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Long-term Observation of Nighttime Clouds over São João do Cariri (7.4º S, 36.5º W)

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Abstract: Using images collected by an all sky imager deployed in São João do Cariri (7.4º S, 36.5º W) from September 2000 to November 2010, the nighttime incidence of clouds has been observed and studied. Most of the nighttime cloudy occurred from February to July, which is related to the rainy season in the area of the observatory. The best period to run optical observations over São João do Cariri starts in the early night up to 22:00 LT (Local Time) throughout the period between August and December. An anti-correlation between the F10.7 cm solar flux index and the number of cloudy nights was observed, which is an evidence of the cosmic rays activity in the lower earth's atmosphere. The location of the all-sky imager provides reliable optical observations all year through.

Key words: Cloud, precipitation, solar activity, atmosphere, airglow.

1. Introduction

Energy from the sun in the form of radiation is fundamental for the earth's climate system [1]. The radiation from the sun ultimately provides the only energy source for the earth's atmosphere and changes in solar activity clearly have the potential to affect climate. There are numerous arguments suggesting that solar variability affects the global climate in different aspects and on different time [2-6]. An important factor affecting the terrestrial environment is the flux of cosmic rays permanently impinging on the cloud formation, and consequently, in earth's climate [7-11].

The presence of clouds can also interfere in the weather system around the world, for example, clouds are important in the determination of the energy and heating on the earth's surface since they can reflect the solar radiation maintaining the planet warm. Otherwise, the absence of clouds makes the atmosphere cold. In the midst of the water cycle, when latent heat is released, clouds may act as a cooling agent depending on the water's phase transition. In general, the circulation of the atmosphere and the increase of the diffuse radiation are affected by the clouds [12-23]. The importance of cloud has also been studied and cirrus clouds' role in the budget atmosphere radiation. Other studies focus on the decisive role of clouds in the Arctic region [24, 25].

The understanding of cloud behavior in a specific region may contribute to the scientific community presenting the relationship among weather factors, precipitation, solar radiation and earth's energy balance. Furthermore, the cover of clouds is very important to preparation and implementation of aeronomic and astronomic experiments, since the clouds interfere in optical observations. In addition to that, since the clouds are related to the precipitation, they have direct impact in all human activities for a given region.

Satellites bring a significant advance in relative cloud cover information, but satellite retrievals have known weaknesses in quantifying small and/or low cloud features due to their limited spatial resolution and unknown surface influences on the measured

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radiances [26]. The satellites are more efficient when they are used together with ground techniques. Hence, researchers have used ground-based imaging devices to study clouds property, and developed techniques for automatic detection from comparison with other instruments, because it is efficient for local cloud cover detection [27-36].

In this paper, characteristics of the cover of clouds in São João do Cariri (7.4º S, 36.5° W) were studied using an all-sky imager. The main goal of this work is to contribute to the understanding of cloudy during nighttime and to enhance to the comprehension of the probable relationship between sun and earth's climate in that region. The observatory is located in the northeast of Brazil, which is one of the driest regions, having long periods of drought and short rainy season period.

2. Instrumentation and Methodology

The data used in this work were collected daily by a high-resolution all-sky imager that has been operated in São João do Cariri (7.4° S, 36.5° W). The all-sky imager is an optical instrument designed with a fish eye lens, a CCD (Coupled-Charge Device) camera, an optical system, an interference filter wheel, a refrigeration system and a microcomputer. The CCD camera consists of a large area (6.45 cm²), high resolution and 1,024 × 1,024 back illuminated array with a pixel with quantization of 14 bits. The high quantum efficiency, low dark noise level, low readout noise and high linearity of this device made it possible to achieve quantitative measures of the airglow, for example, NIR OH, OI 557.7 nm (OI5577), OI630.0 nm (OI6300), O_2, OI777, 4 nm (OI7774) and NaD which are localized in different wavelengths [37-39]. Factors as precipitation (cloudy nights), the presence of the moon and the surrounding lights interfere in the measurements of aeronomic events.

Images from September 2000 to November 2010 of nighttime airglow were used in this paper. The images were collected by an all-sky imager every night, however sometimes it is not possible to observe images every night, i.e, nights or even months of observation can be lost. After analyzing the images, it was identified the presence of clouds in 1,210 nights. The period of occurrence of clouds was defined as the interval between the time of appearance beginning of clouds in this images (as illustrated in Fig. 1 on the left side) and the time in which the clouds leave the images and the sky become clear as shown in Fig. 1 (on the right side).

From the observed images, it was calculated the duration of the cloudy period and the start time of occurrence of the clouds. Whenever the duration of the cloudy period was greater than 6 hours, the night was assumed to be completely cloudy night.

3. Results

Fig. 2 shows the number of nights per month that had completely cloudy nights during the period of observation i.e, the period that clouds appeared was greater than 6 hours. The values over the bars in Fig. 2

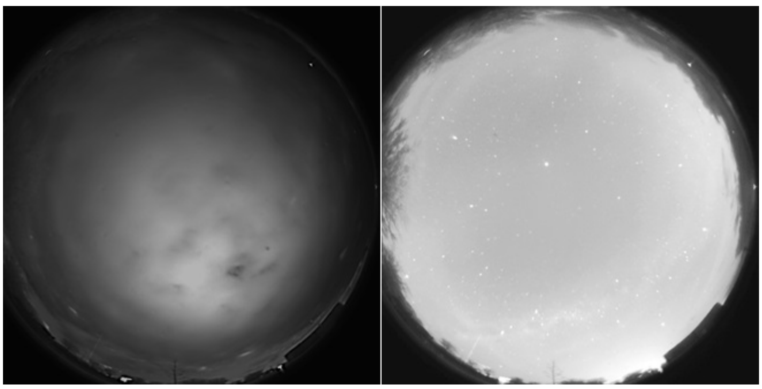

Fig. 1 Example of the airglow images for a cloudy night (on the left side) and a clear night (on the right side).

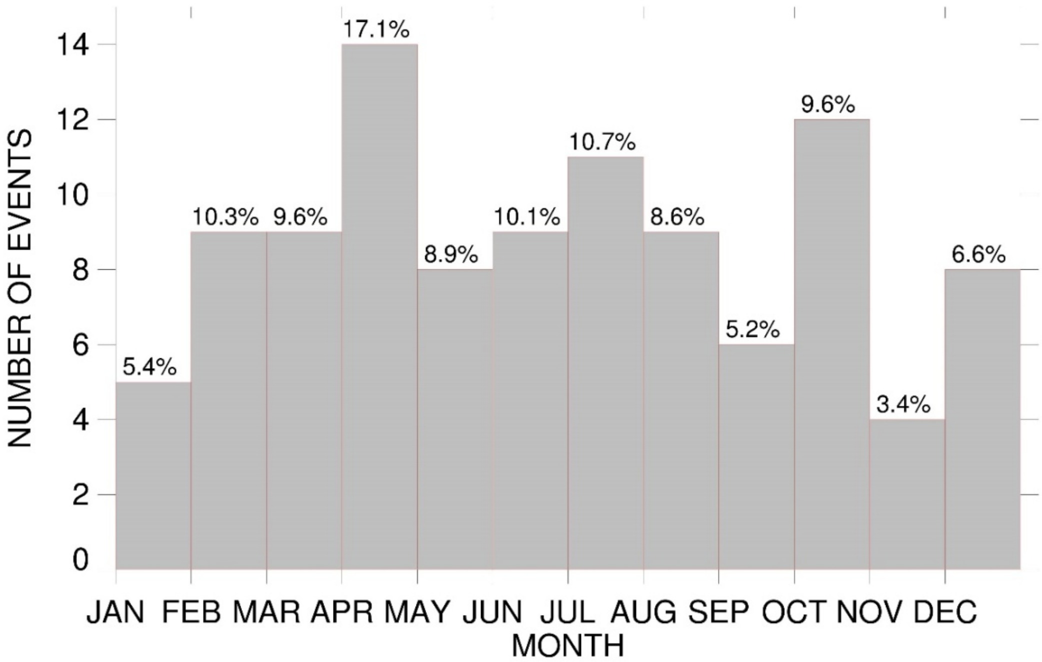

Fig. 2 Histogram for the observed completely cloudy nights along the year; On the top of each bar, one can see the ratio between the completely cloudy nights and the total observed nights.

are the ratios between the quantity of completely cloudy nights and the total number of observation nights in a given month. Note that there are months with a greater number of observations (October for instance) comparing to other months with less observed nights (January for instance).

One can observe in Fig. 2 that the number of completely cloudy nights over São João do Cariri was larger in February and extended to the middle of the winter. April was, by far, the month with the largest number of completely cloudy nights. From August to January, the number of the cloudy nights was reduced, together with a reduction in the ratio of cloudy nights to observed nights, except in October.

Fig. 3 shows a three dimensional histogram for the occurrence of cloudy nights from September 2000 to November 2010. One can observe that the number of cloudy nights is a function of year and the local time. In this image, it was also possible to observe nights with period of occurrence less than 6 hours. Blank space represents that there is no observation or information about it. Fig. 3 shows that the clouds appear more frequently closer to the dawn. The largest occurrence of clouds was registered from 23:00 to 04:00 LT (Local Time) and it was more evident in 2005-2006 and 2008-2009. From the beginning of the night up to 22:00 LT, there was few occurrence of clouds.

From the present dataset, it was possible to make the histogram shown in Fig. 4. One can see the number of nights completely cloudy against the year, from 2000 to 2010. Again, on the top of the bars are shown the ratio of cloudy nights to the total of observed nights.

The ratios in Fig. 4 have, practically, the same shape of the bars, which reveal that the cover of clouds in São João do Cariri increased significantly along the observed years. Furthermore, there is an anti-correlation between the cloudy nights over São João do Cariri and the solar flux at F10.7 cm (overplotted chart in Fig. 4). The solar flux at 10.7 cm is one of the most used indexes to measure the solar activity. Note that the solar activity decreased in 2002 and reached the lower values between 2008 and 2010. In contrast, the number of cloudy nights was larger during this period of minimum solar activity.

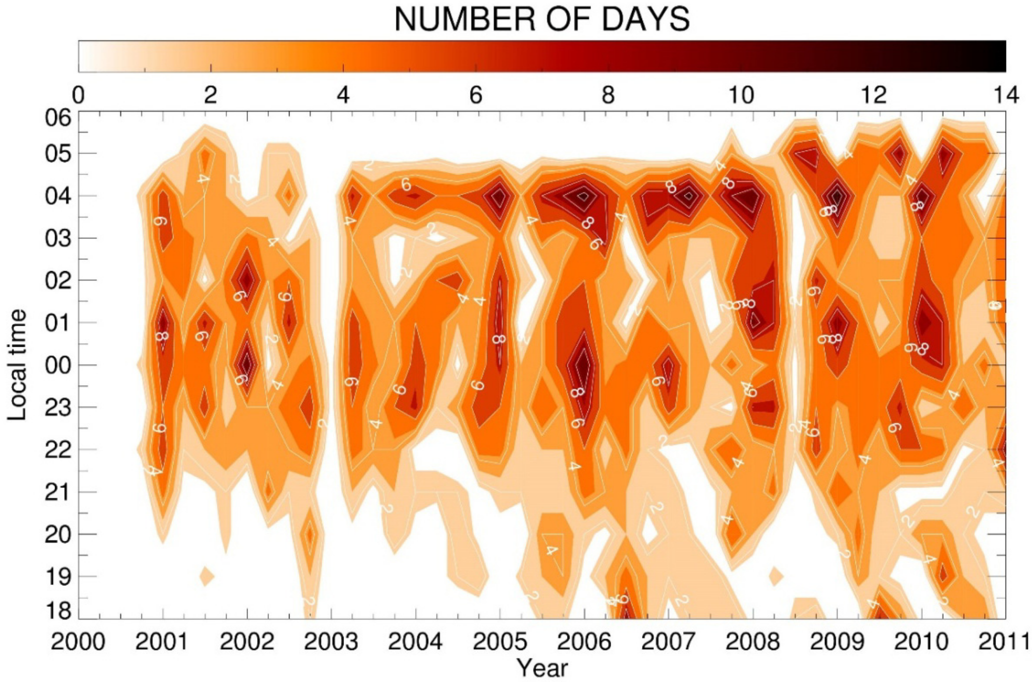

Fig. 3 Three dimensional histogram for the appearance of clouds over São João do Cariri as a function of the local time (y axis) and years (x axis).

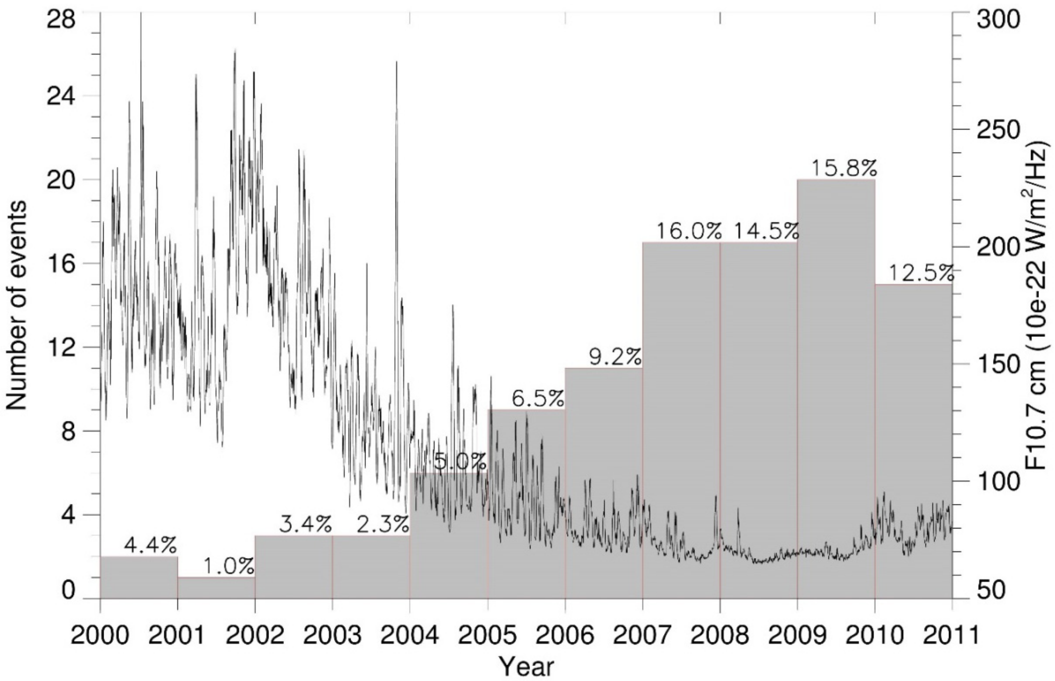

Fig. 4 Histogram for completely cloudy nights as a function of the years; The solar flux at 10.7 cm was overplotted; On the top of each bar, one can see the ratio between the cloudy nights and the total observed nights.

4. Discussion and Conclusions

The occurrence of cloudy nights is not necessarily related to precipitation. However, it reveals a relevant insight about the rainy period of a given region, since without clouds, the precipitation does not occur. Moreover, the occurrence of precipitation depends on the types of clouds and the atmosphere instability, i.e., convective clouds are necessary to rainfall.

The most accepted mechanism to explain the precipitation in the northeast of Brazil is the ITCZ (Inter-Tropical Convergence Zone) [40, 41]. The ITCZ reaches the most southern points around the autumn of the southern hemisphere and it is the responsible by the rainy season to be more pronounced in the first trimester of the year [42]. The results shown in Fig. 2 are in agreement, i.e., the period of year that has a greater number of completely cloudy nights is comprised between February and April, with a decrease of the cloudy nights in May. The precipitation in Paraiba state (northeast of Brazil) may be also associated with others meteorological phenomema as the vortices of high levels, easterly waves systems, instability lines, land and sea breezes, cloud cover, local orographic effects, mesoscale convective system and the ENSO (El Niño Southern Oscillation) [43].

The El Niño occurs due to the temperature anomalies of the sea in the Pacific Ocean, which produces large-scale anomaly in the circulation of the atmosphere [43]. However, the presence of El Niños was registered only in 2002 and 2003. On the other hand, La Niñas are the opposite of El Niños, i.e., they are responsible for the strong rainfall in Brazilian northeast. A strong La Niña was reported, from 2007 to 2008, and it coincided with the period with many cloudy nights observed in this work. This occurs because the El Niño changes the ITCZ position, which controls the rain distribution in Brazilian northeast [44].

An anti-correlation between the cloudy nights and solar activity was clearly in Fig. 4 with a minimum CCC (Cross Correlate Coefficient) of -0.89 using a lag of 0, i.e., the occurrence of cloudy nights was completely out of phase compared to the solar activity.

The anti-correlation between the solar activity and cover of clouds has been explained by using parameters of the cosmic rays. This anti-correlation has been also observed in the present work [45]. The cosmic rays decrease with increasing solar activity. The configuration of the interplanetary magnetic field deflects the entrance of cosmic radiation that transits in the sphere of influence controlled by the Sun. During periods of high solar activity, fewer cosmic rays are detected on the earth's surface. A shower of energetic particles from the cosmic rays may cause ionization, resulting in an increase in cloud condensation nuclei. During the periods of low solar activity, a great amount of cosmic ray flux is observed on the earth's surface and, consequently, there is an increase in the formation of clouds [46].

Explosive events on the sun provide a sudden reduction, over hours to days, in the influx of GCRs (Galactic Cosmic Rays), first noticed by Forbush, S. E. [47] in 1937. This reduction is now known as FD (Forbush Decrease), which is a consequence of heliospheric storms and very often observed simultaneously with a geomagnetic storm. All these three kinds of perturbations: in the solar wind, in the magnetosphere and on the flux of cosmic rays are closely interrelated and caused by the same active processes on the sun [48-51].

The daily averages of climate parameters (preceding and during FD) between 1987 and 2005 demonstrate the whole chain from solar activity to cloud formation [52]. The data gathered by the author presents a clear response to the decrease in cosmic ray's flux: the density of aerosols in the atmosphere and the liquid water to cloud fraction both are reduced following strong FD, also demonstrated in experiments [53, 54]. The ionization is also important for aerosol production and growth in the troposphere, which leads to stable clouds formation [55]. The data presented in this article is in agreement with such hypothesis of direct link between solar activity and cloud formation.

Observations made by an airglow imager deployed in São João do Cariri from September 2000 to November 2010 allowed to observe clouds and study their characteristics, as the duration, seasonality and their relation to the solar activity. The main conclusions from those observations are summarized as:

The months with the largest number of cloudy nights are comprised between February and July, whereas the cloudy nights from February to April are directly associated to the rainy season, caused primarily due to the dynamics of the ITCZ;

The best period to do either astronomic or aeronomic observations (i.e., more likely cloudless nights) in São João do Cariri starts in the early evening up to 22:00 LT during the second semester of the year. In general, there were few nights completely cloudy along the year because São João do Cariri is located in one of the driest regions of Brazil. Thus, the airglow observation at this site is always possible;

The number of cloudy nights over São João do Cariri was inversely proportional to solar activity.

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References

[1] Haigh, J. D. 2007. "The Sun and the Earth's Climate." *Living Reviews in Solar Physics* 4 (1): 2. doi:10.12942/lrsp-2007-2.

[2] Arking, A. 1991. "The Radiative Effects of Clouds and Their Impact on Climate." *Bulletin of the American Meteorological Society* 72 (6): 795-813.

[3] Haigh, J. D. 1996. "The Impact of Solar Variability on Climate." *Science (Washington)* 272 (5264): 981-4.

[4] De Jager, C. 2005. "Solar Forcing of Climate. 1: Solar Variability." *Space Science Reviews* 120 (3-4): 197-241. doi:10.1007/s11214-005-7046.

[5] Versteegh, G. J. M. 2005. "Solar Forcing of Climate. 2: Evidence from the Past." *Space Science Reviews* 120 (3-4): 243-86. doi:10.1007/s11214-005-7047-4.

[6] Ludecke, H. J., Weiss, C. O., and Hempelmann, A. 2015. "Paleoclimate Forcing by the Solar De Vries/Suess Cycle." *Climate of the Past Discussions* 11 (1): 279-305.

[7] Svensmark, H., and Friis-Christensen, E. 1997. "Variation of Cosmic Ray Flux and Global Cloud Coverage—A Missing Link in Solar-climate Relationships." *Journal of Atmospheric and Solar-terrestrial Physics* 59 (11): 1225-32. doi:10.1016/S1364-6826(97)00001-1.

[8] Mursula, K., and Usoskin, I. 2003. "Heliospheric Physics and Cosmic Rays." A lecture in University of Oulu.

[9] Todd, M. C., and Kniveton, D. R. 2004. "Short-term Variability in Satellite-derived Cloud Cover and Galactic Cosmic Rays: An Update." *Journal of Atmospheric and Solar-terrestrial Physics* 66 (13): 1205-11.

[10] Harrison, R. G., and Stephenson, D. B. 2006. "Empirical Evidence for a Nonlinear Effect of Galactic Cosmic Rays on Clouds." In *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 462 (2068): 1221-33. The Royal Society. doi:10.1098/rspa.2005.

[11] Svensmark, H., Bondo, T., and Svensmark, J. 2009. "Cosmic Ray Decreases Affect Atmospheric Aerosols and Clouds." *Geophysical Research Letters* 36 (15). doi:10.1029/2009GL038429.

[12] Randall, D. A. 1989. "Cloud Parameterization for Climate Modeling: Status and Prospects." *Atmospheric Research* 23 (3-4): 345-61. doi:10.1016/0169-8095(89)90025-2.

[13] Machado, L. A. T., and Rossow, W. B. 1993. "Structural Characteristics and Radiative Properties of Tropical Cloud Clusters." *Monthly Weather Review* 121 (12): 3234-60. doi:10.1175/1520-0493(1993)121<3234:SCARPO>2.0.CO;2.

[14] Nemesure, S., Cess, R. D., Dutton, E. G., Deluisi, J. J., Li, Z., and Leighton, H. G. 1994. "Impact of Clouds on the Shortwave Radiation Budget of the Surface-atmosphere System for Snow-covered Surfaces." *Journal of Climate* 7 (4): 579-85. doi:10.1175/1520-0442(1994)007<0579:IOCOTS>2.0.CO;2.

[15] Sun, Z., and Shine, K. P. 1995. "Parameterization of Ice Cloud Radiative Properties and Its Application to the Potential Climatic Importance of Mixed-phase Clouds." *Journal of Climate* 8 (7): 1874-88.

[16] Espinoza, H. R. 1995. "Simple Parameterizations of the

Radiative Properties of Cloud Layers: A Review." *Atmospheric Research* 35 (2): 113-25.

[17] Minnett, P. J. 1999. "The Influence of Solar Zenith Angle and Cloud Type on Cloud Radiative Forcing at the Surface in the Arctic." *Journal of Climate* 12 (1): 147-58. doi:10.1175/1520-0442-12.1.147.

[18] Norris, J. R. 2000. "What Can Cloud Observations Tell Us about Climate Variability?" *Space Science Reviews* 94 (1-2): 375-80. doi:10.1023/A:1026704314326.

[19] Tsushima, Y., Emori, S., Ogura, T., Kimoto, M., Webb, M. J., Williams, K. D., et al. 2006. "Importance of the Mixed-phase Cloud Distribution in the Control Climate for Assessing the Response of Clouds to Carbon Dioxide Increase: A Multi-model Study." *Climate Dynamics* 27 (2-3): 113-26.

[20] Turner, D. D., Vogelmann, A. M., Austin, R. T., Barnard, J. C., Cady-Pereira, K., Chiu, J. C., et al. 2007. "Thin Liquid Water Clouds: Their Importance and Our Challenge." *Bulletin of the American Meteorological Society* 88 (2): 177-90. doi:10.1175/BAMS-88-2-177.

[21] Eastman, R., Warren, S. G., and Hahn, C. J. 2011. "Variations in Cloud Cover and Cloud Types over the Ocean from Surface Observations, 1954-2008." *J. Climate* 24 (22): 5914-34. doi:10.1175/2011JCLI3972.1.

[22] Lee, S. S., Tao, W. K., and Jung, C. H. 2014. "Aerosol Effects on Instability, Circulations, Clouds, and Precipitation." *Advances in Meteorology*: 1-8. doi:10.1155/2014/683950.

[23] Bony, S., Stevens, B., Frierson, D. M., Jakob, C., Kageyama, M., Pincus, R., et al. 2015. "Clouds, Circulation and Climate Sensitivity." *Nature Geoscience* 8 (4): 261-8. doi:10.1038/ngeo2398.

[24] McFarquhar, G. M., Um, J., Freer, M., Baumgardner, D., Kok, G. L., and Mace, G. 2007. "Importance of Small Ice Crystals to Cirrus Properties: Observations from the Tropical Warm Pool International Cloud Experiment (TWP-ICE)." *Geophys. Res. Let.* 34 (13): L13803. doi:10.1029/2007GL029865.

[25] Shupe, M. D., and Intrieri, J. M. 2004. "Cloud Radiative Forcing of the Arctic Surface: The Influence of Cloud Properties, Surface Albedo, and Solar Zenith Angle." *Journal of Climate* 17 (3): 616-28.

[26] Liu, Y., Key, J. R., Frey, R. A., Ackerman, S. A., and Menzel, W. P. 2004. "Nighttime Polar Cloud Detection with MODIS." *Remote Sensing of Environment* 92 (2): 181-94. doi:10.1016/j.rse.2004.06.004.

[27] Long, C. N., Sabburg, J. M., Calbo, J., and Pages, D. 2006. "Retrieving Cloud Characteristics from Ground-based Daytime Color All-sky Images." *Journal of Atmospheric and Oceanic Technology* 23 (5): 633-52. doi:10.1175/JTECH1875.1.

[28] Holle, R. L., and MacKay, S. A. 1975. "Tropical Cloudiness from All-sky Cameras on Barbados and Adjacent Atlantic Ocean." *Journal of Applied Meteorology* 14 (8): 1437-50.

[29] Martins, F. R., Souza, M. P., and Pereira, E. B. 2003. "Comparative Study of Satellite and Ground Techniques for Cloud Cover Determination." *Advances in Space Research* 32 (11): 2275-80.

[30] Pfister, G., McKenzie, R. L., Liley, J. B., Thomas, A., Forgan, B. W., and Long, C. N. 2003. "Cloud Coverage Based on All-sky Imaging and Its Impact on Surface Solar Irradiance." *Journal of Applied Meteorology* 42 (10): 1421-34.

[31] Koren, I., Remer, L. A., Kaufman, Y. J., Rudich, Y., and Martins, J. V. 2007. "On the Twilight Zone between Clouds and Aerosols." *Geophysical Research Letters* 34 (8). doi:10.1029/2007GL029253.

[32] Chiu, J. C., Marshak, A., Knyazikhin, Y., Pilewski, P., and Wiscombe, W. J. 2009. "Physical Interpretation of the Spectral Radiative Signature in the Transition Zone between Cloud-free and Cloudy Regions." *Atmospheric Chemistry and Physics* 9 (4): 1419-30. doi:10.5194/acp-9-1419-2009.

[33] Kreuter, A., Zangerl, M., Schwarzmann, M., and Blumthaler, M. 2009. "All-sky Imaging: A Simple, Versatile System for Atmospheric Research." *Applied Optics* 48 (6): 1091-7.

[34] Heinle, A., Macke, A., and Srivastav, A. 2010. "Automatic Cloud Classification of Whole Sky Images." *Atmospheric Measurement Techniques* 3 (3): 557-67. doi:10.5194/amt-3-557-2010.

[35] He, Q. 2013. "Night-time Cloud Detection for FY-3A/VIRR Using Multispectral Thresholds." *International Journal of Remote Sensing* 34 (8): 2876-87. doi:10.1080/01431161.2012.755275.

[36] Silva, A. A., and de Souza-Echer, M. P. 2013. "Ground-based Measurements of Local Cloud Cover." *Meteorology and Atmospheric Physics* 120 (3-4): 201-12. doi:10.1007/s00703-013-0245-9.

[37] Silva, A. A., and Souza-Echer, M. P. 2016. "Ground-based Observations of Clouds through both an Automatic Imager and Human Observation." *Meteorological Applications* 23 (1): 150-7. doi:10.1002/met.1542.

[38] Taylor, M. J., Bishop, M. B., and Taylor, V. 1995. "All-sky Measurements of Short Period Waves Imaged in the OI (557.7 nm), Na (589.2 nm) and near Infrared OH and O_2 (0,1) Nightglow Emissions during the ALOHA-93 Campaign." *Geophysical Research Letters* 22 (20): 2833-6. doi:10.1029/95GL02946.

[39] Medeiros, A. F., Buriti, R. A., Machado, E. A., Takahashi, H., Batista, P. P., Gobbi, D., et al. 2004. "Comparison of Gravity Wave Activity Observed by Airglow Imaging at

Two Different Latitudes in Brazil." *Journal of Atmospheric and Solar-terrestrial Physics* 66 (6): 647-54. doi:10.1016/j.jastp.2004.01.016.

[40] Paulino, I., Medeiros, A. F. D., Buriti, R. A., Takahashi, H., Sobral, J. H. A., and Gobbi, D. 2011. "Plasma Bubble Zonal Drift Characteristics Observed by Airglow Images over Brazilian Tropical Region." *Brazilian Journal of Geophysics* 29 (2): 239-46. doi:10.1590/S0102-261X2011000200003.

[41] Hastenrath, S. 1990. "Prediction of Northeast Brazil Rainfall Anomalies." *Journal of Climate* 3 (8): 893-904. doi:10.1175/1520- 0442(1990).

[42] Polzin, D., and Hastenrath, S. 2014. "Climate of Brazil's Nordeste and Tropical Atlantic Sector: Preferred Time Scales of Variability." *Brazilian Journal of Meteorology* 29 (2): 153-60. doi:10.1590/S0102-77862014000200001.

[43] Araujo, R. G., Andreoli, R. V., Candido, L. A., Kayano, M. T., and Souza, R. A. F. D. 2013. "Influence of El Niño-Southern Oscillation and Equatorial Atlantic on Rainfall over Northern and Northeastern Regions of South America." *Acta Amazonica* 43 (4): 469-80. doi:10.1590/S0044-59672013000400009.

[44] Menezes, H. E. A., Brito, J. D., Santos, C. D., and Silva, L. D. 2008. "Relationship between the Surface Temperature on the Tropical Oceans and the Duration of Dry Spells in Paraiba State." *Brazilian Journal of Meteorology* 23 (2): 152-61. doi:10.1590/S0102-77862008000200004.

[45] Gomes, O. M., dos Santos, C. A. C., de Souza, F. D. A. S., de Paiva, W., and de Olinda, R. 2015. "Comparative Analysis of Rainfall in the State of Paraiba Using Polynomial Regression Models." *Brazilian Journal of Meteorology* 30 (1): 47-58. doi:10.1590/0102-778620120454.

[46] Krahenbuhl, D. S. 2015. "Investigating a Solar Influence on Cloud Cover Using the North American Regional Reanalysis Data." *J. Space Weather and Space Clim.* 5: A11. doi:10.1051/swsc/2015012.

[47] Forbush, S. E. 1973. "Cosmic Ray Diurnal Anisotropy 1937-1972." *J. Geophys. Res.* 78 (34): 7933-41. doi:10.1029/JA078i034p07933.

[48] Kovaltsov, G. A., and Usoskin, I. G. 2007. "Regional Cosmic Ray Induced Ionization and Geomagnetic Field Changes." *Advances in Geosciences* 13: 31-5. doi:10.5194/adgeo-13-31-2007.

[49] Belov, A. V. 2008. "Forbush Effects and Their Connection with Solar, Interplanetary and Geomagnetic Phenomena." *Proceedings of the International Astronomical Union* 4 (S257): 439-50.

[50] Dragic, A., Anicin, I., Banjanac, R., Udovicic, V., Jokovic, D., Maletic, D., et al. 2011. "Forbush Decreases—Clouds Relation in the Neutron Monitor Era." *Astrophysics and Space Sciences Transactions (ASTRA)* 7 (3): 315.

[51] Dragic, A., Veselinovic, N., Maletic, D., Jokovic, D., Banjanac, R., Udovicic, V., et al. 2013. "Further Investigations into the Connection between Cosmic Rays and Climate." *arXiv preprint arXiv*: 1304.7879.

[52] Svensmark, H. 2015. "Cosmic Rays, Clouds and Climate." *Europhysics News* 46 (2): 26-9. doi:10.1051/epn/2015204.

[53] Svensmark, H., Pedersen, J. O. P., Marsh, N. D., Enghoff, M. B., and Uggerhøj, U. I. 2007. "Experimental Evidence for the Role of Ions in Particle Nucleation under Atmospheric Conditions." In *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 463 (2078): 385-96.

[54] Svensmark, H., Enghoff, M. B., and Pedersen, J. O. P. 2013. "Response of Cloud Condensation Nuclei (> 50 nm) to Changes in Ion-nucleation." *Physics Letters A* 377 (37): 2343-7.

[55] Marsh, N., and Svensmark, H. 2000. "Cosmic Rays, Clouds, and Climate." *Space Science Reviews* 94 (1-2): 215-30. doi:10.1023/A:1026723423896.