Going to Extremes in the “New Arctic”

CESM Tutorial
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Going to Extremes in the New Arctic

When does the Arctic become the “New Arctic” (or is it already)?
How is this Arctic climate “New”?

Changes in the extremes
extreme changes
3 examples:
Sea ice, surface temperatures, rain vs snow

This presentation: focused on description and definitions
(processes will be part of the next step)
Going to Extremes in the New Arctic

Artic
Already a region of “extremes”
Observations – comparatively sparse
“Satellite era” 1979-present
Reanalysis products
Models

We do not have an observational “baseline” for Arctic climate

Model used for results presented here:

**CESM1**

“PI” 1850 control run (1800 yrs)
“LE” Large Ensemble (40 simulations)
20th and 21st (RCP8.5)
Comparisons to observations when available
Going to Extremes in the New Arctic: Sea Ice

Marine access (shipping, resource access)

Indigenous communities – subsistence and culture

Coastal erosion

Ecology/habitat

“Arctic amplification” and feedbacks
Going to extremes in the New Arctic: Sea Ice Extent

When do extreme Arctic sea ice extents become “extreme”?

Annual minimum and annual maximum Sea Ice Extent (SIE)
Arctic SIE: LE 1920-1929

Histograms of annual daily extreme (annual MIN and MAX) Arctic Sea Ice Extent (SIE) 1850 control run
Large Ensemble (LE) 20th-21st Century (RCP8.5) by decade

LE (1920-1929) and 1850 control run are nearly the same for both Arctic MIN and MAX SIE
Satellite observations (SSMI) shown for first (dashed; 1979-1989) and last decadal (solid; 2008-2017) means for comparison.
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Arctic SIE: LE 1990-1999

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Arctic SIE: LE 2000-2009

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Arctic SIE: LE 2040-2049

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Arctic SIE: LE 2060-2069

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Arctic SIE: LE 2010-2019

Extreme changes in an extreme and further range of extremes!
Year of emergence

year at which 10-yr mean lies outside early 20th Century
10-yr mean by more than ±2 STD

- Minimum SIE: 1996 (minimum SIE)
- Maximum SIE: 2013 (maximum SIE)
Going to Extremes in the New Arctic: Surface Air Temperatures

Influences:
- atmospheric circulation
- Ecology
  - phenology, seasonal mis-match
  - (pollinators, grazers, breeding seasons...)
- Permafrost
Going to extremes in the New Arctic: surface air temperature

When do Arctic temperatures become “extreme”? 
Going to Extremes in the New Arctic: Surface Air Temperatures

October emergence:
- influenced by declining summer sea ice concentration
- Timing varies by region
- Land regions not emergent (by this definition) primarily due to high STD

February emergence:
- influenced by winter sea ice thinning
- Central Arctic ocean emerges earliest
- Winter temps emerge later than fall temps
Going to Extremes in the New Arctic:
Surface Air Temperature changes

Changes in mean OCT daily TREFHT

Changes in mean FEB daily TREFHT

Greatest warming over ocean
Fall temperatures increase first
By end of 21st C Arctic ocean warming similar in fall, winter
Going to Extremes in the New Arctic: Precipitation


- rain vs snow seasons
- river runoff
- Snow cover (insolation, water storage)
- Ecology/habitat
- Permafrost
- infrastructure

Starvation killed 80,000 reindeer after unusual Arctic rains cut off the animals’ food supply
Going to extremes in the New Arctic: precipitation phase change

When does the Arctic rain season become “extreme”?
Going to Extremes in the New Arctic: “rainy season” emergence

**rainy day:**
1) precip $\geq 0.2$ mm/day
2) $\geq 60\%$ liquid (rain) rather than solid (snow)

- Land (e.g. Fairbanks) high STD, compared to open ocean (related to TEMP)
- Last day of rain emerges earlier than first day of rain (OCT daily temps emerge earlier than FEB)
Going to Extremes in the New Arctic: Rain Season changes

Changes in first, last rain days and rain-season length

First rain day  Last rain day  Rain season length

(2015-2024)

(2050-2059)

(2085-2094)

21stC changes:

Largest changes over ocean

last rain day ↑ earlier in 21st C than than first rain day ↓

Changes are enormous: season ~60/90-120 days longer by mid/late 21stC!
Going to Extremes in the New Arctic

When will the Arctic become the “New Arctic” (or is it already)?

CESM1 LE suggests:

- **Arctic Sea ice extent**
  - 1996 MIN SIE
  - 2013 MAX SIE

- **Surface Air Temperatures**
  - October: Arctic ocean 2015-2029
  - February: Arctic ocean 2045-2070

- **Rainy season**
  - 2040-2070

How extreme are simulated changes?

- **Arctic Sea ice extent**
  - 3-4 months of 0 ice (1x10^6 km^2 less than “ice free definition!”)

- **Surface Air Temperatures**
  - October and February: Arctic ocean 20°-24°C
  - Arctic lands 8°-12°C warmer

- **Rainy season**
  - Rainy season length ↑ 60-120+ days over most of Arctic by end of century
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“New Arctic”
Cryosphere → Hydrosphere

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**Surface Air Temperatures**
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  Arctic lands 8°-12°C warmer

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Going to Extremes in the New Arctic
Extra slides
Going to Extremes in the New Arctic: Surface Air Temperature changes

Changes in October daily temperatures (2020-2029) over Arctic Ocean 2-10 °C

Changes over Arctic land are substantial (2-6°C) yet not enough to emerge from variability
When does the 10-yr mean daily (by month) surface temperature exceed the early 20thC mean by more than 2 STD?
Going to Extremes in the New Arctic: Surface Air Temperatures

How much warmer is the temperature at year of emergence? 8-18+ °C, Oct-Mar!
Going to Extremes in the New Arctic: Surface Air Temperatures and Sea Ice
Going to Extremes in the New Arctic: Surface Air Temperatures and Sea Ice

Air Temperature

Conductive Heat Flux (ice-to-atm is neg)

Thinnest (<0.64 m) sea ice concentration

Thin (0.64-1.39 m) sea ice concentration

