

# Advanced technologies: opportunities and challenges for developing countries

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**Advanced remote-sensing technologies, complemented by improved computational and communications infrastructure and technical training, will continue to provide opportunities for developing countries to reap economic and societal benefits through improved environmental analysis and prediction.** Much advanced technology development will be related to space-based Earth observations but other environmental sensing technologies will also contribute. To realize fully the benefits from these opportunities, support from the WMO Programme for Least Developed Countries and other WMO scientific and technical programmes will be needed.

With respect to space-based technologies, the incorporation of observations from Earth-orbiting satellites in operational environmental analyses and prediction models will improve the accuracy of weather forecasts and warnings and improve seasonal-to-interannual climate forecasts, making attendant socio-economic benefits possible. In addition to benefits from the assimilation of space-based remotely sensed data, there is considerable benefit to be derived from enhanced products

generated directly from improved satellite observations, that will continue to play important roles in planning, management and warning activities. Some examples of these product-related applications are the monitoring of wildfires, droughts and floods, air-quality and water-resources monitoring and mapping, and detection of volcanic ash and algal blooms.

As well as the benefits available from space-based observations, advances related to the use of radar and new observations such as tsunami monitoring buoys will also provide new opportunities. The international distribution of this information will be facilitated by advanced technology-based systems, such as the WMO Information System (WIS) and GEONetcast.

## Background

Advanced instruments deployed on current and planned satellite missions will increasingly provide large volumes of data related to the atmospheric, oceanic and land-surface states. During this decade, a five-order of magnitude increase will occur in the volume of data available for use by operational and research weather,

A list of the acronyms used in this article is given on page 195.

ocean and climate communities (see Figure 1).

These data will exhibit accuracies and spatial, spectral and temporal resolutions never before achieved. Organizations such as the Joint Center for Satellite Data Assimilation (JCSDA) will ensure that the maximum benefit from the investment in these space-based global observing systems is realized. These organizations will accelerate the use of satellite data from both operational and research spacecraft for weather and climate monitoring and prediction systems. The improved weather and climate prediction information will be available via current dissemination systems, as well as through new distribution technologies such as GEONetcast.

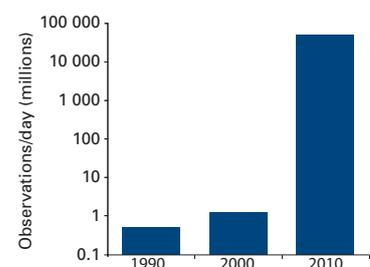


Figure 1 — Expected increase in the volume of observational data available for use by the operational and research weather, ocean and climate community

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Training Seminars), improved model products based on these data will be available to the wider meteorological community.

Platforms	Status	Instruments
DMSP (F 13 - 16)	Current	SSM/I, SSM/T, SSM/T 2, SSMIS, OLS
POES (NOAA 15 - 18)	Current	MSU, HIRS/2, HIRS/3, HIRS/4, AMSU A, AMSU B, MHS, AVHRR, SBUV/2, SEM, DCS, SARSAT
GOES (10 – 12)	Current	Imager, Sounder
METEOSAT (6 - 9)	Current	MVIRI, SEVERI, GERB
METOP	Current	IASI, ASCAT, GRAS, HIRS, AMSU, MHS, GOME-2, AVHRR
MTSAT 1R	Current	Imager
AQUA	Current	AMSU-E, AMSU, HSB, AIRS, MODIS
Terra	Current	MODIS, MISR, CERES, MOPITT, ASTER
TRMM	Current	TMI, VIRS, PR, CERES, LIS
QuikSCAT	Current	Scatterometer
GFO	Current	Altimeter
TOPEX	Current	Altimeter
JASON-1	Current	Altimeter, GPS
ERS 2	Current	Altimeter, SAR, SARWave, ATSR, Scatterometer, GOME
Envisat	Current	Altimeter, MWR, MIPAS, AATSR, MERIS, SCIAMACHY, GOMOS
Windsat	Current	Polarimetric radiometer
Aura	Current	OMI, MLS
INSAT 3A	Current	VHRR, CCD Imager
INSAT-3D	2007	Imager, Sounder
FY-1	Current	CHRPT
FY- 2	Current	VISSR
CHAMP	Current	GPS
COSMIC	Current	GPS
SMOS	2007	MIRAS
NPP	2009	VIIRS, CrIS, OMPS, ATMS
EO-3/IGL	2009	GIFTS
ADM	2009	Doppler lidar
CHINOOK	2010	GPS
GPM	2010	GMI, DPR
GOES R	2012	ABI, Geostationary Sounder
NPOESS	2013	VIIRS, CrIS, ATMS, OMPS, SEM, TSIS

The exploitation of the disparate observations available from these space-based platforms requires considerable effort. Widely dissimilar types of data must be combined to give an accurate and consistent depiction of atmospheric, oceanic and land-surface state. For example, a state-of-the-art global analysis today incorporates hyperspectral infrared radiances from the AIRS and IASI instruments, bending angles from the COSMIC satellites obtained by observing the occultation of Global Positioning System satellites, and polarimetric microwave radiances from the WindSat instrument.

Typical of the efforts of the agencies involved in data assimilation has been recent work at the JCSDA, beginning with the establishment, and iterative development of a Community Radiative Transfer Model, which is freely available to the WMO community. The availability of this model suite has facilitated the incorporation of AIRS data, and its snow, ice and land emissivity components have led to improved use of infrared and microwave sounding observations at high latitudes and over land surfaces. A list of some of the instruments included in the Community Radiative Transfer Model (see <http://www.jcsda.noaa.gov>) is given in the box on the following page.

The JCSDA has emphasized early preparation for the use of data from advanced instruments including, IASI on METOP, the AMSU, the HSB, the SSMIS of the DMSP, CHAMP and COSMIC. This work has required use of advanced assimilation techniques including optimal channel selection and spatial sampling, calibration, and techniques to assimilate retrieved data products for non-radiometric sensors or those for which radiance assimilation remains as yet less practical.

A substantial number of current and next generation instruments will significantly improve characterization of the atmospheric and land and oceanic surface states. Many of these instruments are listed in the table above, which also provides the corresponding satellite platform name, and the status of data availability or the instrument launch date.

Direct use of all these data by smaller National Meteorological

Services, particularly those of developing countries, presents a considerable challenge. However, some larger national and international agencies have resources to access these data and assimilate them in advanced coupled atmosphere-ocean weather and climate models. Through arrangements fostered by WMO (e.g. the High Profile Training Events, which link meteorologists from over 120 countries and the Asia-Pacific Satellite Applications

## Some satellite instruments modelled by the Community Radiative Transfer Model

AMSU A	NOAA 15 – 18, METOP
AMSU B	NOAA 15 – 18
HSB	AQUA
AIRS	AQUA
MODIS	AQUA, Terra
WindSat	Coriolis
AVHRR	NOAA 15 – 18, METOP
MHS	NOAA 18, METOP
MSU	NOAA 14
HIRS	NOAA 10 – 18, METOP
GOES 10 - 12	Imager, Sounder, ABI
SSMI	F 14 – 15
SSMI/S	F 16
VISSR	GMS 5

The work undertaken by JCSDA represents a significant contribution to the formulation of the Global Earth Observing System of Systems (GEOSS), since data assimilation techniques, data impact studies, observing system simulation experiments, and network design studies are key GEOSS activities.

## Benefits and opportunities from space-based observations and data assimilation

The impact of satellite data on improving operational forecasts is indicated in Figure 2, which shows

the anomaly correlation coefficient (AC) for the 500 hPa height calculated for the National Center for Environmental Prediction (NCEP) five-day forecast as a function of time. The correlation is between the observed and predicted deviations from the climatological 500 hPa height field. Neglecting interannual variability, a steady improvement in the anomaly correlation coefficient is evident, with a larger rate of improvement for the southern hemisphere. The remarkable improvements in the late 1990s are due, to a significant degree, to direct radiance assimilation and instruments such as the AMSU.

An explicit example of the impact of the implementation of AMSU-A radiance assimilation was achieved in the US Navy Operational Global Atmospheric Prediction System (NOGAPS) and represented one of the most important advances in NOGAPS skill in a decade. The assimilation of these radiances in the Naval Research Laboratory's Atmospheric Variational Analysis System (NAVDAS) substantially improved the height, wind and temperature forecasts for both hemispheres at all forecast times, reduced tropical cyclone track error forecasts

by up to 25 nautical miles (Figure 3(a)), and resulted in significantly fewer forecast gross errors (Figure 3(b)).

The great extension of forecast skill from the use of satellite data is also clearly illustrated in Figure 4, which shows the improvement in predictability from the use of satellite data in the southern hemisphere. The diagram shows that the inclusion of satellite data in NCEP's operational database doubles the length of a useful forecast (commonly accepted as a forecast with anomaly correlation of at least 0.6). The social and economic benefits from such improvements in the areas of forecast and warning services and planning and management of resources such as water, are very large.

Even with these recent improvements in forecast skill, there still remains room for considerable improvement, in particular toward decreasing the frequency of larger-than-normal forecast errors or "busts" related to significant errors in the initial model fields in areas where existing observing systems do not provide adequate coverage with accurate measurements of temperature,

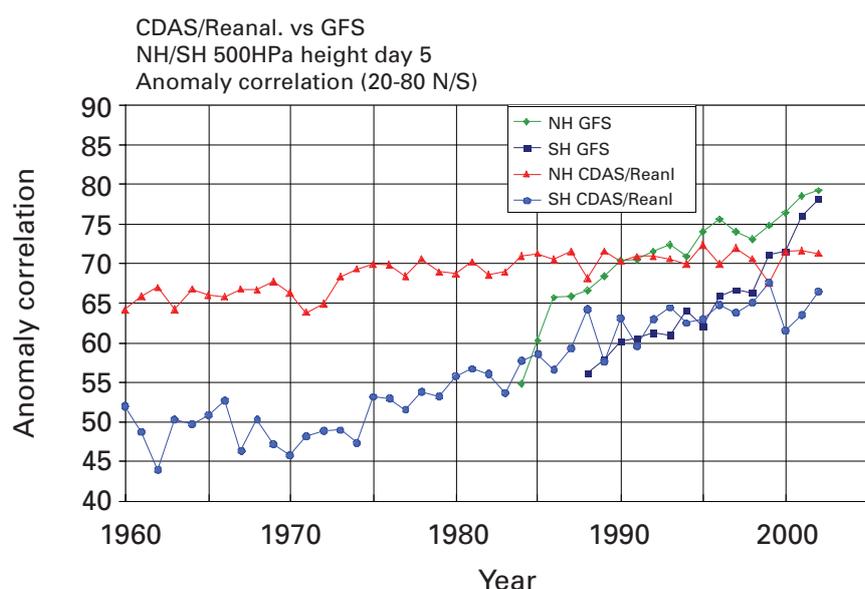


Figure 2 — Anomaly correlation coefficient for 500 hPa height for NCEP's five-day forecast as a function of time. Red and blue (green and black) lines refer to fixed (evolving) model and assimilation system. Red and green (blue and black) lines refer to the northern (southern) hemisphere.

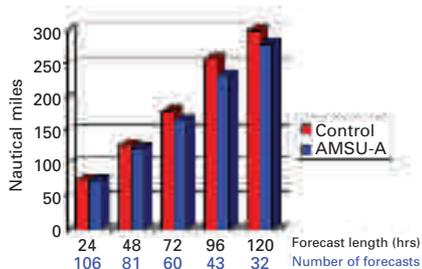


Figure 3 (a) — Tropical cyclone track error forecasts with (AMSU-A) and without AMSU-A (control) in the NRL NAVDAS forecast model

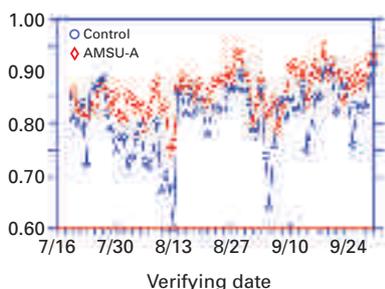


Figure 3 (b) — 500 hPa height anomaly correlation for NAVDAS with (AMSU-A) and without (control) 16 July–30 September 2003

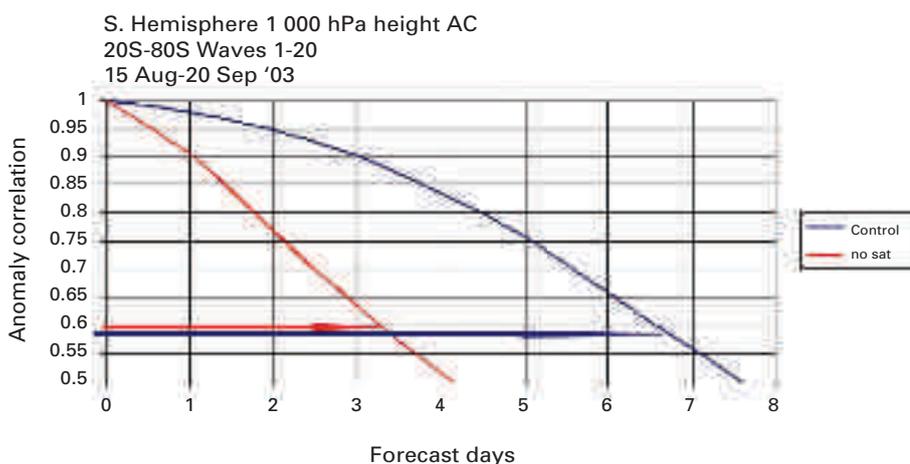


Figure 4 — The accuracy of the southern hemisphere forecast which has used satellite data (blue arrow) and one in which satellite data have not been used (red arrow). Note the doubling of the length of a useful forecast (one with anomaly correlation coefficient > 0.6) with the use of satellite data.

moisture and wind. It is very clear that assimilation of satellite observations will make key contributions to that improvement. Furthermore, the improved global analyses based on the use of high spectral resolution observations will continue to allow models to expand useful prediction into the seven- to ten-day range. As a result, there will be an increasing emphasis on satellite data usage in the data assimilation community, related to the introduction of new and additional satellite data and the refinement of the assimilation methodologies for current and future observation systems. This is a complex challenge, whose solution will provide considerable return on investment made in the satellite observing network. Over the coming years, operational

instruments with the capabilities of the current experimental AIRS will be launched. These instruments will provide data at spatial, spectral and temporal resolutions vastly exceeding those of earlier instruments. These developments will provide the numerical weather prediction and data-assimilation communities with new possibilities and new challenges.

New possibilities arise, for example, because of the unprecedented vertical resolution provided by these instruments. New challenges will emerge because of the sheer volumes of data they will provide and because of many scientific questions that need to be answered to make optimal use of these remotely sensed observations.

Recent advances from the use of advanced technology at JCSDA include the demonstration of significant benefits to the northern and southern hemispheres of forecasts from AIRS radiance assimilation (see below) using the NCEP global forecast model, the demonstration of benefits of MODIS polar atmospheric motion vector assimilation on global forecasts and the beneficial impact of using radiative transfer models in the modelling of ice emissivity in polar regions.

## Benefits and opportunities from space-based observations—direct applications

In addition to the considerable benefits to the global community resulting from the assimilation of space-based observations into environmental models, a significant number of benefits may be derived from direct application of satellite data. A list of such applications may be seen in the table on the next page.

Advances in remote-sensing technology and retrieval methods will continue to improve the quality of these applications, providing new opportunities for environmental planning and management, forecasting and warning and disaster mitigation and response.

A good example of the benefits of advancing technology has been the use of the MODIS instrument on the NASA Terra and Aqua spacecraft to provide maps of the positions of wild- or bushfires. This capability, which uses a comparison of radiances in the short- and middle-infrared regions of the spectrum, enables managers, firefighters and rural dwellers to plan their activities with knowledge of current and recent fire activity. One such system, based around the use of MODIS data, is the Australian Sentinel System ([www.sentinel.csiro](http://www.sentinel.csiro)).

# Atmospheric Infrared Sounder (AIRS)

Recent results from the application of AIRS data at several key centres have highlighted their utility for numerical weather prediction. Evidence of significant positive impact of AIRS data on global forecasts in both the northern and southern hemispheres has been recorded at the JCSDA, where, for the first time, all AIRS fields of view were used. The impact can be seen in Figure 5 (a) and (b). The improvement in forecast

skill at six days is equivalent to gaining an extension of forecast capability of several hours.

This improvement is quite significant when compared to the rate of general forecast improvement over the last decade. A several hour increase in forecast range at five or six days normally takes several years to achieve at operational weather centres.

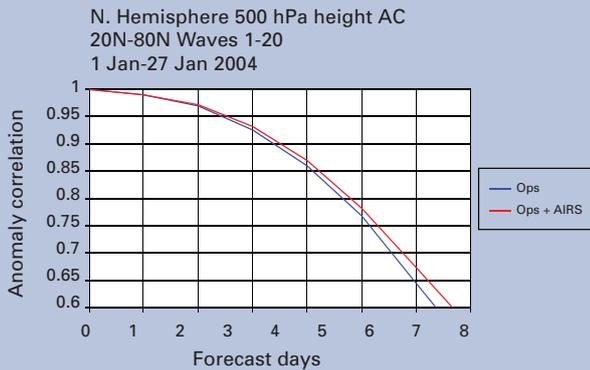


Figure 5(a) — The impact of AIRS data on Global Forecast System forecasts at 500 hPa (20°N–80°N) (1–27 January 2004); the pink (blue) curve shows the anomaly correlation coefficient with (without) AIRS data.

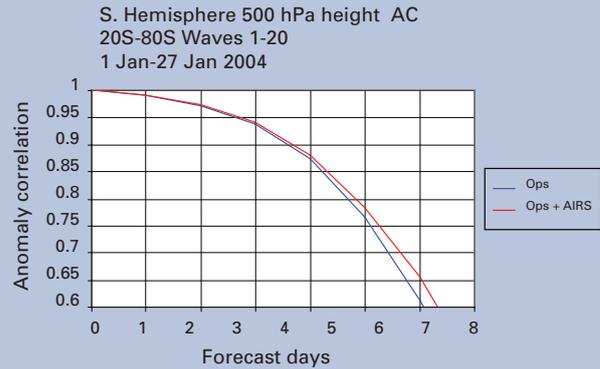


Figure 5(b) — The impact of AIRS data on Global Forecast System forecasts at 500 hPa (20°S–80°S) (1–27 January 2004); the pink (blue) curve shows the anomaly correlation coefficient with (without) AIRS data.

[au/mapping/viewer.htm](#)), established in Australia in 1999, which provides current and historical images of fire activity. This was invaluable during the bushfires that destroyed over one million hectares in the Australian state of Victoria (December 2006/February 2007); firefighters, emergency service

managers and the public, particularly in rural areas, benefited from the information provided by the MODIS instrument. An example of the output from the Sentinel System is seen in Figure 6, which shows fires (dark symbols) over northern Australia on 15 January 2007.

It should also be noted that advancing technology will allow manipulation and downscaling of the products from data assimilation and directly from satellite observations. It will also allow rapid dissemination of information through WIS and new systems such as GEONetcast, which will greatly enhance the distribution of meteorological information to remote areas via affordable groundstations. Direct readout systems will also continue to provide improved and timely high-resolution observational data to many countries, providing an opportunity for improved services and management.

Despite significant recent advances in terms of enhanced benefits from advanced space-based technology, full exploitation of the space-based observing systems will still require basic work on radiative transfer, early preparation for advanced operational instruments, increased use of

## A list of selected satellite data applications

Subsynoptic-scale analysis	Water-resources mapping and monitoring
Severe weather monitoring (tropical cyclones, thunderstorms, etc.)	Snow cover estimation
Cloud-top temperature/cloud height	Sea-ice determination and mapping
Cloud type and amount determination	Detection of volcanic ash
Detection of fog and low cloud	Aerosol estimation
Timing of fog clearing	Forest fire detection
Frost detection	Sea-surface temperature (SST) estimation
Detection of dust clouds	Monitoring vegetation
Detection of inversions	Solar radiation estimation
Rainfall estimation	Surface albedo estimation
Flood monitoring	Land-surface temperature estimation
	Soil-moisture estimation

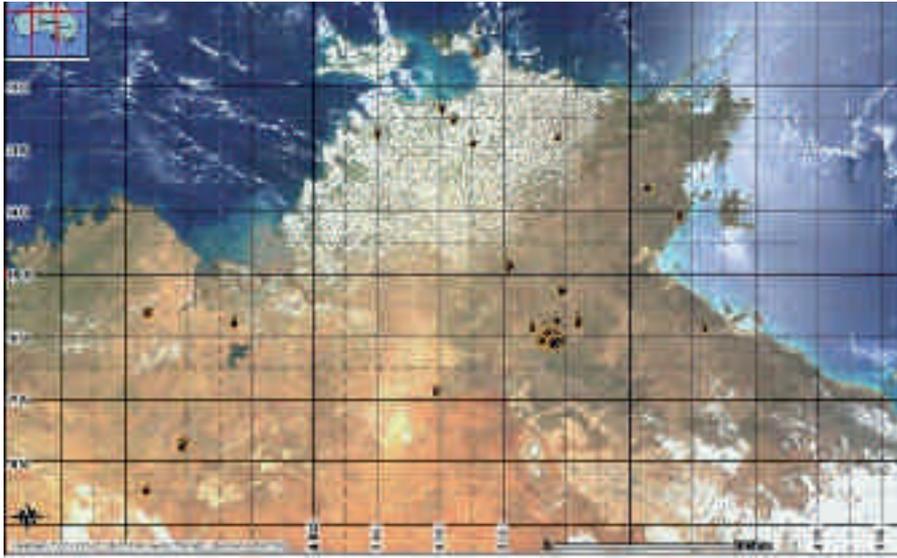


Figure 6 — A Sentinel System MODIS image of northern Australia with positions of wildfires (dark symbols) during the previous 12 hours superimposed. The system may be zoomed to the level of base maps that show roads and buildings.

cloudy and precipitating radiances, enhanced use of oceanic observations and full use of satellite radiance data over land. This work is being addressed through international cooperation and is being aided by WMO support in areas such as the International TOVS Working Group, the International Winds Workshop and the Working Group on Numerical Experimentation.

## Further advanced technologies

While advanced space-based technologies will provide opportunities, advanced technologies in several other areas will also provide significant benefits. For example, advances in radar technology are already improving short-term severe weather forecasts and will be demonstrated in China as part of the World Weather Research Programme Demonstration Project at the 29th Olympiad in 2008. Coupled with advanced numerical weather prediction (e.g. using four-dimensional variational assimilation), this technology will also greatly improve short term forecasting of rainfall.

The detection of tsunamis and dissemination of warnings is another application benefiting from the availability of advanced technologies. In particular, the deployment of NOAA's DART (deep ocean and reporting of tsunamis) detection buoys and their linking to a number of emergency warning systems will considerably improve future preparedness for tsunami events with global benefits.

In terms of communications, technology such as the mobile phone continues to provide more position-related weather and emergency service information, a trend which is expected to continue. The relative low-cost and ubiquity of these devices make them suitable for reporting environmental information to central locations, as well as for receiving timely warnings and localized analyses and forecasts.

## Conclusions

The use of advanced technologies is enabling considerable improvement in measurement and modelling of the current and future environmental state and the communication of this vital information to forecasters,

managers and planners. Key areas of technological advance responsible for major improvements are the use of satellite instrumentation, satellite data assimilation, numerical modelling, computing and communications.

To a significant extent, full benefit of the investment and advances in these areas will be achieved in concert with advances at key data assimilation centres. These centres will ensure that maximum benefit from the space-based observing system is realized. Many nations, particularly developing nations, will benefit considerably from access to, and use of, the resulting improved analyses and improved weather, environment and climate prediction capability. Local capability, in smaller centres, to build on the work done in key centres, will be aided by the availability of information, software (for example, the Community Radiative Transfer Model and prediction models) and advice. This availability has often been sponsored and fostered in the past through WMO activities that have supported, for example, the International TOVS Working Group and the International Winds Workshop. These groups have enabled users in many nations to benefit from recent advances in space-based technology associated with atmospheric sounding and use of space-based wind estimates.

In summary, considerable benefits will be derived in developing countries from the use of advanced technologies. Some benefits will rely on communication with data assimilation centres that can exploit the large and complex environmental data base. The opportunities and benefits will be in areas such as improved forecasts and warnings and improved seasonal and interannual forecasts. In particular, many direct applications, such as fire, water-resources and flood monitoring and tsunami detection will be improved, enabling improved management and planning.

# Acronyms

AATSR	Advanced Along Track Scanning Radiometer	MERIS	Medium Resolution Imaging Spectrometer Instrument
ABI	Advanced Baseline Imager	METOP	Meteorological Operational Polar Satellite
ADM	Atmospheric Dynamics Mission	MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
AIRS	Atmospheric Infrared Sounder	MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
AMSR	Advanced Microwave Scanning Radiometer	MISR	Multiangle Imaging SpectroRadiometer
AMSU	Advanced Microwave Sounding Unit	MLS	Microwave Limb Sounder
ASCAT	Advanced Scatterometer	MODIS	Moderate-resolution Imaging Spectroradiometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	MOPITT	Measurements of Pollution in the Troposphere
ATMS	Advanced Technology Microwave Sounder	MWR	Microwave radiometer
ATSR	Along Track Scanning Radiometer	NASA	National Aeronautics and Space Administration
AVHRR	Advanced Very High Resolution Radiometer	NAVDAS	Naval Research Laboratory's Atmospheric Variational Analysis System
CCD	Charge Coupled Device	NCEP	National Centers for Environmental Prediction
CHAMP	Challenging Mini Payload	NOAA	National Oceanic and Atmospheric Administration
COSMIC	Constellation of Satellites for Meteorology, Ionosphere and Climate	NPOESS	National Polar-orbiting Operational Environmental Satellite System
CrIS	Cross-track Infrared Sounder	NPP	NPOESS Preparatory Project
DART	Deep ocean and reporting of tsunamis	NRL	Naval Research Laboratory
DCS	Data Collection System	OMPS	Ozone Mapping and Profiler Suite
DMSP	Defence Meteorological Satellite Programme	POES	Polar Operational Environmental Satellite
DPR	Dual-frequency Precipitation Radar	SBIV	Solar Backscatter UltraViolet
EOS	Earth Observing System (NASA)	SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
GERB	Geostationary Earth Radiation Budget	SEM	Scanning electron microscope
GFO	GEOSAT follow-on	SMOS	Soil Moisture and Ocean Salinity
GMI	Global Precipitation Mission (GPM) Microwave Instrument	SSMIS	Special Sensor Microwave Imager Sounder
GOES	Geostationary Operational Environmental Satellites	TMI	TRMM Microwave Imager
GOME	Global Ozone Monitoring Experiment	TOVS	TIROS Operational Vertical Sounder
GOMOS	Medium resolution spectrometer	TRMM	Tropical Rainfall Measuring Mission
GPS	Global Positioning System	TSIS	Transportable Satellite Internet System
HIRS	High Resolution Infrared Sounder	VHRR	Very High Resolution Radiometer
HSB	Humidity Sounder for Brazil	VIRS	Visible and Infrared Scanner
IASI	Infrared Atmospheric Sounding Interferometer	VISSR	Visible Infrared Spin-Scan Radiometer
JCSDA	Joint Center for Satellite Data Assimilation		
LIS	Land Information System		

Overall, the potential benefits to be derived from advancing technology in developing countries are considerable and are being aided significantly by multinational cooperation and goodwill, as well as by many specific areas of technological advancement.

Successful outcomes from these opportunities will, however, rely on infrastructure, training and strong programmes such as the WMO Programme for Least Developed Countries in conjunction with other WMO scientific and technical programmes.

## Acknowledgements

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