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Winter survey in Irminger Sea provides strong foundation for UK GLOBEC cruise series

Phil Williamson, University of East Anglia, Norwich, UK (p.williamson@uea.ac.uk)
Steve Hay, FRS, Aberdeen, UK (haysj@marlab.ac.uk)
Raymond Pollard, SOC, Southampton, UK (rtp@soc.soton.ac.uk)

The copepod Calanus finmarchicus is one of the most-studied species of zooplankton. Deservedly so, since it is widely distributed in the North Atlantic (with a range of around 10 million km^2), occurring in high densities (up to 60,000 per m^2, vertically integrated) and it features strongly in the diet of many commercially-important fish. Yet there remain many gaps in our knowledge of the biogeography, life cycle and population dynamics of C. finmarchicus - with a major problem being the difficulty of obtaining data for half of the year when it is in diapause at depth. What are the physical and biological factors determining the species' survival during this period? Are such conditions crucial for the year-to-year changes in the abundance of C. finmarchicus, coherent over large areas and correlated with regional climatic indices such as the North Atlantic Oscillation?

These questions are amongst those being addressed by the field phase of NERC's Marine Productivity thematic programme, the main UK contribution to GLOBEC. The first of four research cruises to the Irminger Sea and parts of the Iceland Basin was successfully completed late last year (1 Nov - 18 Dec 2001) on RRS Discovery. Whilst much of the survey data and samples await analyses, they would seem to provide a very good starting point for follow-through work relating physical changes to ecosystem structure - with emphasis on key zooplankton species such as C. finmarchicus.

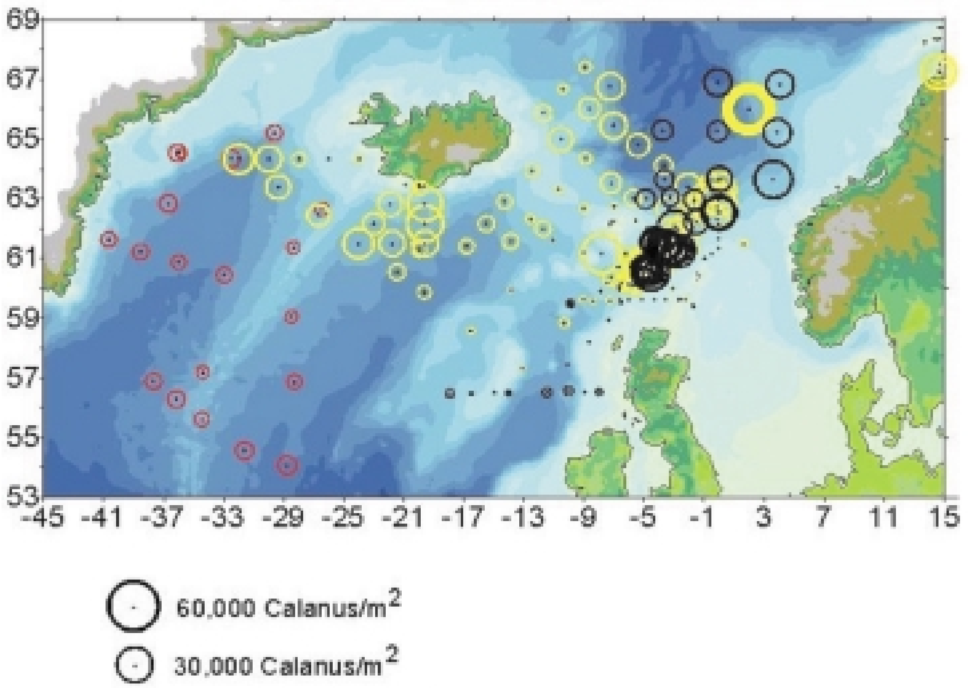

Figure 1: Winter abundance of Calanus finmarchicus stages C4 and C5 in the central and eastern North Atlantic. Combined data 1991 -2001, from ICOS, TASC and other net samples (yellow circles), FRS Marine Laboratory Aberdeen (black circles, calibrated OPC), and the first Marine Productivity Cruise (red circles, preliminary OPC data). Note that definitive MarProd data will not be available until summer 2002, after samples have been sorted and actual counts made.

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GLOBEC SCIENCE

A column for scientific notes of relevance to the GLOBEC community

Assessing wind contribution to the Southern Benguela interannual dynamics

Bruno Blanke [1,2,3] Claude Roy [1,3] Pierrick Penven [4]
Sabrina Speich [1,2] James McWilliams [4] Greville Nelson [5]
[1] Oceanography Department, University of Cape Town, South Africa (bbruno@uctvms.uct.ac.za)
[2] Laboratoire de Physique des Océans, UFR Sciences, Brest, CEDEX, France
[3] Institut de Recherche pour le Développement, Paris CEDEX 10, France
[4] Department of Atmospheric Sciences, University of California Los Angeles, USA
[5] Marine and Coastal Management, Cape Town, South Africa

Much progress has been made in documenting eastern-boundary upwelling areas during the past 20 years, both from a biological and a physical viewpoint (Bakun, 1996; Hill et al., 1998). However, several key questions about the dynamics of marine resources in a coastal upwelling are yet partly unanswered. What are the processes likely to affect their life history? What are the physical mechanisms driving these processes? To what range are seasonal and interannual perturbations of these mechanisms able to account for the observed fluctuations and changes in coastal upwelling living resources? To address these points and by taking advantage of the large amount of knowledge gained in the Benguela during the successive phases of the Benguela Ecology Program (Payne et al., 1987, 1992; Pillar et al., 1998), a suite of models has been designed and implemented by the GLOBEC-affiliated VIBES and IDYLE projects (Fréon, 2000). One of them is a high-resolution coastal model of the Southern Benguela circulation. The main research objectives supporting this modeling effort are the description and understanding of the circulation patterns in the Southern Benguela system.

The hydrodynamic model is the Regional Ocean Modeling System (ROMS) that solves the free surface, hydrostatic, primitive equations over variable topography using stretched, terrain-following co-ordinates in the vertical and orthogonal curvilinear co-ordinates in the horizontal (see Haidvogel et al., 2000). The curvilinear grid is pie-shaped to follow the southwestern corner of Africa from 40ºS to 28ºS and from 10ºE to 24ºE. The resolution ranges from 9 km at the coast up to 16 km offshore. Twenty vertical levels preserve a high resolution near the surface. At the three lateral boundaries facing the open ocean, an implicit active radiative boundary scheme (Marchesiello et al., 2001), forced by seasonal time-averaged outputs of the Agulhas As Primitive Equations (AGAPE) basin-scale ocean model (Biastoch and Krauss, 1999), connects the model to the surroundings. The details of the configuration are given in Penven (2000) and Penven et al. (2001-b). A major outcome of the analyses performed on a 9-year simulation forced by a repeated monthly climatology is the existence of pronounced differences in the model outputs between each individual year. This occurs despite the absence of synoptic or interannual fluctuations in the atmospheric forcing. This interannual variability is generated by local oceanic instabilities that produce variations in the mesoscale dynamics (Penven, 2000; Penven et al., 2001-b). However, one can expect a fraction of the observed sea surface temperature (SST) interannual variability in the Benguela upwelling system to be driven by the local (or nearby) wind stress fluctuations. Several experiments were designed to investigate the importance of the wind stress intra-seasonal and interannual variability in explaining the observed SST variability over the continental shelf. In this study, we compare the response of the model being forced by a climatological wind with the response obtained with genuinely observed winds, while all other constraints (at the surface and at the open boundaries) are kept as

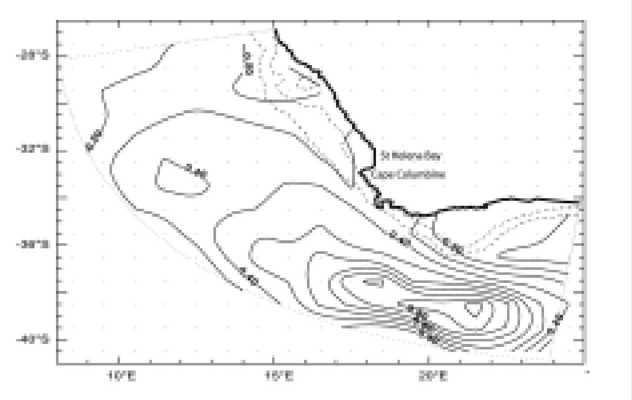

Figure 1: Variance of monthly SST anomalies (in ºC) calculated in the climatological simulation (Run A). Isobaths 200 and 500 m are dashed.

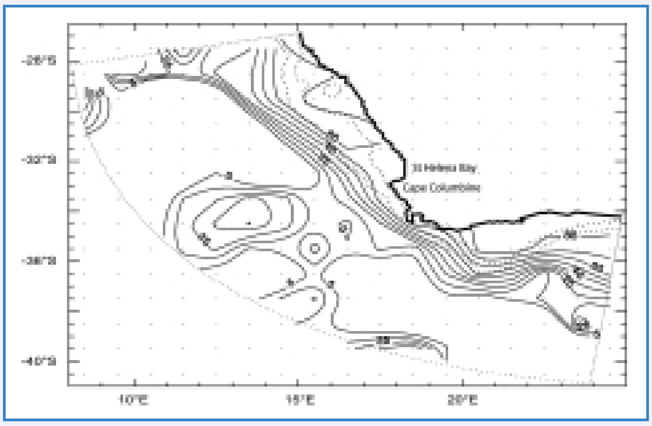

Figure 2: Percentage of variance added to the SST monthly time series when forcing the model by a realistic wind stress.

monthly climatologies. Long simulations (up to 10 years) are run to obtain statistically meaningful numerical solutions.

The wind stress from ERS1/2 satellites is used to account for the observed atmospheric variability. Weekly 1ºx1º gridded time series for the period August 1991 - January 2001 and a monthly climatology were made available by the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) for both horizontal components of the surface wind stress (Bentamy et al., 1996). Comparison between the wind measured at a coastal station (Cape Colombine, 32º50'S) and the wind derived from ERS1/2 shows that the satellite wind provides a fairly relevant product to force a model covering the southern Benguela region (Blanke et al., MS). Starting from rest and using temperature and salinity fields derived from the AGAPE basin-scale ocean model, the model was integrated for 10 years with climatological COADS winds.

One most fascinating aspect of upwelling systems is the very rich mesoscale activity that develops in the coastal domain. In the Benguela, it includes a coastal jet off the Cape Peninsula, an upwelling plume at Cape Columbine, filaments and eddies off the western coast, and Agulhas Current filaments. Previous analysis showed that the model gives a realistic picture of the known large-scale oceanic circulation as well as of the observed mesoscale features. As pointed out by Penven et al. (2001a and b), mesoscale processes project onto the modeled interannual variability though obtained under climatological forcing conditions: eddies and filaments may indeed develop in different times and places year after year. This is illustrated on figure 1 where the variance of the resulting interannual variability for monthly mean SST is averaged over 1º x 1º boxes throughout the 8 years of Run A. The region of maximum variability spreads in the southern portion of the domain, roughly at 38ºS, where the Agulhas Current retroflects and gives rise to several eddies throughout the year (Duncombe Rae et al., 1996).

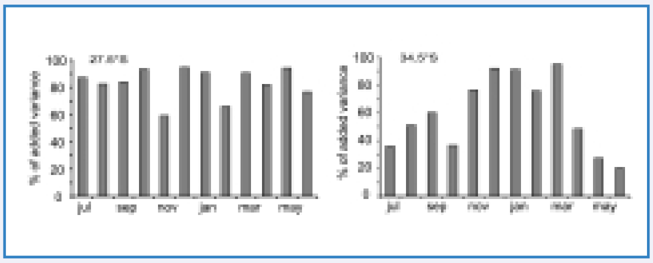

Figure 3: Same as Figure 2, but for independent monthly calculations at two selected locations along the continental shelf.

Substituting the monthly ERS1/2 climatology by truly observed ERS1/2 weekly fields, the model is run twice (interannual Runs B and C) over the full period August 1991 - January 2001, using two distinct initial states from Run A (the last July time step of years 7 and 8). We calculate a new variance for the interannual variability of monthly SST anomalies in both new runs. Assuming that the surface wind stress and the mesoscale activity are independent sources of variability in the model, both new simulations should exhibit more variance than Run A. Under this assumption, the variance added to the SST signal by the observed wind field may be estimated by subtracting the variance of Run A from the variance of Runs B and C. Figure 2 pinpoints the regions where the regional wind stress truly drives the SST interannual variability by showing the ratio of the variance added by the wind stress to the variance of Run A. Values greater than 50% correspond to areas where the wind effect prevails over the mesoscale activity in explaining the modeled SST variance. Up to 90% of the interannual SST variability over the Agulhas bank, and up to 70% over the western continental shelf, can be attributed to the wind stress. On the contrary, the retroflection of the Agulhas Current and the pathway along which detached eddies propagate exhibit little sensitivity to the wind stress interannual variability. Off the west coast, the dominant equatorward winds indeed generate a strong coastal upwelling separated from the open ocean by a well-developed oceanic front. Given the pattern of seasonality of the upwelling-favourable wind along the west coast, one can expect a north-south gradient in the significance of the contribution of the wind. The regional wind stress is more likely to affect deeply the SST in summer, during the core of the upwelling season, in the southernmost region of the Benguela system (September to March), whereas austral winter months must evidence a weaker conditioning. On the contrary, the upwelling that develops further north is known to have weaker seasonal amplitude. In the model, separate monthly calculations of the added variance at two selected locations along the *continental shelf (27.5ºS and 34.5ºS) comfort this vision (Figure 3). For the southern area (Cape Peninsula, 34.5ºS) where the upwelling has a pronounced seasonal cycle, the contribution of the wind in driving interannual SST anomalies is also seasonal with a peak during the austral summer. Further north (27.5ºS), where the upwelling is always fully developed, the wind contribution shows little variability and remains important all year round.*

The final step of our experiment is to assess the ability of the regional wind stress to force a realistic SST field in the Benguela system in absence of any data assimilation scheme. This is evaluated by comparing observed and simulated coastal SST time series. Figure 4 shows the correlation of the SST anomalies obtained in Runs B and C with those diagnosed from global analyses (Reynolds and Smith, 1994), for an equivalent overlapping period (1993-2000). As expected, there is only poor correlation away from the shelf as the model SST is dominated by mesoscale processes that have no reason to synchronize with observed events. On the contrary, the correlation increases significantly over the shelf where the wind stress truly explains most of the variability simulated by the model. The simulated and observed SST time series at the northernmost part of the domain (open and wide shelf area) show the model skill to reproduce observed warm or cold events (fig. 5). Among others, the extreme episode of the austral summer 1999-2000 (Roy et al., 2001) is captured remarkably by the model, showing that this event is likely to have found its origin in the regional wind forcing. Much less skill appears near St Helena Bay (32°S), in an area where Cape Columbine introduces a strong discontinuity in the shape of the coastline and in the width of the shelf (Figure 5). However, the seasonality of the upwelling in that region might also contribute to an apparent decrease of the ability of the model to reproduce the observed local SST signal. Further analyses excluding the austral winter months need to be performed at a later stage.

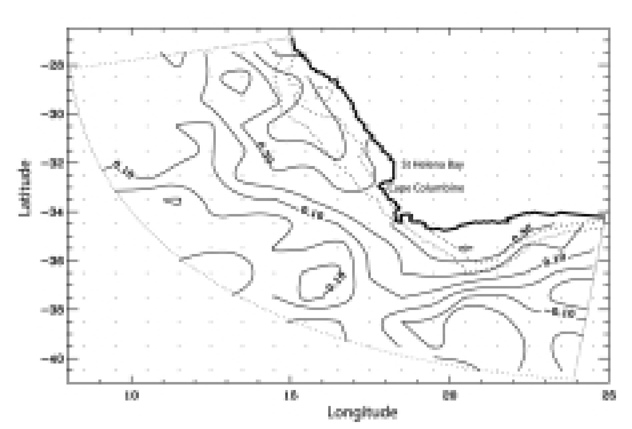

Figure 4: Correlation coefficient between SST monthly time series given by the model (average of Runs B and C) and global analysis of observations (Reynolds and Smith, 1994) for the period 1993-2000.

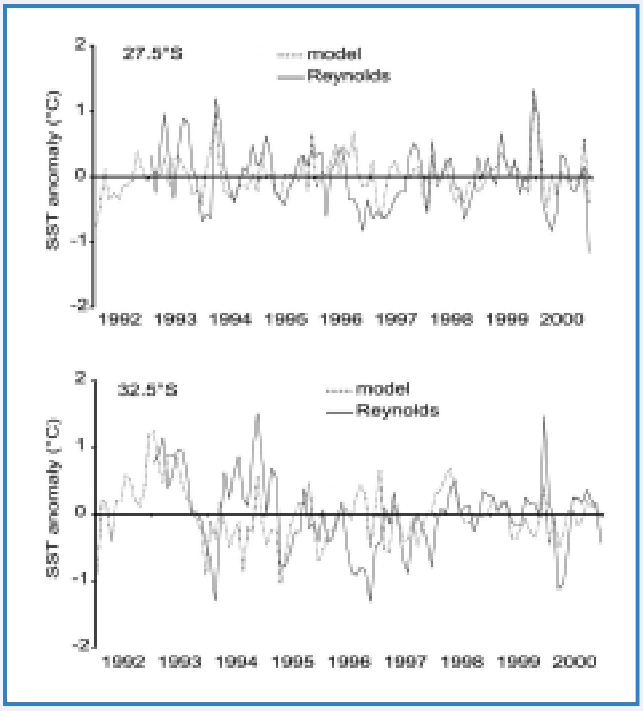

Figure 5: Monthly time series of SST anomalies at two selected locations along the continental shelf, given by the model (average of Run B and C; dashed line) and by global analysis of observations (Reynolds and Smith, 1994; solid line).

The results of our modeling experiments can be summarized as follow. The sensitivity of the simulated SST to added variability in the wind forcing is shown to be maximum over the continental shelf. Changes in the strength and direction of alongshore winds result in periods of anomalously warm temperatures along the coast (relaxed upwelling) or colder conditions (enhanced upwelling). The behaviour of the model away from the shelf exhibits some large interannual variability, but related mostly to internal mesoscale dynamics, poorly or not correlated with observations. As we only used interannual information from the wind stress, a fraction of the variability not captured by the model may be related to variability in the surface heat flux or in the model boundary conditions. For instance, changes in cloud cover are likely to affect the ocean surface on interannual time scales. However, as intrusions of anomalously warm Agulhas water into the Benguela have already been documented, we grant more likelihood to this process in driving, at least partially, the offshore SST (Lutjeharms, 1996). The model in its present configuration accounts only for pure mean seasonal variability of the incoming Agulhas Current. Therefore it gives probably an exaggerated role to regional mesoscale variability in producing interannual changes in SST.

The drastic contrast between the SST's coastal and *oceanic response to change in the wind forcing is relevant to the impact of the global climate dynamics at the scale of a coastal ecosystem. Tremendous knowledge has been gained over the past twenty years on the ENSO and NAO dynamics and their implications for the open ocean regions. However, their regional expression and especially their consequences at a smaller scale remain poorly documented and understood. In our simulations, the differences between the response of the coastal and oceanic areas to the local wind forcing suggest that one needs to be extremely careful when trying to down scale the result from low resolution models, analyses or predictions to smaller spatial scales as coastal ecosystems.*

Finally we deliberately focused on SST since it is a key parameter for both ocean physics and biology. In more thorough investigations, one should not disregard other essential parameters such as ocean currents, integrated mass transports or subsurface thermodynamical fields, for which direct measurements are equally available.

Acknowledgements

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References

Bakun, A., 1996: Patterns in the Ocean: Ocean Processes and Marine Population Dynamics. University of California Sea Grant, San Diego, California, USA, in co-operation with Centro de Investigaciones Biolgicas de Noroeste, La Paz, Baja California Sur, Mexico. 323 pp.

Bentamy, A., Y. Quilfen, F. Gohin, N. Grima, M. Lenaour, and J. Servain, 1996: Determination and validation of average wind fields from ERS-1 scatterometer measurements. Global Atmos. Ocean Syst., 4, 1–29.

Biastoch, A., and W. Krauss, 1999: The role of mesoscale eddies in the source regions of the Agulhas Current, J. Phys. Oceanogr., 29, 2303-2317.

Blanke, A., C. Roy, P. Penven, S. Speich, J. McWilliams and G. Nelson. MS. The contribution of wind forcing to the interannual dynamics of the southern Benguela upwelling.

Duncombe Rae C. M., S. L. Garzoli and A. L. Gordon. 1996. The eddy field of the South-East Atlantic Ocean: a statistical census from the BEST project. J. Geophys. Res., 101, 11949-11964

Fréon, P., 2000: The IDYLE project in the Benguela: interactions and spatial dynamics of renewable resources in upwelling systems. GLOBEC International Newsletter, 6.1, p. 12.

Haidvogel, D. B., H. Arango, K. Hestrom, A. Beckmann, P. Malanotte-Rizzoli and A. Shchepetkin, 2000: Model evaluation experiments in the North Atlantic basin: simulations in nonlinear terrain-following co-ordinates. Dyn. Atmos. Oceans, 32, 239–381.

Hill, A. E., B. M. Hickey, F. A. Shillington, P. T. Strub, K. H. Brink, E. D. Barton and A. C. Thomas, 1998: Eastern Ocean Boundaries (E). In The Sea, Vol 11, The Global Coastal Ocean; Regional studies and syntheses, A. R. Robinson and K. H. Brink, Eds. Wiley, New York, Chap 2, 29-67.

Lutjeharms, J.R.E., 1996. The exchange of water between the South Indian and the South Atlantic. In The South Atlantic: Present and Past Circulation, edited by G.Wefer, W. H. Berger, G. Siedler, and D. Webb, Springer-Verlag, Berlin, pp. 125-162.

Marchesiello, P., J. C. McWilliams and A. Shchepetkin, 2001: Open boundary conditions for long-term integration of regional oceanic models. Ocean Modelling, 3, 1-20.

Payne, A. I. L., J. A. Gulland and K. H. Brink (Eds.), 1987: The Benguela and comparative ecosystems. S. Afr. J Mar. Sci., 5, 957 pp.

Payne, A. I. L., K. H. Brink, K. H. Mann and R. Hilborn (Eds.), 1992: Benguela trophic functioning. S. Afr. J. Mar. Sci., 12,1108 pp.

Penven, P. 2000: A numerical study of the Southern Benguela circulation with an application to fish recruitment. Ph.D. thesis, Université de Bretagne Occidentale, Brest, France, 156 pp.

Penven, P, J. R. E. Lutjeharms, P. Marchesiello, C. Roy and S. J. Weeks, 2001-a: Generation of cyclonic eddies by the Agulhas Current in the lee of the Agulhas Bank. Geophys. Res. Lett., 27, 1055-1058.

Penven, P., C. Roy, G. B. Brundrit, A. Colin de Verdière, P. Fréon, A. S. Johnson, J. R. E. Lutjeharms, and F. A. Shillington, 2001-b: A regional hydrodynamic model of the Southern Benguela upwelling. S. Af. J. Sci. 9, 472-475.

Pillar, S. C., C. Moloney, A. I. L. Payne, and F. A. Shillington (Eds.), 1998: Benguela dynamics. S. Afr. J. mar. Sci. 19, 512 pp.

Reynolds, R. W. and T. M. Smith, 1994. Improved global sea surface temperature analyses using optimum interpolation. J. Climate, 7, 929-948.

Roy, C., S. J. Weeks, M. Rouault, G. Nelson, R. Barlow and C. D. van der Lingen, 2001: Extreme oceanographic events recorded in the southern Benguela during the 1999-2000 summer season. S. Af. J. Sci. 9, 465-471.