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# Applications of satellite imageries for prediction of severe weather events along Maitri, Antarctica

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**सार** – इस शोध पत्र में एंटार्कटिक स्थित भारतीय वैज्ञानिक अनुसंधान स्टेशन 'मैत्री' में कार्य कर रहे मौसम पूर्वानुमानकताओं को विश्व के अनेक उपग्रहों से प्राप्त उपग्रह चित्रों की सहायता से बहत ही खराब मौसम (बर्फीला तुफान) के समय पूर्वानुमान करने के बारे में प्रशिक्षित करने के विषय में बताया गया है। इसमें ध्रुवीय स्थित उपग्रह 'ट्रीआना' के बारे में चर्चा की गई है इसमें विभिन्न प्रकार के चित्रों की उपलब्धता के बारे में भी बताया गया है। इसमें उपग्रह चित्रों की विशेषताओं को स्वचालित मौसम स्टेशन (ए.डब्ल्यू.एस.) से प्राप्त आँकड़ों के साथ–साथ हिम झंझावत उत्पन्न करने वाले अवरोही पवनों के उत्पन्न होने की घटना का विवेचन किया गया है। हिम झंझावात की स्थितियाँ अक्सर पश्चिमोत्तर दिशा में अति तीव्र तूफानी प्रणाली विकसित करती है। इन तुफानों के निम्न दाब और उच्च दाब में अंतर के कारण पश्चिम दिशा में उच्च दाब प्रवणता उत्पन्न होती है जिसके फलस्वरूप बहुत ही तेज हवाएँ अथवा बर्फानी तूफान आते हैं। इस शोध पत्र में एंटार्कटिक उपग्रह मौसम विज्ञान के संबंध में आरंभ से लेकर अब तक के विकास के बारे में भी बताया गया है।

**ABSTRACT.** The present paper is an attempt to educate the weather forecaster at Indian Scientific research Station, Maitri, Antarctica in forecasting severe weather (blizzards) using satellite images of various satellites operating in the world. The Polar stationary satellite 'Trianna' has been discussed .The availability of the various types of images has also been spelt. The characteristics of satellite images has been described along with overlaying of Automatic Weather station (AWS) data explaining the occurrence of Katabatic winds which also causes blizzards. Blizzard conditions often develop on the northwest side of an intense storm system the difference between the lower pressure in the storm and the higher pressure to the west creates a tight pressure gradient, which in turn results in very strong winds or blizzards. The paper also discusses about the development that took place in Antarctic satellite meteorology since beginning.

**Key words** – Satellite imageries, Polar orbiting satellite, Geostationary satellite, Atmospheric motion vectors.

## 1. Introduction

Indian scientific research station Maitri at Antarctica is located at 71° South and 12° East and is near to the coast. Although there are conventional meteorological instruments to take observations and generate forecast but Meteorological satellites is one of the most critical observing tools available to operational Antarctic weather forecasters and decision-makers as they give the big spatial view of the weather. Keeping this in mind, an APT Receiving station was installed at Indian Antarctic station Maitri which receives VIS and IR images from NOAA polar orbiting satellites. Having this information affords improved weather forecasts and ultimately, increased safety for those working and travelling in and around the Antarctic. A number of polar-orbiting and geostationary satellites are available for operational weather forecasting and research purposes as described in the following sections. Antarctic Meteorological Research Centre (AMRC) of University of Wisconsin, USA is doing an excellent job of providing various types of images received from different Geostationary as well as Polar satellites, composite images and the animation of images on their website http://amrc.ssec.wisc.edu/realcomp.html and all these satellite products no doubt will be very useful for the forecasters over Maitri as well as to any other station over Antarctica. This paper describes the available GEO and Polar satellites and the application of their images in forecasting severe weather over Maitri, Antarctica or any such station.

## 2. Geostationary operational satellites

Although the Antarctic tends to be towards the limb of a geostationary satellite's field-of-view the data obtained from such satellites are very useful for Antarctic weather forecasting. Not only do these satellites provide valuable data at least as far south as the Antarctic coast, the regular and relatively high-frequency of availability (often hourly or half-hourly) of the images makes them very useful in monitoring synoptic features. The presently available satellites of various countries in geosynchronous orbit are described below.

2.1. *Geostationary Operational Environmental Satellite (GOES), USA*

The Geostationary Operational Environmental Satellite series is operated by NOAA, USA, which at present has following satellites in operation.

GOES-11 (West) 135° W

GOES-12 (S. America) 60° W

GOES-13 (East) 75° W

GOES-14 105° W stored in orbit

GOES-15 90° W

All GOES satellites in this generation are 3-axis stabilized satellites offering visible, short and long-wave and window infra-red, as well as water-vapour data/imagery. The GOES satellites also offer a 19-channel sounder; however, this does not cover south of 60º S.

2.2 *Meteosat*

The Meteosat Operational Program (MOP) is overseen by Europe's Meteorological Satellite Organisation (EUMETSAT) and has the following satellites in operation.

Meteosat-7 at 57.5° E provides Indian Ocean Data Coverage services.

Meteosat-8 at 9.5° E provides the Rapid Scanning Service and the backup service for Meteosat-9.

Meteosat-9 at 0° provides the primary operational service

All MOP satellites are "spinner satellites" offering visible, infra-red and water-vapour data/images.

2.3 *Geostationary Meteorological Satellite (GMS or Himawari)*

The following Japanese Geostationary Meteorological Satellites are in operation at present.

MTSAT-1R at 140° E

MTSAT-2 at 145° E backup for MTSAT-1R

The GMS satellite series is a "spinner type" series, offering visible, short wave and window infra-red and water-vapour data/images.

2.4 *Feng Yun 2 (FY-2)*

The Chinese geostationary satellite series, operated by the Chinese Meteorological Agency (CMA) have the following satellites in operation.

FY-2C at 123.5° E primary geostationary satellite

FY-2D at 86.5° E backup for FY-2C

FY-2E at 105° E

The Chinese satellites are having five channel imagers for satellite images covering visible, water vapour and infrared bands.

2.5 *INSAT*

The India Meteorological Department operates the INSAT series of geostationary satellites. At present the following satellites are in operation:

KALPANA-1 at 74° E (formerly METSAT) - India's first exclusively meteorological satellite having a three channel VHRR in visible, infrared and water vapour.

INSAT-3A at 93.5°E - This satellite is shared for meteorological and communications use. It has a three channel VHRR in visible, infrared and water vapour and a three channel Charge Coupled Device (CCD) camera.

2.6. *South Korea*

COMS, GEO at 128.2° E South Korea's first geostationary meteorological satellite. It is a five channel imaging satellite.

2.7. *Russia*

Electro-L N1 GEO at 76° E

It has 3 channels in visible range and 7 channels in infrared range.

## 3. Polar orbiting satellites (operational)

The Polar Operational Environmental Satellite system operated by USA's NOAA, EUMETSAT, China and Russia have the following satellites in orbit.

NOAA-15 in Sun Synchronous Orbit (SSO) early morning secondary satellite for Metop-A.

NOAA-16 in SSO afternoon secondary satellite for NOAA-18.

NOAA-17 in SSO mid-morning secondary satellite for Metop-A.

NOAA-18 in SSO afternoon backup spacecraft for NOAA-19.

NOAA-19 in SSO afternoon primary spacecraft of IJPS.

NPP in SSO afternoon

Metop-A in SSO mid-morning primary satellite of the IJPS

Fengyun-1D (FY-1D) in SSO early morning primary polar-orbiting satellite

FY-3A in SSO first of the second generation of Chinese polar-orbiting meteorological satellites

Meteor-M N1 in SSO morning

All NOAA and Metop-A satellites have microwave sounder instruments in addition to five channel AVHRR sensors. The imageries in five channels and the vertical profile of temperature and humidity can be used for weather forecasts over Antarctica. Chinese and Russian polar satellites have 5-channel imaging radiometers.

## 4. Defence meteorological satellite program

The Defence meteorological satellite program is a polar-orbiting satellite series, operated by the United States (NOAA) for both military and civilian (in non-real-time) use. Over the Antarctic (south of 60º S), the DMSP satellites send clear transmissions in what would otherwise be encrypted satellite data signals. These satellites offer high-resolution imagery of infra-red and visible data and microwave sounder data.

## 5. Polar stationary (future satellite)

Meteorological satellites in other orbits are being considered and planned. The first satellite is Trianna, which is proposed to orbit between the Sun and Earth at the LaGrange 1 point. Trianna, which currently has no fixed launch date, is in storage pending identification of launch flight/vehicle. "Geostorm" is another project (joint NOAA and United States Air Force) that proposes to place a solar sail into an orbit similar to Trianna's orbit but which will have a mission of monitoring space weather.

## 6. Applications/uses of satellite data

Antarctic programmes of many nations have used polar-orbiter data almost since its inception: for example, the US Antarctic Programme (USAP) has used POES and DMSP satellite data for nearly all of the last quarter of the last century. Beginning in 1992, the Antarctic composites generated at the University of Wisconsin offered a critical supplement to the USAP. Additionally, the GMS satellite had been used for some years by several Antarctic programmes as yet another supplement to the mainstay polar-orbiting satellites.

It is clear that in the short-term, the satellites that will likely benefit the various Antarctic weather services will be the polar-orbiting satellites, including both research (for example, Terra, Aqua and NPP) and operational (for example, NPOESS and METOP) satellites. In the long-term, the polar-stationary satellite platform offers the most promise. Each of these satellite systems offer huge gains in capability in terms of improved spatial resolution, larger spectral depth and greater temporal coverage. These are the capabilities that will place Antarctic meteorology on equal footing with its mid-latitude counterpart.

The major use of the data from the majority of satellite sources up to the year 2004 has been limited to just viewing the imagery for weather forecasting applications. Some derived products have been utilized such as sea ice depiction, etc. while sounding data have also had an impact on NWP. SSM/I (DMSP payload) and scatterometer data are also used. The following sections give an introduction about the various types of satellite imageries along with their characteristics, examine how some of the satellite data types have been and might be, used for Antarctic and high-latitude weather forecasting purposes.

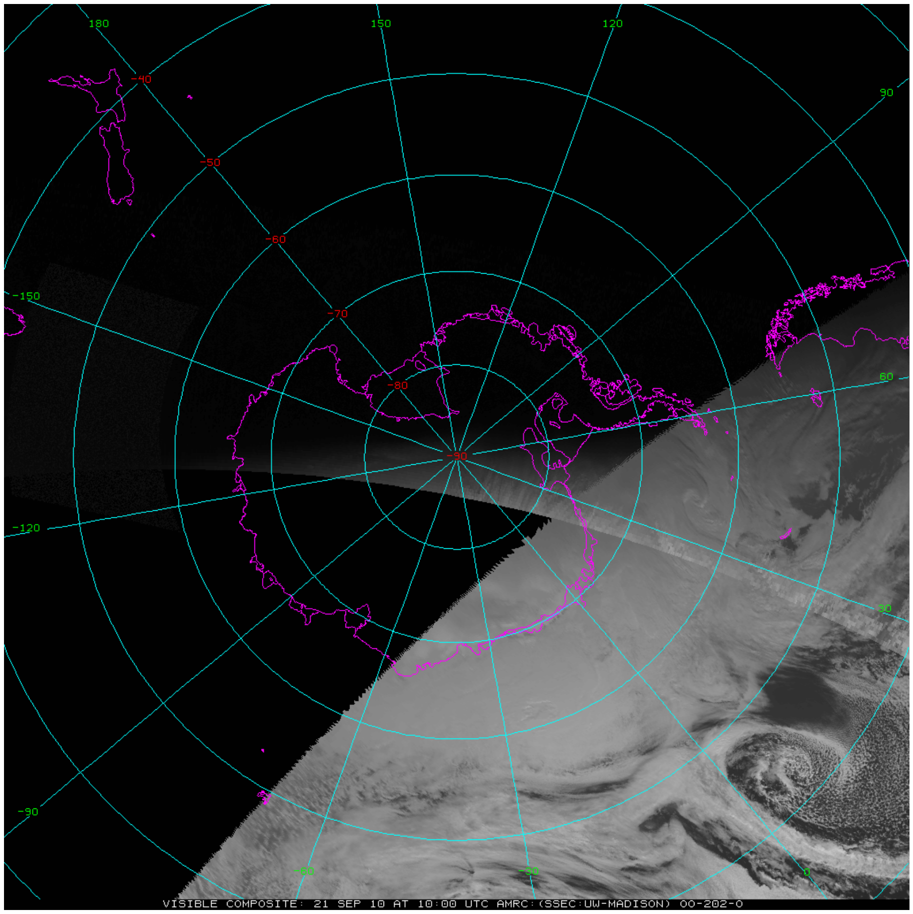


**Fig. 1**. Visible composite image

## 7. Visible images

These images are generated by the reflection of the Solar energy in 0.3 to 0.5 µm range of spectrum. (Fig. 1)

*Albedo* : The fraction of radiation reflected by a surface. The satellite measures sunlight reflected by the clouds and surface of the earth. Water absorbs a lot of sunlight (it reflects just a little) so it appears dark. The per cent of sunlight reflected by the land is called the surface albedo. The albedo of land ranges from about 10-30%, except for snow covered surfaces where the albedo is much higher. A cloud's albedo is generally high but can vary with its thickness and composition. Thick clouds have high albedos and show up bright in the satellite image. Thin cirrus clouds have low albedos and are usually semi-transparent to sunlight. The structure of clouds in the satellite image can tell the meteorologist a lot about the weather and animations tell him/her about the movement of weather systems.

## 8. Infrared images

These are the images generated by the radiation of the energy by the earth and atmosphere in 10-12.5 µm range of spectrum (Fig. 2).

The satellite also measures the temperature of the clouds and the surface of the Earth with an infrared sensor. This allows for the detection of changes in the temperature of clouds and that of the surface during the day and at night. Clouds are usually colder than the surface (land or water). The temperature of the clouds also indicates how tall they are since temperature is inversely proportional to height in the atmosphere. When the satellite meteorologist processes the infrared data, he/she makes the warm clouds gray, the cool clouds whiter and the very cold clouds bright white. Meteorologists may also "enhance" (color code) imagery in order to more easily interpret the data.

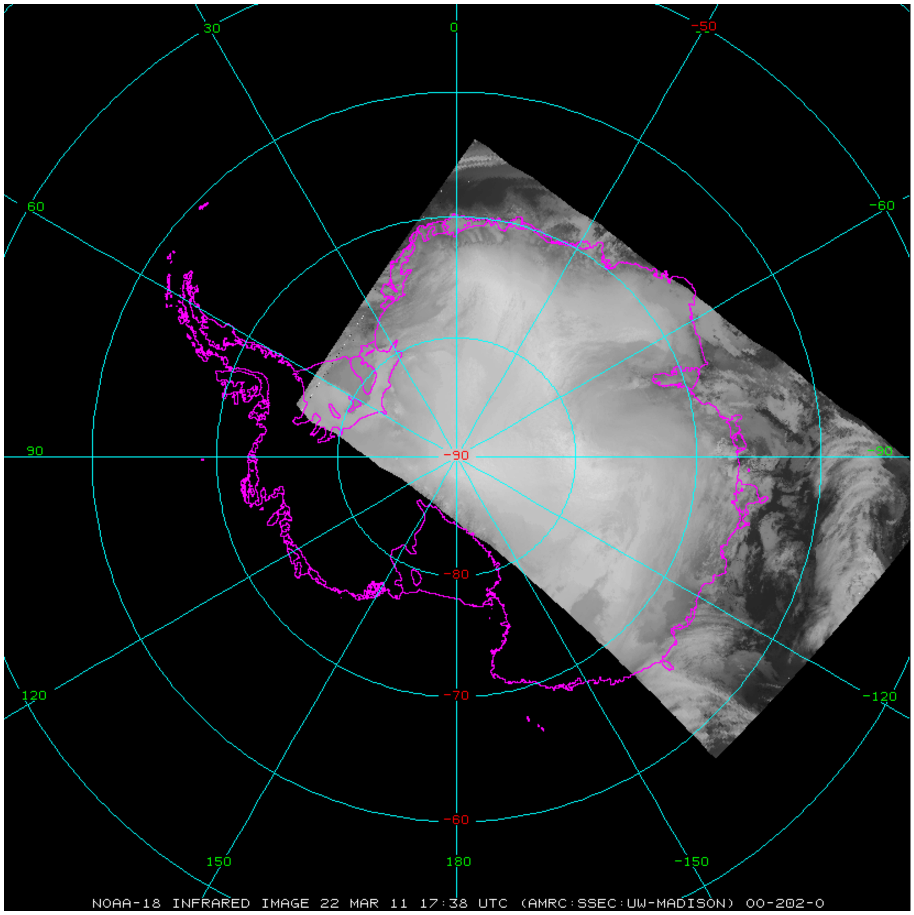


**Fig. 2.** Infrared image

## 9. Water vapor images

This imagery represents a special kind of infrared measurement which measures the temperature of clouds and water vapor in a layer of the atmosphere about 6 to 10 kilometers above the surface. At this altitude, steering currents such as jet streams control the movement of weather systems around the Earth. The water vapor imagery therefore captures these jet streams (elongated dark regions with adjacent clouds and bright regions), "dry" blocking high pressure systems (dark regions) and other weather systems (gray and bright white cloud patterns). By studying these features and tracking them over time, meteorologists can produce more accurate weather forecasts. (Fig. 3)

## 10. Enhanced or colorized images

The colder the cloud the more likely it is to produce rain. The temperature structure of clouds also tells the meteorologist how hard it may be raining and whether the storm may be producing severe weather. In the absence of clouds, the satellite measures the temperature of the surface, which could be land or ocean. In the infrared image, warm temperatures are dark and cold temperatures are lighter. In the image, arid regions are hot and therefore dark, while regions at higher latitudes are usually cooler and brighter. The infrared image can also be used to monitor sea-surface temperature (SST). Since about 70% of the Earth is ocean, this allows the scientist to study how changes in SST (such as El Nino and La Nina) are related to global weather events (such as droughts, hurricanes, and floods) (Fig.4).

## 11. Analysis using visible and infra-red satellite imagery

Visible and infra-red satellite imagery remain one of the most powerful tools available to the forecaster since it allows the preparation of analyses in areas where no

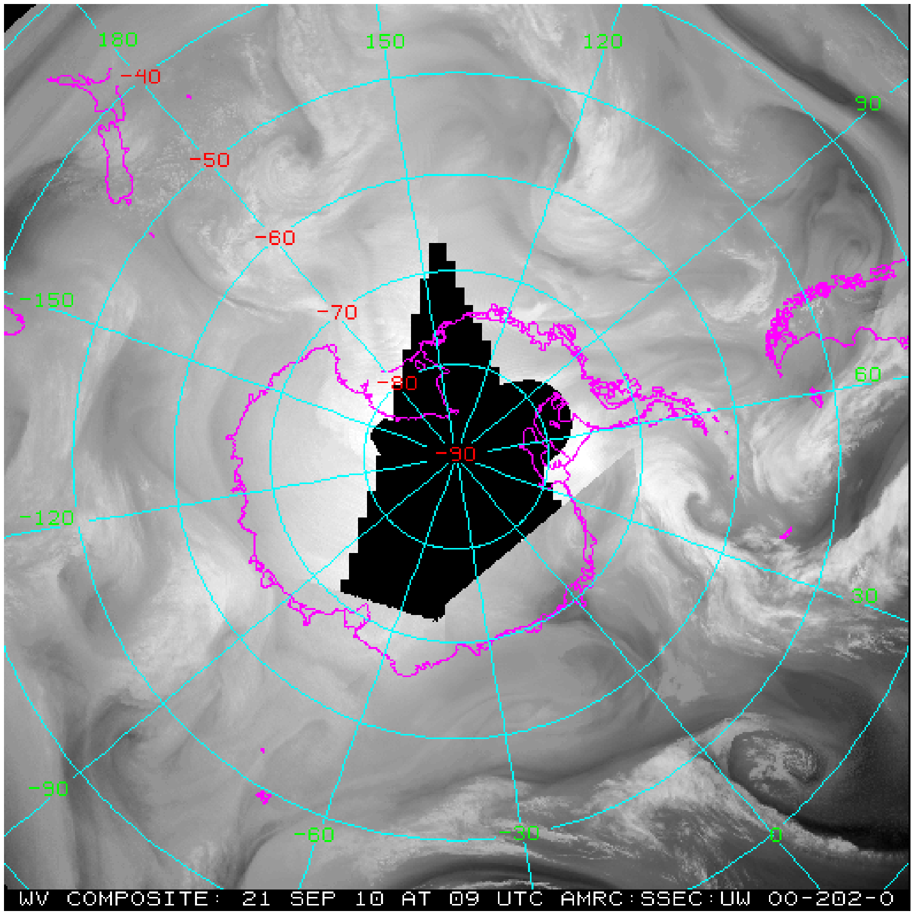


**Fig. 3.** Water vapour composite image

*in situ* observations are available, it can be used to determine whether NWP forecasts are developing according to plan and can be used to extrapolate the movement of cloud features in the production of short-period forecasts (nowcasts). Moreover, in conjunction with other observations (*e.g.*, AWS data), satellite imagery forms a formidable diagnostic tool. For example, the Fig. 5 shows AWS data superimposed on an infra-red image: there is evidence of katabatic flow occurring in the areas where there are darker bands. The AWS data shown in this figure confirm that the coldest surface temperature AWS measurement (–29 ºC in this case) coincides with a bright area in the grey-scale and with relatively light winds. South of this AWS report the dark, approximately west to east, banding is almost certainly indicative of strong katabatic flow with the surface layers warmed by mixing due to the stronger surface winds.

## 12. Microwave channel

Passive microwave instruments are important in Antarctic weather forecasting because they can provide a number of important fields of the high latitude environment, including rain rate, cloud liquid water, surface wind speed and total precipitable water over the ice-free ocean as well as sea ice extent. The unique ability to produce surface data under cloud is particularly valuable around the Antarctic where cloud cover is extensive and persistent. The atmospheric sounding instruments also have passive microwave channels and should be consulted.

For the most part, the algorithms used to convert the satellite measurements into atmospheric parameters are tuned for open-ocean conditions in the tropics and mid-latitude areas. Care should therefore be taken in using passive microwave products in high latitudes.

## 13. Severe weather over Maitri, Antarctica: Blizzards

Blizzards are characterized by low temperatures (usually below 6.6 deg C) and accompanied by winds that are at least 35 mph (23 knots) or greater, there must also be sufficient falling and/or blowing snow in the air that

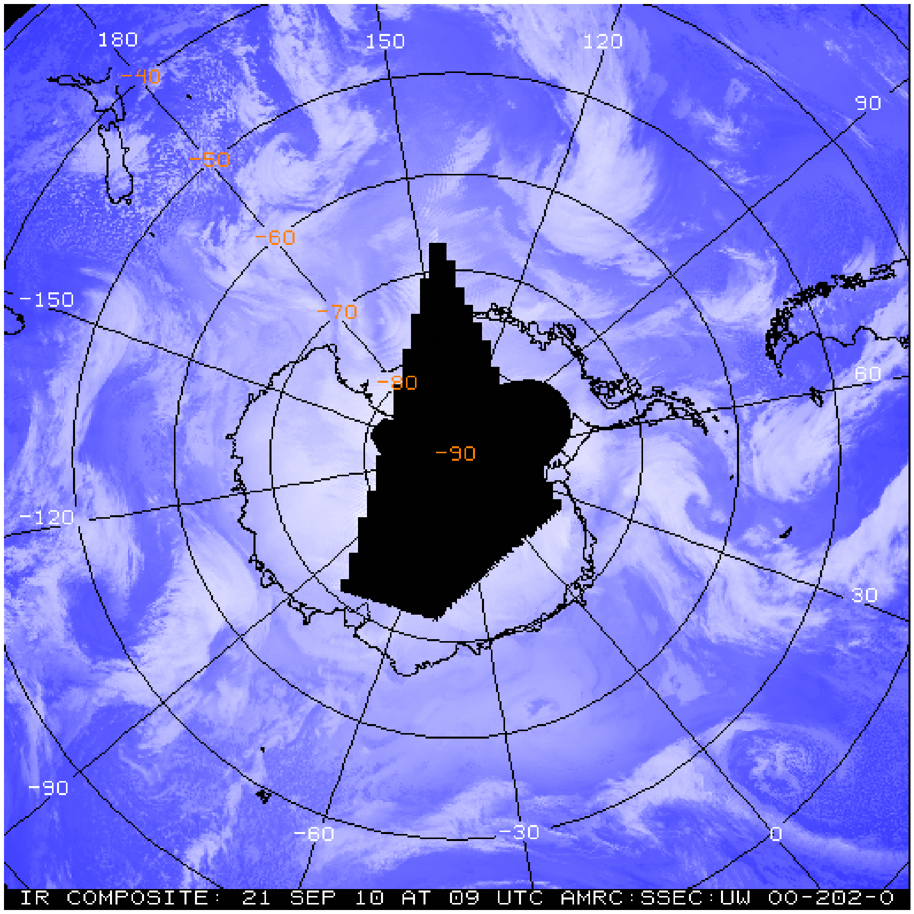


**Fig. 4.** Color Enhanced composite image

will frequently reduce visibility to 1/4 mile or less for a duration of at least 3 hours.

A severe blizzard is considered to have temperatures near or below 10 deg F, winds exceeding 45 mph and visibility reduced by snow to near zero.

Blizzard conditions often develop on the northwest side of an intense storm system. The difference between the lower pressure in the storm and the higher pressure to the west creates a tight pressure gradient, which in turn results in very strong winds.

Therefore whenever a storm is seen in the satellite imageries near Maitri, Antarctica the meteorologists should be careful for any blizzard condition to occur.

Maitri is generally affected by the eastward moving depressions that are synoptic scale frontal systems. These systems move in the circumpolar trough zone that lies between 60 and 66º S meandering north and south between seasons. The large amplitude cloud bands in association with these systems move across the station, producing dramatic variation in cloud cover. The cyclonic circulation associated with these low-pressure systems is frequently also seen on the 500-hPa chart. These systems bring warm and moist air to the coastal areas of the Antarctic continent from northern latitudes. Therefore, when a depression approaches the station, pressure starts falling continuously and temperature starts rising. The rise in temperature, which can be of the order of 10º C during a blizzard, is also due to the fact that the low level inversion is broken due to turbulence caused by increase in wind speed.

The APT images received from NOAA satellites can be of good help for monitoring blizzard like conditions.

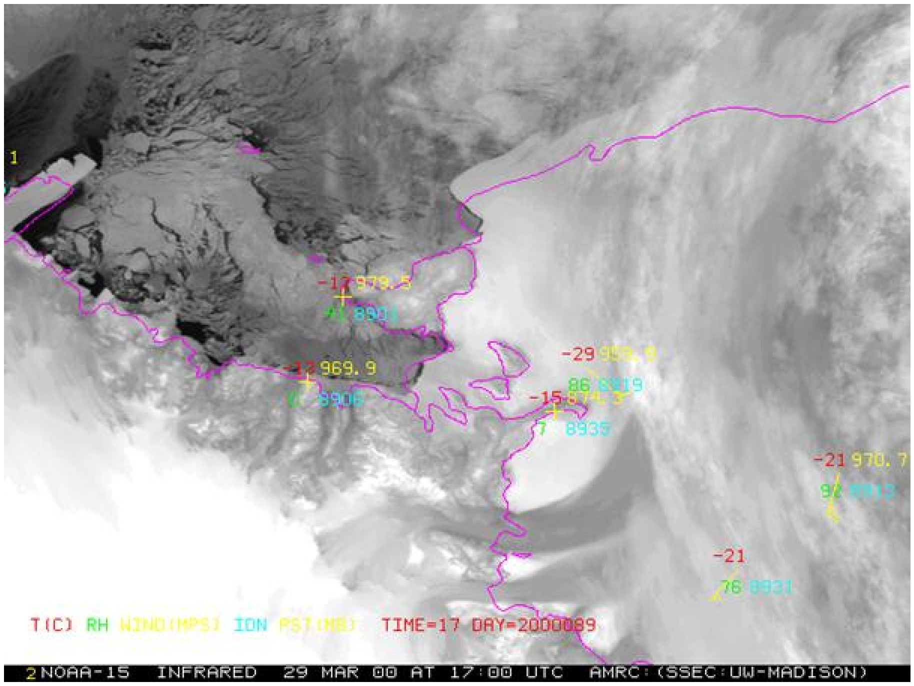


**Fig. 5.** Infrared image with AWS data overlaid

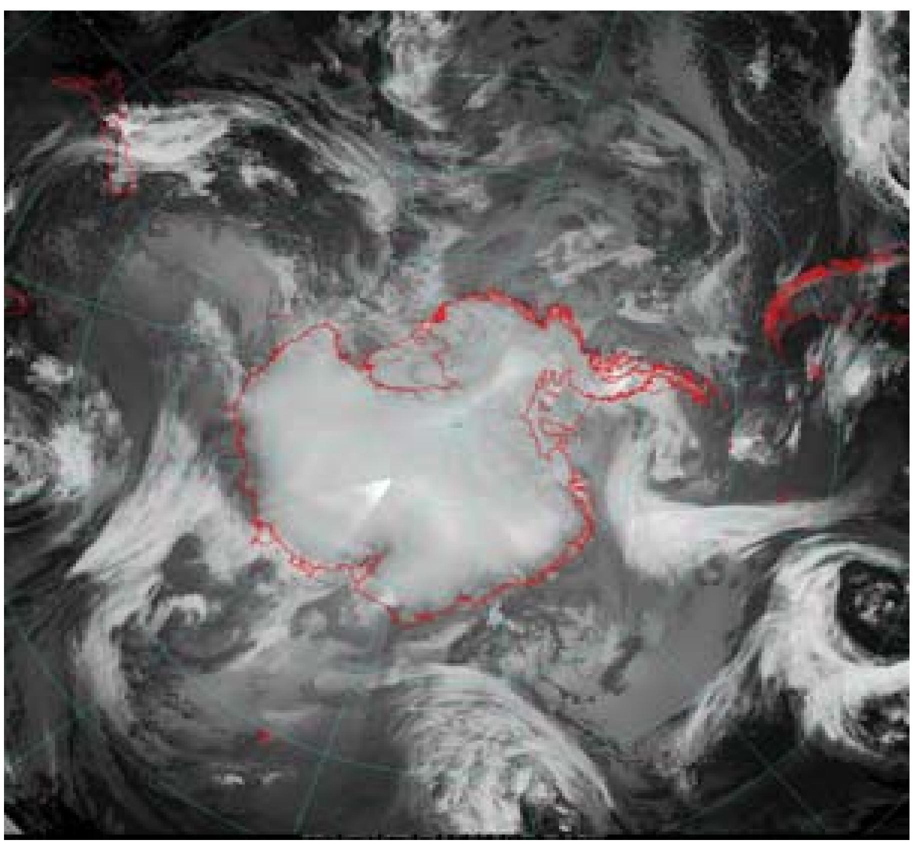

**Fig. 6.** IR composite image

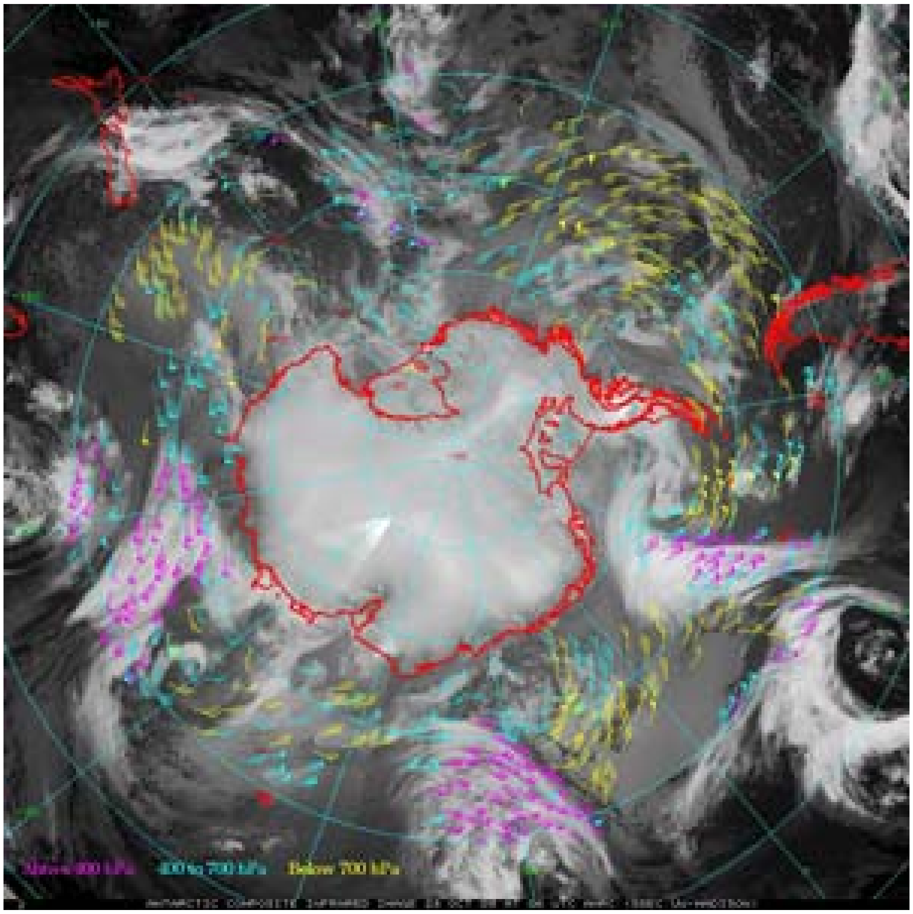


**Fig. 7.** Atmospheric Motion Vectors on composite IR image

## 14. Development in satellite-meteorology for Antarctica

The development of Antarctic satellite composite imagery in 1992 revolutionized the view of weather systems around the Antarctic, especially for weather forecasting. Satellite composites were made from both geostationary and polar-orbiting satellites over the Antarctic and adjacent Southern Ocean as a frequently routinely available product was found to be useful. These observations have supported meteorological research and other science investigations for over a decade and a half. They have inspired a variety of applications (Fig. 6).

A recent application of the composite satellite imagery is tests of deriving atmospheric motion vectors. Currently, geostationary and polar-orbiting satellite observations can be used to generate wind vectors based on cloud motions or water vapour target movements over a series of three satellite images. However, the paths of the geostationary and polar orbiting satellites leave a band of high latitudes not covered near the Antarctic/Southern Ocean (Fig.7).

Current efforts are under way to generate atmospheric motion vectors to fill in these “rings” of missing derived wind vectors. With this gap covered, observations helpful to forecasting efforts in these parts of the world will be advanced and offer input to numerical weather prediction models. Parallel studies are being performed to test the ability to track whole cloud/storm systems with these composites. Improvements to the Antarctic and Arctic satellite composites are always in progress. Creating composites in additional spectral channels, such as water vapor and experimental visible, have been achieved since the development of the initial infrared satellite composite. A “pseudo-color” composite was made, placing clouds and perhaps some sea ice seen in the infrared composite over the NASA Blue Marble background. The resolution of all composites has been improved from the 10 km to the current 5 km nominal resolution. Current efforts underway include expanding the spectral channels to include long wave and short wave infrared and other visible/infrared combinations. Recently, the temporal resolution of the Antarctic composites has been increased to hourly availability, a significant improvement over the previous 3-hourly availability. Improving satellite acquisition, adding recently launched satellites and better combination techniques of the satellite source data mark the third generation of evolution of the satellite composites.

For many years, the AMRC has carried out a grass roots collection of Antarctic meteorological datasets, especially focused on the meteorological holdings of the USAP. Today, the AMRC is one of the primary holders of surface and upper air observations from McMurdo and South Pole Stations, along with surface observations from Palmer Station. Additional collections include other USAP observational data sets from other weather station networks, observing stations around McMurdo area and observations from USAP research vessels operating in the Antarctic.

AMRC data collections also contain Antarctic and adjacent Southern Ocean observation and numerical modeling datasets. These include, but are not limited to surface manned station weather observations; USAP deep field camp observations; ship and buoy observations; Polar orbiting satellite 1 km resolution local area coverage from the Advanced Very High Resolution Radiometer (AVHRR) instrument on the National Oceanic and Atmospheric Administration (NOAA) satellites; and Global Forecast System (GFS) model analyses and forecasts. Weather forecasters at Indian Antarctic Station, Maitri can also make use of these composites and other images and research work available on their website http://amrc.ssec.wisc.edu/realcomp.html for generating weather forecasts.

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