Interdecadal shifts in seabird distributions relative to the Velocity of Climate Change (VoCC) in the Northeast Pacific: a long-term observational study

William J. Sydeman[1], Brian Hoover[1], Gammon Koval[1]

Sarah Ann Thompson[1], Marisol Garcia-Reyes[1], John Piatt[2], Mayumi Arimitsu[3], Kathy Kuletz[1,4]

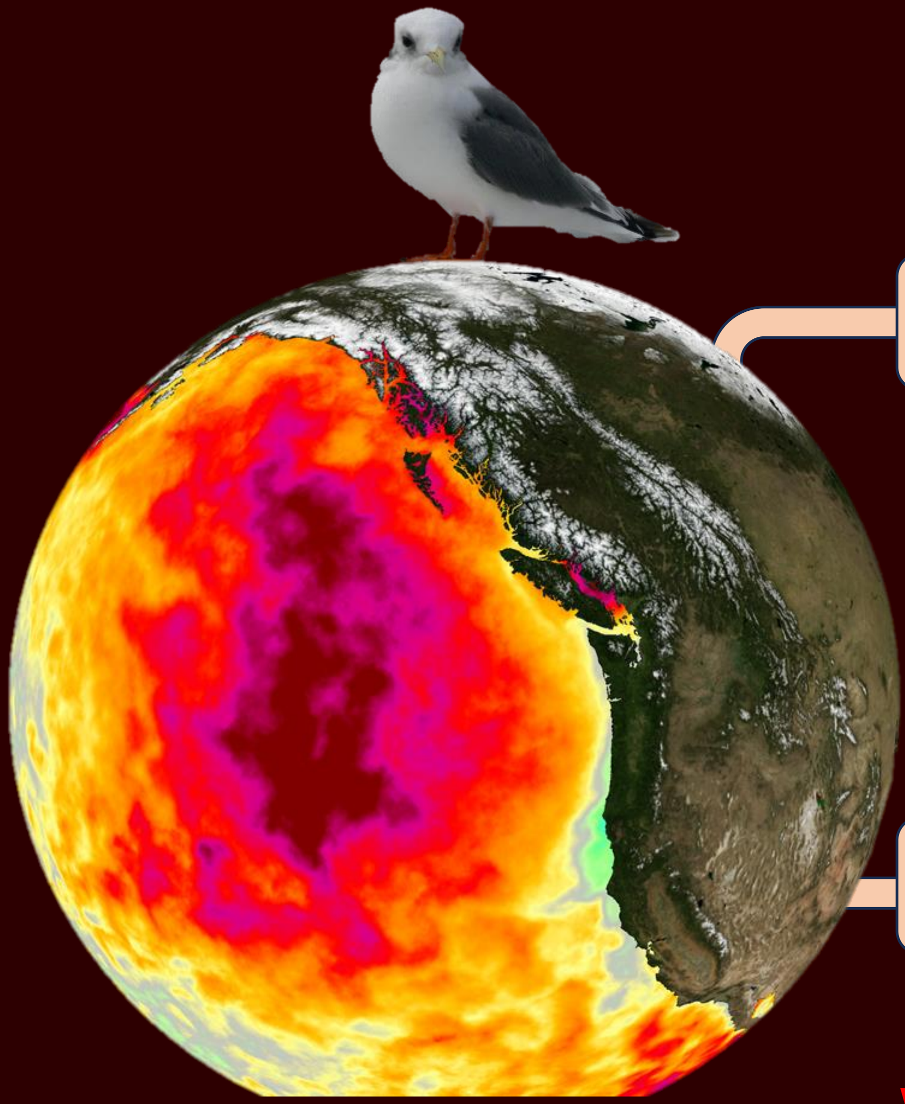
[1]Farallon Institute, Petaluma CA 94952
[2]Puffin Congress, Port Townsend, WA
[3]OceanBight Inc, Juneau AK
[4]US Fish and Wildlife Service, Anchorage AK

FARALLON INSTITUTE

Project 2105

NORTH PACIFIC RESEARCH BOARD

Climate change impacts marine ecosystems and alters epipelagic food-webs: Seabirds respond demographically



Gentemann et al. 2017 GRL

High-Freq.

Mortality Events

(*Piatt et al. 2020; Jones et al. 2024*)


AGU PUBLICATIONS
Geophysical Research Letters
RESEARCH LETTER
Massive Mortality of a Planktivorous Seabird in Response to a Marine Heatwave

PLOS ONE
RESEARCH ARTICLE
Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016
Abstract

LONGER -TERM?

Population Decline

(*Renner et al. 2024*)

What about changes in distribution?

Q: do interdecadal changes in seabird distributions at sea reflect changes in pelagic habitat in the Northeast Pacific?

BIOLOGICAL DATA

- N. Pacific Pelagic Seabird Database
- At-sea survey data: 1975-2022, USGS

PHYSICAL DATA

- "Velocity of Climate Change" (VoCC) (Garcia Molinos et al 2019)
- Hadley SST 100km^2: NOAA OI: 1975-2022

Refined question: Are seabirds "tracking" the Velocity of Climate Change, i.e, the rate and direction of surface isothermal shifts over decadal time scales?

Why VoCC for seabirds?

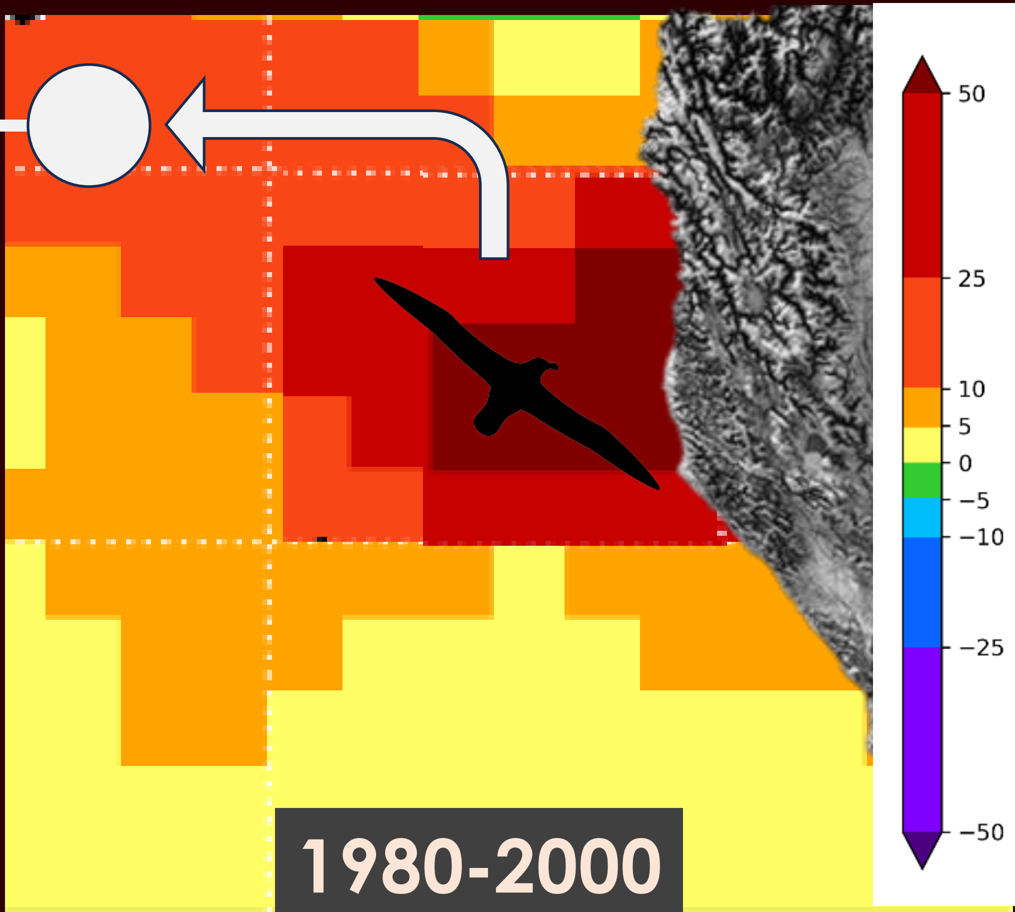
Seabirds reside at the air-sea interface where SST proxies prey-concentrating surface and subsurface habitat structures (e.g., fronts and eddies)

Significance of VoCC

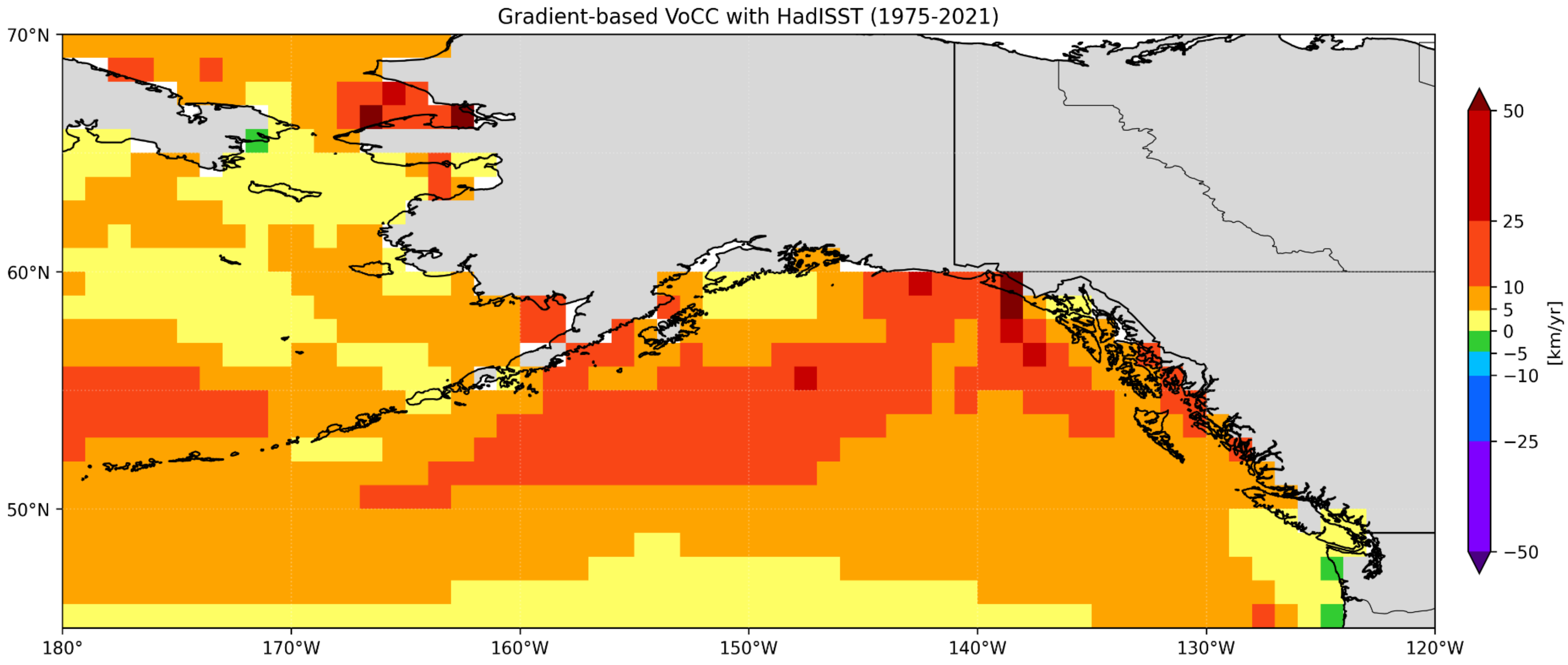
Describes the rate and direction species would need to move to keep pace with spatial shifts in habitat (Burrows et al. 2011 *Science*).

Advances prediction: what should marine organisms do to mitigate habitat shifts? net movements and direction

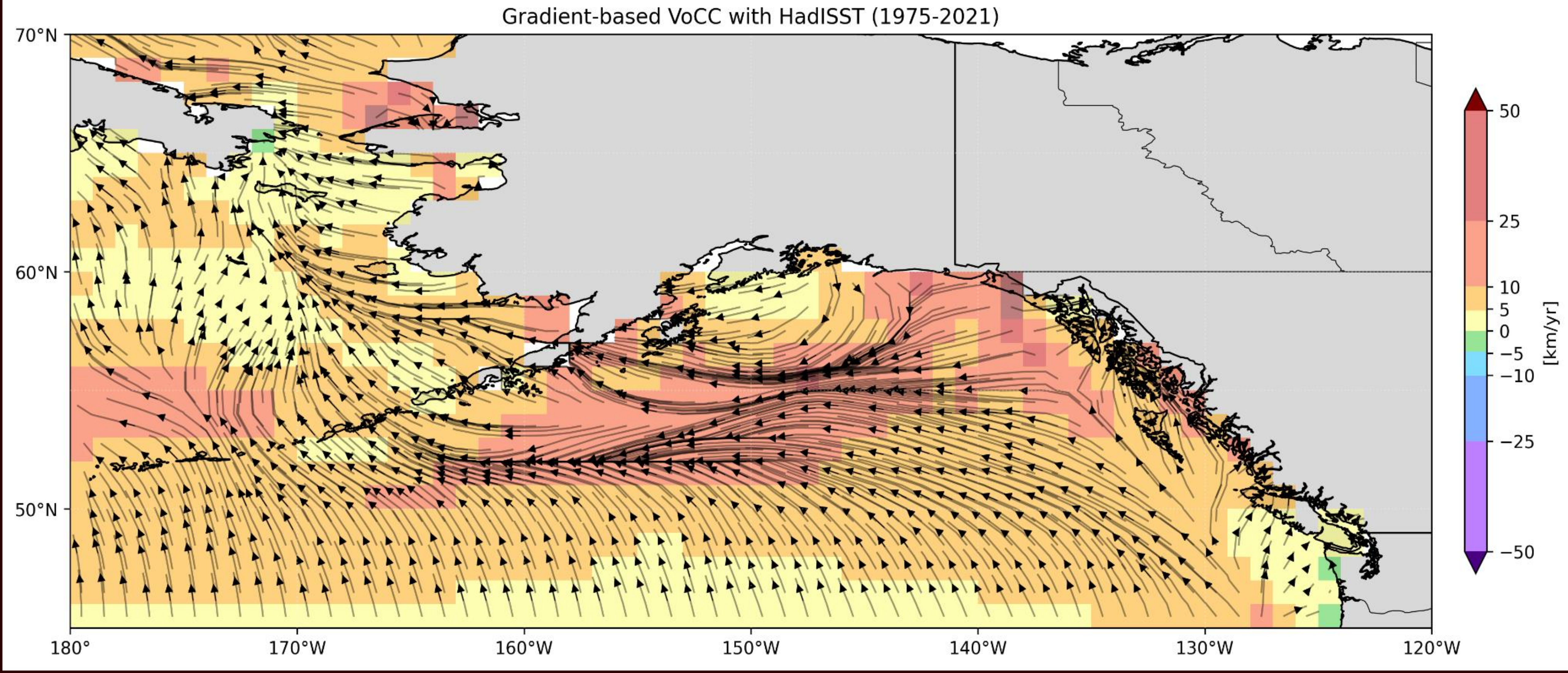
Test: compare VoCC *in range* with observed patterns of distribution across time (decades in this case)



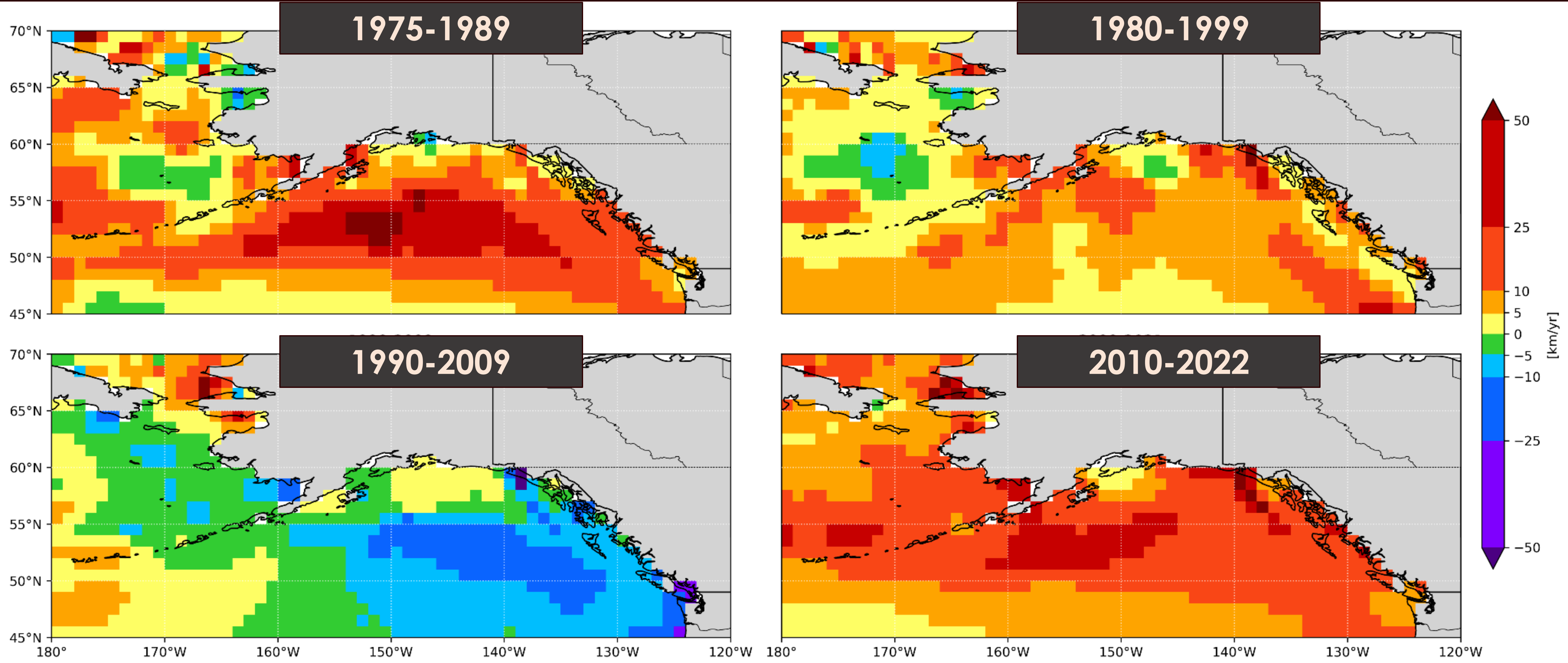
VoCC : Spatial rate of change in NE Pacific (km/year), 1975-2021



VoCC: Vectors of surface habitat shifts



VoCC: varies by decade (~20-yr overlapping periods)

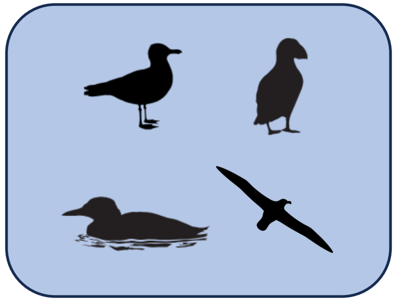


OK, so are seabirds "tracking" this Velocity of Climate Change?
rate (mostly about 5-10 km/year)
direction (east-west in GoA and north-south in EBS) of decadal scale habitat shifts?

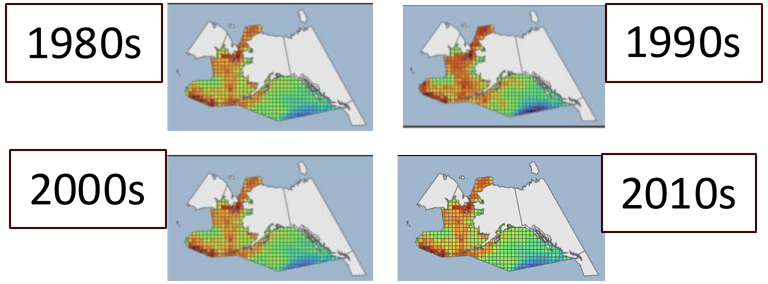
First, need to model seabird densities at sea over an appropriate scale and estimate changes in distribution through time

Seabird Density Modeling

STEP 1: Filtered NPPSD V4.1 seabird data to May-September



STEP 2: JDSDM model by taxa by decade



9 taxonomic groups: auklets, albatrosses, gulls, kittiwakes, murres, northern fulmar, puffin, storm-petrels, shearwaters

Used VAST (Vector Autoregressive Spatio-Temporal) framework --- Joint Dynamic Species Distribution Model (JDSDM) to produce decadal-scale density product.

See method: Arimitsu et al. (2023 Frontiers of Marine Science)

By “quasi”-decade: 1970’s (6 years), 1980s (10y), 1990s (10y), 2000s (10y), 2010s (12 years) – n=5 periods needed to assess between decade shifts in distribution shifts.

Details of SDM: Sydeman et al. 2025 (Marine Ecology Progress Series)

Study region covers Gulf of Alaska, Eastern Bering Sea, and parts of Chukchi Sea

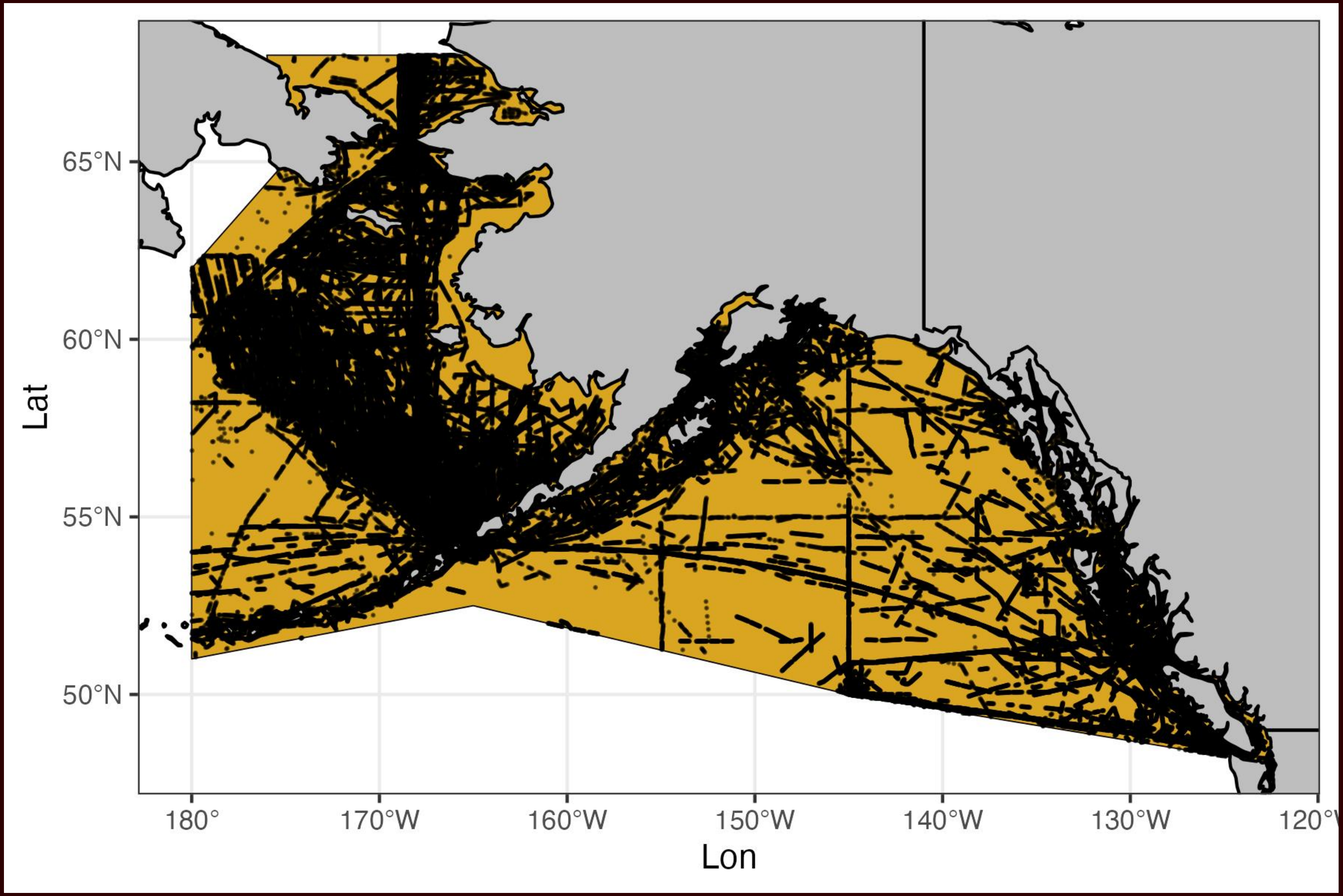


Table 1. Seabird species combined into taxonomic groups used to model density and determine interdecadal shifts in distribution. Differences in foraging depth, primary food habits, and local breeding status are included to provide rationale for predictions of responses to rates and directionality of velocity of climate change (VoCC) displacements. Common names in **bold** reflect numerically dominant species in each group. Prey are listed in order of importance

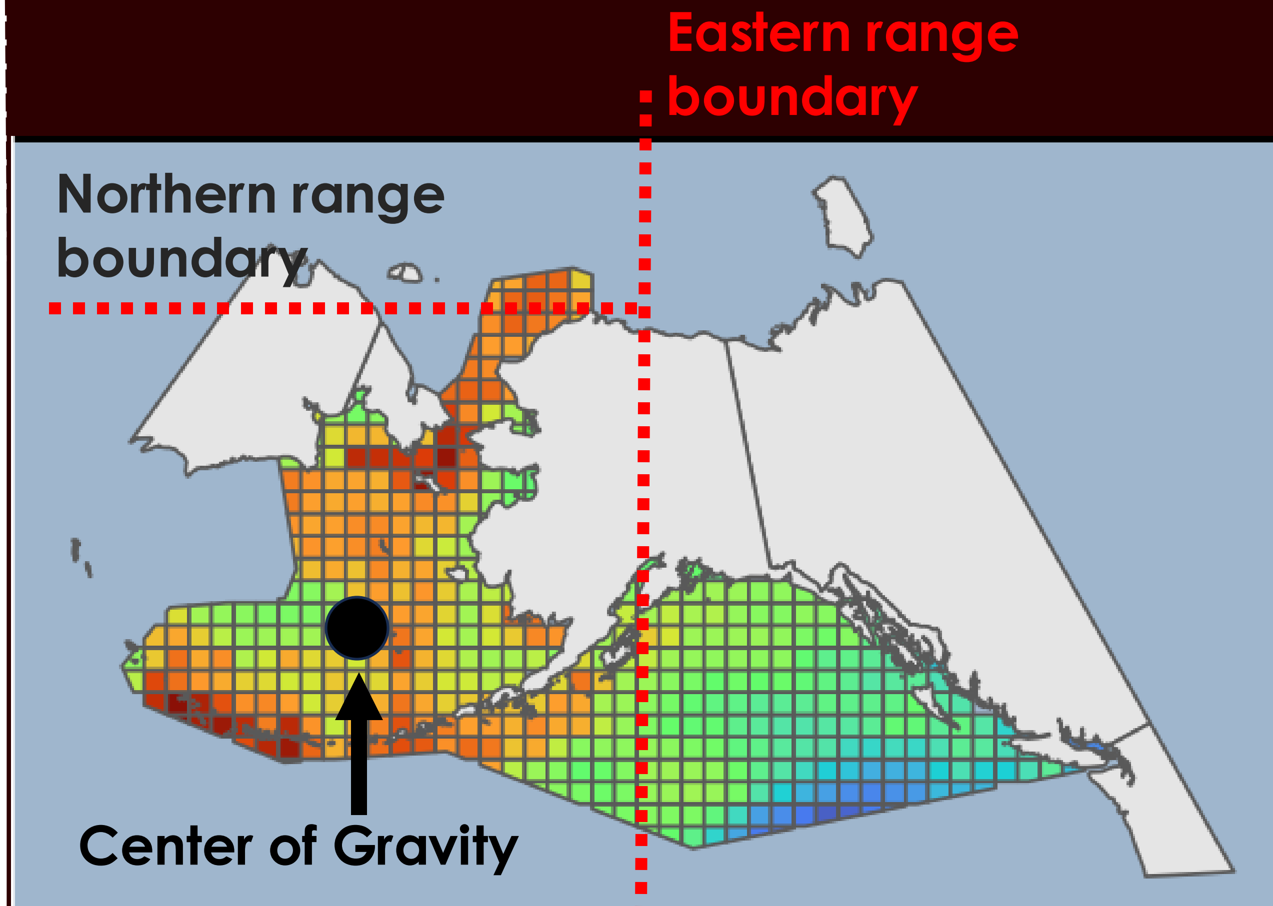
Taxonomic group	Common name	Species	Foraging depth; diet	Breeding status
Albatrosses	**Black-footed albatross**	*Phoebastria nigripes*	Surface; squid, fish	Non-local
	Laysan albatross	*Phoebastria immutabilis*		
	Short-tailed albatross	*Phoebastria albatrus*		
Auklets	Crested auklet	*Aethia cristatella*	Subsurface; crustaceans, ichthyoplankton	Local
	Least auklet	*Aethia pusilla*		
	Parakeet auklet	*Aethia psittacula*		
	Whiskered auklet	*Aethia pygmaea*		
Gulls	**Glaucous-winged gull**	*Larus glaucescens*	Surface; fish, squid, offal	Local
	Glaucus gull	*Larus hyperboreus*		Local
	Herring gull	*Larus argentatus*		Non-local
	Slaty-backed gull	*Larus schistisagus*		Non-local
	Thayer's gull	*Larus thayeri*		Non-local
Kittiwakes	**Black-legged kittiwake**	*Rissa tridactyla*	Surface; fish, squid	Local
	Red-legged kittiwake	*Rissa brevirostris*		Local
Murres	**Common murre**	*Uria aalge*	Subsurface; fish, squid, krill	Local
	Thick-billed murre	*Uria lomvia*		
Northern fulmar	Northern fulmar	*Fulmarus glacialis*	Surface; fish, squid, offal	Local
Puffins	Horned puffin	*Fratercula corniculata*	Subsurface; fish, squid, krill	Local
	Rhinoceros auklet	*Cerorhinca monocerata*		
	Tufted puffin	*Fratercula cirrhata*		
Shearwaters	**Short-tailed shearwater**	*Ardenna tenuirostris*	Subsurface; fish, krill, squid	Non-local
	Sooty shearwater	*Ardenna grisea*		
Storm-petrels	**Fork-tailed storm-petrel**	*Oceanodroma furcata*	Surface; crustaceans, ichthyoplankton	Local
	Leach's storm-petrel	*Hydrobates leucorhous*		

Seabird Distribution Assessments

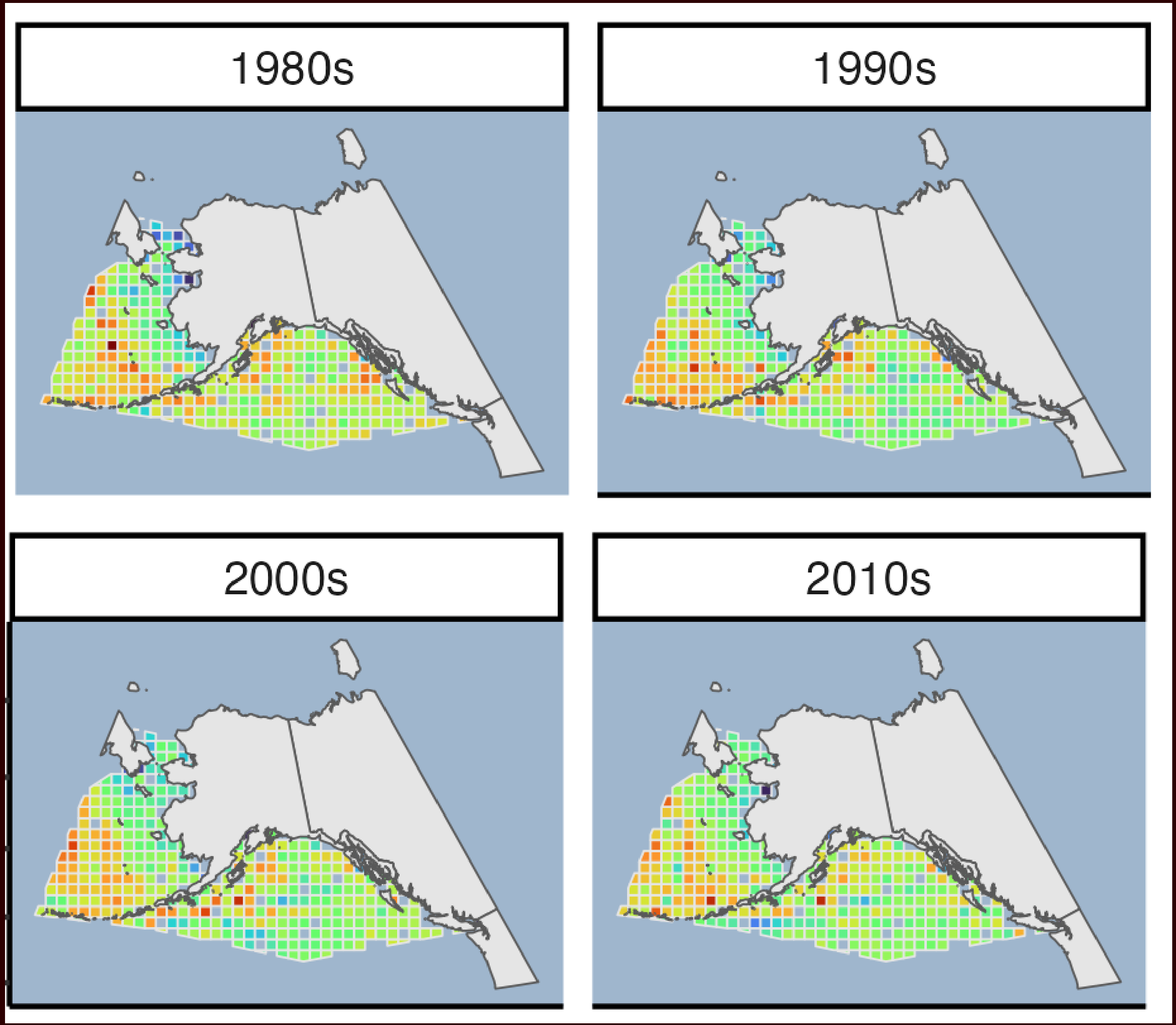
Calculated metrics of "distributional shifts" by comparing CoG, and range edge (lat/long) and core range (lat/long) across 5 decadal periods; this resulted in 4 data points per taxonomic group.

1) Center of Gravity (CoG)

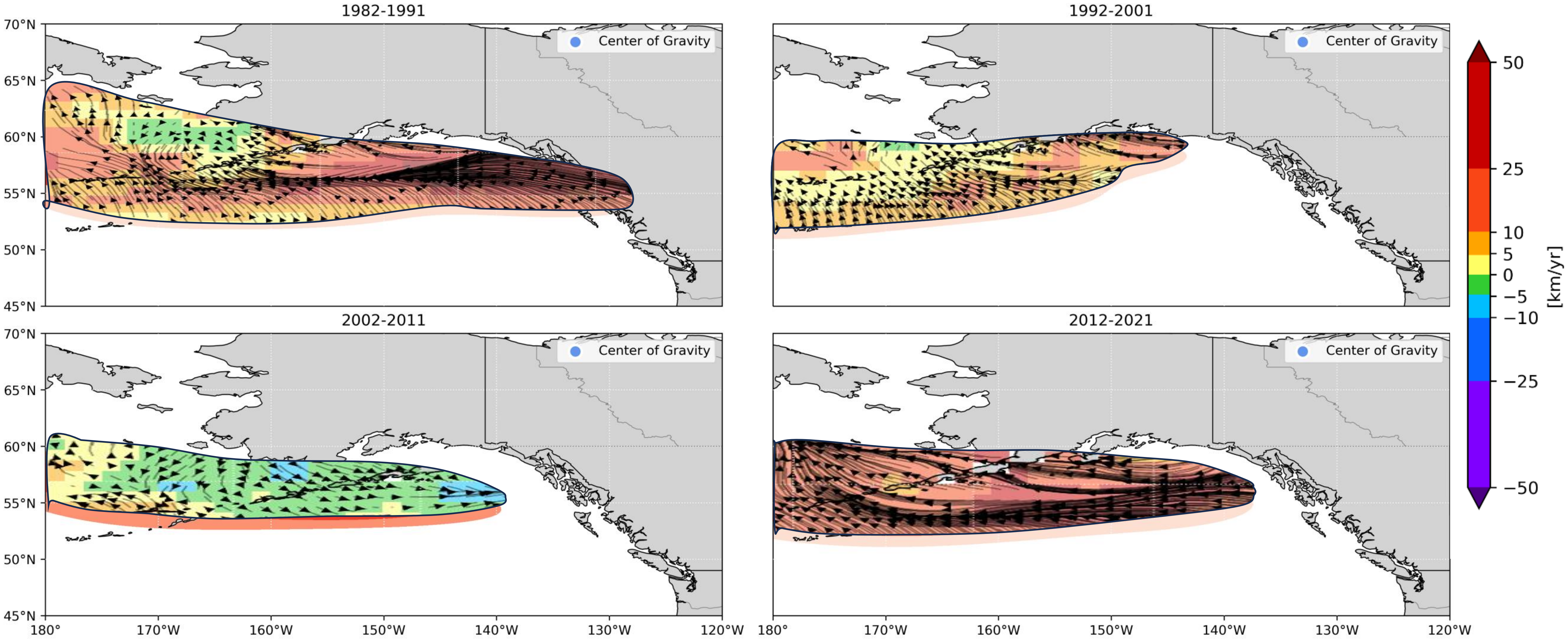
2) Northern and Eastern utilization density distributions (50% ("core") and 90% ("edge") density contours)



Example: modeled density fields of storm-petrels



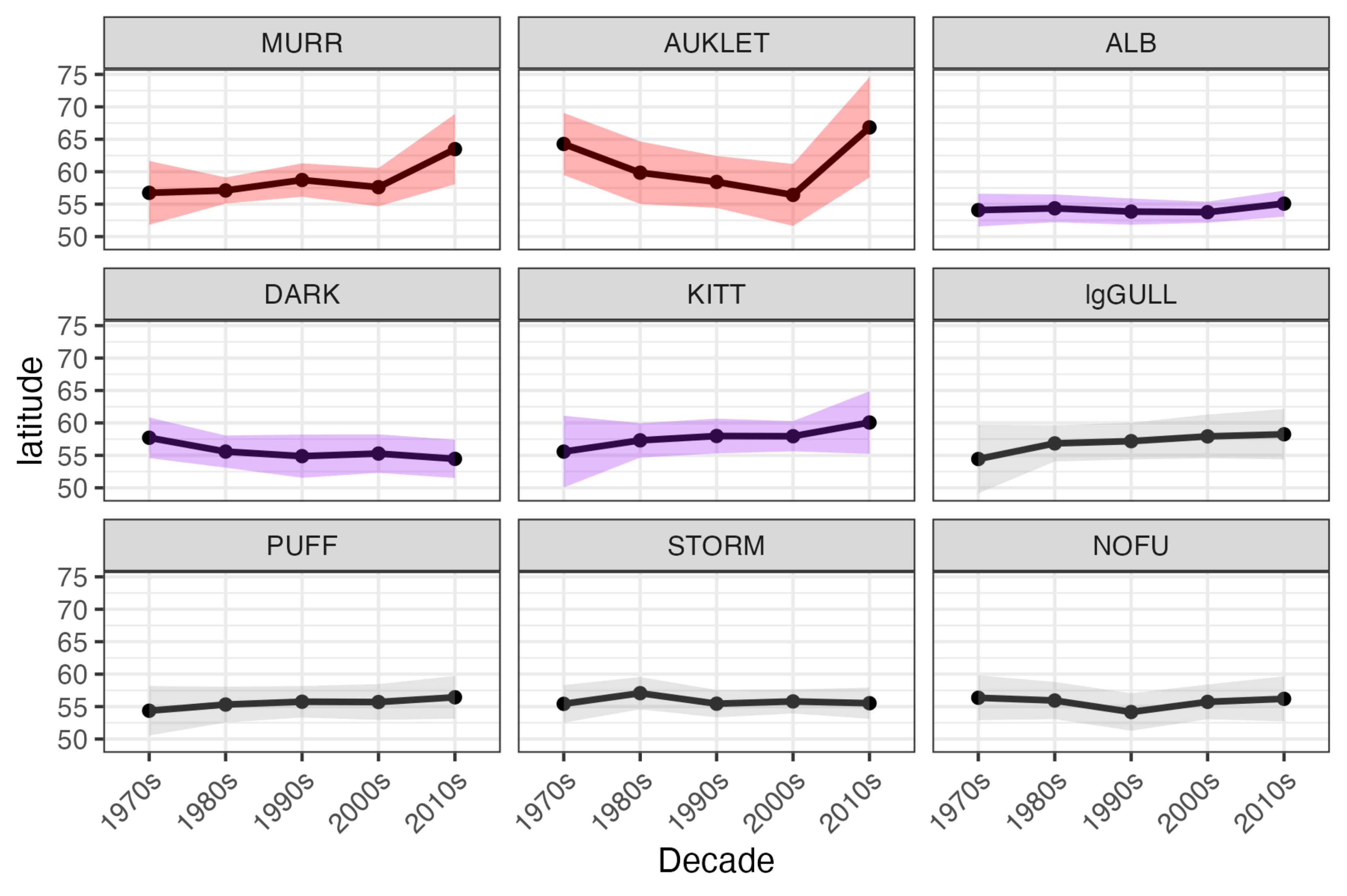
Example: Storm-petrel CoG, range based on modeled density contours, and VoCC rate/vectors within their range



Shifts in Center of Gravity by Latitude

- Auklets and murres showed some movement, but other taxa were stationary

Taxa	Total Latitudinal Shift in CoG
auklets	2034.9 km
murres	996.3 km
kittiwakes	506.8 km
fulmars	469.9 km
dark shearwaters	451.2 km
storm-petrels	433.5 km
gulls	424.3 km
albatross	244.6 km
puffins	240.8 km



Shifts in latitude: range edge (dashed) and range core (solid) by species group by decade

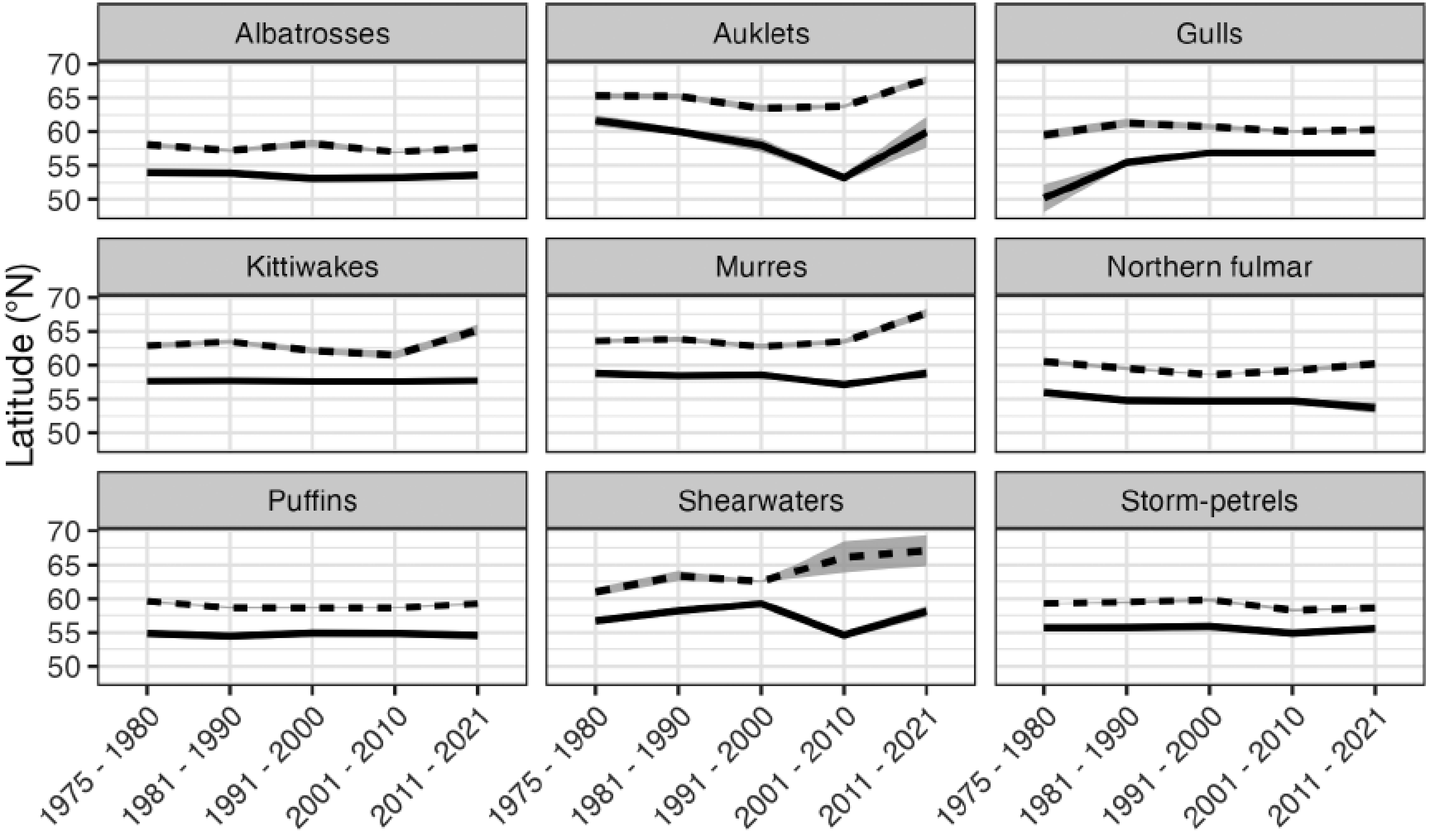


Fig. 5. Interdecadal variation in latitude of range edges (90% density contour, dashed line) and range cores (mean of the 50% density contours, solid line) for each taxonomic group. A resampling protocol was used to estimate error

Overall shifts (km) and rate of change (km/year) in range edge and range core by group with latitude

Table 2. Net north/south shifts (km) of modeled taxonomic groups at leading edge and core range latitudes. Negative numbers represent net southward shifts. **Bold** values show shifts >100 km; rate of change is given in parentheses ($km\,yr^{-1}$)

Taxonomic group	Edge	Core
Albatrosses	−49.2	−42.3
Auklets	**264.5 (5.75)**	**−182.9 (3.97)**
Gulls	85.5	**742.9 (16.13)**
Kittiwakes	**263.4 (5.72)**	6.7
Murres	**456.2 (9.92)**	0.8
Northern fulmar	−34.2	**−248.4 (5.40)**
Puffins	−40.9	−31.8
Shearwaters	**678.0 (14.70)**	**156.1 (3.39)**
Storm-petrels	−76.3	−13.7

Shifts in longitude: eastern range edge (dashed) and range core (solid) by species group by decade

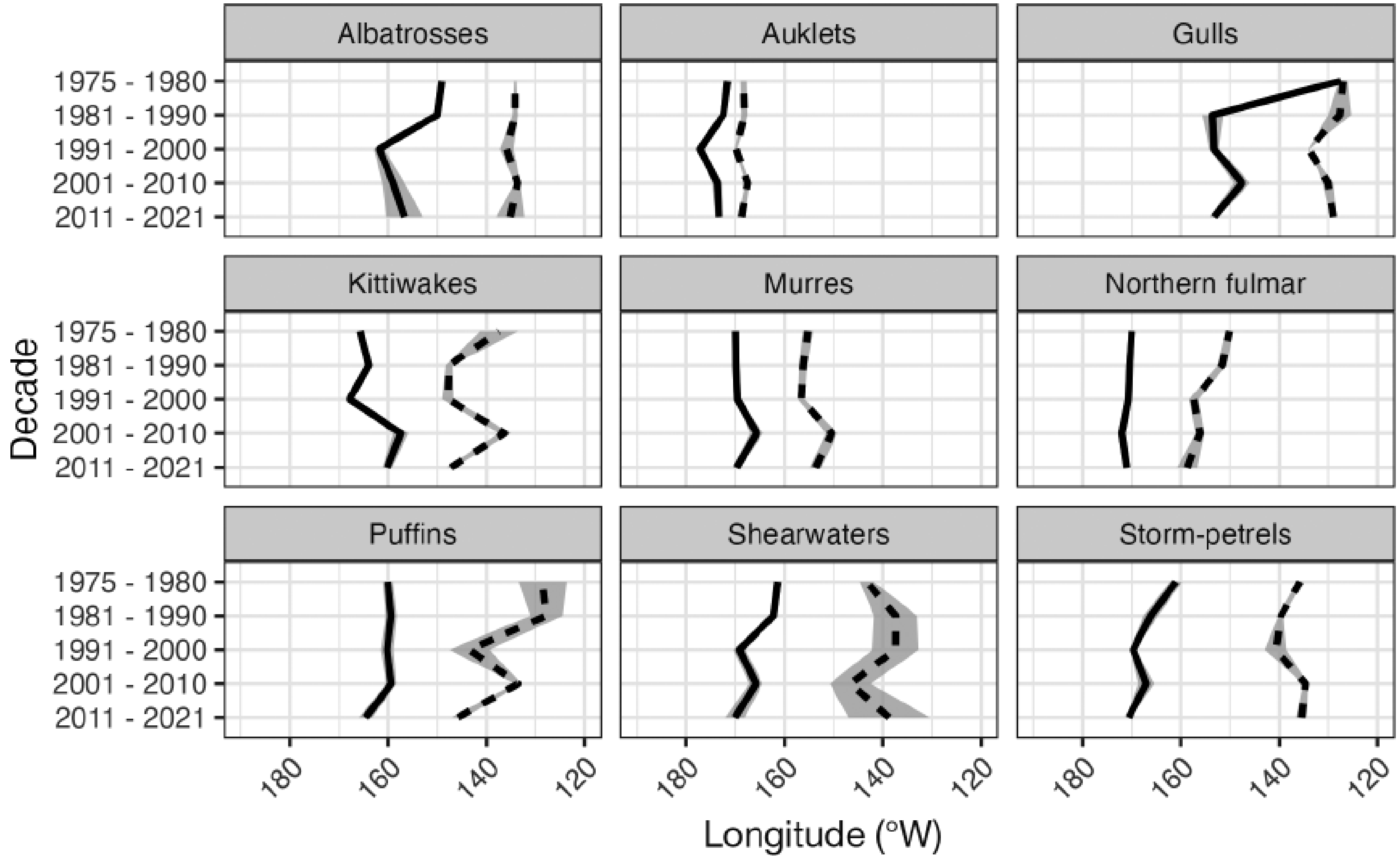


Fig. 6. Interdecadal variation in longitude of range edges (90 % density contour, dashed line) and range cores (mean of 50 % density contour, solid line) by taxonomic group decade. A resampling protocol was used to estimate error

Overall shifts (km) and rate of change (km/year) in range edge and range core by group with longitude

Table 3. Net east/west shifts (km) of modeled taxonomic groups at the leading edge (eastern extent of 90% density contour) and range core longitudes. Negative numbers represent net eastward shifts. **Bold** values show shifts >200 km; rate of change is given in parentheses (km yr^{-1})

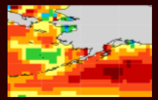
Taxonomic group	Edge	Core
Albatrosses	103.8	**839.2 (18.24)**
Auklets	43.5	202.3 (4.39)
Gulls	222.1 (4.81)	**2850.2 (61.95)**
Kittiwakes	**1103.6 (23.99)**	**−605.1 (13.15)**
Murres	−165.3	−22.1
Northern fulmar	**951.8 (20.69)**	114.8
Puffins	**1915.9 (41.65)**	**498.1 (10.2)**
Shearwaters	**−492.9 (10.72)**	**966.1 (21.00)**
Storm-petrels	−32.6	**1070.2 (23.31)**

Tracking VoCC? Complexity in Responses

Table 4. Spearman rank correlations (ρ) between the rate of change in seabird distributional shifts (leading edge and core range) and velocity of climate change (VoCC) (n = 4 for each correlation); m: non-locally breeding migrants; d: groups that forage at depth; p: planktivores

Code	Taxon	Leading edge (N latitude)	Core (latitude)	Edge (E longitude)	Core (longitude)
m	Albatrosses	−0.4	−0.8	−0.8	−0.8
dp	Auklets	0.2	0.8	−1	−0.6
	Gulls	−0.4	−0.4	0.4	−0.8
	Kittiwakes	0.4	0.4	−0.8	0.8
d	Murres	0.8	0.8	0.4	0.4
	Fulmars	0	0.6	0.6	−0.2
d	Puffins	0.6	0	0.8	−0.4
md	Shearwater	0.2	0.4	−0.4	0.2
p	Storm-petrels	0	0	0	−0.4

Summary and Conclusions



Overall, VoCC patterns indicate SST habitat shifts moving northwestwards in the Alaskan North Pacific, but mostly westerly in the GoA (also observed by Pinsky et al. 2013).

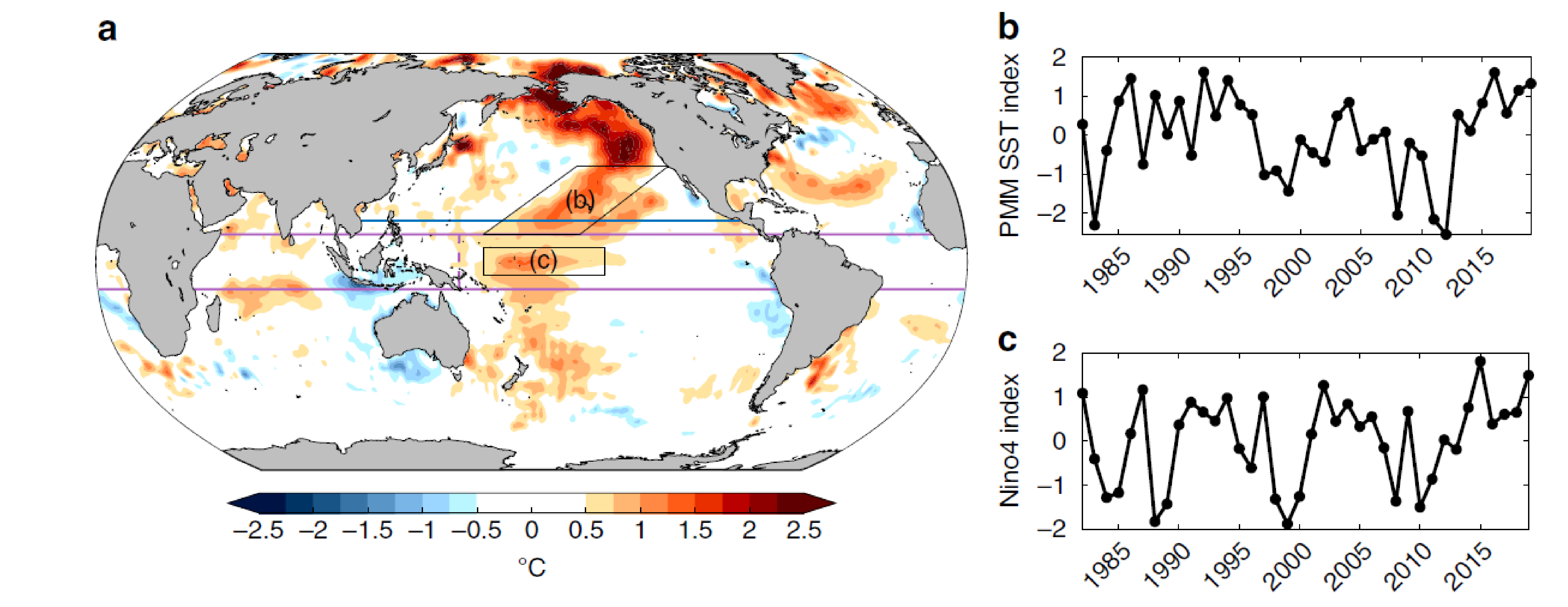
Distributions of many seabird taxa are shifting, particularly in recent periods. CoG is more/less stable, but range boundaries are changing and expanding.

Northern redistributions of range edges for murres, shearwaters, auklets align with VoCC rate/vectors. Auklets, murres, shearwaters consume mesozooplankton and forage fish.

?

Patterns of response are complex/vary by taxonomic group, but somewhat surprisingly it looks like locally-breeding birds are more sensitive to VoCC, perhaps related to their high-energy (coastal divers) lifestyle.

Summary


a
(b)
(c)
−2.5 −2 −1.5 −1 −0.5 0 0.5 1 1.5 2 2.5
°C
b
PMM SST index
2
1
0
−1
−2
1985 1990 1995 2000 2005 2010 2015
c
Nino4 index
2
1
0
−1
−2
1985 1990 1995 2000 2005 2010 2015