

# ML4CC: Lecture 5

Sit with your **new** discussion groups (1-10 left to right)!

# Assignments reminder

Keep doing your weekly PMIRO+Q

Your second coding assignment is due **Feb 27** before the start of class.

# Recap of previous paper

P: Want to track glacier melting rate

M: Train a U-net to segment satellite images of glaciers and compare sizes over time

I: Fully automated method applied to the Alps, specific outlier filtering

R: Model has balanced, high performance in terms of precision and recall and can be used to measure glacier melt

O: Need to capture small glaciers, unclear if it will generalize to other glacier locations

# Climate Change in the News

ADMINISTRATION

## OPM directs agencies to fire government workers still on probation

BY REBECCA BEITSCH - 02/13/25 4:58 PM ET



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Office of Personnel Management (OPM) officials met with agency leaders across government Thursday and directed them to begin firing employees still in their probationary period a year or more after being hired.

Federal employees remain on probation anywhere from one to two years after being hired, depending on their agency, a status that still comes with workplace protections but makes them easier to remove.

The move could impact as many as 200,000 federal employees.

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The U.S. National Science Foundation Division of Earth Sciences (EAR) advances research on the structure, composition and evolution of the planet.

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- Geologic hazards like earthquakes, volcanic eruptions, floods and landslides.
- The structure and physics of the solid Earth, from its core to the lithosphere.
- The underlying mechanisms or controls on the Earth's near-surface environment and how that environment responds to change.
- How the Earth evolved, from its original form to today.
- The patterns and processes relating to the origin and evolution of Earth's climate, environments, life and sedimentary record.



Margaret Fraiser

@margaretfraiser.bsky.social

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Please let the GEO/EAR community know: Program Directors and Mission Support who've been at NSF under two years were just terminated via Zoom. Even those of us whose offer letter stated one probationary year and whose government data states "permanent".

February 18, 2025 at 10:31 AM Everybody can reply

# Climate Change in the News

🏠 > Green > Green News

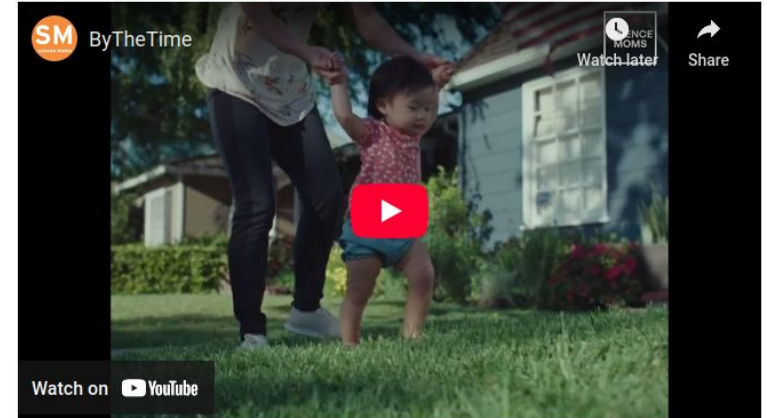
## 'Science Moms': The Super Bowl ad urging climate action for the next generation



### Encouraging climate action through love

A spokesperson told advertising trade publication Adweek that the advert was a “product of extensive research” into what message would have the biggest impact on the greatest number of people.

“Do you know what science shows is the top reason people care about climate change?” Dr Hayhoe asked in a post about the ad on LinkedIn. “LOVE - especially for the next generation.”



While several previous ads during the big game have drawn attention to [climate change](#), these have usually come from companies with products to sell. This is the first to be created by a nonprofit group. The New York Times ranked it as one of the best ads shown during this year's Super Bowl.

# Paper 4 Discussion

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## AtmoDist: Self-supervised Representation Learning for Atmospheric Dynamics

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### Abstract

Representation learning has proven to be a powerful methodology in a wide variety of machine learning applications. For atmospheric dynamics, however, it has so far not been considered, arguably due to the lack of large-scale, labeled datasets that could be used for training. In this work, we show that the difficulty is benign and introduce a self-supervised learning task that defines a categorical loss for a wide variety of unlabeled atmospheric datasets. Specifically, we train a neural network on the simple yet intricate task of predicting the temporal distance between atmospheric fields from distinct but nearby times. We demonstrate that training with this task on ERA5 reanalysis leads to internal representations capturing intrinsic aspects of atmospheric dynamics. We do so by introducing a data-driven distance metric for atmospheric states. When employed as a loss function in other machine learning applications, this Atmodist distance leads to improved results compared to the classical  $\ell_2$ -loss. For example, for downscaling one obtains higher resolution fields that match the true statistics more closely than previous approaches and for the interpolation of missing or occluded data the AtmoDist distance leads to results that contain more realistic fine scale features. Since it is derived from observational data, AtmoDist also provides a novel perspective on atmospheric predictability.

# Attendance

Select one person from the group to go to fill out the attendance form (link in Brightspace)

# Discussion Question 1

How did you feel about this paper?



# Discussion Question 2

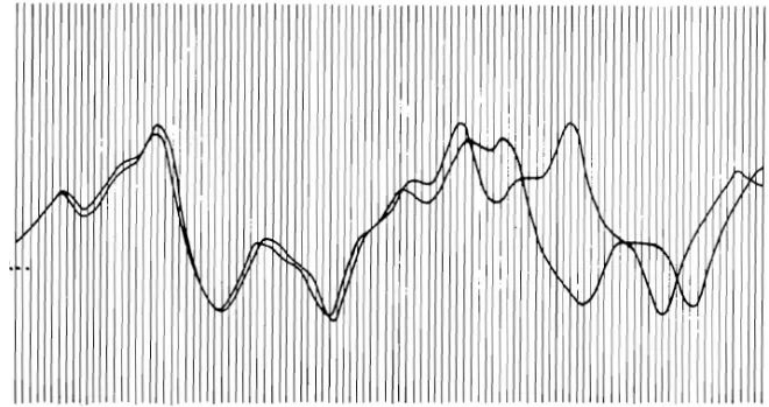
What does the highlighted sentence mean and how does it help motivate this work?

## 2.1 Geoscience

Distance measures for atmospheric states play an important role in classical weather and climate predictions. For example, ensemble methods require a well defined notion of nearby atmospheric states for their initialization. Various distance measures have therefore been proposed in the literature,

# Ensemble climate models

To provide a distribution of possible future climate states, models need to be run multiple times with different but similar starting points. “Similar” is easy to define for a single scalar value like temperature, but not for complex high-dimensional states like atmospheric dynamics



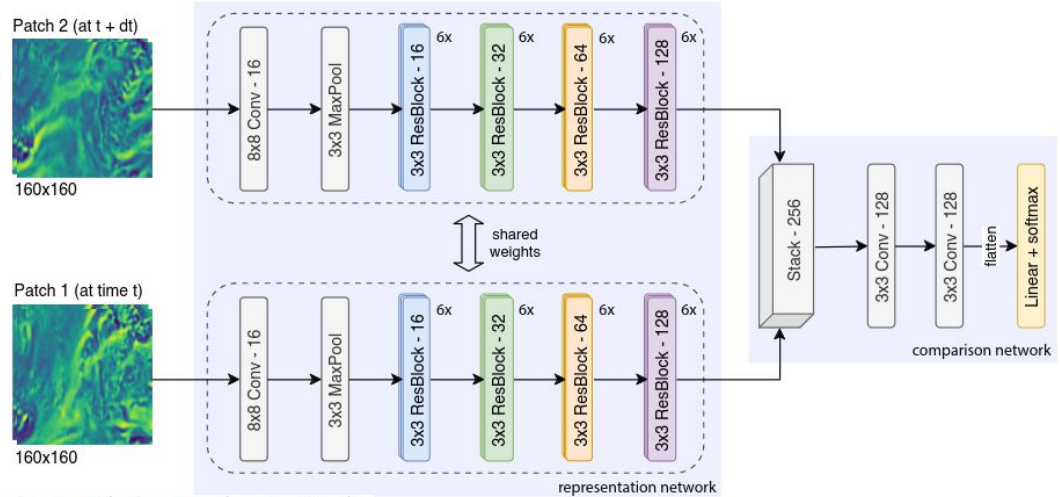
HOW TWO WEATHER PATTERNS DIVERGE. From nearly the same starting point, Edward Lorenz saw his computer weather produce patterns that grew farther and farther apart until all resemblance disappeared. (From Lorenz's 1961 printouts.)

## Discussion Question 3

What self-supervised task is the model trained on and what specific loss function does it use? Give intuition why this task helps the model learn useful representations and why the loss function is appropriate

# Pretext task: how many time points apart are these two images?

Intuition: if these two states happen close together in time they must be similar



two nearby states corresponds to an intrinsic distance between them. As a spatio-temporal pretext task for learning a distance measure for atmospheric dynamics, we thus use the prediction of the temporal separation between close-by states. More specifically, given two local patches of atmospheric states  $X_{t_1}, X_{t_2}$  centered at the same spatial location but at different, nearby times  $t_1$  and  $t_2$ , the task for the neural network is to predict their temporal separation  $\Delta t = t_2 - t_1 = n \cdot h_t$  given by a multiple of the time step  $h_t$  (3h in our case). The categorical label of a tuple  $(X_{t_1}, X_{t_2})$  of input patches, each consisting of the vorticity and divergence field at the respective time  $t_k = k \cdot h_t$  for the patch region, is thus defined as the number of time steps  $n$  in between them. Following standard methodology for classification problems, for each training item  $(X_{t_1}, X_{t_2})$ , our representation network predicts a probability distribution over the finite set of allowed values for  $n$ . Training can thus be performed with cross-entropy loss, which is known to be highly effective.

Is regular cross entropy the best loss function here? 🤔

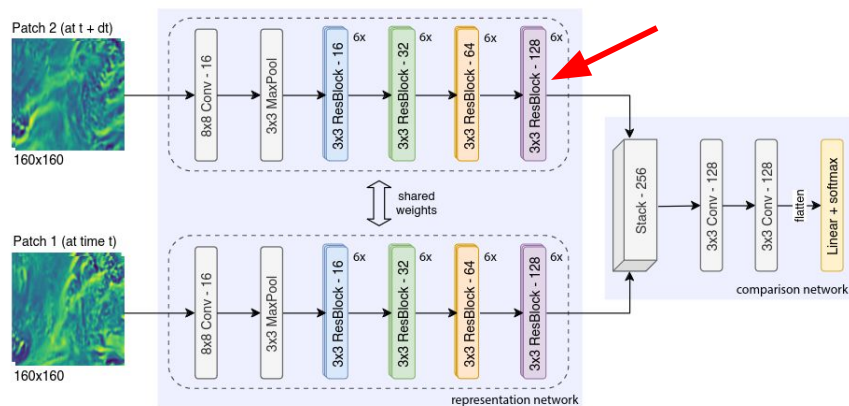
## Discussion Question 4

Which part of the model is used for the AtmoDist metric? What is the size of this representation and how does it compare to the size of the input data?

# Learned representation

AtmoDist uses the final layer of the representation network

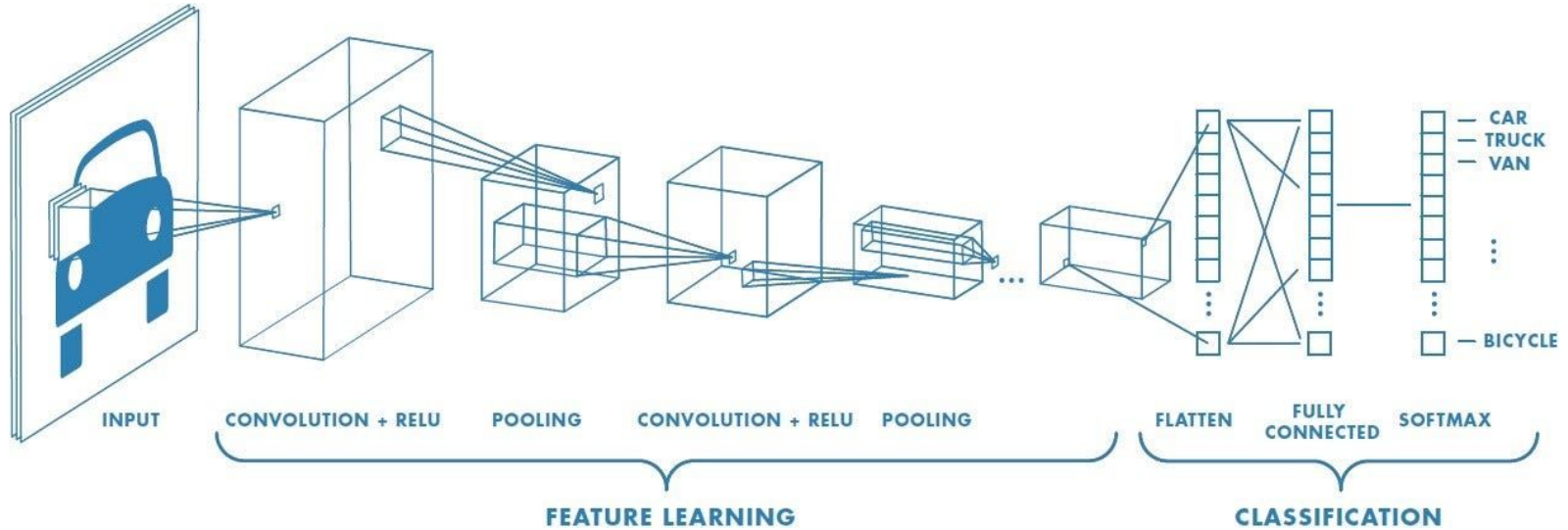
Divergence and vorticity  
plus spatial dimensions



128 features plus  
downsampled  
spatial dimensions

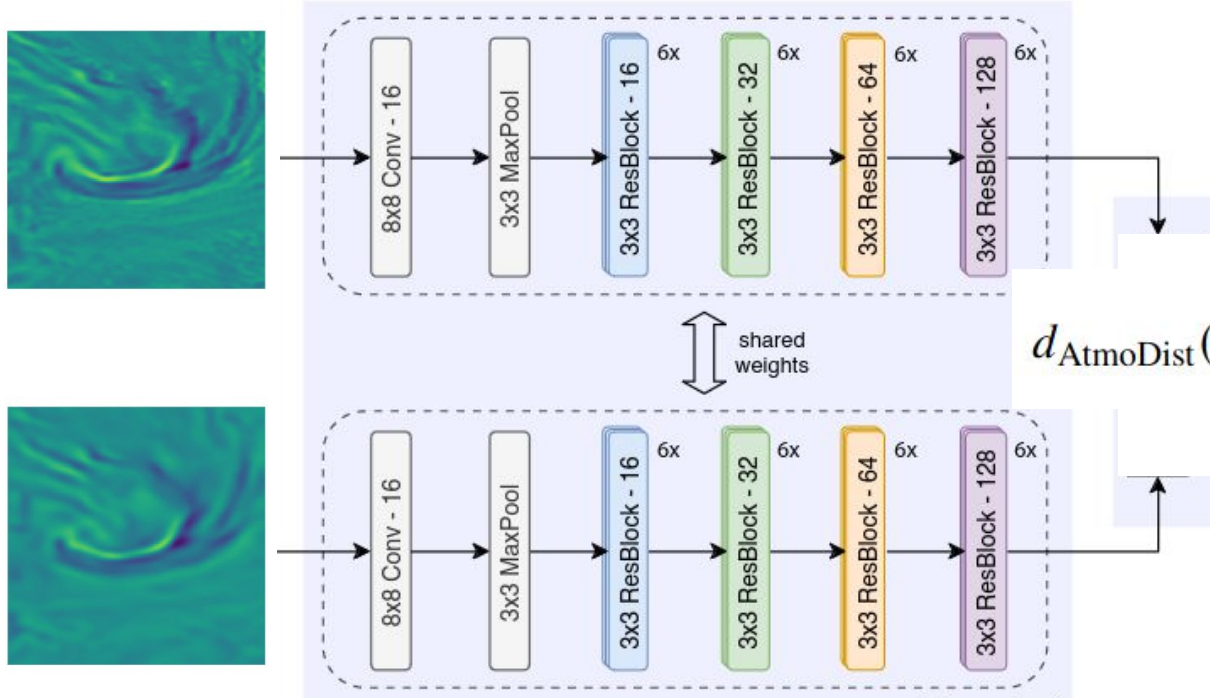
It maps an input  $X$  of size  $2 \times 160 \times 160$  to a representation vector  $\mathcal{F}(X)$  of size  $128 \times 5 \times 5$ . This corresponds to a compression rate of 16. The tail network is a simple convolutional network with a

# Convolutional neural networks



Uses convolution and pooling operations

# Distance Metric



$$d_{\text{AtmoDist}}(X_1, X_2) = \frac{1}{N} \|\mathcal{F}(X_1) - \mathcal{F}(X_2)\|^2$$



## Discussion Question 5

Explain what figure 4 is showing in your own words.

# Demonstrating superiority of AtmoDist representation

Intuitively, we would like a measure of the difference between two inputs to grow as the time difference does, and be consistent.

Their measure (AtmoDist) is better than a basic pixel-wise loss function ( $l_1$  or  $l_2$ ) according to both overall shape and variability.

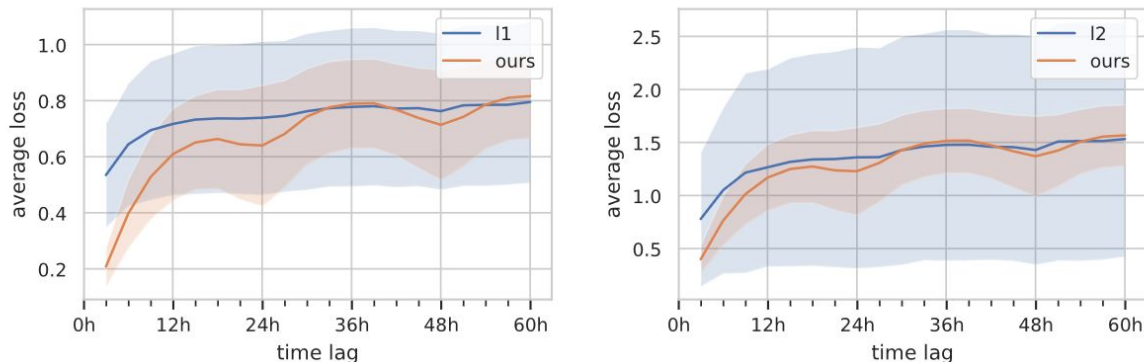


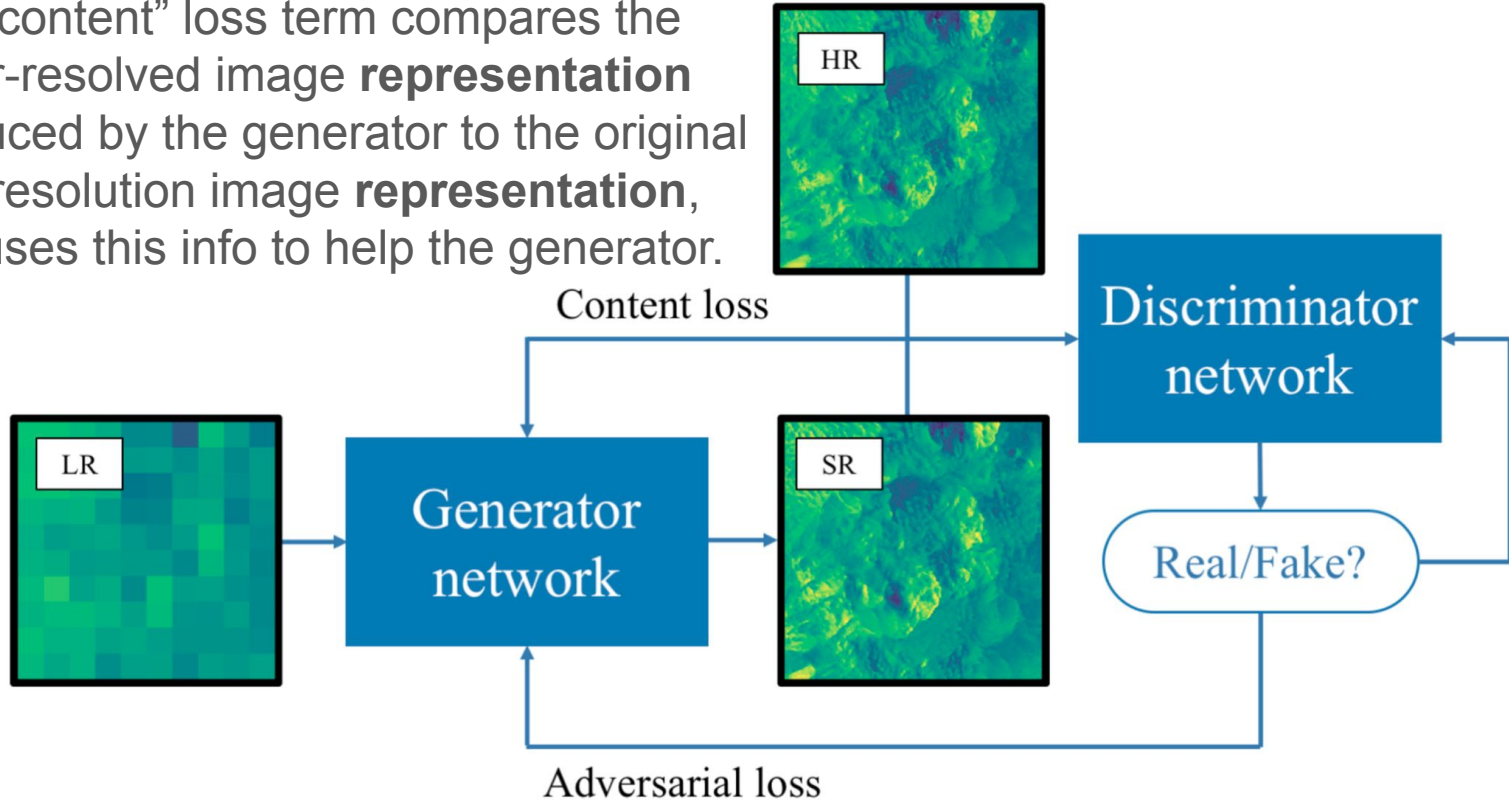
Figure 4: Mean  $l_1$ -norm (left) and mean  $l_2$ -norm (right) between samples that are a fixed time-interval apart, calculated on the training set. Shaded areas indicate standard deviation. For comparability, the AtmoDist distance has been normalized in each case with the method described in Appendix [A.3](#). To give equal weight to divergence and vorticity, they have been normalized to zero mean and unit variance before calculating pixel-wise metrics.

## Discussion Question 6

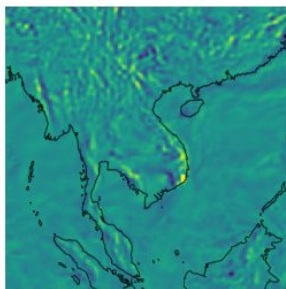
For the super resolution GAN, the AtmoDist loss compared was against two other content loss functions. What were they?

# Generative models can be used to solve super resolution

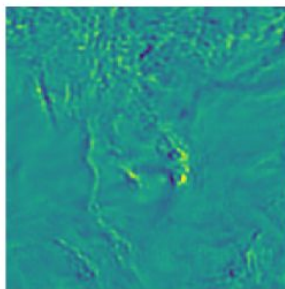
The “content” loss term compares the super-resolved image **representation** produced by the generator to the original high resolution image **representation**, and uses this info to help the generator.



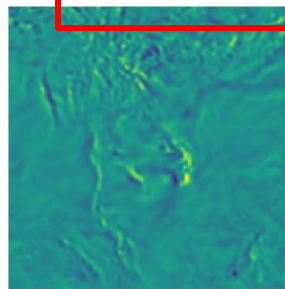
Ground Truth



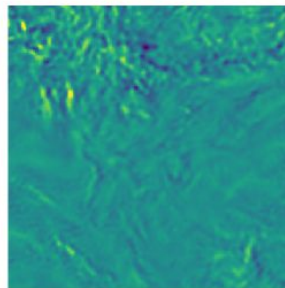
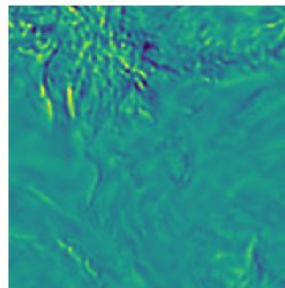
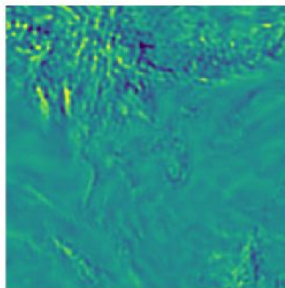
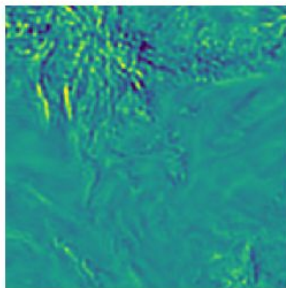
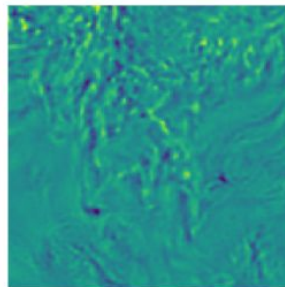
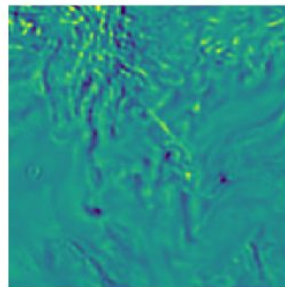
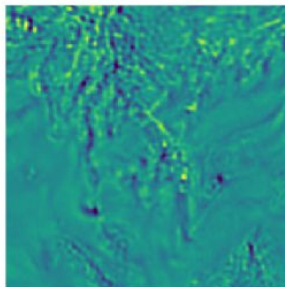
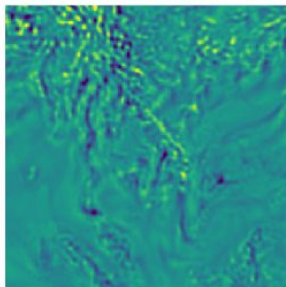
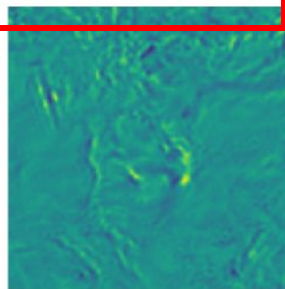
Atmodist



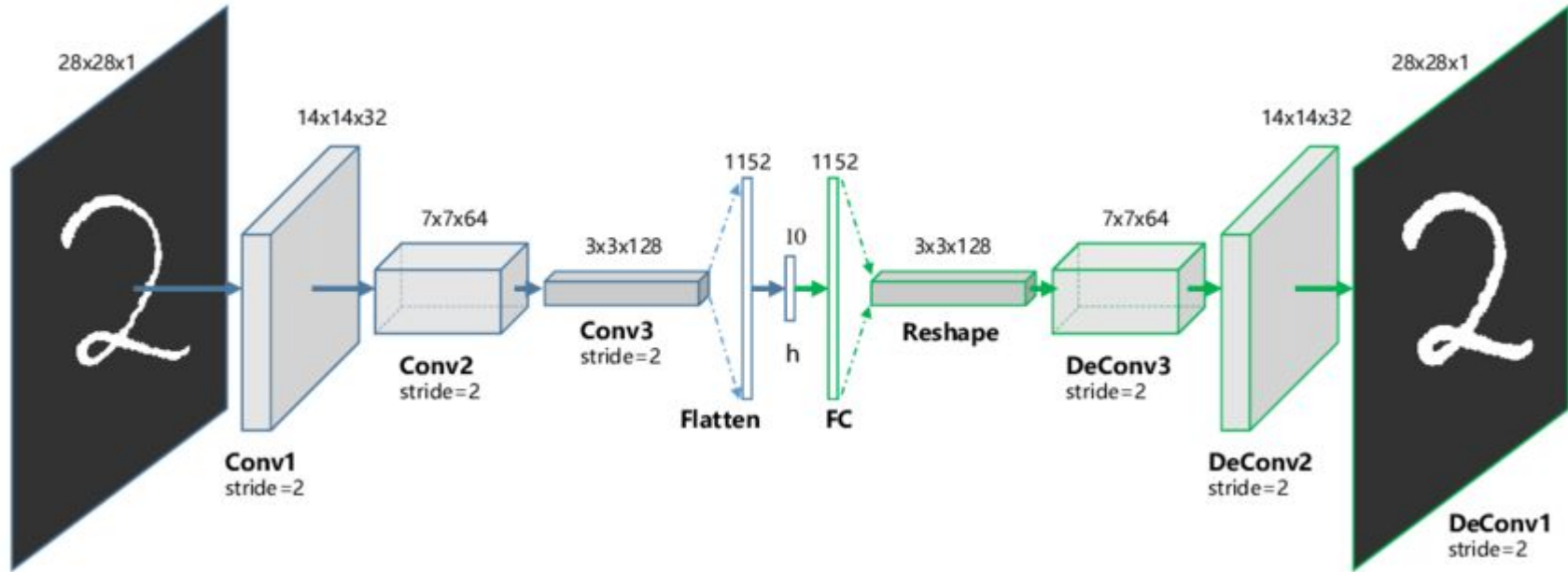
l2



Autoencoder



# Autoencoders are the original “self-supervised” models



Autoencoders are trained to reconstruct their input, but must pass through a “bottleneck” representation

## Discussion Question 7

What did their “ablation study” show?

69h is the best maximum time difference to train on

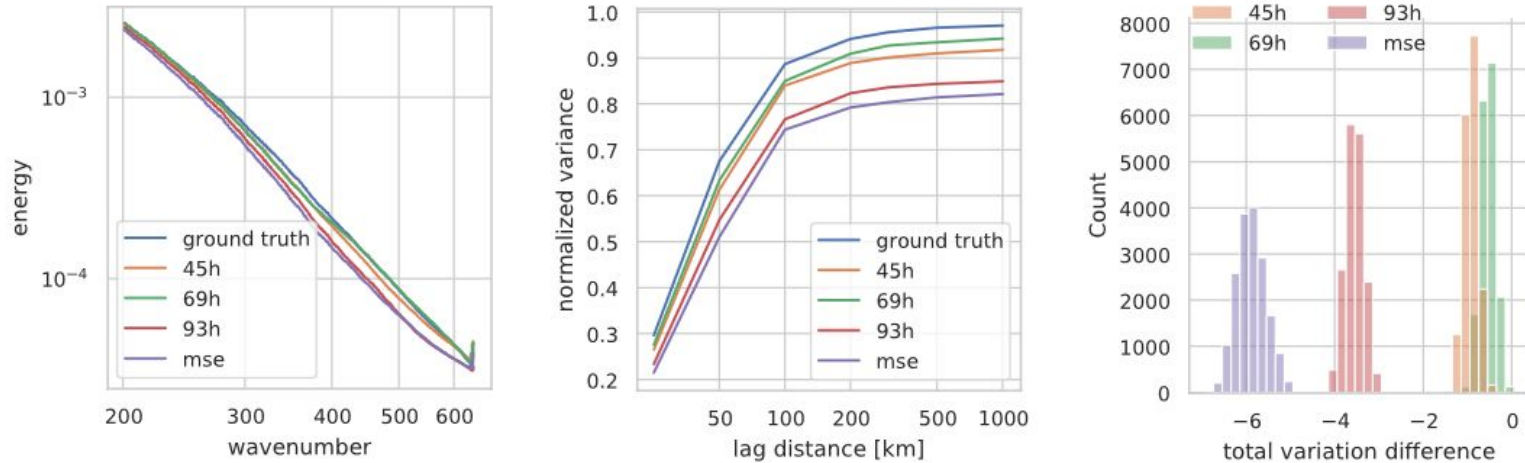


Figure 11: The energy spectrum (left), semivariogram (center), and distribution of total variation difference errors (right) for models trained with different maximum  $\Delta t_{\max}$  for our ablation study. The semivariogram and error distributions are calculated on divergence, but qualitative similar results are obtained for vorticity.



## Discussion Question 8

Share what questions you wrote in your PMIRO+Q and decide as a group what you'd like to ask.

# Update your PMIRO+Q

Submit a second file to the Brightspace assignment (don't overwrite the original):

It should:

Update your PMIRO as needed

Answer your own Q

You can be talking with your group during this!

5 min break

# Lecture

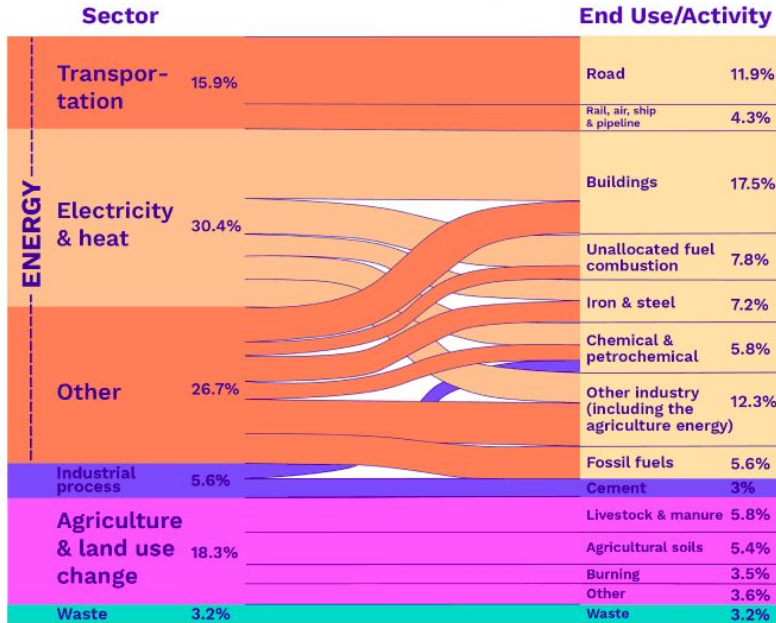
Climate Change: food and agriculture

Machine Learning: time series, recurrent neural networks, and transfer learning

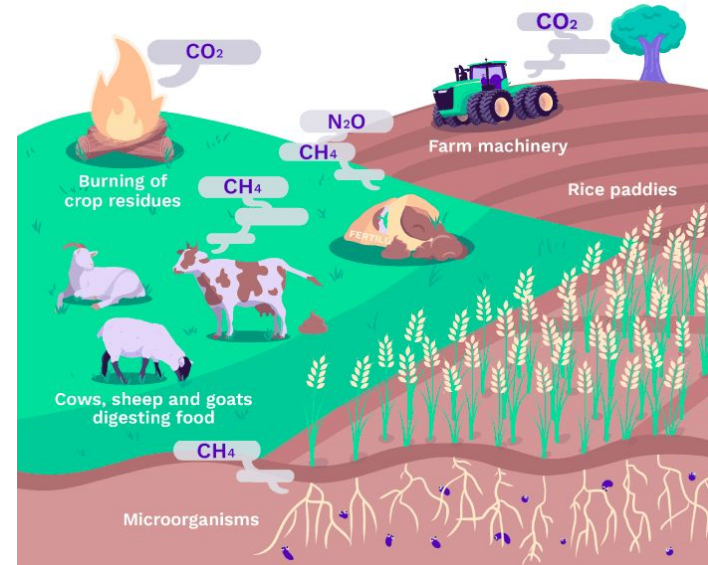
# Which activities contribute to GHG emissions?

## World Greenhouse Gas Emissions in 2016

Total: 49.4 GtCO<sub>2</sub>e



## Greenhouse Gas Emissions from Agriculture

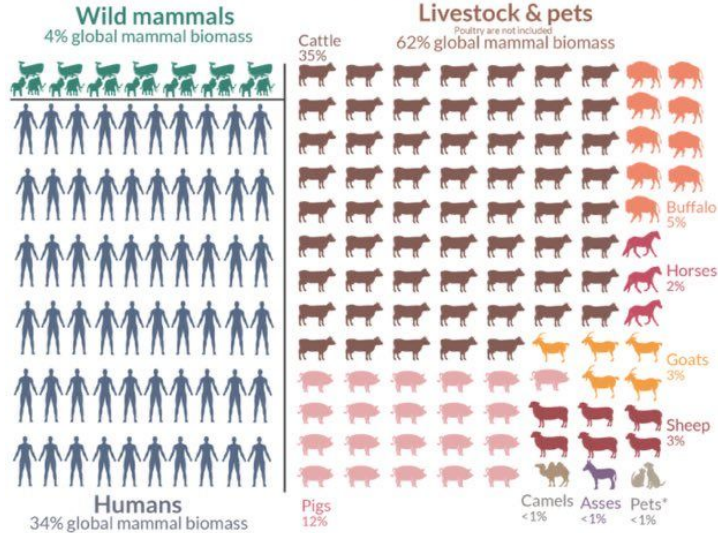


Source: Greenhouse gas emissions on Climate Watch. Available at: <https://www.climatewatchdata.org>

# Agriculture, due to its scale, has a large impact on the planet

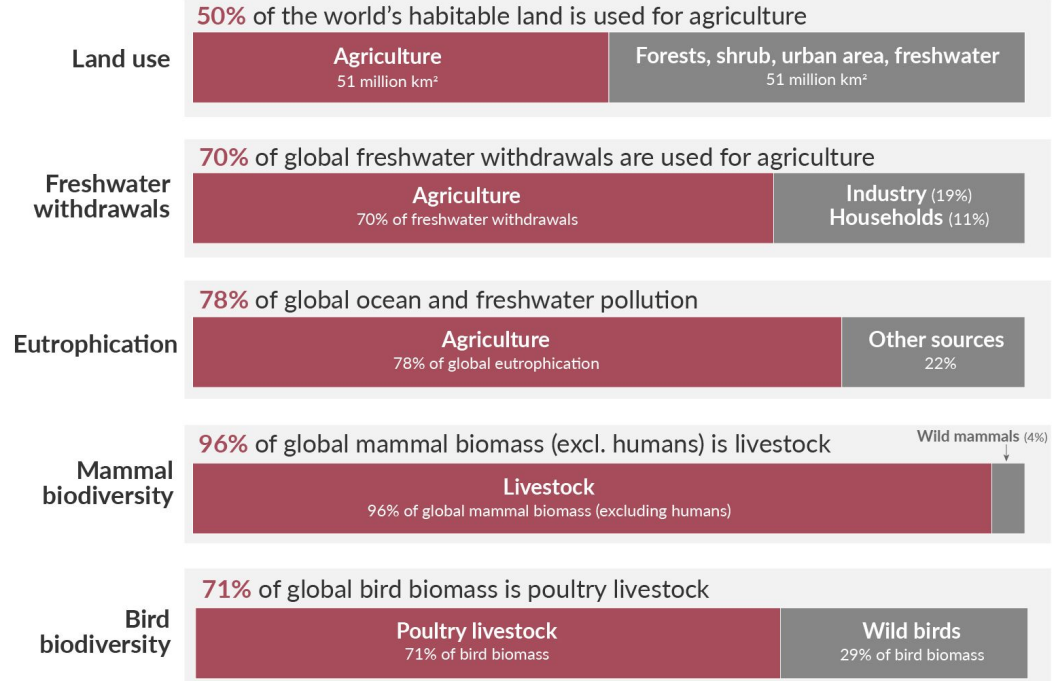
## Distribution of mammals on Earth

Mammal biomass is shown for the year 2015.  or  or  = 1 million tonnes carbon (C)



\*Bar-On et al. (2018) provide estimates of livestock only, without estimates of mammalian pets (e.g. cats and dogs). Pets have been added as an additional category based on calculations from estimates of the number of pets globally and average biomass.

Data source: Bar-On et al. (2018). The biomass distribution on Earth. Images sources from the Noun Project.  
OurWorldinData.org – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the author Hannah Ritchie.

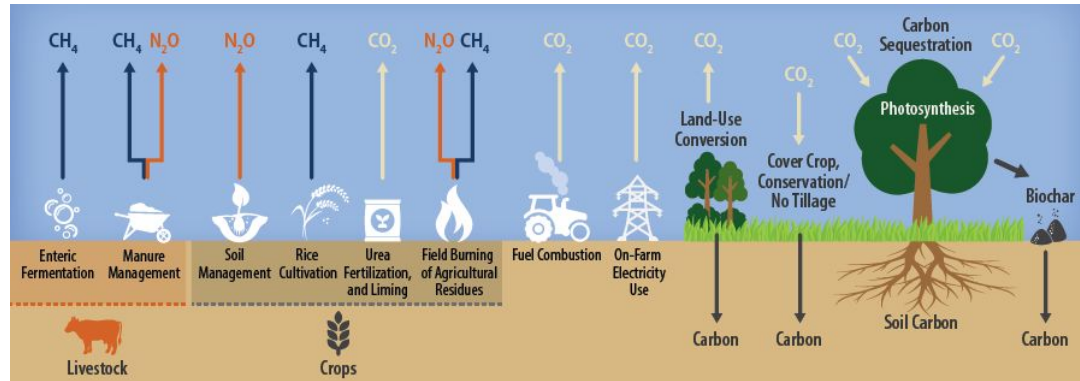


Data sources: Poore & Nemecek (2018); UN FAO; UN AQUASTAT; Bar-On et al. (2018).  
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the author Hannah Ritchie.  
Date published: November 2022.

# Agriculture has multiple impacts on GHGs

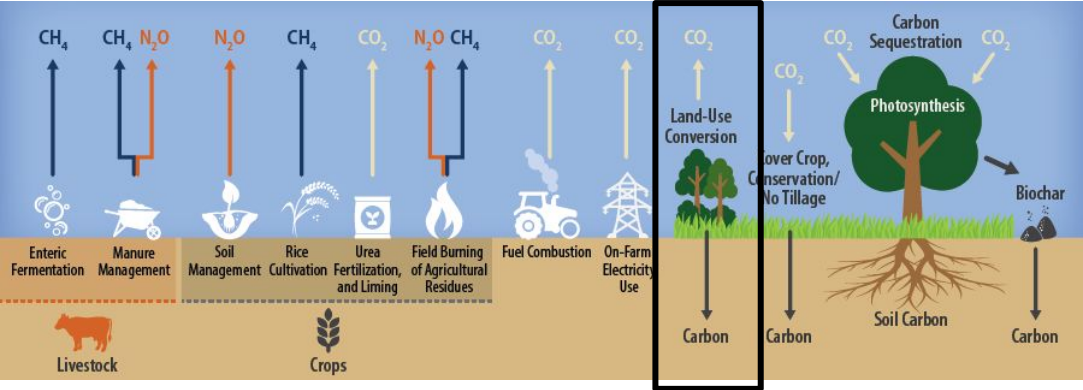
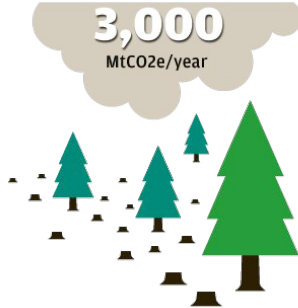
- Farming of plants and animals can capture CO<sub>2</sub>.
- However, modern farming practices lead to far more emissions than reductions in GHGs
- Furthermore, farming requires land that may have been used for other purposes
- GHGs other than CO<sub>2</sub> are also released, which have higher warming potentials



# Forests are cut down for grazing land and farms

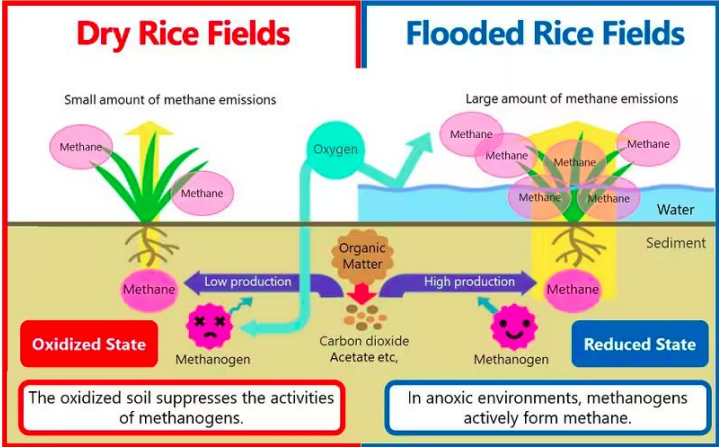


IF TRENDS CONTINUE, **ABOUT 10 MILLION KM<sup>2</sup> OF LAND** WILL BE CLEARED BY 2050 TO MEET FOOD DEMAND

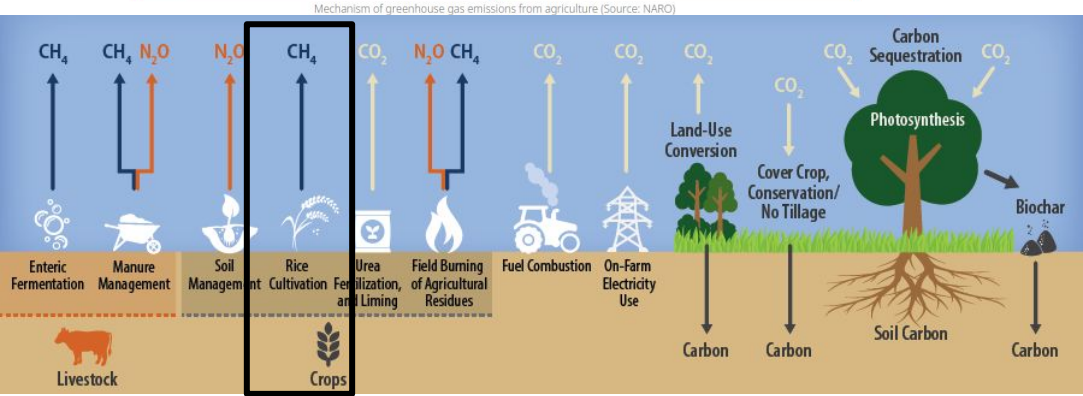




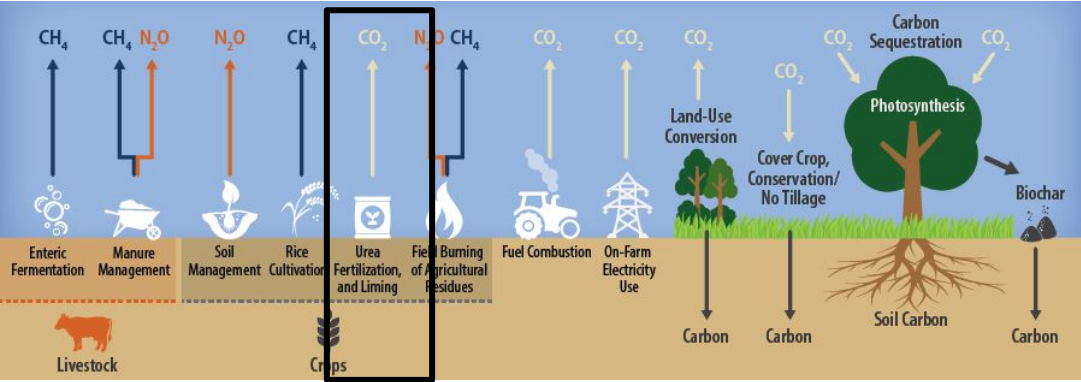
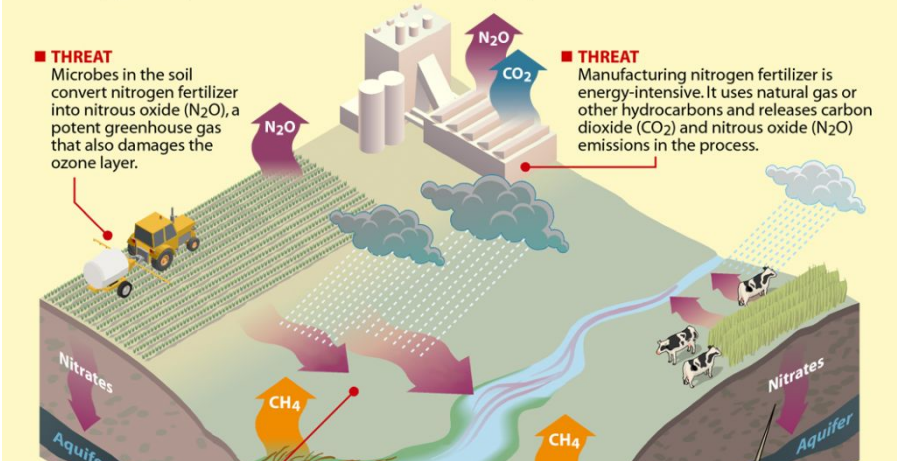
# Flooding of rice paddies releases methane



Rice paddies and their flooding is responsible for 10% of global methane release.



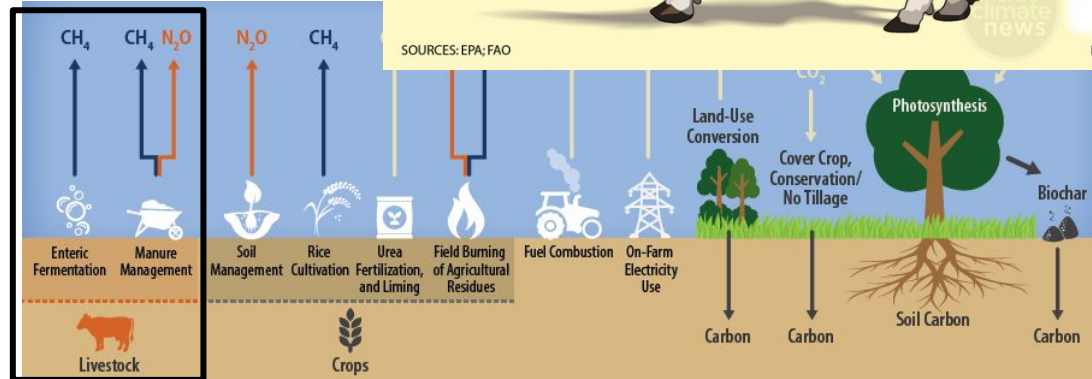
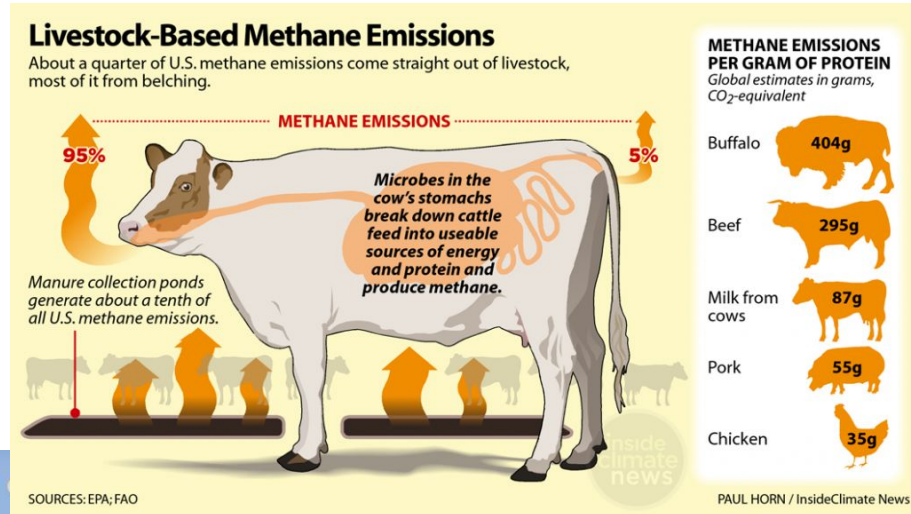
# Manufacture and use of fertilizer releases multiple GHGs



# Livestock digestion is responsible for a large fraction of agriculture emissions

Gas from ruminant animals (cattle, sheep, goats, etc) causes methane release.

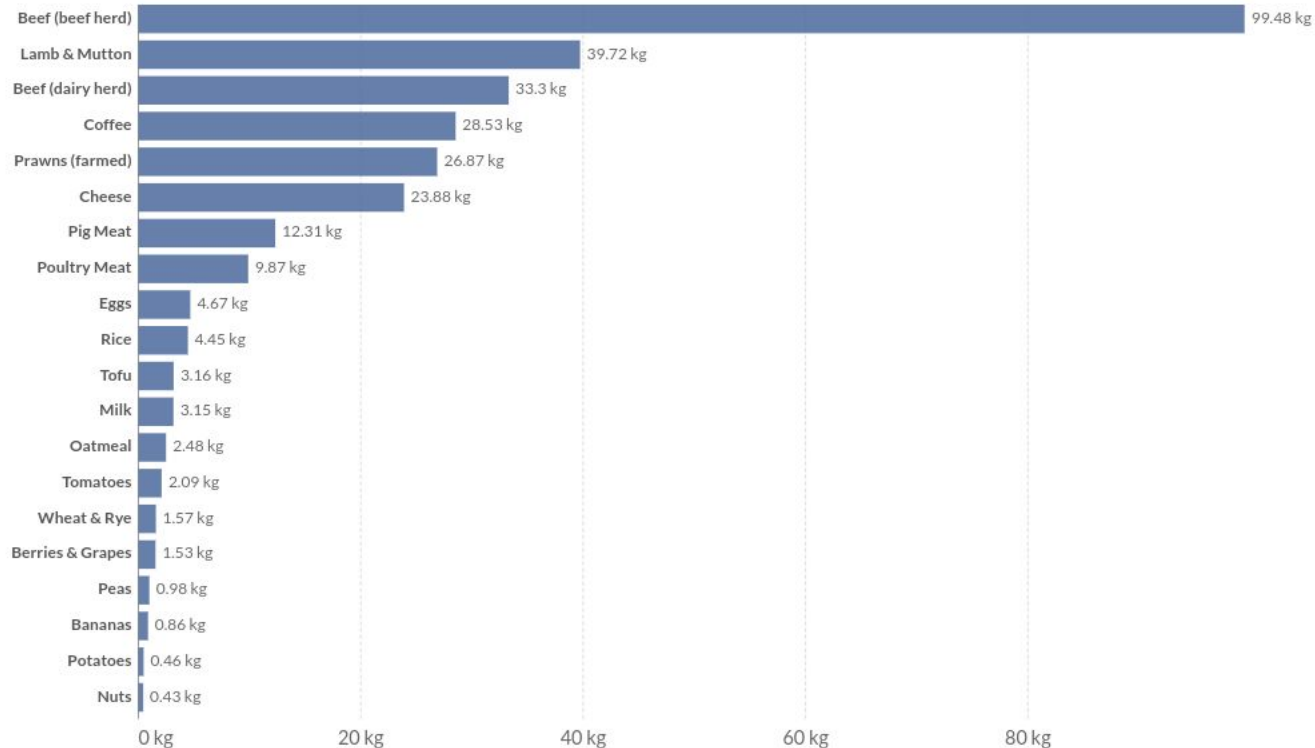
Manure stored in piles creates methane and nitrous oxide.



# Emissions from different foods are *very* different

## Greenhouse gas emissions per kilogram of food product

Emissions are measured in carbon dioxide equivalents (CO<sub>2</sub>eq). This means non-CO<sub>2</sub> gases are weighted by the amount of warming they cause over a 100-year timescale.



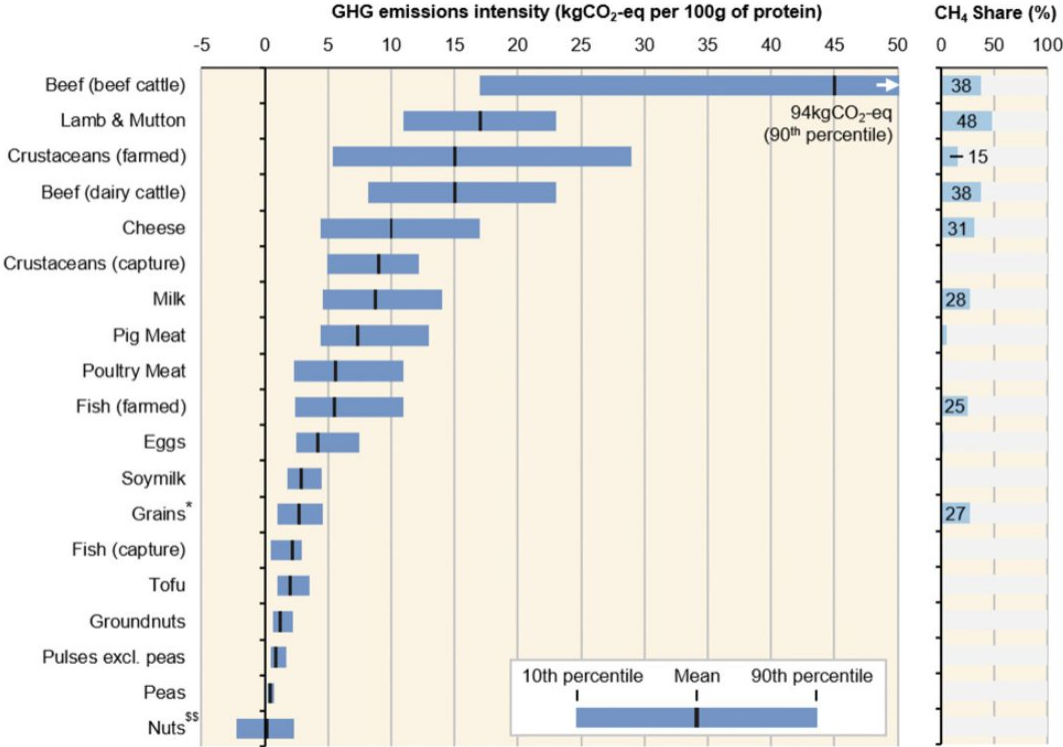
Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers.

[OurWorldInData.org/environmental-impacts-of-food](https://OurWorldInData.org/environmental-impacts-of-food) • CC BY

Note: Greenhouse gases are weighted by their global warming potential value (GWP100). GWP100 measures the relative warming impact of one molecule of a greenhouse gas, relative to carbon dioxide, over 100 years.

# Emissions from different foods are *very* different

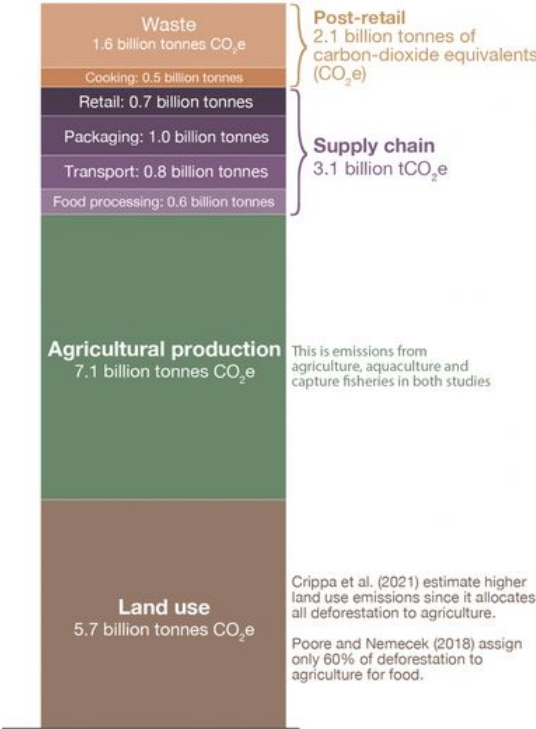
Emissions per 100g of protein





# Food waste also contributes to emissions

74kg (163 lbs) of food waste per person, per year.



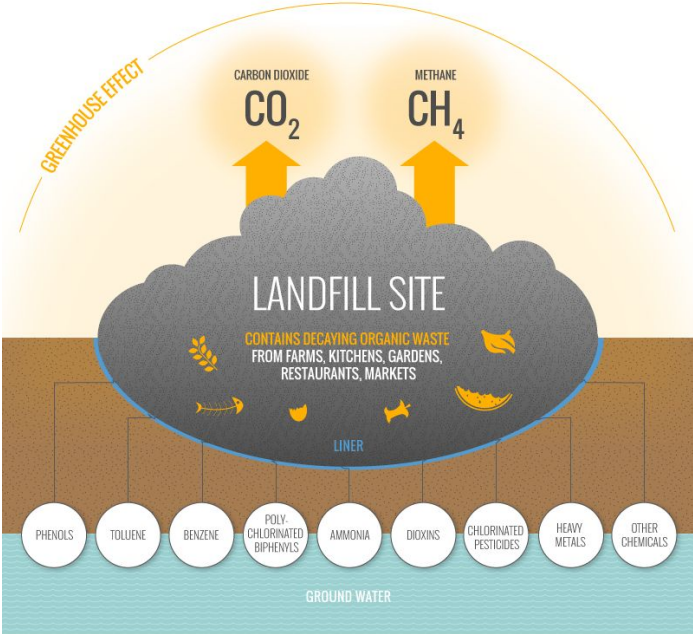
This is emissions from agriculture, aquaculture and capture fisheries in both studies

Crippa et al. (2021) estimate higher land use emissions since it allocates all deforestation to agriculture.

Poore and Nemecek (2018) assign only 60% of deforestation to agriculture for food.

**Crippa et al. (2021)**

17.9 billion tonnes CO<sub>2</sub>e from food\*  
That's 34% of global GHG emissions  
(\*some non-food agricultural products included)



# Too Good to Go



Too Good To Go



## DISCOVER

delicious surplus food at a great discount around you



## PICK-UP

delicious food from shops nearby



## ENJOY

a tasty meal that helps the planet

## WHY IT MATTERS

Globally, more than 1/3 of food is wasted - and that's bad news for our planet. Food waste is responsible for 10% of greenhouse gases, and we use a landmass the size of China to produce food we end up throwing away. It makes no sense, does it?

At Too Good To Go, we're determined to help fix the problem. Our app lets you rescue delicious, unsold food from businesses to save it from being thrown away.

In turn, the app powers our efforts to build an anti-food waste movement. Globally, our dedicated team works within organizations like local governments and schools to shake up the food system, and change the way we think about food.

## Surprise Bags in your area

See all >



### Anthi's Greek Specialties

Tomorrow 11:00 AM - 1:00 PM • 17.4 mi

## Your favorites

See all >



### Baked By Susan

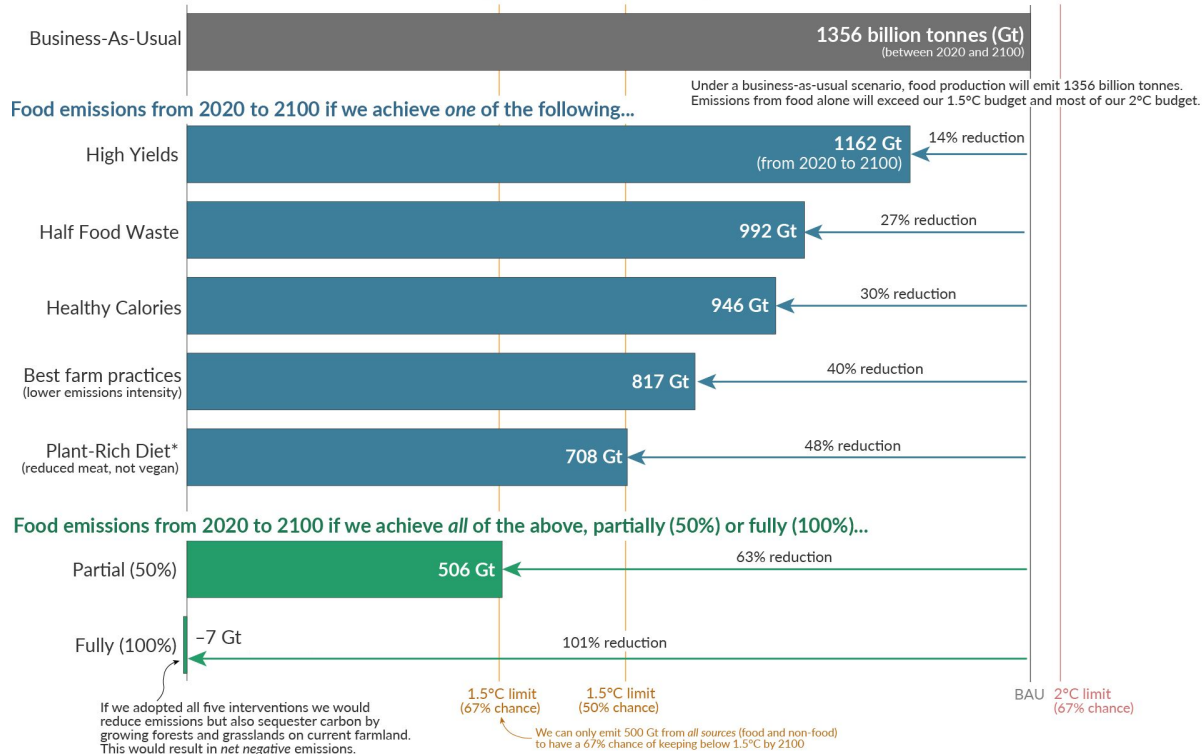
Today 3:00 PM - 4:00 PM • 9.4 mi



# How can we reduce global greenhouse gas emissions from food?

Shown are estimates of cumulative greenhouse gas emissions from food production from 2020 to 2100 under a business-as-usual scenario, and five interventions to reduce emissions.

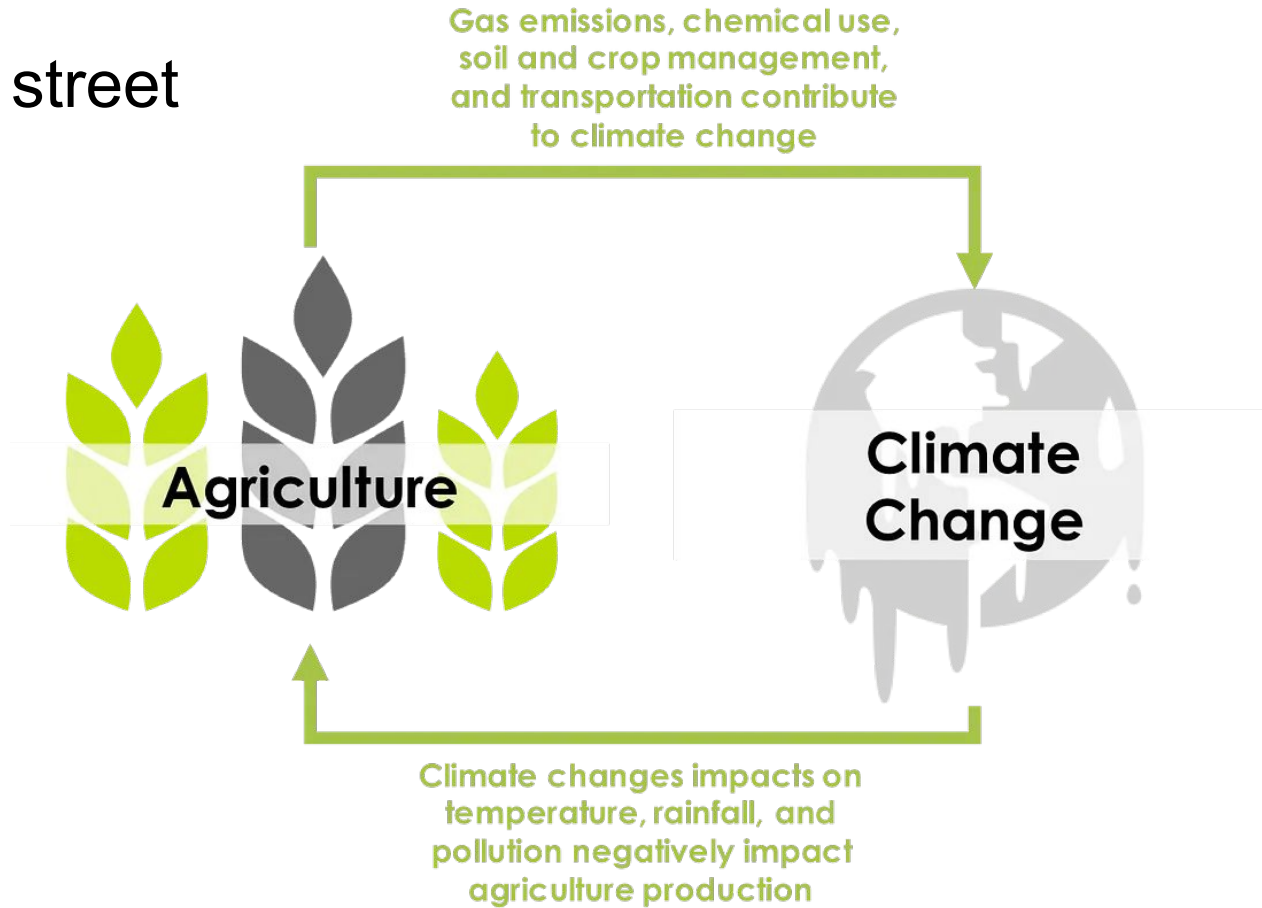
This is measured in global warming potential (GWP\*) CO<sub>2</sub> warming-equivalents (CO<sub>2</sub>-we).



\*Based on the EAT-Lancet Planetary Health diet which reduces but does not eliminate meat or dairy consumption.

Source: Michael Clark et al. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*.

# Two-way street



# Foods at particular risk

**Coffee** - rising temperatures are estimated to reduce the suitable coffee-growing land by 50% by 2050 and support the growth of coffee rust fungus

**Chocolate** - yield will decline as soon as 2030. Growing regions will shift to South America

**Shellfish** - at risk from hotter and more acidic oceans

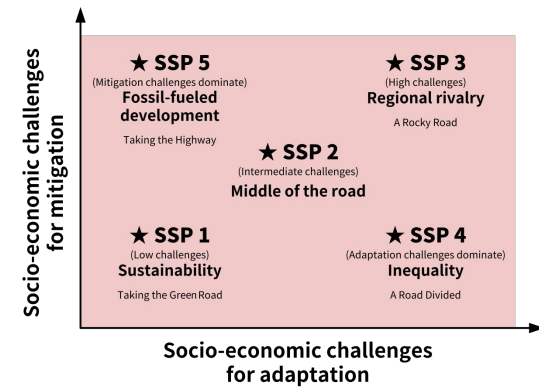
**Corn** - yield for corn grain will decrease within the U.S. Corn Belt by 20 to 40% from 1991-2000 levels by 2046-2055 with large economic impact

**Livestock** - impacted by more heat stress, disease, and water availability

**Rice** - increase and severity of hot weather can cause yields to decrease by 40% within this century

**Honey** - Shifts in the flowering plant cycles can cause nutritional stress on bee populations.

# Predicted impacts on food security



Shared Socioeconomic Pathway	Production		Storing/Processing/ Packaging		Trade		Transport	
	P	W	P	W	P	W	P	W
SSP1	Green	Green	Green	Green	Green	Green	Green	Green
SSP2	Yellow	Green	Yellow	Green	High Risk	Yellow	Yellow	Green
SSP3	High Risk	Yellow	Yellow	Green	Very High Risk	High Risk	Yellow	Green
SSP4	Very High Risk	Yellow	Yellow	Green	Very High Risk	Yellow	Yellow	Green
SSP5	Green	Green	Green	Green	Green	Green	Yellow	Green

Key
Low Risk
Medium/Low Risk
Medium Risk
High Risk
Very High Risk

(P: poorer nations, W: wealthier nations)

**Figure ES- 5. Relative risks to food availability for different SSPs.** The risks to food availability would be lowest under the economic conditions described in in SSP 1 and SSP 5 for a given scenario of climate change, with poorer nations being at higher risk across all food production, distribution and trade categories for all SSPs. Shading represents higher or lower risks for each SSP from climate change. Risks reflect the informed judgment of the authors of this report based on the available literature.

Climate change will impact production and distribution of food

# Impacts on health

## Impact of climate change on food production could cause over 500,000 extra deaths in 2050

03 March 2016



<https://www.oxfordmartin.ox.ac.uk/news/201601-climate-food-production/>

- Lead to average per-person reductions in food availability of 3.2% (99 kcal per day), in fruit and vegetable intake of 4.0% (14.9g per day), and red meat consumption of 0.7% (0.5g per day).
- Almost three-quarters of all climate-related deaths expected to occur in China (248,000) and India (136,000).

# Accurate knowledge of crops will be crucial for planning

For example, during the COVID-19 pandemic, the government of the Togolese Republic used satellite imagery to identify crop locations and distribute aid to increase production

*“We present results for this method in Togo, where we delivered a high-resolution (10 m) cropland map in under 10 days to facilitate rapid response to the COVID-19 pandemic by the Togolese government. This demonstrated a successful transition of machine learning applications research to operational rapid response in a real humanitarian crisis.”*

KDD '20 Humanitarian Mapping Workshop, August 24, 2020, San Diego, CA

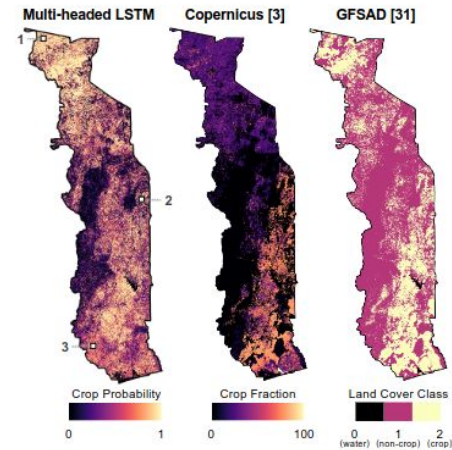


Figure 3: Cropland maps of Togo generated using our method, Buchhorn et al. [4], and Xiong et al. [33]. White boxes indicate locations of insets shown in Figure 4.

# Sentinel-1

We have previously seen work that uses data from the Sentinel-2 (optical) satellite. The current paper uses Sentinel-1 data, which is an “active sensing” satellite



# Sentinel-1 Terminology

“Synthetic Aperture Radar”

Transmits pulses and listens for echoes, called backscatter.

Phase of the backscatter is used to determine the distance from the sensor to a target

Amplitude provides information about the roughness, geometry, wetness, etc of the Earth at that location

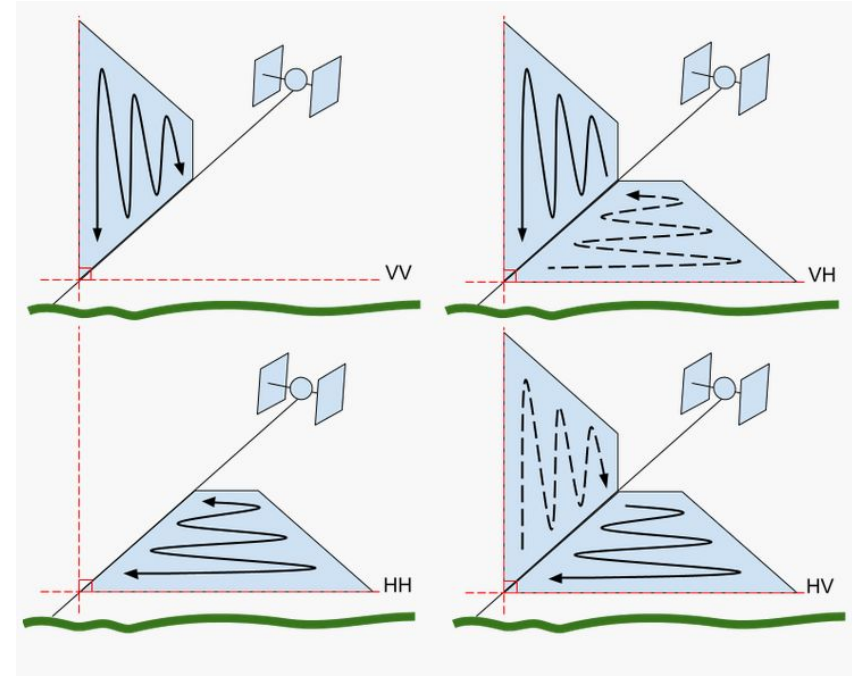
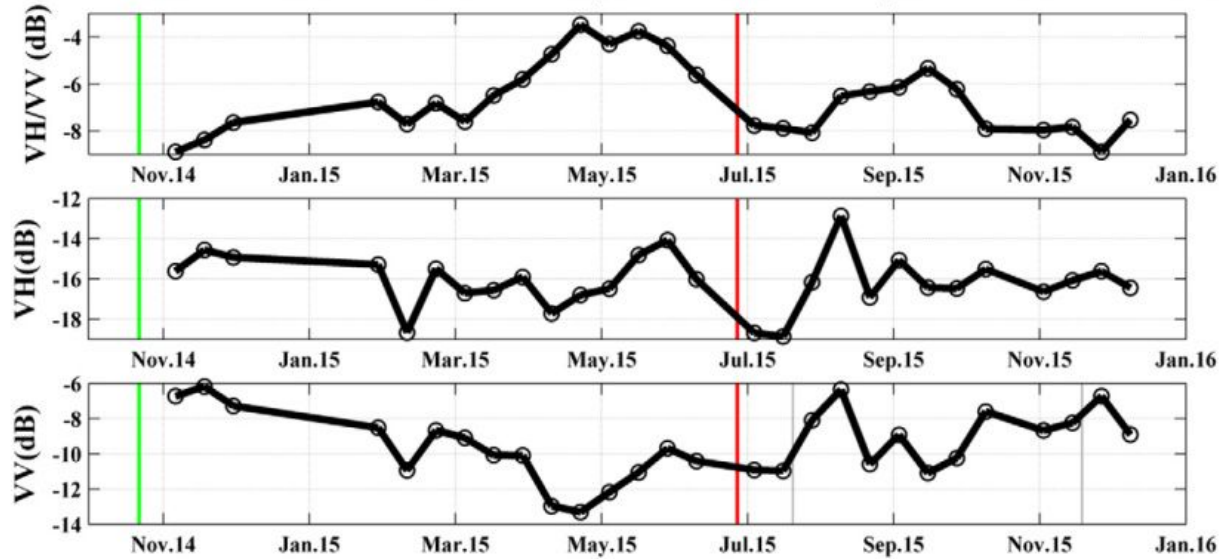


Figure 2: SAR signals are transmitted and received either vertically (V) or horizontally (H). This gives the potential for four different polarization combinations (transmit listed first, receive second): VV, VH, HH, and HV. Credit: ASF



# SAR values over time

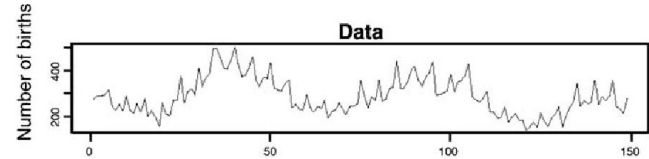


# Time Series Data

Data that

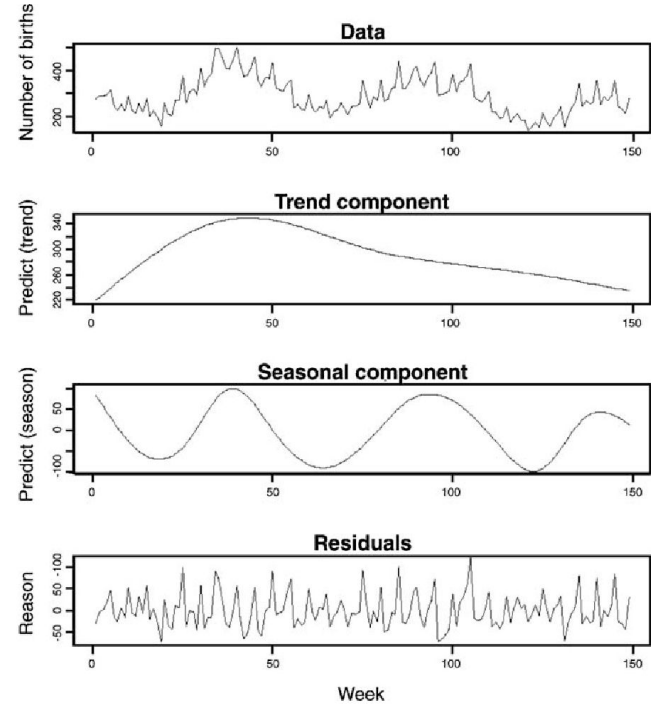
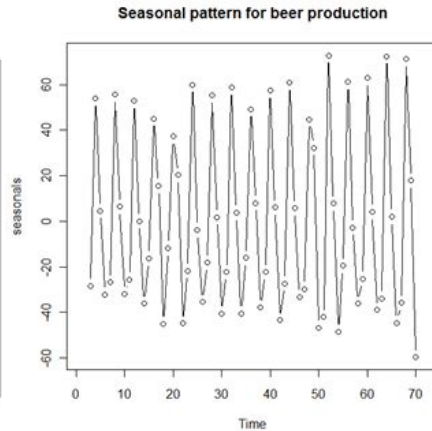
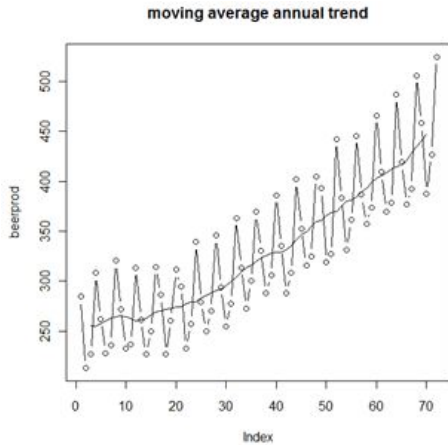
- is sampled at regular intervals
- has some discernible trends
- can be univariable
- a type of “sequence” data

Have we seen any time series data in this class?



# What you can do with time series data:

Identify trends and patterns with smoothing and subtraction



# What you can do with time series data:

## “Auto” regression for prediction

### *Autoregressive (AR) Models*

A common approach for modeling univariate time series is the autoregressive (AR) model:

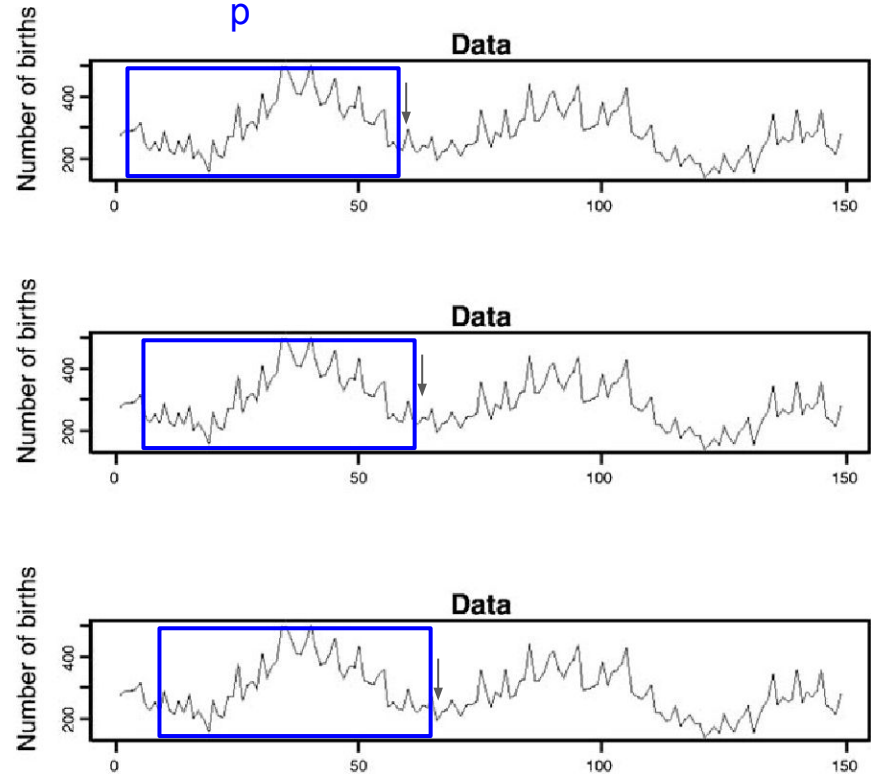
$$X_t = \delta + \phi_1 X_{t-1} + \phi_2 X_{t-2} + \cdots + \phi_p X_{t-p} + A_t$$

where  $X_t$  is the time series,  $A_t$  is white noise, and

$$\delta = \left(1 - \sum_{i=1}^p \phi_i\right) \mu,$$

with  $\mu$  denoting the process mean.

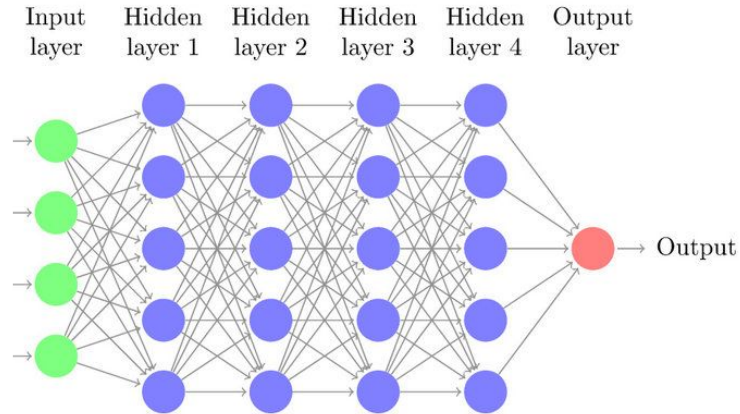
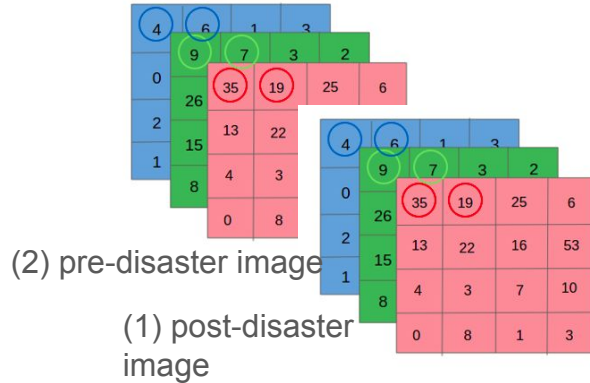
An autoregressive model is simply a [linear regression](#) of the current value of the series against one or more prior values of the series. The value of  $p$  is called the order of the AR model.



# What you can do with time series data:

Put them into artificial neural networks for prediction, classification, etc

All time points go into the model at once (concatenated):

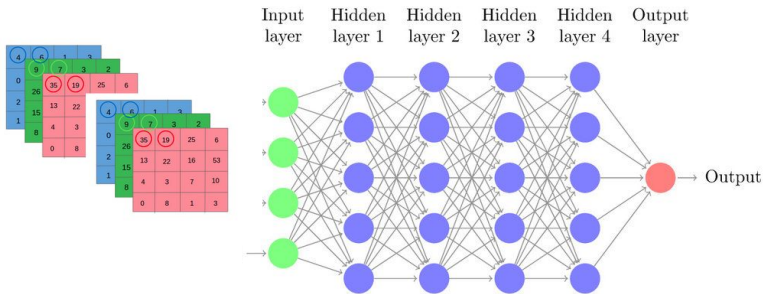


# What you can do with time series data:

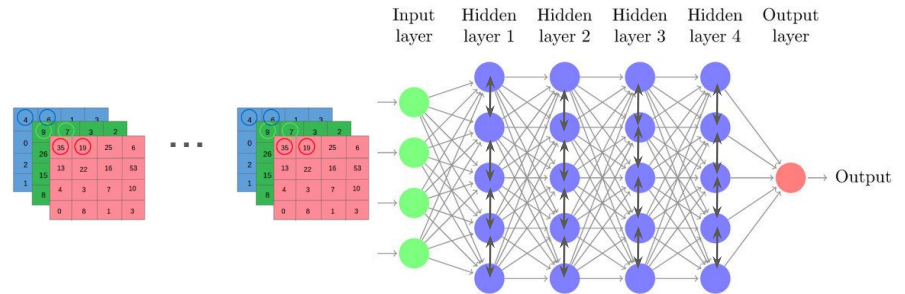
Put them into artificial neural networks for prediction, classification, etc

Or time points go in one at a time with **recurrent neural networks**

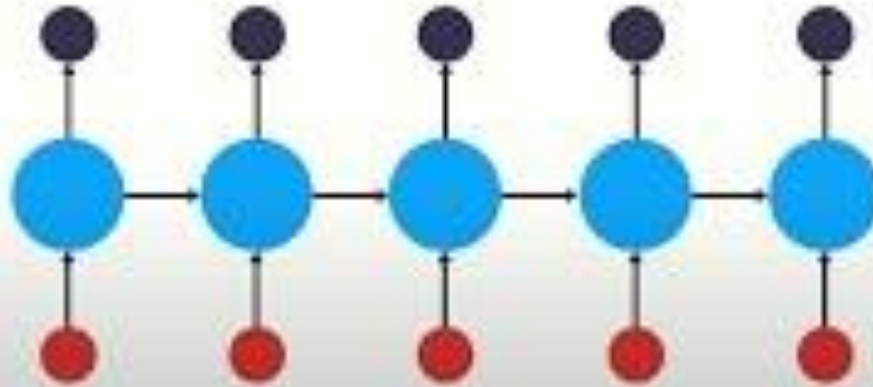
## Feedforward Network:



## Recurrent Network:

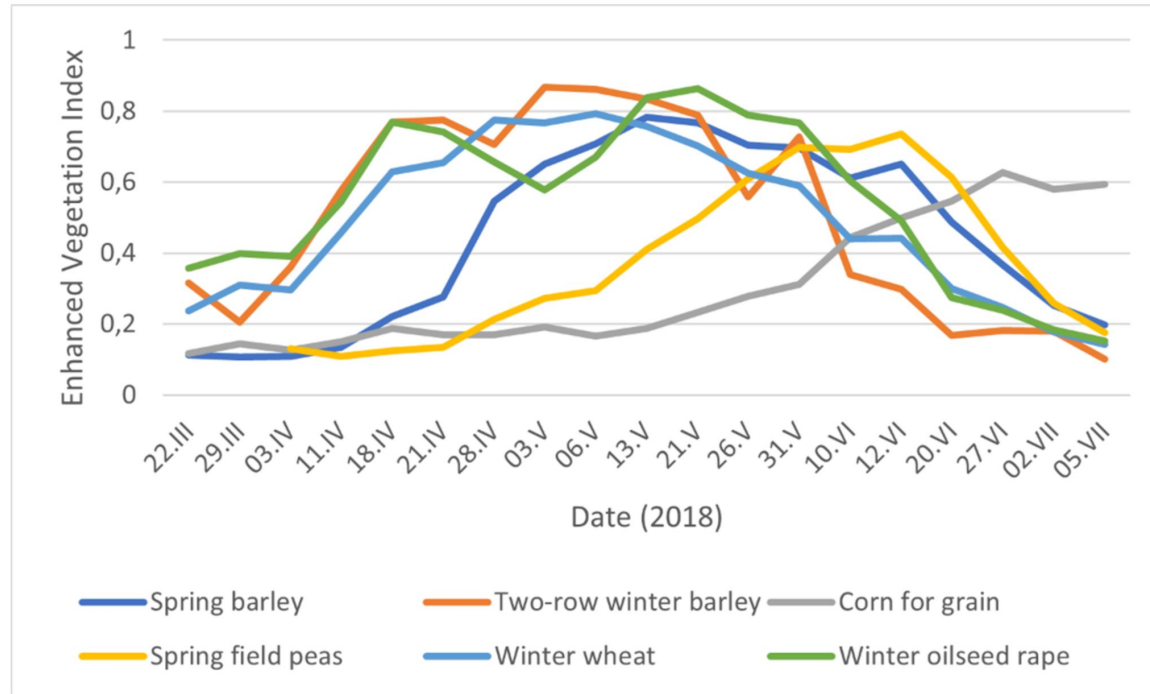


# An Illustrated Guide to Recurrent Neural Networks



Recurrent neural networks have **memory**

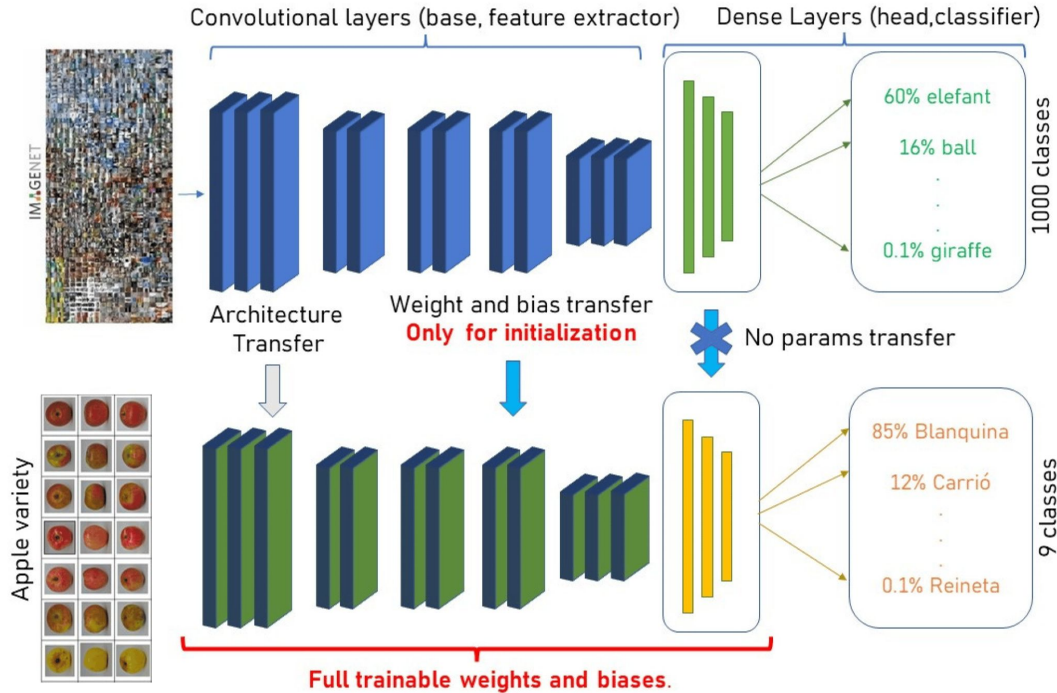
# If our goal is to identify a specific crop, why do we want time series data?



Crops have specific temporal signatures



# What if we don't have a lot of labeled data for the region we want to study?



**Transfer Learning:** Train a neural network on a large related dataset and then adapt it for your specific task

**Fine-tuning:** Adapt to your specific task by making small changes to the weights of your pre-trained network

**Frozen weights:** Weights that aren't changed during fine tuning

# For your reading

There may be a mistake in how the model in Figure 4 is described