Fine resolution SSS and SST based on low-resolution in-situ maps stirred by altimetry

The Southern Ocean region south of Tasmania

Introduction

Surface Lagrangian advection with time-evolving altimeter derived SSH geostrophic velocities have been recently shown to simulate quite successfully submesoscale processes (D'Ovidio et al., 2009). Observations based on combined satellite and in-situ data sets are beginning to allow for such studies. In-situ underway observations from ship cruises, particularly from thermosalinographs, offer sufficient horizontal resolution along each transect for studying fronts at scales of a few km (Chaigneau and Morrow, 2002; Desprès et al., 2011).

This technique has been tested in the Southern Ocean region south of Tasmania, a domain marked by strong meso to sub-mesoscale features such as the fronts of the Antarctic Circumpolar Current (Dencausse et al., 2012). This study is based on his work. Starting with large scale surface tracer fields that we stir with altimetric velocities, we can derive higher-resolution surface tracer fields. We then compare the 'advected' fields with high resolution in-situ data.

1. Principle

Lateral advection from altimetry allows us to derive small scales patterns on the ocean surface, starting from larger temporal and spatial scale observations.

This technique consists of advecting particles on the ocean surface using satellite altimetry surface currents (zonal and meridian speeds (u,v)). It can be applied to any tracer whose evolution is primarily governed by lateral advection.

The “advected field” is simply a lagrangian advection between the initial positions of particles and their final positions after a certain number of days of advection. This advection field can then be used to advect or compute the lateral stirring of any observation data (2D fields such as Sea Surface Salinity (SSS) or Sea Surface Temperature (SST) maps or transects data) between the initial and final advection times.

However this method has some limitation: after some days of advection the advected solution will diverge from the reality due to missing physics during the advection: surface forcing or internal mixing or diffusion. More generally, we can have certain parameters of the advection (total number of days, time steps and spatial resolution) depending on the dynamics of the considered region.

Thus the difficulty is to determine the most adequate parameters for each specific region. To do that, we computed the lagrangian advection of different tracer fields observations using various sets of parameter values and compared the results to real small scale.

Usually this lagrangian advection is done using a forward integration. That is, for an initial regular grid of particles (coordinate vector (LAT0, LON0)) at T0, we compute their final positions (coordinate vector (LATF, LONF)) at TF after applying incrementally the speed fields (+u,+v). However, these final positions are no longer on a regular grid.
Thus, when we apply this method to an initial regularly gridded tracer observation, we obtain at the end some sparse tracer data over the region that must be re-interpolated back onto the original grid.

An alternate solution is to compute backward advections. Now the (LON0, LAT0) regular grid corresponds to the final positions at TF and at these positions we incrementally apply the backward speed field (-u,-v) at each time step T=TF - k*DT. We obtain finally a set of initial positions (LONF, LATF) sparsely distributed for date T0 = TF – NB_D (with NB_D the number of days of advection). The large-scale tracer field is then extracted at the initial date from the sparsely distributed particles. We assume the tracer field is not modified during its short advection time, but simply stirred. So the initial, sparsely distributed tracer field, extracted at date T0, is then applied to the regular grid points, at the final date, TF.

2. Lagrangian advection technique

The velocity fields used for the lagrangian advection are from altimetric data, over the period 2002-2012. They were produced by Ssalto/Duacs and distributed by Aviso, with support from CNES (http://www.aviso.oceanobs.com/duacs/). They consist of weekly or daily global 1/3 degree gridded fields of surface geostrophic velocities calculated from sea surface height (SSH) fields also distributed by Aviso.

For this study, these Aviso altimetric currents were linearly interpolated to on a finer space-time grid, at 3 hour intervals, and on to a 0.04° grid. Then the lagrangian advection is performed and each particle is advected with its velocity and position computed every 3 hours.

The lagrangian advection uses Octave with programs by Francesco D'Ovidio.
The result gives the new positions calculated by date and by the number of days of advection. For example, a final advected field on the 20 November 2005 with -15 days of advection will give one result and a final advected field on the same date, the 20 November 2005 but this time with -10 days of advection will give another result.
We have used weekly or daily altimeter data to create the advected fields. Since the first step is to interpolate the fields onto an finer time step (3 hours typical). There is a very little difference in the final result after about two weeks of advection.

3. Tracer data

3.1 Initial fields

The tracer data we use is provided from the CORIOLIS data center. It produces temperature and salinity gridded fields on a weekly basis for the period 2002-2009 and on a daily basis after 11/2009. The system is based on a statistical estimation method (objective analysis). It is the In Situ Objective analysis operational nominal product for the Global Ocean. The dataset contains data from different types of instruments: mainly T,S profiles from Argo floats, XBT, CTD and XCTD, and Mooring.

Products are mapped onto 3-D grids with ¼ degree horizontal spacing and between 59 and 152 vertical levels depending on the period. They are available from the Coriolis website (http://www.coriolis.eu.org), where they are referred to as Global Ocean - Real Time In-situ Observations Objective Analysis. These data were collected and made freely available by the Coriolis project and programmes that contribute to it.
Here is example of weekly SSS Coriolis fields extracted for the region south of Tasmania (Figure 1).

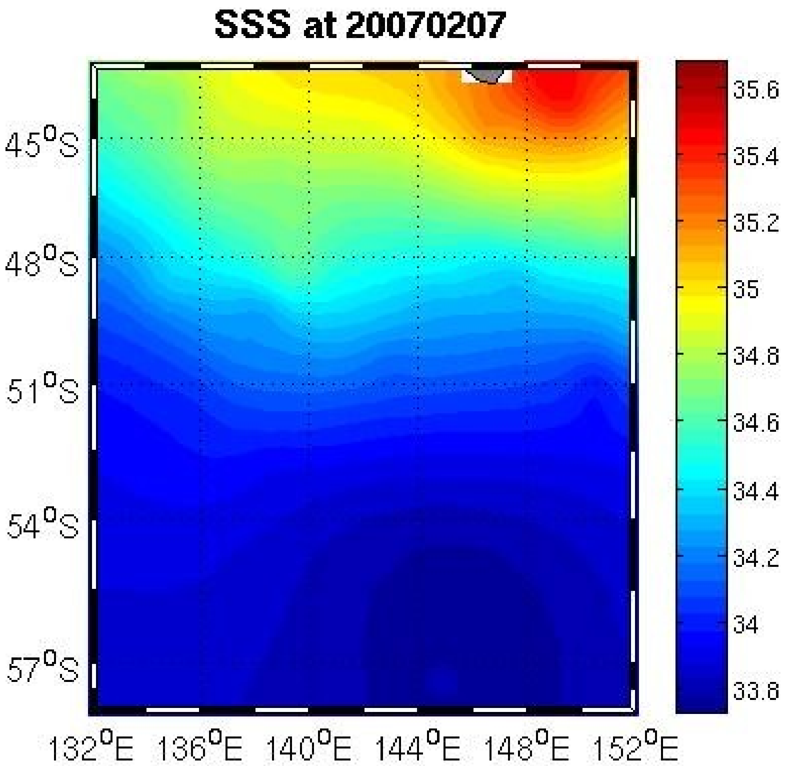

Figure 1: SSS Coriolis fields the 07/02/2007.

3.2. Output tracer files, after advection

We use these large-scale tracer fields to visualize the result of the advection. As we work in backward advection mode, we search for the SSS and SST Coriolis fields NB_D days before the selected date (with NB_D the number of days of advection, +/-3 days for weekly data) and we apply the values of these initial tracers fields extracted from the backward advected particle positions.

Here is a result of an advection in backward mode for the 20 February 2007 with -13 days of advection (Figure 2). The Coriolis SSS tracer values were extracted at the positions of the sparsely distributed backward particles on 7 February 2007 (ie: 20 February -13 days of advection).

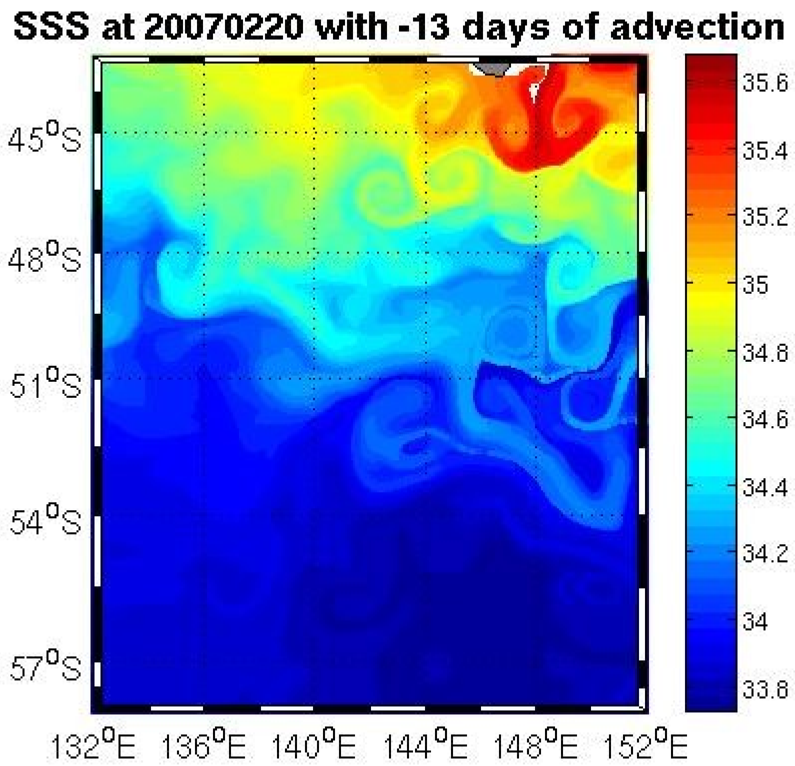

Figure 2: SSS advected fields for the 20/02/2007 with -13 days of advection

4. Validation data

In-situ underway observations from ship cruises, particularly from thermosalinographs (TSG), offer sufficient horizontal resolution along each transect for studying fronts at scales of a few km (Chaigneau and Morrow, 2002; Desprès et al., 2011).

4.1. Survostral data

To validate the advected fields, we use the high resolution underway SSS and SST data since 2002 from the Survostral repeat cruise south of Tasmania (ftp://ftp.legos.obs-mip.fr/pub/soa/salinite/survostral/dm_data_2002-ongoing/) aboard the Astrolabe (IPEV). Underway SSS and SST data are measured by a Seabird Thermosalinograph (TSG) and are available every minute. The vessel links Hobart and the French Antarctic base in Dumont d'Urville, although measurements can only be made as far south as the seasonal ice cover permits. There are usually five round trips per year - and thus twice as many transects – taking place between October and March.

4.2. Comparison

To further analyse the advected large scale Coriolis tracer fields and to determine an optimal advection time, we compare the 2D advected fields of SST and SSS with the underway in-situ data. We calculate a set of advection periods leading up to the mean date of each cruise. The 2D advected fields are then projected onto the TSG measurement points along the cruise line. Here is an example of a comparison of SSS data for the 1 January 2005.

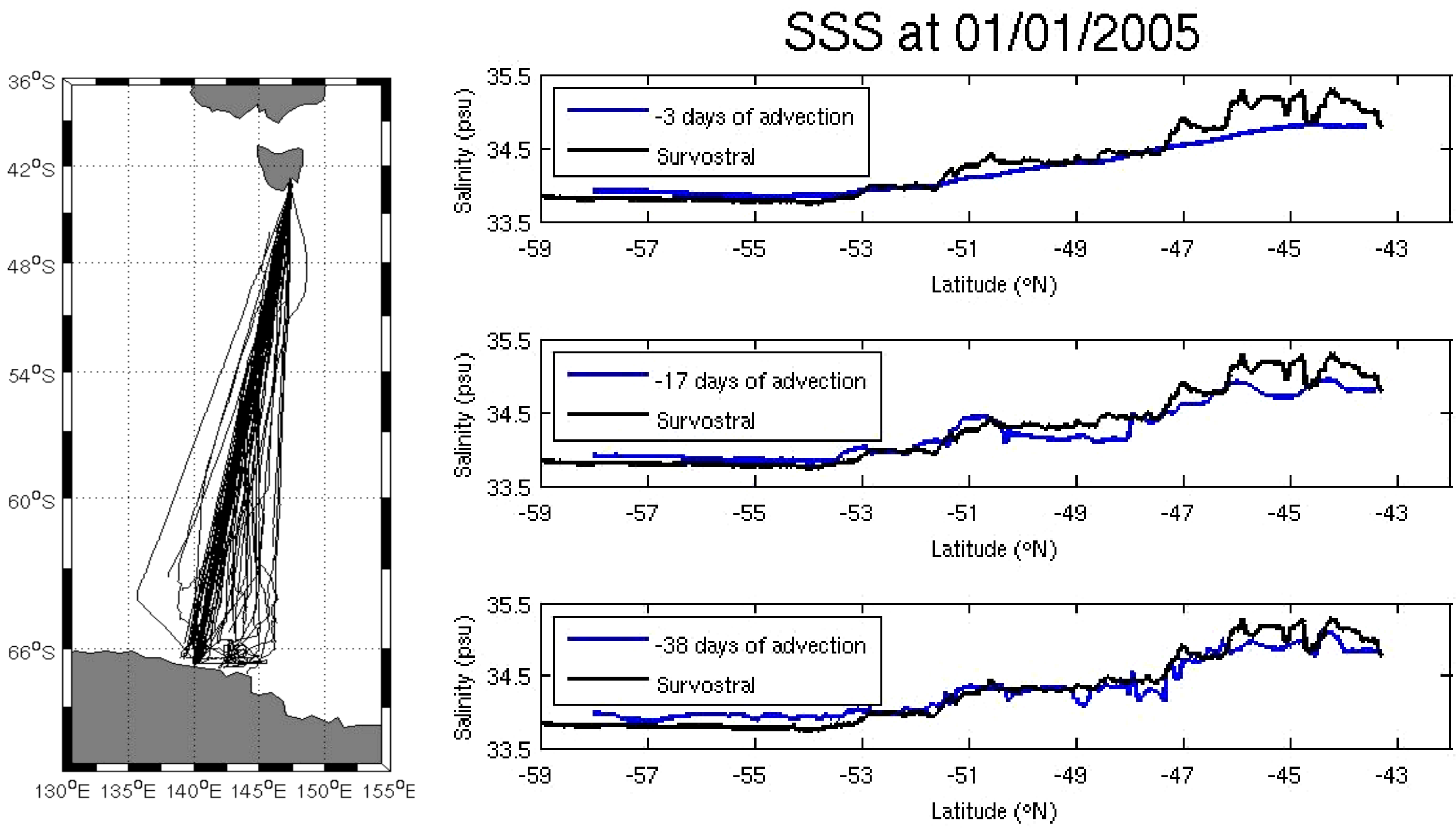

Figure 3: Left selected Survostral cruises (<150°E). Right, comparison between advected fields of SSS and TSG values on the 1 January 2005.The thermosalinograph values are unchanged, but the advection time for the Coriolis fields increases from top to bottom.

4.3. Time evolution of the tracer bias

We have also quantified the temporal evolution of the bias between underway in-situ data and advected SSS and SST fields. For each cruise transect, we define this bias as the difference between the value of the advected tracer field interpolated onto a measuring point and the thermosalinograph data at that point.
However, the value of the bias depends on the quality of the original large scale tracer field which varies with the oceanic region. Hence we define three sub domains in which we calculate the bias (the sub domains are shown in Figure 4). The first domain extends from Tasmania (44°S) to the average position of the STF (47°S). The front coincides with the southernmost penetration of the EAC Extension, where tracer bias can be strong. This region is referred to as the Subtropical Zone (STZ). We also define an Antarctic Zone (AZ) from 55°S to 58°S, south of the average position of the Polar Front, where the tracer bias in the Coriolis fields can also be important due to the lack of Argo float data. Finally, we define an intermediate domain named Sub Antarctic Zone (SAZ), between the average latitudes of the Subtropical and Sub Antarctic Fronts – from 47°S to 50°S - where the initial tracer bias appears to be less important.
Having defined a quantitative bias, we study its evolution over the 2002-20012 period advections of 15 days (+/-3 days for weekly data) (Figure 4). Over this period, the bias is progressively reduced, mainly due to the increased number of Argo floats in the region. For more discussion see Dencausse et al. (2012).

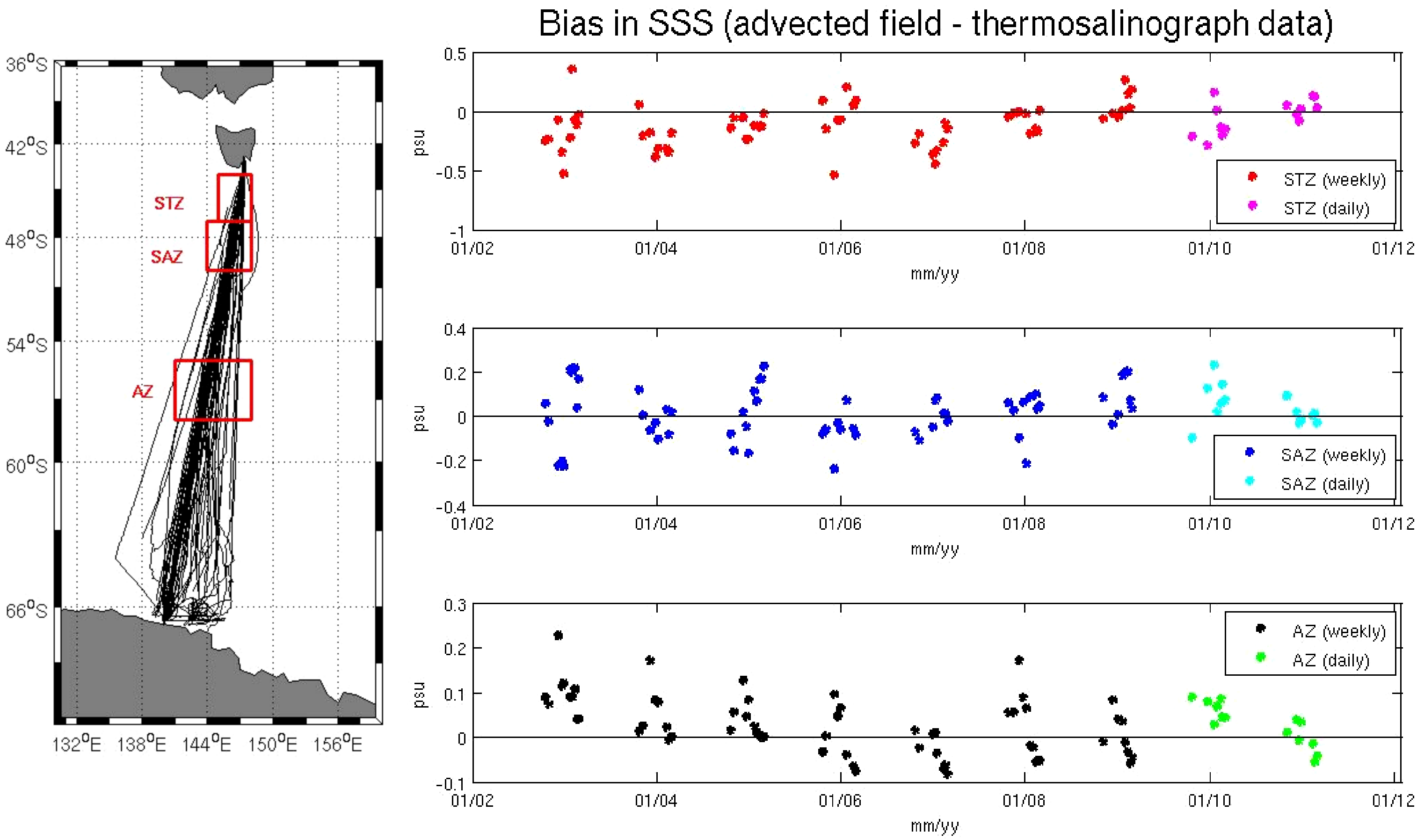

Figure 4: Left, the selected Survostral ship transects (<150°E) performed over 2002-2012 are plotted, along with the rectangular domains referred to as the Subtropical, Subantarctic and Arctic Zones (STZ, SAZ and AZ respectively). Right, the time evolution of the mean SSS biases between the advected Coriolis fields and the thermosalinograph measurements in each domain (the advection time is 15 days (±3 for weekly data)).

Conclusion

The Lagrangian trajectory calculation technique described here and used in previously studies developed by Francesco D'Ovidio and Guillaume Dencausse shows promising results when applied to the improvement of the horizontal resolution of large scale upper ocean tracer fields.

The advection of tracer fields is passive, and only takes into account the stirring of the tracer fields by horizontal geostrophic velocities resolved by altimetry. Improvements would involve implementing neglected thermodynamical factors, such as air-sea fluxes which are significant in the ocean domain studied, Ekman velocities, or diffusion.

Dynamics at fine scales in the upper ocean affect the general ocean circulation. The current need is for the improvement of salinity fields to bridge the gap with the better knowledge we have of temperature in the upper ocean. This technique could also be applied to SMOS and Aquarius data, starting with tropical or subtropical regions where the data should have better precision.

References

Chaigneau, A. and R. Morrow (2002). "Surface temperature and salinity variations between Tasmania and Antarctica, 1993-1999." Journal of Geophysical Research-Oceans 107(C12).

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