Time and Space Scales in the AMSR-E SST Fields

Theodoros Yemenis and D. Stammer

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2 Copies of this Report are available at www.ecco-group.org or from Detlef Stammer, Scripps Institution of Oceanography, La Jolla CA 92093-0230, ph.: (858) 822-3376; fax: (858) 534-4464; e-mail: dstammer@ucsd.edu
Abstract

Global SST fields obtained by the microwave AMSR-E instrument on board of the EOS Aqua platform are being analyzed with respect to time and space scales of SST variability. Over most parts of the world ocean, the SST variability is dominated by changes on the annual cycle. After removing a climatological annual cycle from the data, the remaining variability shows amplitudes less than 1° over large parts of the world ocean and on period beyond about 4 days. Enhanced amplitudes can only be found in western boundary current regions and along the tropical oceans.
1 Introduction

SST fields play an important role in the interaction of the ocean with the atmosphere. For that matter it is important to understand its variability and the role that the ocean and atmosphere play dynamically in setting observed variations of SST. At the same time it is important to understand the statistics of SST variability in order to provide the required input in ocean data assimilation efforts by which ocean models are being constrained by ocean data sets, including SST fields (compare [1] and [2]).

An understanding of space and time scales of SST variations is also important for observing the ocean using satellites. This is especially the case for passive microwave remote sensing of the ocean: To properly design the missions and to obtain maximum accuracies of microwave sensors SST is one of the important input fields that need to be know to invert the microwave measurements for target physical environmental quantities. At the time of writing this report, the development of several microwave mission is underway and new sensors are in their planing stage. Among the new missions are ESA’s SMOS mission or the NASA Aquarius mission, both intended to measure the surface salinity over the ocean and soil moisture over land and this report is written in partial support of the mission preparations.

In the following we will provide an analysis of SST statistics over the global ocean, including that of space and time scales of SST. The analysis is based on daily SST fields provided by the Remote Sensing Company (RemSen) as an objective analysis of AMSR-E and TMI fields. Estimated space and time scale will be provided as a function of geographic positions. Given the fact that the AMSR-E time series is relatively short and given the requirements for the SMOS mission designers to know in particular the short space and time variations of SST fluctuations, our emphasis here will be on the high-frequency variations.

2 Methodology

The TMI and AMSR-E objective analysis used here is produced by Remote Sensing Systems through the sponsorship of NASA Earth Science Enterprise (ESE). It is a daily
analyses of SST on a 25 km spatial grid available globally between ±90°latitudes. Fields available to us cover the period 1-JUN-2002 and 1-MAY-2004. AMSR-E fields are available since June 2002 from the EOS Aqua platform. TMI SST fields are available since January 1998 over the latitude range ± 40°. See [3] and [4] for a detailed description of both data sets. A complete description of the data, validation results, and browse imagery are also available at www.remss.com. Correlation scales that were used during the objective analysis are 4 days and 100 km in time and space. These scales need to be kept in mind when interpreting results below. Essentially through the analysis all variability on temporal scales smaller than 4 days was removed. Mooring data might be an essential ingredient to perform test of the very high frequency variations in some parts of the world ocean that are not captured by the satellite data. This will include especially the daily SST cycle. A time-mean SST field, computed from the micro-wave data for the period 1-JUN-2002 through 1-MAY-2004, is shown in Fig. 1.

Because the emphasis here is on the temporal and spatial SST variations that cannot be described by climatological annual cycle, we will base the study on the SST anomaly defined as

$$SST' = SST - < SST >$$

where $< SST >$ comprises the time mean (Fig. 1) and an annual harmonic estimated from 11 years of Reynolds SST fields. A resulting daily field of $SST'$ is shown in the lower panel of Fig. 1, representing June 2003. Amplitudes of $SST'$ are typically ± 5°C. Largest anomalies (i.e., deviations from the climatological seasonal cycle) are visible over the tropical Pacific, over major current system of the world ocean and near Greenland. We note also the SST variations on relatively small spatial scales (order 100km) that are clearly visible in the figure over large parts of the world ocean. To what extent those variations are resulting from the analysis procedure or represent actual SST variability is not obvious.

However, as can be seen from Fig. 5 showing the temporal difference of SST during two successive daily SST fields (July 21 - July 20, 2002), high frequency changes between two successive daily SST estimates are dominated by changes on similar spatial scales suggesting that we see here either rapid changes in the ocean, e.g., through vertical mixing,
or possibly remaining sampling issues in the SST analysis. The banded structures in the SST differences seem to point toward satellite tracks and thus sampling issues.

The amplitude and phase of the annual harmonic as it was inferred from the Reynolds SST data that is removed from the SST fields in the following to form $SST'$ time series, is shown in Fig. 3. $SST'$ time series will be analyzed below with respect to their space time scales of fluctuations. From the daily fields a correlation was computed in time according to

$$r(\tau) = \frac{1}{N} \sum_{t=1}^{N} (SST'(t)SST'(t - \tau))$$

A spatial two-dimensional correlation function was computed as well according to

$$\tilde{r}(x, y) = \frac{1}{(N \times M)} \sum_{i=1}^{N} \sum_{j=1}^{M} (SST'(i, j)SST'(i - x, j - y))$$

From both correlation functions a decorrelation scale was computed as the e-folding scale.

3 Results

As a starting point of this analysis we show in Fig. 4 time series of SST and SST' from three selected locations representing the Gulf Stream, the Kuroshio and the eastern tropical Pacific. The dominance of the seasonal cycle in all three SST time series is obvious. Once a climatological seasonal cycle was removed, the resulting $SST'$ time series show primarily variability on the monthly time scale with high-frequency jitter showing amplitudes of around 1-2°C. In the Gulf Stream and Kuroshio region, some part of the variability will come from meanders of the stream that lead to variability on time scales of a few weeks to months. This type of variability is missing in the eastern tropical Pacific where the variability of $SST'$ seems to change predominantly on time scales of a few days to weeks.

A summary of the variability of a scalar field can be given by its Standard Deviation (STD). STD fields of SST and SST' are shown in Fig. 4. The difference in the RMS variability between both maps represents the energy of the climatological annual cycle in SST. Once it is removed from the data, the resulting $SST'$ time series show variability...
exceeding 1°C only in few regions of the world ocean, notably the western boundary currents and the tropical oceans. We note, however, that this is a lower limit of the actual variability. Variability on timescale shorter than the 4 day decorrelation time scale used in the SST OI procedure was removed. This eliminates especially the daily cycle which can reach amplitudes of 1 °C or more in some regions (needs ref.).

We show in Fig. 6 time-longitude plots of $SST$ and $SST'$ for the North Atlantic at 42°N. The $SST$ field is clearly dominated by the seasonal SST cycle due to heating and cooling. Variations of SST on shorter time and space scales are only visible in the time-longitude section of $SST'$ once the seasonal cycle was removed. From the figure, coherent west- and eastward moving anomalies of close to 1°C are obvious that can be followed for several months. The slope of the SST anomalies in the time-longitude plain represent a phase speed by which the anomalies propagate east, but mostly westward. As can be seen from Fig. 7, showing time-longitude sections of $SST'$ anomalies along 31°N and 15°N in the North Atlantic, the phase speed depends on latitude and is essentially related to the first mode Rossby wave phase speed with which also sea surface height anomalies are found to propagate westward.

While Figs. 6 and 7 allow to infer the nature of SST variations, a quantitative way to infer $SST'$ time scale is to study SST temporal autocorrelation functions given by eq. (1). Respective temporal $SST'$ autocorrelation functions $r(\tau)$ are shown in Fig. 8 from four locations along 180°E. The detailed geographical location is given in the figures caption. While around 40°N and on the equator the variability has a long-period has a clear contribution from periods close to the annual cycle or beyond, changes in the subpolar basin and in the North-equatorial Current (around 20°N) are mostly short period: in both places the variability drops significantly over the first few days and weeks suggesting that a significant fraction of the SST variability resides on the very short time scale. The same holds for many other locations as can be seen from temporal autocorrelation functions plotted along various locations along 85°W in Fig. 9 and along 85°E in Fig. 10.

Zonal averages of autocorrelation functions are plotted in Fig. 11 as a function of latitude. The four panels represent the Pacific, the North Atlantic and the Indian Ocean. Also plotted in the figure is the temporal decorrelation scale measured here as the $1/e$
decay time scale. Quite clearly the SST field is de-correlated after less than 20 days over most parts of the ocean. However, the figure also illustrates the rapid initial drop in correlation which illustrates the SST noise component that is present in most tropical and subtropical regions.

Examples of maps showing a spatial autocorrelation function, \( \hat{r} \), are provided in Fig. 12 again from locations in the Gulf Stream, the Kuroshio and the tropical Pacific. In all three maps the zonal scale is substantially larger than the meridional scale illustrating the predominantly zonal character of the \( SST' \) fields there. A global summary of spatial decorrelation scales of \( SST' \) is provided in Fig. 13. Largest scales in zonal and meridional direction are present in the eastern subtropical and subpolar regions and in the central tropical Pacific. It is noteworthy than in contrast to Fig. 12 the variability of \( SST' \) is to first order isotropic over large parts of the open ocean.

4 Discussion and Summary

Variations of the SST field are clearly dominated by the seasonal cycle. Deviations from a climatological seasonal cycle generally seem small (order 0.5 °C), however the residual signal in the RemSen analysis of AMSR-E and TMI SST observations underlying our study does show coherent structures in a longitude-time plot that provide clear signatures of ocean dynamics on small spatial scales. In the vicinity of the equator imprints of upwelling or instability waves is visible. And near coastal upwelling regions the wind effect on SST is likewise obvious. On large spatial scales, a mixture of atmospheric and ocean impacts will be the causes for the observed changes.

Changes of \( SST' \) that we encountered here on amplitudes exceeding 1°C on high frequencies reside primarily in energetic currents and along the tropical oceans. Over most parts of the open ocean amplitudes are around 0.5 °C or smaller. However, we recall that theses estimates do not include contributions of a daily cycle in SST that by itself could be of the order of 1 °C.
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References


Figure Captions

**Fig. 1**: (top) Time mean of AMSR-E SST field computed from the period 1-JUN-2002 to 1-MAY-2004. (bottom) Instantaneous SST anomaly field from 5. June, 2003 relative to a climatological SST annual cycle.

**Fig. 2**: SST difference between 20. July and 21. July 2002.

**Fig. 3**: (top) Amplitude of the annual harmonic SST estimated from 11 years of Reynolds SST data. (bottom) Phase of the annual harmonic of SST.

**Fig. 4**: (left) Time-mean SST field from the Gulf Stream, the Kuroshio and the eastern tropical Pacific regions. (middle) Absolute SST time series from the positions marked by bold dots in the left-hand side panels. (right) SST time series from the same positions which have a climatological SST annual harmonic and time mean removed. Both where estimated before from Reynolds SST data from the period 1992 to 2002.

**Fig. 5**: (top) Standard Deviation (STD) of AMSR-E SST fields estimated during the period 1-JUN-2002 and 1-MAY-2004. (bottom) STD of AMSR-E SST anomaly fields from which an annual harmonic was removed previously.

**Fig. 6**: (left) Time-longitude sections of SST anomalies relative to a time mean for the latitude 41°N in the Atlantic Ocean. (right) Same as shown in the left panel but showing SST minus a climatological annual harmonic.

**Fig. 7**: (left) Time-longitude sections of SST anomalies relative to a climatological annual harmonic in the Atlantic Ocean at the latitude 31.5°N (right) Same for latitude 12°N.

**Fig. 8**: Temporal autocorrelation function of SST anomaly time series relative to an annual cycle from the four positions at longitude 180°E (Middle Pacific) and latitude 0°N, 20°N, 40°N and 60°N.

**Fig. 9**: Temporal autocorrelation function of SST anomaly time series relative to an annual cycle from the four positions at longitude 40°W (Atlantic Ocean) and latitude 0°N, 20°N, 40°N and 60°N.

**Fig. 10**: Temporal autocorrelation function of SST anomaly time series relative to an annual cycle from the four positions at longitude 85°E (Indian Ocean) and latitude 0°N,
20°N, 40°N and 60°N.

**Fig. 11:** Temporal autocorrelation function of SST anomaly time series relative to an annual cycle from the four positions at longitude 180° (Middle Pacific), 150°W (East Pacific), 40°W (Atlantic Ocean) and 85°E (Indian Ocean).

**Fig. 12:** Spatial autocorrelation functions for tree regions (top) North Atlantic (middle) Kuroshio (bottom) Equatorial East Pacific.

**Fig. 13:** Global map of spatial autocorrelation functions of SST anomaly time series relative to an annual cycle.
Figure 1: (top) Time mean of AMSR-E SST field computed from the period 1-JUN-2002 and 1-MAY-2004. (bottom) Instantaneous SST anomaly field from 5 June, 2003 relative to a climatological SST annual cycle.
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