Slide 2

Much of the coupling between the atmosphere and the sea involves disequilibria at the interface between the two fluids:

Differences in sea surface temperature (SST short) and surface air temperature, along with an unsaturated atmosphere drive

Thermodynamical Turbulent fluxes of latent and sensible energy, which will be the core topics of today’s talk.

The presence of clouds is impacted by the distribution of surface fluxes and in turn it is affecting the radiative budget, with increased albedo for example.

depending on the alignment of wind with oceanic currents Kinetic energy is then also exchanged,

Now the curious fact is that the action of each one of these effects changes dramatically depending on the scales of motion under consideration

Slide 3

And that is what Gentemann et al demonstrate in this pair of figures in a paper from 2020: they looked at correlations between observed surface wind speed and SST, which appear to be negative when computed with the whole global statistics: this means that upwelling of cold ocean waters is induced when the wind is faster, and thus it the atmosphere that is forcing the ocean.

If instead anomalies are every time computed over smaller regions , let’s say 1000km wide , correlations flip signs: so to warmer SSTs, there correspond faster winds. This is a sign that the ocean is forcing the atmosphere in this case, and notice that the flipping in sign happens over energetic regions in the oceans, where spatial patterns of SST are very diverse.

So as to probe the exchanges between air and sea on a more regional perspective

Slide 4

Different instrumental campaigns have been carried out, the most recent of which is EUREC4A – Atomic from January and February 2020. The mail goal of this campaign was to probe the coupling and feedbacks between shallow convection and oceanic features in a region that is expected to be very sensitive to changes in a warming climate, the NWTA, close to the Barbados archipelago.

The infrastructure involved was massive, both as for platforms deployed in situ and for the accompanying numerical experiments

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It is in this context that IRD Toulouse and Univ. MiB have collaborated in running a 1-year long WRF simulation, where the coupling between the oceanic component and the atmospheric counterpart is active both for surface stresses and thermodynamics.

With the aid of this numerical experiment, our goal is to shed light on the small scale effects of sea surface temperature on surface fluxes and how such effects propagate over the lower troposphere: we do this through statistical analyses over one month of daily averages computed for the month of February 2020.

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so called mesoscale anomalies are going to be Key for the discussion . Let’s proceed with order

the convolution product of a field of interest PSI and a gaussian kernel is called low-pass filtering: low passing makes the original field spatially smoother.

mesoscale anomalies are eventually obtained by subtracting the low passed field from the original variable, a procedure which is instead defined as high pass filtering. it isolates the contribution of scales approximately smaller than the parameter lambda here, which is the cutoff scale that we set for filtering.

So lets take for example an SST map (show image now) you can somehow already distinguish colder areas from warmer ones, but its with the high pass filter that differences become much more visible. As you can see , The SST here is characterized by a widespread presence of front-like structures, which very likely are inducing changes in the local surface energy exchanges.

*slide 7*

Naturally, surface fluxes do not only depend on SST alone, but are the product of different other variables, as we will see: despite this fact, As a first step in today’s talk, we shall focus our attention on how surface turbulent heat fluxes and the local thermodynamics vary given a change in sea surface temperature.

Given the limited variability of SST in the present context, we used linear relationships to assess how effective such link between SST and thermodynamics: regression slopes , be it between unfiltered or filtered data, will be from now on referred to as sensitivities.

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To start, lets see what the sensitivity between SST and LHF is. The LHF bulk formulation takes mainly three ingredients: wind speed, the saturation mixing ratio computed with the Clausius Clapeyron law at SST; and the actual moisture content, q2 .

On the one hand, we see that there is no link whatsoever between the large-scale values (low-passed , anything beyond 200km) ;

At variance with that, high-passed values (mesoscale anomalies), do show a much stronger link: for every 1K change in SST, LHF increase by approximately 47 Wm2 .

If mesoscale SST anomalies have such a strong effect on the overall LHF , they must be affecting either all or at least one of the quantities driving LHF themselves

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For this, we turn our attention to understanding how surface moisture is modulated by changes in SST***, because the sensitivity of the moisture term in the LHF formulation is part of the total sensitivity***.

we look at the large scale behaviour in water vapour mixing ratio at 2m: the resulting coefficient in this case is well in accord, even if with large uncertainties, with the CC scaling, this means that the large scale atmosphere can adjust to moisture changes keeping the RH likely constant.

Whereas corresponding mesoscale anomalies really seem not to be constrained by SST at all! Changes in surface fluxes are thus all concentrated in the Clausius-Clapeyron scaling!

Moreover, our results point to the fact that surface moisture is possibly set by different forcing terms.

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Then similarly to what done for LHF, we ran the same analysis on sensible heat fluxes and found again a significant enhancement of the link between SST and fluxes at the mesoscale (left plot).

This time, though, the thermodynamic term of interest which is driving SHF is the air-sea temperature contrast, rather than the moisture difference as before: in particular, look at how mesoscale T2 values are not adjusting to SST anomalies: for 1K increase in SST, T2 only increases by one third. Eventually mesoscales imply a stronger air-sea thermal contrast simply because the atmosphere cannot catch up with the fast variability of the underlying sea surface temperatures.

In the end, how much do the sensitivities of these thermodynamic terms that we have just seen contribute to the total coupling with fluxes?

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The violin plots here represent the distributions of the thermodynamic sensitivities in W/m2 , obtained by multiplying the driving terms of LHF that we didn’t consider by the sensitivities that instead we have obtained numerically.

As you can see, the values for the mesoscale anomalies (orange violins) are much compatible with the sensitivity values of the full unfiltered fields, both for LHF on the left and SHF on the right: Notice that the large scale coupling, meaning sensitivities computed on the low-passed fields, does not contribute at all.

But are surface fluxes the end of the story as for the effects on and feedbacks by the atmospheric boundary layer characteristics?

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To address this point we thought of an idealized, homogeneous MABL subject to surface fluxes only and computed the time scales necessary for the atmosphere to adjust to such fluxes: it turns out that the atmosphere would saturate water vapour much faster than it would adjust thermally!

But since the atmosphere we are studying does not saturate, there must be some additional flux that is drying up the BL: we thus conclude that dry entrainment fluxes from the top of the BL can oppose surface evaporation fluxes and thus set the moisture concentrations.

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Slide 17

So far we have seen that mesoscale anomalies of SST do play a significant role in modifying the boundary layer , but we still cannot tell whether sea surface temperature is always the only one leading factor in shaping the variability of surface heat fluxes.

For this, we chose to study the instantaneous correlations between LHF and its three main drivers.

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Namely SST, wind speed U and surface humidity mixing ratio q

What we do is linearizing LHF and split it into a large scale and mesoscale component; the mesoscale fraction is eventually a first order expansion in the mesoscale anomalies of the three variables.

This construction is particularly valuable because it allows to obtain a direct formulation for the variance of LHF and every other component, but also of covariances between the different variables: indeed the overbar denotes averaging through the Gaussian kernel.

If one divides then the covariance, between LHF and any field of interest PSI by the square root of their respective variances, what is obtained is what we defined as local correlations between the two fields: without this procedure, covariances would not be dimensionally consistent and thus would not be comparable with each other.

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The resulting density functions for such correlations are shown here.

When all scales of motion below the cutoff are kept, as in the case here on the left, SST wins over wind speed as for correlation values and is thus the dominant driver of LHF.

If instead we were to delete scales smaller than a second threshold, as it could be 60km, with another application of the low-pass filter, we would discover that wind speeds take the lead in driving the LHF variability (right)

At variance, surface moisture is always acting as a brake to LHF , but again its role is most prominent when intermediate scales of motion are considered.