Towards Downscaling Global AOD with ML

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Poor air quality is a significant health threat, especially in urban areas.

High-resolution (HR) **Aerosol Optical Depth (AOD)** forecasts are needed as proxy for improve air pollutant mass concentrations. Current GCM forecasts of AOD **lack spatial resolution**, making it difficult to accurately represent local-scale variability.

Here, we evaluate GCM/reanalysis-scale to local-scale **downscaling** of **global AOD**, and **bias correction**, using ML.

Data

Dataset	Size	Resolution	Temporal Extent
MODIS MOD04_L2	16.0K/3.0K/1.0K images	0.9°/0.09°	2000/02/24 - 2023/07/19
CAMS	14.0K images	0.75°	01/01/2009 - 31/12/2016
AERONET	50.0K points	N/A	01/01/2009 - 31/12/2016

Note: focus on AOD at 550nm resolution (AOD_{550})

MODIS Level 2 Satellite Observations (MOD04_L2)
- used for training ResNet CNN
- reprojected from sinusoidal onto regular lat-lon grid
- HR data coarsened for LR input-target pairs
- mean imputation used for gap-filling.

CAMS Reanalysis
- used for bias correction evaluation.

AERONET Station Measurements
- used for bias correction evaluation
- obtained from selected well-maintained stations (Fig 1.)
- AOD_{550} interpolated from neighbouring wavelengths
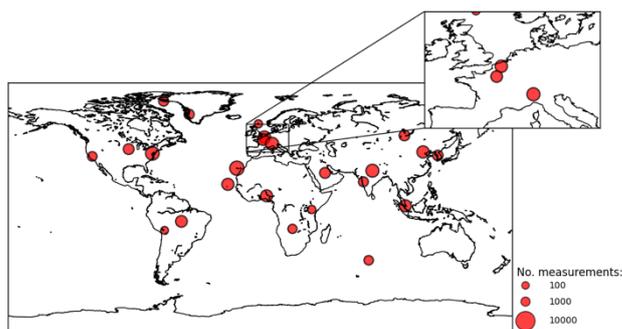- fixed 2.1km scale-height correction for collocation.

Fig 1. The AERONET stations selected for evaluation; the number of measurements obtained from each station is proportional to the area of its circle.

Method
Architecture + Experimental Setup
- SR-ResNet with modifications
  - two-stage progressive upsampling
  - maintained ReLU layers outside residual blocks for non-negative outputs
  - removed BatchNorm layers within residual blocks.
- modified Mean Squared Error (MSE) loss function for sparse HR target images; calculates loss on non-sparse pixels only
- early stopping on validation loss
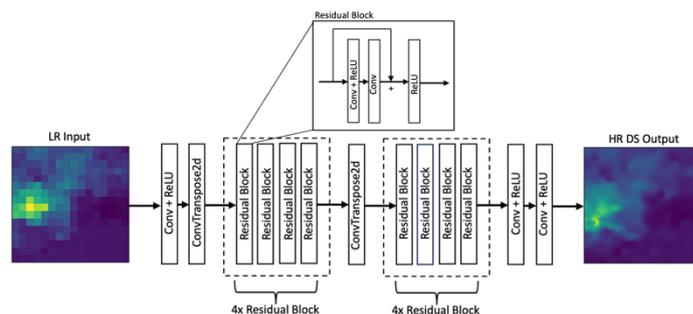- **Baseline:** Lanczos interpolation (non-trainable)

Fig 3. The modified SR-ResNet used.

Results and Limitations

ResNet CNN shows potential for global downscaling
- outperforms interpolation baseline on MODIS AOD
- struggles with bias correction on CAMS reanalysis

Limitations
- gap-filling introduces potential bias
  - or bias inherent in MODIS data
- wavelength shift from AERONET 550nm to nearest-available
- emphasizes need for improved AOD satellite data

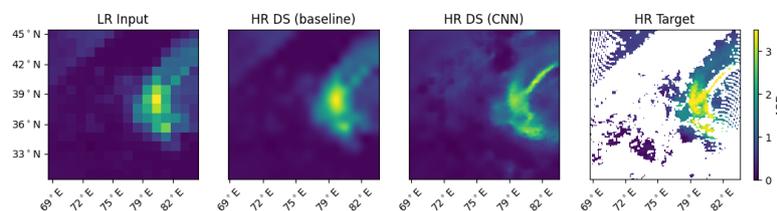|	MODIS (MOD04_L2)		CAMS		
	HR DS (baseline)	HR DS (CNN)	LR	HR DS (baseline)	HR DS (CNN)
KGE	0.571	**0.939**	0.646	**0.758**	0.738
MSE	0.008	**0.005**	0.075	**0.066**	0.069
NMBE	**0.017**	0.039	0.203	**0.092**	0.098

Fig 4. Example outputs, from baseline and ResNet (CNN), on a MOD04_L2 image. The sparsity of the HR MODIS data is visible in the target image. The LR image shows the results of the coarsening and gap-filling.
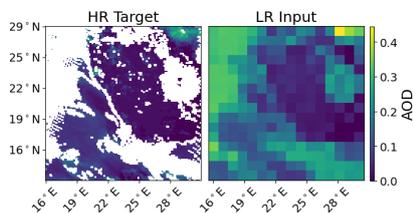

Fig 2. reprojected HR MOD04_L2 AOD image crop alongside its coarsened LR equivalent, with mean imputation, forming a LR-HR input-target pair.

Future Work
- incorporate physical constraints / enforce conservation laws
- temporal regularization via recurrence mechanisms
- unsupervised fine-tuning on reanalysis/GCM data
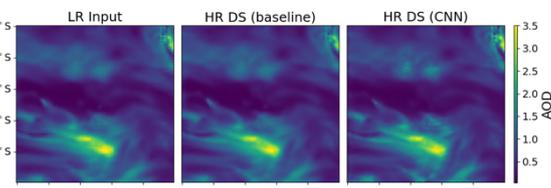 - could help mitigate distribution shift issues

Fig 5. Example outputs, from baseline and ResNet (CNN), on a CAMS image.