Flow Matching for Domain Adaptation in Earth Observation

Georges Le Bellier[1], Nicolas Audebert[1,2]
[1]CNAM CEDRIC, [2]Univ. Gustave Eiffel, ENSG, IGN, LASTIG

Earth Observation Context

EO models often face distribution shift at inference time:

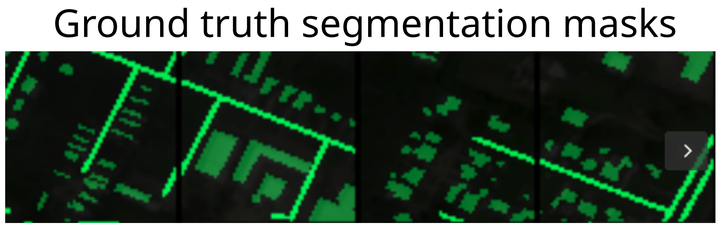
- different geographical areas
- seasonal changes
- different sensors
- extreme events (flooding, fire)

...

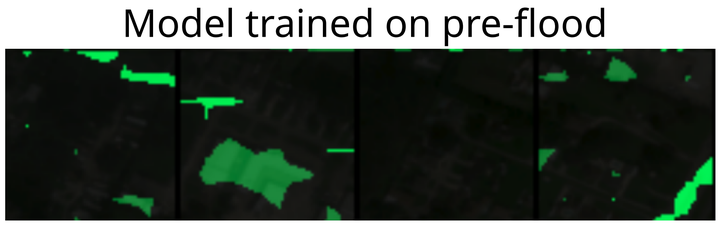
→ **Their predictive capabilities are severely reduced.**

Post-flood satellite images

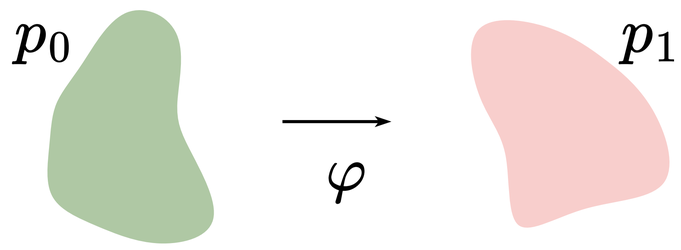
Ground truth segmentation masks



Model trained on pre-flood



Domain Adaptation

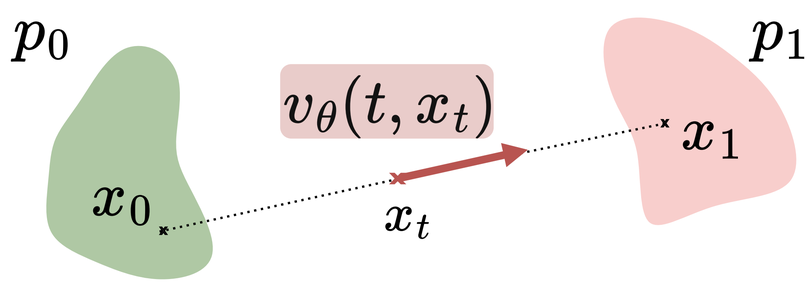


1. Train a segmentation model f_ϕ on labelled dataset $\{\mathcal{X}_1, \mathcal{Y}_1\}$
2. Lean a mapping φ between p_0 and p_1
3. Inference time: apply segmentation model to the transferred data

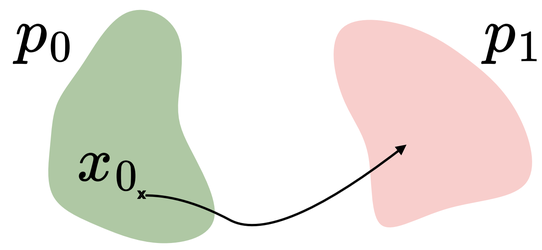
$$\hat{y} = f_\phi(\varphi(x_0))$$

Flow Matching

Training



Inference



$$\varphi(x_0) = \mathrm{ODE}_\theta(x_0, 0 \to 1)$$

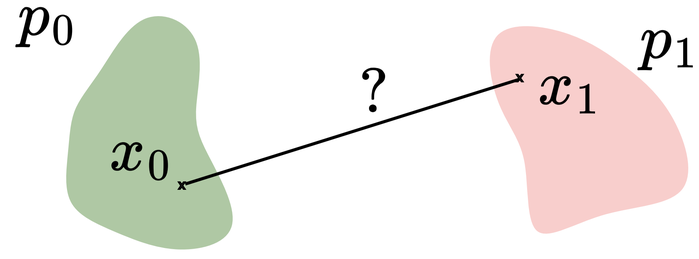
- Flow Matching generalizes diffusion models
- Simple regression loss

Neural network

$$\mathcal{L}_{\mathrm{CFM}} = \mathbb{E}_{\substack{x_0, x_1 \sim p(x_0, x_1) \\ t \sim \mathcal{U}([0,1])}} \left[\left\| v_\theta(t, x_t) - (x_1 - x_0) \right\|^2 \right]$$

True conditional velocity

Coupling



How to select (x_0, x_1) pairs during training?

Available pairs → pair as a natural coupling

$$x_1 = T(x_0)$$

No prior information → independent coupling

$$(x_0, x_1) \sim p(x_0)p(x_1)$$

Efficient sampling objective → OT coupling

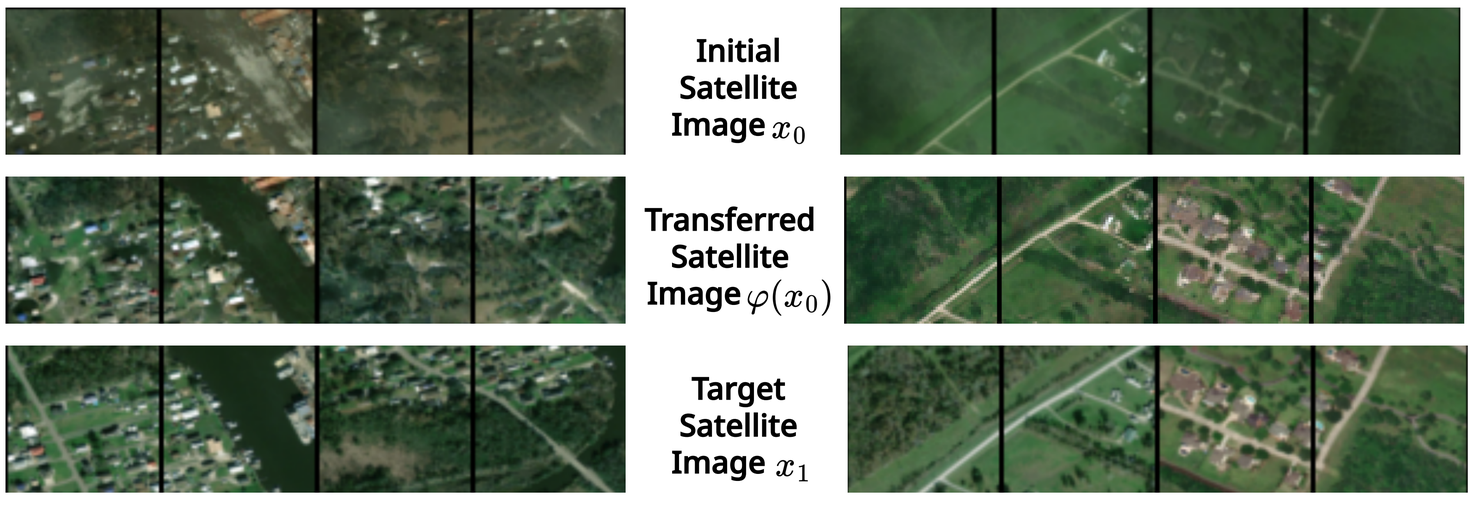
$$(x_0, x_1) \sim \pi(x_0, x_1)$$

Preliminary Results

Setup:

- SpaceNet 8 dataset
- Two locations: Germany and Louisiana
- 256x256 RGB images
- Segmentation model: DeepLabV3+

Initial distribution p_0 → Pre-Flood
Target distribution p_1 → Post-Flood



Quantitative results

	Pre/Post-Flood F1 ↑	Pre/Post-Flood mIoU↑
No transfer	04.63	05.21
On target (upper bound)	35.67	35.94
Independent coupling	01.89	02.12
OT coupling	05.63	06.15
Aligned coupling	**25.45**	**26.56**

Takeaways:

1. Flow Matching training is similar to diffusion models
2. Flow Matching provides a gain with respect to the segmentation metrics.
3. Independent and OT couplings fail to preserve semantic information during transfer