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Building on belief

DEEP NEURAL NETWORK FRAMEWORK FOR INVERTING REMOTELY SENSED CO2 MEASUREMENTS

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Outline

- **Introduction**
  - Flux claculation of carbon
- **Proposed method**
  - DL based inversion
- **Results and discussion**
  - Validation challenges
  - Observation
- **Future work**

Flux calculations

Estimating Surface Emission/Sink Distribution of CO_2

- **Bottom-up Methods**
  Inventory of individual sources, activity data & emission factors.
- **Top-down Methods**
  Measurements of atmospheric concentrations of the gas, and physics based inversion

Atmospheric Transport Model + Direct measurements of CO_2 concentrations ➡ Past emission/ sink distribution

e.g. Data assimilation methods: Ensemble Kalman Filter, 4-D Variational Methods

Flux calculations pros and cons

Data Assimilation Methods

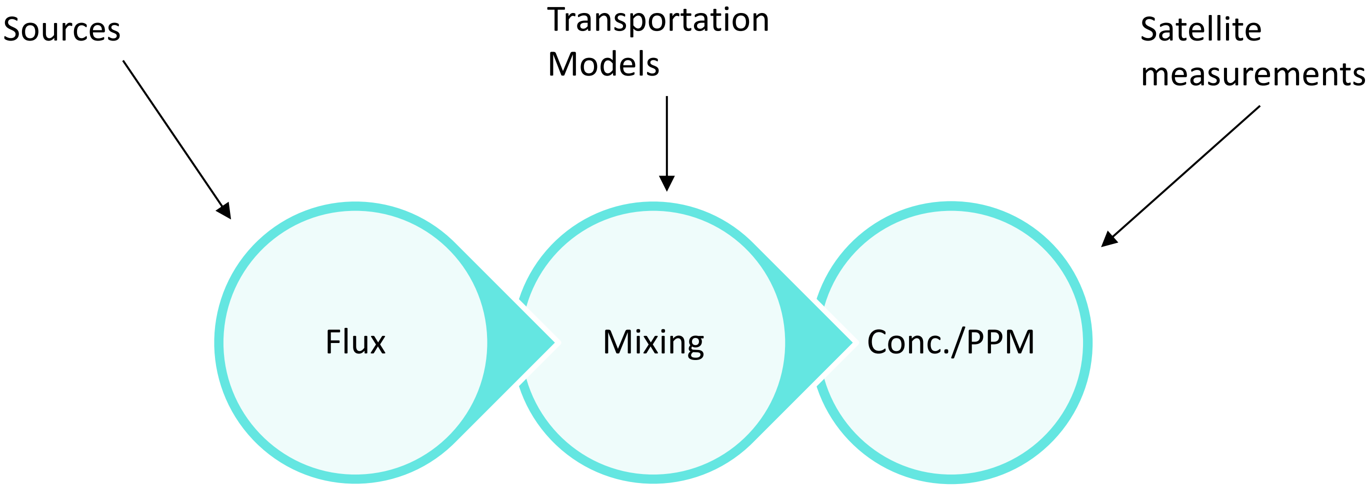
- computationally expensive
- require expertise in complex numerical code
- numerical errors, errors from parametrizations

Advantages of Deep Learning Methods

- Learning non-linearities,
- Ease of implementation, less requirement of domain expertise
- Scalability and Parallelizability

Can we use deep learning to invert the concentrations?

Intuition



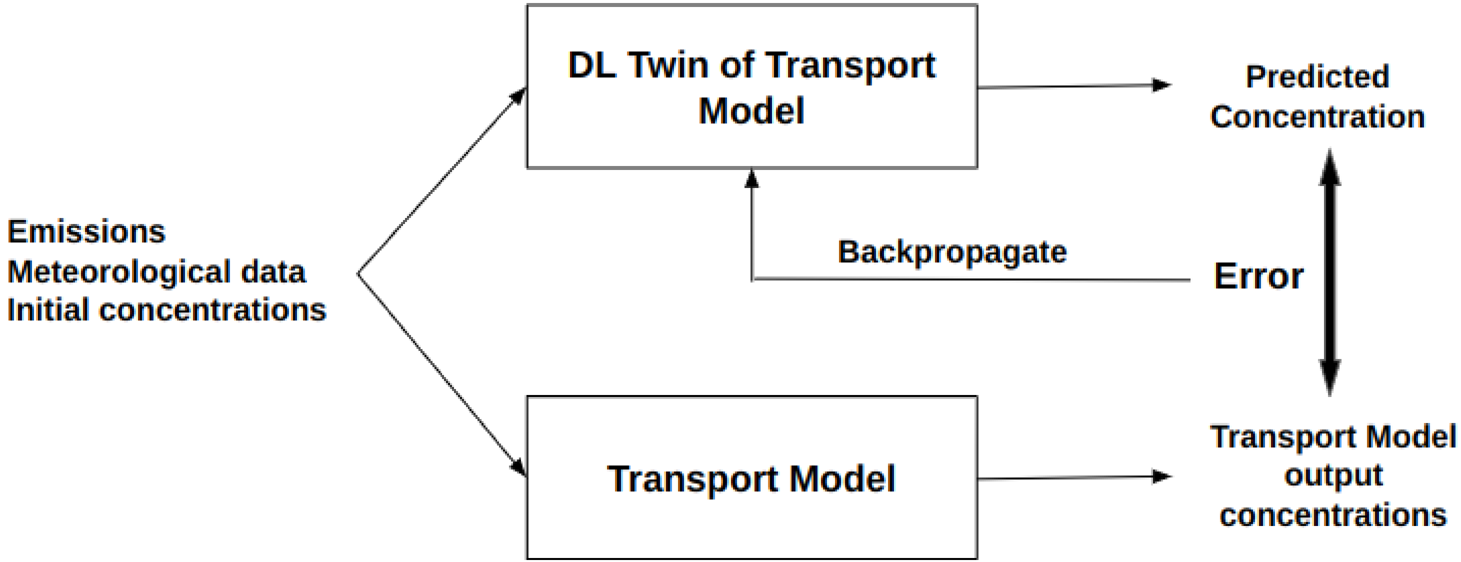
Unified network doing double duty

DL for twin for transportation

DL for flux correction based on the consistency of the measurements and model output

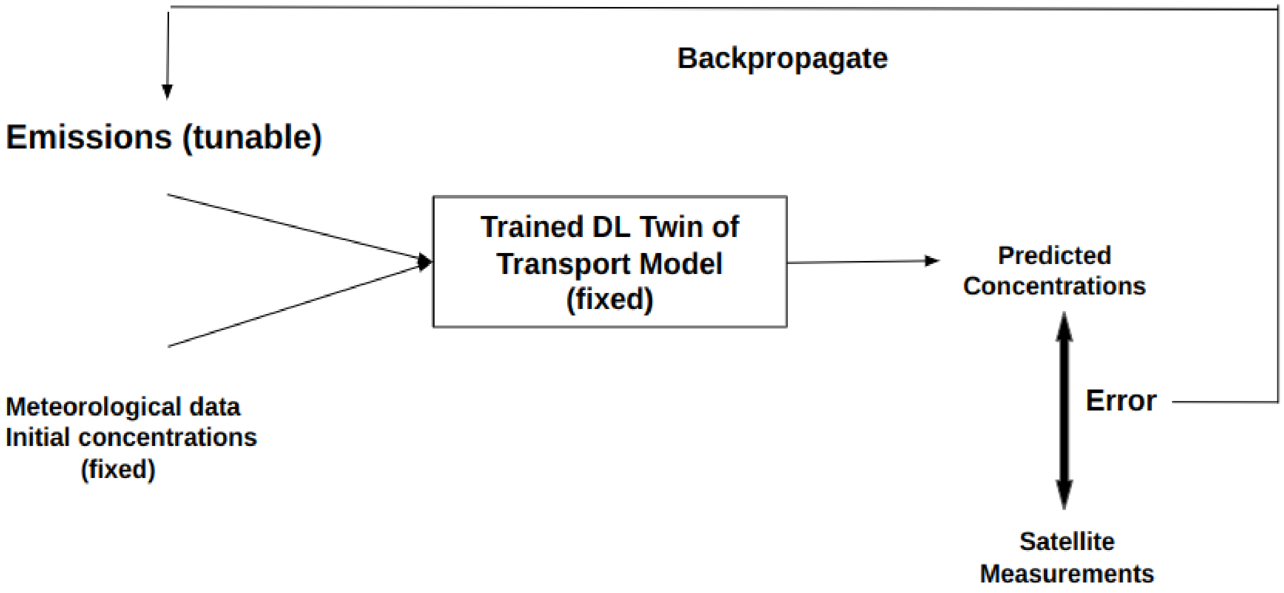
Digital twin for transportation

Part 1: Take Numerical Transport Model → Train its Deep Learning Twin/Surrogate



Deep network for inversion

Part 2: DL Twin Model + Satellite Concentration Measurements ⟶ Corrected Emissions



Digital twin training

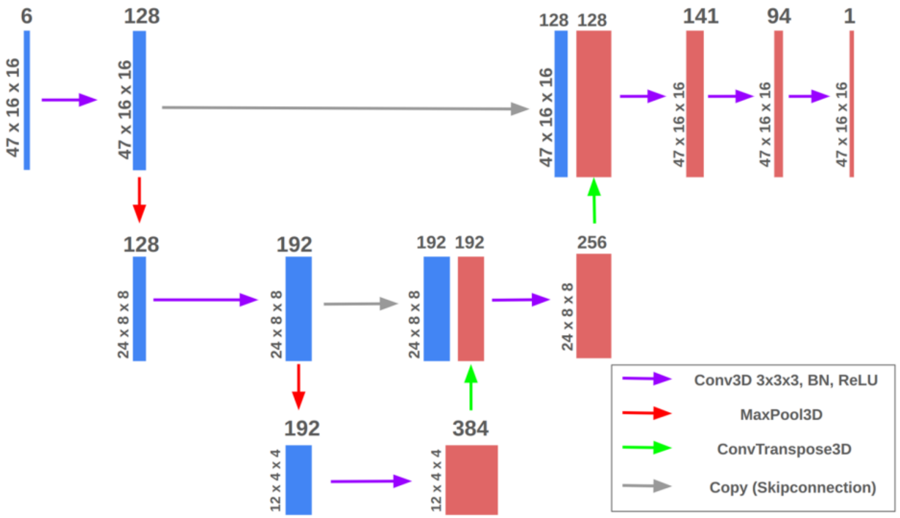
Training Data Generation

Emissions (fossil fuels …)
+ Initial Concentrations
+ Meteorological Data (NASA)

GEOS Chem

Numerical Model: GEOS-Chem

Daily Average Concentrations (PPM)



Input: Emissions, Initial Concentrations, Winds, P, T
Output: 1-day concentration change (ppm)
Grid: 4° x 5° (Asia)
Model Size: 7.6 Million parameters

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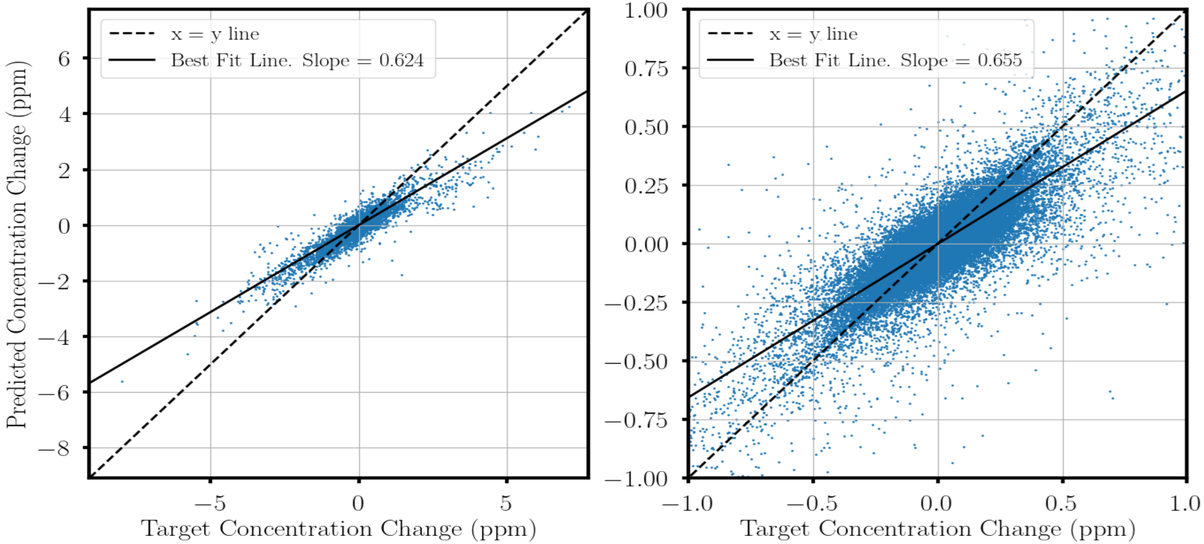
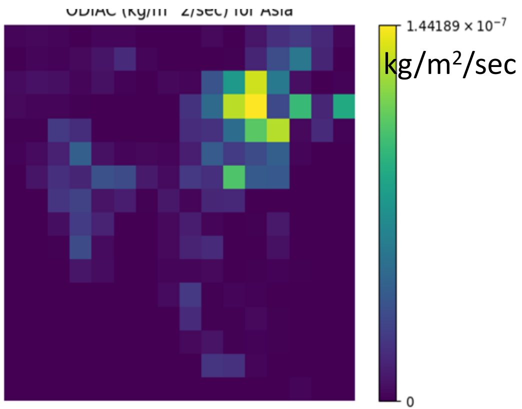
	Concentrations	Change in Concentrations
Percentage Error (Loss x 100)	0.045%	47.9%
Pearson Correlation Coeff.	0.996	0.885
Coeff. Of Determination	0.992	0.751



Inversion

Backpropagate

Prior Emissions (ODIAC) 1st July 2018



Trained DL Twin of Transport Model (fixed)

Meteorological data
Initial concentrations
(1st July 2018)

Predicted Concentrations (2nd July 2018)

Error

OCO-2 Satellite Measurements (2nd July 2018)

No. of Iterations = 200

Validations challenges

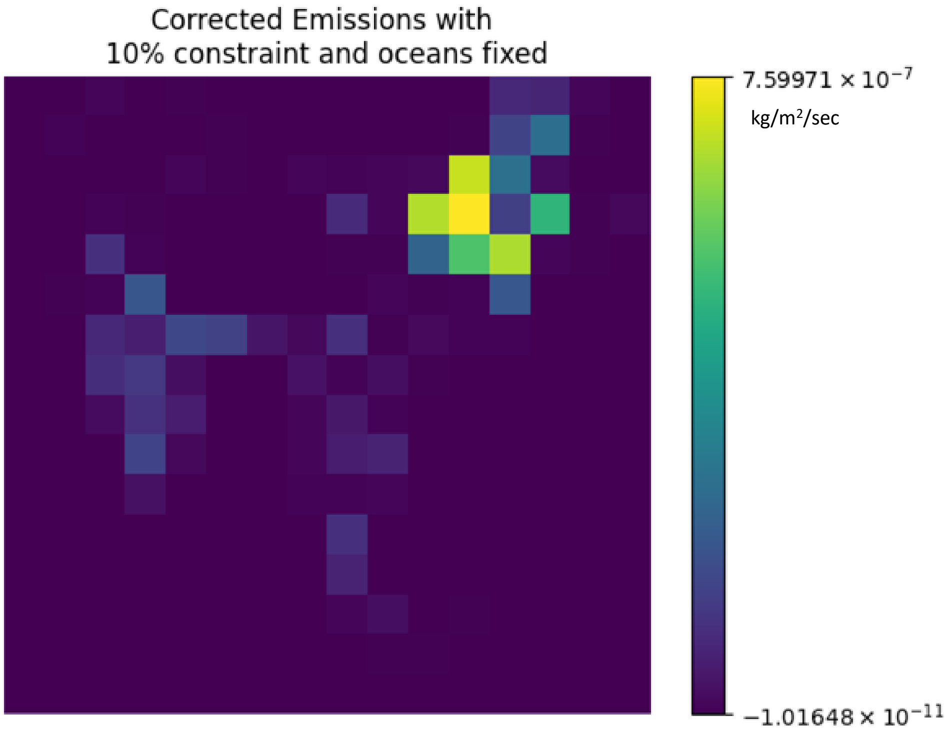
- EDGAR (Emissions Database for Global Atmospheric Research) report and, ODIAC data
  - Based on the inventory data
  - Emissions because of antropogenic activities (fossile fuel burning)

- **ODIAC (prior) and EDGAR account only for anthropogenic emissions**. But satellite measurements are affected by all sources.

- Small to negligible differences in fluxes for short time span

Validation

- Predict the daily averages using the input condition as per the ODIAC and aggregate for a year
- Total emissions for 2018 according to **EDGAR report** : (17.811 Gt) Gt
- Total emissions of the region (extrapolated to the whole year) increase from (prior) 19.6 Gt to 60.2 Gt



Concluding remarks

Results are encouraging, however need further investigation

- Building more accurate model using better computing infrastructure
- Incorporating additional complex transportation processes
- Incorporating domain knowledge in the formulations - Considering emission dynamics other sources more constraints and so on

Key takeaway

- A unique framework for inversion
- Potential to create most accurate flux data product

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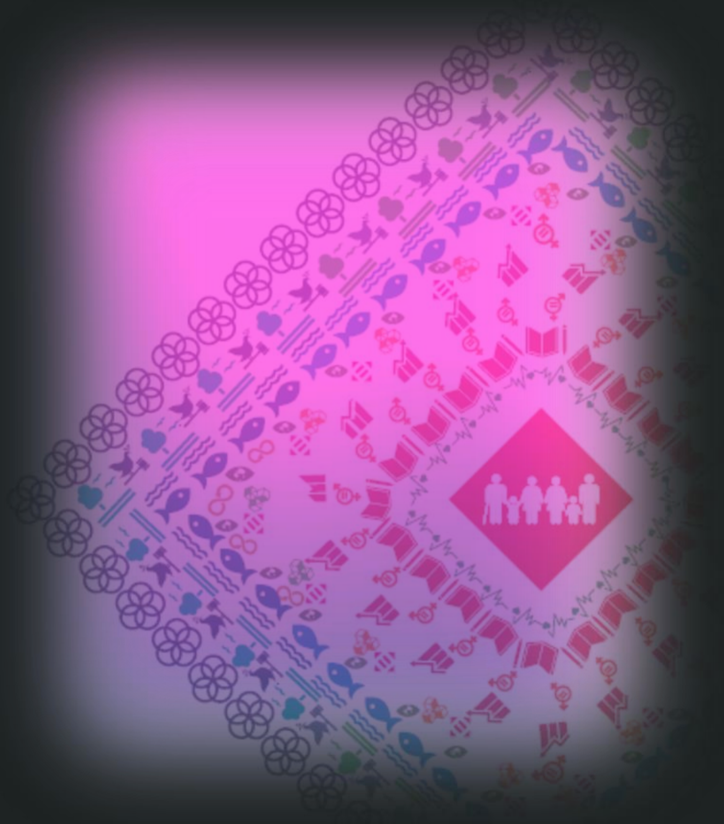
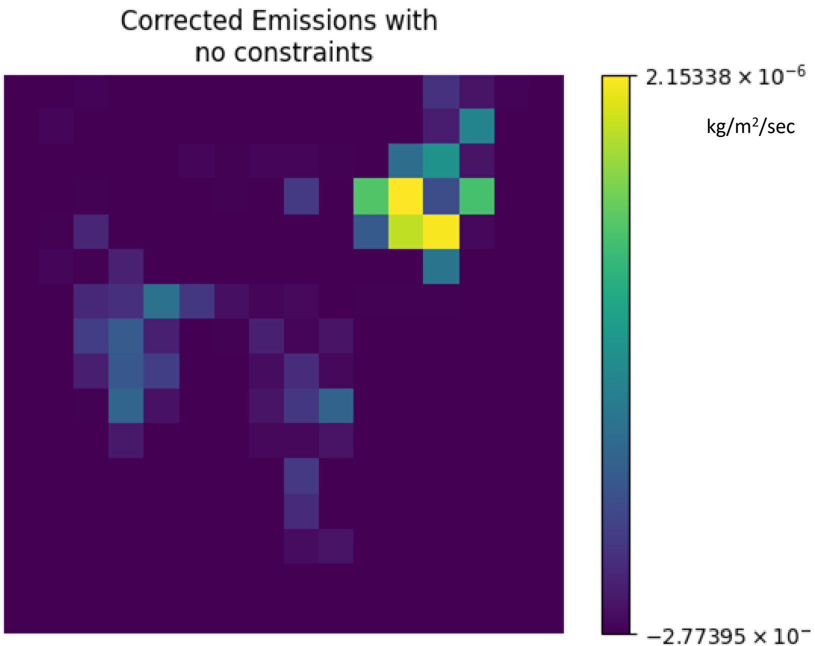
Thank You



Experiment 1 – no constraints on sources and sinks

- After 200 iterations, RMS error with satellite measurements: ~9.14%
- Intensified hotspots in China and India
- Ocean regions turned to sinks
- Total emissions of the region (extrapolated to the whole year) increase from 19.6 Gt (prior) to 185.0 Gt



Experiment 2 – Fixed ocean emissions

- ODIAC emissions are only terrestrial so we neglect emissions from oceans.
- After 200 iterations, RMS error with satellite measurements: ~9.14%
- Emissions reduce very slightly
- Total emissions of the region (extrapolated to the whole year) increase from 19.6 Gt to 181.0 Gt