Industry-Scale CO2 Flow Simulations with Model-Parallel Fourier Neural Operators

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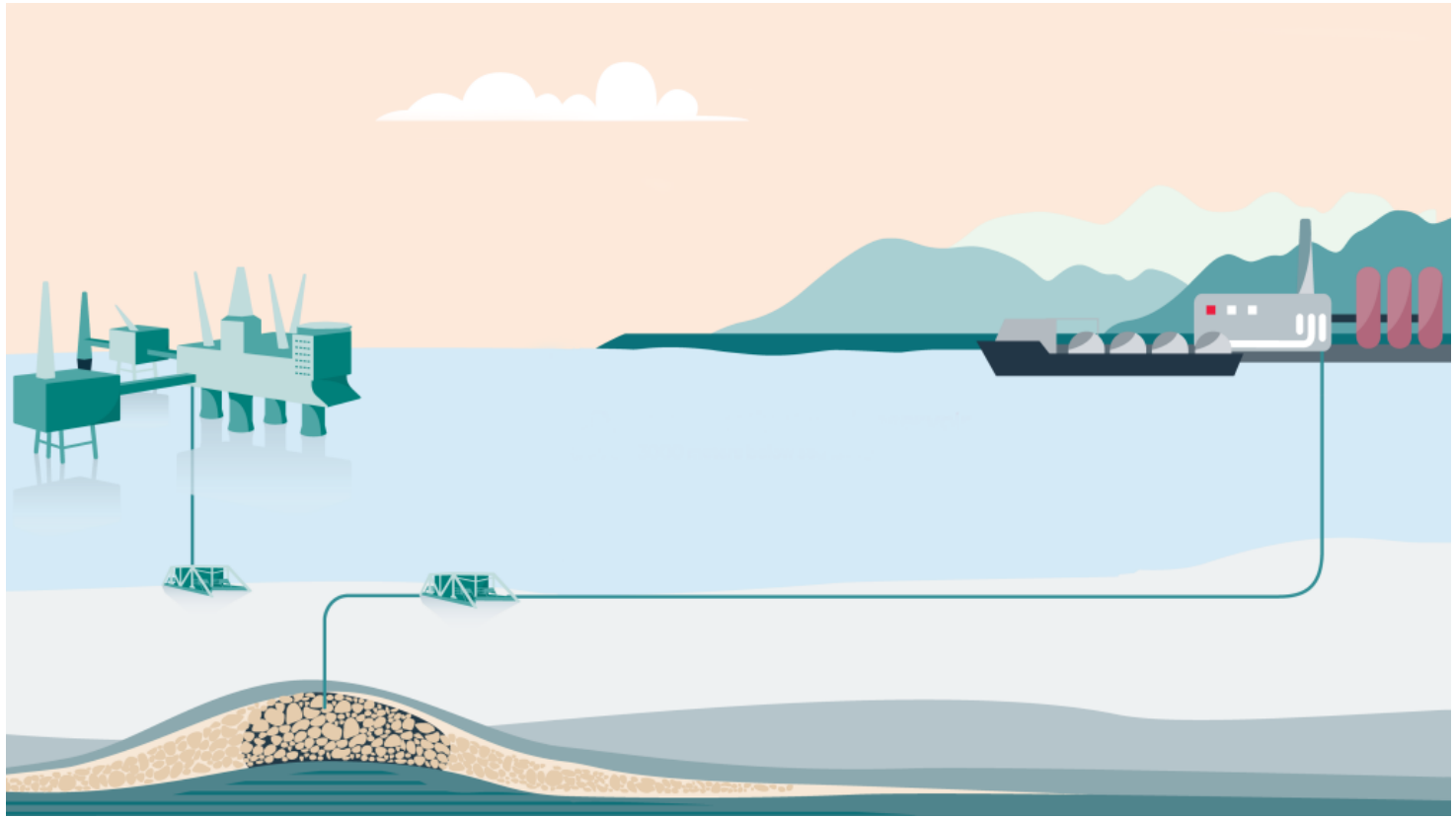
Simulations for Geological Carbon Storage

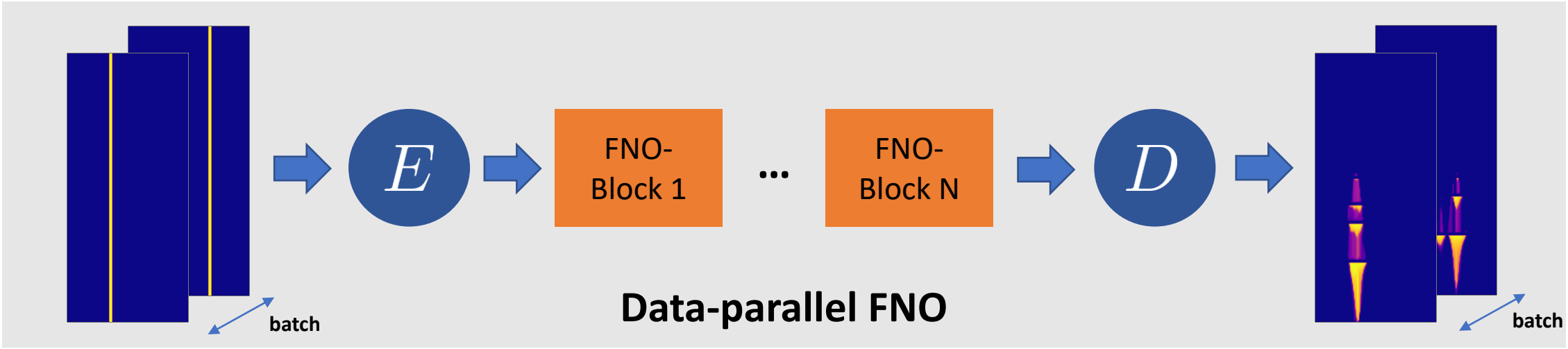


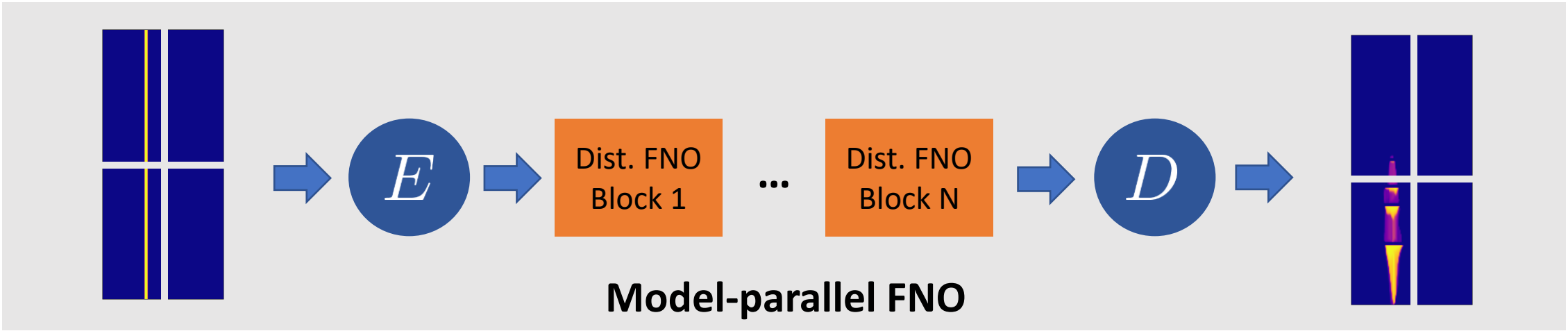
[Figure from *https://www.equinor.com/news/archive/20201215-northern-lights-go-ahead*]

Need simulations to answer:

- Where can I store CO2?
- How much CO2 can I inject?
- Is it safe? Can it leak?
- Can we store it cost effectively?

Model-parallel Fourier Neural Operators





[Li et al. (2020), "Fourier Neural Operator for Parametric Partial Differential Equations"]
[Hewett at al. (2020), "A Linear Algebraic Approach to Model Parallelism in Deep Learning"]
[Grady et al. (2022), "Towards Large-Scale Learned Solvers for Parametric PDEs with Model-Parallel Fourier Neural Operators"]

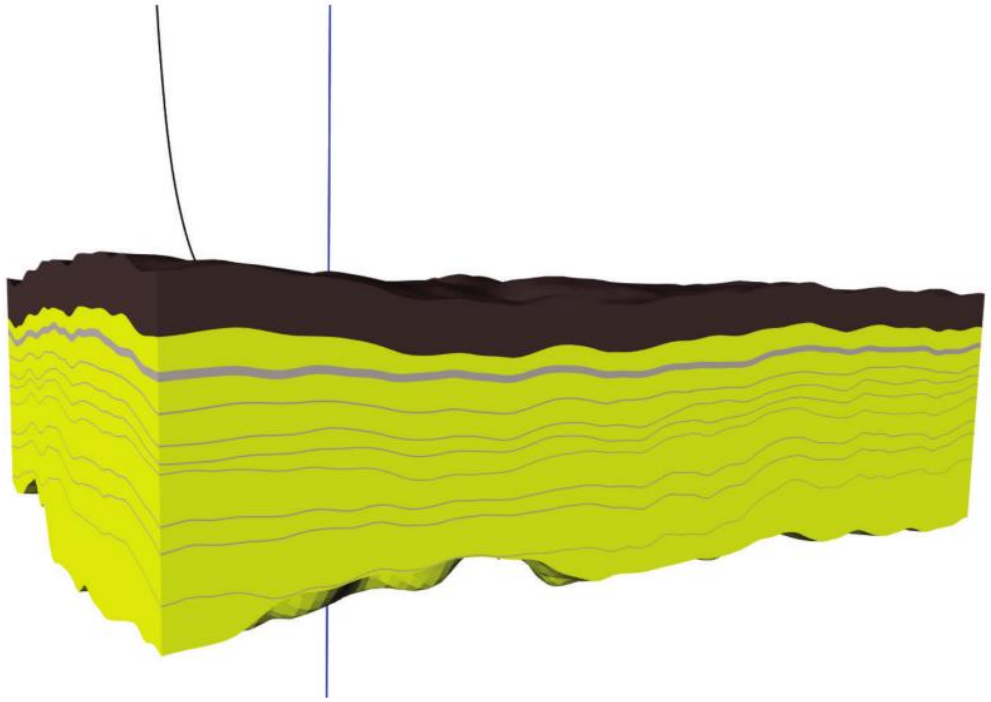
CO2 Flow Simulation at Sleipner

[Figure from *https://www.equinor.com/news/archive/2019-06-12-sleipner-co2-storage-data*]

Sleipner CCS Project
North Sea, Norway

CO2 Flow Simulation

- Simulate 1,600 CO2 plumes with OPM
  - Vary CO2 injection location (1-4 wells)
  - Geo model fixed
- Training
  - 8 x Nvidia A100s (640 GB memory total)
  - 50 epochs
  - Batch size 2
- Code available at:
  - *https://github.com/microsoft/AI4FluidSimulations*



[263 x 64 x 116] -> 2 million cells

[Figure from *https://co2datashare.org/dataset/sleipner-2019-benchmark-model*]

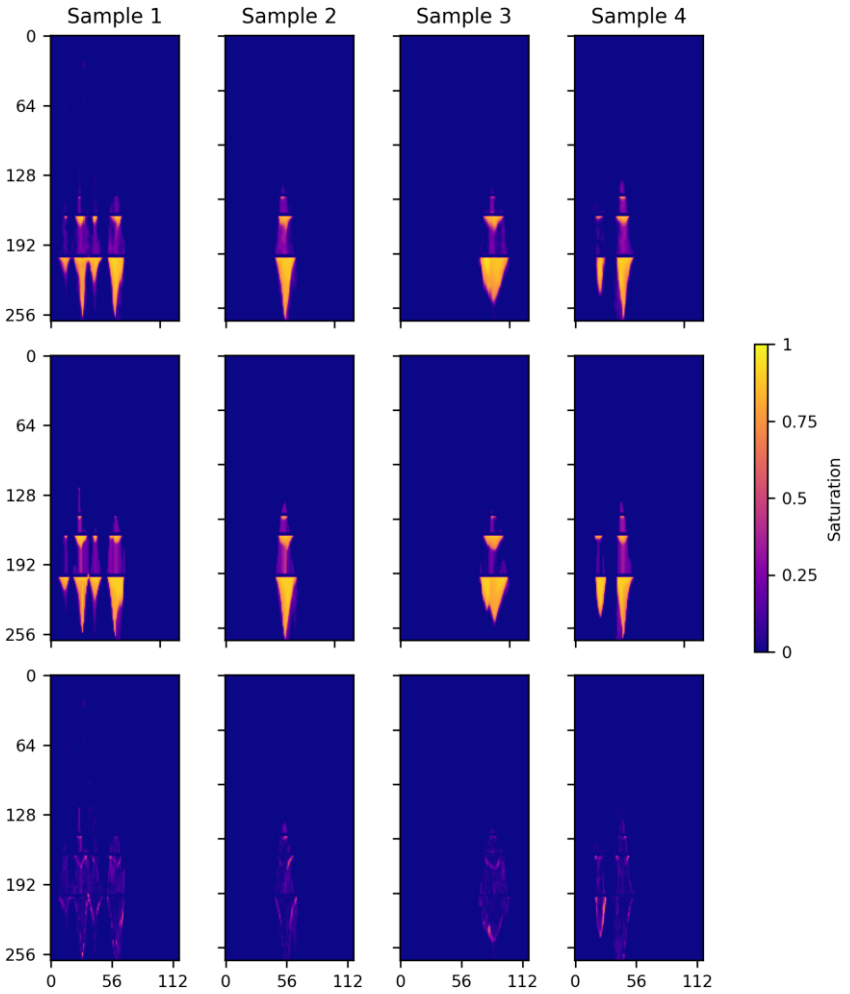
[Rasmussen et al. (2021), "The Open Porous Media Flow Reservoir Simulator"]

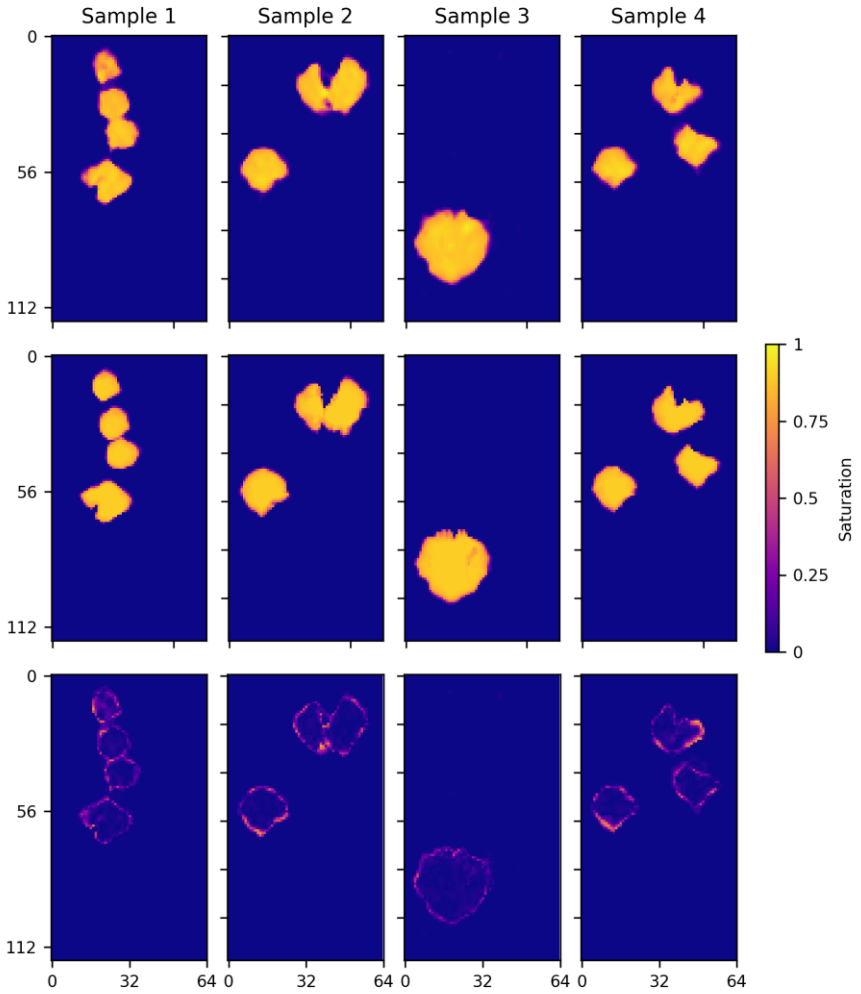
CO2 Flow simulation

FNO

OPM

Difference





CO2 Flow – Economics & Performance

- At what point do you break even?

	OPM	FNO
Training cost	-	$5,487 + $557
Simulation time	~ 1 hour (120 CPU cores)	.12 s (8 x A100)
Cost per simulation	$3.4	0.11 cents (3,000X)
Amortize training cost	-	1,778 simulations

- Scores

	MSE	R2
Validation Data	1.1104e-4	0.9453
Test Data	1.1603e-4	0.9487

Many thanks to:

- Erik Skjetne (Northern Lights)
- John Godlewski (SLB)
- Seismic Laboratory for Imaging and Modeling (Georgia Tech)

FNO examples:

https://github.com/microsoft/AI4FluidSimulations

DistDL:

https://github.com/distdl/distdl

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