Land-Atmosphere Interactions: Practicals

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2025-06-25

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Preface

In these practicals, we will use computer simulations to quantitavely explore land-atmosphere interactions. For this purpose, we will use a spatially lumped model called CLASS (Chemistry Land-sufrace Atmosphere Soil Slab), developed by Waegeningen University the Netherlands. The main purpose of the model, which simulates the diurnal evolution of the atmospheric boundary layer (ABL) is to allow for easy experimentation and provide insights on the soil-vegetation-atmosphere continuum. For more background information on the model, the reader is referred to the Atmospheric Boundary Layer handbook (Vilà-Guerau de Arellano et al. 2015).

Throughout the text, variables are used consistent with how they were defined in the introductory slides of the practicals. Variables not mentioned during the introduction, are explicitly introduced in the text. Note that no text, including this one, is guaranteed to be free of mistakes or imperfections. If you were to encounter these, please don't hesitate to contact the author (Olivier.Bonte@UGent.Be).

1 Practical 1: Atmospheric state and forcings

Before conducting experiments with CLASS, you are first tasked to perform some introductory analysis on ABL theory.

1.1 Problem 1: Observed atmospheric temperature profile

The left panel of Figure 1.1 illustrates a typical observed atmospheric temperature profile (red line) during the day with a well-mixed boundary layer formed as a result of daytime turbulent mixing. In the mixed ABL the temperature profile is nearly dry adiabatic, i.e. it closely follows the dry adiabatic lapse rate $\Gamma_D \approx -10$ K/km (see Theory L2.5). The ABL top is capped with a strong temperature inversion (increase of T with height).

1.1.1 Task A

Find the temperature inversion on Figure 1.1 below (left panel) and note down in the Table 1.1 the height (in pressure) of the ABL top and the absolute temperature (in Kelvin) corresponding to that ABL height. Also, identify the pressure and absolute temperature for the two air parcels, P1 and P2. Note, that in absolute terms, temperature in the atmosphere decreases with height, i.e $T_2 < T_{top,ABL} < T_1$.

Based on the right pane of Figure 1.1, also fill in the potential temperature in the third column of Table 1.1

1.2 Problem 2

The concept of potential temperature takes into account effects of compression or expansion on air parcel's temperature, and hence, allows for a comparison of a parcel's buoyancy at any height. Use Equation 1.1 to calculate potential temperatures of the two parcels (P1 and P2) and the ABL top.

$$\theta = T \left(\frac{p_0}{p} \right)^{R_d/c_p} \tag{1.1}$$

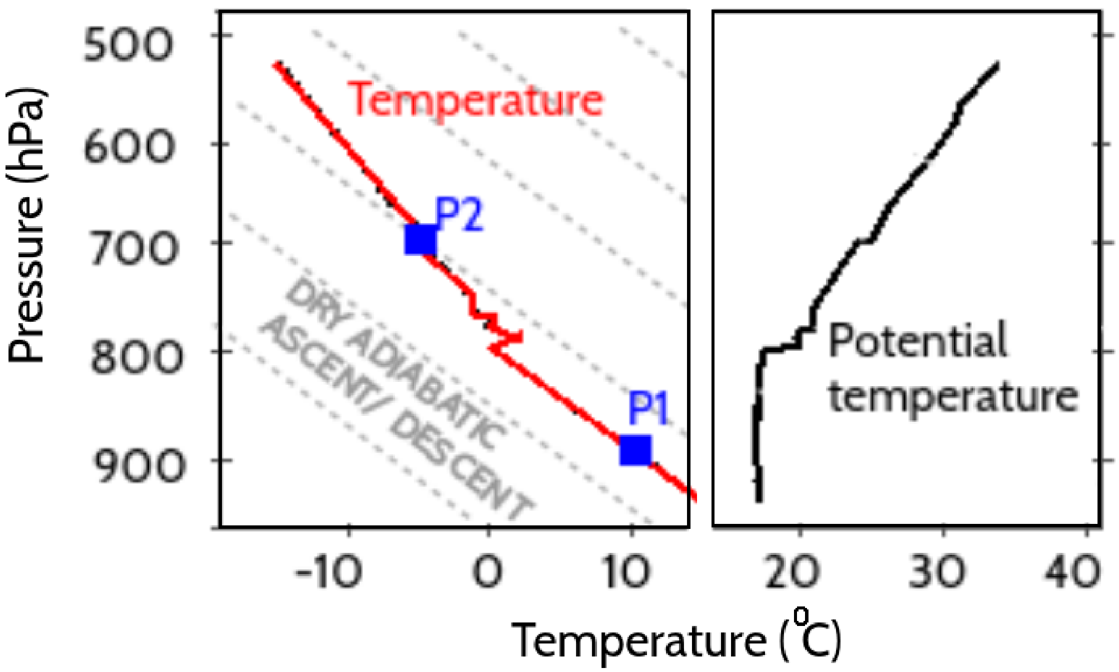

Figure 1.1: Observed atmospheric profiles of absolute temperature (red line) and potential temperature (black line). Gray dashed lines indicate a temperature decrease corresponding to Γ_d. Blue squares indicate two coordinates on the temperature profile selected for the exercises

Note that p_0 is the reference surface pressure of 1000 hPa, $R_d = R/MW_{\text{dry,air}} = \frac{8.314 \text{ J/(K mol)}}{29e{-}3 \text{ kg/mol}} \approx 287$ J/(K kg) the gas constant of dry air and $c_p = 1013$ J/(K kg) the specific heat of dry air at constant pressure. For the derivation of Equation 1.1, the reader is referred to the supplementary material of Theory L2, more specifically to the section *Vertical pressure and temperature gradients* of Shuttleworh (2012).

Complete the fourth column of Table 1.1 with the three calculated θ values: at ABL height, and at parcels' levels P1 and P2.

Table 1.1: Readings of atmospheric temperature profile Figure 1.1

	P: Pressure [hPa]	T: Absolute temperature [K]	θ : Potential temperature read [K]	θ : Potential temperature calculated [K]
top, ABL				
Parcel P1				
Parcel P2				

1.2.1 Task A

Now, imagine that you (dry adiabatically) descend parcels P1 and P2 down to the same level, for example the surface. Using the notion and formula of potential temperature, answer the question: which parcel will be warmer and more buoyant, P1 or P2?

1.2.2 Task B

Compare your findings with the profile of potential temperature in the right hand side of Figure 1.1. Explain now in your own words why it is said that the entrainment flux transports warmer air from the free troposphere (i.e. P2) down to the mixed ABL, even though absolute temperatures of free troposphere are colder than those of the ABL (i.e. $T_2 < T_{top,ABL} < T_1$)?

1.3 Problem 3

Surface turbulent fluxes, $(\overline{w'\theta'})_s$ and $(\overline{w'q'})_s$, are called eddy-covariance fluxes, because they can be estimated as the amount of common variation between temperature and vertical velocity for the surface heat flux $(\overline{w'\theta'})_s$ or between humidity and vertical velocity for the surface moisture flux $(\overline{w'q'})_s$.

Remember that for a generic turbulent variable ψ, Reynolds decomposition yields

$$\psi = \mathrm{E}[\psi] + \psi' = \overline{\psi} + \psi'$$

with $\mathrm{E}[\psi] = \overline{\psi}$ the averaged value and ψ' the random fluctuating part. In addition with the assumption of no mean vertical wind velocity ($\bar{w} = 0$, see introductory slides), it follows that:

$$\begin{aligned}\mathrm{cov}[w\psi] &= E[(w - \mathrm{E}[w])(\psi - \mathrm{E}[\psi])] \\ &= E[w'\psi'] = \overline{w'\psi'}\end{aligned}$$

1.3.1 Task A

Using measurements from an eddy-covariance sensor given in the Excel file `pract1_eddy_cov_data.xls`, calculate surface sensible (H) and latent heat (λE) fluxes. Note that latent and sensible heat fluxes are related to the eddy-covariance fluxes by the following relationship (see Theory L3.4):

$$\begin{aligned}H &= \rho c_p (\overline{w'\theta'})_s \\ \lambda E &= \rho \lambda (\overline{w'q'})_s\end{aligned}$$

where $\rho = 1.2$ kg/m^3 is the air density and $\lambda = 2.45e6$ J/kg the latent heat of vaporisation.

> **Tip**
>
> Use a programming language of your choice to perform the analysis.

1.4 Description of the changes in large-scale atmospheric forcing

With the introductory analysis performed, it is now time to carry out sensitivity experiments with CLASS. For more information on how to use the graphical user interface of CLASS, see `CLASS_model_guide.pdf`. The model parameters are set to be representative of a site in the mid-latitude (approximately 50°N).

As mentioned in the introductory slides, the goal of this practical is to explore what effect the changing synoptic situation over Central Europe, from cyclonic (C, low pressure) to anti-cyclonic (AC, high pressure) – typical for a drought onset conditions - has on the evolution of the ABL state during the day, primarily its (potential) temperature (θ) and height (h).

Table 1.2 and Figure 1.2 summarise the change that have occurred in the large-scale atmospheric forcing parameters in the free troposphere: ABL jump (inversion) ($\Delta\theta$ [K]), free tropospheric lapse rate (γ_θ [K/m]) and horizontal wind divergence ($\nabla \cdot \mathbf{u}_h$ [1/s]).

Table 1.2: Observed values for the three large-scale atmospheric forcing parameters for both cyclonic and anti-cyclonic conditions in the free troposphere

	$\Delta\theta$: ABL jump (inversion) [K]	γ_θ: Free tropospheric lapse rate [K/m]	$\nabla \cdot \mathbf{u}_h$: Horizontal wind divergence [1/s]
Cyclonic (C)	1.0	0.001	0
Anti-cyclonic (AC)	4.0	0.009	1e-5

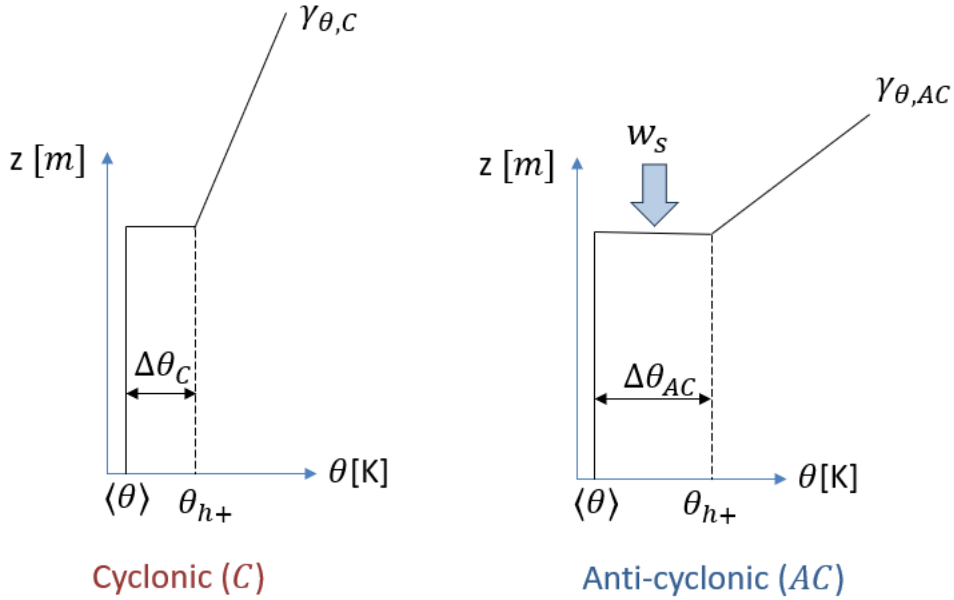

Figure 1.2: Sketch of vertical profiles of θ for both cyclonic and anti-cyclonic conditions

Before moving to the problems, the three considered governing equations as given in the introductory slides are repeated:

$$\frac{\partial \langle\theta\rangle}{\partial t} = \frac{\left(\overline{w'\theta'}\right)_s - \left(\overline{w'\theta'}\right)_e}{h} \tag{1.2}$$

$$\frac{\partial h}{\partial t} = -\frac{(\overline{w'\theta'})_e}{\Delta\theta} + w_s = w_e + w_s \tag{1.3}$$

$$\frac{\partial \Delta\theta}{\partial t} = w_e\gamma_\theta - \frac{\partial\langle\theta\rangle}{\partial t} = \gamma_\theta\left(\frac{\partial h}{\partial t} - w_s\right) - \frac{\partial\langle\theta\rangle}{\partial t} \tag{1.4}$$

When writing down your answers to the problems, please use the equation numbers used above (Equation 1.2, Equation 1.3 and Equation 1.4) to support your reasoning.

1.5 Problem 4

Start from investigating the influence of a stronger morning contrast between the cooler ABL and warmer free troposphere, i.e. larger morning inversion ($\Delta\theta(t_0) = \Delta\theta_0$). Note that there is a physical explanation for this larger morning inversion: in anti-cyclonic conditions, clear sky nights typically occur, which results in more cooling (via longwave outgoing radiation) during the night.

Open the interactive window of CLASS model with its initial default set up. Under tab ´Basic´ make sure that only the mixed-layer module is activated; the diurnal cycle of surface fluxes is off, and all the moisture parameters (i.e. q, Δq, γ_q, q_{adv} and $(\overline{w'q'})_s$) are set to zero for now. See the screen-shot in Figure 1.3. This setup is your control experiment.

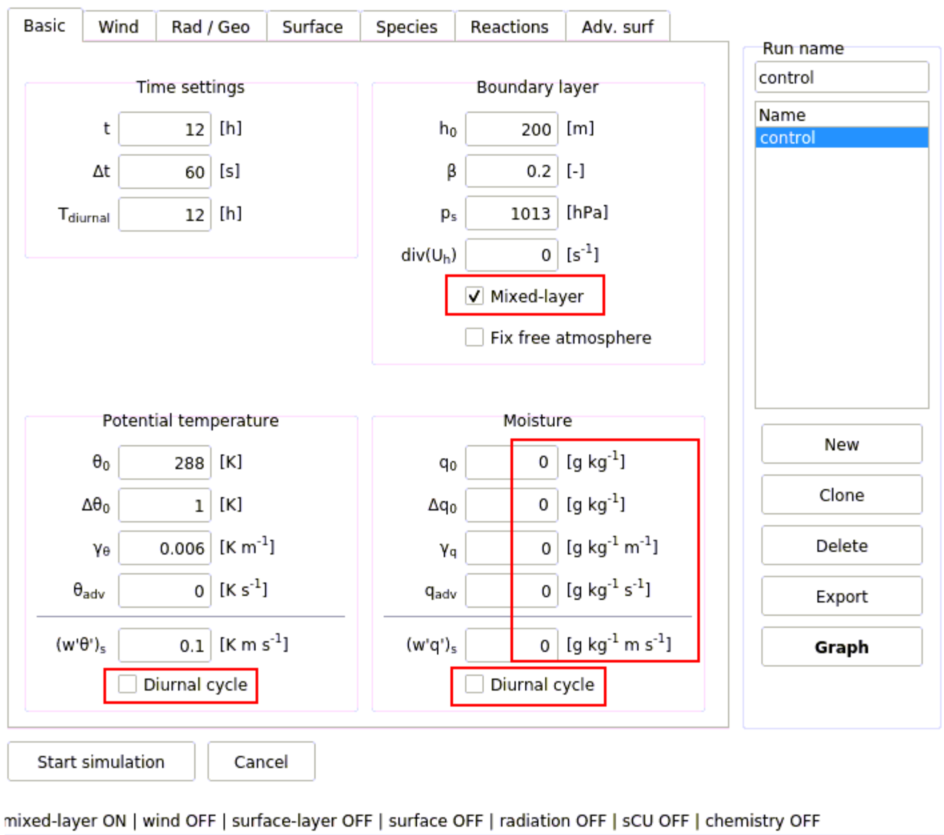

Figure 1.3: Control setup of the initial ABL state with activated mixed-layer module, assumption of a dry atmosphere, and constant surface heat flux during the day (i.e. no diurnal cycle)

Now set up two sensitivity experiments: one for a weak initial nocturnal inversion (experiment

WI with the inversion value $\Delta\theta_C$) and one for a strong initial nocturnal inversion (experiment SI with the inversion value $\Delta\theta_{AC}$). Use the values from Table 1.2.

Set up and run both experiments. Use the `Graph` option in the interactive window to plot and compare the results for the temporal evolution of h, $\langle\theta\rangle$ and $\Delta\theta$.

1.5.1 Task A

By analysing the evolution of $\Delta\theta$, find at which time step (t_i) $\Delta\theta$ starts increasing in the experiments. Describe the differences in the growth rate of h and $\langle\theta\rangle$ before and after this time t_i for both experiments. Use Equation 1.3 and Equation 1.2 to support your discussion.

> Tip
>
> Save plots in the `Graph` interface in order to compare the temporal evolution of ABL variables against each other. Also include the plots later on in your report.

1.5.2 Task B

Do you have a guess on why $\Delta\theta$ is first decreasing, and then starts increasing? Support your discussion with the dependencies between the variables given by Equation 1.4.

> Tip
>
> Exploring vertical profiles of $\langle\theta\rangle$ in `Graph` interface may help you find the answer.

1.5.3 Task C

Summarise your conclusions about the influence of the larger morning temperature inversion on the evolution of the daytime ABL properties and fill out the feedback diagram in Figure 1.4 below. Use solid lines with arrows to indicate positive relationships between any two variables, and dashed lines with arrows to show negative relationships. To clarify:

- Positive relationship between A and B: increase in A leads to increase in B
- Negative relationship between A and B: decrease in A leads to increase in B

> Tip
>
> Look at the 3 main state equations to support the arrows you draw.

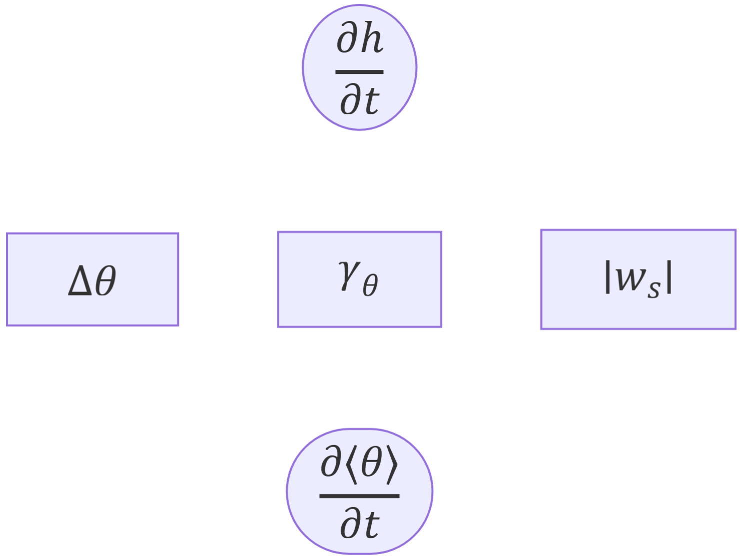

Figure 1.4: Feedback diagram illustrating the effect of large-scale forcing conditions on the evolution of the ABL. In squares, forcing parameters; in round shapes, time derivatives of key state variables.

1.6 Problem 5

Another important variable that changed with the onset of the high pressure system (AC) was γ_θ. Under conditions characterized by a high pressure system, warm air is slowly transported downward by subsidence, increasing the stability of the free troposphere, i.e. resulting in larger values of γ_θ. This is called a subsidence inversion (for more info on temperature inversions, see e.g. here)

Using this knowledge, design two experiments to study the influence of larger free-tropospheric lapse rate (higher stability). Using the values provided in Table 1.2, consider conditions before the onset of an anticyclonic situation (experiment LO with $\gamma_{\theta,C}$) and another after the onset of a persistent high pressure system (experiment HI $\gamma_{\theta,AC}$). For the rest, use the same initial set up as in Section 1.5, i.e. no moisture in the ABL and no diurnal cycle for both fluxes. Perform the simulations and compare the evolution of h, $\langle\theta\rangle$, and $\Delta\theta$ for the two experiments.

1.6.1 Task A

Using Equation 1.2, Equation 1.3 and Equation 1.4 to support your discussion, analyze the role of γ_θ in the boundary layer growth and temperature evolution.

Tip

Study vertical profiles in 'Graph´ interface for easier interpretation.

1.6.2 Task B

Does the effect of stronger morning inversion $\Delta\theta_0$ (from Section 1.5), and larger γ_θ (this exercise), act at similar or different time periods of the day on the evolution of h and $\langle\theta\rangle$?

1.6.3 Task C

Summarize the role of $\Delta\theta$ and γ_θ as capping (limiting) factors of the diurnal evolution of the boundary layer. Add these newly identified relationships into the feedback diagram in Figure 1.4.

1.7 Problem 6

Analogously to the experiments in Section 1.5 and Section 1.6, explore the sensitivity of the ABL evolution to the strong large-scale atmospheric subsidence w_s developed under high-pressure system (see Figure 1.2). Remember from the introductory slides that $w_s = -(\nabla \cdot \mathbf{u}_h)h$.

Again starting from Figure 1.3, set up two experiments: one with zero wind divergence, and another with the divergence given in Table 1.2 for AC.

1.7.1 Task A

Compare the boundary layer characteristics ($\langle\theta\rangle$, h and $\Delta\theta$) in the situation with and without subsidence. As before, support your answers below with the main state equations.

1.7.2 Task B

Summarize the effect of subsidence and complete the feedback diagram in Figure 1.4.

1.8 Summary

In this first practical, you have investigated the change in large-scale synoptic situation from a cyclonic to anti-cyclonic one, which - if the high pressure system persists - will likely cause a multi-day drought. You identified three main large-scale atmospheric forcing parameters: subsidence (w_s), inversion ($\Delta\theta$) and atmospheric stability (as determined by γ_θ), which have changed alongside the onset of the high pressure system. These factors will definitely influence daytime dynamics of the ABL, and in the long run, rainfall occurrence, surface water availability, temperature peaks and ecosystem productivity.

Examine one more time the feedback diagram (Figure 1.4) you worked upon, and summarize the expected change in the ABL dynamics due to the established large-scale synoptic situation.

1.8.1 Task A

What is the common effect of the changed large-scale forcing conditions on ABL growth? And on temperature?

1.8.2 Task B

We did not look specifically into the effect of clear sky conditions (typical for anti-cyclone) versus cloudy weather (typical for cyclone) on the evolution of the ABL height and temperature. Do you expect the change to a clear sky conditions to have a positive or negative effect on ABL growth and temperature? Why?

2 Practical 2: Role of land state and vegetation

In Chapter 1, the focus was on the effect of large-scale conditions on the daytime evolution of the boundary layer. With this understanding, we can now proceed to examine a second very important influence on the atmospheric boundary layer: **land surface conditions**. More specifically, CLASS will be used to investigate the following:

1. Explore land surface factors which control the magnitude of heat and moisture fluxes into the atmosphere
2. Assess the possibility of a heatwave development over different regions of Belgium, which have different land covers and states.

2.1 Description of the land surface conditions

For this practical, we'll focus on Belgium during a drought onset situation. From Chapter 1, we know that in this case the large-scale atmospheric state is characterised by a stationary, anticyclone (see *AC* on Figure 1.2).

Although the large-scale atmospheric condition will be similar all over Belgium, this will not be te chase for the land conditions, which vary quite significantly over the country. This can lead to big differences in the partitioning of incoming solar radiation to heat and moisture fluxes, and as a result, lead to higher air temperature and humidity in some regions relative to others.

The goal of this practical will be to use CLASS to explore the effect of different land surface conditions over Belgium on the radiation balance and the magnitude of heat and moisture fluxes.

More specifically, we'll focus on the difference in land cover and soil moisture (represented in CLASS in 2 layers with w_1 and w_2), as given by Table 2.1.

Table 2.1: Observed values of volumetric soil moisture content ($w_1 = w_2$) and dominant vegetation type for two Belgian region

Region	$w_1 = w_2$	Vegetation cover
West Flanders	0.18	Short grass
East Wallonia	0.31	Broadleaf trees

2.1.1 Task A

Over the course of the practical, fill in Table 2.2. Remember that the evaporative fraction is defined as:

$$EF = \frac{\lambda E}{R_n - G}$$

with λE the latent heat flux, R_n the net surface radiation and G the ground heat flux (all in W/m^2). The strength of the coupling between EF and soil moisture (SM) is characterised by $\frac{dEF}{dSM}$.

2.2 Problem 1

First, the effect of different moisture content in the soil will be investigated. This will be done by setting up a dry (D) and wet (W) experiment with identical land cover conditions.

To set up the experiments, start by opening the interactive window of CLASS model with its initial default setup. Then per tab, perform following changes:

- `Basic`:
  - t: from 12 to 10 h
  - Untick the box `Mixed-layer`. Remember from the introductory slides that the mixed layer model is disabled so that there is no feedback from atmosphere to the land (i.e. the effect of the land, soil moisture here, on the atmosphere is isolated)
- `Rad/Geo`:
  - Tick the box `Radiation`
- `Surface`:
  - Tick the box `Surface scheme`
  - Do **not** tick[1] the box `Surface layer`

[1]The reasoning here is that in this way, we exclude the effect of roughness on the aerodynamic resistance

From the surface tab, one can see that for this first set of experiments, it is assumed that the dominant land cover is short grass and that the soil type is sandy loam.

Now set up thee different experiments. Remark that volumetric soil moisture in the upper layer (w_1) and lower layer (w_2) are denoted by w_{soil1} and w_{soil2} in the `Surface` tab of the CLASS user interface. The values are the initial SM values at the beginning of the simulation:

1. Dry (D): $w_1 = w_2 = 0.18$, SM conditions reflective of West Flanders
2. Wet (W): $w_1 = w_2 = 0.31$, SM conditions reflective of East Wallonia
3. Control (C): $w_1 = w_2 = 0.21$

Once the three experiments are run, exported the data following the instructions in `CLASS_model_guide.pdf` so that these can be analysed in a programming language of your choice (i.e. MATLAB, R or Python). Note that contrary to the naming convention in the theory, R_n is denoted by Q in CLASS.

2.2.1 Task A

For every major term in the surface energy balance (i.e. R_n, G, λE and H), build a graphic illustrating its temporal evolution for all three (W, D and C) experiments. Label them properly and examine the differences in partitioning of the total energy R_n into the ground heat flux, heat and moisture fluxes for various levels of soil moisture. Pay attention to the different value range on the graph axes when comparing the magnitudes of the energy balance components.

2.2.2 Task B

Under which soil moisture conditions does most of the available energy at the surface (R_n–G) go into the heating the atmosphere? To moistening the atmosphere?

> Tip
>
> When comparing the experiments, ignore the slight differences in the total energy R_n, i.e assume that R_n is the same for all the experiments.

2.2.3 Task C

Calculate for each experiment the EF parameter and plot its temporal evolution in a way that facilitates an easy comparison beteween the three experiments.

Tip

You may need to adjust the axis limits on your graph, since the boundary values of EF are too high due to the negative values of the fluxes around/just after sunrise.

2.2.4 Task D

Compare the graphs and discuss what percentage of the total energy available at the surface was used for evaporation or heat release in every experiment case on average? For that, calculate the daily EF value for every experiment using its daily sums (or averages) of λE, R_n and G.

Based on this result, in which region, West Flanders or East Wallonia, would you expect larger increase in daytime air temperature and humidity considering differences in soil moisture values between experiments only?

2.2.5 Task E

Fill out the feedback diagram in Figure 2.1 to complete the task. Use the `Graph` interface in CLASS to explore the diagram relationships if needed. Place the arrows only between dependent variables. For the conventions of dashed versus solid lines, see Section 1.5.3.

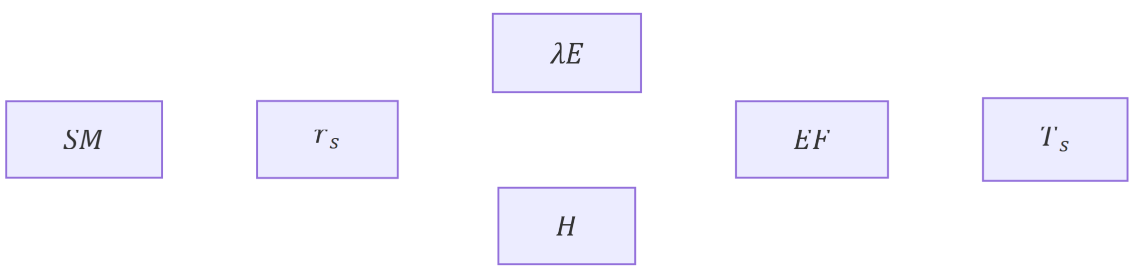

Figure 2.1: Feedback diagram illustrating the effect of SM conditions on EF and surface temperature (T_s) via the concept of surface resistance r_s

2.3 Problem 2

Use the daily EF values of the three experiments from the exercises in Section 2.2 and build a scatter plot of EF dependence on soil moisture SM. Use the x-axis to indicate the SM value (i.e. $w_1 = w_2$ at the beginning of the simulation) and use the y-axis to mark the EF (for a comparable figure from literature, see Figure 5 of Seneviratne et al. (2010)).

To have a clearer view of the relation between SM and EF, repeat the calculation of a daily EF (as in Section 2.2.4) for a range of $w_1 = w_2$ values between 0.1 and 0.4 complementing the values of 0.18, 0.21 and 0.31 from Section 2.2. Add these extra data points to your SM-EF graph.

2.3.1 Task A

According to Seneviratne et al. (2010), a linear relationship between EF and SM is a good approximation for SM between critical and wilting point. Do the model results of CLASS confirm this hypothesis?

2.3.2 Task B

Do you suspect the existence of some critical, i.e. maximum and minimum EF values? If yes, what would the min and max EF values be in your case?

2.3.3 Task C

The EF-SM curve that you built is often used in classical hydrology and climate science to illustrate the coupling (strength of dependence) of EF to SM, helping to differentiate between the regimes of water and energy limitation.

Examine your EF-SM curve and characterize the EF-SM relationship in terms of coupling regimes. Can you define three soil moisture ranges which differ in the strength of the coupling between SM and EF ?

> Tip
>
> To define the SM values which mark the transition between two regimes, reflect on the concepts of critical SM and permanent wilting point.

Additionally, decide in which regime the soil moisture conditions in West Flanders and East Wallonia fall. In which of the two regions is the EF-SM coupling the strongest?

2.4 Additional influence of vegetation

Until now, only the effect of different soil moisture amounts on the partitioning of the energy available at the surface was considered. Remember however that soil moisture depletion is strongly regulated by both vegetation conditions and soil properties.

- The soil regulates depletion of soil moisture via water infiltration and evaporation linked to **soil structure and porosity**.
- Vegetation controls the depletion of soil moisture via its **root-stem-leaf system** functionality and its featured type of **response to the environmental conditions**. Hence, different vegetation and soil conditions will result in different EF values, and hence, the EF-SM relationship will change.

In CLASS, the effect of both soil and vegetation type can be explored. Under the `Surface` tab (subsection `Surface properties`), one can select:

- Dominant vegetation cover: short grass (default), broadleaf trees and needleleaf trees
- Soil type: sandy loam (default), sand and clay

For the remainder of the practical, we'll focus on the effect of vegetation on the surface energy partition, while keeping the default soil type across simulations.

2.5 Problem 3

As mentioned above, the goal is to now explore the effect of different vegetation conditions on the partitioning of surface energy into heat and moisture fluxes and on the EF-SM relationship. More specifically, the focus will be on the difference between short grass (reflective of the dominant vegetation cover in West Flanders) and broadleaf trees (reflective of the dominant vegetation cover in East Wallonia).

To set up the simulations, first clone experiment C from Section 2.2. This simulation is for short grass (SG). Now clone the latter experiment, and under the `Surface` tab, change the dominant vegetation cover from short grass to broadleaf trees, yielding a new experiment abbreviated by BT. By this change, key parameters influencing the calculation of r_s are altered such as LAI and $r_{s,min}$ parameter from the Jarvis-Stewart model (see introductory slides)[2]. For simplicity, we only want to focus on the effects of vegetation type on r_s. Therefore, change following parameters for the BT experiment in the `Adv. surf` tab:

- Thermal conductivity of the skin layer Λ: change the value from 20 W m^{-2} K^{-1} (the default for broadleaf trees) to 5.9 W m^{-2} K^{-1} (the default value for short grass). In this way, SG and BT have the same Λ and consequently the calculation of G via[3] $G = \Lambda(T_s - T_{\text{soil1}})$ (where T_{soil1} is the surface soil temperature) is not influenced by the vegetation type.

[2]For more details on the land surface model in CLASS, the reader is referred to Chapter 9 of Vilà-Guerau de Arellano et al. (2015), which can als be found on Ufora

[3]Equation 9.33 from Chapter 9 of Vilà-Guerau de Arellano et al. (2015)

- Fraction of surface covered by vegetation C_{veg}: change the value from 0.9 (the default for broadleaf trees) to 0.85 (the default value for short grass). In this way, SG and BT have the same C_{veg} and consequently the calculation of the partitioning of λE between soil evaporation, transpiration and interception[4] is only effected by the magnitude of these fluxes, not the fraction of vegetation cover.

2.5.1 Task A

By comparing SG and BT, how did EF change over forest compared to over grass?

2.5.2 Task B

As mentioned above, the LAI differs between BT ($LAI = 5$) and SG ($LAI = 2$). To isolate the effect of LAI, clone the BT experiment, call it BT_{LAI2} and change LAI to 2 in the `Adv. surf` tab. By comparing r_s and λE between BT and BT_{LAI2}, explore following feedback loop by completing Figure 2.2 with dashed or full arrows (again following the convention from Section 1.5.3).

Figure 2.2: Feedback diagram illustrating the effect of LAI on surface fluxes

2.5.3 Task C

Another effect to explore is related to the optimal opening of the stomata in forest leaves and in grass leaves, which is captured by the $r_{s,min}$ parameter in CLASS. A higher $r_{s,min}$ value corresponds to more sensitive stomata (i.e. plants showing more isohydric behaviour, see theory lecture 7)

Comparing BT and SG, $r_{s,min}$ values are 200 s m^{-1} and 110 s m^{-1} respectively. To isolate the effect of $r_{s,min}$, clone the BT experiment, call it $BT_{rsmin110}$ and change $r_{s,min}$ to 110 s m^{-1} in the `Adv. surf` tab. By comparing r_s and λE between BT and $BT_{rsmin110}$, explore following feedback loop by completing Figure 2.3 with dashed or full arrows.

[4] Equation 9.14 from Chapter 9 of Vilà-Guerau de Arellano et al. (2015)

Figure 2.3: Feedback diagram illustrating the effect of $r_{s,min}$ on surface fluxes

2.5.4 Task D

Summarize the effect of the different vegetation cover types on surface fluxes by completing the feedback diagram in Figure 2.4. Which of the two feedback mechanisms covered above dominates the overall effect of going from SG to BT?

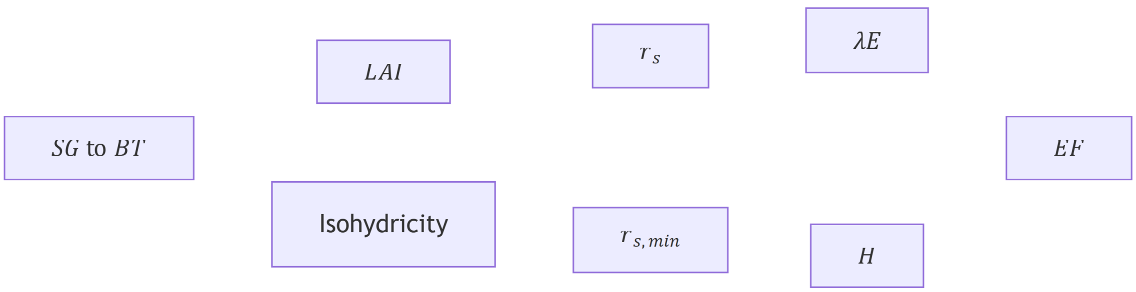

Figure 2.4: Feedback diagram illustrating the effect of different vegetation cover types on the surface fluxes via the concept of r_s

2.6 Problem 4

After investigating the effect of SM (see Section 2.2 and Section 2.3) and vegetation (see Section 2.5) in isolation, we're now interested in simulating the combined effect of high SM and broadleaf tree vegetation cover, as present in East Wallonia.

2.6.1 Task A

To set up a model simulation reflecting the East Wallonia conditions, clone the BT experiment, give it a new name (EW) and modify w_1 and w_2 in the `Adv. surf` tab to 0.31 (as defined in Table 2.1). After simulation, calculate the daily EF (as done in Section 2.2.4). Next, add this point on the EF-SM diagram created in Section 2.2 and mark it in a way that differentiates as the point valid for EW. Does the forest covert shift the coupling relationship up (i.e. higher EF for the same SM) or down?

2.6.2 Task B

Complete Table 2.2 and summarize the effect of different land surface conditions over the country (West Flanders versus East Wallonia) on partitioning of the surface energy into heat and moisture fluxes. Additionally, discuss the potential implications for the ABL temperature and the likelihood of heatwave development in the two regions

> Tip
>
> Remember that the D experiment is reflective of West Flanders (dry and short grass), while the EW experiment is reflective of East Wallonia (wet and broadleaf trees).

Table 2.2: Summarising the effect of SM on atmospheric conditions. To be filled in after completing the problem in Section 2.6.

	Daily EF	SM-EF coupling regime	Likelihood of heatwave
West Flanders			
East Wallonia			

2.6.3 Task C

Does the presence of forests enhance or dampen the likelihood of higher temperatures over East Wallonia (as specified in Table 2.1)?

2.7 The influence of the atmosphere on the surface fluxes

As mentioned in the introductory slides, it is important to remember that in this practical the mixed layer model is not activated. Consequently, the non-negligible influence of atmospheric conditions on the magnitude of the surface fluxes is ignored here. Without going into quantitative simulations, a non-exhaustive list of possible effects is given below:

- $\langle\theta\rangle$ and $\langle q\rangle$ from the ABL influence the gradient of temperature and humidity between surface and atmosphere, hence altering the magnitude of H and λE (think of the bulk resistance approach from theory lecture 5)
- Both wind speed and atmospheric stability influence the aerodynamic resistance r_a, which determines H and λE.
- The plant stomata their functioning is dependent on several atmospheric states such as $\langle\theta\rangle$, $\langle q\rangle$ and CO_2.

2.8 Voluntary problem 5

There are many relationships still unexplored[5]. In this **voluntary** problem, the effect of a higher air temperature on the partitioning of the fluxes is investigated. Consistent with the other problems of this practical, the mixed layer model is still not used, making $\langle\theta\rangle$ constant throughout the duration of the simulation.

2.8.1 Task A

As a control experiment, C from Section 2.2 is used. The new experiment with a warmer ABL (named WA), has a $\langle\theta\rangle$ of 300 K. To make the comparison fair, we want to assure the following:

1. Relative humidity (RH) should be the same for WA and C. Recall from lecture 2 of the theory that RH [%] is defined as
$$RH = e/e^*$$
with e vapour pressure [Pa] and e^* the saturated vapour pressure [Pa]. The latter can be calculated in function of air temperature (T in °C) with the Tetens equation:
$$e^* = 610.78 \exp\left(\frac{17.27T}{237.3+T}\right)$$
Additionally, we know that
$$q = 0.622\frac{e}{p}$$
with p the total atmospheric pressure [Pa]. With this information, calculate the $\langle q\rangle$ for WA based on $\langle q\rangle$ for C so that RH is the same for both scenarios.
2. To assure a similar temperature gradient between the atmosphere and surface for both experiments, the (initial) values of T_{soil1} and T_{soil2} (the deep soil temperature)[6]. In C, the differences (i.e. "gradient") between $\langle\theta\rangle = 288$ K and $T_{\text{soil1}} = 285$ K and $T_{\text{soil2}} = 286$ K are 3 and 4 K respectively. Adapt T_{soil1} and T_{soil2} for WA to have identical differences.

2.8.2 Task B

Once experiments C and WA are simulated, describe the diurnal variability of the H and λE under these different $\langle\theta\rangle$ values.

[5]For the very curious, plenty of additional experiments can be found in Vilà-Guerau de Arellano et al. (2015)

[6]Intuitively, also between T_s and $\langle\theta\rangle$ a similar gradient should be maintained. The T_s value set in the `Surface` tab (290K for C) does not influence the simulations however when the `Surface scheme` box is ticked (and hence the land surface model is run), as T_s is calculated without needing an initial value and is based on (amongst others) $\langle\theta\rangle$ (see Equation 9.17 of Vilà-Guerau de Arellano et al. (2015)).

Additionally, complete the feedback diagrams give in Figure 2.5 and Figure 2.6. Remember that $VPD = e^* - e$ stands for vapour pressure deficit. Based on your results, which one is dominating in this case?

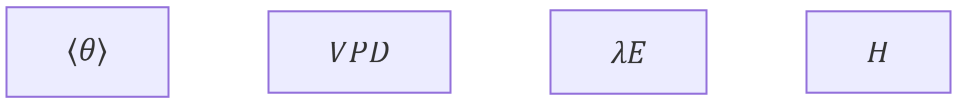

Figure 2.5: Feedback diagram illustrating the effect of $\langle\theta\rangle$ on the surface fluxes via evaporative demand

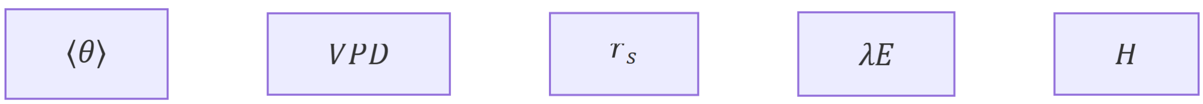

Figure 2.6: Feedback diagram illustrating the effect of $\langle\theta\rangle$ on the surface fluxes via r_s

References

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