S1.1 Observed climate changes

19 May, 09:15 (S1.1-4947) Plenary

Observed ocean climate changes: a review based on the IPCC AR4 and subsequent works

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Changes in ocean temperature, salinity, oxygen and circulation over the past several decades, and their relation to changes in atmospheric forcing, were thoroughly synthesized in the Intergovernmental Panel on Climate Change's Fourth Assessment Report, published in February 2007. The conclusions of that synthesis were based on peer-reviewed materials published prior to 2006. Primary conclusions based on these published materials are as follows: from 1955 to 2003, the oceans were warming, with two-thirds of the heating in the upper 700 m. The warming was not uniform; the subpolar North Atlantic and North Pacific and tropical Pacific warm pool were cooling, but not enough to offset the global warming trend. Global mean sea level was rising, and the rate was increasing; like temperature, sea level changes also exhibited large regional variations. Salinity is changing regionally, with higher latitudes and the Pacific freshening, while lower latitudes and the Atlantic and Indian are becoming saltier, roughly consistent with a stronger atmospheric hydrological cycle, which is consistent with a warmer atmosphere and hence climate change. Oxygen had been decreasing in the pycnocline in subpolar regions, consistent with decreased ventilation at the base of the climatological pycnocline. On the other hand, circulation trends were not robust. The Atlantic meridional overturning circulation was of particular interest, but variability was dominated by interannual and decadal change; any trends were too weak in comparison to be apparent. The work reviewed in the IPCC was principally based on research ship-based observations and local experiments; climatologies were constructed by simple processing of these regional data sets. Many of the newer results that are brought together here are also based on direct regional observations. Newer products also include the growing body of distributed subsurface float profiles (Argo) as well as data assimilation for the Topex/Poseidon altimetry period. Ocean and climate models are also providing important information for interpreting the observed changes.

19 May, 11:20 (S.1.1-4813) Invited

Evolution of Atlantic Ocean properties and circulation from the tropics to the Arctic

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In the second half of the 20th century, the instrumental record revealed pronounced changes in Atlantic Ocean water mass properties and circulation. To first order, these changes were organised around the structure of the atmospheric NAO forcing – which evolved from an extreme negative phase in the late 1960s to its opposite extreme in the early 1990s. Through modulation of air-sea fluxes and surface wind patterns, the NAO gave rise to basin-scale anomalies of ocean temperature and salinity, altered the baroclinic strength of the gyres, and choreographed episodic exchanges of fresh and saline waters between the Arctic and North Atlantic. Despite a protracted 30-year period of freshening in the Nordic and subpolar seas, ocean measurements provided little, if any, evidence of persistent change in the strength of the Atlantic meridional overturning circulation (MOC). Redistribution of ocean temperature and freshwater anomalies by convection, entrainment, mixing and advection inhibited significant alterations of the density contrast that sustained the Atlantic MOC strength. Since the mid-1990s, Atlantic property distributions and anomalies have increasingly resembled the expected response to greenhouse forcing. From the equator to the Arctic, upper ocean thermal content has risen to record highs. Upper ocean salinities have also increased, particularly in the net evaporative regions of the Atlantic. The excess freshwater that caused salinities to plummet in previous decades at high latitudes has largely been exported to the deep subtropical basins via the lower limb of the MOC, while unusually warm and saline waters are presently flushing its upper limb and headwaters.

19 May, 11:45 (S1.1-4891)

Is the Atlantic thermohaline circulation slowing? Results from Deep Western Boundary Current observations at the exit of the Labrador Sea

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Since 1993 moored current and temperature-salinity observations have been carried out in the western Labrador Sea near 56°N (western end of WOCE-AR7 line), 53°N (exit of the Labrador Sea) and east of the Grand Banks (at 43°N) as part of SFB 460. The time series at 53°N are continued under the German CLIVAR NORDATLANTIK project. All moored, shipboard and Argo observations are evaluated for transport and water mass variability of the different deep water layers. While altimetry and model studies have suggested a decline of the overall subpolar gyre circulation since the 1990s, direct current measurements at the 1500 m level along the western continental slope of the Labrador Sea show interannual variability of the order of 10-20% during the 1996-2007 period. At 43°N no significant change in the deep velocities was found between a Canadian moored array 1992/93 and the SFB array between 1999 and 2005. The relationship with other published records of transport variability is discussed.

19 May, 12:10 (S1.1-4725)

Ocean climate variability in the North Atlantic: the importance of large-scale atmospheric forcing

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The ocean climate in the North Atlantic has undergone dramatic changes throughout the last century. The warming event in northwestern areas during the 1920s to 1960s was followed by a 30-year period of extreme, near-decadal, variability with ocean climate trending towards cold-fresh conditions through to the early-1990s. However, an examination of meteorological and oceanographic data from standard stations and sections reveals a remarkable out-of-phase thermal relationship between eastern and western areas of the North Atlantic during this period, confirming a well known phenomenon. When cold ocean conditions dominated the northwest Atlantic and Greenland, temperatures in the Nordic and Barents Seas were generally warmer-than-normal and conversely when conditions were warm. Since the mid-1990s the relationship between the two regions has shifted to a pan-Atlantic ocean warming response with record setting atmospheric and oceanic temperatures in many areas during recent years. In this presentation, we examine the extent and magnitude of ocean climate variability in the North Atlantic and the importance of large-scale atmospheric forcing based on historical and recent observations.

19 May, 12:25 (S1.1-4840)

The recent warming of intermediate waters at the eastern North Atlantic: insights from a monthly hydrographical time series in the Bay of Biscay

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In the early 1990s, the Spanish Institute of Oceanography began some ambitious programmes of continuous hydrographical and biological monitoring around the Iberian Peninsula. A monthly time series in the Bay of Biscay, eastern North Atlantic (NA), sampling the upper 1000 m, has shown local warming rates for the last 15 years that were much higher than the current long-term ocean warming trends, agreeing with other works reporting sustained warming at the mid-depths of the eastern NA. The relatively high frequency of sampling allows a precise description of the local interannual variability of two key water masses in the NA, East North Atlantic Central Water (ENACW) and Mediterranean Water (MW), timing any pronounced shift properly and making it possible to infer relationships with the air-sea fluxes in the areas of influence or large scale climatic indexes, like the NAO. This detailed description of interannual and interdecadal variability helps in the interpretation of the local

warming record either as a consequence of sustained warmer conditions on a wide area (large-scale tendency) or relating it to local intense anomalies or basin-scale circulation changes. In the present work we will exploit the existence of a quarterly series, sampling the water column at the Balearic Sea (Western Mediterranean) to explore the character of local warming through the coherence in hydrographical signals among these different locations that are not directly connected but are affected by the same large-scale atmospheric patterns. The expected future behaviour of the different time series under global warming projections is also considered.

19 May, 12:40 (S1.1-4750)

Reversal of the 1960s-1990s freshening trend in the upper ocean of the north-east North Atlantic and Nordic Seas

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Hydrographic time series in the north-east North Atlantic and Nordic Seas show that the freshening trend of the 1960s-1990s has completely reversed in the upper ocean. Since the 1990s, temperature and salinity have rapidly increased in the Atlantic Inflow from the eastern subpolar gyre to the Fram Strait. In 2003-2006 salinity values reached the previous maximum last observed around 1960, and temperature values exceeded records. The mean properties of the Atlantic Inflow decrease northwards, but variations seen in the eastern subpolar gyre at 57°N persist with the same amplitude and pattern along the pathways to Fram Strait. Time series correlations and extreme events suggest a time lag of 3-4 years over that distance. This estimate allows predictions to be made; the temperature of Atlantic water in the Fram Strait may start to decline after 2007 or 2008, salinity a year later, but both will remain high at least until 2010.

19 May, 12:55 (S1.1-4731)

Responsiveness of water mass properties to climate forcing at the Caribbean Time series station in the northeastern Caribbean basin

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Extended temporal coverage of the Caribbean Time series oceanographic station (CaTS), occupied at near-monthly periodicity since 1994, allows inference regarding responsiveness of Caribbean water mass properties to seasonal, interannual and long-term climate forcing revealing teleconnections of upper water mass properties to tropical and extratropical climatic oscillations. The Caribbean Surface Water (CSW) responds seasonally to continental climate. Surface salinity decreases under the influence of major river (Amazon and Orinoco) discharges and increases when riverine influence wanes. Salinity changes lag continental rainfall climatology by 3 to 4 months. Decreased rainfall during *El Niño* results in anomalously high surface salinity. While sea surface temperature (SST) oscillates seasonally between 25.5 and 30°C, anomalous warming occurs in response to *El Niño* events. Seasonal SST oscillations adjust well to a sinusoidal fit. Sinusoidal parameterisation of SST allows analysis of long-term temperature trends. Our analyses indicate an overall warming trend of about 0.0026 C/y, a trend that, if sustained would result in a SST increase of 2.6°C in 100 years. Similar analysis of the Reynolds ODI-SST-v2 data set in a 1x1 degree box encompassing CaTS yields a trend identical to that observed at CaTS. Properties of the Subtropical Underwater (SUW), a high-salinity water mass underlying the CSW formed in the subtropical North Atlantic, respond to the North Atlantic Oscillation with a time lag of 44 months, a period consistent with the expected transport time from the area of SUW formation. Water mass response is evident in depth of the salinity maximum, temperature and nutrient content.

19 May, 14:30 (S1.1-4951)

Southern hemisphere westerly wind control over the ocean's thermohaline circulation

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Twentieth century climate change has forced a poleward contraction of the southern hemisphere (SH) subpolar westerly winds. The implications of this wind shift for the ocean's thermohaline circulation (THC) is analysed in models and, where available, observations. Substantial heat content anomalies can be linked to changes in the latitude and strength of the SH westerly winds. For example, the Southern Annular Mode projects onto sea surface temperature in a coordinated annular manner - with a conspiring of dynamic and thermodynamic processes yielding a strong SST signal. Subantarctic Mode Water (SAMW) change can be linked to fluctuations in the wind-driven Ekman transport of cool, low salinity water across the Subantarctic Front. Anomalies in air-sea heat fluxes and ice meltwater rates, in contrast, drive variability in Antarctic Surface Water, which is subducted along Antarctic Intermediate Water (AAIW) density layers. SAMW variations also spike T-S variability in AAIW, particularly in the southeast Pacific and southeast Indian Oceans. The location of zero wind stress curl in the SH can also control the distribution of overturning in the North Pacific/North Atlantic. A southward wind shift can force a stronger Atlantic THC and enhanced stratification in the North Pacific, whereas a northward shift leads to a significantly reduced Atlantic THC and the development of vigorous sinking in the North Pacific. This is because the distribution of wind stress over the Southern Ocean influences the surface salinity contrast between the Pacific and Atlantic basins. The implications of these findings for oceanic climate change are discussed.

19 May, 14:45 (S1.1-4759)

Increased ocean heat along the continental margin of west Antarctica

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The Antarctic Peninsula (AP) is undergoing extraordinary climate change, showing: (1) a significant *winter* warming trend during the past half century (~5.4 times the global average), (2) 87% of the glaciers in retreat; and on the western margin of the AP (wAP), (3) the sea ice season has decreased in length by >3 months in the last 2 decades, with complete loss of perennial sea ice, and (4) a southward expansion of the northern maritime system of the northern wAP displacing the continental polar system to the south. The only substantial source of heat in winter is the ocean (specifically, Upper Circumpolar Deep Water: UCDW). Our analysis of the first 12 years of the Palmer LTER project show that during the 1990s an increase in upwelling of UCDW onto the shelf explains over 80% of the estimated ocean heat flux, while another 20% or so can be attributed to increased heat content of the UCDW. Most impressive is comparison of LTER data to historical data in the region, which suggests that the heat content of the UCDW, supplied to the wAP via that Antarctic Circumpolar Current jumped by a tremendous amount near the end of the 1980s, equivalent to uniformly warming 300 m of shelf water by ~0.7°C throughout a 120 km x 500 km sample grid. This is a tremendous increase in the heat content supplied to the wAP, begging the question requiring a global perspective: what is the source of this increased heat content?

19 May, 15:15 (S1.1-4899)

Multi-decadal warming and freshening of the Antarctic Circumpolar Current

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Studies of ocean observations show that a significant fraction of the increase in subsurface ocean heat storage during the last decades has been occurring in the vicinity of the Antarctic Circumpolar Current (ACC) south of 40°S. We have determined the meridional-vertical distribution of multi-decadal trends in the hydrographic

properties across the ACC by utilising the rapidly expanding Argo network of profiling floats. In comparison to data collected between 1960 and 2000 the modern temperature and salinity fields exhibited coherent global-scale trends in water mass properties: averaged on isopycnal surfaces the dense water on the poleward side of the ACC has become warmer and more saline, while in the thermocline north of the Subantarctic Front, above the layer of minimum salinity, widespread cooling and freshening occurred. The observed pattern of trends on density surfaces is similar to the trends obtained in model simulations of climate change during the last century, representing a "fingerprint" of anthropogenic changes in the midlatitude southern hemisphere surface fluxes. The dichotomous trend pattern on density surfaces corresponds to uniform patterns of warming and freshening across the ACC, manifested in a general subsidence of isopycnal surfaces in the upper 1000 m of the water column.

19 May, 15:30 (S1.1-4827)

Variability and trend of the heat balance in the southeast Indian Ocean

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Enhanced surface warming in the Leeuwin Current, the anomalous poleward flowing eastern boundary current off the west coast of Australia in the southeast Indian Ocean, has been observed during the past decades. The warming trend is greater during the austral winter than the austral summer. By analysing the ORCA025 44-year simulation output, the heat budget in the Leeuwin Current region is found to be dominantly balanced by two terms, the Leeuwin Current heat advection and the air-sea heat loss, both of which are stronger during the austral winter. The interannual anomalies of both terms respond to the ENSO cycles, and on both annual and interannual time scales, the variations of the Leeuwin Current advection lead that of the air-sea flux by about two months. From the 1960s to 1990s, the modelled Leeuwin Current has had a 30% reduction of its volume transport, likely driven by the weakening of the trade winds and related thermocline anomalies since the mid-1970s. This leads to an almost 20Wm^{-2} reduction of heat advection into the region, and likely also a reduction of surface heat loss. Although the model does not reproduce the warming trend in the region due to its forcing field, it may help explain the greater warming trend in the austral winter than summer. Long term changes in ocean circulation may play a significant role in re-distributing heat in the ocean, in both temporal and spatial domains.

19 May, 15:45 (S1.1-4562)

Rainfall variations and trends along the coast of the Gulf of Guinea

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This paper examines the variations and trends in seasonal and annual rainfall along the coast of the Gulf of Guinea, West Africa based on a 99-year period, using the Hulme 98 data set. The rainfall series were extracted from the 2.5° latitude by 3.75° longitude grid version of the data set for grid points within 2 degrees of latitude from the coast and south of latitude 10°N. Analyses of rainfall variability reveal that the annual rainfall of the area has a coefficient of variability of 11.77% and that rainfall is most variable in peak of the dry season (59.19%), followed rather distantly by the peak of the rainy seasons (23.57%), while the variability coefficients for the transition seasons are generally lower. Furthermore, analysis of rainfall trends indicates that over the century, annual and seasonal scales, rainfall along the coast of the Gulf of Guinea exhibited net decreases; although, these decreases are not significant. The implications of these findings are highlighted in the light of the Intergovernmental Panel on Climate Change (IPCC) predictions for the region.

19 May, 16:30 (S1.1-4863) Invited

Global changes of the hydrological cycle and ocean renewal inferred from ocean salinity, temperature and oxygen data

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Projections of climate change indicate increased precipitation in the equatorial region, and at high latitudes and decreased precipitation in the subtropics, and a general increase in ocean stratification. We use the available temperature, salinity and oxygen profile data for the period 1970 to 2005 to examine the evidence for such ocean changes. Here we report on results from the first global study to isolate changes of salinity and temperature on density surfaces between 1970 and 2005. Globally we find increased salinities near the upper-ocean salinity maximum and decreased salinities near the intermediate salinity minimum (~700 m deep). These salinity changes imply about a 1% decrease in the precipitation-minus-evaporation over the mid-latitude oceans and about a 5% increase in the precipitation-minus-evaporation at high latitudes since 1970. These new and independent ocean derived estimates of changes in precipitation-minus-evaporation extend the growing evidence for an acceleration of the Earth's water cycle. An analysis of oxygen changes throughout the global oceans shows a coherent decrease in zonal averages at almost all latitudes above 1500 m. Subducting mode and salinity minimum waters in both hemispheres have reduced oxygen concentration, and the upwelling circumpolar-deep water is also reduced (up to 10%). These changes cannot be explained by changes in oxygen saturation due to a warming ocean and are most simply explained by increased biological consumption resulting from reduced renewal rates. The inventories of oxygen, heat and sea-level show that the high latitude density surfaces are driving these decreases in oxygen and increases in heat and sea-level.

19 May, 17:00 (S1.1-4709)

A high resolution Pacific Decadal Oscillation and some of its novel characteristics

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A high resolution Pacific Decadal Oscillation (HR-PDO) Index for the ice-free regions of the North Pacific Ocean (20-60ºN) was computed using monthly-averaged NOAA/OIv2SST data on a 1º grid obtained during the satellite era. While the PDO mode remains as the dominant feature over this period of years, some new and interesting temporal and spatial patterns emerge. Despite its short duration (~25 y), the HR-PDO is oscillatory but the dominant period is 10-11 years whether it is estimated by Fourier analysis or by a least squares fit of the data to a sine wave model. Furthermore, the time series bears a greater resemblance to a square wave than to a sine wave. This 10-11 year period (and its phase) is also a characteristic of the altimetry data in the northeast and tropical Pacific and of certain characteristics of the Kuroshio. The 10-11 year period is not a characteristic of SST data from the pre-satellite era and it does not appear in an index of the atmospheric Aleutian Low for the period 1900-2007. The spatial pattern of the HR-PDO features a broader zone of influence in the eastern North Pacific than the PDO with its greatest expression located offshore. Adjacent to the North American coast, only the region from about Oregon to Pt. Conception is highly correlated with the HR-PDO. Month by month analyses of the OIv2SST data indicate that the strongest expression of a PDO-type pattern occurs in March, diminishing over the summer to the extent that in July and August the HR-PDO appears as EOF2 rather than EOF1. The HR-PDO pattern re-emerges as the dominant EOF in the late fall. The regularity of the phase shifts in the HR-PDO inspired a forecast.

19 May, 17:15 (S1.1-4884)

The shoaling of the oxygen minimum layer in the California Current

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We use historical hydrographic data from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) programme to explore the spatial and temporal variability of dissolved oxygen in the southern California Current System (CCS) over the period 1984-2006. Large declines in dissolved oxygen have been observed throughout the CalCOFI domain and to at least 500 m depth. In the upper 100 m, the largest declines (~0.04 mL/L/y) occurred along the shelf and slope regions, within the Southern California Bight, and within the region impacted by the core of the California Current. The largest relative oxygen declines occurred below the thermocline, with a mean decrease of 21% at 300 m. Linear trends were significant ($p < 0.05$) at a majority of stations down to 500 m. The subsurface oxygen decline is equivalent to a shoaling of the oxygen minimum layer (OML). The hypoxic threshold (1.4 mL/L) has shoaled by up to 90 m within portions of the southern CCS. These trends observed are consistent with a hypothesized decrease in vertical oxygen transport following near-surface warming and increased stratification. Expansion of the OML could lead to significant habitat compression of many marine species, and the habitat expansion of species that can take advantage of low-oxygen environments.

19 May, 17:30 (S1.1-4543)

Influence of rapid regional climate warming on the water mass formation in the Japan/ East Sea

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The Japan/East Sea (JES) is often used as a "miniature" of the ocean to assess influences of global climate change on the marine environment. Sea surface temperatures in the JES have increased as much as three times the world average over the past century, partly due to global warming. As well as effects on ecosystems (e.g. by decrease of the ice cover area), warming could reduce the oceans ability to absorb CO_2. Sea surface temperatures increase more in the winter. The wintertime circulation and water mass formation in the JES are thought to be strongly driven by surface fresh water and heat fluxes. Walin (1982) and Tziperman (1986) developed a theoretical frame to analyse the annual mean water mass formation rates from heat and fresh water fluxes at the ocean surface. The NCEP/NCAR reanalysis data from 1950 to 2000 are used to estimate the rate of water mass formation in the JES. The amount of surface water that sinks and forms the High Salinity Intermediate Water (HSIW) are defined. We found that the formation rate of water with density of the HSIW ($\sigma_\theta > 27{,}3$) decreased (-0.11 Sv/decade) and the formation rate of water with density 26.9–27.3σ_θ (subpolar winter surface mixed layer) increased (0.12 Sv/decade). The total formation rate (1.5 Sv) does not change. The formation of the HSIW is primarily influenced by the Arctic Oscillation (AO; negative correlation, $r = -0.43$) and secondary influenced by the Siberian High (SH; $r = 0.34$). The winter AO influences directly on surface air temperature over the JES region. The SH shows more direct and significant influences on winter northerly monsoon winds. The decreasing of the formation rate of more dense water during the last decade may be due to the combined effects of the winter sea surface warming (positive index phase of AO) and weakness of the East Asian Winter Monsoon (negative index phase of SH). The impact of subgrid mesoscale processes (eddies and upwelling) on the intermediate water formation are investigated using hydrographic data and a simple model of the mixed-layer evolution.

19 May, 17:45 (S1.1-4640)

Upper ocean variability in the equatorial Indian Ocean and the influence of monsoon circulation

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Studies using modelling and observations of Indian monsoon circulation reveal strong intra-seasonal to inter-annual variability. To study the upper ocean variability and its association with the Indian monsoon we have used ocean model simulations and observations. The semi annual reversal of the equatorial winds north of the equator and the associated changes in surface currents, the presence of a barrier layer throughout the year and the absence of equatorial upwelling makes the equatorial Indian ocean different from the Pacific and Atlantic equatorial regions. Our focus is on upper ocean variability with special emphasis on the seasonal heat budget variations and the influence of the monsoon circulation. Ocean General Circulation Model simulation (OGCM, MOM4p1 with sea ice interface, forcing: Quick-scat winds and NCEP reanalysis) from 1992-2006 have been used to study the seasonal variations of the heat budget. Argo and other observational programmes (Triton buoy data) gave a wider opportunity to understand the upper ocean variability of the equatorial Indian Ocean in detail.

19 May, 18:00 (S1.1-4528)

Warming of the upper equatorial Indian Ocean and changes in the heat budget (1960-2000)

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In the equatorial Indian Ocean, sea surface has warmed by 0.5°C to 1°C over the period 1960-2000, while waters have cooled at the thermocline depth and the net atmospheric heat flux has decreased. Among a set of 20th century climate simulations from 12 coupled models, the CNRM-CM3 model most realistically reproduces these observed changes. It is used to investigate changes in the heat budget of the upper equatorial Indian Ocean in order to identify mechanisms responsible for the surface warming. The heat budget can explicitly resolve interannual temperature variability with flux and advection terms only, but not the long-term temperature trend. However, by estimating diffusion as a residual term and comparing 20th century and control simulations, changes in the mean balance of the heat budget between the pre-industrial and the 1960-2000 period can be highlighted. There are significant shifts in the heat budget due to climate change. The decrease in the upwelling-related oceanic cooling is the main cause of the surface warming of the equatorial Indian Ocean, while the observed decrease in net heat flux is a feedback process mostly due to enhanced evaporation.

S1.1 Posters

Poster S1.1-4538

Warming and salinification of intermediate and deep waters in the Irminger Sea and Iceland Basin in 1997-2006

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The Labrador Sea Water (LSW), Iceland–Scotland Overflow Water (ISOW) and Denmark Strait Overflow Water (DSOW) are the main intermediate and deep water masses formed in the northern North Atlantic. These water masses inherit and transfer climate signals from the source regions to the deep ocean. Analysis of intra- and inter-decadal variability of these waters in vicinity to their source regions is thus essential for understanding and quantification of the oceanic response to the observed climate variations. In this study, recent intra-decadal changes in temperature and salinity of LSW and overflow-derived waters are quantified on the basis of the CTD data from four repeats of the zonal transatlantic section along ~60°N carried out in 1997-2006. The changes revealed point to a rapid transition to warmer/saltier conditions at the intermediate and deeper levels in the Irminger Sea and Iceland Basin. In particular, substantial steady warming and salinification of ISOW is revealed in both basins. The latter result means an abrupt reversal or, at least, a decade-long interruption of the long-term freshening of this water lasted since the mid-1960s. The rate of the ISOW salinification in the Iceland Basin is more than twice as high compared to the rate of the preceding long-term freshening. In 2006, salinity in the ISOW core in the Iceland Basin reached the value of 34.99 being back to values typical for the 1970s. The LSW–ISOW–DSOW stratum at the section latitude became 0.20°C warmer and 0.029 saltier on average between 1997 and 2006.

Poster S1.1-4566

Seasonal and interannual heat fluxes variability in the Mediterranean Sea from a 44-year high-resolution atmospheric data set

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We examine 44 years (1958-2001) of model data with the aim of characterising the low frequency (seasonal cycle and lower) variability of surface heat fluxes. The data set was produced in the framework of the HIPOCAS project through a dynamical downscaling (1/2° x 1/2°) from the NCEP/NCAR global reanalysis using the atmospheric limited area model REMO. The added value of this data set is the better representation of regional and local aspects related to thermal and dynamical effects resulting from its higher resolution. The basin mean values of the heat fluxes have been estimated in 168 W/m^2 for the solar radiation (Q_S), 73 W/m^2 for the longwave net radiation (Q_B), 8 W/m^2 for the sensible heat (Q_H) and 88 W/m^2 for the latent heat (Q_E), giving a total heat budget of about 1 W/m^2. The total heat budget has an amplitude of 164 W/m^2 and peaks by mi-June, in agreement with previous works and observations. The interannual variability of each component has been first quantified by the standard deviation of the annual mean values, obtaining ±2.0 W/m^2 for Q_S, ±1.1 W/m^2 for Q_B, ±4.7 W/m^2 for Q_E and ±1.1 W/m^2 for Q_H. From the evaluation analysis, HIPOCAS fluxes show stronger correlations with the observation based NOC fields than are obtained with the original NCEP/NCAR fluxes for the full set of interannually varying heat flux estimates. Thus, the downscaling has led to an improved representation of the interannual variability when compared with observations.

Poster S1.1-4572

Large scale circulation over the west Indian Ocean and the south west monsoon

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The focus of this study is to document the role of the west Indian Ocean over the Indian monsoon during the last decade (1998-2007). Understanding the interannual variability of the southwest monsoon is an important and challenging factor. To date the relationship of the Mascarian high and the southwest monsoon has been well documented in the literature. However, the temporal variation of meteorological parameters, over the region east of Madagascar to the west coast of India, are not yet examined in detail. In the present study extensive analyses of daily outgoing longwave radiation (OLR), zonal wind (u) at 850 and 200 hpa and Global Precipitation Climatology Project (GPCP) rainfall over the region 50-80°E and 30S-30°N from April to September for all 10 years was carried out. In all cases, a 5-day running mean smoother was applied to the data to reduce the large day-to-day oscillations. We have prepared time-latitudinal plots averaged over longitude 50-80°E. Northward movement of large scale circulation and the core of maximum winds are clearly depicted and are found to be closely related with GPCP rainfall region. The study was very useful for understanding monsoon performance in the last decade. It is suggested that large scale circulation over the west Indian Ocean may be the dominating factor in the overall performance of southwest monsoon over India.

Poster S1.1-4583

Sea surface warming in the southern Bay of Biscay modulated by oceanic advection

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One of the consequences of climate change is the world ocean warming. We address the issue of exploring how the rate of sea warming changes in relation to the central waters found in the Bay of Biscay area at any moment. We found that during the early 2000s, the advection of a large volume of cooler and less saline water from the inner part of the bay caused a general sinking of the isopycnals, thus reducing the rate of warming. During the last year, the process reversed due to the flow of warmer and saltier tropical waters which enhanced the warming. Based on these results, we propose a mechanism in which a wavering natural variability would superimpose on the steady global warming, thus modulating it. The combination of these two forcings results in the non linear warming observed in the area.

Poster S1.1-4600

Analysis of a 44-year hindcast for the Mediterranean Sea: comparison with altimetry and climatology

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In this study we used the ORCA025-G70 simulation of the DRAKKAR model developed by Barnier *et al*. (2006) to perform a model assessment in the Mediterranean Sea by using altimetry and climatology data. ORCA025-G70 is a ¼º resolution simulation of a global ocean numerical model aiming at the study of the ocean variability under realistic atmospheric conditions over the last half century (1958-2004). The model simulates the evolution of T, S, velocity, SSH, sea-ice characteristics, and oceanic concentrations of CFC11 and ^{14}C. Comparison of SSH given by the model and from altimetry in the Mediterranean Sea has shown that although the model overestimates the observed altimeter trends (possibly due to drift), the interannual variability is well reproduced, as well as the annual cycle both of which are well correlated, especially at the basin scale. Due to the model's low resolution it is incapable of correctly reproducing most mesoscale features. This is especially notable in the Alboran Sea and Algerian Current where the model is unable to reproduce the gyres and eddies that are formed in these regions.

There are certain cases where the model is incapable of reproducing important features such as the negative trend in the Ionian basin to the east of Sicily which is thought to be caused by a change in the deep water formation. Our aim for the following months is to continue this analysis in more depth and add the comparisons with the MEDAR climatology for the 1960-2004 period.

Poster S1.1-4606

Decadal and interdecadal variations of the Aleutian Low activity and their relation to atmospheric teleconnection patterns

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We investigate long-term variation of the Aleutian Low (AL) which is defined by the sea level pressure minimum within the region of (30°N-60°N, 150°E-150°W) in winter. Time series of the latitude and longitude of the AL, and its intensity reveal different types of activities: the longitudinal shift accompanying intensity variation with an interdecadal (about 20 years) timescale and the latitudinal shift with a decadal (about 10 years) timescale. The AL intensity variation is strongly influenced by the Pacific/North American teleconnection pattern: In the strengthening (weakening) phase of the AL, the AL shifts east (west) in longitude, westerlies strengthen (weaken), and resultantly both subtropical and subpolar gyres are forced to spin-up (spin-down) simultaneously. The latitudinal shift is forced by the western Pacific teleconnection pattern, and is independent from the intensity variation. In the northward (southward) shift phase of AL, the westerlies move northward (southward), and resultantly the gyre boundary also shifts northward (southward).

Poster S1.1-4607

Spatio-temporal upwelling trends along the Canary Upwelling System (1967-2006)

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Spatio-temporal trends in upwelling patterns were studied along the Canary Upwelling System for the period 1967-2006. The NW African coast from 20°N to 32°N is observed to be under a permanent upwelling regime characterised by coastal sea surface temperatures (SST) colder than the oceanic ones at the same latitude, the difference being named temperature upwelling index (UI^{SST}). This regime is consistent with the wind derived Ekman transport (UI^{W}) pointing offshore and observed near shore. This index shows the existence of upwelling-favourable conditions all year long, although with an annual cycle characterised by more upwelling-favourable conditions from April to September, with a peak in July, and less upwelling- favourable conditions from October to March, with a peak in December-January. Although both indices can be used to characterise the phenomenon, only UI^{W} values were used to quantify upwelling change since this index is less sensitive to external factors than UI^{SST}. A strong decrease in upwelling intensity has been observed in all seasons. In particular, the summertime (wintertime) decrease is around 45% (20%) of the mean amplitude of the upwelling cycle.

Poster S1.1-4609

Establishing research objectives to address issues of climate-change

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The implications of global climate change are enormous. However, there are major questions concerning whether climate change is occurring. If it is, subsequent questions should consider when and how the changes will affect society. There are numerous possible expensive research projects that could address each of the many facets of

these questions. Wise decision making about global climate change research is thus seen as important. This paper describes a systematic process to identify and structure the objectives of research on global climate change. The result is a hierarchy of 81 important research objectives. This hierarchy was constructed based on interviews with a diverse set of individuals knowledgeable about climate change, and on discussions at an international workshop on global climate research objectives. The participants in both exercises included scientists, policy analysts, and executives of utility companies and national agencies from Europe, Africa, Asia, and North America. The main uses of these objectives should be to promote constructive communication about research programmes designed to examine climate change issues, to stimulate the creation of potentially significant research tasks, and to provide a basis for evaluating and comparing research tasks.

Poster S1.1-4610

A "trojan" in climatic change: the urban effect

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This paper sets out the preliminary results of an experimental research plan aimed at analysing the thermal processes inherent to the urbanisation effect. Although this effect is undeniable, the extent of its impact is a matter of controversy. In the present study, the urban thermal effect has been examined by installing three duly calibrated, automatic meteorological stations (Davis-Casella). These three stations were located in the Castellón city area, a city that has undergone marked demographic growth in recent years (from 93,000 inhabitants in 1970 to 205,000 inhabitants in 2007). The locations were chosen to record the temperature at the city centre (Casino Antiguo station, 51 m), at the Mediterranean Sea surface (marine station on the BP Oil Platform, 12 m), and on the western outskirts of the city (Universitat Jaume I (UJI) station, 80 m). The three stations are located on an E-W diagonal of just 10 km on the coastal plain. The results obtained in this study show both the nature of the phenomenon and its considerable magnitude. The notable differences in both the maximum and minimum temperatures between the city centre and the outskirts demonstrate the need for further analysis of the process. Failure to take this process into account might seriously bias any analysis of thermal evolution, the cornerstone of the climate change hypothesis.

Poster S1.1-4616

A new satellite algorithm for an accurate determination of the sea surface temperature for climate and meteorological studies

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Sea surface temperature (SST) is a key magnitude for climate and meteorological studies. A high-accuracy determination of SST would permit a better monitoring of climate change evolution and also to improve the forecast of natural hazards, such as torrential rain events (see poster S3.1-4614). The operational algorithms for the determination of SST from satellites do not use Sea Surface Emissivity (SSE) as input, since the sea surface is assumed to be similar to a blackbody surface. Only algorithms for the retrieval of land surface temperature include emissivity-dependent terms. However, the variability of SSE within a satellite image, which depends on observation angle and surface wind speed and is similar to the emissivity variation for land surfaces. Therefore, the SST determination can improve by taking into account the effect of the SSE variation with angle and wind speed in the SST algorithms, at least for the image sections with large observation angles, for which the SSE differs widely from the unity. An angular and emissivity dependent split-window equation is now proposed with the aim of determining SST to a reasonable level of accuracy for any observation angle, including large viewing angles at the image edges of satellite sensors with wide swaths. This is the case for the radiometers on board polar-orbiting satellites such as MODIS, both on EOS Terra/Aqua platforms,

with observation angles of up to 65º at the surface, but mainly for sensors such as the SEVIRI on board the geostationary second generation METEOSAT. The algorithm takes into account the angular dependence of both the atmospheric correction (due to the increase of the atmospheric optical path with angle) and the emissivity correction (since sea surface emissivity decreases with observation angle). The proposed algorithm requires as input data at-sensor brightness temperatures for the split-window bands, the observation angle at each pixel, an estimate of the water vapour content and accurate SSE values for both channels. Simple methods are also proposed for estimating the required SSE and water vapour content data. Preliminary results using SEVIRI and MODIS satellite data show a good agreement between SSTs estimated by the proposed equation and *in situ* SST measurements, even for off-nadir viewings, which proves the soundness of emissivity-dependent SST algorithms.

Poster S1.1-4627

Reconstruction of interdecadal variability of air-sea interaction in the Atlantic 1880-2004

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Using 125 years (1880-2004) of Voluntary Observing Ship (VOS) observations from ICOADS we reconstructed monthly surface ocean-atmosphere heat fluxes over the North Atlantic with a 2-5° spatial resolution. The methodology is based on the homogenisation of sampling density, application of the double-exponential distributions of turbulent fluxes for minimising sampling errors and the use of specially adopted bulk-algorithms for incomplete data coverage. In particular, a multi-regressive approach is used to reconstruct atmospheric humidity, playing an important role in the estimation of surface fresh water fluxes. The methodology was first validated using the time series from VOS and reanalyses for the well sampled recent decades. Further analysis included computation of monthly anomalies of surface fluxes as well as estimation of the subpolar gyre heat and freshwater budgets. These were computed using two-dimensional distributions of surface fluxes of sea-air temperature difference and wind speed. Reconstructed fluxes reveal long-term trends, implying, for example, about 4 W/m^2 per decade growing sensible heat fluxes in the Labrador Sea and about 2 W/m^2 per decade secular increase in the central subpolar gyre. Non-secular signals are represented by the decadal-scale and multidecadal (about 40-50 years variability). Decadal scale signals have a clear association with the NAO-like atmospheric circulation variability during 1880-1915 and after 1955, but have little association with the NAO between 1915 and 1955. The approach formulated allows also for the derivation of heat energy budgets in different Atlantic regions. These budgets can be alternatively quantified form the oceanographic full-depth sections. Time series of the budget estimates were derived for 2 large regions (subpolar, mid latitudes) and their association with ocean dynamics and atmospheric circulation anomalies are discussed.

Poster S1.1-4635

Global warming - stationarity in sea temperature data

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According to the UN's Intergovernmental Panel of Climate Change (IPCC), the earth's climate is already changing. The objective of this paper is to analyse how the average yearly sea temperature has evolved at two different geographical spots along the coast of Norway during the period 1936-2003. The statistical analysis is related to the concept and properties of stationary time series, and the scientific objective is to analyse whether there is any indication of climate change in the time series. Augmented Dickey-Fuller and non parametric Phillips-Perron tests are applied in uncovering the data generation process behind the sea temperature.

Poster S1.1-4638

Geostrophic currents variability in the Drake Passage

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The Drake Passage is the most suitable region for studying the easterly Antarctic Circumpolar Current (ACC) because here it passes between two coasts. The comparative analysis of two hydrographic sections, which were occupied across the Drake Passage during cruises of the Russian research vessels *Akademik Sergey Vavilov* and *Akademik Ioffe* in December 2003 and November 2005, are realised. Both sections were located along the same track from Terra del Fuego to Elephant Island. Temperature, salinity, and velocity profiles in the entire water column were measured by a Sea-Bird 911 CTD profiler and Lowered Acoustic Doppler Profiler (LADCP) at each station. Satellite altimetry data (available at http://www.jason.oceanobs.com) and data of some other sections in the Drake Passage were also used in this investigation. Absolute geostrophic currents across these sections were calculated by correcting the geostrophic calculations using altimetry data and LADCP measurements. The distributions of hydrographic properties over the sections show a strong difference between synoptic situations in December 2003 and November 2005 resulting from ACC fronts splitting and subsequent eddy formation. Despite the differences in the structure, the integrated eastward flows calculated both by altimetry and LADCP corrections across both sections were very similar and approximately equal to 155 Sv. The boundaries between specific water masses were determined using the procedure, which was developed earlier by the author for the South Pacific. The procedure is based on the analysis of the vertical gradients of hydrographic properties. Mean properties and flows of water masses across the sections were assessed.

Poster S1.1-4652

Rainfall variations and trends along the coast of the Gulf of Guinea

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This paper examines the variations and trends in seasonal and annual rainfall along the coast of the Gulf of Guinea, West Africa based on a 99-year period, using the Hulme 98 data set. The rainfall series were extracted from the 2.5° latitude by a 3.75° longitude grid version of the data set for grid points within 2 degrees of latitude from the coast and south of latitude 10°N. Analyses of rainfall variability reveal that the annual rainfall of the area has a coefficient of variability of 11.77% and that rainfall is most variable in the peak of the dry season (59.19%), followed rather distantly by the peak of the rainy season (23.57%), while the variability coefficients for the transition seasons are generally lower. Furthermore, analysis of rainfall trends indicates that over the century, annual and seasonal rainfall along the coast of the Gulf of Guinea exhibited net decreases; although, these decreases are not significant. The implications of these findings are highlighted in the light of the Intergovernmental Panel on Climate Change (IPCC) predictions for the region.

Poster S1.1-4657

Climatic tendencies and changing global-regional linkages in the North Pacific SST

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The climatic tendencies in the Pacific SST north of 30°S and statistical relationships between climatic indexes and SST anomalies are estimated for different periods of the observational records including first half of the 20th century and last 56 years using Hadley (1870/1900-2006) and other data sets. It is shown that SST cooling is typical for the subarctic northwest Pacific during last 56 years while the warming occupies most of the Japan - Okhotsk Sea area and Kuroshio region in the Pacific. It accompanies a decrease of the ice extent in the Okhotsk and Japan Seas from 1956 to 2006 and a change in the relationship between the Arctic Oscillation/NINO3, SSTA, Amur River discharge and ice Extent. The NW Pacific SSTA has significant unlagged or lagged correlations with most of northern hemisphere monthly/seasonal/annual mean different teleconnection indexes. The unlagged correlations between seasonal mean/SOI and SSTA/WP and SSTA in winter-spring show a significant inverse relationship

being negative/positive in the subtropic and positive/negative in the subarctic NW Pacific. Correlation between winter AO and SSTA in spring–summer shows patterns which are similar to the NINO3/SOI-SSTA relationship in winter-spring with a shift of the subarctic core westward and subtropic core eastward. The winter AO-spring/summer SSTA correlation patterns are turned counterclockwise in the second half of the observational records in comparison with the first one. In recent decades the positive AO-SSTA lagged correlation pattern occupies the Okhotsk and Japan (East) Sea area.

Poster S1.1-4680

Atmospheric variables potentially affected by DMS

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The CLAW hypothesis suggests a negative feedback between marine biota and climate through the emission of biogenic sulphur, its conversion into Cloud Condensation Nuclei (CCN), and its influence on the microphysics of clouds and the earth's albedo. Seawater dimethylsulfide (DMS) produced by plankton is the principal natural source of volatile sulfur to the atmosphere. The first part of the hypothesis postulates that an increase in solar radiation would produce an increase in the concentration and emission of DMS-*a* phenomenon that has been observed recently. Our current work focuses on the second part of the hypothesis-namely, that an increase in DMS concentration has consequences for cloud formation and microphysics. Our purpose is to analyse those atmospheric (aerosol and cloud-related) variables that may be affected by DMS emissions. We make global monthly data fields of different satellite-derived variables and calculate their temporal correlation with an oceanic DMS climatology obtained by extrapolation and interpolation of existing data). Our study begins with global distributions of crossed correlations, with the aim of exploring the geographic regions that deserve closer analysis, and at first investigating which atmospheric variables appear to be more sensitive to DMS concentrations, bearing in mind that correlation does not necessarily imply a causal relationship. Once the regions and variables with high correlation coefficients are defined, a detailed analysis of time series is conducted using satellite-derived data and the raw DMS concentrations from the Global Surface Seawater DMS database.

Poster S1.1-4687

Decoupling of sea surface temperature variation during the last two decades and its effect on remotely sensed phytoplankton biomass in the North Atlantic

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Sea surface temperature has increased worldwide during the last century, especially in northern latitudes. The advent of borne on satellite sensors allow the monitoring of these changes with an unprecedented spatial and temporal resolution. Here, we use the time series derived from the Advanced Very High Resolution Radiometer to study the strength and spatial pattern in sea surface warming during the last two decades (1985-2006). Because of its influence on species distributions, we analysed the evolution of the magnitude of annual climate extremes and its timing, and the rates of northward migration of such extremes. A heuristic method was used to derive the length of the stratification period and the scales of the different responses were assessed by estimating geostatistical variograms. The results obtained support the main impacts predicted from climate modelling studies, but important heterogeneities were found both in physical and biological responses. Marked zonal contrasts on the response of the different parameters at northern latitudes suggest that changes were mainly mediated by the North Atlantic current, either through a strengthening of heat transport or a northward migration associated with the expansion of the subtropical gyre. Finally, changes in chlorophyll *a* concentration were derived from SeaWiFS images (1998-2006), and the timing of the spring phytoplankton bloom was assessed. In response to the above described changes a decrease in phytoplankton biomass in the North-east Atlantic occurred. Jointly, the responses observed depict a "black-box" scenario in which future biological responses will be highly nonlinear and difficult to mitigate.

Poster S1.1-4712

Climatic oscillations in the Asian Pacific in terms of cluster analyses of aggregated observation data

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The relationship between parameters of hydrosphere in northeast Asia and atmospheric indices of the Asian Pacific are estimated by cluster and spectral analyses. For 1930-2003 following time series were used: the seasonal anomalies of the Amur River discharge (ARD) and precipitation, ice extent and SST of adjacent area - Tatar Strait, Okhotsk Sea; AO, SOI, NPI, SLP anomalies in Siberian High, Hawaiian High, and Aleutian Low. The changing statistical relationships in the coupled atmosphere-hydrosphere system associated with well-known climatic regime shifts are found using cluster analysis of aggregated observational data for two periods: 1930-1969 and 1970-2003. The cluster tree was subdivided in two large branches, including: (1) atmospheric indices and SST/Ice Extent in Okhotsk Sea and winter precipitation; (2) AO, SOI, SST/Ice Extent in Tatar Strait, in Amur River Basin, and ARD. A change in correlation was observed between the atmospheric indices, AO, SST and ARD and data moved in clusters. Cluster and correlation analysis of time series for the two periods shows changes in the climate system. To understand, how the variables of the regional climatic system are interconnected, we determined the characteristics of the energy spectrum of each hydrosphere parameter and coherency and phases with reference to ice cover of Okhotsk Sea and Tatar Strait. There is a hierarchical connection between different components of regional climatic system. As a result of the influence of atmospheric factors the character of interrelations between hydrospheric components was observed.

Poster S1.1-4715

Analysis of the 18-month variability in the Indian Ocean based on historical data and proxy climate records

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The recent analysis of the interannual variability of the Indian Ocean found the existence of a strong 18-month signal. This signal was discovered based on satellite altimetry sea surface height measurements (1992-2004) and expendable bathythermograph temperature data (1989-2002). It is likely to be important for the dynamics of the Indian Ocean Dipole (IOD) mode; however, understanding of the connection between the 18-month signal and IOD events is difficult due to the small number of such events in the available time period. In this study we investigate the behaviour of the 18-month signal and its connection with IOD mode by wavelet and spectral analysis. We use long period time series from tide gauges and coral records extending back to ~1850 AD, as well as the reconstructed sea level and SST reanalysis data.

Poster S1.1-4729

ENSO and climate change in the West Antarctic Sector

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This study aims to analyse a recent warming episode in the Antarctic Peninsula (AP) region and to find out how atmospheric circulation has changed in the West Antarctic Sector (WAS). The most accelerated warming in the AP has been observed from early 1980s to the turn of millennium, almost coherently with that in Alaska, and is related to well-known shift in PDO-ENSO conditions. Annual surface air temperature (SAT) records on many AP stations show clear ENSO-related sub-decadal oscillations (3-6 years). Anticyclonic MSLP and height anomalies

along with greater meridionality predominate in WAS under warm event whereas westerlies and depressions typically persist under *La Niña*. The AP lies at the boundary of main circulation systems whose behaviour has been changed after 1980s. Winter cold episodes have became less intensive than in the mid-20th century because anticyclones in the SE Pacific shifted north-or eastward allowing more frequent cyclogenesis at the Bellinsghausen Sea with warmer and wetter air inflow to AP. The sign of the SAT anomaly on stations in the western coast of AP show the strongest correlation with the east Pacific SOI on a time shift from 3 to 9 months after mature ENSO episodes. Both SAT and sea-ice anomalies are responsible for live environmental anomalies at coastal area of AP determining conditions for krill development and setting up relationships in food chain.

Poster S1.1-4730

The impact of the oceans on climate change

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Comprising 97% of the Earth's water and covering ~71% of the surface the ocean plays a key role in climate change. As a main heat store for the world it has shown rapid and accelerating change in sea temperatures over the last few decades and is the likely modulator of many of the changes seen on land attributed to climate warming. It is the main store of carbon dioxide (CO_2), each year taking in about 1.3 petagrams (1.3×10^{15}g) from the atmosphere and exporting carbon via physical and biological processes to the deep ocean reservoir. Increases in sea temperature and changing planktonic systems may lead to a reduction in the uptake of CO_2. These and other topics will be discussed at a workshop of international experts planned for March 2008 in London that will focus on the important role that the oceans, including Arctic and Antarctic seas, play in climate change. The meeting will address key feedback processes between the ocean and climate and include discussions on ocean acidification and ocean fertilisation. The report will also discuss the current woefully inadequate status of ocean observations and the need to implement as a high priority improved measurements of ocean processes through the development of a comprehensive, sustained and globally extensive ocean observing system. Initial sponsorship is being provided by WWF. A summary outline of the main conclusions and recommendations of the scientific report that is targeted for publication in July 2008 will be outlined in Gijon.

Poster S1.1-4752

Climatic changes in the deep Norwegian coastal waters and Skagerrak 2000 - 2005 in relation to previous decades

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Climatic conditions in the deep Norwegian coastal water, from the Skagerrak to the Barents Sea, are to a large degree influenced by the Atlantic water. The seasonal variations are also much less than in the upper layer. Temperature and salinity are observed on a regular basis at a set of nine stations from Torungen (Skagerrak) to Ingøy (Finnmark). This takes place two or four times a month from surface to the bottom. The Torungen - Hirthals hydrographic section in the Skagerrak is observed regularly once a month. The decadal mean temperatures in the deep water (150 m) along the Norwegian coast and in the Skagerrak were quite stable in the period from 1950 to 1990. The mean decadal temperature in this period was about 7.2°C in the Skagerrak and along the Norwegian west coast. In the coastal areas off northern Norway the mean temperature was reduced to 6.1°C outside Lofoten (station Eggum) and to 4.7°C close to the North Cape (station Ingøy). In the 1990s the decadal mean temperature in the deep coastal water increased considerably and temperatures in the first part of the 1990s were the highest observed since observations along the Norwegian coast started in 1936. The temperature anomaly in 1990s was closely connected to an increase in the Atlantic inflow to the Norwegian Sea and warm winters (high level of North Atlantic Oscillations - NAO). After a certain temperature decrease in the late 1990s, the temperatures again increased to the same high levels as in early 1990s in the deeper layer of the coastal waters. In 2000 - 2005 the mean temperature in the deep water along the coast from Skagerrak to the North Cape was 0.7-1.0°C higher compared to the period 1960-1989. The mean temperature increase in 2000-2005 was considerable and related to the standard deviation 1960-1989 (diffT/stdev) and varied between 1.2 and 2.1, with the highest value at station

Ingøy. Higher temperatures in the North Sea during winters from the last part of the 1980s caused a lower density in this water mass. This seems to be the main reason for observed reduced inflow of North Sea water to the deepest part of the Skagerrak, resulting in lower oxygen content. During the same period Atlantic water flowing into the Skagerrak along the southern slope of the Norwegian trench also had a too low density (due to high temperatures) to replace the deep water in the Skagerrak. In contrast to the situation in the 1990s, the NAO index and the inflow of Atlantic water has been approximately normal between 2000 and 2005. The relatively high temperatures along the Norwegian coast from the Skagerrak to the Barents Sea must then have another explanation and are probably connected to both increased inflow from the warmer easterly branch of the North Atlantic current and reduced winter cooling.

Poster S1.1-4762

Impacts of air-sea flux variability on the mid-high latitude North Atlantic Ocean

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Various processes by which variability in the air-sea fluxes of heat and freshwater at interannual to interdecadal timescales affect the mid-high latitude North Atlantic Ocean are discussed through a combination of observation based and model analyses. First, the impact of extreme Nordic Seas heat loss on Denmark Strait (DS) dense water transport is examined in a) control runs of the Hadley Centre HadGEM1 and HadCM3 coupled climate models, and b) perturbation experiments with the fast coupled model FORTE which allows heat flux effects to be isolated from wind stress. All three models show an approximately linear increase in southward DS transport of cold dense water with increasing Nordic Seas winter heat loss in the range -80 to -250 Wm^{-2}. In addition, a common response time is found with the strongest decrease in DS temperature occurring within 8-12 months of the heat loss signal. Second, an extension of the surface-forced overturning stream function approach of Marsh (2000) is used to estimate the maximum value of the meridional overturning circulation (MOC) at 48°N. The method provides good agreement with model MOC variability when a past averaging window of 10 years is employed. This method is then applied with NCEP/NCAR reanalysis surface flux fields to reconstruct MOC strength over 1953-2007. Finally, observational data sets and atmospheric reanalyses are used to link freshening of the eastern subpolar gyre over the last 40 years to increases in the surface freshwater flux from the atmosphere to the ocean.

Poster S1.1-4769

Trend analysis of sea surface temperature at the aquarium of Donostia-San Sebastián (1946-2007)

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The results of the trend analysis of sea surface temperature, measured at the aquarium of Donostia-San Sebastian (43°19'N, 02°00'W), are described within this contribution. The time series extends from 2 July 1946 to 10 June 2007; representing almost 61 years of data (22,259 days), recorded daily at 10 am. The time series has gaps in the data, especially between 1967 and 1975; consequently, up to 23% of the total data set (5,121 days) is missing. Nevertheless, it has been proved that the distribution of the gaps is sufficiently homogeneous, so as not to distort the annual mean values. In order to remove fluctuations due to time-scales of less than a year (such as seasonal variability), a running annual mean has been calculated, taking into account missing data within the original time series. Subsequently, a trend analysis has been performed with the annual data. Globally, a very small cooling trend (-0.002°C/year) can be observed, for the whole of the time series. However, a change in the tendency is observed for the latter part of the series, 1991-2007, with a warming trend of 0.040°C/year. This positive tendency can be detected even if extreme periods of hot weather, such as the summer 2003 and the second half of 2006, are removed from the analysis.

Poster S1.1-4776

Long-term variability of sea surface temperature in the Black and Marmara seas and its response to global atmospheric forcing

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Monthly NOAA/NASA AVHRR Pathfinder data (1985-2006) with a spatial resolution of 4 km and available field measurements of different years were used to investigate seasonal and interannual variability of sea surface temperature (SST) in the Black and Marmara Seas and their individual regions. The character of the SST interannual variability in both seas was similar. Warming in 1985-2006 occurred during all the seasons, with general positive trends of the mean annual basin-averaged SSTs in the Black and Marmara Seas of about 0.06 and 0.02°C $year^{-1}$, respectively. Within the period the character of temperature changes and corresponding SST trends were significantly different: a slight negative trend of mean annual SST in 1985-1993, a marked increase in 1993-2001, and a tendency to decrease after 2001. A comparison was carried out between years of marked winter SST anomalies and the yearly phases of the *El Niño* – Southern Oscillation, North Atlantic Oscillation (NAO) and East Atlantic-West Russian (EAWR) pattern. The occurrence of most of the marked winter SST anomalies during the *El Niño* events or in the years immediately after them suggests an influence of the events on the temperature regime of the sea. The winter SST anomalies were better related to the winter indices of the EAWR or to particular combinations of the winter EAWR and NAO indices, which determine the predominance of cold or warm air masses over the Black Sea basin, than to the NAO winter indices. This study was supported by the Russian Foundation for Basic Research (Grant N 07-05-00141).

Poster S1.1-4792

Analysis of an Irish coastal sea temperature time series: interannual variability and sensitivity to global influence (1958-2007)

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The heat content of the world's oceans is estimated to have increased by 14.2x1022 J during the period 1961-2003. The overall temperature increase is superimposed on strong interannual and interdecadal variations, related to atmospheric teleconnection patterns. Understanding the nature of such patterns, and changes in their behaviour over time is central to understanding regional ocean dynamics and the potential impacts of future climate change. Here we describe interannual variability in a coastal sea temperature time series, recorded to the northwest of Ireland, and interpret this variability as the sum of global forcing and regional dynamics. The data reveals recent intense warming, exemplified by a linear trend of +0.85°C over the period 1958-2006, and +1.26°C over the period 1987-2006. Comparison with global SST data sets demonstrates that 74% of the variability in the data can be attributed to global temperature anomalies, 81% to northern hemispheric temperature anomalies and 85% to North Atlantic temperature anomalies. Relationships are demonstrated between the temperature time series and the dominant modes of climate variability in the northeast Atlantic (NAO and East Atlantic Pattern). The East Atlantic Pattern explains a greater proportion of variance in the data. Specific events in the temperature time series are also related to regional changes in ocean dynamics, specifically shifts in the reach of the sub-polar and subtropical gyre systems, shelf edge current dynamics and the Irish coastal current.

Poster S1.1-4801

Recent intra-decadal changes in the water mass temperature, salinity and transport in the 60°N transatlantic section

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The study is based mostly on the data from the 7 repeats of the zonal transatlantic section along 60°N carried out on board Russian research vessels in 1997-2007 within the framework of the Russian research programme "Meridian-plus". In a recent study by Sarafanov *et al*., the transition from the colder/fresher to the warmer/saltier conditions at the intermediate and deep levels in the subpolar North Atlantic during the past decade was reported. Here, the focus was on the water mass transport changes in the 60°N section. The meridional cross-sectional velocity was quantified as the sum of three components: geostrophic, drift and barotropic (from AVISO absolute sea level topography data). Transport estimates in all the section repeats provide high values (50-80 Sv) opposite in sign. The total transport in the surface layer does not differ significantly from year to year being 11-13 Sv (positive values indicate northward transport). The Iceland Intermediate Water transport ranges from 3 to 8 Sv. The Labrador Sea Water (LSW) leaves the region at rates of -5 to -10 Sv, contributing to the deep water export. Transport of the shallow LSW formed after 1995 is roughly two times higher than the transport of the deep LSW formed in the first half of the 1990s. The Iceland-Shetland Overflow Water and Denmark Strait Overflow Water supply the North Atlantic southward outflow with 9-11 and 2-6 Sv, respectively. The MOC intensity shows a substantial variability and does not reveal any distinct trend during the decade.

Poster S1.1-4812

Palaeoceanography of the Agulhas current and ensuing Indian-Atlantic water exchange as a leading component of Atlantic MOC shifts

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The Agulhas Current off South Africa plays a key role in the Atlantic Meridional Overturning Circulation (AMOC) as salty and warm Indian waters are transported to the Atlantic Ocean and influence its buoyancy budgets. Paleoceanographic records have revealed that enhanced transports of Agulhas water occurred near the end of glacial periods when the AMOC shifted to a vigorous interglacial mode. We present 350,000 year long palaeoceanographic profiles from a sediment core positioned in the Agulhas Corridor that monitors the Indian-Atlantic water transports. Sea surface temperature (SST, from planktonic foraminiferal Mg/Ca ratios), sea surface salinity (from SST and planktonic $\delta^{18}O$) and abundance of Agulhas leakage fauna maximise during glacial terminations when the ventilation of the deep Atlantic increases, hence supporting stimulation of the AMOC. Surface warming is recorded during the penultimate glacial period (marine isotope stage 6) suggesting a narrowed near-shore flow of Agulhas water that vanished as the Agulhas corridor widened in the course of deglaciation. Benthic carbon isotopes ($\delta^{13}C$) and Cd/Ca ratios document a continuous influence of deep water from the north during early glacial phases and a subsequent shift to a dominance of southern component water. Variations of the sortable silt index document strengthened near-bottom physical flow speeds during these times which is consistent with similar profiles from other southern hemisphere locations and supports the contention that the Southern Ocean in the past played an active role in the global AMOC.

Poster S1.1-4823

Variability and forcing of the subarctic front in the northwestern Japan/East Sea

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Variability of the northwestern branch of the subarctic front (NWSF) in the Japan/East Sea (JES) is studied from two high resolution daily data sets of sea surface temperature: ew Generation (NG) SST from Tohoku University (July 2002-July 2006) and SST from the Japan Meteorological Agency (October 1993-November 2006). The NWSF index is proposed as a crossfrontal SST difference in the area off North Korea-Vladivostok where the front was documented. The NWSF manifests itself in the second Empirical Orthogonal Function of SST in the northwestern JES; reference locations for the NWSF index are based on its spatial pattern. High (low) index values correspond to the sharp (relaxed) NWSF off North Korea-Vladivostok. The NWSF index sharply increases with the onset of winter monsoon, usually in mid October, reaches its highest in the late November-early December and remains high until the end of a year or until the late winter in some cases, forced by local anticyclonic wind stress curl, as recognised from modelling studies. In the warm season, despite the decreased SST contrasts, the NWSF index reveals events of the NWSF sharpening alternated by the weakened NWSF (1-3 weeks). The NWSF index becomes low by late August-September. Forcings of the NWSF in the warm season are studied from numerical simulations with an oceanic model and shown to be related to a local anticyclonic wind stress curl and bathymetry.

Poster S1.1-4849

Mixed layer variability and its relation to ice cover and distribution of chlorophyll *a* in the Weddell Sea (Southern Ocean)

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The ocean mixed layer depth (MLD) is one of most important quantities of the upper ocean because it defines the quasi-homogeneous surface region of density that directly interacts with the atmosphere and with CO_2 adsorption. In addition, the bulk of the biological productivity of the world oceans critically depends on the physical and chemical changes taking place within this layer. The scientific issue addressed in this study is the role of the mixed layer in the Weddell Sea - the most prominent area of water mass formation in the Southern Ocean - and its relationship with chlorophyll *a*. In an effort to reconstruction the variability of the mixed layer in the Weddell Sea, we used all public high vertical resolution data, available from 1940 to present, and vertical profiles of temperature measured on board the ice-breaker *A. Irizar* from 2004 to 2006 implementing a new method based on critical temperature. Causes of observed variations are investigated using an ocean mixed-layer model, the General Ocean Turbulence Model, forced with heat fluxes. Heat exchanges between the sea and atmosphere, whether ice cover was present or not, were calculated from climatological data obtained from ECMWF, while sea-ice data (ice concentration and thickness) were calculated by new algorithms from brightness temperature (SSM/I). Further, in order to investigate the linkage between the MLD, sea-ice concentration and chlorophyll *a* in the Weddell Sea, SeaWiFS derived chlorophyll *a* were also analysed.

Poster S1.1-4878

Warming and salinification of intermediate waters of southern origin in the eastern subpolar North Atlantic in the 1990s – mid-2000s

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In addition to the quantification of the Labrador Sea Water (LSW) and Nordic overflow-derived waters temperature (Θ) and salinity (S) changes during the past decade (1997–2006), we have examined the Θ–S changes in the layer of intermediate waters of southern origin (tentatively designated "IW" following van Aken and de Boer, 1995) in the eastern subpolar North Atlantic in the 60°N repeated section. Similarly to the positive trends in temperature and salinity of the LSW and deep waters, the IW layer steadily became warmer and saltier during the 1997–2006 time period at the section latitude. We have also inspected the Θ–S changes in the IW layer at the upstream location, 52–53°N, and derived a similar trend for the 1990-2002 time period. The results are discussed in the context of the contemporary climate variations.

Poster S1.1-4894

Recent trends in the tropical Pacific-Atlantic connection

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The Atlantic equatorial mode (or Atlantic *Niño*) is an important component of the Atlantic interannual variability, and is known for impacting regional rainfall over the coast of the Gulf of Guinea. It is also known that remotely forced variability affects very much the Atlantic *Niño*: several authors, using observations from the 1950s, have reported connections with a six-month lag between the Atlantic *Niño* and previous Pacific *Niño*. The present work revisits the relationship using an observational data set in the recent period (1979-2001) and comparing this with the first part of the twentieth century. The lead-lag correlation scores of the anomalous tropical SST and precipitation between these two tropical basins show a "Pacific-Atlantic wave-like relationship" with a 3-4 year period which is only significant from 1979. Possible explanations for this behaviour include the recent trends in warming rates of the individual ocean basins; stronger warming in the Atlantic from the 1980s and cooling in the eastern equatorial Pacific from 1975. Thus, in the recent period "a summer inter-basin SST gradient" trend is found that could suggest a relevant role of the equatorial Atlantic SST anomalies in the tropical belt anomalous circulation. For instance, the recent period is characterised by enhanced divergence in the central Amazon basin, representing a competitive action between basins, in comparison with the first period, when the Amazon cell splits. This also could imply that the Pacific, and in turn its global influence, could be modulated by the Atlantic.

Poster S1.1-4898

Effects of the world's oceans on climate change

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Recent decades have seen relatively quick changes in global climate although there has been a change in surface solar radiative forcing of only 0.1% and a very small change in global mean temperature. Considerable changes in space-time dispersions of temperature, pressure, humidity, wind velocity and other parameters have been observed and should be looked at as global climate change. Our analysis of the world's oceans role in climate change is based on the following statements derived from observations: 1) the world's oceans are the main accumulating and storing systems of the incoming solar energy, 2) solar energy income to the ocean surface and

its assimilation depend on the atmospheric and ocean optical properties, which are affected by phytoplankton biomass and space structure, 3) primary production in the ocean is greatly influenced by different kinds of solar activity, 4) considerable biota changes can forestall the changes of climatic parameters. Basing on these facts and analysing interrelations between water leaving radiance and chlorophyll concentrations, we come to the conclusion that energy for global climate fluctuations can come from fluctuations of the world's oceans heat content via mechanisms of ocean-atmosphere interactions. Assimilation and accumulation of solar heat in the ocean is controlled by the ocean biota, where concentration and properties are greatly influenced by solar and geomagnetic activity. Using these observations we can derive methods for long-term prediction of global climate change.

Poster S1.1-4911

Eastern equatorial Pacific climate variability for the last glacial cycle

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The impact of the tropical ocean-atmosphere system on the global climate is well-recognised on interannual to decadal time scales because of the link to the *El Niño*-Southern Oscillation. On glacial and millenial time scales, however, the potential role of the tropics in driving or amplifying global climate is still not fully understood. The cold tongue of the eastern equatorial Pacific represents a key area if we are to understand some of the potential mechanisms driving global climate change as it is also the major oceanic source of carbon dioxide to the atmosphere. In this region, a marine sediment core was retrieved during ODP Leg 202 at the northern flank of the Carnegie Ridge (0º01.31'N, 86º27.76'W; 2,921 m water depth) in the Panama Basin. ODP Site 1240 is under the influence of the Equatorial Undercurrent (EUC), which flows eastward and transports cool thermocline waters from the western Pacific along the equator. We will present a multiproxy record of climate variability covering the last glacial cycle (~145,000 years) based on the analyses of molecular biomarkers and stable isotopes and trace elements in fossil foraminifera. These analyses will provide two independent methods to reconstruct past sea surface temperature (SST), namely the $U^{k'}_{37}$ index and foraminifera Mg/Ca ratios. Both glacial/interglacial and millenial SST variability will be evaluated in combination with terrestrial input and marine productivity changes over the last glacial cycle.

Poster S1.1-4915

Comparison of *in situ* time series of temperature with gridded sea-surface temperature data sets in the North Atlantic

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Analysis of the effects of climate variability and climate change on the marine ecosystem is difficult in regions where long-term observations of ocean temperature are sparse or unavailable. Gridded sea-surface temperature (SST) products, based on a combination of satellite and *in situ* observations, are often used to examine variability and long term trends as they provide better coverage on both spatial and temporal scales than the limited sets of long *in situ* time series. SST data from two gridded products (Reynolds/NCEP OISST and HadISST) are compared with long time series of *in situ* measurements from ICES standard sections in the North Atlantic and Nordic Seas. The long term variability and trends derived from these two data sources are compared and differences between the data sets are examined and discussed.

Poster S1.1-4916

Recent changes in temperature and salinity in the Canary region

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Based on hydrographic sections carried out during the last decade in the Canary region at 29º10'N, we show that there has been a statistically significant rise in temperature and salinity on isobars between 1500 and 2300 db. The maximum increase, found at 1600 db, is occurring at a rate of 0.29ºC and 0.047 per decade. Isobaric change decomposition into changes on neutral surfaces and changes due to the vertical displacement of the isoneutrals was performed. Results reveal that the lower part of North Atlantic Central Water (NACW) cooled and freshened on neutral surfaces, suggesting changes in the freshwater fluxes at the outcropping region. However, the signal in deep waters (1500-2300 db) was principally due to a downward displacement of the isoneutrals, although water mass modification is observed in the range of Mediterranean Water (MW) influence.

Poster S1.1-4948

The teleconnection between sea surface temperature analysis from *in situ* data at East Mole, Lagos and global warming

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Marine Weather Observers have since 1988 been making sea surface temperature observations at East Mole Station, about 2 kilometres from the coast. The station uses the rubber sea-temperature bucket thermometer and makes observations on an hourly basis. Sea surface temperature influences Lagos coastal weather and it is especially important for coastal fishermen, offshore oil and gas industries, shipping vessels, coastal recreational and port handling facilities. Some evidence of global warming in Nigeria has been observed using sea surface temperature (SST) for the period 1989-2006. Results show that the Nigerian coastal waters are warmest in April and coldest in August. The yearly mean SST during the period 1989-2000 shows some evidence of global warming. This paper attempts to highlight the features of sea surface temperature over the Lagos coastal waters, thus indicating that global warming is evident in the Nigerian coastal waters.

Poster S1.1-4957

Variations of water and air temperature in coastal areas of the north-west Japan/East Sea

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The tendencies of climate change, namely global warming are of great interest. It is an urgent problem to define the most vulnerable areas of the coastal zone by analysis of instrumental observations. We analysed the long-term series of observations of surface temperature of sea water and air temperature, conducted at the hydrometeorological stations on the coast of Primorski Krai from 1881 to 2006. For the last hundred years in Vladivostok water temperature has increased by 0.64°C, and air temperature, by 1.74°C. Our research confirms, that 1989-2000 is the warmest period of the twentieth century for the researched area but the warmest year for each station is different. Up until 1988 there is a fluctuation of temperature about norm, but since 1989 positive anomalies at all stations are marked.

Poster S1.1-4963

Low-frequency changes in sea surface temperature in the eastern South Pacific

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Different IPCC model simulations have shown that the sea surface temperature (SST) increase over the eastern South Pacific is rather small compared to the global trends. This smaller regional trend may be associated with upwelling increasing along this region. Nevertheless, previous results have shown that at low frequencies (interannual and interdecadal time scales) SST and coastal air temperature fluctuations in the eastern South Pacific are closely correlated to changes in the equatorial Pacific and do not covary significantly with changes of the alongshore winds. In this work we analyse SST and sea level height (SLH) data along with winds data from the eastern South Pacific to evaluate long term changes of these variables. We evaluate the local relationships among low frequency fluctuations of SST, SLH and thermocline depth. We also explore possible mechanisms that could contribute to the observed trend and to the low frequency fluctuations in the different variables. In particular we focus on the relationship with the variability observed during the last decades over the equatorial Pacific and changes in the subtropical anticyclone over the eastern South Pacific. Our main hypotheses is that changes in thermocline depth along the Peruvian and Chilean coast are closely related to changes in the equatorial Pacific and those changes significantly impact the SST and SLH in this region. Despite limitations in the different data sets most of the evidence is consistent with the strong modulation of SST off Peru and Chile by the changes in the equatorial Pacific.

Poster S1.1-4979

Effects of regional drivers on the sea water temperature in Kuwait Bay, northern Arabian Gulf

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The water in the northern Arabian Gulf is well mixed by macrotidal semi-diurnal tides. Sea surface temperature (SST) is thus a good proxy of water mass temperature. MODIS (moderate resolution imaging spectroradiometer) satellite data collected over 5 years between 2003 and 2007 (750 SST images) show that SST in the Kuwait Bay has increased by 2.5°C. Regression analysis of a yearly average AVHRR (Advanced Very High Resolution Radiometer) data indicates that the SST in Kuwait Bay has increased by 1°C/decade over the last 20 years and 2°C/decade during the last 10 years. We propose that this rapid recent increase in SST is explained by drivers at global, regional and local scales. This study concentrates on the affect of the regional drivers on SST in Kuwait Bay. The regional drivers considered are: fresh water discharge from the Euphrates River, air temperature, wind speed and relative humidity. The fresh water discharge from the Euphrates is not available after 1994; therefore salinity data measured during 1983-1994 was correlated with discharge data in order to predict the discharge after 1994. Statistical analysis showed that only 30-40% of the variance in sea water temperature is explained by air temperature. We infer that 66-70% of the signal is driven by global and local drivers.

S1.2 Climate model projections

20 May, 08:30 (S1.2-4702) Plenary
Oceans role in climate change

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First, an overview of the role of the oceans in climate change is given. For example, the ocean acts as a large reservoir for heat, water and other tracers. Changes in oceanic transports can also impact the climate. Projections of oceanic changes (e.g. temperature, salinity, circulation and sea level rise) from the IPCC 4th Assessment Report are presented. These projections show that the SSTs warm in most regions when greenhouse gases (GHG) increase in the atmosphere. However, the warming is minimal in high latitudes of the North Atlantic and around Antarctica. The warming only slowly penetrates to depth, indicating the long response time scales found in the ocean. The long temperature response time scales also lead to long response time scales for sea level rise. As GHG increase in the atmosphere, there is also the possibility that the earth will experience large scale abrupt climate changes. These could be related to changes in ocean circulation due to the warming or melting land ice. A discussion of the uncertainties associated with these projections will be presented. For example, the AR4 assessment states that it is *very unlikely* that the Meridional Overturning Circulation (MOC) found in the Atlantic Ocean will shut down this century. Finally some thoughts for discussion are presented. One issue is whether or not the MOC weakening (not an abrupt shutdown!) is good or bad for society; for example, a potentially good result of the MOC weakening as GHGs increase is that the North Atlantic region experiences less warming.

20 May, 10:30 (S1.2-4802) Invited
Comparing past variability of coastal currents and upwelling regimes with plausible future anthropogenic signals – in the framework of millennial AOGCM simulations

Hans von **Storch**[1,2], Eduardo Zorita[1] and Fidel J. González-Rouco[3]

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For assessing the role of anthropogenic factors in changing climate at large, and of ocean features, detection (anthropogenic influenced developments) and attribution (to specific causes) studies are needed. For doing so, extensive data sets of past variability as well as scenarios of plausible future developments are needed. Obviously, such data sets hardly exist for many oceanic features such as the intensity of coastal currents and upwelling regimes. Thus, not surprisingly, only few detection and attribution studies have dealt with oceanic features, while the methodology has multiplied and been successfully applied to atmospheric variables. As a demonstration, we conduct detection and attribution exercises in the framework of millennial simulations (1000-2100), forced by estimated past volcanic, solar and greenhouse gas forcing - with the last 100 years using SRES scenarios. Statistics of coastal currents, of and coastal mean sea level and upwelling regimes are considered. Estimates of early detection times are derived.

20 May, 10:55 (S1.2-4955) Invited
Future projection of extreme events

Seita **Emori**

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Research on extreme events in a future warmer climate has been accelerated in recent years partly because of social demand and partly because of the enhanced skill of climate models to represent extreme events. In this talk, I'd like to start by summarising what is written in IPCC AR4 about extreme events, especially on their changes

in the future. Then I will continue by discussinggeneral reliability issues on projected future changes in extreme events. For example, I'd like to demonstrate that high-resolution climate modelling is useful for realistically representing certain kinds of extreme events, but it is not sufficient. I hope also to mention what climate modellers should be careful about when projected changes in extreme events are used in impact assessment work.

20 May, 11:20 (S1.2-4839)

Freshening of the subpolar North Atlantic: causes and consequences

Markus Scheinert, Claus W. **Böning** and Arne Biastoch

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Recent studies of ocean observations show significant multi-decadal changes in the freshwater content (FW) for the subpolar North Atlantic (SNA), including a prominent freshening between the late 1960s and early 1990s. Two main mechanisms have been invoked to explain the changes in FW: a change in the surface freshwater fluxes, and changes in the export of freshwater out of the Arctic and Nordic Seas. Here we propose an alternative mechanism, which can explain not only the decadal variations in FW, but also its conspicuous, high negative correlation with heat content for the SNA. Our study is based on a sequence of hindcast and sensitivity experiments with a global ocean-sea ice model, using the bulk surface flux formulation for 1958-2000 (the "CORE" forcing protocol) developed by Large and Yeager (2004). The model simulation reproduces the observed changes in both the integrated SNA FW and heat content; it also captures other pertinent features of observed decadal SNA variability: the salinity changes at OWS Bravo in the deep Labrador Sea; the freshwater flux anomalies associated with the "Great Salinity Anomalies"; and the Curry-McCartney index of North Atlantic Current (NAC) variability. The model output has been used to assess the changes in the components of the freshwater budget: it suggests that the largest contribution to the integral changes in the SNA has been due to the FW and heat exchanges with the subtropical gyre; in contrast to previous suggestions, it indicates a minor influence of variations in the surface fluxes, and also a secondary contribution to the SNA FW changes by freshwater exports from the Arctic. The variability in the subtropical-subpolar fluxes can be understood in terms of the response of the gyre circulation to atmospheric forcing variability associated with the North Atlantic Oscillation (NAO).

20 May, 11:35 (S1.2-4622)

A method for using IPCC model simulations to project changes in marine ecosystems

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In preparation for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, an international group of modelling centres carried out sets of global climate simulations. A total of 23 different coupled atmosphere-ocean general circulation models were employed under common emission scenarios. The objective of this paper is to describe a protocol for using these simulations towards the projection of the future states of marine ecosystems, drawing on examples from the North Pacific and Bering Sea. Our method relies on critical evaluation of the models' 20th century hindcasts of variables pertaining to the ecosystems of interest. Experience indicates that typically about one-half of the models are able to replicate the spatial pattern, temporal scale and magnitude of variance in the basin-scale climate forcing observed in the 20th century. Different models tend to have different strengths; a model's capability to hindcast an individual parameter such as sea ice does not guarantee it performs equally well for other parameters such as precipitation. Therefore, the subset of models used for projections into the 21st century should be tailored to the specific application. At the same time, it is desirable to retain as many independent simulations for the 21st century as possible (at least 5) in that an ensemble of simulations is required to ascertain the probable ranges of future extremes in the climate forcing, and the uncertainties in the projections in general.

20 May, 11:50 (S1.2-4766)

Recent warming and changes of circulation in the North Atlantic simulated with eddy-permitting and eddy-resolving ocean models

Robert **Marsh**, Beverly A. de Cuevas, Andrew C. Coward and Simon A. Josey

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The role of ocean heat transport variations in recent warming of the North Atlantic is investigated using three different eddy-permitting (1/4°) simulations and one eddy-resolving (1/12°) simulation of the OCCAM global ocean model, forced with prescribed atmospheric boundary conditions since the mid-1980s. The first eddy-permitting simulation (spanning 1985-2003) is used to investigate links between surface warming and changes in regional heat budgets. Variability of model sea surface temperature compares favourably with satellite and *in situ* observations. Each data set reveals a similar pattern of significant surface warming across much of the North Atlantic since 1985. In the model, significant warming trends exceed 0.1°C per year across a large area of the northwest Atlantic. A second eddy-permitting simulation (1985-2004) includes several model improvements. Both of these eddy-permitting simulations, and an eddy-resolving simulation (1985-2004), are forced using blended NCEP re-analysis and satellite data. A third eddy-permitting simulation (1985-2000) is forced with a different data set, based on the ERA-40 re-analysis data. Inter-comparison of these simulations clarifies the relative importance of resolution and choice of forcing data set, for simulating the mean state and recent variability of ocean circulation. Two broad conclusions are reached: (1) the pattern of recent warming in the mid-latitude North Atlantic is largely due to anomalous convergence of ocean heat transport, associated with changes in overturning and horizontal components of the circulation, in the northern subtropics and the subpolar gyre respectively; and (2) recent changes in the structure of mid-latitude heat transport are more accurately represented if eddies are explicitly resolved.

20 May, 12:05 (S1.2-4642)

A variational model of jet current applied to the Kuroshio Extension

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The border between the subtropic and subarctic regions in the Northern Pacific is considered. There are two climatic fronts - the density front of the Kuroshio Extension and the thermohaline subarctic front. A variational stationary model is used, where a zonal channel on an f-plane with a fixed density difference on the southern and the northern borders is set. The geostrophic approach along the channel is carried out. The hydrostatics equation is applied to the vertical direction. Advection and turbulence forces across the channel are considered. The mathematical model is based on the variational functional of the minimum entropy production. Approximate analytical solutions are constructed by the direct variational method with the addition of the oceanographic information on the physical fields. Convergence across the channel is also set as a priority. The model shows that the existence of the Kuroshio Extension may be limited by climatic factors. There is a critical parity between the north-south difference of water density, convergence, turbulence intensity, when the current is not a jet current anymore.

20 May, 12:20 (S1.2-4697)

Anthropogenic speed-up of oceanic planetary waves

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We have analysed a suite of state-of-the-art climate model simulations, and show that anthropogenic warming of the upper ocean produces a detectable speed-up of low-latitude North Pacific oceanic planetary waves by the end of the 20th century. The projected percent increase in propagation speed for the end of the 21st century is about 35% (relative to pre-industrial) following one of the standard emission scenarios from the Intergovernmental Panel for Climate Change (IPCC). This remarkable simulated effect of oceanic warming on planetary wave propagation speed portends an important observed change in interannual climate variability.

20 May, 12:35 (S1.2-4714)

Fidelity in the present-day simulation and projected changes to the southern hemisphere extratropical ocean/sea-ice system in the AR4 coupled climate models

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The southern hemisphere extratropics boast one of the most profound and robust climate trends observed over the past few decades - a shift to an increasingly positive phase of the dominant mode of southern hemisphere (SH) extratropical variability, the Southern Annular Mode. This is characterised by a poleward shift and strengthening of the midlatitude jet. The surface signature of this atmospheric rearrangement has the potential to significantly modify characteristics of the ocean and sea-ice system. This is on the backdrop of, and intimately related to, unprecedented, large-scale increases in global temperatures and modifications to the hydrological cycle. Here we investigate the ability of the AR4 coupled climate models to realistically simulate the large-scale features of the SH extratropical ocean and sea-ice systems (for the end of the 20th century) pertaining to surface properties, mixed layer depths, water mass characteristics and lateral and overturning circulation. An assessment is further made of the projected changes to these properties over the next 100 years under the SRES A1B forcing scenario. Despite the existence of large inter-model differences many of the projected circulation changes are robust across the models. These changes are particularly associated with a poleward shift in the large-scale horizontal circulation, modifications to the SH overturning, a reduction in sea-ice extent and a shoaling of the deep mixed layers. Changes in oceanic circulation are consistent with a poleward shift in wind stress across the models. An investigation into the inter-model differences in surface forcing goes some way to explaining inter-model circulation variability.

20 May, 12:50 (S1.2-4603)

Antarctic ice-sheet melting provides negative feedbacks on future climate warming

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Anthropogenic greenhouse gas emissions are likely to affect climate for millennia, notably due to the large thermal inertia of the oceans and the long memory of the ice sheets. Archives of the past suggest noticeable Antarctic Ice-Sheet (AIS) melting contributions to sea-level changes during the last deglaciation and glaciation, illustrating the possibility of massive freshwater input into the Southern Ocean, which could have influenced the climate. Recent observations report an accelerated melting of the West Antarctic Ice Sheet. This ice melting may partly explain the observed freshening of the Ross Sea observed during the past four decades. Freshening also appears in the Antarctic Bottom Water (AABW) and could limit this deep-water formation in the future and affect climate. While none of the coupled climate models participating to the IPCC Fourth Assessment Report take into account the AIS melting, it is necessary to evaluate the potential effect of this melting on projected long-term global warming. Here we show by using a three-dimensional climate model, which includes a comprehensive representation of polar ice sheets, that AIS melting moderates warming in the southern hemisphere, by up to 10°C regionally, in a 4xCO_2 scenario of 3000 years. This behaviour stems from the formation of a cold halocline in the Southern Ocean, which limits sea-ice cover retreat under global warming and increases surface albedo, reducing surface warming. Furthermore, we show that AIS melting, by decreasing AABW formation, restrains the weakening of the Atlantic meridional overturning circulation, which is a new illustration of the effect of the bipolar oceanic seesaw. Consequently, it appears that AIS melting strongly interacts with climate and ocean circulation globally. It is therefore necessary to account for this coupling in future climate and sea-level rise scenarios.

20 May, 14:30 (S1.2-4667)

The sensitivity of the circulation, stratification and primary production of the northwest European continental shelf to climate change

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The physical and biological processes of shelf seas are strongly constrained by forcing from the atmosphere, ocean and land. Hence these regions might be expected to be highly sensitive to changing climatic conditions. Since these are regions of exceptionally high biological production and socio-economic importance, such changes may have wide ranging implications, e.g. for fisheries. Moreover, shelf seas have also been identified as playing a significant role in the Earth system as a whole, for example through their role in the global carbon cycle and water-mass formation and mixing. This opens up the possibility of feedbacks on longer time scales. We use multi-annual and multi-decadal model simulations of the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) coupled to the European Regional Seas Ecosystem Model (ERSEM) to investigate how large scale modes of variability in the atmosphere and ocean propagate into the hydrodynamics of the northwest European continental shelf and then consequently to its ecosystem. The simulations are forced by both atmospheric re-analyses of the recent past (ERA-40) and by Met Office Hadley Centre regional climate model simulations of the late 20th century and the 21st century. Results from these two experiments are compared to investigate the variability of shelf-scale circulation, stratification and primary production, focusing on two periods: 1961-1990 and 2070-2100. Observations of hydrography, nutrients, chlorophyll and oxygen from the ICES database provide validation for the reference simulation.

20 May, 14:45 (S1.2-4691)

The Atlantic Multidecadal Oscillation in IPCC coupled model control and climate change simulations

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Coherent variations in basin-wide North Atlantic sea surface temperature (SST) anomalies with a period of about 60-80 years constitute what is now generally referred to as the Atlantic Multidecadal Oscillation (AMO). These fluctuations, which influence distinct aspects of climate in the North Atlantic area, have been connected with changes in the thermohaline circulation and northward oceanic heat transport. The present study investigates the properties of the AMO in a set of global simulations with different coupled models whose output is available in the CMIP3 database. A Multichannel Singular Spectrum Analyses of the annual North Atlantic SST anomalies is used to extract the AMO signal. Its characteristics in different simulations and models are compared. The analysis is then extended to other atmospheric and oceanic fields in order to gain an insight into the physical mechanisms that might operate in different simulations and account for divergences among them.

20 May, 15:00 (S1.2-4807)

Surface wind-stress threshold for glacial Atlantic overturning

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Using a coupled model of intermediate complexity the sensitivity of the last glacial maximum (LGM) Atlantic Meridional Overturning Circulation (AMOC) to the strength of surface wind-stress is investigated. A threshold is found below which North Atlantic deep water formation takes place south of Greenland and the AMOC is

relatively weak. Above this threshold, deep water formation occurs north of the Greenland-Scotland ridge, leading to a vigorous AMOC. This nonlinear behaviour is explained through enhanced salt transport by the wind-driven gyre circulation and the overturning itself. Both the pattern and magnitude of the Nordic Sea's temperature difference between strong and weak AMOC states are consistent with those reconstructed for abrupt climate changes of the last glacial period. Our results thus point to a potentially relevant role of surface winds in these phenomena.

20 May, 15:15 (S1.2-4809)

The AMOC in millennial ECHO-g climate simulations and future climate change scenarios

Pablo **Ortega**, Marisa Montoya and Fidel J. González-Rouco

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The main aim of this study is to analyse the Atlantic Meridional Overturning Circulation (AMOC) variability in one 1000-year long control simulation, two forced simulations of the last millennium and two IPCC climate change scenario simulations, all performed with the ECHO-g Atmosphere-Ocean General Circulation Model (AOGCM). Several Meridional Overturning Indices (MOI) are used to describe the behaviour of the ocean circulation in these simulations. Their evolution shows a weakening in the AMOC during the industrial era that intensifies through the 21st century. No complete collapse of the AMOC is observed in the future scenarios. Fourier and wavelet spectral analysis of the indices reveals an AMOC behaviour close to a red noise process and a tendency to present larger variability at interannual and multidecadal timescales. The short-term AMOC variability is similar in all the simulations, and is associated with atmosphere dynamics that force the ocean through changes in the wind stress. Low frequency forced and unforced AMOC variability responds to anomalies in ocean density. These are localised in the Atlantic basin in the control run, and develop at global-scales in the forced simulations.

20 May, 15:30 (S1.2-4695)

Biosphere-atmosphere-ocean interactions and climate change: the case of Amazon deforestation

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The Amazon rainforest is an important piece of the global climate system. With an annual mean precipitation in the order of 2 metres, it contributes to maintain the general circulation of the atmosphere and the oceans. One of the scenarios of future global warming present in the IPCC 4th Assessment Report is the gradual replacement of the exuberant Amazon rainforest for lower trees and bushes of savanna-type vegetation. This paper uses a suite of atmospheric and coupled biosphere-atmosphere-ocean general circulation models to study the impact of Amazon deforestation on global ocean circulation and climate. The results confirm early findings that Amazon deforestation leads to local increase of surface temperature and decrease of rainfall. In addition, this study suggests that global, ocean-atmosphere interactions are responsible for further Amazon rainfall reduction through the induction of enhanced ENSO-type ocean-atmosphere variability. Changes in tropical ocean temperature and circulation associated with the atmospheric response to the Amazon deforestation are also discussed.

20 May, 15:45 (S1.2-4598)

Influence of coloured noise in the ocean coupling on the thermohaline circulation

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In the last decades it has been established that the thermohaline circulation (THC) plays a major role in regulating the North Atlantic climate. Its formation is very sensitive to air-sea heat exchange and freshwater input in the North Atlantic. Therefore, many modelling studies have been performed in recent years in order to analyse the behaviour of the THC under a changing climate. Results show that the ocean-atmosphere system has more than one stable mode of operation and is very sensitive to different perturbations. In this work the effect of stochastic forcing in the coupling between an atmosphere and ocean system was considered. We have chosen a model where the ocean model couples to the atmospheric model through the restoring temperatures and the equivalent salt flux (differential net surface evaporation). In particular, previous analyses show that the equivalent salt flux presents considerable synoptic-scale variability with fluctuations about the seasonal mean in the order of 10-50%. Moreover, the equivalent salt flux should be related to the hydrological cycle, involving both river runoff (very important in the portion of the freshwater flux into the ocean basin) and the atmospheric meridional transport of water vapour. In this sense, we considered the study of the influence of stochastic forcing on Q_s and we considered a coloured noise such as was suggested by Hasselman. The results corroborate the necessity of considering stochastic forcing in climate models in order to minimise the uncertainty in the thresholds of possible abrupt change climate.

20 May, 16:00 (S1.2-4579)

Future winds off the Pacific coast of Canada

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Global climate model output obtained from the Program for Climate Model Diagnosis and Intercomparison CMIP3 archive is used to examine projected changes in the winds off the Pacific coast of Canada. Extensive observations over the period of 1976 to 1995 at thirteen offshore buoys are first used to validate 10 m winds from eighteen models selected on the basis of data availability, and to establish baselines for statistical downscaling. All models are shown to capture large scale aspects of the seasonal cycle. Magnitude and directional changes over the periods 2030-2049 and 2080-2099 under the SRES A1B scenario are then calculated for nearshore and offshore buoy groupings. Though the average changes are modest, the models do project a slight intensification and clockwise shift in summer winds at the offshore buoys. Winds from the Salathé *et al*. (2008) high-resolution climate model for the US Pacific Northwest are also obtained and used to demonstrate the limitations of statistical versus dynamical downscaling in regions with significant topographic variations.

20 May, 16:15 (S1.2-4855)

A diagnostic model of mixed layer depth variability with application to Ocean Station "P" in the northeast Pacific

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Direct determination of the surface mixed layer depth requires the measurement of turbulent mechanical mixing or observations from high precision temperature-conductivity profilers. Long-term measurements of these variables are difficult to sustain so that investigators typically seek estimators for mixed layer depth that can be derived from more readily available oceanic and meteorological time series. This study uses a simplified heat balance equation and remotely sensed surface data to formulate a simple diagnostic model for determining the depth of

the mixed layer. Daily time series of mixed layer depth from early spring to late fall can be closely approximated using only records of the sea surface temperature and surface heat flux. A test of the diagnostic model using the 55-year series of oceanographic and meteorological data from Ocean Station "P" and recent data from Argo drifters for the northeast Pacific shows that the model provides more accurate estimates of mixed layer depth and is simpler to apply than established models. Application of the model to Station "P" shows that, contrary to what has been reported for late winter, there is no significant trend in the summer mixed layer depth at this mid-ocean location over the observation period 1951 to 2006 despite significant trends in the corresponding buoyancy and turbulent energy fluxes. The lack of trend has implications for studies of climate-induced changes in upper ocean productivity.

20 May, 16:30 (S1.2-4745)

Study of the wind variation effects in the upwelling system along the Peruvian coast and consequences of climate change through numerical modelling

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Considering that the ocean and the atmosphere are a system that interact permanently, it is possible to observe at least two atmospheric forcings on the ocean. These forcings can be identified as wind stress on the sea surface and heat exchange flow: latent heat, absorption and refraction of the radiant sun. The eastern tropical and subtropical Pacific, particularly the coastal region of western South America, is affected by the *El Niño* Southern Oscillation (ENSO) event. In this work ERS-1 and ERS-2 scatterometer data of wind stress climatology are used to study Ekman pumping/suction and transport in the coastal ocean at 15°S and 5°S off Peru. I am tuning the Princeton Ocean Model (POM) to study oceanic circulation and Ekman dynamics along the Peruvian coast when the *La Niña* (1996-1997) and *El Niño* (1997-1998) events occurred. The model is forced by the wind stress and I use as initial conditions the temperature and salinity climatology. The analysis confirms that when strong *El Niño* events occur, the meridional wind stress has a dominant role in the intensity of coastal upwelling; the speed of Ekman pumping was nearly six times larger than the normal speed of Ekman suction and offshore Ekman transport nearly doubled.

S1.2 Posters

Poster S1.2-4539

Representation of the Weddell Sea deep water masses in the ocean component of the NCAR-CCSM model

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The Weddell Sea deep water mass distributions are examined with respect to the results from three different model runs using the oceanic component of the National Center for Atmospheric Research Coupled Climate System Model (NCAR-CCSM). One run is inter-annually forced by corrected NCAR/NCEP fluxes while the other two are forced with the annual cycle obtained from the same climatology. One of the latter runs includes an interactive ice-model. Optimum multiparameter analysis is applied to separate the deep water masses in the Greenwich meridian section (into the Weddell Sea only) to measure the degree of realism obtained in the simulations. First, the distribution of the simulated deep water masses are described using observed source water indices. Since the observed indices do not render an acceptable representation of the Weddell deep water masses as expected, these were specifically adjusted for each simulation. Differences between the water masses representation in the three simulations are quantified through their root-mean-square differences. Results here point out the need for better representation (and inclusion) of ice related processes in order to improve the oceanic characteristics and variability of dense Southern Ocean water masses on the outputs of the NCAR-CCSM model, and consequently in other ocean and climate models.

Poster S1.2-4808

Heat content through the last millennium and in future climate change scenarios: an assessment using ECHO-g AOGCM simulations

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This work analyses the ocean heat content (OHC) described by one 1000-year long control simulation, two forced simulations over the last millennium and two IPCC scenario simulations (A2 and B2), performed with the ECHO-g Atmosphere-Ocean General Circulation Model (AOGCM). Since the deepest layers of the ocean are stable, the heat content is integrated in the upper ocean. The forced experiments show a clear response to the external forcing at high and low-frequencies. A common result in all the simulations is that interannual variability of the OHC is found to be highest close to the equator, while the largest changes at interdecadal and secular timescales occur in the tropics. The amplitude of oscillations is considerably higher in the forced runs. In contrast with observations, our simulations exhibit the largest OHC changes in the Pacific basin, and the smallest in the Indian Ocean. In the future scenarios a gradual increase in the OHC is observed for the three basins, with maximum values above those simulated for the last millennium.

Poster S1.2-4889

A global ocean current and tidal model with varying unstructured grids: application to the East China Shelf

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In this paper a global ocean current and tide model (GOCTM) with varying unstructured grids was developed. The model is developed based on the philosophy of unstructured grids to conserve the water transported through model cells. The model takes advantage of the geometric flexibility of an unstructured triangular mesh system using a realistic global topography which also includes the Arctic. Thus, there is no open boundary condition to be considered. The first six partial tides were included as ephemeredes forcing, and the model is fully baroclinic and 3-dimensional. As a general application, the model is first applied to the East China Shelf, which includes the Bohai Sea, Huanghai Sea and the East China Sea, and which has many marginal seas, channels and islands. In this application the model grids are globally refined over coastal areas, marginal seas and channels, especially those of the East China Shelf. The GOCTM is initialised by WOA05 climatological ocean temperature and salinity data, driven by surface heat flux and surface wind stress. Analysis of the model results indicates that the GOCTM reproduced the realistic global tidal harmonic constants well and the fundamental global general circulation fields, especially, those results over the East China Shelf were almost exactly reproduced. The transport of the Kuroshio and its sub-branches are in good agreement with observations. The seasonal variation of the Kuroshio extension and the main currents over the East China Shelf seems reasonable. The GOCTM provides a robust model to survey the interaction of the global ocean with coastal waters. This will allow us to more easily study the dynamic system and the ecosystem of the western Pacific under the climatic changes induced by the global warming.