INPE's initiative to monitor severe weather events using space technologies: looking forward to Agenda2030

Dr. Kleber P. Naccarato

Earth System Science Centre – CCST
National Institute for Space Research – INPE
kleber.naccarato@inpe.br

Science for Sustainability

Severe Weather Impacts

Figure 1 shows the estimates of losses caused by extreme weather events worldwide. This estimates were published in a Forbes note in 2017. As you can see, in the blue circles, from 1990 to 2016, there were an increase in the number of severe weather events from around 400 to almost 800, which is a 2-fold increase. On the other hand, the blue bars show the losses estimates. There are some high peaks that overpass $ 140 billion in several years, as in 1998, 2004, 2008, 2012. Only data from odd years was provided by the author.

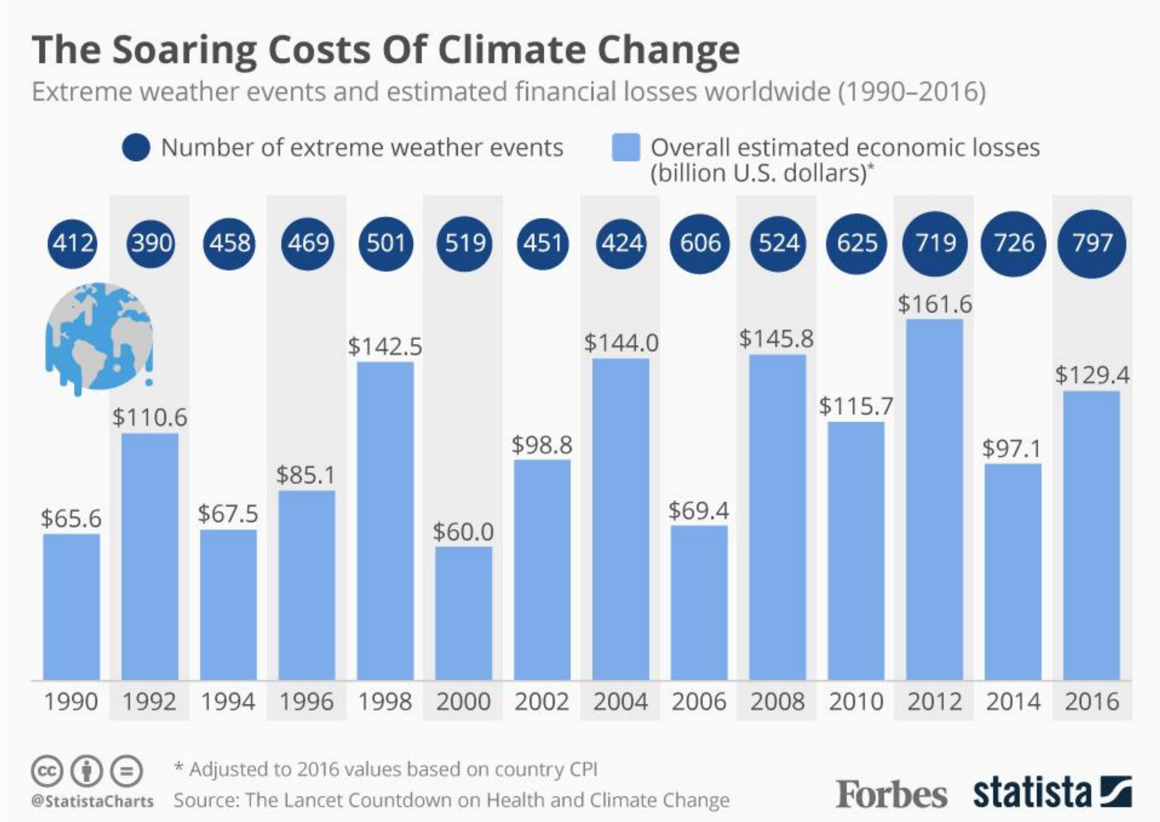

Figure 1 – Extreme weather events and estimated financial losses worldwide (1990-2016). Source: *https://www.forbes.com/sites/niallmccarthy/2017/11/01/extreme-weather-caused-129-billion-of-economic-losses-globally-last-year-infographic/*

Figure 2 shows the global annual deaths caused by natural disasters since 1900 decade. There is a clear and significant decrease in the number of deaths in the last century, however, you can see that the deaths caused by storms (the yellow color) remains almost constant since 1920's. After the 1970's, since the overall number of deaths decreased, the number of fatalities caused by storms became relatively high.

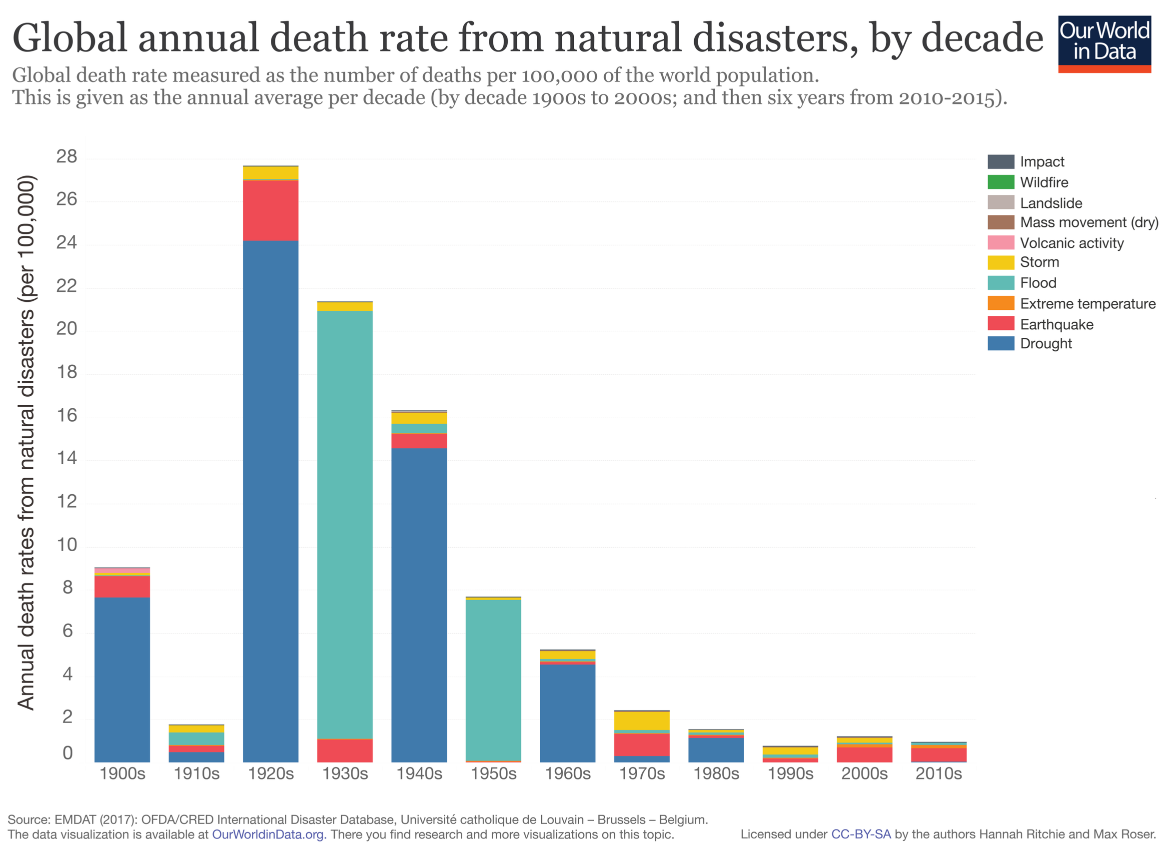

Figure 2 – Global annual death rate from natural disasters, by decade. Source: *https://ourworldindata.org/natural-disasters*

All those data are supported by the IPCC Climate Change Report of 2014 (available at: https://archive.ipcc.ch/report/ar5/syr/). According to this report, changes in extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, human morbidity and mortality. Direct and insured losses from weather-related disasters have increased substantially in recent decades, both globally and regionally. More severe and/or frequent extreme weather events and/or hazard types are projected to increase losses and loss variability in various regions.

Severe Weather Nowcasting

The term nowcasting was created in the mid-1970s. It encapsulates a broad spectrum of observation techniques developed for predicting the weather up to a few hours ahead. These techniques rely on the fast processing of high-resolution data sets collected by weather radars and satellites. Operational weather forecasts are produced by primitive equation models known collectively, as Numerical Weather Prediction (NWP) models. The predictive skill of these models is limited by several factors including the accuracy and coverage of near real-time weather observations and the extent of the formulations and grid lengths which affect how the relevant physical and dynamical processes are accurately simulated.

Operational NWP models can nowadays resolve important processes such as convection, but their predictive skill generally remains very limited. For example, in Figure 3, the mesoscale NWP model can provide average forecast skills in the range of 6 hours ahead. On the other hand, the synoptic-scale NWP models provide better forecast skills only after 12 hours leading time. After 1960s, the availability in near real time of increasingly sophisticated, spatially contiguous, radar and satellite observations offered forecasting by extrapolation techniques with superior accuracy up to 6 hours ahead.

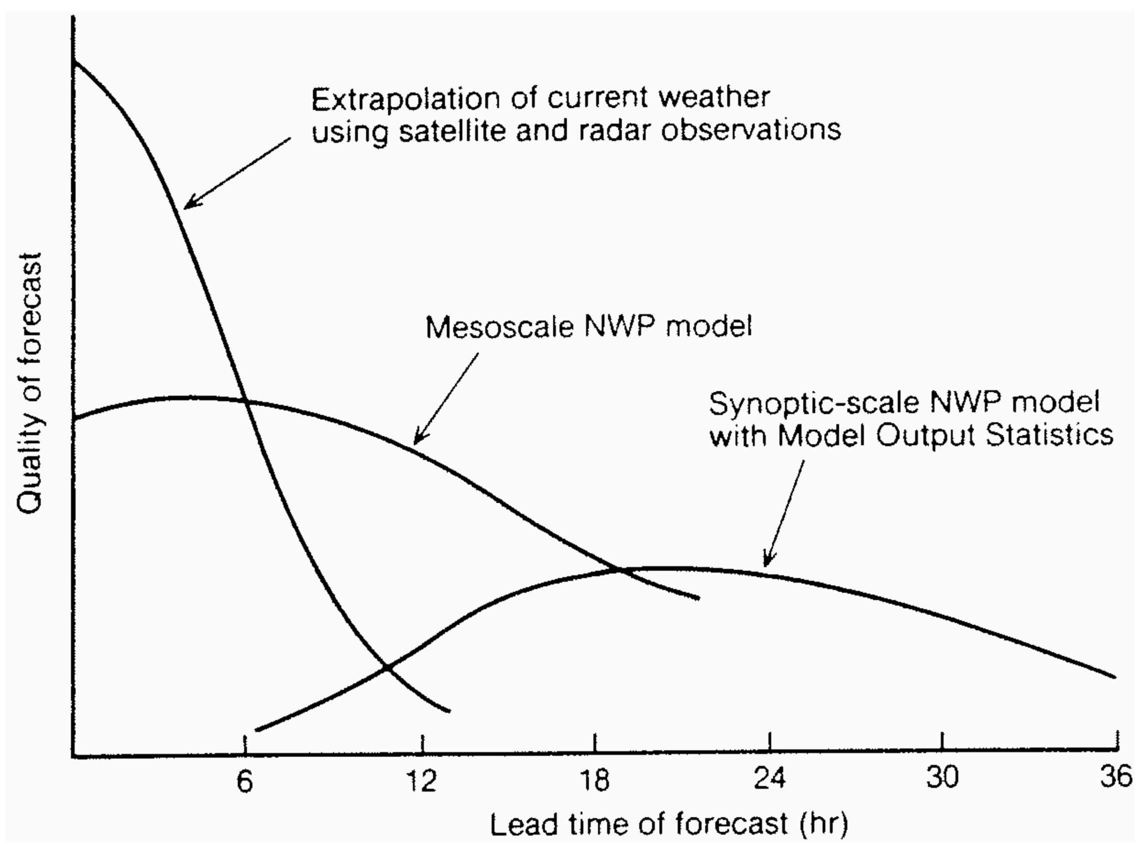

Figure 3 – A schematic diagram conceptualizing the relationship between forecasting methodology, skill and forecast range. Source: *Bech J.; Chau, J.L. Doppler Radar Observations, Chapter 4: Nowcasting, DOI: 10.5772/2036, 2012*

As stated by WMO (World Meteorological Organization) in its Guidelines for Nowcasting Techniques, 2017 Edition, "Nowcasting plays an increasing role in crisis management and risk prevention, but its realization is a highly complex and integrated task". Moreover, weather radars are the single most important instruments for nowcasting, particularly for convective weather phenomena. However, these instruments are extremely expensive, sophisticated and difficult to maintain, particularly for development countries. On the other hand, ground-based networks capable of detecting real-time total cloud-to-ground and intra-cloud lightning are valuable as early indicators of the location and intensity of developing convection, and to track the movement of thunderstorms. By identifying electrically active storms in space and time, these systems increase warning lead times for dangerous thunderstorms. For meteorological applications, these data can be easily combined with other remote sensing data (radar and/or satellite) to better characterizing the convection.

The left panel of Figure 4 shows the largest operational ground-based total lightning detection network in Brazil, composed of 64 sensors. Note that the Amazon Basin is not covered by the network due to the challenging task of installing and maintaining sensors in the middle of the forest. The right panel shows the weather radars installed in Brazil. As you can see, the radar coverage of Brazil is not uniform and thus almost real-time lightning data is essential for severe weather nowcasting.

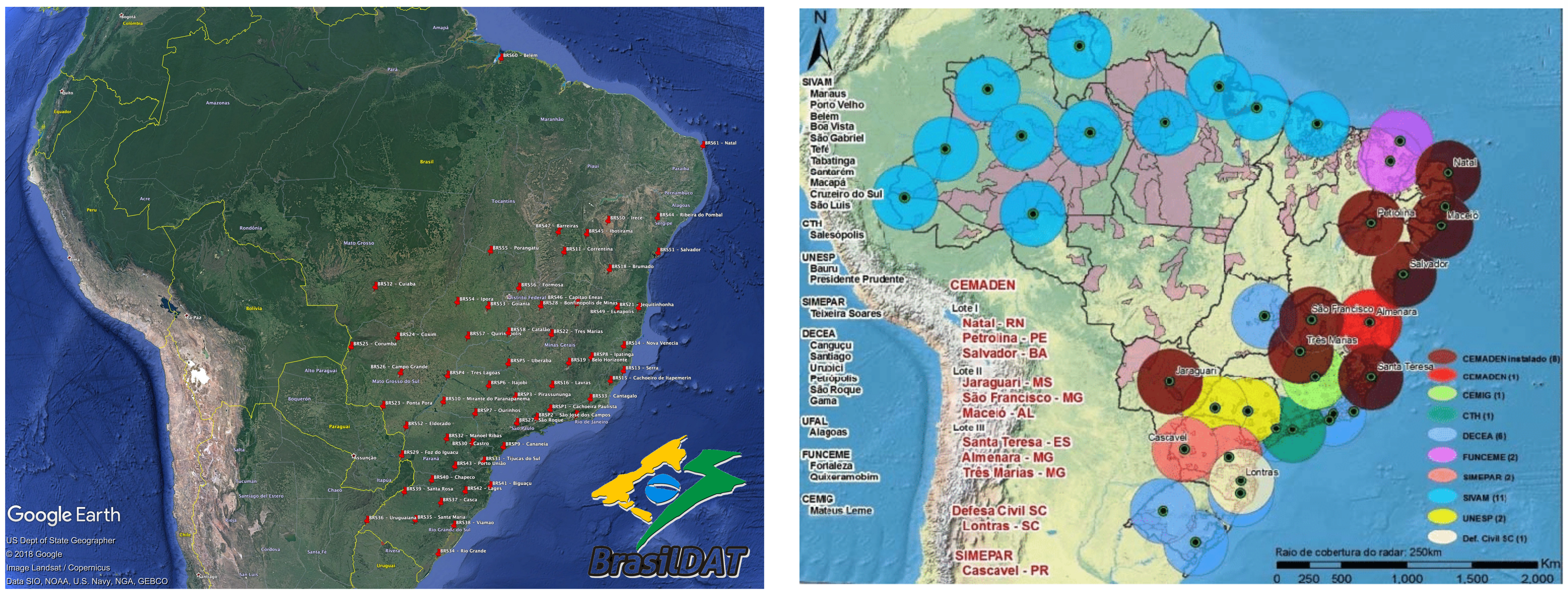

Figure 4 – Left panel: Largest ground-based total lightning detection network in Brazil (64 sensors); Right panel: Inhomogeneous radar coverage in Brazil

The RaioSAT Project

The concept of a lightning location sensor on board of satellites has been developed since the 1980s. Unlike the ground-based lightning detection networks, lightning observation from satellites provides a globally uniform coverage and almost uniform detection efficiency with just a single instrument, which is very important for most of applications. Based on studies of lightning spectroscopy, one of the strongest emission lines is the atomic oxygen triplet line found at 777.4 nm. This line is being used for all space based optical detection of lightning, since it contains about 6% of the total energy of the optical spectrum.

As a result, in April 1995, the first NASA lightning detector was launched into space: the OTD (Optical Transient Detector) on board of the MicroLab-1 satellite and operates until April 2000. Its circular orbit had an inclination of 70° with an altitude of 735 km and an orbital period of about 100 min. The LIS (Lightning Imaging Sensor), part of the Tropical Rainfall Measuring Mission (TRMM) satellite, was launched in November 1997. The observation area is limited to the latitudes lower than 35°, the altitude after 2001 was 402 km and the orbital period of 93 min. The TRMM / LIS mission ended up at April 1995. Also in 1997, a joint project of Los Alamos National Laboratory (LANL) and Sandia National Laboratories launched the FORTE (Fast On-Orbit Recording of Transient Events) satellite in a circular, 825-km altitude with 70° inclination orbit. Besides an optical lightning detection sensor, it carried also a broad band photodiode and VHF receivers which allowed a combined optical and radio frequency lighting observations. The FORTE satellite is still on orbit, but data is not public available.

In this context, we proposed the development of a 3-U CubeSat that intends to detect total lightning from space to provide a near real time dataset covering the entire Brazil, including the Amazon Basin (Figure 5). The challenge here is to use the same detection techniques from larger satellites in a small device. In this way, this mission intends to use: (1) a broad-spectrum VHF radio antenna, (2) an imaging device (CCD) and, (3) a GPS system. The RaioSat project is expected to be then an important starting point for future researches and developments in Earth System Sciences and Space Engineering and Technologies areas at INPE.

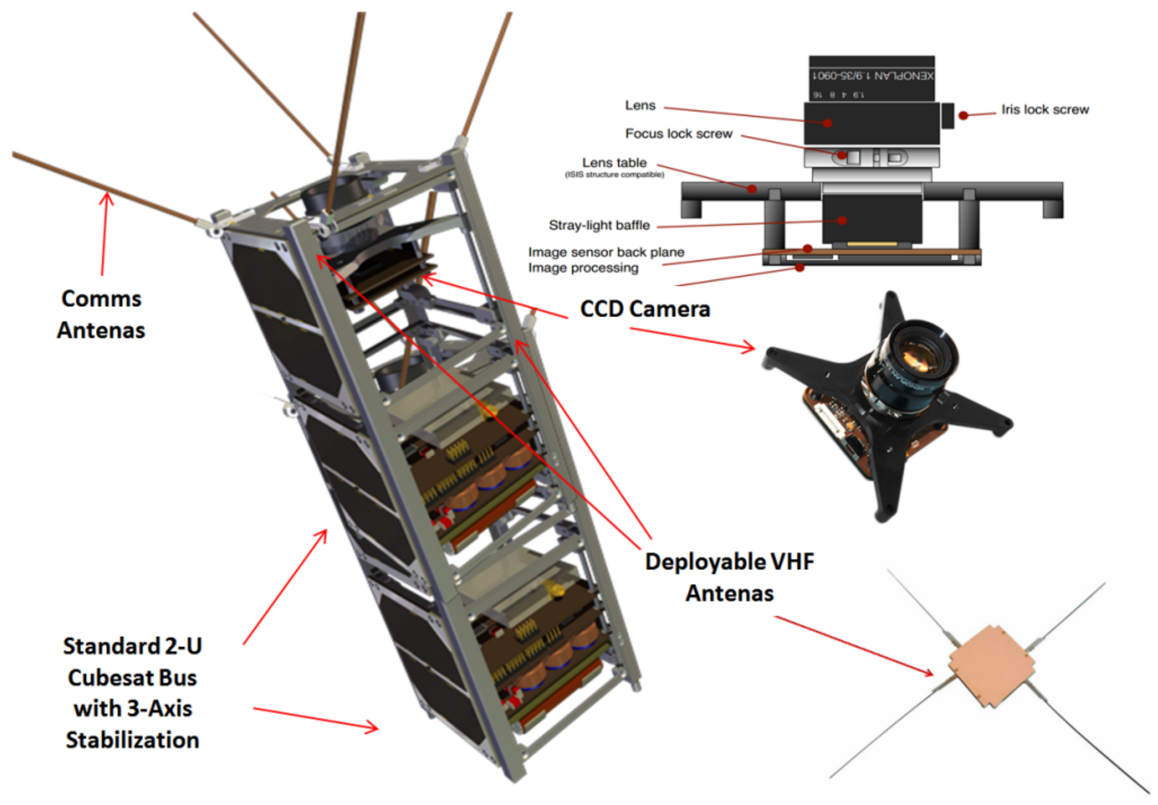

Figure 5 – A schematic conceptualizing of the RaioSAT.

Looking Forward to Agenda2030

Severe weather events are responsible for hundreds of fatalities and billions of dollars of damage annually worldwide. Thus, there is considerable motivation to improve forecast skills for those type of events using NWP models. Toward this goal, the assimilation of total lightning data in the models has been proven to be a promising technique, since total lightning data show an excellent correlation with updraft strength within deep continental storms and, consequently, with the timing of the convective development.

We conclude that predicting severe weather events requires high-resolution NWP models and high amount of observational data, including near real-time lightning data. Thus, where total lightning data are available, a relatively simple and inexpensive assimilation procedure can be readily incorporated into operational mesoscale NWP models. This project allows, for the first time in Brazil, the developing of national technology for total lightning detection from space, allowing data assimilation to NWP models, particularly where weather radar coverage is either sparse or nonexistent, as in several parts of Brazil.