The Phenology of Coastal Upwelling in the California Current:

Interannual Variability and Ecosystem Consequences

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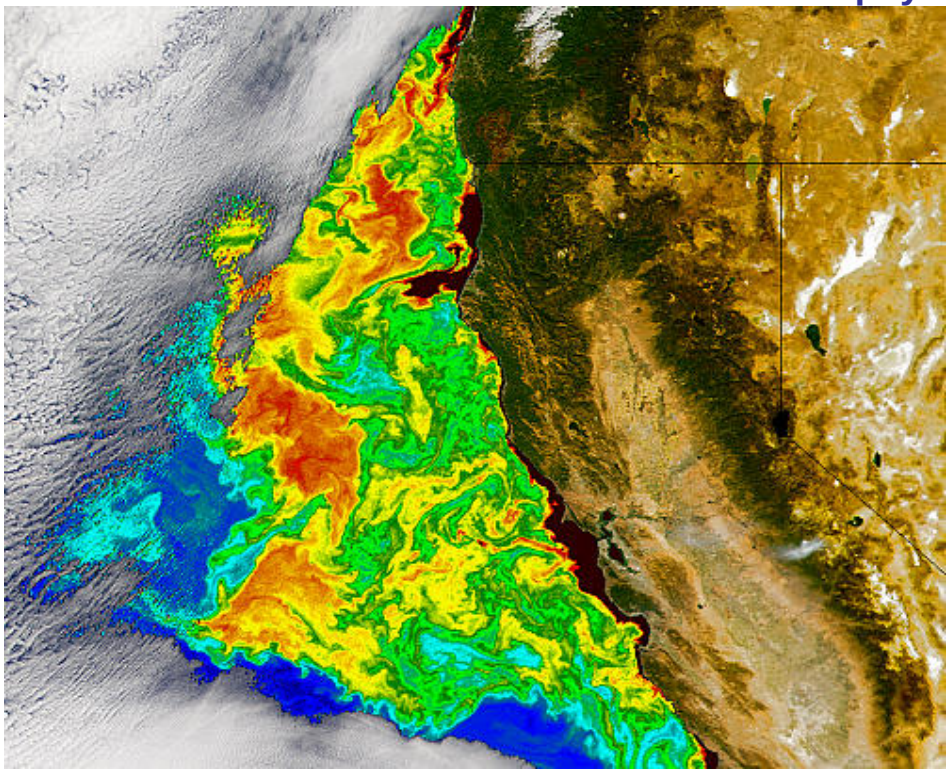
- NOAA Fisheries and the Environment (FATE)
- California SeaGrant, Ocean Protection Council

California Current Large Marine Ecosystem

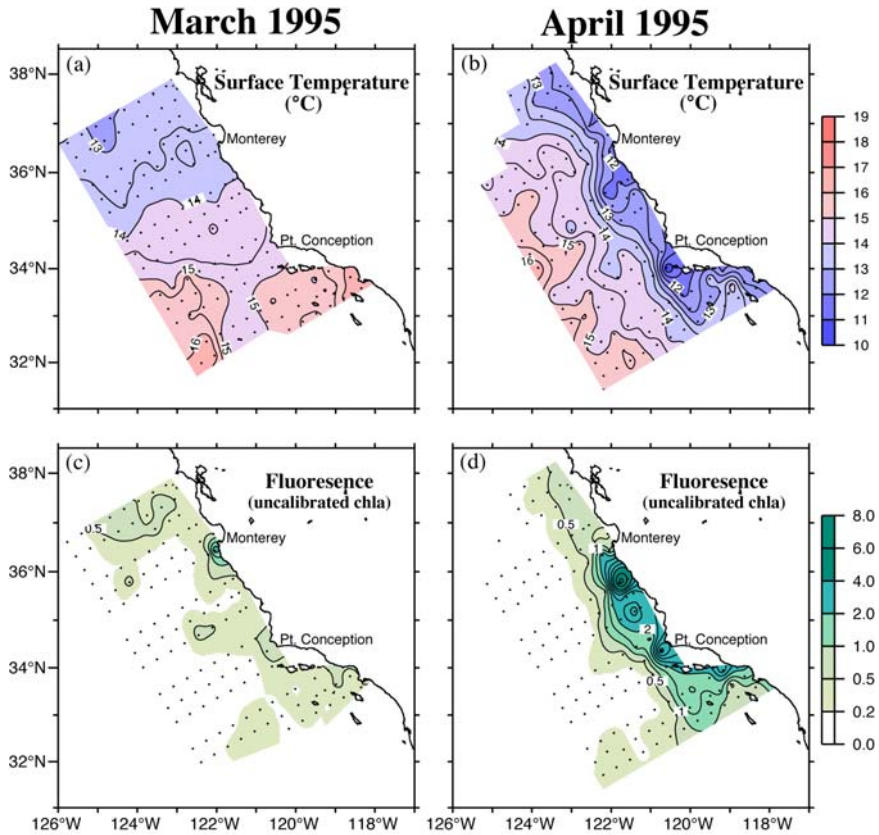
SeaWiFS chlorophyll



- Seasonal (coastal upwelling) & interannual (ENSO) forcing
- Highly productive marine ecosystem
- Eastern Boundary Upwelling System

Phenology (生物气候学):

1. The scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions.
2. The relationship between a periodic biological phenomenon and climatic conditions. (*American Heritage Dictionary*)



e.g., spring transition in the California Current

Lynn et al. (2003)

MOTIVATION

- **Many marine species have life histories adapted to seasonal events in the environment.**





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- **How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?**

Task 1





MOTIVATION

- **Many marine species have life histories adapted to seasonal events in the environment.**

- **How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?**

- **How do phenological variations in upwelling impact foodwebs and trophic interactions?** Task 2

MOTIVATION

- Many marine species have life histories adapted to seasonal events in the environment.

- How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?

- How do phenological variations in upwelling impact seabird reproductive success?

- **What ecosystem impacts can we expect from climate-driven changes in the phenology of coastal upwelling?**





TASK 1: Phenological Upwelling Indices

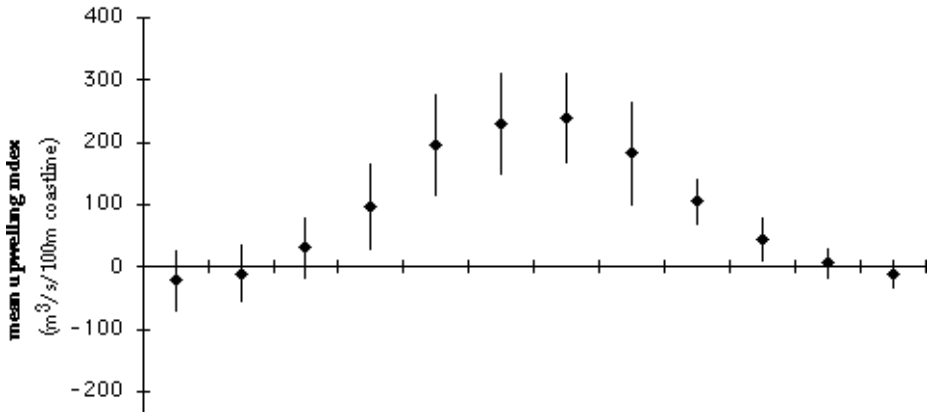
Can we develop simple indices that describe the phenology of coastal upwelling in the California Current?

- Timing of onset (spring transition)
- Duration of upwelling season
- Intensity of upwelling (episodic, integrated)

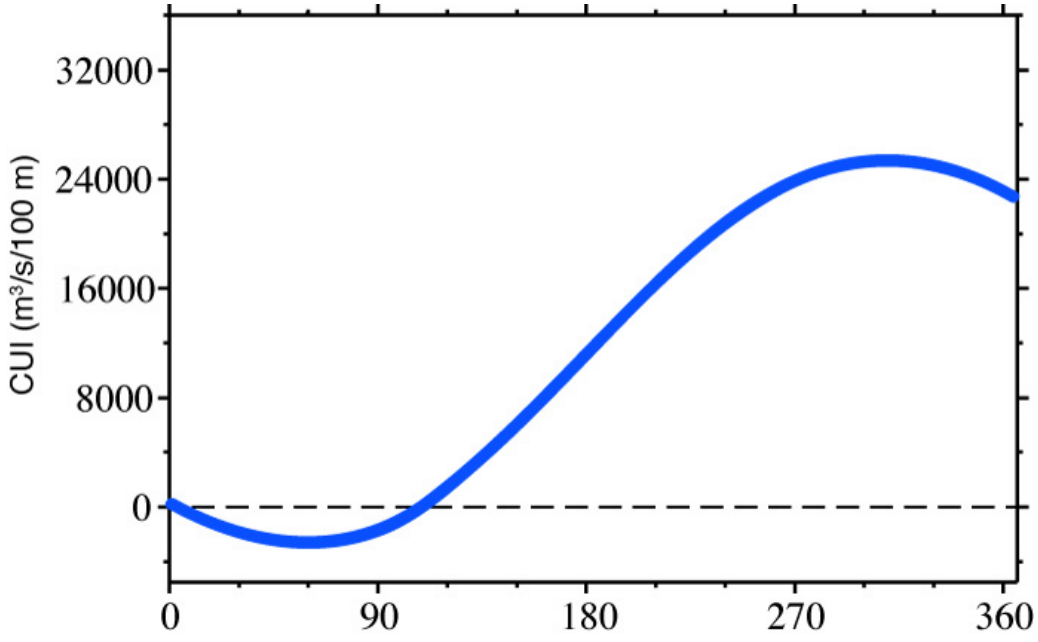
Use classical Bakun Upwelling Index:

- long time series (~40 yrs)
- often used in coastal oceanography, fisheries
- large-scale context
- *does not resolve cross-shelf variability, curl*

CUMULATIVE UPWELLING INDEX

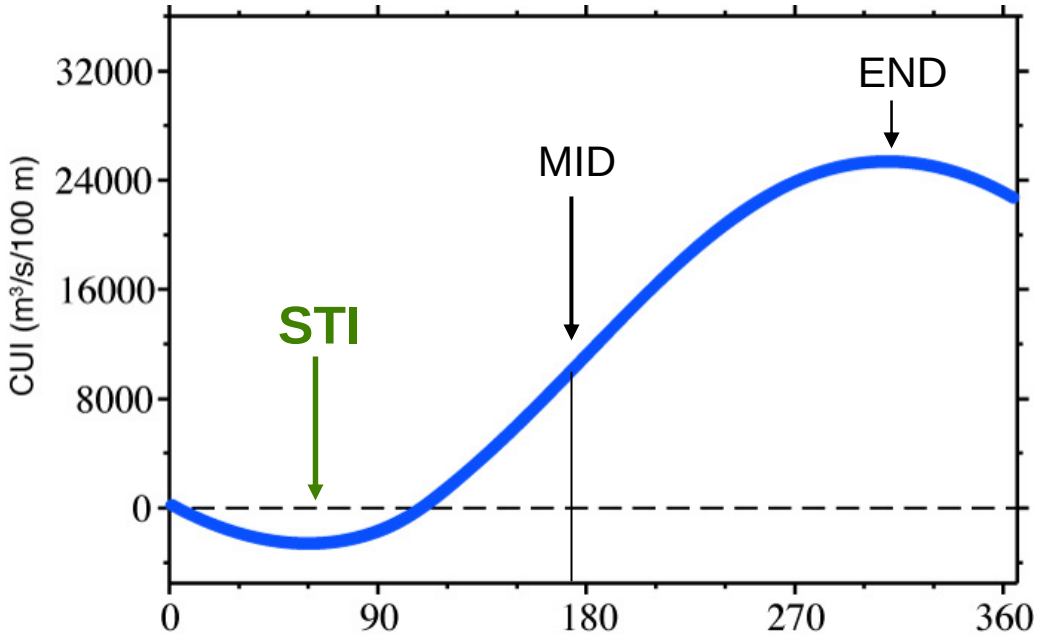


Cumulative Upwelling Index (CUI) = Integrate UI from Jan 1st to Dec 31st



Schwing et al. (2006)
Bograd et al. (2008)

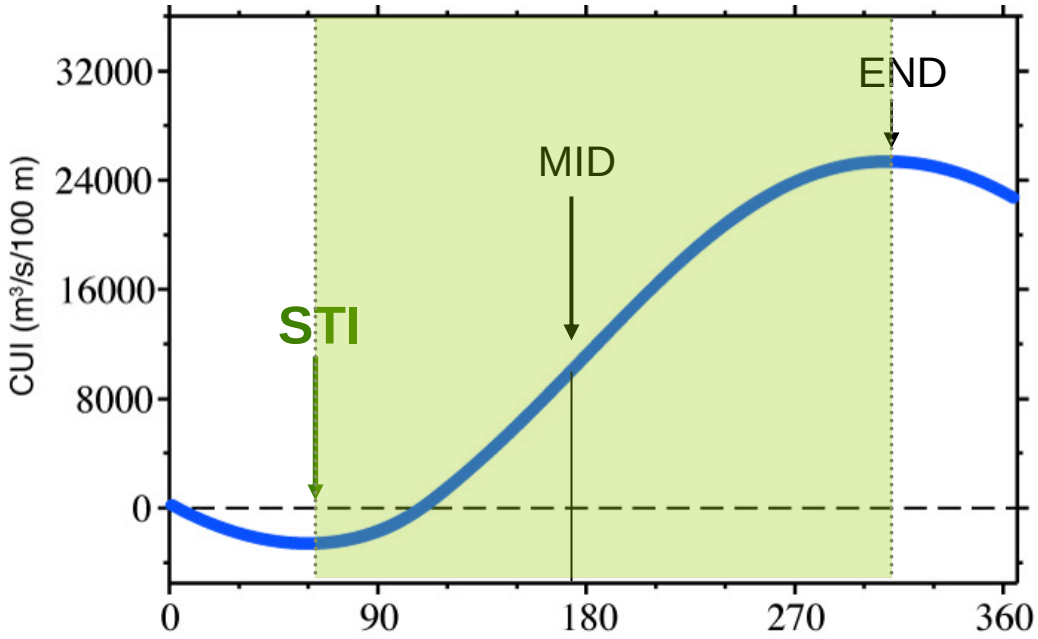
INDICES of COASTAL UPWELLING: (1) Timing



Spring Transition Index (STI) = Date of Minimum CUI

(END = Date of Maximum CUI)

INDICES of COASTAL UPWELLING: (1) Timing



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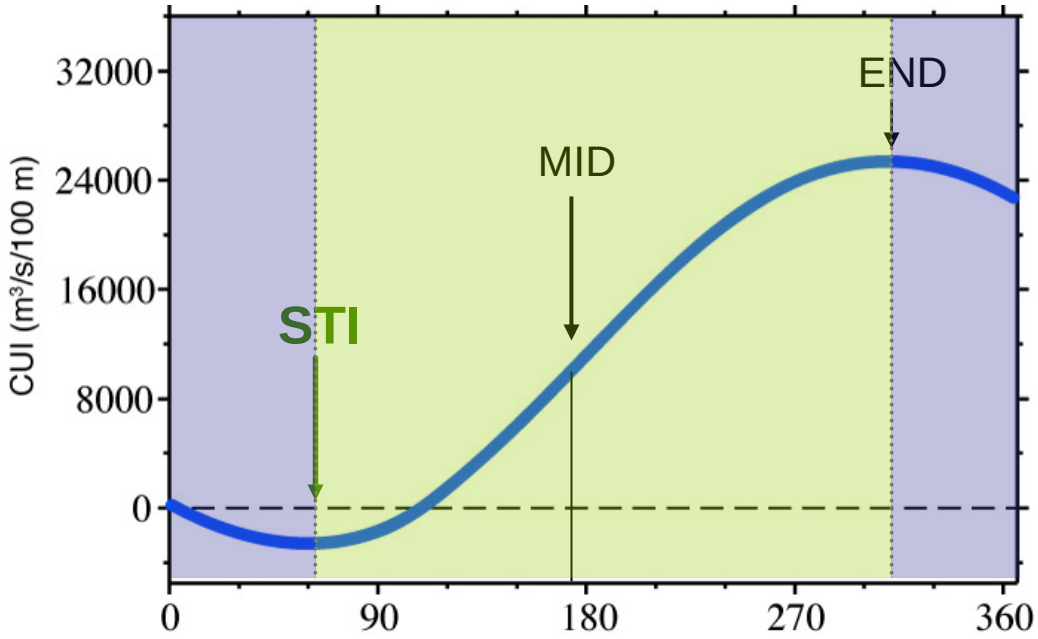
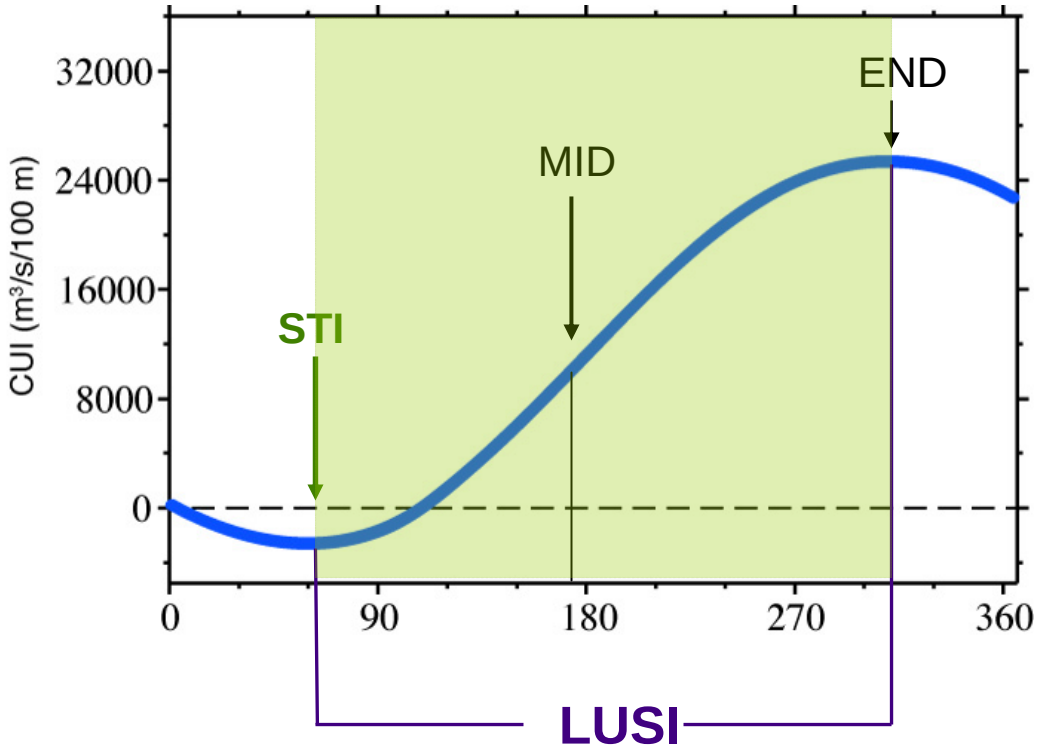
INDICES of COASTAL UPWELLING: (1) Timing



Spring Transition Index (STI) = Date of Minimum CUI

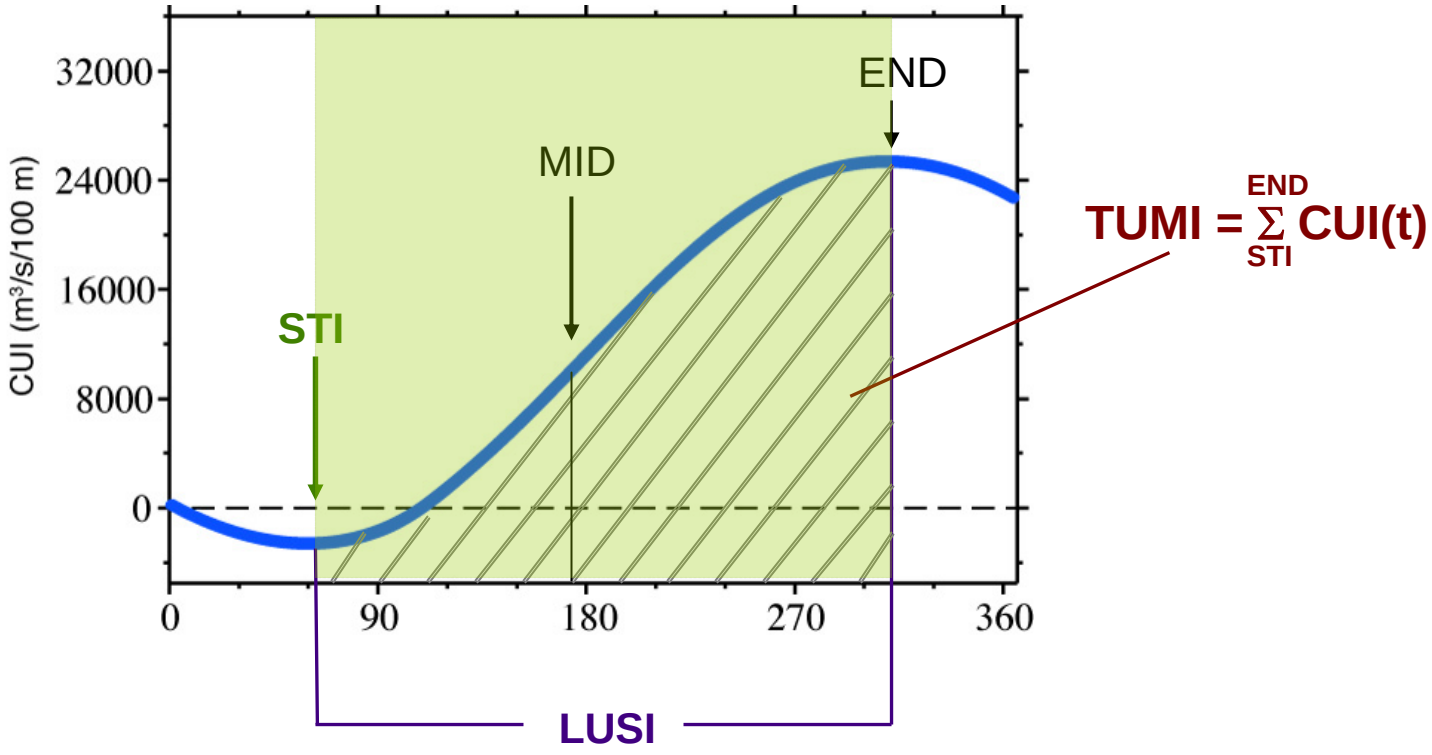
(END = Date of Maximum CUI)

INDICES of COASTAL UPWELLING: (2) Duration



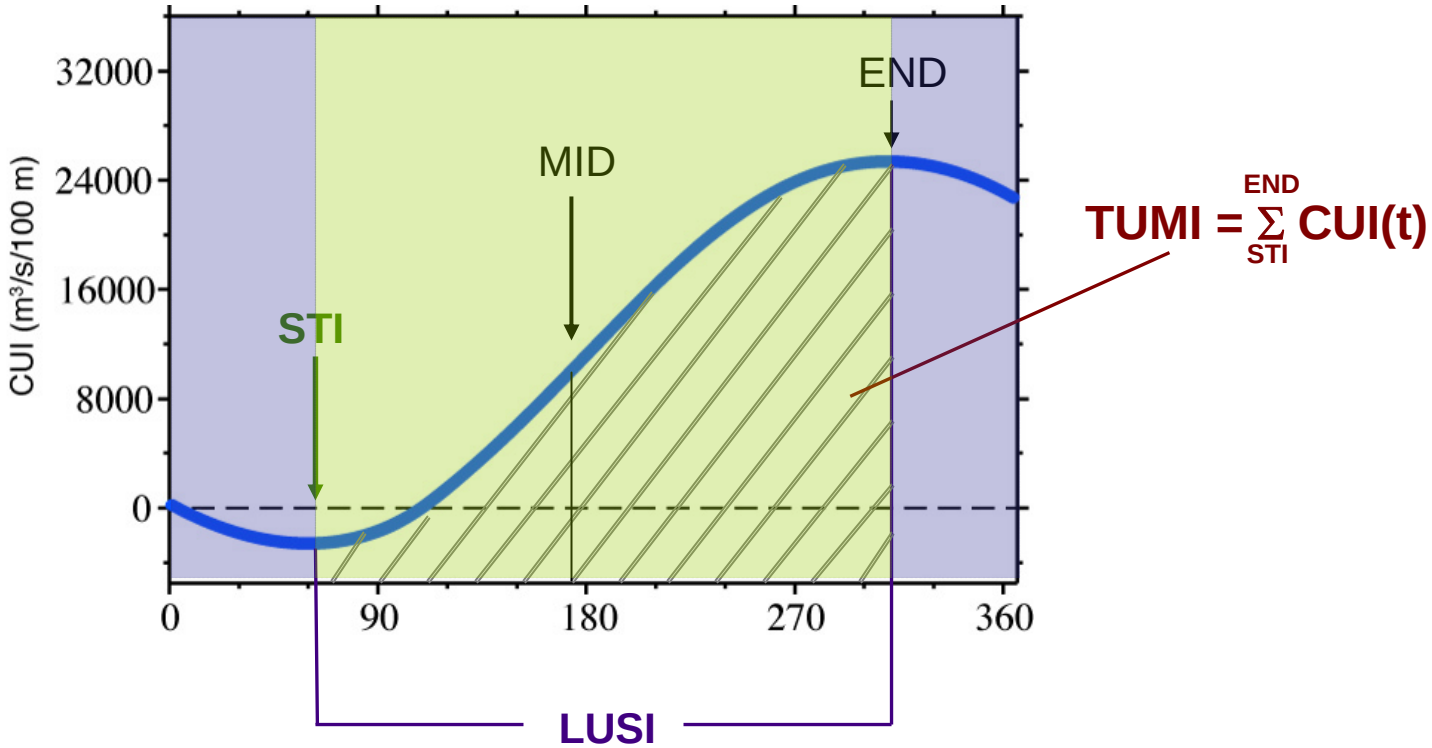
Length of Upwelling Season Index (LUSI) = Total days between STI and END

INDICES of COASTAL UPWELLING: (3) Intensity



Total Upwelling Magnitude Index (TUMI) = CUI Integrated between STI and END

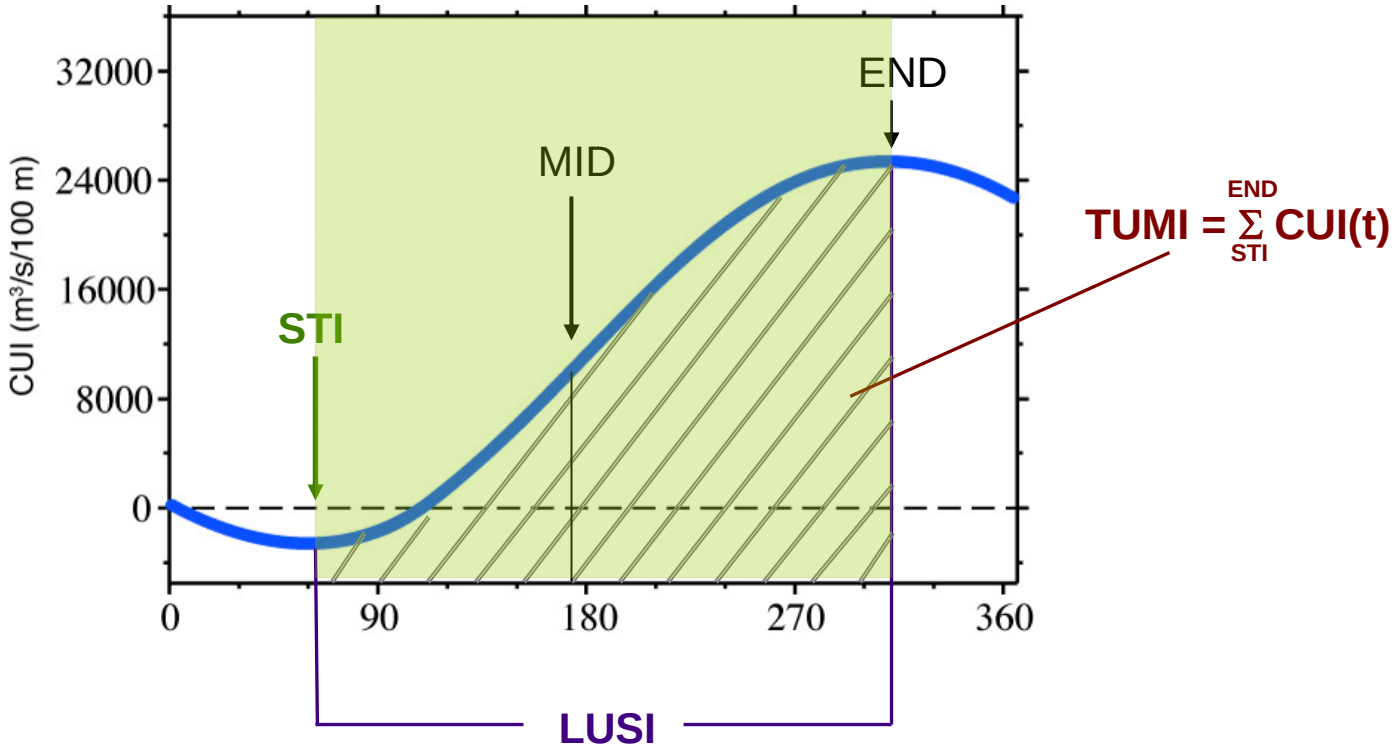
INDICES of COASTAL UPWELLING: (3) Intensity



Total Upwelling Magnitude Index (TUMI) = CUI Integrated between STI and END

(TDMI = CUI Integrated between END and next year's STI)

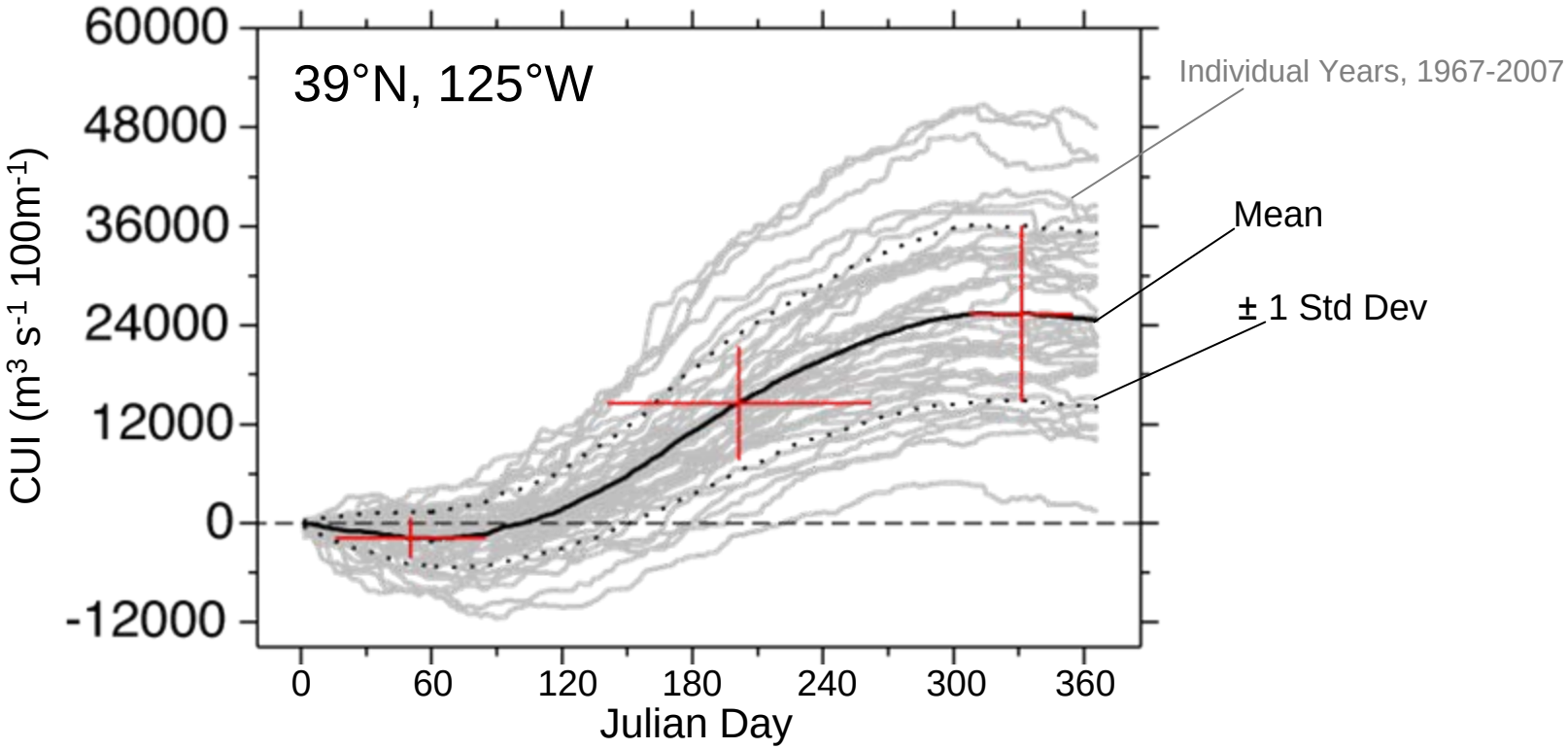
INDICES of COASTAL UPWELLING



CAVEATS:

1) No definitive definition of ‘spring transition’
2) Relevance of indices depends on species life history strategies, plasticity, resilience

Interannual Variability in Cumulative Upwelling Index

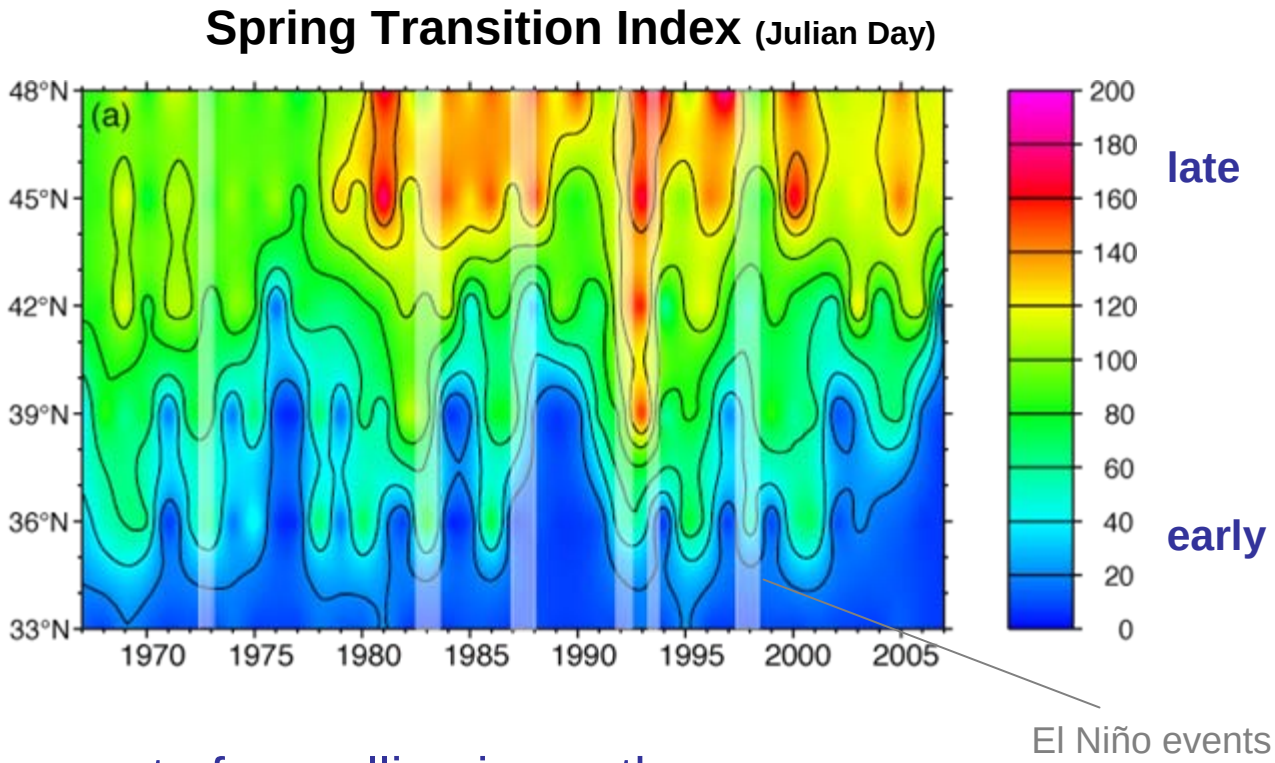


STI = Julian Day 50 ± 34

END = Julian Day 331 ± 24

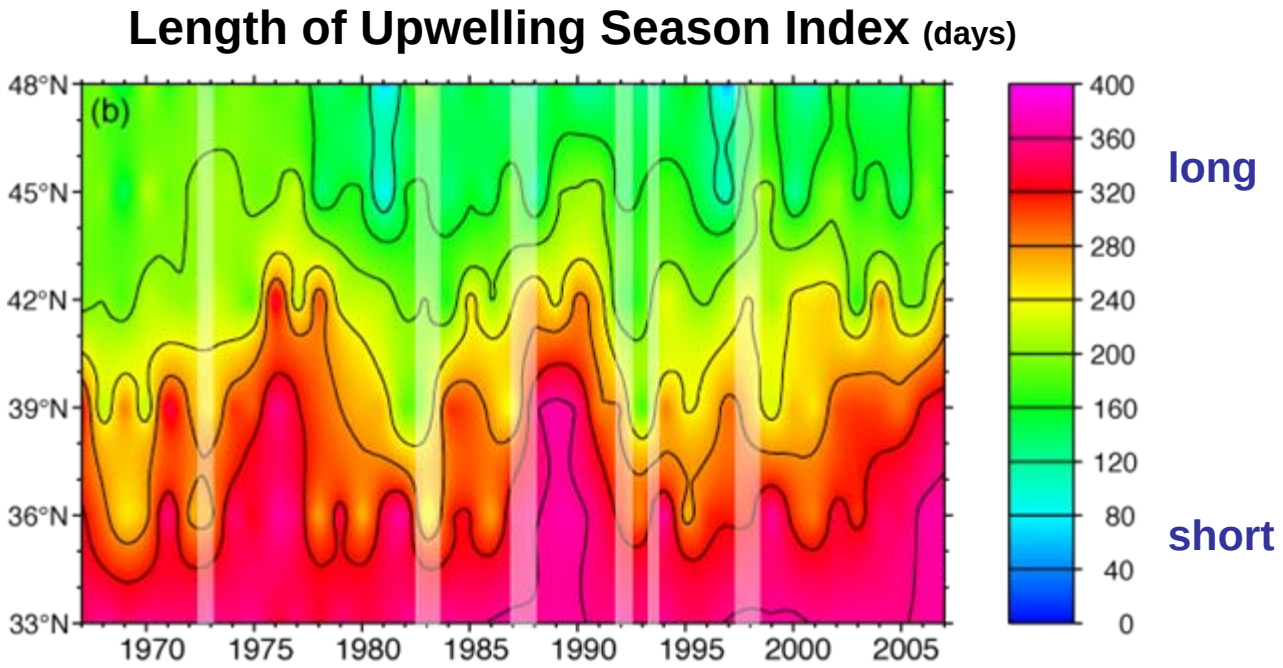
LUSI = 282 ± 45 days

Interannual Variability in Upwelling: (1) Timing



- Earlier onset of upwelling in south
- Trend to later spring transition in north
- Delayed upwelling during El Niño events
- Upwelling “surplus” or “deficit” at climatological transition date

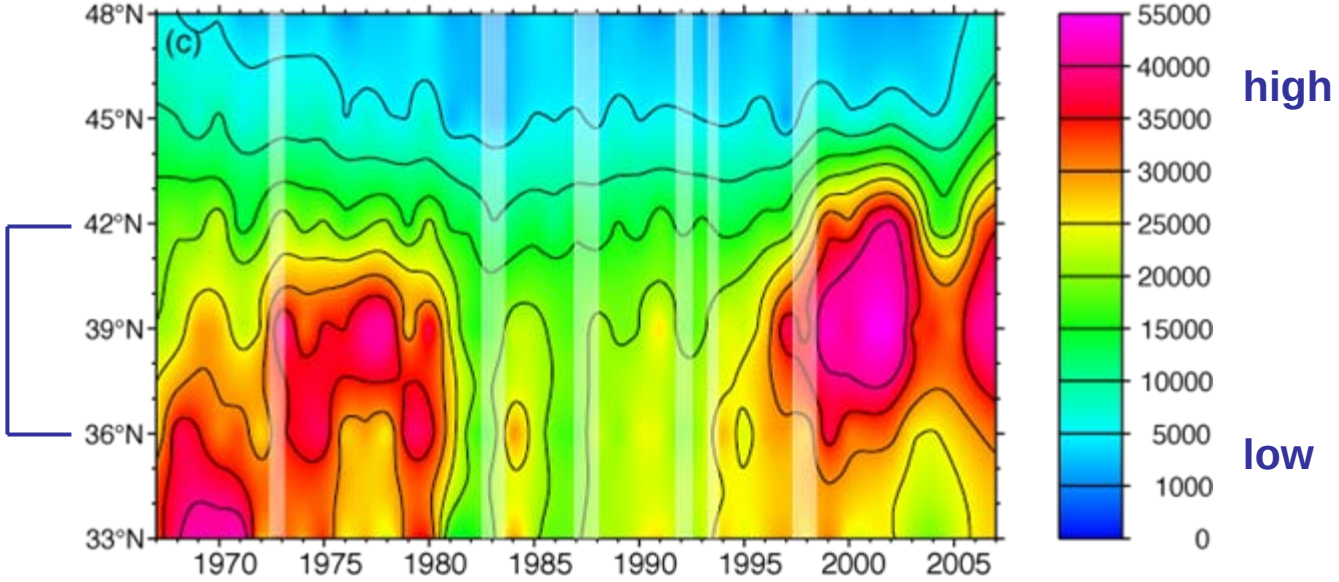
Interannual Variability in Upwelling: (2) Duration



- Upwelling season shorter in north than south
- Trend to shorter upwelling season in north
- Highly variable length of upwelling season in central CCS

Interannual Variability in Upwelling: (3) Intensity

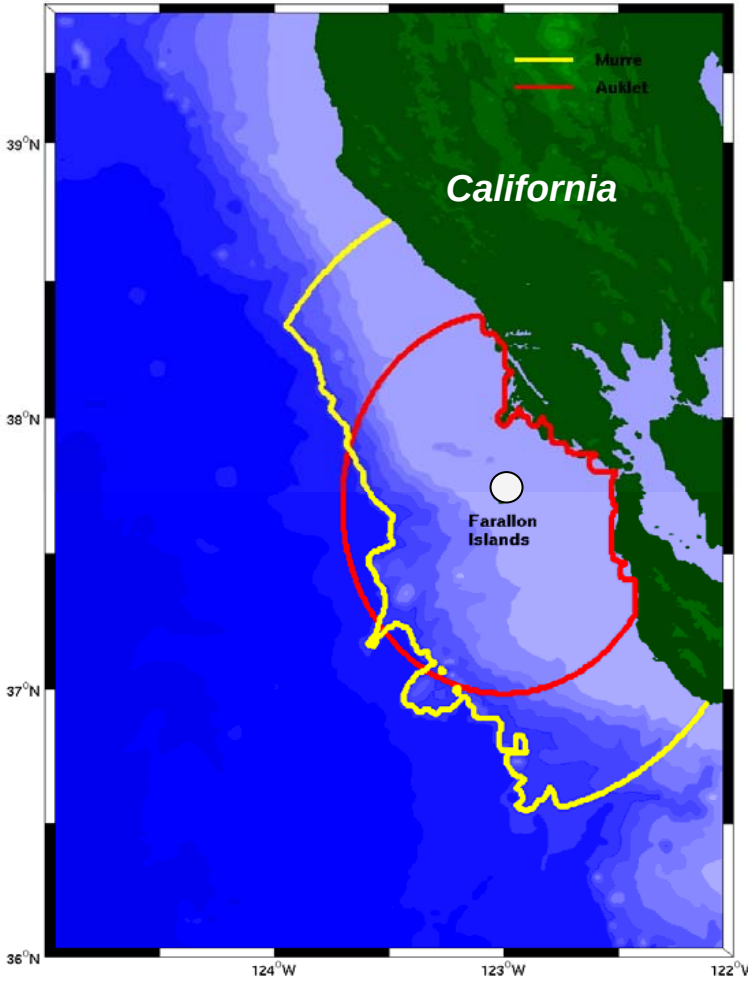
Total Upwelling Magnitude Index **($m^3/s/100m$)**



- High integrated upwelling in 1970s, 1998-2004
- Low integrated upwelling in 1980-1995
- 1998-2004: high TUMI, low LUSI --> intense upwelling
- 1980-1995: frequent El Niño events

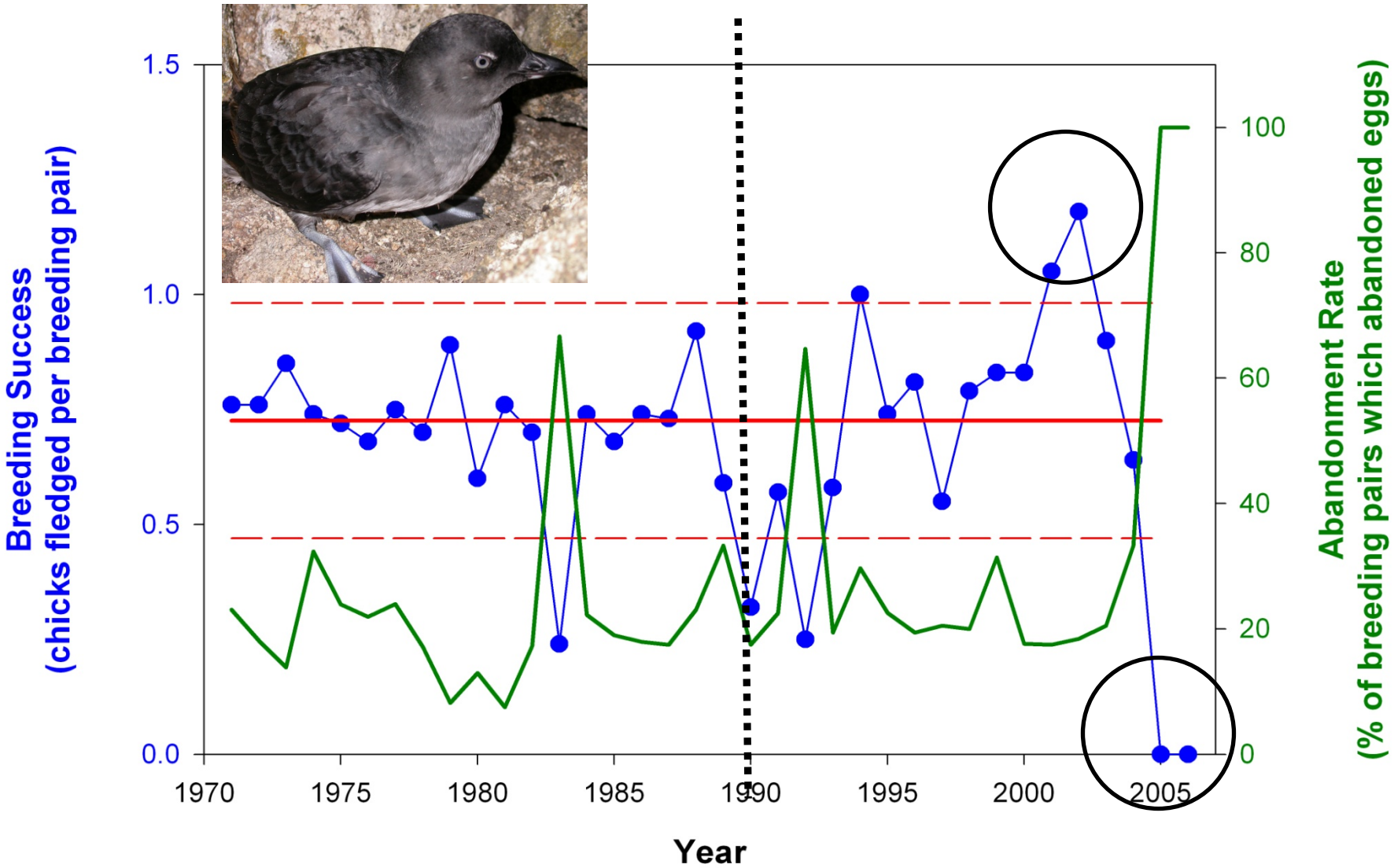
TASK 2: Impact on California Current Seabird Phenology?

SEABIRDS at the FARALLON ISLANDS



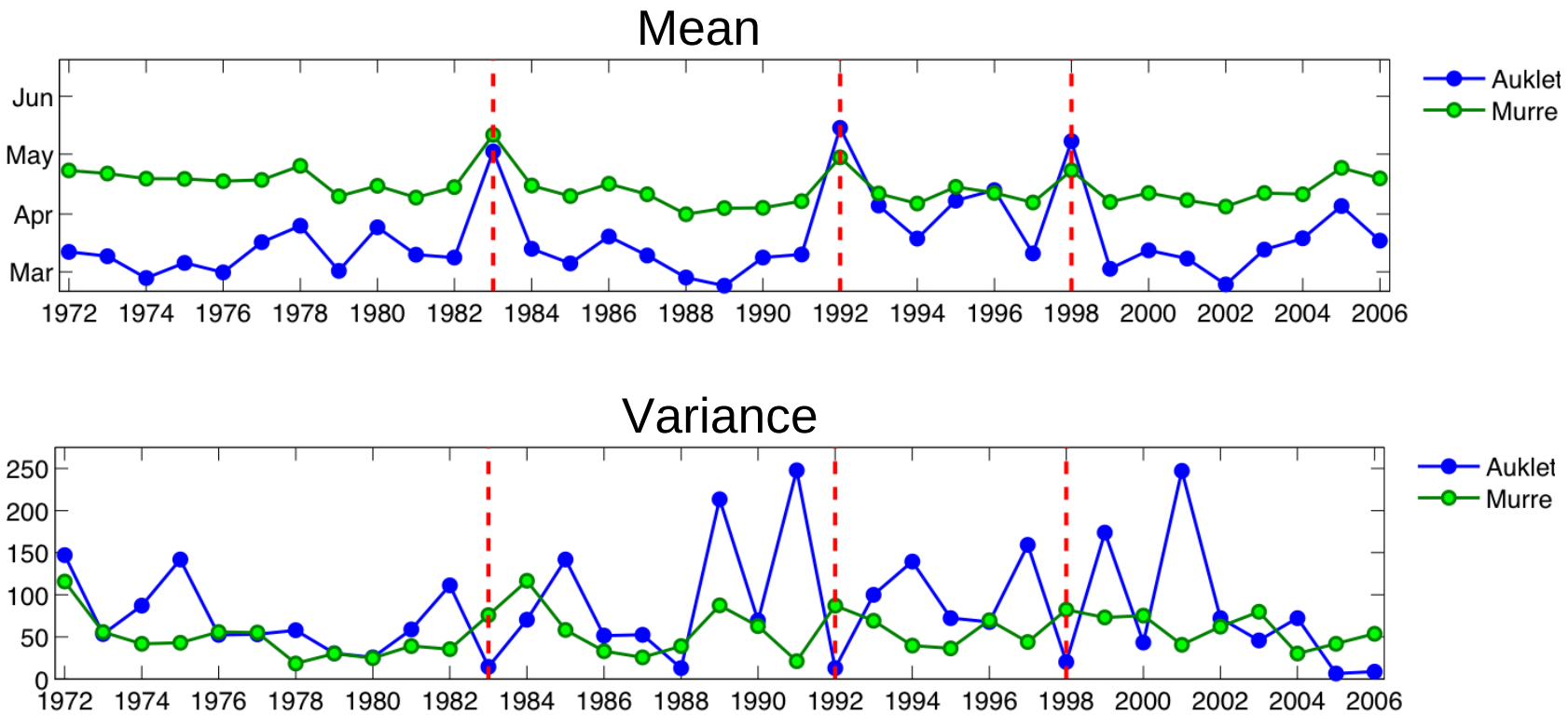
- Two bird species from same location but different life strategies
- Look at the <u>timing of egg laying</u> (mean, variance)

PHENOLOGICAL CONSEQUENCES:
Seabird Reproduction



Sydeman et al (2006); Peterson et al (2007); PRBO (unpublished)

TIMING of SPRING EGG LAYING



- Early egg-laying = high reproductive success for both species
- High variance is good for Auklets, bad for Murres

Abraham and Sydeman (2004); Reed et al (2008); PRBO (unpublished)

Egg-Laying Date vs. Upwelling Indices: Correlations

Egg-Laying Date	Cassin's Auklet	Common Murre
Spring Transition Date	0.46	0.46
Length of Upwelling Season	-0.52	-0.46

Early Upwelling → Early Egg-Laying (good)

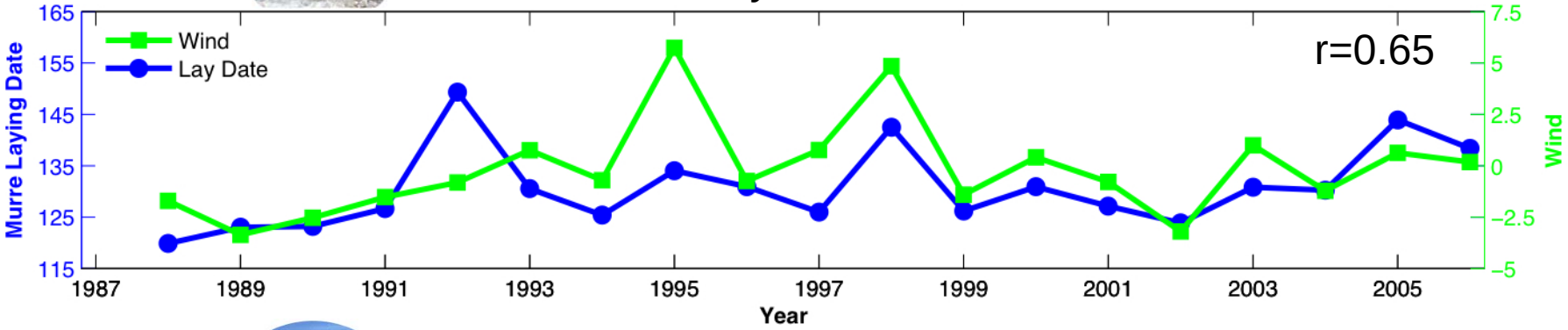
ENVIRONMENTAL DATA

Use satellite winds and SST to describe variations in upwelling:

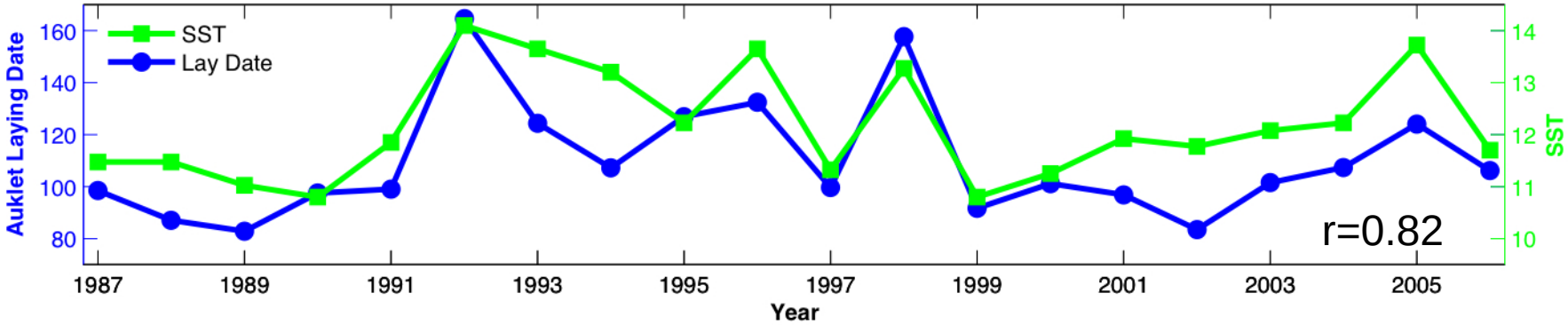
- Northeast Pacific domain: ~ 120°-145°W, 30°-55°N
- NOAA/NCDC blended wind product: 25 km grid
- Pathfinder SST: 4.4 km grid
- Monthly means for 1987-2006

Lagged Correlations at 37.5°N - 123°W (example)

Murre's Mean Lay Date & Jan Wind

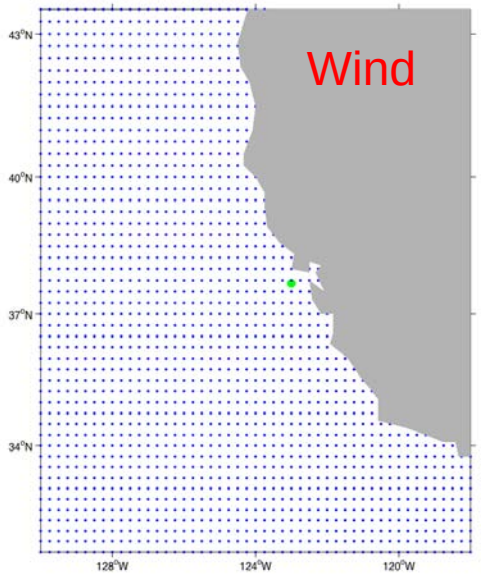


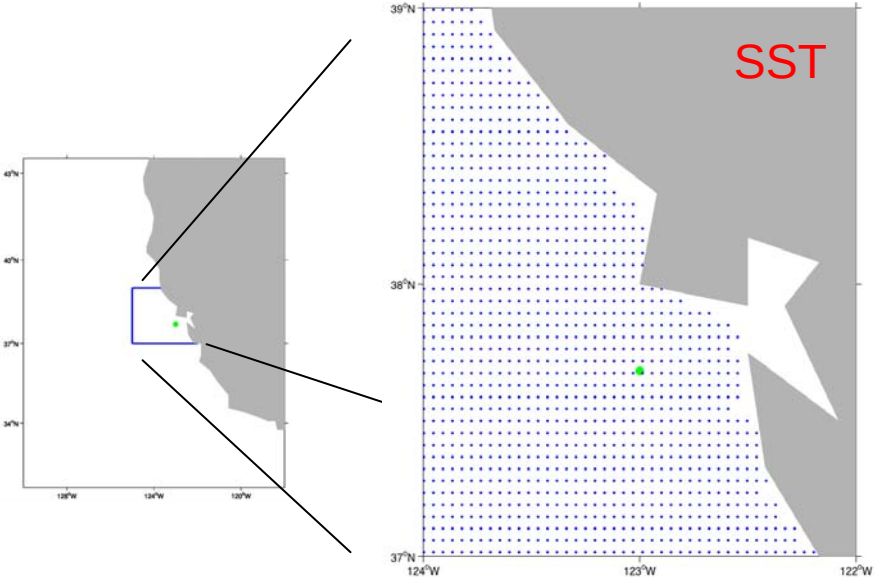
Auklet's Mean Lay Date & March SST



CORRELATION MAPS

- Compute correlations at all grid locations
- For SST and Alongshore Wind (V)
- For Murre and Auklet egg-laying date: mean and variance
- Monthly for September - April
- Different lags between environment and egg-laying

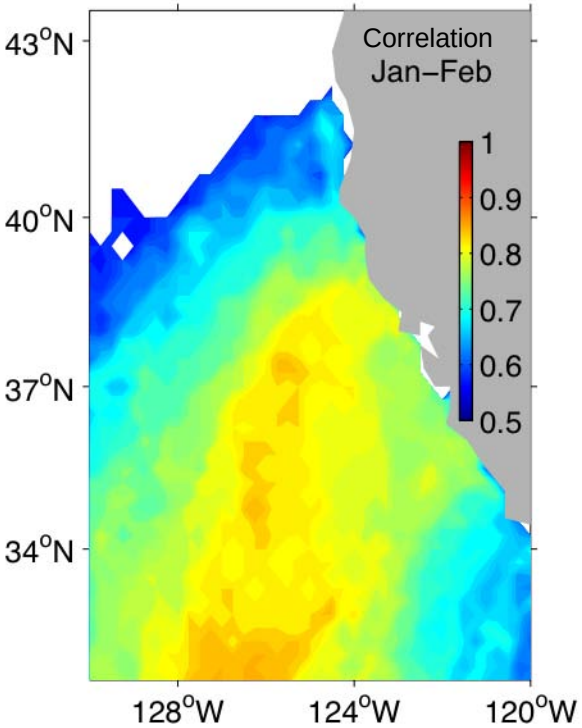


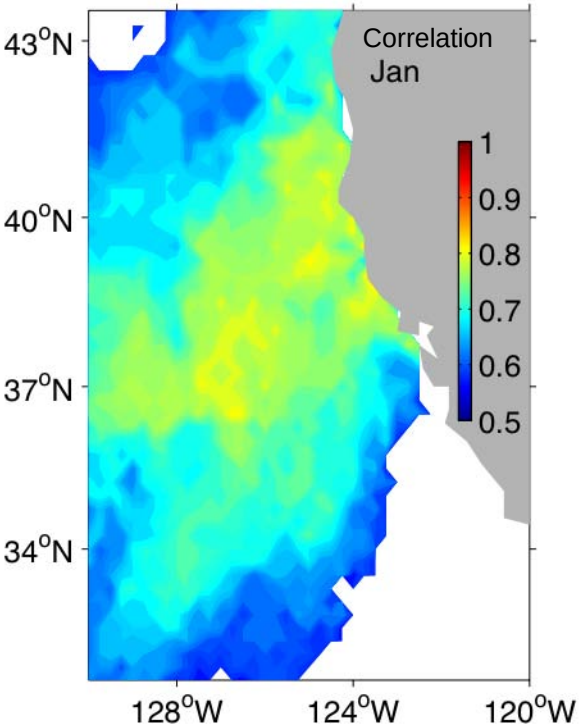


Lagged Correlation Maps: Mean Lay Date vs. Alongshore Wind

+ correlation

Northerly winds =
Early egg-laying

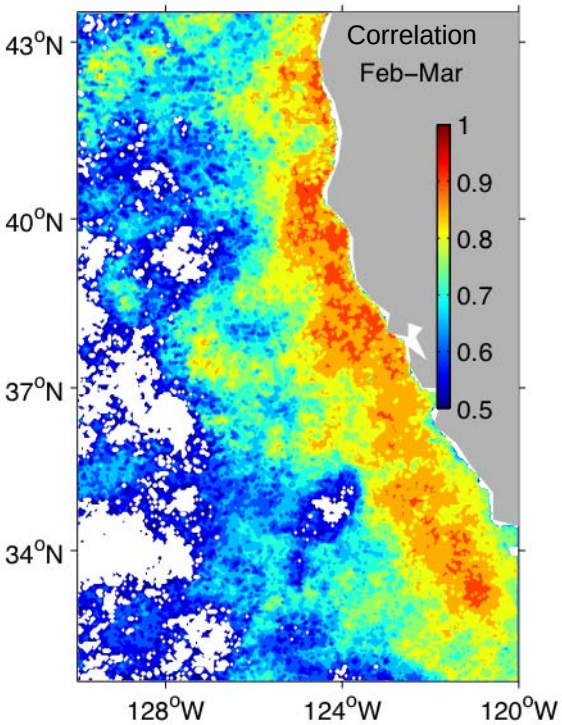


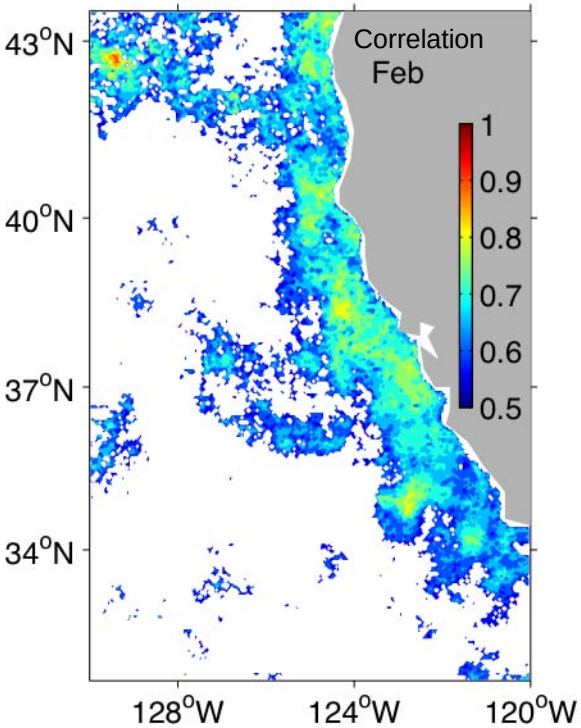


Lagged Correlation Maps: Mean Lay Date vs. SST

+ correlation

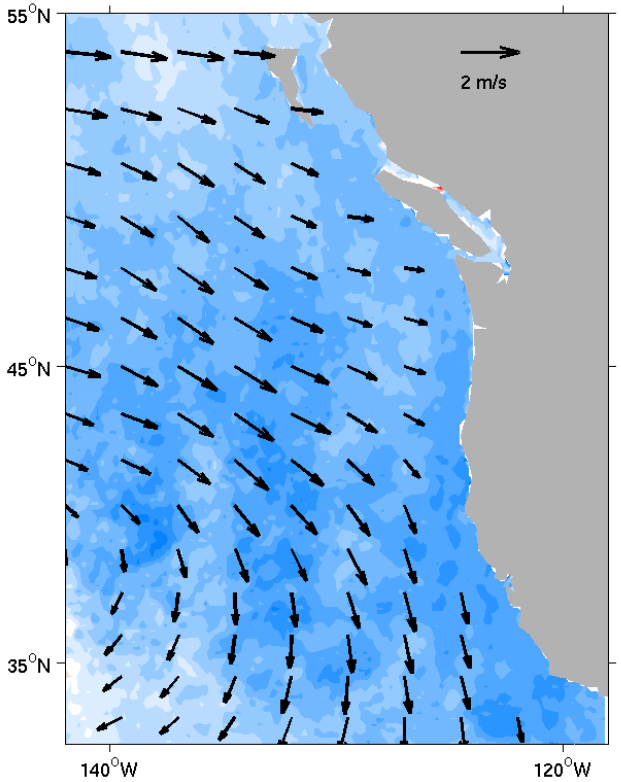
Cool SSTs =
Early egg-laying



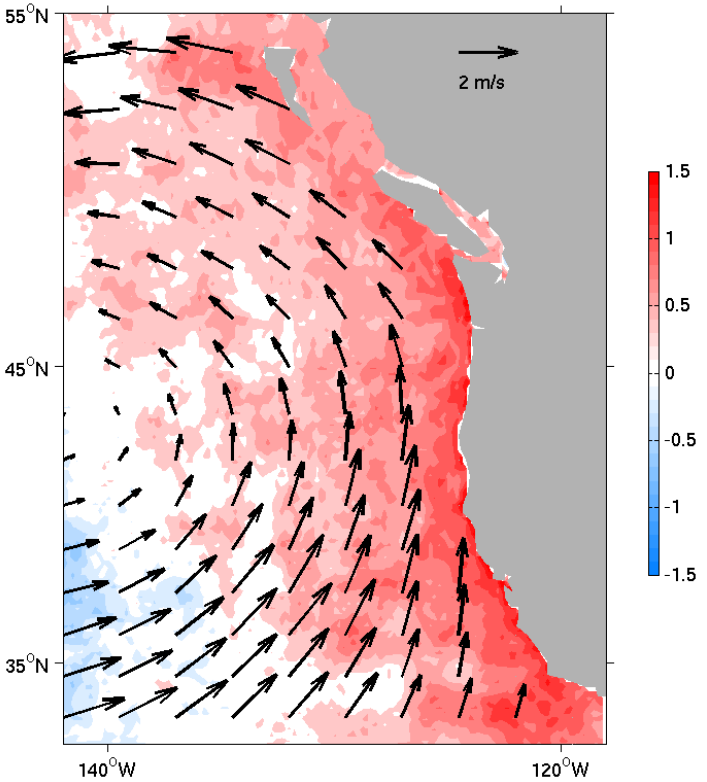


Good (Early) & Bad (Late) Years for Cassin's Auklet

Four <u>earliest</u> Auklet mean egg-laying years



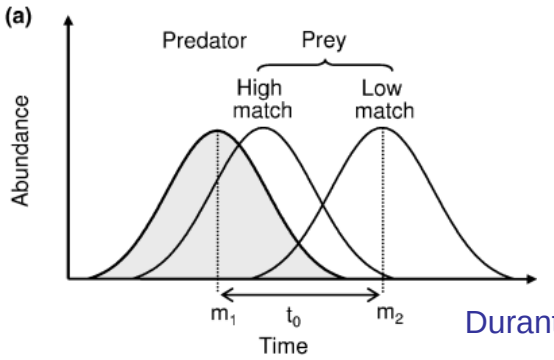
Four <u>latest</u> Auklet mean egg-laying years



- Jan-Feb mean winds (vectors) & Feb-Mar mean SST (colors)
- Good years: strong H, anomalously strong upwelling, cool SSTs
- Bad years: weak H, anomalously weak upwelling, warm SSTs

SUMMARY

1. Upwelling timing, duration and intensity highly variable;
2. Periods of high (low) integrated upwelling in 1970s and 1998-2004 (1980-95);
3. Trend towards later, shorter upwelling in northern California Current;
4. Delayed upwelling in El Niño years;
5. Winter pre-conditioning (upwelling) controls seabird reproductive timing;
6. Climate change → changes in upwelling process;
7. Principal ecosystem effects of interannual-decadal climate variability could be <u>phenological</u>.



Durant et al. (2005)

NEXT STEPS

1. Determine large-scale forcing associated with upwelling phenology regimes;
2. Quantify event-scale indices: relaxation events, Lasker events;
3. Explore multivariate relationships between biological & upwelling series;
4. Include indices in California Current Integrated Ecosystem Assessment;
5. Forecast California Current upwelling & ecosystem response from climate models.

THANK YOU!　谢谢!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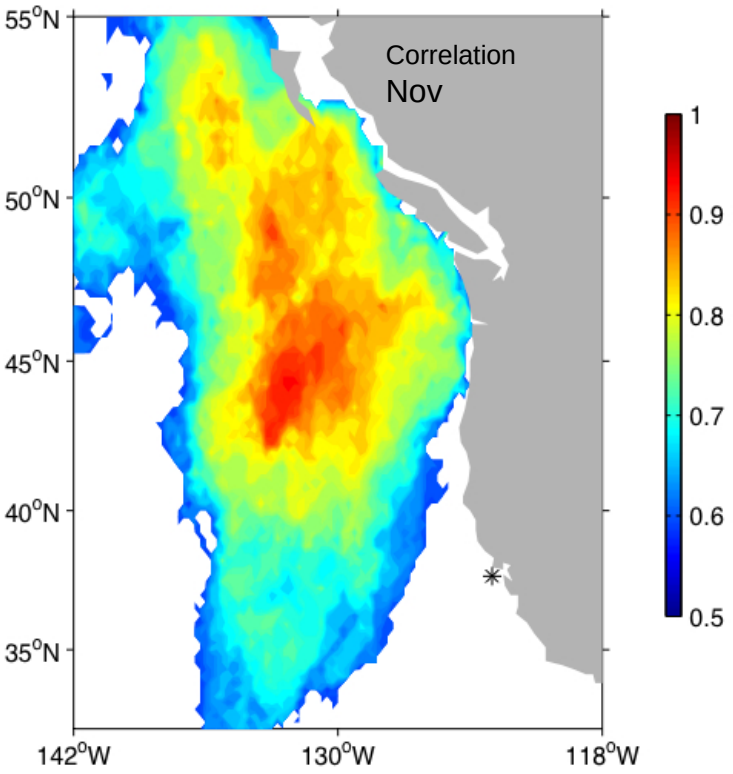
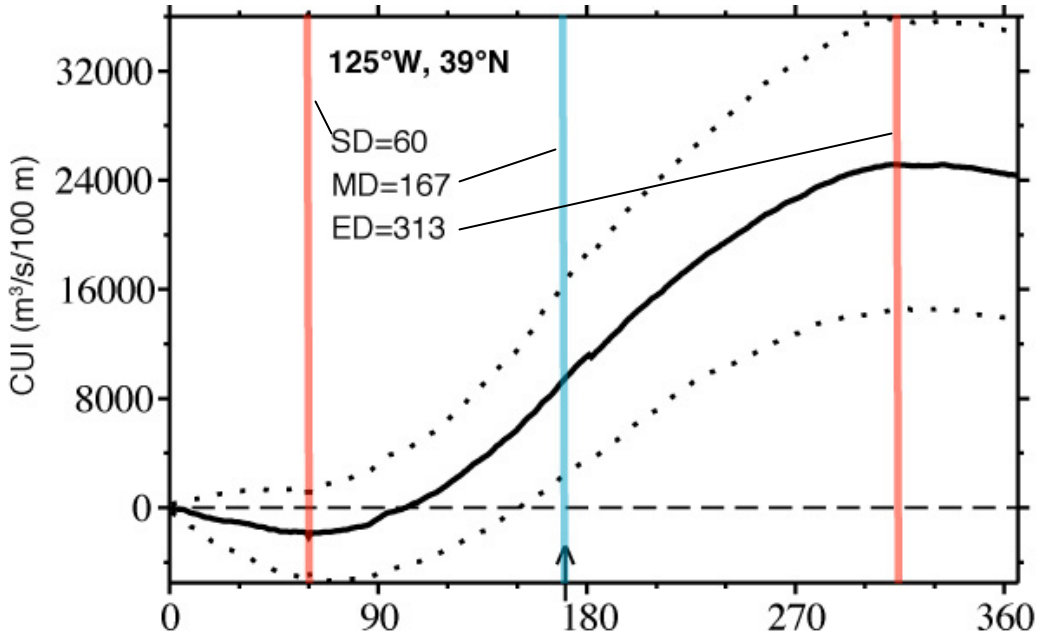
Lagged Correlation Map: Lay Date Variance vs. Alongshore Wind



- November mean winds vs. Murre egg-laying date variance
- strong positive correlation; related to storminess?

CUMULATIVE UPWELLING INDEX

Example: 39°N (NorCal)
1967-2005



Cumulative Upwelling Index (CUI) = Integrate UI from 1/1 to 12/31

SD = Climatological Start Date of Upwelling Season
MD = Climatological Mid-Point of Upwelling Season (Max. Slope)
ED = Climatological End Date of Upwelling Season

Schwing et al. (2006)
Bograd et al. (2008)