AI4Sim

Leveraging AI for numerical simulation

26/11/2024

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Corporate Content Team
Version 2.0

AI4Sim

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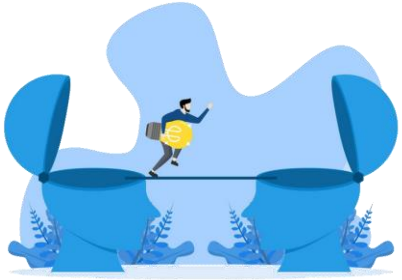
Missions

Scientific and technologic watch on AI for Numerical Simulation

Experiment new concepts and new technologies



Transfer knowledge to internal teams

Communicate internally and externally on the work of the team

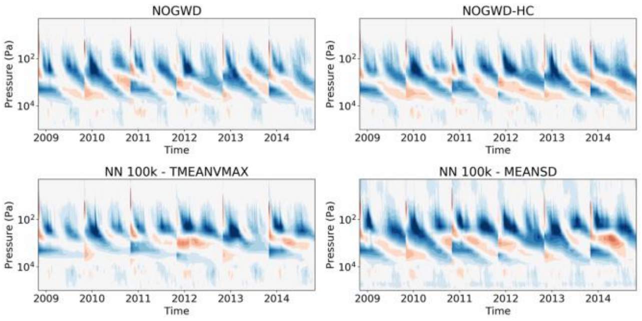
A bit of context

AI for numerical simulations

Increasing development complexity

Usage
Correct bias from a solver
Emulate parametrization
Surrogate a part of the physic in the numerical solver
Create closure models (only for CFD)
Quantify uncertainties
Surrogate a complete numerical solver

Parametrization of non orographic gravity waves (Chantry et al, 2021 ; ECMWF)



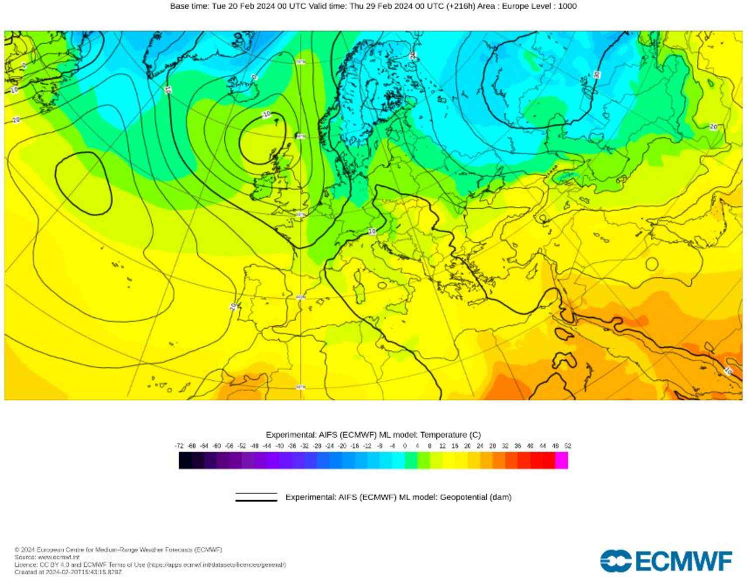
GraphCast (Lam et al, 2022 ; DeepMind)

FengWu (Chen et al, 2023 ; CN)

PanguWeather (Bi et al, 2023 ; HuaWei)

AIFS (ECMWF, 2023)

Experimental: AIFS (ECMWF) ML model: Temperature and geopotential at various pressure levels



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ECMWF

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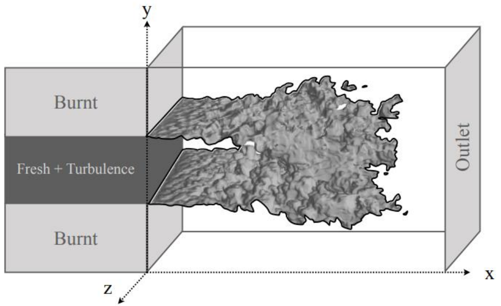
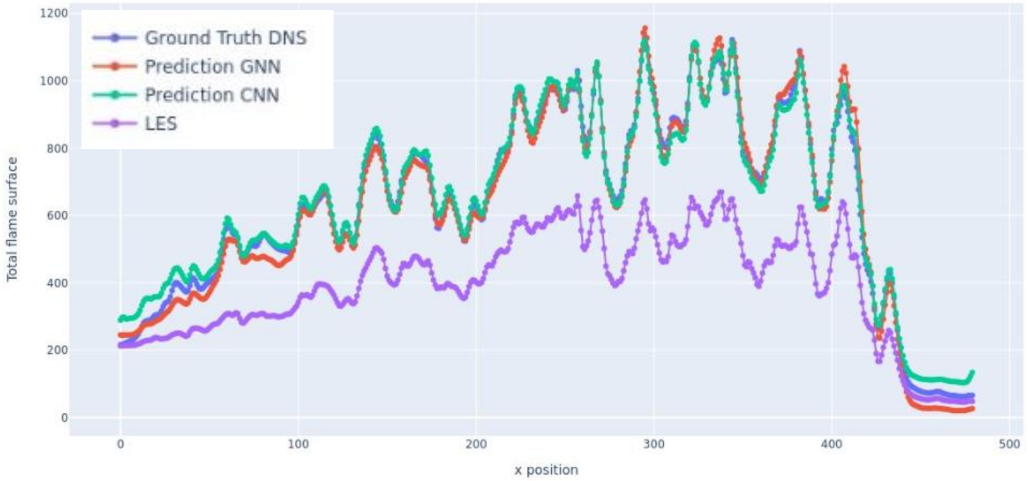
Combustion use case

- **Surrogating *sub-grid scale* physics to improve reduced-order space (*LES-like*) simulations**
- Simulating a combustion requires to resolve:
  - The fluid dynamics (CFD);
  - The chemistry (burnt/unburnt gas);
  - The heat dynamics.
  - With thermo-diffusive instabilities



- ➢ 48% improved accuracy
- ➢ 4 X faster than previous Sota CNN
- ➢ Tackles irregular grids



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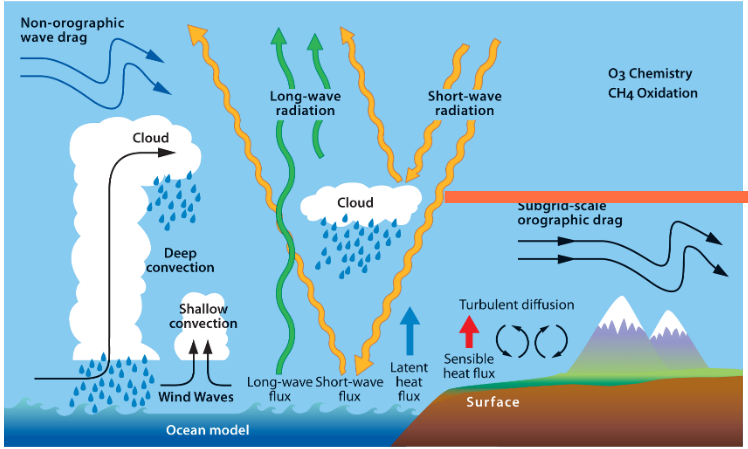
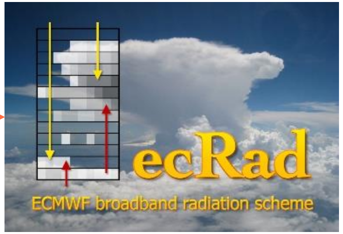
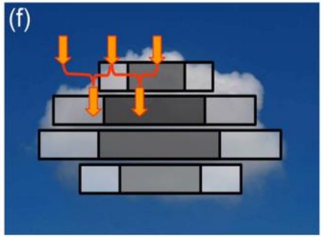
Weather forecast use case

- **Correcting the radiative scheme to reflect 3D cloud effect**

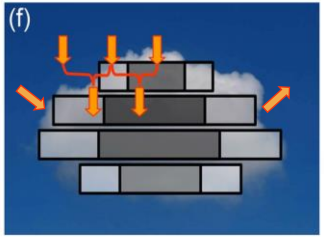




TripleClouds



Spartacus



SPARTACUS
=
Tripleclouds
+
3D effects

- *RNN + coupling solutions*
- *97 % accuracy*
- *A fraction of Spartacus running time*

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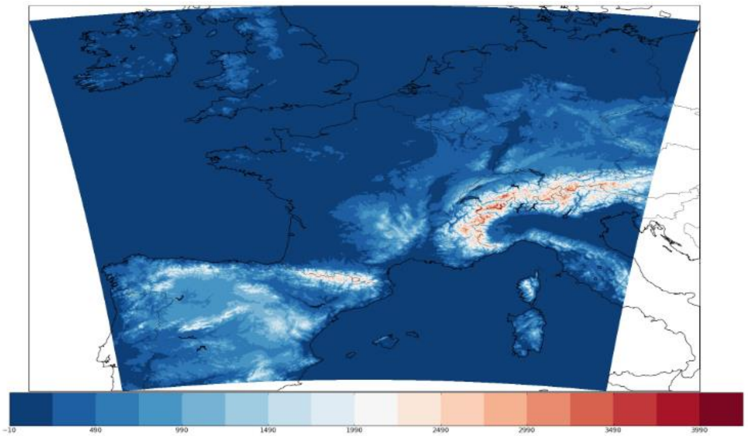
Weather forecast (on going)

- Collaboration with Météo-France
  - Emulating Arome with deep learning
- EXPLEARTH
  - Probabilistic weather forecast with deep learning (PhD student)

Arome

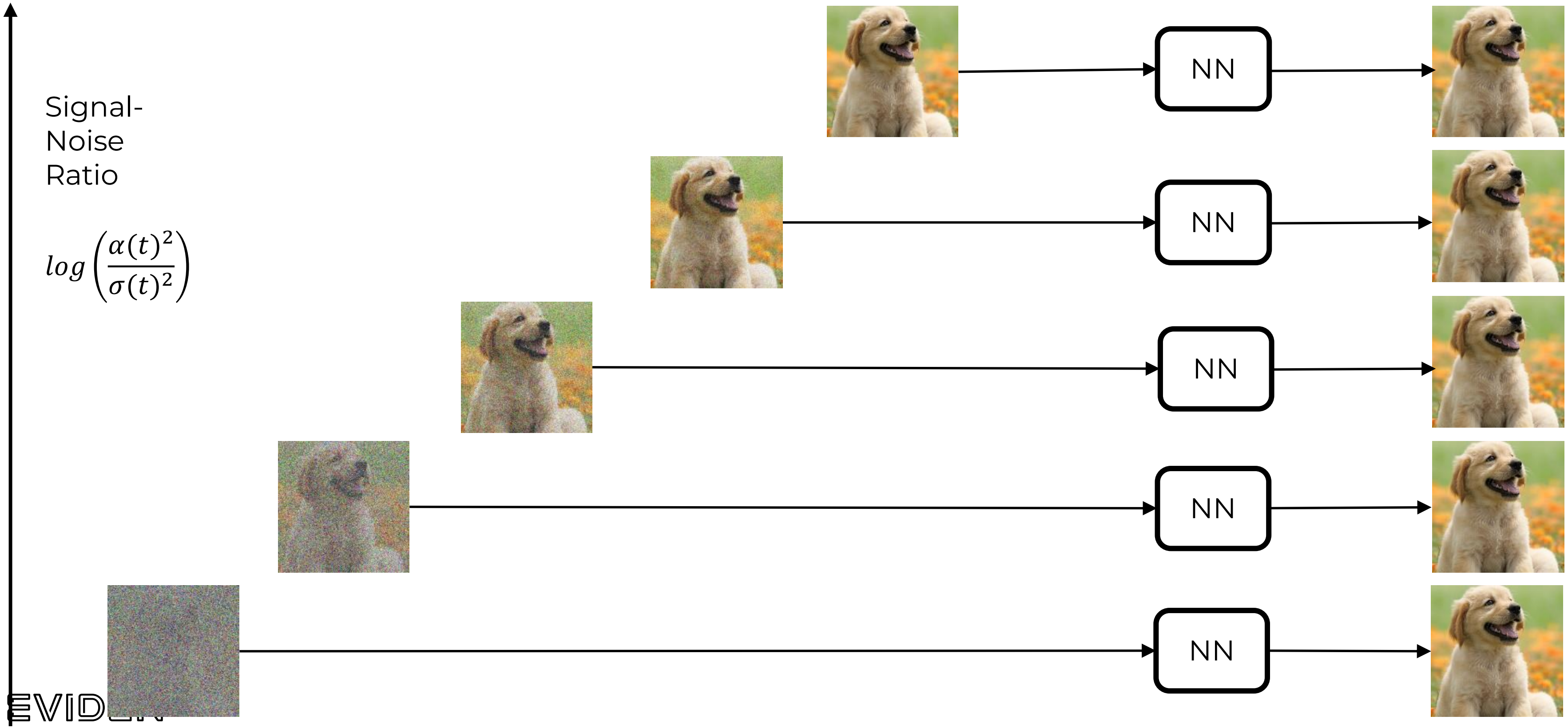


Diffusion Models:

How Generative AI is capable of Downscaling Meteorological Data Effortlessly

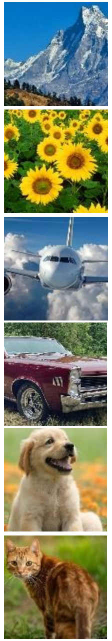
Diffusion Models for Meteorological Data Downscaling

Diffusion model principles

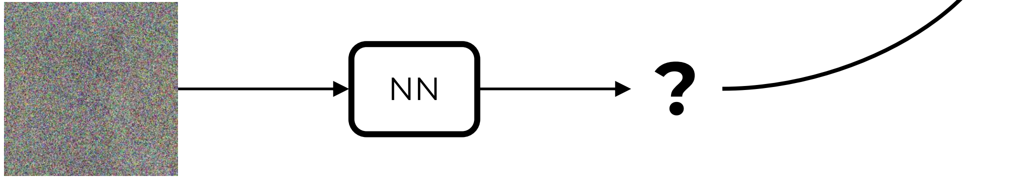


Diffusion Models for Meteorological Data Downscaling

Diffusion model principles



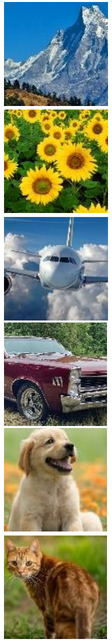
The most likely
given the set set of
6 images is simply
the average

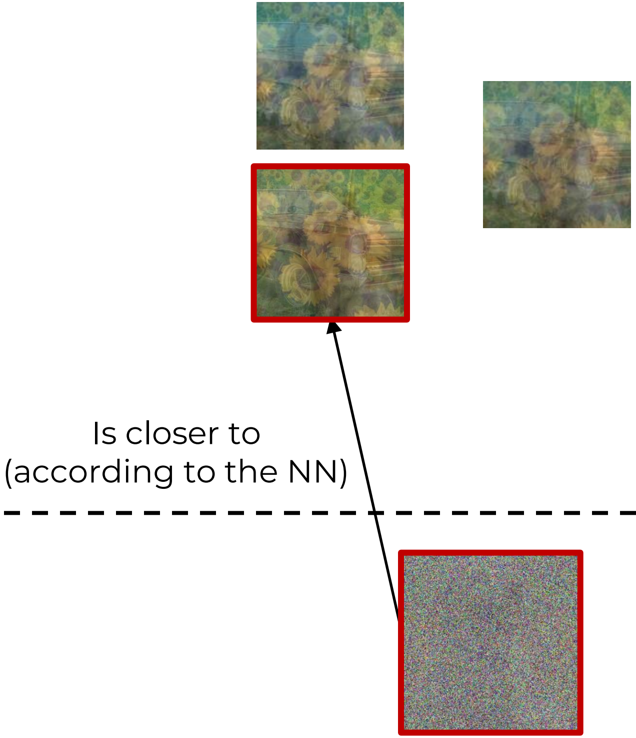


Diffusion Models for Meteorological Data Downscaling

Diffusion model principles

Likelihood Space

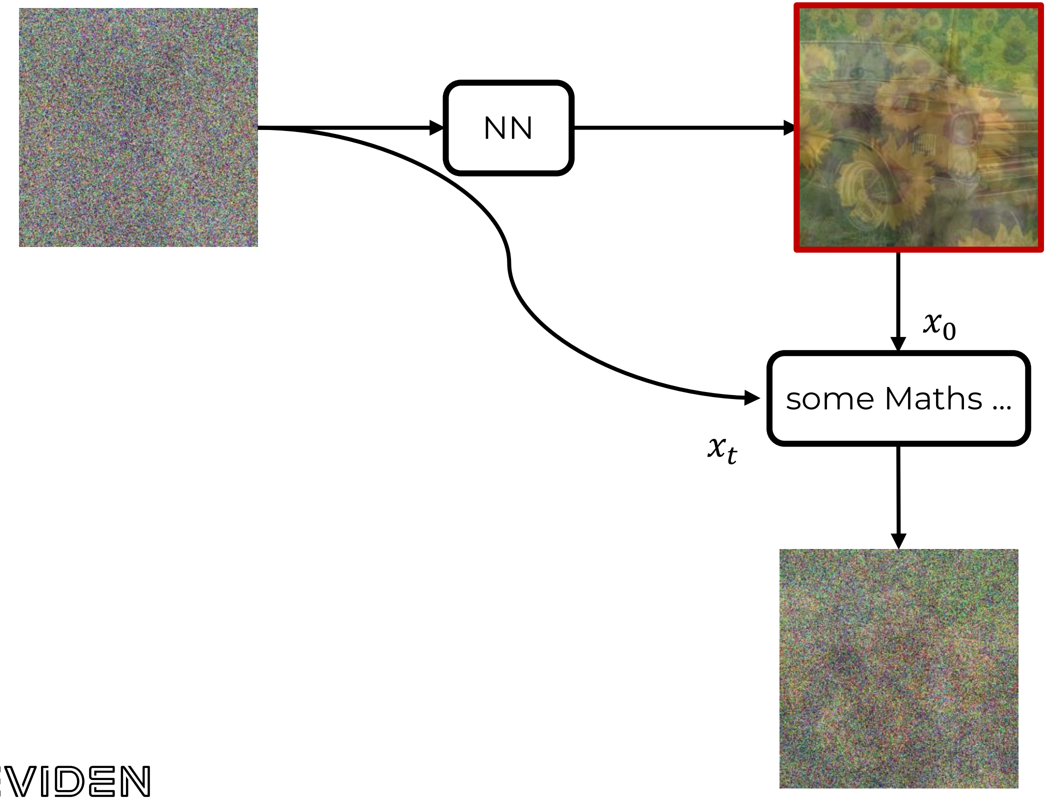




Denoising Space

Diffusion Models for Meteorological Data Downscaling

Diffusion model principles



Slightly denoised version towards the NN prediction

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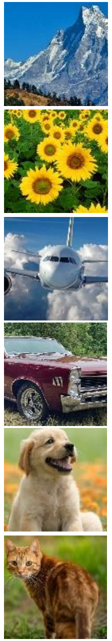
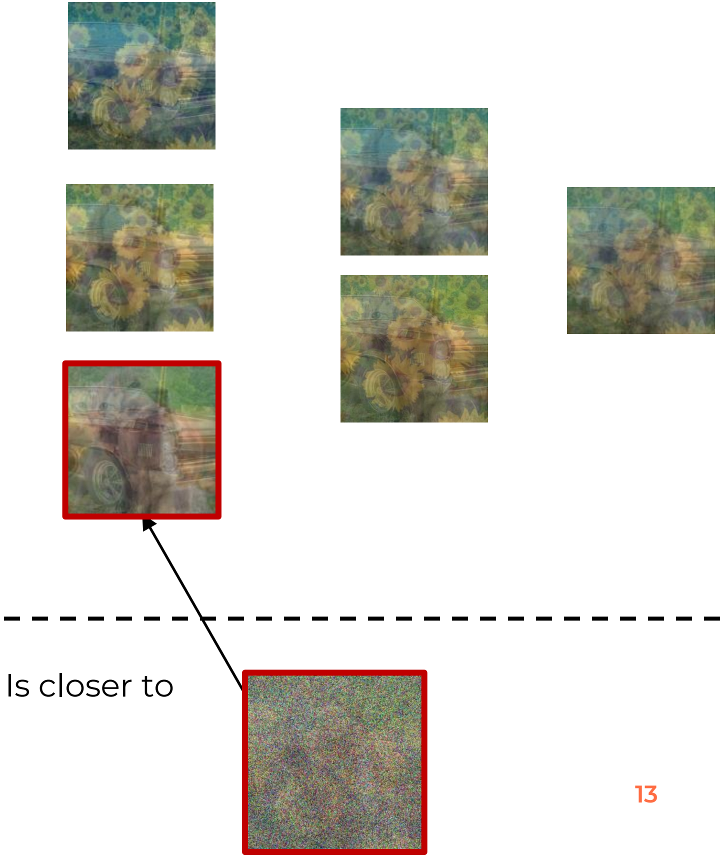
Diffusion Models for Meteorological Data Downscaling

Diffusion model principles

Likelihood Space





Denoising Space

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Diffusion model principles

Likelihood Space

Denoising Space

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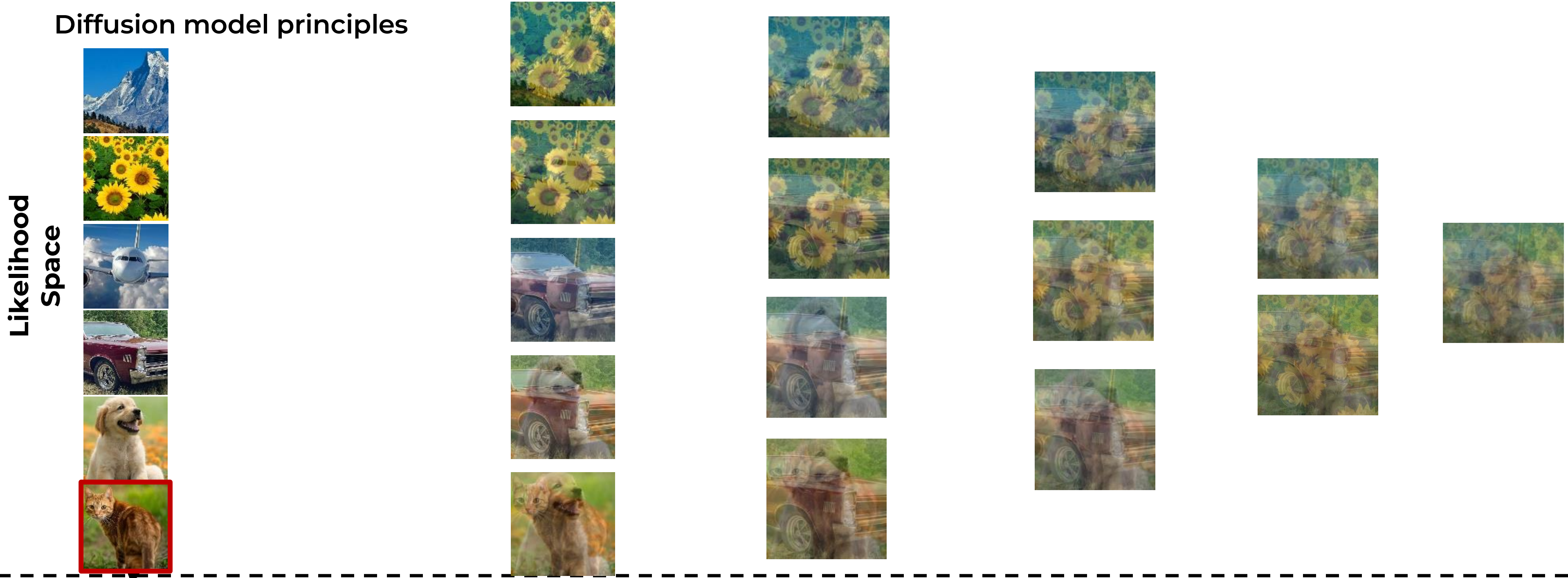

Is closer to

Diffusion naturally downscales the data-set average !!!

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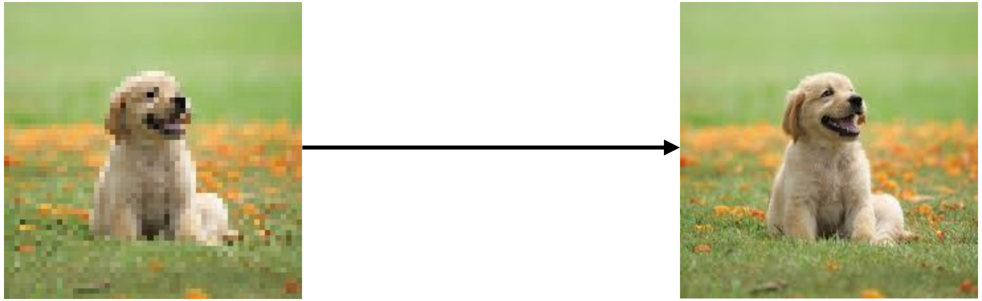
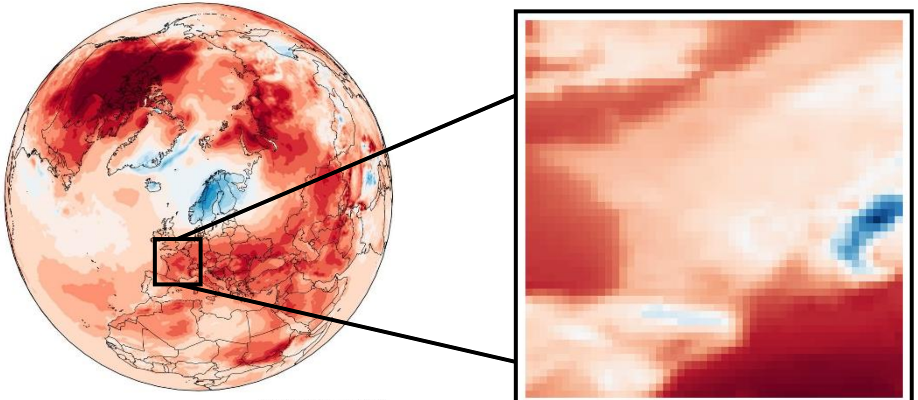
Diffusion Models for Meteorological Data Downscaling

From ERA5 to Arome resolution



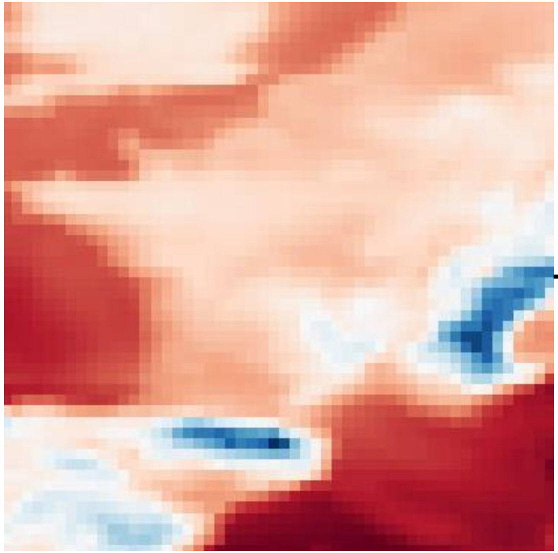


Based on ERA5 reanalysis

How can we increase the resolution ?

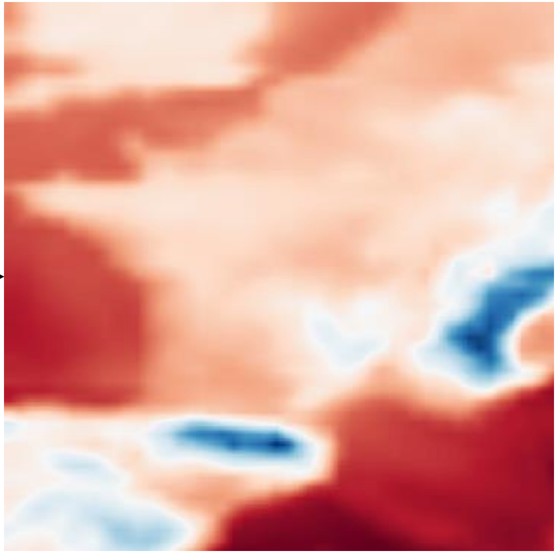
Diffusion Models for Meteorological Data Downscaling

From ERA5 to Arome resolution



ERA5 52x52

linear
interpolation

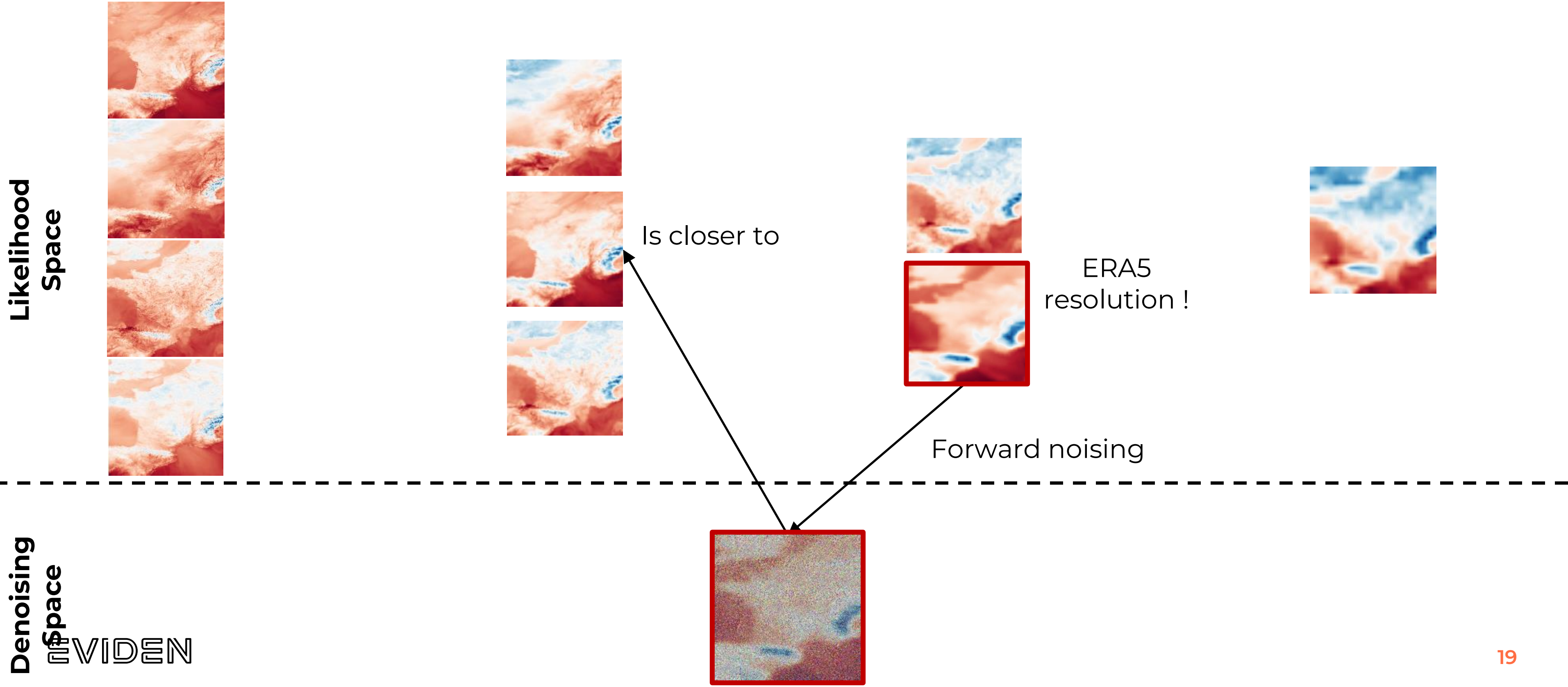


ERA5 512x512

Notice how the interpolated blurred
image looks like an intermediate
prediction in the reverse process

Diffusion Models for Meteorological Data Downscaling

From ERA5 to Arome resolution



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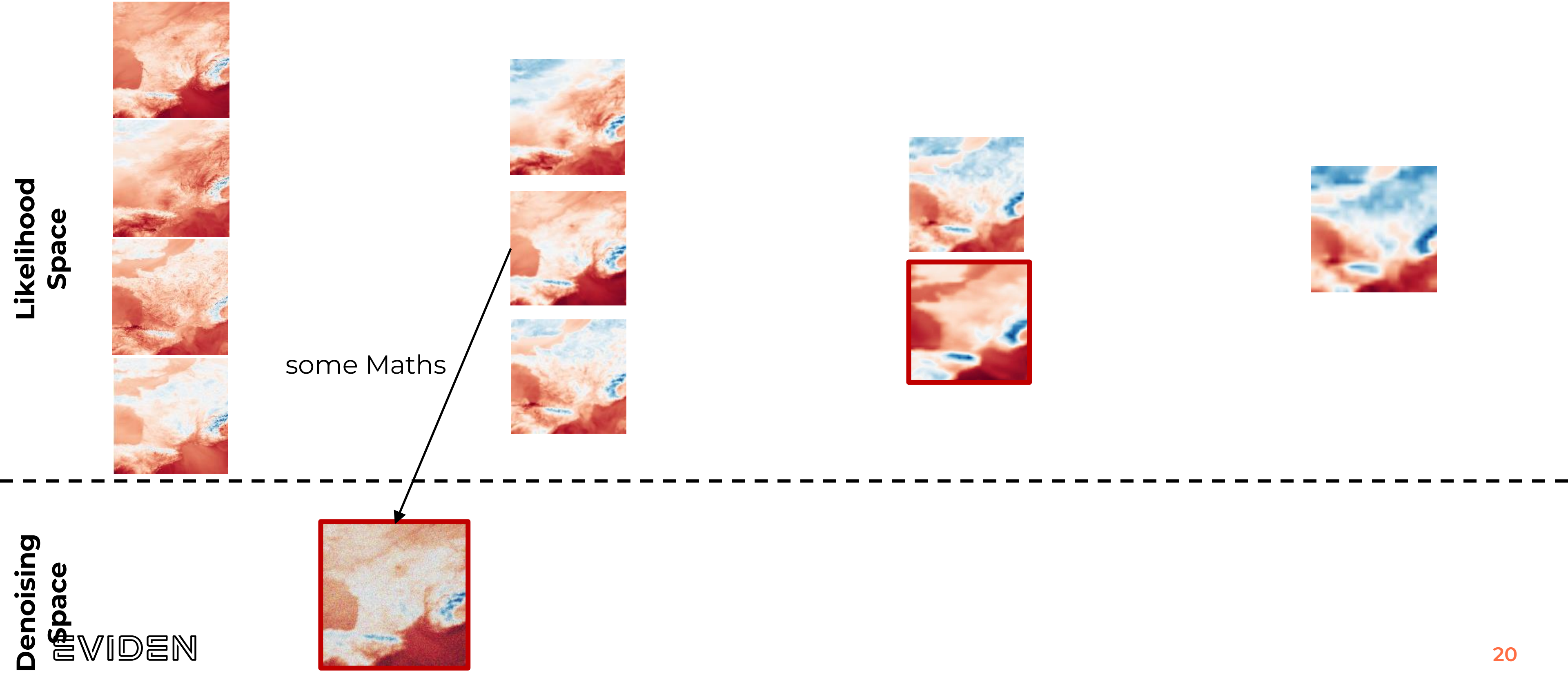
Diffusion Models for Meteorological Data Downscaling

From ERA5 to Arome resolution



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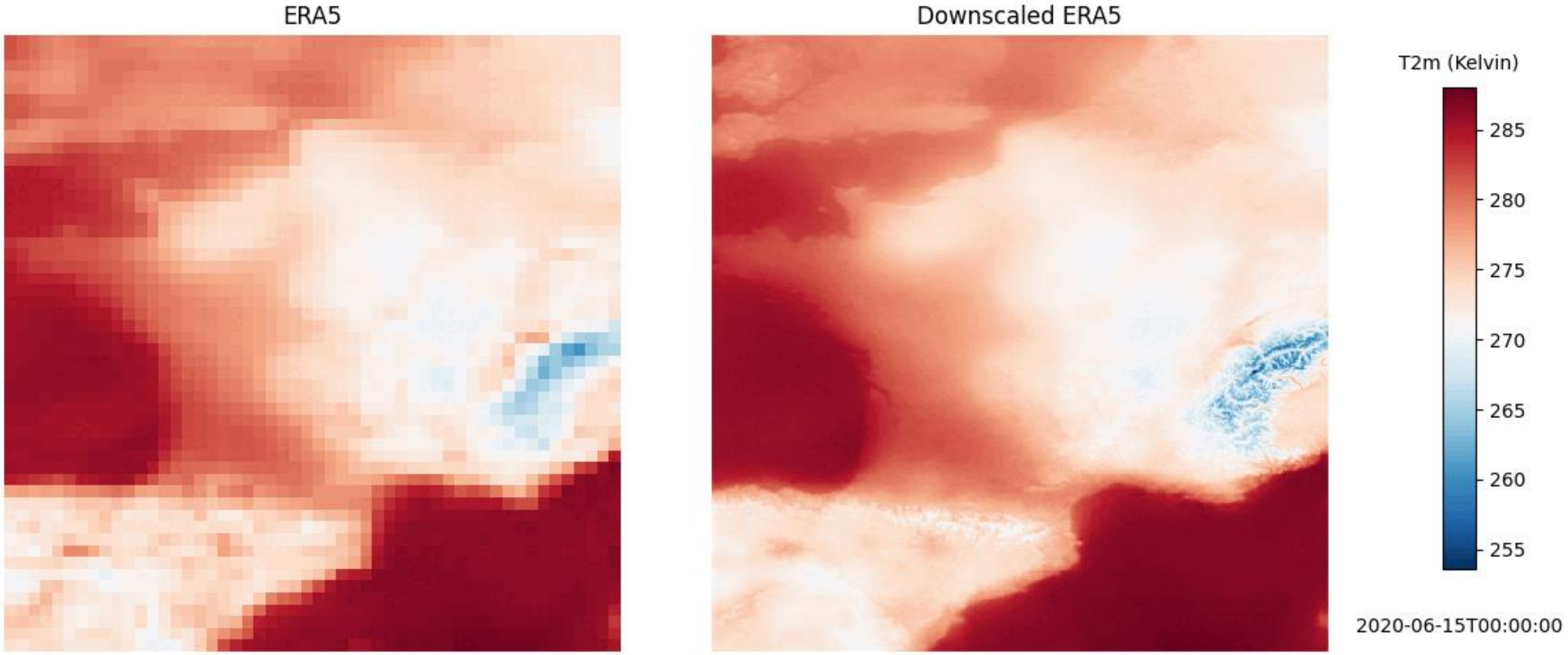
Diffusion Models for Meteorological Data Downscaling

From ERA5 to Arome resolution



Diffusion Models for Meteorological Data Downscaling

Conclusion

- Downscaling images is somewhat a default behavior for diffusion models.
- We can leverage from that behavior to shortcut the denoising process if a low resolution prior is available at inference time (ERA5 data in our case).
- The neural network no longer requires to be trained on the full process. Training the denoiser only on first steps of diffusion is enough.
- This shortcut trick we used to efficiently downscale ERA5 is also known as « Guided Image Synthesis » (*SDEDIT: Guided image synthesis and editing with stochastic differential equations (2022): https://arxiv.org/pdf/2108.01073*).

Thank you !

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