2019 Indian Monsoon Floods

August 2020

AIR

Copyright

AIR Worldwide is a Verisk Analytics (Nasdaq:VRSK) business.

Trademarks

Contact Information

AIR Worldwide is headquartered in Boston, with additional offices in North America, Europe, and Asia. For information on our office locations, visit www.air-worldwide.com/About-AIR/Offices/

Introduction

The 2019 Indian Southwest monsoon season, which lasts from June to September, was significant in several ways. Most of India began the season with major heat waves and slow monsoon. According to the India Meteorological Department (IMD), the rainfall in June was approximately 30% lower than average across the country. The monsoon rainfall arrived late around the second week of June, then picked up in July and continued into September. By the end of September, many regions in India had experienced above-average rainfall for the season and broke many records (Figure 1).

- Highest seasonal rainfall received by the country in the last 25 years
- Seasonal rainfall is more than LPA even though the June rainfall deficiency was more than 30% of LPA
- Highest recorded August rainfall (115% of LPA) since 1996
- Second-highest September rainfall (152% of LPA) in the last 90 years
- Rainfall in all the three months—from July to September—was above LPA for the first time since 2010
- Highest cumulative August–September rainfall (130 %) since 1983 (142 %)

Figure 1. Significant highlights of the 2019 Southwest monsoon compared to the Long Period Average (LPA). (Source: IMD)

The 2019 Southwest monsoon retreat was the most delayed in India’s recorded history; it began on October 9 as compared to the typical date of September 1. The season had 10% more rainfall than the Long Period Average (LPA, the average rainfall over the period 1951–2000) and has been one of the most unusual in recent decades (IMD, 2019). As of November 21, the excess amount of rain filled the combined live storage of 120 reservoirs in India monitored by the Central Water Commission (CWC) to 88% of the total capacity (CWC, 2019). In the following sections, we will briefly summarize the intensity and frequency of these events and the hazards they caused.

Floods Across India

The 2019 Southwest monsoon season caused a series of floods across India from late June to early October 2019. In early July, Mumbai experienced its heaviest rainfall in a decade, resulting in flooding, while Assam experienced serious floods causing mass evacuation. In August, several areas in Maharashtra, Kerala, and Karnataka were inundated. In October, Bihar and Uttar Pradesh received heavy rain within a two-day period, resulting in extensive damage in these states. Many major cities such as Pune, Mumbai, Patna, Varanasi, Bhopal, Mandsaur, Rupnagar, Udupi, Mangalore, Vadodara, Guwahati, and Itanagar experienced significant flooding. Based on the information from the National Disaster Management Authority (NDMA) and other news

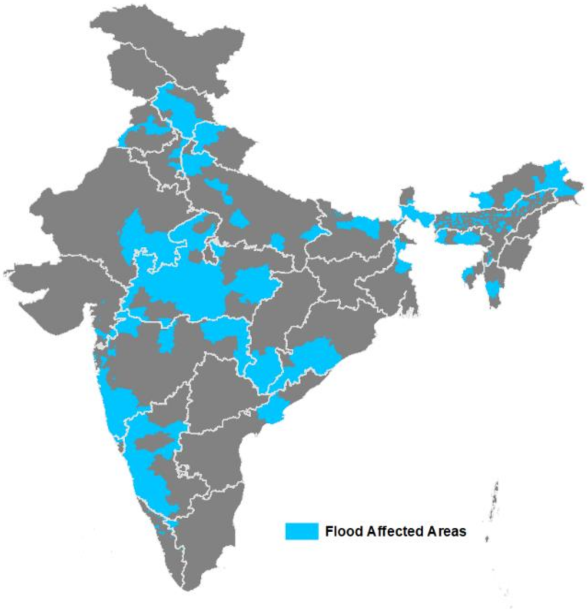

Figure 2. Areas of reported floods in India during the 2019 monsoon season. (Sources: NDMA; media reports)

reports, Figure 2 shows the flood-affected areas from the 2019 floods. More than 1,600 people lost their lives and more than 1 million were displaced (NDTV, 2019). According to the NDMA, approximately 23,000 villages were affected, about 29,000 houses were destroyed, and more than 300,000 houses were damaged across India. The CWC reported that at least 25 stream gauges across various rivers in India surpassed their previously recorded highest flood levels (HFL). Inefficient reservoir operations could have exacerbated the situation. SANDRP cites 21 instances in 2019 across 11 states where floods were a result of failures of or releases from dams, calling the safety of dam operations into question.

Estimating the Severity of the Events

The 2019 Southwest monsoon was severe in terms of total rainfall and the numerous floods it caused across India. AIR researchers analyzed the rainfall data from the TRMM Multi-satellite Precipitation Analysis (TMPA) (Precipitation Processing System (PPS) At NASA GSFC 2018) for the period 1998–2019. The average total rainfall during the Indian Southwest monsoon season (June–September) was estimated using 21 years of data (1998–2018) and then compared to 2019 rainfall during the same season. The deviation of rainfall from the average was then classified as “Large Excess,” “Excess,” “Normal,” “Deficient,” and “Scanty” based on IMD’s classification (IMD, 2015), and the flood-affected areas shown in Figure 2 were overlaid (see Figure 3).

Figure 3 shows that several areas of India, especially the central and western parts, received excess rainfall of 20–59% above the average, with a few areas receiving an excess of more than 60% above the average. There are also places with deficient (20–59% less) rainfall in the central Deccan areas, indicating droughts. Regions classified as “Excess” and “Large Excess” are comparable for the most part to the IMD’s affected areas with few exceptions, such as Himachal Pradesh and Uttaranchal. It is possible to have average rainfall over the season but experience floods if most of that rainfall were to happen over a shorter period.

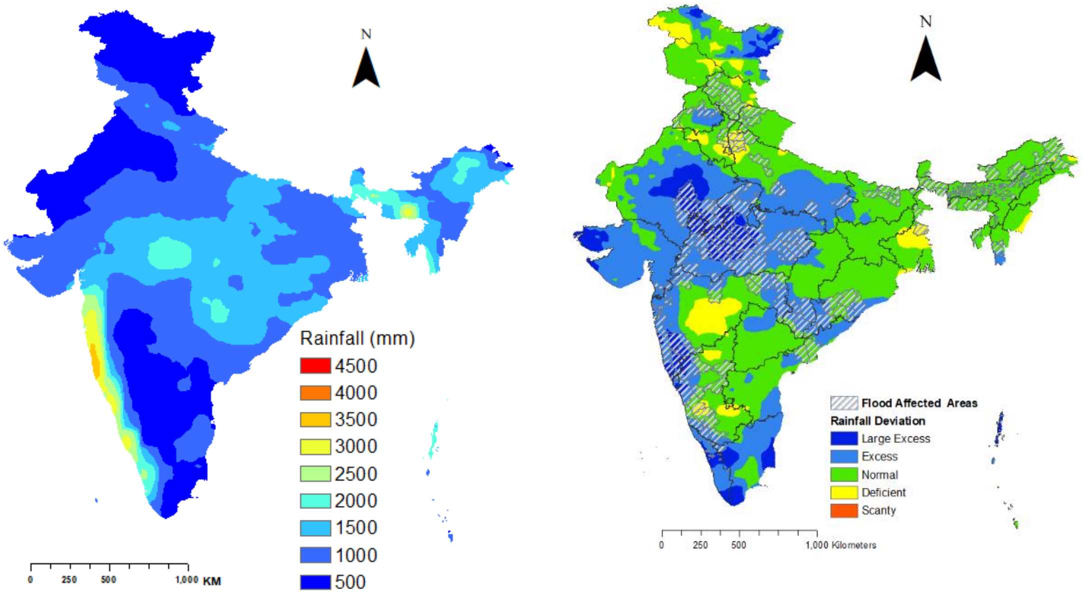

Figure 3. Total rainfall during June–September 2019 across India (left) and its departure from the recent 20-year average (right). (Source: TRMM)

AIR researchers wanted to further understand the severity of the flood events witnessed during the 2019 Southwest monsoon season. To do this, the return period or exceedance probability associated with the peak discharges of rivers in India from June to September 2019 needed to be estimated. There was also a need to assess the economic impact of these floods in the context of the impact to the property insurance industry for which flood extents for these events had to be delineated.

The CWC maintains several flood forecasting stations across India that provide real-time water level information. These water levels were then converted to discharge values using rating curves developed at AIR for about 400 stream gauges. The maximum discharge estimated for the period between June and –September 2019 were then used in this analysis.

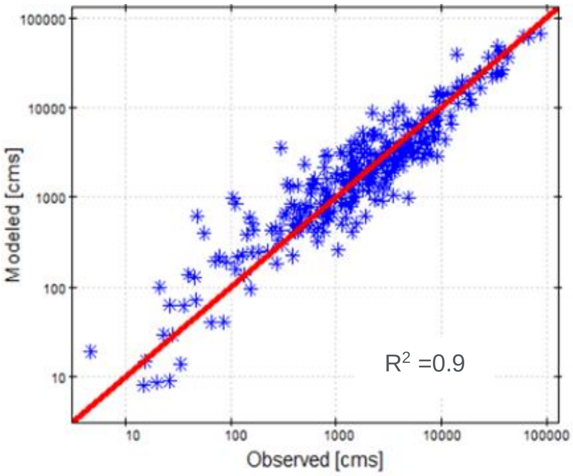

Figure 4. A comparison of observed vs modeled flows in India. (Source: AIR)

The maximum rainfall in a two-week period during June–September 2019 for every catchment in India was estimated using the daily rainfall from TRMM; those two-week maximums were then area-averaged to account for all upstream catchments. In addition, catchment characteristics such as drainage area, curve number, and catchment slope were estimated using Shuttle Radar Topography Mission (SRTM), 90-meter Digital Elevation Model (DEM), and Land Use/Land Cover (LULC) data sets from the European Space Agency (ESA) (GlobCover, 2009). These variables were then used in a regression model as predictors to estimate the discharge values at the gauges using a local prediction model. The model was validated with the observed data, which produced a satisfactory performance (R^2=0.9) (Figure 4), and then used to model the discharge for all catchments across India.

In the following section, we will demonstrate how we can leverage AIR's probabilistic flood hazard maps for India, released in 2017, to get further insights into the 2019 floods. These probabilistic hazard maps were developed using consistent methods for all the river basins, utilizing data from more than 500 CWC river gauge stations. The flood hazard maps provide a view of India's inland flood hazard corresponding to the 25-, 50-, 100-, 200-, 250-, and 500-year return periods. The model framework used to develop these hazard maps was then used to determine the return periods of the discharges observed during the 2019 Southwest monsoon season—estimated earlier and mapped (Figure 5).

The discharges of every catchment were used to delineate the flood extents and depths for the corresponding rivers based on AIR's framework of flood hazard maps. To validate the modeled extents, AIR used the satellite observed footprints from Sentinel-1 Synthetic-Aperture Radar (SAR) data available on the Copernicus Open Access Hub (ESA, 2019) satellite for a few affected areas across India. Figure 6 shows two such examples Using flood extent and observations from August 30, 2019, the first example shows that the severity of flooding along the Ganga and Kosi rivers in Bihar has a 20-year return period, as estimated by AIR. The second example, for the Kabini River in Karnataka, uses observations from September 10, 2019, and is also estimated by AIR to have a return period of about 20 years. The observed extents are slightly larger in the second example due to the impact of additional water released from upstream dams, which the AIR regression model does not account for.

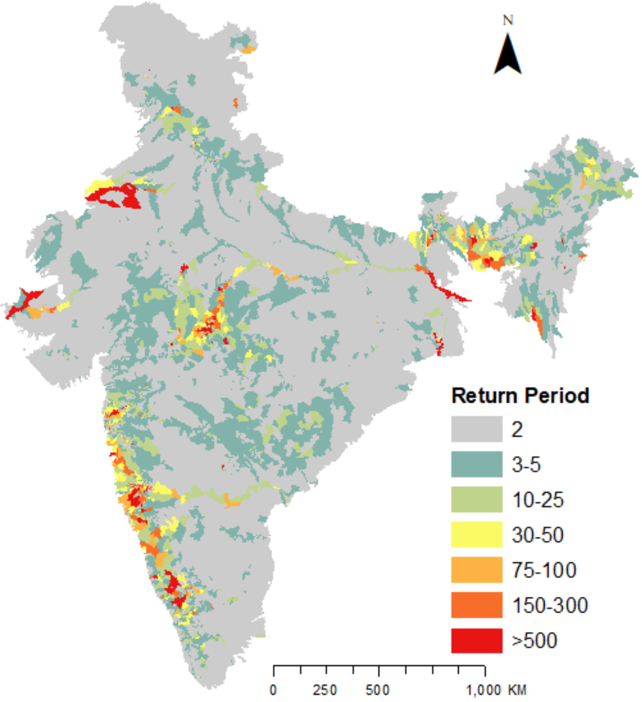

Figure 5. Return periods of 2019 flood events across India. (Source: AIR)

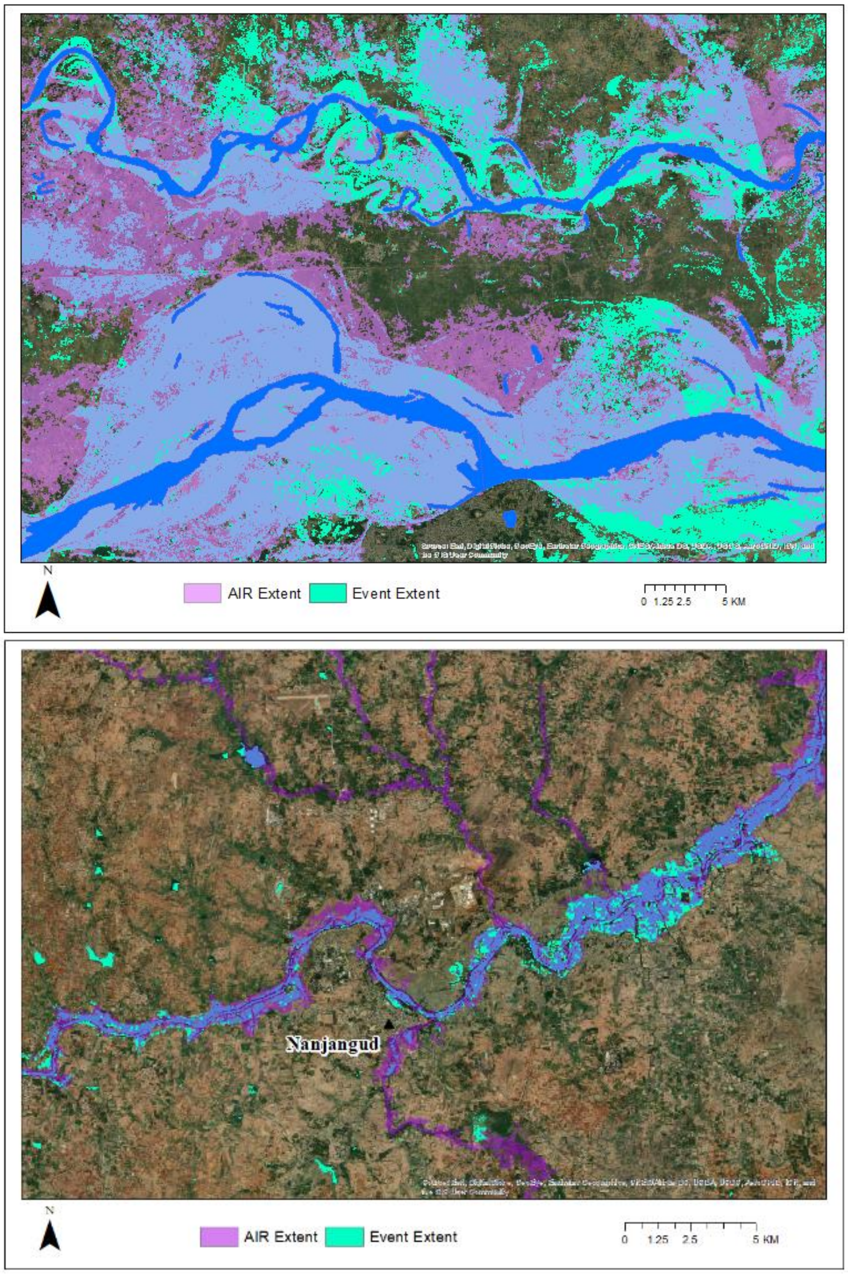

Figure 6. AIR-estimated flood extents overlain on the satellite-observed event footprint along the Ganga and Kosi rivers in Bihar on August 30 2019 (top); AIR-estimated flood extents for along the Kabini River in Karnataka overlain on the satellite-observed event footprint on September 10 2019 (bottom). (Source: AIR)

It is important to note that certain assumptions have been made on estimating the discharge and return periods to obtain an overall view of the season: first, only the largest event in terms of seasonal discharge for a catchment is modeled; second, the maximum two-week rainfall for a catchment is assumed to have contributed to the peak discharge; and third, any effects of regulation have not been accounted for. These assumptions introduce some uncertainties into the process and cause some false positives, as seen in the modeling of western Gujarat and northwestern Rajasthan. Such errors usually occur in arid or semi-arid regions as well as places with heavy regulations. These can only be addressed by a more comprehensive model, such as the AIR Inland Flood Model for the United States.

Discussions and Conclusion

Heavy rains in late September and October, like the ones that occurred in 2019, are rare for the Indian Southwest monsoon season. Among other climatic factors, anomalies in sea surface temperature such as El Niño in the South Pacific Ocean and the Indian Ocean Dipole (IOD) in the Indian Ocean are known to influence the Southwest monsoons (Clark et al., 2000). In 2019 El Niño was reported to be neutral (WMO, 2019), which typically favors average to above-average monsoon rainfall in India (Kumar et al., 2006). The IOD, however, was one of the strongest positives on record (Australia Bureau of Meteorology, 2019) until January 2020. The positive phase of the IOD causes rising motion and enhances the moisture supply over India which is generally known to significantly increase Southwest monsoon rainfall (Ashok et al., 2001; Saji and Yamagata, 2003)[1]. Along with the MJO (Madden-Julian Oscillation), the IOD likely played a role in increasing the total rainfall for the 2019 monsoon (Skymet, 2019).

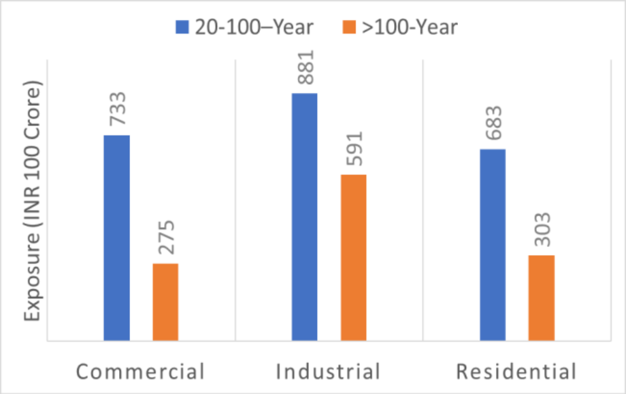

Figure 7. Exposures by line of business and the intensity of floods they experienced in the 2019 monsoon season. (Source: AIR)

AIR used a statistical approach to estimate peak discharges of rivers across India in the 2019 Southwest monsoon season, using observations from rated gauging stations, and estimated the return period of flows and their corresponding flood extents based on AIR's flood hazard maps. From this analysis, AIR infers that the 2019 monsoon season had above-average activity. Many places across India experienced "Large Excess" (Figure 2) of rainfall, which led to widespread floods. The estimated flow return periods indicate that several rivers across India experienced intense floods. Karnataka, Maharashtra, parts of Andhra Pradesh and Telangana in the south, as well as parts of Gujarat, Rajasthan, Bihar, Assam, Arunachal Pradesh, West Bengal, and Orrisa in the north were severely affected. Inferences about significant flooding in these impacted areas are in line with the reported flood footprints shown in Figure 2. In the absence of a more sophisticated flood model that explicitly accounts for various flood-generating processes, this method is a simpler and quicker tool to study the past monsoon season. Based on this analysis, AIR estimated that overall across India, exposures worth ₹28,000 crores of commercial, ₹59,000 crores of industrial, and ₹30,000 crores of residential properties potentially experienced floods more severe than those equal to a 100-year return period (Figure 7). Furthermore, the exposures that experienced

---

[1] It is worth noting that the sinking branch of a positive IOD is located near Australia which last year enhanced the drought conditions that contributed to the disastrous 2019-2020 Bush Fire season there.

flooding equal to between 20- -100–year return periods were worth around ₹73,000 crores of commercial, ₹88,000 crores of industrial, and ₹68,000 crores of residential properties.

Climate change and increased urbanization adds to the increasing frequency of precipitation-induced flood events (Mukherjee et al., 2018). A recent study (Ali et al., 2019) reports a significant increase in the risk of flooding in the future on the Indian sub-continent, which will have profound implications for agriculture and water resources. The year 2019 witnessed high intensity rainfall causing intense flooding—especially in urban areas. In 2019 large, populous cities such as Vadodara and Hyderabad experienced similar rainfall causing waterlogging. The West Kameng district of Arunachal Pradesh and the Uttarkashi district of Uttaranchal also witnessed cloudbursts—rainfall rates exceeding 100 mm/hour as defined by the IMD—that caused large-scale devastation.

As the country's population continues to increase and urbanize, it will become increasingly important for society tobetter prepare to tackle such extreme events; this will require a multifaceted holistic approach ranging from administrative and social awareness to infrastructure development. AIR has developed probabilistic, event-based catastrophe flood models for the U.S. and Europe as well as probabilistic flood hazard maps for several countries, including India. These products are leveraged by insurance companies, and governmental, and non-governmental agencies to provide insurance-based nonstructural flood mitigation solutions on a societal level. Furthermore, AIR's Global Resilience practice helps governments and non-governmental organizations prepare for the impacts of disasters before they occur.

References

Ali, H., Modi, P., Mishra, V., 2019. Increased flood risk in Indian sub-continent under the warming climate. Weather and Climate Extremes 25, 100212. https://doi.org/10.1016/j.wace.2019.100212

Ashok, K., Guan, Z., Yamagata, T., 2001. Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO. Geophysical Research Letters 28, 4499–4502. https://doi.org/10.1029/2001GL013294

Bureau of Meteorology, Australia, 2019. ENSO Wrap-Up archive [WWW Document]. URL http://www.bom.gov.au/climate/enso/wrap-up/archive/20191029.archive.shtml (accessed 1.16.20).

Clark, C.O., Cole, J.E., Webster, P.J., 2000. Indian Ocean SST and Indian Summer Rainfall: Predictive Relationships and Their Decadal Variability. J. Climate 13, 2503–2519. https://doi.org/10.1175/1520-0442(2000)013<2503:IOSAIS>2.0.CO;2

CWC, 2019. BRIEF NOTE ON LIVE STORAGE STATUS OF 120 RESERVOIRS IN THE COUNTRY (WITH REFERENCE TO RESERVOIR STORAGE BULLETIN OF 21.11.2019).

ESA, 2019. Copernicus Open Access Hub [WWW Document]. URL https://scihub.copernicus.eu/ (accessed 1.16.20).

IMD, 2019. 2019 Southwest Monsoon Season Rainfall and IMD's Long Range Forecasts.

IMD, 2015. Revised terms & terminologies in weather forecasting services.

Mukherjee, S., Aadhar, S., Stone, D., Mishra, V., 2018. Increase in extreme precipitation events under anthropogenic warming in India. Weather and Climate Extremes 20, 45–53. https://doi.org/10.1016/j.wace.2018.03.005

NDTV, 2019. Over 1,600 Dead In India's Heaviest Monsoon In 25 Years: Report. NDTV.com.

Precipitation Processing System (PPS) At NASA GSFC, 2018. TRMM (TMPA/3B43) Rainfall Estimate L3 1 month 0.25 degree x 0.25 degree V7. https://doi.org/10.5067/TRMM/TMPA/MONTH/7

Saji, N., Yamagata, T., 2003. Possible impacts of Indian Ocean Dipole mode events on global climate. Clim. Res. 25, 151–169. https://doi.org/10.3354/cr025151

SANDRP, 2019. 2019 Monsoon: Instances when Dam Safety Came into Question. SANDRP. URL https://sandrp.in/2019/10/31/2019-monsoon-instances-when-dam-safety-came-into-question/ (accessed 1.16.20).

Skymet, 2019. IOD and MJO overpower declining El Nino, result in surplus Monsoon rains [WWW Document]. www.skymetweather.com. URL https://www.skymetweather.com/content/weather-news-and-analysis/iod-and-mjo-overpowers-declining-el-nino-results-in-surplus-monsoon-rains/ (accessed 1.16.20).

WMO, 2019. El Niño/La Niña Update [WWW Document]. World Meteorological Organization. URL https://public.wmo.int/en/our-mandate/climate/el-ni%C3%B1ola-ni%C3%B1a-update (accessed 1.16.20).

About AIR Worldwide

AIR Worldwide (AIR) provides risk modeling solutions that make individuals, businesses, and society more resilient to extreme events. In 1987, AIR Worldwide founded the catastrophe modeling industry and today models the risk from natural catastrophes, terrorism, pandemics, casualty catastrophes, and cyber incidents. Insurance, reinsurance, financial, corporate, and government clients rely on AIR's advanced science, software, and consulting services for catastrophe risk management, insurance-linked securities, longevity modeling, site-specific engineering analyses, and agricultural risk management. AIR Worldwide, a Verisk (Nasdaq:VRSK) business, is headquartered in Boston, with additional offices in North America, Europe, and Asia. For more information, please visit www.air-worldwide.com. For more information about Verisk, a leading data analytics provider serving customers in insurance, energy and specialized markets, and financial services, please visit www.verisk.com.

AIR

A Verisk Business