Summary

The research aims at improving the knowledge about ecohydrological and micrometeorological processes of Alpine unmanaged grasslands. The focus is on land (soil) and biosphere-atmosphere interactions principally regarding exchanges of energy (heat), water vapour and carbon dioxide, also known as fluxes. Those fluxes depend on three main topics addressed in this Thesis: i) the meteorological and micrometeorological properties of the area (e.g. available energy, wind regime, air temperature, air humidity, vapour pressure deficit, precipitation); ii) the biomass and vegetation types and distribution; iii) soil properties, soil water movement and availability. Energy and mass fluxes (included evapotranspiration), micrometeorological and soil properties are experimentally evaluated at three mountain sites. For fluxes evaluation, the eddy covariance technique is used, whereas available models are used to evaluate the sites flux footprint. Particular attention is devoted to evapotranspiration analysis and quantification, using collected data at experimental sites and of modelling approaches.

The innovation of the research project relies on the selected ecosystem: few works have focused the attention on mountain regions exploring, also in complex terrains such as slopes, unmanaged grasslands on multiple years and sites. The study is important, since abandoned or unmanaged grasslands are also experiencing shrubs encroachment which alters the ecosystem.

The use of data collected in various years and of modelling approaches gives useful insights since the study area (North-West Italian Alps) is characterised by a high spatial variability (altitudes range from 500 m a.s.l. to more than 4000 m in few kilometres) and by a high meteorological interannual variability. This last point is also due to the relative proximity to the Mediterranean Sea. Besides, it is not

common to use and compare data collected at sites with very different topography in a relatively small area.

Chapters 1 and 2 are, respectively, the general Introduction and Theoretical framework description. Chapter 3 introduces the description of experimental sites.

Chapter 4 investigates what is the quality of the collected data at the eddy covariance experimental stations. Detailed quality control is used, and each important quality test is analysed separately. The objective is to assess what percentage of good quality data exists for the acquired data sets and to quantify the energy balance closure at the sites. The overall available data outreached 60% and the energy balance closure ranged between 60 and 70% at the most complex experimental site and reached values greater than 80% at the second, less complex site.

Chapter 5 explores micrometeorological characteristics of three eddy covariance Alpine sites and deals with two possible causes of energy imbalance: firstly, the net radiation misrepresentation (hence, its correction according to the turbulent fluxes footprint). Secondly, the presence of low-frequency atmospheric structures (vortices) may cause turbulent fluxes underestimations, and phase differences between the vertical wind velocity and scalars such as temperature, water vapour and carbon dioxide.

The net radiation correction was implemented and improvements greater than 5% were found. Low-frequency, structures were detected at one measurement site, as well as the aforementioned phase differences, and both of them contribute to underestimating the turbulent fluxes.

Chapter 6 investigates the evapotranspiration interannual variability and the roles of soil conditions and meteorologically different hydrological years and growing seasons (in terms of precipitation, humidity and air temperature) on evapotranspiration. The first part of the analysis is devoted to understanding whether the aforementioned interannual variability is high and whether years with very different water availability and temperatures can be used as multiple "scenarios" that mimic the climate change ones. The role of evapotranspiration drivers and their interannual variability are also explored. In the second part of the analysis, the impact of two different land covers (i.e. grass and shrubs) on evapotranspiration is assessed.

Results highlight a high interannual variability with precipitation and temperature changes respectively beyond 100 mm and of about 1°C between growing seasons in different years.

The latent heat flux dominates over the sensible heat flux also in dry growing seasons and it always shows a bimodality due to the lack of precipitation in prolonged periods.

A morning inflexion of the same flux was found, and it is likely related to the downslope to upslope wind regime change.

The interannual variability was also found in periods of 15-days comparing different growing seasons, and also in ET drivers, with global radiation, net radiation and VPD being the main drivers. VPD dominated over net radiation in growing seasons with frequent cloudy conditions. The cumulative evapotranspiration showed interannual differences up to more than 100 mm.

The land cover had high impacts on evapotranspiration. Shrubland would be characterised by evapotranspiration more than 110 mm greater than a grassland in a single growing season. At one measurement site, (characterised by a mix of shrubs and grass), the modelled ET agrees with the measured one. Exceptions were found in “meteorologically extreme” years.

Chapter 7 deals with evapotranspiration modelling with a novel, original hydrological model designed by LABFLUX Team, used and temporally validated by the Author of this Thesis which is composed of two modules, namely, the meteorological and the soil ones. The model requires meteorological data as inputs, whereas the soil water module is a simple “bucket model” with multiple layers. The hydrological model operates with literature formulae and parameters, hence it does not require a classical calibration. The model is tested on a wide area in Valle d’Aosta Region (Italy) and it is validated both temporally (using two eddy covariance stations) and spatially (using a well-known model, called METRIC). Results highlight a rather good agreement with measures and with the METRIC model outputs. Hence, even a simple modelling approach leads to an acceptable ET evaluation

Chapter 8 deals with nine fast-melting snowfall events at one site. The aim is to characterise the events from the micrometeorological point of view, quantify the role of longwave on snowmelt and the role of snowmelt on energy balance residuals explanation and quantify the water balance closure and its components (snowmelt and sublimation).

Results highlight that as soon as the snow starts melting, the first sunny day, there is a strong *LE* increase, and when the snow has vanished, *H* flux tends to increase as well. Besides, the friction velocity is only weakly dependent on snow presence.

Longwave radiation is important especially on cloudy nights and, also during daytime, incoming longwave radiation is always at least 20% of the solar radiation.

During the nighttime, the longwave inputs can lead to snowmelt. This finding was also confirmed at a second measurement site.

The snowmelt can explain a highly variable fraction of energy residuals, up to 80%, and using the soil moisture probes to detect snowmelt might be a rather interesting choice when no other available data sources exist.

The water balance is nearly closed in almost all the events and snowmelt is the most important term of the snow water equivalent (SWE) balance, while sublimation accounts for a maximum of 35% of SWE. Snowmelt and sublimation terms are comparable with previous studies, also in sites with higher wind speeds.

Chapter 9 introduces the concept of meandering, which is an oscillating behaviour of the wind flow (and also of scalars) and it typically occurs when the flow evolves into quasi-2D structures. Empirical formulae (elaborated for flat and homogeneous terrains) were applied in a complex terrain context to fit the autocorrelation functions and the spectra of wind speed and temperature. Their performance was evaluated, and they were used to identify the hours characterised by meandering. Results show that the formulae can be used, although with care. Only a few hours (3% of the total) were characterised by "complete meandering", that is when the autocorrelation functions of u, v and T oscillate, and all of them occurred in low wind speed conditions (< 1.5 m s^{-1}). No direct relationship between meandering and atmospheric stability was found, even if no complete meandering occurred in stable hours. Besides, frequently, complete meandering occurred in cloudy conditions.

Meandering conditions might be revealed by adequate indexes. Several options were tested at one measurement site. The friction velocity and the ratio of the squares of vertical and horizontal wind speed components were found as good meandering indices.

When meandering (either complete or not) occurs, the sensible heat flux is lower if compared to non-meandering hours. Sensible heat flux uncertainty is also affected by meandering, with higher values in meandering and almost meandering hours. This finding could be implemented in data quality control where suspect meandering conditions occur.

Concluding, the overall conclusions and perspectives are presented.

Keywords: Eddy-covariance, turbulent fluxes, energy and mass balances, air-land interactions, eco-hydrogy.