

# Processing of satellite data - Standardization

27-28 September 2022

Tree Species Project Workshop, Göttingen

**for tree species classification**

with contributions from  
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@d\_frantz

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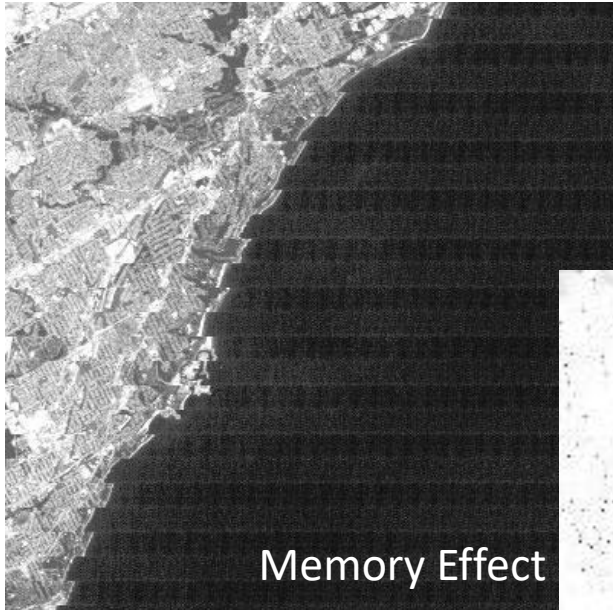
# Earth Observation as key technology



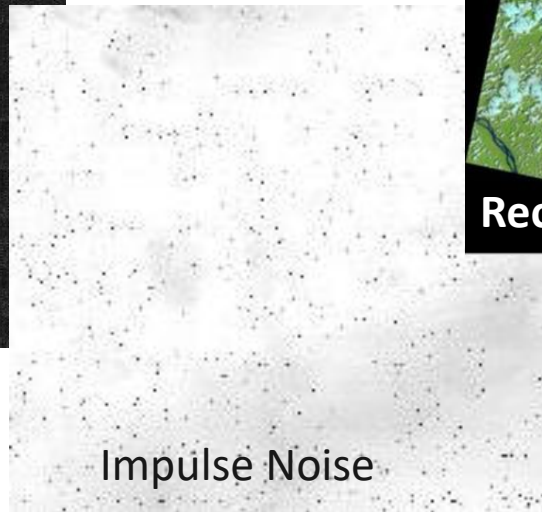
<https://www.opendatacube.org/>



# Raw satellite data are ugly and noisy



Memory Effect



Impulse Noise



Landsat 9 Solid State  
Recorder Bad Block Issue

**Bandings:** Affects Landsat 4-5 Thematic Mapper (TM) data.

**Coherent Noise:** Affects Landsat 5 TM and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data.

**Coherent Noise Storm:** Affects Landsat 7 data on May 29, 2003.

**Data Loss:** Affects Landsat 5 and Landsat 7 data mainly until 2006, although data loss can happen at any time.

**Detector Failure:** Affects Landsat 5 TM data, found once in Landsat 7 data.

**Detector Ringing:** Affects Landsat 7 data.

**Detector Striping:** Can affect data from all sensors.

**Gimbaled X-Band Antenna (GXA):** Affects Landsat 7 data from launch to April 2000.

**Impulse Noise:** Can affect data from all sensors.

**Internal Calibrator (IC) Intrusion:** Affects Landsat 7 data from launch to April 2007.

**Lower Truncation Acquisitions:** Affects Landsat 8 data.

**Memory Effect:** Affects Landsat 1-5 Multispectral Scanner (MSS) and Landsat 4-5 Thematic Mapper (TM) data.

**Optical Leak:** Affects Landsat 5 and Landsat 7 data.

**Oversaturation:** Can affect data from all sensors.

**Scan Correlated Shift:** Affects Landsat 4-5 MSS data.

**Scan Mirror Pulse:** Affects Landsat MSS data.

**Shutter Synchronization Anomalies:** Has affected Landsat 5 TM and Landsat 7 data.

**Single Event Upsets:** Has affected Landsat 7 data.

**Solid State Recorder Bad Block Issue:** Affects Landsat 9 data

**Thermal Infrared Sensor Scene Select Mechanism Anomaly:** Affects Landsat 8 Thermal Infrared Sensor.

<https://www.usgs.gov/landsat-missions/landsat-known-issues>



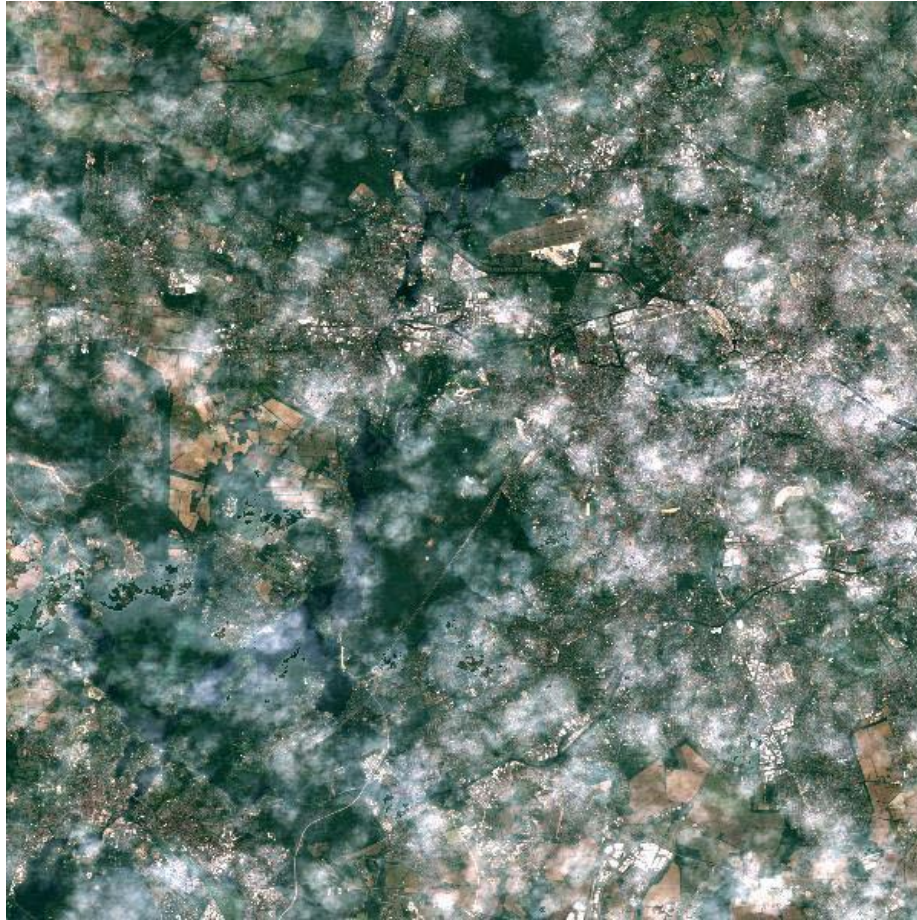
## Clouds cover about 70% of Earth's surface at all times!

Stubenrauch, C. J., Rossow, W. B., Kinne, S., Ackerman, S., Cesana, G., Chepfer, H., Di Girolamo, L., Getzewich, B., Guignard, A., Heidinger, A., Maddux, B. C., Menzel, W. P., Minnis, P., Pearl, C., Platnick, S., Poulsen, C., Riedi, J., Sun-Mack, S., Walther, A., Winker, D., Zeng, S., & Zhao, G. (2013). Assessment of Global Cloud Datasets from Satellites: Project and Database Initiated by the GEWEX Radiation Panel, *Bulletin of the American Meteorological Society*, 94(7), 1031-1049.

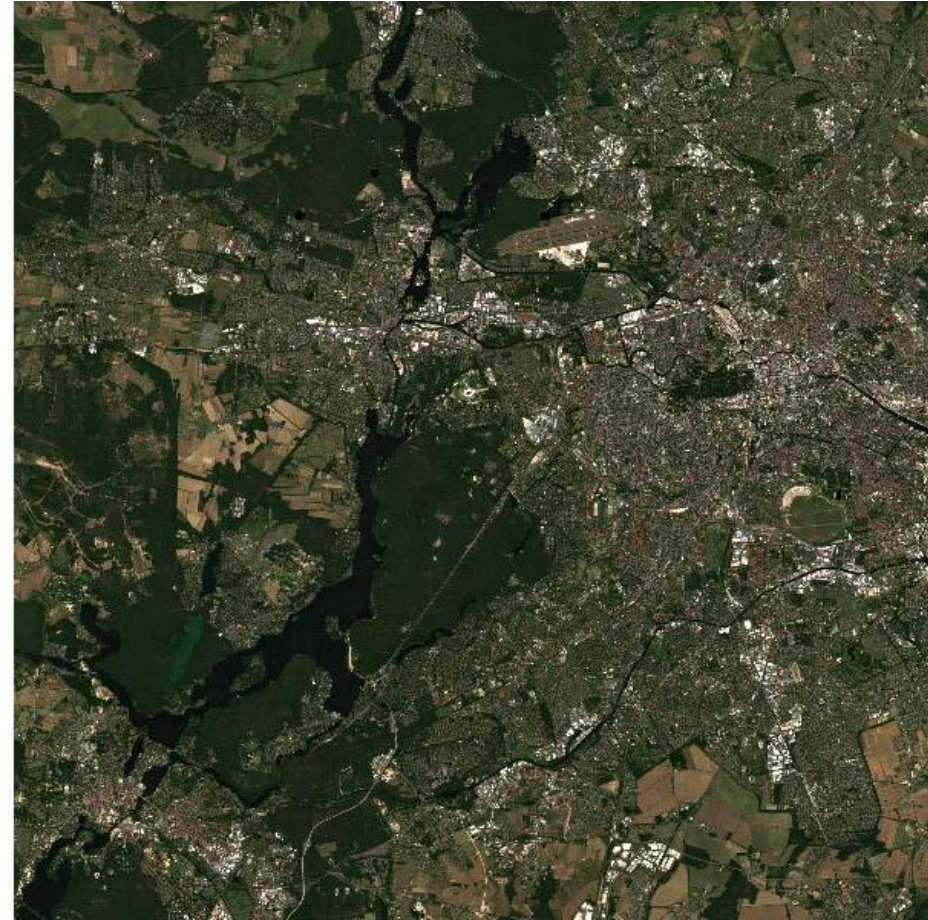
[https://www.giss.nasa.gov/research/briefs/2017\\_tselioudis\\_02/robinson\\_1440.jpg](https://www.giss.nasa.gov/research/briefs/2017_tselioudis_02/robinson_1440.jpg)



# Cloud contamination

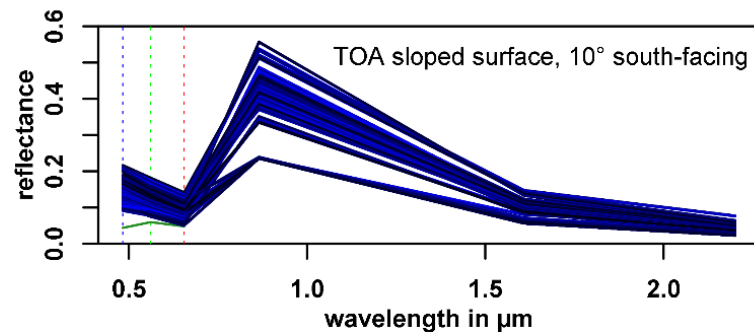
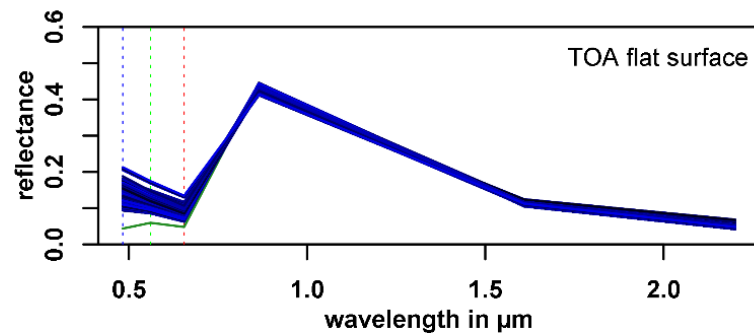
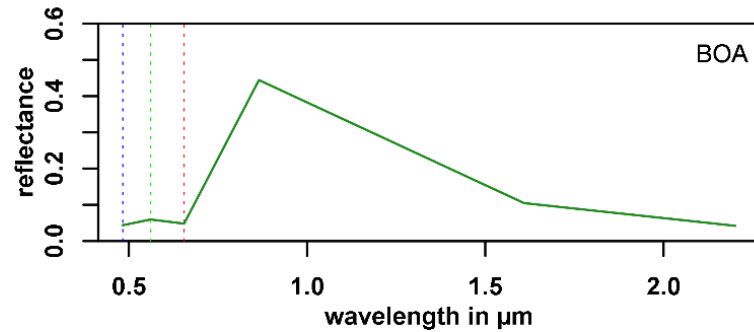


**no cloud mask**



**good cloud mask**





## Different acquisitions

- Solar angles
- Viewing angles
- Air mass
- Aerosol concentration
- Aerosol size distribution
- Water vapor concentration
- Scattering
- Gas. Absorption
- Illumination (topography)
- Anisotropy
- ...



# Atmospheric contamination



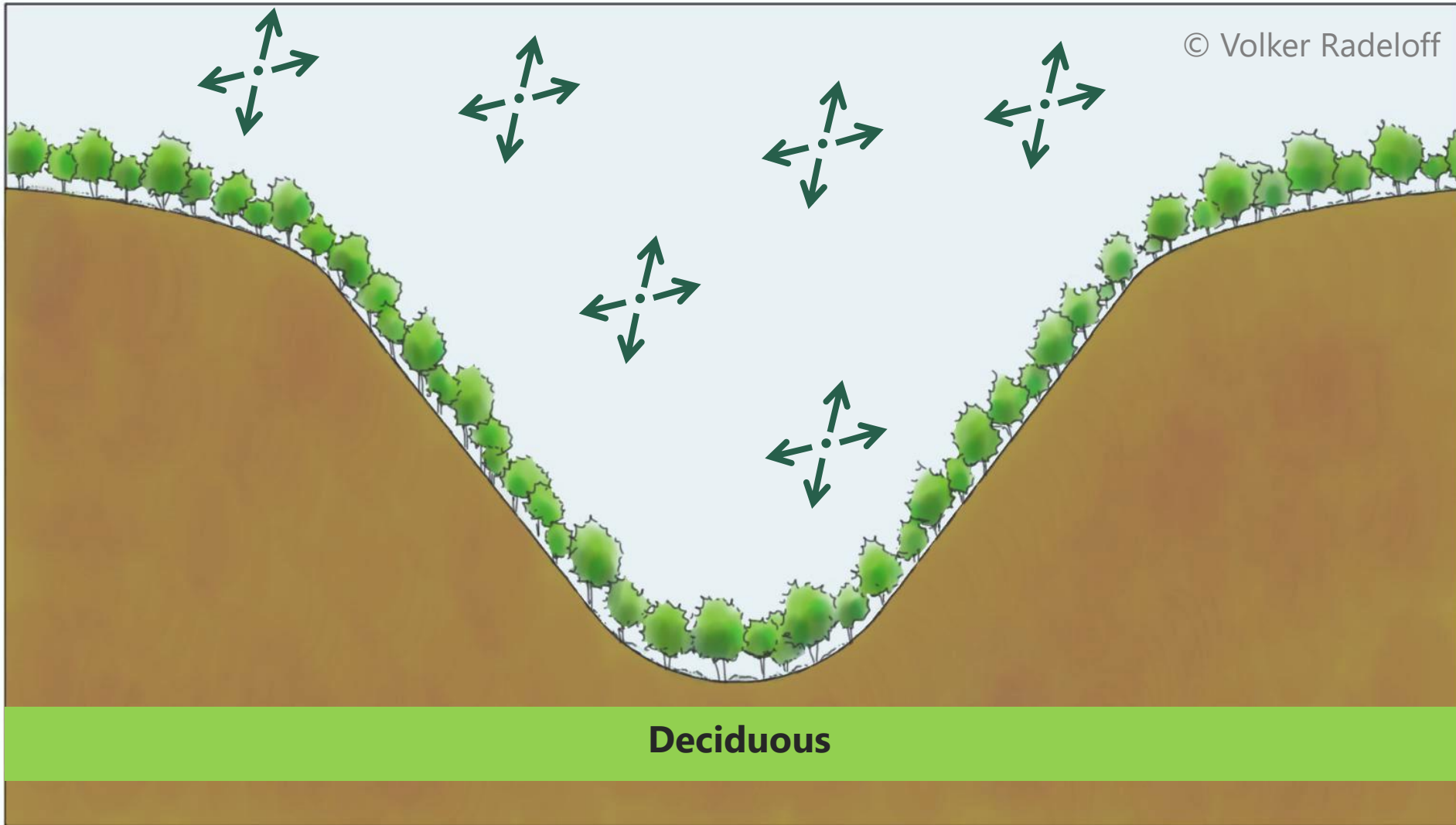
2018-08-06

2018-08-03

Different tree species?

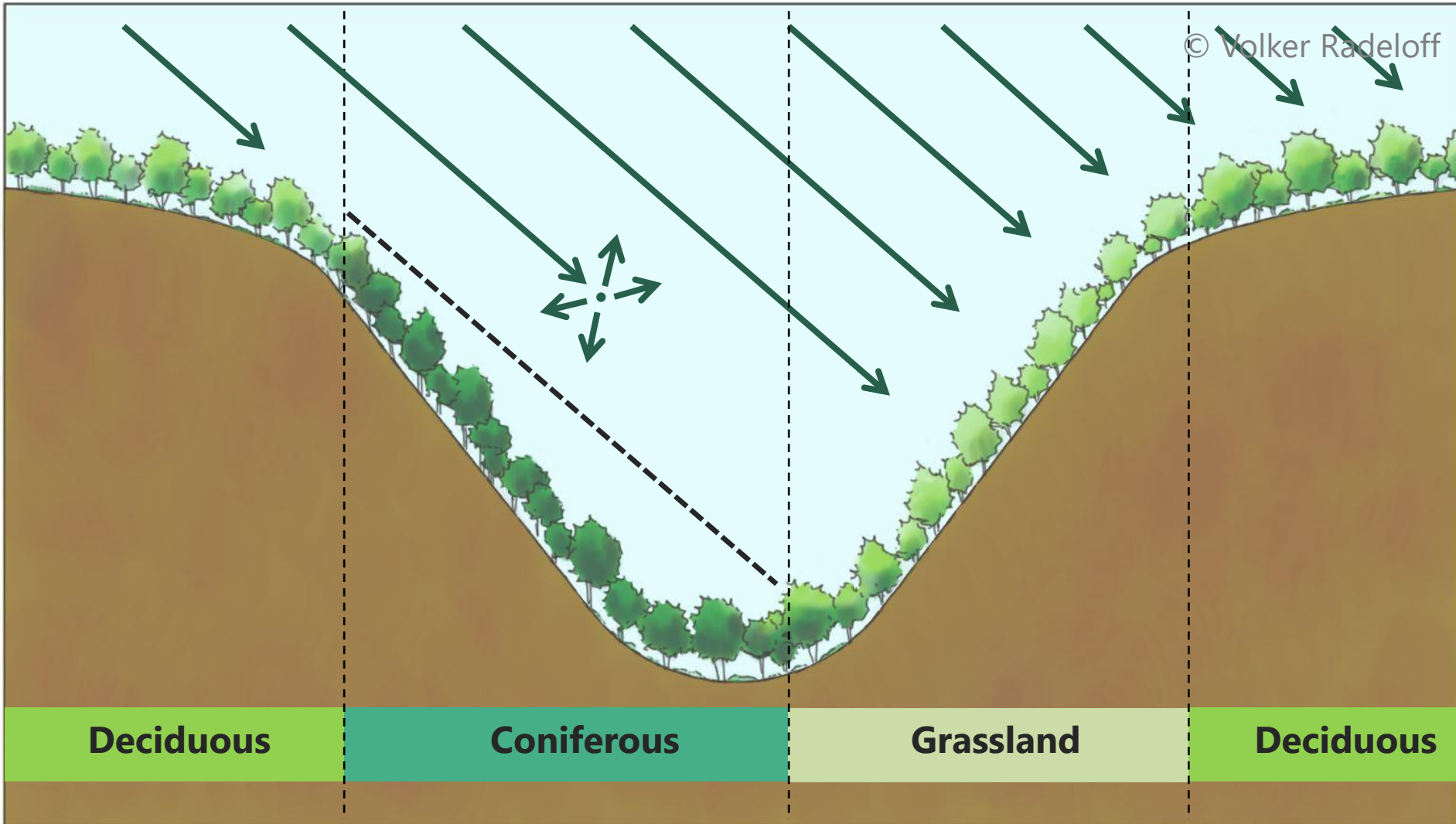


# Illumination of sloped terrain

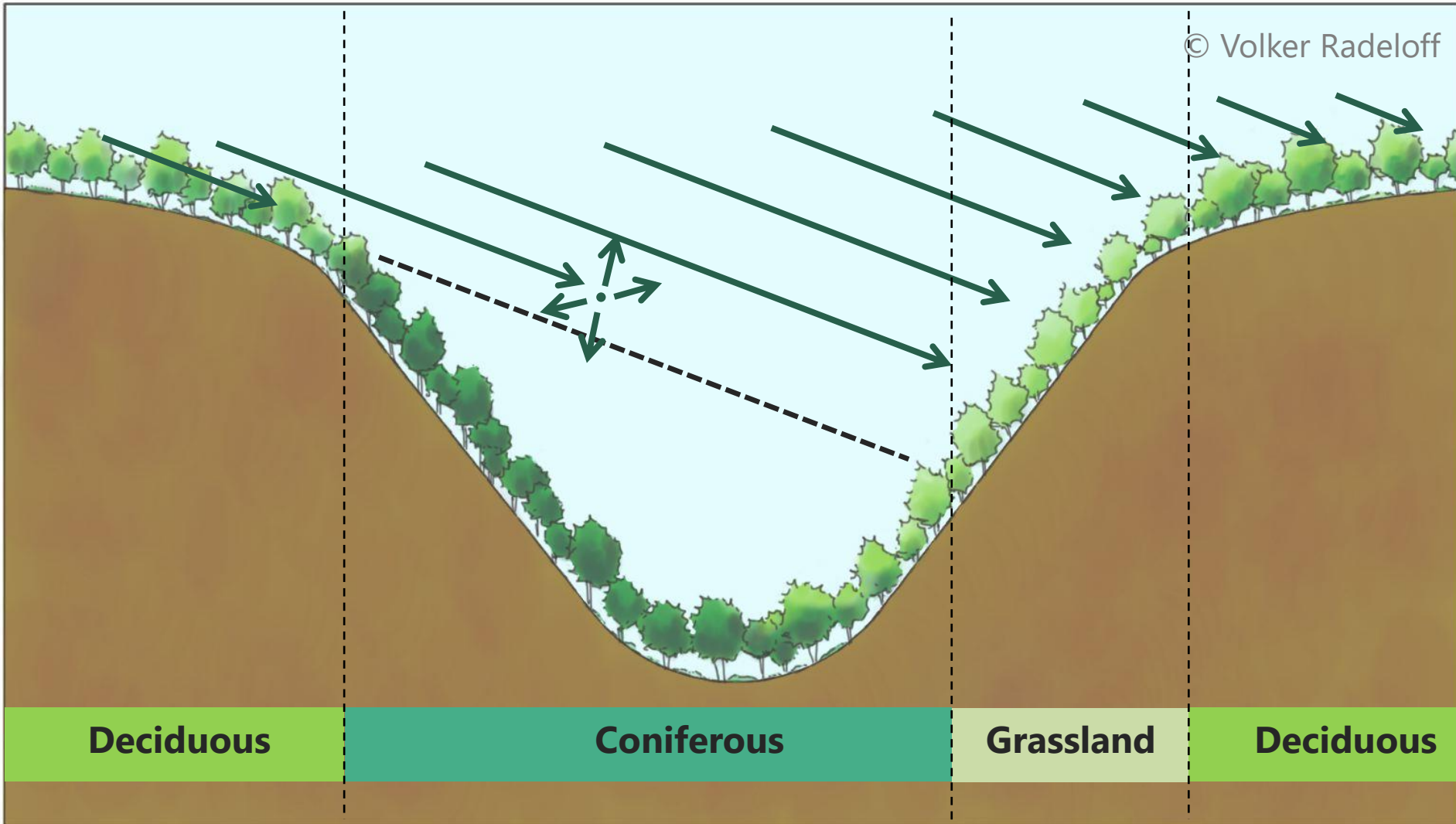




# Illumination of sloped terrain

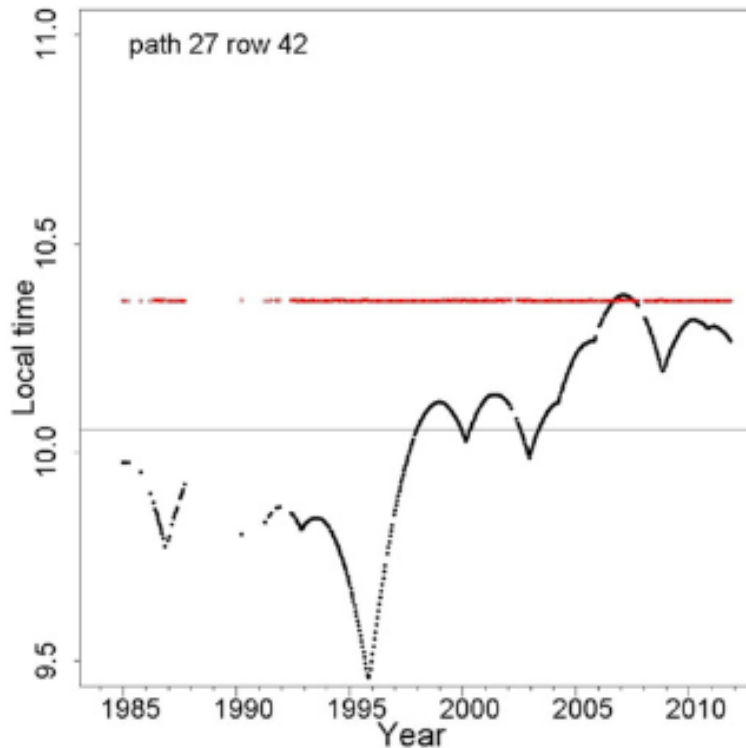


# Illumination of sloped terrain





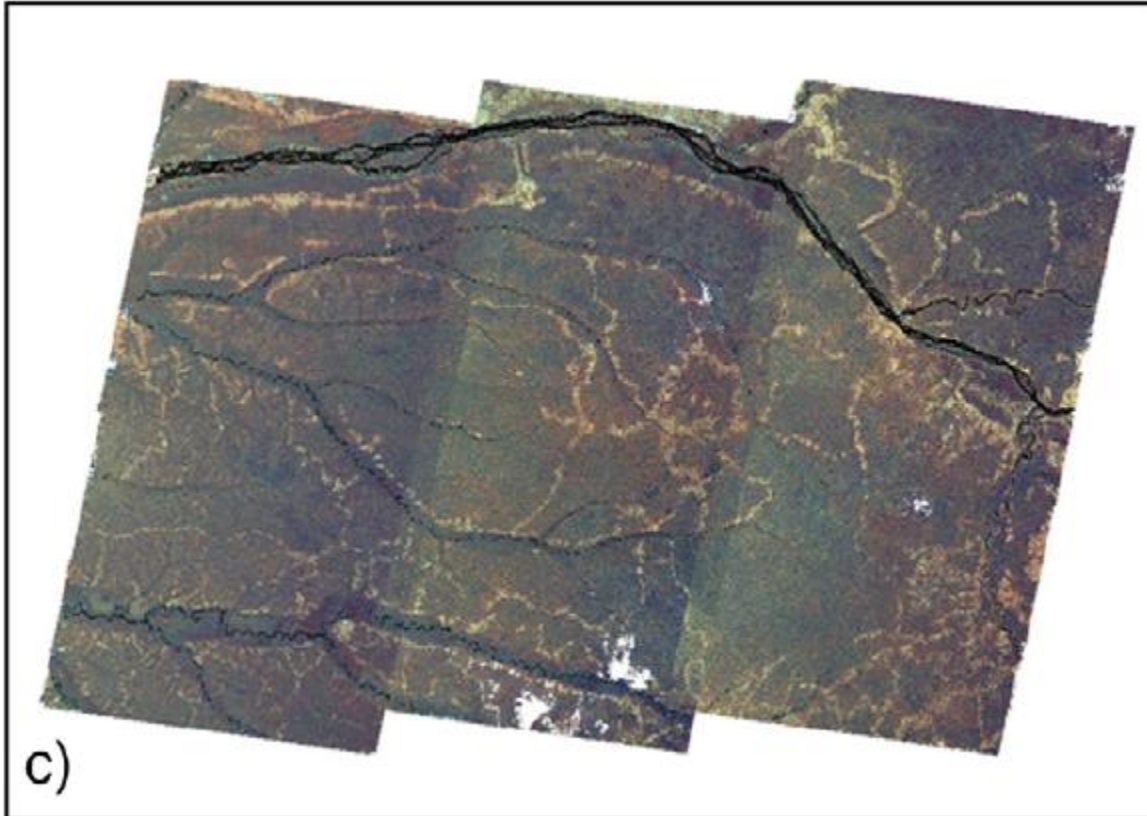
1) Bidirectional reflectance effects are present in satellite reflectance retrievals due to variable solar geometry



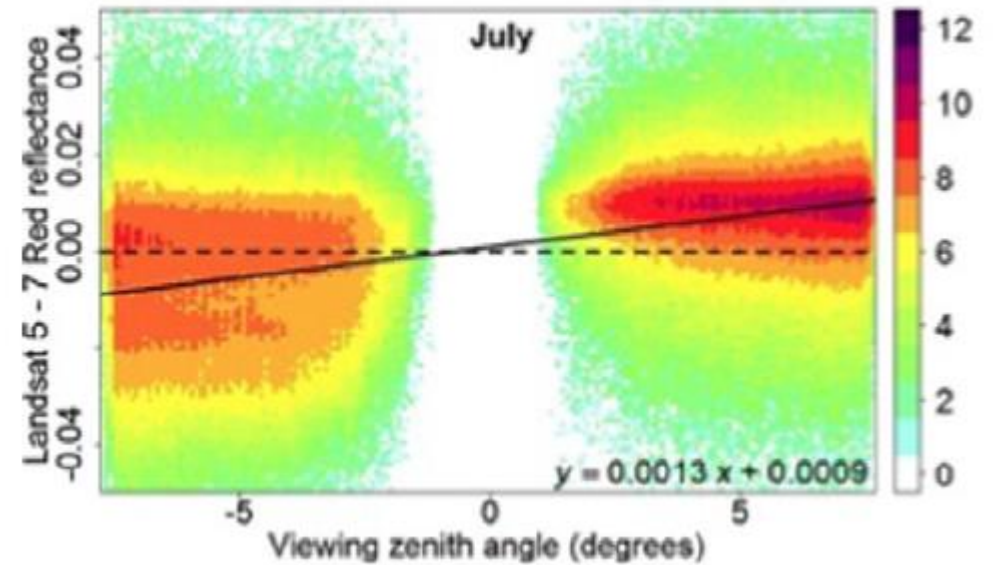
Example: variations in  
Landsat 5 **overpass time**  
between years

Zhang & Roy (2016): <https://doi.org/10.1016/j.rse.2016.08.022>

# BRDF effects



10.1016/j.rse.2007.11.012

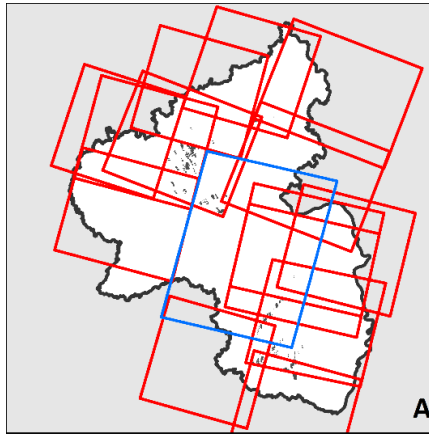


<http://dx.doi.org/10.1016/j.rse.2016.01.023>



# Data processing

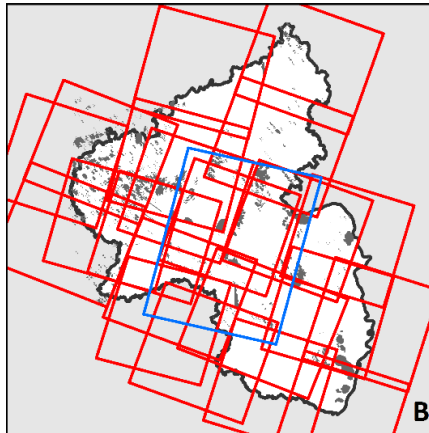
spring



Early-spring acquisition period

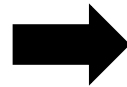
- SPOT 5 Scenes
- RapidEye Scenes
- Total cloud cover

Summer acquisition period



summer

36 individual scenes  
from 2005 to 2011



AtCPro  
Atmospheric Correction Processor for Multi- & Hyperspectral Data

Parameter File ID: D:\David\_Radio\atcpro\LC81970252014157LGN00...

Processing Options:  
 Compute / Document Processing Parameters  
 Process Signature File  
 Process Image File  
 Produce Water Vapour Image

Processing Options:  
 DN -> Reflectance  
 Reflectance -> ToA Radiance  
 Reflectance -> ToA Reflectance  
 DN -> ToA Reflectance

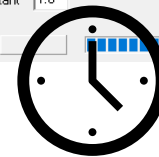
Parameter File Updates: Processing Parameters

Gas absorption parameters: MMLS\_10.dat, E0.dat, H2O - O3 - CO2 - O2 - [CH4], O3 - CO2 - O2 - [CH4], H2O Processing Mode: horizontally stable, H2O Path Length Scaling Factor: 1.00, Water Vapour Coefficient File ID: none selected.

Aerosol Mode: Define Angstrom Relation, Estimation Mode: Inhomogeneous Ground, Scattering Characteristics: Rayleigh and aerosols, Reference Target Type: Water.

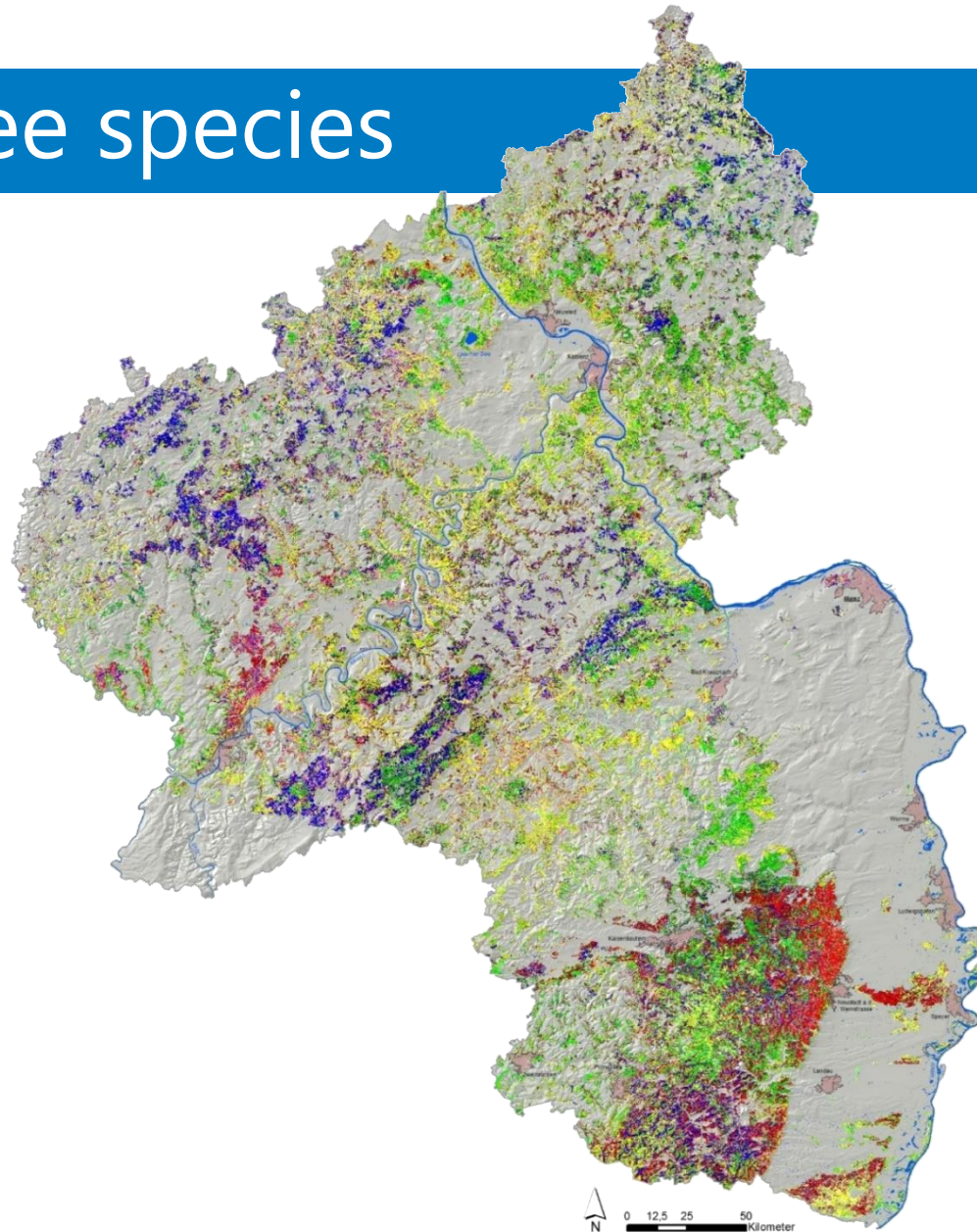
Parameter File Updates: Scene Parameters

Scene Descriptor: Landsat 8/OLI 6 June 2014  
Sensor System: TM 8 OLI  
Acquisition Date: 2014 6 6  
Base Directory: D:\David\_Radio\atcpro\atmdata  
Work Directory: D:\David\_Radio\  
Log File ID: landsat8\_test1\_log  
Wavelength File ID: tm8.wvl  
Calibration File ID: OLI\_Meta\_20140606.cal  
Sensor Altitude: 705,000 km  
Sensor Heading: 190.56



wait 40(?)min, repeat...

# Tree species

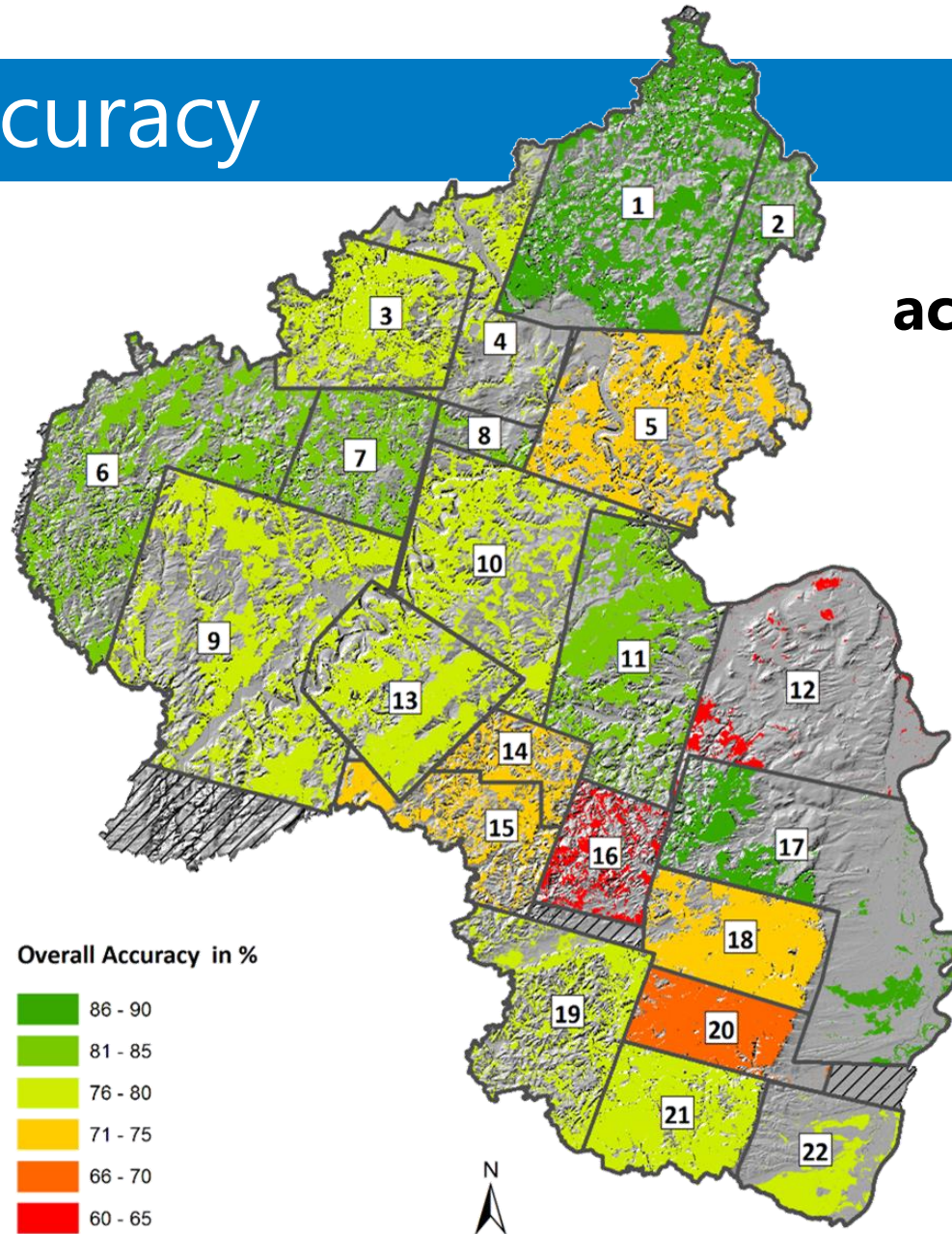


1st tree species map with age classes for RLP (2013)

- Forest extent (OA ~97%)
- Forest type (OA ~ 95%)
- Tree species (OA ~ 71%)





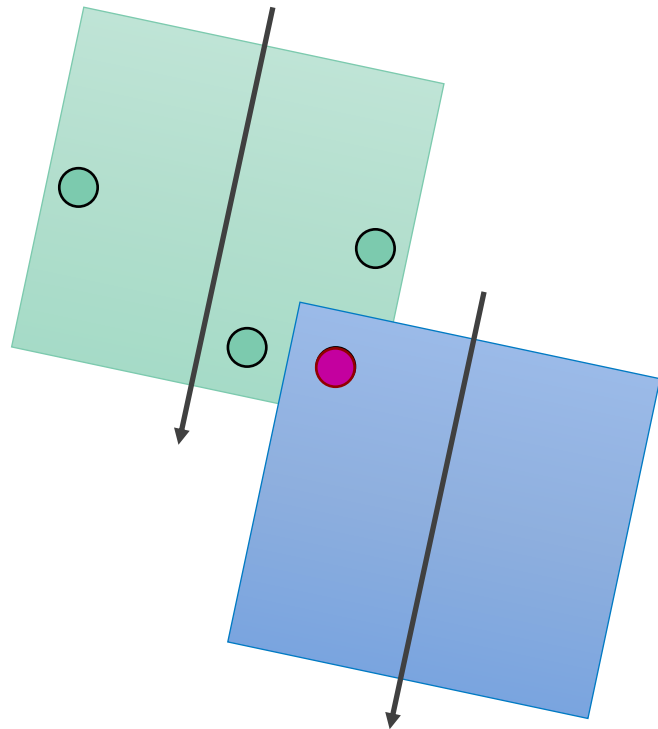


## accuracy varies per processing unit – a lot

### Reasons:

- Different complexity of tree species distribution
- Generalization issues for some processing units
- **Data:** different years and suboptimal phenological phases, off-nadir pointing, no multi-temporal coverage for some parts

# What we want to have!



## Goal

increase consistency and comparability through space and time to allow

- consistent usage across large areas
- consistent usage across time
- consistent usage across sensors

And everything fully automatic +

usage of satellite data with better standardization of observation





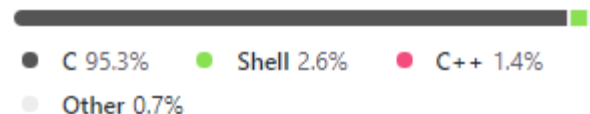
## Framework for Operational Radiometric Correction for Environmental Monitoring

**all-in-one processing engine** for medium-resolution Earth Observation image archives to perform all essential tasks in a typical EO Analysis workflow: **from data to information**

Open Source (GPL v.  $\geq 3$ )  
[github.com/davidfrantz/force](https://github.com/davidfrantz/force)

Releases 20

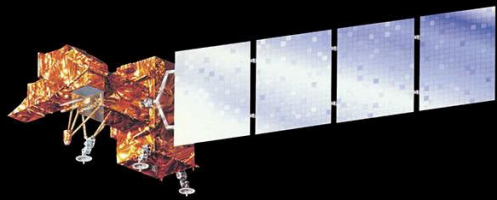
v.3.7.8 Latest  
 16 days ago



# Supported Satellites

## Landsat 4 – 5

Landsat 4: 1982 – 1993  
Landsat 5: 1984 – 2013

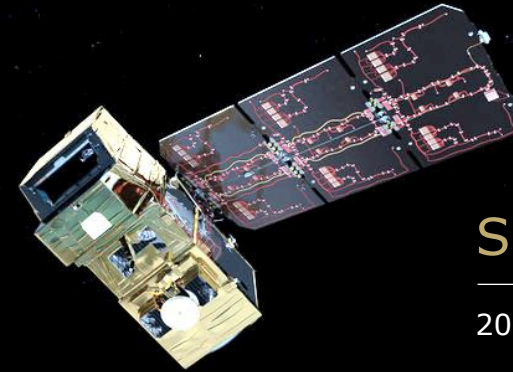


## Landsat 7

1999 – present

## Landsat 8

2013 - present



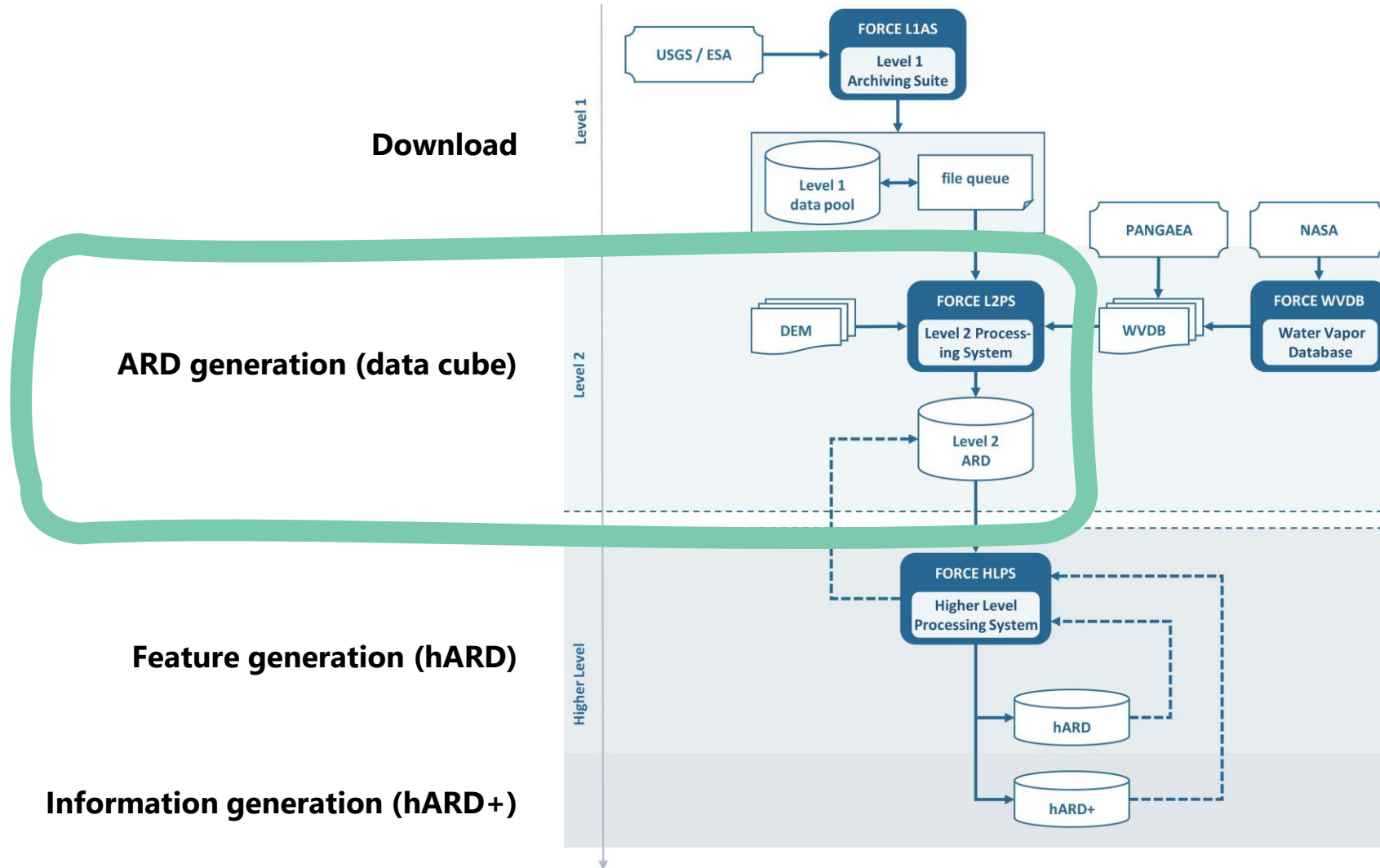
## Sentinel-2 A/B

2015/2017 - present

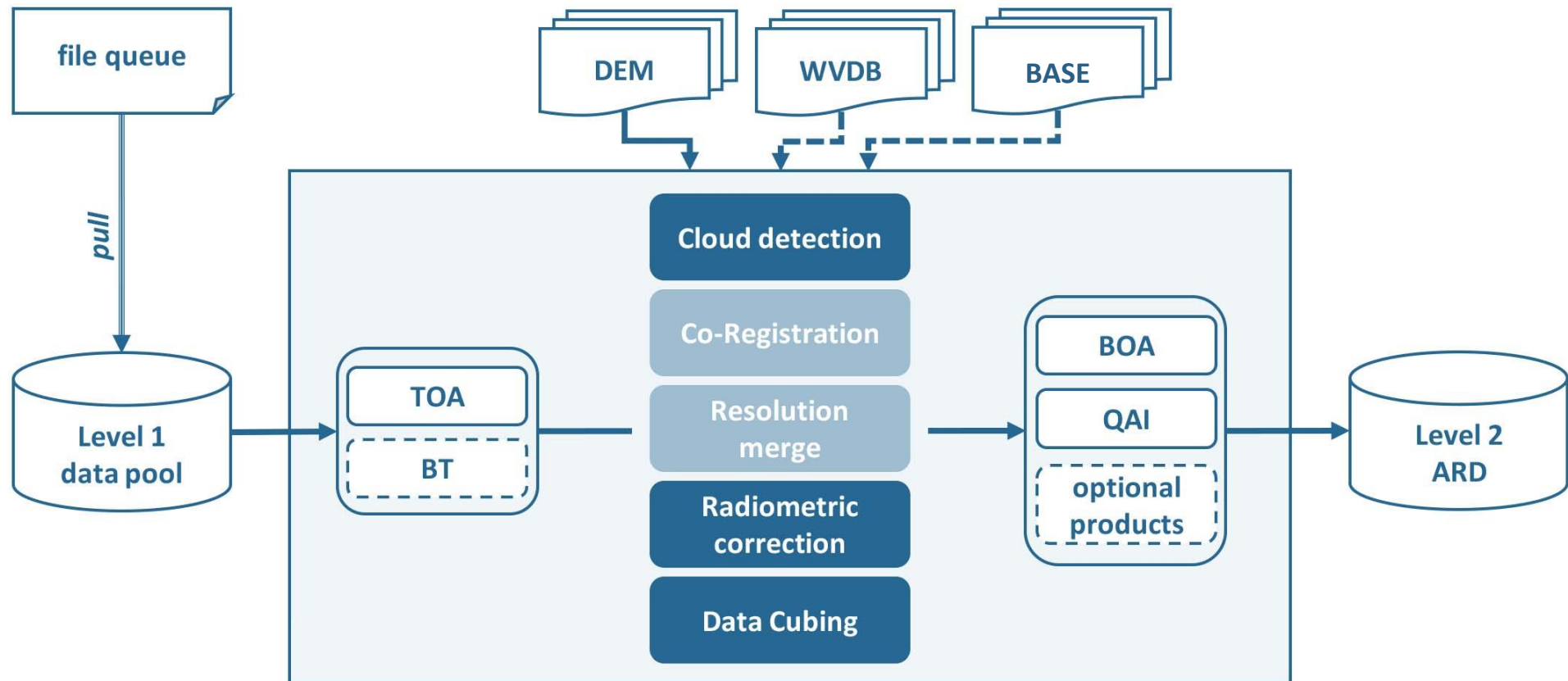
<https://www.usgs.gov/media/images/landsat-program>  
<https://www.esa.int/spaceinimages/Images>



# High Level Overview

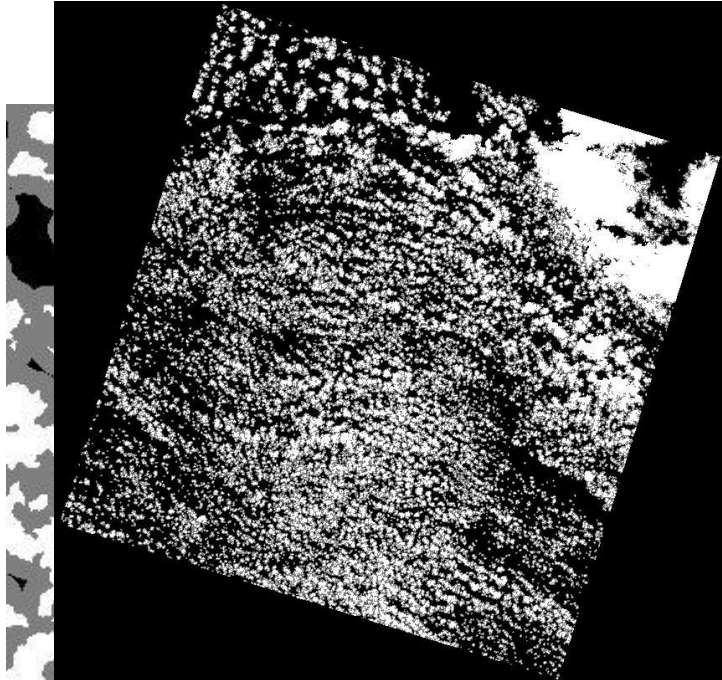


# Level 2 Processing / ARD Generation

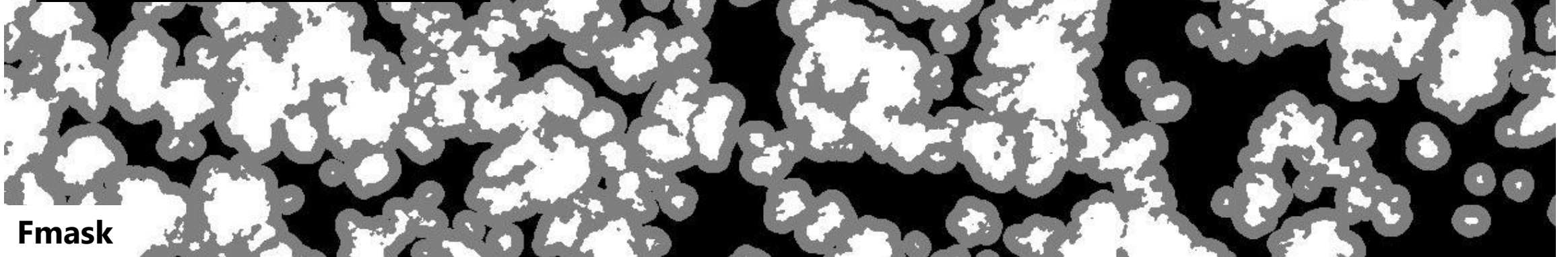




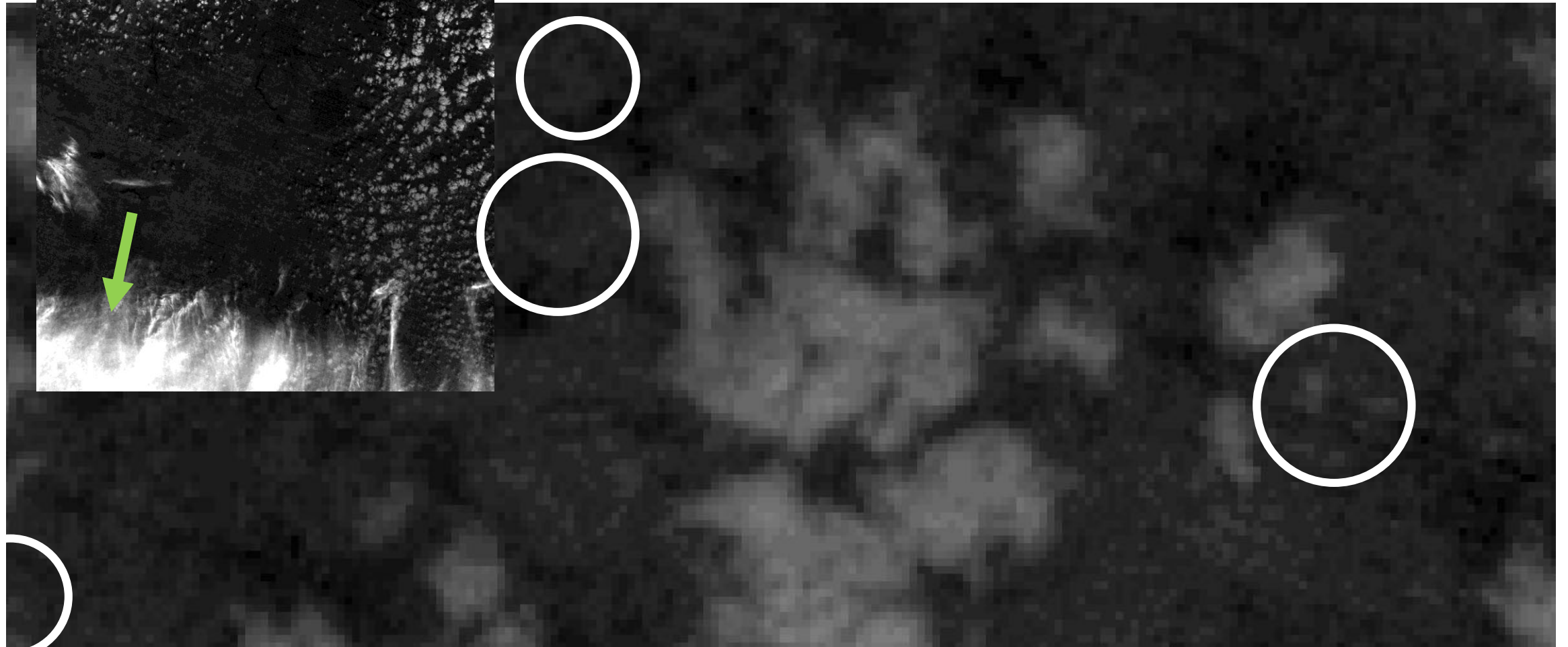
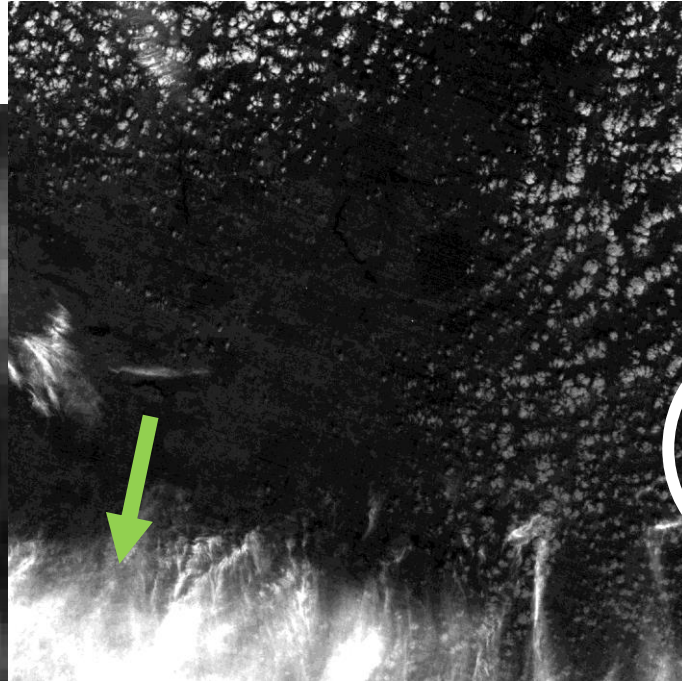
# Thermal Infrared for cloud detection



**Zhu, Woodcock** (2012): Object-based cloud and cloud shadow detection in Landsat imagery. *Remote Sensing of Environment*  
**Frantz, Röder, Udelhoven, Schmidt** (2015): Enhancing the Detectability of Clouds and Their Shadows in ...: Extending Fmask. *IEEE GRSL*  
**Frantz, Röder, Stellmes, Hill** (2016): An Operational Radiometric Landsat Preprocessing Framework .... *IEEE TGRS*

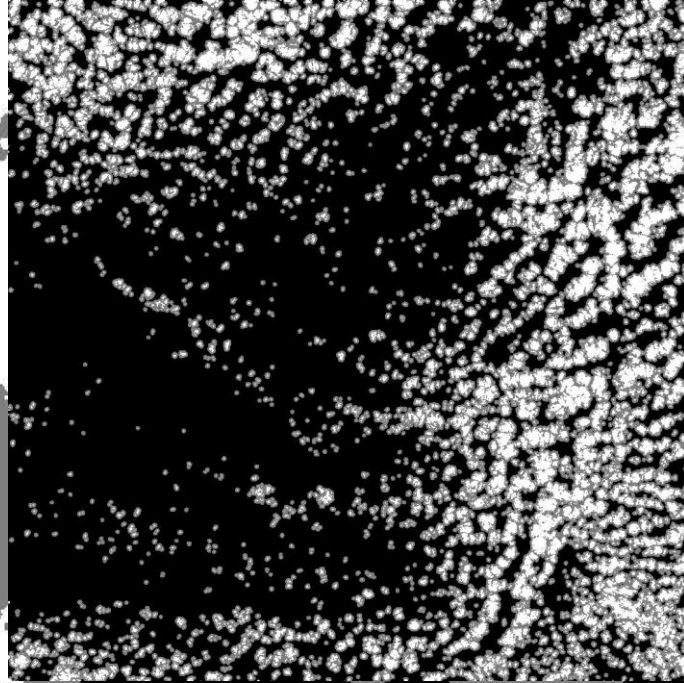


# The Cirrus band

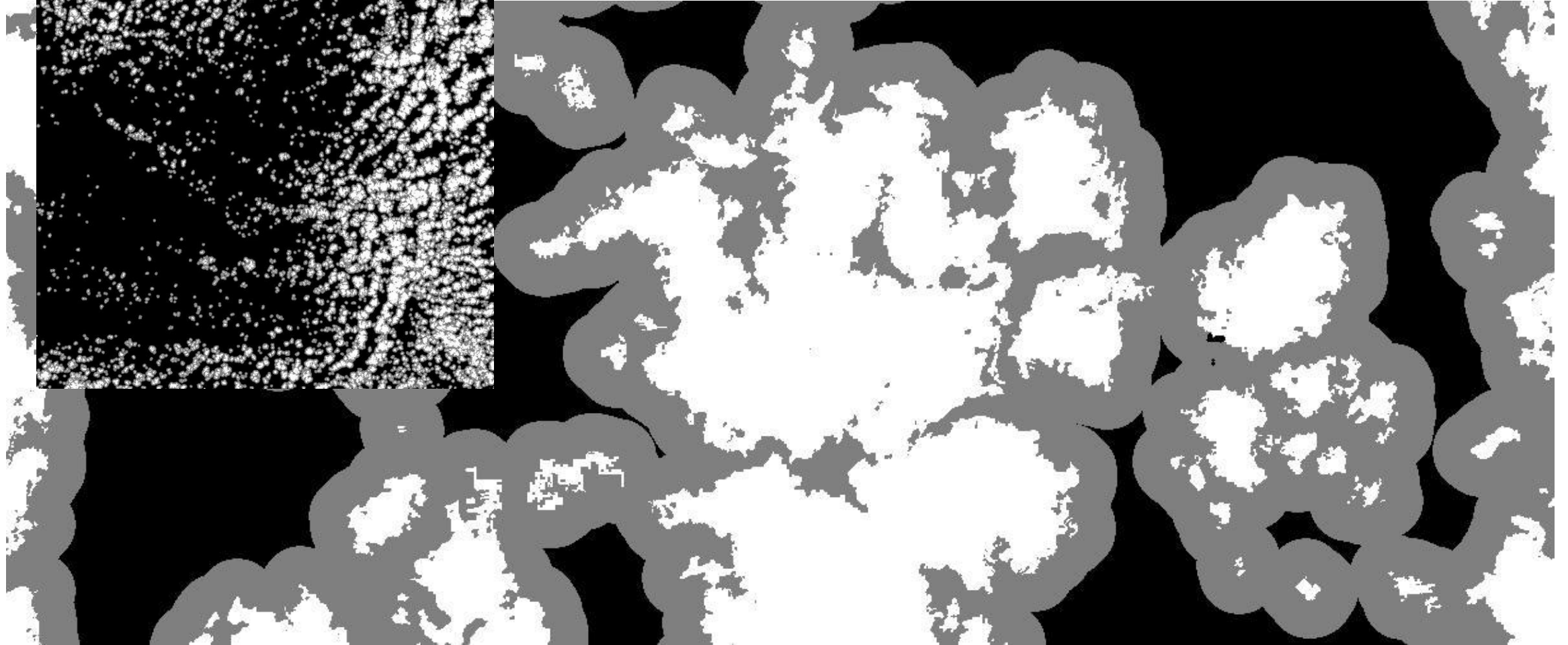




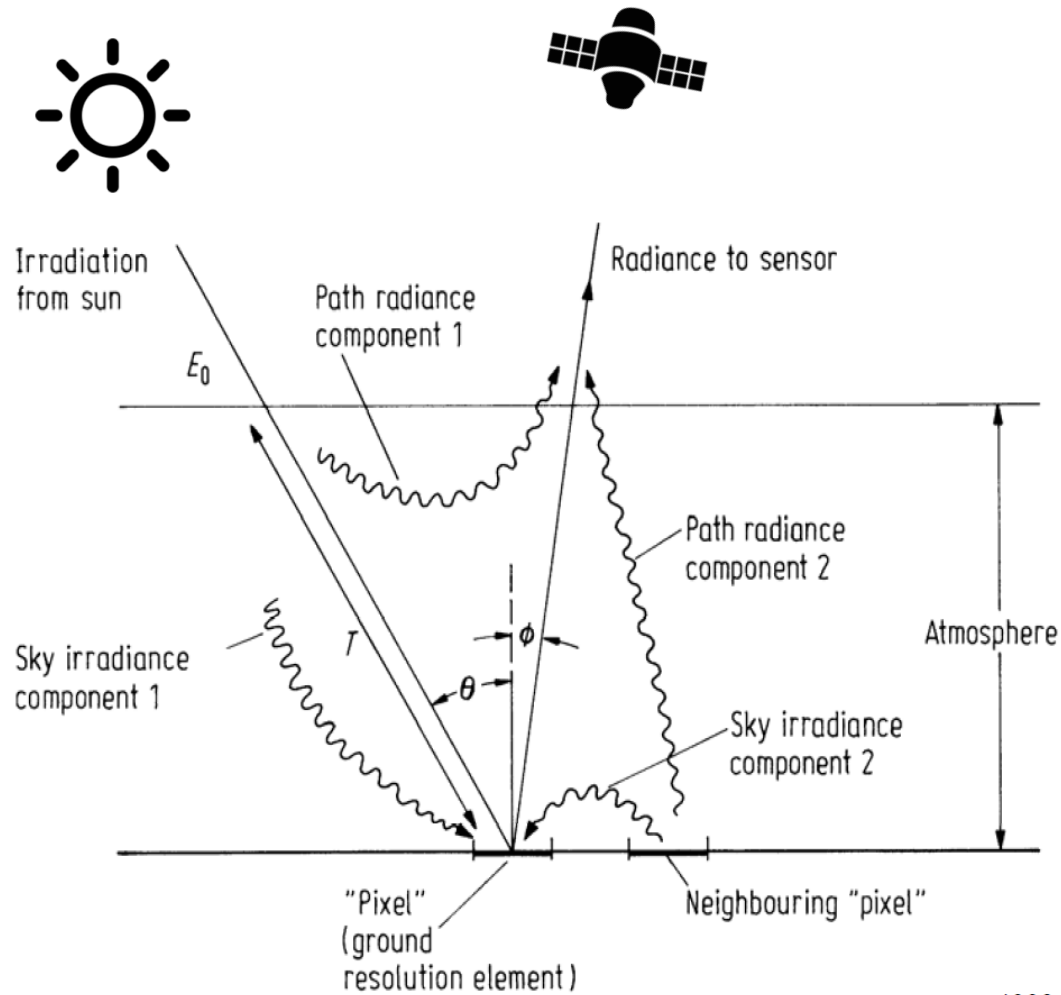
# Parallax effects



**Frantz, Haß, Uhl, Stoffels, Hill (2018):** Improvement of the Fmask algorithm for Sentinel-2 images: Separating clouds from bright surfaces based on parallax effects. *Remote Sensing of Environment*



# Atmospheric Correction



Richards (1993)

TOA reflectance  $\rho^*$   $\rightarrow$  BOA reflectance  $\rho$

Radiative transfer modelling:

$$\rho = A \cdot c \cdot \frac{\rho^* / T_g(\mu_s, \mu_v) \cdot [1 - \langle \rho \rangle \cdot s] - \rho_p \cdot [1 - \langle \rho \rangle \cdot s] - T(\mu_s) \cdot t_s(\mu_v) \cdot \langle \rho \rangle}{T(\mu_s) \cdot t_d(\mu_v)}$$

Atmospheric scattering

- Optical depths  $\tau, \tau_r, \tau_a$
- Path reflectance  $\rho_p$
- Spherical albedo  $s$
- Total, direct, scattered (diffuse) transmittances  $T, t_d, t_s$

Gaseous transmission  $T_g$

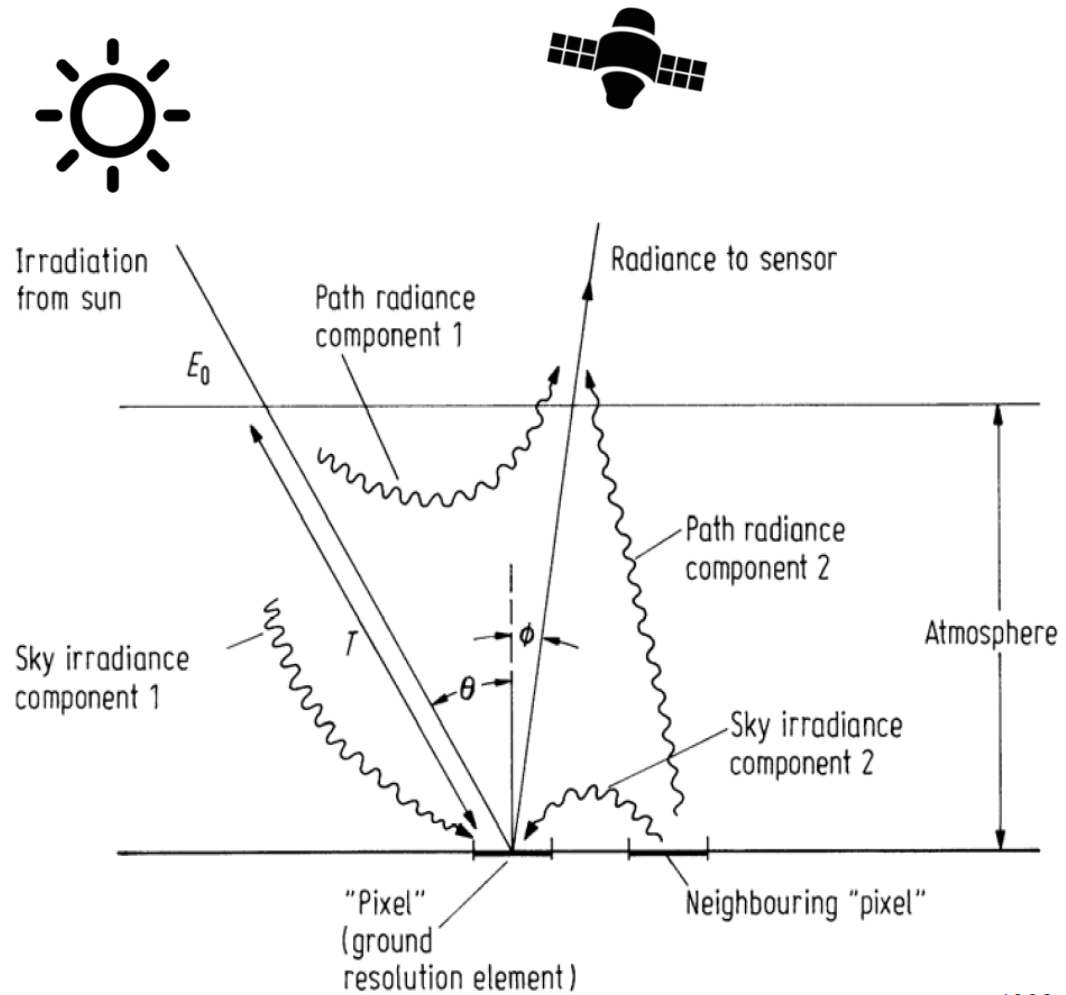
Background contribution  $\langle \rho \rangle \rightarrow$  adjacency effect

Topographic correction factor  $A$

BRDF correction factor  $c$



# Atmospheric Correction



Richards (1993)

Bottom-of-Atmosphere reflectance

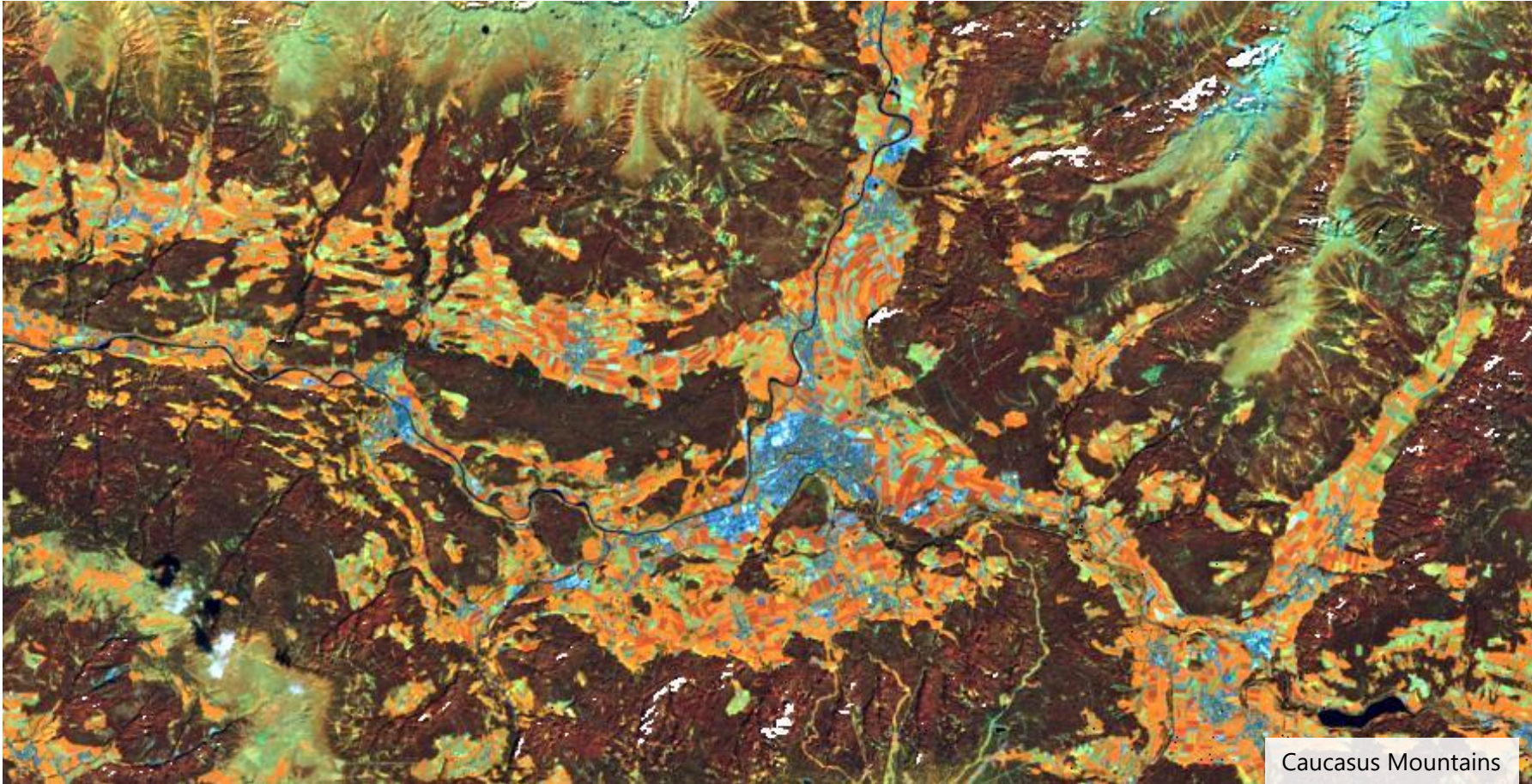


2018-08-06

2018-08-03



# Topographic correction



Integrated atmospheric +  
topographic correction

→ enhanced C-correction

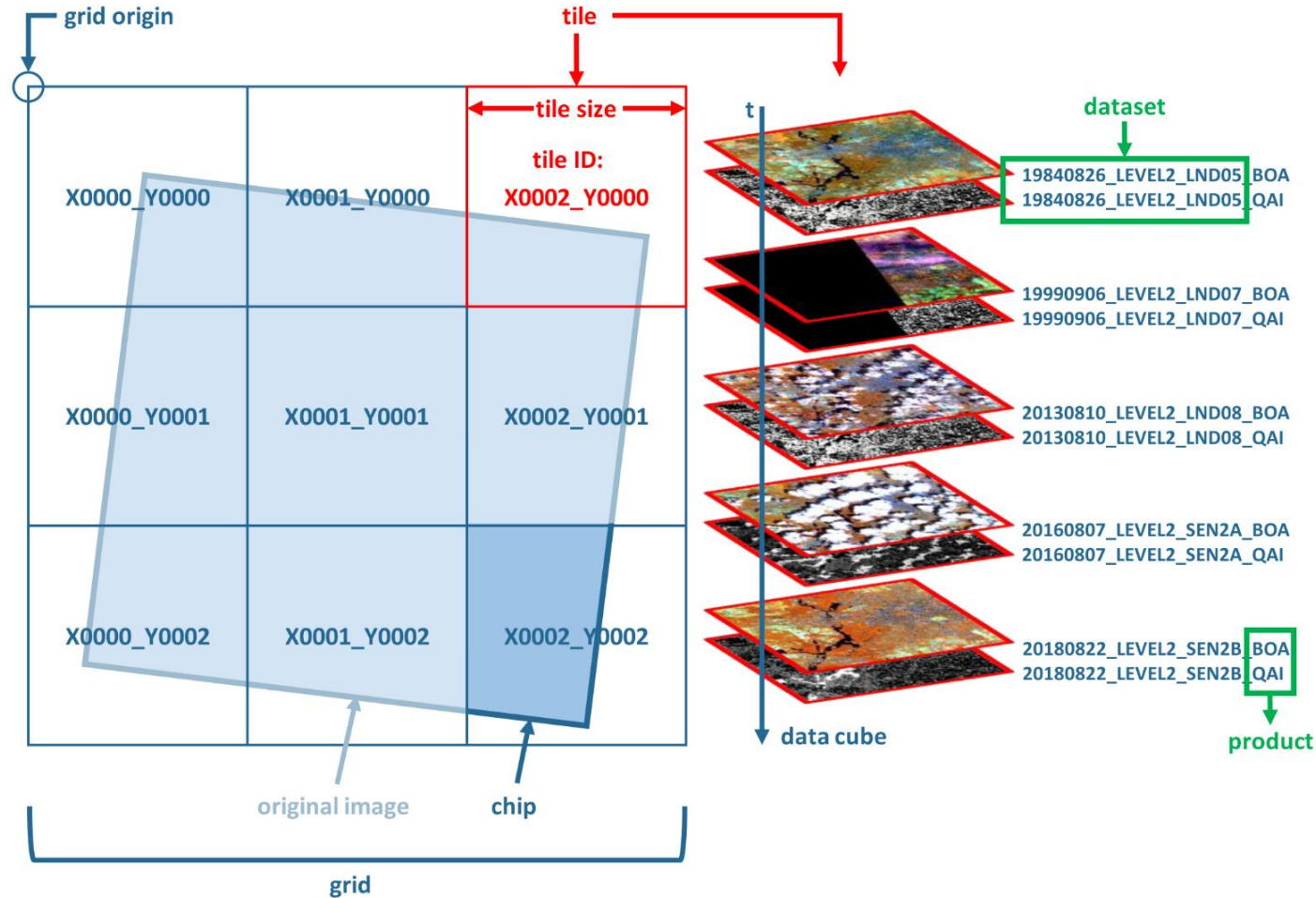
$$A_{\lambda} = (\cos \Theta_S + C_{\lambda} h_0^{-1}) / (\cos i + C_{\lambda} h_0^{-1} h)$$

white = deep shadows

**Frantz**, Röder, Stellmes, Hill (2016). An Operational Radiometric Landsat Preprocessing Framework for Large-Area Time Series Applications. *IEEE TGRS* 54

Buchner, Yin, **Frantz**, Kuemmerle, Askerov, Bakuradze, Bleyhl, Elizbarashvili, Komarova, Lewińska, Rizayeva, Sayadyan, Tan, Tepanosyan, Zazanashvili, Radeloff (2020): Land-cover change in the Caucasus Mountains since 1987 based on the topographic correction of multi-temporal Landsat composites. *Remote Sensing of Environment*

# Data Management: the Data Cube

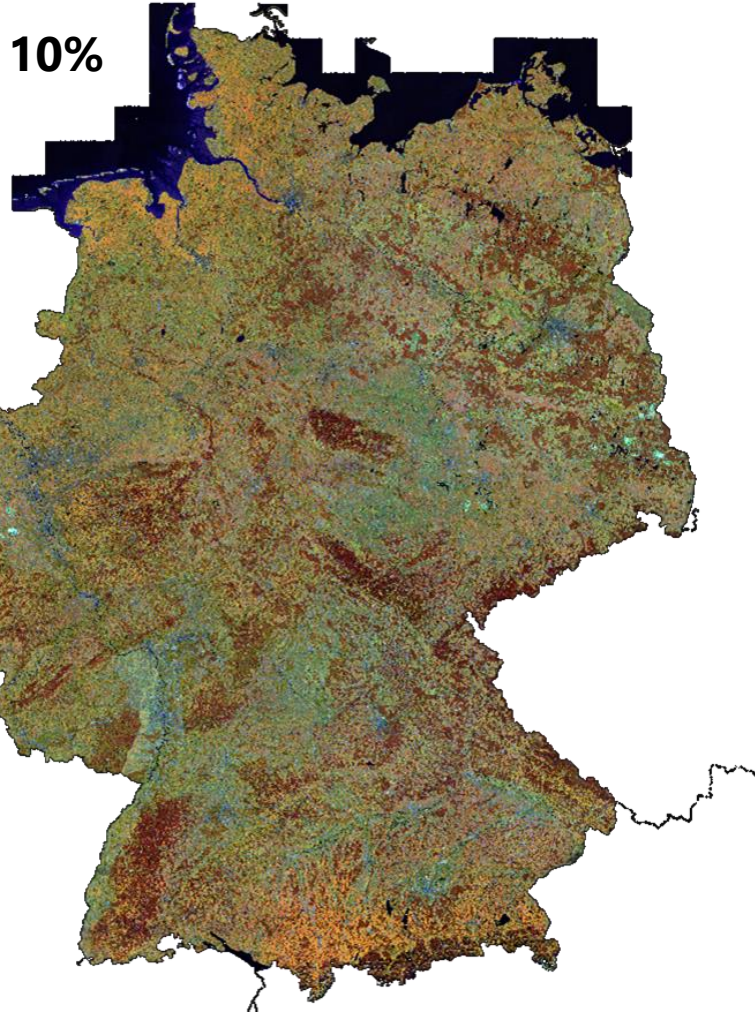


Frantz (2019). FORCE—Landsat + Sentinel-2 Analysis Ready Data and Beyond. *Remote Sensing* 11

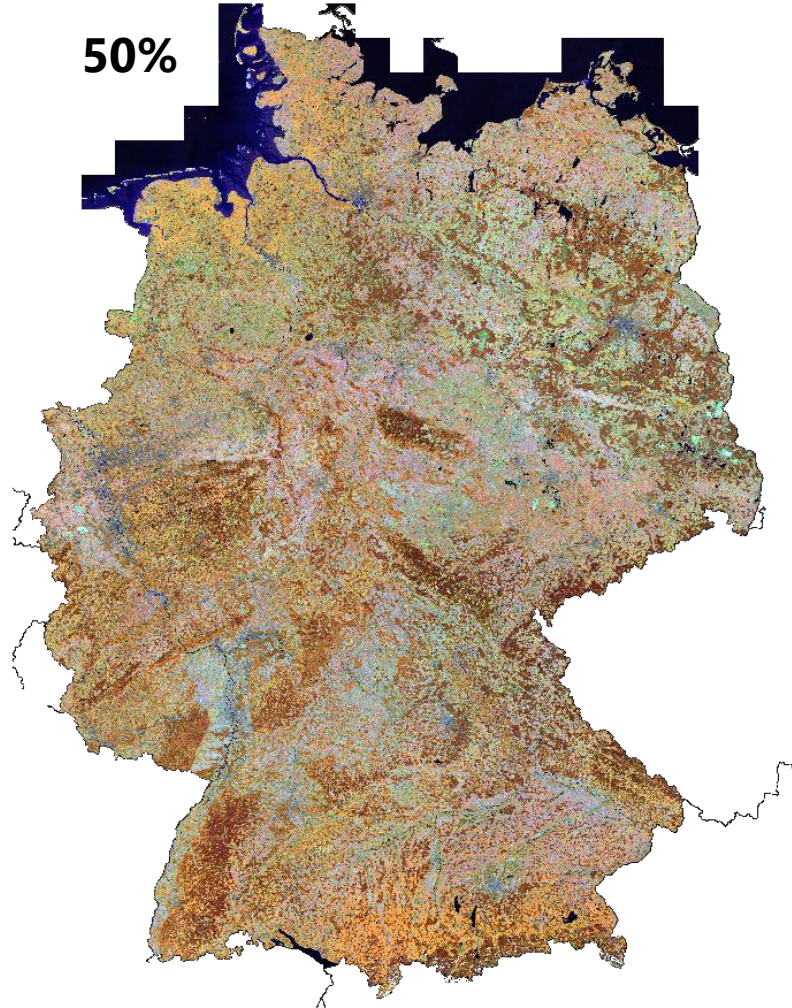


# highly Analysis Ready Data

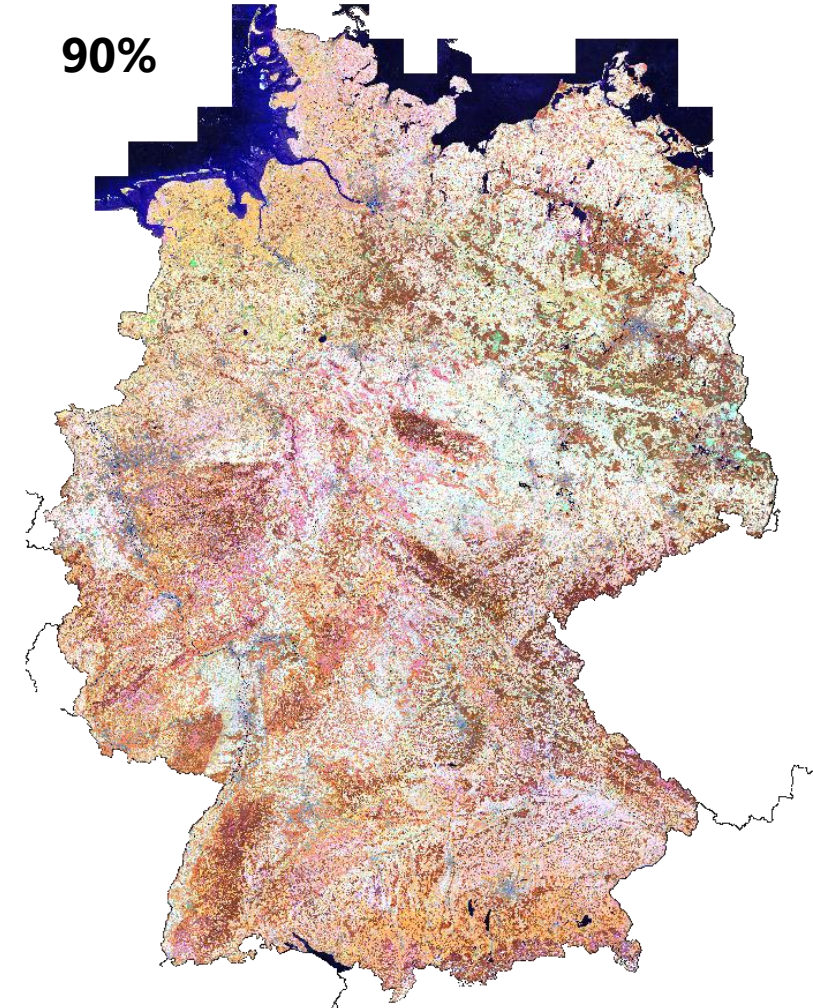
10%



50%



90%

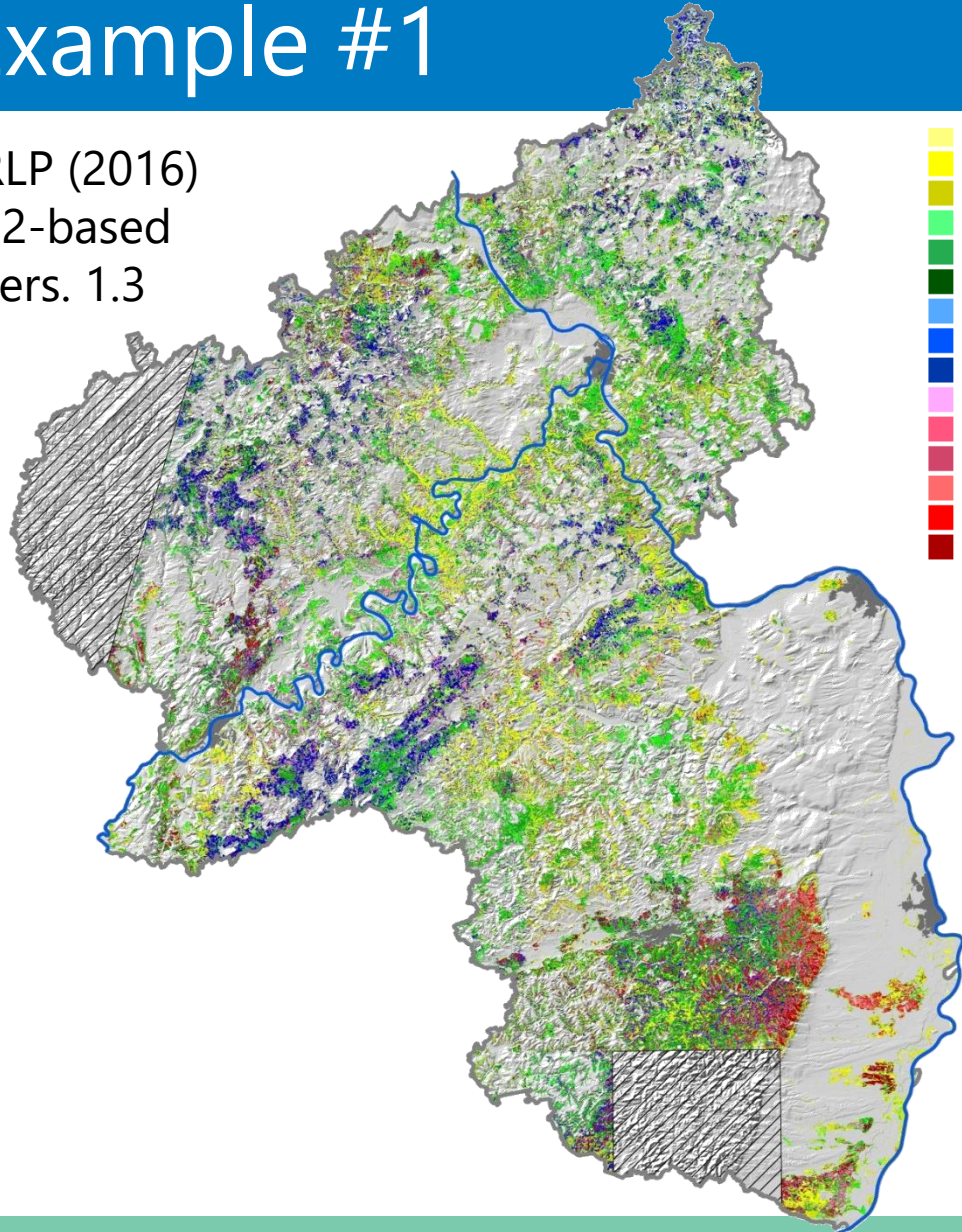


RGB = NIR / SWIR1 / RED [same stretch for all]

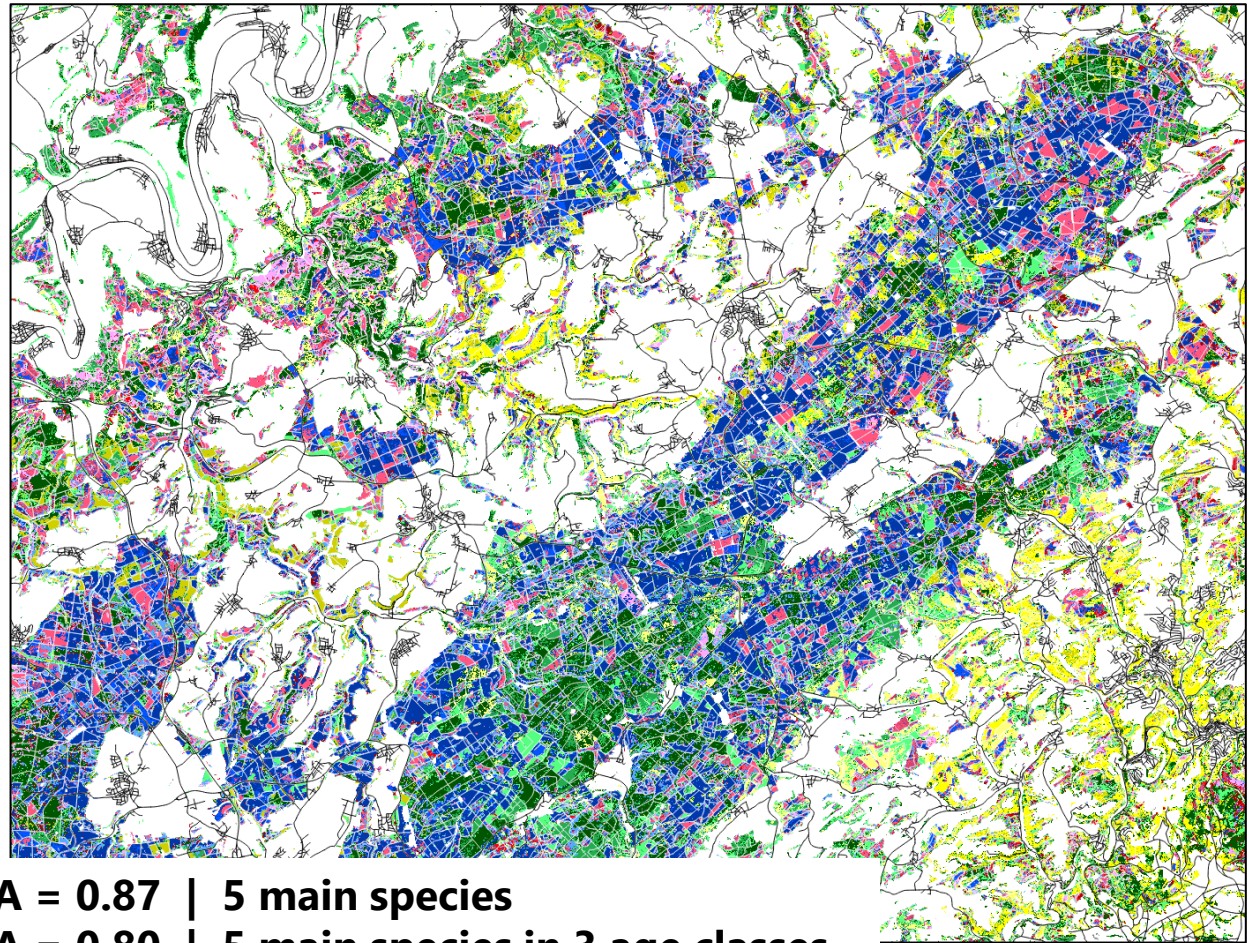


# Example #1

RLP (2016)  
S2-based  
vers. 1.3



- Ei Qua
- Ei Dim
- Ei Rei
- Bu Qua
- Bu Dim
- Bu Rei
- Fi Qua
- Fi Dim
- Fi Rei
- Dou Qua
- Dou Dim
- Dou Rei
- Ki Qua
- Ki Dim
- Ki Rei

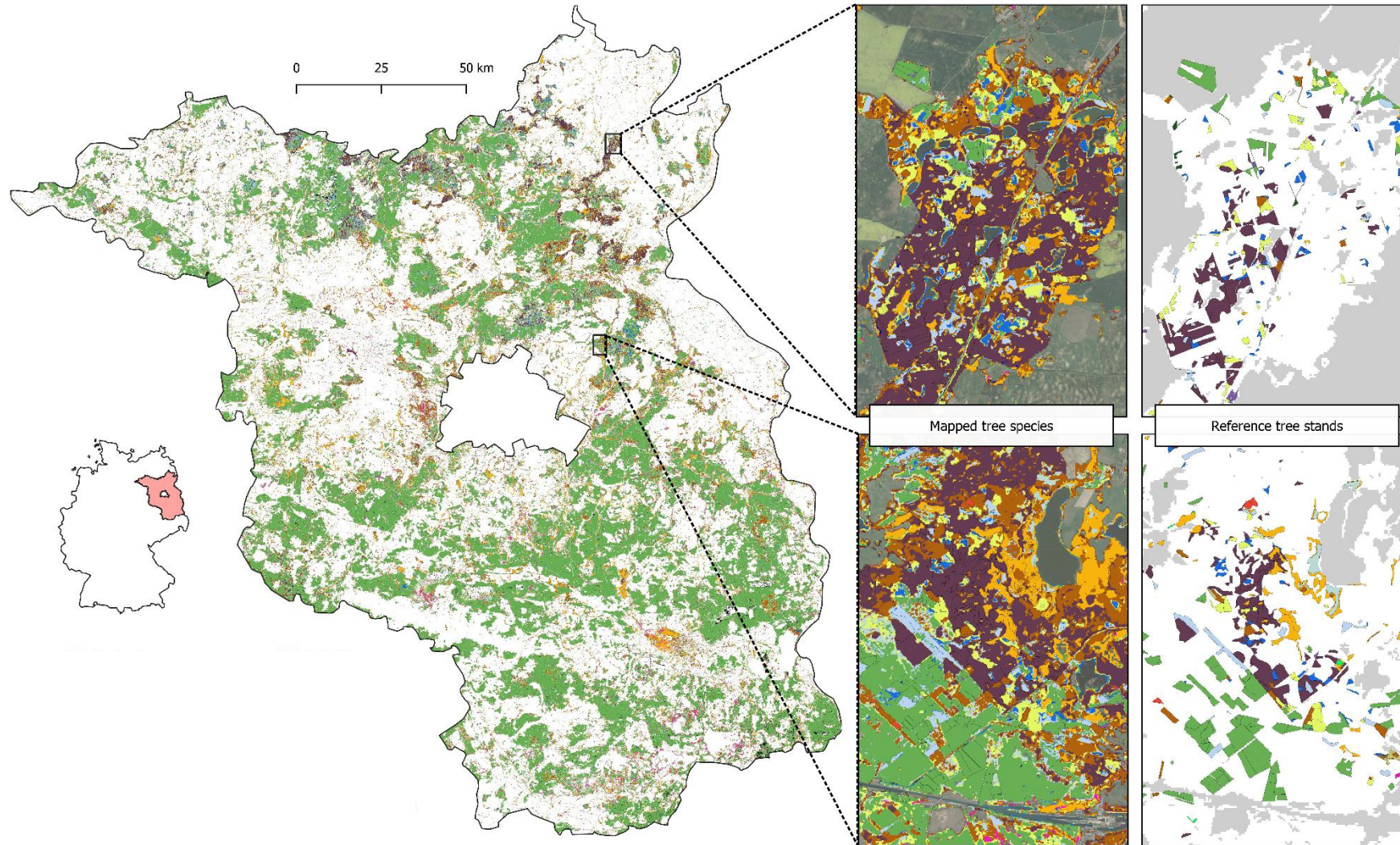


**OA = 0.87 | 5 main species**

**OA = 0.80 | 5 main species in 3 age classes**



# Example #2

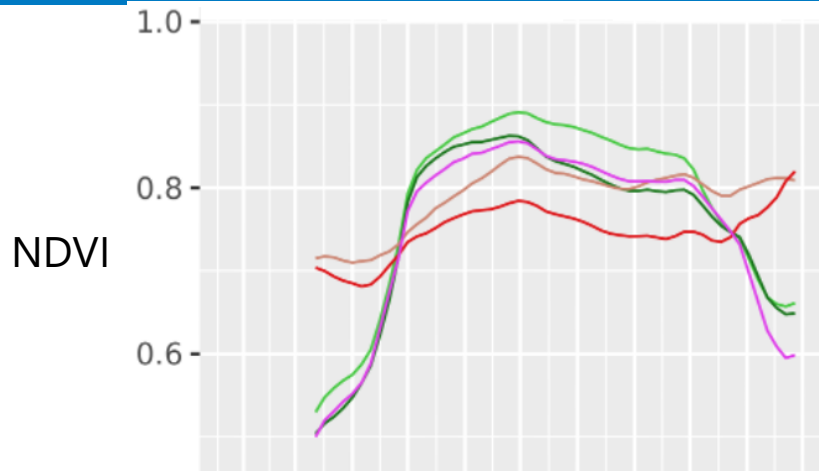
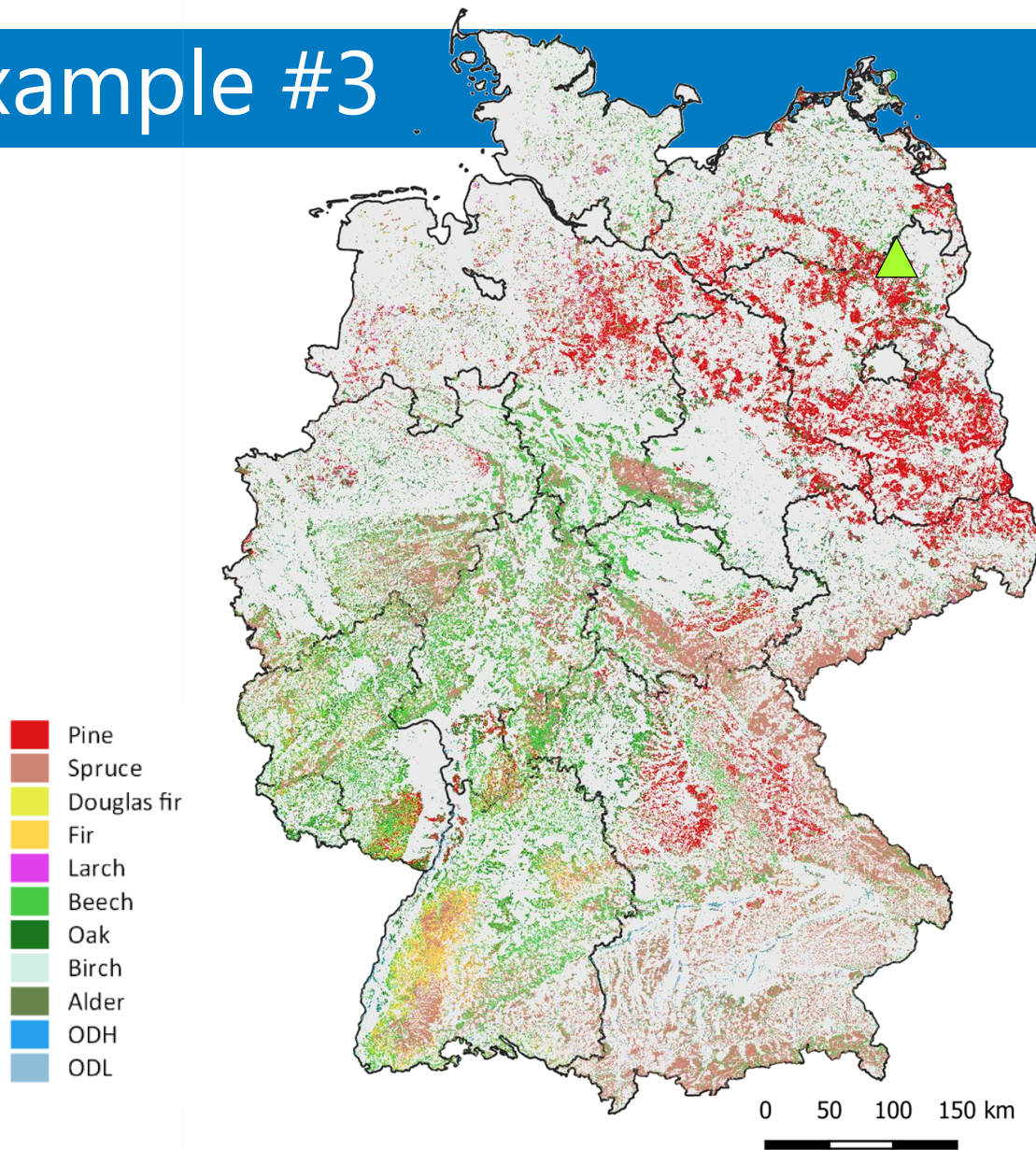


- Scots pine
- European beech
- Silver birch
- Red & Common alder
- Common & Sessile oak
- European & Japanese larch
- Norway spruce
- Douglas fir
- Red oak
- Robinia
- European ash
- Poplar
- Weymouth pine
- Black pine
- Hornbeam
- Great maple
- Small-leaved lime

Hemmerling, J., Pflugmacher, D., & Hostert, P. (2021). Mapping temperate forest tree species using dense Sentinel-2 time series. *Remote Sensing of Environment*, 267, 112743.

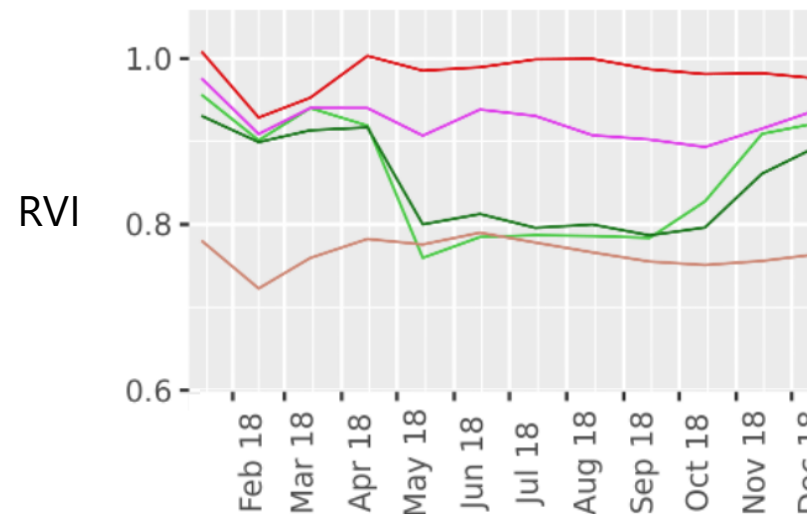


# Example #3

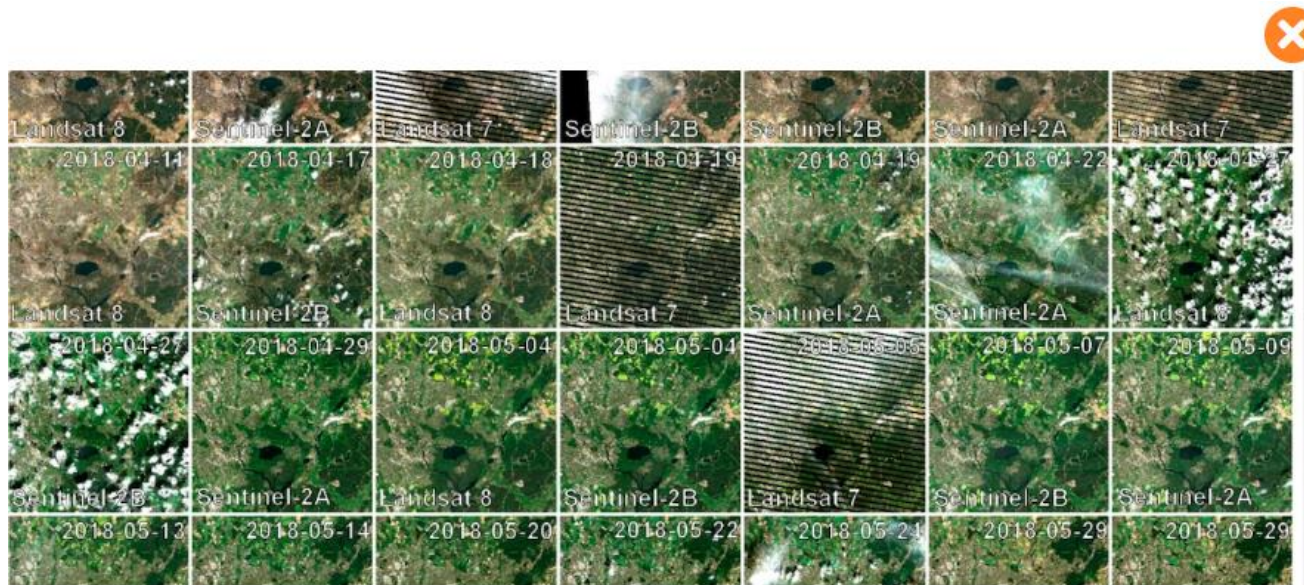


Blickensdörfer, L. et al.  
*(in review)*

— Beech — Oak — Spruce — Pine — Larch



# Do I need to preprocess all data on my own?



## FORCE DataCube Collection

Der FORCE DataCube enthält eine Sammlung analysefähiger Landsat- und Sentinel-2-Daten. Die multispektralen optischen Bilder haben eine räumliche Auflösung von 10m bis 30m und sind für Deutschland von 1984 bis heute verfügbar. Sie können z.B. genutzt werden, um den Zustand und die Prozesse auf der Erdoberfläche zu überwachen.

# FORCE Data Cube Collection 1

## Landsat 4, 5, 7, 8, 9

Collection 2  
Level 1 TP, Tier 1  
1984 – today  
cc < 70%

## Sentinel-2 A/B

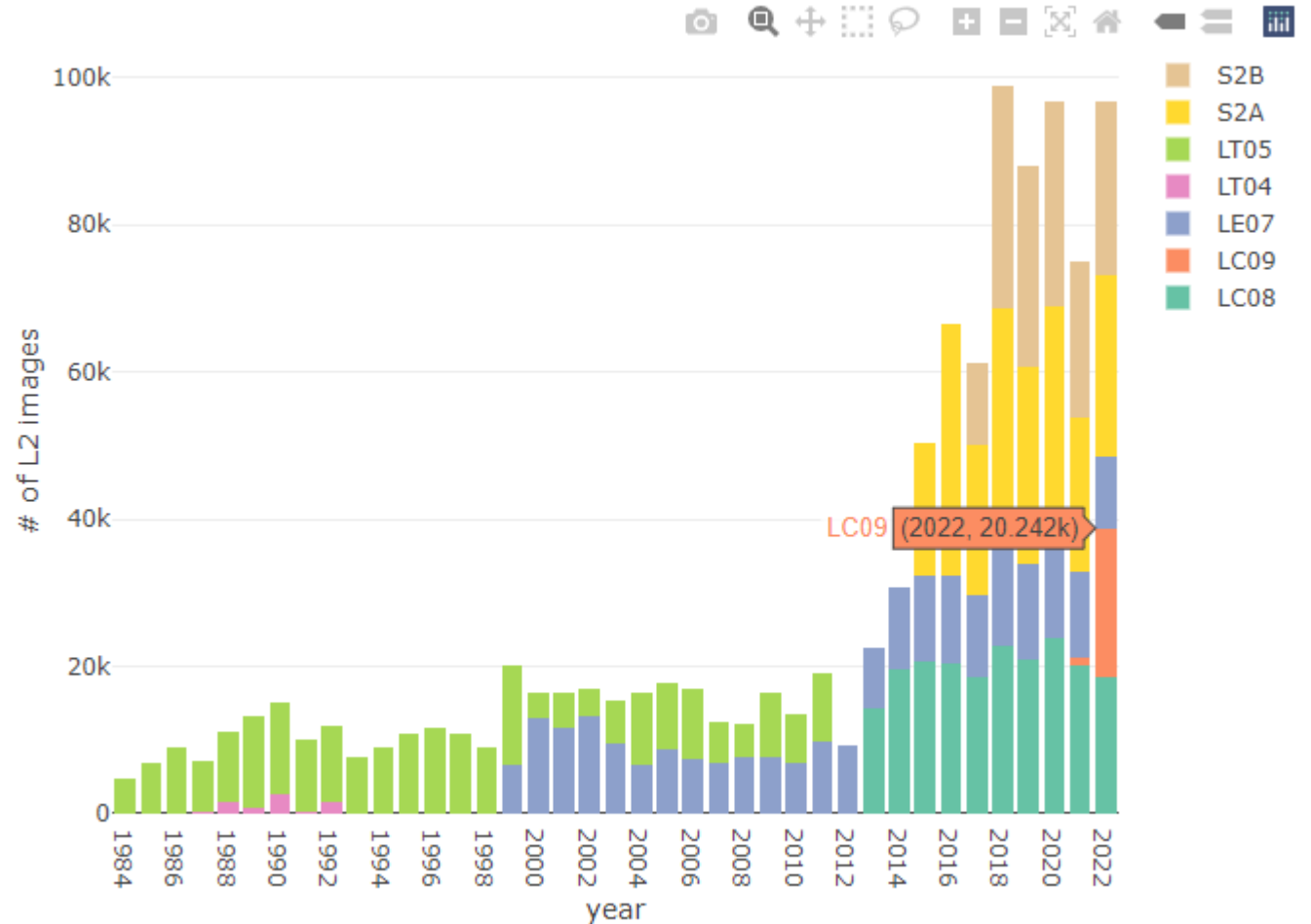
*no collection*  
Level 1C  
2015 – today  
cc < 70%

DEM: Copernicus DEM @30m

**Total ARD cube: 21TB+**  
**30 x 30km tiles**  
**EPSG: 3035**

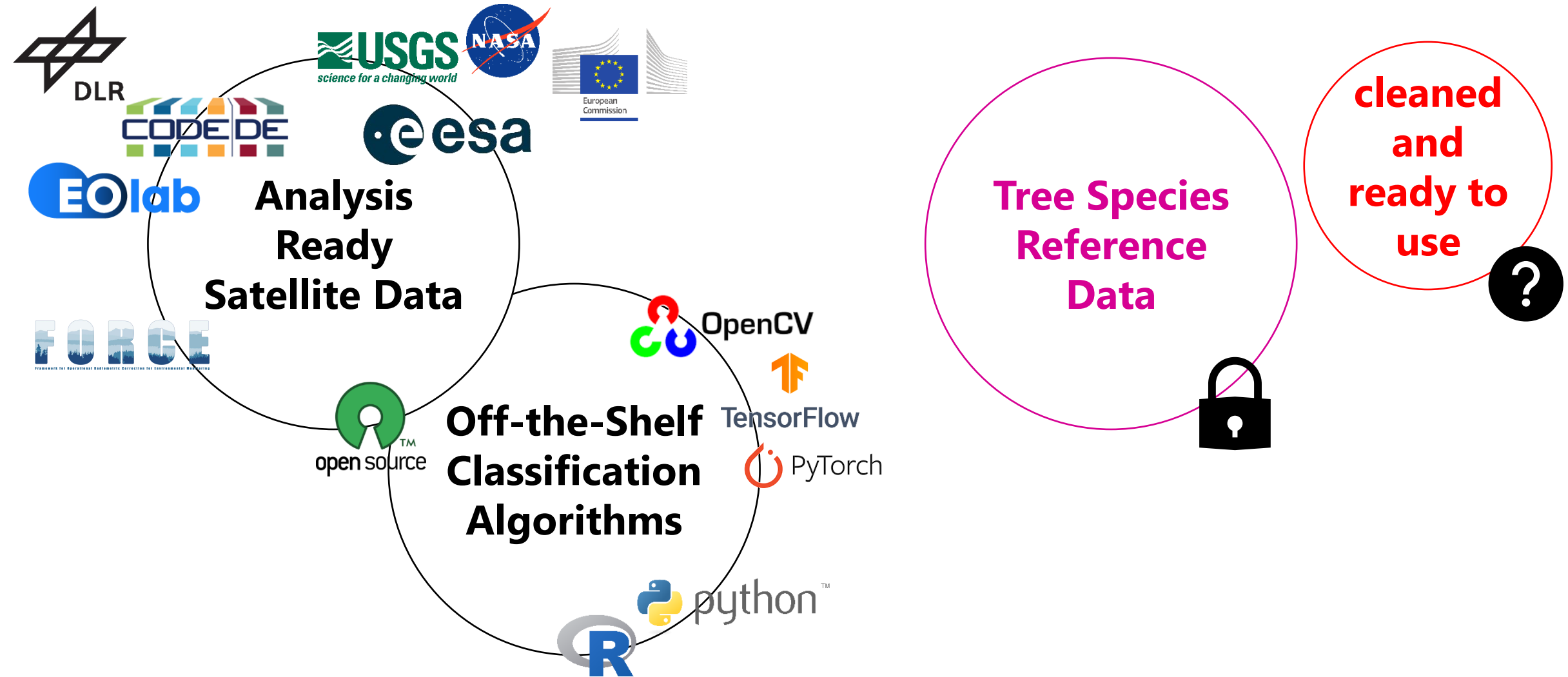


\* nightly update





# Tree Species Classification



## **Contact**

JProf. Dr. David Frantz  
david.frantz@uni-trier.de  
twitter.com/d\_frantz

## **Software**

[github.com/davidfrantz/force](https://github.com/davidfrantz/force)

## **Documentation**

[force-eo.readthedocs.io](https://force-eo.readthedocs.io)

## **Data Cube on CODE-DE / EOLab**

[github.com/CODE-DE-EO-Lab/  
community\\_FORCE](https://github.com/CODE-DE-EO-Lab/community_FORCE)