Engaging Content
Engaging People

Remote Sensing for Climate, Air Quality, and Weather Prediction

AI for Sustainability

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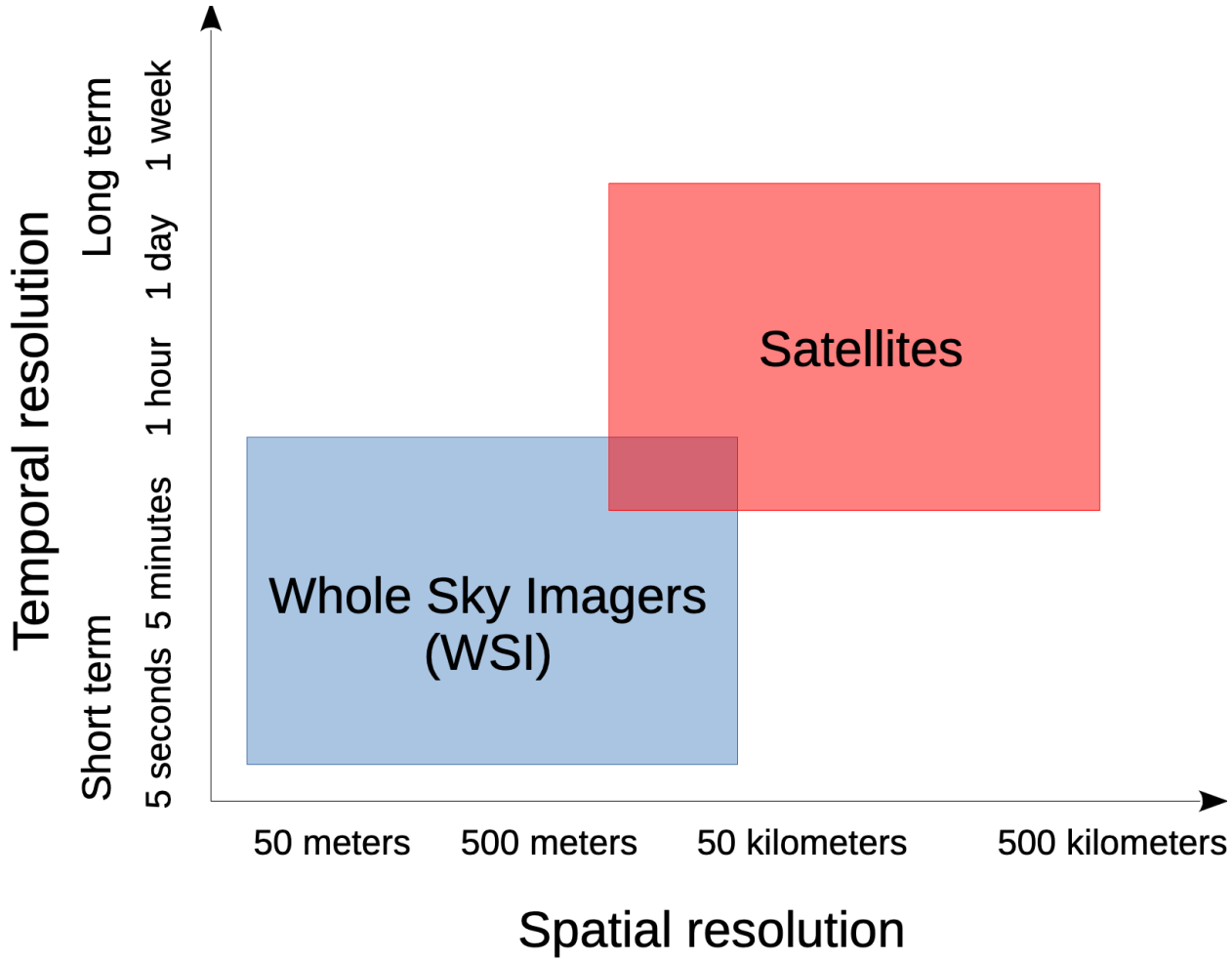
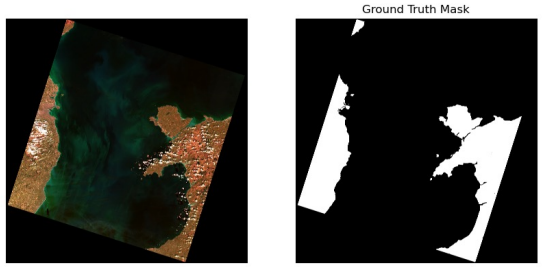
Earth + AI

- Can machine learning + computer vision assist in understanding our earth observations better?
- Advancement of computing power + open-source datasets is key:
  - Satellite images
  - Ground-based images



Coastal Monitoring



O'Sullivan *et al.* 2023

Air Pollutants

https://geography.name
(Accessed Sep 2023)

Sustainable Grid Management

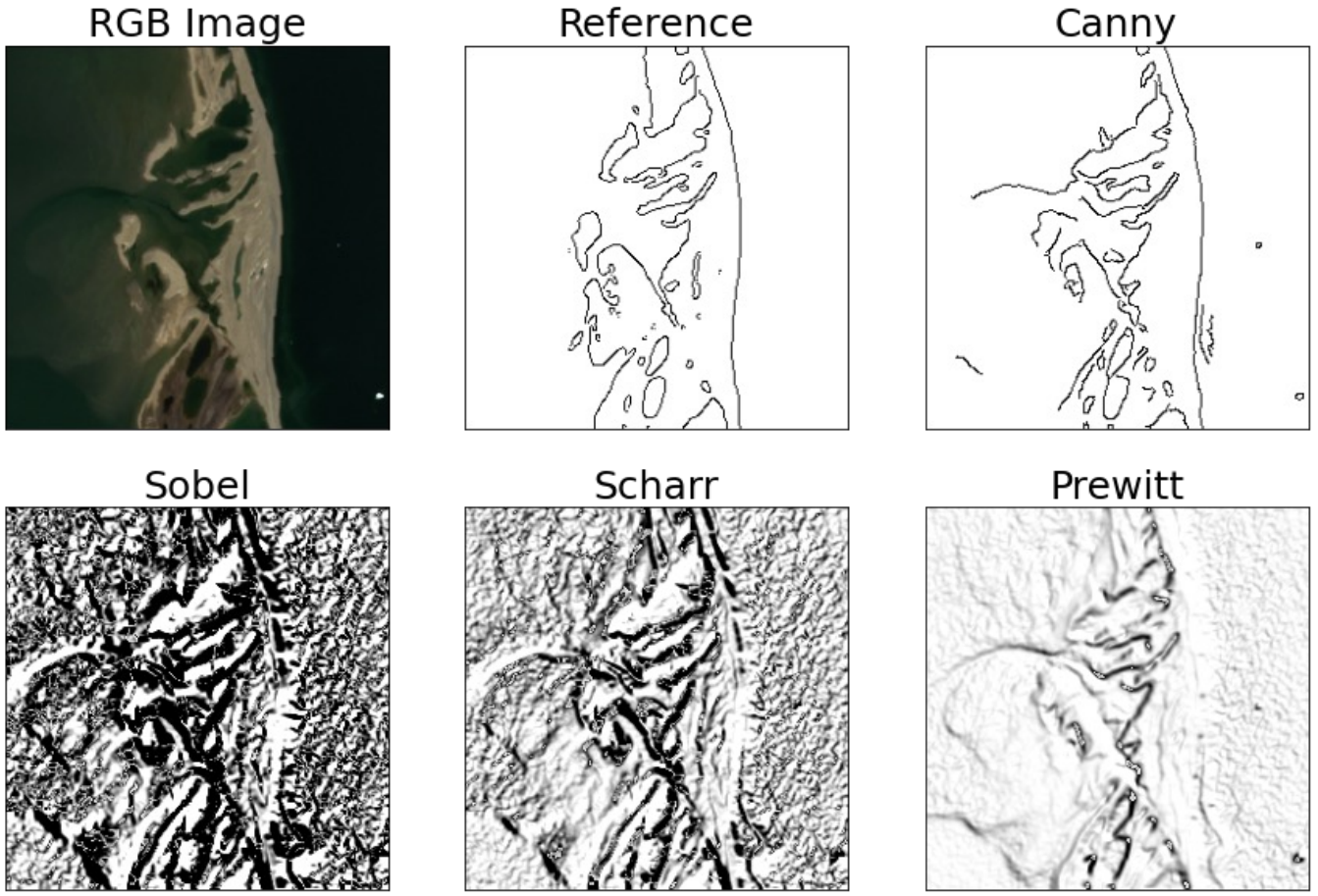
Dev *et al.* 2018

Why monitor Irish coastlines?

- Republic of Ireland has approximately 3171 km of coastline
  - Important for coastal management and being prepared for natural disasters.
- Manually identifying and mapping the coastline can be a time-consuming process.
  - Need to develop automated approaches as well as methods of evaluating those approaches.

Detecting coastlines

- Can be modeled as an edge detection problem.

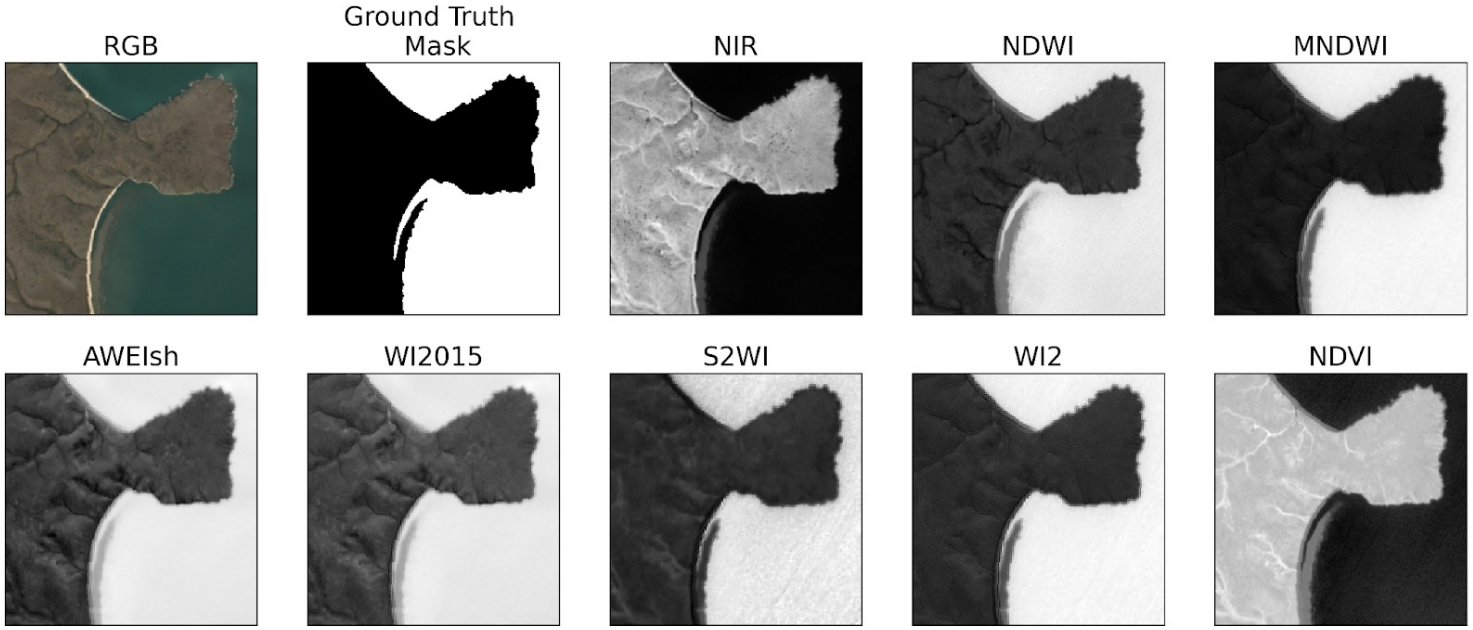


- Canny edge detector[1] produces the best results when compared to ground-truth edge maps.
- Deep neural networks[2] can be possibly used if sufficient labeled dataset is available.

[1]C. O'Sullivan, S. Coveney, X. Monteys, and S. Dev, Automated Coastline Extraction using Edge Detection Algorithms, *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2023.
[2]C. O'Sullivan, S. Coveney, X. Monteys, and S. Dev, Interpreting a Semantic Segmentation Model for Coastline Detection, *Proc. Progress In Electromagnetics Research Symposium (PIERS)*, 2023.

Multi-spectral satellite images

- Satellite images consists of several bands.



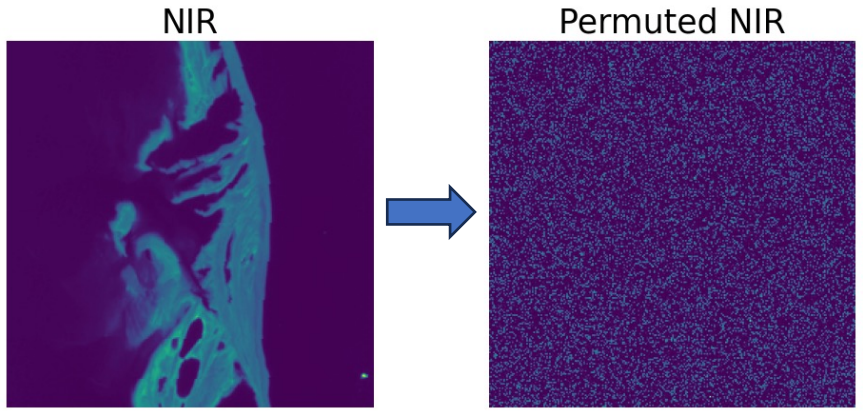
Index	Acronym	Formula
Normalized Difference Water Index	NDWI	(G-N)/(G+N)
Modified Normalized Difference Water Index	MNDWI	(G-S1)/(G+S1)
Automated Water Extraction Index with Shadows Elimination	AWEIsh	B+2.5*G-1.5*(N+S1)-0.25*S2
Water Index 2015	WI2015	1.7204+171*G+3*R-70*N-45*S1-71*S2
Sentinel-2 Water Index	S2WI	(RE1-S2)/(RE1+S2)
Water Index 2	WI2	(B-S2)/(B+S2)
Normalized Difference Vegetation Index	NDVI	(N-R)/(N+R)

- Few open-ended questions:
  - Which band should we use for land-water distinction[3]?
  - Which metric should we compute to perform best performing models[4]?

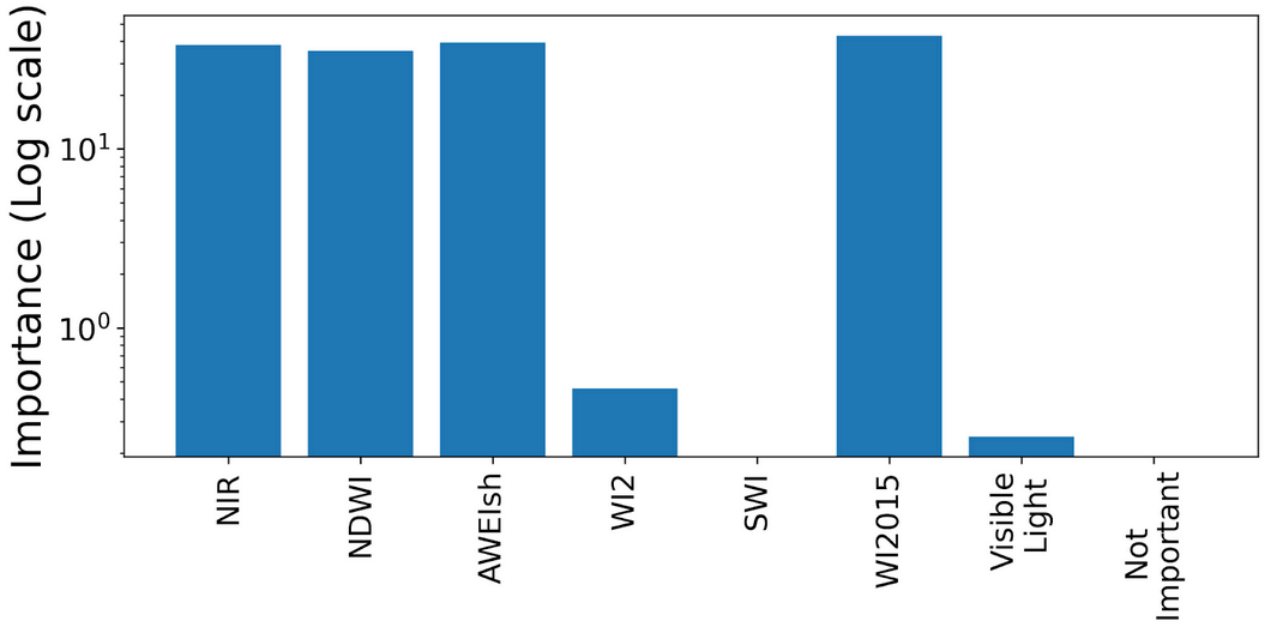
[3]C. O'Sullivan, S. Coveney, X. Monteys, and S. Dev, Analyzing Water Body Indicies for Coastal Semantic Segmentation, *Proc. Progress In Electromagnetics Research Symposium (PIERS)*, 2023.
[4]C. O'Sullivan, S. Coveney, X. Monteys, and S. Dev, The Effectiveness of Edge Detection Evaluation Metrics for Automated Coastline Detection, *Proc. Progress In Electromagnetics Research Symposium (PIERS)*, 2023.

Which bands are useful?

We use[5] a permutation-based importance score to find the importance of satellite bands.



Permutation of NIR band for a test image

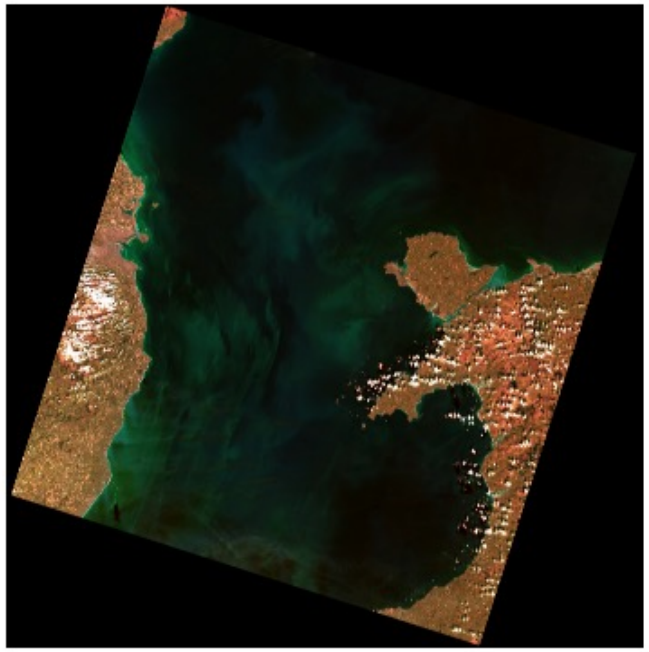


So what?

- Build trust with non-technical stakeholders
- Potential for new spectral indices based on water vapour

[5]C. O'Sullivan, S. Coveney, X. Monteys, and S. Dev, Analyzing Water Body Indicies for Coastal Semantic Segmentation, *Proc. Progress In Electromagnetics Research Symposium (PIERS)*, 2023.

What’s next? : Irish Coastline Dataset



Dataset (to be!) released[6] for Irish coastline semantic segmentation. This will focus on Ireland's coastline using 40 years of LANDSAT satellite images.

[6]C. O’Sullivan, S. Coveney, X. Monteys, and S. Dev, Landsat Ireland Coastline Dataset, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, under review 2023.

Coastal Monitoring

Air Pollutants

Sustainable Grid Management

O'Sullivan *et al.* 2023

https://geography.name
(Accessed Sep 2023)

Dev *et al.* 2018

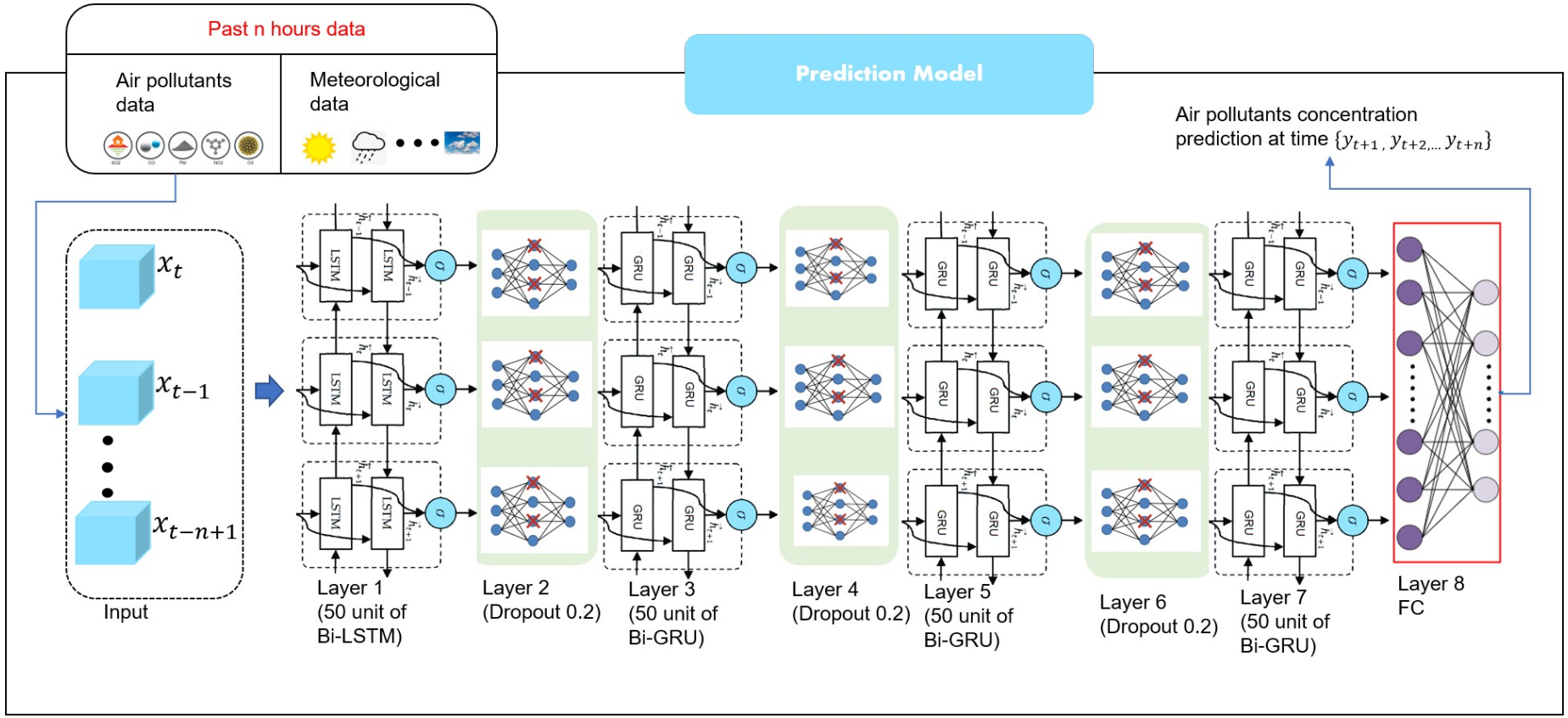
Air Pollutants

- Rapid worldwide growth, industry, and urbanization have contributed to considerable air quality deterioration[7].
- Major air pollutants such as $PM_{2.5}$, NO_2 , SO_2, and O_3 can cause serious health issues[8].

[7]Khan, Irfan, et al. "Do natural resources, urbanization, and value-adding manufacturing affect environmental quality? Evidence from the top ten manufacturing countries." *Resources Policy* 72 (2021): 102109.
[8]Grzywa-Celińska, Anna, Adam Krusiński, and Janusz Milanowski. "'Smoging kills'-effects of air pollution on human respiratory system." *Annals of Agricultural and Environmental Medicine* 27.1 (2020): 1-5.

Forecasting of $PM_{2.5}$ concentration

We develop[9] a bidirectional long-short-term memory and a bidirectional gated recurrent unit (BiLSTM-BiGRU) to predict $PM_{2.5}$ concentrations for different lead times.



[9]P. Dey, S. Dev, B. Schoen-Phelan, BiLSTM-BiGRU: A fusion deep neural network for predicting air pollutant concentration, *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2023.

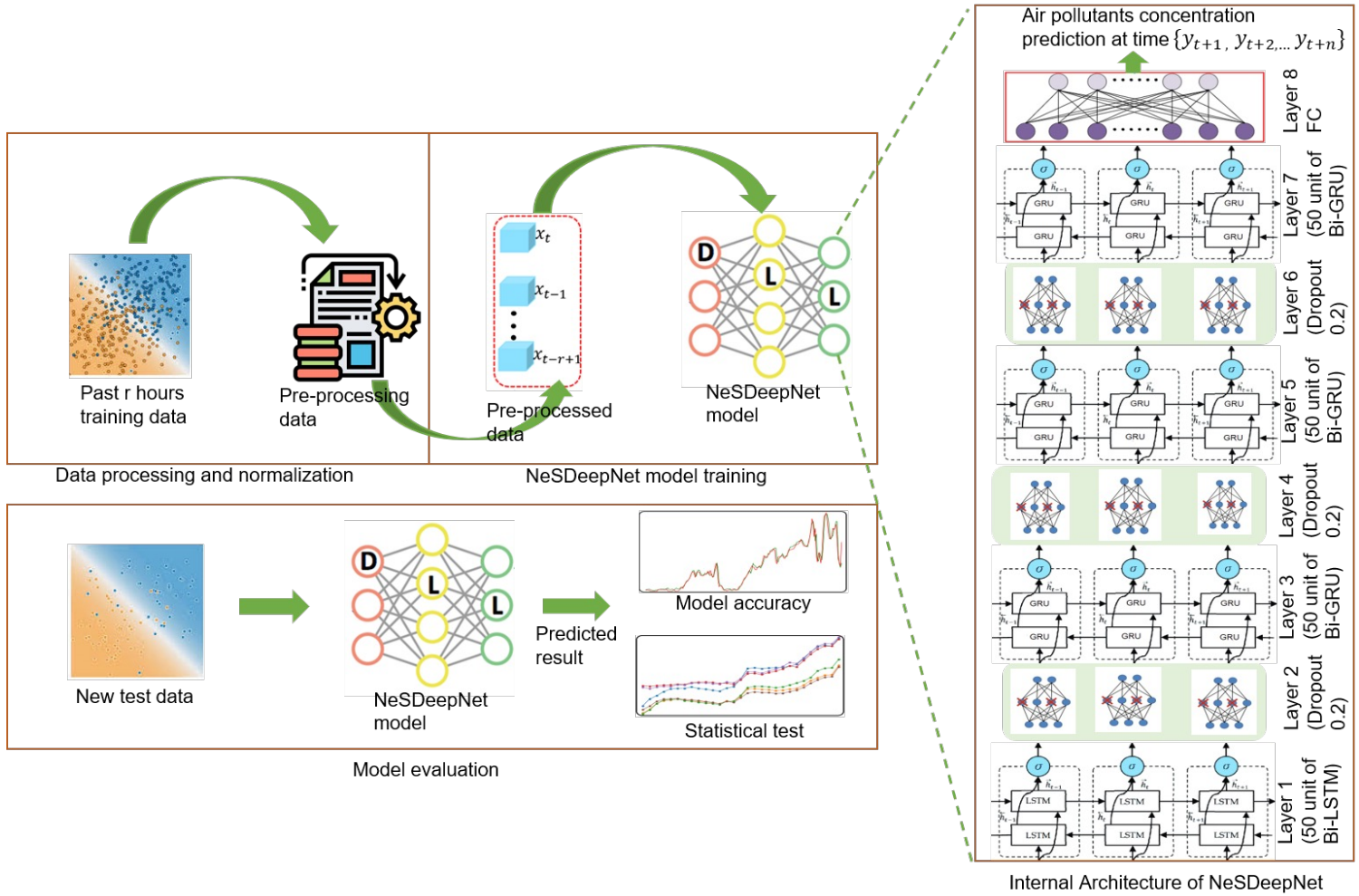
Forecasting of $PM_{2.5}$ concentration

	Methods	60h	90h	120h	150h	180h
RMSE	CNN	12.2	20.3	21.2	21.7	40.9
	CNN–LSTM	13.9	16.1	16.5	18.6	28.6
	CNN–GRU	22.6	23.3	22.8	21.1	30.6
	GRU	11.9	13.3	14.1	13.6	24.2
	LSTM	8.64	10.3	13.0	12.8	24.8
	Proposed	8.13	10.2	12.4	12.0	22.0
MAE	CNN	3.03	3.53	3.65	3.76	4.88
	CNN–LSTM	3.55	3.75	3.73	3.97	4.53
	CNN–GRU	4.62	4.65	4.52	4.29	4.79
	GRU	3.25	3.35	3.32	3.20	3.90
	LSTM	2.61	2.71	2.93	2.93	3.74
	Proposed	2.51	2.60	2.78	2.82	3.51
R^2	CNN	0.91	0.76	0.89	0.92	0.83
	CNN–LSTM	0.86	0.81	0.91	0.93	0.90
	CNN–GRU	0.72	0.68	0.85	0.92	0.88
	GRU	0.89	0.87	0.94	0.97	0.94
	LSTM	0.95	0.93	0.96	0.98	0.95
	Proposed	0.95	0.93	0.96	0.98	0.96

Table: Comparison of the performance of the proposed model with other models over multiple lead times.

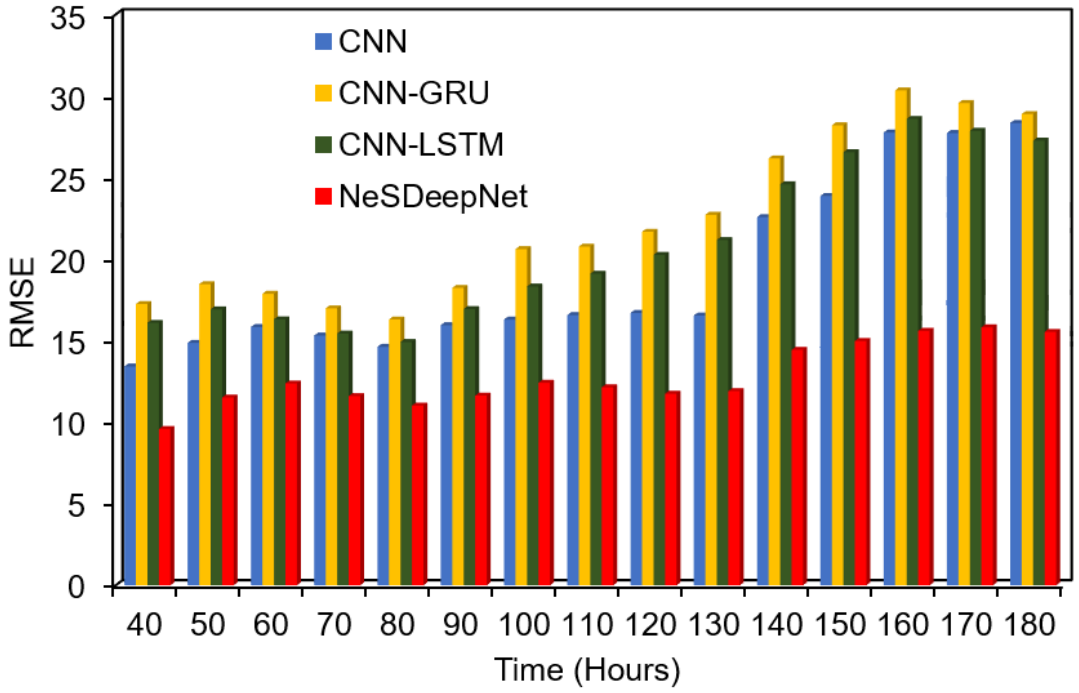
Forecasting of NO_2 and CO concentration

We propose[10] a near-surface deep network (NeSDeepNet) to form a hybrid forecasting system.

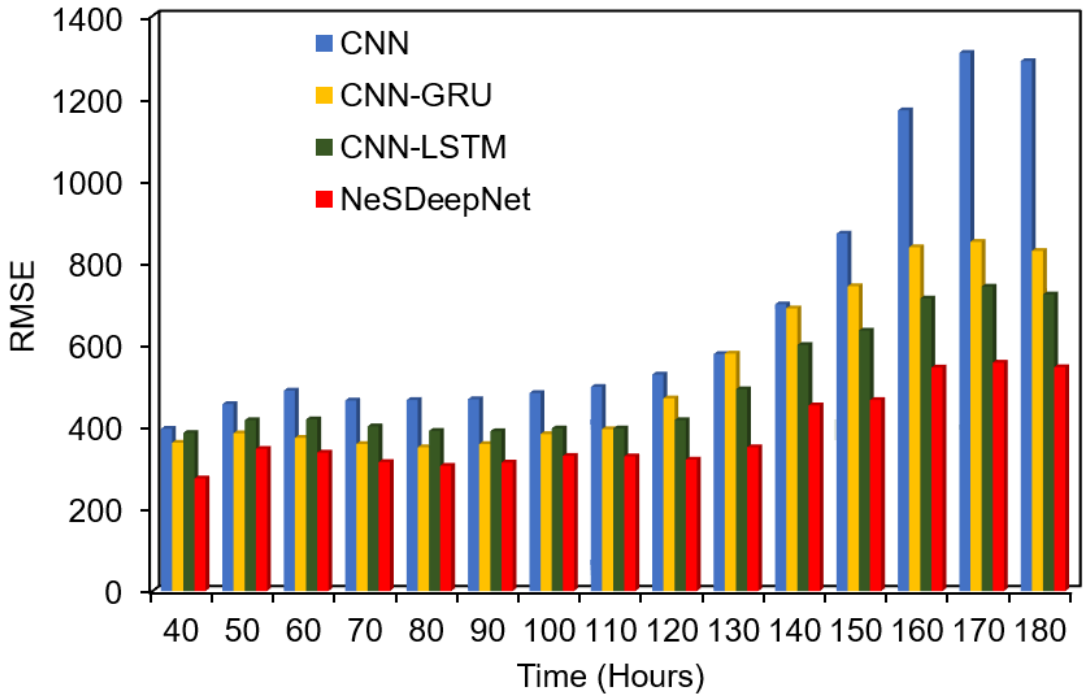


[10]P. Dey, S. Dev, B. Schoen-Phelan, NeSDeepNet: A Fusion Framework for Multi-step Forecasting of Near-surface Air Pollutants, Proc. Progress In Electromagnetics Research Symposium (PIERS), 2023.

Forecasting of NO_2 and CO concentration



(a)

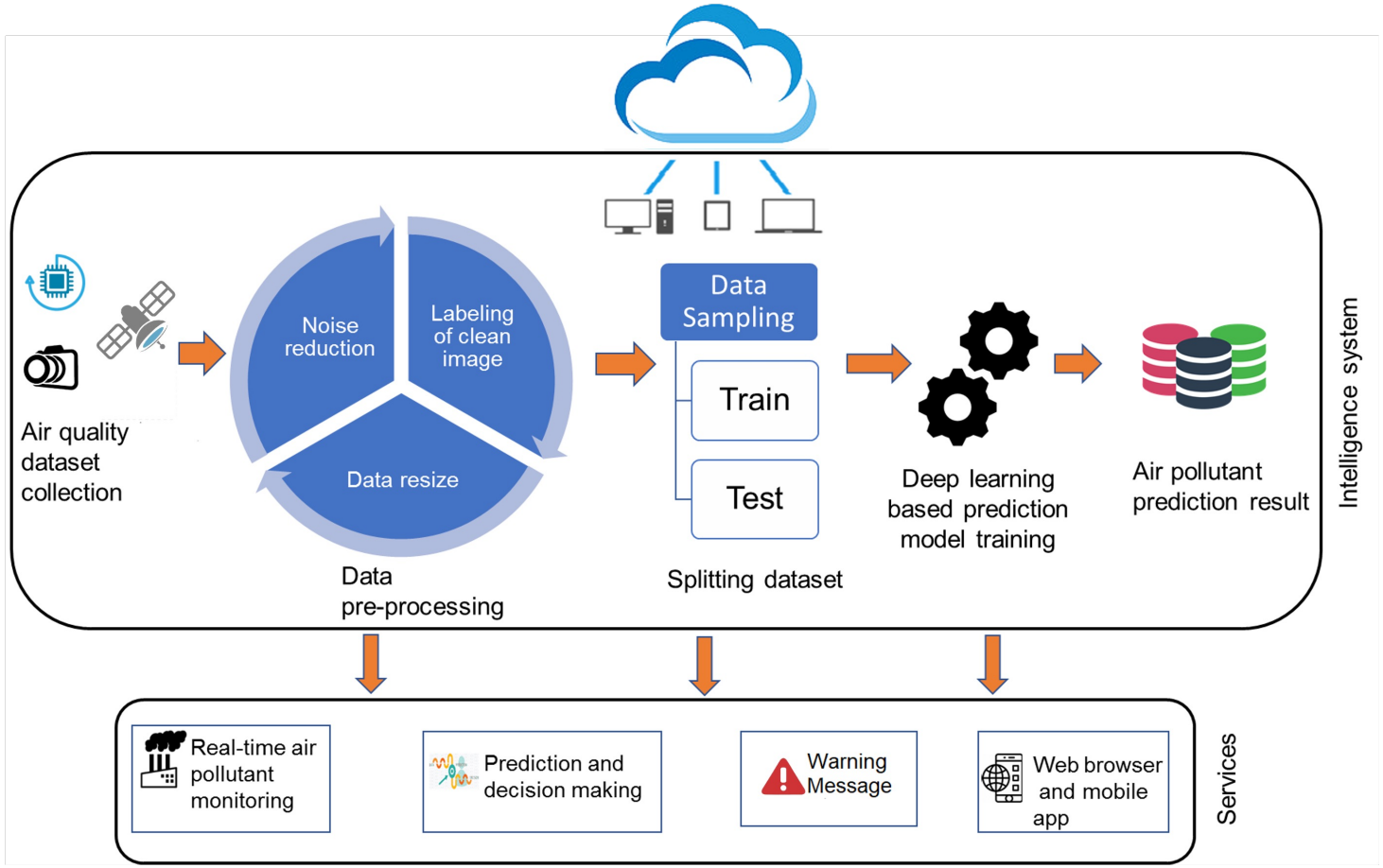


(b)

RMSE-based comparison of the performance of the NeSDeepNet model to other models for the prediction of (a) NO_2 and (b) CO concentrations

What's next? : Real-time prediction

- Urgent need of an intelligent system for real time prediction.



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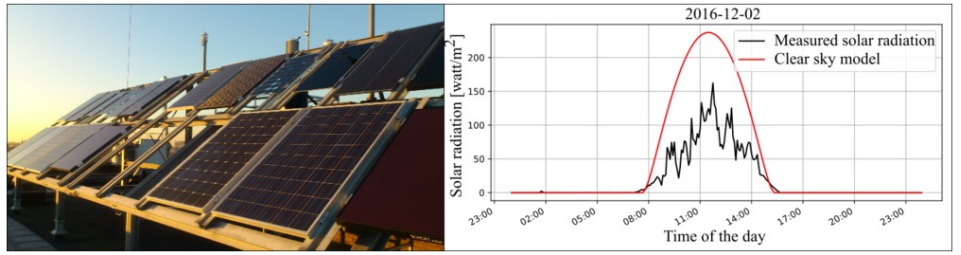
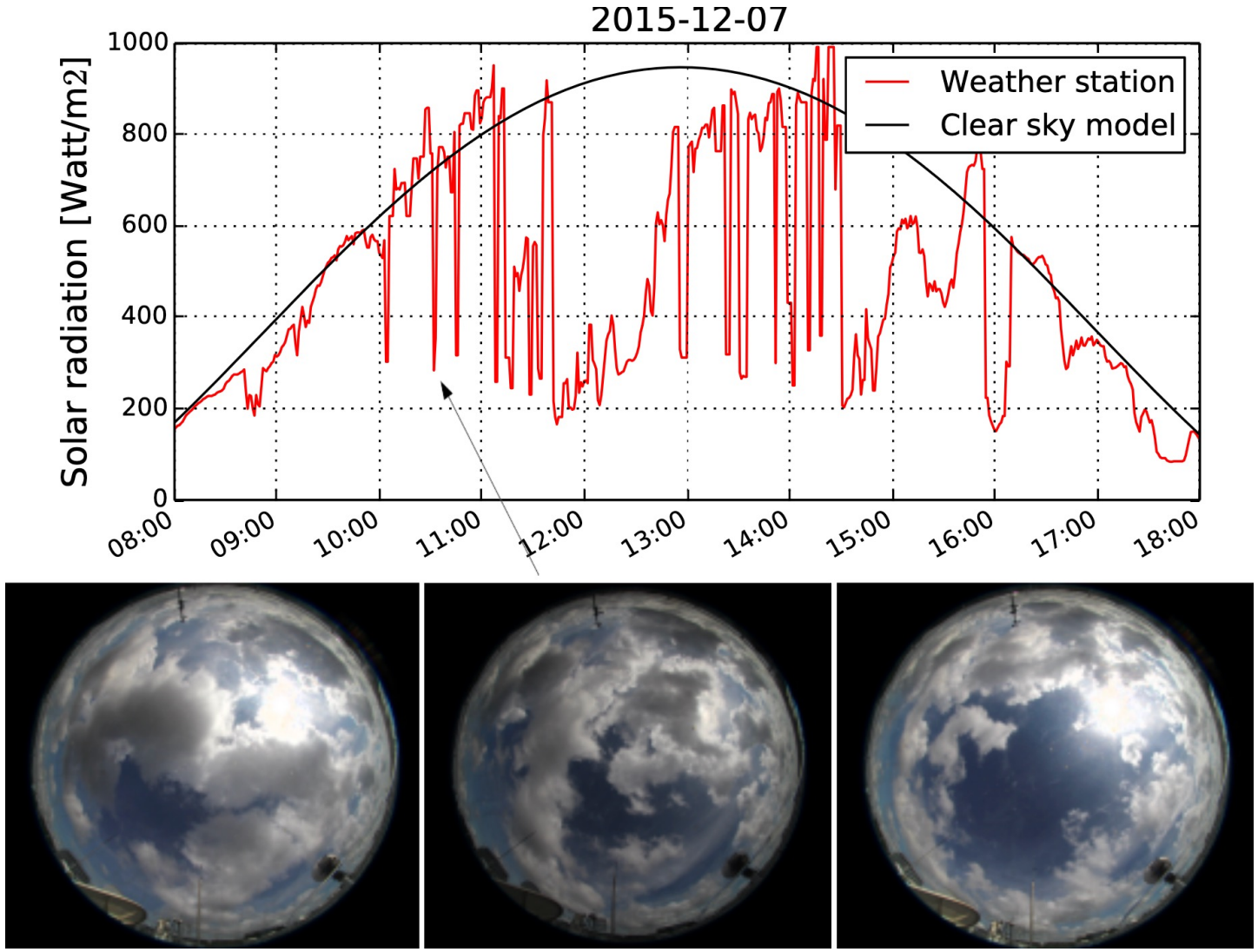


Dev *et al.* 2018

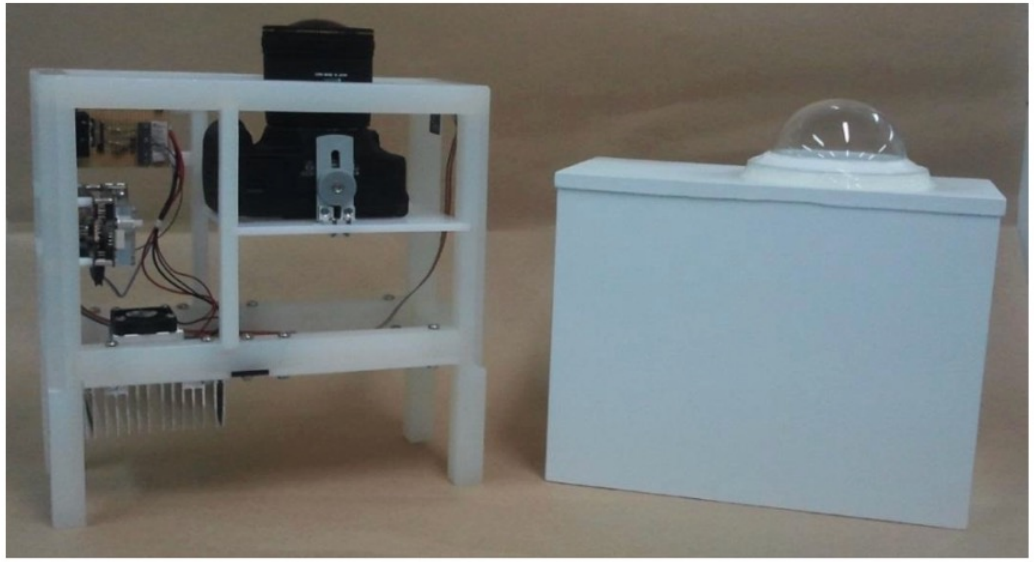
Understanding solar energy

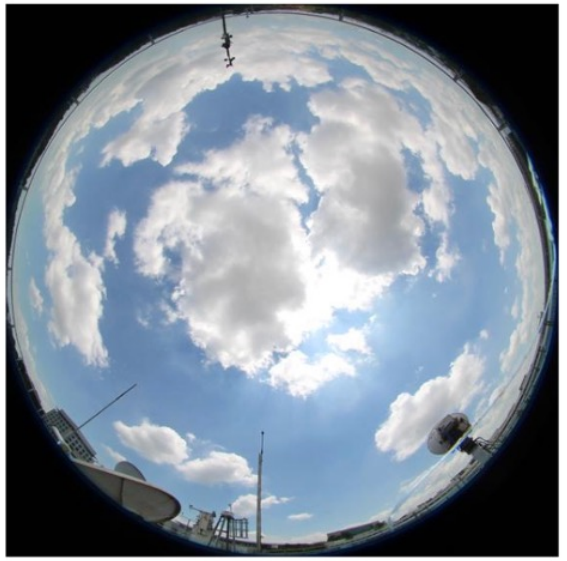


Manandhar *et al.* 2018

Sky cameras

- We have built several[11,12,13,14] models of sky cameras

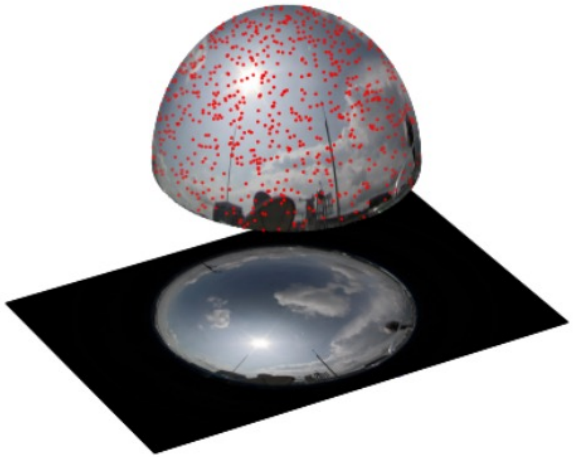




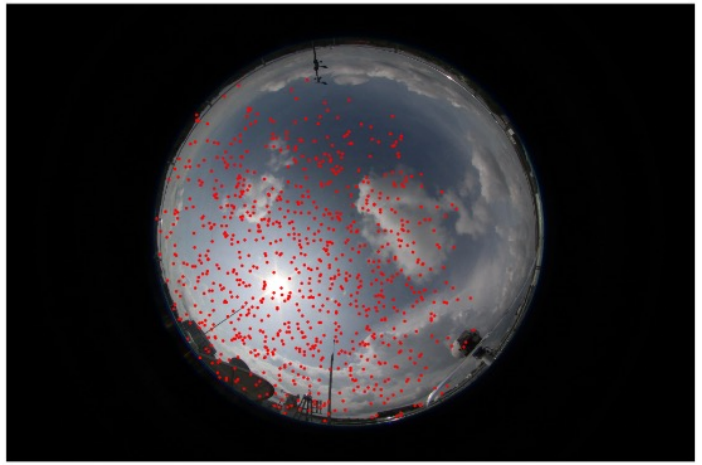
[11]S. Dev, F. M. Savoy, Y. H. Lee and S. Winkler, DIY Sky Imager For Weather Observation: A complete guide to build a ground-based sky imager using off-the-shelf components with automatic cloud coverage computation, SPM Student Design Project Series Documents, *IEEE Signal Processing Society*, 2016.
[12]S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, WAHRSIS: A low-cost, high-resolution whole sky imager with near-infrared capabilities, *Proc. IS&T/SPIE Infrared Imaging Systems: Design, Analysis, Modeling, and Testing*, May 2014.
[13]S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, Design of low-cost, compact and weather-proof whole sky imagers for high-dynamic-range captures, *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, July 2015.
[14]M. Jain, I. Gollini, M. Bertolotto, G. McArdle, and S. Dev, An Extremely-Low Cost Ground-Based Whole Sky Imager, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2021.

Estimating Solar Irradiance

- In what ways can the rapid fluctuations of the solar irradiance be best captured[15]?
- Estimating solar energy from captured sky camera images[16].



Hemispheric sampling

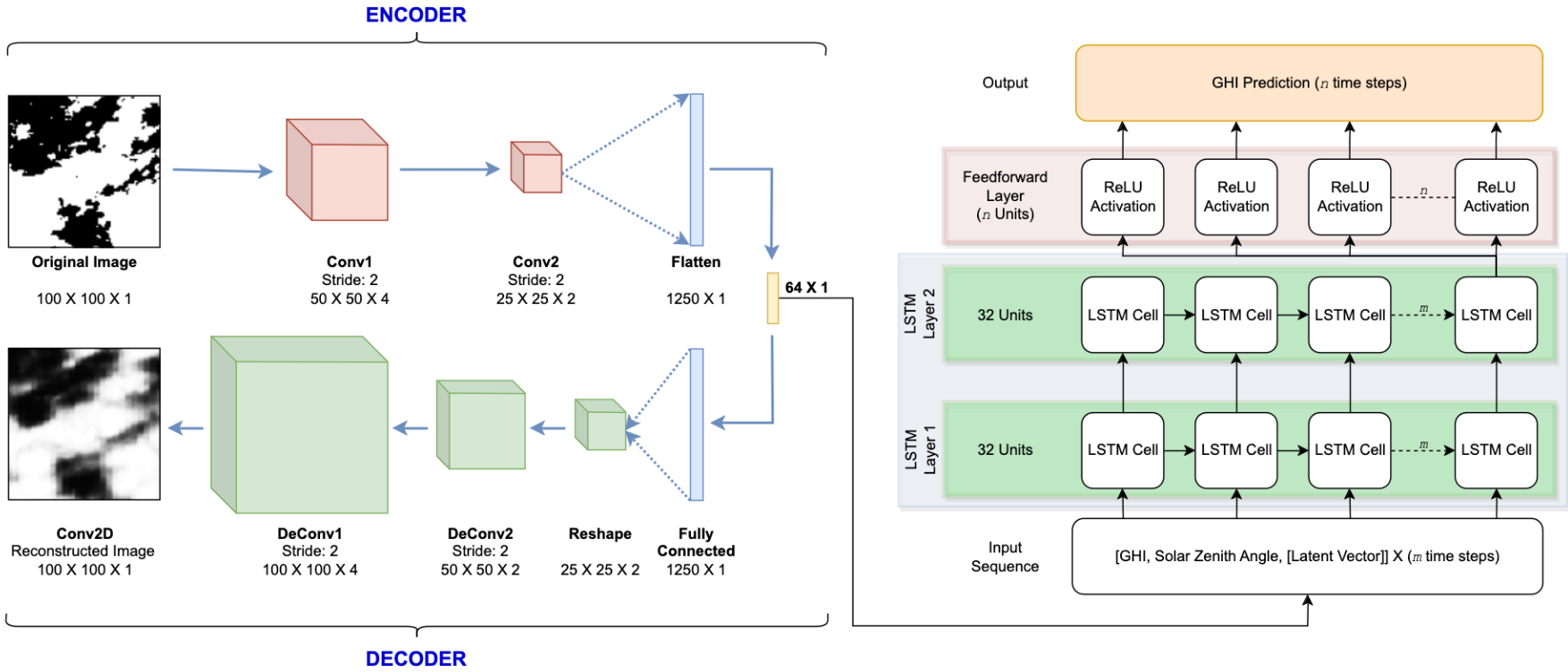


Projection on the image.

[15]S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, Estimation of solar irradiance using ground-based whole sky imagers, *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, July 2016.
[16]S. Dev, F. M. Savoy, Y. H. Lee, S. Winkler, Estimating Solar Irradiance Using Sky Imagers, *Atmospheric Measurement Techniques (AMT)*, 2019.

Forecasting Solar Irradiance

- Lightweight convolutional autoencoder proposed[17] to encode key cloud cover information from the satellite imagery in smaller latent space
- Simple lightweight LSTM model integrates cloud mask features for solar irradiance forecasting



[17]M. Jain, C. Kumari, A. Kumar, and S. Dev, Using METEOSTAT Cloud Masks for Solar Irradiance Nowcasting, *Proc. IEEE International Geoscience and Remote Sensing Symposium (IGARSS),* 2023.

My concluding thoughts

- Computer vision helps identify changes in coastline and assess the impact of climate change.
- AI-powered image analysis can detect sources of pollution aiding in air quality monitoring and public health management.
- Smart grids powered by AI enhance the reliability and sustainability of solar energy systems.

Team behind our research

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