Session 1: Instrumental observations of the AMOC

Oral session

OVIDE-A25, a biennial hydrographic transect across the North Atlantic Subpolar Gyre since 2002: Overview of the main scientific findings about the variability of the meridional overturning circulation and its impact on the CO2 physical pump

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Abstract: The meridional overturning circulation (MOC) transports heat from the subtropics to high latitudes and hence plays an important role in the Earth's climate. A region crucial for the MOC is the northern North Atlantic, where waters transported northwards in the MOC upper limb gain density and eventually sink into the southward flowing lower limb. The variability of the subpolar gyre circulation, the MOC and heat transport was quantified from a joint analysis of hydrographic and velocity data from eight repeats of the Greenland to Portugal OVIDE section. The obtained circulation patterns revealed remarkable transport changes in the whole water column and evidenced large variations in the magnitude of the MOC computed in density coordinates (MOC_σ). The extent and timescales of the MOC_σ variability in 1993–2016 were then evaluated using a monthly MOC_σ index built upon altimetry and Argo data at the OVIDE section location. The MOC_σ index, validated by the good agreement with the in situ estimates, shows a large variability on monthly to decadal time scales. The heat transport estimated from the repeated hydrographic OVIDE sections is linearly related to the MOC_σ intensity. The uptake of atmospheric carbon dioxide in the subpolar North Atlantic Ocean is also strongly impacted by the variability of the MOC_σ. We found that the uptake of anthropogenic carbon dioxide occurred almost exclusively in the subtropical gyre. In contrast, natural carbon dioxide uptake dominated in the subpolar gyre. We attributed the weakening of total carbon dioxide uptake observed between 1997 and 2006 in the subpolar North Atlantic to a reduction in the natural component. We also showed that the transitory slowdown of the MOC_σ was largely responsible for this phenomenon, through a reduction of oceanic heat loss to the atmosphere, and for the concomitant decline in anthropogenic carbon dioxide storage in subpolar waters.

Calculation of the mean Atlantic Meridional Overturning Circulation with Argo floats and temperature-salinity data.

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LPO-Brest

Abstract: A direct calculation of the mean AMOC is made possible using the Argo float displacements from the 2000-2009 Andro data base and the World Ocean Atlas Temperature-salinity 2009 distribution. The calculation is carried out in 3 steps:
(1) The mean geopotential is first computed from the mean flow obtained from Argo floats mean displacements. Hydrostatics then allow to obtain the absolute geopotential and geostrophic mean flow at all depths.
(2) The Ekman currents + geostrophic currents are then vertically averaged to obtain the barotropic vorticity. The barotropic vorticity is then inverted to obtain the barotropic stream function and the non divergent barotropic currents.
(3) The absolute meridional current is now written as a sum of Ekman and baroclinic contribution with zero vertical average and the barotropic term. Zonally integrating this expression gives the AMOC.

Mass and heat transports are discussed at various latitudes in the Atlantic and compared to previous estimates.

Investigating a new record of Atlantic sea surface salinity from 1896–2013

Andrew Friedman
LOCEAN-IPSL

Abstract: We investigate an unprecedented Atlantic SSS compilation from 1896 to 2013 and analyze the main modes of SSS decadal variability. Using principal component analysis, we find that the low-latitude (tropical and subtropical) Atlantic and the subpolar Atlantic have distinct variability. Subpolar and low-latitude SSS are negatively correlated, with subpolar anomalies leading low-latitude anomalies by about a decade. Subpolar SSS varies in phase with the Atlantic Multidecadal Oscillation (AMO), whereas low-latitude SSS varies in phase with the North Atlantic Oscillation (NAO). Additionally, northern tropical SSS is anticorrelated with Sahel rainfall, suggesting that SSS reflects the Intertropical Convergence Zone latitude. The 1896–2013 SSS trend shows amplification of the mean SSS field, with subpolar freshening and low-latitude salinification. The AMO and NAO have little effect on the long-term trend but contribute to the trend since 1970.

AMOC variability from decades to multi-decades

Gerard McCarthy

Abstract: The Atlantic Meridional Overturning Circulation (AMOC) plays a crucial role in the climate system, in particular in maintaining the mild climate in northwestern Europe relative to similar maritime climates. Fluctuations in AMOC strength have been hypothesised as the main driver of Atlantic Multidecadal Variability (AMV) of SSTs. A cool period in the 1970s and 1980s was linked to droughts in the Sahel region of Africa and the recent warm period associated with accelerating temperature rise in the northern hemisphere and an active hurricane period in the Carribean. There is growing evidence that the Atlantic is currently entering a cool period.

We examine a number of proxies for the AMOC in the 20th century, including the sea level gradient along the US east coast and Labrador Sea density, and place this recent cooling in the context of long term atmospheric variability, viewed through the North Atlantic Oscillation, and changing patterns of ocean circulation.

We analyse direct observations of the AMOC made by the RAPID programme since 2004 to look at emerging long term changes. These observations support a cooling Atlantic driven by a declining AMOC. We discuss this change in the context of predicted slowdowns of the AMOC due to anthropogenic climate change relative and consider what is needed to detect and attribute changes to natural and man-made sources.

Comparison of conditions of oceanic deep convection between the Irminger and Northwestern Mediterranean Seas

Robin Waldman
CNRM

Abstract: Oceanic deep convection is an important process because it forms intermediate and deep waters that feed the global circulation. Convection is limited to a small number of sites in the world ocean. If deep convection in the Northwestern Mediterranean is well known (MEDOC group, 1970; Leaman and Schott, 1991; Estournel et al 2016), deep convection in the Irminger Sea has only been established recently (e.g. Pickart et al., 2003; de Jong et al., 2012) and its various phases and properties described only in the very last years (Piron et al., 2016, 2017; Fröb et al 2016). While the Northwestern Mediterranean is known to be the site of the formation of the Western Mediterranean Deep Water (WMDW), the Irminger Sea participates in the formation of Labrador Sea Water (LSW). In this study we analyze gridded altimetry (AVISO) data and ERA-INTERIM reanalysis to characterize the surface circulation, buoyancy budget and frictional forcing in both regions. We find a large similarity in the basin-scale circulation characterized by a cyclonic gyre surrounded by an intense boundary current flowing above a sloping bathymetry. Winter buoyancy fluxes have a similar spatial distribution but they differ in magnitude and in nature, with an opposite contribution of the water budget between both basins. Finally, frictional fluxes differ highly due to the contrasted continental topography surrounding each basin. The Ekman pumping, the kinetic energy input and the frictional potential vorticity fluxes are all favorable to deep convection in the Irminger Sea, whereas their contribution to deep convection is very contrasted in the Northwestern Mediterranean Sea. These elements are likely to impact the magnitude, properties and variability of deep convection.

AMOC-driven nutrient flux variability across the RAPID-26N section

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Abstract: The Atlantic Meridional Overturning Circulation (AMOC) plays a major role in the climate system by zonal and meridional redistribution of heat, carbon, oxygen and nutrients. Using observations from the RAPID, Argo and GO-SHIP International Programs in the North Atlantic, and combining them with MLR-derived nutrient fields, we generate the

first continuous ocean nutrient (silicate, nitrate and phosphate) basin-scale flux time-series across the 26.5^{O}N transatlantic section for the 2004-2012 period. The AMOC dominates the net nutrient flux variability, contributing 73% (58%) of the net silicate (nitrate and phosphate) flux, and explaining up to a 99% (94%) of its variance. We examine the separate influence of this overturning component of the transport in controlling the long-term trend, interannual and seasonal variability of the nutrient fluxes.

Poster session

Instrumental observations of the AMOC

Patricia Zunino

Abstract: The GEOVIDE cruise was carried out in the subpolar North Atlantic (SPNA), along both the OVIDE section and across the Labrador Sea, in May-June 2014. It was planned to elucidate the distribution of the trace elements and their isotopes in the SPNA under the umbrella of the GEOTRACES international program. This poster focuses on the state of the circulation and distribution of thermohaline properties during the cruise. In terms of circulation, the comparison with the 2002 – 2012 mean state shows a more intense Irminger current and also a weaker North Atlantic Current with a transfer of volume transport from its northern to its central branch. However, those anomalies are compatible with the variability already observed along the OVIDE section in the 2000s. In terms of properties, the surface waters of the eastern SPNA were much fresher and colder than the average over 2002 – 2012. Remarkably, in spite of negative temperature anomalies in the surface waters, the heat transport across the OVIDE section, 0.56 ± 0.04 PW, was the largest measured since 2002. It is explained by the intensity of the Meridional Overturning Circulation measured across the OVIDE section during GEOVIDE, 18.7 ± 3.0 Sv, which was high enough to compensate the low temperature of surface waters. Analyzing the anomalies of air-sea flux over the eastern SPNA in relation to the heat and freshwater content in winter-spring 2014, we demonstrated that local air-sea buoyancy fluxes, rather than the ocean circulation, drove the ocean heat loss and freshwater gain in the eastern SPNA.

Influence of the NAC on the lower limb of the MOC? A combined analysis Deep-Argo/Altimetry

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LOPS - IFREMER

Abstract: The North Atlantic Subpolar gyre (NASPG) is a privileged region for the formation of the water masses of the lower limb of the Meridional Overturning Circulation (MOC) by winter heat loss. The formation of these dense water masses contributes to the uptake and transfer of anthropogenic carbon and dissolved oxygen (O_2) to the deep ocean. While knowledge in deep circulation is required for understanding long term changes in heat content, acidification and ventilation of deep ocean interior, the spatio-temporal variability of the deep circulation and its driving mechanisms are still poorly documented. To address such issues, the NAOS project developed a Deep-Arvor profiling float able to sample the ocean

down to 4000m. In this context, the *Laboratoire d'Océanographie Physique et Spatiale* (LOPS, Plouzané) deployed simultaneously three Deep-Arvor at Charlie Gibbs Fracture Zone (CGFZ) during summer 2015 (RREX cruise). These floats drifted at 2750m in the deep layer of the lower limb of the MOC (sigma 0 > 27.8) and, every 10 day provided a 0-4000m profile of temperature, salinity and O_2. First results are unforeseen. None of these floats circulated northward in the Irminger basin as initially expected considering recent general deep circulation schemes [e.g. Daniault et al., Prog. Oceanogr. 2016], and one of them revealed a new pathway westward till the western boundary current. Based on float trajectories combined to satellite observations, we show that surface circulation strongly influenced float displacements and that the North Atlantic Current shaped the deep circulation between the eastern and western parts of the NASPG, as well as with the subtropical gyre. Finally, analysis of the water masses characteristics from the Deep-Arvor data set are used to investigate the mechanisms at play.

Session 2: Paleo-climatic reconstructions of the AMOC

Oral session

Reconstructing the dynamics of Atlantic Meridional Overturning Circulation changes over the last 40 ky

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Abstract: Reconstruction of past water mass properties classically relies on oxygen and carbon isotopic ratio, and trace element measurements, performed on planktonic and benthic foraminifer calcite. These proxies yield information on the physical and chemical properties of the water masses (temperature, salinity, nutrient content, …), but do not allow quantifying changes in their overturning rate. Over the last decade, research teams from LSCE and LGL-TPE have developed in France the measurement technique of a sedimentary proxy directly recording changes in deep water mass renewal rate: the sediment $^{231}Pa/^{230}Th$ ratio (Gherardi et al., 2005; 2009; Guihou et al., 2010; 2011; Burckel et al., 2015; 2016).

I will present recent $^{231}Pa/^{230}Th$ records from two North-Brazilian cores and a preliminary reconstruction of the strength and geometry of the AMOC during the last glacial based on a combination of $^{231}Pa/^{230}Th$ data, benthic carbon isotopic data, and numerical simulations.

Do benthic foraminifera and their geochemical signature from the Celtic margin differentiate the effects of European and Laurentide Ice Sheets meltwaters on the AMOC across Termination 1?

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Abstract: Using benthic foraminiferal-based proxies for the first time in fine-grained sediments from the Celtic margin, we provide a well-dated record over the past ~23 ka (with a focus on the last deglaciation) for the Channel River dynamics. At site MD99-2328 (942 m depth), the transition between the LGM and Heinrich stadial 1 *sensu stricto* (late HS1) was marked by a thick fine-grained laminated deposit; the laminae being the result of seasonal EIS (European Ice Sheet) melting dynamics (early HS1) which preceded LIS (Laurentide Ice Sheet) iceberg outbursts (late HS1) by some 1500 years. During early HS1, the heavy surface waters $\delta^{18}O$ signature and the low benthic Mg/Ca indicated cold surface and deep water temperatures. The isotopic lightening of benthic $\delta^{18}O$ during early HS1 recorded the cascading turbid EIS meltwaters that freshened episodically bottom waters. This is the first time where we evidence a clear impact of EIS meltwaters on intermediate water masses in the area and comfort the non-negligible role of EIS meltwater discharges in the weakening of north Atlantic deep ocean convection. Furthermore, assemblage-based oxygen index and benthic Mn/Ca indicated oxygen depleted bottom waters, and the negative $\delta^{13}C$ excursion indicated high respiration rates in a context of enhanced riverine activity. During late HS1 (Heinrich Stadial 1 *s. s.*), decreasing planktonic $\delta^{18}O$ values indicated freshwater releases from LIS icebergs, whereas increasing benthic Mg/Ca ratio indicated a progressive warming of intermediate water masses. In the general context of a near shutdown of the AMOC and the consequent limited formation of the GNAIW, our data described an intensified slope current, probably of southern origin actively transporting heat to our latitudes at intermediate water depths. The significantly low benthic Sr/Ca ([CO_3^{2-}] proxy) support the presence of Antarctic waters (AAIW) at intermediate depths at our study site.

The Bay of Biscay: a key spot for past AMOC reconstructions

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EPOC

Abstract: The Bay of Biscay is a semi-enclosed basin from the north-eastern Atlantic Ocean bounded by French coasts to the east and Spanish ones to the south. This triangular portion of the western European margin extends from the Galician Finisterre Cap at 44°N to the Goban Spur at 50°N. Its modern hydrography is complex and shows marked seasonal trends mostly related to the North Atlantic proximal gyre dynamics (i.e. from the subpolar gyre –SPG- and the subtropical gyre - STG- as well) along modal forcings such as the Atlantic Multi-decadal Oscillation (AMO) or East Atlantic (EA) pattern. The thermocline depth is highly variable on a seasonal and annual scale: it varies from 20 to 50m depth during summer, whereas the mean mixed layer in winter reach about 200mwith some maxima up to 450 m under strong winds. Three water masses have been identified below the thermocline: the upper part of the water column is occupied by Eastern North Atlantic Waters (ENAW), showing relatively high temperature and salinity properties. Below, Mediterranean Outflow Waters (MOW) flow around the 1000 m isobath. From 1300 m down to 3500 m depth, lies the North Atlantic Deep Water (NADW) and deepest depths are occupied by low temperature and low salinity Antarctic Bottom Waters.
Since more than twenty years many efforts have been conducted to document its paleoceanography over the last climatic cycles. The Bay of Biscay actually provides

exceptional sedimentological archives which will be the focus of this work documenting, over the last 350 ka at least, a close link with long term changes in the Atlantic Meridional Overturning Circulation (AMOC).

Dynamics of North Atlantic deep currents from the onset to the demise of the Last Interglacial period (145-110 ka)

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Abstract: Although most climate models simulate a future reduction in the deep North Atlantic circulation in response to increased atmospheric greenhouse gas concentrations, the rate and magnitude of simulated weakening remain uncertain. With sea levels higher than nowadays due to enhanced ice sheet melting under strong orbital forcing, the Last Interglacial period (~129-116 ka) represents an excellent case study to investigate the response of the deep North Atlantic circulation to a warmer-than-present climate that could be reached in the coming decades. However, our understanding of processes controlling the deep North Atlantic circulation at that time remains limited, because (1) existing paleo-records mostly inform on the qualitative distribution of water-masses within the North Atlantic, and (2) very little information is available on the dynamics (e.g. intensity) of deep-water currents.

Here we will present an on-going multi-tracer study (environmental magnetism, particle size distribution, stable isotopes of benthic foraminifera) applied on North Atlantic sediment cores selected at water-depths between 1800 and 3400 m, in order to document the dynamical evolution of North Atlantic bottom currents from the onset to the demise of the Last Interglacial (145-110 ka). Benthic foraminifera stable isotopes and paleointensity variations of the geomagnetic field are combined to optimize the cores' chronologies.

Preliminary results suggest:
(1) no major changes in the intensity of bottom currents at 2800 m throughout this period;
(2) increased and decreased intensity of bottom currents at 1800 m and 3400 m, respectively, during the deglacial interval of strong meltwater input from icebergs, suggesting a shoaling of the deep North Atlantic circulation during this so-called "Heinrich Event 11";
(3) increased intensity of bottom currents at 1800 m and 3400 m during the Last Interglacial, suggesting a deep and intense North Atlantic circulation during the period of peak warmth.

This is part of the LEFE-funded CircLIG project.

Regional seesaw between North Atlantic and Nordic Seas during the last glacial abrupt climatic events

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Abstract: The last glacial period has been punctuated by millennial abrupt climatic variations strongly imprinted in Greenland ice core records, where cold phases are associated with pan-North Atlantic ice-sheet collapses and iceberg delivery. These variations are thought to be linked to changes in the North Atlantic meridional overturning circulation, potentially in response to iceberg-derived freshwater injections in the North Atlantic. Indirect marine proxy records and sensitivity tests performed with atmospheric models have also suggested that the expansion of sea ice in the Nordic Seas during cold phases could be a key amplifier, explaining the large 5-16 °C magnitude of Greenland cooling. Here we provide direct and quantitative evidence of a regional paradoxical seesaw pattern: cold Greenland and North Atlantic phases coincide with warmer sea-surface conditions and shorter seasonal sea-ice cover durations in the Norwegian Sea as compared to warm phases. Our results are based on dinocyst analyses conducted in four sediment cores from the northern Northeast Atlantic and southern Norwegian Sea, for Marine Isotopic Stage 3 (48- 30 ka BP). Such regional seesaw is also simulated in freshwater hosing experiments from five state-of-the-art climate models. These simulations and reconstructions suggest that during cold Greenland and North Atlantic phases, reduced Atlantic overturning and cold North Atlantic sea-surface conditions were accompanied by the subsurface propagation of warm Atlantic waters that re-emerged at the entrance of the Nordic Seas, warming the topmost layer, limiting sea-ice extent, and providing high deuterium excess moisture towards Greenland summit. This mechanism potentially enhanced iceberg discharges from the bordering ice sheets. This new scheme of variability, with complex regional hydrological reorganizations, can be regarded as a new case study for ocean – cryosphere – atmosphere interactions.

Poster session

New constraints on Atlantic Meridional Overturning Circulation changes during the past 40 ky from combined $^{231}Pa/^{230}Th$, benthic $\delta^{13}C$ and ^{14}C benthic-planktonic ventilation ages

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Abstract: The Atlantic Meridional Overturning Circulation (AMOC) is a major component of the climate system through its impact on low to high latitude heat transport and CO_2 air-sea exchange. Despite numerous studies, its role in abrupt climate changes of the last glacial period is still poorly constrained.
This study aims at better understanding the evolution of the AMOC by combining, within the same core, different circulation proxies such as the sedimentary $^{231}Pa/^{230}Th$, which documents changes in water masses flow rate, benthic $\delta^{13}C$ which reflects the ventilation state of the bottom water and paired benthic-planktonic ^{14}C measurements which indicate deep and shallow water masses ages.

We present new multi-proxy time series from North Atlantic core SU90-08 (43°N, 30°W, 3,080m) for the last 28 ky and around Heinrich Stadial (HS) 4 interval.

$^{231}Pa/^{230}Th$ exhibits lower values for the Last Glacial Maximum (LGM) compared to the rest of the dataset. This suggests a substantially stronger flow rate at the LGM than during the Holocene above the core site. $^{231}Pa/^{230}Th$ also suggests slightly reduced circulation over HS 1 and HS 4.
Benthic $\delta^{13}C$ displays slightly depleted values for Heinrich Stadial 4 and very depleted values from 27 calendar ky BP to the onset of the deglaciation. This would imply that the deep water mass that bathed this location at the LGM was poorly ventilated while $^{231}Pa/^{230}Th$ over the same period indicates that the circulation was vigorous.

We will discuss the apparent decoupling between $^{231}Pa/^{230}Th$ and benthic of $\delta^{13}C$ during the LGM in light of benthic and planktonic ^{14}C ages spanning the last 25 ky.

Application of Neodymium isotopic ratio to reconstruct North-eastern Atlantic deepwater mass sources over the last 1Myr

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Abstract: The oceanic circulation plays a significant role in climatic change. It is suggested to have contributed to the changes of the climatic cyclicity during the Mid Pleistocene Transition (1250 to 700 kyr) and to the variations of the magnitude between glacial and interglacial periods from the Mid Brunhes Event (430 kyr). Neodymium (Nd) isotopic ratio ($^{143}Nd/^{144}Nd$ or ε_{Nd}) recorded in authigenic oxides in foraminiferal tests has been successfully used to evaluate northern and southern sourced water mass contribution in relation to the variability in Atlantic meridional overturn circulation (AMOC). Previous studies conducted in deep Southern and North-western Atlantic Ocean showed more radiogenic values during glacial periods compared to interglacials, indicating a weakening of North Atlantic Deep Water formation at that time. However, Nd isotopic records covering the last 1 Myr are still scarce to describe long-term variability. We applied foraminiferal Nd isotopic composition to a marine sediment core MD03-2507 (3.1 km water depth) from the North-eastern Atlantic Ocean off the West Africa to trace the glacial/interglacial AMOC changes for the past 1 Myr. Core-top εNd value of -12.3 is in good agreement with the modern seawater value. The preliminary low-resolution record indicates εNd ranging from -12.5 to -10.8 over the whole study period with higher values during glacials. This glacial/interglacial εNd amplitude is consistent with a recent study focusing on the last 30,000 yrs from the same region and is smaller than for deep Southern and North-western Atlantic Ocean showing a shift of 3 ε-units. Considering that the core location is under the Saharan dust plume, the results will be discussed as a deep-water circulation tracer by comparing with benthic stable isotopic records and by taking into account possible Nd contribution from detrital carbonates.

High Frequency Variability of the Upper Ocean Circulation in the Glacial Northeast Atlantic

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IFREMER / REM-GM-LES

Abstract: It is widely accepted that past global climate changes (including those recognized during MIS 3, ca. 30-50 kyr ago; i.e. D/O oscillations) resulted from changes in the Atlantic meridional overturning circulation (AMOC) and attendant change in cross-equatorial ocean heat transport. However, in-situ records for past AMOC changes are still scarce (at both spatial / bathyal scales) and not fully resolved in particular for MIS 3. Here we report new high-resolution records of near-bottom flow speed and water masses chemistry records from the intermediate NE Atlantic (~1000 m) showing a clear D/O variability. AMOC weakening (strengthening) occurred during northern stadials (interstadials), thus highlighting the ocean's central role in past climate changes. Comparison with reconstructions of ice-sheet oscillations in the surrounding region (i.e. European Ice Sheet) suggests strong cryosphere-ocean coupling at the D/O timescale, with clear evidence that retreat of terrestrial-terminating (e.g. Baltic) ice-streams and attendant Channel River meltwater pulses triggered the weakening of AMOC and subsequent Heinrich Stadial conditions (including Heinrich Events). Finally, our data also reveal some centennial- to millennial-scale AMOC instabilities during the warmest D/O interstadials (e.g. 12, 11 and 8), suggesting possible AMOC negative feedbacks originating from increased freshwater flux as a result of negative ice-sheet mass balance from mid-latitude ice margins. This highlights the fractal nature of millennial-scale climate changes, with the mechanism (i.e. cryosphere-ocean interactions) operating during the course of a D/O interstadial and leading to the development of subsequent stadial conditions being similar to that operating over a Bond cycle and leading to Heinrich Stadial.

Glacial $\delta^{13}C$ decreases in the western Tropical Atlantic during Heinrich stadials of the last 45 kyr

Natalia VAZQUEZ RIVEIROS, LSCE, France, Claire Waelbroeck, LSCE, France; Didier Roche, LSCE, France; Santiago Moreira, LSCE, France; Evelyn Boehm, LSCE, France; Pierre Burckel, IPGP, France; Helge Arz, IOW, Germany; Trond Dokken, BCCR, Norway.

Abstract: During Heinrich Stadial (HS) 1, $\delta^{13}C$ decreased throughout most of the upper Atlantic between ~ 1000 – 2500 m, and in some deeper Atlantic sites. Atlantic Meridional Overturning Circulation (AMOC) during this time is believed to have been weaker. Most explanations of the $\delta^{13}C$ decrease suggest that it was a response to the AMOC reduction, but different mechanisms have been proposed. Some studies point to a reduction of the fraction of the glacial equivalent to North Atlantic Deep Water in the upper North Atlantic during the events, which promoted the extension of “southern sourced waters” to shallower depths. Other studies suggest that northern sourced waters flowed still, but with a lower $\delta^{13}C$ due to changes in source water composition. The behavior of mid- and deep waters during previous HS is even less well constrained, in part due to the lack of available records.

In this study, we present carefully dated high-resolution records from marine sediment cores off the Northeast Brazilian margin, covering the last 45 ky. Stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) were measured on the benthic foraminifer *Cibicides wuellerstorfi*. Marked minima in $\delta^{13}C$ at mid-depths off the Brazilian margin are visible during the last four HS. During all these periods, $\delta^{18}O$ and $\delta^{13}C$ values converge with those of the deeper core at ~3600 m, indicating that the same water mass bathed depths between ~ 2300 – 3600 m in the western Tropical Atlantic during HS. We explore different scenarios of the origin of this water mass by comparing our records with previously published ones, and with simulations of the

isotope-enabled Earth System Model of intermediate complexity *i*LOVECLIM, but preliminary results do not support a southern origin of the low-$\delta^{13}C$ water mass.

Session 3 : Drivers of the AMOC: Theoretical approaches

Oral session

On the buoyancy-driven theory of the Atlantic Meridional Overturning Circulation

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Abstract: In the mid-late 90s, the classical buoyancy-driven view of the Atlantic meridional overturning circulation (AMOC), according to which the AMOC is set up by high-latitude cooling, was challenged by two alternative mechanically-driven views. The first one is related to the 'Drake passage' effect, according to which the AMOC responds nearly linearly to changes in zonal winds at the latitude of Drake Passage. The second-one is related to the mixing-driven view of the AMOC, according to which the upwelling branch of the AMOC is supposed to be powered by small-scale mixing occurring in response to the mechanical stirring by winds and tides. These developments led to attacks against Lorenz's theory of available potential energy – which had until then been the standard framework for the buoyancy-driven view of the AMOC --- ranging from omitting APE theory from reviews of ocean energetics to constructing an ad-hoc new definition of buoyancy power input consistent with the idea that the latter is negligible. In this talk, I will explain how the 'ocean heat engine controversy' can be traced back to incompatible views on the energy pathways taking place in stratified turbulent mixing. I will also explain how the buoyancy-driven theory of the AMOC is most naturally formulated in terms of the local theory of APE, which permits to treat APE as a local quantity that can be created by surface buoyancy fluxes, transported, converted into kinetic energy, and dissipated by mixing. I will also show that both the Drake Passage effect and Munk and Wunsch's view on ocean mixing can naturally be incorporated into local APE theory, and hence that neither mechanically-driven views of the AMOC actually contradict the buoyancy-driven view of the AMOC, contrary to what is often assumed.

Determination of diapycnal mixing rates in the world ocean from a T/S climatology

Olivier Arzel
LOPS

Abstract: The turbulent diapycnal mixing in the ocean is currently obtained from microstructure and fine structure measurements, dye experiments and inverse models. We present a new method which infers the diapycnal mixing from low resolution numerical calculations of the World Ocean whose temperatures and salinities are restored to the climatology. At the difference of robust general circulation ocean models, diapycnal diffusion is not prescribed but inferred. At steady state the buoyancy equation shows an equilibrium between the large scale diapycnal advection and the restoring terms which take the place of the divergence of eddy buoyancy fluxes. The geography of the diapycnal flow reveals a strong regional variability of water mass transformations. Basin average of diapycnal diffusivities

are small in the first 1500 m ($O(10^{-5})$ m^2 s^{-1}) and increase downward with bottom values of about 2.5$\times$10^{-4} m^2 s^{-1} in all ocean basins at the exception of the Southern Ocean (50S-30S) where they reach 12$\times$10^{-4} m^2 s^{-1}. This study confirms the small diffusivity in the thermocline and the robustness of the higher canonical Munk's value in the abyssal ocean. It indicates that the upward dianeutral transport in the Atlantic mostly takes place in the abyss and the upper ocean, supporting the quasi-adiabatic character of the mid-depth overturning. This result is in agreement with the recent theories proposed by Cessi, Wolfe and Vallis who suggest that the mid-depth overturning is essentially adiabatic, controlled by Southern Ocean winds, while diapycnal diffusion mainly acts in the abyss and at the base of the thermocline.

Oceanic control of multidecadal variability in the North Atlantic

Thierry Huck, Olivier Arzel, Alain Colin de Verdière, Quentin Jamet, Florian Sévellec

Abstract: The origin of multidecadal variability in the North Atlantic (AMO/AMV) has not yet been settled, and a wide range of hypothesis have been proposed in various coupled model simulations but none allow a straightforward comparison or validation with (maybe too short) observations.
On the other hand, multidecadal variability appears spontaneously in idealized ocean simulations forced by prescribed surface buoyancy flux, through baroclinically-unstable Rossby waves. Such mechanism was also found in more realistic North Atlantic configurations (OPA ORCA2°), with and without eddies, with and without atmospheric coupling. The signature of this mode in the more realistic simulations is comparable to the signature of the AMO in the observations, as far as it can be identified and distinguished from global warming.
We review several results from the most idealized studies to the more realistic in ocean and coupled GCMs to support the relevance of such a mechanism for the Atlantic Multidecadal Oscillation.

Arctic climate change driving a decline in the Atlantic Meridional Overturning Circulation

Florian Sévellec
University of Southampton

Abstract: A dramatic consequence of ongoing climate change is the retreat of Arctic sea ice that occurred over the past several decades. This sea ice loss exposes the ocean to additional heat and freshwater fluxes, generating positive anomalies in surface buoyancy fluxes over the Arctic. In this study using the optimal flux perturbations framework, we estimate the sensitivity of the Atlantic meridional overturning circulation (AMOC) to changes in surface buoyancy forcing over the Arctic and globally. We find that, whereas on a decadal timescale the subpolar North Atlantic region is the primarily driver of the AMOC weakening, on multidecadal timescales (20 years and longer) it is the Arctic region that largely controls the AMOC intensity. Over one century Arctic surface fluxes are nearly twice as effective for weakening the AMOC as those in the North Atlantic. Moreover, anomalous surface fluxes in

the Arctic reduce oceanic poleward heat transport in the entire Atlantic, which can explain the "Warming Hole" in the subpolar North Atlantic typically attributed to the AMOC decline. We conclude that the remote control of the AMOC intensity and heat transport from the Arctic is a robust feature of global climate change.

Session 4: Lessons from numerical modelling of the ocean and climate for the AMOC dynamics

Oral session

Mechanisms of seasonal to decadal AMOC variability

Claus Böning
Geomar

Abstract: Observational records of the AMOC or its major constituents (e.g., western boundary currents) exhibit a rich spectrum of variability from (intra-)seasonal to (inter-)decadal time scales, presenting a formidable challenge for the detection of possible anthropogenic trends. In this talk I will review the progress in understanding the spatio-temporal characteristics and causes of this variability obtained from a host of modelling studies, focusing on the following questions: How well are the observational records captured by current model simulations, and what are the critical modelling factors? What do models tell us about the spatio-temporal characteristics of the AMOC varaibility, e.g., its meridional coherency? What can we infer about the main drivers, e.g., the role of intrinsic (stochastic) vs. external forcing, of local vs. remote influences, and of wind vs. buoyancy forcing mechanisms? A particular topic of current research concerns the question of potential future trends associated with a decline in subarctic deep water formation vs. influences emerging from the southern hemisphere.

The Atlantic Meridional Overturning in the ocean reanalysis

Clotilde Dubois
Météo-France/Mercator Ocean

Abstract: The Atlantic meridional overturning circulation (AMOC) plays a key role in the North Atlantic climate. The AMOC controls global ocean climate at decadal and longer time scales, as well as the formation of new water-masses connecting the two through its exchange mechanisms between the surface and deep ocean and ventilating and renewing water layers of the interior ocean. Recent observations of the AMOC at 26°N from the RAPID array suggest that a weakening has occurred in the past decade associated with a decrease in the Labrador density, which lags a decrease in the AMOC by a few years (Smeed et al., 2014, Jackson et al. 2016). Such changes in the North Atlantic are driven by physical interaction at the atmosphere-ocean interface controlling heat and momentum transfer but also by freshwater inflow from the Arctic, which in turn induces changes in the North Atlantic density field (Rahmstorf et al., 2015).

Using the ocean reanalysis produced at Mercator-Ocean (Global MFC Glorys2V4), we evaluated the AMOC and compared it with RAPID observations. The AMOC in the ocean reanalysis are in good agreement with the observations We found a very good agreement

between the two time series with a mean value of 14.4 Sv compared to 17 Sv in the observations. The 10-days average timeseries between the ocean reanalysis and the observations ir interannual variabilities are correlated at 0.86 and the trend of is -0.413+/-0.18 Sv.yr-1 find by the RAPID array during the observation period is is found. However, no significant trend is found over the all period of the reanalysis (1993-2015) Sv/y, The MOC trend is -0.43 Sv/y, which is consistent with RAPID observations . Further comparaison will be done with the twin simulation with no data assimilation, where the AMOC is significantly different.

Impact of freshwater release in the Mediterranean Sea on the North Atlantic climate

Didier Swingedouw
EPOC

Abstract: During the early Holocene, sediments from the Mediterranean Sea show a period of Sapropel deposition, characteristic of events where this basin was under anoxic conditions. A possible explanation for such an event is that of a very stratified sea, possibly related with freshwater input through increased rivers and runoff discharge, among which the River Nil discharge intensity may have played a crucial role. The impact of such a stratified Mediterranean Sea on the large-scale ocean and climate has led to a few interesting qualitative suggestions, but remains unclear at the moment

Here, I analyse the impact of such a freshwater release using the IPSL-CM5A-LR model. I have performed a few multi-centennial simulations including different a freshwater release rates in the Mediterranean Sea. I focus the analysis on the exchanges between the Mediterranean and the Atlantic through Gibraltar Strait and the impact of a decrease in the Mediterranean overflow water (MOW) on the large-scale Atlantic circulation. I find that the decrease of the MOW lead to an increase of the AMOC in the first century followed by a decrease the following centuries until a steady state where the AMOC is divided by around two. To explain these two opposing signals, I show that the impact of the decreased MOW on the Azores current first leads to enhanced North Atlantic drift increasing convection in the Irminger Sea, while the decrease of density at depth due to the collapse of MOW reduce in the long term the AMOC through thermal wind balance. A third mechanism can play a crucial role for freshwater release larger than the mean freshwater budget over the Mediterranean Sea, where strong negative salinity anomalies are advected in the North Atlantic and induce a collapse of the AMOC in less than five centuries.

Atlantic meridional overturning circulation variability in forced versus coupled simulations

Eric Chassignet and Xiaobiao Xu
Florida State University, USA

Abstract: The Atlantic meridional overturning circulation (AMOC) plays a fundamental role in the earth climate system. In this presentation, we first compare the interannual, decadal, and multidecadal variability of the AMOC in two model configurations: Phase 2 of the Coordinated Ocean-ice Reference Experiment (COREII) in which a common atmospheric state is prescribed and Phase 5 of the Coupled Model Inter-comparison Project (CMIP5) in

which the atmospheric state is fully coupled. We show that all the forced COREII simulations display similar AMOC variability, whereas the coupled CMIP5 models do not. The results seem to indicate that on interannual to decadal scales, the modeled AMOC variability is intrinsic and insensitive to atmospheric state, whereas on long-term multi-decadal scale, the modeled AMOC variability is external, and is sensitive as to whether the atmosphere is coupled to ocean dynamics. The second part of the presentation will discuss the AMOC representation in our high resolution (~ 10km grid spacing) experiments.

Potential for deep convection in the Arctic Basin under a warming climate and contribution to the AMOC

Camille Lique, Matthew Thomas, Helen Johnson, Yves Plancherel
LOPS, Ifremer

Abstract: Model studies have previously suggested a link between variations in the rate of deep water formation in the northern North Atlantic and variations in the strength of the Atlantic Meridional Overturning Circulation (AMOC), but the dynamical link between the two is not fully understood. The goal of this study is to investigate the potential for deep Mixed Layer Depths (MLDs) to appear close to the sea ice edge in the Arctic Basin under a warming climate, and to quantify the potential contribution of deep convection in the Arctic Basin to the AMOC.

This study uses results from "present day" simulations of two climate models, CNRM and HiGEM, and also from simulations with a four times increase in atmospheric CO2 levels, representing a future, warmer climate. Under a warming climate, we expect (i) a reduction of the AMOC, (ii) a shoaling of the MLD in the North Atlantic and (iii) a northward retreat of the sea ice edge.

First, we document the changes affecting the MLD in the Arctic and the North Atlantic under a warming climate. There is a strong shoaling of the MLD in the present-day areas of deep convection in the North Atlantic, but also a deepening in the Eurasian Basin of the Arctic Ocean, where the MLD can episodically reach up to ~600m. A detailed examination of the temporal and spatial structures of the changes affecting the ocean surface properties reveals that the Eurasian Basin undergoes a strong surface warming (linked with the retreat of the sea ice edge) and a strong salinization (possibly due the intensification of the surface gyres in the Arctic driven by stronger surface stress as the sea ice pack is thinning and shrinking). Together, these changes decrease the stratification, which triggers convective events in the basin.

Second, a quantitative Lagrangian diagnostic is applied to climate model output in order to determine where the mixed layer subduction contributes to the Atlantic Meridional Overturning Circulation at 26°N. We find that, for "present-day" conditions, the main contributions to the AMOC are mixed layer subduction in the Labrador, Irminger and Greenland Seas. In contrast, in the 4xCO2 simulations, the AMOC is greatly reduced and mixed layer subduction in the Arctic Basin and the subtropical gyre contribute significantly to the AMOC, the latter being likely related to a change of the stratification in this region.

Intrinsic and atmospherically-forced variability of the AMOC : insights from a large ensemble ocean hindcast

Leroux S[1], Penduff T[1]., Bessieres L.[2] Molines J.-M[1]., Brankart J.-M[1]., Sérazin G.[3], Barnier B. [1], Terray L. [2]

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Abstract: This study investigates the origin and features of the low-frequency AMOC variability from several ocean simulations, including a large (50-member) ensemble of global, eddy-permitting (1/4°) ocean/sea-ice hindcasts performed in the context of the OCCIPUT project. After an initial stochastic perturbation, each member is driven by the same realistic atmospheric forcing over 1960-2015. The magnitude, spatio-temporal scales and patterns of the atmospherically-forced and intrinsic/chaotic interannual AMOC variability are then characterised from the ensemble mean and ensemble spread, respectively. The analysis of the ensemble-mean variability shows that the AMOC fluctuations north of 40°N are largely driven by the atmospheric variability, which forces meridionnally-coherent fluctuations reaching decadal time-scales. The amplitude of the intrinsic interannual AMOC variability never exceeds the atmospherically-forced contribution in the Atlantic basin, but it reaches up to 100% of the latter around 35°S, and 60% in the northern mid-latitudes. The intrinsic AMOC variability exhibits a large-scale meridional coherence, especially south of 25°N. An EOF analysis over the basin shows two large-scale leading modes explaining together 60% of the interannual intrinsic variability. The first mode is likely excited by intrinsic oceanic processes at the southern end of the basin and affects latitudes up to 40°N; the second mode is mostly restricted to, and excited within, the northern mid-latitudes. These features of the intrinsic, chaotic variability (intensity, patterns, random phase) are barely sensitive to the atmospheric evolution, and strongly resemble the "pure intrinsic" interannual AMOC variability that emerges in climatological simulations under repeated seasonal-cycle forcing. These results raise questions about the attribution of observed and simulated AMOC signals, and about the possible impact of intrinsic signals on the atmosphere.

Role of ocean-atmosphere coupling for AMOC decadal variability

Guillaume Gastineau

Abstract: In order to investigate the coupling of the Atlantic Meridional Overtunring Circulation (AMOC) with the atmosphere and the importance of ocean-atmosphere feedback, we used the atmospheric field retrieved from a control run of the IPSL-CM5A-LR model. We first use the raw daily fluxes to force an ocean-only model. This ocean-only model is the same as the one used in the IPSL model, but the ice cover is prescribed to a mean climatological cycle. This simulation reproduces the AMOC variability from the coupled model simulation. Then, climatological fields were calculated for the wind stress and buoyancy forcing and used to force an ocean-only experiment. This simulation shows a clear 20-yr variability which has been widely documented in this model, which further confirm that it is linked to oceanic intrinsic variability. Lastly, idealized daily atmospheric fluxes were derived from random permutations of the coupled model fluxes, and were used to force a last set of ocean-only simulations. This simulation shows a larger AMOC variance, which suggests that ocean-

atmosphere feedbacks increase the AMOC variability (positive feedback). The nature of the ocean-atmosphere feedbacks and the specific role of the NAO will be revealed.

Similar modelling setup when applied the IPSL-CM5A-MR model, with a similar ocean model and an atmospheric model using smaller horizontal resolution, shows different results, because of a warmer state over the subpolar gyre region, which inhibits the occurrence of the North Atlantic 20-yr variability.

Poster session

Abrupt cooling over the North Atlantic in modern climate models

Giovanni Sgubin[1,2], Didier Swingedouw[2], Sybren Drijfhout[3,4], Yannick Mary[2] & Amine Bennabi[5]

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5 Institut de Mecanique et d’Ingenierie (I2M), Universite´ de Bordeaux, 33615 Pessac, France.

Abstract: Observations over the 20th century evidence no long-term warming in the subpolar North Atlantic (SPG). This region even experienced a rapid cooling around 1970, raising a debate over its potential reoccurrence. Here we assess the risk of future abrupt SPG cooling in 40 climate models from the fifth Coupled Model Intercomparison Project (CMIP5). Contrary to the long-term SPG warming trend evidenced by most of the models, 17.5% of the models (7/40) project a rapid SPG cooling, consistent with a collapse of the local deep-ocean convection. Uncertainty in projections is associated with the models’ varying capability in simulating the present-day SPG stratification, whose realistic reproduction appears a necessary condition for the onset of a convection collapse. This event occurs in 45.5% of the 11 models best able to simulate the observed SPG stratification. Thus, due to systematic model biases, the CMIP5 ensemble as a whole underestimates the chance of future abrupt SPG cooling, entailing crucial implications for observation and adaptation policy.

The North Atlantic eddy heat transport and its relation with the vertical tilting of the Gulf Stream axis

A.M. Treguier, J Deshayes, C. Lique, Jean-Marc Molines

Abstract: Correlations between temperature and velocity fluctuations are a significant contribution to the North Atlantic meridional heat transport, especially at the northern boundary of the subtropical gyre. In satellite observations and in a numerical model at 1/12° resolution, a localized pattern of positive eddy heat flux is found northwest of the Gulf Stream, downstream of its separation at Cape Hatteras. It is confined to the upper 500 m. A

simple kinematic model of a meandering jet can explain this eddy flux, taking into account a spatial shift between the maximum velocity of the jet and the maximum cross-jet temperature gradient. In the Gulf Stream such a spatial shift results from the nonlinear temperature profile and the vertical tilting of the velocity profile with depth. The numerical model suggests that the meandering of the Gulf Stream could account for the large eddy heat transport (of order 0.3 PW) near 36°N in the North Atlantic, and for its compensation by the mean flow.

Session 5: Climatic impact and implication of AMOC variations

Oral session

AMOC variability and predictability in climate models

Juliette Mignot

In climate models, AMOC variations at the decadal timescale are largely responsible for low frequency SST variations, which may themselves have an influence on the surrounding climate. This chain of events is crucial for climate predictability and predictions. Here, we will present the consequences of AMOC variations for the North Atlantic ocean, and possible impacts on the atmosphere. We will then review the potential predictability of AMOC variations as inferred from climate model experiments, as well as the effective predictability obtained with the CMIP5 coordinated experiment. Implications for CMIP6 design and expected results will be discussed.

Impacts of the Atlantic Multidecadal Variability on the tropical climate and tropical cyclone activity

Yohan Ruprich-Robert
Princeton University – AOS / GFDL

Abstract: The Atlantic Multidecadal Variability (AMV) is associated with marked modulations of climate anomalies over many areas of the globe. This includes droughts in Africa and North America, decline in sea ice, changes of tropical cyclone activity in the Atlantic, and changes in the atmospheric large-scale circulation. However, the shortness of the historical observations compared to the AMV period (~60-80yr) makes it difficult to show that the AMV is a direct driver of these variations. To isolate the AMV climate response, we use a suite of global coupled models from GFDL and NCAR, in which the North Atlantic sea surface temperatures are restored to the observed AMV pattern, while the other oceanic basins are left fully coupled. To explore and robustly isolate the AMV impacts on weather extremes (e.g., heat waves, tropical cyclones), we perform large ensemble simulations (between 30 and 100 members) that are integrated for 10 years.

During boreal summer, in all models the AMV warming alters the Walker Circulation and modifies the surface winds over the tropical Pacific Ocean. During boreal winter, the AMV warming is associated with large anomalies over the Pacific that project onto a negative phase of the Interdecadal Pacific Oscillation (IPO). This IPO response comes from a lagged adjustment of the tropical Pacific to the summer AMV forcing, highlighting the necessity of using a global coupled framework to fully capture the AMV climate impacts. Finally, it is shown that the AMV warming leads to changes in the tropical cyclone activity over the entire tropical belt, with more tropical cyclones over the Atlantic and less tropical cyclones over the Pacific. These changes are very similar to the decadal fluctuations of the observed tropical

cyclone activity associated with the 1995/96 phase shift of the AMV, which suggests that the AMV has partly driven these variations.

An anatomy of the projected North Atlantic warming hole in CMIP5 models.

Matthew Menary and Richard Wood.
Met Office Hadley Centre, UK.

Abstract: Global mean surface air temperature has increased over the past century and climate models project this trend to continue. However, the pattern of change is not homogenous. Of particular interest is the subpolar North Atlantic, which has cooled in recent years and is projected to continue to warm less rapidly than the global mean. This is often termed the North Atlantic warming hole (WH). In climate model projections, the development of the WH is concomitant with a weakening of the Atlantic meridional overturning circulation (AMOC). Here, we further investigate the possible link between the AMOC and WH and the competing drivers of vertical mixing and surface heat fluxes. Across a large ensemble of 41 climate models we find that the spatial structure of the WH varies considerably from model to model but is generally upstream of the simulated deep water formation regions. A heat budget analysis suggests the formation of the WH is related to changes in ocean heat transport. Although the models display a plethora of AMOC mean states, they generally predict a weakening and shallowing of the AMOC also consistent with the evolving depth structure of the WH. A lagged regression analysis during the WH onset phase suggests that reductions in wintertime mixing lead a weakening of the AMOC by 5 years in turn leading initiation of the WH by 6 years. Inter-model differences in the evolution and structure of the WH are likely to lead to somewhat different projected climate impacts in nearby Europe and North America.

Predicting the high latitude AMOC and its impacts

Leon Hermanson
Hadley Center

Abstract: One of the key regions for decadal prediction is the Atlantic subpolar gyre. The ocean heat content in this region can be predicted several years ahead and its changes gives rise to predictable impacts across the Atlantic basin. These include Sahel precipitation, Mediterranean temperatures and Atlantic tropical cyclones. It appears that the historical subpolar gyre heat content changes arise from changes in ocean heat transport convergence, which is driven by changes in the AMOC around 45N. The decadal variability of salinity in the Labrador Sea appears to be important for good predictions of local density anomalies connected to the AMOC, but is poorly predicted by NEMO025. A slow-down of the AMOC might produce the biggest climate impacts: wide spread cooling, reduced precipitation and a strengthened storm track. Higher resolution models have allowed a better understanding of how changes in circulation can counter-act some changes over Europe.

On the wintertime atmospheric response to the AMOC variability

Claude Frankignoul and Guillaume Gastineau, LOCEAN/IPSL, UPMC

A significant influence of the variability of Atlantic meridional overturning circulation (AMOC) on the wintertime Northern Hemisphere atmospheric circulation has been found in climate models. In most models (e.g., IPSL-CM5-LR, HadCM3, CCSM4, and FLOR), a negative phase of North Atlantic Oscillation (NAO) lags an intensification of the AMOC by a few years. The response seems to be due to the southward shift of the region of maximum transient eddy growth caused by the AMOC SST footprint, although tropical SST forcing may play a role. In two models, the NAO response has the opposite polarity but the AMOC SST footprint is different. A negative NAO response to the AMOC would be consistent with the observed and simulated response to the Atlantic Multidecadal Oscillation (AMO), if the latter were largely driven by the AMOC. However, it has recently been suggested that the AMO is primarily due to stochastic atmospheric forcing, and indeed the AMOC SST footprint differs somewhat from the AMO in climate models. The differences will be discussed using two large ensembles of historical climate simulations

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The impact of the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation onto the Northern Hemisphere storm tracks during the Twentieth Century

F. Varino (CNRM), P. Arbogast (CNRM), B. Joly (CNRM), G. Rivière (LMD)

Abstract: The multi-decadal variations of the Northern Hemisphere wintertime extra-tropical cyclones during the last century are shown to strongly depend on both the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO). Extratropical cyclones are detected via a vorticity-based cyclone tracking algorithm applied to the long-term ERA-20C reanalysis from ECMWF. The period between 1935 and 1980 is marked by a significant increase in Northern Hemisphere cyclones frequency. During the latter period, polar regions underwent a significant cooling over the whole troposphere that increased and shifted poleward the mid-latitude meridional temperature gradient and the baroclinicity. This is linked to rapid positive-to-negative shifts of the PDO between 1935 and 1957 and of the AMO between 1957 and 1980 which mainly reinforced the storm-track eddy generation in the North Pacific and North Atlantic regions respectively, as seen from baroclinic conversion from mean to eddy potential energy. As a result, both the North Pacific and North Atlantic extra-tropical storms activity increase in frequency during the two subperiods (1935-1957 and 1957-1980), together with other storm-track quantities such as the high-frequency eddy kinetic energy.
Other periods covered by the reanalysis (1900-1935 and 1980-2010) do not show any significant trend in extra-tropical cyclone frequency because they do not correspond to particular changes in PDO or AMO phases or because the impact of the two climate modes of variability tend to cancel each other. Despite the heterogeneous assimilated observations throughout the analysed period, we are confident in the detected cyclone trends because they are shown to be dynamically linked to barolinicity trends and changes in phase of large-scale modes of climate variability.

Modulation of the climate response to a volcanic eruption by the Atlantic Multidecadal Variability

Martin Ménégoz

BSC, Spain

Abstract: The climate dynamical response to a Pinatubo-like eruption during the boreal winter season and its modulation by the Atlantic Multidecadal Variability (AMV) is investigated here based on a suite of large ensemble experiments using the CNRM-CM5 Coupled Global Circulation Model. The volcanic eruption induces a strong reduction/retraction of the Hadley cell during two years. The mean extratropical westerly circulation accordingly weakens throughout the entire atmospheric column, except at very high Northern latitudes where the polar vortex is slightly strengthened, but without any significant alteration of the surface atmospheric modes of variability such as the North Atlantic Oscillation (NAO). Extratropical changes are modeled over the North Atlantic/Europe sector only for the third winter. Using clustering techniques, we provide evidence for inhibition of the occurrence of the negative NAO regime and this response is significantly amplified in cold AMV conditions. The modulation by the AMV is related to Arctic sea ice/atmosphere interaction and to diabatic heating/convection anomalies at the origin of tropical-extratropical teleconnections, whose roles are amplified because of the colder background state in the tropics and over the northern hemisphere when the AMV is negative. The delay observed between strong volcanic eruptions and NAO signal could be related to these sea-ice and ocean feedbacks. We insist on the fact that a large number of members is required to make volcanic imprints emerge from climate noise at midlatitudes. Using small size ensemble could easily lead to misleading conclusions especially those related to the NAO.

Poster session

Impacts of the Atlantic Multidecadal Variability on North American Summer Climate and Heat Waves

Yohan Ruprich-Robert
Princeton University – AOS / GFDL

Abstract: The impacts of the Atlantic Multidecadal Variability (AMV) on the summer North American climate are investigated using three ocean-atmosphere Global Climate Models (GCMs) in which the North Atlantic sea surface temperatures (SSTs) are restored to observed AMV anomalies. Large ensemble simulations are performed in order to estimate how AMV can modulate the occurrence of extreme weather events like heat waves. We show that, in response to an AMV warming, all models simulate a precipitation deficit and a warming over North Mexico and South US that yield to an increased number of heat wave days by about 30%. The physical mechanisms associated with these impacts are discussed. The positive tropical Atlantic SST anomalies associated with the warm AMV drive a Matsuno-Gill-like atmospheric response that favors subsidence over North Mexico and South US. This leads to a warming of the whole tropospheric column, and to a decrease in atmospheric relative humidity, cloud cover, and precipitation. The soil moisture also plays a role in the modulation of heat wave occurrence by AMV. An AMV warming favors dry soil conditions over North America by driving precipitation all the year round through atmospheric teleconnections coming both locally from the North Atlantic and non-locally from the Pacific. The indirect AMV teleconnections highlight the importance of using coupled ocean-atmosphere GCMs to fully assess the AMV impacts on North America. Given the potential predictability of the AMV, the teleconnections discussed here imply a source of predictability for the North

American climate variability and in particular for the occurrence of heat waves at multi-year timescale.