Riemannian Flow Matching for InSAR

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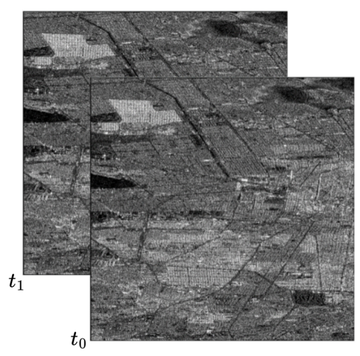
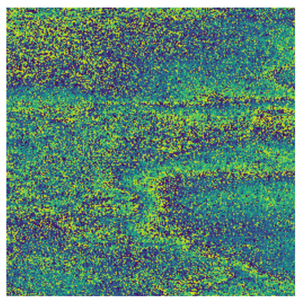
1.Context





Noisy interferogram $\mathbf{w}$

InSAR interferometry for displacement estimation:

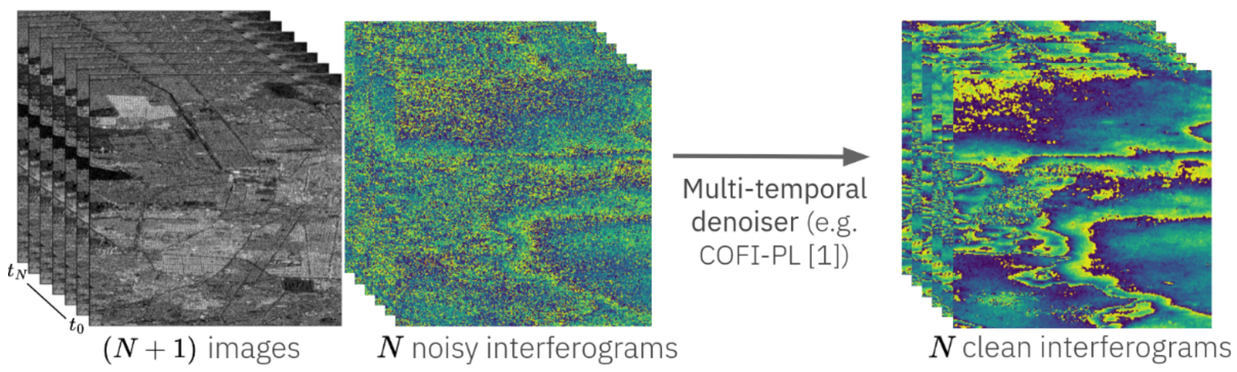
$$\mathbf{w} = \Delta\Phi = \Delta\Phi_{\text{disp}} + \Delta\Phi_{\text{topo}} + \Delta\Phi_{\text{orb}} + \Delta\Phi_{\text{atm}} + \Delta\Phi_{\text{noise}}$$

Surface Displacement — Remove during preprocessing — We want to remove it

1. Generative models for interferogram denoising?
2. Generate new valid interferograms?

Validity: $\mathbf{w}^i \in [0, 2\pi[$ i.e. $\mathbf{w} \in \mathbb{T}_d$

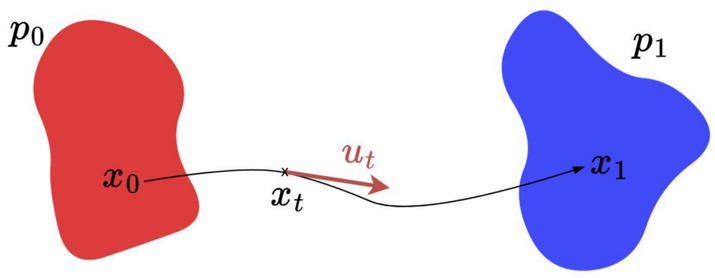
2.Dataset



- 40 SAR Sentinel-1 SLC images of Mexico City (10m/px)
- Interferograms cleaned with COFI-PL
- Every 12 day between 14/08/19 and 6/12/20
- Downsampled (x4)
- 128x128px patches
- Spatial split (train/test)

3.Flow Matching

Generalize diffusion models to data-to-data transport



$$x_1 = \varphi_1(x_0) = \text{ODE}_u(x_0, t: 0 \to 1)$$

Training:

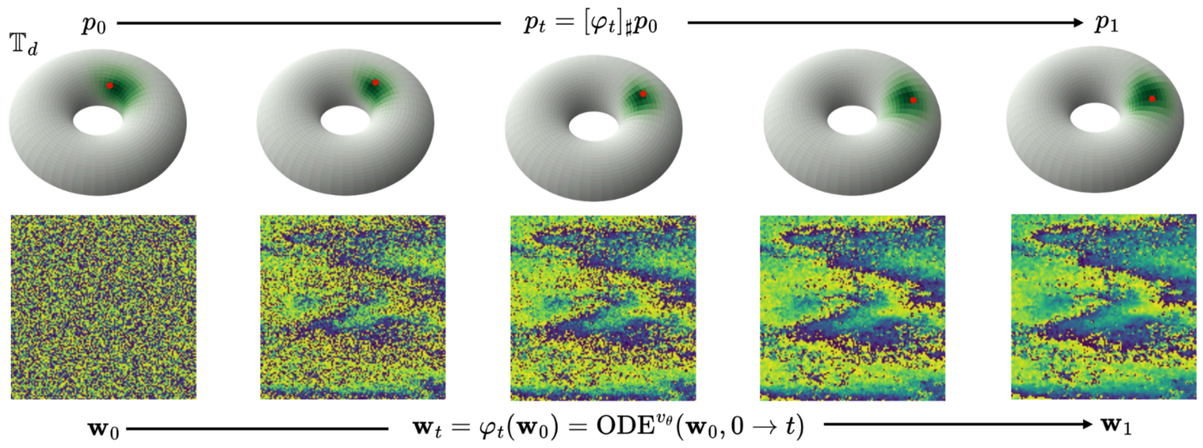
1. Sample $(x_0, x_1) \sim p(x_0, x_1)$
2. Sample $t \sim U(0,1)$
3. Interpolant $x_t = (1-t)x_0 + tx_1$

$$\mathcal{L}(\theta) = \mathbb{E}\|v_\theta(t, x_t) - (x_1 - x_0)\|^2$$

4.Riemannian Flow Matching

Generalizes flow matching models to Riemannian manifolds
Uses geodesic interpolation instead of linear interpolant

3. $x_t = (1-t)x_0 + tx_1 \longrightarrow x_t = \exp_{x_1}(\kappa(t)\log_{x_1}(x_0))$



5.Generation

p_0 = noise

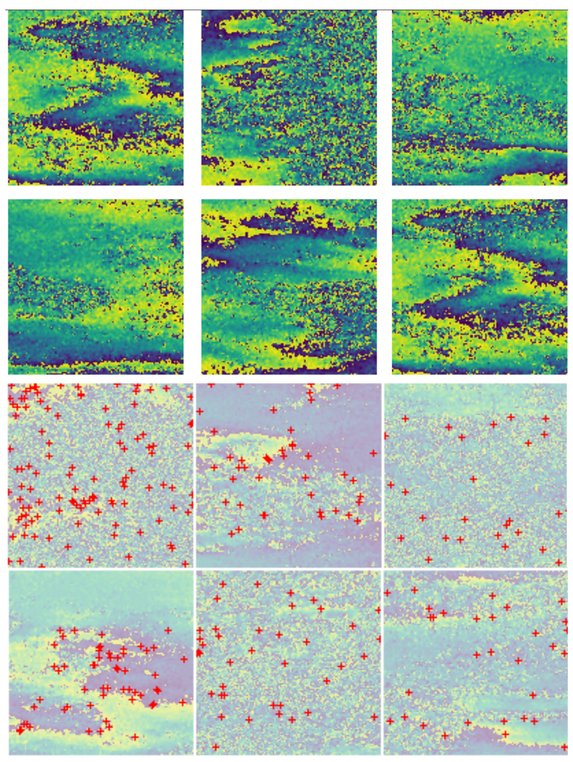
p_1 = clean interferograms

Riemannian FM generates new valid interferograms

- phase fringes
- salt-and-pepper noise

Standard FM fails to generate phase differences

Red crosses
$\mathbf{w}^i \notin [0, 2\pi[$



6.Denoising

p_0 = noisy interferograms

p_1 = clean interferograms