ENGO 697

Remote Sensing Systems and Advanced Analytics

session 1

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Outline

- ➔ Introduction to get to know each other
- ➔ Course overview
- ➔ Learning outcomes and expectations
- ➔ Questions

Key Research Areas

CHINA UNIVERSITY OF GEOSCIENCES

UNIVERSITY OF WATERLOO | FACULTY OF ENVIRONMENT Department of Geography and Environmental Management

WATERLOO ENGINEERING

Academic background: **Geomatics Engineering**, **Computer Science**, **Remote Sensing, Machine Learning**, & **Geograph**

2003 – 2010: *Undergraduate & master* in China University of Geosciences (CUGB)
2010 – 2016: *PhD & postdoc* in Geography & Engineering, University of Waterloo (UW).
2016 – 2018: *Associate Professor* in CUGB
2018 – now: *Research Assistant Professor*, Systems Design Engineering (SYDE), UW

Linlin Xu
University of Waterloo
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AI & machine learning Hyperspectral LiDAR SAR Environmental monitoring Geospatial data science

Cited by VIEW ALL

	All	Since 2019
Citations	1907	1593
h-index	23	20
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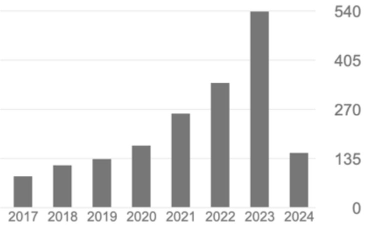


Secured Funds as PI or Co-PI:

1. **NSERC DG (2019 – 2026), PI**
2. **MITACS (2024 – 2027), PI**
3. *CSA-ROSS (2024 – 2027), Co-PI*
4. *NSERC Alliance Option 2 (2022 – 2025), Co-PI*
5. *MITACS with SkyWatch (2023 – 2025), Co-PI*
6. OCI with SkyWatch (2022 – 2024), Co-Applicar
7. MITACS with AtlasAI (2019 – 2021), Co-PI
8. NFSC (2016 – 2019), PI

How to harness cutting-edge AI and advanced Remote Sensing techniques to advance Environmental Studies

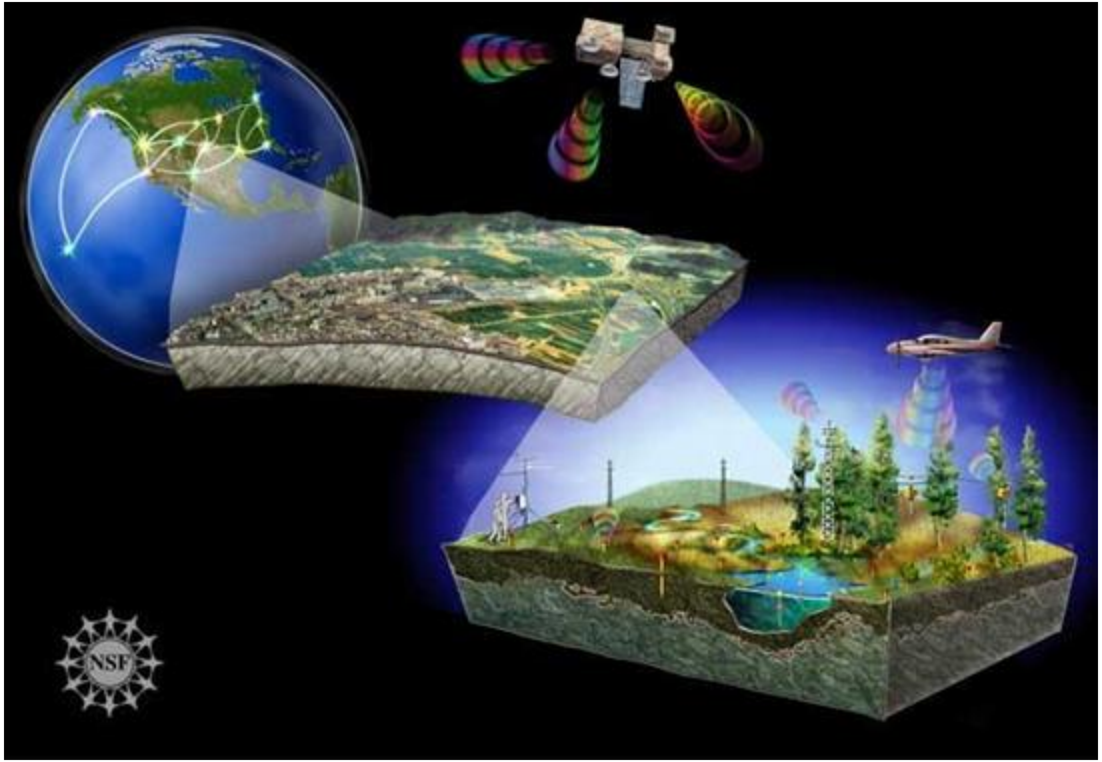
1. Hyperspectral, LiDAR, Visible Mapping of Urban and Land Use Environment, *e.g., buildings, vegetation, crop, forestry, and soil.*

2. SAR, Passive Microwave, Infrared & Visible mapping of Pan-Arctic Environment, *e.g., ice, water, Arctic species*

3. AI-powered Integrated Remote Sensing Analytics, *e.g., geospatial data science, machine learning and deep learning, spatial spectral analysis*

I have secured several ***competitive research funds (e.g., NSERC DG)***, published ***a total of 75 journal papers*** and ***a total of 45 conference articles*** on high-impact remote sensing journals and conferences; created ***software systems and solutions*** that ***benefit government agencies, indigenous communities, and Canadian industries***.

Remote Sensing: An Essential Tool for Environmental Monitoring and Management



(Credit: Nicolle Rager Fuller, NSF, USA).

Remote sensing is an essential tool to ***estimate key environmental variables*** in various applications, such as

---- ***Crop/tree*** status monitoring and assessment

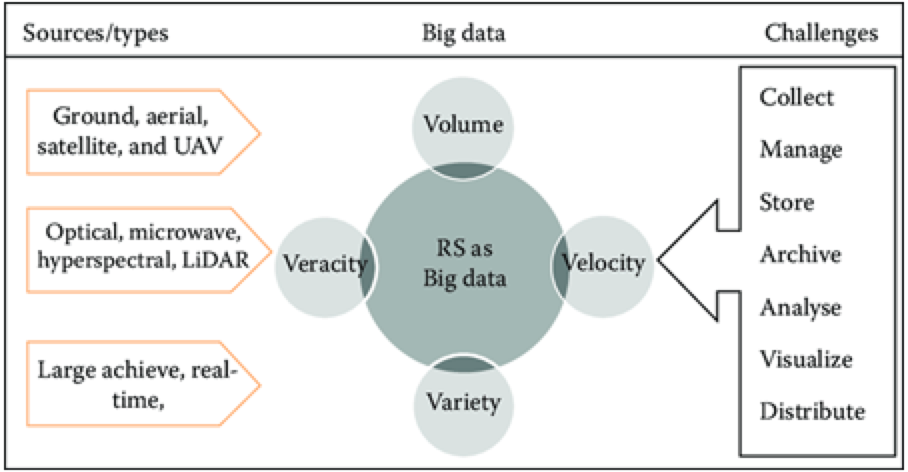
---- ***Water*** and ***air*** pollution monitoring

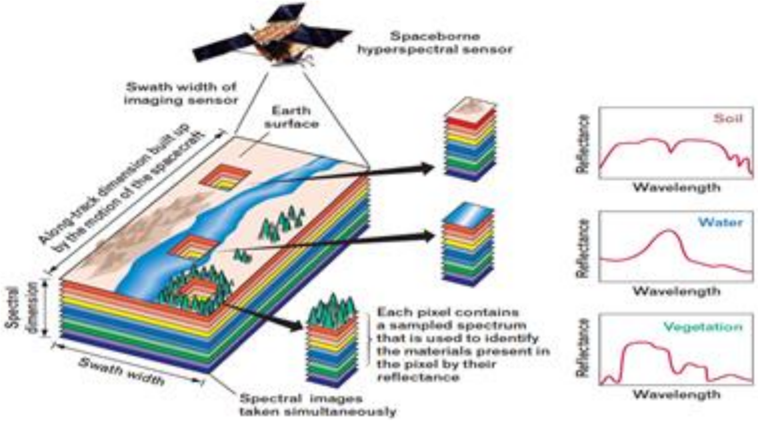
---- ***Ice, snow and glacier*** monitoring

---- ***Soil*** pollution management

With its ability to derive key ***environmental variables*** (e.g., *biochemical/biophysical parameters, soil heavy metal content*, *water nutrient content*), Remote Sensing empowers decision-makers to make informed choices and implement effective environmental management strategies.

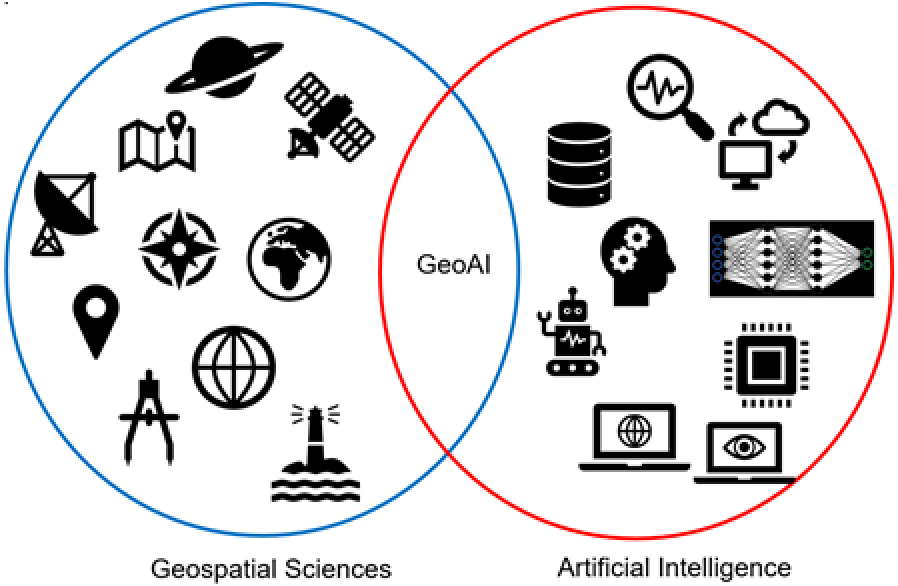
Big Remote Sensing Data -> Opportunities & Challenges





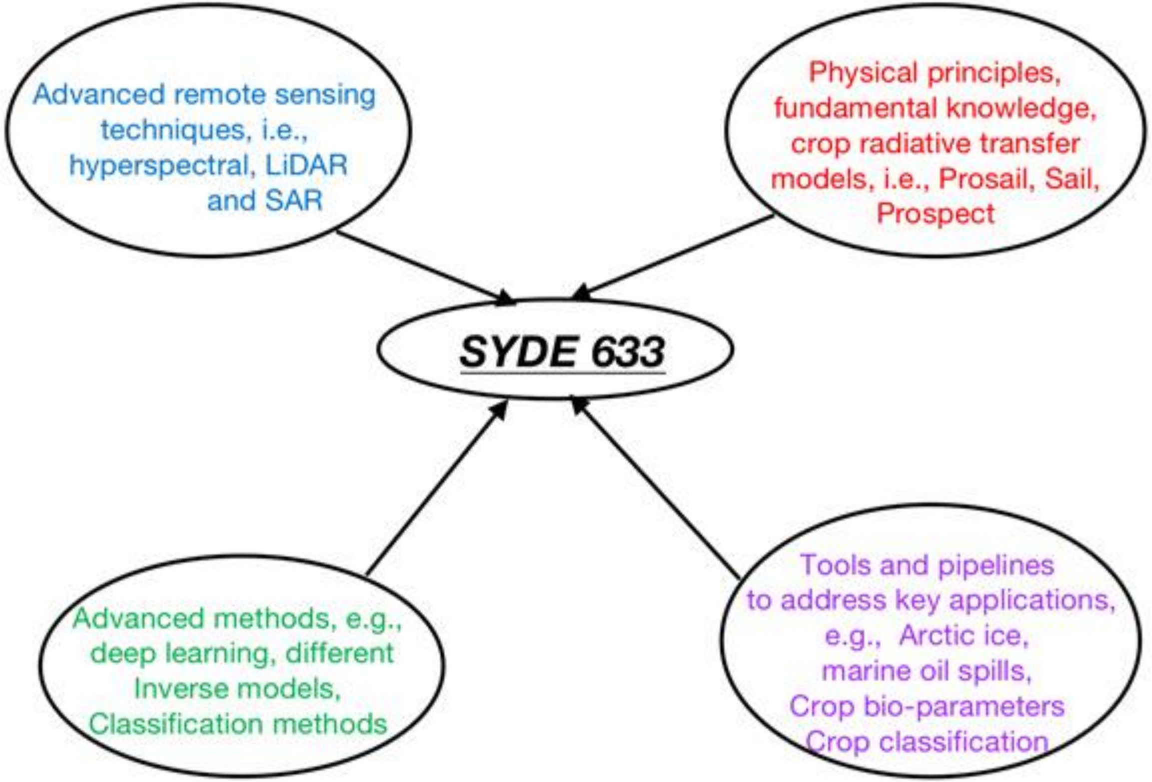
Images from markelowitz.com and GeoAI lab

The environmental application of the ***big and ever-increasing remote sensing (RS) data*** tends to be ***bottlenecked by*** the limited ability of ***Geospatial data analytics*** to effectively transform the ***data*** into value-added ***information***.



➔ ***GeoAI = Geospatial data science in the AI era***

Course Description

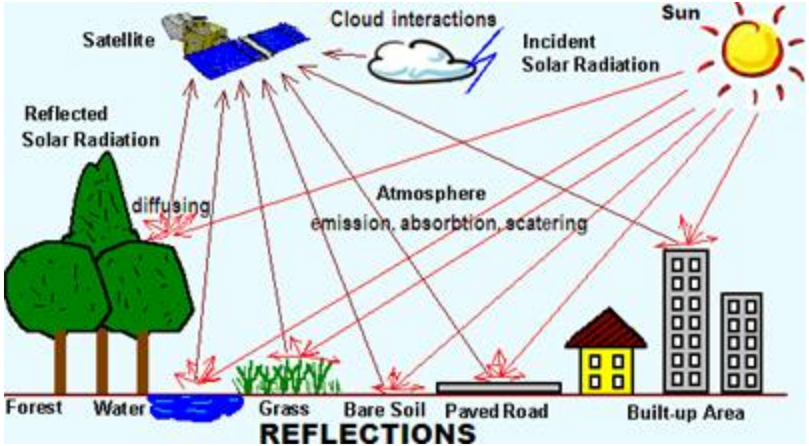


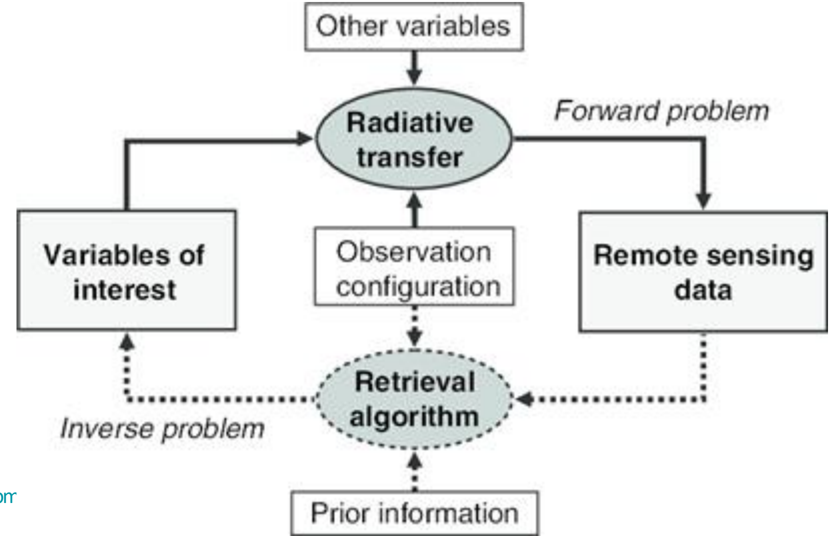
This course introduces advanced remote sensing techniques, physical and quantitative aspects and remote sensing, and advanced image processing and inverse modelling techniques to efficiently and accurately extract key environmental parameters from remote sensing images to better support different environmental and natural resource management applications.

Course Learning Goals:

- ➔ Understand fundamentals of different *remote sensing techniques*
- ➔ Understand the ***physical principles*** (i.e., radiative transfer models) underlying remote sensing systems.
- ➔ Develop expertise in applying ***appropriate image processing and data inversion techniques*** to extract environmental parameters in selected applications (*e.g., land cover classification, sea ice mapping, water pollution mapping, crop biochemical/biophysical parameter retrieval*).
- ➔ Evaluate ***uncertainties/errors*** in remote sensing systems and results.
- ➔ Learn to use standard remote sensing image processing *pipeline* and processing *tools*
- ➔ Develop *active learning and creative thinking* capability through project presentations and term paper

Theoretical Framework for Environmental Remote Sensing





Pictures from maps.unom

Forward model / radiative transfer model (RTM):

Y = f(X)

(1) Y: *remote sensing images* captured by the sensor

(2) X: *environmental variable* that you want to estimate, e.g., *crop chlorophyll content, leaf area index, ice concentration, class identity (e.g., diseased class)* etc.

How to characterize f(X)? Examples?

What are the uncertainties and assumptions in f(X)?

Inverse model:

X = g(Y)

What are the approaches to achieve g(.)? Their advantages and disadvantages?

In g(.), how to use all possible information sources, e.g., data, knowledge and prior information?

how to get the “best” g(.) to estimate X?

How to evaluate errors and uncertainties?

Key Questions:

(1) What are advanced representative remote sensing techniques?

(2) how to describe radiative transfer process in f(.)?

(3) What are typical examples of f(.)

(4) How to solve these f(.) to estimate X?

(5) How to solve these f(.) using deep learning approaches?

(6) How do we solve image classification using deep learning models.

(7) How to apply the learnt principles, methods and code to develop your own projects? How to promote discussion, collaboration and active learning?

Course Content:

Topic 1: Multi-/Hyper-spectral remote sensing
Topic 2: SAR and LiDAR remote sensing

Topic 3: - Radiation and radiative transfer equations in remote sensing systems
Topic 4 - Leaf and canopy radiative transfer models, Prospect, Sail, and Prosail

Topic 5: Approaches for solving inverse problems
Topic 6: Biochemical and biophysical parameter retrieval from PROSAIL model

Topic 7: Introduction to deep learning methods in remote sensing context
Topic 8: Solving PROSAIL model using deep learning approaches.

Topic 9: Deep learning classification of Arctic sea ice
Topic 10: Deep learning classification of hyperspectral images

Course project
Presentation 1: Presentation on the topics of course projects
Presentation 2: Presentation on the progress of course projects
Term paper

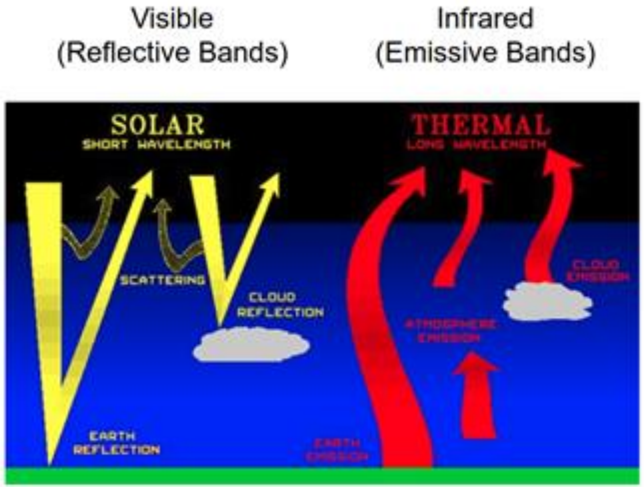
Tentative Schedule - SYDE 633 Winter 2024

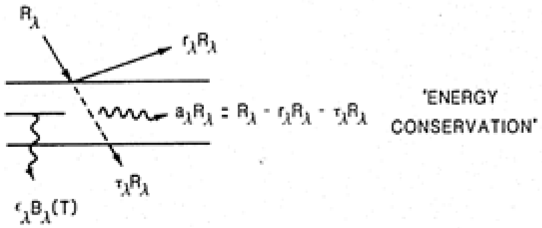
Lecture: Monday 11:30am – 12:50pm (E7 4437)
Wednesday 11:30am – 12:50pm (E7 4437)

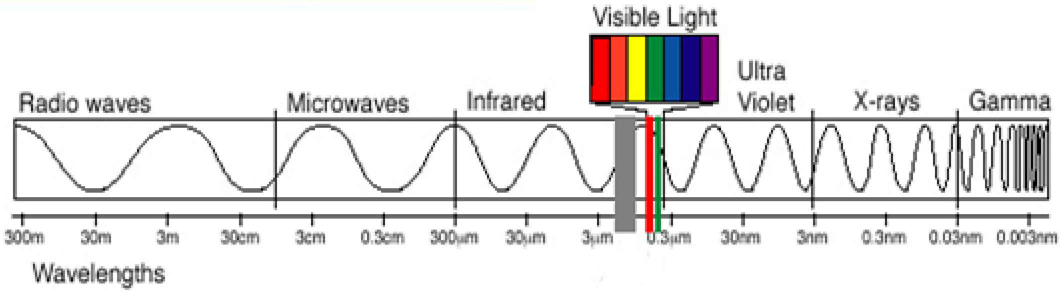
- Week 1 - Introduction
- Week 2 - Radiation and radiative transfer equations
- Week 3 - Microwave, Thermal, Lidar and Optical remote sensing
- Week 4 - Leaf and canopy radiative transfer models
- *Week 5 - Presentation of course project proposals*
- Week *6* - Approaches for solving inverse problems
- *Week 7 - No class due to reading week*
- Week 8 - Biochemical and biophysical parameter retrieval from PROSAIL model
- Week 9 - Introduction to deep learning methods
- Week *10.* Solving PROSAIL model using deep learning approaches
- Week 11 - Deep learning methods for Arctic sea ice classification
- Week 12 - Deep learning methods for hyperspectral image classification
- *Week 13 - Presentation of final projects*

- ***Week 14. Apr. 13 - Project papers due***

Week 2 - Radiation and radiative transfer equations







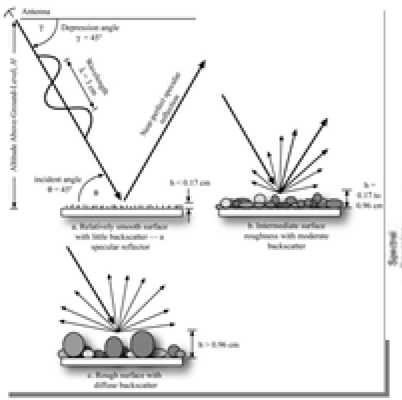
How to quantify and characterize radiation and radiative transfer process in remote sensing systems?

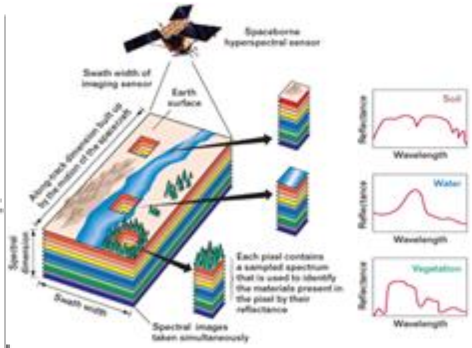
- Key concepts, e.g., Energy, flux, irradiance, radiance, brightness temperature
- Radiative transfer: e.g., emission, reflection, absorption, scattering
- Radiative transfer laws and equations: e.g., Planck's law, Wien's law, Stefan-Boltzmann Law, radiative transfer equation for earth-atmosphere system

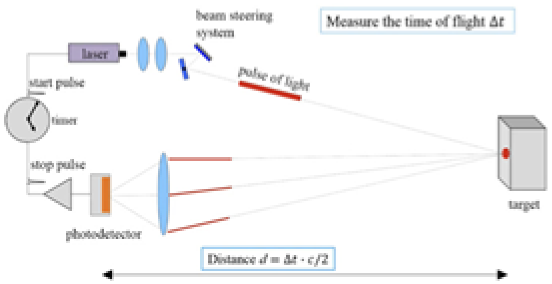
Picture from maps.unomaha.edu

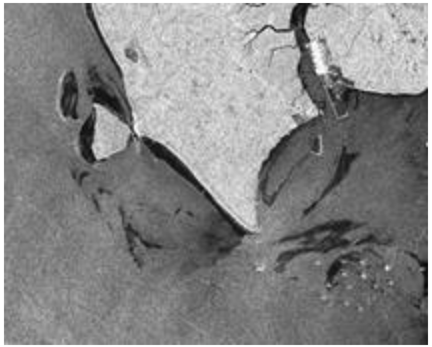
Week 3 - SAR, LiDAR and Multi/Hyperspectral remote sensing

- ***SAR system***, e.g., backscattering, influence of surface roughness, geometric distortions, polarization, incidence angle noise, speckle noise, SAR image processing, etc.
- ***Hyperspectral system***, e.g., pushbroom vs. snapshot, mixed pixel, noise, spectral unmxing and classification, other hyperspectral image processing tasks, etc.
- ***LiDAR system***, e.g., principle of LiDAR system, data collection, lidar data processing, etc.
- ***Applications***: e.g., SAR Arctic sea ice (marine oil spills) monitoring, hyperspectral crop mapping, airborne LiDAR tree classification, etc.

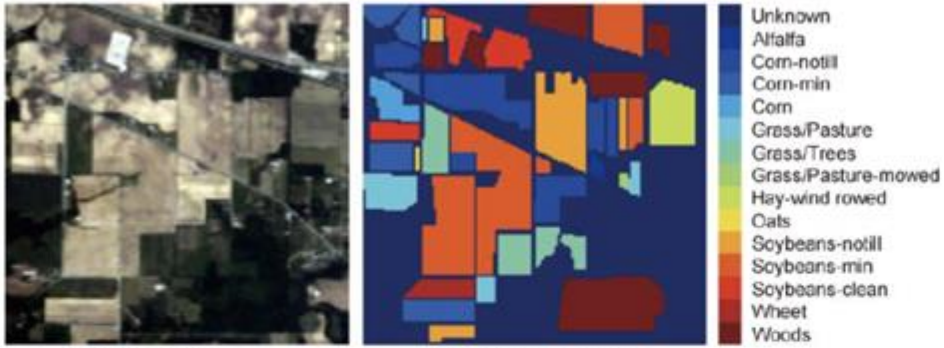








SAR images with ships and marine oils spills

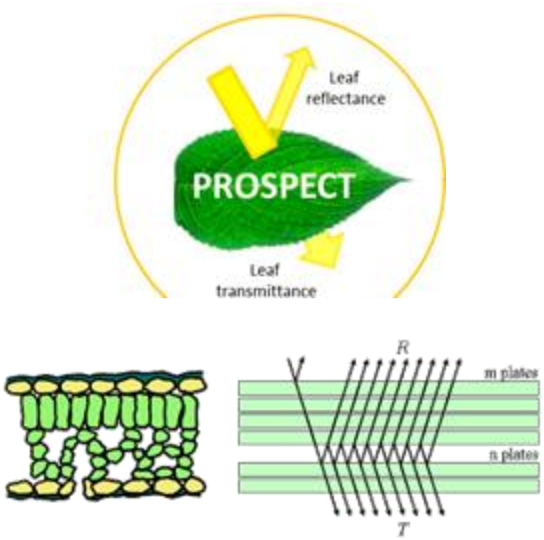


RGB image Y   Classification map X

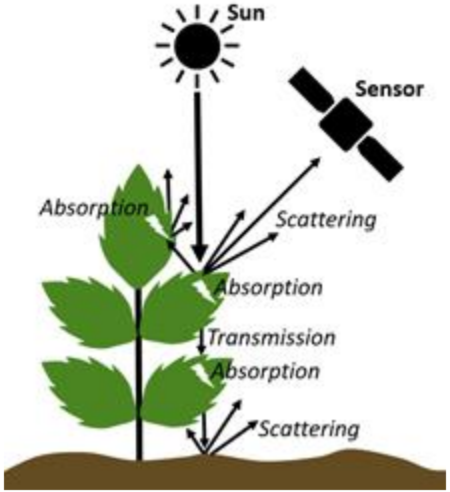
Pictures from markelowitz.com, Jensen 2008

Week 4 - Leaf and canopy radiative transfer models

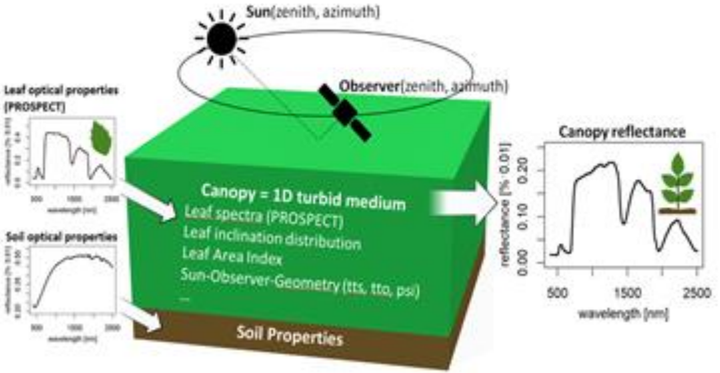
- ***Prospect model***, e.g., model assumptions and uncertainties, how was it derived, model inputs and outputs, biochemical parameters, data simulations, etc.
- ***Sail model***, e.g., model assumptions and uncertainties, how was it derived, model inputs and outputs, biophysical parameters, data simulations, etc.
- ***Prosail model***: e.g., model assumptions and uncertainties, how was it derived, model inputs and outputs, biochemical and biophysical parameters, data simulations, sensitivity analysis, etc.



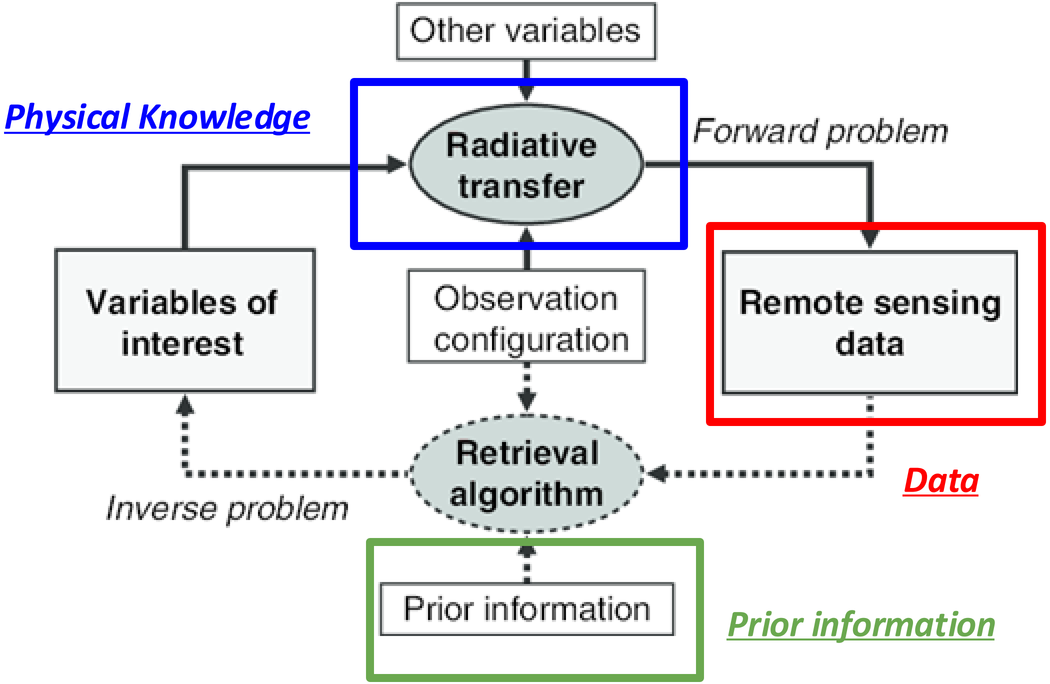
Prospect model (Allen et al. 1969, Jacquemoud and Barret, 1990)



Sail model - Radiative transfer in plant canopies, i.e. transmission, absorption and scattering (Kattenborn, 2018)



Week 6 & 8 - Approaches for solving inverse problems with Canopy RTMs



Introduce and compare different data inversion approaches:

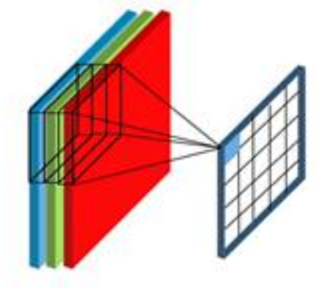
- ➔ What are different methods, e.g., Direct inversion, Look up table (LUT), Numerical approaches, Simulation and machine learning (or regression analysis), Deep learning
- ➔ Advantages and disadvantages
- ➔ How to select the "best" model
- ➔ How to evaluate uncertainty/errors

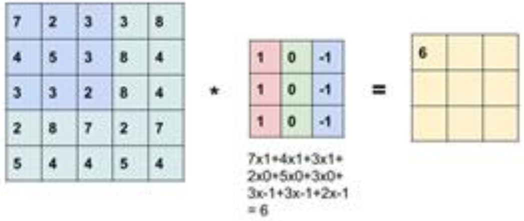
To accurately estimate biophysical/biochemical parameter

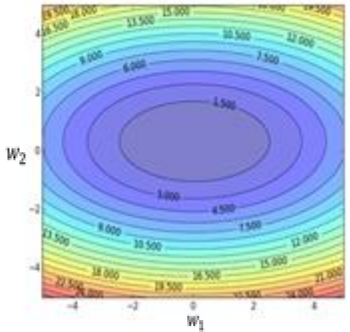
- ➔ How to use remote sensing ***data*** and GT samples?
- ➔ How to use the ***knowledge*** in RTM models
- ➔ How to use ***prior information***?
- ➔ How to use ***all three of them***, if they are available?

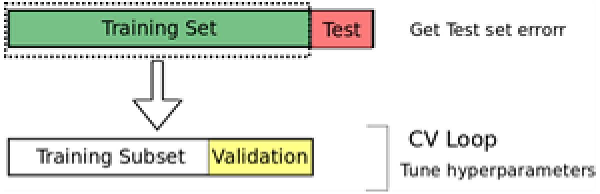
Pictures from Baret and Buis (2008)

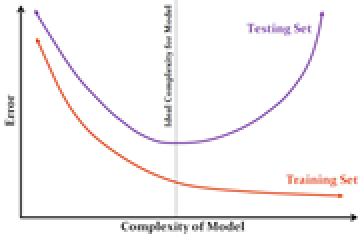
Week 9 - Introduction to deep learning methods for remote sensing images







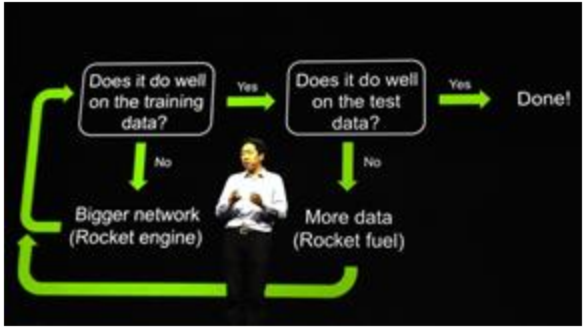


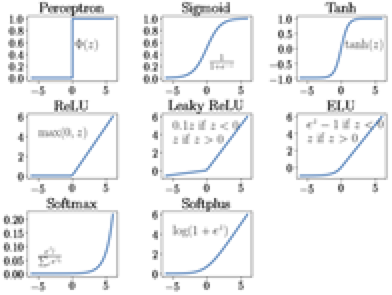


Key concepts, principles, tools, e.g.,

- ➔ Convolution, pooling, fully connected layers
- ➔ Different activation functions
- ➔ Benchmark deep learning architectures
- ➔ Different objective functions
- ➔ Gradient descents and its variants
- ➔ Training strategies
- ➔ Overfitting, underfitting, model complexity
- ➔ Bias and variance trade-off
- ➔ Frameworks, Pytorch, tensorflow

Typical Tasks, e.g., Image classification, Semantic segmentation, Generative AI





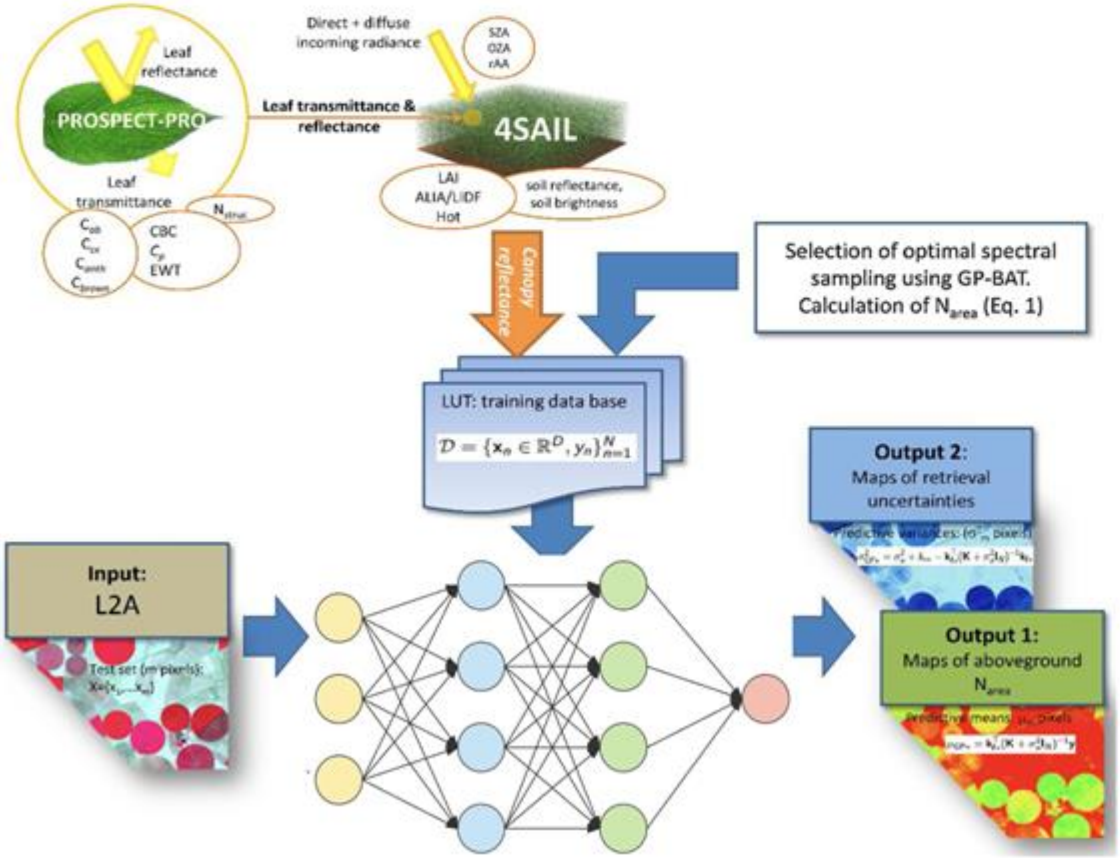
Caffe2

PyTorch

TensorFlow

Pictures from speech.ee.ntu.edu.tw, ml4a.github.io

Week 10 - Solving PROSAIL model using deep learning approaches



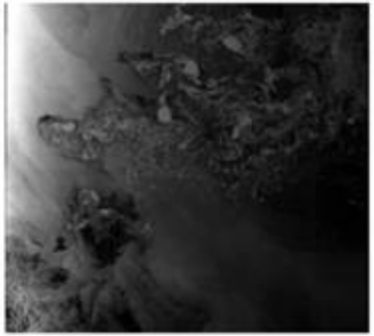
Key steps, e.g.,

- ➔ Variable sampling
- ➔ Data simulation
- ➔ Sensitivity analysis
- ➔ Build training data pairs
- ➔ Train deep learning models
- ➔ Model selection
- ➔ Observed data preparation
- ➔ Prediction
- ➔ Accuray assessment

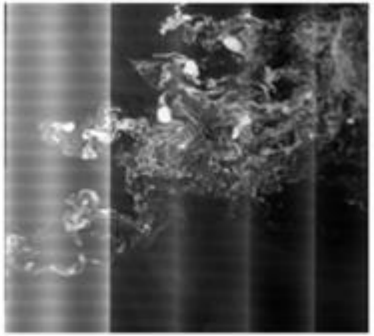
Deep learning architecture design?
How to handle overfitting?
How to handle underfitting?
How to select the “best” model?
How to evaluate the influence of noise?

Pictures from Berger, Katja, et al. 2020

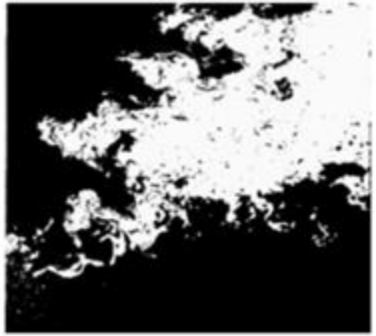
Week 11 and 12 - SAR, LiDAR, multi/hyperspectral image classification using deep learning



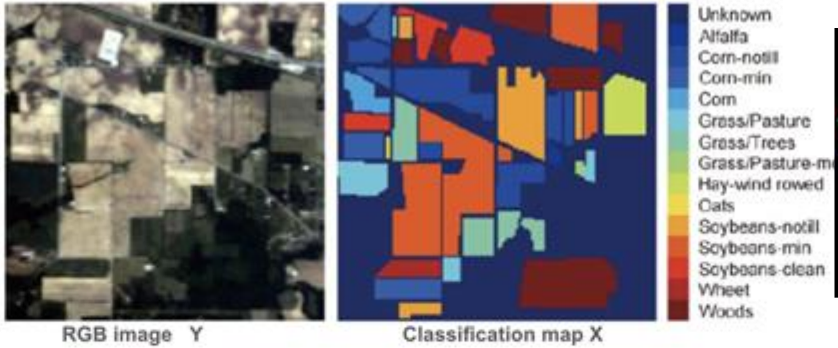
Sentinel-1 HH channel

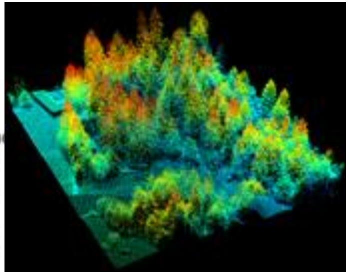


Sentinel-1 HV channel



Sea ice / open water map



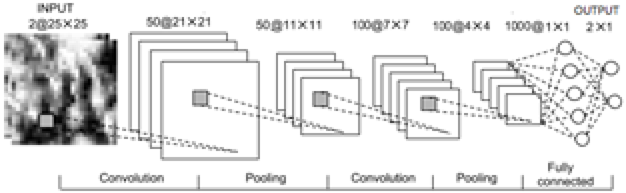


LiDAR point cloud for tree classification

Key steps, e.g.,

- ➔ Training sample preparation
- ➔ Models architecture design
- ➔ Training
- ➔ Model comparison and selection
- ➔ Model prediction
- ➔ Accuracy assessment

Deep learning architecture design?
How to handle overfitting?
How to handle underfitting?
How to select the "best" model?



Learning outcomes

At the end of this class, you should be able to:

(1) understand *different remote sensing observation approaches* for environmental monitoring

(2) understand the *physical and quantitative aspects of remote sensing* (e.g., radiative transfer models for vegetation, Prospect, Sail and Prosail)

(3) understand *deep learning methods*, and know how to use them to solve RTM and perform image classification.

(4) apply judiciously *different inverse models* for environmental parameters extraction

(5) evaluate quantitatively the *error/uncertainty* of the results, and reflects critically on the methods/procedure adopted.

(6) master the use of *open-source (Python) language and Pytorch* for information extraction from remote sensing data;

(7) gain substantial *practical skills* to conduct real-world environmental mapping.

Course materials

1. Jensen, J.R. 2015. Introductory Digital Image Processing. A Remote Sensing Perspective. 4th Ed. Pearson Education, Inc. 656 p.

2. Mather, P.M. 2022. Computer Processing of Remotely-Sensed Images. 5th Ed. Wiley-Blackwell. 384 p.

3. Jensen, J.R., 2007, "Remote Sensing of the Environment: An Earth Resource Perspective", 2nd Edition, Prentice Hall. (ISBN 978-0-13-188950-7).

4. Campbell, J.B., 2011 Introduction to Remote Sensing (Fifth Edition), The Guilford Press, 626pp.

5. Richards, J.A. 2013 Remote Sensing Digital Image Analysis An Introduction (5th Edition). Springer.

6. *Liang S. Quantitative remote sensing of land surfaces. John Wiley & Sons; 2005 Mar 11.*

7. *Goodfellow, Ian, Yoshua Bengio, and Aaron Courville. Deep learning. MIT press, 2016.*

8. *Hastie, Trevor, et al. The elements of statistical learning: data mining, inference, and prediction. Vol. 2. New York: springer, 2009.*

Grading Criteria

- Lecture attendance and participation: 30%
- Presentations 30%
- Term paper: 40%

Actively participate in class discussion

- Answer questions
- Interact frequently with your nearest neighbors to promote discussion and debate
- Talk about real-world problems

Image from learninginnovation.duke.edu

Questions?