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EUMETSAT Geostationary Satellite Monitors the Sea Surface Temperatures of the Atlantic and Indian Oceans since 2004

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The atmosphere and oceans have been monitored by a EUMETSAT Meteosat Second Generation Geostationary Satellite in the Eastern Atlantic and Western Indian Oceans and adjacent Seas since 2004. This satellite provides daily atmospheric weather conditions and is a valuable climate research tool. We demonstrate that it is also useful for monitoring ocean surface temperatures and oceanic patterns associated with currents, eddies and upwelling. Meteo-France provides an hourly, cloud cleared, validated sea surface temperature product at intervals of 5 km with an accuracy of about 0.5° C relative to in-situ values. Image composites are used to reduce cloud cover at daily and seasonal time scales. Several examples of surface ocean patterns and temperature profiles are used to illustrate the advantages and limitations of the composites and include: Atlantic Tropical Instability Waves, cold core eddies in the lee of the Canary Islands, meanders of the Agulhas Current off South Africa, coastal upwelling along southwestern Spain and temperatures between Gotland Island and the shallow Curonian Lagoon on the coast of Lithuania.

Keywords: *ocean, Atlantic, sea surface temperatures, circulation, upwelling.*

1. Introduction

There is increased interest in meso-scale sea surface temperatures patterns since ocean models suggest that currents and eddies have an impact on the global ocean circulation (Hallberg et al. 2006) as well as on coastal resource management (Klemas 2009). Our motivation is to observe the surface patterns of sea surface temperature (SST) related to ocean currents, eddies and upwelling in the Atlantic using the frequent, high-resolution data from a EUMETSAT Meteosat Second Generation (MSG) Geostationary satellite (Schmetz et al. 2002).

The MSG provides visible and infrared images every thirty minutes from an altitude of about 40,000 km from a stationary location above the equator at longitude 0°W (Fig.1). Meteo-France combines two visible and three thermal infrared channels to produce hourly, validated (0.5°C), cloud-cleared MSG SST images, at intervals of 5 km (nadir) (Brisson et al. 2002). The hourly spatial data (3001x3001 image samples) are mapped +/- 60 degrees around nadir.

Infrared radiation emitted at the ocean surface does not penetrate clouds. As a result, hourly SST images contain many random clouds (blank areas) and ocean patterns are not easily recognizable. Since clouds move rapidly relative to ocean surface patterns, cloud cover can be reduced by compositing hourly images at intervals between 1 and 30 days.

To select the proper averaging interval, the SST images are animated in sequence to verify the continuity of low frequency surface ocean patterns. By adjusting the rate of image animations, it is possible to detect the evolution of SST fronts, eddies and upwelling. To reduce data volume, we first convert the hourly data to 8-bit SST images (-3.15°C to 35.1°C at intervals of 0.15°C). An Apple G5 computer and Image SXM software (Barrett 2002) are used for data processing, evaluation of SST animations and the extraction of SST profiles.

In general, areas poleward of Latitudes +/- 45° are cloudier and therefore more difficult to evaluate.

Seasonal warming creates isothermal surface conditions that can mask the surface SST patterns.

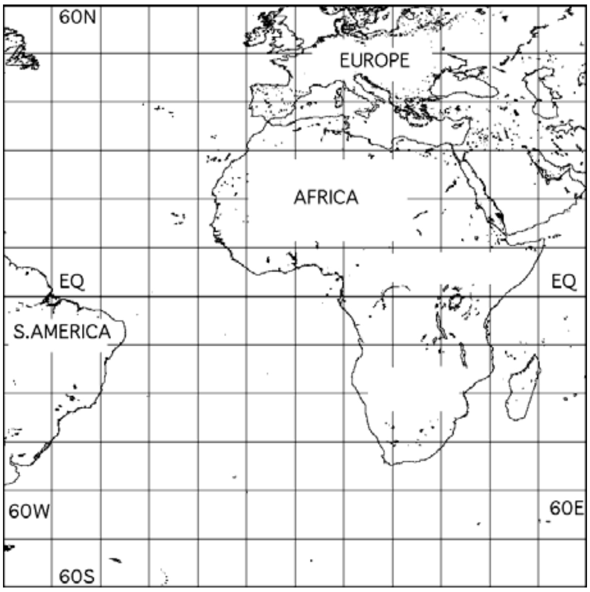

Fig. 1. The MSG SST area map is an equal angle projection

To provide an overview of the capabilities and limitations of the MSG SST data, we show several cases of ocean surface patterns that can be observed in MSG SST image composites

2. Examples of MSG SST patterns

2.1. Atlantic Tropical Instability Waves (TIW)

Large meanders of the surface Atlantic South Equatorial Current and the subsurface Undercurrent were first detected in current meter data in 1974 during the international GATE experiment (Duing et al. 1975). Current meter data revealed low frequency meanders but the spacing of the current meter array did not provide sufficient information to establish the meander length and speed characteristics unambiguously.

During 1975, similar low frequency meanders were observed in the Eastern Equatorial Pacific in infrared images provided by a relatively new NOAA Geostationary Operational Environmental Satellite (GOES) located at Longitude 75°W with a spatial resolution of 8 km.

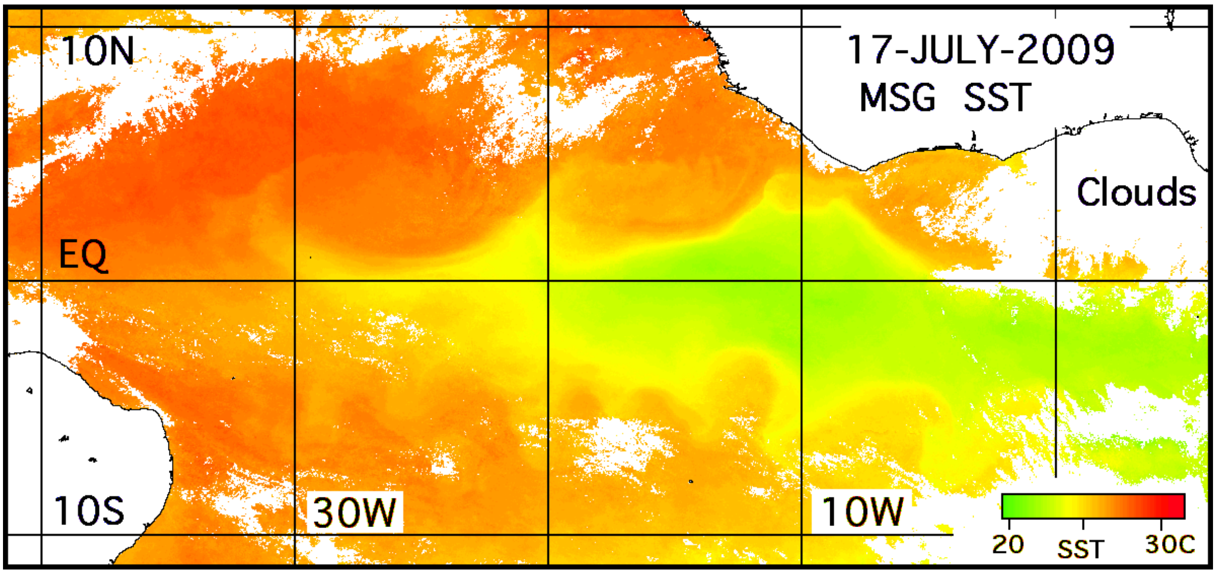

Fig. 2. The daily average EUMETSAT MSG geostationary satellite sea surface temperatures in the equatorial Atlantic on 17 July 2009. The Tropical Instability Waves (TIW) are evident at the SST fronts north of the equator with wave peaks at 10°W, 20°W and 31°W. The upwelling became evident in mid-June of 2009. Residual clouds are blank ocean areas

At this time, the GOES had only one thermal infrared channel so that clouds and ocean water at similar temperature values could not be distinguished. However, since clouds move rapidly during each day, while the ocean fronts (SST gradients) move relatively slowly, the westward displacements of the SST TIW wave patterns provided sufficient continuity to determine the wavelength (~1000 km) and period (~ 25 days) of the equatorial current meanders (Legeckis 1977). During 1975, the Pacific TIW persisted for nearly six months.

Subsequently, similar TIW characteristics were resolved in the Equatorial Atlantic (Weisberg 1984). These large-scale equatorial meanders have now been observed in all equatorial oceans and became known as the Tropical Instability Waves (TIW). The waves appear to draw their energy from the instability of the shear between the seasonal westward surface equatorial currents and the eastward equatorial undercurrent (~ 200 m depth).

An example of Atlantic TIW during 2009 is shown in Fig. 2 and a MSG SST profile along Latitude 2°N in Fig. 3. The asymmetric appearance of the TIW is due to the stronger westward currents north of the equator as well as a northward wind component crossing the equator. The MSG SST images can be used to monitor the seasonal onset and decay of TIW SST patterns for verification of ocean circulation models.

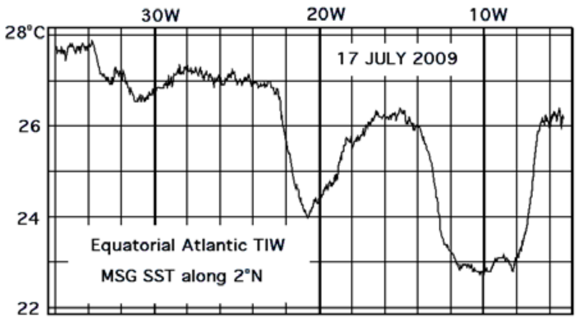

Fig. 3. The MSG SST along latitude 2°N on 17 July 2009

The TIW are most evident seasonally from May - Dec (Pacific) and June - August (Atlantic). The colder waters appear along the equator due to surface divergence of equatorial upwelling forced by the westward wind component and the change in the direction of the Coriolis force at the equator (Bachelor 1967). The TIW are some of the longest waves in the oceans and are linked to the inter-annual global El Nino cycle. During El Nino events, the westward winds are weak, warm surface currents flow eastward along the equator and the TIW are difficult to detect in SST images.

2.2. Coastal Upwelling - Southwestern Spain

Seasonal winds along the western continental boundaries produce coastal upwelling events all over the world. Ocean upwelling is a major source of nutrient replenishment for fisheries. The MSG SST can be used to monitor upwelling along the coastlines of the Mediterranean Sea, Somalia, Portugal, Spain, and Northwestern and Southwestern Africa, among others. An example of upwelling along the southwestern coast of Spain is shown in Fig. 4.

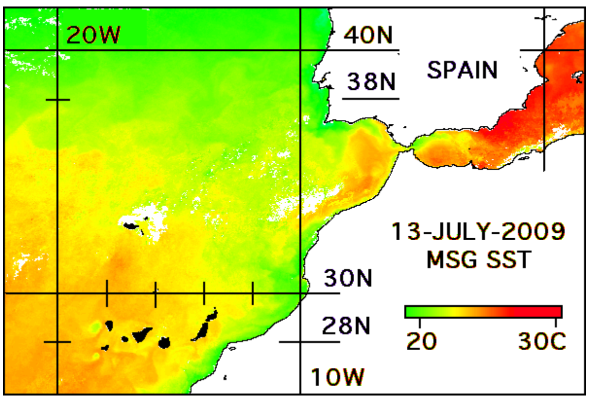

Fig. 4. The daily MSG SST on 13 July 2009. Two small eddies were detected west of the Canary Islands as shown in Fig. 6.

On 13 July 2009 in Fig. 5, the SST deceases by 3°C along Latitude 38°N between Longitudes 9°W and 10°W. Upwelling has seasonal and inter-annual cycles that can be monitored by the MSG.

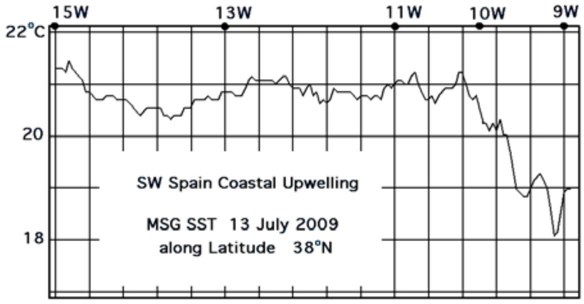

Fig. 5. Coastal upwelling along Latitude 38 °N in Fig. 4

2.3. Eddies at the Canary Islands

It is well known that eddies can form in the lee of islands due to the interactions of the currents with an island barrier (Bachelor 1967). An example of two such eddies are shown in the lee of the Canary Islands in Fig. 4. The MSG SST profile along Longitude 18.4°W on 13 July 2009 in Fig. 6 shows two small cyclonic (cold-core) eddies southwestward of the Canary Islands with diameters estimated as 50 km (E1 at 23°C) and 30 km (E2 at 23.5°C). The eddies may be formed by an instability associated with a von Karman Vortex (Bachelor 1967).

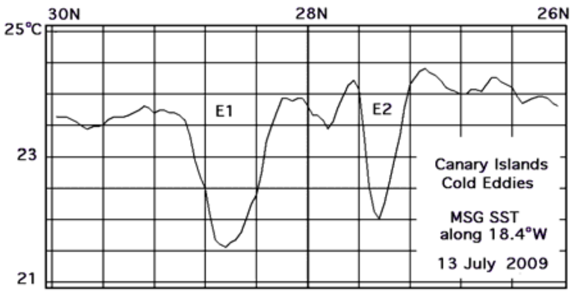

Fig. 6. The MSG SST profile along Longitude 18.4°W on 13 July 2009 shows two small cold-core cyclonic eddies to southwest of the Canary Islands in Fig. 4

2.4. Baltic Sea

The Baltic Sea is more difficult to monitor with MSG SST due to the persistence of clouds, the reduced spatial resolution (~10 km/pixel) at high latitudes and the ice cover during severe winters. The summer season is optimum for making MSG observations as shown on 13 July 2009 in Fig. 7. The MSG SST profile in Fig. 8 shows the steady increase of SST from Gotland Island to the Curonian Lagoon at the coast of Lithuania.

The MSG resolves the SST maxima (19-20°C) in the shallow water of the narrow Lagoon in Fig. 8.

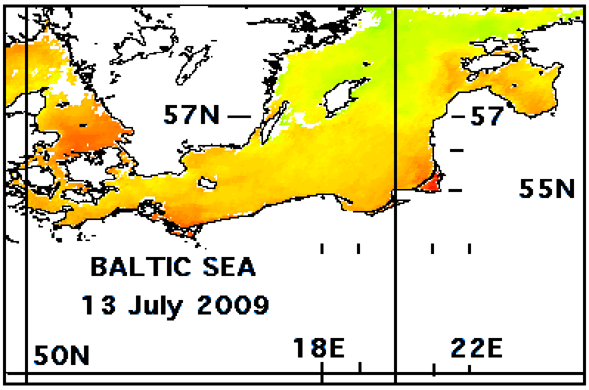

Fig. 7. The MSG SST in the Baltic Sea on 13 July 2009. The warmest water is in the shallow Curonian Lagoon in Fig. 8

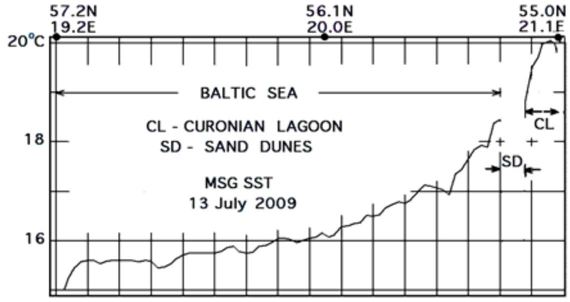

Fig. 8. The MSG SST profile from the Danish Island of Gotland to the Curonian Lagoon (CL) in Lithuania

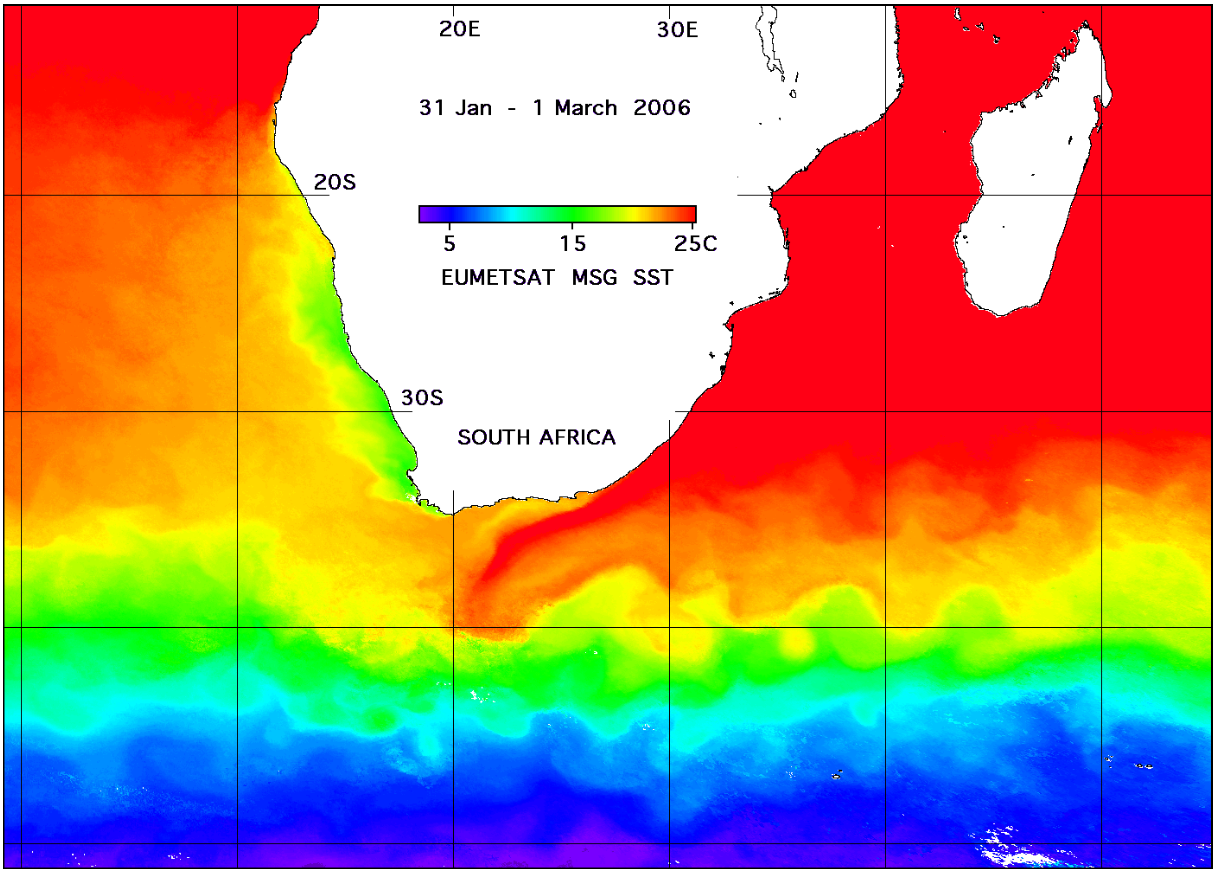

Fig. 9. The 60-day average MSG SST image of the South Atlantic from 31 January to 1 March 2006. The SST fronts reveal the standing waves of the Agulhas Return Current along Latitude 39°S, the zonal polar fronts along Latitude 45°S and upwelling along the coastline of Southwestern Africa

2.5. Agulhas Current in the South Atlantic

The Agulhas Current is a major Western Boundary Current flowing southwestward along the southeast coast of Africa and contributes to the exchange of heat and salt between the South Atlantic and Indian Oceans (Lutjeharms 2006). The Agulhas retroflects south of South Africa and becomes the eastward flowing Agulhas Return Current. Due to the rapid formation and mixing of large eddies and meanders at the retroflection region, it has been named the Agulhas Cauldron (Boebel et al. 2003).

Due to the rapid mixing in the Cauldron, it is difficult to track individual Agulhas eddies for longer than a few days using infrared methods. However, a 60 day MSG SST average in Fig.9 reveals that the warmer waters of the eastward Agulhas Return Current form standing waves along Latitude 39°S due to their interactions with the Agulhas Plateau, a large undersea mountain centered at Longitude 26°E and Latitude 40°S (Smith and Sandwell, 1997). The MSG SST profile in Fig. 10 shows four standing wave peaks along Latitude 39°S between Longitudes 25°E and 45°E with wavelengths of 400 km and Polar SST fronts, associated with the eastward flowing Antarctic

Circumpolar Current, appear along Latitude 45°S (Lutjeharms , 2006). .

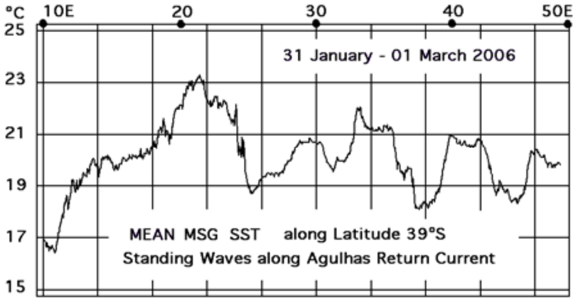

Fig. 10. The 60-day average MSG SST profile in the South Atlantic. from 31 January to 01 March 2006. Standing wave patterns along the Agulhas Return Current appear at Latitude 39°S, downstream of a large undersea mountain centered at Longitude 26°E and Latitude 40°S

3. Conclusions

The EUMETSAT MSG images provide hourly SST in cloud free ocean areas at a resolutions of 5 km at nadir. The hourly time step allows an ocean data user to select the most cloud free hourly image or to average a sequence of images to reduce cloud cover. Both absolute SST values as well as SST patterns are useful for evaluation of the position and the propagation of ocean surface currents, eddies and upwelling. The geostationary platforms have the unique capability to provide information for both meteorologists and oceanographers. The entire globe is now monitored by an international (NOAA, EUMETSAT, MTSAT) series of geostationary satellites. Advanced resolution SST products are expected to be available from Meteo-France in 2010. The next generation geostationary satellites with additional spatial and spectral resolutions, such as the NOAA GOES-R, will improve the detail required by models to resolve the influence of meso-scale eddies on ocean circulation and global climate (Schmit et al. 2005)

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Nuo 2004 metų EUMETSAT palydovų matuojama Atlanto ir Indijos vandenynų temperatūra

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Atlanto ir Indijos vandenynų atmosferos ir jūros temperatūra jau nuo 2004 metų matuojama EUMETSAT palydovais. Palydovai išdėstyti virš ekvatoriaus ir lekia aplink Žemę tokiu pačiu kampiniu greičiu, kaip pati Žemė. Todėl palydovai nuolatos gali stebėti tą patį trečdalį Žemės. Rytų Atlanto ir Vakarų Indijos vandenynų paviršiaus temperatūra yra matuojama šiluminės infraraudonosios energijos prietaisais. Palydovai kas valandą padaro temperatūros nuotraukas, kuriose galima matyti jūros sroves, sūkurius ir arčiau prie kranto iškylančius šaltesnius vandenis. Prancūzų organizacijoje (*Meteo-France*) atliekami matavimai palydovais veikia panašiai, kaip skaitmeniniai fotoaparatai: kiekviena nuotrauka turi daug taškų sujungtų vienas su kitu. Kiekvienas taškas nuotraukoje atitinka temperatūrą su 5 kilometrų skiriamąja geba ir matuoja jūros paviršiaus temperatūrą 0,5 ºC tikslumu. Matavimams įtakos turi debesys, kurie matosi nuotraukose. Siekiant sumažinti debesų įtaką, galima sujungti kelių dienų nuotraukų seriją į vieną sudėtinę nuotrauką. Taip galima matyti, kaip keičiasi vandenyno paviršiaus temperatūra. Straipsnyje pateikti keli matavimų pavyzdžiai: Atlanto vandenyno pusiaujyje esančių nestabilių tropinių bangų, Kanarų sąlu šalto vandens sūkurių, šaltų iškylančių vandenų prie Ispanijos krantų, Aguljo greitosios srovės (~ 10 km/h), esančios prie Pietų Afrikos ir Baltijos juros vasaros vandens temperatūrų tarp Gotlando salos ir Kuršių marių.

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