Carbon sequestration in the subsurface: The atlas and the monitoring

Yunyue Elita Li (elitali@purdue.edu)

Atlas coauthors: Xiangnan Wang, Jingchen Jiao, Anuar Togaibekov;

Monitoring coauthor: Bei Li

SUSTAINABILITY GEOPHYSICS PROJECT

PURDUE UNIVERSITY | Department of Earth, Atmospheric, and Planetary Sciences

NUS National University of Singapore

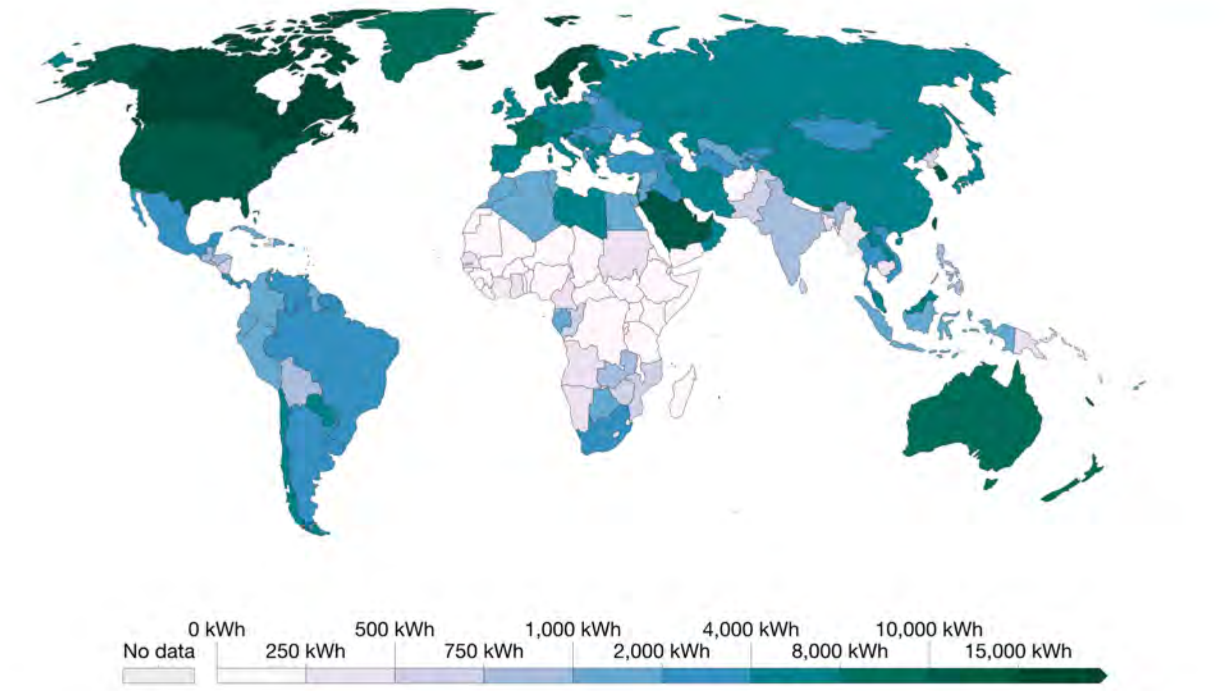
Immediate threat of climate change

- 26th UN Climate Change Conference of the Parties: Goals

Energy disparity

Per capita electricity consumption, 2020

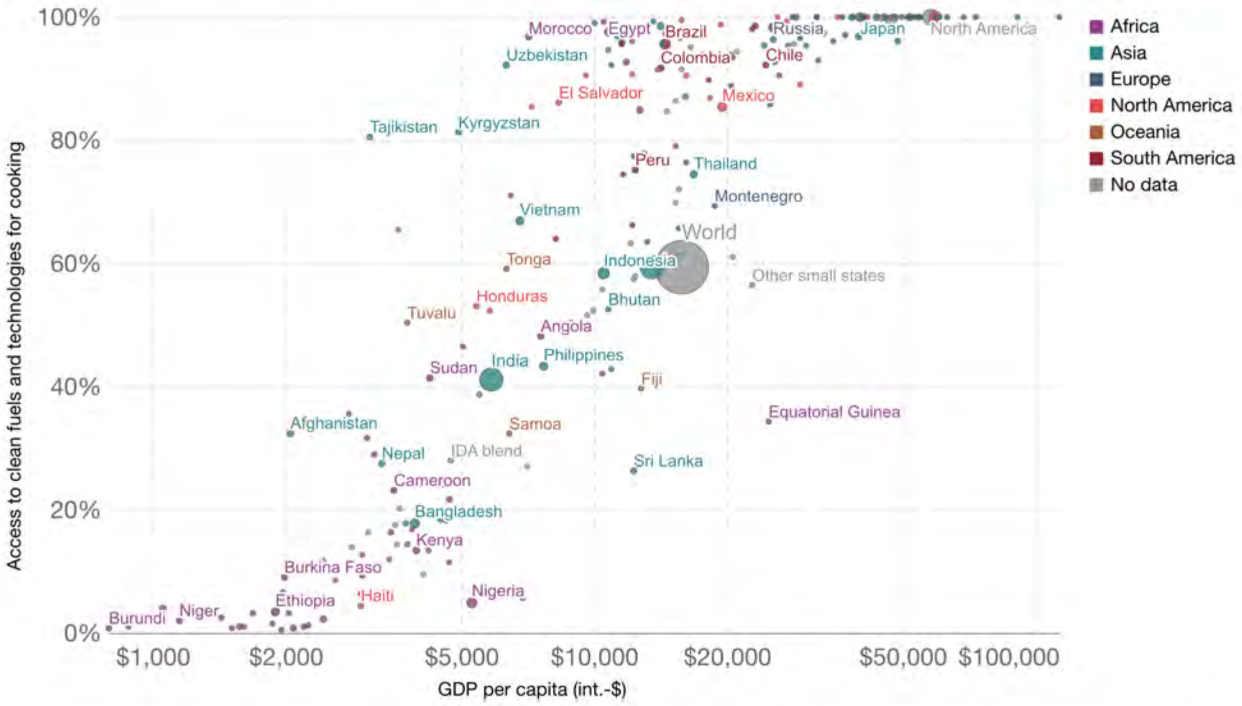
Average annual electricity consumption per capita, measured in kilowatt-hours (kWh) per year.



Source: Our World in Data based on BP Statistical Review of World Energy & Ember (2021)

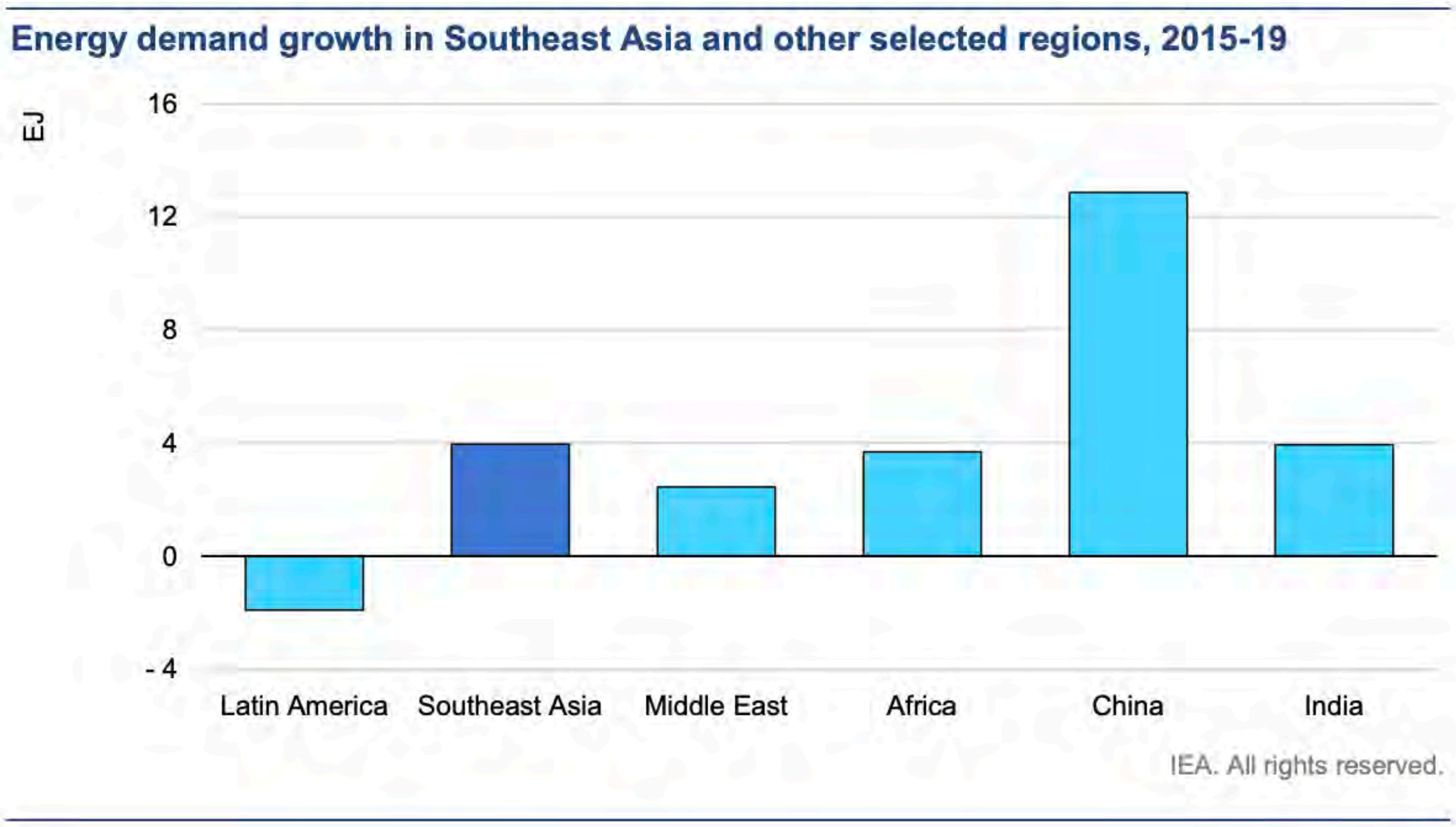
Access to clean fuels for cooking vs. GDP per capita, 2016

Access to clean fuels for cooking is vital in reducing the burden of health and mortality impacts of indoor air pollution.

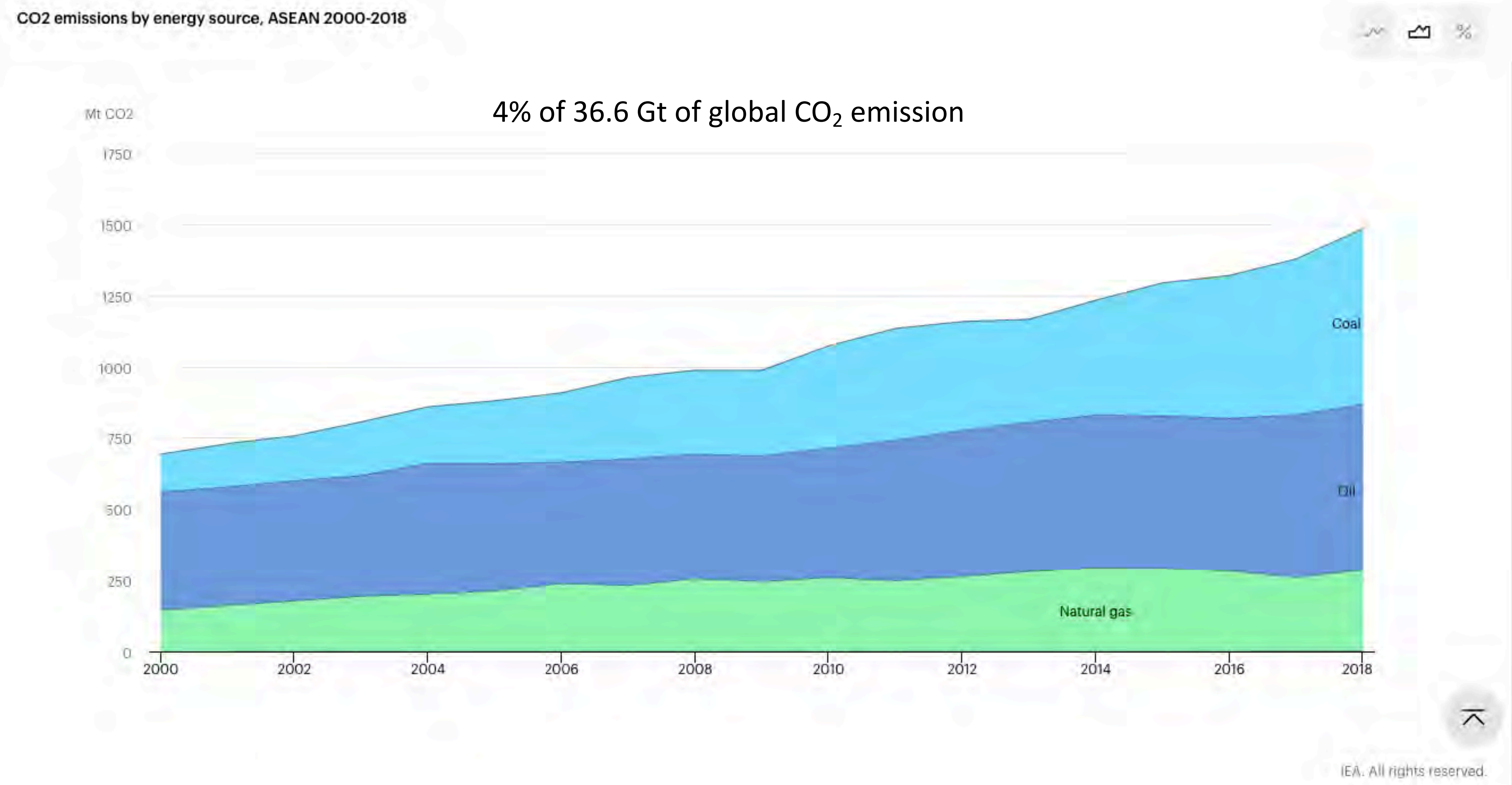


Source: World Bank

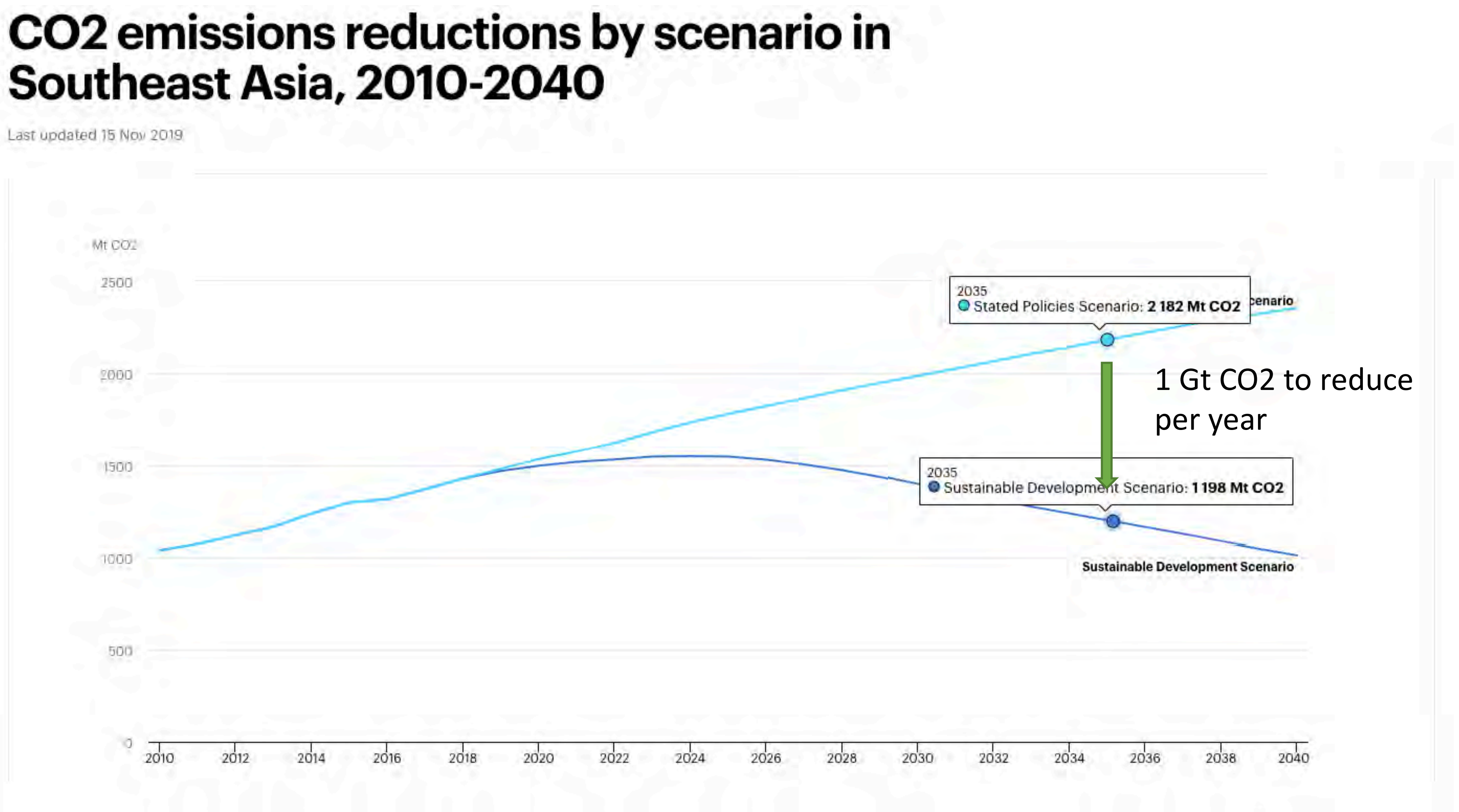
IEA (2021) report on energy demand



How much CO_2 has ASEAN produced?



How much CO_2 do we need to reduce?



Pathways for CO_2 reduction from the atmosphere

2.5 ton per year per acre

SEQUOIA NATIONAL PARK, CALIFORNIA, UNITED STATES - 2018/09/01: Upward view of giant sequoias in Sequoia National Park, California, USA. *Photo by Marji Lang/LightRocket via Getty Images*

0.5 ton per year per acre

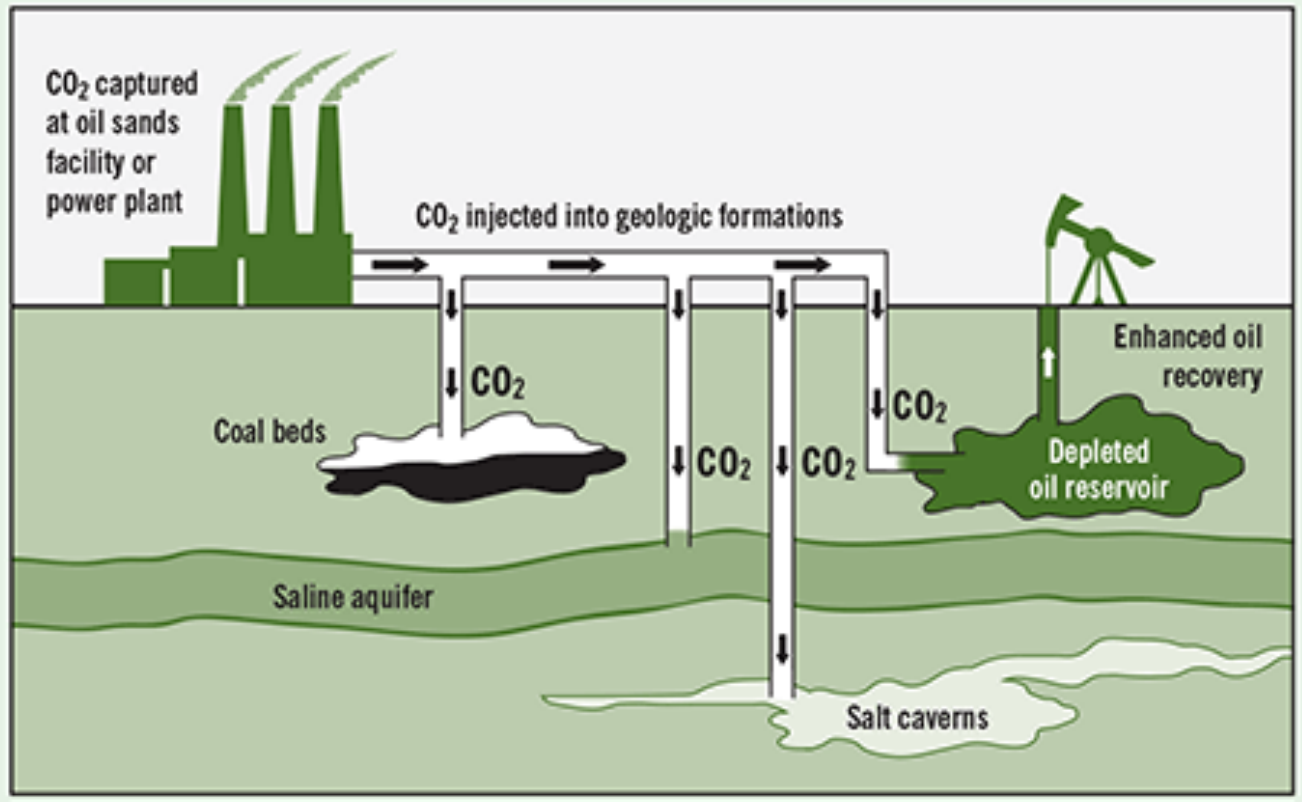
Shutterstock Foto

ASEAN data (2018)

- Forest: 48% of total land area
- Farmland: 17% of total land area

Carbon sequestration in the subsurface

- Four potential geological media
  - Depleted oil and gas (O&G) reservoirs
  - Deep saline aquifers
  - Coal beds
  - Shale and basalts



https://energywatch-inc.com/carbon-capture-utilization-storage-pipe-dream-potential-solution/

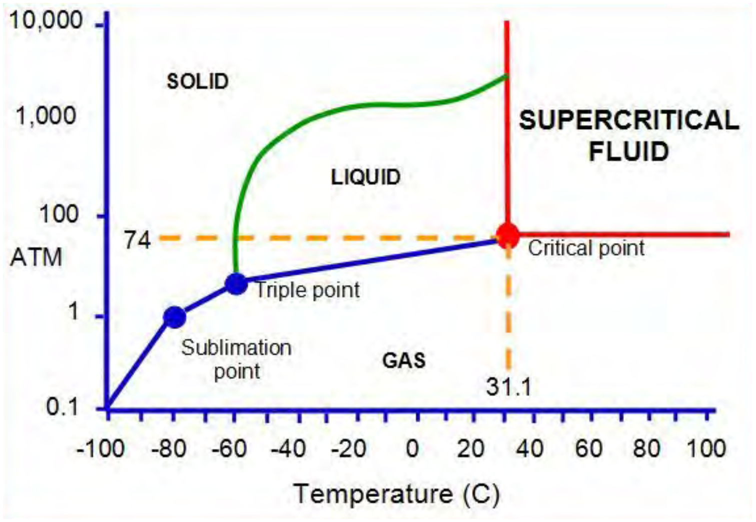
The research questions:

1. Do we have enough pore space for CCS in Southeast Asia? If so, where are the pore spaces?
2. Once we put CO_2 in the subsurface, how to make sure it stays in place?

Workflow for O&G fields: Storage capacity and injectivity estimation

Data
C&C Reservoir reports
Wood Mackenzie database
Published literature

62 fields from C&C Reservoirs
2720 fields from Wood Mackenzie



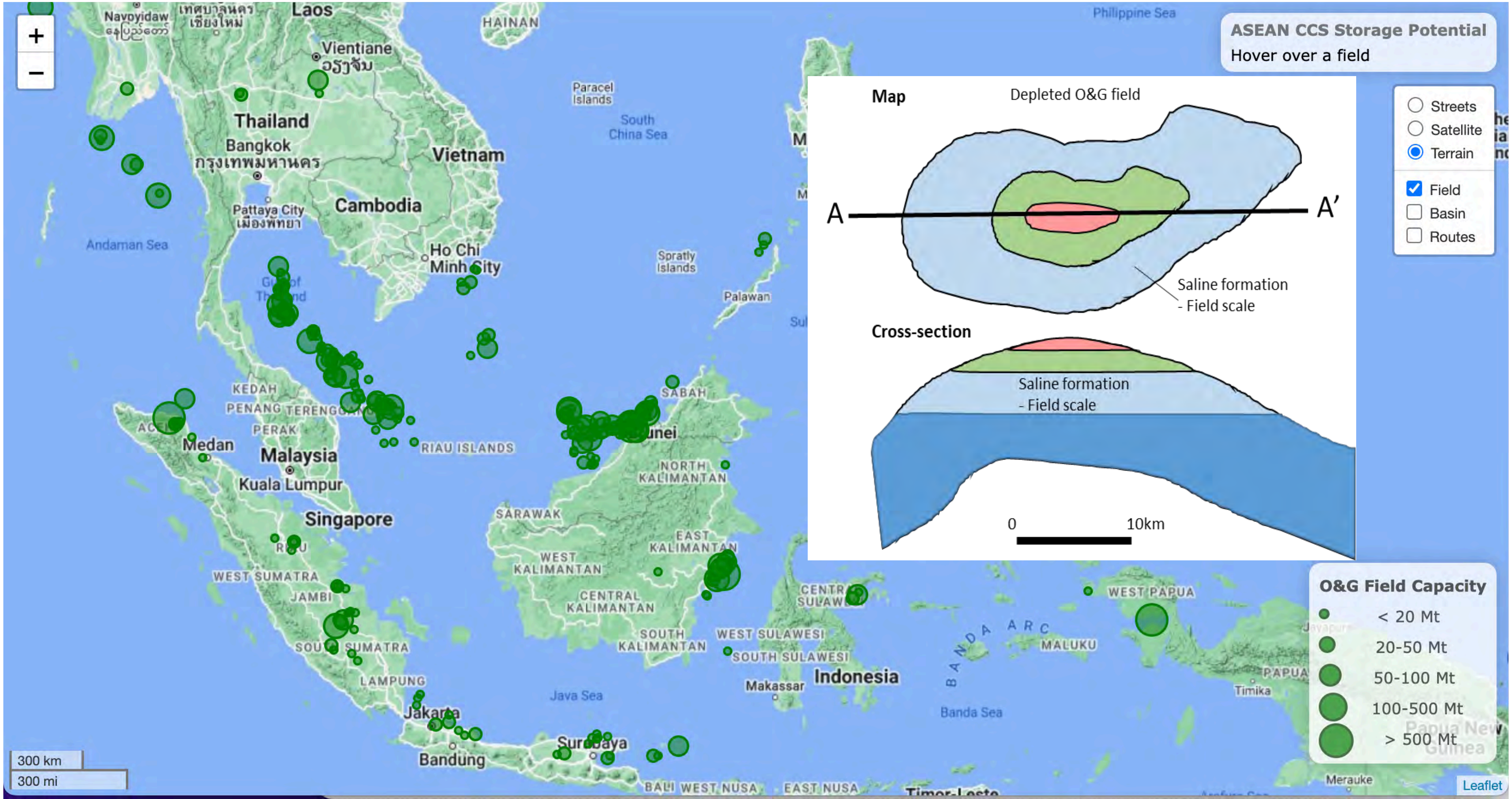
38 fields from C&C Reservoirs
196 fields from Wood Mackenzie

Deduced Information
1) Basin-scale geothermal gradients
2) Basin-scale pressure gradients

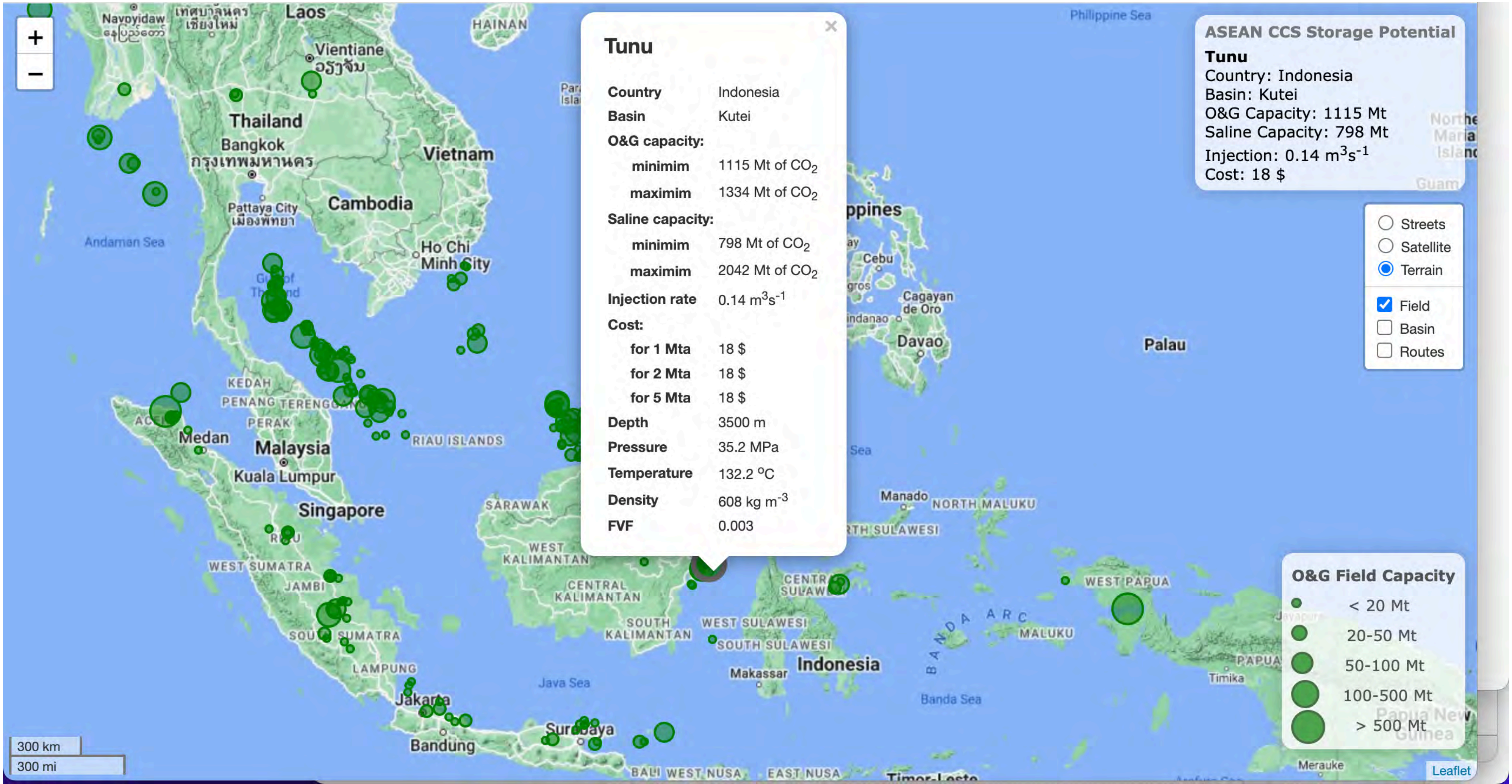
USGS Storage methodology for O&G zone
Injection rate estimation using **production data**

Li et al., submitted to J. of Greenhouse Gas Control, 2021

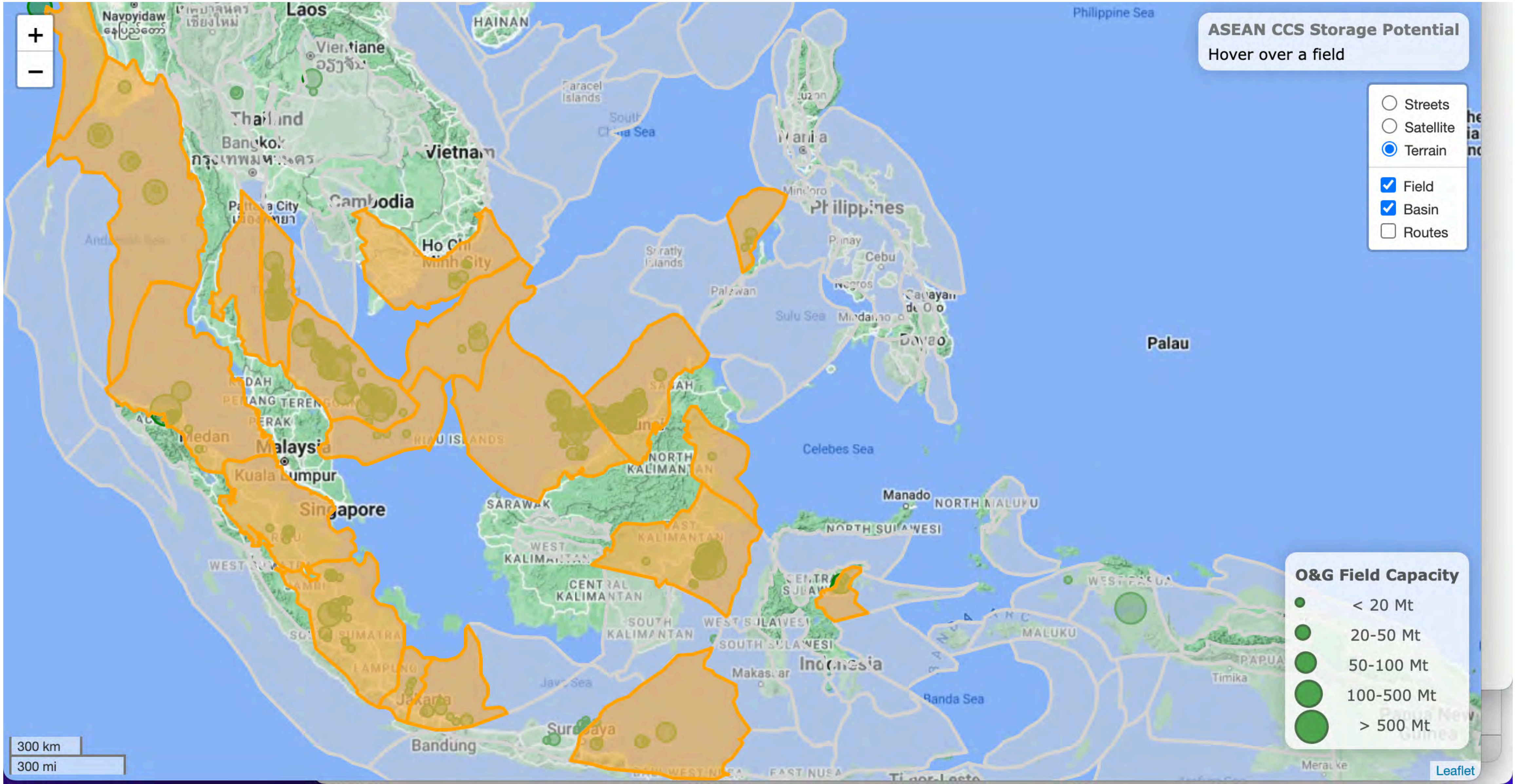
CO_2 Storage capacity at depleted O&G fields



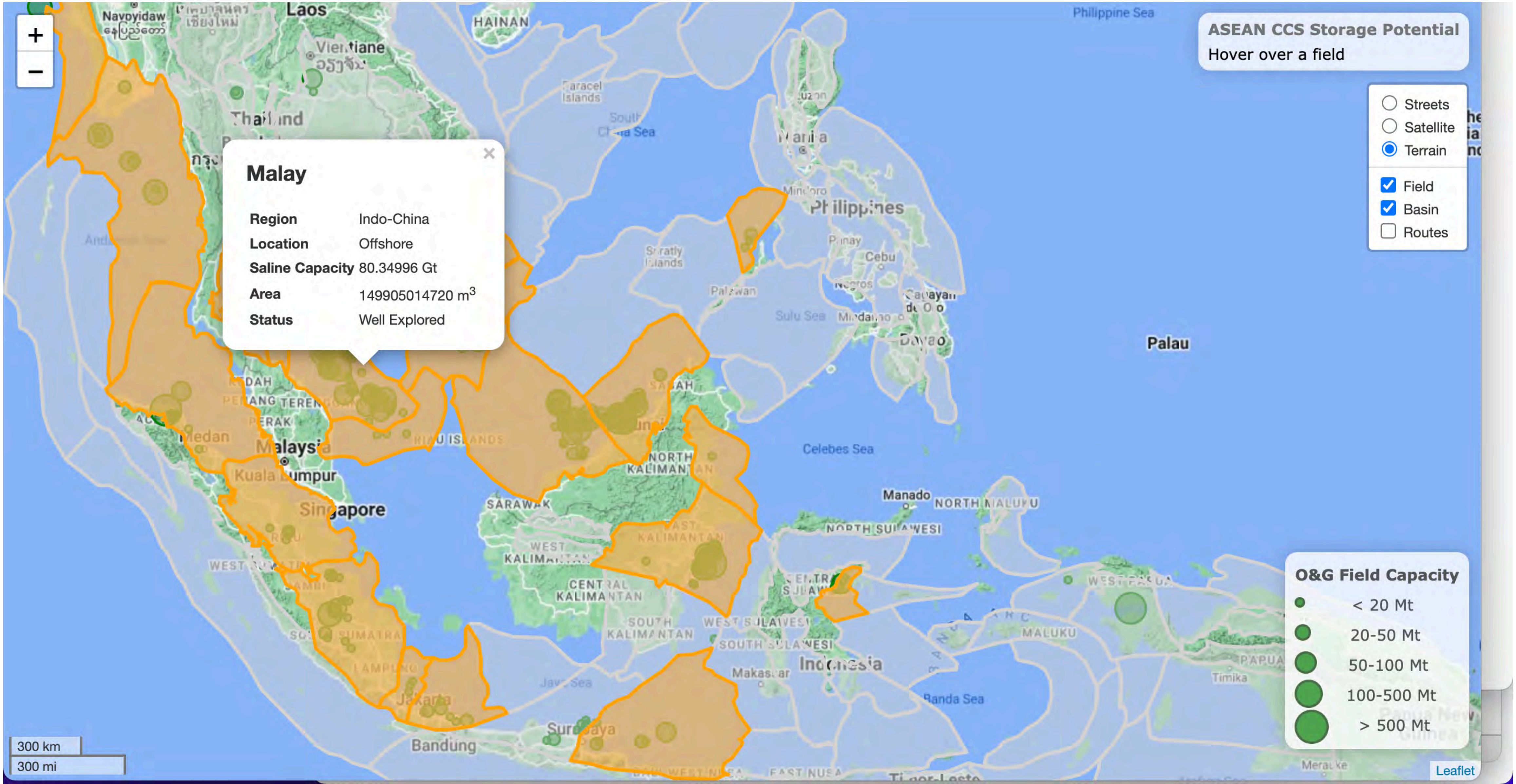
CO_2 Storage capacity at depleted O&G fields



CO_2 Storage capacity at basin scale

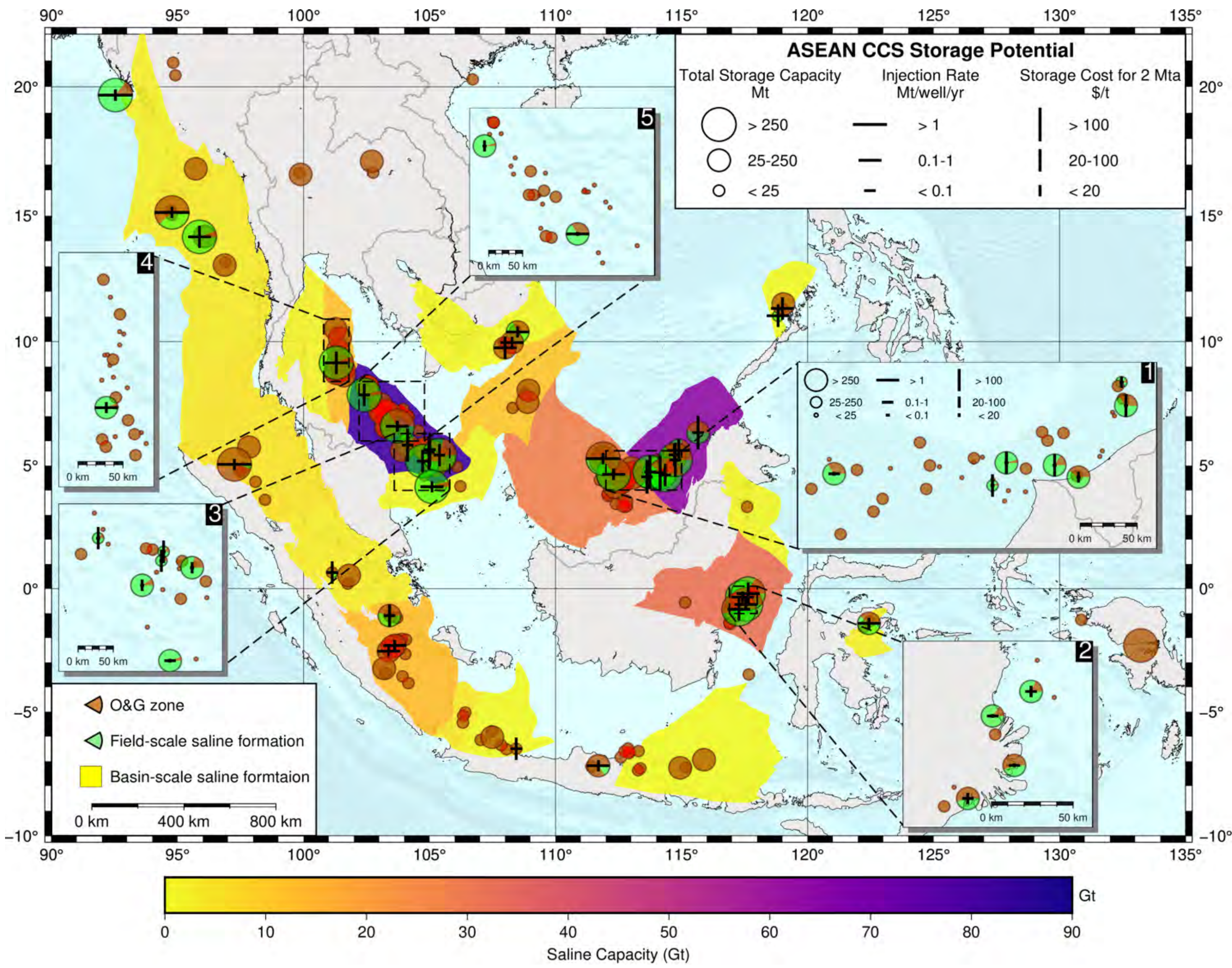


CO_2 Storage capacity at basin scale



CCS potential in ASEAN

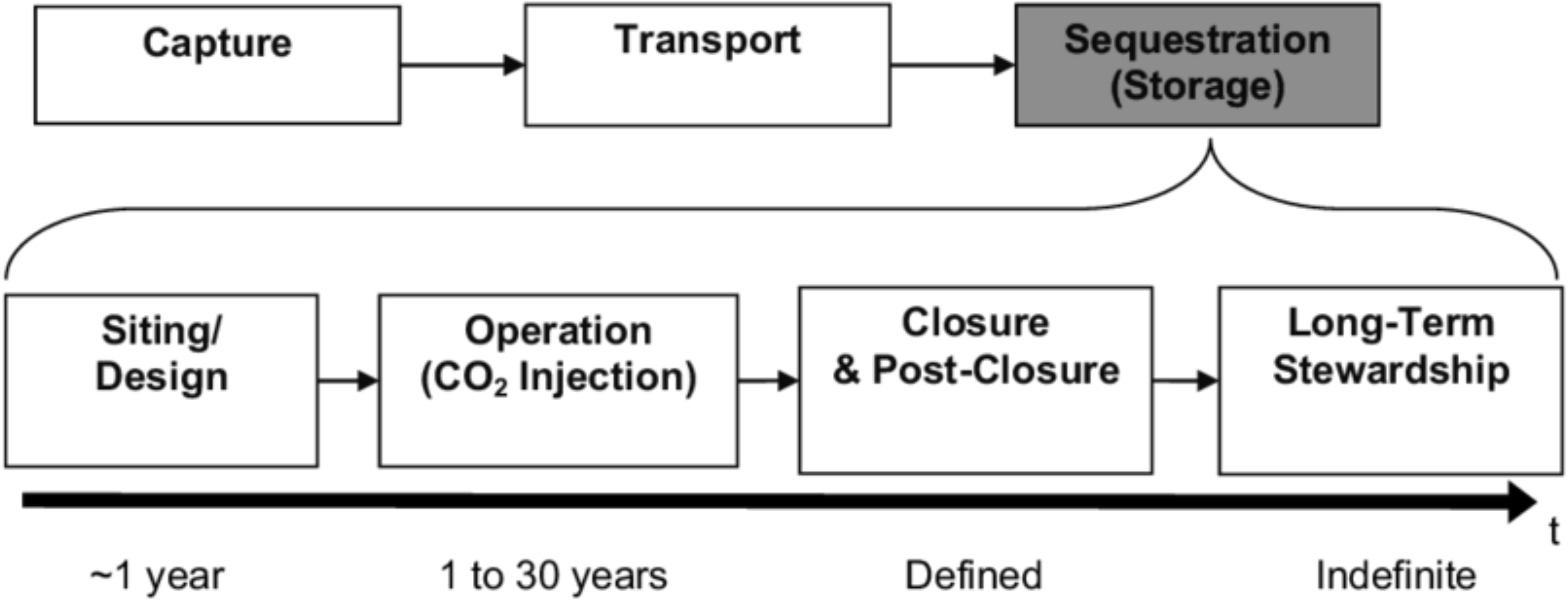
- Do we have enough pore space?
  - YES, in three tiers of storages
  - 11.7 Gt in 234 fields
  - 24.2 Gt in field-scale saline formations
  - 275 Gt in basin-scale saline formations



The research questions:

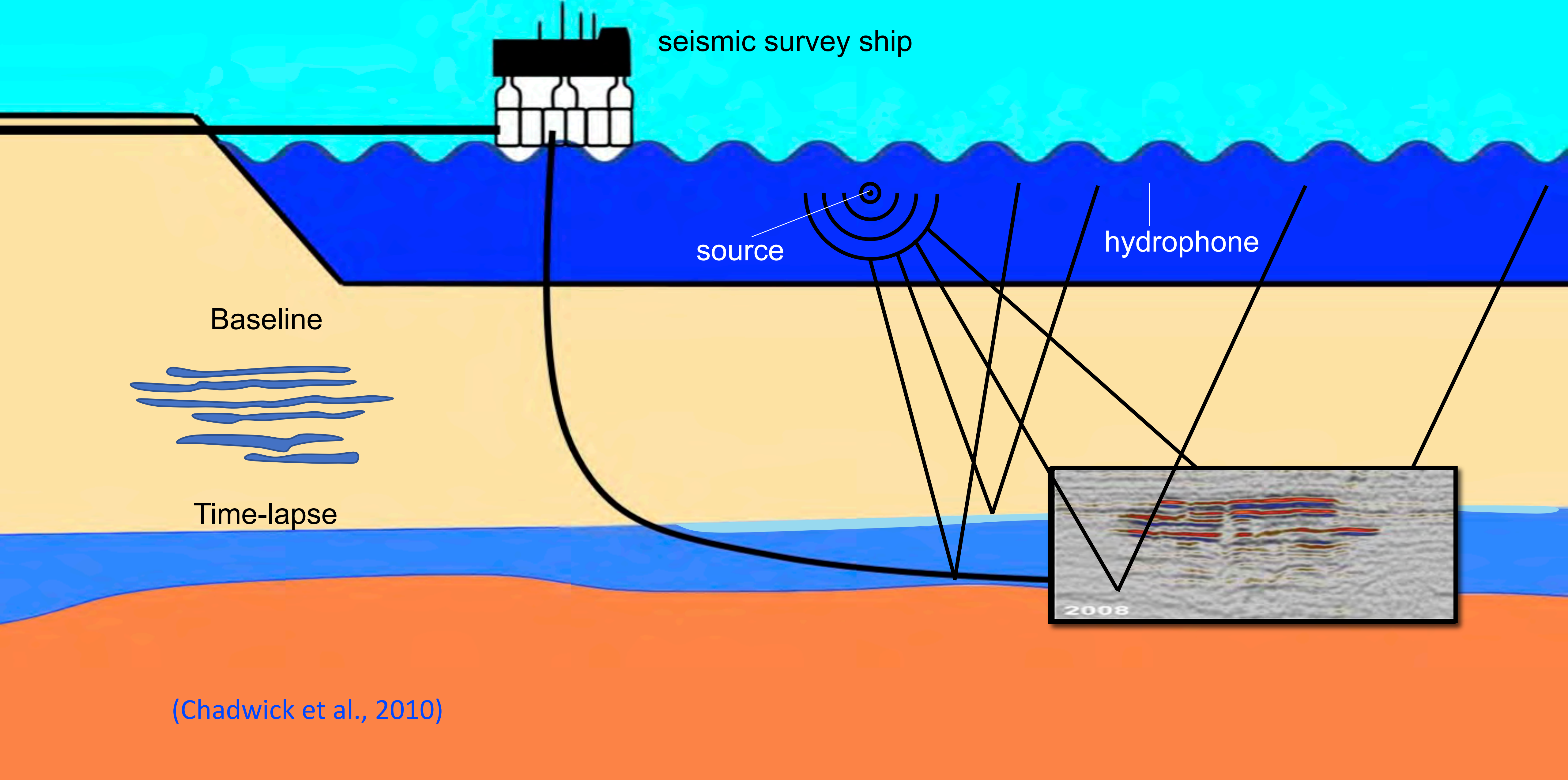
Once we put CO_2 in the subsurface, how to make sure it stays in place?

CCS timeframe



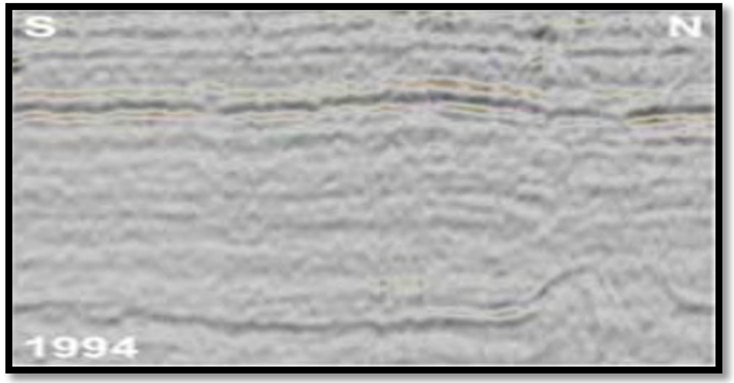
Trabucchi, Chiara & Patton, Lindene. (2008). Storing Carbon: Options for Liability Risk Management, Financial Responsibility.

Time-lapse (4D) seismic monitoring

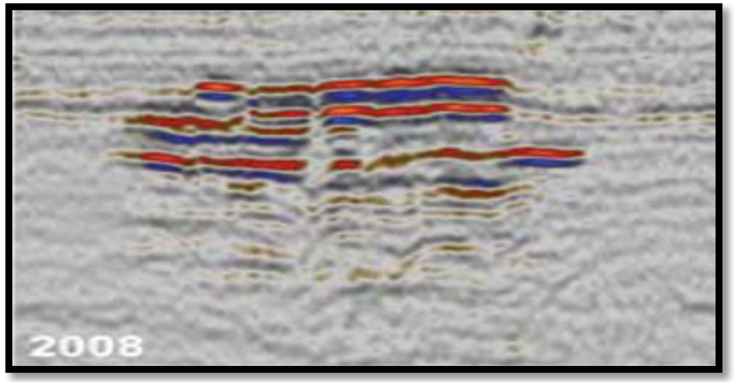


(Chadwick et al., 2010)

Baseline



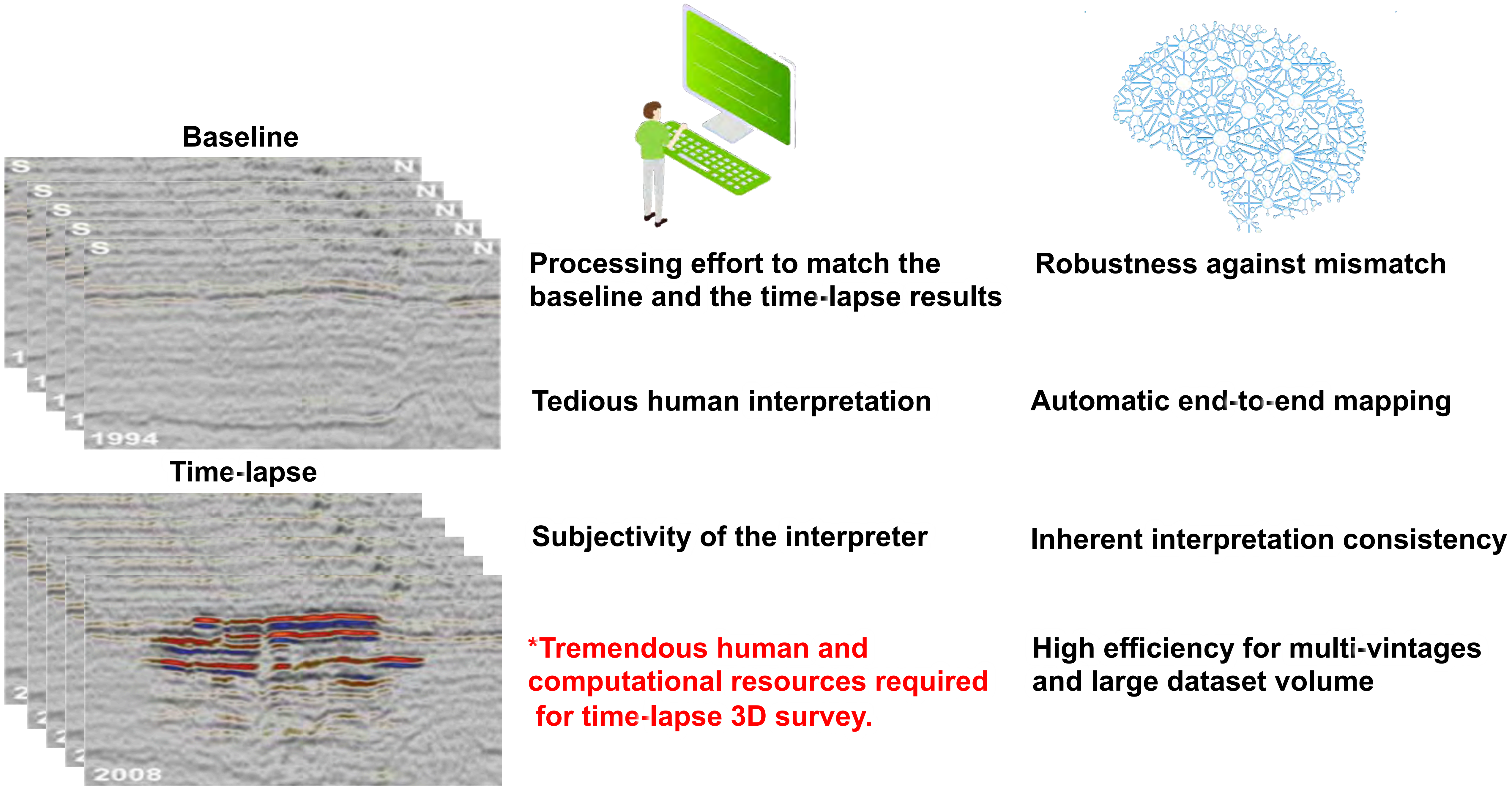
Time-lapse



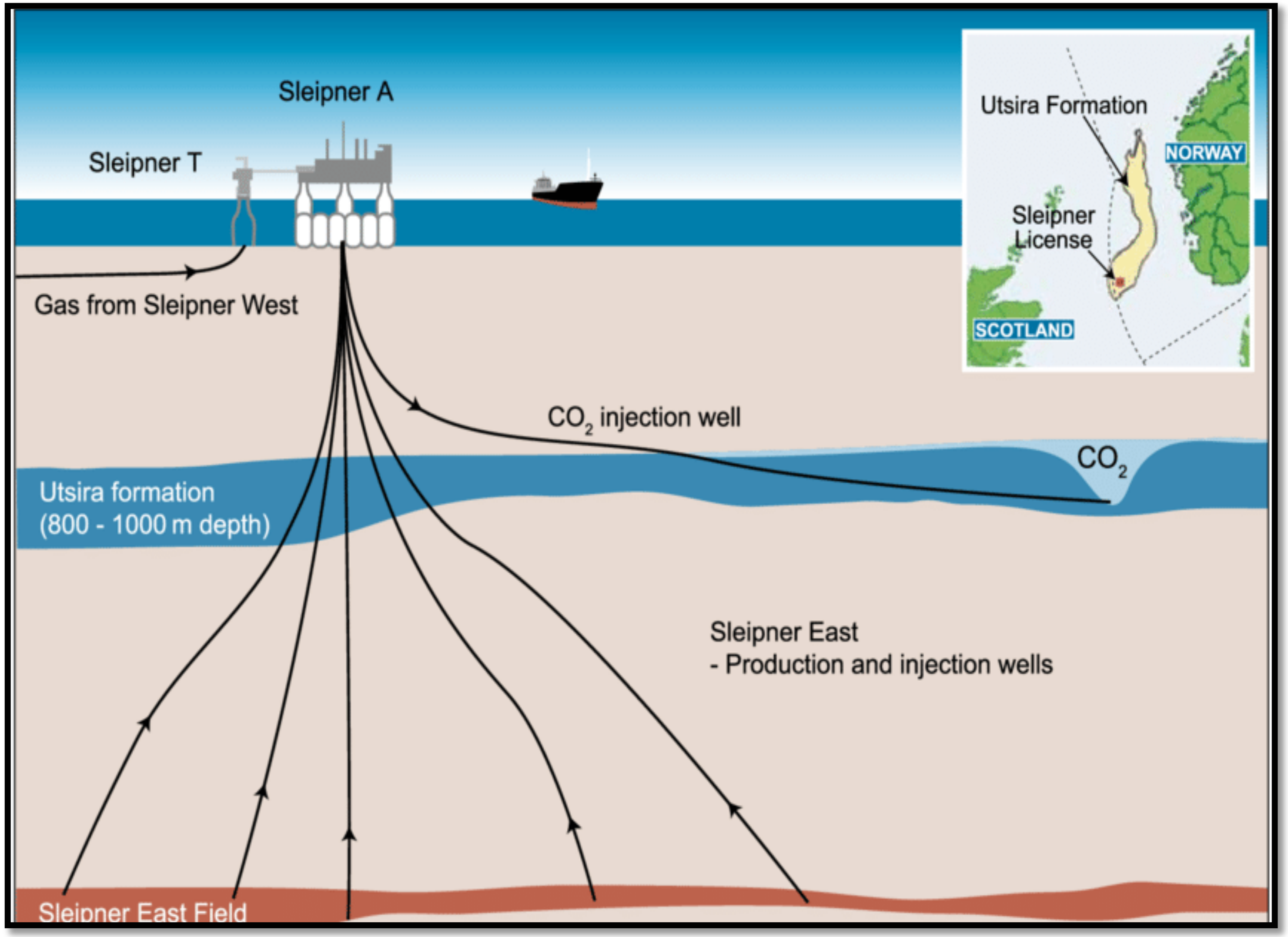
Processing effort to match the baseline and the time-lapse images

Tedious human interpretation

Subjectivity of the interpreter


Baseline
1994
Time-lapse
2008
Processing effort to match the baseline and the time-lapse results
Tedious human interpretation
Subjectivity of the interpreter
*Tremendous human and computational resources required for time-lapse 3D survey.
Robustness against mismatch
Automatic end-to-end mapping
Inherent interpretation consistency
High efficiency for multi-vintages and large dataset volume

Datasets: Sleipner CO_2 injection project



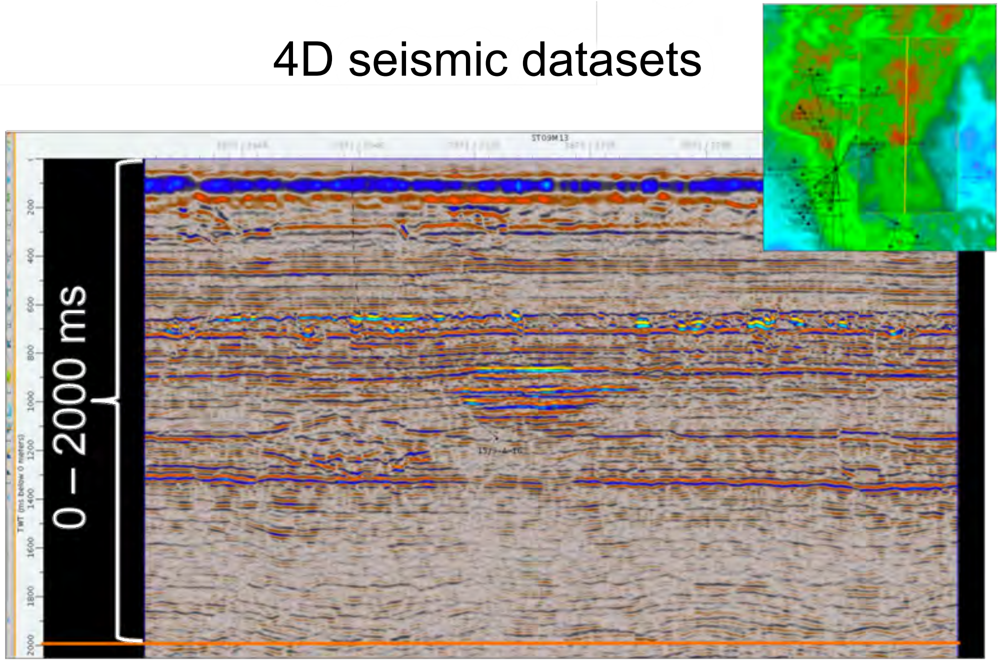
In book: IPCC Special Report on CO_2 capture and sequestration. (pp.195-265)

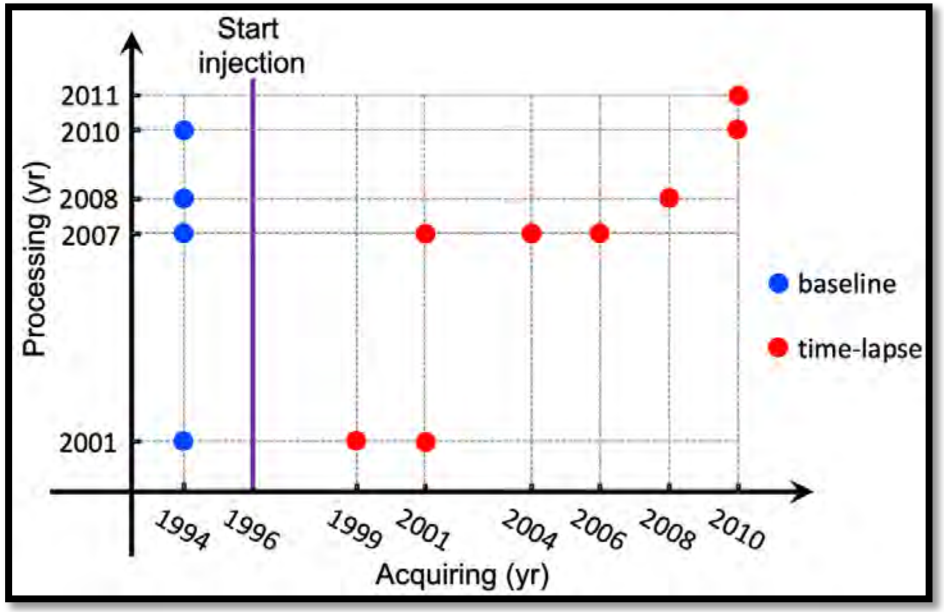
- **Frist industrial offshore project**
- **Saline aquifer as storage unit**
- **Injection started in 1996**
- **18.5 million tons stored by 2020**

equinor

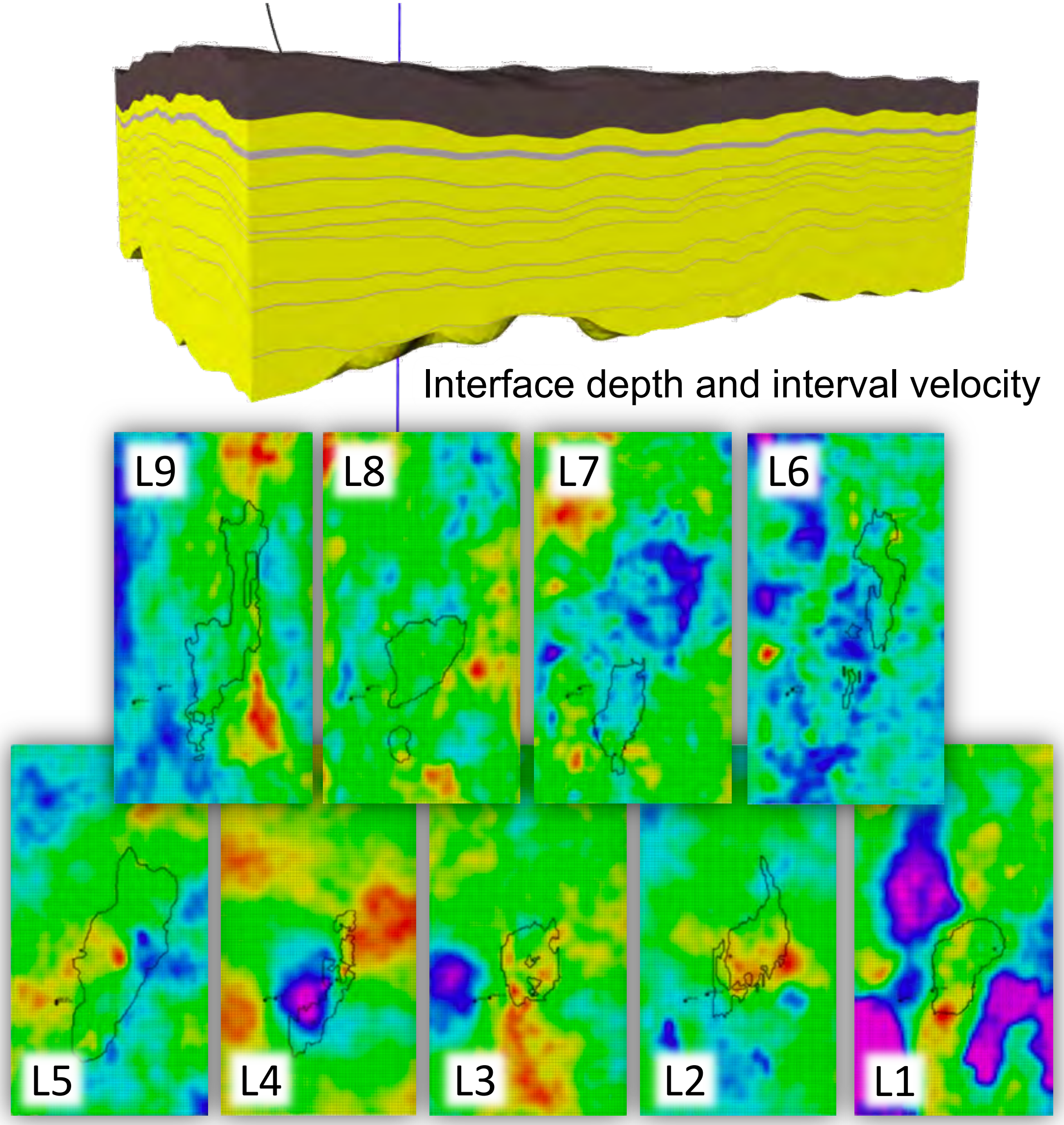
Datasets: Sleipner CO_2 injection project

4D seismic datasets



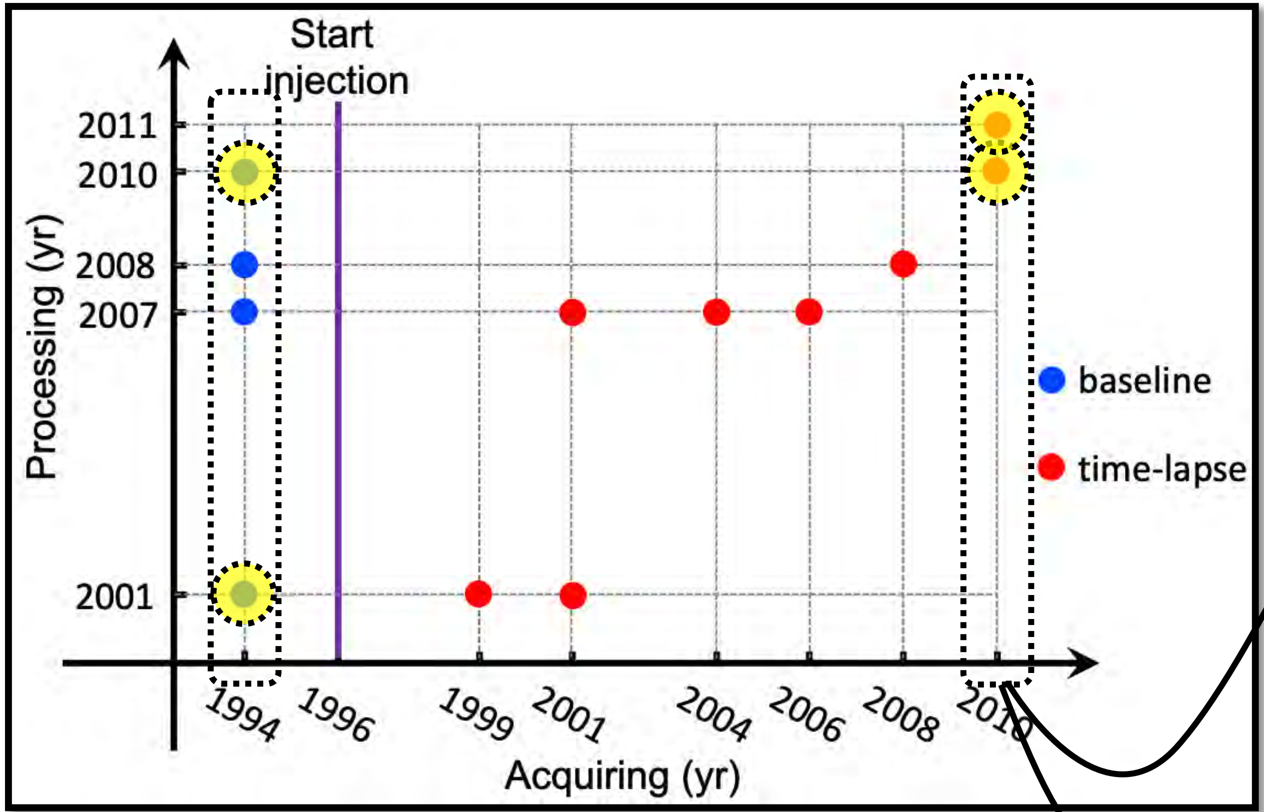


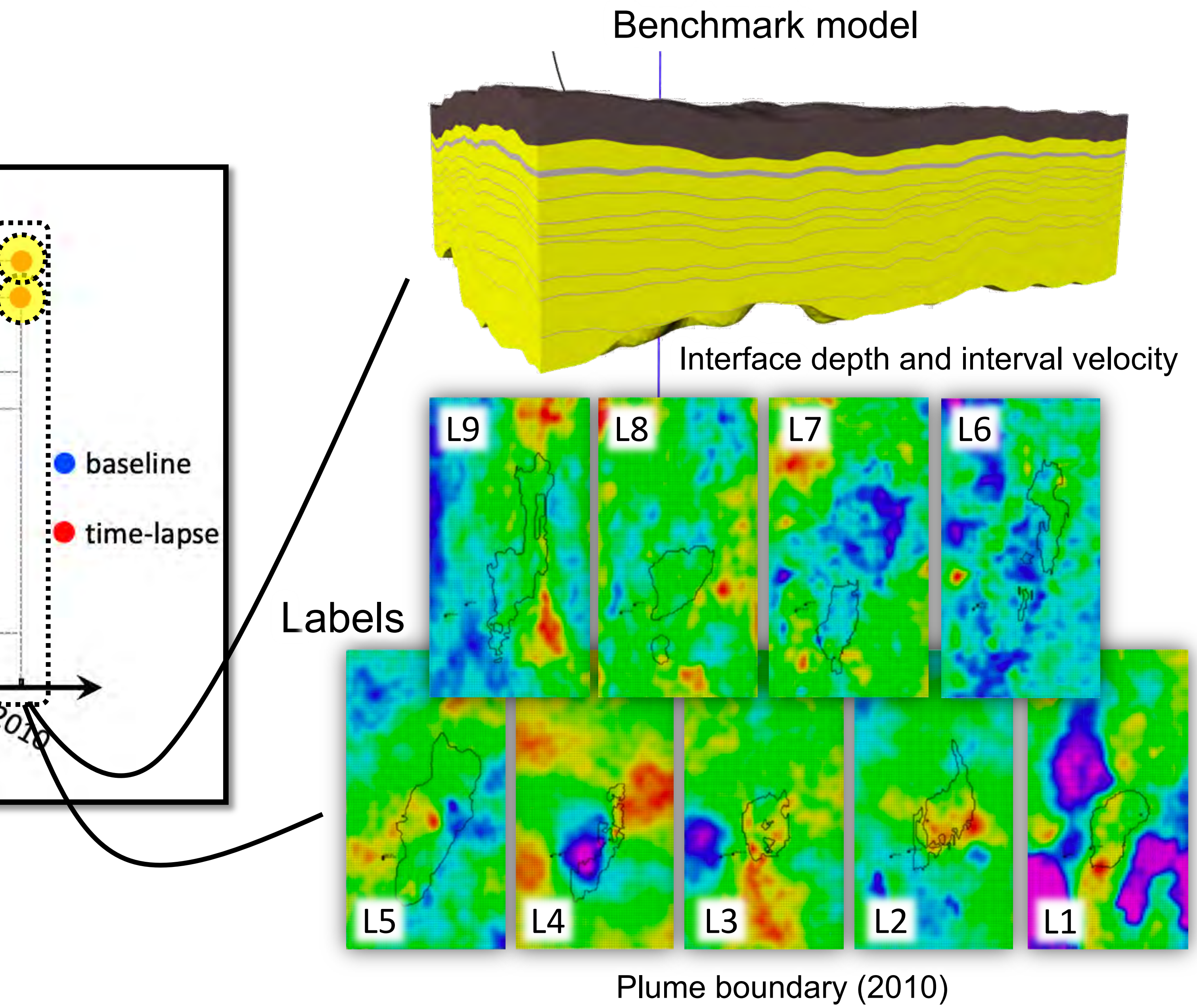
Benchmark model



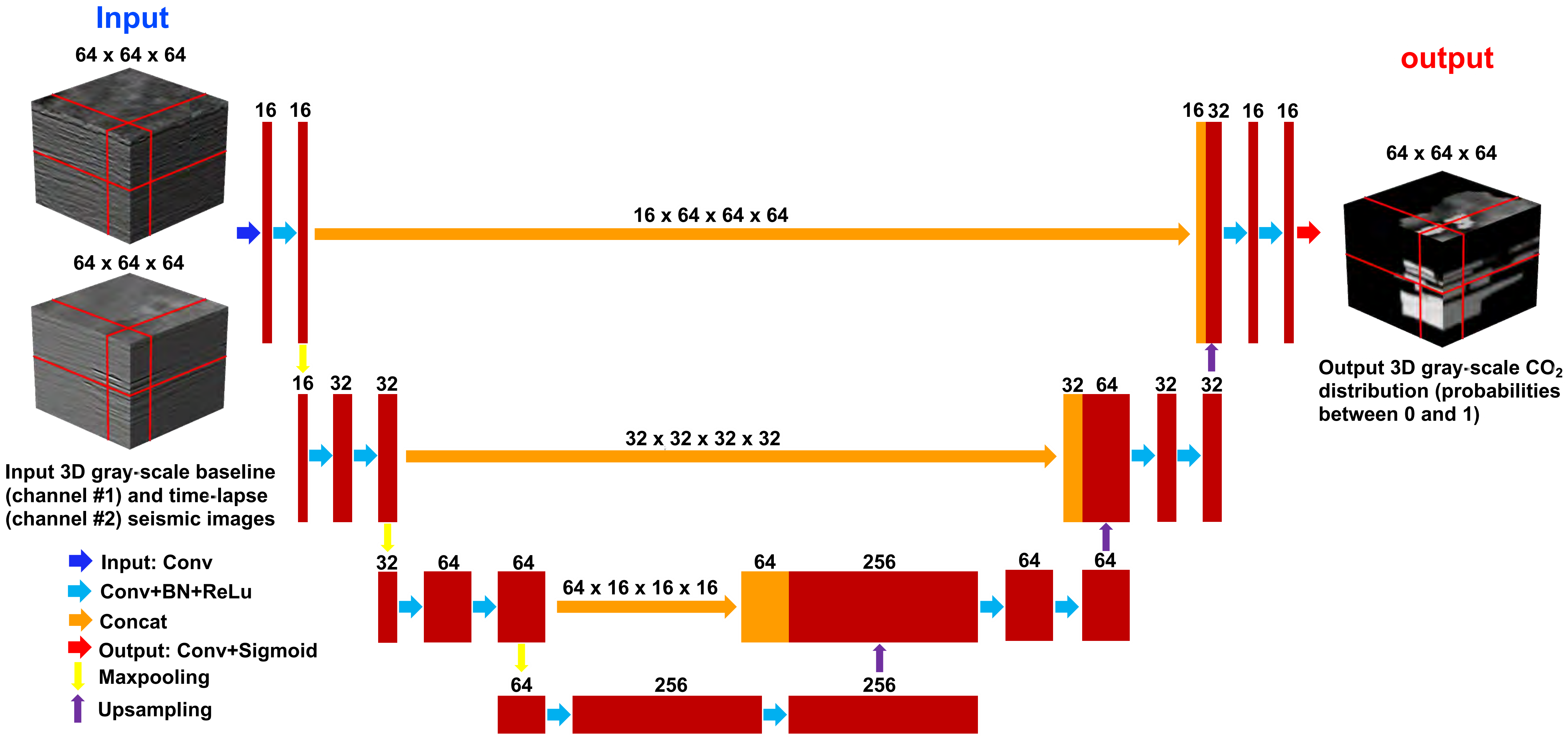
Plume boundary (2010)

Datasets: Sleipner CO2 injection project





NN architecture

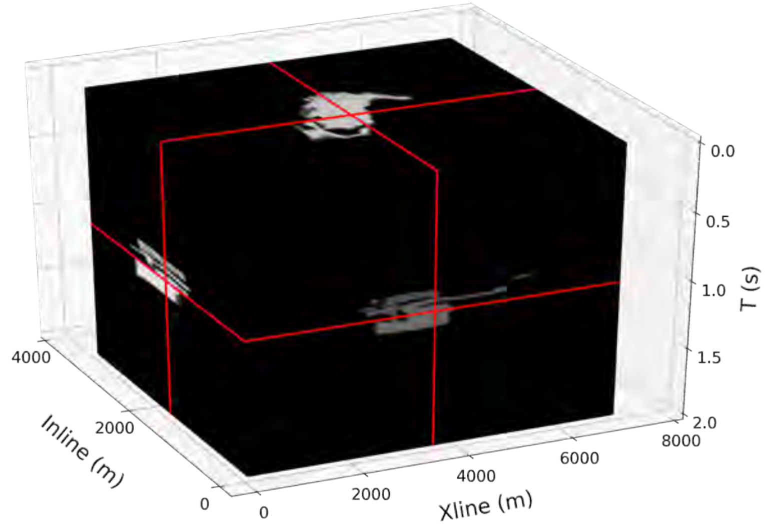


Adapted from Wu et al. (2019)

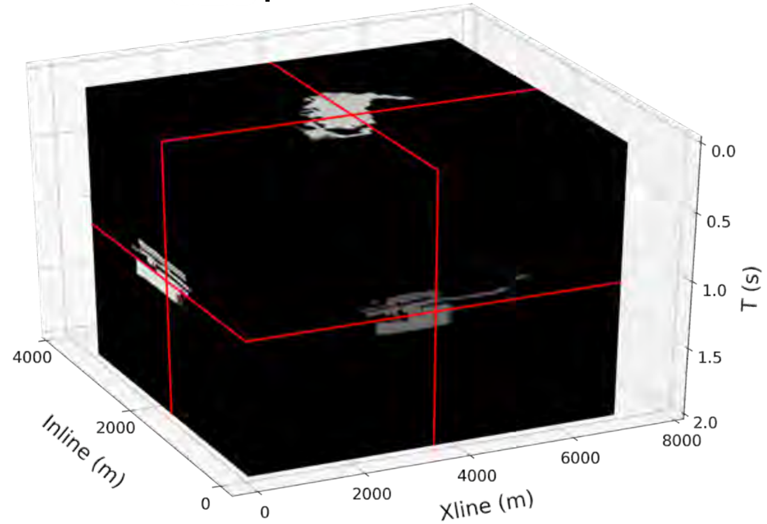
Predictions

2010

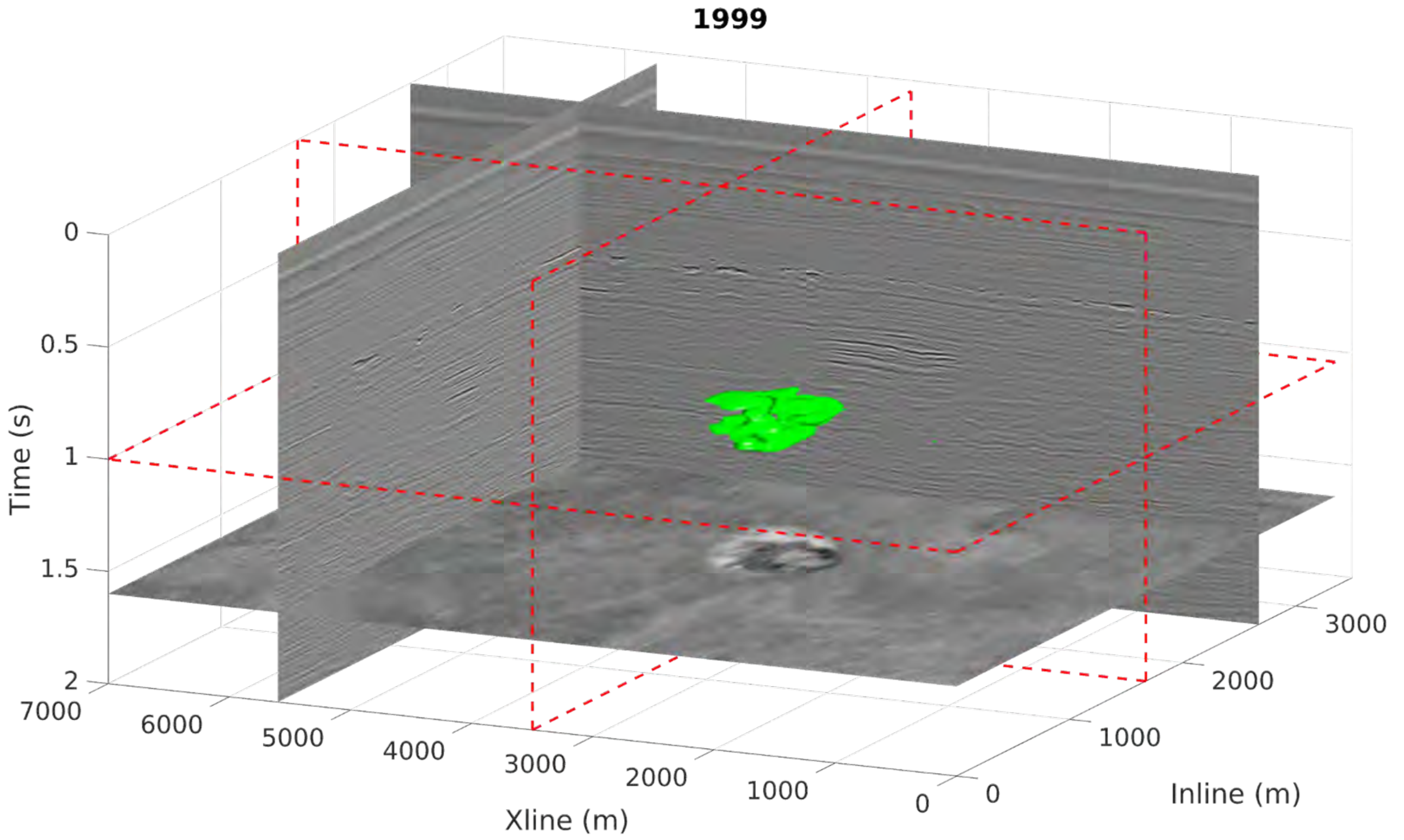
Label



NN prediction



1999 - 2010

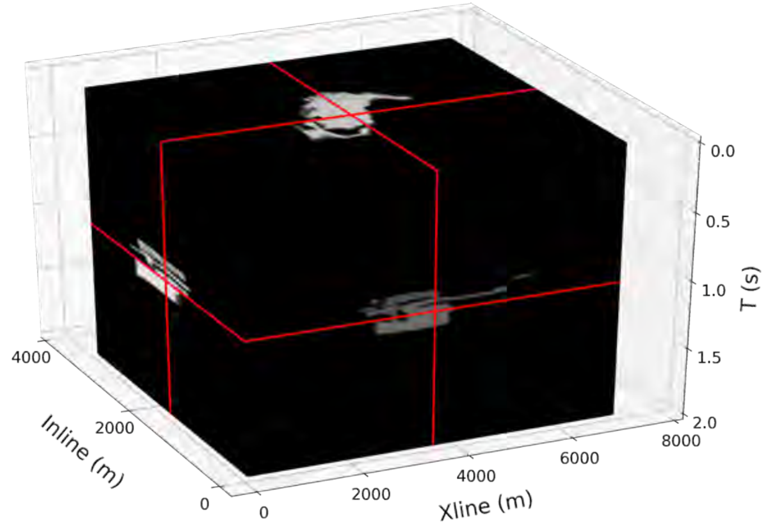


Li and Li, JGR: Solid Earth, 2021

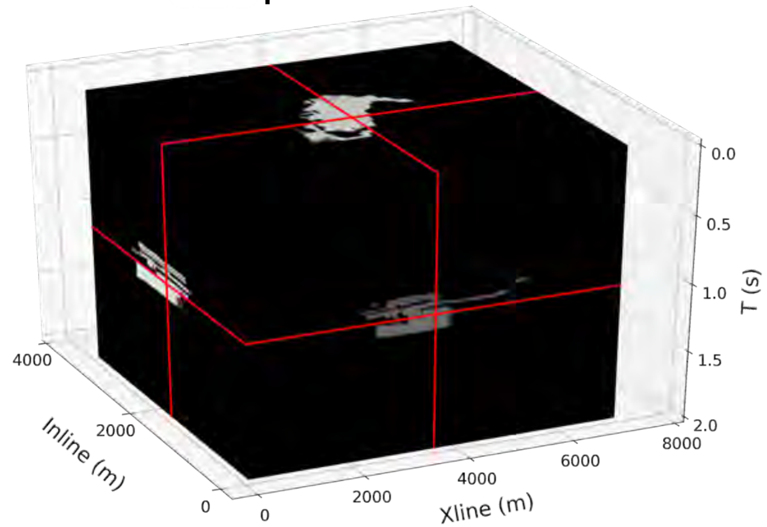
Predictions

2010

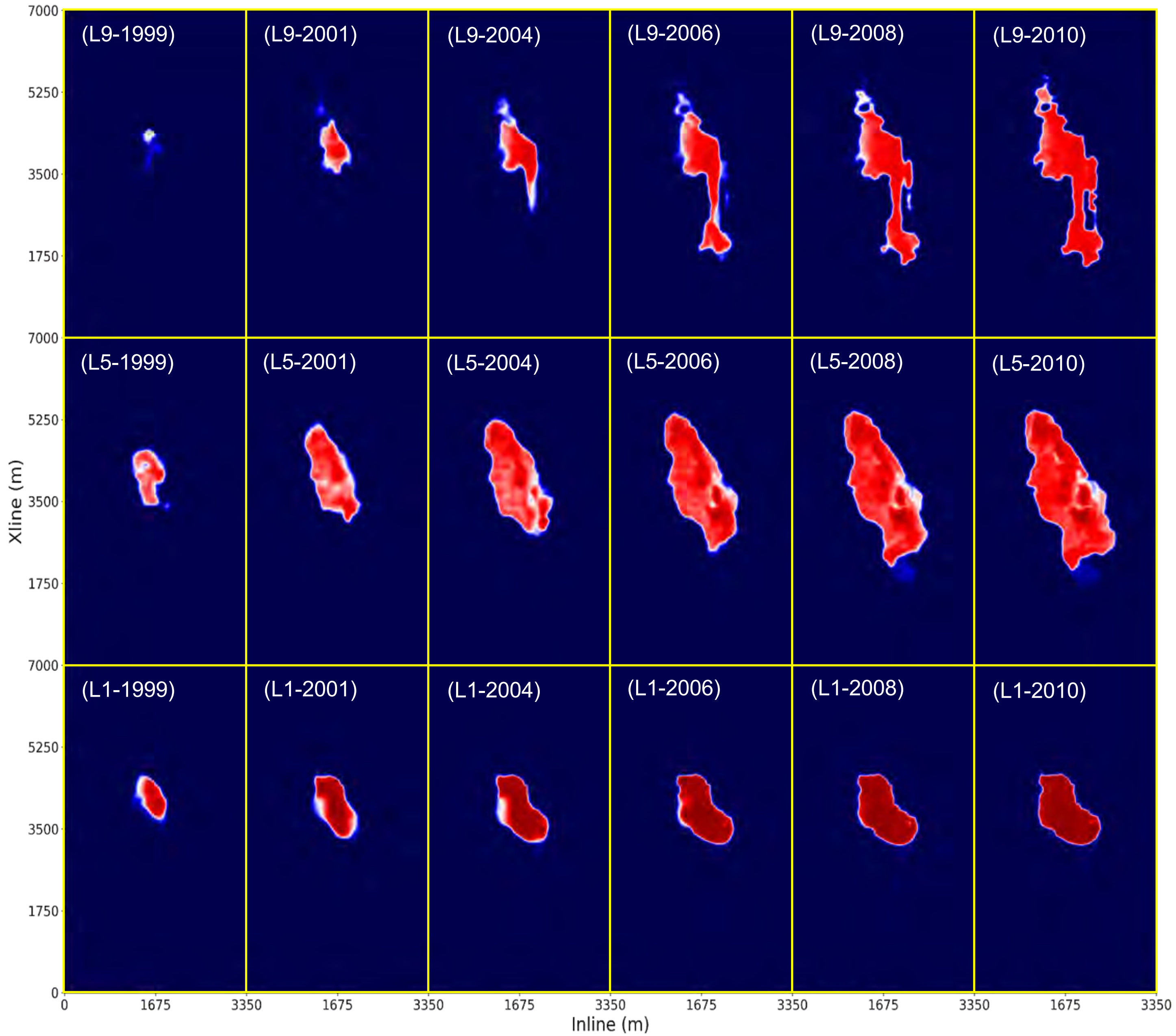
Label



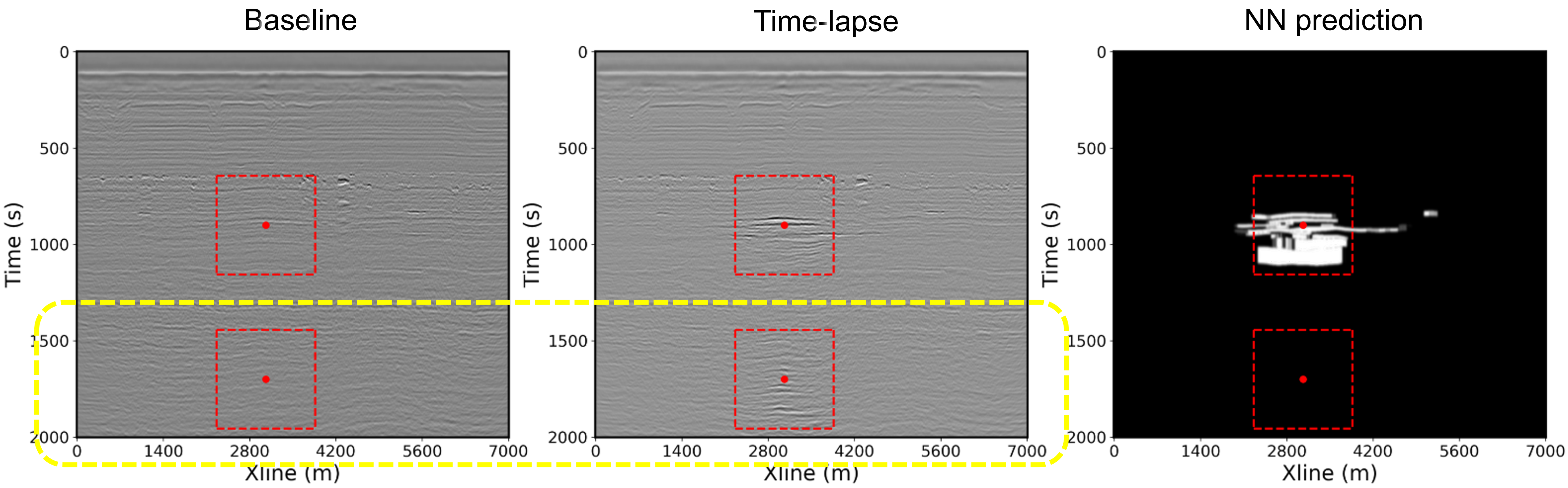
NN prediction



1999 - 2010



What has the NN learned?

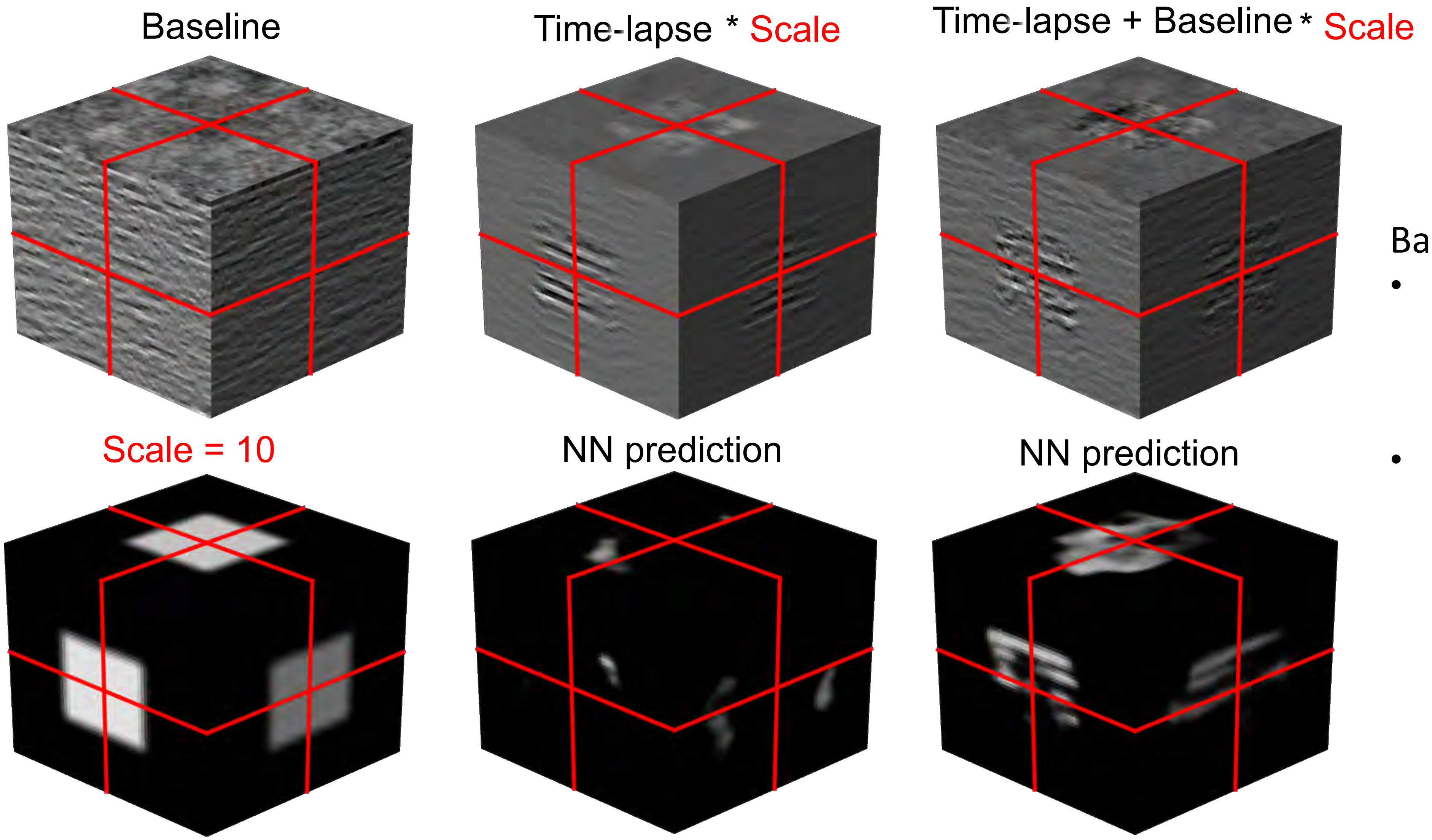


Bases for human interpretation:

- Locations with large amplitude changes between time-lapse and baseline images
- Locations within the reservoir formation

Li and Li, JGR: Solid Earth, 2021

What has the NN learned? - Let's break the NN



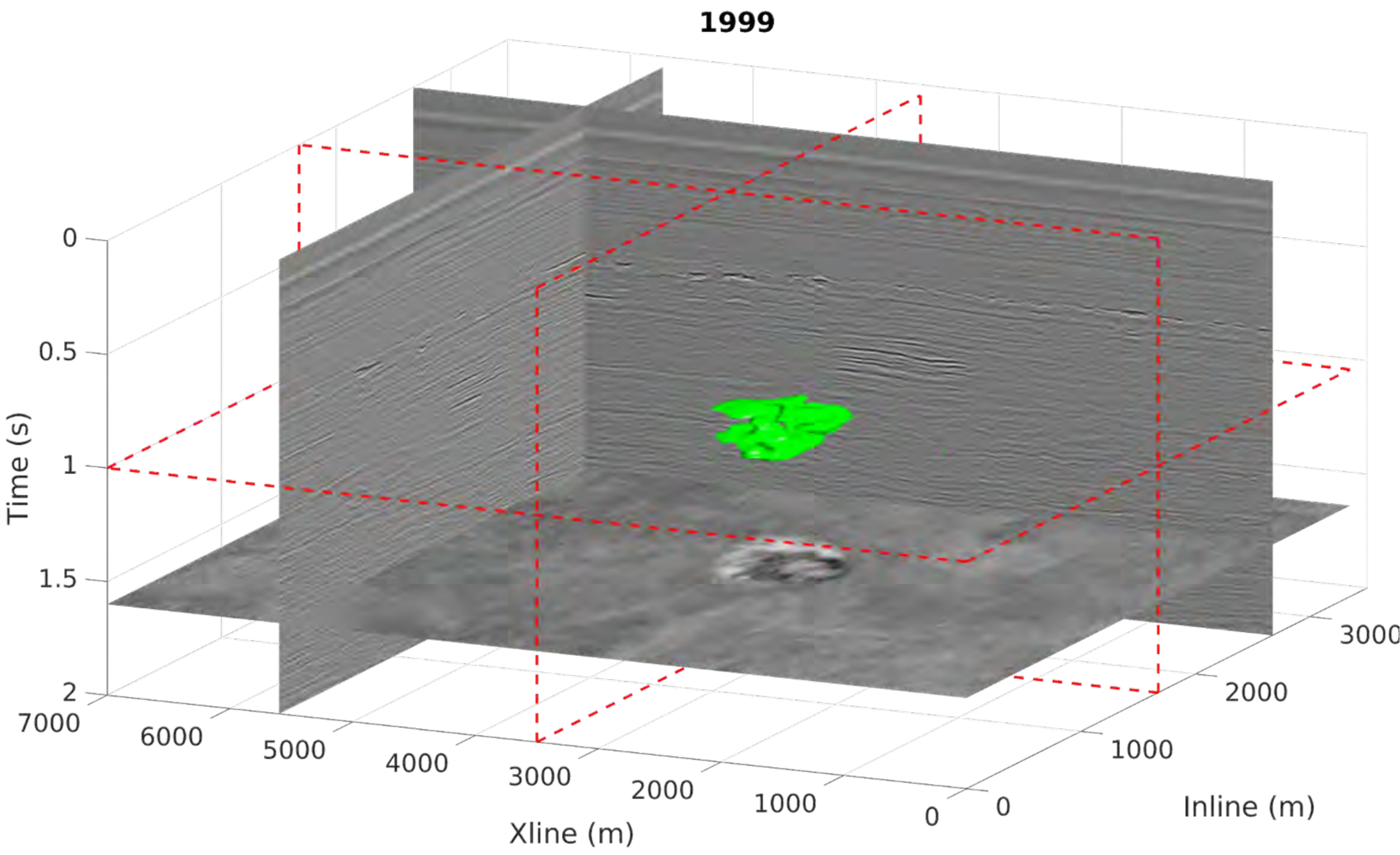
Bases for NN interpretation:

- Locations with large amplitude changes between time-lapse and baseline images
- Structure of the changes correlates with the baseline images at the corresponding location

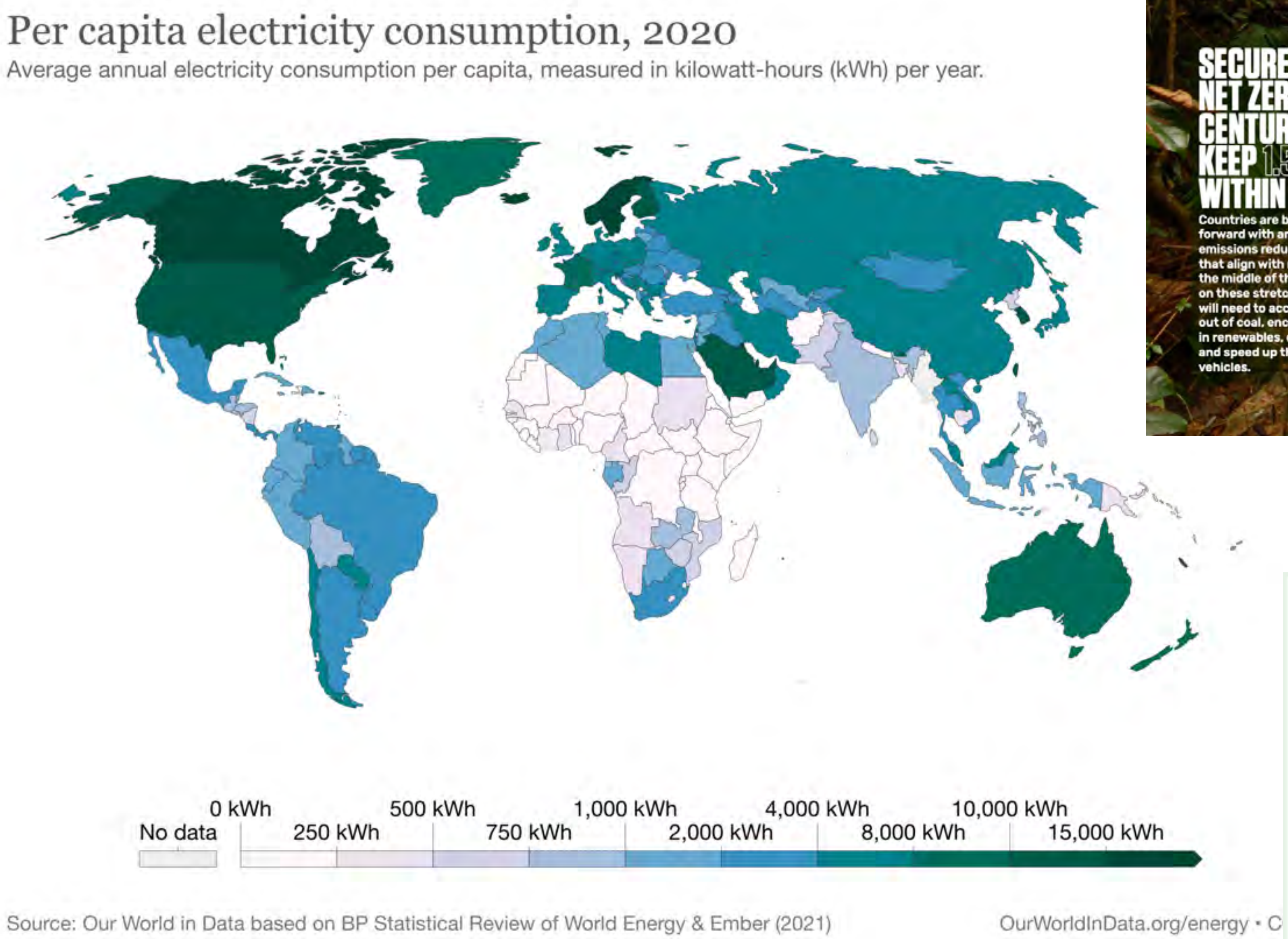
Li and Li, JGR: Solid Earth, 2021

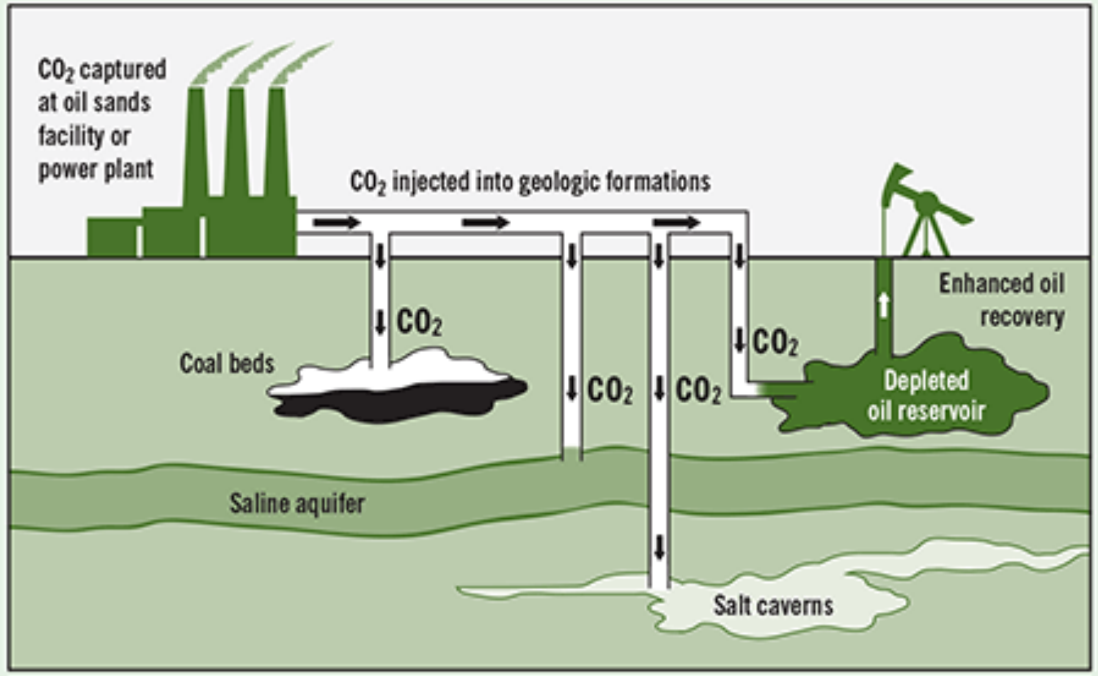
4D CCS monitor with ML

- Efficient: 3D interpretation in seconds
- Consistent: guaranteed for long CCS life span
- Robust: against processing and random noise



Li and Li, JGR: Solid Earth, 2021





CCS is a critical tool for

- Satisfying energy demand
- Mitigating climate change effects

Thank you!

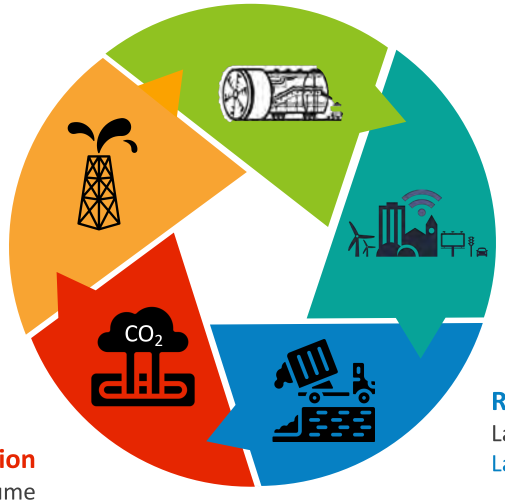
Acknowledgements:

- ExxonMobil
- Singapore Economic Development Board

Geophysical Applications Around The Energy Cycle

Optimized Energy Usage
Passive methods for civil engineering site investigation
Risk identification ahead of TBM construction

Efficient Energy Recovery
Fundamental understanding of wave/rock/flow physics
Fast subsurface imaging/inversion algorithms



Real-time monitoring and management
Geohazard early warning
Smart city/infrastructure applications

Reclaim and Recycle
Land reclamation using waste materials
Landfill material reuse and recycle

Carbon Sequestration
Mapping subsurface storage volume
Real-time, long-term monitoring of CCS

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