# Application of satellite informatics in mitigating climatic challenges within the atmosphere

## Selected case studies of Asian cities

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### Abstract

The climate crisis is considered one of the most pressing global issues today, due to its devastating impacts on the natural environment, urban resilience, and human health in affected cities. Recent extreme weather events in the atmosphere have also brought climate shocks to not only developing cities but also to urban clusters of developed countries. Some local governments and city-dwellers of Asia were found lacking of comprehensive plans to regain resilience after encountering a serious climatic disaster, thus the use of innovative latest technologies has become crucial for identifying variations of selected environmental attributes, assessing potential climatic risks, and predicting the probability of occurrence of extreme weather events via scientific approaches. This article examines how remotely sensed datasets and satellite informatics can be effectively integrated to mitigate climatic challenges at urban scales. Selected case studies in Asia were extracted as illustrations, to shed light to combat with relevant climatic risks, as well as maintaining a sustainable and healthy neighbourhood environment via data analytic means.

## Introduction

Climate change, which refers to the long-term and widespread change in average weather patterns, has exacerbated and imposed threats to environmental and human well-being within different means (Abbass et al., 2022), for example, global warming in land and ocean (Venegas et al., 2023), accelerated rate of rising global mean sea level (Horton et al., 2020), the loss of ice sheets at Greenland and West Antarctic (Wunderling et al., 2020), as well as the occurrence of extreme weather events, like heatwaves, flooding, droughts, changing intensities and frequencies of tropical cyclones (Konisky et al., 2016; Kropf et al., 2025). The persistence of high temperature and drought for 79 consecutive days in China during Summer and Autumn 2022 (Chen and Wang, 2022); the heavy rainfall event in South Korea in August 2022 (Park et al., 2024); the record-breaking monsoon rainfall in China and South Korea in 2020 (Liu et al., 2020; Park et al., 2021); and extreme landslide events in Hong Kong due to super typhoons in 2017 and 2018 (CEDD, 2022), have all imposed pervasive impacts on agriculture and vegetation cover, ecosystem and moisture transport (Drumond et al., 2024; Liu et al., 2023). As a result, irretrievable altering of climatic system has led to environmental and public health challenges, for example, environmental degradation and biodiversity loss (Price et al., 2024), enhanced risks of illnesses (e.g., cardiovascular diseases and heatstroke) due to heatwaves and excessive traffic pollutants (Mak and Ng, 2021; Patel et al., 2022). The impacts are more grievous in developing cities and can exacerbate the already existing urban social and health inequities, as well as the urban-rural income gap (Xie et al., 2023), because climate change can directly influence mobility trends (McMichael, 2023). Nevertheless, the actual impact of climate changes will depend on resilience of individual city, the level of engagement from government officials and town planners to individual city-dwellers (Mak and Lam, 2021), community involvement (Daniel and Fernandes, 2024), together with the advancement of digital technology and information management (Dwivedi et al., 2022) in establishing short-term and long-term plans to combat with induced spatial challenges and promoting sustainability. According to the Resilient Cities Index 2023, developed cities like New York and Los Angeles were in top positions in terms of resilience, but there is still room for improvement in the recovery from extreme weather events (Economist Impact, 2023). Wealthy cities and places could also be unprepared for a spectrum of environmental shocks, for example, Hong Kong, as a cosmopolitan city, is still highly vulnerable to flooding and tropical cyclones (Choy et al., 2020). On the other hand, devastating impacts could take place for groups settling in cities without a detailed heat map, like Bangkok, Jakarta, and New Delhi (PreventionWeb, 2023), and Indian cities rank poorly in terms of congestion management within the Index as well. In recent years, some Asian cities have established ground monitoring networks to trace and detect climatic patterns; however, due to observational sparsity and the impossibility of obtaining complete raw datasets, the actual spatial and temporal features and transitions cannot be systematically reviewed (Kennedy, 2013). Further, the amount and quality of observational datasets could vary temporally and spatially (Garcia-Soto et al., 2021), which induces bias, misinterpretations, and uncertainties when these in-situ measurements are adopted for future climatic predictions (Brune et al., 2015). Thus, one attempts to seek an alternative approach that provides consistent measurements of concerned climatic attributes in both space and time so that respective historical and current trends can be acquired for conducting risk analysis. Given the need, climate data records (CDRs) have become indispensable for monitoring change detection, retrieving historical variations, and predicting environmental changes in local, continental, and global contexts (Yang et al., 2016). To develop informative CDPs, sensors installed onboard both polar-orbiting and geostationary satellites have become essential because they can provide trustworthy informatics of land, oceans, atmosphere, and ice sheets in continuous manners (NCEI, NOAA). This article explores how the advancement of data analytics, remote sensing technologies, and satellite informatics can effectively monitor part of our climate system and then focus on their applications in selected case studies of Asia. With these inspirations, one can gain insights into establishing a robust, sustainable, and healthy neighbourhood environment, mitigating negative impacts due to sudden climatic variations, and at the same time developing strategies to cope with associated environmental challenges in the future.

## Brief review of selected climatic risks in Asia

According to the report from the World Meteorological Organization (WMO), the mean temperature of Asia in 2023 reached its second highest in history (WMO, 2024), and was 0.84 °C–0.96 °C above the corresponding average level from 1991-2020 and 1.81 °C-1.92 °C above that from 1961-1990 (IPCC, 2021). Doubled warming trend took place in Asia and was particularly serious from western Siberia to central Asia (Li et al., 2021) and from eastern China to Japan (Zhang et al., 2021). Figure 1 shows the mean surface air temperature trends of all 6 WMO regions and the corresponding mean in land and ocean over 4 specific time periods. On top, it was also reported that climatic, weather, and water-related hazards were most frequent in Asia in 2023. Out of 163 natural disasters attained, 17, 17, 15, and 15 of them occurred in China, India, Indonesia, and the Philippines, respectively (CRED, 2024), which included heatwaves, drought, storm, flooding, and wildfires. The Emergency Events Database also recorded that over 80% of these natural disasters were related to flood and storm events, which altered the prevailing natural system and ecosystems (Walz et al., 2021). The effect was further amplified by phenomena like the rise of sea level (Hens et al., 2018), projected rising atmospheric $CO_2$ level in Asia (Labzovskii et al., 2019), and the decreased cumulative mass balance of glaciers in the High Mountain Asia region (WMO, 2024).

Recently, the El Niño–Southern Oscillation (ENSO) event had also led to unusual wet and warm winters in the

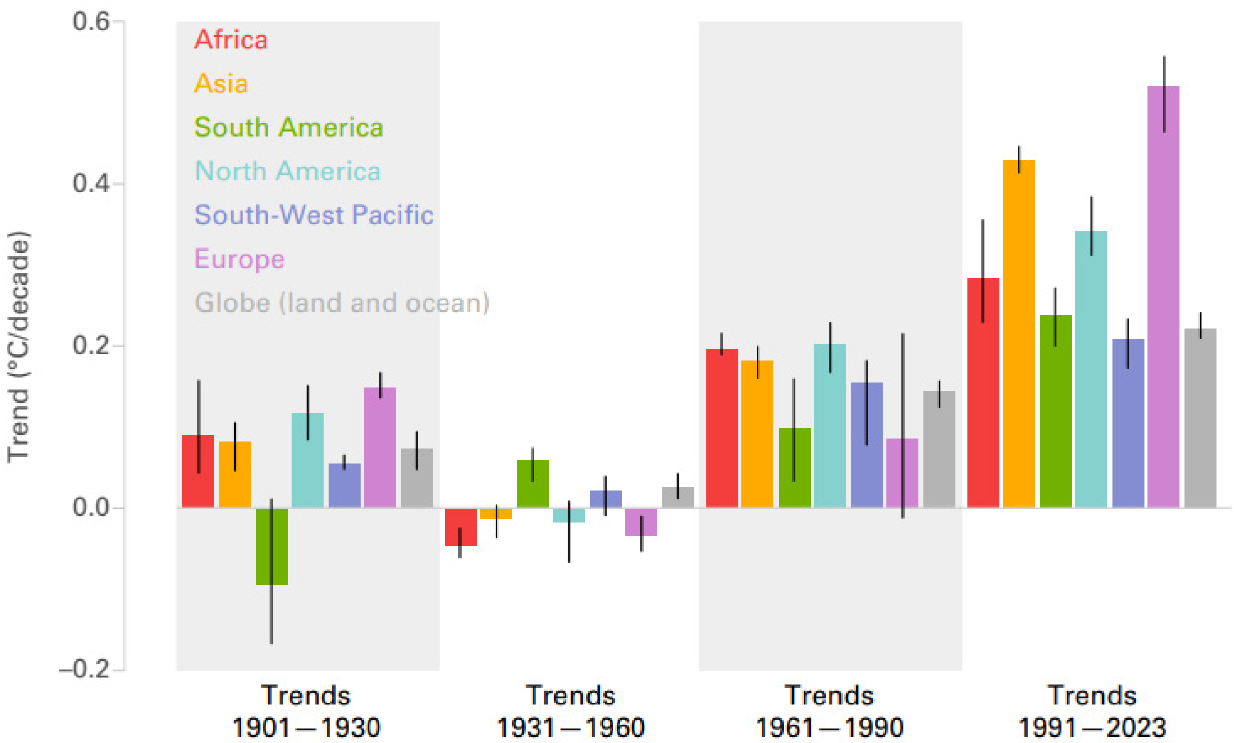


**Figure 1:** Mean surface air temperature of all 6 WMO regions (Africa, Asia, South America, North America, South-West Pacific, Europe), and the corresponding mean temperature trend in globe (land and ocean) over 4 periods (1901-1930, 1931-1960, 1961-1990, 1991-2023) - Figure 4 of WMO's 2024 report: https://www.uncclearn.org/wp-content/uploads/library/1350_State-of-the-Climate-in-Asia-2023.pdf

Republic of Korea and eastern China, summer monsoon in Asia, hot and dry summer in southern Asia during summer-autumn 2023, the highest monthly averaged temperature and deficit of rainfall in India (WMO, 2024), as well as huge spatiotemporal variability of rainfall content and precipitation in various Asian countries (An et al., 2023). As a result, massive flooding and fatalities occurred in selected countries or cities, namely South Korea (summer 2023), Hong Kong (Sep 2023), central provinces of Vietnam (Oct 2023), Madinah of Saudi Arabia (Nov 2023), and Dubai (Nov 2023). The climatic phenomenon Mei-yu was also observed in East Asia, and the persistent rain belt posed huge challenges to water management and urban planning (Takahashi and Fujinami, 2021; Sun et al., 2023), at the same time leading to the widespread of waterborne diseases and increased risk of vector-borne illnesses (Acosta-España et al., 2024). In particular, a fog event off the coast of the Hangzhou Bay occurred in 2013 (Wang et al., 2018), increased rainfall and severe flooding were found in Hangzhou and Jakarta (Climate, 2025), extreme rainfall events and enhanced rainfall during afternoons at Kuala Lumpur (Miniandi et al., 2024), and elevated mortality risks for respiratory diseases in 30 cities across mainland China, Taiwan, South Korea and Japan due to exposure to heavy rainfall (He et al., 2024).

On top of the aforementioned unexpected phenomenon, many countries in Asia experienced prolonged heatwaves in 2023, especially from April to July. The highest or second highest land temperature on record was detected in cities of China, India, Japan, Lao People's Democratic Republic, Singapore, Thailand and Vietnam (Lyu et al., 2024; Satyanarayana et al., 2024; Sun et al., 2024; Today's WorldView, 2023; WMO, 2024). In the presence of urban heat island (UHI) effects, around 25 heatwave days were found in Phnom Penh, Cambodia per year (GFDRR, 2025); heatwaves amplified urban warming in Guangzhou, China (Luo et al., 2023); and different synoptic patterns led to contrasting interactions between UHIs and heatwaves in Seoul, South Korea, from 1997-2021 (Park et al., 2023). These heatwaves were not only formed on land but also along the marine, which led to the restructuring of the ecosystem and coral bleaching. Thus, it is of paramount importance to fully utilize the strengths of modern technological frameworks to perform precise climate projections, identify high risk spatial regions, and then develop early warning systems and appropriate public health infrastructures that can minimize potential damages induced by sudden climatic changes. Moreover, communication with relevant government organizations and the engagement of the community in adapting to climate change phenomena are equally crucial for strengthening a country's resilience in the long run.

## Roles of satellite informatics and remote sensing in assessing climatic conditions of Asian cities

Due to sparsity of in-situ monitoring network, numerical uncertainties in filling data gaps, the complicated spatial correlations of different meteorological attributes for determining overall climatic condition, technical shortcoming of handling datasets of different formats and resolutions, as well as surrounding environmental constraints that possibly diminish data quality, it is almost impossible to perfectly describe spatiotemporal variations of climatic conditions within Asia and the Pacific. Global climate models (GCMs) established as many realistic and high-resolution climate scenarios as possible, so that associated risks of climate change can be anticipated (Wang et al., 2014; Wang et al., 2022), however the reliability of these projected figures depends on model inputs and settings, for example, greenhouse gas emissions, physical parametrization schemes adopted, and the resolution chosen for performing simulations (Wang et al., 2022). With the advancement of technologies, scientists have developed high-resolution regional climate models, statistical downscaling approaches, and even artificial intelligence techniques to retrieve, quantify and predict climatic attributes, then connect the useful informatics with disease prevention and city management (Camps-Valls et al., 2025; Esfandeh et al., 2024; Li et al., 2019). Despite concerted efforts spent, downscaling approaches require intermediate projection and location-specific error of up to 9.8% (Miller et al., 2025), while it is not easy to understand the physical significance of specific climatic attributes when artificial intelligence is applied (O'Loughlin et al., 2025).

In view of aforementioned deficiencies and to provide continuous measurements against time, satellite products have become useful for regional applications, because satellites can measure different aspects of weather conditions on Earth, provide multi-decade datasets for monitoring and assessing climatic variations at sufficiently high spatiotemporal resolutions (ESA, 2021), and possibly fill up spatial subgrids with missing attributes. Satellite imagery and missions can also govern the change in different portions of our nature, including the atmosphere, land, ocean, and ice, which are hugely influenced by climate change. Table 1 shows some selected environmental risks or undesirable natural events due to climate change, as well as highlighted satellite retrieval mechanisms and/or missions that were implemented for monitoring and forecasting within Asia. Overall, after a series of data pre-processing and radiometric calibration stages, raw datasets obtained from sensors installed onboard or from remotely sensed instruments are ingested into climate models. Afterward, Geographic Information System (GIS) provides a standardized interpretation of the Earth's surface (Yang et al., 2024), while the integration of machine learning and data analytic approaches allow more accurate digital assessments within a prescribed timeframe, especially for attributes of land and ocean. Such approach facilitates climate risk assessments and encourages humanitarian efforts in tackling climate change problems (Yang et al., 2024), and the detected footprints could verify changes impacted by natural disasters arisen from climate change (Wu et al., 2021), which are tremendously useful for spatial risk management and laying down urban planning strategies from national perspective.

**Table 1:** Selected environmental risks associated with climate change and respective satellite products/missions used for conducting spatiotemporal assessments in Asia

| Environmental Risk | Highlighted Satellite Products / Missions at City / Country level |
|---|---|
| Increased Greenhouse gases (e.g., $CO_2$ and $CH_4$) | Greenhouse gases Observing SATellite (GOSAT) and the TROPOspheric Monitoring Instrument (TROPOMI) aboard Sentinel-5: $XCH_4$ concentration in the Asian monsoon region (North China Plain, southern China, South Asia, and Southeast Asia) (Song et al., 2023)<br>China National Space Administration's TanSat mission provides continuously measured datasets of greenhouse gas concentrations *(Source: https://earth.esa.int/eogateway/missions/tansat)*<br>Greenhouse gases Observing SATellite (IBUKI) in Japan, covering Zhangjiakou, Anshan, Harbin, and Tianjin (China), Kolkata (India), eastern Uzbekistan, etc. *(Source: https://www.nies.go.jp/whatsnew/2014/20141210/20141210-e.html)* |
| Changing meteorological conditions (e.g., precipitation, ground temperature) | MODIS (moderate resolution imaging spectroradiometer) for estimating land surface temperature (LST) over South Asia (Shawky et al., 2023)<br>FengYun geostationary meteorological satellites (Du et al., 2024) – focus on Chinese cities<br>TRMM 3B42, the IMERG Final Run, the PERSIANN-CDR, and the PERSIANN-CCS-CDR (Huang et al., 2022) – focus on Luzon and adjacent seas<br>South Korean Geo-KOMPSAT-2A (GK-2A) across Northeast Asia (Yin et al., 2022) |
| Air Pollution (e.g., increased $PM_{2.5}$, $NO_2$ and $O_3$ concentrations) | BEHR-HK OMI-based $NO_2$ products for more accurate and promising tropospheric $NO_2$ columns in southern China (Mak et al., 2018)<br>Geostationary Environment Monitoring Spectrometer (GEMS) for estimating and retrieving columns of atmospheric pollutants (e.g., $O_3$, $NO_2$, $SO_2$, HCHO, CHOCHO, aerosols, etc.) in Korea (Kim et al., 2020)<br>Ozone Monitoring Instrument (OMI) daily VCD of $NO_2$, $SO_2$, and $O_3$, and MOPITT for AOD product in Guangdong Province (Li et al., 2024) |
| High-altitude cirrus clouds | Ground-based Aerosol Robotic Network (AERONET) sun photometer data for baseline AOD product in Singapore (Chew et al., 2024)<br>CloudSat 2B-CLDCLASS-LIDAR in East Asian countries (Li et al., 2018) |
| Variation of ozone layer and ozone depletion | Variations of Antarctic total column ozone (TCO) in East Asia (Zhu and Wu, 2024)<br>SBUV merged ozone datasets (MOD) from SBUV/SBUV-2 satellite in East Asia (Shin et al., 2021)<br>Suomi NPP OMPS, Aura MLS, and Sentinel-5P TROPOMI are useful for acquiring vertical profiles of ozone in Asia (Malina et al., 2024) |
| Increased drought | Geostationary operational environmental satellite (GOES) - produce Evaporative stress index (ESI) of East Asia based on LST and leaf area index (LAI) - focus on South Korea (Yoon et al., 2020)<br>GIMMS NDVI3g bimonthly dataset and NASA's MERRA dataset in the East Asian region (including Mongolia, China, Korea, and Japan) (Ali et al., 2023) |
| Warming and rising ocean (e.g., increase of sea level) | Gridded sea-level anomalies (SLA) produced by the Copernicus Climate Change Service and coastal along-track SLA produced by the Climate Change Initiative Coastal Sea Level Team, adopted in Southeast Asia (e.g., Manila, Bangkok, Indonesia, etc.) (Peng et al., 2024)<br>TOPEX, Jason-1, Jason-2, Jason-3, ERS-1, ERS-2, Envisat, CryoSat-2, SARAL, and Sentinel-3A - satellite altimetry missions in the Southeast Asian region (Affandi et al., 2025) |

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|---|---|
| Declining crop yields due to diminished water and grasslands for grazing | CHARMS - NDVI anomaly maps and development in Chinese cities & CropWatch - NDVI anomaly and VCIx over the last five years, NDVI development and clustering (Wu et al., 2015)<br>Four multispectral RapidEye datasets and one Landsat5 TM image, conducted in Fergana Valley, Uzbekistan (Conrad et al., 2013) |
| Change in ice cover within Asia domain | ERA5-Land reanalysed dataset for categorizing Frost Days (FD) and Frost-Free Periods (FFP) in China (Li et al., 2022)<br>Landsat-7 panchromatic images and Sentinel-2 panchromatic images for assessing changes in glacier velocity and flow patterns in the Himalayas, Asia (Zhou et al., 2021) |
| Change in sea-surface temperature and salinity – influence ocean circulation patterns | Ocean Color and Temperature Scanner (COCTS) onboard the China HY-1C satellite – measured sea-surface temperature in Southeast Asia seas (Sun et al., 2023)<br>Optimal Interpolation SST (OISST) version 2 based on measurements by the Advanced Very High-Resolution Radiometer (AVHRR), CMEMS based on observation of multi-mission satellite altimeters – quantified sea-surface temperature and salinity of the Oyashio Region, Japan (Miyama et al., 2021) |
| Fluctuations in the carbon-rich biomass, soil, and variations of Land Cover | Landsat datasets together with the selection of remote-sensing classifiers for detecting land-use land-cover (LULC) changes in Pakistan (Ul Din and Mak, 2021)<br>Advanced Microwave Scanning Radiometer 2 (AMSR2), The Soil Moisture Active Passive (SMAP) satellite, The Soil Moisture and Ocean Salinity (SMOS) satellite, The European Space Agency (ESA)'s Climate Change Initiative (CCI) for soil moisture dataset in northern China (Liu et al., 2022) |
| Occurrence of wildfires | Copernicus Sentinel-2, Sentinel-3, and Sentinel-5P missions provide a wealth of information for monitoring blazes<br>Landsat (30 m resolution), VIIRS (S-NPP, NOAA-20 & NOAA-21) (375 m resolution), MODIS (Aqua & Terra) (1 km) in FIRMS (Fire Information for Resource Management System) provide dynamic imageries for acquiring the spatial location of wildfire via graphical display<br>*(Source: https://firms.modaps.eosdis.nasa.gov/map/#d:24hrs;@0.0,0.0,3.0z)* |
| Massive flooding and landslides | Gaofen (GF) series and Zhuhai-1 hyperspectral satellite datasets for flood monitoring in Chinese cities situated at the Yangtze River Delta Plain, as well as Dabie Mountain, Xuefeng Mountain, and Luoxiao Mountain (Zhang and Xia, 2022)<br>A high-resolution (1 m) diverse mountainous landslide remote sensing dataset (DMLD), including 990 landslide instances across different terrain in Yunnan, China (Chen et al., 2024) |

## Selected case studies from Asia contexts

The following are two case studies in Asia that illustrate how satellite informatics and remotely sensed datasets can be synergized to identify, analyze and mitigate environmental challenges ahead, thus provide insights for future scientists and policymakers to fully utilize the strengths of remote sensing in environmental monitoring, climate assessments and implementing relevant policies and governance within city-level.

### Assessing flood risks in Jakarta

According to "Environmental Risk Outlook 2021", Jakarta is one of the world's most vulnerable cities when facing environmental hazards caused by climate change (Verisk Maplecroft, 2021), however it still suffers from "riverine floods" and "coastal floods", where the former one is normally influenced by rainfall, while the later one is due to the rise of sea-level, tides and storms. Yang et al. (2024) attempted to assess hazards induced within city-level, where the level of riverine floods is determined via a modelling approach, and coastal floods are analyzed via a digital elevation model. The overall

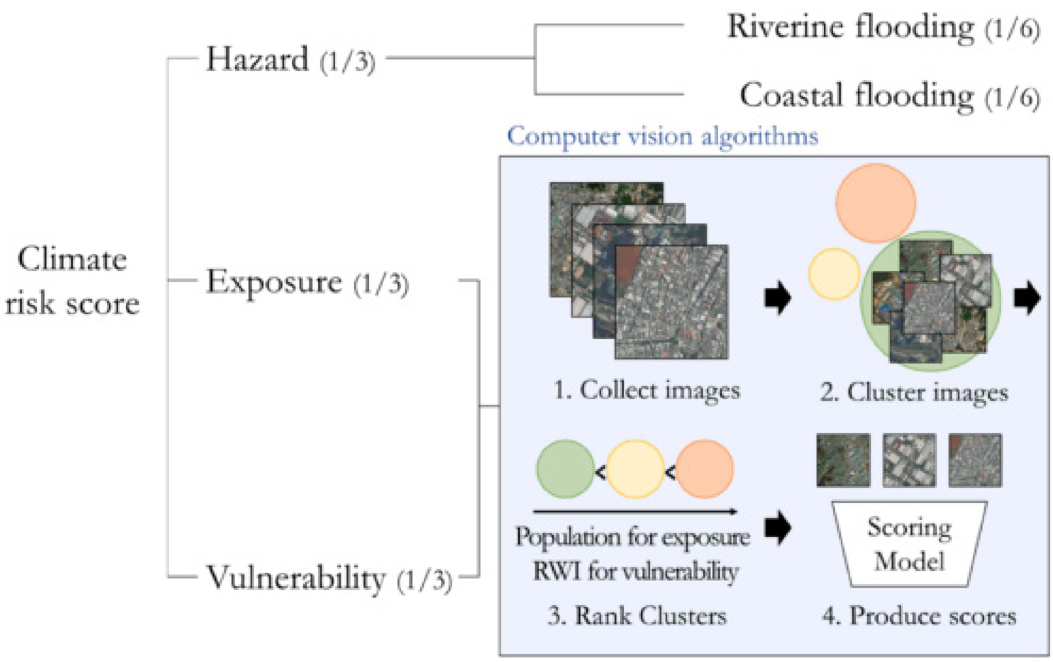


**Figure 2:** Three components of climate risk assessment in Jakarta, Indonesia, as well as the measurements and procedures needed. The figure extracted from Yang et al. (2024).

climate risk score consists of three equal-weighted components, namely hazard, exposure, and vulnerability, and is defined as in Figure 2.

Satellite images from The World Imagery dataset were first downloaded from the ESRI ArcGIS REST API website (https://tiledbasemaps.arcgis.com/arcgis/rest/services/World_Imagery/MapServer). The images acquired from three visible bands cover the entire Jakarta (excluding small inland areas), with exposure and vulnerability scores assigned at each prescribed sub-grid. Rescaling of available geospatial datasets is conducted for the assignment of hazard score, and the climate risk score of each grid was then calculated and aggregated into the 262 districts of Jakarta.

When determining hazard scores, the riverine flood hazard score at each subgrid is estimated by the SOBEK model (Deltares, 2024), which integrates a set of hydrological and hydraulic indicators to perform simulations, while the coastal flood hazard score was based on a global digital elevation model of 30 m spatial resolution. Available satellite images were grouped into 20 clusters based on the supervised Deep Cluster Algorithm (Caron et al., 2018), followed by the combination of a machine learning model that considers interpolated and extrapolated population density and Relative Wealth Index (RWI) parameters, so that respective exposure and vulnerability scores of each grid were computed at cluster level, with learning process conducted at the same time. Spatial results and scoring obtained were intercompared against two regression models and validated by building and road footprints obtained from OpenStreetMap, together with municipal statistics. As a result, the occurrence of compound floods, human exposure patterns, and vulnerability of each individual district within Jakarta can be identified so that its sensitivity to climate change can be revealed, and rainfall trends can be more effectively predicted in the future.

## Retrieval of Land Surface Temperature (LST) over the Tibetan Plateau

LST is crucial in monitoring climate variability (Oduro et al., 2025) and estimating urban heat island phenomenon (Mohamed et al., 2017). The Tibetan Plateau (TP), situated mainly in southwestern China, spans through central and eastern Asia, experiences significant environmental changes due to rapid surface warming, and exerts strong thermal forcing over the Asian monsoon region (Yang et al., 2014). Due to the coarse spatial resolution of land surface models in China and the heterogenous nature of its surface types, uncertainty of LST in TP often arises (Jiang et al., 2020). Due to the complicated surface properties and hydrometeorological conditions of TP, obtaining synchronized atmospheric profiles in TP has become challenging. Most satellite retrieval algorithms have assumed clear-sky conditions (Wan and Dozier, 1996) and possessed prescribed sensor characteristics and geographical contexts (Becker and Li, 1995), but these assumptions are usually not applicable for TP. Novel LST retrieval algorithms were proposed in recent years, for example, predicting LST via a deep learning and knowledge-driven model (Wang et al., 2021) and Random Forest approach (Wang et al., 2022). Although these algorithms have effectively accounted for atmospheric effects and changes over time, they have not considered the spatiotemporal relationship in between all input environmental variables, and require vast amount of training data for distinguishing the complicated spa-

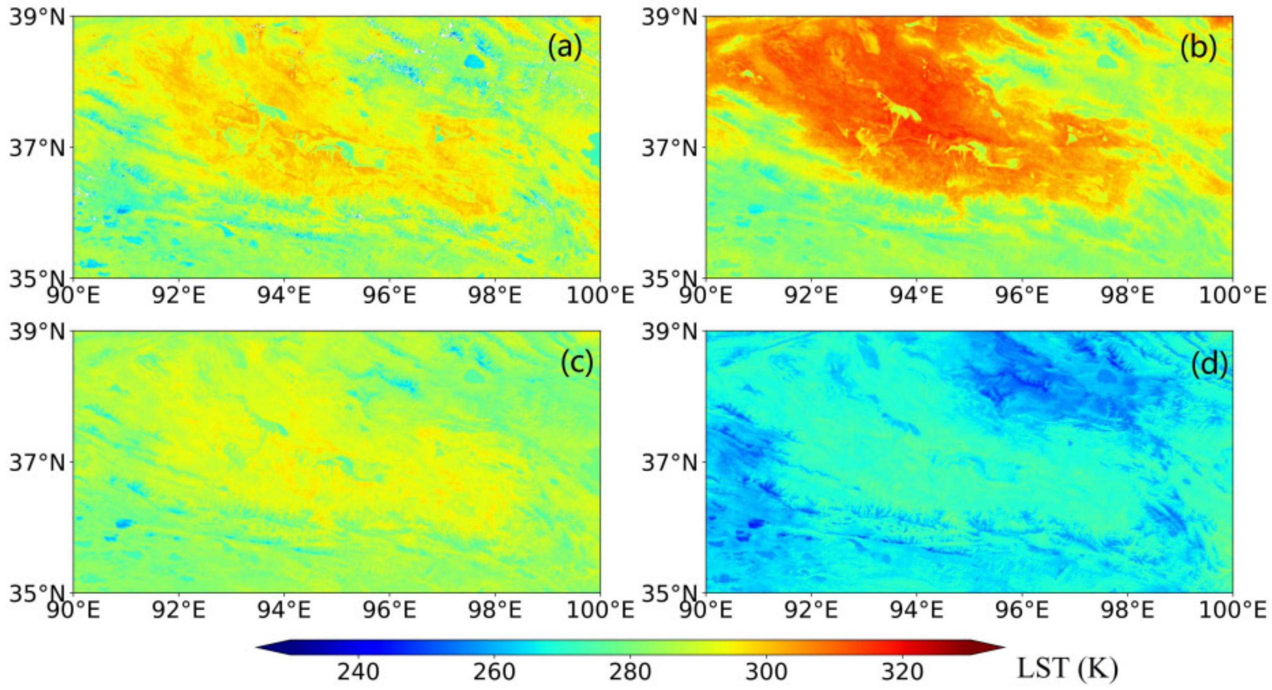


**Figure 3:** Spatial distribution of averaged seasonal daytime LST ((a) Spring 2020; (b) Summer 2020; (c) Autumn 2020; (d) Winter 2020) from SLSTR satellite datasets in Qaidam Basin. Figure extracted from Qi et al. (2023).

tial and temporal LST patterns. Thus, these deficiencies have laid down the importance of combining satellite sensor outputs with an optimized machine learning model for TP or other developing cities in Asia.

Qi et al. (2023) adopted remotely sensed datasets acquired from sea and land surface temperature radiometer (SLSTR) installed on Sentinel-3, which provide radiometric measurements, fractional vegetation cover, land cover type, total column water vapor, SZA and quality control flags, together with high resolution Landsat images for LST retrieval. MODIS/Terra LST products (MOD11A1) and MODIS Level 1B Calibrated Radiances serve as datasets for validating and calibrating aforementioned datasets before introducing inputs into the machine learning based model for training (Li et al., 2021). The near-surface air temperature, specific humidity and air pressure from CLDAS V2.0 were used to calculate the atmospheric total column water vapor (TCWV) in TP (Shi et al., 2011). All these datasets together with specific coefficients and Land Surface Emissivity (LSE) retrieved from SLSTR, were fit into the well-established single-channel (SC) and split-window (SW) algorithms for estimating the spatial distribution of LST in TP.

Within the case study, 4190 samples (with 2933 training samples and 1257 validation samples), together with relevant meteorological attributes from satellites were fit into the traditional Linear Regression model, Decision Tree model, Random Forest model and Back Propagation Neural Network for retrieving and predicting LST across different regions of TP. Upon validating against the derived in-situ LSTs from the 6 stations in TP, it was found that Random Forest model best describes the spatiotemporal distribution of LST in the prescribed spatial context, and the retrieval uncertainties are mainly attributed to the attenuation of water vapor content and land surface emissivity. It was also found that hot and humid atmospheric conditions could lead to significant errors when estimating LST (Jimenez-Munoz and Sobrino, 2010), which has to be dealt with when designing geostationary satellites for atmospheric retrieval. Figure 3 shows the spatial distribution of the SLSTR-based daytime LST in four seasons of 2020 over the Qaidam Basin, where significant discrepancies of LST and temporal variations could be observed.

## Insights in technological advancement, city development and conclusion

The amplification of frequency and intensity of global climatic risks and disasters during the past decades has caused undesirable impacts to city development, economic and political instability, as well as diminishing overall health qualities of individuals and liveability of Asian cities, as a result hinder the future smart city development (Chi and Mak, 2021). Strengthening the environmental dimension of early warning has become one of the key focuses of the UN Environment Programme, Agenda 2030, thus the existing approaches, strategies and measures of conducting climatic assessments should be continuously reflected, so that the city's environmental conditions can be kept under review in timely basis. Meanwhile, modelling approaches should be adopted into tackling environmental problems of selected thematic areas (United Nations, 2012; United Nations, 2019), which range from climate change, nature and environmental pollution, so that new strategic repositioning can be effectively implemented.

Regional meetings of UN have also reached consensus to advance four key multi-hazard early warning systems pillars, namely risk knowledge and management, observations and forecasting, dissemination and communication, preparedness and response (WMO, 2024). The preparatory efforts in facing environmental challenges, the ways of regaining resilience after natural disasters, and the plans of incorporating innovative technologies and data analytics into understanding causes and possible consequences of natural disasters are currently the most important tasks for all Asian countries. In particular, a city government should first promote scientific advancement in relevant disciplines, like healthcare technologies, air pollution monitoring and the way of delivering information to public; create a harmonious, sustainable and low-carbon economy within the society; as well as associate technological breakthrough with practical environmental needs of individual city. With the advancement of algorithms and satellite informatics, humans possess the potential to monitor and project the spatial and temporal transitions of highlighted environmental quantities in nature, for example, ground pollutant concentrations (Mak, 2019), greenhouse gas concentrations (Imasu et al., 2023), and ice motion in Antarctica (Dirscherl et al., 2020), so that potential climatic risks in specific region can be effectively identified. These information should then be associated with health-risk and liveability assessments, and can act as advice and suggestions for policymakers and decision-makers to implement practical actions that combat with climate crises, thus steering city development forward in gradual but continuous manners.

## References


- ✓ Abbass, K., Qasim, M.Z., Song, H., Murshed, M., Mahmood, H., Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ Sci Pollut Res*, 29, 42539–42559. https://doi.org/10.1007/s11356-022-19718-6
- ✓ Acosta-España, J.D., Romero-Alvarez, D., Luna, C., Rodriguez-Morales, A.J. (2024). Infectious disease outbreaks in the wake of natural flood disasters: global patterns and local implications. *Infez Med.* 32(4), 451-462. https://www.infezmed.it/media/journal/Vol_32_4_2024_4.pdf
- ✓ Affandi, M.L.A., Din, A.H.M., Hamden, M.H., Rasib, A.W. (2025). Investigation of Long-Term Sea Level Variation from Satellite Altimeter and Tide Gauge in Southeast Asia Region. In: Abdul-Rahman, A., Musliman, I.A., Hassan, I., Zamzuri, A. (eds) Advances in Geoinformation Sciences. GeoWeek 2024. Lecture Notes in Geoinformation and Cartography. Springer, Cham. https://doi.org/10.1007/978-3-031-86654-8_13
- ✓ Ali, S., Basit, A., Umair, M., Makanda, T.A., Khan, F.U., Shi, S., Ni, J. (2023) Spatio-temporal variations in trends of vegetation and drought changes in relation to climate variability from 1982 to 2019 based on remote sensing data from East Asia. *Journal of Integrative Agriculture,* 22(10), 3193-3208. https://doi.org/10.1016/j.jia.2023.04.028
- ✓ An, D., Eggeling, J., Zhang, L., He, H., Sapkota, A., Wang, Y.C., Gao, C. (2023). Extreme precipitation patterns in the Asia–Pacific region and its correlation with El Niño-Southern Oscillation (ENSO). *Sci Rep* 13, 11068. https://doi.org/10.1038/s41598-023-38317-0
- ✓ Becker, F., Li, Z.L. (1995). Surface temperature and emissivity at various scales: Definition, measurement, and related problems. *Remote Sens. Rev.,* 12, 225-253. https://doi.org/10.1080/02757259509532286
- ✓ Brune, S., Nerger, L., Baehr, J. (2015) Assimilation of oceanic observations in a global coupled earth system model with the SEIK filter. *Ocean Model*. 96, 254–264. https://doi.org/10.1016/j.ocemod.2015.09.011
- ✓ Camps-Valls, G., Fernández-Torres, MÁ., Cohrs, KH. et al. (2025). Artificial intelligence for modeling and understanding extreme weather and climate events. *Nat Commun*, 16, 1919. https://doi.org/10.1038/s41467-025-56573-8
- ✓ Caron, M., Bojanowski, P., Joulin, A., Douze, M. (2018). Deep clustering for unsupervised learning of visual features. In: Proceedings of European Conference on Computer Vision (ECCV) (eds Ferrari, V., Herbert, M., Sminchisescu, C., Weiss, Y.), Munich, Germany, 8-14 September 2018, pp. 132-149. Cham: Springer
- ✓ CEDD, HKSAR Government. (2022). Information Note 25/2022: Climate Change and Extreme Landslide Events. https://www.cedd.gov.hk/filemanager/eng/content_454/IN_2022_25E.pdf
- ✓ Chen, J., Zeng, X., Zhu, J., Guo, Y., Hong, L., Deng, M., Chen, K. (2024). The Diverse Mountainous Landslide Dataset (DMLD): A High-Resolution Remote Sensing Landslide Dataset in Diverse Mountainous Regions. *Remote Sensing*, 16(11), 1886. https://doi.org/10.3390/rs16111886
- ✓ Chen, Y., Wang, A. (2024). Role of land–atmosphere coupling in persistent extreme climate events in eastern China in summer 2022. *Atmospheric and Oceanic Science Letters*, 17(2), 100419. https://doi.org/10.1016/j.aosl.2023.100419
- ✓ Chew, B.N., Campbell, J.R., Reid, J.S., Giles, D.M., Welton, E.J., Salinas, S.V., Loew, S.C. (2011). Tropical cirrus cloud contamination in sun photometer data. *Atmospheric Environment,* 45(37), 6724-6731. https://doi.org/10.1016/j.atmosenv.2011.08.017
- ✓ Chi, Y. L., Mak, H. W. L. (2021). From Comparative and Statistical Assessments of Liveability and Health Conditions of Districts in Hong Kong towards Future City Development. *Sustainability*, 13(16), 8781. https://doi.org/10.3390/su13168781
- ✓ Choy, C.W., Wu, M.C., Lee, T.C. (2020). Assessment of the damages and direct economic loss in Hong Kong due to Super Typhoon Mangkhut in 2018. *Tropical Cyclone Research and Review*, 9(4), 193-205. https://doi.org/10.1016/j.tcrr.2020.11.001
- ✓ Climate (2025). Extreme Weather Swings Threaten Cities Across Asia, Europe, Study Finds. https://www.tovima.com/climate/extreme-weather-swings-threaten-cities-across-asia-europe-study-finds/

- ✓ Conrad, C., Rahmann, M., Machwitz, M., Stulina, G., Paeth, H., Dech, S. (2013) Satellite based calculation of spatially distributed crop water requirements for cotton and wheat cultivation in Fergana Valley, Uzbekistan. *Global and Planetary Change*, 110(A), 88-98. https://doi.org/10.1016/j.gloplacha.2013.08.002
- ✓ CRED (2024). 2023 Disasters in Number, Brussels. https://files.emdat.be/reports/2023_EMDAT_report.pdf
- ✓ Daniel, A. D., Fernandes, J. (2024). Promotion of community resilience: Do citizens have a role to play? *Local Environment*, 29(8), 987–1003. https://doi.org/10.1080/13549839.2024.2345621
- ✓ Deltares (2024). 1D/2D modelling suite for integral water solutions SOBEK. Deltares, Delft. https://content.oss.deltares.nl/sobek2/SOBEK_User_Manual.pdf
- ✓ Dirscherl, M., Dietz, A.J., Dech, S., Kuenzer, C. (2020). Remote sensing of ice motion in Antarctica – A review. *Remote Sensing of Environment*, 237, 111595. https://doi.org/10.1016/j.rse.2019.111595
- ✓ Drumond, A., de Oliveira, M., Reboita, M. S., Stojanovic, M., Nunes, A. M. P., da Rocha, R. P. (2024). Moisture Transport during Anomalous Climate Events in the La Plata Basin. *Atmosphere*, 15(8), 876. https://doi.org/10.3390/atmos15080876
- ✓ Du, M., Luo, S., Shi, J. et al. (2024). Operational application of Fengyun geostationary meteorological satellites to cloud observation products. *Sci Rep*, 14, 17880. https://doi.org/10.1038/s41598-024-68593-3
- ✓ Dwivedi, Y.K., Hughes, L., Kar, A.K., Baabdullah, A.M. et al. (2022) Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action. *International Journal of Information Management*, 63, 102456. https://doi.org/10.1016/j.ijinfomgt.2021.102456
- ✓ Economist Impact. (2023). Resilient Cities Index. https://impact.economist.com/projects/resilient-cities/assets/documents/Resilient-Cities_Report.pdf
- ✓ European Space Agency (ESA). (2021). Climate Change From Space – Climate Kit. https://climate.esa.int/media/documents/CLIMATE_KIT-4.pdf
- ✓ Esfandeh, S., Danehkar, A., Salmanmahiny, A., Alipour, H., Kazemzadeh, M.„ Marcu, M.V., Sadeghi, S.M.M. (2024). Climate change projection using statistical downscaling model over southern coastal Iran. *Heliyon*, 10(8), e29416. https://doi.org/10.1016/j.heliyon.2024.e29416
- ✓ Garcia-Soto, C., Cheng, L., Caesar, L., Schmidtko, S., Jewett, E.B. et al. (2021). An overview of ocean climate change indicators: Sea surface temperature, ocean heat content, ocean PH, dissolved oxygen concentration, arctic sea ice extent, thickness and volume, sea level and strength of the AMOC (Atlantic meridional overturning circulation). *Front. Mar. Sci.*, 8, 642372. https://doi.org/10.3389/fmars.2021.642372
- ✓ GFDRR (2025). Combating Extreme Heat in East Asia. https://www.gfdrr.org/en/feature-story/combating-extreme-heat-east-asia
- ✓ He, C., Kim, H., Hashizume, M. et al. (2024). The overlooked health impacts of extreme rainfall exposure in 30 East Asian cities. *Nat Sustain*, 7, 423–431. https://doi.org/10.1038/s41893-024-01294-x
- ✓ Hens, L., Thinh, N. A., Hanh, T. H., Cuong, N. S., Lan, T. D., Thanh, N. V., Le, D. T. (2018). Sea-level rise and resilience in Vietnam and the Asia-Pacific: A synthesis. *Vietnam Journal of Earth Sciences*, 40(2), 126–152. https://doi.org/10.15625/0866-7187/40/2/11107
- ✓ Horton, B.P., Khan, N.S., Cahill, N., Lee, J.S.H., Shaw, T.A., Garner, A.J., Kemp, A.C., Engelhart, S.E., Rahmstorf, S. (2020). Estimating global mean sea-level rise and its uncertainties by 2100 and 2300 from an expert survey. *Clim Atmos Sci*, 3, 18. https://doi.org/10.1038/s41612-020-0121-5
- ✓ Huang, W., Hsu, J., Liu, P., Deng, L. (2022). Multiple satellite-observed long-term changes in the summer diurnal precipitation over Luzon and its adjacent seas during 2000–2019. *International Journal of Applied Earth Observation and Geoinformation*, 10, 102816. https://doi.org/10.1016/j.jag.2022.102816
- ✓ Imasu, R., Matsunaga, T., Nakajima, M. et al. (2023). Greenhouse gases Observing SATellite 2 (GOSAT-2): mission overview. *Prog Earth Planet Sci*, 10, 33. https://doi.org/10.1186/s40645-023-00562-2
- ✓ Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds.; Cambridge University Press: Cambridge, United Kingdom. https://www.ipcc.ch/report/ar6/wg1/
- ✓ Jiang, H., Zheng, G., Yi, Y., Chen, D., Zhang, W., Yang, K., Miller, C.E. (2020). Progress and challenges in studying regional permafrost in the Tibetan Plateau using satellite remote sensing and models. *Front Earth Sci.*, 8, 11501. https://doi.org/10.3389/feart.2020.560403
- ✓ Jimenez-Munoz, J.C., Sobrino, J.A. (2010). A single-channel algorithm for land-surface temperature retrieval from ASTER data. *IEEE Geosci. Remote Sens.*, 7(1), 176-179. pp. 176–179. https://doi.org/10.1109/LGRS.2009.2029534
- ✓ Kennedy, J.J. (2013). A review of uncertainty in in situ measurements and data sets of sea surface temperature. *Reviews of Geophysics*, 52(1), 1-32. https://doi.org/10.1002/2013RG000434
- ✓ Kim, J., Jeong, U., Ahn, M., Kim, J.H., Park, R.J., Lee, H., Song, C.H., Choi, Y., Lee, K., Yoo, J.; et al. (2020). New Era of Air Quality Monitoring from Space: Geostationary Environment Monitoring Spectrometer (GEMS). *Bull. Am. Meteorol. Soc.*, 101, E1–E22. https://doi.org/10.1175/BAMS-D-18-0013.1
- ✓ Konisky, D.M., Hughes, L., Kaylor, C.H. (2016). Extreme weather events and climate change concern. *Climatic Change*, 134, 533–547. https://doi.org/10.1007/s10584-015-1555-3

- ✓ Kropf, C.M., Vaterlaus, L., Bresch, D.N., Pellissier, L. (2025). Tropical cyclone risk for global ecosystems in a changing climate. *Nat. Clim. Chang*. 15, 92–100. https://doi.org/10.1038/s41558-024-02194-w
- ✓ Labzovskii, L.D., Mak, H.W.L., Kenea, S.T., Rhee, J.S., Lashkari, A., Li, S., Goo, T.Y., Oh, Y.S., Byun, Y. H. (2019). What can we learn about effectiveness of carbon reduction policies from interannual variability of fossil fuel $CO_2$ emissions in East Asia? *Environmental Science & Policy*, 96, 132-140. Retrieved from https://doi.org/10.1016/j.envsci.2019.03.011
- ✓ Li, J., Lee, K.H., Qian, K., Wong, M.S., Chan, P.W. Zhang, Z. (2024) Synthesis of satellite and ground data provide unique perspectives for discovering the air pollution patterns: A case study in Guangdong Province, China. *Environmental Pollution*, 362, 124968. https://doi.org/10.1016/j.envpol.2024.124968
- ✓ Li, H., Li, R., Yang, Y., Cao, B., Bian, Z., Hu, T. (2021). Temperature-Based and radiance-based validation of the collection 6 MYD11 and MYD21 land surface temperature products over barren surfaces in Northwestern China. IEEE Trans. *Geosci. Remote Sens*., 59(2), 1794–1807. https://doi.org/10.1109/TGRS.2020.2998945
- ✓ Li, H., Liu, G., Han, C., Yang, Y., Chen, R. (2022). Quantifying the Trends and Variations in the Frost-Free Period and the Number of Frost Days across China under Climate Change Using ERA5-Land Reanalysis Dataset. *Remote Sensing*, 14(10), 2400. https://doi.org/10.3390/rs14102400
- ✓ Li, X., Zheng, X., Zhang, D., Zhang, W., Wang, F., Deng, Y., Zhu, W. (2018). Clouds over East Asia Observed with Collocated CloudSat and CALIPSO Measurements: Occurrence and Macrophysical Properties. *Atmosphere*, 9(5), 168. https://doi.org/10.3390/atmos9050168
- ✓ Li, X., Lu, R., Ahn J.B. (2021). Combined Effects of the British-Baikal Corridor Pattern and the Silk Road Pattern on Eurasian Surface Air Temperatures in Summer. *Journal of Climate*. 34(9), 3707-3720. https://journals.ametsoc.org/view/journals/clim/34/9/JCLI-D-20-0325.1.xml
- ✓ Li, Y., Li, Z., Zhang, Z., Chen, L., Kurkute, S., Scaff, L., Pan, X. (2019). High-resolution regional climate modeling and projection over western Canada using a weather research forecasting model with a pseudo-global warming approach, *Hydrol. Earth Syst. Sci.,* 23, 4635–4659. https://doi.org/10.5194/hess-23-4635-2019
- ✓ Liu, B., Yan, Y., Zhu, C., Ma, S., Li, J. (2020). Record-breaking meiyu rainfall around the yangtze river 2020 regulated by the subseasonal phase transition of the North Atlantic oscillation. *Geophys. Res. Lett.*, 47 e2020GL090342. https://doi.org/10.1029/2020GL090342
- ✓ Liu, J., Wei, L., Zheng, Z., Du, J. (2023). Vegetation cover change and its response to climate extremes in the Yellow River Basin. *Science of The Total Environment,* 905, 167366. https://doi.org/10.1016/j.scitotenv.2023.167366
- ✓ Liu, W., Wang, J., Xu, F., Li, C., Xian, T. (2022). Validation of Four Satellite-Derived Soil Moisture Products Using Ground-Based In Situ Observations over Northern China. *Remote Sensing*, 14(6), 1419. https://doi.org/10.3390/rs14061419
- ✓ Luo, F., Yang, Y., Zong, L., Bi, X. (2023) The interactions between urban heat island and heat waves amplify urban warming in Guangzhou, China: Roles of urban ventilation and local climate zones. *Front. Environ. Sci.*, 11, 1084473. https://doi.org/10.3389/fenvs.2023.1084473
- ✓ Lyu, Y., Wang, J., Zhi, X. et al. (2024). The characterization, mechanism, predictability, and impacts of the unprecedented 2023 Southeast Asia heatwave. *Clim Atmos Sci*, 7, 246. https://doi.org/10.1038/s41612-024-00797-w
- ✓ Mak, H. W. L., Laughner, J. L., Fung, J. C. H., Zhu, Q., Cohen, R. C. (2018). Improved Satellite Retrieval of Tropospheric NO2 Column Density via Updating of Air Mass Factor (AMF): Case Study of Southern China. *Remote Sensing*, 10(11), 1789. https://doi.org/10.3390/rs10111789
- ✓ Mak, H.W.L. (2019). Improved Remote Sensing Algorithms and Data Assimilation Approaches in Solving Environmental Retrieval Problems. Ph.D. Thesis, Hong Kong University of Science and Technology, Hong Kong, China. https://lbezone.hkust.edu.hk/rse/?p=51454
- ✓ Mak, H.W.L., Lam, Y.F. (2021). Comparative assessments and insights of data openness of 50 smart cities in air quality aspects. *Sustainable Cities and Society*, 69, 102868. https://doi.org/10.1016/j.scs.2021.102868
- ✓ Mak, H. W. L., Ng, D. C. Y. (2021). Spatial and Socio-Classification of Traffic Pollutant Emissions and Associated Mortality Rates in High-Density Hong Kong via Improved Data Analytic Approaches. International *Journal of Environmental Research and Public Health*, 18(12), 6532. https://doi.org/10.3390/ijerph18126532
- ✓ Malina, E., Bowman, K. W., Kantchev, V., Kuai, L., Kurosu, T. P., Miyazaki, K., Natraj, V., Osterman, G. B., Oyafuso, F., Thill, M. D. (2024). Joint spectral retrievals of ozone with Suomi NPP CrIS augmented by S5P/TROPOMI. *Atmos. Meas. Tech.*, 17, 5341–5371. https://doi.org/10.5194/amt-17-5341-2024
- ✓ McMichael, C. (2023). Climatic and Environmental Change, Migration, and Health. *Annu. Rev. Public Health*, 44, 171–191. https://doi.org/10.1146/annurev-publhealth-071421-045148
- ✓ Miller, S., Ormaza-Zulueta, N., Koppa, N., Dancer, A. (2025). Statistical downscaling differences strongly alter projected climate damages. *Commun Earth Environ*, 6, 145. https://doi.org/10.1038/s43247-025-02134-2
- ✓ Miniandi, N.D., Muhammad, M.K.I., Jamal, M.H., Shahid, S. (2024). Urbanization signature on hourly rainfall extremes of Kuala Lumpur. *Sustainable Cities and Society*, 112, 105610. https://doi.org/10.1016/j.scs.2024.105610
- ✓ Miyama, T., Minobe, S., Goto, H. (2021). Marine Heatwave of Sea Surface Temperature of the Oyashio Region in Summer in 2010–2016. *Front. Mar. Sci.*, 7,

576240. https://doi.org/10.3389/fmars.2020.576240

- Mohamed, A.A., Odindi, J., Mutanga, O. (2017). Land surface temperature and emissivity estimation for urban heat island assessment using medium and low-resolution space-borne sensors: A review. *Geocarto Int.,* 32(4), 455-470. https://doi.org/10.1080/10106049.2016.1155657
- National Centers for Environmental Information (NCEI), National Oceanic and Atmospheric Administration (NOAA). Climate Data Records. https://www.ncei.noaa.gov/products/climate-data-records
- Oduro, C., Lim Kam Sian, K.T.C., Hagan, D.F.T. et al. (2025). The influence of land surface temperature on Ghana's climate variability and implications for sustainable development. *Sci. Rep.,* 15, 2595. https://doi.org/10.1038/s41598-025-86585-9
- O'Loughlin, R. J., Li, D., Neale, R., O'Brien, T. A. (2025). Moving beyond post hoc explainable artificial intelligence: a perspective paper on lessons learned from dynamical climate modeling, *Geosci. Model Dev.*, 18, 787–802. https://doi.org/10.5194/gmd-18-787-2025
- Park, C., Kang, M., Hwang, J., Cho, H., Kim, S., Son, S. (2024). Multi-scale drivers of catastrophic heavy rainfall event in early August 2022 in South Korea. *Weather and Climate Extremes*, 44, 100681. https://doi.org/10.1016/j.wace.2024.100681
- Park, K., Jin, H-H., Baik, J-J. (2023). Contrasting interactions between urban heat islands and heat waves in Seoul, South Korea, and their associations with synoptic patterns. *Urban Climate,* 49, 101524. https://doi.org/10.1016/j.uclim.2023.101524
- Park, C., Son, S., Kim, H., Ham, Y., Kim, J., Cha, D., Chang, E., Lee, H., Kug, J., Lee, W., Lee, Y., Lee, H., Lim, H.C., Lim, B. (2021). Record-breaking summer rainfall in South Korea in 2020: synoptic characteristics and the role of large-scale circulations. *Mon. Weather Rev*., 149, 3085-3100. https://doi.org/10.1175/MWR-D-21-0051.1
- Patel, L., Conlon, K.C., Sorensen, C., McEachin, S., Nadeau, K., Kakkad, K., Kizer, K.W. (2022). Climate Change and Extreme Heat Events: How Health Systems Should Prepare. *NEJM Catal Innov Care Deliv,* 3(7). https://catalyst.nejm.org/doi/full/10.1056/CAT.21.0454
- Peng, D., Ng, G., Feng, L., Cazenave, A., Hill, E.M. (2024) Coastal vertical land motion across Southeast Asia derived from combining tide gauge and satellite altimetry observations. *Science of Remote Sensing*, 10, 100176. https://doi.org/10.1016/j.srs.2024.100176
- PreventionWeb (2023). World's cities across the wealth divide, critically unprepared as climate events become more extreme, new study shows. https://www.preventionweb.net/news/worlds-cities-across-wealth-divide-critically-unprepared-climate-events-become-more-extreme
- Price, J., Warren, R., Forstenhäusler, N. (2024). Biodiversity losses associated with global warming of 1.5 to 4 °C above pre-industrial levels in six countries. *Climatic Change*, 177, 47. https://doi.org/10.1007/s10584-023-03666-2
- Satyanarayana, G.C., Velivelli, S., Rao, K.K., Chowdary, J.S., Parekh, A., Gnanaseelan, C. (2024). Increasing heat waves frequencies over India during post-El Niño spring and early summer seasons. *Global and Planetary Change,* 241, 104561. https://doi.org/10.1016/j.gloplacha.2024.104561
- Shawky, M., Ahmed, M.R., Ghaderpour, E., Gupta, A., Achari, G., Dewan, A., Hassan, Q.K. (2023). Remote sensing-derived land surface temperature trends over South Asia. *Ecological Informatics,* 74, 101969. https://doi.org/10.1016/j.ecoinf.2022.101969
- Shi, C.X., Xie, Z.H., Qian, H., Liang, M.L., Yang, X.C. (2021). China land soil moisture EnKF data assimilation based on satellite remote sensing data. *Sci. China Earth Sci.*, 54(9), 1430–1440. https://doi.org/10.1007/s11430-010-4160-3
- Shin, D., Oh, Y.-S., Seo, W., Chung, C.-Y., Koo, J.-H. (2021). Total Ozone Trends in East Asia from Long-Term Satellite and Ground Observations. *Atmosphere*, 12(8), 982. https://doi.org/10.3390/atmos12080982
- Song, H., Sheng, M., Lei, L., Guo, K., Zhang, S., Ji, Z. (2023). Spatial and Temporal Variations of Atmospheric CH4 in Monsoon Asia Detected by Satellite Observations of GOSAT and TROPOMI. *Remote Sensing*, 15(13), 3389. https://doi.org/10.3390/rs15133389
- Sun, B., Xue, R., Li, W., Zhou, S., Li, H., Zhou, B., Wang, H. (2023). How does Mei-yu precipitation respond to climate change? *National Science Review,* 10(12), 246. https://doi.org/10.1093/nsr/nwad246
- Sun, L., Zhu, X., Li, W., Ai, W., Chen, X., Jiang, Y., Wang, L., Zou, X., Zhao, S., Zeng, H., Zhong, H. (2024). State of China's climate in 2023. *Atmospheric and Oceanic Science Letters*, 17(5), 100519. https://doi.org/10.1016/j.aosl.2024.100519
- Sun, W., Sangmanee, C., Jiang, Y., Ma, Y., Li, J., Zhao, Y. (2023). Quality Analysis and Correction of Sea Surface Temperature Data from China HY-1C Satellite in Southeast Asia Seas. *Sensors*, 23(18), 7692. https://doi.org/10.3390/s23187692
- Takahashi, H.G., Fujinami, H. (2021). Recent decadal enhancement of Meiyu–Baiu heavy rainfall over East Asia. *Sci Rep* 11, 13665. https://doi.org/10.1038/s41598-021-93006-0
- Today's WorldView, The Washington Post. (2023). Asia's heat waves are a grim sign of the times. https://www.washingtonpost.com/world/2023/05/09/heat-wave-asia-cambodia-laos-india/
- Ul Din, S., Mak, H. W. L. (2021). Retrieval of Land-Use/Land Cover Change (LUCC) Maps and Urban Expansion Dynamics of Hyderabad, Pakistan via Landsat Datasets and Support Vector Machine Framework. *Remote Sensing,* 13(16), 3337. https://doi.org/10.3390/rs13163337
- United Nations (2012). A Framework for Advancing Environmental and Social Sustainability in the United Nations System. https://sustainabledevelopment.un.org/content/documents/2738sustainabilityfinalweb-.pdf

- ✓ United Nations (2019). Environment Management Group. Moving towards a Common Approach to Environmental and Social Standards for UN Programming. https://unemg.org/wp-content/uploads/2019/07/FINAL_Model_Approach_ES-Standards-1.pdf
- ✓ Venegas, R.M., Acevedo, J., Treml, E.A. (2023). Three decades of ocean warming impacts on marine ecosystems: A review and perspective. *Deep Sea Research Part II: Topical Studies in Oceanography*, 212, 105318. https://doi.org/10.1016/j.dsr2.2023.105318
- ✓ Verisk Maplecroft (2021) Environmental Risk Outlook 2021. https://www.maplecroft.com/insights/analysis/environmental-risk-outlook-2021/
- ✓ Walz, Y., Janzen, S., Narvaez, L., Ortiz-Vargas, A., Woelki, J., Doswald, N., Sebesvari, Z. (2021) Disaster-related losses of ecosystems and their services. Why and how do losses matter for disaster risk reduction? International *Journal of Disaster Risk Reduction*, 63, 102425. https://doi.org/10.1016/j.ijdrr.2021.102425
- ✓ Wan, Z.M., Dozier, J. (1996). A generalized split-window algorithm for retrieving land-surface temperature from space. *IEEE Trans. Geosci. Remote Sens*., 34, 892-905. https://doi.org/10.1109/36.508406
- ✓ Wang, H., Mao, K., Yuan, Z., Shi, J., Cao, M., Qin, Z., Duan, S., Tang, B. (2021). A method for land surface temperature retrieval based on model-data-knowledge-driven and deep learning. *Remote Sensing of Environment*, 265, 112665. https://doi.org/10.1016/j.rse.2021.112665
- ✓ Wang, Q., Zhang, S.P., Wang, Q., Meng, Z.X., Koračin, D. and Gao, S.H. (2018). A Fog Event off the Coast of the Hangzhou Bay during Meiyu Period in June 2013. *Aerosol Air Qual. Res*., 18, 91-102. https://doi.org/10.4209/aaqr.2016.11.0489
- ✓ Wang, X., Huang, G., Liu, J. (2014). Projected Increases in Intensity and Frequency of Rainfall Extremes through a Regional Climate Modeling Approach. *J. Geophys. Res. Atmospheres,* 119 (23), 13–271. https://doi.org/10.1002/2014JD022564
- ✓ Wang, X., Fan, Y., Zhao, S., Xie, Y., Von Storch, H. (2022) Editorial: Future Climate Scenarios: Regional Climate Modelling and Data Analysis. *Front. Environ. Sci.,* 10, 858153. https://doi.org/10.3389/fenvs.2022.858153
- ✓ Wang, X., Zhong, L., Ma, Y.M. (2022). Estimation of 30 m land surface temperatures over the entire Tibetan Plateau based on landsat-7 ETM+ data and machine learning methods. *Int. J. Digit Earth,* 15(1), 1038-1055. https://doi.org/10.1080/17538947.2022.2088873
- ✓ WMO (2024). State of the Climate in Asia 2023 - WMO-No. 1350. https://library.wmo.int/records/item/68890-state-of-the-climate-in-asia-2023
- ✓ Wu, B., Gommes, R., Zhang, M. et al. (2015). Global crop monitoring: a satellite-based hierarchical approach. *Remote Sens,* 7(4), 3907–3933. https://doi.org/10.3390/rs70403907
- ✓ Wu, C., Zhang, F., Xia, J., Xu, Y., Li, G., Xie, J., Du, Z., Liu, R. (2021). Building Damage Detection Using U-Net with Attention Mechanism from Pre- and Post-Disaster Remote Sensing Datasets. *Remote Sensing,* 13(5), 905. https://doi.org/10.3390/rs13050905
- ✓ Wunderling, N., Willeit, M., Donges, J.F., Winkelmann, R. (2020). Global warming due to loss of large ice masses and Arctic summer sea ice. *Nat Commun* 11, 5177. https://doi.org/10.1038/s41467-020-18934-3
- ✓ Xie, Y., Wu, H., Yao, R. (2023). The Impact of Climate Change on the Urban–Rural Income Gap in China. *Agriculture*, 13(9), 1703. https://doi.org/10.3390/agriculture13091703
- ✓ Yang, K., Wu, H., Qin, J., Lin, C.G., Tang, W.J., Chen, Y.Y. (2014). Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: A review. *Glob. Planet. Change*, 112, 79–91. Retrieved from https://doi.org/10.1016/j.gloplacha.2013.12.001
- ✓ Yang, J., Ahn, D., Bahk, J., Park, S., Rizqihandari, N., Cha, M. (2024). Assessing climate risks from satellite imagery with machine learning: A case study of flood risks in Jakarta. *Climate Risk Management*, 46, 100651. https://doi.org/10.1016/j.crm.2024.100651
- ✓ Yang, W., John, V. O., Zhao, X., Lu, H., Knapp, K. R. (2016). Satellite Climate Data Records: Development, Applications, and Societal Benefits. *Remote Sensing*, 8(4), 331. https://doi.org/10.3390/rs8040331
- ✓ Yin, G., Baik, J., Park, J. (2022). Comprehensive analysis of GEO-KOMPSAT-2A and FengYun satellite-based precipitation estimates across Northeast Asia. *GIScience & Remote Sensing*. 59(1), 782–800. https://doi.org/10.1080/15481603.2022.2067970
- ✓ Yoon, D.-H., Nam, W.-H., Lee, H.-J., Hong, E.-M., Feng, S., Wardlow, B. D., Tadesse, T., Svoboda, M. D., Hayes, M. J., Kim, D.-E. (2020). Agricultural Drought Assessment in East Asia Using Satellite-Based Indices. *Remote Sensing*, 12(3), 444. https://doi.org/10.3390/rs12030444
- ✓ Zhang, J., Ding, T., Gao, H. (2021). Record-breaking high temperature in Southern China in 2017 and influence from the middle-latitude trough over the East of Japan. *Atmospheric Research*, 258, 105615. https://doi.org/10.1016/j.atmosres.2021.105615
- ✓ Zhang, L., Xia, J. (2022). Flood Detection Using Multiple Chinese Satellite Datasets during 2020 China Summer Floods. *Remote Sensing*, 14(1), 51. https://doi.org/10.3390/rs14010051
- ✓ Zhou, Y., Chen, J., Cheng, X. (2021). Glacier Velocity Changes in the Himalayas in Relation to Ice Mass Balance. *Remote Sensing*, 13(19), 3825. https://doi.org/10.3390/rs13193825
- ✓ Zhu, L., Wu, Z. (2024). Climatic influence of the Antarctic ozone hole on the East Asian winter precipitation. *Clim Atmos Sci,* 7, 184. https://doi.org/10.1038/s41612-024-00732-z