International Group for Marine Ecological Time Series

Assessing global oceanic changes through joint time series analysis

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1) BACKGROUND

Marine ecological & biogeochemical time series are a vital source of information about the functioning of the ocean.

Sustained ship-based observations allow us to:

- observe processes such as ocean warming, circulation, eutrophication and deoxygenation.
- understand key ecological processes and how the marine environment is being affected by climate change.
- differentiate between natural & anthropogenic changes in marine ecosystems.

However, significant advances in regional and global ocean ecosystem science can be gained by combining data from individual time series.

2) IGMETS

The International Group for Marine Ecological Time Series was established by the UNESCO Intergovernmental Oceanographic Commission (IOC) to build on previous initiatives (**Fig. 1**).

By integrating and broadening the utilization of existing time series data, IGMETS aims to:

- help promote cost-efficiency for new and established sampling programs.
- increase awareness of these programs and the importance of maintaining them.
- create a platform for modeling studies by analyzing time series data at the global level.
- provide a strong basis for future predictions to support sound policy decisions and advice.

3) GLOBAL ANALYSIS

IGMETS goals include the creation of a Report based on Joint Time Series Analysis to identify and interpret temporal and spatial patterns of key ocean parameters on a global scale.

The Report will contain chapters on the Arctic, Atlantic, Pacific, Indian, and Southern Oceans, with separate sub-chapters for the North and South Atlantic and Pacific, as well as a unifying Global chapter.

The North Pacific consists of a large central Oceanic Region surrounded by a number of Boundary Currents and Marginal Seas *[1]*. It also includes the North Pacific Subarctic Gyre, the largest ecosystem on Earth *[2]*.

Figure 1. Previous and ongoing activities within the scientific community that led to IGMETS.

4) PICES and DFO

Engaging organizations that support regional ocean time series is central to IGMETS' mission.

PICES has made enormous contributions to our understanding of the North Pacific through its programs, publications and working groups.

Canada and its federal Department of Fisheries and Ocean (DFO) have also contributed through membership of PICES and its working groups, and by maintaining time series such as Line P.

The PICES Technical Committee on Monitoring (MONITOR), chaired by Jennifer Boldt (DFO), has played an important role in identifying North Pacific time series and key contacts (see Sec.6).

PICES Special Publications *[1]* and DFO State of the Ocean Reports *[3]* also help with the interpretation of North Pacific time series data.

5) METHODOLOGY

With the help of contributing organizations from around the world, IGMETS has compiled data from ~300 ship-based marine ecological time series, along with ~100 estuarine sites (**Fig. 2**).

Building on concepts developed during more than 15 years of time series work (**Fig. 1**) the IGMETS global assessment uses an expanded set of the variables originally applied by ICES working groups to the North Atlantic.

In situ biogeochemical measurements and plankton data are combined with satellite observations of sea surface temperature and chlorophyll, which provide a broader regional and global context and add layers of information about changing conditions and ecosystems.

Looking at the magnitude, rate and direction of changes occurring within different regions and time windows (from 5 to 30 years) helps us to:

- see where change is happening most rapidly.
- explore connections between variables and ocean basins, and with long-term natural and anthropogenic climate drivers.
- resolve variability from long term change.

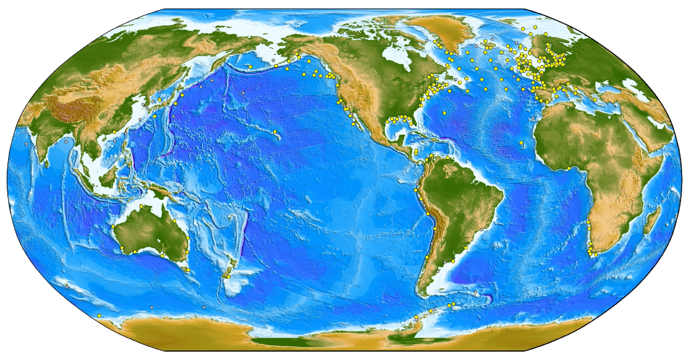
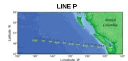


Figure 2. Map showing Time Series sites involved in the IGMETS assessment.

6) NORTH PACIFIC TIME SERIES

LINE P



Line P and OWS Papa; Canada – ca-50901
Northern Vancouver Island; Canada – ca-50301
Southern Vancouver Island; Canada – ca-50302
IMECOCAL – Northern Baja; Mexico – mx-30101
IMECOCAL – Southern Baja; Mexico – mx-30102
Pacific CPR – Southern Bering Sea; multiple countries – uk-40201-001
Pacific CPR – Aleutian Shelf; multiple countries – uk-40201-002
Pacific CPR – Western Gulf of Alaska; multiple countries – uk-40201-003
Pacific CPR – Alaskan Shelf; multiple countries – uk-40201-004
Pacific CPR – Cook Inlet; multiple countries – uk-40201-005
Pacific CPR – Northern Gulf of Alaska; multiple countries – uk-40201-006
Pacific CPR – Offshore BS; multiple countries – uk-40201-007
Pacific CPR – BC Shelf; multiple countries – uk-40201-008
CALCOFI California Current region; United States of America – ua-50301
CALCOFI Southern California Current region; United States of America – us-50302
Hawaii Ocean Time-series (HOT); United States of America – us-10201
Newport Line NH-5; United States of America – us-50501
San Francisco Bay; United States of America – us-30401
US WIES San Pedro Ocean Time-series (SPOT); United States of America – us-10301
Western Kodiak Island (western Gulf of Alaska) – EcoFOCI; United States of America – us-50401
Pearl River (Hong Kong); Hong Kong, China – hk-30101
Hokkaido University Fisheries and Oceanography database (HUFO) – Bering Sea surveys; Japan – jp-30201
Hokkaido University Fisheries and Oceanography database (HUFO) – central North Pacific surveys; Japan – jp-30201
Japanese Meteorological Agency oceanographic monitoring – East China Sea; Japan – jp-30401
Kuroshio Current; Japan – jp-30101
Oyashio Current; Japan – jp-30102
Oyashio-Kuroshio Extension; Japan – jp-30103
PM Line; Japan – jp-30104
Korea East – Japan Sea; Republic of Korea – kr-30103
Korea South – East China Sea; Republic of Korea – kr-30102
Korea West – Yellow Sea; Republic of Korea – kr-30101
Northeast Korea; Republic of Korea – kr-30104

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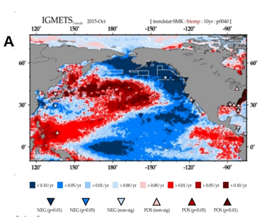
Figure 3. Area maps showing trend-based cumulative change in the North Pacific using satellite (background) and *in situ* (symbols) time series data.
A) SST for 2003-2012
B) CHL for 2003-2012

A



B)

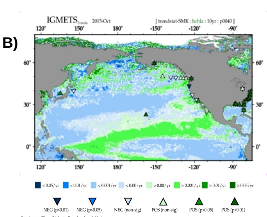
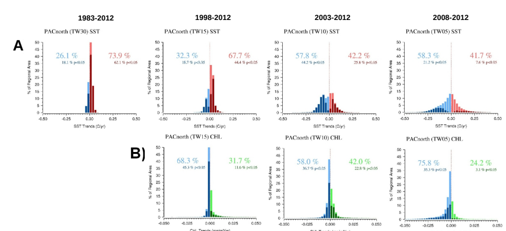


Figure 4. Histograms showing the % area of the North Pacific that underwent net positive or negative changes in SST and CHL during different time periods.
A) SST (30, 15, 10, 5 yrs)
B) CHL (15, 10, 5 yrs)



7) SPATIAL vs. TEMPORAL TRENDS

Spatially coherent patterns observed in North Pacific trend plots for sea surface temperature (SST) and surface chlorophyll (CHL) correlate with major oceanographic features in the North Pacific .

- The 10-year SST trend plot for 2003-2012 (**Fig. 3A**) shows significant cooling in the Alaska Gyre and Bering Sea & warming in the Western Subarctic Gyre, North Pacific Gyre and Sea of Okhotsk.
- The corresponding 10-year CHL trends (**Fig. 3B**) show decreasing chlorophyll in the warming North Pacific Gyre and Sea of Okhotsk and increasing chlorophyll in areas of coastal upwelling along the California Current and between the Northern Equatorial Current and Counter Current.
- These observations are consistent with higher primary production in cooler, nutrient-rich waters.
- Available *in situ* nutrient data for the same 10-year period confirm a net increase in nitrate, phosphate and silicate in the Alaska Gyre and in coastal areas along the California Current.

Temporal trends in SST and chlorophyll are driven by large-scale atmospheric forcing, characterized by several modes of variability (e.g. NPI, PDO, ONI, NPGO) in the North and Equatorial Pacific.

- The 10-year SST trend data are strongly correlated with the PDO across an arc formed by the Bering Sea, Alaska Gyre and California Current, and in the Kuroshio Current to the west.
- Opposite patterns are observed for 10-year CHL and the PDO, and for SST and the NPGO.
- These observations suggest that, in general, the effects of climate forcing are spatially defined by established circulation patterns and reflect an inverse relationship between SST and chlorophyll.

8) VARIABILITY vs. LONG TERM CHANGE

During the 30-year focus period (1983-2012) about 74% of the total surface area of the North Pacific underwent overall warming (**Fig. 4A**) whereas 26% underwent overall cooling. Most of the warming occurred during the first 20 years (1983-2003) in the western and central North Pacific.

During the last 10 years (2003-2012) about 58% of North Pacific surface water underwent overall cooling and 42% overall warming (**Fig. 4A**). Cooling occurred primarily in the eastern North Pacific (including the Alaska Gyre and California Current) and in the Kuroshio Current (**Fig 3A**).

The last 5 years of the focus period (2008-2012) saw further breakdown in the established spatial pattern accompanied by greater extremes of variability in SST (**Fig. 4A**) and CHL (**Fig. 4B**), with warming along the North American west coast and in the central North Pacific.

The onset of these changes (including the initial cooling of the Kuroshio Current) coincides with the abrupt shift from the intense El Niño of 1997 to the La Niña of 1998. Annual DFO State Of the Pacific Ocean reports also confirm that the waters of the eastern North Pacific were cooler than average between 2008 and 2011 due to a Pacific-wide weather pattern associated with La Niña conditions *[3]*.

REFERENCES

[1] PICES Special Publication 4: Marine Ecosystems of the North Pacific Ocean 2003-2008.
[2] Di Lorenzo et al. (2013) Synthesis of Pacific Ocean Climate and Ecosystem Dynamics, Oceanography 26 (4), 69.
[3] http://www.pac.dfo-mpo.gc.ca/science/oceans/reports-rapports/state-ocean-etat/index-eng.html

MARINE ECOLOGICAL TIME SERIES: PART OF OUR OCEAN HERITAGE

I. There are no substitutes for high-quality time series measurements.
II. These must be sustained to avoid data gaps that can never be filled.
III. Time series data are of limited use if they are not made accessible.
IV. The value of individual datasets increases when they are combined.
V. Models may evolve and improve, but need *in situ* data for validation.
VI. Adequate sampling of key parameters will provide an enduring legacy.

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Intergovernmental Oceanographic Commission
KIOST KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY
Fisheries and Oceans Canada
Pêches et Océans Canada
PICES
ICES CIEM
NOAA

For more information please consult the Group's website: http://igmets.net