Arctic Ocean satellite observing system

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Principles of satellite remote sensing
NASAs Earth observation fleet

International Space Station
LIS on ISS
SAGE III on ISS
TSIS-1 on ISS
ECOSTRESS on ISS (EVI-2)
GEDI on ISS (EVI-2)
OCO-3 on ISS

Suomi NPP (NOAA)

DSCOVR (NOAA)

GRACE-FO

ICESat-2

CYGNSS (EVM-1)

Landsat 8 (USGS)

OCO-2

Aqua

CALIPSO

CloudSat

GPM Core Observatory

Landsat 7 (USGS)

Terra

Aura

OSTM/Jason 2 (NOAA)

SORCE
Principles of satellite remote sensing

- Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).
- Visible light observable from Earth, with some atmospheric distortion.
- Most of the infrared spectrum absorbed by atmospheric gases (best observed from space).
- Radio waves observable from Earth.
- Long-wavelength radio waves blocked.
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

• Retrieved from passive microwave observations
• Sea ice has high contrast with open water
Sea ice extent & concentration

• Daily observations since 1978!

Data: National Snow and Ice Data Center
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: $\pm$ ~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
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**

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
  - CO₂
- In Arctic can monitor intrusion of warm Atlantic/Pacific/river water
- Monitored by infrared and passive microwave instruments
Sea surface temperature

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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

Sentinel-3 (ongoing)
- EC Copernicus mission
- Radar altimeter
  - Sea ice thickness, sea level and currents

2018 2020 2025 2030

Sentinel-3A
Sentinel-3B
Sentinel-3C
Sentinel-3D
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

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

• Earth observing satellites provide massive value-added for Arctic science:
  – They are essential for our large-scale understanding of high latitudes
  – They are highly compliment 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
Arctic Ocean satellite observing system

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