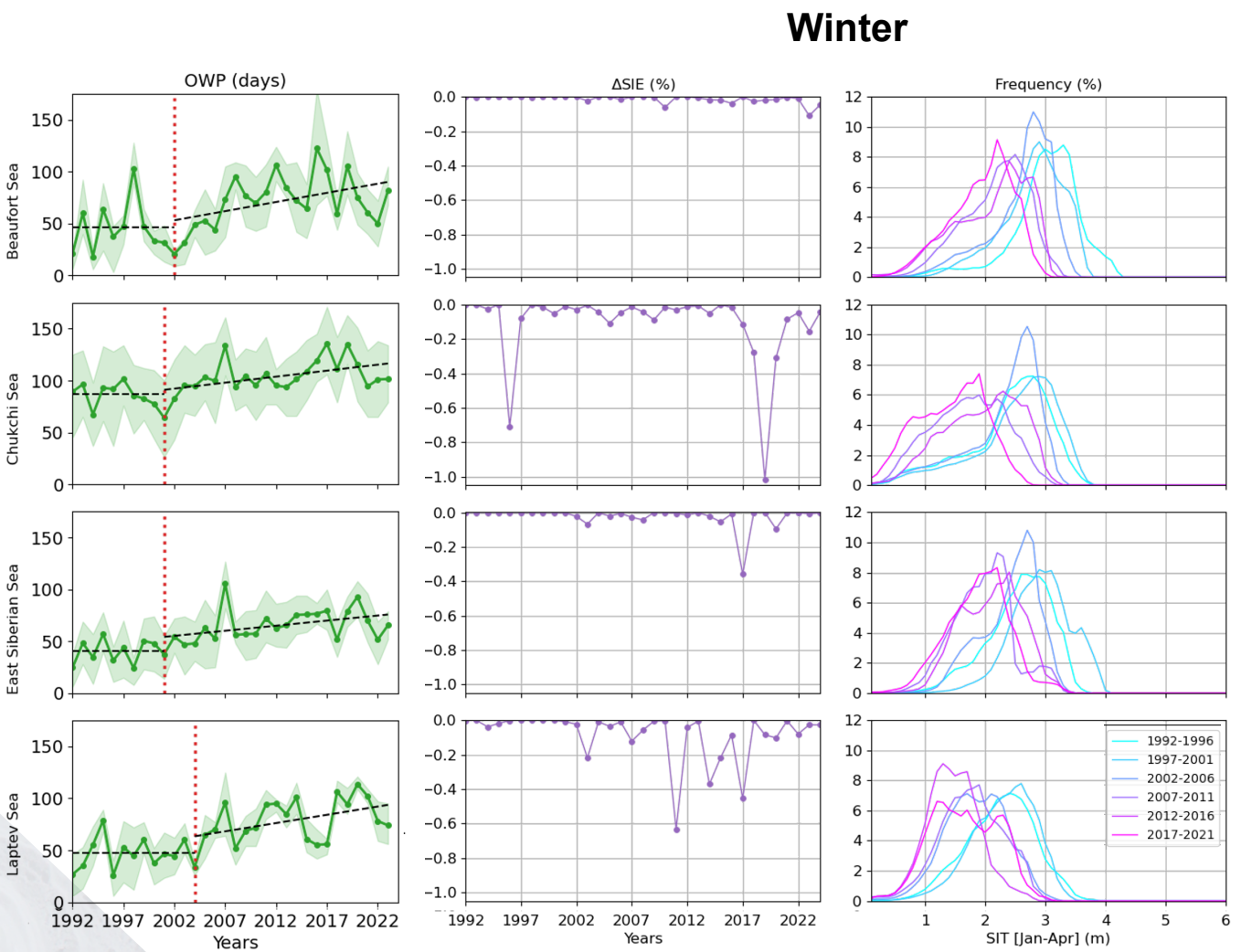
- New **ECCOv5** developments allow for an **accurate representation** of the Arctic sea-ice
- We can study the **regional response** of sea-ice to the dynamic loss of oldest ice.
- In **all** the marginal seas:
  - **SIE decreases** until reaching ~0 km² in 2007 or 2012 > **evolution close to 0** after
    - ↳ concomitant with Marine Heat waves
  - SIT exhibit different distribution:
    - ↳ Before 2007: mix of MYI and first-year ice (FYI)
    - ↳ After 2007: only FYI > seasonally ice-free

Summer



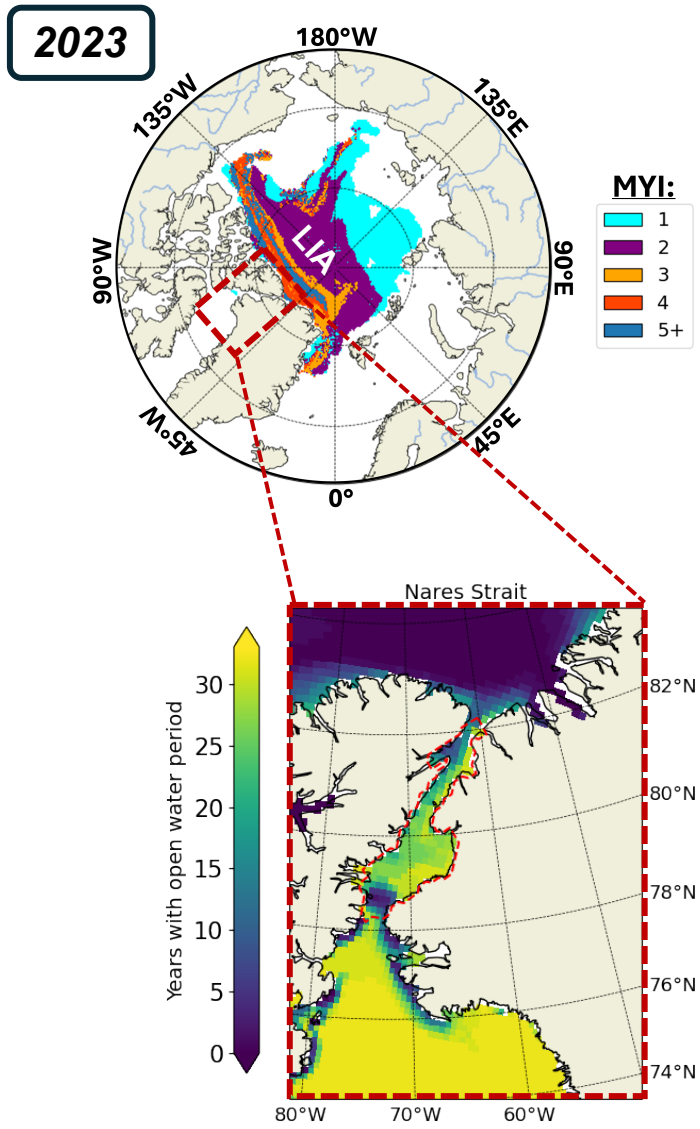
EARLY WARNING INDICATORS OF THE STATE CHANGE

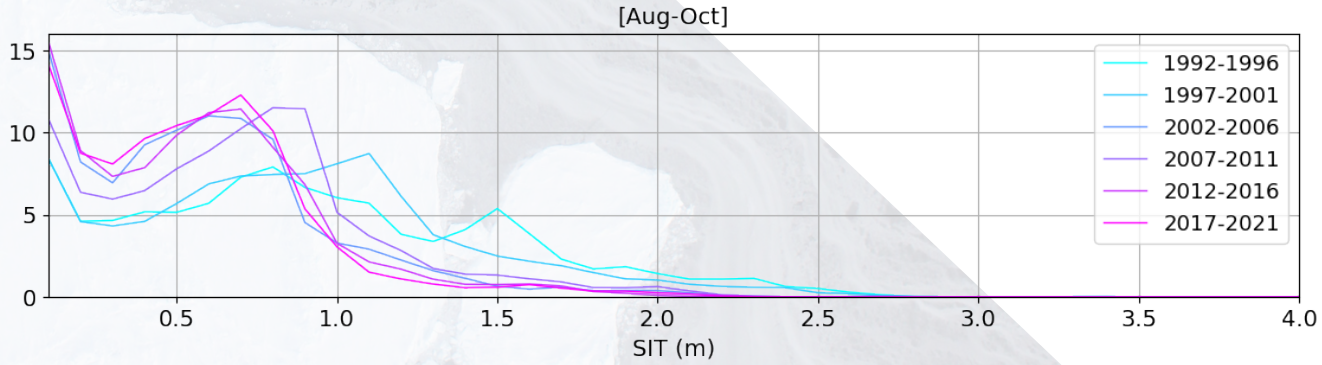
- **Open Water Period** (OWP) = period when SIC <15%
  - Started to increase in 2002 ± 1 year at a rate of 0.98 to 1.94 days per year
- **Maximum** SIE:
  - Started to exhibit regular deviations of less than 1% from complete ice cover
    - ↳ formation of leads
- Winter SIT distribution:
  - Constant decrease from 1992
  - Particular distribution from 2002 to 2006 > transition



EARLY WARNING OF COLLAPSING LAST ICE AREA

- **Loss of MYI** through Fram Strait is now **in balance with replenishment** in the Arctic Ocean [Babb et al. 2023]
- Remaining old ice is packing up in the **last ice area** (LIA)
- Nares Strait:
  - Formation of an **ice bridge** that **blocks old ice exports**
  - **Ice bridge failed** several years since 2007 >> increased exports
- Consistent opening of the ice bridge + SIT decrease in Arctic Archipelago will flush out the MYI in 10 to 20 years.





CONCLUSION

1. **Dynamic loss of oldest ice** (MYI5+) **triggered a tipping point in 2007**: **abrupt** and **irreversible** state change

2. Dynamical and thermodynamical **response in the marginal seas** switching to **seasonally ice-free** regions

3. **Balance** between **MYI loss** and **export** through Fram Strait

} No trend in sea ice loss since 2007

4. **Early warnings** in the early 2000s foreshadowed the incoming tipping point

5. Secular **collapse** in Nares Strait **ice bridge** and opening of the Canadian Archipelago: Early indicator of the **loss of the LIA**

↳ First seasonally ice-free Arctic Ocean in 10 to 20 years

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