Quantifying the value of Antarctic polynyas on the ecosystem from phytoplankton to penguins

Alice DuVivier - duvivier@ucar.edu

Kristen Krumhardt, Laura Landrum, Zephyr Sylvester, Marika Holland, Stephanie Jenouvrier, Sara Labrousse, Lucie Bourreau, Marthe Vienne, Michelle LaRue, Bilgecan Sen, Francesco Ventura, Matthew Long, Cassandra Brooks
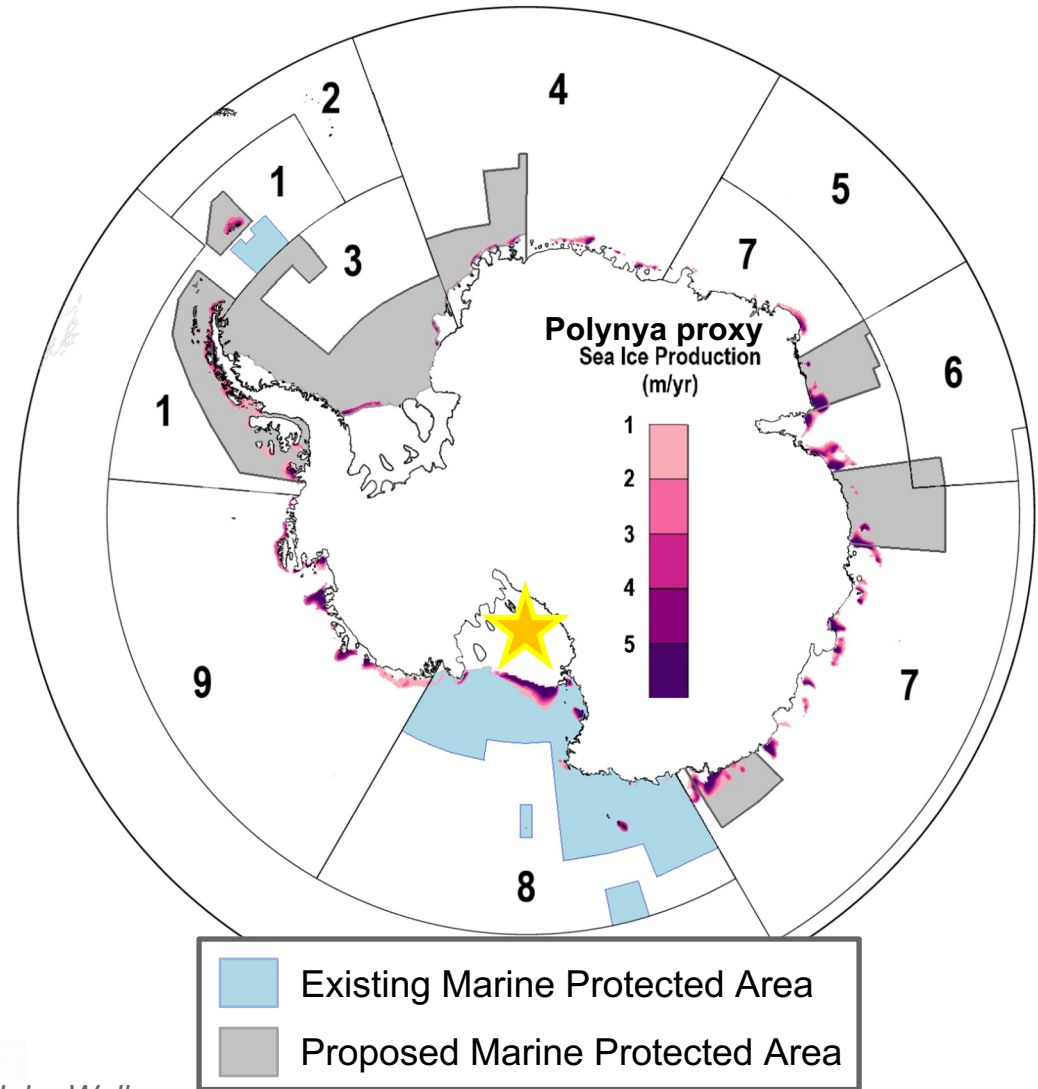
Photo: John Weller

Project Goal:

Provide information about the conservation value of polynyas (areas of lower ice concentration or thinner ice) in different Antarctic regions over policy relevant timescales.
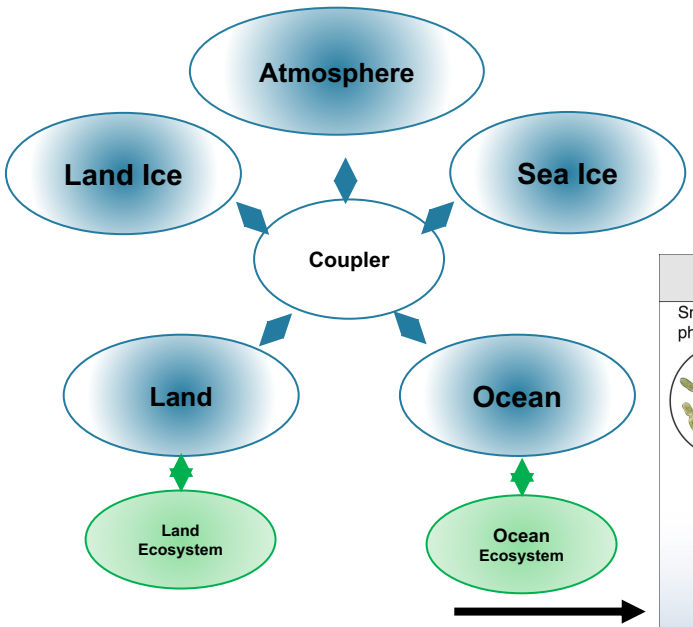
Photo: John Weller

Polynya proxy
Sea Ice Production
(m/yr)

1
2
3
4
5

Existing Marine Protected Area
Proposed Marine Protected Area

duvivier@ucar.edu

Using the CESM2 Large Ensemble to project future physical and ecosystem changes

Community Earth System Model (CESM2)

CESM2 Large Ensemble (CESM2-LE)
- 50 simulations from 1850-2100 (focusing on 1950-2100)
- Capture range of internal climate variability for a given forcing scenario
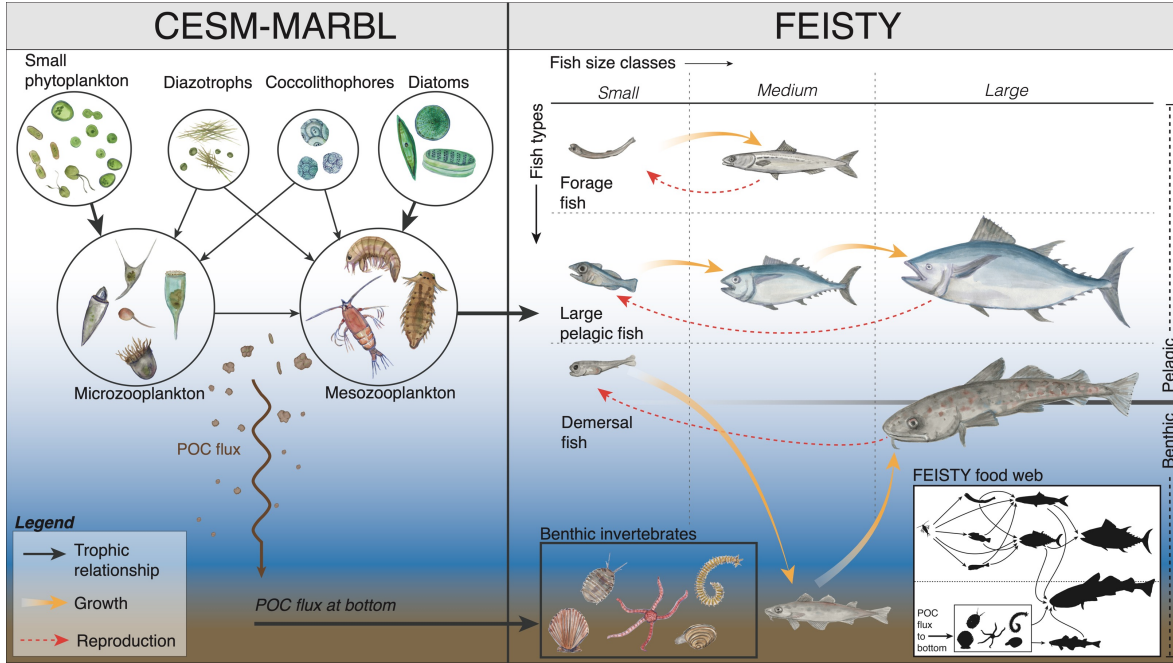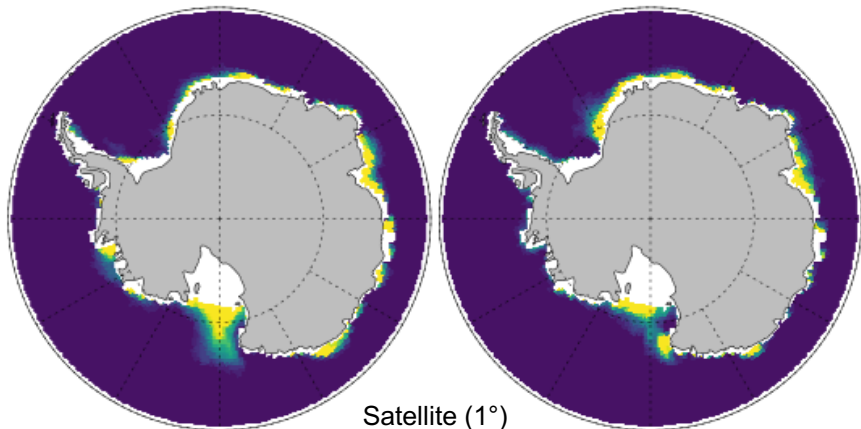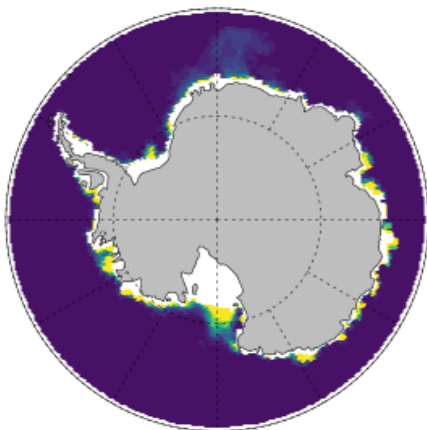
Offline Model
Uses CESM data

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Satellite and model areas with frequently occurring polynyas match well.

CESM (1°)
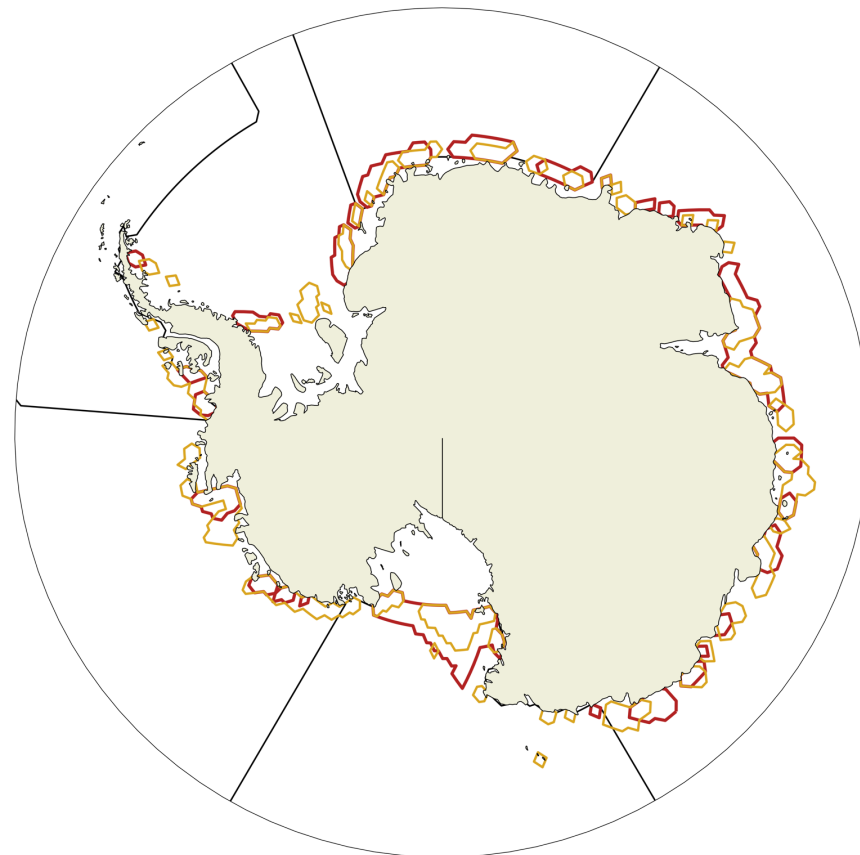thresh: SIT = 40cm

CESM (1°)
thresh: SIC = 85%

Satellite (1°)
thresh: SIC = 85%

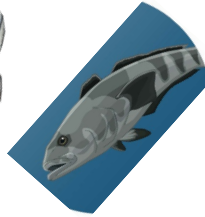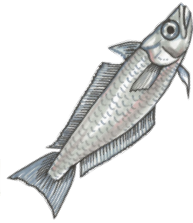1979-2020 "typical" polynyas
(identified >10% of the year)

0   0.01   0.02   0.03   0.04   0.05   0.06   0.07   0.08   0.09   0.1
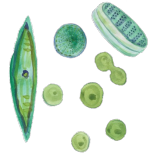
Fraction of Year   *Data from Landrum et al. (in prep)*

— satellite (85% SIC threshold)
— CESM hindcast (0.4m SIT threshold)

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Combining the data layers into an Ecosystem Index

$$EI_{ij} = \frac{\left(\dfrac{NPP_{ij}}{NPP_{max}} + \dfrac{KGP_{ij}}{KGP_{max}} + \dfrac{FF_{ij}}{FF_{max}} + \dfrac{FD_{ij}}{FD_{max}} + \dfrac{EP_{ij}}{EP_{max}} + \dfrac{AP_{ij}}{AP_{max}} + \dfrac{WS_{ij}}{WS_{max}} + \dfrac{SES_{ij}}{SES_{max}}\right)}{n_{layers}}$$
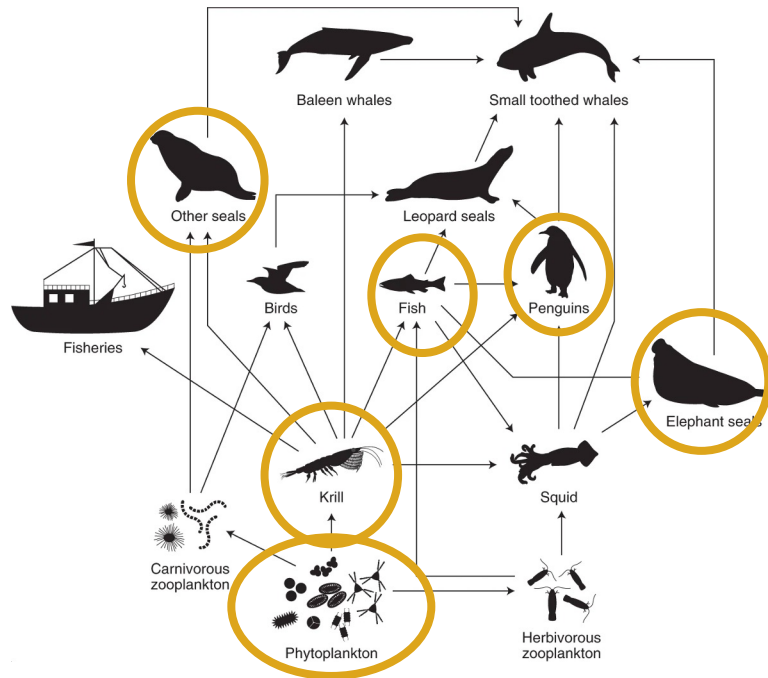

Image: McBride et al. 2019

* Evenly weighted each species, but tool has toggles to look at individual species depending on user interest

Krill Growth Potential (KGP)
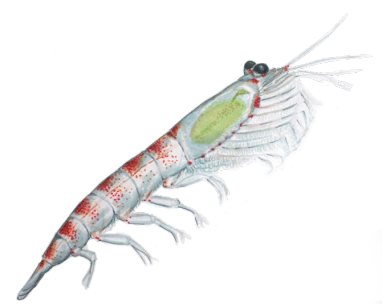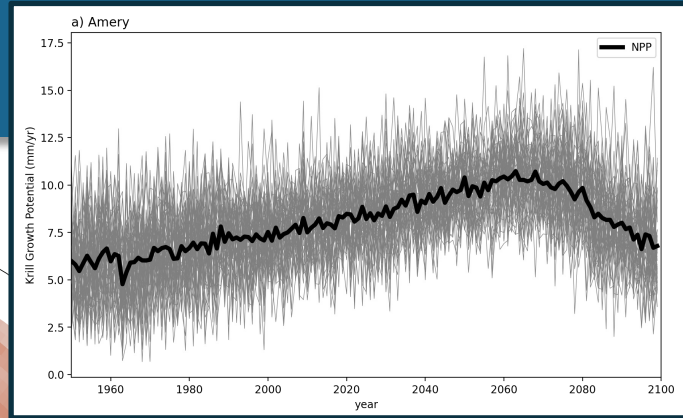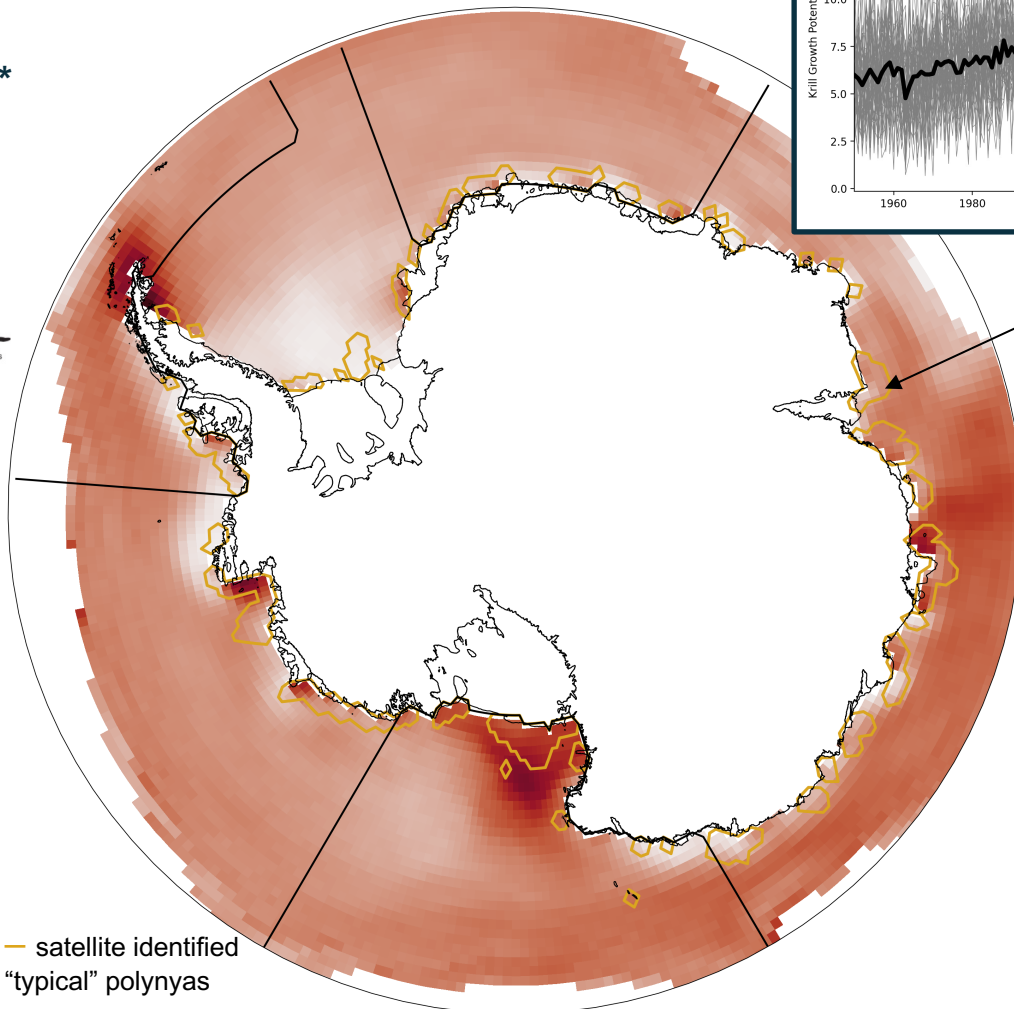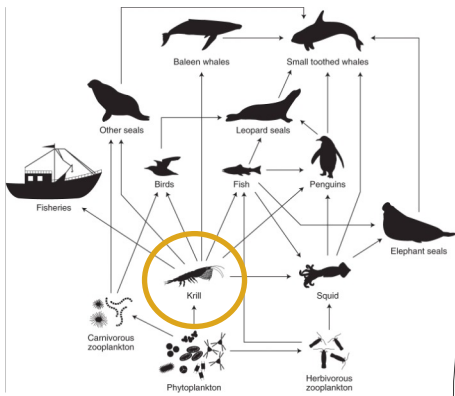
CESM2-MARBL
+
Empirical Relationship*

a) Amery

* Antarctic krill (Euphausia superba) empirically derived growth potential:

$$KGP = LEN_0 + CHL_{sfc} + SST$$

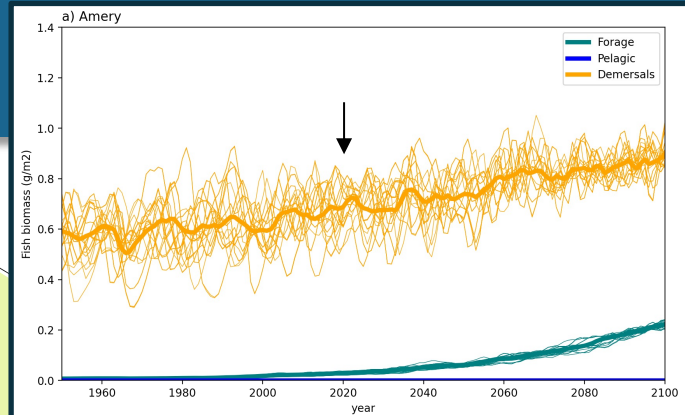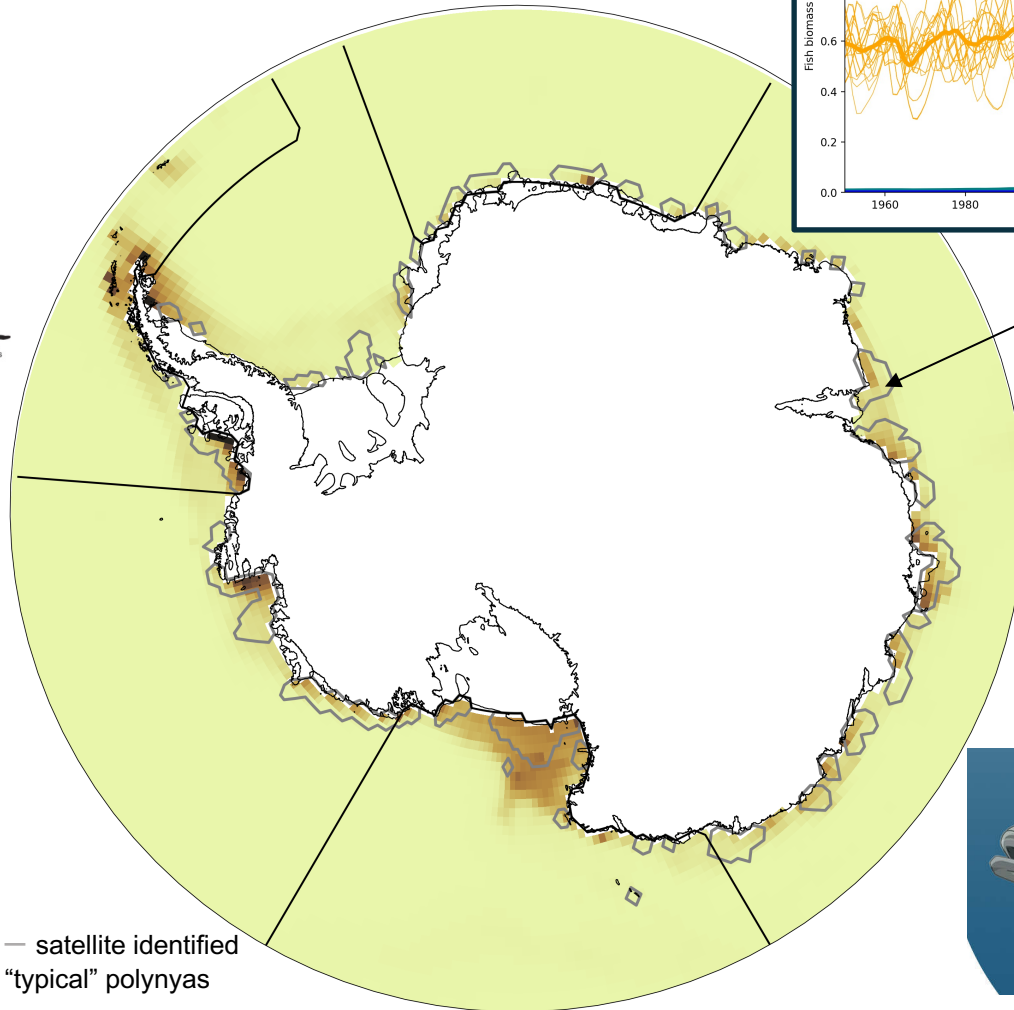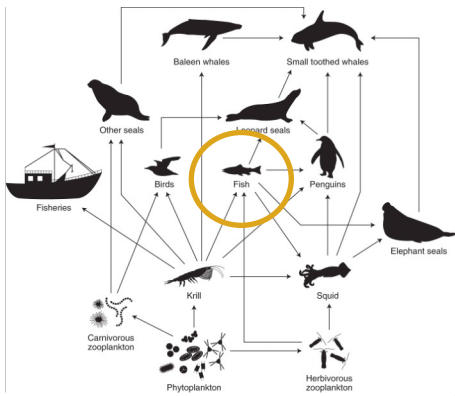*From Atkinson et al. 2006 (https://www.doi.org/10.4319/lo.2006.51.2.0973)*

— satellite identified "typical" polynyas

Data from DuVivier et al. (in prep)

mm/year

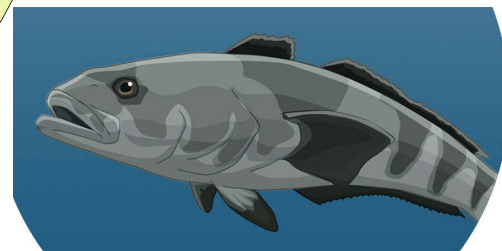*Illustration: Kristen Krumhardt*

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Demersal Fish Biomass
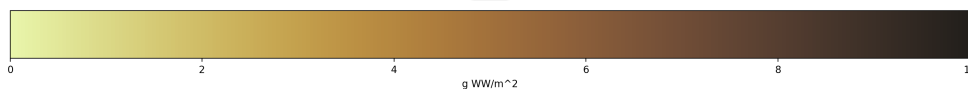
CESM2-MARBL
+
FEISTY

Demersal fish →
Antarctic toothfish-like
- seal prey
- fishery species

― satellite identified
"typical" polynyas

Data from
DuVivier et al. (in prep)

g WW/m^2

Image: PEW Chaitable Trusts

duvivier@ucar.edu

Emperor Penguin Accessibility

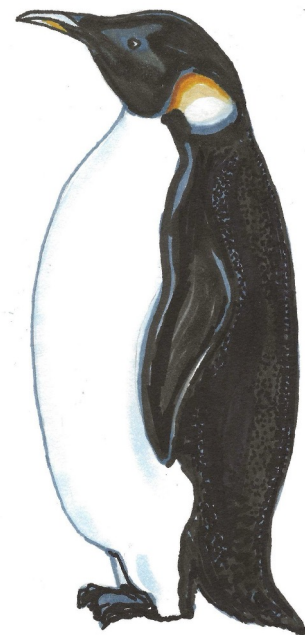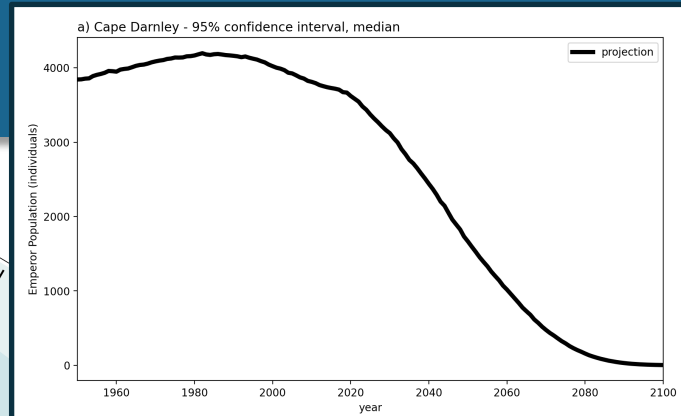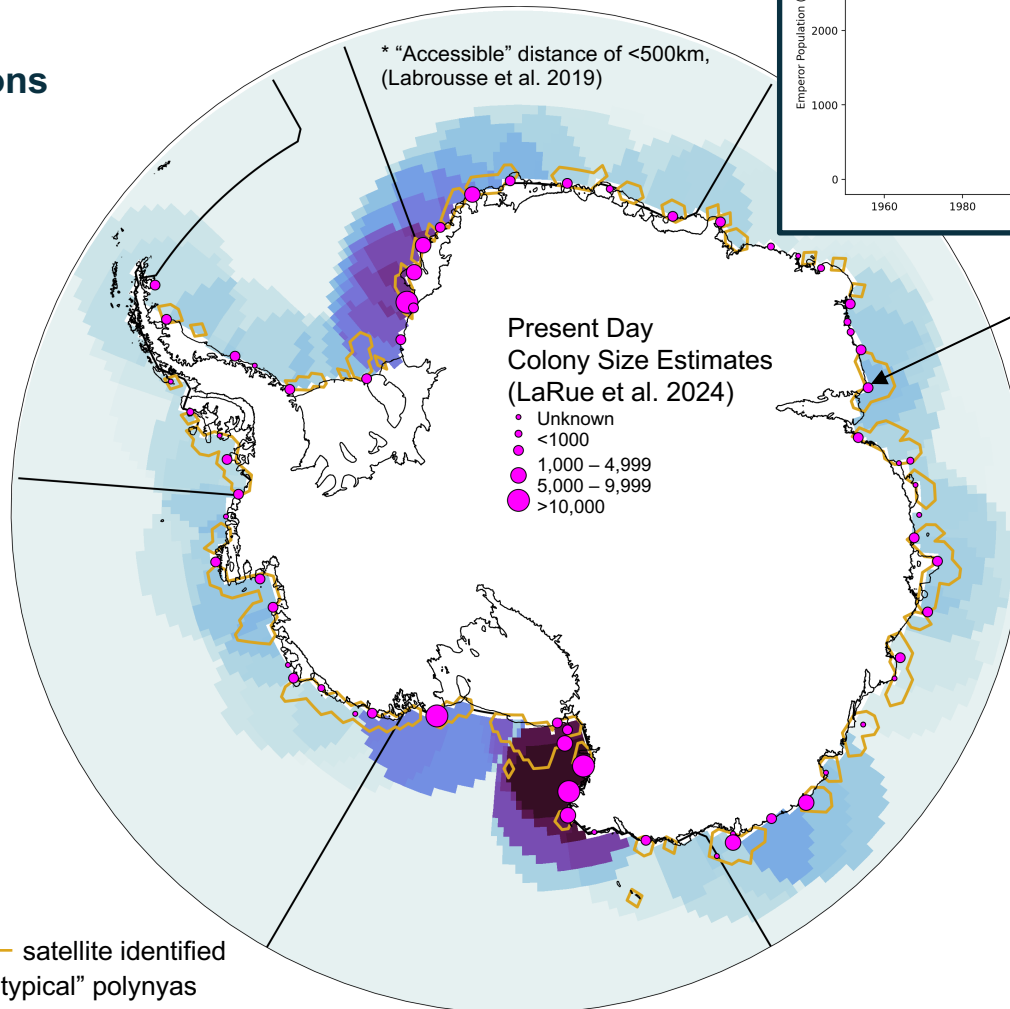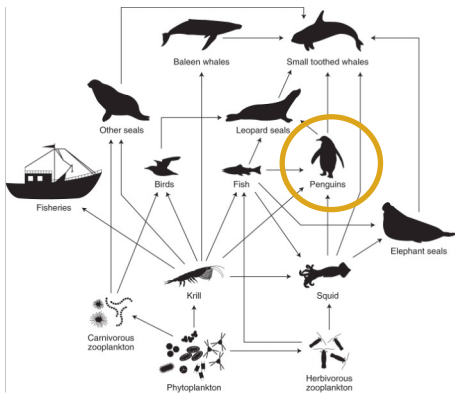**Demographic modeling using CESM2-LE environmental projections**

* "Accessible" distance of <500km, (Labrousse et al. 2019)

a) Cape Darnley - 95% confidence interval, median

Present Day
Colony Size Estimates
(LaRue et al. 2024)

- Unknown
- <1000
- 1,000 – 4,999
- 5,000 – 9,999
- >10,000

— satellite identified "typical" polynyas

penguins

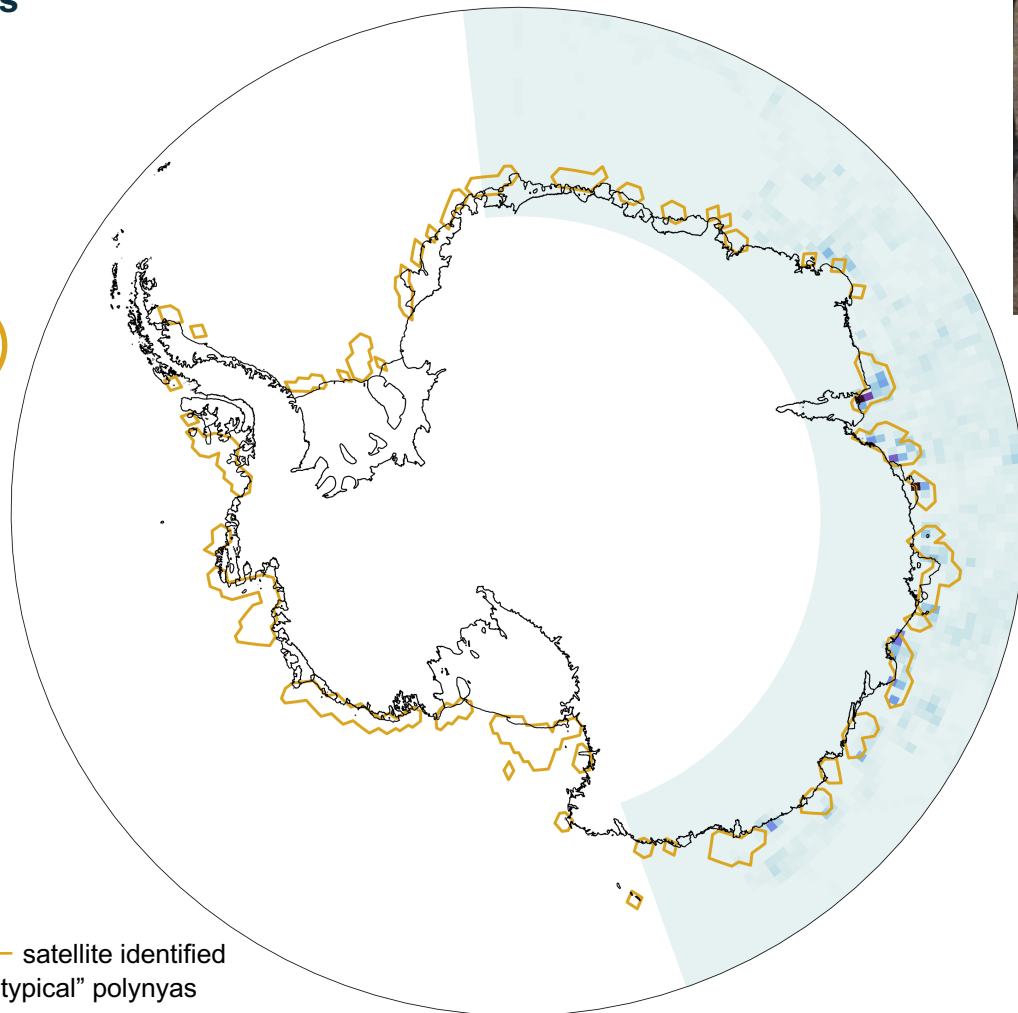*Data from DuVivier et al. (in prep)*

Illustration: Kristen Krumhardt

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Southern Elephant Seal Residence Time

In-situ seal observations*
* Not time varying

— satellite identified
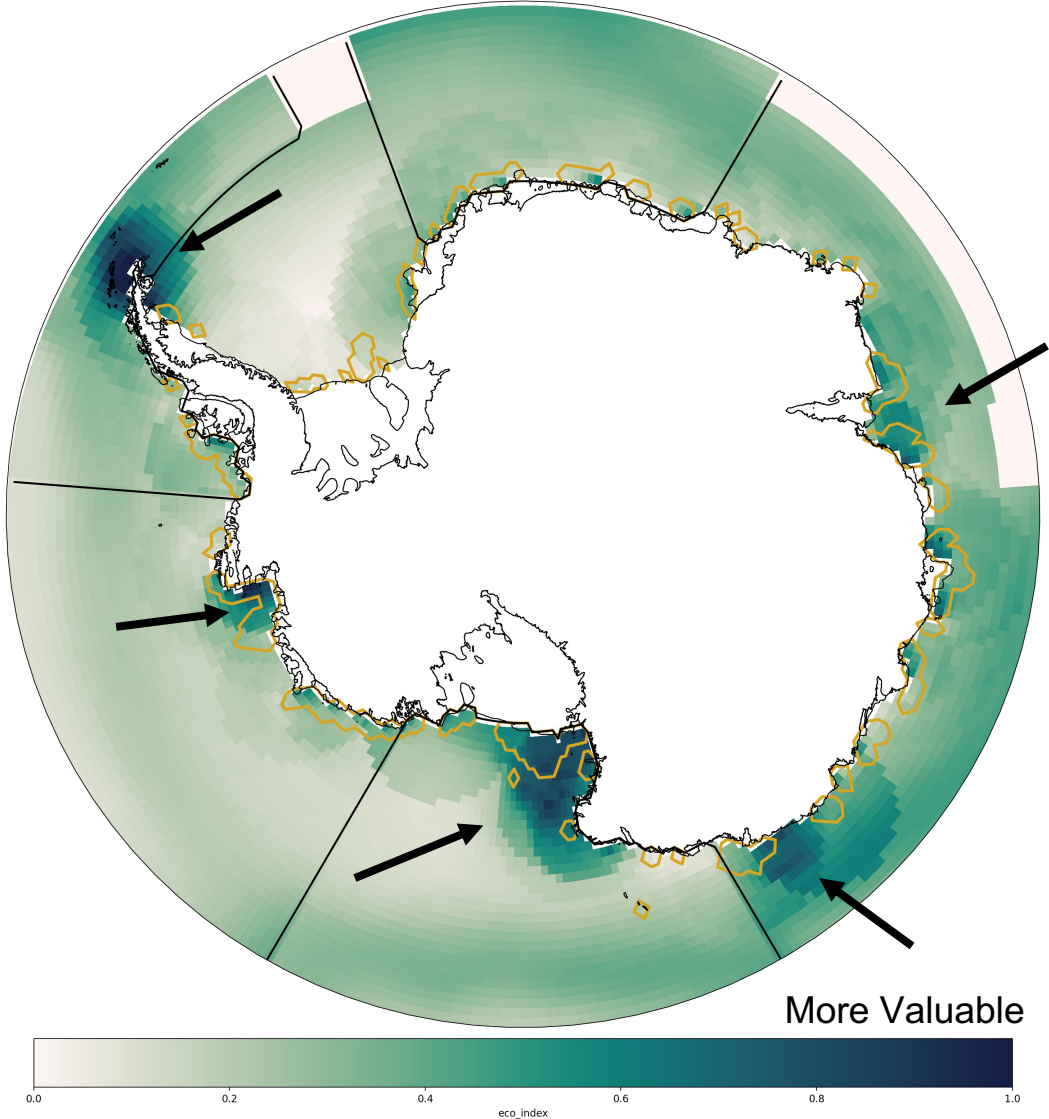"typical" polynyas

0   20   40   60   80   100
hours

Data from
DuVivier et al. (in prep)

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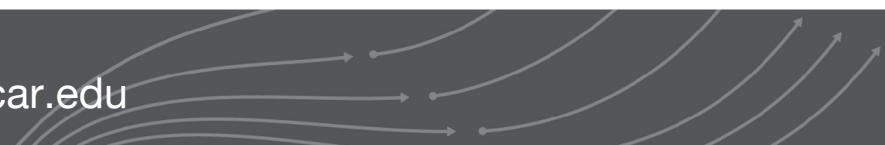# Ecosystem Index identifies areas of highest value over whole food web

Present Day

More Valuable

eco_index

duvivier@ucar.edu

duvivier@ucar.edu

Upcoming milestones

- OnlyOne tool development – Spring/Summer 2024
  - Science team has provided data and mapping files
  - OnlyOne is populating tool and building narrative content
- End user meeting – June 2024
  - Antarctic Treaty meeting – May 2024
- SCAR meeting in Chile – August 19-23, 2024
  - Workshop to get feedback on tool
  - Science team presenting results
- Finalize data layer inputs – Summer 2024
- CCAMLR working group meetings – Summer 2024
- CCAMLR annual meeting – October 2024
- OnlyOne ongoing tool development – 2024-2025
  - Finesse website
  - Create narrative content
- Complete science manuscripts – 2024-2025
- CCAMLR lunch event and tool launch – October 2025

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Thanks for your attention! Questions?
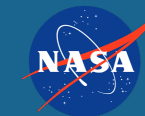
Thanks to the entire science team!

Alice DuVivier - NCAR

Laura Landrum - NCAR

Kristen Krumhardt - NCAR

Marika Holland - NCAR

Matt Long - NCAR

Stephanie Jenouvrier – WHOI

Francesco Ventura - WHOI

Bilgecan Sen – WHOI, UMCES

Sara Labrousse – L'OCEAN

University of Colorado Boulder

Zephyr Sylvester – CU Boulder

Cassandra Brooks – CU Boulder

Michelle LaRue – Uni. of Canterbury

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Lucie Bourreau – L'OCEAN

Marthe Vienne – L'OCEAN

duvivier@ucar.edu

Extra slides
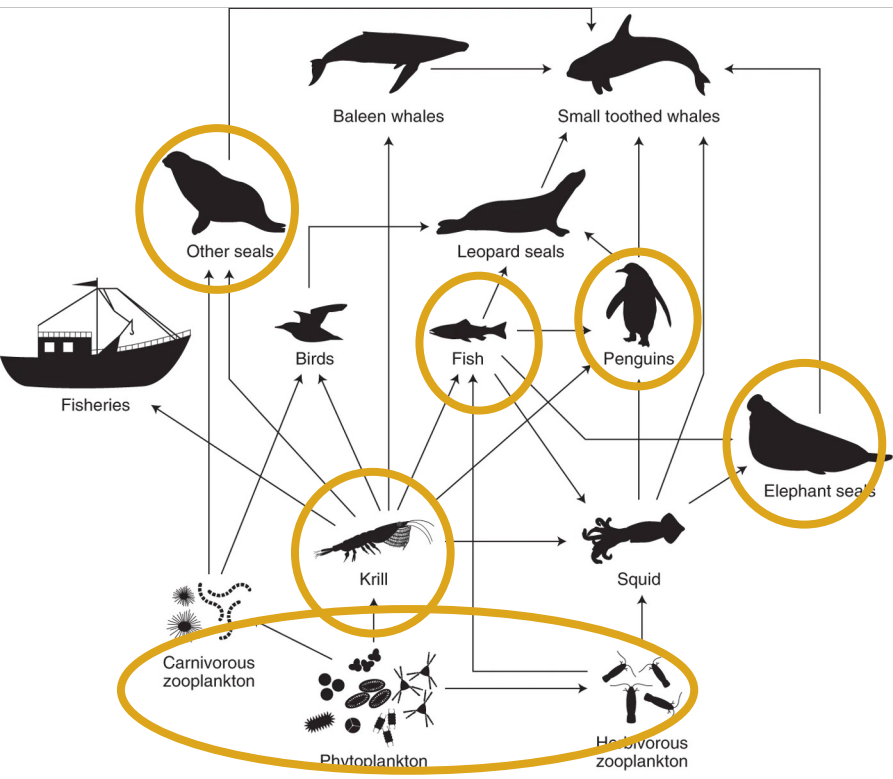
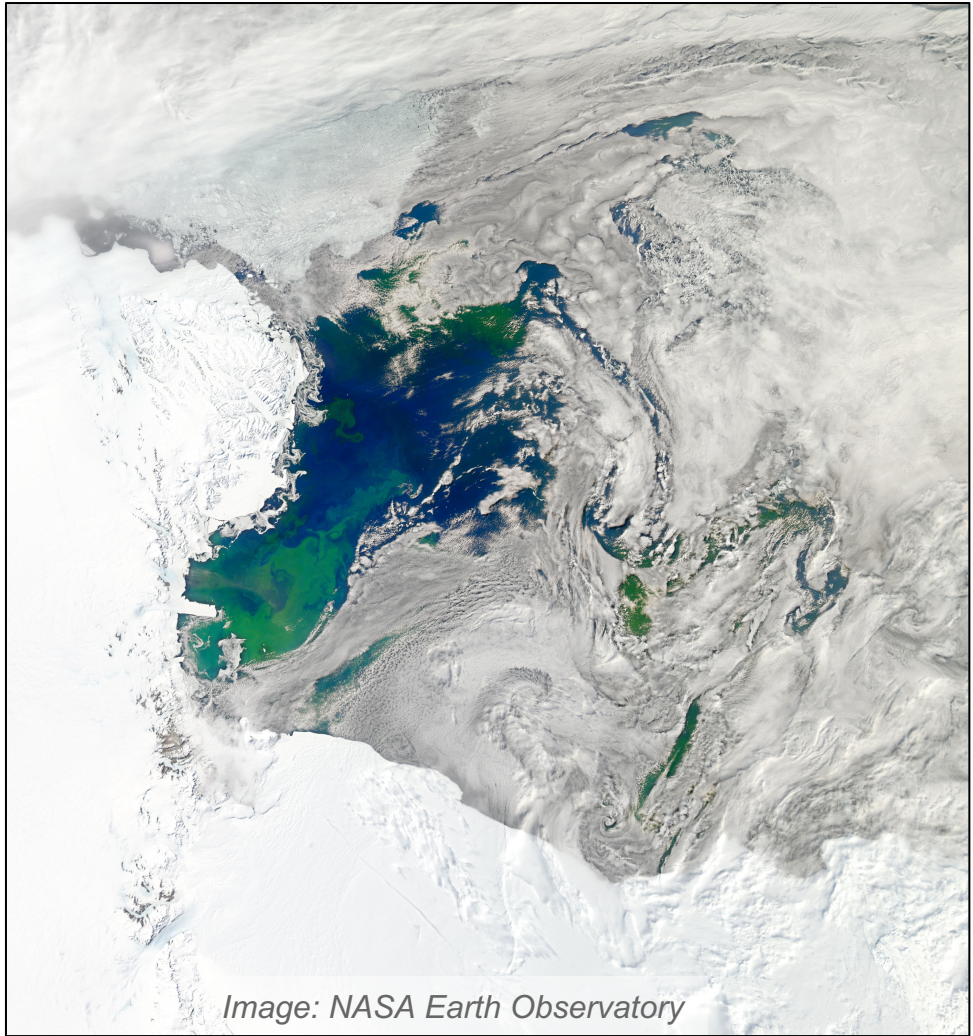# How important are polynyas for the Antarctic ecosystem?

Image: McBride et al. 2019

Image: NASA Earth Observatory

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Polynya: Area bounded by land or sea ice that has lower sea ice concentration than surrounding region

Terra Nova Bay Polynya
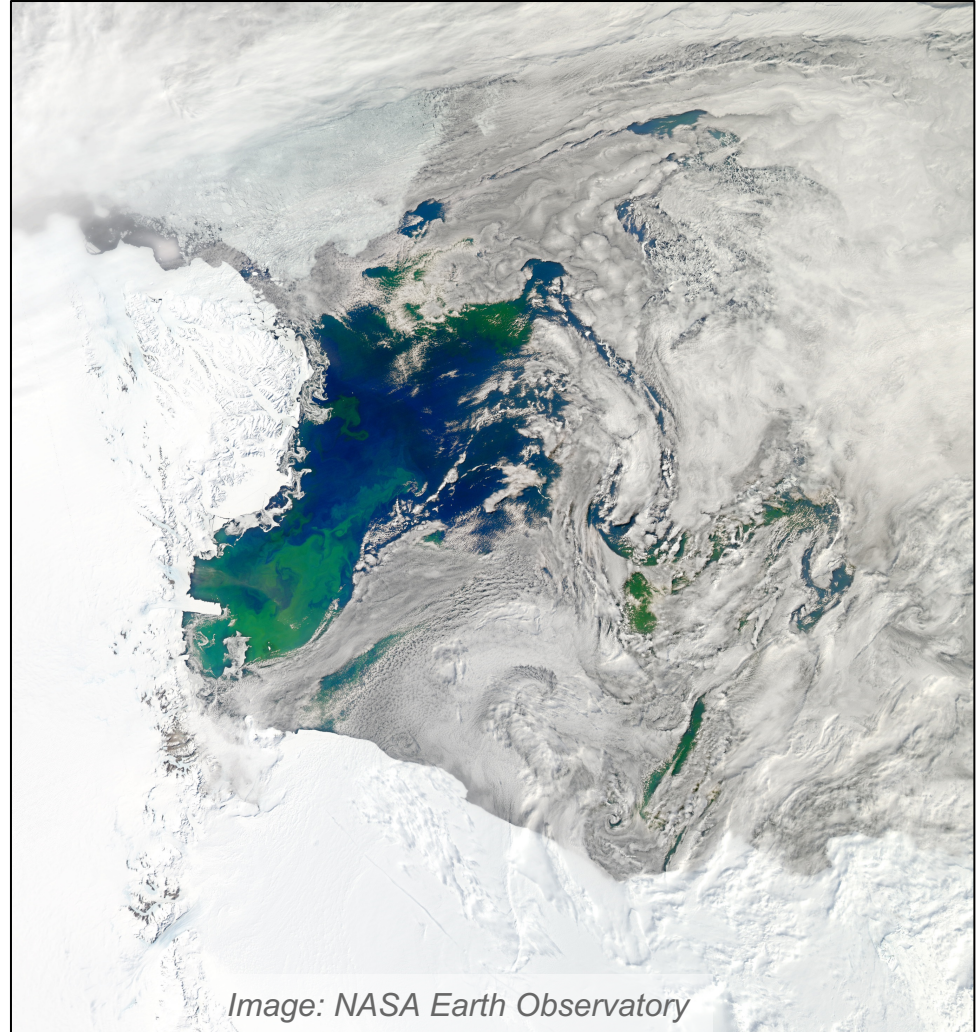
Ross Sea Polynya

Image: NASA Earth Observatory


Image: NASA Earth Observatory

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| Input layer	Long name	Reference time	Time Varying?	Years	Data source
Poly	Polynyas	Winter or annual? TBD…	Y	1979-2023 1950-2100	Satellite SSMI & CESM2-LE
NPP	Phytoplankton net primary productivity	Growth season integrated	Y	1950-2100	CESM2-LE
KGP	Krill growth potential	Growth season integrated	Y	1950-2100	CESM2-LE + empirical
TL3	Trophic level 3 (all predators – penguin, seal, whale, etc.)	Growth season integrated	Y	1950-2100	CESM2-LE + known relationship
Forage	FEISTY forage biomass (silverfish like)	Annual mean	Y	1950-2100	CESM2-LE + FEISTY
Demersal	FEISTY demersal biomass (toothfish like)	Annual mean	Y	1950-2100	CESM2-LE + FEISTY
Benthic	FEISTY benthic biomass	Annual mean	Y	1950-2100	CESM2-LE + FEISTY
Emp	Emperor Penguin population	Annual	Y	1950-2100	CESM2-LE + Steph model
Adel	Adelie Penguin population	Annual (ish?)	Y	1950-2100	CESM2-LE + Bilgecan model
SES	Southern Elephant Seal residence time	Summer?	N		In situ sensors
Wed	Weddell Seal location	?	N		Michelle Satellite
Crab	Crabeater Seal population	Dropped	Dropped	Dropped	Dropped

Identifying polynyas is not trivial!

CESM (1°)
thresh: SIT = 40cm
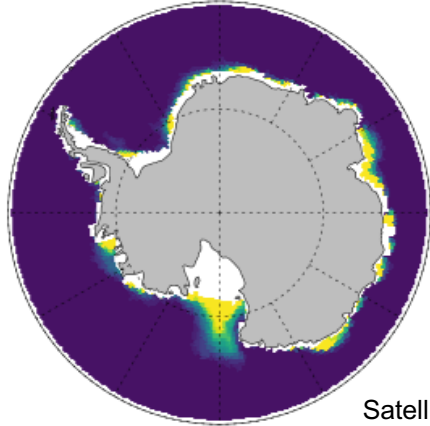
CESM (1°)
thresh: SIC = 85%
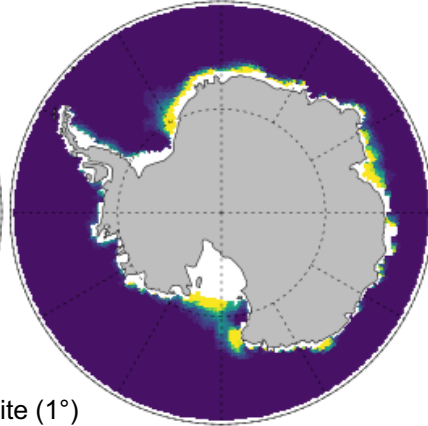
Satellite (1°)
thresh: SIC = 85%
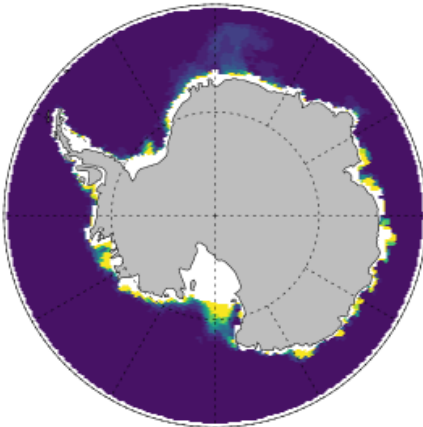
We developed a polynya ID tool that is reproducible, verifiable, and applicable to both satellite and model gridded data using sea ice concentration (SIC) or sea ice thickness (SIT).

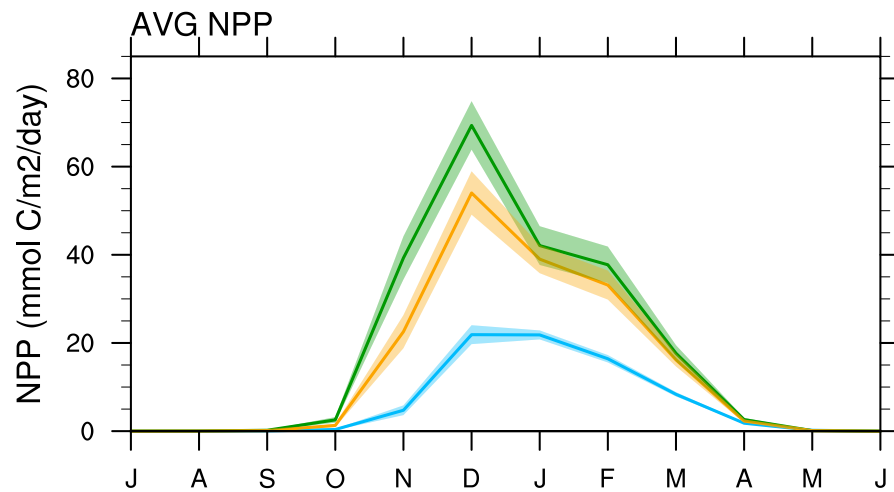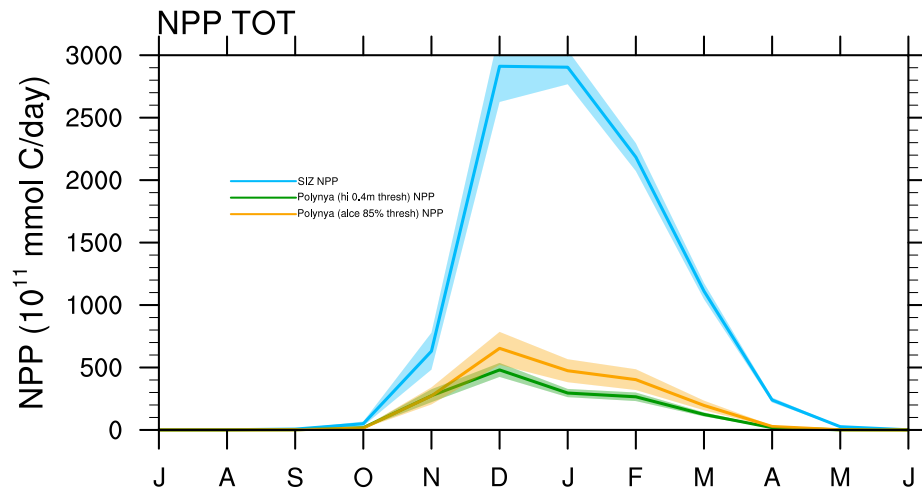More often identified as "polynya"

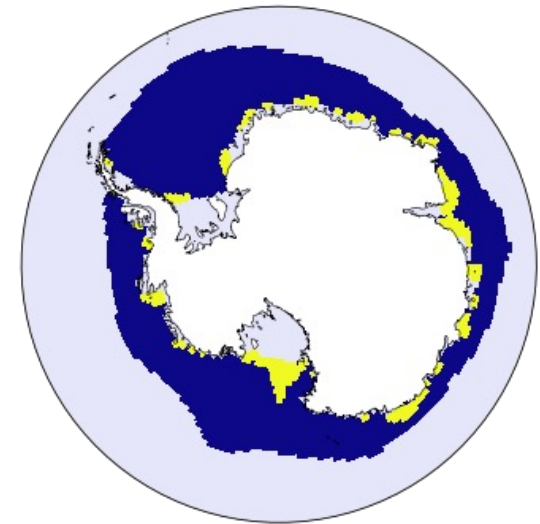0   0.01   0.02   0.03   0.04   0.05   0.06   0.07   0.08   0.09   0.1

Fraction of Year

Data from Landrum et al. (in prep)

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NPP TOT

SIZ NPP
Polynya (hi 0.4m thresh) NPP
Polynya (alce 85% thresh) NPP

AVG NPP
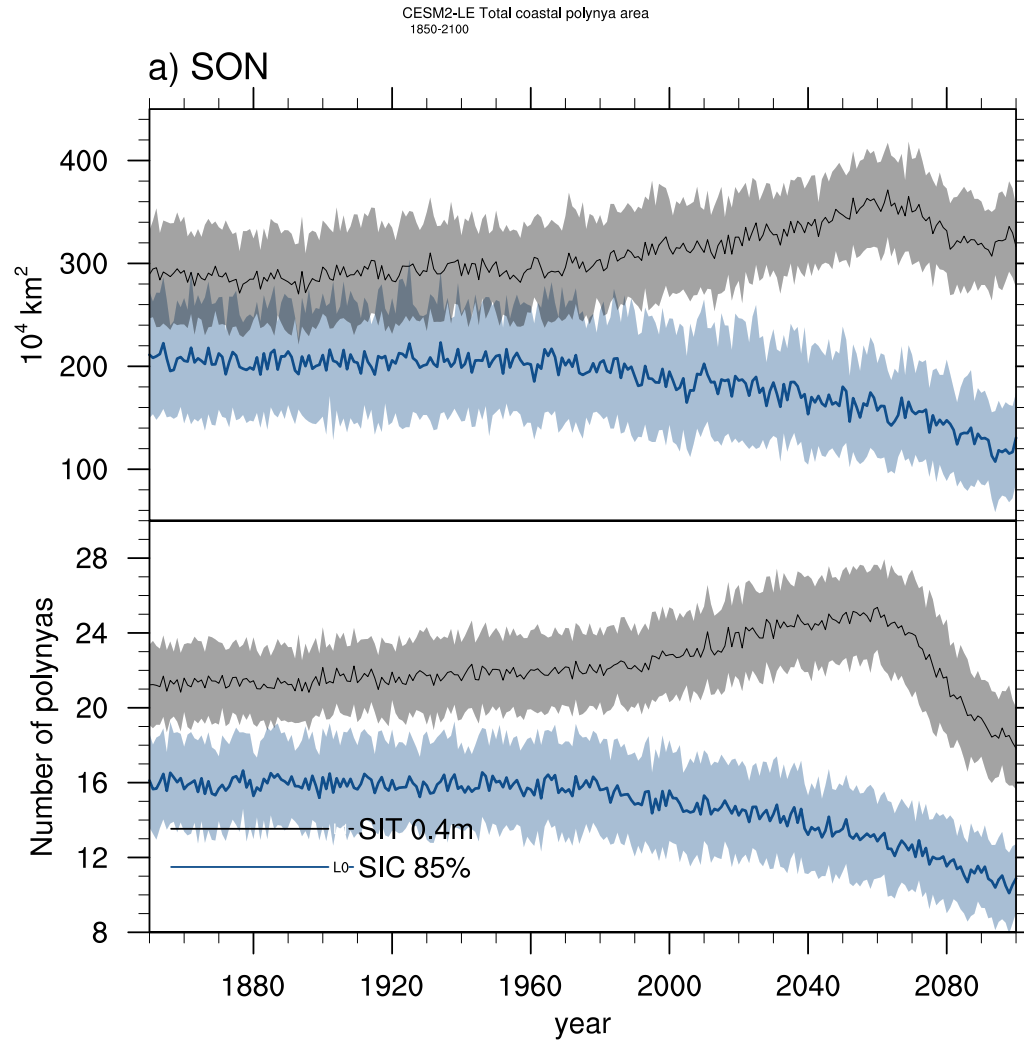
Polynya Area Mask:
(area with a polynya > 10% of year)

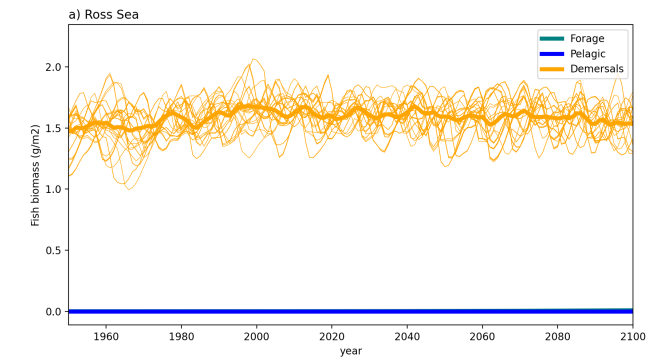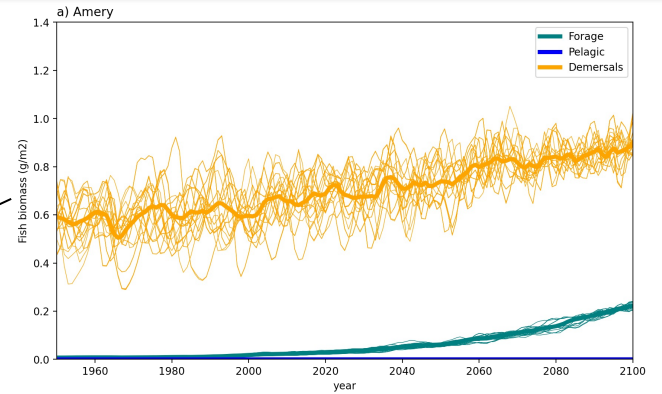polynya area: ~759416521500.0 m²
or approx ~7.72 % of the SIZ (~9831650056100.0 m²)

How Polynyas are changing over time

CESM2-LE Total coastal polynya area
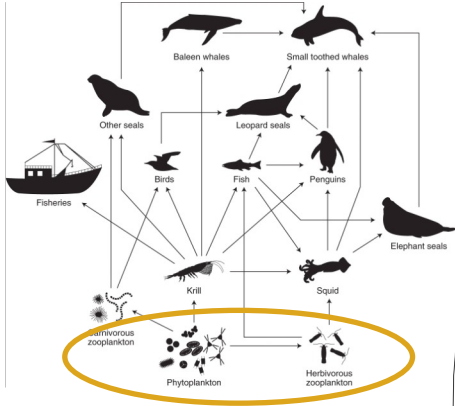1850-2100

a) SON

SIT 0.4m
SIC 85%

FEISTY projections
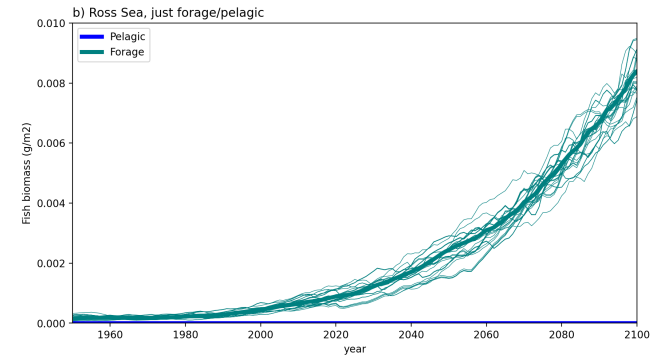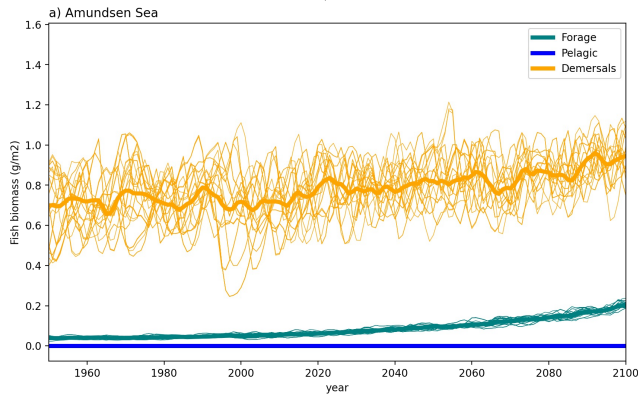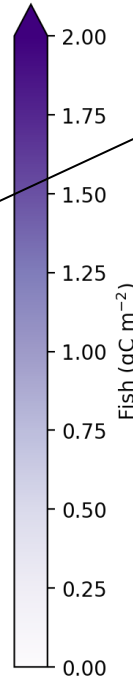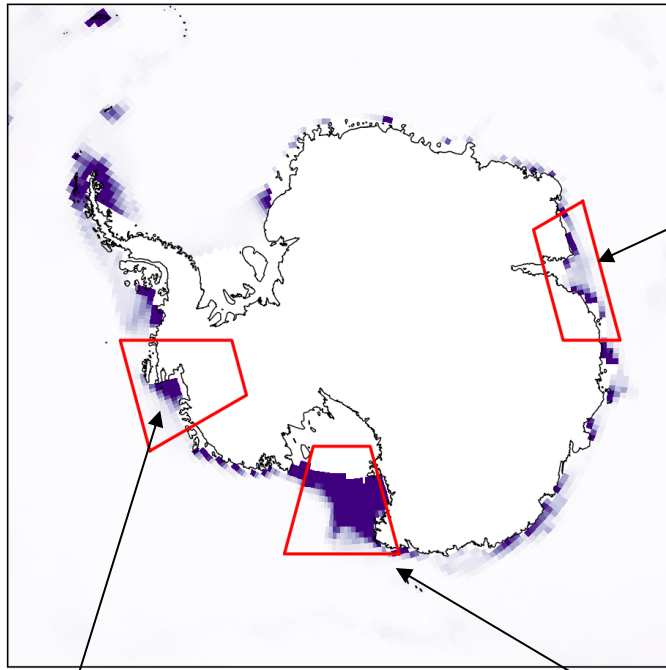
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Net Primary Productivity (NPP)

CESM2-MARBL

a) Amery

— satellite identified
"typical" polynyas

mol/m2/year
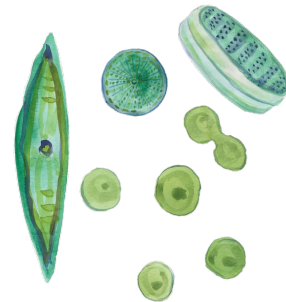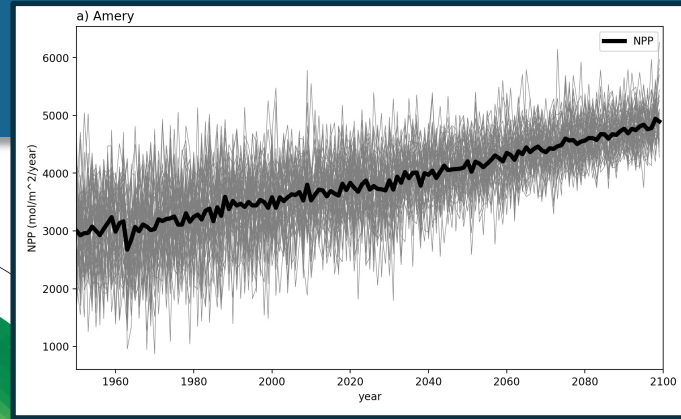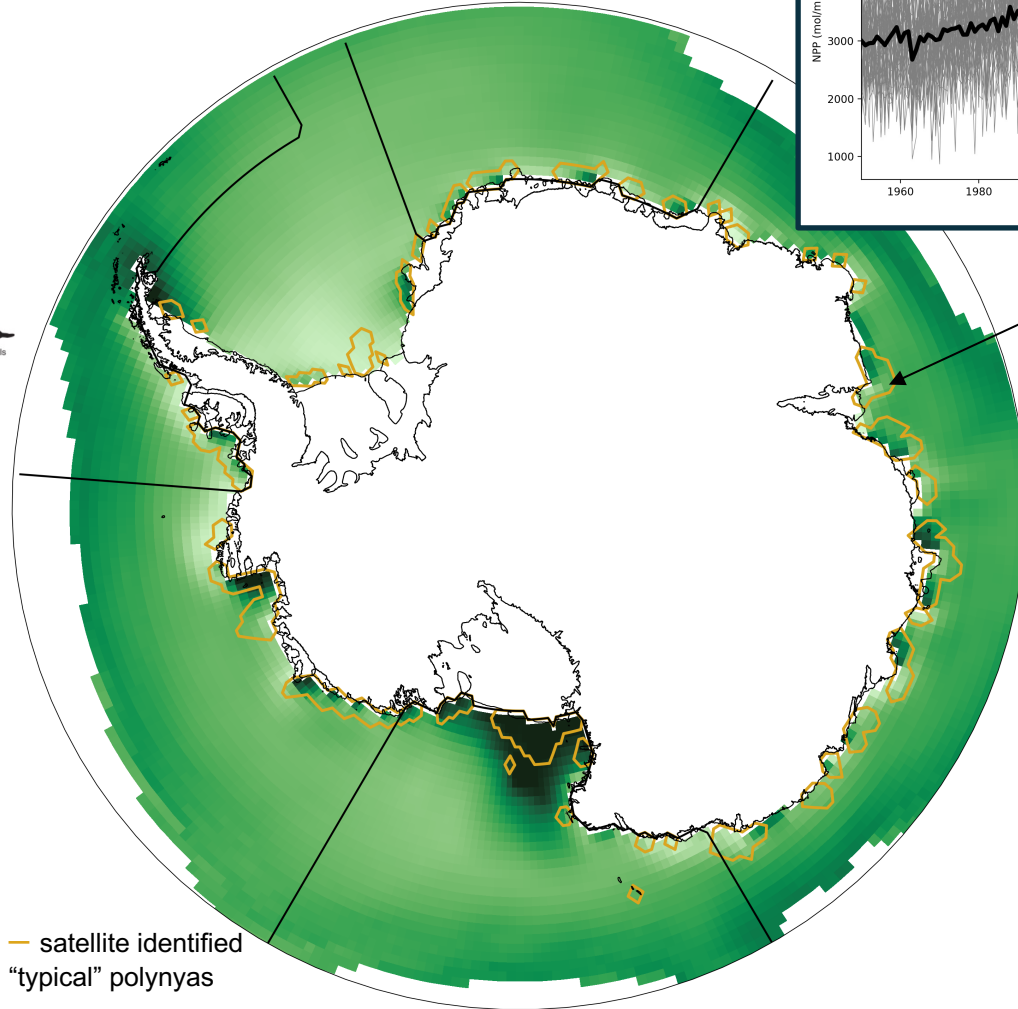
*Data from
DuVivier et al. (in prep)*

Illustration: Kristen Krumhardt

duvivier@ucar.edu

Krill Growth Potential (KGP)
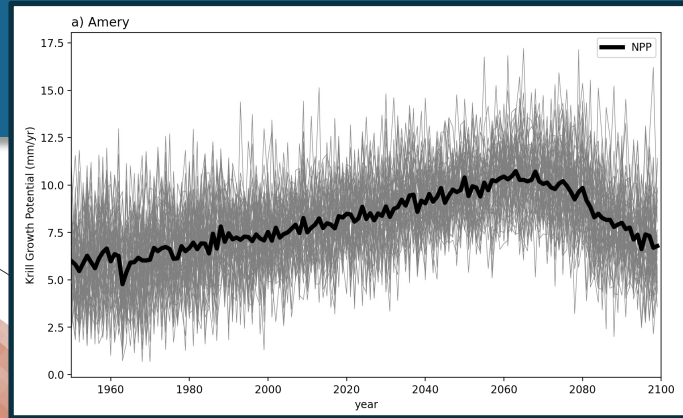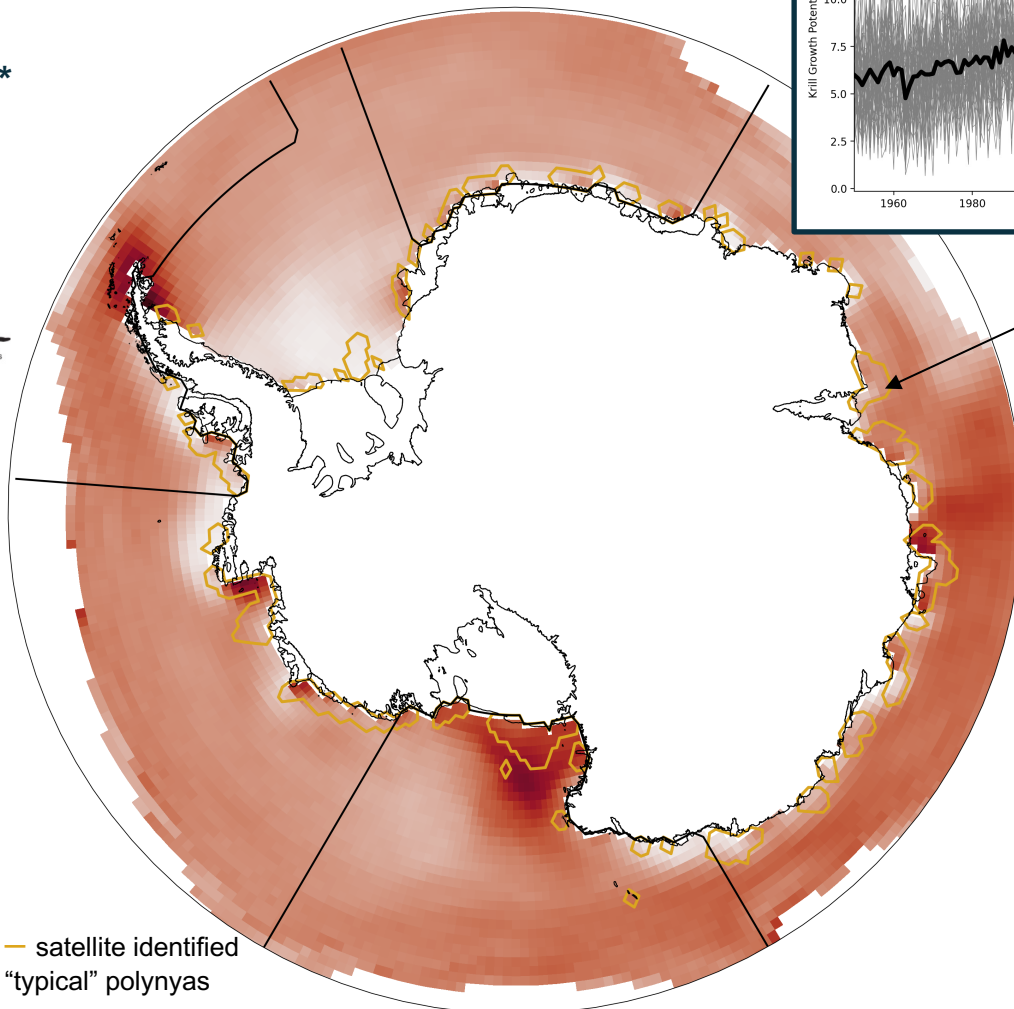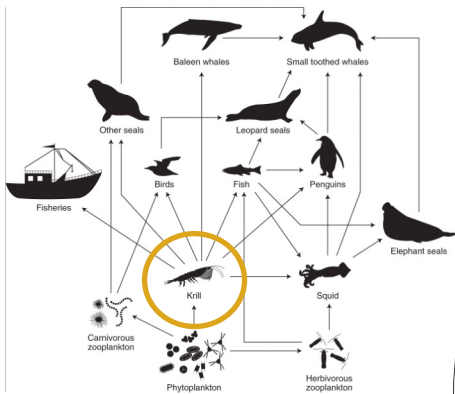
CESM2-MARBL
+
Empirical Relationship*

a) Amery

* Antarctic krill (Euphausia superba) empirically derived growth potential:

KGP = LEN$_0$ + CHL$_{sfc}$ + SST

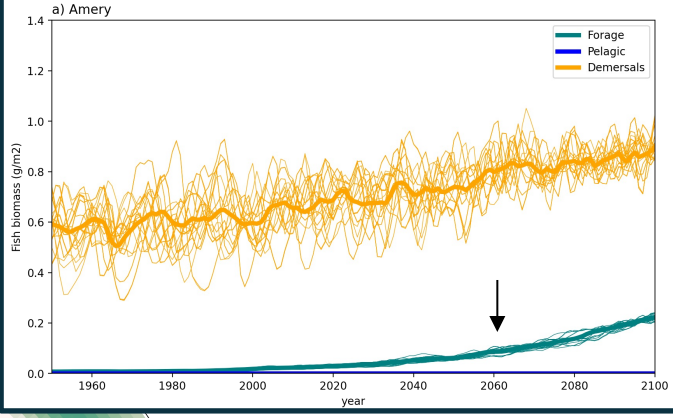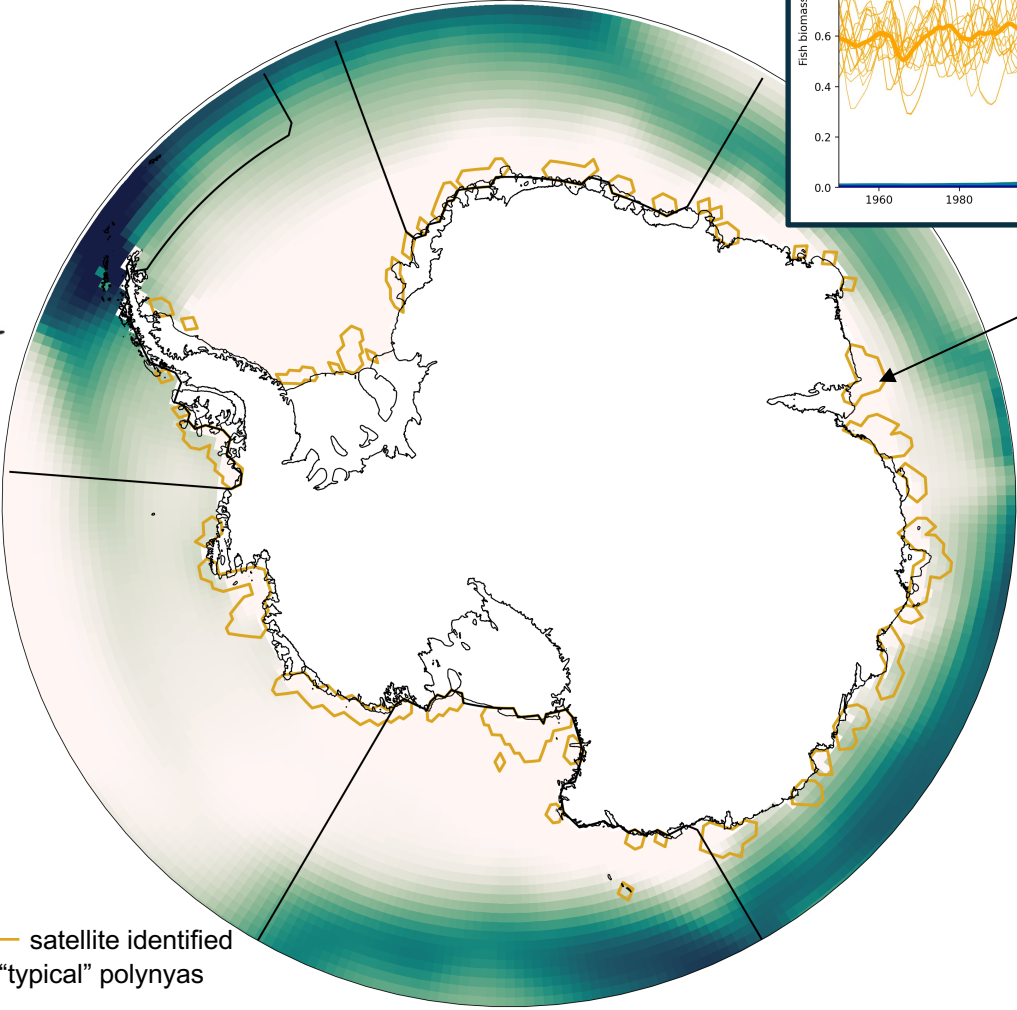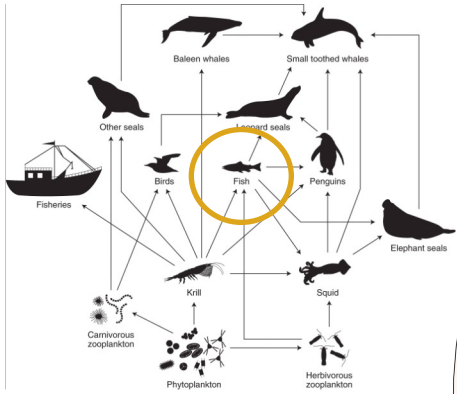*From Atkinson et al. 2006 (https://www.doi.org/10.4319/lo.2006.51.2.0973)*

— satellite identified "typical" polynyas

Data from DuVivier et al. (in prep)

mm/year

Illustration: Kristen Krumhardt

duvivier@ucar.edu

Forage Fish Biomass

CESM2-MARBL
+
FEISTY

Forage fish → Antarctic silverfish-like
- Penguin prey
- seal prey

— satellite identified "typical" polynyas
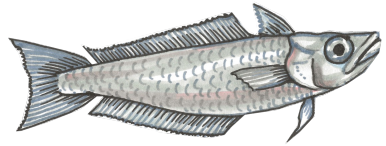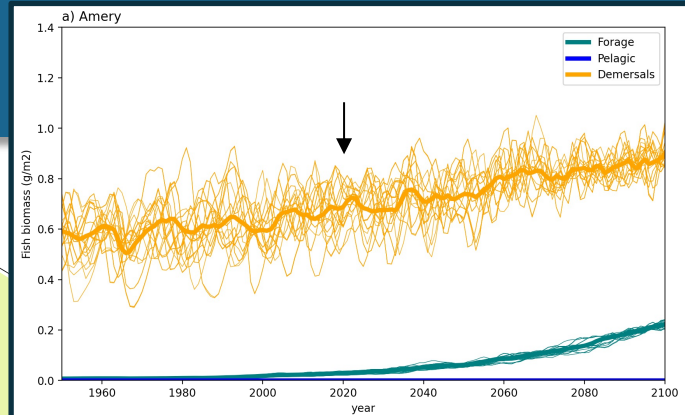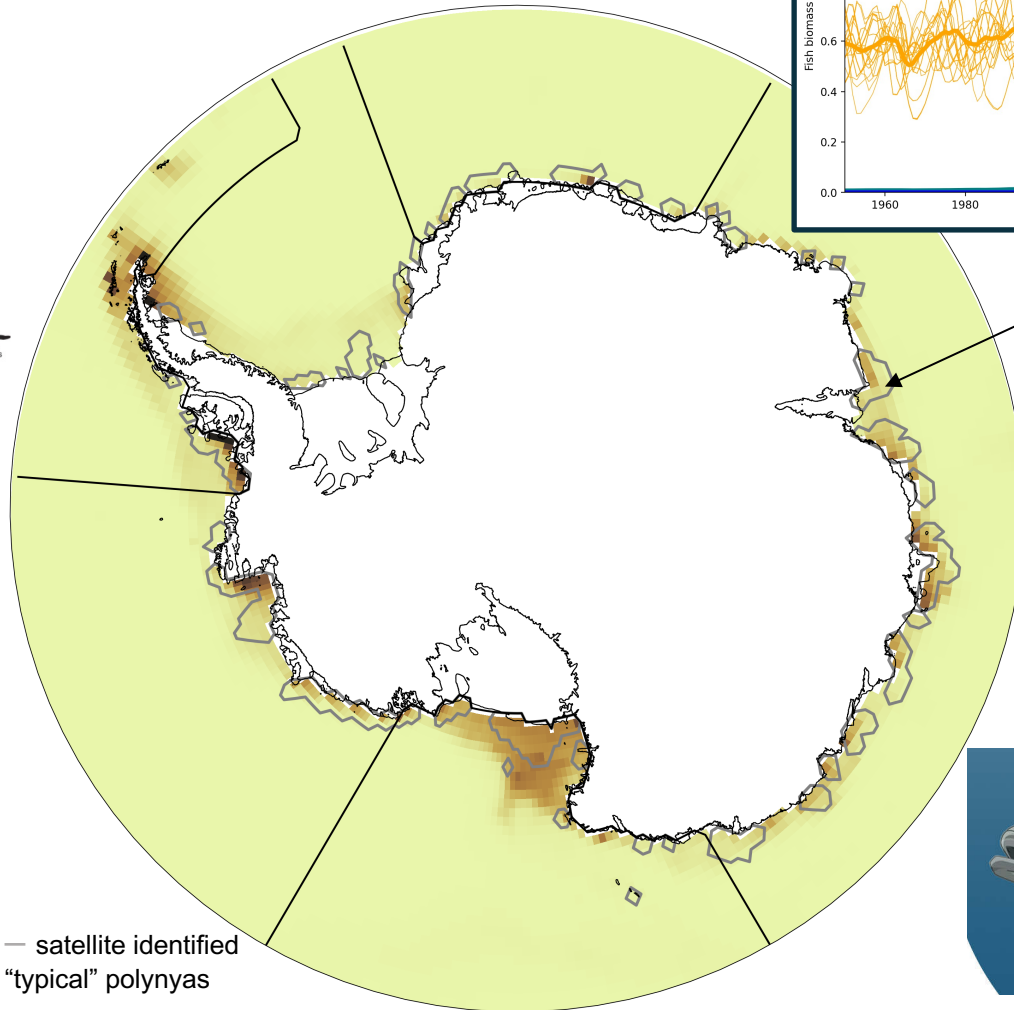
Data from DuVivier et al. (in prep)

g WW/m^2

a) Amery

Fish biomass (g/m2)

- Forage
- Pelagic
- Demersals

year

Illustration: Kristen Krumhardt

duvivier@ucar.edu

Demersal Fish Biomass

CESM2-MARBL
+
FEISTY

Demersal fish →
Antarctic toothfish-like
- seal prey
- fishery species

— satellite identified
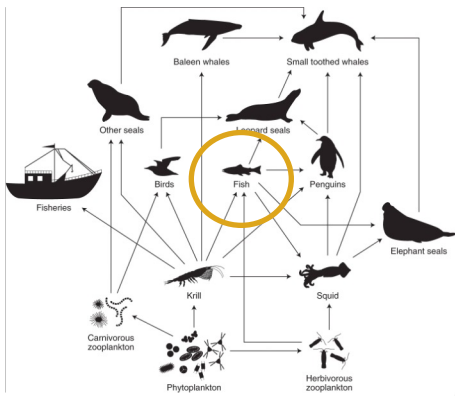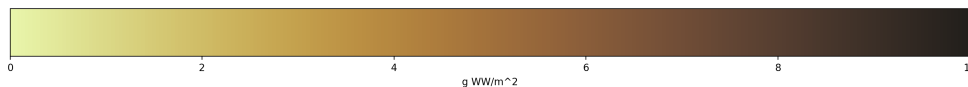"typical" polynyas

Data from
DuVivier et al. (in prep)

g WW/m^2

Image: PEW Chaitable Trusts

duvivier@ucar.edu

Emperor Penguin Accessibility

Demographic modeling using CESM2-LE environmental projections

a) Cape Darnley - 95% confidence interval, median

* "Accessible" distance of <500km, (Labrousse et al. 2019)

Present Day
Colony Size Estimates
(LaRue et al. 2024)

Colony Size:
- Unknown
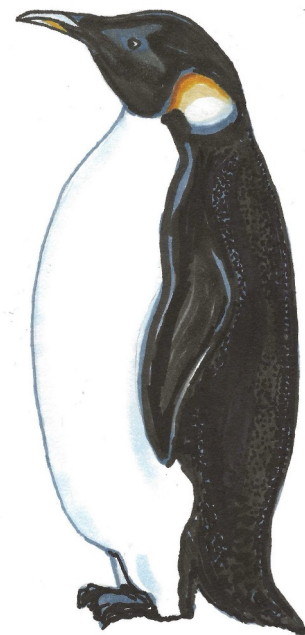- <1000
- 1,000 – 4,999
- 5,000 – 9,999
- >10,000

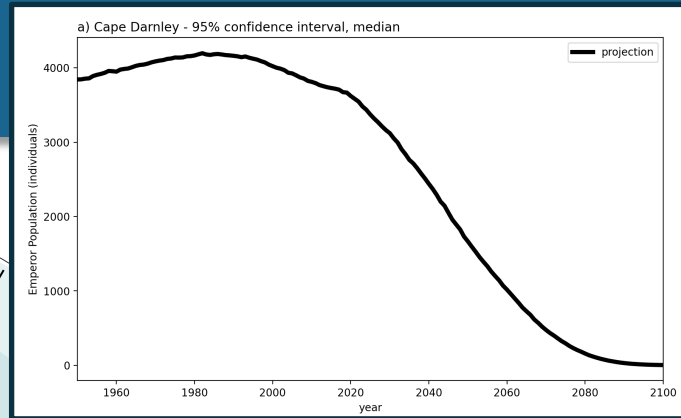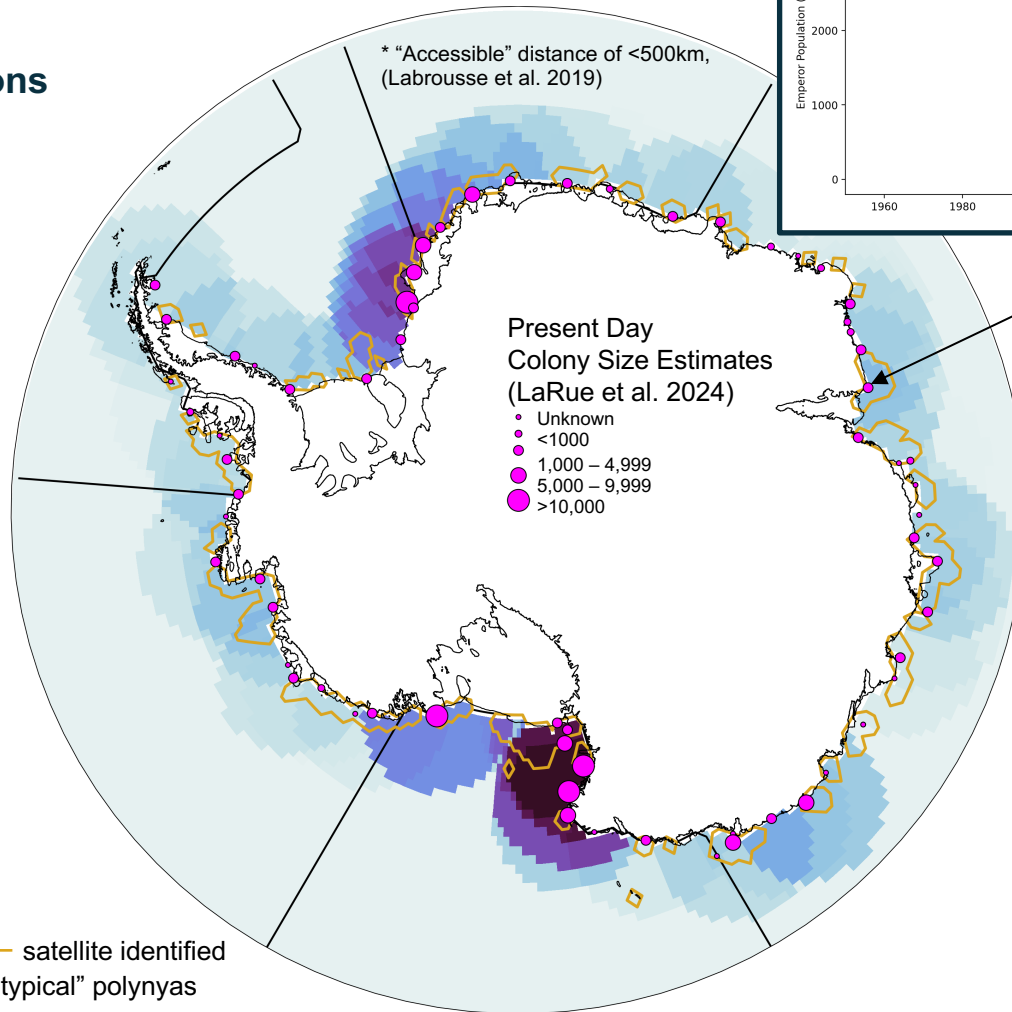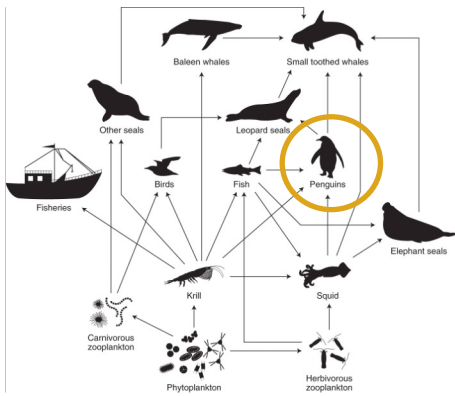— satellite identified "typical" polynyas

penguins
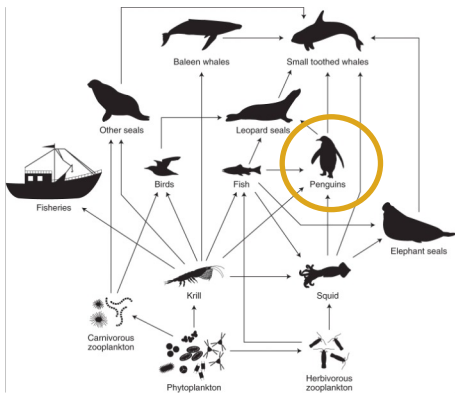
Illustration: Kristen Krumhardt

Data from DuVivier et al. (in prep)

duvivier@ucar.edu

Adelie Penguin Accessibility

Demographic modeling using CESM2-LE environmental projections

Projections in progress….

* "Accessible" distance of <300km, (Labrousse et al. 2019)

Present Day
Colony Size Estimates
(Lynch and LaRue et al. 2014)
- Unknown
- <2000
- 2,000 – 19,999
- 20,000 – 99,999
- >100,000

— satellite identified "typical" polynyas

penguins

0   100000   200000   300000   400000   500000   600000   700000
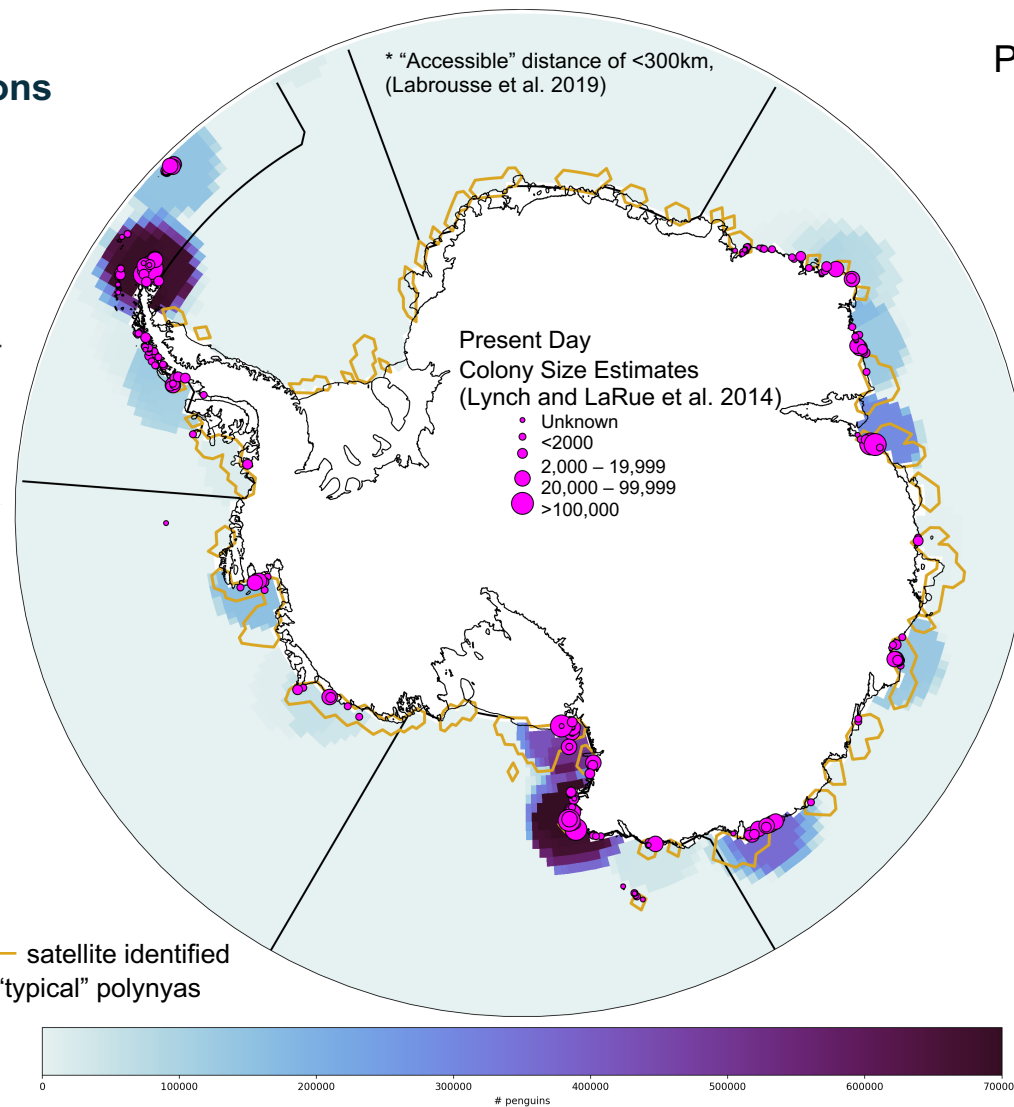
Illustration: Kristen Krumhardt

Data from DuVivier et al. (in prep)

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Weddell Seal Accessibility

Satellite seal observations*
* Not time varying

Present Day
Observations
(LaRue et al.)
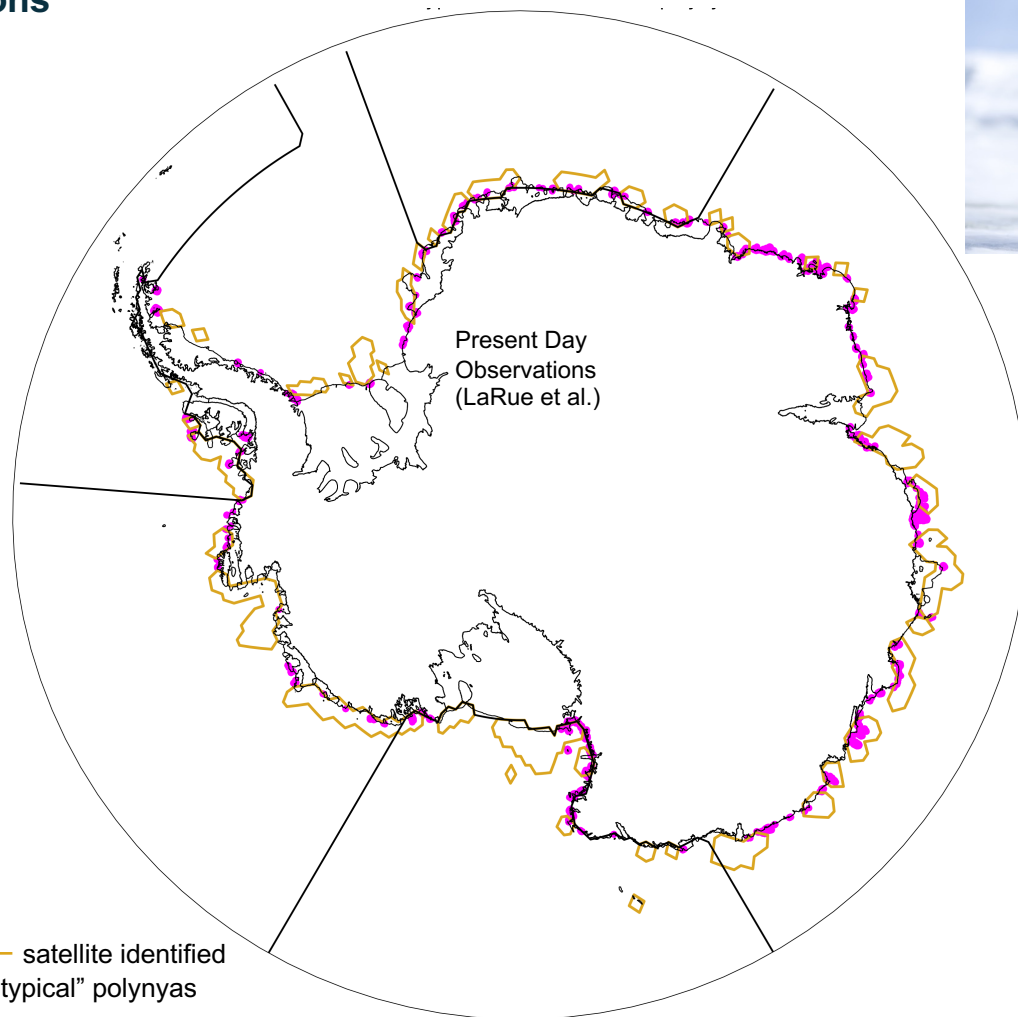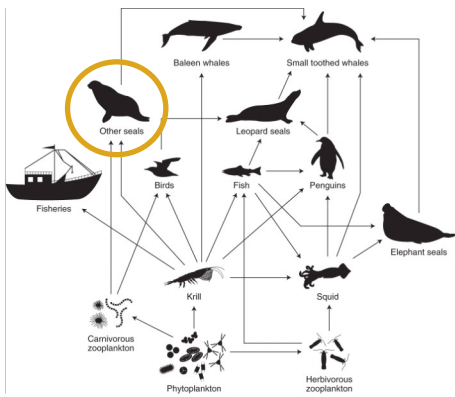
Still in discussion ….

* "Accessible" distance of <100km

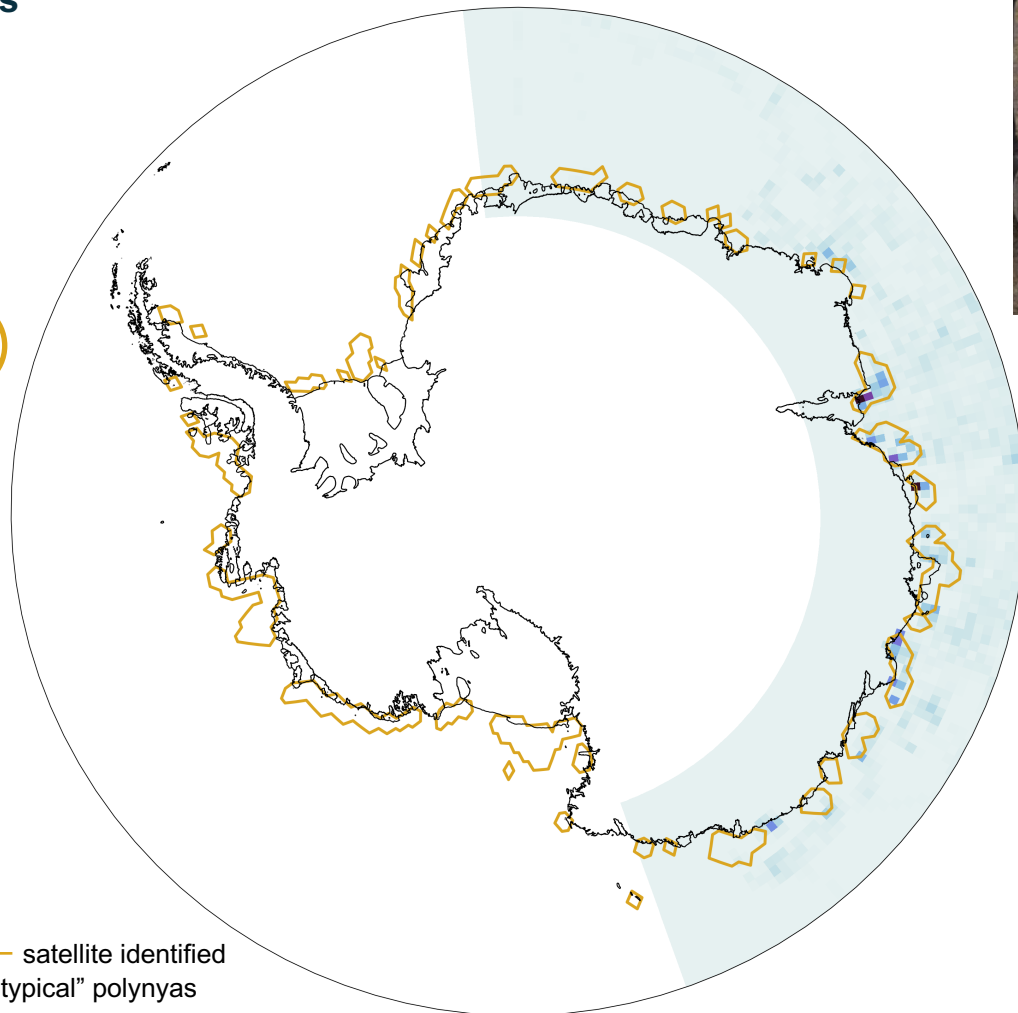— satellite identified
"typical" polynyas

Data from
DuVivier et al. (in prep)
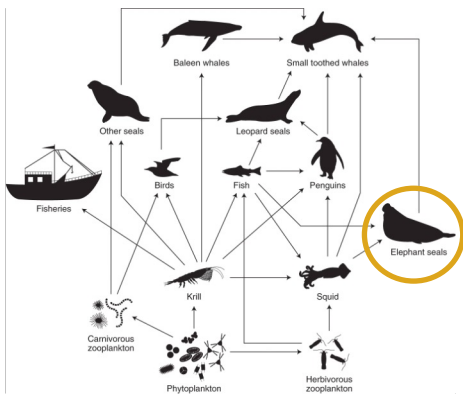
duvivier@ucar.edu

Southern Elephant Seal Residence Time

In-situ seal observations*
* Not time varying

— satellite identified "typical" polynyas

Data from
DuVivier et al. (in prep)

0   20   40   60   80   100
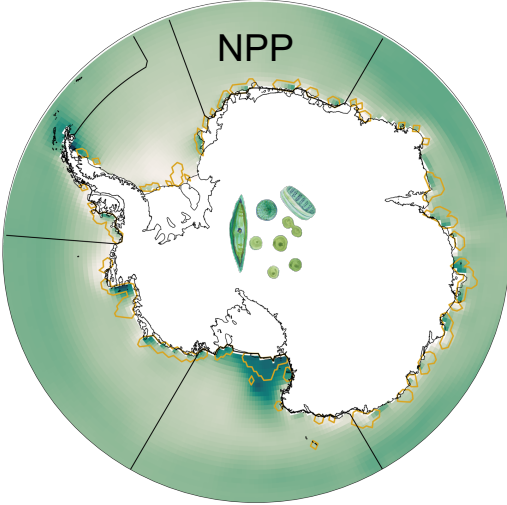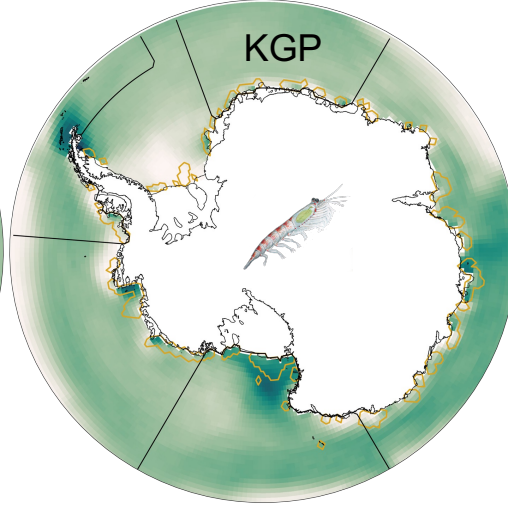hours

duvivier@ucar.edu

Combining the different ecosystem levels into an Ecosystem Index
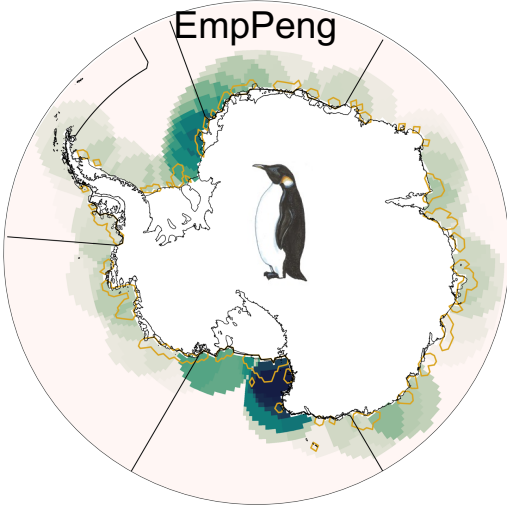

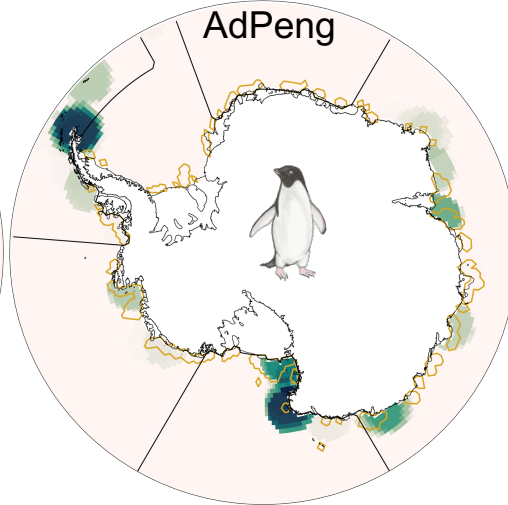2020 Eco-Index: NPP input

NPP

2020 Eco-Index: KGP input

KGP

2020 Eco-Index: EP input

EmpPeng

2020 Eco-Index: AP input

AdPeng

$$EI_{ij} = \frac{\left(\dfrac{NPP_{ij}}{NPP_{max}} + \dfrac{KGP_{ij}}{KGP_{max}} + \dfrac{EP_{ij}}{EP_{max}} + \dfrac{AP_{ij}}{AP_{max}} \right)}{n_{layers}}$$
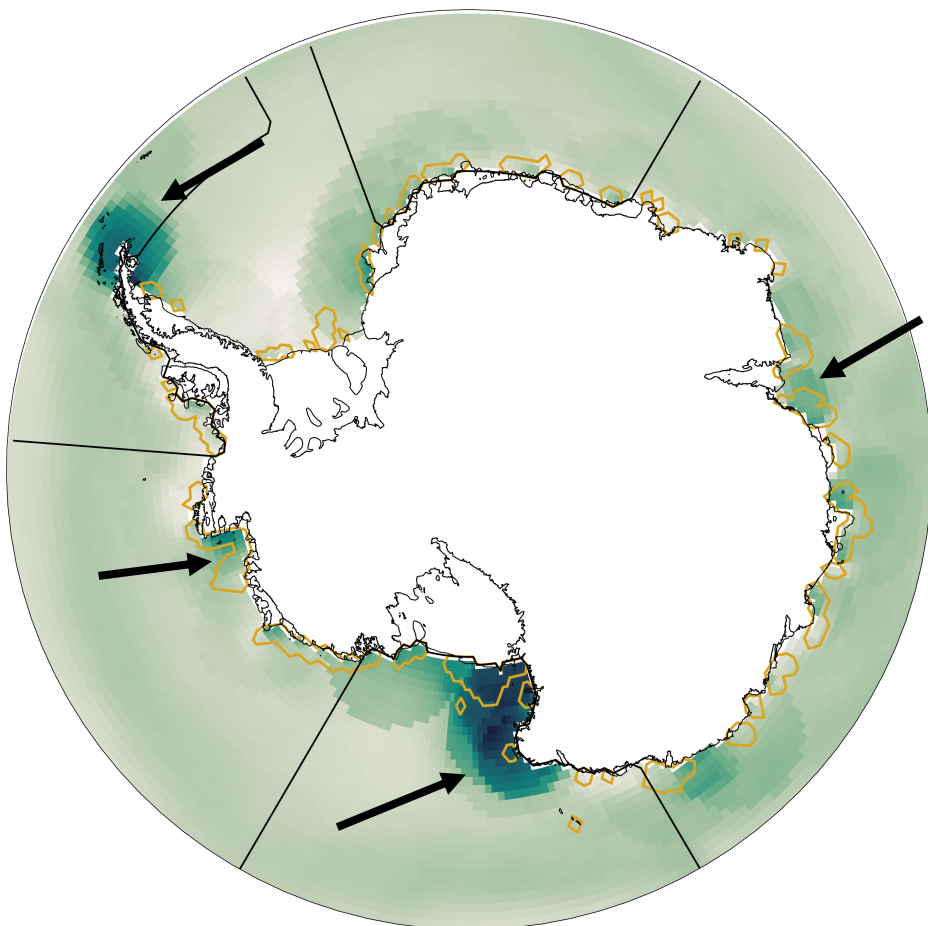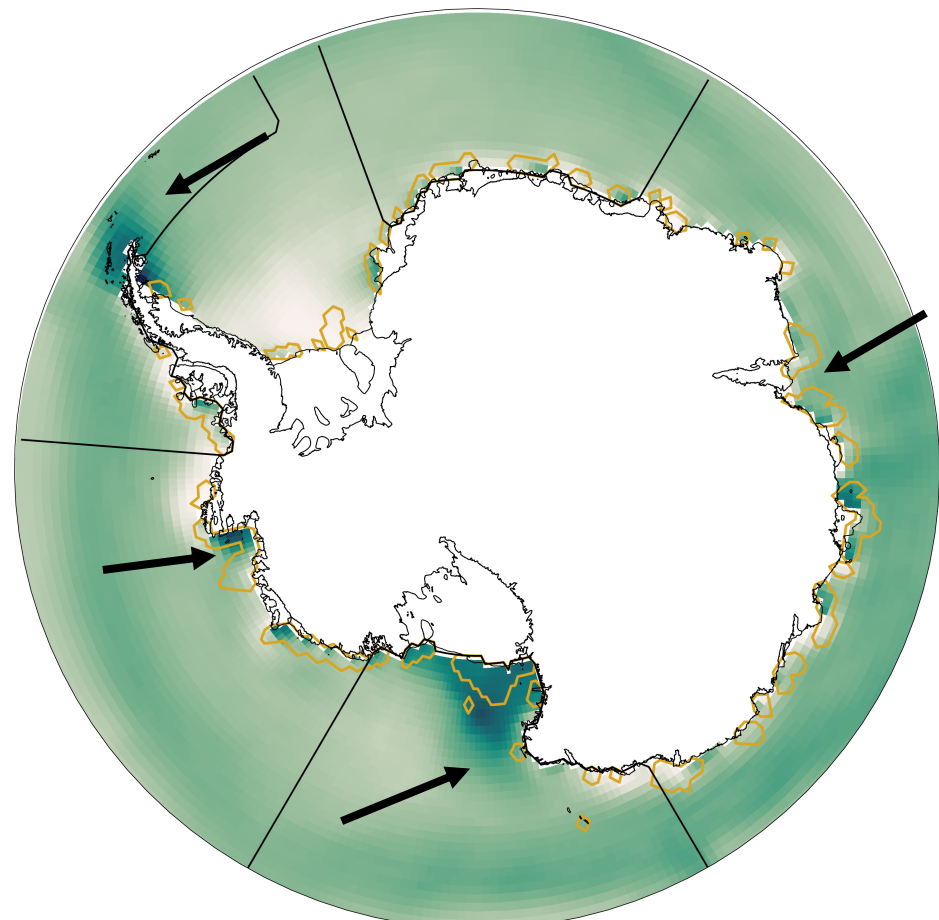
(Showing present day only)

duvivier@ucar.edu

Present Day Eco Index – Phyto+Krill+Penguins

Present Day Eco Index – Phyto+Krill

eco_index

More Valuable

eco_index

More Valuable

duvivier@ucar.edu
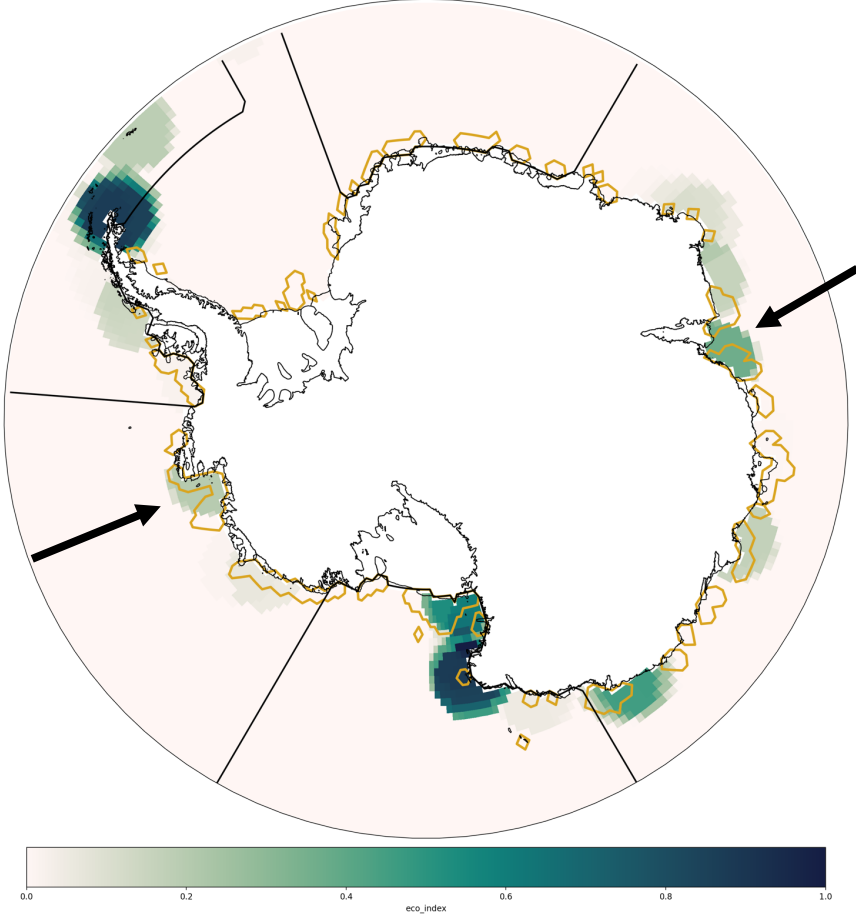
Hemispheric vs. regional scaling makes a difference!

Present Day Adelie input – hemispheric scaling

Present Day Adelie input – regional scaling

duvivier@ucar.edu