E.C.M.W.F.'s data and products for GMES

HALO
report
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Content

1 Introduction

The report gives an overview of E.C.M.W.F. data and products. The overview intends to meet the need for a description of the E.C.M.W.F. data flow and archives relevant to GMES activities. E.C.M.W.F is the European centre for medium range weather forecast. It is an international organisation supported by 25 European States.

GMES is a joint initiative of the European Commission and the European Space Agency, designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security. GMES's thematic priorities are land & vegetation, ocean and atmosphere as well as water resources and natural risks (floods, fire).

The following thematic IP's (integrated projects) are an integral part of GMES:

- MERSEA for ocean theme
- GEOLAND for land theme
- to be announced for atmosphere theme

HALO is a GMES specific support action (SSA), which will be responsible for the harmonization of atmosphere, land and ocean GMES backbones. The objective of HALO is to enable an efficient and coherent data exchange between the relevant IP's of GMES. HALO will provide proposals for the data architecture within GMES in its operational phase starting in 2008.

E.C.M.W.F.'s data handling is important for GMES since MERSEA and GEOLAND IP's have decided to use E.C.M.W.F. products as their meteorological data. Moreover, E.C.M.W.F. may be involved in GMES's atmosphere IP. The IP will focus on satellite and in situ monitoring as well as data assimilation and modelling of greenhouse gases, global reactive gases, global aerosol and air quality.

Since GMES data needs and architecture have not been set up completely, the report will not be restricted to certain data but will give an overview of all available products and data in E.C.M.W.F. core activities, which are medium range and seasonal weather, wave and ocean forecast. Focus will put on data and products, which are already known as to be important for GMES.

The information sources used for this report are E.C.M.W.F. web based documentation and user support documents, web sites of WMO and space agencies as well as personal communication to E.C.M.W.F. people. The report tries to cover the current status, which will quickly develop further.

E.C.M.W.F. data and products presented here can be divided in the following types:

- **Observations.** Observational data are received from WMO data exchange facilities and other sources and archived by E.C.M.W.F.
- **E.C.M.W.F. forecast and analysis products.** These data is produced (and archived) by E.C.M.W.F.'s integrated forecast system IFS.
- Prospective observational data, which may be included in further development steps of E.C.M.W.F. and GMES

Besides a description of content and meaning of the data and products the following technical issues will be taken up whenever possible in order to organize an effective data exchange within GMES.

- Data access, availability and dissemination policy
- Data volume, storage requirements & coding/decoding
- Spatial and temporal coverage and resolution
- Data quality in terms of errors, representativeness
- Links to documentation (web based or hard copy)

The report starts with a general overview of data acquisition and production at E.C.M.W.F. in chapter 2. Chapter 3 introduces E.C.M.W.F.'s meteorological observation system, the data types and their handling at the Centre. A discussion of the satellite data and their application is content of separate chapter 4. They are the core of E.C.M.W.F. operational and research activities in GMES. A description of the individual satellite instruments and products is given in the appendix. Chapter 5 presents the data products generated by E.C.M.W.F.'s Integrated Forecast System (IFS). Both observation and product data are stored in and disseminated from archive MARS, which is presented in chapter 6. E.C.M.W.F.'s data policy is summarised in chapter 7.

2 Overview of E.C.M.W.F 's Operational Meteorological System EMOS

E.C.M.W.F provides state-of-the-art weather forecast data and products to E.C.M.W.F Member States. It manages a super-computer facility, which provides resources for weather forecasting research and computer modelling of the global weather, which includes the interaction between atmospheric, ocean and land surface processes.

Operational data flow, production and archiving within **E.C.M.W.F. O**perational **M**eteorological **S**ystem (EMOS) can be summarised by considering three interacting parts representing, first, the observations, second, the model and, third, the data archive and dissemination system (see figure 1) :

1. Global Observations received from Global Telecommunication Systems and ftp sites
2. **I**ntegrated **Fo**recast **M**odel (IFS)
3. **M**eteorological **A**rchival and **R**etrieval **S**ystem(MARS)

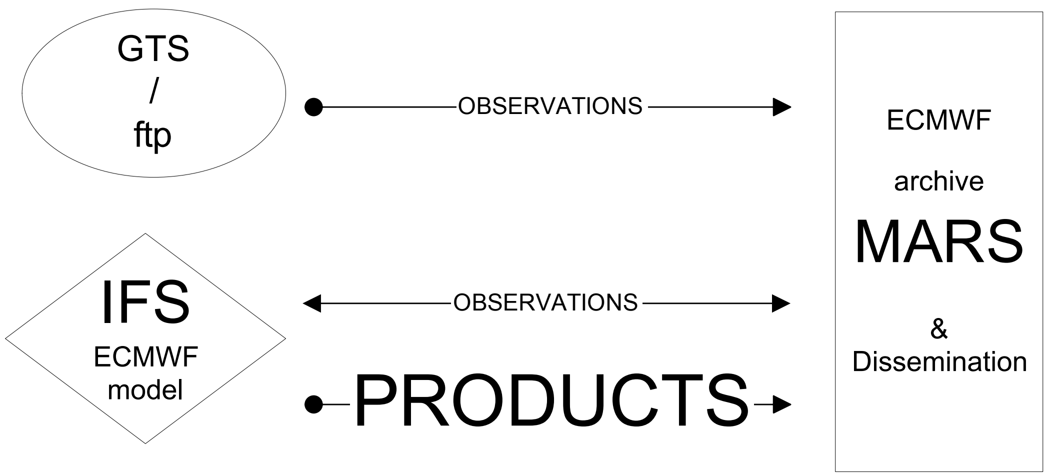

Figure 1 Overview of E.C.M.W.F.'s operational data flow. A more detailed schematic of the data and product data flow is given in Figure 7 (p. 37).

E.C.M.W.F acquires global meteorological and satellite observations, which represent the state of the atmosphere, the ocean and the land surfaces. The received observation data are pre-processes in order to use them in IFS and to archive them in MARS. The main pre-procession tasks are coding & decoding operations, initial error checking, retrieval from a few satellite data and observation error assignment.

The comprehensive global earth-system model **IFS** developed at E.C.M.W.F. forms the basis for all weather and ocean forecasting as well as data assimilation activities. All the main applications required are available through one integrated computer software system. IFS operationally produces medium range weather and wave forecast by a coupled atmosphere - wave model in a high -resolution deterministic and an ensemble mode. A coupled atmosphere - ocean model generates monthly and seasonal forecasts. IFS performs many observation related operations since data assimilation is an integral part of IFS. These operations include a observation data quality testing by comparison with the simulated data and the retrieval of satellite radiances into variables presented in the model.

E.C.M.W.F runs the comprehensive data archive **MARS** of IFS products and observation data, which allows efficient access to outside bodies. MARS contains terabytes of operational and research data and data from special projects. MARS data are freely available to registered users in the Member States and Cooperating States. For research and commercial use, data access can be arranged. Observational data are stored in the BUFR - format whereas the fields produced by IFS are compressed in the GRIB - format. MARS is accompanied by the ECFS (E.C.M.W.F file system) archive, which stores data for research purposes.

3 Global meteorological observations at E.C.M.W.F.

The review of observation data starts with an overview of WMO's activities in section 3.1 since they are the main data source for E.C.M.W.F. The different meteorological data types, either conventional or satellite data, are briefly introduced in section 3.2. An overview of observation data handling and pre-processing at E.C.M.W.F is given in section 3.3 and 3.4. Data quality issues concerning data coverage and observation errors are discussed in section 3.5

3.1 WMO programmes for operational observations of the atmosphere

To predict the weather, modern meteorology depends on near instantaneous exchange of weather information across the entire globe. Therefore WMO (Worlds Meteorological Organisation) runs the following programs:

- World Weather Watch **WWW**
- World Climate Programme **WCP**
- World Space Programme **WSP** to improve the space part of GOS in WWW

The World Weather Watch (WWW), the core of the WMO Programmes, combines observing systems, telecommunication facilities, and data-processing and forecasting centres - operated by Members - to make available meteorological and related geophysical information needed to provide efficient services in all countries.

WWW consists of:

- The Global Observing System **GOS**
- The Global Telecommunications System and Data Management **GTS**
- The Global Data-Processing System **GDPS**

Besides the Global Observation System (GOS), which focuses on the needs of weather forecasting, the Global Climate Observing System (**GCOS**) was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). The GCOS will be based upon, inter alia:

- Existing and enhanced World Weather Watch (WWW) systems
- The Global Atmosphere Watch (**GAW**) and related atmospheric constituent observing systems
- The Global Ocean Observing System (**GOOS**) for physical, chemical and biological measurements of the oceans
- The Global Terrestrial Observing System (**GTOS**) for land surface ecosystem, hydrosphere, and cryosphere measurements

3.2 Overview of GOS data types

E.C.M.W.F. relies on GOS observation components, which are depicted in Figure 2. Ground and sea based synoptical observation, radiosondes, instruments on operational aircrafts supply in-situ geophysical data of the atmospheric state. Ground based profiles as well as the wealth of satellite remote sensing instruments observe indirectly the atmospheric and surface properties by detecting the interaction of radiation or acoustic signals with the atmosphere or the surface.

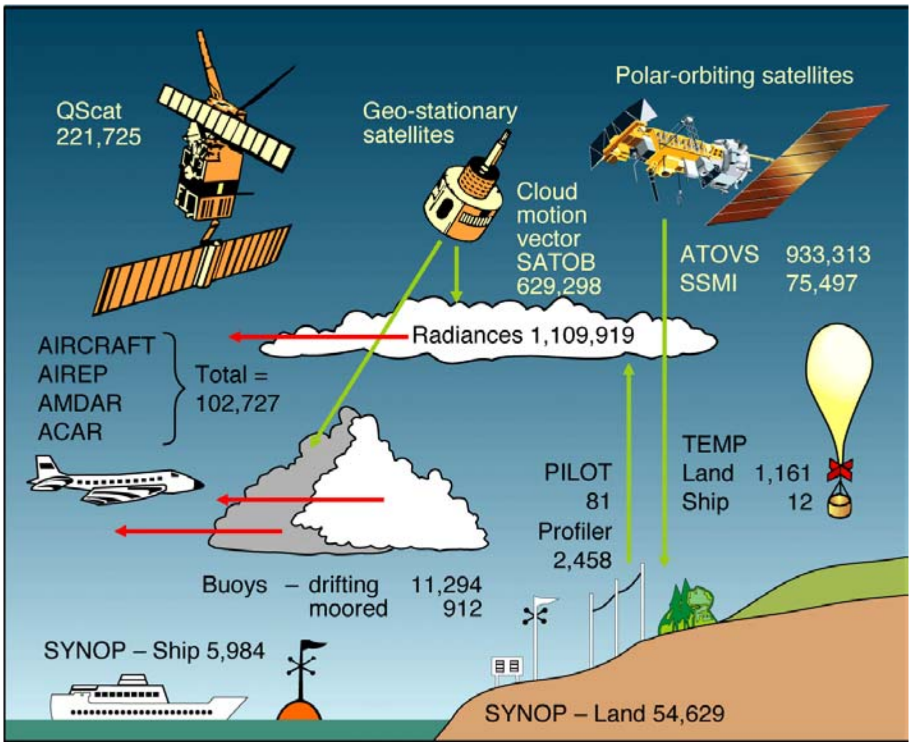

Figure 2 Observation used by E.C.M.W.F.'s meteorological operational system. Numbers refer to all data items received over a 24-hour period in May 2003.

The following description of the GOS components used at E.C.M.W.F. has been partly compiled from the WMO web site (see chapter 8).

3.2.1 Stations on Land

a. Surface Observing

The backbone of the surface-based sub-system continues to be about 11,000 stations on land making observations at or near the Earth's surface, at least every three hours and often hourly, of meteorological parameters such as atmospheric pressure, wind speed and direction, air temperature and relative humidity.

Some 4000 of these stations comprise the Regional Basic Synoptic Networks (RBSNs) drawn up by the six WMO Regional Associations. Data from these stations are exchanged globally in real time. A subset of these surface stations is used in Global Climate Observing System (GCOS) Surface Network (GSN).

Observation platforms and parameters used at E.C.M.W.F are:

- Meteorological weather stations (SYNOP LAND)

- Aeronautical weather stations (METAR)
- Used parameters: all in 2 m height but wind in 10 m

b. Upper-air Observing

From a network of roughly 900 upper-air stations, radiosondes, attached to free-rising balloons, make measurements of pressure, wind velocity, temperature and humidity from just above ground to heights of up to 30km. Over two thirds of the stations make observations at 0000UTC and 1200UTC. Between 100 and 200 stations make observations once per day. In ocean areas, radiosonde observations are taken by about 15 ships, which mainly ply the North Atlantic, fitted with automated shipboard upper-air sounding facilities (ASAP). See a subset of upper air-stations used in the GCOS Upper-air Network (GUAN).

Observation platforms and parameters used at E.C.M.W.F are:

- Radiosondes stations (TEMP LAND & SHIP)
- Dropsondes from scientific aircrafts (DROPSONDES**)**
- Used parameters: temperature, wind, pressure, humidity
- Pilot balloons (PILOT)
- Used parameter: wind

3.2.2 Observing Stations at Sea

Over the oceans the GOS relies - in addition to satellites - on ships, moored and drifting buoys and stationary platforms. Observations made by ships recruited under the WMO Voluntary Observing Ship Programme, comprise much the same variables as at surface land stations with the important additions of sea surface temperature and wave height and period. The number of observing ships is about 7,000. About 40% are at sea at any given time. The operational drifting buoy programme comprised about 750 drifting buoys providing 6,000 sea surface temperature and surface air pressure reports per day. These ships and buoys are part of the WMO Marine Programme, which maintains lists of ships and observing standards.

Observation platforms and parameters used at E.C.M.W.F are:

- Ships (variable height, default=25m)
- Used parameters: all
- Moored buoys (from TAO PIRATA network) and drifters (BUOYS**)**
- Used parameters: wind, pressure, temperature
- Sea level pressure bogus provided by Australian analysts (PAOB**)**

3.2.3 Observations from Aircraft

Over 3000 aircraft provide reports of pressure, winds and temperature during flight. The Aircraft Meteorological Data Relay (AMDAR) system makes high quality observations of winds and temperatures at cruising level as well as at selected levels in ascent and descent. The amount of data from aircraft has increased dramatically during recent years - from 78,000 reports in 2000 to 140,000 reports in 2002. Providing great potential for measurements in places where there is little or no radiosonde data, these systems are making a major contribution to the upper-air component of the GOS.

Observation platforms (AIRCRAFT) and parameters used at E.C.M.W.F are:

- "manual" reports from pilots (AIREPS)
- automated (high quality) report (AMDAR, ACAR, ASDAR):
- Used parameters: wind, pressure, temperature (no humidity)

3.2.4 Lidars, Radar and further observations

GOS also includes solar radiation observations, lightning detection, and tide-gauge measurements. In addition, wind-profiling and Doppler radars are proving to be extremely valuable in providing data of high resolution in both space and time, especially in the lower layers of the atmosphere. Wind profilers are especially useful in making observations at times between balloon-borne soundings, and have great potential as a part of integrated networks. Doppler radars are used extensively as part of national, and increasingly of regional networks, mainly for short range forecasting of severe weather phenomena. Particularly useful is the Doppler radar capability of making wind measurements and estimates of rainfall amounts.

Observation platforms and parameters used at E.C.M.W.F. are:

- UHF/VHF Doppler "clear air" radars (US, Europe and Japan) (PROFILER)
- Used parameter: Wind

3.2.5 Satellites

Currently, the Environmental Observation Satellite network includes five operational near-polar-orbiting satellites and six operational geostationary environmental observation satellites as well as several Research and Development satellites. Polar orbiting and geostationary satellites are normally equipped with visible and infrared imagers and sounders, from which one can derive many meteorological parameters. Several of the polar-orbiting satellites are equipped with sounders instruments that can provide vertical profiles of temperature and humidity in cloud free areas. Geostationary satellites can be used to measure wind velocity in the tropics by tracking clouds and water vapour. Satellite sensors, communications and data assimilation techniques are evolving steadily so that better use is being made of the vast amount of satellite data. Improvements in numerical modelling in particular, have made it possible to develop increasingly sophisticated methods of deriving the temperature and humidity information directly from the satellite radiances. Research and Development (R&D) satellites comprise the newest constellation in the space-based component of the GOS. R&D missions provide valuable data for operational use as well as for many WMO supported programmes. Instruments on R&D missions either provide data not normally observed from operational meteorological satellites or improvements to current operational systems.

Satellite data are supplied either as more or less direct measured radiance or brightness temperatures or as co called retrievals, which are data of the geophysical parameters as temperature, humidity, wind or ozone profiles. In the first case the retrieval is done at E.C.M.W.F., whereas retrievals are obtained directly from the data providers.

Section 4.2 introduces the various types of satellite data used at E.C.M.W.F..

3.2.6 Ground based GPS & Satellite GPS-data

GPS techniques for atmospheric observations exploit the change of phase delay, Doppler shift or bending angel of GPS signals to infer temperature and water vapour in the atmosphere. GPS is the Global Position system consisting of several geostationary satellites. There are space born instruments (CHAMPS, in future GRAS and COSMIC) and ground-based stations, which measure the alteration of the GPS signal in order to retrieve atmospheric observations.

The satellite instruments applying radio occultation measurements provide data with a high vertical resolution whereas the benefit from the ground based measurements is their high temporal resolution.

3.3 E.C.M.W.F data acquisition and pre-processing

The observational data reaches the E.C.M.W.F message database from the RMDCN or are pulled from ftp sites via the ftp gateway. RMDCN is the European Regional Meteorological Data Communications Network between European meteorological centres including EUMETSAT and CIMSS/NESDIS. The ftp - data are mainly satellite data and products from other satellite data providers as the research platforms run by ESA.

RMDCN is based on Frame Relay services provided by Equant, using TCP/IP as transport protocol. FTP. Besides, observational data E.C.M.W.F. receives a number of forecast products from other NWP centres for verification purposes. The volume of this data is about 30 Mbyte per day and rather small compared to the volume of the observational data.

At present E.C.M.W.F receives around 2.0 Gbytes of observation data per day. The data volume from the RMDCN and ftp streams is about the same. Figure 3 shows the number of observations for different observation types. It is obvious that the largest data volumes are coming from satellite data, i.e. Clear Sky radiances (GRAD) from geostationary satellites, infrared soundings from NOAA -satellites (ATOVS) and Atmopsheric Motion Vectors (labelled AMV) (see section 4.2). Frequently updated statistics of the data spatial and temporal coverage of data used operationally is given at E.C.M.W.F.'s web site (see chapter 8).

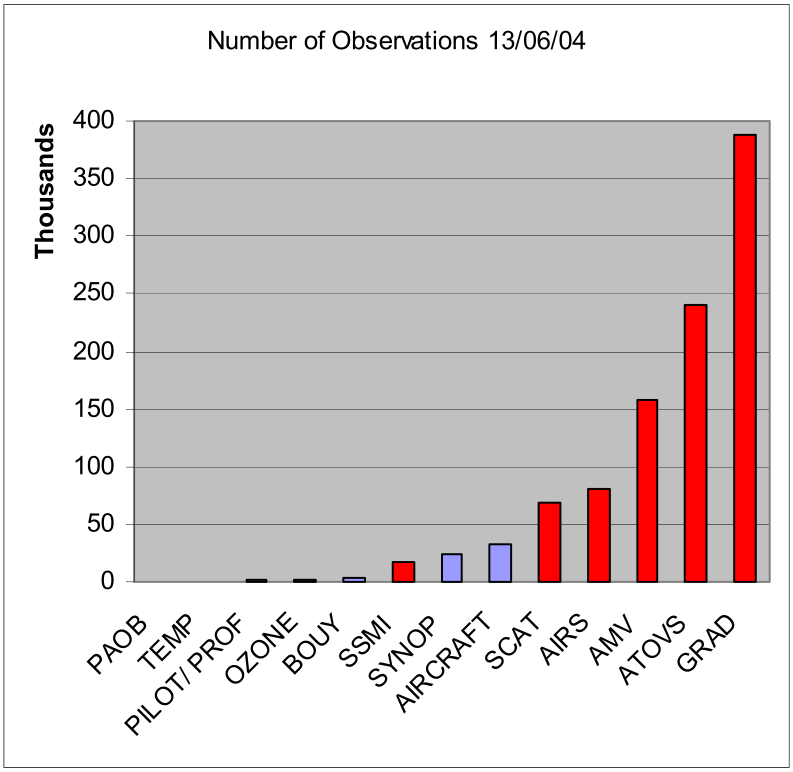

Figure 3 Number of observations acquired by E.C.M.W.F 13/06/2004 0 UTC. Satellite data types are in red colour. (see sections 3.2 and 4.2 for detailed meaning of the various observation types)

The observations data is archived in MARS (see chapter 6) from where it is fed to the data assimilation system of IFS. The feedback of IFS in respect to the observations is stored in MARS as well. MARS holds the observations in the form of files as they are presented to the Analysis (Analysis Input), as well as the feedback files (Analysis Feedback). These are mainly used to allow reproducing in the future any past operational run. There is one set of files per synoptic time.

The data arrive at E.C.M.W.F on one node (happ1) is processed and passed onto a second node (happ2). On node happ2 data is fed into the message database (MDB) and is then further processed and fed into the reports database (RDB). Data from the reports database is pre-processed and fed into observations database ODB for ingestion into the operational models IFS (see also chapter 6.2 and Figure 8). ODB software is a subset of ANSI/SQL query language and was developed at E.C.M.W.F in order to manage the large amounts of satellite data.

At present E.C.M.W.F has three operational databases for observation data residing on a high availability system (HA) and the super computer system (HPC) :

- Message database (MDB) that stores incoming bulletins on HA
- Reports database (RDB) that stores individual reports, at this stage almost exclusively in a compressed binary format BUFR, on HA
- Observation data base (ODB) on HPC that stores observations to be assimilated by IFS in different version of the CMA (central memory array) format (ECMA, CCMA) which includes the data as well derivations from background & analysis, feedback and error information

3.4 Screening of the observation

All observation data received at E.C.M.W.F is subjected to a comprehensive monitoring, screening and thinning process, which is often based on the large sample statistics of the differences between the observations and the model first guess and on information exchange between NWP- centres. The monitoring process leads to bias corrections or black listing of certain data sources when they are obviously erroneous. Feedback of the data quality is given back to the data providers.
Observation screening is either based on the quality of observation itself (independent screening) or on the comparison with other measurements (dependent screening).

Important independent screening operations are:

- Check completeness of the report and blacklist
- Background Quality Control, which is based on the deviation of the observations and the model (background) and their error statistics
- Bias correction

Bias correction is of special importance for satellite data. The bias correction coefficients are recomputed from the past weeks of departure statistics. The feedback files are used for monitoring the performance of the observing and assimilation system. If the removed bias is a model forecast bias, the subsequent assimilation will enforce it. Usually, only half bias is removed.

Dependent screening operations are:

- Vertical consistency test of multilevel reports
- Removal of duplicated report
- Gross check
- Redundancy check and Thinning.

Thinning applies mainly to data with a spatial resolution much higher than the model resolution, i.e. aircraft and many satellite data. Selection criteria for thinning can account for measurement quality and geometry, pixel cloudiness and the time lag to the centre of the assimilation window.
After the screening and thinning operations about 10-20% of the satellite data and ca. 40% of the conventional observations are retained for being assimilated in the model. More precisely percentages of data use are as follows (see section 3.2 for meaning of the acronyms):

- 90% Pressure from SYNOP and SHIP, humidity from SHIP
- 70-90% Pressure from DRIBU, temperature from TEMP, wind from DRIBU, PILOT and TEMP.
- 50-70% Humidity from land SYNOP and TEMP, pressure from PAOB winds from SHIP and AIREP, temperatures from AIREP.
- < 15% satellite observations from ATOVS (radiances), QUIKSCAT (scatteometer winds), SSM/I (humidity observations) and SATOB (cloud wind observations)

3.5 Observation errors used at E.C.M.W.F

The assignment of observation errors is vital for data assimilation since the combination of observations and model fields are based on the respective error statistics. The observation error assumed for data assimilation within IFS illustrates the quality of the observations in relation to the model resolution.
The observational error combines the instrument error and a more general error causing from the transformation of the respective model variable to observation. The latter error accounts for the limited representativeness of the measurement and for errors in the retrieval algorithms.
Three types of observation errors are considered in the IFS:

- Persistence error
- Prescribed observation error
- Combination of these two above, so called final observation error.

The persistence error accounts for the change in the observed variable in the period between the time of the measurement and the time of the analysis. The persistence error is formulated in order to reflect its dependence on the season, and on the actual geographical position of an observation. Seasonal dependency is introduced by identifying winter/summer hemispheres and tropics - regimes. (Typical values)
Prescribed observational errors have been derived by statistical evaluation of the performance of the observing systems, as components of the assimilation system, over a long period of operational use. The prescribed observational errors are given in the IFS documentation (see chapter 8). Currently, observational errors are defined for:

- Wind components
- Height,
- Temperature, and
- Relative humidity
- Brightness temperatures

Figure 4 and Figure 5 show observation errors for surface pressure and 10m winds from selected observation types and the respective global background, i.e. model errors. In all cases the observation error (RMS) is larger than the typical model error. The numbers represent global averages at all observation locations.

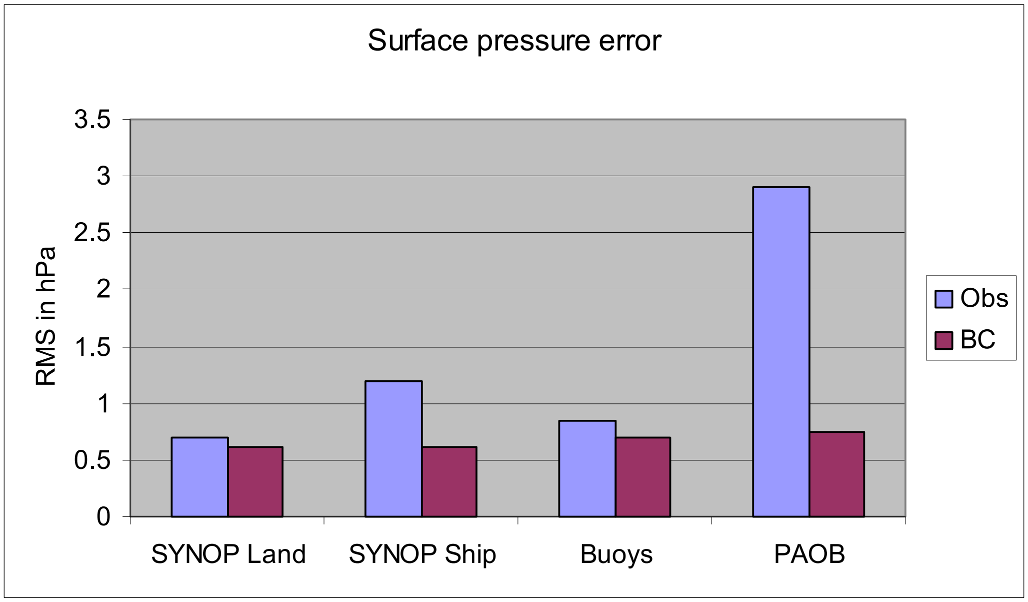

Figure 4 Observation error and typical global value of background error for surface pressure from different observation types.

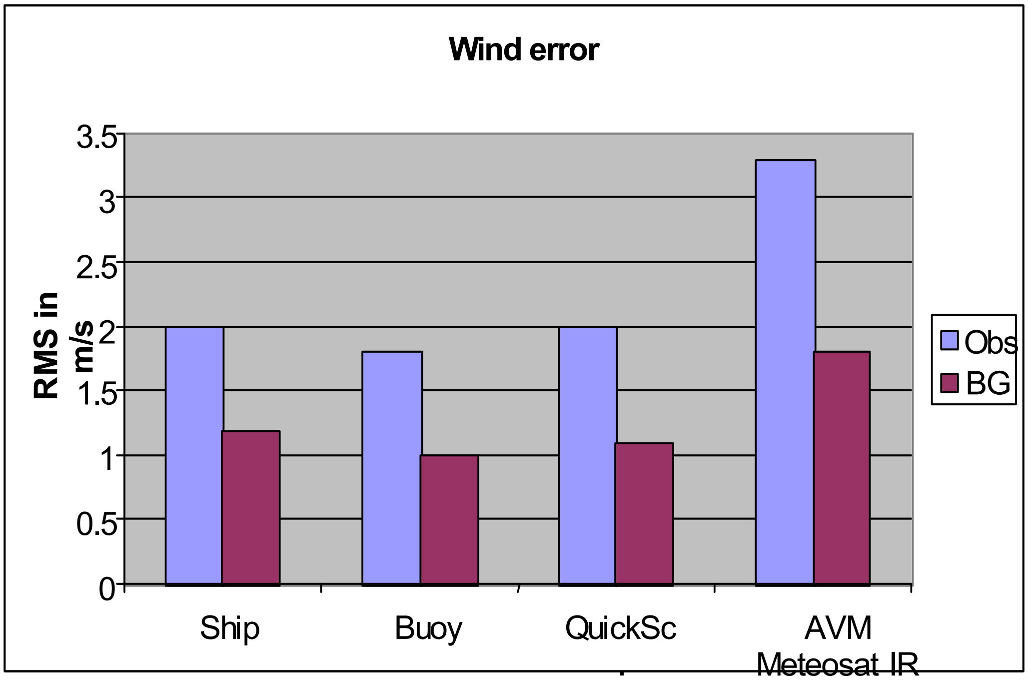

Figure 5 Observation error and typical global value of background error for surface winds from different observation types.

4 Satellite data at E.C.M.W.F

There is a wealth of satellite data measured by numerous instruments on many satellite platforms. The radiances measured at different wavelength are the basis for retrieving information about the state of the atmosphere, the ocean and the land. However, there is no unique classification of the instruments in terms of the geophysical parameters, which could be retrieved. The interaction between the radiance and the atmosphere or the earth surface is manifold and consequently the raw radiances from the certain channels of an instrument can be utilized to extract different quantities, such as humidity and temperature, in different levels of the atmosphere or at the earth surface. At the same time specific product, such as atmospheric motion vector, are retrieved by a combination of several instruments. The quality of the retrieved data depends strongly on the quality of our knowledge of the state atmosphere, which is obtained by models, in situ measurements and other satellite data.

4.1 Classification principles for satellite data

Both instruments and platforms are labelled with abbreviations, which makes it sometimes difficult to find a structure. Most of the satellites carry several instruments and equal or similar instruments are carried on different satellites. The classification of satellite data and instruments considers the following characteristics:

- Orbit of satellite
- Range and spectral resolution of the electro-magnetic spectrum used by the observation instrument
- Active or passive instruments
- Temporal and spectral resolution
- Raw data or retrieved products

The satellites can be discriminated by their orbit:

- Polar orbiting or low earth orbiting **LEO** (distance . 600-1000 km, orbit time 70- 90 minutes, global coverage in several days)
- Geostationary **GEO** (distance . 36000 km, fixed position to earth , high temporal resolution, no view to polar areas)

The length of the wavelength of the measured radiation controls the interaction with the atmosphere and the earth and ocean surface. The wavelength determines which information about geophysical parameters can be retrieved.

- Ultra-violet (sensitive to back scatter due to zone)
- Visible and Near Infra-red sensing (sensitive to vegetation and land surface properties and cloud)
- High-spectral-resolution thermal infra-red sounding data (sensitive to profiles of atmospheric temperature, water vapour and CO_2)

- Microwave sounding and sensing (sensitive to sea-ice, ocean wind, land characteristics, cloud, rain rate and atmospheric temperature and water vapour profiles)

The satellite instruments may be considered as one of 3 different types

- Atmospheric **sounding passive** radiometers (spectrometers) for atmospheric profiles
- Surface **sensing** channels from **passive** radiometers (spectrometers)
- Surface **sensing** channels from **active** instruments (Scatterometer, Radar, Altimeter)

Sensors mainly use radiation ranges (i.e. IR in "atmospheric windows" or MW), which is little influenced by the atmosphere whereas sounders rely more on the interaction of the radiation with the atmosphere. Since the influence of the atmosphere or the earth surface can never be disregarded sensor channels may be used for sounding and vice versa. Clouds, hydrometeors and aerosols in the atmosphere as well as ice or snow cover at the surface can disguise the information of the satellite observation. Therefore their prior detection is important for the retrieval process.

Active sensors send out radiation and receive the reflected or backscattered fraction mainly in the MW range. One distinguishes

- Scatterometers, measuring ocean surface wind speed and direction, land surface properties
- Altimeters, measuring dynamic anomalies in the ocean surface height, as well as ocean surface waves and surface wind speed
- Synthetic aperture radars measuring ocean surface wave spectra and land surface properties

Laser based active sounders (LIDAR) are mainly ground based but will put on satellites as well (Aeolus in 2007).

Temporal and spatial coverage depends first of all on the orbit. Geostationary satellites, which stay about 36000 km above the surface, can supply data in high temporal resolution (~15-30 min) whereas polar orbiting satellites, orbiting at ca. 870 km, need several days to revisit the same spot. Spatial resolution refers to the area for which the satellite observation is valid in an average sense. The spatial sampling rate defines the distances between the measurement locations and is sometime expressed in the number of measurements/profiles per day. The swath width is the area on the ground, which is observed in one line of pixels measured by the sensor of polar orbiting satellites.

Satellite data are supplied either as:

- **Raw radiances**, which are more or less the measurements of the instruments after calibration and quality checking.
- **Retrievals (or products),** which are the geophysical parameters (temperature, wind, ozone profiles, vegetation indices etc.) extracted / retrieved from the radiance information of one or a combination of more instruments

Most of the satellite data received at E.C.M.W.F are products from satellite agencies and other providers. In some cases the data products contain information from several instruments. Most of the raw radiances have been already quality checked and pre-processed as in the case of cloud checking for Clear sky radiances.

At E.C.M.W.F the raw radiances are converted into geophysical parameters in a pre-processing step without directly using model data, in local retrieval with model data using 1D-VAR methods or by direct assimilation in the model by means of 4D-VAR data assimilation techniques. 4D-VAR is the most common and most advanced approach. 4D- variational data assimilation techniques have the advantage of being able to cope with non-linear observation operators. The non-linear retrieval process of the raw radiances can be done in optimal way within the model in accordance with the geophysical parameters given by the numerical model. Direct assimilation avoids complicated errors (random and systematic) introduced by (unnecessary) pre-processing such as cloud clearing, angle (limb) adjustment and surface corrections. Additionally, one has not to change (retune) the assimilation system when the data provider changes the pre-processing, which allows faster access to data from new platforms. Besides, a consistent treatment of historical data for re-analysis projects (ERA-40) is possible.

4.2 Space based atmospheric soundings and sensing used at E.C.M.W.F.

E.C.M.W.F. uses satellite data for operational assimilation in the daily forecast and analysis runs, for operational monitoring without assimilation and for research and verification purposes.

Table 1 lists satellite instruments, whose data are either actively assimilated or just about to be assimilated in the very near future. Table 2 contains a selection of important satellite data, which are used and monitored passively at E.C.M.W.F. for research and verification purposes.

The tables classify the satellite instruments according to the principles discussed in the previous section 4.1. The information concerns the potential of geophysical parameters retrievable from the data and the subset of data, which is actually assimilated or used at E.C.M.W.F. The distinction between the active and passive type is in many cases not precise since new data will be assimilated in the near future and the assimilation of certain data will stop due to diverse quality problems.

Actively assimilated satellite data can be summarized in the following products groups. The name of the satellite is given in brackets behind the instrument name.

Raw radiances (GRAD)

- IR-range
  - HIRS (NOAA 16/17) called ATOVS
  - AMSU-A,B (NOAA 15/16/17/Aqua) called ATOVS
  - AIRS (Aqua)
- MW-range
  - SSM/I (DMSP F-13,13,15)
- VIS-range:
  - Clear sky radiances (GOES 9/10/12, METEOSAT 5/7)

Retrieved products

- AMV - Atmospheric Motion Vectors

  - retrieved from geostationary satellites (GOES 9/10/12, METEOSAT 5/7)
  - retrieved from polar orbiting MODIS (Terra)
  - Unknown parameter: height
- Winds above ocean from Scatterometer
  - Active MW instruments at ERS-2 and Quikscat
  - parameter: sea wind
- Ocean wave characteristics
  - SAR instrument at ERS-2
  - parameter: SAR wave spectrum
  - Radar altimeter instrument at ENVISAT
  - parameter: significant wave height
- Ozone retrievals
  - SBUV (NOAA 16, (14, 17))
  - MIPAS (ENVISAT) but currently black listed

The research type data is mainly products from the following satellites:

- ERS-2 (ESA environmental satellite)
- ENVISAT (ESA environmental satellite)
- Jason (CNES and NASA ocean observing satellite)
- TRMM (NASA Tropical Rainfall Measurement Mission)
- CHAMPS (GPS - radio occultation)
- Ssalto/Duacs - altimeter ocean surface height product from different satellites (Jason ERS-2) compiled at CLS (France).

A more detailed description of the individual instruments and products is given in Appendix A. The text is a compilation of web-based descriptions of the instruments.

SPACE CRAFT ORBIT	INSTRUMENT	RADIATION RANGE / ACTIVE	RETRIEVABLE GEOPHYSICAL MEASUREMENT	ASSIMILATED IN IFS RAW / RETRIEVED	RESOLUTION	REMARKS
Meteosat-5,7 GEO	Imager	VIS, WV, IR	water vapour, winds, cloud data surface temperature, vegetation	WV Clear Sky Rad. (80km) / humidity in upper troposphere AMV	30 min 5 km	
GOES-9, 10, 12 GEO	Imager	VIS, WV, IR	cloud data etc., surface temp, vegetation	WV Clear Sky Rad. (40km) / humidity in upper troposphere AMV	30 min 5 km	
NOAA-16, 17 LEO	HIRS	IR T/q sounder	temperature & humidity profiles, cloud height and surface albedo	raw radiances thinned at 120 km	10 km	ATOVS
NOAA-16,17 LEO	AMSU-B	MW humidity sounder	humidity profiles, atmospheric water	raw radiances thinned at 120 km	15 km	ATOVS
NOAA-15, 16 LEO	AMSU-A	MW temperature sounder	temperature profiles in upper troposphere and stratosphere, atmospheric water	raw radiances thinned at 120 km	40 km	ATOVS
NOAA-14,16,17 LEO	SBUV/2	Scattered UV light from sun	Ozone layers	Ozone retrievals from NOAA-16	200 km	
AQUA LEO	AMSU-A	MW temperature sounder	temperature & humidity profiles, atmospheric water (except of small ice particles)	raw radiances thinned at 120 km	40 km	ATOVS

SPACE CRAFT ORBIT	INSTRUMENT	RADIATION RANGE / ACTIVE	RETRIEVABLE GEOPHYSICAL MEASUREMENT	ASSIMILATED IN IFS RAW / RETRIEVED	RESOLUTION	REMARKS
DMSP F-13, 14, 15 LEO	SSM/I-imager	MW sensor	total column vapour water & sea wind speed	raw radiances thinned at 120 km		
QuikSCAT LEO	Scatterometer	active MW sensor	retrieved surface wind speed and direction above ocean	surface wind above ocean 50 km (assimilated)	25 km (original)	
AQUA LEO	AIRS	high res. IR sounder	Temperature / humidity profiles, O3, CO_2	raw radiances	13 km	
TERRA LEO	Modis	Medium resolution VIS imager	land surface, vegetation status, cloud cover, wind retrieval	AMV water vapour channel (validation)	1 km	
MSG (Meteosat 2nd generation) GEO	SEVIRI Imager	12 channels VIS, IR, WV	water vapour, winds, cloud data surface temp, vegetation	2 WV channels Clear sky radiation in 40 km	3 km	to be used soon
ENVISAT LEO	MIPAS	IR sounder	trace gas, H_2O, temperature and pressure profiles	received: H_2O, Temp, O3 used: O3	3-4 km vertical 1000 profiles per day	ESA retrieval black listed 3/2004
ENVISAT LEO	RA-2	radar altimeter MW	Sea surface height, polar ice sheets, sea ice, surface wind speed, ocean significant wave height, and Earth surface elevation and characteristics	ocean significant wave height retrieved by ESA assimilated in Wave model	1.7 km footprint overlapped to have 20 in the 7 km disseminated product	also contribution to Ssalto/Duacs altimeter product

SPACE CRAFT ORBIT	INSTRUMEN T	RADIATION RANGE / ACTIVE	RETRIEVABLE GEOPHYSICAL MEASUREMENT	ASSIMILATED IN IFS RAW / RETRIEVED	RESOLUTION	REMARKS
ERS2 LEO	SAR (AMI= SAR+WS)	Synthetic Aperture Radar MW	Ocean wave spectrum, land use and cover, soil moisture, ice type and cover	retrieved ocean wave spectra operationally assimilated in Wave model ESA retrieval covering North Atlantic	mode ~5 km x 5 km sampled every 300 km in image mode ~ 30 m	part of AMI together with WindScatterometer
ERS2 LEO	SCAT	active MV Scatterometer	Wind vector above ocean	Backscatter triplet/ quadruplet	assimilated in 100km resolution	ESA retrieval

Table 1 Satellite data operationally assimilated in E.C.M.W.F.s IFS.

SPACECRAFT ORBIT	INSTRUMENT	RADIATION RANGE	RETRIEVABLE GEOPHYSICAL MEASUREMENTS	USED AT E.C.M.W.F. RAW / RETRIEVED	RESOLUTION	REMARKS
ENVISAT LEO	ASAR	Radar active	Ocean wave spectrum, sea ice, snow, ice, surface properties	SAR and ocean wave spectra	in wave mode 5*5 km resolution 150 km sampling	ocean wave spectra is a retrieved product
ENVISAT LEO	AATSR	VIS and IR	sea surface temperatures and the vegetation cover of land surfaces	sea surface temperatures vegetation indices tiles in model grid resolution	0.5 km 500 km swath	
ENVISAT LEO	GOMOS	UV-VIS NIR	trace gas & H_20, temperature profiles in 20-100 km	Ozone profile black listed	20-100 km height, 1.7 km vertical resolution	ESA retrieval
ENVISAT LEO	MWR	MW Radar	total column water vapour	verification		correcting path delays of RA
ENVISAT LEO	SCIAMACHY	Sun UV,VIS,NIR	trace gas profiles and total columns in troposphere, stratosphere	Ozone total column blacklisted	total column 80000 profiles per day	ESA retrieval planed to use operational
ENVISAT	MERIS	Vis - NIR Imager	Ocean colours (chlorophyll activity), Clouds, Albedo, Aerosol, total water vapour	total vapour water column and clouds for verification	4 km	ESA retrieval
ERS2 LEO	RA	radar altimeter MW	Sea surface height, polar ice sheets, sea ice, surface wind speed, ocean significant wave height, and Earth surface elevation and characteristics		1.7 km footprint overlapped to have 20 in the 7 km disseminated product	also contribution to Ssalto/Duacs altimeter product

SPACECRAFT ORBIT	INSTRUMENT	RADIATION RANGE	RETRIEVABLE GEOPHYSICAL MEASUREMENTS	USED AT E.C.M.W.F. RAW / RETRIEVED	RESOLUTION	REMARKS
ERS2 LEO	ATSR	IR	sea surface temperatures and the vegetation cover of land surfaces	vegetation indices tiles in model grid resolution	1 km resolution 500 km swath	along track scanning
ERS2 LEO	GOME	absorption spectrometer	ozone, trace gases and aerosols in the stratosphere and troposphere.	ozone actively assimilated from April 2002 - June 2003		assimilated in era 40 re-analysis
ERS2 LEO	MWR	MW sounder	atmospheric humidity		22 km resolution 500 km swath	
ERS2 LEO	Wind Scatterometer AMI=WS+SAR	MW Scatterometer	Wind speed and direction	500 x 500 km product	22 km resolution 500 km swath	ESA product part of AMI together with SAR
Jason	POSEIDON-2	Altimeter	Sea surface height, polar ice sheets, sea ice, surface wind speed, ocean significant wave height	surface wind speed, ocean significant wave height	~3 km footprint overlapped to have 20 in the 6 km disseminated product	
	·JMR.	Microwave Radiometer	total column water vapour	verification		
TRMM	TMI	multi frequency microwave radiometer	Microwave Brightness Temperature (BT) and	products and raw data		
	PR	precipitation radar	Rain fall rates	verification		
	CERES	a broad band radiometer	earth radiation budget	verification		

SPACECRAFT ORBIT	INSTRUMENT	RADIATION RANGE	RETRIEVABLE GEOPHYSICAL MEASUREMENTS	USED AT E.C.M.W.F. RAW / RETRIEVED	RESOLUTION	REMARKS
Earth Probe etc.	TOMS	Total ozone mapping spectrometer		verification	40 km	various satellite platforms
Jason, ENVISAT, ERS2 etc.	Ssalto/Duacs	altimeter product	Sea Level Anomaly data Geostrophic currents	validation research assimilation for seasonal forecast	twice a week 1/3° Mercator grid	merged by CLS (France)
CHAMP		phase delay Doppler shift, bending angel of GPS signals	temperature and humidity Profiles	bending angel product is received and assimilated in research mode	high vertical resolution 400 km resolution 160 profiles per day	currently only above 4 km off line tests

Table 2 Satellite data assimilated in E.C.M.W.F.s IFS for research and validation purpose

4.3 Future satellite data

E.C.M.W.F. will make extensive use of the new generation of operational and research type satellites. Table 3 lists new satellites and their instruments for meteorological applications expected to be used at E.C.M.W.F. in the next years. The satellites are in many case successions of current operational meteorological satellites with improved instruments supplying data in better coverage and higher resolution. New developments are space born lidars for wind measurements (Aelous) and the GPS receiving system COSMIC.

SATELLITE ORBIT / ORGANISATION	INSTRUMENTS	HERITAGE / PURPOSE	START DATE (PROJECTED)
DMSP F-16 & F17 LEO	SSM/IS	~ SSM/I +AMSU-A + AMSU- B	May 2003, June 2005
MSG-2 GEO /Eumetsat	SERVI	Succession of METEOSAT imager	Nov 2005
WINDSAT LEO / NOAA	Coriolis polarimetric radiometer.	intended to measure ocean surface wind speed and wind direction	January 2003
NOAA-N LEO	HIRS AMSU-A, AMSU-B	follow up of current NOAA satellites	June 2004
NPP (NPOESS preparatory program) LEO	CRIS ATMS VIIRS	~AIRS ~AMSU-A, B ~AVHRR	2006
METOP-1 LEO /ESA	IASI AMSU-A +MWS GOME-2 GRAS ASCAT AVHRR-3 HIRS/4	~AIRS ~AMSU-B ~ GOME ~ GPS radio occultation ~ Scatteromter ~AVHRR ~HIRS	Dec 2005
Aura LEO / NOAA	HIRDLS MLS OMI TES	Atmospheric chemistry measurements	June 2004
COSMIC LEO / USA&Taiwan	GPS - receiver system system	~ CHAMPS (but more than one satellite)	2006

Aeolus LEO / ESA	ALADIN Doppler Lidar	Wind speed and direction measurements	2007
SMOS LEO / ESA	MIRAS (MW Aperture Synthesis Rad.)	Soil Moisture & Ocean Salinity in 30 – 60 km	from 2007
NPOESS LEO / NOAA	CRIS ATMS VIIRS CMIS GPSOS OMPS APS	~ AIRS ~ AMSU-A ~ AVHRR ~ SSM/I ~GPS instrument ~Ozone suite ~Aerosol Pol. Sensor	2011

Table 3 Future satellites and instruments for meteorological applications to be used at E.C.M.W.F.

4.4 Satellite data relevant to GMES at E.C.M.W.F .

E.C.M.W.F. observation data and products are involved in the GMES projects on the atmosphere (tbd), ocean (MERSEA) and land theme (GEOland) in many ways. The following sections briefly mentions satellite data, which are already available or may be used in the respective projects.

4.4.1 Atmospheric trace gas and aerosol data

Satellite monitoring of greenhouse gases, global reactive gases, global aerosols and air pollution are core activities in a proposed project on the GMES atmosphere theme. Envisat instruments GOMOS, MIPAS, SCHIAMACHY (see Table 5) and NASA's Aura satellite (see Figure 6) will play a key roll in providing the measurements.

Ozone

Ozone is already a prognostic variable in the E.C.M.W.F atmospheric model. It kinetics is parameterised by means of ozone and temperature anomalies as well as the annual chlorine content. Ozone satellite products derived from the following instruments are either passively monitored or actively assimilated in IFS by 4D-VAR.

INSTRUMENT	SATELLITE	STATUS	PRODUCT	REMARK
SBUV/2	NOAA-16	active	ozone profiles	
MIPAS	Envisat	active	ozone profiles (+T, H_2O)	currently blacklisted
SBUV/2	NOAA-14, NOAA-17	passive	ozone profiles	currently blacklisted
SCHIAMACHY	Envisat	passive	total column ozone	currently blacklisted
GOMOS	Envisat	passive	ozone profiles (+T, H_2O)	currently blacklisted
GOME	ERS2	passive	total column ozone	used between 4/2002 and 6/2003

Table 4 Ozone products from satellite instruments used actively or passively at E.C.M.W.F.

CO_2

The project COCO aims to use measurements from the latest (and future) satellite missions to monitor carbon dioxide levels in the atmosphere. E.C.M.W.F.'s contribution to the project COCO is the estimation of atmospheric CO_2 by assimilating radiances from the Atmospheric Infrared Sounder AIRS (Aqua) in the 4D-Var system of IFS. Currently two individual values are estimated, a tropospheric mean value and a stratospheric mean value. The tropopause level is dynamically estimated from the forecast model temperature profile. Because CO_2 is currently not a model variable, concentrations are only estimated at the observation locations. Within the COCO project weekly and monthly CO_2 fields are produced.

Global Aerosols
Tests have started to introduce an aerosol tracer in E.C.M.W.F. global atmospheric model. Satellite measurements in clear sky conditions in the spectral range of 0.35 - 2 microns (VIS, near IR) can be applied to infer information about atmospheric aerosol. In the future development of GEMS, retrieved raw radiances and products as aerosol optical depth, aerosol type and size distribution (MODIS on Aqua and Terra) will be assimilated in IFS. Candidate instruments for the satellites aerosol data are:

- MERIS (Envisat)
- MODIS (Aqua and Terra)
- SAGE (Meteor)
- HIRDLS (Aura, see below)
- ATSR (Ers2), AATSR (Envisat)
- SERVI, GERB (MSG)

AURA-Satellite
NASA's Aura Satellite, which is the third in the series of the environmental satellites Aqua and Terra, will be launched June 2004 (see Table 3). It is specially dedicated to the measurements of Earth's ozone, air quality and green house gases. Aura's chemistry measurements will also follow up on measurements, which began with NASA'S Upper Atmospheric Research Satellite (UARS) and continue the record of satellite ozone data collected from the TOMS missions.
Aura carries HIRDLS (High resolution dynamics limb sounder), MLS (Micro wave limb sounder), OMI (Ozone monitoring instrument) and TES (Tropospheric Emission Spectrometer) instrument. The species retrievable from these instruments in different levels of the atmosphere are depicted in Figure 6. Most of the measurements will be valid for the upper troposphere, stratosphere and mesosphere. Ozone, CH_4, CO and HNO_3 profiles can be obtained from TES in the lower troposphere.

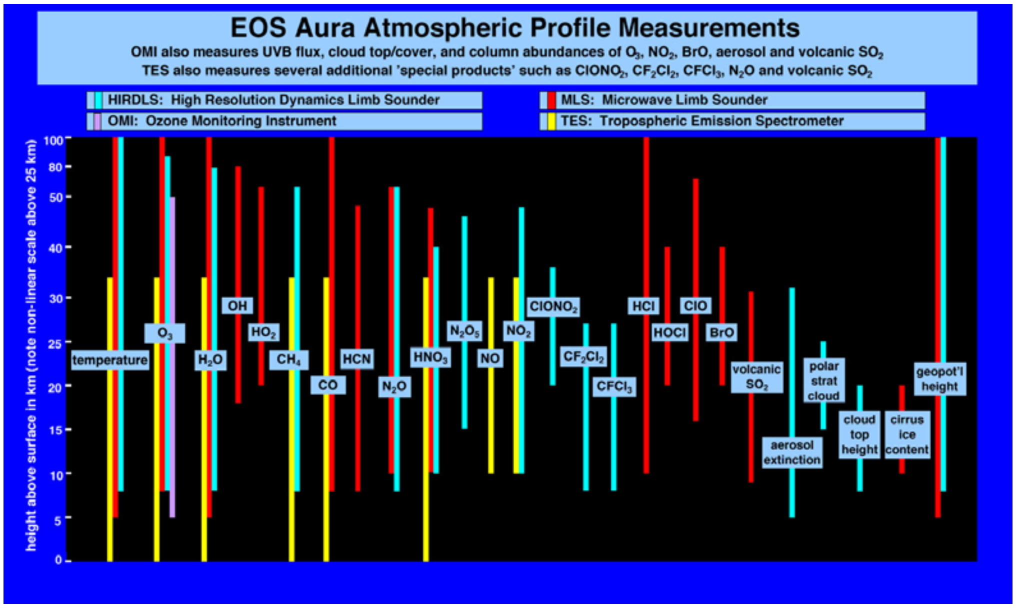

Figure 6 Chemical species, whose concentrations are retrievable in different levels from the AURA satellite instruments HIRDLS, MLS, OMI and TES. Picture form AURA web site (see chapter 8)

GOMOS	MIPAS	SCHIAMACHY			SCHIAMACHY		
Dark Limb		Nadir			Limb		
		UV/Vis	IR	UV-IR	UV/Vis	IR	UV-IR
Density	p					p	
T	T					T	
O_2							
O3	O3	O3			O3		
H_2O	H_2O		H_2O			H_2O	
NO_2	NO_2	NO_2			NO_2		
	N_2O		N_2O			N_2O	
NO3							
	HNO3						
OCLO		OCLO					
		BrO			BrO		
		H_2CO					
			CO			CO	
	CH4		CH4			CH4	
		SO_2					
				Cloud frac.			
				Cloud top h.			
Aerosol				Aeros. Ind.			Aeros. Ind
				UV index			
						CO_2	

Table 5 Chemical species, whose atmospheric concentrations can be derived from the Envisat instruments MIPAS, GOMOS and SCHIAMACHY. http://envisat.esa.int/workshops/acve2/

4.4.2 Land surface properties

GEOLAND activities at E.C.M.W.F. will lead to a near operational land data assimilation system which includes a carbon-water-energy land surface scheme, fitted with a photosynthesis-based evaporation scheme, an evolution equation for leaf biomass, and simplified treatments of carbon dynamics in woody biomass and soil pools. The following satellite data will be used to get information about the vegetation status and soil moisture:

- 1 km resolution visible range data for preparing vegetation indices, preferably as tiled products already in the model resolution
- 20-40 km resolution for soil moisture

Candidate instruments for providing global near realtime vegetation indices (e.g. LAI, NDVI) of past, present and future in a high resolution are AATSR (ENVISAT), MERIS (ENVISAT), MODIS (TERRA), AVHRR (NOAA), AVHRR-3, (Metop, 2005), POLDER (lost in 2003), POLDER II (ADEOS II), and VEGETATION (SPOT). The products have to be up-scaled to the model resolution (~100 km) in so called tiles, which represent subregions of the grid cell containing a single plant functional type.

Passive MW radiometer instruments can measure soil moisture in a thin top soil layer (<10 cm), since soil moisture influences the MW emissivity. The sensitivity of brightness temperature to soil moisture increases with decreasing frequency. Therefore, L-band (1.4 GHz) data are best suited for soil moisture retrievals. The SMOS L-band sensor (see Table 3) will provide these measurements globally from 2007. Currently the 6.9 GHz channel of the AMSR sensor on Aqua may provide soil moisture information.

4.4.3 Ocean forcing

Determination of forcing global meteorological fields for MERSEA's global ocean model will be a primary task of E.C.M.W.F. Near real-time satellite data can be used to improve the forcing fields for wind stress and turbulent heat fluxes, which are the most important forcing.

Scatterometer wind data are already assimilated in E.C.M.W.F. but at present the meteorological assimilation truncates often many small spatial and temporal scales, which are critical for ocean dynamics. Higher resolution of the E.C.M.W.F. atmospheric model will lead to the assimilation of high resolution (25/12.5 km) wind data from SeaWinds (on board QuikScat and ADEOS-2) and ASCAT (METOP) in the coming years.

5 E.C.M.W.F.'s data products

This chapter introduces the IFS products, which are finally stored in the MARS archive. Operationally, a high resolution medium range deterministic forecast and a medium range ensemble forecast are carried out by coupled atmosphere - wave model.

A coupled atmosphere - ocean model is applied for monthly and seasonal ensemble forecasts since ocean dynamics have to be considered in this time scale.

The products are forecasted and analysed fields of the deterministic model, ensemble prediction products and accumulated climatological fields.

5.1 Forecast and analysis from deterministic atmosphere and wave model

Every day, E.C.M.W.F. integrated forecast system IFS produces a global analysis and forecast to ten days ahead and archives them in MARS. Currently (2004), the spectral truncation is extended to wave number 511 (ca. 0.35 ° , lat, lon,) which means a horizontal resolution of about 40 km. 60 layers represent the atmosphere up to 70 km height. An ocean wave model is integral part of IFS, which forecast the state of the ocean surface.

An analysis is the best gridded estimate of the state of the atmosphere combining information from observations and the model. Data assimilation for the analysis is based on 12h 4D-VAR cycling for the atmosphere. Although atmospheric and wave model are coupled in the forecast mode, the analysis of ocean waves and land surface is carried out independently by a more simpler Optimum Interpolation scheme.

The following products are available from the global analysis of the Atmosphere:

- Global analyses for the four main synoptic hours 00, 06, 12 and 18 UTC.
- First guess: a forecast with base time from the previous synoptic hour and a forecast time step of (usually) 6 hours.
- Errors in Analysis and first guess
- Boundary conditions for limited area models

The following products are available from the global forecast of the Atmosphere:

- Forecast to ten days from 12 UTC at 40 km resolution (high-resolution model)
- Forecasts to three days from 00, 06, 12, 18 UTC at 40 km resolution to provide boundary conditions for Local Area Modelling in the Member States
- Boundary conditions for limited area models.

Since 1998, E.C.M.W.F. s deterministic atmospheric model is coupled with a wave model. The wave model that is used for ocean wave forecasting at E.C.M.W.F. is the WAM model. It describes the rate of change of the wave spectrum due to advection, wind input, dissipation due to white capping and non linear wave-wave interactions. The wave spectrum gives the distribution of wave energy over frequency and direction and gives a complete specification of the sea state. The WAM model is the first model that solves the complete energy balance equation, including the computationally expensive non linear interactions.

The following products are available from the global analysis of the ocean waves:

- global analyses of the surface of the oceans for the four synoptic hours at 55 km resolution
- European waters analysis of the surface of the oceans for the four synoptic hours at 27 km resolution.

The following products are available from the global forecast of the ocean waves:

- Global forecast to ten days from 00 and 12 UTC at 55 km resolution
- European waters forecast to five days from 00 and 12 UTC at 27 km resolution

The daily forecasted and analysed geophysical variables from the deterministic atmospheric model runs are listed in Table 6 and Table 7. Table 8 contains a selection of variables by the wave model. The atmospheric multi-level data are given on the following vertical coordinate systems:

- Surface, these fields represent the meteorology at the surface.
- Pressure levels, computed by the model from its Model Levels.
- Isentropic levels, either potential vorticity or potential temperature.

VARIABLE NAME	ACRONYM
Mean sea level pressure	MSL
10m U-velocity	10U
10m V-velocity	10V
2m temperature	2T
2m dew point	2D
2m max temperature	MX2T
2m min temperature	MN2T
Total cloud cover	TC
Total precipitation	TP
Surface temperature of soil	ST
Snow depth	SD
Large scale precipitation	LSP
Convective precipitation	CP
Snow fall	SF
Log surface pressure	LNSP
Land/sea mask	LSM
Wind gust at 10 metres	10FG
Surface solar radiation downward	SSRD
Total Column Ozone	TCO3

Table 6 Single level parameters Atmosphere

VARIABLE NAME	ACRONYM
Geopotential height	GH
U-velocity	U
V-velocity	V
Specific humidity	Q
Relative humidity	R
Vertical velocity	W
Vorticity	VO
Temperature	T
Divergence	D
Potential vorticity	PV

Table 7 Multi-level parameters atmosphere

VARIABLE NAME	ACRONYM
Significant wave height	SWH
Mean wave direction	MWD
Peak period of 1D-spectra	PP1D
Mean wave period	MWP
2D wave spectra	2DFD
Significant height of wind waves	SHWW
Mean direction of wind waves	MDWW
Mean period of wind waves	MPWW
Significant height of primary swell	SHPS
Mean direction of primary swell	MDPS
Mean period of primary swell	MPPS

Table 8 Some wave model fields (over ocean)

5.2 Forecast of the Ensemble Prediction System

In addition to the deterministic forecast, E.C.M.W.F. operates an Ensemble Prediction System (EPS) by means the following model runs:

- An ensemble of 50 forecasts to ten days from 12 UTC at 80 km resolution - the Ensemble Prediction System (EPS)
- Control run forecast to 21 days from 12 UTC at 80 km resolution

EPS explores the concept of probabilistic forecasting by creating perturbations on the initial conditions, then running a forecast for each of the perturbations. The E.C.M.W.F. weather prediction model is run 51 times from slightly different initial conditions. The EPS control forecast runs from the operational E.C.M.W.F. analysis. 50 additional integrations, the perturbed members, are made from slightly different initial conditions, which are designed to represent the uncertainties inherent in the operational analysis. The initial perturbations are generated using the singular vector technique. To take into account the effect of uncertainties in the model formulation, each forecast is made using slightly different model equations. E.C.M.W.F.'s Ensemble Prediction System has a coupled atmospheric and wave model.

The variables of the EPS are the same as in the deterministic system and are listed in Table 5, Table 6 and Table 7. Typical products, derived from the ensemble and the control run are:

- Control forecasts, an unperturbed forecast at a lower resolution than the main 10-day forecast. Forecast runs to 21 days. Data is available at Surface, Model and Pressure levels.
- Perturbed forecasts, different forecasts to 10 days with perturbed initial conditions. They are numbered from 1 to N depending on the EPS setup. Data is available at Surface and Pressure levels.
- Forecast probabilities , a statistical distribution of the weather parameters from all ensemble members is used to produce probabilistic weather forecasts.
- Forecast mean probabilities, are means of the above over certain periods of time.
- Ensemble means, are means of the ensemble forecast members.
- Clusters, similar ensemble members are grouped together into clusters. The mean and standard deviation of these clusters are computed (as well as the mean and standard deviation of the overall ensemble). Five sets of clusters are computed, one for the entire European area, and four for smaller areas.
- Tubes, use the tube method for clustering ensemble forecast members.

5.3 Seasonal and monthly forecast from coupled atmosphere-ocean-model

Seasonal forecast

Every month, the coupled atmosphere - ocean model is applied to make a 6 month forecast with about 40 members. Full coupling is applied between the atmosphere and ocean. The ensemble members are generated by wind and sea surface temperature perturbations and by stochastic physics.

Seasonal forecasting is justified by the long predictability of the oceanic circulation (of the order of several months) and by the fact that the variability in tropical SSTs has a significant global impact on the atmospheric circulation. Since the oceanic circulation is a major source of predictability in the seasonal scale, the E.C.M.W.F. seasonal forecasting system is based on coupled ocean-atmosphere integrations.

The coupled model consists of the E.C.M.W.F. atmospheric model (cycle 15r8), coupled to an ocean general circulation model which is a version of the Hamburg Ocean Primitive Equation model (HOPE) developed at the MPI Hamburg. The coupling happens once per 24 hours by means of the module OASIS. Currently the atmospheric model is run at T63 resolution (1.8 x 1.8 degrees, ca. 200 km) with 31 levels in the vertical. The ocean model has lower resolution in the extratropics but higher resolution in the equatorial region in order to resolve ocean baroclinic waves and processes, which are tightly trapped to the equator. The ocean model has 20 levels in the vertical, 8 of which are in the upper 200m.

Because of model error, a drift occurs after coupling which is not small compared with the size of the signal being predicted. This drift is subtracted from the model fields once the integration is complete. Typical products of the seasonal are based on monthly averages.

The ocean model provides forecasts about various variables of which the most important are:

- Ocean potential temperature
- Ocean salinity
- Ocean potential density
- Velocities in the ocean model layers and correlation products
- Wind stress
- Radiation and heat fluxes
- Mixed layer depth
- Sea level
- Depth of the isothermal surface

Monthly forecast

The main goal of monthly forecasting is to fill the gap between the medium-range and seasonal systems and produce forecasts for the time range 10 to 30 days. With the same model setup as the seasonal forecast, this project runs weekly producing forecasts to 32 days, again, coupling atmospheric, wave and ocean models. The monthly forecasting system has been built as a combination of the medium-range EPS and the seasonal forecasting system. It contains features of both systems and, in particular, is based on coupled ocean-atmosphere integrations, as is the seasonal forecasting system and with a 51-member ensemble. The resolution is higher as for the seasonal forecasts. Typical products of the seasonal are based on weekly averages.

5.4 Special Projects and Climatological data sets

Output of research projects run on an regular basis, such as Seasonal Forecast, Multi-Analysis Ensemble, Monthly Forecast and Sensitivity forecast, or the E.C.M.W.F. Re-Analysis (ERA 40) are available in MARS.

Monthly and climatology datasets

E.C.M.W.F. maintains an archive of monthly means data from the atmospheric and wave model archive. The resolution and internal representation of the archive may change according to changes in E.C.M.W.F.'s operational practice. Atmospheric Analysis monthly means are averaged over the calendar month for each of the synoptic times 00, 06, 12 and 18 UTC. All monthly means are archived at model resolution.

E.C.M.W.F. Re-Analysis ERA 40

The E.C.M.W.F. Re-Analysis (ERA) project has produced a new, validated 40 year data set of assimilated data for the period 1957 to mid 2002. This has been named ERA-40, and available datasets include: analysis, forecast and forecast accumulations as output from atmospheric model, as well as analysis and forecast from a wave model re-analysis. There is also a Monthly Means data sets contain data at the resolution of the data assimilation and forecast system used by ERA-40.

DEMETER

It is the acronym of the EU-funded project named Development of a European Multi model Ensemble system for seasonal to inTERannual prediction. The objective of the project is to develop a well-validated European coupled multi-model ensemble forecast system for reliable seasonal to inter annual prediction. Six comprehensive European global coupled atmosphere- ocean models are being installed at E.C.M.W.F., those of: E.C.M.W.F., Meteo-France, LODYC, Met Office, MPI, INGV, INM-HIRLAM and CERFACS.

PROVOST

Provost stands for Prediction Of climate Variations On Seasonal to inter annual Time scales. They are a set of experiments from four centres: E.C.M.W.F., MétéoFrance, EDF and Met Office. The experiments are 120 day runs from 9 consecutive starting days, with write-ups every 24 hours of Pressure level and Surface data.

ECSN-HIRETYCS

ECSN is the European Climate Support Network. HIRETYCS is the High Resolution Ten Year Climate Simulation. This data set consist of 10-year climate simulation produced at three centres: Centre National de Recherches Météorologiques (CNRM), Max Planck Institute (MPI) and United Kingdom Met Office.

Multi-Analysis Ensemble

Every day E.C.M.W.F. receives Analyses from four centres, National Center for Environment and Prediction, The Met Office, Meteo-France and Deutscher Wetterdienst, and runs 5 forecasts, 1 based on each different analyses plus one compound of all the analyses (consensus) including E.C.M.W.F. s Analysis.

6 E.C.M.W.F. data archive MARS

6.1 Overview

E.C.M.W.F.'s **M**eteorological **A**rchival and **R**etrieval **S**ystem (MARS) is the main repository of meteorological data at E.C.M.W.F. It contains currently (mid-2004) 870 terabytes of data, which are mainly

- Operational observation data and feed back reports (see chapter 3 & 4)
- Daily produced forecasts and analysis from E.C.M.W.F.s IFS (see chapter 5)
- Special datasets for verification & research purposes and from special research projects (see chapter 5.4)

This chapter intend to briefly introduce the technical basis of the archive in terms of data format, architecture and post processing operations. Most of the data produced at E.C.M.W.F. is archived in MARS, and therefore available to users. MARS data is freely available to registered users in the Member States and Cooperating States. There is no public access to MARS but for research and commercial use, data can be obtained through E.C.M.W.F. data services. For research use only, datasets are freely available.

There are a number of factors differentiating MARS from other archive systems around the world:

- Facilities to Archive and Retrieve meteorological data, enabling very easy access to the Archives via a pseudo-meteorological language
- Different requirements imposed by E.C.M.W.F.'s Operational and Research environments. They force MARS to be a 24 hour service with as very little down-time as possible
- Batch and interactive modes have to be supported
- Large amount of data, both in size and number of items stored
- Large number of users with different requirements. Some users retrieve large datasets rarely, whereas others retrieve few fields very often.
- Heterogeneous environment, involving Supercomputers, user workstations and remote systems all interconnected with a variety of network technology

The MARS system is based on a client/server architecture, which makes it more flexible and adaptive to changes in a complex environment like E.C.M.W.F.'s. The interaction between clients and servers is based on MARS requests. Clients send MARS requests to a server, which looks for the data on-line or off-line, depending on the capabilities of the given server. The request can also include post-processing of the data like sub area extraction and grid conversion.

6.2 MARS within EMOS Architecture

Figure 7 depicts MARS within the data flow in E.C.M.W.F. meteorological operational system EMOS. MARS gets observation data from the Reports Data Base

(RDB) and feedback from the Observation Data Base (ODB). E.C.M.W.F. forecast and analysis products are acquired from the Field Data Base (FDB).

RDB contains on-line observations received via E.C.M.W.F.s acquisition system (see chapter 3.3). This system has been interfaced with MARS to allow real-time observation access. Access to this server is meant for monitoring and operational archive purpose only. Together with the Message Data Base (MDB), RDB is part of the High Availability hardware system.

ODB contains observation data to be used directly by the model and model feedback data. FDB is where the integrated forecast system (IFS) writes its outputs. ODB and FDB belong to the High Performance Computer System. FDB contains data produced by the most recent cycles. Depending on the configuration and disk resources, it can contain up to several days of operational data and more recent research experiments. It is meant to provide very fast access as all the data resides on-line. This makes it very suitable for model input data retrieval or last cycles data access. Operational products are directly extracted from ODB for dissemination to the member states.

The hard and soft ware basis for E.C.M.W.F.'s data handling system (DHS) which host the MARS archive and an additional file based archive ECFS consists of:

- IBM servers running AIX 4.3
- StorageTek and IBM Tape robots
- Data management Software systems written in C++ linked with the EMOS-library
- High Performance Storage system (HPSS)

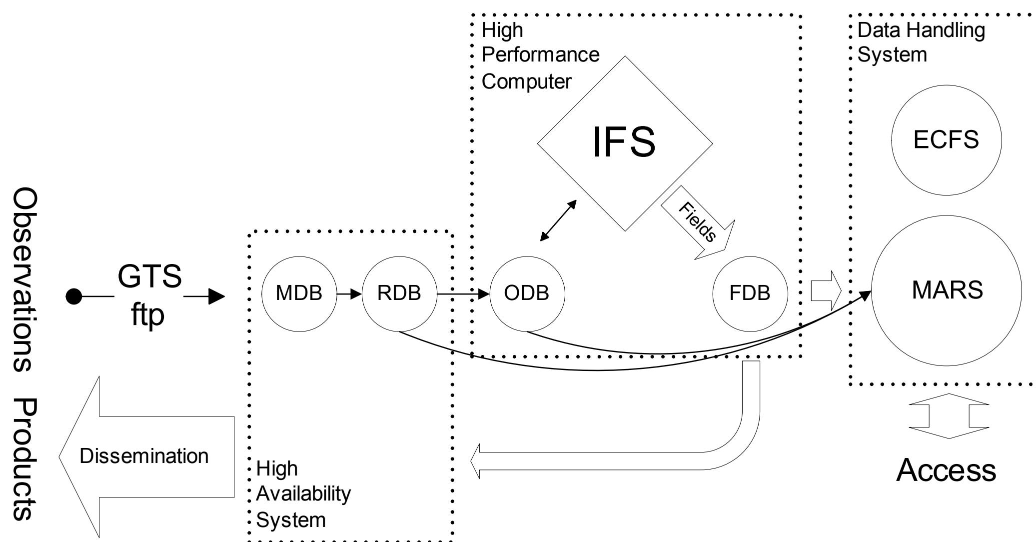

Figure 7 Operational data flow in EMOS. RDB, MDB, ODB and FDB refer to report, message, observation and field data base. Lines indicate flow of observation data and arrows of E.C.M.W.F. products. IFS is the integrated forecast system, MARS is the main archive, dotted lines indicate hardware systems.

6.3 Data formats

MARS uses GRIB format for meteorological fields and some satellite data and BUFR format for all other point wire meteorological observations including many satellite data. Both formats are WMO standard.

GRIB (GRId in Binary, WMO FM 92-IX Ext) is a WMO defined format for meteorological field data, or (more generally) any regularly spaced gridded data. All E.C.M.W.F. model output is in GRIB format with E.C.M.W.F. local extensions in their headers. The GRIB format is handled via the GRIBEX subroutine, part of the EMOS-library at E.C.M.W.F..

GRIB data is archived in one of the following spatial coordinate systems:

- Spherical Harmonics (SH), mainly for upper air fields
- Gaussian Grid (GG), mainly for surface data, although some upper air fields as well
- Latitude/Longitude (LL), other centre's data, wave and ocean data

BUFR (Binary Universal Form Representation) is a WMO defined format for point data (irregularly spaced). Archived observations are in BUFR format. The BUFR format is handled via the BUFRDC subroutine, part of the EMOS-library at E.C.M.W.F.

6.4 Post-processing

Requested data manipulation or post-processing is carried out by the MARS client, except in the case of a local Member State s client where data is first processed at E.C.M.W.F. prior to its transmission over the network. The post-processing is carried out by a set of routines present in the EMOS-library. The following post-processing operations are available

- Sub-area extraction
- Conversions of grids
- Derivation of fields which are not archived directly
- Defining accuracy for GRIB
- Truncation before interpolation
- Rotation of grid

6.5 Present and future data requirements

The amount of daily archived observation data is about 1,5 Gbytes in Mid-2004. E.C.M.W.F is expecting to receive around 25 Gbytes per day by the end of 2007 due to new high resolution satellite data (see Table 3.) The estimated increase in observation data volumes is shown in Table 9. The estimate assumes that the principle components method for compressing the data is satisfactory for all research's needs.

The daily data volume of the E.C.M.W.F products (forecasts and analysis) stored in MARS every day is about 1000 Gbytes in Mid-2004. About 200 - 400 Gbytes are produced by the operational forecast system whereas the larger rest of the data is output of research activities.

The data volumes of the products will increase due to new products and to higher resolution of the model. Next steps in respect to resolution will be the increase in the vertical to a 90 layer model (currently 60) and in the horizontal resolution T 799 (25 km) in 2005. The new early delivery suite, introduced in 2004, increases the daily data volume as well.

The total data volume of MARS has an average growth rate of about 60% per year and will reach the size of 1 Peta byte this year. The size of the archive growth is exponentially and proportional to the increase of the computer power of E.C.M.W.F.

The estimation of future data volumes presented here is based on current figures and "scaled" estimates of the data volume growth rate. UK Met Office satellite data volume plan (Roger Saunders, 2003) was the basis for the observation data volume increase and the invitation to tender E.C.M.W.F./2001/172 (Acquisition of a replacement data handling system) for the overall data volume in MARS.

YEAR	ESTIMATED MAXIMUM OBSERVATION DATA VOLUME STORED (GBYTES PER DAY)	E.C.M.W.F OPERATIONAL FORECAST PRODUCTS (GBYTES PER DAY)
mid 2004	1,5	300
mid 2005	2,8	500
mid 2006	25,0	800
mid 2007	25,0	1200
mid 2008	150,0	2000

Table 9 Estimated maximum data volume stored in Gbytes per day at MARS.

7 E.C.M.W.F. data policy

Products originating from E.C.M.W.F. and observation data held in archive MARS are made available to sustain World Meteorological Organization (WMO) Programmes and in particular to assist receiving National Meteorological Services (NMSs) in the provision of meteorological support in their countries.

Resolution 40 (Cg-XII) of the WMO controls the conditions of the data exchange. As a fundamental principle of the WMO, and in consonance with the expanding requirements for its scientific and technical expertise, WMO commits itself to broadening and enhancing the free and unrestricted international exchange of meteorological and related data and products. Resolution 40 distinguishes between:

- Essential data and products,
- Additional data and products

Essential data are available on a free and unrestricted basis whereas additional data are freely available under certain restrictions on their use. Essential data include basic surface synoptic network data, upper-air sounding network data, marine observations and satellite images. Further product and data exchange can be based on bilateral agreement.

Moreover, resolution 40 foresees that members should provide to the research and education communities, for their non-commercial activities, free and unrestricted access to all data and products exchanged under the auspices of WMO.

E.C.M.W.F. products are labelled as "additional", in the sense of resolution 40 (Cg-XII) of the WMO have the following conditions placed on their use and all receiving "Recipients" should be notified accordingly. These conditions apply equally to the Recipient and to third parties to whom the products are made available by the Recipient. Where these conditions are not maintained, even after notification of default to the Recipient, E.C.M.W.F. reserves the right to introduce denial of access to those "additional" products to the Recipient (for all purposes).

1. Intellectual property rights in the products are retained by E.C.M.W.F.. Nothing in this transmission shall operate or have effect of any transfer or assignment of the proprietary or intellectual property rights of E.C.M.W.F.. The Recipient should make its best efforts to ensure that the present conditions which have been applied by E.C.M.W.F. are made known to initial and subsequent recipients.

2. The products are made available to the Recipient in order to sustain WMO programmes at the global, regional and national levels and to help NMSs meet their national responsibilities. The conditions attached to the products will remain attached during further transmissions as part of those WMO programmes.

3. Any commercial use of the products outside the territory of the Recipient is prohibited, unless a specific agreement is concluded between the NMS of an E.C.M.W.F. Member State or Co-operating State and the operator which wants to make the commercial use of the products.

4. If the Recipient uses these products as input for any regional Numerical Weather Prediction (NWP) model output which covers part of or/all of the E.C.M.W.F.

territory, the commercial use of that model output within the E.C.M.W.F. territory (directly or indirectly) will continue to carry the conditions attached to the products.

5. If the Recipient implements new products or services whose construction would suffer significant degradation by removal of the products and from which the products can be retrieved easily, or their use can be identified unambiguously, the commercial use of these new products or services outside the territory of the Recipient is prohibited unless a specific agreement has been concluded between a NMS of an E.C.M.W.F. Member State or Co-operating State and the operator which makes the commercial use.

6. Free use of the products for research and education which has no commercial application is granted; but all other conditions (as listed above) remain attached, particularly where the products are subsequently released or used outside the receiving territory. The Recipient shall make best efforts to make these conditions known to the entities which might make use of the products for research or education. The Recipient should also make best efforts to satisfy itself that this special allowance is properly limited to the use for research and education envisaged under WMO Resolution 40. (If it proves necessary, E.C.M.W.F. reserves the right to request those entities which wish to make use of the products for research and education to sign a statement recognising that they have been made aware of the conditions).

7. Except for the case of WMO programmes, or of specific agreements provided for in paragraph 3 to 6, any transmission of the products outside the territory of the Recipient, or any release which may be followed by a transmission by a non-encrypted radio, satellite broadcast or publicly accessible information system and which are thus available for commercial use, directly or indirectly, is considered to be in breach of these conditions.

8. The Recipient shall make its best efforts to make all these conditions known to potential operators which might wish to make commercial use of the products.

The following E.C.M.W.F. products are available via WMO's GTS network, but under above listed restricted conditions. GTS is the global telecommunication network and is freely available under the conditions of resolution 40.

PARAMETER	LEVEL	DOMAIN	STEPS
Z	500	G	H+00,24,48,72,96,120,144,168
T	850	G	H+00,24,48,72,96,120,144,168
u,v	850	G	H+00,24,48,72,96,120,144,168
u,v	700	G	H+00,24,48,72,96,120,144,168
u,v	500	G	H+00,24,48,72,96,120,144,168
u,v	200	G	H+00,24,48,72,96,120,144,168
Rel Humidity	850	G	H+00,24,48,72,96,120,144,168
Rel Humidity	700	G	H+00,24,48,72,96,120,144,168
MSL pressure surface		G	H+00,24,48,72,96,120,144,168
Divergence	700	T	H+00,24,48,72,96,120,144
Vorticity	700	T	H+00,24,48,72,96,120,144

Table 10 E.C.M.W.F. deterministic model products available via WMO's GTS, G = Global T = Tropics between 35S and 35N

PARAMETER	LEVEL	DOMAIN	STEPS
Prob Pecip>10mm	surface	NH,SH	H+72,96,120,144
Prob Pecip>20mm	surface	NH,SH	H+72,96,120,144
Wind gusts>15m/s	surface	NH,SH	H+72,96,120,144
Wind gusts>25m/s	surface	NH,SH	H+72,96,120,144

Table 11 E.C.M.W.F. EPS products available via WMO's GTS, NH = Northern Hemisphere north of 20 deg SH = Southern Hemisphere south of 20 deg

8 Links to documentations on the web

- Satellite instruments and products
  - Envisat Instruments http://www.esa.int/envisat/instruments.html
  - ERS-2 instruments : http//earth.esa.int/ers/instruments
  - AURA satellite instruments HIRDLS, MLS, OMI and TES http://aura.gsfc.nasa.gov/index.html
  - NESIS ozone products from SBUV http://orbit-net.nesdis.noaa.gov/crad/sit/ozone/
  - EUMETSAT atmospheric motion vectors http://www.eumetsat.de/en/index.html?area=left7.html&body=/en/dps/mpef/aqc_winds/aqc_description.html&a=730&b=1&c=700&d=700&e=0
  - EUMETSAT SAF satellite facilitation project http://www.eumetsat.de/SAF
  - Tropical Rainfall Measurements Mission (TRMM) http://esapub.esrin.esa.it/pff/pffv9n2/tev9n2.htm
  - Jason Instruments http://www.jason.oceanobs.com/html/missions/jason/
- E.C.M.W.F. documents
  - E.C.M.W.F. daily observation data coverage map: http://www.E.C.M.W.F..int/products/forecasts/d/charts/monitoring/coverage
  - Overview MARS archive: http://www.E.C.M.W.F..int/services/archive/overview.html) http://www.E.C.M.W.F..int/publications/manuals/mars/guide/Products.html
  - E.C.M.W.F. products: http://www.E.C.M.W.F..int/products/forecasts/guide/
  - E.C.M.W.F. data service: (http://www.E.C.M.W.F..int/products/data/).
  - E.C.M.W.F. IFS model http://www.ecmwf.int/research/ifsdocs/
- Miscellaneous
  - WMO web site on global observation system http://www.wmo.ch/web/www/OSY/gos-components.html
  - GMES general information: http://www.gmes.info/
  - GMES and ESA http://earth.esa.int/gmes/
  - GMES cross - cutting assessment team http://www.gmes-cca.co.uk

Appendix A

Description of satellite instruments and retrieved products

Instruments assimilated in IFS at E.C.M.W.F.

- **High resolution Infrared Radiation Sounder (HIRS).** HIRS is an atmospheric sounding instrument that provides important information on atmospheric temperatures in cloud-free conditions since 1978. HIRS is a twenty channel atmospheric sounding instrument for measuring temperature profiles, moisture content, cloud height and surface albedo. HIRS instruments on the NOAA-16 and NOAA-1 satellites are currently assimilated actively in operations. All other radiances are monitored passively.
- **Advanced Microwave Sounding Unit A (AMSU-A).** AMSU-A is a 15-channel microwave temperature/humidity sounder that measures atmospheric temperature profiles and provides information on atmospheric water in all of its forms (with the exception of small ice particles). The first AMSU was launched in May 1998 on board the National Oceanic and Atmospheric Administration's (NOAA's) NOAA 15 satellite. AMSU-A instruments on the NOAA-15, NOAA-16, NOAA-17 (currently no data due to faulty sensor) and AQUA satellites are currently assimilated actively in operations.
- **Advanced Microwave Sounding Unit B (AMSU-B).** AMSU-B is a 5-channel microwave sounder. The purpose of the AMSU-B instrument is to receive and measure radiation from a number of different layers of the atmosphere in order to obtain global data on humidity profiles. It works in conjunction with the AMSU-A instruments to provide a total of 20 microwave channels for atmospheric sounding. AMSU-B instruments on the NOAA-16 and NOAA-17 satellites are currently assimilated actively in operations All other radiances are monitored passively.
- **Special Sensor Microwave Imager (SSM/I).** SSM/I is a seven-channel, four frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0 and 85.5 GHz. The first satellite equipped with a SSM/I instrument was F8, launched in 1987, aboard the Defense Meteorological Satellite Program (DMSP). SSM/I instruments on the F-13, F-14 and F-15 satellites are currently assimilated actively in operations.
- **Atmospheric InfraRed Sounder (AIRS).** AIRS onboard AQUA is the first high-spectral-resolution infrared sounder developed by NASA. AIRS has an unprecedented 2378 spectral channels, complemented with a 4-channel visible/near-infrared imaging module. NASA currently provides a subset of 324 AIRS channels for use in near real-time. Currently, seven of these channels are used (active).

- **Solar Backscatter UltraViolet radiometer (SBUV/2)**. SBUV/2 is a nadir-viewing instrument with a 200-km square field of view at the sub-satellite point. One measurement is made every 32 seconds along the orbital track, approximately every 1.8 degrees in latitude, from 80 degrees south to 80 degrees north. SBUV/2 directly measures solar ultraviolet radiation scattered by the atmosphere at 12 wavelengths from 252 to 340 nm. The vertical ozone profiles are inferred from the eight shortest wavelengths (308-252 nm), while the four longest wavelengths are used to retrieve the ozone column amount. At E.C.M.W.F. retrieved SBUV/2 ozone layer observations are assimilated. The data come from NESDIS (see http://orbit-net.nesdis.noaa.gov/crad/sit/ozone/ for more information) and are combined at E.C.M.W.F. into six ozone layers (0.12 - 0.99 hPa, 0.99 - 1.98 hPa, 1.98 - 3.96 hPa, 3.96 - 7.92 hPa, 7.92 - 15.83 hPa, 15.83 - 1013.25 hPa). The data in the lowest layer mainly reflect the difference between the total column ozone and the profile amounts above this layer and provide no real information about ozone in the lower stratosphere and troposphere. SBUV/2 instruments are onboard several NOAA satellites. At E.C.M.W.F. SBUV/2 data from NOAA-16 are actively assimilated, while SBUV/2 data from NOAA-14 and NOAA-17 are monitored passively.

Products assimilated in IFS at E.C.M.W.F.

- **Atmospheric Motion Vectors (AMV)**. AMVs are retrieved from a number of different geostationary platforms and different channels. MODIS on Terra provides AMV in polar regions. Monitoring of speed departures is presently available. Data from operational geostationary satellites are monitored from IR, VIS and WV (cloudy only, clear-sky only or mixed) channels. Time series and maps of time-averaged mean fields are available. There are only low-level data for VIS winds and only high-level data for WV winds. There is further monitoring information available on the NWP SAF Integrated Satellite Wind Monitoring Report website, including details on the usage of AMVs at E.C.M.W.F.. (see chapter 8)
- **Geostationary RADiances (GRAD)**. Clear-sky radiances (CSR) from geostationary satellites are taken from Meteosat infrared (IR) and water vapour (WV) channels, and from GOES longwave infrared and water vapour channels. The CSR observations received at E.C.M.W.F. are area averages of those pixels of the images that were diagnosed as clear by the data providers (EUMETSAT, CIMSS/NESDIS). Area averages are for about 80*80 km^2 for METEOSAT and 45*45 km^2 for GOES. From 7 October 2003, the following satellites and channels are assimilated actively in operations METEOSAT-5 (WV), METEOSAT-7 (WV), GOES-9 (WV), GOES-10 (WV) and GOES-12 (WV). All other radiances are monitored passively.
- **Quikscat Winds** (QuikSCAT) The Seawinds scatterometer aboard the QuikSCAT satellite, finally, consists of two rotating beams operating at Ku-band frequency with incidence angles w.r.t. the normal of the ocean surface of respectively . Each beam provides a fore and an aft measurement. They cover a swath of 1,800 km in diameter, although only the inner 1,400 km is illuminated by both beams. The product is determined on a 25 km resolution, defining 76 across nodes. The first eight and last eight nodes contain two

backscatter measurements (outer beam only), the other nodes can have up to 4 backscatter measurements

ENVISAT instruments

ENVISAT was launched by the European Space Agency (ESA) on 1 March 2002. It is a polar orbitting satellite with a payload of 10 instruments which provide measurements of the atmosphere, ocean, land, and ice. At E.C.M.W.F., data from several of the ENVISAT instruments are being monitored. These data include wave products from ASAR and RA-2, and atmospheric constituent products from MIPAS, GOMOS and SCIAMACHY.

- **Advanced Synthetic Aperture Radar (ASAR).** ASAR is a high-resolution, wide-swath imaging radar instrument that can be used for site specific investigations as well as land, sea ice and ocean monitoring and surveillance. Its main objective is to monitor the Earth's environment and to collect information on: 1. ocean wave characteristics, 2. ocean mesoscale features, 3. sea ice extent and motion, 4. snow and ice sheet extent, 5. surface topography, 6. land surface properties, 7. surface soil moisture and wetland extent, 8. deforestation and extent of desert areas, 9. disaster monitoring (flooding, earthquake, oil spills, ...). The major advantage of using a SAR instrument for these Earth observation tasks is its capability to obtain images independent of weather conditions, cloud coverage and sun illumination. Considering in particular observations of disaster like floods or hurricanes which usually happen in adverse weather conditions, this weather independence is of vital importance. ASAR data from the wave mode are currently passively monitored at E.C.M.W.F.. In wave mode, ASAR measures the change in radar backscatter from the sea surface due to ocean surface waves. In this mode images of 5 km x 5 km are taken over the ocean at a distance of 100 km.
- **Radar Altimeter 2 (RA-2).** RA-2 is supported by ENVISAT instruments MWR, DORIS, LRR. RA-2 is a dual-frequency (Ku-band, S-band) altimeter derived from the ERS-1/2 Radar Altimeters, providing improved measurement performance and new capabilities. The main objectives of the RA-2 are the high-precision measurements of the time delay, the power and the shape of the reflected radar pulses for the determination of the satellite height and the Earth surface characteristics. RA-2 transmits radio frequency pulses which propagate at approximately the speed of light. The time elapsed from the transmission of a pulse to the reception of its echo, reflected from the Earth's surface, is proportional to the satellite's altitude. The magnitude and shape of the echoes contain information on the characteristics of the surface which caused the reflection. Operating over oceans, these measurements are used to determine the ocean surface topography, thus supporting studies of ocean waves, circulation, bathymetry, gravity anomalies and marine geoid characteristics. Furthermore, the RA-2 is able to map and monitor ocean wave heights, surface wind speed, sea ice and polar ice sheets. In the operational E.C.M.W.F. system, Radar Altimeter-2 ocean wave height data from ENVISAT are actively assimilated.
- **Global Ozone Monitoring system by Occultation of Stars (GOMOS)** GOMOS makes use of the occultation measurement principle by tracking stars as they set behind the atmosphere. GOMOS has an UV-visible and a near-

infrared spectrometer, covering the wavelength region 250-950 nm. It allows the retrieval of atmospheric trace gas profiles in the altitude range 20-100 km, with an altitude resolution better than 1.7 km. GOMOS gives day- and night time measurements with about 600 profiles per day. The primary GOMOS target species are O_3, NO_2, NO_3, OCLO, H_2O and temperature. At E.C.M.W.F., near-real time ozone, temperature and water vapour retrievals from GOMOS (GOM_RR_2P) are routinely monitored. For more information about GOMOS see http://envisat.esa.int/. In the operational E.C.M.W.F. system, GOMOS temperature, ozone and water vapour profiles are blacklisted and monitored passively.

- **Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)** MIPAS is a limb-viewing high-resolution Fourier-transform spectrometer on board ENVISAT. It measures atmospheric emissions in the mid infrared part of the spectrum (4.15 microns to 14.6 microns), allowing the retrieval of concentration profiles of more than 20 atmospheric trace gases. MIPAS provides global coverage, including coverage of the polar regions, independent of illumination conditions. The six main species (O_3, H_2O, HNO_3, CH4, N_2O and NO_2) as well as temperature and pressure profiles are routinely retrieved by the ESA ground segment. Near-real time ozone, temperature and water vapour retrievals from MIPAS (MIP_NLE_2P) are monitored at E.C.M.W.F.. For more information about MIPAS see http://envisat.esa.int/ In the operational E.C.M.W.F. system, MIPAS ozone profiles are actively assimilated, while MIPAS temperature and water vapour profiles are blacklisted and monitored passively.
- **Scanning Imaging Absorption Spectrometer for Atmospheric ChartographY (SCIAMACHY)**. SCIAMACHY is a spectrometer on board ENVISAT that measures backscattered, reflected, transmitted or emitted radiation from the atmosphere and the Earth's surface in the wavelength region 240 nm - 2380 nm at moderate spectral resolution (0.2 nm - 1.5 nm). The primary scientific objective of SCIAMACHY is the global measurement of various trace gases in the troposphere and stratosphere, which are retrieved from the solar irradiance and Earth radiance spectra, as well as the determination of aerosols and clouds. SCIAMACHY measures in three viewing modes: nadir, limb and occultation. The combination of limb-nadir measurement modes, enables the tropospheric column amounts of several trace gases to be determined. At E.C.M.W.F., near-real time SCIAMACHY total column ozone retrievals from nadir measurements (SCI_RV__2P) are monitored routinely. For more information about SCIAMACHY see http://envisat.esa.int/ or http://www-iup.physik.uni-bremen.de/sciamachy/ . In the operational E.C.M.W.F. system, SCIAMACHY total ozone columns are blacklisted and monitored passively.
- **MEdium Resolution Imaging Spectrometer Instrument (MERIS)** The primary mission of MERIS is the measurement of sea colour in the oceans and in coastal areas. Knowledge of the sea colour can be converted into a measurement of chlorophyll pigment concentration, suspended sediment concentration and of aerosol loads over the marine domain. MERIS is, also capable of retrieving cloud top height, water vapour total column, and aerosol load over land. These measurements constitute MERIS secondary mission.

ERS-2 monitoring.

The second European Remote Sensing Satellite ERS-2, launched on 20 April 1995, operates in a sun-synchronous, near-polar orbit at an altitude of 785 km and an inclination of 98.5 degrees ,known as the reference orbit. The mission consists of an only phase (phase A), using a 35 day repeat cycle, from 21 April 1995 to the present. ERS-2 is almost identical to the European Remote Sensing Satellite ERS-1 launched in 1991. ERS-2 is capable of measuring, on a global scale, the Earth's atmospheric and surface properties with a high degree of accuracy. In fact it uses advanced microwave techniques to collect global measurements and images (much of the data are collected from remote areas such as the southern oceans and the Antarctic) independent of time of day and weather conditions. ERS-2 carries on-board a number of instruments consisting of a core set of active microwave sensors supported by additional, complementary instruments: the **Active Microwave Instrument (AMI)**, which combines a **Synthetic Aperture Radar (SAR)** operating in image or wave mode and a wind scatterometer, the Radar Altimeter (RA), the Along-Track Scanning Radiometer and Microwave Sounder (ATSR-2), the **Precise Range and Range-rate Equipment (PRARE)**, the Global Ozone Monitoring Experiment **(GOME)**, and Laser Retroreflectors **(LRR)**. For more information about the ERS missions see http://earth.esa.int/ers or http://earth.esa.int/ers/satconc2. At E.C.M.W.F., data from several of the ERS-2 instruments are being monitored.

- **Radar Altimeter (RA)** see ENVISAT RA-2
- **Synthetic Aperture Radar (SAR).** SAR provides two-dimensional spectra of ocean surface waves. For this function the SAR records regularly spaced samples within the image swath. The images are transformed into directional spectra providing information about wavelength and direction of wave systems. Automatic measurements of dominant wavelengths and directions will improve sea forecast models, but the images can also show the effects of other phenomena, such as internal waves, slicks, small scale variations in wind and modulations due to surface currents and the presence of sea ice. At E.C.M.W.F., SAR data from ERS-2 are actively assimilated.
- **Wind scatterometer WS.** The purpose of the WS is to obtain information on wind speed and direction at the sea surface for incorporation into models, global statistics and climatological datasets. It operates by recording the change in radar reflectivity of the sea due to the perturbation of small ripples by the wind close to the surface. This is possible because the radar backscatter returned to the satellite is modified by wind-driven ripples on the ocean surface and, since the energy in these ripples increases with wind velocity, backscatter increases with wind velocity
- **Global monitoring of atmospheric Ozone (GOME)** Gome is a nadir-scanning ultraviolet and visible spectrometer for global monitoring of atmospheric Ozone, was launched on-board ERS-2 in April 1995. Since summer 1996, ESA has been delivering to users three-day GOME global observations of total ozone, nitrogen dioxide and related cloud information, via CD-ROM and internet. A key feature of GOME is its ability to detect other chemically active atmospheric trace-gases as well as aerosol distribution.

- **Microwave Radar (MWR).** MWR is operationally devoted to the determination of the wet tropospheric Radar Altimeter path delay. However, the two poles are the only places where the MWR can be used to map radiometric properties. The sea-ice and ice-shelf have actually there a slower time evolution than the ocean (the contribution of which is related to the wind), and than the atmosphere that, being very dry, adds but a very small contribution to the signal.

Along-Track Scanning Radiometer and Microwave Sounder (ATSR) ATSR consists of two instruments, an Infra-Red Radiometer (IRR) and a Microwave Sounder (MWS). On board ERS-1 the IRR is a four-channel infra-red radiometer used for measuring sea-surface temperatures (SST) and cloud-top temperatures, whereas on board ERS-2 the IRR is equipped with additional visible channels for vegetation monitoring. The MWS is a two channel passive radiometer.

Jason (from NASA & CNES)

Jason-1 is a follow-on to the highly successful TOPEX/POSEIDON mission that measured ocean-surface topography to an accuracy of 4.2 cm. TOPEX/POSEIDON enabled scientists to forecast the 1997-1998 El Niño and has improved understanding of ocean circulation and its effect on global climate. Jason-1 altimeter data will be part of a suite of data provided by other JPL-managed ocean missions. Objectives of the Jason are to extend ocean surface topography measurements into the 21st century, to provide a 5-year view of global ocean surface topography. Jason data will help to increase understanding of ocean circulation, to improve forecasting of climate events and to measure global sea-level change. Sensors and primary functions are:

- **POSEIDON-2** POSEIDON-2 is the main instrument on the satellite. Derived from the experimental POSEIDON-1 altimeter on TOPEX/POSEIDON, it is a compact, low-power, low-mass instrument offering a high degree of reliability. POSEIDON-2 is a radar altimeter that emits pulses at two frequencies (13.6 and 5.3 GHz, the second frequency is used to determine electron content in the atmosphere) and analyses the return signal reflected by the surface. The signal round-trip time is estimated very precisely to calculate the range, after applying corrections. (Instrument supplied by CNES).
- **JMR** The Jason Microwave Radiometer measures radiation from the surface at three frequencies (18, 21 and 37 GHz). Measurements acquired at each frequency are combined to determine atmospheric water vapour and liquid water content. Once the water content is known, we can determine the correction to be applied for radar signal path delays. (Instrument supplied by NASA).
- **DORIS** The DORIS system uses a ground network of 50 orbitography beacons around the globe, which send signals at two frequencies to a receiver on the satellite. The relative motion of the satellite generates a shift in the signal's frequency (called the Doppler shift) that is measured to derive the satellite's velocity. These data are then assimilated in orbit determination models to keep permanent track of the satellite's precise position (to within three centimetres) on its orbit. (Instrument supplied by CNES)

Tropical Rainfall Measurements Mission (TRMM)

TRMM is a co-operative space mission, jointly funded by the USA and Japan, with the following scientific objectives: 1. to obtain and study multi-year science data sets of tropical and subtropical rainfall measurements 2. to understand how interactions between the sea, air and land masses produce changes in global rainfall and climate; 3. to help improve modelling of tropical rainfall processes and their influence on global circulation in order to predict rainfall and variability at various time scale intervals; 4. to test, evaluate, and improve the performance of satellite rainfall estimates measurements and techniques. The instrument complement is composed of five instruments, a precipitation radar (PR), a multi frequency microwave radiometer (TMI), a visible and infrared imager (VIRS), a broad band radiometer (CERES) and a lightning imaging sensor (LIS).
The first three instruments (PR, TMI and VIRS) form what is called the 'rain package'. the main characteristics of these instruments are:

	TMI	PR	VIRS
Frequency/wavelength	10, 19, 22, 37 and 85 GHz	13.8 GHz	0.63, 3.75, 10.8, 12 µm
Horizontal Resolution	21 km at 19 GHz	4.3 km footprint	2.2 km
Swath	760 km	215 km	720 km

Table 12 Summary of the rain package instruments on-board TRMM, * all frequencies except 22 GHz have horizontal and vertical polarisation

AURA instruments

Earth Observing System (EOS) Aura is a NASA mission to study the Earth's ozone, air quality and climate. This mission is designed exclusively to conduct research on the composition, chemistry and dynamics of the Earth's upper and lower atmosphere employing multiple instruments on a single satellite. EOS Aura is the third in a series of major Earth observing satellites to study the environment and climate change and is part of NASA's Earth Science Enterprise. The first and second missions, Terra and Aqua, are designed to study the land, oceans, and the Earth's radiation budget. Aura's chemistry measurements will also follow up on measurements which began with NASA'S Upper Atmospheric Research Satellite and continue the record of satellite ozone data collected from the TOMS missions.
The EOS Aura satellite, instruments, launch, and science investigations are managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland. The satellite will be launched in June 2004 and operated for five or more years. Scientific investigations will continue throughout the years the spacecraft is in operation and several years afterwards.
Aura carries HIRDLS, MLS, OMI and TES.

- **HIRDLS** (High Resolution Dynamics Limb Sounder) is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, $ClONO_2$, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

- **MLS** (micro wave limb sounder) The scientific priorities and objectives of the MLS investigation are to improve understanding of the following processes and parameters vital to global change research and environmental policy. 1. Chemistry of the lower stratosphere 2. upper troposphere, middle and upper stratosphere , 3. Water in the upper troposphere and 4. the effect of volcanoes on global change.

- **OMI** (Ozone Monitoring Instrument) is a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the EOS Aura mission. It will continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate. OMI measurements will be highly synergistic with the other instruments on the EOS Aura platform. The OMI instrument employs hyperspectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet. The expanded wavelength characteristics will provide the following features.
  - Continue global total ozone trends from satellite measurements beginning in 1970 with BUV on Nimbus-4.
  - Map ozone profiles at 36 x 48 km, a spatial resolution never achieved before.
  - Measure key air quality components such as NO2, SO2, BrO, OClO, and aerosol characteristics.
  - Distinguish between aerosol types, such as smoke, dust, and sulfates. Measure cloud pressure and coverage, which provide data to derive tropospheric ozone.
  - Map global distribution and trends in UV-B radiation.

- **TES** (Tropospheric Emission Spectrometer) is a high-resolution infrared-imaging Fourier transform spectrometer with spectral coverage of 3.2 to 15.4 µm at a spectral resolution of 0.025 cm^{-1} , thus offering line-width-limited discrimination of essentially all radiative active molecular species in the Earth's lower atmosphere. TES has the capability to make both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 34 km. In the downlooking modes, TES has a spatial resolution of 0.53 x 5.3 km with a swath of 5.3 x 8.5 km. TES is a pointable instrument and can access any target within 45° of the local vertical, or produce regional transects up to 885-km length without any gaps in coverage. TES employs both the natural thermal emission of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe. TES will provide global maps of tropospheric ozone and its photochemical precursors. These observations will serve as primary inputs to a database of the three-dimensional distribution (on global, regional, and local scales) of gases important to tropospheric chemistry, troposphere-biosphere interactions, and troposphere-stratosphere exchange. Other objectives include:

- Simultaneous measurements of NOy, CO, O_3, and H_2O for use in the determination of the global distribution of OH, an oxidant of central importance in tropospheric chemistry;
- measurements of SO_2 and NOy as precursors to the strong acids H_2, SO_2 and HNO_3, which are the main contributors to acid deposition;
- measurements of gradients of many tropospheric species in order to understand troposphere-stratosphere exchange;
- and determination of long-term trends in radiative active minor constituents in the lower atmosphere to investigate effects on global radiative balance and atmospheric dynamics.