

Indian Institute of Technology Kanpur
Proposal for a New Course - Elective

1. Course No: KSS6XX

2. Course Title: AI for Weather and Climate Modelling

3. Per Week Lectures: 3 (L), Tutorial: 0 (T), Laboratory: 0 (P), Additional Hours [0-2]:0 (A),
Credits ($3*L+0*T+P+A$): 9

Duration of Course: Full Semester

4. Proposing Department/IDP: Kotak School of Sustainability

Other Departments/IDPs that may be interested in the proposed course: CE, AE, ME, PHY, ChE

Other faculty members interested in teaching the proposed course: Prof. Mahendra K. Verma, Prof. Sachchida Nand Tripathi

5. Proposing Instructor(s): Prof. Sarosh Alam Ghausi (KSS), Prof. Rajesh Ranjan (AE)

6. Course Description:

A) Objectives:

This course introduces students to artificial intelligence (AI), machine learning (ML), and scientific machine learning techniques for weather and climate modelling and prediction. Students will gain foundational knowledge of atmospheric processes, climate datasets, Earth system modelling and numerical weather prediction. The course covers classical machine learning methods, deep learning architectures, graph-based learning, neural operators, and emerging foundation models for weather forecasting. Students will learn to analyze observational, reanalysis, and climate datasets, develop data-driven forecasting models, evaluate modern AI-based forecasting systems and gain hands-on experience with state-of-the-art tools for weather forecasting, and Earth-system modeling.

B) Contents:

S. No	Broad Title	Topics	No. of Lectures*
1	Introduction to Weather, Climate, and Numerical Forecasting	- Weather versus climate - Earth-system components relevant to weather prediction - Atmospheric circulation and weather systems - Challenges in weather and climate prediction	2

		● Evolution of numerical and AI-based forecasting	
2	Atmospheric Data and Computational Foundations	● Surface observations and weather stations ● Radiosondes and upper-air observations ● Satellite observations ● Reanalysis datasets (ERA5, MERRA-2) ● Climate model datasets (CMIP6) ● Data preprocessing and feature engineering ● Forecast verification datasets and benchmarks (e.g., WeatherBench)	3
3	Fundamentals of Numerical Weather Prediction	● Governing equations of atmospheric motion ● Numerical weather prediction workflow ● Initial and boundary conditions ● Model parameterizations ● Data assimilation: concept and role in NWP ● Sources of forecast error and uncertainty	3
4	Review of Machine Learning Foundations for Weather Prediction	● Introduction to machine learning algorithms ● Supervised and unsupervised learning ● Linear and nonlinear regression ● Decision trees and random forests ● XGBoost and ensemble methods ● Training, validation, testing, and model evaluation	2
5	Deep Learning for Weather Forecasting	● Artificial neural networks ● Convolutional Neural Networks (CNNs) ● Recurrent Neural Networks (RNNs) ● LSTMs and GRUs ● Attention mechanisms ● Transformers for spatiotemporal prediction	5
6	AI-Physics Frameworks	● Physics-guided machine learning ● Physics-Informed Neural Networks (PINNs) ● Hybrid physics-AI approaches	6
7	Neural Operators and Surrogate Modeling	● Motivation for operator learning ● Fourier Neural Operators (FNOs) ● DeepONet ● Surrogate modeling for PDEs ● Accelerating weather and climate simulations	4
8	Graph Neural Networks and Spatiotemporal Learning	● Graph representations of physical systems ● Graph Neural Networks ● Message passing ● Spatiotemporal forecasting ● Motivation for GraphCast-like architectures	4

9	Foundation Models for Earth Systems	● Concept of foundation models: GraphCast, GenCast, FourCastNet, Pangu-Weather, Prithvi etc. ● Comparison with traditional NWP systems	6
10	Uncertainty Analysis, and Future Directions	● Statistical and AI-based downscaling ● Bias correction of NWP forecasts ● Ensemble forecasting and probabilistic prediction ● Uncertainty quantification and forecast reliability	4
		Total	39

* 50 mins each lecture

C) Recommended pre-requisites: Basic Linear Algebra, Probability and Statistics, and programming experience (preferably in Python), A fundamental course on Machine Learning.

D) Short summary for inclusion in the Courses of Study /Booklet

Introduction to weather and climate prediction; atmospheric observations, reanalysis and climate datasets; fundamentals of numerical weather prediction; machine learning methods including regression, random forests, and XGBoost; deep learning techniques including CNNs, LSTMs, and Transformers; scientific machine learning approaches such as Physics-Informed Neural Networks (PINNs), Graph Neural Networks (GNNs), and Neural Operators; modern weather foundation models including GraphCast, GenCast, FourCastNet, Pangu-Weather, Aurora, and ClimaX; downscaling, data assimilation, and ensemble forecasting; applications of AI to weather and climate prediction.

7. Recommended Books

Textbook:

- Wilks, D.S. (2019). *Statistical Methods in the Atmospheric Sciences*.
- Camps-Valls, G., Tuia, D., Zhu, X.X., and Reichstein, M. (2021). *Deep Learning for the Earth Sciences: A Comprehensive Approach to Remote Sensing, Climate Science, and Geosciences*.

References:

1. Gilbert Strang, Linear Algebra and Learning from Data, Wellesley-Cambridge Press, 2019, ISBN: 978-0692196380.
2. Steven L. Brunton and J. Nathan Kutz, Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control, 2nd Edition, Cambridge University Press, 2022. Available at: <https://databookuw.com/>

3. Ian Goodfellow, Yoshua Bengio, and Aaron Courville, Deep Learning, MIT Press, 2016. Available at: <https://www.deeplearningbook.org/>
4. Kevin P. Murphy, Probabilistic Machine Learning: An Introduction, MIT Press, 2022. Available at: <https://probml.github.io/pml-book/>
5. Christopher M. Bishop and Hugh Bishop, Deep Learning: Foundations and Concepts, Springer, 2024.
6. Schultz et al., “Machine Learning for Weather and Climate Modelling”, Nature Reviews Earth & Environment, 2021.
7. Pedram Hassanzadeh, Karthik Kashinath, and David Hall, “Physics-informed Machine Learning for Earth System Science”, Nature Reviews Physics, 2024.
8. WeatherBench: A Benchmark Dataset for Data-Driven Weather Forecasting. Available at: <https://weatherbench2.readthedocs.io/>
9. ECMWF Learning Resources and Open Data Documentation. Available at: <https://www.ecmwf.int/>
10. Ministry of Earth Sciences (MoES), Government of India, Assessment of Climate Change over the Indian Region, Springer Nature, 2020. ISBN: 978-981-15-4327-2. Available at: <https://link.springer.com/book/10.1007/978-981-15-4327-2>
11. underPINN: A Modular JAX-Based Framework for Physics-Informed Neural Networks. Open-source framework for scientific machine learning, Physics-Informed Neural Networks (PINNs), inverse problems, and PDE-constrained learning using JAX.



Dated: 09 Oct 2026

Proposers:



Dated: 09 Oct 2026

DPGC Convener: