Die Erde im Anthropozän:
Der Blick aus dem Weltall mit Sentinel-1

Wolfgang Wagner

Department für Geodäsie und Geoinformation
Technische Universität Wien

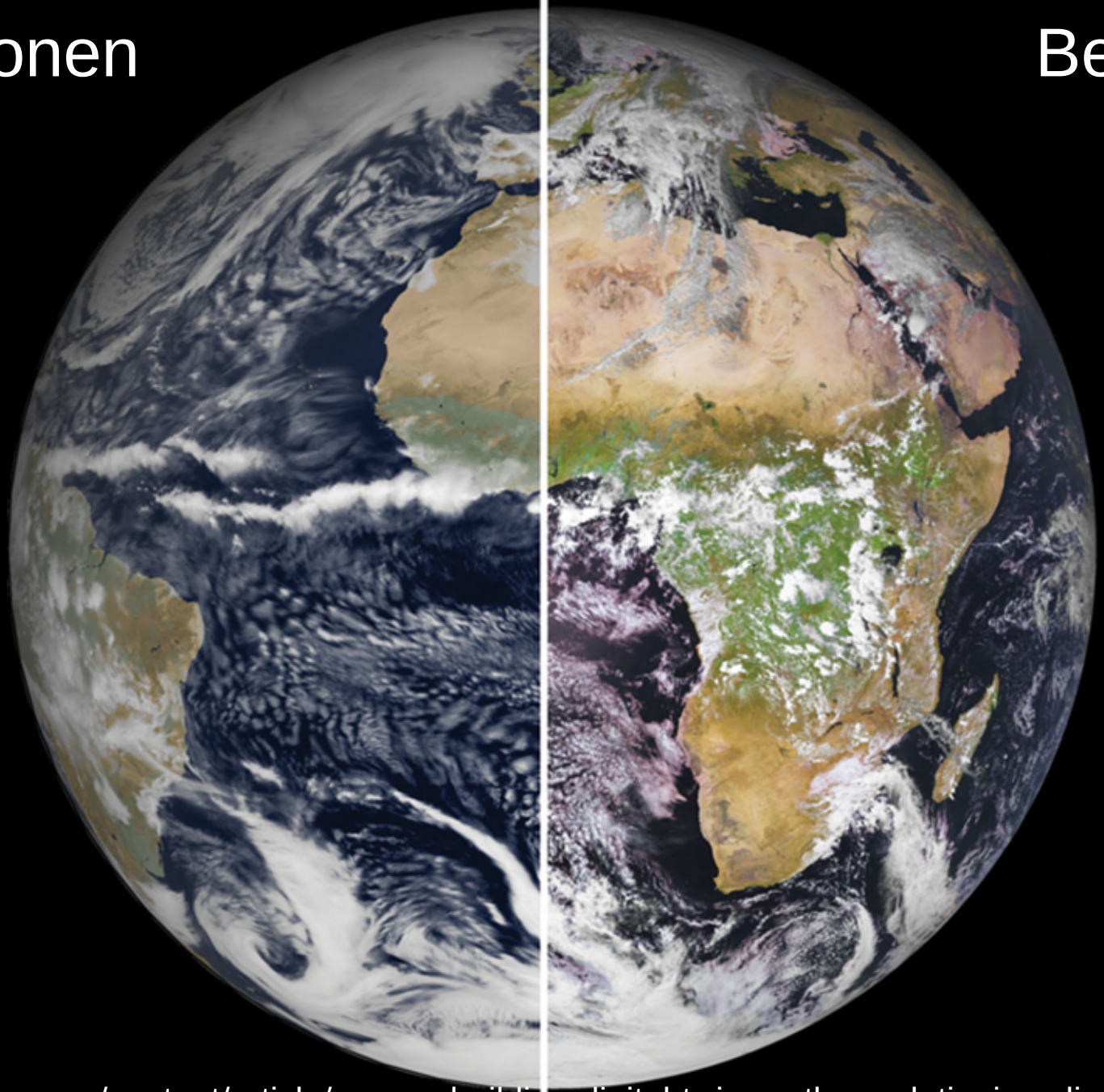
Earth Observation Data Centre
for Water Resources Monitoring

Modelsimulationen

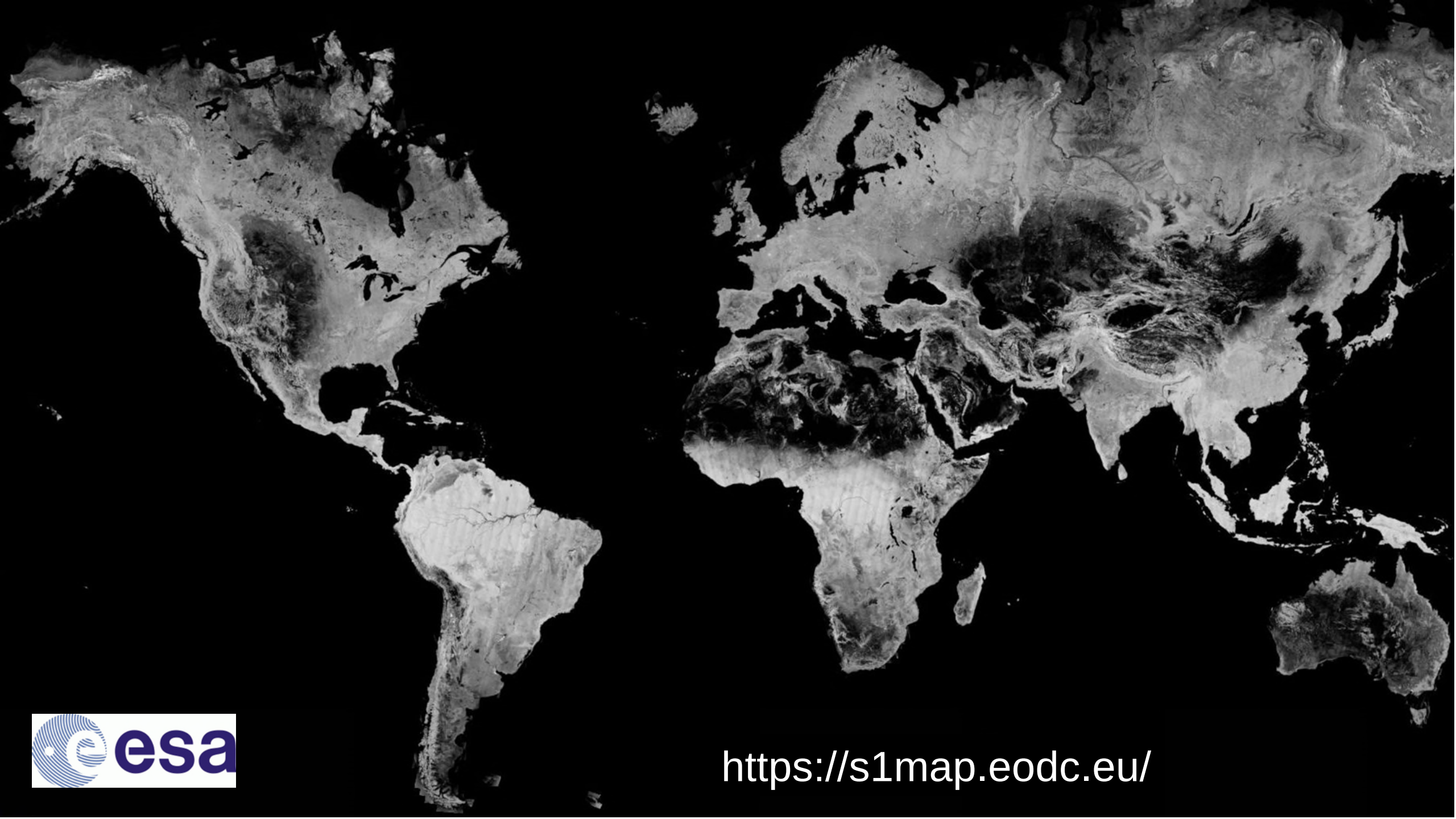
ECMWF

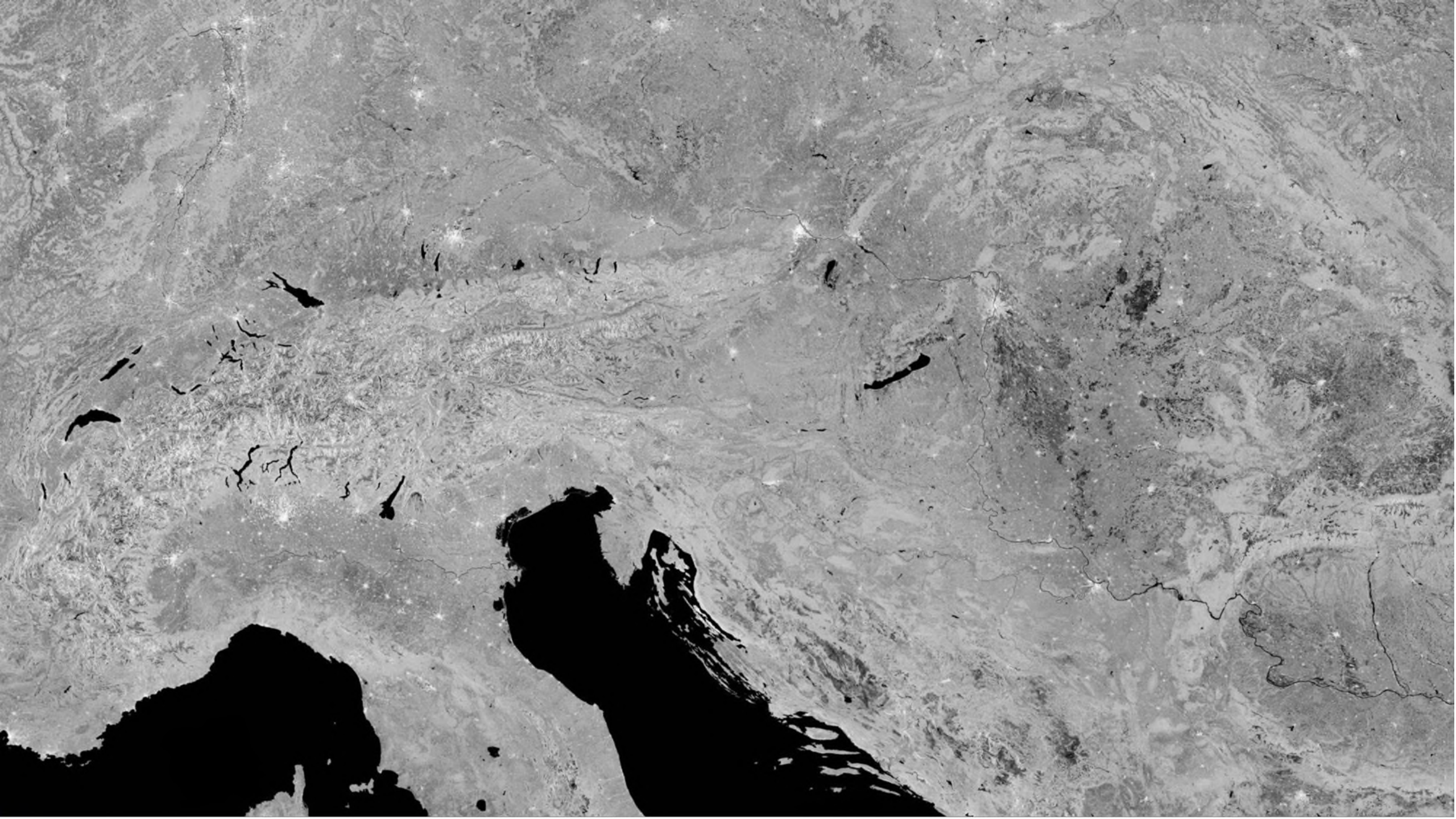
Beobachtungen

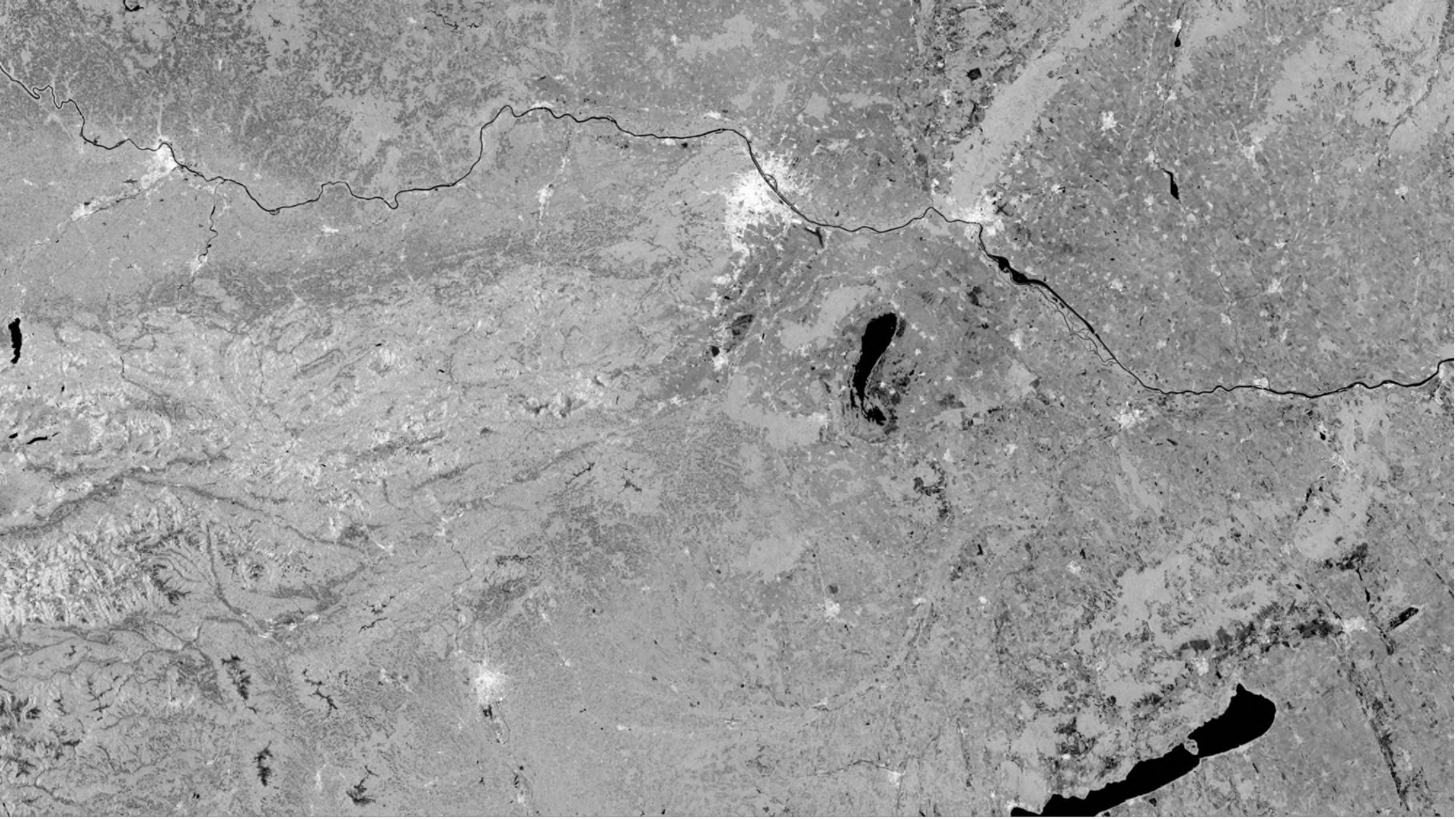
EUMETSAT

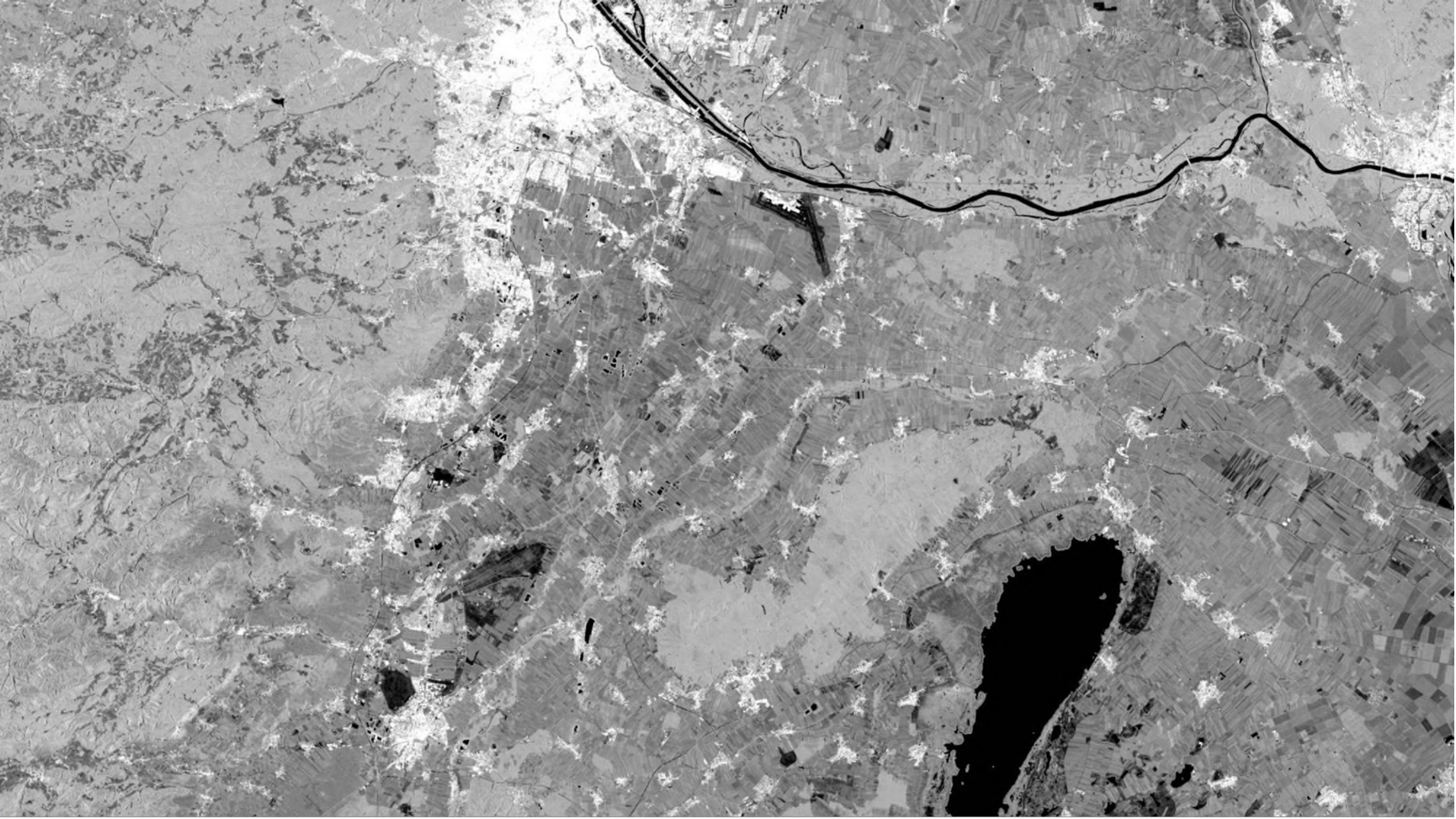


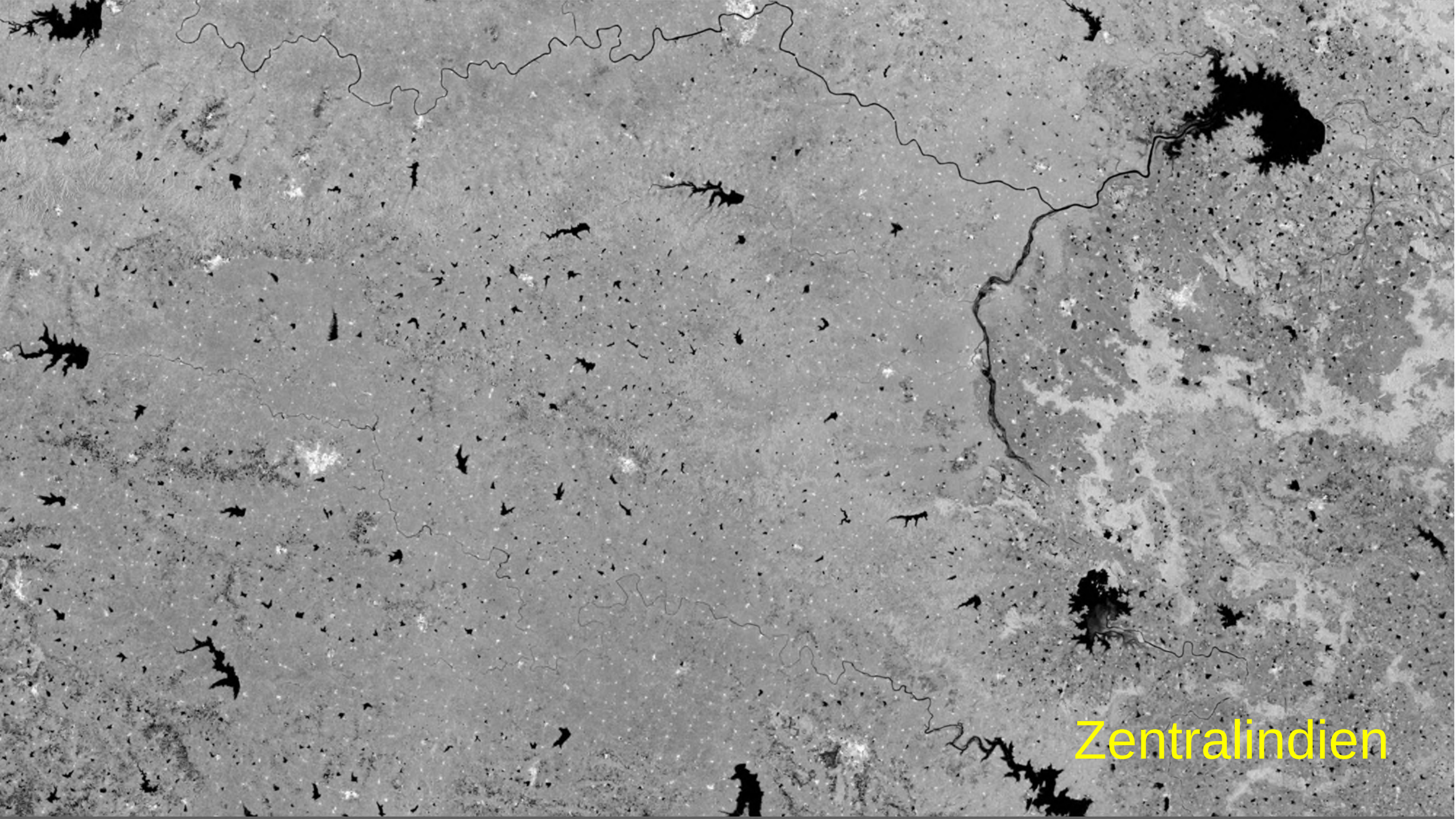
https://www.science.org/content/article/europe-building-digital-twin-earth-revolutionize-climate-forecasts


esa
https://s1map.eodc.eu/







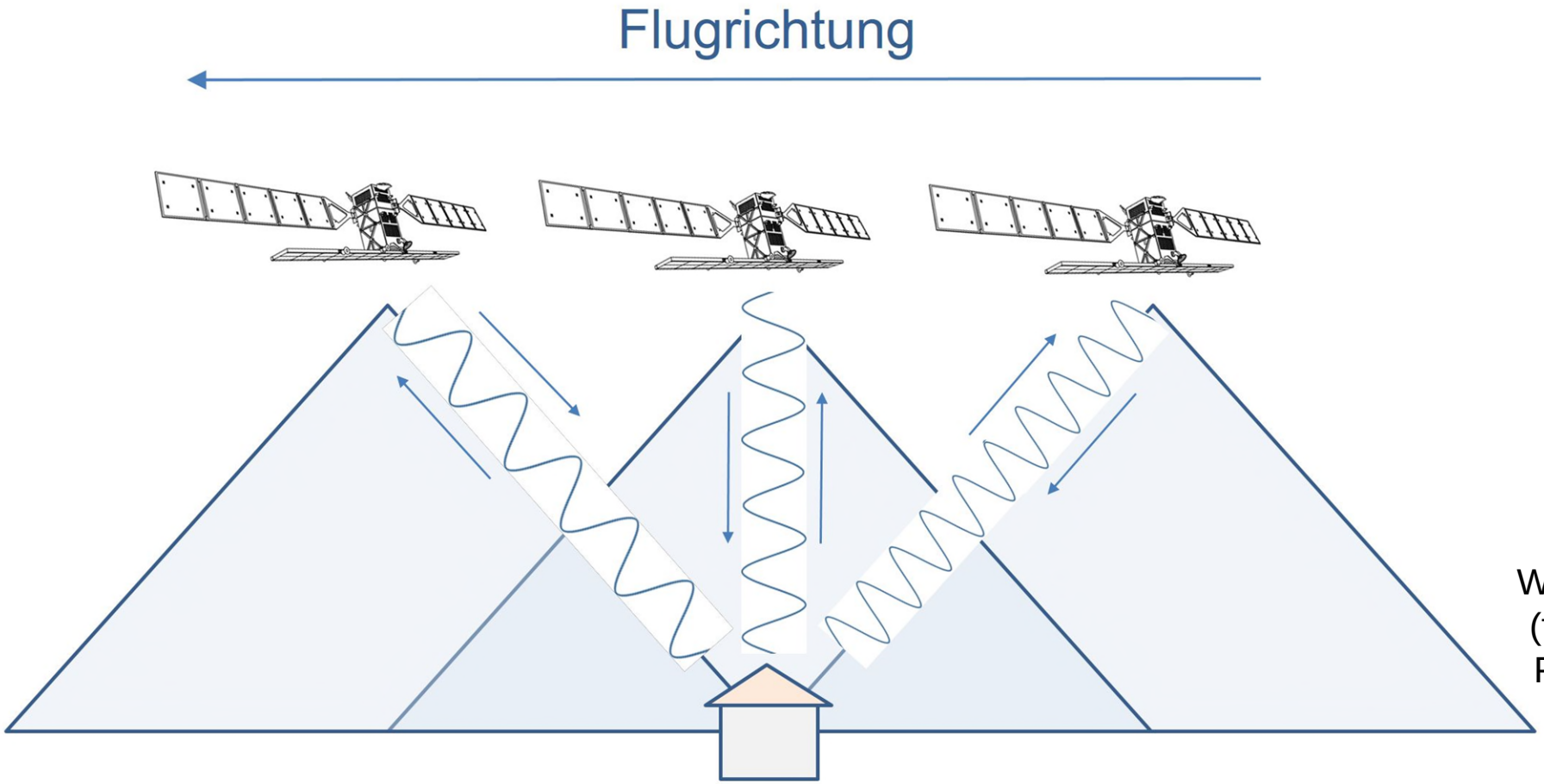

Zentralindien


Grenze Israel-Jordanien


Westlich von Kairo

Sentinel-1

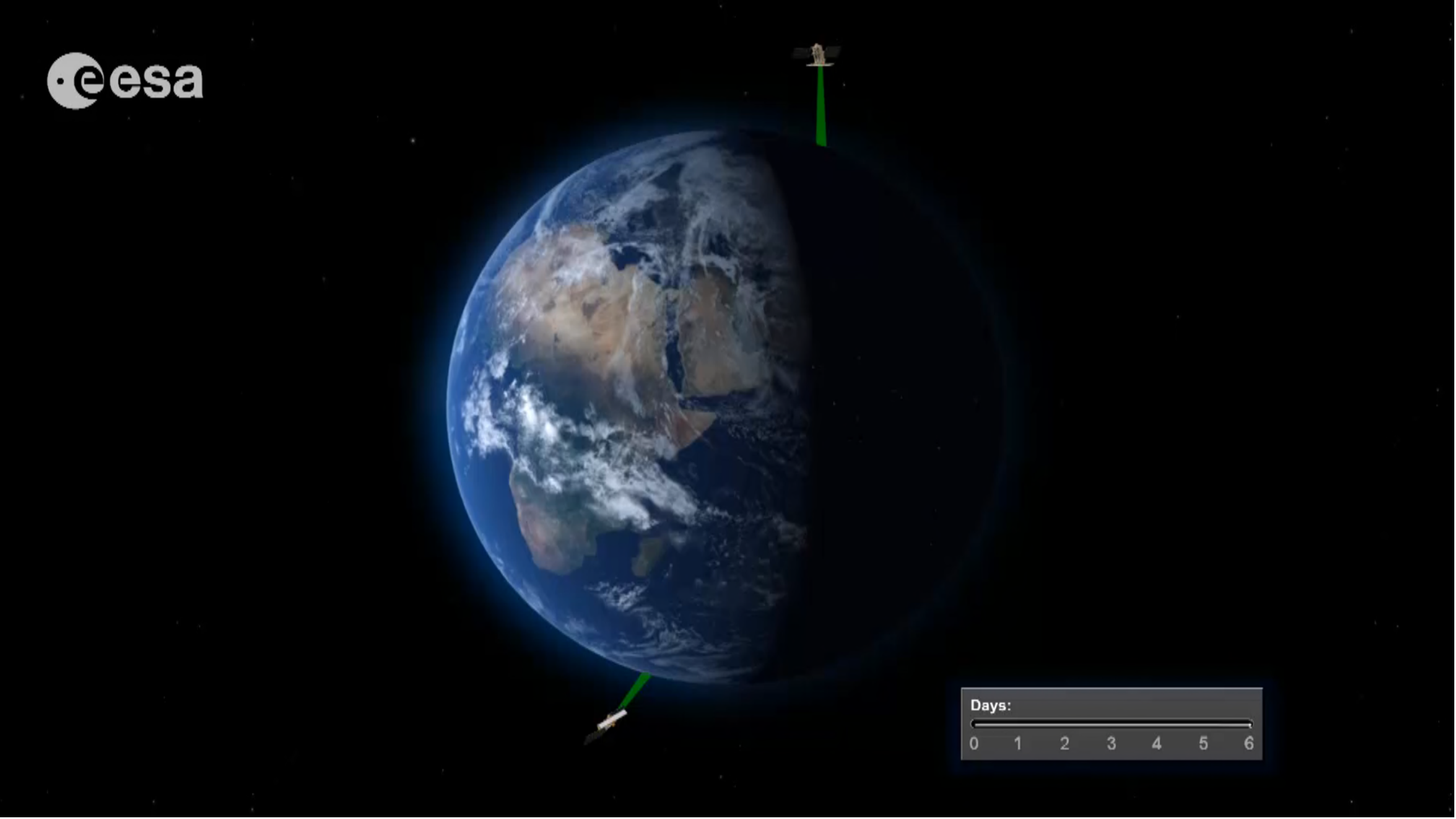
- Synthetisches Apertur Radar (SAR)
  - Dank des Doppler-Effekts und Chirp-Pulsen kann trotz der großen Wellenlänge (5.6 cm, C-Band) ein hochauflösendes Bild (5m x 20m) erzeugt werden



Christian Doppler

War u.a. Student und Professor (für praktische Geometrie) am Polytechnischen Institut Wien


esa


esa
Days:
0 1 2 3 4 5 6

Globale SAR Rückstreumodelle

ENVISAT ASAR

- Veröffentlichung in 2012
- Basierend auf 110,000 SAR Bilder
- Zeitraum 2004-2009
- Polarisation: HH
- Räumliche Auflösung: 1 km

- Sabel et al. (2012) Development of a Global Backscatter Model in support to the Sentinel-1 mission design, Remote Sensing of Environment, 120, 102-112, DOI 10.1016/j.rse.2011.09.028

Sentinel-1 SAR

- Veröffentlichung in 2021
- Basierend auf 500 000 SAR Bilder
- Zeitraum 2016-2017
- Polarisation: VV und VH
- Räumliche Auflösung: 10 m

- Bauer-Marschallinger et al. (2021) The normalised Sentinel-1 Global Backscatter Model – mapping Earth's land surface with C-band microwaves, Scientific Data, 8, 277, DOI 10.1038/s41597-021-01059-7

Sentinel-1 Datenmengen

1 Kilobyte = 1 000 Bytes

1 Megabyte = 1 000 000 Bytes

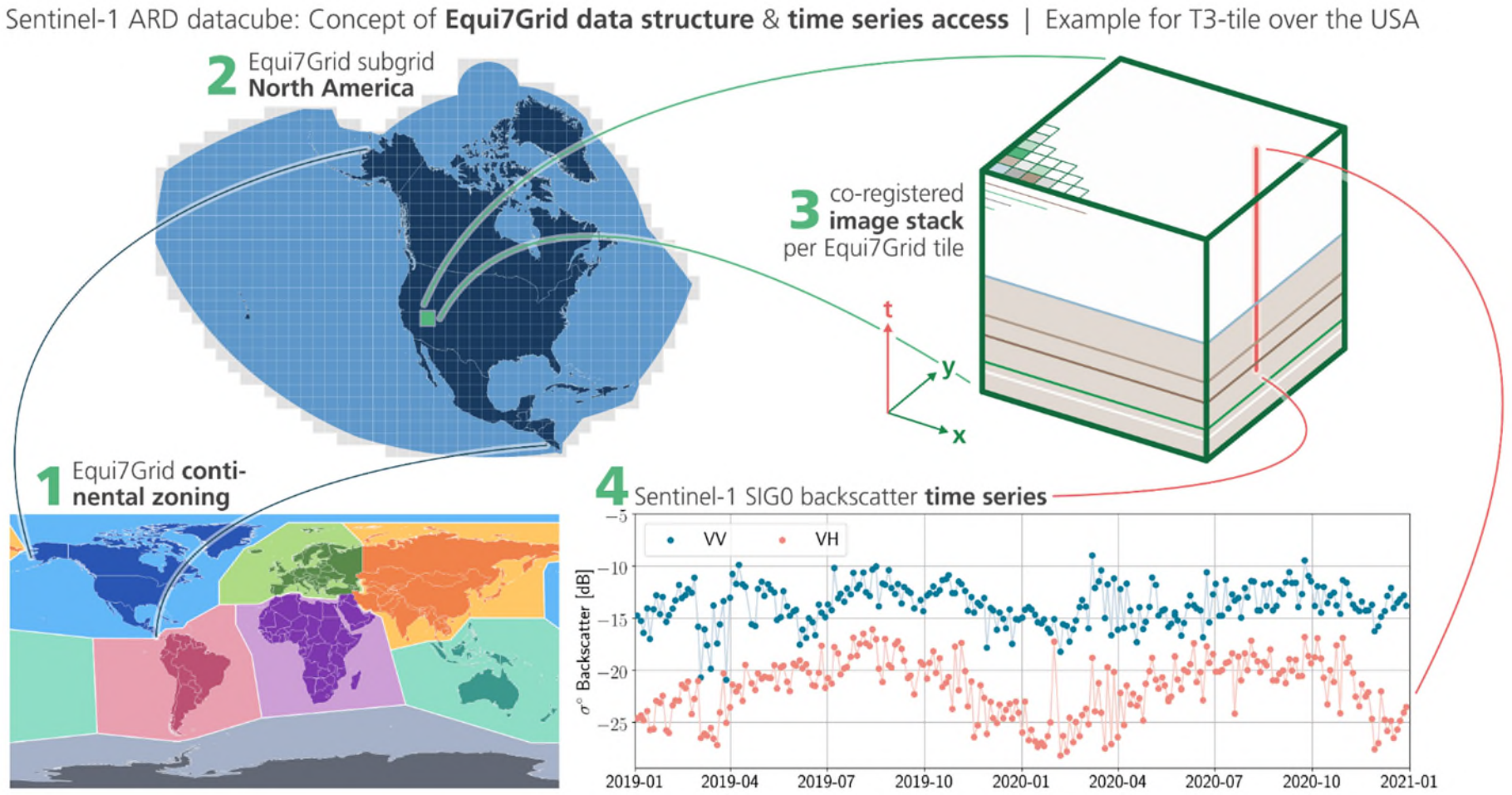
1 Gigabyte = 1 000 000 000 Bytes

1 Terabyte = 1 000 000 000 000 Bytes ← pro Tag

1 Petabyte = 1 000 000 000 000 000 Bytes ← 7 Jahre, 2 Satelliten

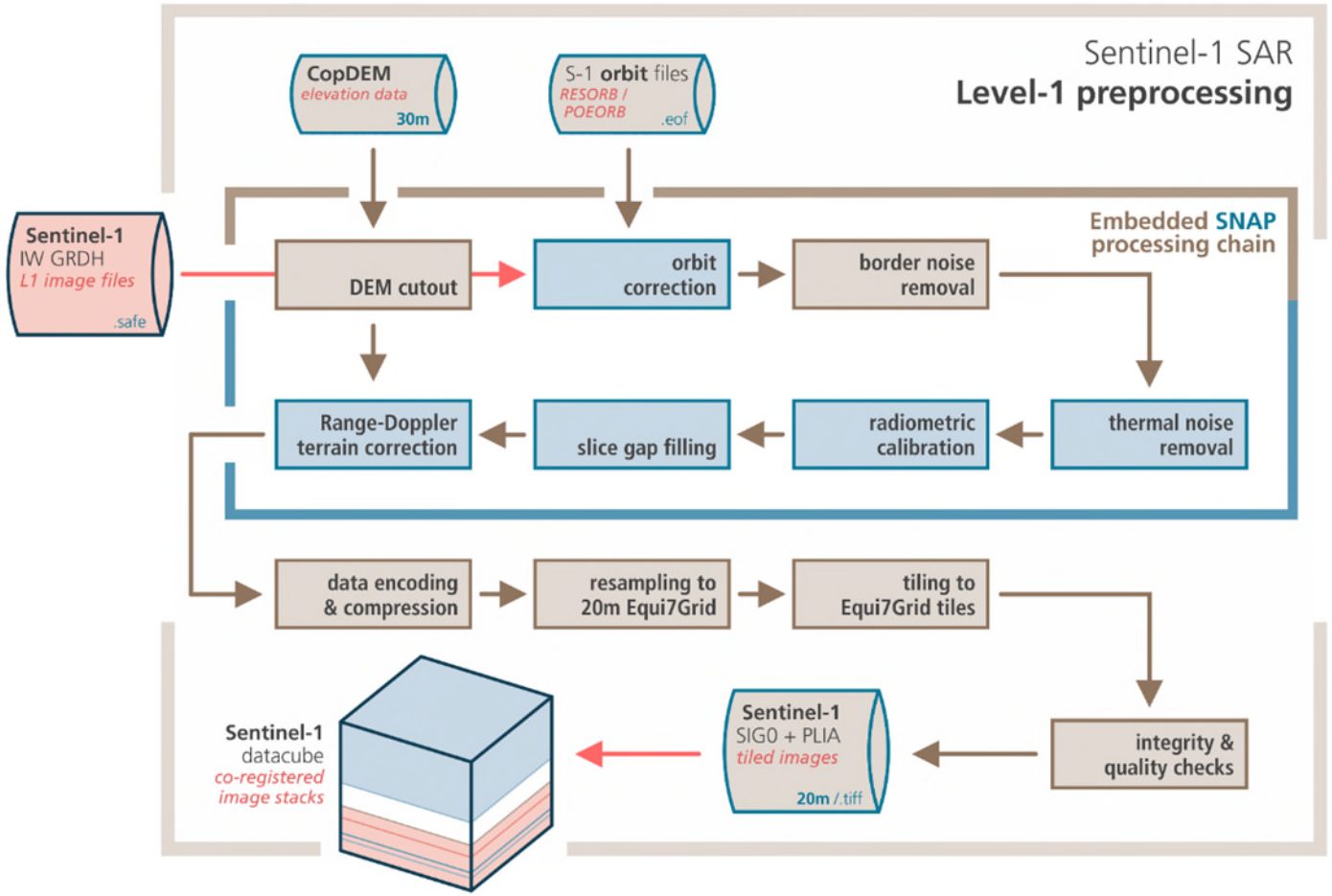
1 Exabyte = 1 000 000 000 000 000 000 Bytes

Sentinel-1 Datacube System basierend auf dem Equi7Grid



Bauer-Marschallinger et al. (2014) Optimisation of global grids for high-resolution remote sensing data, Computers & Geosciences, 72, 84-93, DOI 10.1016/j.cageo.2014.07.005.

Sentinel-1 Datenvorverarbeitung



Data Volume in TB

Level-1 Sentinel-1 IW GRD data

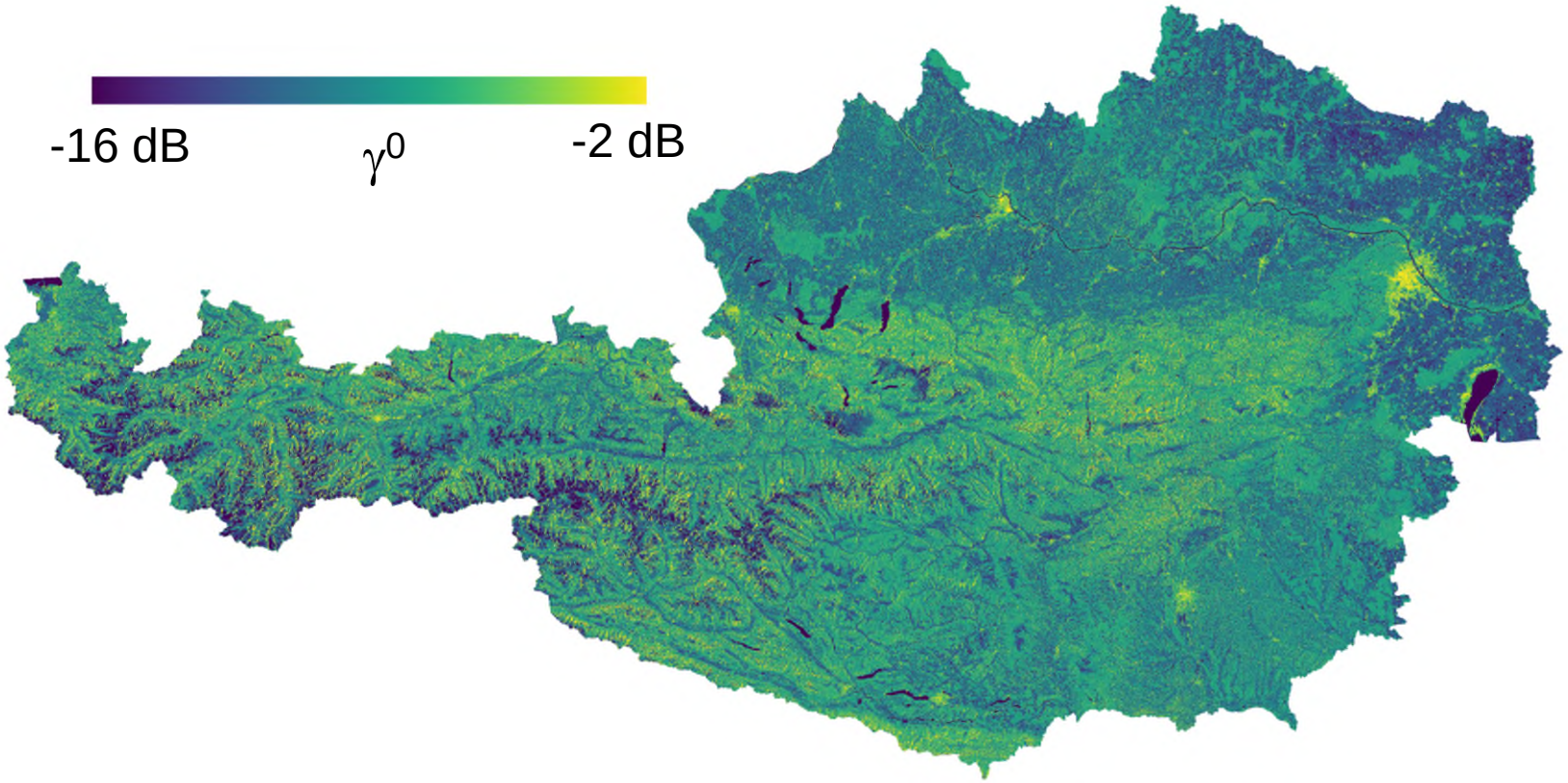
Year	Africa	Asia	Europe	NA	Oceania	SA	Total
2015	12.7	15.1	22.0	6.2	4.9	5.3	66.2
2016	20.6	19.2	31.9	11.5	6.6	9.0	98.8
2017	45.0	53.9	71.8	31.4	18.4	23.1	243.6
2018	48.0	58.1	70.3	35.3	20.2	24.7	256.6
2019	94.4	61.1	119.9	38.5	21.1	26.9	361.9
2020	97.3	63.3	130.7	41.4	21.3	28.6	382.6
Total	318.0	270.7	446.6	164.3	92.5	117.6	1409.7

20 m Sentinel-1 datacube

Year	Africa	Asia	Europe	NA	Oceania	SA	Total
2015	2.5	2.9	4.3	1.2	1.1	1.0	13.0
2016	4.4	4.0	6.4	2.5	1.5	1.9	20.7
2017	9.8	11.9	14.6	6.9	4.3	4.9	52.4
2018	10.3	12.8	12.8	7.6	4.7	5.2	53.4
2019	16.9	19.4	23.5	13.4	7.6	8.6	89.4
2020	17.3	20.1	25.0	14.6	7.7	9.4	94.1
Total	61.2	71.1	86.6	46.1	26.9	31.0	323.0

Wagner et al. (2021) A Sentinel-1 Backscatter Datacube for Global Land Monitoring Applications, Remote Sensing, 13, 4622, DOI 10.3390/rs13224622

Verbesserungen in der Datenvorverarbeitung

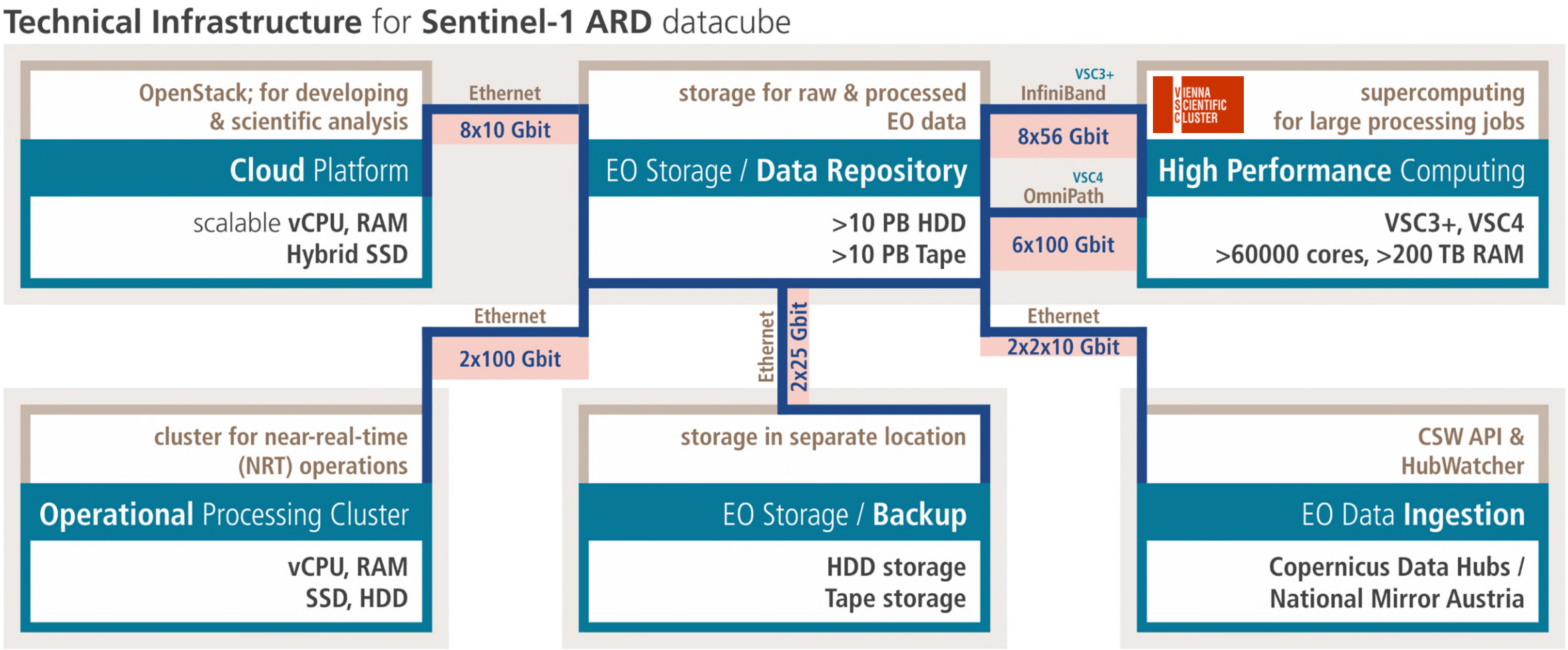


- Berücksichtigung der Geländeneigung bei der Berechnung des Rückstreukoeffizientens
- Schnellere Geokodierung durch das Ausnützen der hohen Stabilität der Sentinel-1 Orbits

Dostálová et al. (2022) The effects of radiometric terrain flattening on SAR-based forest mapping and classification, Remote Sensing Letters, 13(9), 855-864, 10.1080/2150704X.2022.2092911.

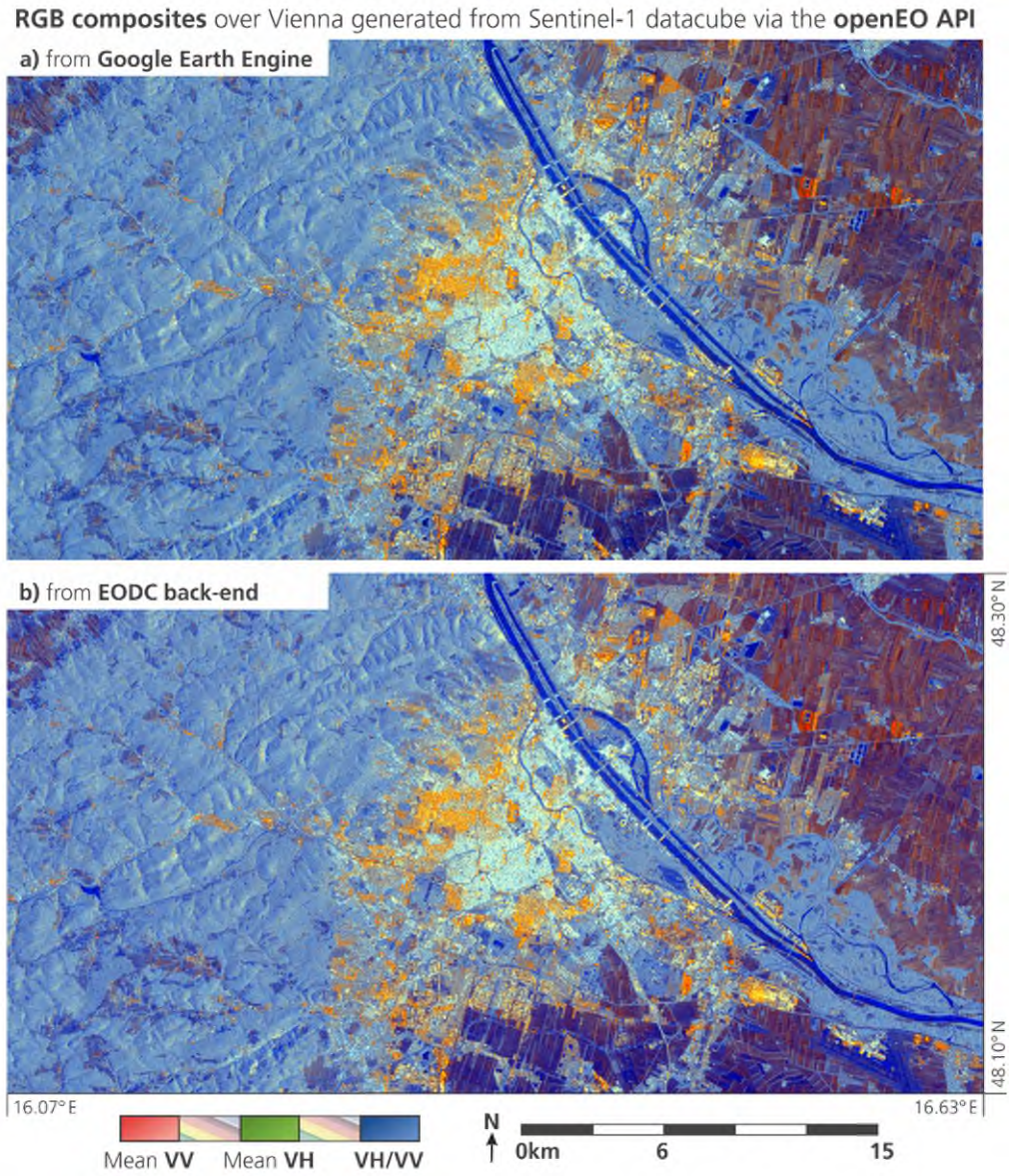
Navacchi et al. (2022) Utilising Sentinel-1's orbital stability for efficient pre-processing of Sigma Nought backscatter, ISPRS Journal of Photogrammetry and Remote Sensing, 192, 130-141, 10.1016/j.isprsjprs.2022.07.023.

Datenverarbeitung am EODC



Wagner et al. (2021) A Sentinel-1 Backscatter Datacube for Global Land Monitoring Applications, Remote Sensing, 13, 4622, DOI 10.3390/rs13224622

Vereinfachter Zugriff auf die Daten



- Mittels Open Source Software
  - Open Data Cube
  - Jupyter Services
  - openEO
  - ….
- Demonstration der openEO API
  - Erstellung eines Sentinel-1 Falschfarbenbilds von Wien (März 2017) auf der Google Earth Engine (oben) and EODC (unten) mit der openEO API

Schramm et al. (2021) The openEO API - Harmonising use of Earth Observation cloud services using virtual Data Cube functionalities, Remote Sensing, 13, 1125, DOI 10.3390/rs13061125

Beobachtung von Wasserflächen und Feuchtgebieten

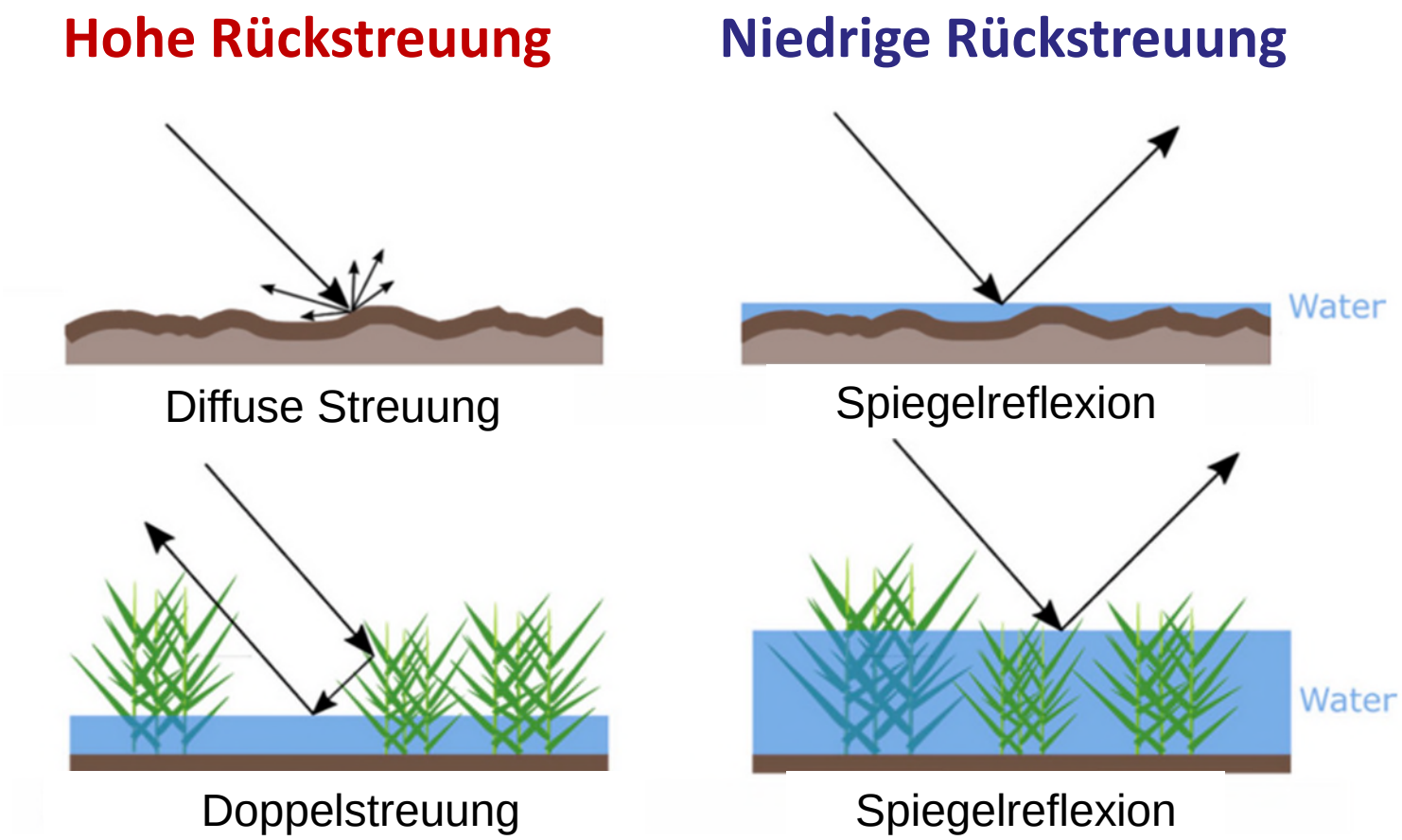


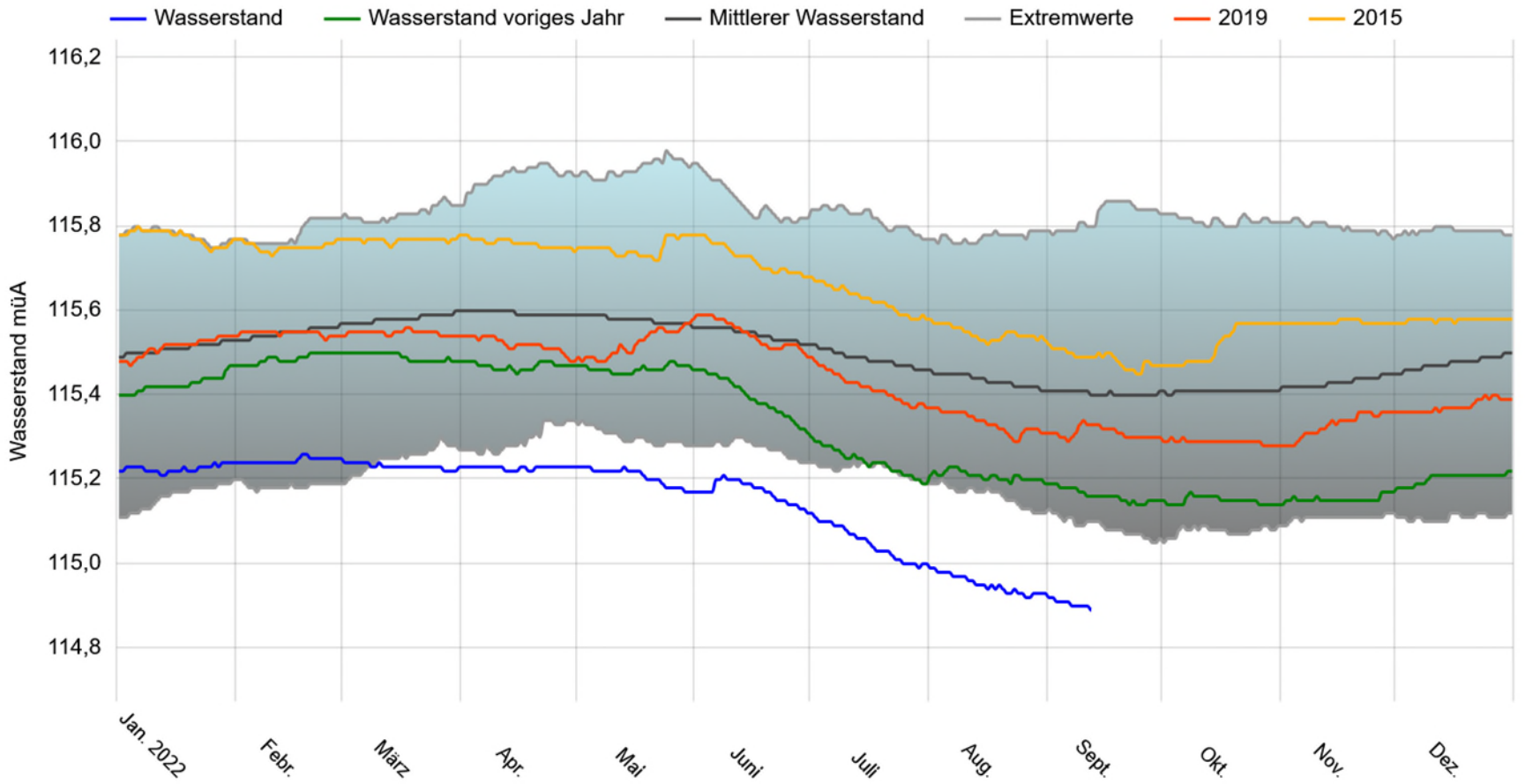
Abbildung modifiziert von Ottinger and Kuenzer (2020) Spaceborne L-Band Synthetic Aperture Radar Data for Geoscientific Analyses in Coastal Land Applications: A Review, Remote Sensing, 12(14).

Mittlerer Wasserstand Neusiedler See

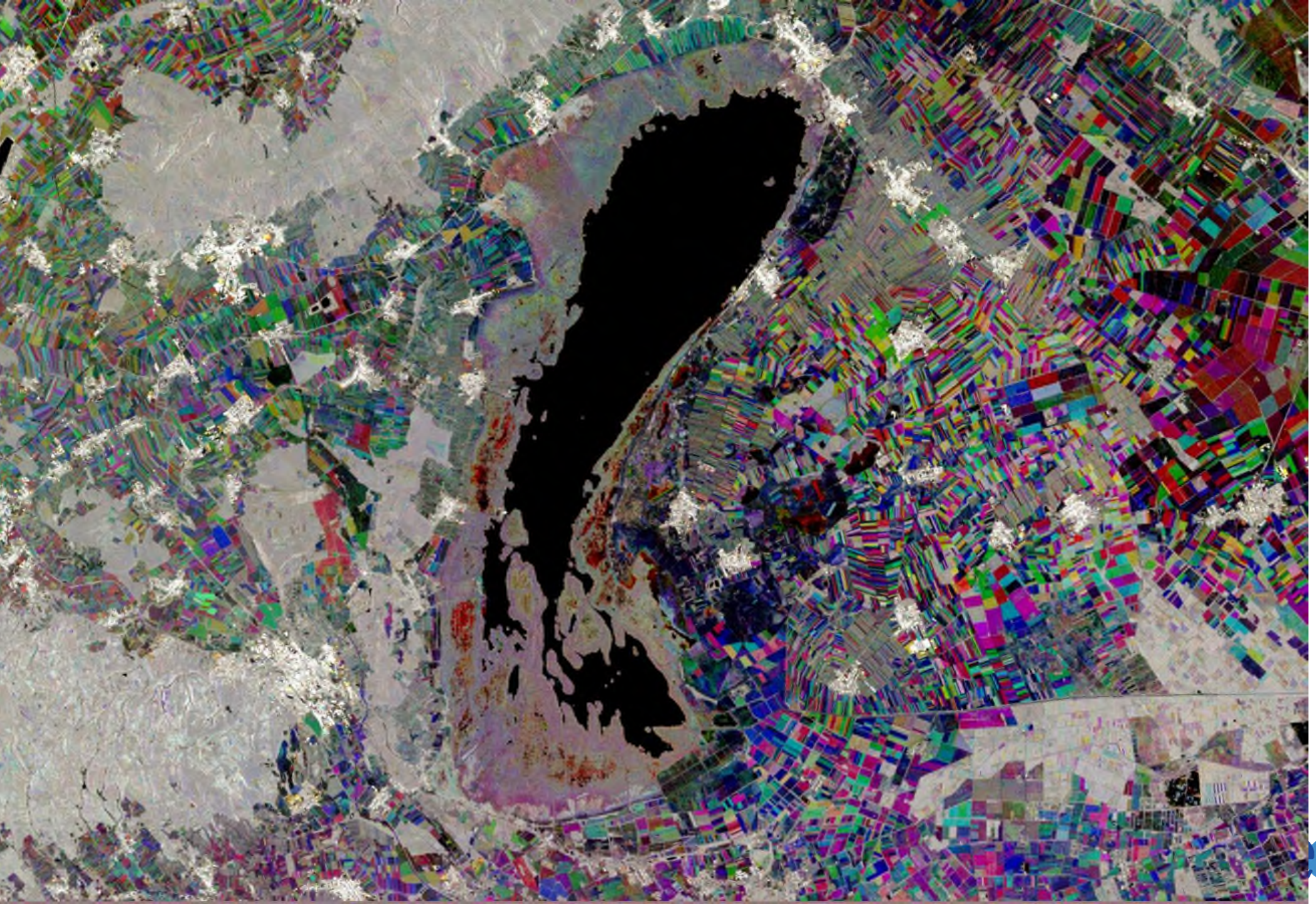
WASSERPORTAL BURGENLAND

Hydrographie | Wasserbuch | Hochwasserprognose | Siedlungswasserwirtschaft | Studien

Langzeitvergleich Wasserstand seit 1965



https://wasser.bgld.gv.at/hydrographie/die-seen/mittler-wasserstand-neusiedler-see



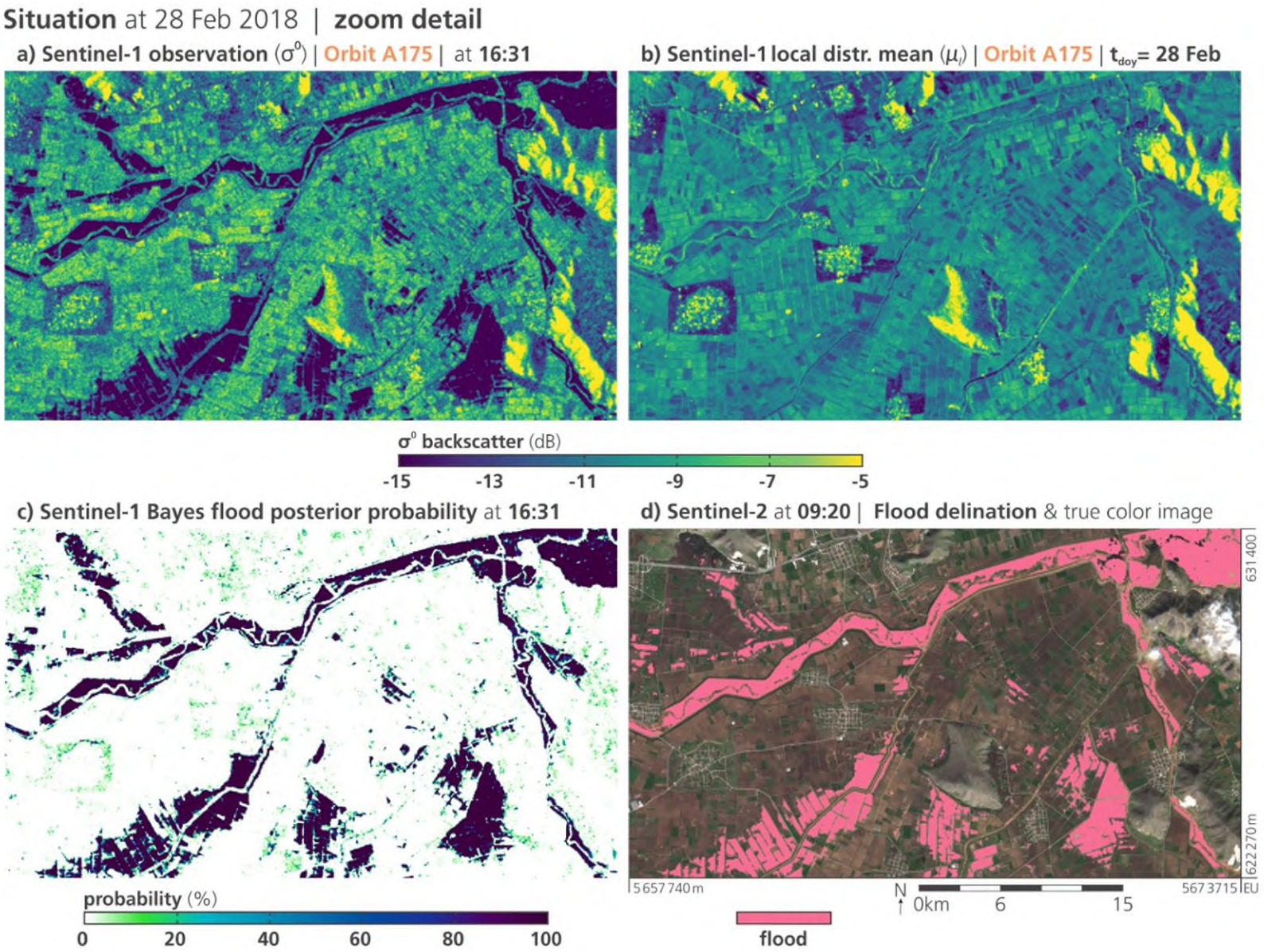
Jahr

2022

2019

2015

Kartierung von Überflutungen



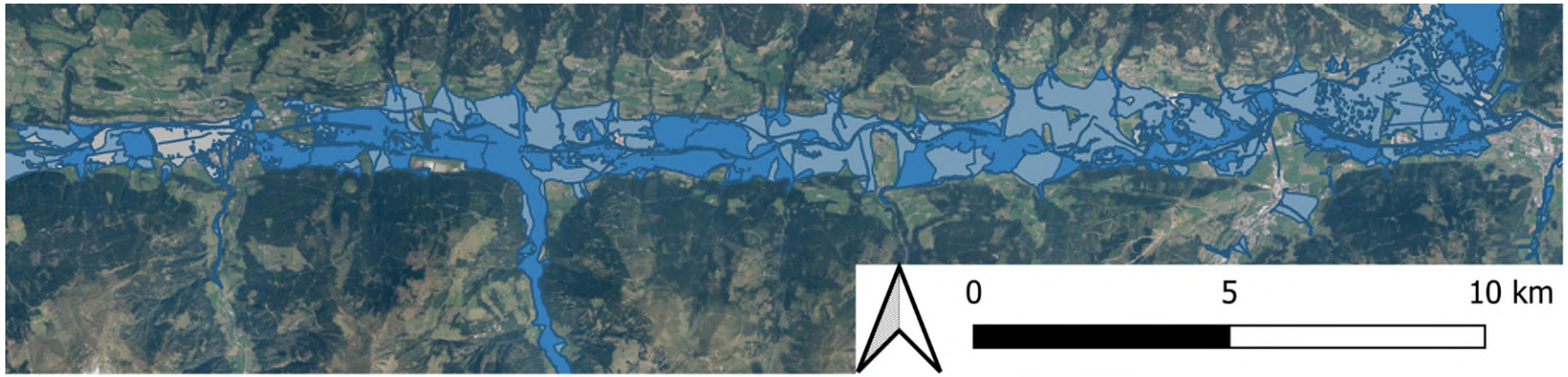
- Vergleich der tatsächlichen mit der erwarteten Rückstreuung
- Rückstreuung von Wasser bekannt
- Bayessche Inferenz

Fallbeispiel über Griechenland

Bauer-Marschallinger et al.(2022) Satellite-based flood mapping through Bayesian inference from Sentinel-1 SAR datacube, Remote Sensing, 14, 3673, DOI 10.3390/rs14153673

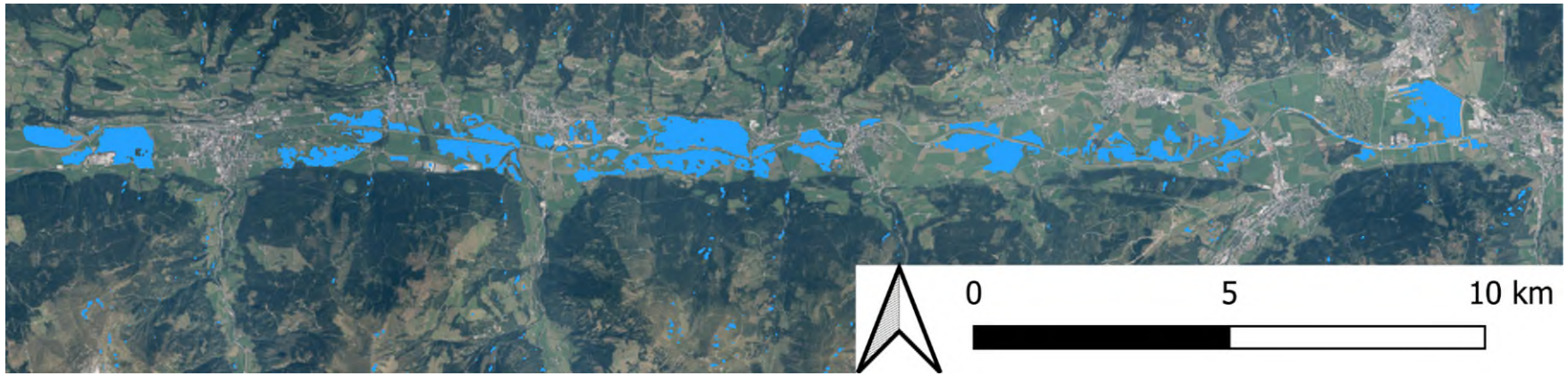
Überflutung der Salzach im Juli 2021

Überflutungsszenarien für alle 30, 100 und 300 Jahre auftretende Hochwasserereignis



Bundesministerium
Landwirtschaft, Regionen
und Tourismus

Sentinel-1 Flutkarte 19 Juli 2021 05:18 UTC



ACube4Floods

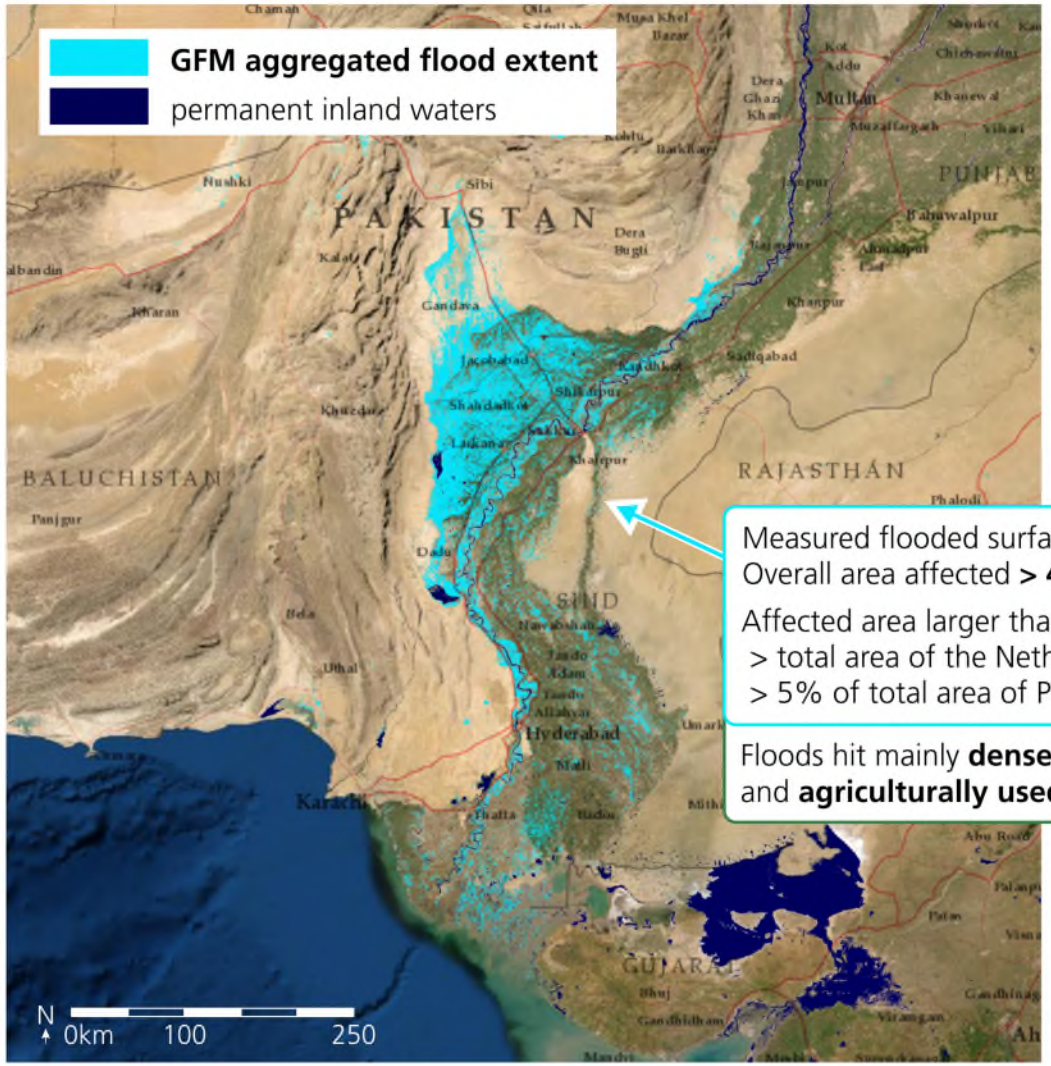
eodc

TU WIEN GEO

Pakistan Floods 2022

Flood extent maps from **CEMS Global Flood Monitoring (GFM) product**

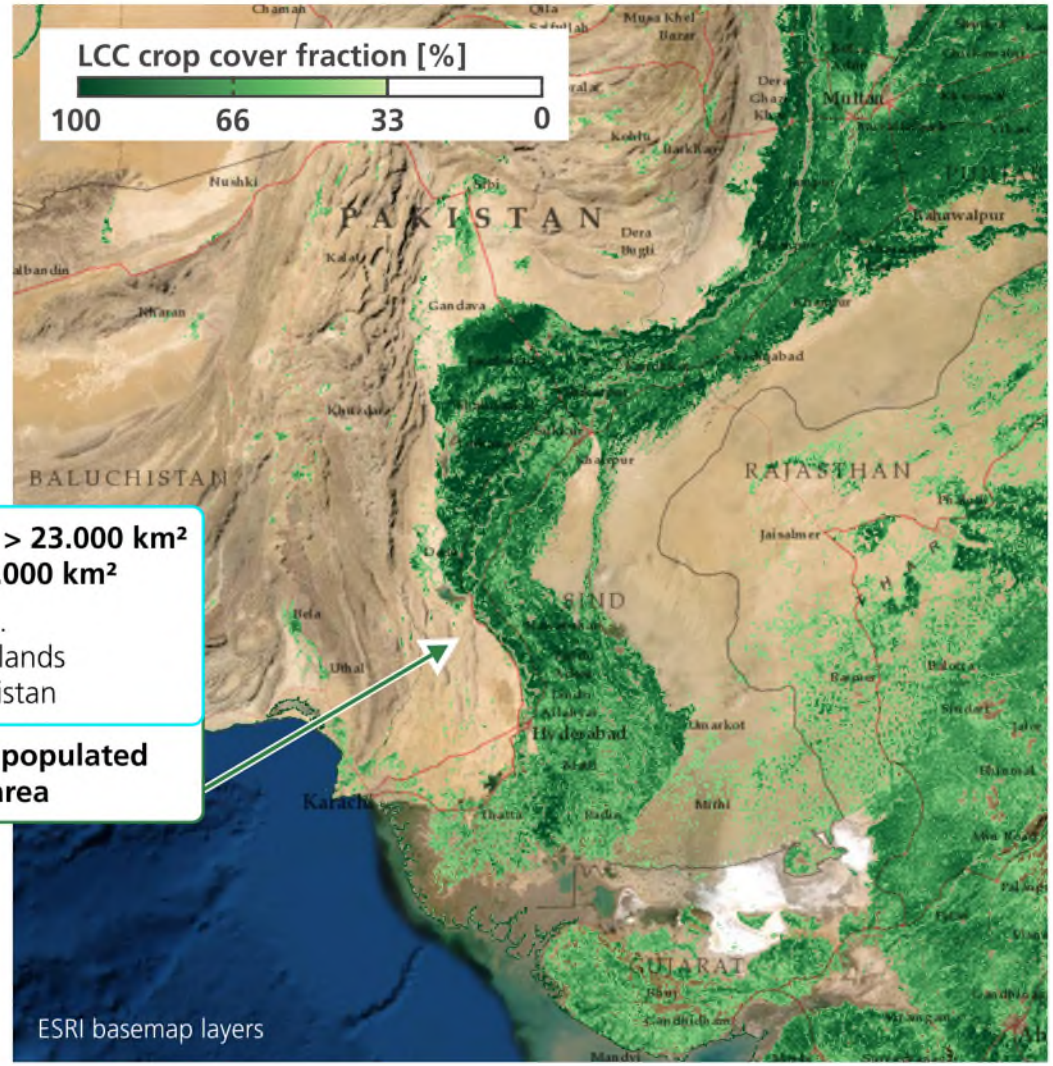
which automatically analyses images acquired by the **Copernicus Sentinel-1** radar satellite



Measured flooded surface **> 23.000 km²**
Overall area affected **> 40.000 km²**

Affected area larger than...
> total area of the Netherlands
> 5% of total area of Pakistan

Floods hit mainly **densely populated** and **agriculturally used area**



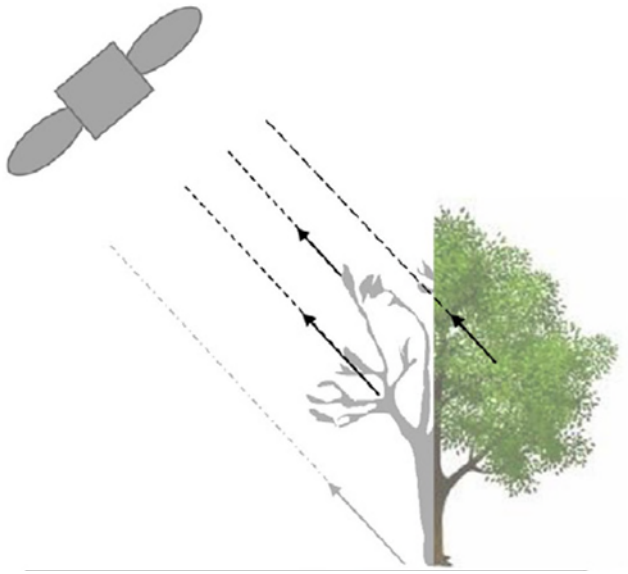
total flooded area | Pakistan / Indus Valley

aggregated GFM flood extent in period **18 Aug - 9 Sep 2022**

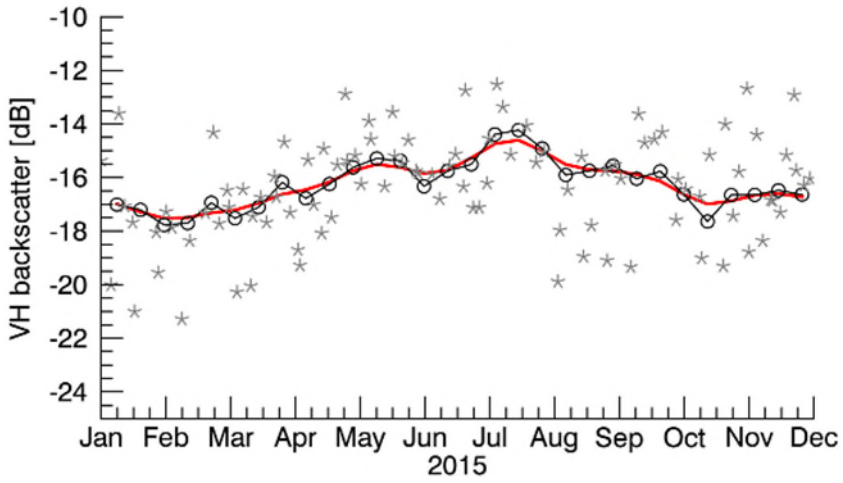
agricultural area

crops cover fraction > 33% from **Copernicus GLS LandCover LCC100**

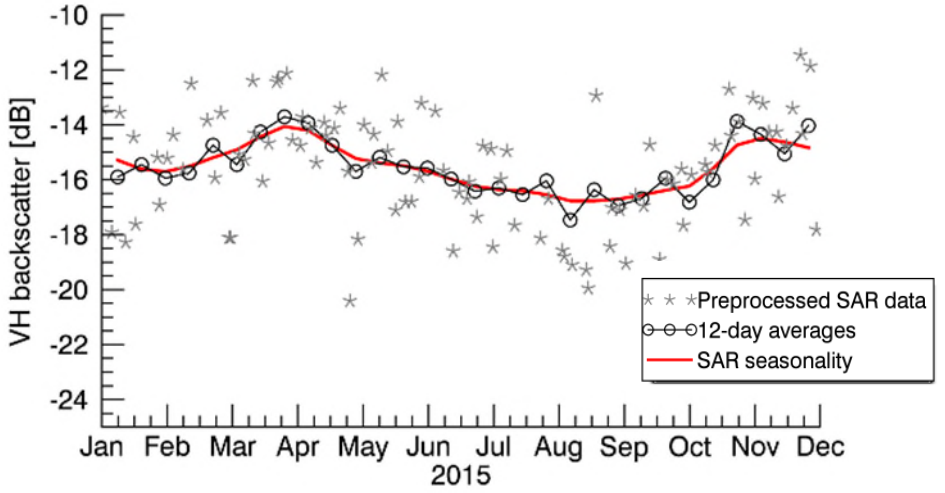
Rückstreuverhalten von Nadel- und Laubwald

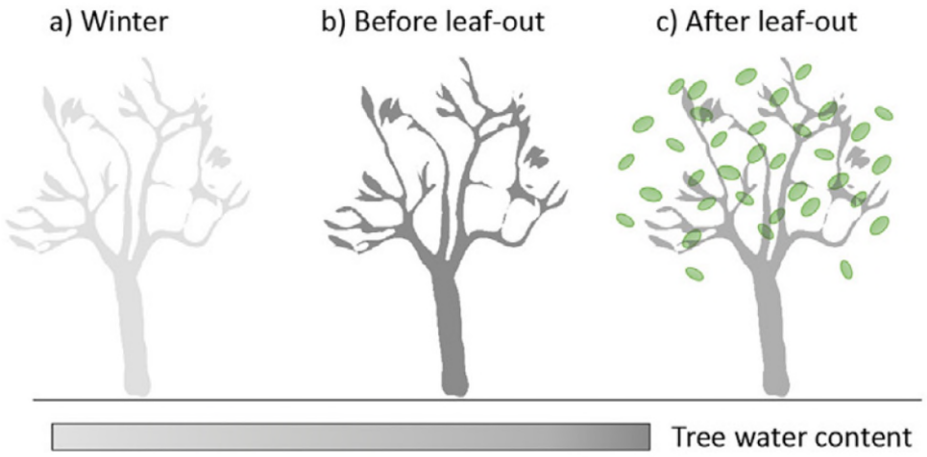


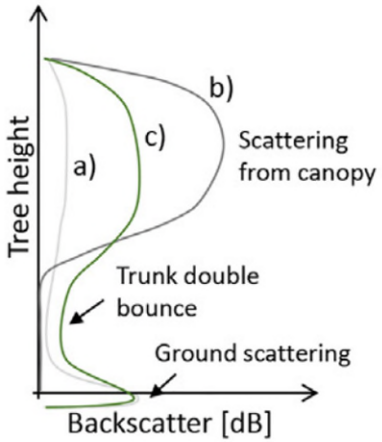
Nadelwald



Laubwald



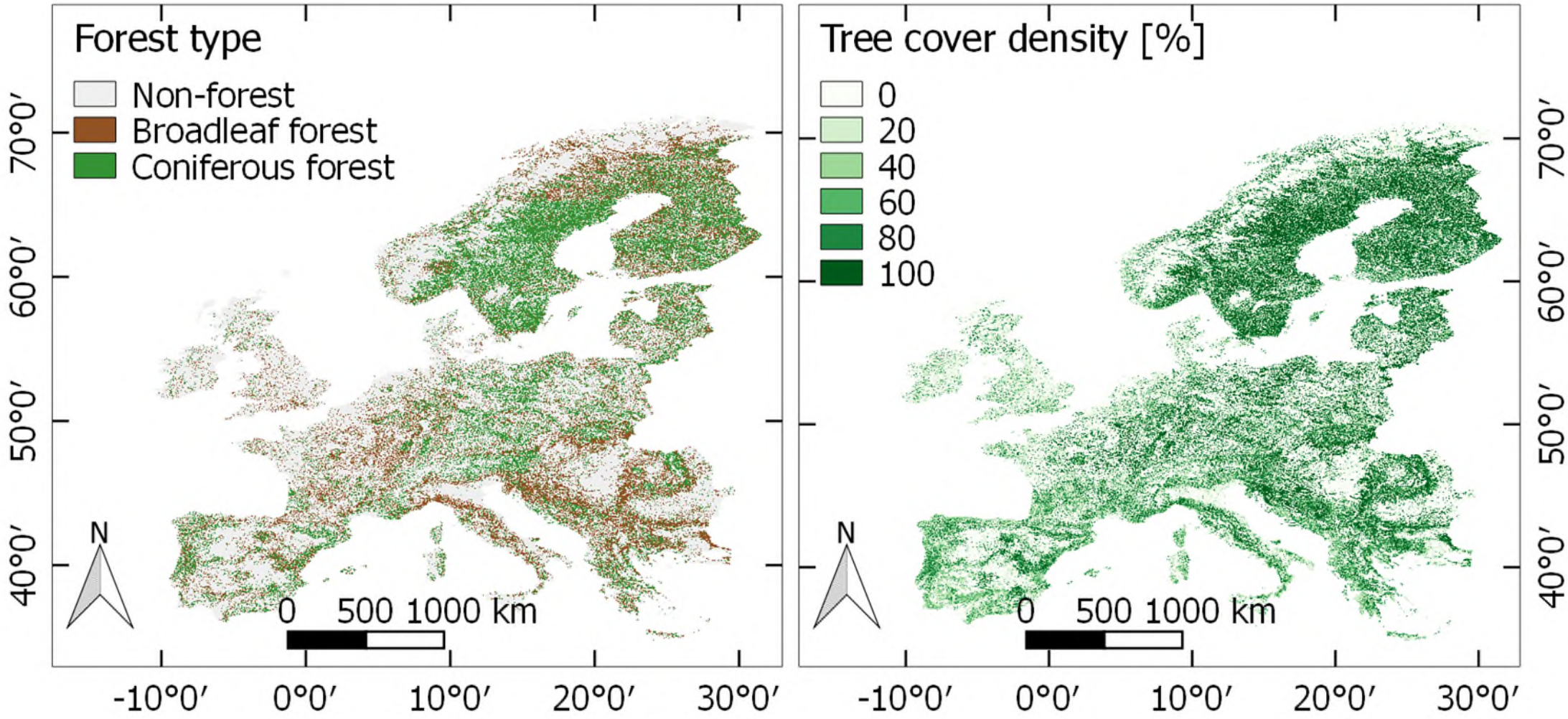




Dostálová et al. (2017) Annual seasonality in Sentinel-1 signal for forest mapping and forest type classification, International Journal of Remote Sensing, 39(21), DOI 10.1080/01431161.2018.1479788

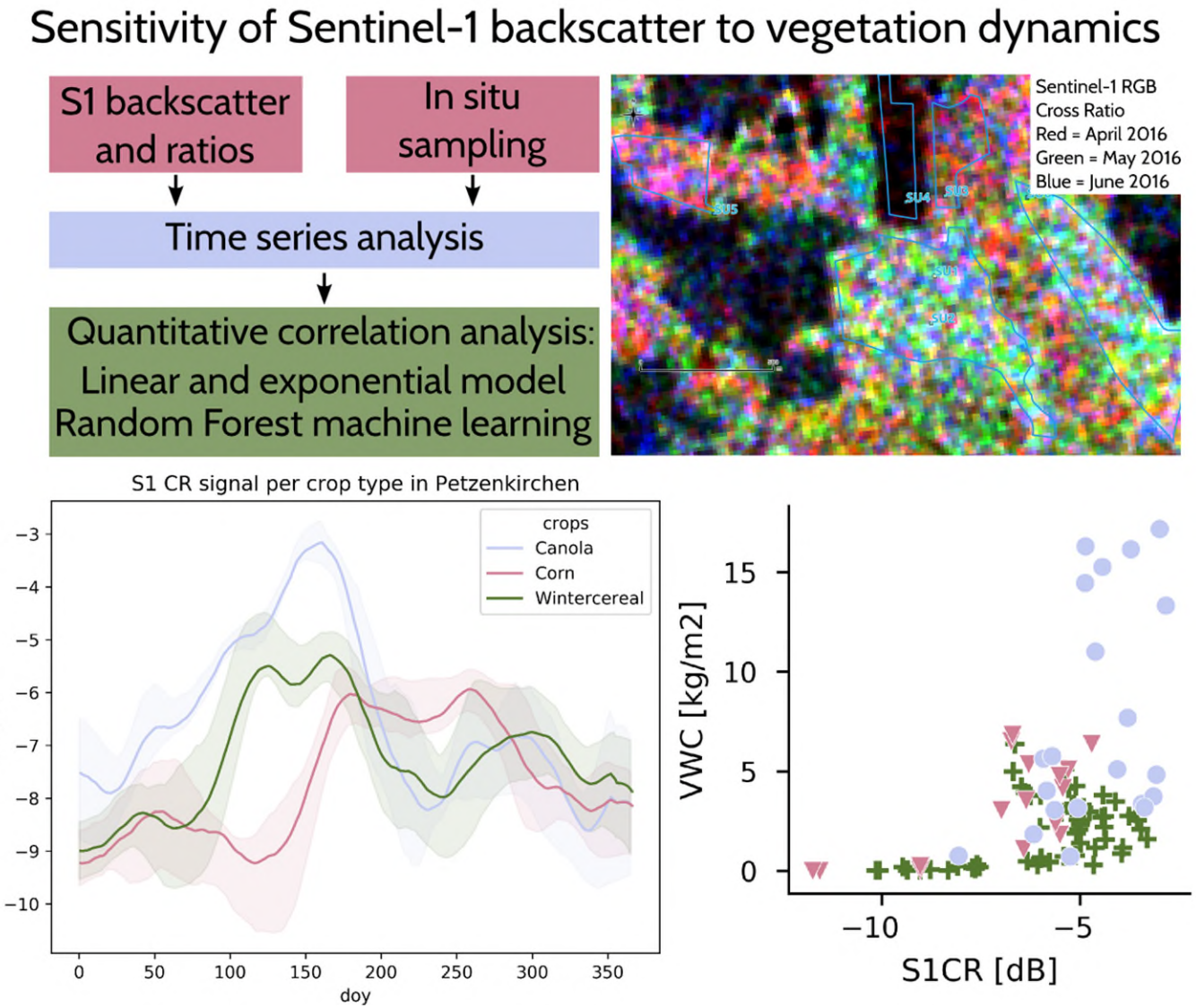
Pfeil et al. (2020) Does ASCAT observe the spring reactivation in temperate deciduous broadleaf forests? Remote Sensing of Environment, 250, 112042, DOI 10.1016/j.rse.2020.112042

Europaweite Waldklassifikation



Dostálová et al. (2021) European wide forest classification based on Sentinel-1 data, Remote Sensing, 13, 337, DOI 10.3390/rs13030337

Rückstreuverhalten über Landwirtschaftlichen Flächen



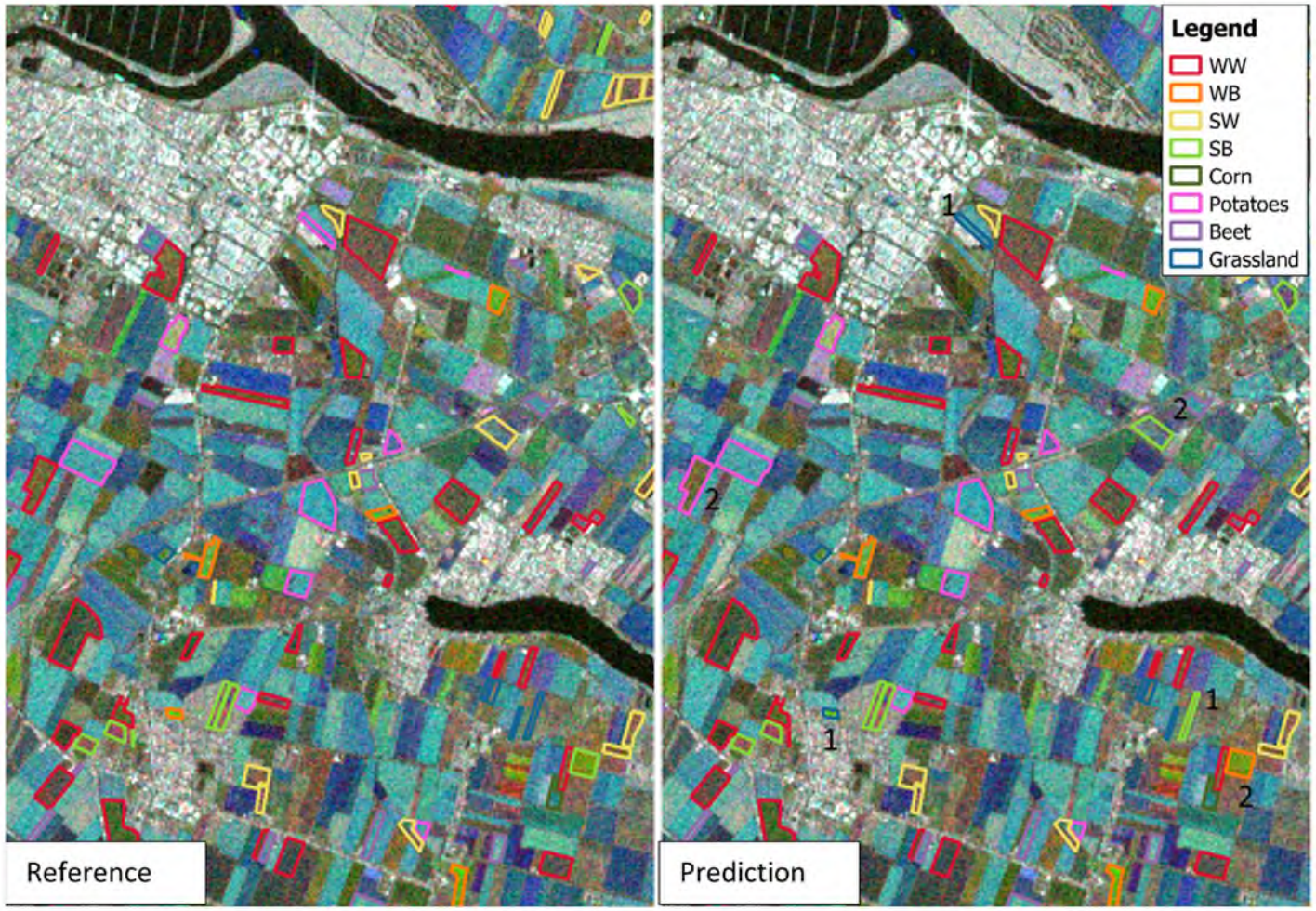
- Nutzung des Informationsgehalts der Kreuzpolarisation (VH)
- Cross Polarisation Ratio

$$CR = \frac{VH}{VV}$$

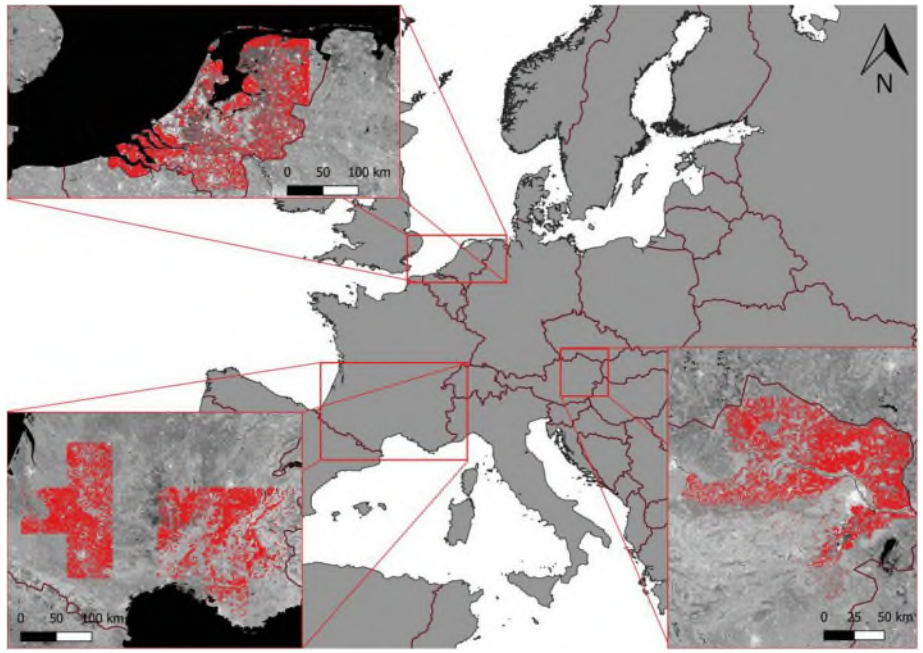
- Hydrology Open Air Laboratory
  - TU Wien Hydro (Prof. Blöschl)
  - Bundesamts für Wasserwirtschaft

Vreugdenhil et al. (2018) Sensitivity of Sentinel-1 backscatter to vegetation dynamics: An Austrian case study, Remote Sensing, 10(9), 1396, DOI 10.3390/rs10091396

Großflächige Klassifikation Landwirtschaftlicher Anbauflächen



- Verwendung von Methoden der künstlichen Intelligenz und Machine-Learning

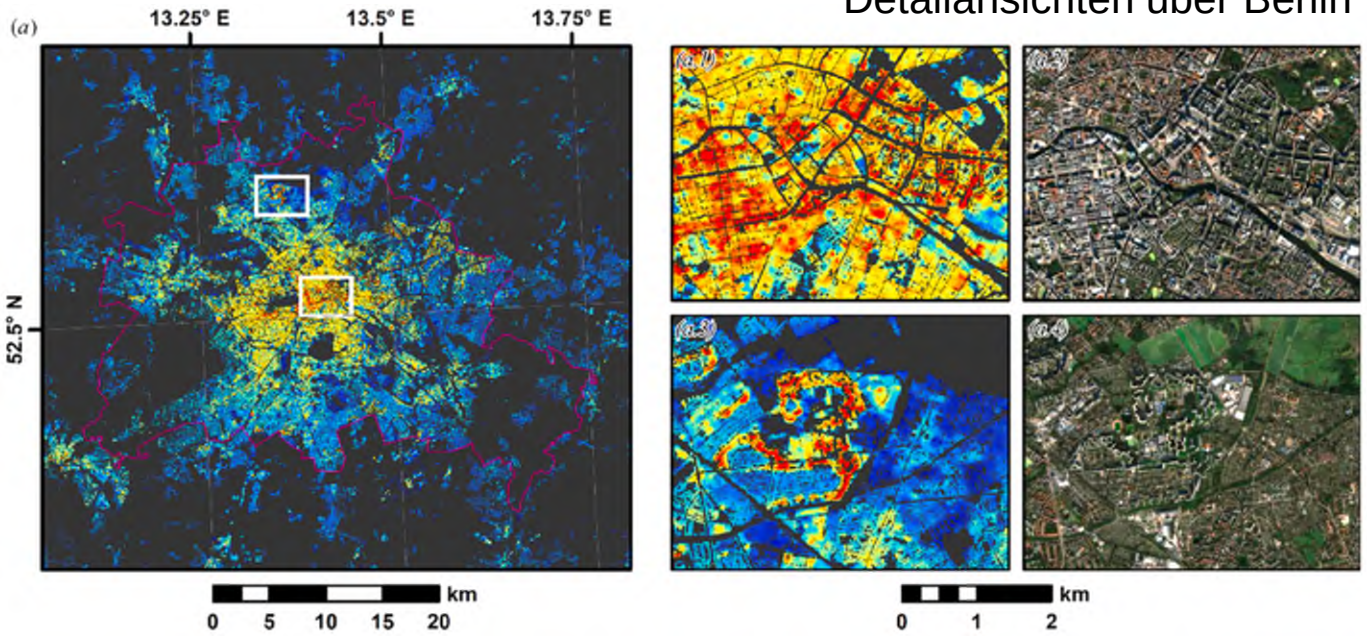


Reuß et al. (2021) Comparison of Long-Short Term Memory Networks and Random Forest for Sentinel-1 time series based large scale crop classification, Remote Sensing, 13, 5000, DOI 10.3390/rs13245000

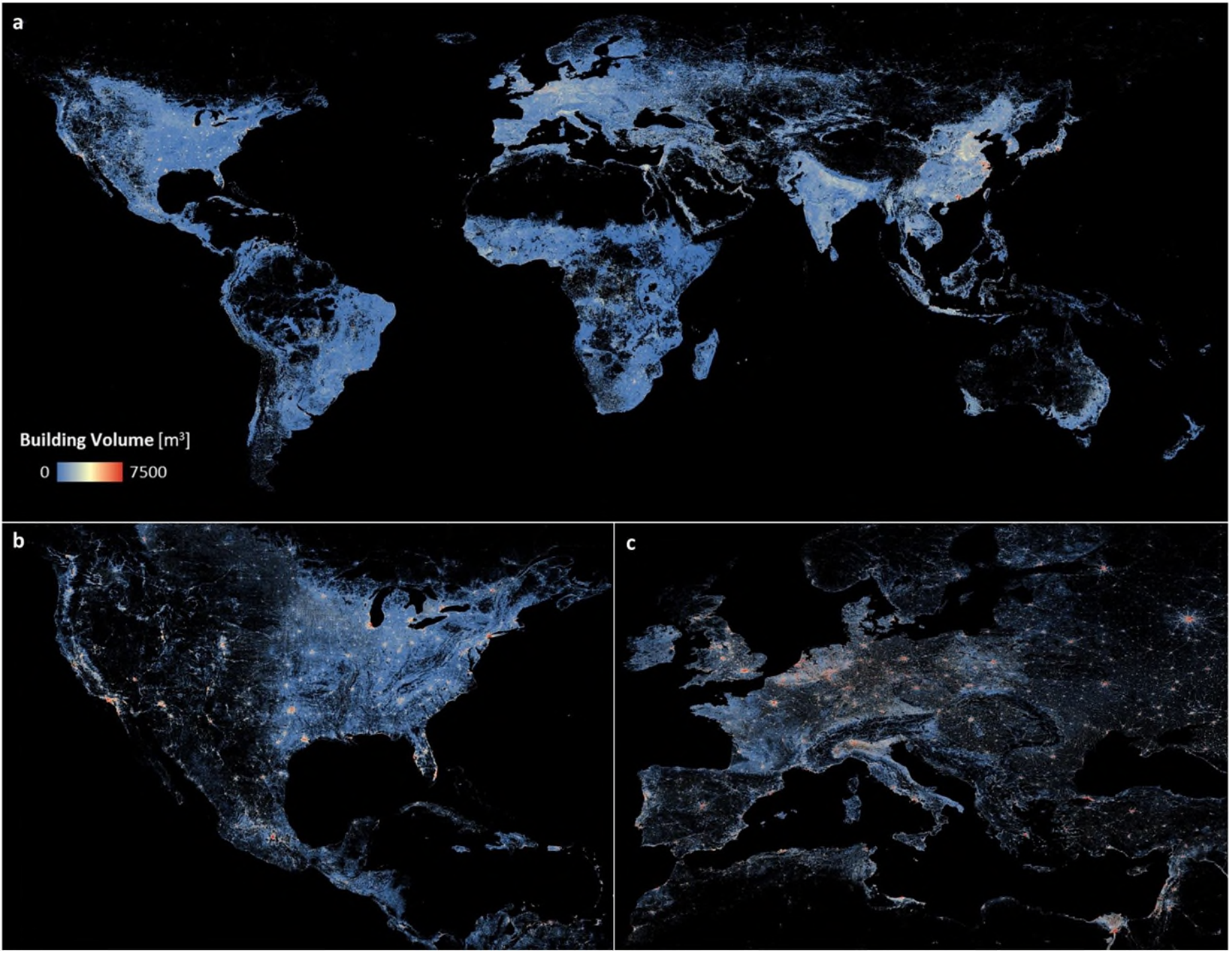
Gebäudehöhen

- Abgeleitet aus Sentinel-1 und Sentinel-2 Zeitserien über Deutschland
  - Support Vector Machine Regression (SVR)

Detailansichten über Berlin



Frantz et al. (2021) National-scale mapping of building height using Sentinel-1 and Sentinel-2 time series, Remote Sensing of Environment, 252, 112128, DOI 10.1016/j.rse.2020.112128

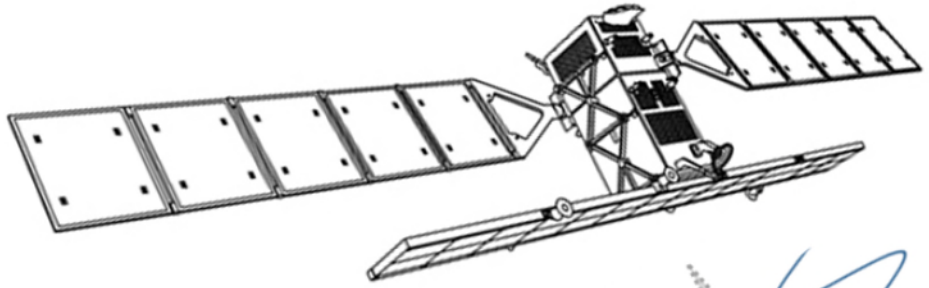


Gebäudevolumen

- Sentinel-1
- Sentinel-2
- TanDEM-X

Esch et al. (2022) World Settlement Footprint 3D - A first three-dimensional survey of the global building stock, Remote Sensing of Environment, 270, DOI 10.1016/j.rse.2021.112877

Modellierung der Rückstreuung von Boden und Vegetation

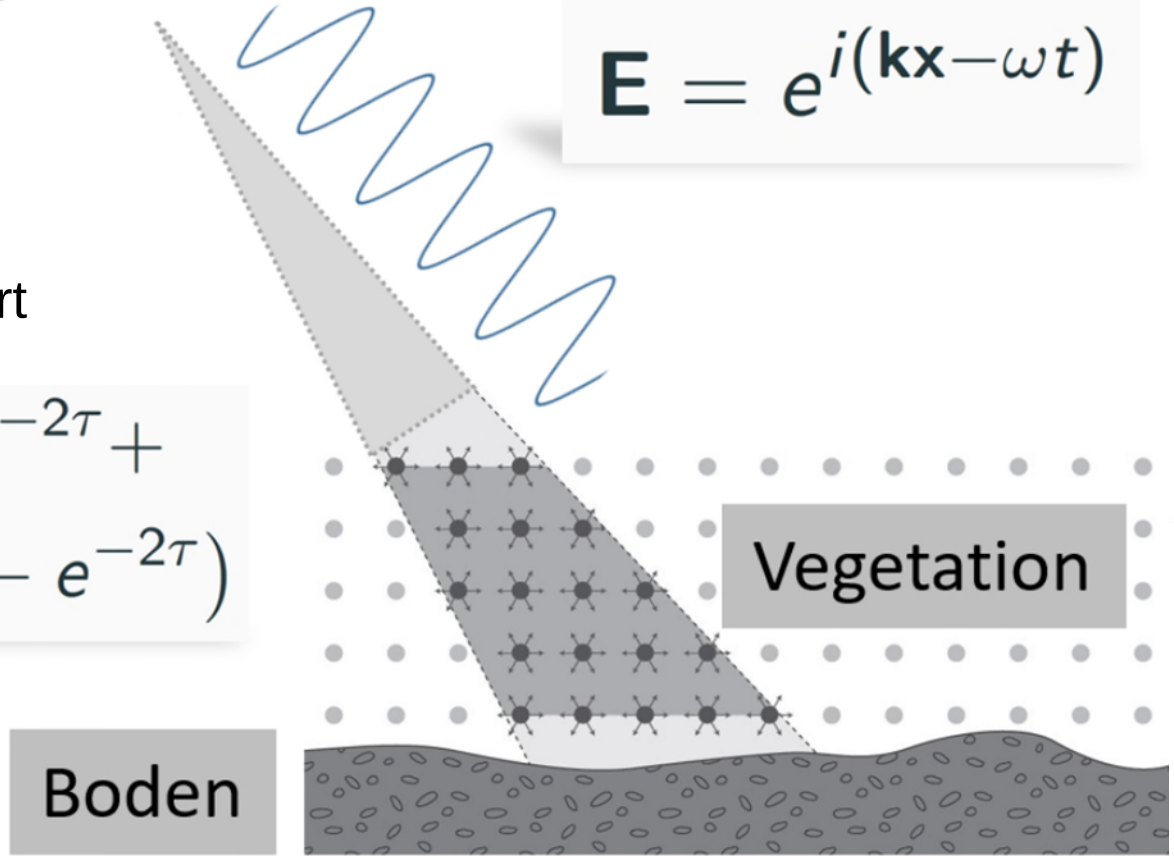


Elektrodynamik

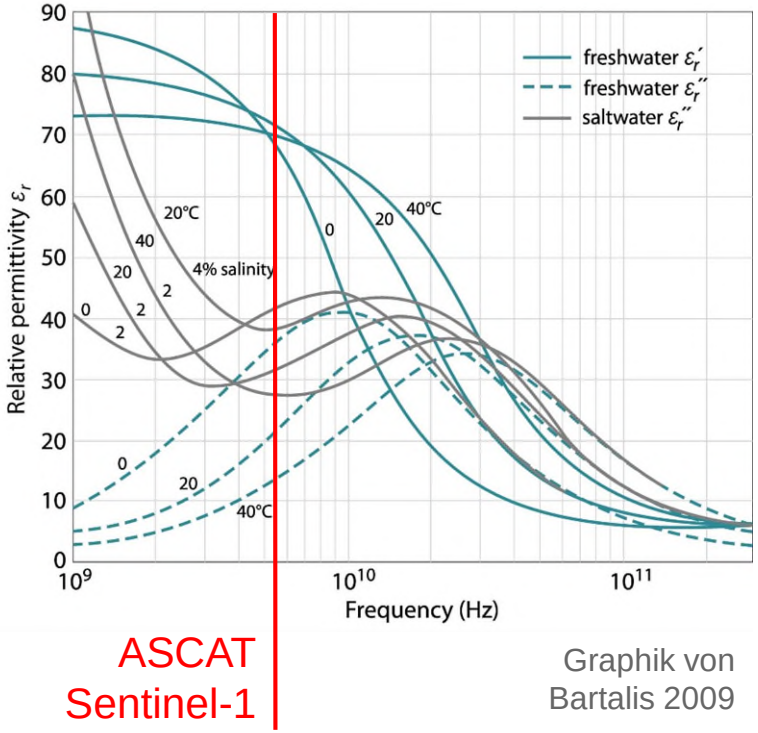
$$\mathbf{E} = e^{i(\mathbf{kx}-\omega t)}$$

Strahlungstransport

$$\sigma^{\circ} = \sigma^{\circ}_{soil} e^{-2\tau} + \omega\left(1 - e^{-2\tau}\right)$$



Dielektrizitätskonstante von Wasser



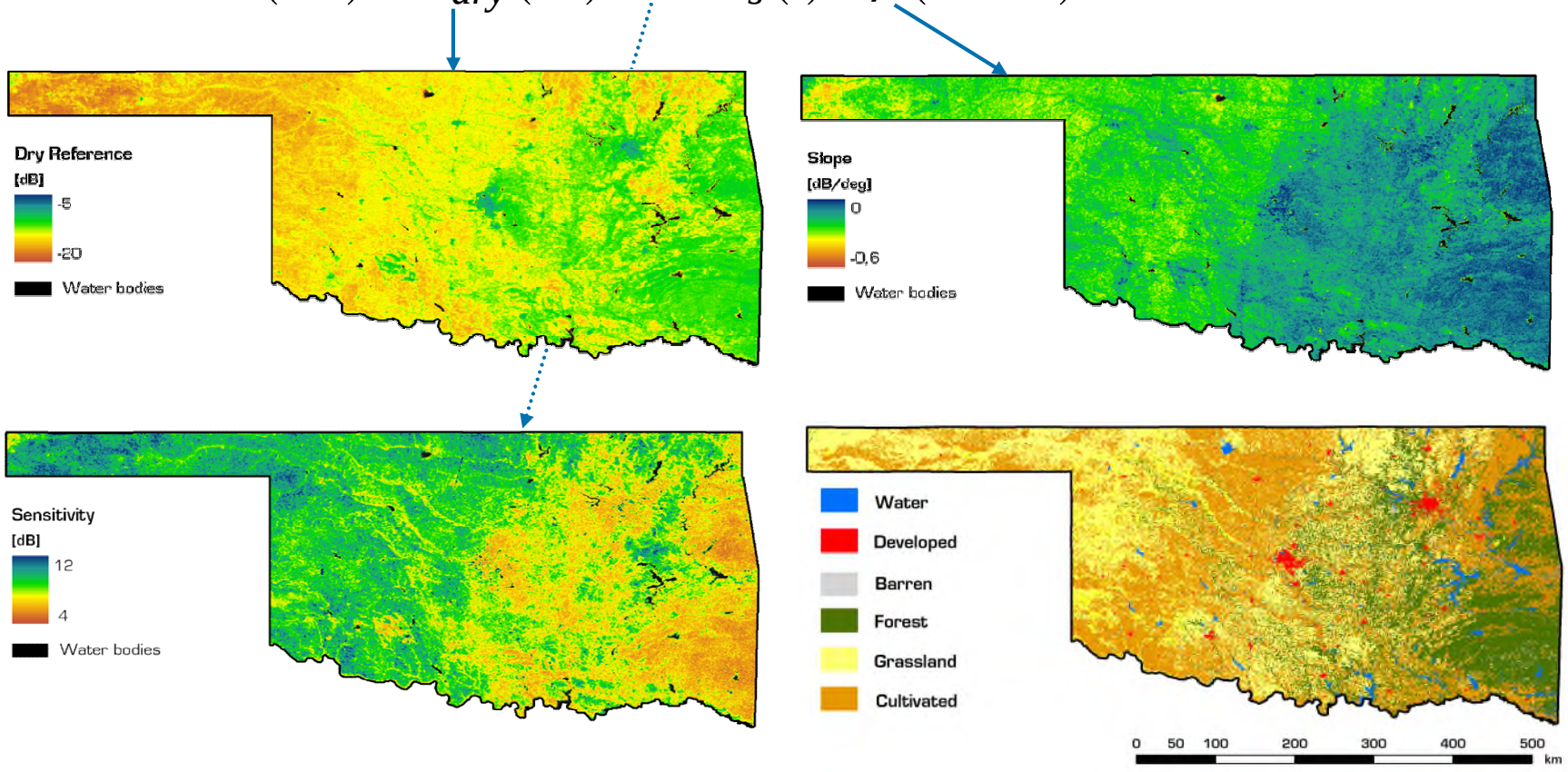
Graphik von Bartalis 2009

Change Detection Modell für die Ableitung der Bodenfeuchtigkeit

- Rückstreumodelle für ENVISAT ASAR und Sentinel-1 beruht auf vereinfachten Modell für europäische Scatterometer (ERS SCAT, METOP ASCAT)

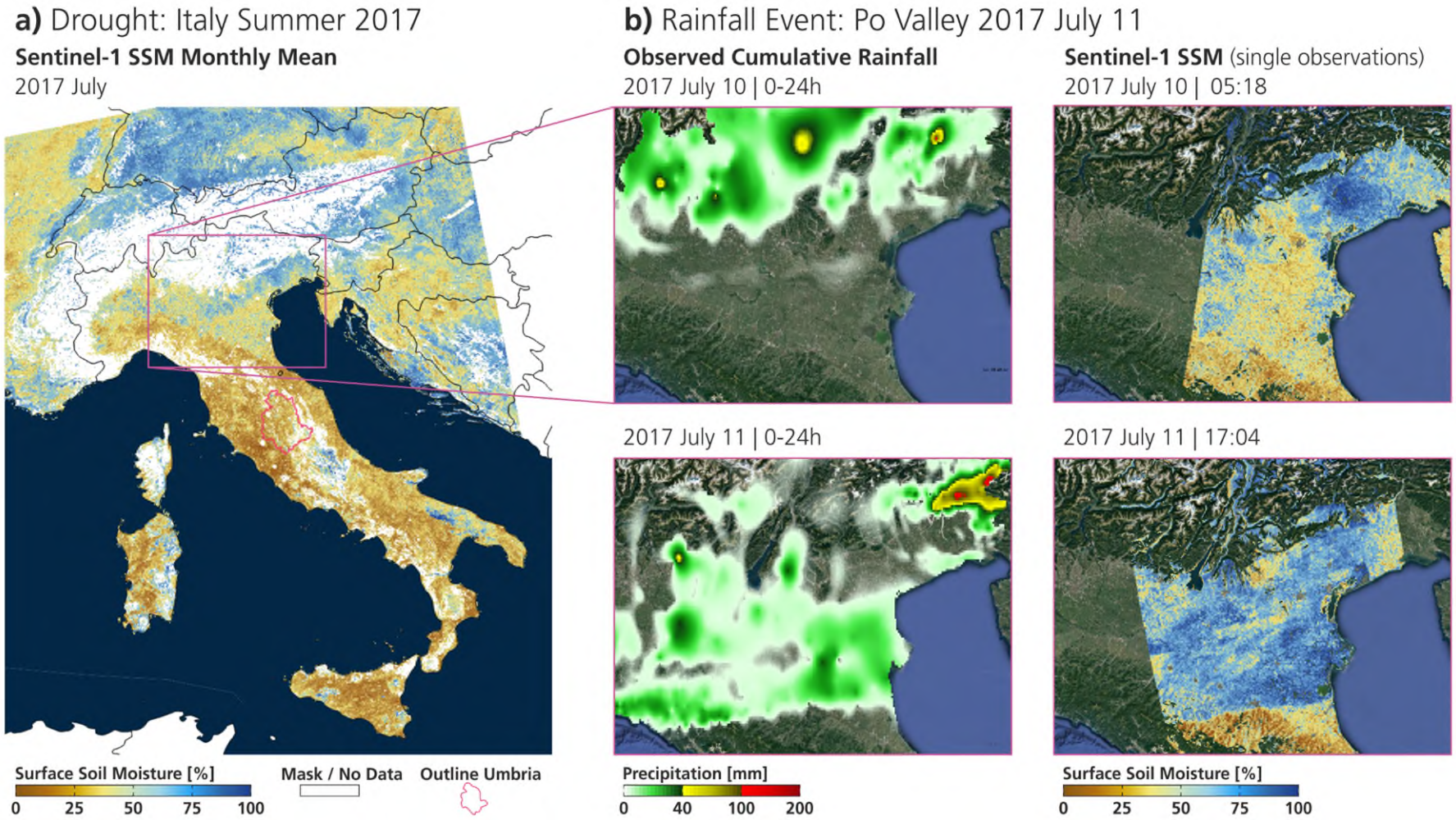
$$\sigma^0(t,\theta) = \sigma^0_{dry}(30) + S \cdot m_s(t) + \beta(\theta - 30)$$

Per-Pixel Kalibrierung der Modellparameter



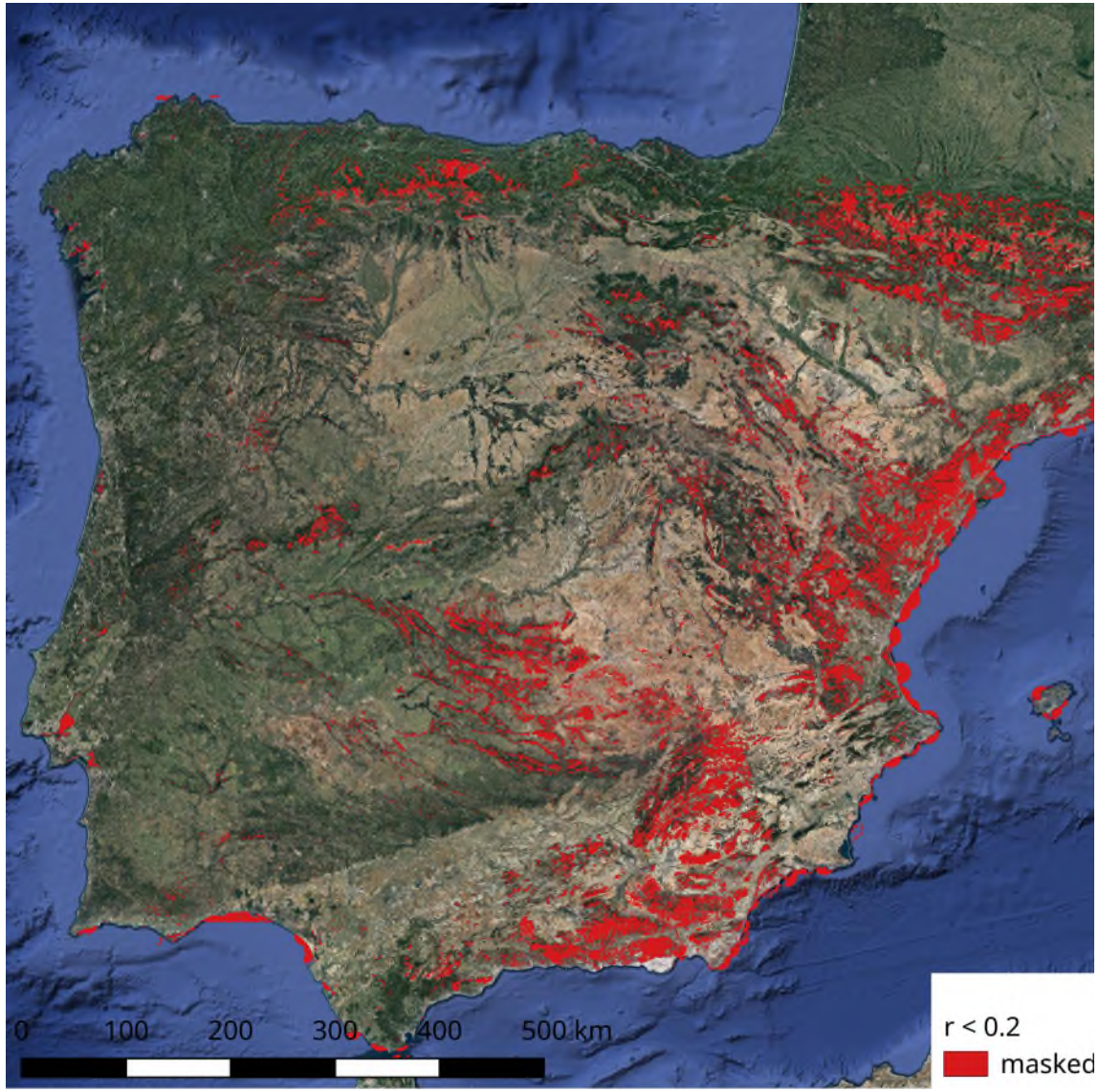
Pathe et al. (2009) Using ENVISAT ASAR Global Mode data for surface soil moisture retrieval over Oklahoma, USA, IEEE Transactions on Geoscience and Remote Sensing, 47(2), DOI 10.1109/TGRS.2008.2004711

1 km Sentinel-1 Bodenfeuchtigkeit



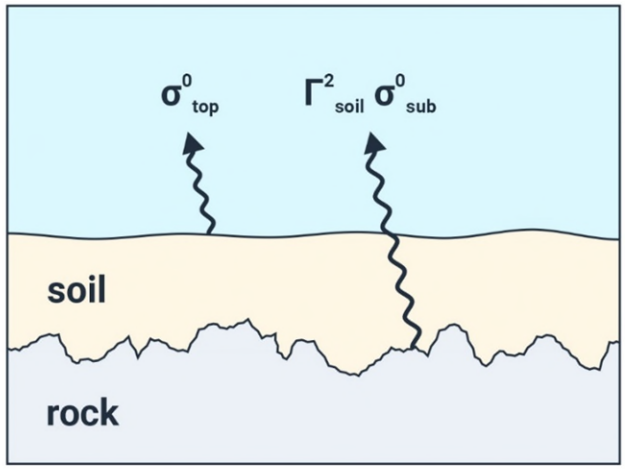
Bauer-Marschallinger et al. (2019) Towards global soil moisture monitoring with Sentinel-1: Harnessing assets and overcoming obstacles, IEEE Transactions on Geoscience and Remote Sensing, 57(1), 520-539.

Störsignale von Felsen und Steinen in den obersten Bodenschichten



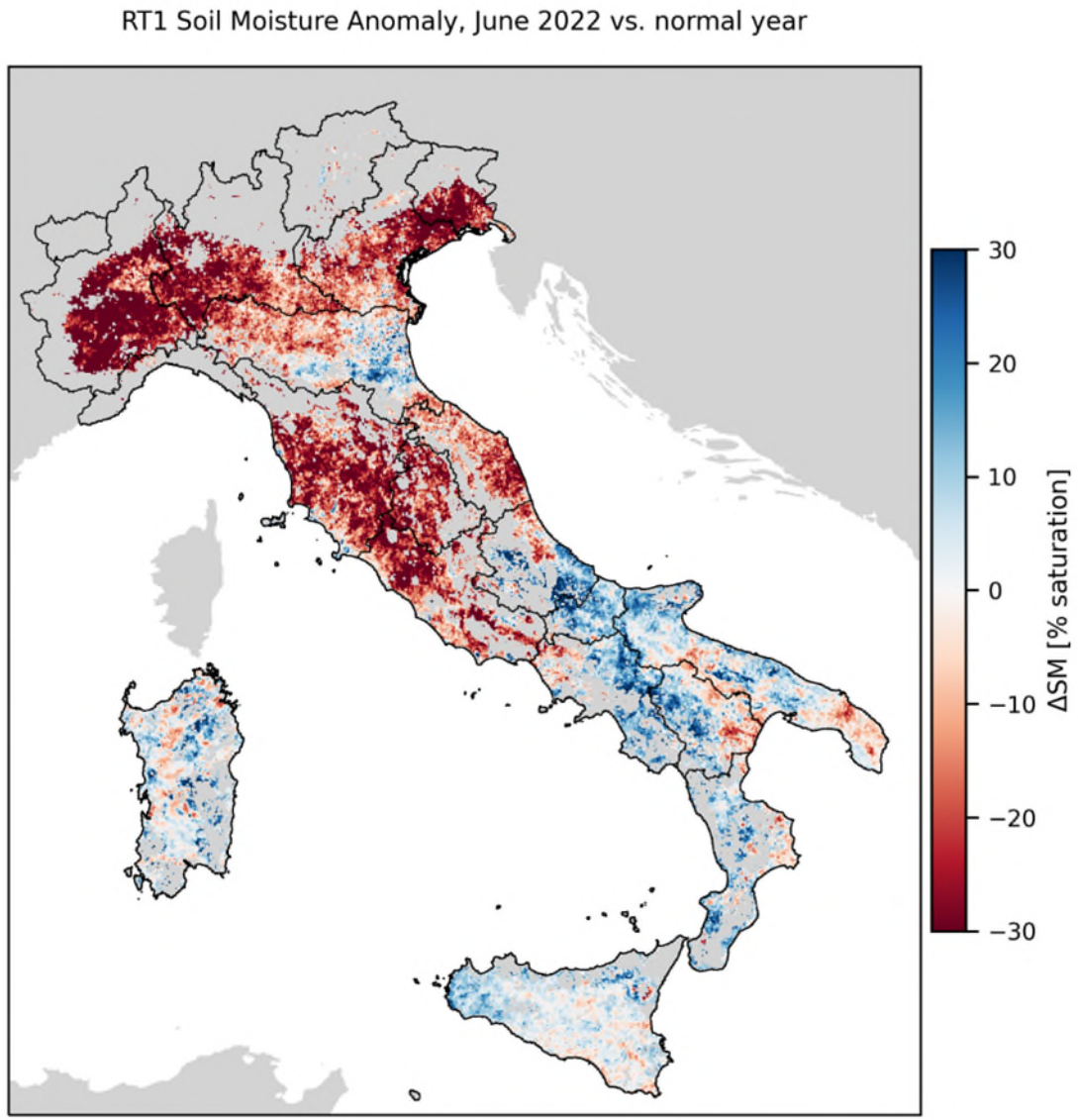
- Wenn die Böden komplett austrocknen können die Mikrowellen tief in eindringen
- Führt zu einer Erhöhung der Rückstreuung

Sentinel-1 basierte Kartierung steiniger Böden und nahe an der Oberfläche liegender Felsen (B. Raml, unveröffentlicht)



Wagner et al. (2022) Widespread occurence of anomalous C-band backscatter signals in arid environments by subsurface scattering, Remote Sensing of Environment, 276, 113025, DOI 10.1016/j.rse.2022.113025.

Sentinel-1 Bodenfeuchtigkeitsanomalie über Italien im Juni 2022



- Vergleich mit Bedingungen in Juni 2020
- Neues Rückstreumodell: RT1

Quast et al. (2019) A generic first-order Radiative Transfer modelling approach for the inversion of soil- and vegetation parameters from scatterometer observations, Remote Sensing, 11, 285, DOI 10.3390/rs11030285

Twitter Tweet von Luca Brocca (IRPI) erreichte über 60000 Views innerhalb eines Tages


Hydrology IRPI-CNR
@Hydrology_IRPI

Fantastica novità TOP
Siamo in grado di fornire mappe di #siccità alla risoluzione di 500 m ecco la mappa di anomalia per Giugno 2022
Impressionante nel nordovest e centro
@ESA_EO #Sentinel1
Elab @jetvreugdenhil R Quast
@Giulio_Firenze @LArcidiaco @DPCgov
@CopernicusEU

Ausblick & Danksagung

- Die Erde ändert sich mit rasender Geschwindigkeit
  - Zunehmender Ressourcenverbrauch
  - Wachsende Bevölkerung
  - Klimawandel & Energiewende

- (Zivile) Erdbeobachtung wichtiger den je!

Danke an ein unglaubliches Team!

Fördergeber

ESA, Europäische Kommission, EUMETSAT, FFG, FWF, BMBWF, Weltbank