Causality linkages in atmosphere, ocean and marine ecosystem over the North Pacific: Modes, processes and prediction

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With

Hanako Gotoh (Hokkaido University)

International symposium “Drivers of dynamics of small pelagic fish resources”, March 6th, 2017, at Victoria, Canada

20-year anniversary

A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production*

Nathan J. Mantua,+ Steven R. Hare,* Yuan Zhang,+
John M. Wallace,+ and Robert C. Francis@

Vol. 78, No. 6, June 1997

3368 times cited

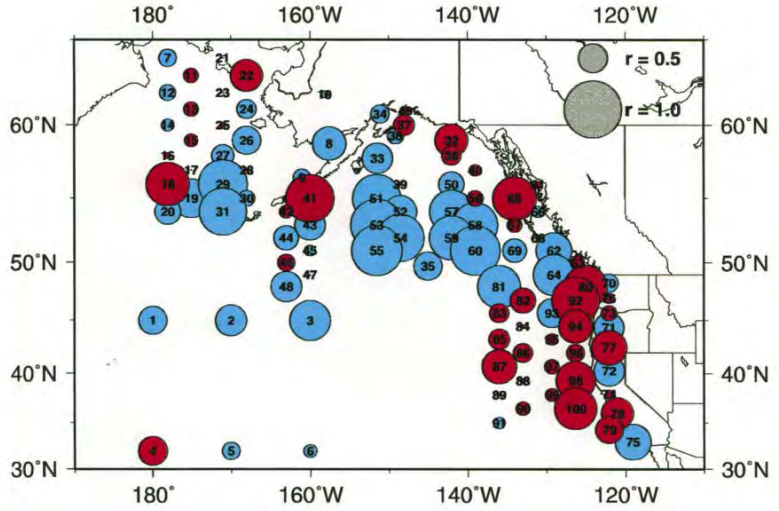
GEOPHYSICAL RESEARCH LETTERS, VOL. 24, NO. 6, PAGES 683-686, MARCH 15, 1997

A 50–70 year climatic oscillation over the North Pacific and North America

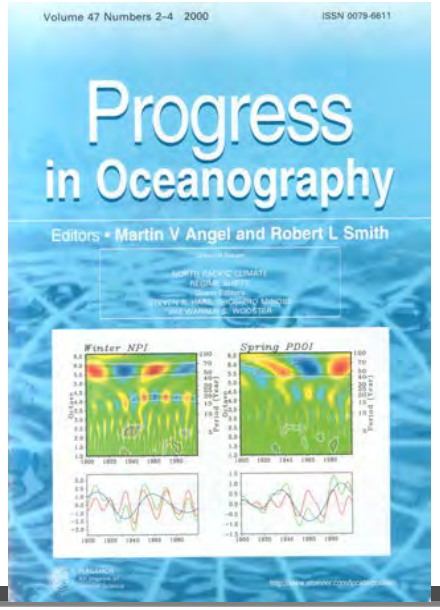
Shoshiro Minobe

PICES promoted collaboration between physical and ecosystem sciences for decadal variability

- In 1996, science board symposium of PICES V dedicated decadal variability at Nanaimo in this island.
  - Nate Mantua and I were there.
- In 1999, Wooster, Hare and I convened a symposium for decadal variability in PICES VIII at Vladivostok, and published special issue including Hare and Mantua (2000) and Minobe (2000) within a year.



Hare and Mantua (2000)



More recent PICES's activity follows development of this research field

- Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems (FUTURE) (2009-)
- PICES WG27 on *North Pacific Climate Variability and Change* (2011-15)
- PICES study group on *Climate and Ecosystem Predictability* (2015-16)
- Proposed WG on *Climate and Ecosystem Predictability* (2017?-)

- In the 20-years before, we tried to discover phenomena or features of Pacific Decadal Variability (PDV).
- Since then, much of efforts are paid to understand the mechanisms of PDV.
- Now based on those findings and understandings, we want to provide useful application to society, and the most important one is prediction.

Outline

1. Review of possible mechanisms of PDO or decadal Aleutian Low Variability
2. Three prediction strategies for marine ecosystem indicators & appropriate one for the western North Pacific
   - since good one for the eastern Pacific is already explained by Di Lorenzo and Miller (2017 US-CLIVAR Variations

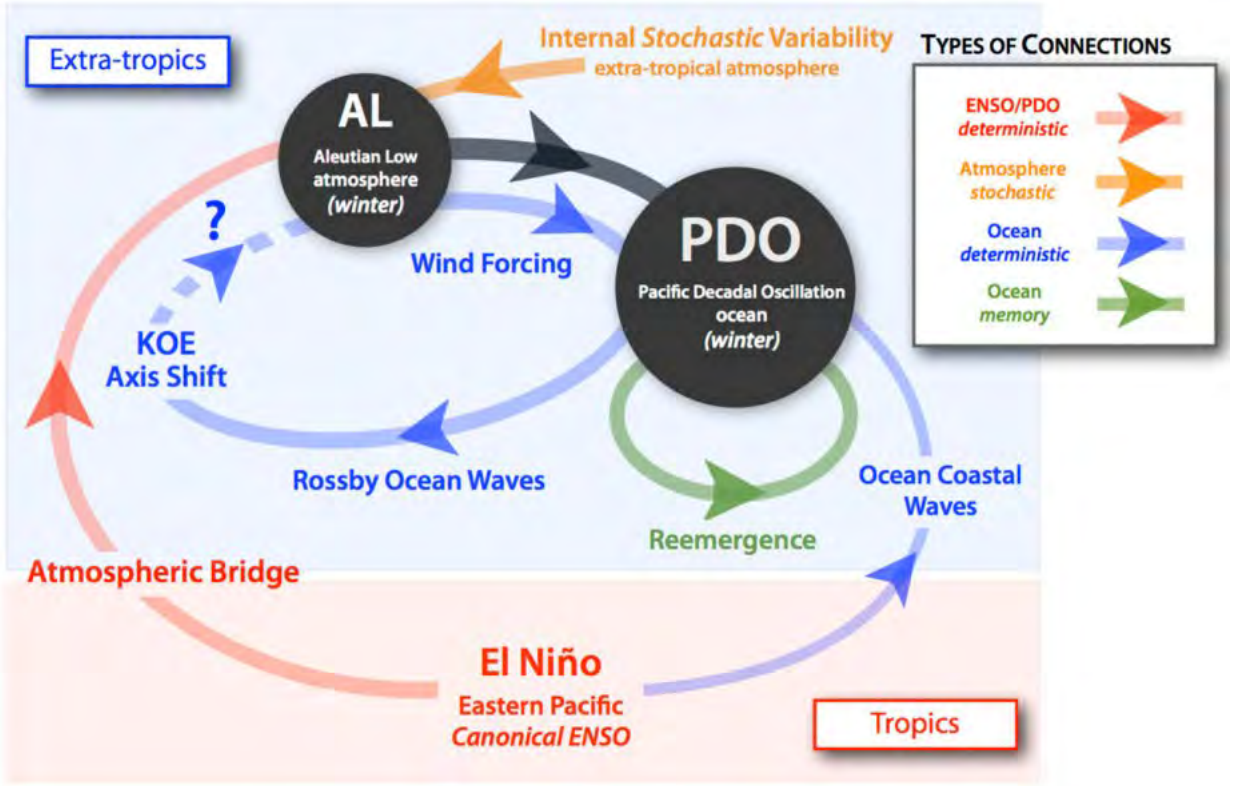
1. Review of possible mechanisms of PDO or decadal Aleutian Low Variability

What are consensuses on PDO?

- PDO is not a single phenomenon but a combination of multiple SST responses forced by Aleutian low variability
  - The SST responses are modified by oceanic processes such as Rossby wave propagation and reemergence.
- An essential question for PDO mechanism can be “What mechanisms cause Aleutian Low variability?” Then, what consensuses are obtained for this question?

The Pacific Decadal Oscillation, Revisited

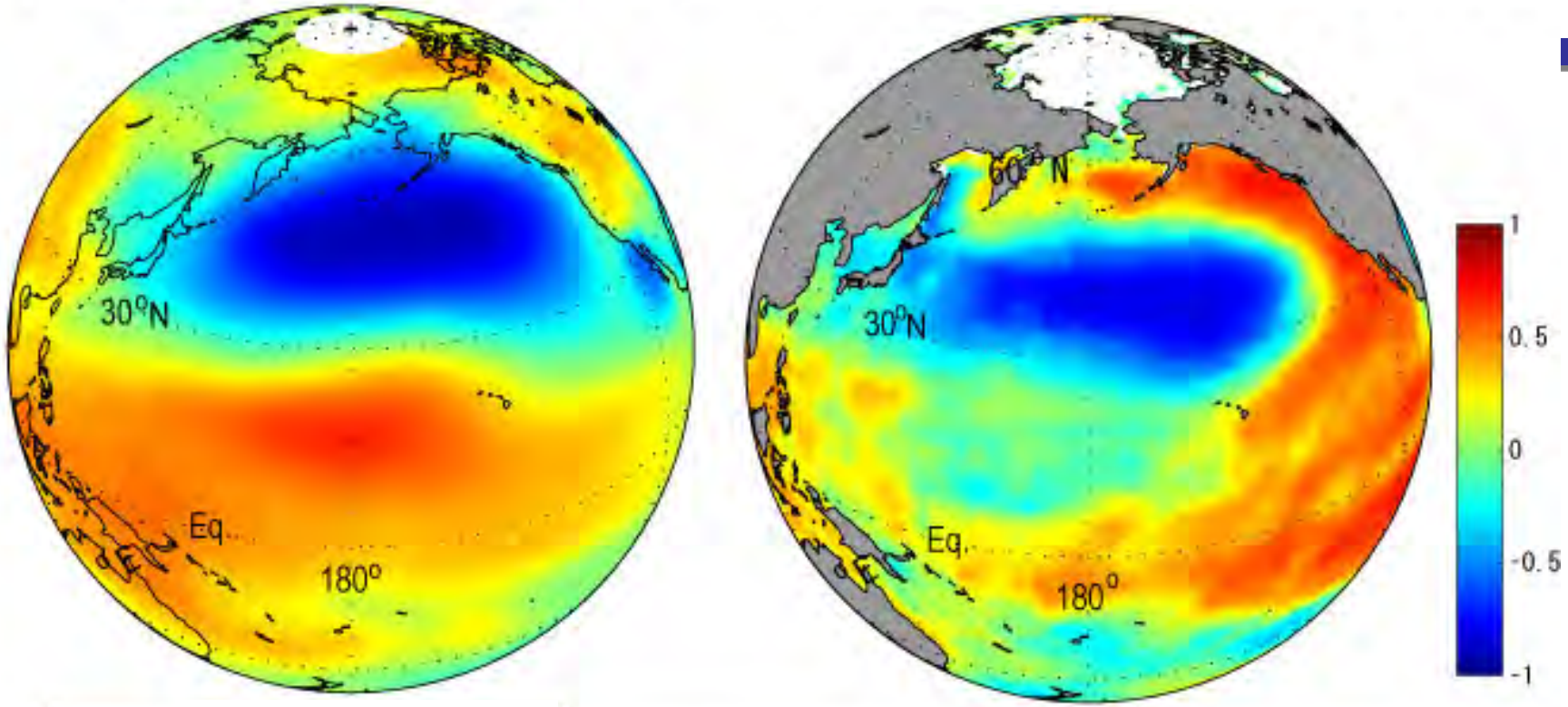
MATTHEW NEWMAN,[a,b] MICHAEL A. ALEXANDER,[b] TOBY R. AULT,[c] KIM M. COBB,[d] CLARA DESER,[e] EMANUELE DI LORENZO,[d] NATHAN J. MANTUA,[f] ARTHUR J. MILLER,[g] SHOSHIRO MINOBE,[h] HISASHI NAKAMURA,[i] NIKLAS SCHNEIDER,[j] DANIEL J. VIMONT,[k] ADAM S. PHILLIPS,[e] JAMES D. SCOTT,[a,b] AND CATHERINE A. SMITH[a,b]

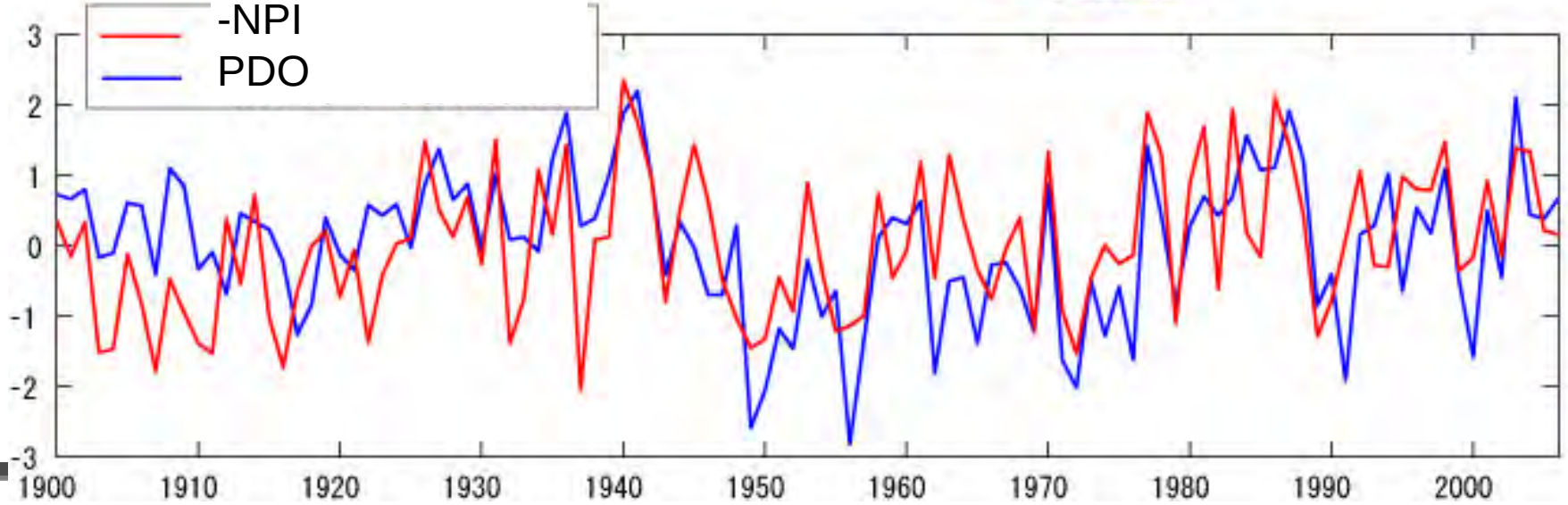


Newman et al. (2016 J. Climate)

Corr. –NPI and SLP

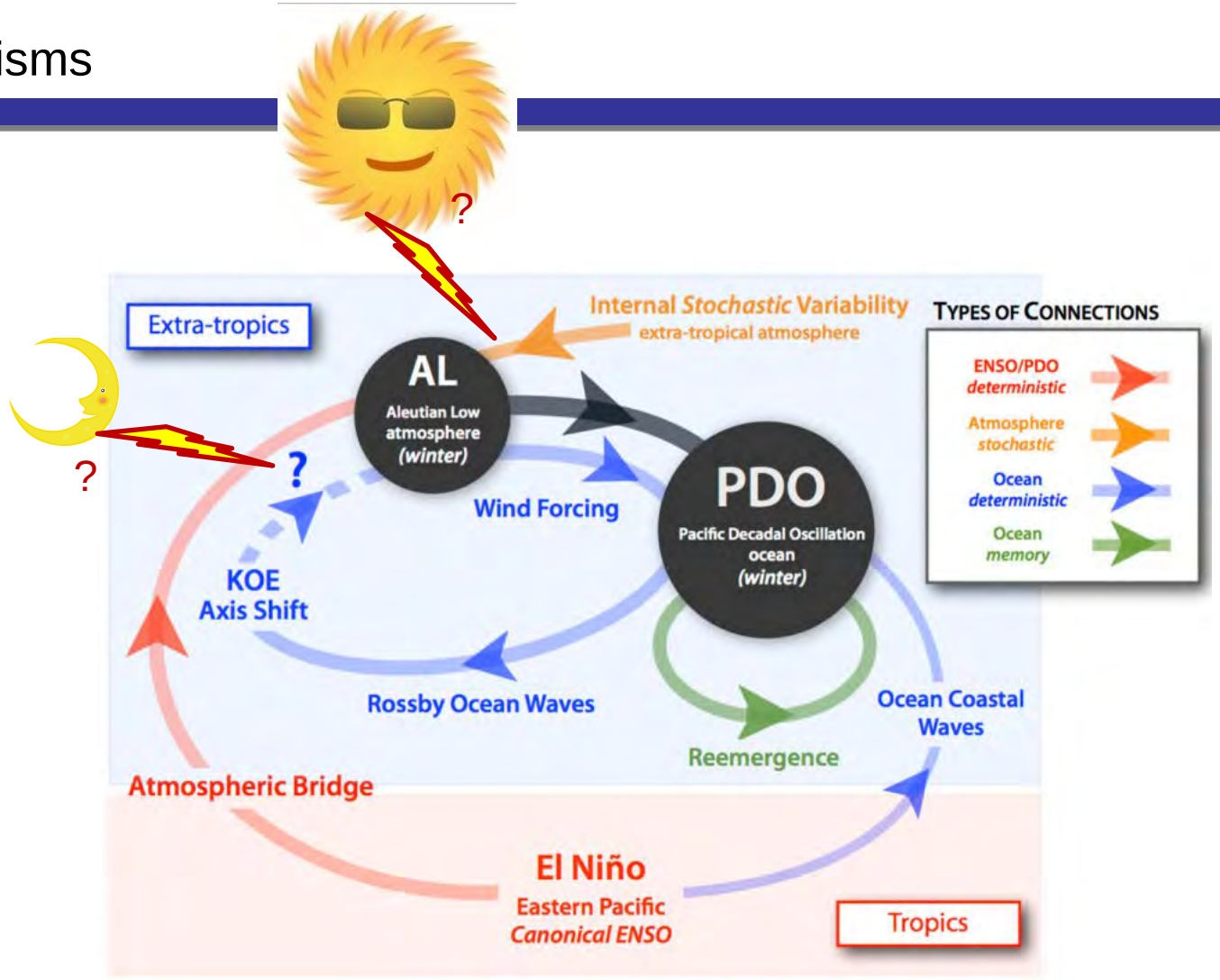
Corr. PDO and SST





Proposed Aleutian Low variability mechanisms

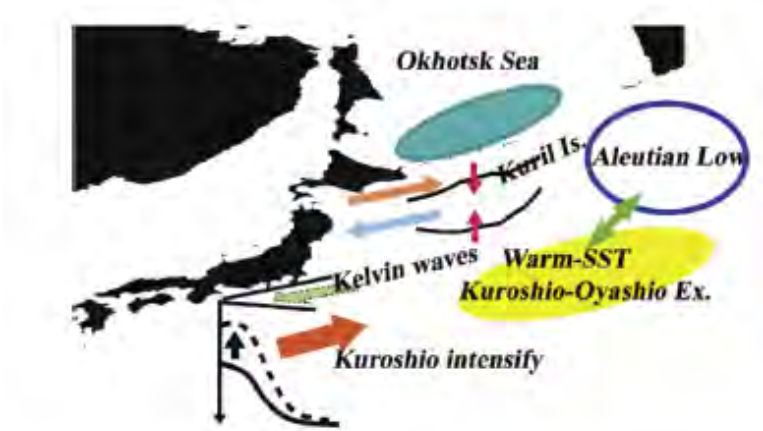
Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise



Manu's style figure in the latest review paper
Of Newman et al. (2016)

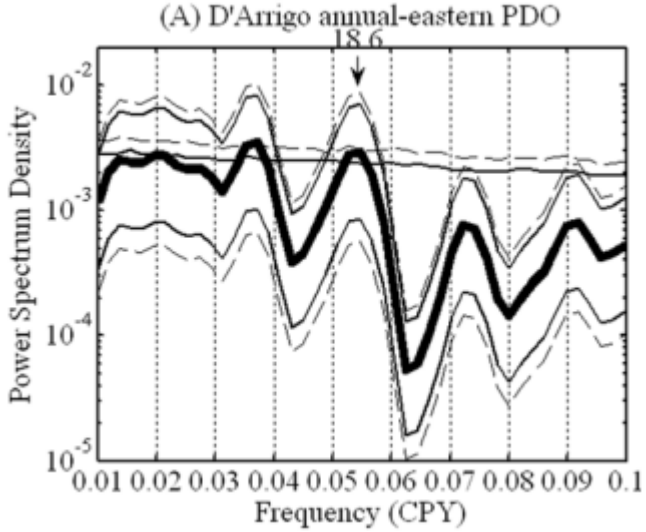
18.6 year modulation of diurnal tide

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise



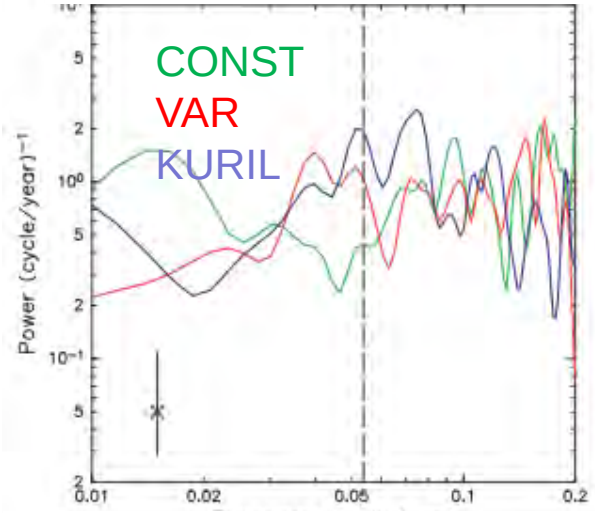
Yasuda et al. (2006 GRL)

Spectrum of reconstructed PDO



Yasuda et al. (2009 GRL)

NPI spectrum in AOGCM

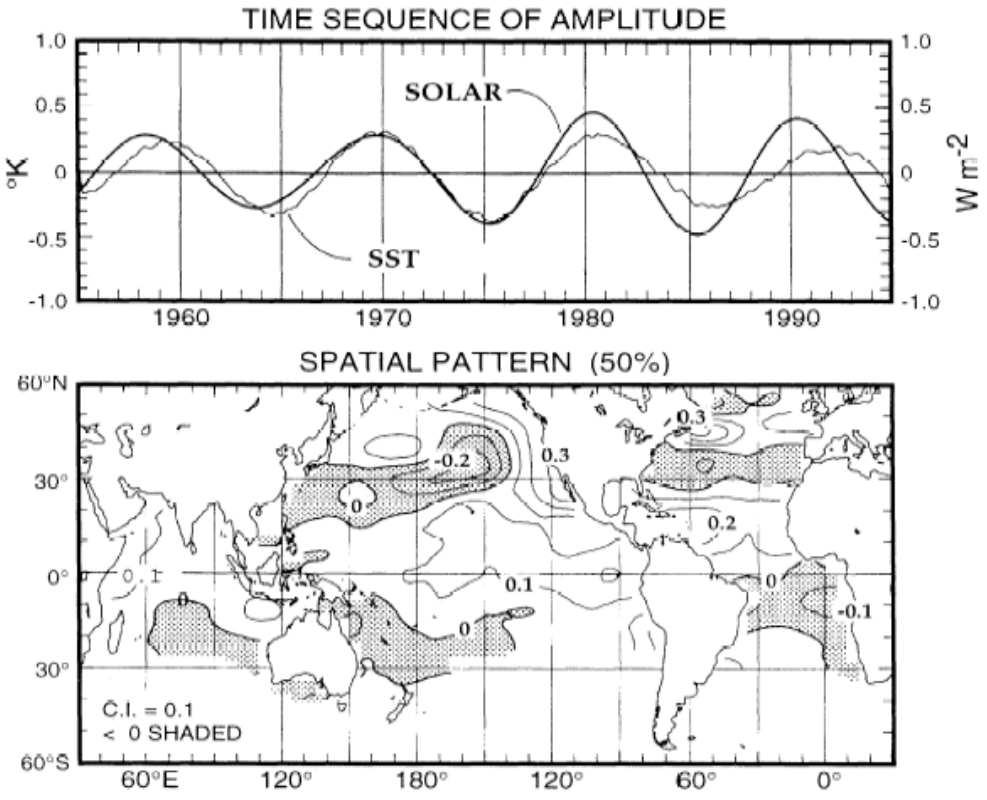


(Tanaka Yasuda et al. 2012 JC)

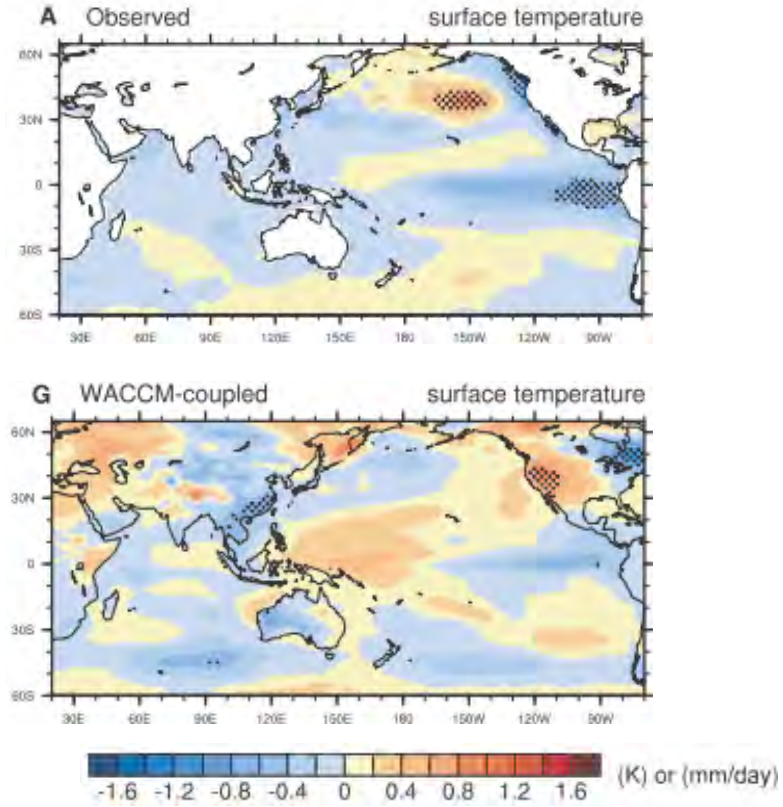
Yasuda and his colleagues have been very active for 18.6 year tidal modulation, and provide strong evidence for oceanic mixing (not shown) but evidence for 20-year Aleutian low variability is weak.

11-year solar forcing

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise



Observational analysis of White et al. (1997)

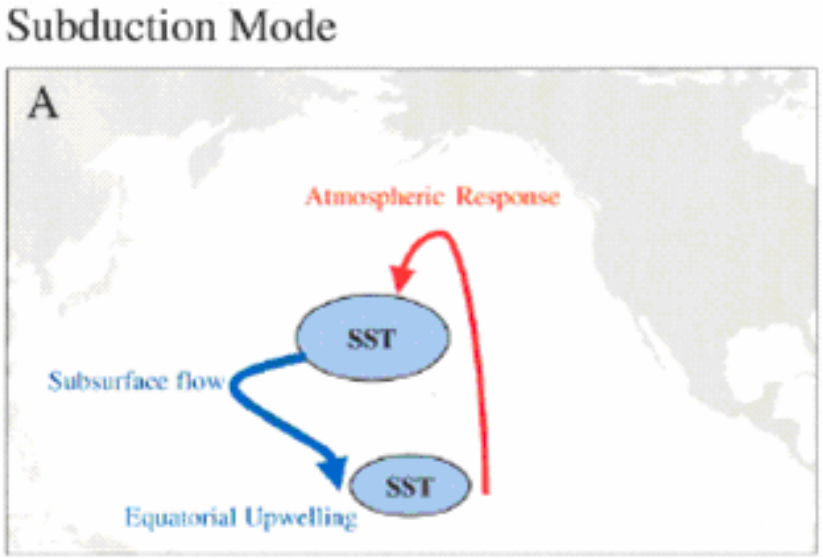


Modelling study by Meehl et al. (2009 Science)

Also, recent studies by Scaife et al. (2013 GRL) and Thiéblemon et al. (2015 Nature Comm) suggests that solar 11-yr forcing substantially influence quasi-decadal variability of NAO.

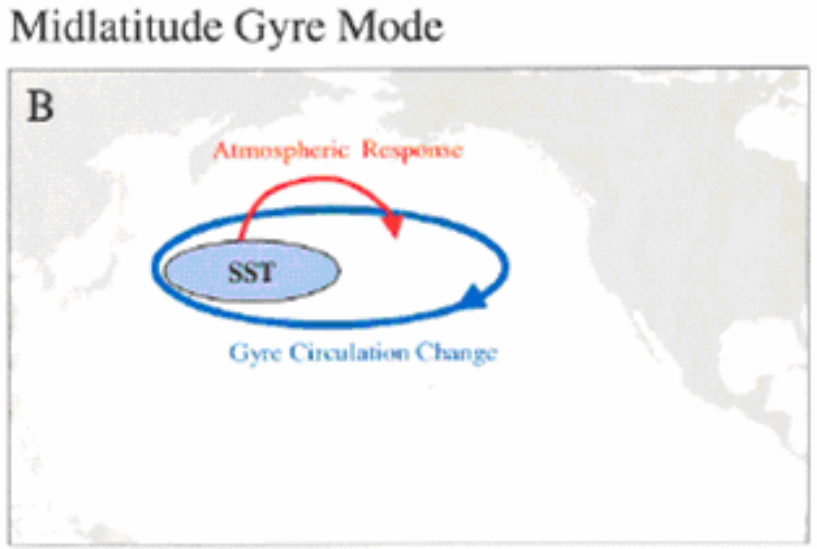
Air-sea coupled mode

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise



Conceptual model by Gu & Philander (1994 Science)

For the equatorial & South Pacific, this mechanism can be important (e.g., Luo & Yamagata 1998).

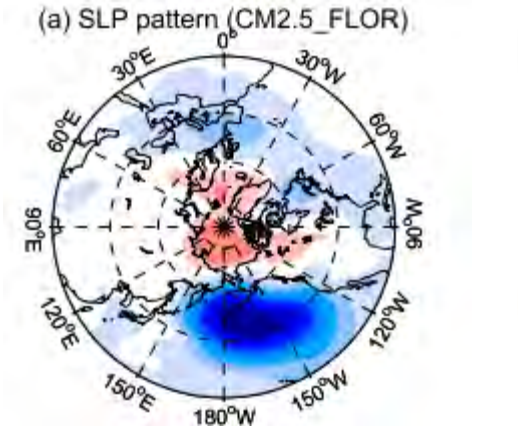


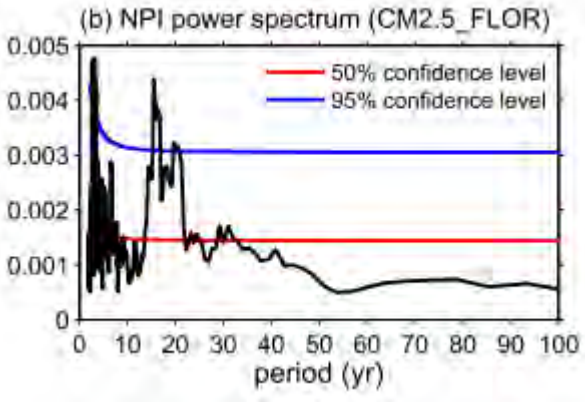
Pioneering work by Latif & Barnett (1994 Science.

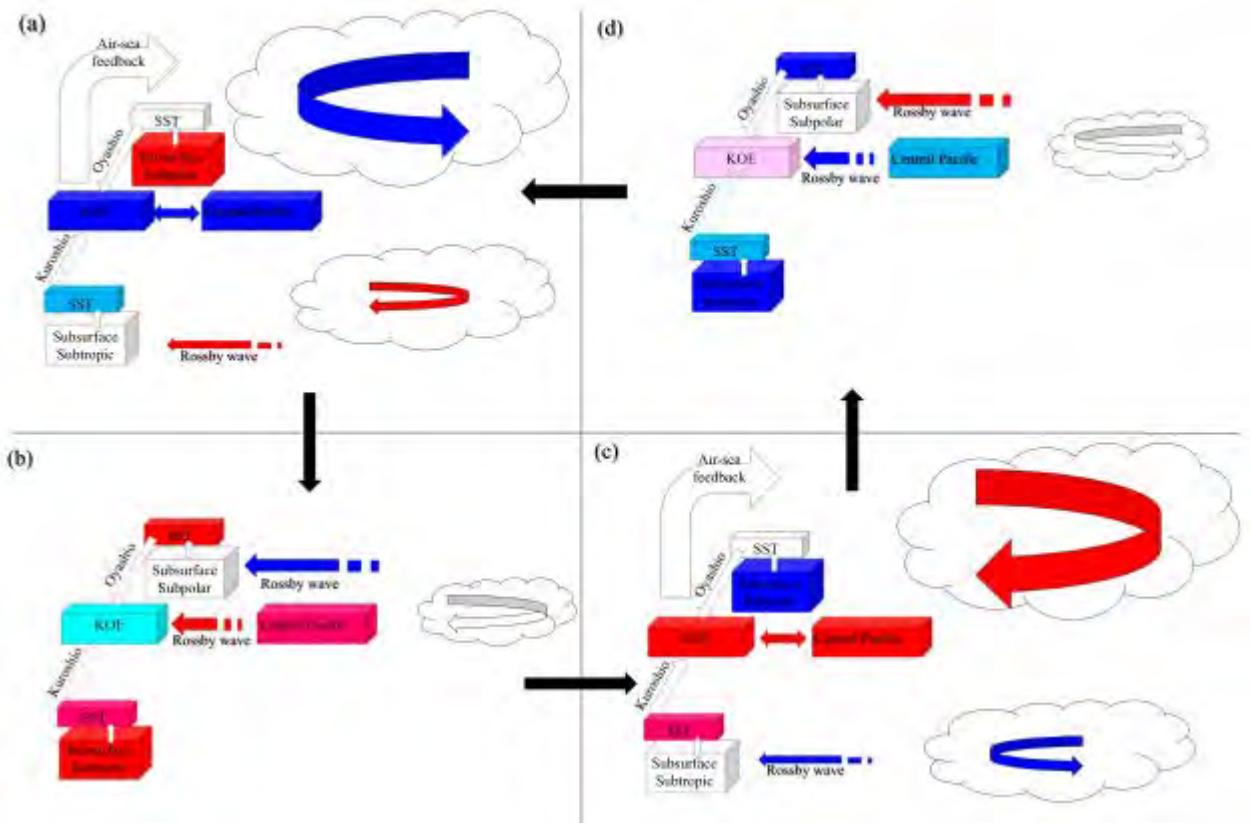
Several air-sea coupled models show 10-20-yr or 50-70-yr oscillations, but it is not clear whether this mechanism is important in observed PDV.

Air-sea coupled mode for ~20-year period

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise





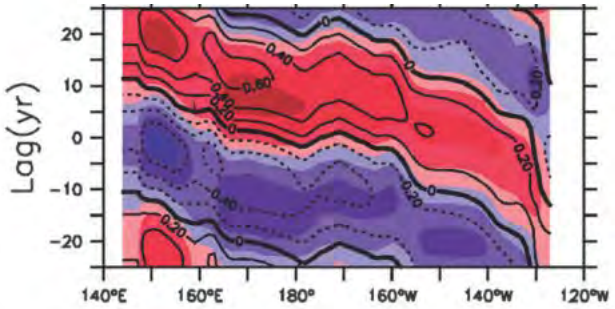


Zhang and Delworth (2015)

Air-sea coupled mode on 50-70-yr timescales

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise

Lag correlation of dynamic height (color) and 0-500 m salinity (contour) along 50N onto KEI SST with 20-80 yr filter.



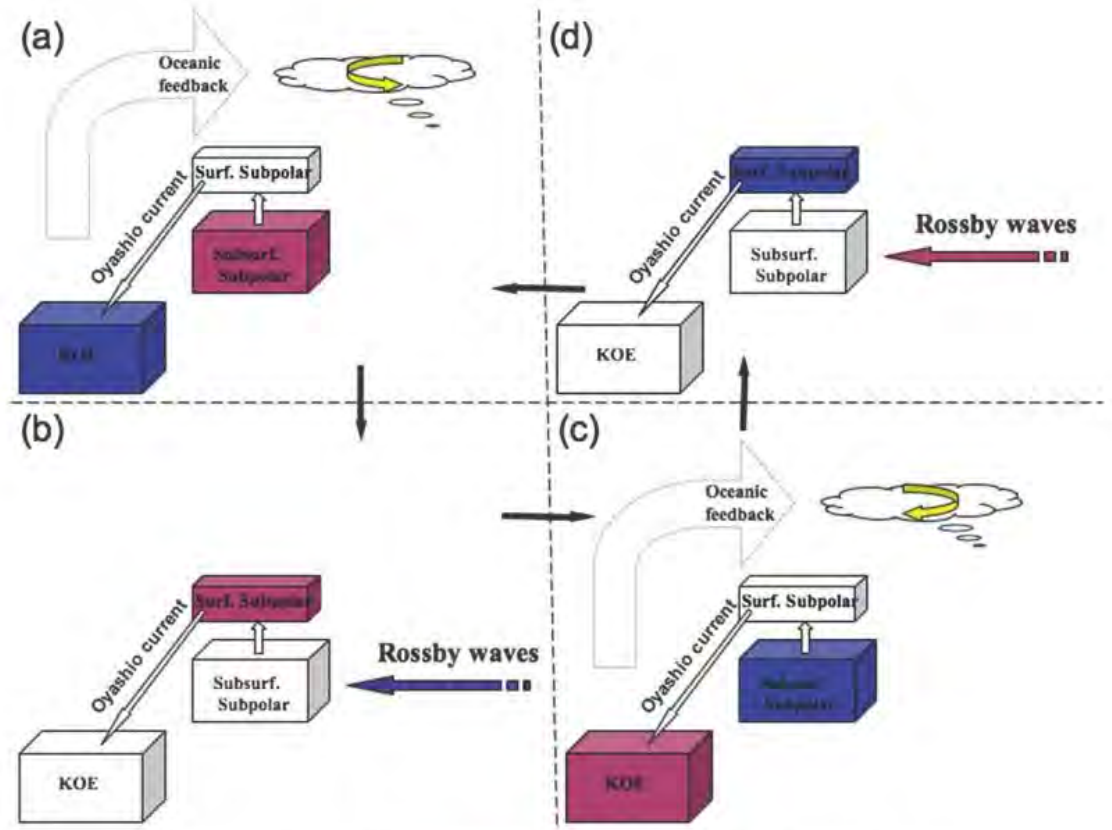


FIG. 11. Schematic picture of a full cycle of PMV. Explanation is given in the text.

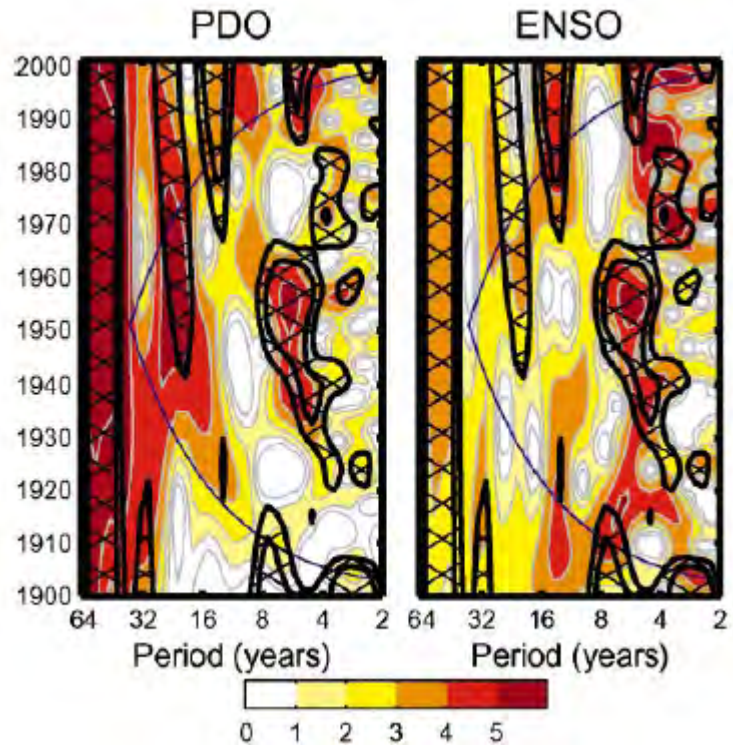
Zhong and Liu (2009 J. Climate)

Salinity propagation is key process for multidecadal air-sea coupled mode in this model, but we cannot confirm this hypothesis from observed salinity data. Maybe we need another 50-year data accumulation.

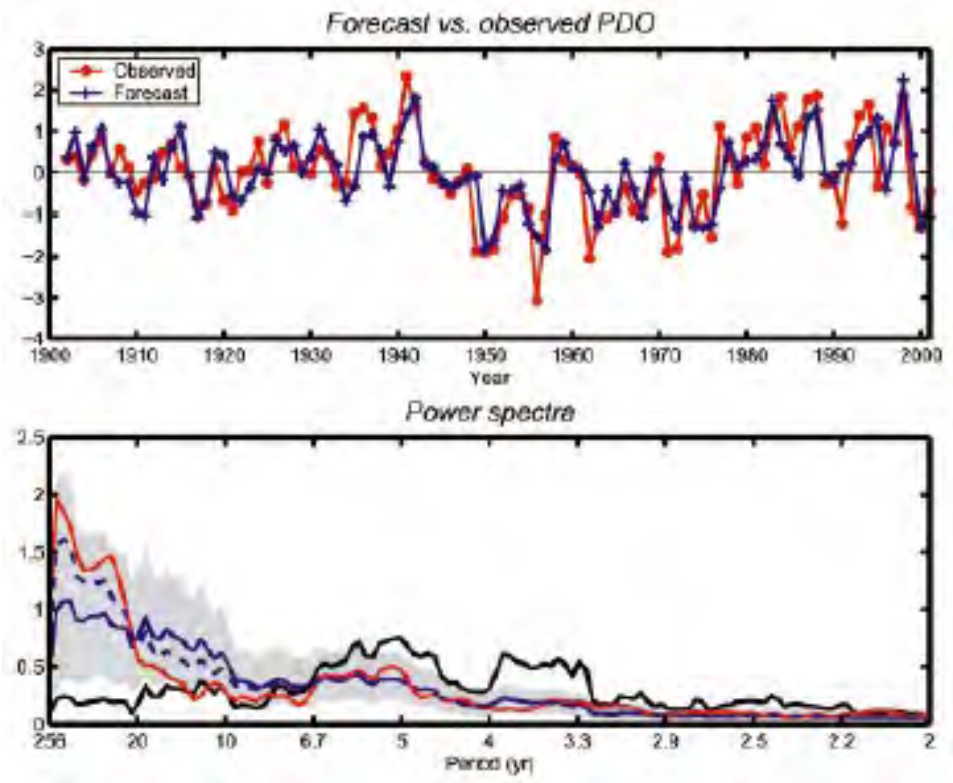
ENSO influences on PDO

Mechanisms
18-year tidal modulation
11-year solar cycle
Air-sea coupled mode
ENSO
Climate Noise

PDO (n year)
= α PDO (n-1 year) + β ENSO (n year) + noise



Newman (2003 J. Climate)



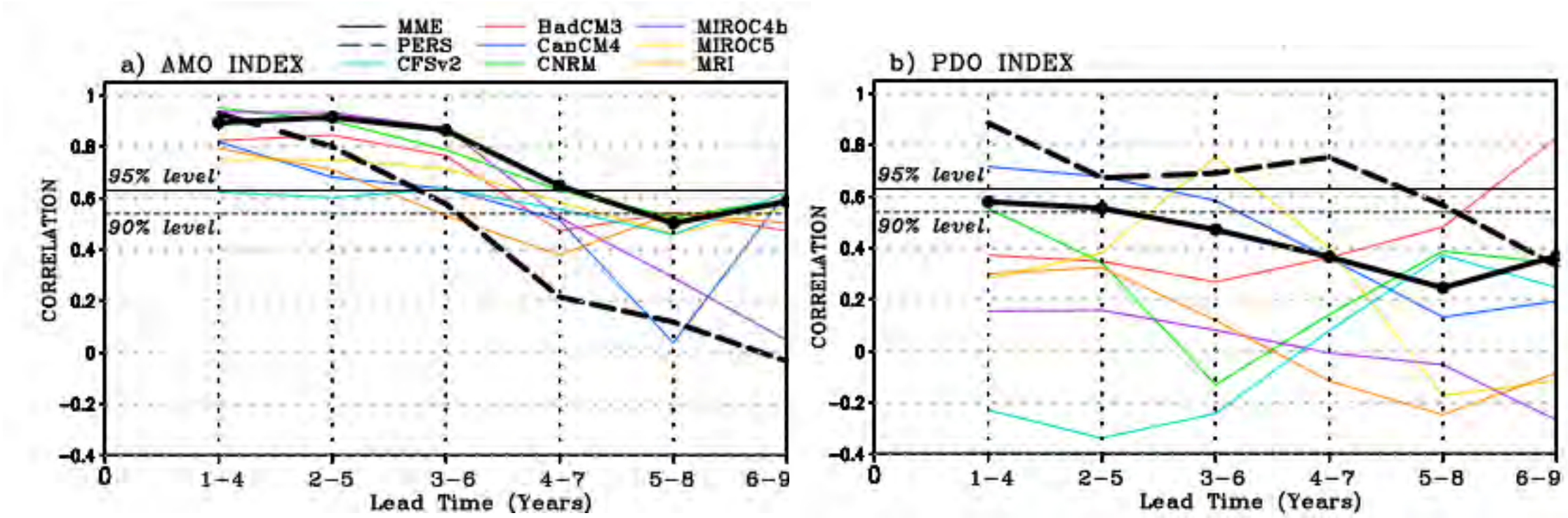
Major feature of PDO can be explained by ENSO plus noise and the reddened effect of ocean.

Consensus of Aleutian Low variability mechanisms

Mechanisms	Consensus	Predictability
18-year tidal modulation	OK for ocean mixing, not for atmosphere	Infinite
11-year solar cycle	OK but limited influence	A decade
Air-sea coupled mode	No	From several years to decades
ENSO	OK	1 year
Climate Noise	OK	Week

Unfortunately, we can be confidence only short predictability for atmospheric variability, oceanic signatures can have longer memories

Predictability in CMIP5 models



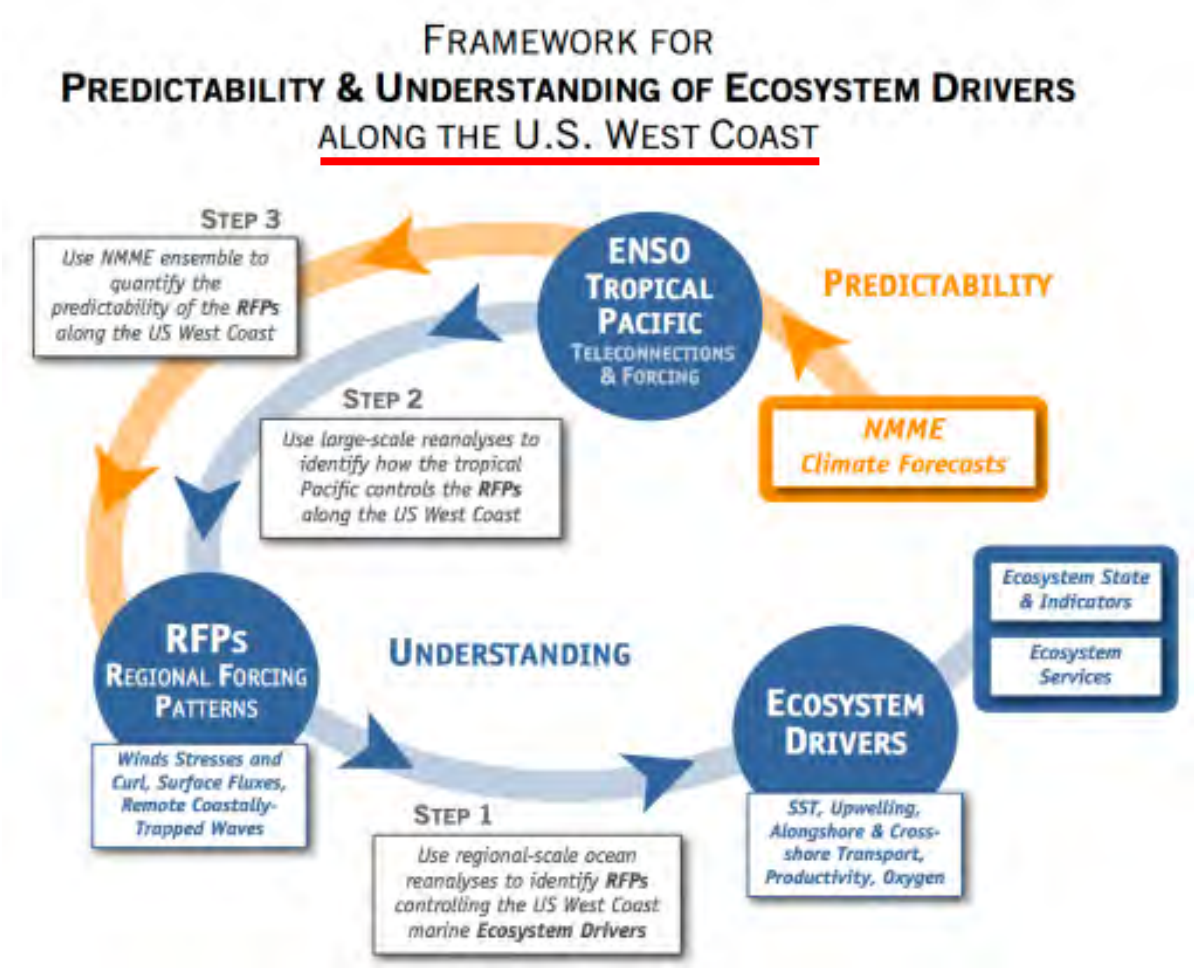
Kim et al. (2012 GRL)

- Unfortunately, prediction power of climate models for PDO is quite poor, weaker than persistency prediction in most cases.
- Better chance for AMO, but there are debates of aerosol influences that are not included properly in the prediction experiment settings.

2. Three prediction strategies for marine ecosystem indicators & appropriate one for the western North Pacific

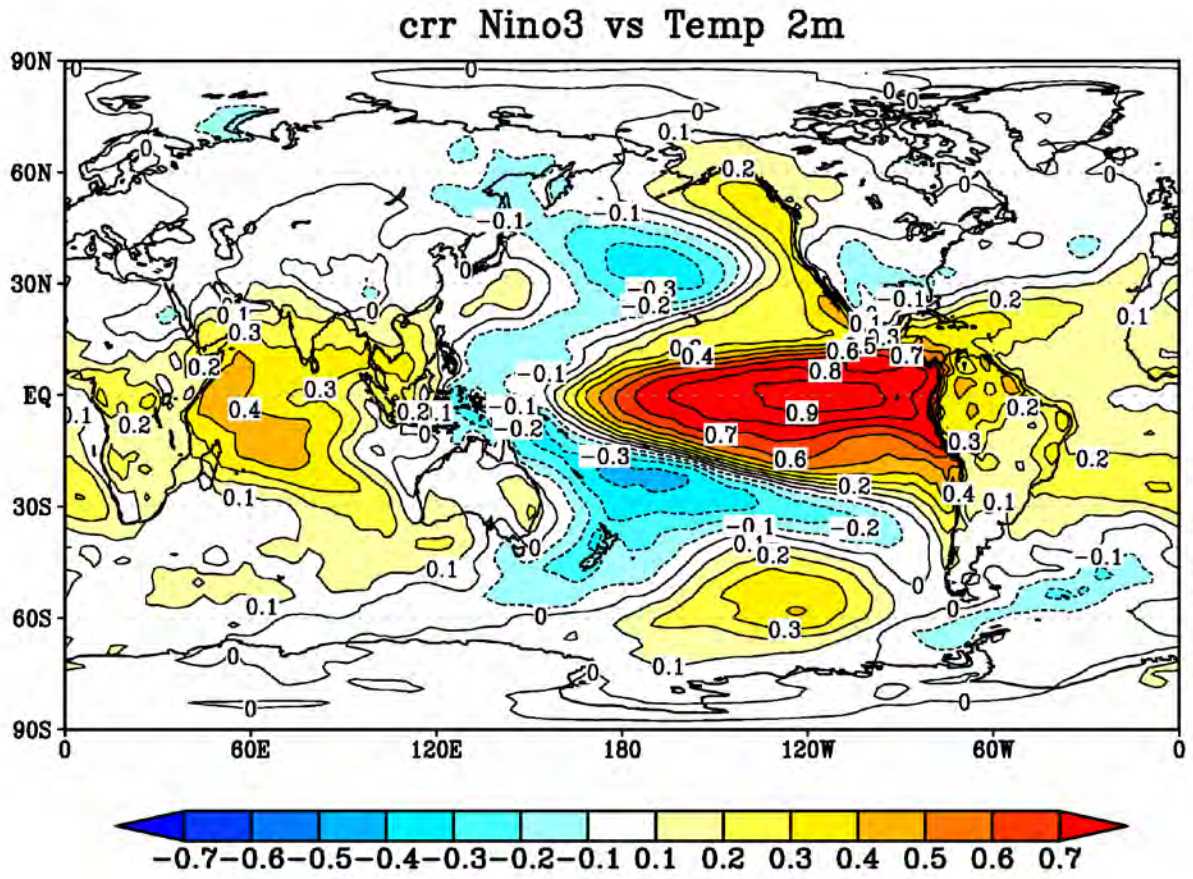
An excellent predictability & understanding framework, along the US west coast

- Given the fact that among proposed Aleutian Low variability mechanisms, we have consensus only on ENSO influence and climate noise, it is reasonable to utilize ENSO for the basis of ecosystem prediction.
- Indeed, Di Lorenzo and Miller (2017, US CLIVAR variations) proposed implementation framework of this direction.



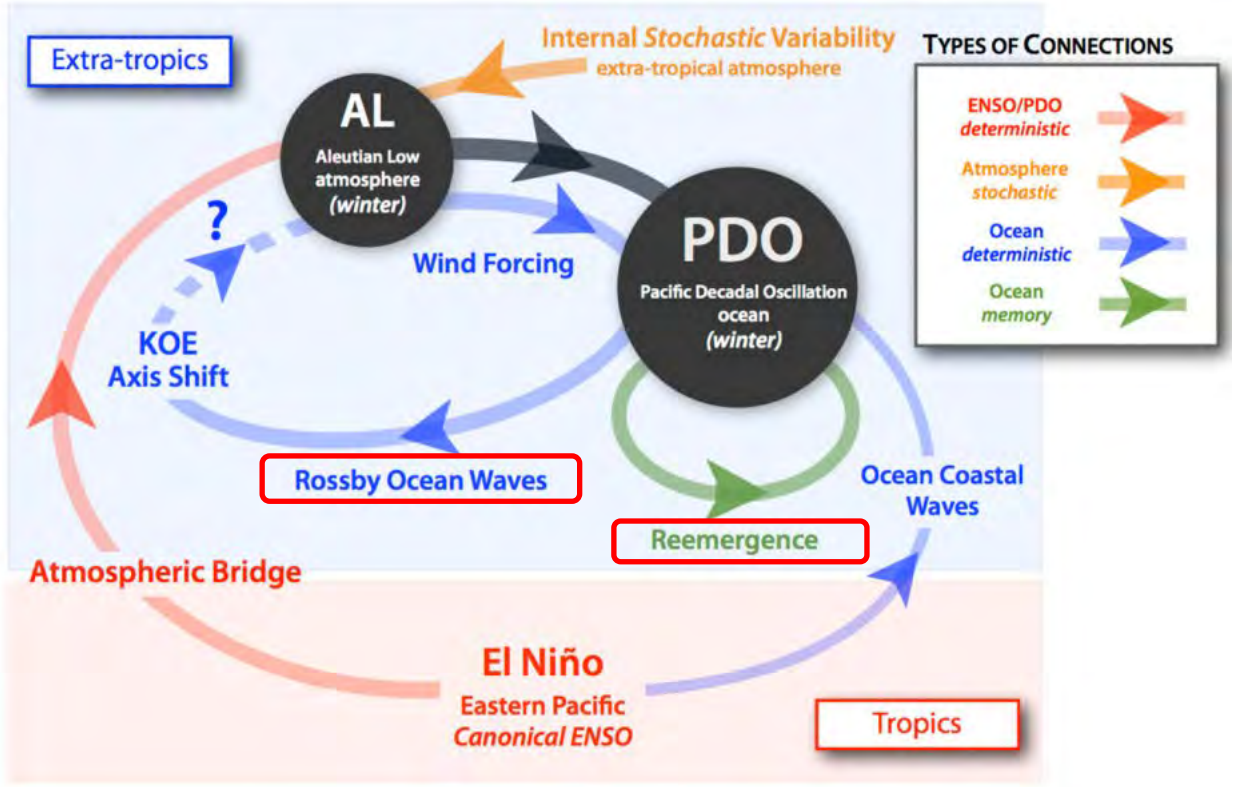
An excellent predictability & understanding framework, along the US west coast

- However, ENSO based predictability is weak in the western side of the basin, where we need different framework for predictability and understanding.



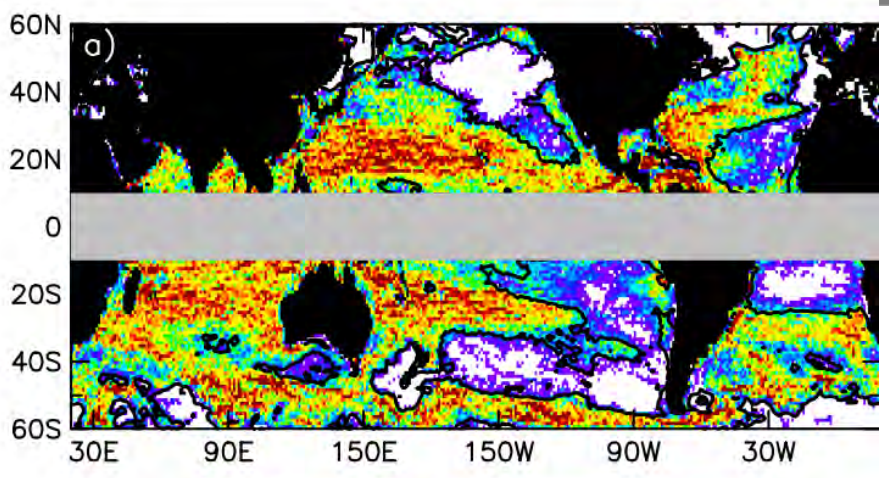
Not only ENSO that provides predictability

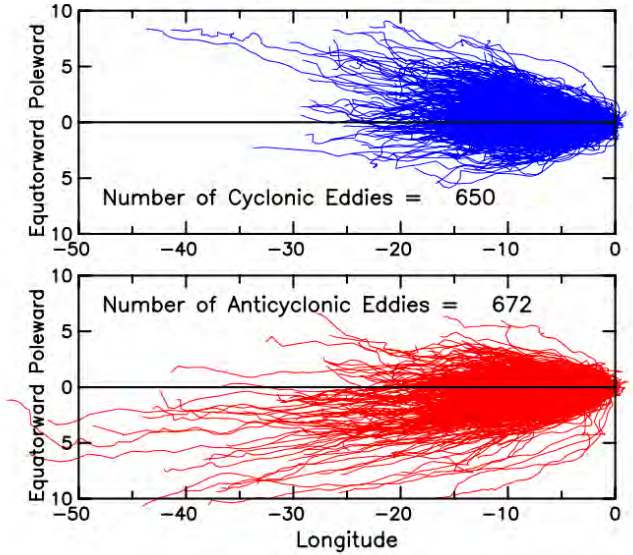
- Ocean predictability also can comes from Rossby wave propagation, reemergence, and mesoscale eddy migrations.
- Furthermore, Indian Ocean dipole, El Nino Modoki, Arctic sea ice, soil moisture over Eurasia continent may provide some predictable atmospheric forcing to the ocean.



Manu's style figure in the latest review paper of Newman et al. (2016)

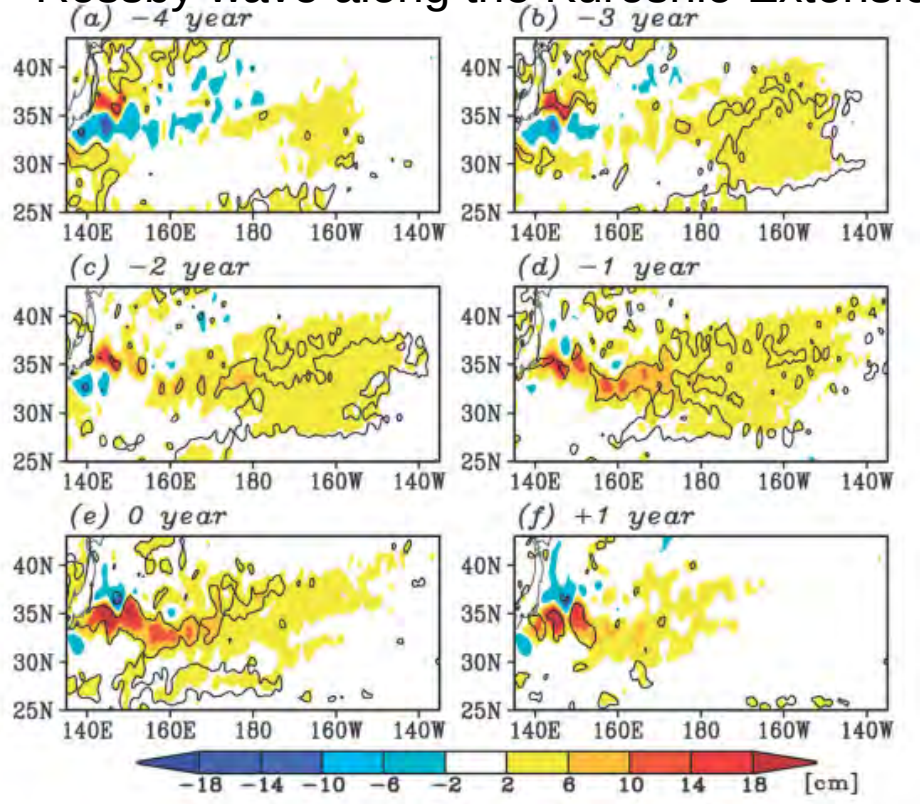
Propagations of Mesoscale eddies, Rossby waves, jet-trapped Rossby waves are all westward





Chelton et al. (2007 GRL)

Westward propagation of jet-trapped Rossby wave along the Kuroshio Extension



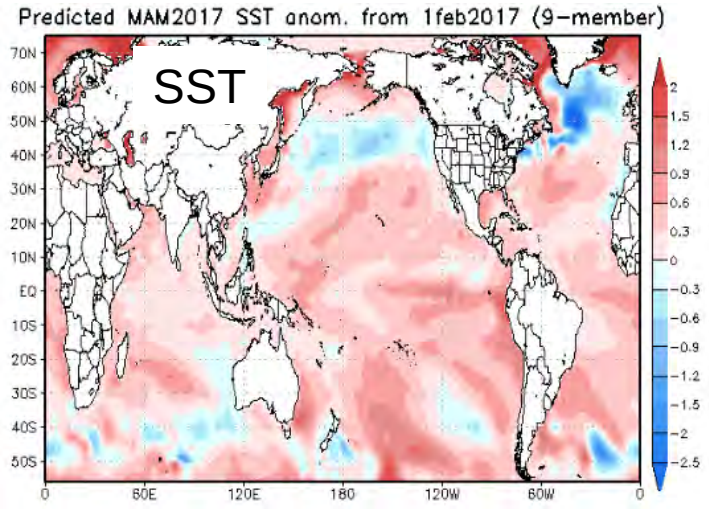
Sasaki Minobe et al. (2012, J. Phys. Oceanogr)

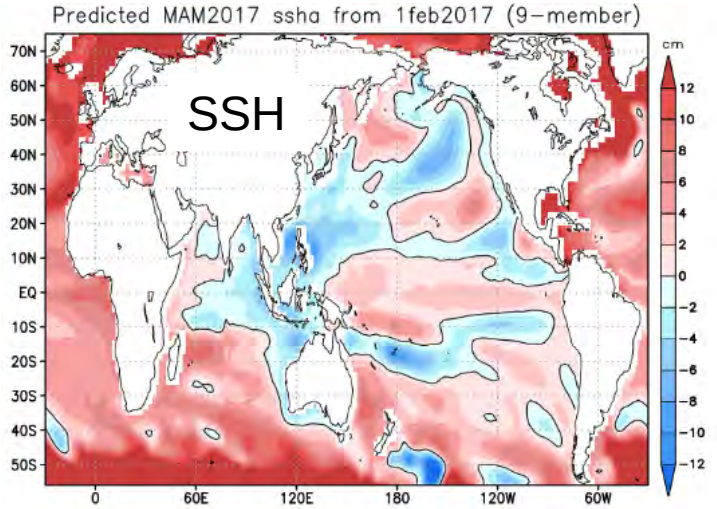
These propagating phenomena may give some predictability in the ocean. But we cannot watch each of phenomena specifically for actual forecast (no man-to-man defense).

We need to use combined effects of these phenomena using numerical prediction model.

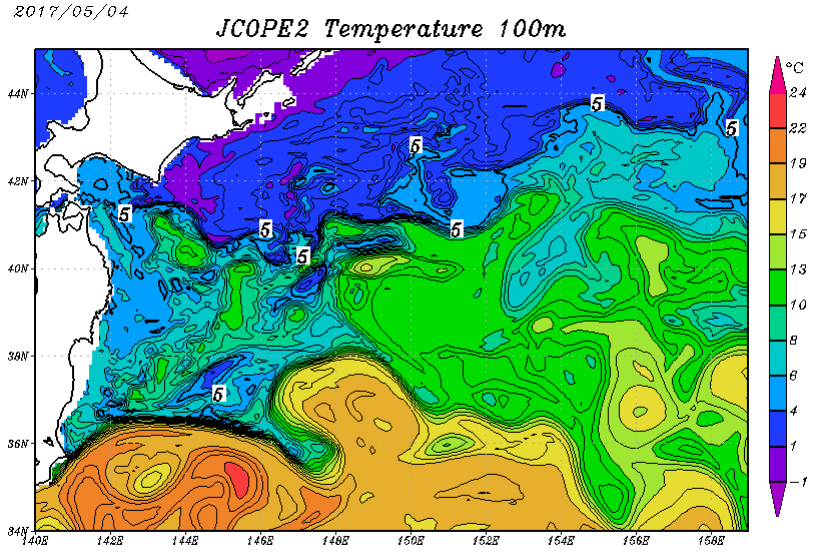
Examples of operational prediction models of Japan

Air-sea coupled model JAMSTEC's SYNTEX-F prediction, up to 2-years, no eddies





JAMSTEC's JCOPE-2 prediction up to 2 months, forced by NCEP Global Forecast System data. Eddies are resolved.

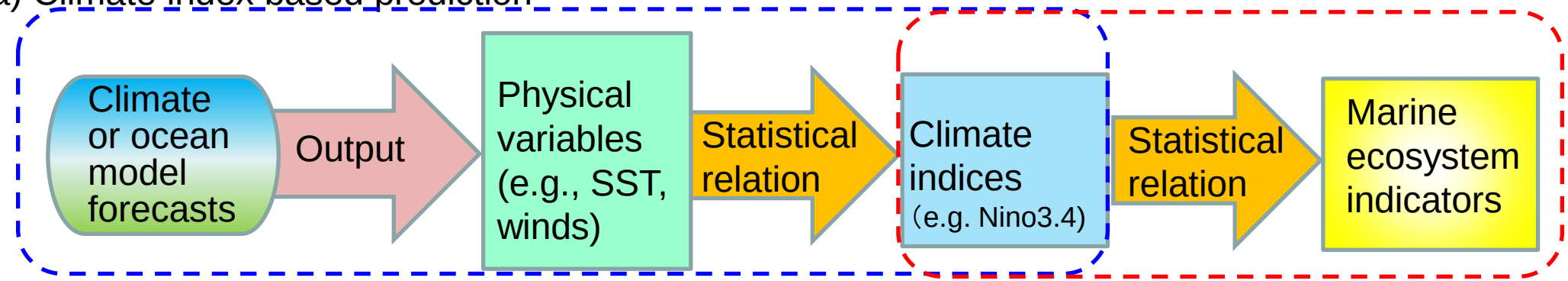


Three typical prediction methods for marine ecosystem indicators

climate center's basic work

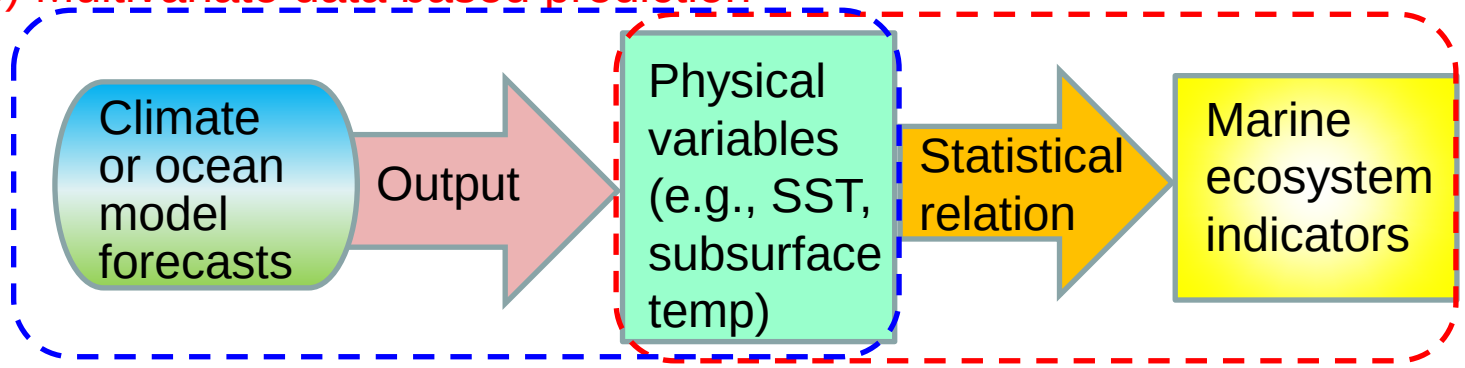
additional works for ecosystem prediciton

a) Climate index based prediction



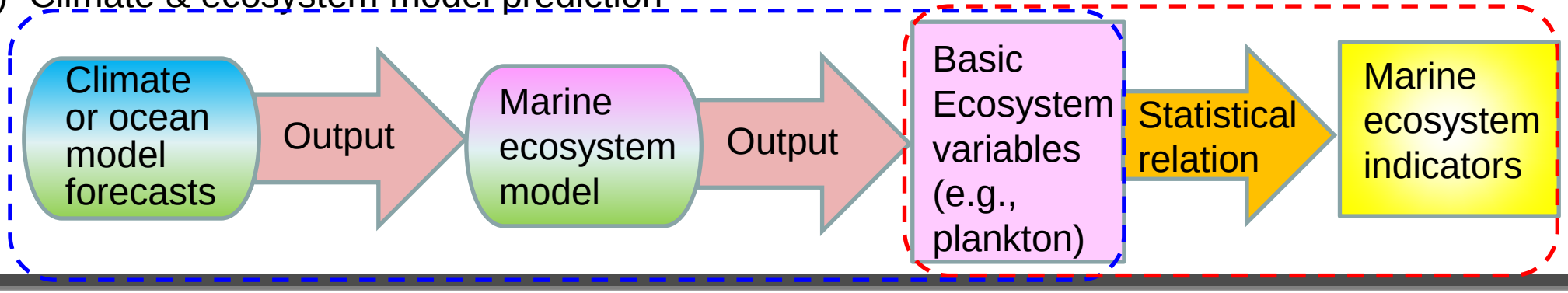
Very feasible and relatively light work for ecosystem prediction.

b) Multivariate data based prediction



Feasible but we need climate center's to provide their prediction data that may not be available for public yet. Work is relatively heavy.

c) Climate & ecosystem model prediction



Probably not feasible in near future (3-years), but success of (b) will encourage to seek this in future.

Three steps for multivariate data based prediction.

- Step 1. Identify promising marine ecosystem indicators for prediction using observed physical ocean data.
  - The simultaneous correlation must be significant with proper estimation of degrees of freedom, and should be larger than a prescribed threshold ($|r|=0.5$ or $|r|=0.6$) at a proper lead time (one, three, six months and a year).
- Step 2. Examine statistical relation between marine ecosystem indicator and predicted physical ocean data.
  - Note that the relation between ecosystem indicator and predicted physical data should be smaller than the relation between the indicator and observed physical data, because prediction of physical fields cannot be perfect due to chaotic nature of atmospheric forcings and some oceanic processes.
  - If the relation is strong enough, then go to next step.
- Step 3. Build a operational system for predicting ecosystem indicator on a regular basis.

- Step 1 can be done without prediction data.

Conclusions

- PICES played great roles in promoting collaborations between physical climate studies and marine ecosystem studies for the last two decade.
- We reach the stage of forecast, and reasonable forecast system should be build on consensus of physical climate studies.
  - We need to ignore a number of interesting hypotheses “under debate”.
  - Thus, ENSO + noise are atmospheric forcing, and propagation of eddies and Rossby waves in the ocean are important factors.
- ENSO based predictability will be very useful for west coast of US and Canada.
- For the western North Pacific, multiple phenomena should be taken into account in prediction, and thus direct linkages between predicted physical variables and marine ecosystem indicators should be explored.
  - This means that we need to collaborate climate centers.
  - This actually helps climate centers to make their prediction data more useful and thus valuable.