Hemispheric and Seasonal Differences in Dominant Modes of Field-Aligned Currents (FAC) Variability: Principal Component/Canonical Correlation Analysis (PCA/CCA) of AMPERE-NEXT Magnetic Field Data

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Background

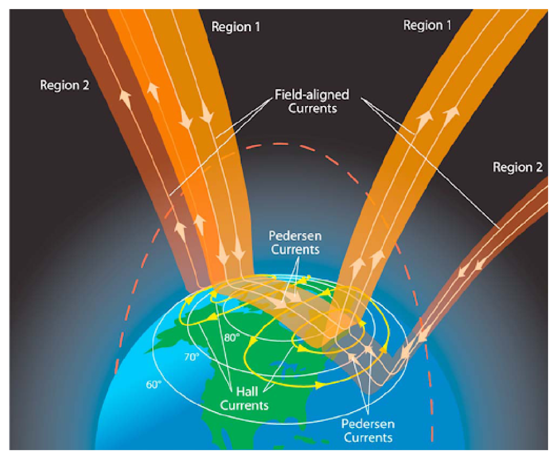

Figure 1. Illustration of Earth's Field Aligned Currents (1)

An asymmetry exists between field aligned currents (FAC) in the northern and southern hemispheres. This asymmetry is believed to be caused by compound effects of multiple geophysical properties and conditions such as: the deviation of Earth's magnetic fields from a simple dipole field, the offset of magnetic and geographic poles, the Earth's orbital inclination, the Interplanetary Magnetic Field (IMF), and solar irradiance differences on annual timescales.

Goal

The goal of this study is to quantify FAC hemispheric asymmetry and its variability in terms of EOFs using years worth of Iridium-NEXT magnetometer data obtained from the AMPERE program (2-4).

Method

Large volumes of data have been analyzed to determine FAC variability through Empirical Orthogonal Function (EOF) analysis. The FAC is decomposed as:

$$J(r,t) = \overline{J}(r) + \sum_{\nu=1}^{4} \alpha_\nu(t) EOF_\nu + \cdots$$

where EOF_ν represents spatially coherent signatures deviating from the mean, and α_ν is a time-dependent scaling factor. EOFs and αs are estimated by a nonlinear sequential regression which allows for a comprehensive examination of global modes of high-latitude FAC variability from sparsely sampled data such as those sampled by Iridium-NEXT satellites (5).

Interpreting the FAC Plots

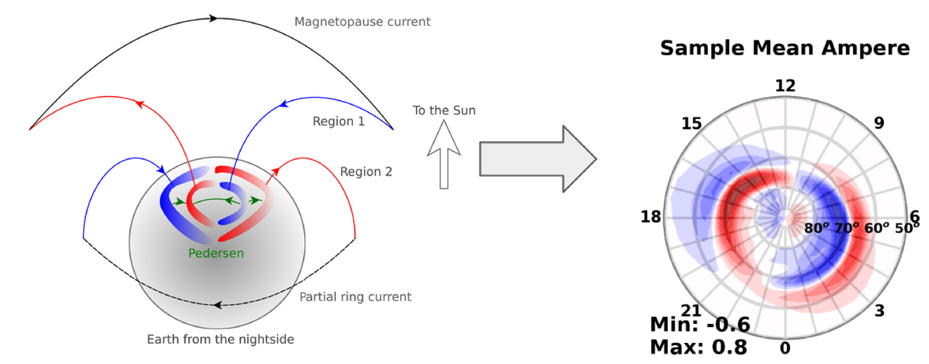

Figure 2. The blue portion represents field aligned currents flowing into the polar region while red represents these currents flowing out (6).

Acknowledgements

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References

[1] G. Le et al., 2010, doi:10.1029/2009ja014979.
[2] Anderson et al., 2002, doi:10.1029/2001JA000080.
[3] Anderson et al., 2021, doi:10.1029/2020GC009515.
[4] Waters et al., 2020, doi:10.1007/978-3-030-26732-27.
[5] T. Matsuo, 2002, doi:10.1029/2001gl014077.
[6] J. A. Carter et al., 2016, doi:10.1002/2015ja021567.
[7] D. L. Green et al., 2009, doi:10.5194/angeo-27-1701-2009.
[8] A. A. Nielsen and M. J. Canty, 2005, 10.1109/amtrsi.2005.1469864

Local Summer

Northern Hemisphere, Summer

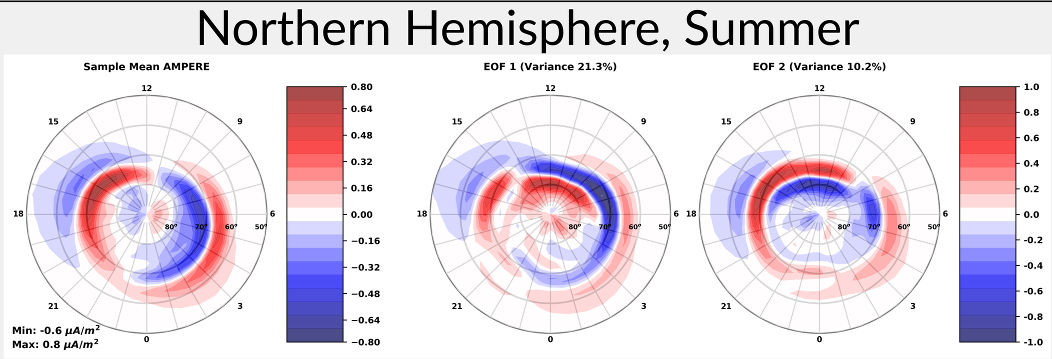

Figure 3. Total Variance of First Four EOFs is 41%

Southern Hemisphere, Summer

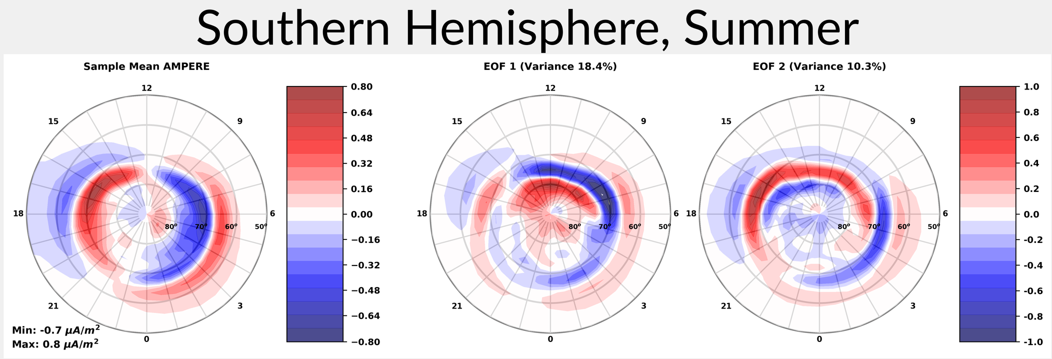

Figure 4. Total Variance of First Four EOFs is 37.4%

- The leading EOFs show prevalent day side features and correlates with the following indices: ASY-H, AE, AL, B_y, and the Newell coupling function.
- Both of the second EOFs show a strong day side component with the Southern hemisphere having stronger dusk side features. Additionally, the Northern summer shows a relatively strong correlation with the folliwng geophysical parameters and indices: ASY-H, AL, B_y, B_z, and the Newell coupling function.

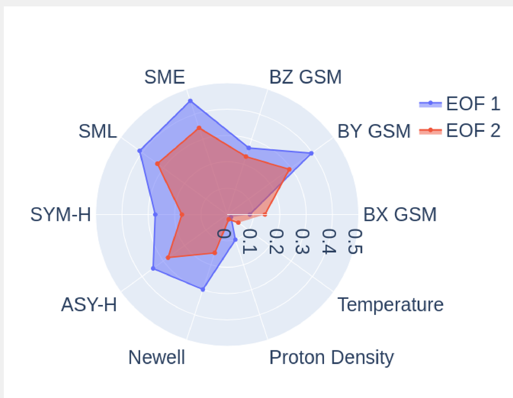

Figure 5. Northern Summer

Integrated Field-Aligned Currents (Sample Mean)
FAC Down: -3.10 MA
FAC Up: 3.05 MA

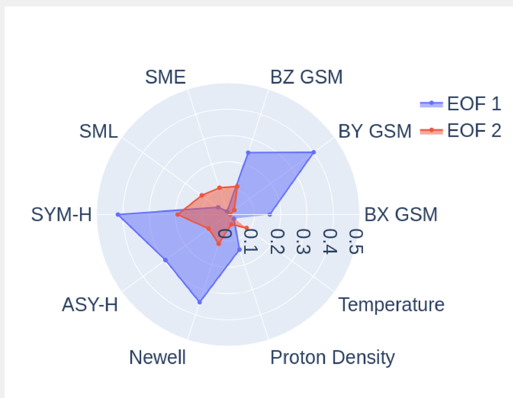

Figure 6. Southern Summer

Integrated Field-Aligned Currents (Sample Mean)
FAC Down: -3.50 MA
FAC Up: 3.49 MA

Local Winter

Northern Hemisphere, Winter

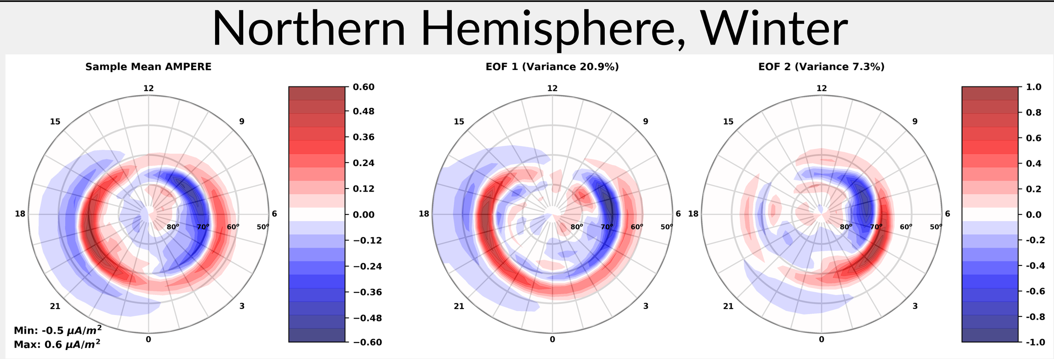

Figure 7. Total Variance of First Four EOFs is 36.2%

Southern Hemisphere, Winter

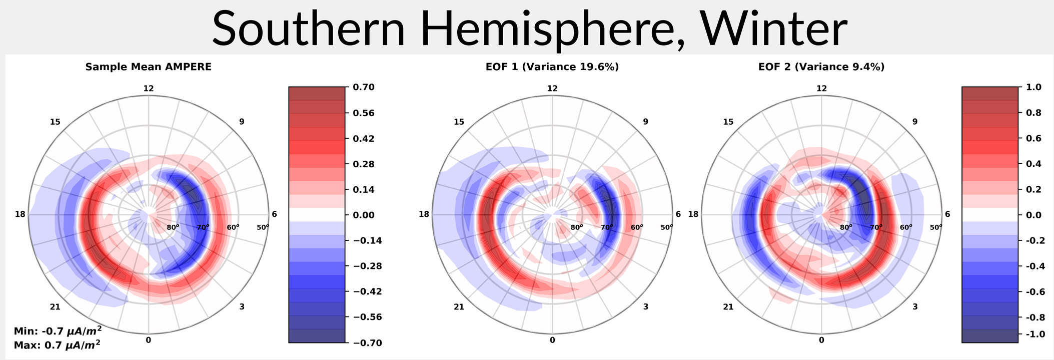

Figure 8. Total Variance of First Four EOFs is 35.8%

- Both Northern and Southern hemispheres' first EOFs represent a strengthening mode of the mean FAC pattern (in that they largely exhibit features of the mean pattern).
- Both of the second EOFs show a strong dawn side component with the Southern hemisphere showing an additional strengthening mode of the mean FAC on the dusk side and correlates well with AE.

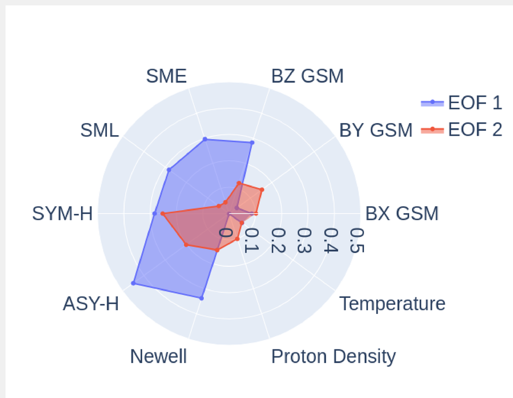

Figure 9. Northern Winter

Integrated Field-Aligned Currents (Sample Mean)
FAC Down: -2.44 MA
FAC Up: 2.37 MA

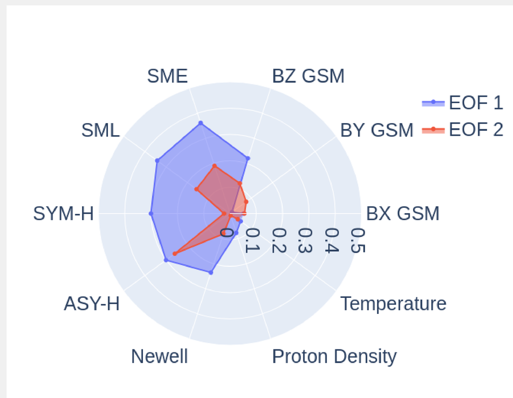

Figure 10. Southern Winter

Integrated Field-Aligned Currents (Sample Mean)
FAC Down: -2.82 MA
FAC Up: 2.80 MA

Canonical Correlation Analysis - Multivariate Alteration Detection

CCA is closely related to PCA and helps to characterize relationships of two variables or data sets. In this study, CCA is applied to a pair of EOFs between the hemispheres for a given season to find a pair of linear combinations of 4 EOFs that represent high cross-correlation between them.

Local Summer's EOF and CCA Correlation

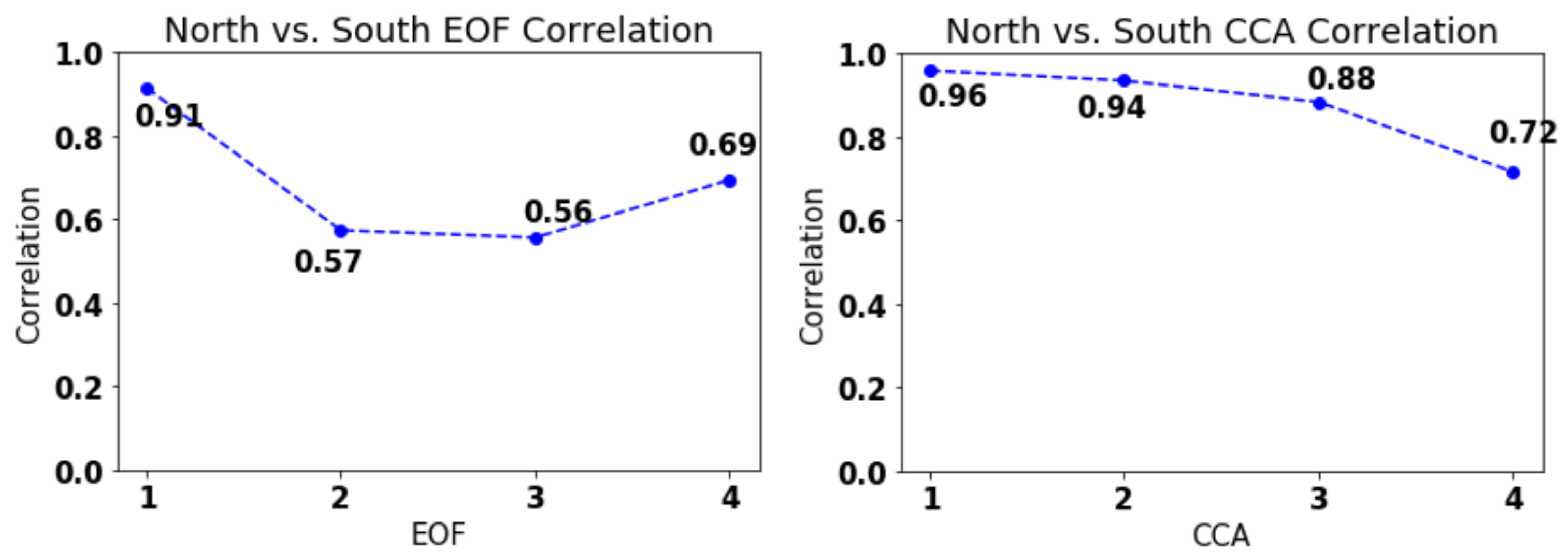

Figure 11. Shown is the grid point-by-grid point correlation between the two hemispheres' local summer.

Local Summer MAD

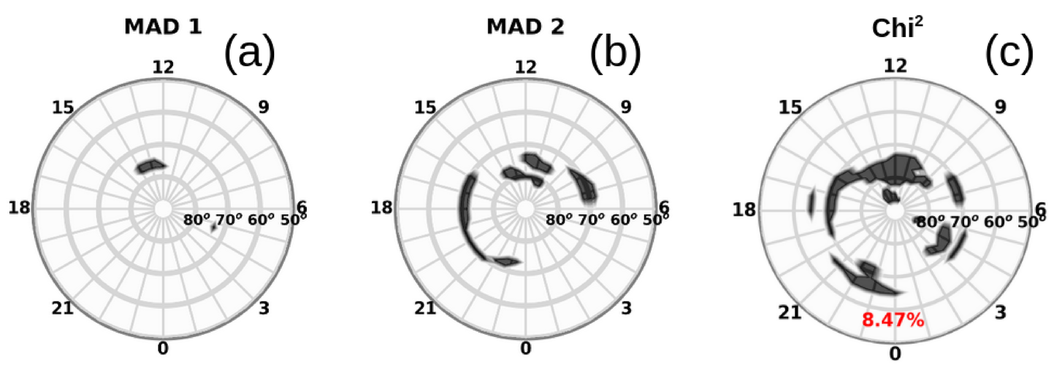

Figure 12. MAD for local summer's first two EOFS.

Local Winter MAD

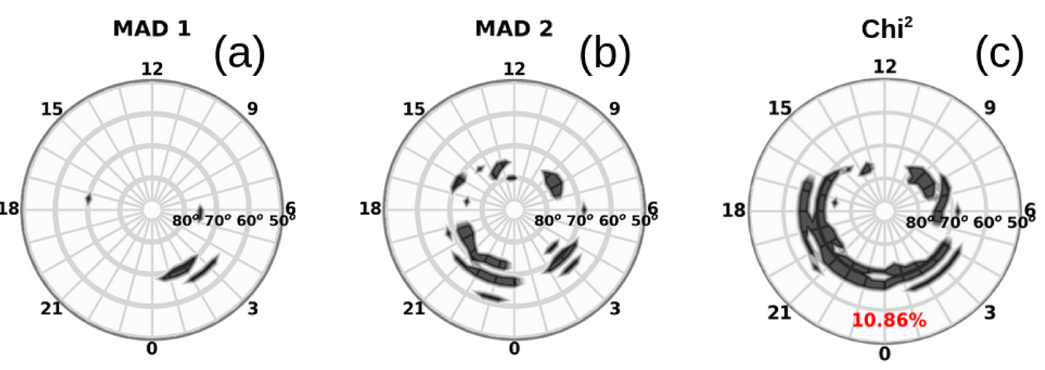

Figure 13. MAD for local winter's first two EOFS.

Multivariate alteration detection (MAD) is a change detection method that builds on the CCA, designed to highlight differences between two sets of images (8).

Data Selection

Local Seasonal Categories	Time Frames of AMPERE-NEXT Data	Selected Data [hr]
Northern Summer Southern Winter	May 7 - Aug 5 in 2019, 2020 & 2021	168
Northern Winter Southern Summer	Nov 7 - Dec 31 in 2019, 2020 & 2021 Jan 1 - Feb 5 in 2020, 2021 & 2022	231
Northern Spring Southern Fall	Feb 4 - May 4 in 2019, 2020 & 2021	351
Northern Fall Southern Spring	Aug 9 - Nov 7 in 2019, 2020 & 2021	411

Table 1. Specific time frames of Iridium-NEXT data included in each seasonal category, along with median, minimum and maximum values of monthly sun spot numbers observed over respective time frames, are listed. The minimum and maximum values are given in the parenthesis. In the last column, the total amount of selected Iridium-NEXT data after filtering by the Kp threshold criteria is shown in terms of total sampling time in hours.

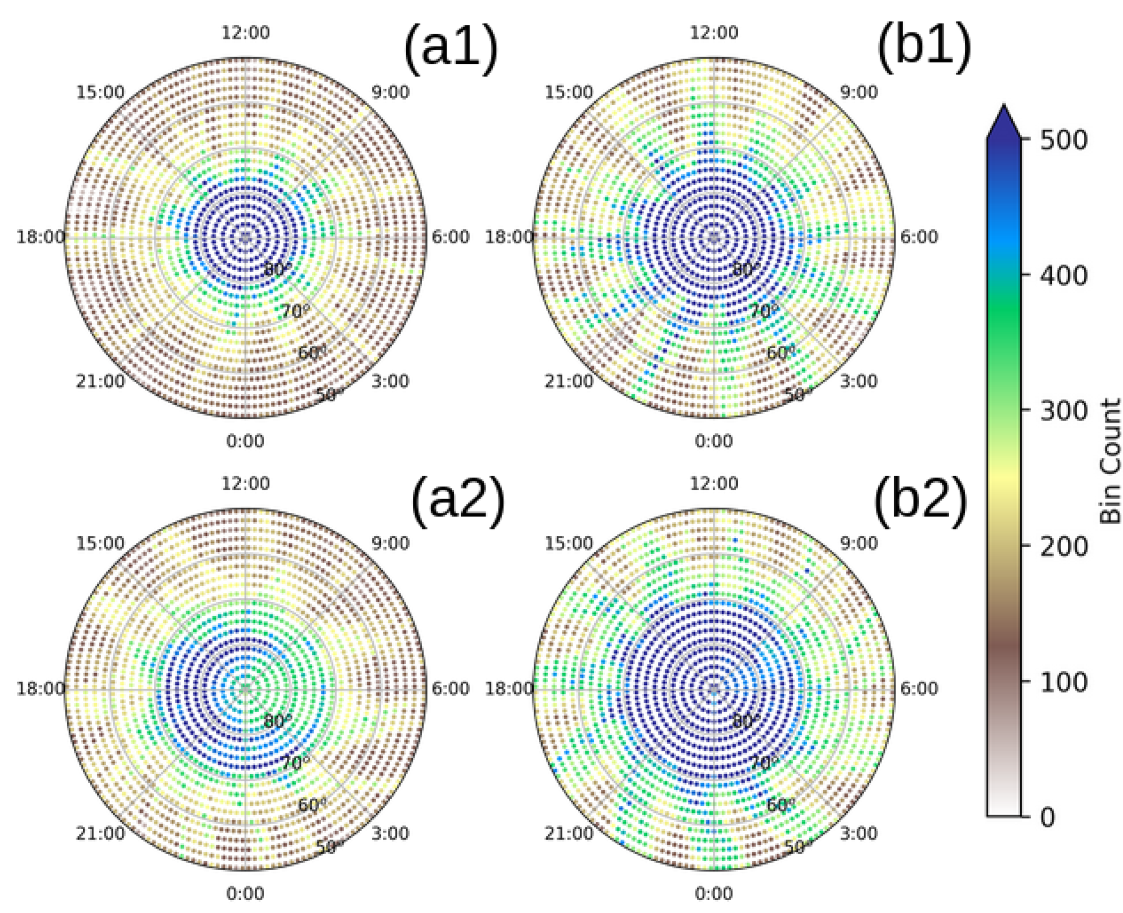

Figure 14. The Iridium-NEXT magnetic perturbation measurement data count is dis- played for both hemispheres across all four seasons, plotted in APEX coordinates using equal-area bins, for (a1) Northern Summer, (b1) Northern Winter, (a2) Southern Winter, and (b2) Southern Summer. The equal-area bins are positioned five at the pole, 88-90 degrees magnetic latitude. As the plots extend towards lower latitudes, these bins are separated by two degree in latitude.

Conclusion

With the use of AMPERE Iridium-NEXT data, this study addresses how hemispheric asymmetries in FAC patterns are affected by various external environmental conditions. We have determined:

- PCA shows the mean and leading modes of FAC variability are very similar between both hemispheres under same solar irradiance conditions. For the same season, the southern hemisphere integrated FAC is greater.
- The leading modes for summer show strong dayside variability, contrasting with pronounced variability seen on the dusk-night side for winter.
- CCA highlights areas of significant hemispheric contrast across four seasons, with the highest similarities observed in local summer.