

# Earth watching from space: how remote sensing reveals water and vegetation changes



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Remote Sensing Department, UFZ



Data Week Leipzig 2025

# Our earth system

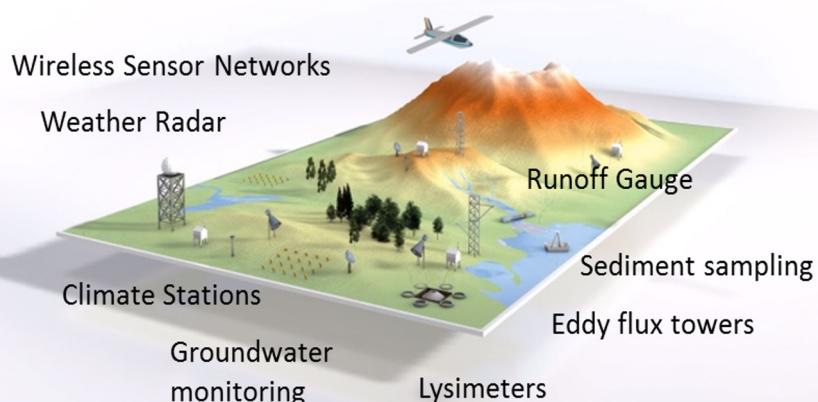


<https://serc.carleton.edu/eslabs/climate/index.html>

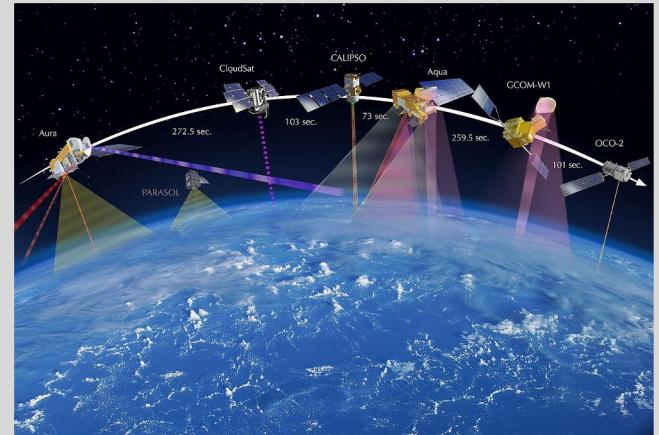
# Monitoring our earth system



## Multi-scale observations platforms



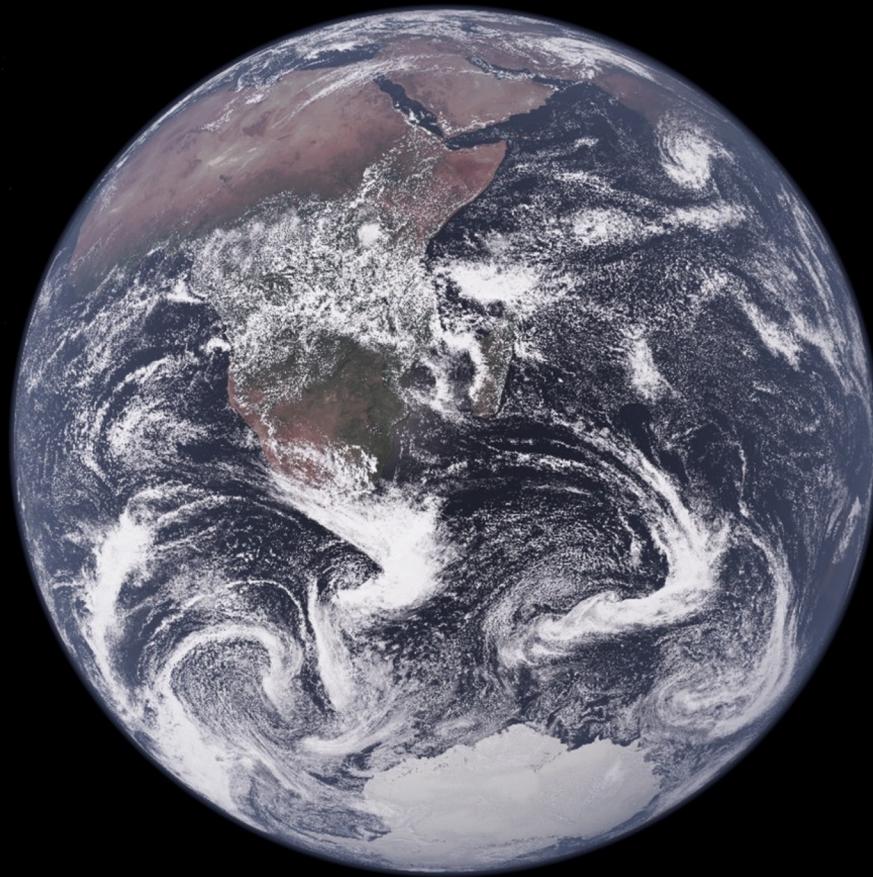
## Satellite remote sensing



[https://en.wikipedia.org/wiki/Earth\\_observation\\_satellite](https://en.wikipedia.org/wiki/Earth_observation_satellite)



Credit: MPI-M, DKRZ, NVIDIA

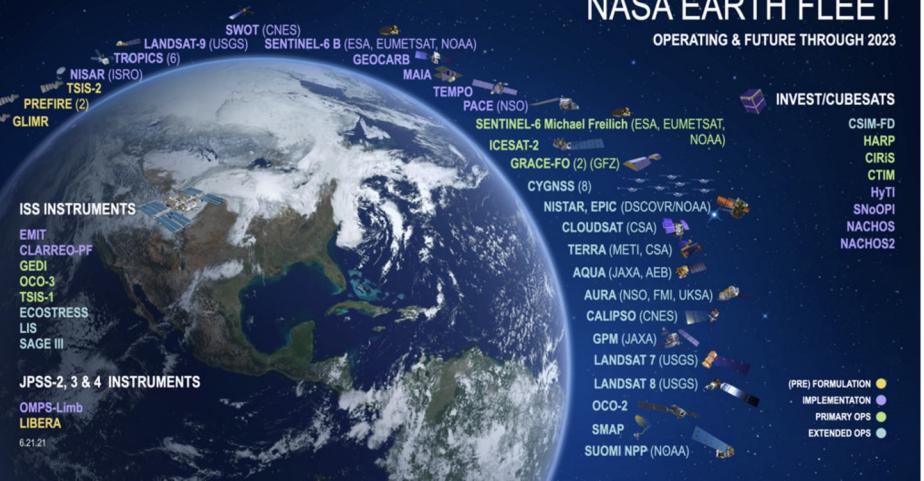


07.12.1972 : 10:39

# Earth observation missions



Credit: NASA

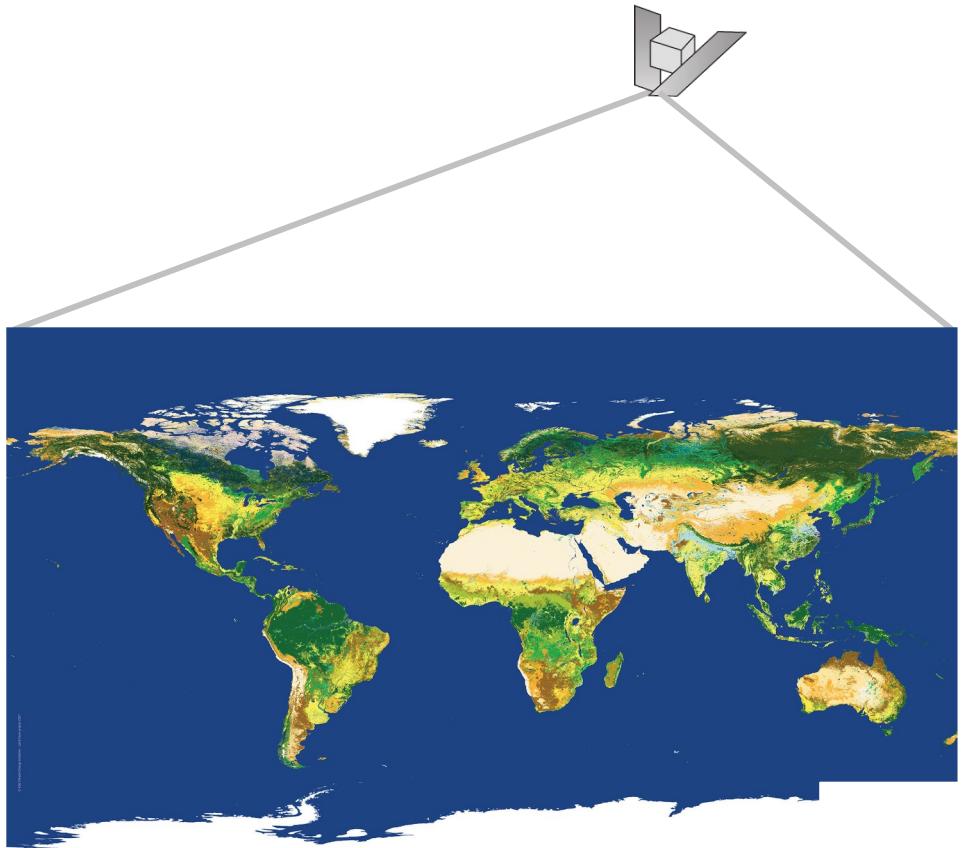
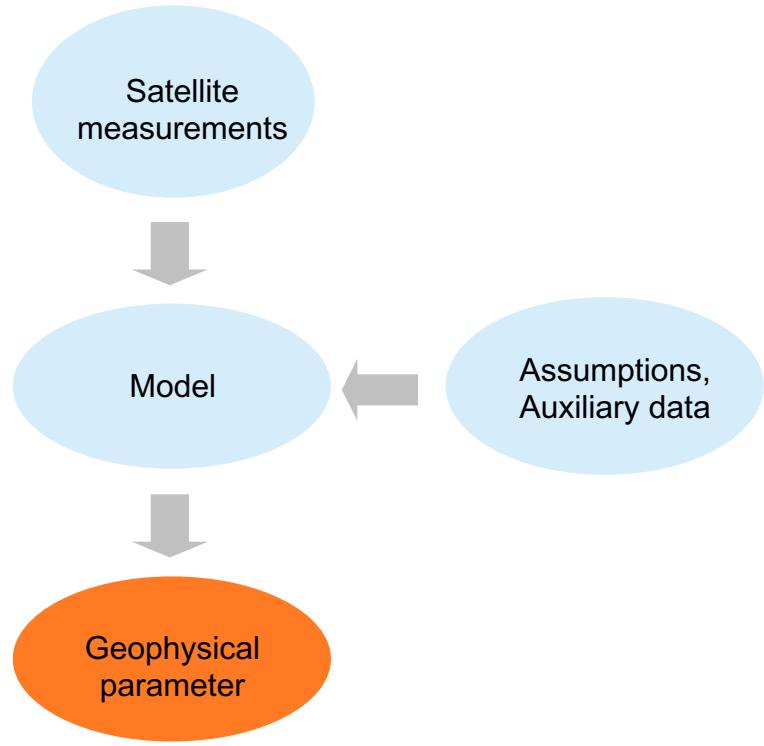


Credit: ESA

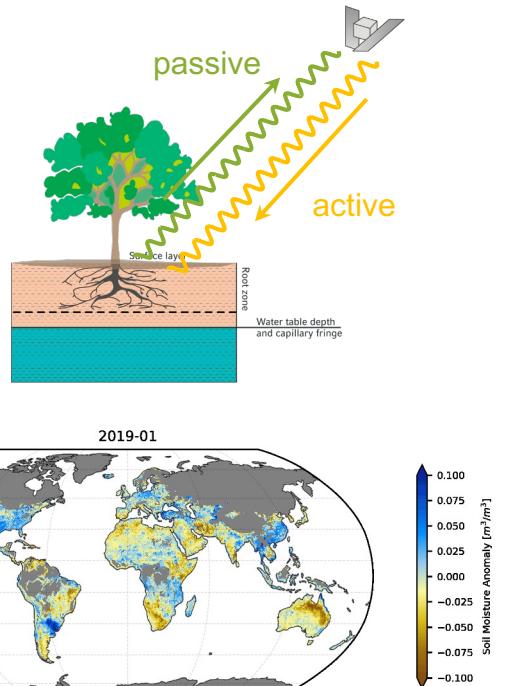


## Long-term climate data records and high-resolution monitoring capacities

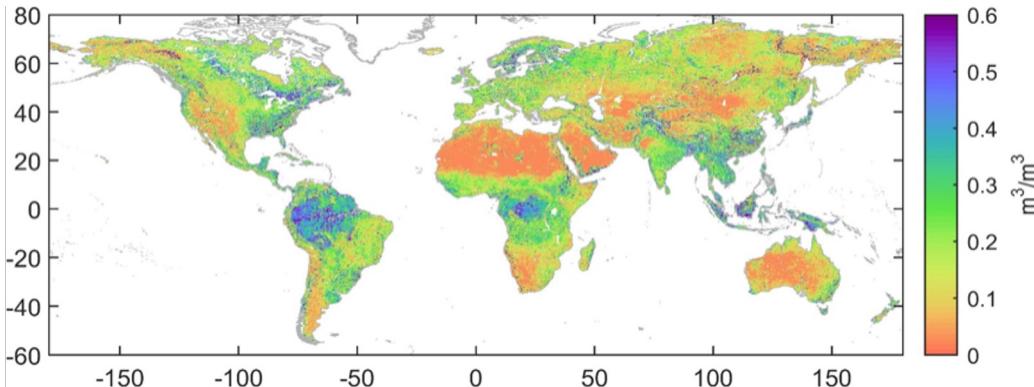
# Remote sensing of land dynamics



# Remote sensing of soil moisture

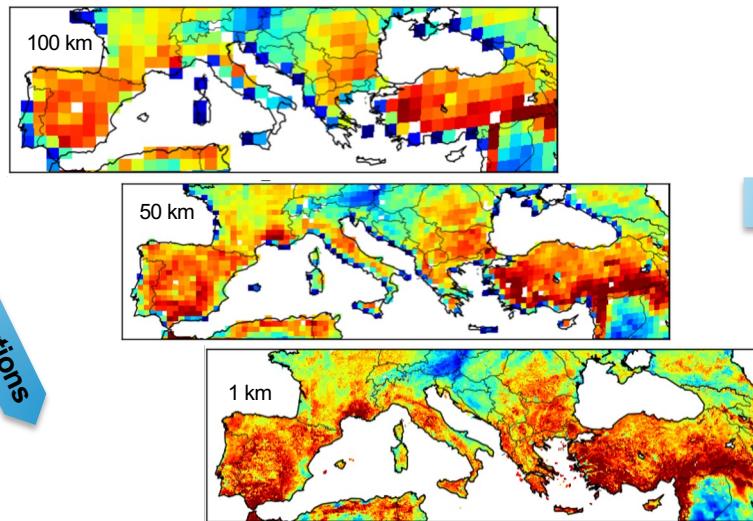


Global 1 km soil moisture from Sentinel 1 & 2



- Filling the gap of no global high resolution products
- Improving high resolution hydrological simulations

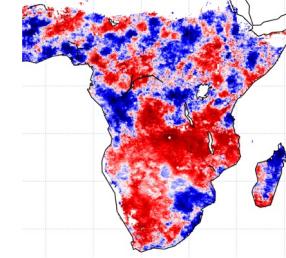
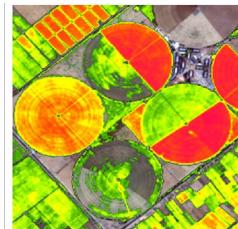
# Application of remote sensing products



Agriculture/irrigation

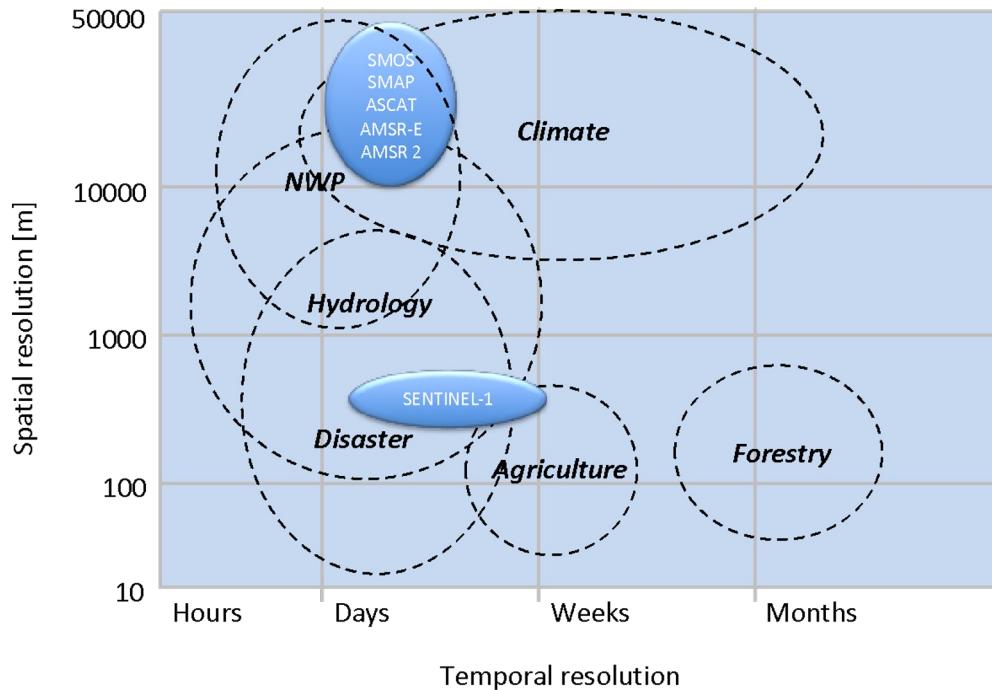


Climate extremes



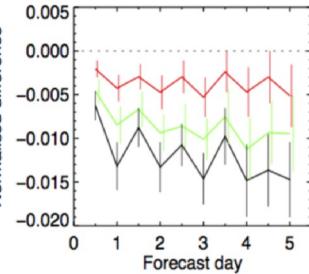
Scalable resolutions

# Application of soil moisture products

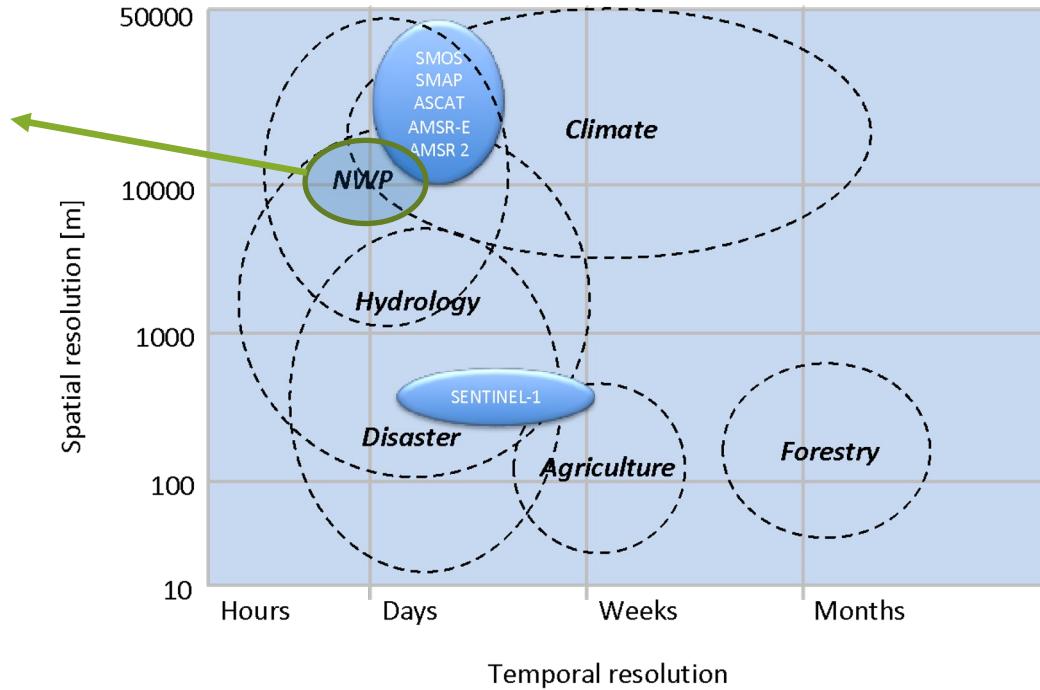


# Application of soil moisture products

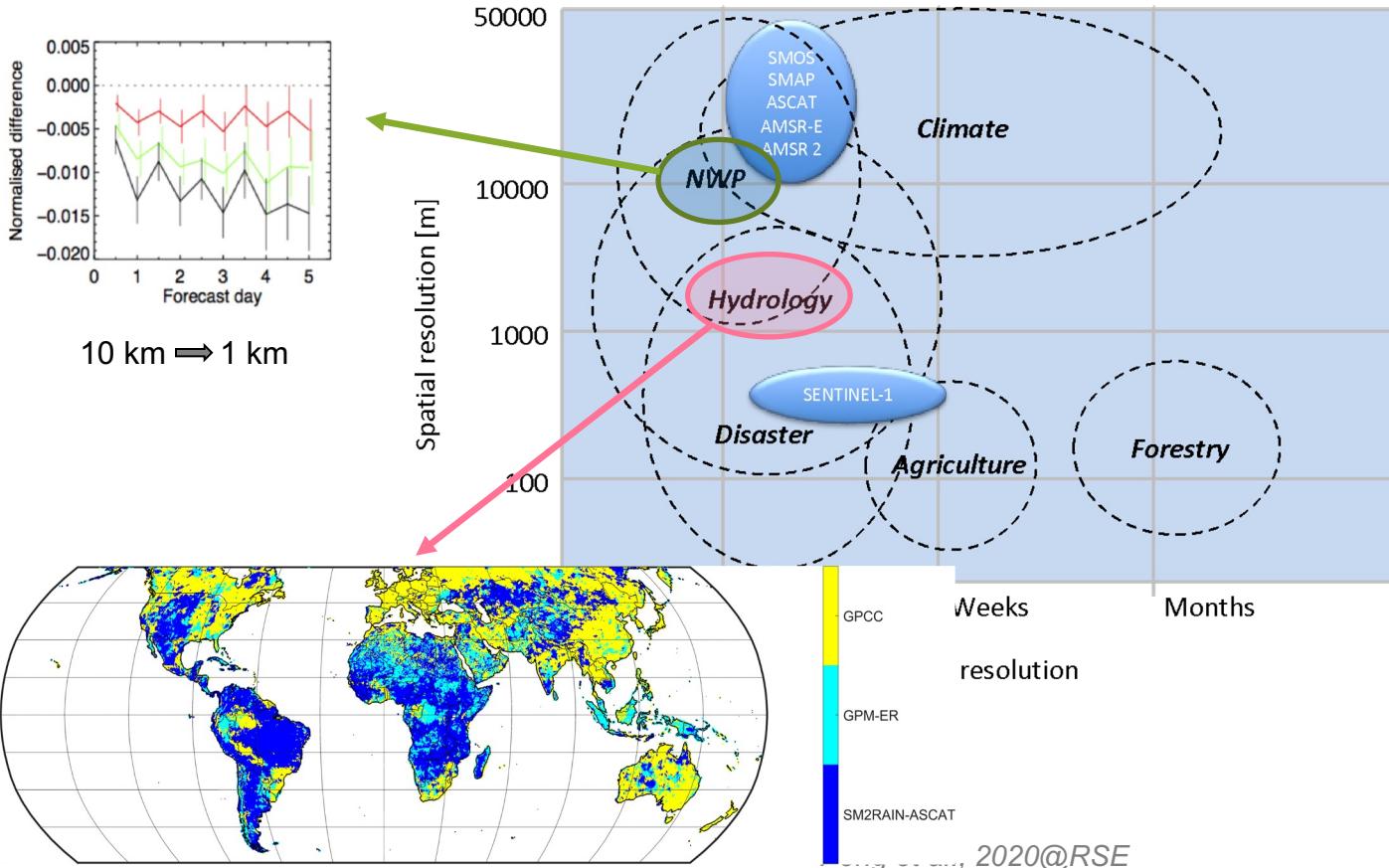
Normalised difference



10 km  $\rightarrow$  1 km

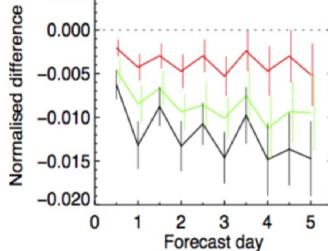


# Application of soil moisture products

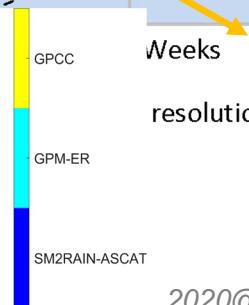
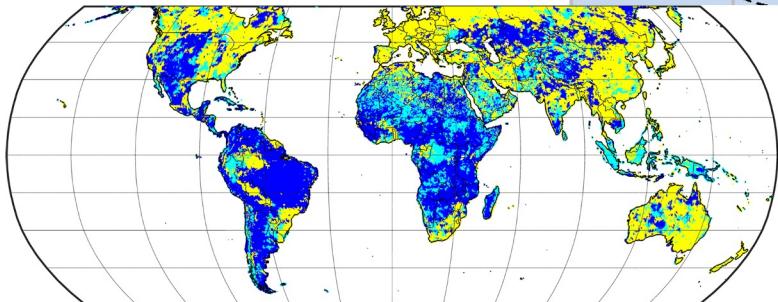
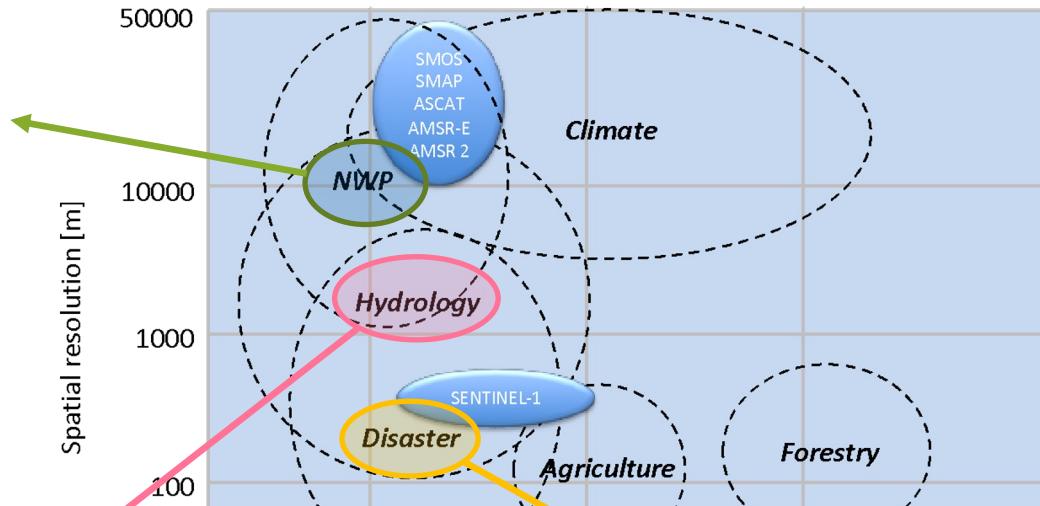




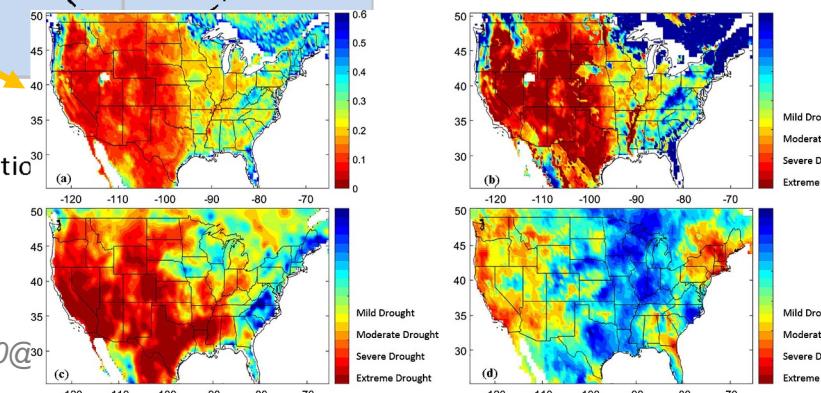
# Application of soil moisture products



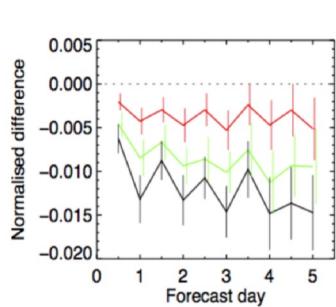
10 km → 1 km



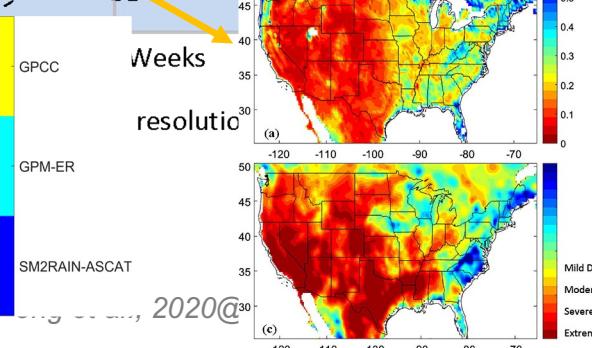
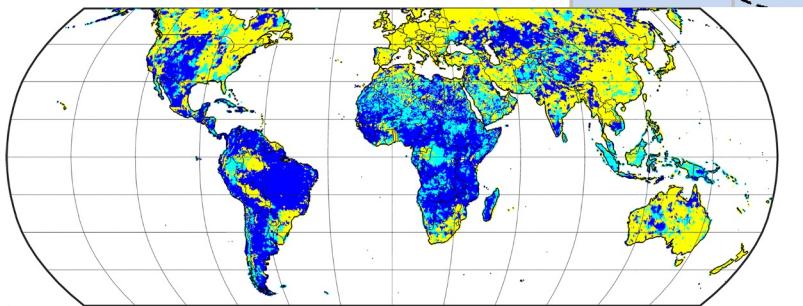
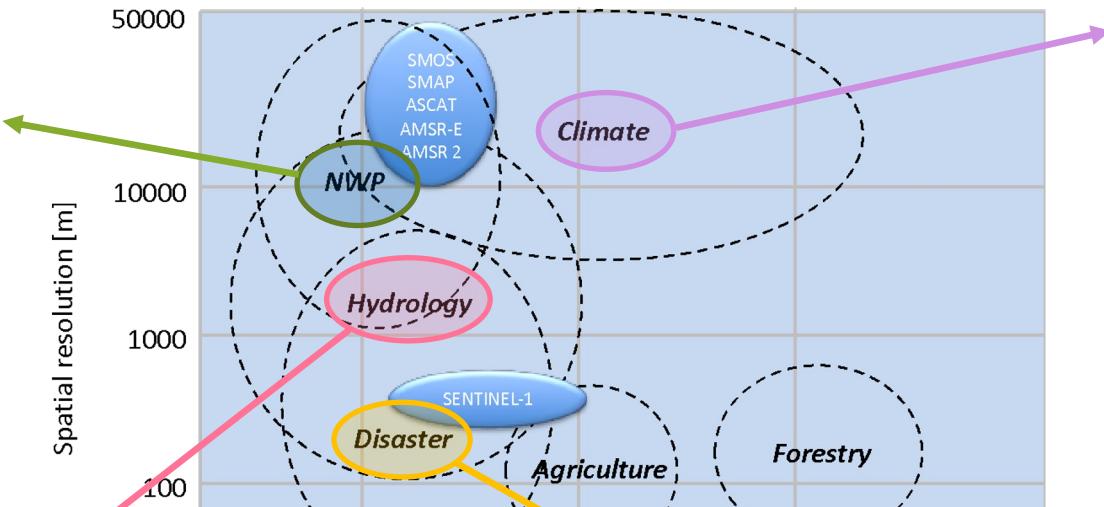
2020@



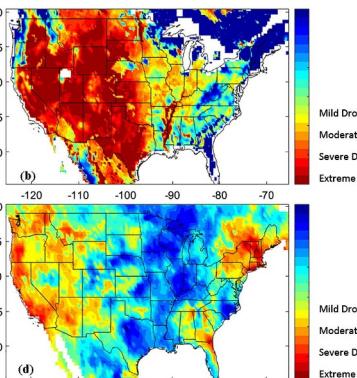
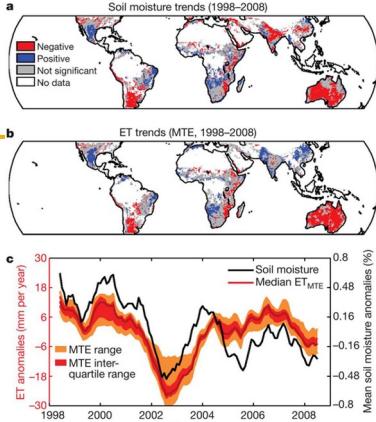
# Application of soil moisture products



10 km  $\rightarrow$  1 km



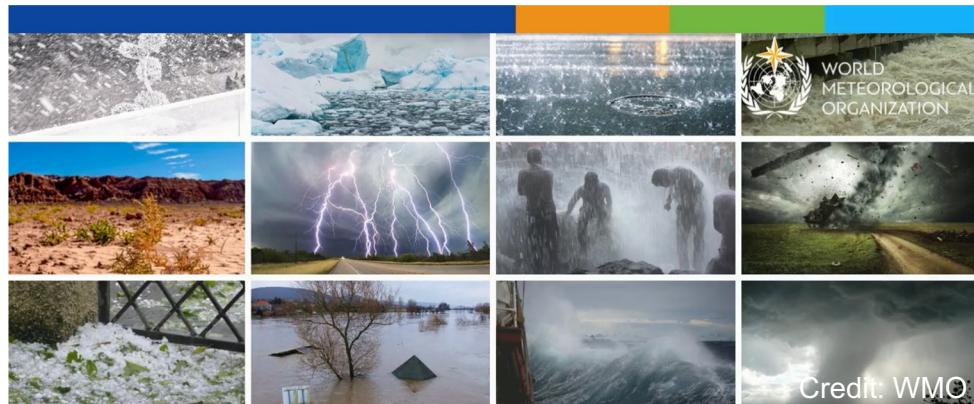
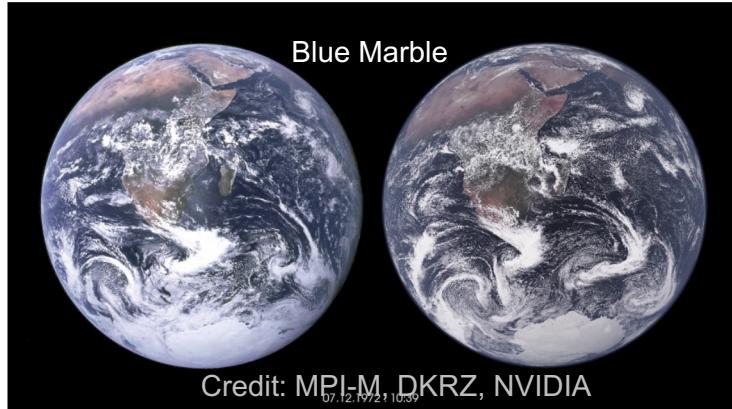
2020@



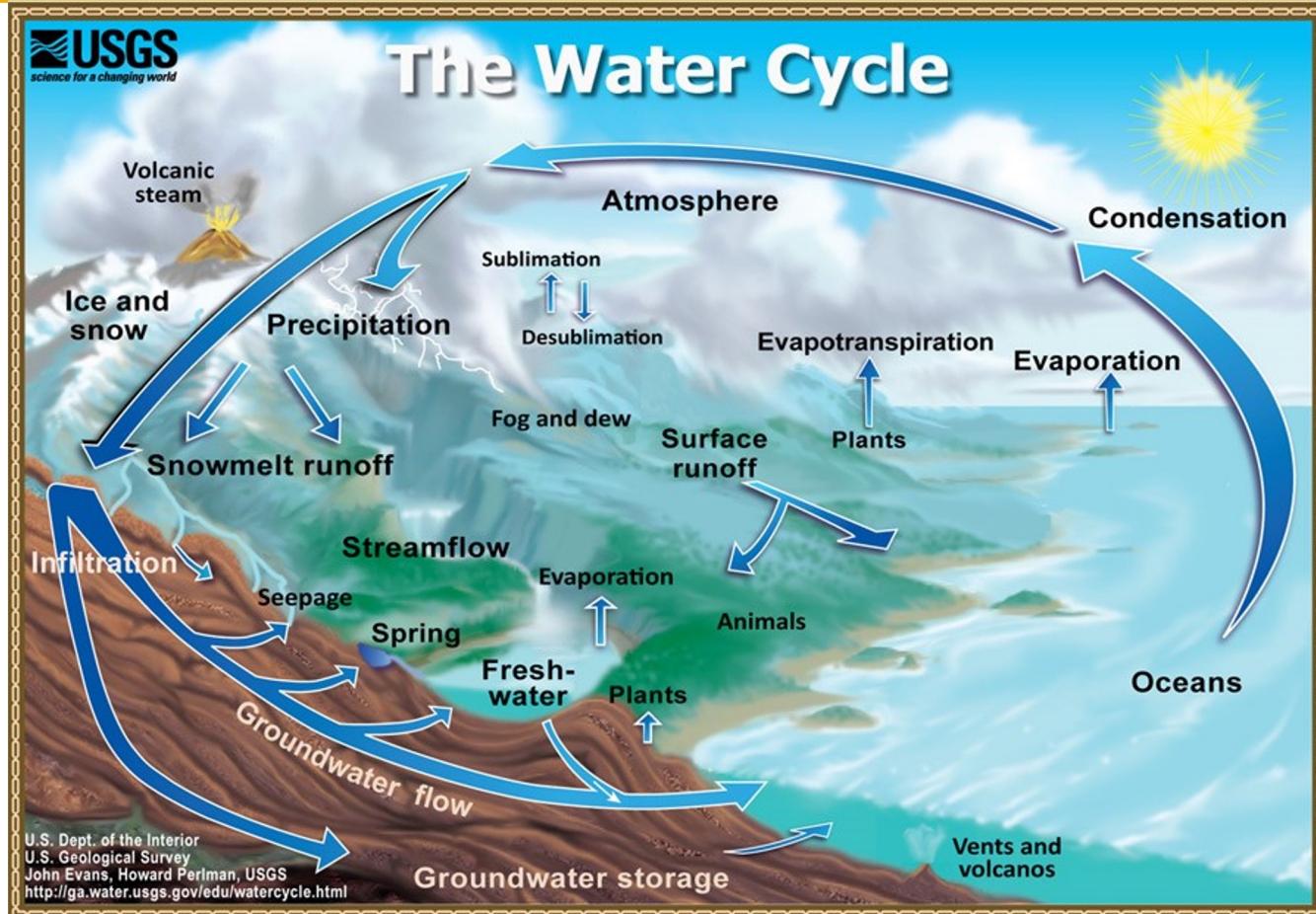
# Our research questions



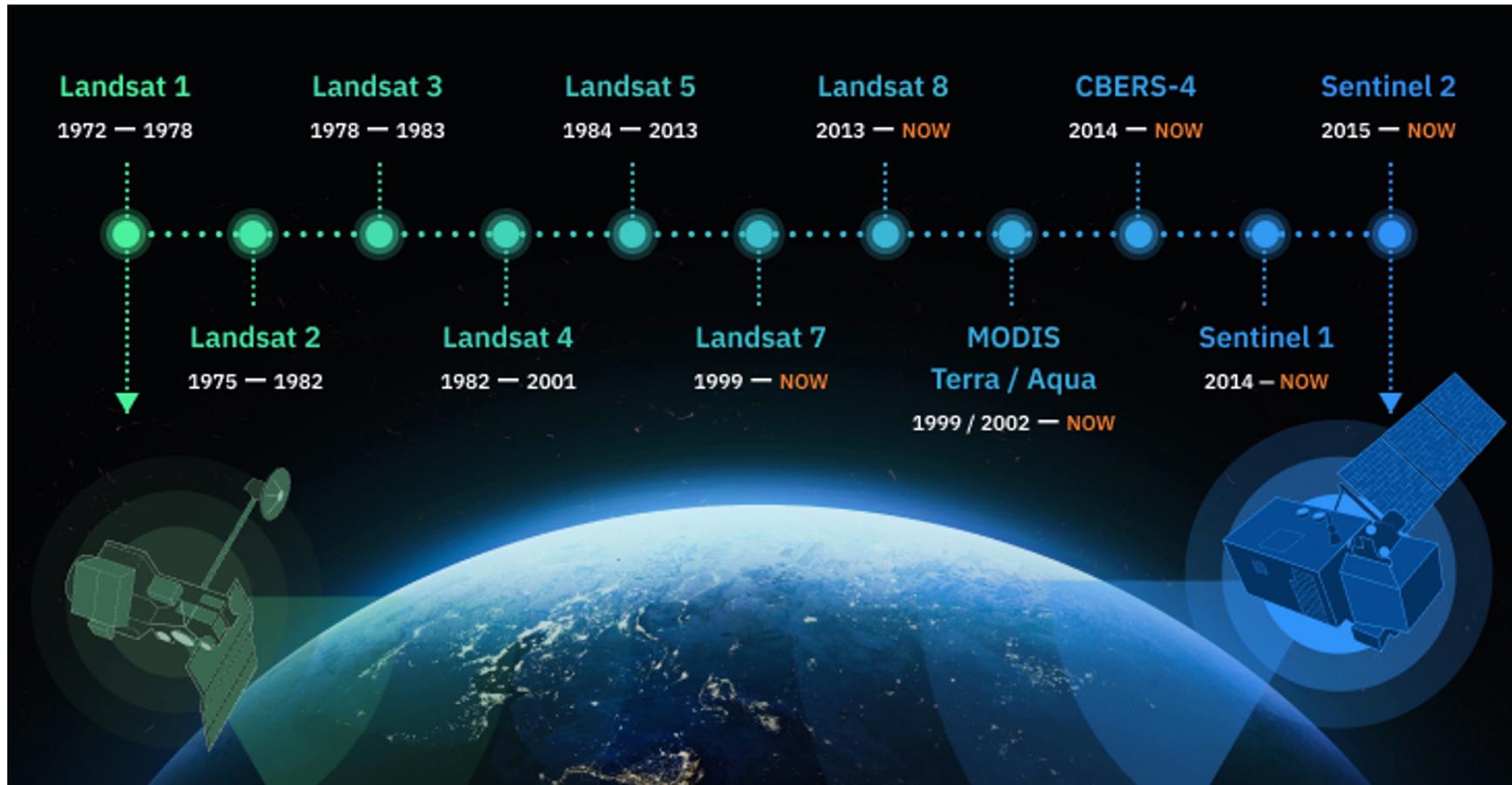
- What are the impacts of climate change on water/energy resources and ecosystem functions?
- How can we quantify water and vegetation dynamics across scales through the integration of multi-source remote sensing data, physical models and machine learning methods?
- What are the benefits of transferring our remote sensing expertise to address societal challenges?



# Remote sensing for water



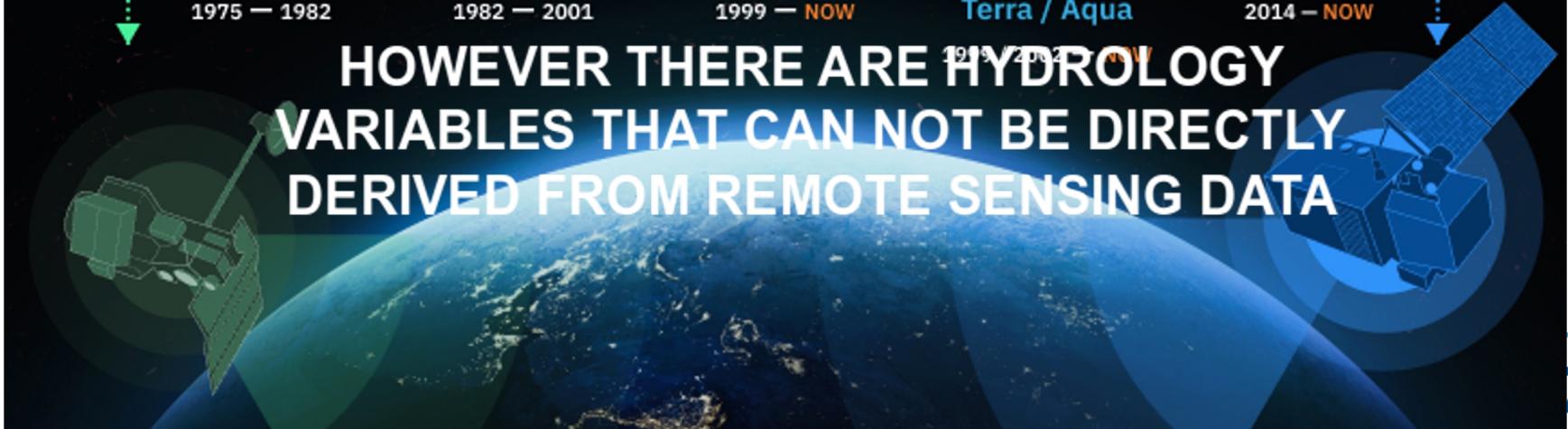
# Remote sensing for water



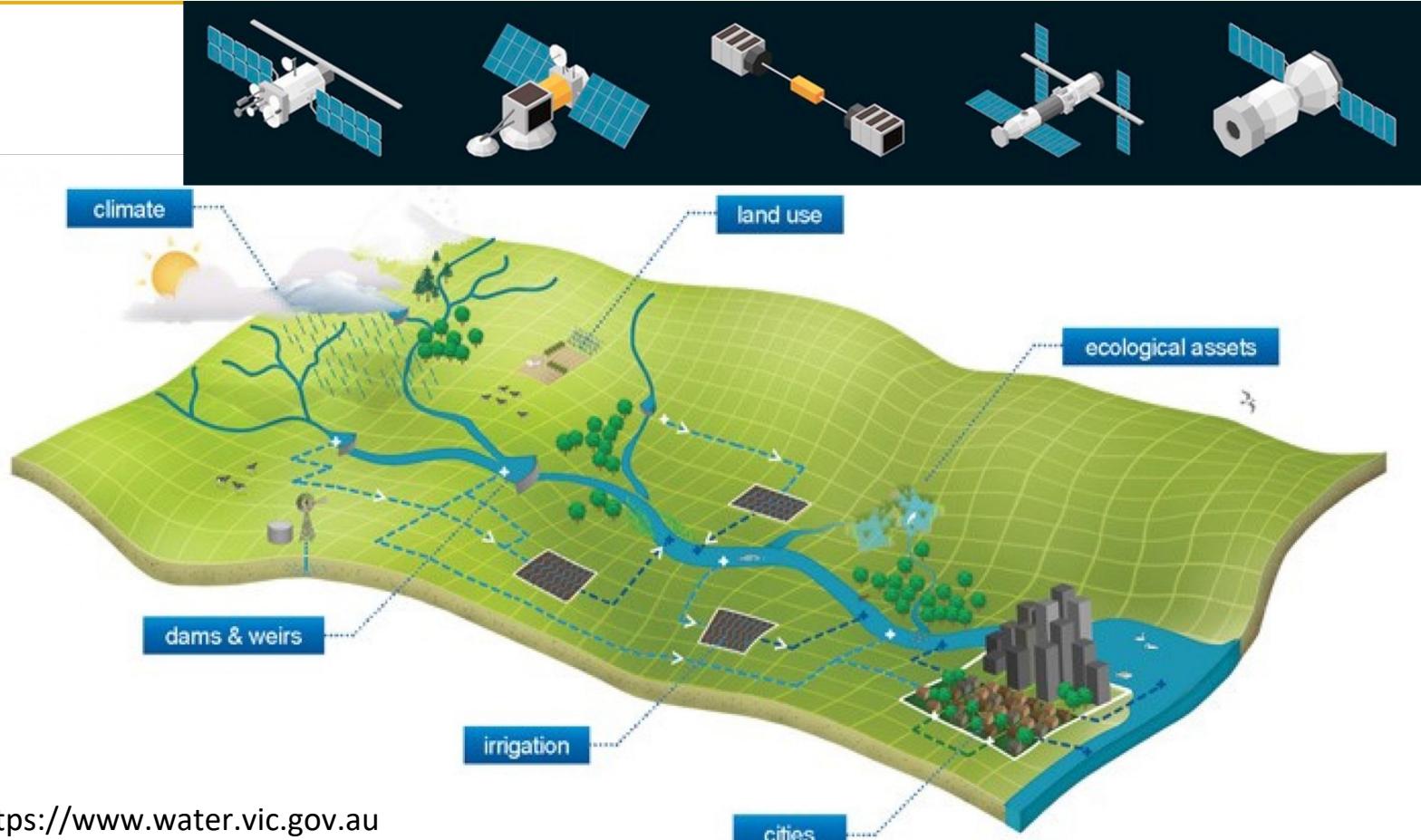
# Remote sensing for water



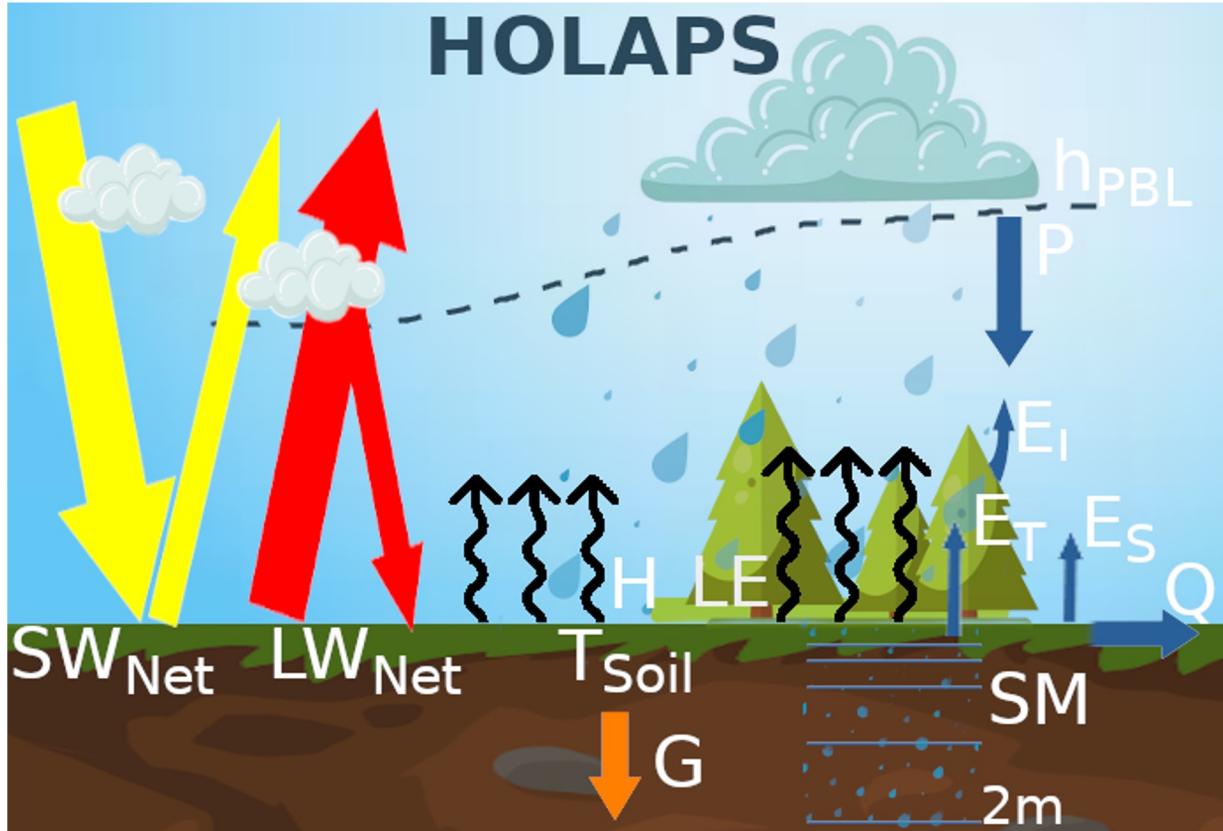
HOWEVER THERE ARE HYDROLOGY  
VARIABLES THAT CAN NOT BE DIRECTLY  
DERIVED FROM REMOTE SENSING DATA



# Combination of RS with physical-based models



# Example: HOLAPS



The High resolution Land Atmosphere Parameters from Space (HOLAPS) framework uses as much remote sensing products as possible to produce hourly consistent estimates of energy and water fluxes over Europe at 5 km resolution.

# Example: HOLAPS

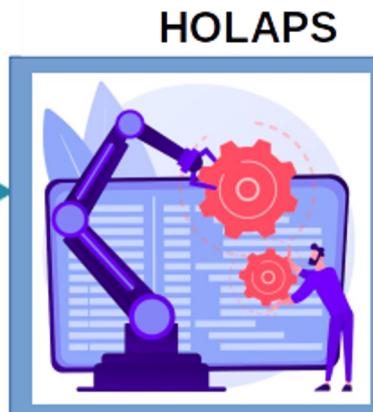


## SATELLITES

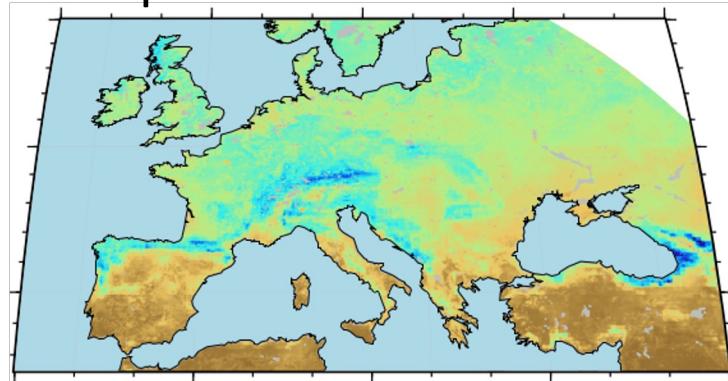
CMSAF SARAH Radiation  
NOAA-AVHRR LAI  
MODIS Albedo  
GLASS Emissivity  
ESA-CCI Land Cover  
GPL-IMERG Precipitation

## Other observation-based products

ERA5Land Air Temperature  
ERA5Land Surface Pressure  
ERA5Land Wind Speed  
ERA5 Column Water Vapour  
SoilGrids Clay Sand Silt



Consistent hourly estimates of energy and water fluxes at the land surface with 5 Km spatial resolution over Europe from 2001 to 2020

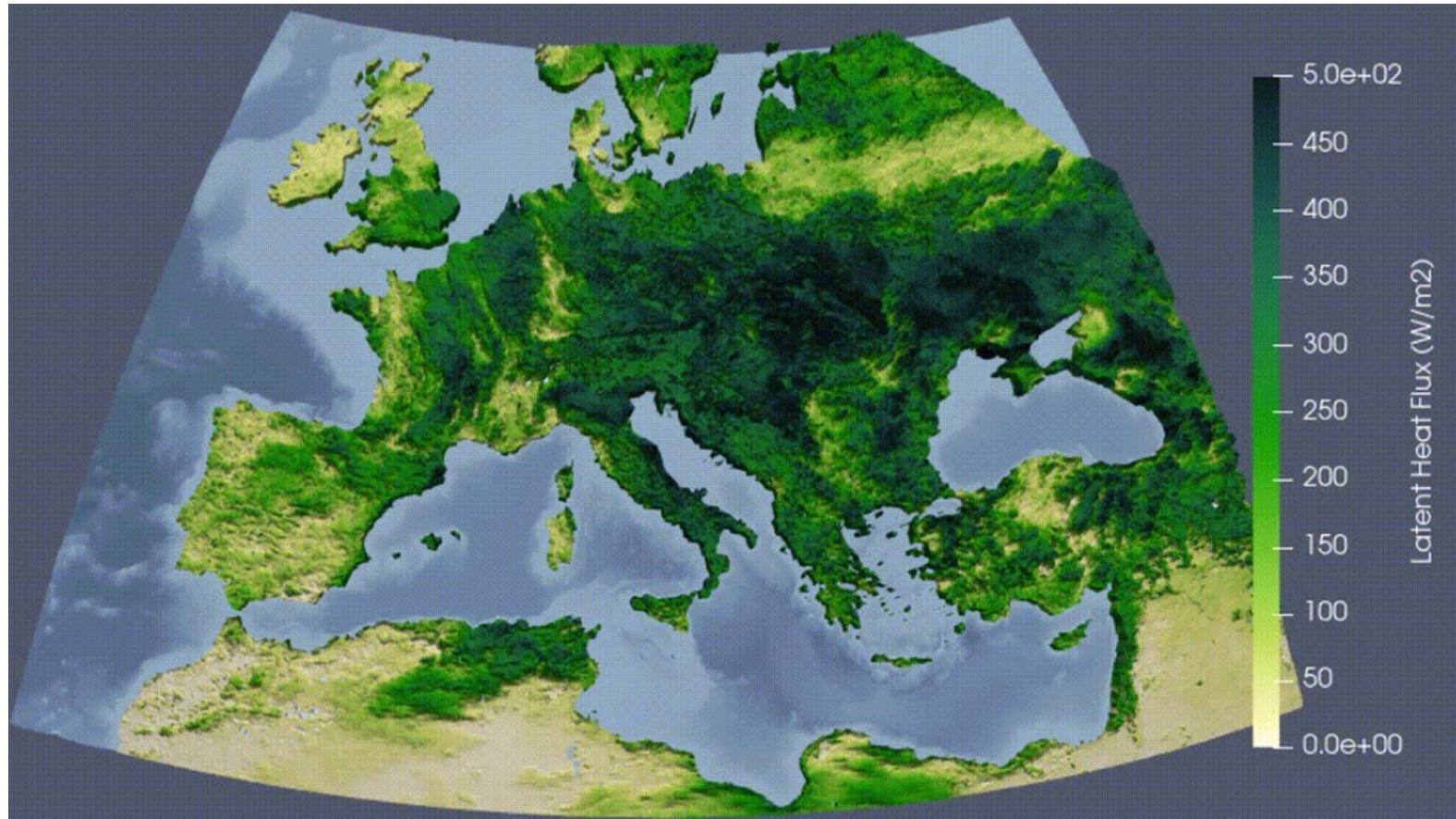


Almudena Garcia-Garcia

Almudena.garcia-garcia@ufz.de



# Example: HOLAPS



# Example: Other examples



## 4DHydro

# Hyper-resolution Earth Observations And Land-surface Modeling For A Better Understanding Of The Water Cycle

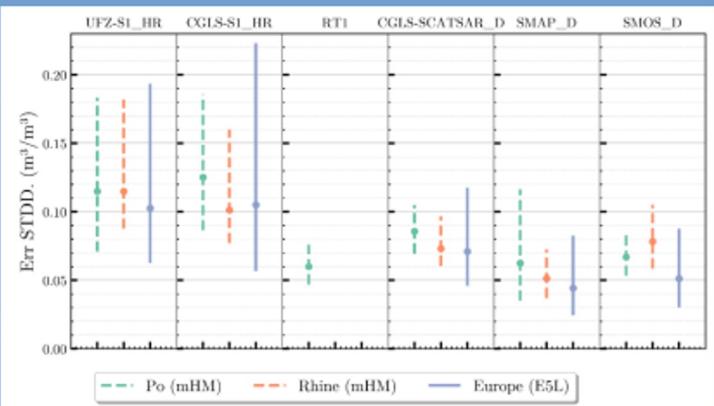




# Example: Other examples

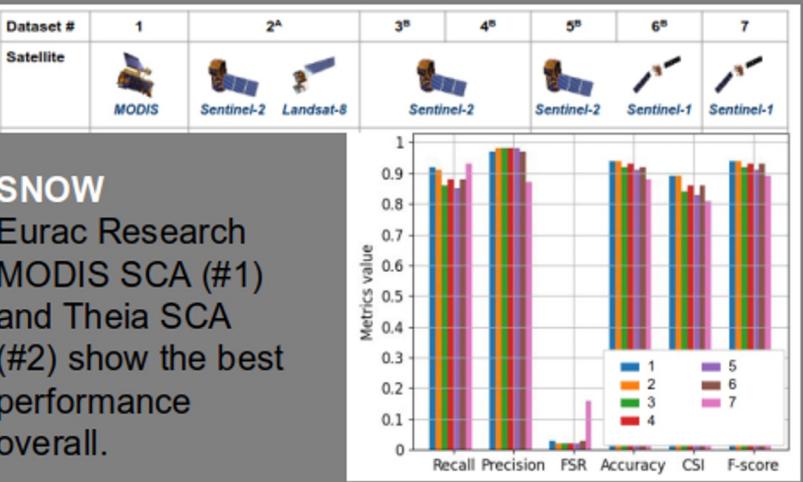
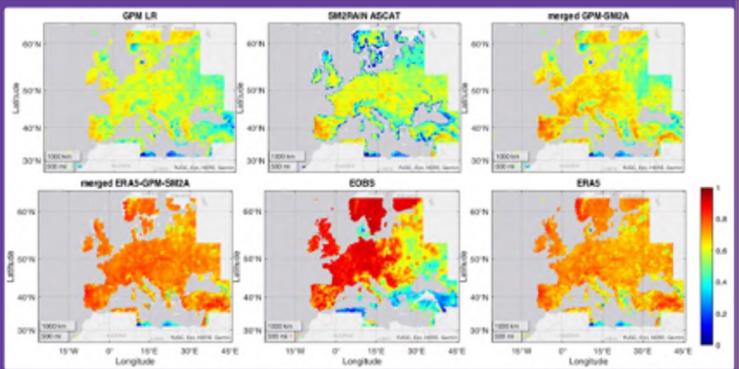
## SOIL MOISTURE

No conclusive evidence of improved spatial and/or temporal skill with reference to a coarse resolution.



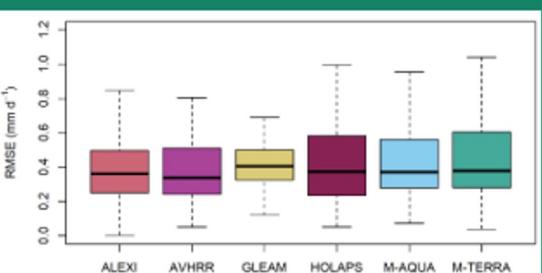
## PRECIP- ITATION

Merged downscaled product has the best Performance.



## EVAPOTRANS- PIRATION

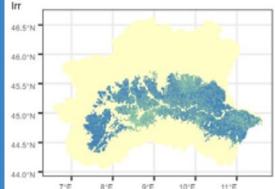
No product showing the best performance everywhere.



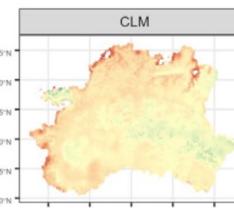
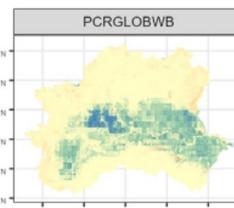
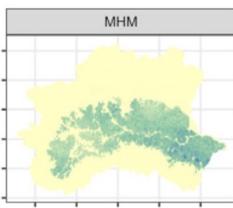
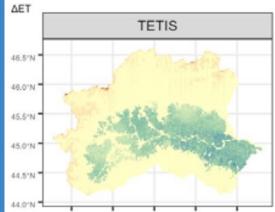
# Example: 4DHydro



Resolution = 1km



SC (UPV): Irrigation effect on water balance



4DHydro webpage: <https://4dhydro.eu/>

The screenshot shows the 4DHydro website homepage with a blue header containing the logo, navigation links (Home, Research, Products, Open science catalog, News, Blog, Contact), and search functions. The main content area features a map of Europe with various hydrological data overlays.

Catalogs (40)

Tiles

Ascending

Descending

Filter catalogs by title

CLM 0.0275 degree discharge (REA6) for Europe

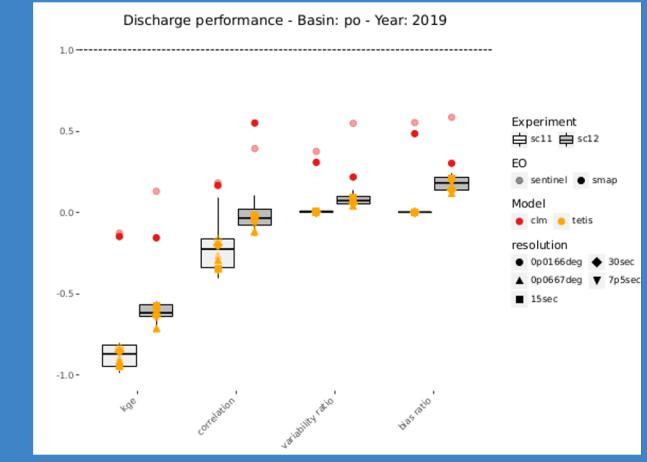
TETIS\_EMO\_Po\_30sec\_exp10  
TETIS\_EMO\_Po\_30sec\_exp10

The mesoscale Hydrologic Model - mHM 0.125 degree discharge (ERA-5) for Rhine

CLM 0.0275 degree discharge (REA6) for Europe

The mesoscale Hydrologic Model - mHM 0.125 degree discharge (ERA-5) for Rhine

SC (FZJ): Forecasting extreme streamflow





**How many computational resources are needed for generating the HOLAPS product (Europe, 5km, 1 year)?**

< 10 core-hour

≈500 core-hour

≈million core-hour



## How many computational resources are needed for generating the HOLAPS product (Europe, 5km, 1 year)?

AI forecasting  
models

< 10 core-  
hour

HOLAPS

≈500 core-  
hour

Global climate model  
(25 km, 1year)

≈million  
core-hour

# Waldzustandsmonitor

Daniel Doktor: Projektleitung

Maximilian Lange: Prozessierung, Waldzustand, WebGIS

Anne Reichmuth: Forstexpertise, Artverbreitungsmodellierung, WebGIS

Sebastian Preidl: Baumartenklassifikation

Gundula Schulz: Feldarbeiten

Andreas Schmidt: Lagegenauigkeit Satellitendaten

Steffen Lehmann: Webseite, Feldarbeiten

Leipzig, 10. Juni 2025

Wissenstransferprojekt „Waldzustandsmonitor“

Data Week



Copyright André Künzelmann, UFZ



## WALDWÄR

Themen Schwerpunkte Ministerium Service Aktuell

### Massive Schäden - Einsatz für die Wälder

Stürme, die extreme Dürre, überdurchschnittlich viele Waldbrände und Borkenkäferbefall – das hat den Wäldern in Deutschland in den vergangenen zwei Jahren immens zugesetzt. Setzt sich die trockene Wetterlage fort, stehen die Wälder auch 2020 vor enormen Herausforderungen.



<https://www.bmel.de/DE/themen/wald/wald-in-deutschland/wald-trockenheit-klimawandel.html>

### Waldschäden bedingt durch Dürre, Schädlinge, Stürme:

- 285.000 Hektar müssen wiederbewaldet werden (2,5 % der Fläche) \*
- Fichte in den Flachlandregionen / Norddeutschland stärker geschädigt
- Aber auch potenziell natürliche Vegetation (Buche) teilweise geschädigt
- Wälder verloren in vergangenen Trockenjahren ihre Senkenfunktion und wurden zu einer Kohlenstoffquelle \*\*

\* Waldzustandsbericht 2019

\*\* Ciais, P. et al. (2005), 'Europe-wide reduction in primary productivity caused by the heat and drought in 2003', NATURE 437(7058), 529-533.)



Quelle: bild.de

## Waldschäden bedingt durch Dürre, Schädlinge, Stürme:

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\* Waldzustandsbericht 2019

\*\* Ciais, P. et al. (2005), 'Europe-wide reduction in primary productivity caused by the heat and drought in 2003', NATURE 437(7058), 529-533.)



Quelle: Nationalparkverwaltung Hainich

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\* Waldzustandsbericht 2019

\*\* Ciais, P. et al. (2005), 'Europe-wide reduction in primary productivity caused by the heat and drought in 2003', NATURE 437(7058), 529-533.)



Quelle: Sächsisches Staatsministerium für Energie,  
Klimaschutz, Umwelt und Landwirtschaft

## Instrumente für effizientes Risikomanagement im Klimawandel nicht ausreichend:

- Sehr genaue Information auf plot Ebene, aber:
- Vergleichsweise lange Zeitintervalle (1-2 x pro Jahr) mit nachfolgender Zeitverzögerung der Schadensmeldung aufgrund der zeit- und personalintensiven Erhebungen
- Nur geringe Flächenanteile werden beobachtet, z.B. ganz Sachsen mit 283 Erhebungspunkten
- Dadurch Skalierung der Beobachtungen sowie Detektion von lokalen Abweichungen herausfordernd

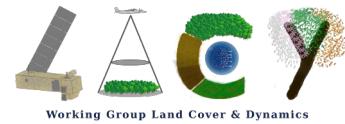
# Motivation



Wälder Deutschland, ATKIS



# Motivation



Wälder Deutschland, ATKIS



WZE Standorte, Faktor 100



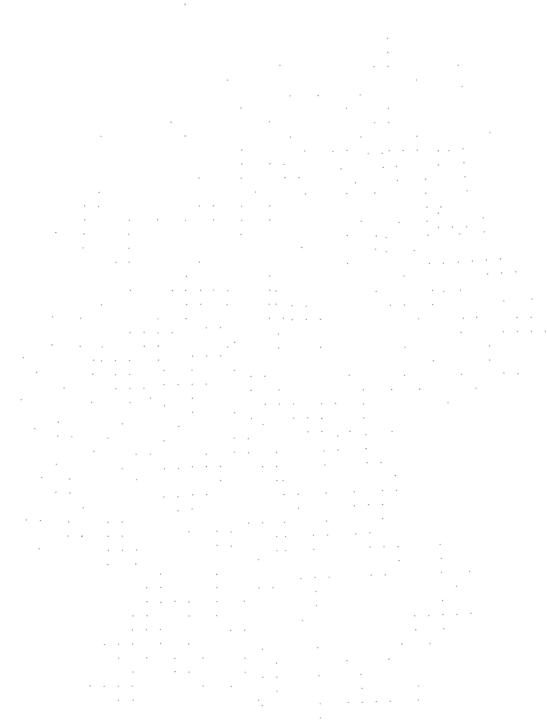
# Motivation



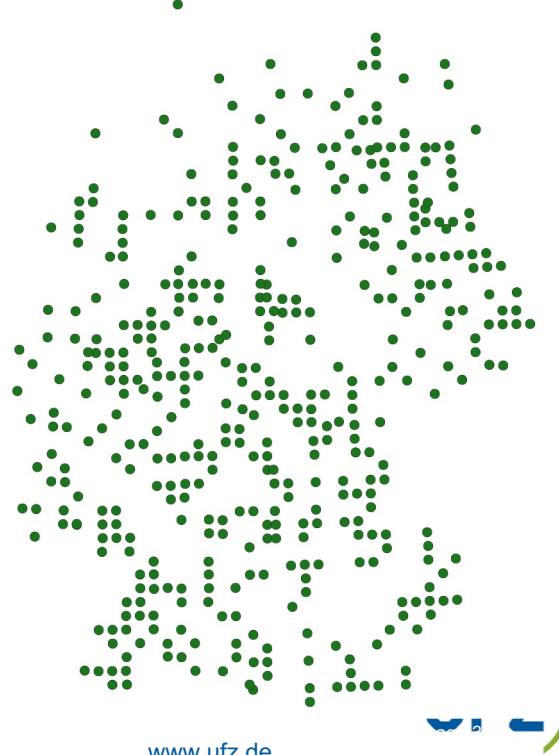
Wälder Deutschland, ATKIS



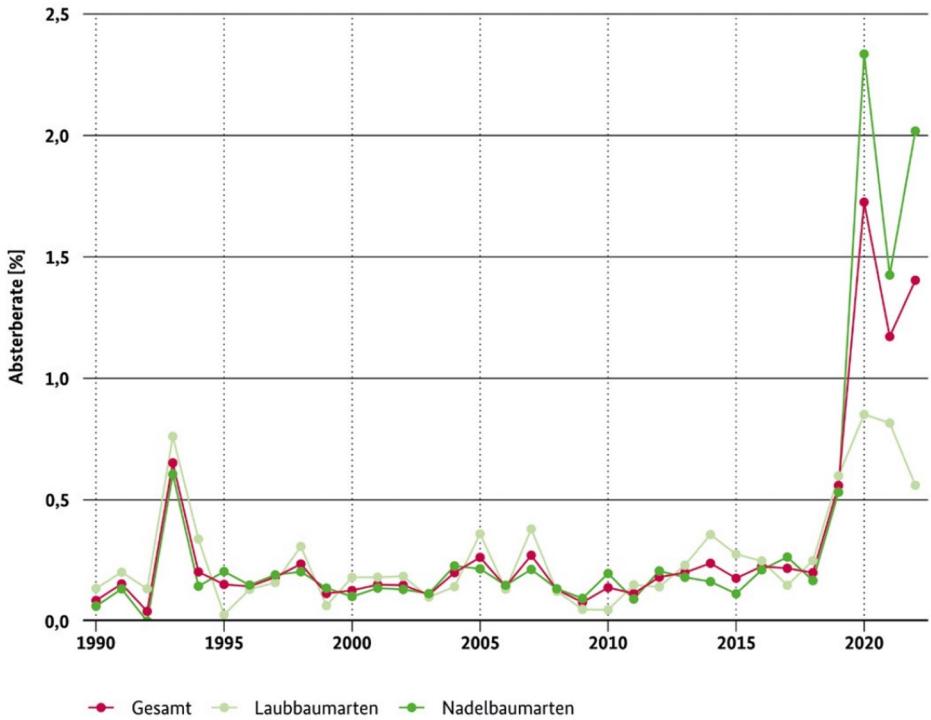
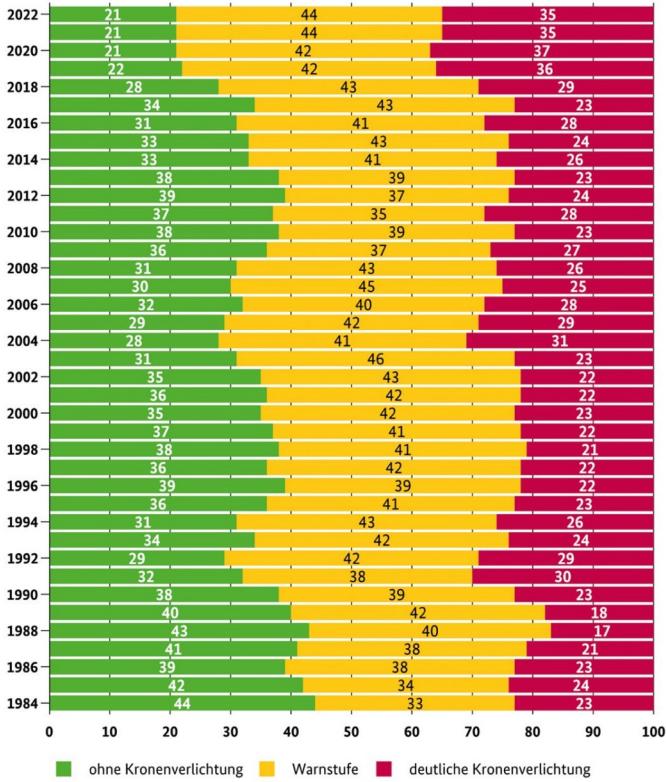
WZE Standorte, Faktor 100



WZE Standorte, Faktor 10 000



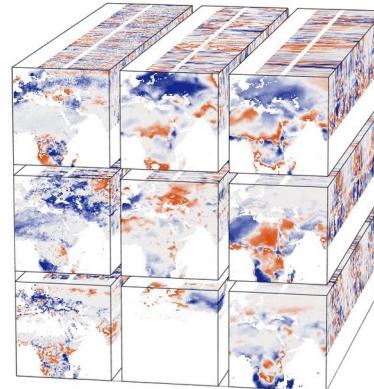
# Motivation



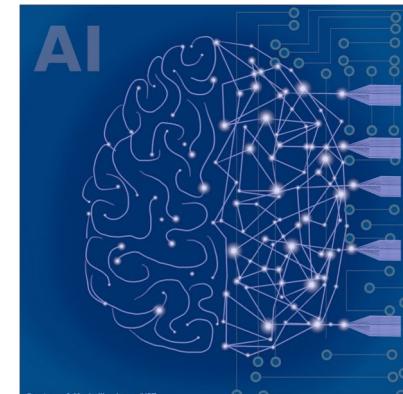
■ ohne Kronenverlichtung ■ Warnstufe ■ deutliche Kronenverlichtung

Flächendeckende Erfassung der Dynamik für

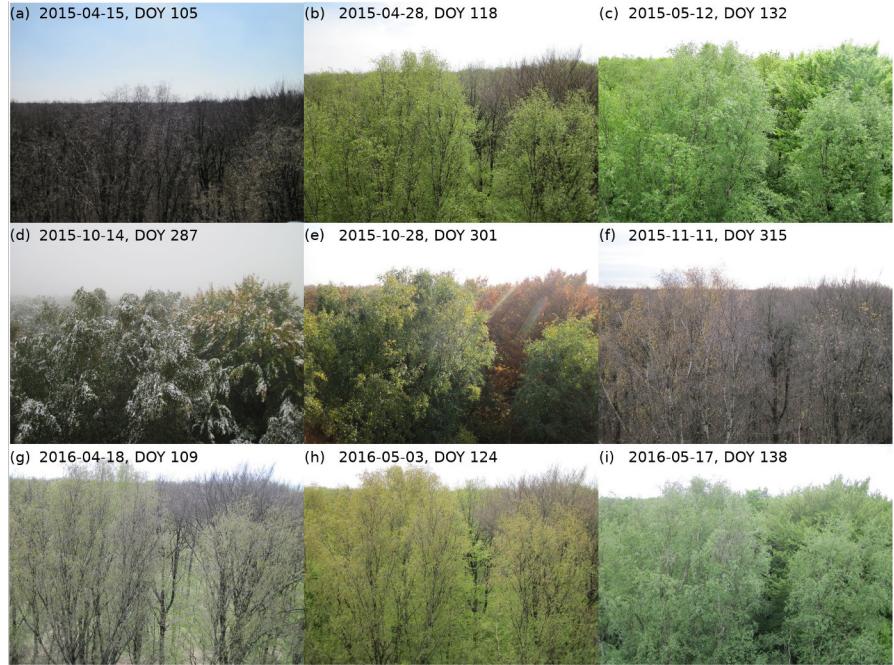
- Sofortmaßnahmen
- verbesserten Waldzustandsbericht
- Waldumbau, Risikohotspots,  
Schädlingsbekämpfung, Modellanpassungen  
(Phänologie) ...



<https://www.earthsystemdatalab.net/>



# Fernerkundung & Wald



Aufnahmen vom Eddy-Turm auf den umgebenden Laubmischwald, Hohes Holz

- Hohe räumliche Auflösung
- Hohe zeitliche Auflösung



Der UZF Eddy-Turm im Hohen Holz

Copyright, André Künzelmann, UFZ

- Hohe räumliche Auflösung
- Hohe zeitliche Auflösung
- Beobachtung spektraler Bereiche, die indikativ für Pigmente, Kronenwassergehalt und Blattfläche sind



Drohnenbilder von der Dübener Heide

- Hohe räumliche Auflösung
- Hohe zeitliche Auflösung
- Beobachtung spektraler Bereiche, die indikativ für Pigmente, Kronenwassergehalt und Blattfläche sind



## Anforderungen der maßgeblichen Interessengruppen:

- Waldinformationssystem
- Lagegenaue Identifikation Schäden
- Baumartenverteilung, Phänologie
- zeitnahe Bereitstellung Informationen
- Früherkennung Borkenkäferbefall
- Zukünftige Artverbreitung

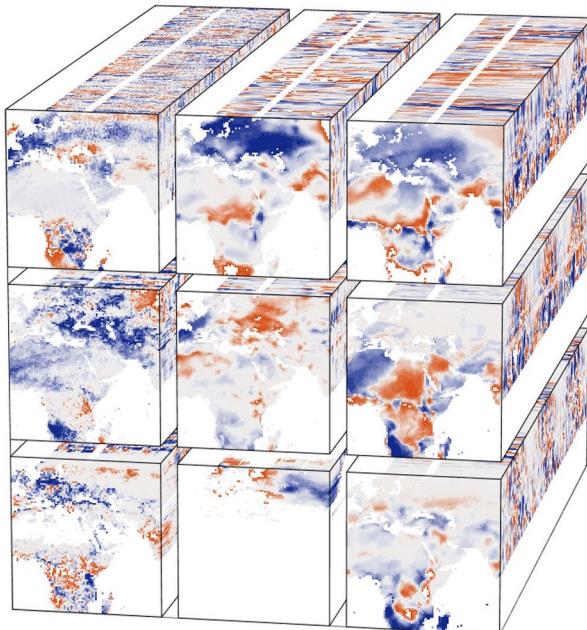


Arbeitspakete

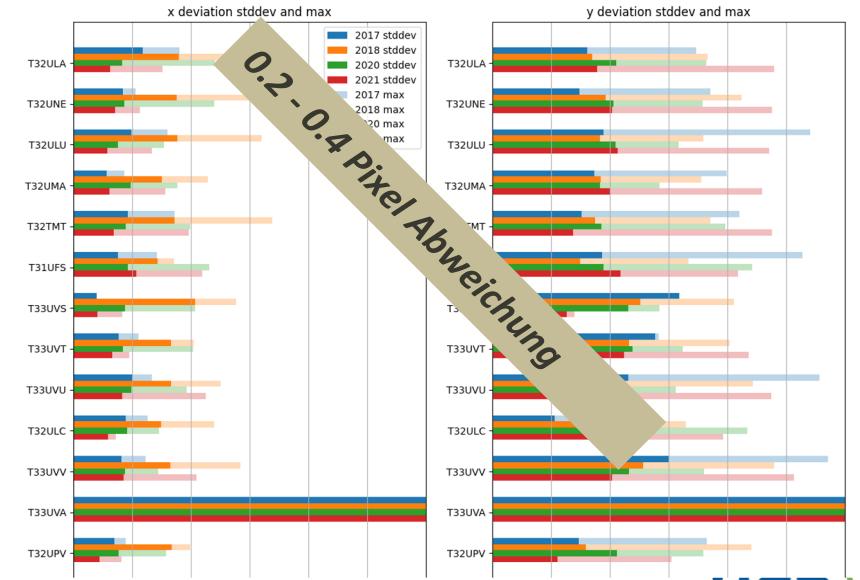
# Prozessierung Satellitendaten: DataCube



- Überführung Satellitendaten in performante Datenstruktur
- Variablen für Räume als Zeitreihe vorhanden



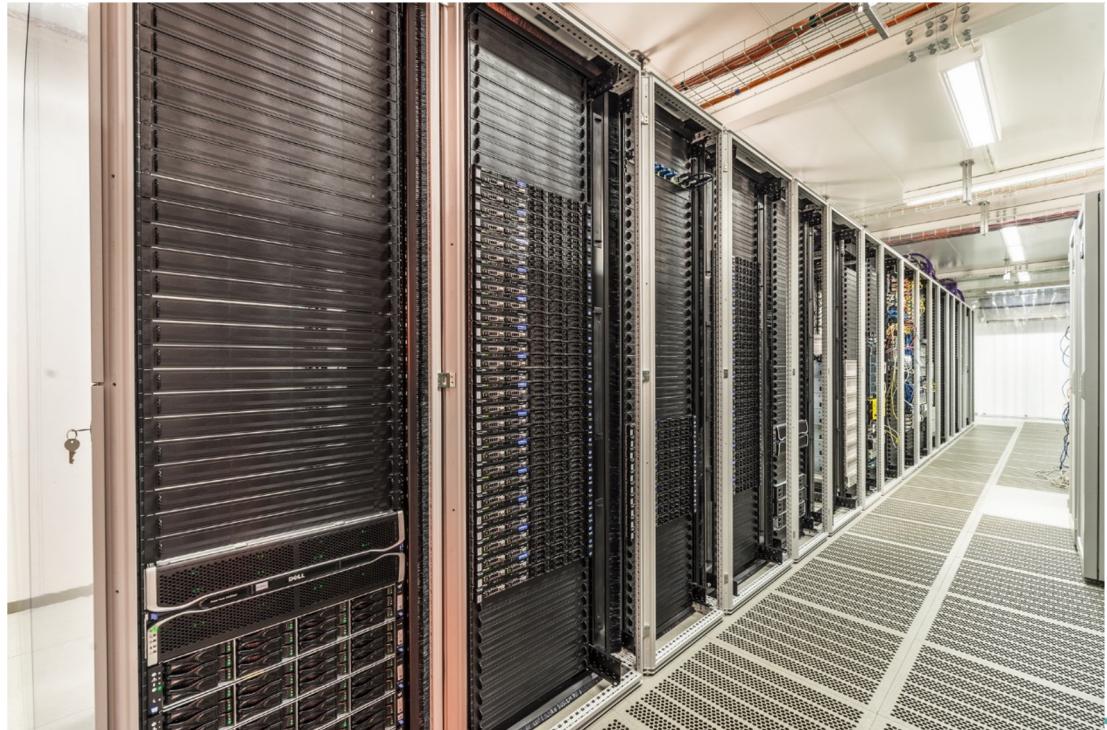
- Und gute Lagegenauigkeit





## HPC EVE @UFZ

- 400.000 core-h Rechenzeit für die Verarbeitung von einem Jahr an Sentinel-2 Daten (Deutschlandweit)
- Künstliche Intelligenz mittels GPU @EVE
- IT-Department „WKDV“ pflegt den Superrechner

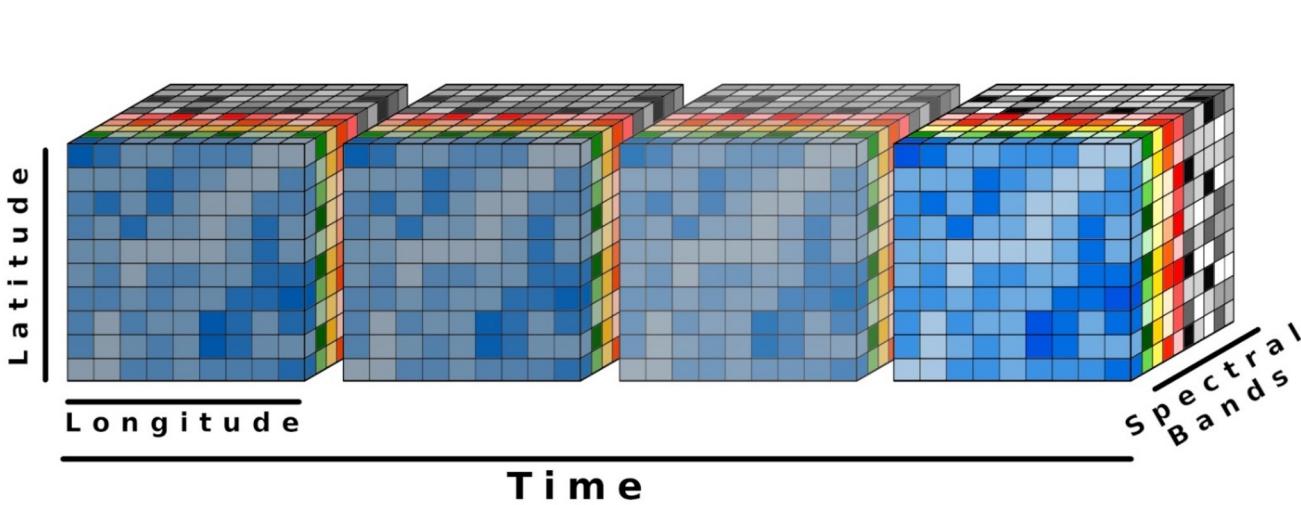


© UFZ, André Künzelmann

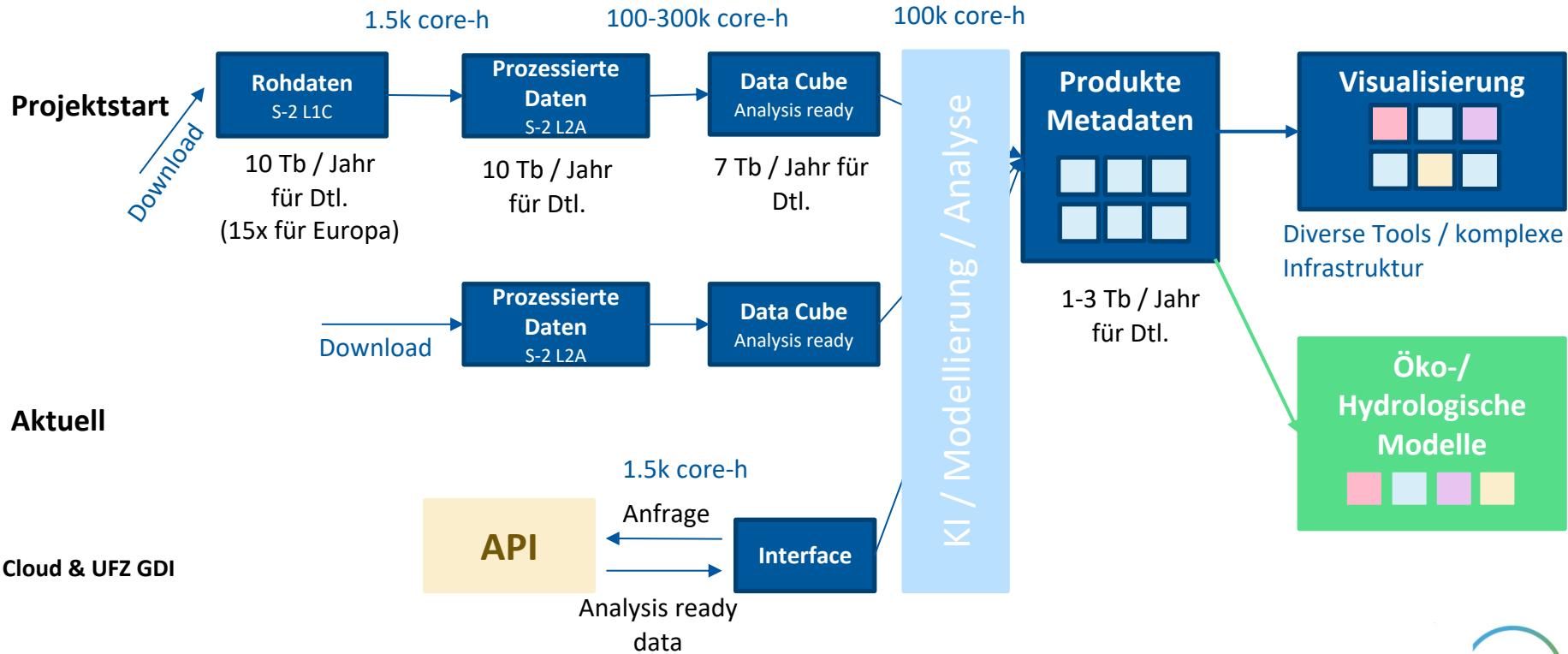


## Data Cube

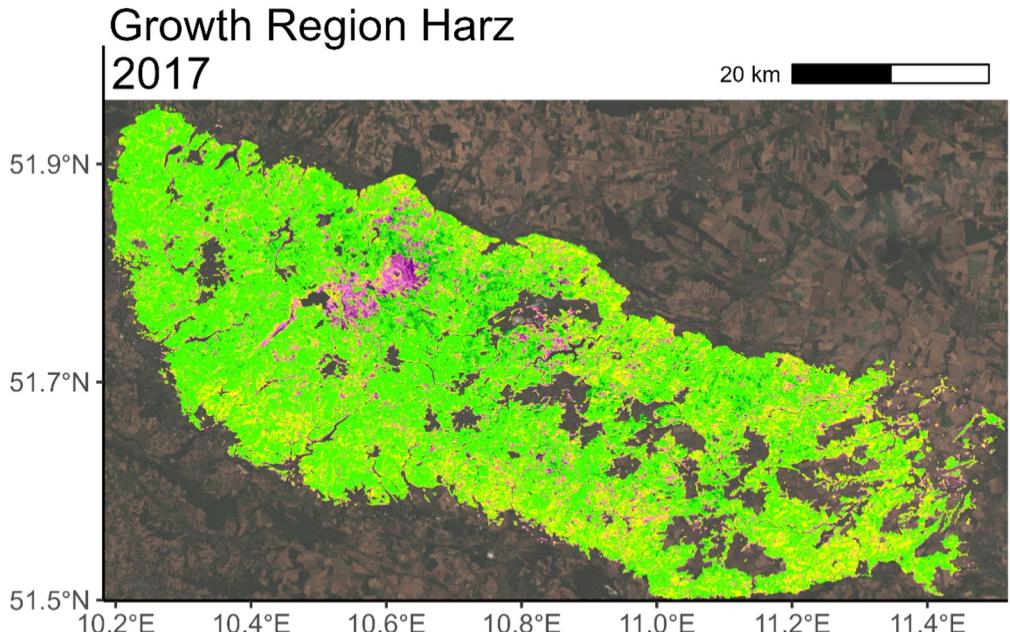
- Performanter Zugriff auf spektrale Zeitreihen für Milliarden von Pixeln
- Vereinfachung flächendeckender Ableitungen
- Verschneidung mit anderen Produkten möglich (z.B. Baumartenkartierung)



# Prozessablaufplan, Datendownload & -prozessierung

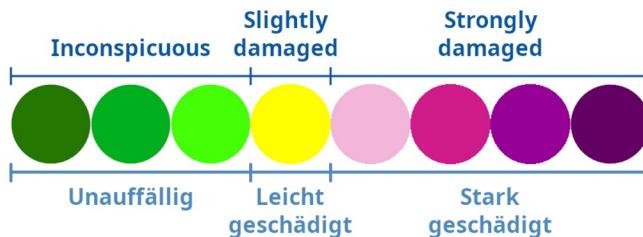


# Waldzustandsanomalien: Harz 2017



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The UFZ Forest Condition Monitor was developed within the Land Cover & Dynamics Working Group of the Department Remote Sensing at the Helmholtz Centre for Environmental Research - UFZ in Leipzig. The project was funded by the Helmholtz Association, the Federal Ministry of Education and Research (BMBF), and the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). Images were produced from ESA remote sensing data (Copernicus Sentinel-2 2016-2022).

## FOREST CONDITION



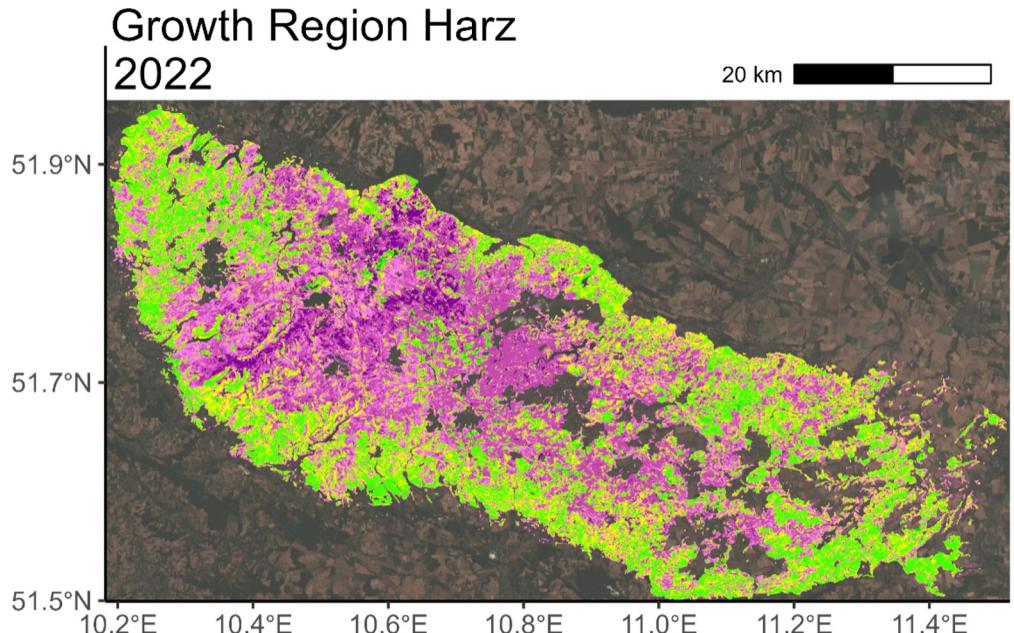
## WALDZUSTAND

## FOREST CONDITION ANOMALY INDEX (FCA)



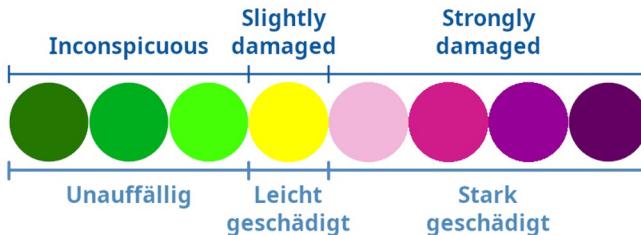
© UFZ / Department RS, AG LACY

# Waldzustandsanomalien: Harz 2022



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The UFZ Forest Condition Monitor was developed within the Land Cover & Dynamics Working Group of the Department Remote Sensing at the Helmholtz Centre for Environmental Research - UFZ in Leipzig. The project was funded by the Helmholtz Association, the Federal Ministry of Education and Research (BMBF), and the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). Images were produced from ESA remote sensing data (Copernicus Sentinel-2 2016-2022).

## FOREST CONDITION



## WALDZUSTAND

## FOREST CONDITION ANOMALY INDEX (FCA)



# Waldzustandsanomalien: Statistiken



## Wuchsgebiet Harz

| Jahr | alle Bäume  |                      |             | Laubabwerfende      |                      |             | Immergrüne          |                      |             |
|------|---|----------------------|-------------|---------------------|----------------------|-------------|---------------------|----------------------|-------------|
|      | Flächenanteil, der mit hoher Wahrscheinlichkeit folgenden Waldzustand aufweist: |                      |             |                     |                      |             |                     |                      |             |
|      | stark<br>geschädigt   | leicht<br>geschädigt | unauffällig | stark<br>geschädigt | leicht<br>geschädigt | unauffällig | stark<br>geschädigt | leicht<br>geschädigt | unauffällig |
| 2016 | 10 %  | 21 %                 | 69 %        | 10 %                | 26 %                 | 65 %        | 10 %                | 17 %                 | 73 %        |
| 2017 | 9 %   | 25 %                 | 66 %        | 10 %                | 36 %                 | 54 %        | 8 %                 | 17 %                 | 75 %        |
| 2018 | 15 %  | 22 %                 | 63 %        | 14 %                | 25 %                 | 61 %        | 16 %                | 20 %                 | 64 %        |
| 2019 | 25 %  | 27 %                 | 48 %        | 22 %                | 34 %                 | 44 %        | 27 %                | 22 %                 | 51 %        |
| 2020 | 41 %  | 32 %                 | 27 %        | 28 %                | 42 %                 | 30 %        | 51 %                | 24 %                 | 25 %        |
| 2021 | 45 %  | 27 %                 | 28 %        | 18 %                | 38 %                 | 43 %        | 67 %                | 18 %                 | 16 %        |
| 2022 | 52 %  | 23 %                 | 25 %        | 22 %                | 35 %                 | 43 %        | 76 %                | 13 %                 | 11 %        |

| Jahr | alle Bäume                       |       | Laubabwerfende |       | Immergrüne     |       |
|------|----------------------------------|-------|----------------|-------|----------------|-------|
|      | Waldzustandsanomalie-Index (FCA) |       |                |       |                |       |
|      | $\bar{\theta}$                   | $\pm$ | $\bar{\theta}$ | $\pm$ | $\bar{\theta}$ | $\pm$ |
| 2016 | 0.05                             | 0.15  | 0.03           | 0.14  | 0.07           | 0.16  |
| 2017 | 0.04                             | 0.14  | 0              | 0.12  | 0.07           | 0.14  |
| 2018 | 0.01                             | 0.16  | 0              | 0.15  | 0.02           | 0.17  |
| 2019 | -0.04                            | 0.18  | -0.05          | 0.16  | -0.03          | 0.2   |
| 2020 | -0.13                            | 0.18  | -0.09          | 0.14  | -0.16          | 0.2   |
| 2021 | -0.14                            | 0.19  | -0.04          | 0.14  | -0.22          | 0.2   |
| 2022 | -0.16                            | 0.19  | -0.05          | 0.15  | -0.26          | 0.18  |

FCA                ... Forest condition anomaly index  
 $\bar{\theta}$                 ... Mittelwert  
 $\pm$                 ... Standardabweichung  
hohe Wahrscheinlichkeit für folgenden Waldzustand:  
stark geschädigt    ... FCA < -0.15  
leicht geschädigt    ... FCA zwischen -0.15 und 0  
unauffällig            ... FCA  $\geq$  0

Die obere Tabelle zeigt den jährlichen Anteil der Fläche der Waldbestände, die im Zuge der Analysen mittels des Waldzustandsanomalie-Indexes mit hoher Wahrscheinlichkeit stark geschädigt, leicht geschädigt oder unauffällig sind.

Die untere Tabelle zeigt die Entwicklung des mittleren Waldzustandsanomalie-Indexes und dessen Standardabweichung innerhalb der Flächen im Verlauf mehrere Jahre.

Die Tabellen zeigen die Entwicklung sowohl für den gesamten Wald innerhalb der Region, als auch nur für laubabwerfende oder immergrüne Bestände.

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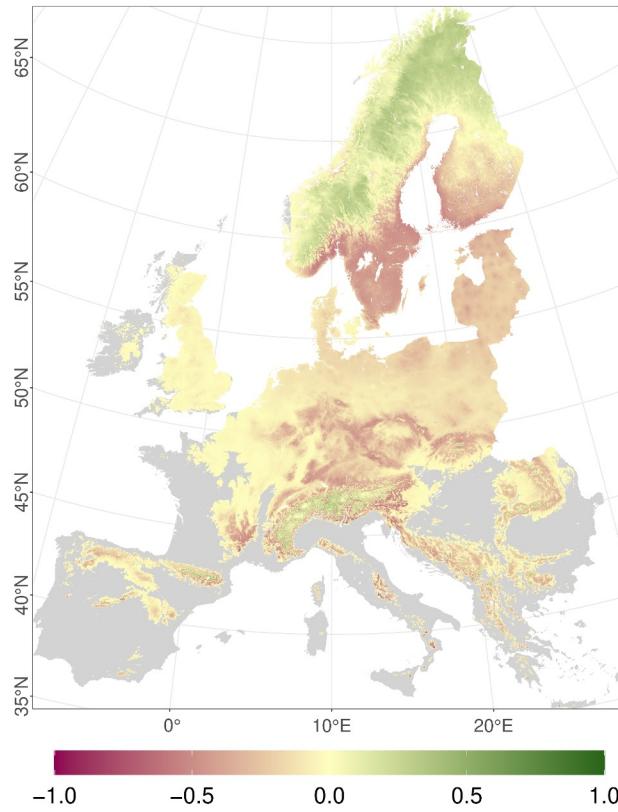
Der UFZ-Waldzustandsmonitor wurde in der Arbeitsgruppe Landbedeckung & Dynamik des Departments Remote Sensing am Helmholtz-Zentrum für Umweltforschung - UFZ in Leipzig entwickelt. Das Projekt wurde von der Helmholtz-Gemeinschaft, dem Bundesministerium für Bildung und Forschung (BMBF) und dem Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (BMUV) gefördert.

Lange, L., Preidl, S., Reichmuth, A., Heurich, M., Doktor, D. (2024). A continuous tree species-specific reflectance anomaly index reveals declining forest condition between 2016-2022 in Germany. *Remote Sensing of Environment* 312, 114323.  
<https://doi.org/10.1016/j.rse.2024.114323>

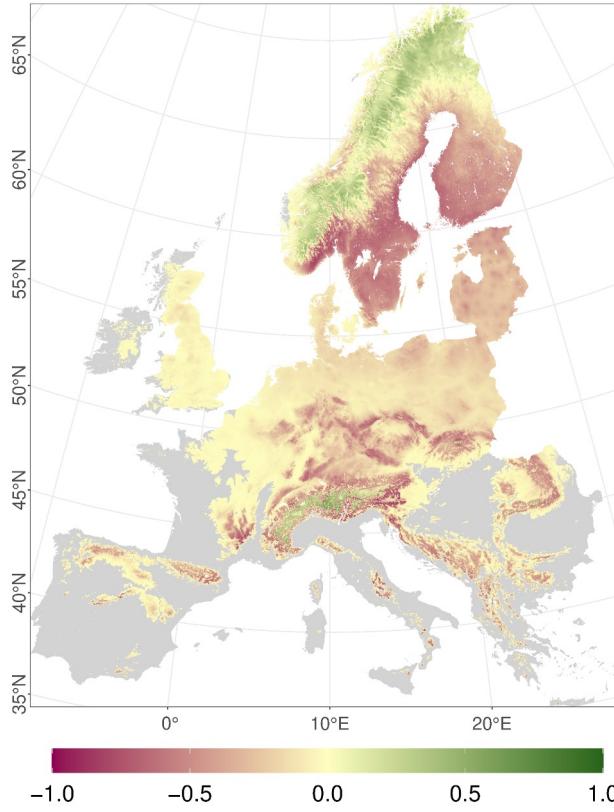
# Artverbreitungsmodellierung



Picea abies, RCP 4.5, 2079-2098



Picea abies, RCP 8.5, 2079-2098



Reichmuth, A., Kühn, I., Schmidt, A. and Doktor, D. (2025) Forested Natura 2000 sites under climate change: effects of tree species distribution shifts. *Web Ecology* (25), pp. 59–89, <https://doi.org/10.5194/we-25-59-2025>

Reichmuth A., Rakovec O., Boeing, F., Müller, S. Samaniego, L., Marx, A., Komischke, H., Schmidt, A., Doktor, D. (2025) BioVars - A bioclimatic dataset for Data Descriptor Europe based on a large regional climate ensemble for periods in 1971–2098. *Scientific Data* (12) 217. <https://doi.org/10.1038/s41597-025-04507-w>



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Many thanks!