

**PhD PROJECT PROPOSAL (FULL)
UNIVERSITY/PE&RC**

WAGENINGEN

MAIN RESEARCH GROUP : Laboratory of Geo-Information Science and Remote Sensing.....

OTHER WU GROUPS INVOLVED : None.....

Please read appendix first and fill in with a Personal Computer.

1. PROJECT LEADER

Prof. Dr. sc. nat. M.E. (Michael) Schaepman

2. PROJECT TITLE (English)

Physiological status assessment of coniferous forest affected by natural disturbances using imaging spectroscopy and radiative transfer modelling

3. PROJECT TITLE (Dutch)

Bepaling van de fysiologische status van naaldbossen met behulp van beeldvormende spectroscopie en stralingsinteractiemodellen

4a. Duration of the project: from: 15 October 2007 to: 15 October 2011

4b*. If it is a joint project of two (or more) research groups, note that appointments have to be made about dividence of the capacity awarding at graduation. Please be so kind to inform the Research- and Education Department

5a. The project will be executed (partly) outside The Netherlands, namely in:
Šumava Mountains National Park, Czech Republic

b. Does the project aim at co-operation with developing countries? NO

6a ANIMAL EXPERIMENTS: will vertebrates be used? NO

6b Does the project involve biotechnological research NO

7. PARTICIPANTS PROJECTGROUP AND ESTIMATED TIME INVOLVED

Name + title of the PhD student (if already available)	male/female	Nationality
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Msc. Lucia Yanez	female	Spanish
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Period of appointment: from: 2007/October/15 to: 2011/October/15 for 40 hours/week
(Year/month/day)

Kind of Appointment: Research assistant employed at WU:
1.3 Funding by a third party

	NAME AND TITLE	ORGANISATION	HOURS/WEEK
Promotor(s):	Prof. Dr. sc. nat. M.E. (Michael) Schaepman	WUR	1
Co-promotor(s):	Dr. Z. (Zbynek) Malenovsky	WUR / ISBE*	2
	Dr. ir. J.G.P.W. (Jan) Clevers	WUR	2

(* Institute of Systems Biology and Ecology, Academy of Sciences of the Czech Republic.

Financial source(s):

(in case of NWO: please mention NWO-foundation i.e. WOTRO, STW, ALW)

(in case of EU: please mention EU-programme and number)

HYPER-I-NET Marie Curie Research Training Network (MC-RTN) (MRTN-CT-2006-035927)

Is the financial support (on behalf of 3rd money stream PhD-students also education budget) and equipment sufficient to carry out the research?

YES

If no, please indicate the reason why!

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8. COLLABORATION: with which organisations outside the University will collaboration take place?

The Netherlands: other Universities :
 research institutes, experimental stations :
 Ministries, other organisations :

International organisations such as FAO, WHO:

Foreign universities and organisations: Academy of Sciences of the Czech Republic
 Alcala University, Madrid, Spain.

9. SUMMARY OF PROBLEM DESCRIPTION AND OBJECTIVES

Massive bark beetle outbreaks in needle-leaf forests during last decades have caused a gradual forest degradation of large spatial extent. Methods for mapping potential pest spread and for early stage detection of the infestations are highly demanded to prevent the outbreaks. Optical remote sensing (RS) may spatially locate early disturbances by efficient detection of biochemical processes accompanying the early post-attack stress reaction of trees. RS may as well propose the areas with high risk of bark beetle attack by assessing the general physiological state of trees. Imaging spectroscopy combined with radiative transfer modelling at the appropriate scale has proven to be a suitable tool for state monitoring of coniferous forest stands. However, an appropriate parameterization and the assumptions of canopy reflectance models, especially concerning the influence of forest structure on up-scaling the leaf properties to canopy level, are still an issue of scientific questioning and investigation. The objective of this research is to use coupled radiative transfer models to develop an inversion routine for the retrieval of quantitative forest canopy biochemical parameters (water content and chlorophyll concentration) based on imaging spectroscopy data. The estimation of biochemicals will focus on monitoring Norway spruce physiological status for early detection of bark beetle infestations and for infestation risk assessment.

10. OBJECTIVES

a. History (please, literature references in an appendix)

Impact of insect disturbance in forest ecosystems

Forests are being inherently changed through continuous and long-time succession development, but also through discontinuous, occasional, and sudden natural or human-induced disturbances (Wulder and Franklin 2007). Particularly in the last decades, forest ecosystems are under increasing pressure from environmental stressors such as human population, growth or climatic changes (global warming) increasing the frequency of wildfires, forest insect outbreaks, and diseases (Goodenough, Li et al. 2006). Increasing international concern towards sustainable forest management policies and conservation strategies is promoting the development of new techniques for monitoring progress and effects of such disturbance processes on forest ecosystems.

Biotic disturbances can have a major influence on the composition, structure, and dynamics of forest ecosystems (Wulder and Franklin 2007). Many forest pests at endemic population levels selectively eliminate the least vigorous individuals without causing major changes in forest composition or structure. However, forest insect epidemics can have severe impacts on ecosystem dynamics by causing mortality and reducing the growth of millions of trees over extensive forest areas (Kurz, Dymond et al. 2008). Beyond the ecological impacts, there are some important economic and social effects associated with such intensive forest disturbances.

Massive insect outbreaks of the last decade are leaving behind a gradual forest degradation of large spatial patterns difficult to control (Lieutier 2004; Wulder, Dymond et al. 2006). The colonization of such infestations seems to be spreading into new geographic areas with the expansion believed to be related to changes in climate (Hódar and Zamora 2004; Wulder, White et al. 2008). Change in temperature has been shown to influence the winter survival of insects and many areas, which are presently protected by low winter temperatures, will be most probably susceptible to attacks (Wolf, Kozlov et al. 2008). Some recent studies have emphasized the importance of considering the impact of disturbances by insects on carbon dynamics and global climate modelling (Cook, Bolstad et al. 2008; Kurz, Dymond et al. 2008). In North America, increasing disturbance levels of the mountain pine beetle population (*Dendroctonus ponderosae*) has been documented in the last decade. In western Canada, the areas of infested forest increased from 164,000 ha in 1999 to 8.5 million ha in 2005, and by 2006 the area impacted had increased to 9.2 million ha (Westfall 2007). It is estimated that by 2013, 80% of the mature pine in British Columbia will be killed by the bark beetle (Wulder, White et al. 2008). In the United States, the area affected by the same insect increased from a total of approximately 156,090 ha in 1999 to 898,040 ha in 2003 (Wulder, Dymond et al. 2006).

In Europe, the devastating effect of insect outbreaks is also recognized (Jonášová and Prach 2004; Lieutier 2004). As an example, a spatially large disturbance of Norway spruce forests can be found in Central Europe resulting from the bark beetle (*Ips typographus* [L.]) pest. Outbreaks occurred after severe storms taking place in the 1990s. The spread of the infestation started in the Bavarian Forest National Park (Germany) in the late 1980s and propagated to the Šumava Mountains National Park (Czech Republic) in the 1990s. In 2001 the extension of damaged Norway Spruce forest in the region was around 3620 ha (Zemek and Heřman 2001; Jonášová and Matejková 2007; Hais and Kucera 2008). The outbreaks are still gradually occurring almost every year. Thus, early stage monitoring and potential prevention of these events is being the reason of important investments and the motivation for this research. A particular region of Norway spruce forest at the Šumava Mountains National Park has been proposed as study area of this research project.

Remote sensing of insect infestations

Currently, several governmental agencies are focusing their efforts on developing new technologies to detect, monitor and control outbreaks of insect pests. Due to the quick spread and devastating effects of such outbreaks, tools for risk assessment and early stage detection are highly demanded. Optical remote sensing (RS) may have the potential to spatially locate insect infestations by detecting biochemical processes occurring before and after the disturbance. Successful detection and quantification of biochemical parameters by means of RS will depend mainly on: (i) changes of plant spectral characteristics induced by the different stages of the infestation, (ii) the resolution of the sensors used, (iii) the specific methods applied for biochemical parameter estimation, and (iv) the translation of such biochemical responses into insect infestation damage levels.

Plant spectral characteristics of bark beetle infestation

The reaction of plants to stress impacts, such as insect infestations, involves changes in leaf physiology, chemistry, and photosynthetic efficiency that affect their reflectance response (Lawrence and Labus 2003). Stressed leaves tend to reduce photosynthetic activity and chlorophyll content, altering reflectance patterns in the visible and near-infrared (NIR) spectrum (Horler, Dockray et al. 1983; Pontius, Hallett et al. 2005). Also water stress induced by disturbances produces direct spectral changes in the near infrared and short-wave infrared wavelengths (1300 to 2500 nm) (Ceccato, Flasse et al. 2001; Sims and Gamon 2003; Clevers, Kooistra et al. 2008).

Similarly to previous mountain bark beetle (Wulder, Dymond et al. 2006) and Douglas-fir beetle studies (Lawrence and Labus 2003), Norway spruce bark beetle attacked trees can be clustered into 4 tree health classes: (i) non-attacked and healthy; (ii) non-attacked but stressed; (iii) attacked and (iv) dead. The first and second category is related to trees with no sign of beetle infestation. In (i) neither bark beetle nor other damage is detected. In (ii), however, symptoms of stress caused by other impacts are detectable. This difference becomes important for the purpose of risk assessment by means of RS. Although the dynamics of bark beetle (*Ips typographus* [L.]) outbreaks are not fully understood, tree susceptibility plays a major role when a beetle population is at the endemic level. Vital trees possess defence mechanisms at several levels to prevent attacking bark beetles from successfully establishing broods. Thus, tree stress and vigor are important factors that may affect primary host selection by bark beetle species, weakened and decadent trees being preferred (Wermelinger 2004). In this case, monitoring of general tree physiological status through RS might give an opportunity for risk assessment studies. Nevertheless, it was observed that at the epidemic level the bark beetles also attack trees of high vigor.

Once the infestation is taking place, the initial phase of bark beetle attack is such that an infected tree presents evidence of beetle infestation in the bark, but there are no apparent visual symptoms detectable at the canopy level. This phase is what we refer to here as “attacked”, analogue to the “green attack” described by (Wulder, White et al. 2007) for mountain pine beetle. The tree is still physiologically alive and the crown remains green with no visual signs of decline. However, due to the infestation, trees will likely experience a progressively severe water stress caused by xylem disruption (Niemann and Visintini 2004). This effect will induce direct spectral changes in the near infrared and short-wave infrared wavelengths that might be detectable through optical sensors with the appropriate resolution. Thus, RS might have the potential to spatially detect such tree reactions of early post-attack stress. It should be noted, though, that a possible offset from the early stress detection in some conifer species is given by their ability to store water in their sapwood to be used by the tree to cope with an extended period of drought. In addition, conifer needles have developed anatomical structures to minimize water loss, protect the photosynthetic system from absorption of excess energy, and deal with

freezing temperatures. As a result, visible water-stress symptoms in tree foliage could be retarded for many weeks or even months. This has important implications for RS detection of trees in green attack stages. It is possible that during the green attack stage, changes in foliar optical properties do not exceed the natural range of variation of healthy vegetation (Niemann and Visintini 2004). Category (iv) denotes a successful and advanced beetle infestation stage. The defences of the tree have been overcome by the beetles and the progress of the infestation is evidenced by a quick foliage discolouration and progressive defoliation. This phase is comparable to the “red-attack” described by (Wulder, White et al. 2008) and at this stage changes in the spectral response are evident.

Traditionally the detection of insect infestation through RS has been focus in the use of known stress- (particularly water stress and moisture) and chlorophyll-sensitive indices to predict the different decline phases of affected trees (Wulder, Dymond et al. 2006; White, Coops et al. 2007). However few studies have focused on early stage detection analysis (Lawrence and Labus 2003; Pontius, Hallett et al. 2005) compared to those focused on advanced stages of infestation. Thus, the objective of the present study is to develop a methodology to retrieve biochemical parameters like water content and chlorophyll concentration to improve early stage detection of bark beetle infestations as well as monitoring of the general physiological status of trees previous to a potential attack.

The resolution of the sensor: spatial and spectral scale

Optical sensor specifications such as the spectral and spatial resolution play as well a role in the estimation of biochemical parameters like water content or chlorophyll concentration. Spatial resolution of an optical sensor refers to the smallest parts of an object that the sensor can distinguish, which is the pixel size of the RS image (Dungan 2001). The spectral resolution is related to the ability of an optical sensor to discriminate fine spectral differences or to its capability to construct a continuous reflectance spectrum. Changes in reflectance response of plants could be subtle and thus not detectable by a sensor with low spectral resolution. At the same time, the capability to detect such changes at a canopy/ sub-canopy level requires a high enough spatial resolution.

Typical methods of forest reconnaissance to detect infestations include analysis of multispectral imagery. However, multispectral data often lack the sensitivity to detect subtle changes in tree canopy reflectance accompanying early signs of plant stress. Multispectral imagery has been shown to be appropriate for advanced stages of infestation, when evident signs of stress and desiccation or defoliation are taking place within the stands (Wulder, White et al. 2007). In this situation, the use of RS data allows the location of the infestation spots over large areas more quickly and efficiently than by ground observations. This is particularly important in terms of inaccessibility of certain forested areas and to organize a rapid response for the ground based teams. Conversely, monitoring general physiological status of trees for infestation risk assessment purposes or detecting early stages of attack is more difficult and elusive, particularly for such multispectral data (Niemann and Visintini 2004).

Imaging spectroscopy data, in contrast to multispectral data, contain a high number of narrow spectral bands. Moreover, they can be acquired from several oblique viewing angles and with a higher revisit frequency by means of modern satellite systems (e.g. spectrometer CHRIS on satellite PROBA). The use of imaging spectrometry, also known as hyperspectral RS, has enlarged the possibilities for RS applications in relation to the spectral domain. Thus, imaging spectroscopy data of very high spatial and spectral resolution can increase the potential to detect not only early stages of infestation at tree level/sub-canopy level, but also to assess potential spread of pests from centers of small infestation, thereby aiding mitigation and control efforts (White, Coops et al. 2007). For that purpose, the present project will focus on the use of very high spatial and spectral resolution imaging spectroscopy data acquired by the Airborne Imaging Spectroradiometer AISA.

Quantitative methods for biochemical parameter estimation

A number of methods based on (i) empirical algorithms and (ii) physically-based canopy models have been proposed to retrieve canopy biochemical indicators from imaging spectroscopy. The first group consists of regression equations (linear or non linear) established on the correlation between the spectral signature and the measured biophysical or biochemical properties of the canopy. The physical-based canopy models are able to simulate the cause-and-effect relationships. They specify the relation between the biophysical/biochemical variable of interest and the canopy leaving radiation field based on physical laws (Liang 2004; Liang 2007).

Many studies have demonstrated the capability of imaging spectroscopy to retrieve vegetation water content and canopy biochemistry by means of empirical approaches (Cho and Skidmore 2006; Gitelson, Keydan et al. 2006; Clevers, Kooistra et al. 2008) or canopy reflectance models (Kötz, Schaepman et al. 2004; Colombo, Meroni et al. 2008; Malenovsky, Homolová et al. 2008; Moorthy, Miller et al. 2008; Trombetti, Riaño et al. 2008; Zhang, Chen et al. 2008). In the field of insect infestation assessment, not much work using quantitative imaging spectroscopy has been published. The analyses used have been mostly restricted to empirical methods (Lawrence and Labus 2003; Pontius, Hallett et al. 2005; White, Wulder et al. 2005; White, Coops et al. 2007; Pontius, Martin et al. 2008). Physically based methods are the only methods that can use the versatile hyperspectral and multi-angular information provided by the modern satellite sensors (Stenberg, Möttus et al. 2008) and so they are more universal and flexible compared to the empirical approaches. Therefore, they have become more attractive for the assessment and monitoring of biophysical and biochemical characteristics of vegetation. However, they require a higher number of input parameters and variables and their development is quite time demanding.

Physically based canopy reflectance models are parameterized using mathematical descriptions of canopy structure together with optical properties of the plant elements and the underlying surface to produce spectral signatures of canopy leaving reflectance. The spectral composition of a canopy reflectance signature depends on the resolution of the measurement (i.e., pixel size), which needs to be considered when defining the spatial scale of the model (Stenberg, Möttus et al. 2008). The final retrieval of the parameter of interest is done through model inversion. For coniferous forests, like Norway spruce, the description of the canopy is quite challenging because of their complex and highly heterogeneous structure (Widłowski, Taberner et al. 2007). Thus, the canopy model must be able to offer an appropriate representation of details as well as an adequate parameterization of the structural heterogeneity of the forest ecosystem (Malenovský 2006). Currently, the main challenges in assessing the biochemical parameters at canopy levels by inverting canopy reflectance models in needle-leaf forests include proper estimates of clumping of the vegetation at various scale levels, proper separation of understory and overstory vegetation (Rautiainen, Suomalainen et al. 2007), as well as the separation of the canopy in photosynthetic and non-photosynthetic (litter, stems, branches, etc) components (Malenovský, Martin et al. 2008). A common approach for the retrieval of biochemical parameters by means of canopy reflectance models is to couple a leaf radiative transfer model and a canopy model, which allows the scaling of optical characteristics from leaf up to canopy level (Kötz, Schaepman et al. 2004; Riaño, Vaughan et al. 2005; Colombo, Meroni et al. 2008; Lauvernet, Baret et al. 2008; Malenovský, Homolová et al. 2008; Trombetti, Riaño et al. 2008).

As a final summary of all mentioned improvements and challenges presented in the field of insect infestation monitoring and quantitative imaging spectroscopy techniques, the ideas that have led to the development of this project proposal and to the objectives of this research are the following:

1. Early stages of infestation detection and risk assessment techniques are highly demanded and few publications have been presented in the field of advanced quantitative remote sensing methods.
2. Imaging spectroscopy allows not only direct identification of vegetation stress but also a quantitative estimation and monitoring of plant stress indicators. Combination of these continuous indicators, retrieved from data acquired by imaging spectrometers, can be used to assess the overall vegetation physiological status.
3. Canopy radiative transfer models include structural information influencing canopy reflectance and they are more universal than biochemical parameter estimations through empirical methods. Such models have not been applied so far in insect outbreaks studies.

Therefore, the use of coupled radiative transfer models to develop an inversion routine for the retrieval of quantitative forest canopy biochemical parameters (water content and chlorophyll concentration) based on imaging spectroscopy data might improve the early detection of bark beetle infestation and potentially allow risk assessment studies on Norway spruce heterogeneous canopies.

b. Problem definition

Massive bark beetle outbreaks in needle-leaf forests during last decades have caused a gradual forest degradation of large spatial extent. Methods for mapping potential pest spread and for early stage detection of the infestations are highly demanded to prevent the outbreaks. Optical remote sensing (RS) may spatially locate early disturbances by efficient detection of biochemical processes accompanying the early post-attack stress reaction of trees. RS may as well propose the areas with high risk of bark beetle attack by assessing the general physiological state of trees. Imaging spectroscopy combined with radiative transfer modelling at the appropriate scale has proven to be a suitable tool for state monitoring of coniferous forest stands. However, the modelling assumptions and an appropriate parameterization of canopy reflectance models, especially in relation to the influence of forest structure on up-scaling the leaf properties to canopy level, are still an issue of scientific questioning and investigation.

Based on the problem definition described above, the objectives of this research can be summarized in the following points:

1. Review of RS techniques applied to insect infestations with focus on bark beetle outbreaks and advanced quantitative, imaging spectroscopy based techniques.
2. Sensitivity analysis and performance tests of the leaf radiative transfer model PROSPECT (the latest version 4 /5) (Feret, François et al. 2008) for Norway spruce needles as a first step for the up-scaling methodology for biochemical parameter retrieval, with particular focus on canopy water content.
3. Analysis of the variability in optical properties of (young) Norway spruce trees under controlled water stress conditions at leaf and canopy level.
4. Development of a physically-based methodology using coupled radiative transfer models for up-scaling water content conditions from Norway spruce needles to canopies.
5. Generation of continuous fields of Norway spruce physiological status through the combination of water content estimation and existing chlorophyll concentration retrieval techniques (Malenovský 2006). Subsequent generation of a bark beetle-propagation risk map for forestry applications. In already infected areas, mapping of early stage damage trees will be generated.

The following research questions are formulated linked to each of the objectives presented above:

- A. What is the state-of-art of optical RS approaches applied to insect pests monitoring?
- B. To what extent can the leaf model PROSPECT (version 4 and 5) simulate leaf optical properties of Norway spruce needles taking into account recent advances in calibration of the model?
- C. How is water stress influencing Norway spruce leaf and canopy optical properties?
- D. How can water stress be retrieved at canopy level using radiative transfer modelling in heterogeneous Norway spruce canopies?
- E. Can leaf water content be used as a bio-indicator for the assessment of the general physiological state of Norway spruce canopies before and during early stages of bark beetle infestations?

The novelty of this work can be summarized in four different domains:

1. Update of the leaf radiative transfer model PROSPECT (4 and 5) for Norway spruce needles, previously not existing.
2. Development of a physical-based methodology for water content estimation using a very high resolution 3D radiative transfer model for heterogeneous Norway spruce canopies taking into account geometrical, optical and structural variation of the canopy within individual crowns.
3. Combination of an existing chlorophyll content retrieval methodology (Malenovský 2006) with the methodology for water content estimation to assess the risk of Norway spruce bark beetle attacks and early stages of infestation.
4. Generating various continuous fields maps of forest structural, biochemical and biophysical parameters.

c. Methodology

A flowchart of the main steps concerning the methodology is presented in Figure 1. The following points present more detailed information about each step planned to be done during the research to fulfil the objectives.

1. Field campaign over the study area of Šumava Mountains (Czech Republic) for sample collection of Norway spruce needles and subsequent measurement of optical properties with an imaging spectrometer device coupled to an integrated sphere as well as extraction of pigment concentration, dry matter and water thickness inside the needles. For details about protocols see (Malenovský, Albrechtová et al. 2006).
2. Optical properties data processing including calculation of gap fraction between needles produced by the needles carrier used to measure reflectance and transmittance with the integrated sphere.
3. Sensitivity analysis of the existing leaf radiative transfer model PROSPECT version 4 and 5 for Norway Spruce (Feret, François et al. 2008). The methodology will be based on the one applied by (Malenovský, Albrechtová et al. 2006) to PROSPECT version 3.0 but extended to the SWIR range of the spectrum. If needed, a subsequent adaptation and validation of a re-calibrated version for Norway spruce needles will be performed
4. Monitoring variability of young spruce leaf and canopy optical properties when different water supply regimens are applied: a decreasing gradient of water supply will be applied and the progressive water stress effects analyzed. The environment where the trees are growing will be controlled (light, water). The measurements will be done using a field spectroradiometer located above the canopies.
5. Flight campaign flying imaging spectrometer AISA dual and a thermal camera over the study area of Šumava Mountains, and simultaneous ground truth data collection for validation of the hyperspectral images at the beginning of the bark beetle flying season (May 2009).
6. Second flight campaign over the same area at the end of the season (September 2009).
7. Data processing (atmospheric correction and geo-referencing of image data) using MODTRAN/ or ATCOR and ENVI image processing software.
8. Parameterization of DART 3D canopy radiative transfer model based on the methodology of (Malenovský 2006).
9. Sensitivity analysis and development of canopy water content retrieval methodology by means of inversion of the coupled leaf-canopy radiative transfer models PROSPECT-DART and the continuum removal approach (Curran, Dungan et al. 2001).
10. Combination of chlorophyll and water content retrieval for physiological status monitoring of Norway spruce.
11. Reproduction of a canopy chlorophyll concentration continuous map as well as a water content status continuous map of the study area from both the data collected during May 2009 and September 2009.
12. Translation of the previous map into a bark beetle-propagation risk map establishing different ranges of risk. Validation of results with the remote sensing data collected during the second flight campaign at the end of season 2009, where the attacked trees can be detected and their physiological status compared to the conditions they presented before being attacked. In already infected areas, mapping of early stage damage trees will be generated.

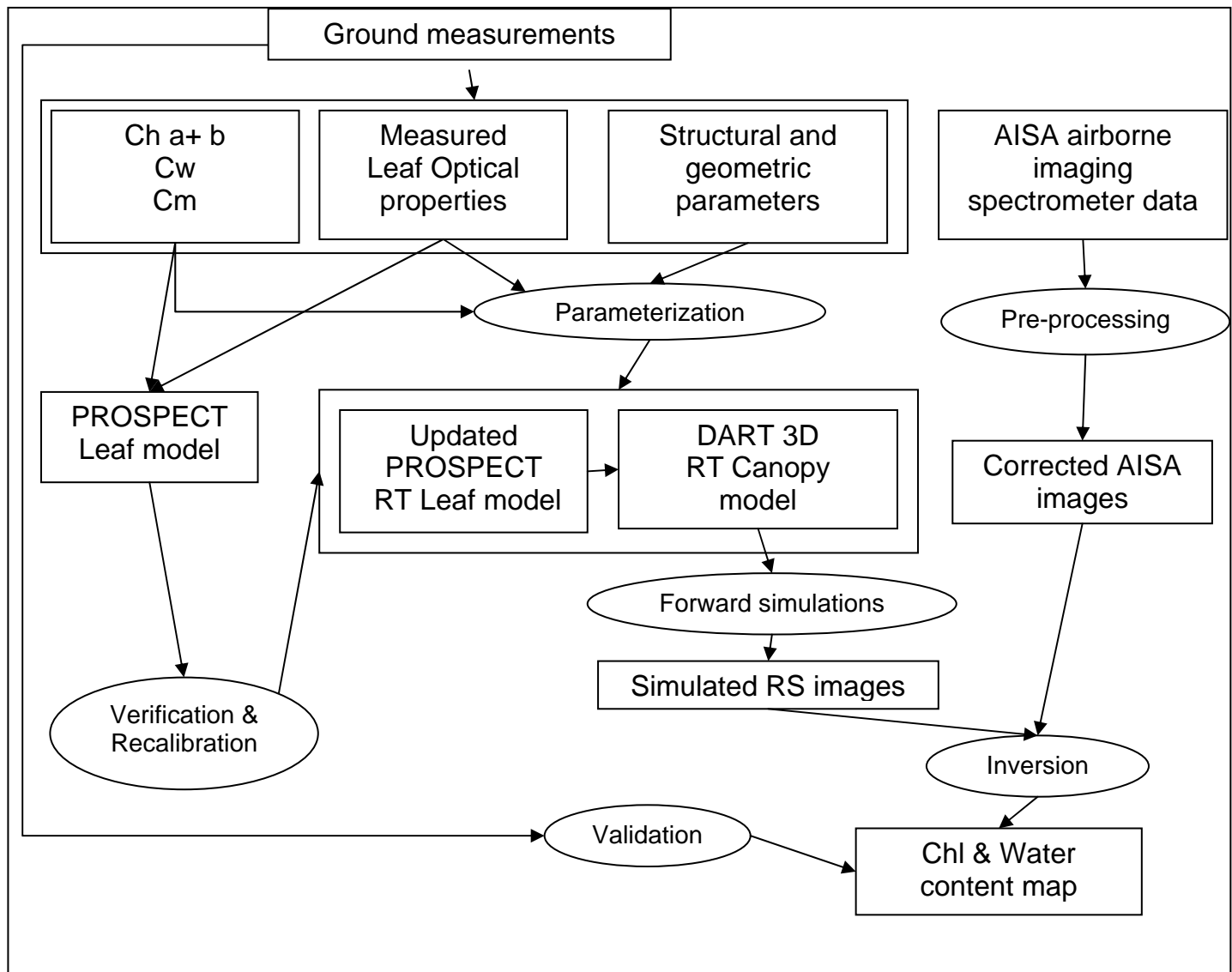


Figure 1. Methodology. RT: radiative transfer; Ch a+b refers to Chlorophyll concentration [$\mu\text{g}/\text{cm}^2$]; Cw: Water thickness [cm]; Cm: Dry matter content [g/cm^2].

11. FEASIBILITY

a. How is adequate supervision guaranteed?

Members of the department(s) or institute(s) involved that will supervise the PhD student and their roles

Principal Supervisor (Prof) (Promotor) Michael Schaepman

Daily Supervisor(s) (1) Jan Clevers; (2) Zbynek Malenovsky

If during the project period changes will occur in the project team, in what way will supervision be continued?

There will be changes in the location of the promotor of the project but the supervision team will not change: Michael Schaepman will become the Hyper-I-Net responsible for the Swiss contribution, Zbynek Malenovsky will be appointed also in Switzerland during the project.

b. How is execution of the project guaranteed

Available knowledge and know how within the project group:

Knowledge about the remote sensing related work with focus on imagery spectroscopy, radiative transfer models, field and flight campaigns, data processing, up-scaling methodology, and biochemical and biophysical parameters retrieval approaches is located at the Centre for Geo-information at WUR including supervision team (Michael Schaepman, Jan Clevers and Zbynek Malenovsky). More specific knowledge about the study area and the biology of the outbreak and non-invasive bark beetle attacks is located at the Academy of Sciences in Czech Republic (Pavel Cudlín).

remote sensing of forests workshop													
2nd HYPER-I-NET summer school													
2ND YEAR Oct 2008 to Oct 2009	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Recalibration PROSPECT radiative transfer model													
Recalibration PROSPECT scientific paper writing													
Preparation Flight campaign over study area													
Flight campaign over study area													
Laboratory experiment of water stress development													
<u>PhD courses</u>													
Techniques for writing and presenting Scientific papers													
Presentation Skills													
e-learning courses HYPER-I-NET													
Multivariate analysis													
<u>Conferences/workshops</u>													
Preparation 6th EARSeL SIG IS conference contribution (Israel)													
6th EARSeL SIG IS conference (Israel)													
Preparation IEEE International Geoscience and Remote Sensing Symposium, (South Africa)													
IEEE International Geoscience and Remote Sensing Symposium (South Africa)													

Colour Legend:

	Done so far
	Planned

b. A rough work plan for the second part of the project (including finishing and defence of the thesis).

- October 2009 to April 2010: finishing analysis of water stress experiment and writing paper. Attendance to 3rd HYPERINET summer school (Germany, October 2009).
- May 2010 to December 2010: working on the up-scaling methodology. Processing of the image data, and parameterization of DART model. Contribution in an international conference (IGARSS 2010).
- January 2011 to April 2011: water content retrieval methodology and writing paper.
- April 2011 to October 201: Writing and defending PhD thesis.

13. All requirements (personnel and equipment) are available and/ or arranged

YES

14. SIGNATURE

Chairman of the Research Group
Name:

Project leader
Name:

Signature:

Signature:

|

15. APPENDIX: REFERENCES

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