



Linking technological and POC advances over the past 25 years

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PICES



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Background & Outline

1. Many technological advances but focus on POC research arising from

a) Bigger & faster computers (better models)

b) Observations from

i. Satellites (SST, Chlorophyll, SSH)

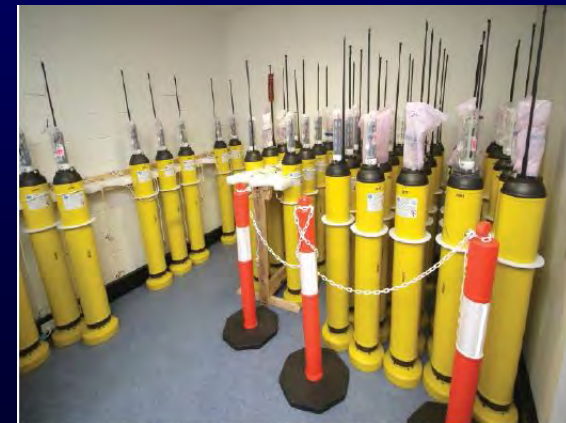
ii. Autonomous platforms (Argo floats, gliders)

2. Examples from 2003-2014 POC-Paper & POC co-sponsored presentations on

http://www.pices.int/meetings/past_annual_meetings.aspx

3. What lies ahead

4. Summary



Bigger & Faster Computers

1. Earth Simulator in Japan

- First opened March 2002
- Replaced 2009 & 2015



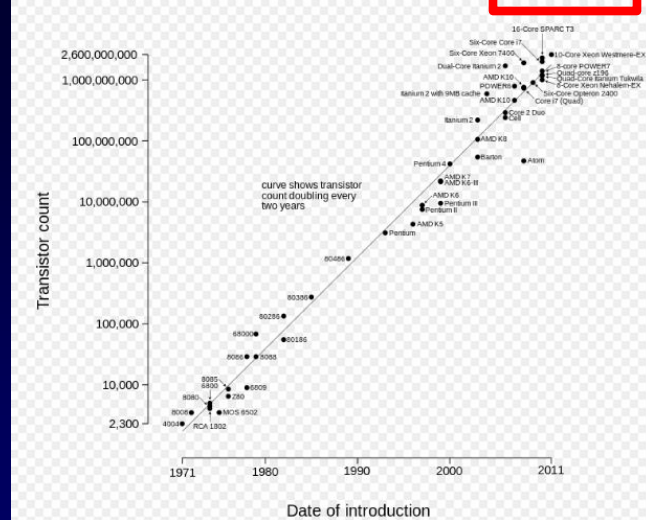
2. Similar hardware in USA & other PICES countries

3. Software improvements e.g. parallelization

4. Allow models with

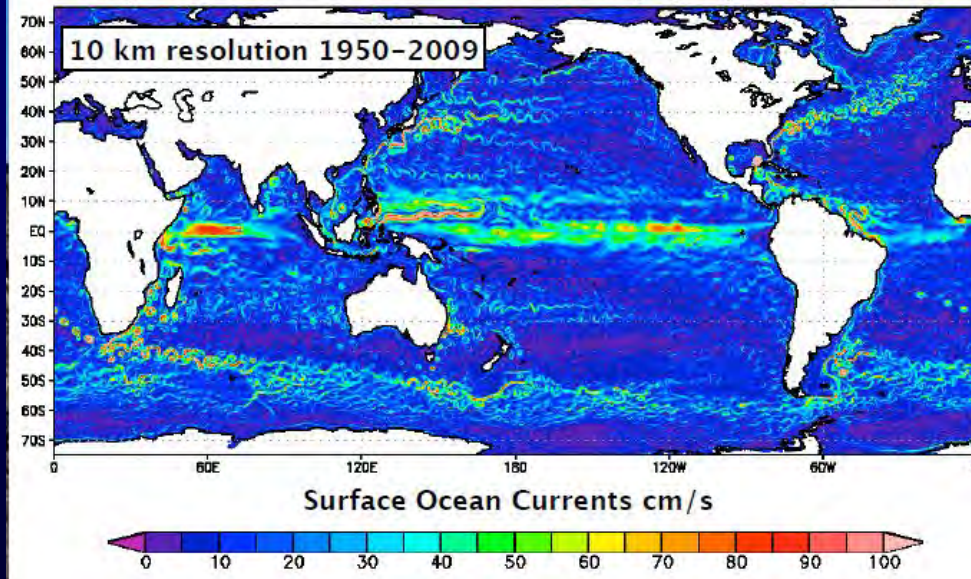
- Higher resolution
- Data assimilation
- More complexity
- Longer simulations (e.g., climate) & more ensembles

Microprocessor Transistor Counts 1971-2011 & Moore's Law



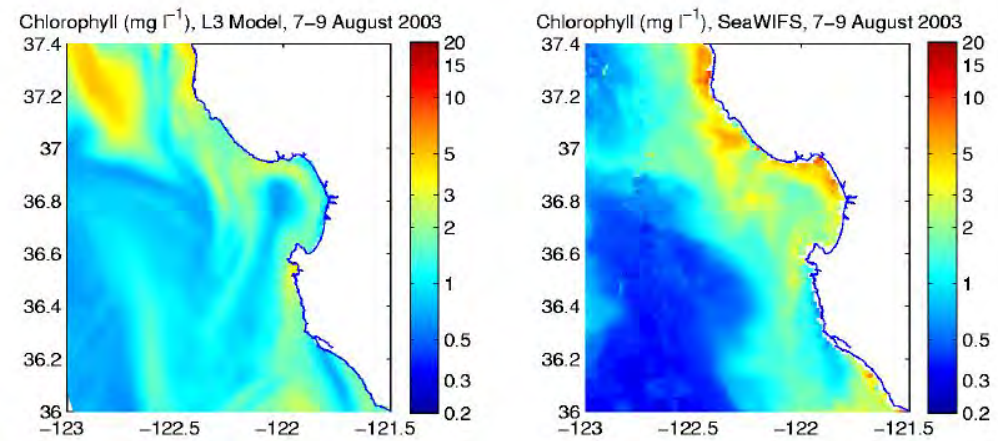
2000 times increase from 1990 to 2011

Japanese Earth Simulator Global Eddy-Resolving Model (OFES)
Monthly Mean of Surface Current Velocity [cm/sec] (FEB/50YR)



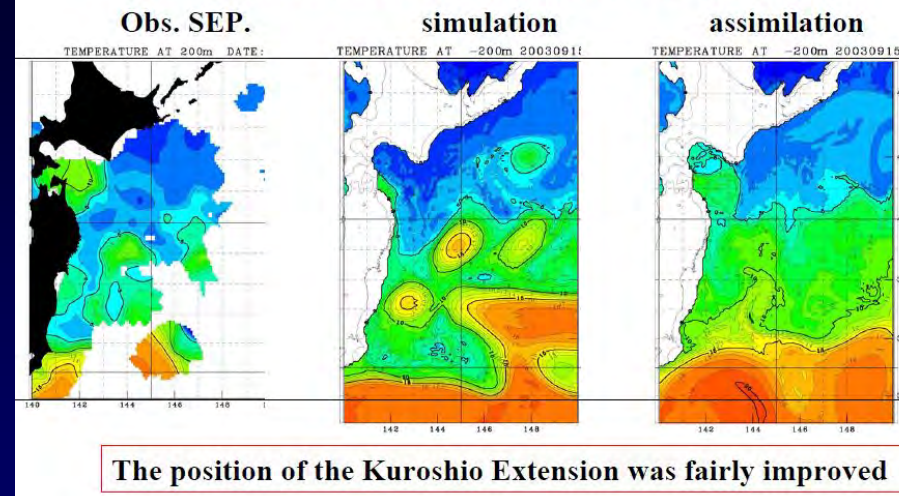
Davis & Di Lorenzo, Hiroshima 2012

Model and SeaWiFS Surface Chlorophyll Comparison



Chai, Honolulu 2004

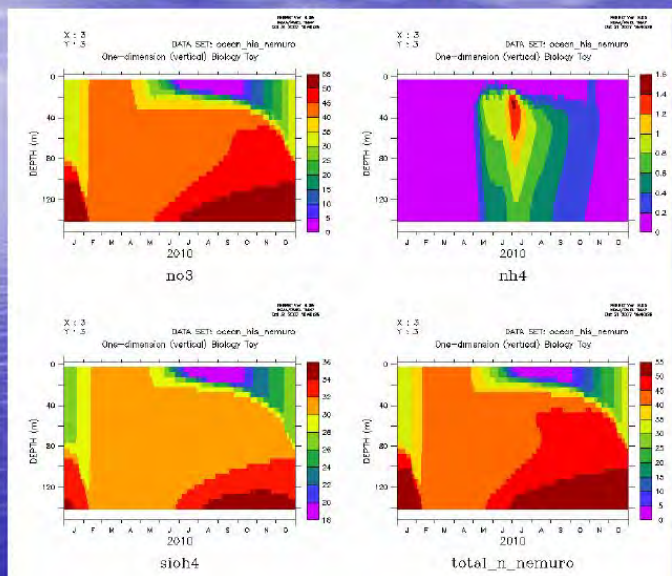
North limit latitude of the Kuroshio Extension



The position of the Kuroshio Extension was fairly improved

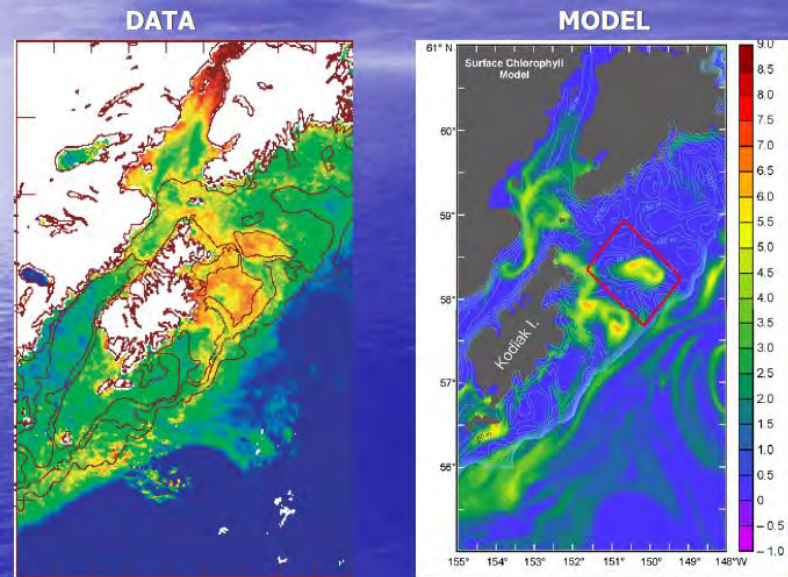
Ito et al., Vladivostok 2005

NEMUROMS annual cycles



Hermann et al., Victoria 2007

Rings of chlorophyll are a dominant feature



Hermann et al., Dalian 2008

multi-trophic-level ecosystem model of Japanese sardine

Climate Model MIROC 3.2

1/4 x 1/6
Climatological Physical fields
SST, V, Kz, etc.

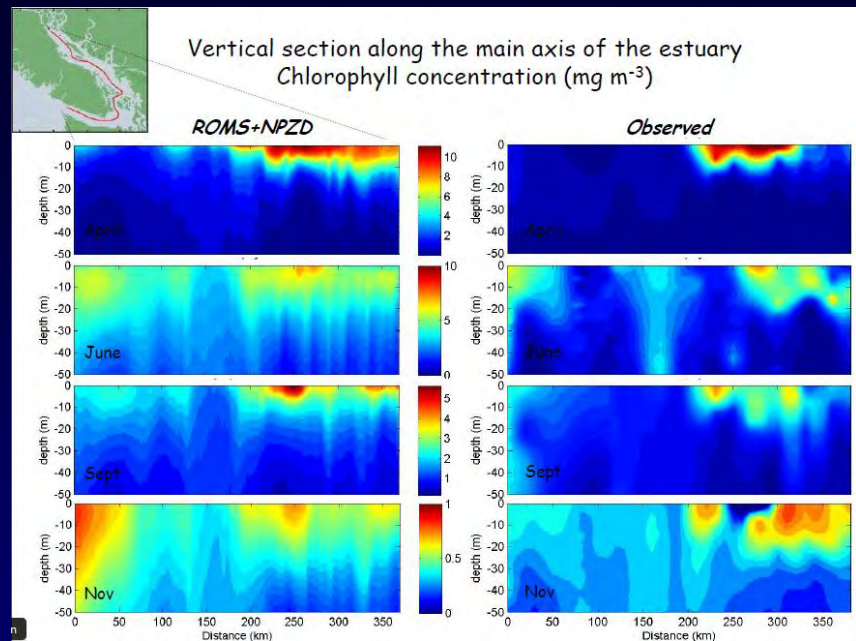
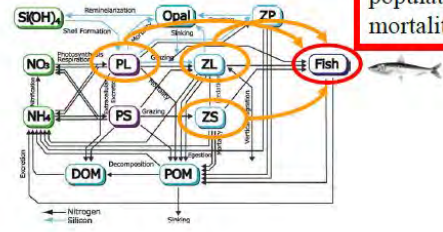
LTL Ecosystem Model NEMURO

1/4 x 1/6
prey plankton density

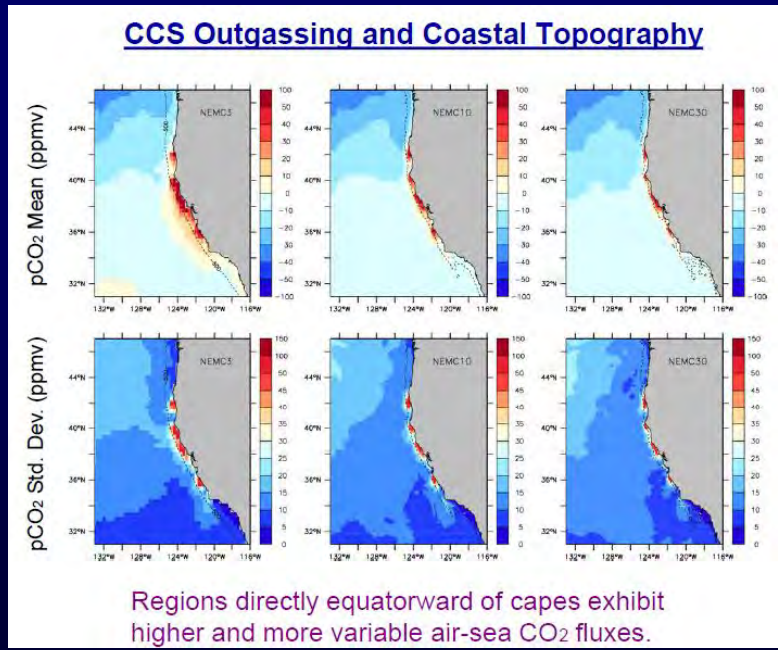
Sardine Migration Model (Okunishi et al., 2009)

growth: NEMURO.FISH
migration: fitness+GA
population: size dependent mortality

2-way



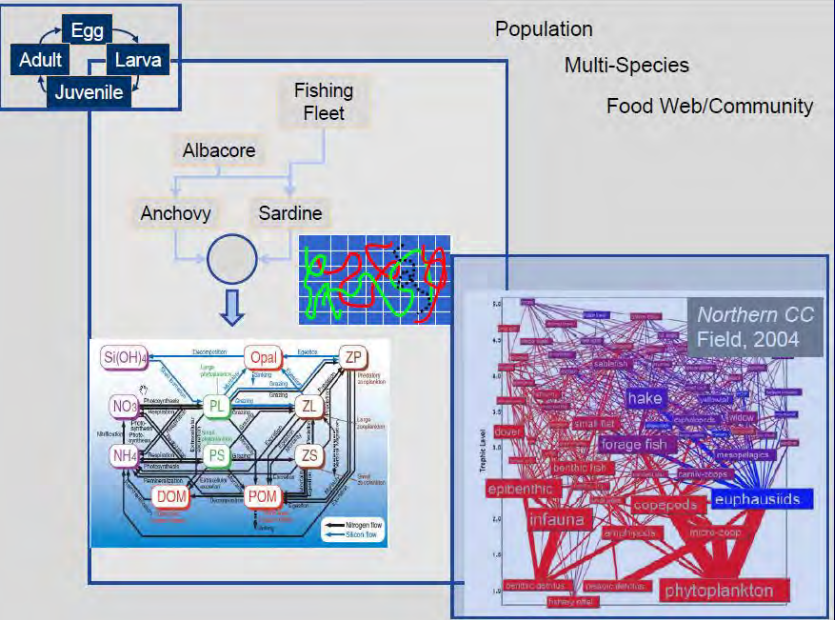
Peña & Masson, Khabarovsk 2011



Regions directly equatorward of capes exhibit higher and more variable air-sea CO₂ fluxes.

Fiechter et al., Nanaimo 2013

Ito et al., Portland 2010

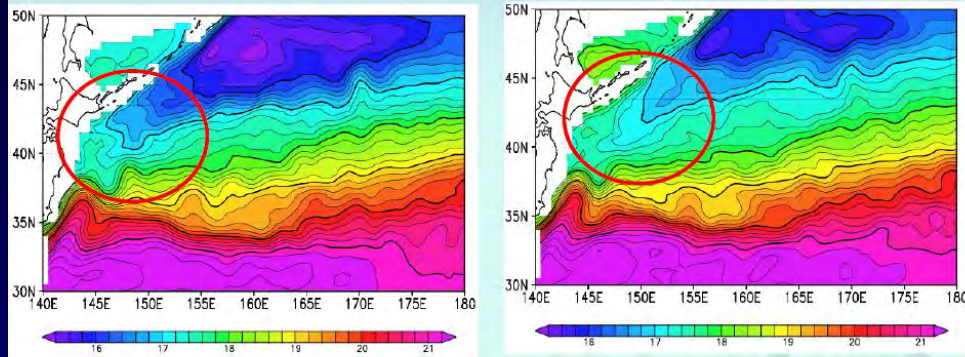


Rose et al., Khabarovsk 2011

Impact of Salinity correction on the subarctic gyre

With salinity correction

Without salinity correction



The subarctic circulation is intensified in the run with salinity correction.

Kamachi et al., Honolulu 2004

Best Demonstration:

**COMPASS-K
(Operational Ocean Assimilation/Prediction System
in Japan Meteorological Agency)
Success of 60-day Prediction
of the 2004 Kuroshio Large Meander**

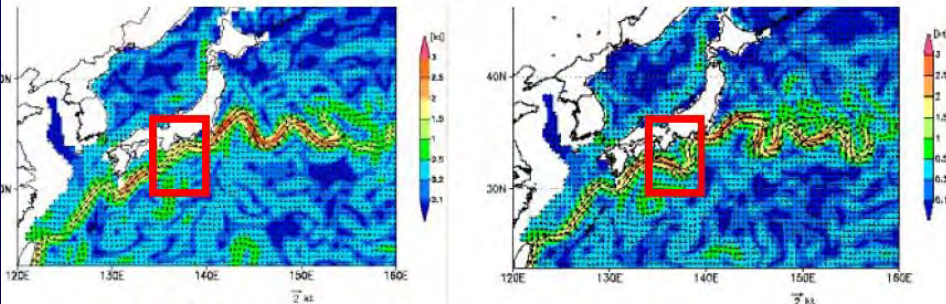


図1 最近の黒潮流路

図2 気象研究所で開発中の海洋大循環モデルによる黒潮の数値予測結果

Assim/initial state (2004/05/09)

Forecast (2004/06/30)

JMA Japan-GODAE SERVER <http://godae.kishou.go.jp/>

Kamachi et al., Victoria 2007

Water mass structure in the Kuroshio-Oyashio mixed water region reproduced by JCOPE2

Yasumasa Miyazawa, Takashi Kagimoto (JAMSTEC), Kosei Komatsu (FRA)

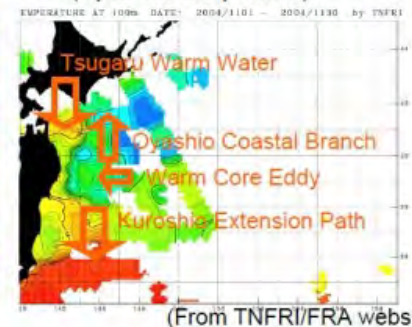
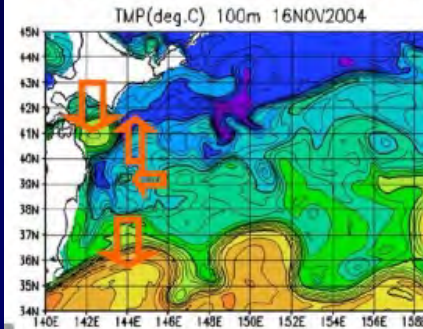


**Victoria
2007**



JCOPE2 + Fishery Community Data

Fishery Community Data
(Optimum Interpolation)



(From TNFRI/FRA website)

The Oregon coastal ocean data assimilation system: performance assessment

Alexander Kurapov,
College of Oceanics and Atmospheric Sciences,
Oregon State University

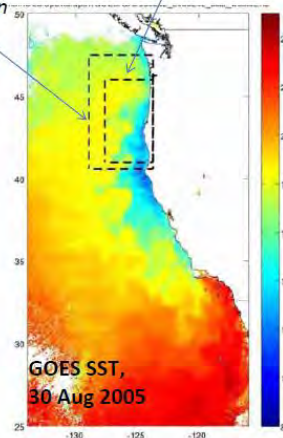
in collaboration with J. Osborne, P. Yu, S. Erofeeva,
G. D. Ebgert, J. S. Allen, P. T. Strub, P. M. Kosro,
D. Foley, L. Miller /NOAA/

Support by:

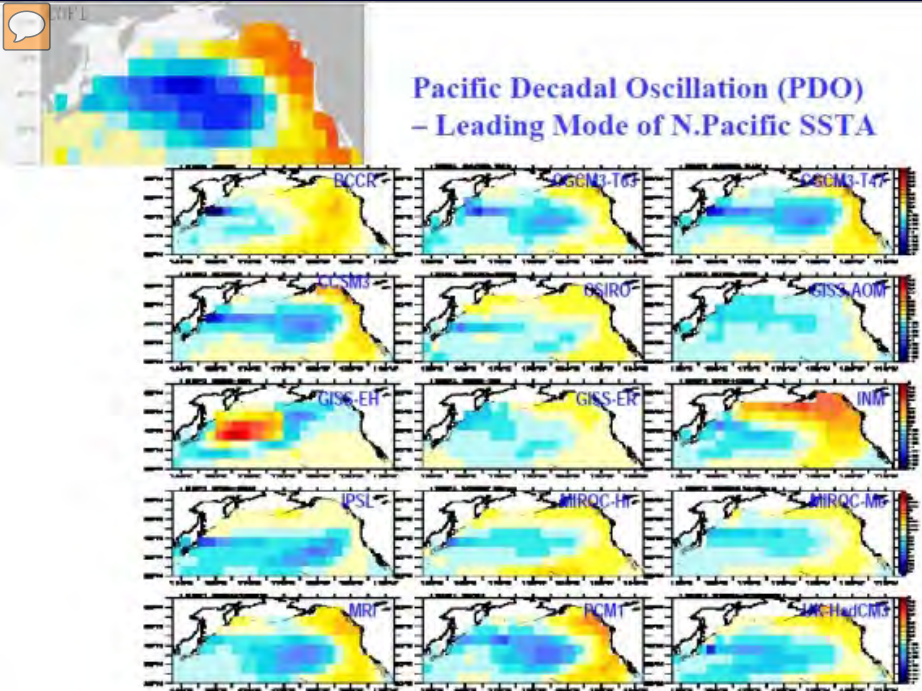
- ONR (DA methods in the coastal ocean)
- NOAA (IOOS-NANOOS: real-time forecast model; CIOSS: utility of RADS SSH, GOES SST)
- NSF (influences of tide- and wind-driven flows, interior - coastal ocean interactions)

3-km forecast
model domain

1-km model



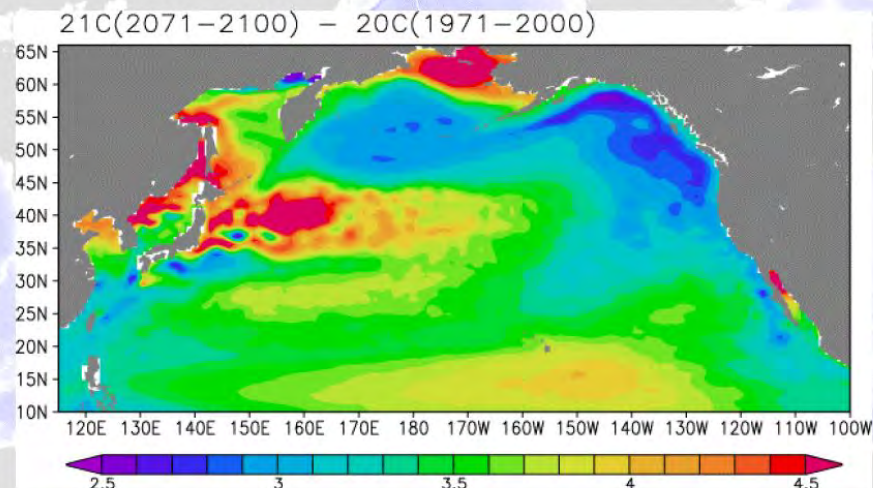
Kurapov et al., Khabarovsk 2011



Wang & Overland, Vladivostok 2005

Global Warming Climate

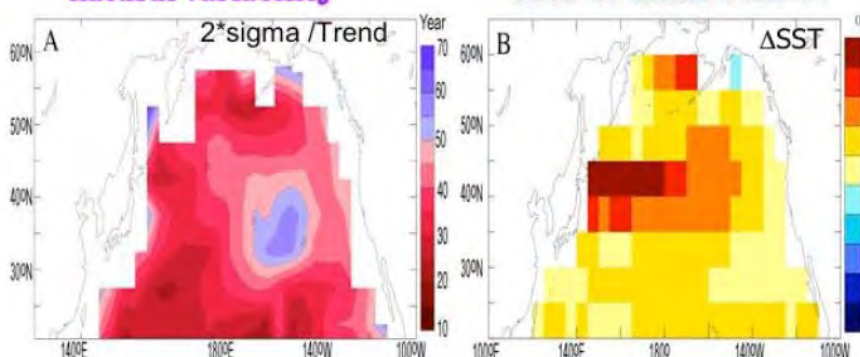
Pacific SST change for A1B scenario



Hasumi et al., Vladivostok 2005

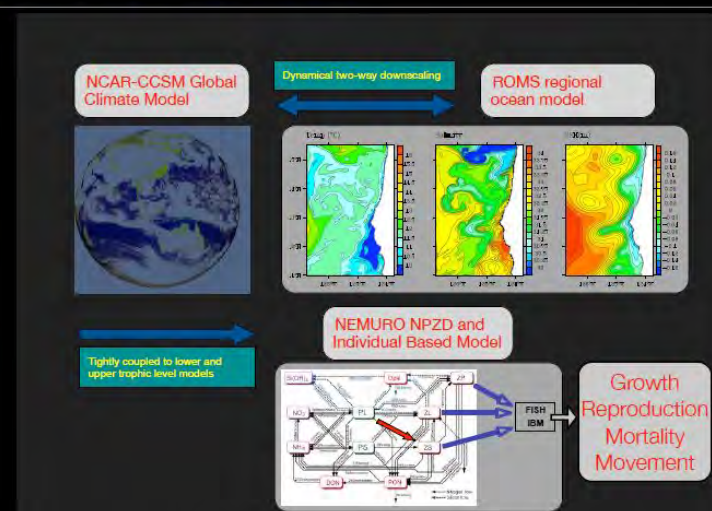
Estimate of years when trend over pass the magnitude of natural variability

**Projected SST Change by Models
Winter SST Anomaly
2040-49 minus 1980-99**



Wang & Overland, Victoria 2007

Climate-to-fish-to-fishers



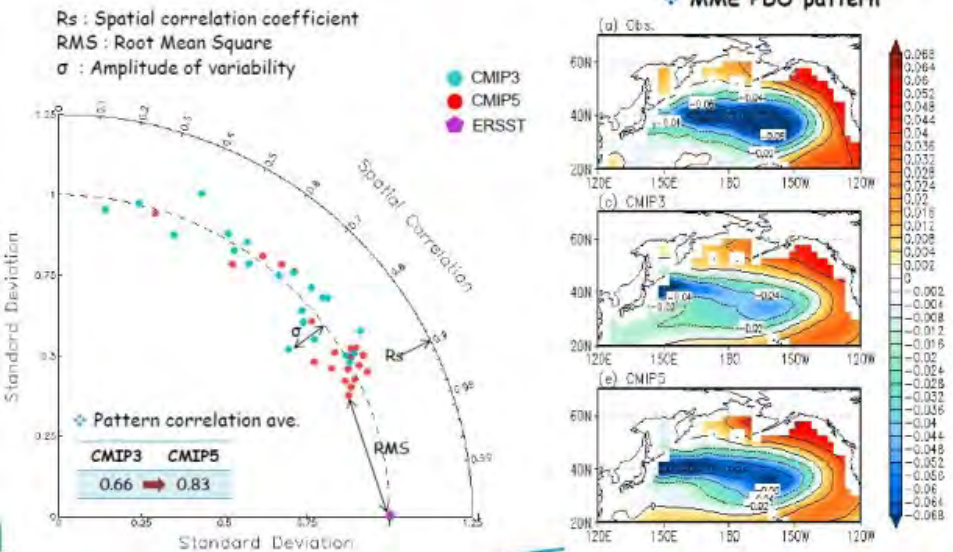
Curchitser et al., Portland 2010

PDO patterns in CMIP3 and CMIP5



MME : Multi-model ensemble mean

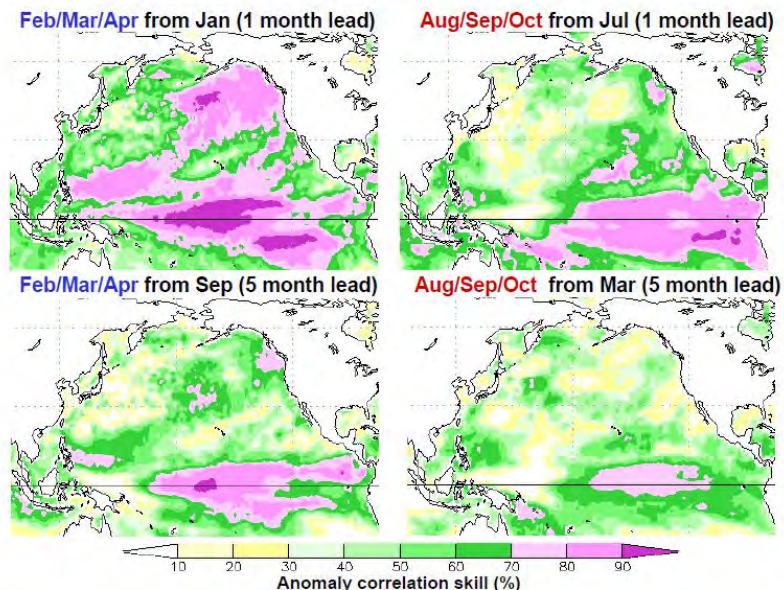
MME PDO pattern



Joh et al., Nanaimo 2013

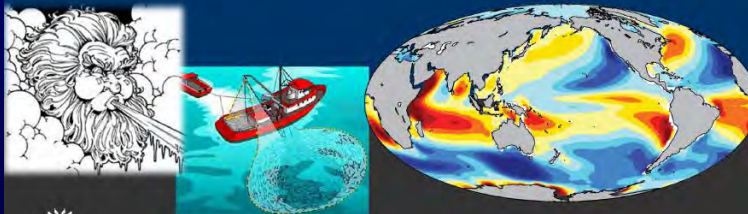
North American Multi-Model Ensemble

www.cpc.ncep.noaa.gov/products/NMME



Merryfield, Nanaimo 2013

Investigating the upwelling intensification hypothesis using climate-change simulations



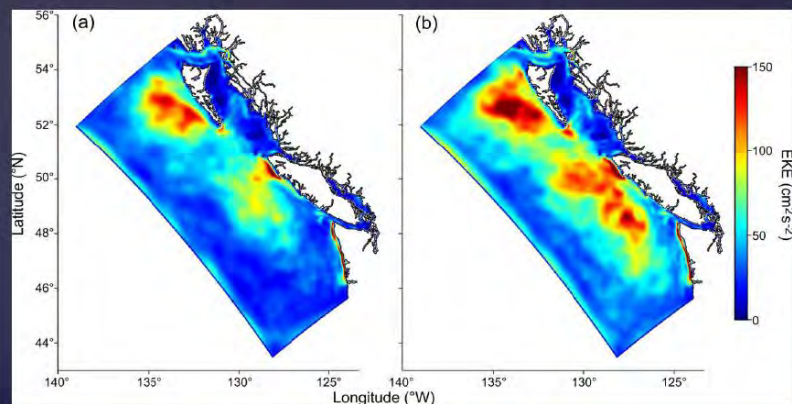
UNIVERSITY OF SOUTH CAROLINA

Ryan R. Rykaczewski
 USC Marine Science Program

John Dunne, Charles Stock, William Sydeman, Marisol García-Reyes, Bryan Black, and Steven Bograd

Rykaczewski et al., Nanaimo 2013

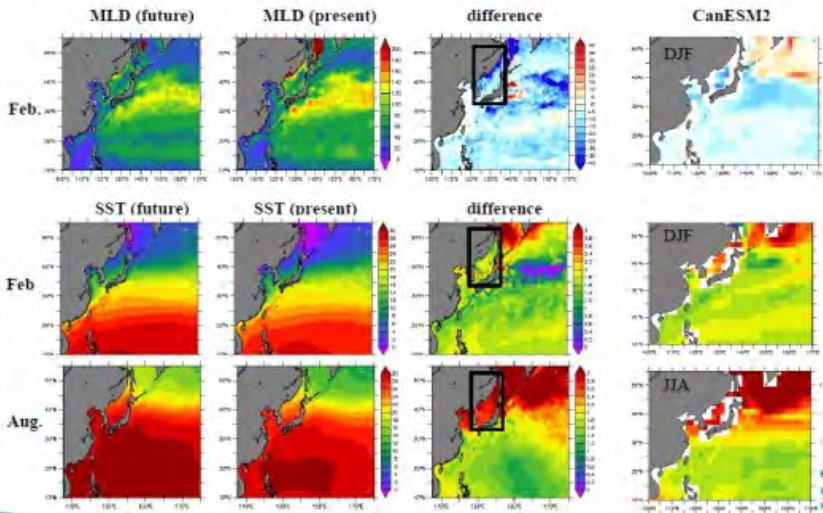
Eddy Kinetic Energy



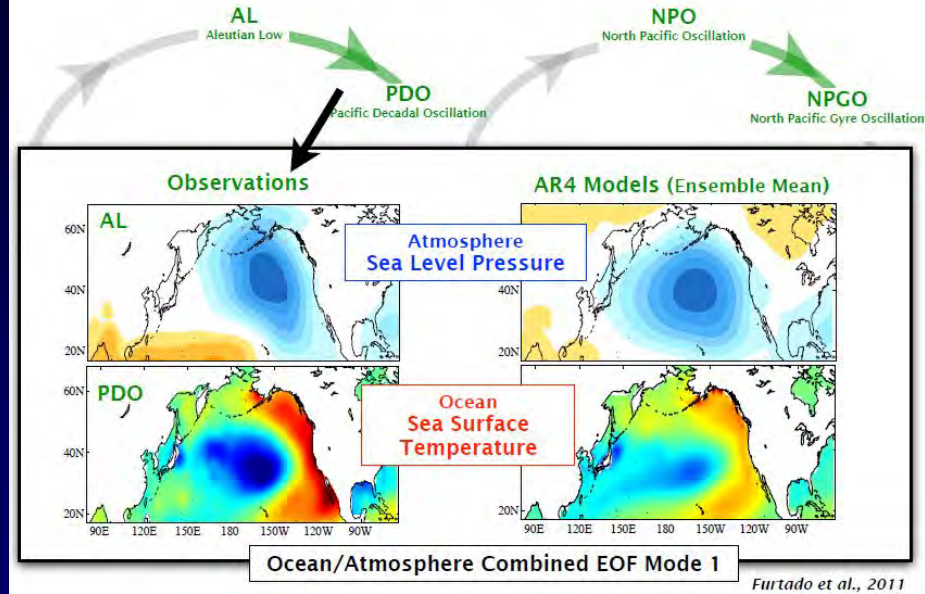
- Stronger, not more, Haida Eddies due to stronger winter winds

Foreman et al., Nanaimo 2013

Future ocean climate change using the RCM



Test the AR4 models Pacific decadal dynamics 1800-2000



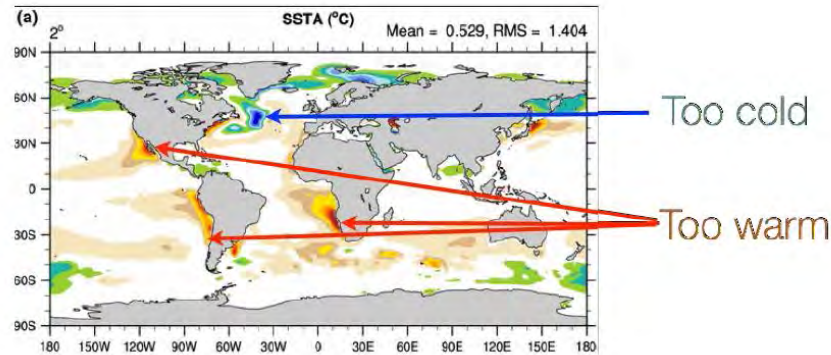
Ko, Jang et al., Nanaimo 2013

Di Lorenzo et al., Nanaimo 2013

RUTGERS

Multi-scale boundary currents

Motivation: Climate model biases in coastal regions

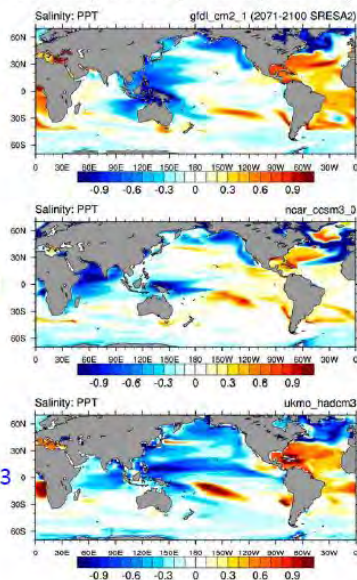


Curchitser et al., Yeosu 2014

Salinity changes

CM2.1

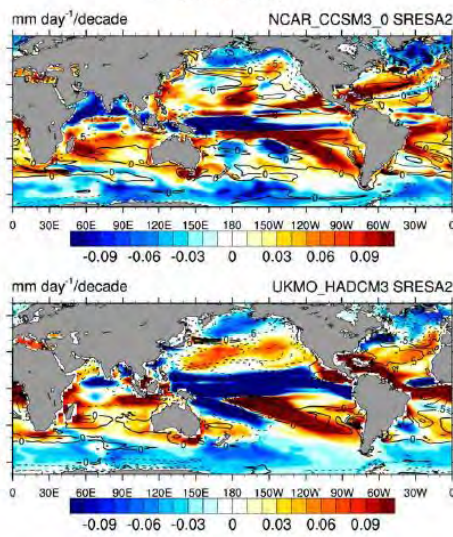
SRESA2(2050-2099) - 20C3M(1950-1999)



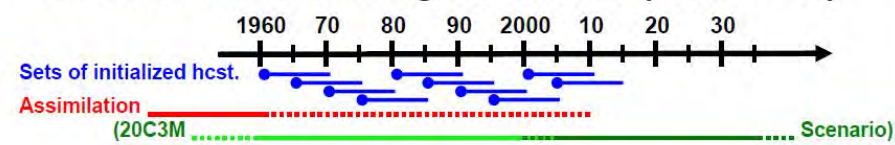
CCSM3

HadCM3

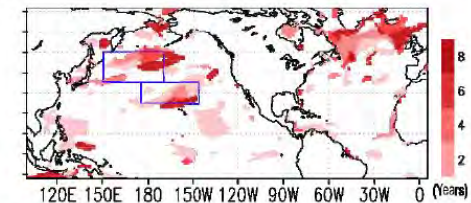
E-P (SSS contour)



Decadal Hincasts using old version (MIROC3m)

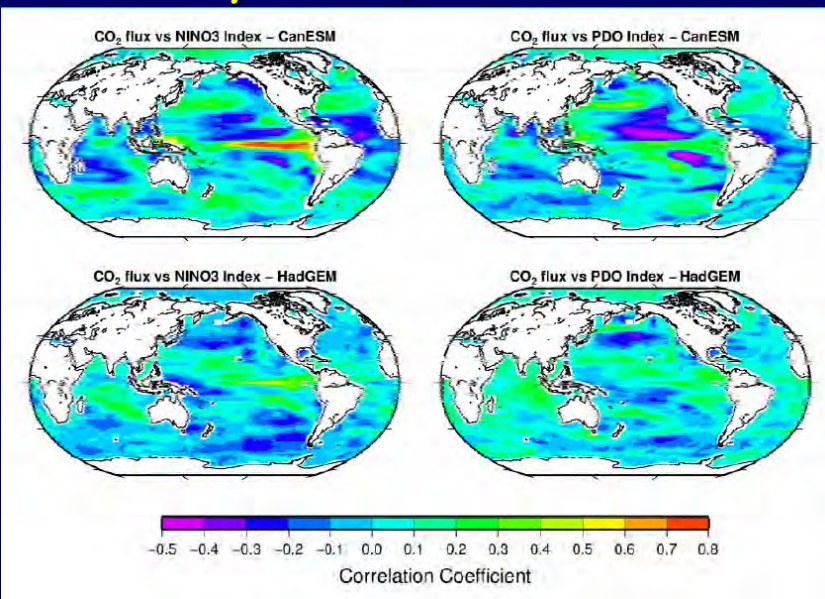


- 10 ensemble assimilation & sets of 10 ensemble decadal hindcasts
- Design of assimilation experiments
 - Objective analysis of T/S (Ishii et al. 2003, 2006, 2009)
 - Anomaly assimilation relative to averages during 1961-1990
 - Interpolated from monthly means
 - Upper 700m depth
 - Incremental Analysis Update
 - No assimilation for sea ice



Predictable regions for 5-yr mean VAT300 (vertically averaged ocean temperature upper 300m) at specific hindcast years. (Anomaly Correlation Coefficient > 90% significance levels)

Capotondi, Portland 2010

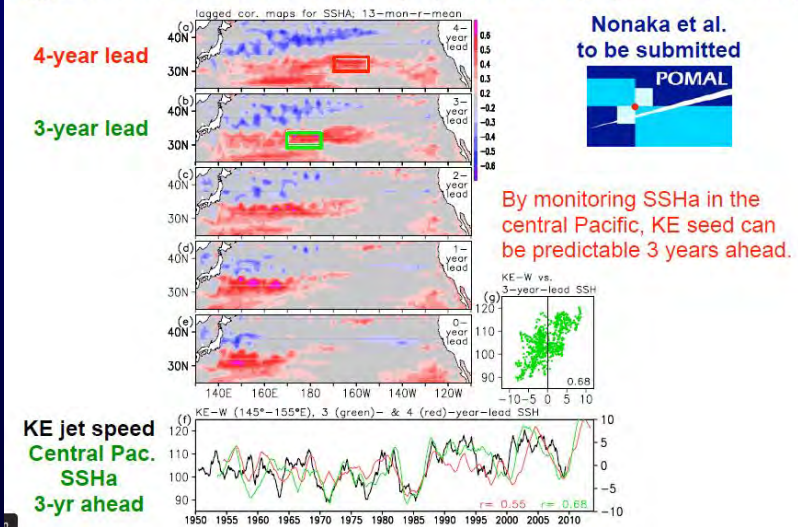


Christian, Khabarovsk 2011

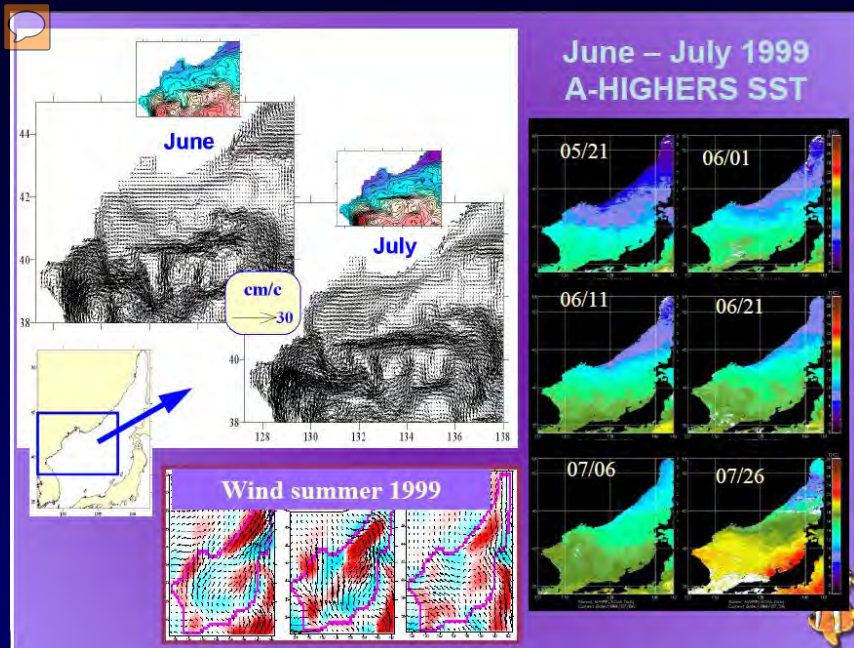
Mochizuki et al., Khabarovsk 2011

Potential predictability of the KE jet speed variability

Lagged correlation between anomalous KE jet speed and SSHa (60-year OFES hindcast)

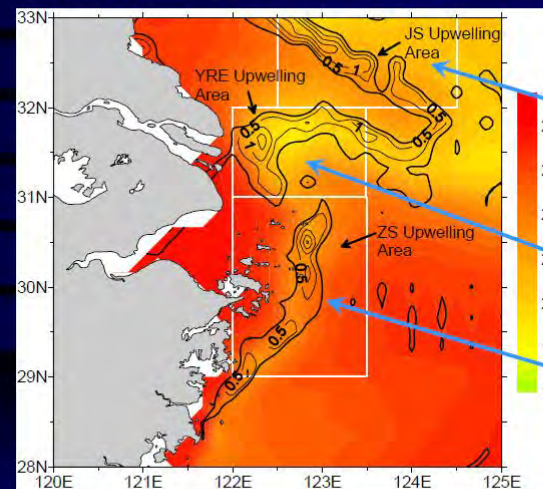


Taguchi et al., Khabarovsk 2011



Trusenkova et al., Vladivostok 2005

Results — Control Test



Verified by:

Zhao [1987]
(Observation in the
China-US joint
survey in July, 1984)

Zhao [1993]
(historical observations)

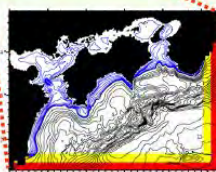
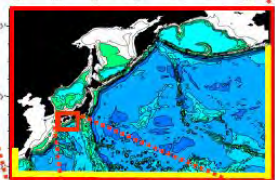
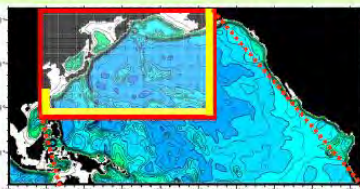
Satellite SST images

Upwelling patterns (10^{-5} m s^{-1}) superimposed
on the color image of temperature ($^{\circ}\text{C}$).

Qiao & Lv, Yokohama 2006

Dynamical downscaling system

ROMS
Regional
Ocean
Modeling
System



one-way
nesting system

1/2 degree
Basin-scale
($O(10^3)$ km)

1/10 degree
Mesoscale
($O(10^2)$ km)

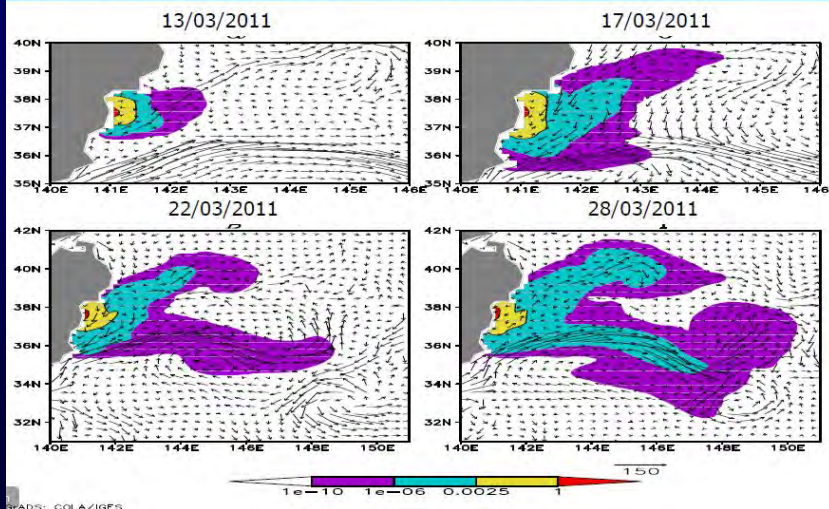
1/50 degree
Submesoscale
($O(10^1)$ km)

Forcings

1. Climatological monthly mean flux at the sea surface
2. Lateral boundary forcings based on daily mean output from each parent model

Kuroda et al., Portland 2010

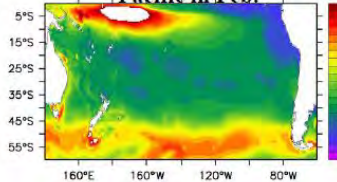
The concentration of PT (colored) vs surface currents (arrows) for March 13, 17, 22 and 28 of 2011. Red shows concentration greater than MPC (Maximum Permissible Concentration). So there is not any dangerous concentration of radioactive with exception of very small area near Fukushima-1.



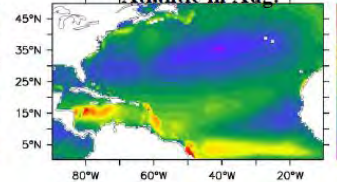
Diansky & Zalesny, Khabarovsk 2011

MLD in summer (Qiao et al, OD, 2010)

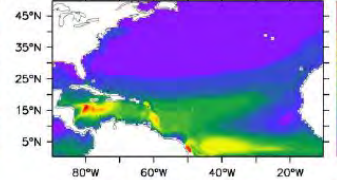
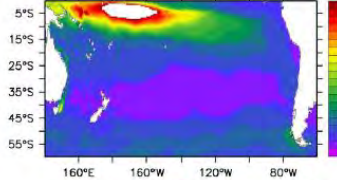
MLD of the Southern Pacific in Feb.



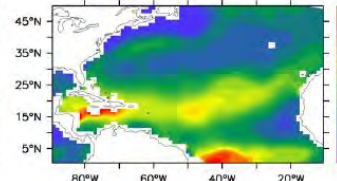
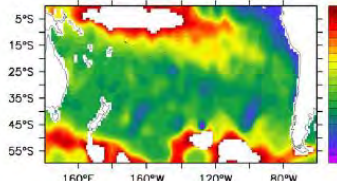
MLD of the Northern Atlantic in Aug.



With wave-induce mixing

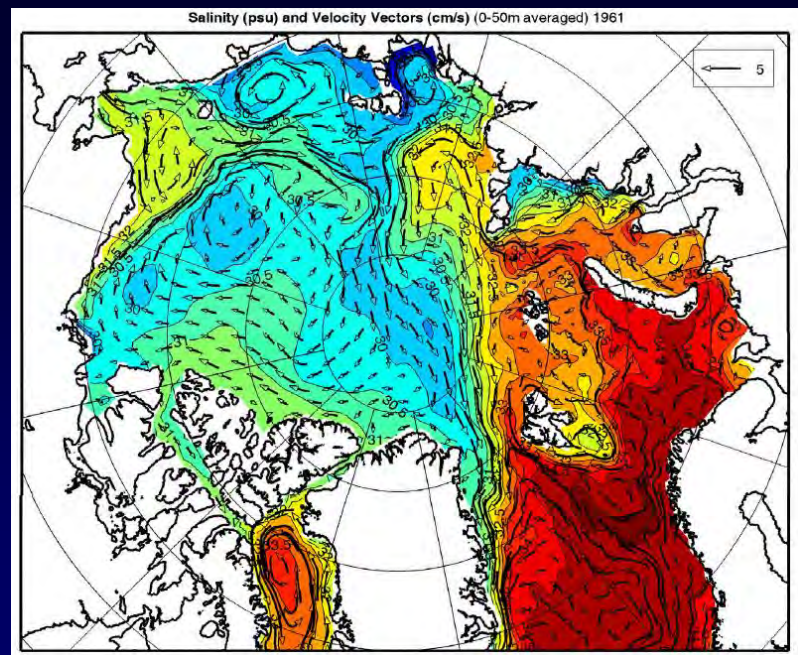


Without wave-induce mixing



World Ocean Atlas

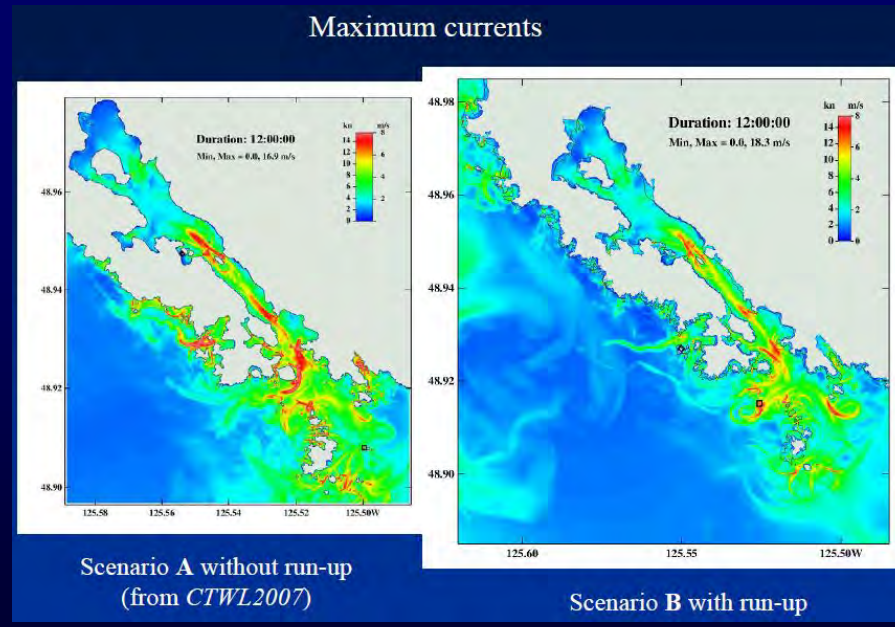
Qiao & Huang, Hiroshima 2012



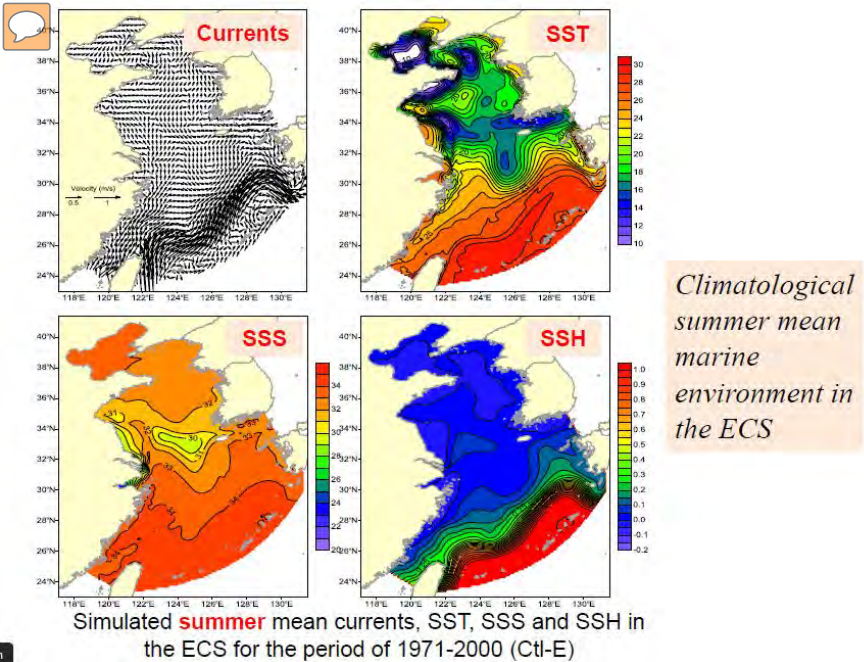
Kuzin, Hiroshima 2012



Li et al., Hiroshima 2012



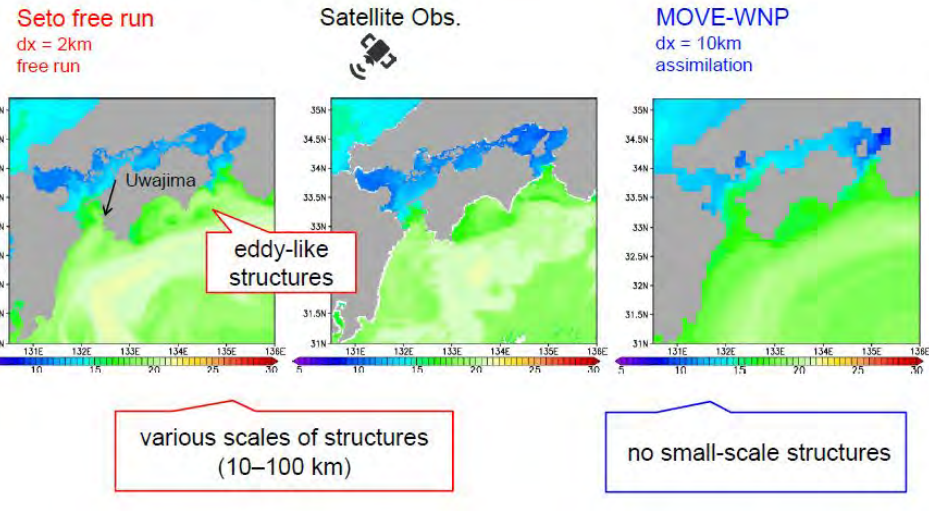
Cherniawsky et al., Hiroshima 2012



Cai & Zhang, Nanaimo 2013

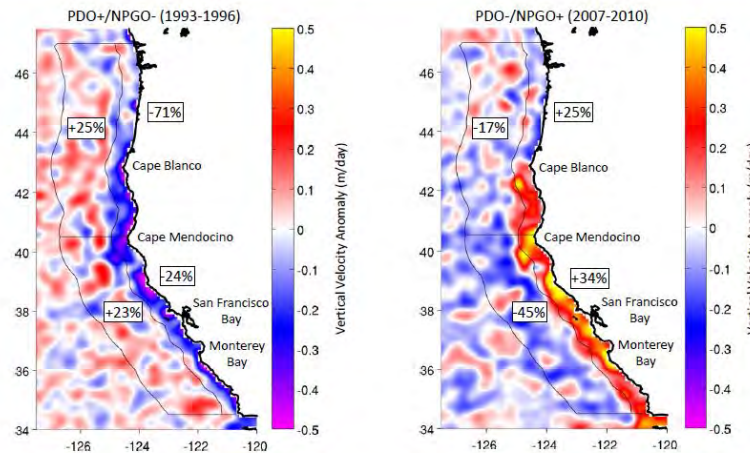
SST Snapshot

SST snapshot on Mar 1, 2011.



Sakamoto et al., Yeosu 2014

The Central/Northern CCS Response to PDO/NPGO



Jacox et al. (2014)

Jacox et al., Yeosu 2014

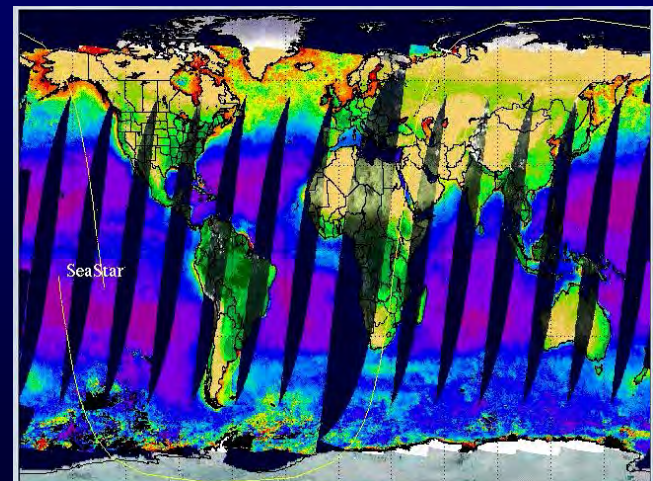
Satellite Observations

1. Topex/Poseidon/Jason altimetry

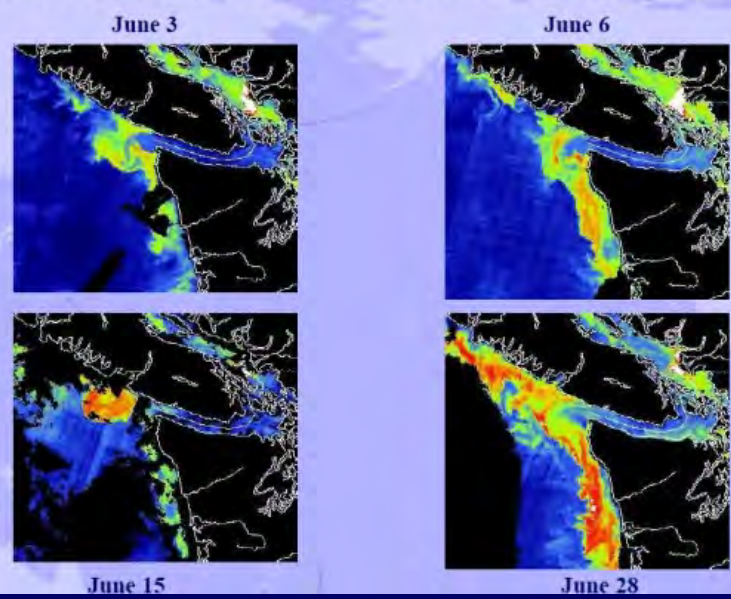
- Lifetimes:
 - TP1: 1992-2006
 - Jason 1: 2001- 2013
 - Jason2: 2008 -
 - Jason3: 2016 -
- <http://sealevel.jpl.nasa.gov/missions/topex/>
- Measure sea level to within few cm
 - Sea level rise
 - Tides, eddies, El Niño, PDO, ...
 - Assimilation into models

2. MERIS, Modis, AVHRR, SeaWiFS, Landsat

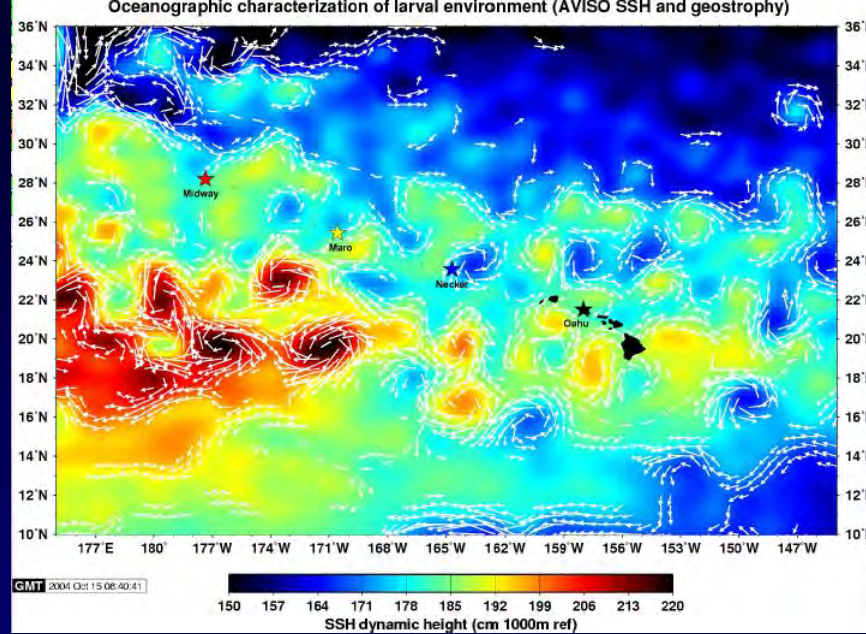
- SST, chlorophyll, winds



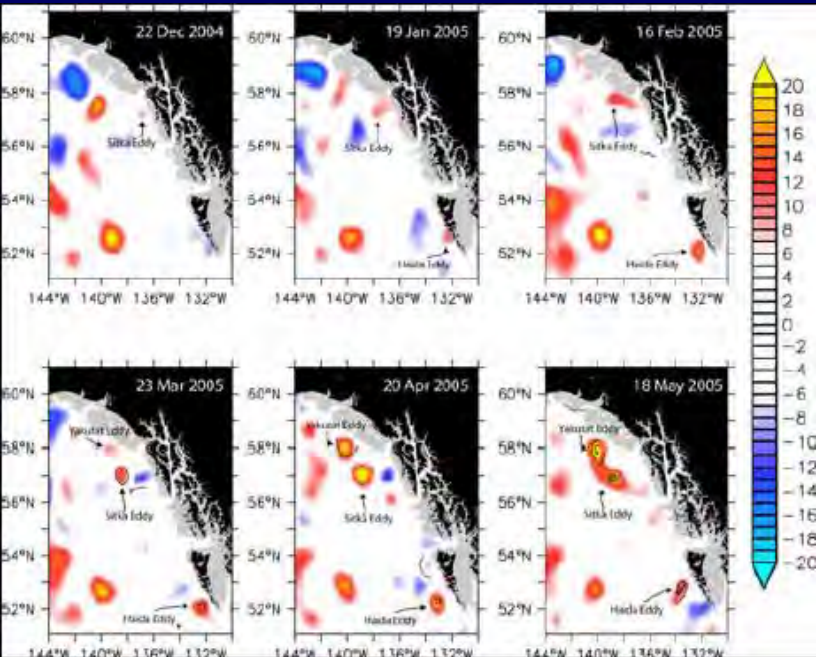
Fluorescence (chlorophyll) from MERIS Satellite



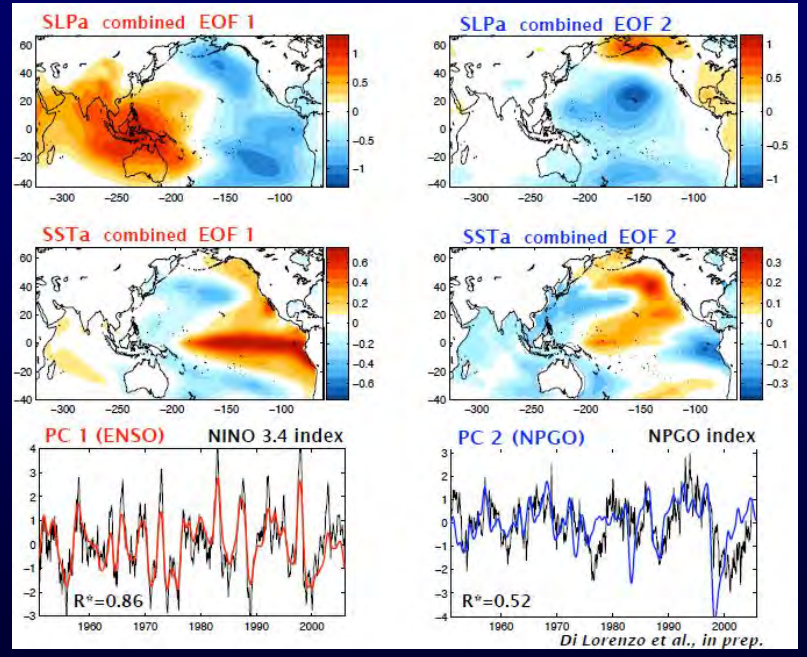
Foreman et al., Seoul 2003



Kobayashi, Honolulu 2004

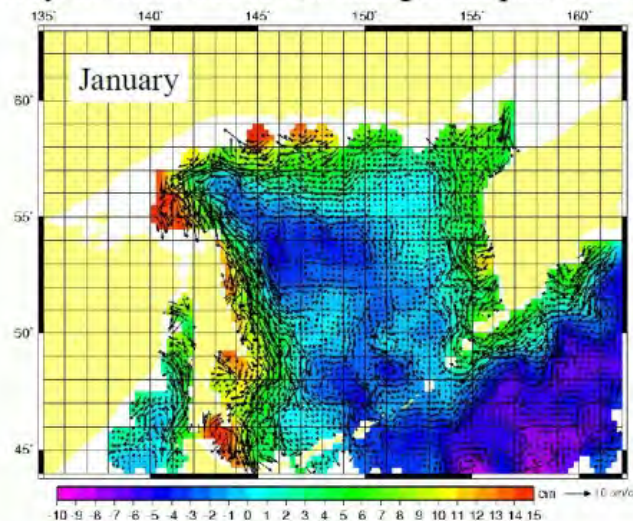


Ladd et al., Victoria 2007



Di Lorenzo et al. Dalian 2008

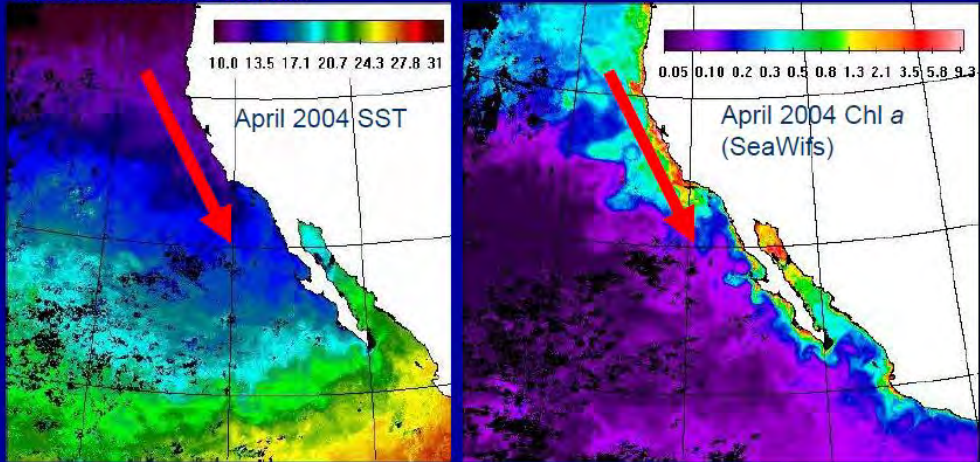
Multiyear mean sea levels and geostrophic currents



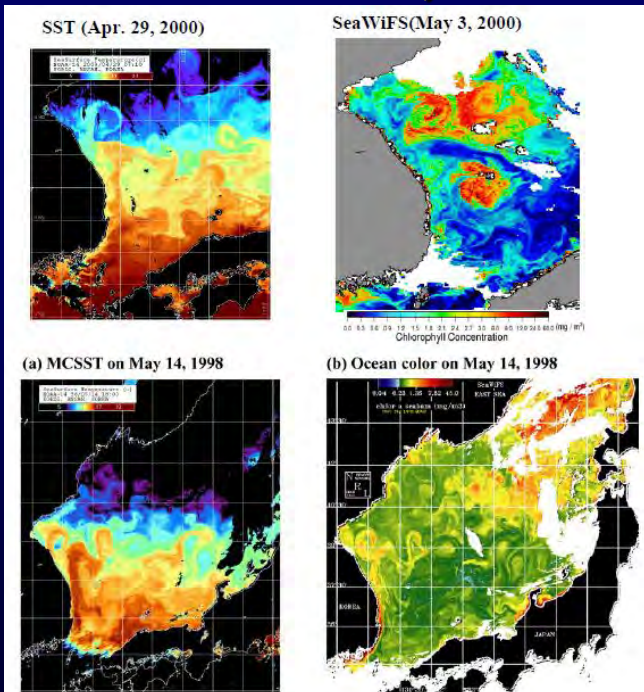
Shevchenko & Romanov, Honolulu 2004

Production in the California Current Ecosystem

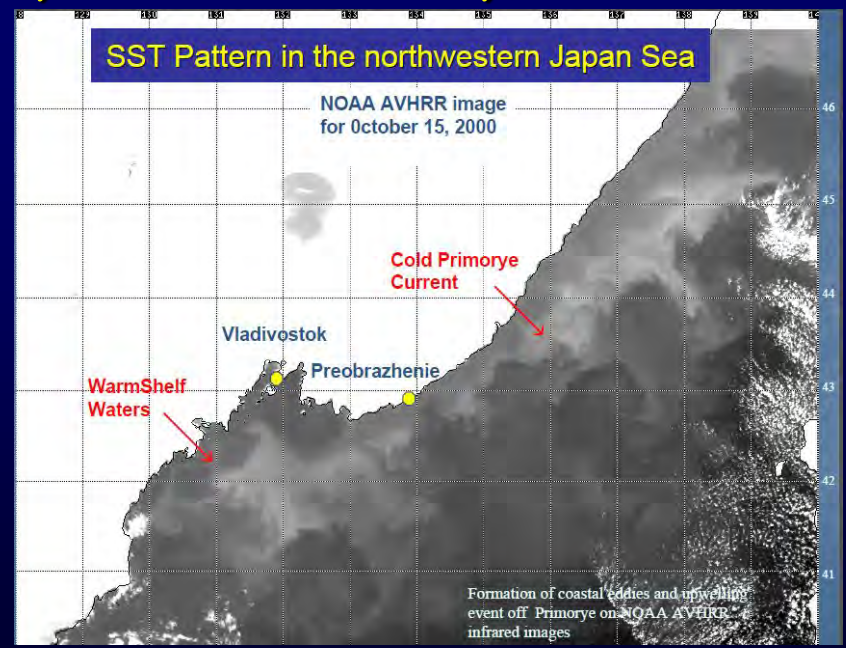
Alongshore, equatorward winds force cold, high-nutrient waters to the surface.



Rykaczewski & Checkley, Yokohama 2006

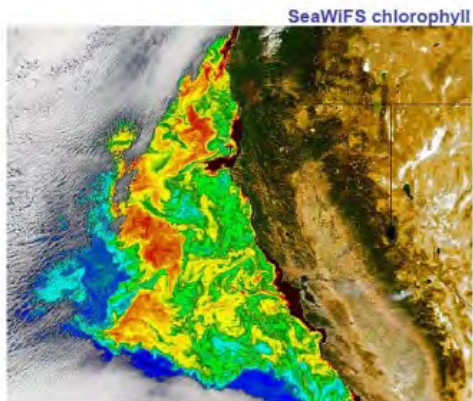


Kim et al., Dalian 2008



Lobanov et al., Dalian 2008

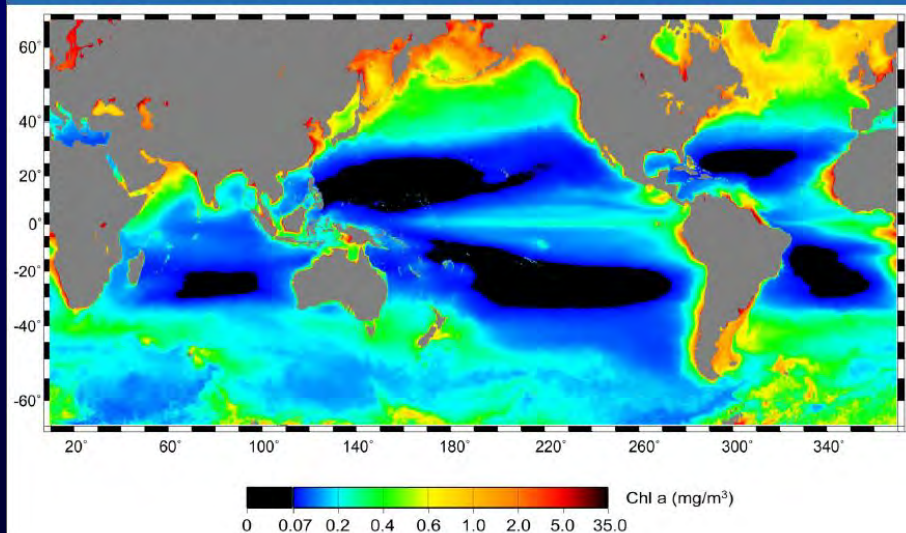
California Current Large Marine Ecosystem



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

Bograd et al., Dalian 2008

SeaWiFS surface chlorophyll climatology with oligotrophic gyres in black



Polovina et al., Jeju 2009

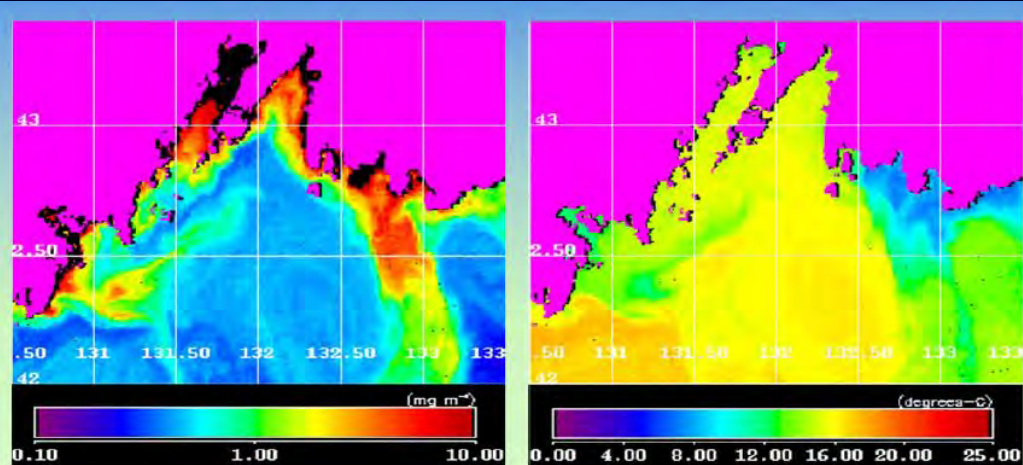
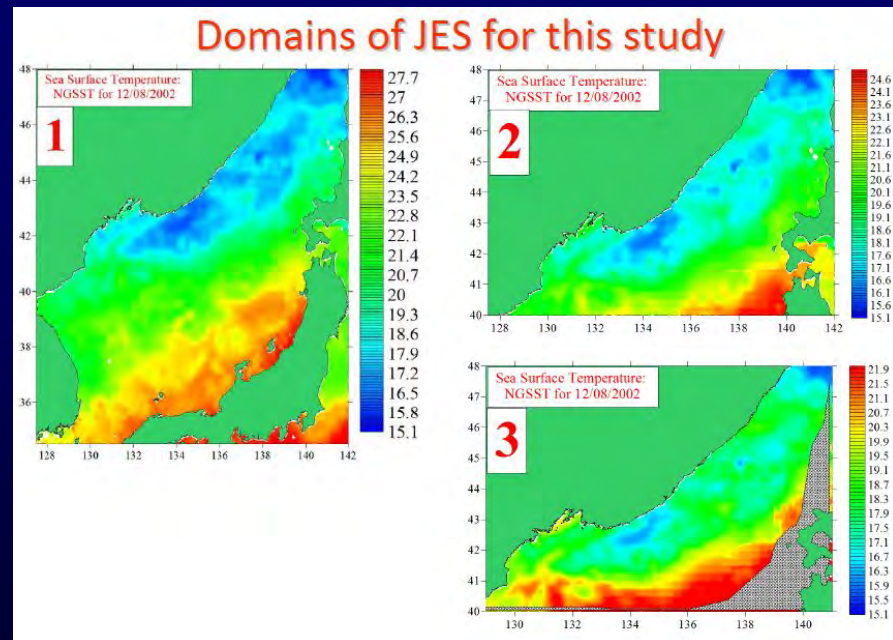


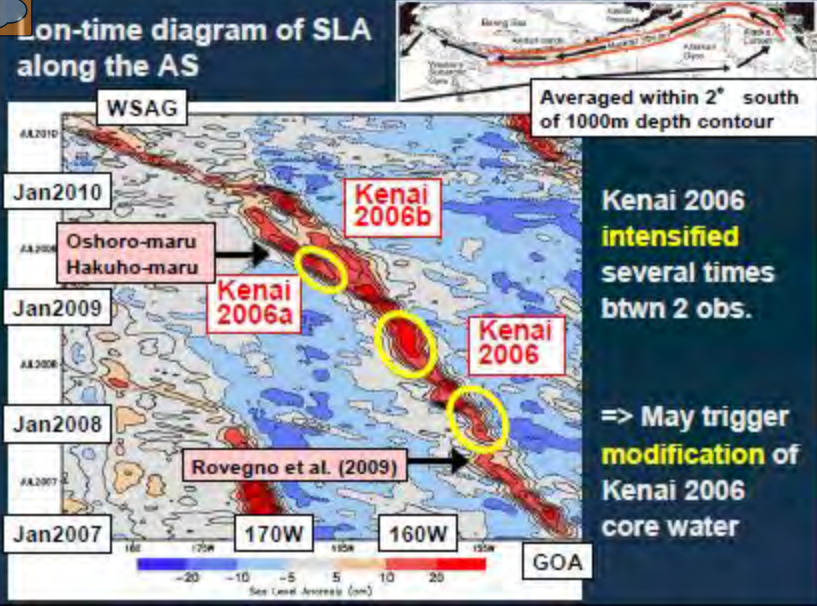
Figure 11. Chlorophyll-a and SST distribution in Peter the Great Bay at the wind upwelling on November 13, 2007.

Schtraikhert et al., Dalian 2008

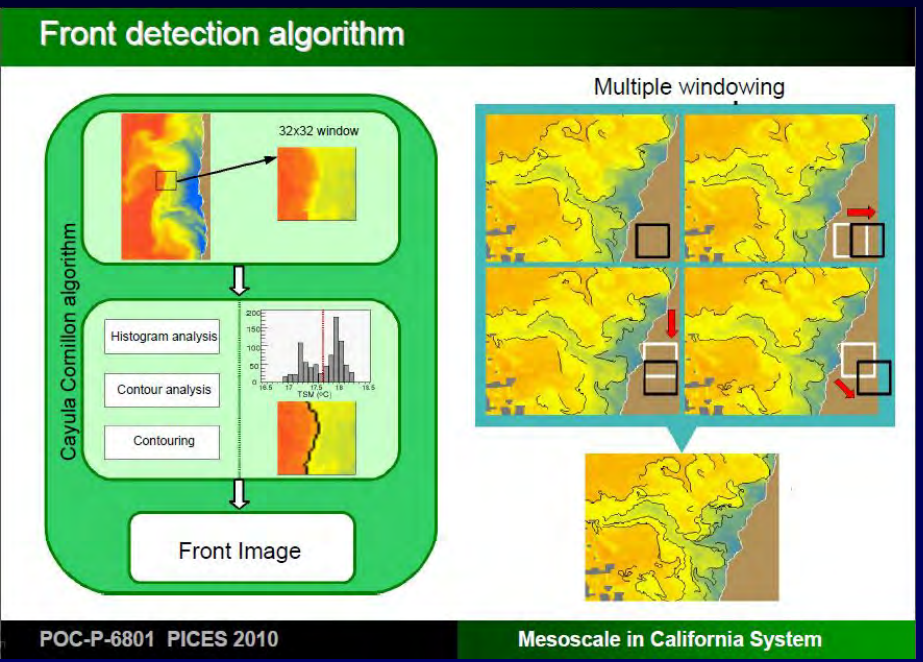
Domains of JES for this study



Kaplunenko et al., Jeju 2009

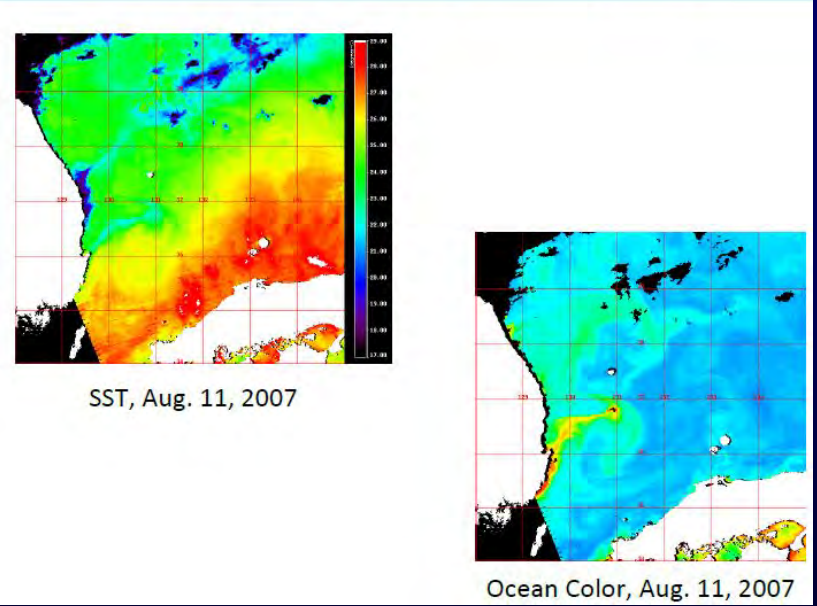


Ueno et al., Portland 2010



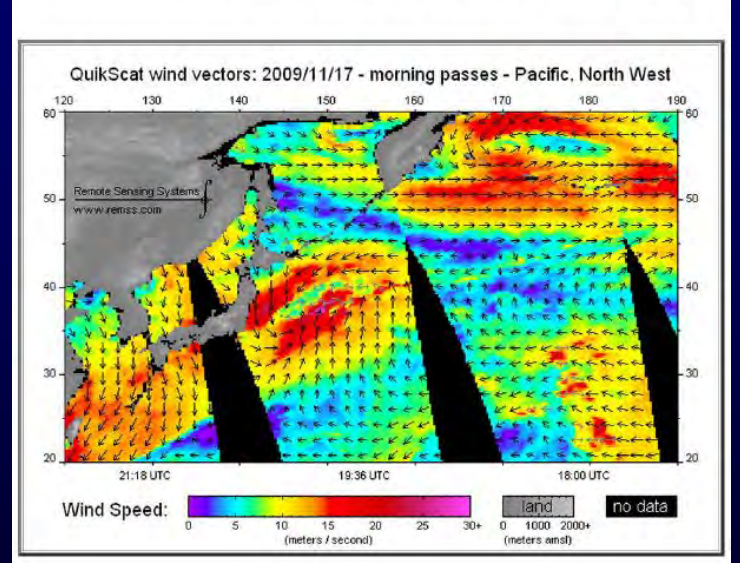
Nieto et al., Portland 2010

Coastal Upwelling in Summer 2007

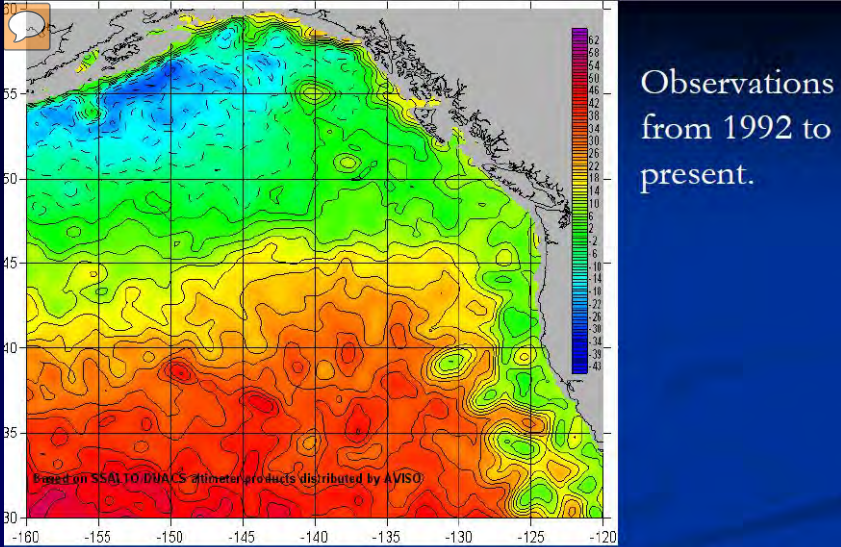


Park et al., Portland 2010

Sea winds from QuikSCAT

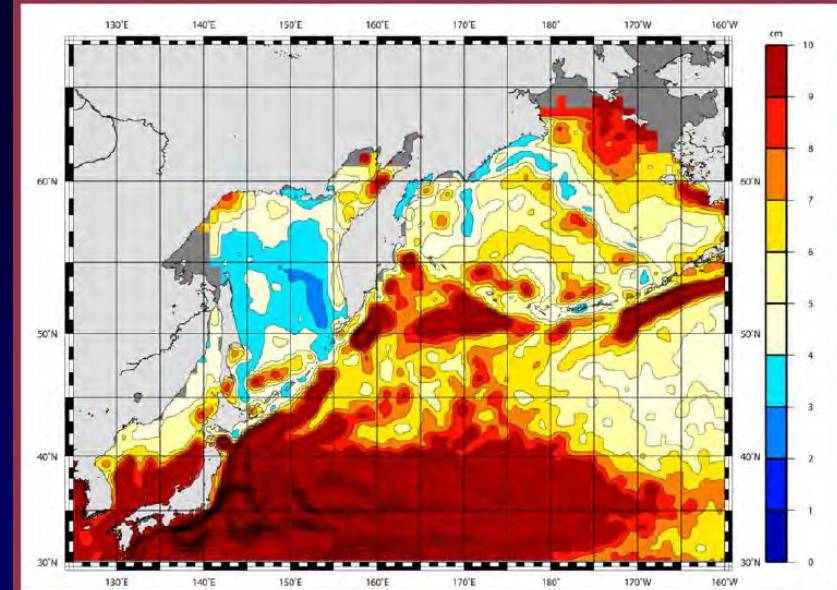


Trusenkova, Portland 2010



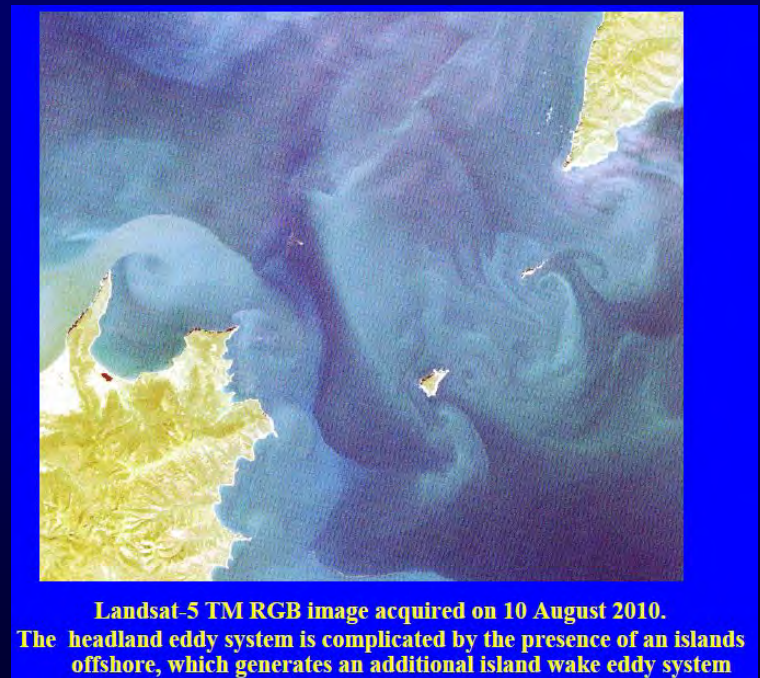
Sea level from AVISO, based on TOPEX/Poseidon, Jason-1, 2, ERS-1, 2, Envisat, GFO. Referenced to Foreman et al. (2008) average sea level.

Crawford, Portland 2010



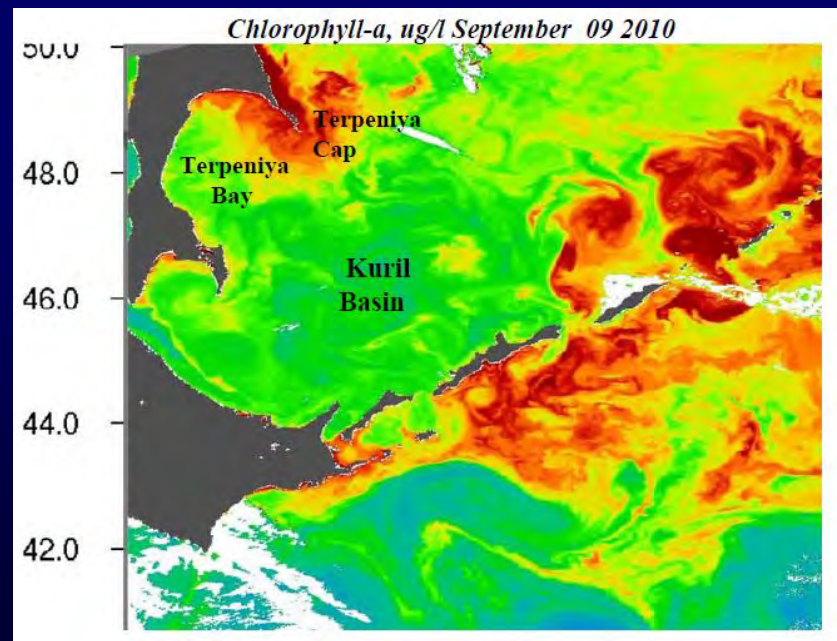
The root-mean-square deviation from the mean multiyear values of absolute dynamical sea-surface topography

Belonenko, Khabarovsk 2011



Landsat-5 TM RGB image acquired on 10 August 2010. The headland eddy system is complicated by the presence of an islands offshore, which generates an additional island wake eddy system

Zhabin, Khabarovsk 2011

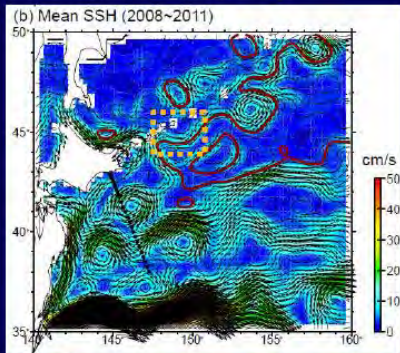
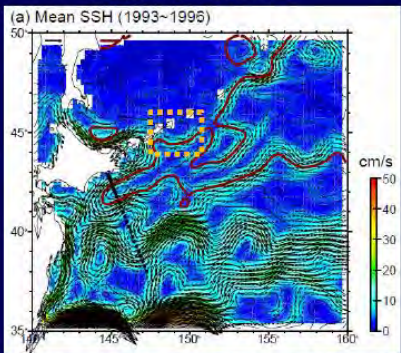


Andreev & Zhabin, Hiroshima 2012



4-year mean (1993-1996)
absolute geostrophic velocity
at the sea surface

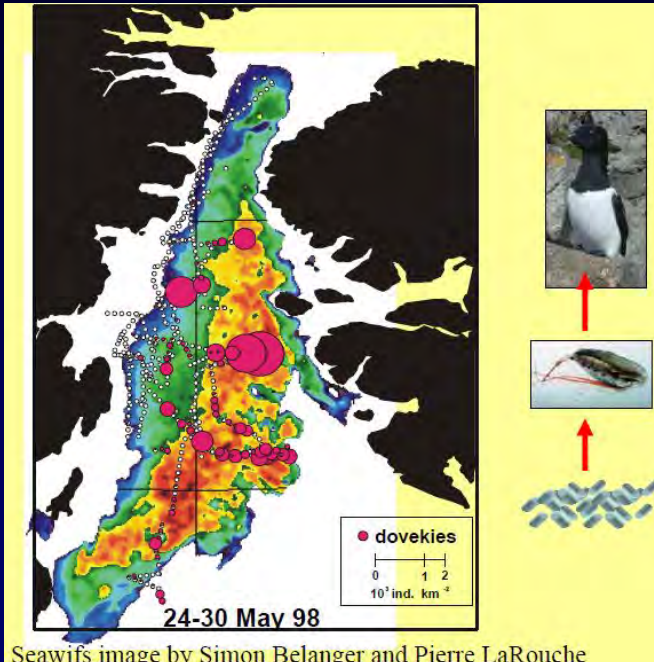
4-year mean (2008-2011)
absolute geostrophic velocity
at the sea surface



Estimation from AVISO MADT (Map of Absolute Dynamic Topography)

Thick red line corresponds to the Oyashio main stream position
: an isoline of 4-year mean absolute dynamic topography
which is averaged along the Oyashio stream within the orange box

Kuroda et al., Nanaimo 2013



Seawifs image by Simon Belanger and Pierre LaRouche

Hunt, Khabarovsk 2011

Predator Aggregations



Photo: Mike Brittain

Shearwaters feeding with ~ 100 humpback whales.

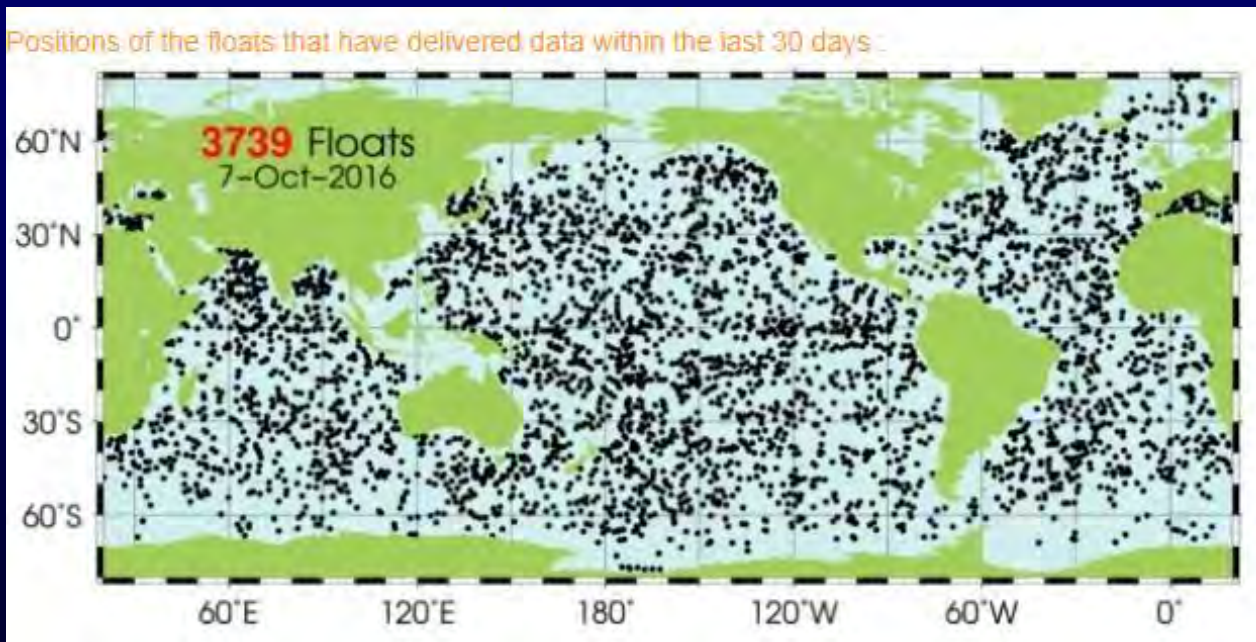
Hunt, Khabarovsk 2011

Autonomous Floats

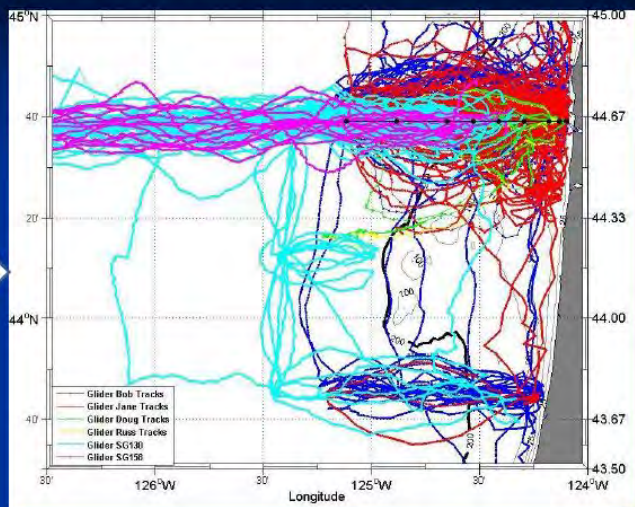
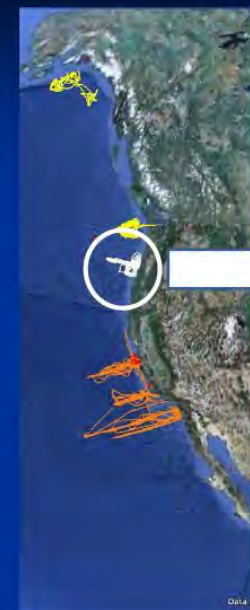
1. Gliders

2. Argo floats

- *First deployed in 2000*
- *Millionth profile by Nov 2007*
- *Now over 3700 floats*
- *<http://www.argo.ucsd.edu/>*

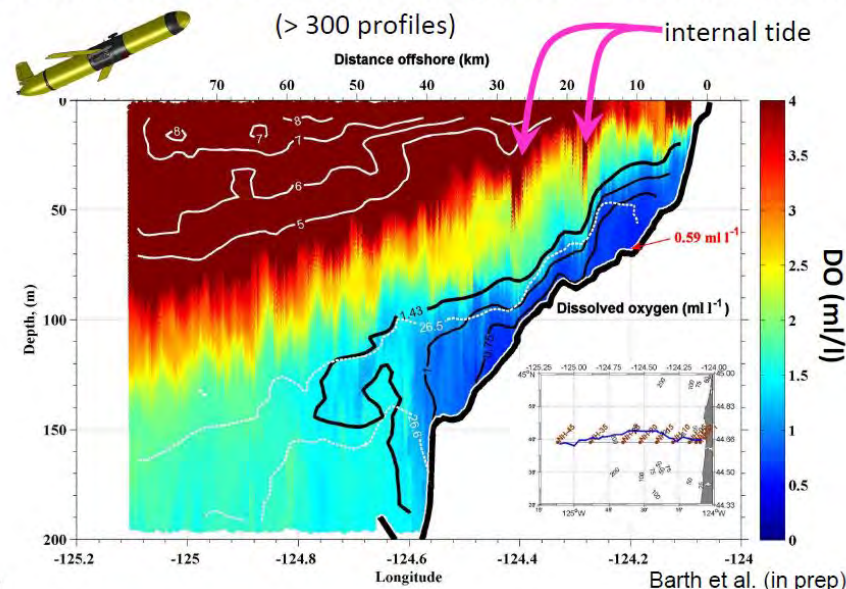


U.S. west coast glider measurements



Oregon State University April 2006–Sep 2014
 3485 glider-days 260,190 vertical profiles
 82,000+ km

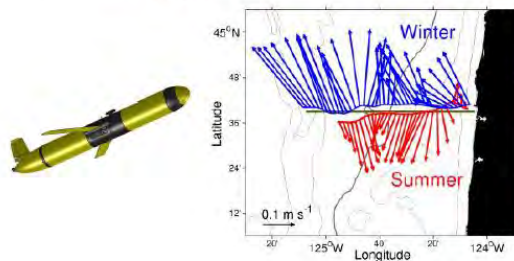
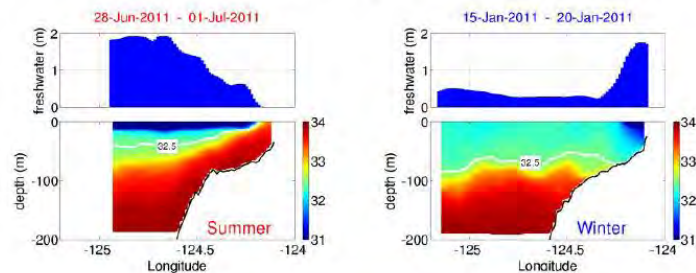
Glider section of Dissolved Oxygen off Oregon in summer



Barth et al., Yeosu 2014

*S12, Nov 10, 15:00:
 "The subsurface and inner-shelf structure of 25 years of variability in the Northern California Current"*

Example glider lines: summer vs. winter



Analyze 67 fall/winter glider sections →

The Argo Project

New observations of the physical state of the ocean and their potential application to climate including fisheries and ecosystems impacts

John Gould,
Argo Project Director

Dean Roemmich
Argo Steering Team Chair

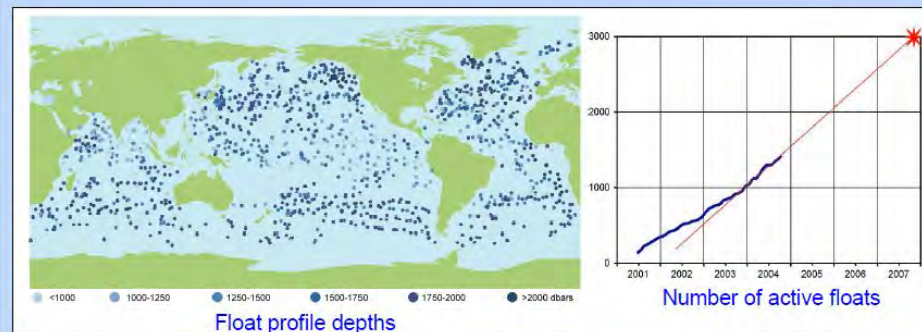
Scripps Institution of Oceanography
La Jolla , USA



Profiling the global ocean

The array

- Presently almost 1500 floats
- Sparse array in four oceans



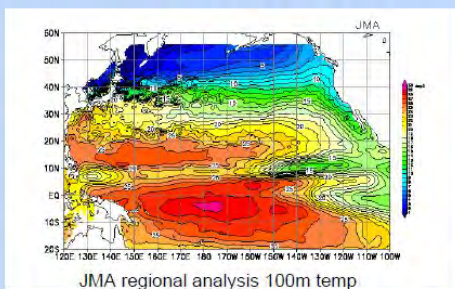
- Array growth depends on
 - Number of floats deployed
 - Their survival rate
- Data are unique
 - Quasi random spatial
 - No seasonal bias
 - Deeper than XBTs
 - + salinity



Profiling the global ocean

Argo data use

- Many operational centres now produce products and forecasts based on Argo data.
- ENSO analysis and forecasts (Argo expands the area covered by the ENSO observing system)



Profiles 29 Sept - 8 Oct 2004 From :
• Argo • XBT • TAO array



Profiling the global ocean

Argo ecosystem applications

- Argo can help define the physical conditions of the open ocean (Temperature/salinity/velocity)
- The Argo array is sparse so it needs to be combined with other data to resolve frontal and mesoscale features) (e.g altimetry, infrared imagery, ocean color)
- Argo cannot provide data from continental shelves (Models are needed to link open ocean to shelf. Gliders may help with observations)

The future

- Routine products based on Argo data
- Learn how to use these novel data
- New sensors - Now dissolved oxygen, shear, microstructure
- In future nutrients, fluorometers, rain and wind, + +

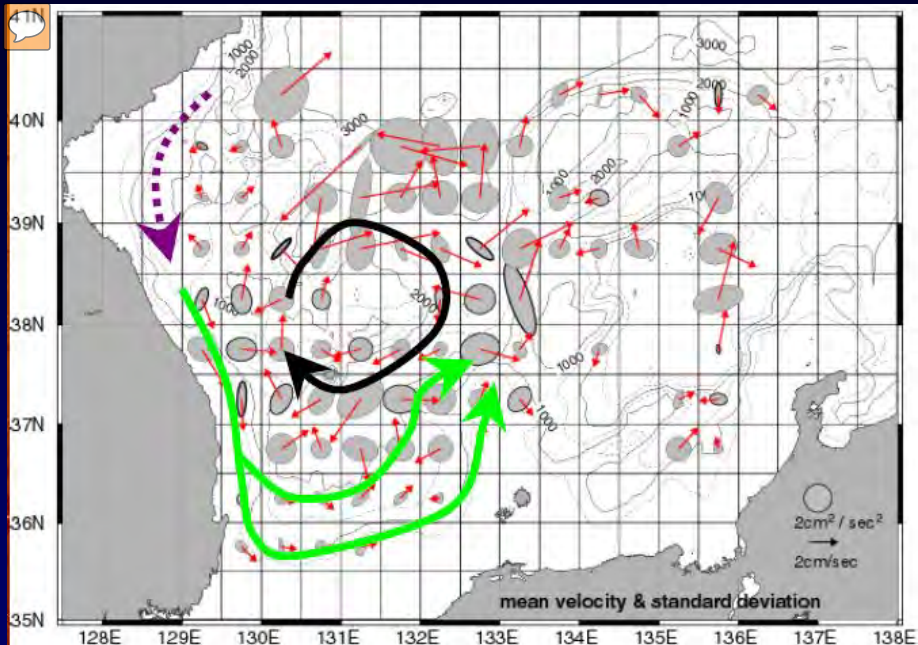
Develop new technologies in parallel with Argo

- Better communication (cleaner data, more points per profile)
- Argo still needs ship-based CTD data to update climatologies
- How to sustain Argo in the long term?
Operational - but still needs strong research involvement - partnership.

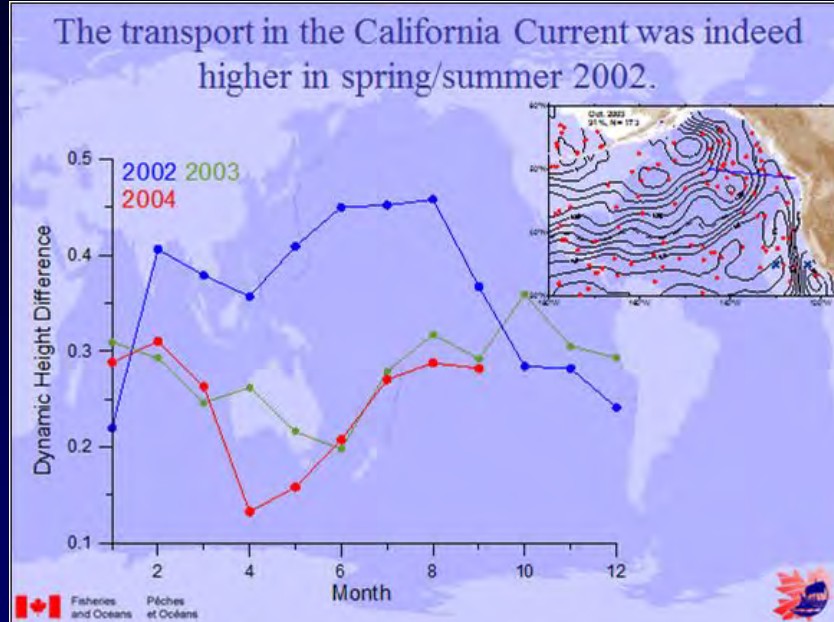


Profiling the global ocean

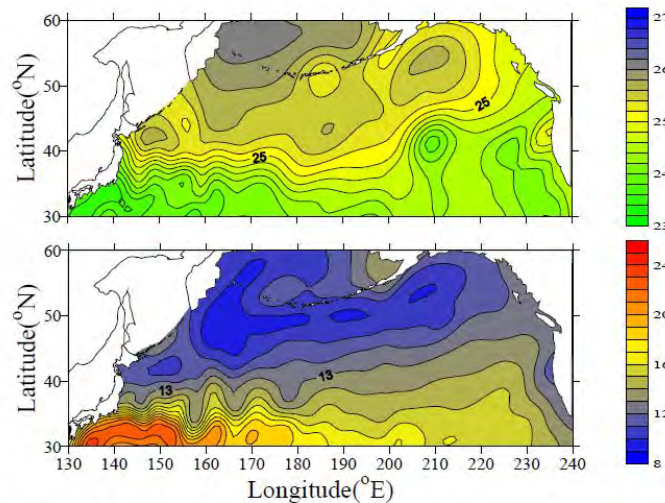
Honolulu 2004



Park et al., Seoul 2003



Freeland & Cummins, Honolulu 2004

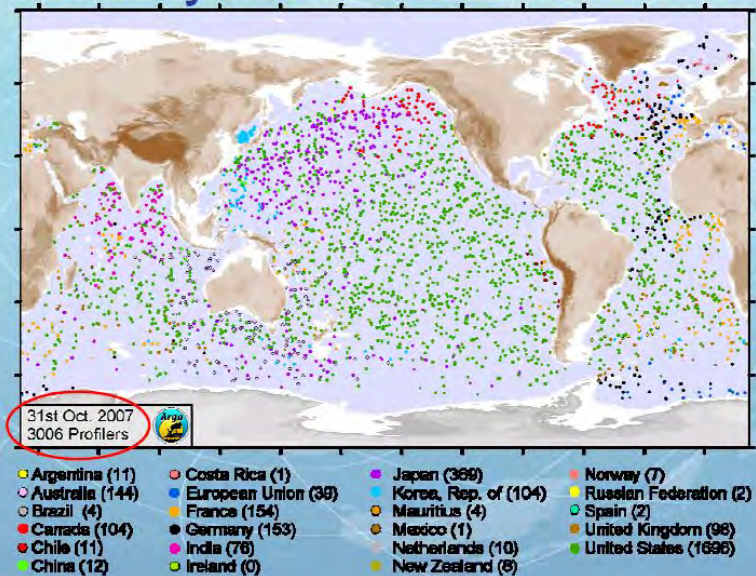


e.g (top) potential density and (bottom)geopotential anomaly(m^2/s^2) on 20db in Nov-Dec 200

The data($1^\circ \times 1^\circ$) of every 20db was made between 20db and 1000db.

Sato & Kono, Yokohama 2006

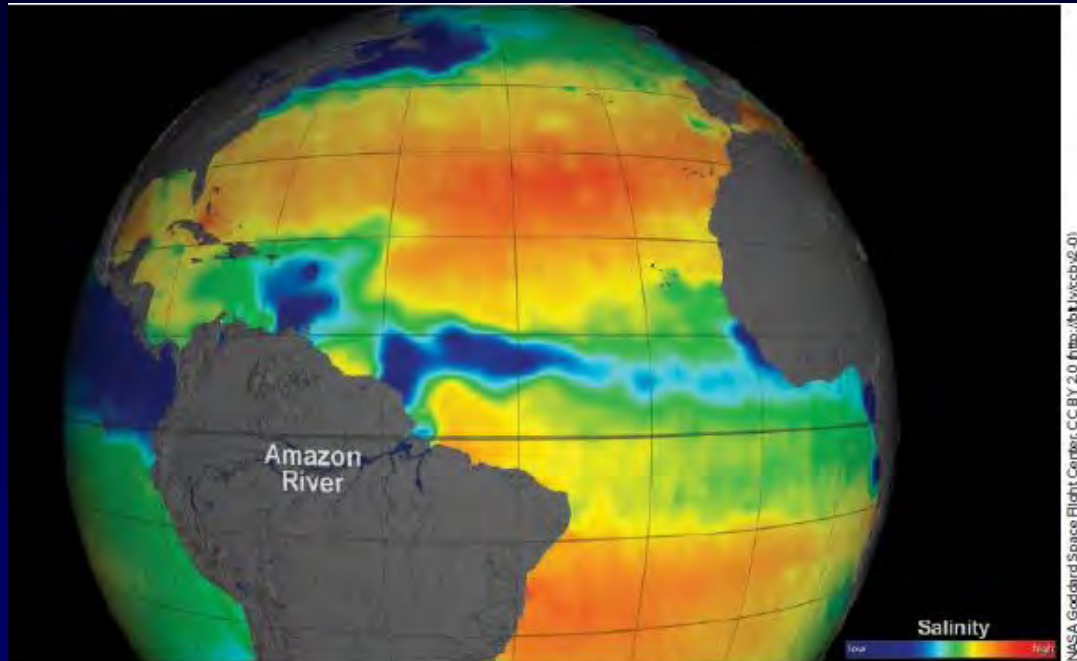
Nobody has seen this before



Freeland et al., Victoria 2007

What Lies Ahead

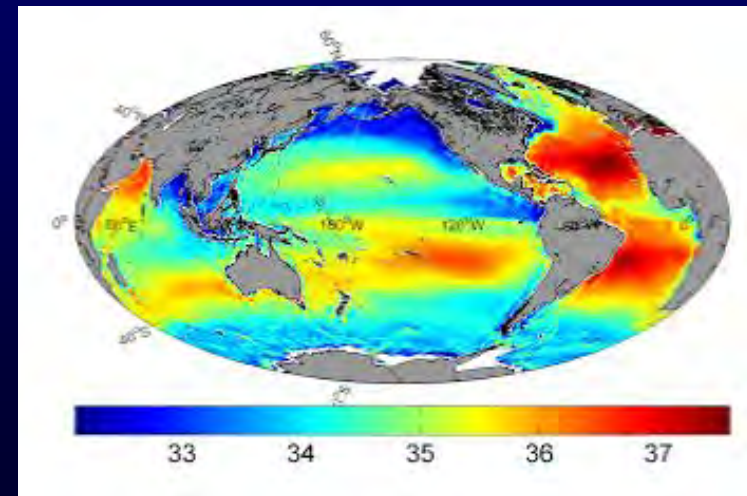
1. Sea Surface Salinity Observations



Data from NASA's Aquarius instrument reveal seasonal changes in the Amazon River's plume. (This map shows conditions on 27 February 2013. Red indicates high salinity, and blue indicates low salinity.) Depending on the prevailing currents, the river's freshwater outflow heads east toward Africa or bends north toward the Caribbean. Salinity variations are one of the main drivers of ocean circulation.

NASA/Goddard Space Flight Center, CC BY 2.0 (<http://bit.ly/cby2-0>)

- *NASA Aquarius image, Stammer, EOS, June 15, 2016*
 - *ceased operation June 2015*
 - *<http://aquarius.nasa.gov>*
- *But European Space Agency's Soil Moisture and Ocean Salinity (SMOS) spacecraft continues*
 - *<http://bit.ly/SMOS-spacecraft>*



2. SWOT Altimetry



- *Surface Water and Ocean Topography mission (NASA/CNES/CSA)*
- *Planned launch in 2020*
- *10 times resolution of present technology*
 - *120km swath*
 - *Resolve 100m rivers & 1km² lakes*
 - *Coverage twice every 21 days*
- *<https://swot.jpl.nasa.gov/mission/> & <http://ctoh.legos.obs-mip.fr/products/altimetry/future-missions/swot>*

3. Continuing Bigger & Faster Computers



- *New architectures for computing & storage*
- *Models will continue to*
 - refine their spatial resolution*
 - simulate for longer time periods*
 - Compute ensembles over larger sets*
 - Increase their complexity in terms of*
 - incorporating more biogeochemistry + physics + human factors (e.g., end-to-end)*
 - including more subgrid-scale processes*

Summary

1. *POC research has benefited from many technological advances over the past 25 years*

2. *Focused on those arising from*

a) *Bigger & faster computers (better models)*

b) *Satellites (SST, Chlorophyll, SSH)*

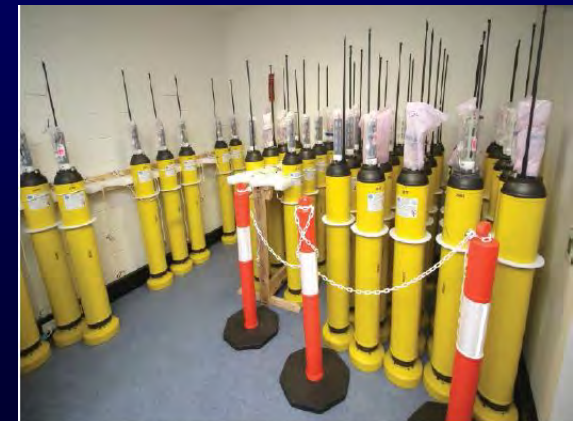
c) *Autonomous platforms (Argo floats, gliders)*

But of course, there are others

3. *Examples from past POC-Paper & POC co-sponsored presentations*

4. *Some thoughts on what lies ahead*

The next 25 years will be interesting!



Acknowledgements

- 1. PICES Secretariat (Julia) for archiving presentations from previous annual meetings*
- 2. All presenters who allowed their talks to be posted for me to use*
 - Hopefully I didn't misrepresent your work!*
- 3. And to everyone who has contributed to POC over these 25 years.*



Thanks for your attention!