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COMMISSION FOR BASIC SYSTEMS  
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ITEM: 4

EXPERT TEAM ON OBSERVATIONAL DATA REQUIREMENTS  
AND REDESIGN OF THE GLOBAL OBSERVING SYSTEM

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REDUCED SESSION

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**REVISION OF THE STATEMENT OF GUIDANCE  
FOR GLOBAL NUMERICAL WEATHER PREDICTION**

(Submitted by Dr. J. Eyre)

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**Summary and purpose of Document**

The document consists of a proposed revision to the Statement of Guidance for Global Numerical Weather Prediction.

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**ACTION PROPOSED:**

The Expert Team may wish to note this draft revision in connection with the review of OSEs and OSSEs and when updating its recommendations with respect to the design of the future composite GOS.

## **DISCUSSION**

What follows is a proposed revision of the Statement of Guidance for Global Numerical Weather Prediction.

### **3.1 Global Numerical Weather Prediction**

Global Numerical Weather Prediction (NWP) models are used to produce short- and medium-range weather forecasts (out to 10 days) of the state of the troposphere and lower stratosphere, with a horizontal resolution of typically 50-100 km and a vertical resolution of ~1km. Forecasters use NWP model outputs as guidance to issue forecasts of important weather parameters for their area of interest.

To initialise these models, an accurate estimate of the complete atmospheric state is required. Observations from surface-based, airborne and space-based platforms are all used to define this initial state. The observational requirements for global NWP are based on the need to provide an accurate analysis of the complete atmospheric state at regular intervals (typically every 6 hours). Through a “data assimilation” system, new observations are used to update and improve an initial estimate of the atmospheric state provided by a short-range forecast.

Most benefit is derived from data available within 3 hours of measurement time, although most centres can get benefit from data up to 9 hours old. The key model variables for which observations are needed are: 3-dimensional fields of wind, temperature and humidity, and the 2-dimensional field of surface pressure. Also important are boundary variables, particularly sea surface temperature, and ice and snow cover. Of increasing importance in new NWP systems will be observations of cloud and precipitation.

Modern data assimilation systems are able to make effective use of asynoptic observations. Observations are most easily used when they are direct measurements of the model variables (temperature, wind, etc.), but recent advances have also facilitated the effective use of indirect measurements (e.g. satellite radiances, which are linked in a complex but known way to the model fields of temperature, humidity, etc.) and also the extraction of dynamical information from frequent (e.g. hourly) time series of observations.

In general, satellite data provide very good horizontal resolution and coverage but limited vertical resolution and coverage, and they are more difficult to interpret and use effectively. Conventional observations have limited horizontal resolution and coverage, but high accuracy and vertical resolution. Single *in situ* observations from remote areas can occasionally be of vital importance. Also, a baseline network of *in situ* observations is currently necessary for “tuning” the use of some satellite data. Observations are more important in some areas than in others; it is desirable to make more accurate analyses in areas where forecast errors grow rapidly, e.g., baroclinic zones. Identifying these areas and “targeting” observations to them is an active area of research.

The following sections provide an assessment, for the main variables of interest, of how well the observational requirements are met by existing or planned observing systems.

#### **3D wind field (horizontal component)**

Wind profiles are available from radiosondes over populated land areas and from aircraft (ascent/descent profiles) and wind profilers over some of these areas. In these areas, horizontal and temporal coverage is acceptable and vertical resolution is good. Over most of the Earth – ocean and sparsely-inhabited land – coverage is marginal or absent. Profile data are supplemented by single-level data from aircraft along main air routes only, and by single-level satellite winds (motion vectors from cloud or humidity tracers in geostationary imagery) over low and mid-latitudes. In these areas, horizontal and temporal resolution is acceptable or good, but vertical coverage is marginal. There is almost no wind coverage in Polar Regions. In the lower stratosphere, only radiosondes provide information. Accuracy is good/acceptable for *in situ* systems and acceptable/marginal for satellite winds. The geostrophic component of the wind can be deduced from temperature information in the extra-tropics.

Extension of AMDAR technology (principally for ascent/descent profiles but also for flight level information) offers the best short-term opportunity for increasing observations of wind,

although large areas of the world would still remain uncovered. From satellites, Doppler wind lidar technology is being developed to provide 3D winds of acceptable coverage and vertical resolution, but there are significant technical problems and thick cloud will provide limitations. Advanced geostationary imager-sounders (e.g. GIFTS) offer wind profile information in cloud-free areas through tracking of highly resolved features in water vapour channels. In the lower stratosphere, coverage may be supplemented in future by tracking ozone features in satellite imagery (see *Ozone* below).

### ***Surface pressure and surface wind***

Over ocean, ships and buoys provide observations of acceptable frequency. Accuracy is good for pressure and acceptable/marginal for wind. Coverage is marginal or absent over large areas of the Earth. Polar satellites provide information on surface wind - with global coverage, good horizontal resolution and acceptable accuracy - in two ways. Scatterometers give information on wind speed and direction but, because of their narrow measurement swaths, of marginal temporal resolution. Recently launched and planned scatterometers will provide acceptable coverage via broader swaths. Passive microwave imagers already provide information of acceptable temporal resolution but on wind speed (only). Several NWP centres have noted the positive impact from both data types, including the analysis and prediction of tropical cyclones. Passive polarimetric radiometers, to be tested in the near future, represent another possible way of providing wind speed and direction information.

Over land, surface stations measure pressure and wind with horizontal and temporal resolution, which is good in some areas and marginal in others. Measurement accuracy is generally good, though this can be difficult to use (particularly for wind) where surface terrain is not flat, because of the sensitivity of the measurements to small-scale circulations that global NWP models do not resolve.

Surface pressure is not observed by present or planned satellite systems, with the exception of some contribution from radio occultation data (which has been demonstrated theoretically and merits further study).

### ***3D temperature field***

Temperature profiles are available from radiosondes over populated land areas and from aircraft (ascent/descent profiles) over some of these areas. In these areas, horizontal and temporal resolution is acceptable and vertical resolution and accuracy are good. Over most of the Earth – ocean and sparsely inhabited land – coverage is marginal or absent. Profile data are supplemented by single-level data from aircraft along main air routes, where horizontal and temporal resolution and accuracy are acceptable or good.

Polar satellites provide information on temperature with global coverage, good horizontal resolution and acceptable accuracy. However, vertical resolution is currently marginal. Until recently performance in cloudy areas was poor, but the new microwave measurements from AMSU have provided substantial improvements here, and strong positive impact has been demonstrated by several NWP centres. Geostationary infra-red soundings (GOES) are also helping to expand coverage in some regions by making measurements hourly and thus creating more opportunities for finding cloud-free areas. Vertical resolution will be substantially improved in cloud-free areas with the launch of high-resolution infrared sounders on EOS-Aqua, METOP and NPOESS. Satellite sounding data are currently under-utilised over land, but progress in this area is anticipated in the near future. Radio-occultation measurements for planned satellites will complement other systems through high accuracy and vertical resolution in the stratosphere and upper troposphere (thus helping to improve analyses around the tropopause).

### ***3D humidity field***

Tropospheric humidity profiles are available from radiosondes over populated land areas. In these areas, horizontal and temporal resolution is usually acceptable (but sometimes marginal, due to the high horizontal variability of the field), vertical resolution is good and accuracy is good/acceptable. Over most of the Earth – ocean and sparsely inhabited land – coverage is marginal or absent.

Polar satellites provide information on tropospheric humidity with global coverage, good horizontal resolution and acceptable accuracy. However, vertical resolution is currently marginal. Until recently performance in cloudy areas was poor, but the new microwave measurements from AMSU offer substantial improvements. Geostationary infra-red soundings (GOES) are also helping to expand coverage in some regions by making measurements hourly and thus creating more opportunities for finding cloud-free areas. Over ocean, coverage is currently supplemented by information on total column water vapour from microwave imagers.

Vertical resolution will be substantially improved in cloud-free areas with the launch of high-resolution infrared sounders on EOS-Aqua, METOP and NPOESS. Satellite sounding data are currently under-utilised over land, but progress in this area is anticipated in the near future. Radio-occultation measurements from planned satellites will complement other systems by providing information on the humidity profile in the lower troposphere. Over populated land areas, growth is expected in the availability of total column water vapour data from ground-based GPS measurements. Very few aircraft currently provide humidity measurements, and these data are not generally available, but technical advances in this area are anticipated in the next decade.

### ***Sea surface temperature***

Ships and buoys provide observations of sea surface temperature of good temporal frequency and accuracy. Coverage is marginal or absent over large areas of the Earth. Instruments on polar satellites provide information with global coverage, good horizontal resolution and accuracy, except in areas that are persistently cloud-covered. Temporal coverage is adequate for short-medium range NWP but, for seasonal/inter-annual forecasting, observation of the diurnal cycle is required, for which planned geostationary satellites offer a capability.

### ***Sea-ice***

Sea ice cover is observed by microwave instruments on polar satellite with good horizontal and temporal resolution and acceptable accuracy. Data interpretation can be difficult when ice is partially covered by melt ponds. Operational ice thickness monitoring will be required in the longer term, but is not currently planned.

### ***Snow***

Over land, surface stations measure snow cover with good temporal resolution but marginal horizontal resolution and accuracy (primarily because of spatial sampling problems). Visible / near infra-red satellite imagery provides information of good horizontal and temporal resolution and accuracy on snow cover (but not on its equivalent water content) in the day-time in cloud-free areas. Microwave imagery offers the potential of more information on snow water content (at lower but still good resolution) but data interpretation is difficult. Snow cover over sea-ice also presents data interpretation problems.

### ***Soil moisture***

Microwave imagery is sensitive to surface wetness, but no present or planned operational missions meet minimum requirements for measurement of soil moisture (i.e. below the surface). Research instruments such as SMOS offer some progress here. Some land surface stations report soil moisture routinely with marginal accuracy, but most do not report.

### ***Surface air temperature and humidity***

Over ocean, ships and buoys provide observations of acceptable frequency and good accuracy. Coverage is marginal or absent over large areas of the Earth. Over land, surface stations measure with horizontal and temporal resolution that is good in some areas and marginal in others. Measurement accuracy is generally good, though this can be difficult to use where surface terrain is not flat, because of the sensitivity of the measurements to local variability that global NWP models does not resolve. Satellite instruments do not observe these variables, or do so only to the extent that they are correlated with atmospheric variables that significantly affect the measured radiation (i.e. skin temperature and atmospheric layer-mean temperature and humidity).

***Land and sea-ice surface skin temperature***

Satellite infra-red and microwave imagers and sounders provide data containing information on these variables, although retrieval accuracy is affected by cloud detection problems and surface emissivity uncertainties, and interpretation is difficult because of the heterogeneous nature of the emitting surface for many surface types. Otherwise, planned instruments offer data of good resolution and frequency.

***Vegetation type and cover***

Present-day operational satellite imagery from visible/near-infrared channels offers good resolution and frequency, and marginal accuracy. Research instruments, such as MODIS, offer considerably improved accuracy.

***Clouds***

Surface stations measure cloud cover and cloud base with a temporal resolution and accuracy that is acceptable but a horizontal resolution that is marginal in some areas and missing over most of the Earth.

Satellite instruments offer a wealth of information on cloud. Infrared imagers and sounders can provide information on cloud cover and cloud-top height of good horizontal and temporal resolution and good/acceptable accuracy. Microwave imagers and sounders offer information on cloud liquid water of good horizontal resolution and acceptable temporal resolution, with an accuracy that is probably acceptable (though validation is difficult).

At present the primary problem is not with the cloud observations themselves but with their assimilation, arising from weaknesses in data assimilation methods and in the parameterisation of clouds and other aspects of the hydrological cycle within NWP models. Substantial improvements in these areas will be needed in order to make more use of the available observations over the next decade.

Current and planned visible/infra-red imagers offer some information on cloud drop-size at cloud top. Active microwave instruments are required to give more information on the 3D distribution of cloud water/ice amounts and cloud-drop size; research instruments are planned.

***Precipitation***

Surface stations measure accumulated precipitation with a temporal resolution and accuracy that is acceptable but a horizontal resolution that is marginal in some areas and missing over most of the Earth. Ground-based radars measure instantaneous precipitation with good horizontal and temporal resolution and acceptable accuracy, but over a few land areas only.

Microwave imagers and sounders offer information on precipitation of marginal horizontal and temporal resolution, and acceptable/marginal accuracy (though validation is difficult). Satellite-borne rain radars, together with plans for constellations of microwave imagers, offer the potential for improved observations.

***Ozone***

Developments are under way to add ozone as a new NWP model variable, primarily to allow ozone observations to be used to provide information on wind. In addition, more accurate model ozone fields will improve model radiation calculations and the assimilation of infra-red temperature sounding data. The accuracy of total column ozone obtained from satellite instruments is acceptable and will be improved with the launch of high-resolution infra-red sounders and more accurate solar backscatter instruments. However, to maintain realistic vertical distributions of ozone in NWP models, some observations of ozone profiles are also needed at lower horizontal and temporal resolution.

***Wave height, direction and period***

Ships and buoys provide observations of acceptable frequency and acceptable/marginal accuracy. Coverage is marginal or absent over large areas of the Earth.

Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy. However, horizontal/temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy but marginal horizontal/temporal resolution. Moreover, future continuity of satellite coverage is not assured.

### ***3D aerosol***

Operational visible / near infrared satellite imagery is used to provide estimates of total column amounts over the ocean with good horizontal resolution and acceptable temporal resolution but marginal accuracy. Advanced imagers such as MODIS are expected to improve accuracy for total column amounts and to provide information on aerosol particle size and type. However, retrieved quantities will be of column totals and means only. Lidar measurements will be required to provide vertically resolved information. Research demonstrations of lidars are planned.

### ***3D wind – vertical component***

No present or planned capability. Research required on indirect observation via sequences of geostationary infrared imagery.

### ***Additional observations for model validation***

Outgoing longwave and shortwave radiation fluxes can be estimated, with varying degrees of accuracy, from several broadband or multi-spectral infra-red and visible satellite radiometers designed primarily for other purposes. Specialised instruments designed to measure accurately some component(s) of the Earth's radiation budget include CERES on TRMM, TERRA and Aqua, and GERB on MSG. Horizontal resolution is good. Accuracy is acceptable and depends on the accuracy of the absolute calibration and of the radiance to flux conversions.

Advanced infra-red sounders (e.g. AIRS, IASI, CrIS), providing complete or near-complete spectral coverage of the thermal infra-red at high spectral resolution, should offer the opportunity to monitor the infra-red spectrum of surface emissivity with good horizontal resolution and accuracy, although further research is required.

Surface albedo can be estimated from shortwave broadband or multi-spectral radiometer measurements with good horizontal resolution. Clouds, aerosols and atmospheric gases affect the accuracy achievable, which is currently marginal/acceptable but should become good as progress is made in interpreting data from high-resolution, multi-spectral instruments.