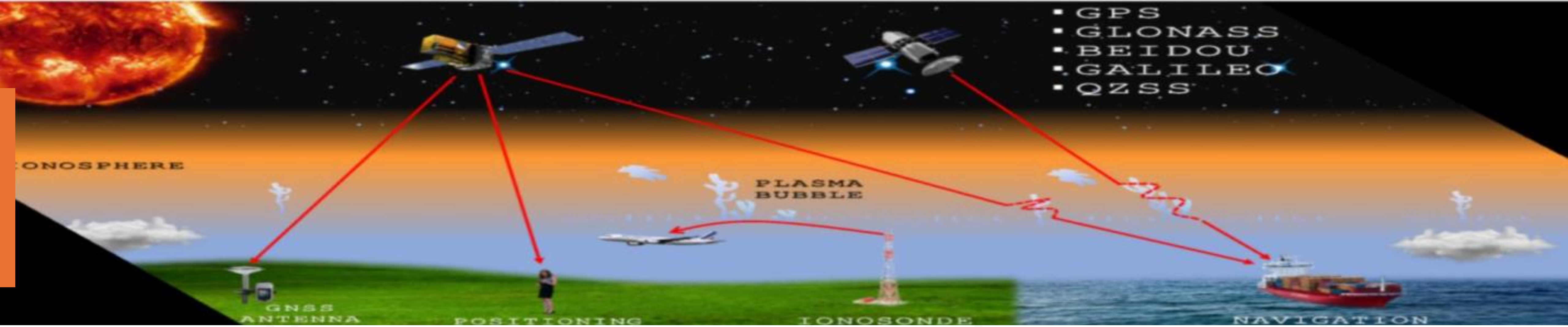

Artificial Intelligence Applications in Ionospheric Irregularities: A Bibliometric Analysis

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Outline

- Background
- Equatorial Plasma Bubbles (EPBs)
- Traditional Methods and Limitations
- AI Applications in Ionospheric Research
- Bibliometric Analysis Results

Background

- The Earth's ionosphere is a region of the upper atmosphere that extends from about 60 to 1,000 kilometers above the Earth's surface
- This layer plays a crucial role in global communication systems and satellite-based technologies, as it reflects and modifies radio signals used for communication and navigation

Background

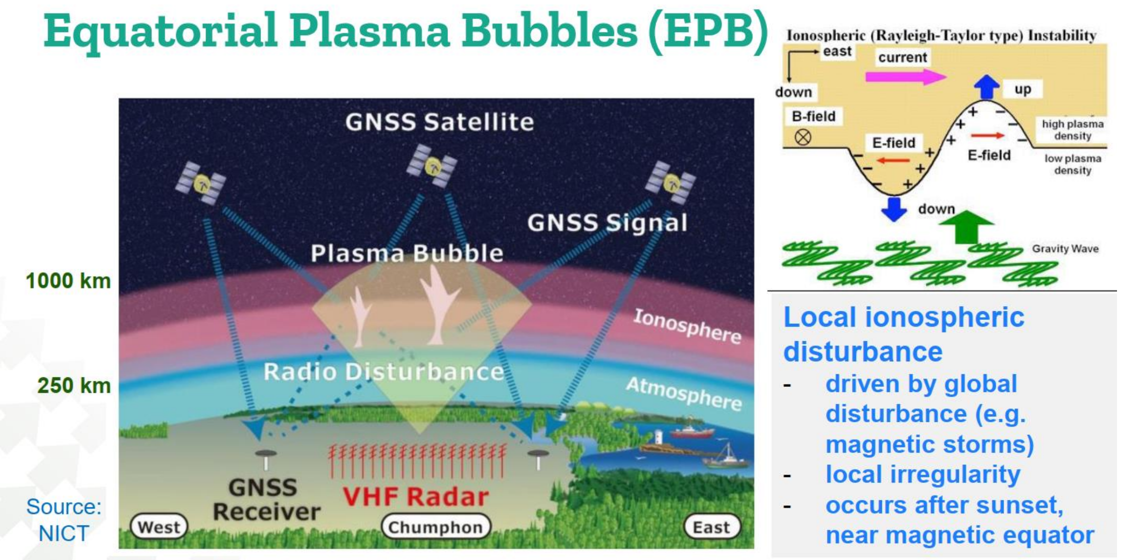
SEALION Project (since 2003)

- SEALION is an ionospheric observation network in Southeast Asia conducted by NICT, Japan, and five ASEAN countries
- to monitor equatorial ionospheric disturbances, especially plasma bubbles that poses a big impact on radio waves.
- Conjugate observational points in the northern and southern hemispheres and around the magnetic equator.

https://aer-nc-web.nict.go.jp/sealion/

Equatorial Plasma Bubbles (EPBs)

- Equatorial plasma bubbles (EPBs) are significant irregularities within the ionosphere, particularly near the magnetic equator
- These bubbles are regions of significantly lower plasma density that form during the post-sunset hours
- EPBs can disrupt the propagation of radio waves, leading to potential interruptions in satellite communications and GPS signals.
- Understanding and monitoring EPBs are essential for mitigating their adverse effects and ensuring the reliability of systems that depend on ionospheric conditions



Effects of EPB

Could Plasma Bubble Have Doomed U.S. Copter in Afghanistan Battle?

A U.S. military rescue mission in Afghanistan went horribly wrong when a crucial radio message wasn't received.

Source: NBC News

Traditional methods

- Ground-based observations
  - Ionosondes: These are ground-based instruments that transmit high-frequency radio waves into the ionosphere and measure the reflected signals. By analyzing the returned signals, ionosondes can provide data on ionospheric layers and detect irregularities such as EPBs.
  - GPS Receivers: Ground-based GPS receivers monitor signal disruptions caused by EPBs. The variations in the signal phase and amplitude observed by these receivers can indicate the presence of EPBs.

Limitations of Traditional Methods

- Complexity and Dynamic Nature of EPBs
  - EPBs change rapidly, and traditional methods struggle to track these changes in real-time, leading to incomplete data.
- Limited Spatial and Temporal Coverage
  - Ground-based tools only monitor specific areas
- Difficulty in Real-Time Detection
  - Traditional methods often require time-consuming data processing, delaying the detection and response to EPBs
- Sensitivity to Environmental Factors
  - Environmental conditions and signal interference can affect the accuracy of data collected by ground-based instruments

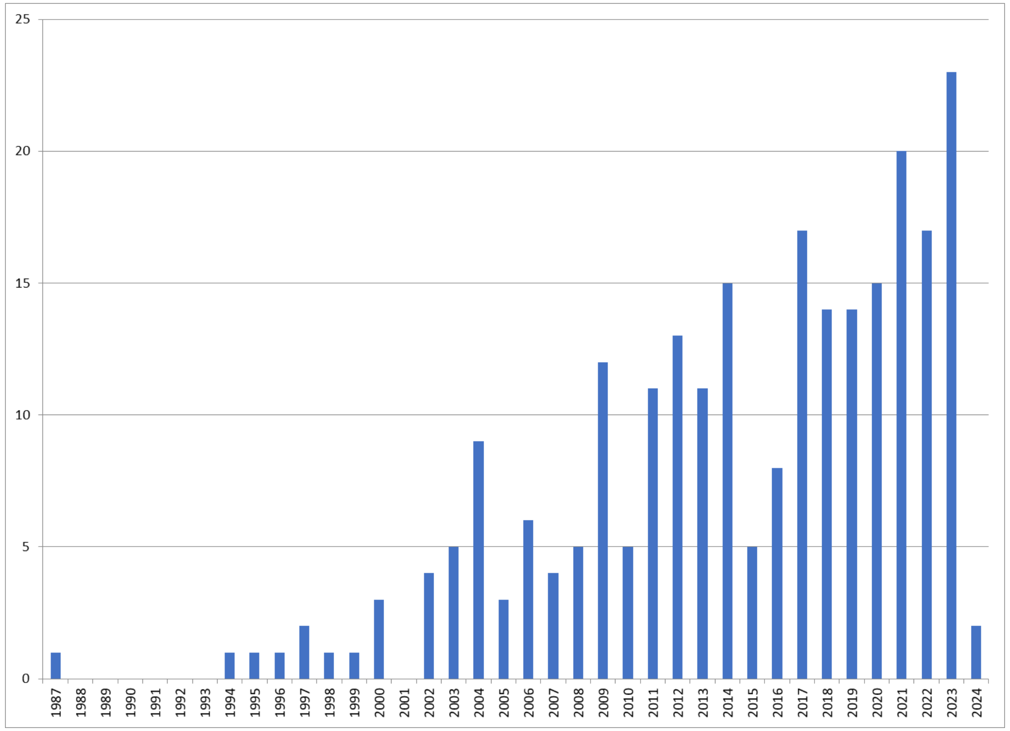
AI Applications in Ionospheric Research

- Forecasting Ionospheric Parameters:
  - Total Electron Content (TEC) Prediction:
    - AI techniques like deep learning models, including Long Short-Term Memory (LSTM) networks, have been used to predict global ionospheric Total Electron Content (TEC). These models can analyze complex time series data, improving the accuracy of TEC forecasts, which is crucial for GPS and satellite communications.
- Detecting Anomalous Ionospheric Behaviors:
  - Equatorial Plasma Bubbles (EPBs) Detection:
    - Machine learning techniques such as support vector machines (SVM) and convolutional neural networks (CNNs) have been employed to automatically detect EPBs and other ionospheric irregularities. These AI models analyze data from satellites and ground-based instruments to identify anomalies in real-time.

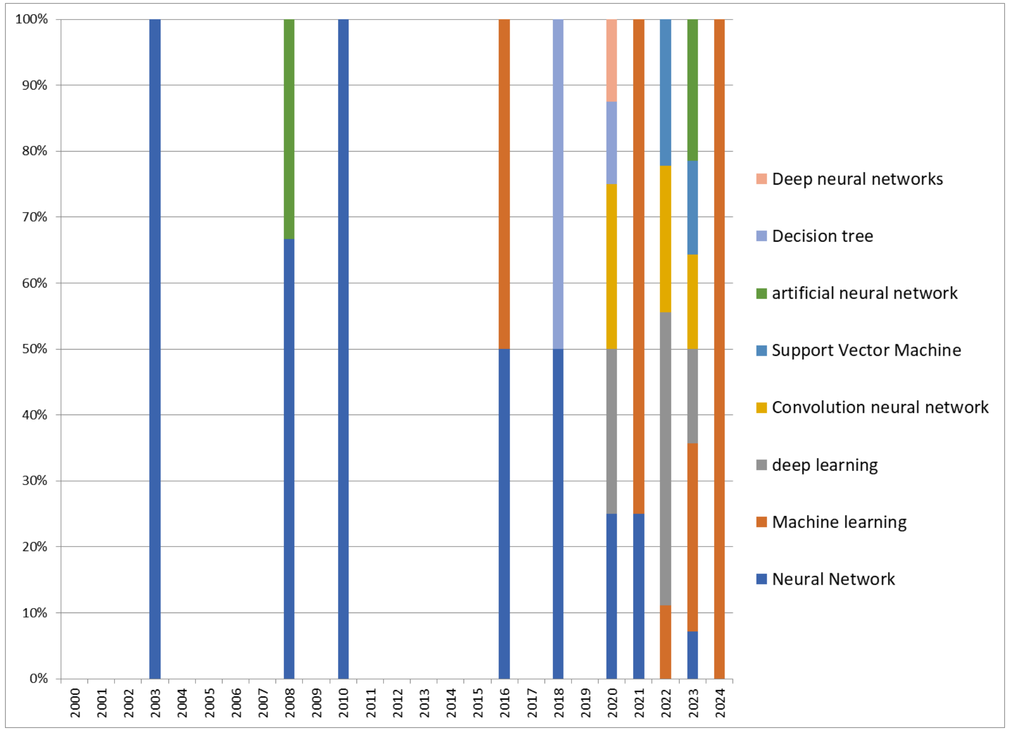
Bibliometric Analysis

- Search Query for Scopus
  - (TITLE-ABS-KEY ("Ionospheric irregularit*" OR "Equatorial plasma bubble*" OR "spread F") AND TITLE-ABS-KEY ("forecast*" OR "artificial intelligence" OR "deep learning" OR "machine learning" OR "natural language processing" OR "artificial neural network*" OR "deep neural network*" OR "convolution neural network*" OR "neural network*" OR "support vector machine"))
- 249 records from 1987 – 2024
- Vantagepoint Software

Results: Research Trends



Trend of Research in AI applications in Ionospheric Irregularities during 1987 – 2024



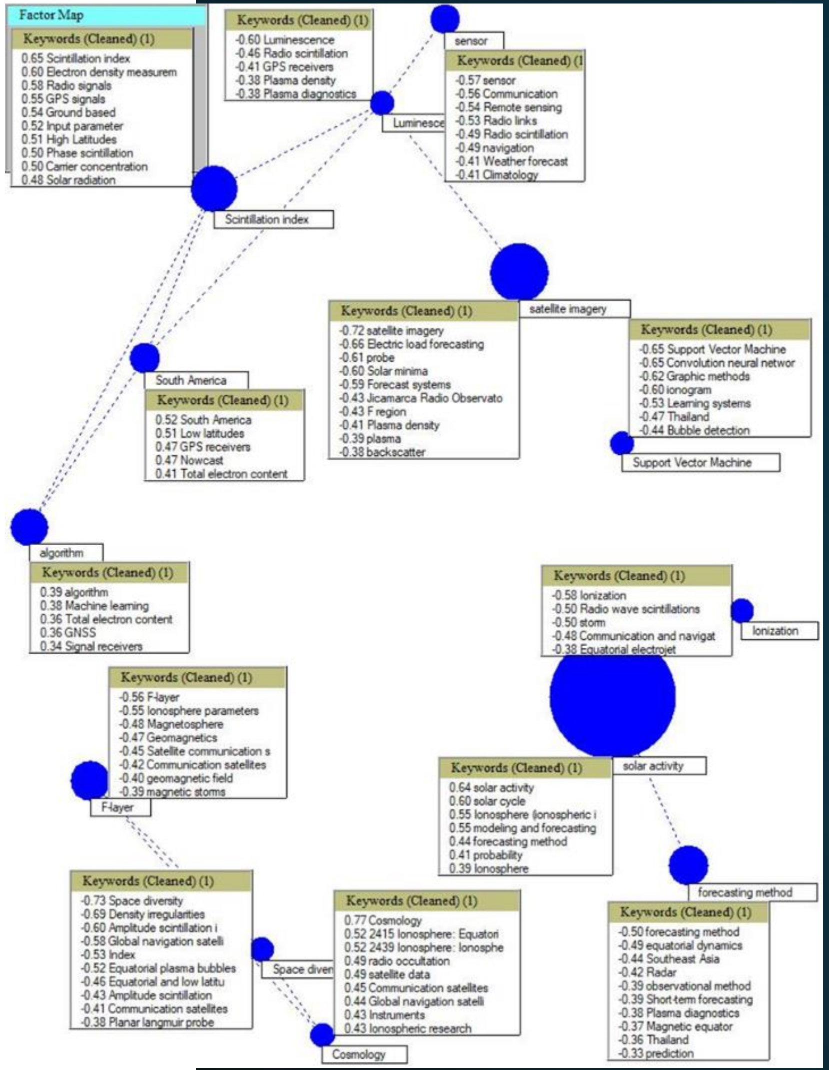
Trend of AI Algorithms during 2000-2024

Results: Top Countries with Keywords related to AI Algorithms

# Records	Country	Machine Learning	Neural Network	Convolution Neural Network	Deep Learning	Support Vector Machine	Artificial Neural Network
130	USA	5	3	1	1	1	
33	India	1	1	1			
31	China	2		2	6		
24	Japan		1	3	1	3	2
21	Brazil	1	1				
12	Italy	1					1
11	Thailand		4	3		3	3

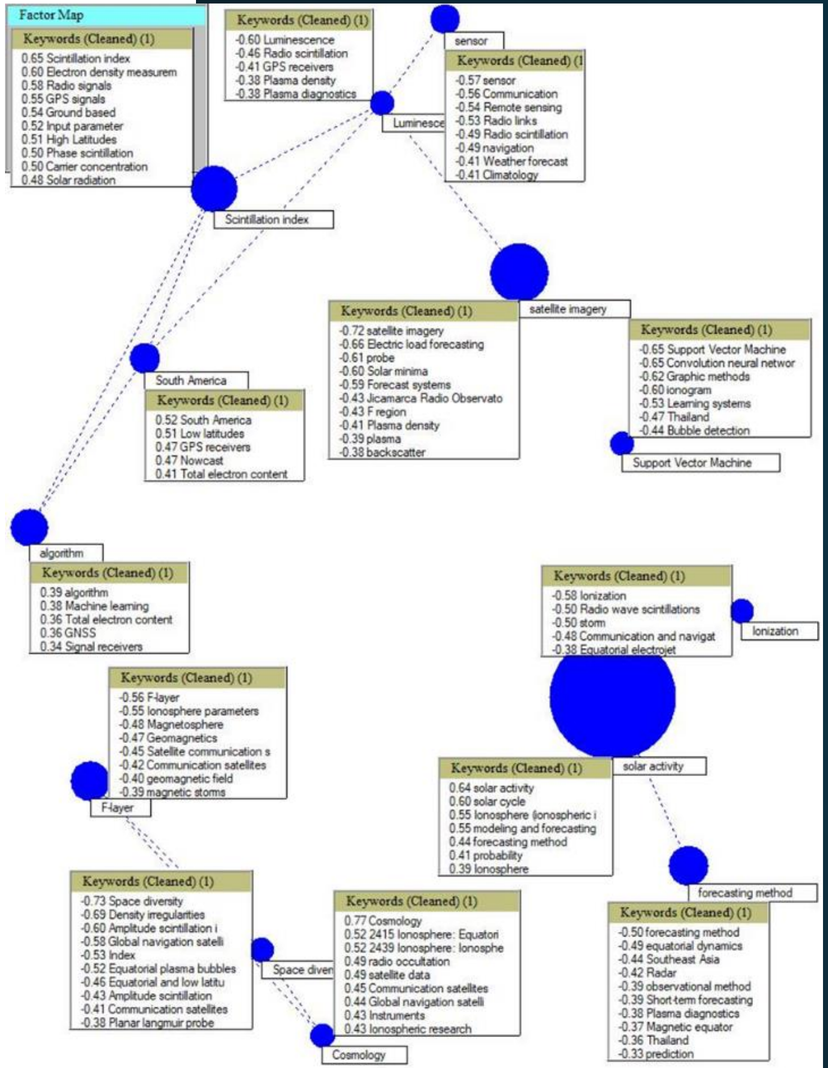
Results: Research Landscape of AI Applications in Ionospheric Irregularities

- Ionospheric and Magnetospheric Dynamics: Focus on understanding how the ionosphere and magnetosphere interact with satellite communication systems, especially in equatorial and low-latitude regions, and the effects on communication and navigation technologies.
- Ionospheric Modeling and Forecasting: Focus on creating models and forecasting methods to understand the dynamic behavior of the ionosphere in equatorial regions, especially in response to solar activity and environmental factors.



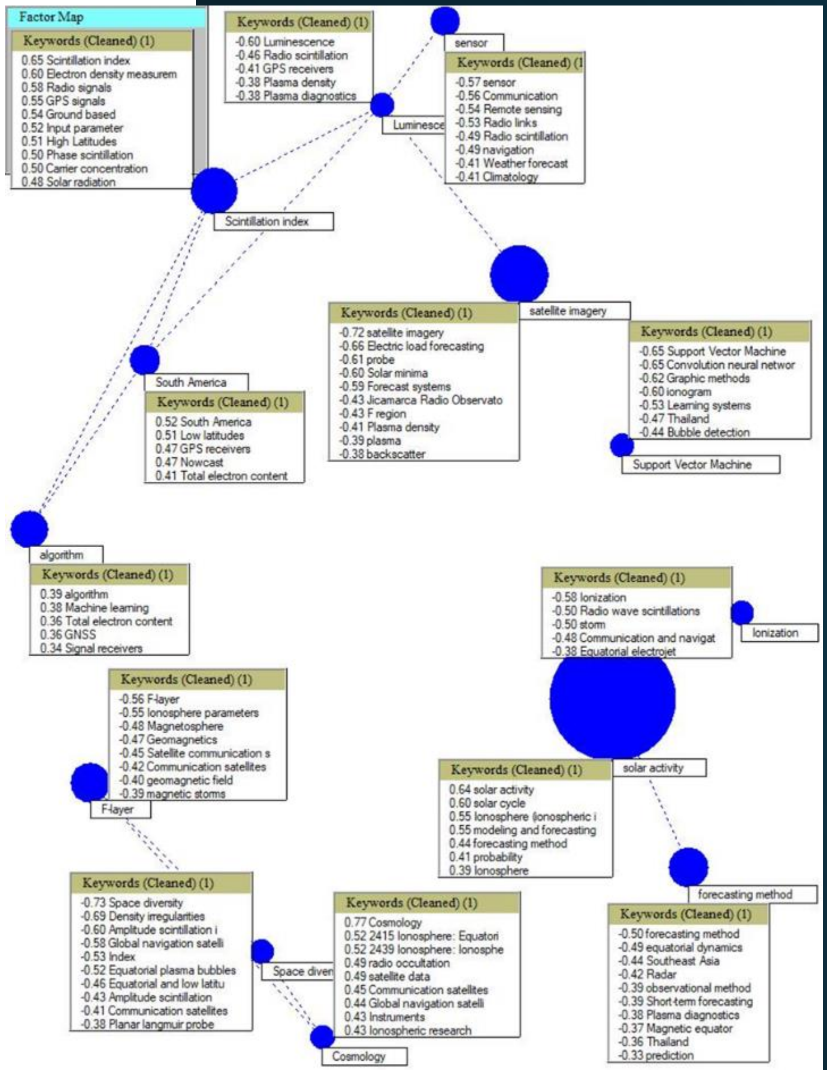
Results: Research Landscape of AI Applications in Ionospheric Irregularities

- Machine Learning for Bubble Detection: Focus on using machine learning and deep learning techniques, like convolutional neural networks and support vector machines, to detect ionospheric bubbles, especially through ionogram analysis.
- Plasma Density Forecasting in the F-Region: Focus on forecasting and analyzing plasma density variations in the F region of the ionosphere using satellite imagery and other data sources.



Results: Research Landscape of AI Applications in Ionospheric Irregularities

- Ionospheric Effects on Satellite Signals: Focus on studying how ionospheric phenomena impact satellite signal reception and measurement, particularly in high-latitude regions, and the key factors influencing these effects.



Conclusions

- A growing interest and recognition of AI's potential in this field
- Key techniques include machine learning, support vector machines, neural networks, and deep learning
- AI has been applied to detection, classification, forecasting, and modeling of ionospheric irregularities
- Continued advancement in AI and ionospheric observation promises to enhance understanding and prediction of ionospheric dynamics

Acknowledgement

The ASEAN IVO (http:// www.nict.go.jp/en/asean_ ivo/index. html) project, Precise positioning and Artificial Intelligence (AI) for Ionospheric Disturbances in Low-Latitude Region in ASEAN, was involved in the production of the contents of this publication and financially supported by NICT (http:// www. nict.go.jp/en/index. html).