OSNAP
OVERTURNING IN THE SUBPOLAR NORTH ATLANTIC PROGRAM

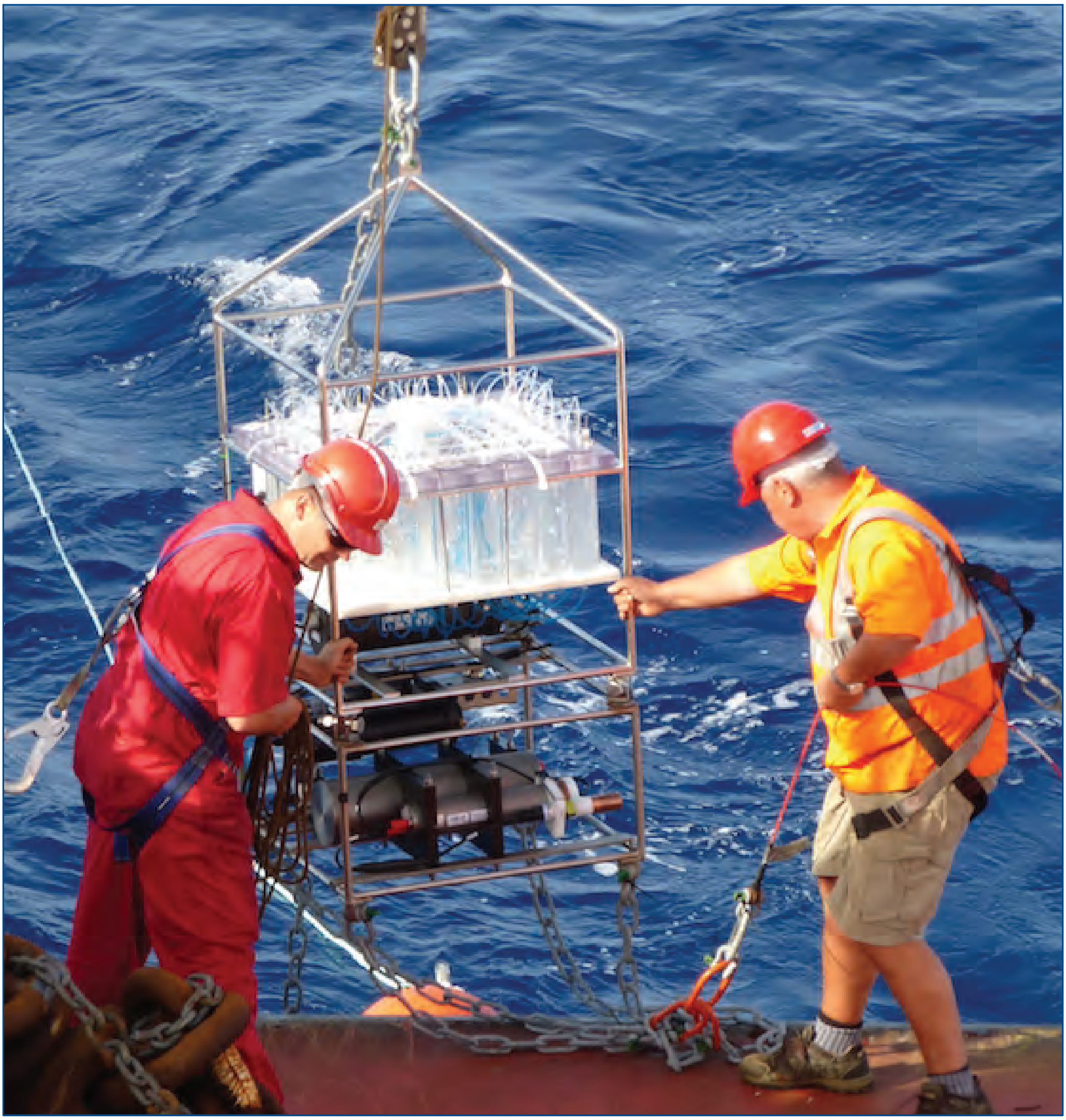
ACSIS

Rapid Climate Change

Joint Science Meeting
19-21 September 2017, Oxford, U.K.

Understanding Change and Variability in the North Atlantic Climate System

Programme and Abstracts



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The meeting is organised by the UK Natural Environment Research Council's Rapid Climate Change programme (RAPID) and the UK OSNAP and ACSIS programmes.

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Cover photo courtesy of Peter Brown, NOC.

Content

Programme

Tuesday 19 September

14.00 Welcome

14.10 Theme 1: Ocean-Atmosphere-Cryosphere Interactions.
Chair: David Anderson

14.10 Tor Eldevik: On observed northern climate change and predictability. *Invited*

14.50 Nick Dunstone: Skilful predictions of Northern European summer rainfall.

15.10 Albert Osso: Observational evidence of European summer weather patterns predictable from spring.

15.30 Tea / coffee

16.00 Theme 1 continues. Chair: Elaine McDonagh

16.00 Gokhan Danabasoglu: Modulation of Arctic Sea Ice Loss by Atmospheric Teleconnections from Atlantic Multi-decadal Variability.

16.20 Doug Smith: How does Arctic sea ice affect the North Atlantic Oscillation?

16.40 Christopher O'Reilly: Oceanic control of turbulent heat flux on decadal timescales in observations and models.

17.00 Simon Josey: Causes and Consequences of the Recent Atlantic Cold Anomaly.

17.20 Sybren Drijfhout: Simulated Atmospheric Response to the 2015 North Atlantic SST Cold Blob.

17.40 Christophe Cassou (on behalf of Said Qasmi): Understanding CMIP5 model diversity in simulating the teleconnection between Atlantic Multidecadal Variability and European temperature.

18.00 Reception and poster session (themes 1, 2 and 4)

Wednesday 20 September

09.00 Theme 3: Understanding Change and Variability.
Chair: Lesley Gray

09.00 Adam Scaife: Long Range Predictability of the Atmosphere in the North Atlantic Sector. *Invited*

09.40 Leonard Borchert: A Link between Interannual Heat Transport Variability and Surface Temperature Predictability in the North Atlantic.

10.00 Tim Woollings: Decadal modulation of Atlantic jet variability.

10.20 Steve Yeager: Skilful multi-year predictions of precipitation over land using CESM.

10.40 Tea / coffee

11.10 Theme 3 continues. Chair: Rowan Sutton

11.10 Pablo Ortega: The role of subsurface salinity in controlling decadal variability of convection: A model-based study.

11.30 David Thornalley: Shift to modern weaker state of Labrador Sea convection and reduced AMOC during the Industrial-era.

11.50 Paola Moffa Sanchez: North Atlantic variability and its links to European climate over the last 3000 years.

12.10 Leon Hermanson: Volcanic impacts on large-scale climate modes in a multi-model ensemble.

12.30 Lunch

14.00 Theme 3 poster session with tea/coffee at 15:30

16.00 Theme 3 continues. Chair: David Marshall

16.00 Elaine McDonagh: Biogeochemical Fluxes in the N. Atlantic: results for the ABC fluxes project. *Invited*

16.40 David Smeed: The late 2000's decrease in the Atlantic Meridional Overturning Circulation.

17.00 Florian Sevellec: Arctic sea ice decline weakens the Atlantic Meridional Overturning Circulation. .

17.20 Helene Langehaug: Thermohaline variability along the Atlantic water pathway in the forced Norwegian Earth System Model.

17.40 Agathe Germe: Chaotic vs externally forced variability of the Atlantic Meridional overturning circulation on intra and inter-annual timescales.

18.00 Day 2 closes

20.00 Conference dinner

Thursday 21 September

09.00 Theme 3 continues. Chair: Jon Robson

09.00 Ioana Colfescu: Attribution of Atlantic Multidecadal Variability to External Forcing, Internal Variability, and Weather Noise.

09.20 Dan Jones: Understanding North Atlantic Ocean heat content variability and heat transport variability using adjoint sensitivity experiments.

09.40 Lesley Allison: Recent changes in North Atlantic heat content in the GloSea5 ocean reanalysis.

10.00 Tobia Tudino: Anthropogenic impacts on carbon uptake variability in the subtropical North Atlantic: 1992 - 2010.

10.20 Tea / coffee

10.50 Theme 2: Characterising the North Atlantic Climate System in 4D. Chair: Penny Holliday

10.50 Lynne Talley: The AMOC and the global overturning circulation: controls and interactions. *Invited*

11.30 Gerard McCarthy: The importance of deep, basin wide measurements in optimized Atlantic Meridional Overturning Circulation observing arrays.

11.50 Bill Johns: Transport of the Iceland-Scotland Overflow plume along the eastern flank of the Reykjanes Ridge: New observations from OSNAP.

12.10 Alain Colin de Verdiere: Determination of the Overturning and meridional heat transports in the North Atlantic subpolar gyre with Argo Floats.

12.30 Laura Jackson: Using a multi-model ensemble of ocean reanalyses to understand recent changes in the North Atlantic ocean.

12.50 Lunch

14.00 Theme 2 continues. Chair: Meric Srokosz

14.00 Yavor Kostov: Sensitivity of the subtropical AMOC to variability in the North Atlantic subpolar gyre.

14.20 Mike Bell: Toward useful conceptual models of Meridional Overturning Circulations and Ocean Heat Uptake.

14.40 Theme 4: Towards budgets. Chair: Meric Srokosz

14.40 Ben Moat: Transports of freshwater and heat in the subtropical North Atlantic.

15.00 Jennifer Mecking: The effect of model bias on Atlantic freshwater transport and implications for AMOC bi-stability.

15.20 Claire Macintosh: Uncertainty in Steric Sea level.

15.40 Nick Bates: A Year in the Life of Gulf Stream Seasonality and Transport of Inorganic Carbon at Florida Strait.

14.00 Meeting closes

Posters

There are two formal poster sessions:

Session 1: Tuesday 19 September, 18:00 - 20:00 Theme 1, 2 and 4 posters

Session 2: Wednesday 20 September, 13:30 - 16:00 Theme 3 posters.

All posters will remain on display throughout the meeting, and participants are encouraged to visit them during the tea/coffee breaks, as well as during the formal poster sessions. Presenters of posters from Themes 1, 2 and 4 will be present to discuss their posters during Poster Session 1 on Tuesday 19 September, from 18:00. Theme 3 poster presenters will be present discuss their posters during Poster Session 2, Wednesday 20 September, 13:30-16:00.

Poster Session 1

Tuesday 19 September 18:00-20:00

Theme 1: Ocean-Atmosphere-Cryosphere Interactions

T1-01 Bresson, Helene: Polar lows and the North Atlantic Climate System.

T1-02 Grist, Jeremy: Re-emergence of North Atlantic subsurface ocean temperature anomalies in a seasonal forecast system.

T1-03 Lee, Robert: Impact of Gulf Stream SST biases on the global atmospheric circulation.

T1-04 Schroeder, David: An observations and model based analysis of meridional transports in the South Atlantic

T1-05 Souan, Cindy: Impact of the cold temperature anomalies in the North Atlantic on the summer european climate, case study of the summer 2015. (Presented by Clotilde Dubois)

T1-06 Swingedouw, Didier: Impact of freshwater release in the Mediterranean Sea on the North Atlantic climate.

Theme 2: Characterising the North Atlantic Climate System in 4D

T2-01 Allison, Lesley: Using synthetic profiles to assess the ability of the ocean observing system and mapping methods to constrain estimates of ocean heat content and spatial patterns of change.

T2-02 Berrisford, Paul: An overview of ERA5.

T2-03 Dubois, Clotilde: Deep convection in the North Atlantic and associated decadal variability.

T2-04 WITHDRAWN

T2-05 Ma, Liping: How do different weather regimes affect cold and warm air outbreaks and air-sea heat flux over the North Atlantic?

T2-06 Megann, Alex: 20th Century ocean/sea ice integrations for the ACSIS project.

T2-07 Rayner, Darren: The status of the RAPID 26N mooring array as serviced in 2017.

Theme 4: Towards budgets

T4-01 Brown, Peter: Circulation-driven variability of North Atlantic anthropogenic carbon transports.

T4-02 Carracedo, Lidia: 2004-2012 basin-scale nutrient transport across the RAPID-26.5°N section.

T4-03 Houpert, Loic: Transport Structure of the North Atlantic Current in Subpolar Gyre from observations.

T4-04 King, Brian: Moored oxygen measurements at 26N.

T4-05 Withdrawn

T4-06 Darren Rayner: Developing a telemetry system for the RAPID 26N moorings.

T4-07 Neill Mackay (presented by Chris Wilson): A Regional Thermohaline Inverse Method for Estimating Circulation and Mixing, Applied to the Arctic.

T4-08 Paul Halloran: Can RAPID and OSNAP biogeochemical measurements constrain the North Atlantic CO2 sink?

Poster Session 2

Wednesday 19 September 14:00-16:00

Theme 3: Understanding Change and Variability

T3-01 Alexander-Turner, Rhea: High-resolution ocean model simulations with interactive icebergs to estimate AMOC sensitivity to increased Greenland ice sheet melt. (Presented by Pablo Ortega)

T3-02 Ashby, Sophia: Comparing eddy properties from tracked ocean eddies in a high-resolution coupled climate model.

T3-03 WITHDRAWN

T3-04 Bracegirdle, Thomas: Recent multi-decadal trends in the mean and inter-annual variability of the winter NAO: comparing observations and CMIP5 simulations.

T3-05 Brown, Peter: Meridional overturning circulation variability drives anomalous air-sea CO2 fluxes in the subtropical North Atlantic.

T3-06 Carvalho Oliveira, Julianna: The influence of the AMOC strength at 26°N on seasonal SST predictability in the North Atlantic.

T3-07 Cooper, Fenwick: Pre-calculation and efficient presentation of geophysical correlations.

T3-08 Desbruyères, Damien: Great Spice Anomalies Control Deep Heat Uptake in the North Atlantic Ocean.

T3-09 Gastineau, Guillaume: The intrinsic North Atlantic Ocean decadal variability: role of atmospheric resolution and ocean-atmosphere.

T3-10 Gray, Lesley: Solar Cycle Influence on the North Atlantic Circulation.

T3-11 Jackson, Laura: AMOC hysteresis in a state-of-the-art GCM.

T3-12 Lee, Robert: Teleconnections between the Madden Julian Oscillation (MJO) and North Atlantic-European patterns of variability as a source of predictability.

T3-13 Liberato, Margarida: Evaluation of warming SST in the explosive cyclogenesis over Eastern North Atlantic.

T3-14 Lobelle, Delphine: The barotropic circulation at 26°N and the estimation of the overturning circulation.

T3-15 Lu, Hua: Downward Wave Reflection as a Mechanism for the Stratosphere-Troposphere Response to the 11-year Solar Cycle.

T3-16 Marsh, Robert: Large-scale oceanic influences on the European Slope Current and the downstream impacts.

T3-17 Menary, Matthew: The mechanisms driving systematic biases in the North Atlantic in decadal prediction models.

T3-18 Messias, Marie-Jose: Temporal evolution of CFCs and SF6 signals at 25°N for the 1992-2016 period.

T3-19 Moat, Ben: Relationship between changes in the North Atlantic heat content and SST.

T3-20 Moneries, Paul-Arthur: A role of the Atlantic Ocean in predicting summer surface air temperature over North East Asia?

T3-21 Ortega, Pablo: A multi-model comparison of the ocean contributions to multidecadal variability in the North Atlantic.

T3-22 Reynolds, David: A skilful annually resolved and absolutely dated marine spatial network reconstruction of North Atlantic subpolar gyre dynamics.

T3-23 Robson, Jon: Understanding the role of the North Atlantic subpolar gyre in near-term climate predictions.

T3-24 Roussenov, Vassil: Partitioning of heat and salt transport, and the partial compensation of heat and salt in the North Atlantic.

T3-25 Solodoch, Aviv: Instabilities and Interior Transport Pathways of the Deep Western Boundary Current in the North Atlantic.

T3-26 Spooner, Peter: High-resolution records of the Northeast Atlantic from the Late Holocene: Exceptional 20th century changes?

T3-27 Thomas, Chris: Using lagged covariances to assimilate RAPID data.

T3-28 Wood, Richard: What are the main factors influencing the position of AMOC stability thresholds?

T3-29 Worthington, Emma: Estimating the deep overturning transport variability at 26°N using bottom pressure recorders.

T3-30 Årthun, Marius: Arctic-Atlantic climate variability and predictability provided by poleward ocean heat transport.

T3-31 Irene Polo: Can the western boundary profile at 26N be used to extract buoyancy-forced AMOC signals?

Abstracts in alphabetical order by first author

A

Testing the robustness of observed AMOC fingerprints in a perfect model framework

Rhea Alexander-Turner[1] Pablo Ortega*, Jon Robson

** Presenting author*

NCAS Climate/University of Reading, Reading, United Kingdom

The Atlantic Meridional Overturing Circulation (AMOC) plays a key role in the climate of the North Atlantic, and is thus related to important climate impacts (or fingerprints). These AMOC fingerprints could prove useful to estimate the AMOC's variability back in time, or to predict its impact in the future. For example, direct measurements from the RAPID array suggest that the AMOC can drive sea-surface temperature (SST) changes several months ahead (Duchez et al., 2016), an encouraging result for seasonal predictability. However, with only 11 years of continuous observations, the validity of this result over longer time periods is uncertain. In this study, we use a 120-yr long preindustrial control simulation from the HadGEM3-GC2 climate model to test the stability and robustness of AMOC fingerprints for lead-times of several months ahead when using different model "observation" lengths. We first show that the model can satisfactorily reproduce the observed seasonal cycle of the AMOC and its components for any given 11-year period. However, the AMOC SST fingerprints are sensitive to the window length considered. Only the Ekman component shows robust lagged SST fingerprints using 11-years of model "observations". By contrast, both the Florida current and the upper mid ocean (UMO) transport produce highly inconsistent lagged SST fingerprints at sampling windows shorter than 30 years. Therefore, these results suggest that at least two more decades of RAPID observations would be necessary to determine the real potential for seasonal prediction using the RAPID array observations.

Theme 3 Poster T3-01

Recent changes in North Atlantic heat content in the GloSea5 ocean reanalysis

Lesley C. Allison*, Laura C. Jackson, K. Andrew Peterson, Richard A. Wood

** Presenting author*

Met Office, Hadley Centre, UK

The RAPID array has revealed changes in the Atlantic Meridional Overturning Circulation (AMOC) on a wide range of time scales, with a gradual weakening detected since 2004. Previous work has suggested that this weakening is part of a wider decadal variability rather than an anthropogenically-driven decline, and that the dynamical changes associated with a weakening AMOC are consistent with the cooling of the North Atlantic ocean that has been observed over the same period.

The GloSea5 ocean reanalysis combines a state-of-the-art dynamical ocean model with global observations and historical atmospheric forcing to produce a synthesis of the ocean state that can be used to understand climate variability and change. It has been previously shown that the GloSea5 reanalysis closely reproduces the observed AMOC variability at 26.5N, despite the RAPID observations themselves not being assimilated. In this work, we examine changes in North Atlantic ocean heat content in the reanalysis since 1995, and compare them with changes seen in the EN4 observational analysis. We explore the heat budget in the GloSea5 reanalysis to determine the relative contributions of ocean heat transport, surface fluxes and data assimilation, with the aim of determining the extent to which the reproduced AMOC change drives changes in North Atlantic heat content in the reanalysis.

Theme 3 Oral presentation Thursday morning

Using synthetic profiles to assess the ability of the ocean observing system and mapping methods to constrain estimates of ocean heat content and spatial patterns of change

Lesley C. Allison[1*], Matthew D. Palmer[1], Chris D. Roberts[2]

** Presenting author*

1) Met Office, Hadley Centre, UK
2) ECMWF, UK

For a wide variety of purposes in climate science, sparse point-based subsurface ocean observations need to be interpolated, or mapped, to a 3D field. The resulting gridded data can then be used to identify spatial patterns of ocean variability and change (which are needed for the initialisation of seasonal and decadal forecasts as well as for elucidating mechanisms of variability), and can also be used to calculate global or regional integrated quantities such as ocean heat content and thermosteric sea level. A variety of mapping methods exist, ranging from a simple grid binning approach to methods based on optimal interpolation or using covariances obtained from climate models, to complex model-based data assimilation techniques. These mapping methods can yield rather different results, particularly prior to the Argo era and in the deep ocean due to the sparseness of ocean observations. Assessing the merits of different mapping methods is difficult due to the lack of a known truth which the infilling is seeking to replicate. In this work, we extract 'synthetic profiles' from a historical simulation of the coupled climate model HadGEM3-GC2 by sampling the model temperature field at the spatial and temporal locations of real historical ocean observations. From the synthetic profiles we then attempt to recreate the known model truth using a variety of mapping methods. The first method we consider is that used to calculate the EN4 observational analysis, which is the gridded monthly objective analysis calculated operationally at the Met Office. We will present results that inform about model bias and observation influence, as well as informing about errors associated with particular mapping methods. In the longer term, the aim is to use this approach to assess how well the existing observing system can constrain estimates of ocean heat content, and potentially use the results to help inform the design of an optimal future observing system.

Theme 2 Poster T2-01

Comparing eddy properties from tracked ocean eddies in a high-resolution coupled climate model

Sophia Ashby[1*], David Ferreira[1], Helene Hewitt[2], Malcolm Roberts[2]

** Presenting author*

1) University of Reading, Department of Meteorology, United Kingdom
2) Met Office, Exeter, United Kingdom

Mesoscale eddies in the North Atlantic play a fundamental role in heat transport and variability in large-scale ocean circulation, as well as exchanging heat, momentum and freshwater with the overlying atmosphere. Their representation in climate models is therefore crucial. Here we compare surface eddy characteristics in three datasets: AVISO satellite observations and coupled climate model configurations of HadGEM3-GC3 at eddy-permitting (1/4°) and eddy-resolving (1/12°) resolution. The eddy identification and tracking algorithm used inputs sea level anomaly (SLA) and is adapted from Mason et al., 2014. By identifying and tracking individual ocean eddies, we are able to compare eddy properties, counts and their tracks in the Western Atlantic and Gulf Stream region.

In the Gulf Stream as expected smaller, faster eddies are able to be tracked at an increased ocean resolution from ORCA025 to ORCA12. Eddies identified from ORCA025 appear be solely found close to the Gulf Stream jet itself and not elsewhere in the region: unlike ORCA12 and AVISO where eddies are identified uniformly across the region. These eddies outside the jet tend to drift

westward as expected, due to the beta effect. Although ORCA025 identifies intense Gulf Stream rings, the eddy-permitting resolution fails to capture weaker (but not necessarily smaller) eddies. This indicates the grid size, relative to the Rossby radius, is not a reliable indicator of the model's ability to produce eddies.

Our results also highlight possible limitations of the AVISO dataset. Eddy properties (radius and amplitude) are more evenly distributed across all tracked eddies in AVISO, than in the model. Indeed both model resolutions present a more positively skewed distribution: a higher percentage of eddies have a smaller amplitude and radius. Despite the similar resolution of AVISO and ORCA025, ORCA025 contains a higher percentage of small eddies not seen in AVISO. This result is a potential consequence of the initial smoothing and temporal/ spatial interpolation of the AVISO dataset from satellite tracks. The tracked eddy statistics in the North Atlantic are validated against other regions globally, such as the Algulhas Current and Southern Ocean.

Theme 3 Poster T3-02

B

A Year in the Life of Gulf Stream Seasonality and Transport of Inorganic Carbon at Florida Strait

Nicholas Bates[1,3*], Elaine McDonagh[2], Sinhue Torres-Valdes[2], Peter Brown[2], Rebecca Garley[1], Ute Schuster[4], Molly Baringer[5], Rik Wanninkhof[5]

** Presenting author*

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5) NOAA/AOML, Miami, Florida

Over the last two years, as part of the NERC funded ABC Fluxes program, we have repeated numerous transects across Florida Strait to observe the seasonal variability of hydrography, ocean carbon and nutrient distributions associated with the Gulf Stream. Using gridded velocity fields produced by NOAA, we estimate weighted inorganic carbon transport for each property for each of the fifteen occupations across Florida Strait. These data show substantial seasonality variation of dissolved inorganic carbon (DIC) in Gulf Stream waters with winter values about 30 µmoles/kg higher than summertime values. Our analysis indicates that the Gulf Stream transports approximately 28 Pg C of inorganic carbon northward each year, with a seasonal variability of up to 0.5 Pg C. Such seasonal variation in inorganic transport in the Gulf Stream is an important factor in preconditioning the downstream, far field, controls of surface pCO2, pH, calcium carbon saturation states, the carbon dioxide buffer capacity, and air-sea carbon dioxide fluxes in the subpolar North Atlantic Ocean.

Theme 4 Oral presentation Thursday afternoon

Toward useful conceptual models of Meridional Overturning Circulations and Ocean Heat Uptake

Michael J. Bell [1*], Helen Johnson [2], David P. Marshall[2]

** Presenting author*

1) Met Office, Science, UK
2) Oxford University

Our aim is to develop simple conceptual pictures of the Meridional Overturning Circulations (MOCs) and Ocean Heat Uptake (OHU) that are consistent with observations, numerical models and simple

dynamical concepts. We show, using both historical observations and model-based re-analyses, that the climatological average and monthly-mean depths of isopycnals along the eastern boundaries of the major ocean basins are remarkably flat. Some aspects of this fact can be interpreted in terms of Kelvin wave and planetary geostrophic dynamics. It strongly suggests that the near surface ocean on eastern boundaries at high (low) latitudes will be warm (cold) relative to the atmosphere. Making use of this boundary condition, Bell (2015a,b) derives simple conceptual models of mid-depth steady state MOCs using 2- and 3-layer models with simple geometries that are governed by planetary geostrophic dynamics and driven by Ekman pumping and surface buoyancy forcing. The warm water reaching high latitudes at the eastern boundary is transformed into cold water by surface heat loss. Cold water that is driven to the surface at lower latitudes (50-60oS) in the Southern Hemisphere by Ekman upwelling is transformed into warmer water by surface heating. It is assumed that western boundary currents are able to close the resulting MOC.

The results from a set of numerical experiments for the upwelling limb in the Southern Hemisphere are summarised in a simple conceptual schematic. Simple analytical solutions are found for the down-welling limb assuming the wind stress in the Northern Hemisphere is negligible. Expressions for the depth of the isopycnal interface on the eastern boundary and the strength of the MOC obtained by combining these solutions in a 2-layer model are generally consistent with and complementary to those obtained by Gnanadesikan (1999).

We discuss the application of these ideas to: interpretation of the geographical distribution of the net sea surface heat flux; the interpretation of the MOC in two basins when one of them has a strong halocline; and the dynamics of ocean heat uptake forced by changes to surface fluxes of heat, fresh-water and momentum.

Bell, M. J. 2015a Water mass transformations driven by Ekman upwelling and surface warming in sub-polar gyres. J. Phys. Oceanogr., 45, 9, 2356-2380.

Bell, M. J. 2015b Meridional overturning circulations driven by surface wind and buoyancy forcing. J. Phys. Oceanogr., 45, 11, 2701-2714.

Gnanadesikan 1999 A simple predictive model of the structure of the ocean pycnocline. Science, 283, 2077-2081.

Theme 2 Oral presentation Thursday afternoon

An overview of ERA5

Paul Berrisford[1,2*], Gionata Biavati[2], Per Dahlgren[2], Dick Dee[2], Hans Hersbach[2], Andras Horanyi[2], Joaquin Munoz-Sabater[2], Carole Peubey[2], Raluca Radu[2], Iryna Rozum[2], Dinand Schepers[2], Adrian Simmons[2], Cornel Soci[2]

** Presenting author*

1) NCAS, Climate, UK
2) ECMWF, Copernicus, UK

Reanalyses are an invaluable resource for studying the four dimensional nature of the atmosphere. ERA5, the replacement for ERA-Interim, is the 5th "full observing system" reanalysis from the ECMWF and is being produced by the Copernicus Climate Change Service. ERA5 is being made available during 2017 and 2018, with an ongoing NRT commitment. Here we present an overview of ERA5, including a discussion of the improvements made to the ERA5 reanalysis system, as compared to that for ERA-Interim, such as the 31 km global resolution and 62 km 10 member ensemble.

Theme 2 Poster T2-02

Integrating Altimetry and Vessel-Mounted Current Velocity Observations to improve estimates of Atlantic Water volume, temperature and salt transport in the Faroe-Shetland Channel

Barbara Berx[1*], Léon Chafik[2], Stuart Cunningham[3], Charles Flagg[4], Stefan Gary[3], Hjalmar Hátún[5], Karin Margaretha H. Larsen[5], Jan Even Ø. Nilsen[6,7], Roshin P. Raj[6], Thomas Rossby[8], Kamila Walicka[3]

** Presenting author*

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5) Havstovan, Faroe Marine Research Institute, Faroe Islands
6) Nansen Environmental and Remote Sensing Center, Bergen
7) Bjerknes Centre for Climate Research, Bergen
8) University of Rhode Island, Graduate School of Oceanography, USA

The exchange of warm, saline surface waters between the Atlantic Ocean and Arctic Mediterranean occurs via three pathways across the Greenland-Scotland Ridge: to the west of Iceland, over the Iceland-Faroe Ridge and via the Faroe-Shetland Channel (FSC). Sustained observations since the 1990s have established that the transport through the FSC accounts for approx. 40 % of the Atlantic Water exchange. Recently, we incorporated sea surface height estimates from satellite altimetry in our methodology to estimate a continuous time series of the net Atlantic Water volume transport in the FSC from 1993 to present. Now, to improve this altimetry-based transport time series and to develop a methodology to obtain time series of temperature and salt transport, we investigate the use of the merchant vessel Norröna observational programme which measures water column profiles of velocity (ADCP) and temperature (XBT) on regular transits through the channel.

The accurate calculation of sea surface geostrophic velocities from altimetry requires a good observation of the geoid and accurate measurements of sea surface height. Despite improvements from the GRACE and GOCE satellite missions, our knowledge of the geoid is still poor in regions of steep topography, high eddy activity, and close to land (such as the FSC). Using hydrography and repeat measurements of velocity from a vessel-mounted ADCP on the merchant vessel Norröna, we will present an improved geoid estimation in the FSC. Reducing inaccuracies in the geoid will allow scientists to better estimate surface geostrophic velocities in the FSC, which can then be used to reference geostrophic calculations to obtain time series of volume, temperature and salt transport of Atlantic Water and hence more accurate fluxes of the meridional overturning circulation.

Theme 3   Poster T3-03 WITHDRAWN

A Link between Interannual Heat Transport Variability and Surface Temperature Predictability in the North Atlantic

Leonard Borchert[1,2*], Wolfgang A. Müller[3], Johanna Baehr[1]

** Presenting author*

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2) Max Planck Institute for Meteorology, International Max Planck Research School on Earth System Modelling, Hamburg
3) Max Planck Institute for Meteorology, Hamburg

We examine how meridional ocean heat transport (OHT)-anomalies influence the predictive skill of North Atlantic surface temperatures in the years following the anomaly. We use an ensemble of initialized coupled model simulations from the MPI-ESM-LR covering the period 1901-2010 (Müller, W. et al., 2014, GRL). We find that 0-6 years after strong OHT anomalies at 50N, a characteristic pattern of sea surface temperatures emerges. This pattern is characterized by warm SST anomalies in the North-East Atlantic and cold SST anomalies in the Gulf Stream region 3-6 years. SST anomalies of opposite sign emerge 0-2 years after weak OHT anomalies. The different lengths of the emergence of these SST anomalies can be related to the different durations of heat convergence in the subpolar gyre following strong and weak OHT anomalies.

Analyzing predictive skill of yearly initialized hindcasts against the assimilation experiment and HadISST observations shows that SST hindcast skill in the North Atlantic region is dominated by the OHT-related SST anomaly pattern. SSTs in the North Atlantic show predictive skill higher than the overall average on time scales of 1-2 years after weak OHT anomalies, and predictive skill higher than the overall average 3-5 years after strong OHT anomalies. We find ocean-atmosphere heat fluxes to be predictable in the North Atlantic on a similar time scale. Therefore, we also investigate potential implications of this enhanced interannual predictability of North-East Atlantic SSTs and surface heat fluxes for the predictability of central European surface air temperatures.

Theme 3 Oral presentation Wednesday morning

Recent multi-decadal trends in the mean and inter-annual variability of the winter NAO: comparing observations and CMIP5 simulations

Thomas Bracegirdle

British Antarctic Survey, United Kingdom

During the 20th century and the start of the 21st century there have been large multi-decadal shifts in the polarity of NAO indices and their inter-annual variability. These have key implications for predictability of seasonal conditions over Europe and for ocean-atmosphere interactions. The causes of these shifts in variability are not well known.

To address this we have assessed relationships between multi-decadal shifts in the mean winter NAO and inter-annual variability in the CMIP5 models. It is found that there is a statistically significant relationship between 30-year shifts in the mean and inter-annual variability of the NAO in randomly-sampled segments across the historical CMIP5 simulations. However, although statistically significant, the linear relationship is weak. Slightly stronger relationships were found when indices of the North Atlantic eddy driven jet strength and latitude were evaluated. Implications of these results for our understanding of the observational record and potential links to ocean variability will be discussed.

Theme 3 Poster T3-04

Polar lows and the North Atlantic Climate System

Helene Bresson*, Kevin Hodges, Len Shaffrey, Giuseppe Zappa

** Presenting author*

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Polar lows (hereafter PLs) are intense mesoscale cyclones that form at high latitudes during the cold season (Rasmussen and Turner, 1998). Their size is typically around 200-600 km and their wind speeds are usually above 15 m.s-1. Their strong winds can have substantial impacts on shipping, coastal communities and offshore infrastructure such as oil and gas exploitation (Zahn and von Storch, 2010). Cold air outbreaks (CAO) and the proximity of relatively warm open water to the cold sea ice are two conditions that are conducive to the formation of PLs (Kolstad and Bracegirdle (2008), Rojo et al. (2015)). The high wind speeds and heat fluxes associated with PLs may have a strong impact on deep-water formation in the Nordic Seas, which can affect the Atlantic Meridional Overturing Circulation or AMOC (Condron and Renfrew, 2012). This interaction between the atmosphere and oceans have led to PLs being considered as important for the climate system. Despite their importance, there are still large uncertainties in how frequently they occur, how they are spatially distributed and how they might respond to climate change.

In the context of climate change, simulations from Zahn and von Storch (2010) showed that PLs occurrences may experience a future decrease over the North Atlantic. This possible decrease, associated with results from Condron and Renfrew (2012), would imply a future reduction in the deep convection and a weakening of the AMOC, over the twenty-first century. However, as Condron and Renfrew (2012) used simulations of not only PLs but all polar mesoscale cyclones, the PLs impact on the deep-water formation, and thus on the AMOC, might be uncertain and difficult to quantify.

To investigate in a more detailed way this possible link between PLs and the AMOC, we are using the 98 years (2008-2105) of FEBBRAIO data from the Met Office HadGEM3-GC2 couple climate model (Williams et al., 2015). The model horizontal resolution is 25km (N512) in the atmosphere and 0.25° in the ocean. The purpose is to explore how PLs are simulated in high-resolution coupled climate model, and how do they interact with the ocean. We first track PLs in the model thanks to a tracking algorithm (Hodges, 1995) and identification criteria (Zappa et al., 2014). Then we investigate their interactions with the ocean through the sea surface temperature, the surface heat fluxes and the deep ocean circulation. Early results will be presented on PLs climatology and on this potential impact of PLs on the deep-water formation.

Theme 1 Poster T1-01

Circulation-driven variability of North Atlantic anthropogenic carbon transports

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The ocean absorbs approximately a quarter of the carbon dioxide (CO2) currently released to the atmosphere by human activities (Canth), with a disproportionately large fraction accumulating in the North Atlantic. Both air-sea exchange and transport in ocean currents contribute to this accumulation, with the meridional overturning circulation (MOC) dominating the latter. Here we use observations to estimate Canth transport on 10-day timescales between 2004-2012, finding substantial short-term and interannual variability, and a deep southward transport equivalent to nearly 5% of global Canth uptake. For the first time, we account for uppermost water-column seasonality, enabling substantial reductions in transport uncertainties. We find that while MOC strength declined during this period, Canth transport showed no significant trend due to the counteracting effect of increasing atmospheric CO2. However, the relative contribution to increasing North Atlantic Canth storage from oceanic transport decreased from 47% to 41% between 2004-2012, with air-to-sea fluxes supplying the difference.

Theme 4 Poster T4-01

Meridional overturning circulation variability drives anomalous air-sea CO2 fluxes in the subtropical North Atlantic

Peter J. Brown[1*], Elaine L. McDonagh[1], Richard Sanders[2], Vlad Macovei[3], C. Mark Moore[3], Ute Schuster[4], Andrew J. Watson[4], Peter Landschützer[5], Brian A. King[1], Damien Desbruyères[1], Sue Hartman[2], Stephanie Henson[2]

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The 2009-2010 event that saw a downturn in the strength of the Atlantic meridional overturning circulation (AMOC) has been observed to have substantial effects on the heat content of the subtropical North Atlantic between 25°N - 45°N, 60°W-20°W. Due to the strong inverse relationship that exists between temperature and the solubility of carbon dioxide (CO2) within seawater it is postulated that this anomalous heat content may have led to a similarly anomalous uptake in CO2 from the atmosphere. Here we show that estimates of air-sea CO2 flux derived from sea-surface fCO2 observations indeed identify a 41% increase in CO2 uptake over the same timeframe. However, we find that temperature changes drive only 38% of the anomalous flux, with the remainder accounted for by enhanced biological activity and carbon export to depth. The increased primary production is sustained by substantial nutrient supply to the usually nutrient-depleted euphotic layer. However, there is no evidence of mixed layer deepening that is sufficient enough to support this nutrient supply. Instead changes in the wind stress field that lead to the AMOC downturn cause large scale vertical movements in the water column across the subtropical region. This shoaling of isopycnals lifts denser, nutrient-replete waters to the surface where local biology can take advantage. This is a clear identification of short-term large–scale circulation shifts having a direct impact on both physical and biological carbon pumps.

Theme 3 Poster T3-05

C

2004-2012 basin-scale nutrient transport across the RAPID-26.5ºN section

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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. Model projections point to an 11-34% AMOC decline in the 21st century due to climate change. Motivated by this anthropogenically-induced change, the monitoring of AMOC variability -and its associated heat and anthropogenic carbon transport- has been subject to a thorough research effort during the last decade. However, how that variability in circulation is affecting the meridional transport of nutrients remains poorly understood. Using observations from the RAPID, Argo and GO-SHIP International Programs in the North Atlantic, we generated the first continuous ocean nutrient (silicate, nitrate and phosphate) basin-scale transport time-series every 10 days for the 2004-2012 period across the 26.5ºN transatlantic section. The average net nutrient fluxes for the period of study were -295 ± 15 kmol-Si s-1, -130 ± 16 kmol-N s-1 and -8 ± 1 kmol-P s-1 (negative fluxes southwards). The results showed pronounced variability of the basin-scale net nutrient transports at seasonal, interannual and long-term scales. AMOC was revealed as the main driver of the magnitude and variability of those net nutrient transports at the studied temporal scales, contributing 73% (58%) of the net silicate (nitrate and phosphate) transport, and explaining up to a 99% (94%) of its variance. Still, horizontal circulation was found to play an important role in the advection of the nitrate and phosphate remineralised fraction. At seasonal scale, the amplitude of the nutrient transport variability (±80 kmol-Si s-1, ±46 kmol-N s-1 and ±3 kmol-P s-1) represented 30% (40%) of the mean net silicate (nitrate, phosphate) flux. As for the interannual variability, the amplitude was higher than for the seasonal cycle (112 kmol-Si s-1, 52 kmol-N s-1 and 3.5 kmol-P s-1) due to the 30% AMOC drop occurred during the 2009/2010 extreme event, which led to a 4-month South-to-North reversal on the net nutrient fluxes across the section. Finally, the meridional silicate (nitrate, phosphate) net fluxes exhibited a remarkable 8-year decline of 55% (40%), i.e., net silicate (nitrate, phosphate) fluxes decreased by 155 kmol-Si s-1 (42 kmol-N s-1, 3 kmol-P s-1). If such rate of decrease were sustained in time, that would imply a change of sign on the net nutrient transports at 26.5ºN (i.e., from southwards to northwards) by 2022 (2029).

Theme 4 Poster T4-02

The influence of the AMOC strength at 26°N on seasonal SST predictability in the North Atlantic

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We investigate the potential of using the knowledge of the state of the AMOC at 26°N in the prediction of sea surface temperature anomalies (SSTA) at the seasonal time scale. We evaluate the mechanism proposed by Duchez et al. 2016, which relates anomalies in the AMOC strength, as

measured in the RAPID array at 26°N, with SSTA in the tropical and subtropical North Atlantic as a see-saw pattern. We analyse a simulation with MPI-ESM-MR, nudged to reanalysis for the atmosphere and ocean component, and to observations for the sea-ice component. Using the AMOC anomalies as a precursor to SSTA, we find that the AMOC leads a SSTA dipole pattern in the tropical and subtropical North Atlantic with maximum correlations at 2-4 months; in agreement with Duchez et al., 2016. In extension to Duchez et al., we find that this pattern varies with the starting season, and is more pronounced when the most recent decade is considered than the entire time series back to 1982. In a set of ensemble hindcast simulations with 30 members, starting each May and November between 1982 and 2014, we also perform a hindcast skill analysis for both SST and AMOC. We find different spatial patterns in the SST hindcast skill at 2 – 4 months lead time for the hindcasts started in November and May, with higher skill over both the subpolar gyre and the eastern North Atlantic for hindcasts started in November over those started in May. We find an improvement of SST hindcast skill at 2 – 4 months lead-time, when the strength of the AMOC at the start of the hindcast period is considered, which is in agreement with the seesaw mechanism.

Reference: Duchez, A., Courtois, P., Harris, E., Josey, S.A., Kanzow, T., Marsh, R., Smeed, D.A. and Hirschi, J.M., Climate Dynamics 46, pp.3351-3370 (2016)

Theme 3 Poster T3-06

Attribution of Atlantic Multidecadal Variability to External Forcing, Internal Variability, and Weather Noise

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The mechanisms of the Atlantic Multidecadal Variability (AMV) and Atlantic Meridional Circulation (AMOC) simulated by the CCSM3 CGCM in a 110 year run with 20th century forcing are isolated and compared. For attributing the AMV and AMOC to internal variability, external forcing and weather noise our procedure employs an auxiliary configurations of the CCSM3 component models – the “ Interactive Ensemble (IE)” version of CCSM3 forced by specified weather noise. The IE is a CGCM in which the ensemble mean of an AGCM ensemble is coupled to an OGCM.

Each AGCM ensemble member is forced by the same SST, as produced by the OGCM, while the ocean and its SST are simultaneously forced by the ensemble mean of the AGCM surface fluxes. The IE coupling effectively parameterizes the atmospheric transient eddy fluxes, while suppressing the weather noise forcing of the ocean, leaving SST variability due only to external forcing, coupled atmosphere-ocean feedbacks and ocean internal variability. Due to the suppression of the weather noise, the IE responds quasi-deterministically to specified forcing applied to the IE OGCM.

Our results show that all of the potential mechanisms are playing a role in the simulated AMV, with a predominant role for NAO-like weather noise forcing, associated especially with heat flux in the eastern North Atlantic, an ocean dynamical response to the weather noise involving the AMOC and gyre circulations that could be acting as a positive coupled feedback and a non-trivial role for 20th century external forcing.

Theme 3 Oral presentation Thursday morning

Determination of the Overturning and meridional heat transports in the North Atlantic subpolar gyre with Argo Floats

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It is now possible to estimate directly the meridional overturning and meridional heat fluxes in the North Atlantic using geostrophic dynamics, the World Ocean Atlas temperature-salinity climatology and the measured float displacements of the Argo float program. The latter provide a reference level giving access to the absolute velocity field. The calculation is carried out in 4 steps: (1) Estimate the geopotential at 1000 db from the float time mean velocity data. This is done through a projection of the Argo float velocity data on the geostrophic mode to filter out unwanted velocity divergences. It requires solving a Poisson equation for the geopotential. (2) Hydrostatics then allow to obtain the absolute geopotential and geostrophic mean flow at all depths. (3) The sum of the Ekman currents and geostrophic currents are then vertically averaged to obtain the total barotropic velocity. To eliminate the barotropic velocity divergences a second Poisson equation is solved for the barotropic streamfunction. (4) Once the absolute velocities are known and the constraint of no net coast-to-coast transport is satisfied, it is possible to obtain the overturning stream function and meridional heat fluxes. The mean circulation of the subpolar gyre is discussed and mass and heat transports are provided at various latitudes in the North Atlantic and compared to previous estimates.

Theme 2 Oral presentation Thursday morning

Pre-calculation and efficient presentation of geophysical correlations

Fenwick Cooper

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Huge geophysical data sets can be difficult to get to grips with. The time and technical knowledge required to process data is considerable and this takes away from time spent exploring and understanding what the data set represents.

Movies can show the time evolution of various 2D fields. The time or climatological mean of a large data set, can be presented in a reasonably small catalogue, or even summarised on paper. The second moment, or covariance however, cannot easily be stored or explored in a catalogue because it is so large, (approximately the size of the time mean data squared). And yet the covariance represents the relationships between variables, which is often precisely the thing we wish to understand.

We pre-compute correlations (covariance) and present them in a user-friendly web page, so that they can be explored quickly and efficiently. As an example, we show correlations of the ERA-interim atmosphere reanalysis, and the 311 year HadGEM3-GC2 model output.

Theme 3 Poster T3-07

D

Modulation of Arctic Sea Ice Loss by Atmospheric Teleconnections from Atlantic Multi-decadal Variability

Gokhan Danabasoglu[1*], Frederic S. Castruccio[1], Yohan Ruprich-Robert[2,3], Stephen G. Yeager[1], Rym Msadek[4], Thomas L. Delworth[3]

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Observed Arctic sea ice has declined sharply over the satellite era. While most climate models simulate a decline, few show trends matching the observations, suggesting either model deficiencies or significant contributions from natural variability. Using perturbed climate model experiments, we show that Atlantic Multi-decadal Variability (AMV) teleconnections drive low-frequency Arctic sea ice fluctuations. Even without AMV–related changes in ocean heat transport, imposing AMV–like surface temperature anomalies gives rise to shifts in atmospheric circulation that produce similar Arctic sea ice changes in three different climate models. Positive AMV anomalies induce a weaker Beaufort Sea High and an increased prevalence of the Arctic Dipole. The resulting anomalous winds produce a thinner Arctic sea ice pack that is more prone to melt in summer. Decadal trends in Arctic sea ice volume due to AMV–related atmospheric teleconnections are found to be of the order of 4–20% of the anthropogenic forced trends.

Theme 1 Oral presentation Tuesday afternoon

Great Spice Anomalies Control Deep Heat Uptake in the North Atlantic Ocean

Damien Desbruyères[1*], Elaine Mcdonagh[2], Bablu Sinha[2], Alexis Megann[2], Simon Josey[2], Adrian New[2], David Smeed[2], Penny Holliday[2]

** Presenting author*

1) IFREMER, LOPS, France
2) NOC, MPOC, UK

Because of its Meridional Overturning Circulation (MOC), the North Atlantic Ocean is a key region for the sequestration of heat below the energetic and primarily wind-driven upper oceanic layer. Here we analyse an historical hydrographic dataset (EN4) to characterize decadal temperature anomalies in the North Atlantic during 1950-2016 and detail three main stages in their evolution: formation in the upper layer, sinking at high latitudes, and deep southward export. A decomposition of the temperature changes into dynamically-active (heave) and dynamically-passive (spice) components confirms the importance of salinity variability and density-compensation in the western Subpolar Gyre for long-term heat uptake in the deep North Atlantic Ocean.

Theme 3 Poster T3-08

Simulated Atmospheric Response to the 2015 North Atlantic SST Cold Blob

Sybren Drijfhout[1*], Jennifer Mecking[1], Joel Hirschi[0,2], Aurelie Duchez[0,2], Adam Blaker[0,2]

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2) National Oceanography Centre, UK

In the summer of 2015 central Europe experienced a major heat wave which in the months before was preceded by the development of anomalously cold sea surface temperatures in the northern North Atlantic. A previous study has shown that the cold ocean anomaly preceded a pronounced southward deviation of the Jet Stream path in early June which favoured the development of the heat wave over central Europe. However, whether the cold SST anomaly in the North Atlantic was the cause of the change in the atmospheric circulation was not yet clear. Here, we further investigate the connection between the Atlantic cold blob of 2015 and the heat wave over central Europe through the use of a state-of-the-art coupled climate model, HadGEM3. The coupled model is initialized with 3D anomalies of temperature and salinity, obtained from an ocean-only hindcast run for the 1958 to 2016 period. The ocean-only model simulates the cold blob event very well. Also, it is nearly the same model (NEMO ORCA025) as the ocean component of HadGEM3, implying that using ORCA025 T and S fields minimizes the adjustment/initialisation shock compared to assimilating observations. Two different model ensembles have been generated:

1) Applying the initial temperature and salinity anomalies globally (GLOBAL) and

2) applying the initial temperature and salinity anomalies only to the North Atlantic (ATLANTIC).

In both GLOBAL and ATLANTIC the application of the ocean anomalies leads to a heat wave over central Europe for the ensemble mean. The GLOBAL ensemble shows a stronger signal for the central European heat wave than ATLANTIC. This suggests that remote signals (from outside the North Atlantic, i.e. ENSO) likely helped to enhance the heat wave. We also studied the impact of soil moisture anomalies in the development of the heat wave. It appears that both North Atlantic SSTs and soil moisture anomalies over Europe preconditioned the atmosphere to generate the heat wave. This is one of the first studies where extratropical SSTs, associated with internal variations in the North Atlantic subtropical gyre are shown to have a major impact on the overlying atmosphere and eastward, downstream of the SST forcing area, affecting human populations over land.

Theme 1 Oral presentation Tuesday afternoon

Deep convection in the North Atlantic and associated decadal variability

Clotilde Dubois[1*], Laura Jackson[0,2]

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2) Met Office, Hadley Centre, UK

Winter convection occurs in the North Atlantic at four specific sites: Labrador Sea, Cape Farewell, Irminger and Nordic Seas. Where, using state of the art ocean reanalysis from CMES (GloSea5, Glorys2v4, ORAS5, CGLORS), we investigate the decadal variability of the convection and the processes involved. We find a maximum depth of more than 1500m, that has been recently observed in the last years in the Labrador Sea. Such deep convection in the Labrador Sea has not been observed in the last decade. Further more, we will try to characterise how this decadal variability in the convection regions can be link with the decadal variability of the AMOC. A focus will be done on its recent decline observed over the past decade.

Theme 2 Poster T2-03

Skilful predictions of Northern European summer rainfall

Nick J. Dunstone[1*], Doug Smith[1], Adam Scaife[1]

** Presenting author*

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Year-to-year variability in European summer rainfall has profound societal and economic impacts. Very wet summers, such as those between 2007-2012, often lead to flooding with impacts on the agricultural, tourist and transport sectors. Very dry summers, such as 1976 and 2003, can lead to drought and severe water shortages. To date, seasonal forecast systems have shown no significant skill for predicting summer Northern European rainfall. Here we show that skilful predictions are possible ($r \sim 0.5$, $p<0.001$) using the latest high-resolution Met Office near-term prediction system from 1960-2016 when very large ensembles (~80 members) are used. The model captures both low frequency changes (e.g. wet summers 2007-2012) and some of the large events (e.g. dry summer 1976). We find low frequency skill is primarily linked to predictable North Atlantic sea surface temperatures, which modulate the supply of moisture and so, the convective precipitation rate over Northern Europe. High frequency changes are linked to skill in predicting the variability in the North Atlantic jet. However, as found recently for the winter NAO, the amplitude of the forced model response is much too weak relative to the skill, suggesting missing or weak model responses. This work is encouraging for the future development of seasonal European summer rainfall climate services.

Theme 1 Oral presentation Tuesday afternoon

E – G

On observed northern climate change and predictability

Tor Eldevik[1,2*], Marius Årthun[1,2], Ingrid H. Onarheim[1,2]

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Already more than 100 years ago Helland-Hansen and Nansen envisioned a predictable northern climate and ecosystem provided by the ocean. The degree of predictability nevertheless remains unresolved; particularly to what extent variable ocean heat is imprinted on the atmosphere to realize its predictive potential over land. Here we assess from observations whether anomalous heat in the Gulf Stream's northern extension provides predictability of northwestern European and Arctic climate. We show that variations in ocean temperature in the high latitude North Atlantic and Nordic Seas are reflected in the climate of northwestern Europe and in winter Arctic sea ice extent. Particularly, we predict that Norwegian air temperature and precipitation will decrease over the coming years, although staying above the long-term (1981–2010) average, whereas UK temperatures will be relatively mild. Winter Arctic sea ice extent will remain low but with a general increase towards 2020. If time permits, the presentation will also reflect a little on how the observed predictability may extend to the ecosystem (fisheries), and also provide a future outlook on seasonal and regional manifestation of Arctic sea ice loss.

Theme 1 Invited talk Tuesday afternoon

The intrinsic North Atlantic Ocean decadal variability: role of atmospheric resolution and ocean-atmosphere interaction

Guillaume Gastineau

Sorbonnes Universités, UPMC, CNRS

In order to investigate the processes of the Atlantic Meridional Overturning Circulation (AMOC) decadal variability and the importance of ocean-atmosphere feedback, we used the fields retrieved from a control run of the ocean-atmosphere IPSL-CM5A-LR coupled 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 coupled model, but the ice cover is prescribed to a mean climatological cycle. This control simulation reproduces the AMOC variability from the coupled model simulation. Then, climatological fluxes were calculated to force another ocean-only experiment. This simulation shows a clear 20-yr variability. This variability is linked to intrinsic oceanic processes, with clear westward propagations of density anomalies in the subpolar gyre. Lastly, idealized daily fluxes were derived from random permutations from the coupled models fluxes, and were used to force a last set of ocean-only simulations. This simulation shows a smaller AMOC variability when compared to the control simulation, which demonstrates that ocean-atmosphere feedbacks increase the AMOC variability (positive feedback): the AMOC forces an NAO-like atmospheric response with a time lag of 10 years that contributes to further amplify the AMOC 10 years later.

We applied similar modelling setup to the IPSL-CM5A-MR ocean-atmosphere coupled model, similar to IPSL-CM5A-LR, but uses a higher atmospheric resolution. In this model, the surface westerlies shifts poleward and the Icelandic low is more intense, which warms the surface ocean in the Eastern North Atlantic subpolar gyre region. This leads to a damping of the oceanic intrinsic variability with increased atmospheric resolution. The ocean-atmosphere interactions only lead to a weak damping of the decadal variability in this model using increased atmospheric resolution.

Theme 3 Poster T3-09

Chaotic vs externally forced variability of the Atlantic Meridional overturning circulation on intra and inter-annual timescales

Agathe Germe, Joël Hirschi, Adam Blaker*, Bablu Sinha

* *Presenting author*

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The ocean, like the atmosphere, is chaotic, which means that even under the same external forcing (atmospheric conditions), a small difference in the oceanic initial state can result in a different oceanic state beyond a decorrelation time. In this analysis, we use the ORCA12 configuration of NEMO forced by DFS5.2 atmospheric forcing to investigate the fraction of chaotic variability of the Atlantic meridional overturning circulation (AMOC). The variability of the AMOC in ORCA12 shows good agreement with the RAPID-MOCHA array observations of the AMOC for the 2004-2012 period. To estimate the amplitude of the chaotic AMOC variability two 4-member ensembles, starting in 2007 and 2009 respectively and integrated over 4 years, have been performed. The structure of the chaotic variability of the AMOC, assessed from the ensemble spreads, shows similarities with the finding of Hirschi et al. (2013) and Gregorio et al. (2015) with a peak of chaotic variability around 35°N. To gain some insight into the physical processes behind the chaotic variability we decompose the AMOC into its geostrophic, barotropic and Ekman components. Particular emphasis is on a comparison with the AMOC decomposition and reconstruction as performed in the RAPID-MOCHA observations at 26°N. This analysis highlights the importance of knowing the external barotropic component of the AMOC in order to avoid an overestimation of the chaotic variability in the observed AMOC.

Theme 3 Oral presentation Wednesday afternoon

Solar Cycle Influence on the North Atlantic Circulation

Lesley Gray

NCAS, University of Oxford, Physics

There has been substantial controversy surrounding the possibility that the Sun's 11-yr cycle could have an impact on the North Atlantic and European weather. Recent progress in understanding the observed signals in the north Atlantic Oscillation will be described and potential mechanisms reviewed, with particular emphasis on the transfer and amplification via the stratospheric circulation in Northern Hemisphere winter.

Theme 3 Poster T3-10

Re-emergence of North Atlantic subsurface ocean temperature anomalies in a seasonal forecast system

Jeremy P. Grist[1*], Bablu Sinha [1], Aurelie Duchez[1], Helene Hewitt[2], Pat Hyder[2], Craig MacLachlan[2], Simon A. Josey[1], Adrian L. New[1], Adam T. Blaker[1], Joel. J.-M. Hirschi[1]

** Presenting author*

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A high-resolution coupled ocean atmosphere model is used to study the effects of seasonal re-emergence of North Atlantic subsurface ocean temperature anomalies on northern hemisphere winter climate. A 50-member control simulation is integrated from September 1 to 28 February and compared with a similar ensemble with perturbed ocean initial conditions. The perturbation consists of a density-compensated subsurface (deeper than 180m) temperature anomaly corresponding to the observed subsurface temperature anomaly for September 2010, which is known to have re-emerged at the ocean surface in subsequent months. The perturbation is confined to the North Atlantic Ocean between the 23º S and 65º North.

The model has 1/4 degree horizontal resolution in the ocean and the experiment is repeated for two atmosphere horizontal resolutions (~60km and ~25km) in order to determine whether the sensitivity of the atmosphere to re-emerging temperature anomalies is dependent on resolution.

The Experiment ensembles display a wide range of re-emergence behaviour, in some cases re-emergence occurs by November, in others it is delayed or does not occur at all. When the range of re-emergence times is taken into account, it is evident that a pressure pattern that brings, stronger, colder, drier air and enhanced latent heat loss is required to set up re-emergence. Whereas in response to re-emergence (negative SST anomalies), there is reduced latent heat loss, colder surface air temperature and positive low level pressure anomalies downstream. The results highlight a potentially important process whereby ocean memory of conditions up to a year earlier may significantly enhance seasonal forecast skill.

Theme 1 Poster T1-02

H – K

Can RAPID and OSNAP biogeochemical measurements constrain the North Atlantic CO2 sink?

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The North Atlantic contains the most intense ocean CO2 sink on the planet. We hypothesise that the background chemistry that is supplied to the North Atlantic via its Northern and Southern boundaries plays a crucial role in priming this sink and controlling its magnitude and variability. Chemical measurements are now being made along the RAPID line as part of the Atlantic Biogeochemical Fluxes project, and could in theory be rolled out to the OSNAP section. In an idealised modelling study, we demonstrate that assimilating such measurements into a model could allow the North Atlantic CO2 sink to be monitored, adding significant value to the arrays' capabilities.

Theme 4 Poster

Volcanic impacts on large-scale climate modes in a multi-model ensemble

Leon Hermanson[1*], Nick Dunstone[1], Martin Menegoz[2], Holger Pohlmann[3], Jon Robson[4], Doug Smith[1], Gary Strand[5], Claudia Timmreck[3]

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4) University of Reading, Department of Meteorology, UK
5) NCAR, USA

Large volcanic eruptions in the tropics have global impacts, but have been found to especially affect the North Atlantic climate system in the first few winters after the eruption. This is primarily through the NAO and its climate impacts, but the tropical Pacific is also thought to contribute to changes over the North Atlantic. During the last 55 years, a period when the earth system has been relatively well observed, there have been three major eruptions: Agung (1963), El Chichon (1982) and Pinatubo (1991). These are mid-sized eruptions compared to what has been found further back in time. Palaeo reconstructions appear to show clear impacts on the NAO end ENSO for the largest eruptions, but for mid-sized eruptions the evidence is less clear. This result has also been found in model simulations of the last millennium. However, climate proxies are noisy and many models used so far have had relatively low resolution and poorly resolved stratospheres.

In this work, we use five state-of-the-art decadal prediction systems, to investigate the climate response the three most recent volcanic eruptions. Four of which have relatively high resolution for climate models and two of which have well-resolved stratospheres. We compare hindcasts started before each respective eruption with identical hindcasts that have no volcanic aerosols. We focus on the mechanisms in each model that lead (or not) to responses in large-scale climate modes such as the NAO and ENSO. As the hindcasts are initialized with the observed initial conditions before each eruption, this allows us to study how initial conditions can affect the response to the volcanic aerosols.

Theme 3 Oral presentation Wednesday morning

Transport Structure of the North Atlantic Current in Subpolar Gyre from observations

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** Presenting author*

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There is mounting evidence of the importance of the transports of heat and freshwater by the North Atlantic Subpolar Gyre (NASPG) for impacts on European and global climate via temperature, precipitation and wind strength. To adequately measure the NASPG, an international transoceanic observing system was set up in the subpolar North Atlantic in the framework of the Overturning in the Subpolar North Atlantic Program (OSNAP). The main aims of OSNAP are to: (i) provide a continuous record for four years (2014–18) of full-depth, trans-basin mass, heat, and freshwater fluxes in the NASPG; (ii) quantify and understand the response of circulation, and heat and freshwater fluxes to local and remote forcing, within the conceptual framework of the AMOC.

One of the objectives of the Eastern boundary array is to quantify the northward-flowing flux in Rockall Trough and on Rockall Hatton Plateau (RHP). Although previous observations suggest that the net northwards flux over the RHP is small and that the local circulation is weaker than in the Rockall Trough, OSSE model shows a core northward transport of 5 Sv over the western Plateau slope with, and an additional ~1 Sv transport over the RHP. Uncertainties over the net circulation in this region led to the design of a glider endurance line from the Rockall Trough mooring array to the US Iceland Basin end-point mooring.

From July 2014 to August 2016, 15 gliders sections were realized along 58N, between 22°W and 15°W. We are using glider densities and depth-average currents (deduced from glider dead reckoning navigation and GPS fixes at surface) to calculate absolute geostrophic velocity and characterise the horizontal and vertical structure of the transport. The mean absolute geostrophic transport ± standard deviation from May to October over the RHP (20.5°W to 15°W) is 7.2 ± 1.8 Sv. We identified three main branches: (i) a northward flow of 6.4 Sv± 2.4 Sv over the eastern flank of Iceland Basin (20.5°W to 18.5°W); (ii) a southward flow of 1.4 Sv ± 1.2 Sv over the western flank of the Hatton-Rockall Basin (18.5°W to 16.0°W); (iii) a northward flow of 1.8 Sv ± 0.5 Sv over the eastern flank of the Hatton-Rockall Basin (16°W to 15°W). Uncertainties deriving from glider-based measurement are 10-15% of our absolute transport estimates. Altimetry-based estimates of circulation on the RHP show the same northward & southward branches but with stronger net transport.

Repeated glider observations on the eastern portion of the OSNAP line highlight the importance of these measurements for estimating absolute meridional geostrophic velocity and transport, especially in a region with narrow and intense currents.

Theme 4 Poster T4-03

AMOC hysteresis in a state-of-the-art GCM

Laura Jackson[*], Richard Wood

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We conduct idealised experiments with HadGEM3-GC2, which is a pre-CMIP6 eddy-permitting GCM, to test for the presence of thresholds in the AMOC. We add fresh water to the North Atlantic for different rates and lengths of time, and then examine the AMOC recovery. In some cases the AMOC recovers to its original strength, however in others the AMOC does not recover, and even continues decreasing. There appears to be a threshold of ~8 Sv: the AMOC mostly recovers if the hosing stops before the AMOC reaches 8 Sv, and mostly does not recover if the AMOC weakens more than this.

We examine the mechanisms controlling the presence of the recovery in order to understand what sets the threshold, and why this GCM exhibits hysteresis behaviour.

Theme 3 Poster T3-11

Using a multi-model ensemble of ocean reanalyses to understand recent changes in the North Atlantic Ocean.

Laura Jackson[1*], Clotilde Dubois[2], Lesley Allison[1], K.A. Peterson[1]

** Presenting author*

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2) Mercator Ocean, France

The observational network around the North Atlantic has improved significantly over the last few decades with the advent of ARGO and satellite observations, and the more recent efforts to monitor the Atlantic Meridional Overturning Circulation (AMOC) using arrays such as RAPID and OSNAP. These have shown decadal timescale changes across the North Atlantic including in heat content, heat transport and the circulation.

However there are still significant gaps in the observational coverage, and significant uncertainties around some observational products. Ocean reanalyses integrate the observations with a dynamically consistent ocean model and are potentially tools that can be used to understand the observed changes, however the suitability of the reanalyses for the task must also be assessed.

We use an ensemble of global ocean reanalyses in comparison with observations in order to examine recent changes in the North Atlantic. In particular we assess changes in the AMOC strength as observed by the RAPID array and the OSNAP array. Some reanalyses do well at capturing the AMOC as measured by the RAPID array, including the decadal weakening trend.

Theme 2 Oral presentation Thursday morning

Transport of the Iceland-Scotland Overflow plume along the eastern flank of the Reykjanes Ridge: New observations from OSNAP

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Since 2014, an array of current meters deployed as part of the OSNAP trans-basin observing system has provided new measurements of the southward flow of Iceland-Scotland Overflow water (ISOW) along the eastern flank of the Reykjanes Ridge in the Iceland Basin. The location of the array, near 58-59°N, captures the ISOW Deep Western Boundary Current at the farthest downstream location in the Iceland Basin before significant amounts of ISOW can flow into the Irminger Basin through deep fractures in the Reykjanes Ridge. The transport of the ISOW DWBC at this location - based on the first two years of OSNAP observations (July 2014 to July 2016) - is 5.8 ± 0.9 Sv for $\sigma\theta > 27.8$. Most of this transport is carried in a main branch of the DWBC along the upper ridge crest in depths from 1400-2200 m, while a secondary branch in depths of 2400-2700 m along the lower ridge crest carries about 1 Sv. The branching of the DWBC at this location is consistent with numerical model results and is caused by an upstream topographic plateau at mid-depths along the ridge crest. The T-S properties of the flow confirm that the flow in both branches is derived from ISOW and its entrainment products. The transport of the ISOW plume varies over a considerable range, from about 2-10 Sv on weekly to monthly time scales (std. dev. = 2.4 Sv);

however the mean currents from two individual year-long deployments are very similar and indicate a robust mean flow structure. The observed ISOW transport at this location is larger by almost 2 Sv than previous values obtained (mostly) farther north in the Iceland Basin, suggesting that additional entrainment or recirculation into the ISOW plume occurs as it approaches the southern tip of the Reykjanes Ridge. The fraction of pure Norwegian Sea Overflow Water (NSOW) contained in the plume is however only about 2.6 Sv, consistent with - or slightly smaller than - the amount of NSOW known to be flowing over the northern sills into the Iceland Basin.

Theme 2 Oral presentation Thursday morning

Understanding North Atlantic Ocean heat content variability and heat transport variability using adjoint sensitivity experiments

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2) National Oceanography Centre, United Kingdom
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We address heat content variability and heat transport variability in the North Atlantic Ocean using a set of adjoint sensitivity experiments in both the upper (1000 m) and intermediate (1000-1800 m) ocean. We employ the ECCOv4 global ocean configuration of MITgcm, which is a data-constrained state estimate covering the period 1992-2011. Using this adjoint modelling setup, we examine the sensitivities of ocean heat content and ocean heat transport to surface heat fluxes, net freshwater fluxes, wind stress, and ocean dynamics. We also compare local and non-local sensitivity patterns in order to quantify the relative impact of local and remote atmospheric/oceanic conditions. Finally, we discuss how adjoint sensitivity experiments can help ensure a high signal-to-noise ratio in non-linear forward perturbation experiments, i.e. by highlighting those places and times where/when perturbations may have the largest effect on heat content and heat transport.

Theme 3 Oral presentation Thursday morning

Causes and Consequences of the Recent Atlantic Cold Anomaly

Simon. A. Josey[1*], Joel J.-M. Hirschi[1], Bablu Sinha[1], Aurelie Duchez[1], Ben Moat[1], Jeremy P. Grist[1], Robert Marsh[2]

** Presenting author*

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Mid-high latitude North Atlantic Ocean temperature anomalies have been observed across a wide range of timescales from interannual to centennial. Recently, a large region of persistently low surface temperatures was evident in the subpolar gyre from winter 2013-14 to 2016, accompanied by a sharp reduction in ocean heat content. The presence of this feature at a time of pervasive warming elsewhere has stimulated considerable debate. The role of air-sea interaction and ocean processes in generating the cold anomaly will be reviewed and the event will be placed in a longer-term context using a combination of observation-based datasets (HadISST, EN4, NCEP/NCAR) and high-resolution ocean model output (1/12o NEMO). Trajectory analysis will be employed to identify differences in newly formed water mass pathways in the eastern subpolar gyre prior to and after the cold anomaly event. In addition, impacts of subpolar gyre temperature anomalies for the

atmosphere, including the North Atlantic Oscillation and European heat waves will be discussed with a focus on re-emergence. Finally, the recent behaviour of the Atlantic will be contrasted with the North Pacific extreme warm surface event observed over a similar timescale.

Theme 1 Oral presentation Tuesday afternoon

K – L

Moored oxygen measurements at 26N

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The ABC Fluxes program has enhanced the 26N array with moored SeaBird Optical Dissolved Oxygen sensors, and sample measurements on the mooring service cruises, JC103, DY039, JC145. Two columns of oxygen sensors at six levels (50, 400, 800, 1500, 2000, 3500 metres) were deployed at the western boundary (WB1, WBH2, WB4) from May 2014 to Nov 2015, and four columns of six levels from Nov 2015 to March 2017: two at the western boundary as before, and one each at MAR1 and EB1. A total of 33 out of a possible 36 complete records have been recovered; three records were lost or short because of interaction with collocated pH sensors. The presentation will discuss the measurements and the methodology required for calibration of the sensors in long moored deployments. Sensors deployed at and deeper than 1500 metres show a drift towards lower oxygen values over the duration of the records. This is a mechanical response of the sensor to long-term immersion at high pressure, with an initial exponential decay and then a long slow drift. The sensor recovers from this drift immediately upon mooring recovery, so it is not apparent in 'post deployment calibration casts'. The pattern appears to be reproducible across the deep sensors on six moorings. The presentation will also assess the contribution of moored and float-borne oxygen measurements to estimates of the time-varying oxygen distribution at 26N.

Theme 4 Poster T4-04

Sensitivity of the subtropical AMOC to variability in the North Atlantic subpolar gyre

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** Presenting author*

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We explore the delayed impact that temperature and salinity variability in the North Atlantic subpolar gyre exert on the evolution of the AMOC in the subtropics. We analyse the physical mechanisms governing the oceanic teleconnections across the basin. To that end, we conduct adjoint runs that estimate the sensitivity of the AMOC to surface momentum and buoyancy fluxes, as well as to interior density and spice anomalies. We compute the linear sensitivities about a realistic background state based on ECCO version 4. We utilize an MITgcm ocean-only configuration that represents the global domain including an Arctic Ocean. In addition, our configuration includes an eddy parameterization, a vertical mixing scheme, and a sea ice package. We drive the ocean model with optimized atmospheric forcing provided by ECCO.

Our cost function in the adjoint experiments is the strength of the subtropical AMOC, and we explore several different metrics that can be used to define the meridional transport. First, we

consider the zonally integrated northward transport along the RAPID line at 26N in depth space. Then we compare with results in density space using potential density referenced to 1000 dbar. At lags longer than one year, both the depth and the density-space calculation suggest a pronounced sensitivity of the subtropical AMOC to temperature and salinity perturbations in the region monitored by the OSNAP observing system: in the Labrador and Irminger Seas and off the southern tip of Greenland. On multiannual lags, the AMOC sensitivity to surface heat fluxes and interior temperature perturbations peaks in the winter months. In contrast, the sensitivity to interior salinity anomalies and surface freshwater fluxes exhibits a much weaker seasonality.

Theme 2 Oral presentation Thursday afternoon

Thermohaline variability along the Atlantic water pathway in the forced Norwegian Earth System Model

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5) Uni Research Climate, Norway

The increasing attention on mechanisms that can provide predictability in our climate system, and particularly on those related to the warm poleward flow in the North Atlantic Ocean on interannual-to-decadal time scales, makes it necessary and important to identify how well climate models represent such mechanisms. In this study we use a high (0.25° horizontal grid) and a medium (1°) resolution version of a forced Norwegian Earth System Model to assess the impact of increased resolution on simulated temperature and salinity anomalies along the pathway of warm water in the subpolar North Atlantic and the Nordic Seas. Although the high-resolution version has larger biases in general at the ocean surface, the poleward propagation of thermohaline anomalies is better resolved, i.e., the time for an anomaly to travel northward is more similar to observation-based estimates. The extent of the anomalies is rather large in both model versions, covering large domains in the centre of the subpolar region and the entire stretch from Scotland to northern Norway and Svalbard. The easternmost branch, carrying warm Atlantic Water, into the Nordic and Barents Seas is also improved by higher resolution, both in terms of mean heat transport and variability in thermohaline properties. A more detailed assessment of the link between the Subpolar Gyre strength and the thermohaline anomalies at the entrance of the Nordic Seas reveals that the high resolution is more consistent with mechanisms that are previously published. This suggests better variability and dynamics in the subpolar region and the Nordic Seas in the high resolution compared to the medium resolution. However, the medium and high resolution share similarities. For instance, both model versions show a dominant pattern of temperature anomalies occurring regularly (i.e., 5-10 years between each warm anomaly) along the pathway of warm water in the subpolar region and the Nordic Seas, and these anomalies are largely in phase with observations. Hence, the analysis used herein demonstrates that a forced Earth System Model can capture key properties associated with the warm water pathway. As the poleward propagation of ocean heat anomalies is considered to be a key source of climate predictability, we recommend that similar methodology presented herein should be performed on coupled Earth System Models that are used for climate prediction.

Theme 3 Oral presentation Wednesday afternoon

Impact of Gulf Stream SST biases on the global atmospheric circulation

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3) Atmospheric Physics, University of Oxford, UK
4) Met Office, UK

The role of winter Gulf Stream biases are examined with a focus on the tropospheric response. The UK Met Office Unified Model in the Global Coupled 2 (GC2) configuration has a warm bias of up to 6 K, which is associated with surface heat flux biases and potentially related to biases in the atmospheric circulation. To test the tropospheric response to the Gulf Stream bias, three sensitivity experiments were performed. The SST biases is imposed on the atmosphere-only configuration of the model over three different-sized regions, to cover a small and medium section of the Gulf Stream, and the wider North Atlantic. The dynamical response to this anomalous Gulf Stream heating is to enhance vertical motion in the transients over the Gulf Stream, rather than balance the heating with a linear dynamical meridional wind or meridional eddy heat transport. Together with the imposed Gulf Stream heating bias, the response affects the troposphere not only locally but also in remote regions of the Northern Hemisphere via a planetary Rossby wave response. The sensitivity experiments are able to partially reproduce some of the differences in the coupled configuration of the model relative to the atmosphere-only configuration and to the ERA-Interim reanalysis. These biases may have implications for the ability of the model to respond correctly to variability or changes in the Gulf Stream.

Theme 1 Poster T1-03

Teleconnections between the Madden Julian Oscillation (MJO) and North Atlantic-European patterns of variability as a source of predictability

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The MJO, acting as a Rossby-wave source, can provide teleconnections to the extratropics including: the NAO; the strength of the Northern Hemisphere winter polar stratospheric vortex including the occurrence of Sudden Stratospheric Warmings; and Arctic sea-ice. This tropical sub-seasonal variability and correctly represented teleconnections may provide a source of predictability for sub-seasonal variability in extra tropical polar regions. The ERA-Interim reanalysis is used to analyse the MJO teleconnections to the extra tropical North Atlantic-European region on sub-seasonal timescales, and their dependence on slowly varying basic state. This includes the dependence of these teleconnections on interannual and longer timescale modes of variability. The ability of climate and seasonal prediction models to capture these dependencies will then be investigated using data from the WMO Sub-seasonal to Seasonal Prediction Project (S2S) database.

Theme 3 Poster T3-12

Evaluation of warming SST in the explosive cyclogenesis over Eastern North Atlantic

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A large number of weather driven extreme events has occurred during the last decade, namely in the Iberian Peninsula, that has been struck by record breaking extreme events with unprecedented socioeconomic impacts. Outstanding costly windstorms such as Klaus in 2009 (Liberato et al. 2011), Xynthia in 2010 (Liberato et al. 2013) or Gong in 2013 (Liberato 2014) experienced explosive development over Eastern North Atlantic, making landfall on the Iberian Peninsula. Some of these storms had their genesis on a region characterized by warm and moist air associated with anomalously high sea surface temperatures (SSTs), according to ERA-Interim reanalysis data (e.g. Xynthia; Ludwig et al. 2014). The recent availability of several products, such as the high-resolution 1/12º Physical IBI reanalysis product covering the altimetric decade (2002-2014), for the Atlantic-Iberian Biscay Irish-Ocean – providing hourly mean values of surface fields such as SST – is an opportunity for a better assessment of the evolution and variability of warming SSTs and potentially enhanced latent heat releases during the explosive development of most extreme storms. The improvement of ocean reanalysis allows for a better understanding of storms' dynamics and will contribute to the study on Eastern North Atlantic extreme storms' variability, in view of improved windstorm risk assessment for the Iberian Peninsula. In this work the variability of SST over Eastern North Atlantic prior to and during the occurrence of explosive cyclogenesis is discussed.

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Theme 3 Poster T3-13

The barotropic circulation at 26°N and the estimation of the overturning circulation

Delphine Lobelle[1*], David A. Smeed[2], Gerard D. McCarthy[2], Florian Sévellec[1], Eleanor Frajka-Williams[1], Claudie Beaulieu[1], Valerie Livina[3]

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The Atlantic Meridional Overturning Circulation (AMOC) plays a key role in transporting heat northwards from the tropics to the polar region, leading to Europe's climate being milder than the global average at the same latitudes. In the RAPID framework, the AMOC at 26°N is monitored in

three parts: the Florida Straits transport, the surface Ekman transport (governed by the winds) and the transport east of the Bahamas that has been estimated by the mooring array since 2004. The geostrophic meridional velocity is inferred from the thermal wind balance and the zonal gradients dynamic height derived from the temperature and salinity measurements on the RAPID moorings, but these do not determine the absolute velocity. We examine a key assumption in the RAPID methodology that the absolute velocity at 4820 m is approximately uniform east of 76.75°W. First, using data from six cruises since 2010, underway Vessel-Mounted Acoustic Doppler Counter Profilers (VMADCP) velocity data are compared with geostrophic velocities from AVISO 10-day average altimetry sea surface height data. Surface velocities inferred from altimetry data are then integrated across the eastern and western basins of the RAPID array in order to compare them with the equivalent surface transport estimated from the RAPID methodology.

Theme 3 Poster T3-14

Downward Wave Reflection as a Mechanism for the Stratosphere-Troposphere Response to the 11-year Solar Cycle

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The effects of solar activity on the stratospheric waveguides and downward reflection of planetary waves during northern early to mid- winter are examined. Under high solar (HS) conditions enhanced westerly winds in the subtropical upper stratosphere and the associated changes in the zonal wind curvature led to an altered waveguide geometry across the winter period in the upper stratosphere. In particular, the condition for barotropic instability was more frequently met at 1 hPa near the polar night jet centred at ~55°N. In early winter the corresponding change in wave forcing was characterized by a vertical dipole pattern of the Eliassen-Palm (E-P) flux divergent anomalies in the high-latitude upper stratosphere accompanied by poleward E-P flux anomalies. These wave forcing anomalies corresponded with negative vertical shear of zonal mean winds and the formation of a vertical reflecting surface. Enhanced downward E-P flux anomalies appeared below the negative shear zone; they coincided with more frequent occurrence of negative daily heat fluxes and associated with eastward acceleration and downward group velocity. These downward reflected wave anomalies had a detectable effect on the vertical structure of planetary waves during November to January. The associated changes in tropospheric geopotential height contributed to a more positive phase of the North Atlantic Oscillation in January and February. These results suggest that downward reflection may act as a ‘top-down’ pathway by which the effects of solar ultraviolet (UV) radiation in the upper stratosphere can be transmitted to the troposphere.

Theme 3 Poster T3-15

M

How do different weather regimes affect cold and warm air outbreaks and air-sea heat flux over the North Atlantic?

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In this study, the daily data from NCEP and ECMWF ERA-Interim reanalyses are used to explore how different weather regimes force air-sea heat flux anomalies over the Atlantic in wintertime. We define the weather regimes in terms of Greenland blocking, the British Isles blocking, positive and negative North Atlantic Oscillation (NAO hereafter) and the central Atlantic Ridge. These weather regimes affect cold and warm air outbreaks, and so alter the surface temperature patterns and possibly ultimately boundary density and ocean overturning.

Blocking weather regime is associated with negative NAO, which is a prominent phenomenon in wintertime over the Atlantic. The sea surface air-sea heat flux loss decreases due to warm air outbreaks to the regions controlled by blocking highs. For a climatological mean, there are typically 13 blocking days around Scandinavia and the British Isles and 9 days around Greenland for each winter. Greenland blocking and Iceland/Nordic Sea blocking regimes cause warm air out breaks (correlation coefficient 0.75) over most of the subpolar region around the Greenland region, including the east and south Greenland Sea and the Labrador Sea. A case study for the winter in 2009/2010 reveals a strong positive air temperature anomaly about 12 to 14℃ over these regions, which collectively covers 82 blocking days. Under these circumstances, the ocean surface air-sea heat flux anomaly is about 50 to 400 W/m^2 (positive anomaly means ocean gains heat) over these regions around Greenland, the maximum positive anomaly centre is 350 to 400W/m^2 around the Labrador Sea. The ocean anomaly gains total heat about 5 to 30×10^20 Joules during blocking periods. This signal is due to the transport of south-westerly and southerly warm air from the subtropical region along the west side of blocking anticyclones.

In contrast, the cold air outbreaks around Greenland and Iceland and the surrounding Sea are associated with a strong +NAO regime (correlation coefficient 0.80). For December 2013, the surface air temperature anomaly is about -10 to -15°C continuously persisting for 20 days. The cold air outbreaks from North America are transported downstream by the strong westerly jet between latitudes 50 to 70°N. The surface temperature drops to around -5°C over the Atlantic in the 50 to 60°N belt, while some regions are colder by 5 to 10°C. Consequently, the air-sea heat flux anomaly reaches -100 to -350 W/m^2 (negative anomaly means ocean loses heat) and the ocean loses heat between 1 to 4×10^20 Joules from west to east between 50 to 70°N over the region during this period. The maximum heat loss is located in the 50 to 60°N belt on the eastern side of North Atlantic.

In summary, the warm air outbreaks over mid-high latitudes are associated with Greenland and British Isles blocking events, which are linked to negative NAO phases. In contrast, most of the cold air outbreaks are associated with strong positive NAO periods.

Theme 2 Poster T2-05

The importance of deep, basinwide measurements in optimized Atlantic Meridional Overturning Circulation observing arrays

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The Atlantic Meridional Overturning Circulation (AMOC) is a key process in the global redistribution of heat. The AMOC is typically defined as the maximum of the overturning stream function, which occurs near 30°N in the North Atlantic. The RAPID mooring array has provided full-depth, basinwide, continuous estimates of this quantity since 2004. Motivated by both the need to deliver near real-time data and optimization of the array to reduce costs, we consider alternative configurations of the mooring array and the utilisation of satellite altimetry data. Results suggest that the variability observed since 2004 could be reproduced by a single tall mooring on the western boundary and a mooring to 1500 m on the eastern boundary. This timescale of variability can also be captured by satellite altimetry based estimates. We consider the potential future evolution of the AMOC in two generations of the Hadley Centre climate models and a suite of additional CMIP5 models. The modelling studies show that deep, basinwide measurements are essential to capture correctly the future decline of the AMOC. We conclude that, while a reduced array or satellite measurements could be useful for estimates of the AMOC on subseasonal to decadal time scales as part of a near real-time data delivery system, extreme caution must be applied to avoid the potential misinterpretation or absence of a climate time scale AMOC decline that is a key motivation for the maintenance of these observations.

Theme 2 Oral presentation Thursday morning

Biogeochemical Fluxes in the N. Atlantic: results for the ABC fluxes project

Elaine McDonagh

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Atlantic BiogeoChemical (ABC) fluxes has used the transport information from the RAPID time series and Argo data and combined this with observations of carbon parameters and inorganic nutrients to calculate the transports of anthropogenic carbon and inorganic nutrients across 26.5N. While the overturning circulation dominates the variability there are also significant trends in the transport of properties associated with the horizontal (gyre) circulation. The uncertainty associated with our calculations and the potential impact of the observations that we are making as part of ABC fluxes are assessed through the use of models that include biogeochemistry.

Theme 3 Invited talk Wednesday afternoon

Uncertainty in Steric Sea level

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Steric sea level describes sea level change related to temperature and salinity changes. On a global scale, it provides an integrated measure of energy storage in the oceans.
Closure of the sea level budget is still a significant challenge for the community. In addition to understanding the processes that contribute to changes in sea level, budget closure studies require frameworks for understanding uncertainty address the classification and propagation of uncertainty information. For this approach to succeed, an understanding of relevant contributions and appropriate methods to combine uncertainties must be developed.
In this study we combine real world and synthetic Argo profiles to discuss contributions to the uncertainty budget for a particular estimate of steric sea level.

Theme 4 Oral presentation Thursday afternoon

A Regional Thermohaline Inverse Method for Estimating Circulation and Mixing, Applied to the Arctic

Neil Mackay[1], Chris Wilson[1*], Jan Zika[2], Penny Holliday[1]

** Presenting author*

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Methods which categorise water masses in the ocean according to their temperature and salinity have been demonstrated to provide insight into aspects of the global overturning circulation. This thermohaline framework is particularly useful in studying the fluxes of heat and freshwater within the ocean, and allows the relative contributions of different processes to the circulation to be determined.

In contribution to OSNAP (the Overturning in the Subpolar North Atlantic Programme), we have developed a novel inverse method in thermohaline coordinates called the Regional Thermohaline Inverse Method (RTHIM). Defining a control volume bounded by the surface and an enclosed vertical section, RTHIM invokes a balance between advection through the section, fluxes of heat and freshwater into the volume through the surface, and interior mixing within the volume, for each temperature-salinity (T-S) class. Taking known surface fluxes and a known distribution of T and S within the volume and along the section, RTHIM determines unknown section velocities and unknown rates of interior mixing.

Using outputs from the Nucleus for European Modelling of the Ocean (NEMO), we have validated RTHIM for an Arctic control volume bounded to the south by a section at around 60°N by comparing section velocities and interior mixing rates from the inverse solution with those diagnosed from the model. We run a range of ensembles of RTHIM and find that the solutions are robust to various model parameters and initial conditions. We calculate the Meridional Overturning Circulation, Meridional Heat Transport and Meridional Freshwater Transport from the RTHIM solutions and find they are in good agreement with NEMO. We also see good agreement between interior mixing rates obtained from the RTHIM solution and those diagnosed from the model.

Theme 4 Poster

Large-scale oceanic influences on the European Slope Current and the downstream impacts

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** Presenting author*

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Oceanic influences on European shelf seas are mediated by flow along and across the continental slope, with consequences for regional hydrography and ecosystems. To first order, poleward flows along isobaths at the continental slope are fed from the west by geostrophic zonal flows that are supported in turn by mid-latitude meridional density gradients. This density gradient has undergone substantial changes in recent decades, with consequences for the large-scale inflow and the provenance of Slope Current water. As a consequence of subpolar warming around 1997, a northern branch of the inflow was substantially reduced, while a southern branch strengthened. In broad terms, cold, fresh waters of subpolar provenance were replaced by warm, saline waters of subtropical provenance, along the slope. These changes have considerable implications for the downstream shelf regions that are strongly influenced by Atlantic inflow, the northern North Sea in particular - a region where subtropicalization of ecosystems has been observed since the 1990s.

Theme 3 Poster T3-16

The effect of model bias on Atlantic freshwater transport and implications for AMOC bi-stability

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Evidence from paleo-proxy records suggests that the Atlantic Meridional Overturning Circulation (AMOC) can be in both an AMOC on state, the AMOC as we observe it today, and an AMOC off state, where the AMOC becomes extremely weak or even collapses. The freshwater transport due to the AMOC (Mov) at 34°S in the Atlantic has often been used as an indicator for bi-stability, with a positive Mov suggesting a monostable AMOC and a negative Mov suggesting a bi-stable AMOC. Often studies have shown that the sign of the divergence of the Mov might be a good indicator of AMOC bi-stability. In this study we investigate how model bias affects the sign of Mov across all latitudes in the Atlantic basin, through a detailed analysis of the Coupled Model Inter-Comparison Project 5 (CMIP5) model ensemble. Mov, in the CMIP5 models is generally too positive in the southern Atlantic due to a salinity bias, while in the subtropical North Atlantic the values of Mov are influenced by a combination of velocity and salinity biases. We compare these results to observations, reanalysis products and Hadley Centre Global Environmental Model version 3 global configuration version 2, a current generation coupled model which exhibits a stable AMOC off state, and discuss the differences that can lead to the possibility of a bi-stable AMOC as opposed to a monostable AMOC.

Theme 4 Oral presentation Thursday afternoon

20th Century ocean/sea ice integrations for the ACSIS project

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A suite of NEMO/CICE configurations is being set up under ACSIS, which will be integrated in forced mode at both 1/4° and 1/12° resolutions from 1958 to the present decade. The principal aim of the initial stage of the project is to select a forced ocean configuration that reproduces changes in the ocean over the last fifty years with an acceptable realism. An ensemble of trial integrations at 1° and 0.25° using CORE2, DFS5.2 and JRA55 forcing reveals a range of responses to the different forcing datasets; in particular, the large-scale evolution of the upper ocean is found to be more sensitive to the choice of forcing than to the horizontal resolution. We will present preliminary results from the 1/4° production integrations using both CORE2 and DFS5.2 forcing.

Theme 2 Poster T2-06

The mechanisms driving systematic biases in the North Atlantic in decadal prediction models

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Previous work has shown how misrepresentation of the drivers of interannual density variability in the Labrador Sea could cause poor predictive skill in DePreSys3. This implies two further questions:

1) Is this result systematically the case across all available CMIP5 hindcasts?

2) Could the assimilation itself be biased in favour of one type of variability over another?

In order to answer these questions we build upon our previous single-model work and add 15 CMIP5 multi-annual hindcast systems and an additional assimilation, which we will show has the opposite density drivers. We will show that, though these 15 hindcast sets and 2 assimilations give different estimates of the AMOC and “skill”, they are consistent with our previous work and show that models revert to their “control” nature within only a few years. Further, the disparate estimates of skill in the AMOC streamfunction can be simply understood by considering these preferred climates and their similarity (or not) with the “truth” (assimilation) in the Labrador Sea.

This suggests that making reliable predictions (i.e. predictions where we understand the origins of the skill) of the AMOC into the future will rely on first understanding both 1) the “truth” in Labrador Sea T/S variability (mostly S) and 2) how this is similar or not to the preferred state of a given prediction system (i.e. the driver of density variability in the control simulation).

Theme 3 Poster T3-17

Temporal evolution of CFCs and SF6 signals at 25ºN for the 1992-2016 period

Marie-Jose Messias[1*], Tobia Tudino[1], Sinue Torres-Valdes[2], Brian King[2], Ben Mills[3], Eleanor Frajka-Williams[4], John Bullister[5], Fine Rana[6], Andrew Watson[1]

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Five reoccupations of the A05 hydrography section along ~25°N in the Subtropical North Atlantic enable us to observe the progression of oceanic transient tracers in this region key to the monitoring of the Atlantic Meridional Overturning Circulation (AMOC). The measured tracers, chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF6), are anthropogenic passive tracers of ocean circulation with known time varying sources functions and are used to visualise the penetration of newly ventilated waters and to calculate water age. Here, we present the variation of the mean transport timescales inferred from the tracers transit time distributions (TTDs) for the 1992-2016 period. The patterns of changes for TTDs mean ages are compared to apparent oxygen utilisation and the reported variability of the overturning circulation.

Theme 3 Poster T3-18

Relationship between changes in the North Atlantic heat content and SST

B. I. Moat[1*], B. Sinha[1], S. A. Josey[1], N. P. Holliday[1], G. D. McCarthy[1], J. Robson[0,2], P. Ortega[0,2]

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The North Atlantic is known to undergo swings in sea-surface temperature (SST) on multidecadal timescales, with consequent impacts on the climate of adjacent land areas. However the mechanisms behind this Atlantic Multidecadal Variability (AMV) remain debated. A wide variety of mechanisms have been proposed, ranging from external forcing due to anthropogenic aerosols to coupled ocean-atmosphere modes of variability involving the Atlantic Meridional Overturning Circulation (AMOC). Whatever the detailed mechanisms, it seems likely that horizontal ocean heat transport convergence will play an important role. However the relationship between the changes in oceanic heat transport and the SST is not well understood. Here we develop a framework to investigate which physical processes determine SST variability on decadal-multidecadal timescales by evaluating contributions from the net ocean-atmosphere heat flux, the divergence of the horizontal temperature transport, and entrainment between the mixed layer and the layer beneath, using the NEMO-LIM2 1/12° ocean circulation/sea ice model (for the period 1958-2015) and a 300-year present-day control simulation of the HADGEM3-GC2 coupled climate model. Between the years 2007 and 2011, when the AMOC underwent substantial reductions in 2009 and 2010, the model suggests that a key process connecting the AMOC to the SST is entrainment of heat into the mixed layer. This term is determined both by the state of the AMOC, and the prevailing atmospheric conditions.

Theme 3 Poster T3-19

Transports of freshwater and heat in the subtropical North Atlantic

B. I. Moat[1*], E. L. McDonagh[1], B. A. King[1], W. E. Johns[0,2], D. A. Smeed[1], G. D. McCarthy[1], D. Rayner[1], M. Baringer[0,3], C. S. Meinen[0,3]

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The climate of northwest Europe and indeed the whole of the Northern Hemisphere is profoundly influenced by the oceanic transport of freshwater and heat from the tropics to the subpolar regions. At 26.5°N the circulation carries about 1.3 PW (1 PW = 10^15 W) of heat northwards. This poleward heat transport is dominated by the meridional overturning circulation (MOC), in which the northward surface waters are transformed into North Atlantic Deep Water formed primarily by cooling in the subpolar regions. The quantity of the deep-water formation is strongly influenced by the upper layer salinity and hence the poleward freshwater transport.

Estimates of the transports of freshwater and heat are calculated using observations from the RAPID-MOCHA-Western Boundary Time Series (WBTS) array and Argo floats every 10 days between April 2004 and October 2015. The mean fresh water transport is -1.18 ± 0.21 Sv (1 Sv = 10^6 m^3 s^-1 ; negative transport is southwards), implying a freshwater convergence of -0.38 ± 0.21 Sv between the Bering Strait and 26.5°N. Consistent with a freshwater loss from the region. While the majority of the variability in this divergence can be described by variability in the MOC, there is a detectable but small change in the fresh water transport that is not correlated with the MOC. We will explore the long-term variability in the fresh water transport that isn't correlated with the MOC.

Theme 4 Oral presentation Thursday afternoon

North Atlantic variability and its links to European climate over the last 3000 years

Paola Moffa Sanchez[*], Ian R. Hall

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Intense winter air–sea heat exchange in the centre of the Labrador Sea creates dense ocean mixed layers, which ventilate the intermediate depths of the North Atlantic and beyond, and also modulate the surface circulation of warm waters around the subpolar gyre. Model studies suggest changes in the vertical and horizontal circulation in the North Atlantic driven by the intensity of deep-water formation in the Labrador Sea can modify the northward heat transport. Recent observations reveal considerable spatial and temporal variability, associated with the formation and meridional transport of Labrador Sea Water, over the past few decades. Yet, crucially, its longer-term history and interactions with European climate at centennial time-scales remain limited. In this study, we present new decadally resolved multi-proxy records from marine sediment cores recovered from the Southern Greenland Margin and Iceland Basin spanning the last 3000 years. The new results, in combination with other published marine reconstructions, collectively suggest that increased southward flow of Arctic waters forced weakening of deep water formation in the Labrador Sea and associated gyre strength with similar timing to the cold periods recorded in terrestrial records around the North Atlantic at 3000-2500, 1100-1500 and 500-100 years BP. These new data strongly support that changes in the subpolar North Atlantic circulation, forced by freshwater input from the Arctic Ocean, played an active role in modulating the climate of Europe with important impacts on societies as revealed in European history.

Theme 3 Oral presentation Wednesday morning

A role of the Atlantic Ocean in predicting summer surface air temperature over North East Asia?

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We assess the ability of the DePreSys3 prediction system to predict the summer (JJAS) surface-air temperature over North East Asia. DePreSys3 is based on a high resolution ocean-atmosphere coupled climate prediction system (~60 km in the atmosphere and ~25 km in the ocean), which is full-field initialized from 1960 to 2014 (26 start-dates). We found skill in predicting surface-air temperature, relative to a long-term trend, for 1 year and 2-5 year lead-times over North East Asia, the North Atlantic Ocean and Eastern Europe. DePreSys3 reproduces the interdecadal evolution of surface-air temperature over the North Atlantic subpolar gyre and North East Asia along with the strong warming that occurred in the mid-1990s over both areas and for both lead-times. Composite analysis reveals that the mid-1990s warming was associated with the propagation of a Rossby wave, which follows the subtropical jet and modulates surface-air temperature from Europe to Eastern Asia. We hypothesise that the excitation of the circumglobal teleconnection pattern is due to the warming over the Atlantic Ocean and an associated increase in precipitation over the Sahel and the subtropical Atlantic Ocean. This mechanism is robust for the 2-5 year lead-time. For the 1 year lead-time we also stress a potential role of the Pacific Ocean in leading to skill in predicting SAT over Northeast Asia. Increased temperatures and precipitation over the western Pacific Ocean was found in association with a Pacific-Japan like-pattern, which can strongly impact East Asia's climate.

Theme 3 Poster T3-20

O – Q

Oceanic control of turbulent heat flux on decadal timescales in observations and models

Christopher H. O'Reilly[1*], Laure Zanna[1], Tim Woollings[1]

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The Atlantic Multidecadal Oscillation (AMO) significantly influences the climate of the surrounding continents and has previously been attributed to variations in the Atlantic Meridional Overturning Circulation. Recently, however, similar multidecadal variability was reported in climate models without ocean circulation variability. SST anomalies associated with the AMO are positively correlated with heat fluxes on decadal time scales in both observations and coupled climate models with varying ocean circulation, whereas in models without ocean circulation variability the anomalies are negatively correlated when heat flux anomalies lead. These relationships are captured in a simple stochastic model and rely crucially on oceanic forcing of SST. These relationships are examined in other regions - many of which contrast strongly with the North Atlantic - which reveal various regionally specific mechanisms through which the ocean exerts control on turbulent heat flux anomalies on decadal timescales.

Theme 1 Oral presentation Tuesday afternoon

A multi-model comparison of the ocean contributions to multidecadal variability in the North Atlantic

Pablo Ortega[1*], Jon Robson[1], Rowan Sutton[1], Blaker Adam[2], Germe Agathe[2], Hirschi Joel[2], Sinha Bablu[2], Hermanson Leon[3], Menary Matthew[3]

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In this study, we analyse the inter-relationships between the Labrador Sea densities, the boundary currents, the AMOC and, more generally, the wider climate of the North Atlantic across an ensemble of climate models. The study mostly relies on the analysis of two 300-year long high-resolution coupled control simulations (with HadGEM3-GC2 and HiGEM, respectively), and is completed with several forced ocean-only simulations (with NEMO) at 1/4 and 1/12 of a degree covering the last 40 years. This heterogeneous ensemble allows us to evaluate the robustness and realism of the results, as well as their sensitivity to the model configuration and resolution.

We have characterised the main modes of Labrador Sea density variability across these models. The leading EOF of Labrador Sea density is reasonably consistent across the ensemble. All models show a fairly uniform vertical structure, with maximum positive density values near the surface that slowly decrease with depth. In addition, both the control and historical experiments show comparable multidecadal variability in Labrador Sea density. There is also a good agreement between density evolution in the ocean-only forced experiments; all depict an increase in the Labrador Sea densities from the 60s to the mid 90s, followed by a decreasing trend up to the present. These coherent Labrador Sea density changes are encouraging, but do not appear to translate to coherent changes in the AMOC strength. Only two of the ocean-only forced runs show first an increase (until the mid90s) and subsequently a decrease in the AMOC strength at 45N. These discrepancies between the AMOC evolutions are enhanced at 26N, and seem to be associated with initial drifts in the ocean-only forced runs. Other potential ocean impacts of the Labrador Sea densities are then explored, in particular their link with the western boundary currents and the North Atlantic subpolar gyre. A selection of key diagnostics is finally evaluated for an ensemble of CMIP5 preindustrial control experiments, to better assess the model dependence of the previous results.

Theme 3 Poster T3-21

The role of subsurface salinity in controlling decadal variability of convection: A model-based study

Pablo Ortega[*], Jon Robson, Rowan Sutton

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NCAS Climate/University of Reading, Reading, United Kingdom

There is considerable evidence that deep ocean convection plays a key role in North Atlantic decadal variability. This study exploits a high-resolution preindustrial climate simulation with HadGEM3-GC2 to investigate the mechanisms that govern decadal variability of convection in the Irminger Sea, which is a unique region in the model characterised by decadally-paced intermittent activity. We find that surface cooling, ultimately driven by the North Atlantic Oscillation, is a necessary trigger for the sustained convection events, but persistence of convection arises from other influences. Specifically, Irminger Sea convection is found to be preceded by a density-compensated subsurface salinification, that in the model seems to be linked to changes in the overflow waters. Its influence on convection is explained by the presence of a feedback mechanism that leads to an amplification of salinity at the surface. The proposed chain of events unfolds as follows: 1) after the arrival of subsurface positive salinity anomalies, 2) convection events triggered by surface winter cooling, 3) lead to a warming and a salinification at the surface through increased mixing. Throughout the year, the warm temperature anomaly is substantially damped by the atmosphere, leaving a salty and dense anomaly at the surface that reduces stratification, and provides a positive feedback on convection.

The validity of this mechanism is tested with the help of a conceptual model for convection, which suggests that the feedback can only occur in regions where salinity increases with depth, a climatological condition that is met in several areas of the northern North Atlantic. The conceptual model also suggests that while decadal modulations in subsurface salinity are not essential for the mechanism to occur, they can notably enhance the persistence of convective activity in regions where the salinity increases with depth, and thus lead to intermittent decadal variations.

Theme 3 Oral presentation Wednesday morning

Observational evidence of European summer weather patterns predictable from spring

Albert Osso*, Rowan Sutton, Len Shaffrey, Buwen Dong

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NCAS-Climate, University of Reading, UK

Forecasts of summer weather patterns months in advance would be of great value for a wide range of applications. However, operational seasonal forecasts for European summers have very little skill. It has not been clear whether this low skill reflects inherent unpredictability of summer weather or, alternatively, is a consequence of weaknesses incurrent forecast systems. We analyse atmosphere and ocean observations and identify evidence that a specific pattern of summertime atmospheric circulation – the Summer East Atlantic (SEA) pattern – is predictable from the previous spring. An index of North Atlantic sea surface temperatures in March-April can predict the SEA pattern in July-August with a correlation skill above 0.6. Our analyses show that the sea surface temperatures influence atmospheric circulation and the position of the jet stream over the North Atlantic. The SEA pattern has a particularly strong influence on rainfall in the British Isles, which we find can also be predicted months ahead with significant skill. Our results have immediate application to empirical forecasts of summer rainfall for the UK, Ireland and northern France and also suggest that current operational forecast systems have large potential for improvement.

Theme 1 Oral presentation Tuesday afternoon

Can the western boundary profile at 26N be used to extract buoyancy-forced AMOC signals?

Irene Polo*, Jon Robson, Keith Haines, Chris Thomas

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Department of Meteorology, University of Reading,

The AMOC circulation is driven both by direct wind stresses and by the buoyancy driven formation of North Atlantic Deep Water over the Labrador and Nordic Seas. In many models low frequency density variability down the western boundary of the Atlantic basin is linked to changes in the buoyancy forcing over the Atlantic Sub-Polar Gyre (SPG) region, and is also found to explain part of the geostrophic AMOC variability at 26N. In this study, using different experiments with an OGCM, we develop a statistical method to identify characteristic vertical density profiles at 26N at the western boundary, which relate to the buoyancy-forced AMOC. We show that density anomalies due to anomalous heat loss over the SPG propagate equatorward along the western Atlantic boundary, through 26N, and then eastward along the equator, and poleward up the eastern Atlantic boundary. The timing of the density anomalies appearing at the boundaries at 26N reveals two propagation speeds leading to ~7months and ~3years lags between the boundaries. The propagating modes have different vertical density profiles, with maxima along ~1300m and ~2700m respectively. Results suggest that depth structure, and the lagged covariances between the boundaries at 26N may together provide useful information for detecting density anomalies of high latitude origin in more complex models, and potentially in the observational RAPID array.

Theme 3 Poster

Understanding CMIP5 model diversity in simulating the teleconnection between Atlantic Multidecadal Variability and European temperature

Saïd Qasmi, Christophe Cassou*, Julien Boé

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Properties of the Atlantic Multidecadal Variability (AMV) and its teleconnection with summer temperature over Europe are studied in an ensemble of climate simulations. Model results are compared to observations, factoring the large uncertainties associated with the shortness of the observational record when dealing with multi-decadal properties, and the estimation of the forced signal. A very large inter-model spread of AMV properties is found and many models are not compatible with the observations. The causes of this spread are then studied. The strength of modelled teleconnections is found to depend on the correlation between subpolar gyre and tropical North-Atlantic sea surface temperatures. Additionally, models with more persistent AMV have stronger teleconnections. Our results also suggest that the strength of the teleconnections depends on the ratio between climatological oceanic and atmospheric meridional energy transport. Overall, our results underline the need to be cautious when dealing with decadal properties in climate models.

Theme 1 Oral presentation Tuesday afternoon

R – S

The status of the RAPID 26N mooring array as serviced in 2017

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National Oceanography Centre, Marine Physics and Ocean Climate, UK

The RAPID 26N mooring array was serviced in Spring 2017 meaning we now have data from 13 years of observations. Here we present the current configuration of the array including biogeochemical sensors added for the ABC Fluxes project and other sensors added for the MerMEED project. There is also some discussion of changes in the data return and sensor drift experienced from moving to 18-month service intervals since 2012.

As part of the mooring servicing operations we recovered the MYRTLE-X lander based telemetry system, so we present information on the performance of the system since it was deployed in Autumn 2015.

Theme 2 Poster T2-07

A skilful annually resolved and absolutely dated marine spatial network reconstruction of North Atlantic subpolar gyre dynamics

David J. Reynolds[1*], Ian R. Hall[1], Sophie S. Slater [1], Madelyn Mette[2], Alan D. Wanamaker[2], James D. Scourse[3], Freya Garry[4], Paul R. Halloran[4]

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Spatial network analyses of precisely dated, and annually resolved, tree-ring proxy records have facilitated robust investigations of atmospheric climate variability. In contrast, a lack of similarly dated marine archives has constrained the use of such techniques in the marine realm, despite the potential for developing a more robust understanding of the role basin scale ocean dynamics play in the global climate system. Here we show a spatial network of marine molluscan sclerochronological oxygen isotope (d18O) series spanning the North Atlantic region provide a skilful, annually resolved and absolutely dated, reconstruction of basin scale North Atlantic sea surface temperatures (SSTs). Our analyses demonstrate that the composite marine series (referred to as d18Oproxy_PC1) is significantly sensitive to inter-annual variability in North Atlantic SSTs ($R=-0.61$ $P<0.01$) and surface air temperatures (SATs; $R=-0.67$, $P<0.01$) over the 20th century. Subpolar gyre (SPG) SSTs dominates variability in the δ18Oproxy_PC1 series at sub-centennial frequencies ($R= 0.51$, $P<0.01$). Split calibration and verification statistics indicate that the d18Oproxy_PC1 series provides a skilful reconstruction of North Atlantic and SPG SSTs. Comparison of the d18Oproxy_PC1 series against variability in the strength of the European Slope Current strength and maximum North Atlantic overturning derived from numeric climate models (CMIP5), indicates that variability in the SPG region, associated with the strength of the surface currents of the North Atlantic are likely playing a significant role in driving the variability in the d18Oproxy_PC1 series. The precise nature of the reconstruction combined with the annual resolution and absolute dating precision makes these reconstructions a powerful archive for validating numeric climate models. The application of these data in integrated data-model analyses will ultimately facilitate the reduction in simulation uncertainties and stimulate a more robust quantitative understanding of the role the North Atlantic Ocean plays in the wider climate system.

Theme 3 Poster T3-22

Understanding the role of the North Atlantic subpolar gyre in near-term climate predictions

Jon Robson

NCAS-Climate, University of Reading, Department of Meteorology

The North Atlantic subpolar gyre has been highlighted as the region that is most improved in near-term climate predictions where climate models are initialised from observations. However, it is not clear what the impact of the improved subpolar gyre predictions has on the wider climate. Therefore, in this paper we compare hindcasts where the subpolar gyre was initialised from observations or from climatology. In particular, the focus will be on the hindcasts initialised prior to the mid-1990s warming. Results will focus on understanding the processes that lead to the successful predictions of upper Ocean heat content and sea surface temperature. Furthermore, we will show that initialisation of the SPG in the early 1990s also appears to play an important role in the prediction of the atmosphere, and particularly the North Atlantic Oscillation. Therefore, these results highlight the role of the North Atlantic Ocean in improving climate predictions further afield.

Theme 3 Poster T3-23

Partitioning of heat and salt transport, and the partial compensation of heat and salt in the North Atlantic

Vassil M. Roussenov*, Richard G. Williams

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University of Liverpool, School of Environmental Sciences, UK

There have been marked gyre-scale property changes in the North Atlantic over the past 50 years: the subtropics warmed and became more saline, whereas the subpolar ocean cooled and freshened. However, increasing upper ocean temperatures and salinities across the whole basin dominate the recent period from 1995 to 2013, leading to a gradual decrease of the density. These property changes are partly driven by the convergence of heat and salt transports. Transport of heat and salt are achieved in a different manner: heat is transferred by the Ekman cell at low latitudes, MOC-Ekman cell at mid-latitudes and also by the horizontal circulation at high latitudes. In contrast, salt is transferred by the Ekman cell at low latitudes, MOC-Ekman cell at mid-latitudes with opposing horizontal circulation at low and mid-latitudes, and mostly by the horizontal transport reinforced by MOC-Ekman cell at high latitudes. The resulting temperature and salinity anomalies have similar signs in general leading to potentially compensating effects on the density. However, the temperature and salinity contributions are not fully compensated with the temperature variations dominating over the upper 3000m and the salinity changes dominating the deep ocean density anomalies. The decreasing density in the sub polar gyre since 1995 is due to the warming of the upper 1500m and freshening below 1500m. The decreasing boundary density in the Labrador Sea leads to decrease of the overturning and reduced exchange of heat and salt between the subtropical and subpolar gyres.

Theme 3 Poster T3-24

Long Range Predictability of the Atmosphere in the North Atlantic Sector

Adam A. Scaife

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Skilful climate predictions of the winter North Atlantic Oscillation and Arctic Oscillation out to more than a year ahead have recently been demonstrated. Here we investigate the sources of this predictability. We show high levels of skill in tropical rainfall predictions, and associated signatures in the atmospheric circulation that are approximately symmetric about the equator and resemble steady poleward propagating linear Rossby waves. This mechanism explains a sizable fraction of the predicted variation in the winter North Atlantic Oscillation. We will also show the outcome of recent real time forecasts, including the extreme events of northern winter 2015/16. Finally, we present an update on an outstanding issue with these climate predictions: a "signal to noise paradox", whereby predictable signals in the model appear to be smaller than predictable signals in the real world, lead to predictions that can be underconfident.

Theme 3 Invited talk Wednesday morning

Using CryoSat-2 sea ice thickness distribution to constrain the CICE sea ice model

David Schroeder[1*], Michel Tsamados[2], Danny Feltham[1], Andy Ridout[2]

** Presenting author*

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What can we learn from the recent CryoSat-2 sea ice thickness measurements for sea ice modelling? Are the CryoSat-2 thickness data accurate enough to derive sub-grid scale ice thickness distribution (ITD)?

For the first time the ITD is derived from the along track CryoSat-2 individual thickness measurements for 5 winter periods October to April from 2010 to 2015. The monthly mean ITD is calculated with respect to 5 CICE ice categories used in e.g. HadGEM3 simulations: (1) ice thickness h < 60 cm, (2) 60 cm < h < 1.4 m, (3) 1.4 m < h < 2.4m, (4) 2.4 m < h < 3.6 m, (5) h > 3.6 m. We perform stand-alone CICE simulations initialized with CryoSat-2 ITD in November 2010 to 2014 and April 2011 to 2015. Winter sea ice growth is underestimated applying the default CICE setup during all years. An increase in ice and snow conductivity can match the mean simulated ice growth with the CryoSat-2 ice growth and also improves the simulation of summer ice extent. The width of ITD is generally wider in CICE than in CryoSat-2. A reduction of ice strength and of the area participating in ice ridging can reduce the width of ITD within CICE. Impacts of these changes on longer CICE simulations are discussed.

Theme 1 Poster T1-04

The late 2000's decrease in the Atlantic Meridional Overturning Circulation

David Smeed[1*], Simon Josey[1], Claudie Beaulieu[2], Bill Johns[3], Ben Moat[1], Eleanor Frajka-Williams[2], Darren Rayner[1], Chris Meinen[4], Molly Baringer[4], Harry Bryden[2], Gerard McCarthy[1]

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Variability of the Atlantic Meridional Overturning Circulation (AMOC) plays a central role in the climate of the North Atlantic. Observations in the sub-tropical North Atlantic showed that the AMOC reduced by 10% over the period from 2007 to 20111, and it has been suggested that the reduction was forced by changes in the properties of Labrador Sea deep-water. Using new data from the RAPID array at 26°N we show that the AMOC has not reduced further but now occupies a weaker circulation state relative to the first years of observations. Changes of both surface and deep waters contributed to this change. This change of AMOC state is concurrent with other changes in the North Atlantic including a more northerly path of the Gulf Stream, evidenced by a change in the currents observed by satellite altimetry, and by an altered pattern of sea-surface temperature (SST)

The observed change in SST is described by a dipole that resembles the pattern of response to a declining AMOC predicted by coupled climate models3. Concurrent changes in air-sea fluxes reveal that the changes in ocean heat transport and sea-surface temperature have altered the pattern of ocean-atmosphere heat exchange over the North Atlantic. These results provide strong evidence to support the hypothesis that the AMOC is a major factor in decadal scale internal variability of North Atlantic climate.

Theme 3 Oral presentation Wednesday afternoon

How does Arctic sea ice affect the North Atlantic Oscillation?

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Changes in Arctic sea ice have the potential to influence the North Atlantic Oscillation (NAO) and hence affect winter climate in Europe and North America and drive changes in the North Atlantic Ocean. Given that Arctic sea ice extent has reduced substantially over the last few decades and is expected to continue to decline with further warming in future, understanding the influence on the NAO is crucial for predicting how climate will evolve over the coming decades. However, despite many modeling studies there is no consensus even on the sign of the NAO response to reduced Arctic sea ice. Here we use a comprehensive set of atmosphere only and fully coupled simulations with the Hadley Centre climate model, HadGEM3, to show that the sign of the NAO response to reduced Arctic sea ice is controlled by the refraction of planetary waves. Since the refractive index depends on the climatological zonal winds this highlights the role of model biases, and could help to resolve differences in previous studies. It also potentially provides an "emergent constraint" to narrow the uncertainties in the NAO response, highlighting the need for future multi-model coordinated experiments. To address this, a new CMIP6 MIP, Polar Amplification MIP, is currently being developed and will be briefly outlined.

Theme 1 Oral presentation Tuesday afternoon

Instabilities and Interior Transport Pathways of the Deep Western Boundary Current in the North Atlantic

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Recent observations and modelling of the Deep Western Boundary Current (DWBC) in the North Atlantic have revealed that its role as a southward conduit for the Atlantic Meridional Overturning Circulation (AMOC) is less coherent than implied by classical theories. Instead, the southward AMOC transport is accomplished not only by the coherent, relatively steady component of the DWBC, but also via interior pathways. These pathways tend to have chaotic trajectories, leaving the continental slope to the basin interior before returning southwestward, and hence have longer transit times in the North Atlantic. Floats released within the DWBC almost invariably escape into the ocean interior, sometimes returning to the DWBC much further downstream.

We investigate the development of interior pathways from the DWBC by conducting nested high-resolution (2.5 km horizontal grid spacing) numerical simulations of the northwest Atlantic using the UCLA Regional Ocean Modelling System (ROMS). We focus on the formation and development of instabilities near the Grand Banks of Newfoundland (GB), a site known to exhibit pronounced eddy activity. We find that production of eddy kinetic energy (EKE) is dominated by conversion from available potential energy (APE), indicating that baroclinic instabilities dominate eddy generation over the continental slope and throughout the GB region. We further investigate the intermittent occurrence of DWBC restratification events that contribute to the time-averaged APE->EKE transformation, and their statistical and dynamical relation to external disturbances such as Gulf Stream Rings and proximity to the North Atlantic Current. Finally, the finite-time evolution of these disturbances into coherent eddies, and their propagation and relation to interior pathways are investigated via the use of particle tracking.

Theme 3 Poster T3-25

Impact of the cold temperature anomalies in the North Atlantic on the summer European climate, case study of the summer 2015

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For the last coupled of years, the North Atlantic Ocean is dominated by a strong negative sea temperature anomaly of about 2 degrees. Previous studies have shown a strong link between this cold ocean anomaly and heat wave in Central Europe in 2015. Here, we want to investigate the role of this extreme cold temperature in the ocean using the fully coupled seasonal forecast system of Météo France, also for the summer 2015. Several experiments are carried out where this particular temperature anomaly in the North Atlantic is added or removed in the seasonal prevision. Preliminary results show an effect of the temperatures and precipitations in Central Europe.

Theme 1 Poster T1-05

High-resolution records of the Northeast Atlantic from the Late Holocene: Exceptional 20th century changes?

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The North Atlantic Ocean plays a key role in modulating global climate via its role in the Atlantic meridional overturning circulation (AMOC). However, instrumental records of the region are sparse prior to 1950 CE. To assess whether recent oceanographic change in the region is due to natural multidecadal cycles or to anthropogenic impacts requires the use of high-resolution paleo-proxy archives spanning the last several hundreds/thousands of years. Of particular interest is the strength of the subpolar gyre, which affects the distribution of water masses in the north Atlantic. The transport and mixing of water in the region south of Iceland is very dependent on subpolar gyre strength. Here we present planktonic foraminifera faunal assemblage data and associated Mg/Ca-δ18O records from cores in the Iceland basin with ~4 year resolution. We report a dramatic increase in the percept abundance of the subtropical species Robeline universe during the late 20th century, as well as significant changes in three other main species of planktonic foraminifera. These changes could be related to both 20th century warming and/or exceptional regional hydrographic variability.

Theme 3 Poster T3-26

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

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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 Nile 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 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. For a 0.1 Sv release in the Mediterranean catchment, I find that the collapse of the MOW leads 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 (i) the impact of the decreased MOW on the Azores current first leads to enhanced North Atlantic drift increasing convection in the Irminger Sea, while (ii) 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 (iii) 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 weakens the AMOC in the long term. The weight of these three processes for the fate of the AMOC depends on the freshwater release rate, leading to weakening for rates larger than 0.05 Sv and enhancement for lower rates.

Theme 1 Poster T1-06

Arctic sea ice decline weakens the Atlantic Meridional Overturning Circulation

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The on-going decline of Arctic sea ice exposes the ocean to anomalous surface heat and freshwater fluxes, resulting in positive buoyancy anomalies that can affect ocean circulation. In this study, we use an optimal flux perturbation framework and comprehensive climate model simulations to estimate the sensitivity of the Atlantic meridional overturning circulation (AMOC) to such buoyancy forcing over the Arctic and globally, and more generally to sea ice decline. It is found that on decadal timescales flux anomalies over the subpolar North Atlantic have the largest impact on the AMOC, while on multi-decadal timescales (longer than 20 years), flux anomalies in the Arctic become more important. These positive buoyancy anomalies spread to the North Atlantic, weakening the AMOC and its poleward heat transport. Therefore, the Arctic sea ice decline may explain the suggested slow-down of the AMOC and the "Warming Hole" persisting in the subpolar North Atlantic.

Theme 3 Oral presentation Wednesday afternoon

The AMOC and the global overturning circulation: controls and interactions

Lynne Talley

UCSD, Scripps Institution of Oceanography, USA

The North Atlantic overturning circulation (AMOC) is inextricably linked to the global overturning circulation (GOC), as reviewed here based on a number of recent process models and global model analyses, matched with observed transports and water properties. Controls are exerted on:
(i) the basin of deep water ventilation by large-scale freshwater transports through the atmosphere that create a contrast between saline (Atlantic/Indian) and fresher basins (Pacific);
(ii) AMOC overturning strength by winds in the Southern Ocean;

(iii) AMOC density range by isopycnal outcropping in the Southern Ocean;
(iv) relative density of NADW vs. Pacific and Indian Deep Waters in the Southern Ocean, and hence contribution to Antarctic Bottom Water formation, by abyssal diapycnal diffusion.
Observed age tracers and Southern Hemisphere modelled tracers indicate a timescale on the order of a century for North Atlantic deep waters to reach the surface in the Southern Hemisphere, where they influence centennial climate variability.

Theme 2 Invited talk Thursday morning

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Using lagged covariances to assimilate RAPID data

Chris Thomas[1*], Keith Haines[1], Irene Polo[1], Jon Robson[1]

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The motivation of this work is to assimilate the observations of the AMOC made by the RAPID array by modifying ocean densities 'upstream' in the Labrador Sea. Previous studies have shown that the AMOC is robustly sensitive to anomalies in the Labrador Sea, which occur at a time lag of several years earlier. The RAPID data will be assimilated into a high-resolution (0.25°) global NEMO-CICE model. Assimilating the data using a standard variational procedure with a multi-year time window would be impractical in such a model. Instead, the aim is to use robust covariance information to make earlier increments without the need for an adjoint. The covariances are used to assimilate the lagged data on top of the trajectory produced by an initial (standard) variational assimilation. Using earlier assimilation increments should give better continuity to the circulation and the heat transports, making the model more useful for coupled forecasting. We will present the lagged covariance methodology and show results from simulation studies of an idealised system. We will also show the results of the assimilation of RAPID data.

Theme 3 Poster T3-27

Shift to modern weaker state of Labrador Sea convection and reduced AMOC during the Industrial-era

David Thornalley[1,2*], Delia Oppo[2], Pablo Ortega[3], Jon Robson[3], Chris Brierley[1], Ian Hall[4], Lloyd Keigwin[2], Paola Moffa-Sanchez[4], Neil Rose[1], Peter Spooner[1], Igor Yashayaev[5]

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Several proxy and modelling studies suggest that there may have been considerable change in the operation of the Atlantic Meridional Overturning Circulation (AMOC) during the last two millennia. Yet despite its importance for regional and global climate, the recent history of the AMOC is poorly constrained. An apparent recent decline in the AMOC may be due to decadal variability in the formation of Labrador Sea Water (LSW), but short observational datasets preclude a longer-term perspective on the current state and variability of LSW formation and AMOC. We present a suite of AMOC related proxies from high resolution marine sediment cores from the North Atlantic, spanning the last ~2000 years, including proxies for both deep ocean circulation and surface ocean climate,

which can be compared to modern observational datasets. We provide multiple sources of palaeo-oceanographic evidence that show, ~150 years ago, a coherent shift in LSW formation, the strength of the deep western boundary current (DWBC), and upper ocean temperature patterns, all of them anomalous in the context of the last 2000 years and indicative of a weaker AMOC. We suggest the likely cause of weaker LSW and AMOC was enhanced freshwater fluxes from the Arctic to the North Atlantic, sourced from melting circum-Arctic glaciers and thickened sea-ice that had developed during the earlier Little Ice Age. Later twentieth century melting of the Greenland ice sheet may have contributed to maintaining the relatively weak state of LSW and AMOC. Our study reveals the atypical, weak background state of the modern Industrial era LSW and AMOC, upon which the recent decadal variability has occurred. These results have significant implications for the sensitivity of the AMOC to climate forcing, and the cause of late Holocene climate events.

Theme 3 Oral presentation Wednesday morning

Dissolved inorganic and organic nutrient transports across Florida Strait

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As part of the Atlantic Biogeochemical Fluxes (ABC Fluxes) Research Programme –the biogeochemical component of RAPID-, samples have been taken bimonthly across Florida Strait (FSt) at about 27N. These samples are collected for the measurement of dissolved inorganic and dissolved organic nutrients. Nutrient fields will be combined with velocity fields to compute nutrient transports.

Thus far we have data from eleven crossings; from May 2015 to February 2017. These data set is particularly relevant because it will allow us to assess 1) temporal variability in nutrient transports and 2) its relevance to the wider redistribution of inorganic and organic nutrient species in the North Atlantic (Natl), which has implications for primary production, nitrogen fixation and carbon export in the subpolar and subtropical regions.

By the time of the meeting we will be able to present an initial assessment of nutrient transports across FSt.

Theme 4 Poster T4-05 - WITHDRAWN

Anthropogenic impacts on carbon uptake variability in the subtropical North Atlantic: 1992 - 2010

Tobia Tudino

University of Exeter, Geography, UK

Since 1860, anthropogenic emissions have increased the atmospheric CO2 concentrations from 275ppm to more than 400ppm. The global ocean has taken around a third of the emitted CO2, reducing potential climate impacts, with the highest storage per unit area of anthropogenic CO2 occurred in the North Atlantic. Here, we investigate the upper-ocean (0-1000m) carbon uptake and storage in the subtropics (20°N - 30°N), examining data from a repeat (1992 - 2010) ocean transect and finding an average increase in dissolved inorganic carbon of 1.0µmol kg-1 yr-1. We attribute the measured rise to an expected anthropogenic CO2 (0.5 - 0.7µmol kg-1 yr-1, depending on the method used), and a previously unrecognized biological remineralisation (0.3µmol kg-1 yr-1) contributions. The contributing carbon from remineralised soft-tissues is then linked to the possible Atlantic meridional overturning circulation slow-down (2004 - 2012) and associated changes in the physical (one-quarter) and biological (three-quarters) carbon pump efficiencies. To investigate this hypothesis, we calculate correlations between North Atlantic meridional mass stream function (used as a ventilation proxy), sea surface chlorophyll (used as a biogeochemical proxy), and subtropical remineralised carbon in a 2kyr long climate model (CM2Mc) preindustrial control simulation. At high frequency (decadal), the effect of oceanic ventilation and biogeochemistry in the model broadly match the observations, accounting for three-quarter of the estimated North Atlantic subtropical remineralised carbon. However, at low frequency (multi-decadal), changes in ventilation are the most influential, accounting for more than a half of the carbon rising stock. We suggest that changes in the ocean state could impact the remineralised carbon pool in the subtropical North Atlantic, potentially making it a greater sink for carbon than previously thought.

Theme 3 Oral presentation Thursday morning

What are the main factors influencing the position of AMOC stability thresholds?

Richard Wood[1*], Jose Rodriguez[1], Robin Smith[2], Laura Jackson[1], Ed Hawkins[2]

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Is there a threshold in the fresh water forcing of the Atlantic basin beyond which a strong AMOC becomes unstable? If so, how far are we from that threshold? The Stommel salinity advection feedback, in which ocean fresh water transport into the Atlantic basin across 34°S responds to changes in the AMOC strength, plays an important role in determining the position of the threshold. The sign of the Somme feedback is estimated by the overturning component of the fresh water transport into the Atlantic (Fov), with Fov<0 implying a destabilising feedback. Hence Fov has been proposed as a diagnostic of AMOC stability.

However the Stommel feedback is not the whole story, and other feedbacks also play stabilising and destabilising roles. These include heat and fresh water transports by other elements of the ocean circulation, and changes in atmospheric moisture transport. The overall stability of the AMOC is determined by the sum of these feedbacks. Based on a hierarchy of models of differing complexity, we present a framework to compare the effects of a number of large-scale feedbacks, and to identify which particular feedbacks are likely to dominate in the present and projected future climate states.

Theme 3 Poster T3-28

Decadal modulation of Atlantic jet variability

Tim Woollings

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The variance of a jet's position in latitude is found to be related to its average speed: when a jet becomes stronger its variability in latitude decreases. This relationship is shown to hold for observed mid-latitude jets around the world and also across a hierarchy of numerical models. North Atlantic jet variability is shown to be modulated on decadal timescales, with decades of a strong, steady jet being interspersed with decades of a weak, variable jet. These modulations are also related to variations in the basin-wide occurrence of high-impact blocking events. A picture emerges

of complex multidecadal jet variability in which recent decades do not appear unusual. We propose an underlying barotropic mechanism to explain this behaviour, related to the change in refractive properties of a jet as it strengthens, and the subsequent effect on the distribution of Rossby wave breaking.

Theme 3 Oral presentation Wednesday morning

Estimating the deep overturning transport variability at 26ºN using bottom pressure recorders.

Emma L. Worthington

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Atlantic meridional overturning circulation (AMOC) transports estimated from over a decade of RAPID array measurements at 26.5ºN identify a decline in the strength of its deep return flow. The deep transport is usually calculated as a residual from the other components of the AMOC, assuming a zero-net transport across the section. An alternate method to estimate deep transports uses bottom pressure data. However, bottom pressure sensors suffer from instrument drift, and although this can be removed during processing, any real low-frequency tendencies are also removed.

This study will use 13 years of bottom pressure data from both the RAPID array and the Gravity Recovery and Climate Experiment (GRACE) satellite mission. The GRACE ocean bottom pressure data will be used to remove only the instrument drift from the sensor measurements. The deep transport variability at 26.5ºN will then be estimated from the corrected bottom pressure data, and used in conjunction with other components to determine the total AMOC variability. If the deviation from the zero net AMOC flow is within an expected measurement uncertainty of +/- 2 Sverdrup, then this approach will provide a valid alternative to the zero-net transport method of determining AMOC variability. Comparing the estimated and calculated residual deep transports will also provide additional validation of the zero-net transport method. The results should also provide additional evidence whether there has been a decline in AMOC strength over the last 13 years, and if so, how much is due to a reduction in the deep transport.

Theme 3 Poster T3-29

Skilful multi-year predictions of precipitation over land using CESM

Stephen Yeager*, Nan Rosenbloom, Gary Strand, Keith Lindsay, Gokhan Danabasoglu, Alicia Karspeck, Susan Bates, Jerry Meehl

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We present results from a new large ensemble (LE) of initialized decadal prediction (DP) experiments carried out with the Community Earth System Model (CESM). This 40-member CESM-DP-LE suite of experiments represents the "initialized" complement to the CESM large ensemble of 20th century runs (CESM-LE) documented in Kay et al. (2015). Both simulation sets share the same model configuration, historical radiative forcings, and ensemble sizes. CESM-DP-LE exhibits significant skill improvement over persistence and CESM-LE in retrospective predictions of summer precipitation over South America and the African Sahel. This skill appears to emanate primarily from long-lead time skill at predicting Atlantic subpolar gyre heat content and SST variations, but the tropical Pacific is also implicated. The mechanisms underpinning skill at predicting precipitation over land in the Atlantic sector, and the relative impacts of SST in different regions, are explored using conditional subsampling of the large ensemble.

Theme 3 Oral presentation Wednesday morning

Arctic-Atlantic climate variability and predictability provided by poleward ocean heat transport

Marius Årthun

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A potential for climate predictability is rooted in anomalous ocean heat transport and its consequent influence on the atmosphere above. Here we investigate, using both observations and output from coupled climate models, to what extent ocean heat anomalies are communicated along the Atlantic water pathway toward the Arctic, with a special emphasis on the exchange between the subpolar North Atlantic and Nordic Seas. A potentially predictable relation between anomalous ocean heat and climate in the Nordic Seas region is identified. Ocean heat anomalies along the Atlantic water pathway are reflected in Arctic winter sea ice extent and found to influence the atmosphere by driving changes in surface air temperatures through anomalous air-sea fluxes. The coherence between ocean and atmosphere is manifested in a common and dominant 14-yr time scale of variability. Statistical regression models show that a significant part of Arctic-Atlantic climate can thus be predicted up to a decade in advance based on the state of the ocean.

Theme 3 Poster T3-30

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Rapid Climate Change

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