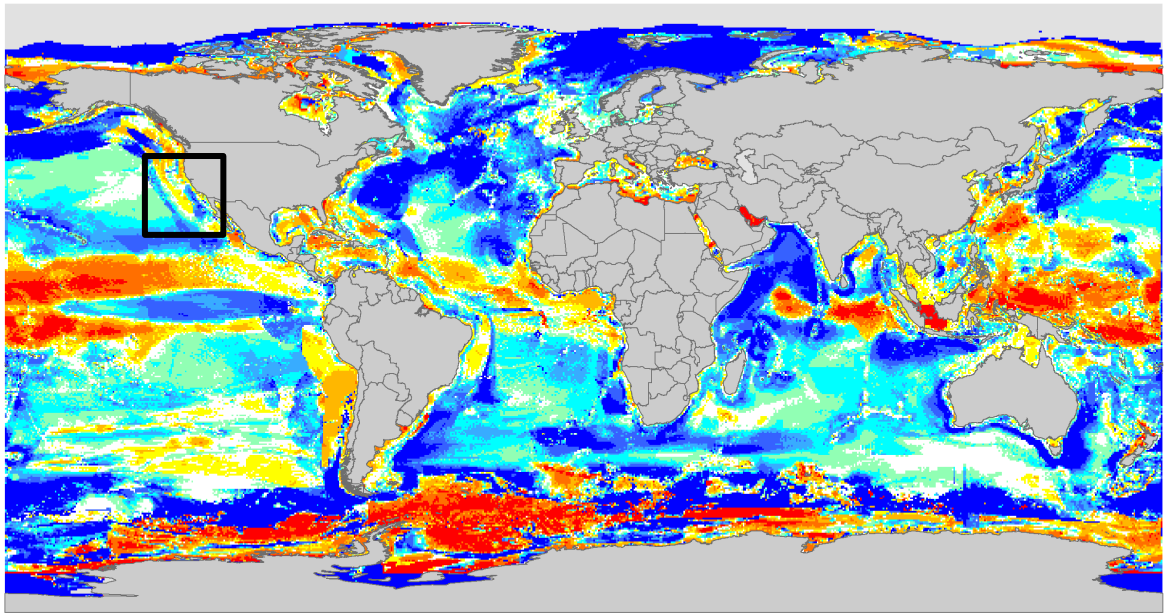
What Do We Expect to Happen in the California Current Under Climate Change?



Cheung et al. (2009)

Mike Jacox, Nate Mantua, Steven Bograd

NOAA Southwest Fisheries Science Center

OUTLINE

Part 1: Anticipated climate change in the California Current System

Part 2: A 'Climate Stress Test': recent anomalies in the CCS

Part 3: Fisheries management challenges in a changing climate

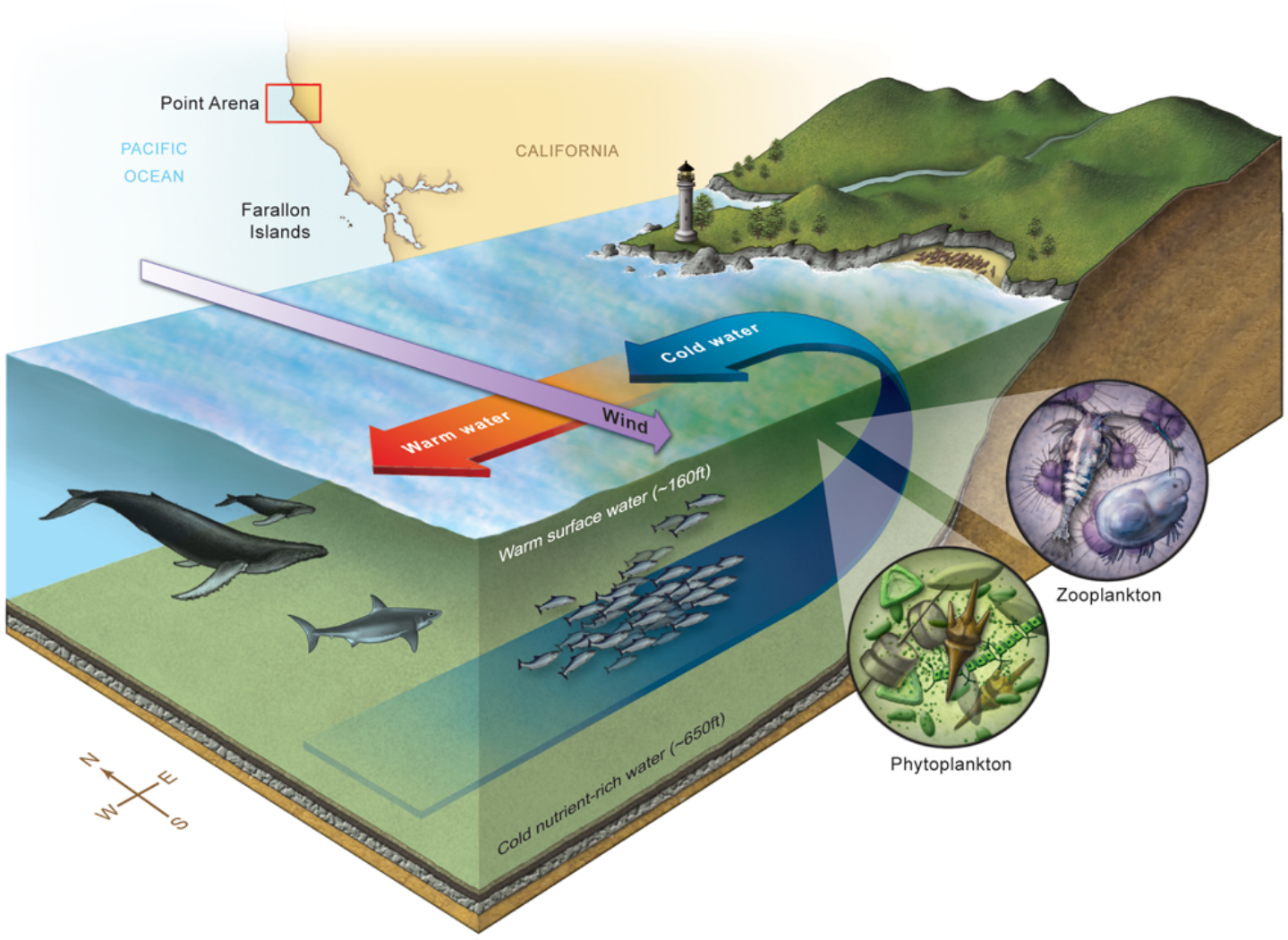
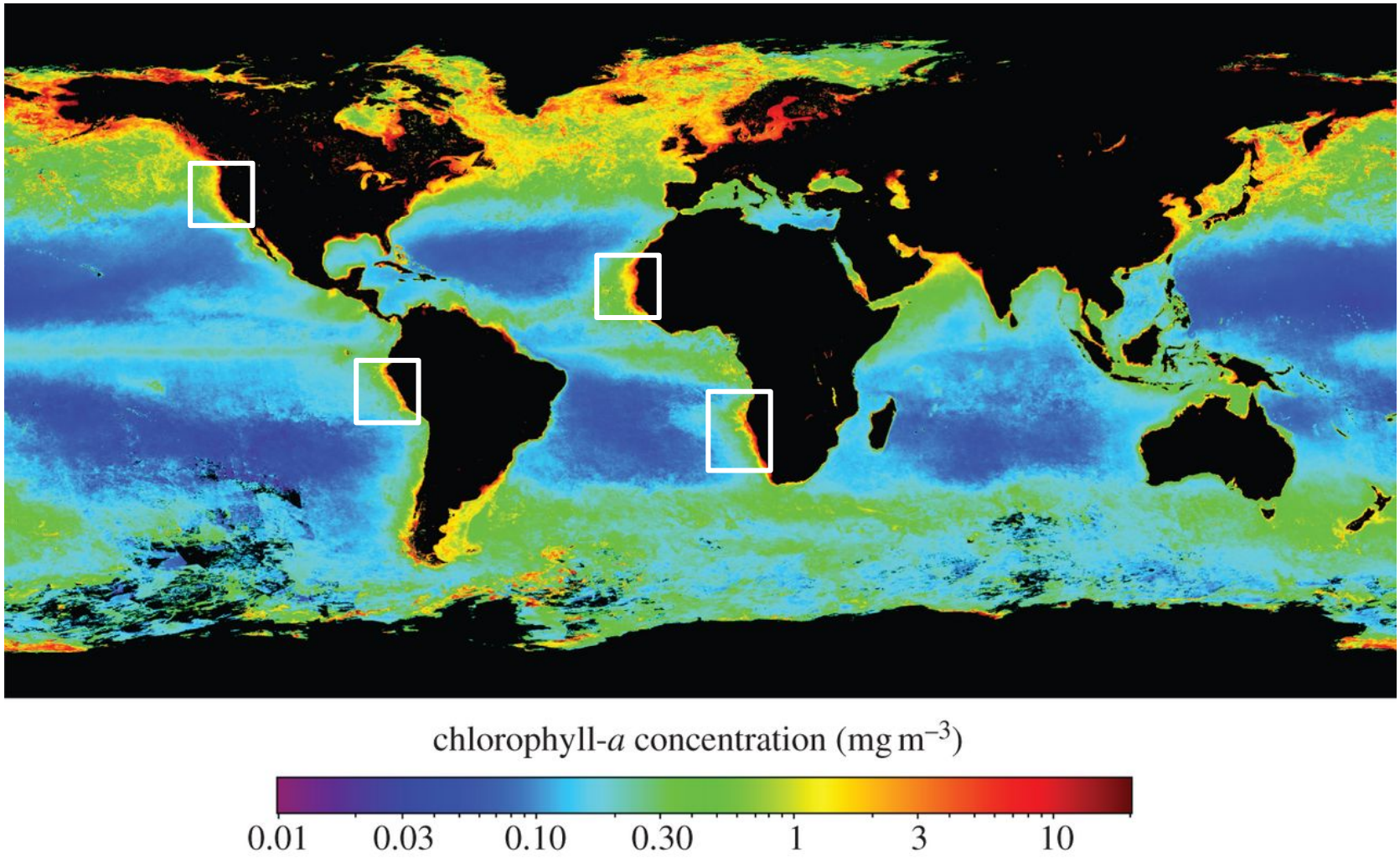
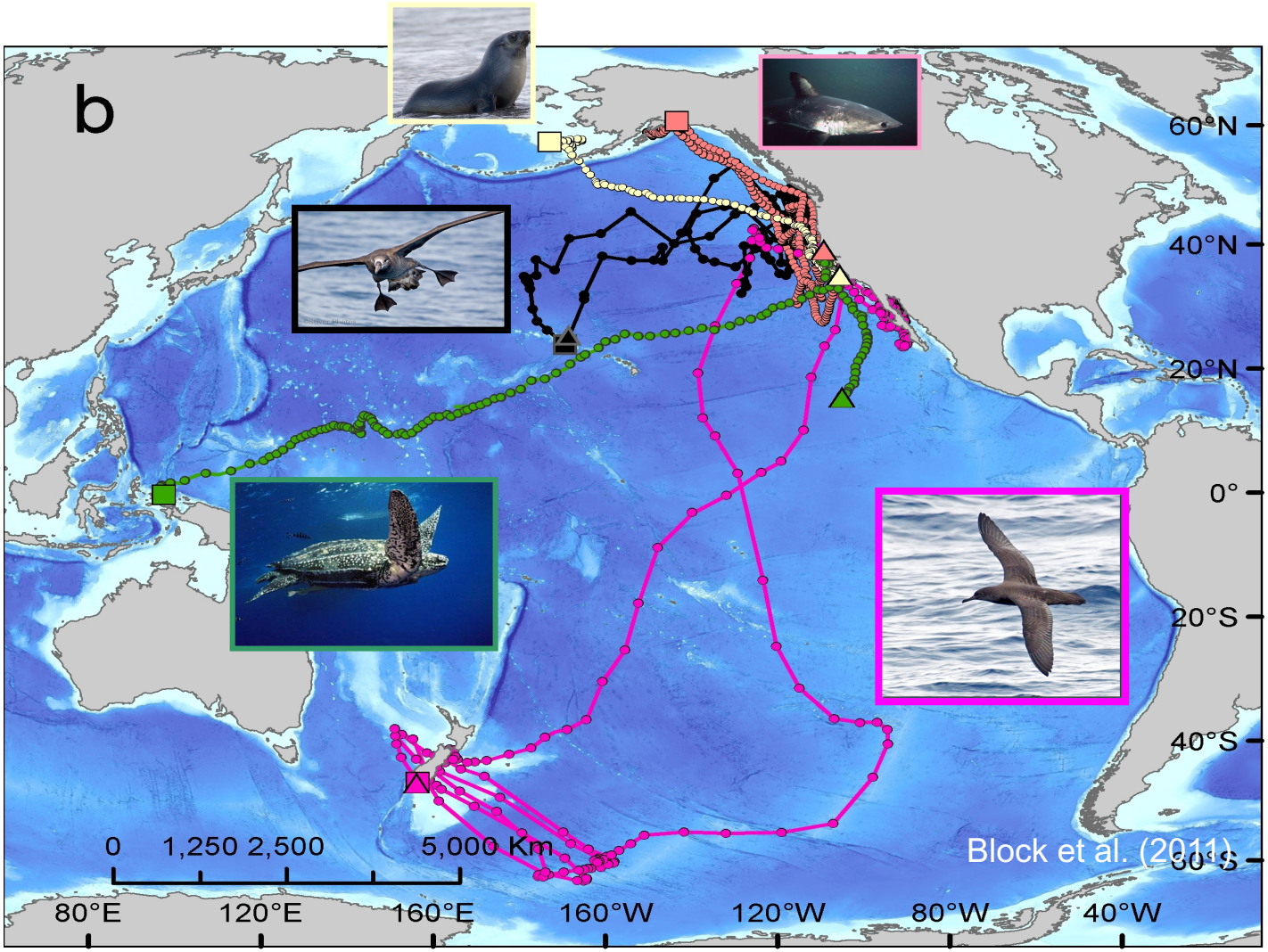


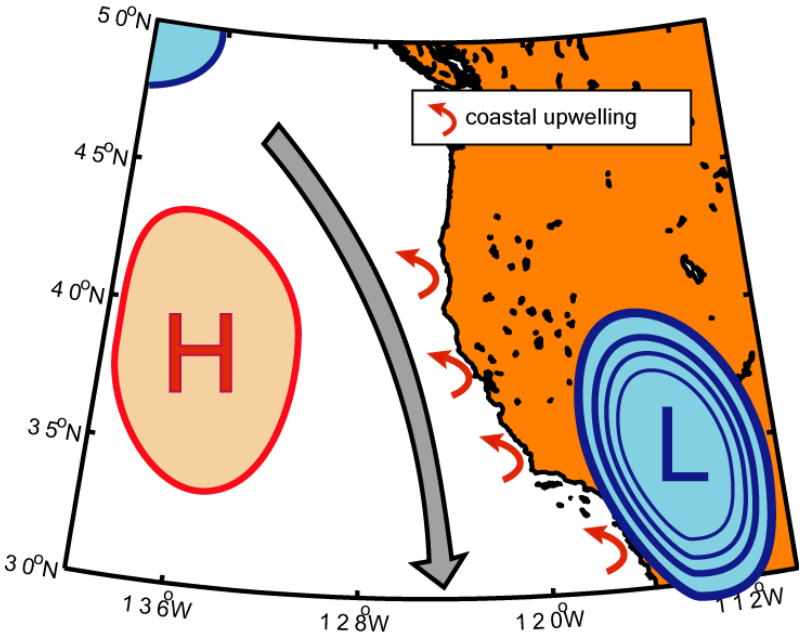
Illustration by Fiona Morris


chlorophyll-a concentration (mg m−3)
0.01
0.03
0.10
0.30
1
3
10



Life cycles of many marine organisms tied to seasonal processes

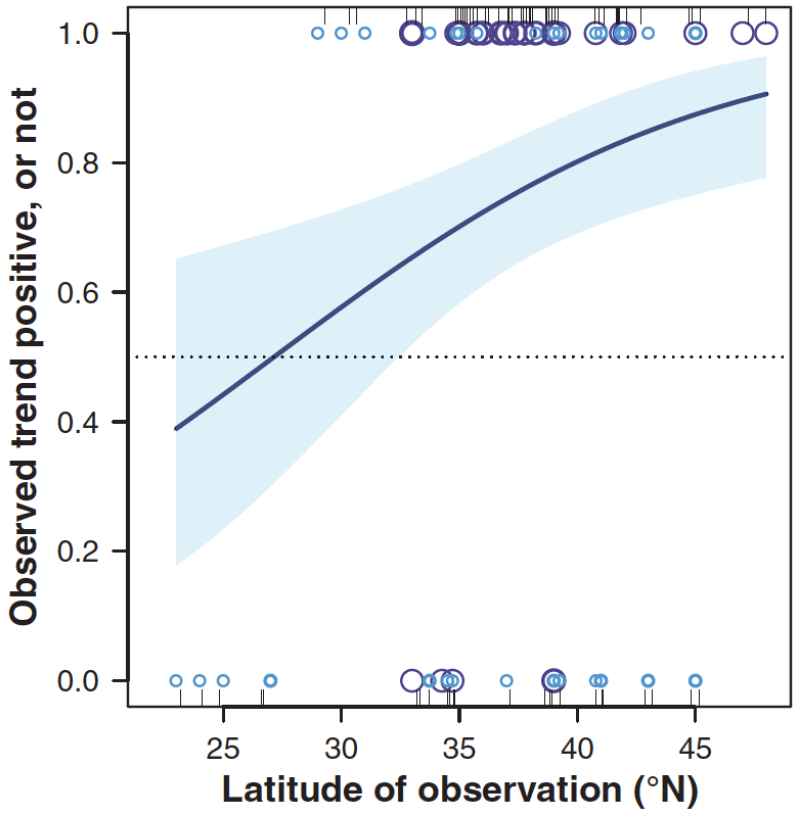
Observed Changes in Coastal Upwelling



Differential heating of the surface air over the landmass relative to the ocean…

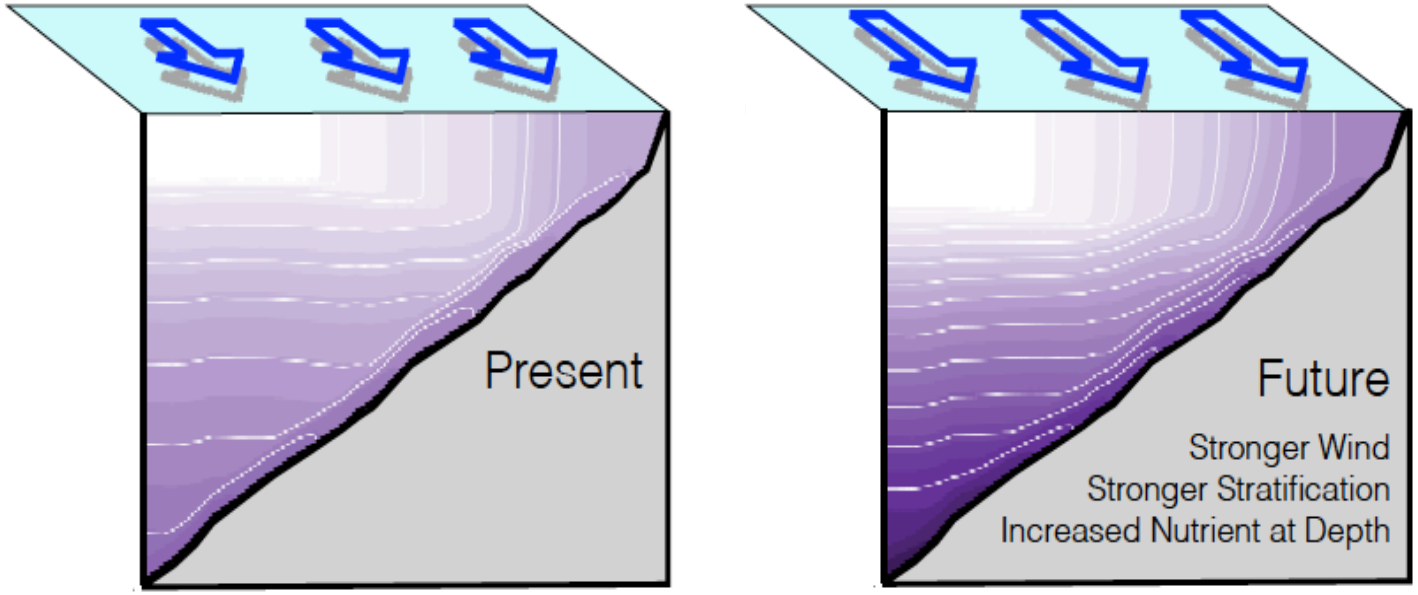
…will result in intensification of the thermal Low over the Southwest, generating a stronger pressure gradient.

Bakun *(1990)*



Sydeman *et al.* (2014)

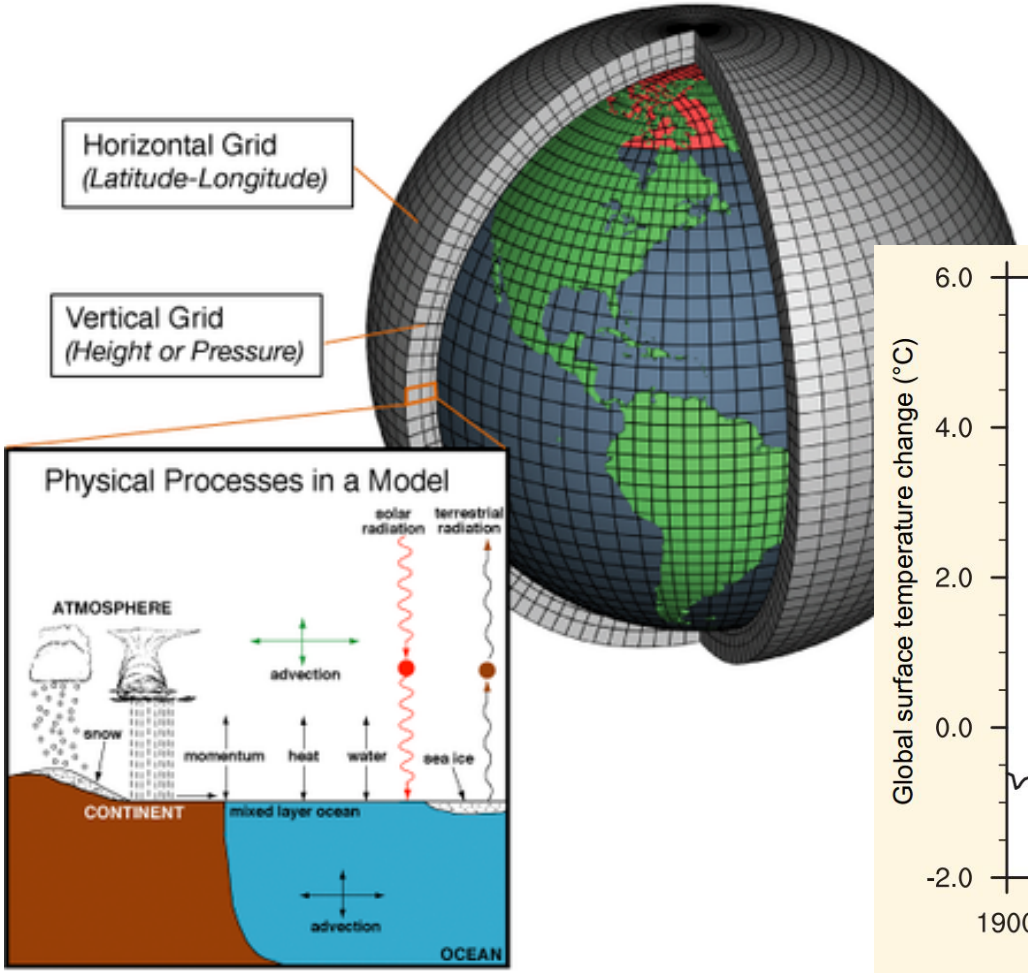
Anticipated Changes in Upwelling Systems

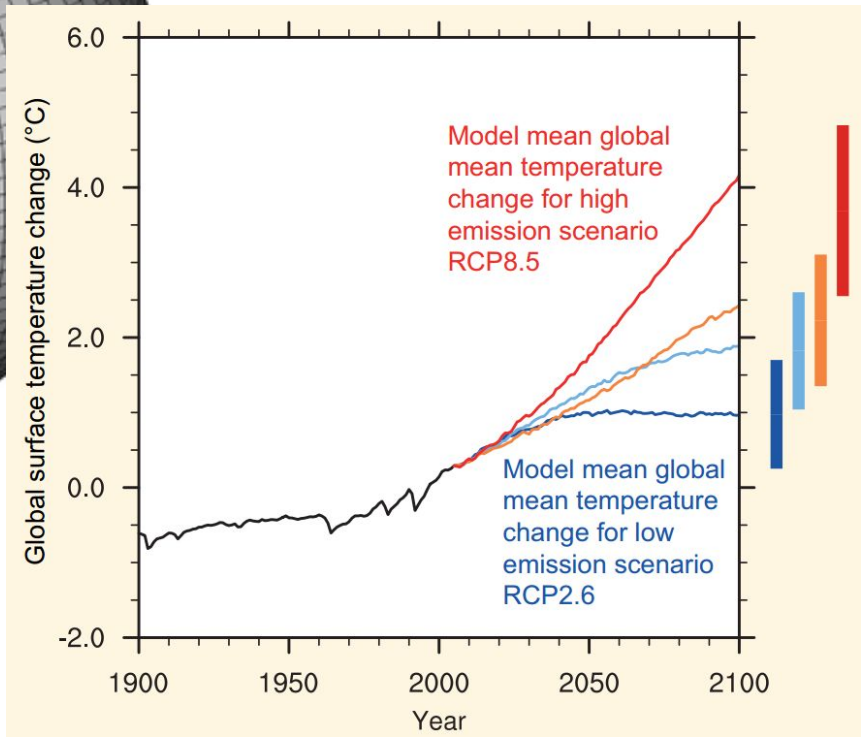


Jacox *et al.* (2015)

- Changes in upwelling?
- Changes in stratification?
- Changes in nutrient content of source waters?
- Increased hypoxia and ocean acidification?

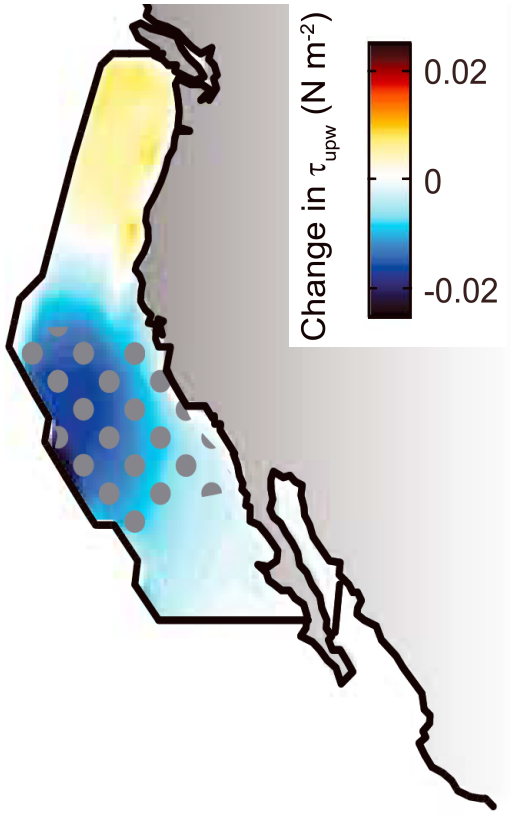
CLIMATE PROJECTIONS



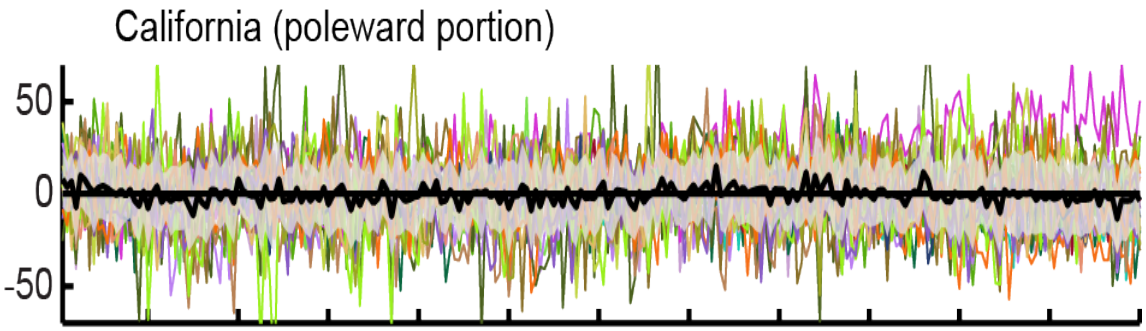


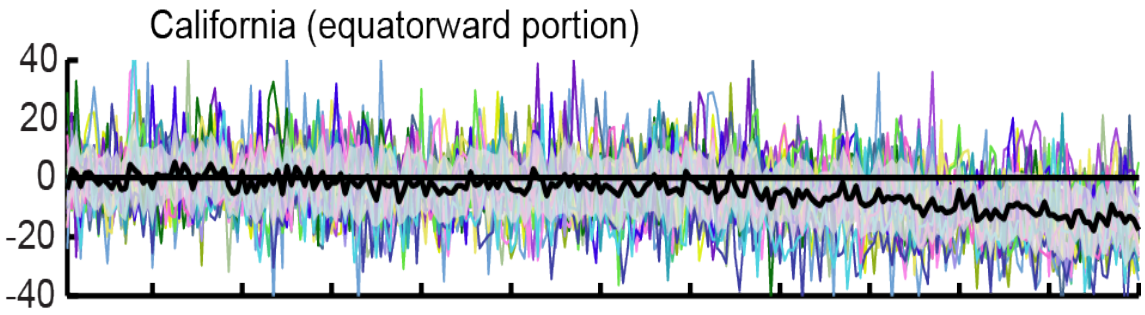
RCP 8.5 offers the largest “signal to noise”

Climate Projections: Coastal Upwelling



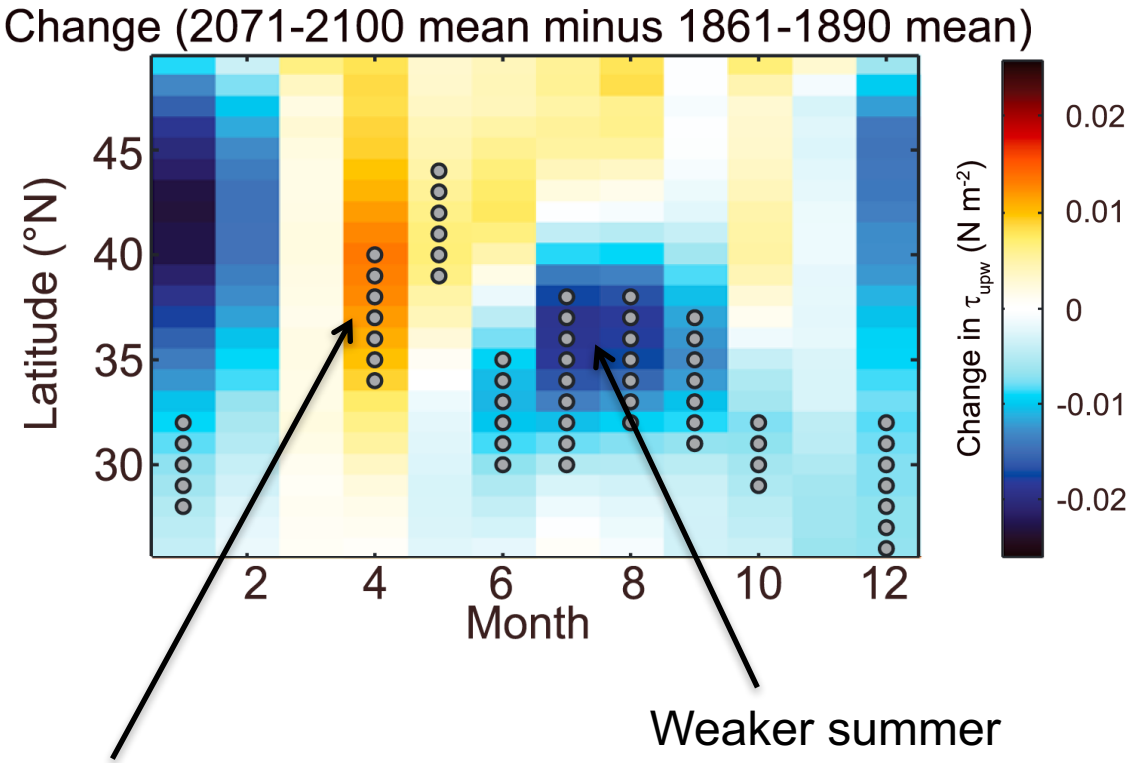
= robust change





Rykaczewski *et al.* (2015)

Climate Projections: Coastal Upwelling

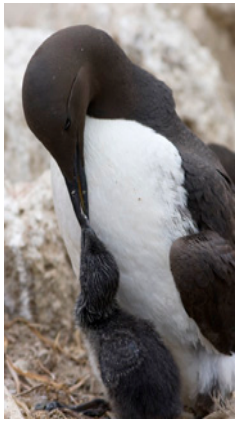


Earlier upwelling, longer upwelling season

Weaker summer upwelling south of 40N

Summer Sensitive

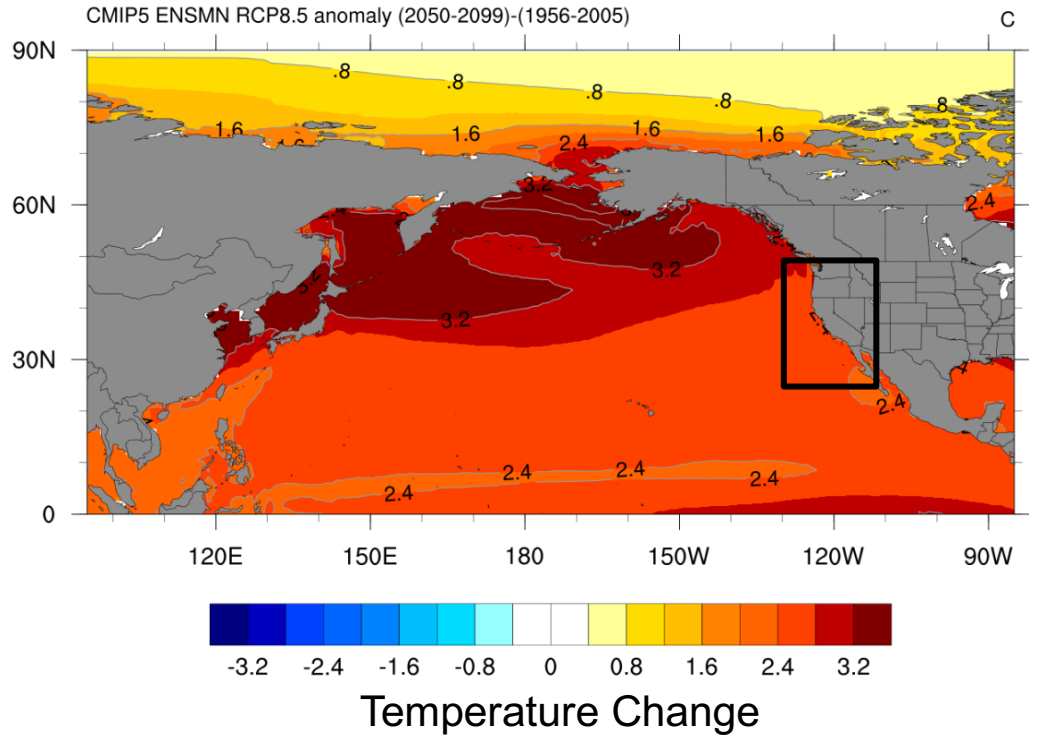
Winter Sensitive

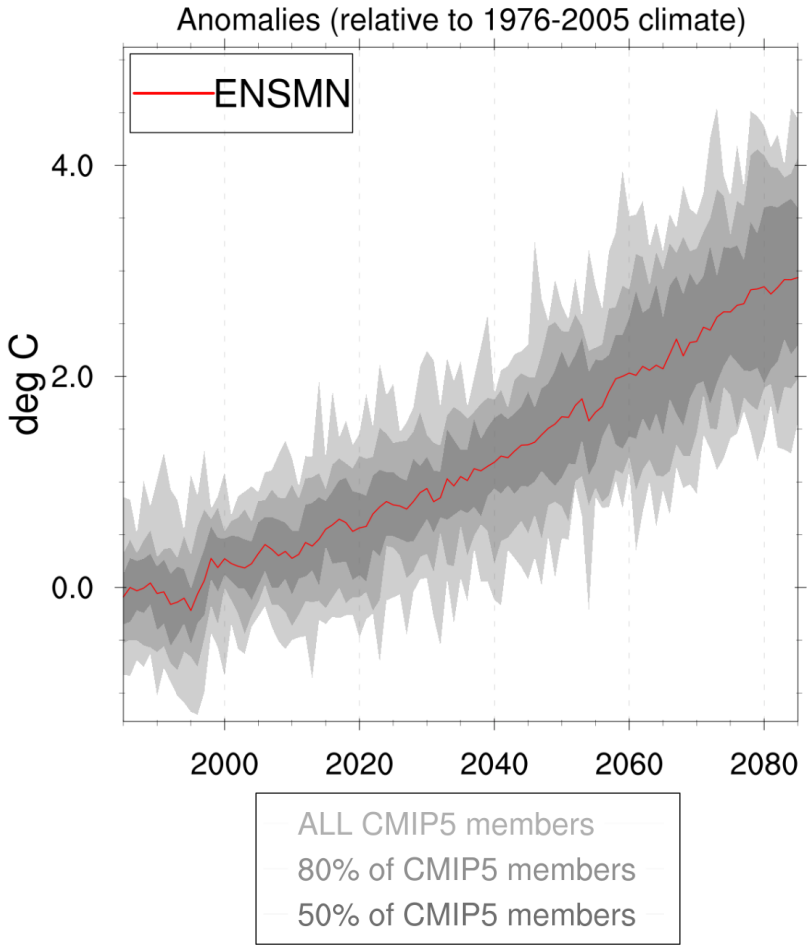


Black *et al.* (2011)

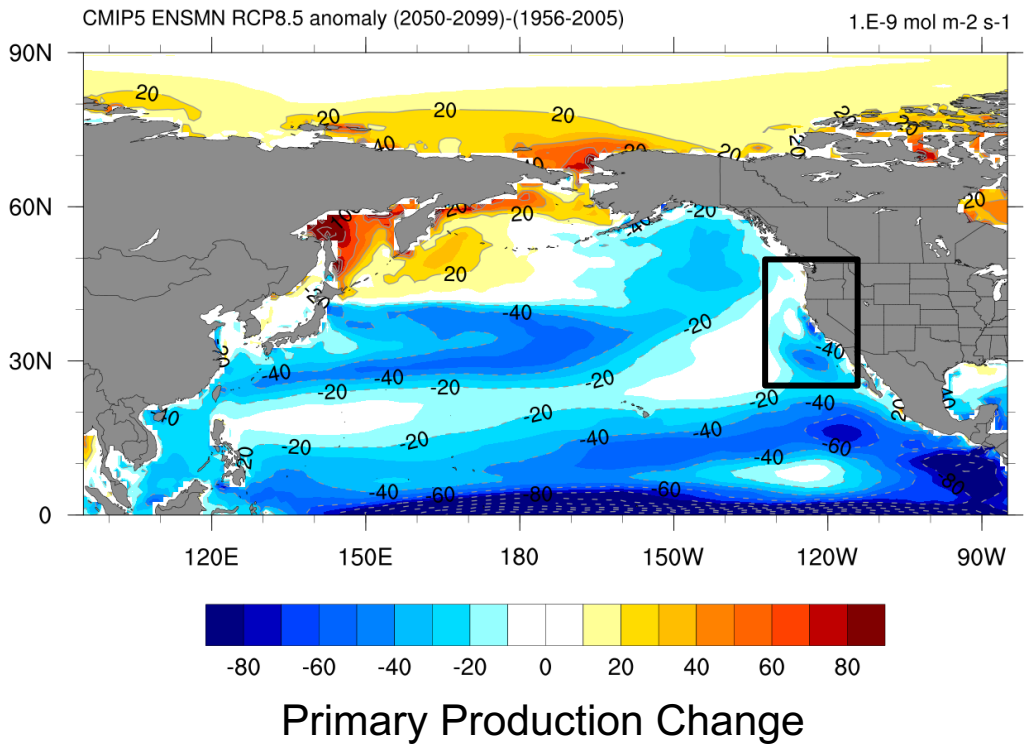
Rykaczewski *et al.* (2015)

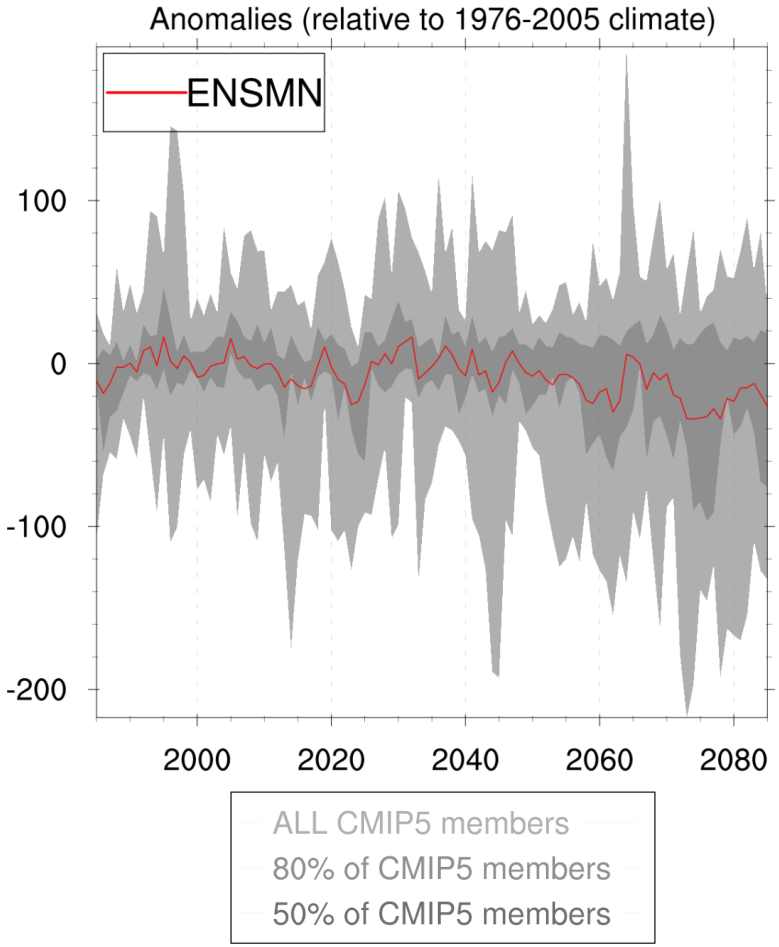
CLIMATE PROJECTIONS: SEA SURFACE TEMPERATURE





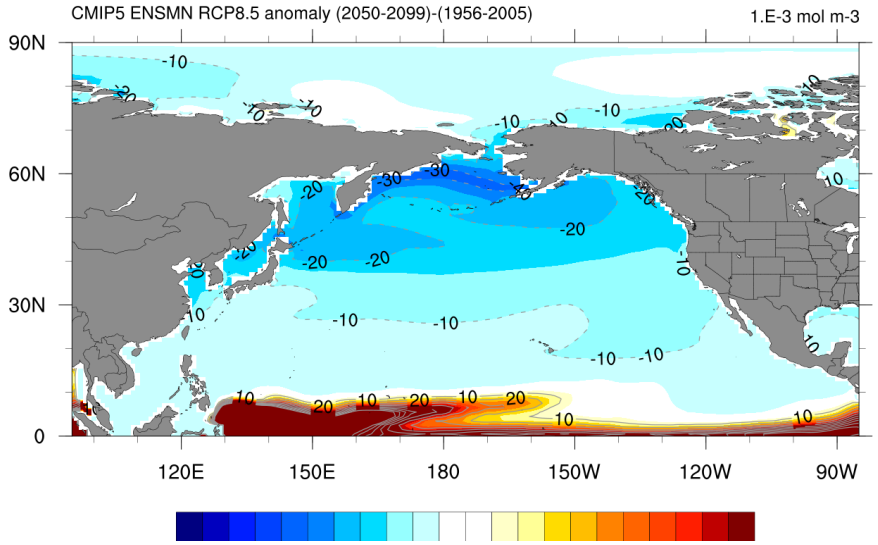
CLIMATE PROJECTIONS: PRIMARY PRODUCTION



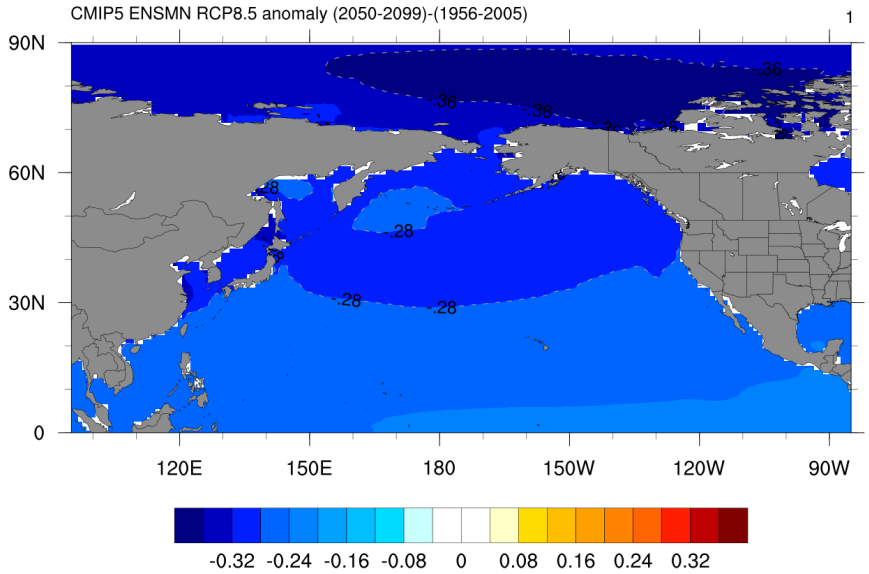


Climate Projections: Oxygen, pH

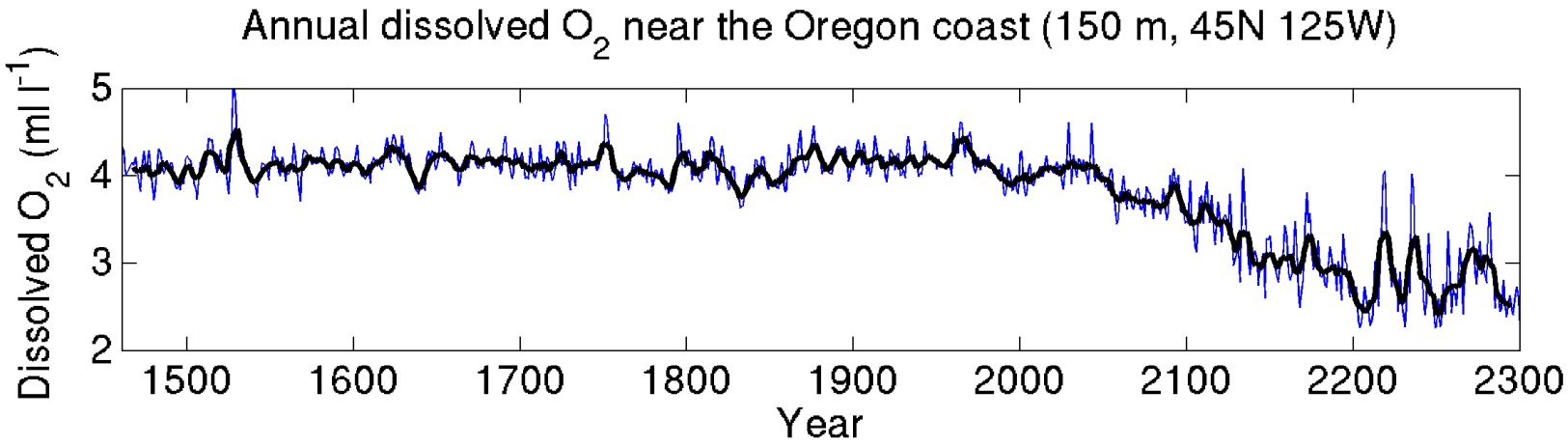
Oxygen

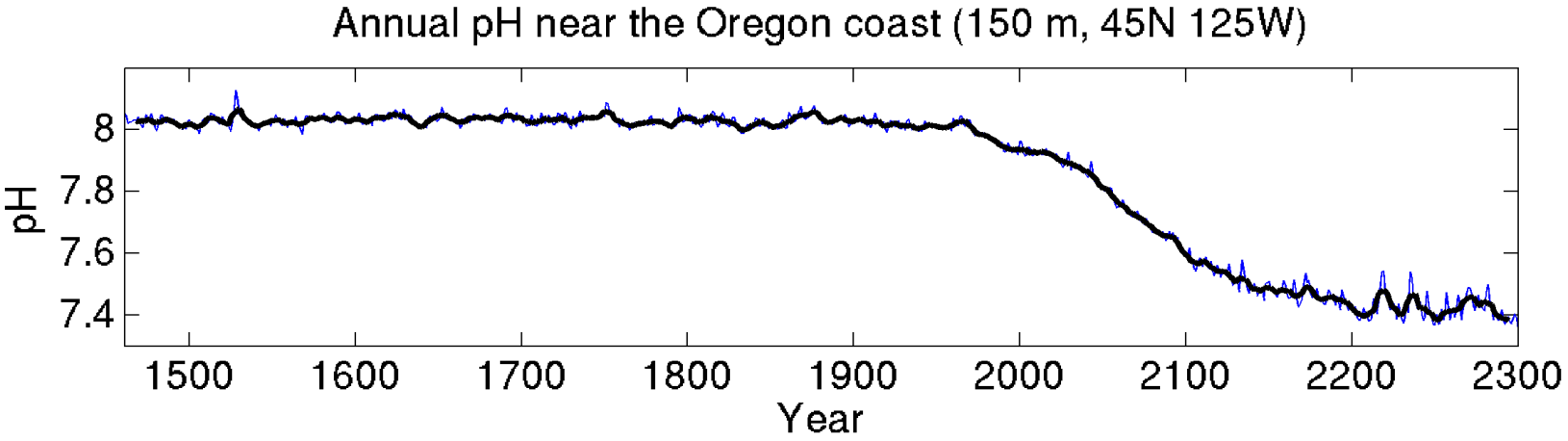


pH



CLIMATE PROJECTIONS: OXYGEN, PH

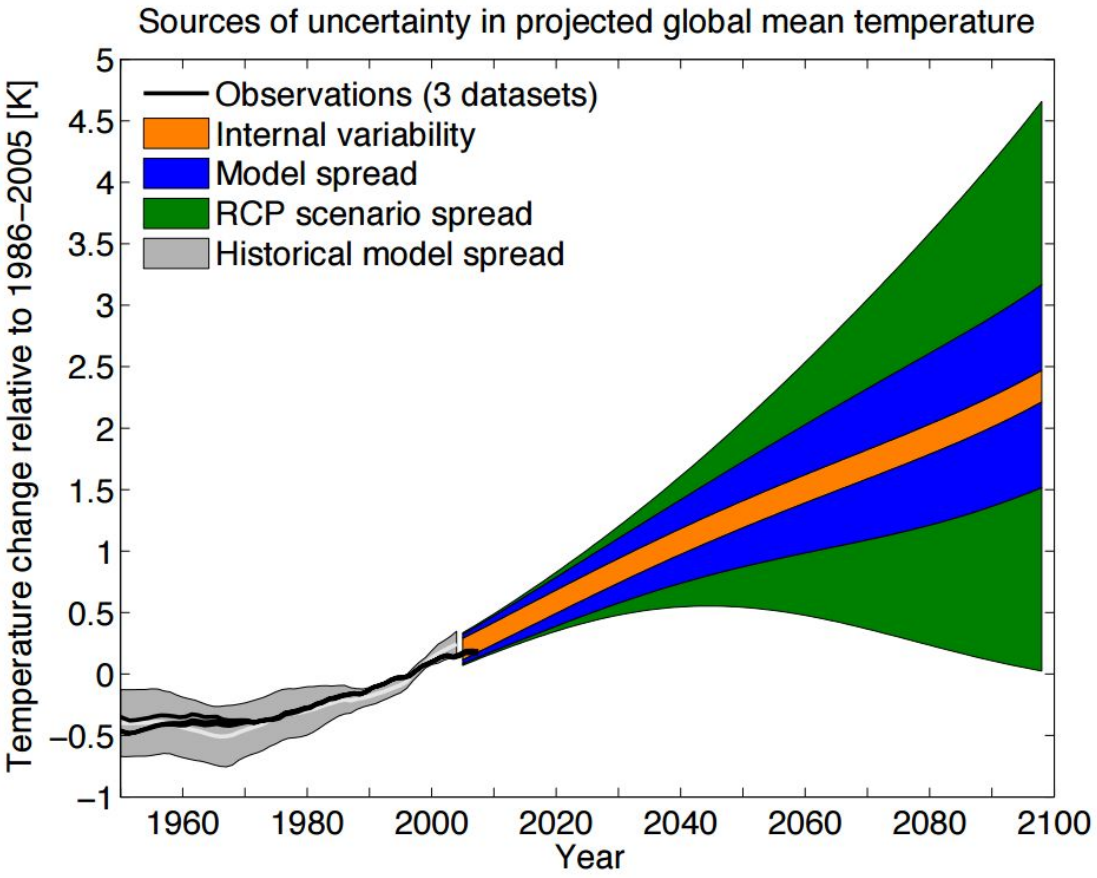




R. Rykaczewski

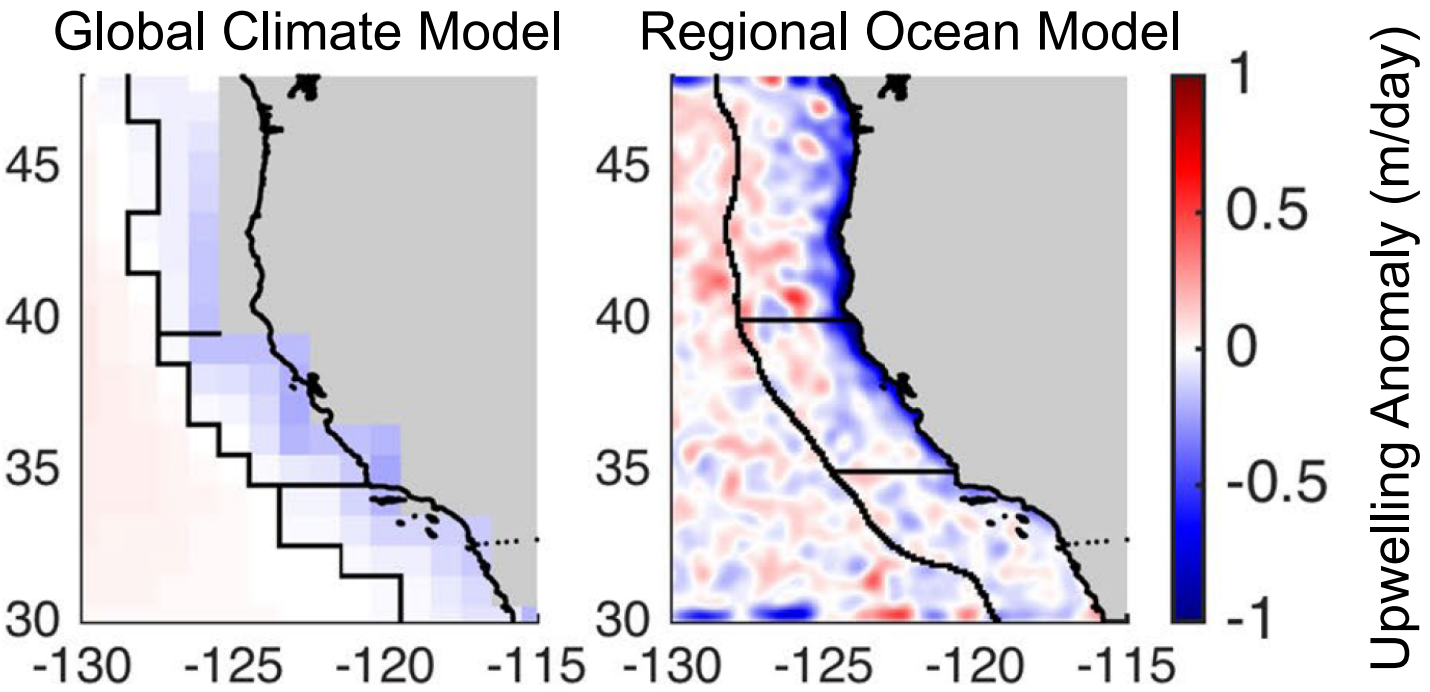
Caveats in Climate Projections

- Model uncertainty: model spread, internal variability, emissions scenario



Caveats in Climate Projections

- Model uncertainty: model spread, internal variability, emissions scenario
- Important coastal processes not resolved with typical spatial resolutions



Jacox et al. (2017)

Caveats in Climate Projections

- Model uncertainty: model spread, internal variability, emissions scenario
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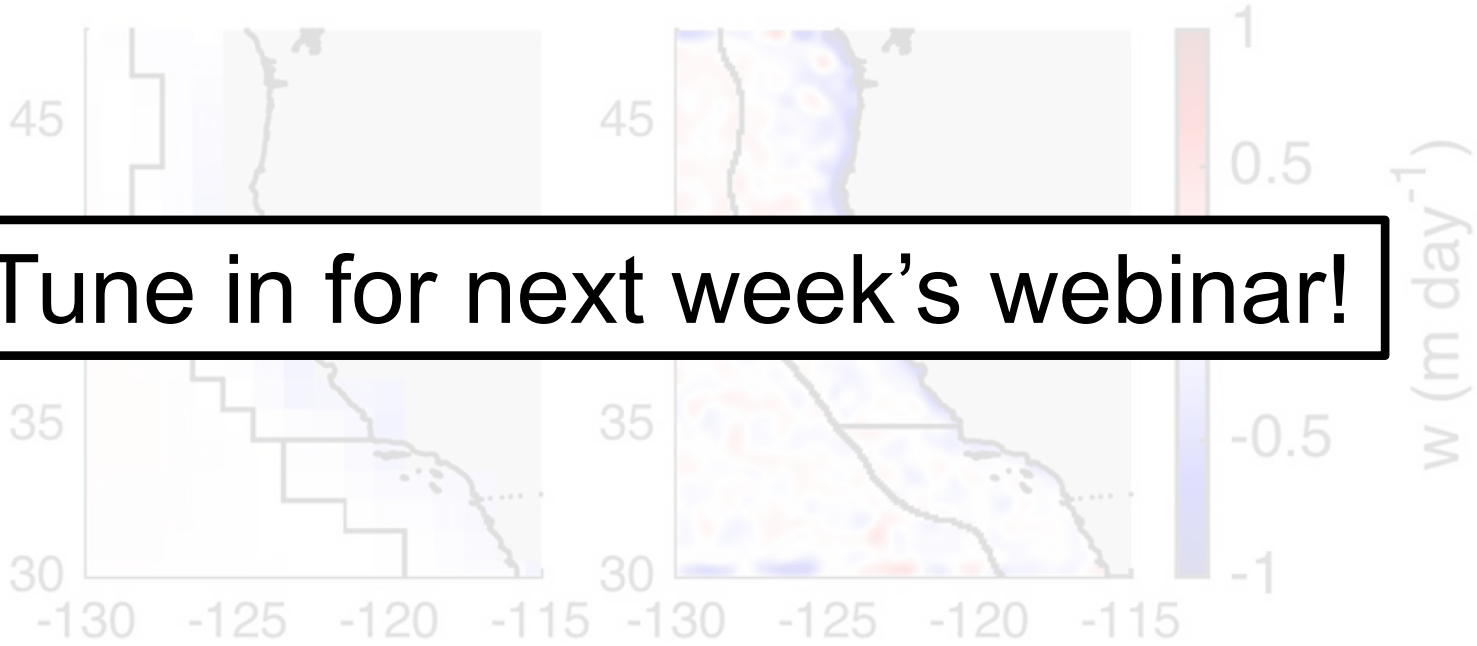


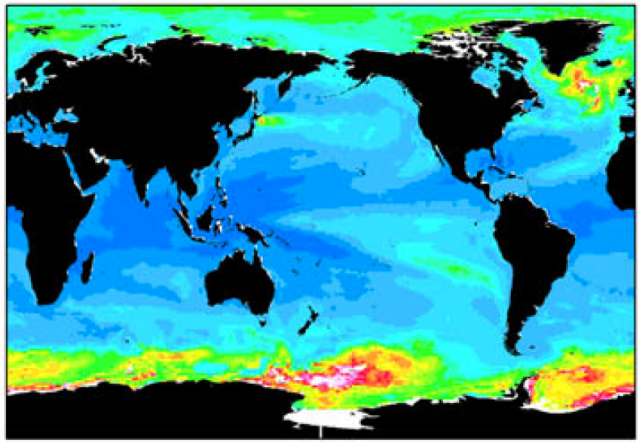
Tune in for next week's webinar!

Jacox et al. (2017)

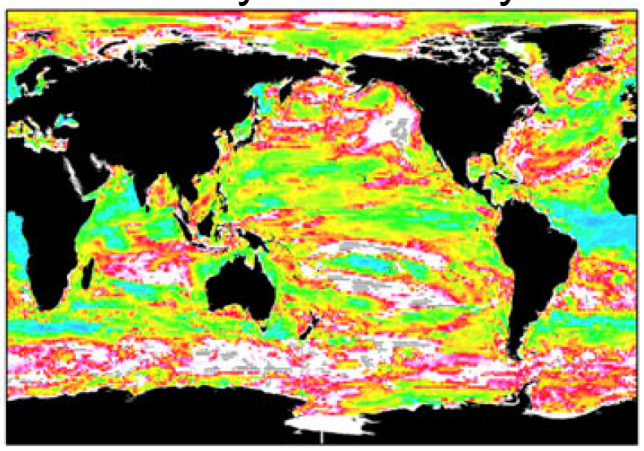
Caveats in Climate Projections

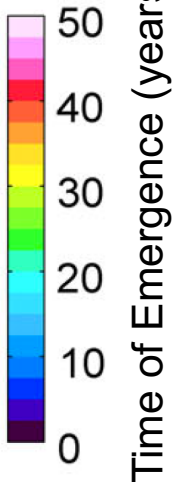
- Model uncertainty: model spread, internal variability, emissions scenario
- Important coastal processes not resolved with typical spatial resolutions
- Signal:Noise ratio of anthropogenic climate change signal can be small. Time of emergence can be long.

Sea Surface Temperature



Primary Productivity





Henson et al. (2016)

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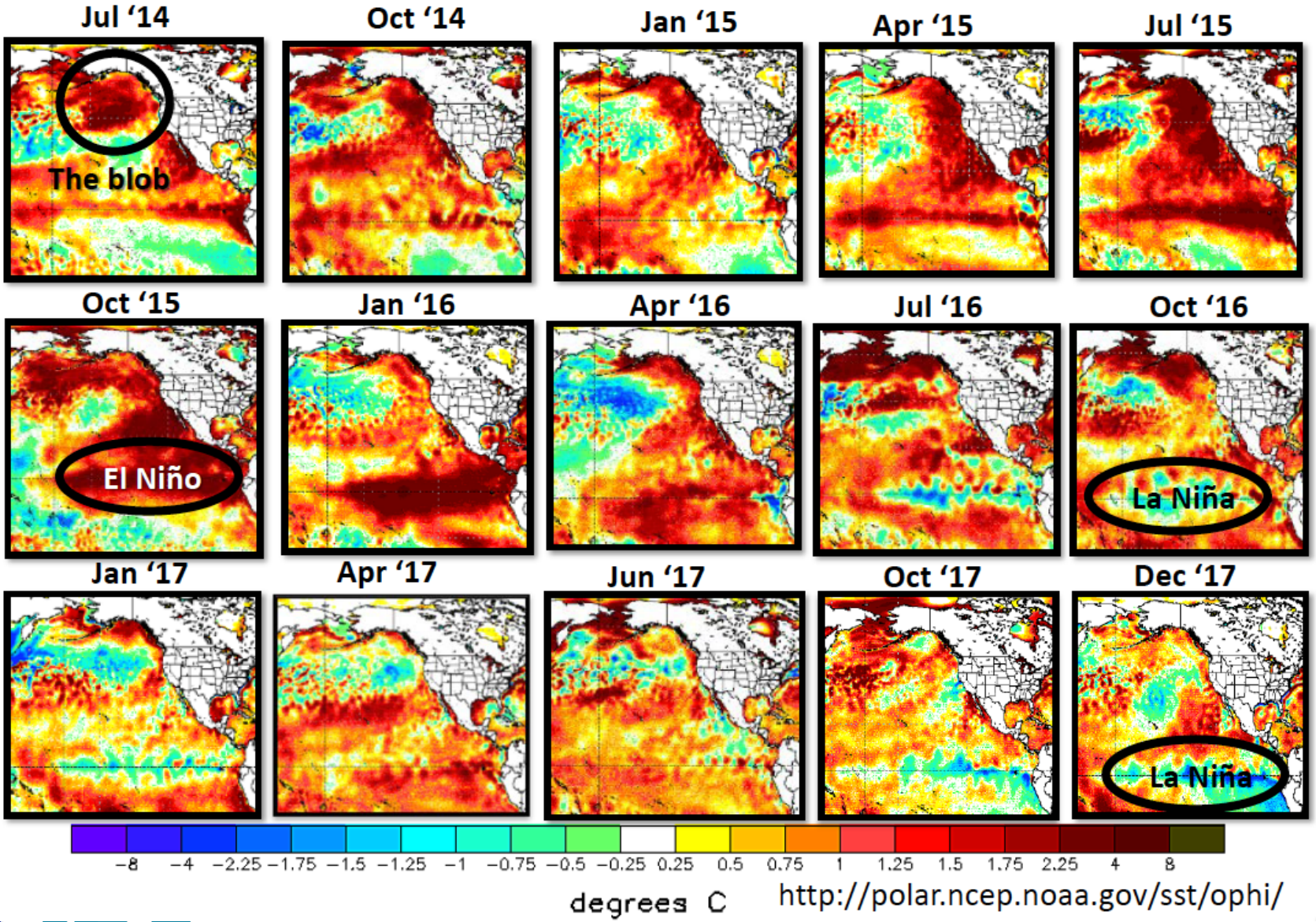
North Pacific surface temperature anomalies



MARINE SCIENCE

'The Blob' invades Pacific, flummoxing climate experts

Persistent mass of warm water is reshuffling ocean currents, marine ecosystems, and inland weather

By **Eli Kintisch**

Marine biologist Robert Pitman thought he'd seen it all after decades of conducting marine mammal surveys off the coast of southern California. But little prepared him for what he noticed off

tained by a
ated a mass
pressure th
western No
winds that
and push c
tudes south

Blob 2.0

MARINE SCIENCE

North Pacific 'blob' stirs up fisheries management

Unusual warmth strengthens calls for ecosystem-based decisions.

BY VIRGINIA GEWIN

Unprecedented conditions in the Pacific Ocean have sent fisheries managers into uncharted waters. 'The blob', an unusually warm mass of water that has been parked in the northern Pacific for 18 months, has quelled upwelling that delivers nutrients to

Fisheries Society annual meeting in Portland, Oregon, last week. Managers tend to base limits on assessments that focus on individual species and presume that population trends are stable. Ecosystem-based fisheries management aims for a more comprehensive approach that considers variables such as predator–prey relationships, climate conditions and

The biggest barrier may be the need to collect and analyse relevant biological data, such as information on how fluctuations in the population of a prey species will affect its predators. Supporters of ecosystem-based fisheries are creating tools such as the California Current Predator Diet Database, which is amassing information about the eating habits of 119 species. At the fisheries meeting, Amber Szoboszlai, a research analyst at the Farallon Institute for Advanced Ecosystem Research in Petaluma, California, showed how she had used the database to determine that fish eat 75% of the anchovies consumed in the Pacific, whereas mammals eat only 16% and seabirds 7%.

If the blob signals a regime change in the Pacific, conservationists argue that ecosystem-based management will be essential to preventing a catastrophe. "The whole system seems to be changing radically," says Rebecca Goldburg, director of ocean science for the Pew Charitable Trusts in Washington DC. ■

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Latest forecast suggests 'Godzilla El Niño' may be coming to California

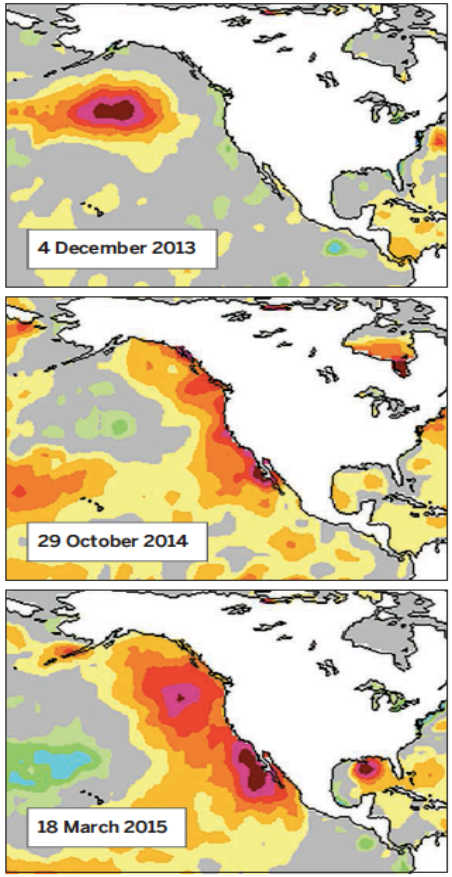
By **Rong-Gong Lin II**
Contact Reporter

AUGUST 13, 2015, 12:54 PM | REPORTING FROM SAN FRANCISCO

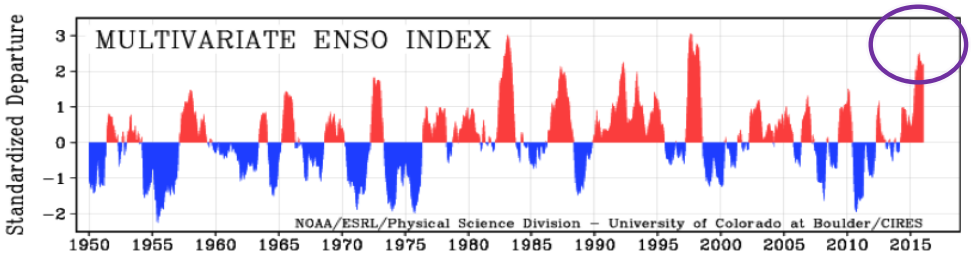
The strengthening El Niño in the Pacific Ocean has the potential to become one of the most powerful on record, as warming ocean waters surge toward the Americas, setting up a pattern that could bring once-in-a-generation storms this winter to drought-parched California.

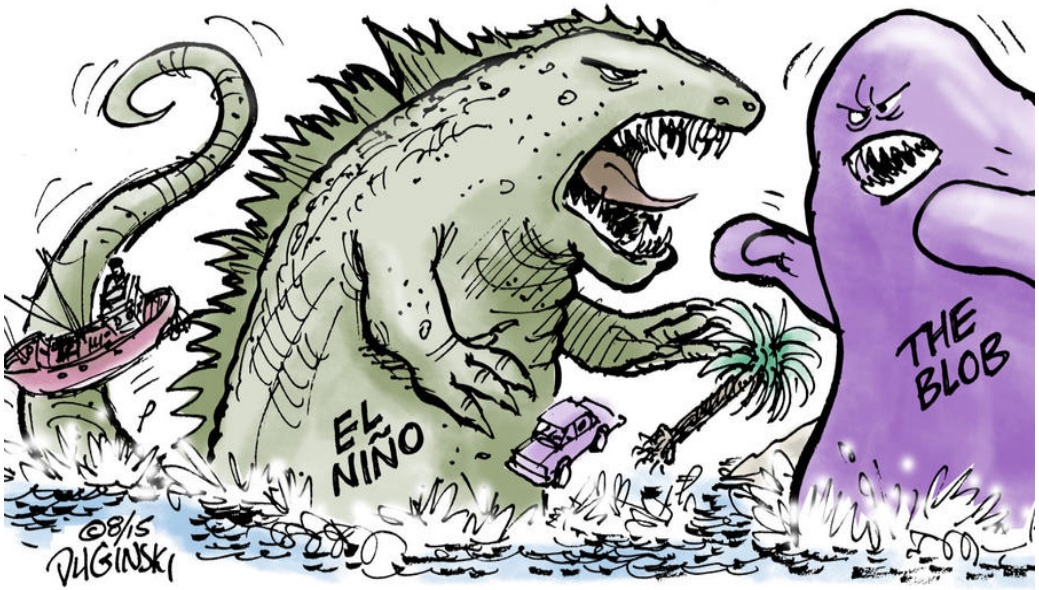
HIGHLY ANOMALOUS ENVIRONMENTAL CONDITIONS SINCE 2013!

The 'Blob'

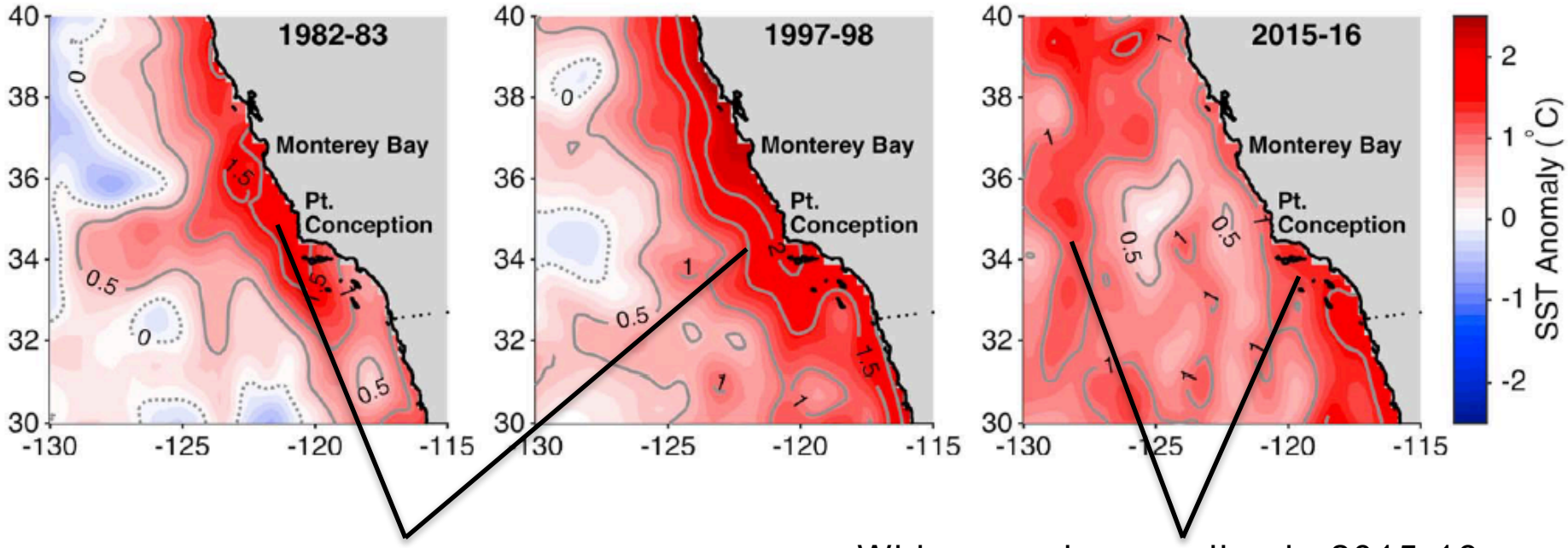


Godzilla El Niño





Comparison of SST Anomalies in Strong El Niños

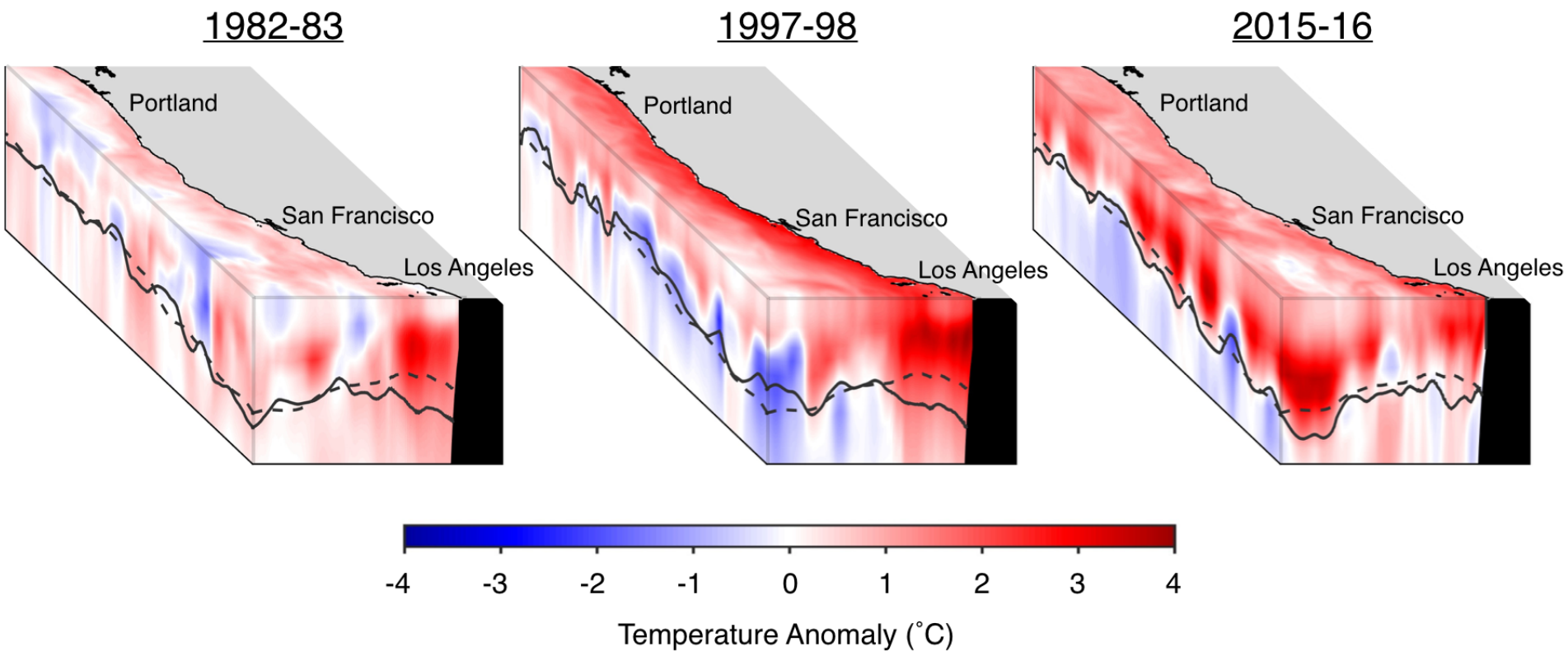


Coastal anomalies in 1982-83 and 1997-98

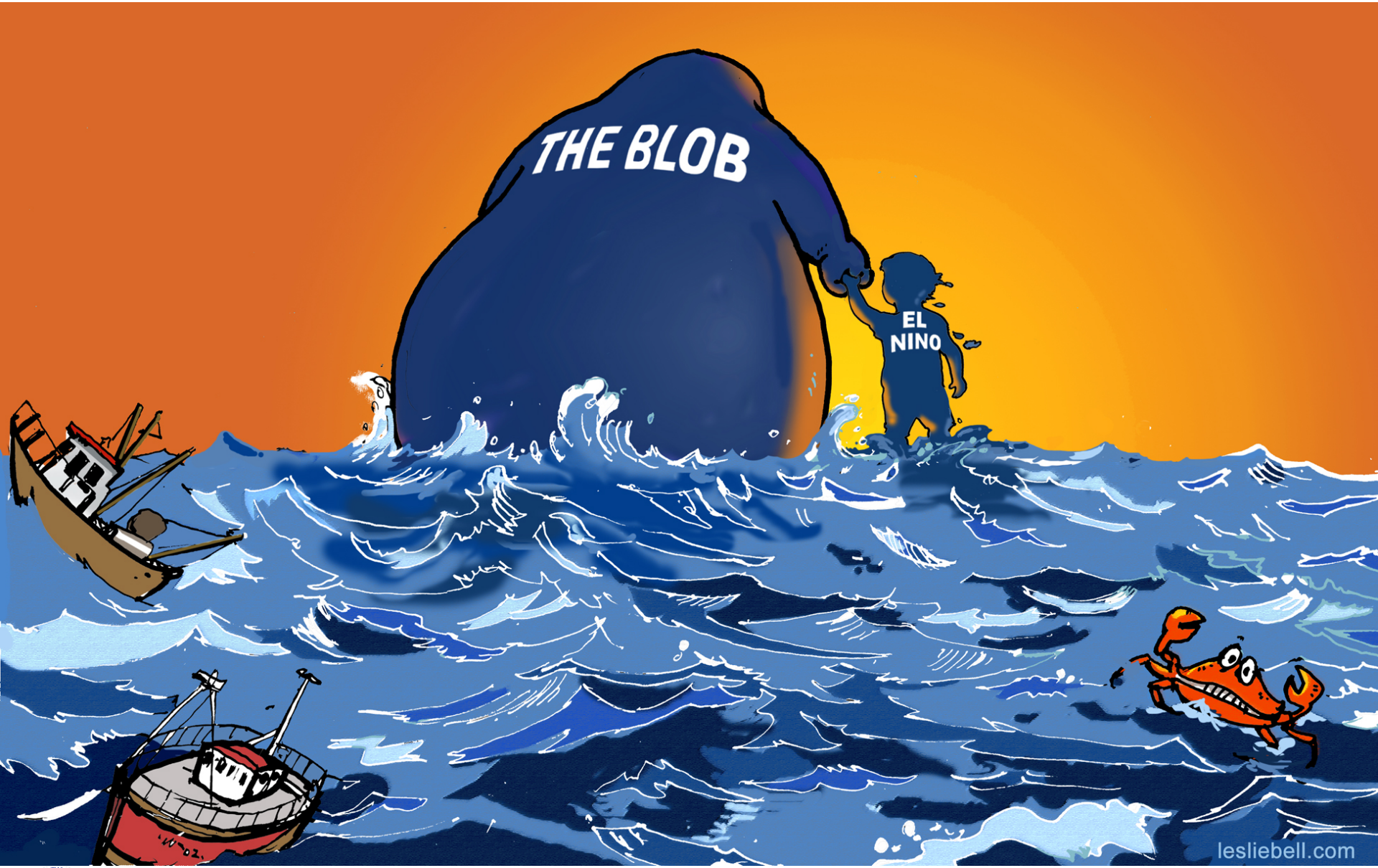
Widespread anomalies in 2015-16 (Blob + El Niño)

Jacox et al. (2016)

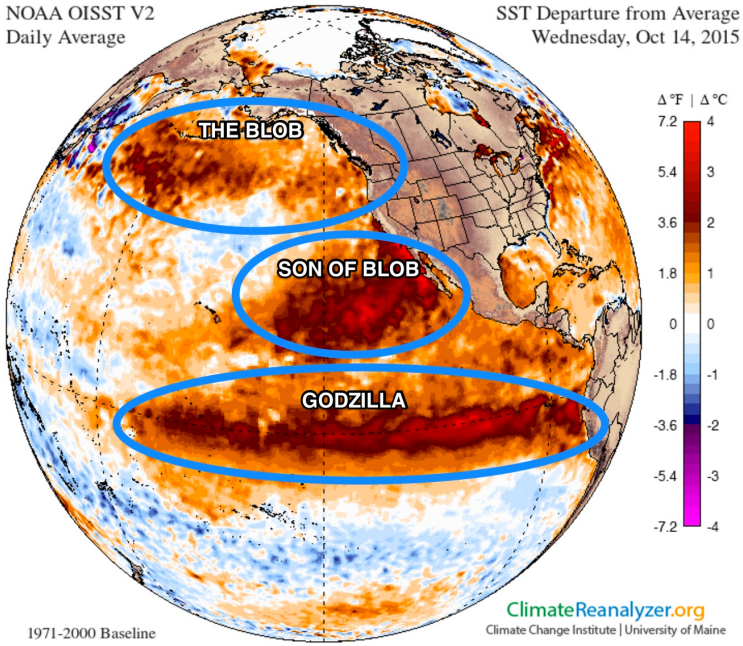
Comparison of SST Anomalies in Strong El Niños

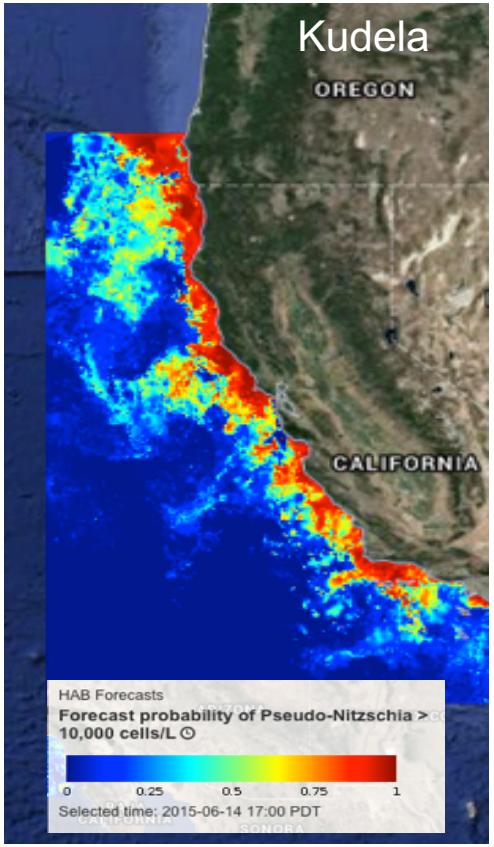


Jacox et al. (2016)


THE BLOB
EL NINO
lesliebell.com

2014-16 'Climate Stress Test'



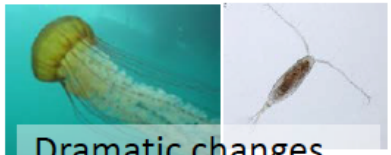


Biological Impacts in the California Current

2015

Tropicals In Oregon

Species range extensions from CA to AK



Dramatic changes to food webs

Domoic acid closes crab and clam fisheries AK-CA

Young Chinook & coho in ocean very skinny

2016

Red pelagic crabs in Oregon!

Anchovies invade the Salish Sea

Changes to food webs continue

Crab and clam fishery closures

2017

High Pacific lamprey counts at Bonneville Dam

Pyrosomes explode AK-CA

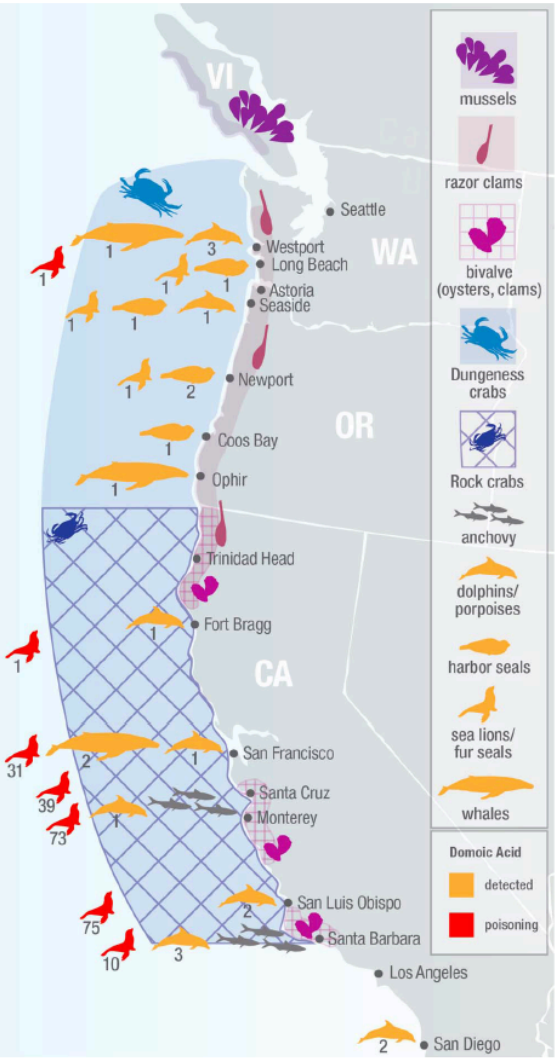
Swordfish off Vancouver Island

Extremely low Pacific cod abundance in Gulf of Alaska

Crab and clam fishery closures

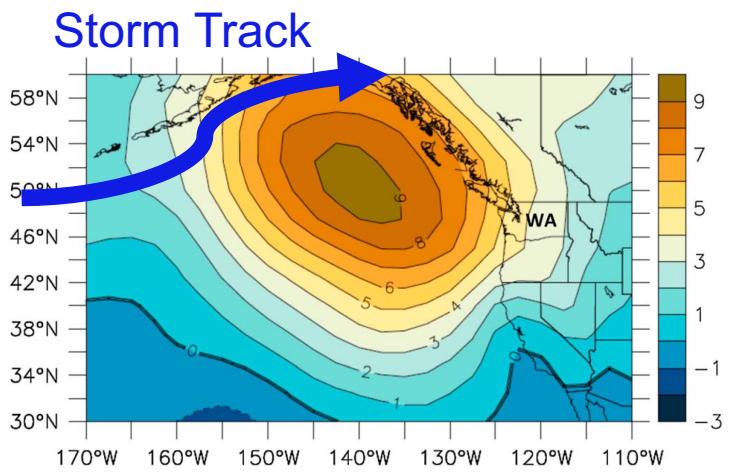
Biological Impacts in the California Current

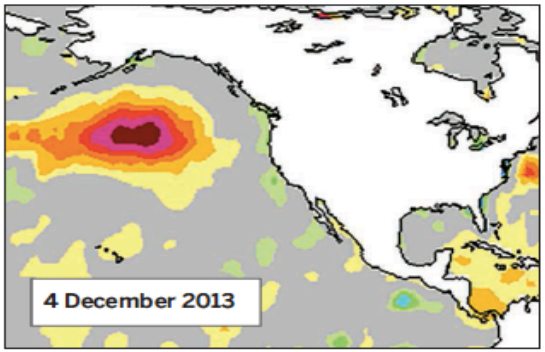
2015	Shellfish Harvest and Fishery Closures with Maximum Domoic Acid Values
7-May	Quinault tribe razor clam harvest closure (WA)
8-May	Commercial, tribal & recreational razor clam harvest closure (WA)
9-May	Razor clam harvest closure (northern OR)
14-May	State wide razor clam harvest closure (OR)
15-May	Shellfish harvest closure (BC Canada)
29-May	Anchovy viscera maximum 1671 ppm (CA)
1-Jun	Anchovy, sardine fishery closure (CA)
3-Jun	Dungeness crab maximum 65 ppm (WA)
5-Jun	Dungeness crab fishery closure (WA)
3-Jul	Anchovy, sardine, mussel, & clam closures expanded to southern CA
11-Sep	Dungeness crab maximum 140 ppm (northern CA)
27-Oct	Razor clam maximum 170 ppm (southern OR)
3-Nov	Dungeness crab & rock crab warning for recreational harvest (CA)
6-Nov	Commercial rock crab fishery closed (CA)
8-Nov	Dungeness crab maximum 70 ppm (southern OR)
11-Nov	Dungeness crab & rock crab recreational & commercial fishery closure (CA)
22-Nov	Dungeness crab maximum 270 ppm (northern CA)
23-Nov	Rock crab maximum 1000 ppm (southern CA)
23-Nov	Delayed opening of commercial Dungeness crab fishery (WA, OR, CA)
9-Feb-2016	CA seeks federal disaster declaration for commercial crab fishery



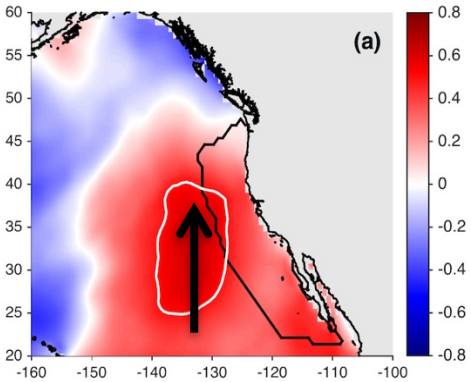
McCabe et al. (2016)

What Caused the Recent Extreme Ocean Temperatures?

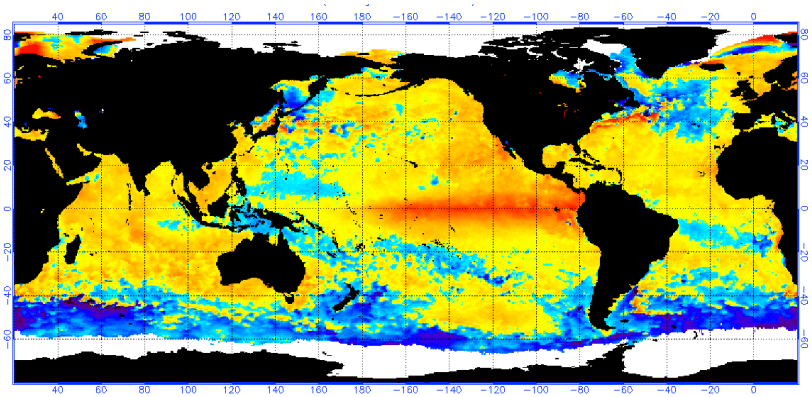




High pressure ridge → Reduced storm-driven mixing → Warm Gulf of Alaska

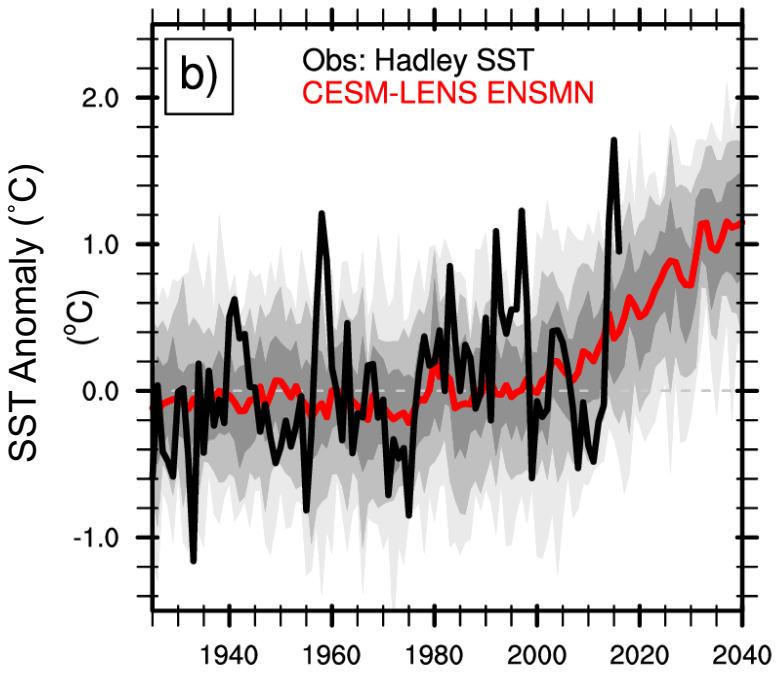


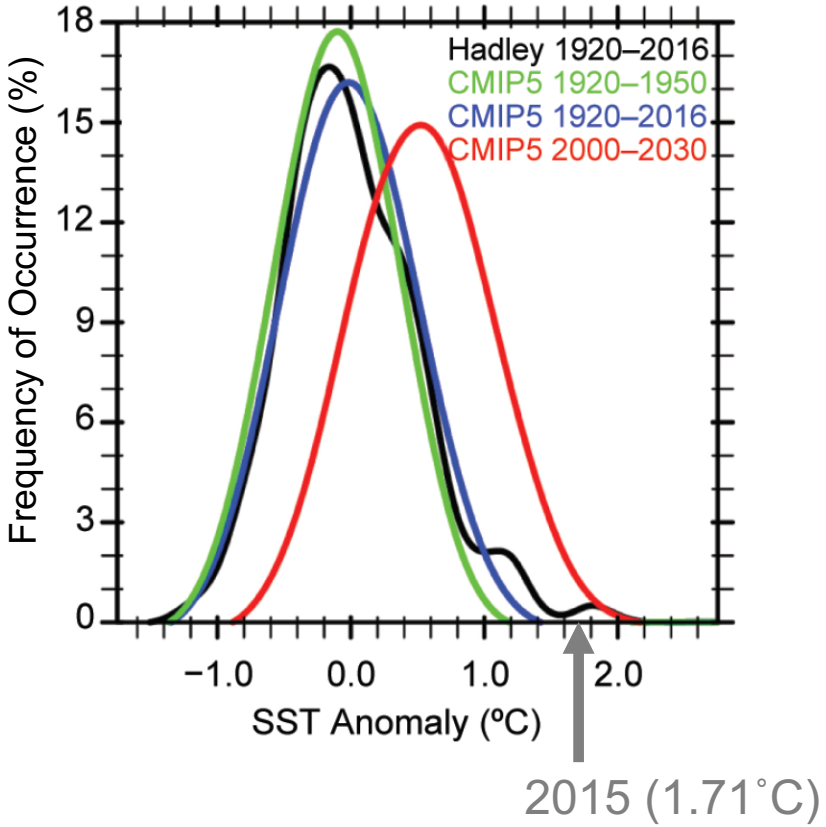
+ Anomalous winds off US west coast



+ One of the strongest El Niños on record

What Was the Contribution of Anthropogenic Forcing?

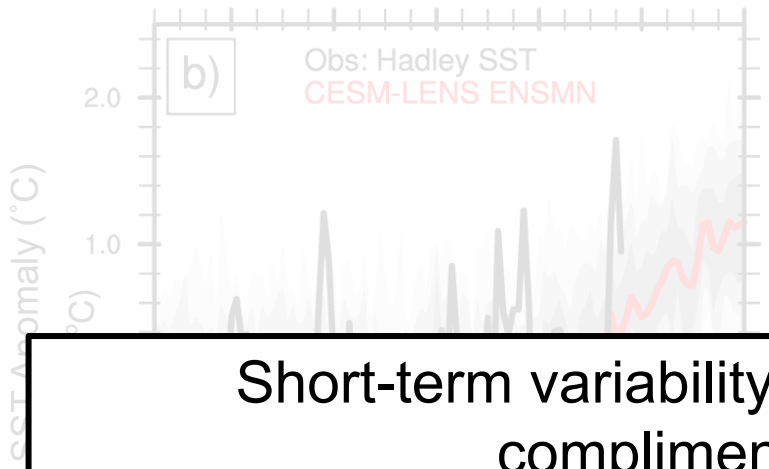


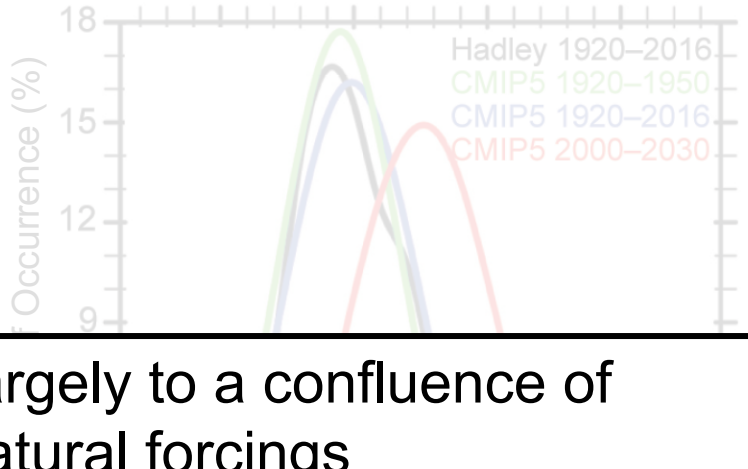


Under 1920-1950 forcing, there was a 0% chance of a 1.71˚C anomaly
Under 2000-2030 forcing, there is ~ 2-4% chance of a 1.71˚C anomaly

Jacox et al. (2017)

What Was the Contribution of Anthropogenic Forcing?





Short-term variability due largely to a confluence of complimentary natural forcings

BUT

Extreme/unprecedented conditions are far more likely due to long-term climate change

Under 1920-1950 forcing, there was a 0% chance of a 1.71˚C anomaly
Under 2000-2030 forcing, there is ~ 2-4% chance of a 1.71˚C anomaly

OUTLINE

Part 1: Anticipated climate change in the California Current System

Part 2: A 'Climate Stress Test': recent anomalies in the CCS

Part 3: Fisheries management challenges in a changing climate

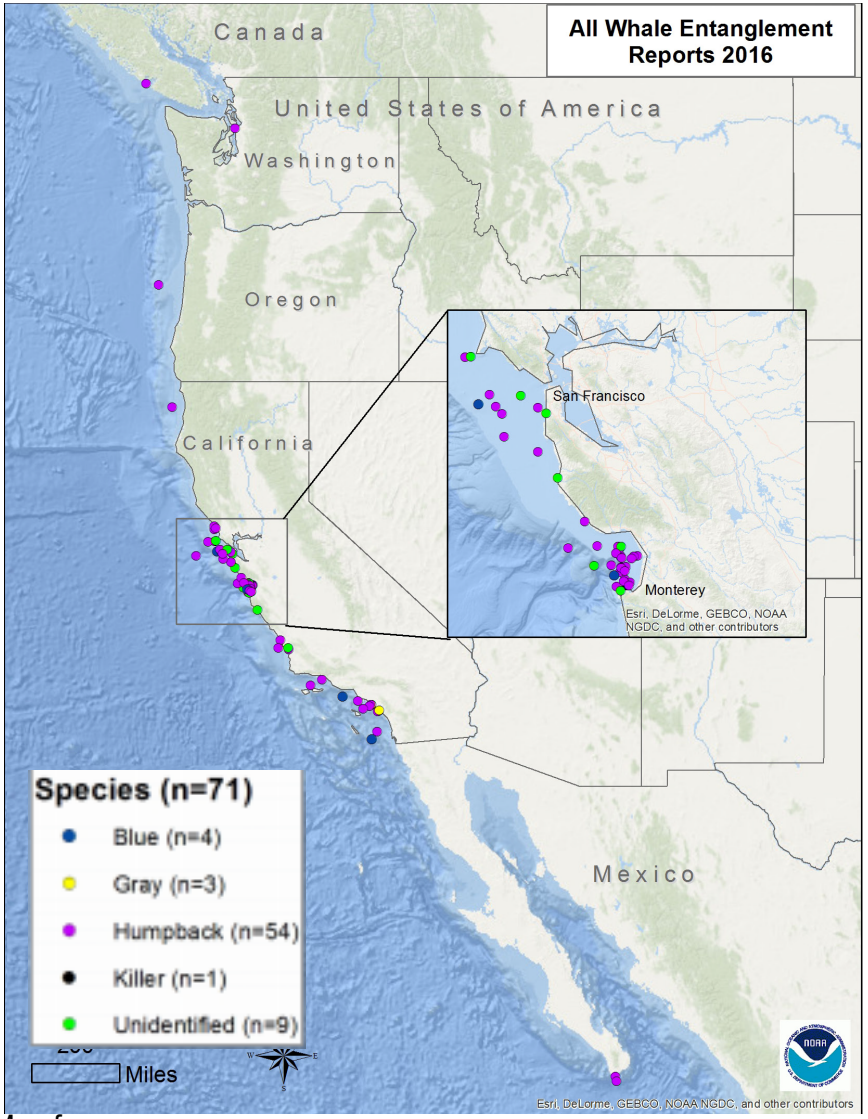
2 examples of emerging challenges in West Coast fisheries management

Episodic: 2015-16 spike in West Coast whale entanglements in fishing gear

- 71 entangled whales reported in 2016 with gear from U.S. fisheries (54 humpback, 3 gray and 4 blue whales), mostly California

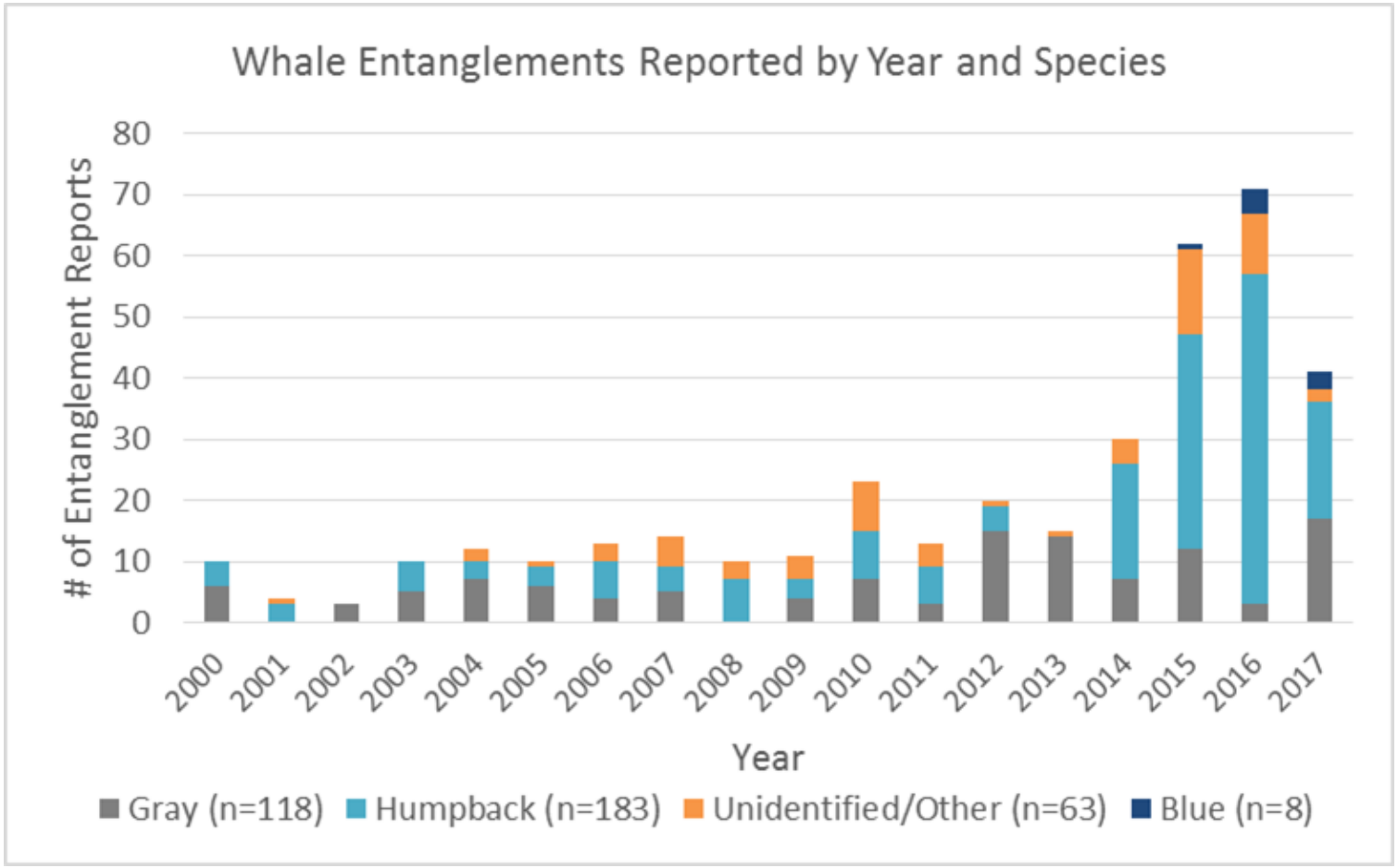
Chronic: West coast salmon fishery declines and the increased frequency of federal fishery disasters

- 1980s (1), 1990s (3), 2000s (5+)



Map from http://www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/cetaceans/wcr_2016_whale_entanglements_3-26-17_final.pdf

2015-16 whale entanglements: what happened?



From Dan Lawson NOAA

2015-16 whale entanglements: what happened?

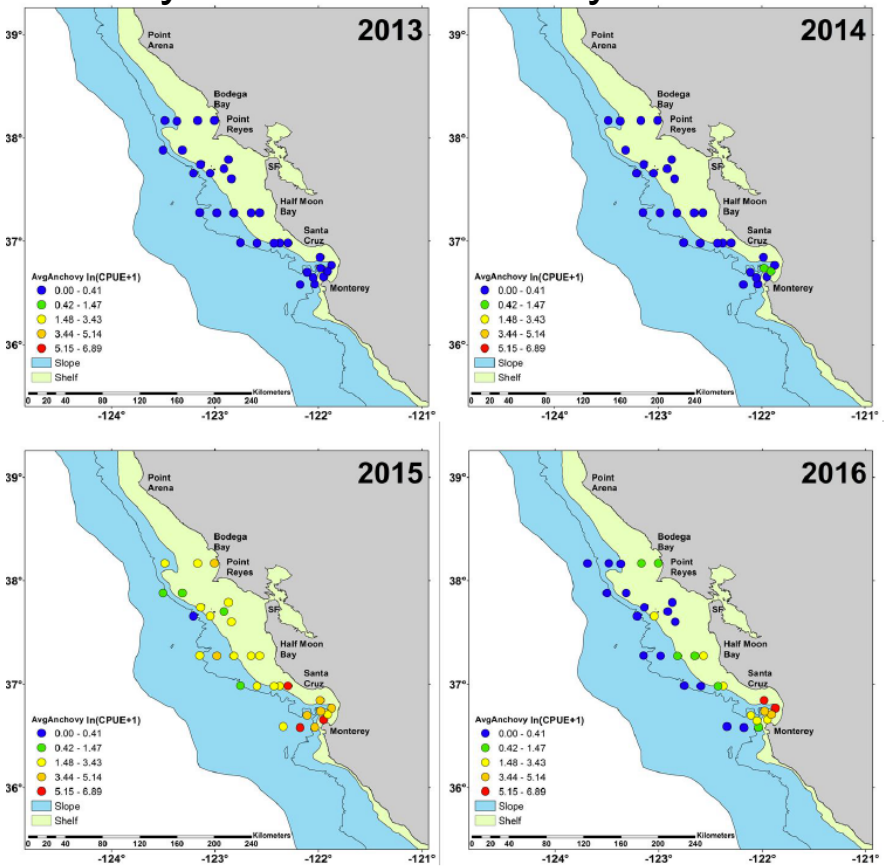
Key ecosystem ingredients:

- Persistent marine heat wave
- Record harmful algal bloom in 2015 caused widespread domoic acid contamination in Dungeness crab
- Declines in krill, increased inshore abundance of anchovy in Monterey Bay/Gulf of the Farallones
- Humpback prey-switching from shelf-break/slope krill to on-shelf anchovy

Key human-dimension:

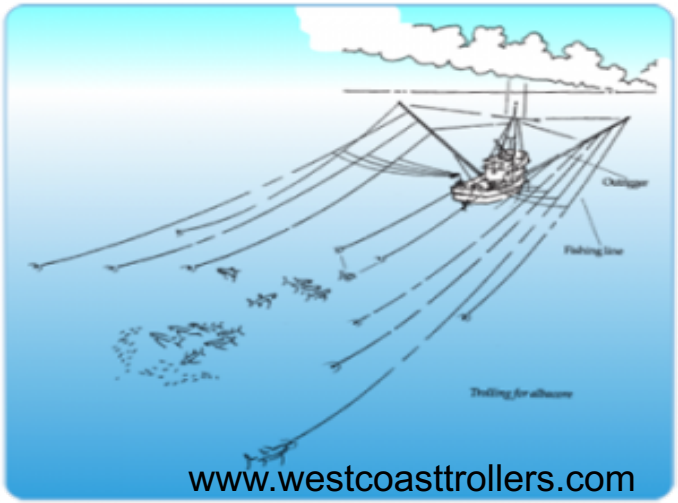
- 5-month delay in the opening of central California's Dungeness crab fishery

May-June YOY Anchovy CPUE



End result: unusual time-space overlap of large numbers of foraging humpback whales and crab pots/lines (image from Jarrod Santora)

West Coast Troll Chinook Salmon Catch



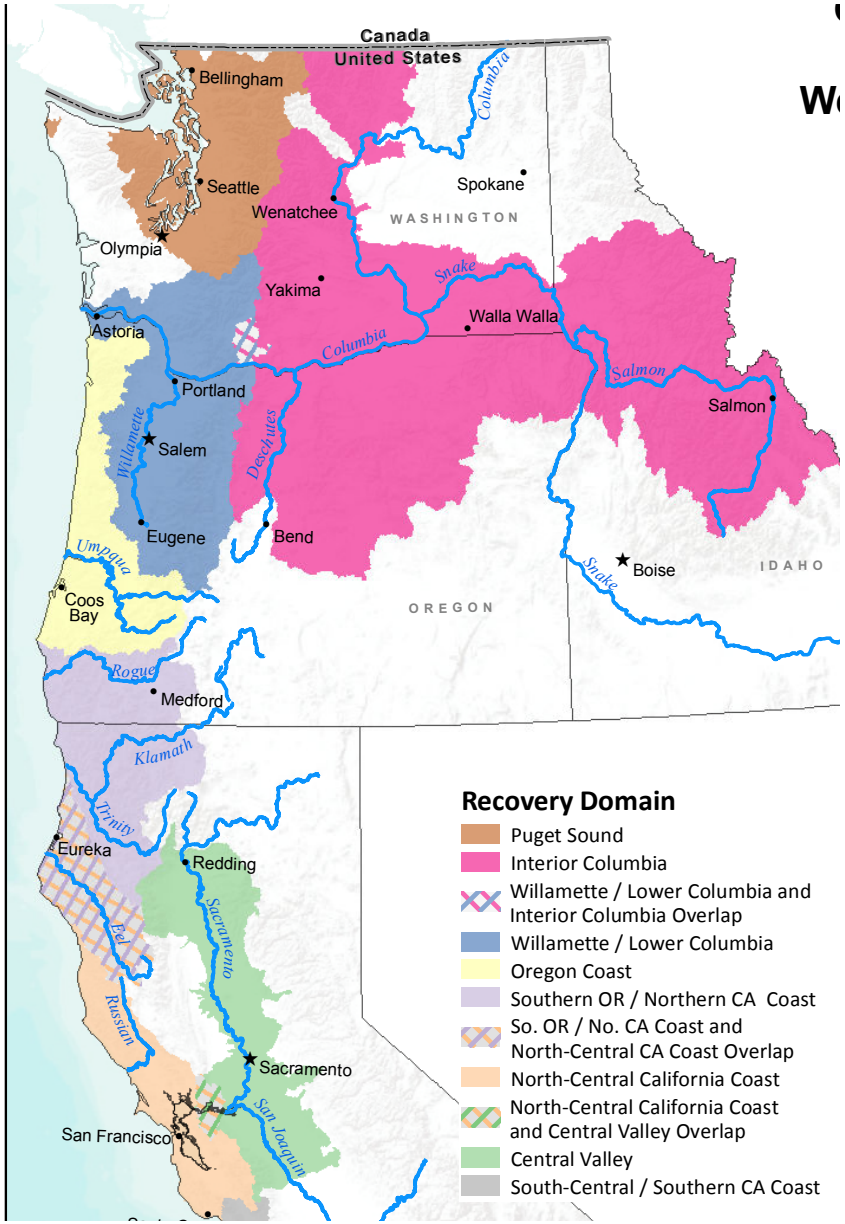
ESA listings and the era of weak stock management

Chinook Salmon ESA listings

1989 Sacramento Winter Run
1992 Snake Fall and Spr/Su
1999 Puget Sound, Lower Columbia, Upper Willamette, Upper Columbia Spr, Central Valley Spr, California Coastal

Coho Salmon ESA listings

1996 CC CA Coho
1997 SOR-NCA Coho
1998 OR coast Coho
2005 Lower Columbia Coho



Federal Fishery Disaster Timeline

1984: coastwide catch/escapement declines in 1983 due to El Niño-related **warm/poor ocean conditions** in the CCS in 1982-1983; catch declines in 1984 also due to harvest limits

1994: poor catches in 1993 related to **CA drought** from 1987-1992, **very low snowpack** west-wide in 1992, WA **flooding** in 1992-93, CCS **warm ocean** conditions related to El Niño in 1992-93; $16M aid package

1995: requested and received another $12M relief

1998: record **flooding in WA** in winters 95-96 and 96-97

2005: unprecedented restrictions on commercial ocean and in-river fisheries in northern CA and OR due to poor adult salmon returns to the Klamath R; multi-year **drought** and **poor stream conditions** in 2001-5

2006: severely restricted or closed fisheries from Cape Falcon, OR to Pt Sur, CA (700 miles of coastline); "**recent decline in ocean conditions and 2001-5 Klamath drought**"

2008-09: extremely poor CA fisheries and escapements in 2007, closed fisheries in 2008, collapse of Sacramento R fall Chinook salmon;

2010-11: no fishery and record low escapement of Sacramento R. Fall Chinook in 2009; NMFS report concludes *"**poor ocean conditions in 2005-6** in conjunction with degradation of FW and estuary habitat, reliance on 4 hatcheries"* were the proximate and underlying factors

2016-17: (1 granted, more pending): Klamath Tribes, CA/OR Governors – very poor catch in 2016, severe fishery restrictions or closures for 2017; caused **by poor ocean conditions** (2014-16)**, 2015 western snow drought, CA "hot drought"** (2012-2015), **poor water quality and related parasites and fish disease in the Klamath R.**

The Changing Climate and Context of West Coast Salmon Fisheries

- A warming climate and an era of frequent drought
- An increased frequency of ocean extremes
- Evolution of the salmon productions system: CA – increasing hatchery contributions and reliance on off-site releases of large smolts; evidence for increased synchrony among populations

- Evolving marine food webs: increases in top predators (whales, sea lions, harbor seals, and some sea birds); boom-bust cycles in key forage fish (California sardines, northern anchovy)

Summary

We are entering an era of rapid ocean change:

- High frequency of extreme warm events in the CCS since the 1980s caused widespread ecosystem and fishery impacts
- Climate models predict ocean extremes will become more frequent and intense as warming trends accelerate

Ecosystem responses to future climate change:

- In the next decade or two, slower trends may be hard to detect in the presence of large year-to-year variations
- Chronic, climate-sensitive fishery challenges likely to become more frequent and intense (*West Coast Chinook salmon)
- A “no-anolog future”? As we move deeper into ocean states without historical analogs, expect novel and surprising ecosystem ocean impacts and fishery management challenges

Questions?

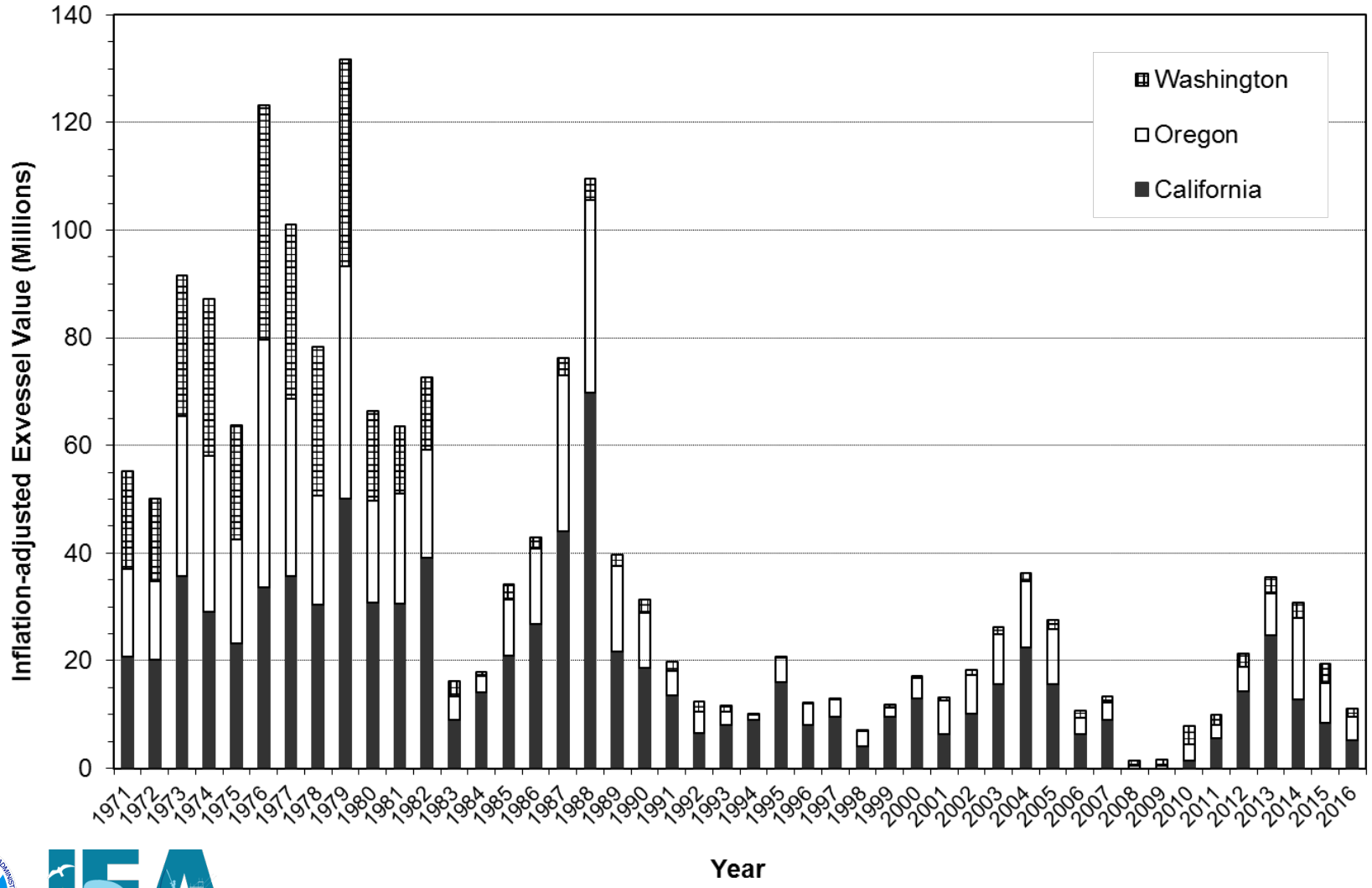
Climate ‘Stress Test’: Summary

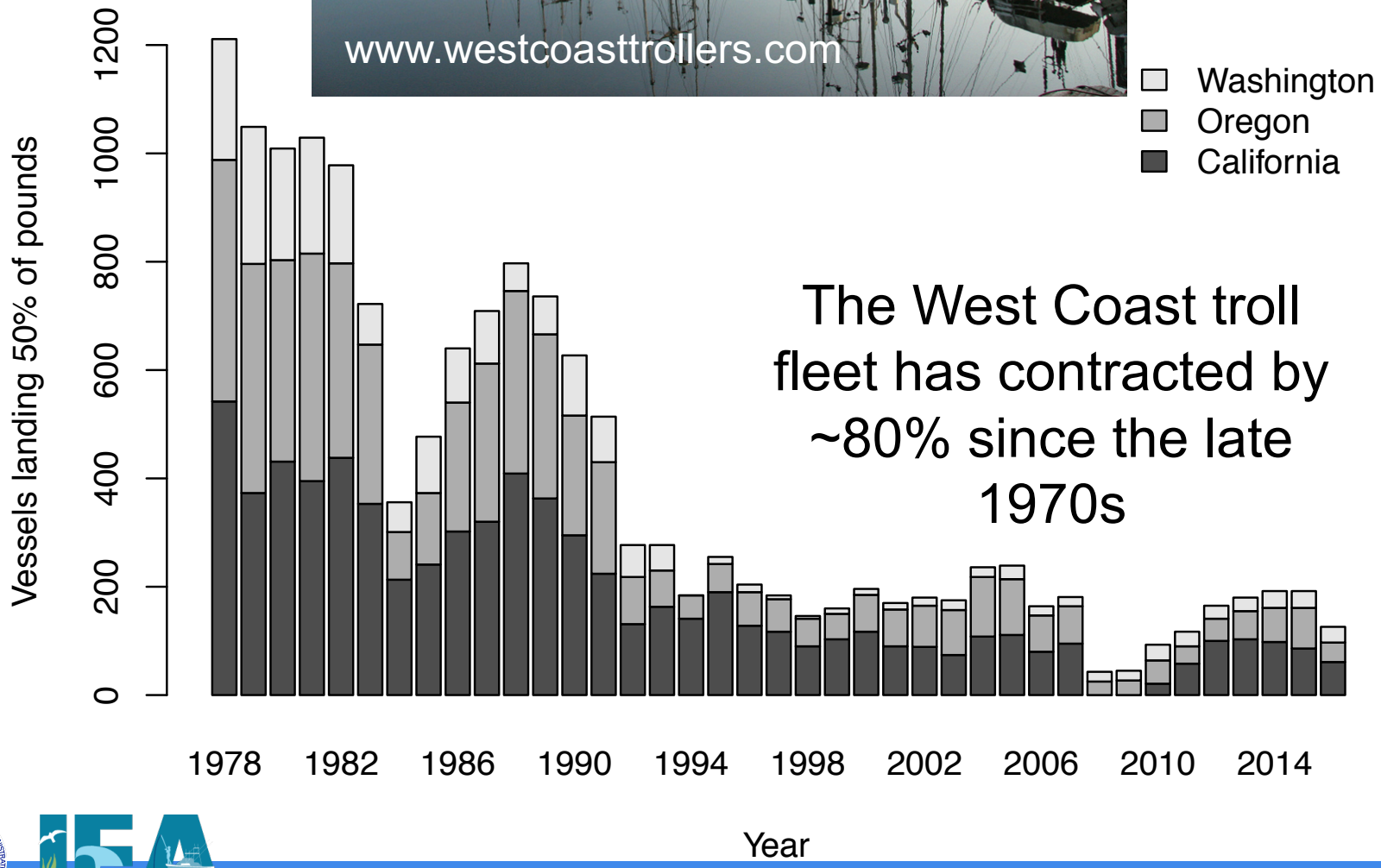
- **Environmental conditions dominated the CCLME with record-high SST anomalies (the warm ‘Blob’) in the NE Pacific and off Baja California in 2014–2016, continued drought, followed by one of the largest El Niños of the past 100 years in 2015-2016**

- **Multiple indicators → poor productivity & anomalous events including:**
  - Huge harmful algal blooms → fishery closures,
  - In-stream pre-spawn Chinook salmon die-offs & low catches
  - Mass mortalities of CA sea lions, Guadalupe fur seals, & common murres,
  - Record entanglements of baleen whales in nearshore fishing gear,
  - Observed high numbers of juvenile leatherback turtles.

- **Need for EBFM tools (IEA); ‘climate-ready’ strategies; dynamic ocean management**

US West Coast Chinook Salmon commercial troll landed value





The West Coast troll fleet has contracted by ~80% since the late 1970s