# Impact of a SST front on the atmospheric boundary layer and turbulent surface fluxes.

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## Introduction

SST front corresponds to a sharp sea surface temperature gradient. In terms of impact on the atmosphere, the air mass is likely more unstable or less stable over the warm zone than over the cold one. Horizontal and vertical gradients are then susceptible to appear in the transition area, and to generate secondary circulations which will, in turn, produce a feedback on the atmospheric parameters. The Marine Atmospheric Boundary Layer (MABL) heat and momentum fluxes variations are likely correlated with the surface temperature – in a positive way at the sub meso-scale, and in a negative way at the very large scale as shown by recent studies (e.g. Small et al., 2008).
In typical SST fronts (Fig. 1), the hydrostatic pressure gradient induced by the SST gradient in the MABL results in higher pressure above the cold zone, lower pressure above the warm zone. This generates a secondary circulation (sea breeze alike) with surface wind accelerating from the cold side towards the warm side, resulting in a wind gradient. In the warm side, the stronger mixing results in a vertically homogeneous horizontal wind (Fig. 1). As a consequence, the surface wind is stronger in the warm side and generates a stronger sea state, with larger roughness length and a stronger momentum transfer.

The aim of this study was to investigate to what extent this theoretical model may be confirmed by observations on the Ushant SST front, in the Iroise Sea (see Fig.4b). This SST front is generated by a very strong tidal current bringing cold water to the surface on the shoreward side.

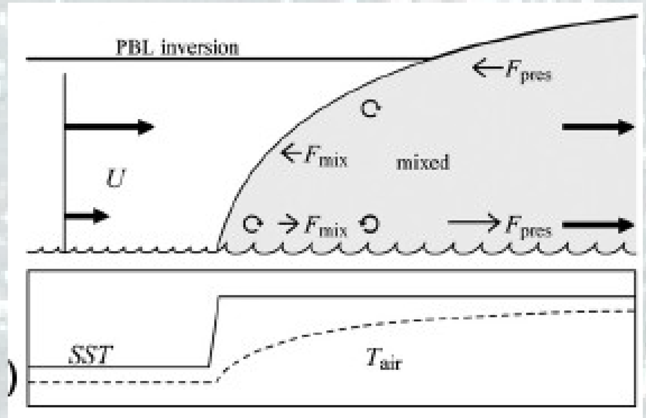


Figure 1: Schematic representation of a SST front, with effects on the atmosphere (top) and evolution of the SST (solid line) and surface air temperature (dashed line, bottom); Small et al., 2008

## Datasets: the FromVar campaign

This study used datasets collected during the FromVar 2011 campaign, that took place between the 02 and 15 September in the Iroise Sea (Marié et al., 2011).
Basic meteorological and surface hydrological parameters were measured continuously onboard the R/V Cotes de la Manche (CDLM). A Scanfish provided 2D profiles of the sea temperature and salinity almost every night. Radiosoundings launched from the ship (once or twice a day) provided vertical profiles of the atmospheric parameters up to 10 km. The atmospheric turbulent (and radiative) fluxes were measured both on the ship mast and on the innovative autonomous platform OCARINA (Bourras et al., 2014, see Fig. 3). These data were completed by numerical simulations issued from operational forecasts: the French high resolution weather prediction model AROME (Seity et al., 2011) for the atmosphere, the MARS3D (Lazure and Dumas, 2008) high resolution ocean model for the ocean, and the WW3 wave model (Ardhuin et al.,, 2012) for the sea state.

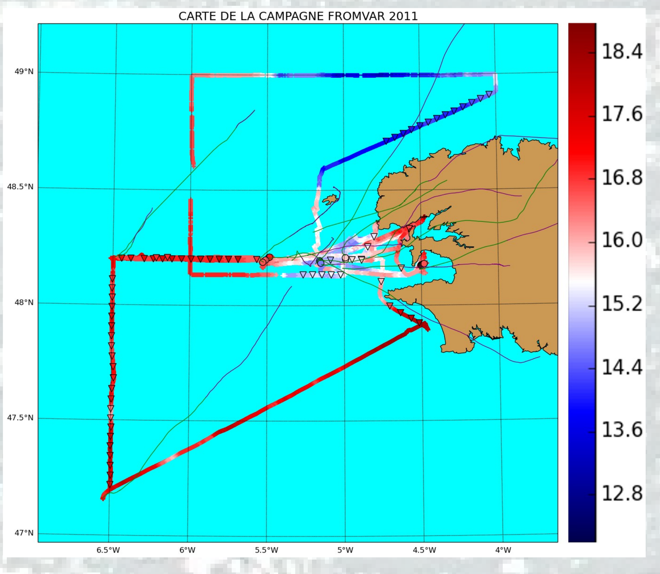


Figure 2: Map of the FromVar campaign with SST measured by the ship (colour scale, in degrees C), radiosoundings (upward: green; downward: purple) and turbulent flux measurements (onboard the CDLM: inverted triangle; with OCARINA: dots)

Figure 3: the CDLM ship (top) and the OCARINA platform used to measure turbulent fluxes (bottom)

## Assessment of the model simulations

AROME

The MABL is generally well represented by the AROME model outputs (in comparison with RS). The surface layer is more homogeneous above the warm part of the front and more stratified above the cold part.
However, in weak easterly flow, the transition zone in the MABL between the stable and unstable parts is shifted north: this is due to the SST forcing of AROME, OSTIA (Donlon et al., 2012) whose horizontal resolution is too crude to properly represent the front (Fig. 4).

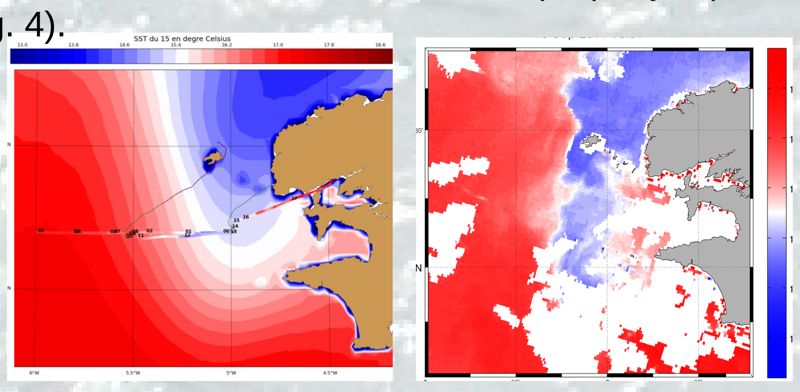

Figure 4: (a) Map of the OSTIA SST, 15 Sept. 2011, with the SST measured by the CDLM/Scanfish superimposed, and (b) SST from METOP B on the same day.

MARS3D

The simulated temperature compares favourably with the SST and the in-depth temperature measured by the Scanfish across the SST front (Fig.5). Especially, the gradient structure and values are well reproduced by the model. A warm bias of 0.8°C is observed on the model, with an RMS less than 2.8 °C.

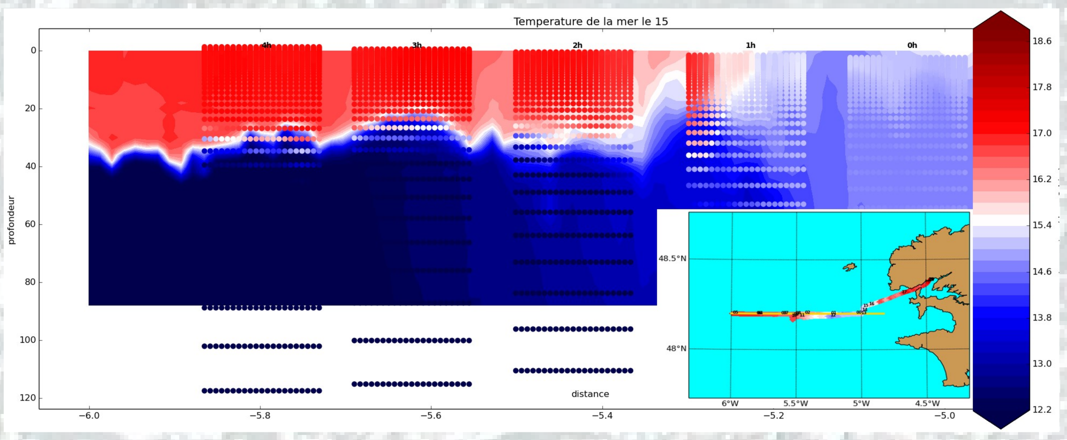

Figure 5: 2D view of the sea temperature (colour chart) modelled by MARS3D compared with the Scanfish temperature measurements, 15 Sept. 2011, along the Scanfish trajectory.

## Results – MABL and heat fluxes

The comparison of temperature and wind profiles from RS realized in the cold/warm zones of the front at close times show an influence of the SST on the atmosphere in two respects:
- the surface layer is more homogeneous due to stronger turbulent mixing on the warm side (Fig. 6, 15 Sept 2011).
- the surface wind (and above in the MABL) is slighter stronger on the warm side (11 m/s) than on the cold side (9 m/s) – not shown. This result is confirmed by the CDLM surface wind measurements

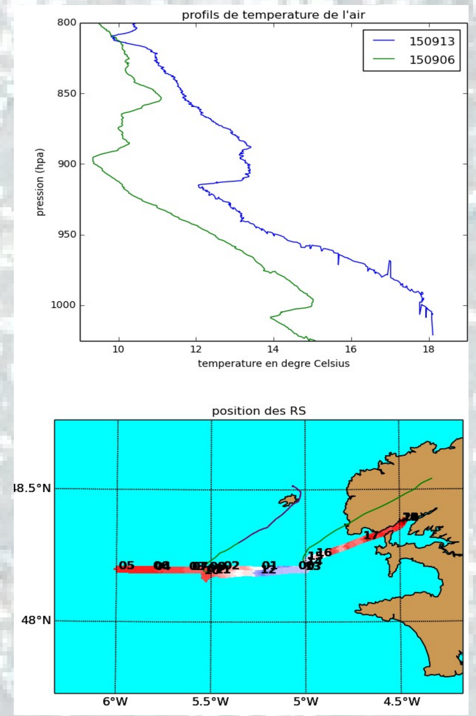


Figure 6: Temperature profiles of two RS launched on the same day, at 06 UT in the cold zone and at 13 UT in the warm area

We compared the latent heat fluxes measured by the CDLM with SST and atmospheric surface parameters (T, RH, wind) in order to detect an impact of the SST front on the evaporation (Fig. 7). For similar wind and relative humidity conditions, the latent exchanges are higher in the warm area of the front than in the cold one. This demonstrates the strong influence of the SST front on the surface layer of the atmosphere

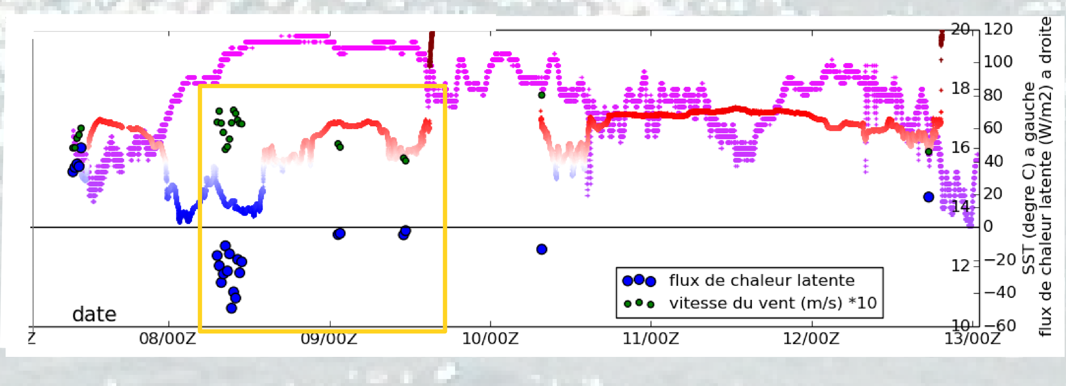


Figure 7: 10-m wind speed (m/s, green dots), relative humidity (pink), SST (colour scale) and latent heat flux (blue dots) as measured by the CDLM, 8 – 13 Sept. 2011.

## Results – momentum flux

Only the momentum fluxes derived from the OCARINA measurements using the EC method are used to study the sea state effect. They are less susceptible to be biased by distorsion effects and the instrument is much closer to the sea surface.
A comparison of the EC friction velocity with the bulk estimates (using the COARE3.0 algorithm, Fairall et al., 2003) shows a systematic positive bias, corresponding likely to the effects of wind sea and (mainly) swell on the wind stress (Fig. 8). All the measurements were made during swell-dominant conditions and wind speed under 10 m/s.

We then used the method of Grachev et al. (2003) to compute the part of the wind stress related to swell: the EC-derived stress vector is decomposed in parts corresponding to viscous, turbulent and wind-sea growth exchanges (which corresponds to the bulk stress vector) and in a remaining part, corresponding to the swell wind stress (green arrows in Fig. 9)

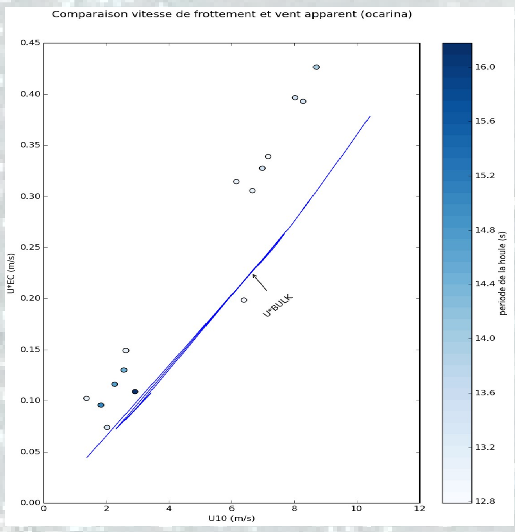

Figure 8: EC-derived friction velocity (colour scale dots) with respect to 10-m wind speed compared with the COARE3.0 bulk friction velocity (solid line).

According to the results of Grachev et al. (2003), the swell-related stress vector should be aligned with or opposed to the swell. As no collocated measurements of the sea state were performed during FromVar, we used outputs of the WW3 model for the comparison (Fig. 9, cyan). We obtain a very good agreement between the direction of the swell wind stress and the swell direction, confirming that there is a clear influence of the swell on the momentum, and the OCARINA platform is well adapted to detect and quantify this effect.

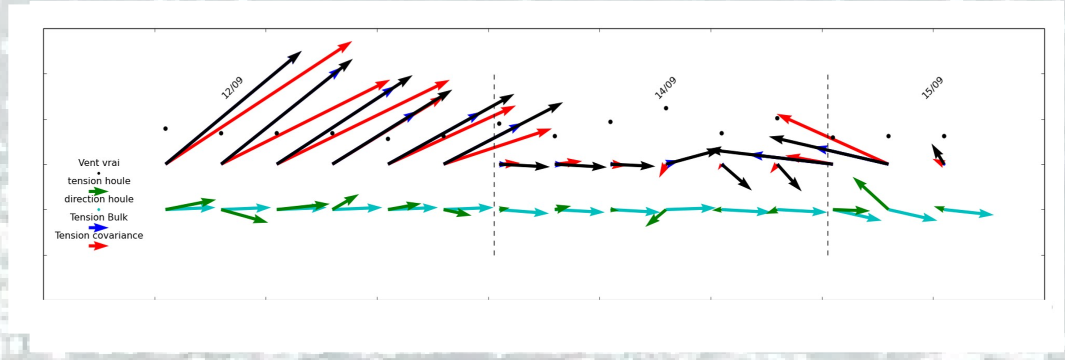

Figure 9: Comparison of the EC-derived wind stress (red) with the bulk wind stress (dark blue) aligned with the wind (black). The swell wind stress (green) is compared with the swell direction computed using WW3 (cyan).

## Conclusions

The FromVar 2011 observations completed by model outputs are used to investigate the air-sea exchanges in the Iroise Sea and the influence of the Ushant SST front on the surface fluxes and MABL.
The AROME atmospheric model performs well in this area but its representation of the MABL is biased by the SST forcing used, which does not reproduce correctly the SST front and its dynamics.
The MARSD ocean model temperatures give a slight warm bias but provide a very good picture of its horizontal and vertical structure and time evolution.
The MABL in the observations (surface parameters, RS) and in the model is clearly influenced by the SST gradient, in terms of surface wind and stratification.
The observed turbulent heat fluxes are also markedly influenced by the SST, for similar wind and humidity conditions.
We observe no direct influence of the SST front on the momentum flux, but the wind stress is clearly impacted by the presence of swell, which was ubiquitous during the campaign.

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