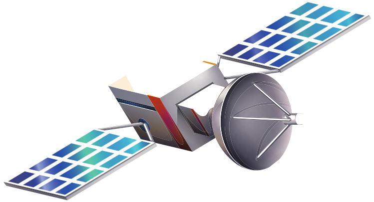
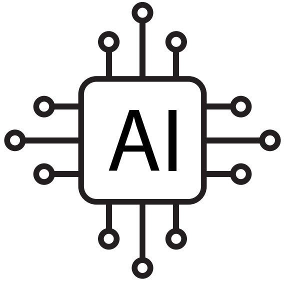
EPFL

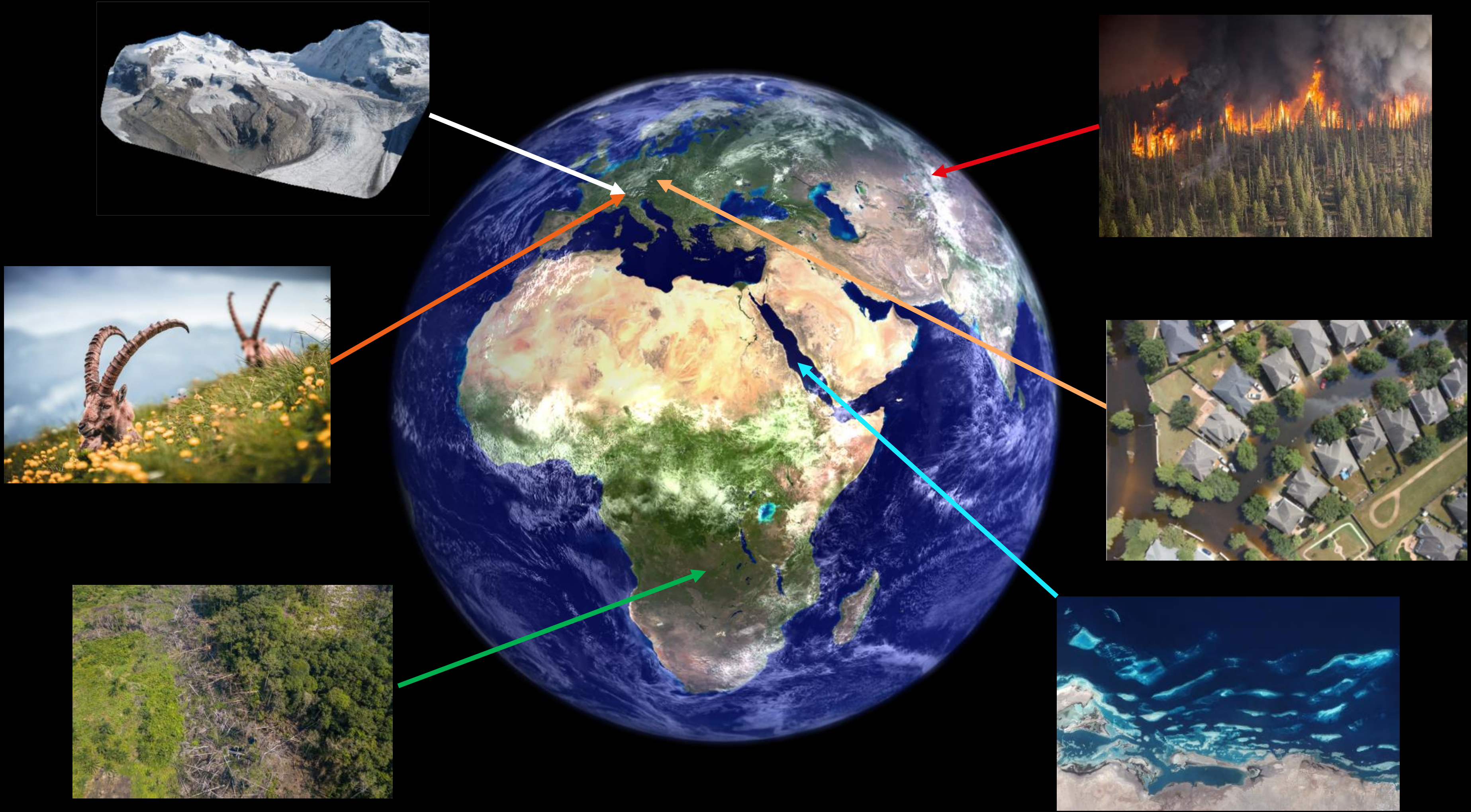
Machine learning for the environment: monitoring the pulse of our Planet with remotely sensed data

Prof. Devis Tuia, EPFL



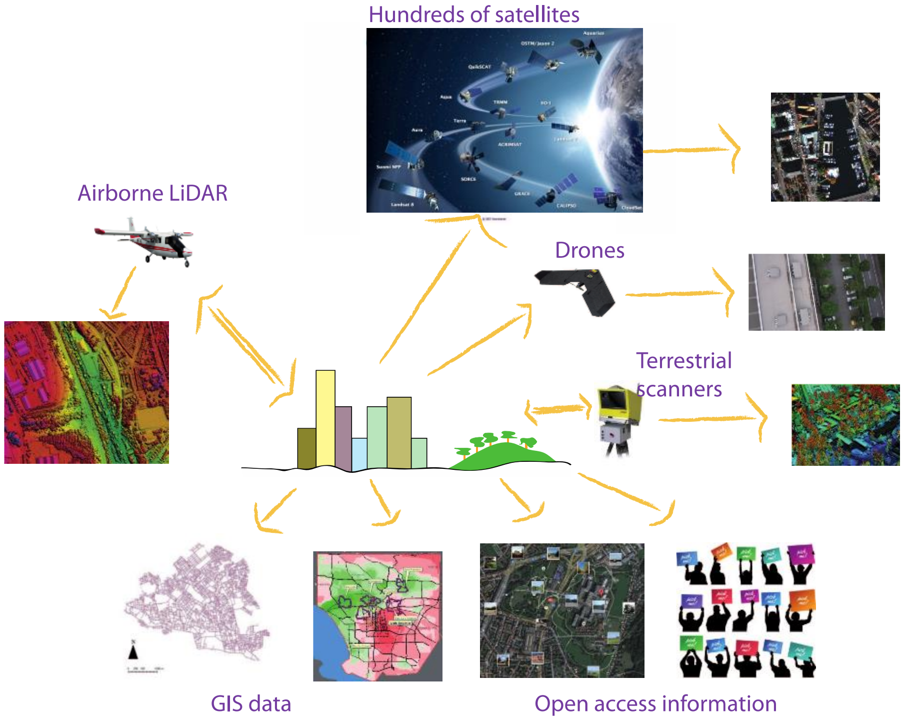


École
polytechnique
fédérale
de Lausanne



There were many sensor data to monitor Earth in 2015

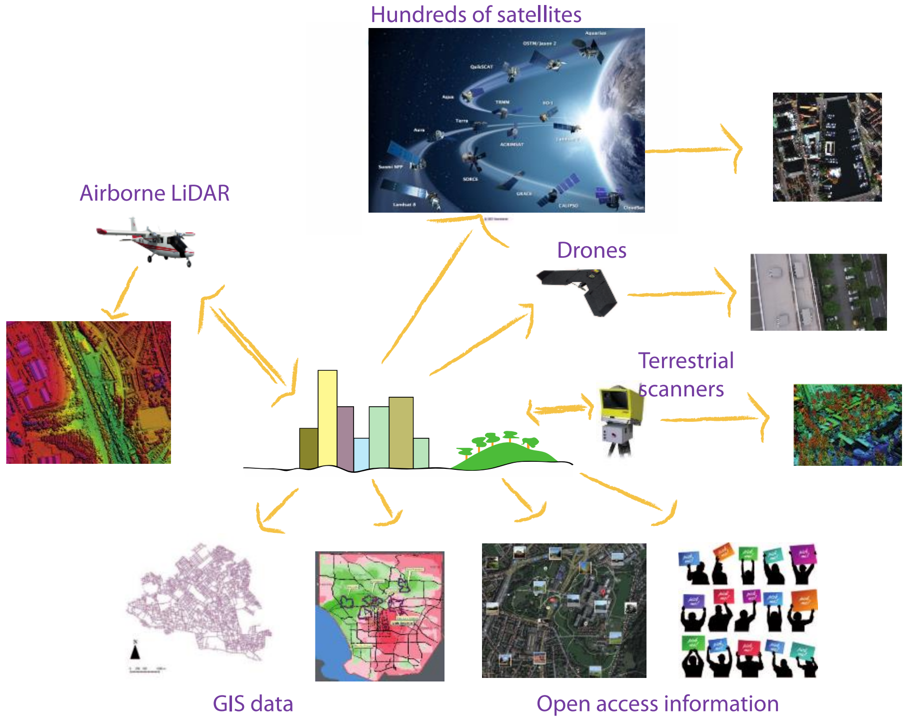
- 333 Earth Observation satellites in orbit in 2015 [ucsusa.org].
- 10’000 recreational drones registered in the U.S. by 2020 [FAA].
- 20 Pb of oblique photos in Google Street View in 2015 [Google Maps].



Sources of figures: usgs, astrium, aerialsurvey, senseFly, vimeo, GEOSS, Purdue, Google, thelogofactory

There are many sensor data to monitor Earth in ~~2015~~ 2023

- ~~333~~ 1’005 Earth Observation satellites in orbit in 2023 [ucsusa.org].
- ~~10’000~~ 1’100’000 recreational drones registered in the U.S in 2023. [FAA].
- 170 billions of oblique photos in Google Street View in 2020 [Google Maps].



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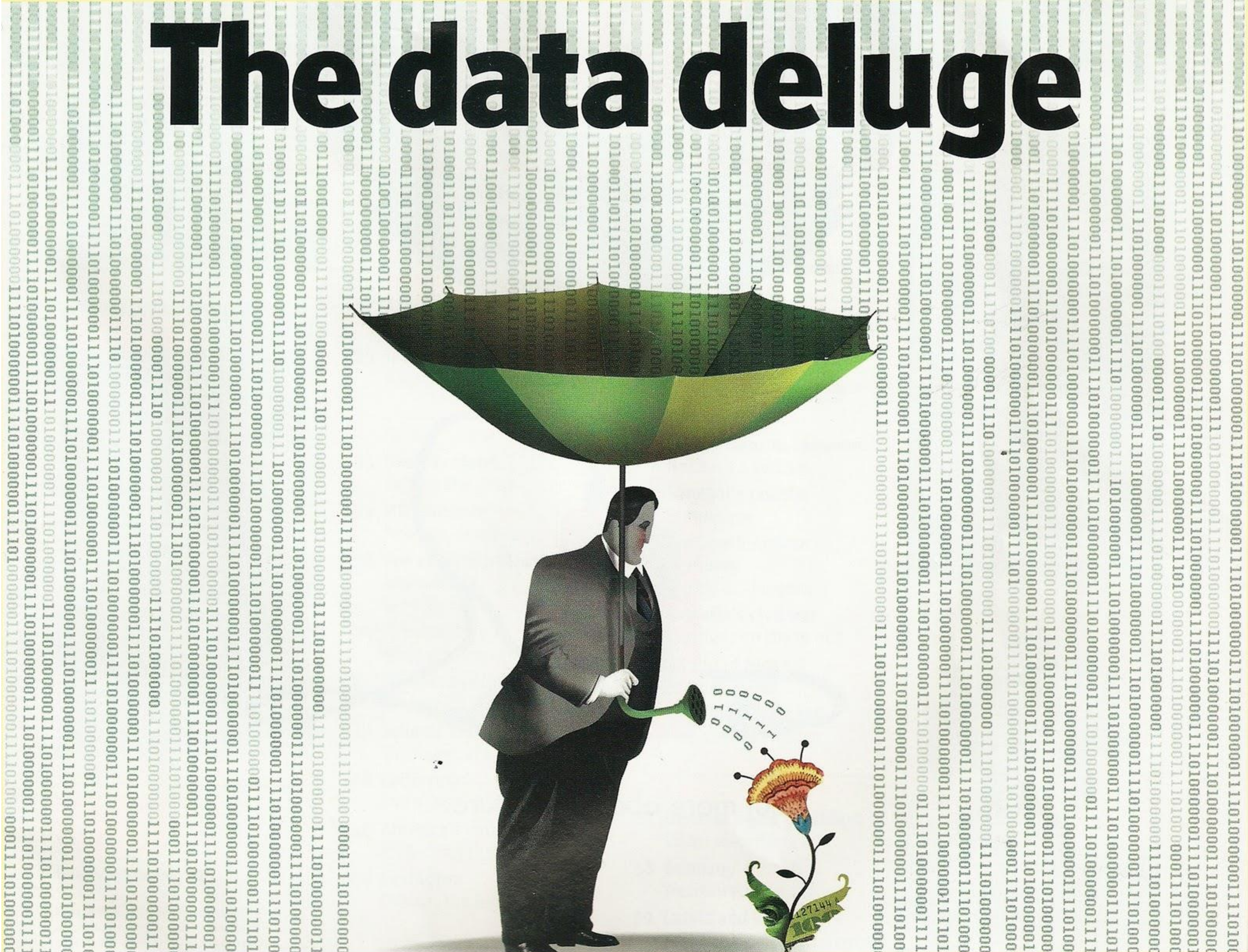
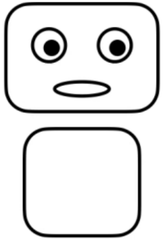

The data deluge

MACHINE LEARNING

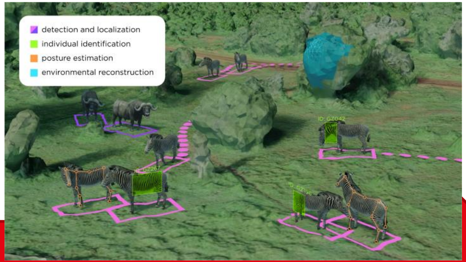
Machine learning in two minutes

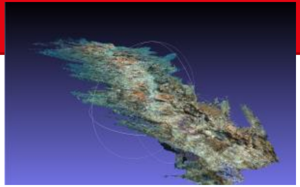


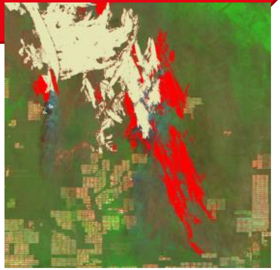
Why now : statistical and computational models are good enough...

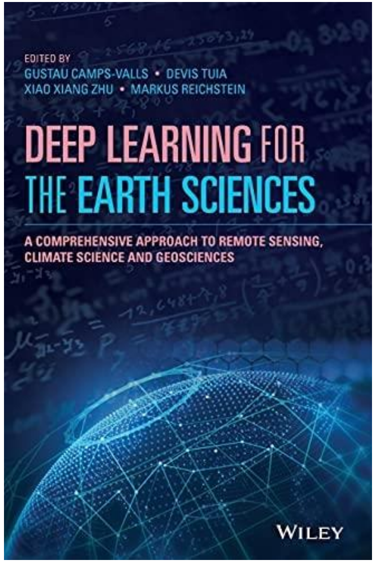
- Machine learning has reached a certain maturity... and percolated in many fields of science.

2022



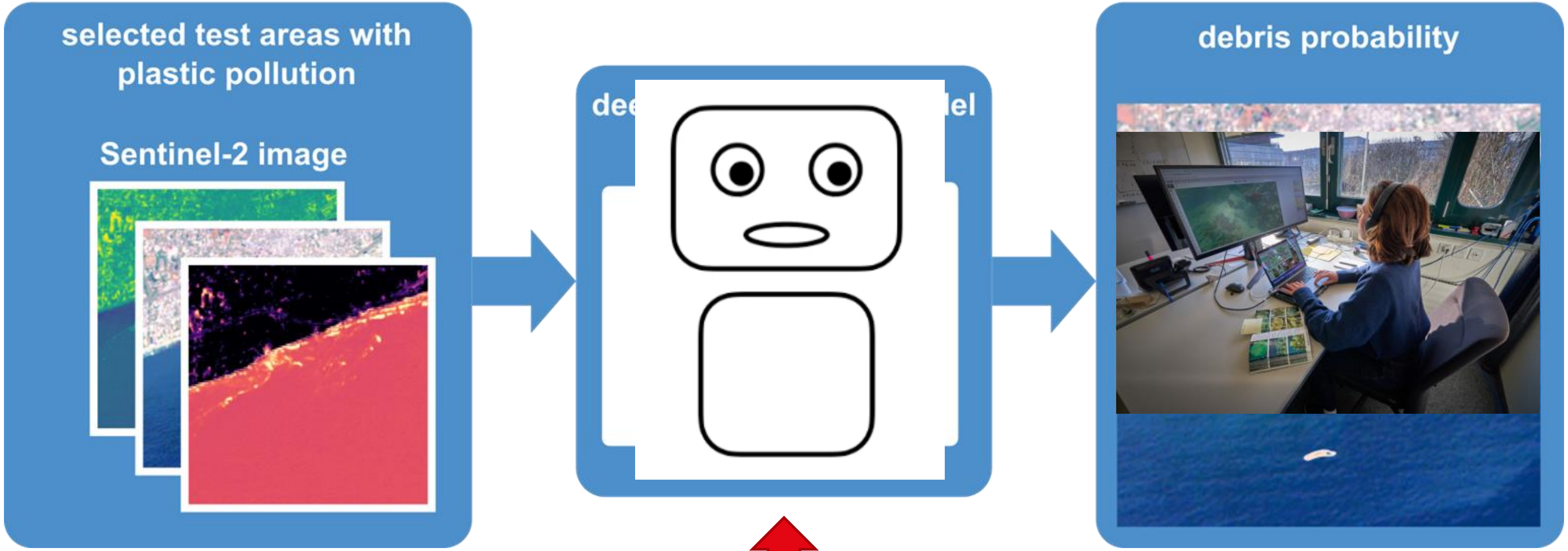






2015

Building environmental deep learning models



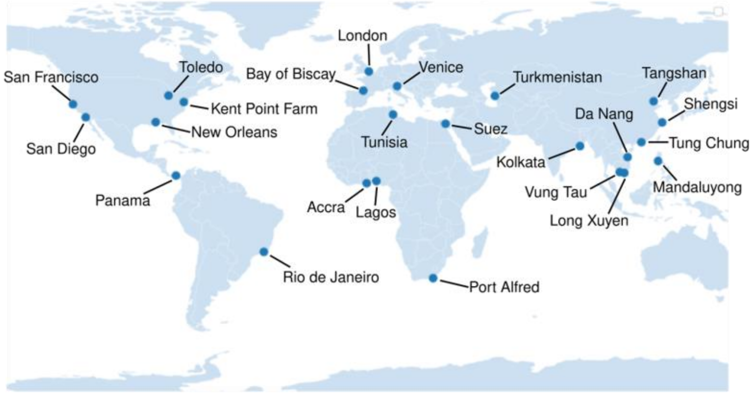
Images

Neural network
with some millions
of learnable parameters

Examples of process to be
monitored

Building environmental deep learning models

- We used debris events found in news and social media, then hand labeled on images by experts.



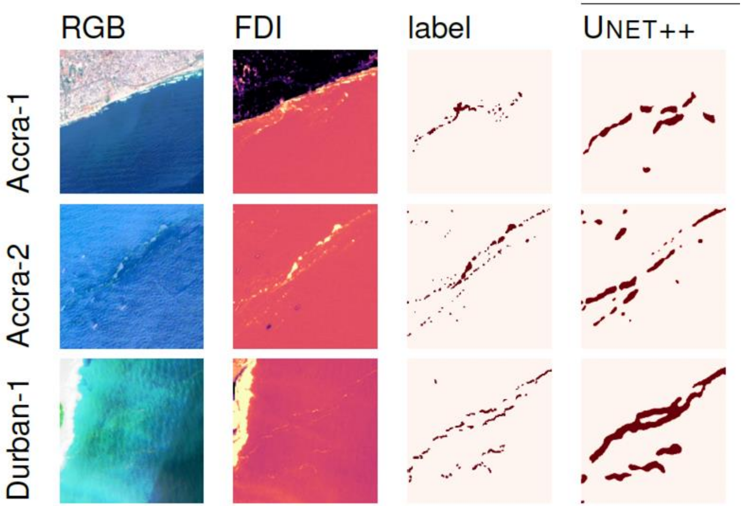
[Mifdal et al., 2020]

Mifdal, J., Longépé, N., and **Rußwurm, M.**: Towards detecting floating objects on a global scale with spatial features using Sentinel-2, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-3-2021, 285–293,

EPFL

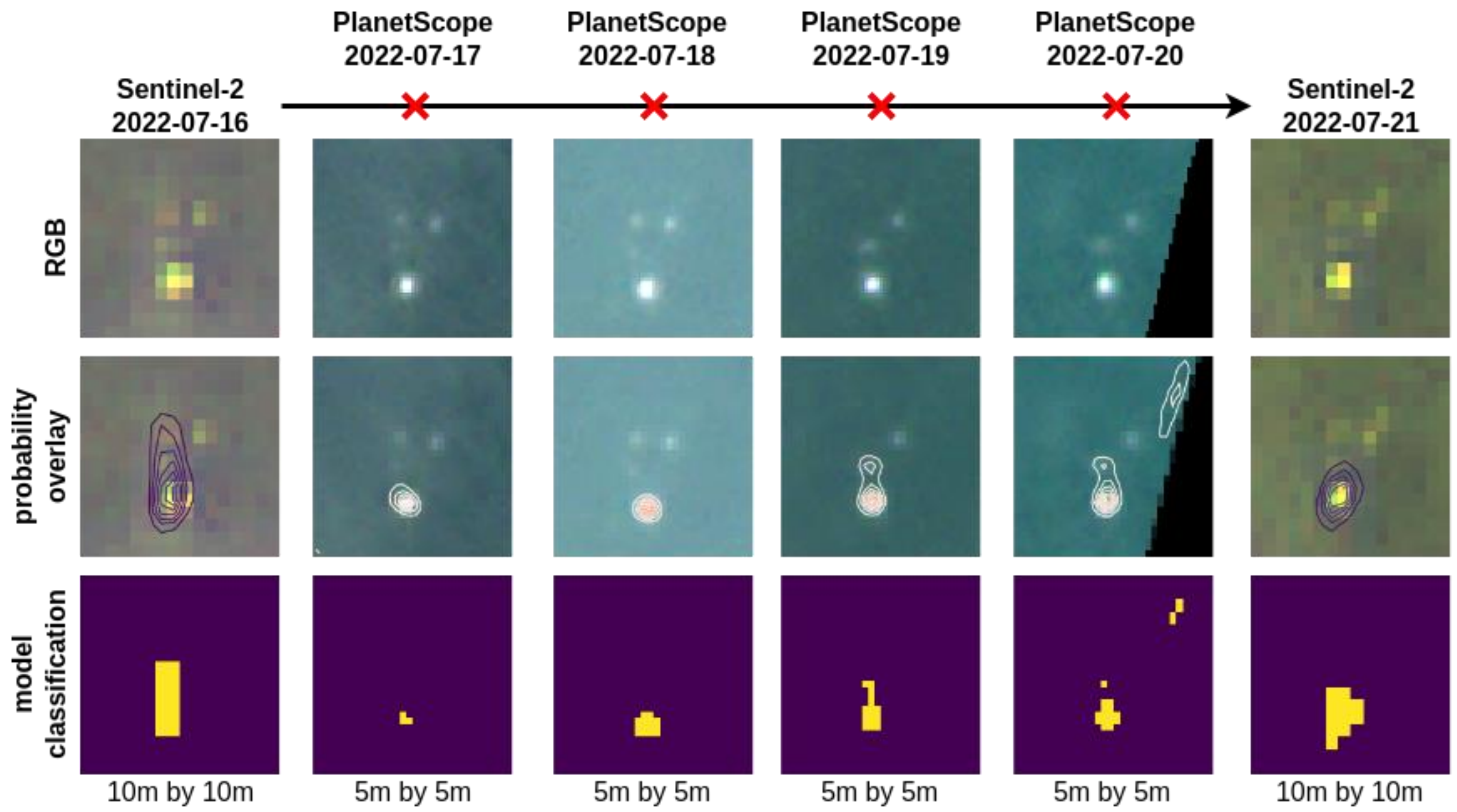
Building environmental deep learning models that are accurate

- We used debris events found in news and social media, then hand labeled on images by experts.
- Our learning models detect plastics at sea from space with ~ 85% accuracy



M. Russwurm, Venkatesam S. J., and **D. Tuia.** Large-scale detection of marine debris in coastal areas with Sentinel-2. *Under review.*

Detections on the Plastic Litter project 2022

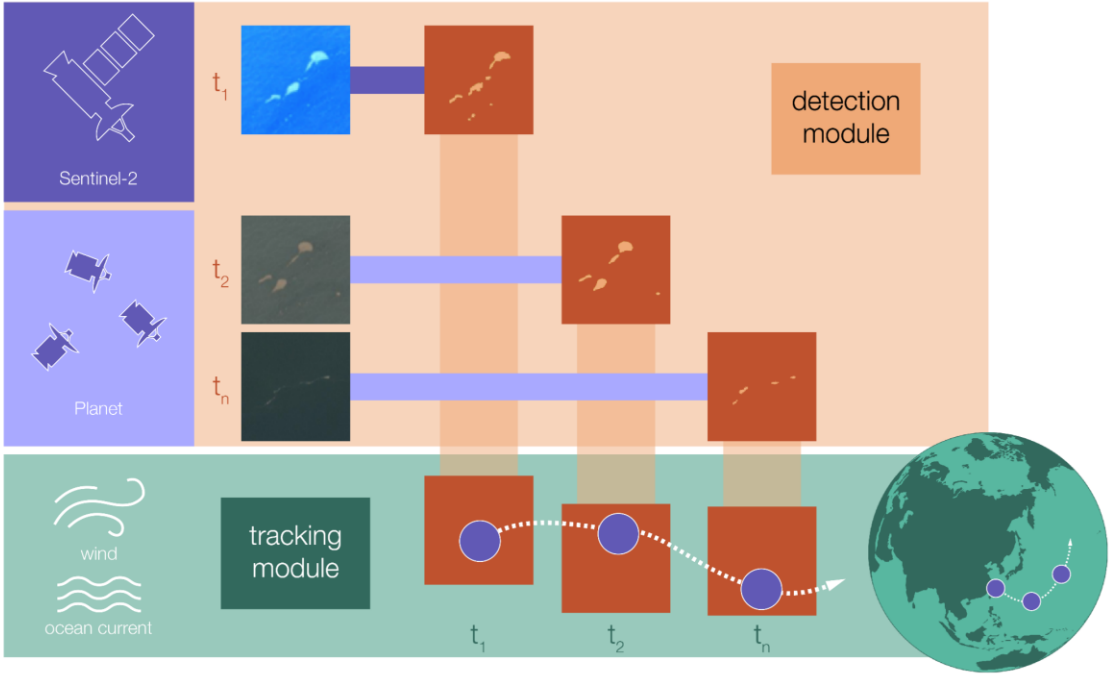


EPFL

SDSC

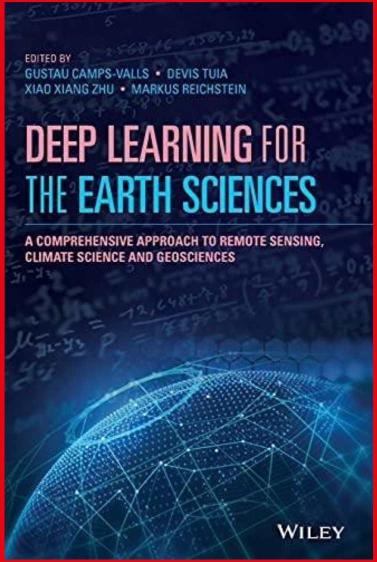
THE OCEAN CLEANUP

Building environmental deep learning models that are accurate and useful



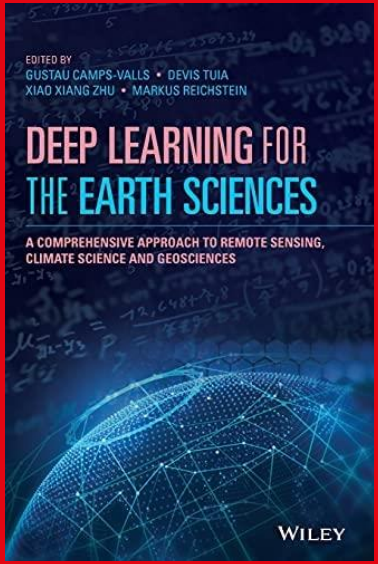
With Earth observation and AI, we can

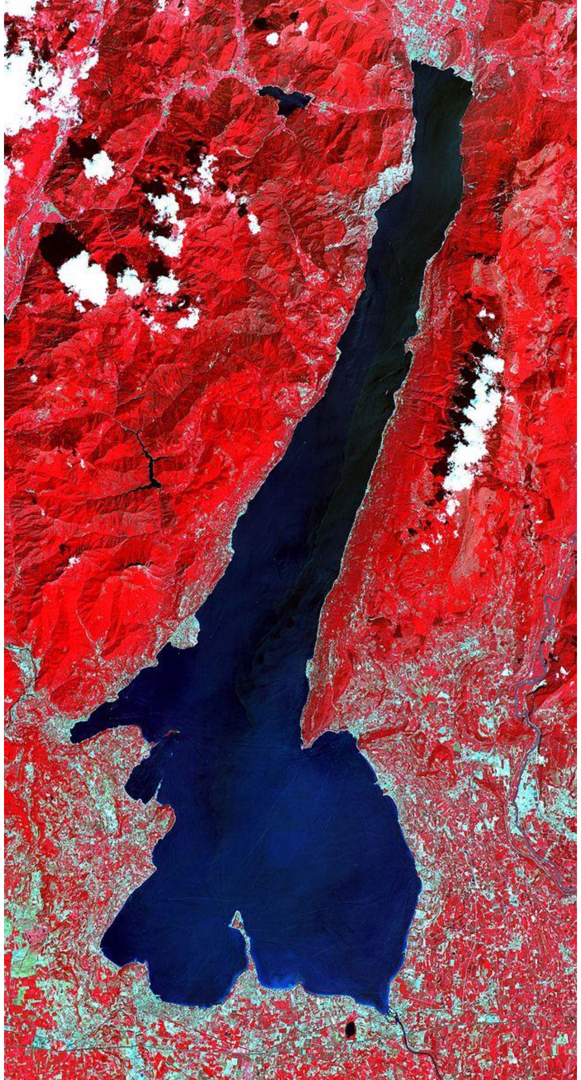
develop computational approaches to the environmental sciences that are accurate



With Earth observation and AI, we can

develop computational approaches to the environmental sciences that are accurate, but also scalable, knowledge-driven and accessible to everyone.





Towards environmental deep learning that is

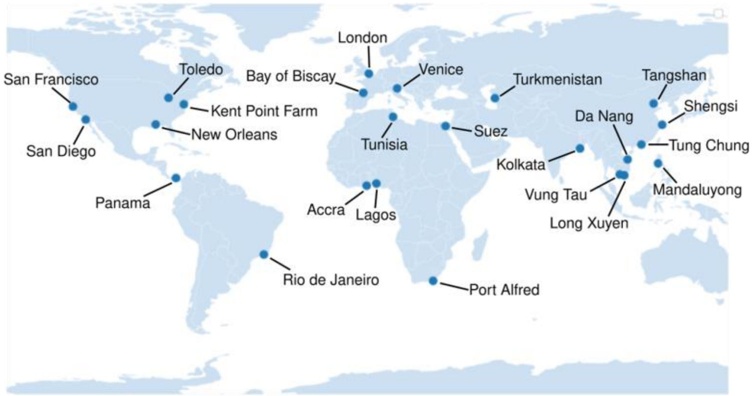
Accurate

Scalable

Knowledge-driven

Accessible to anyone

Scalable



[Mifdal et al., 2020]

- No model should work only on
  - one image
  - one region of the world
  - one task

Mifdal, J., Longépé, N., and **Rußwurm, M.**: Towards detecting floating objects on a global scale with spatial features using Sentinel-2, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-3-2021, 285–293,

Scalable

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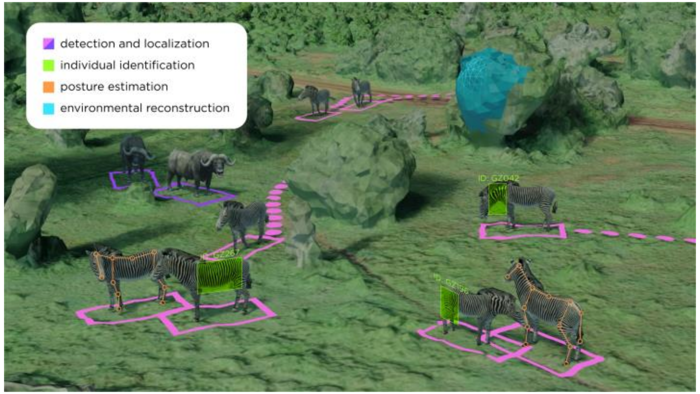
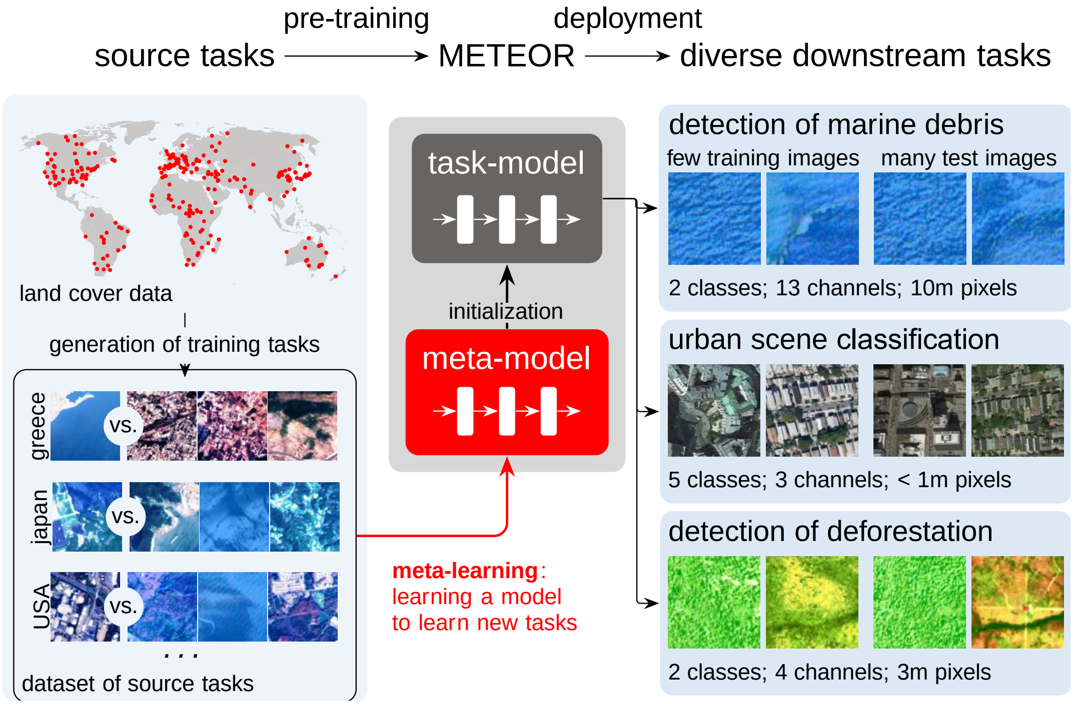


D. Tuia, **B. Kellenberger**, S. Beery, B. Costelloe, S. Zuffi, B. Risse, A. Mathis, M. W. Mathis, F. van Langevelde, T. Burghardt, R. Kays, H. Klinck, M. Wikelski, I. D. Couzin, G. van Horn, M. C. Crofoot, C. V. Stewart, and T. Berger-Wolf. Perspectives in machine learning for wildlife conservation. *Nature Comm.*, 13(792), 2022.

Going even further: scaling across locations and tasks



M. Russwurm, S. Wang, **B. Kellenberger**, R. Roscher, and **D. Tuia.** Meta-learning to address diverse earth observation problems across resolutions. *Under review.*

Going even further: scaling across locations and tasks

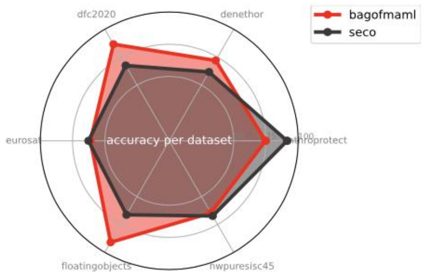
Small, but distributed learning problems!

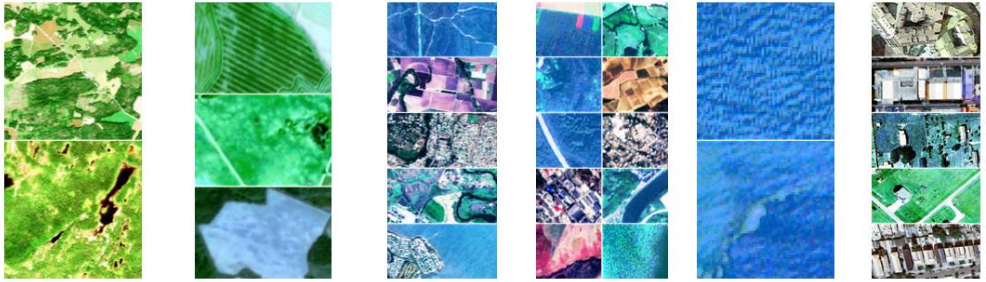
	5-shot problem	human influence	crop type mapping	land cover classification		marine debris	urban scenes
	dataset	AnthPr. [40]	DENETHOR [20]	DFC2020 [37]	EuroSAT [14]	fl. obj. [26]	NWPU [8]
	spatial res.	10m	3m	10m	10m	10m	$<$ 1m
	spectral res.	10 bands	4 bands	13 bands	13 bands	12 bands	3 bands
	# classes	2	3	5	10	2	5
	# training imgs	10	15	25	50	10	25
model	**rank** (↓)	accuracy (↑)					
METEOR	**3.6**	83.7	75.6	**87.7**	60.9	**90.8**	57.4
SwAV [5]	4.2	**96.7**	69.8	54.2	**67.7**	65.4	70.4
MOSAIKS [31]	4.3	86.4	**76.4**	82.3	57.9	88.8	54.0
DINO [6]	5.0	91.2	66.2	56.6	61.3	65.1	**70.6**
SeCo [24]	4.7	91.4	61.7	67.6	62.7	65.9	67.4
SSLTransRS [34]	5.3	90.7	65.5	76.3	59.7	78.9	52.1
SSL4EO [52]	5.5	96.2	58.0	80.2	59.1	82.4	49.9
BASELINE	6.8*	89.0	60.8	87.4	39.8	69.8	36.7
PROTO [39]	8.3**	59.7	56.2	76.9	46.1	67.3	39.1
IMAGENET	8.8*	83.7	59.7	50.8	42.7	64.1	60.5
SCRATCH	9.5**	64.8	61.1	66.5	25.7	64.4	32.3

Meta-L

Self-sup.

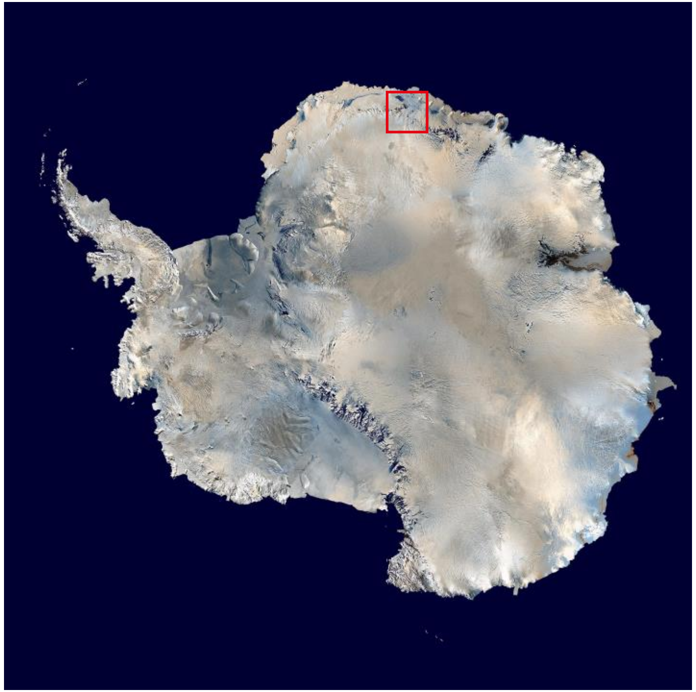
Traditional





This opens opportunities for large scale studies

https://earthobservatory.nasa.gov/images/149554/finding-meteorite-hotspots-in-antarctica



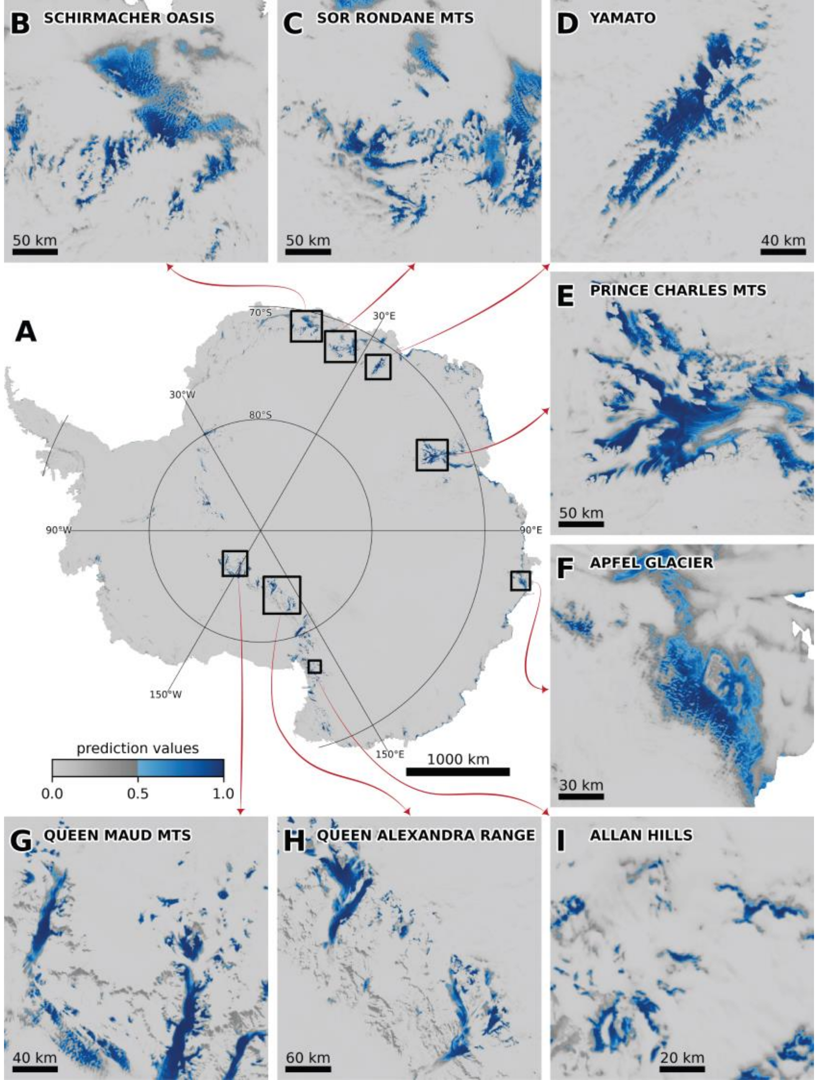
V. Tollenaar, H. Zekollari, **M. Russwurm, B. Kellenberger**, S. Lhermitte, and F. Pattyn, **D. Tuia**. A new blue ice area map of Antarctica. In *European Geoscience Union (EGU) Meeting*, 2023.

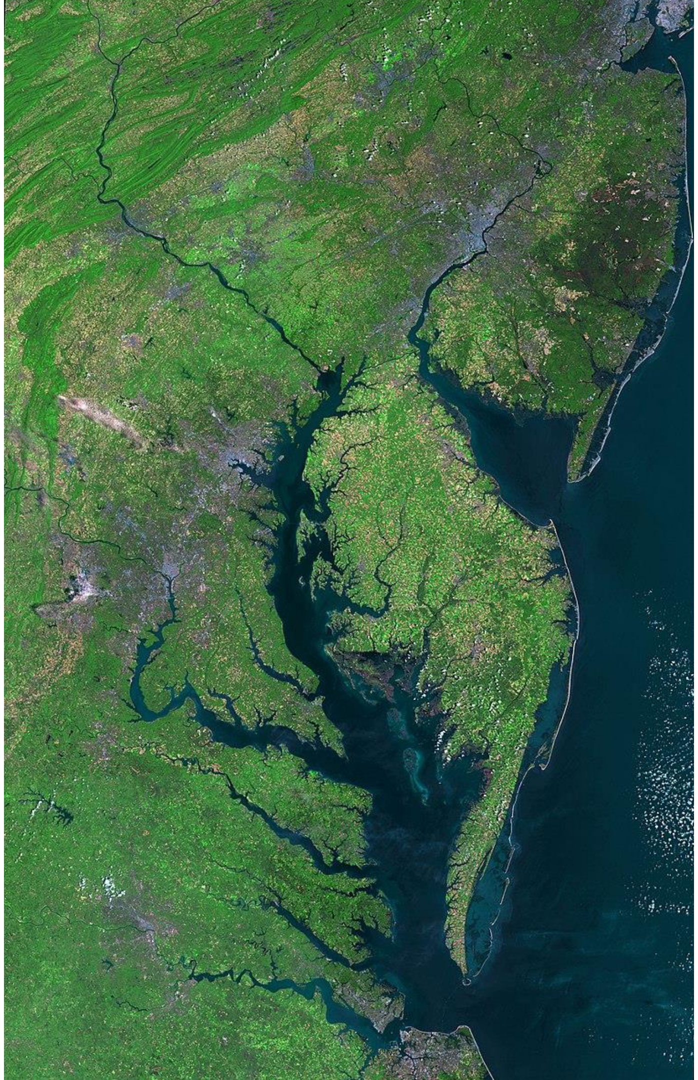
And here comes the BIA map!

- Based on
  - 3 years of MODIS data (Jan-March 2008-2010)
  - RadarSat data 2008
  - Surface elevation data

- Developed a deep learning algorithm to predict presence of blue ice

V. **Tollenaar** et al., in preparation.





Towards environmental deep learning that is

Accurate

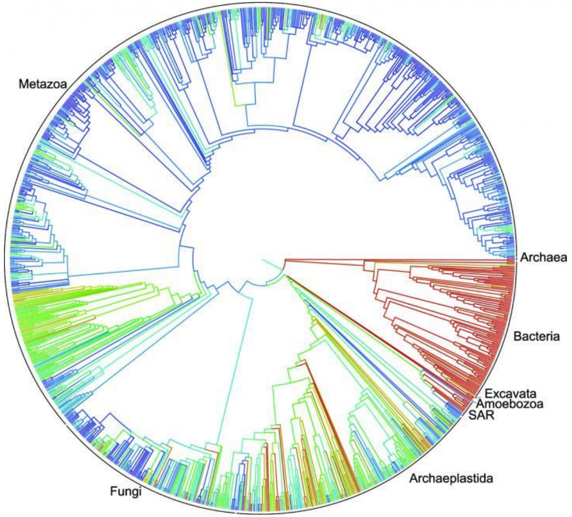
Scalable

Knowledge-driven

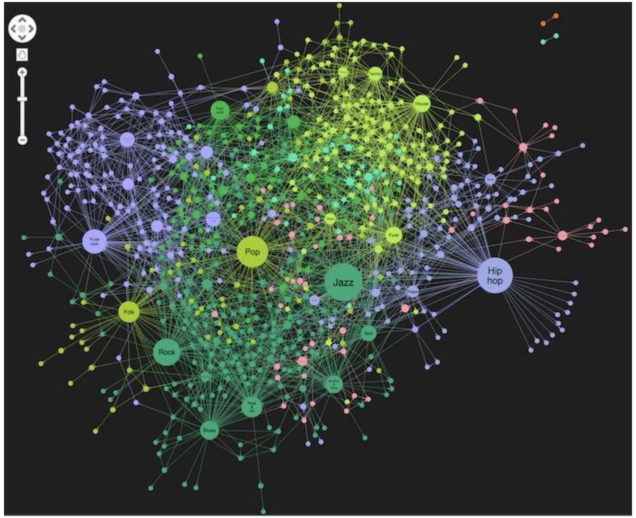
Accessible to anyone

Do we need to extract all information from data?

- Many things about the world, we know them from knowledge



Scientific knowledge

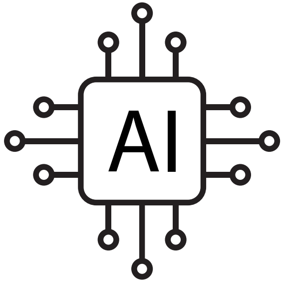


Common sense knowledge

Do we need to extract all information from data?

- Many things about the world, we know them from knowledge.

- Machine learning models tend to learn <u>everything</u> from data, as if we knew nothing about the world.



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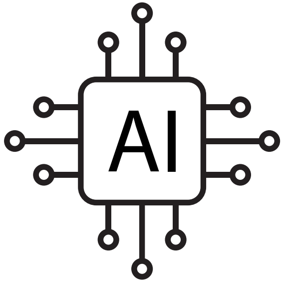
Do we need to extract all information from data?

- Many things about the world, we know them from knowledge.

- Machine learning models tend to learn everything from data, as if we knew nothing about the world.
- Intergrating domain knowledge is crucial for models that are meaningful



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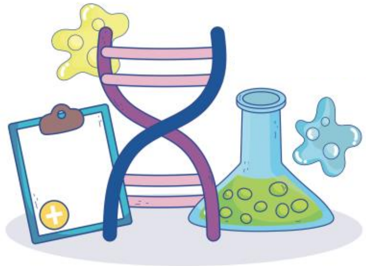

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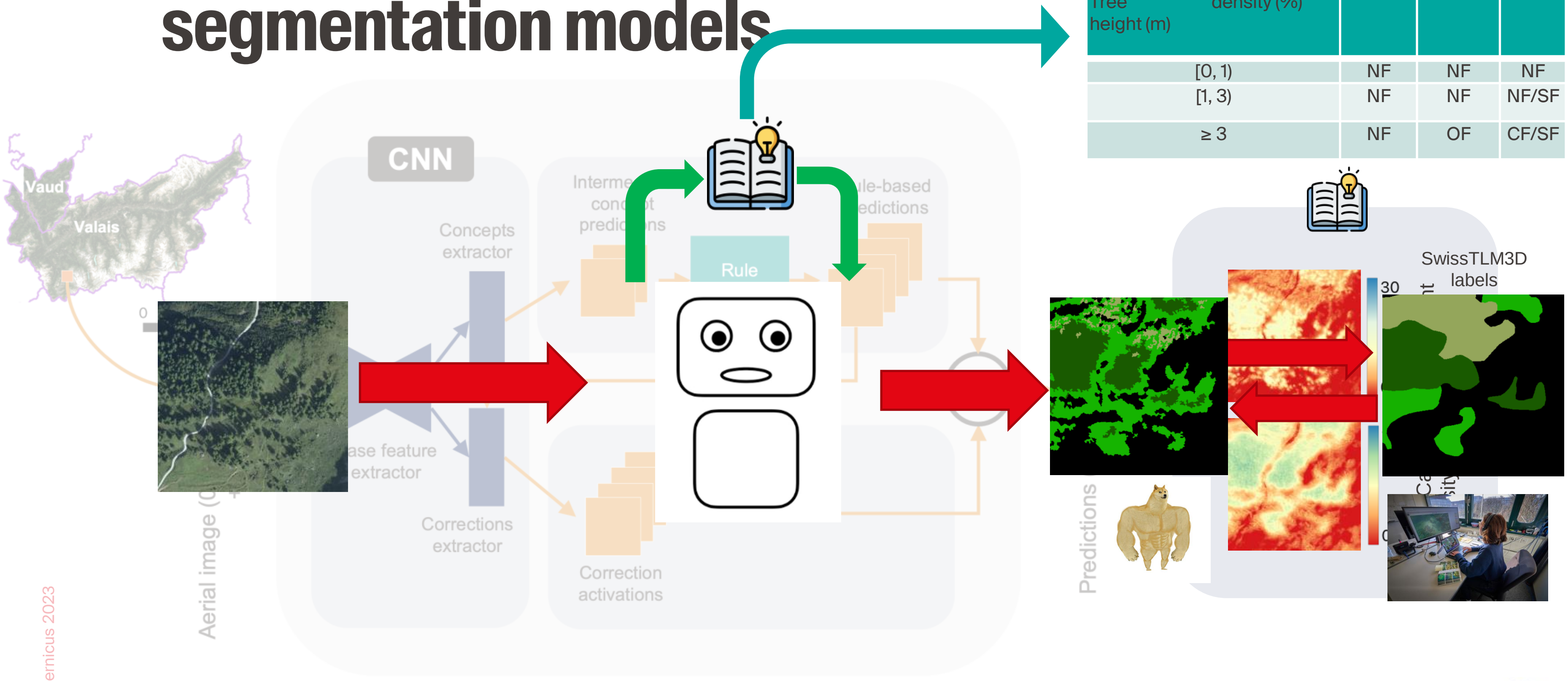
Integrating forest definitions in segmentation models

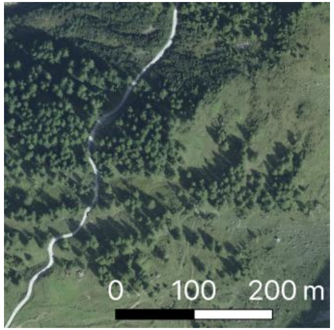
Tree height (m) / Tree canopy density (%)	[0, 20)	[20, 60)	≥ 60
[0, 1)	NF	NF	NF
[1, 3)	NF	NF	NF/SF
≥ 3	NF	OF	CF/SF



T.-A. Nguyen, B. Kellenberger, and D. Tuia. Mapping forest in the Swiss Alps treeline ecotone with explainable deep learning. *Remote Sens. Environ.*, 281(113217), 2022.

Results better align to forest definitions

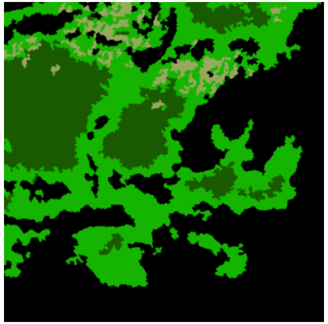
Aerial image



SwissTLM3D labels

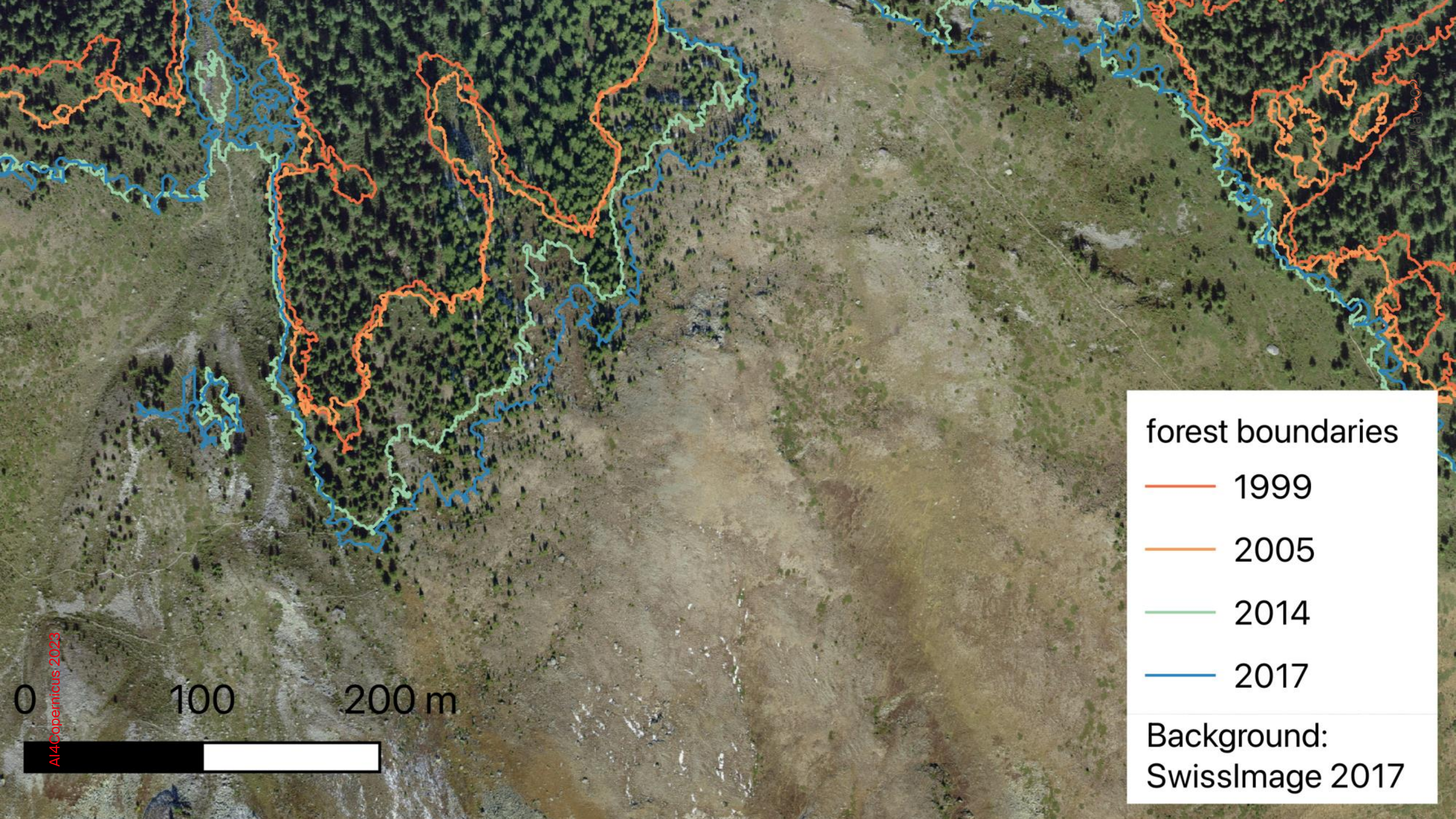
"Black-box" model predictions

Hybrid model predictions



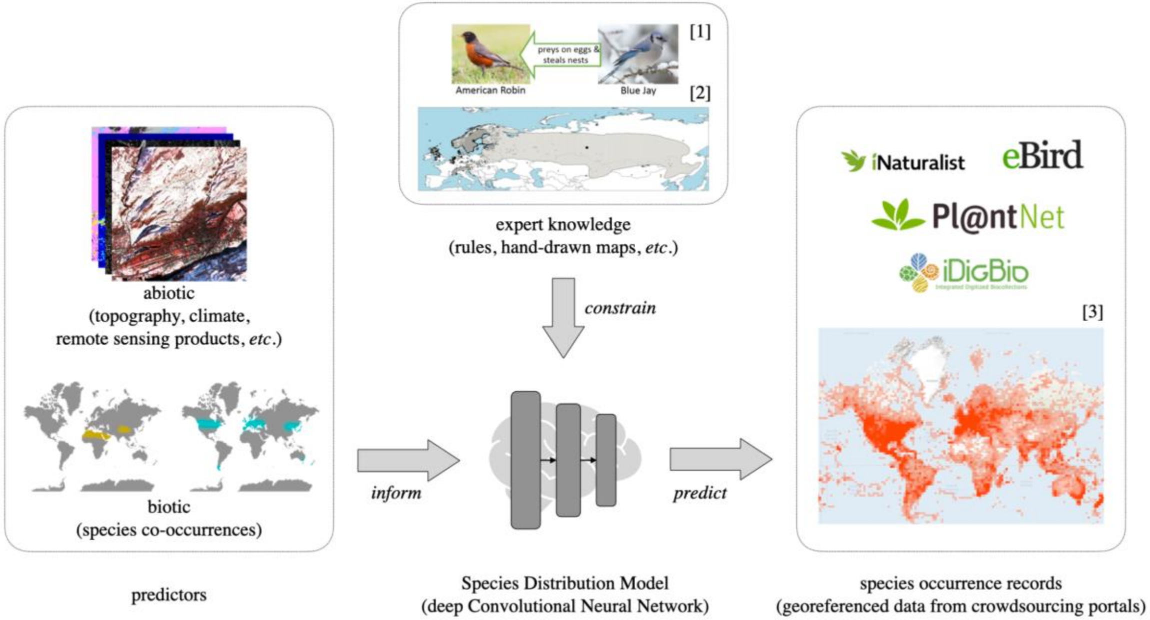
non-forest (NF) open forest (OF) closed forest (CF) shrub forest (SF)

T.-A. Nguyen, B. Kellenberger, and **D. Tuia**. Mapping forest in the Swiss Alps treeline ecotone with explainable deep learning. *Remote Sens. Environ.*, 281(113217), 2022.



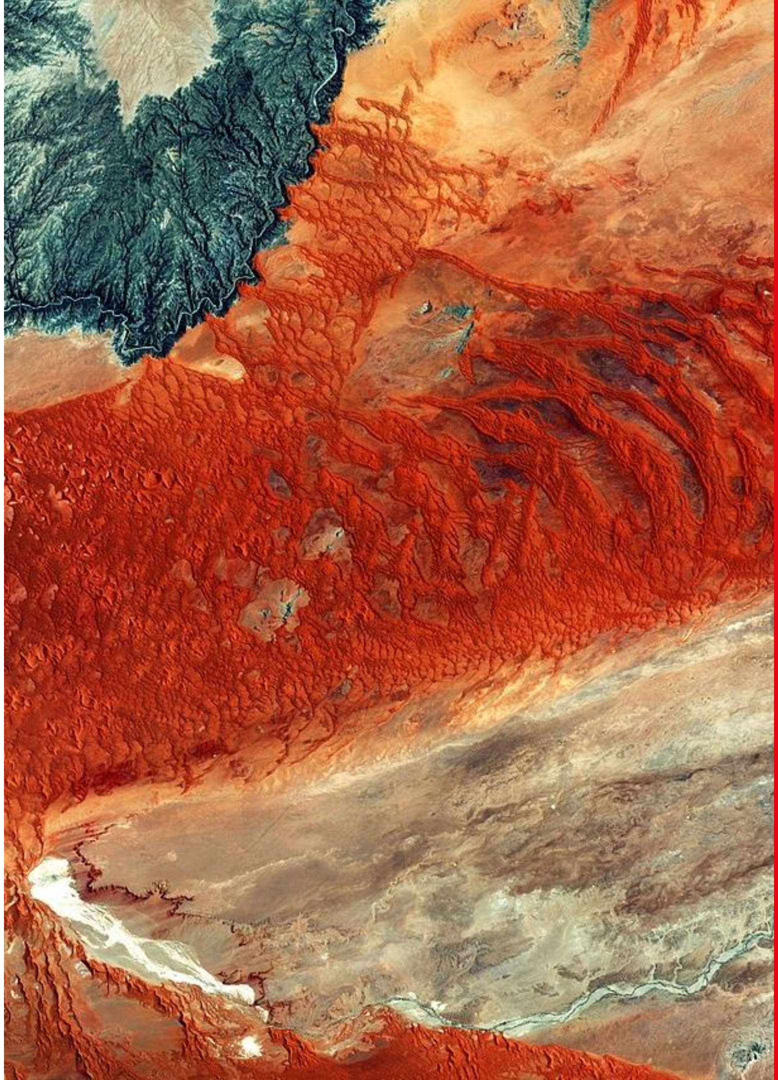
forest boundaries
1999
2005
2014
2017
Background:
SwissImage 2017
0
100
200 m
AI4Copernicus 2023

Injecting domain knowledge in species distribution models



Zbinden. R., N. van Tiel, **B. Kellenberger**, **L. Hughes**, and **D. Tuia.** Exploring neural networks and their potential for species distribution modeling. *Under review*.



My view on Remote sensing and AI

Advance remote sensing science to monitor and protect Earth

Interface disciplines and approaches

Bring new, open tools making EO science accessible to anyone

@devistuia

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