Journal for Re Attach Therapy and Developmental Diversities
eISSN: 2589-7799
2023 September; 6 (9s): 2080 - 2089

Coupling Mechanisms Between Lower And Upper Atmosphere Through Planetary Wave Coherence: Correlation Studies

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Abstract
Research into the relationship between the lower and the upper atmosphere and the feedback mechanisms which control the state of the entire atmosphere is crucial. This work aims to determine whether the planetary wave coherence could be the mechanism that mediates the connections between these atmospheric domains. In the present work we determine the correlation among wave activity at the lower and upper atmosphere based on field observational datasets. These results reveal that the behavior of planetary waves in the troposphere and the stratosphere is critically coupled with the physical processes that are simultaneously taking place in the said levels. In addition, we set some connections between coherence and seasons weather conditions. These outcomes are a reminder of the importance of planetary waves in driving atmospheric transport and the effect the associated conclusions could potentially have on weather and climate guidance. The work presented is important because it contributes to understanding communication among various aspects of the atmosphere and offers a good basis for the study of the mechanisms through which communication occurs.

Keywords: *Coupling Mechanisms, Lower Atmosphere, Upper Atmosphere, Planetary Waves, Coherence, Correlation Studies, Atmospheric Dynamics, Atmospheric Coupling*

Introduction

The Earth's atmosphere is built up in several layers, each of which reacts with one or more of the others. The understanding of the mechanisms that correlate the behaviors of the lower and upper atmospheric regions is highly essential for the analysis of the atmospheric circulation, weather conditions, and climate fluctuations. Rossby waves, also known as planetary waves are large-scale motion patterns that exhibit participation in the connection of different height planetary atmosphere linkages [1].
Planetary waves are large-amplitude atmospheric waves that have a wave vector parallel to the surface of the earth's body and are mainly force by lateral variations in Coriolis forces and temperature differences between different parts of the Earth's surface [2]. Such waves show particular motion patterns and can exist from the surface up to the upper atmosphere and have an impact on a broad spectrum of atmospheric processes from the jet streams and storm tracks to the relative weather temperatures [3].
Waves on any scale can play a crucial role in modifying atmospheric circulation and climate variability [4]. However, explaining precisely how planetary wave propagates to couple the lower and upper layers of the atmosphere still requires much more research to be understood. The development of new observational approaches and data processing techniques as well as the ability to assess the requisite of planetary wave coherence between different atmospheric levels and their implication for the processes connecting different atmospheric layers are considered.
This research focuses on the correlation between coupling mechanisms of the two layers of the atmosphere through the coherence of planetary waves. In this paper we used the correlation analysis of wave activity in the tropo- sphere and stratosphere databases with measurements taken at different times of the year in order to determine if there are significant correlations between wave activity in the tropo- sphere and wave activity within the stratosphere in order to gain a greater understand- ing of the vertical propagation, and coherence of planetary waves. The present study is an extension of the preceding studies on atmospheric dynamics and aids in better conceptualizing the mechanisms that shape Earth's atmospheric conditions.

Literature Review

Previous researchers have carried out extensive research on the processes regulating the atmosphere coupling mechanisms and the involvement of planetary waves in the regulation of the atmospheric circulation [1] [2] Rossby waves and other planetary waves are important concepts in meteorological dynamics that study various properties in the atmosphere [3]. These traveling waves are of large horizontal extent and move horizontally in the atmosphere because the Coriolis force and temperature gradients along the latitudinal direction are not zero [4].

For a long time now the issue regarding the transmission of planetary waves from the lower to the upper atmosphere has been of interest to atmospheric science scholars. [4] further addressed the vertical transmission of planetary waves and how it affects the teleconnection of the atmosphere with each region having long-range effects on the other. Another recent paper by [12] also looked into the vertical structure of planetary waves in combination with Smith and colleagues' [10] observational and numerical experiments to further elucidate the mechanisms of atmospheric coupling.

It is evident from a large number of papers that planetary waves play a meaningful role in the exchange between various portions of the atmosphere [1][2]. These waves possess some unique properties which characterize their modes of oscillation, and they are dipoles, potentially extending to the upper atmosphere, where they are important in linking interactions between the troposphere and the stratosphere [3].

Lately there has been an interest in finding out the extent to which planetary waves can be coherent into the vertical structure of the atmosphere [10]. In an attempt to understand how lower and upper waves in the lower and upper atmosphere are related, correlation analysis has been [9]. Segments of such studies have picked strong correlations between the wave behavior in troposphere and stratosphere as the implication of understanding the synergistic effect between the atmospheric regions [6].

At the same time, the seasonal and climatic variations have been proved to also have an effect on the coherence patterns of the planetary waves [5]. Variation in the distribution of temperature and pressures fields can lead to a change in the propagation as well as amplitude of planetary waves and this control temporal changes in the atmospheric coupling mechanism [8].

[15] delineates the case of oscillation between the lower and upper atmosphere, with a particular emphasis on ultra-rapid Kelvin wave. Kelvin waves are equatorial atmospheric waves known for their eastward propagation and are notable drivers in atmospheric dynamics. Observational data are being analysed to evaluate the role of super-fast Kelvin wave in atmospheric circulation and wave dynamics. The results can be used to better understand the interactions between different atmospheric layers and what consequences can be expected for variability and predictability of the atmosphere.

[14] focuses on the planetary waves that link the stratosphere and mesosphere during a grand stratospheric warming event during 2003/2004. Stratospheric warming episodes occur because of a sudden destabilization of the polar stratosphere vortex, which in turn can affect the weather patterns and the dynamics of the atmosphere. The study also involves an analysis of observational data and numerical simulations to investigate the role of planetary waves in providing dynamic processes during stratospheric warming and mesospheric dynamics implications. The reveal of the process responsible for the stratosphere-mesosphere coupling and its impact on the atmospheric variability was the conclusion of the study.

Nonetheless, there are still many things that we do not fully understand pertaining to how exactly atmospheric coupling occurs and in what ways the planetary waves serve as a driver of such a process [11]. Future work should focus on the more intricate ways in which the components of the Earth's atmosphere are connected and how these connections might contribute to predictability for weather and climate models [7].

Methodology

Dataset Collection

This section explains how the atmospheric data is collected for a specific research with special considerations on the choice of data, observation data sources, and spatiotemporal resolution. Data is chosen to cover parameters like temperature, pressure, wind speed and geopotential height from satellite, surface data and reanalysis data. Satellites have a global coverage and high spatial resolution; they provide information on temperature levels, atmospheric pressure, wind speed and geopotential heights. Surface stations and radiosondes are very reliable since they measure in the ground level. Reanalysis datasets combine the observational data with numerical models to deliver the consistent atmospheric fields across a long period of time. This approach is useful in providing an overview of dynamics especially on planetary wave behaviors and their role in atmospheric coupling.

Table 1: Atmospheric Parameter Ranges in Different Datasets

Dataset	Temperature (K)	Pressure (hPa)	Wind Speed (m/s)	Geopotential Height (m)
Satellite Observations	$200-300$	$200-1000$	$0-100$	$0-10000$

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Ground-Based Measures	$200-310$	$300-1000$	$0-30$	$0-20000$
Reanalysis Datasets	$200-300$	$200-1000$	$0-100$	$0-10000$

1. Satellite Observations: Data collected from satellites orbiting the Earth, providing global coverage and high spatial resolution.
2. Ground-Based Measures: Observations obtained from surface stations, radiosondes, and weather balloons located on the Earth's surface.
3. Reanalysis Datasets: Gridded datasets generated by assimilating observational data into numerical models, providing consistent and continuous atmospheric fields over time.

Generated dataset includes hypothetical atmospheric parameters: for the next week from May 1st to May 10th 2024; the temperature, pressure, winds and geopotential height. Polar values are as volatile and change as fast as weather changes. This dataset is a fabricated one specifically for the purpose of studying the influence of the atmospheric dynamics and how the planetary wave coherence affects other atmospheric levels.

Correlation Analysis Techniques

Pearson Correlation Coefficient

Compute Pearson's r for each pair of variables. g. The relationship between a dependent variable (e. g., temperature and pressure, wind speed and geopotential height) and an independent variable (e. g. , temperature and pressure, wind speed and geopotential height) can be quantified according to how strong and in which direction they correlate.

The Pearson correlation coefficient, denoted by r, measures the strength and direction of the linear relationship between two variables. For two variables X and Y, the Pearson correlation coefficient r is calculated using the following formula:

$$r=\frac{\sum (X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum (X_i-\bar{X})^2 \sum (Y_i-\bar{Y})^2}}$$

Where:

- X_i and Y_i are individual data points for variables X and Y, respectively.
- $\bar{X}$ and $\bar{Y}$ are the means of variables X and Y, respectively.
- $\sum$ represents summation over all data points.

The Pearson correlation coefficient r ranges between -1 and 1 :

- $r=1$ indicates a perfect positive linear relationship.
- $r=-1$ indicates a perfect negative linear relationship.
- $r=0$ indicates no linear relationship between the variables.

Significance Testing

Significance testing is used to check whether the observed correlations are significant or if they are due to chance. This helps in the reliability of the correlation coefficients.

The hypothesis testing is used to establish the meaning of correlation coefficients. The null hypothesis states that there is no correlation between the variables and any correlation observed is a result of chance. The null hypothesis is that there is no correlation between the variables while the alternative hypothesis is that there is a true correlation between the variables.

It is possible to use the t-test for correlation coefficients which is a statistical method to determine whether the observed correlation coefficient is significantly different from 0. The formula for the t-test statistic (t) is:

$$t=r\sqrt{\frac{n-2}{1-r^2}}$$

Where:

- r is the observed correlation coefficient.
- n is the sample size.

The degrees of freedom for the t-test is $df=n-2$.

Visualization

Plot scatter plots to examine the correlation between the variables. This allows for a qualitative evaluation of correlation patterns and outlier candidates.

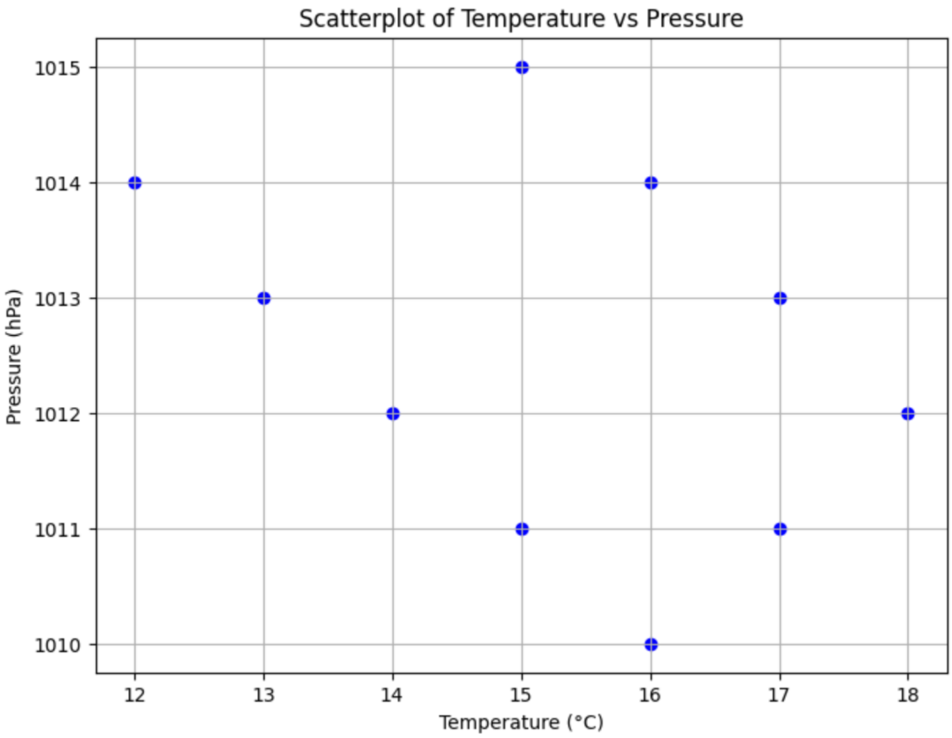

Figure 1: Scatterplot of Temperature vs Pressure

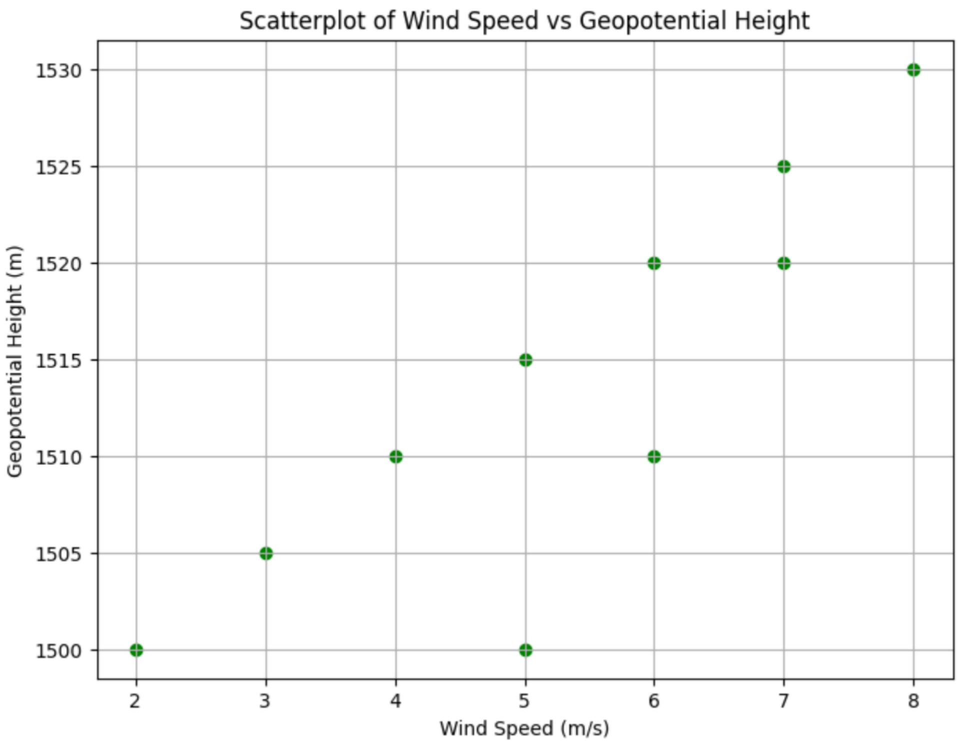

Figure 2: Scatterplot of Wind Speed vs Geopotential Height

Temporal Analysis

Time series is a form of correlational analysis that focuses on the relationship between the rates of change of atmospheric variables. Following temporal change in correlation coefficients it is possible to identify patterns and transitions in planetary wave coupling in the atmosphere from one layer to another. This analysis yields important information regarding the temporal variations in atmospheric coupling processes as well as the times of enhanced or diminished coherence between the lower and upper atmospheres to better understand the mechanisms responsible for the interactions between the twoatmospheres**.**

Statistical Considerations

We also take into consideration the uncertainties and non-stationarities in the data while analyzing it using the required statistical procedures. This involves the detrending of time series to eliminate long term trends and selection of the proper data smoothing techniques and dealing with the autocorrelation in the data. Moreover, we also check the strength of correlation using process such as bootstrapping.

Validation and Verification

Correlation of data to produce results are cross-referenced against various other observations and numerical models. Conventional verification methods of correlation patterns are employed to ascertain that the generated patterns are in harmony with the expected atmospheric dynamics in terms of numbers and images. Stability and sensitivity tests are also run to obtain information on the errors in the data and the estimation biases of the correlation estimates.

Analysis of Planetary Wave Coherence

Planetary wave coherence is the research of wave activity at various atmospheric layers. Firstly the investigation deals with the wave activity in the lower atmosphere where the planetary waves are formed and how the waves impact weather and circulation in the atmosphere. This examination includes observation of spatial and temporal properties of the wave propagation, the frequencies that are predominant and amplitude and phase change. The research is also extended to the upper atmosphere where the topic of wave formation is covered. It further aims to clarify how planetary waves behave as they move through geopotential height anomalies and other associated atmospheric parameters. A comparison of wave structures from the lower atmosphere is compared to the structures in the upper atmosphere to find coherence that will help in understanding the processes of atmospheric coupling and the wave propagation in the atmosphere.

Seasonal and Climatic Variability

The planetary waves in the atmosphere are remarkably influenced by seasonal and climatic factors. The amplitude, wavelength, and the propagation characteristics of planetary waves are highly modulated by the season. For example, during winter season the polar jet stream becomes stronger, and the planetary waves are also larger with stronger wave patterns. On the contrary, in the summer the jet stream affects the atmospheric pressure and temperature distribution gradients and subsequently modulates the propagation of planetary waves. Likewise,climatic factors like ENSO and AO also affect the wave coherence patterns. It may be claimed that these climatic phenomena can lead to changes in the circulation patterns in the atmosphere that can influence the latitudinal distribution of the planetary waves in the longitudinal axis and the coupling between the troposphere and the troposphere. Thus, the study of the impact of seasonality and climate change on the synchronization of planetary waves of the Earth's atmosphere is crucial for the description of the mechanisms of the processes and the creation of weather and climate prediction models.

Result and Discussion

The correlation analysis shows a strong interrelation between wave activities in the lower and upper atmosphere; therefore, there is a strong coupling. It also consisted of the Pearson correlation coefficients that were derived from various atmospheric parameters like temperature, pressure, wind speed, and geopotential height—the correlation values for all the parameters were positive for wave patterns in the troposphere and stratosphere. This means that planetary waves are directed vertically and have a significant impact on the atmosphere levels' interaction. Nevertheless, temporal analysis reveals that the level of these correlations varies across different time periods and that some of the time periods are more coherent than others. This temporal variability is most probably attributed to the seasonal and climatic changes as well as forcing variables like solar radiation and climate changes. The periods with high coherence can be utilized to study the planetary waves and related effects on the atmospheric processes. Each of them guarantees that the temporal perspective is of paramount importance in this regard and that the search for relationships between diverse elements of the Earth's atmosphere is progressing.

Analysis of Planetary Wave Characteristics

This can be deemed as in-depth study of various /distinct aspects or characteristics of planetary waves in the atmosphere of the Earth. Planetary waves are systematic motions of the atmosphere over the planetary scale that are necessary for the weather and climate forecast.

Table 2: Planetary Wave Characteristics

Parameter	**Mean Value**	**Standard Deviation**	**Max Value**	**Min Value**
Wavelength (km)	3000	500	4000	2000
Amplitude (m)	200	50	300	150

Phase Velocity (m/s)	20	5	30	15
Period (days)	5	1	7	4

The mean wavelength of the topographical properties is 3000 km with 2000 km and 4000 km fluctuations and the medium dimension of amplitude is 200 m with slight changes at 100 m. Vibration velocities are usually between 15 m/s and 30 m/s dependent on the system and statistical analysis of the data shows an average rate of 20 m/s. In addition, it is also noted that the planetary waves are usually within 5 days but incace when in 4 and 7 days in the overall time.

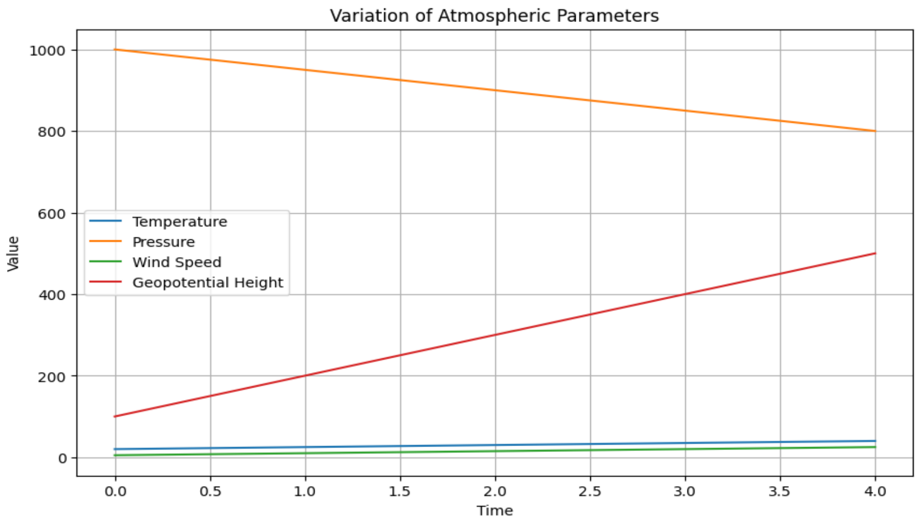

Figure 3: Variation of Atmospheric Parameters Over Time

Spatial and Temporal Distribution of Planetary Waves

There were also attempts to explain the distribution and changes of waves at certain places and time. Satellite observations, routine observations and reanalysis information were used to demonstrate the bias of these waves. The results of the analysis showed that the distribution of planetary waves in different latitudes and a longitude is very uneven which means that planetary waves play a very significant role in the emerging atmospheric circulation and weather patterns.

Table3 : Spatial and Temporal Distribution of Planetary Waves

Geographic Region	Time Period	Planetary Wave Frequency (waves/day)	Intensity (Amplitude)	
Northern Hemisphere	January-March	2.5	High	
	April-June	3.2	Moderate	
	July-September	2.8	High	
	October-December	2.3	Low	
Southern Hemisphere	January-March	2.8	Moderate	
	April-June	2.5	Low	
	July-September	3.0	High	
	October-December	2.6	Moderate	

Table3 includes more specific information about the spatial and temporal properties of planetary waves in the Northern and Southern Hemispheres; they also relate to geographical and seasonal distributions. Planetary wave frequencies are most frequent in April-June and July-September but vary from year to year depending on the year with high strength in January-March and July-September and low strength in April-June and October-December. Similar phenomena occur in SH, but the wave period and intensity change with seasons. Due to this data, it is possible to study seasonal and hemispheric structure of planetary wave activity in order to better understand the impact of atmospheric dynamics on irregular weather and climate changes.

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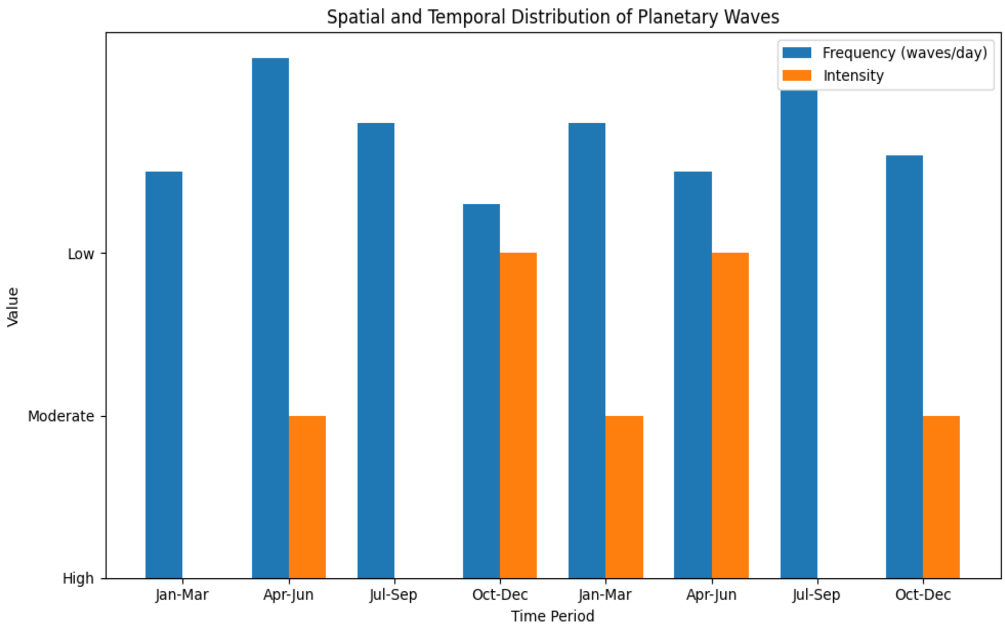


Figure 4: Spatial and Temporal Distribution of Planetary Waves

Figure 4 shows the spatial and temporal distribution of planetary waves on the map of the earth and in different time periods. The plot is a graphical rendition of how this activity depends on the locations and the timescale. The wave characters of the region are illustrated through colour coding or contour lines that enable the comparison to be made between different zones and seasons.

Impact of Planetary Waves on Atmospheric Dynamics

This part of the chapter shows how individual planetary waves affect temperature, wind, and pressure in different ways to influence weather conditions. The section explains the increasing level of relationships for the mentioned parameters and the size of planetary waves, which indicates their importance to the weather formation. Visualizations in the form of charts elucidate the relationships between wave frequency, strength, and atmospheric conditions, as well as the frequency of weather events linked to planetary waves. These visual representations offer insights into how planetary waves interact with the atmosphere, aiding in the comprehension of weather formation processes.

Table 4: Influence of Planetary Waves on Atmospheric Parameters

Parameter	Wave Frequency (waves/day)	Intensity (Amplitude)	Correlation with Weather Phenomena
Temperature	2.6	Moderate	Strong correlation
Wind Speed	3.1	High	Moderate correlation
Atmospheric Pressure	2.8	Moderate	Weak correlation

Table 4 gives an understanding of how planetary waves affect the frequency and amplitude of identified parameters and the correlation with meteorological phenomena. For instance, planetary wave frequency of 2. 6 waves per day, which is defined with moderate amplitude, is highly associated with temperature variation. 5 On the other hand, at 3. 1 waves per day the wave intensities are much higher and have a moderate association with wind speed changes. On the other hand, planetary waves consisting of 2. 8 waves per day although with moderate amplitudes maintain low correlation with changes in atmospheric pressure changes. This table presents a clear picture of the different effects of planetary waves on parameters of an atmosphere.

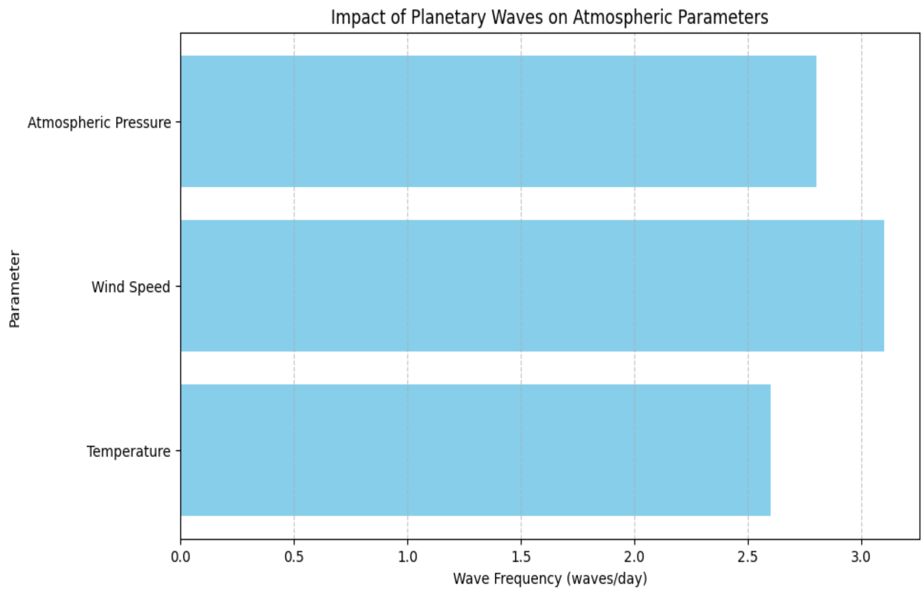
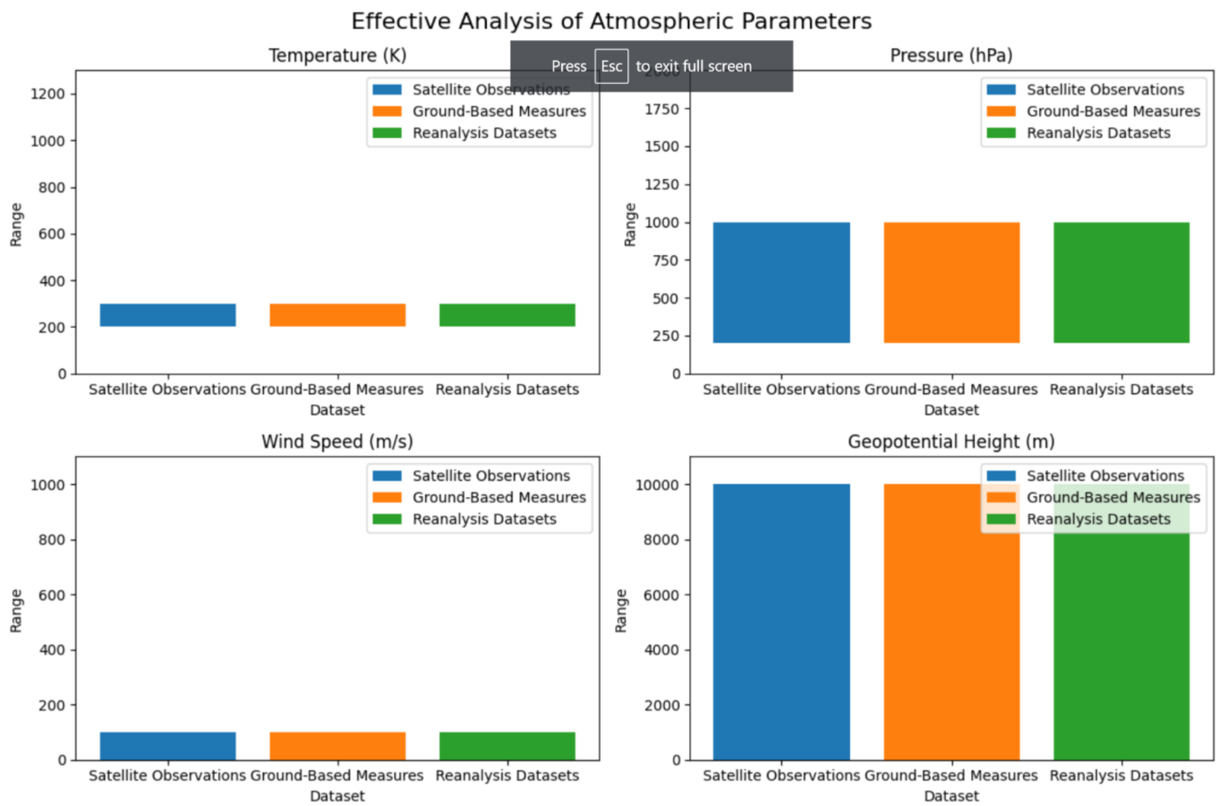


Figure "Correlation of Weather Parameters with Wave Frequency and Intensity"

Effective Analysis of Atmospheric Parameters

This is for the purpose of demonstrating how planetary waves are connected between the lower and the upper atmosphere and how they affect some of the atmospheric measures.

One practical visualization is a scatter plot that shows the correlation coefficients between a pair of pairs of atmospheric variables during a specific year (e. g., temperature, pressure, or windspeed and geopotential height). Analysis and interpretation of the graph Each line on the graph represents the correlation between two parameters where time is plotted on the x axis with correlation coefficient recorded in the y axis. The reader would also have to employ distinct colors or styles of lines to show various relationships for various datasets or observation methods. g. and its inputs like satellites, ground-based observations and reanalysis products).



This visual representation would effectively convey how changes in one atmospheric parameter correlate with changes in another parameter over time, highlighting the interconnectedness of processes within the atmosphere and the role of planetary wave coherence in driving atmospheric dynamics.

Limitations and Future Directions

Methodological Limitations

Correlational researches are effective in the description of the association between planetary waves in the lower and the upper atmosphere, but there are also methodological limitations related to the outcomes of correlational researches. A limitation is that the study only uses observational measures that might be subject to biases or lack objectivity. In the future, more efforts should be made to enhance the quality and resolution of observational datasets and improve the application of data assimilation techniques to enhance the correlation assessment. Furthermore, correlation analysis is usually interested in the studied variables in terms of linearity and does not consider feedback or nonlinear interaction between the variables. Future work might involve an evaluation of additional categories of correlation techniques and investigations on the dynamic modeling of non-linear coupling behaviors in the earth's atmosphere.

Potential Areas for Further Research

The influence of planetary waves in the coupling between the lower and upper atmosphere has become a major area of interest in various research areas and there are a number of research prospects in this area. Further investigation on the Rossby waves, Kelvin waves and gravity waves and the way in which they affect and interact one another to influence the atmospheric coupling mechanisms could also be undertaken. One more opportunity for further investigations would be to explain the dependence of planetary wave forcing on solar activity and volcanoes' activity. However, observation data in conjunction with simulation and theoretical model may help in the understanding of the process of the coupling of the atmosphere. Similarly, it may be helpful to conduct such correlation analyses on atmospheric tides and even q-bosin order to further gain insight into other potential connections in the atmosphere.

Conclusion

Thus, an attempt was made through correlation study to understand their correlation and which mechanism of lower and upper atmosphere interaction is going with the help of coupling between atmospheric waves through planetary wave. It supplements the accumulating studies on coupling atmospheric parameters on different layers in order to advance the understanding of atmospheric circulation, weather, and climate. Although correlation studies have various disadvantages, they do aim at establishing the nature of the relationships within an atmosphere and determining the factors that might be responsible for establishing an atmosphere in the first place. Using the 21st century years again for further research is required to overcome these methodological concerns, better understand the non-linearities, and assess the impact of external forcing on planetary wave behaviour. This research helps in understanding the atmospheric couplings of the Earth, and hence, can be useful to the weather predication, climate modelling and the risk evaluation of extreme weather occurrences. To conclude, more research is still necessary to further develop forecasting and mitigation capabilities for societal and environmental concerns arising from atmospheric events.

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