The Leverhulme Trust

APPLICATION FORM – Research Fellowship

Applicant: Dr Eleanor Frajka-Williams	ID/Ref:
Project Title: Variability of Ocean Transports in the Atlantic from Space	

Applicant Details

Submission Date:	N/A
Total Requested:	14,350

General Details

Title	Dr	**Gender**	Female
First Name(s)	Eleanor	**Date of Birth**	23/12/1979
Surname	Frajka-Williams		

Contact Details

Department	Ocean and Earth Sciences		
Institution	University of Southampton		
Address	National Oceanography Centre Southampton Empress Dock Southampton SO14 3ZH	**Telephone Number** **Email**	02380596044 e.frajka-williams@soton.ac.uk

Career Details

Are you self employed	No

Employment

Employment 1	02/2012 To
Job Title:	Lecturer
Employer:	University of Southampton, National Oceanography Centre

Employment 2	08/2009 To
Job Title:	Senior Research Fellow
Employer:	University of Southampton, National Oceanography Centre

Education Details

Degree/Qualifications

Degree 1	06/2002 To 06/2005
Degree/Qualification : Subject	MSc : Physical Oceanography
Institution:	University of Washington

Degree 2	06/2002 To 08/2009
Degree/Qualification : Subject	MSc : Applied Mathematics
Institution:	University of Washington

Degree 3	09/1998 To 06/2002
Degree/Qualification : Subject	BA : Applied Mathematics
Institution:	Harvard University

Doctoral Degrees

Degree 1	07/2002 To 08/2009
Degree/Qualification : Institution	PhD : University of Washington
Title of Thesis:	he spring phytoplankton bloom and vertical velocities in the stratified and deeply convecting Labrador Sea, as observed by Seagliders.
Supervisor Name:	Peter B. Rhines

Research Details

Title of research proposal	Variability of Ocean Transports in the Atlantic from Space
Main/sub field of study	Computing, Earth Sciences, Physics

Abstract

The meridional overturning circulation (MOC) transports heat poleward, playing a key role in climate. A collapse of this circulation has been linked to dramatic predicted cooling in the UK. Since 2004, the RAPID project has been monitoring the strength of the MOC to better understand variability. We propose to use the RAPID observations to develop a satellite and autonomous float-based estimate of transport variability. Validating the method at two further locations, we will extend the observation-based estimate across the subtropical Atlantic to reveal how the ocean transports heat, and further use these estimates to understand atmospheric drivers of variability.

Places where you will carry out the proposed research

A majority of the work will be carried out at the NASA Jet Propulsion Laboratory in Pasadena, California. I will collaborate with Josh Willias (project scientist on the JASON-3 altimeter) and Felix Landerer (scientist on GRACE ocean bottom pressure), both of whom are ocean scientists now using satellite observations to study circulation. While based in Pasadena, I also propose to visit the 3 major oceanographic institutes in the US: nearby Scripps, WHOI and Univ of Washington, where scientists are responsible for observational projects at other latitudes in the Atlantic.

Relevant experience/skills/training

I have 5 years of experience working with the RAPID observations at 26N; during 2 of these years was responsible for data quality from the array. I have written and co-written a range of peer-reviewed papers on these observations, including using them with satellite data to broaden our understanding. Prior to this time, I also used satellite and other insitu observations to study ocean dynamics. With recent work on the transport estimates and using satellite observations, I am well-placed to leverage the RAPID in situ observations against satellite data across the Atlantic.

Research and Publications

Detailed statement of proposed research

File: Proposed Research

1. Background and Motivation

The meridional overturning circulation (MOC) in the ocean—commonly referred to as the global ocean conveyor—transports heat and properties (carbon, oxygen) around the ocean. The strength of the Atlantic MOC has been linked to the temperate climate over the UK and Europe, with climate models predicting that a collapse of the MOC would result in a substantial cooling here. Due to its importance in the global climate system, the UK/US-funded RAPID project at 26N has been monitoring the MOC since 2004.

The expectation intrinsic in making measurements at one latitude is that they will be representative of the broader ocean circulation. Indeed, numerical modelling studies (e.g., Bingham et al. (2007)) have indicated that the MOC is coherent across the subtropics. But using the transports at 26N and a reconstruction at 41N (Willis, 2010) showed instead a distinct divergence between these latitudes. This divergence resulted in a cooling of the Atlantic (Cunningham et al., 2014), likely affecting ocean-atmosphere interactions.

To widen our understanding of the MOC at 26N, we propose to leverage satellite observations of ocean circulation. Willis and colleagues at JPL previously used altimetry and Argo floats to estimate transports at 41N. For interannual timescales, we propose to use a combination of altimetry, Argo and ocean bottom pressure to estimate transport variability across the subtropics.

2. Objectives

1. Quantify the relationship between ocean transport and satellite data across 26N. Establish what portion of the dynamic height profile is captured by sea level and bottom pressure.
2. Using these relationships, reconstruct the 26N transports from the best combination of sea level, in situ bottom pressure, GRACE bottom pressure and Argo data.
3. Replicate for 16N/39N in situ observations.
4. Analyse the meridional coherence of the MOC and estimated MHT over the past 1–2 decades and its relationship to drivers of variability across the subtropical basin.

If time permits, and pending the success of (1)–(3), we will proceed to objective (4) using the newly constructed estimates of transport.

3. Methods and Outcomes

The most complete observations are available at 26N, so we propose to start with relating transports and satellite data here. Prior results showed that sea level variations can capture boundary current variability (Frajka-Williams et al., 2013). Modelling results (Williams et al., 2014) and new preliminary evidence at 26N (see Fig, also verified in 30-year 1/12 degree model simulations) suggest that sea level can covaries with transbasin transports on interannual timescales. Combining the RAPID observational expertise of Frajka-Williams and satellite ocean expertise at JPL, these preliminary satellite-based transport estimates can be refined, improved and pushed to the limit to establish the best relationship between in situ transport estimates and satellite/Argo-derived transport estimates.

Capitalising on the success at 26N, we will replicate the investigation at two additional latitudes: 16N at the MOVE array, and 39N at the Line W array. At both locations, observations are localized in the west. Fortunately, from RAPID observations, we find that on interannual timescales, transbasin transport variability is primarily governed by western boundary changes (McCarthy et al., 2012).

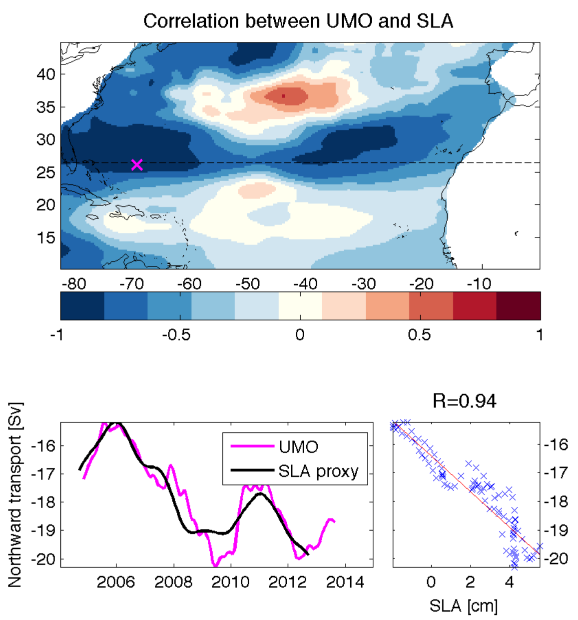

Figure. (top) Correlation coefficient between sea level anomaly (spatially- and temporally-smoothed) and the top 1000m transports from the in situ RAPID observations. (bottom left) Best time series of sea level (scaled) and transport time series. (bottom right) Scatter plot, showing linear regression.

Based on the findings from the first three objectives, the research may take two different directions. (1) If we can show that satellites capture ocean transport variability, we will use the spatial- and temporal-coverage of satellite data to estimate meridional volume transports across the full subtropical Atlantic. From this we can access transport divergence and estimate associated heat transport/divergence to speculate on the ocean's role in heat content changes since 1992 across the subtropics. (If Argo float profiles are needed, the reconstruction will be limited to the period since 2002.) (2) If instead we find that satellite data cannot reconstruct transport variability at 16N or 39N, then we will focus on using satellite data to elucidate the drivers of transport variability at 26N.

The majority of this research will take place during a research visit to JPL, though considerable effort will be invested before and after to maximize the benefit of the collaboration. Visits are planned to Scripps (responsible for MOVE 16N) and WHOI (responsible for Line W 39N), as well as UW where they are using altimetry to look at ocean heat content.

As Deliverables, we anticipate one paper on the method of recovering transport variability at 26N from satellite/alternate observations and either second for the basin-wide transports at 16N and 39N. A third paper on the full basin transport estimates or drivers of variability would follow from continuing collaboration rather than be completed during the visit.

This work is relevant to a large community of scientists studying the Atlantic MOC, including the CLIVAR US AMOC group and the RAPID groups in the US and UK. The impact of complete success of this proposed work would be broad: If we can use satellite-based estimates to recover interannual variability of ocean volume and heat transports, we will have extended the RAPID estimates of the MOC in time (back to 1993) and in space (across the subtopics). A partial success of the project will expand our understanding of transport variability at 26N into the wider context of the subtropical basin. This is timely with the recent installation of the OSNAP array in the subpolar North Atlantic.

References (not listed in next section)

Bingham, R. J., Hughes, C. W., Roussenov, V., and Williams, R. G. (2007). Meridional coherence of the North Atlantic meridional overturning circulation. Geophys. Res. Lett., 34:L23606.

Williams, R. G., Roussenov, V., Smith, D., and Lozier, M. S. (2014). Decadal evolution of ocean thermal anomalies in the North Atlantic: The effects of Ekman, overturning and horizontal transport. J. Climate, 27:698–719.

Willis, J. K. (2010). Can in situ floats and satellite altimeters detect longterm changes in Atlantic Ocean overturning? Geophys. Res. Lett., 37:L06602.

Major publications

File: Publications

Baringer, M. O., et al., Frajka-Williams, E., Macdonald, A., Dong, S., and Marotzke, J. (2013). Global oceans: Meridional overturning circulation and heat transport observations in the Atlantic Ocean. In Blunden, J. and Arndt, D., editors, *State of the Climate in 2012*, volume 94, S65–S68. Bull. Amer. Meteor. Soc.

Carton, J., Cunningham, S. A., Frajka-Williams, E., Kwon, Y.-O., Marshall, D. P., and Msadek, R. (2014). The Atlantic overturning circulation: More evidence of variability and links to climate. *Bull. Amer. Meteor. Soc.*, 95:163–166.

Clement, L., Frajka-Williams, E., Sheen, K. L., Brearley, J. A., and Naveira Garabato, A. C. (2015). Internal wave generation by mesoscale eddies impinging on the western boundary of the North Atlantic. *J. Phys. Oceano.*, in prep. (Word Count: 2643)

Clement, L., Frajka-Williams, E., Szuts, Z. B., and Cunningham, S. A. (2014). The vertical structure of eddies and Rossby waves and their e□ect on the Atlantic meridional overturning circulation at 26N. *J. Geophys. Res.*, 119:6479–6498.

*Cunningham, S. A., Roberts, C., Frajka-Williams, E., Johns, W. E., Hobbs, W., Palmer, M. D., Rayner, D., Smeed, D. A., and McCarthy, G. D. (2014). Atlantic meridional overturning circulation slowdown cooled the subtropical ocean. *Geophys. Res. Lett.*, 40:6202–6207.

Duchez, A., Cunningham, S. A., Hirschi, J. J.-M., Blaker, A., Bryden, H., Atkinson, C., McCarthy, G., Frajka-Williams, E., Rayner, D., and Smeed, D. (2014a). A new index for the Atlantic meridional overturning circulation. *J. Climate*, 27:6439–6455.

Duchez, A., Frajka-Williams, E., Castro, N., Hirschi, J. J.-M., and Coward, A. (2014b). Seasonal to interannual variability in density around the Canary Islands and their influence on the AMOC at 26.5N. *J. Geophys. Res.*, 119:1843–1860.

Elipot, S., Frajka-Williams, E., Hughes, C., and Willis, J. (2014). The observed North Atlantic meridional overturning circulation, its meridional coherence and ocean bottom pressure. *J. Phys. Oceano.*, 44:517–537.

Frajka-Williams, E. (2014). Sustaining observations of an unsteady ocean circulation. *Phil. Trans. Royal Soc. A*, 372:20130335.

Frajka-Williams, E., Cunningham, S. A., Bryden, H. L., and King, B. A. (2011a). Variability of Antarctic Bottom Water at 24.5°N in the Atlantic. *J. Geophys. Res.*, 116:C11026.

Frajka-Williams, E., Eriksen, C. C., Rhines, P. B., and Harcourt, R. R. (2011b). Determin- ing vertical velocities from Seaglider. *J. Atmos. Oceanic Tech.*, 28:1641–1656.

*Frajka-Williams, E., Johns, W. E., Meinen, C. S., Beal, L. M., and Cunningham, S. A. (2013). Eddy impacts on the Florida Current. *Geophys. Res. Lett.,* 40:349–353.

*Frajka-Williams, E., McCarthy, G. D., Johns, W. E., Smeed, D. A., Meinen, C. S., Duchez, A. D., Bryden, H. L., Rayner, D., and Moat, B. I. (2015). Observed covariability of the MOC at 26N in the Atlantic, 2004–2014. *Geophys. Res. Lett.*, in prep. (Word Count: 2817, Manuscript: http://bit.ly/1E6PgRC)

Frajka-Williams, E., Rhines, P., and Eriksen, C. (2009). Physical controls and mesoscale variability in the Labrador Sea spring phytoplankton bloom observed by Seaglider. *Deep Sea Research I*, 56:2144–2161.

Frajka-Williams, E. and Rhines, P. B. (2010). Physical controls and interannual variability of the Labrador Sea spring phytoplankton bloom in distinct regions. *Deep Sea Research I*, 57:541–552.

Frajka-Williams, E., Rhines, P. B., and Eriksen, C. C. (2014). Horizontal stratification during deep convection in the Labrador Sea. *J. Phys. Oceano.*, 44:220–228.

*Holton, L., Frajka-Williams, E., Duchez, A., Johns, W. E., Bryden, H. L., and Houk, A. (2015). The Antilles Current and wind forcing of transports at 26N in the Atlantic. *J. Geophys. Res.*, in prep. (Word Count: 6770, Manuscript: http://bit.ly/10WJSnY)

*McCarthy, G., Frajka-Williams, E., Johns, W. E., Baringer, M. O., Meinen, C. S., Bryden, H. L., Rayner, D., Duchez, A., Roberts, C. D., and Cunningham, S. A. (2012). Observed interannual variability of the Atlantic meridional overturning circulation at 26.5N. *Geophys. Res. Lett.*, 39:L19609.

McCarthy, G. D., Smeed, D. A., Johns, W. E., Frajka-Williams, E., Moat, B. I., Rayner, D., Baringer, M. O., Meinen, C. S., and Bryden, H. L. (2014). Measuring the Atlantic meridional overturning circulation at 26N. *Prog. Oceanography*, in press. (Word Count: 14327)

Mielke, C., Frajka-Williams, E., and Baehr, J. (2013). Observed and simulated variability of the AMOC at 26N and 41N. *Geophys. Res. Lett.*, 40:1159–1164.

Rayner, D., Hirschi, J. J.-M., Kanzow, T., Johns, W. E., Wright, P. G., Frajka-Williams, E., Bryden, H. L., Meinen, C. S., Baringer, M. O., Marotzke, J., Beal, L. M., and Cunningham, S. A. (2011). Monitoring the Atlantic meridional overturning circulation. *Deep Sea Research II*, 58:1744–1753.

Roberts, C. D., Waters, J., Peterson, K. A., Palmer, M., McCarthy, G. D., Frajka-Williams, E., et al..

(2013). Atmosphere drives observed interannual variability of the Atlantic meridional overturning circulation at 26.5N. *Geophys. Res. Lett.*, 40:1–7.
Smeed, D. A., McCarthy, G., Cunningham, S. A., Frajka-Williams, E., Rayner, D., Johns, W. E., Meinen, C. S., Baringer, M. O., Moat, B. I., Duchez, A., and Bryden, H. L. (2014). Observed decline of the Atlantic meridional overturning circulation 2004 to 2012. *Ocean Science*, 10:29–38.

Other matters you wish to bring to the notice of the Committee

This project comprises the major objective for my sabbatical in 2015/16. My teaching responsibilities for this period are covered.

Duration and Timing

Duration of whole project

The whole project will involve a period of preparation in the UK prior to the stay at JPL. This will commence in January 2015 (following the end of teaching activities) with the visit to JPL beginning from mid-February. It is anticipated that the visit will lead to continued collaborative research, both during the remainder of my study leave in 2016 and beyond. Finalisation of manuscripts is tentatively planned for Sep 2016, so the whole project will span 9 months. After this time, continued collaboration can be regarded as beyond the scope of the present project.

Duration of Fellowship (3-24 months)	6
Proposed start date	01/01/2016
Percentage of time to be spent on the project during the Fellowship	100

Details of other research projects and commitments during the Fellowship

I will maintain contact with my PhD students and postdoc while I am away. However, all students and postdoc also have an additional Southampton supervisor.

Referees

Referee 1	Professor David Marshall
Department : Institution	Physics : Oxford University
Position:	Professor
Email:	d.p.marshall@atm.ox.ac.uk

Referee 2	Professor Luanne Thompson
Department : Institution	Oceanography : University of Washington
Position:	Professor
Email:	luanne@uw.edu

Referee 3	Dr Matt Palmer
Department : Institution	Hadley Centre : Met Office
Position:	Scientist
Email:	matthew.palmer@metoffice.gov.uk

Previous and Current Applications

Previous Leverhulme awards or pending applications to the Trust

None

Other awards received in the last 3 years related to this research

DynOPO - Dynamics of the Orkney Passage Outflow studying circulation changes using moored observations at the Orkney Passage outflow from the Weddell Sea
GliSENEX - Using glider-based vertical velocity estimates to determine vertical nutrient fluxes in the ocean.

Applications you have made or intend to make to other bodies related to this research proposal

I will apply for a Royal Society travel grant for £3000.

Finance

Replacement costs or loss of earnings

No costs have been added.

Research Expenses

	Total
UK travel Heathrow airport (to/from Southampton), by taxi £200	£200
Overseas travel Return flight to Los Angeles (leaving Feb 2016, returning May 2016) - estimated cost £900 Return flight between Los Angeles and Boston, and ground travel, estimated cost £600 Return flight between Los Angeles and Seattle, and ground travel, estimated cost £350	£1,850
Overseas subsistence 3 months housing in Pasadena, CA estimated at £1100 per month (total £3300) 3 months hire car, est. at £400 per month (total £1200) A daily rate of £30 for food and other miscellaneous costs, so total daily rate for residential stay in Pasadena of £66.67. 90 days x £66.67 = £6000 Subsistence elsewhere in the US (hotels plus meals), at £120 per day: Accommodation during visit	£12,300

to Scripps Institution of Oceanography in San Diego (5 days): £600 Accommodation during visit to University of Washington (5 days): £600 Accommodation during visit to Woods Hole Institute of Oceanography (5 days): £600	
Total	**£14,350**

Budget Summary

Research Expenses	
UK travel	£200
Overseas travel	£1850
Overseas subsistence	£12300
Research Expenses Total	£14350

Grand Total	£14350

Study Leave Details

Your institution's policy for paid or unpaid study leave

We are eligible for one term paid study leave every 4 years.

Amount of paid study leave in the last 4 years

None.

Amount of unpaid study leave in the last 4 years

None.

Study leave eligibility in the next 3 years

I am eligible for study leave in the 2015/16 academic year.

Details of teaching and/or administrative activities to be replaced.

I have arranged for my teaching and administative activities to be covered during my leave.

Institutional Approver

I confirm on behalf of the applicant's head of department/school and this institution:

- That this institution will grant the application the period and proportion of time requested for the Fellowship requested in the Duration and Timing section;
- That if replacement costs are requested the applicant will be in receipt of his/her normal salary during tenure of the award, and that the institution will accept the sum requested to provide such cover as requested in the Budget section;
- That if research expenses are requested, this request has the support of the head of department/school and institution.

Name	
Position	
Email	