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Data Driven Stormwater Management for Climate Resilience

Abhijeet Patel | WSP

Disclaimer

- The following presentation on AI applications in hydrology science reflects recent trends and findings from current research.
- I am not an author of the research discussed herein; this presentation is based on my personal interest in the topic.
- The views and opinions expressed are solely mine and do not represent those of WSP.

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https://neuralhydrology.github.io/

Presentation Outline

- Problem statement
- Case study of ML application in context of Hydrology and Climate Change
- Other avenues to be explored with AI and ML
- Summary, conclusion and Q&A

This presentation is NOT about…

- Application of AI /ML for government policy and regulation pertaining to climate resilience
- Financial aspect of climate resilience planning using AI/ML
- In-depth technical analyses of concepts discussed however the github repositories mentioned in the video will be shared in the end

Word Definitions

- Climate resilience: It is the capacity or ability to **anticipate** and **cope with shocks**, and **to recover** from changing climate conditions and disruptions in a timely and efficient manner.
- Examples:

- Increased Capacity for Water Storage

- Integration of Nature-Based Solutions

- Flexible Infrastructure Design

- Climate-Informed Planning and Decision-Making

Word Definitions

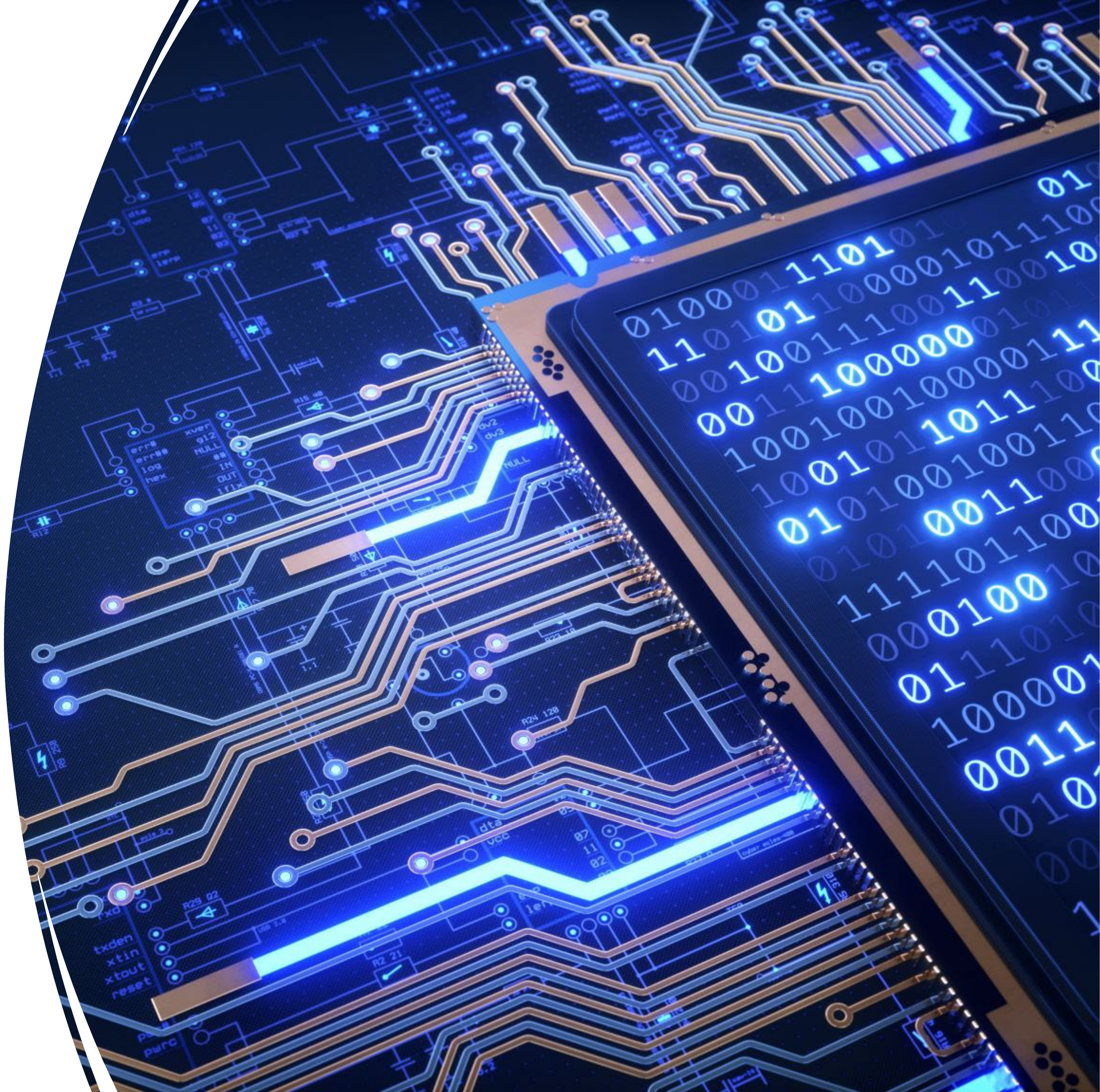
- Artificial Intelligence: AI refers to the development of computer systems or algorithms that can perform tasks typically requiring human intelligence, such as understanding **natural language**, **recognizing patterns in data**, and **making decisions**.
- Examples of AI :

  - Natural Language Processing (NLP)

  - Computer Vision

  - Robotics

  - Expert Systems



Word Definitions

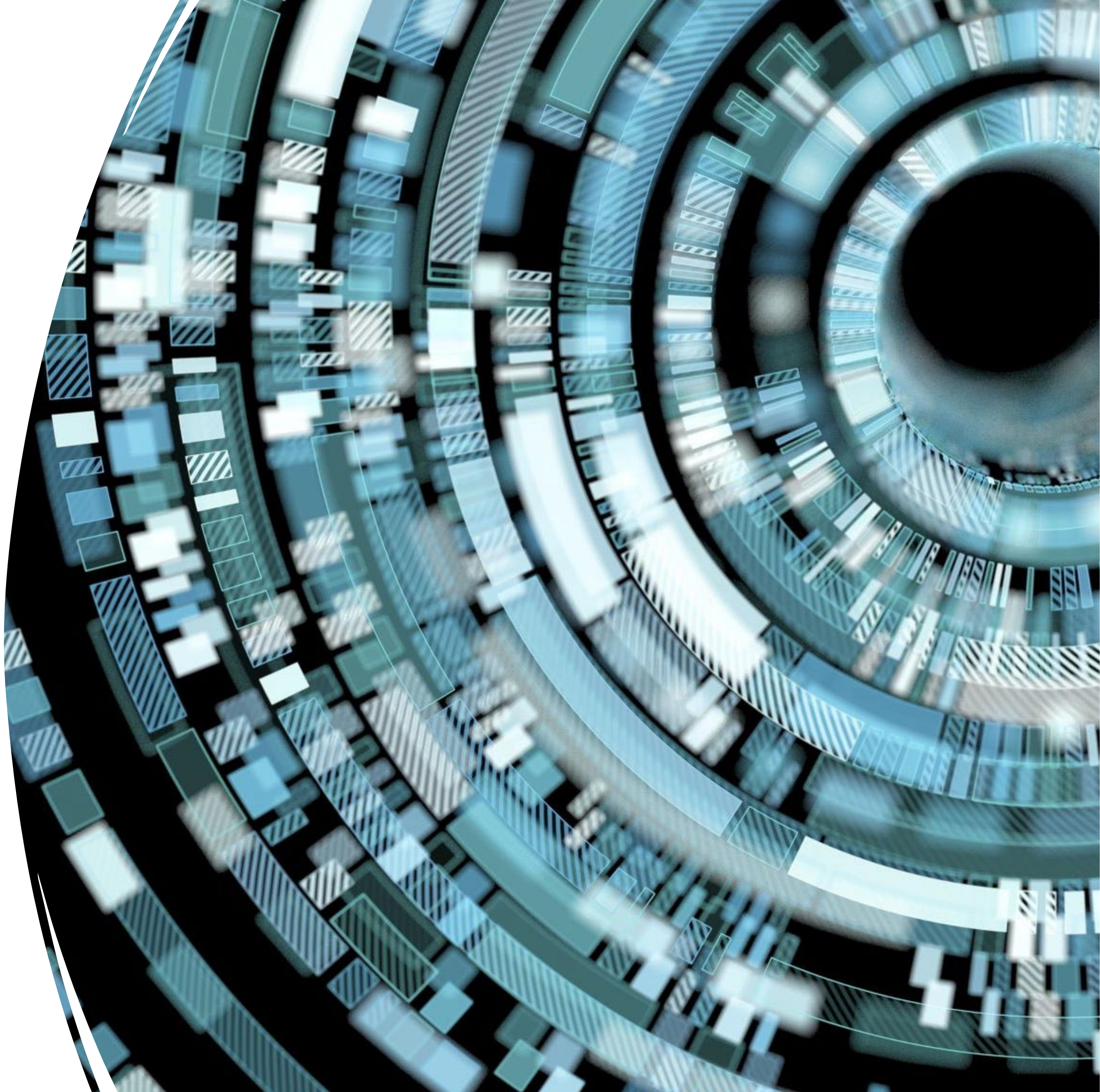
- Machine Learning: ML is a subset of AI that focuses on algorithms and techniques that enable computers to **learn from data** and improve their performance on **specific tasks over time**, without being explicitly programmed.
- Examples of ML :

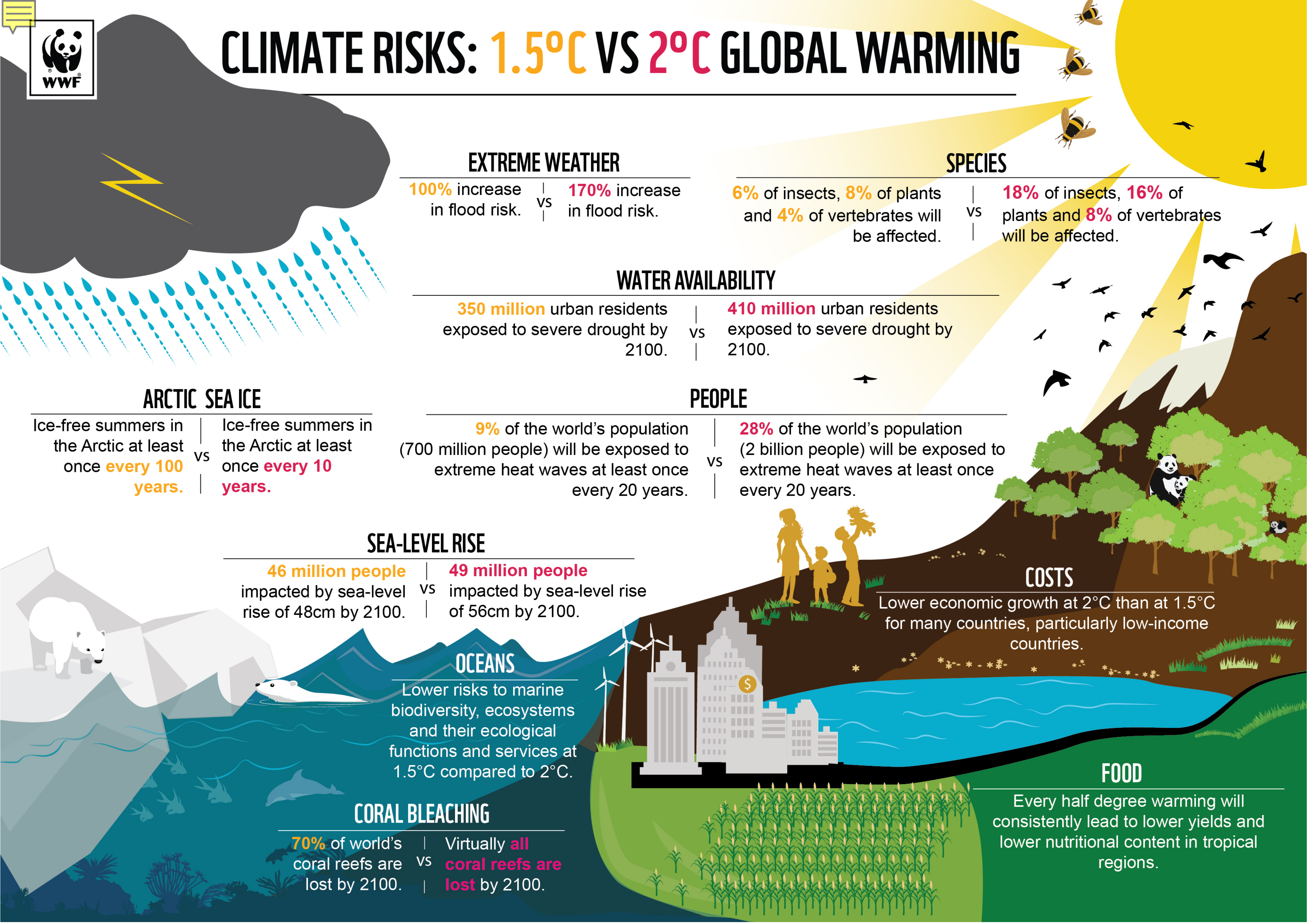
  - Supervised Learning

  - Unsupervised Learning

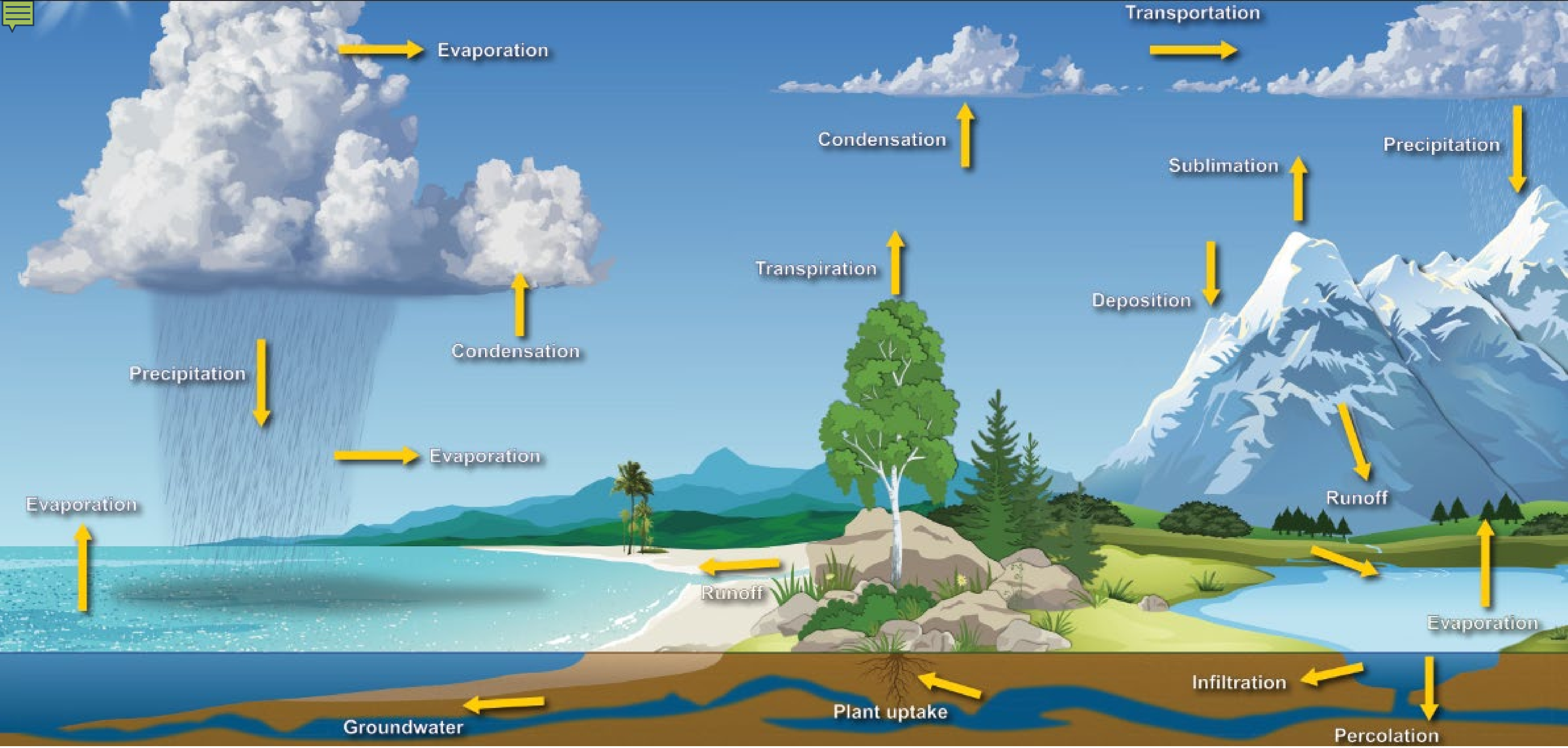
  - Reinforcement Learning

  - Deep Learning



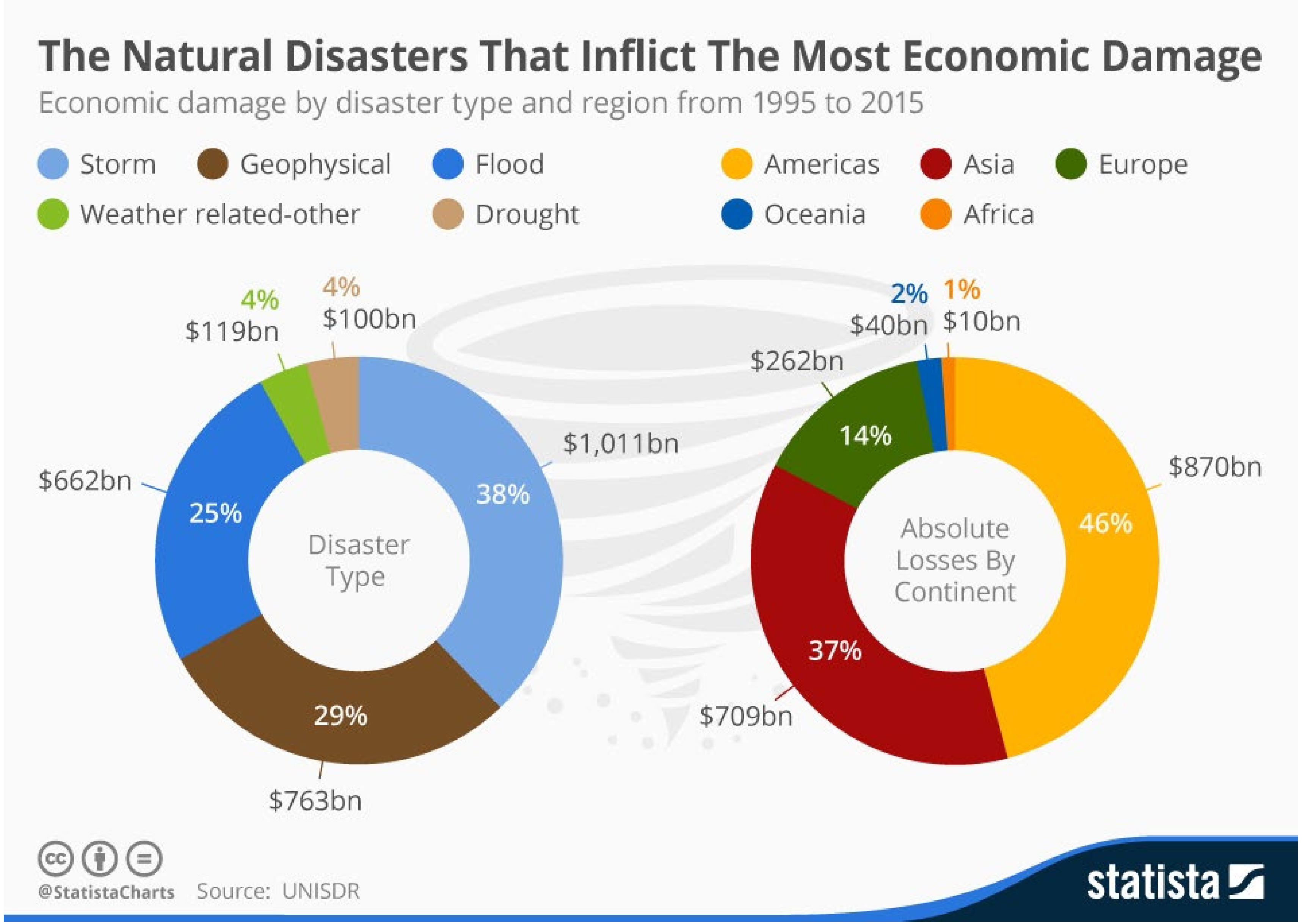


Problem statement



Climate change is affecting where, when, and how much water is available.

Problem statement

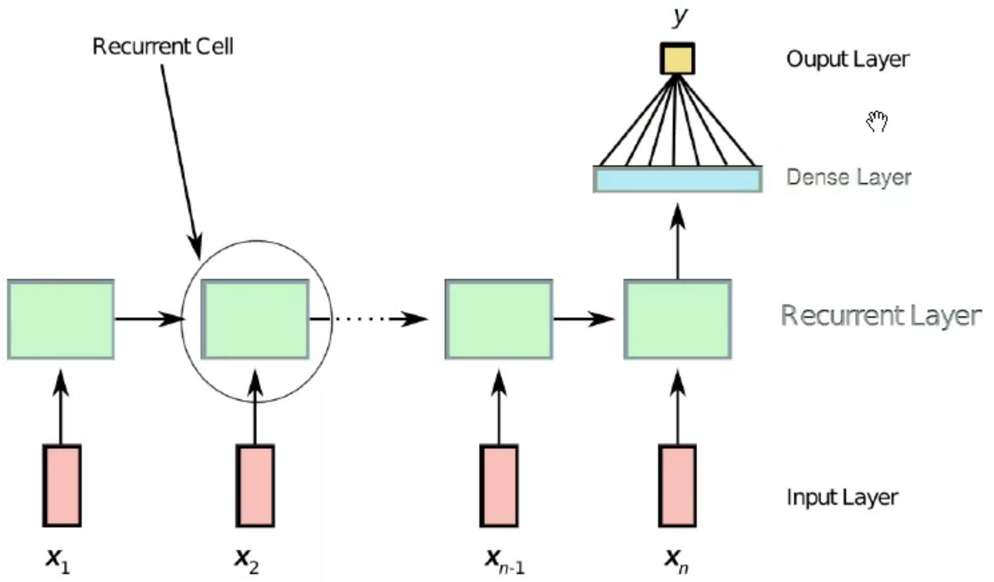


Accurate predictions and planning are one of the most successful predictors of survival
Better forecasting models are needed For climate resilience


SENIOR WOODCHUCK COUNCIL
Mother
Father
Matilda
Hortense
Grandpa
Clan McDuck
Good for The Goose
the Traitor
Scrooge's Worst Nightmare
Dirty Dingus
friend or F.O.W.L
BeagleBurg
Beagle Boy Names:
• Burger
• Bigtime
Neither World War II
Hortense
Who is D.B.? Gigi?
What Looms Larger then McDuck's Shadow?
$crooge McDuck
Scotty McDuck → Alternate Timeline? ???
Quackmore Duck
• Sir Roast McDuck
• Seafoam McDuck
• Malcol McDuck
• Sir Quackly
• Sir Elder
Granny
DUCKBURG DAILIES
SKYPIRATES SPOTTED ABOVE PLAIN AWFUL!
NEWS!
SIGHTING!
Donald Duck
Dismal Downs
Huey, Dewey, Louie
who's cleaning my room??
The Last Treasure
friends
Me!!!!!
Webby!!!
GRANNY
DuckTales
Disney Channel

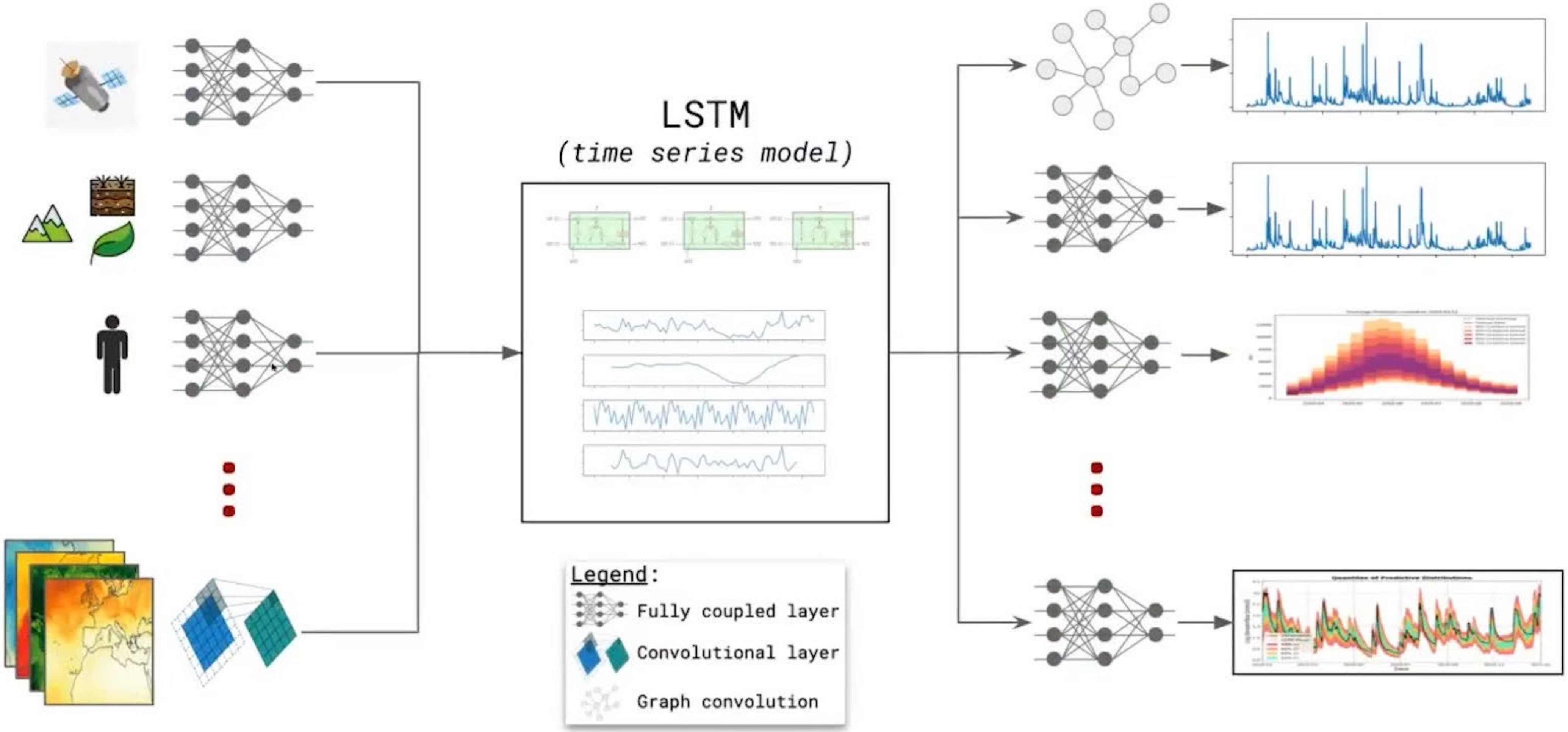
The LSTM

- **R**ecurrent **N**eural **N**etwork with explicit memory (Hochreiter and Schmidhuber, 1997)
- Used across a wide range of applications
  - E.g. language modeling, machine translation, image captioning, etc.



Water Resources Research, Volume: 55, Issue: 12, Pages: 11344-11354, First published: 23 November 2019, DOI: (10.1029/2019WR026065)

Embedding into Deep Learning Models



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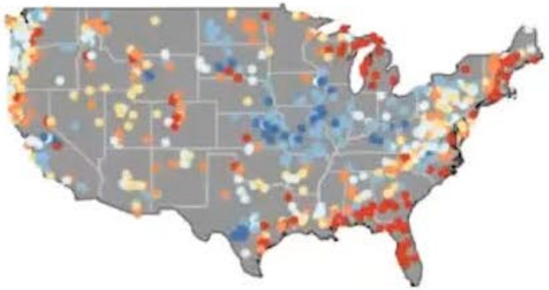
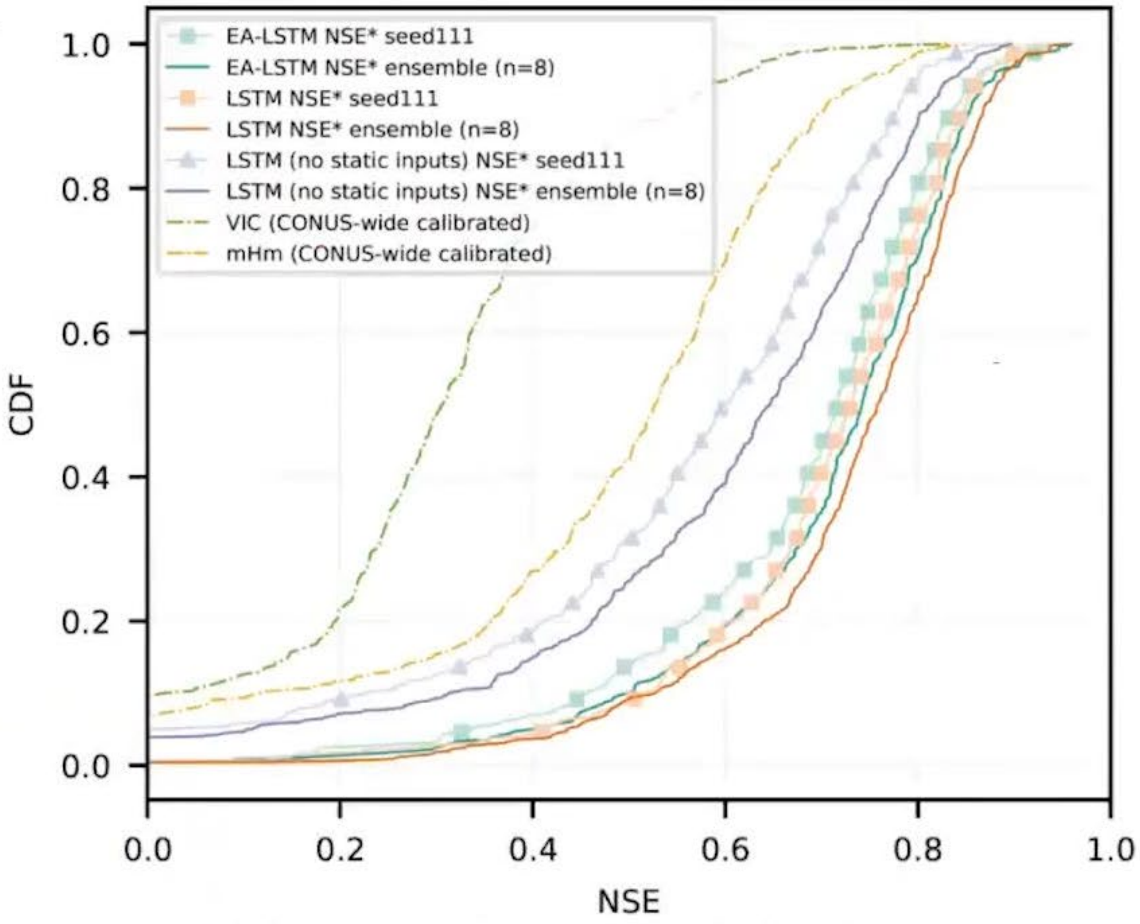


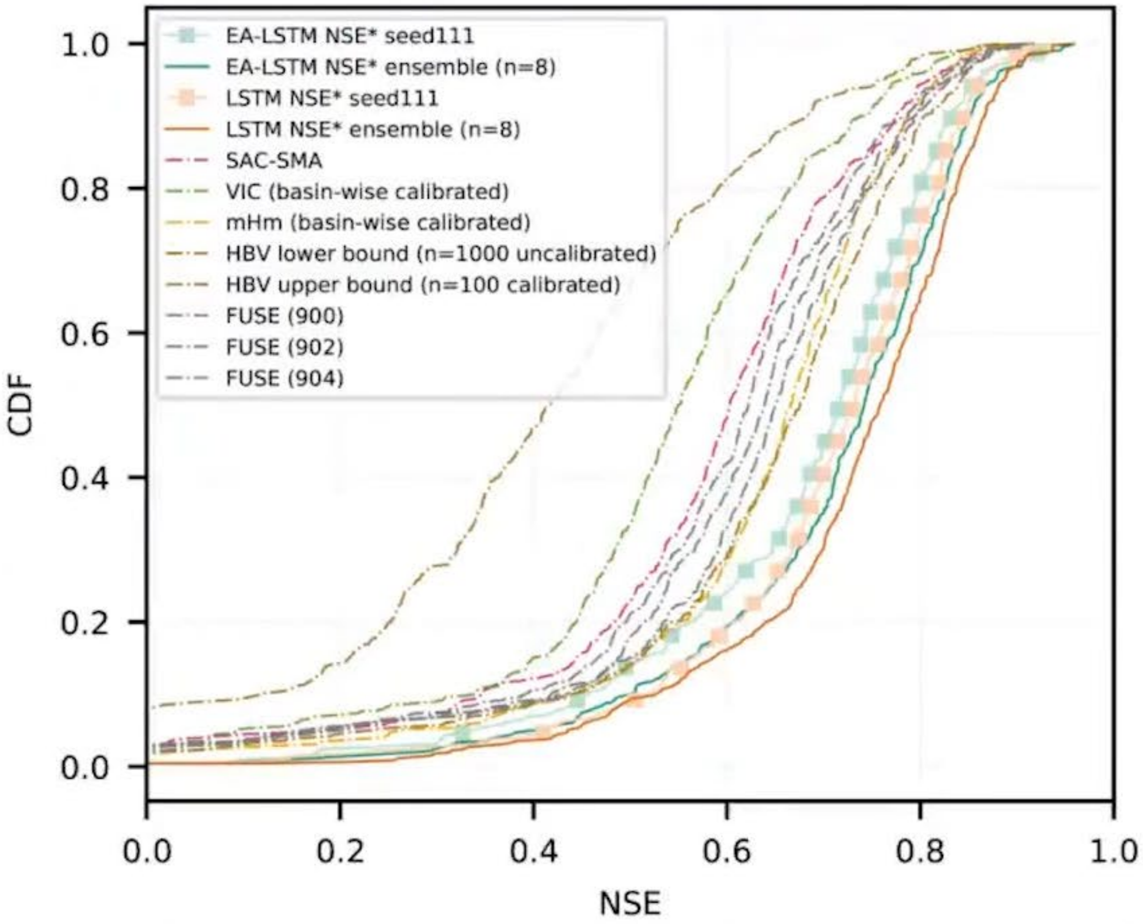
Regional Modeling

Regional LSTMs are better than catchment-specific hydro models.

Benchmarking vs CONUS-wide calibrated models



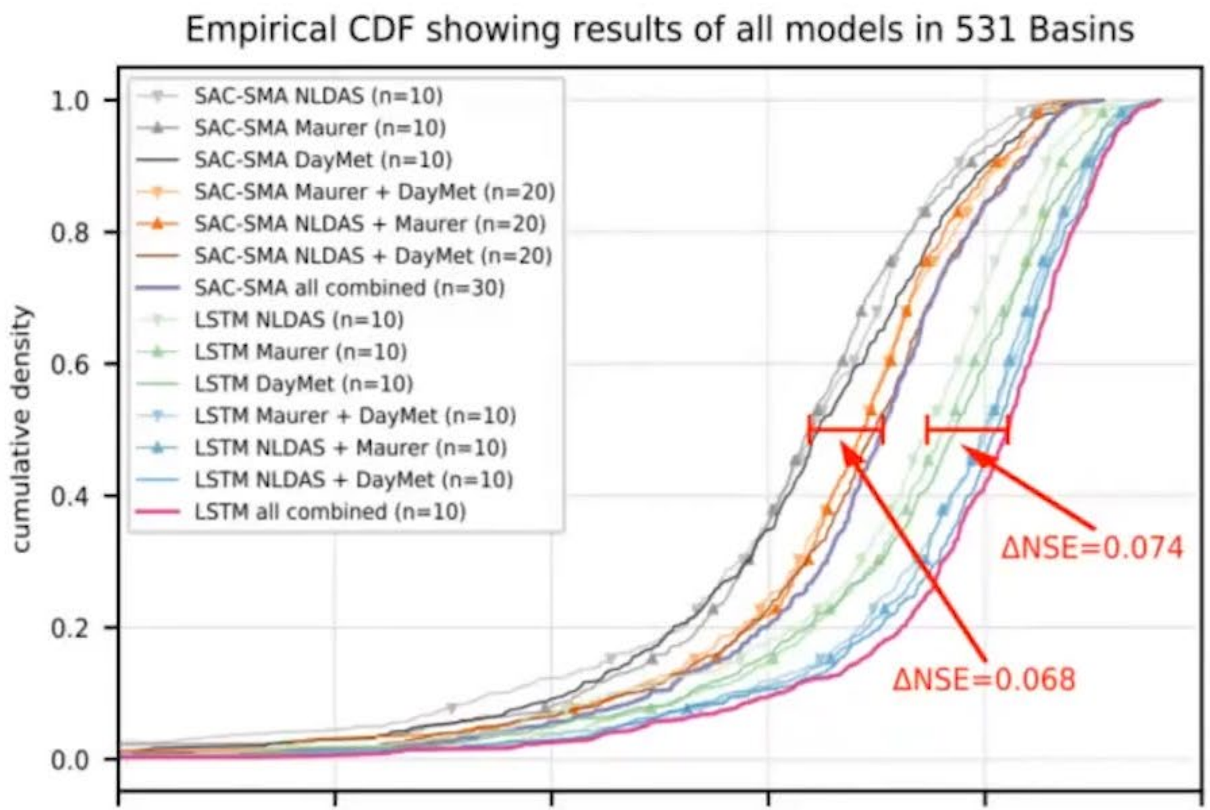
Benchmarking vs. basin-wise calibrated models

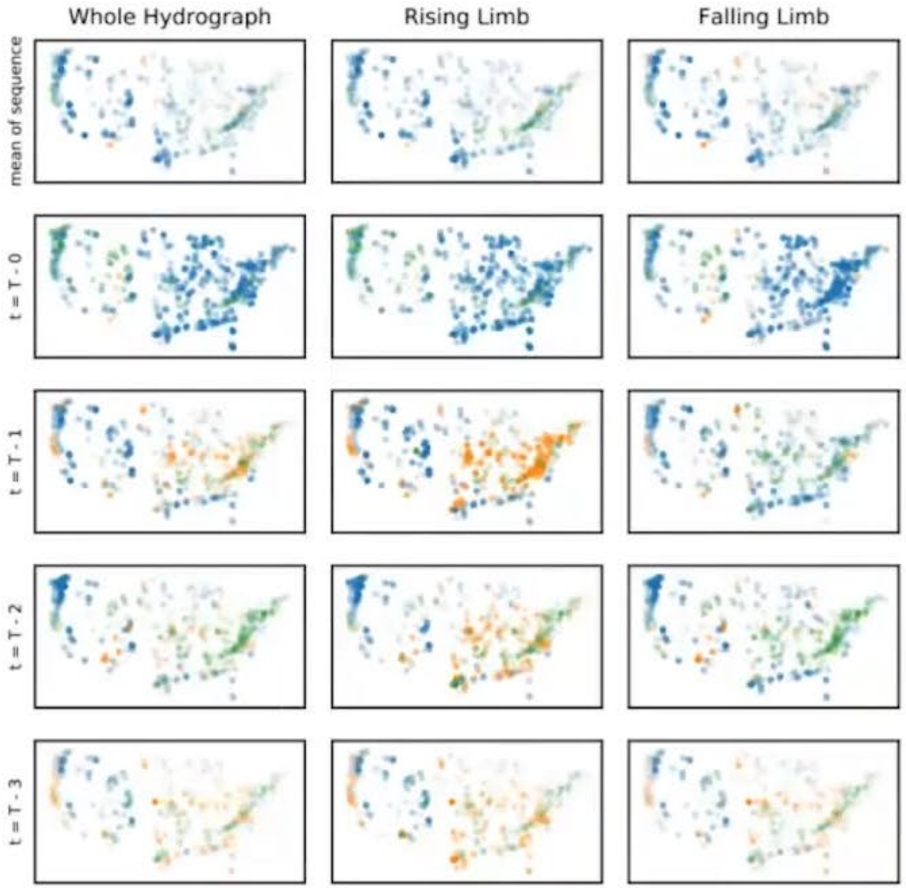


Kratzert, F., Klotz, D., Shalev, G., Klambauer, G., Hochreiter, S., & Nearing, G. (2019). Towards learning universal, regional, and local hydrological behaviors via machine learning applied to large-sample datasets. *Hydrology & Earth System Sciences*, *23*(12).

Certain "hard" tasks are easy with DL

Multiple Forcings w/o Ensembles

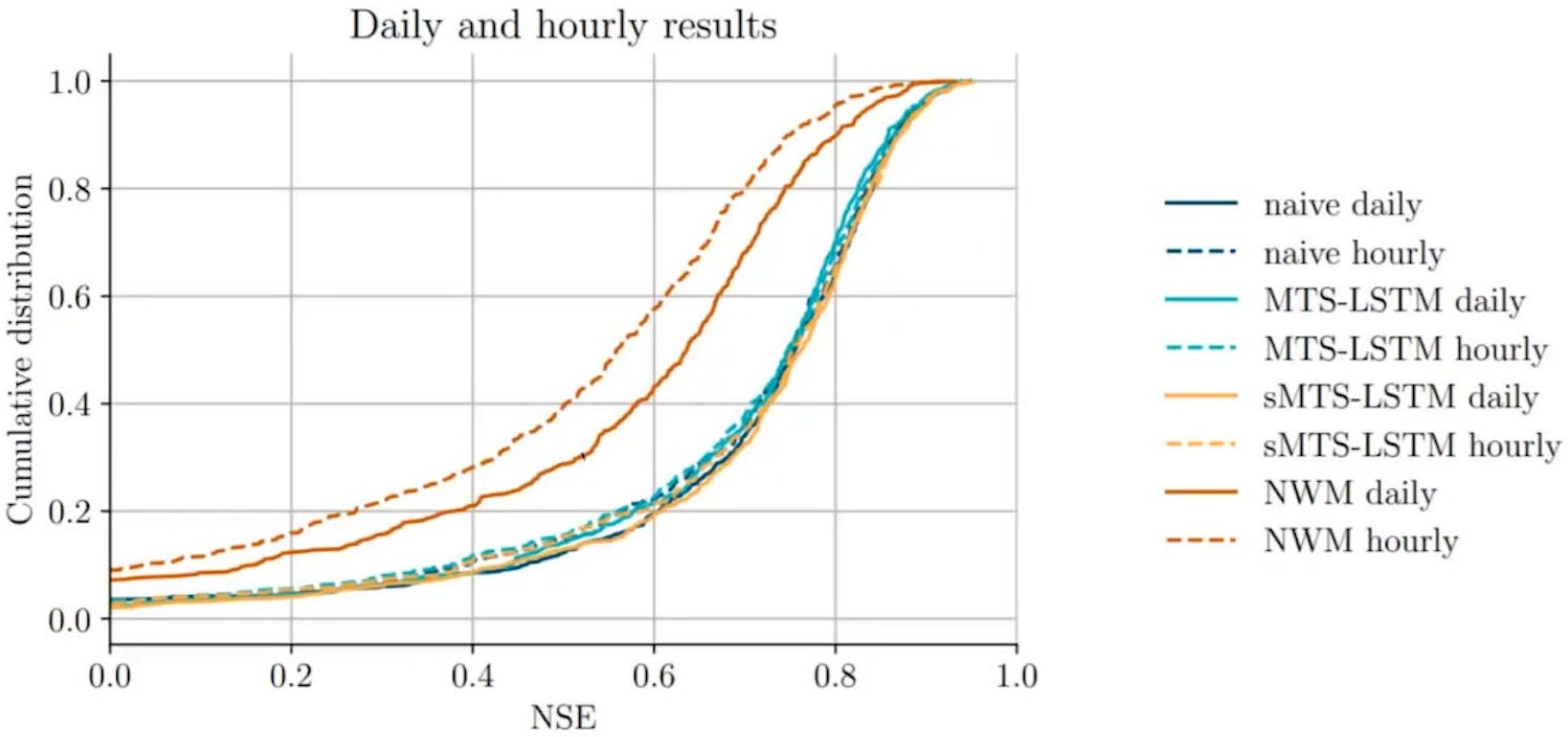




Kratzert, F., Klotz, D., Hochreiter, S., & Nearing, G. S. (2020). A note on leveraging synergy in multiple meteorological datasets with deep learning for rainfall-runoff modeling. *Hydrology and Earth System Sciences Discussions*, 1-26.

Certain "hard" tasks are easy with DL

Multiple Time Scales



Gauch, M., Kratzert, F., Klotz, D., Nearing, G., Lin, J., & Hochreiter, S. (2020). Rainfall-Runoff Prediction at Multiple Timescales with a Single Long Short-Term Memory Network. *arXiv preprint arXiv:2010.07921*.

Physics into Deep Learning Models

Table 1: Benchmarking Results. All values represent the median over the 447 basins.

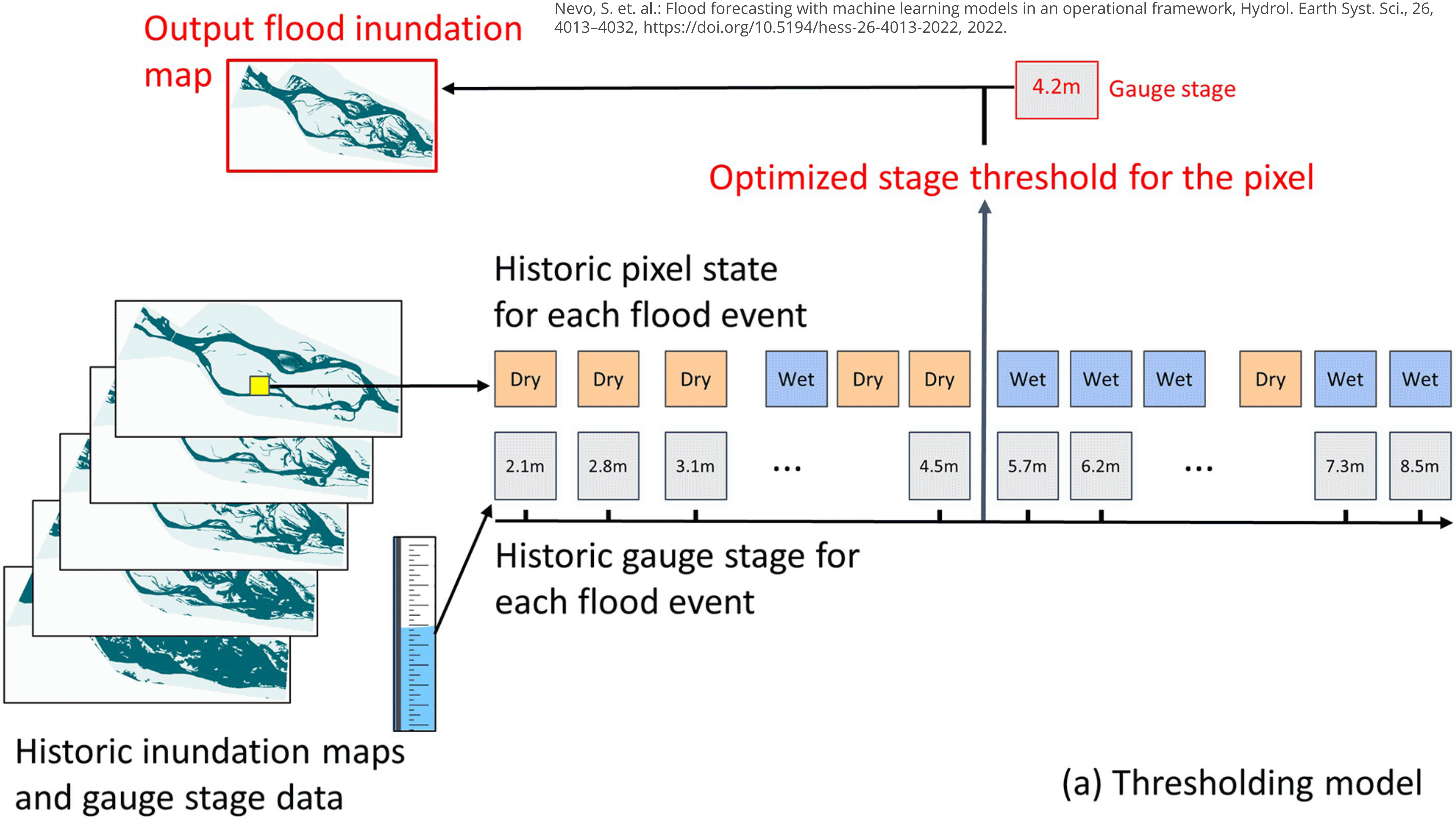
Model	MC?[a]	KGE[b]	Bias[c]	σ_{rat}[d]	r^2	FHV[e]	FLV[f]
Deep Learning Models							
MC-LSTM Ens.	yes	0.764*	-0.020*	0.842	0.873*	-14.689*	-24.651*
LSTM Ens.	no	0.762	-0.034	0.838	0.886	-15.740	36.267
Conceptual Hydrology Models							
SAC-SMA	yes	0.632	-0.066	0.779	0.792	-20.356	37.415
VIC (basin)	yes	0.588	-0.018	0.725	0.760	-28.139	-74.769
VIC (regional)	yes	0.257	-0.074	0.457	0.651	-56.483	18.867
mHM (basin)	yes	0.691	-0.040	0.807	0.832	-18.640	11.433
mHM (regional)	yes	0.468	-0.039	0.589	0.793	-40.178	36.795
HBV (lower)	yes	0.391	-0.023	0.584	0.713	-41.859	23.883
HBV (upper)	yes	0.681	-0.012	0.788	0.833	-18.491	18.341
FUSE (900)	yes	0.668	-0.031	0.796	0.815	-18.935	-10.538
FUSE (902)	yes	0.690	-0.047	0.802	0.821	-19.360	-68.224
FUSE (904)	yes	0.644	-0.067	0.783	0.808	-21.407	-67.602

[a] *Mass conservation (MC).*
[b] *Kling-Gupta Efficiency:* $(-\infty, 1]$, *values closer to one are desirable.*
[c] *Bias:* $(-\infty, \infty)$, *values closer to zero are desirable.*
[d] *Variance Ratio:* $(-\infty, \infty)$, *values closer to one are desirable.*
[e] *Top 2% high flow bias:* $(-\infty, \infty)$, *values closer to zero are desirable.*
[f] *Bottom 30% low flow bias:* $(-\infty, \infty)$, *values closer to zero are desirable.*
[*] *MC-LSTM is significantly different than the LSTM by Wilcoxon rank test at* $\alpha = 0.05$.

What does it mean for Climate change?

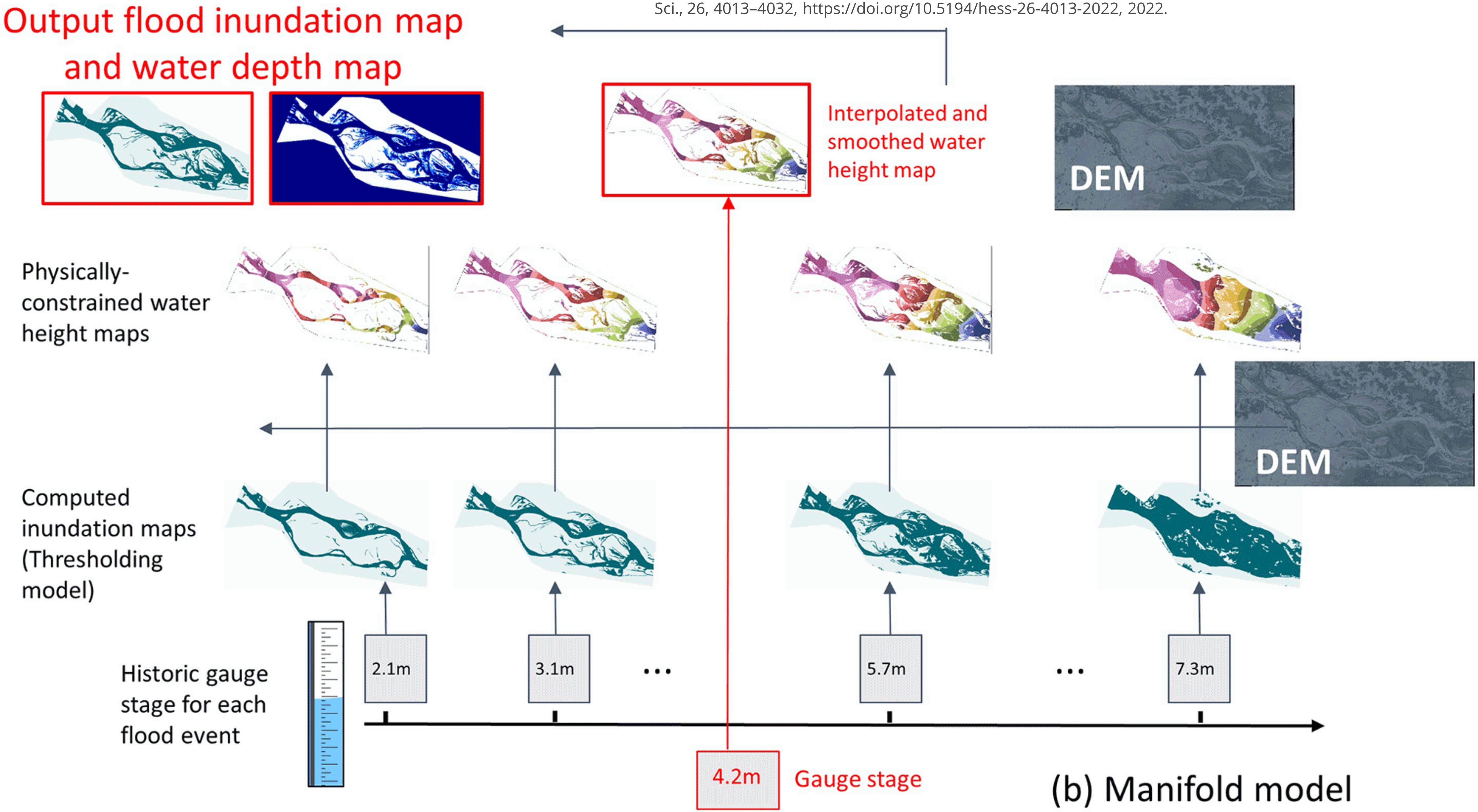
Slight performance increase over LSTM, but currently the best peak-flow model we've tested.

Nevo, S. et. al.: Flood forecasting with machine learning models in an operational framework, Hydrol. Earth Syst. Sci., 26, 4013–4032, https://doi.org/10.5194/hess-26-4013-2022, 2022.



(a) Thresholding model

Nevo, S. et. al.: Flood forecasting with machine learning models in an operational framework, Hydrol. Earth Syst. Sci., 26, 4013–4032, https://doi.org/10.5194/hess-26-4013-2022, 2022.



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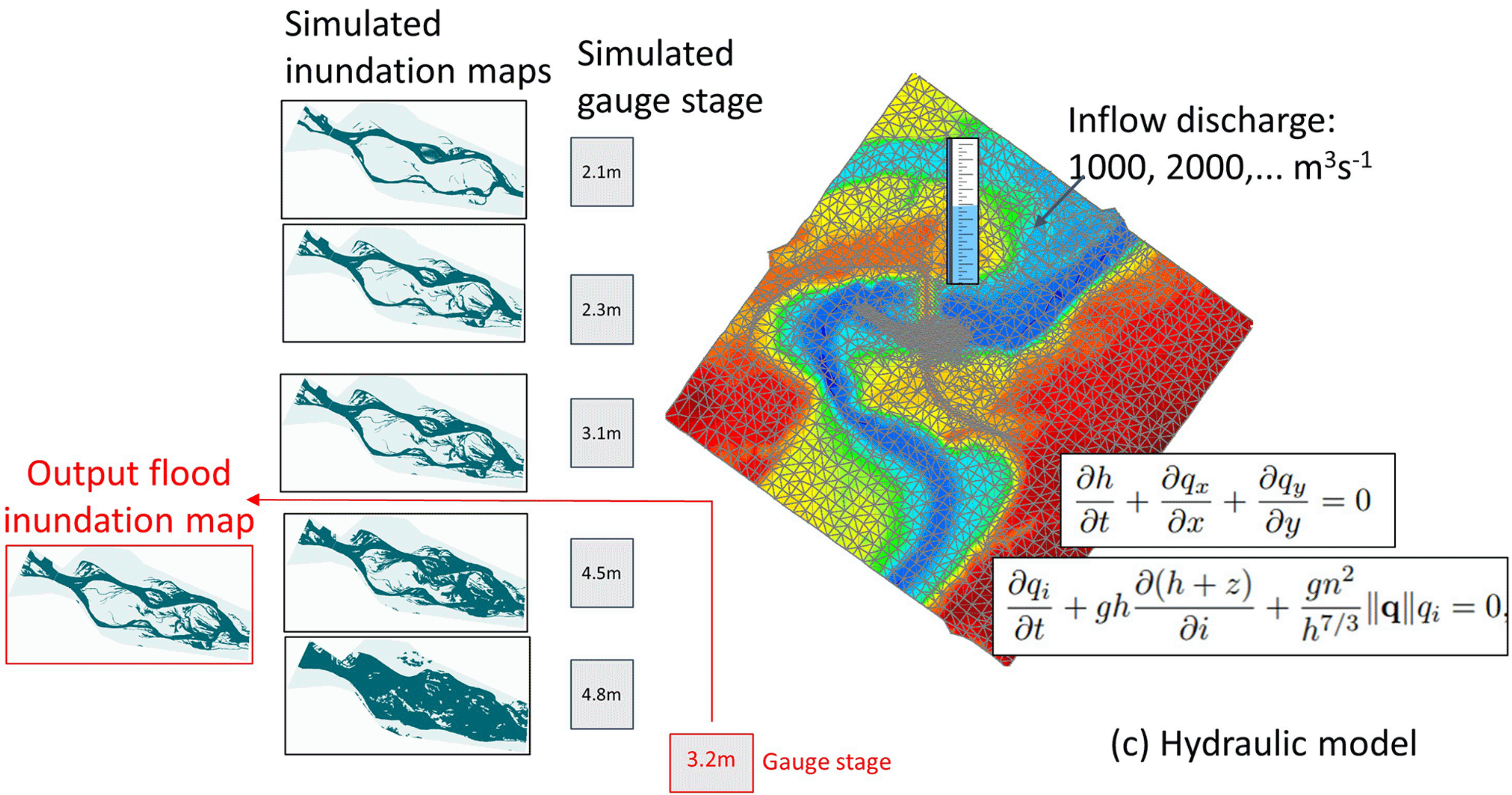
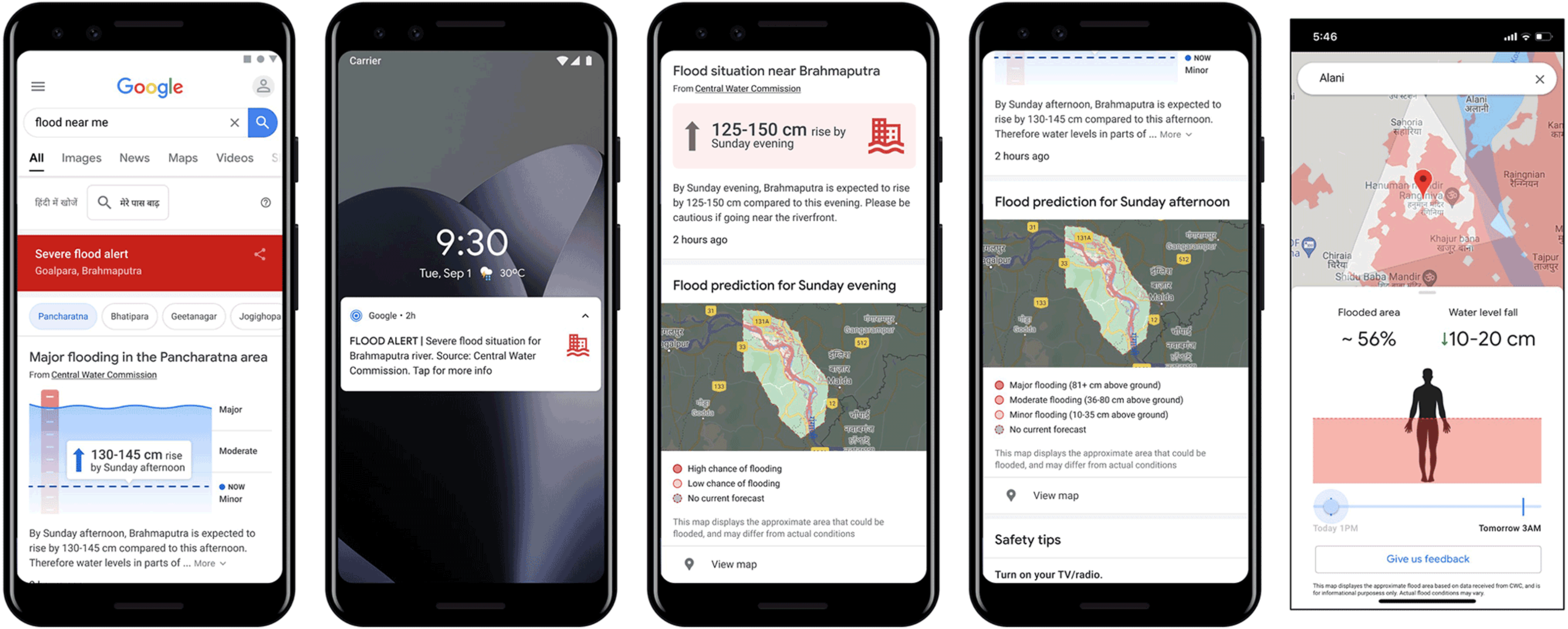


Google Flood Hub

https://sites.research.google/floods



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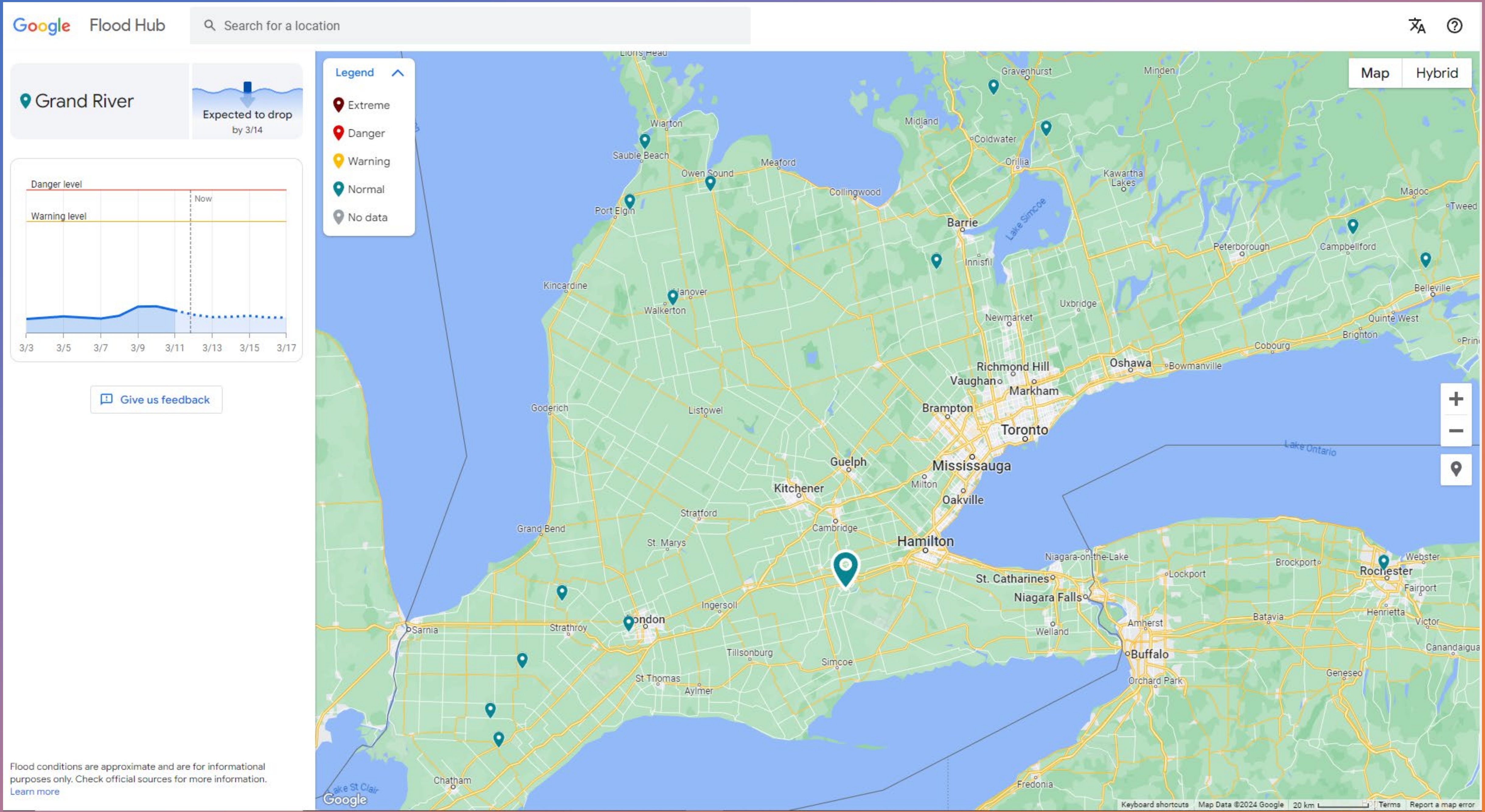

Google Flood Hub
Search for a location
Grand River
Expected to drop
by 3/14
Danger level
Warning level
Now
3/3
3/5
3/7
3/9
3/11
3/13
3/15
3/17
Give us feedback
Flood conditions are approximate and are for informational purposes only. Check official sources for more information.
Learn more
Legend
Extreme
Danger
Warning
Normal
No data
Map
Hybrid
Wiarton
Sauble Beach
Owen Sound
Meaford
Collingwood
Port Elgin
Midland
Coldwater
Orillia
Gravenhurst
Minden
Kawartha Lakes
Barrie
Lake Simcoe
Innisfil
Peterborough
Campbellford
Madoc
Tweed
Belleville
Quinte West
Brighton
Cobourg
Kincardine
Hanover
Walkerton
Uxbridge
Newmarket
Richmond Hill
Vaughan
Markham
Oshawa
Bowmanville
Brampton
Toronto
Lake Ontario
Goderich
Listowel
Guelph
Mississauga
Milton
Kitchener
Oakville
Stratford
Cambridge
Grand Bend
St. Marys
Hamilton
Niagara-on-the-Lake
St. Catharines
Niagara Falls
Welland
Lockport
Brockport
Rochester
Webster
Fairport
Henrietta
Victor
Batavia
Canandaigua
Geneseo
Amherst
Buffalo
Orchard Park
Ingersoll
London
Sarnia
Strathroy
Tillsonburg
Simcoe
St Thomas
Aylmer
Chatham
Fredonia
Lake St Clair
Google
Keyboard shortcuts
Map Data ©2024 Google
20 km
Terms
Report a map error

Other Applications

- **Urban Flooding Prediction and Management:** AI algorithms can analyze historical flood data, urban topography, and land use patterns to predict areas at high risk of urban flooding during heavy rainfall events.

- **Water Quality Monitoring and Contamination Detection:** ML algorithms can analyze water quality data collected from sensors and monitoring stations to detect contaminants, pollutants, and harmful bacteria in stormwater runoff.

Other Applications

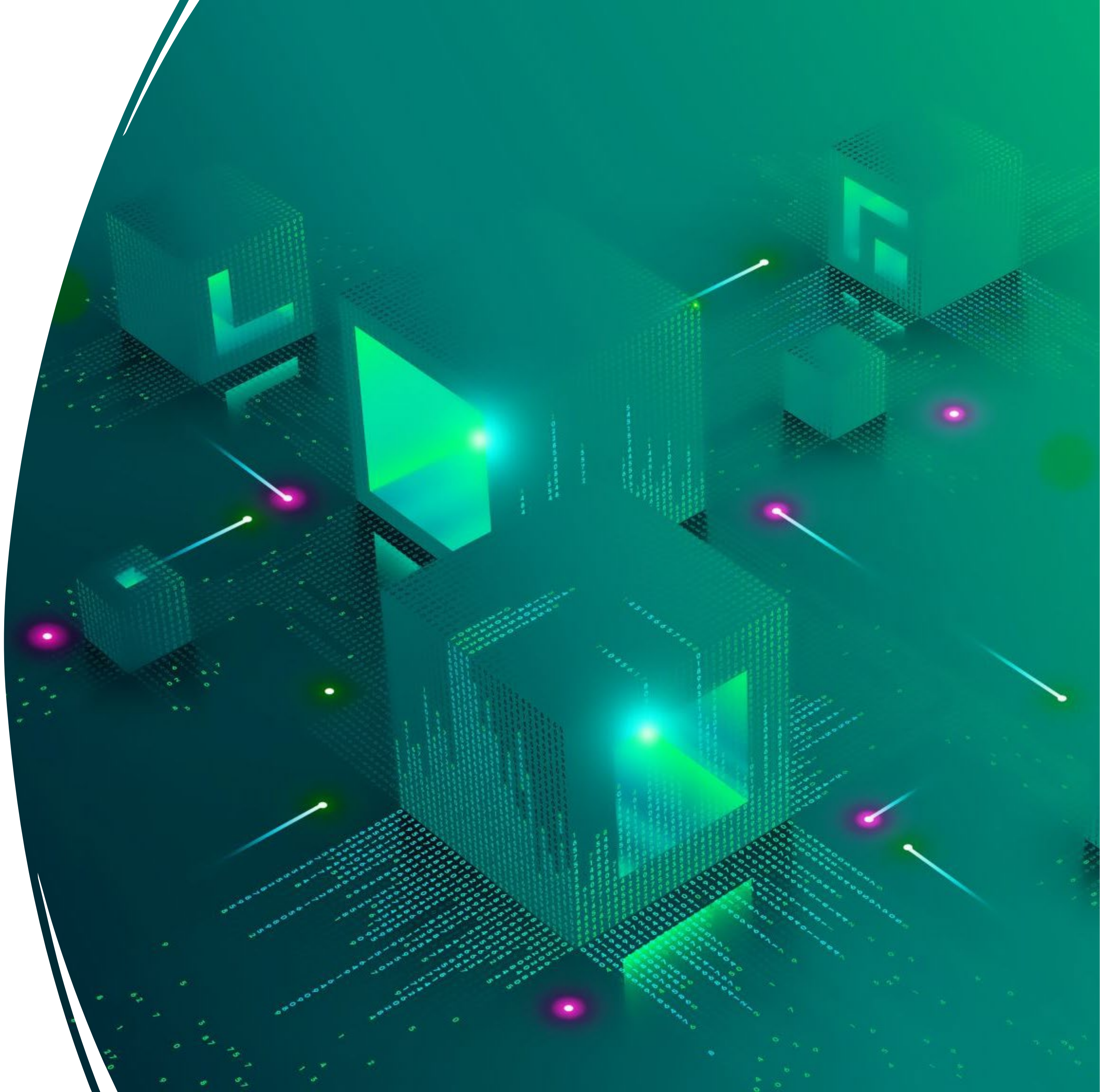
- **Smart Irrigation Systems:** AI-powered irrigation systems can optimize water use efficiency in urban landscapes, parks, and green spaces by analyzing weather forecasts, soil moisture levels, and plant water requirements.

- **Floodplain Mapping and Risk Assessment:** ML algorithms can analyze remote sensing data, LiDAR imagery, and elevation models to map floodplains and assess flood risk levels in vulnerable areas.

Other Applications

- **Green Infrastructure Performance Monitoring:** AI-powered sensors and IoT devices can monitor the performance of green infrastructure assets, such as bioswales, retention ponds, and permeable pavements, in real-time.

- **Dynamic Stormwater Management:** AI algorithms can optimize stormwater management strategies by dynamically adjusting stormwater storage, detention, and infiltration systems based on forecasted weather conditions and anticipated runoff volumes.



Other Applications

- **Community Resilience Planning:** AI-powered decision support tools can facilitate community engagement and participatory planning processes to develop climate resilience strategies at the neighborhood level.

- **Infrastructure Maintenance and Upgrades:** AI-powered image recognition can analyze CCTV footage and aerial imagery to assess the condition of stormwater infrastructure, such as culverts, pipes, and drainage channels.

Some other examples…

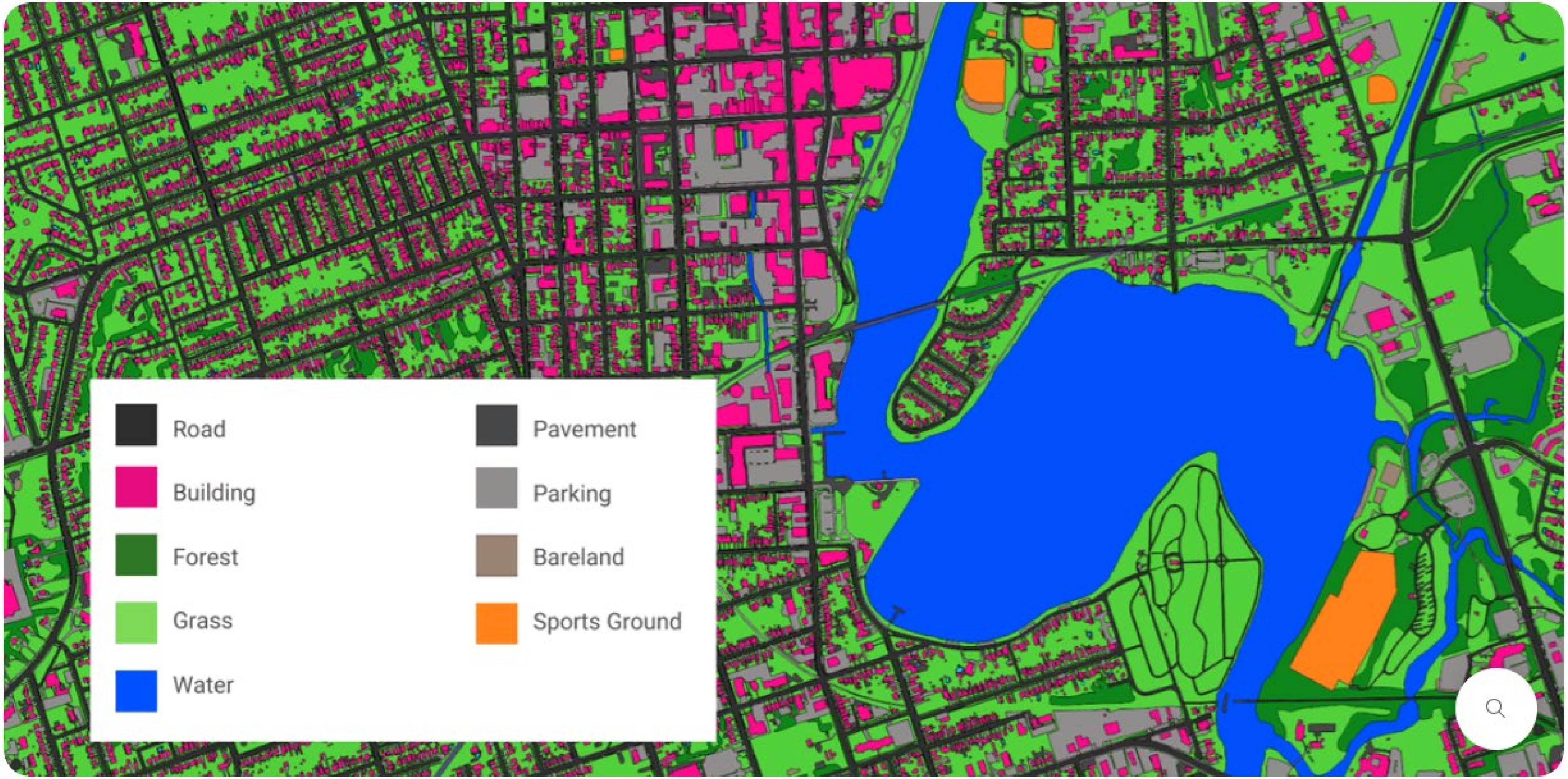
- **Hydroinformatics Institute**: applying AI techniques such as ML and DL to address water-related challenges such as hydrological forecasting, water supply optimization, and climate change impact assessment. Read More: **h2i.sg**

- **HydroLabs**: : provides AI-powered solutions for water quality monitoring, pollution detection, and environmental assessment, using sensors, drones, and satellite imagery for data collection and analysis. Read More: **hydrolabs.co**

- **Aquaoso**: develops AI-powered software solutions for water risk management in agriculture and real estate by utilizing ML algorithms to analyze water data, identify water-related risks, and facilitate informed decision-making for water resource management. Read More: **aquaoso.com**

City of Peterborough builds integrated flood model with updated land cover data

Ecopia® is using AI to build a digital twin of the world, converting high resolution geospatial imagery into comprehensive, accurate, and up-to-date vector maps for use in data-driven decision-making across industries.



A sample of land cover data extracted by Ecopia for use in the City of Peterborough's integrated flood model

Timeline of Geo-Sciences' modelling

CMIP Climate Models
Physics
Several Decades

ML Based Parameters & Post-Processing
AI supports Physics
1-2 Decades

ML Based Parametization
AI + Physics
5+ Years

Conceptual Graph Models
AI on concepts
1-2 Years

Semi-supervised Embeddings (Task-focused)
AI
Months

What are the conclusions?

Questions?