Enhancing Biogenic Emission through Deep Learning Techniques

Antonio Giganti, Sara Mandelli, Paolo Bestagini, Marco Marcon, Stefano Tubaro

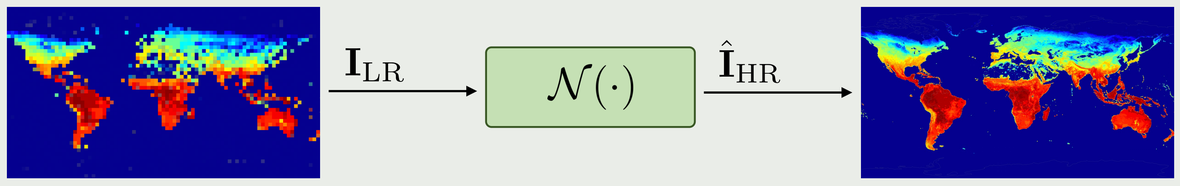
Dipartimento di Elettronica, Informazione e Bioingegneria - Politecnico di Milano – Milan, Italy

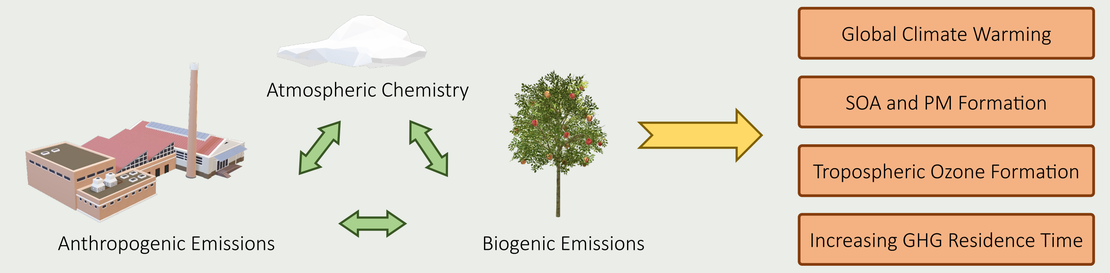
ISPL Image and Sound Processing Lab

POLITECNICO MILANO 1863

Objective

Biogenic VOC Emission **Super-Resolution** (SR)





Biogenic VOC

Previous Works

Giganti, A., et al. (2023). *Super-Resolution of BVOC Maps by Adapting Deep Learning Methods*. ICIP

- **Single-Image SR** (SISR) approach for Biogenic SR
- Robust data transformation based on statistical information
- Comparison of multiple SOTA SR networks
- Generalization study on unseen compounds

Giganti, A., et al. (2023). *Multi-BVOC Super-Resolution Exploiting Compounds Inter-Connection*. EUSIPCO

- **Multi-Image SR** (MISR) approach for Biogenic SR
- Exploitation of multiple Biogenic VOC for SR
- Emissions' spatial interconnection analysis

Giganti, A., *et al.* (2023). *Super-Resolution of BVOC Emission Maps Via Domain Adaptation*. IGARSS

- Leverage simulated emissions for satellite-derived emission SR
- Huge domain mismatch between simulated and satellite-derived emissions
- **Domain Adaptation** (DA) strategies on data transformation and SR network

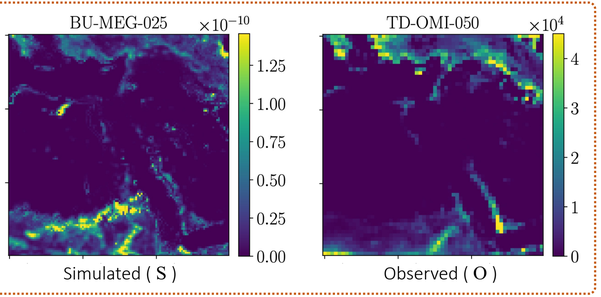
Code Repository

Problem

Numerically **Simulated** (S) and **Observed** (O) (satellite-derived) emissions exhibit differences in:

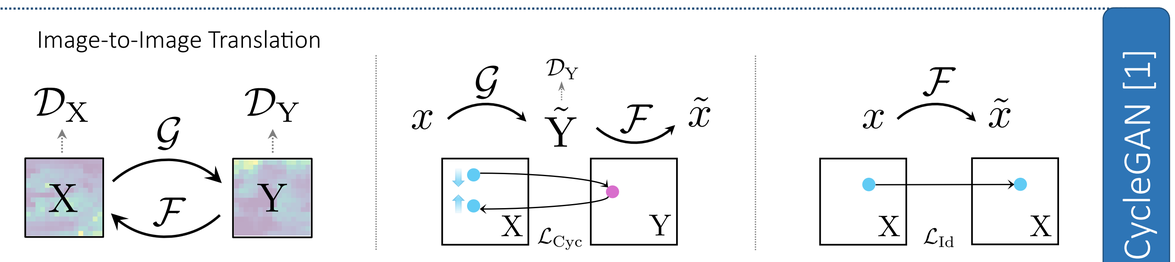
- Dynamic Range
- Emission Pattern
- Spatial/Temporal Resolution

Exploit S emissions (fine-grained) for super-resolving the O ones (coarser) <u>requires adaptation !</u>

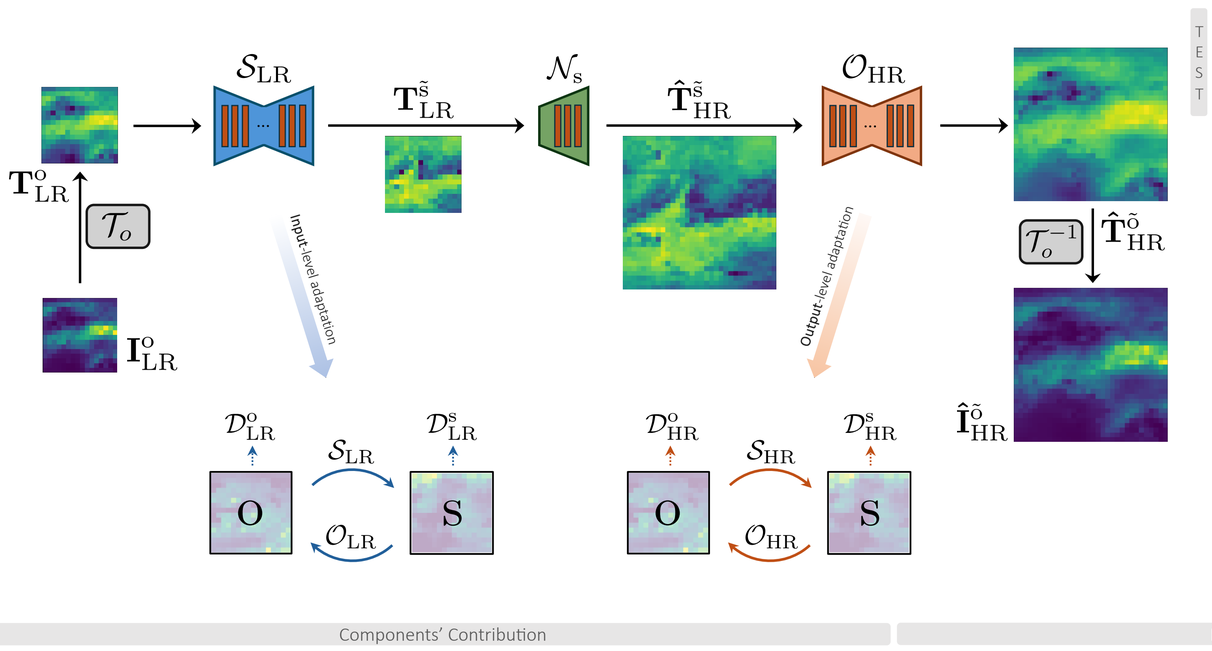


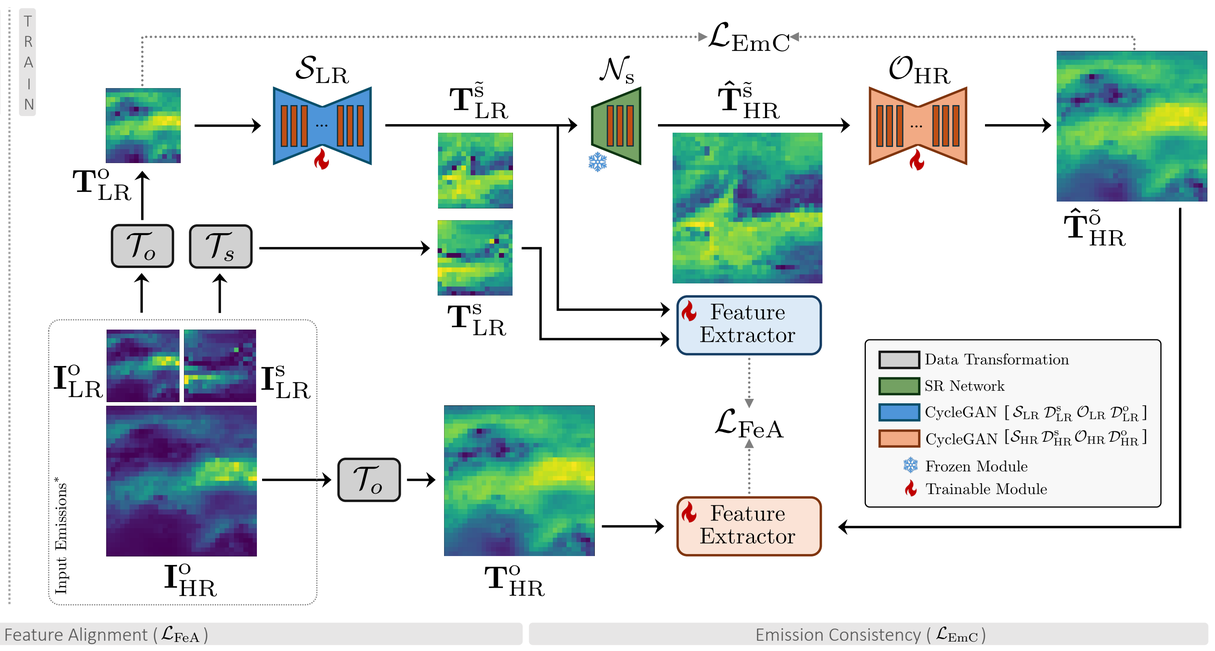
CycleGAN [1]

Image-to-Image Translation



Proposed Methodology





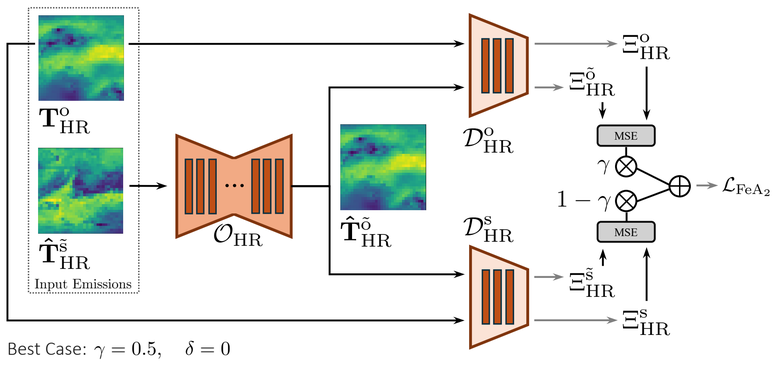
Training Loss Components

Components' Contribution

$\mathcal{L}_{\mathrm{CG}}$	$\mathcal{L}_{\mathrm{FeA}}$	$\mathcal{L}_{\mathrm{EmC}}$	SSIM ↑	NMSE ↓	UIQI ↑	SCC ↑	MaxAE ↓
✓			0.257	-1.460	0.065	0.008	57533.932
✓	✓		0.806	**-10.763**	**0.721**	0.585	34207.770
✓		✓	0.294	-2.099	0.096	0.018	55961.351
✓	✓	✓	**0.812**	-10.744	0.716	**0.642**	**30228.780**

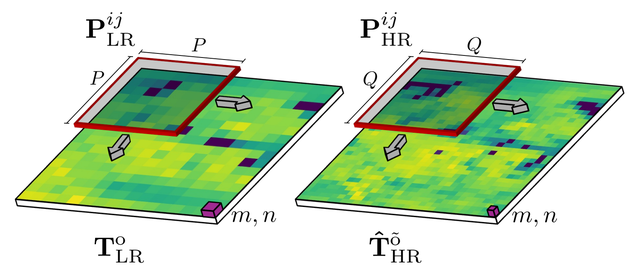
$$\left.\begin{aligned}\mathcal{L}_{\mathrm{CG}} &= \mathcal{L}_{\mathrm{GAN}} + \mathcal{L}_{\mathrm{Cyc}} + \mathcal{L}_{\mathrm{Id}}\\ \mathcal{L}_{\mathrm{FeA}} &= \delta\mathcal{L}_{\mathrm{FeA}_1} + (1-\delta)\mathcal{L}_{\mathrm{FeA}_2}\\ \mathcal{L}_{\mathrm{EmC}} &= \frac{1}{N_x \cdot N_y}\sum_{i=0}^{N_x-1}\sum_{j=0}^{N_y-1}\left|\overline{P}^{ij}_{\mathrm{LR}} - \overline{P}^{ij}_{\mathrm{HR}}\right|\end{aligned}\right\} \mathcal{L}_{\mathrm{Train}} = \mathcal{L}_{\mathrm{CG}} + \lambda_1\mathcal{L}_{\mathrm{FeA}} + \lambda_2\mathcal{L}_{\mathrm{EmC}}$$

Feature Alignment ($\mathcal{L}_{\mathrm{FeA}}$)



Best Case: $\gamma = 0.5, \quad \delta = 0$

Emission Consistency ($\mathcal{L}_{\mathrm{EmC}}$)



We compare the performance of 5 different scenarios:

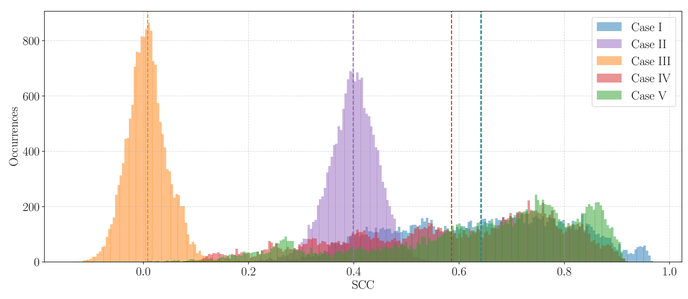
I. $\hat{\mathbf{I}}^{\mathrm{o}}_{\mathrm{HR}} = \mathcal{T}_o^{-1}\left(\mathcal{N}_o(\mathcal{T}_o(\mathbf{I}^{\mathrm{o}}_{\mathrm{LR}}))\right)$, i.e., train the <u>entire system</u> with O emissions

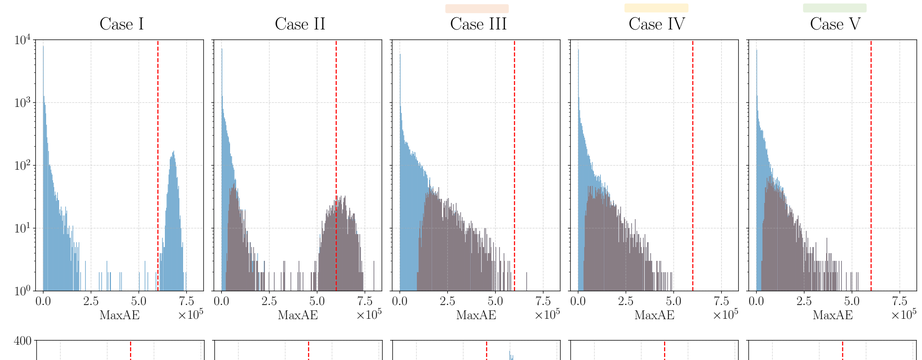
II. $\hat{\mathbf{I}}^{\mathrm{o}}_{\mathrm{HR}} = \mathcal{T}_o^{-1}\left(\mathcal{N}_s(\mathcal{T}_o(\mathbf{I}^{\mathrm{o}}_{\mathrm{LR}}))\right)$, i.e., train just the <u>data transformation</u> with O emissions

III. $\mathcal{L}_{\mathrm{Train}} = \mathcal{L}_{\mathrm{CG}}$

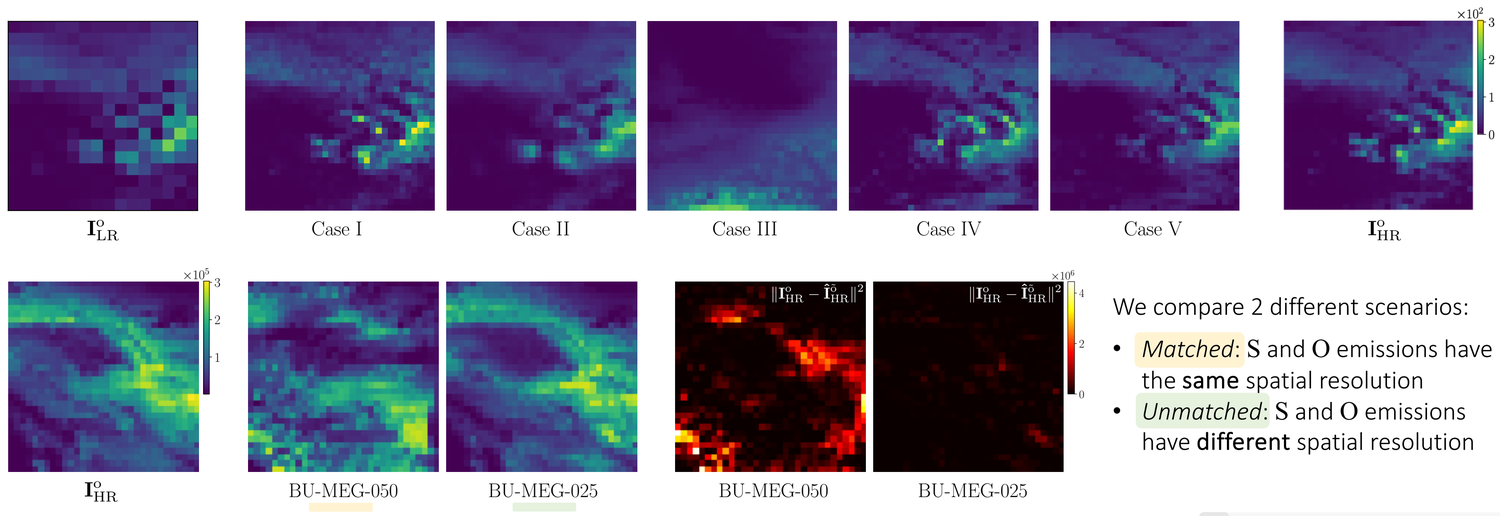
IV. $\mathcal{L}_{\mathrm{Train}} = \mathcal{L}_{\mathrm{CG}} + \mathcal{L}_{\mathrm{FeA}}$

V. $\mathcal{L}_{\mathrm{Train}} = \mathcal{L}_{\mathrm{CG}} + \mathcal{L}_{\mathrm{FeA}} + \mathcal{L}_{\mathrm{EmC}}$



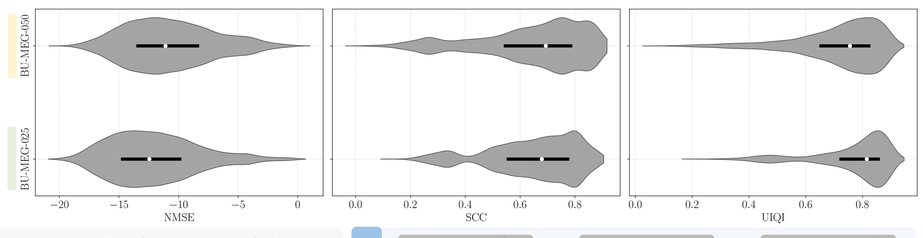


Spatial Resolution



We compare 2 different scenarios:

- *Matched*: S and O emissions have the **same** spatial resolution
- *Unmatched*: S and O emissions have **different** spatial resolution



Biogenic Inventories

Parameter	Biogenic Inventory			
	BU-MEG-050	BU-MEG-025	TD-OMI-050	TD-GOME2-050
Domain	**S**	**S**	**O**	**O**
Method	MEGANv3.2	MEGANv2.1	OMI-based Inversion	GOME-2-based Inversion
Variable	Isoprene Flux	Isoprene Flux	Isoprene Flux	Isoprene Flux
Reference	[3]	[4]	[5]	[6]
Spatial Coverage	Global	Global	Global	Global
Spatial Resolution	$0.50° \times 0.50°$	$0.25° \times 0.25°$	$0.50° \times 0.50°$	$0.50° \times 0.50°$
Temporal Coverage	$2001 - 2020$	$2000 - 2019$	$2005 - 2014$	$2007 - 2012$
Temporal Resolution	Hourly (Monthly Avg)	Hourly (Monthly Avg)	Daily	Daily
Num. Emissions Maps	5760	5760	3652	2192
Emission Range [min, max]	$[0, 8.0 \times 10^{-9}]$ $\frac{kg}{m^2 \cdot s}$	$[0, 6.6 \times 10^{-9}]$ $\frac{kg}{m^2 \cdot s}$	$[0, 2.3 \times 10^{6}]$ $\frac{kg}{area_{cell} \cdot day}$	$[0, 3.5 \times 10^{6}]$ $\frac{kg}{area_{cell} \cdot day}$

References

[1] Zhu, J.Y. *et al.* (2017). *Unpaired Image-to-Image Translation Using Cycle-Consistent Adversarial Networks*. IEEE International Conference on Computer Vision (ICCV), pp. 2242–2251

[2] Giganti, A. *et al.* (2024). *Learn from Simulations, Adapt to Observations: Super-Resolution of Isoprene Emissions via Unpaired Domain Adaptation*. Remote Sensing, 16(21), 3963

[3] Wang, *H. et al.* (2024). *Regional to global distributions, trends, and drivers of biogenic volatile organic compound emission from 2001 to 2020*. Atmos. Chem. Phys., 24, 3309

[4] Sindelarova, K. *et al.* (2022). *High-resolution biogenic global emission inventory for the time period 2000–2019 for air quality modelling*. Earth Syst. Sci. Data, 14, 251

[5] Stavrakou, T. *et al.* (2015). *How consistent are top-down hydrocarbon emissions based on formaldehyde observations from GOME-2 and OMI?*. Atmos. Chem. Phys., 15, 11861

[6] De Smedt, I. *et al.* (2015). *Diurnal, seasonal and long-term variations of global formaldehyde columns inferred from combined OMI and GOME-2 observations*. Atmos. Chem. Phys., 15, 12519.

Links: Paper · Code · Podcast

This work was supported by the Italian Ministry of University and Research (MUR) and the European Union (EU) under the PON/REACT project.

PON RICERCA E INNOVAZIONE 2014 - 2020 · MUR Ministero dell'Università e della Ricerca · UNIONE EUROPEA Fondo Sociale Europeo