

Tackling Climate Change with Machine Learning, NeurIPS 2022

Generating physically-consistent, high-resolution climate data

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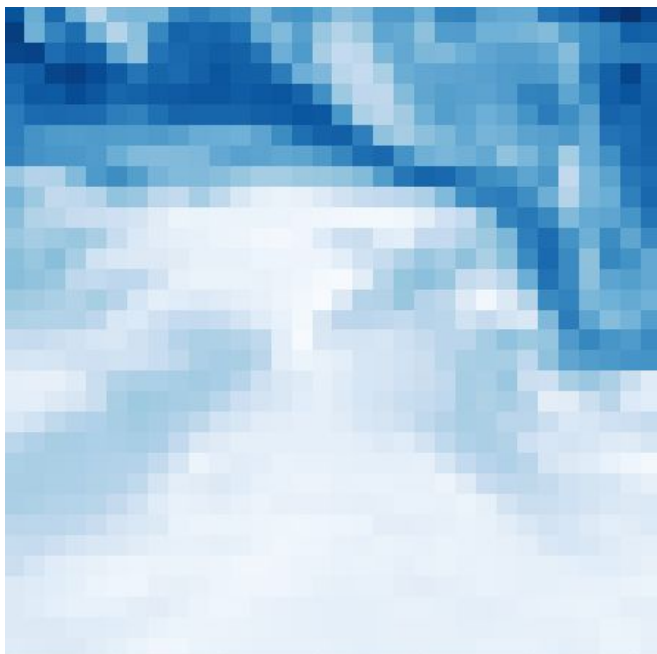
The background of the slide is a marbled pattern in shades of light blue and white, resembling a liquid or stone texture. The word "Intro" is centered in the middle of the slide in a black, sans-serif font.

Intro

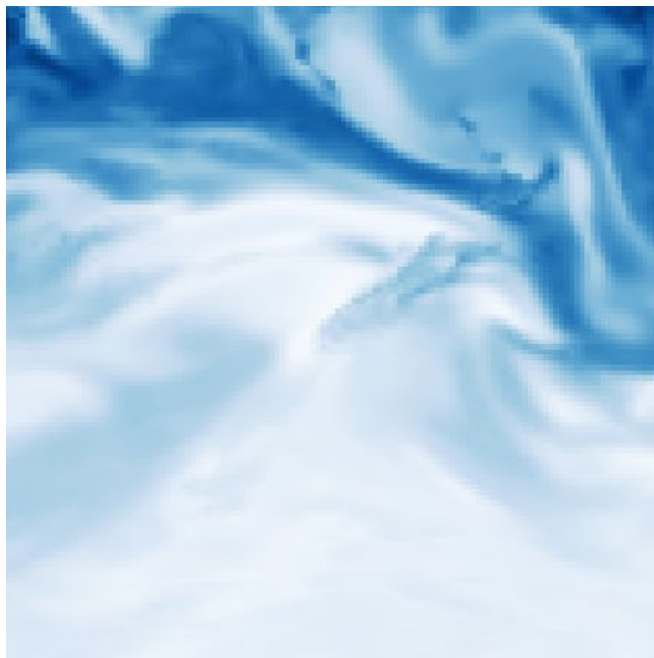
Goal

Increasing climate data's resolution

Low-resolution (LR) input



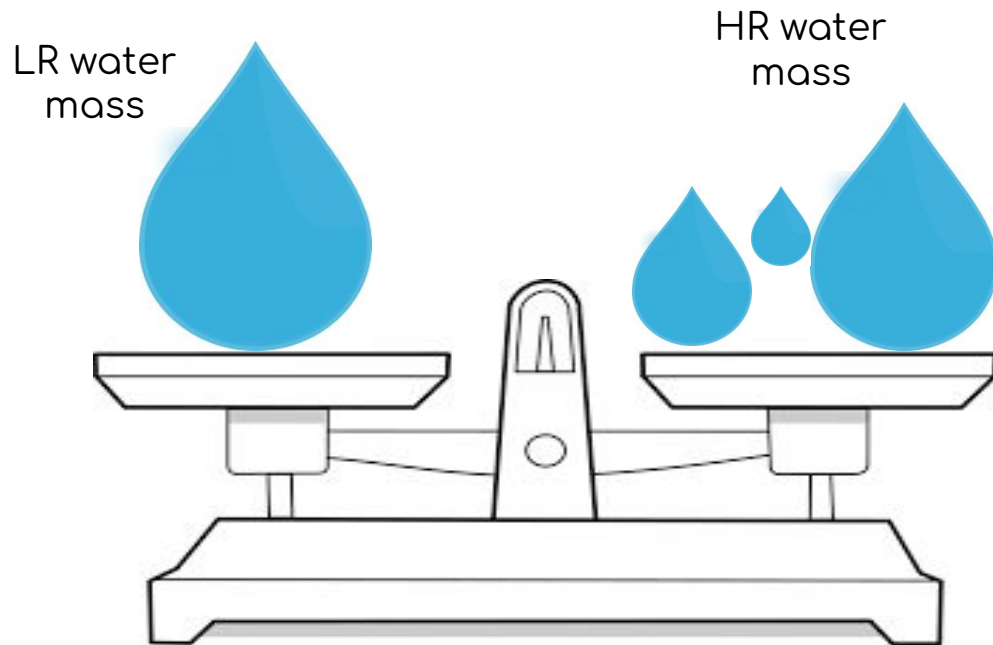
High-resolution (HR) target



Goal

Increasing climate data's resolution ...

while obeying laws of physics



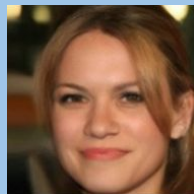
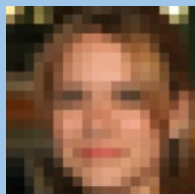
Terminology

Machine Learning

super-resolution

upsampling/downsampling

standard images



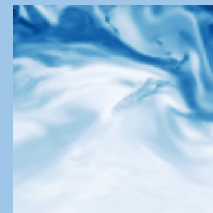
vs

Climate Science

statistical downscaling

downscaling/upscaling

physical quantities



Motivation

High-resolution climate data - useful, but hard to obtain

Useful

Motivate action to combat climate change

Inform climate adaption locally

Impact on agriculture, transportation etc.

Hard to obtain

Computationally intensive

Long runtimes

High energy consumption

Observation not available in some areas

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Methods

Data

Underlying climate
data

ERA5 reanalysis
data

Total column water
Global, hourly
~25 km resolution

ML ready data set

Pytorch data set

LR, HR pairs
HR is 128x128 pixels
LR is created by average
pooling
Different upsampling factors
(2, 4, 8, 16)
40k train/10k val/10k test

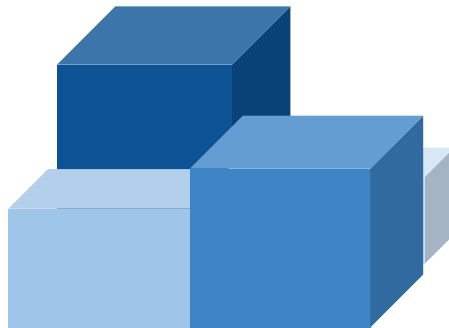
Physics constraints

Predicted quantity is water mass

Want to enforce conservation of mass between low-res input and super-res prediction



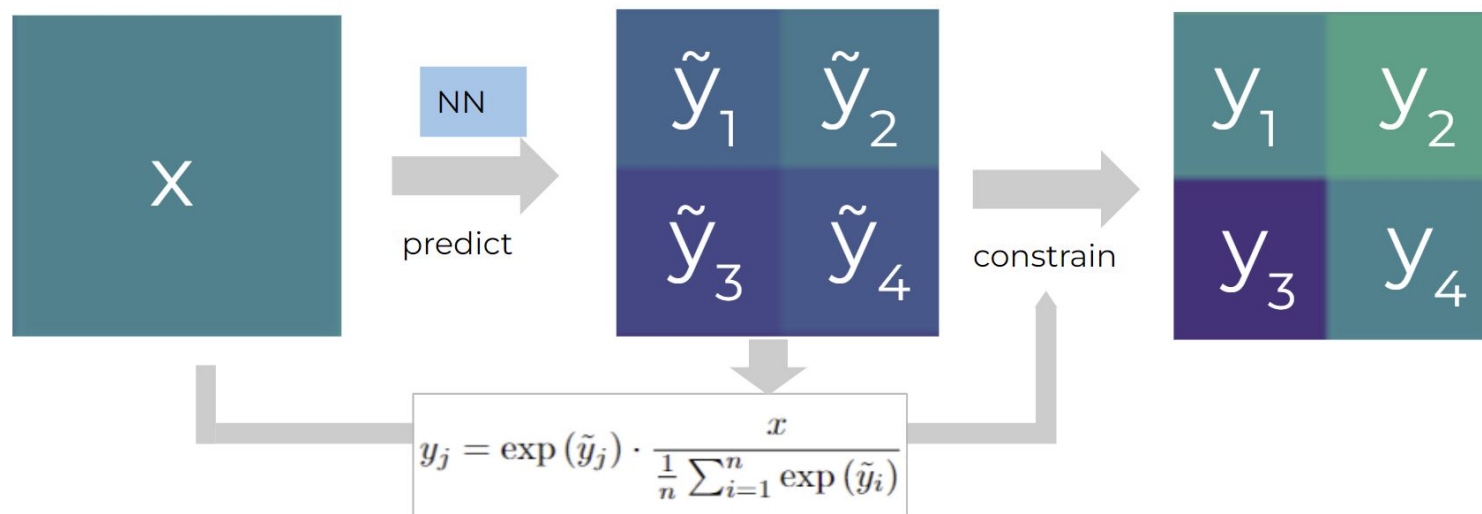
Low-res water mass



Super-res water mass

Enforcing constraints - Softmax Constraints Layer (SMCL)

SMCL guarantees conservation of mass and positivity



Enforcing constraints - architecture

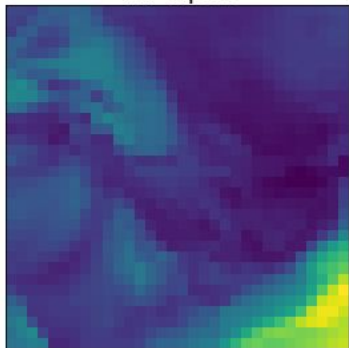


The background of the slide is a marbled pattern in shades of light blue and white, resembling watercolor or stone. The word "Results" is centered in a black, sans-serif font.

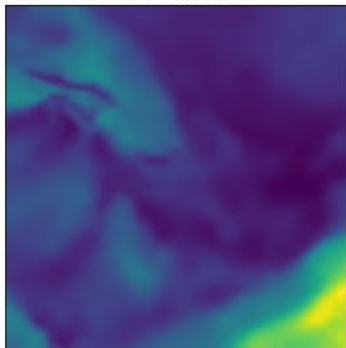
Results

Results

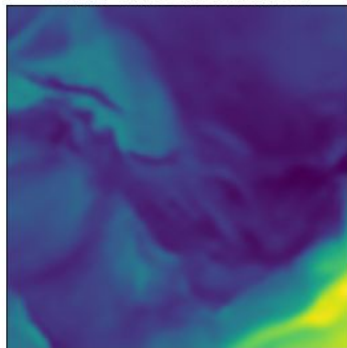
LR input



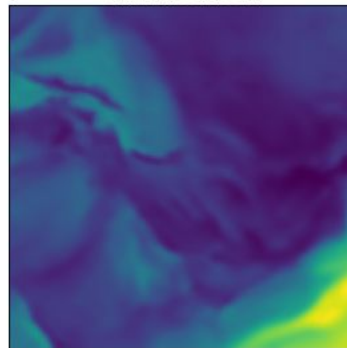
Bicubic



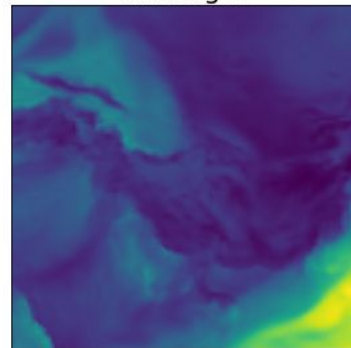
CNN unconstrained



CNN+SMCL

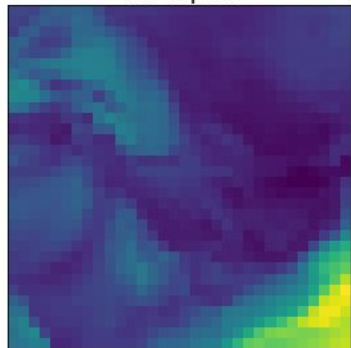


HR target

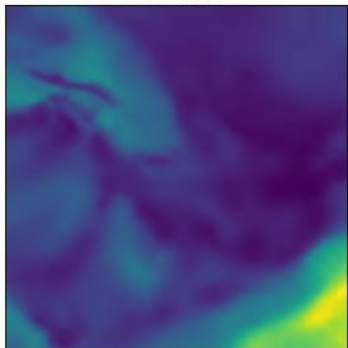


Results- 4 times downscaling

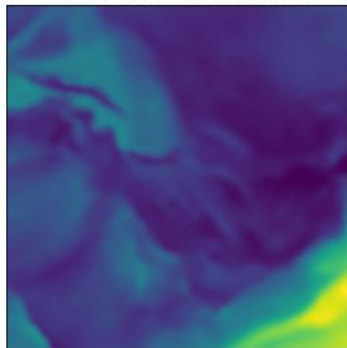
LR input



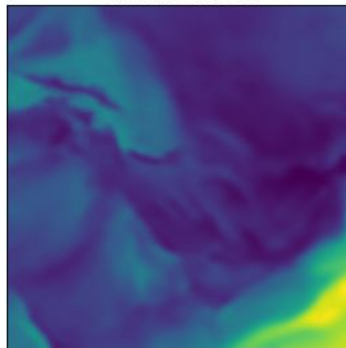
Bicubic



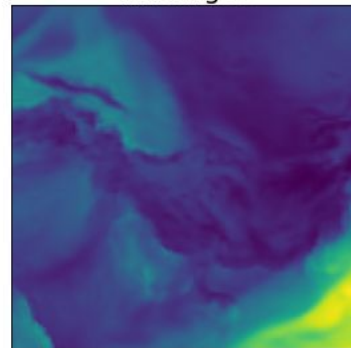
CNN unconstrained



CNN+SMCL



HR target



PSNR

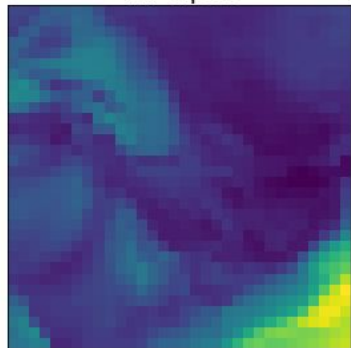
44.3

47.5

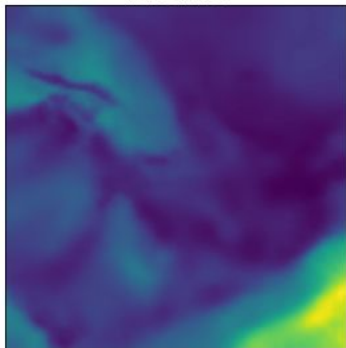
47.9

Results- 4 times downscaling

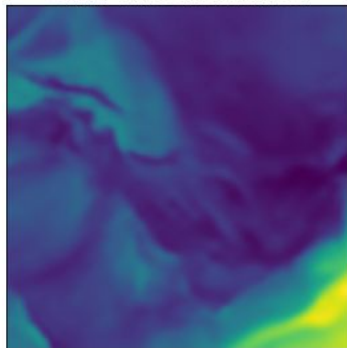
LR input



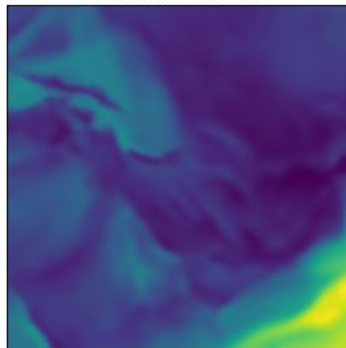
Bicubic



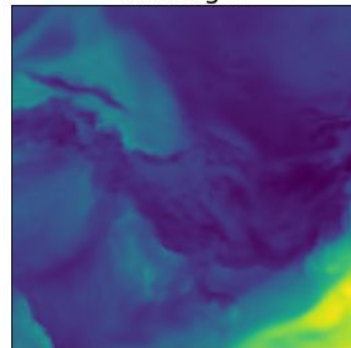
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CNN+SMCL



HR target



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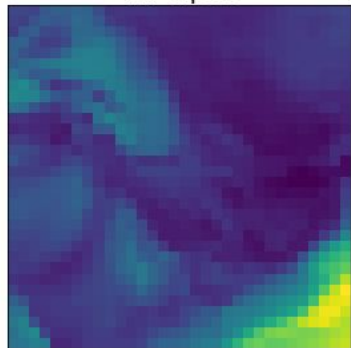
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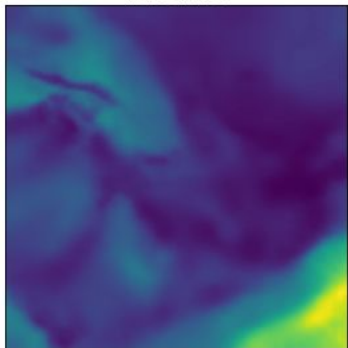
$$PSNR = 20 \log_{10} \left(\frac{MAX_f}{\sqrt{MSE}} \right)$$

Results- 4 times downscaling

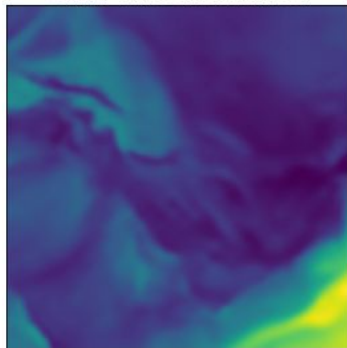
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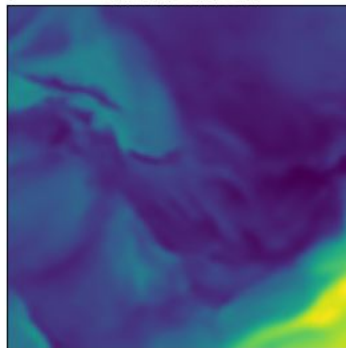
Bicubic



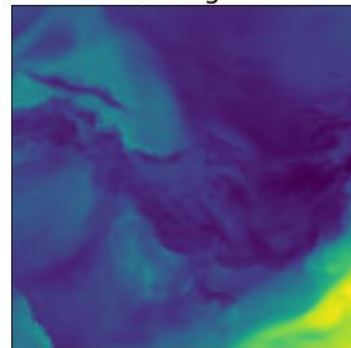
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HR target



PSNR

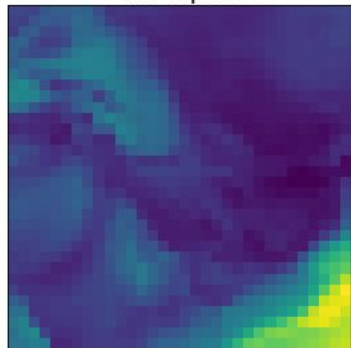
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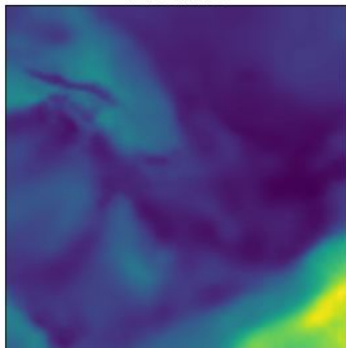
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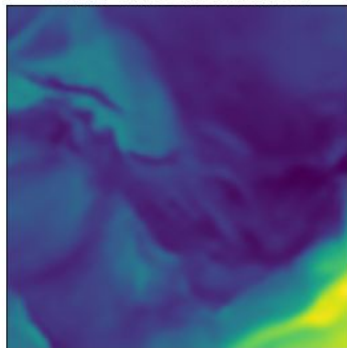
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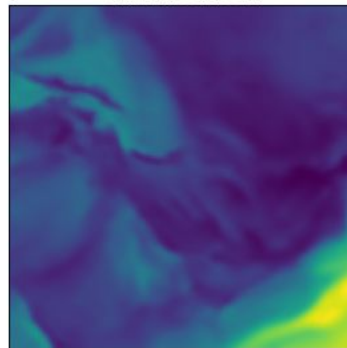
Bicubic



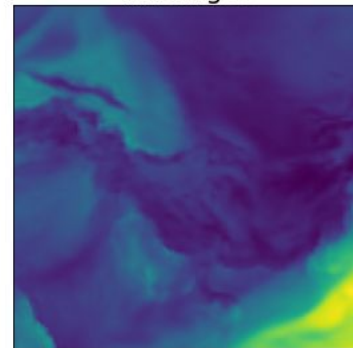
CNN unconstrained



CNN+SMCL



HR target



PSNR

44.3

47.5

47.9

Average mass
conservation
violation

0.17

0.031

0.0000011

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Summary

Summary

Applying our Softmax Constraints Layer to deep learning downscaling architectures



enforces physical laws in neural networks



increases predictive accuracy for downscaling

Thanks for your
attention!

