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Plenary

REPORT ON
REDESIGN OF THE GLOBAL OBSERVING SYSTEM (GOS)

(Submitted by WMO)

Summary and purpose of document

A report from the Expert Team on Observational Data Requirements and Redesign of the Global Observing System within the WMO Commission for Basic System Open Program Area Group on Integrated Observing Systems for CGMS consideration.

ACTION PROPOSED

CGMS Members to note and comment on the report for the redesign of the WWW Global Observing System

Appendix: ET-ODRRGOS Recommendations for the Evolution of the GOS

REPORT ON THE REDESIGN OF THE GLOBAL OBSERVING SYSTEM

W. Paul Menzel [1] and James F. W. Purdom [2]
[1] Chairman, ET-ODRRGOS, NOAA/NESDIS/ORA, Madison, Wisconsin
[2] Chairman, OPAG-IOS, Colorado State University, CIRA, Ft Collins, Colorado

1. Introduction

The WMO/CBS/OPAG IOS Expert Team on Observational Data Requirements and Redesign of the Global Observing System (ET-ODRRGOS) has been working on two main tasks: (a) to continue the Rolling Requirements Review (RRR), under which requirements for observations to meet the needs of all WMO programmes are compared with the capabilities of present and planned observing systems to provide them, and; (b) to make recommendations to the Commission for Basic Systems (CBS) of WMO on the “re-design” of the Global Observing System (GOS).

ET-ODRRGOS is now coming towards the end of its 4-year work programme during which the following was accomplished.

- Users Requirements and Observing System Capabilities were charted in eleven application areas (after engaging ocean and climate communities), the Rolling Requirements Review (RRR) was pursued, and Statements of Guidance were issued in all eleven applications areas (available in several WMO technical documents (WMO/TD No. 913, 992, 1052) and summarized in the final report of the July 2002 ET-ODRRGOS meeting).
- Several Observing System Experiments were pursued to test possible re-configurations of the GOS
- Candidate Observing Systems Technologies (space based and ground based) and their use in the next decade were studied and a WMO Technical Document was published (WMO/TD No. 1040).
- Recommendations for evolution of space based and surface based components of GOS were drafted, reviewed, and submitted to CBS. A document summarizing the most pressing observational needs and recommendations for the most cost-effective actions is appended.
- A vision for the GOS of 2015 and beyond was drafted (included in the Appendix).

2. Observing System Experiments

ET-ODRRGOS considered coordinated development and utilisation of a comprehensive software tool for carrying out Observing System Simulation Experiments (OSSEs) as well as preparation, maintenance, and evolution of a realistic OSSE data base with user-friendly access. As undertaking of an OSSE requires huge human and computer resources with considerable leveraging and coordinating of individual investments, ET-ODRRGOS felt that the limited resources for evaluating changes to the GOS would probably be better focussed on well-defined Operational System Experiments (OSEs).

In course of the development a global approach to redesign of the GOS, the ET-ODRRGOS kept under permanent review the impact assessments studies being conducted by NWP centres under regional programmes such as COSNA, EUCOS and NAOS. The ET-ODRRGOS found that findings of COSNA, EUCOS and NAOS as well as conclusions and recommendations of The Toulouse Workshop on Impact of Various Observing Systems on NWP (see WMO/TD No. 1034) provided essential input to the redesign process of the GOS. However, the ET-ODRRGOS strongly supported the workshop recommendation that impact studies should be carried out for a sufficiently long period, preferably in each of four seasons and that the statistical significance of the results should be established. In addition, the ET ODRRGOS suggested eight OSEs for consideration by NWP centres and asked the OSE/OSSE rapporteurs (Jean Pailleux and Nobuo Sato) to engage as many as possible in this work. Good response was received and results are coming in. The OSEs and the initial results from the contributing NWP centres are listed below:

- Impact of hourly versus 6-hourly surface pressures. Using 4DVAR assimilation ECMWF found positive impact especially over the north Atlantic and southern oceans.
- Impact of denial of radiosonde data globally above the tropopause. The Canadian AES report is anticipated autumn 2002.
- Information content of the Siberian radiosonde network and its changes during last decades. The Main Geophysical Observatory in St Petersburg found that information content was ascending until 1985, descending thereafter. NCEP related a decrease in performance of 500 hPa height analysis over NA to a decrease in Siberian raobs.
- Impact of AMDAR data over Africa through data denial in a 4D-Var analysis and forecasting system. ECMWF showed that denial over NH of observations below 350 hPa has large significant impact in summer and winter. Investigation of African AMDAR impact is pending at MétéoFrance.
- Impact of tropical radiosonde data. Met Office varied the density of SE Asia raobs used in assimilation and produced high impact on winds at all levels with occasional propagation of impact to mid latitudes. Temperature and wind information is the most important potential measurements from AMDAR in less well observed tropical areas (eg Africa, Central America).
- Impact of three LEO AMSU-like sounders (NOAA –15, - 16, and -17 plus AQUA). ECMWF showed large positive impact from two AMSUs over one MSU. Met Office showed positive impact of three over two AMSU when NOAA-17 was added to the GOS.
- Impact of AIRS data. ECMWF, Met Office, NCEP, BMRC, and JMA will be reporting on this in late 2002.
- Impact of better than 3 hourly ascent descent AMDAR data. Preliminary NH AMDAR ascent/descent impact suggests positive effect of higher frequency data. EUCOS is arranging higher frequency observations in 2003 to enable this study by Met Office and ECMWF.
- Polar winds from MODIS water vapour tracking. A 30-day case study at ECMWF and NASA DAO indicates that forecasts of geopotential heights for the Arctic, Northern Hemisphere extra-tropics, and Antarctica are improved significantly.

3. Statements of Guidance (SoGs)

SoGs in eleven applications areas had been written and are being updated with further RRR iterations. They are in

Global NWP
Regional NWP
Synoptic Meteorology
Nowcasting and Very Short Range Weather Forecast
Seasonal to Inter-annual Forecast
Aeronautical Meteorology
Atmospheric Chemistry
Agricultural Meteorology
Ocean Weather Forecasts
Coastal Marine Services
Hydrology

The most recent version of many of these SoGs was published in SAT-26, Statement of Guidance Regarding How Well Satellite Capabilities Meet WMO User Requirements in Several Applications Areas (WMO/TD No. 1052) and Annex B addressing specific applications areas. Review of these documents by experts within the applications areas is being pursued.

4. Recommendations for the Redesign (Evolution) of the GOS

ET-ODRRGOS used the results from the OSEs (as well as conclusions and recommendations of The Toulouse Workshop on Impact of Various Observing Systems on NWP), their estimate of available technologies of the future, and the SoGs to make their recommendations for the evolution of the GOS. An annex containing these recommendations is attached. The ET noted that the future GOS should build upon the existing components, both surface and space based, and capitalize on existing observing technologies not presently incorporated or fully exploited into the GOS. All experiments in testing hypotheses towards the redesign have indicated that each incremental addition to the GOS will be reflected in better data, products and services from the National Meteorological and Hydrological Services (NMHSs). In consideration of the surface based component of the GOS, ET-ODRRGOS made 22 recommendations that include: improved data distribution; enhanced AMDAR ascent/descent as well as flight level data, especially over data sparse areas; optimized radiosonde launches; targeted observations; inclusion of ground based Global Positional System (GPS), radars and wind profilers into the GOS; increased oceanic coverage through expanded Automated Ship balloon observations, drifting buoys, and ARGO; and use of Unmanned Aeronautical Vehicles. Regarding the space based component of the GOS, ET-ODRRGOS made 20 recommendations (9 for operational geostationary and polar orbiting, 11 for R&D satellites) that build upon the known plans of the operational and R&D satellite operators that call for rigorous calibration of remotely sensed radiances as well as improved spatial, spectral, temporal, radiometric accuracies. In particular, the wind profiling and global precipitation measurement missions were singled out for their importance to the future GOS. The ET-ODRRGOS emphasized their belief that the benefits to be derived from the new GOS will be tremendous.

ET-ODRRGOS noted that the scope of the changes to the GOS coming in the next decade will be so massive that new revolutionary approaches for science, data handling, product development, training, and utilization will be required. To emphasize this, the ET recommended that the CBS-EXT should be advised of the urgent need to study comprehensive strategies for anticipating and evaluating changes to the GOS and that a focused funded activity needs to be developed to study observing system design.

ET-ODRRGOS recommendations for evolution of the GOS are being forwarded to the CBS through the OPAG IOS chair.

Future work includes to (a) continue updating data bases of user requirements and observing system capabilities and include user reviewed R&D expected performances (b) continue RRR for eleven application areas and expand to new areas as advised by CBS, (c) update SoGs, (d) organize next Workshop on Impact of Various Observing Systems on NWP, (e) follow up on progress in OSEs, especially those now possible with AIRS and 3 AMSUs and EUMETNET.

ET-ODRRGOS RECOMMENDATIONS FOR THE EVOLUTION OF THE GOS

Recommendations for Evolution of Space based component of GOS

The ET-ODRRGOS investigated an appropriate evolution towards the future space based component of the GOS using the Rolling Review of Requirements (RRR) process and observational requirements for the following applications areas: Global NWP, Regional NWP, Synoptic Meteorology, Nowcasting and Very Short Range Forecasting, Aeronautical Meteorology, Hydrology, Seasonal to Inter-Annual (SIA) Forecasting, Coastal Marine Services, Ocean Weather Forecasting, and Atmospheric Chemistry. Since the decision by the WMO Executive Council in 2001 to expand the space based component of the GOS to include appropriate research and development missions, space based contributions fall in three categories: the operational polar orbiting, the operational geostationary, and the R&D (research and development) satellites. This considerably extends the range of user requirements that can be addressed and provides the mechanism for R&D demonstrations to evolve into operational systems. Recommendations were founded upon Observing System Experiments (OSEs), operational NWP experience, and evidence from field experiments with enhanced observations from ground-, aircraft-, and space-borne instruments. Operational satellite system evolution requires more than a decade to proceed from plans to demonstration to implementation; the individual satellite operator plans for change in the near term are already well formed and in place and change is not likely. Thus the ET focussed on comments / suggestions for coordination of these plans in the near term and recommendations for change in global satellite systems for the longer term.

As the space based remote sensing system of the future develops and evolves, four critical areas (all dealing with resolution) will need to be addressed in order to achieve the desired growth in knowledge and advanced applications. They are: (1) spatial resolution – what picture element size is required to identify the feature of interest and to capture its spatial variability; (2) spectral coverage and resolution – what part of the continuous electromagnetic spectrum at each spatial element should be measured, and with what spectral resolution, to analyze an atmospheric or surface parameter; (3) temporal resolution – how often does the feature of interest need to be observed; and (4) radiometric accuracy – what signal to noise is required and how accurate does an observation need to be. Each of these resolution areas should be addressed in the context of the evolving space based observing system wherein the satellite(s) exist, or will exist.

High priority system specific recommendations for additional capabilities in the space based component of GOS (in order of priority for each category) are listed below; they are followed by comments on the planned improvements to space based component of GOS

High-Priority General Recommendations

Calibration

1 A major issue for effective use of satellite data, especially for climate applications, is calibration. There should be more common spectral bands on GEO and LEO sensors to facilitate intercomparison and calibration adjustments; globally distributed GEO sensors can be intercalibrated using a given LEO sensor and a succession of LEO sensors in a given orbit (even with out the benefit of overlap) can be intercalibrated with a given GEO sensor. The advent of high spectral resolution infrared sensors will enhance accurate intercalibration.

High Priority System Specific Recommendations for Additional Capabilities in the Space Based Component of GOS (in order of priority for each category)

GEO satellites

2 GEO Imagers - Imagers of future geostationary satellites should have improved spatial and temporal resolution (appropriate to the phenomena being observed), in particular for

those spectral bands relevant for depiction of rapidly developing small scale events and retrieval of wind information.

3 GEO Sounders - All meteorological geostationary satellites should be equipped with hyper-spectral infrared sensors (to be demonstrated by GIFTS) for frequent temperature/humidity sounding as well as tracer wind profiling with adequately high resolution (horizontal, vertical and time).

4 GEO Imagers and Sounders - To maximize the information available from the geostationary satellite systems, they should be placed “nominally” at a 60-degree sub-point separation across the equatorial belt. This will provide global coverage without serious loss of spatial resolution (with the exception of Polar Regions). In addition this provides for a more substantial backup capability should one satellite fail. In particular, continuity of coverage over the Indian Ocean region is of concern.

LEO satellites

5 LEO data timeliness - More timely data are needed. Improved communication and processing systems are required to meet the timeliness requirements in some applications areas (e.g. Regional NWP).

6 LEO temporal coverage - Coordination of orbits for LEO missions is necessary to optimize temporal coverage while maintaining some orbit redundancy.

7 LEO Sea Surface Wind - Sea-surface wind data from R&D satellites should continue to be made available for operational use; 6-hourly coverage is required. In the NPOESS and METOP era, sea surface wind should be observed in a fully operational framework. Therefore it is urgent to assess whether the multi-polarisation passive MW radiometry is competitive with scatterometry.

8 LEO Altimeter - Missions for ocean topography should become an integral part of the operational system.

9 LEO Earth Radiation Budget - Continuity of ERB type global measurements for climate records requires immediate planning to maintain broad-band radiometers on at least one LEO.

R&D satellites

10 LEO Doppler Winds - Wind profiles from Doppler lidar technology demonstration programme (such as Aeolus) should be made available for initial operational testing; a follow-on long-standing technological programme is solicited to achieve improved coverage characteristics and reduced instrument size necessary for operational implementation.

11 GPM - The concept of the Global Precipitation Measurement Missions (combining active precipitation measurements with a constellation of passive microwave imagers) should be supported and the data realized should be available for operational use, thereupon, arrangements should be sought to ensure long-term continuity to the system.

12 RO-Sounders - To complement the METOP and NPOESS radio-occultation sounders, the opportunities for a larger constellation should be explored and expanded operational implementation planned. International sharing of ground network systems (necessary for accurate positioning in real time) should be achieved to minimise development and running costs.

13 GEO Sub-mm - An early demonstration mission on the applicability of sub-mm radiometry for precipitation estimation and cloud property definition from geostationary orbit should be provided, with a view to possible operational follow-on.

14 LEO MW - The capability to observe ocean salinity and soil moisture for weather and climate applications (possibly with only limited horizontal resolution) should be demonstrated in a research mode (as with ESA’s SMOS and NASA’s OCE) for possible

operational follow-on. Note that the horizontal resolution from these instruments is unlikely to be adequate for salinity in coastal zones and soil moisture on the mesoscale.

15 LEO SAR - Data from SAR should be acquired from R&D satellite programmes and made available for operational observation of a range of geophysical parameters such as wave spectra, sea ice, land surface cover.

16 LEO Aerosol - Data from process study missions on clouds and radiation as well as from R&D multi-purpose satellites addressing aerosol distribution and properties should be made available for operational use.

17 Cloud Lidar - Given the potential of cloud lidar systems to provide accurate measurements of cloud top height and to observe cloud base height in some instances (stratocumulus, for example), data from R&D satellites should be made available for operational use.

18 LEO Far IR - An exploratory mission should be implemented, to collect spectral information in the Far IR region, with a view to improve understanding of water vapour spectroscopy (and its effects on the radiation budget) and the radiative properties of ice clouds.

19 Limb Sounders - Temperature profiles in the higher stratosphere from already planned missions oriented to atmospheric chemistry exploiting limb sounders should be made operationally available for environmental monitoring.

20 Active Water Vapor Sensing - There is need for an exploratory mission demonstrating high-vertical resolution water vapour profiles by active remote sensing (for example by DIAL) for climate monitoring and, in combination with hyper-spectral passive sensing, for operational NWP.

Comments on Planned Improvements to Space Based Component of GOS

GEO satellites

1 GEO Imagers -The GEO imagers will evolve in a synergistic way with the GEO Sounders. Depending on the characteristics of the evolved temperature/humidity sounder, the imager can focus on different channels with an emphasis on monitoring rapidly developing small scale events.

2 GEO Imagers - Future geostationary satellites will have improved capability for observing land surface temperatures and characterising fire size and temperature.

3 GEO Sounders - IR sounding spectrometers from geostationary orbit are unlikely to be able to follow diurnal variations in boundary layer ozone important in air quality and hazard warnings, and thus will not meet the stated requirements of atmospheric chemistry.

LEO satellites

4 LEO Imagers - In the near and mid term future, vegetation and surface albedo data from R&D and operational satellites will be available for operational use. In the NPOESS era, continued access will improve small-scale applications.

5 LEO Sounders - The advent of hyper-spectral IR sounder on Aqua, METOP, NPP, and NPOESS will improve temperature and moisture profiling; plans for making early hyper-spectral IR data available for operational evaluation are being realized.

6 LEO GPS - Radio occultations offer the potential for very stable long term measurements of upper tropospheric and lower stratospheric temperature and moisture relevant for climate applications.

R&D satellites

7 LEO Imagers - Until the advent of NPOESS, high-quality sea-surface temperature data from R&D satellites (e.g. ATSR, AATSR, MODIS) will be made available for operational use, specifically for climate monitoring. Future geostationary satellites will have improved capability of observing sea surface temperatures and their diurnal variation.

8 LEO Imagers - Imagers on future polar satellites will enable trace motion wind determination in overlapping areas at high latitudes, similar to those from geostationary satellites.

9 LEO Imagers - On orbit channel selection for multi-disciplinary utilization is being demonstrated by ENVISAT's Medium Resolution Imaging Spectrometer (MERIS). The MERIS primary mission is ocean related (colour), however its flexibility allows for definition of spectral bands that can be used to retrieve information on clouds, vegetation, aerosols and total column water vapour.

10 LEO Ocean Colour - In the near and mid term future, ocean colour data from R&D satellites will be available for operational use. Even in the NPOESS era, continued access from R&D satellites will be complementary, especially in coastal zones.

Table linking observed parameters with a given system of the space based component of the GOS (If space agencies implement their current plans and recommendations listed above are acted upon, the space based component of the GOS would have the following characteristics)

System	Improved parameters	Instrumentation
GEOs upgraded	Temperature, humidity, ozone profiles, winds at tracer heights Atmospheric instability index, OLR	Frequent-sounding and imaging IR spectrometer
	Cloud pattern, cover, type, top temp and height, Low stratus / fog sea-surface temp, land surface temp, fires, volcanic ash	Fast VIS/IR imager
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LEOs upgraded (post-METOP)	Temp, humidity, & ozone profiles; total columns of key trace gases	IR/MW sounder
	Sea/land/ice surface temperatures, sea-ice cover, NDVI, fires, Aerosol size, Cloud pattern, cover, type, top height, cloud optical thickness, drop size, low stratus/fog, high lat winds at tracer heights	Improved VIS/NIR/IR imager
	Short- and long-wave outgoing radiation at TOA	Broadband imager
	Sea-surface wind and temp, sea-ice cover and surface temp snow cover, snow water equivalent, precipitation	MW radiometer with multi-polarisation/viewing
	Water and ice cloud properties, aerosol properties Ozone LAI, PAR, FPAR (large scale). Ocean colour	Imagers covering parts of UV, VIS, NIR, IR, FIR, & Sub-mm, with multi-polarisation
	Wave height, sea level, ocean topography, geoid	Altimeter
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R&D GEO SubMM	Cloud water / ice, precipitation	Sub-mm radiometer
R&D LEO for ocean topography	Significant wave height, sea level, ocean topography, geoid. Polar ice thickness and sheet topography	Medium-class altimeter (follow-on Jason)
R&D LEO for wind Profiles	Wind profile in clear air. Aerosol profile (large scale), cloud top and base height	Doppler lidar (follow-on Aeolus)
R&D LEO for land & ocean ice	Wave spectra, ocean ice. Land snow & ice	SAR
R&D LEO for salinity & moisture	Ocean salinity (large scale). Soil moisture (large scale)	Low-frequency MW radiometer
R&D Constellation of mini-sats	UT/LS temperature profile, height of tropopause., LT moisture profile (with ground GPS)	Radio-occultation sounders

Vision of the Space-Based Component of the GOS in 2015

The space-based component of the GOS will provide observations crucial to maintaining and improving performance of systems in several application areas - in operational meteorology and in other aspects of WMO programmes. A few examples follow. It will provide multi-spectral images of cloud and water vapour at high spatial and temporal resolution for use in synoptic meteorology, nowcasting, hydrology, and aeronautical meteorology. It will also provide quantitative measurements of key atmospheric variables for assimilation into operational numerical weather prediction systems. Hyperspectral space borne measurements will expand the atmospheric chemistry applications. The space based component of the GOS must also provide long term stable global measurements of radiation for climate applications.

An analysis of user requirements in applications areas within WMO programmes indicates the need for an operational satellite constellation comprising four polar and six geostationary satellites. The geostationary component will provide visible/infra-red imagery of improved quality and also advanced infrared atmospheric sounding capability. The polar-orbiting component will provide many capabilities including advanced microwave and infrared atmospheric sounding, high-resolution multi-spectral visible/infrared imagery, microwave imagery, ultraviolet ozone sounding, GPS radio occultation sounding, and information from scatterometers, altimeters and microwave radiometers. These will provide quantitative information on many atmospheric and surface variables such as atmospheric profiles of temperature, humidity and ozone; surface temperature; clouds and precipitation; ice and snow cover; vegetation; and ocean surface wind and waves.

Beyond this, data from instruments on R&D satellites will make major new contributions to the GOS including:

- wind profiles from Doppler wind lidars;
- precipitation measurements from a constellation of active and passive microwave instruments;
- GPS radio occultation (RO) constellation;
- ocean colour;
- soil moisture;
- air quality.

Expansion of the space-based component of the GOS will require international collaboration. There will be efforts to facilitate contributions of single instruments to larger platforms. Replacement strategies of the current or near future GOS satellites by the next generation satellites will proceed with a phased implementation approach. The role of small satellites in the GOS will be expanded. Coordination of international contributions to the polar orbiting observing system to achieve optimal spacing for a balance of spectral, spatial, temporal and radiometric coverage will be a goal. Operational continuation of research capabilities with proven utility to the GOS will be occur as much as possible without interruption of the data flow.

There must be a commitment for adequate resources to sustain research developments necessary for improved utilization of these measurements. As much as possible, preparation for utilization of any new measurement will begin prior to launch with distribution of simulated data sets that test processing systems; this will increase the fraction of post-launch lifetime during which the data are used effectively in operational systems. (The current post-launch familiarization period of 6-24 months will be reduced). International development of data processing and assimilation methods and systems will assure best use of available talent and effort, and it will enhance uniformity in derived products.

The following table summarizes the space-based component of GOS in 2015.

GOS (2015)

6 operational GEOs
- all with multispectral imager (IR/VIS)
- some with hyperspectral sounder (IR)

4 operational LEOs
- optimally spaced in time
- all with multispectral imager (MW/IR/VIS/UV)
- all with sounder (MW)
- three with hyperspectral sounder (IR)
- all with radio occultation (RO)
- two with altimeter
- two with conical scan MW or scatterometer

Plus R&D satellites serving WMO members:
- Constellation small satellites for radio occultation (RO)
- R&D LEO with wind lidar
- R&D LEO with advanced altimeter
- R&D LEO with active and passive microwave precipitation instruments
- LEO and GEO with advanced hyperspectral capabilities
- GEO lightning
- GEO microwave

It is envisaged after 2015 that many of the imaging and sounding functions will be served by hyperspectral instruments from both LEO and GEO orbit. R&D developments in wind profiling and precipitation monitoring will also be operational. Remote sensing needs for coastal monitoring and boundary layer chemistry will be addressed by R&D missions. Data movement, processing and utilization will be a large challenge; exploration of Alternative Dissemination Methods will be necessary to seek new solutions. The opportunity for instruments in L1 orbit to serve as environmental sentinels will be explored.

Recommendations for Evolution of Surface-Based Component of GOS

The recommendations below take into account known upgrades to current satellite systems and entirely new space-based instrumentation to be deployed by 2015. Proposed changes in surface-based and in situ atmospheric and oceanic observing systems include automation and greater utilization of existing systems and the development of a few relatively new systems - all designed to complement, and be fully consistent with, future satellite capabilities. The goal is to maximize the benefits of the composite observing system for a variety of operational weather services.

Ten years from now, two things are virtually certain: observations will increase markedly in volume, and they will be stored and transmitted almost entirely in binary formats. It is hazardous to guess what kind of surface and in situ atmospheric and oceanic observations will be available beyond ten years merely because new technologies may revolutionize how the atmosphere is measured. For example, ten years ago, few could anticipate the evolution of the AMDAR system or the exploitation of the Global Positioning System in meteorology. Therefore, the present strategy is to extrapolate into the future promising trends in observation technology.

The recommendations below address the Rolling Review of Requirements in a number of applications areas: Global NWP, Regional NWP, Nowcasting and very short-range forecasting, Synoptic meteorology, Ocean weather forecasting, Coastal Marine services, Aeronautical meteorology, Season and inter-annual prediction, and Atmospheric chemistry.

The relevant impact studies that support the recommendation are cited in brackets; often the Observing System Experiment is just listed by number (see Jul 2002 report of ET-ODRRGOS for the list).

High-Priority General Recommendations

Data distribution and coding

1. Exchange internationally observational data not yet centrally collected but potentially useful in NWP, e.g., radar measurements to provide information on precipitation and wind, surface observations, including those from local or regional mesonets, wave buoys. Encourage WMO Members in regions where these data are collected to make them available via WMO real time information systems.

2. Data available at high temporal frequency should be distributed at least hourly. Recent studies have shown that 4D-Var data assimilation system or analysis system with frequent update cycles can make excellent use of hourly data, eg from SYNOPs, buoys, profilers, aircraft (AMDAR). [OSE-1]

3. Assure that all sources are accompanied by good documentation including metadata, careful QC, and monitoring.

4. Use coding standards that assure that the content (e.g vertical resolution) of the original measurements, sufficient to meet the user requirements, is retained during transmission. Some current coding/formatting standards in the character codes degrade potentially useful information in meteorological reports. (Example: lost information at various levels in a rawinsonde sounding in the TEMP code could be retained in the BUFR code). [CBS decision to migrate to table driven and binary codes].

Broader use of ground based and in situ observations

5. Calibration of measurements from satellites depends on using ground-based and *in situ* observations, such as ozone profiles from sondes. Near real-time distribution of ozone sonde data is required for calibration and validation of newly launched instruments and for potential use in NWP. [Joint ECMWF / WMO expert team meeting on real time exchange of ground based ozone measurements, ECMWF, 17-18 October 1996]

Moving towards operational use of targeted observations

6. Transfer into operations the proven methodology of observation targeting to improve the observation coverage in data sensitive areas. This concept is in operational use at the US Weather Service in the north-eastern Pacific during the winter storm period. EUCOS is planning on field experiments in the Atlantic, possibly in the context of a THORPEX study. Designated major operational centres should share the responsibility for determining the target areas. [FASTEX results and Toulouse report]

High Priority System Specific Recommendations

Optimisation of rawinsonde launches

7. Optimise the distribution and the launch times of the rawinsonde sub-system (allowing flexible operation while preserving the GUAN network and taking into consideration regional climate requirements). Examples include avoiding duplication of Automated Ship-borne Aerological Program (ASAP) soundings whenever ships are near a fixed rawinsonde site (freeing resources for observations at critical times) and optimising rawinsonde launches to meet the local forecasting requirements. [EUCOS Studies, OPAG IOS Chairman]

Development of the AMDAR programme

8. AMDAR technology should provide more ascent/descent profiles, with improved vertical resolution. A good way to accomplish this is to extend the AMDAR programme to short-haul commuter flights, business aviation, and air freight. Emphasis should be to expand into areas where vertical profile data from radiosondes and pilot balloons are sparse a well as into times that are currently not well observed such as 11 pm to 5 am local times. [Toulouse report, ECMWF northern hemisphere AMDAR impact study, OSEs 4, 5, 8]

9. AMDAR coverage is both possible and sorely needed in several currently data-sparse regions, especially Africa and South America, Canadian arctic, northern Asia and most of the world's oceans. Moreover, the timing and location of reports, whose number is potentially very large, can be optimised while controlling communications costs. The recommendation is to optimise the transmission of AMDAR reports taking into account, en route coverage in data-sparse regions, vertical resolution of ascent/descent reports, and targeting related to the weather situation. [Toulouse report, ECMWF northern hemisphere AMDAR impact study]

10. Lower-tropospheric water vapour measurements are vital in many forecast applications. To supplement the temperature and wind reports from AMDAR, the further development and testing of water vapour sensing systems is strongly encouraged. Example: WVSS-2 employs a laser diode to measure the absorption by water vapour of energy in the laser beam over a short path length. This is an absolute measurement of water vapour content that is expected to be accurate from the ground to flight altitudes. [Toulouse report]

Tropospheric Aircraft Meteorological Data Reporting (TAMDAR)

11. TAMDAR could potentially supplement AMDAR and radiosonde data by providing lower level en route observations and profiles over additional, regional airports not served by larger AMDAR compatible aircraft. Instrumentation would not necessarily be designed to function in the high troposphere and would therefore be less expensive. The development of the TAMDAR system should be monitored with a view towards operational use. [EUCOS Programme Plans]

Ground based GPS

12. Develop further the capability of ground-based GPS systems for the inference of vertically integrated moisture with an eye toward operational implementation. Distribute globally the measurements of total column water vapour from available and emerging ground based GPS systems for use in NWP. Such observations are currently made in Europe, North America and Japan. It is expected that the global coverage will expand over the coming years. [COSNA/SEG, NAOS, JMA reports]

Improved observations in ocean areas

13. Increase the availability of high vertical resolution temperature, humidity, and wind profiles over the oceans. Consider as options ASAP and dropsondes by designated aircraft. [EUCOS programme plan]

14. Considering the envisaged increase in spatial and temporal resolution of *in situ* marine observing platforms and the need for network management, either increase the bandwidth of existing telecommunication systems (in both directions) or establish new relevant satellite telecommunications facilities for timely collection and distribution. Examples include drifting buoys, profiling floats, XBTs. [JCOMM Operations Plan]

15. For both NWP (wind) and climate variability/climate change (sub-surface temperature profiles), it is recommended to extend the tropical mooring array into the tropical Indian Ocean at resolution consistent with what is presently achieved in the tropical Pacific and Atlantic Oceans. [JCOMM Operations Plan]

16. Ensure adequate coverage of wind and surface pressure observations from drifting buoys in the Southern Ocean in areas between 40S and the Antarctic circle based upon adequate mix of SVPB (surface pressure) and WOTAN technology (surface wind). The pressure observations are a valuable complement to the high density surface winds provided by satellite. [Toulouse report, ODRRGOS OSE study]

17. For Ocean Weather Forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature/salinity profile data from XBTs and Argo floats. [JCOMM Operations Plan]

18. For NWP purposes, increase coverage of ice buoys (500 km horizontal resolution recommended) to provide surface air pressure and surface wind data. [JCOMM Operations Plan]

Improved observations over tropical land areas

19. Enhance the temperature, wind and if possible the humidity profile measurements (from radiosondes, pilots and aircraft) in the tropical belt, in particular over Africa and tropical America. There is evidence from recent impact studies with the radiosonde/pilot balloon network over the Indonesian/Australian region that such data give a better depiction of winds in the tropics and occasionally strongly influence the adjacent mid-latitude regions. [OSE-5]

New Observing Technologies

20. Demonstrate the feasibility of ground based interferometers and radiometers (e.g. microwave) to be an operational sub-system providing continuous vertical profiles of temperature and humidity in selected areas.

21. Demonstrate the feasibility of Unmanned Aeronautical Vehicles (UAVs) to be an operational sub-system.

22. Demonstrate the feasibility of high altitude balloons to be an operational sub-system

Vision of the Surface Based Component of the GOS in 2015

It is envisaged that by 2015 the technical advances will have led to substantial innovations in the surface based components of the global observing system. Measurements will be provided by automated systems, manual intervention and the role of humans in the observing chain will have been reduced to a minimum, and may not be required at all any more.

Automation will facilitate the targeting of data sensitive areas through an optimal operation of the upper air observing components, such as radiosondes, ASAP systems, data collection from aircraft in flight and vehicles on the road.

Rawinsondes

Automated launches with computerized data processing and real-time data transmission at high vertical resolution. The network will have been optimized to provide the measurements for the calibration of satellite data and to provide the baseline observing system for ground based vertical atmospheric profiling.

Aircraft observations

Fully automated observing system providing temperature, wind and humidity measurements of high quality from the majority of the civilian aircraft, both in-flight and ascent/descent data at high temporal resolution. Tropospheric profile data will be available from most aerodromes around the world, including from the currently data void airports in Asia, Africa and South America.

Surface observations

From land and ocean observing platforms all measurements will be provided by automated systems. It is expected that the land areas will be covered by a network of sensors at a high spatial resolution, supporting local applications such as road weather. Such data will be of benefit to global and local NWP applications alike. Over the oceans an adequate number of platforms (ship, buoys, moorings will be available to complement the satellite measurements.

Radar observing systems

Multi-parameter scanning Doppler radars will enable hydrometeor identification and perhaps give information on their size distributions. This in turn will improve estimation of precipitation rate and accumulation. It will also assist in the initialization of cloud physics parameters for NWP Assimilation of high resolution reflectivity and radial velocity data will have reached the point of resolving the basic mass and wind structures of convective storms. Millimeter-wavelength radars will be able to observe multiple cloud layers, including the altitude of their bases and tops.

Data transmission

The fully automated observing system will produce data volumes which will exceed today's volumes by several orders of magnitude. Data communication technology is expected to have developed accordingly. The technical means to provide the appropriate and affordable communication will have become available. All observational data will be transferred by digital means in a highly compressed form. Data processing will be computerized entirely.

In summary

The rapid development of information technology in all areas of life will continue to give opportunities for obtaining and communicating observations as a by-product of systems installed (and paid for) for other purposes. Currently AMDAR and GPS observations fall into this category and other examples will emerge and should be exploited in the future. It is likely that such observations will form an important part of a cost effective future global observing system.

Table linking observed parameters with a given system of the surface based component of the GOS (If agencies pursue recommended actions and encourage indicated developments, surface based component of GOS would have the following characteristics)

System	Parameter	Action/Development
AMDAR	Vertical profiles of temperature and wind at airports	Increase coverage, increase vertical resolution Extend programme to short-haul, commuter and freight flights
	Flight level data	Study feasibility of adaptive use, demonstrate the need for high frequency data, in particular over Africa, South America
	Vertical profiles of humidity	Develop capability
TAMDAR	Vertical profiles of temperature and wind at regional airports	Develop the programme (currently undertaken by NASA), suitable for expansion to other regions, such as the Arctic, Siberia, etc.

System	Parameter	Action/Development
Radiosondes	Vertical profiles of temperature wind and humidity	Optimise horizontal spacing of raobs and vertical resolution of reports and operation of sub-system (launch times, adaptive operation) Increase the availability over the oceans (ASAP, dropsondes, etc.)
Ozone soundings	Vertical profile of ozone	Integrate into GOS
UAVs	Spatial coverage and vertical profile of wind, temperature and humidity	Demonstrate feasibility of an operational sub-system; target areas for operation are the ocean storm tracks (planned in THORPEX)
High-altitude balloons deploying sondes	Vertical profile of temp, wind and humidity	Demonstrate feasibility of an operational sub-system
Drifting buoys	Surface measurements of temp, wind and pressure, SST	Extend coverage especially in SH based on SVPB and WOTAN technology
Moored buoys	Surface wind, pressure, sub-surface temp profiles Wave height	Improve timely availability for NWP (monthly & seasonal forecasting) Extend coverage into Indian Ocean Provide data
Ice buoys	Ice temp, air pressure, temp and wind	Increase coverage
VOS	Surface pressure, SST, wind	Maintain their availability to provide complementary mix of observations
Ships of opportunity (SOOP)	Sub-surface temperature profiles (XBT)	Improve timely delivery and distribute high vertical resolution data
Subsurface profiling floats Argo programme	Sub-surface temperature and salinity	Improve timely delivery and distribute high resolution data
Tide gauges (GLOSS)	Sea level observations	Establish timely delivery
SYNOP and METAR data	Surface observations of pressure, wind, temperature, clouds and 'weather' Visibility Precipitation Snow cover and depth Soil moisture	Exchange globally for regional and global NWP at high temporal frequency (at least hourly), develop further automation Ditto Ditto Distribute daily Distribute daily
Wind profiling radar	Vertical profile of wind	Distribute data
Scanning weather radar	Precipitation amount and intensity Radial winds, Velocity Azimuth Display (VAD)	Provide data, demonstrate use in hydrological applications (regional and global NWP) Demonstrate use in regional NWP Ensure compatibility in calibration and data extraction methods
Ground Based GPS	Column Water Vapour	Demonstrate real-time capability

System	Parameter	Action/Development
Ground Based Interferometers and other radiometers (e.g. MW)	Time continuous vertical profile of temp/humidity	Demonstrate capability