ESA–MOST Dragon Cooperation

中国科技部-欧洲空间局“龙计划”合作

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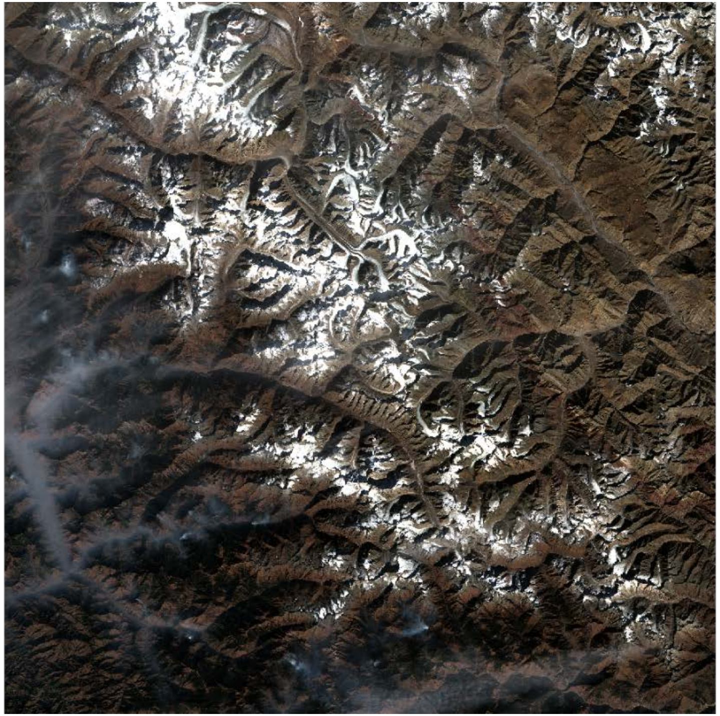
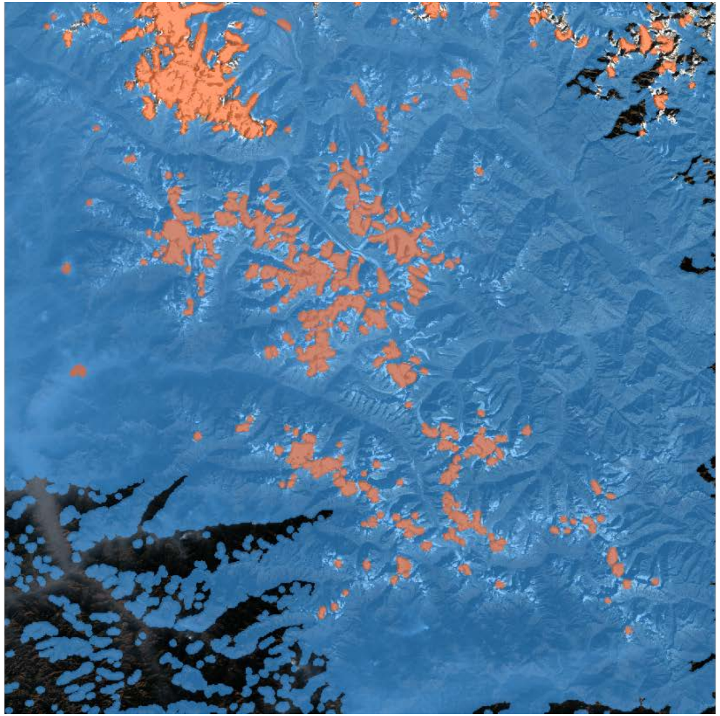
AN ASSESSMENT OF CLOUD DETECTION METHODS OVER HIGH ALTITUDE SNOW AND GLACIAL ENVIRONMENTS WITH SENTINEL-2

Philip van der Lugt*, Roderik Lindenbergh, Massimo Menenti, David Tax

Example of Cloud Detection over Mountains – 1





Example of Cloud Detection over Mountains - 2

- Sentinel-2's Default L1C mask
- Image of Himachal Pradesh, India
- Sentinel-2 Tile 43SGR, Scene 20161221 (yyyymmdd)
- Mostly cloud-free scene
- Blue indicates thin clouds
- Orange indicates thick clouds
- **Rampant misclassification observed**

Introduction

- Clouds obstruct optical imagery
- Cloud detection and separation from cloud-free data commonly desired for optical image analysis
- Clouds share similar spectral properties with snow and ice
- Cloud detection has rarely been applied to mountainous regions, but clouds are often reported as a problem for glacier outline analysis
- Snow/ice can be detected with NDSI (Normalized Difference Snow Index), but may include clouds

Questions to Answer

Primary

- Which cloud detection methods are the most accurate for detecting clouds over mountainous terrain?

Secondary

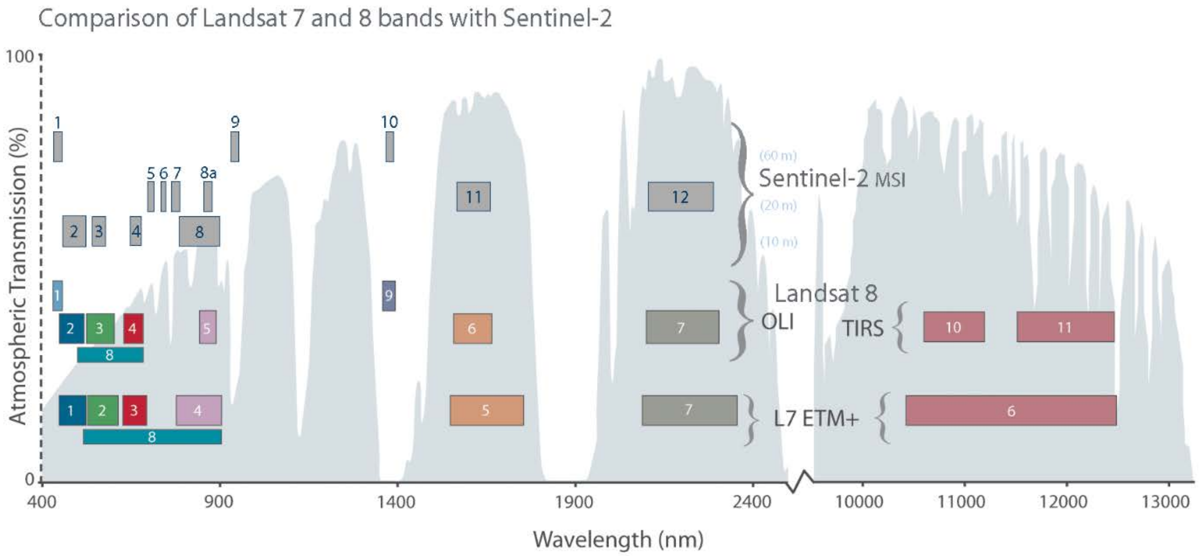
- How difficult is it to separate snow and ice from clouds? How similar are their spectral responses?

- What impact does mountain topography have on cloud detection?

- How can cloud detection contribute to glacier research as a preliminary step?

Sentinel-2 (S2)

- Latest ESA optical Earth observation satellites (S2A, S2B)
- High spatial resolution (10m, 20m, and 60m)
- Revisit time of 5 days (10 days for single satellite)



Cloud Types

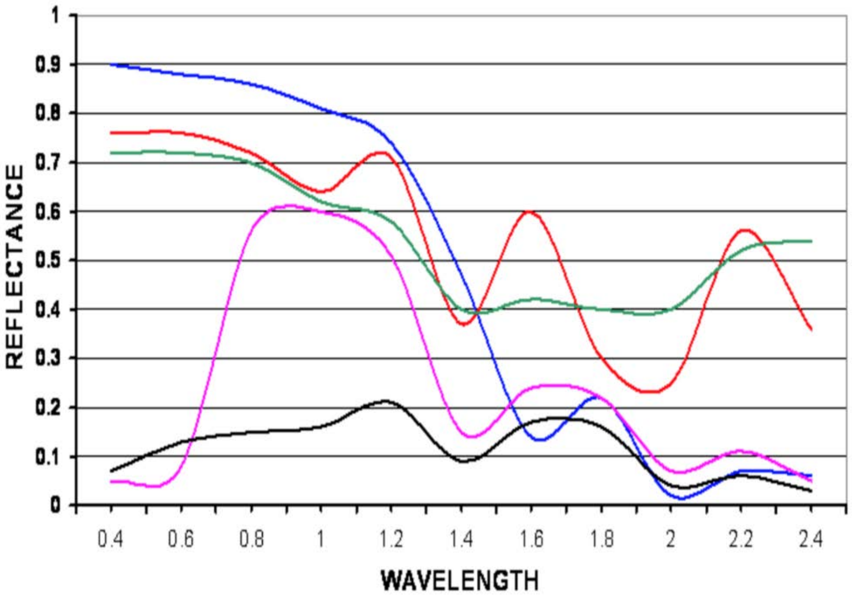
Thick water-based cloud

Thin ice-based cloud (aka cirrus)

(think of airplane condensation trails)

Spectral Signature of Clouds

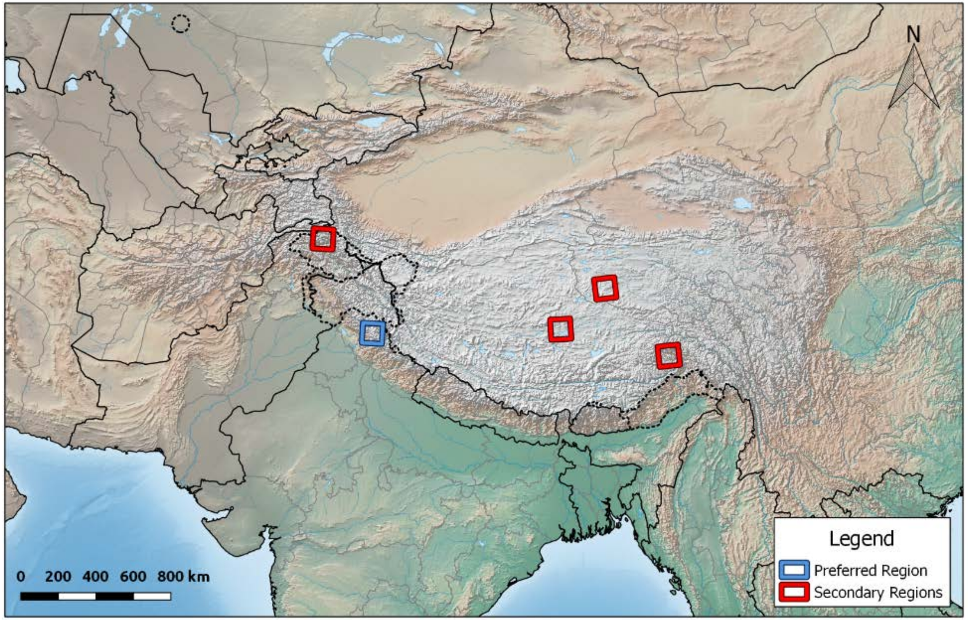
- Clouds usually bright and white
- Large variability (light, dark, transparent, opaque, stacked, solitary, etc.)
- Important bands are:
  - Visible Green (S2 Band 3)
  - Shortwave IR (S2 Band 11)
  - Cirrus (S2 Band 10)
  - Thermal (not on Sentinel-2)



Blue = Snow, Black = Bare Soil, Pink = Forest Canopy,
Red = Cirrus, Green = Stratus

Study Area

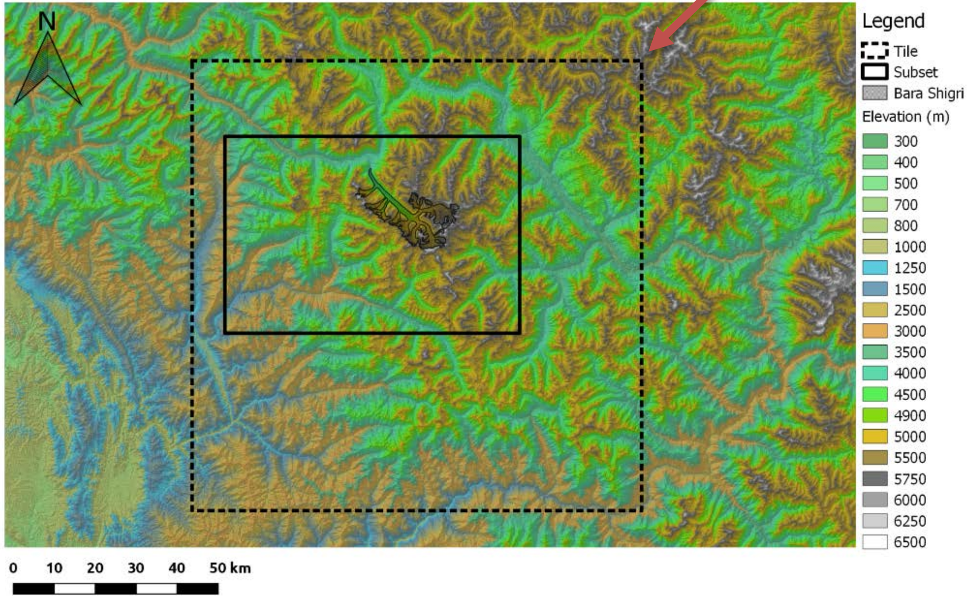
- High elevation topography
- Glaciers
- Variant land covers (arid vs vegetation)
- Water bodies, if possible



Sentinel-2 Data Preparation

- 19 temporally spaced scenes
- Data cropped
- 6 scenes eventually used
- Bara Shigri glacier

S2 Tile: 43SGR



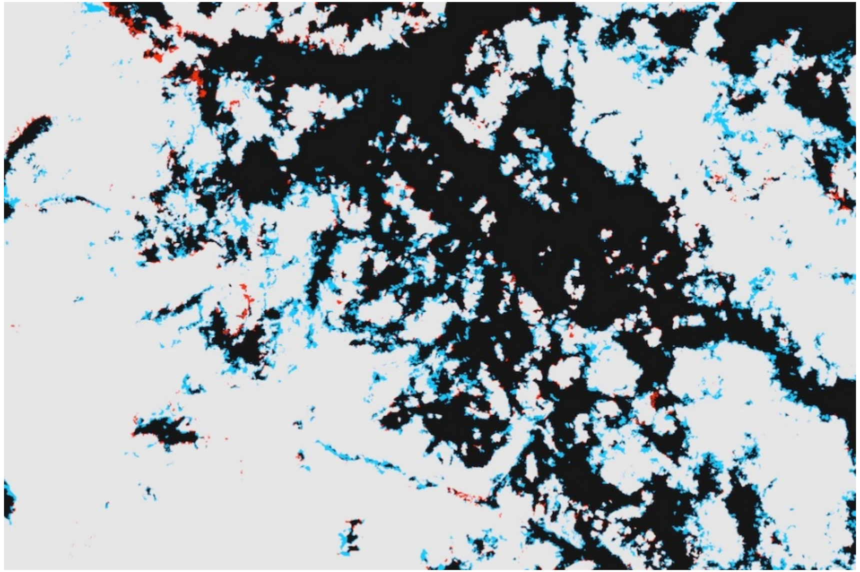
Cloud Detection Methods

1. Sentinel-2 Default L1C Cloud Mask
2. Sentinel-2 Sen2Cor Scene Classification
3. Maximum Likelihood Classification (MLC, done with SCP plugin in QGIS)
4. Fmask
5. Temporal Averaging (new approach)

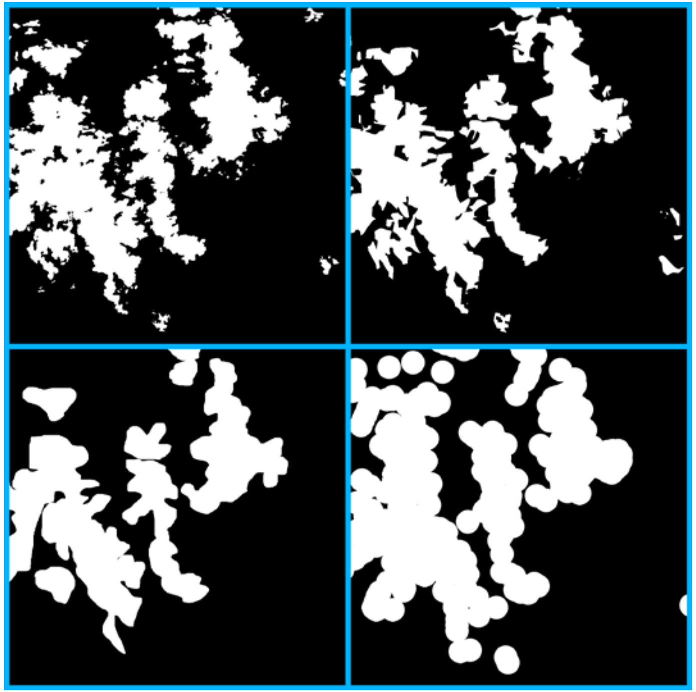
Validation data: Manual Masking in Photoshop

Manual Mask

Scene
20160714



Grey/Black = Agreement cloud/clear
Blue/Red = Disagreement mask HD and mask MD



Manual mask comparison, high detail (HD), medium detail (MD), and 2 low detail (Black = Clear, White = Cloud)

Sample Input – Scene 20160915

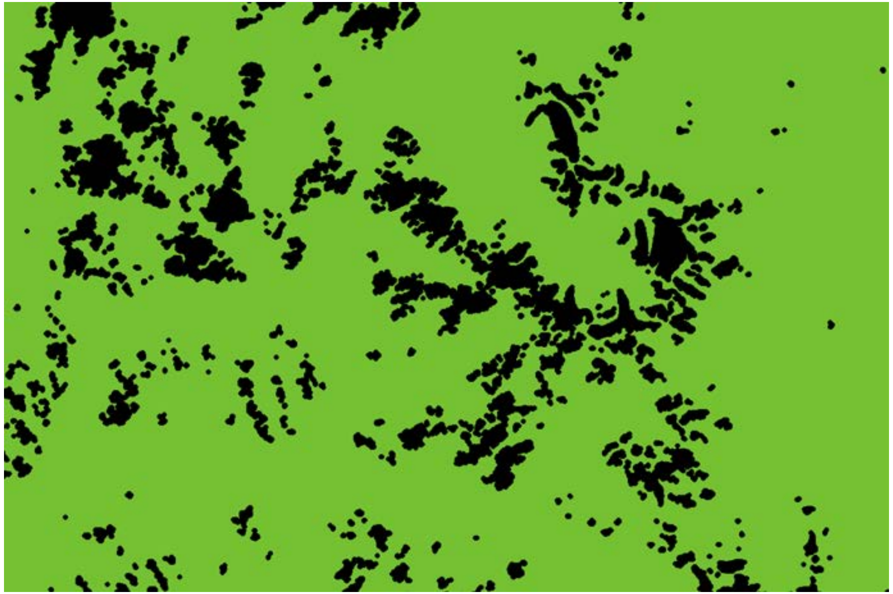
Output - Manual Mask

Grey = Cloud, Green = Clear (Cloud-free)

NRSCC

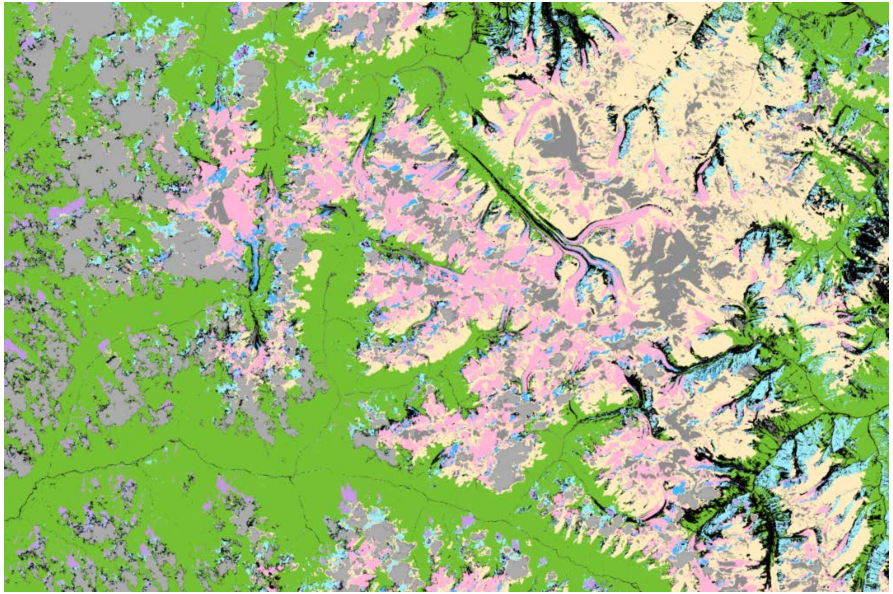
esa

Output - L1C Mask (Thick Clouds Only)



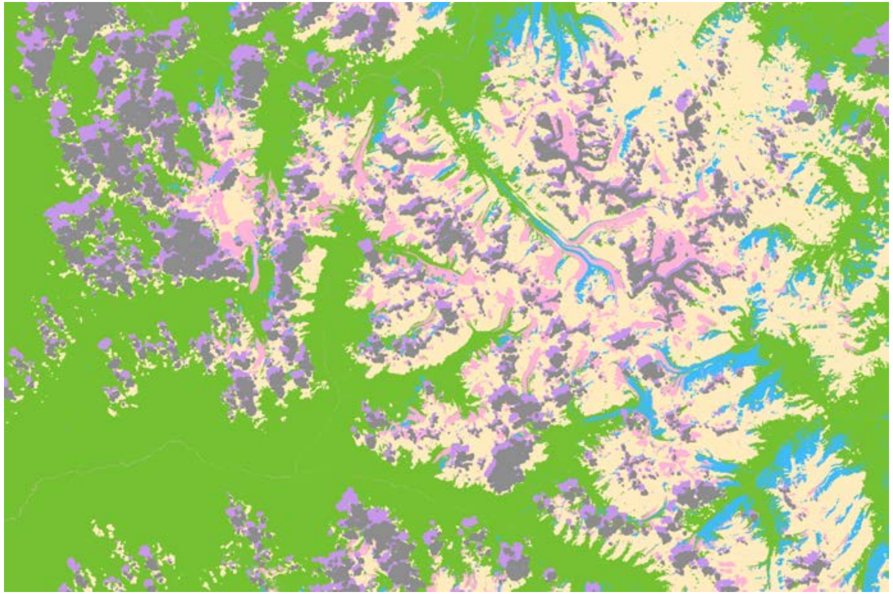
Black = Cloud, Green = Clear (Cloud-free)

Output - Sen2Cor



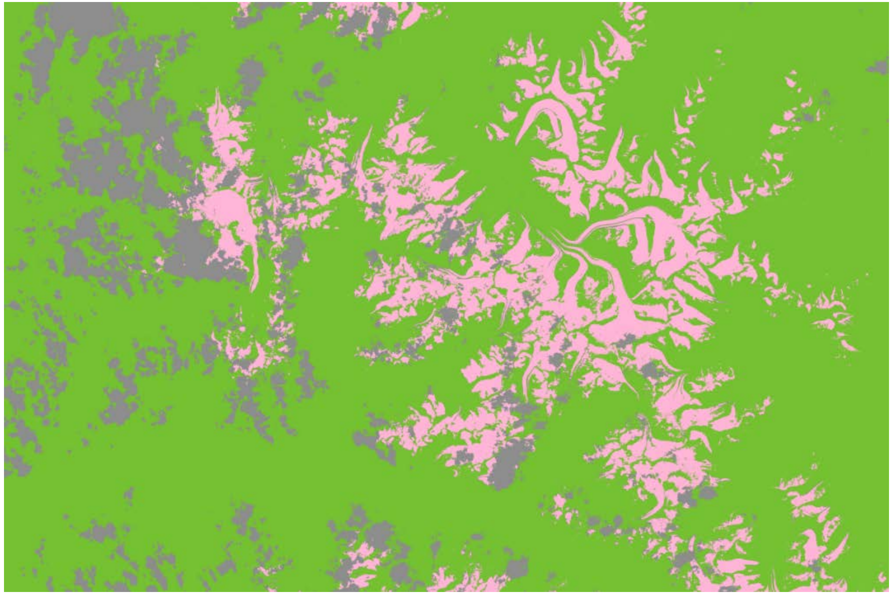
Levels of Grey/Black = Cloud, Yellow = Thin Clouds Green = Clear (Cloud-free), Pink = Snow/Glacier, Purple = Shadow, Blue = Water, Light Blue = Dark Feautures/No Data/Saturated

Output - Fmask



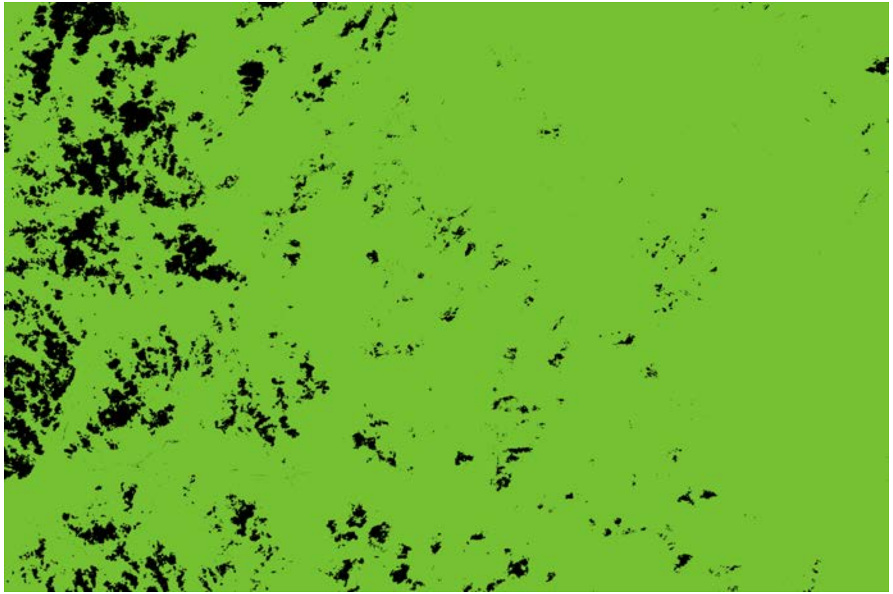
Grey = Cloud, Green = Clear (Cloud-free), Yellow = Thin Clouds, Pink = Snow/Glacier, Purple = Shadow, Blue = Water

Output - MLC



Grey = Cloud, Green = Clear (Cloud-free), Pink = Snow/Ice

Output - Temporal Averaging (new approach)



Black = Cloud, Green = Clear (Cloud-free)

All 19 scenes used for obtaining threshold, tested on 6 scenes

Method Strengths and Weakness

	Advantages	Disadvantages
Def. L1C	Included with L1C products	Worst results
S2C	High quality, automated	Chaotic interpretation, many classes, slow
Fmask	Automated, fast	Originally for Landsat, varies per implementation
MLC	High quality, fast once trained	Requires training, slow training
Temporal Ave.	Easy to implement, large potential to improve	Needs temporal inputs, underclassifies
Manual	Very high quality	Very time consuming to make, not automated

Questions to Answer Revisited

Primary

- Which cloud detection methods are the most accurate for detecting clouds over mountainous terrain?

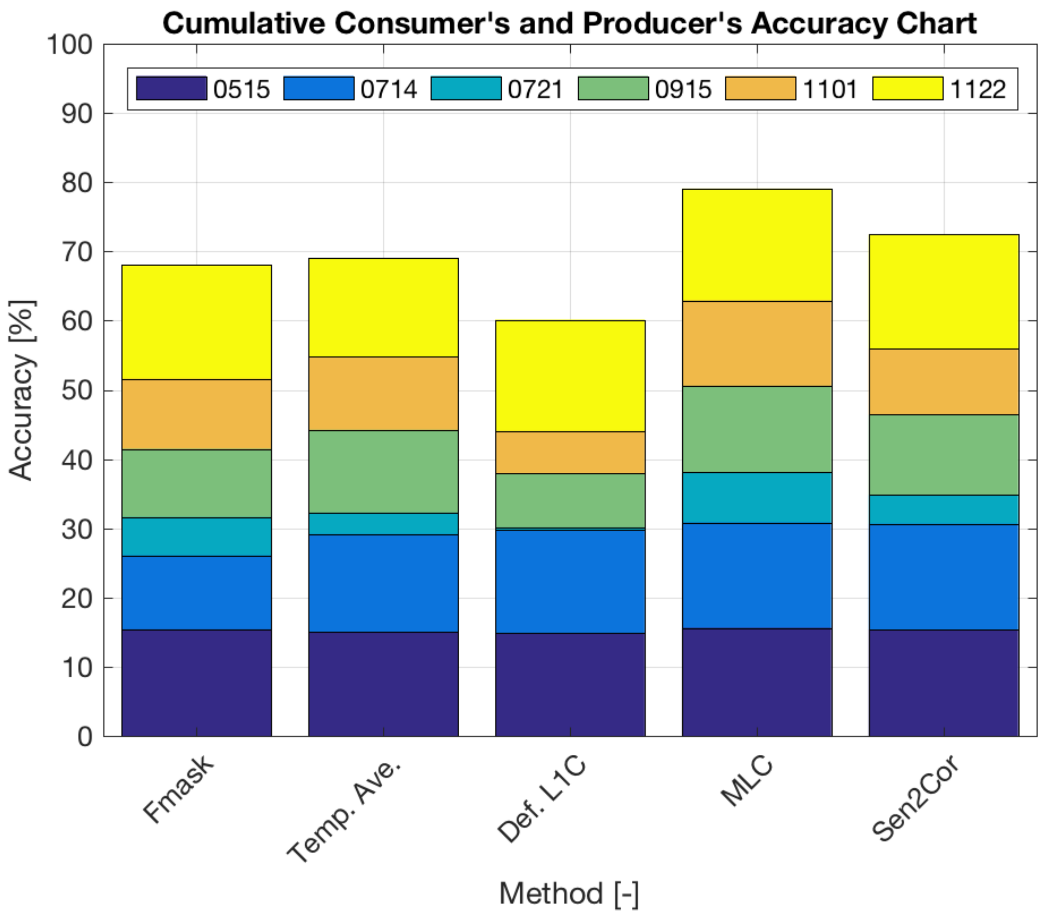
Secondary

- How difficult is it to separate snow and ice from clouds? How similar are their spectral responses?

- What impact does mountain topography have on cloud detection?

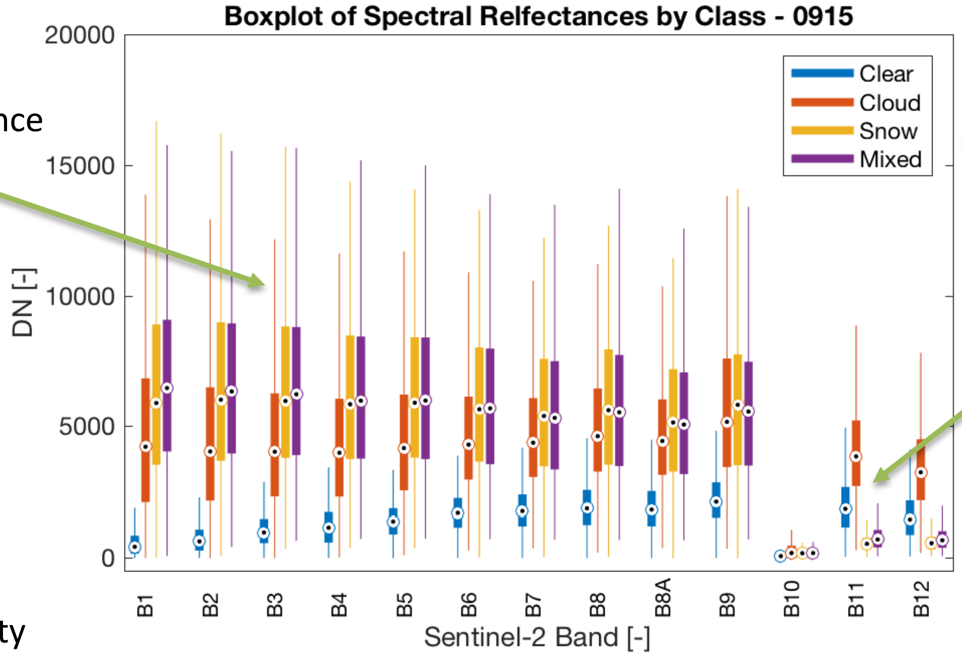
- How can cloud detection contribute to glacier research as a preliminary step?

Accuracy Scores



Boxplot of Spectral Reflectances

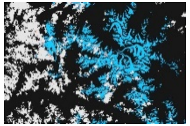
Similar class reflectance signatures



Mixed = Pixel labelled as snow and cloud

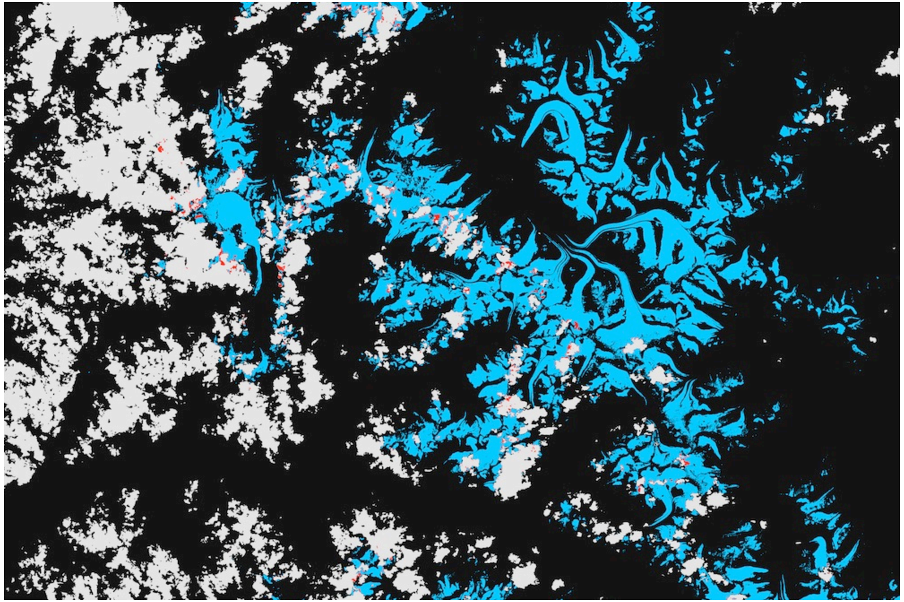
Different class reflectance signatures

DN = Digital Number, intensity value of reflected pixel

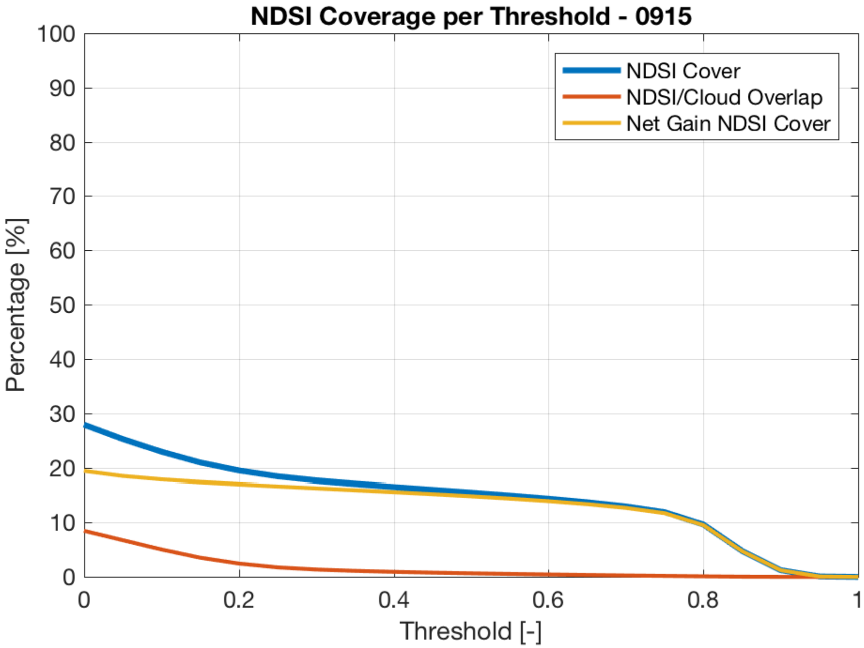


Plot data obtained from NDSI/Cloud difference map (see next slide)

Amount of NDSI* and Cloud Overlap



Grey = Manual Mask Cloud, Blue = NDSI (> 0.7), Red = NDSI/Cloud Overlap, Black = Clear



*NDSI = (B3 - B11) / (B3 + B11)

Glacier Research and Mountain Topography

Current cloud detection methods offer limited value to glacier research, NDSI remains top dog

- Cloud detection possibly useful for dirty glaciers? Or when lacking certains bands?
- Cloud detection still useful for non-glacier related research in mountains
- Challenge of choosing NDSI threshold

Strong evidence that mountains significantly affect cloud detection

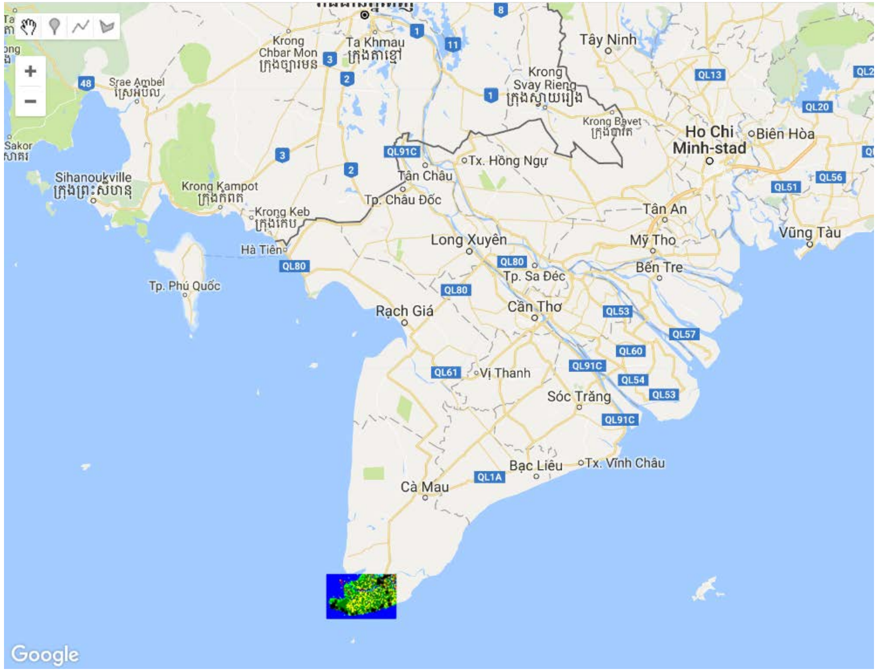
- Cirrus cloud signal, mountain shadows, cloud formation
- Caused by weather, solar incoming and outgoing reflectance angles, semi-transparent clouds decisions, etc.

Final Remarks

- Cloud detection over mountains = not great
- More research required to determine best ways to improve cloud detection over mountains
- Current methods very dependent on spectral data
- Addition of temporal or spatial dimension for classification is promising solution
- **Need to study snow and ice? Use NDSI with high threshold**
- **Need to detect clouds? Do manual masking → MLC → Sen2Cor**

Questions?

Leonoor Portengen: Monitoring Mangroves in Vietnam



Monitoring Mangroves by combined S1 & S2 data

CART Classification S2

Random Forest Classification S2

Stijn Pinson: Glacier Movement from Landsat time series

Displacement between epoch 1 and epoch 2: $d_{1\text{-}2}$

d1-2

Displacement between epoch 1 and epoch 3: $d_{1\text{-}3}$

d1-3

d1-2 d2-3

Thus displacment between epoch 1 and epoch 3 is also: d1-3 = d1-2 + d2-3

But also: d1-2 = d1-3 – d2-3

Displacement between epoch 1 and epoch 4: $d_{1\text{-}4}$

Thus displacment between epoch 1 and epoch 4 is also: d1-4 = d1-2 + d2-4

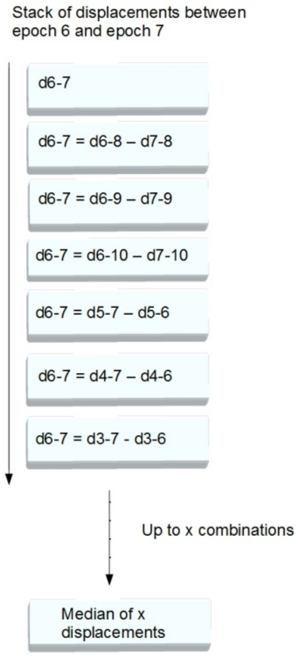
But also: d1-2 = d1-4 – d2-4

d2-3 d3-4

d2-4

Finally, also works with previous epochs: Displacement between epoch 3 and epoch 4 is

d3-4 = d2-4 – d2-3

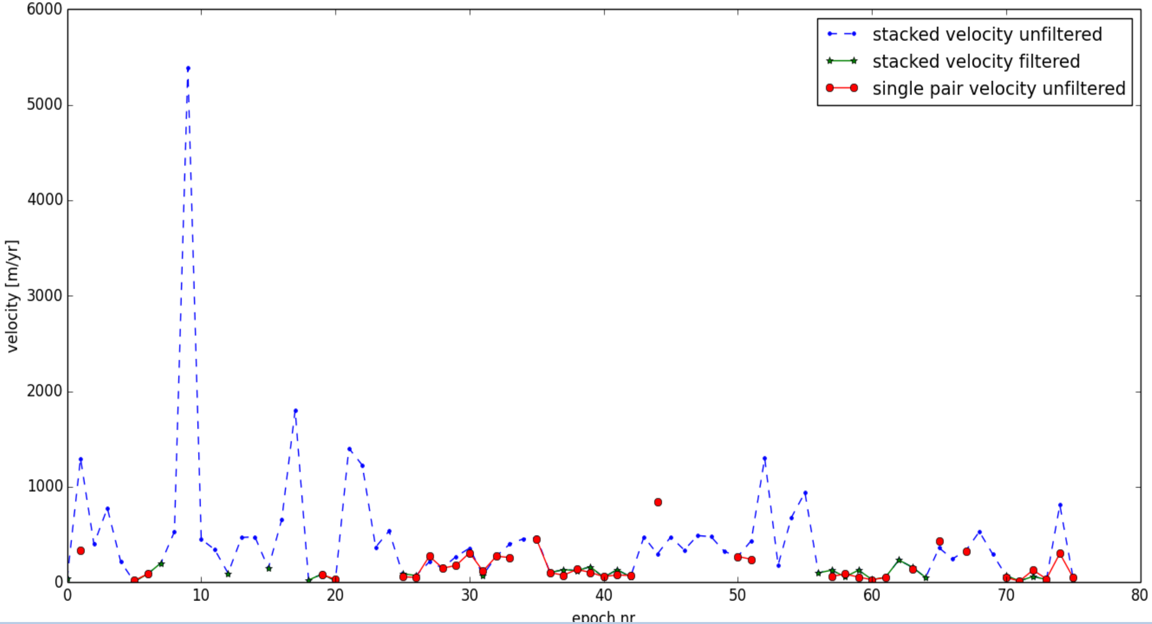


Stijn Pinson: Glacier Movement in Karakorum

Landsat 8 velocity time series of one glacier pixel.

Filtering:

- temporal outliers
- very low SNR filter.



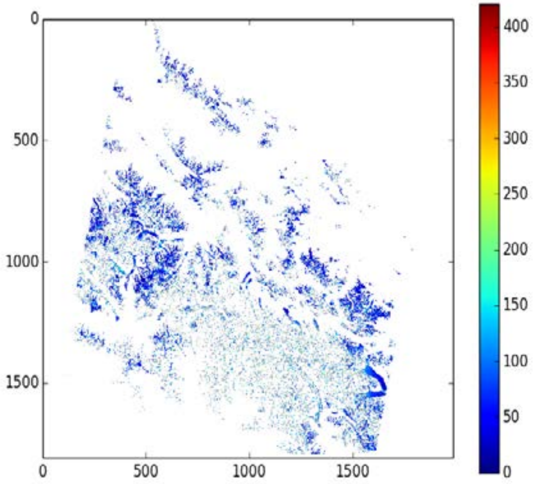
MSc visitor of Noel Gourmelen.

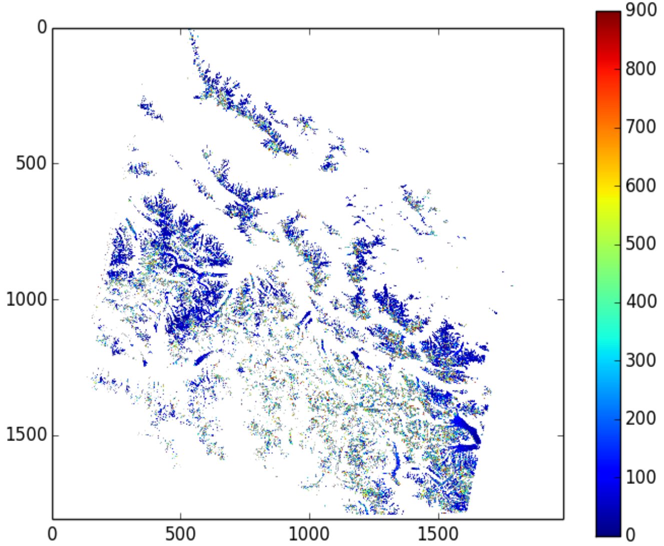
Stijn Pinson– Glacier Movement in Karakorum

Two velocity fields, Karakoram region, start of 2014 Landsat 8.

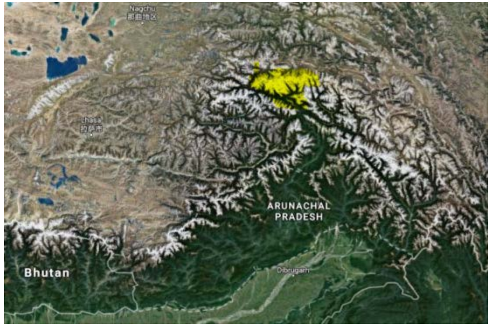
Left: single pair velocity field.

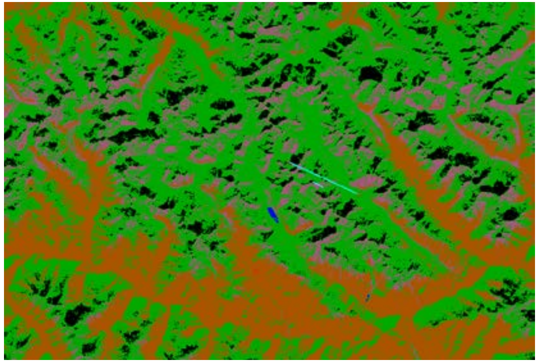
Right median stacked velocity field (30 combinations)

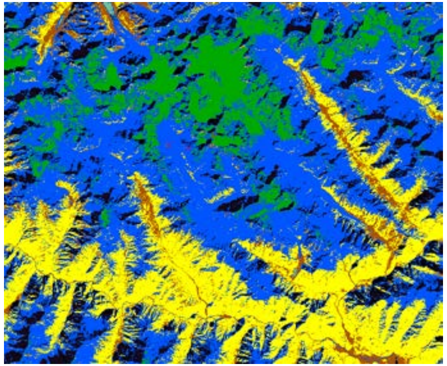




Najoua Essaf: differences, Sentinel 2 images

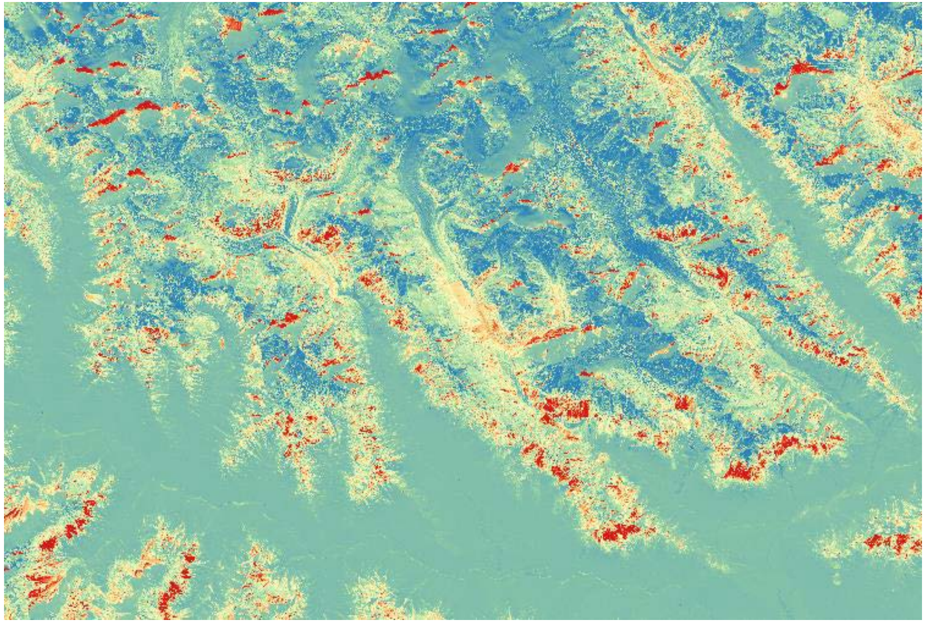






Comparing classifications, 10/12/2016 - 18/02/2017
(colors don’t match yet)

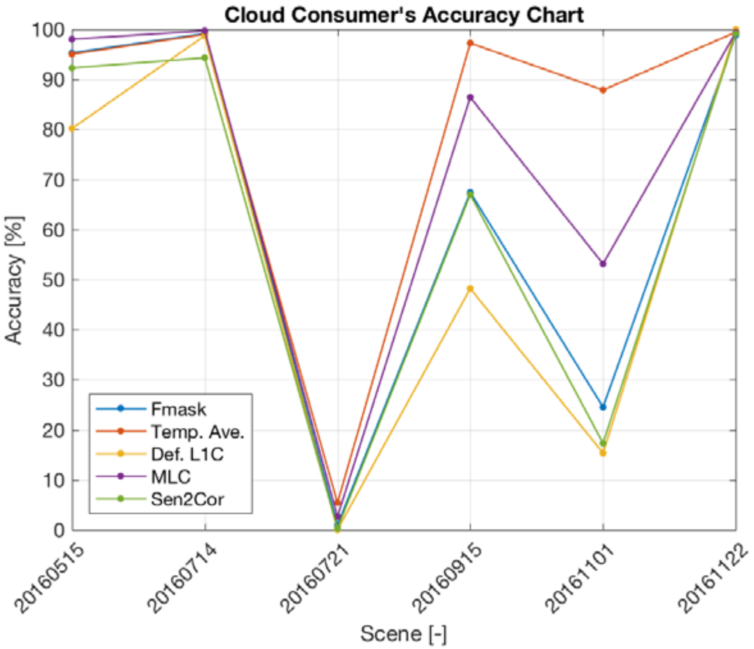
Najoua Essaf: differences, Sentinel 2 images

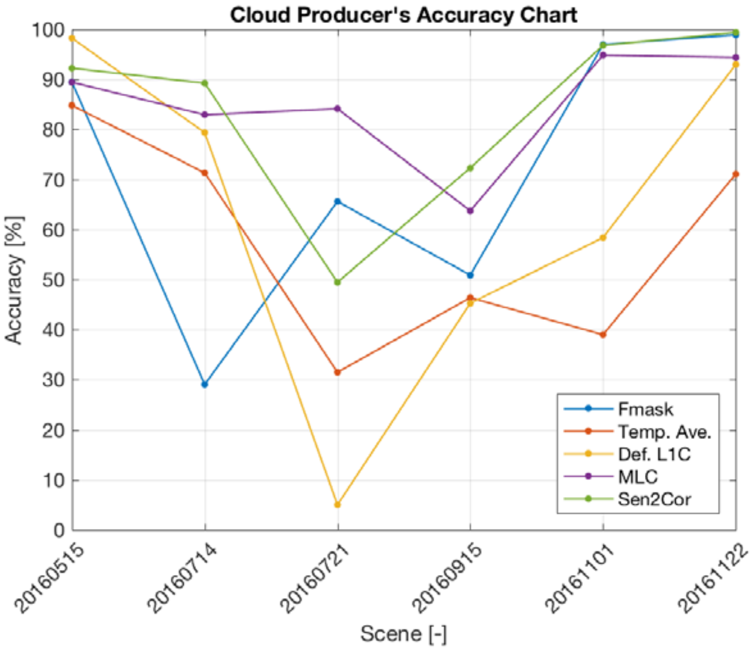


Subtracting visual bands, 10/12/2016 - 18/02/2017

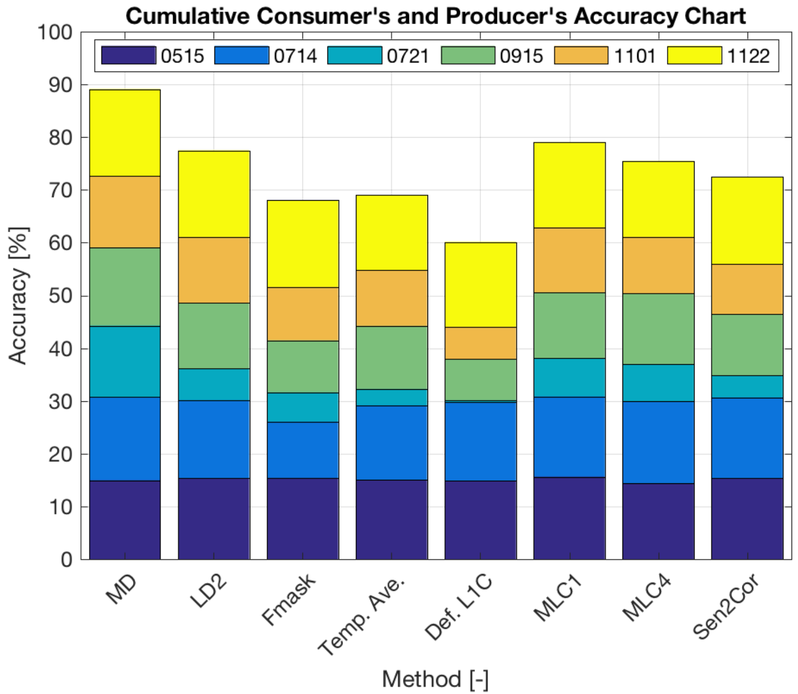
Extra Slides

Consumer's and Producer's Accuracies

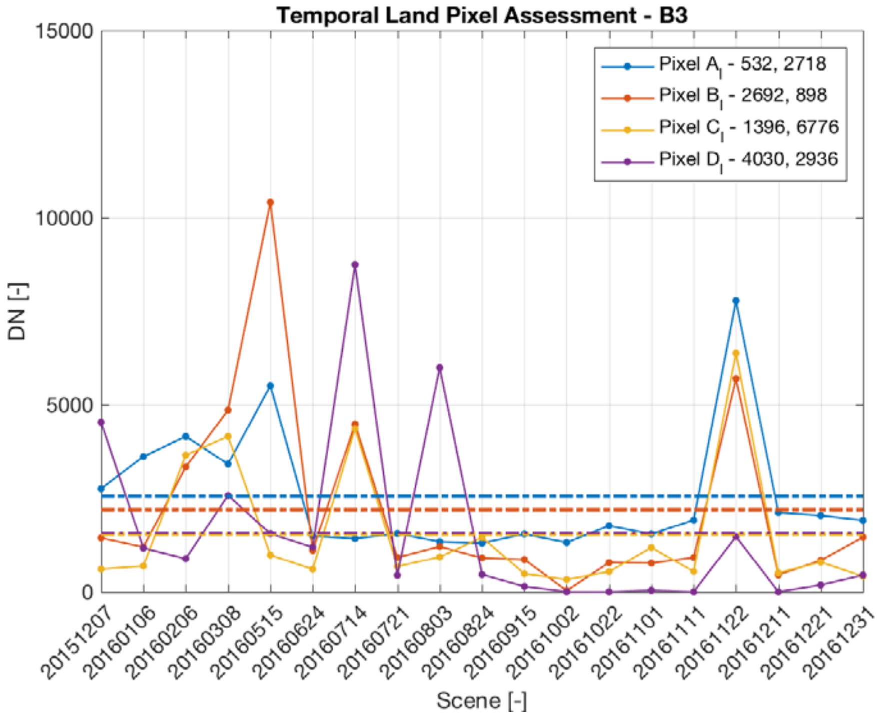




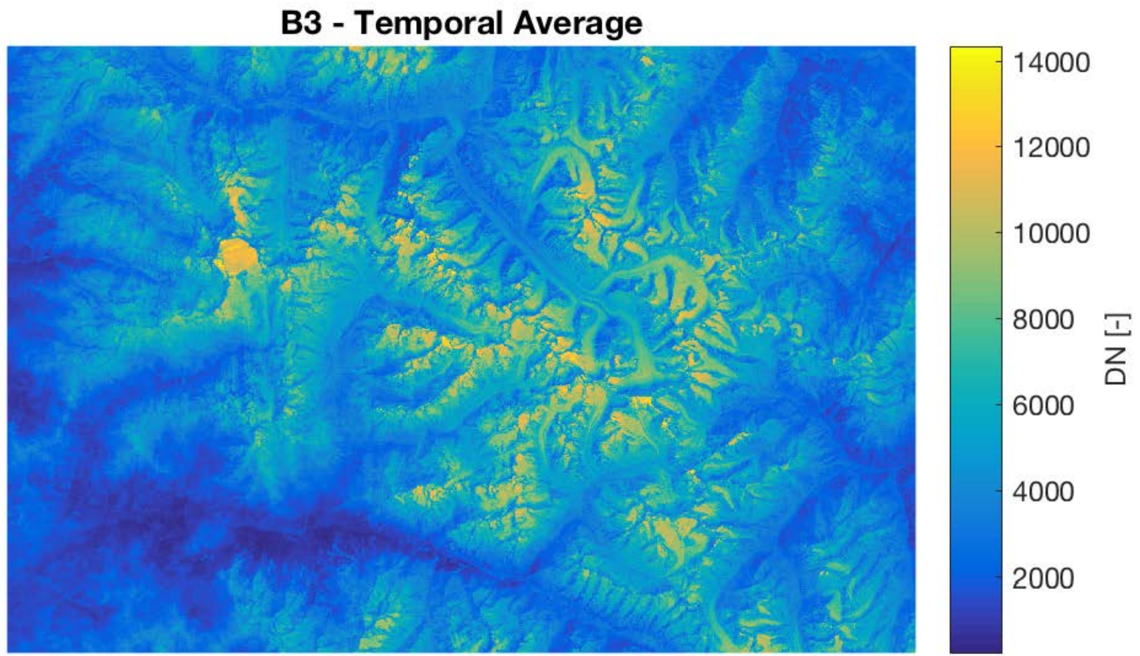
Accuracy Score



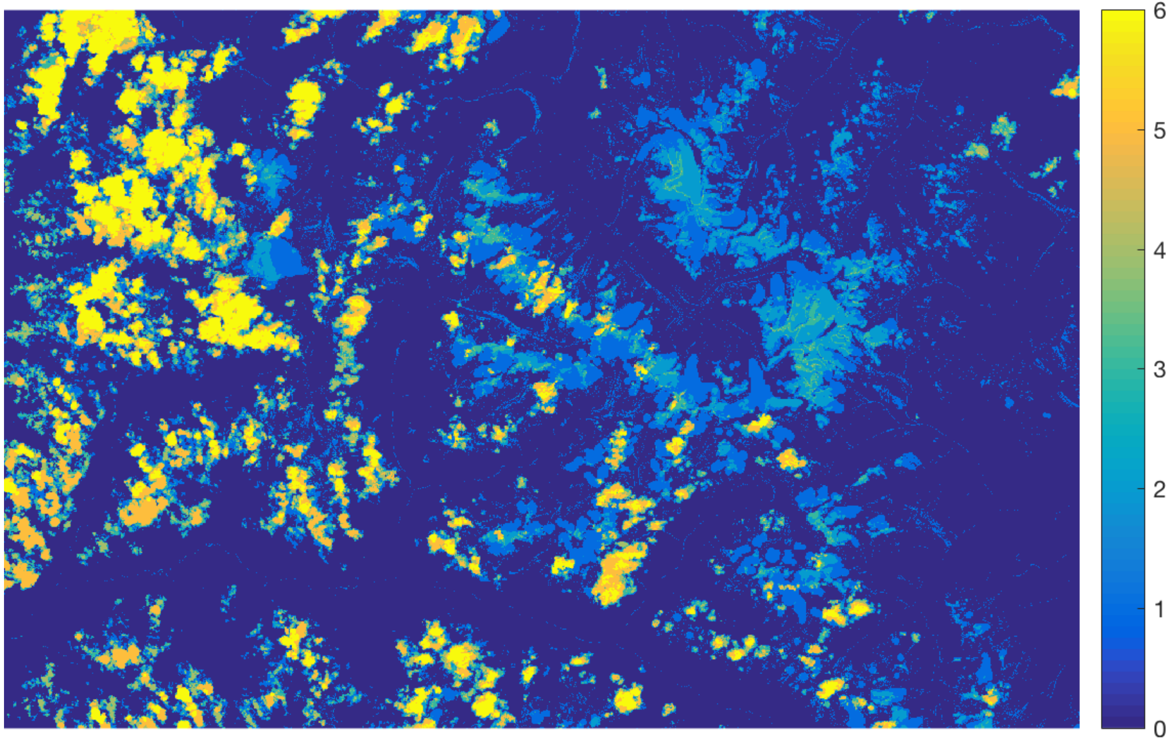
Temporal Averaging - Threshold



Temporal Averaging – Average Map



All Cloud Masks Overlay



Patch Analysis

Cumulative R-squared chart per method

Based on spatial kernels plots from Sedano et al., 2011