4.3 OCEAN-ATMOSPHERE INTERACTIONS AND COUPLING ASSOCIATED WITH MEDITERRANEAN HEAVY RAINFALL EVENTS

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1. Introduction

Heavy rainfall events that often occur over the Mediterranean coastal areas in autumn are characterized by large amounts of precipitation (>100-200 mm) in a short time (24h). These extreme events are favoured by a slow-evolving synoptic situation and by the Mediterranean basin near-coastal reliefs. They are generally induced by quasi-stationary mesoscale convective systems (MCS) or frontal disturbances that stay over the same area for several hours to a few days. Sometimes, the two types of precipitating systems may combine.

The Mediterranean Sea is an important source of heat and moisture for these systems. Moreover, the strong low-level winds that prevail during these events constitute a strong forcing on the oceanic mixed layer through momentum exchanges. The Meso-NH research model (Lafore et al. 1998) running with two nested grids at 10 and 2.5 km resolution respectively and coupled to its surface scheme SURFEX, is used here as a numerical laboratory to study energy exchanges at the air-sea interface and their impacts on the torrential rainfall forecast. This study concerns three heavy rainfall events that occurred over Southern France: *i)* Two MCS cases: over Aude, 12-13 November 1999 (Ducrocq et al. 2003) and over Gard, 8-9 September 2002 (Delrieu et al. 2005), and *ii)* a stationary frontal system with embedded convection over Hérault, 3 December 2003 (Lebeaupin et al. 2006). See Figure 1 for geographical names.

Lebeaupin et al. (2006) have examined the sensitivity of these events to the Sea Surface Temperature (SST) for high-resolution and short range atmospheric forecasts. Various SST fields were tested as well as increasing or decreasing the analysed SST over the sea basin. The averaged value of SST overall the basin was found modulating the convection intensity and the precipitation amounts, and in some extent the stationarity of the precipitating systems. The SST effect relies however on how the air-sea fluxes are parameterized in the model and is examined here for the same heavy rainfall events using various air-sea surface fluxes parameterizations (section 2).

To go one step further in the study of the air-sea coupled processes during heavy precipitation events, a two-way coupling between Meso-NH and a oceanic model has been developed and applied to the same precipitation events. First results are described in section 3.

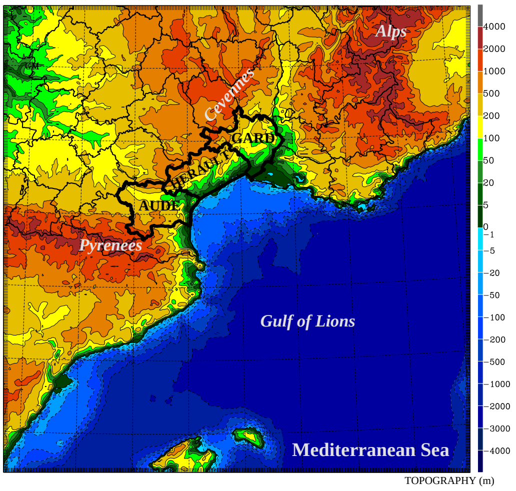

Figure 1: South-eastern France topography.

2. Sensitivity to the air-sea fluxes parameterizations

2.1. *Description of the air-sea flux parameterizations*

In order to evaluate the sensitivity to the sea surface turbulent fluxes parameterization, we introduced in the Meso-NH surface scheme (*i.e.* SURFEX) two parameterizations based on bulk iterative algorithms:

– The UNIfied Turbulent Fluxes Parameterization (UNITFP - Belamari, 2005) developed within the MERSEA project framework: It includes a multi-campaign calibration of the exchange coefficients obtained by compiling turbulent air-sea fluxes measurements of the ALBATROS experimental database (Weill et al. 2003);

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- The algorithm developed for the TOGA COARE experiment (Weller et al. 2004): last version described in Fairall et al. (2003) has been introduced (called here after COARE 3.0). The precipitation corrections and the gustiness effect are included as options, whereas the cool-skin or warm layer corrections are not taken into account.

These two parameterizations are compared to the standard fluxes formulation of the Meso-NH surface scheme following Louis (1979), called hereafter STD.

The TOGA COARE experiment data set has been used to validate the new parameterizations (Figure 2). When the air-sea fluxes parameterizations are forced by the TOGA COARE atmospheric data, the simulated momentum and heat fluxes are closer to the observed fluxes for the UNITFP and COARE 3.0 parameterizations than for STD one. For strong wind regime ($\geq$10 m.s^{-1}), the standard parameterization of Meso-NH strongly overestimates the momentum and latent heat fluxes. The UNITFP and COARE 3.0 parameterizations provide very close values of fluxes.

2.2. *Impact on the heavy precipitation forecast*

We examined the sensitivity to the sea surface turbulent fluxes parameterization for the same heavy precipitation events as Lebeaupin et al. (2006). Reference simulations are those using the STD parameterization.

Simulations using the bulk iterative parameterizations produce very different sea surface turbulent fluxes values compared to the reference ones especially for the latent heat and momentum fluxes in strong to intense wind regime. Changing the parameterization has therefore a significant impact on the atmospheric dynamics in the region of high winds. Decreasing the larger values of latent heat flux results in less water vapor available for the convection and consequently the precipitation amounts are weaker in COARE3.0 and UNITFP simulations. The largest differences are therefore found for the torrential rainfall event with the strongest low-level jet, *i.e.* the Aude case, where the low-level wind exceeded 30 m.s^{-1}. The surface evaporation is in that case strongly decreased. Indeed, when using the UNITFP and COARE 3.0 parameterizations, latent heat flux is decreased by nearly 200 W.m^{-2} within the low-level jet area compared to the reference simulation, and the maximum value of rainfall totals is decreased by about 10% (Figure 3). For situations with weaker wind regime over sea (<10 m.s^{-1}) as for the Gard case, changing the air-sea parameterization has almost no impact on the rainfall amount.

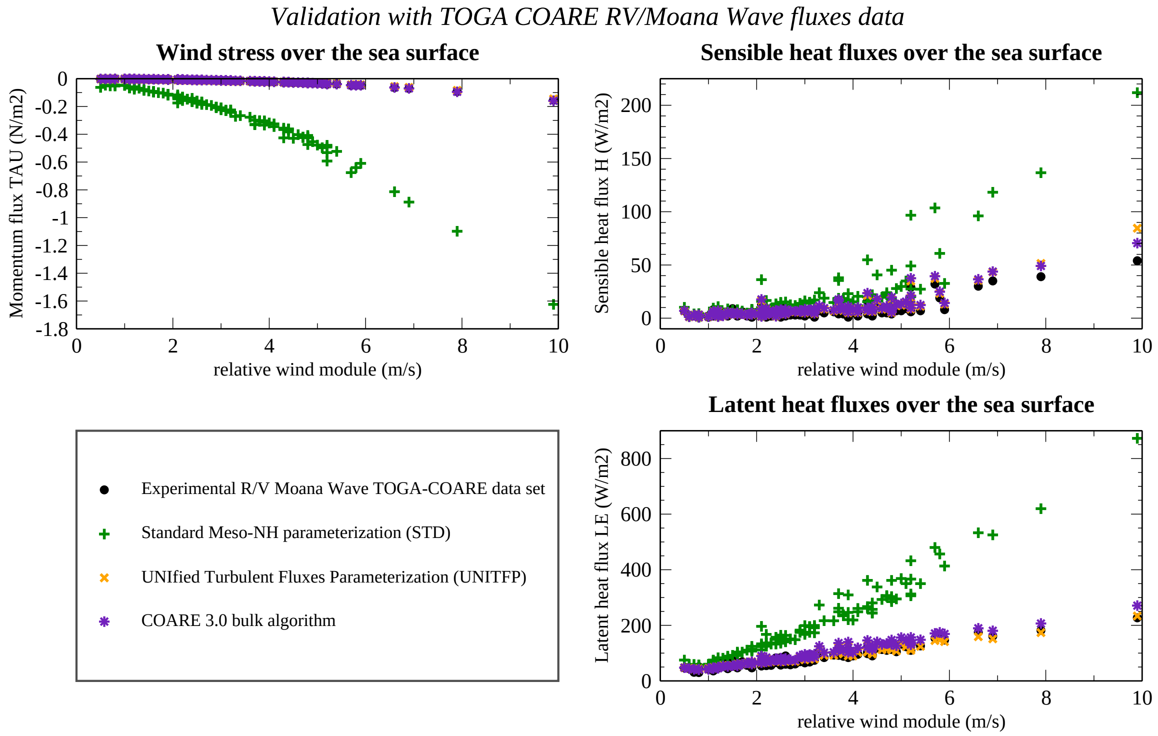

Figure 2: Momentum and heat fluxes over sea observed and computed off-line from the TOGA COARE experimental atmospheric data (T_a, T_s, q_a, q_{sat} and $\vec{v_a}$) according to the UNITFP, COARE 3.0 and STD parameterizations.

Even tough using the iterative parameterizations does not improve the short-range high-resolution atmospheric convection forecast, the strong differences of momentum fluxes over sea surface could be significant for the oceanic dynamics in case of air-sea coupling forecasts as illustrated in section 3.

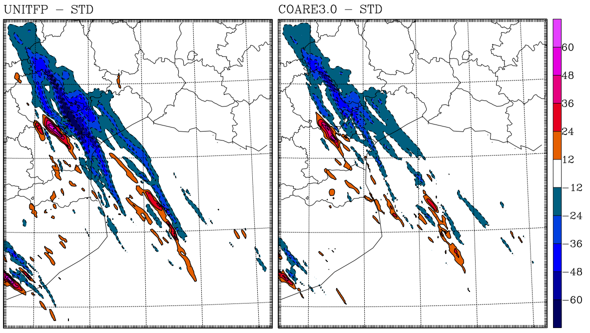

Figure 3: Differences from the reference experiment (using STD parameterization) of the 18h-accumulated surface rainfall totals (mm) for the Aude case.

3. Mesoscale ocean-atmosphere coupling

3.1. *The coupled system*

A full two-way coupling was developed between the Meso-NH model and the Gaspar et al. (1990) 1D oceanic model in turbulent kinetic energy equations. The principles are to modelled a seawater-column under every sea grid points of Meso-NH (Figure 4). The two models exchange through the intermediary of the Meso-NH surface scheme (*i. e.* SURFEX), the SST, the air-sea surface momentum and heat fluxes according to the chosen parameterization, the fresh water and the radiation fluxes (Fig. 5). Meso-NH is initialized with the ARPEGE analysis. The initial state of the oceanic model is taken from a 3D Mercator analysis (Bahurel et al. 2004). Only the inner Meso-NH domain is coupled with the oceanic model. Meso-NH time-step is 5s, whereas it is 300s for the oceanic model.

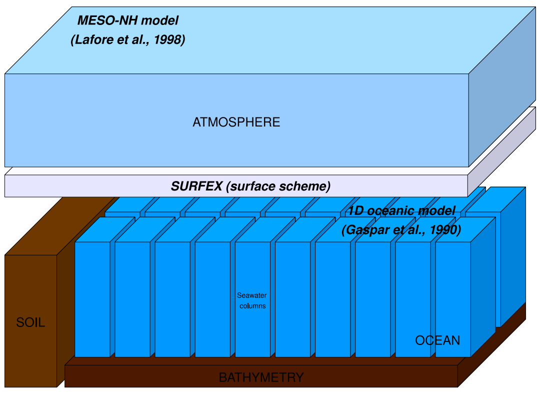

Figure 4: Schematic representation of the air-sea coupled system.

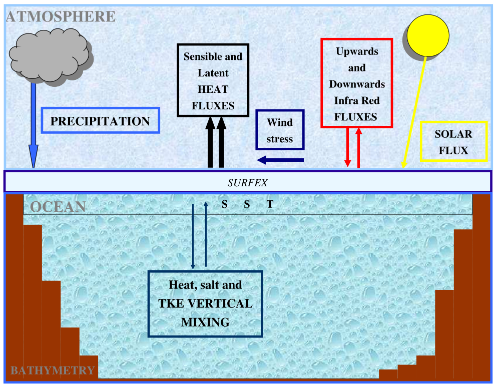

Figure 5: Schematic representation of the air-sea interface exchanges and oceanic processes involved in the coupled system.

This mesoscale coupled system allows us to study with more details the air-sea interactions during Mediterranean heavy rainfall events and the atmospheric forcing impact (wind and precipitation) on the oceanic mixed layer. We compare one-way (corresponding to a simple forcing of the oceanic model with the atmospheric fluxes) versus a full two-way coupling. We also test different sea surface fluxes parameterizations and the impact of precipitation on the oceanic dynamics. The characteristics of simulations are summarized in Table 1. The CFCOA simulations constitute the reference. More details about the precipitation corrections H_p and τ_p could be found in Gosnell et al. (1995) and Fairall et al. (1996), respectively. We present here only the results for the Hérault case (3 December 2003). The results for the Aude and Gard cases will be exposed during the conference.

	Meso-NH	SURFEX	1D oceanic model
	SST	*Fluxes parameterization*	*Atmospheric forcing*
CFCOA	forced	COARE 3.0 +gustiness +precipitation	Full
CFSTD	forced	STD	Full
CFCwp	forced	COARE 3.0 +gustiness	without precipitation
CPLCO	two-way coupling (every 300s)	COARE 3.0 +gustiness +precipitation	Full

Table 1: Simulations experienced with the coupled system.

3.2. *SST and air-sea fluxes evolution*

Sea surface heat fluxes simulated evolution averaged over sea domain is represented in Figure 6. The CFCOA and CPLCO simulations experienced almost the same sensible and latent heat fluxes simulation. The fluxes obtained in the CFSTD simulation show the same tendencies than when testing the sensitivity to sea surface fluxes parameterizations, *i. e.* a strongest latent heat fluxes and a slightly weaker sensible heat fluxes simulated when the STD parameterization is used instead of the COARE3.0 parameterization. The CFCwp have almost the same latent heat fluxes than the reference simulation but weaker sensible heat fluxes. The difference is induced by the precipitation correction on the sensible heat fluxes H_p which is omitted in CFCwp.

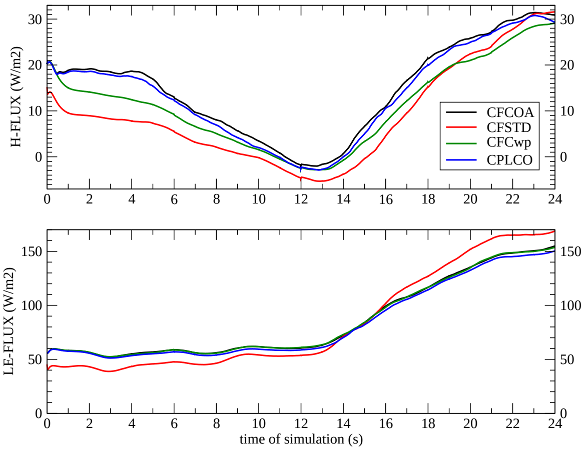

Figure 6: Temporal evolution of the sensible and latent heat fluxes averaged over the sea domain.

For every simulations, the mean SST is decreased by nearly 0.15^{o}C (Fig. 7). The strongest decreased is found in CFSTD simulation because of larger values of latent heat fluxes obtained with the standard parameterization. The Sea Surface Salinity (SSS) after 24h is almost not changed on averaged except in CFCwp simulation: Without precipitation, only the evaporation acts by increasing the salinity (Fig. 7).

3.3. *Effects on the oceanic mixed layer*

The effects observed for surface values are also found for the whole oceanic mixed layer values. As the frontal disturbance moves, the mixing in the oceanic boundary layer is intense under high wind (>20 m.s^{-1}). But this strong forcing doesn't remain more than two hours over the same seawater columns. However, the vertical profiles obtained show significant tendencies after only 24h with for example a mean temperature in the oceanic mixed layer decreased by 0.1^{o}C on average over the basin in CFCOA experiment (not shown) and locally the decrease could reach 0.3^{o}C.

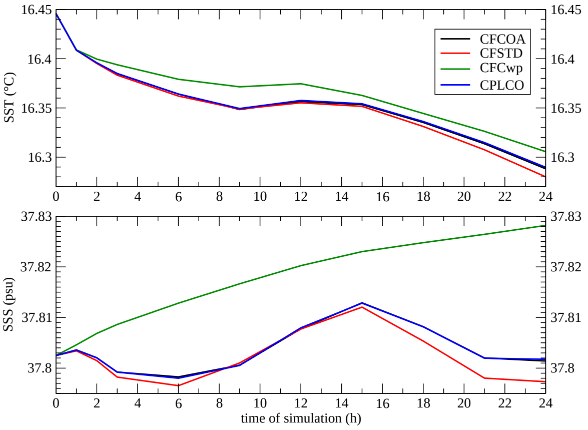

Figure 7: Temporal evolution of the sea surface temperature and salinity averaged overall the basin.

A simple criterion was adopted to evaluate the oceanic mixed layer depth, corresponding to a change in density of 0.02 kg.m^{-3} relative to the density at 5 m in depth. Based on this criterion, a deepening of the oceanic layer is visible after 24h in the Gulf of Lions for every simulations: the maximum mixed layer depth reaches 200 m (not shown).

Beneath heavy precipitation, a thin upper layer of fresh cold water is formed locally under precipitation. In general, this effect is smooth in surface as the front with embedded convection moves, but the precipitation effect is sometime still visible after 24h in both oceanic mixed layer temperature and salinity profiles in the upper oceanic levels (Fig. 8). The salinity is the most affected by precipitation as shown by CFCwp.

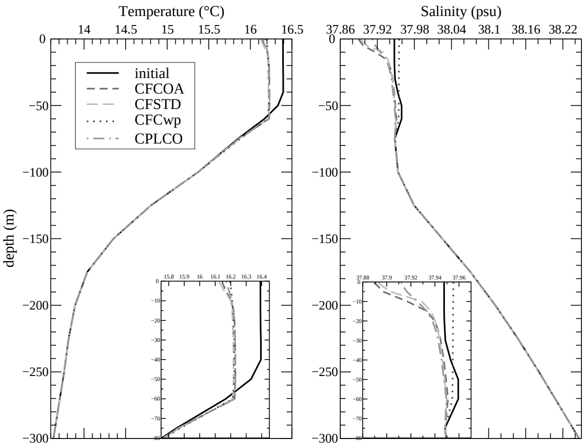

Figure 8: Temperature and salinity vertical profiles at sea point location 42.45N-5.80E and zoom in the oceanic mixed layer.

3.4. *Feedbacks on the atmospheric convection*

The CFSTD experiment with strong value of latent heat fluxes simulations over-estimates the atmospheric convection intensity with a maximum rainfall amount at the end of simulations of 327 mm (Table 2). The three other experiments simulate almost the same atmospheric event with rainfall totals values closer to raingauge observations. The full two-way coupling experienced in CPLCO give the smallest bias and rms values.

Note that the Ekman oceanic current induced by stress has an orientation that will interact with the Rhône river discharge into the Mediterranean sea (Fig. 9) and thus has contributed to worsen the floods (Hontarrède et al. 2004). The induced current plays also a key role in the oceanic mixed layer dynamics, especially on the vertical mixing.

		CFCOA		CFSTD		CFCwp		CPLCO	
Maximum		283		327		277		290	
Bias	RMS	2.1	23.2	2.2	24.1	1.8	22.5	1.6	22.9

Table 2: Maximum value of 24h-rainfall amounts and bias/rms scores in mm from raingauge observations.

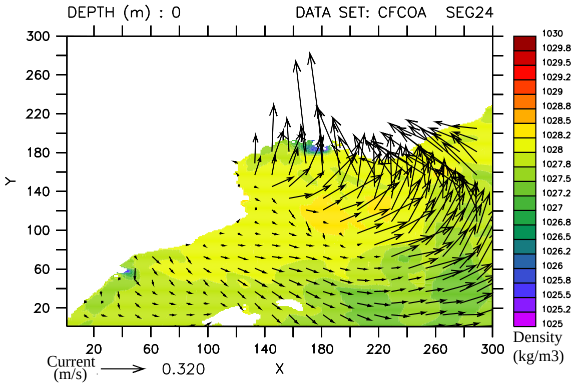

Figure 9: Sea surface water density and stress-induced current in the Gulf of Lions, 4 December 2003, 00UTC.

4. Conclusions and perspectives

Sensitivity to the sea surface conditions have been examined on three heavy rainfall events over the Mediterranean regions through modifying the turbulent fluxes parameterizations: Two iterative air-sea fluxes parameterizations (UNITFP and COARE 3.0), more accurate in strong wind regime, have been introduced in the surface scheme SURFEX common to Meso-NH and the future operational model AROME of Météo-France, and compared to the standard parametrization. Differences in rainfall forecasts when the sea surface parameterization is changed are visible for cases where a high-wind regime prevails over sea.

Using the high-resolution coupled system Meso-NH(SURFEX)/1D model Gaspar et al. (1990) shows the importance of a realistic sea surface fluxes parameterization for well simulated the oceanic mixed layer dynamics during heavy precipitation situations. The mesoscale air-sea coupled simulations using one-way coupling show the effects of high-precipitation and strong wind on the oceanic mixing for Mediterranean heavy rainfall events over the South-eastern France. The oceanic state is significantly modified in the Gulf of Lions by these extreme atmospheric events. The full two-way coupling allows to investigate the feedbacks on the atmospheric convection.

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