CGMS-XXIX
WMO WP-7
Prepared by WMO
Agenda item: E.1
Plenary

REDESIGN OF THE WWW GLOBAL OBSERVING SYSTEM

(Submitted by WMO)

Summary and purpose of document

To inform CGMS Members on activities related to the redesign of the WWW Global Observing System (GOS).

ACTION PROPOSED

CGMS Members to note the latest activity on the redesign of the WWW GOS and comment as appropriate.

Appendix: Summary of the Coordination Group for Meteorological Satellites (CGMS) Workshop on Evolution of LEO-GEO Remote Sensing Post 2015

DISCUSSION

1. At CGMS-XXVIII, the reconfiguration of future combinations of LEO and GEO missions was discussed. NOAA provided a discussion that was a follow-on to a CGMS-XXVII paper entitled “Compliance of the post-2000 satellite-based component of GOS with requirements and possible approach to update/upgrade future systems”. These discussions were centred around whether important gaps existed in the post-2000 satellite-based component of the Global Observing System (GOS) and how they could be filled and how to prepare for the replacement of the elements currently in use or being developed, in view of next generation satellite systems to be used in the post-2015 era.

2. CGMS agreed that a workshop should be held, concurrent with the WMO Expert Team on Observational Data Requirements and Redesign of the Global Observing System. The following action item was agreed upon:

ACTION 28.07 - USA-WP-08 to be submitted to the Expert Team on Redesign of the Global Observing System as input for consideration and the draft Terms of References to be finalised by the Chairman of the Expert Team in preparation for the workshop.

3. The CBS OPAG on IOS Expert Team on Observational Data Requirements and Redesign of the GOS (ET-ODRRGOS) held its special reduced session in the WMO Headquarters in Geneva, 23-27 April 2001. The major goal of the session was to discuss issues related to the planning and implementation of Operational System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) within the framework of redesign of the GOS. On the first two days, the Coordination Group for Meteorological Satellites (CGMS) held a workshop to discuss the evolution of remote sensing in various specialised areas over the next 10-15 years and its potential contribution to the GOS.

CGMS Workshop

4. The CGMS workshop presentations included concepts for evolving geostationary (GEOs) satellites with high spectral resolution Infra-Red for improved soundings and winds and microwave for precipitation and cloud studies. They discussed enhancing the low earth-orbit (LEOs) satellites with active microwave for ocean surface determinations and high spatial resolution multi-spectral capabilities for sea/land/ice surface feature discrimination. The proposals provided for supplementing both with mini- and small-satellites for Lidar winds and tropospause and stratospheric definition. One goal suggested for the GOS of 2020 is for all citizens of the planet to have “weather in the palm of their hands.” This vision utilises LEOs and GEOs as well as *in situ* sensors, advanced computers, twenty-first century communications to provide timely and detailed weather information and forecasts to individuals in a “Palm Pilot” sized instrument. LEO observations would provide global coverage, high spatial resolution, microwave sounding, Global Positioning System (GPS) density profiles, Doppler LIDAR winds, and water vapour while GEO observations would provide high temporal resolution (weather dynamics), tracer wind velocities, synergism with ground-based observations, lightning measurements, and microwave precipitation determinations. It was pointed out that there will be considerable economic benefits for extending forecasts (by 2020 a 7-day forecast that is as accurate as today’s one day forecast will change the way the world functions). The above presentations provided by eight speakers have been posted on the WMO Web. A more detailed description of the CGMS Workshop can be found in the Appendix.

Expert Team on Observational Data Requirements and Redesign of the GOS Meeting

5. The Expert Team on Observational Data Requirements and Redesign of the GOS (ET-ODRRGOS) discussed studies carried out by NWP Centres on changes in the GOS that have occurred during the past decade and their impact on the skills of NWP both regionally and globally.

ECMWF reported on NWP impact studies using satellite sounding data (both infra-red and microwave instruments), cloud-drift winds from geo-satellites, and wind scatterometer data from ERS, NSCAT and QuikSCAT research satellites. In all cases, the impact was studied using variational data assimilation systems (3DVAR and 4DVAR). Of note was the positive impact of two Advanced Microwave Sounder Units over that achieved by just one; as well as the positive impact of scatterometer data. The UK Met Office reported on systematic “data denial” experiments testing the impact of satellite atmospheric motion vectors (AMVs), ERS-2 scatterometer data, and ATOVS data. The ATOVS results showed an impact of two AMSUs consistent with the ECMWF results. The use of tropospheric ATOVS data over land is also showing a positive impact. Météo France showed examples of degradation of forecasts for Europe from satellite derived AMVs in the region of 50° N and 35° W; additionally, it was noted that errors in winter-time forecasts for the European area have often been traced back to a lack of observations in the polar areas. NOAA National Centers for Environmental Prediction (NCEP) provided information on impact tests with targeted observations in the North Pacific Ocean (overall 70% of the additional observations showed clear improvement with rms error reduction of 10 to 25% in the 24 to 96 hr forecast). The NOAA Cooperative Institute for Meteorological Satellite Studies presented 24-hour forecast results for North America indicating that removal of satellite data (NoSAT) has a bigger impact on the model forecasts of temperature and moisture than removal of conventional RAOB data (NoRAOB). Isolating the impact of the GOES Sounder revealed that summer GOES moisture information has up to five times more impact than RAOBs. The South African Weather Bureau submitted ‘with-AMDAR’ and ‘without-AMDAR’ tests for some 50 cases. Early subjective evaluations are indicating positive impact in a majority of the cases, although not uniformly so. WMO presented a “Statistical Analysis of Forecast Verification Scores from Six Forecast Centres, 1991-2000”. Significant improvement in skill was evident at all NWP centres and anomalous poor performance was evident in 1999, but it could not be traced with certainty to the reduction in radiosonde launches over the northern and central Asian parts of RA II.

6. ET-ODRRGOS also discussed a coordinated development and utilization of a comprehensive software tool for carrying out Observing System Simulation Experiments (OSSEs) as well as preparation, maintenance, and evolution of a realistic OSSE database with user-friendly access. It was noted that undertaking an OSSE is often abandoned because of the huge human and computer resources required. The major task, therefore, would be aimed at leveraging and coordinating individual investments to facilitate more and better OSSEs. After some debate, the ET-ODRRGOS felt that the required resources for OSSEs are still so large that the limited resources for evaluating changes to the GOS would probably be better focused on well-defined Operational System Experiments (OSEs).

7. ET-ODRRGOS then suggested seven OSEs for consideration by NWP centres and asked the OPAG/IOS rapporteurs on Scientific Evaluation of OSEs and OSSEs to engage as many as possible in this work. They include studying the following:

- Impact of hourly SYNOPs;
- Impact of denial of radiosonde data globally above the tropopause;
- Information content of the Siberian radiosonde network and its changes during last decades;
- Impact of AMDAR data over Africa through data denial in a 4D-Var analysis and forecasting system;
- Impact of tropical radiosonde data;
- Impact of three LEO AMSU-like sounders;
- Impact of AIRS data.

8. The status / results of the experiments will be presented and discussed at the next ET-ODRRGOS meeting.

SUMMARY OF THE COORDINATION GROUP FOR METEOROLOGICAL SATELLITES (CGMS) WORKSHOP ON EVOLUTION OF LEO-GEO REMOTE SENSING POST 2015

23 – 24 April 2001
at the
World Meteorological Organization (WMO) Headquarters
Geneva, Switzerland

1. Background

At the October 2000 meeting of the Coordination Group for Meteorological Satellites (CGMS-XXVII) there was discussion concerning whether important gaps existed in the post-2000 space-based component of the Global Observing System (GOS), how they could be filled, and how to prepare for the replacement of the current satellite systems with the next generation satellite systems in the post-2015 era. CGMS made an action to hold a workshop, concurrent with the World Meteorological Organization (WMO) Expert Team on Observational Data Requirements and redesign of the Global Observing System (ET-ODRRGOS). The ET-ODRRGOS has been studying user requirements versus observing capabilities (for the combined space based and *in situ* observing systems) and considering options for redesign of the GOS towards more comprehensive observations for the World Weather Watch and other WMO supported programmes. This CGMS workshop was intended to assist them in their efforts. Eight speakers were invited to consider how remote sensing in various specialized areas would evolve in the next 10 – 15 years and what its contribution could be to the GOS.

2. Opening the Workshop

The workshop was opened by the Assistant Secretary-General of WMO, Dr A.S. Zaitsev. On behalf of the Secretary-General, he welcomed the participants to Geneva and to the Secretariat. Dr Zaitsev noted that the Global Observing System (GOS), which had evolved over the past four decades, was eroding for numerous reasons, not the least of which was financial. It had now become necessary to replace those elements that had fallen into disrepair or disuse. He also stated, “how better than to build this new GOS upon a solid foundation of durable, higher performance, technology.” He challenged the ET-ODRRGOS to play a significant role in the Redesign of the Global Observing System by devising practical Observing System Experiments and Observing System Simulation Experiments. These experiments, in turn, could be used to evaluate the impact of new technologies on NWP globally.

3. CGMS and CBS Synergy

Dr Paul Menzel, Chairman and organizer of the workshop, noted that the meeting followed the 31st celebration of Earth Day, where the global conscience is focused toward striving for the sustainable society (“A place where humans and their use of the environment are in balance with nature”). He suggested this offered an important goal for environmental remote sensing. He also pointed out that the terms of reference for the workshop matched well with the tasks assigned to the ET-ODRRGOS by the WMO Commission for Basic Systems (CBS).

CGMS organized the workshop in order to (a) identify gaps in the post-2000 satellite-based component of the Global Observing System (GOS), how they could be filled, and how to prepare for the replacement of the current satellite systems with the next generation satellite systems in the post-2015 era; (b) review requirements for temperature/humidity sounding and medium-resolution imaging missions and perspective technological capabilities; (c) provide a vision of an optimal split of roles between geostationary and low orbiting satellites; and (d) outline a strategic approach.

CBS has asked the ET-ODRRGOS to (a) review strengths and deficiencies in existing GOS and evaluate capabilities of new observing systems and possibilities for improvements of existing observing systems to reduce deficiencies in the existing GOS; (b) carry out studies of hypothetical changes to the GOS with the assistance of NWP centres; (c) prepare prioritised list of proposals for modification to the GOS that are both practicable and amenable to testing, and propose mechanisms for testing them; offer redesign options for CBS consideration; and (d) develop criteria for dealing with design issues of the composite GOS, paying particular attention to developing countries and the southern hemisphere.

4. Satellite Contributions to the Global Observing System (GOS)

Dr James Purdom (Chair of the CBS Open Programme Area Group for an Integrated Observing System wherein ET-ODRRGOS resides) gave an overview of his impressions of how satellite contributions to the GOS will evolve. He perceived that research satellites will continue to become a larger part of the GOS (several systems such as scatterometer, altimeter, synthetic aperture radar are already contributing). He stressed that international cooperation is increasing and is essential. His vision is that the GOS of 2020 will offer a spectral shell of global observations and require four dimensional data assimilation approaches to produce coherence in the observations. Hyperspectral and advanced microwave (MW) systems will be a natural progression. Nowcasting in the 21st century will be a major challenge of the GOS. Dr Purdom stressed that there will be considerable economic benefits for extending forecasts (in 2020 a 7-day forecast that is as accurate as one day forecast will change the way the world functions). Additionally, there is a challenge to engage a vibrant workforce with a creative training / education approach. Finally, he noted that fuller utilization of current systems remains a significant challenge.

5. High Spectral Resolution from GEOs of the Future

Dr William Smith spoke on the needs of a global observing system of the future and how geostationary remote sensing will be a critical component. His goal for 2020 is for all citizens of the planet to have "weather in the palm of their hands". He listed the needs as:

(a) **Computer systems** capable of continuous real-time 4-D assimilation of global data.

(b) **Accurate modelling** of

- hydrological processes on all scales;
- physics of surface/atmosphere energy exchange processes;
- coupling of chemistry and dynamics;
- microphysics and dynamics of clouds and aerosols and their feedback processes;
- synergistic multi-satellite/multi-sensor and processing algorithm system that is internationally coordinated;
- high spatial and temporal resolution profiles of atmospheric variables (p,T,q,V);
- continuous cloud, multi-level H_2O, precipitation, and lightning observations;
- all weather synoptic scale density profiles;
- land and ocean surface observations;
- air quality (CO and O_3) measurements.

(c) **Observing Systems** that utilize low earth orbiting (LEO) and geostationary earth orbiting (GEO) remote sensing advantages along with in situ measurements where:

- LEO observations give global coverage, high spatial resolution, microwave sounding, GPS density profiles, Doppler LIDAR winds, and water vapour;

- GEO observations provide high temporal resolution (weather dynamics), tracer wind velocities, synergism with ground-based observations, lightning measurements, and microwave precipitation determinations.

(d) **Communication Systems** that support data and information flow.

The associated requirements were summarized as

- quantitative measurements for input to 4-D continuous global data assimilation system;
- international coordination of satellite, sensor, and processing algorithm characteristics;
- synergistic multi-satellite/multi-sensor system;
- hourly atmospheric state variables (T,q,V) with a global system of GIFTS-like satellites;
- continuous cloud and multi-level H_2O imagery;
- GEO-microwave precipitation and lightning;
- small-satellite GPS occultation density profiles;
- land and ocean surface observations;
- air quality (CO and O3) monitoring.

He then detailed the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) that NASA is demonstrating in 2005 that will provide a balance of spectral (vertical) and temporal resolution in measurements for first time. GIFTS will put within reach two orders of magnitude improvement of GEO remote sensing; it is being made possible through the partnership of NASA research and NOAA and Navy operations.

6. Microwave Sensors for LEO and GEO

Dr David Staelin spoke on passive microwave capabilities that he sees for the future. His major points were that: (a) measuring precipitation with appropriate temporal resolution (on the order of tens of minutes) requires geostationary microwave measurements, (b) strong positive impact of advanced microwave sensing with AMSU on numerical weather prediction and tropical cyclone sensing suggests that there should be consideration of 3 LEOs with like capability, (c) the AMSU offers untapped capabilities for detecting precipitation events, (d) AMSU/ATMS will provide data useful for climate studies if rigorous calibration efforts are undertaken, and (e) limb scanning microwave instruments offer unique temperature profile and trace gas information opportunities. Some of the details of these five major points follow.

(a) Precipitation observations should be made from GEO since rapid (10 to 60 min) observations of precipitation are important, LEO strategies < 60 min are relatively uneconomic, only microwaves see through overlying cirrus, etc., and a GEO antenna of about 2 metres at 50 – 425 GHz sees most precipitation above 5 km and is practical for 10 – 60 min observations. Therefore, engineering and scientific studies of this concept should be aggressively promoted.

(b) A three LEO constellation of AMSU-like instruments is desirable because the presently observed impact of passive microwave sensors on NWP is about 8-12 hrs of forecast skill in the northern hemisphere (about 1 - 1.5 days in southern hemisphere). Therefore, such observations in 3 LEO slots should be planned.

(c) AMSU/ATMS offer untapped precipitation capabilities since their opaque bands sense precipitation in multiple ways over land and sea, in rain or snow, within a range of about 0.5 – 100 mm/hr in approximate agreement with radar observations. Therefore, existing and planned instruments should be exploited for this application together with window channels.

(d) AMSU/ATMS offer climate useful observations if rigorous calibration is undertaken since AMSU/ATMS are very stable and insensitive to most clouds. Sensitivities of about 0.01 K to layer temperatures (over months and very large areas) can be inferred, and no other instruments are so global and consistently calibrated. Therefore, calibration specifications and tests should reflect such climatological uses and these should continue with further technique development and validation.

(e) Limb scanning microwave approaches offer opportunities for new information since spectrometers at 200 – 1500 GHz have unique sensitivities to temperature variations with height and to certain trace gas species. Therefore, consideration should be given to such techniques for the GOS post 2015.

His presentation was followed with discussion of the planned SSMI/S / CMIS sounding capability. There was consensus that it was not yet proven and that the contribution level of these instruments to NWP must be explored.

7. OCEAN OBSERVATIONS FROM SPACE

Dr Alain Ratier provide a summary of the ocean remote sensing opportunities and needs as gleaned from the Global Ocean Data Experiment (GODAE), Ocean Observations 99, and the Integrated Global Observing Strategy (IGOS) Ocean Theme.

In the short term, it is felt that there is a need to continue

(a) altimetry measurements by committing to JASON-2 and
(b) ocean surface wind vector measurements by extending ERS-2 and QuikScat operations (in AMI/Wind mode) beyond 2002.

In the medium term regarding

(c) altimetry, it is necessary to:
- plan and start implementation of a joint US-European operational system;
- define configuration of and cooperation scenarios; and
- commit to post-ENVISAT precursor mission.

(d) surface winds, it is necessary to:
- achieve US/Japan commitment to Alphascat on GCOM-B; and
- evaluate WINDSAT / Coriolis passive measurement capaibilities.

(e) SST, it is necessary to:
- evaluate new IR and low frequency MW sensors; and
- continue ATSR beyond ENVISAT.

(f) ocean colour, it is necessary to:
- evaluate current missions;
- demonstrate their operational value; and
- assess additional need with respect to NPOESS and GCOM-B.

(g) sea ice/waves, it is necessary to:
- demonstrate the operational value of a global, real time, “wave mode” service with ENVISAT; and

- secure allocation of SAR resources for sea ice/wave monitoring on planned missions.

(h) research missions, it is necessary to:
- assess the value of CRYOSAT/ICESAT and SMOS.

In the long term, for:

(a) winds, the trade off between passive and active instrument concepts must be explored (i.e., post-EPS), and
(b) ocean colour/SST, the next generation of operational imagers should be defined.

Expanding on these areas, Dr Ratier noted that the challenges in each area are formidable.

(a) Altimetry should be pursued with a two-orbit system fully operational with real time capability wide swath (non-scanning) altimeters to enhance mesoscale capabilities. The challenges would be to commit to JASON-2 (a CNES-NASA-EUMETSAT-NOAA discussion is underway) and to plan/start implementation of joint US-European operational system (ESA-NASA-CNES-NOAA/IPO-EUMETSAT discussions should define configuration of the joint system and outline cooperation scenarios). Furthermore, it is necessary to define a post-ENVISAT precursor mission based on a trade off study of implementation options (WSOA, KA altimeter/µ-sat…). Finally there is a need to assess/demonstrate the potential of new techniques, including GPS reflection.

(b) Wind vectors are currently achieved with active techniques; passive techniques that are planned for the follow-on instruments need to be evaluated; therefore WINDSAT/Coriolis data need to be distributed to the NWP and ocean community as soon as possible and implications for the NPOESS programme need to be assessed. Related challenges are to extend ERS-2 (AMI/Wind mode) and Quickscat operations (if possible until 2005), to convince USA/Japan to commit to Alphascat on GCOM-B (there is no alternative), to evaluate trade off instrument concepts for the future (active and passive), and to plan post-EPS.

(c) SST will evolve to a combined LEO and GEO systems of measurements; it is necessary to combine all sources into a coherent composite SST determination. This will include evaluating low frequency microwave measurements from LEO, utilizing high spectral resolution IR to account for ocean surface reflection of atmospheric radiation, generalizing broad band IR split window measurements on all GEOs, and maintaining ATSR class accuracy in the SST determinations. Definition of requirements for imagers in the era of the Joint Polar System (post EPS/METOP, post NPOESS) should be a goal.

(d) Ocean Color capabilities are expanding; the community encourages that the LEO capabilities be secured, the operational needs be assessed, and OSEs be undertaken. Challenges/issues include demonstration of the operational value of planned missions through evaluation/cross-calibration/use, exploration of the utility of the increased horizontal resolution for coastal areas from new research instrument (such as MODIS and MERIS), and assessment of possible additional needs with respect to NPOESS, FY-1/3, and GCOM-B.

(e) SAR will hopefully evolve to a multi-satellite system; resources need to be secured. Further challenges/issues include demonstrating the operational value of a global, real time “wave mode” service (with ENVISAT), secure allocation of SAR resources for sea ice/wave monitoring (TERRASAR/INFOSAR, COSMO-SKYMED, RADARSAT-2/3), and analyse potential of other techniques and combined observations

Finally, Dr Ratier commented on some horizontal issues. They include:

- Coordination of orbits for LEO missions to generate some necessary orbit redundancy, as there are risks with “just necessary” service;
- Resolution of communications issues (GTS next ? Others ?) for real time availability of global data and products needs to oceanographic users (as well as other users);
- Cooperation for calibration / validation / harmonization of basic products; and
- Continuation of data collection services (ARGOS) that are crucial for collection of in situ data (e.g., ARGO) as well as investigation into the viability of commercial services (ORBCOM).

8. Scatterometry and Active Microwave Measurements in the Next Decade

Dr Michael Freilich continued discussion on ocean remote sensing. He summarized the issues regarding all weather vector surface wind measurements as follows.

- Presently approved scatterometer missions (SeaWinds on ADEOS-II, ASCAT on METOP 1-3) will enable continuous measurements from a single polar orbiting wide swath or dual swath instrument through 2020. However, simultaneous (i.e., tandem) missions of broad swath instruments are required for adequate sampling of surface wind fields for oceanographic use. A possible near term solution to enable tandem missions is for NASDA to fly a NASA scatterometer on GCOM-B1 and the missions of QuikScat and SeaWinds on NASDA’s ADEOS-II to be extended as long as possible;
- Rain degradation of Ku-band scatterometer data may be important. Several groups (including researchers at KNMI in collaboration with ECMWF) have made significant progress in understanding this issue. Following QuikScat, future Ku-band scatterometers are planned to fly in association with co-located multi-channel microwave radiometers (e.g., NASDA’s AMSR instrument on ADEOS-II and GCOM-B1 missions) that enable rain identification, correction for attenuation, and unified vector wind retrievals utilizing combined active and passive information;
- NPOESS provision of near all weather wind direction information over the full range of environmental conditions requires successful validation of the radiometric (passive polarimetry) techniques from space. Attention must be given to assure that accurate direction information is available from NPOESS so that the continuity of the vector wind data stream in the post-METOP era (after 2020) is not at risk.

Some major points that he made to support this summary follow. Scatterometery (both Ku- and C-band) are proven space-borne techniques for measuring near all weather surface vector winds (speed and direction) over the oceans. There is a long ERS time series (500 km wide swath) at C-band and NSCAT (dual, 600 km swath) and QuikScat (contiguous 1800 km swath) have acquired global vector wind measurements at Ku-band. The ESA and NASA research scatterometer missions have provided data routinely to operational meteorological centres in near real time from early in the mission for joint calibration / validation, quality control, and assimilation into forecast/analysis systems. (In the cases of NSCAT and QuikScat, NOAA processes and distributes scatterometer data in near real time using a complete set of processing algorithms provided by NASA).

Passive polarimetric microwave radiometry may provide an alternative vector wind measurement approach. The U.S. WINDSAT / Coriolis mission will launch in 2002 as a proof of concept mission (1100 km one look swath, 400 km dual look swath). The follow-on CMIS polarimetric microwave radiometer instrument on NPOESS is tasked with providing accurate vector wind measurements over a 1700 km swath (one look). Early evaluation of the accuracy and utility of the CMIS surface vector wind measurements by operational meteorological centres should be facilitated to assure rapid and efficient operational use of the data.

In addition to the primary vector wind measurements, the backscatter cross section data from active scatterometry are presently being used to calculate operational daily ice edge maps in polar regions. The operational ice edge products have been validated against Radarsat and shown to have higher resolution and accuracy than SSMI derived ice edges.

9. Possibilities for active remote sensing in near future

Dr Edward Browell spoke about experiences with air-borne and plans for space-based lidar systems. Noting that it is necessary to cover three orders of magnitude of water vapour mixing ratio in troposphere, he concluded that one needs measurements at more than one absorption line (perhaps three). Stronger absorption lines provide information on moisture high in the troposphere; it is possible to get 0.5-1.0 km resolution in the troposphere and thin clouds have been shown not to be a problem.

Concepts for Differential Absorption Lidar (DIAL) systems have been demonstrated from aircraft. Technology for space-based water vapour DIAL measurements from low earth orbit is rapidly advancing; it should enable that an initial space water vapour DIAL system can be deployed.

The goals of such a mission would be tropospheric water vapour profiles and column measurements with simultaneous aerosol and cloud profiles. It would address key global environmental issues in radiation budgets, climate change, meteorology, natural hazards, atmospheric dynamics, tropospheric – stratospheric exchange processes, and atmospheric chemistry. Measurement resolutions and accuracy goals would be for

- water vapour in the lower troposphere: 0.5 km x 100 km (10%);
- water vapour in the middle-upper troposphere: 1.0 km x 100 km (10%);
- aerosols and clouds: 60 m x 1 km (10%).

Spectral regions would be 820 / 940 nm narrowband; at least one aerosol and cloud channel with depolarization measurements should also be considered. DIAL technology could be deployed within ten years for 2015 era. Active DIAL complements other passive moisture measurements with effective four-dimensional data assimilation (4DDA) approaches. It is the only path to moisture vertical resolution necessary for water vapour observations. Knowing water vapour mixing ratio from active system enables higher vertical resolution and accuracy temp profile retrieval from passive observing system.

Dr. Browell emphasized that

- The Differential Absorption Lidar (DIAL) technique for the remote measurement of water vapour profiles is very mature, and an autonomously operating water vapour DIAL system has already been demonstrated from a high-altitude aircraft;

- The technology necessary for the development of a space-based water vapour DIAL system is maturing rapidly with the expected deployment of a space validation mission within the next decade;

- Simultaneous aerosol and cloud data available from a space-based water vapour DIAL system with less than 100 m vertical resolution will provide important information on atmospheric structure that can be interpreted with respect to atmospheric dynamics, transport, and water vapour distributions and used synergistically with the DIAL measurements of water vapour and with passive measurements of water vapour, temperature, aerosols, and clouds from GEO or LEO;

- Measuring water vapour to less than 1 km vertical resolution from space requires the addition of an active lidar system in LEO to complement the passive measurements of water vapour (which have generally lower vertical resolution but higher horizontal resolution). The combination of the different types of water vapour measurement systems in the future Global Observing System will be much more capable than any one single system by itself;

- It is expected that the development of a space-based water vapour DIAL system will require an international cooperative effort.

The workshop resonated with the powerful idea that combined active and passive sensing offered the best opportunity to measure water vapour measurements at resolutions commensurate with its variability in nature. Passive FTS measurements would get high horizontal resolution and active DIAL would get vertical resolution; together they would be used for a comprehensive determination of water vapour, temperature, RH, aerosol and cloud distributions with high spatial resolution and high accuracy. It was concluded that it is probably best to perform active measurements from LEO; data assimilation can sort out the synergy between active and passive measurements.

10. Radio occultation measurements

Dr Juha-Pekka Luntama presented recent experiences with and future hopes for radio-occultation measurements. They have be shown to be most useful for inferring temperature in those parts of the atmosphere where water vapour is present in trace amounts, namely above 5 km. Below 5 km, a humidity profile can be inferred when combined with independent temperature measurements. The vertical resolution is about 0.5 km in troposphere and 1.0 - 1.5 km above; horizontal resolution is about 150 - 300 km spread out along the tangent line. Temperature accuracy is about 1 K for altitudes between 5 - 30 km. Because of the large horizontal resolution radio occultation is not a mesoscale observing system; it is believed to be the best approach for sensing near the tropopause. Their high accuracy around tropopause and in lower stratosphere complements the atmospheric soundings by passive infra-red and microwave satellite sounders for NWP. Climate applications are a natural; radio occultation makes tropospheric as well as stratospheric measurements and has a long-term stable calibration. A suitable constellation of LEOs can provide globally dense coverage.

GPS Met was a proof of concept mission in 1995 - 97. Comparisons between radio occultation derived soundings and radiosondes or NWP fields were as close as 1.5 – 2 K. Very few radio occultation soundings reached below 5 km altitude. GPS/MET was able to perform only a small number of observations per day; an impact study with sufficient amount of real data has not been possible. It is felt that there is a critical need for further missions to fully understand the possible implementation of a radio occultation concept and to characterize associated errors. Several future missions are planned (CHAMP, GRAS, GPSOS, and possibly ROCSAT, ACE, WATS).

Several remaining issues were identified:

- Detecting and removal of atmospheric (and ocean induced) multi-path occurrences and enhancing resolution with back propagation into the lower troposphere;
- Sounding of the lower troposphere requires special techniques; a potential approach is through “raw sampling”;
- Getting precise orbit information for GPS and LEO satellites and clock offsets in near
- real time is still challenging but surmountable;
- Near time utilization makes system implementation considerably more complex; development of a near real time infrastructure is imperative and subsequent coordination of international utilization is encouraged;
- Maintaining availability of radio occultation data past the JPS era has not been addressed.

11. Wind-finding by space-based lidar

Dr Paul Ingmann presented the background information and plans for the first demonstration for measuring wind profiles from; ESA will be launching the Advanced Dynamics Mission (ADM) that will demonstrate Doppler lidar wind (DLW) measurements on a single satellite that can provide single line-of-sight measurements in 2006 or 2007. It involves a combination of Mie (aerosol) and Rayleigh (molecular) scattering measurements. Line-of-sight accuracy ranges from 0.5 m/s in lower troposphere to 1.2 m/s at high altitudes; vertical resolution ranges from 0.5 km in the lower troposphere to 2 km in the stratosphere

Dr Ingmann reminded the workshop that the mass and motion fields are very complementary; better wind determinations will also lead to better temperature, moisture, and pressure determinations. Remote sensing wind estimates fall short of the NWP user requirements, more so than sounding estimates do. Removing rawinsondes from NWP analyses has been demonstrated to cause negative impact; thus it is reasonable to assume that a DWL, providing wind data of similar quality, would be extremely useful. One Observing System Simulation Experiment (OSSE) has already been performed; another is in progress.

The DWL on ADM will provide line-of-sight winds not vector winds; however the difference in impact between the two on NWP models was marginal so the decision was made to measure only line-of-sight winds in this initial mission.

12. UPDATING THE GOS

Dr Bizzarro Bizzarri concluded the presentations in the workshop with an overview of his perception of the necessary updates and augmentations required for the GOS, if it is to meet user requirements in several of the applications areas important to the WMO. He studied CGMS plans for evolving the GOS, estimated where shortfalls would occur in meeting user requirements, and projected possible avenues for augmentation. He referred to the *Statement Of Guidance Regarding How Well Satellite And In Situ Sensor Capabilities Meet WMO User Requirements In Several Application Areas, 2001, SAT-26, Technical Document WMO/TD No. 1052* wherein considerations for six applications areas (global NWP, regional NWP, synoptic meteorology, nowcasting and very short-range forecasting, seasonal to inter-annual forecasting, and aeronautical meteorology) are presented; additionally three other applications (hydrology, agricultural meteorology and atmospheric chemistry) were considered by referring to *Statement Of Guidance Regarding How Well Satellite Sensor Capabilities Meet WMO User Requirements In Several Application Areas, 2001, SAT-20.*

To achieve compliance with WMO user requirements, in Dr Bizzarri's view, the GOS-proper (defined as the satellites operationally supported by CGMS members and those anticipated for transition from R & D space agencies after their initial demonstration) must be augmented in the following way.

- GOS-proper needs to be reinforced, possibly by adding SmallSats (defined to be 500 to1000 kg) or MiniSats (100 to 500 kg) to fill gaps;
- For many parameters, break-through impact within GOS-proper will require cooperation with other scientific/technological/commercial programmes;
- For the development/demonstration phase of the additional elements to be integrated in GOS-proper, organizations external to CGMS, such as R & D space agencies, should be relied upon.

He made the following recommendations:

- planning the evolution of the GOS should be done in a co-planning mode with CGMS;

- a minimum performance level of GEOs (and LEOs) that should be pursued by CGMS members within the post-2015 timeframe should be established;
- replacement strategies of the current or near future GOS satellites by the next generation satellites need to be determined;
- a role for small satellites supplementing the GOS needs to be studied further;
- cooperation within GOS elements is necessary;

and to assist the WMO in planning forward through the Consultative Meetings on High Level Policy on Satellite Matters

- CGMS should identify those missions that have operational long-term perspective, thus indicating demonstration mission priority areas for R & D space agencies;
- CGMS should list the data that scientific / technological / applications / commercial programs should deliver to complement or support the GOS in areas unlikely to be fully covered by meteorological satellites.

His presentation included concepts for evolving the GEOs with high spectral resolution IR sounding, faster VIS/IR imaging and possibly microwave for precipitation and cloud studies, enhancing the LEOs for atmospheric chemistry studies and sea/land/ice surface feature discrimination, and supplementing both with mini- and small-satellites for ocean topography, clouds and radiation, ocean salinity and soil moisture, a constellation for special measurements (radio occultation sounding, sea state, convective precipitation), and clear air winds when lidar technology matures.

The workshop felt that the suggested approach had some merit and agreed to study the many tables in Dr. Bizzarri's paper to see if consensus could be achieved within the workshop experts. Iteration of this paper was suggested as more information became available.

13. Conclusions

The workshop concluded that the following strategy should be adopted.

- Post the workshop presentations/papers on the web so that the various new and emerging technologies which might offer breakthrough progress in applications areas could be placed under consideration;
- Summarize the major recommendations of each speaker in a report ;
- Let the ET-ODRRGOS re-consider the RRR results and associated Statements of Guidance (SOGs);
- Report summary and results at the next CGMS.

All presentations are available on the CGMS web-site at <http://www.wmo.ch/hinsman/long-ter.htm>.