Time of Emergence for Antarctic Sea ice and Ecosystems

Laura Landrum
National Center for Atmospheric Research

PCWG CESM Workshop, June 13, 2023

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Time of Emergence for Antarctic Sea ice and Marine Ecosystems in a warming world

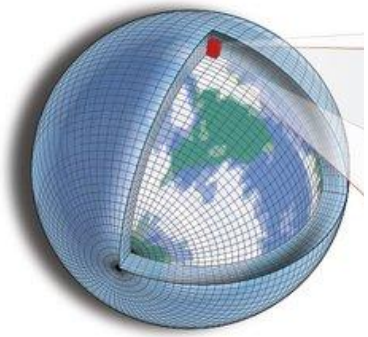
CESM as a tool for Societally Relevant Science

Laura Landrum, Marika Holland, Alice DuVivier, Kristen Krumhardt, Stephanie Jenouvrier, ***Cassandra Brooks,*** *Christian Che-Castaldo, Bilgecan Sen,* ***Zephyr Sylvester****, Francesco Ventura, Sara Labrousse, Michelle LaRue, Lucie Bourreau, Marte Vienne, Matthew Long*

PCWG CESM Workshop, June 13, 2023

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

The Team



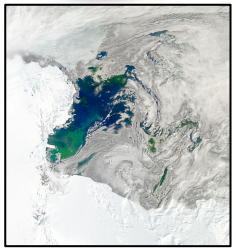
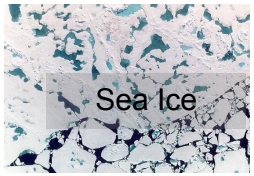


Image from NASA Earth Observatory



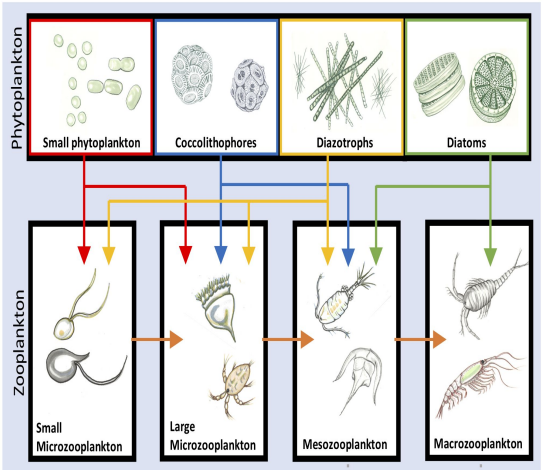


Image: Kristen Krumhardt

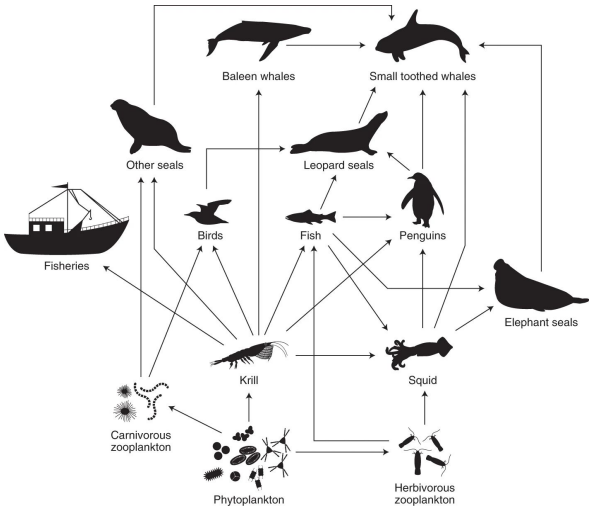
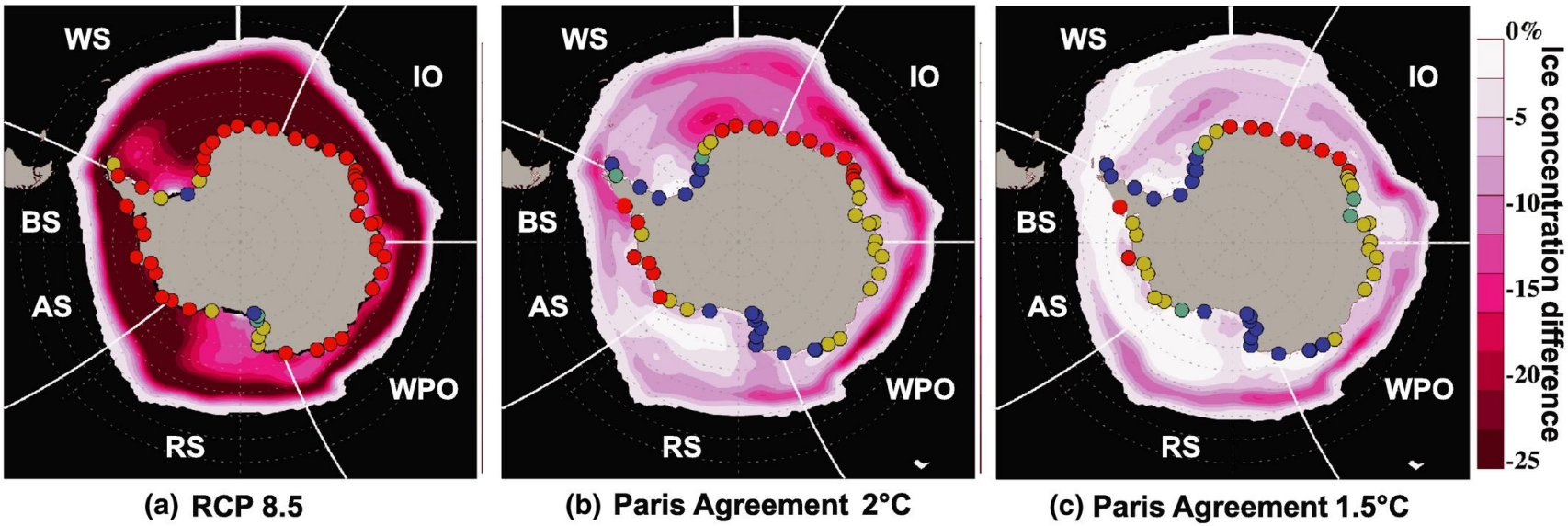


Image: McBride et al. 2019

Laura Landrum, Marika Holland, Alice DuVivier, Kristen Krumhardt, Stephanie Jenouvrier, Cassandra Brooks, Christian Che-Castaldo, Bilgecan Sen, Zephyr Sylvester, Francesco Ventura, Sara Labrousse, Michelle LaRue, Lucie Bourreau, Marte Vienne, Matthew Long

Previous work:
Projected Antarctic change and biological and policy impacts

Using projected Antarctic sea ice changes and a climate-dependent-metapopulation (emporer penguin colonies) model, Jenouvrier et al. (2019) projected different levels of population decline for different future forcing scenarios – high emissions and two Paris agreement objectives (2°C and 1.5°C)



Conservation status of emporer penguin colonies by 2100 and sea ice concentration changes between the 20th and 21st centuries.

- Not likely to decline
- Vulnerable
- Endangered
- Quasi-extinct

Jenouvrier et al., 2019

Projected Antarctic change and biological and policy impacts

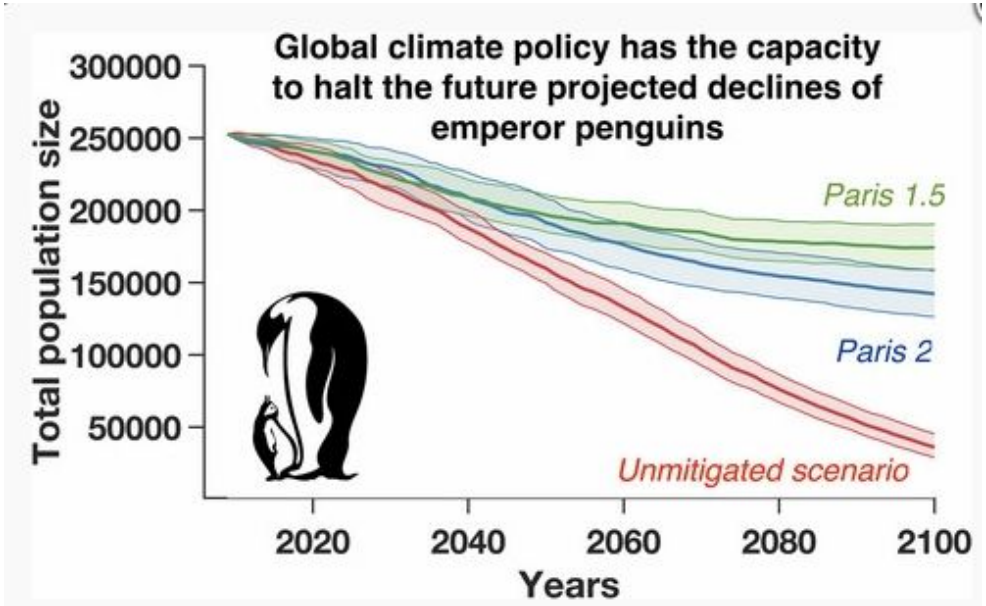
Global Change Biology

PRIMARY RESEARCH ARTICLE | Full Access

The Paris Agreement objectives will likely halt future declines emperor penguins

Stéphanie Jenouvrier, Marika Holland, David Iles, Sara Labrousse, Laura Landrum, Jimmy Garnier
Hal Caswell, Henri Weimerskirch, Michelle LaRue, Rubao Ji, Christophe Barbraud

First published: 07 November 2019 | https://doi-org.cuucar.idm.oclc.org/10.1111/gcb.14864 |



Endangered and Threatened Wildlife and Plants; Threatened Species Status for Emperor Penguin With Section 4(d) Rule

A Rule by the Fish and Wildlife Service on 10/26/2022

PUBLISHED DOCUMENT

AGENCY:
Fish and Wildlife Service, Interior.

ACTION:
Final rule.

SUMMARY:
We, the U.S. Fish and Wildlife Service (Service), determine threatened species status under the Endangered Species Act of 1973 (Act), as amended, for the emperor penguin (*Aptenodytes forsteri*), a flightless bird species from Antarctica. This rule adds the species to the List of Endangered and Threatened Wildlife. We also finalize a rule issued under the authority of section 4(d) of the Act that provides measures that are necessary and advisable to provide for the conservation of this species.

DATES:
This rule is effective November 25, 2022.

DOCUMENT DETAILS

Printed version: PDF
Publication Date: 10/26/2022
Agencies: Fish and Wildlife Service
Dates: This rule is effective November 25, 2022.
Effective Date: 11/25/2022
Document Type: Rule
Document Citation: 87 FR 64700
Page: 64700-64720 (21 pages)
CFR: 50 CFR 17
Agency/Docket Numbers:

"We have determined that climate change …presents the most substantial threat facing the emperor penguin" (DOI, Fish & Wildlife Service, Oct, 2022)

Current work:
Antarctic marine ecosystems, predators, habitats now and under future climate scenarios

Antarctic Sea Ice functioning in marine ecosystems

- Light availability
- Nutrient availability
- Platform for marine predators (breeding, food access, escape from larger predators)

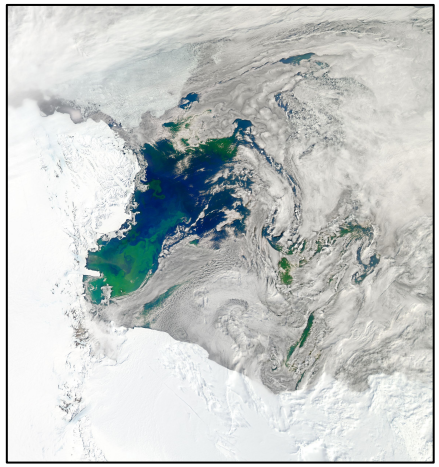


Image from NASA Earth Observatory

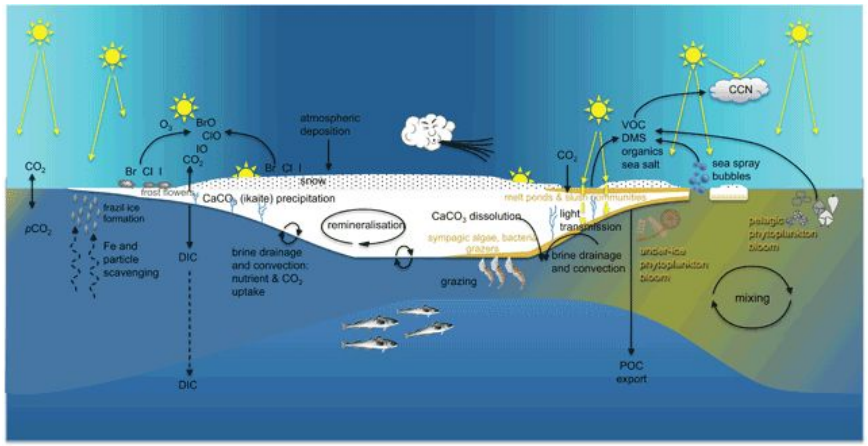


Figure 1 from Nadja Steiner, Jacqueline Stefels, Jody W. Deming, Commentary on the outputs and future of Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII), Elementa: Science of the Anthropocene, 2017

Photo courtesy Glen Grant, U.S. Antarctic Program, National Science Foundation

YOE Antarctic marine ecosystems and sea ice

Time of Emergence: when the forced response emerge from internal variability

CESM2 Large Ensemble

50 members (CMIP6 forcing) – historical (1850-2014) and “high emission” scenario (SSP370; 2015-2100)

Last 1000 yrs of the pre-industrial (1850) control run

50 members initialized from the control run:

10 members initialized every 20 yrs, 1001-1181

Ideally the simplest definition – we are applying to diverse data (climate model output, observationally based data, ecological, physical, etc.)

Start with:

Year of emergence = YOE = year when $\overline{LE}$ lies outside the range of $\overline{LE}_{base} \pm 2\ STD_{base}$

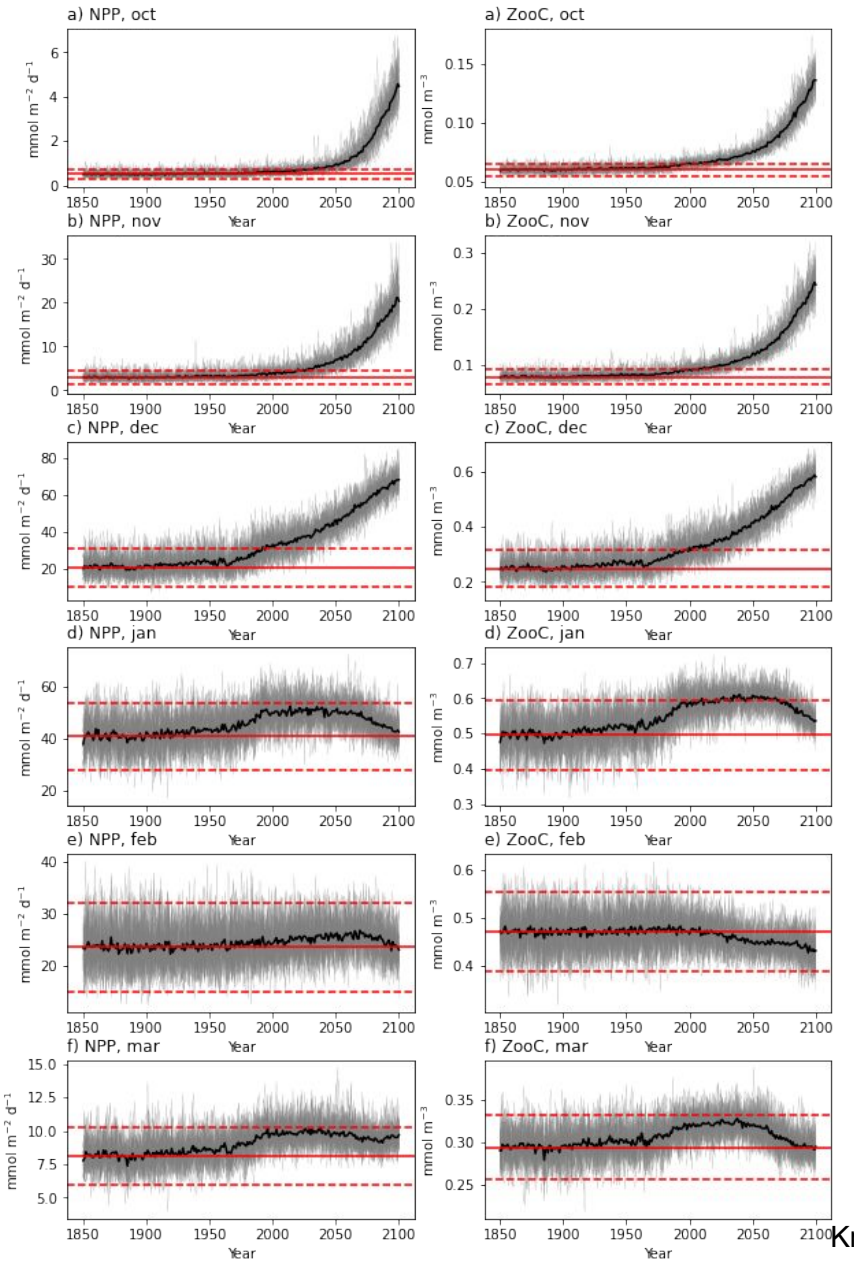
Where

$\overline{LE}$ = ensemble mean

base = base period

Antarctic Net Primary Productivity (NPP) and Zooplankton (ZooC) Biomass

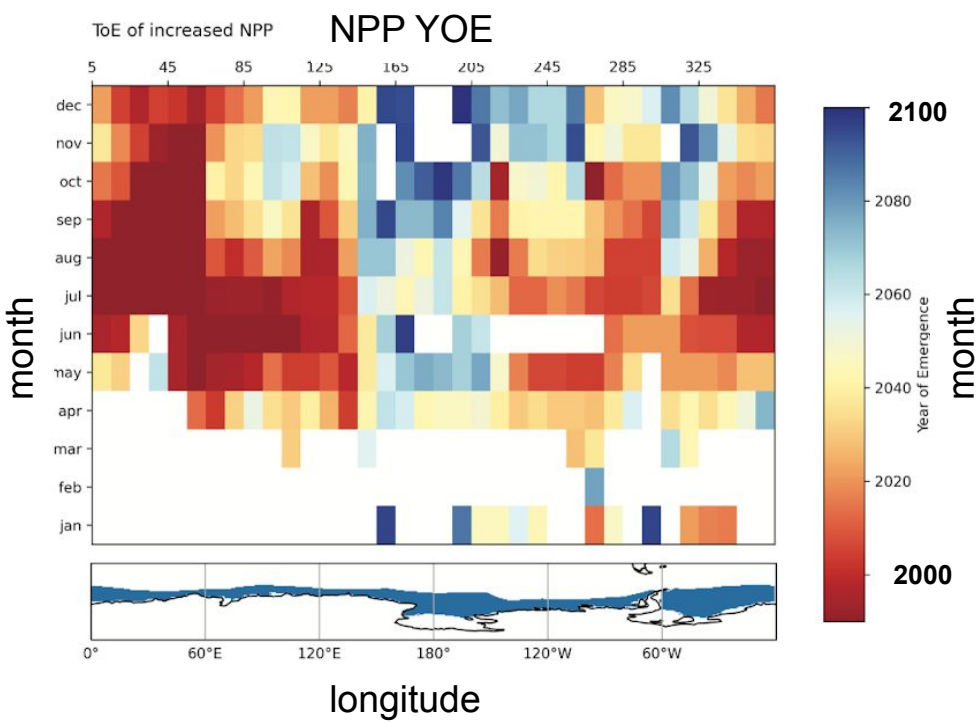
CESM2 LE
Eastern Antarctica
NPP (left)
ZooC (right)
Growing season: October (top)- March (bottom)

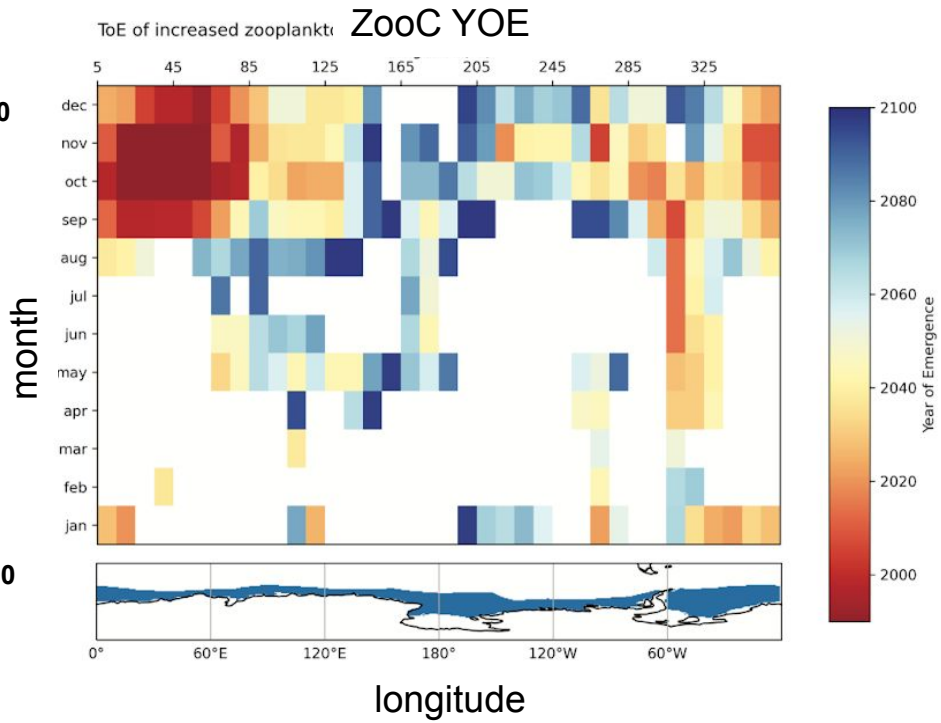


individual ens. Members
Ensemble mean
1850-1950 mean
1850-1950 mean ± 2STDs

Kristen Krumhardt, NCAR

Antarctic NPP and ZooC YOE

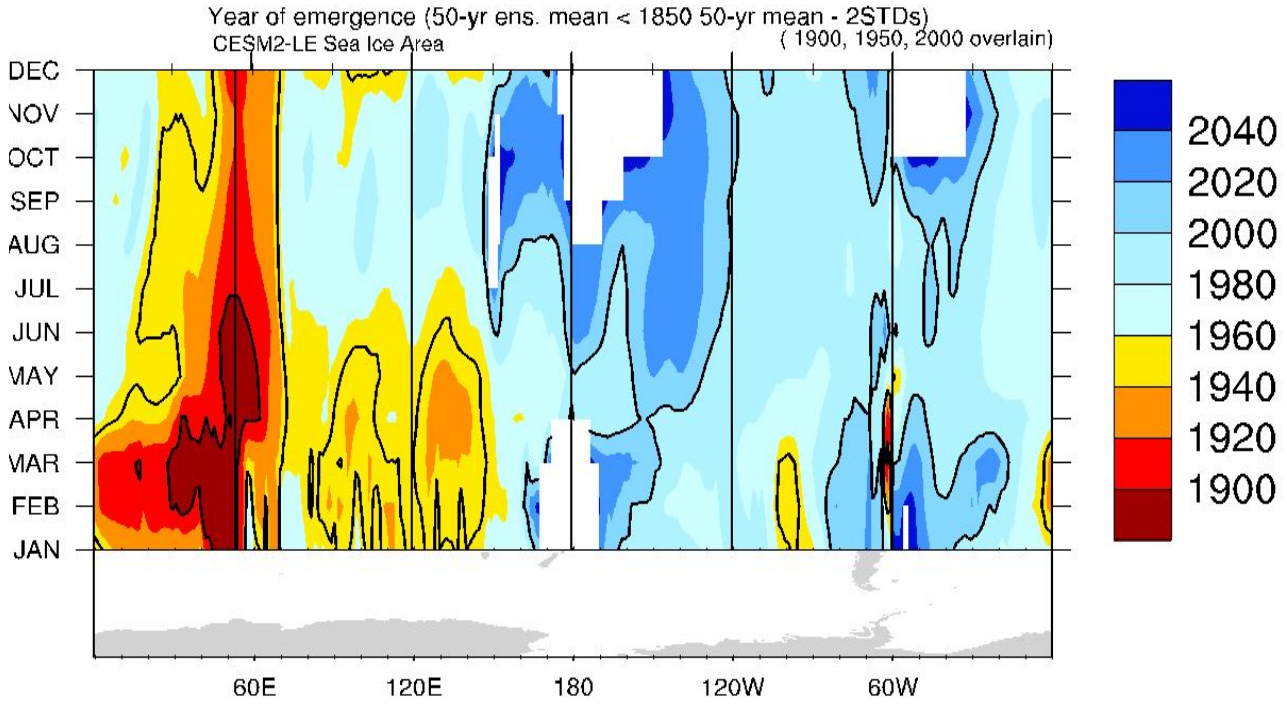




- NPP and ZooC in the “sea ice zone” (shown in blue in the maps)
- Month (Yaxis) and longitude (Xaxis)
- Earliest YOE late 20th C, and ~30°W-120°E

Kristen Krumhardt, NCAR

Antarctic Sea Ice YOE

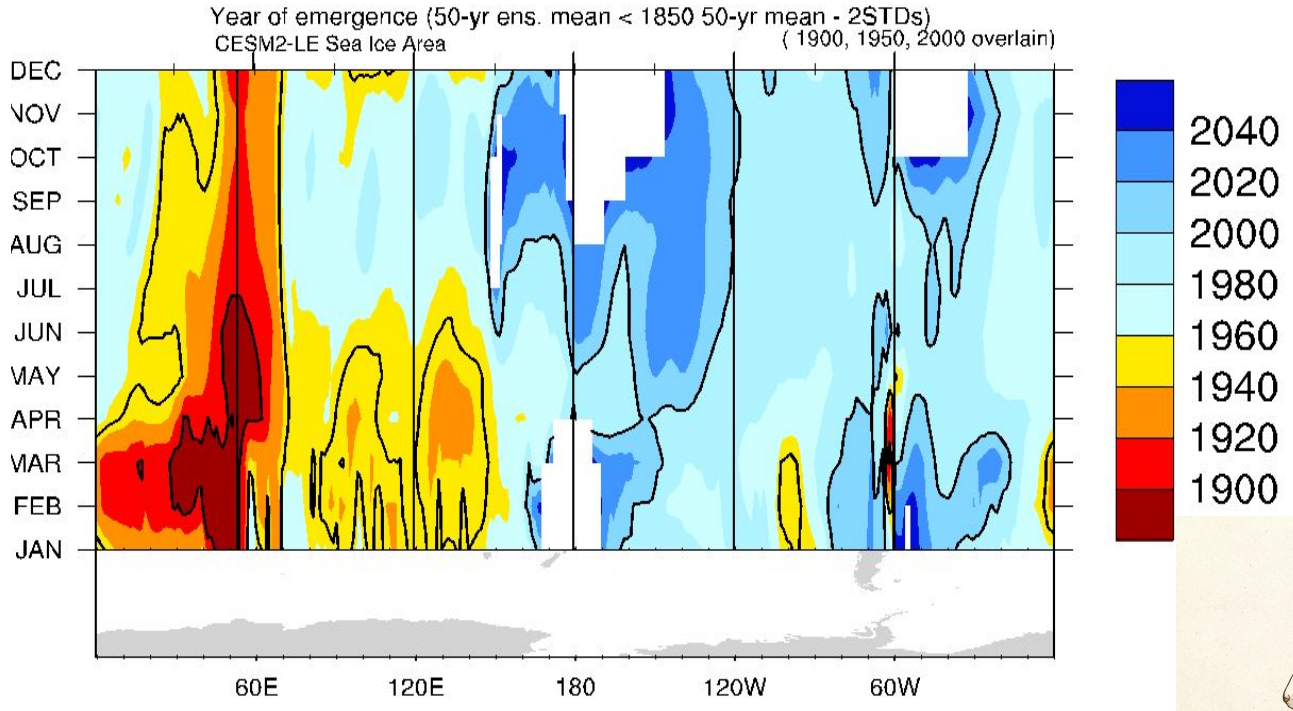


50-yr ensemble mean

1850-1899 base period

Broad regional similarities to NPP YOE

Antarctic Sea Ice YOE



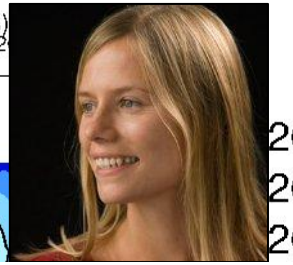
YOE is earlier than end of base period in some regions/months!

Disentangling long term trends from internal variability? NO…..

Antarctic Sea Ice YOE

Let me know what you find out!

Very interesting…



Will hold off on further ecosystem emergence for a bit….

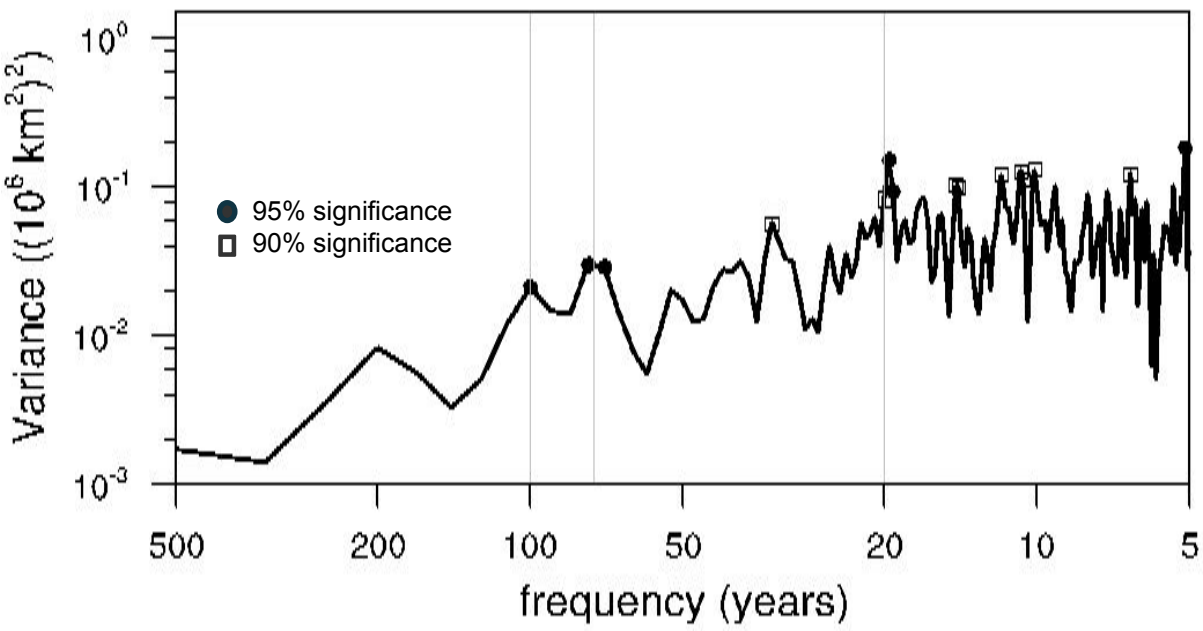
Good Luck!

YOE is earlier than end of base period in some regions/months!

Disentangling long term trends from internal variability? NO…..

Antarctic Sea Ice Variability in the CESM2 1850 control run

CESM2 1850 control run yrs 1001-2000
Total Antarctic Annual Sea Ice Area
Power spectra



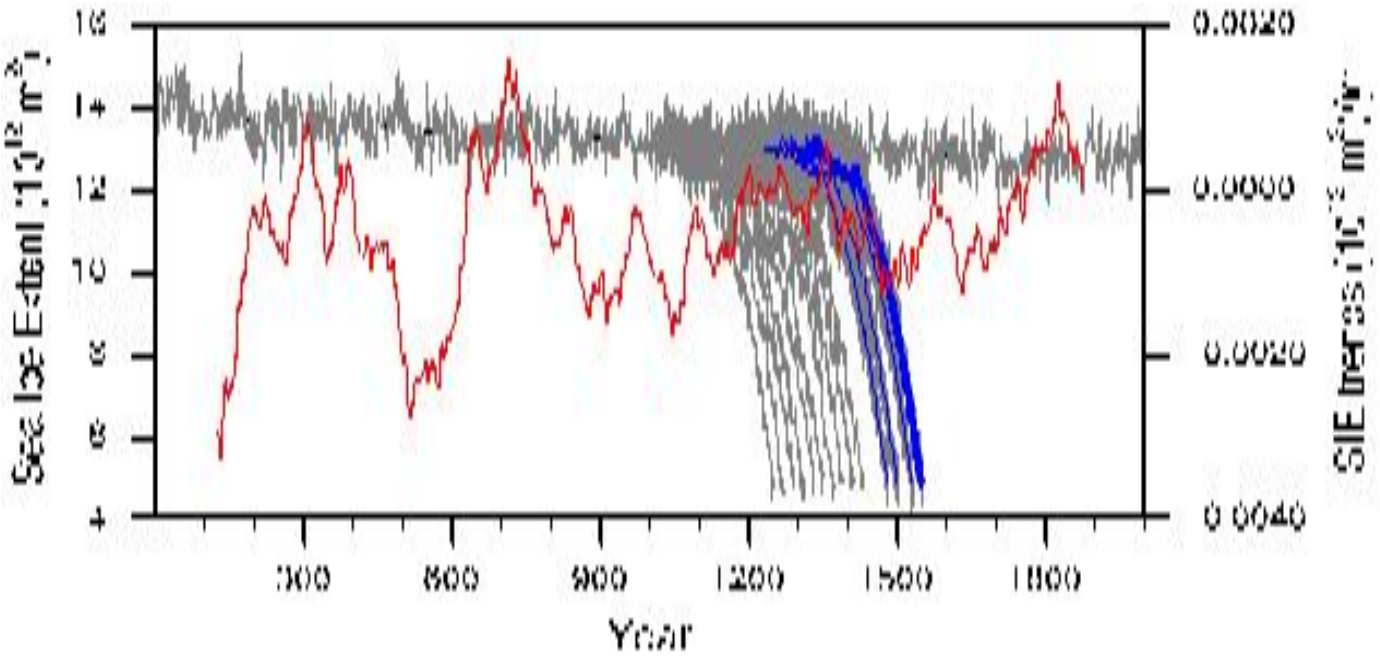
50 members initialized from the control run:

10 members initialized every 20 yrs, 1001-1081

10 members each initialized at 1231, 1251, 1281, 1301

Antarctic Sea Ice Variability: remove long-term trends?

ANN SH Sea Ice Extent (SIE)



250-yr mean (1850 control)

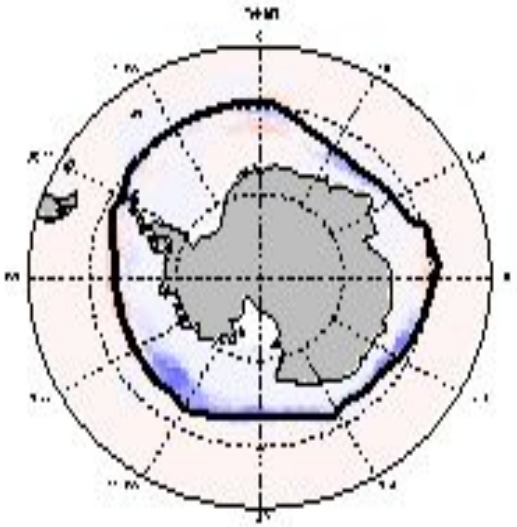
individual simulations

LE mean (by initialization yr)

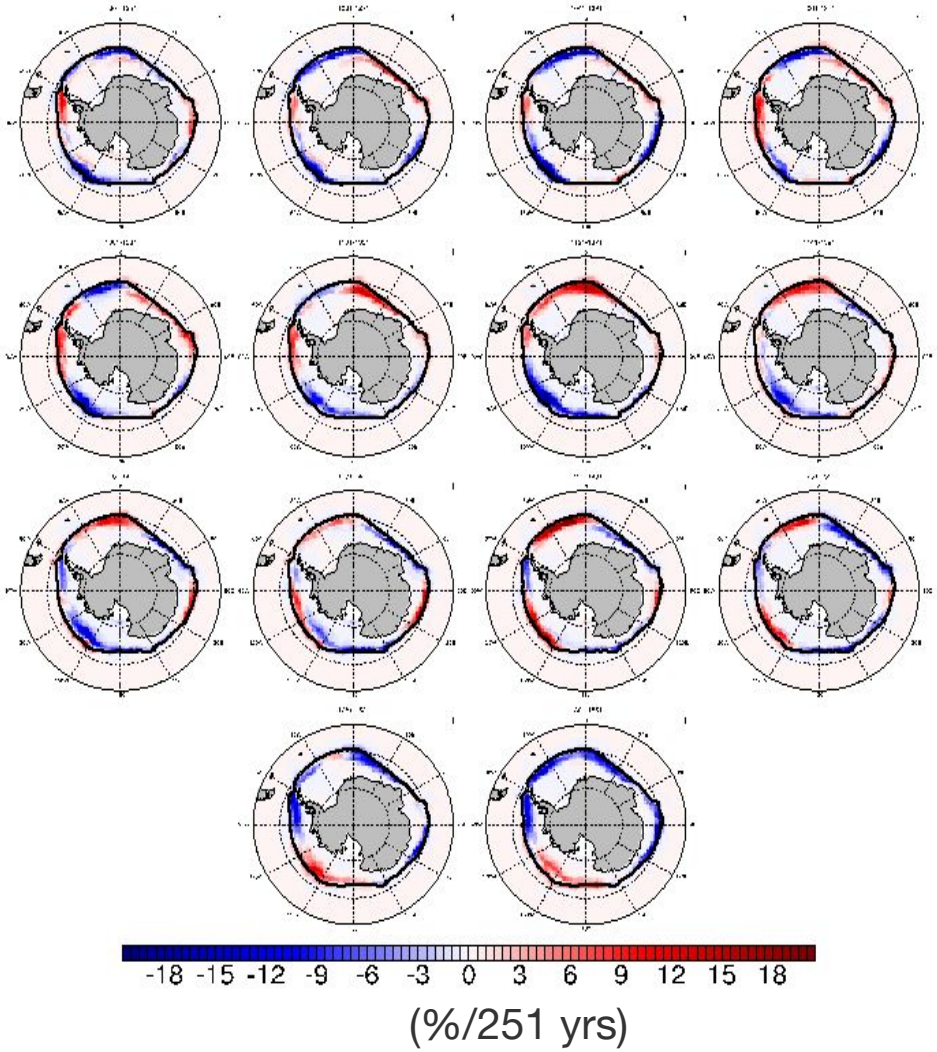
250-yr running trends (1850 control)

Regional Antarctic Sea Ice 251-yr trends

Average (over 14 initialization dates)



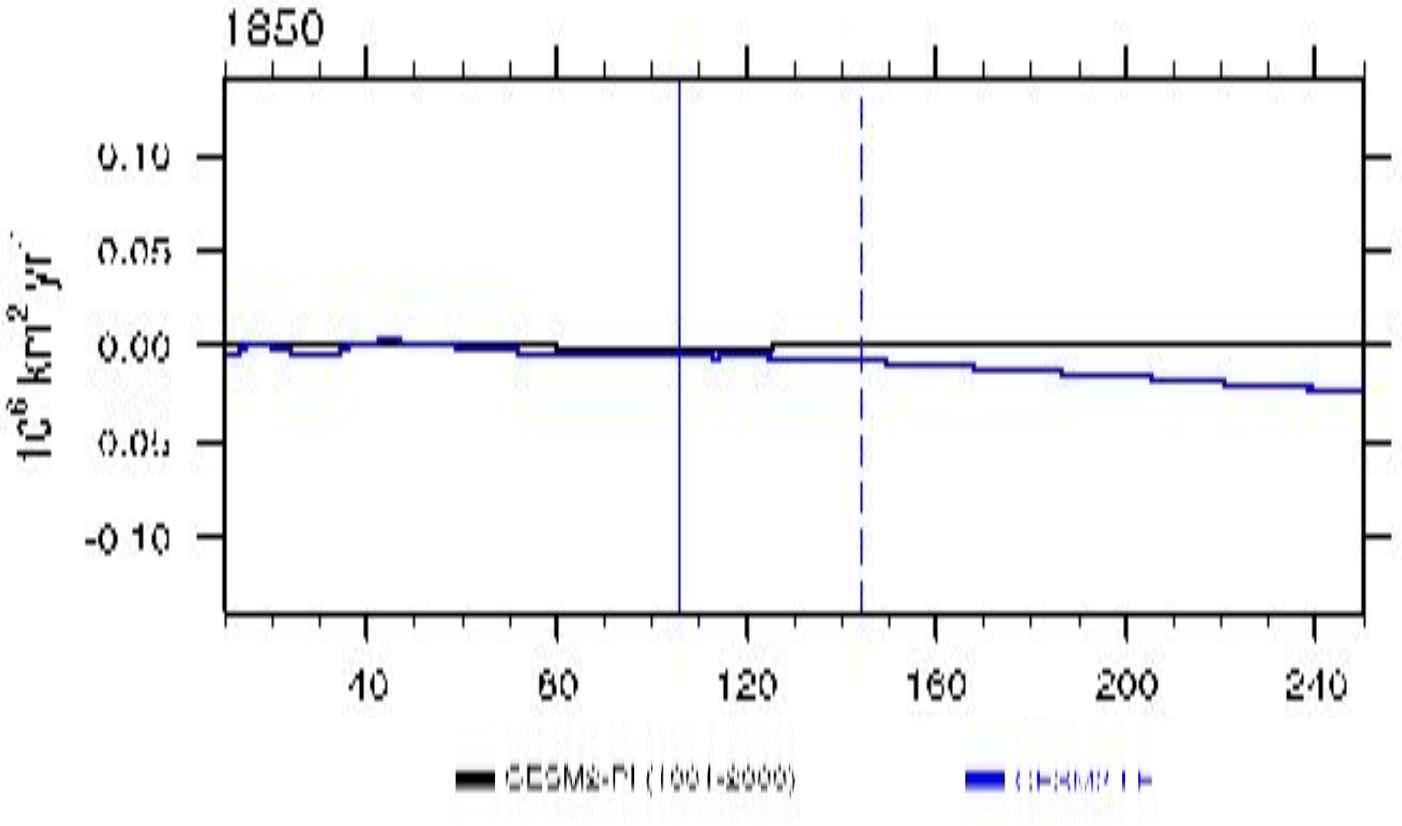
Trends at each initialization date of the CESM2-LE



(SIC)
CESM2 1850 control run
251-yr trends

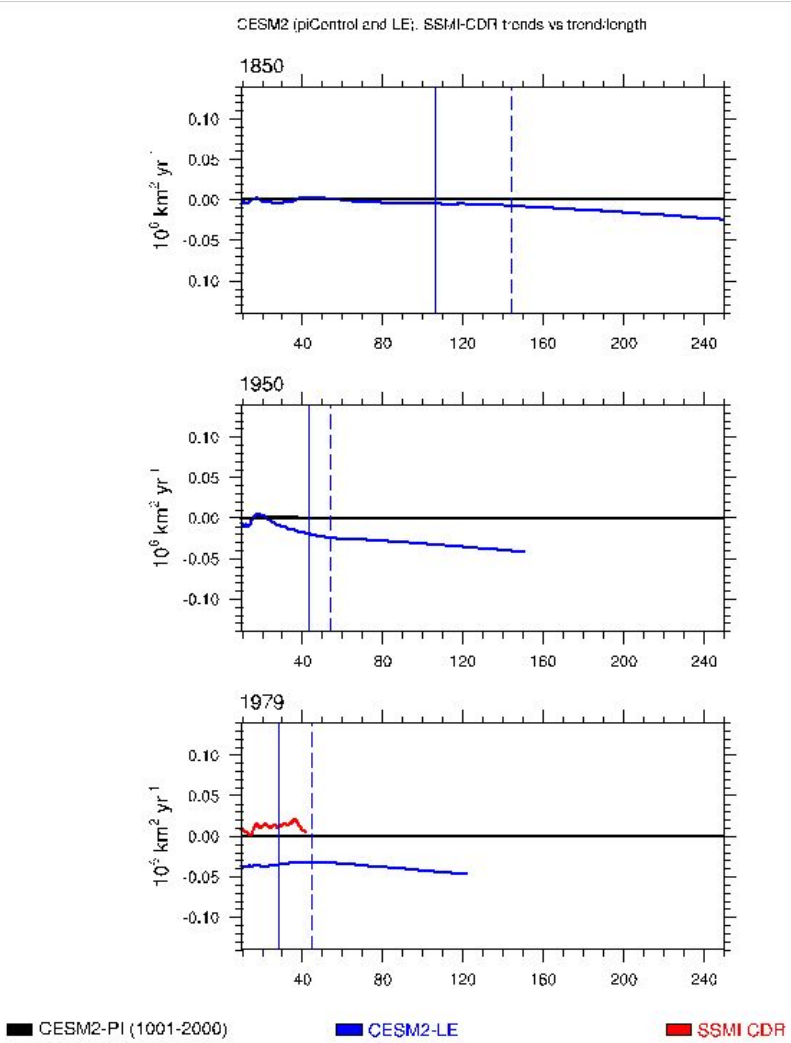
Antarctic Sea Ice trends

Distribution of trends as a function of trend-length

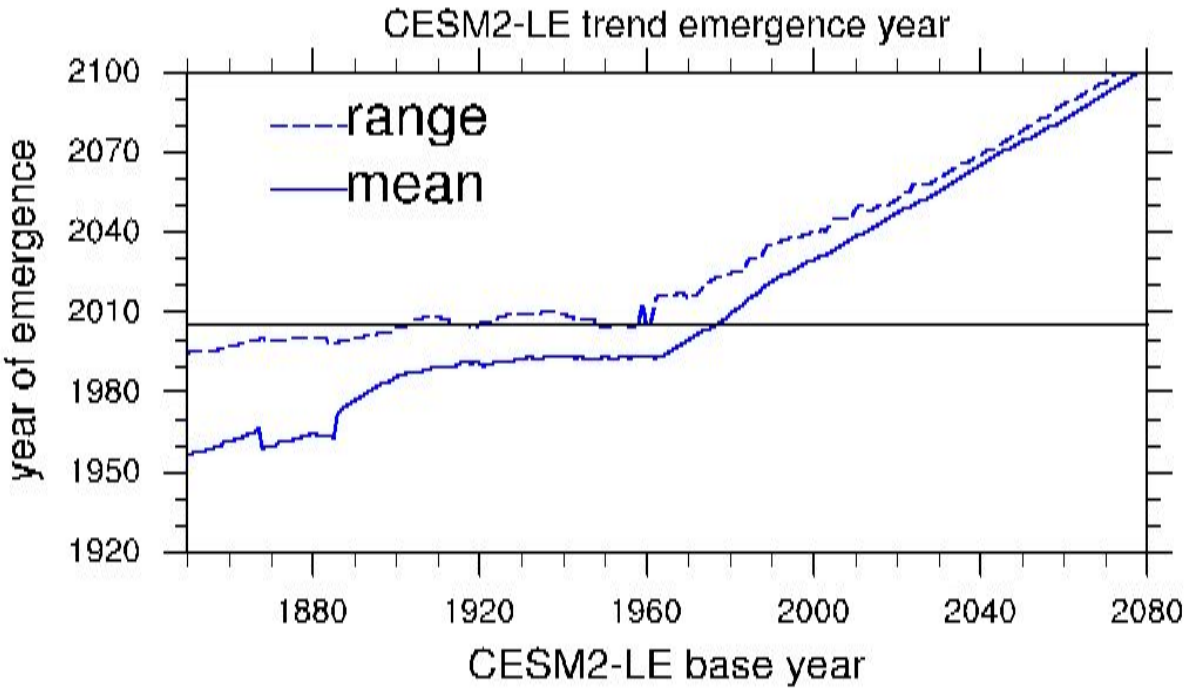


Another definition of year of emergence:
Year at which the mean (——) or range (------) of trends in the CESM2-LE falls outside the range of trends in the 1850 control run

Antarctic Sea Ice trends



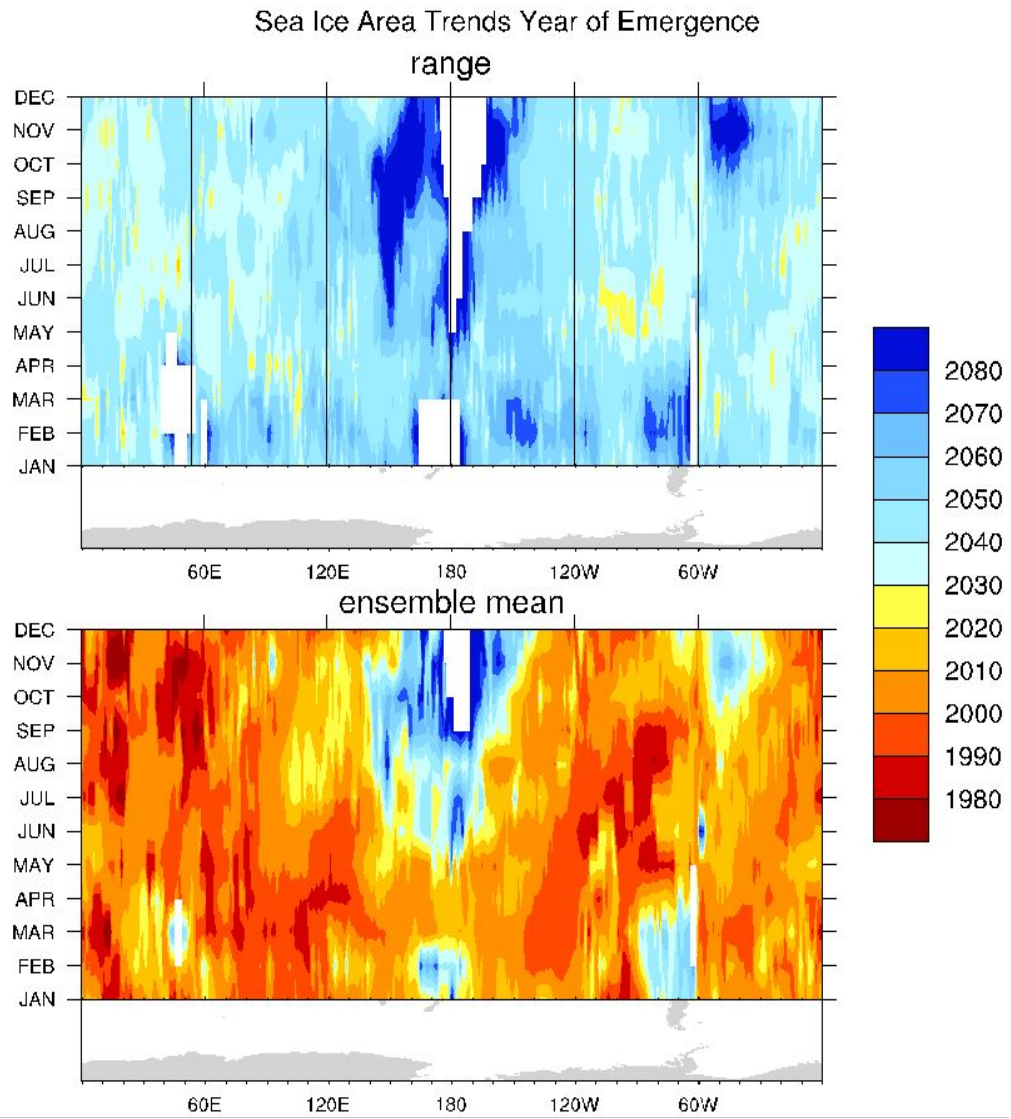
Antarctic Sea Ice YOE calculated from trends



SH Annual Sea Ice Area

Antarctic Sea Ice highly variable not only temporally, but regionally and seasonally

Antarctic Sea Ice YOE based on trends



Time of Emergence for Antarctic Sea ice and Marine Ecosystems in a warming world

Antarctic sea ice variability in the CESM2: some conclusions from "down the rabbit hole"

Multi-decadal variability in SH Antarctic Sea ice is significant

Peak power at ~6, 20, 75, 100 yrs

Regional variability significant also significant on multidecadal time scales

50 members of CESM2-LE may not capture full range of variability of trends at shorter time-scales (<70 yrs)

Using ensemble mean and std insufficient to disentangle internal variability from forced response

Divergence of trends may be tricky in some regions/seasons

Ross and Weddell Sea region emerge later than other regions

Ross Sea trends do not emerge for some months (late winter-early summer) even by the end of the 21st C

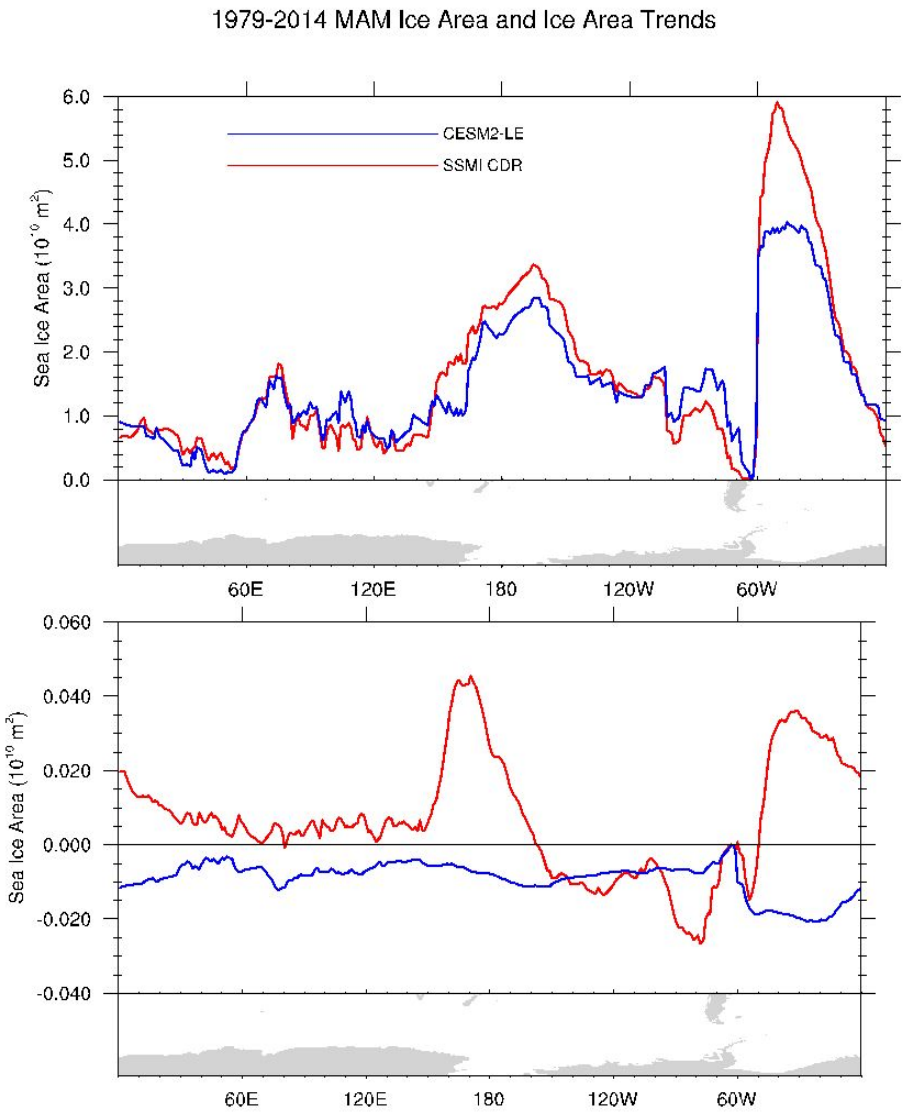
landrum@ucar.edu

Observed and modeled fall trends in Antarctic Sea ice

Most GCMs do not capture observe trends in sea ice in the Ross Sea during austral fall

CESM2 is no exception

- Antarctic sea ice variability is significant on multi-decadal time scales
- Points to oceanic processes
- Recent work suggest possible players:
  - Correct sea ice drift bias (Sun & Eisenman, 2021)
  - Nudged to observed winds (Blanchard-Wrigglesworth, 2021)
  - Nudged to observed winds and SSTs (Blanchard-Wrigglesworth, 2021)
  - High resolution (Rackow et al., 2022)
  - Internal variability and ocean mean state at initialization (Singh et al., 2019)



Time of Emergence for Antarctic Sea ice and Marine Ecosystems in a warming world

Thank you!

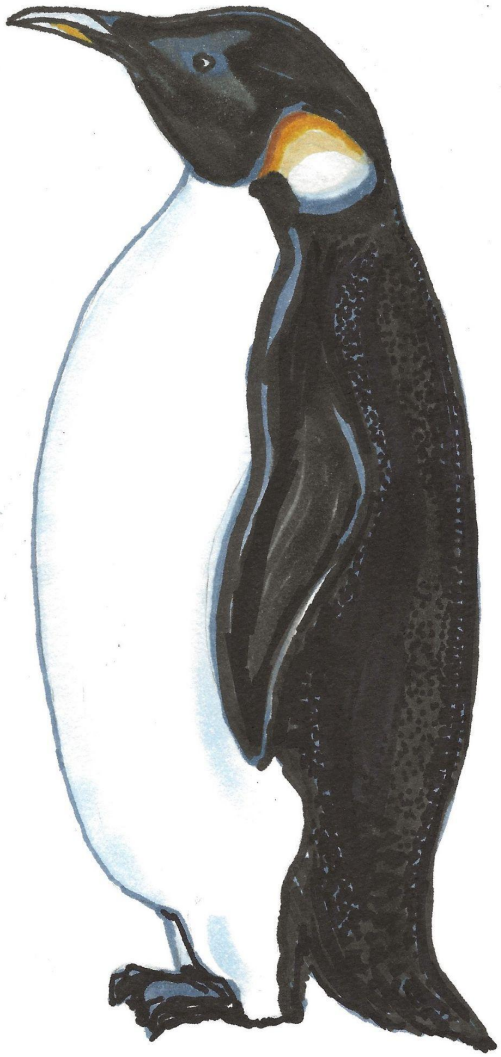
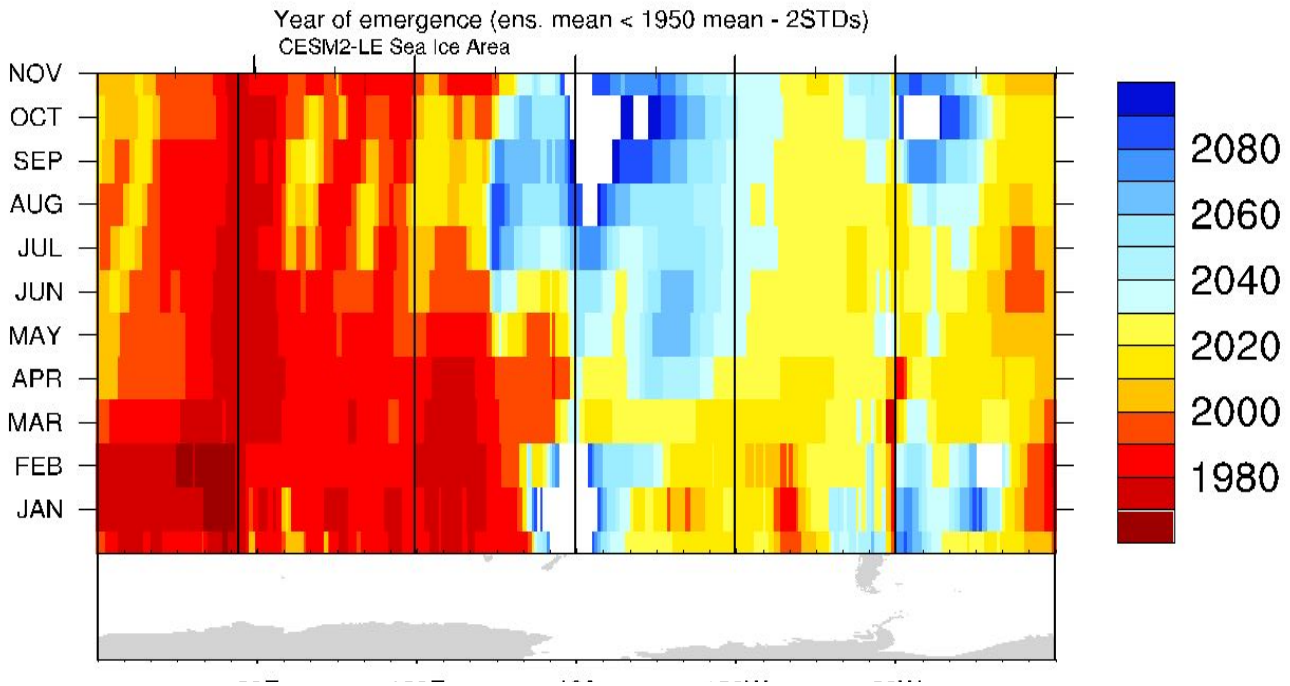


Image: Kristen Krumhardt

 landrum@ucar.edu

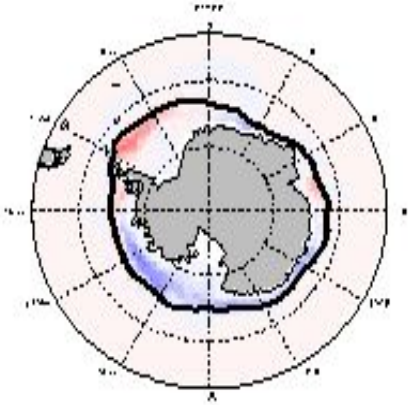
Antarctic Sea Ice YOE



Similar patterns using different base periods and years over which to average.

Antarctic Sea Ice 251-yr trends in 1850 control run

Average trends



251-yr April SIC trnds

Trends for each initialization date of the CESM2-LE