Description of the Lagrangian composite cases

Irina Sandu and Bjorn Stevens
Max Planck for Meteorology, Hamburg, Germany

Introduction

The latest GCSS-CFMIP meetings emphasized the importance of further evaluating the ability of both SCM and LES to reproduce the transition between marine stratocumulus and shallow cumulus. In this context two Lagrangian transitional cases are proposed for an intercomparison study of both SCM and LES within the EUCLIPSE-GCSS framework. The first case is the *revisited* ASTEX case, based on the Atlantic Stratocumulus to Cumulus Transition Experiment field campaign (*Albrecht et al.*, 1995), which already served in the past for an intercomparison of SCMs (*Bretherton and Pincus*, 1995). The increase in computational power allows us now to perform 3-D Large Eddy Simulations of this case as well. The second case gathers in fact a set of three *composite* transitions, based on the observational study of the transitions in boundary layer cloudiness described in *Sandu et al.* (2010). While ASTEX offers the opportunity to evaluate models against in situ data, this set of *composite* transitions represents a more idealized framework for model evaluation. Indeed, being based on averaged large-scale conditions, a quantitative evaluation of the model behavior against satellite data is rather difficult. However, this framework offers the possibility of comparing the models for a variety of transition cases, which differ for example in terms of amplitude or timescale of the transition. The other noticeable difference between ASTEX and the *composite* transitions lies in the strength of the inversion. Recent DNS (*Mellado*, 2010) showed that the cloud top entrainment instability (CTEI) criterion cannot, by itself, rapidly break the cloud layer. However, if we were to classify the various cases from the CTEI point of view, ASTEX can be considered as a case in which the inversion jump structure gradually crosses the buoyancy reversal regime (*De Roode and Duynkerke*, 1997) from the stable side, while at least two of the three *composite* cases are unstable to cloud break-up.

One of the novelties of this exercise is that the diurnal cycle of the solar forcing will be taken into account. Moreover, as for the latest GCSS-CFMIP intercomparison, the radiative transfer will be computed with more sophisticated radiative codes than the simple GCSS parameterization used for the previous intercomparison exercises.

Composite transitions

Presentation

These stratocumulus-to-cumulus transition cases are based on the observational study of the transitions in boundary layer cloudiness occurring in the eastern subtropical oceans described in *Sandu et al.* (2010). In that study, we computed a large number of Lagrangian trajectories of air parcels in four subtropical oceans (using the wind fields provided by reanalysis of past observations) and we documented the evolution of the cloud and of its environment along each of these individual trajectories from satellite data sets and meteorological reanalysis (MODIS Level 3 data for cloud properties, and ERA-INTERIM for environmental properties).

Our study showed that the spatial structure of the climatology in the trades captures the mean temporal evolution of tradewind air masses during the months of maximum cloudiness in the stratocumulus region, particularly in the North East Pacific (NEP). This suggests that for certain regions and time periods, satellite observations with a more limited footprint and temporal coverage and which thus insufficiently sample individual trajectories (as for e.g. CALIPSO and CloudSat), could, by documenting the structure of the climatological transition, provide useful information concerning the evolution of the cloud field. Moreover it implies that averaged forcings can be considered as representative of individual trajectories, and can therefore be used to initialize numerical simulations of the transition between the two cloud regimes.

Building on these findings, we recently used a composite of the large-scale conditions encountered along the trajectories performed for the NEP during June-July-August 2006 and 2007, to set-up a case study of the stratocumulus-to-cumulus transition, that will be referred to hereafter as our *reference* case study (Sandu and Stevens, 2010, in preparation). We choose to focus on the first three days of the trajectories only, as this is the period when the bulk of the transition in cloud fraction takes place (*Sandu et al.*, 2010).

Both the initial profiles (liquid water potential temperature, total water content and wind speed) and the large-scale conditions (sea surface temperature and large scale divergence), used to perform the simulations, represent the medians of the distributions of these various properties obtained for the set of trajectories analyzed for NEP for the selected time period. We limited ourselves to the years 2006 and 2007, because for this period, in addition to the data sets used in our Lagrangian analysis, CALIPSO and CloudSat observations are also available. Note however that both the transition in cloud fraction and its environmental context are very similar to those obtained for the summer months of the ensemble of years considered for our Lagrangian analysis (2002-2007).

We also derived two variations of this *reference* case corresponding to a faster, and respectively, to a slower transition in cloud fraction. For that, we divided the transitions analyzed for the NEP during June-July-August 2006 and 2007, into three categories (fast, intermediate and slow), on the basis of the mean cloud fraction over the first 48 hours. As for the *reference* case, the initial profiles and the large-scale conditions represent the medians of the distributions of the various properties obtained for the subsets of fast and slow trajectories (each of these two subsets represent 25 % of the number of trajectories analyzed for NEP during the selected period).

Scientific questions

The intercomparison of the different models for the *reference* case will mainly try to assess whether they agree on :

- the decrease in cloud albedo and cloud cover during the 3 days;
- the time evolution of the cloud fraction (the time scale of the transition);
- the growth rate of the boundary layer height.

Futhermore, by simulating the two proposed variations of the *reference* case, we hope to understand whether the models are able to reproduce the differences in the amplitude and the timescale of the transitions induced by changes in the environmental context.

Set-up of the *reference* case

Initial conditions

As the inversion strength is not accurately reproduced by the ERA-INTERIM reanalysis, we decided to reconstruct the initial profiles of liquid water potential temperature and total water content. Given that at the initial time the conditions are typical for a stratocumulus topped boundary layer, we assumed the boundary layer to be well-mixed. And we considered the cloud top to be equal to the average cloud top height at the initial location obtained from CALIPSO for JJA 2006 and 2007. This cloud top height differs in fact quite little from the median MODIS cloud top height obtained for the analyzed set of trajectories. While reconstructing the profiles, we made sure that the integrated quantities of energy and total water content are conserved. For the horizontal wind components we used a linearization of the median ERA-INTERIM profiles.

The initial vertical profiles of liquid water potential temperature (θ_l), total water content (q_t) and horizontal wind components (u and v) can be summarized as follow:

$$\theta_l = \begin{cases} 290.97 & 0 \leq z \leq 902.52\text{m} \\ 302.13 + 5.7 \times 10^{-3} \times (z - 945.54) & 945.54 \leq z \leq 3200\text{m} \end{cases}$$

$$q_t = \begin{cases} 10.46 & 0 \leq z \leq 902.52\text{m} \\ 4.12 - 0.37 \times 10^{-3} \times (z - 945.54) & 945.54 \leq z \leq 3200\text{m} \end{cases}$$

$$u = -2.25 \qquad 0 \leq z \leq 3200\text{m}$$

$$v = -5.69 + 1.44 \times 10^{-3} \times z \qquad 0 \leq z \leq 3200\text{m}$$

As this information is needed both for SCM and for the radiative transfer computations, these profiles were extended above 3200 m, by using the mean ERA-INTERIM profiles (for the period JJA 2006-2207) at the initial point. The complete profiles (up to 1000 Pa) for temperature, liquid water potential temperature, total water content, wind components (u, v, w), vertical pressure velocity (omega) and ozone mixing ratio are included in the file composite_ref_init.nc.

The simulations start on at 10 local time on 15 July and last for 72 hours. The initial coordinates are : 25° N and 125° W.

The random fluctuations of the liquid water potential temperature and total water content are the same as for ASTEX.

The domain should be translated in the x and y directions with -2 and -4 ms^{-1}.

Surface Conditions

Surface fluxes of heat and moisture should be computed from the prescribed sea surface temperature. We are using a roughness lenght computed interactively with *Charnock* (1955) formulation. The surface pressure is also given in the file composite_ref_init.nc.

Radiation

The radiation should be computed interactively, with one of the available radiative transfer codes, such as for e.g. the code used in the UCLA LES (*Pincus and Stevens*, 2009) or the code developed by Peter Blossey (University of Washington/Center for Multiscale Modeling of Atmospheric Processes).

Time varying boundary conditions and large-scale forcings

The SST is increasing gradually during the 3 days, while the large-scale divergence D is considered constant. A sensitivity test performed with UCLA LES has shown that changes in the large scale divergence during the last day do not affect significantly the transition in cloud fraction. We therefore decided, for simplicity, to keep the divergence constant during the 72 hours, its value being given by the average over the first two days of the median divergence (1.86×10^{-6} s^{-1}).

The values of the SST and the large-scale divergence are given in the file composite_ref_init.nc (every 6 hours). A linear interpolation should be used to compute the SST at every time step, from these 6 hourly values. For LES, the subsidence velocity shoud be computed as $w_s = -D \times z$ up to 2000 m, and should be considered constant and equal to the one at 2000m above. For SCM, a ω profile has been derived and is included in the file composite_ref_init.nc.

Microphysics

The cloud droplet concentration is 100 cm-3. The geometric standard deviation of the cloud droplet spectrum needed to calculate the cloud droplet sedimentation flux is σ_g= 1.2.

Model parameters (for LES)

Duration: 72 hours

Domain size: 4.48 X 4.48 X 3 km

Number of grid points: Nx=Ny=128, Nz=428

Resolution: x = y = 35 m. On the vertical: z = 5 m within the cloud, z = 15 m beneath the cloud base. A stretching factor of 1.1 is used to decrease the resolution from 15 to 5 m and respectively to increase it above 2.4 km (see zgrid_composite.f and zm_vgrid_composite, which contains the altitude of the cell edges).

Lateral boundary conditions: Periodic

Top of the domain : sponge layer

Requested output

The same netcdf files containing the time series of scalars and hourly averaged profiles as for ASTEX are required (see Stephan de Roode's webpage).

For the first round, only LES of the *reference* case are requested, while simulations of the *fast* and *slow* cases are optional. Instead, SCM may simulate the 3 cases from the beginning and the output data should be written in the same format as for the CGILS case.

Set-up of the *fast* and *slow* transition cases

The set-up of these two transition cases was derived similarly to the one for the *reference* case described above. The main differences consist in the initial profiles and the imposed SST (Figs. 1 and 2). The initial boundary layer depth is also slightly different. According to the composite MODIS cloud top height at the initial location, the boundary layer is 50 m deeper/shallower in the fast/slow cases compared to the reference case.

For the *fast* transition, the initial profiles can be written as:

$$\theta_l = \begin{cases} 291.78 & 0 \leq z \leq 952.52\text{m} \\ 300.97 + 6.4 \times 10^{-3} \times (z - 986.04) & 986.04 \leq z \leq 3200\text{m} \end{cases}$$

$$q_t = \begin{cases} 10.75 & 0 \le z \le 952.52\text{m} \\ 6.04 - 1.32 \times 10^{-3} \times (z - 986.04) & 986.04 \le z \le 3200\text{m} \end{cases}$$

$$u = -3.36 \qquad 0 \le z \le 3200\text{m}$$

$$v = -5.37 + 1.08 \times 10^{-3} \times z \qquad 0 \le z \le 3200\text{m}$$

The domain should be translated in the x and y directions with -3 and -4 ms^{-1}.
For the *slow* transition, the initial profiles can be written as:

$$\theta_l = \begin{cases} 289.24 & 0 \le z \le 852.52\text{m} \\ 302.79 + 5.35 \times 10^{-3} \times (z - 901.68) & 901.68 \le z \le 3200\text{m} \end{cases}$$

$$q_t = \begin{cases} 9.27 & 0 \le z \le 852.52\text{m} \\ 3.3 - 0.292 \times 10^{-3} \times (z - 901.68) & 901.68 \le z \le 3200\text{m} \end{cases}$$

$$u = -0.74 \qquad 0 \le z \le 3200\text{m}$$

$$v = -6.06 + 1.65 \times 10^{-3} \times z \qquad 0 \le z \le 3200\text{m}$$

Above 3200m, the same profiles are considered for the three cases.
The domain should be translated in the x and y directions with -1 and -4 ms^{-1}.

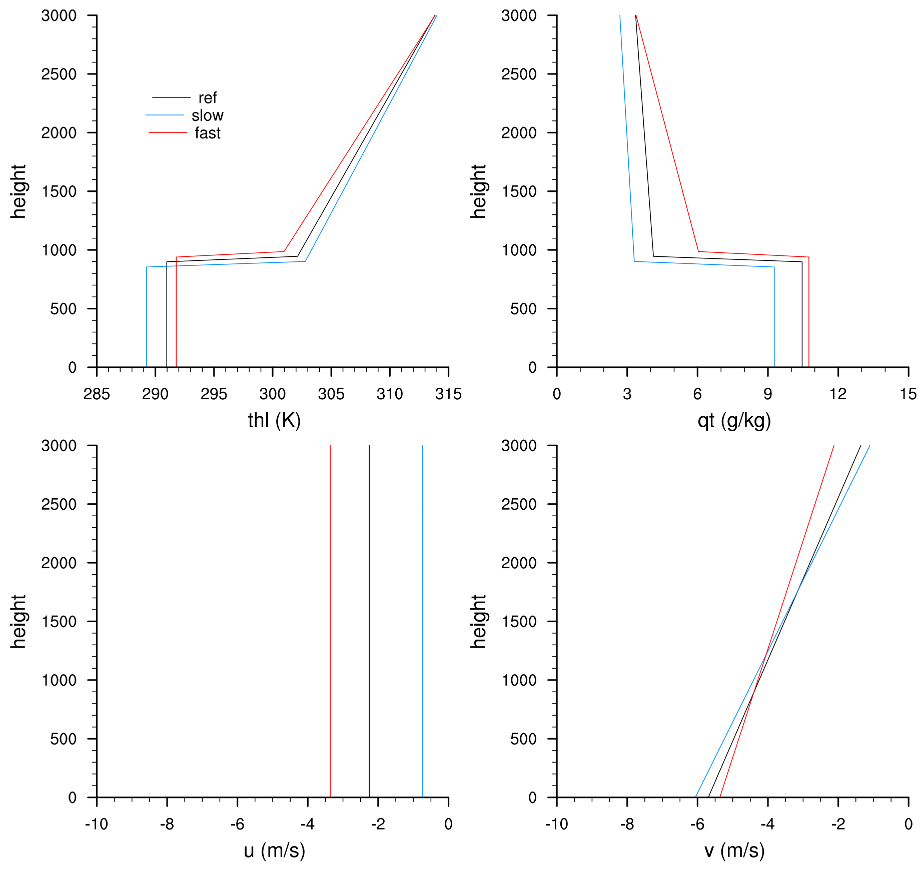

Figure 1: Initial profiles for the *reference* (black), *fast* (red) and *slow* transition cases.

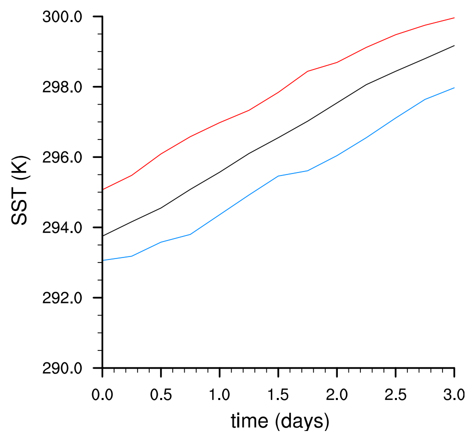

Figure 2: Time evolution of the SST for the *reference* (black), *fast* (red) and *slow* transition cases.

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