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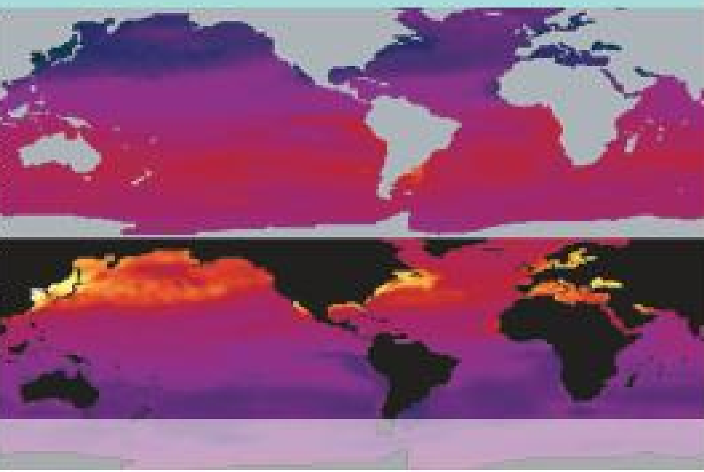
Future climate change and regional fisheries: a collaborative analysis



Cover photo:
Top: Southern hemisphere summer sea surface temperature minus winter
Bottom: Northern hemisphere summer sea surface temperature minus winter

Future climate change and regional fisheries: a collaborative analysis

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PREPARATION OF THIS DOCUMENT

This document has been prepared as part of the Regular Programme activities of the Marine Resources Service, Fishery Resources Division of FAO, aimed at reviewing and monitoring long-term environmental variability and climate change impacts on marine fisheries. While reviewing and synthesizing the most recent work on climate change and fisheries, this document also includes as Annex I, a list of recommended published material that, while not cited in the document itself, is considered useful reading on the subject matter. A Glossary of most used terms in this field is also included as Annex II.

Several people have contributed to the preparation of this document and the author wishes to express his particular gratitude to those who have most directly collaborated in the production of this review, particularly to Messrs Leonid Klyashtorin and A. Nikolaev, Fisheries Science, VNIROV, Moscow, Russian Federation; James Goodridge, California State Climatologist, (retired), Chico, CA, United States of America, and Joseph Fletcher, Director (retired), National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research (NOAA, OAR), Sequim, WA, United States of America.

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ABSTRACT

First, issues of Global Change versus Global Warming are discussed. The larger perspective is presented of earth as a warm, wet planet, that experiences frequent cold periods via climate history graphics of Earth's recent million years of climate variation, from paleoclimate research. The hydrological cycle is described, and its relevance to fisheries is made clear. Climate-related dynamics have had serious consequences in evolution of species, society and fisheries variability. Both production variabilities and changes in vulnerability due to constant dynamics of ocean motion affects are described. The records available for major fisheries are interpreted as we understand them from a century of in-depth research and analysis of various proxies, in particular, bioindicators. The history of climate as it relates to fisheries is addressed. The various spatial and temporal scales that are reflected in fisheries responses are described in an attempt to isolate weather from climate, or other events. Regional ecological responses to climate change are reviewed. Examples are given for the main ocean ecosystems, as defined by seasonal thermal properties. Synchrony and systematic transitions are discussed. Several forecast approaches are described, and their similar conclusions merged to provide a realistic expectation over the next few decades, and beyond. Likely impacts are ranked by fishery system type, and coping measures identified, where they are known, emphasizing the role of humans in habitat protection and maintenance of options.

CONTENTS

INTRODUCTION

This article attempts to explain several interacting physical climatic and ecological processes that play critical roles in maintaining Earth's ecological support systems, particularly those related to fish and fisheries. Always necessary for studies of complex systems are reasonable monitoring schemes, operated for sufficiently long periods so that they capture the full system dynamics. For example, there are few long-term observations that provide time series that cover more than one or two complete rise and fall cycle for the fisheries involved. Even fewer are accompanied by observations of the forcing system(s) that directly or indirectly affect them. This last problem determines the limits of our capabilities to forecast ecological changes. Rarely is the necessary data available to avoid "surprises", simply because our observation systems are so young, our time series so short, and our measurements so local, despite the recent emergence of observing satellites.

Earth's most widely observed Physical Dynamics start with surface wind measurements. These typically reflect Earth's relative temperature gradients, regional and overall. Usual regional seasonal patterns are somewhat similar on decadal and longer climatological scales. The shortest term perturbations of expected climate are associated with El Niño Southern Oscillation (ENSO) scale atmospheric dynamics or with volcanic activity. Volcanoes eject gases and particles into the upper atmosphere. These form long-lived, reflective clouds that generally cause cooling under them. Both volcanoes and ENSO Events impose unique signatures on seasonal weather. Both are defined as Climate Change.

All of the processes that are related here started long before humans existed, and will likely persist long after we have gone. Ecosystem processes in part regulate themselves. They are also strongly influenced by physical forcing processes that drive the Earth's atmosphere and oceans, hence most human activities.

Providing adequate protein is a paramount goal if humanity is to be sustained within these constantly changing conditions. The oceans, large lakes, and connecting waterways provide the majority of protein for human consumption. Hence our focus on the ebb and flow of the aquatic ecosystems and fisheries within the larger context of Earth's System Dynamics. The main points will be illustrated using analyses of several regional fisheries activities, recognizing the increasing influences of fishing and non-fishing activities on humanity's major protein food supply as humanity expands, and changes the world's waterways and shorelines. Core concepts about the major natural factors that force aquatic ecosystems are "melded" within a larger whole. Various insights and concepts are generally attributed to their originators, while still maintaining cause-and-effect links necessary to understand the interdependencies.

The following points will be discussed: (1) Earth's recent million years of climate variation, from paleoclimate research; (2) fisheries variability, as understand from a century of in-depth research and analysis of various proxies, in particular, bioindicators; (3) the basics of the solar irradiance information from the satellite generation; followed up with Hoyt and Schatten's estimation of solar variations over the last few centuries; (4) introduce climate forecasts by Doug Hoyt, Werner Mende, and others as brought together by Dr Joseph Fletcher in a recent lecture series on Climate of the twenty-first century. The decadal to centennial future casts are supported by Klyashtorin and Nikolaev's recent look into forecasting fisheries regimes from monitoring Earth's rotation rate (-LOD); and finally, (5) a brief review of regional fisheries responses to likely climate change as inferred from the previously described work. These discussions will be interpreted regionally from a meld of all these studies, employing insights from Marcel Leroux's (1998) climate-system concepts, and the lead author's penchant for integration and describing connections from recent efforts to explain decadal to century-term ecological variations leading to fisheries variations. These descriptions will introduce readers to important results of emergent environmental and geophysical science.

The fundamental message promoted herein is about coping with constant change. The larger picture that results from these collaborations is intended to help laymen and scientists alike to refocus their objectives within our Solar-System and our own Earth's Grand Fugue in which humans hold so many instruments, but… alas, not the Time-Keeper's baton.

1. GLOBAL CHANGE VS GLOBAL WARMING – ISSUES

Climate is the result of the exchange of heat and mass between the land, ocean, atmosphere, polar regions (ice sheets) and space. Barnett, Pierce and Schnur (2001) point out that "A major component of the global climate system is the oceans; covering roughly 72 percent of the planet's surface, they have the thermal inertia and heat capacity to help maintain and ameliorate climate variability. Although the surface temperature of the oceans has been used in detection and attribution studies, apparently no attempt has been made to use changes in temperature at depth. A recent observational study (Levitus *et al*. 2000) has shown that the heat content of the upper ocean has been increasing over the last 45 years in all the world's oceans, although the warming rate varies considerably among different ocean basins." Barnett, Pierce and Schnur (2001) also point out that "... a climate model that reproduces the observed change in global air temperature over the last 50 years, but fails to quantitatively reproduce the observed changed in ocean heat content, cannot be correct", thereby providing fuel for the arguments against the recent and early reports of the Intergovernmental Panel on Climate Change, (IPCC 1990, 1996 and IPCC 2001) and modeling future climate scenarios choosing to emphasize anthropogenic greenhouse gas forcing to explain the recent 150 years of Earth's surface warming.

German researchers Zorita and Gonzalez-Rouco (2000) compared the Arctic Oscillation (AO) in two sophisticated state-of-the-art Global Climate Models (GCM). That particular oscillation is important because it is strongly related to winter climate in the Northern Hemisphere, and some of the world's more productive fisheries. When the AO is strong, for example, Eurasia has milder-than-normal winters, and west African pelagic fisheries thrive. They then compared AO forecasts using two models: the Hadley Center GCM and the Max-Planck Institute of Meteorology model. First, both models agree with each other in reproducing the mean Northern Hemisphere winter circulation patterns, and their variability. But when the models are forced by increasing greenhouse gas levels, these model predict different AO trends that should also impact the simulated regional air-temperature change. A negative AO trend should weaken the [predicted] temperature increases over Eurasia and Southeastern USA and reinforce temperature increases over Greenland and Western Canada; positive trends should show opposite tendencies. They conclude, "the predictions of the intensities of the main patterns of atmospheric circulation, even at planetary scales, are either not yet reliable or they depend strongly on internal model variability."

Similarly, Giorgi and Francisco (2000) assembled the output of five different GCMs for 23 terrestrial regions across the globe and compared model predictions for temperature and precipitation for the years 2070–2099 relative to the 1961–1990 baseline period. First, they determined how good each model was at reproducing the 1961–1990 baseline climate. This latter comparison is very important, for if the models fail to reproduce current climate, then what they say about the future is irrelevant. They found that some models were pretty close to the base observations (no error) in some regions, but data points were quite scattered about the mean. In some cases the temperature errors were more than 5ºC. Some precipitation errors approached 200 percent but most were generally less than 100 percent, at least from June to August. No one model does much better than any other across all regions. Given their inability to map present conditions, it is not worthwhile to consider model projections as valid for the future. At present, GCMs provide little information about either future general circulation, or oceanic responses.

The present document is not intended as one more redundant refutation of the IPCC's Global Warming scenarios, but is intended to help others recognize the larger scale climate forcing that has been recorded in natural systems. Such records have been extracted from laminated sediments, ice cores, and a variety of other sources such as tree rings and corals, located in diverse environments over the globe. For example, in the same volume as the previously referenced Barnett, Pierce and Schnur (2001) article, Zachos *et al*. (2001) showed climate and ocean carbon chemistry variances were concentrated at all Milankovitch frequencies (see Glossary), reflecting various Solar System forces that modify Earth's annual orbits around the sun, as the sun's dominant gravitational forces drag our Solar System along it's path through space.

Zachos *et al*. (2001) performed spectral analyses on an uninterrupted 5.5-million-year chronology of the late Oligocene – early Miocene from two deep-sea cores. These cores were recovered in the western equatorial Atlantic. They revealed climate-related spectral power recorded at the 406 000-year period eccentricity band over a 3.4-million-year period (20 to 23.4 million years ago) as well as in the 125– and 95–1 000 year bands over a 1.3-million-year period (21.7 to 23 million years ago). Moreover, a major transient glaciation at the epoch boundary (~23 million years), Mi-1, corresponds with a rare orbital congruence involving obliquity and eccentricity of Earth's orbit about the sun. The anomaly, which consists of low-amplitude variance in obliquity (a node) and a minimum in eccentricity, results in an extended period (~200 000 years) of low seasonality orbits favourable to ice-sheet expansion on Antarctica.

Why should such ancient records and processes be of relevance to our futurecast? The most important thing to remember as we move through time and space is that *change is the rule*. Stability is unlikely at almost any scale – given the hierarchy of external forcing, the transfer of energy and momentum between these external forces and Earth's atmosphere, oceans, and internal structures. And, more importantly, if a pattern of change related to the behaviour of Earth within the larger solar system has happened before, it its likely to re-occur. The message form these paleo-studies' is that the climate patterns are repetitive, hence they provide regional process and consequence forecasts via historical analogy. That concept is the basis for what follows, and why there are extensive descriptions of relevant studies.

1.1 The big picture

First, it must be accepted that Earth is a warm, wet planet that has undergone a complex series of changes that initiated and evolved life, under a sequence of very different conditions. These, in turn, led to such dramatic changes as to successively destroy many of the resultant species. The first such dramatic environmental crisis occurred millions of years after the initial sulfur-fixing bacteria became dominant life forms. Carbon dioxide-fixing photosynthetic life forms eventually evolved, and began shedding oxygen as a result of their night or dark time metabolism, creating an oxygen rich atmosphere that was not just toxic, but "poisonous" to innumerable susceptible species. Today, there are many oxygen sensitive anaerobes that survive, that still perform important roles in Earth's ecosystems, included amongst our own and other animal's intestinal flora, where these symbiont bacteria convert an array of carbohydrate chemical forms such as cellulose and complex sugars into various soluble compounds that sustain us. Methane, CO_2 and water are the result of any metabolic work that gets done by us and our symbionts.

Nitrogen fixation was the next step toward a productive interactive ecology, as the resource that provides the building blocks for proteins. Given the naturally high levels of nitrogen in Earth's atmosphere, it turns out that carbon dioxide is the limiting factor in ecological production, and as such, any extra CO_2 steps up plant production, and "greens" our world, producing both more carbohydrate food stuff, as well as more oxygen. Extra CO_2 is not a big problem, despite the news media rhetoric (c.f. Idso 1982). Many colonial ocean species, such as Coccolithophores, incorporate CO_2 into their shell structures, and as they sink to the ocean floor, and over time they can build up to form remarkable geomorphological features, e.g. the White Cliffs of Dover. Plant and animal carbon can also be stored as coal beds, or in petroleum fields, given adequate time and climatic conditions. Nor is carbon dioxide the only limiting chemical element in bio-productivity. Martin, Gordon and Fitzwater (1991) pointed out that iron can be limiting to primary and secondary production in the oceans. Iron is made available in the upper ocean via offshore winds, volcanism, or from disturbed sediments and resurfaced via strong turbulence.

Next, it must be understood that the Earth's heat budget is controlled by two distinct processes. There is a continuous loss of heat at the poles, and similarly, nearly continuous heat absorption into the equatorial regions, particularly the oceans – both modulated by cloud cover dynamics. The resulting energy dynamics across the planet are manifested in the interplay of atmospheric moisture (i.e. clouds and cloud types, and various forms of precipitation), ground-level heating and cooling, and ocean motion. These all interact with different inbound and outbound portions of the electromagnetic energy spectra. It is only from the most recent generations of orbiting satellites that there is now a more complete view of the Earth's heat dynamics. It must also never be forgotten that the upper few meters of the ocean contains more thermal energy than the entire atmosphere. Also, the majority of atmospheric energy is located within a few thousand meters of the Earth's surface. In fact, you can think of the Earth as a warm ball, covered by thin fuzzy warm fluid layers, with two cold poles. All the heat/energy flows follow stringent physical Laws of Thermodynamics, which humans cannot perturb.

History provides clear evidence that a warm wet world is optimal for humans. Societies can be distinguished by their abilities to cope, or not, with the Earth System changes of the recent 3–4 million years. Dependencies have shifted continuously, in order to survive. There are no guarantees that we can continue along our present growth pattern, particularly as habitats are altered and other resource bases that have provided options in the past. The obligation to manage our growth and competitive interactions is too often ignored while some place blame for misfortune on wrong causes. Denial is one of humanity's worst personality traits.

Figures 1a to 1c show that the Earth is more often than not, a warm, wet planet, providing for the array of habitats and species that have been used to support human development. Another important fact is that all extant species evolved and adapted within these same climate dynamics. The more mobile and adaptable species are most likely to survive any future climate dynamics, while locally adapted species with lesser capabilities to move from location to location as their habitats are overlain by new climate conditions are most likely to be lost – to go extinct.

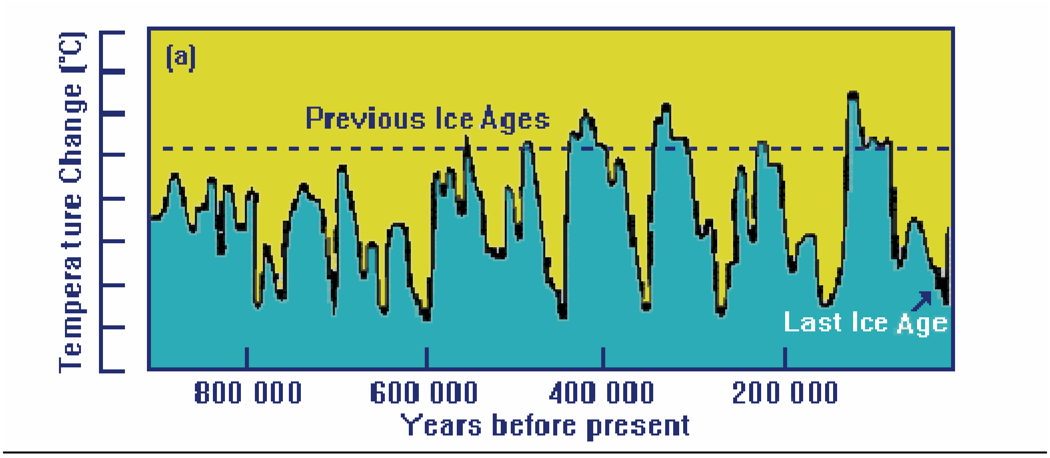


Figure 1a Is a 900 000 year long picture of the changes in the Earth's surface temperatures, as interpreted by many paleo-climate scientists from various proxy records in sedimentary rock strata, laminated ocean bottom sediments, selected high and low latitude ice cores, and, more recently, tree rings, and other time-sequenced laminae. Extensive temperature declines resulting in glacial expansion have occurred more than ten times, with the most recent interglacial warming having occurred only about 18 000 years ago. This suggests that many species have recolonized the higher latitudes (>45 degrees North or South) since the ice cover abated.

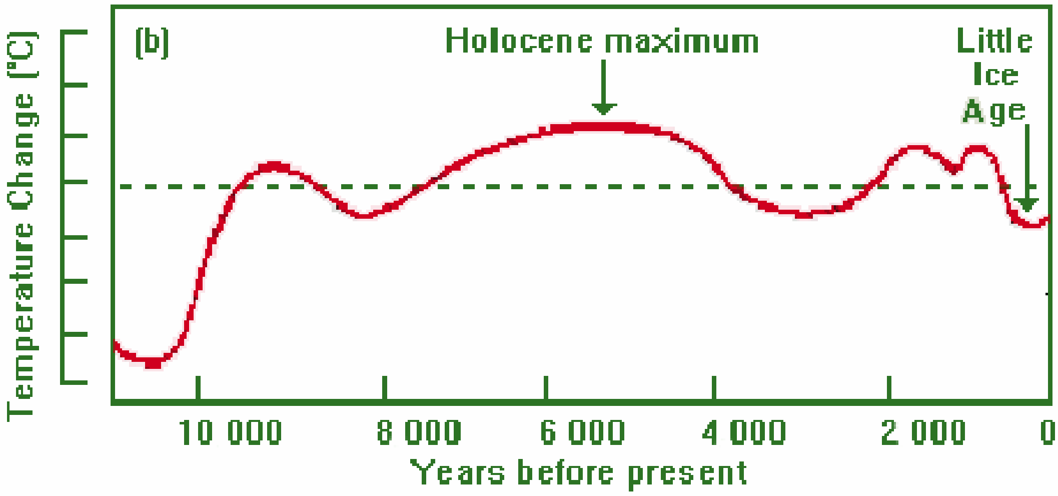


Figure 1b Shows the global temperature pattern since 11 000 years Before Present (BP), with a mean temperature reference line provided to help visualize this period (which would start in the lower right corner of Figure 1a).The extended periods of relative warm climate provided a backdrop for most of humanities civilization, and expansion into the higher latitudes, as well.

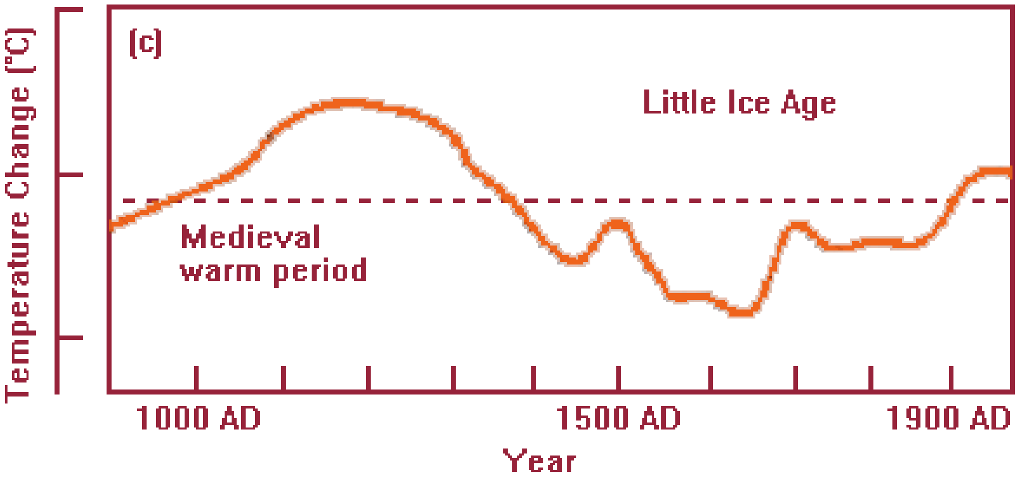


Figure 1c Shows the global temperature record since 900CE, again with a mean temperature reference line provided. This graph starts at about the mid-point of the right hand double hump in Figure 1b. Note the time scale is the modern calender.

1.2 The seasons as a basis for understanding Earth's variability

It is important to accept that the Earth is a warm, wet planet that endures excursions into colder periods, with more ice formation. The seasonal oscillations of Earth's sunlight/energy levels are exaggerated at the poles, while they remain relatively constant about the equator. The lower seasonal variability and the relatively vast amount of light and heat absorbing ocean around the equator leads to the general warming at the equator. Historical paleo-proxy records show that the equatorial ocean does not change temperature dramatically during Ice Ages. However, the polar oceans expand greatly, therefore the North-South thermal gradients also steepen, narrowing the climate zones.

The annual seasonal weather cycle that is experienced is the basis for Earth's major ecological patterns and species diversity, both consequences of continuous changes in Earth's physical contexts. Continuous change is paramount in Earth's contextual framework, within which life as we know it has evolved. Virtually all species are adapted to change, or they do not have any chance of surviving beyond a few generations. The near-spherical nature of the Earth, and the direct relation between incident light/energy and available heat, along with Earth's slowly varying central axis of rotation intensifies regional differences in solar irradiation. The imbalance is a result of the waxing and waning of incident sunlight, as the Earth orbits around the sun, spinning on its somewhat wobbly, 28 degree off-centre axis. Thus seasonality is the result of Earth's off-axis wobble. If there were no wobble, the Earth would have no seasons.

Absorption of the sun's irradiance energy and the re-radiation of infra-red (IR) energy are affected by albedo, or relative reflective-absorptive properties of the Earth's atmosphere, water bodies, and various land-cover surfaces. Albedo is strongly affected by cloud cover and type, ice cover, vegetation types and their developmental phase, as well as both liquid water and water vapour. All of these have dynamic seasonal distributions.

An excellent example of our relatively new insights comes from the solar science community, whose centuries of observations have shown that the sun's surface exhibits a pattern of rise and decline in sunspot numbers that take place with about an 11–13 year period. The occurrence of large numbers of sunspots was “assumed” to mean that the sun was less active. Also, until satellites were finally deployed to measure the sun’s output from beyond the earth’s atmosphere, scientists readily accepted the concept of a “solar constant”. Only recently was it recognized that there were remarkable changes in solar emissions, associated with the sunspot cycle, and that more sunspots meant more solar energy emission – just the opposite case of the “general assumption” made previously. Also, there are actually two cyclical phenomena involved, the added one being the reversal of the sun’s magnetic polarity with every solar cycle, leading to a double peaked pattern, with a period of about 22 years.

While it is now quite clear that the sun’s irradiance output is not “constant”, from satellite measurements made since 1979, the variation is still relatively small (~2 Watts per square meter – Figures 2a and 2b) so far – from the short available time series. Despite this relatively small variation, there are innumerable studies that show climate change patterns that suggest the double (2 x 11–13) ~22 year solar cycles of irradiance and solar magnetic field reversal are involved (Friis-Christensen and Lassen 1991), and are often observed in regional hydrologic patterns (c.f. Perry 1994; 1995; 2000).

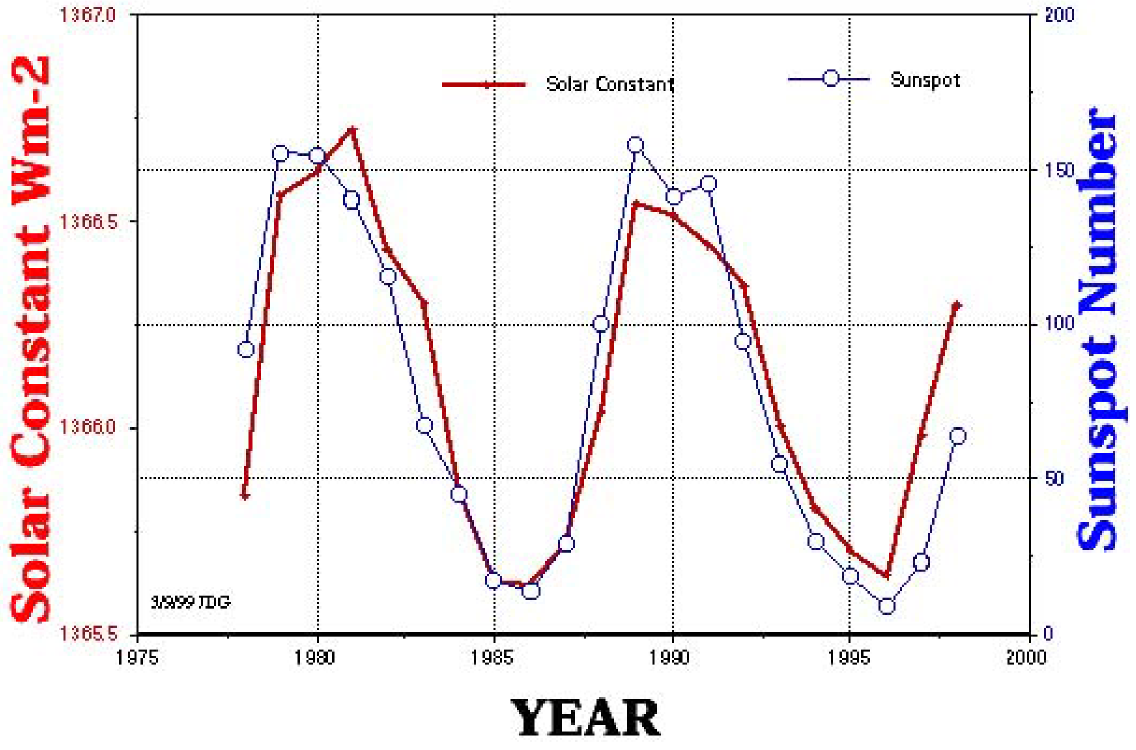


Figure 2a Is a time-plot of satellite measurements of solar irradiance and observed sunspot numbers since satellite measurements began, in 1979 from Hoyt and Schatten (1997). Measured solar irradiance differences are very small, around 0.05 percent between maxima and minima. Therefore the estimated values are quite small, too. But a long-term increase of approximately 0.2 percent in total irradiance seems to have occurred since the Maunder Minimum.

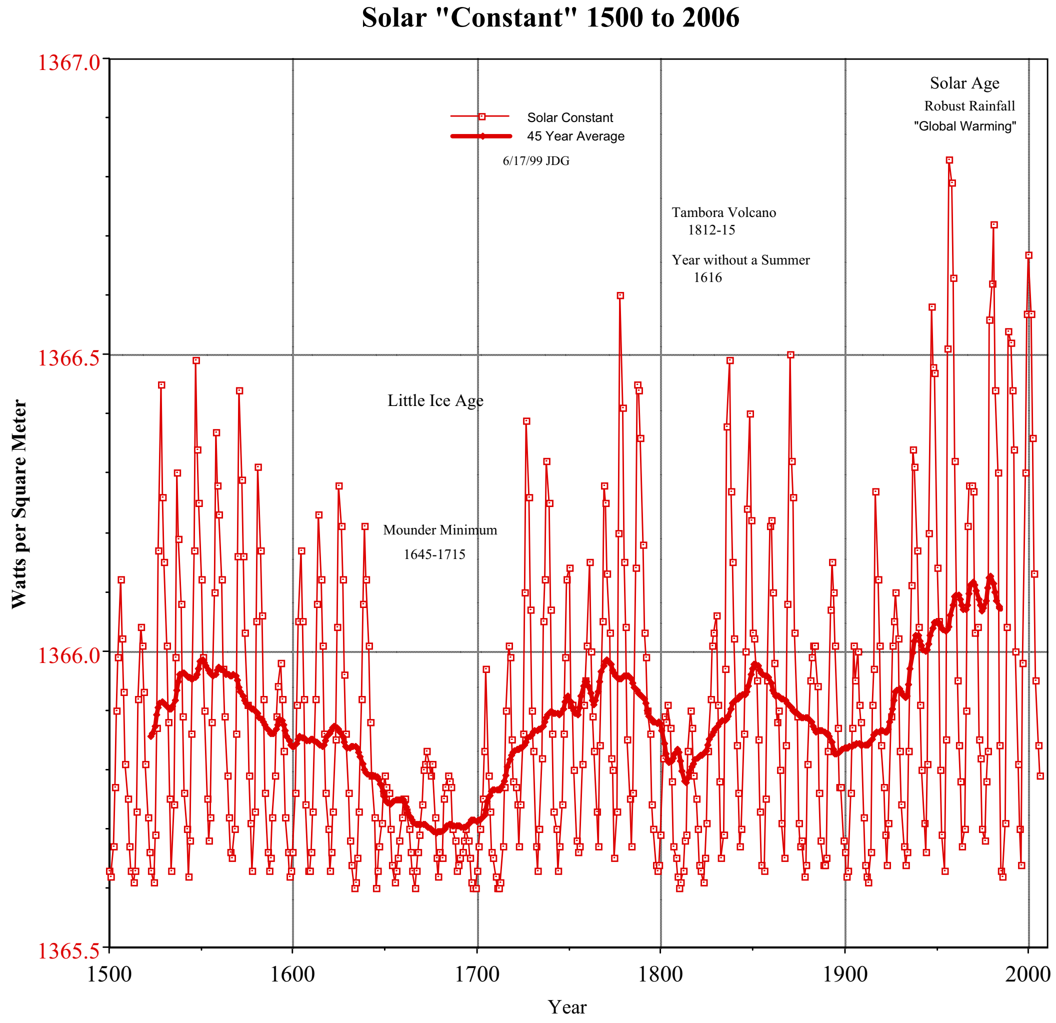


Figure 2b Shows the solar irradiance in this annual translation of the SunSpot observations into solar irradiance, using the Hoyt and Schatten (1997) calibration derived from observations depicted in Figure 2a. The Solid lines shows the application of forty-five year smoothing, to expose the long-term trends in solar activity.

To summarize basic facts: (1) there is continuous heat loss at the poles, and simultaneously, (2) nearly continuous heat absorption into the equatorial oceans. The resulting energy dynamics over the planet are manifested in the interplay of atmospheric moisture (i.e. clouds, cloud types, and various forms of precipitation); ground heating/cooling; and ocean motion. These all interact with inbound and outbound radiant energy spectra. It must also never be forgotten that the upper few meters of the ocean contains more thermal energy than the entire atmosphere. Most atmospheric energy is located within a few thousand meters of the Earth's surface.

1.3 Hydrological cycle and climate zones

The equatorial regions (the tropical zone) receives relatively more energy input, depending upon the sun's electromagnetic spectral irradiance patterns. Clouds moderate both the irradiance reaching the surface, and the retention rate of the IR back radiation at all such interfaces. The seasons cycle within earth's annual orbit, with the atmosphere transferring any energy disparities at the most rapid rate. For example, starting with deep convection – in which the ocean's surface energy is transferred to the atmosphere – the ensuing cloud movements and precipitation deliver warmth (energy) from the tropical zone, poleward into the Temperate Zone. These processes can take days to weeks. While an entire transfer cycle to the polar regions via the atmosphere can take months to years, if the energy is retained in the form of snow, ice, or even dependent on spring river flows. At the Poles heat is lost continuously into the void of space lost in the form of IR.

The cycle of delivery out of tropical zone heat into the higher latitudes via the ocean currents occurs at a much slower rate. Forced by winds and thermo-haline dynamics, currents form and their pathways are subject to Earth's rotational forces – described by Ekman in the last century (c.f. Bakun 1996 for descriptions), and tidal forces. Oceans, lakes, and rivers perform similar energy transfers, subject to local seasonal precipitation patterns, surface wind stress, and gravitational forces as liquid seeks its own equilibrium level within various basins. The Earth's internal ocean-atmosphere dynamics and hydrologic cycles are the all-important result.

All these mass and energy transfers create local dynamics. These dynamics are functions of local heat disparities that also generate subsidence or convection; that in turn cause surface winds; that again interact to either evapourate the water (cooling the local surfaces); or bring in more precipitation. Evaporative surface cooling can cause both condensation, increased salinity and increased density that in turn induces surface water sinking – at various scales of current formations. Whether or not our present situation is unique, or not, is not really the prime question, as some would have you believe.

From the perspective of an observer or laboratory scientist, the individual transfers can appear reasonably simple, and readily modeled. That is until one begins to follow each and every process from its source(s), through the myriad interaction points, each a site of transition or transformation. For example, physical oceanographers treat fresh or open-ocean water as simple systems of wind-driven densities, and gravitational forces. However, as each water type encounters a more or less saline environment, these interfaces are immediately modified, as interactions ensue. The usual patterned subtle density changes of either the fresh water – or the more complex interactions of temperature and salinity of saline water – are recognizable by their physically measurable interfaces, each of which can lead into another time-scale, and a usually slower resolution of any disparate energy contents. The end result is Earth's quite complex hydrological System (c.f. Enzel *et al.* 1989; Gray 1990; Gray and Scheaffer 1991; Gross *et al.* 1996; Perry 1994, 1995, 2000; Perry and Hsu 2000; White *et al.* 1997; White, Chen and Peterson 1998; Lean and Rind 1998).

There are myriad discontinuities and phase changes, each interacting at another spatio-temporal scale of resolution of energy disparities. Changes in state or chemical composition of water are the principle contributors to the many important physical climate patterns in which time scales vary. These interfaces can also form somewhat identifiable ecological boundary conditions. These too shift, depending upon their general position: (1) within Earth's slowly changing geomorphology, and, (2) with the relatively mobile seasonal boundaries – as Earth makes its annual foray around the sun, and onward through time and space. These dynamic patterns are referred to as climate zones, or at the local scale – so-called micro-climates.

At sea level, near the coast, the climate reflects the average seasonal thermal dynamics of the ocean's surface and surface winds that push-and-pull their energy loads toward a more stable state. Each medium works to reach some more uniform energy state. As we climb the beach onto the terrain relief, we often encounter various scales of hilly coastal area, or even a mountain. These orographic features rapidly lift the often near saturated water-vapour laden surface air into a generally cooler atmosphere, forming clouds, or even ice crystals, depending upon the latitude and season. As this air mass continues upward, to follows a path of energy/density resolution, precipitation may form and fall. Depending upon what conditions are encountered below, the moisture can again evapourate, or fall as rain, or aggregate to be blown upward in updrafts, sometimes to form and fall as hail stones, that melt as they gain heat energy from the surface air and terrain.

Similar events over the ocean are often more quickly resolved, by dilution. However, ocean surface water can quickly be sealed over with lenses of fresh, warmer, low salinity water. This phenomenon is often reinforced by river run-off, resulting in another layer of complexity, as these fresh water lenses can suppress normal wind mixing, until the salinity profile eventually becomes more amenable to mixing, functions of both salinity differences and external forcing. For example, if there is strong atmospheric subsidence, lets say from a polar region, the fresh surface water can freeze, sealing even more firmly the underlying ocean against surface wind mixing. On the other hand, when little precipitation has occurred, the same polar subsidence can evapourate the saline ocean water, creating super-cooled, high density currents which can sink well into the ocean's interior, along density interfaces that are specific to temperature and salinity conditions. The warmer, moist air produced is transferred often very long distances before it is cooled, condenses, and eventually precipitates.

Snow often results when dense dry cold air masses meet moister, warmer air masses – from another climate zone – creating rapidly cooled strata in which the water vapour freezes into crystalline forms. These crystals, or flakes, settle relatively slowly to the ground, again forming an insulating cover; or drifts in the wind, to be transported to eventually coalesce into banks – even glaciers under specific conditions – or merely melt to join local water resources. Which process occurs where, depends as much on altitude as latitude, providing for glaciers on the equator at 5 000 meters, or seasonal rainfall from 60°N or 60°S at lower altitudes. Seasonal snowmelt generates freshwater flows, often entering the oceans hundreds to thousands of miles downstream from the initial precipitation events.

Freshwater flow is critical to many fisheries, such as shrimp, crabs, and anadromous species such as salmon and eels. Even seasonal ice formation has its ecological consequences (Loeb *et al.* 1997). Any climate processes that shift climate zone boundaries will affect precipitation patterns and will therefore affect these species' fisheries. Regional and Global Climate can and does change rapidly if certain thresholds are crossed. Certain fisheries systems reflect these changes quite dramatically, as noted by Hjorth (1914, 1926) and Russell (1931, 1973) in their seminal works. Today it is well recognized, although poorly accounted for in regional fish stock assessments, that fisheries catches provide unique ecological climate indicators, as described in recent literature (Southward 1974a,b; Southward, Butler and Pennycuick 1975; Southward, Boalch and Mattock 1988; Sharp and Csirke 1983; Loeb, Smith and Moser 1983a,b; Garcia 1988; Ware and McFarlane 1989; Glantz and Feingold 1990; Kawasaki *et al.* 1991; Ware and Thompson 1991; Glantz 1992, Gomes, Haedrich and Villagarcia 1995; Mantua *et al.* 1997; Taylor 1999; Klyashtorin 1998, 2001). We have come a long way since Baranov's (1918, 1926) insights.

1.4 Paleo-observations and climate shifts

In the recent few decades, high resolution paleoclimate researchers – using long-term records such as ice cores, coastal ocean and lake sediments, corals, and other living systems – have reached the remarkable conclusion that dramatic climate patterns changes have occurred frequently, on time scales of a few years to decades. For example, a consortium of paleoscientists studied long sediment cores from Elk Lake, Wisconsin (Anderson 1992; Dean *et al*. 1984). Using an array of modern techniques, on materials teased from annual sediment cores containing up to 11 000 years in sequence, they learned that climate-driven ecological switches from prairie, to northern forest, to eastern forest ecotomes took place in only a few years to a decade.

The first – the prairie ecotome – represents the dominance of our now-normal North Pacific High weather systems. The latter – the eastern forest ecotome – represents the dominance and onshore movement of the atmospheric feature labelled the Bermuda High, that pumps warm, moist air into the heartlands of North America to support pine forests. The Mid-type, or northern forest ecotome periods, occur during periods when both the North Pacific and Bermuda Highs are weaker, farther offshore, and seasonal patterns are dominated by Arctic subsidence, i.e. Mobile Polar Highs (c.f. Leroux 1998) dominate the terrain, bringing harsh dry winters that support northern forest species, and push the two other ecotomes equatorward and oceanward.

These sorts of pattern changes are "written" in sediments, ice cores, and plant distribution patterns around the world (c.f. Markgraf 2001). How do we learn about the oceans, given their dynamics? The problems are not trivial, as oceans are indeed more difficult to sample, and processes unravelled and described in terms that can be translated into "climate analogies". Yet, there are growing numbers of studies, particularly since the hallmark work of Soutar and Isaacs (1974) and the follow-up by Baumgartner *et al.* (1989) that show that ocean realms undergo parallel patterned shifts, with dramatic results in species abundance, composition, and distribution changes.

These climate related changes have had notable consequences on local to regional societies, from the Arctic to Tierra del Fuego, Australia, South Africa, and into the world's oceans. There are compelling reasons to address any and all options to forecast, or identify symptoms of pending Climate Transitions, or Regime Shifts. There have been several recent advances in the geosciences that might lead toward this objective. For example, the Earth's rotation rate or negative day length (-LOD) varies, apparently also reflecting the sum of all the Earth System's "internal" dynamics. Russian fisheries and geophysical scientists (Klyashtorin, Nikolaev and Klige, (1998) and Klyashtorin, Nikolaev and Lubushin, in review) find that changes in –LOD as well as patterned Atmospheric Circulation Indices (ACI) lead the manifestation of some important processes related to fisheries. These concepts are critical to changing the manner in which fisheries are managed, from hindcast methods to true proactive forecast approaches. Our working hypothesis is that changes in Earth's surface air temperature (dT) and regional atmospheric circulation dynamics (ACI) can provide insights into ocean and environmental variations, hence fisheries production patterns (Klyashtorin 1998; Sharp 2000; Sharp, Klyashtorin and Goodridge 2001).

An index of global climate changes is the surface air temperature anomaly (dT) that has been measured continuously over 140 years. Annual variability of dT is known to be very high, and a considerable (13 years) smoothing of the corresponding time series is necessary to reveal long-term temperature trends (Figure 3a). Smoothed time series of the average annual dT (Figure 3b) exhibit several multidecadal fluctuations with maximums at the 1880s, 1930s, and 1990s (Halpert and Bell 1997; Bell *et al*. 2000), and ACI (Figure 3c) also responds. These fluctuations take place on the background of the age-long ascending trend of 0.06°C/10 years (Sonechkin, Datsenko and Ivaschenko 1997, Sonechkin 1998).

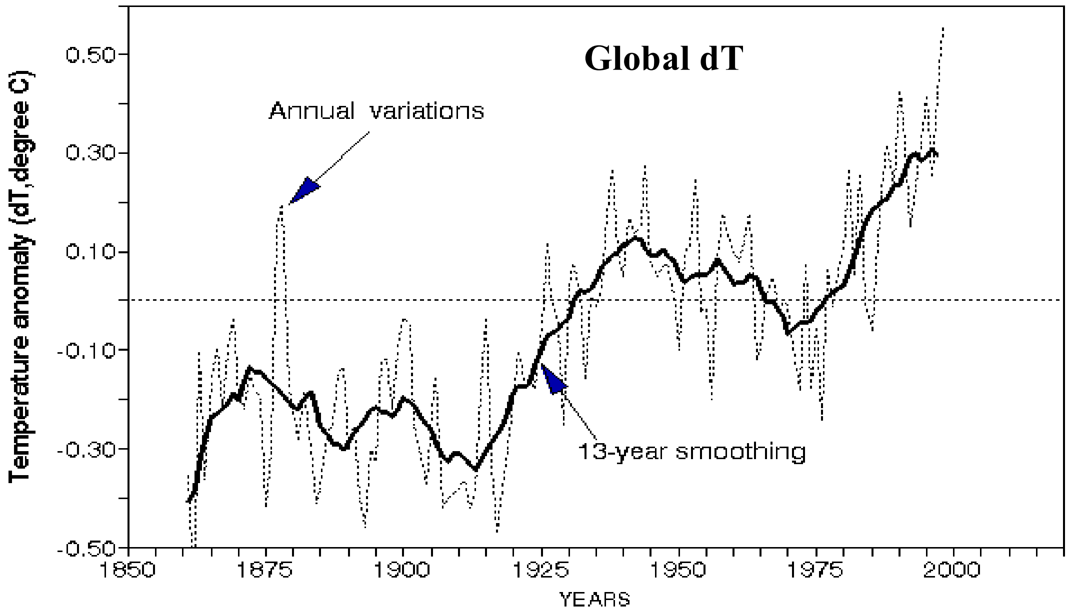


Figure 3a

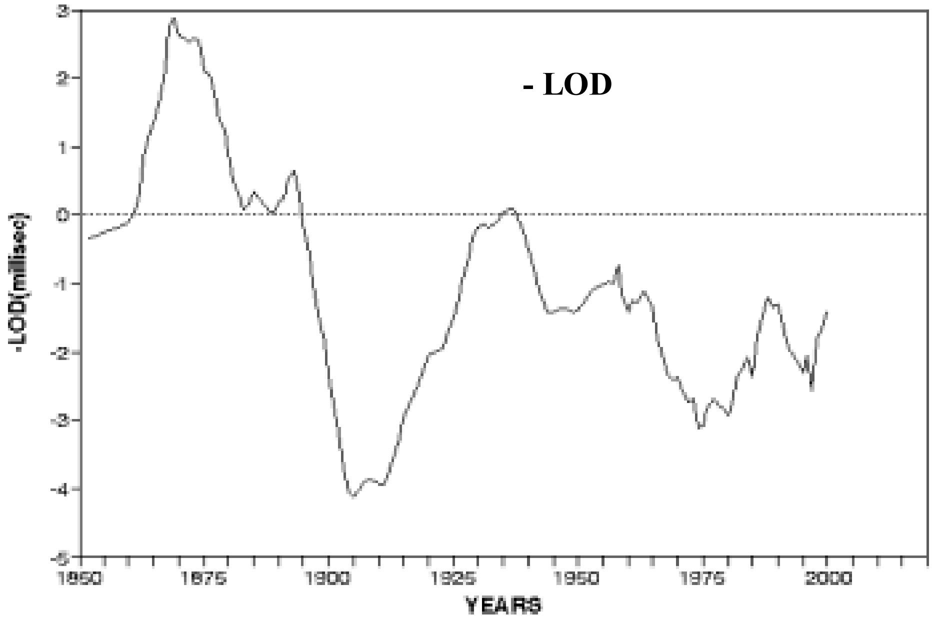


Figure 3b

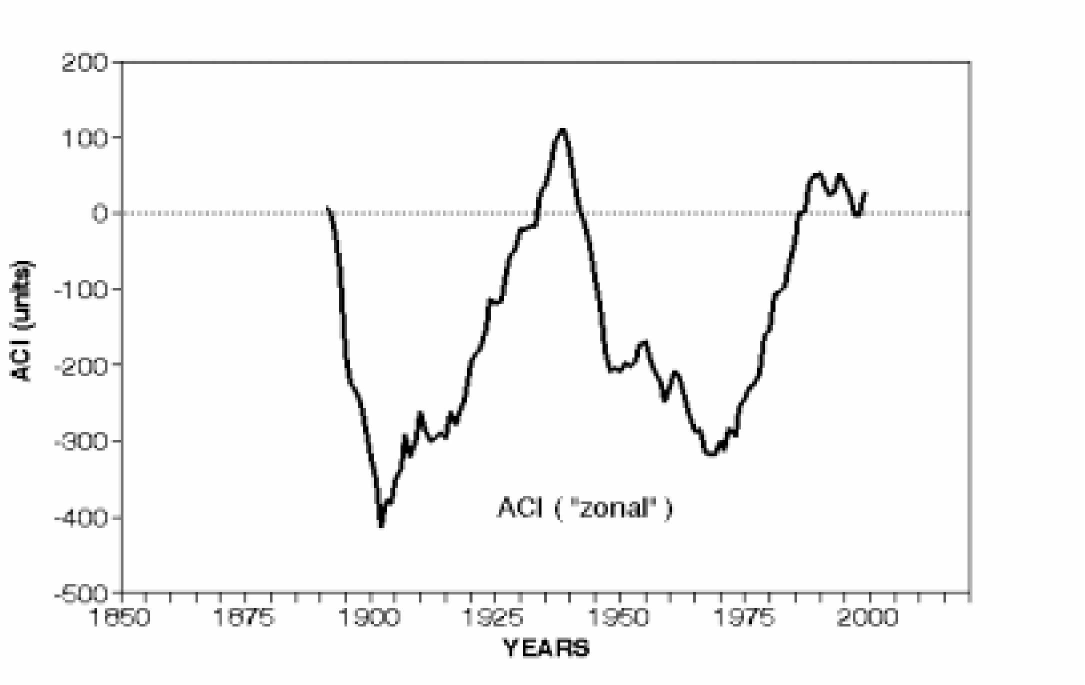


Figure 3c

Figure 3 Long-term dynamics of the investigated climatic and geophysical indices: **3a** The global temperature anomaly (dT): 1- average annual, 2 - average annual, smoothed by 13-years running average; **3b** The earth rotation velocity index (-LOD); **3c** The latitudinal atmospheric circulation Index (zonal ACI) Figures provided by Leonid Klyashtorin, personal communication.

The Atmospheric Transfer (AT anomaly and Atmospheric Circulation Index), global temperature anomaly (dT), and Length of Day Index (-LOD) have been well measured for the last 100–150 years. The long-term regular fluctuations of these indices are well correlated, although shifted in time. The multidecadal oscillations of the AT anomaly are ahead of periodical fluctuations of LOD (for 14–16 years) and dT (for 16–20 years) making it possible to predict probable dynamics of the latter well in advance. For practical reasons, meteorologists do not work with the AT anomaly itself, but they use the product of its accumulation (i.e. sequential summation of the AT anomalies).

The Atmospheric Circulation Index (ACI) was suggested by Vangeneim (1940) and Girs (1971) to characterize atmospheric processes on a hemispheric (global) scale. Reliable time series for these indices exist for only the recent 110+ years. The predominant direction of the air mass transport for each component depends on the atmospheric pressure pattern over a huge territory, e.g. from the Atlantic to West Siberia. This information is first analyzed and then presented as daily maps of the atmospheric pressure fields over the region limited by 45°W, 75°E and 20°N to the North Pole. Similar patterns likely exist for the southern hemisphere, for similar data.

The occurrence of each component (C, W or E) is defined as the number of days with corresponding predominant direction of air mass transfer. Total occurrence of all three components in a year is equal to 365. For each range of years, the occurrence of predominant atmospheric transfer is expressed as the Atmospheric Transfer anomaly (AT anomaly) which as have shown, is the result of subtraction of the corresponding average for some defined time period. Therefore, the sum of the AT anomalies of three basic components (C, W and E) for the same period is always equal to zero. The resulting time series (accumulated AT anomaly) is called the Atmospheric Circulation Index (ACI), where ACI is the AT anomaly time series integrated for any period of measurements. Klyashtorin (1998) pointed out the strong relation between commercial fish catches from the world's major fisheries and the Russian Arctic Institute's ACI indices (Figure 4).

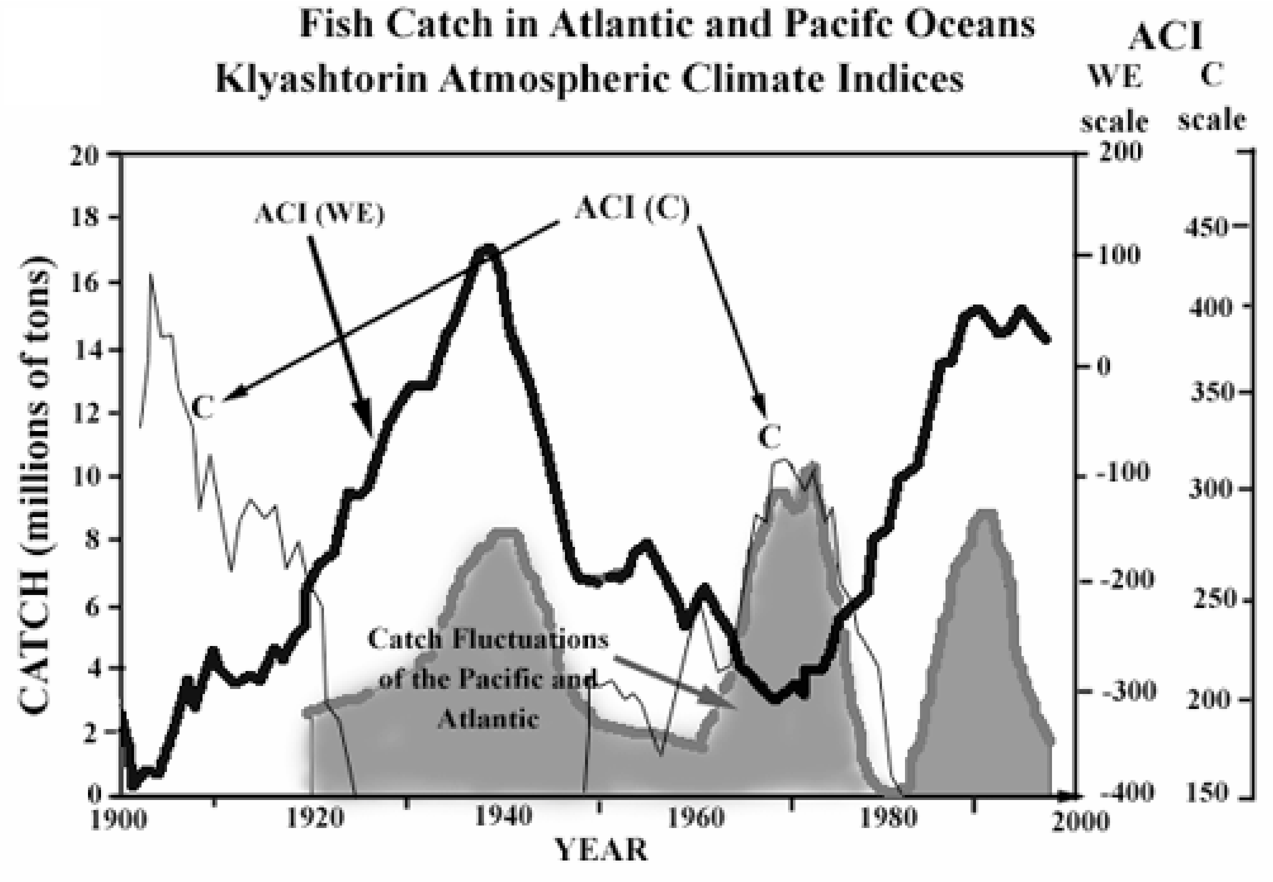


Figure 4 Shows the Atmospheric Climate Indices for the same period plotted with regional "warm regime" Commercial Landings Data for the twelve major fisheries described in Klyashtorin (2001 c.f. Figure 14). ACI (W-E) designates periods when the dominant surface wind fields are zonal, and ACI (C) indicates the periods when the wind fields are predominantly meridional. Note the relative coherence of the fisheries production peaks within the two ACI (WE & C) patterns.

The concept that hemispheric weather patterns are cyclical, and related to atmospheric forces is neither new, nor particularly controversial. The typical relations between Climate Regimes Shifts and large system hydrological records can be quickly accepted, given the data sets are coherent, long term and correct. The rise and fall of continental lake systems have been recorded for many decades, and in some cases, such as the Nile River Flows, for nearly 2 000 years. For example, it is well known to Russian water resources specialists that the dominant ACI-C atmospheric pressure-form means an increase of north to south transfer of precipitation. Alternatively, regional climate as a whole become more continental during "meridional epochs", i.e. difference between summer and winter temperatures are greater.

Over the recent few decades there has been considerable debate over the cause of the lowering of the Aral Sea and other Russian waterways, as agriculture has expanded, and more waterways have been tapped for irrigation. Figure 5 helps explain the previously disturbing long-term decreases in the level of the Aral Sea, just to the west of lake Balkhash.

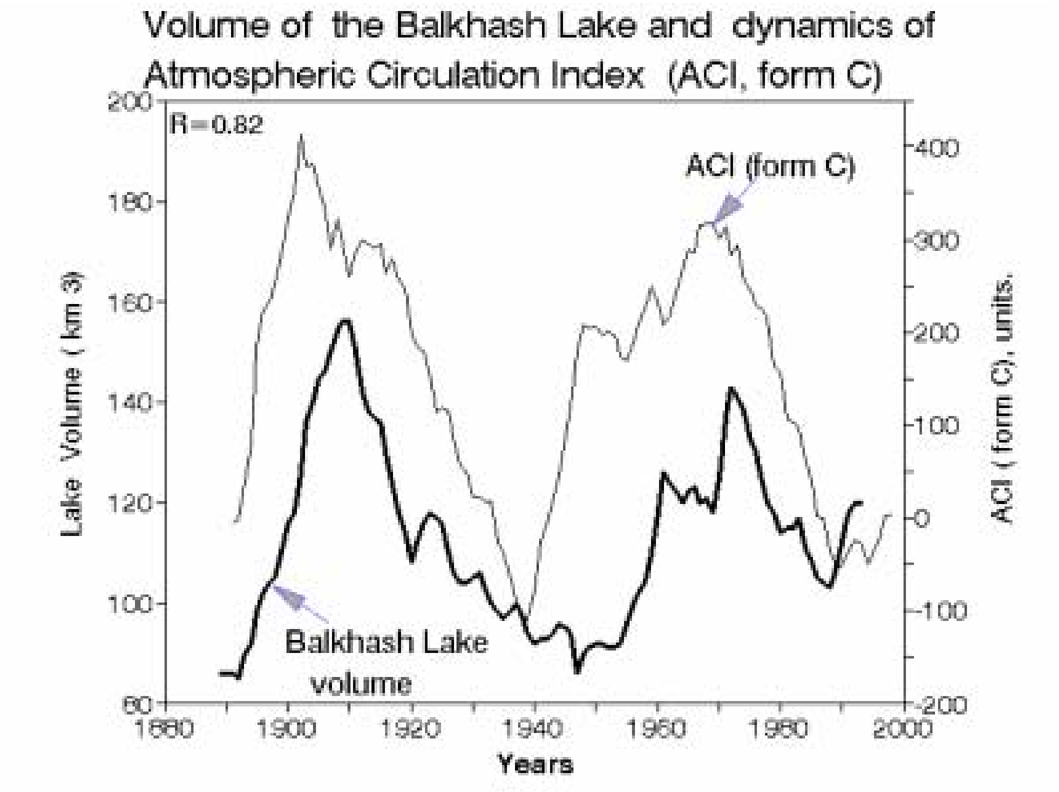


Figure 5 Shows good agreement between Balkhash-lake volume and the ACI-C-form (meridional) of Klyashtorin's (above) atmospheric climate index. The Aral Sea and other regional hydrologic basins have also recently begun to slowly increase. These data also support reasonably positive forecasts for ecological changes.

1.5 Local challenges

The basic need to find food, and in particular, provide adequate protein for an ever-increasing population, is an epic dilemma. The now obvious fact is that with the present leveling off and declines of some ocean fisheries production options have begun to run out as habitats are shifted from agricultural emphasis and as more food fish is used to support fish and shrimp culture. Under the pressures of today's human population growth, perhaps better use could be made of fish protein if a larger portion of the fish catch were sold for direct human consumption rather than used to support culture of higher value products via the added inefficient conversion step of feeding it to another species.

Figure 6 places in temporal and climatic context examples of known social and fisheries pattern changes that appear to be in response to similarly well-described, if somewhat longer term gross climate changes (see Figure 1c). The examples of climate-related responses by the North Atlantic, the Bohuslan herring, and Andean cultures related to changes in to Solar influences do not connect well the local causalities for each phenomenon. The coming and going of glacial ice, general ocean habitat cooling and warming, and sequences of wet and drought periods can be documented across the globe, as is the mission of the PAGES Pole-Equator-Pole Program (C.f. PEP-PAGES website) Regional and Global climate patterns are studied and archived by national institutions (c.f. NOAA Climate Prediction Center website, CSIRO website), the oldest being the Nile River gauge near Cairo. The recent few decade's focus in the applied climate sciences has been on El Niño, now broadened to include alternative La Niña or neutral patterns.

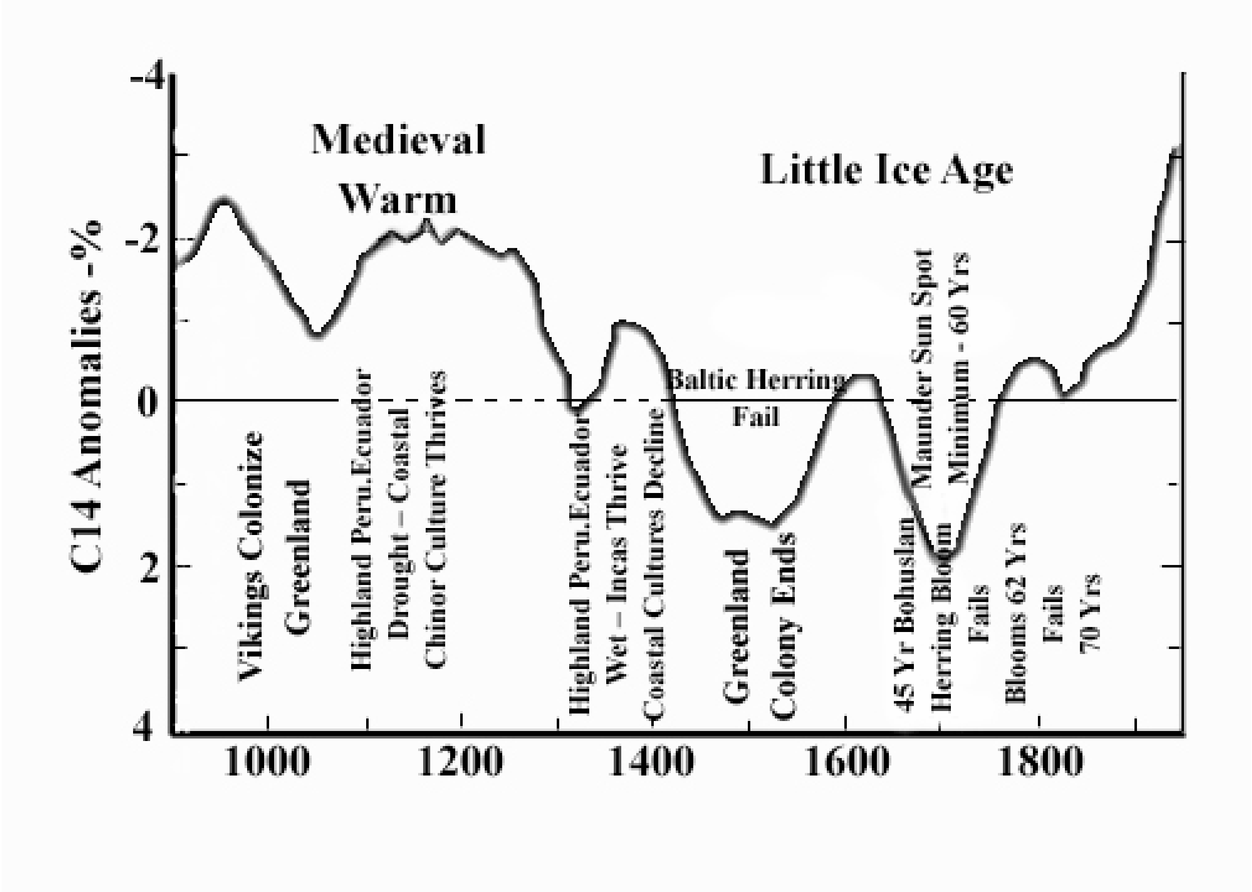


Figure 6 Is a time series of C14 anomalies, resulting from solar emissions, annotated with recognized societal responses, and comparable information about the rise and fall of Baltic herring, and the subsequent formation of the Hanseatic League in response to the region's dramatic cooling/warming patterns during the Little Ice Age. Meanwhile the earlier Norse colonies in Iceland, and Peruvian lowland-highland cultures underwent dramatic changes. Many other social consequences have been identified with both continuous and abrupt changes, supporting the concept that human cultures, too, have responded to such climate changes, as have all species over the course of history.

From the onset of the ~1285AD–1400AD post Medieval Warm period, chronic cool dry weather, local drought and extreme weather, along with regional low food security, started various competitive societal forces into motion (c.f. Thompson *et al.* 1995, Braudel 1985). This epoch of climate-related social stress was further exacerbated by the cooler era now called the Little Ice Age, and was the general motivating social force that began the Age of Exploration.

2. THE PAST, PRESENT AND FUTURE CLIMATE RELATED TO FISHERIES

People have documented the coming and going of local fish resources for centuries. How much these changes were due to fishing or other causes has been a dilemma. The many issues of habitat protection, restoration, and utilization are beyond the scope of this document, but are definitely worthy of concern. As humanity has enjoyed the benefits of the recent two centuries or so of relatively amicable climate, ever more conflicts have risen as the Tragedy of the Commons evolves into fierce competition for access to limiting resources – particularly clean water and living space. The dilemma is how to cope with the uncertainty of future climate changes. Lessons from the past seem a good place to start.

Since systematic research into understanding fish reproduction success began, numerous fish species have been reared and studied to discover various keys to relatively better survival, diverse life history and growth patterns, and predation effects – in order to stabilize fisheries. Research into cause and effect in ocean productivity and fisheries production have been reviewed extensively elsewhere (c.f. Pearcy 1966; Smith 1978; Ursin 1982; Kawasaki 1983; Bakun 1996; Caddy and Bakun 1994; Longhurst *et al.* 1995; Polovina, Mitchum and Evans 1995; Schulein, Boyd and Underhill 1995; McFarlane, King and Beamish 2000; Harrison and Parsons 2000). With the collapse of the California sardine, in the 1940–50 period, and then the Peruvian anchoveta in the early 1970s, fisheries research was intensified in the eastern boundary currents (see historical reviews in Scheiber 1990; Crawford *et al.* 1991; Sharp 2000). Throughout this century, lessons from each study were carried from region to region, and then applied to more offshore species, by analogy, as fleets grew, and spread out onto the high seas (c.f. Schwartzlose *et al.* 1999, Harrison and Parsons 2000). The collapse of cod and other major fisheries in the northwest Atlantic in the late 1980s caused a complete shift in emphasis, as the public finally began to grasp that it takes more than only good science to manage living resources (Finlayson 1994, Dobbs 2000; Glavin 2000).

Coastal pelagic fishes of the world, particularly those off California, are amongst the best-studied populations in the world (reviewed in Sharp 1998, 2000). Following leads from early studies by Lasker (1978), and colleagues around the world, Cury and Roy (1989) evolved the theory of “Optimal Environmental Windows” for fish survival. Climate and weather-related drivers of the alternative states within the eastern boundary current regions are reasonably well understood. These forces, along with decadal scale and longer fisheries sequences are now tied together in many studies of Climate Regime Shifts and their fisheries implications. The story simplifies to taking measures of wind speed and direction, and other measures, and comparing the results to upper ocean temperatures, primary production, and various fish species’ annual recruitment records (Figure 7).

2.1 Ecosystem responses to various scale climate forcing

Twentieth Century fisheries scientists have provided abundant examples and documentation to show that fisheries dynamics involves much more than only isolated fish stocks and fishing mortality (see for example reviews by: Hjort 1914, 1926; Roger Revelle 1947 (in note to John Isaacs, quoted in Scheiber 1990); Bakun *et al.* 1982; Bakun 1996; Sharp and Csirke 1983; Csirke and Sharp 1983; Glantz 1992; Sharp 1997, 2000; Boehlert and Schumacher 1997 – amongst many others). Their common thesis is that the oceans, hence fisheries are connected to larger scale dynamic forces and processes.

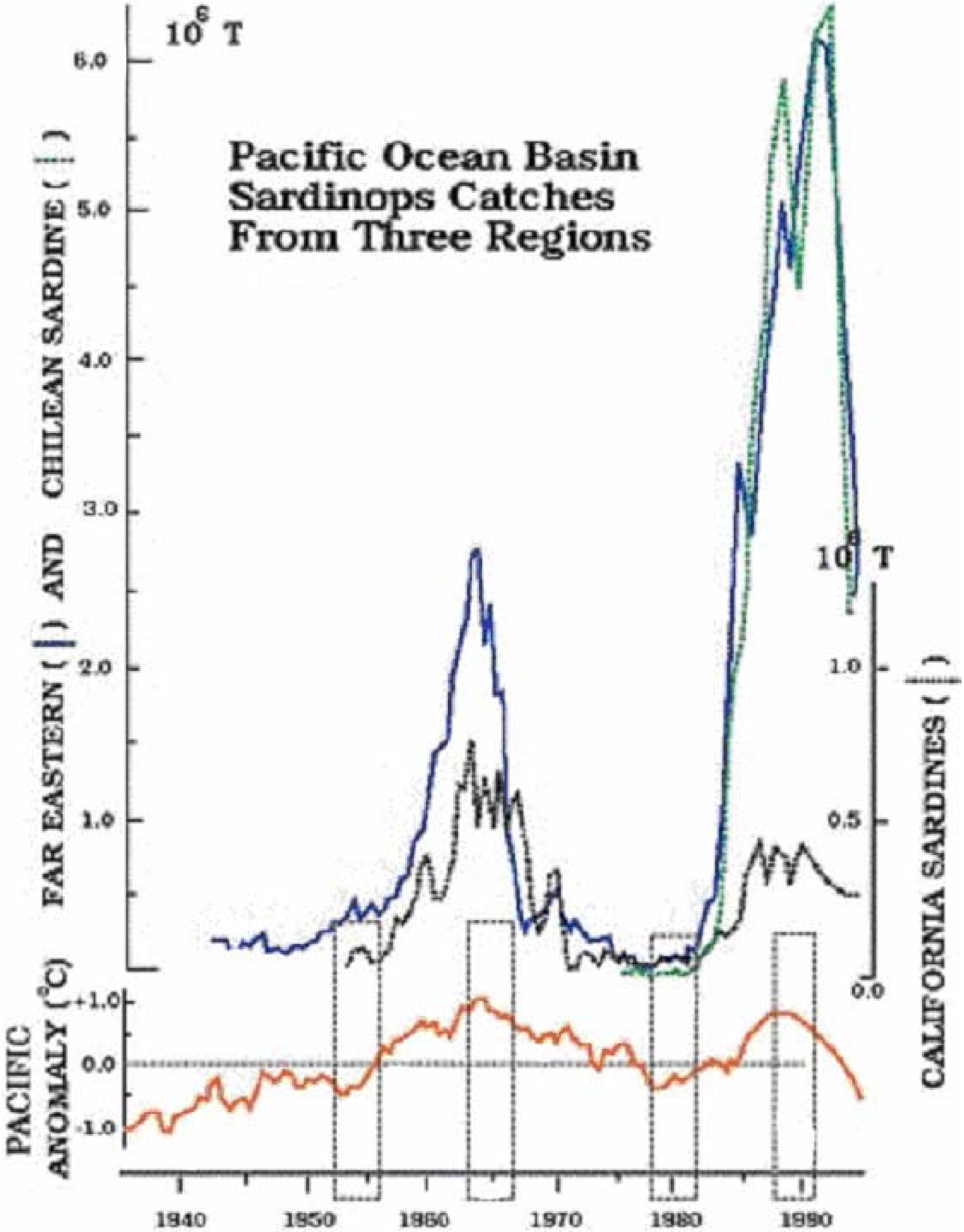
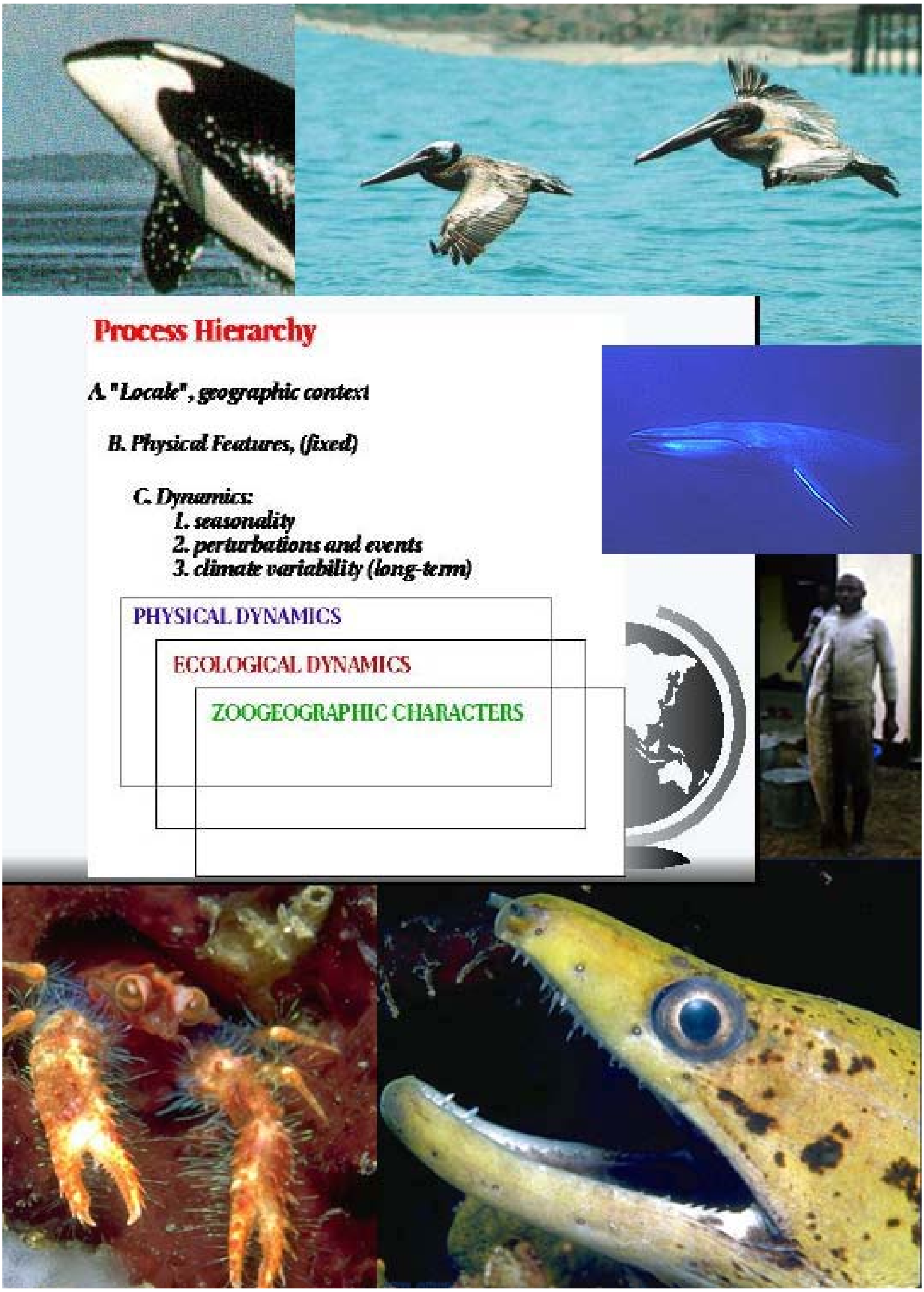


Figure 7 Is an update of the now famous Pacific Sardine Trilogy from Kawasaki *et al.* (1991) in which plots of ocean temperature changes off coastal Japan show the insightful relation of population blooms to upward sea surface temperature (SST) trends – as a starting place. Declines appear to be related to ocean cooling (along shore wind-driven upwelling periods – see Figure 4 – and related explanations).

Figures 8 and 9 show that many forces and processes interact, and ultimately reach downward to the all-important local scale where the critical life-history processes of fishes – and other species – take place (Sharp 1981a, 1988).



Process Hierarchy

A. "Locale", geographic context

B. Physical Features, (fixed)

C. Dynamics:
1. seasonality
2. perturbations and events
3. climate variability (long-term)

PHYSICAL DYNAMICS

ECOLOGICAL DYNAMICS

ZOOGEOGRAPHIC CHARACTERS

Figure 8 The Process Hierarchy (Sharp 1988, 1997) extends outward from each local living resource's (or researcher's) perspective: The objective is to understand the patterns of change in each of the three coloured strata, and how they result in the spatio-temporal dynamic zoogeography that we depend upon for sustenance.

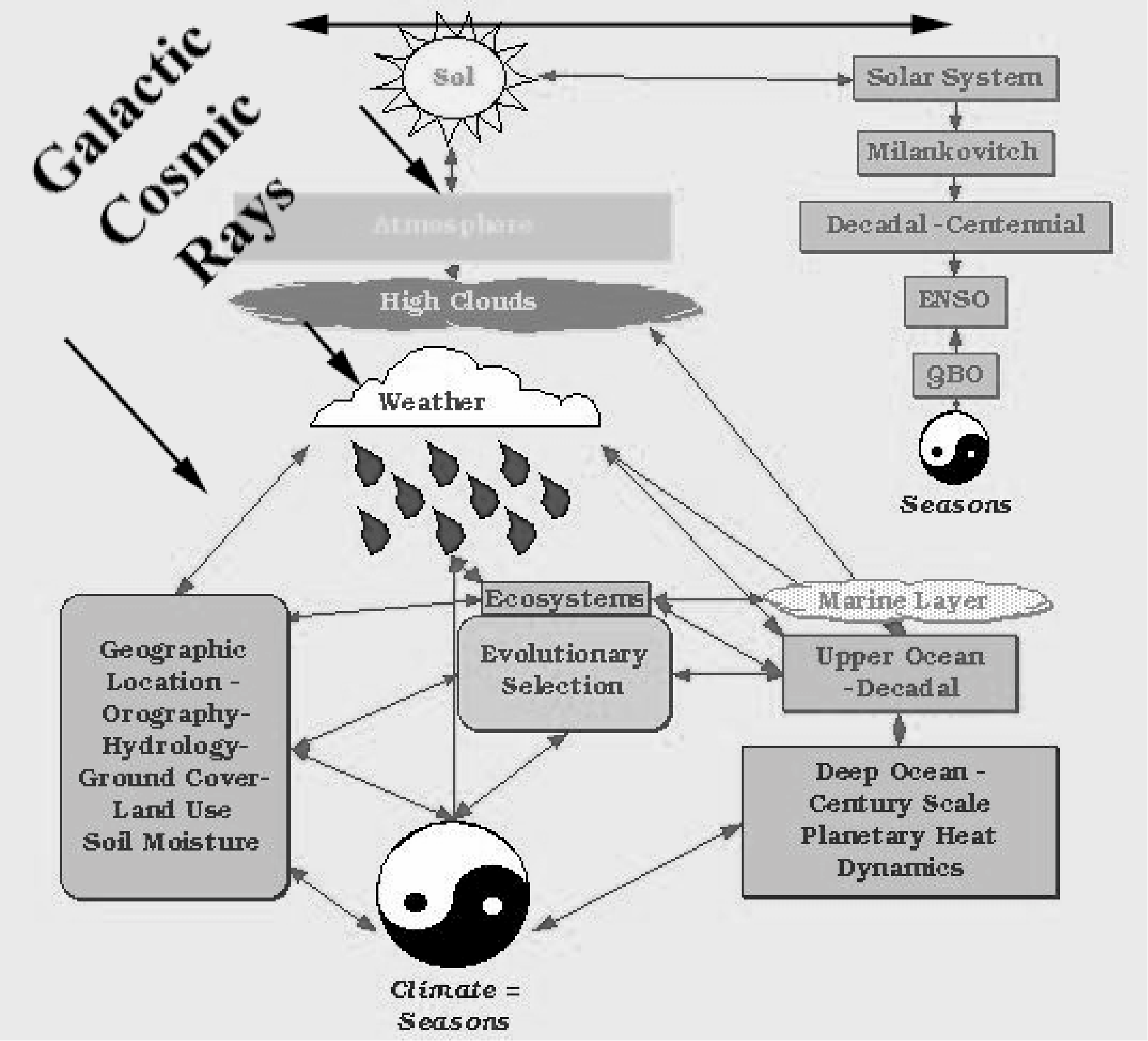


Figure 9 Connected icons show some conventional sun/climate/ecological interactions. These are shorthand for very complex, non-linear processes that are many cases difficult to measure and model. They each operate on very different time and space scales. (Note that all these processes take place within a steady hail of Galactic Cosmic Rays (c.f. Ed Mercurio's URL for website review), arriving from all directions, and myriad sources beyond our influence, or general knowledge, providing forcing for poorly understood processes).

The fisheries questions have converged on somewhat direct local and regional measures of an array of factors, from wind speed, upwelling and downwelling rates, primary production, and species interactions. This has evolved into Fisheries Physiological Ecology, hopefully now maturing into Systems Ecology. For example, ocean primary productivity is a measure of growth and reproduction of algae and other plants. The resulting growth is a complex consequence of available nutrients, light, and temperatures, as well as predation rates and parasite loads. The oceans, and therefore their all-important plants, also respond to local weather such as wind speed, cloud cover, and incident sunlight. Primary production is only the first of several stages in transformation of nutrients and carbon dioxide into living cell building blocks Meanwhile there are ongoing debates over how to truly measure and quantify primary production (c.f. Welchmeyer *et al.* 1999). It is difficult to start from conventional Light/Dark bottle measures and deduce potential fisheries production. In all aquatic ecosystems, primary production is seasonal, as the winds, light levels, and needed nutrients vary over time, with the weather/climate. So here the initial connections to biological variability are found.

The predator-prey network, known as the food web, takes over after these initial light-driven chemical transformations, and relays the energy and materials throughout the Trophic Pyramid, and on into the broader Ecosystem. Systematic variations, i.e. annual seasonal, ENSO-related and longer, involve processes that are usually found to be analogous to the Warm/Cool ocean fish faunal dominance shifts that result in the 50–70 year start-to-end phenomena that are now recognized as two 25–35 year "Climate Regimes" within the basic cycle. These issues are reasonably well described in several early and recent compendia of research and monitoring requirements for ecosystem-based fisheries management (Caddy and Sharp 1986; Gomes, Haedrich and Villagarcia 1995; Boehlert and Schumacher 1997).

Many have asked "Why has fisheries management been so ineffective?"

Within the contexts that most ocean fisheries operate, the causalities for many of the observed phenomena have been quite elusive. It seems that every year we learn about more influences from beyond any locally measured fishery, or ecosystem, that can affect resource status and thus fisheries productivity. We have also learned that, primarily, the essential system-wide information collection has been resisted due to "cultural differences" between agency-based stock assessment staff, fisheries scientists, and fisheries oceanographers. Stock assessment has evolved into an accounting art form that employs generic mathematical logic structures and an array of simplifying assumptions to create "model" populations whose major interactions are defined as post-recruitment fishing mortality. Most every other source of variability is "assumed away", or combined within a "well recognized" constant (i.e. q, the catchability coefficient – c.f. Sharp, Csirke and Garcia 1983) – and ignored. The other two applied fisheries sciences' methodologies adopt mostly simplifying assumptions that are appropriate to dynamic ecosystems and subsequent fisheries interactions.

Does that mean that everything in the oceans needs to measured – everything that effects every component of marine ecosystems? Not really. It does, however, strongly suggests that more integrated approaches amongst the geosciences, fisheries science, and fisheries management need to be encouraged.

Many fisheries scientists and managers would find fisheries forecasts to be very useful. They would also value any proxy information that offered reasonable lead-time, and yield insights into when, for example, changes might occur in the warm-low upwelling – or the contrasting cooler, wind-driven upwelling periods. Time and space scales of the phenomena needing monitored by climate and ocean researchers provide the major dilemmas. It is not only the local fisheries variations that cause problems, but the ever-expanding time and space scales of the various forces that shape these local phenomena. The questions and their respective answers become particularly complex when dealing with ocean ecosystems.

2.2 Climate patterns vs weather patterns

Likewise, the distinction between weather and climate needs to be made clear, reflecting the various media involved. While daily weather patterns are most dynamic, within their seasonal and local contexts, ocean weather has its own time and space scales. These ranging from near instantaneous responses to changes in surface winds and light levels, to lagged responses associated with the hierarchic transfers of forcing processes, into the depths, and outward from the stimulus force in the form of waves, at the surface and otherwhere.

The relative stability of essential habitat and other essential conditions for locale-specific fish population survival have been described elsewhere (c.f. Sharp 1988, and the Aquatic Ecosystems series within Elsevier's Ecosystems of the World, David Goodall, editor in Chief). Surface Winds, Currents, Tides create the physical movements associated with diurnal, monthly, and seasonal weather that affects ocean processes. Sunlight is fundamental to the biological productivity, and is modulated by clouds, seasons, and general circulation dynamics forced by the surface winds, currents and tides. Bakun and Parrish (1980) made the first comparative study of eastern boundary current upwelling systems, focused on seasonal surface wind field forcing. Hunter and Sharp (1983) provided the insight into comparative global and regional consequences of tidal forcing. While others have focused on specific regional patterns of responses, Caddy and Bakun (1994) surveyed global production processes related to fisheries. Seasonal currents are best evidenced in monsoon related studies, such as those described by Thompson and Tirmizi (1995) and Pauly and Matsubroto (1996) while the entire ocean reflects the complexities of seasonal and longer term wind field changes that along with the earth's rotation and tidal forces that produce the complex seasonal to climate-scale ocean current dynamics, and diverse ecological responses.

Events vs Weather vs Climate – define the dilemma of those studying and hoping to forecast ocean fisheries production. Nowhere in Nature is this dilemma more obvious. When the oceans' constant motions are enhanced or perturbed by "unique" events, such as the closure of the Panama Isthmus, or a Tsunami (unleashed by a strong seismic event) – currents and tides are subjugated to novel forces, depending upon the longevity of the changes and forces. In the first case, somewhat permanent changes are forced, both locally, and basin wide. In the other, once the Tsunami's energies have been dissipated, only minor oceanic ecological influences are likely, despite any permanent changes that occur nearshore or upland. On short time scales, locales can be altered in dramatic fashions, and become important to ecological processes within entirely different contexts.

Weather, on the other hand, is the "normal" expected pattern of change shaped by both seasonal forces and remaining footprints from previous forces, embedded in the ocean's fluid dynamics. These "footprints" are the first vestiges of climate processes, and can be observed as measurable deviations from the "normal" expectations for each site, and time period. Therefore, the annual seasonal cycle is considered to be the limit of weather, per se. Anything that substantially perturbs this pattern is termed a Climate Change, or maybe just an "Event". El Niño – Southern Oscillation Events are the most frequent of these "expected" climate perturbation processes. These phenomena have been most identifiable in their tropical contexts (c.f. Allan, Lindesay and Parker 1996), but recently, with more sophisticated space-based observing tools their influences can be tracked from their source into the polar oceans (c.f. White, Chen and Peterson 1998, Wyllie-Echevarria and Wooster 1998). Varying in frequency and intensity, over time, ENSO Events often create the dilemma of defining real Climate Changes. Certainly there is a lot more to be learnt about the various larger scale forces, so that their sequential effects are better understood.

2.3 Historic climatic changes and social and fisheries responses

From the results of paleoclimatic, paleosediment and climate studies, it deals with global patterns of climate change and marine ecological responses. For example, studies of undisturbed anoxic sediments from the Santa Barbara Basin, off Los Angeles, provided a dynamic changing abundance sequence for sardine, anchovy, and other fishes for nearly two millennia (c.f. Soutar and Isaacs 1974, Baumgartner *et al.* 1989, Sharp 1992). Clearly, humanity is dependent upon many uncontrolled, yet patterned processes. The race to discover climate indices that provide forecast capabilities for known phenomena has escalated.

The key to understanding and relating the relationships between these extended time scale observations and the shorter record sets used by Global Warming buffs, is to compare the relative variability of the shorter and longer sequences, on a standard scale. Because the majority of instrumental measurement records extend from 1950 or more recently to the present, it is easy to, do analyses, and make graphics to present trends that too often turn out to be out of context, or misleading. One of the more important points that is made is the fact that the recent 50-year period of extensive climate records is notable for its lack of dynamics, and low variance in comparison to century or longer time-scale records.

Climate is the long-term average expected seasonal pattern, while weather is the more variable seasonal phenomena that are observed. The most powerful, identifiable sequence of ocean-atmosphere interaction-driven events that perturb expected seasonal Climate Patterns are ENSO Warm and Cold Events, respectively known as El Niño and La Niña. But even the intensity and frequency of ENSO Warm Events vary in time, on decadal and longer time scales as documented in Figure 10. So, the need to recognize, as well, that climate – and related ocean productivity (c.f. Hubbs 1960; Laevastu and Favorite 1980; Nixon 1982, 1988, 1997; Ebbesmeyer *et al.* 1991; Murawski 1993; Polovina, Mitchum and Evans 1995; McGowan, Cayan and Dorman 1998; Reid, Planque and Edwards 1998; Reid *et al.* 1998; Hollowed and Wooster 1992, 1995) – varies on several time and space scales – but discounted as being an unaffordable requirement by Hilborn and Walters (1992), to which I respond “If it is not monitored and accounted for, what value are the estimates and analyses without it?” However, climate indices and fisheries Bloom and Bust cycles appear to vary in similar patterns (Figure 11). The real issue is whether, once again, there is a direct causal link, or these are merely correlated consequences of larger scale processes. The answers lie in monitoring linked processes and collation of observations on all time and space scales.

From studies of Earth climate history, from weather observations made routinely since 1854, it can be seen that the Earth’s last half of the twentieth century’s seasonal dynamics were really not very great, relatively speaking. These are records from the Comprehensive Ocean and Atmosphere Data Set, or COADS, which have been compiled for climate research. One important lesson from the COADS observations, as is that the strongest climatic signals are found in the winter month patterns, rather than other seasons – or annual means. The Winter-Only patterns are therefore a good place to start looking for right questions about climate variation. Figures 12a, b, and c, show the Winter Surface Wind departures from the long-term mean since 1854. Note that although the scales vary by latitudinal band, and ocean basin, the patterns are quite similar, with short regional leads or lags. Also note the monotonous slow upward trend of the recent 50 years, in contrast to the previous century.

Everyone should be aware that the last deep Ice Age ended only 18 000 years ago, and that most of the Earth, at latitudes higher than about 45ºN and about 50ºS were under or affected by glacial ice. Every species, fish, mammal or birds, that can be found today at these and higher latitudes have “recolonized” during the ensuing warming period. These same populations have also more often than most people recognize, been pushed back and forth in response to decadal to century-scale climate changes by repeated glaciation/deglaciation.

Without recounting all of human history, humans actively responded to these changes through migrations, and myriad colonizations, and recolonizations.

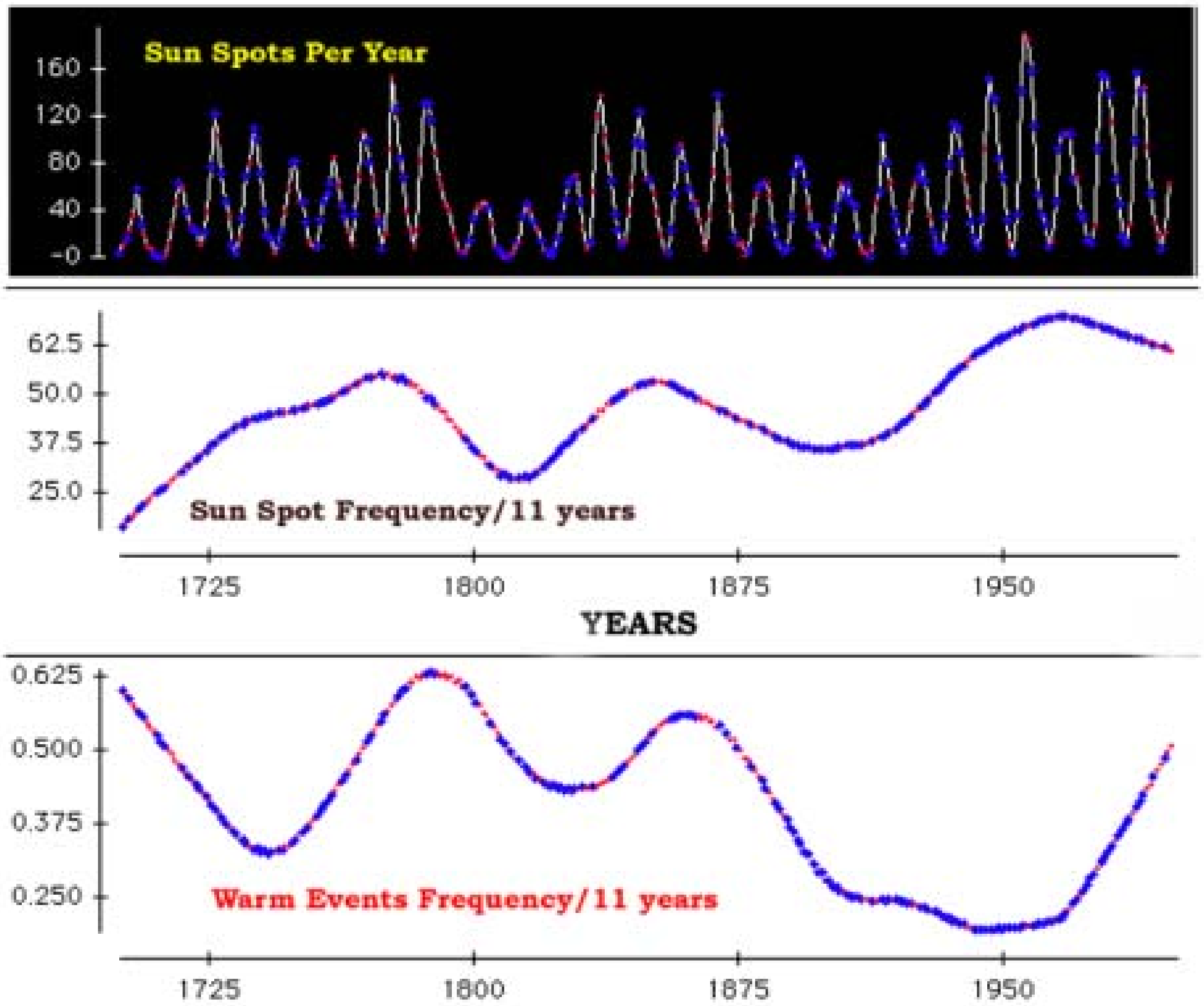


Figure 10 Shows the time series of ENSO Warm Event Frequency from Quinn (1992) plotted against sunspot numbers (top), and sunspot frequency for averaged 11 year records. Quinn employed the Nile River gauge data, ships logs, and assorted local records from various missions, outposts and family steads to create the time series. Note that the frequency records were the lowest from about 1890 until about 1975, suggesting that Average Global Temperatures have little to do with ENSO Warm Events.

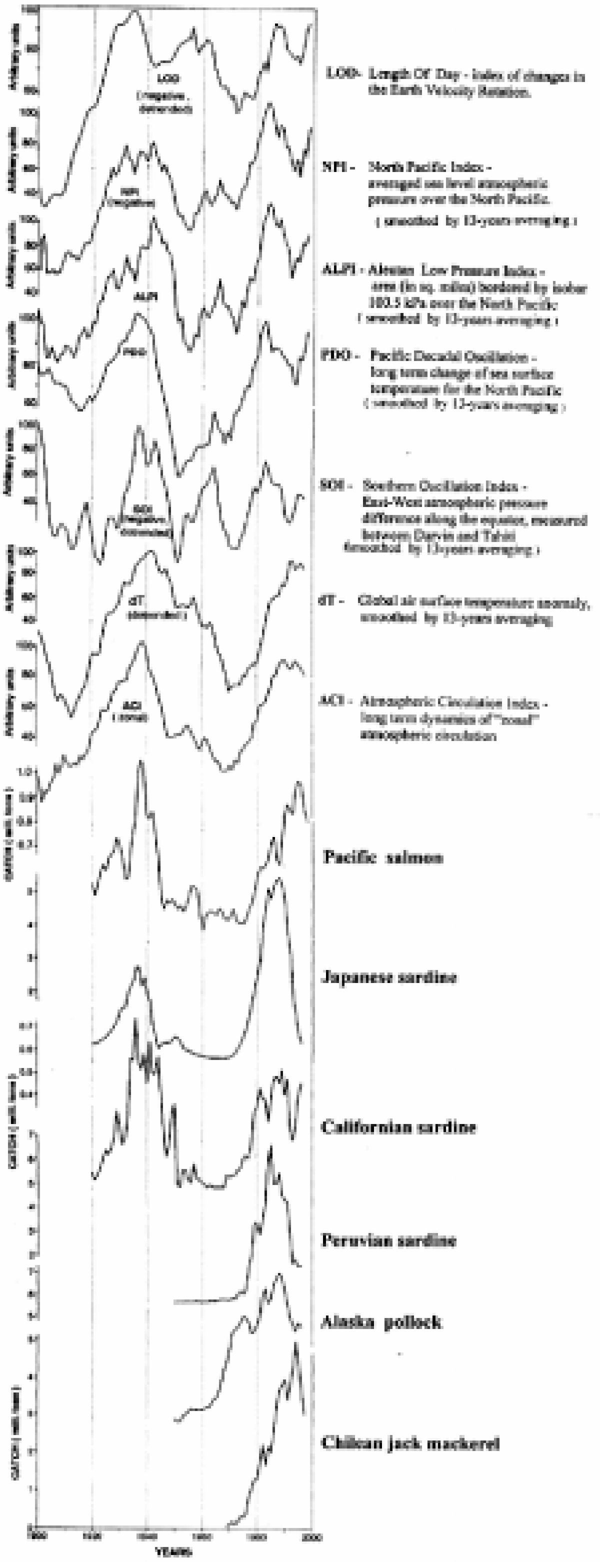


Figure 11 Provides a comparison of several of the available climate indices, including the rise and fall of a characteristic group of the Warmer ocean associated major fisheries catches. Correlates – or causes?

Hunting and gathering dwindled as they were replaced by integration of farming, herding and ranching, done outside the walls of larger population centres. People thrived under stable warm wet periods. As a result, at the end of the Medieval Warm period (twelfth century) it has been estimated that there were about 300 million humans.

Despite enormous losses of life and displacements due to plague, smallpox, and other diseases transported about the world by travelers, or into homes by vermin during the cooler era that intervened, by the early Nineteenth Century the human population had attained about one billion. It has taken less than two hundred years since then to reach six billion. Meanwhile, on the oceans, fishing activities expanded. Navigation tools and many other technologies were developed, allowing fleets and new methods to spread unrestrained, until fleet growth and landings from the sea finally began to slow down in the mid 1980s, and eventually, decline – as fished populations responded, and quantities and qualities of products shifted (c.f. Pauly *et al.* 1998).

Aquaculture also expanded more or less continuously with human population growth, since early Chinese efforts and local projects (Sharp 2001). Most of the fish culture activity was "put-and-take" in the sense that the organisms, e.g. carp, *Tilapia*, oysters, etc., were most usually only relocated. They were expected to "feed themselves" by eating the algae production and other nutrients from pond systems. Heavily utilized habitats, e.g. rice paddies or ponds, were fertilized using human and animal wastes. However, as many regional fisheries leveled off – or failed, the "enhancement" of natural fish populations became a focus.

Atlantic Ocean Wind Speed Departures

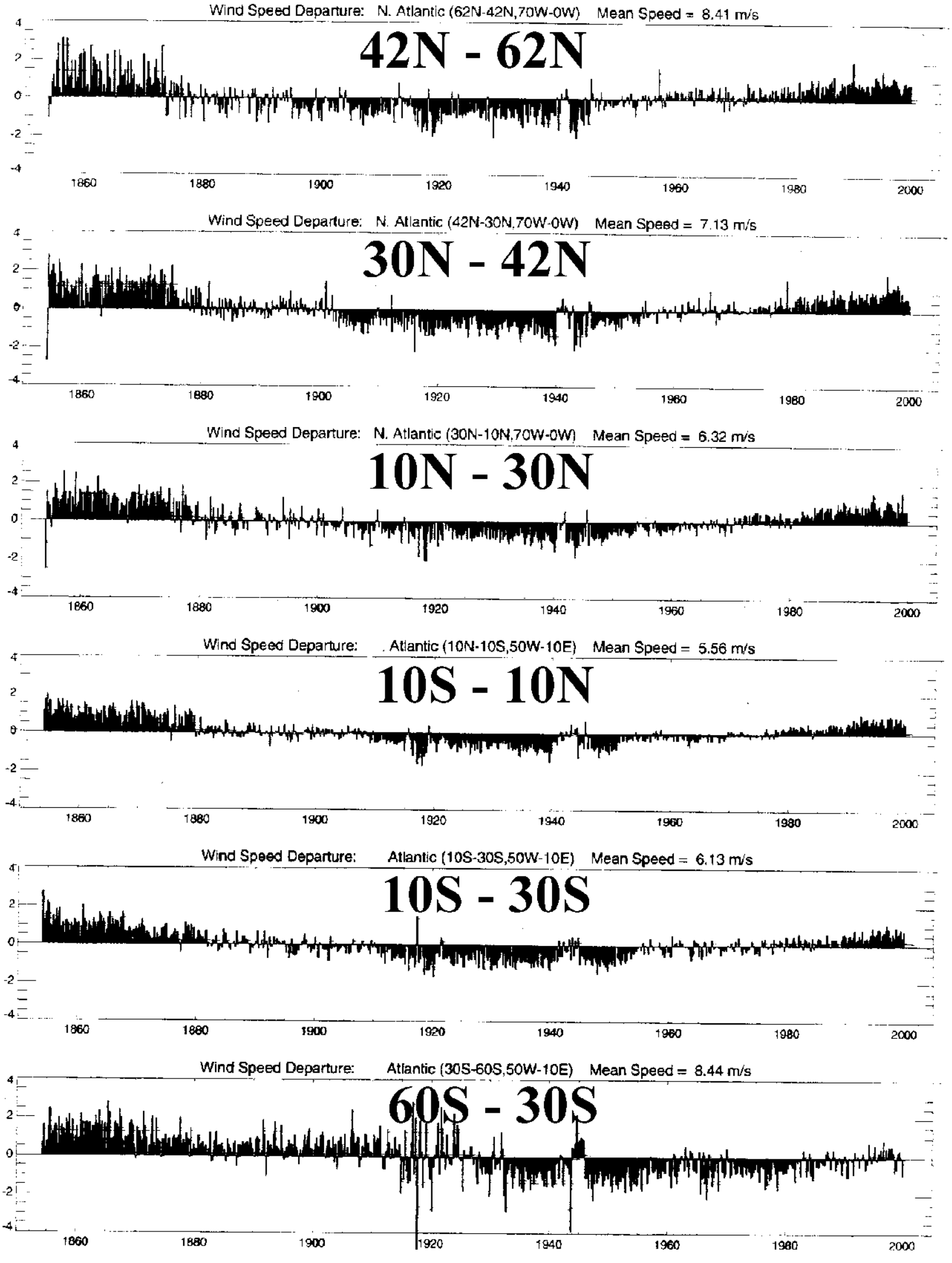


Figure 12 a

Pacific Ocean Wind Speed Departures

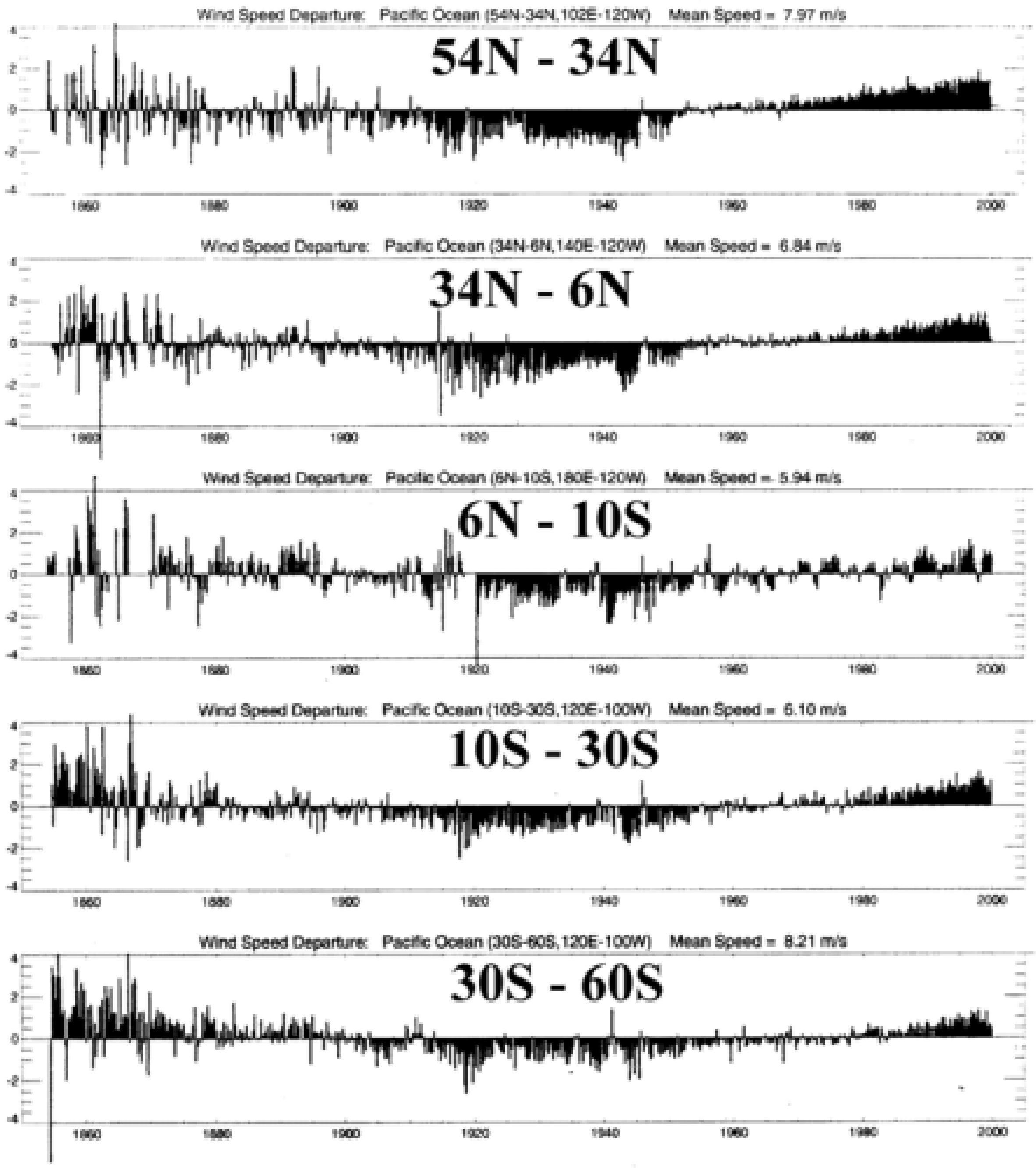


Figure 12 b

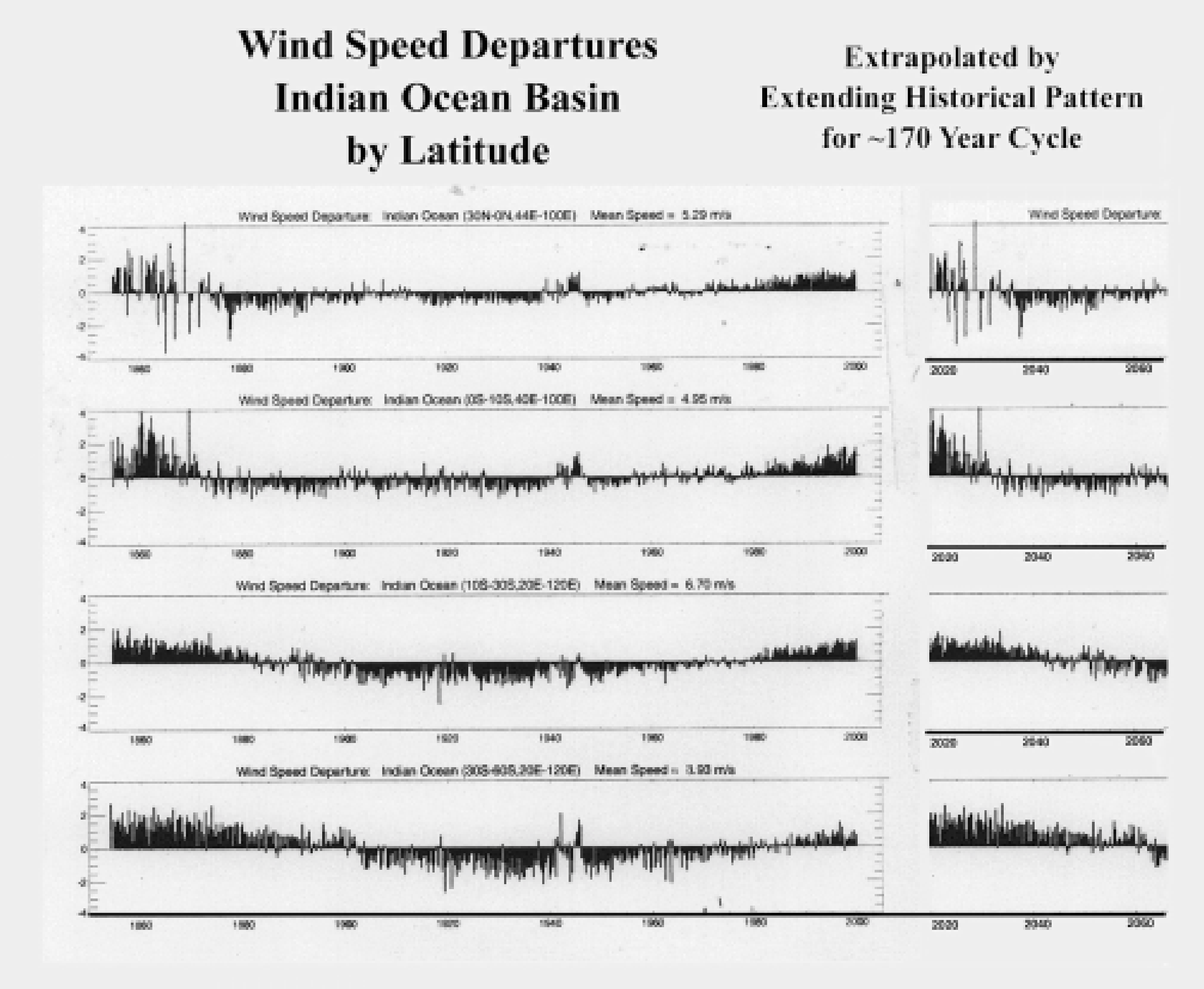


Figure 12 c

Figure 12 Are time series of average Wind Speed Departures from the mean wind speeds, (given for each sector) since 1854 for latitudinal sections of the three ocean basins, (a) The Atlantic; (b) The Pacific; and (c) the Indian Ocean. Note the similarity of the trends for each record and all the regions. The Indian Ocean records (c) has had the early part of the records “added” onto the right side of the graphic, to show the likely pattern of these wind records, if they do indeed follow the 170–180 year repetitive pattern as suggested by paleological records that measure solar activities. These are used by Dr Fletcher to help construct a Climate Futurecast for the twenty-first century.

The first seafarers were likely the folks who colonized Australia from Southeast Asia, some 40 000 years ago, about the same time that the last Glaciation began. There have been many pulses in and out of Africa, due to extended drought, and then recovery. The development and rise of seafaring under the influence of the seasonal monsoon around North Africa and the Indian Ocean was a major contribution to the cultures that evolved along these shores. People that colonized inland areas or coastlines where more erratic climate influences dominated tended to be migrant. They were also more likely dependent upon hunting and gathering, with some local fishing activities. There were also several well-documented subsequent climate changes that supported the aggregations of agricultural communities, and the development of specialty trades, and barter economies. Recurrent drought was their nemesis. These peoples' primary assets were the evolving technologies that made agriculture more efficient.

Various fisheries had undergone collapses, and the fishermen either learned to fish for other species, moved into other areas where they would look for similar resources, or took up other means of making a living. This included crewing exploratory vessels, industrial whaling ships, or eventually, trading ships. The mid nineteenth century collapse of the Arcto-Norwegian cod resource stimulated G.O. Sars to develop the concept of rearing early life history stages, to protect them against natural predation and starvation, and thus enhance their survival to stages and ages at which they were less vulnerable, and more able to fend for themselves. He developed artificial propagation of marine fish fry in Norway. Sars fertilized, hatched and released 67 million cod yolk-sac fry. G.O. Sars is credited for starting modern fish hatcheries for restocking declining fish resources – and modern fisheries science as well. This approach has thrived since the 1850s until today.

The next era began in 1872 as North America's history of fish hatcheries began when the American Fish Culturists Association Appropriated $17 000 for the Government to begin fish culture development. Also in 1872 Livingston Stone made the first salmon egg collection for artificial fertilization, at Baird Station on the McCloud River. On 10 October 1872 he shipped the first 30 000 chinook salmon eggs via rail, of which 700 survived to fingerling size.

Back in Norway, in 1882 Capt. Gunder Dannevig founded the Flødevigen hatchery at Arendal, Norway, beginning a century-long cod enhancement program that was finally closed in the 1980s, only because the hatchery staff had never really bothered to prove that the released codlings were caught in local fishery. Also in 1882 – Adolf Nielson, a Norwegian fish hatchery employee visited Newfoundland, on request, and helped create an initiative to build a fish hatchery at Dildo Island, to refurnish the failing cod recruitment off Newfoundland. The project was halted in the late 1880s, as the cod had recovered on their own, thus providing early insights into Nature's patterns. Apparently there was a sequential failure of Atlantic cod, that spread from east to west, as environmental conditions shifted in time and space. Their recovery occurred in similarly lagged temporal and spatial contexts. During these "collapse periods" other species thrived, some from absence of predation by cod, and others due to the distinctly different ambient patterns.

In 1981, the Norway's Svanøy Foundation sponsored a workshop on cod culture to review the history and ongoing activities in Norway. Of particular interest was the concept of raising codlings in nets underneath their burgeoning industrial salmon culture pens, to take advantage of the uneaten feed that passed through the pens as a result of the satiation-feeding approach that was used. This resulted in a cod culture effort that was sometimes quite successful. Other times, and places, it failed. Workshop attendees encouraged Norwegian fish farmers to include cultured cod juvenile-tag-and-recapture studies. The eventual results of the tag/recapture studies that ensued were more than encouraging, as within the first few years, up to 20 percent of the tagged cultured fish were returned from the local fishery, proving, finally, the worth of cod culture. Of course, there were years when entire stocks of the young codlings were wiped out by blooms of various invertebrate predators in the grow-out ponds before they were released, and other years when they were likely eaten by abundances of predators within the fjord system before they got to sea.

The major message that stimulated most of the ensuing stock-enhancement activity is that there are no guarantees from Nature about year to year recruitment successes (c.f. Smith 1978; Csirke 1980; Sharp 1981a,b; Bakun *et al*. 1982; Kawai and Isibasi 1983), nor decade to decade population stability (Kondo 1980; Csirke and Sharp 1983; Sinclair 1988; Ware 1995; Ware and McFarlane 1989; Ware and Thompson 1991). Thus the generic failure of most conventional stock forecast models based on "mean" expectations (Sharp, Csirke and Garcia 1983; Koslow, Thompson and Silvert 1987; Koslow 1992). The obvious answer to the individual species dynamics is best expressed through the various unique population responses of the major fisheries stocks identified by Klyashtorin (1998, 2001) for which Catch Statistics exist for nearly a complete century, or about the minimal reference time to relate climatic causes and effects (see Figure 13, below).

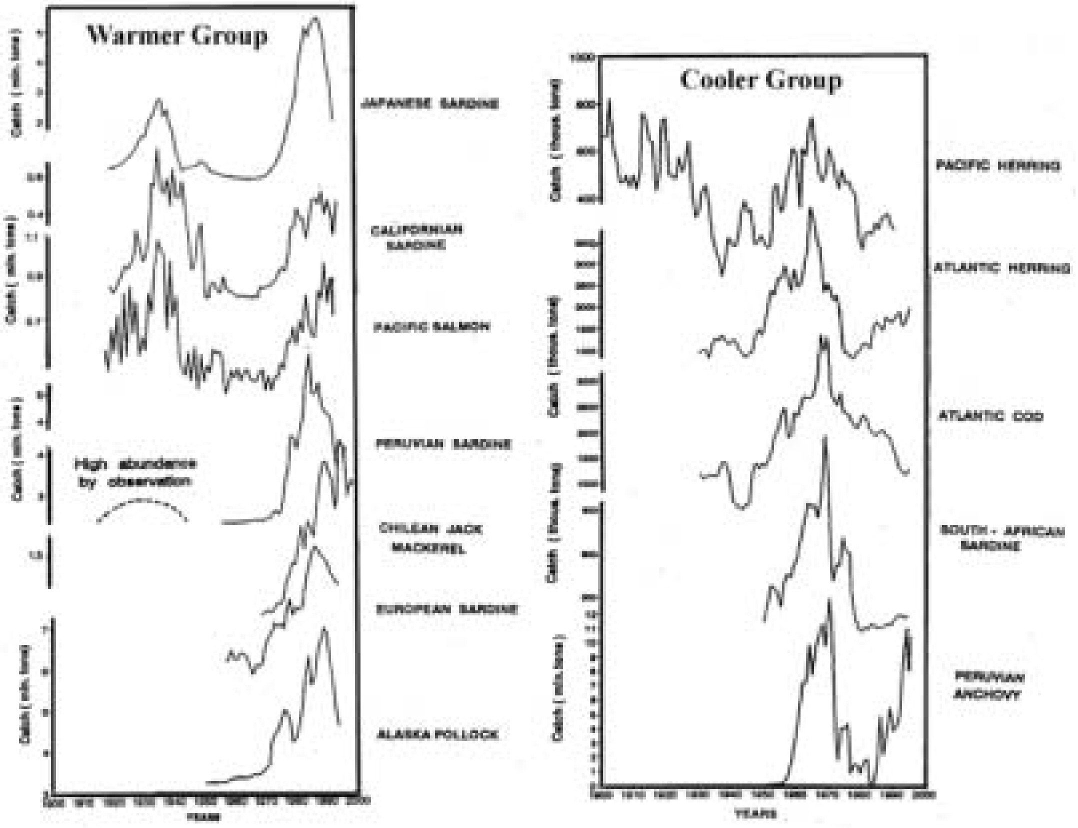


Figure 13 Provides species by species commercial catch histories for 12 of the world's most productive fisheries (Klyashtorin 2001). Each region has a major fishery production from each period when warmer corresponds to more zonal (east-west) winds, and the cooler period are dominated by meridional (north-south) winds. The latter tend to induce coastal upwelling, and nearshore production, while the warm periods depend upon other modes of nutrification and ecological production. Both are reflected in patterns of specific ACI and -LOD changes.

For most productive regions, there are two quite responsive populations, each of which thrives on opposite extremes of the normal climate variations within the ~55–70 year dipolar periods. A third, less responsive, usually much more numerous species group simply wobbles along throughout this variation, some never blooming, others like the *Sebastes* species, having spikes in larval survival and rercruitment successes that carry them for periods longer than 50 to 100 years (Norton and Mason, in press).

The efforts to culture fishes, and then enhance natural populations is closely related, perhaps even analogous to the transition from hunting and gathering to early herding and farming activities in the middle east. During the third–fourth millennia BC, when people began to plow, channel waterways and create large-scale irrigation projects (c.f. Fagan 1999). These activities provided support and access to exotic species. Many dilemmas occurred as a result of these introductions, including fish from other geographic locations.

Historically, aquatic and other species have been introduced from various homelands and from many ecosystems into otherwise once-isolated ecosystems, including islands and lakes, to provide food and sport. There were many unintended “exotic species” introductions that have plagued humans since migrations and ocean explorations began. Favoured food and servant species were also shipped as people immigrated and colonized other continents and oceanic islands via the ocean. Today, ballast water, shipping containers, and various other sources dominate these “surprise” deliveries, and created havoc and unplanned species competition wherever waterways are involved. Entire ecosystems have been modified, and in some cases, “natural” fish production substituted with culture or introduction of more valued species such as tropical shrimp, and Nile perch.

3. REGIONAL ECOLOGICAL RESPONSES TO CLIMATE CHANGE

Regional ocean primary productivity is a measure of growth and reproduction of algae and other plants (see reviews: Smith 1978; Ursin 1982; Pauly and Tsukayama 1987, Pauly *et al* 1989; Longhurst 1995; Longhurst *et al.* 1995; Polovina*,* Mitchum and Evans 1995; Ware 1995; Sharp, Klyashtorin and Goodridge 2001a,b; 2002). Like a backyard garden, the resulting growth is a complex consequence of available nutrients, light, and temperatures. The ocean, and therefore oceanic plants respond to local weather such as wind speed, cloud cover, and incident sunlight. Primary production is only the first of several stages in transformation of nutrients and carbon dioxide into living cell building blocks.

To help introduce ecological and regional scale dynamics, focus has been given on the COADS data set, above, with the periods of greatest transition in the available fisheries records outlined, as in the Pacific sardine or northwest Africa’s fisheries. Wind speed is directly related to thermal energy (temperature), and resulting global hydrologic cycle dynamics. There are many measured proxies for regional climate states. Analyses of various atmosphere and wind indices are described. One of the results of climate-ocean-atmosphere-biosphere dynamics are measured changes in the Earth’s rotation rate, or negative Length of Day (-LOD). The intent of the following discussions is to help promote the general understanding about these nested processes, their proxies, and the several time and space scales that need considered in order to make better decisions.

3.1 Long-term productivity changes

Twentieth Century fisheries scientists have provided abundant examples and documentation to show that fisheries dynamics involves much more than only fish and fishermen. (c.f. reviews by: Hjort (1914, 1926), Revelle (1947 note to John Isaacs, quoted in Scheiber 1990), Bakun *et al.* (1982), Bakun (1996), Sharp and Csirke (1983), Csirke and Sharp (1983), Glantz (1992), Sharp (1997), Boehlert and Schumacher (1997), amongst many others). Their common thesis is that the oceans, hence fisheries are connected to larger scale dynamic processes and remote forces. Together, these forces and processes reach downward to the all-important local scales where the individual critical life-history processes of fishes take place. Fisheries related questions have converged on somewhat direct local and regional measures of an array of factors, from wind speed, upwelling/downwelling rates, primary production, and species interactions. This has evolved slowly, and quite independently from limnological science. The basis derives from laboratory and field studies on early history of ocean fishes (reviewed in Sharp 1981a, 2000). Systems Ecology has finally arrived in the pragmatic world of fisheries management.

Most ocean species thrive near the middle of their temperatures tolerence ranges, see Figure 14 below, in which the commonest ecostrata are represented by the separate colours. For most local species, increased thermal stress occurs at or beyond either warm or cold extremes (Sharp 1998). Primary production is driven by seasonal processes, modulated by wind and light levels and often is most active at the interfaces of these “compartments”. Species with broader tolerances often have unique physiological and anatomical features, and many of this group have evolved large adult sizes, and wide migrations. There are not really many generalities about where in the food web that these species are most likely to be found, as most of the fishes start life as small, lower trophic level feeders, and work their way upwards. Others, like the balleen whales, whale shark and manta rays, never graduate from their need to filter feed on planktonic forms. These species thrive within the edges, while sea turtles consume primarily jelly fish, which comprise 90% water, a seemingly impossible scenario.

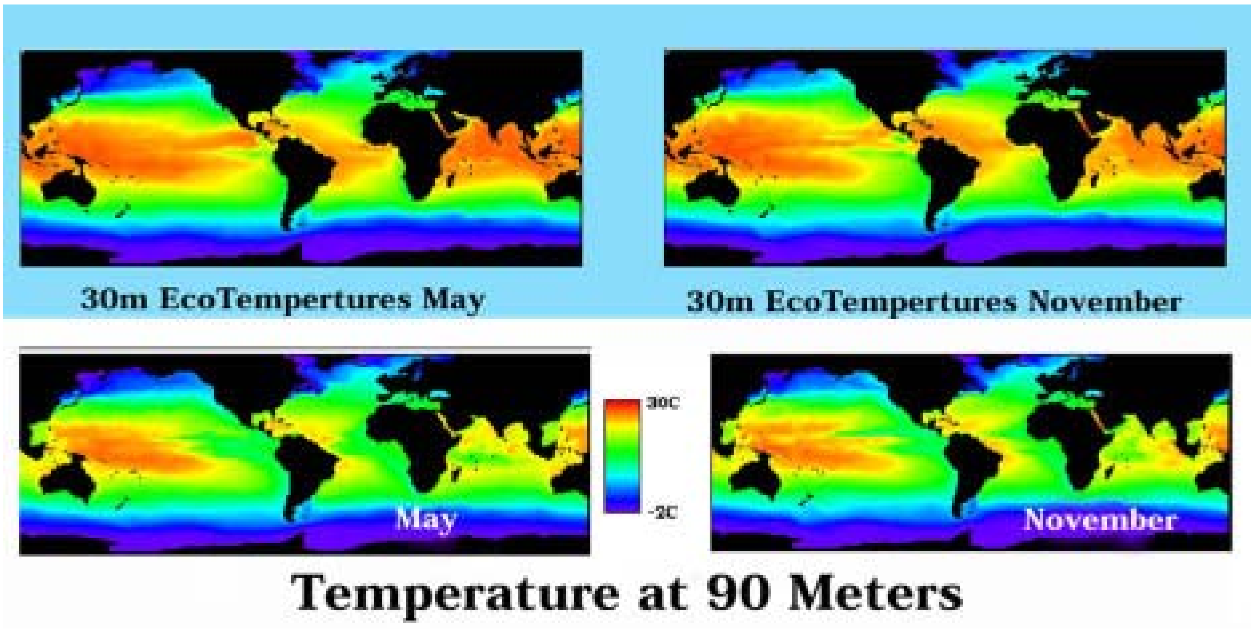


Figure 14 Provides pragmatic perspectives of the seasonal Global Oceans Climate Zones, for May and November, the months with the most extreme seasonal signals. The transition zones in the climatological 30 meter temperatures, i.e. where thermal gradients are strongest, form natural EcoTemperature compartments, or ecotomes. Temperature boundaries are >26ºC; 23ºC; 20ºC; 14ºC; 9ºC; 5ºC; and 2ºC and below – within which the various ocean ecosystems have evolved. The 90 meter patterns imply more about light limitations and temperature related primary production than do SSTs, alone. Each ecotome’s seasonal overall productivity reflects dynamic physical and ecological interactions.

The predator-prey network, known as the food web, takes over after the initial light-driven chemical transformations, defining the relays of energy and materials throughout the Trophic Pyramid, and on into the broader Ecosystem. In all aquatic ecosystems, primary production is seasonal, as the winds, light levels, and needed nutrients vary over time, with the weather/climate. So the first connection to biological variability is found. From the results of paleoclimatic, paleosediment and climate studies, global patterns of climate change and marine ecological responses are clearly being dealt with. For example, studies of undisturbed anoxic sediments from the Santa Barbara Basin, off Los Angeles, provided a dynamic changing abundance sequence for sardine, anchovy, and other fishes for nearly two millennia (c.f. Soutar and Isaacs 1974, Baumgartner *et al*. 1989, Sharp 1992b), obviously not driven by fisheries, as none existed prior to the late nineteenth century.

Because the majority of instrumental environmental measurement records extend from about 1950 or more recently to the present, it is too easy to make graphics, do analyses, and present trends from these short series that often turn out to be misleading relative to future climate patterns. The key to understanding and relating the relationships between the available extended time scale observations and the shorter record sets used by Global Warming buffs, is to compare the relative variability of the shorter and longer sequences, on a standard scale. One of the more important points that are made is the fact that the recent 50 year period of extensive climate records is notable for its lack of dynamics, and low variance, in comparison to century or longer time-scale records. Despite the Earth's longer term changes in energy balance these appear to provide for reasonably stable seasonal climatic patterns, although there is clear evidence that these can shift from one extreme state to another in very short term (i.e. a few decades – c.f. Shen *et al*. 1992; Southward, Butler and Pennycuick 1975; Southward, Balch and Mattock 1988; Allen and Anderson 1993). These are referred to as Climate Changes. Climate is the long-term average expected seasonal pattern, while weather is the more variable seasonal phenomena that are observed. ismissal of these dynamics, and their fisheries contexts (i.e. Gulland 1983; Hilborn and Walters 1992 – reviewed in Sharp 2000) has driven the continual resource management model failures.

3.2 Behaviours of particular ocean ecosystems

1. **Tropical Systems,** provide one of the best examples of general beneficiaries of intensification of climatic processes, or climate change, as the boundaries expand and contract, accordingly, but the interior near-equatorial portions undergo little that threatens any particular ecological dynamic. The vast tropical shelves and reef systems are pretty much defined by their abilities to cope with rapid changes. It is worth remembering that even the Great Barrier Reef system is a relative newcomer into the recent warming since the last Ice Age, only 18 000 years ago. The 130 meter or so rise in sea level has not been a hindrance, as much as it has created new substrate, and allowed this great system to advance it's ecological offerings.

(a) Volcanically active islands and seamounts have wakes or Taylor Columns that provide regional oceanic species with upper water column mixing, and nutrients that create, in turn, either steady, or sometimes seasonal production. Within and around these features an amazing amount of species interact, and thrive. Reefs, depending upon their locations and climate zone, provide for incredible numbers of species, some of the larger sessile forms such as Tridacna, the giant clam, attain very large size and old age, while others live briefer, more frantic lives, as they struggle up the size hierarchy, and graduate from one "refuge" or niche to the next size, as these are opened up by Top-Down predation (Polovina 1984a,b).

(b) Oceanic migrators such as the dolphin fishes and scombroids also have amazing growth rates, and huge appetites that keep them on the move from one location to another throughout their lives, looking for ever-larger prey (Abbes and Bard 1999, Bertrand and Josse 1999). Local recruitment of most reef and island fishes is certainly affected more by currents, seasonal winds, and occasional storms, but most of the species tend to stay put as adults. The young are subject to transport to and from their nursery habitats by living at or near the surface, where they “blow with the winds”, to either be eaten, or eventually find an open “hole” to fill. Failure rates for each reef species are likely unimaginably large. Or perhaps it is better to state the problem thus: survival rates are erratic, and small, at best.

Figure 15 Tropical waterspouts and stratocumulus clouds mark active deep convection cells from the ocean surface. Ocean energy, in the form of water vapour, is transferred to the atmosphere, for transport downstream, and poleward.

(c) Deep convection (Figure 15, above) in the equatorial warm ocean and along the Intertropical Convergence Zone (ITCZ), differs conceptually from surface wind forcing that drives the predominantly evapourative heat loss at higher latitudes, and the subsequent upper ocean energetic changes. Cloud cover is the primary driving force for heat retention in the higher latitudes, while the marine layer dynamics, higher water-vapour capacity and somewhat rapid nighttime turnover and sequestration of tropical ocean heat loading (particularly at SSTs >27.5C) dominates equatorward. What this implies is that under every nightime cloud, the tropical ocean deepens, and the tropical habitat grows. Several advantages accrue to oceanic tropical predators such as tunas, billfishes and marine mammals at the highly mobile transition interfaces where temperature gradients form ecotome boundaries. These gradients induce, in turn, nutrient concentrations, primary production, plankton species, and aggregations of predators, small and large. The gradients also generate surface pressure differences, hence wind to affect convergence and divergence, both important forces in the ecological interplay, and fisheries production and vulnerabilities.

During periods of ENSO Warm Events, the ITCZ shifts equatorward, e.g. the ITCZ spends more time over south Central America and North Africa, and causes great changes in hydrological and precipitation patterns over the land, as well as changes in seasonal locations of ocean features. These weather dynamics form another set of opportunities. Climate events such as ENSO Warm and Cold events promote different levels of productivity. Warm Events and fresh water run-off often cause dramatic algal blooms that sometimes cause anoxia or toxic effects, and subsequent vast fish die-offs that result in rapid energy dispensation into lower trophic forms, promoting a certain level of directed nutrient recycling that avoids the Top-Down predation pathways. Guano islands are particularly important to local production. Benthic and insular invertebrates can thus obtain irregular "boosts" in food resources that can help them attain high population levels, via enhanced reproduction and unique current-related dispersion. Erratic currents can provide for colonization of sparse or depauperate habitats. These colonies might not attract predators away from more densely populated coastal and island areas, allowing for future repopulation via habitats beyond anoxia, toxins, or predator blooms.

2A. Subtropical Transition Ecoystems – are well documented fisheries systems. After the collapse of the California sardine, in the 1940–50 period, and then the Peruvian anchoveta in the early 1970s, fisheries research was intensified in the eastern boundary currents (c.f. reviews by Schwartzlose *et al.* 1999, Sharp 2000). Throughout this century, lessons from regional fisheries studies were carried around the world, and eventually applied to many coastal and offshore species by analogy. The collapse of the cod and other major fisheries in the northwest Atlantic in the 1980s caused another shift in emphasis, as the public finally understood that it takes more than good science to manage living resources. Policy making is at least as important to consider, as are catch statistics and/or badly conceived fisheries independent survey techniques. Overzealous fleet developments seem to be a common denominator in today's crises, as national governments and foreign aid programs have pushed to increase catches, despite obvious biological and economic signals that limits have been reached or exceeded.

(a) The California and Humboldt Currents share an amazing array of species, and periodic cycling of their distributions and abundances, but differ dramatically in production potential. The peak sardine catches in the 1930–40 period off California ranged from about 500 000 to 700 000 tonnes per year, while anchovy catches peaked in the early 1980s at about 300 000 tonnes. The California sardine fishery was kept at low levels, while the Gulf of California sardine fishery bloomed starting in about 1980, and peaked at just over 250 000 tonnes in 1988, with another rise in 1996–97 to around 200 000 tonnes. The west coast of Baja California sardine catches delivered by the Cedros Island and Magdalena Bay fleets totaled from 10–35 000 tonnes since 1960. Recent total catches of California sardine that now range from Baja California to British Columbia, are stabilized at around 360 000 tonnes.

(b) The three production regions for sardine and anchovy off northern Peru, southern Peru-Northern Chile, and Central Chile produced peak catches of anchovies of 12 million tonnes (mostly from northern Peru) in the early 1970s, then collapsed. Nearly nil landings of South American sardines began to rise in about 1976, and peaked after they had recolonized all three regions, to attain 12 million tonnes, in 1984–85. Recent catches total just over 400 000 tonnes. Meanwhile, the South American anchoveta landings have been around 8 million tonnes per year, except for 1998, when the very strong El Niño caused landings to fall below 1.7 million tonnes.

(c) The jack mackerel that coexists within the coastal region feeding on these other two pelagic species apparently undergoes similar blooms, on a slightly extended schedule. They extend their range from the coastal feeding areas, along the west-wind convergence zone from Central Chile to New Zealand, and into the Tasman Sea. Early museum samples in New Zealand were dated 1946. The most recent bloom, range extension, and collapse took place from the mid-1980s until about 1995, when nearly 5 million tonnes were reported.

(d) South Africa-Namibia fisheries enjoy a similar patterned bloom and collapse as do Japan, and South America, with two primary production centres, one off the Cape region, the other north of Walvis Bay. Both are regions of strong coastal upwelling, with the Cape region more directly under the influences of Indian Ocean ENSO dynamics. Direct transport of warm surface water from Indonesia, southwestward to South Africa as a consequence of ENSO Warm Events creates extended periods of coastal warming and cooling that create very different opportunities for the two dominant pelagic species, and their predators.

(e) Fréon (1984) and Belvèze and Erzini (1983) studied relationships between upwelling indices (wind speed and direction), and changes in sardine catches off west Africa, for the same period described by Gray and Scheaffer (1991) in Figure 16, and described the relation between these 1969–1971 transitional processes and the region's fisheries production shifts. Today, these results would not surprise anyone, as other eastern boundary current systems. In fact, most other fisheries exhibit similar epochal regime shifts, which are focused on later.

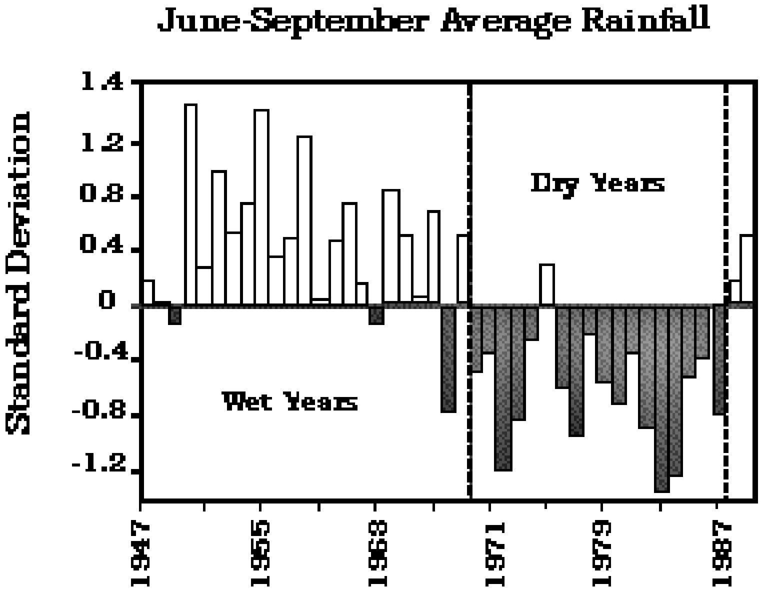


Figure 16 Provides insights into a regional climate shift in the Sahel just east of Morocco's coastal upwelling fisheries system during the late 1960s from studies by Gray and Scheaffer (1991).

2B. Western Boundaries – The South Atlantic Bight – Gulf Stream, the Brazil Current, and Kuroshio Current have very little in common, in either species arrays, or productivity levels. The South Atlantic Bight and Gulf of Mexico coast provide North America with one of its largest fisheries, for menhaden. The array of predator species, tunas, billfishes, striped bass, etc., that form the majority of the region's fisheries are seasonal, in response to annual nearshore upwelling-driven production cycles. The Brazil Current is very coastal, creating a much warmer, more tropical situation with more influence from the fresh water delivered from the Amazon and other rivers than observed in the other two example regions. Brazil's sardinella fishery is the only equivalent species, and catches are much less variable, tending to vary from about 100–200 000 tonnes per year.

(a) The Northwest Pacific Ocean borders the Warm Pool, and responds to those dynamics, and as well, the Sea of Japan is directly influenced by the cold Oyashu Current that derives from the Polar region, and has its own decadal scale pulses. The sardine cycle has been well described, and exhibits the same off-cycle pattern with regional anchovy abundances. Sardine appears to benefit from stronger southerly influences, that enhance the temperatures in the Japan Sea and along the east coasts of Korea and Japan, while anchovies and Hokaido herring seem to thrive on a more northerly influence, when the Oyashu is stronger and Hohaido and the Sea of Japan are subject to more cold inflow from the north. In 1998 landings of Japanese anchovy attained over 2 million tonnes, up from around 1 million tonnes caught by Chinese and Taiwanese fleets, and less than 200 000 tonnes around Japan. Landings of Japanese sardine peaked in the late 1980s at around 5.5 million tonnes, and then declined steadily to around 300–500 000 tonnes in recent years (c.f. Figure 7).

(b) Somalia – Arabian Sea Dynamics, as pointed out, are directly responsive to the monsoon, as are the various fisheries that operate within this highly seasonal, and productive region. There are abundant sardinella within the region, but only minor fisheries, and those that exist are quite seasonal, as affected by nearshore anoxia from hyper-development of algae, under the influence of monsoonal winds. The sardinella are forced into estuaries, or to migrate into more amicable conditions, or they die. Their predators face similar conditions, and are even more sensitive, thus their migrations reflect the region's seasonal dynamics, and exit the stressful coastal regions for more oceanic, conditions, creating abundant resources for the region's many island communities.

3. **Temperate Zones and Ocean Gyres** – the Sub-Polar ocean ecosystems seem to respond well to all stages and phases of climate forcing. The North Sea is another unique situation, in which the majority of the species that occupy the habitat were excluded for thousands of years, during the recent Ice Age. The recolonization and development over this relatively shallow environment of the many species that have become the basic fish resources of so many diverse cultural groups is interesting on its own. Then again, the species that make up the major fisheries resources seem to be particularly adept at taking advantage of short-term climate changes. There is a strong message in that fact, as well.

(a) The eastern North Atlantic and North Sea fisheries is where fisheries research began its long arduous journey toward understanding of climate and fisheries relations. Southward, Butler and Pennycuick (1975) described changes in the sardine eggs and plankton nearer the base of the food web in the English Channel, that shifts in synchrony with what has been called the "Russell Cycle" (c.f. Russell 1973 – Figure 17 next section). Cushing and Dickson (1976) reviewed the state of knowledge for the North Atlantic fisheries in response to climate forces, and arrived at several limits. Recognizing that the various regions were "connected" by atmospheric processes and that several distinct "states" existed, and varied on different time scales, they posed connections.

(b) Cushing (1982) eventually took advantage of the growing long-term collations that became more available, and made great strides toward integrating the information sets from various locations around the globe. Of particular value were his interpretations of the northward movements of animals during the warm period from the 1920s into the 1940s. He identified various species transport patterns with changes in surface wind direction, and others with intensified currents, while more oceanic species clearly responded to expansion of their warmer habitats into higher latitudes. A review of his Chapter 5, and its tables, offer good preparation for forecasts of fish behaviours in response to warming for specific regions. It is now known that such observations are invaluable.

(c) More recently Alheit and Hagen (1997) described the European herring and sardine fisheries' relation to winter weather and the influence of the North Atlantic Oscillation (NAO). The history of the herring fisheries of the Bohuslan region that connects the Baltic Sea with the North Sea is a series of lessons needing learned. Figure 6 provides the approximate periods of the coming and going of the Baltic herring. Alheit and Hagen show various periods of strong winters – periods of fresh water flows, subsequent overturn and anoxia in the Baltic Sea region – that force these fishes out into the more amicable offshore environments, via the Bohuslan region, where there are deep fjords. There are decade-long periods when the herring are found onshore, where they were caught with beach seines and set nets, and others when they were simply unavailable nearshore. This situation was changed once the purse seine was adopted, and fishermen became more mobile.

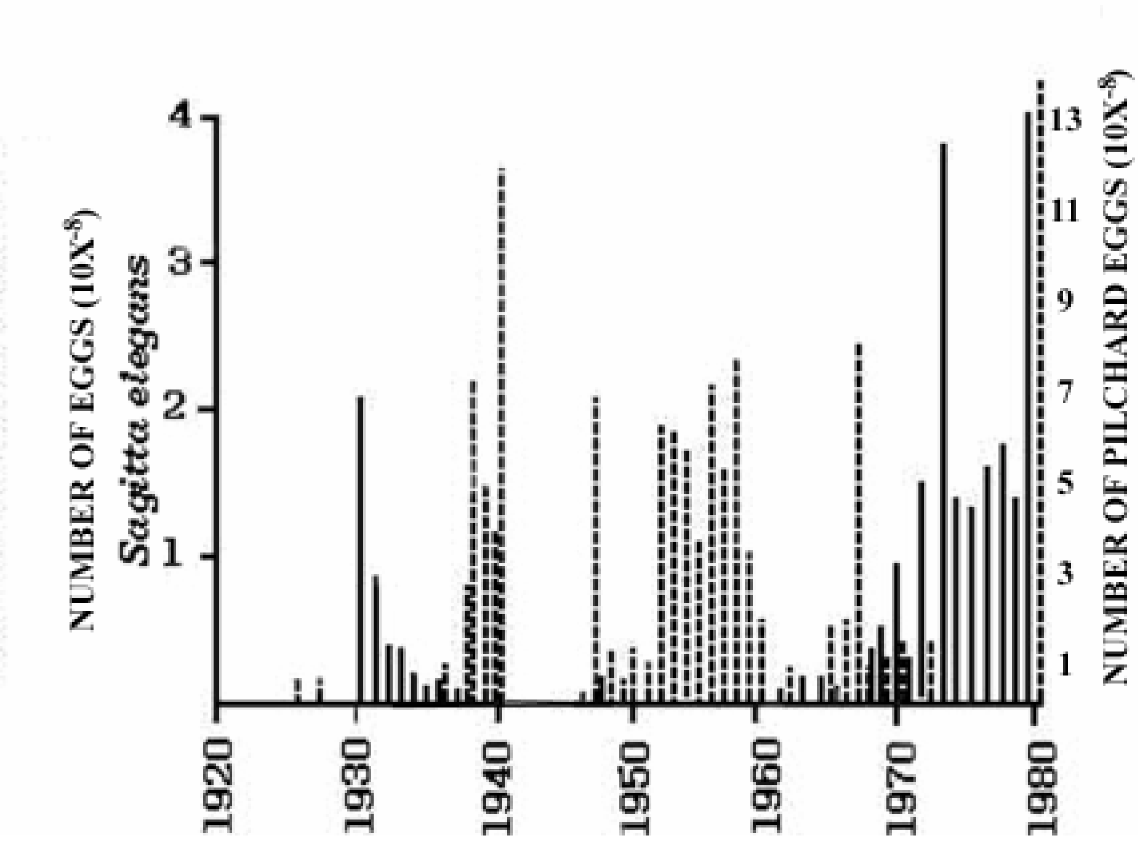


Figure 17 Provides data from Southward (1974a,b), and Southward, Butler and Pennycuick (1975) that show a bipolar (Russell Cycle) shift in English Channel fauna starting about 1938, that reversed in the late 1960s.

The European sardine prefers a warmer habitat than do the herrings, and has been observed to have abundance periods that alternate with the Bohuslan herring fisheries. The Norwegian spring-spawning herring fisheries follow the similar pattern to the sardine. The oscillations are apparently tied to the severity of the winters, that is forced by the low NAO in response to low sea level pressures off Iceland, that allow cold air masses from Siberia. The high NAO alternate state enhances the westerlies that preclude the Siberian air masses, and bring in warmer air from over the North Atlantic.

These two states of the NAO have somewhat opposite consequences on the western North Atlantic, in that the high NAO state draws cold air masses from the Alaska-Greenland region, that force the Labrador Current, and enhance its cooling effects and subsidence, likely leading to the Canadian/US region's cod and herring cycles. Similar forces are at work in the Sea of Japan where the herring come and go from the North Korean coastline, in alternation with the previously described sardine periods. The dynamics are more thoroughly described in Kawasaki *et al*. (1991).

(d) The Ocean Gyres have been given short shrift by many fisheries researchers, due to the biological oceanographer's definition of these being oceanic deserts, due to the low levels of primary production that they have measured within these regions. However, the perusal of time series of oceanic longline fisheries (Fonteneau 1997, reviewed in Sharp 2001) tells another story. The obvious question becomes: "if these gyres are so unproductive, why are so many hundreds of thousands of tonnes of predator fishes and marine mammals found in them, spawning, feeding, and otherwise thriving?" Of course, much of fishing success depends upon seasonal forcing, and the attendant availability of the various species to the fishing gear (c.f. Hela and Laevastu 1971; Sharp1976, 1978; Marsac and Hallier 1991; Abbes and Bard 1999). Mostly, these fishes and their prey live deep.

4. Polar – **or Deep-Ocean Species** are the least well understood group of fish species. Fish from very high latitudes are difficult to access on a year-round basis, and most fisheries for these were essentially subsistence level, until relatively recent developments in the Antarctic domain. Deep-Ocean fishes are also poorly understood. Longevity of some these species has attained a near-mythological situation, where some species have been guesstimated to live well over 200 years. Yet, many other deep-water species, notably the decapod molluscs, are known to have annual or comparatively limited life cycles. The group of arctic and deep water species' annual recruitment successes are quite difficult to assess as year classes tend to move about, and then the complex issues of aging individuals (Gauldie *et al.*1991; Gauldie and Sharp 2001).

Clearly, the denizens of the very high latitudes and very deep oceans have the least to be concerned about under potential climate cooling epochs. They might, however, be affected by great warming epochs, for no other reason than their shrinking habitat will also be encroached upon by many more predators, as they too respond to concentration effects due to expansion of the warmer climate zones. The result will be shortening of distances, hence steepened gradients between the various ocean eco-compartments – defined by the temperature ranges within the gradients. The majority of deep-sea fishes are simply unavailable to commercial scale fisheries, due to their relative diffuse nature. One of the more productive single species fisheries in the world is that for Alaska pollock, that produces about 4 million tonnes per year. Given the species' omnivory, and fundamental cannibalism, it seems unlikely that much will change its relative abundance, other than too much focus onto breeding groups, should these be concentrated by the same set of ecological and physiological pressures described above.

Now, there are some questions needing answers, particularly about the apparent synchrony of many of the observed, hemispheric and ocean basin–wide regime shifts. It seems that what is needed is an organized look into Polar Forcing.

3.3 Simultaneity vs systematic transitions

Leroux’s (1998) book entitled *Dynamic Analysis of Weather and Climate* provides the most probable connections with Polar Cooling Events, as manifest by what Leroux labels Mobile Polar Highs (MPHs). He defines as "huge discs of dense air which are in the main responsible for variations in pressure, the speed and direction of winds, temperature, humidity, cloudiness and rainfall." These are the results of patterned Polar heat loss, chilling the air, causing subsidence and creating cold dense air, that travels eastward, and equatorward, to interact with the terrain and oceans, (as described in the European sardine and herring cases, above). These cold dense air masses pick up surface heat, moisture, and continue on into the warmer latitudes. As they gather sufficient energy, they can eventually interact with highly energized, moist tropical atmosphere that, in turn is a result of the deep convection along the Inter-Tropical Convergence, and the ocean’s Warm Pool in the western Pacific and eastern Indian Ocean. The end-result of these local deep convection-generated processes is the poleward transfer of Equatorial Heat. Leroux (1998) lists the reasons why the lower layers of the troposphere, particularly the planetary boundary layer deserves the most attention in explaining local dynamics of weather and ocean forcing:

- “they are the densest, with half the atmosphere contained in the first 5 500 metres…;
- they contain nearly all the water vapour, which is involved in rainfall and supplies energy, and the greenhouse gases which include water vapour), the greenhouse effect being imperceptible above 5 000 metres;
- paradoxically, the principle source of heat is not from the Sun, but the Earth's surface, which warms the atmosphere... interactions… arising from differences in … substratum, thermal gradients, … deep thermal lows … and vast horizontal circulation;
- among geographical factors, and in conjunction with the distribution of oceans and continents, [orographic] relief acts upon surface temperature, and…is a powerful aerological factor, … determining the paths of a great number of meridional exchanges.”

Leroux goes on to argue for the importance of Mobile Polar Highs. He further offers the hypothesis that the Mobile Polar Highs " control the perpetual variations of the weather, and climatic variability, on all time scales. This all ends up being related to Earth’s long-term Rotation Rate, or negative Length of Day variations, also, as the interactions are all about water vapour moving from the Earth surface, into the atmosphere, and various energy swaps that the contrary motions of the lower atmosphere and terrain/ocean systems. This will get fuller discussion later.

The ecological consequences are manifold, including everything from seasonal flooding, drought, and cloud cover that modifies terrestrial productivity, to the wind speed/direction induced ocean upwellings, cloud modified light levels, and their ecological cascades through aquatic ecosystems. At the end of all this there stands Everyman, with his growing array of technologies, and ever more hungry masses, trying to cope with all the variations. This dilemma is the underlying basis for most of humanity's ecological interactions, and fears about those many Earth System processes that cannot be controlled, compared to those which have already been clearly modified.

On reflection, from our convergent interpretations, it is found that Leroux's arguments comply with much of our own experience, and interpretations of the origins of forcing, particularly manifest in ocean dynamics, and resulting ecosystem responses, on all time scales.

The core of the convergence lies with several "facts":

1. The Polar Regions are always in a state of negative radiation budget, hence generate subsidence via basal cooling that produce these Mobile Polar Highs, that subsequently drift equatorward, and eastward, impelled by the energy of the Earth's rotation, onward through the paths of least resistance, i.e. across the ice and polar ocean, or through the plains, onto continents. In the Antarctic, the MPHs circulate northeastward in the Southern Ocean until they encounter a continental boundary, where they follow that boundary more northward, and then westward, forming the southern Tradewinds, and, as well contributing to seasonal monsoons across the equator in the Indian Ocean.

2. Because there are more and extensive land masses in the northern hemisphere, the MPH circulations are more diverse, and dramatically affected by the seasonal weather along their terrestrial pathways. They create not only the Tradewinds, but also the storm frequency patterns associated with differing modal MPH pathways. Each region in the northern hemisphere has assigned names to seasonally strong MPH interactions with terrain relief, i.e. venturi effect, the Balkan restriction creating etesian (subregionally, also called also meltemi, vardar, struma, or buria) winds (Leroux 1998), and in western North America there are southern California's Santana winds, or so-called Chinook winds on the eastern side of the Rockies.

3. Where MPHs from the Siberian and Gobi desert, converge with those from the Bering Sea, they are reinforced, and sweep across the southeastward North Pacific until they are deflected southwards by the Rockies. Others forming north and east of the Rockies, pass southeastward down the plains of North America, to bring about such extreme events as the three "freezes" during the winters between 1983 and 1988 that decimated the Florida citrus industry. It had been over 40 years since such an Event had occurred in the region.

4. The strength and frequencies of the MPHs vary, such that their convergences create a broad array of patterns, and consequences, and as well, either reinforce – or not – the "expected" regional Tradewinds. The Equatorial Trades are dominated by eastward surface flows, leading to the erosion of surface ocean temperatures in the eastern portions of the equatorial Atlantic and Pacific Oceans, and a pressure driven accretion of warm, low-salinity surface waters in the western Pacific as evapourated moisture is transported east to west and precipitation occurs. Sea levels are enhanced by these effects combined with those of the Earth's eastward rotation, the Asian-Australian land boundaries, and the shallow sill effects of the Indonesian Archipelago.

Upon relaxation of the Equatorial Pacific Trades, the gravity (or Kelvin) wave that characterizes ENSO Warm Events for many is released. This phenomenon is accompanied by an eastward movement of SSTs, a complex result of the gravity waves' displacement of Warm Pool surface waters (although the eastward transport is primarily warm subsurface water). Interactive enhancement of deep convection from the expanding eastern edge of the Warm Pool occurs as the processes entrain both equatorial heat and moisture. As the resulting clouds and moisture are transported eastward and poleward, they trap more heat in the upper ocean under the advancing clouds, recreating their origins in a sequential fashion.

The ENSO-related phenomena have attracted immense research effort over the recent decade or so since the 1982–83 El Niño. Despite the intense observing programs, from satellites or in situ, there remain a series of questions regarding the "trigger" mechanism(s) for the relaxation of the equatorial Trades that lead to the release of the stored surface energy in the western Pacific (White *et al.* 1997; White, Chen and Peterson 1998). Analogously, but in reverse, the Indian Ocean stores heat in its Warm Pool-adjacent eastern extremes, the Indonesian Archipelago, where only a few significant gaps permit throughflow of the high temperature, enhanced sea level surface waters from the Pacific Warm Pool. LeBlanc and Marsac (1999) provide a useful description the related western and eastern Indian Ocean behaviour, as well as the relationship to the Pacific Warm Pool dynamics.

Leroux's thesis leads one to examine the true nature of the sources of variation, on all time scales, of the equatorial Tradewinds. Remarkably, a satisfying answer to the ENSO Warm Event "trigger" emerges. A relatively small change in strength and frequency of MPHs would tend to increase or decrease the equatorial Tradewinds. Obviously, their cessation – or great diminishment of the strength, hence reach of the MPHs – perhaps due to lesser heat loss at the poles – could or would decrease the Equatorial Trades, while potentially increasing the higher latitude Trades. These phenomena suggest direct mechanisms that could explain the somewhat seasonal triggering of ENSO Warm Events. Given the previous insights into northern hemisphere Temperate Zone fisheries, and their forcing, the dynamics of MPHs also suggest reasons why there might be epochal changes in frequencies and intensities of ENSO processes.

Winter cooling in the southern hemisphere is very vigorous, and frequent intense MPHs flow freely around the southern ocean – and equatorward. Their frequency and intensities diminish only slightly during the summer season, reflecting both the region’s seasonal insolation patterns, and cloud cover dynamics. The northern hemisphere’s trans-Asia, trans-north Atlantic, and trans-North America and trans-oceanic MPHs change in frequency and intensity dynamically, as functions of cloud cover over the polar regions, as well as the short-term pre-history climates of the large continental land masses over which they must travel. In order to affect lower latitude processes they must be further enhanced by either the terrain or ocean surface energy – or both. Hot, dry summer months would tend to reinforce the southward transfers of MPH energy across the vast expanses of Asia and North America. Once an energetic MPH encounters the moist equatorial air masses moving eastward and poleward, they reinforce these, to further enhance their poleward motion, moving the latent heat they contain, poleward. Thus, the two phenomena interact to facilitate the energy transfers that are needed to balance the Earth’s surface heat gradients. All of these processes, of course, are embedded within the respectively longer ocean surface and subsurface physical dynamics (Broecker 1991, 1997), and longer term climate-driven processes.

In summary, what seems to be a likely dominant scenario is that the intensity of subsidence at both or either of the Poles facilitates thermodynamic balance of the Equator to Pole(s) thermal gradients. As well, the trajectories of strong MPHs contribute to the atmospheric transport of Equatorial heat, both sensible and latent, transported poleward (eastward in the Pacific and Atlantic, westward in the Indian Ocean, c.f. website from the Warm Pool, or other equatorial sources). The available Equatorial Energy is a function of Deep Convection over Tropical SSTs (or rain forests) that exceed the threshold temperatures of 27º–28ºC, and upper tropospheric winds. The common denominator is the loss of heat, and subsidence at the Poles. What regulates these processes? Whatever source, it is has a quasi-periodic 50–70 year pulse that can be read from both physical records, and from patterns of ecosystem changes.

3.4 Forecasts – from the past into the future

The ultimate lessons about climate change are that close attention must be paid to the past, and then learn to deal with the patterns that have occurred before. There are three sets of global climate projections that involve past history, two with more than a thousand years of proxy data by Dr Doug Hoyt (Figure 18) and Dr Joseph Fletcher, both internationally acknowledged climatology experts. The third is a description of the recent century's patterns that have been related the earth's Rotation Rate (-LOD), to ACI and AT, as described in the earlier section. This is from a study that has been submitted, peer reviewed, and finalized for immediate publication in a respected Russian geophysics journal.

If Hoyt's perspective is accepted as realistic expectation, in about 8 000 years the world will be about 3ºC or 5ºF cooler. In the next 2 000 years, the Earth will cool about 0.4ºC. Also note that 70 percent of the last 10 000 years were warmer than the present. A visit to Hoyt's website provides the necessary background information that explains the cause and effect reasoning that he (and others) have used to forecast a relatively near-term cooling trends will begin in around 2016–2020.

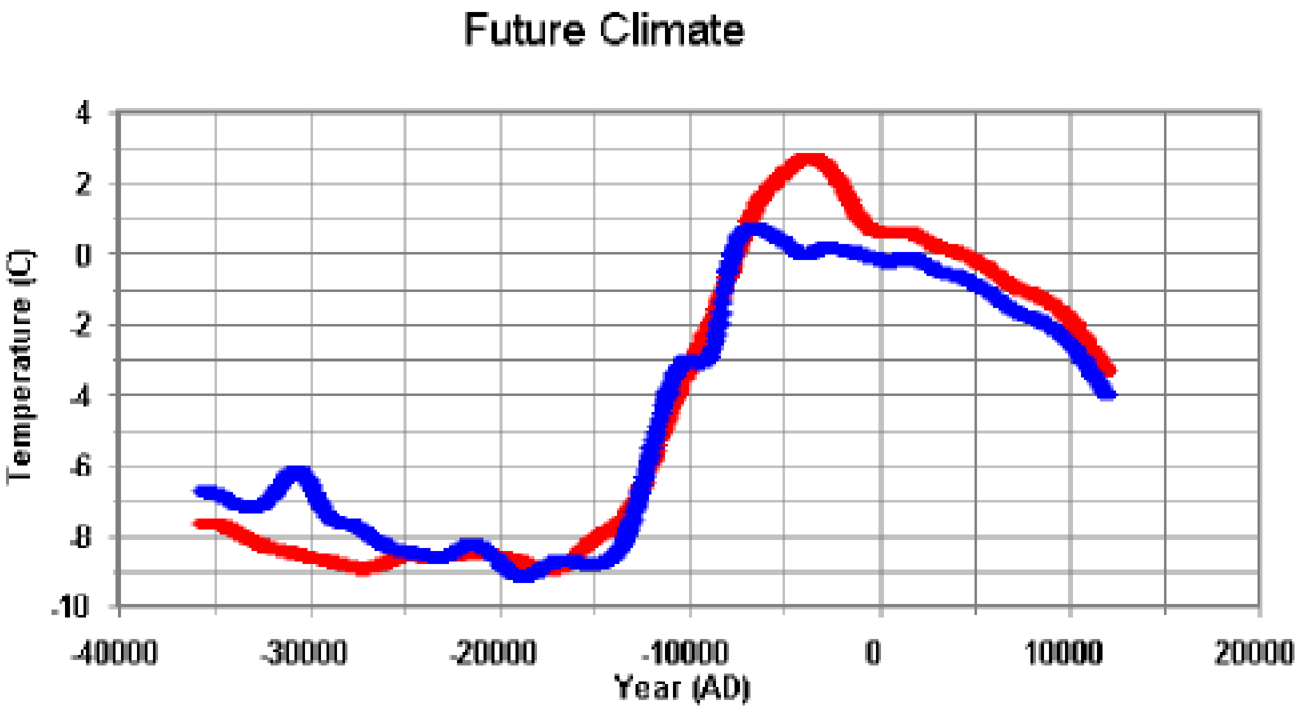


Figure 18 Shows Doug Hoyt's contribution to our Climate Future Cast, in terms of solar influences on Earth's average temperature. The blue line is the present interglacial and the red line is the last interglacial. These curves were lined up so that they matched what occurred when the Earth came out of the previous ice age, following the same time line. (From D. Hoyt's website, URL link in appendix).

Dr Joseph Fletcher, provides a uniquely cogent review of present climate insights, and has made a projection into the next 100 years of Global Climate (Figure 19). Dr Fletcher was the major force behind the initial collation and continuation of the Comprehensive (Consolidated) Ocean and Atmosphere Data Sets (COADS) that provides most of the recent climate research community with their basis in historical observations. He keeps these records up to date as a basis for much of his synthesis. His hypothesis about twenty-first century Climate is based on the likelihood that past processes are cyclic, and will repeat themselves with a period of 170–180 years.

His primary projection is based on the longest available records of solar activity; those from glacial Ice Cores. Beryllium 10 concentrations are used as a proxy of the solar wind driven by the sun's activity. The next step in Dr Fletcher's projection exercise was to find the parts of the historical Be10 data set that matched up with the recent data trends, on a period of about 170 years. The present surface solar emission trend is about 1.3 or so watts per meter warmer than 170 years ago, when the Little Ice Age was left behind and the solar irradiance trended upward toward previous Warm period levels. The projection period was offset by 1.5 Watts per meter beginning about 1970, and extended by using the "clipped" 170 years of records after 1810 or so, overlain on the recent record, and extended.

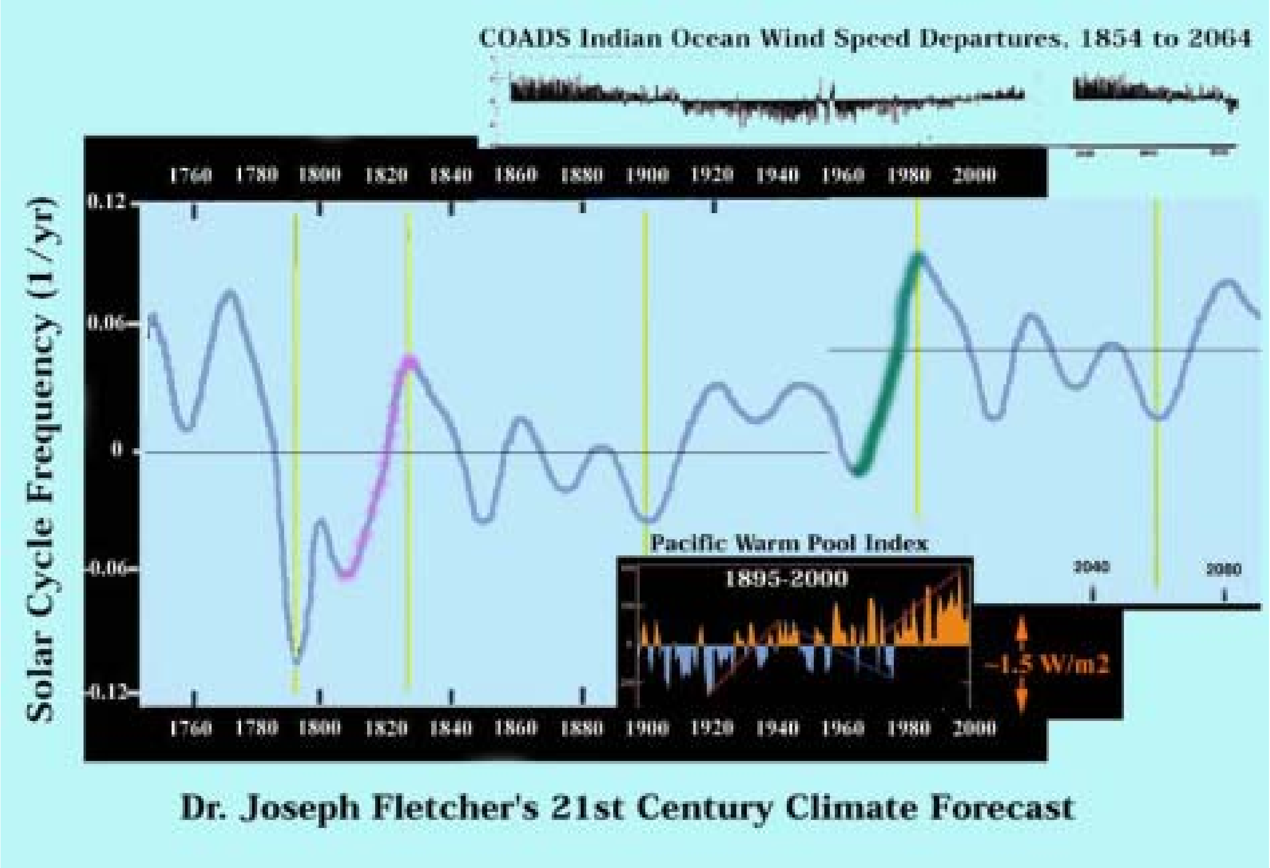


Figure 19 Provides Joseph Fletcher’s Global Climate projection, under the basic hypothesis that patterns will repeat on an approximately 170 year cycle. By adding the COADS wind speed departures, along with the Index of the size or coverage of the Indo-Pacific Warm Pool (bottom graph inset), the general agreement of the trends in the various independently collected data sets provide reason to accept Dr Fletcher's projection of climate to be "expected over the next century".

These are marked in purple (historical) and green (matched points beginning the projection) on the trend line in Figure 19. Also included in this figure are two other reliable measures, the one (at the top) is from Figure 12c, in which the southernmost (and most energetic global region) record of the Indian Ocean COADS surface wind speed departures were extended using the 170 year similarity concept. The bottom graphic insert is a simple Index of the number of 4x4 latitude-longitude squares that have SSTs >=29°C in the Indo-Pacific Warm Pool region. The two records accord with the long-term solar record's trends.

Meanwhile, let us not forget what is already known, from other available records, and previous discussion. Recently, Klyashtorin *et al.* (1998, in review) found that the curve of AT anomaly is similar in shape to that of the –LOD. However, the latter trails the first by 14–16 years. Shifting the AT anomaly forward (to the right) by 15 years results in a good coincidence of the AT and -LOD curves (Figure 20). The right part of the AT anomaly curve may therefore serve as an approximation of the -LOD trend into the first decade or so of the twenty-first century. Unlike the AT anomaly, the -LOD dynamics are characterized by doubled peaks (**a** and **b**) – as seen earlier in Figure 4. Primary peaks (a) coincide with the maximums of shifted AT anomalies and secondary peaks (b) are out of phase with these maximums. The reasons of this phenomenon are not clear yet, but the current increase in -LOD is likely to change with a decline by 2004–2007, as occurred within the 1890s and 1950s.

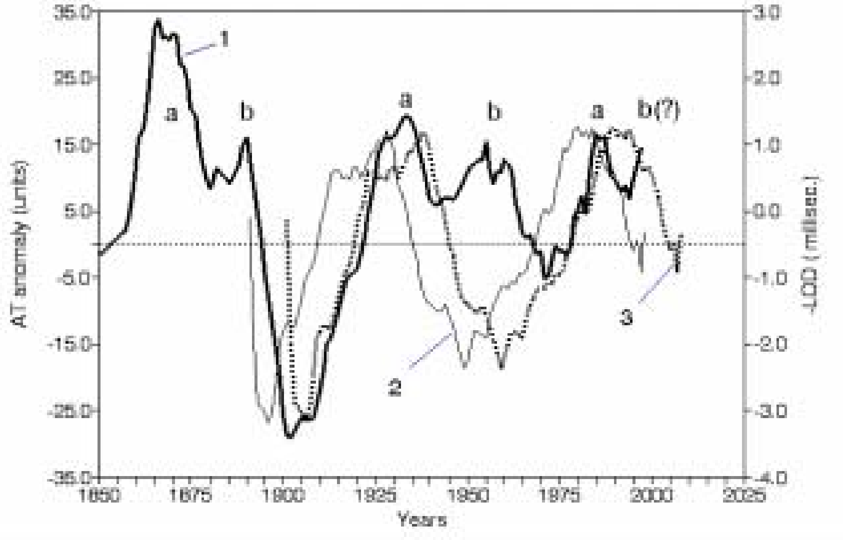


Figure 20 Provides the time series dynamics of -LOD and AT anomaly from 1850 until 2010 or so: (1) -LOD (average annual, detrended); (2) AT anomalies smoothed by 21 year averaging; (3) the latter record shifted to the right 12 years; Peaks denoted with **a** and **b** – are the primary and secondary peaks of -LOD. See the text for fuller explanation.

Figure 21 presents the original detrended Earth surface air temperature (dT) and AT time series and their dominant cyclic trends. The delay in phase of the cyclic trend of dT in relation to that of AT is about 19 years. This accords with preliminary conclusions made on the basis of qualitative analysis (visual comparison) of the time series.

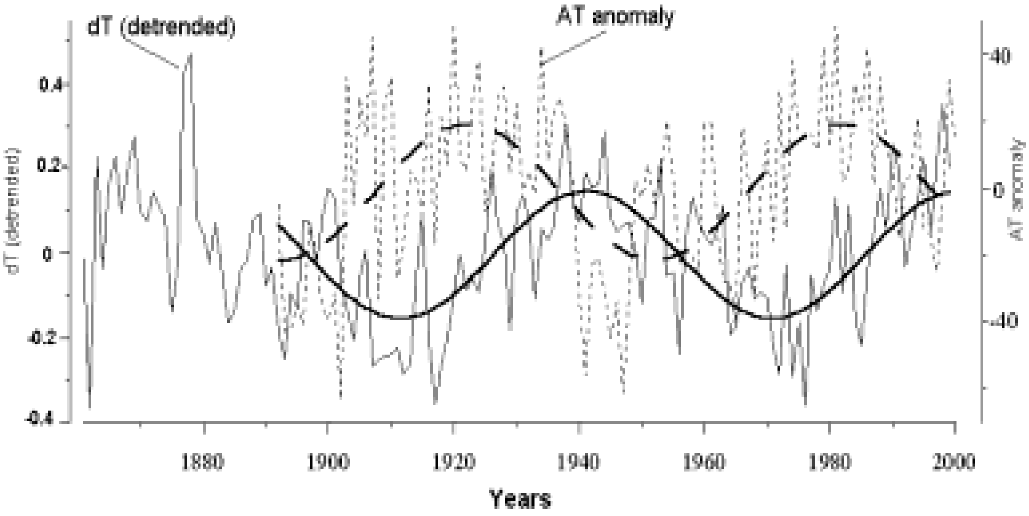


Figure 21 Shows the comparison of AT anomaly and detrended dT dynamics. (1) Thick dashed line – dominating cyclic trend of AT anomaly with a period of 59.35 years; (2) Thick solid line—dominating cyclic trend of detrended dT with a period of 59.42 years). The dT cyclic trend lags the AT anomaly cyclic trend by 19 years.

The curves of AT anomaly and dT (Figure 22 below) are also similar in shape, but the AT anomaly leads dT by 16–18 years. Shifting the AT anomaly right by 18 years results in almost complete coincidence of the curves, but in this case the rest of the AT anomaly continues into the future making it possible to predict dT dynamics for at least 15 years ahead.

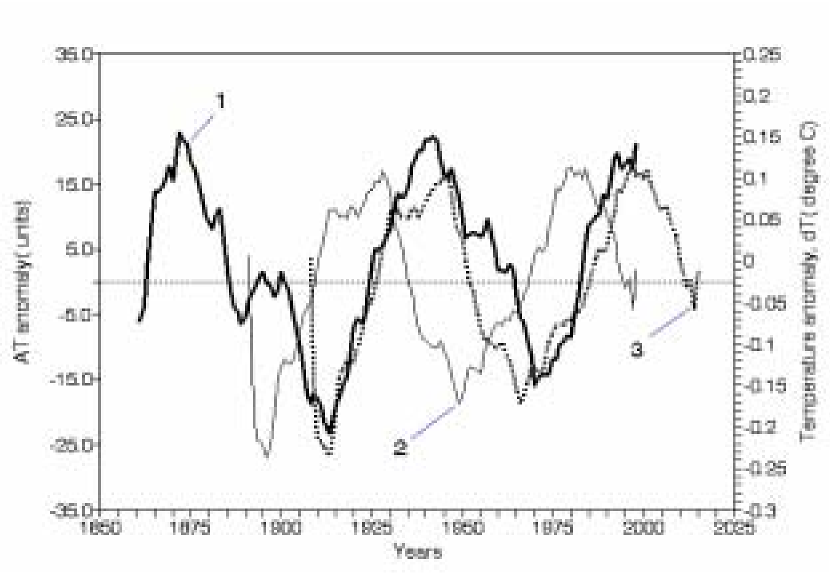
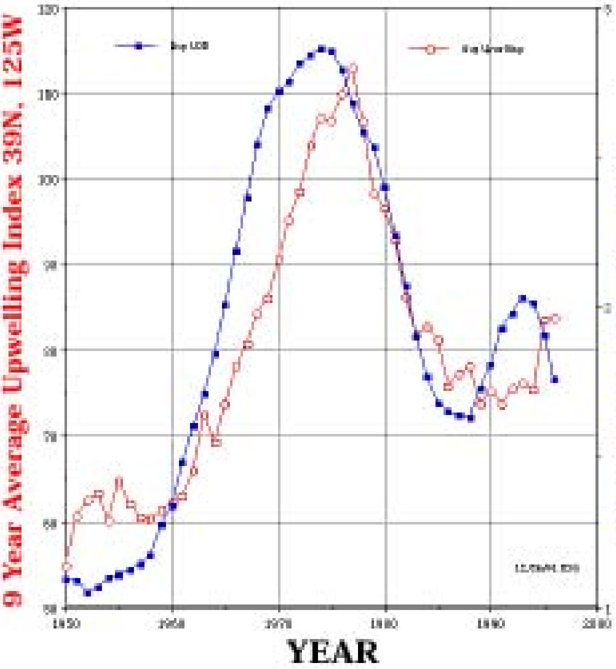


Figure 22 Shows the time series of dynamics of the global temperature anomaly (dT) and AT anomaly: (1) dT (detrended and smoothed by 13-years averaging), (2) AT anomalies smoothed by 21 years averaging; and (3) the latter shifted by 17 years.

The shifted AT anomaly (line 3) in Figure 22 gives grounds to expect that the current increase in global dT will slow down or stop in the next 2–3 years, followed by somewhat steady decrease (by about 0.18°C compared to its present value) by 2015. It should also be taken into account that Figure 21 presents a detrended dT curve. If the current age-long temperature trend (described by Sonechkin 1998; Sonechkin, Datsenko and Ivaschenko 1997) continues into the future, the expected decrease in global temperature anomaly (dT) by 2015 will be about 0.12°C. It is possible, however, that the age-long trend will slow down by the early 2000s. In that case, the expected decrease in dT will be about 0.15°C by 2015. At this point it is emphasized that this forecast refers only to the dT trend, and cannot predict accurately the average global temperature in 2015.

James Goodridge, retired California State Climatologist, maintains constant updates for the State of the newly arrived climate records. He also has a strong interest in the large framework of climate forcing, and prediction, as offered by Klyashtorin and colleagues. Among the first analyses that Goodridge did on learning of the –LOD relations was to some of the local processes, and differences across the Pacific basin. Figure 23 and Figure 24 provide more insights into the linkages between local upwelling and basin-wide sea level pressure with the –LOD signal.

Figure 23 Is a plot of Length of Day and the Upwelling Index off San Francisco California. Both were created using nine year running averages, and scaled to match ranges. This and the graphic in Figure 24 tell us is that there is direct wind-driven forcing that occurs in synchrony with LOD, in accord with Klyashtorins ACI/E-W atmospheric indices.



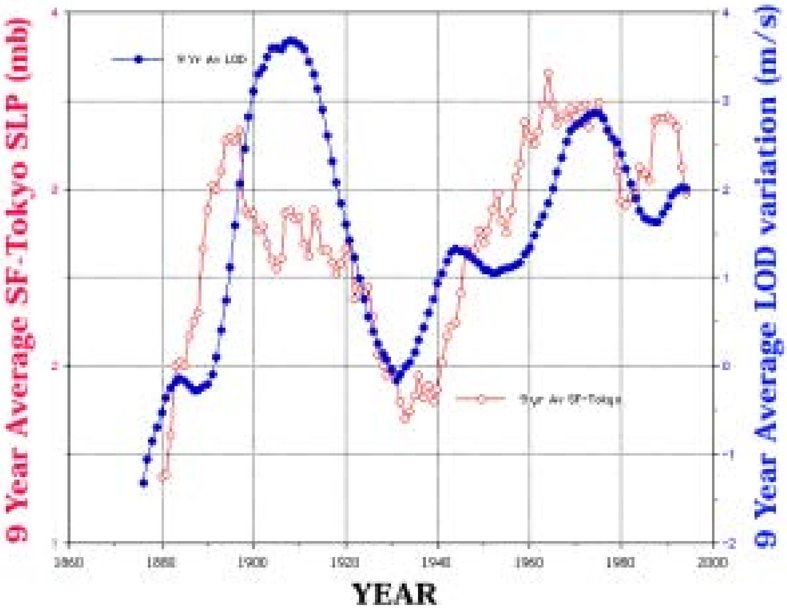


Figure 24 Shows the interesting relationships with Length of Day and the sea level pressure of Tokyo, over the recent 125 years. Note that this is also in synchrony with a Warm/Cold see-saw of ocean surface temperatures that affects the marine faunas of the North Pacific Ocean.

The common denominator is that anchovies and other associated Eastern Boundary Current species thrive on cooler coastal ocean upwelling periods. Sardine and their warmer preferring kin seem to “cope” with these strong upwelling periods by subsisting in small colonies, usually equatorward as well as offshore, just beyond direct influences of lowest temperatures due to coastal upwelling. They await opportunities to recolonize the near shore environments, and to “bloom” during the periods of relatively weaker upwelling associated with lesser along-shore winds and onshore overlay of slightly warmer oceanic conditions.

Longer life cycles and migratory propensities also provide sardine and herring with distributional advantages allowing them to quickly take advantage of any relaxation along the extensive upwelling zones. Similarly, North Sea-Baltic Sea or Newfoundland herrings search from offshore, along coastal habitats (Iles and Sinclair 1982; Alheit and Hagen 1997), to recolonize any locales that fit their requirements. On the other hand, the anchovies and their kin are relegated the shorter term options, of finding local habitats that provide the upwelling intensities, and spawning options which they seem to find along coastlines wherever promontories form eddies. These are often associated with small permanent features such as bays with good tidal flushing and reasonably stable backwater circulation that minimizes anoxia. All the related ocean dynamics are forced from remote climate-driven ocean-atmosphere physics.

There are also arrays of demersal species that are similar “tuned” to these alternative “regimes”. Most migratory predators distribution and abundance cycles also reflect the same patterns as their preferred prey species. Still, the most dramatic changes in fisheries production occur in the massive pelagic fisheries of Eastern Boundary Current systems, although virtually all temperate to polar fishery systems exhibit strong variations (c.f. Parrish and MacCall 1978; Iles and Sinclair 1982; Sharp and Csirke 1983; Leggett, Frank and Carscadden 1984; Moser, Smith and Eber 1987; Wyatt and Larrañeta 1988; Baumgartner, Soutar and Ferreira-Bartrina 1992; Hollowed and Wooster 1992; Hollowed, Bailey and Wooster 1995; Beamish and Boulton 1993; Francis and Hare 1994; Hare and Francis 1995; Polovina, Mitchum and Evans 1995; Mantua *et al*. 1997. The very powerful presentation, and follow-up by Kawasaki (1983) and Kawasaki *et al*. (1991) of the Japanese sardine story, and the apparent synchrony of northern hemisphere Pacific sardine population cycles and those of the Humboldt Current stimulated the present era of climate and fisheries research.

4. SOME EXPECTATIONS

Humans and fishes share a long history. The long road to understanding fish reproduction successes, as described above, was a result of concerned researchers attempting to stabilize fisheries production. The one thing that can be certain is that climate will continue to change, and fisheries distributions and abundances will continue to respond as they have in the past (Soutar and Isaacs 1974; Soutar and Crill 1977; Baumgartner *et al*. 1989; Baumgartner, Soutar and Ferreira-Bartrina 1992; Kawasaki *et al*. 1991). Climate prediction is one well-defined objective, although our poor knowledge of the many interactions and complexities described above is still quite limiting. Lots of basic information about fisheries responses related to likely changes are available, i.e. those factors that involve known patterns in environmental change.

What is hoped to have been made clear by this presentation of diverse information resources, and their apparent interrelations is that these environmental changes are neither "random", nor "stochastic" in the parlance of would-be modelers. All are components of a long sequence of patterns and processes that tend to fall into rhythms, and patterns of their own, within the larger and longer time and space scales. The fact that each of the particular patterns or cycles involved is interactive reshapes the sequences such that they create "harmonics" and long epochs with flat trends, as well as sharp spikes. All are, none-the-less, patterned. In particular, transitions from one state to another are forecastable, given the insights and observations that would provide that possibility.

Given the recent centuries' historical regional synchronies, what does not make sense, or likely pose anything very useful for society is for great amounts of effort and resources to be squandered on creating digital simulacra of equilibrium or stability-based population models, or any more attempts to assume "Closed Systems" such as the individual fish populations – or regarding the Earth's atmosphere and surface air temperatures – sans ocean interactions.

The future and hope for credible forecasting of anything beyond persistence time scales requires dynamic interactions be learnt, i.e. observed and understood. The methods now available that seem to offer most useful forecastive results, in the sense of producing pragmatic event and pattern forecasts, are the somewhat more complex phase of information collation and analysis that is referred to as "Pattern Matching". This seems to work when there are clearly defined "System States" or extremes of the sort offered by ENSO "Warm" and "Cold" Events, or the growing climate Indices for large regions of the world's oceans. Although no two ENSO Events seem to ever be really alike, from our very short record sets, at their fullest manifestations, El Niño and La Niña consequences fall into two notably separate distributions, both bringing considerable damage/good to distinctly different regions.

William Gray's annual forecasts (c.f. 1990, 1991 – see also website in annex) of Atlantic and Gulf of Mexico hurricane landings provide a useful example of "Pattern Matching" techniques, as well as successful modern credible approaches to climate/weather forecasting. As well, his continuous monitoring and updates provide valuable corrections, as new interactions and responses factor into the regional information. The more conventional numerical model-based ENSO forecasts offer a hybrid of "digital simulacra" and Pattern Matching that seems to be improving as more information about the internal oceanography is included in the primarily atmosphere dominated models. There have been vast improvements by including ever more diverse observational data within the forecast models, over the "Closed System" digital models of prior research and forecast-modeling epochs. This was predictable, too, as the early generations of computer modelers quickly broke into various "schools" of how to build projection models. The more is known, the better are model projections. The fewer observations that are included in models, the poorer the model output. Of course, there is always the GIGO problem. Without clear connections between cause and effect, using presumed related data sets can be misrepresentative, and entirely misleading.

To date Climate Change research, per se, has been limited to post-hoc explanations in fisheries contexts, due to the recent generations' fisheries managers emphasis on blunted stock assessment tools (c.f. Sharp, Csirke and Garcia 1983; Sharp 1987, 1988, 1991, 1995b, 1997, 2000). Fortunately, there remain active fishery research programs that focus on both physiological ecology and related climate-scale changes ongoing around the world. It is expected that progress will continue, and fisheries forecasts will displace hindcasts as the basis for fisheries resource management.

Impacts of climate change on regional fisheries can be ranked in terms of likelihood (for either warming or cooling) of impacts. Most of this knowledge comes from empirical studies over the recent 50 years, when weather and environmental records became fundamental to explaining individual species' behaviours and population responses to changes in local conditions.

Fisheries most responsive to climatic variables are listed below in descending order of sensitivity:

(a) Freshwater fisheries in small rivers and lakes, in regions with larger temperature and precipitation change.
(b) Fisheries within Exclusive Economic Zones (EEZ), particularly where access-regulation mechanisms artificially reduce the mobility of fishing groups and fleets and their abilities to adjust to fluctuations in stock distribution and abundance.
(c) Fisheries in large rivers and lakes.
(d) Fisheries in estuaries, particularly where there are species sans migration or spawn dispersal paths or in estuaries impacted by sea-level rise or decreased river flow.
(e) High-seas fisheries.

One can quickly see that the larger scale production sea fisheries are not under any direct or immediate threat due to climate changes. The fisheries most sensitive to climate change are also amongst the most affected by human interventions such as dams, diminished access to up- or down-river migrations, filling in of wetlands, and other issues of human population growth and habitat manipulation, particularly expanded agricultural water use and urbanization.

Options are also known for coping that provide large benefits irrespective of climate change (as stated in early Climate Change documents IPCC 1990, 1996):

(a) Design and implement national and international fishery-management institutions that recognize shifting species ranges, accessibility, and abundances and that balance species conservation with local needs for economic efficiency and stability.
(b) Support innovation by research on management systems and aquatic ecosystems.
(c) Expand aquaculture to increase and stabilize seafood supplies, help stabilize employment, and carefully augment wild stocks.
(d) In coastal areas, integrate the management of fisheries with other uses of coastal zones.
(e) Monitor health problems (e.g. red tides, ciguatera, cholera) that could increase under climate change and harm fish stocks and consumers.

The subjects that do not show up in the IPCC Reports are those that might resolve the more critical habitat and waterway access problems, or the rapidly degrading water quality as urbanization and agriculture expand. Today's most obvious series of environmental issues needing attention are those about controlling human growth and development, while monitoring, assessing and maintaining critical habitat – and retrofitting much of the that has been lost or manipulated.

This is primarily important because more options are necessary under known patterns of climate changes. Grand plans, for example, regarding increasing our dependence upon aquaculture, do little good if access to both clean, unpolluted water resources and adequate protein to feed to cultured species cannot be assured.

5. CONCLUSIONS

Regime shifts occur on several time and space scales. Identifying the precursors, or other indicators, can provide forecast capability that is key to better management of anthropogenic impacts on natural ecosystems. The negative Length of Day or Earth's Rotation Rate appears to offer useful insights into future ecosystem transitions, and potentially for more defined changes, once serious monitoring, and applied research is initiated. Monitoring the Atmospheric Indices and the consequent changes in “condition indicators”, distributions, and abundances of particularly responsive species provides the information necessary to initiate effective management of human activities that affect “ecosystems” and the production that is needed from them to sustain ourselves over the long term.

The sun is the primary source of energy in our solar system. The sun’s broad spectral radiance provides for life on our small piece of the universe. Nowhere is it so obvious that life is totally dependent upon the sun’s light, as in the world’s oceans where life evolved, and continues to respond to the continuous challenges of a rapidly changing environment. The issues involved are many, and complicated to interpret due to their interlocking dynamics – and to deal with as many of these influences remain obscure – but are not really outside our general human experience.

The seasonal oscillations of Earth’s sunlight levels are exaggerated at the poles, while remaining nearly constant about the equator. Lower seasonal variability and the relatively vast amount of light and heat absorbing ocean around the equator leads to the general warming at the equator. The critical fact that needs to be accepted before our messages can be converged and understood is that there is a continuous heat loss at the poles, and similarly, nearly continuous heat absorption into the equatorial oceans. Whatever processes modulate the polar heat losses, controls the Earth’s Climate Change patterns.

There are several distinct patterns of interest to those who track precipitation and drought in particular, and both coastal and ocean fisheries, in general. Many are related in somewhat obscure ways to the readily monitored changes in -LOD, as well as indices of the dominant wind-field, SST and Sea Level Pressure patterns over large Climate Zone Regions. Some of these have been identified as useful indicators of Climate Regime Shifts, as well as precursors of fisheries ecosystem responses, on decadal scales. Many are simply correlated, not forecastive. -LOD seems to offer the bast forecast indicator, to date, although it is certain that the changing -LOD per se, is Not the direct cause. It is an integrated signal that provides insight into future generic changes in ocean production, due to various forces, and allow the careful study of the links to ecological responses. Relevant forces include cloudiness and resultant light levels, wind speed and direction, coastal habitat temperatures, upwelling event frequencies, and freshwater runoff, all of which stimulate ecological cascades on all time scales.

While it is recognized that the energy at the equator “powers” the Earth’s Climate System, it is more convincing that much of the Earth’s Climate Forcing is initiated by Polar Cold Events (heat loss likely associated with low cloud densities), and resulting subsidence – that spawn Mobile Polar Highs. These, in turn, sweep equatorward, to gather surface energy and eventually energize the Trade Winds. If these MPHs are frequent and intense enough (and they encounter sufficiently energy-laden surface conditions), their role is enhanced and they continue their equatorward transfers. This leads to their further encounters with moisture laden frontal clouds likely resulting from Equatorial Deep Convection, causing state changes and precipitation, that enhances the transport of equatorial heat and energy poleward. Regimes shifts can be measured in terms of MPH frequencies and intensities, (c.f. Leroux 1998). Of course, Equatorial Heating and Warm Pool Dynamics are also important part of the processes involved, creating periods with more Equatorial Deep Convection (low SOI), and periods of lesser EDC (high SOI). All of these processes have local, regional and basin-scale ecological consequences.

The periodicity of various indices (PDO, NOA, and AO, ENSO, etc.) represent bipolar Ocean Climate Regimes (dominated by either East-West or Pole-Equator winds) and subsequent temperate to polar ocean physical and production responses, are being related to fisheries production patterns. Climate forcing is “noisy” within these various decadal and longer patterns, but never the less, provide useful insights into where, and what to monitor, that will help track the likely ecological responses. Transition periods are quite identifiable, if not particularly well studied, in ecological terms, simply because there are usually crises associated with the transition periods, as local expectations are not met due to shared debilities of the species arrays involved. Faunal changes observed by fishing communities are probably one of the most useful of all Climate Indicators.

It appears that over millennia, at least two quite distinct and dynamic faunas have evolved in each such marine ecosystem, only one half of which benefits from either side of the divergent contexts that result from the climate-driven physical processes. Several correlated physical dynamics can be identified, such as changes in precipitation patterns, related storage periods and water flow rates from rivers and streams, as well as local coastal ocean processes. It is also suggested that many migratory predator species are closely tuned to these changes, and can act as indicators of physical changes often only identified after the fact by oceanographers and climate researchers. There is not terrible concern about climate change and its consequences regarding most mobile ocean species as, historically, they have had considerable experience and have been selected for rapid response, and adaptability. Those regions with the strongest seasonal dynamics are home to species that are more adapted to change, and dynamic in both distribution and abundances, hence the amazing productivity of high latitude transition zones. Figure 25 provides insights into the regions of greatest seasonal dynamics.

While, little has been mentioned of the several hundred other species that are found and exploited to varying degrees in each marine ecosystem, there are several reasons to be just as concerned about their management. Once the focus on the major production fisheries shifts, there are always tendencies to adjust by maintaining production rates from lesser populous species. There is good reason to minimize the implicit refocus from production fisheries, until these secondary species have had time to adjust to the new conditions within their ecosystems. Perhaps, as in the case of Newfoundland's coastal fisheries during the period following the collapse of the cod fishery, an array of highly valued species might responded to decrease in predation, leading to more successful year class survival, hence very lucrative fishing for those fishermen equipped to fish them. On the other hand, the shift from one species set to another in tropical situations can lead to disasters, such as suffered by the giant clam, Tridacna, in the western Central Pacific Ocean due to intense removals.

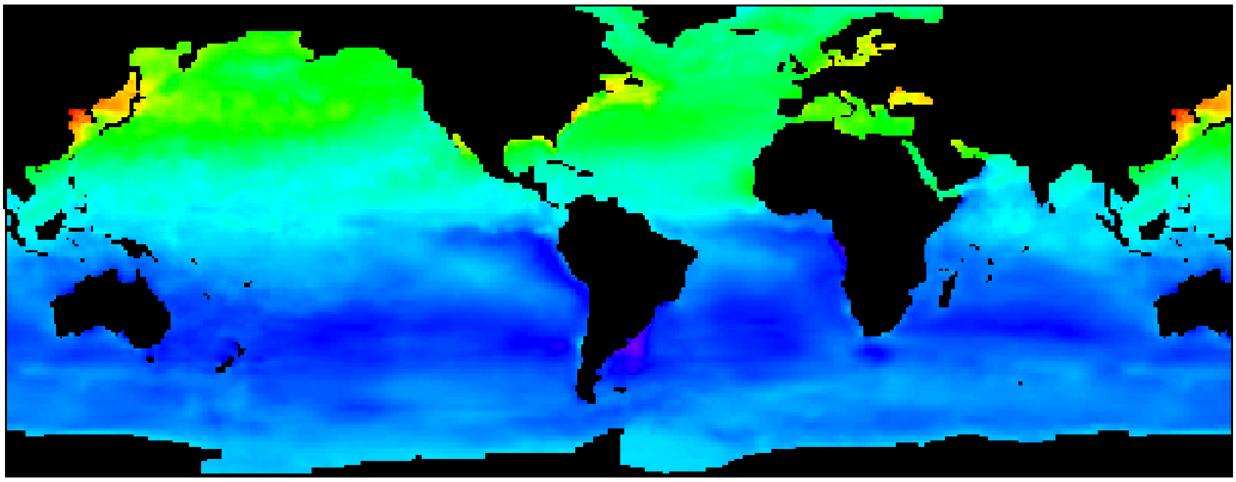


Figure 25 Shows the regions that have the greatest seasonal changes, and most adaptable species, and unusually productive ecosystems. Climatological 30-metre temperatures for the Northern Hemisphere Summer (August mean) have had the February mean values subtracted for each one degree square. The resulting difference were colour-scaled, and show that in the northern hemisphere the red to orange regions (i.e. the northwestern Atlantic and Pacific and the Mediterranean have large seasonal differences). In the southern hemisphere, it is the deep purple to maroon colour (e.g. off Argentina, Gulf of Guinea) that indicates strong seasonal differences. Coping with all such ecosystem dynamics "define" local survivors – another lesson to be learnt from the fishes.

At the same time, there is concern that the predominant effect on ocean and aquatic ecosystems, in general, is increasingly challenging the Earth's carrying capacity – not only for humans, but many other species – as havoc is caused for all species amongst all ecosystems by erasing habitats and removing options. It can assumed that despite human activities, the solar system will continue to reflect the long harmonic interactions that have evolved over millennia, long before life evolved, and will continue long after the present amicable conditions have shifted from today's supportive environments, toward ever more harsh ones – with inevitable consequences.

Perspectives on what is truly controllable needs to be revised, and recognize that ocean ecosystems begin on the highest mountains. Waterways and all downstream and coastal water quality are very much at the heart of the dilemma. High latitude dynamics and related ecological processes have been somewhat underemphasized, since most humans are averse to such extreme environments. If that should change, or our impacts in these regions become greater, it is clear that there will be dire consequences for those ecosystems, as well, as the species involved are truly specialized, and quite responsive to minor changes. They and all species need options even more than humans do, the most highly adaptable predators on Earth. In this respect, Earth's services to mankind are tightly linked to maintaining any and all options for the many species that comprise the many dynamic, interactive ecosystems that either cope with natural dynamics, or expire – the ultimate lesson from Nature.

REFERENCES

Abbes, R. & Bard F.-X. eds. 1999. ECOTAP, Etude du comportement des thonidés par l'acoustique et la pêche en Polynésie Française, Rapport Final. Convention Territoire, EVAAM-IFREMER – ORSTOM, Number 951070, 523 pp.

Alheit, J. & Hagen, E. 1997. Long-term climate forcing of European herring and sardine populations. *Fisheries Oceanography* 6(2): 130–139.

Allan, R., Lindesay, J. & Parker, D. 1996. El Niño Southern Oscillation & Climatic Variability, CSIRO Publication, 405 pp. plus CD-ROM.

Allen, B.D. & Anderson, R.Y. 1993, Evidence from western North America for rapid shifts in climate during the last glacial maximum. *Science*, 260: 1920–1923.

Anderson, R.Y. 1992. Possible connection between surface winds, solar activity, and the Earth's magnetic field, *Nature*, 358: 51–53.

Bakun, A. 1996. Patterns in the Ocean. California Sea Grant/CIB 323 pp.

Bakun, A. & Parrish, R.H. 1980. Environmental inputs to fishery population models for eastern boundary current. *In* G.D. Sharp, ed. Report and Documentation of the Workshop on the Effects of Environmental Variation on the Survival of Larval Pelagic Fishes, pp. 68–79. *IOC Workshop Rep. Ser*. No.28 Unesco, Paris.

Bakun, A., Beyer, J., Pauly, D., Pope, J.G. & Sharp, G.D. 1982. Ocean sciences in relation to living resources. *Can. J. Fish. Aquat. Sci.*, 39: 1059–1070.

Baranov, F.I. 1918. On the question of the biological basis of fisheries. *Nauchn. Issled. Ikhtiol. Inst. Izv*., 1: 81–128 (in Russian).

Baranov, F.I. 1926. On the question of the dynamics of the fishing industry. *Nauchn. Byull. Rybn. Khoz*., 8(1925): 7–11 (in Russian)

Barnett, T.P., Pierce, D.W. & Schnur, R. 2001. Detection of Anthropogenic Climate Change in the World’s Oceans. *Science*, 292: 270–274.

Baumgartner, T.R., Soutar, A. & Ferreira-Bartrina, V. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. *CalCOFI Report,* 33: 24–40.

Baumgartner, T.R., Michaelsen, J., Thompson, L.G., Shen, G.T., Soutar, A. & Casey, R.E. 1989. The recording of interannual climatic change by high-resolution natural systems: tree-rings, coral bands, glacial ice layers, and marine varves. *In* Aspects of Climate Variability in the Pacific and Western Americas, pp. 1–15. *AGU Geophysical Monog*., 55.

Beamish, R.J. & Boulton, D.R. 1993. Pacific salmon production trends in relation to climate, *Canadian Journal of Fisheries and Aquatic Sciences,* 50: 1002–1016.

Bell, G.D., Halpert, M.R., Schnell, R., Higgins, J., Laevermore, V., Kousky, R., Tinker, W., Thiaw, M., Chelliah, M. & Artusa, A. 2000, Climate Assessment for 1999*. Bull. Am. Meteo. Soc,* 81: 1328–1370.

Belvèze, H. & Erzini, K. 1983. The influence of hydroclimatic factors on the availability of the sardine (*Sardinops pilchardus* Walbaum) in the Moroccan fishery. *In* G.D. Sharp & J. Csirke, eds. Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources, pp. 285–327. San Jose, Costa Rica, April 1983. *FAO Fisheries Report* No. 291(2).

Bertrand, A. & Josse, E. 1999. Acoustic characterisation of micronekton distribution in French Polynesia. *Prog. Mar. Ecol. Ser.*, 191: 127–140.

Boehlert, G.W. & Schumacher, J.D. 1997. Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management. *NOAA Tech. Memo*. NOAA-TM-NMFS-SWFSC-239. 146 pp.

Braudel, F. 1985. Vol.1. The Structures of Everyday Life: the limits of the possible; Vol. 2. The Wheels of Commerce; Vol. 3. The Perspective of the World. Perennial Library – Harper and Row, New York.

Broecker, W.S. 1991. The great ocean conveyor. *Oceanography,* 4: 79–89.

Broecker, W.S. 1997. Thermohaline circulation, the Achilles heel of our climate system: Will man-made CO2 upset the current balance? *Science,* 278: 1592–1588.

Caddy, J.F. & Bakun, A. 1994. A tentative classification of coastal marine ecosystems based on dominant processes of nutrient supply. *Ocean and Coastal Management*, 23: 201–211.

Caddy, J.F. & Sharp, G.D. 1986. An ecological framework for marine fishery investigations. *FAO Fisheries Technical Paper* No. 283: 152 pp.

Crawford, R.J.M., Underhill, L.G., Shannon, L.V., Lluch-Belda, D., Siegfried, W.R. & Villacastin-Herero, C.A. 1991. An empirical investigation of trans-oceanic linkages between areas of high abundance of sardine. *In* T. Kawasaki, S. Tanaka, Y. Toba & A. Taniguchi. eds. *Long-Term Variability of pelagic Fish Populations and Their Environment*, pp. 319–332. Pergamon Press, Tokyo.

Csirke, J. 1980. Recruitment in the Peruvian anchovy and its dependence on the adult population. *Rapp. P.-v. Réun. CIEM.* 177: 307–313.

Csirke, J. & Sharp, G.D. eds. 1983. Report of the expert consultation to examine changes in abundance and species composition of neritic fish resources, San José, Costa Rica, 18–29 April 1983. *FAO Fisheries Report* No. 291 Vol. 1: 102 pp.

Cury, P., & Roy, C. 1989: Optimal environmental window and pelagic fish recruitment success in upwelling areas. *J. Can. Fish. Aquat. Sci.*, 46(4): 670–680.

Cushing, D.H. 1982. Climate and Fisheries. London, Academic Press, 373 pp.

Cushing, D.H. & Dickson, R.R. 1976. The biological response in the sea to climatic changes. *In* F.S. Russell & M. Yonge, eds. Advances in Marine Biology 14, pp. 1–122. Academic Press, London.

Dean, W.E., Bradbury, J.P. Anderson, R.Y. & Barnosky, K.W. 1984. The variability of Holocene climate change: evidence from varved lake sediments. *Science,* U.S. 226: 1191–1194.

Dobbs, D. 2000. *The Great Gulf.* Island Press, Shearwater Books, Washington DC. 206 pp.

Ebbesmeyer, C.C., Cayan, D.R. McClain, D.R. Nichols, F.H. Peterson, D.H. & Redmond, K.T. 1991. 1976 step in Pacific climate: Forty environmental changes between 1968–1975 and 1977–1984, *In* J.L. Betancourt & V.L. Tharp, eds. *Proceedings of the 7th Annual Pacific Climate (PACLIM) Workshop, April 1990,* pp. 115–126. California Department of Water Resources. Interagency Ecological Study Program Technical Report 26.

Enzel, Y., Cayan, D.R., Anderson, R.Y. & Wells, S.G. 1989. Atmospheric circulation during Holocene lake stands in the Mojave Desert: evidence of regional climatic change. *Nature*, 341: 44–47.

Fagan, B. 1999. Floods, Famines and Emperors:El Niño and the fate of civilizations. Basic Books, New York. 300 pp.

Finlayson, A.C. 1994. *Fishing for Truth* (Institute of Social and Economic Research) Memorial University, St. John's, Newfoundland.

Fonteneau, A. 1997. *Atlas of Tropical Tuna Fisheries: World Catches and the Environment*. L'Institut Français de Recherche Scientifique pour le Développement en Coopération, Paris.

Francis, R.C. & Hare, S.R. 1994. Decadal-scale regime shifts in the large marine ecosystems of the Northeast Pacific: a case for historical science. *Fish. Oceanogr.,* 3: 279–291.

Fréon, P. 1984. La variabilité des tailles individuelles a l'intérieur des cohortes et des bancs de poissons. 1. Observations et interprétation. *Oceanol. Acta,* 7(4): 457–468.

Friis-Christensen, E. & Lassen, K. 1991. Length of the solar cycle: An indicator of solar activity closely associated with climate. *Science*, 254: 698–700.

Garcia, S. 1988. Tropical penaeid prawns. *In* J.A. Gulland, ed. *Fish population dynamics: the implications for management*, pp. 219–249. Chichester, John Wiley and Sons Ltd., 422 pp.

Gauldie, R.W., Coote, G., Mulligan, K.P., West, I.F. & Merrett, N. 1991. Otoliths of deep water fishes: Structure, chemistry and chemically coded life histories. Comparative Biochemistry and Physiology, 100: 1–32.

Gauldie, R.W. & Sharp, G.D. 2001. Growth rate and recruitment: evidence from year-class strength in the year-to-year variation in the distribution of otolith weight, and fish length of *Hoplostethus atlanticus*. Vie et Milieu, 51(4): 267–287.

Giorgi, F. & Francisco, R. 2000. Evaluating uncertainties in the prediction of regional climate. *Geophysical Research Letters*, 27: 1295–1298.

Girs, A.A. 1971. *Macrocirculation method for long-term meteorological prognosis*. Hydrometizdat Publ., Leningrad, 480 pp. (in Russian).

Glantz, M.H. ed. 1992. *Climate Variability, Climate Change and Fisheries*. Cambridge University Press. 450 pp.

Glantz, M.H. & Feingold, L.E. eds. 1990. *Climate Variability, Climate Change and Fisheries.* Environmental and Societal Impacts Group, NCAR, Boulder, CO. 139 pp.

Glavin, T. 2000. *The Last Great Sea*. Greystone Books, Douglas & McIntyre Publishing Group, Vancouver. 244 pp.

Gomes, M.C., Haedrich, R.L. & Villagarcia, M.G. 1995. Spatial and Temporal Changes in the Groundfish Assemblages On the Northeast Newfoundland Labrador Shelf, Northwest Atlantic, 1978–1991. *Fisheries Oceanography*, 4(2): 85–101.

Gray, W.M. 1990: Strong association between west African rainfall and U.S. landfall of intense hurricanes. *Science*, 249: 1251–1256.

Gray, W.M. & Scheaffer, J.D. 1991. El Niño and QBO influences on tropical cyclone activity. *In* M.H. Glantz, R. Katz & N. Nicholls, eds. *ENSO Teleconnections linking worldwide climate anomalies: Scientific basis and societal impacts,* pp. 257–284. Cambridge university Press, Cambridge, UK.

Gross, R.S., Marcus, S.L., Eubanks, T.M., Dickey, J.O. & Keppenne, C.L. 1996. Detection of an ENSO signal in seasonal length-of-day variations, *Geophysical Research Letters*, 23: 3373–3376.

Gulland, J.A. 1983. Fish Stock Assessment. Wiley, London. 223 pp.

Halpert, M. & Bell, G. 1997. Climate Assessment for 1996. *Bull. Am. Meteo. Soc*., 8: 1–98.

Hare, S.R. & Francis, R.C. 1995. Climate change and salmon production in the Northeast Pacific Ocean. Spec. *In* R.J. Beamish, ed. Climate change and northern fish populations. *Pub. Can. Fish. Aquat. Sci*. 121: 357–372.

Harrison, P.J. & Parsons, T.R. eds. 2000. Fisheries Occeanography: An integrative approach to fisheries ecology and management. Fish and Aquatic Resources Series 4. Blackwell, *Science*, UK. 347 pp.

Hela, I. & Laevastu, T. 1971. Fish. Oceanogr. Blackwell, Fishing News, London.

Hilborn, R. & Walters, C.J. 1992. *Quantitative fisheries stock assessment. Choice, dynamics and uncertainty.* Chapman and Hall, Inc., London, New York: 570 pp. (with programs on diskette)

Hjort, J. 1914. The fluctuations in the great fisheries of northern Europe viewed in the light of biological research. *Rapp. P-v. Réun. Cons. Int. Explor. Mer.,* 20: 1–228.

Hjort, J. 1926. Fluctuations in the year classes of important food fishes*. J. Cons. Int. Explor., Mer.* 1: 5–38.

Hollowed, A.B. & Wooster, W.S. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. *ICES Marine Science Symposia* 195: 433–444.

Hollowed, A.B. & Wooster, W.S. 1995. Decadal-scale variations in the eastern subarctic Pacific: II. Response of Northeast Pacific fish stocks. *In* R.J. Beamish, ed. Climate change and northern fish populations. *Can. Spec. Pub. Fish. Aquat. Sci.*, 121: 373–385.

Hollowed, A.B., Bailey, K.M. & Wooster, W.S. 1995. Patterns of Recruitment in the northeast Pacific Ocean. *Biol. Oceanog.*, 5: 99–131.

Hoyt, D.V. & Schatten, K.H. 1997. *The Role of the Sun in Climate Change*, Oxford University Press, 279 pp.

Hubbs, C.L. 1960. Quaternary paleoclimatology of the Pacific coast of North America. *CalCOFI Rep.* VII: 105–112.

Hunter, J. & Sharp, G.D. 1983. Physics and fish populations: Shelf sea fronts and fisheries. *In* G.D. Sharp & J. Csirke, eds. Proceedings of the Expert Consultation to Examine the Changes in Abundance and Species Composition of Neritic Fish Resources, pp. 659–682. San Jose, Costa Rica, 18–29 April 1983. *FAO Fisheries Report* No. 291, vol. 2. FAO, Rome.

Idso, S. 1982. Carbon Dioxide: Friend of Foe? 72 pp.

Iles, T.C. & Sinclair, M. 1982. Atlantic Herring. Stock discreteness and abundance. *Science*.215: 627–633.

IPCC. 1990. Impacts Assessment of Climate Change. The policymaker's summary of the Report of Working Group II to the Intergovernmental Panel on Climate Change. WMO/UNEP. Australian Government Publishing Service. Canberra.

IPCC. 1996. Climate Change 1995 – The Science of Climate Change – Working Group I report, 1996, 584 pp., Climate Change 1995 – Impacts, Adaptations and Mitigation of Climate Change – Working Group II report, 1996, 880 Climate Change 1995 – Economic and Social Dimensions of Climate Change – Working Group III report, 1996, 608 pp. Cambridge Univ. Press, New York.

IPCC. 2001. Climate Change 2001: Synthesis Report. contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. R.T. Watson & Core Writing Team, eds. Contains Synthesis Report, Summaries for Policymakers and Technical Summaries of the three Working Group volumes, and supporting Annexes. Cambridge University Press, UK. 398 pp.

Kawai, T. & Isibasi, K. 1983. Change in abundance and species composition of neritic pelagic fish stocks in connection with larval mortality caused by cannibalism and predatory loss by carnivorous plankton. *In* Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources, pp. 1081–1111. *FAO Fisheries Report* No. 291(3).

Kawasaki, T. 1983. Why do some fishes have wide fluctuations in their number? – A biological basis of fluctuation from the viewpoint of evolutionary ecology. *In* G.D. Sharp & J. Csirke, eds. Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources, pp. 1065–1080. *FAO Fisheries Report* No. 291(3).

Kawasaki, T., Tanaka, S. Toba, Y. & Taniguchi, A. eds. 1991. *Long-term Variability of Pelagic Fish Populations and Their Environment.* Pergamon Press, Tokyo.

Kendall, A.W. Jr., Perry, R.I. & Kim, S. 1996. Fisheries oceanography of the walleye pollock in Shelikof Strait, Alaska. *Fish. Oceanogr.,* 5(Suppl.1): 203 pp.

Klyashtorin, L.B. 1998. Long-term climate change and main commercial fish production in the Atlantic and Pacific. *Fisheries Research* 37: 115–125.

Klyashtorin, L.B. 2001. Climate change and long term fluctuations of commercial catches: the possibility of forecasting. Rome, *FAO Fisheries Technical Paper* No. 410: 98 pp.

Klyashtorin, L.B., Nikolaev A., & Klige, R. 1998. Variation of global climate indices and Earth rotation velocity. *In* Book of Abstracts GLOBEC First Open Science Meeting, Paris, 17–20 March 1998. 55 pp.

Klyashtorin, L.B., Nikolaev, A.V. & Lubushin, A.A. (. Fluctuations of Global Climatic Indices and the Earth Rotation Velocity. *Geoecology, Engineering Geology, Hydrogeology, Geocryology*, Proceedings of Russian Academy of Sciences series, Moscow.

Kondo. K. 1980. The recovery of the Japanese sardine – the biology basis of stock size fluctuations. *Rapp. P-v. Réun. Cons. Int. Explor. Mer.,* 177: 332–352.

Koslow, J.A. 1992. Fecundity and the Stock-Recruitment relationship *Can. J. Fish. Aquat. Sci.,* 49: 210–217.

Koslow, J.A., Thompson, K.R. & Silvert, W. 1987. Recruitment to northwest Atlantic cod, *Gadus morhua* and haddock, *Melanogrammus aeglefinus* stocks: influence of stock size and climate, *Canadian Journal of Fisheries and Aquatic Sciences,* 44: 26–39.

Laevastu, T. & Favorite, F. 1980. Holistic simulation models of shelf-sea ecosystems. *In* A.R. Longhurst, ed. *Analysis of Marine Ecosystems,* pp. 701–727. Academic Press, London.

Lasker, R. 1978. The relation between oceanographic conditions and larval anchovy food in the California current: factors leading to recruitment failure. *Rapp. P-v. Réun. Cons. Int. Explor. Mer.,* 173: 212–230.

Le Blanc, J-L. & Marsac, F. 1999. Climate Information and Prediction Services for Fisheries: the case of tuna fisheries, CLIMAR 99 – WMO Workshop on Advances in Marine Climatology, Vancouver (CA) 8–15 September 1999, pp. 30.

Lean, J. & Rind, D. 1998. Climate forcing by changing solar radiation, *Journal of Climate*, 11(12): 3069–3091.

Leggett, W.C., Frank, K.T. & Carscadden, J.E. 1984. Meteorological and hydrographic regulation of year-class strength in capelin (*Mallotus villosus*). *Canadian Journal of Fisheries and Aquatic Sciences,* 41: 1193–1201.

Leroux, M. 1998. *Dynamic Analysis of Weather and Climate*, Wiley/Praxis series in Atmospheric Physics, John Wiley & Sons, Publishers. 365 pp.

Levitus, S., Antonov, J.I., Boyer, T.P. & Stephens, C. 2000. Warming of the world ocean. *Science*, 287: 2225–2229.

Loeb, V.E., Smith, P.E. & Moser, H.G. 1983a. Ichthyoplankton and zooplankton abundance patterns in the California Current area, 1975. *CalCOFI Rep.,* 24: 109–131.

Loeb, V.E., Smith, P.E. & Moser, H.G. 1983b. Geographical and seasonal patterns of larval fish species structure in the California Current area, 1975. *CalCOFI Rep.,* 24: 132–151.

Loeb, V., Siegel, V., Holm-Hansen, O., Hewitt, R., Fraser, W., Trivelpiece, W. & Trivelpiece, S. 1997. Effects of sea-ice extent and krill or salp dominance on the Antarctic food web. *Nature,* 387: 897–900.

Longhurst, A.R. 1995. Seasonal cycles of pelagic production and consumption. *Prog. Oceanog*., 36: 77–167.

Longhurst, A.R., Sathyendranath, S., Platt, T. & Cayerhill, C.M. 1995. An estimate of global primary production in the ocean from satellite radiometer data, *J. Plankton Res.*, 17(6): 1245–1271.

McFarlane G.A., King, J.R. & Beamish, R.J. 2000. Have there been recent changes in climate? Ask the fish, *Progress in Oceanography*, 47: 147–169.

McGowan, J.A., Cayan, D.R & Dorman, L.M. 1998. Climate-ocean variability and ecosystem response in the northeast Pacific. *Science,* 281: 210–217.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. & Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteor. Soc.,* 78: 1069–1079.

Markgraf, V. ed. 2001. *Interhemispheric Climate Linkages*, Academic Press, San Diego, CA.

Marsac, F. & Hallier, J.P. 1991. The recent drop in the yellowfin catches by the western Indian Ocean purse fishery: overfishing or oceanographic changes. *In* Proceedings of the Expert Consultation on the Stock Assessment of Tunas in the Indian Ocean. Bangkok, Thailand, 2–6 July 1990. Colombo Sri Lanka, Indian Ocean Commission.

Martin, J.H., Gordon, R.M. & Fitzwater, S.E. 1991. Iron limitation? The case for iron. *Limnol. Oceanogr.* 36(8): 1793–1802.

Moser, H.G., Smith, P.E. & Eber, L.E. 1987. Larval fish assemblages in the California Current, 1951–1960, a period of dynamic environmental change. *CalCOFI Rep.* XXVIII.

Murawski, S.A. 1993. Climate change and marine fish distributions: forecasting from historical analogy. *Transactions of the American Fisheries Society,* 122: 647–658.

Nixon, S.W. 1982. Nutrient dynamics, primary production and fisheries yields of lagoons. *Oceanol. Acta,* 4(suppl): 357–371.

Nixon. S.W. 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. *Limnol. Oceanogr.,* 33(4, part2): 1005–1025.

Nixon, S.W. 1989. Microscale and finescale variations of small plankton in coastal and pelagic environments. *J. Mar. Res.,* 47: 197–240.

Nixon, S.W. 1997. Prehistoric nutrient inputs and productivity in Narragansett Bay. *Estuaries,* 20(2): 253–261.

Norton, J.G. & Mason, J.E. Environmental influences on species composition of the commercial harvest of finfish and invertebrates off California. *CalCOFI Report Series.* Accepted for publication June 2003. (In press).

Parrish, R.H. & MacCall, A.D. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. *Calif. Dep. Fish. Game Fish. Bull.,* 167: 109 pp.

Pauly, D. & Matsubroto, P. 1996. Baseline Studies of Biodiversity: the Fisheries Resources of Western Indonesia. *ICLARM Stud. Rev.* 21, 321 pp.

Pauly, D. & Tsukayama, I. eds. 1987. *The Peruvian Anchoveta and its Upwelling Ecosystem: Three Decades of Change*. IMARPE; GTZ; ICLARM, Callao, Peru. 351 pp.

Pauly, D., Muck, P., Mendo, J. & Tsukayama, I. eds. 1989. *The Peruvian Anchoveta and its Upwelling Ecosystem: Dynamics and Interactions*. IMARPE;GTZ;ICLARM, Callao, Peru. 438 pp.

Pauly, D., Christensen, J., Dalsgaard, J., Froese, R. & Torres, F. Jr. 1998. Fishing down marine food webs. *Science,* 279: 860–863.

Pearcy, W.G. 1966. Salmon production in changing ocean domains. *In* D.J. Stouder, P.A. Bisson & R.J. Naiman, eds. *Pacific Salmon and their Ecosystems: Status and Future Options,* pp. 331–352. Chapman and Hall, New York.

Perry, C.A. 1994. Solar-irradiance variations and regional precipitation fluctuations in the western United States: *International Journal of Climatology*, 14: 969–983.

Perry, C.A. 1995. Association between solar-irradiance variations and hydroclimatology of selected regions of the USA. *In* Proceedings of 6th International Meeting on Statistical Climatology, Galway, Ireland, June 19–23, 1995, pp. 239–242. Steering Committee for International Meetings on Statistical Climatology.

Perry, C.A. 2000. A regression model for annual streamflow in the upper Mississippi River Basin based on solar irradiance. *In* G.J. West & L. Buffaloe, eds., Proceedings of the Sixteenth Annual Pacific Climate Workshop, Santa Catalina Island, California, May 24–27, 1999; *Interagency Ecological Program for Sacramento-San Joaquin Delta Technical Report*. 65: 161–170.

Perry, C.A. & Hsu, K.J. 2000. Geophysical, archaeological, and historical evidence support a solar-output model for climate change: Proceedings of National Academy of Science, 97(23): 1244–1248.

Polovina, J.J. 1984a. An overview of the ECOPATH model. *ICLARM Fishbyte,* 2(2): 5–7

Polovina, J.J. 1984b. Model of the coral reef ecosystem. Part I. The ECOPATH model and its application to French frigate shoals. *Coral Reefs*, 3(1): 1–11.

Polovina, J.J., Mitchum, G.T. & Evans, O.T. 1995. Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific. 1960–88. *Deep Sea Res*., 42: 1710–1716.

Quinn, W.H. 1992. A study of Southern Oscillation-related climatic activity for A.D. 622–1900 incorporating Nile River flood data. *In* H.F. Diaz & V. Markgraf, eds. *El Niño*: *historical and paleoclimatic aspects of the Southern Oscillation,* pp. 119–149. Cambridge University Press.

Reid, P.C., Planque, B. & Edwards, M. 1998. Is observed variability in the long-term results of the Continuous Plankton Recorder survey a response to climate change? *Fisheries Oceanography,* 7: 282–288.

Reid, P.C., Edwards, M., Hunt, H.G. & Warner, A.J. 1998. Phytoplankton change in the North Atlantic, *Nature,* 391: 546.

Russell, F.S. 1931. Some theoretical considerations on the "overfishing" problem. *J. Cons. CIEM*, 6: 1–20.

Russell, F.S. 1973. A summary of the observations of the occurrence of planktonic stages of fish off Plymouth 1924–1972. *J. Mar. Biol. Assn. NS UK*, 53: 347–355.

Scheiber, H.N. 1990. California marine research and the founding of modern fisheries oceanography: CALCOFI's early years, 1947–1964. *CalCOFI Rep*., 31: 63–83.

Schulein, F.H., Boyd, A.J. & Underhill, L.G. 1995. Oil to meal ratios of pelagic fish taken form the northern and southern Benguela system: seasonal patterns and temporal trends, 1951–1993. *S. Afr. J. Mar. Sci.,* 15: 61–82.

Schwartzlose, R.A., Alheit, J. Bakun, A. Baumgartner, T.R., Cloete, R., Crawford, R.J.M., Fletcher, W.J., Green-Ruiz, Y., Hagen, E., Kawasaki, T., Lluch-Belda, D., Lluch-Cota, S.E., MacCall, A.D., Matsuura, Y., Nevarez-Martinez, M.O., Parrish, R.H., Roy, C., Serra, R., Shust, K.V., Ward, M.N. & Zuzunaga, J.Z. 1999. Worldwide large-scale fluctuations of sardine and anchovy populations. *S. Afr. J. Mar. Sci.,* 21: 289–347.

Sharp, G.D. 1976. Vulnerability of tunas as a function of environmental profiles. *In* Maguro Gyokyo Kyogikay Gijiroku, Suisano-Enyo Suisan Kenkyusho. Proceedings of the Tuna Fishery Research Conference, Fisheries Agency – Far Seas Fisheries Research Laboratory, Shimizu, Japan. (In English and Japanese).

Sharp, G.D. 1978. Behavioural and physiological properties of tunas and their effects on vulnerability to fishing gear. *In* G.D. Sharp & A.E. Dizon, eds. *The Physiological Ecology of Tunas,* pp. 397–449. Academic Press. San Francisco and New York.

Sharp, G.D. 1981a. Report of the Workshop on Effects of Environmental Variation on the Survival of Larval Pelagic Fishes. *In* G.D. Sharp, ed. Report and Documentation of the Workshop on the Effects of Environmental Variation on the Survival of Larval Pelagic Fishes, pp. 6–62. *IOC Workshop Rep. Ser*. No.28 Unesco, Paris.

Sharp, G.D. 1981b. Colonization: modes of opportunism in the ocean. *In* G.D. Sharp, ed. Report and Documentation of the Workshop on the Effects of Environmental Variation on the Survival of Larval Pelagic Fishes, pp. 125–148. *IOC Workshop Rep. Ser.* No. 28 Unesco, Paris.

Sharp, G.D. 1987. Climate and Fisheries: cause and effect or managing the long and short of it all. *In* A.I.L. Payne, J.A. Gulland & K.H. Brink, eds. The Benguela and Comparable Ecosystems. *S. Afr. J. Mar. Sci*., 5: 811–838.

Sharp, G.D. 1988. Fish Populations and Fisheries: their perturbations, natural and man induced. *In* H. Postma & J.J. Zijlstra, eds. *Ecosystems of the World 27, Continental Shelves,* pp. 155–202. Elsevier, Amsterdam.

Sharp, G.D. 1991. Climate and Fisheries: Cause and Effect – A system review. *In* T. Kawasaki, S. Tanaka, Y. Toba & A. Taniguchi, eds. *Long-term Variability of Pelagic Fish Populations and Their Environment,* pp. 239–258. Pergamon Press, Tokyo.

Sharp, G.D. 1992a. Climate Change, the Indian Ocean Tuna Fishery, and Empiricism. *In* M.H. Glantz, ed. Climate Variability, Climate Change and Fisheries, pp. 377–416. Cambridge University Press.

Sharp, G.D. 1992b. Fishery Catch Records, ENSO, and Longer Term Climate Change as Inferred from Fish Remains From Marine Sediments. *In* H. Diaz & V. Markgraf, eds. *Paleoclimatology of El Niño – Southern Oscillation*, pp. 379–417. Cambridge University Press.

Sharp, G.D. 1995. Its about time: new beginnings and old good ideas in fisheries science. *Fish. Oceanogr.*, 4(4): 324–341.

Sharp, G.D. 1997. Its About Time: Rethinking fisheries management. *In* Hancock, Smith, Grant and Beumer, eds. *Developing and Sustaining World Fisheries Resources*: *The state of science and management,* pp. 731–736. CSIRO, Australia.

Sharp, G.D. 1998. The Case for Dome-Shaped response Curves by Fish Populations *In* M-H. Durand, P. Cury, R. Mendelssohn, C. Roy, A. Bakun & D. Pauly, ed. *Global versus Local Changes in Upwelling Systems*, pp. 503–524. A report from the CEOS Workshop, Monterey, California, September, 1994. ORSTOM Editions, Paris.

Sharp, G.D. 2000. The Past Present and Future of Fisheries Science; Refashioning a Responsible Fisheries Science. *In* P.J. Harrison & T.R. Parsons, eds. *Fisheries Oceanography*: *an integrative approach to fisheries ecology and management,* pp. 207–262. Blackwell Science, UK.

Sharp, G.D. 2001. A Brief Overview of the History of Fish Culture and its Relation to Fisheries Science. Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July, 2000, available on CD-ROM from IIFET Secretariat, OSU, Corvallis, Oregon.

Sharp, G.D. & Csirke, J. eds. 1983. Proceedings of the Expert Consultation to Examine the Changes in Abundance and Species Composition of Neritic Fish Resources, San Jose, Costa Rica, 18–29 April 1983. *FAO Fisheries Report,* No. 291, Vols 2–3. 1294 pp.

Sharp, G.D., Csirke, J. & Garcia, S. 1983. Modelling Fisheries: What was the Question? *In* G.D. Sharp & J. Csirke, eds. Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources. San Jose, Costa Rica, April 1983, pp. 1177–1224. *FAO Fisheries Report* No. 291(3).

Sharp, G.D., Klyashtorin, L. & Goodridge, J.G. 2001a. Forecasting Ocean Ecosystem Responses to Various Climate Clocks, 2001. *In* G.J. West & L.D. Buffaloe, eds. *Proceedings of the Seventeenth Annual Pacific Climate Workshop,* pp. 65–90. Technical Report 67 of the Interagency Ecological Program for the San Francisco Estuary.

Sharp, G.D., Klyashtorin, L. & Goodridge, J.G. 2001b. Climate and Fisheries: Costs and benefits of Change. *In Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July, 2000,* available on CD-ROM from IIFET Secretariat, OSU, Corvallis, Oregon.

Sharp, G.D., Klyashtorin, L. & Goodridge, J.G. 2002. The New Regimes: Fish Stories and Society, Extended abstract/joint poster on long-term consequences of Climate Forcing, PACLIM, Asilomar, April 2001. *In* G.J. West & L.D. Buffaloe, eds. Proceedings of the Eighteenth Annual Pacific Climate Workshop, Technical Report (in press) of the Interagency Ecological Program for the San Francisco Estuary.

Shen, G.T., Cole, J.E. Lea, D.W., Linn, L.J., McConnaughey, T.A. & Fairbanks, R.G. 1992. Surface ocean variability at Galápagos from 1936–1982: Calibration of geochemical tracers in corals. *Paleoceanography,* 7: 563–583.

Sinclair, M. 1988. *Marine populations*: *An essay on population regulation and speciation. Books in recruitment fishery oceanography*. Washington Sea Grant Program. University of Washington Press, Seattle and London. 252 pp.

Smith, P.E. 1978. The biological effects of ocean variability: time and space scales of biological response. *Rapp. P-v. Réun. Cons. Int. Explor. Mer.,* 173: 112–127.

Soutar, A. & Crill, P.A. 1977. Sedimentation and climatic patterns in the Santa Barbara Basin during the 19th and 20th centuries. *Bull. Geol. Soc. of America,* 88: 1161–1172.

Soutar, A. & Isaacs, J.D. 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediments of the Californias. *Fish. Bull., US,* 72: 257–273.

Southward, A.J. 1974a. Changes in the plankton community in the western English Channel. *Nature*, 259: 5433.

Southward, A.J. 1974b. Long term changes in abundance of eggs in the Cornish pilchard (*Sardina pilchardus*, Walbaum) off Plymouth. *J. Mar. Biol. Assn. UK NS,* 47: 81–95.

Southward, A.J., Boalch, G.T. & Mattock, L. 1988. Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th century. *J. Mar. Biol. Assoc. UK*, 68: 423–445.

Southward, A.J., Butler, E.I. & Pennycuick, L. 1975. Recent cyclic changes in climate and abundance of marine life. *Nature*, 253: 714–717.

Sonechkin, D.M. 1998. Climate dynamics as a nonlinear Brownian motion. *International Journal of Bifurcation and Chaos,* 8(4): 799–803

Sonechkin, D.M., Datsenko, N.M. & Ivaschenko, N.N. 1997.Estimation of the global warming trend by Wavelet Analysis. *Izvestia, Atmospheric and Oceanic Physics,* 33(2): 184–194.

Taylor, K. 1999. Rapid Climate Change. *American Scientist.* July–August 1999 issue.

Thompson, M-F. & Tirmizi, N.M. eds. 1995. *The Arabian Sea – living marine resources and the environment.* Vanguard books (PVT) LTDm Lahore, Pakistan. 732 pp.

Thompson, L.G., Mosely-Thompson, E., Davis, M.E., Lin, P.-N., Henderson, K.A., Cole-Dai, J., Bolzon, J.F. & Liu, K.-B. 1995. Late glacial stage and holocene tropical ice core records from Huascaran, Peru, *Science*, 269: 46–48.

Ursin, E. 1982. Stability and variability in the marine ecosystem. *Dana*, 2: 51–67.

Vangeneim, G.Ya. 1940. Long-term prediction of air temperature river debacle. *National Hydrological Institute*, 10: 207–236 (in Russian).

Ware, D.M. 1995. A century and a half of change in the climate of the NE Pacific. *Fish. Oceanogr.*, 4(4): 267–277.

Ware, D.M. & McFarlane, G.A. 1989. Fisheries production domains in the Northeast Pacific Ocean. *In* R.J. Beamish & G.A. McFarlane eds. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, pp. 359–379. *Canadian Special Publication of Can. Fish. Aquat. Sci.,* 108.

Ware, D.M. & Thompson, R.E. 1991. Link between long-term variability in upwelling and fish production in the northeast Pacific Ocean. *Can. J. Fish. Aquat. Sci*., 48(12): 2296–2306.

Welchmeyer, N.A and several others. 1999. EOS, 80: 248 pp.

White, W.B., Chen, S.-C. & Peterson, R. 1998. The Antarctic Circumpolar Wave: A beta-effect in ocean-atmosphere coupling over the Southern Ocean. *J. Physical Oceanography*, 28: 2345–2361.

White, W.B., Lean, J., Cayan, D.R. & Dettinger, M.D. 1997. A response of global upper ocean temperature to changing solar irradiance. *J. Geophysical Research*, 102: 3255–3266.

Wyatt, T. & Larrañeta, M.G. eds. 1988. Long Term Changes in Marine Fish populations. *Proceedings of a Symposium in Vigo, Spain 18–21 Nov. 1986*. Imprento REAL, Bayona.

Wyllie-Echevarria, T. & Wooster, W.S. 1998. Year-to-year variations in Bering Sea ice cover and some consequences for fish distributions, *Fish. Oceanogr*., 7: 159–170.

Zachos, J.C., Shackleton, N.J., Revenaugh, J.S., Heiko Palike & Flower, B.P. 2001. Climate Response to Orbital Forcing Across the Oligocene-Miocene Boundary. *Science,* 292: 274–274.

Zorita, E. & Gonzalez-Rouco, F. 2000. Disagreement between predictions of the future behaviour of the Arctic Oscillation as simulated in two different climate models: Implications for global warming. *Geophysical Research Letters*, 27: 1755–1758.

ANNEX I

RECOMMENDED FURTHER READING
(relevant papers and web pages not cited in the main document

Anderson, R.Y. 1992a. Long term changes in the frequency of occurrence of El Niño events. *In* H.D. Diaz & V. Markgraf, eds. *El Niño*: *historical and Paleoclimatic Aspects of the Southern Oscillation,* Cambridge University Press.

Anderson, R.Y. 1992b. Solar Variability Captured in Climatic and High-Resolution Paleoclimatic Records: A Geological Perspective. *In* C.P. Sonnet, M.S. Giampapa & M.S. Matthews, eds. The Sun in Time, University of Arizona Press.

Anderson, R.Y. & Allen, B.D. 1993. Evidence from western North America for rapid shifts in climate during the last glacial maximum, *Science*, 260: 1920–1923.

Bakun, A. & Parrish, R.H. 1990. Comparative studies of coastal pelagic fish reproductive habits: the Brazilian sardine (*Sardinella aurita). J. Cons. Int. Explor. Mer.*, 46: 269–283.

Bakun, A. & Parrish, R.H. 1991. Comparative studies of coastal pelagic fish reproductive habitats: the anchovy (*Engraulis anchoita*) of the southwestern Atlantic. *J. Cons. Int. Explor. Mer.*, 48: 342–361.

Beamish, R.J. 1993. Climate change and exceptional fish production off the west coast of North America, *Canadian Journal of Fisheries and Aquatic Sciences,* 50: 2270–2291.

Beamish, R.J. & McFarlane, G.A. eds. 1989. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. *Canadian Special Publication of Can. Fish. Aquat. Sci.,* 108.

Beverton, R.J.H. & Holt, S.J. 1957. On the dynamics of exploited fish populations. *Fish. Invest. Minist. Agric. Fish. Food G.B. (2 Sea Fish.)*, 19: 533 pp.

Beyer, J. & Sparre, P. 1983. *Modelling exploited fish stocks. In* S.E. Jørgensen, ed. *Application of ecological modelling in environmental management. Part A.*, pp. 485–582. Amsterdam, Elsevier Scientific Publishing Co.

Bigg, G.R., T. D. Jickells, P. S. Liss, T. J. Osborn, 2003. The Role of the Oceans in Climate. *International Journal of Climatology* 23(10):1127–1159, August 2003.

Broecker, W.S., Sutherland, S. & Peng, T.-H. 1999. A possible 20th-Century slowdown of Southern Ocean deep water formation. *Science,* 286(5442): 1132–1135.

Cole, J.E., Dunbar, R.B., McClanahan, T.R. & Muthiga, N.A. 2000. Tropical Pacific forcing of decadal SST variability in the western Indian Ocean over the past two centuries. *Science*, 287: 617–619.

Dore, J.E. R. Lukas, D.W. Sadler & D.M. Karl. 2003. Climate-driven changes to the atmospheric CO2 sink in the subtropical North Pacific Ocean. *Nature,* 424, 754–757 (14 August 2003)

Durand, M.-H., Cury, P., Mendelssohn, R., Roy, C., Bakun, A. & Pauly, D. eds. 1998. *Global versus Local Changes in Upwelling Systems – a report from the CEOS Workshop, Monterey, California, September, 1994*. ORSTOM Editions, Paris. 594 pp.

Fasham, M.J.R. ed. 1984. *The Flows of Energy and Materials in Marine Ecosystems, Theory and Practice*. Plenum Press, New York. 733 pp.

Garcia, S. & LeReste, L. 1981. Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. *FAO Fisheries Technical Paper* No. 203: 215 pp. (original in French, same ref.).

Glantz, M.H. 1996. Currents of Change: *El Niño's Impact on Climate and Society*. Cambridge University Press, 200 pp.

Glantz, M.H. & Thompson, J.D. eds. 1981. Resource Management and Environmental Uncertainty: Lessons from coastal upwelling fisheries. *P. Adv. Env. Sci.,* 11, Wiley-Interscience. 491 pp.

Glantz, M.H., Katz, R. & Krenz, M. 1987. *The Societal Impacts Associated with the 1982–83 Worldwide Climate Anomalies.* NCAR/ESIG, Boulder, Colourado. 105 pp.

Glantz, M.H., Katz, R. & Nicholls, N. eds. 1991. *ENSO Teleconnections linking worldwide climate anomalies*: *Scientific basis and societal impacts*. Cambridge university Press, Cambridge, UK.

Glynn, P.W. ed. 1990. Global Ecological Consequences of the 1982–83 El Niño-Southern Oscillation. Elsevier Oceanography Series, 52, Elsevier, Amsterdam. 563 pp.

Graham, M. 1935. Modem theory of exploiting a fishery and application to North Sea trawling. *J. Cons. CIEM*, 10(3): 264–274.

Helle, J.H. & Hoffman, M.S. 1995. Size decline and older age at maturity of two chum salmon (*Oncorhynchus keta*) stocks in western North America, 1972–92. III: *In* R.J. Beamish, ed. Climate and northern fish populations. *Can. Spec. Pub. Fish. Aquat. Sci*., 121: 245–260.

Hunter, J.R. & Sharp, G.D. 1983. Physics and fish populations: Shelf sea fronts and fisheries. *In* G.D. Sharp & J. Csirke, eds. Proceedings of the Expert Consultation to Examine the Changes in Abundance and Species Composition of Neritic Fish Resources, pp. 659–682. San Jose, Costa Rica, 18–29 April 1983. Rome. *FAO Fisheries Report* No. 291, Vol. 2.

Isaacs, J.D. 1976. Some ideas and frustrations about fishery science. *CalCOFI Rep.* XVIII: 34–43.

Larkin, P.A. 1977. An epitaph for the concept of maximum sustainable yield. *Trans. Am. Fish. Soc*., 106(1): 1–11.

Laevastu, T. 1993. *Marine Climate, Weather and Fisheries*. Wiley and Sons, Inc. Halstead press. 204 pp.

Lluch-Belda, D., Schwartzlose, R.A., Serra, R., Parrish, R., Kawasaki, T., Hedgecock, D. & Crawford, R.J.M. 1992. Sardine and anchovy regime fluctuations of abundance in four regions of the world oceans: a workshop report. *Fish. Oceanogr.*, 1(4): 339–347.

Lluch-Belda, R., Crawford, J.M., Kawasaki, T., MacCall, A.D., Parrish, R.H., Schwartzlose, R.A. & Smith, P.E. 1989. World-wide fluctuations of sardine and anchovy stocks: The regime problem. *S. Afr. J. Mar. Sci*., 8: 195–205.

Mallicoate, D.L. & Parrish, R.H. 1981. Seasonal growth of California stocks of northern anchovy, *Engraulis mordax*, Pacific mackerel, *Scomber Japonicus*, and jack mackerel, *Trachurus symmetricus*. *CalCOFI Rep.* Vol XXII: 69–81.

Murphy, G.I. 1982. Recruitment of tropical fishes. *In* D. Pauly & G.I. Murphy, eds. 1982. *Theory and management of tropical fisheries. Proceedings of the ICLARM/CSIRO workshop on the theory and management of tropical multispecies stocks*, 12–21 January 1981, pp. 141–148. Cronulla, Australia. *ICLARM Conf. Proc.*, 9: 360 pp.

Overpeck, J.T. 1996. Warm climate surprises. *Science,* 271: 1820–1821.

Owen, R.W. 1981 Patterning of flow and organisms in the larval anchovy environment. *In* G.D. Sharp, ed. Report and Documentation of the Workshop on the Effects of Environmental Variation on the Survival of Larval Pelagic Fishes, pp.167–200. *IOC Workshop Rep. Ser.* No. 28. UNESCO, Paris.

Parrish, R. & Mallicoate, D. 1995. Variation in the condition factors of California pelagic fishes and associated environmental factors. *Fish. Oceanogr*., 4(2): 171–190.

Parrish, R.H., Nelson, C.S. & Bakun, A. 1981. Transport mechanisms and reproductive success of fishes in the California Current. *Biol. Ocean*., 1(2): 175–203.

Parker, K.S., Royer, T.C. & Deriso, R.B. 1995. High-climate forcing and tidal mixing by the 18.6-year lunar nodal cycle and low-frequency recruiting trends in Pacific halibut (*Hippoglossus stenolepis*). *In* R.J. Beamish, ed. Climate Change and Northern Fish Populations, pp. 447–459. *Pub. Can. Fish. Aquat. Sci.,* 121.

Pauly, D. 1983. Some simple methods for the assessment of tropical fish stocks. *FAO Fisheries Technical Paper* No. 234: 52 pp. Issued also in French and Spanish.

Pearcy, W.G. ed. 1984: The Influence of Ocean Conditions on the Production of *Salmonids In the North Pacific*: *a workshop*. 8–10 November 1983, Newport, Oregon. Oregon State University Sea Grant College Program. 327 pp.

Pearcy, W.G. 1992. *Ocean ecology of North Pacific salmonids*. Univ. Washington Press, Seattle 179 pp.

Pearcy, W.G., Fisher, J., Brodeur, R. & Johnson, S. 1985. Effects of the 1983 El Niño on coastal nekton off Oregon and Washington. *In* W.S. Wooster & D.L. Fluharty, eds. *El Niño North*: *Niño effects on the eastern subarctic Pacific,* pp. 188–204. Washington Sea Grant Pub. WSG-WO-85–3.

Polovina, J.J. 1996. Decadal variation in the trans Pacific migration of northern bluefin tuna (*Thunnus thynnus*) coherent with climate-induced change in prey abundance, *Fisheries Oceanography,* 5: 114–119.

Quinn, W.H., Neal, V.T. & Antunez de Mayolo, S.E. 1987. El Niño occurrences over the past four and a half centuries. *J. Geophys. Res*., 92: 14449–14461.

Ricker, W.E. 1954. Stock and recruitment. *J. Fish. Res. Board Can*., 11: 559–623.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.*, 191: 382 pp.

Royer, T.C. 1993. High Latitude Oceanic Variability Associated with the 18.6 Year Luni-Solar Tide, *Journal of Geophysical Research*, 84: 4639–4644.

Schaefer, M. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bull. I-ATTC/Bol. CIAT*, 1(2): 27–56.

Sharp, G.D. 1979. Areas of potentially successful exploitation of tunas in the Indian Ocean with emphasis on surface methods. Indian Ocean Programme*, FAO, Rome, Tech. Reports* IOFC/DEV/79/47. 50pp.

Sharp, G.D. 1984. Ecological efficiency and activity metabolism. *In* M.J.R. Fasham, ed. *Flows of Energy and Materials in Marine Ecosystems*: *theory and practice,* pp. 459–474. Plenum Press. New York and London.

Sharp, G.D. 1992. Climate Change, the Indian Ocean Tuna Fishery, and Empiricism. *In* M.H. Glantz, ed. *Climate Variability, Climate Change and Fisheries,* pp. 377–416. Cambridge University Press.

Sharp, G.D. 1995. Arabian Sea Fisheries and Their Production Contexts. *In* Thompson & Tirmizi, eds. *Arabian Sea Oceanography and Fisheries*, pp. 239–264. Karachi, Pakistan.

Sharp, G.D. 1997. Its About Time: Rethinking fisheries management. pp. 731–736. *In* Developing and Sustaining World Fisheries Resources: The state of science and management. Hancock, Smith, Grant and Beumer, eds. CSIRO, Australia.

Sharp, G.D. & McLain, D.R. 1993a. Comments on the global ocean observing capabilities, indicator species as climate proxies, and the need for timely ocean monitoring. *Oceanogr.*, 5(3): 163–168.

Sharp, G.D. & McLain, D.R. 1993b. Fisheries, El Niño-Southern Oscillation and upper-ocean temperature records. *Oceanogr.,* 6(1): 13–22.

Shen, G.T. & Dunbar, R.B. 1995. Environmental controls on uranium in reef corals. *Geochim. Cosmochim. Acta,* 59: 2009–2024.

Shen, G.T., Boyle, E.A. & Lea, D.W. 1987. Cadmium in corals as a tracer of historical upwelling and industrial fallout. *Nature*, 328: 794–796.

Smith, P.E. & Moser, G.H. 1988. CalCOFI time series: an overview of fishes. *CalCOFI Rep.* XXIX: 66–90.

Sparre, P. & Venema, S.C. 1998. Introduction to tropical fish stock assessment. Part 1. Manual. *FAO Fisheries Technical Paper* No. 306.1, Rev. 2. Rome, FAO. 407 pp.

Ueber, E. & MacCall, A. 1992. The rise and fall of the California sardine empire. *In* M.H. Glantz, ed. *Climate Variability, Climate Change and Fisheries*, pp. 31–48. Cambridge University Press, Cambridge.

Wooster, W.S. & Fluharty, D.L. eds. 1984. *El Niño North*: *Niño Effects in the Eastern Subarctic Pacific Ocean.* Wash. Sea Grant, University of Washington, Seattle. 312 pp.

Web Pages and URLs that contain relevant information about climate and fisheries issues:

Start with: http://sharpgary.org and scan the various topics and links.

AFS Climate & Fisheries Symposium: “Fisheries in a Changing Climate”. 2001.
http://www.fisheries.org/climate/climate_symposium.htm

AGU Solar Variability and Climate Change – A Historical Overview, T.S. Feldman
http://www.agu.org/history/sv/articles/ARTL.html

Antigua and Barbuda. 2000.
http://www.cpacc.org/antbar_pg.htm

Arctic Climate Issues, essay by N. Bond, J. Overland and N. Soriede. 2000.
http://www.arctic.noaa.gov/essay_bond.html

Atlantic Climate Change Program
http://www.aoml.noaa.gov/phod/accp/

Causes of Climate Change – Basics
http://www.geog.ouc.bc.ca/physgeog/contents/7y.html

Charles Perry, USGS
http://ks.water.usgs.gov/Kansas/climate/

Climate Change and Impact on US Water Resources:
http://www.pacinst.org/CCBib.html

Climate Change and Salmon Stocks (see oversell of Most Alarming Consequences, etc.). 1999.
http://www.fish.bc.ca/conferences/oct_1999/cover.html

The Role of Convection in Global Climate (Kininmonth & Sharp
http://sharpgary.org/UnConvectGCM.html

Coping With Climate Change, Based on Historical Experiences. 2000. G.D. Sharp.
http://www.vision.net.au/~daly/sharp.htm

Coral Bleaching, Coral Mortality, and Global Climate Change. Rafe Pomerance. 1999.
http://www.state.gov/www/global/global_issues/coral_reefs/990305_coralreef_rpt.html

David Welch’s salmon threat hypothesis: Welch/map
http://sts.gsc.nrcan.gc.ca/adaptation/sensitivities/map5.htm

Doug Hoyt's Solar Climate Projection:
http://users.erols.com/dhoyt1/annex1.htm
http://users.erols.com/dhoyt1/bio.htm

Ed Mercurio's Review of the roles of Galactic Cosmic Waves in Erath's Climate
http://www.hartnell.cc.ca.us/faculty/mercurio/download.html

El Niño/La Niña Forecasting Made Good by Theodore Landscheidt
http://sharpgary.org/landscheidt.html
http://www.vision.net.au/~daly/sun-enso/sun-enso.htm

Fisheries and Biology of the Indian Ocean. J-L LeBlanc. 2001.
http://indianocean.free.fr/fish.htm

Fisheries and Climate Change: The Danish Perspective. 2000.
http://www.dmi.dk/f+u/publikation/dkc-publ/klimabog/CCR-chap-19.pdf

Fleet Numerical Oceanography and Meteorlogical Center – Global Ocean Updates
See OTIS links for Now-Casts of World Ocean
http://www.fnoc.navy.mil/PUBLIC/

Fred Oliver Beware of Global Cooling
http://www.vision.net.au/~daly/cooling.htm

Global Temperature Trend Calculator
http://www.co2science.org/temperatures/ghcn.htm>

GISP Global Station Surface Temperature Data:
http://www.giss.nasa.gov/data/update/gistemp/station_data/

Guest papers
http://www.vision.net.au/~daly/guests.htm

Impacts of Climate Change and Fishing on Pacific Salmon Abundance over the Past 300 Years. B. Finney and others. Science, 27 October 2000.
http://www.uaf.edu/seagrant/NewsMedia/00news/10-20-00_Finney.html

International Earth's Rotation Service – -LOD or Rotation Rate indices
http://www.iers.org/iers/

T. Kawasaki's review of state of knowledge of Climate-Fisheries:
http://www.icsu-scope.org/downloadpubs/scope27/chapter06.html

Implications of Climate Change for Fisheries Management. Gunnar Knapp. 2001.
http://www.orst.edu/Dept/IIFET/2000/abstracts/knapp2.html

International Earth Rotation Service
http://www.iers.org/

IPCC Regional Impacts: Fisheries and other related activities. 2001.
http://www.grida.no/climate/ipcc/regional/299.htm

IPCC Report, 1995. Chapter 16, Climate Change 1995 Fisheries: Executive Summary – John T. Everett, USA
http://www.st.nmfs.gov/st2/climatec.htm

JISAO Climate and Ocean Science Resources
http://tao.atmos.washington.edu/science2.html

Jonathan Adams' Global land environments since the last interglacial
http://www.esd.ornl.gov/projects/qen/nerc.html

John Daly – Waiting for Greenhouse
http://www.vision.net.au/~daly/

Jean_Lu LeBlanc's Indian Ocean Fisheries and Oceanography website:
http://indianocean.free.fr/

Latent Heat Flux Imagery
http://www.icess.ucsb.edu/esrg/lh/latent_heat_flux.html

Long-term Climate Trends and Salmon Population. George Taylor. 1997.
http://www.ocs.orst.edu/reports/climate_fish.html

NAO: http://www.ldeo.columbia.edu/NAO/
http://www.cgd.ucar.edu/~jhurrell/PaperCopy/naobook.ch1.pdf

NAO Forecasting:
http:/www.john-daly.com/theodor/naonew.htm

NOAA Pacific Fisheries Environmental Laboratory website:Climate and Marine Fisheries
http://www.pfel.noaa.gov/research/climatemarine

Ocean Climate and Regime Shifts Bibliography:
http://www.cqs.washington.edu/crisp/ocean/ocean.html

Ocean Climate/ENSO Forecasts:
http://www.cqs.washington.edu/crisp/rel/ocean.html

Pål Brekke's recent Presentations on NASA/SOHO and Solar Influences – and Imagery
http://zeus.nascom.nasa.gov/~pbrekke/presentations/talks.html
http://folk.uio.no/paalb/research.html

Pangloss Fndtn Ocean calculator
http://www.dnai.com/~patwilde/ocean.html

PDO: http://www.jisao.washington.edu/pdo

Selected Bibliographies
http://www.pfel.noaa.gov/research/climatemarine/cmfpublications/cmfpublications.html#BIBLIO

Sherwood and Kieth Idso's CO2 Science website:
http://www.co2science.org/

Solar Influences and Commentary by Doug Hoyt:
http://users.erols.com/dhoyt1

SPC Ocean Fisheries Links;
http://www.spc.org.nc/coastfish/links.html

Sudden climate transitions during the Quaternary. Progress in Physical Geography.
Jonathan Adams, Mark Maslin, Ellen Thomas. 1999.
http://www.esd.ornl.gov/projects/qen/transit.html

Taylor Dome Ice Laminae Climate Record
http://depts.washington.edu/isolab/taylor

The Great Climate flip-flop. William Calvin. 1998.
http://faculty.washington.edu/wcalvin/1990s/1998AtlanticClimate.htm

The Pleistocene and the Origins of Human Culture: Built for Speed.
Peter J. Richrason and Robert Boyd. 1998.
http://www.des.ucdavis.edu/faculty/Richerson/Speed.htm

UN Atlas of the Oceans:
http://www.oceansatlas.org/index.jsp

UN Framework Convention on Climate Change – Climate Change Information Kit:
http://www.unfccc.de/resource/iuckit/fact10.html

Understanding and Predicting Global Climate Change Impacts on the Vegetation and Fauna of Mangrove Forested Ecosystems in Florida. USGS. 2000.
http://www.nrel.colostate.edu/brd_global_change/proj_29_florida_mangroves.html

Workshop: Climate Change and the Great Lakes: What Are the Potential Impacts, and What Can We Do? EPA. 2001.
http://www.epa.gov/glnpo/climate/workshops.html

ANNEX II

GLOSSARY

Atmospheric Climate Indices – (ACI): characterizes the large-scale (hemispheric) air mass transfer that can be classified into three main components by a predominant direction of the air mass transport: "meridional" (C), "western" (W) and "eastern (E). According to their names, (C) component indicates predominant air transport from North to South and back, while (W) and (E) components indicate predominant West–East and East–West air transport The Atmospheric Circulation Index was suggested by Vangeneim (1940) and Girs [1971] to characterize atmospheric processes on a hemispheric (global) scale.

Condensation: the change of water vapour into a liquid. In order to condense water vapour, the air must be at or near saturation in the presence of condensation nuclei.

Condensation nucleus: a particle, liquid or solid, upon which condensation of water vapour begins in the air, i.e. dust, salt, water droplet, etc.

Continental climate: characterizes the interior of a large land-mass, marked by large annual, day-to-day, or day/night temperature ranges; low relative humidity; and moderate to low irregular rainfall. Annual temperature extremes occur soon after the solstices. (See maritime climate)

Coriolis force: the deflection of moving objects (air and water currents) due to the rotation of the Earth – to the right in the northern hemisphere, and to the left in the southern – important in the formation of anticyclones, cyclones, gyres, eddies.

Cyclone: an area of low pressure, with circulation counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

Doldrums: The narrow, low-pressure belt centred on the equator, characterized by light, variable winds, rising air currents, and heavy rainfall.

El Niño, Southern Oscillation (ENSO): an interannual see-saw in tropical sea-level pressure between the eastern and western hemispheres. During El Niño, unusually high atmospheric sea-Level pressures develop in the western tropical Pacific and Indian Ocean regions, and unusually low sea-level pressures develop in the southeastern tropical Pacific. So tendencies for unusually low pressures west of the date line and high pressures east of the date line have also been linked to periods of anomalously cold equatorial Pacific sea-surface temperatures sometimes referred to as La Niña.

Geoid: the baseline figure of the Earth, considered as a sea-level surface including local gravitational effects, without accounting for topographic features, and extended over the entire Earth's surface.

Geostrophic velocity vectors: Ocean currents are a function of wind forcing, the Earth's rotation, tidal forcesand movement of water from areas of higher water levels (pressure) to lower water levels (pressure). The component of the current that is caused by watermoving from areas of higher pressure to lower pressure is known as the geostrophic velocity vector. In some regions most of the current is geostrophic current.

Infrared radiation: electromagnetic radiation comprising wavelengths between 0.75 and 1000 mm that occupies that part of the electromagnetic spectrum with a frequency less than that of visible light and greater than that of most radio waves, although there is some overlap. The name infrared means “below the red,” i.e., beyond the red, or lower frequency (longer wavelength), end of the visible spectrum. Infrared radiation is thermal, or heat, radiation.

Intertropical Convergence Zone (ITCZ): nearly solid ring of thunderstorms surrounding the globe in the tropics as easterly trades of both hemispheres converge at equator.

Maritime climate: characterizes oceanic islands or coastal regions of continents, marked by small annual, day-to-day, or day/night temperature ranges; high relative humidity; and regular rainfall. Annual temperature extremes lag after the solstices. (See continental climate).

Mediterranean Climate: mid-latitude climate found on the western coasts of continents, characterized by mild, rainy winters and dry summers.

Ocean season: seasonal change in sea-level height caused by change in heat content and prevailing winds.

Ocean tide: effect of lunar and solar gravity on mid-ocean water. Pacific Decadal Oscillation (PDO) long-term (20 to 30 years) fluctuation in sea-surface heights/ocean temperature along eastern/western coasts of the Pacific Ocean.

Milankovitch Cycles: The first of the three Milankovitch Cycles is the Earth's eccentricity. Eccentricity is, simply, the shape of the Earth's orbit around the Sun, a constantly fluctuating orbital shape ranges between 0 to 5% ellipticity on a cycle of about 100,000 years;

- The second is Axial tilt: the inclination of the Earth's axis in relation to its plane of orbit around the Sun. Earth's axial tilt oscillations range from 21.5 to 24.5 degrees with a periodicity of 41,000 years;

- The third of the Milankovitch Cycles is Earth's precession. Precession or slow wobble as it spins on axis. This wobbling can be likened to a top running down, that begins to wobble back and forth on its axis. The precession of Earth wobbles from pointing at Polaris (North Star) to pointing at the star Vega. When this shift to the axis pointing at Vega occurs, Vega would then be considered the North Star. This precession, has a periodicity of 23,000 years.

North Atlantic Oscillation (NAO): The NAO index is often defined as the difference of sea-level pressure between two stations situated close to the "centres of action" over Iceland and the Azores. Stykkisholmur (Iceland) is invariably used as the northern station, whereas either Ponta Delgada (Azores), Lisbon (Portugal) or Gibraltar are used as the southern station. The NAO has strong impacts on weather and climate in the North Atlantic region and surrounding continents and is a dominant exogenous factor in many ecological systems.

Pacific Decadal Oscillation (PDO): long-term (20 to 30 years) fluctuation in sea-surface heights/ocean along eastern/western coasts of the Pacific Ocean.

Rossby waves: an extraordinarily slow westward-moving ocean wave of low amplitude (10 to 20 centimeters) and great width (hundreds of kilometers) that crosses the Pacific over several decades.

Scatterometer: a microwave (radar) sensor that scans the surface of the earth from an aircraft or satellite and reads the reflection or scattering coefficient of the return pulse to measure surface roughness and derive wind speed and direction.

Sea level anomaly: the difference between the actual, measured sea level height and a mean sea level based on a mathematical reference. See geoid, reference ellipsoid, reverse barometer.

Sea level height: the actual, measured height of sea level against a standard reference. See geoid, reference ellipsoid, sea level anomaly.

Seasat: JPL-designed Earth-orbital mission, launched in 1978, to flight-test five instruments(a synthetic aperture radar, a radar altimeter, a scatterometer, a scanning multichannel microwave radiometer, and a visible and IR radiometer) to study the ocean surface; important legacy for many later Earth-orbiting instruments developed at JPL.

Sea surface height: Sea surface height is defined as the distance of the sea surface above the reference ellipsoid. The sea surface height is computed from altimeter range and satellite altitude above the reference ellipsoid. The "reference ellipsoid" is the first-order definition of the non-spherical shape of the Earth as an ellipsoid of revolution with equatorial radius of 6378.1363 kilometers and a flattening coefficient of 1/298.257. Also, the variable height of the sea surface above or below the geoid. Sea surface height is often shown as a sea-surface anomaly or sea-surface deviation, this is the difference between the sea surface height at the time of measurement and the average sea surface height for that region and time of year.

Southern Oscillation Index: an interannual see-saw in tropical sea-level pressure between Darwin Australia and Tahiti, the developmental history of which is described fully in Allan *et al*. 1996. Positive values indicate non-El Niño patterns, while negative values indicate pending or ongoing Warm Events.

Subsidence: for air, sinking, usually over a broad area, with associated increase in air pressure and rise in temperature.

Temperate climate: Characterizes mid-latitude regions with hot summers and cold winters.

Temperate zone: The mid-latitude climatic zone stretching from the tropic of Cancer to the arctic circle or from the tropic of Capricorn to the Antarctic circle and characterized by hot summers and cold winters.

TOPEX/Poseidon: Joint US-French orbital mission, launched in 1992 to track changes in sea-level height with radar altimeters.

Topography: The shape of a surface, including its relief and the relative position of features – the general configuration of a surface, including its relief.

Tropical zone: The low-latitude climatic zone centred on the equator, extending between the tropics of Cancer and Capricorn, and characterized by year-round hot weather.

Water vapour: the gaseous phase of water.

Weather: The short-term state of the atmosphere at a specific site with respect to temperature, humidity, wind speed and direction, clarity, and cloud cover. Refers to short-term events.