



AI and the Climate Crisis

Yoshua Bengio

*Climate Informatics
Paris, France*

Keynote, October 4th 2019



The Neural Net & Deep Learning Approach to AI: Amazing Progress but far from Human Level

- **Brain-inspired**
- Synergy of a large number of simple adaptive computational units
- Focus on **distributed representations**
 - **E.g. word representations** (Bengio et al NIPS'2000)
- View intelligence as arising of combining
 - an objective or reward function
 - an approximate optimizer (learning rule)
 - an initial architecture / parametrization
- End-to-end learning (all the pieces of the puzzle adapt to help each other)



What did I have to do with Deep Learning?

- End-to-end training (1991-1998), understanding recurrent nets (TNN 1994), theory of distributed representations (NeurIPS 2000 to 2014)
- New methods to enable training of deeper networks + theoretical understanding
 - (Bengio et al NIPS'2006): pre-training stacks of auto-encoders before supervised training, greedy supervised and unsupervised pre-training
 - (Glorot & Bengio AISTATS'2010): initialization with near 1 e-values Jacobians
 - (Glorot & Bengio AISTATS'2011): importance of ReLU for training deep nets
- Beyond pattern recognition:
 - Progress in deep unsupervised models, generative models
 - (Vincent et al & Bengio 2008)++: denoising auto-encoders, self-supervised objectives
 - (Goodfellow et al & Bengio 2014): GANs = generative adversarial networks
 - Attention mechanisms, for arbitrary data structures, neural machine translation (Bahdanau et al & Bengio 2014)
 - Meta-learning (Bengio & Bengio 1991; many more in last 2 years)

AI Scientists have a Responsibility

- How does my job fit with my values? Ask
 - How is this technology going to be used?
 - Who will benefit or suffer from it?
 - How much and what impact?
- I do not wish to work on
 - military applications, especially lethal autonomous weapons
 - ML to beat the stock market
 - increasing the efficiency of advertising or surveillance
 - increasing the efficiency of oil & gas industry, meat industry...

AI for Social Good

- Beyond developing the next gadget
- AI is powerful, can be misused or bring much good
- Actionable items:
 - Favor ML applications which help the poorest countries, may help with fighting climate change, improve healthcare, education, etc.
 - **AI Commons**: an organization in construction, which will coordinate, prioritize and channel funding for such applications



Amir
Banifatemi

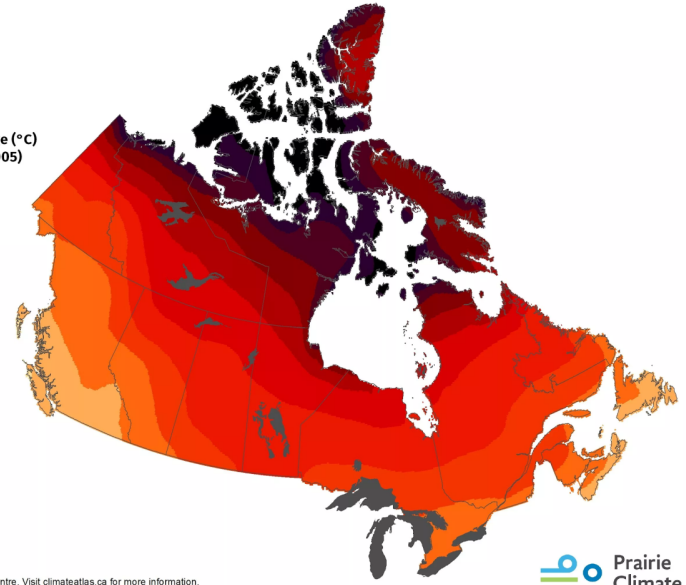
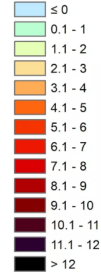


Humanity's Biggest Crisis



2051-2080 Projected Change in Mean Temperature: December
Under the RCP8.5 scenario, relative to a baseline of 1976-2005

Temperature Change (°C)
(Relative to 1976-2005)



© 2017 by the Prairie Climate Centre. Visit climateatlas.ca for more information.
Map Data: Ensemble of 12 CMIP5 models (BCSD Statistically Downscaled Climate Scenarios)
provided by the Pacific Climate Impacts Consortium, University of Victoria (pacificclimate.org).

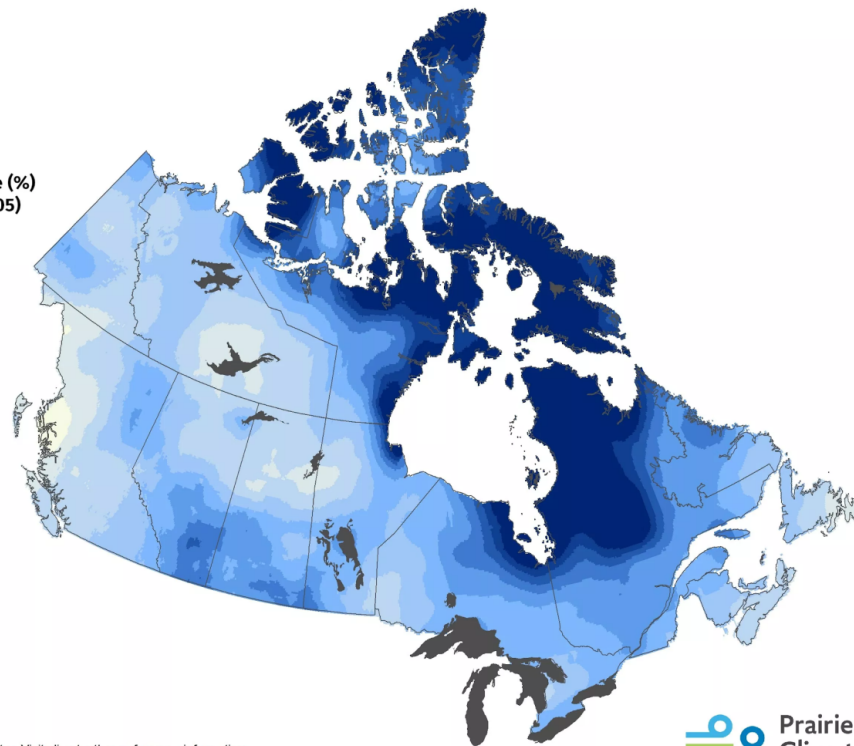
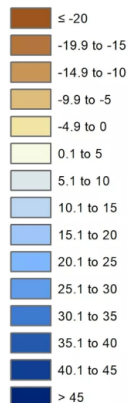
Climate Change in Quebec

Climatic patterns
(**temperature** and
flooding) will change if
emissions continue to rise.

2051-2080 Projected Change in Total Precipitation: February

Under the RCP8.5 scenario, relative to a baseline of 1976-2005

Precipitation Change (%)
(Relative to 1976-2005)



Source:
<http://prairieclimatecentre.ca/2017/10/new-map-series-highlights-changes-coming-to-canadas-climate/>

© 2017 by the Prairie Climate Centre. Visit climateatlas.ca for more information.
Map Data: Ensemble of 12 CMIP5 models (BCSD Statistically Downscaled Climate Scenarios)

Political Will

- It may still technically be possible to limit warming to 1.5C if drastic action is taken now
- Politicians may act if there is sufficient priority given to climate change in the general population
- How do we convince those who are not yet and increase the priority they give to this issue?
 - there is a large **intention-action gap**



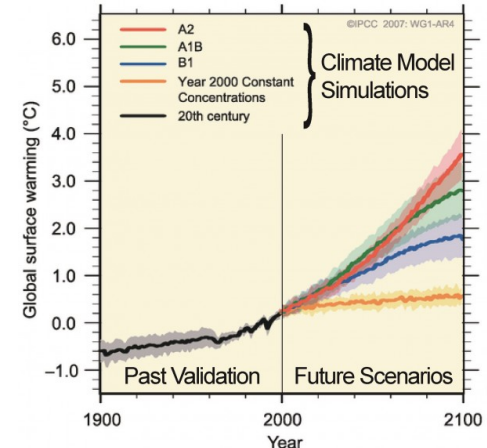
Why is it Difficult to Act?

1. Fear of negative economic impacts of mitigation
 - Better estimate economic impacts, understand the high uncertainty
 - Yet adaptation costs > mitigation costs
 - Nash equilibrium between countries
2. Insufficient priority for the population and decision-makers
 - **Psychological factors** due to cognitive bias
3. Lobby of a few large and powerful companies whose market will disappear, trying to delay the changes

Table A1

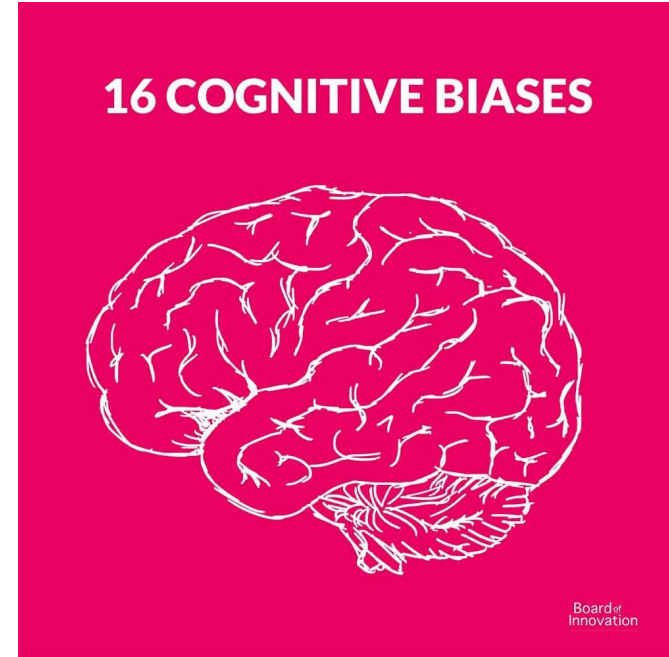
Estimation of Long-Term GDP Loss per Year Under Global Warming Scenarios (US\$ Billion/Year) to the Year 2100

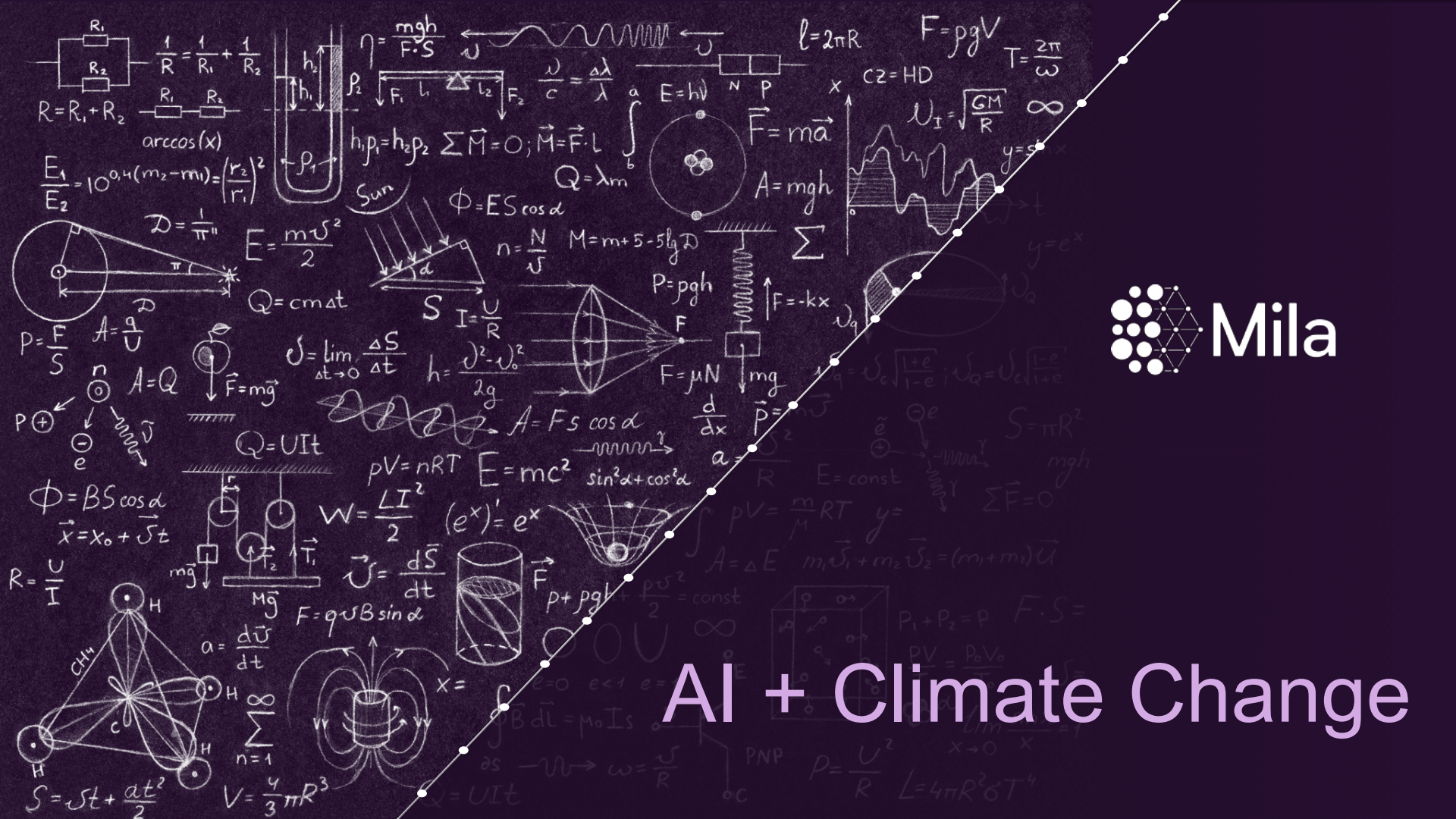
	4°C	3°C	2°C
World total	-23,149.18	-9,593.71	-5,659.47
United Kingdom	17.78	4.06	0.35
Germany	23.85	5.38	2.46
France	26.92	7.11	1.80
Italy	32.42	12.20	7.26
Canada	45.29	11.40	5.20
Rest of EU25	64.19	18.47	9.68



Psychological Factors

- Out of sight, out of mind
- Far away in space (the catastrophes are always somewhere else)
- Far away in time
- Concepts are abstract
- Humans suffer from **cognitive biases** that are well-known: we underestimate the stakes!
- It is hard to compete with short-term economic issues
- Information bubbles/biases





AI + Climate Change

Tackling Climate Change with Machine Learning

David Rolnick^{1*}, Priya L. Donti², Lynn H. Kaack³, Kelly Kochanski⁴, Alexandre Lacoste⁵,
Kris Sankaran^{6,7}, Andrew Slavin Ross⁸, Nikola Milojevic-Dupont^{9,10}, Natasha Jaques¹¹,
Anna Waldman-Brown¹¹, Alexandra Luccioni^{6,7}, Tegan Maharaj^{6,7}, Evan D. Sherwin²,
S. Karthik Mukkavilli^{6,7}, Konrad P. Kording¹, Carla Gomes¹², Andrew Y. Ng¹³,
Demis Hassabis¹⁴, John C. Platt¹⁵, Felix Creutzig^{9,10}, Jennifer Chayes¹⁶, Yoshua Bengio^{6,7}

¹University of Pennsylvania, ²Carnegie Mellon University, ³ETH Zürich, ⁴University of Colorado Boulder,

⁵Element AI, ⁶Mila, ⁷Université de Montréal, ⁸Harvard University,

⁹Mercator Research Institute on Global Commons and Climate Change, ¹⁰Technische Universität Berlin,

¹¹Massachusetts Institute of Technology, ¹²Cornell University, ¹³Stanford University,

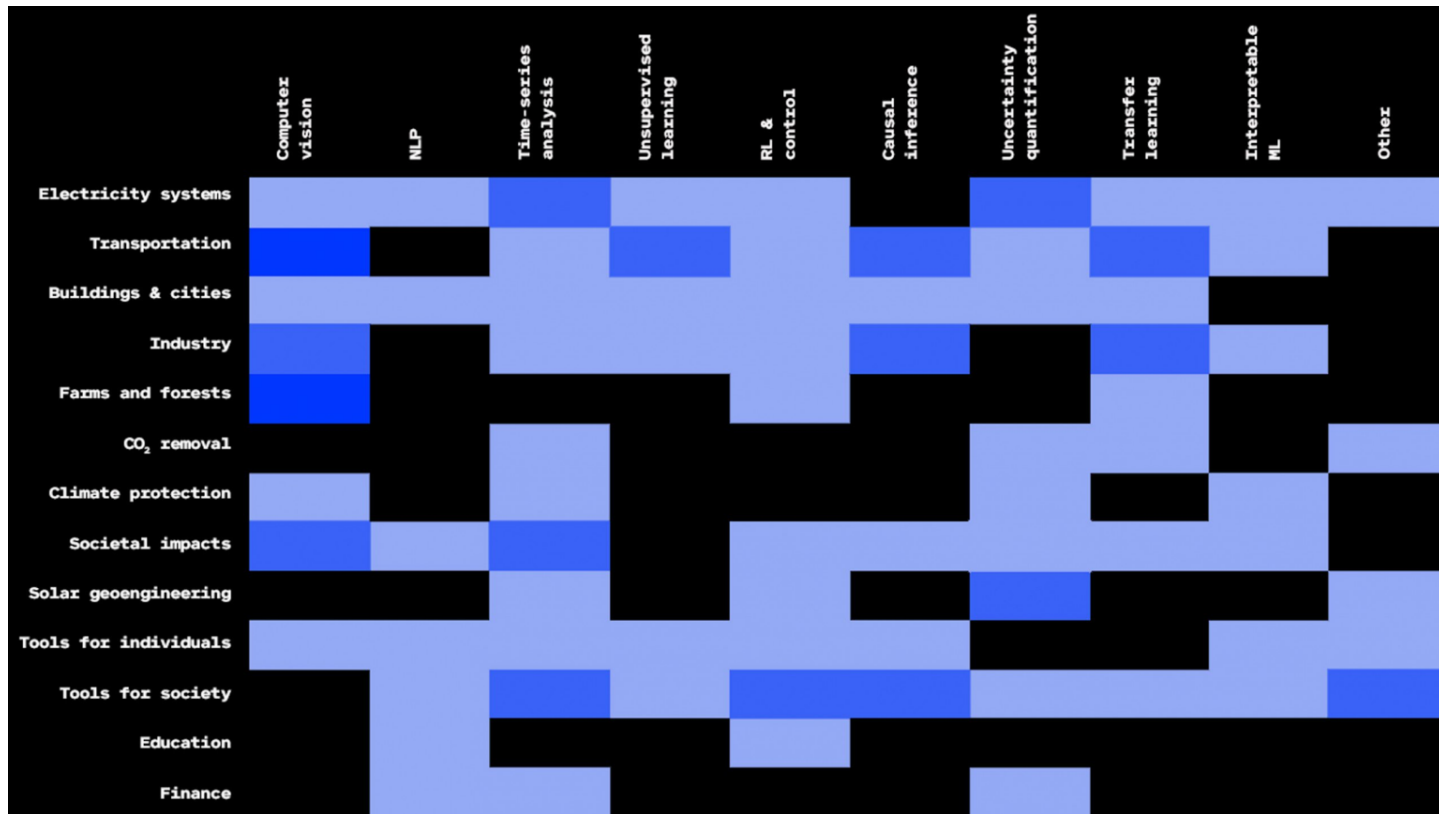
¹⁴DeepMind, ¹⁵Google AI, ¹⁶Microsoft Research



Mila

A menu for action:

www.climatechange.ai



A menu for action:

www.climatechange.ai

Find a section of
our paper
describing
change- related
problems

Find an AI
topic you're
interested in /
working on

	Computer vision	NLP	Time-series analysis	Unsupervised learning	RL & control	Causal inference	Uncertainty quantification	Transfer learning	Interpretable ML	Other
Electricity systems	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Transportation	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Buildings & cities	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Industry	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Farms and forests	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
CO ₂ removal	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Climate protection	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Societal impacts	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Solar geoengineering	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Tools for individuals	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Tools for society	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Education	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black
Finance	Blue	Black	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Black

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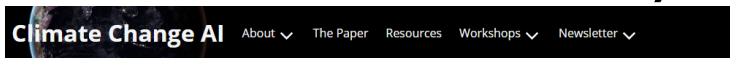
	Computer vision	NLP	Time-series analysis	Unsupervised learning	RL & control	Causal inference	Uncertainty quantification	Transfer learning	Interpretable ML	Other
Electricity systems										
Transportation										
Buildings & cities										
Industry										
Farms and forests										
CO ₂ removal										
Climate protection										
Societal impacts										
Solar geoengineering										
Tools for individuals										
Tools for society										
Education										
Finance										

Look for an intersection,
and read that section of our
paper!

Resources

(readings, datasets, tools, and more)

www.climatechange.ai



Resources

This page presents some readings, datasets, and tools for the areas outlined in our paper, “Tackling Climate Change with Machine Learning.” These resources include general references about climate change, as well as resources organized by section of the paper.

If you find that we are missing some important resources, please submit them through [this form](#)!

+ 0. General
+ 1. Electricity Systems
+ 2. Transportation
+ 3. Buildings and Cities
+ 4. Industry
+ 5. Farms and Forests
+ 6. CO2 Removal
+ 7. Climate Prediction
+ 8. Societal Impacts
+ 9. Solar Geoengineering
+ 10. Tools for Individuals
+ 11. Tools for Society
+ 12. Education
+ 13. Finance

Resources (readings, datasets, tools, and more)

General

e.g. :

- [Public Utility Data Liberation \(PUDL\) Project](#)
- US independent system operators/regional transmission organizations (ISOs/RTOs):
[CAISO](#), [ERCOT](#), [ISO-NE](#), [MISO](#), [NYISO](#), [PJM](#), and [SPP](#)

Variable Generation and Demand Forecasting

- [Global Energy Forecasting Competition](#)
- [SubseasonalRodeo](#)
- [American Meteorological Society 2013-2014 Solar Energy Prediction Contest](#)

Accelerated Science for Materials

- [The Materials Project](#)
- [Inorganic Crystal Structure Database](#)
- [SciFinder](#) (paid)
- [UCI Machine Learning Repository datasets](#), e.g. “Concrete Compressive Strength”

Reducing Life-cycle Fossil Fuel Emissions

- [Global methane data](#)
- *Also see satellite imagery listings under [low-data settings](#)*

Applying AI to problems of Climate Change

Tools for Individuals

- Individual and household consumption optimization
 - ML can provide predictive tools and decision support
- Bias and individual behaviour change
 - e.g. using NLP for identifying bias in text, or helping users assess their own biases using chatbots

Tools for Society

- Modeling collective behaviour
 - Game theory, mechanism design, multi-agent RL
- Managing tradeoffs
 - Operations research, multi-criteria optimization
- Markets and pricing (e.g. dynamic pricing of renewables)

Applying AI to problems of Climate Change

Education

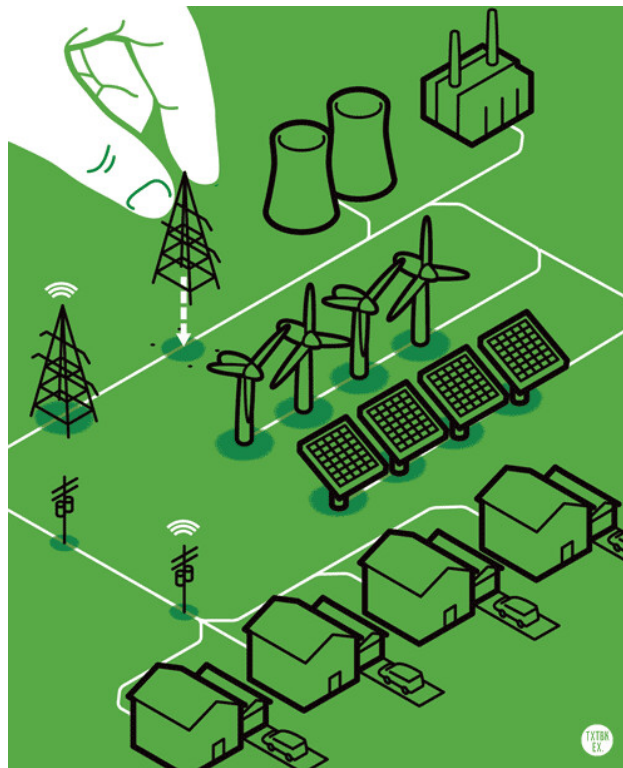
- Analysis of learning
 - What do people understand about information when it is presented to them?
- Intelligent tutoring systems

Finance

- Carbon markets and carbon pricing
- Identifying climate-related investment opportunities
- Auditing sustainability / carbon neutrality

Applying AI to problems of Climate Change

- **Optimizing energy resources**
 - **Predicting output** from variable sources (solar, wind, hydro)
 - **Estimating generated GHG** to tax them and incite individuals and markets to change
 - **Predict electricity demand to**
 - optimize **distribution** to respond to fluctuating demand
 - optimize **price** to reduce consumption
 - Minimize **losses** and **costs** of transportation



Applying AI to problems of Climate Change

- **Transportation:** predict demand (roads & public transport), improve urban infrastructure
- **Construction:** reduce electrical consumption of buildings
- **Industry:** optimize supply chains, maritime transport routes, waiting times



Applying AI to problems of Climate Change

Farms and forests

- Farms:
 - Real-time maps of Green House Gases emissions
 - Precision agriculture
- Forests:
 - Tracking deforestation
 - Automating afforestation



Buildings

- Smart buildings:
 - tracking occupation, heating, lights
- Urban planning:
 - to optimize travel routes



Applying AI to problems of Climate Change

CO2 Removal

- Direct air capture
 - ML can help the materials discovery process
- Sequestration
 - identify and characterize potential locations
 - monitor and maintain active sites



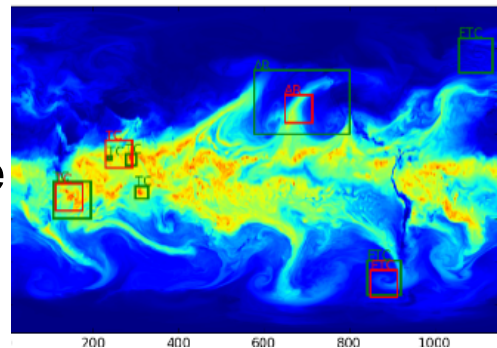
Solar Geoengineering

- ML can help by:
 - modeling aerosols
 - defining objectives and targets

Applying AI to problems of Climate Change

Climate modeling & prediction

- “Downscaling” (linking models at different scales)
 - e.g. between a physics-based climate ensemble model and daily weather reports
- Identifying extreme weather events etc.
 - Very similar to object detection in images/video



Societal impacts

- Disaster prediction and response
- Adaptation and mitigation
 - e.g. modeling effects of climate change on cities/infrastructure
- Computational sustainability
 - optimizing resource use to support life long-term



Mila

CC Projects at Mila

HighRes-net

MFSR by Recursive Fusion

ELEMENT^{AI}



Michel Deudon (& deer)



Freddie Kalaitzis



Julien Cornebise



Zhichao Lin

Md Rifat Arefin



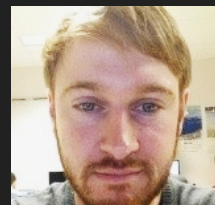
Israel Goytom



Kris Sankaran



Samira E. Kahou



Vincent Michalski



Yoshua Bengio



Low-resolution



Single Image Super-Resolution



High-res

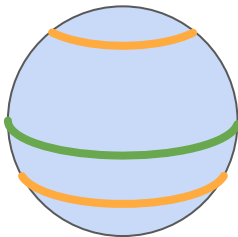
Low-res public satellites

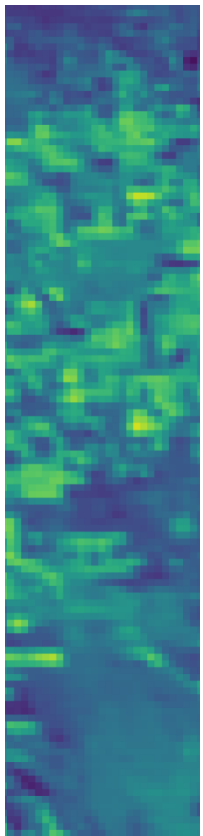
- Sentinel 2 10 m
- Landsat 30 - 15 m
- PROBA-V 300 - 100 m

\$ cheap / free

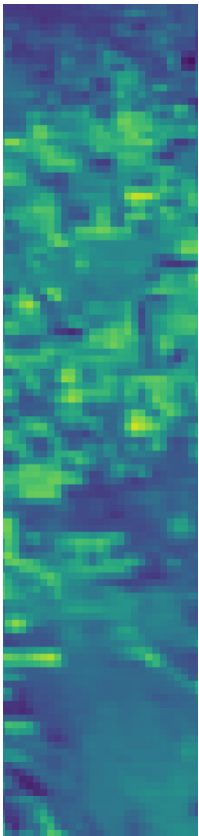
↪ high revisit frequency

PROBA-V
2-daily
coverage



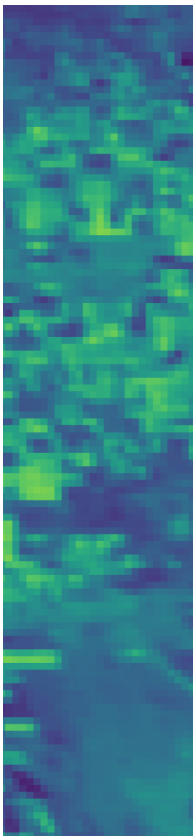


Low-res 1



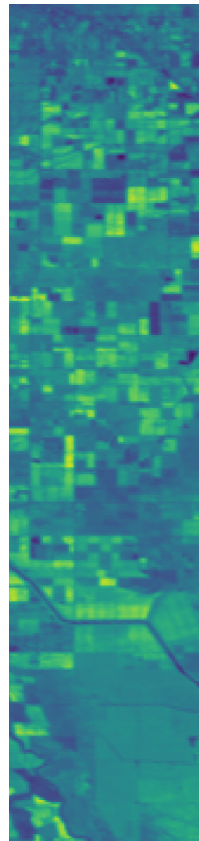
Low-res 2

...

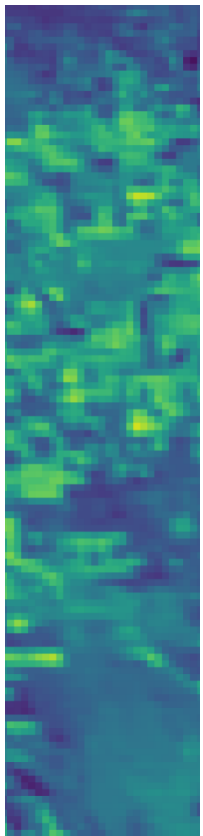


Low-res 9

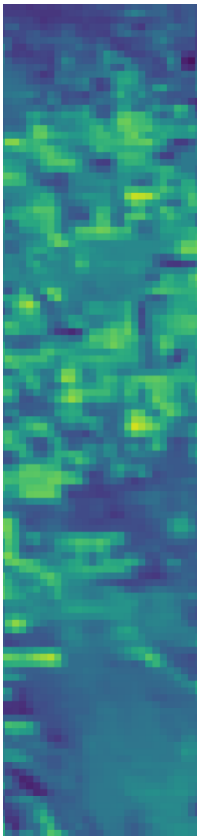
Super-res



High-res

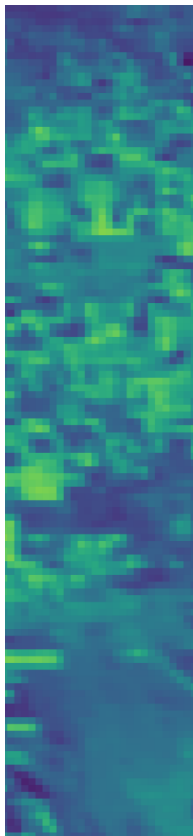


Low-res 1

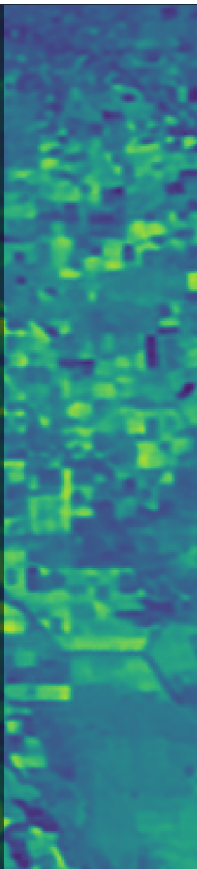
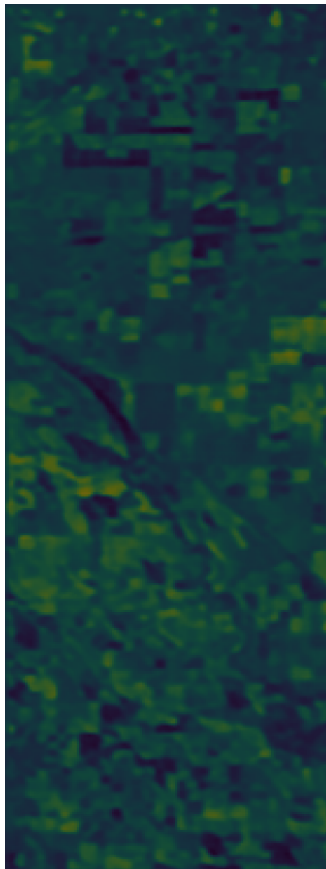


Low-res 2

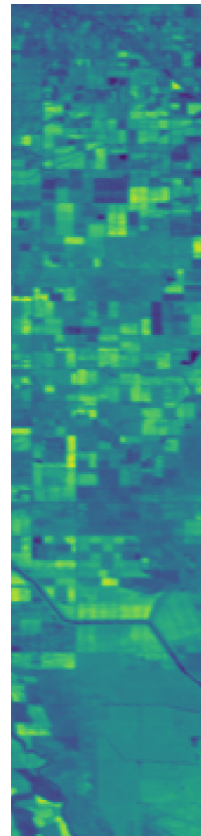
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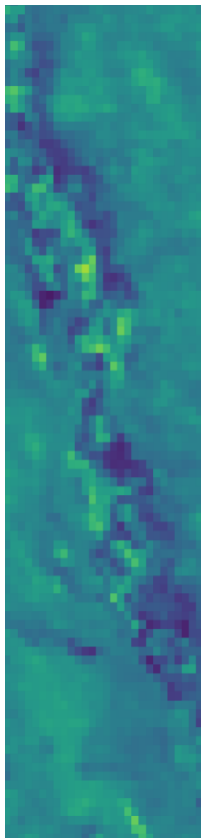
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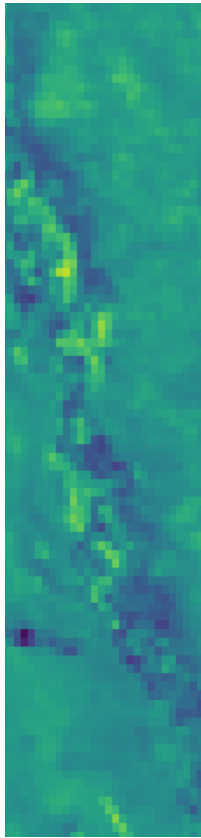
Super-res



High-res

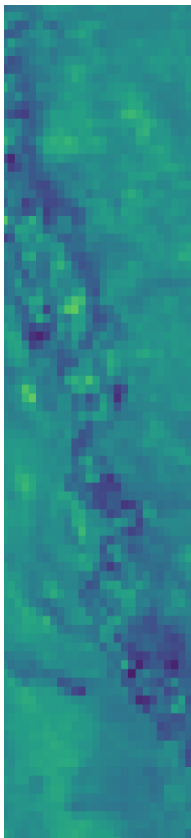


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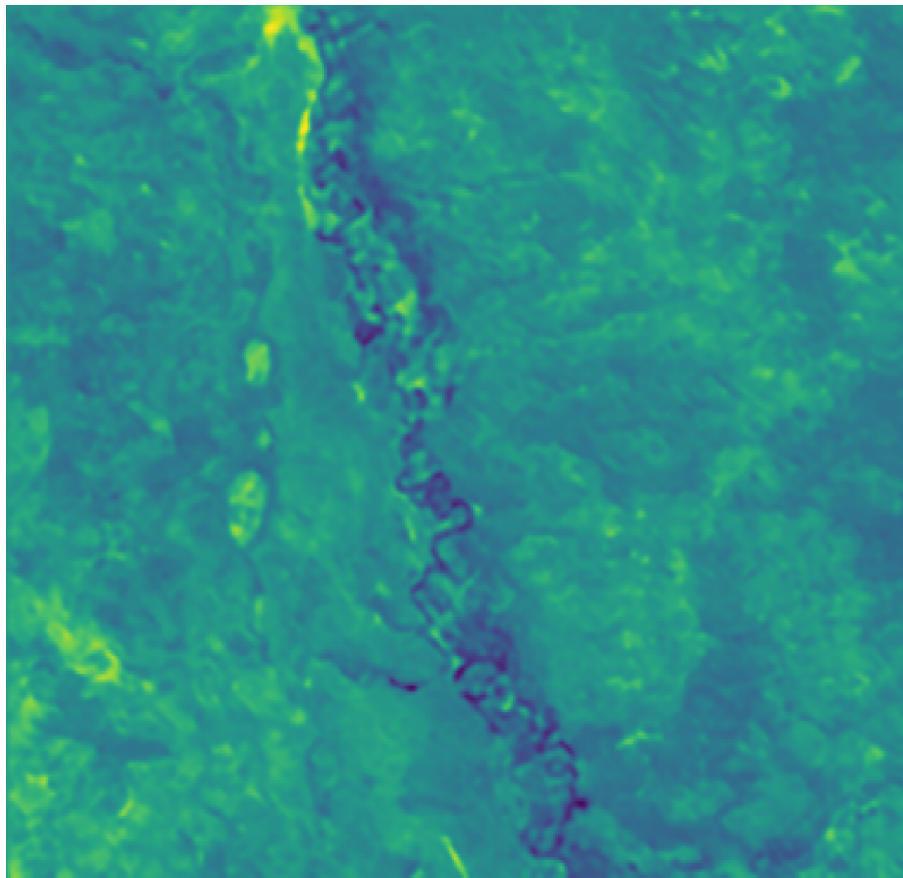


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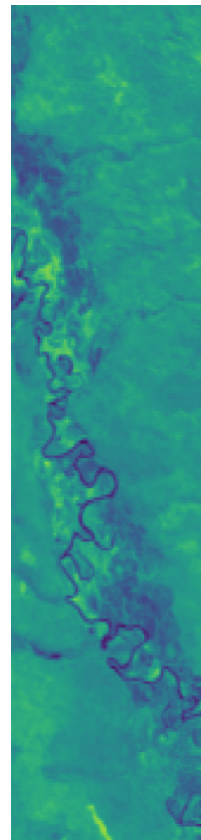
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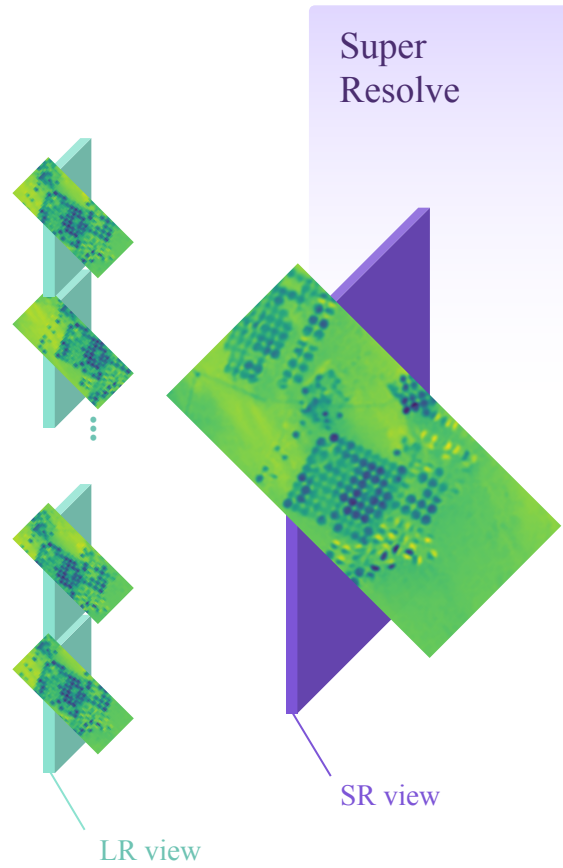
Low-res 9



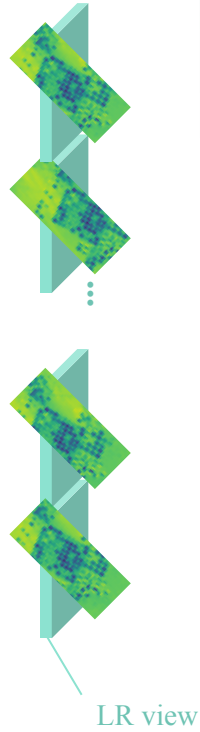
Super-res



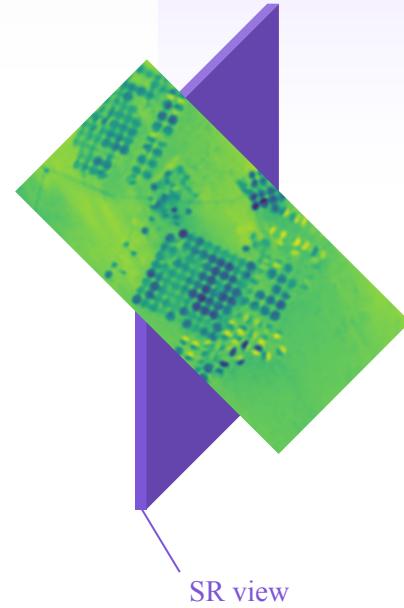
High-res



HighRes-net

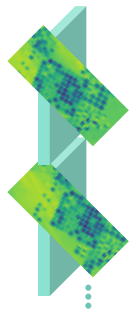


Super
Resolve



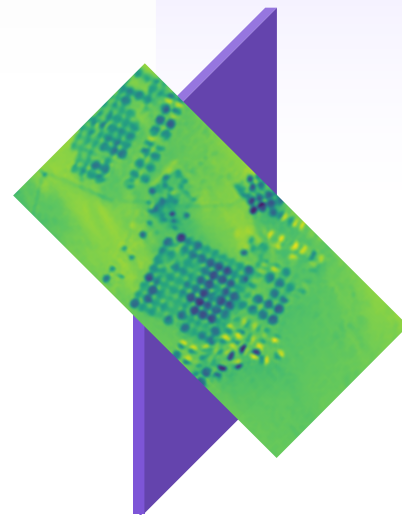
HighRes-net

Encode



LR view

Super
Resolve



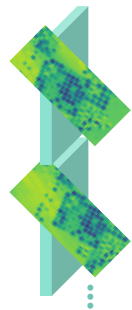
SR view

HighRes-net

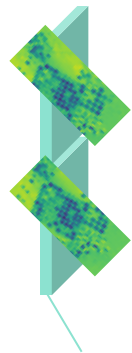
Encode

Decode

Super
Resolve



...



LR view



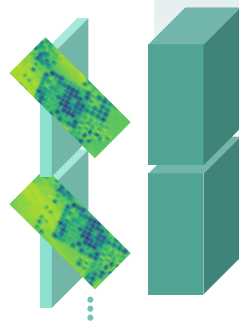
SR view

HighRes-net

Encode

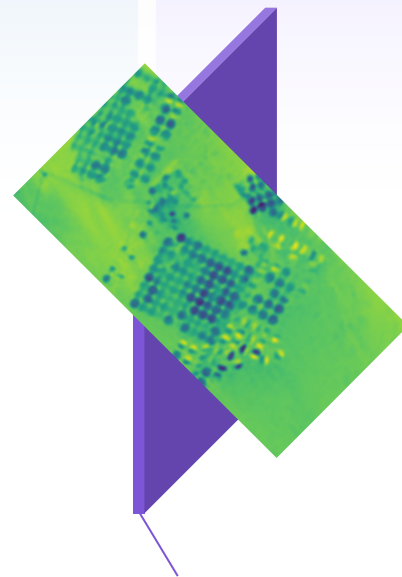
Decode

Super
Resolve



LR view

LR encoding



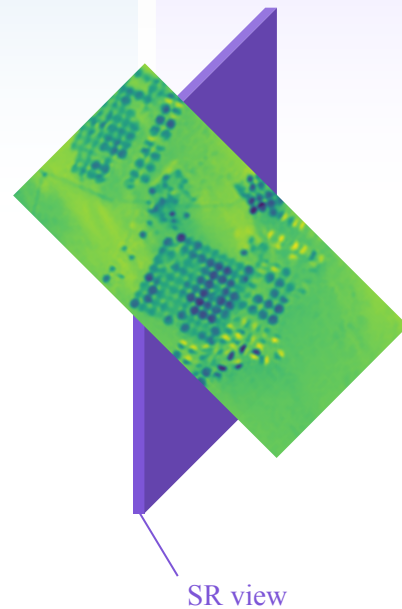
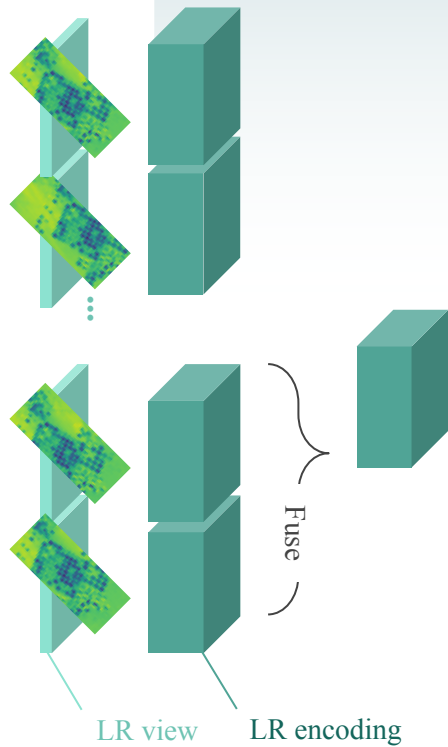
SR view

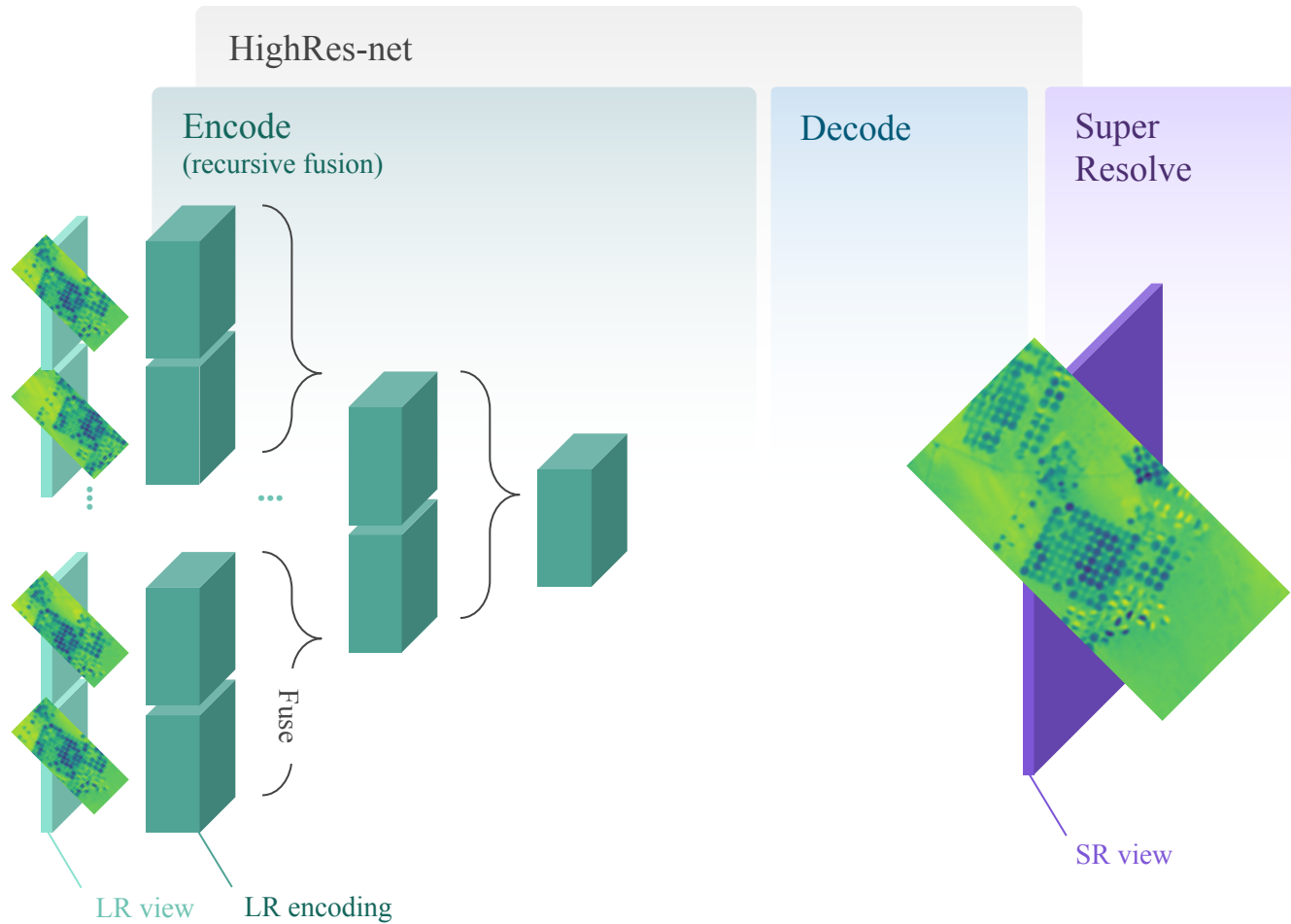
HighRes-net

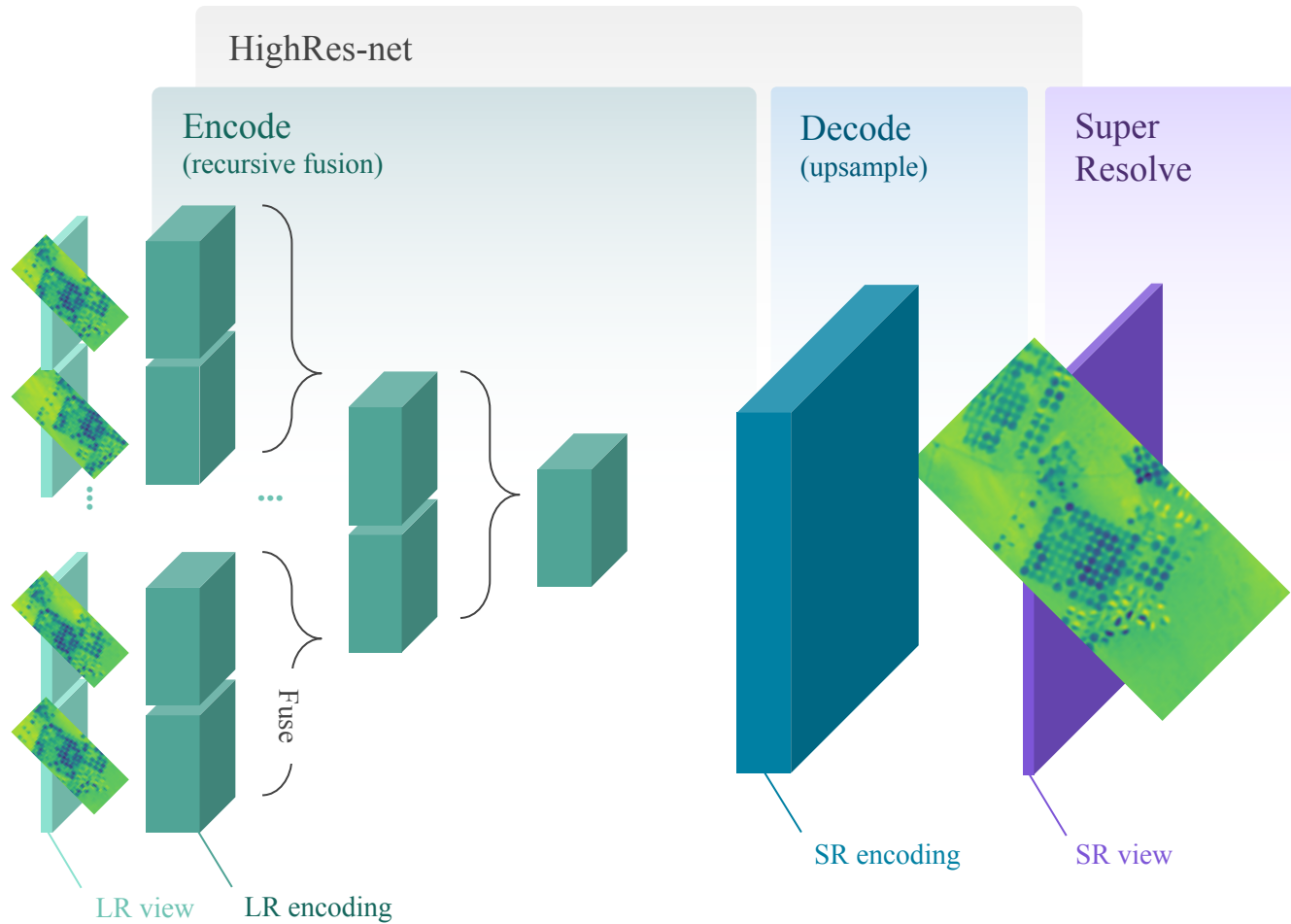
Encode
(recursive fusion)

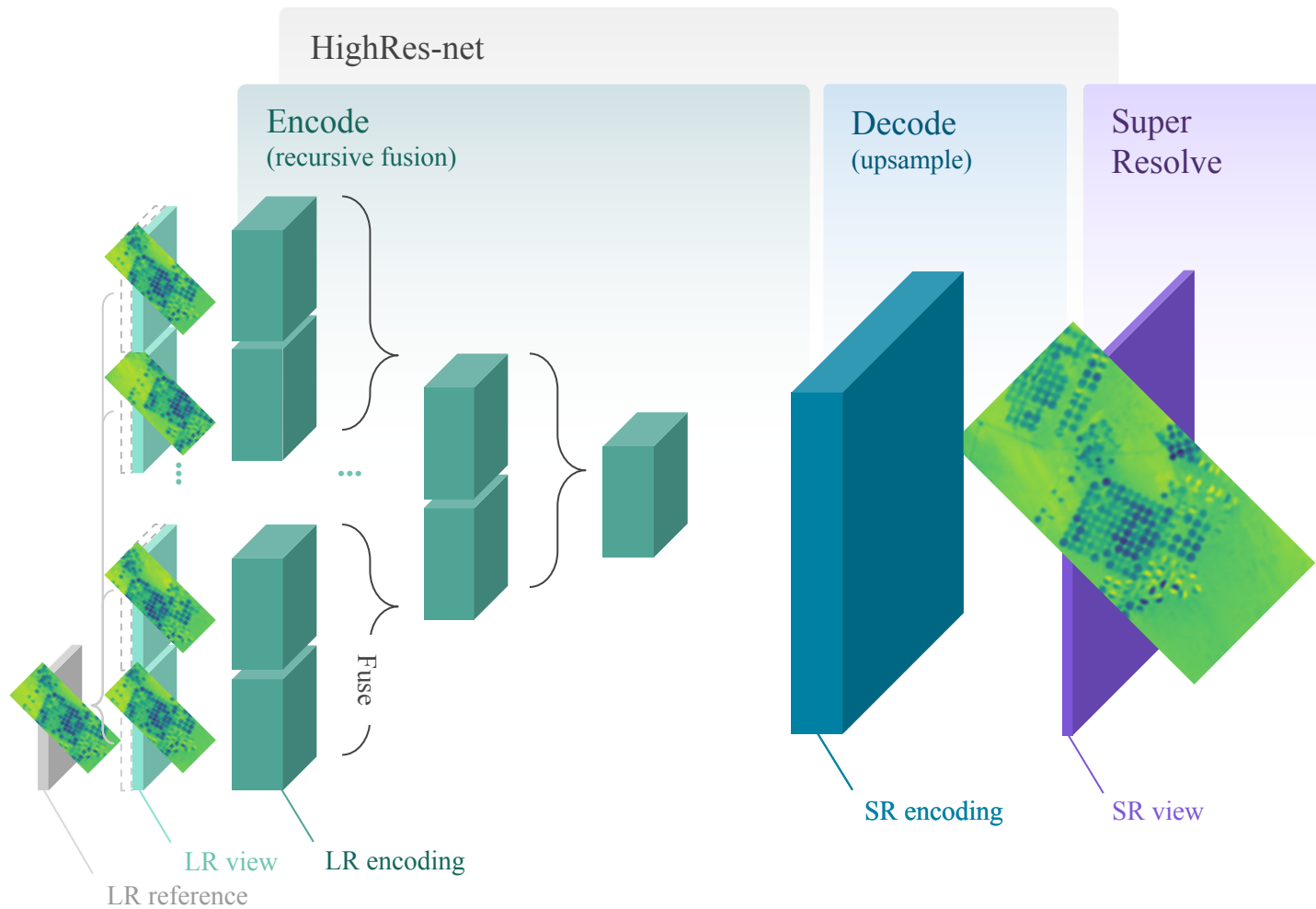
Decode

Super
Resolve

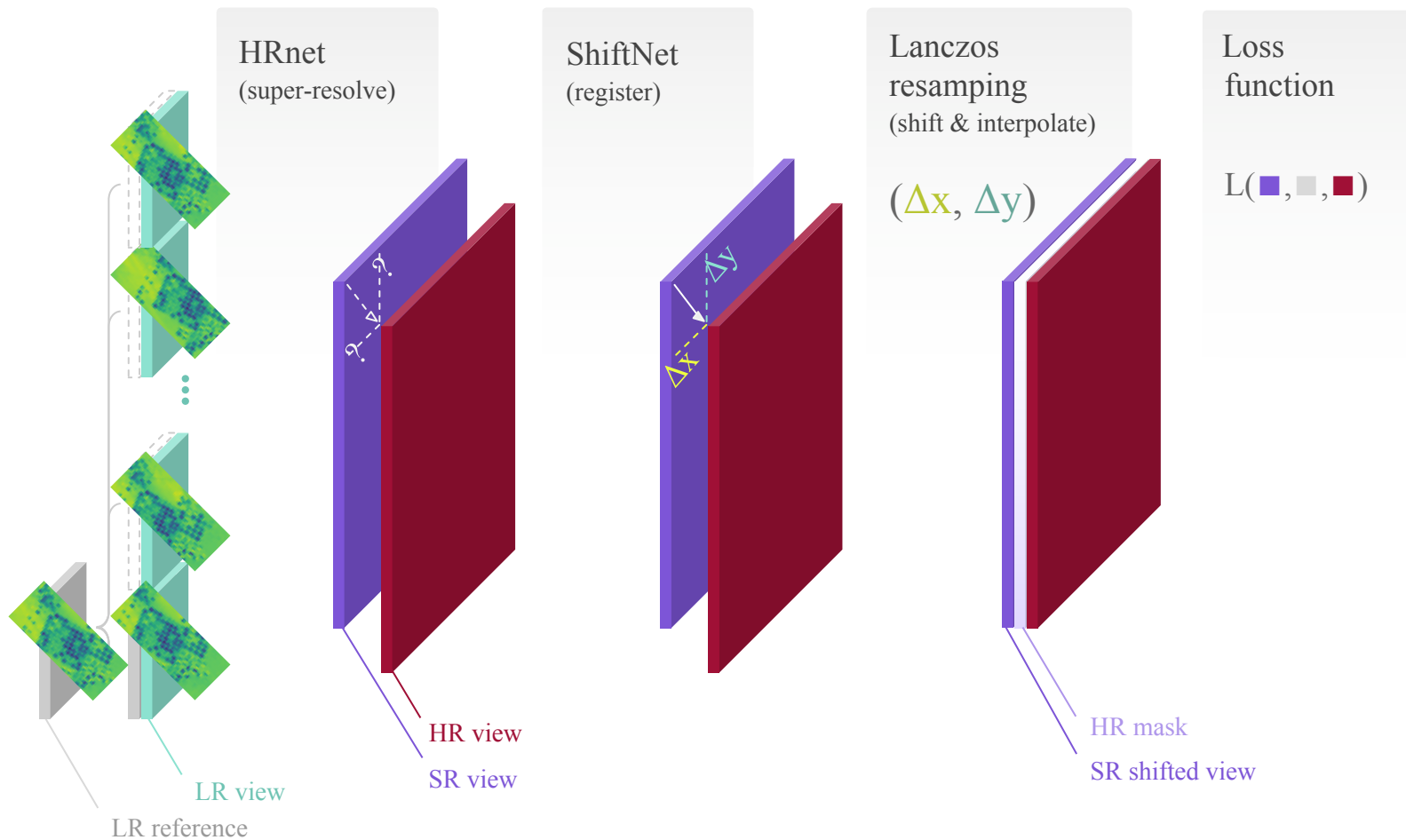








End-to-end training



ESA Super-Resolution challenge

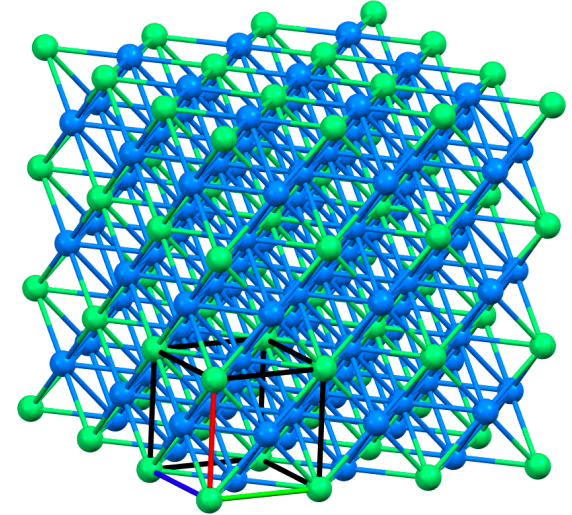
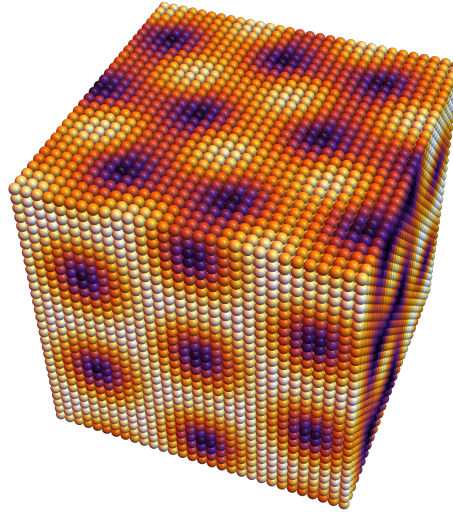
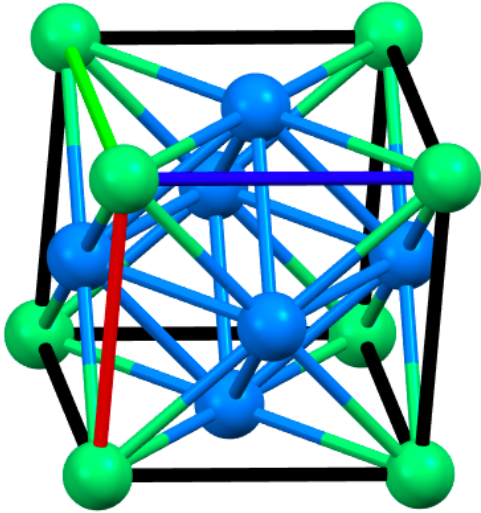
Results

Name	Final Score
SuperPip	0.9474466476281652
rarefin	0.9477450367529225
ledzeppelin	0.9576339586408439
luis	0.9626599626701344
PIC4SeR	0.9721971077481462
EscVM	0.9785367146826757
SuperDeep	0.9807595119230784

Leaderboard

Name	Submissions	Best Score
rarefin	46	0.947388637793901
SuperPip	43	0.948844910272775
ledzeppelin	86	0.955016888143629
luis	9	0.964599100320855
PIC4SeR	15	0.971175807378147
EscVM	20	0.976616253152054
SuperDeep	38	0.981791472111074

Synthesizing New Materials for Batteries using Deep Generative Models

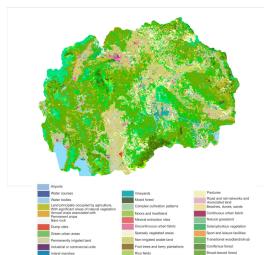


Mila projects combining physics, chemistry and AI

Societal Impacts of Climate Change

ML has a great potential to support societal adaptation

1. Identifying and prioritizing the areas of highest risk, by using evidence of risk from historical data.
2. Providing annotation: Extracting actionable information or labels from unstructured raw data.
3. Promoting exchange: Making it easier to share resources and information to pool and reduce risk.

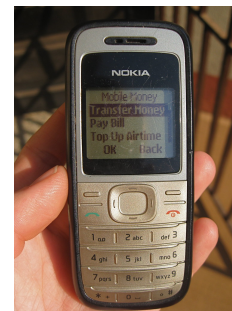


Free text lines: 19
Serious Metadata
Structure Names
Shunts, Cleared
Referred Tickets
Cable Sizes

Kickstart: H000016965
Line: 28
Emergency: SORRILE IS SHOUTING VERY BAD
05/18/00 04:10 NOELBROWN DISPATCHED BY 05198
05/18/00 04:10 NOELBROWN ARRIVED BY 05198
05/18/00 04:35 LANNON WITTON-HALL BOX P/O 119 SOUTH ST.
DUE TO HEAVY FISH MARKET TRAFFIC...BOX SHUTTING LIGHTS...
STRUCTURE ON HANDING AT THIS TIME...WILL HAVE ACCESS TO BOX
05/18/00 04:40 HSE...
05/18/00 05:19 HSE...
05/18/00 05:19 HSE...
CO = 0 PER 05/18/00 05:19 HSE...
CG = 0 L OE = 2.0 L

05/21/00 09:50 NICHOLSON REPORTS FISH COMPLETE
CLOSING 8:05 P TO 8:10:00 P/O 119 SOUTH ST. BY 58101
05/21/00 11:00 NICHOLSON REPORTS ALL 8:00 P CLEARED
18 18-00000 P/O 119 SOUTH ST. - JOB COMPLETE .. PM
05/21/00 11:00 NICHOLSON REPORTS FISH COMPLETE BY 58101
*****ELLEN REPORT MADE OUT*****
SEE TICKET H000016967

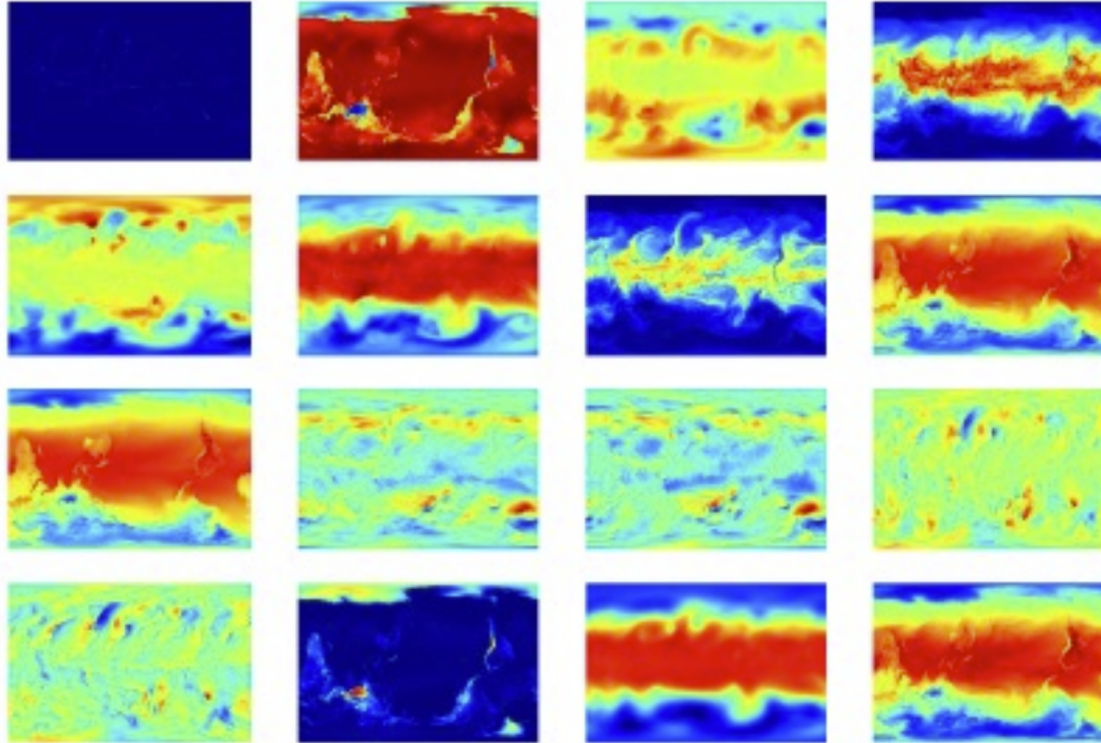
06/23/00 18:17 VETH REPORTS IN 18-13630 N/E/C PRINCE ST &
NORTH ST FOUND 2-40 & 2-500,3-200 BLOWN OUT OF SOUTH DUCT
CUT FOR REPLACEMENT P-10L425F AND 2-10L200L 1 JONHEUT 1"
2" FROM 18-13630 N/E/C PRINCE ST & MERCEDES ST TO 18-14030



Using NLP to detect misinformation in media coverage of climate change

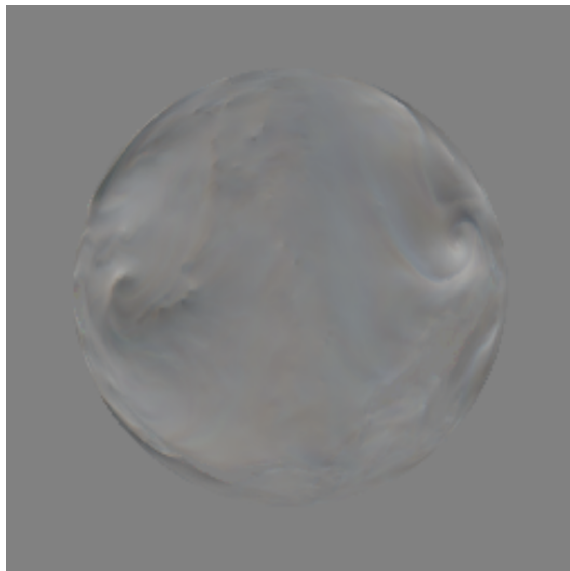
Term	Left-wing Articles	Right-wing Articles
global_warming	human_activity (0.76)	climate_change (0.91)
	climate_crisis (0.75)	catastrophic_
	ACD (0.69)	unprecedented (0.80)
	man_made (0.68)	claim (0.75)
	scientific_	man_made (0.74)
	community (0.67)	warming_AGW (0.72)
	climate_	sublime (0.69)
	scientists (0.67)	Ehrlichs (0.68)
	scientific_	catastrophic (0.68)
	consensus (0.66)	groundless (0.66)
	human_activities (0.66)	scientists_agree (0.66)

Predicting Extreme Weather Events

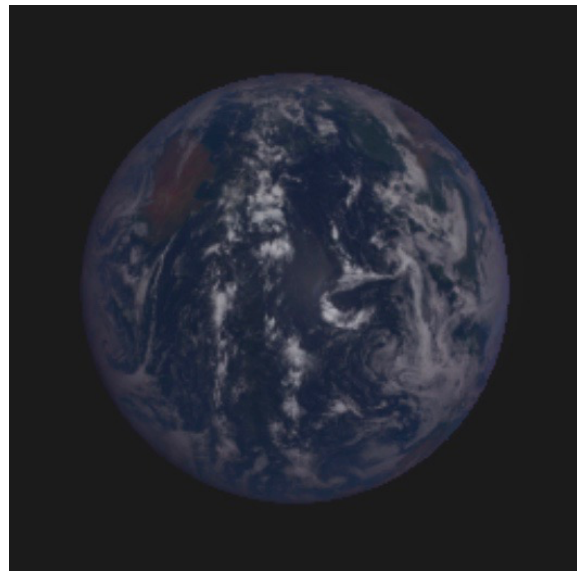


*Mila points of contact:
Evan Racah, Christopher
Beckham, Tegan Maharaj,
Samira Ebrahimi Kahou,
Chris Pal*

Cloud Distribution Prediction using GANs



Location, temperature, winds, humidity, reflectance



Image

*Mila points of contact: Victor Schmidt,
Mustafa Alghali, Kris Sankaran*

Measuring the Climate Emissions of ML



The screenshot shows the ML CO2 Impact website. At the top left is the logo "ML CO2 Impact". At the top right are navigation links: "Compute", "Act", "Learn", and "About". The main heading "ML CO2 IMPACT" is centered in large white letters. Below it is the text "Machine Learning has an impact on Climate. But not all models are born equal." A red button labeled "COMPUTE YOUR MODEL'S IMPACT" is centered below the text. At the bottom, there are four input fields: "Hardware type" (dropdown menu showing "RTX 2080 Ti"), "Hours Used" (text input showing "3"), "Cloud Provider" (dropdown menu showing "Azure"), and "Region of Compute" (dropdown menu showing "Central US"). A red "COMPUTE" button is centered below these fields.

ML CO2 Impact

Compute Act Learn About

ML CO2 IMPACT

Machine Learning has an impact on Climate.
But not all models are born equal.

COMPUTE YOUR MODEL'S IMPACT

Hardware type
RTX 2080 Ti

Hours Used
3

Cloud Provider
Azure

Region of Compute
Central US

COMPUTE



+ Alex Lacoste (Element AI)

Mila point of contact: Victor Schmidt, Sasha Luccioni

<https://mlco2.github.io/impact>

Personalized Visualization of the Impact of Climate Change



- Allow people to **educate** themselves about the effects of climate change
- Do it in a **personalized** and **visual** way, to minimize cognitive biases
- Be **positive**: show that we can make the changes in time, by visualizing the impact of today's choices, such as the price of carbon
- Be **rigorous** and **scientific**, based on the most accurate climate models
- First prototype: a **website** that visualizes your home in 50 or 100 years, with the effect of floods, whose probabilities are calculated based on climate models

Personalized Visualization of the Impact of Climate Change



*Mila point of contact: VICC team
(Yoshua, Sasha, Karthik, Vahe,
Victor, Gautier, Melisande...)*

Prospective Projects



- Recognition of objects, rivers, plant cover, good conditions for planting trees in satellite imagery and aerial photographs, tree-planting drones
- Applying ML to mechanism/incentive design for policy research
- Using NLP to analyze climate disclosures
- Transfer learning for recognizing extreme weather events in weather data



Mila

Takeaway messages

Takeaway Messages

- Machine learning, like all technology, does not always make the world a better place – **but it can.**
- How you can get involved:
 - **Learn:** Identify how your skills may be useful (e.g. “*Tackling Climate Change with Machine Learning*” paper)
 - **Collaborate:** Find collaborators, who may be researchers, entrepreneurs, established companies, or policy-makers.
 - **Listen:** Listen to what your collaborators say is needed, and gather input more broadly as well to make sure your work will have the desired impact.
 - **Deploy:** Ensure that your work is deployed where its impact can be realized.

Half a million citizens at the Climat March in Montreal last Friday Sept 27th, 2019.

