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ORIGINAL RESEARCH ARTICLE

Fisher—Shannon analysis of the time variability of remotely sensed sea surface temperature at the Brazil—Malvinas Confluence[☆]

Jorge O. Pierini [a], **Michele Lovallo** [b], **Eduardo A. Gómez** [c], **Luciano Telesca** [d,*]

[a] *Comisión de Investigaciones Científicas (CIC)—UCALP-CCT-BB (IADO-CONICET), CC 804, Bahía Blanca, Argentina*
[b] *ARPAB, Potenza, Italy*
[c] *CCT-BB (IADO-CONICET), UTN Facultad Regional Bahía Blanca, Bahía Blanca, Argentina*
[d] *National Research Council, Institute of Methodologies for Environmental Analysis, Tito, PZ, Italy*

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Summary The collision of the warm and salty southward flowing Brazil Current and the cold and relatively fresh northward flowing Malvinas Current produces a strong frontal zone known as the Brazil—Malvinas Confluence Zone (BMCZ). This is featured by intense presence of eddies and meanders and is one of the most energetic areas of the world oceans. We apply the statistical method of Fisher—Shannon (FS) to the time series of sea surface temperature, derived from the satellite Advanced Very High Resolution Radiometer (AVHRR) imagery, acquired from 1984 to 1999. The FS method consists of the joint application of Fisher information measure (FIM) and Shannon entropy (SE), measuring respectively the degree of organization and the disorder of a system. Our findings indicate that the FS method is able to locate very clearly the BMCZ, which corresponds to the less organized and more disordered area within the area of confluence between the Brazil and Malvinas Currents.

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[*] Corresponding author at: National Research Council, Institute of Methodologies for Environmental Analysis, Tito, PZ, Italy
E-mail address: luciano.telesca@imaa.cnr.it (L. Telesca).

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1. Introduction

The South Atlantic's circulation presents several characteristics that are very significant for climate variability. In this region, which is the main source of equatorial surface and thermocline waters (Blanke et al., 1999; Matano et al., 1993; Speich et al., 2007), the circulation affects the climate of the surrounding continents by influencing the distribution of the sea surface temperature (SST) through lateral advection and/or by propagation of anomalies within the mixed layer (Kushnir et al., 2002). The South Atlantic is linked with the Indian and Pacific Oceans, and therefore it provides a gateway by which the Atlantic meridional overturns.

In the South Atlantic, the Brazil—Malvinas Confluence Zone (BMCZ) is crucial to understand circulation and heat transport processes (Wainer et al., 2000). The BMCZ is located off the coast of Argentina and Uruguay, at the convergence between the warm poleward flowing of the Brazil Current and the cold equatorward flowing of the Malvinas Current, between 35°S and 45°S latitude and 50°W to 70°W longitude. The confluence of these two currents originates a strong thermocline and the formation of many high energy eddies (Maamaatuaiahutapu et al., 1998) (Fig. 1).

The Brazil Current carries warm subtropical water with typical temperature values between 18 and 28°C. It generally flows in the upper 600 m of the ocean and its volume transport at the confluence zone is upwards of 20 Sv with speeds over a half a meter per second (Evans et al., 1983; Memery et al., 2000; Peterson and Stramma, 1990). The Malvinas Current, a branch off of the Antarctic Circumpolar Current, carries cold and relatively fresh subantarctic water, between 60 and 90 Sv and speeds varying from about 0.5 m s^{-1} to about 1 m s^{-1}. Interestingly, the Malvinas Current extends all the way to the sea-floor, contrarily to the Brazil Current that is a surface current. The temperature ranges typically around 6°C (Vigan et al., 2000; Vivier and Provost, 1999).

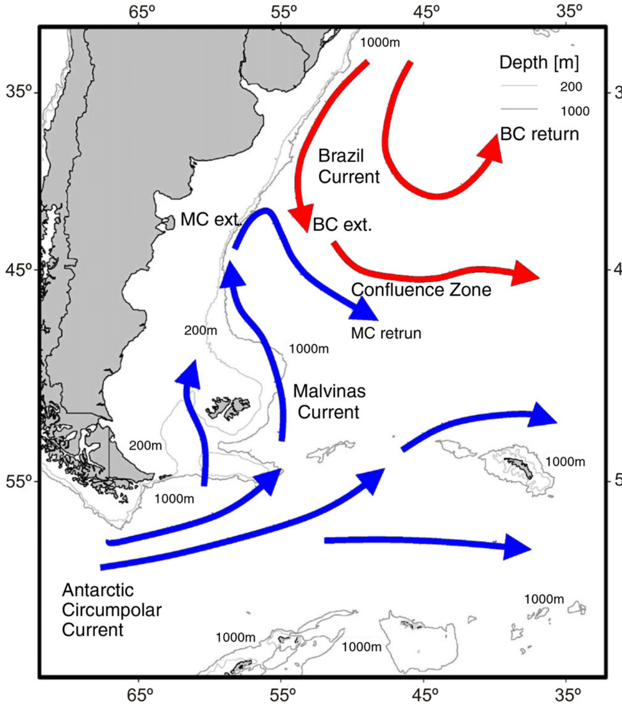

Figure 1 Map of the Argentinean continental shelf with the warm poleward flowing Brazil Current (red) and the cold equatorward flowing Malvinas Current (blue). Also indicated are the Malvinas Current return (MC return), the Brazil Current extension (BC ext.) and the Brazil Current return (BC return). The continent and the shelf up to the 1000 m and 200 m isobath are indicated by dark gray and light gray line respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

After the collision with the Malvinas Current at around 38°S, the Brazil Current branches off into two different paths: the first path is redirected back to the equator creating a large anticyclonic eddy with the original Brazil Current; the second one, which is much stronger than the first one deflects about 45°E of its original tract poleward (Maamaatuaiahutapu et al., 1998). On the contrary, after the collision the surface flow for the Malvinas Current becomes much simpler, being redirected poleward, till about 50°S latitude where it once again is detached back up by the Antarctic Circumpolar Current and heads East (Matano, 1993).

The southeast deflected Brazil Current flows just east of the redirected Malvinas current at around 57.5°W and between 40°S and 45°S (Saraceno et al., 2004, 2006). In this region SST gradients can be as high as 1°C per kilometer. In this zone, which is characterized by very high energy among the world oceans (Gordon, 1989), the meanders, eddies, and filaments are extraordinary. The strong mixing processes cause high-speed cooling of subtropical waters conveyed by the Brazil Current, characterizing this area as very important for the circulation and heat transport processes (Wainer et al., 2000). Provost and Le Traon (1993) report the high inhomogeneity and anisotropy of the BMCZ at the mesoscale. At shorter frequencies, the Brazil—Malvinas Confluence variability is intense and is principally governed by the yearly and semi-annual cycles (Fu, 1996). Podesta et al. (1991) show that the yearly periodicity is responsible for the most of the SST variability in the southwestern Atlantic, and, in particular, of more than 80% of the SST variability on the continental shelf off the southwestern Atlantic Ocean. The eddies, extremely energetic, are featured by intense rotational velocity. Eight or nine different mesoscale eddies with many other microscale eddies could exist at any time. Even if many studies have been done on these high energy turbulent mixing areas, the deep knowledge of these mesoscale processes is still challenging and far from being completely understood (Tokinaga et al., 2005).

Joint use of advanced statistical techniques and satellite images have advanced our knowledge of the relevant scales and features of ocean properties (i.e., Denman and Abbott, 1994; Doney et al., 2003; Lentini et al., 2002; McClain et al., 1998; Stammer, 1997). The application of singularity analysis to SST images has recently suggested a different conceptual approach to the identification of flow patterns from satellite images (Isern-Fontanet et al., 2007; Turiel et al., 2005). Experimental studies of the chaotic properties of oceanic processes have been performed for several years; for instance, Osborne et al. (1986) and Brown and Smith (1990, 1991) investigated deeply the chaotic behavior of oceanic large and mesoscale motions.