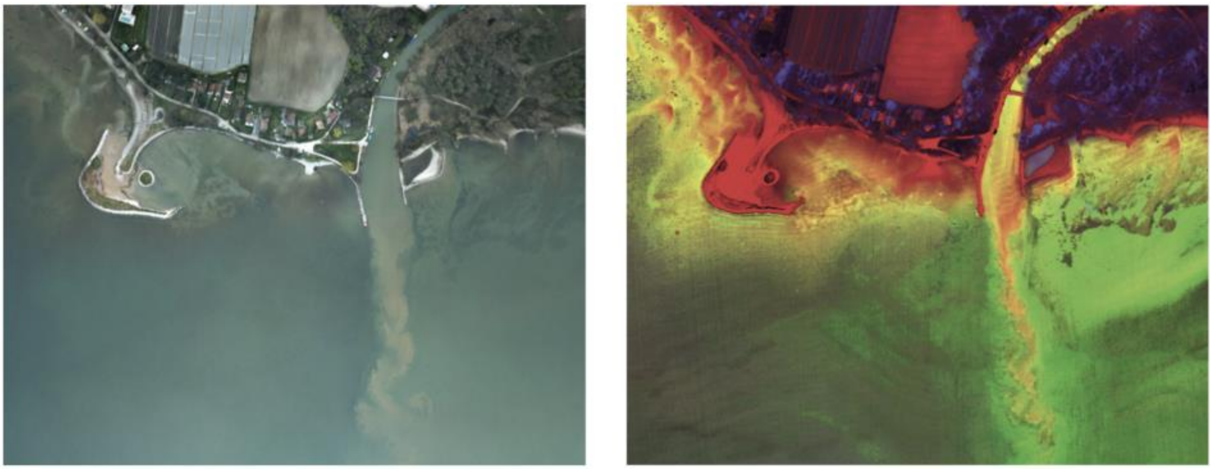
Léman-Baikal Project

Annual report 2013



RGB and hyperspectral images of the Venoge (Lake Léman) outflow

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Résumé

Le projet Léman-Baïkal est une initiative de recherche internationale entre la Suisse et la Russie dans le domaine de la limnologie physique à l'aide d'ultra-léger motorisés (ULM). Son but principal est de comparer les qualités des eaux du Lac Léman en Suisse et du Lac Baïkal au Sud de la Sibérie dans la Fédération de Russie. En particulier, les objectifs scientifiques comprennent l'analyses des processus hydrologiques des lacs, comme leurs mélanges avec les ruissellements naturels et anthropiques et leurs bilans énergétiques, ainsi que l'étude des processus particuliers liés aux interfaces terrestres-lacustre et eau-atmosphère proche des lacs.

Ce projet multidisciplinaire regroupe différents laboratoires de l'Ecole Polytechnique Fédérale de Lausanne: les laboratoires de topométrie (TOPO), des systèmes d'information géographique (LASIG), de physique des systèmes aquatiques - Chaire Margaretha Kamprad (APHYS), de technologie écologique (ECOL), d'ingénierie éolienne et d'énergie renouvelable (WIRE), de l'université de Princeton en collaboration avec le laboratoire de mécanique des fluides de l'environnement (EFLUM) et le laboratoire des systèmes cryosphériques (CRYOS).

Pour ce projet, une plateforme de télédétection spatiale a été développée pour enregistrer des images multispectrales et hyperspectrales des surfaces terrestres et aquatiques à partir d'ULM. Pendant la phase de test en avril et mai 2013, cette plateforme a permis de récolter une série initiale de données pendant onze vols au-dessus du Lac Léman. Nos points d'intérêt étaient principalement les embouchures des rivières de la Venoge et du Rhône, qui montrent une palette visuelle particulièrement riche de phénomènes hydrologiques.

Dans la seconde phase en juin et juillet 2013, des observations multispectrales et hyperspectrales ont été collectées au-dessus Lac Baïkal près du Delta de Selenga pendant trente-deux vols. Le succès de cette campagne a été assuré par la collaboration avec les universités russes impliquées dans le projet.

Etant donné les quantités importantes de données récoltées, leurs traitements est toujours en cours. Cependant, les premiers résultats sont tout à fait prometteurs et montrent une grande similarité entre les spectres mesurés depuis l'ULM et ceux mesuré depuis la surface du lac. Ces résultats encourageant vont bientôt permettre d'évaluer l'hétérogénéité des paramètres de la qualité des eaux sur de larges parties des deux lacs. Ils permettront aussi de décrire des phénomènes locaux de mélanges à des résolutions spatiales et temporelles encore jamais obtenues.

Concernant la couche limite de l'atmosphère, des senseurs spéciaux pour mesurer les turbulences, l'humidité et la température à très haute résolution sont toujours en phase de développement. Ils ont pu être testés brièvement en 2013 et devraient être prêts pour la prochaine phase du projet en 2014.

En 2014, chaque groupe planifie de récolter des données supplémentaires sur le Lac Léman pendant trois campagnes en février/mars, avril/mai et septembre/octobre. La prochaine campagne sur le Lac Baïkal aura lieu en juillet/aout 2014 en étroite collaboration avec nos collègues russes. Avec ces nouvelles données, les différents groupes espèrent décrire de nouveaux phénomènes observables sur les lacs et sur la dynamique de la couche limite de l'atmosphère au-dessus de ces lacs.

Summary

The Léman-Baikal project constitutes an international Swiss-Russian collaborative research initiative in the field of physical limnology using ultralight aircraft. The primarily aim of the project is to conduct a comparative study of the functioning of Lakes Léman (Switzerland) and Baikal (Southern Siberia region of Russian Federation). The scientific objectives of the project include the analysis of hydrological processes, such as the runoff dynamics of both natural and anthropogenic origin, lake energy balance, and the study of processes pertaining to the land-water and air-water interfaces in lakes.

This multidisciplinary project regroups different laboratories within EPFL: Geodetic Engineering Laboratory (TOPO) / Laboratory of Geographic Information Systems (LASIG), Physics of Aquatic Systems Laboratory - Margaretha Kamprad Chair (APHYS), Ecological Engineering Laboratory (ECOL), Wind Engineering and Renewable Energy Laboratory (WIRE), Princeton University in collaboration with the Environmental Fluid Mechanics and Hydrology Laboratory (EFLUM) and the Laboratory of Cryospheric Sciences (CRYOS).

For this project, a remote sensing platform was developed to collect multispectral and hyperspectral observations of both land and water surfaces from ultralight aircraft. During the test phase in April and May 2013, this platform was used to collect an initial dataset during a series of flights above Lake Léman. The fights focussed on the mouths the Venoge and Rhône Rivers, which exhibit a particularly rich range of visually observable hydrodynamic phenomena.

In the second phase carried out in June and July 2013, multispectral and hyperspectral observations were collected above Lake Baikal near the Selenga delta during thirty-two flights. The success of this campaign was ensured by the collaboration of the Russian universities implicated in the project.

Given the massive dataset, data processing is still underway. However, preliminary results look promising. They showed a high similarity of the spectra measured from the air and in situ from the lake surface. These encouraging results will soon allow assessment of the heterogeneity of water quality parameters on large portions of the two lakes, and to describe local mixing phenomena at a higher spatial and temporal resolution than ever achieved.

Concerning the atmospheric boundary layer, special sensors to measure turbulence, humidity and temperature at high resolution are still under development. They could only be tested briefly in 2013, but will be ready for the next phase of the project in 2014.

In 2014, each group plans to collect additional data on Lake Léman during three campaigns in February/March, April/May and September/October. Another campaign on Lake Baikal is planned in July/August 2014 in close collaboration with Russian colleagues. With such a large dataset, the different groups hope to discover new findings on the limnology of both lakes as well as on the dynamics of the atmospheric boundary layer above lakes.

Table of Content

1. Remote sensing platform – TOPO / LASIG laboratory

Dr. Y Akhtman, D Constantin, Prof. B Merminod, Prof. F Golay, M Parkan, M Rehak, Dr. D Tuia

1.1. Methodology

Over eight months starting in October 2012, we developed and deployed a remote sensing platform optimised for collection of multispectral and hyperspectral observations of both land and water surfaces from an ultralight aircraft. The platform is comprised of four cameras, auxiliary position and orientation sensors, as well as data recording equipment.

The main principle of the research methodology is constituted by the concurrent acquisition of airborne wide-area and surface point-based data. The corresponding data collection process is illustrated in Figure 1. Specifically, we have employed the ultralight aircraft in order to carry an airborne remote sensing platform, and a boat equipped with a range of sensing and water sampling equipment.

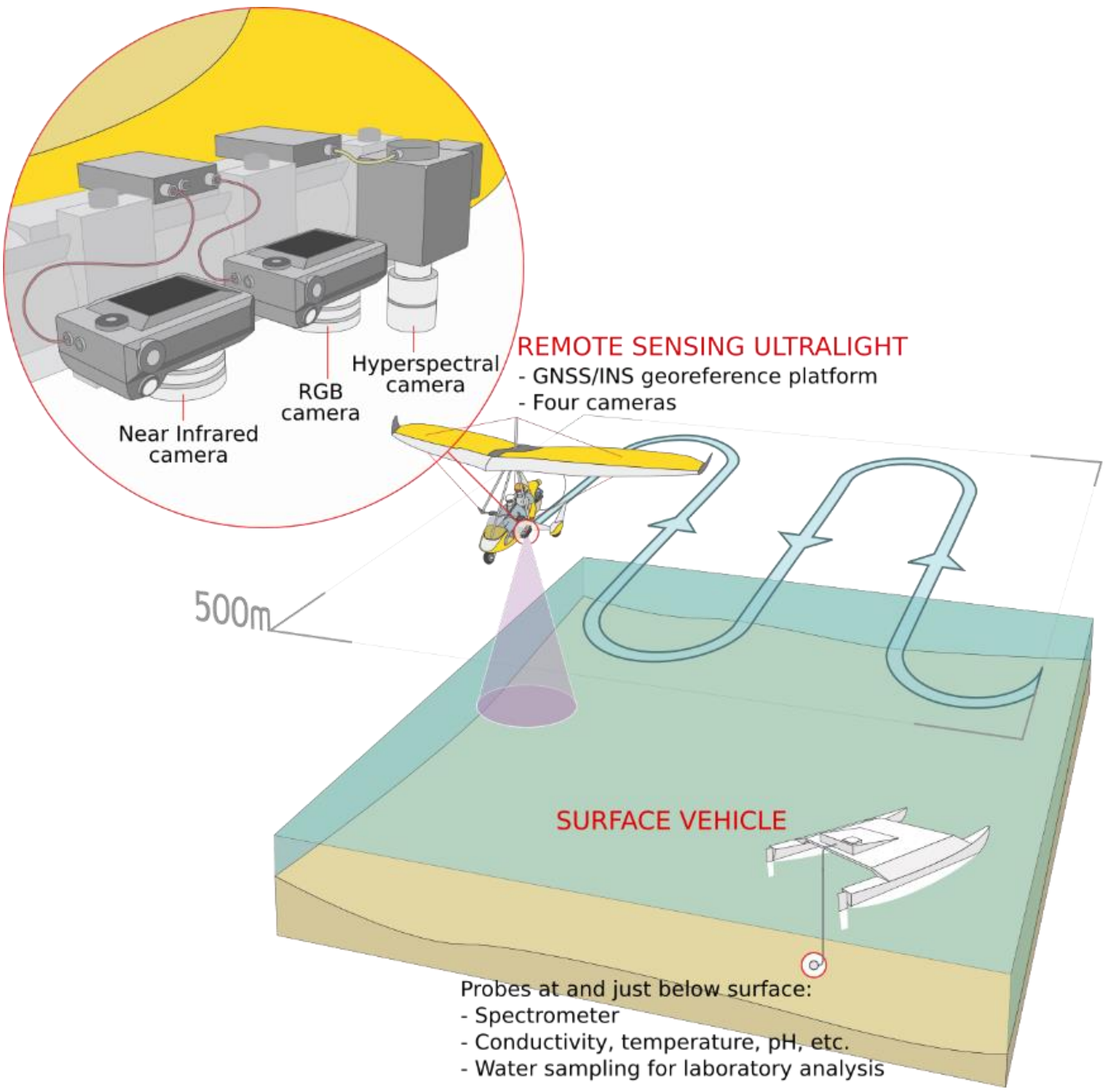


Figure 1: Concurrent airborne and surface collection of data

The surface-based samples, measured in collaboration by APHYS and ECOL laboratories, are used to produce a detailed characterisation of the water properties at sampling locations. Additionally, the reflected spectral response of the water surface at each sampling point is registered. The reflectance properties are correlated with the various water characteristics and the spectral response-based indicators for the various chemical and biological water properties are derived. The resultant spectral signature-based indicators are subsequently utilised in order to derive a wide-area maps of water properties using the multispectral and hyperspectral data collected with the use of the airborne remote sensing platform.

In this context, the concurrent airborne and surface based data acquisition is essential for the sake of calibration of the airborne data, as well as the data quality and the methodological accuracy analysis.

1.1.1. Airborne remote sensing platform and operations

Our main instrument is constituted by an Alava ARS3 system, which is based on a Headwall Photonics Micro Hyperspec VNIR sensor. In addition, the platform includes two high-resolution RGB and near-infrared sensors based on consumer-grade Sony NEX-5R cameras, as well as a thermal infrared sensor based on the DIAS Pyroview 640L Compact camera. The resultant remote sensing platform is portrayed in Figure 2.

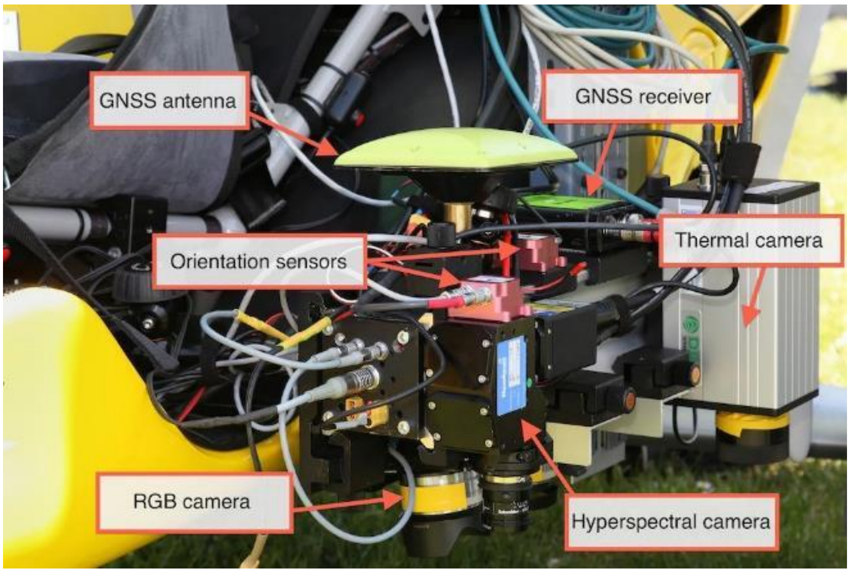


Figure 2: Multispectral and hyperspectral remote sensing platform installed on an Air Creation Tanarg ultralight aircraft

As our airborne carrier we have utilised the Air Creation Tanarg ultralight aircraft depicted in Figure 3.

Figure 3: Air Creation Tanarg 912S ultralight aircraft with the remote sensing platform installed

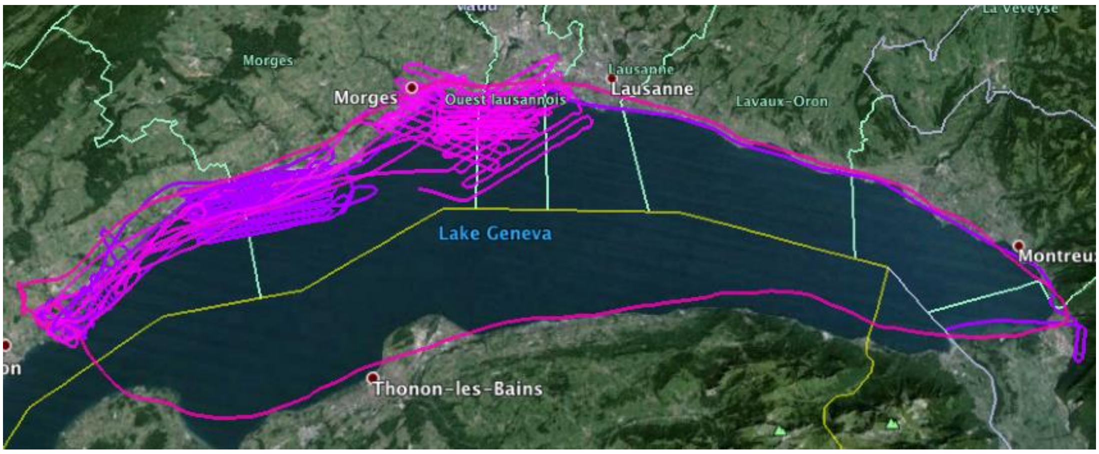
1.1.2. Data acquisition

The field campaign resulted in the collection of the total of around 7 Terabytes of airborne remote sensing data covering the area in excess of 2000 km^2, including more than 100 in situ sampling sites.

The entire field campaign spanning both Lake Léman and Lake Baikal phases included over 83 hours of flight having an accumulate flight trajectory length in excess of 7,700 km. In particular, the data collected to date is comprised by 580,000 airborne images and nearly 15,000,000 hyperspectral scan lines.

Lake Léman phase

During the stage of the system development, as well as during the collection of the initial data, we conducted a series of flights in the area of Lake Léman. Our initial points of interest included the mouths of the Venoge and Rhône Rivers, which exhibit a particularly rich range of visually observable hydrological phenomena.



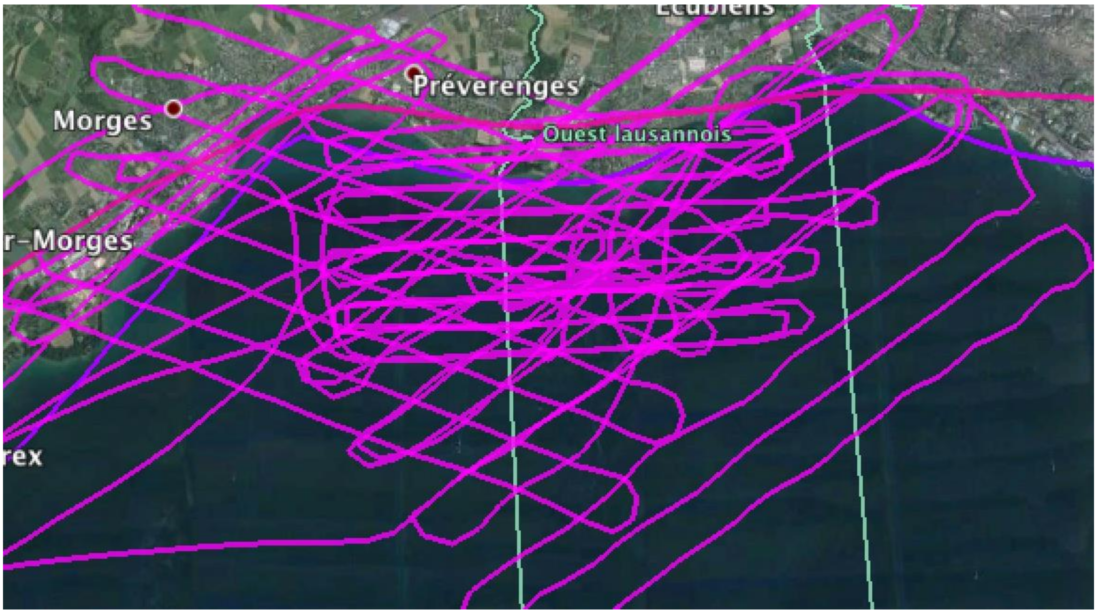


Figure 4: Flight trajectories performed during the months April and May of 2013 over the coastline of Lake Léman (top), and the particular region of interest in the outflow of river Venoge

Date	Time	Location	Altitude	Measurements
2013-04-16	10:30-11:40	Gland shoreline	500m	HSI
2013-04-16	16:10-16:50	Gland shoreline	700m	HSI
2013-04-17	10:10-11:50	L'Aubonne outflow	700m	HSI, RGB, nIR
2013-04-17	15:30-17:10	North shoreline, Rhône outflow	1500m	HSI, RGB, nIR
2013-04-18	9:30-11:40	North shoreline	1000m	HSI, RGB, nIR
2013-04-22	15:30-16:50	Venoge outflow	700m	HSI, RGB, nIR
2013-04-23	15:30-17:40	Lake perimeter, Rhône outflow (high altitude)	3500m	HSI, RGB, nIR, thermal
2013-04-24	9:30-11:30	Venoge outflow	1000m	HSI, RGB, nIR, thermal
2013-04-24	15:30-17:00	Venoge outflow	700m	HSI, RGB, nIR, thermal
2013-05-13	9:30-11:00	Vidy Bay	700m	HSI, RGB, nIR, thermal
2013-05-22	10:10-11:40	Venoge outflow	700m	HSI, RGB, nIR, thermal

Table 1: Flight details of the 11 flights over Lake Léman carried out in April and May 2013

Lake Baikal phase

In the consecutive stage of the project, taking place during the months June and July of 2013, we carried out a comprehensive field campaign in the area of the Selenga River delta in the Southern Siberia region of the Russian Federation. The campaign was conducted in close collaboration with the Geography Faculty of the Moscow State University and the Institute of Nature Resource Management in Ulan Ude. Our airborne observations were complemented by extensive ground work, which included the collection and analysis of in situ samples, as well as the recording of the corresponding spectral reflectance signatures of the water surface.

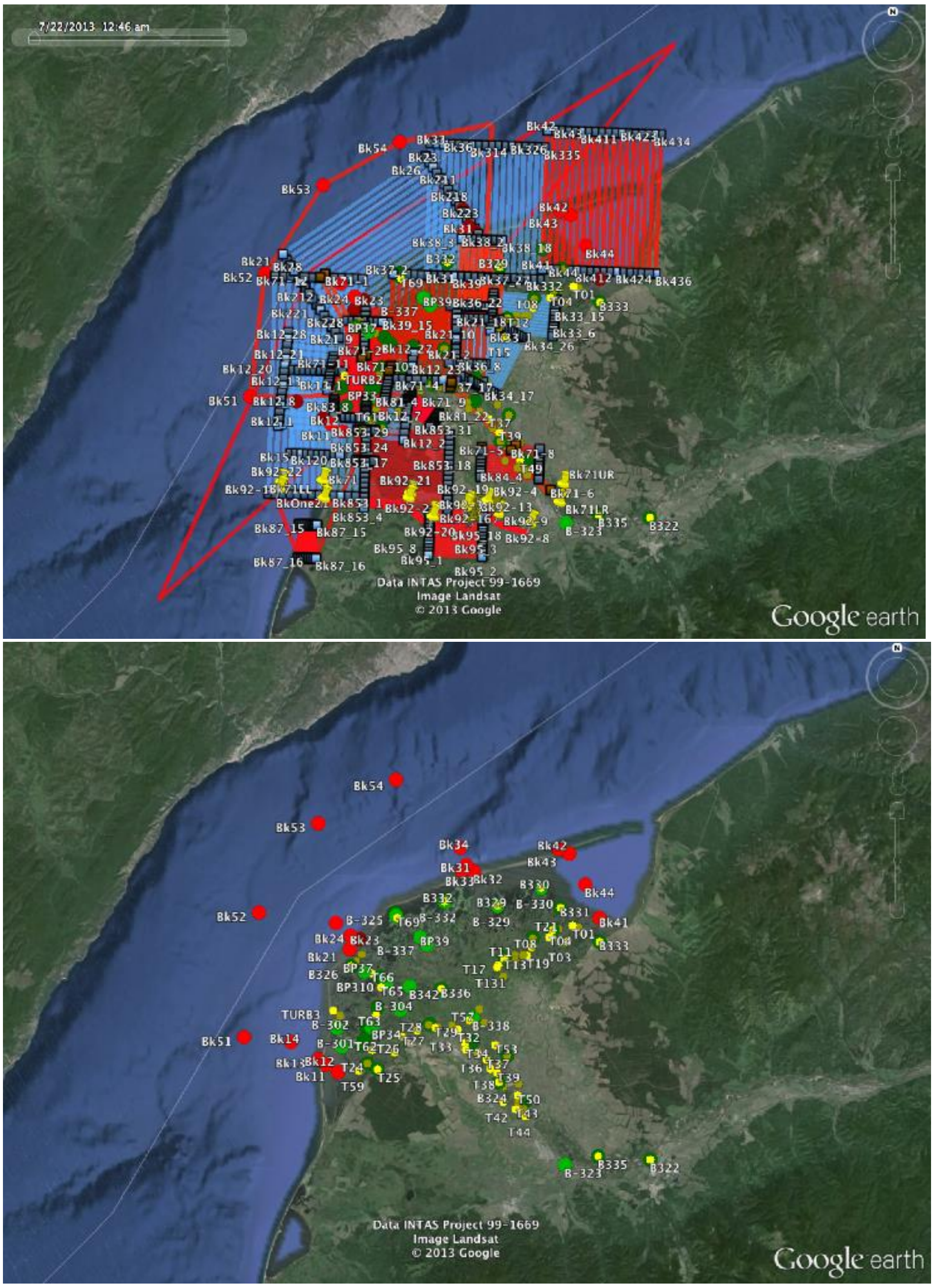


Figure 5: Flight trajectories (top) and in situ sampling sites (bottom) for the Lake Baikal phase of the Léman-Baikal project, which took place during July of 2013

1.1.3. Data processing

The airborne remote sensing data processing chain depicted in Figure 6 is being actively developed for effective analysis of the material collected in the course of the various phases of the field campaign. The raw data is comprised of multiple data types including image files, image sequences, line scan sequences, as well as auxiliary navigation data logs. The aim of the data processing methodology is the production of a data management system, which will facilitate access to synchronised, calibrated, as well as time and space referenced multimodal data.

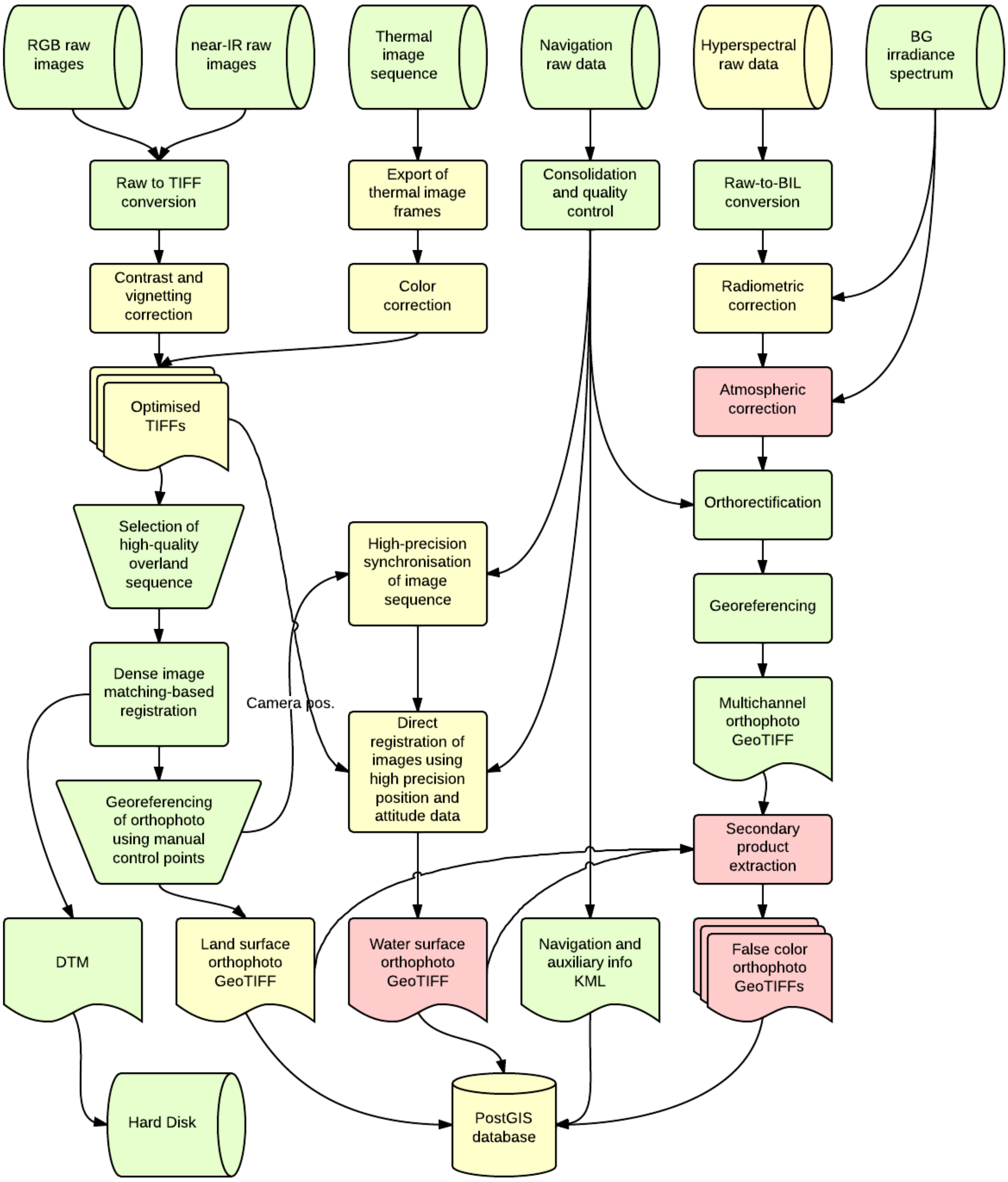


Figure 6: Airborne remote sensing data processing chain. The development progress is indicated by completed steps (green), work in progress (yellow) and steps, which are planned to be developed in the near future (red)

As part of the Léman-Baikal project we have developed and deployed a dedicated database system and a web-based GIS data management framework detailed in Figure 7, which facilitates an effective and highly structured storage, search, retrieval and visualisation of multi-modal scientific data collected in the course of the field campaign.

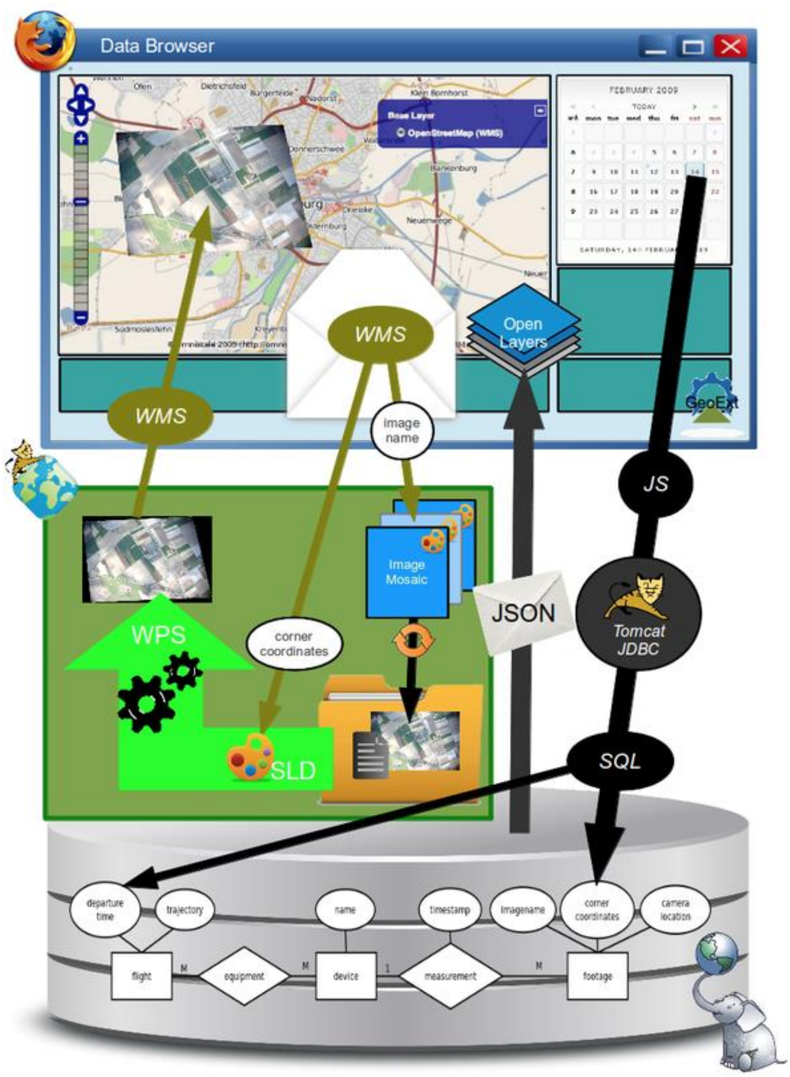


Figure 7: The underlying architecture of the Web GIS data management and visualisation system

The cloud-based approach to data management is motivated by the need for collaborative access to a particularly large volume of collected data.

1.2. Preliminary results

We have conducted a range of methodological experiments, while collecting data from different altitudes between 500m and 2500m, resulting in the ground resolution for the high-resolution RGB/nIR imagery of approximately 16 to 80 cm per pixel, respectively.

The results of the preliminary analysis of the collected data demonstrate its suitability for the generation of a wide range of remote sensing products exemplified in Figure 8.

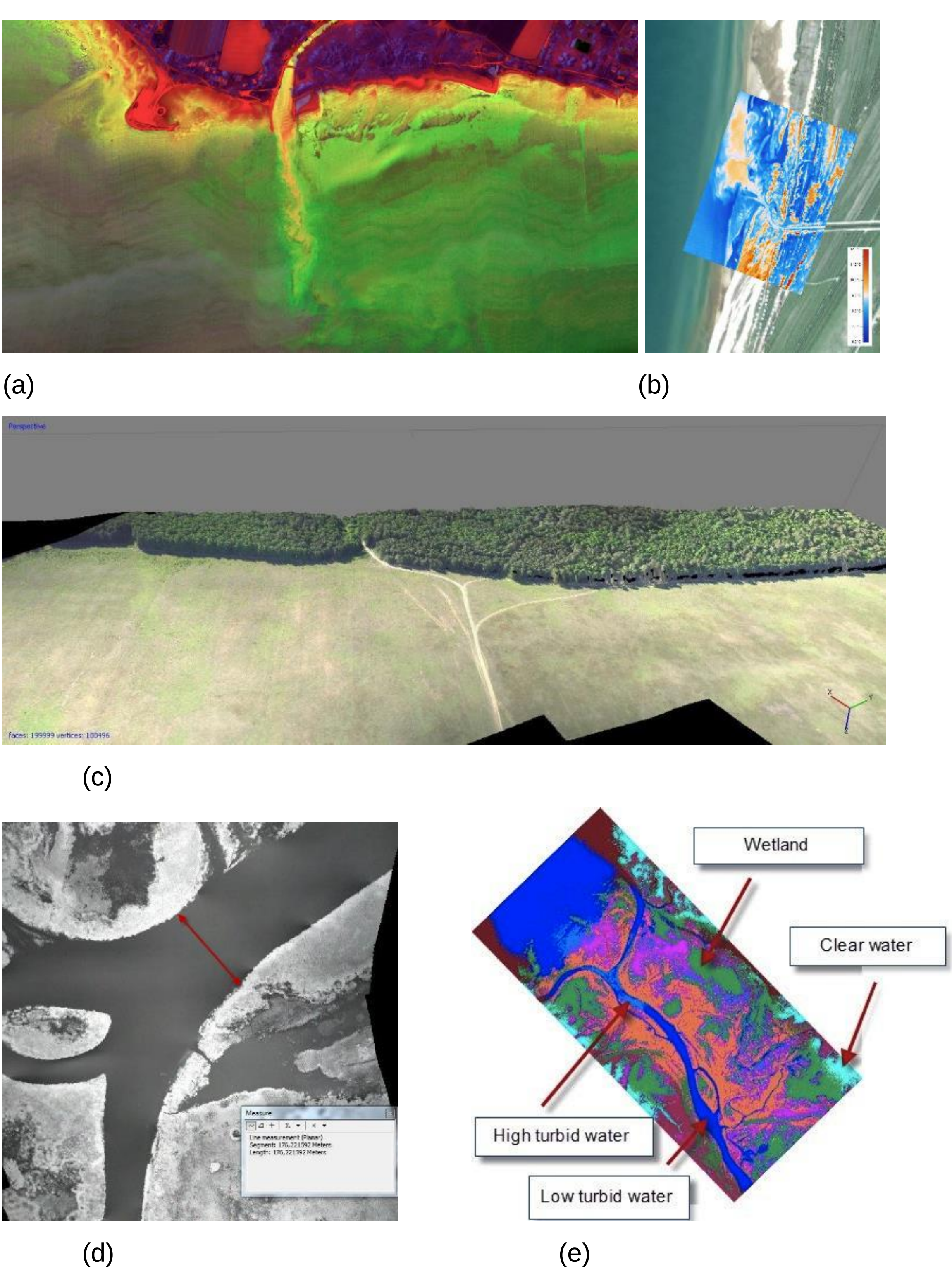


Figure 8: Examples of remote sensing products including hyperspectral cubes (a), thermal maps (b), DTMs (c), metric surface morphology analysis (d), as well as various types of automated land cover classification maps (e)

2. Thermal images – ECOL Laboratory

Prof. D A Barry, A Irani Rahaghi

The objective of ECOL laboratory is to utilize satellite, ULM and point measurements to estimate the lake surface energy balance and its effect on 3D hydrodynamics.

2.1. Surface temperatures from remote sensing

The heat balance at the air-water interface includes different mechanisms. In general for lakes, heat flows from groundwater and inflow/outflow are insignificant compared to other heat transfer mechanisms. Therefore, the heat flux equation at the lake surface is given by:

$$\rho_w C_p h \frac{\partial T}{\partial t} = Q_{tot} = Q_{sn} + Q_{an} - Q_{br} - Q_{ev} - Q_{co}, \tag{1}$$

where the RHS (right-hand side) terms are, respectively, net incident solar radiation (short-wave), net incident atmospheric radiation (long-wave), back radiation (long-wave), evaporation and convection. Also, h is the mixed layer thickness, T is temperature, t is time, ρ_w is the water density and C_p is the heat capacity.

Methods to evaluate the heat flux at the lake surface in (1) have been investigated by ECOL laboratory. For this, we have acquired a radiometer for measuring the first three terms in the RHS (i.e., the net radiation). For estimating evaporative and convective heat flux over lakes, different approaches are possible (bulk aerodynamic methods, surface energy balance system, etc.). These methods require measurement of air temperature, surface water temperature, wind speed, humidity, and air pressure within a precise temporal scale (e.g., hourly). The air temperature, wind speed, humidity and air pressure can be obtained using some of our own instruments as well as MeteoSuisse COSMO data. For calculating the local temperature derivatives (left-hand side, LHS), surface temperature values in different times are needed. Therefore, the lake surface water temperature (LSWT) plays an important role in three terms of the heat flux equation.

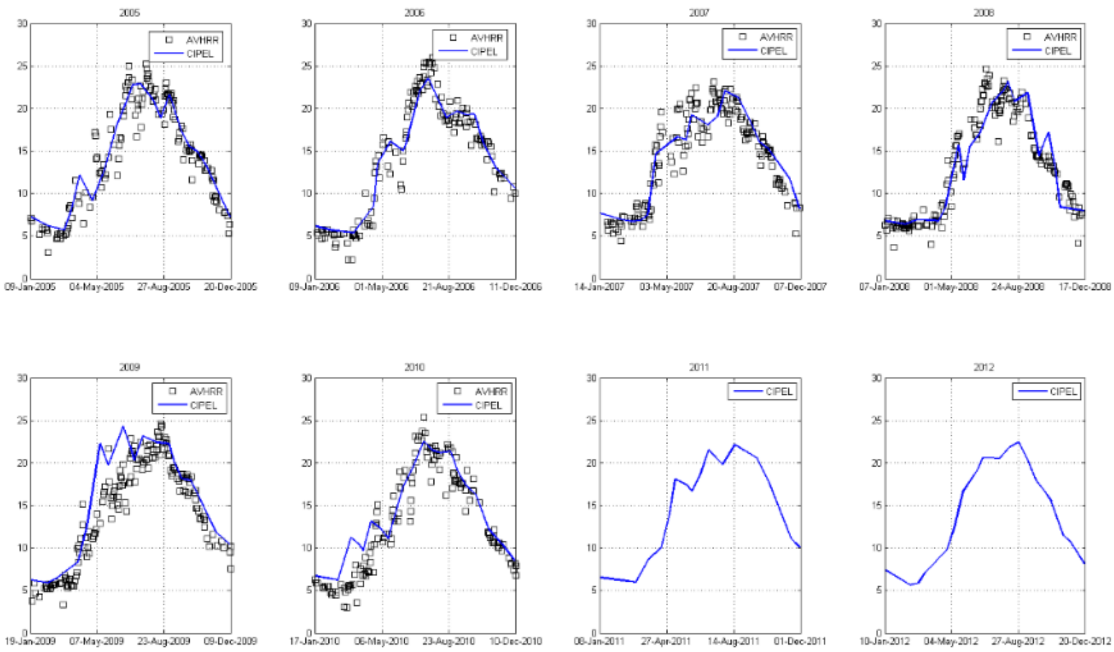


Figure 9: LSWT at the centre part of Lake Léman's Grand Lac: comparison of AVHRR data and CIPEL data, 2005-2010

Concerning the LSWT, in the present study satellite data are considered together with ULM data and point measurements. As the preliminary step, the comparison of AVHRR satellite data and CIPEL data (from the centre of the lake) is underway. Figure 9 shows this comparison for 2005-2010. The overall trends of both data sources are the same. However, in some points there is a noticeable difference. The ULM data sets will provide the missing scale between the satellite and point measurements, and are expected to help to explain the differences evident in Figure 9.

Preliminary analysis of the ULM data obtained in the first field campaign has begun. Before using the data, the question of their reliability and accuracy must be addressed. Figure 10 shows two sample images retrieved from 2013 ULM flights on Lakes Léman and Baikal. These figures are examples of the data collected, and will be used in conjunction with other measurements and 3D modelling to help elucidate hydrodynamics and mixing processes.

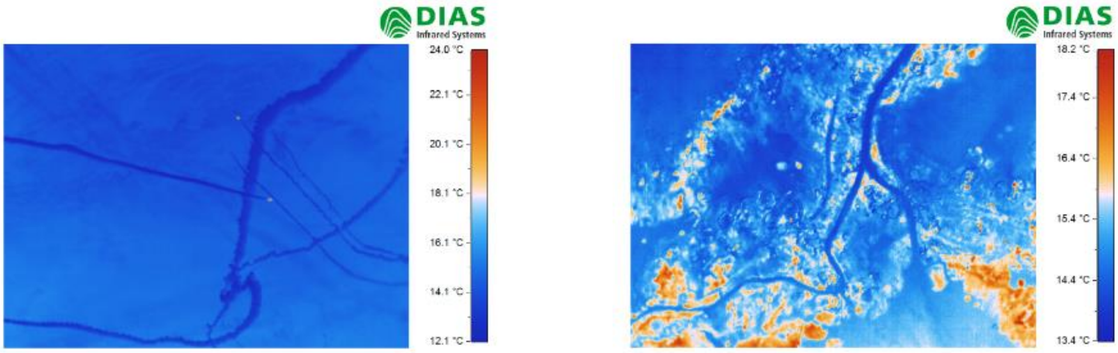


Figure 10: Left: image from Lake Léman, showing mixing processes (as gradations in the background). The strong contrasts in the image are caused by the tracks of boats – indeed, some boats are in the image. Right: Selenga River delta, Lake Baikal. The river and different temperature signatures due to different land cover are apparent.

2.2. Development of equipment and data handling for ground truthing

2.2.1. Catamaran – actual state and next steps

In order to study and understand better the processes that govern fluxes and pathways of water masses and transported compounds, the ECOL laboratory is developing a mobile, semi-autonomous floating platform. This platform is implemented on a catamaran basis (Figure 11) and development has been focused on modularity and high payload capacity in order to accommodate a large number of sensors both in terms of electronic (power and data) and mechanical constraints of integration.

At the current state, the catamaran structure is modular and customizable thanks to a set of piecewise-movable deck sections. It allows quick optimization of platform stability and new equipment installation.

The catamaran has two navigation modes, manual and automatic. In manual mode, the boat is controlled with a joystick or with a mouse, whereas in automatic mode it follows a predefined path (waypoints). The current accuracy of the automatic navigation system is shown in Figure 12.

A set of sensor types (PT100, anemometer, radiometer) is pre-configured and ready to use. Installation of sensors from the listed types is plug and play.

In order to control the boat and live monitor the measurement, a Q_t-based interface has been developed. As is the case for the whole platform, it has been developed with a focus on modularity. It, thus, enables simple sensor configuration, and fast sensor addition.

Figure 11: Catamaran – ECOL semi-autonomous measuring platform

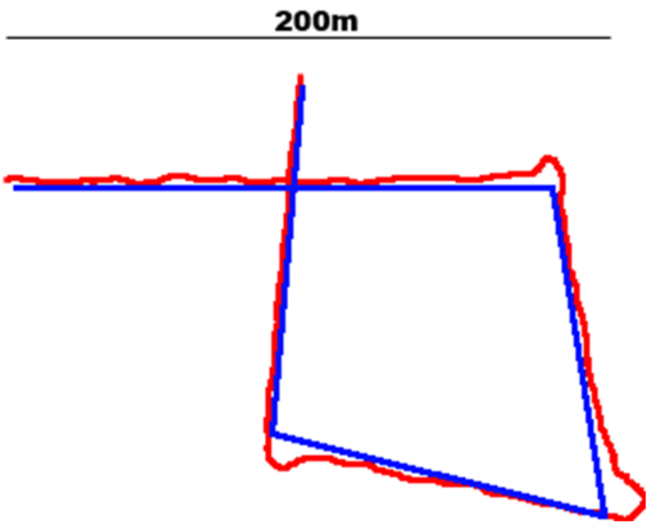


Figure 12: Navigation system accuracy (lake test). In blue: line to follow, in red: actual catamaran trajectory.

Given the current state of the platform, the next steps are:

- ADCP integration – An ADCP (down-looking) is to be installed on the catamaran to measure lake currents.
- CTD and winch integration – A winch is to be installed on the catamaran so that sensors that require varying depth can be used. A CTD will be the first equipment to take advantage of it.
- GPS replacement – The current GPS will be replaced by one with a higher sampling frequency for better position and speed measurement.

2.2.2. Data visualization

In order to visualize the data that is collected by the catamaran, a visualization interface has been developed. Indeed, each measurement occurs at a specific point along boat's trajectory, and has thus a geographical position (GPS coordinates) and a timestamp in addition to the sensor measurement. The GPS position of the boat is obtained via the on-board GPS receiver, and the timestamp is set by the on-board computer when the measurement is acquired.

All the collected data is stored in a central server hosted at EPFL, which is being integrated with the TOPO database (e.g., Figure 7). This server is actually a full data portal that provides all the essential features to work with the acquired data, such as import, export, filtering, and visualization. The system is composed of a PostgreSQL database, with a PostGIS extension to handle the geographic position of the boat, a Scala backend that implements the web services that enable data manipulation (insert, get, filter), and a set of dynamic web pages for the visualization interface.

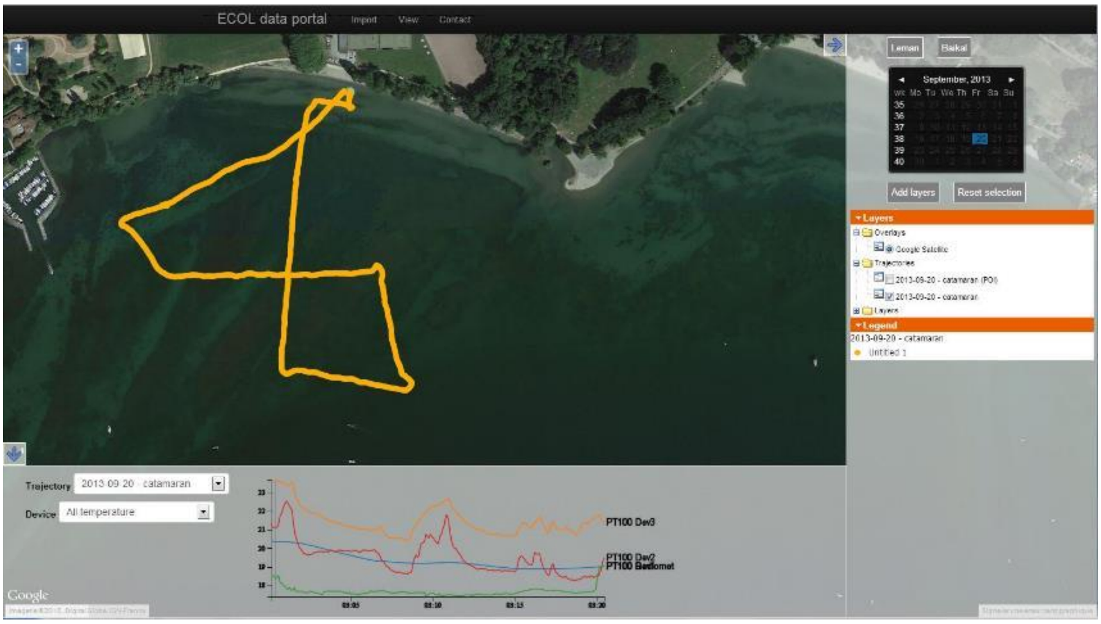


Figure 13: Visualization interface (example)

The visualization interface, an example of which is shown in Figure 13, is composed of three parts:

1. The centre, with the map, is the part where the trajectories of the catamaran are plotted.
2. The right is the “control part”. It allows selection of a date when field data were collected. Below the calendar, there is a list of layers that have been added to the map. Multiple layers correspond to multiple trajectories. Thanks to this control, one can show/hide any trajectory on the map.
3. The bottom part lists sensors. It displays plots of the data collected by the selected sensors on the catamaran.

3. Water Quality - Margaretha Kamprad Chair (APHYS)

Dr. D Bouffard, V Nouchi, and Prof. A Wüest

The goal of APHYS laboratory within the Léman-Baikal project is to monitor the water quality of both lakes using the hyperspectral data collected by the remote sensing platform on the ULM. Remote sensing has proven its potential for such a task but there is no universally valid method to interpret the water colour of these lakes. Indeed, they have different optical characteristics: Lake Léman is comparatively a more productive lake while the Selenga delta and the surrounding shores of Lake Baikal contain a larger quantity of particles. In this context, APHYS has collected spectra of the lake surface from a boat and has analysed water samples as ground truthing for the remote sensing data. This step is essential for the production of subsequent data for calibration and validation of the different models that we will develop.

3.1. Methodology

As the dominant light harvesting pigment in phytoplankton, chlorophyll-a is often used as an integrative bio-indicator of primary production in lakes. This pigment is universally present in all red and green algae, and cyanobacteria. The optical properties of water are further dependent on the amount of particles and dissolved organic matter present in the water.

In this project, we will test the following remote sensing equation with the standard optical properties that we have measured in situ:

Rrs(λ) $\propto \gamma \frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}$ with: $a = a_w + a_{chl} + a_{cdom}$ and $b = b_w + b_{tsm}$

where Rrs is the Remote Sensing Reflectance observed from the ULM, b_b is the backscattering coefficient, *b* the scattering, *a* is the absorbance, λ is the wavelength and the subscript *w*, *chl*, *cdom* and *tsm* stands for water, chlorophyll-a, yellow substances, and total suspended matter respectively.

The first objective of ground truthing is to validate the Rrs reflectance measured by the hyperspectral camera on the ULM. Therefore, Rrs is also calculated using the downwelling and upwelling radiances and irradiances measured with the *Water Insight* WISP3 and the *Ocean Optics* USB2000+ just above the surface, and in the water column with *TriOS* Ramses spectrometer.

The second objective is to provide a calibration dataset for machine learning methods and band-ratio algorithms and ultimately retrieve the constituents of both lakes. To do so, reference measurements of water constituents are taken from water samples. Concentrations of chlorophyll, *cdom*, and *tsm* are compared with data from a *Seabird* CTD *19plusV2* equipped with a fluorometer and a turbidity meter that measure chlorophyll, *tsm*, and *cdom* as well as with a *CTG* Trilux/Unilux fluorometer for chlorophyll and tsm calibration.

The third objective is to collect vertical profiles of the optical and chemical properties of the water column. Profiles were made every 50 cm down to 5 m with the Ramses radiometer and the Trilux fluorometer, and continuously until the bottom of the lake with the CTD. The goal is to correlate the vertical distributions of the different constituents of the water column with the water leaving radiance observed from the ULM and other airborne and spaceborne platforms

3.1.1. Summary of ground truthing points

For ground truthing, at least four in situ measurements were sampled during each flight. Sampling sites were chosen within the trajectories of the aircraft where the strongest variability of water quality parameters could be observed. Tables 2 and 3 list all ground truthing points for Lake Léman and Lake Baikal, respectively.

Table 2: List of sampled sites and instruments used on Lake Léman (+ = instrument used)

Site	Date	CTD	TriOs Ramses	WISP3	CTG Trilux/Unilux	Water samples
S1	24.04.2013	+	+	-	-	+
	13.05.2013	+	+	-	-	+
	22.05.2013	+	+	+	+	+
S2	24.04.2013	+	+	-	-	+
	13.05.2013	+	+	-	-	+
S3	24.04.2013	+	+	-	-	+
	13.05.2013	+	+	-	-	+
	22.05.2013	+	+	+	+	+
S4	24.04.2013	+	+	-	-	+
S4b	13.05.2013	+	+	-	-	+
	22.05.2013	+	+	+	+	+
S5	24.04.2013	+	+	-	-	+
	13.05.2013	+	+	-	-	+
	22.05.2013	+	+	+	+	+
R1	14.05.2013	+	+	+	-	+
R2	14.05.2013	+	+	+	-	+
R3	14.05.2013	+	+	+	-	+
R4	14.05.2013	+	+	+	-	-
R5	14.05.2013	+	+	+	-	+
R6	14.05.2013	+	+	+	-	+

Table 3: List of sampled sites and instruments used on Lake Baikal (+ = used)

Site	Date	CTD	WISP3	USB2000+	CTG Trilux/Unilux	Water samples
Bk11	04.07.2013	+	+	+	+	+
	13.07.2013	+	+	+	+	+
Bk12	04.07.2013	+	+	+	+	+
	13.07.2013	+	+	+	+	+
Bk13	04.07.2013	+	+	+	+	+
	13.07.2013	+	+	+	+	+
Bk14	04.07.2013	+	+	+	+	+
	13.07.2013	+	+	+	+	+

Bk21	05.07.2013	-	+	+	+	+
	10.07.2013	+	+	+	+	+
Bk22	05.07.2013	-	+	+	+	+
	10.07.2013	+	+	+	+	+
Bk23	05.07.2013	-	+	+	+	+
	10.07.2013	+	+	+	+	+
Bk24	05.07.2013	-	+	+	+	+
	10.07.2013	+	+	+	+	+
Bk31	06.07.2013	+	+	+	+	+
	18.07.2013	+	+	+	+	+
Bk32	06.07.2013	+	+	+	+	+
	18.07.2013	+	+	-	+	+
Bk33	06.07.2013	+	+	+	+	+
Bk34	06.07.2013	+	+	+	+	+
Bk41	10.07.2013	+	+	+	+	+
Bk42	10.07.2013	+	+	+	+	+
Bk43	10.07.2013	+	+	+	+	+
Bk44	10.07.2013	+	+	+	+	+

3.2. Preliminary results

3.2.1. Water quality parameters

The following figures represents the concentrations of chlorophyll-a and particles for each sampling point and near Vidy Bay in Lake Léman and in Lake Baikal.

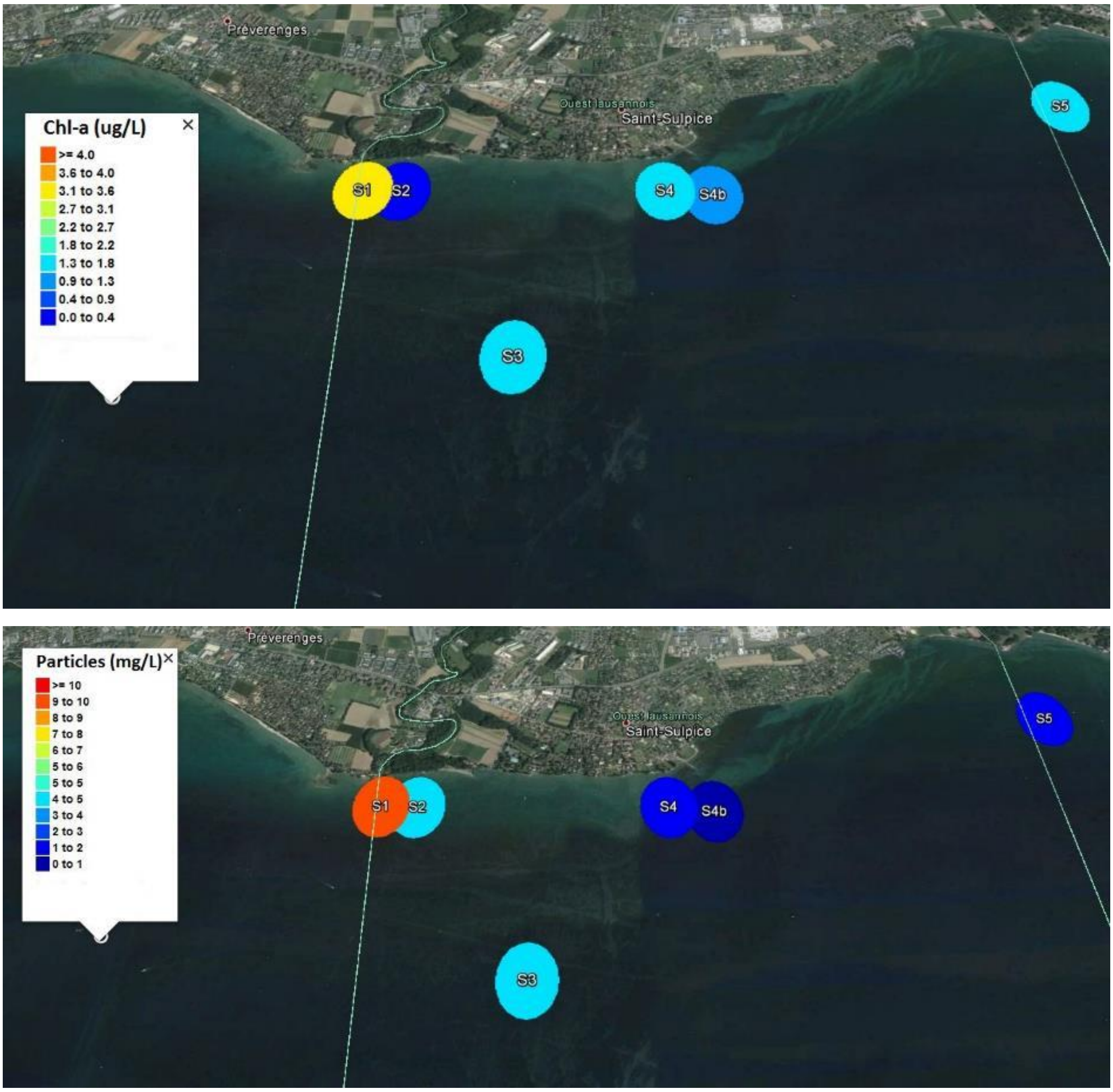
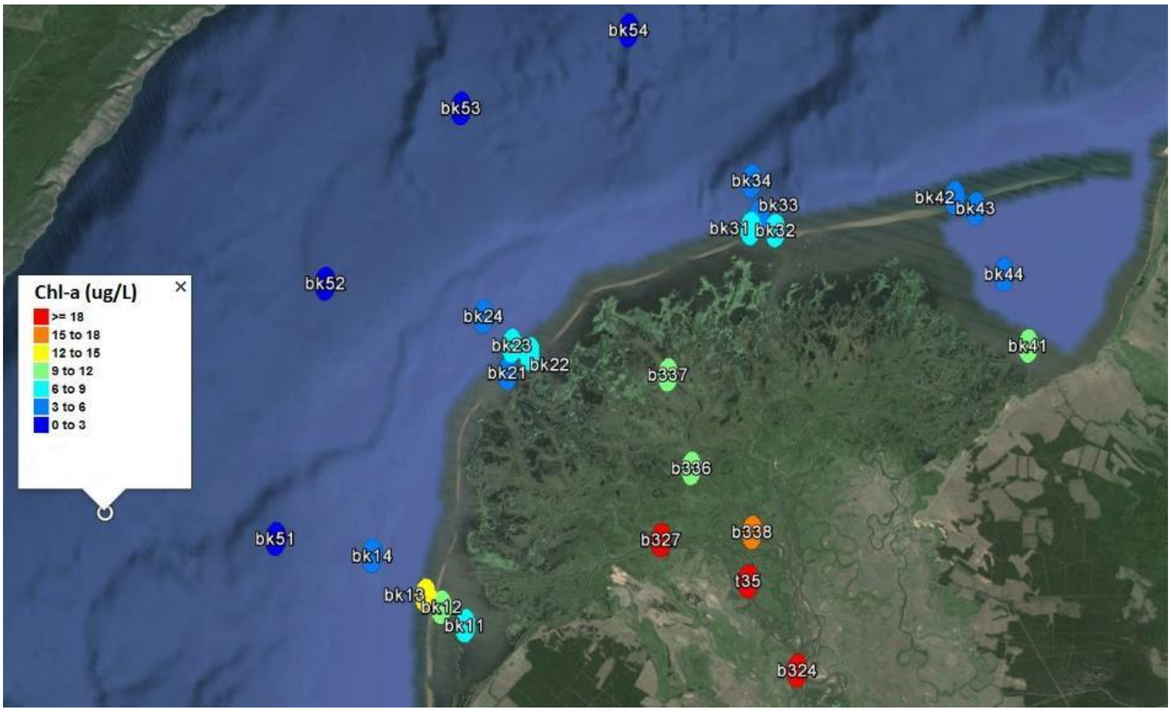


Figure 14: Chlorophyll-a (top) and particle (bottom) concentrations in Vidy Bay and at the outlet of the Venoge river



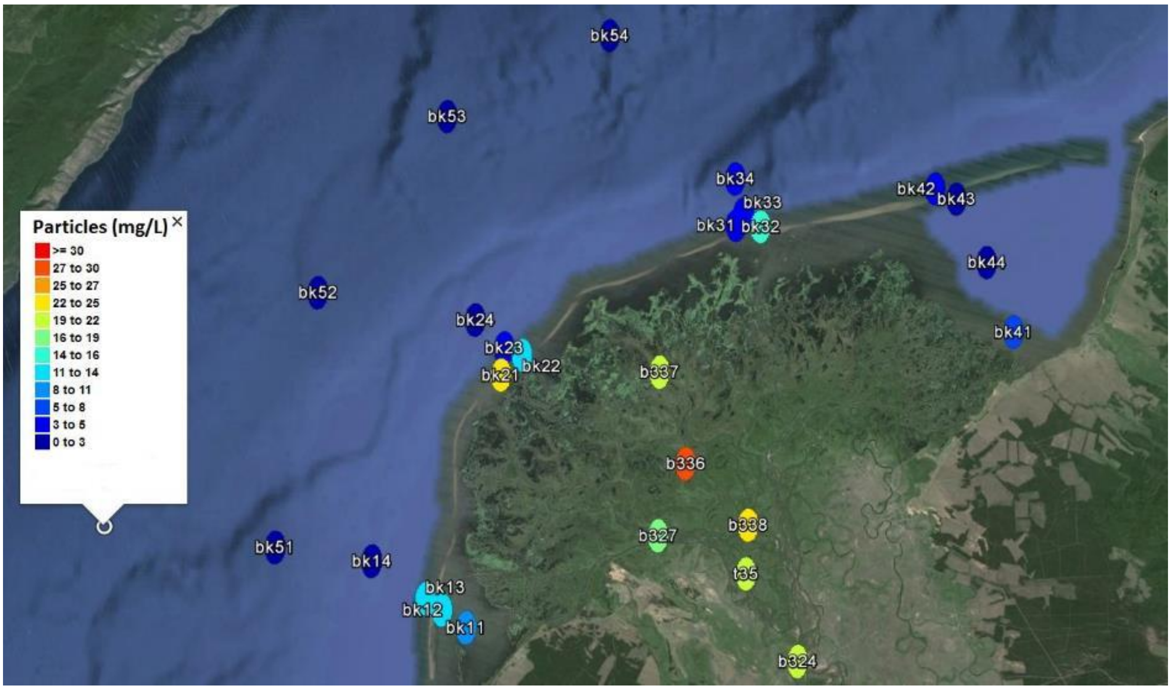


Figure 15: Chlorophyll-a (top) and particle (bottom) concentration in the Selenga Delta and the surrounding Lake Baikal

3.2.2. Comparison of remote sensing and in-situ spectrums

In close collaboration with the TOPO/LaSIG laboratories, we first compared the spectral response of the ULM sensor with the WISP spectrometer used for ground trothing (Figure 16). In the lower left corner, the blue curve corresponds to the spectra averaged over the red box in the hyperspectral image, and the red curve corresponds to the WISP. In the latter, both spectra have been normalized for comparison. Note that the hyperspectral response is not yet corrected for atmospheric interactions, but the two curves are very similar showing the potential for data interpretation.

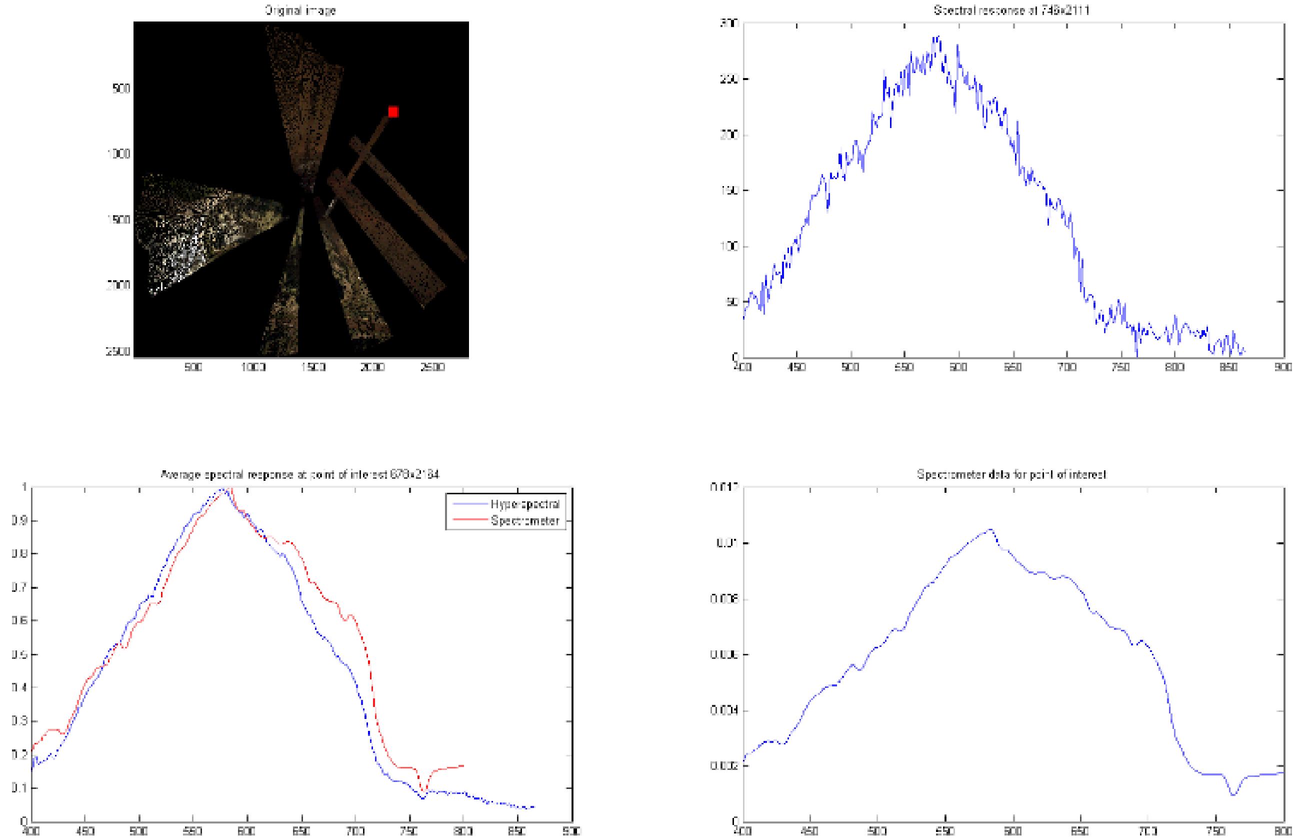


Figure 16: Hyperspectral image (upper left), spectral response of one pixel (upper right), spectral response of WISP3 spectrometer (lower right), comparison between both spectra (lower left).

3.3. Perspectives

The spatial and temporal resolution of ULM data will be most valuable to scale up water quality parameters from ground truthing to satellite.

In 2014, we plan to fly at higher altitudes (around 4 km) with the ULM, in order to cover the entire Lake Léman. Such high-resolution data could be assimilated to couple a 3-D hydrodynamic model with an ecological model.

In addition, flights at lower altitudes will track individual features over time and space. Over a small area, we will track the development of algae filaments, or small-scale physical processes like convection early in the morning in fall, or mixing of the river plumes. For this, the ULM will fly four times a day on an area between 2x2 and 10x10 km at an altitude below 1000 m. Over a larger area (up to 20 x 20 km), it will be possible to track algae blooms, mixing of Rhône River discharge and the plume from the Vidy wastewater treatment plant, especially via thermal contrasts in the winter. To do so, the ULM will fly twice a day over an area comprised between 10x10 and 20x20 km at an altitude below 2500m.

4. Atmospheric Boundary Layer over Lake Léman - WIRE

Dr. G V Lungo and Prof. F Porté-Agel

4.1. Introduction

The Wind Engineering and Renewable Energy (WIRE) Lab contributes to the project “A study of the micrometeorology and heat fluxes over Lake Léman using ULM and lidars”, which is coordinated by the Limnology Center, with turbulence measurements of the atmospheric boundary layer (ABL). Those measurements will be performed through three different setups: instrumented towers, wind lidars and turbulence probes installed on a ULM. The synergistic analysis of those data will improve our understanding on turbulence and transport phenomena within the ABL over the Lake Léman. Moreover, those data will be useful to evaluate if standard turbulence models are suitable for prediction of a turbulent atmospheric flow for this test case where the surrounding topography and land/water transition play a significant role. Measurements will be performed in proximity of the land/water with instrumented towers, while wind lidars will acquire wind data within a range of heights from 45m up to 1500m. Finally, turbulence measurements will be carried out through probes installed on a ULM.

The scientific goal of this field campaign is mainly devoted to the characterization of the turbulent flow within the ABL over Lake Léman, and of transport phenomena associated with it. A better physical understanding of the physics occurring in presence of such a heterogeneous domain will be fundamental to investigate on the consequent effect on the local micrometeorology and on air quality of the Léman region. Furthermore, the characterization of the wind field at different heights and for different ABL stability regimes will allow to estimate the potential for wind energy harvesting, especially connected to wind flows at higher altitudes and due to thermals.

4.1.1. Experimental setup

As already mentioned in the previous section, measurements will be performed with three different setups: instrumented towers, three wind lidars and turbulence probes installed on a ULM.

Several (3-4) 10 m towers can be installed on the considered site in order to characterize the wind/atmospheric conditions. Those towers are typically instrumented with sonic anemometers, temperature probes, radiometers and eventually hygrometers. This setup can be also installed on shorter 3m tripods and eventually it can be deployed over a floating platform or on a catamaran. This setup is essential for the characterization of the ABL in the surface layer, thus in proximity of the land/water, and to evaluate if classical models to predict ABL flows, which need just measurements in proximity of the surface, are satisfactory in areas with heterogeneous topography.

Wind measurements will be performed with three lidars. The lidars allow the measurement of the wind velocity component parallel to the direction of the laser beam, which is denoted as the line-of-sight velocity. By combining three lidars, different measurement techniques can be designed in order to perform measurements over planes, volumes or to obtain 3D velocity components of the wind in a single point. The frequency resolution varies with different measurement procedures, thereby involving different measurement volumes. Wind lidar measurements can be typically performed from a minimum distance from the lidar location of 45m up to distances larger than 1000m. The maximum achievable distance is a function of the aerosol concentration within the ABL.

4.2. Field campaign in 2013

Measurements of the ABL over Lake Léman will be also carried out through turbulence probes installed on a UML. For the 2013 field campaign, two fast-response five-hole pressure probes were purchased for turbulence measurements of the three wind velocity components. Furthermore, two total air temperature probes were also purchased to measure air temperature. All the measurements was acquired with a standard National Instrument Data Acquisition System.

For the field campaign 2013, two weeks (10 days) were devoted to the ULM measurements. Unfortunately, the ULM was not accessible for test setup before the campaign. Due to delays in setting up our equipment, just half day was allocated to the WIRE group for the setup of the probes and to carry out a 15 minute flight to check its structural robustness.

Due to miscommunication, the AC power supply and the GPS/IMU data for the post-processing were not provided on the ULM. Therefore, no data were acquired through this preliminary flight.

4.3. Assessment of the existing setup and upgrade for 2014

For the next field campaign the first goal is to perform measurements with the setup designed for the field campaign 2013. The setup will be initially tested in the WIRE wind tunnel. A new DC light power supply will be designed and purchased. All the data acquisition will be performed with a portable NI-Compact RIO. GPS/IMU data will be acquired directly by WIRE and synchronized with the NI-Compact RIO. Access to the ULM three months before the test flights will allow tests that ensure an accurate setup. WIRE will acquire data over different atmospheric conditions during the three planned periods. Finally, we will coordinate ULM tests with the lidar and ground/tower measurements.

For the field campaign 2014 we are also planning to upgrade the setup by adding other instruments. In addition to the turbulence fast-response probes, we are planning to also install two sonic anemometers. The latters are characterized by a lower frequency resolution, but they represent a more robust solution. The sonic anemometer data will be used to assess the data acquired through the fast-response probes. Regarding the temperature measurements, we intend to explore the possibility of performing very high frequency measurements through a cold-wire probe. The water vapour content can be also measured through hygrometers. We are also considering to use shortwave and longwave radiometers to measure net radiation, surface temperature and albedo.

5. Princeton effort in collaboration with EFLUM/CRYOS

Prof. M Hultmark, Dr. H Huwald and Prof. M B Parlange

5.1. Objective

The ultimate goal for this project is to mount new and unique ultra-fast-response temperature and humidity sensors on the ULM and measure humidity and temperature fluctuations in the lower atmosphere, in order to investigate the full range of turbulent scales present in the atmospheric humidity field and relate it to the macroscopic boundary layer properties. We propose to combine the ULM measurements with Doppler lidar measurements, where the lidar is pointed straight upwards. This will allow us to accurately estimate the boundary layer thickness, a parameter that is very important for the atmospheric turbulence. The ULM should be flown as low as possible with a path that intersects the lidar beam and extends from over the lake to over the land. These fast response measurements will be supported by more conventional slow response sensors for calibration purposes as well as mean measurements. These measurements will be the first fully resolved measurements of the humidity field in the atmospheric boundary layer, which will allow us to compare the resulting turbulent humidity spectrum to existing theoretical analysis.

5.2. Sensor development

During our development of the humidity sensor we noted that the state of the art temperature sensors were lacking in frequency response – a feature necessary for correcting humidity sensors.

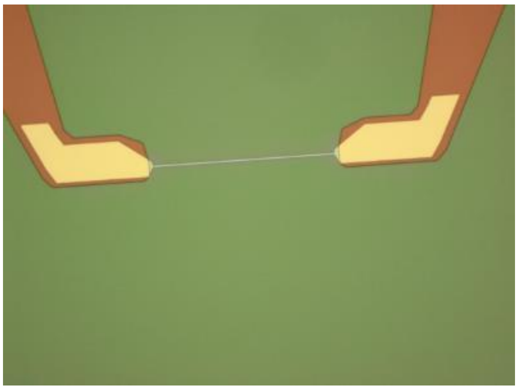
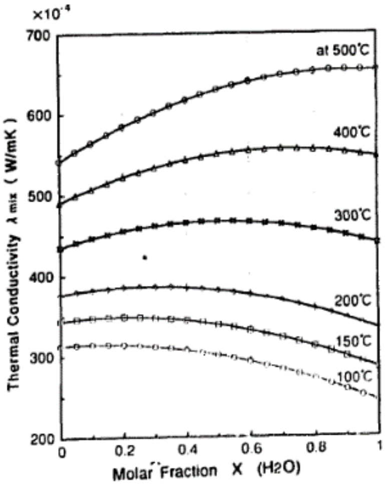


Figure 17: Newly designed MEMS temperature sensor

As a result we spent a lot of effort understanding the limitations in these sensors, and as a result we created a model for how the frequency response behaves with different sensor designs (see Arwatz et al. Meas. Sci. Tech., *in press*). This model is now being used to design and manufacture ultra-fast temperature sensors. These new MEMS temperature sensors (Figure 17) have been shown to have much faster frequency response than conventional sensors, and will be used for correcting the new MEMS humidity sensors. Ongoing studies are carried out to evaluate exactly how fast they are, but it is always challenging to evaluate the fastest sensors since there is nothing to compare them to. The goal is for the temperature sensor to have a bandwidth of 10kHz (several order of magnitude faster than conventional sensors).

The limitations for the humidity sensors are even more limiting than those for the temperature sensor, and we have been developing a brand new sensor based on a previously unexplored principle. For the humidity sensor a nano-wire is heated by an electrical current being fed through it. By relating the heat transfer characteristics to the thermal parameters of the surrounding fluid, measurements of the thermal conductivity of air can be conducted. However, such a wire can also be sensitive to velocity (see hot-wire anemometry). The novelty of the new sensor lies in the separation of the sensitivity of thermal conductivity from the velocity, as well as the manufacturing of a free standing nano-wire. If the local Péclet number ($Pe = LU/\alpha$, where L is the diameter of the wire, U the velocity over it and α the thermal diffusivity of the air) is much smaller than unity, molecular diffusion is the dominant mode of heat transfer. This allows one to relate the heat transferred from the wire to the thermal properties of the fluid only, eliminating sensitivity to velocity. In order to decrease the magnitude of the Péclet number without decreasing the air velocity the length scale, L, can be decreased. Obviously, for this project we are interested in measuring humidity in the surrounding air. The thermal conductivity of air is a strong function of humidity (as shown in Figure 18), thus it can be measured by the new device (a provisional patent application (#61,864,127) has been submitted for this invention).



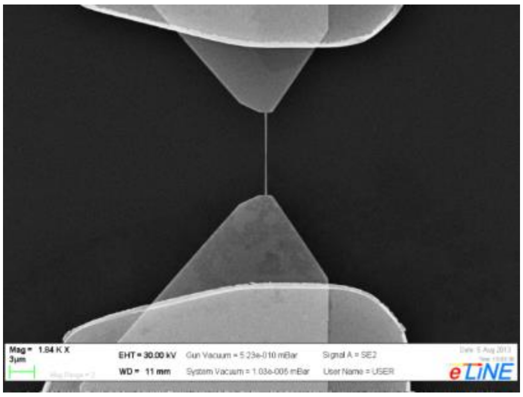


Figure 18: Left: Thermal conductivity of air as a function of humidity, and right: MEMS humidity sensor

Due to the complications of the temperature sensors the development of the humidity sensor has been slightly delayed. We have successfully manufactured a sensor with a cross section of 100x400 nm, an order of magnitude smaller than any previous free-standing wire MEMS device. This wire promises sensitivity to humidity at up to 10m/s. In the process we have been forced to change the manufacturing technique since we experienced nano-cracks in the platinum layer and other stress related issues when releasing the nano-wires. We are optimistic that the new method will allow us to manufacture these sensors with a fairly high yield, suitable for field experiments. The next step will be to evaluate the humidity sensors response both static and dynamic. A custom made humidity chamber has been constructed for the static measurements. An alternating dry-wet-jet setup with adjustable alternating frequency has been designed and built. This jet setup can be used to observe the new sensors behaviour and output signal in dynamic fluctuating conditions. This will allow us to evaluate its true frequency response. We hope to do this within the next coming months.

5.3. Outlook and Proposal for 2014

The EFLUM/CRYOS laboratories are interested in the energy balance and the atmospheric boundary layer at and above the lake and near-lake shore land surface. Our principal questions and goals are:

- understand the dynamics, magnitude, and timing of heat and moisture exchange associated with turbulent heat fluxes;
- link turbulent exchange processes at the surface level to turbulence and convective processes within and at the top of the atmospheric boundary layer. This has not been done so far and the Léman-Baikal project offers a unique possibility to address such questions thanks to the availability of the ULM;
- explore and quantify differences in turbulent fluxes related to land and water surfaces and investigate spatial heterogeneity in these variables.

In 2014, the specific plans and tasks will be:

- assist Princeton with planning and preparing the ULM (while being accessible at EPFL) for accommodating the high-frequency nano-wire systems developed by Princeton/Hultmark. Princeton intends to carry out their measuring campaign during the 2-weeks flight slot in May 2014.
- Installation of two energy balance/turbulent fluxes measurement systems, one over water (floating or fix platform) and one over land near the lakeshore. Data acquisition simultaneous with ULM “turbulence flights” in May 2014. Ideally, the two sites should be operational for a longer period and data will allow addressing the abovementioned research questions.
- We would like to install a novel sensible heat flux sensor on the ECOL Catamaran to take measurements over the lake while the catamaran moves along a predefined trajectory. The measurement principle of this sensor is not based on the Eddy-Covariance technique (as many of the standard instruments are) but rather on a flux variance method that we judge to be fairly robust to wave-induced motion of the carrying vehicle.
- Observations from the land and water-based platforms will be linked with measurements from the Princeton/WIRE “turbulence ULM” and the WIRE Wind lidar observations if available during this period.