Arctic Ocean satellite observing system

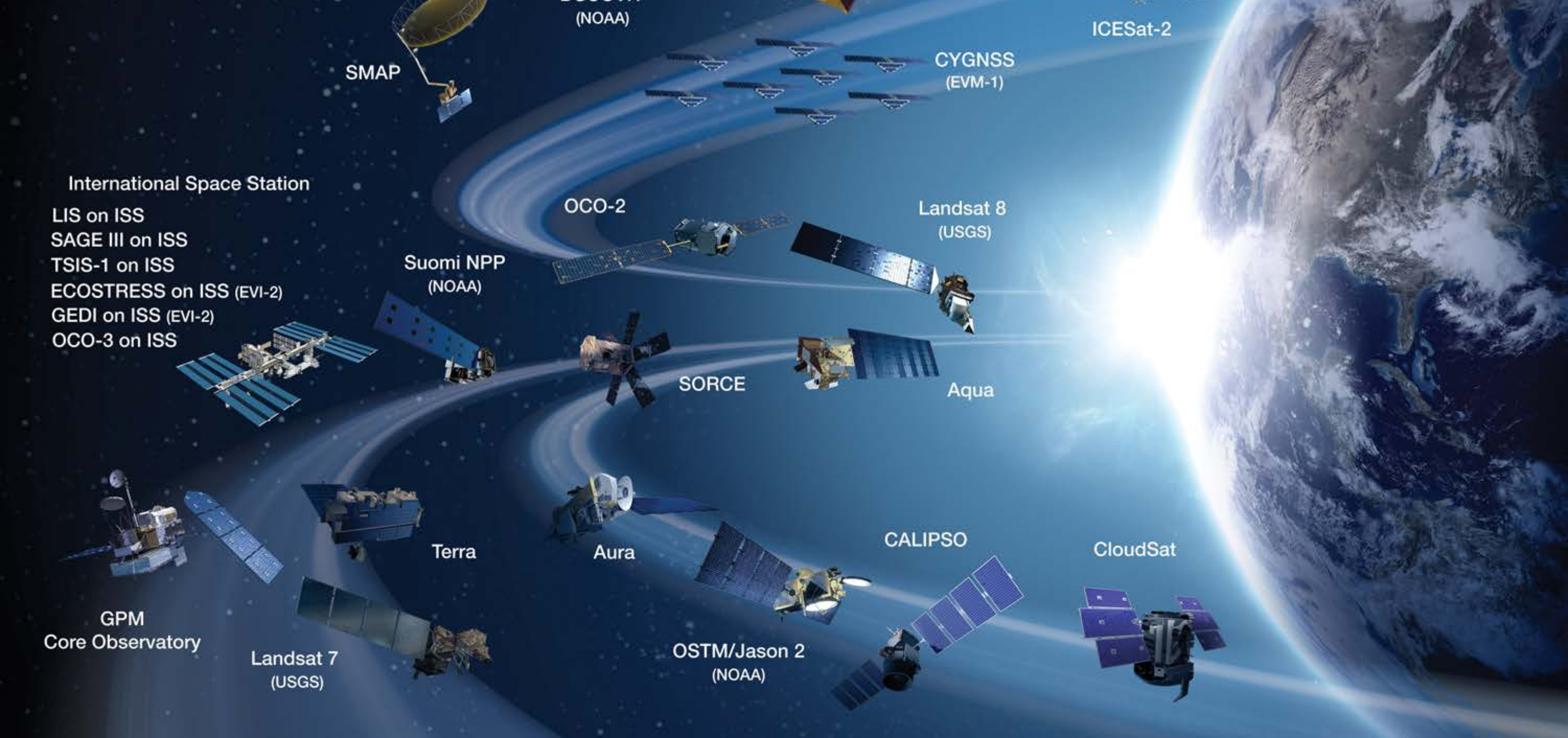
Tom Armitage
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Jet Propulsion Laboratory
California Institute of Technology

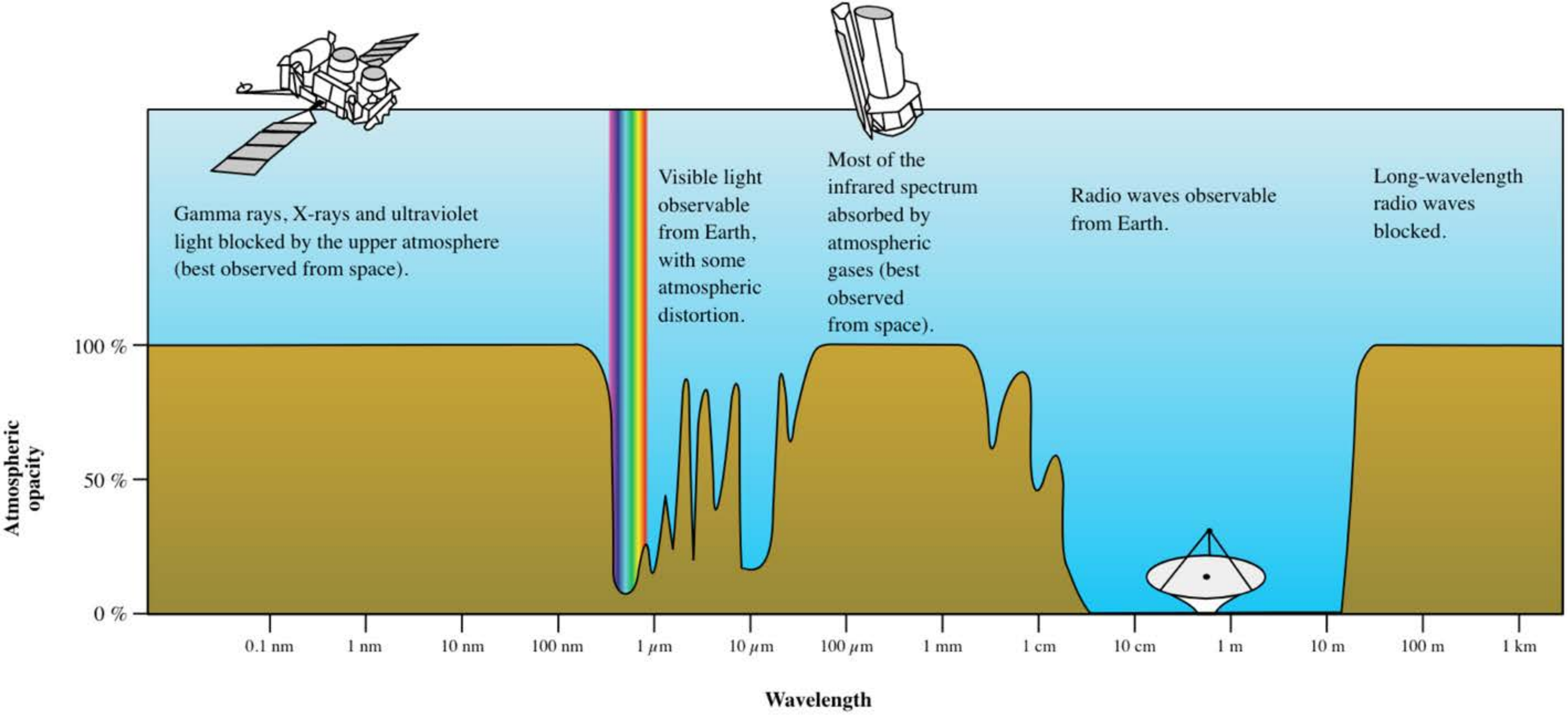
Principles of satellite remote sensing

Photo: Apollo 8

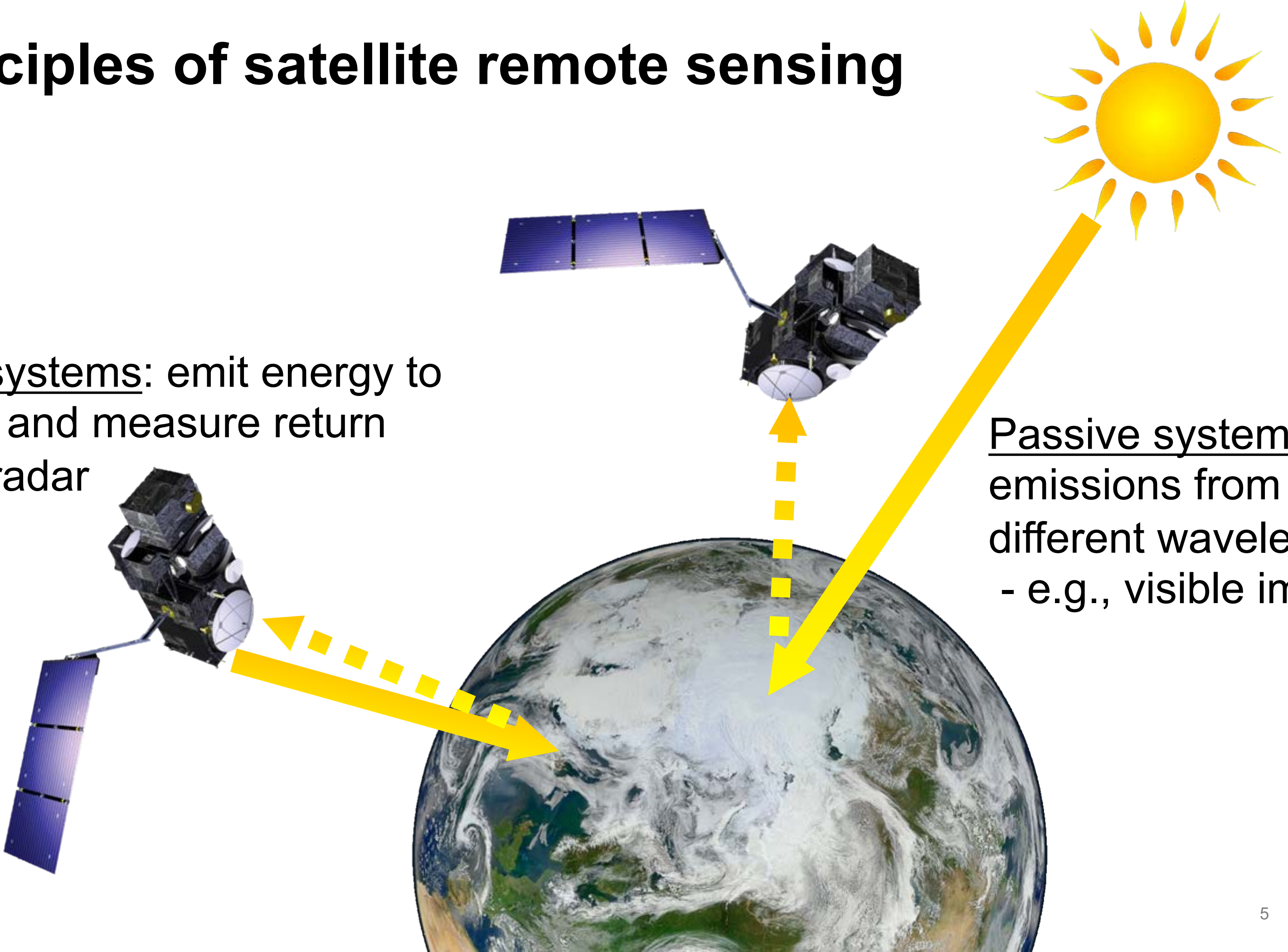
NASAs Earth observation fleet



Principles of satellite remote sensing



Principles of satellite remote sensing

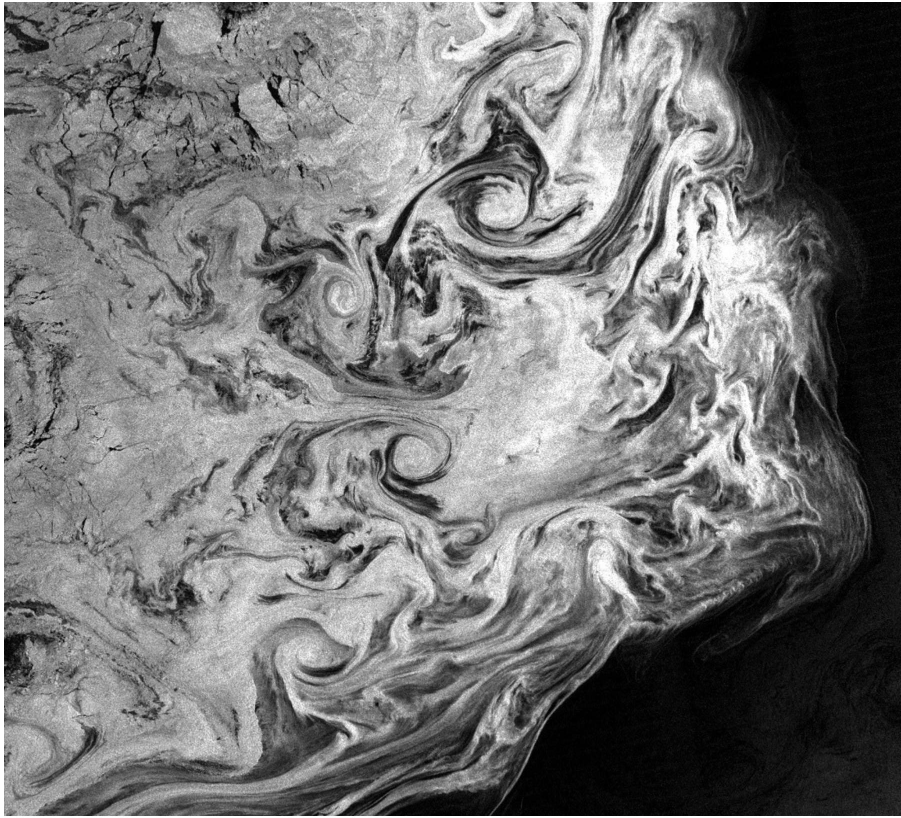


Active systems: emit energy to surface and measure return
- e.g., radar

Passive systems: Measure emissions from the Earth at different wavelengths
- e.g., visible imagery

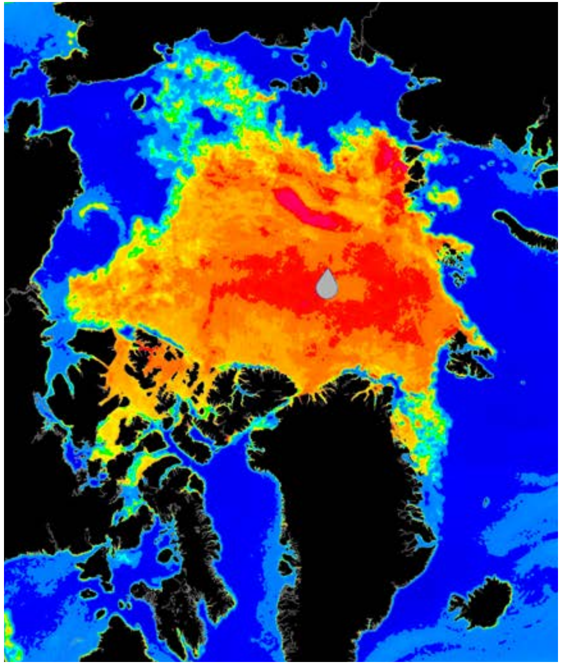
Remote sensing of the Arctic Ocean

- Polar regions are difficult to observe:
  - Harsh climate
  - Expensive to operate
  - Specialized equipment
- Remote sensing has high value-added in polar regions
  - Extensive coverage
  - Frequent repeat
- Highly complimentary to *in situ* measurements

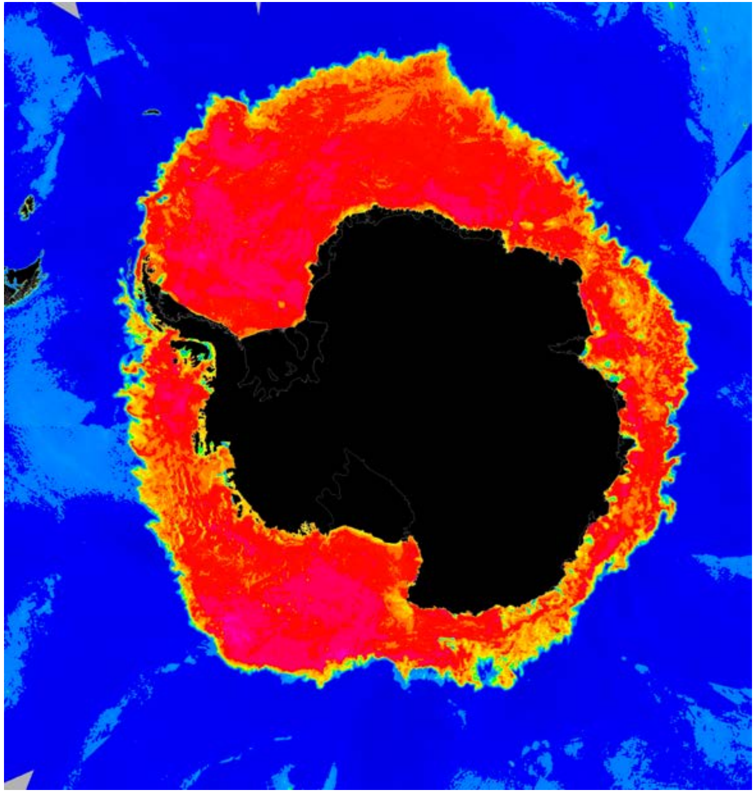


Remote sensing of sea ice

Sea ice extent & concentration



Images: Sea ice Denmark (http://www.seaice.dk/)

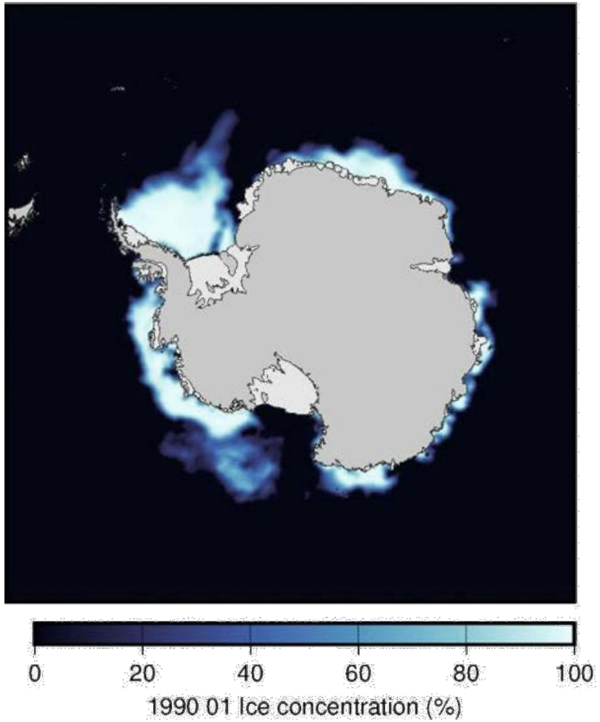


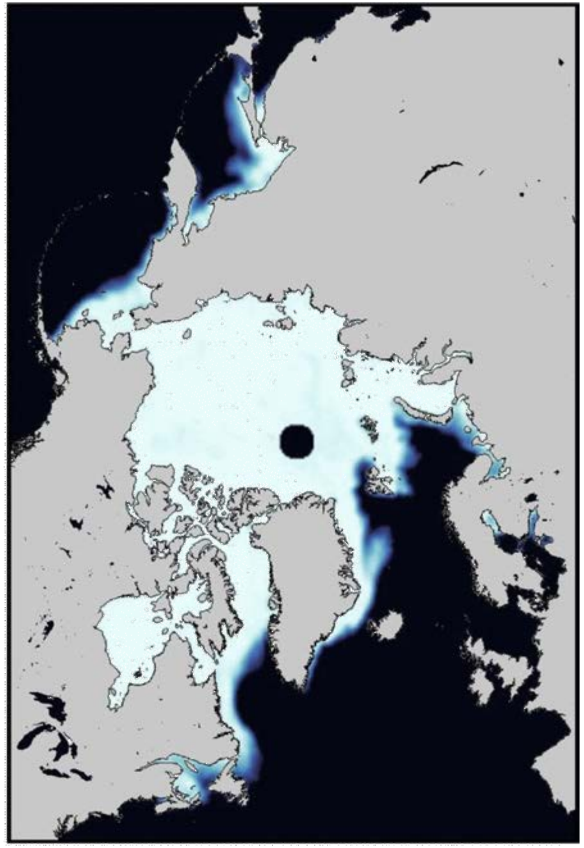
- Retrieved from <u>passive microwave</u> observations
- Sea ice has <u>high contrast</u> with open water

Sea ice extent & concentration

Data: National Snow and Ice Data Center

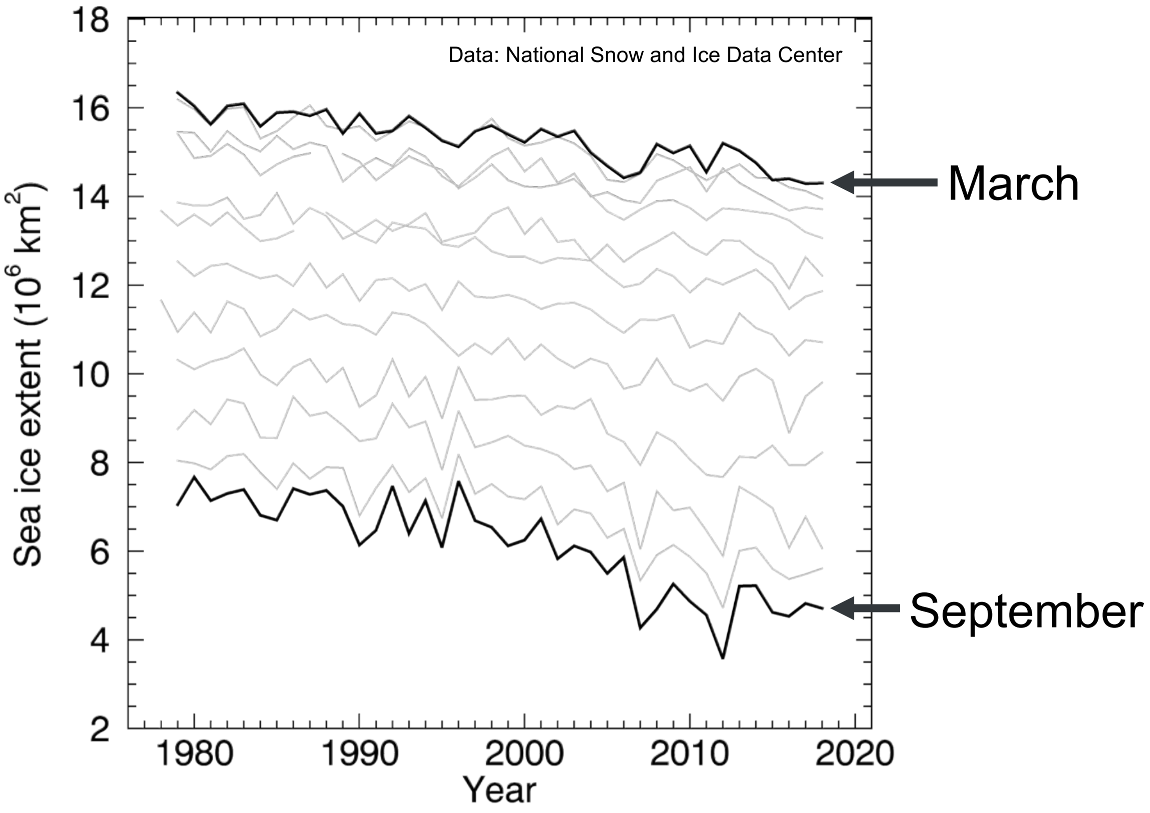
- Daily observations since 1978!





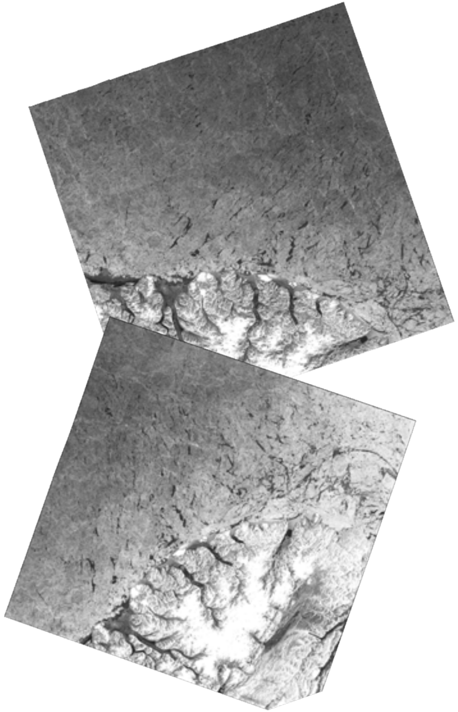
Sea ice extent & concentration

- Arctic sea ice extent is one of the most important climate datasets
  - See the imprint of climate change
  - Have seen the emergence of Arctic amplification

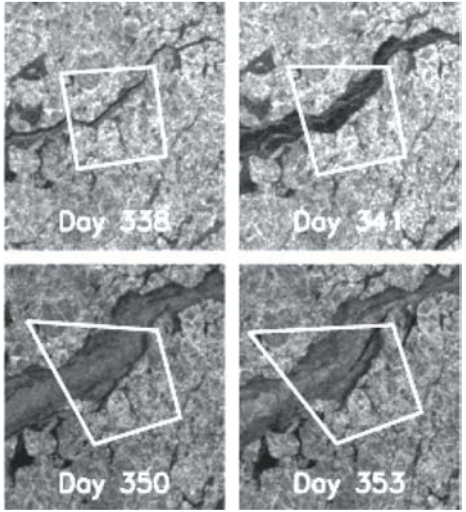


Sea ice motion

- Use repeat imagery (passive microwave or radar) to track parcels of ice
  - Passive microwave: low-resolution, daily since 1978
  - Radar: high-resolution, sporadic coverage

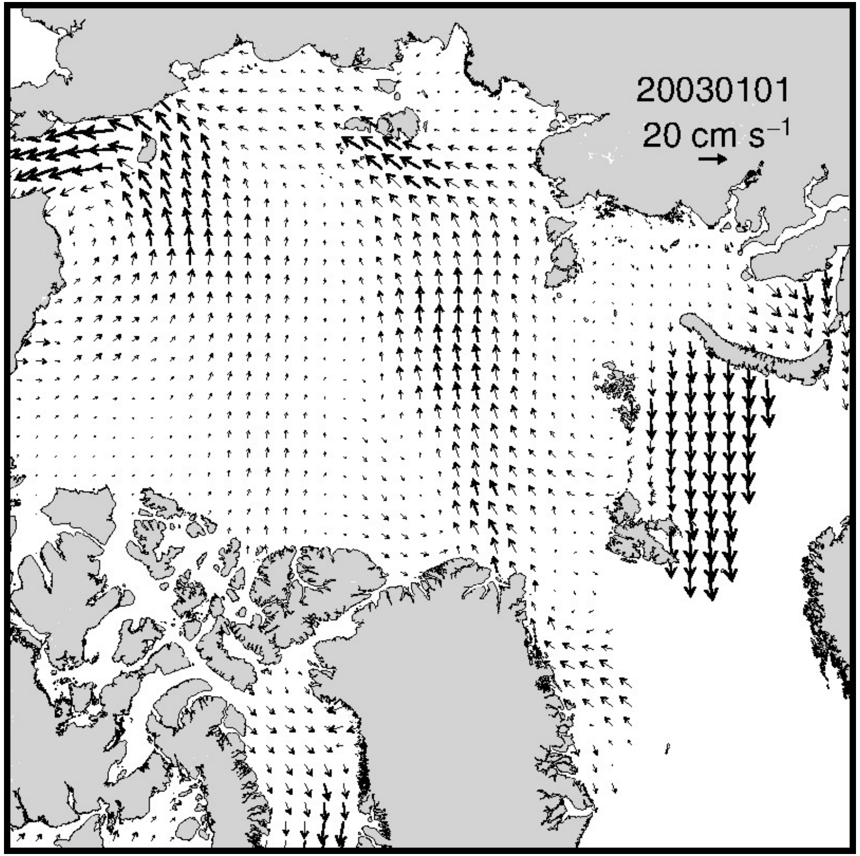


Separation: ± ~1 day



Sea ice motion

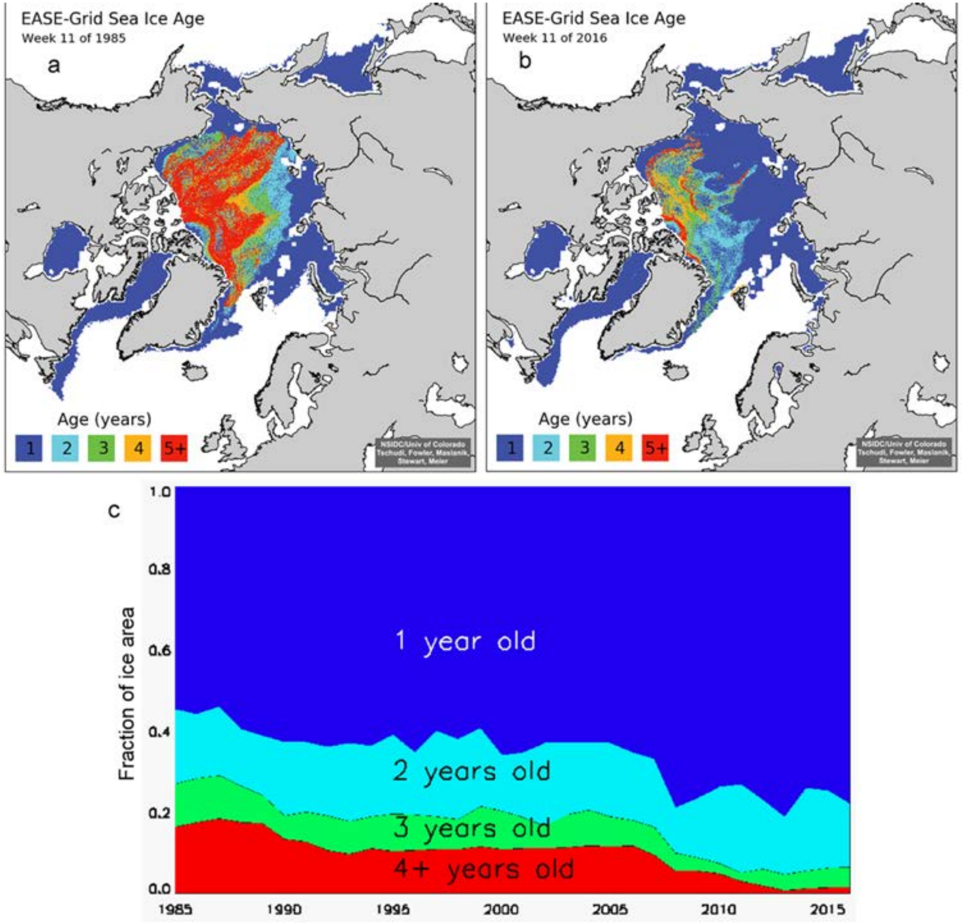
- Motion driven by wind
- See areas of convergence and divergence
  - Drives sea ice deformation
- Sea ice has weakened and sped up in recent decades



Sea ice age

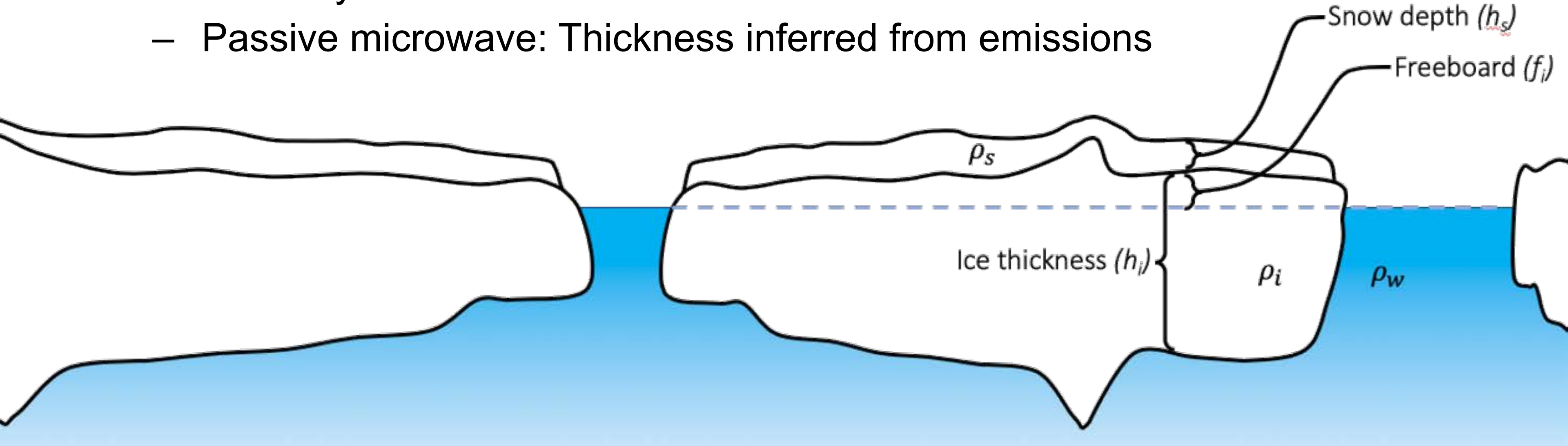
- By tracking ice parcels over many years can determine ice age
- In the 1980s the Arctic was full of old ice (5+ years)
- Today it is nearly all gone

Image: NOAA



Sea ice thickness

- Important for climate:
  - Total ice volume, heat & freshwater fluxes, ice strength
- Two measurement techniques
  - Altimetry: Thickness inferred from freeboard
  - Passive microwave: Thickness inferred from emissions



Sea ice thickness

- Altimetry
  - Relative error is small for thicker sea ice (>1m)
- Passive microwave
  - Relative error is small for thinner sea ice (<0.5m)
- Combined data gives better picture of the full ice thickness distribution

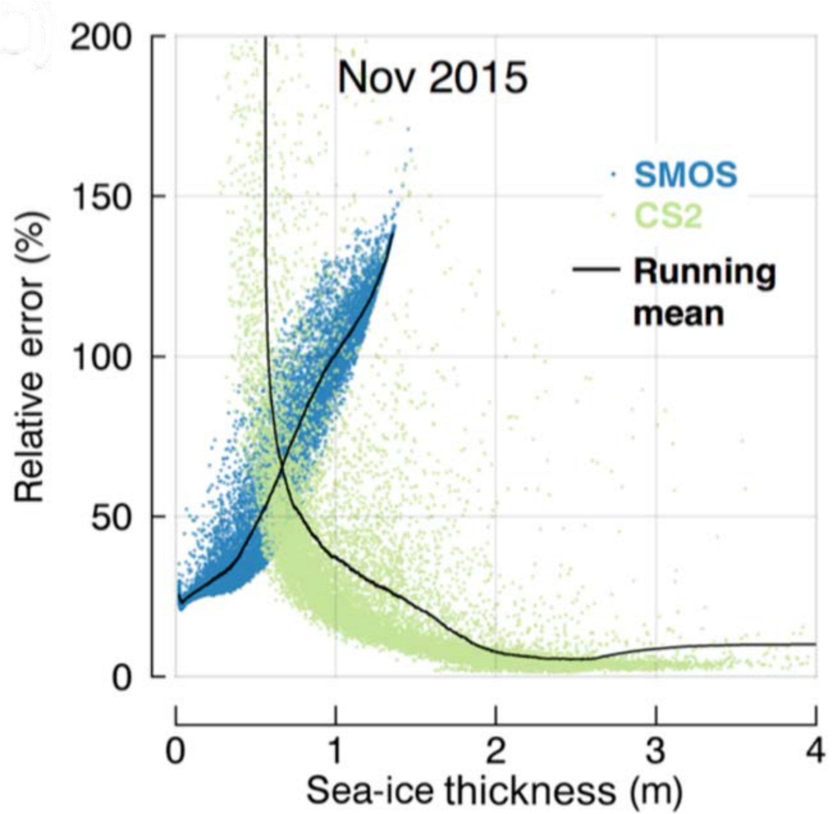
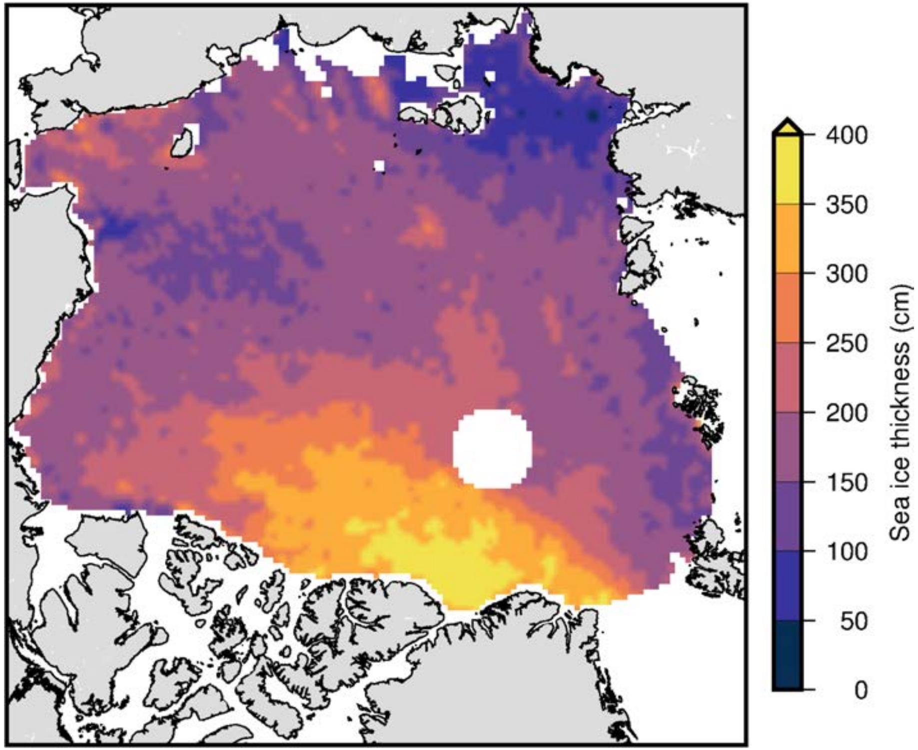
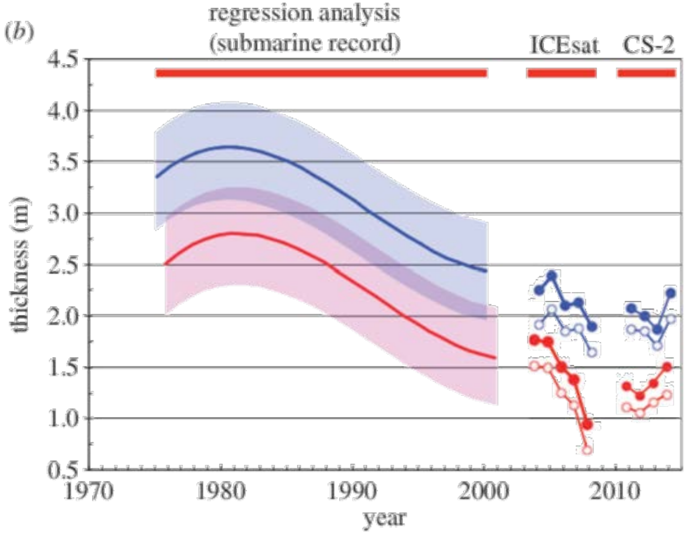


Image: Ricker et al. (2017), *The Cryosphere*, DOI: 10.5194/tc-11-1607-2017

Sea ice thickness

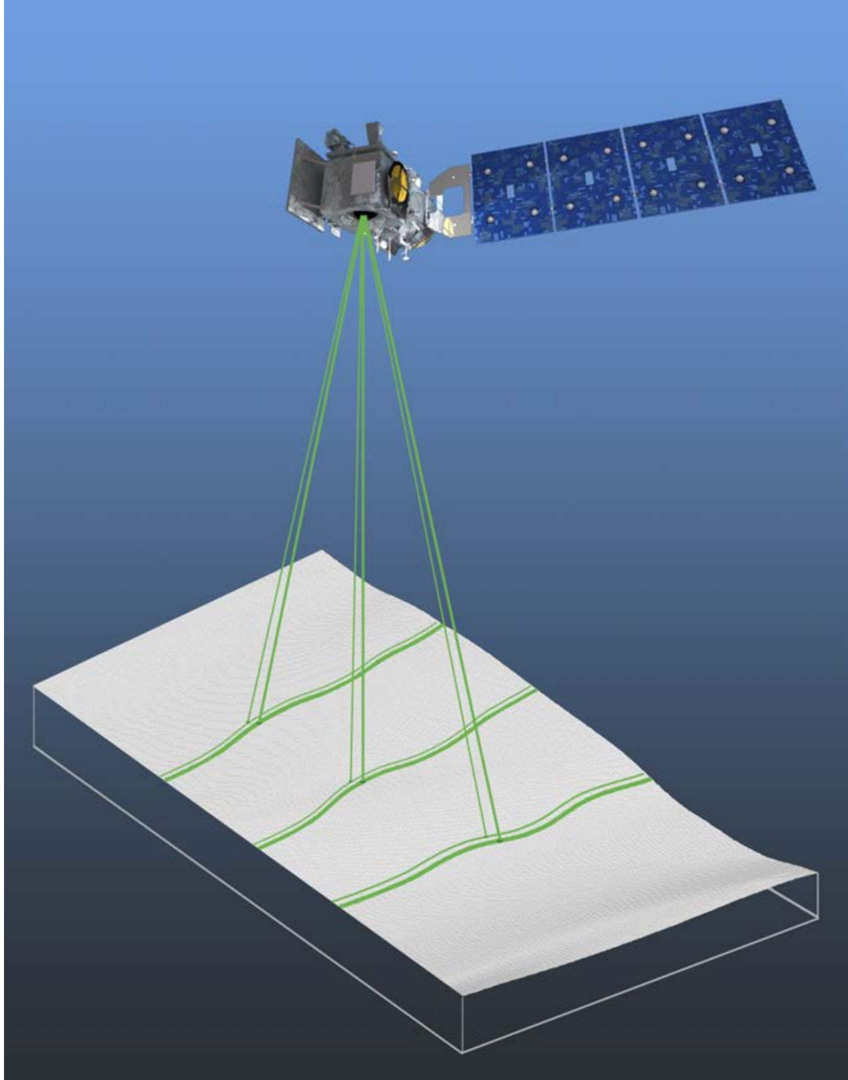


- Typical sea ice thickness distribution in winter
  - Driven by ice convergence along Greenland/Canada



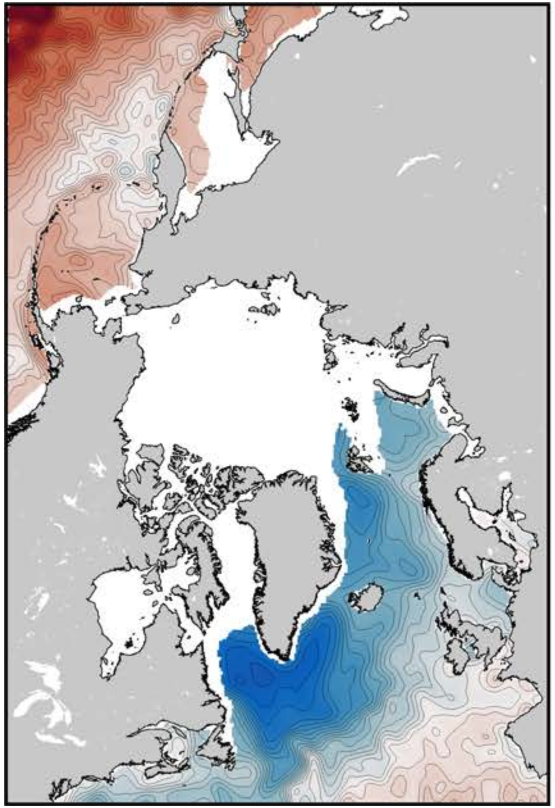
ICESat-2 (2018—)

- Lidar altimetry
- High resolution sea ice thickness and sea level measurements



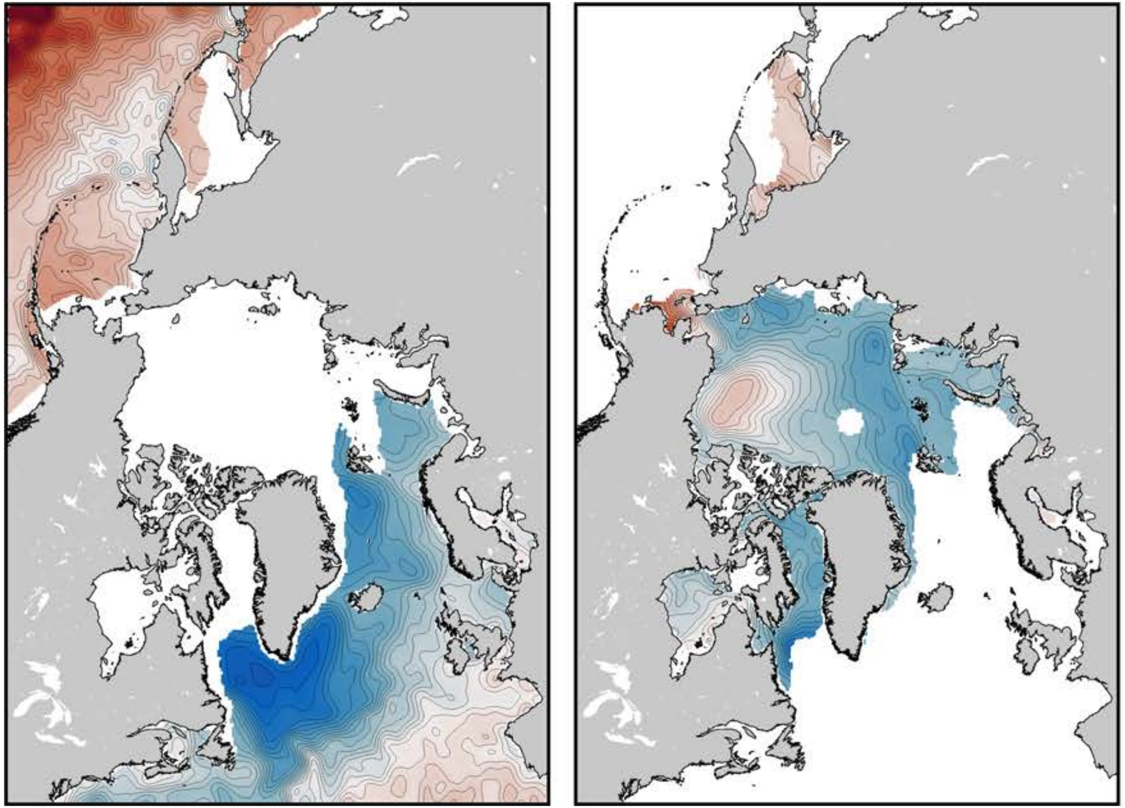
Remote sensing of the Arctic Ocean

Sea level and circulation



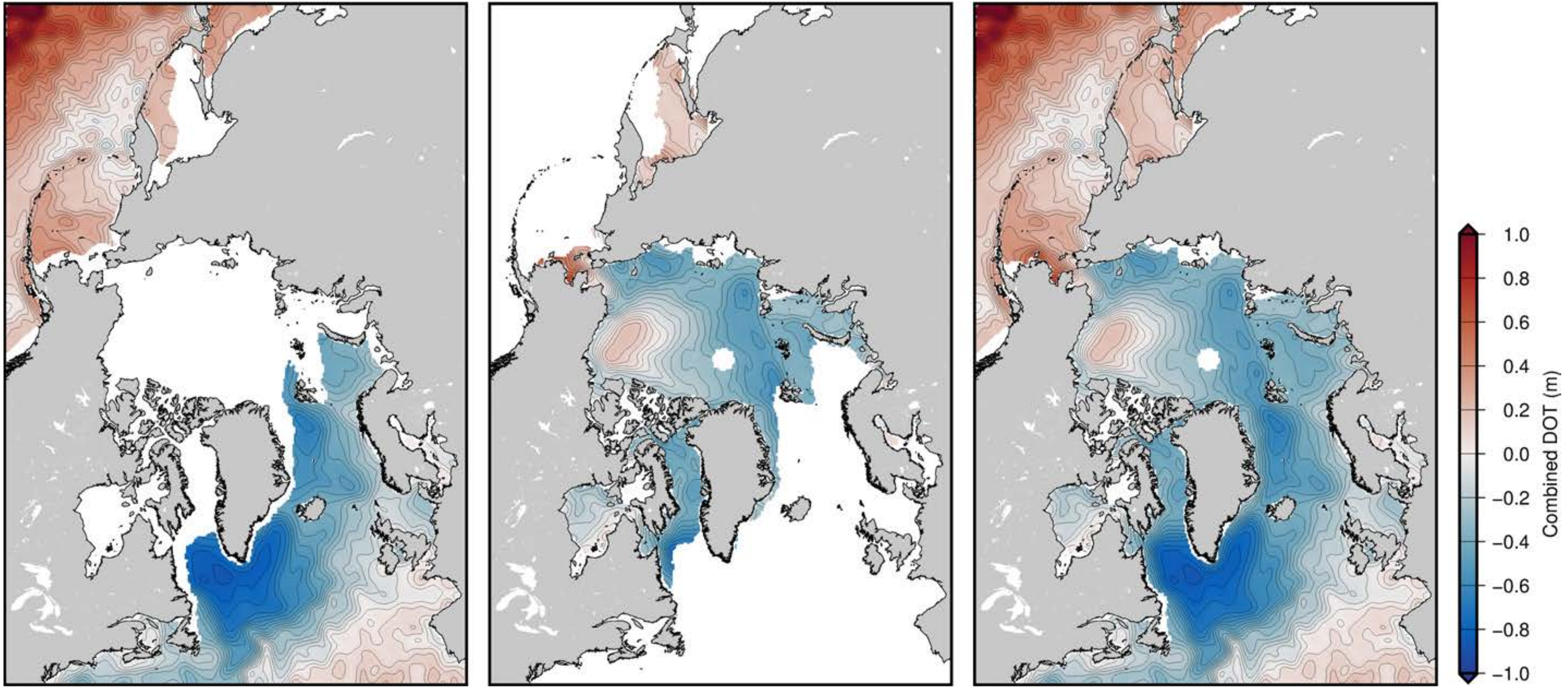
Altimeters are adept at measuring sea level in the open ocean

Sea level and circulation



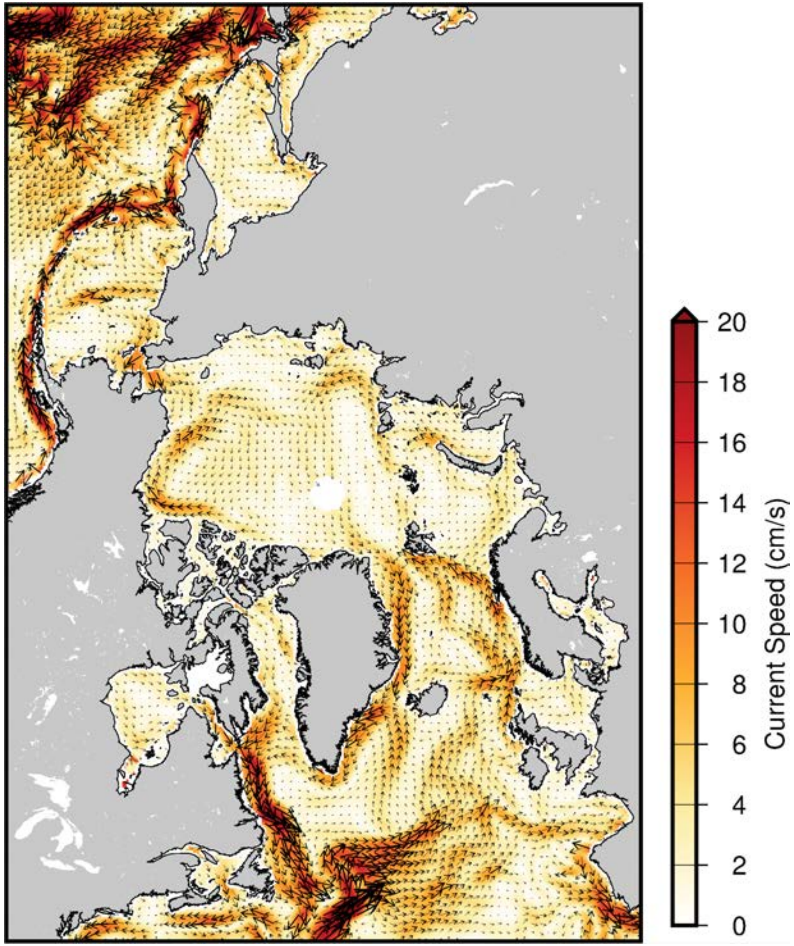
Get sea level ‘under’ the sea ice using specialized processing

Sea level and circulation



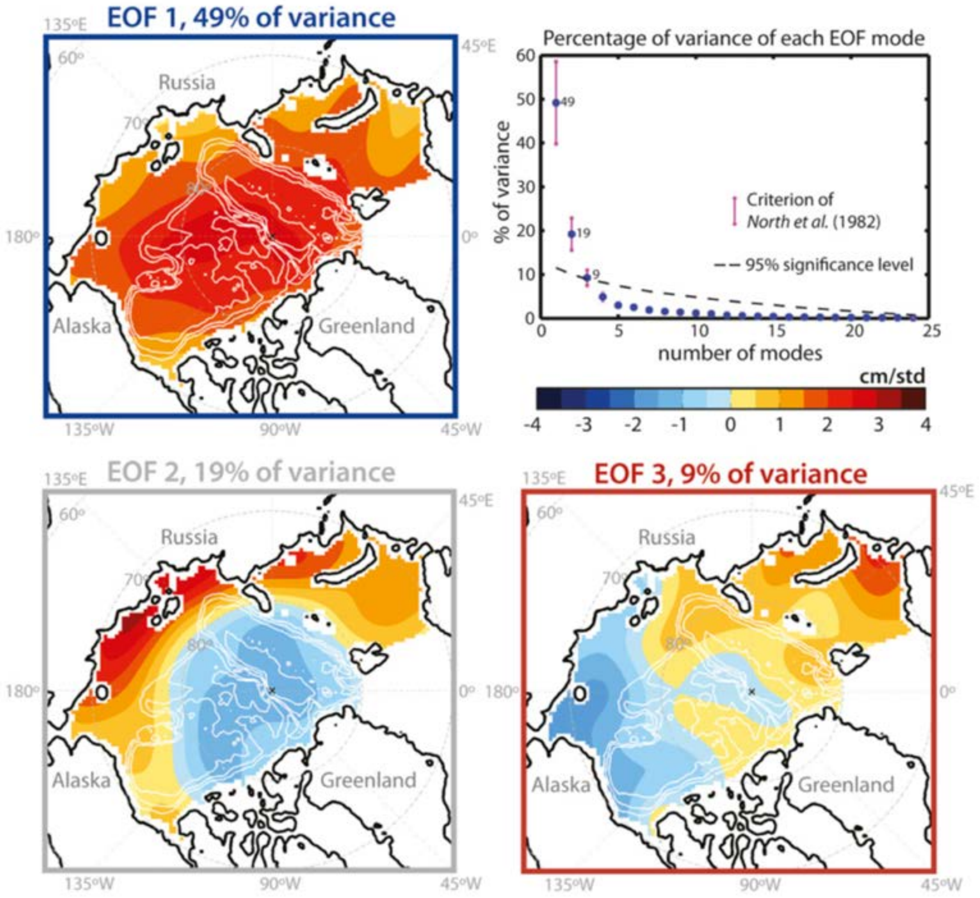
Sea level and circulation

- Sea level is related to upper ocean currents
  - Currents proportional to sea level slope



Gravimetry

- GRACE has been ‘weighing’ the ocean since 2002
- Globally reflects increased sea level due to increased terrestrial water input
- Locally reflects (barotropic) redistribution by wind
- Reveals Arctic Ocean response to climate variability (Arctic Oscillation)



Sea surface salinity

- SSS drives ocean density changes in the Arctic Ocean
  - Gradients drive circulation & mixing
  - Salinity maintains Arctic stratification
- Important biogeochemical tracer
- Linked to freshwater cycle

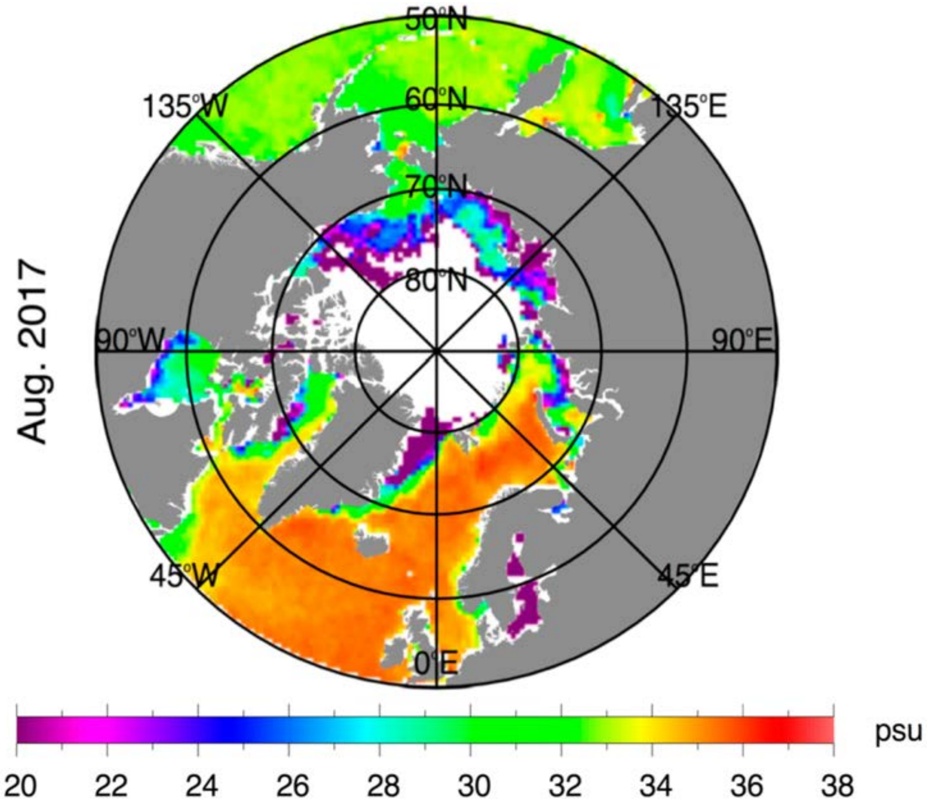


Figure: Tang et al. (2018), *Remote Sensing*, DOI: 10.3390/rs10060869

Sea surface salinity

- Monitored globally by L-band passive microwave emissions
- Higher uncertainty in polar oceans due to:
  - Lower sensitivity at cold temperatures
  - Narrow bandwidth
  - Less in situ validation data
- Future missions may address these issues

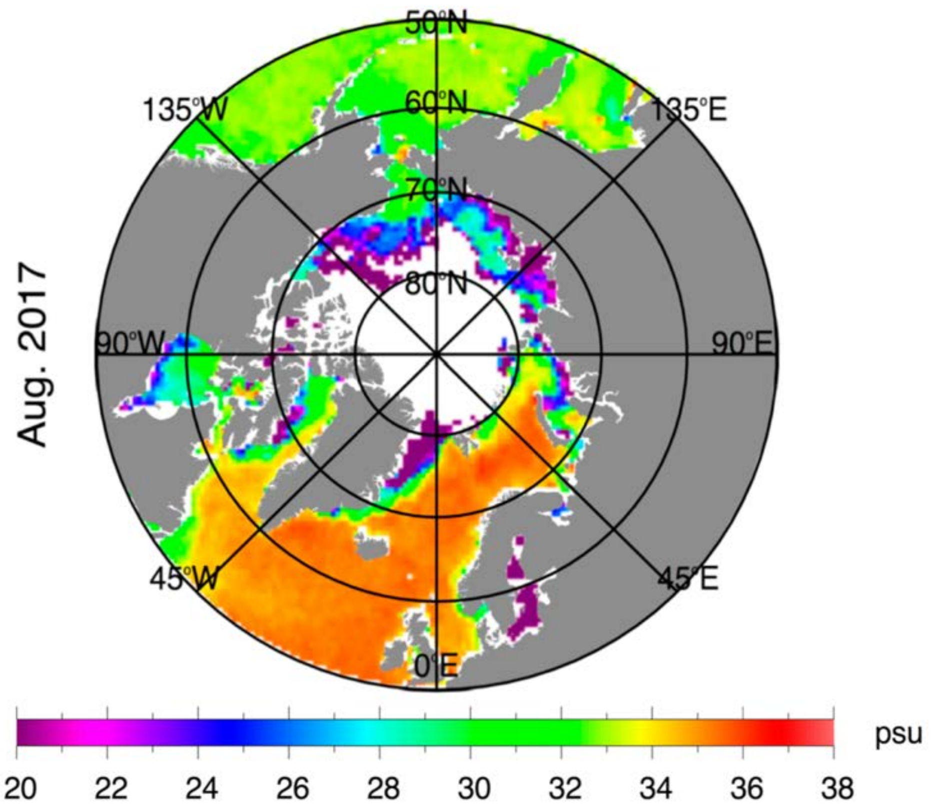


Figure: Tang et al. (2018), *Remote Sensing*, DOI: 10.3390/rs10060869

Sea surface temperature

- Important for air-sea fluxes
  - Heat
  - Moisture
  - Momentum
  - CO_2
- In Arctic can monitor intrusion of warm Atlantic/Pacific/river water
- Monitored by infrared and passive microwave instruments

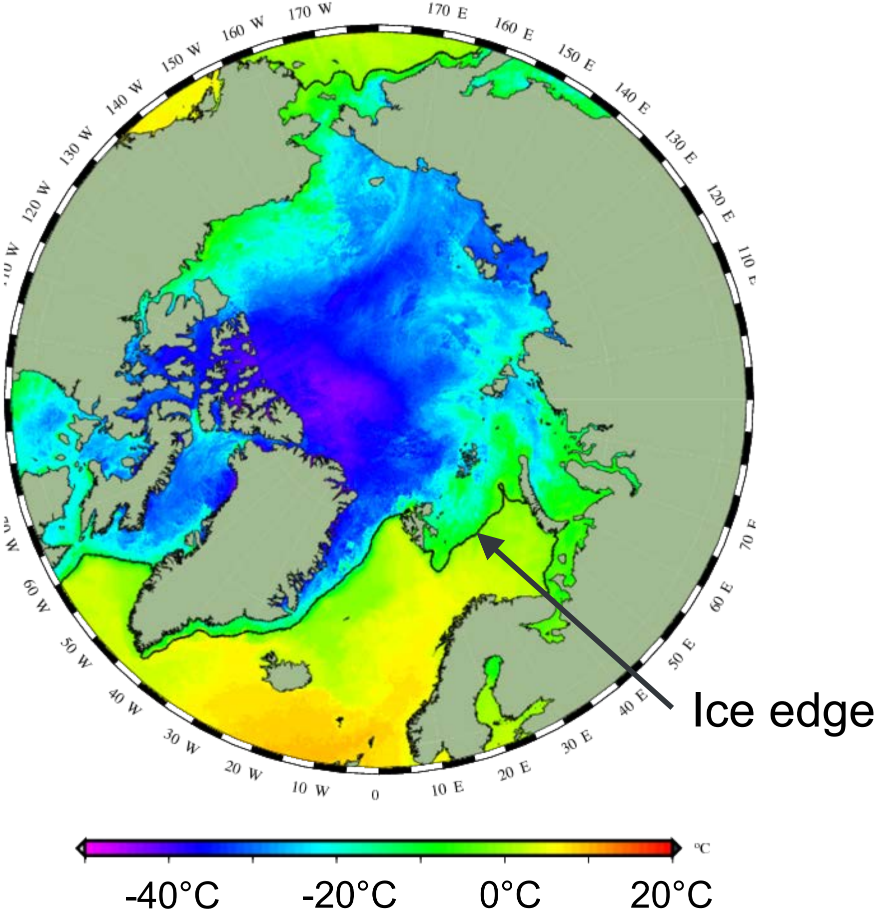
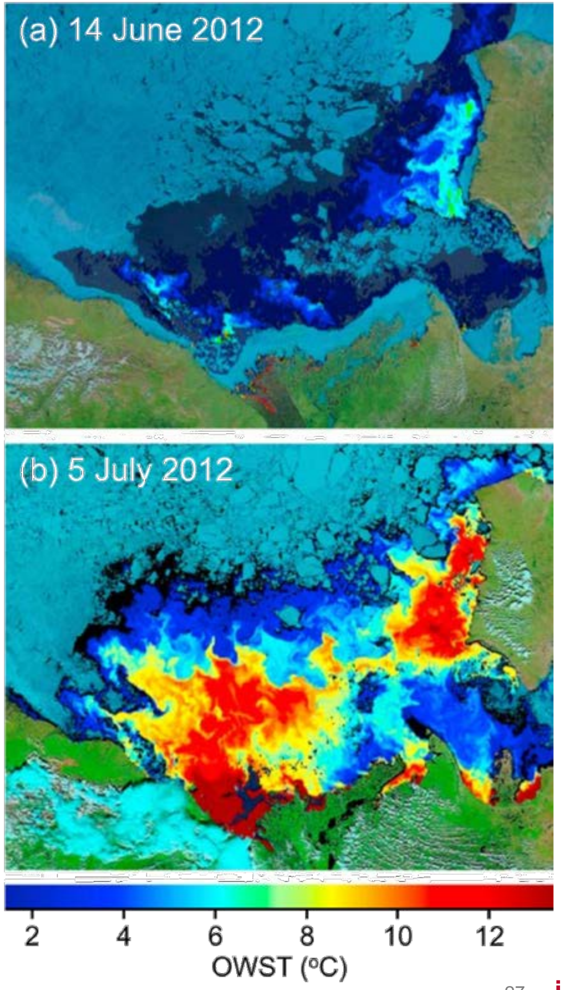


Image: Polar Portal (www.polarportal.dk)

Nghiem et al. (2014, *Geophys. Res. Lett.*, doi:10.1002/ 2013GL058956.

Sea surface temperature

- Important for air-sea fluxes
  - Heat
  - Moisture
  - Momentum
  - CO_2
- In Arctic can monitor intrusion of warm Atlantic/Pacific/river water
- Monitored by infrared and passive microwave instruments

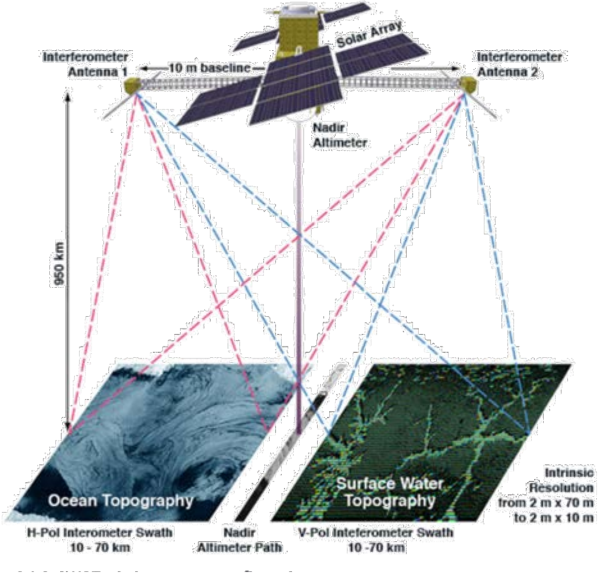


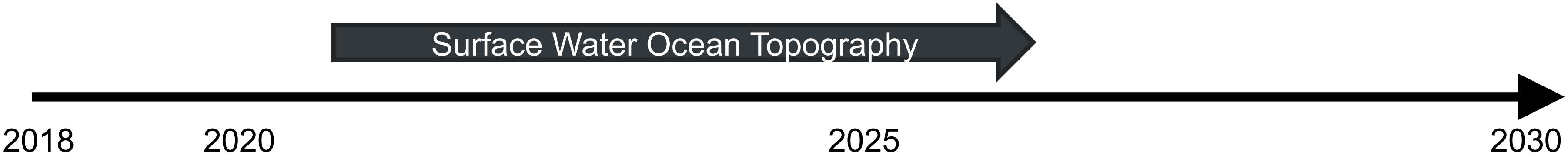
Upcoming & proposed missions

Upcoming missions

SWOT (launch 2021)

- NASA-JPL/French & UK Space Agencies
- Swath altimetry
  - 2-D ice thickness, sea level & currents

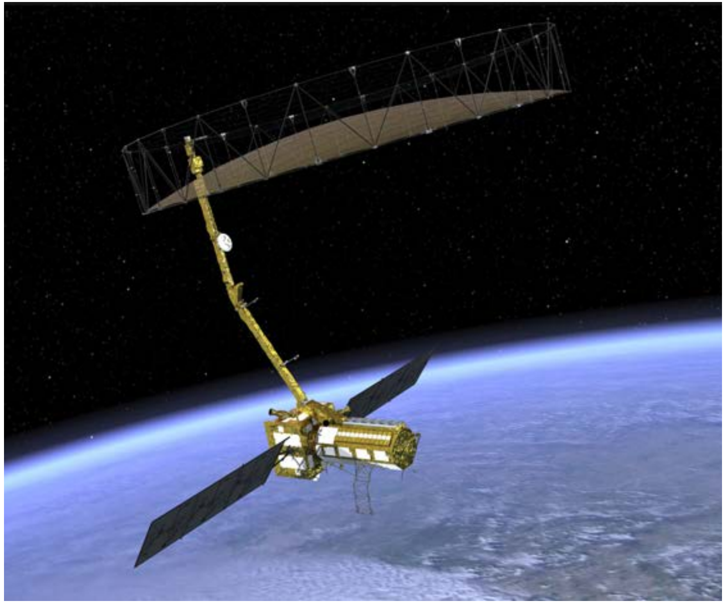


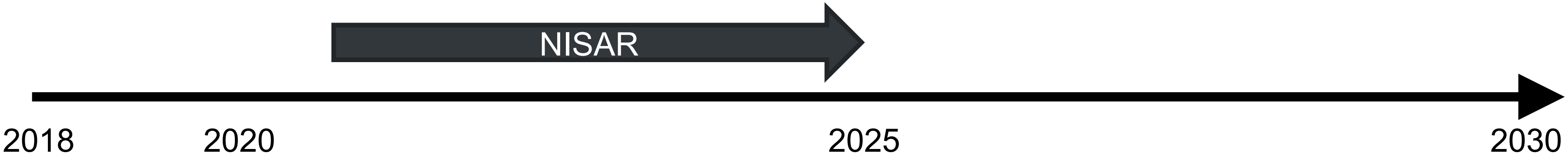


Upcoming missions

NISAR (launch 2021)

- NASA-JPL/Indian Space Agency
- Radar imager
  - Daily sea ice velocity

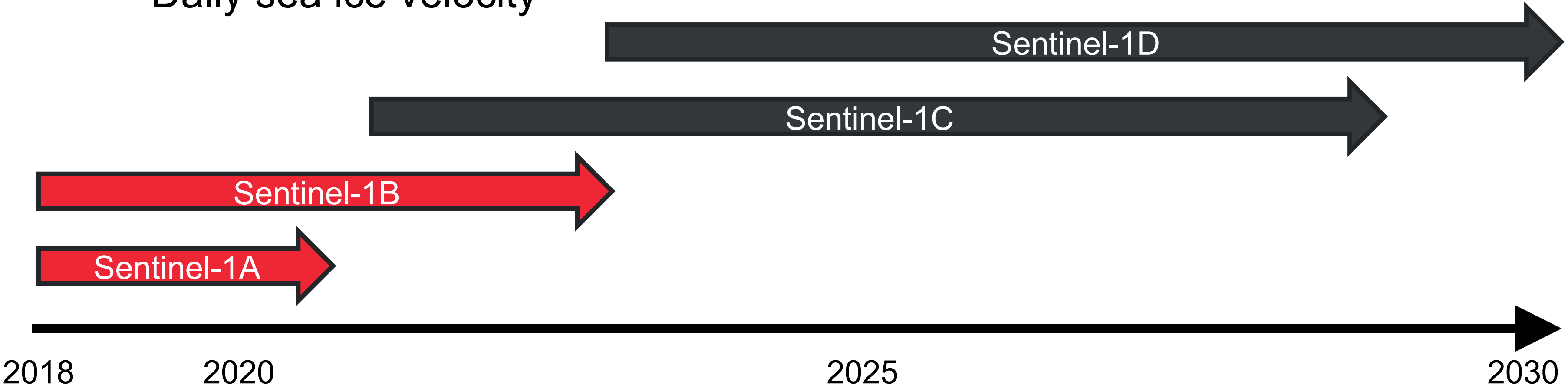




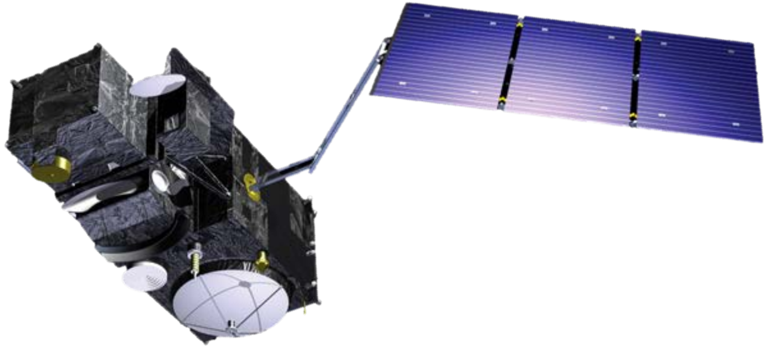
Upcoming missions

Sentinel-1 (ongoing)

- EC Copernicus mission
- Radar imager
  - Daily sea ice velocity



Upcoming missions



<u>Sentinel-3</u> (ongoing)

- EC Copernicus mission
- Radar altimeter
  - Sea ice thickness, sea level and currents

Sentinel-3D

Sentinel-3C

Sentinel-3B

Sentinel-3A

2018 2020 2025 2030

Proposed missions

CIMR (launch 2025+)

- EC Copernicus mission
- Passive microwave imager
  - Ice concentration
  - Sea surface salinity
  - Sea surface temperature
  - Sea ice motion
  - Surface vector wind

CRISTAL (launch 2025+)

- EC Copernicus mission
- Radar altimetry
  - Sea ice thickness
  - Snow depth
  - Sea level
  - Ocean currents

Observational limitations and gaps

	Ice conc. & extent	Ice motion & age	Ice thickness	Sea level & mass	SSS	SST
Outlook & potential gaps	• Potential break in SSM/I record	• PM: low resolution • SAR: infrequent coverage	• Mid-range uncertainty • Snow cover • High-latitude coverage after CS2/IS2	• High-latitude coverage after CS2/IS2 • GRACE resolution	• Lack sensitivity at high-latitudes • Bandwidth	• Potential break in SSM/I record
Future missions	CIMR	CIMR/RCM/Sentinel-1/NISAR	CRISTAL/ Sentinel-3/CIMR/SWOT	CRISTAL/SWOT	CIMR	CIMR

Conclusions

- Earth observing satellites provide massive value-added for Arctic science:
  - They are <u>essential</u> for our large-scale understanding of high latitudes
  - They are <u>highly compliment</u> in situ and other observations
- Regular basin-scale observations of important climate variables:
  - Sea ice concentration, thickness, motion, age; sea level, salinity, temperature
- The future of Arctic satellite observations is bright
  - Upcoming NASA missions will enhance capabilities
  - EC Copernicus program will sustain observations into 2030s and beyond

Jet Propulsion Laboratory
California Institute of Technology

Arctic Ocean satellite observing system

Tom Armitage

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

@twkarmitage