Deployment of Weather and Meteorological Observation via Stratospheric Platform Stations (SPS)

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Abstract: Deployment of space remote sensing, meteorological and weather observations network based on new developed Stratospheric Platform Systems (SPS) via High Altitude Platforms (HAP) of airships or Unmanned Aerial Vehicles (UAV) of aircraft has gained a significant momentum through several initiatives where space vehicles and telecommunications payloads have been researched and adopted. This initiative is resulting in more efficient and more cost effective solutions of proposed stratospheric platforms for Communication, Navigation and Surveillance (CNS) applications. In this paper is introduced and proposed possibility of special HAP implementation as an alternative to the current satellite systems or as a complementary fast-evolving technology to improve weather observation system especially in developing countries. The advantages of HAP in relation to the weather observation, proposals of an observation framework for weather observation via HAP and its modern requirements are taken into consideration and are discussed.

Key Words: SPS, HAP, UAV, CNS, GEO, PEO, LEO, GWO, VSAT, DVB-RCS

1. Introduction

The combination of Geostationary Earth Orbit (GEO) and Polar Earth Orbit (PEO) meteorological (weather) satellites is one of the most important parts of the existing Global Weather Observation (GWO). The existing meteorological satellites are used to observe the Earth environments, sea surfaces, ocean currents and atmosphere from the space. They gather information about temperature, pressure, water vapor and critical trace gases (i.e. carbon dioxide) in the Earth atmosphere through Vertical Atmospheric Sounder (VAS) for both nowcasting and future weather forecast. The GEO spacecraft is using a circular orbit of about 36 thousand kilometers above the equator following the direction of the Earth rotation. Satellites in GEO are far enough away from Earth that courses communication latency to become significant.

The PEO spacecraft at an altitude of approximately 1000 km passes above or nearly above both poles once in a 12-hour period, so satellites in such orbit can observe the full Earth surface twice a day, what is sometimes not enough to provide observation. Due to the importance of the real-time accurate observations in weather forecasting, However, GEO satellite is mostly used because it provides continuous observations every fifteen minutes, while polar orbit satellites only provide two observations a day.

Satellites and especially GEO satellites compared to HAP are very expensive and more sophisticated tools and therefore world researchers and satellite operators are looking for more cost effective solutions. The ground station for weather observation system is very expensive to be located in all the corners worldwide, which is still inhibited by high latency, down times and it cannot be accessible in all the areas.

All of the above mentioned factors affecting weather observation networks indirectly affect the economy and the understanding of weather and climate change. Economy is affected where a budget gets committed on not adequate decisions made from poor observations. Satellite observation has been used not for only weather forecasting, but also climate change detection and atmospheric research. Most of these observation needs are not feasible especially from developing countries.

This solution requires some innovative way to fulfill the above mentioned needs that will be affordable, reliable and easy to maintain that can be easily integrated with the current weather observation network. At this point, even many developed countries are providing research and experiments with new HAP or UAV worldwide, which initiatives may follow developing countries in Africa as well.

2. Weather and Meteorological Observation via Satellites and HAP

The first weather satellite, Vanguard 2, was launched in February 1959. It was designed to measure cloud cover and resistance, but a poor axis of rotation and its elliptical orbit kept it from collecting a notable amount of useful data. In April 1960 NASA launched TIROS-1 which operated for 78 days and proved to be much more successful than Vanguard 2.

The Television InfraRed Operational Satellite (TIROS) of Next-generation (TIROS-N/NOAA) was launched in 1978 where the name was changed to NOAA. The next satellite of this series is NOAA-19 launched in 2009. In October 1975 the first Geostationary Operational Environmental Satellite (GOES1) was launched and after that a series of this GEOS series of satellite was launched in 2005). The project GEOS supports weather forecasting, severe storm tracking and meteorology research, so one of the latest GEOS-15 was launched in 2010. The first Meteosat was launched in November 1977 and after that a series of these satellites have been launched with improved capabilities. The latest in used satellite of Meteosat series is Meteosat Second Generation (MSG) that was launched in 2005.

On the other hand, HAP airships are the latest space techniques with advanced technology for fixed and all mobile applications, including military and rural solutions. These systems employ unmanned or manned, solar or fuel energy airships or aircraft carrying payloads with transponders and antennas. Airships had been modeled not as the successor to either the terrestrial or satellite systems but as a complementary system.

The HAP stratospheric stations are a significant concept that has been proposed several decades ago for telecommunications and other services for local and even global applications. The HAP airships are stationary and operate at the stratosphere at an altitude between 16 and 30 km, to take advantage of usually lower winds facilitating for location keeping. In all the regions worldwide frequency bands of 47.2 - 47.5 GHz and 47.9 - 48.2 GHz is assigned to systems using Space AP and UAV stations. In the following **Table 1** is presented the differences between airship, unmanned aircraft and manned aircraft.

Table 1. Comparisons of SPS Stations

Sources	Airships (unmanned)	Solar-powered UAV	Manned Aircraft
Size	Length 150 ~ 200 m	Wingspan 35 ~ 70 m	Length ≈ 30 m
Total weight	≈ 30 ton	≈ 1 ton	≈ 2.5 ton
Power source	Solar cells (+Fuel cells)	Solar cells (+Fuel cells)	Fossil Fuel
Flight Duration	Up to 5 years	Unspecified (≈ 6 hours)	4 – 8 hours
Position Keeping (Radius)	Within 1 km cube	1 – 3 km	≈ 4 km
Mission Payload	1000 ~ 2000 kg	50 ~ 300 kg	Up to 2000 kg
Power for Mission	≈ 10 kW	≈ 3 kW	≈ 40 kW
Example	Japan, Korea, China, ATG, Lockheed Martin, SkyStation etc.	Helios, Pathfinder Plus (AeroVironment), Heliplat (European project)	HALO (Angel Technologies) M-55 (Geoscan Network)

3. Overview to Stratospheric Network

The space HAP airships and UAV aircraft denomination was defined in the World Radio Communications Conference (WRC) in 1997, in the Radio Regulations (RR) No. S1.66A as a station located on an object at an altitude of 20 to 50 Km and at a specified, nominal, fixed point relative to the earth [WRC-122, 97]. In this definition, it has not been determined yet if the object is manned or unmanned or even how is it powered. Thus, several countries are now proposing many alternative technologies for the development of such an object in stratosphere.

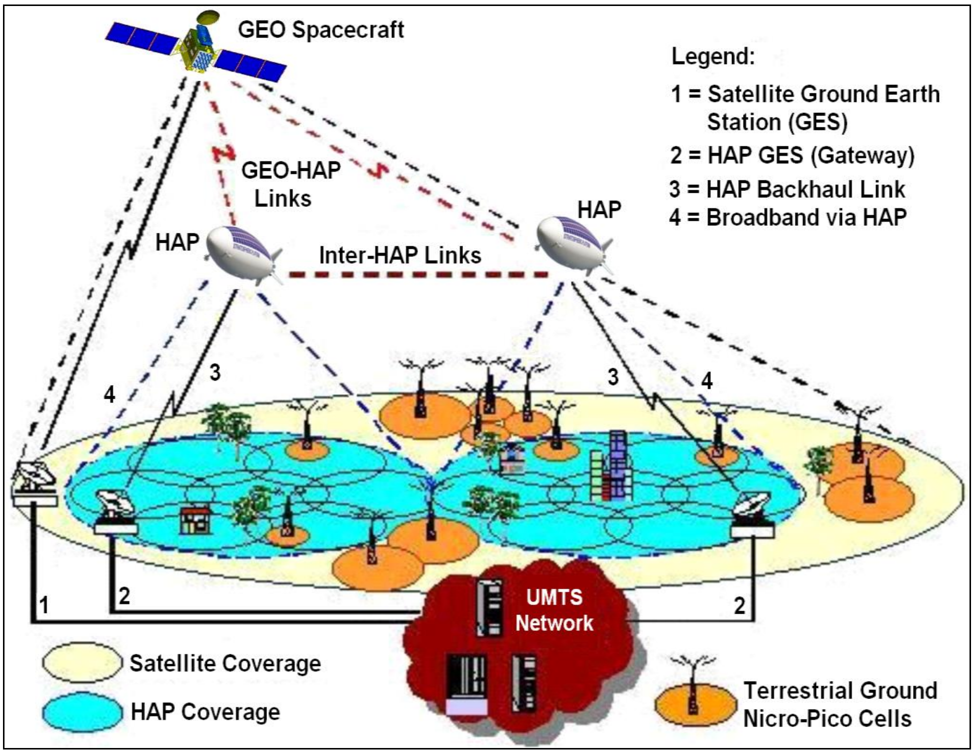

Figure 1. SCP Network with IPL – Source: Ilcev

The HAP and UAV stations have to be positioned well above commercial airplane corridors at an altitude that is high enough to provide service to a large area or spot footprint, providing telecommunication, broadcasting and environment observation services with minimal ground network infrastructure.

The common vision of weather observation and communication system predicts that it will contains one or more HAP airships with inter links to the spacecraft as illustrated in **Figure 1.** However, the same network can be developed without interlinks, so all platforms have to communicate via Ground Earth Station (GES) or Gateways located in the overlapping areas. Stratospheric platforms will provide service via area (regional) or spot coverage cells for mobile and fixed networks using GES or Fiber backhauls. The HAP fixed networks will provide service for broadcast, broadband, communication, surveillance, emergency, meteorological and other users.

The systems based on HAP and UAV stations SCP represent a technological alternative that has been under study and development for the last several years, although the investigation of unmanned aerial vehicles had started at a few universities and research centres on the world as early as the late 1950s. These systems could have many advantages compared with terrestrial and satellite systems, while at the same time avoiding many of the pitfalls [ITU-Q/2, 98], which can be solved. Various applications and services are planned to be provided by platform stations that could be classified as narrowband or broadband service, depending on the bandwidth required. Different subscribers will transmit their information directly to the platform or vice versa for weather information, where onboard switching devices will route traffic directly to other subscribers within the same platform coverage area or through heterogeneous networks.

Various applications and services are planned to be provided by HAP and UAV stations that could be classified as narrowband or broadband service, depending on the bandwidth required, for CNS, remote sensing and weather observations. Different fixed and mobile subscribers will transmit their Voice, Data and Video over IP (VDV) and messages for all applications directly to the platform, where onboard platform switching devices will route traffic directly to other subscribers within the same platform coverage area with possible overlapping platform network or through heterogeneous networks. On the other hand the stratospheric HAP or UAV will provide weather observation and transmit images to the ground stations for processing.

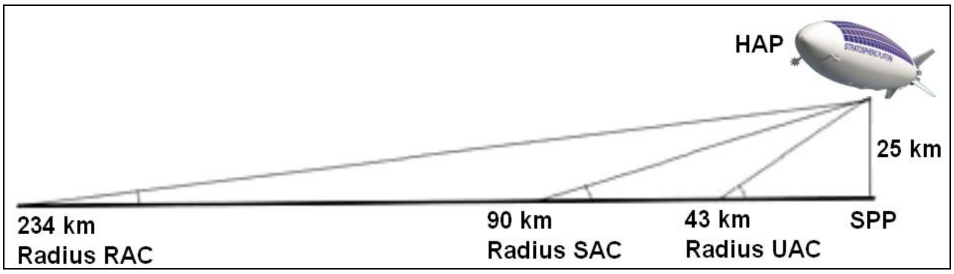

Figure 2. Coverage Area Radius of HAP – Source: Zavala

The platform stations also experiences less propagation delay with regards to satellite systems. In comparison with cellular system, platform and satellite systems suffer less from shadowing and multipath distortions because they are exposed to high angle-of-arrival signals (elevation angles). Each platform station can deploy onboard a multi-beam antenna capable of projecting numerous spot beams within its potential coverage area.

The platforms act as the highest cell tower in urban areas, but for area of up to 600 km will be necessary one or two platforms only. In a system based on HAP or UAV stations, the platform is positioned above the ground to create a radio electric coverage and service area of up to 500 km in diameter. The ITU-R defines three coverage areas: Urban Area Coverage (UAC), Suburban (SAC) and Rural (RAC), which are determined by the position of the ground receiver; i.e. coverage depends on the minimum elevation angle accepted from the subscriber's location and the distance from the Sub-Platform Point (SPP). These areas are shown in **Figure 2**, while some important parameters related to them are listed in **Table 2**, where **h** represents height above ground level.

Table 2. Characteristics of Coverage area Radius for HAP

Areas	Elevation Angle (degree)	Coverage Radius (Km)	
		h = 21 Km	h = 25 Km
UAC	90 - 30	0 - 36	0 - 43
SAC	30 - 15	36 - 76.5	43 - 90.5
RAC	15 - 5	76.5 - 203	90.5 - 234

Currently there are two well-established methods for providing wireless and space communication services. First method is terrestrially based systems, as it is widely used in VHF/UHF radio systems and the second method is the space systems using GEO and PEO satellites including both HAP and UAV platforms. Cellular radio systems can be used for weather transmissions of meteorological images on shorter distances between UAV and ground meteorological station. However, for transmission of weather observation images can be used International Telecommunications Union (ITU) frequency designation bands such as frequencies at L, X, Ku and Ka-band.

4. Satellite Optical Downlink and High Speed Data Link via HAP

Optical links offer significantly higher bandwidth, but they are blocked by clouds. As a consequence downlinks from satellites to a ground station have a limited availability depending on the cloud situation over a site. For Non-Earth Observation (EO) application like communications or broadcast, a nearly hundred percent availability is required for the satellite link. This problem can be solved by using a relay station in form of an HAO stations, which has to be positioned above the clouds in about 20 km altitude. Besides, an optical link from the satellite to the HAP would have 100% availability for Non-EO and EO applications, as it is not hindered by clouds. The final "last mile" to the ground could then be bridged by a standard Micro Wave (MW) or optical point-to-point link as used today in terrestrial applications, but with a large bandwidth compared to a satellite link due to the short distance. An optical link in parallel to the MW link could increase the bandwidth of the last 20 km several times during cloud-free conditions.

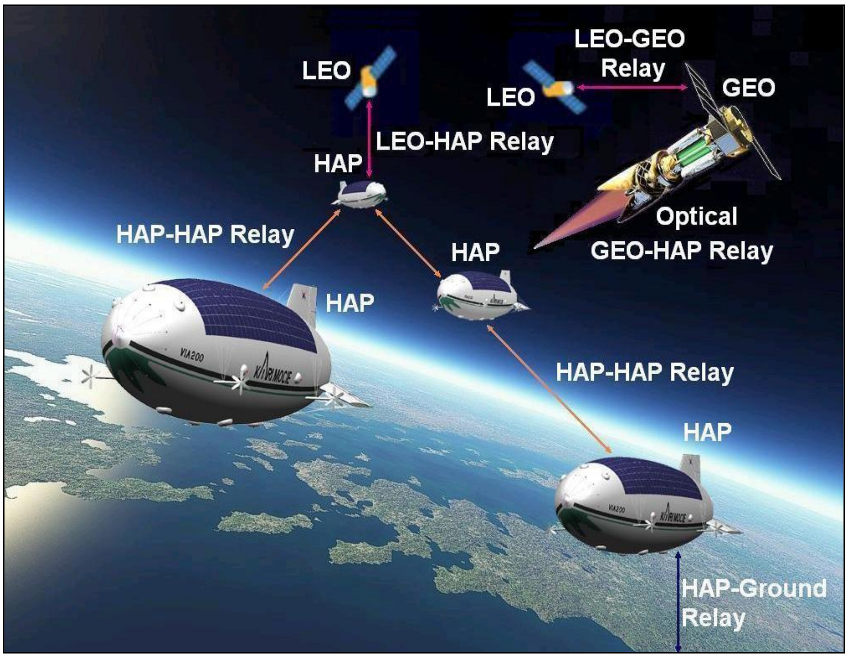

Figure 3. Relay Optical Links from Satellites via SCP – Source: Ilcev

In **Figure 3** are shown two scenarios for optical downlinks from two Leo Earth Orbit (LEO) satellites. Namely, relay link from a LEO satellite to the ground via HAP relay (left) and from a LEO satellite over a GEO satellite and a SCP (right). The "last mile" downlink from the HAP to a ground station would be either bridged by a high-bandwidth optical or microwave link. Therefore, in the SCP Relay scenario the data is sent directly via HAP to the ground (HAP-GND). In the scenario GEO satellite (GEO-HAP) Relay the data is first transmitted to a GEO satellite and then via HAP to the ground.

However, the link HAP-ground can be established by an optical link or alternatively by an MW link and provide full availability. Link duration between the LEO satellite and the HAP will be up to 12 minutes for each contact, with about 3-15 contacts depending on the geographic latitude of the HAP. In order to increase contact times an GEO satellite time would be about half of the LEO orbit, i.e. about 12 hours per day. From the GEO satellite the data would be transmitted on a continuous link to the HAP. The increased link duration would be at the cost of significantly longer link distances with a more stringent link budget and the additional expenses of an GEO satellite.

5. Airship Platform System Description

The stratospheric platform is an unmanned airship kept at a stratospheric altitude of about 20 km for multimedia communications and EO and Weather observation purposes. It is equipped with communications payload, observation sensors, surveillance radar systems or other equipment. The HAP airship for communication system is designed similar to a satellite space segment as a relay station to receive signals from ground stations using feeder links and to retransmit them to subscribers using service links. Thus, HAP airship for remote sensing, EO and weather observation using adequate onboard equipment. In such a way, an airship like an GEO satellite is stationary in stratosphere and carrying a payload with corresponding transponders and antenna system.

The launch of SCP into position is much simpler than putting a satellite into any orbit. After careful preparation in the hanger space, the airship is launched in 4 ascent phases through the troposphere and interface location point in the stratosphere and finally, it shifts to the station-keeping position. After of about 6 months of service the recovery phase goes in the opposite direction, namely, the airship platform is slowly moved from the station-keeping position towards the interface point and from there descends down to the ground in 4 descent phases. In the same time another airship is taking stationary position and taking over all operations.

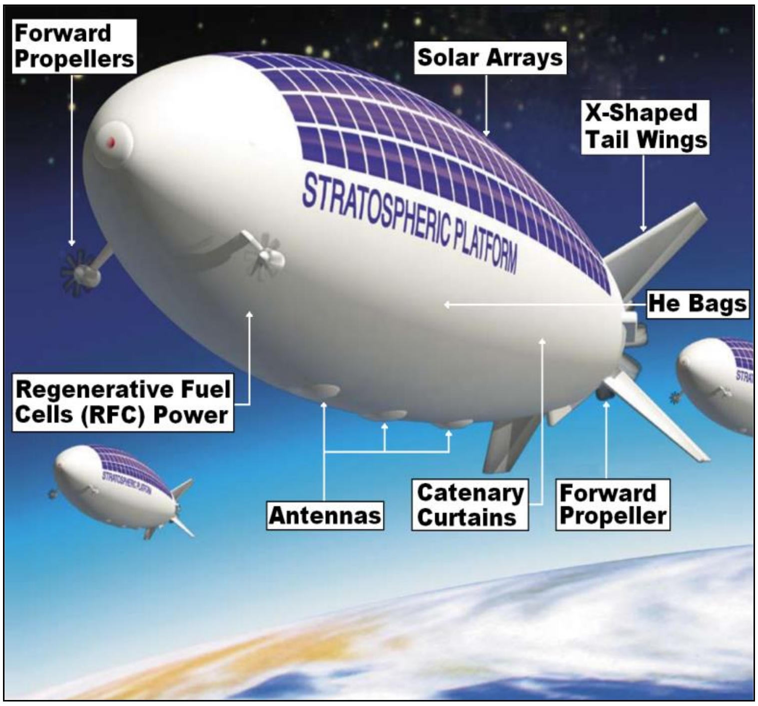

Figure 4. HAP with Main Components – Source: TAO

The airship construction has a semi-rigid hull of ellipsoidal shape, with an overall length of about 200 m, shown in **Figure 4.** It is composed of an air-pressurized hull for maintaining a fixed contour and internal special bags filled with the buoyant helium gas. Two air ballonets are installed inside the hull is designed to keep the airship at a required attitude. For a load balance to the lifting force, catenary curtains are connected to the lower rigid keel, directly attached to the envelope. Propulsive propellers of HAP are mounted on both the stem and stern of the airship and tail fins are installed on the rear end of the hull. A solar photovoltaic power system of solar cells and Regenerative Fuel Cells (RFC) is provided to supply a day/night cycle of electricity for airship propulsion.

The length of an airship in general is about 250 m and 60 m diameter. This is about 4 times as long as Jumbo jet passenger airplanes and so its weight is about 32 tons. Thus, 50% of the weight corresponds to those of structures and membrane materials. Hence, solar arrays and fuel batteries, related to the electric power system, are also heavy. And the weight of mission equipment is supposed to be about 1 ton.

The necessary condition for an airship to float at a certain altitude is that the gravity and buoyancy forces, which are exerted on the airship, are in a state of equilibrium. When the shape and volume of the airship are supposed to be constant, unlike a balloon, the buoyant force at an altitude of 20 km becomes about 1/15 that at sea level. Accordingly, a buoyancy of 15 times as much is necessary for equilibrium. Therefore, in order to float a HAP station in the stratosphere, it is necessary to make the weight of the airship light and to make the buoyancy as large as possible. Inside the airship there are several internal bags filled with He gas to obtain enough buoyancy.

6. Benefits of Stratospheric Platforms and Applications

The main potential benefits of HAP and UAV stations that can be summarized large area coverage, compared with terrestrial observation systems. The geometry of HAP station deployment means that long-range links experience relatively little rain attenuation compared to terrestrial links over the same distance, due to a shorter slant path through the atmosphere. Low propagation delay, particularly compared with satellites, and the platforms facilitate very high spatial resolution. The cost of design and construction of HAP airship and UAV aircraft definitely is lower than deployment of any kind of spacecraft.

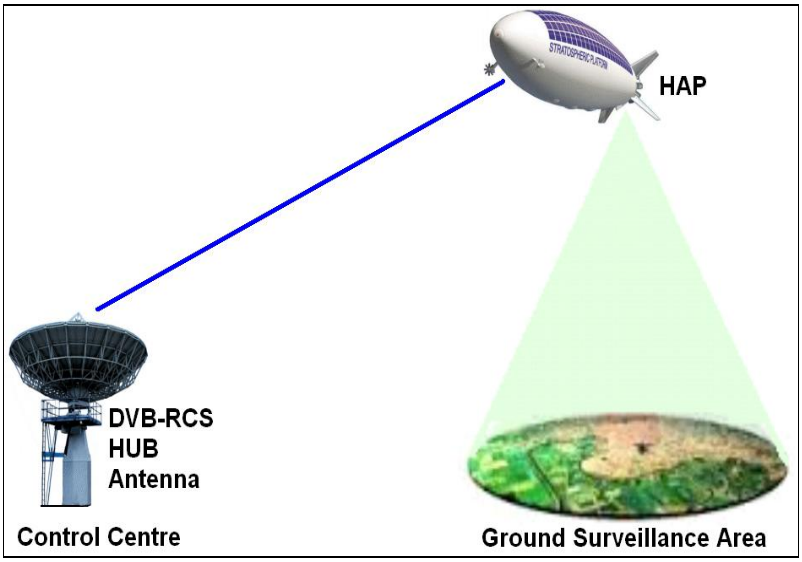

Figure 5. Weather Observation via HAP – Source: Ilcev

Although there is no direct experience of the operating costs for the weather observation and remote sensing HAP and UAV, are more cost effective than GEO or LEO spacecraft. Another advantage is that any type of stratospheric platform over satellites is that launching is much simpler and cheaper. Thus, what is very important, platforms can be returned to the ground for eventual repairation and maintenance, and in such a way can be reused for additional 6 months. However, the scenario of satellie landing is impossible to carry out in such a way.
The service of stratospheric platforms can be incrementally deployed wherever they are needed and their network can be expanded gradually as greater coverage and/or capacity is required. Given the availability of suitable platforms, it should be possible to ensure that services benefits from the advantages of latest technologies as they become available relatively quickly. Satellites, on the other hand, usually take several years from initial procurement through launch to on-station operation and without possibility to be landed from their position in the orbit.
All kind of stratospheric platforms are environmentally very friendly, because they do not require launch vehicles with their associated fuel implications and and do not remain in the space as garbage. They represent environmentally friendly reusable airships or aircraft by reason that can be returned down for payload maintenance and eventual reparation. Thus, modification on the vehicle itself can be carried out before it is put into operation again. In fact, this also contributes positively to the reduction of emissions that contributes to climate change.

7. Weather Observation and Communication of Data via HAP

Weather satellites carry different types onboard cameras, Space Synthetic Aperture Radar (SSAR) and other instruments pointed toward Earth’s atmosphere and surface. They can provide advance warning of severe weather and are a great aid to weather forecasting.
Observations and monitoring of the entire Earth’s atmosphere, ocean, land and the related environment via stratospheric platforms form the foundation for the production of weather, climate, water and related environmental services. Development of weather and climatology observations via stratospheric platforms requires deployment of one or more HAP airships or even UAV aircraft with adequate equipment onboard, which HAP space and ground segment infrastructure is presented in **Figure 5**.
Onboard HAP spacecraft is necessary to deploy onboard communication payload, which contain transmitter, receiver and antenna known as transponder. Therefore, satellite payloads may carry conventional satellite transponders, such as Transparent or Bent-pipe and more complex Regenerative transponder or contemporary Very Small Aperture Terminal (VSAT) Spacecraft Transponders for Digital Video Broadcasting-Return Channel via Satellite (DVB-RCS) service.

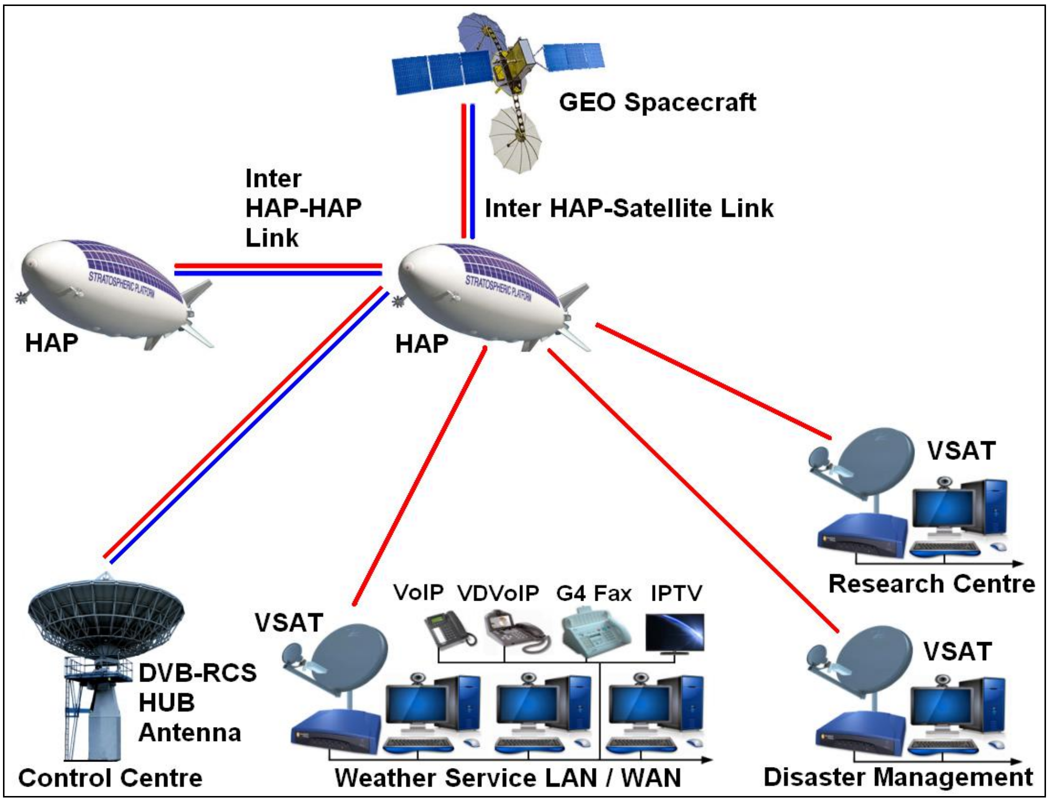

Figure 6. Space/Ground Segment for Weather Observation – Source: Ilcev

On the other hand, HAP needs some sort of control, monitoring and maintenance of payload, transponders, propellant system, electrical power, correction of position and maneuvering. In effect, to provide all above listed requirements, HAP also incorporates Telemetry, Tracking and Command (TT&C) remotely to transmit data and maintain redundant systems to serve as back-up measures, then features that are designed to provide HAP with a high level of availability, reliability and safety. Position of HAP is usually higher than all commercial flight corridors, so practically airships do not interfere commercial aircrafts flights, because they are located over 10 km. Airship itself leverages Lighter-Than-Air (LTA) technology being made of very high strength and lightweight materials. It is accompanied by advanced propulsion systems that maintain proper positioning and equipped with autonomous navigation, radio controlled command and communications payload stabilization systems.

The stratospheric airship is launched using a specified volume of helium separated from the air to maintain its shape. As the HAP rises the helium expands and at the proper altitude displaces all of the air within the platform. Once it is in the stratosphere the HAP is remotely controlled and moved into right determined position. A combination of solar cells, batteries and fuel cells will power the HAP during its minimum 6 months planned deployment. Thus, the HAP airship is being designed to hold approximately 1,000 kg of communications payload accompanied with other onboard subsystems for surveillance and weather remote sensing, imaging and observation capable of supplying fixed ground stations and observatories by meteorological data and images. On the other hand, the main HAP configurations can be dynamically changed in very short time, to reallocate capacity, to reprogram tasks and to provide mew requirements as needed.

The proposed space segment for weather observation and satellite communication network for transmission of data and images comprises HAP airships and GEO satellites with VSAT Spacecraft Transponders, shown in **Figure 6.** The communication between these HAP stations and GEO satellites is via optical links. In fact, HAP stations are getting weather and observation data from GEO satellites and forwarding together with own data to the HUB antenna and Control Centre via up (red lines) and down-links (blue lines).

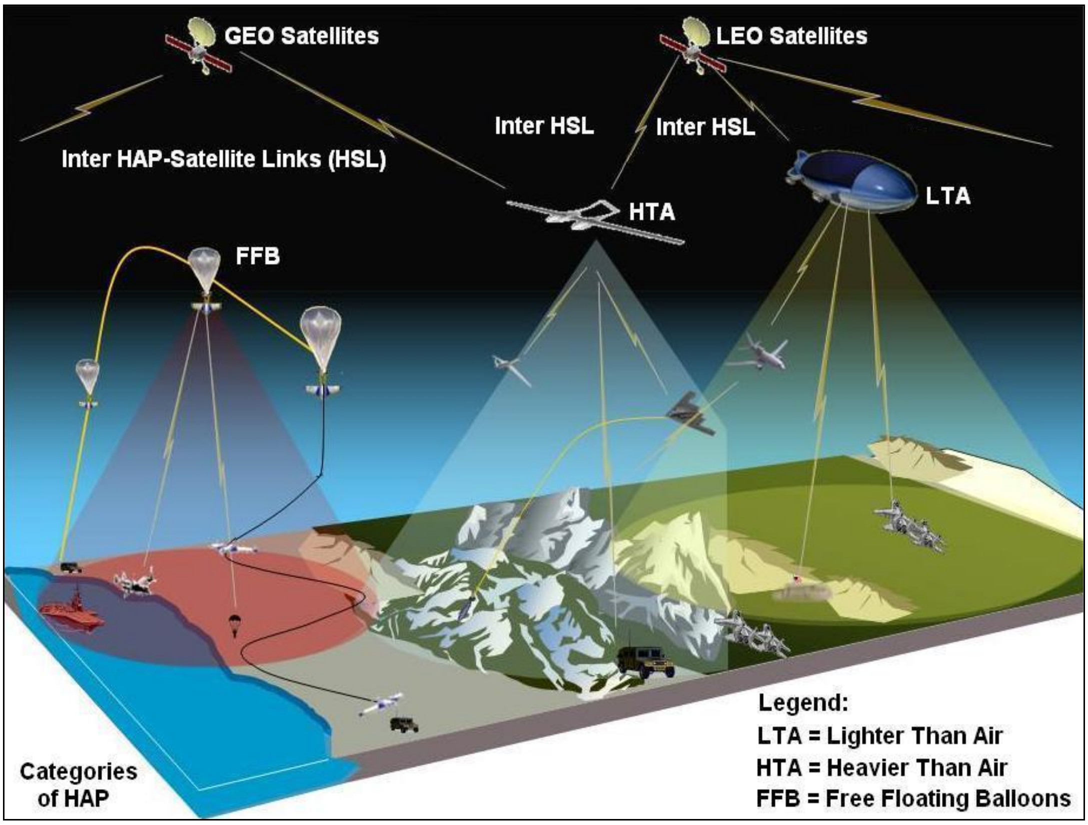

Figure 7. Integrated Satellite and SCP Networks – Source: Ilcev

The meteorological information, images and climate observation data are essential for weather and forecasting observation centres, which will conduct research to improve services, assessing changes in the climate system and for developing and new operating structures. This will improve information for weather and climate dependent sectors such as agriculture, forestry, water, transport, tourism, construction, mining and energy, in support of communities efforts to reduce disaster risks and to easier adapt for climate variability and changes. Meteorological observation and weather monitoring via HAP airships is also one of the pillars of the global framework for climate services.

Thus, the ground segment is composed by the DVB-RCS HUB antenna, Control Centre connected to the remote VSAT stations, such as Research Centre, Disaster Management, Weather Service LAN/WAN and other observation and weather centres. Ground Control Centre is dedicated to control ground HUB with antenna, manage HAP stations and provide very redundant and reliable data transfer and backup.

The connection between the VSAT ground segment and the HAP stations is established via Digital Video Broadcasting - Return Channel via Platform (DVB-RSP) similar to DVB-RCS scenario. The connections between VSAT modem is conducted via LAN or WAN and new WiFi or WiMAX to the peripheral of equipment such as Voice over IP (VoIP), VDVoIP, G4 Fax and IPTV configurations. Otherwise, the principal task of the ground Control Centre is to process, backup meteorological information and disseminate processed data to weather and forecasting. It also monitors and manages the operations of the stratospheric platforms

8. Integrated Satellite and HAP Networks for Weather Observation

The modern HAP network will be deployed together with terrestrial and GEO/LEO and even Medium Earth Orbits (MEO) satellites networks to provide another degree of flexibility for system integration that can be easily adjusted to the needs of the weather and metrological observations and forecasting, which integrated network is shown in **Figure 7.**

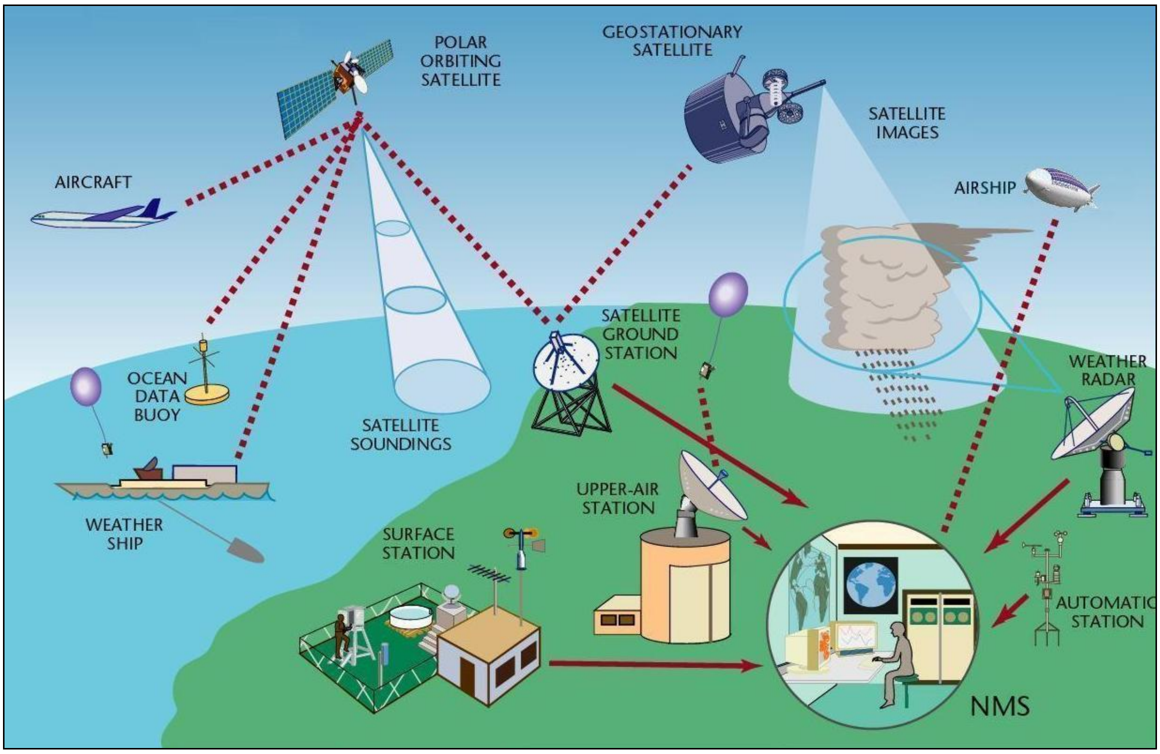

Figure 8. Global Weather Observing System and Network – Source Ilcev

In fact, HAP stations will play a complementary role in future weather and forecasting infrastructures such as Free Floating Balloons (FFB), Heavier Than Air (HTA) and Lighter Than Air (LTA). This integration may be also interfaced with the existing terrestrial, cellular and mobile systems to provide easy deployment and roll out of the 3G and beyond 4G services.
The modern integration of advanced multimedia service over heterogeneous networks is one of the key objectives in the development of future communication systems for weather and observation integrations. Anyway, satellites have played an important role in some niche markets, such as navigation and localization services, broadcast and some specific applications such as Earth observation and remote sensing. However, despite its advantages in terms of coverage and bandwidth, the level of penetration of infrastructures of satellite communications in the current telecommunications infrastructure is still low. Two of the main limits in the performance of satellite broadband communications are the throughput degradation of TCP/IP over the existing satellite links, as well as the limited satellite capacity in point-to-point mode.
While HAP stations present some advantages over satellite and terrestrial systems, they present some limitations as well. For example, HAP coverage area is limited to a radius of approximately 200 – 400 km considering an elevation angle of 15º. Therefore, all these negative effects and disadvantages of GEO/PEO satellites and HAP stations will be lees presented if proper integration occurs in the future, shown in **Figure 8.**

9. Conclusion

In this report is introduced the alternative system for space weather observation based on integration of current LEO, PEO and GEO satellite systems with HAP spacecraft or/and UAV aircraft. By early of this decade it became apparent knowledge that, despite many modern, significant technologies and advances in this area, worldwide weather and satellite operators were still struggling to achieve the design goals of the development program. To improve current program for enhanced weather observation and monitoring in general globally and in particular for some region or in one country, here are proposed integrations of existing satellite networks and stratospheric platforms.

This integration also has to improve communication facilities for transmission of weather and meteorological observation data and images to the ground meteorological and forecasting stations and centres. Observations and monitoring of the entire Earth atmosphere, oceans, land and the related environments form the foundation for the production of weather, climate, water and related remote sensing services will be improved with deployment integration of HAP airship or aircraft with PEO, LEO, MEO and GEO satellite constellations.

These observations are also essential for conducting intensive research to improve services, assessing changes in the climate system and for development operating systems in weather and climate-dependent sectors such as agriculture, water, transport and energy, in support of communities' efforts to reduce disaster risks and adapt to climate variability and change. The final output of this research work will look at how the proposed framework can improve the output of application such as veld fire detection, bad weather monitoring (hurricane, ice melting, flooding, earthquakes).

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