PLANET EARTH SEEN FROM SPACE: BASIC CONCEPTS

J. R. Eyre

Met Office, Bracknell, UK

1. INTRODUCTION

The use of satellite data in numerical weather prediction (NWP) has advanced substantially in the last decade. In 1990, the satellite data assimilated into operational NWP models was very limited, both in the number of types of data used and in their volume. Moreover, their impact on forecast skill was mixed; although clearly positive in the Southern Hemisphere (SH), their impact was marginal in the Northern Hemisphere (NH) to the extent that, for a short period in the early 1990s, satellite sounding data were not assimilated into the ECMWF NWP model in the NH troposphere. In 2000, the position has improved radically. Several operational NWP centres are now assimilating satellite data of many different types with clear positive impact; benefits in the SH are much improved and benefits in the NH and tropics are now clear. In fact the combined impact of satellite data on NH medium range forecasts is now comparable with that of radiosonde data (e.g. see Simmons 2000).

To achieve these results, much improvement has been required in the processing and assimilation of satellite data, which in turn has needed an improved understanding of the true information content of these data and of their strengths and weaknesses. Central to this effort have been improvements in our understanding of the signals measured when we observe the Earth/atmosphere system from space, and in our ability to model these relationships and incorporate them in our data assimilation systems.

This paper presents some of the basic ideas important for understanding the role of satellite data in NWP. It considers first the satellite systems that carry instruments relevant to NWP and gives an overview of the instrument technologies. It discusses the observational requirements of NWP and the contribution made by measurements from satellites towards meeting these requirements, and it summarises the main deficiencies. Other papers in this volume describe how satellite data are assimilated into NWP models, both in terms of the general theory and its application to data from specific instruments. Here we consider only some general issues: how well does the NWP model already "know" what the satellite instruments are going to measure, leading to concepts of "signal-to-noise" which are subsequently important in understanding the data assimilation process as applied to satellite data. We also consider why the use of satellite imagery in NWP has been rather limited to date and discuss some possible future developments in this area.

2. SATELLITE PLATFORMS AND INSTRUMENT TECHNOLOGIES

2.1 Satellite platforms for operational meteorology

Satellites that carry instruments used in operational meteorology are of two types: geostationary satellites (GEOs) and low-Earth orbiting satellites (LEOs).

GEOs have a near-circular equatorial orbit with an altitude of about 36000 km. They orbit the Earth with the same angular velocity as the Earth's rotation, and thus they have a fixed view of part of the Earth. This allows them to achieve a high frequency of observation: down to a 15-minute repeat cycle for the full Earth's disk and even more frequent if the scan is restricted to a small portion of the disk.

LEOs occupy a much lower orbit: usually between 600 and 1000 km altitude and near-circular. For operational satellites, they are usually placed in a near-polar, sun-synchronous orbit at an altitude of about 800 km, giving them an orbital period of about 100 minutes. Their instruments generally scan a swath either side of the ground-track which, if sufficiently wide, provides coverage of every point on the Earth at least every 12 hours from one satellite. An operational system of two satellites with appropriately spaced orbital planes can therefore provide 6-hourly coverage. If the orbit is sun-synchronous, the observations are provided at the same local time each day.

Because GEOs are so much further away from the Earth, it is more difficult to make measurements of the same quality (horizontal resolution, accuracy, etc.) from that orbit. The main reason, and perhaps the only good reason, for using the geostationary orbit is for applications or techniques that require observations at high temporal frequency.

2.2 Instrument technologies relevant to NWP

This section provides an overview of instrument technologies under the general headings of: passive, active and GPS. Passive instruments sense natural radiation emitted by the Earth/atmosphere system or solar radiation reflected by it. Active instruments emit radiation themselves and then measure how much of it is reflected/scattered back by the Earth/atmosphere. GPS meteorology makes use of signals emitted from global positioning satellites and measured by instruments either on the ground or on LEOs.

This section is not intended to cover all satellite remote sensing relevant to meteorology and atmospheric science, but to focus on those instruments of most importance for NWP. Many textbooks contain introductions to these technologies. A useful introductory reference in this rapidly developing field, both to technologies and some applications within meteorology, is the CGMS Directory of Meteorological Satellite Applications (EUMETSAT 1998).

2.2.1 Passive remote sensing

The best known satellite data come from **visible and infra-red imaging radiometers**. They include the imagers on all operational GEOs and the AVHRR instrument on the NOAA polar-orbiters. They sense (mainly) in atmospheric "windows" regions – parts of the electromagnetic spectrum where the atmosphere is quite transparent – and thus "see" down to the cloud top or, in cloud-free areas, to the Earth's surface. Infra-red imagery provides, both day and night, information on cloud cover, cloud type and cloud top temperature (and hence cloud-top pressure/height), and on surface temperature either of the sea or the land. Visible imagery provides daytime information on cloud cover and type, and on land surface type and snow/ice and vegetation cover. Sequences of images from GEO satellites are used to track the movement of cloud features which, in suitable conditions, provide estimates of wind at the cloud altitude.

Although imagery of this type is the most widely used satellite data in meteorology as a whole, its use in NWP has been comparatively limited. Satellite winds play an important role in NWP, and sea-surface temperatures derived from infra-red imagery are also widely used. In mesoscale NWP, cloud imagery is used to initialise the cloud field in the model, but overall these data are far from fully exploited in NWP. This issue is discussed further in section 4.3.

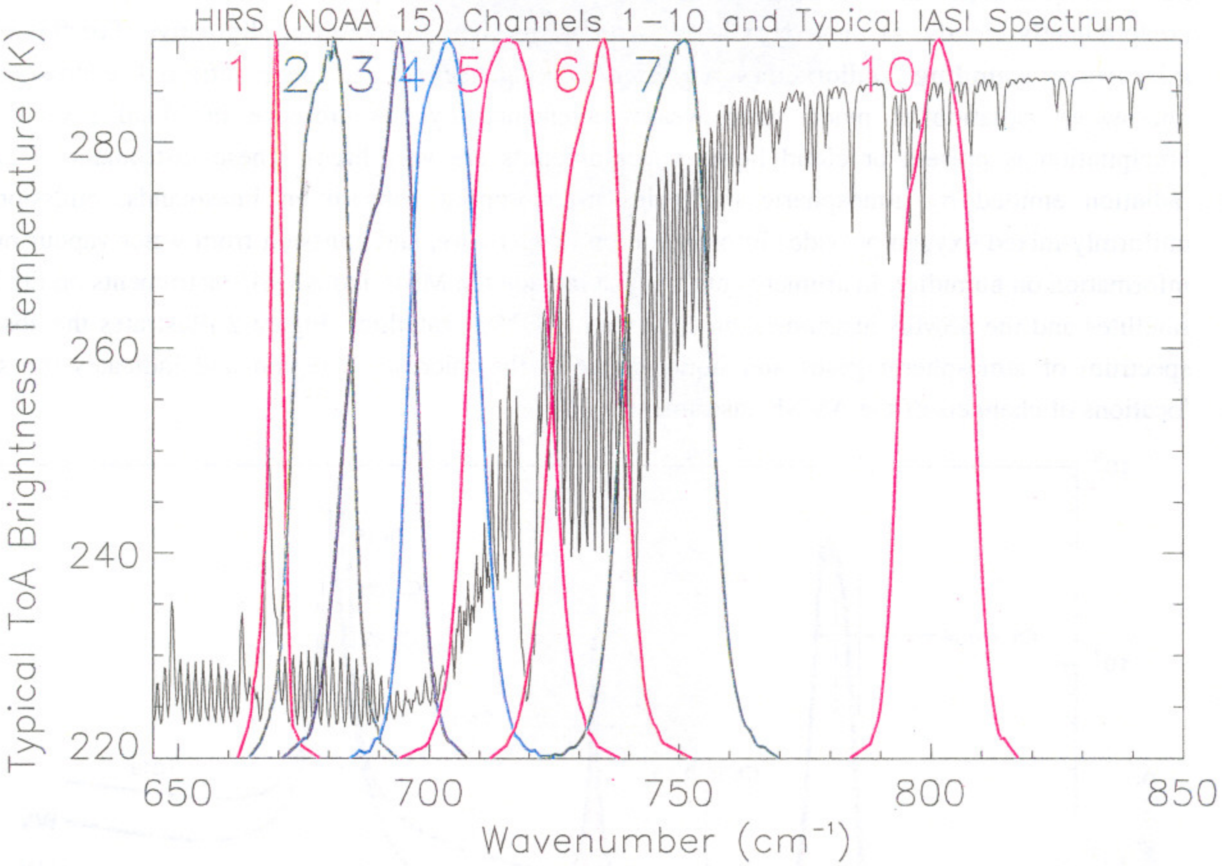

Figure 1 A typical brightness temperature spectrum for IASI and the spectral response functions of HIRS channels 1-7 and 10.

Another class of instrument is the **infra-red sounding radiometer**. These sense primarily in gaseous absorption bands and measure the radiation emitted by molecules of these gases in the atmosphere. By careful selection of the wavelengths detected, radiation emanating from different layers of the atmosphere can be sensed, permitting information to be recovered ("retrieved") on atmospheric vertical profiles; measurements of radiation intensity from gases of known concentration such as carbon dioxide provide information on the temperature profile, whereas measurements from gases of variable concentration such as water vapour and ozone provide information on the mixing ratio profiles of these gases. Instruments in this class include filter radiometers such as HIRS on the NOAA satellites and the sounders on the GOES geostationary satellites. The chief deficiency of these instruments is their low vertical resolution (typically ~3 km). This will be improved (to about 1 km) with the next generation of "advanced" infra-red sounders, which will have much higher spectral, and hence vertical, resolution. Operational NWP centres are currently preparing to receive data from advanced sounders such as the spectrometer AIRS on NASA's Aqua satellite and the interferometer IASI on EUMETSAT's METOP satellite. Figure 1 illustrates the data to be obtained from such instruments, compared with the typical spectral responses of filter radiometers. All these instruments provide information on the profiles of temperature, humidity and ozone profiles, and on surface temperature. They are fundamentally limited by the presence of cloud; where the cloud is opaque, no radiation from below the cloud can be sensed, and so no information on atmospheric profiles below the cloud can be obtained. However, as with infra-red imagery, these measurements do contain information on cloud cover and cloud top pressure.

For NWP, it is important to obtain information on atmospheric temperature and humidity in areas that are predominantly cloudy, as these regions are usually the most meteorologically active. For this reasons, **microwave sounding radiometers** are highly complementary to their infra-red counterparts, as microwave radiation is much more weakly attenuated by the presence of cloud (except where precipitation is present or cloud liquid water amounts are very high). These instruments also sense radiation emitted by atmospheric molecules in appropriate absorption lines/bands; emission from uniformly-mixed oxygen provides information on temperature, and emission from water vapour provides information on humidity. Instruments of this type include the MSU and AMSU instruments on the NOAA satellites and the SSMIS instrument on forthcoming DMSP satellites. Figure 2 illustrates the absorption spectrum of atmospheric gases and liquid water in the microwave region and indicates the spectral locations of channels of the AMSU instrument.

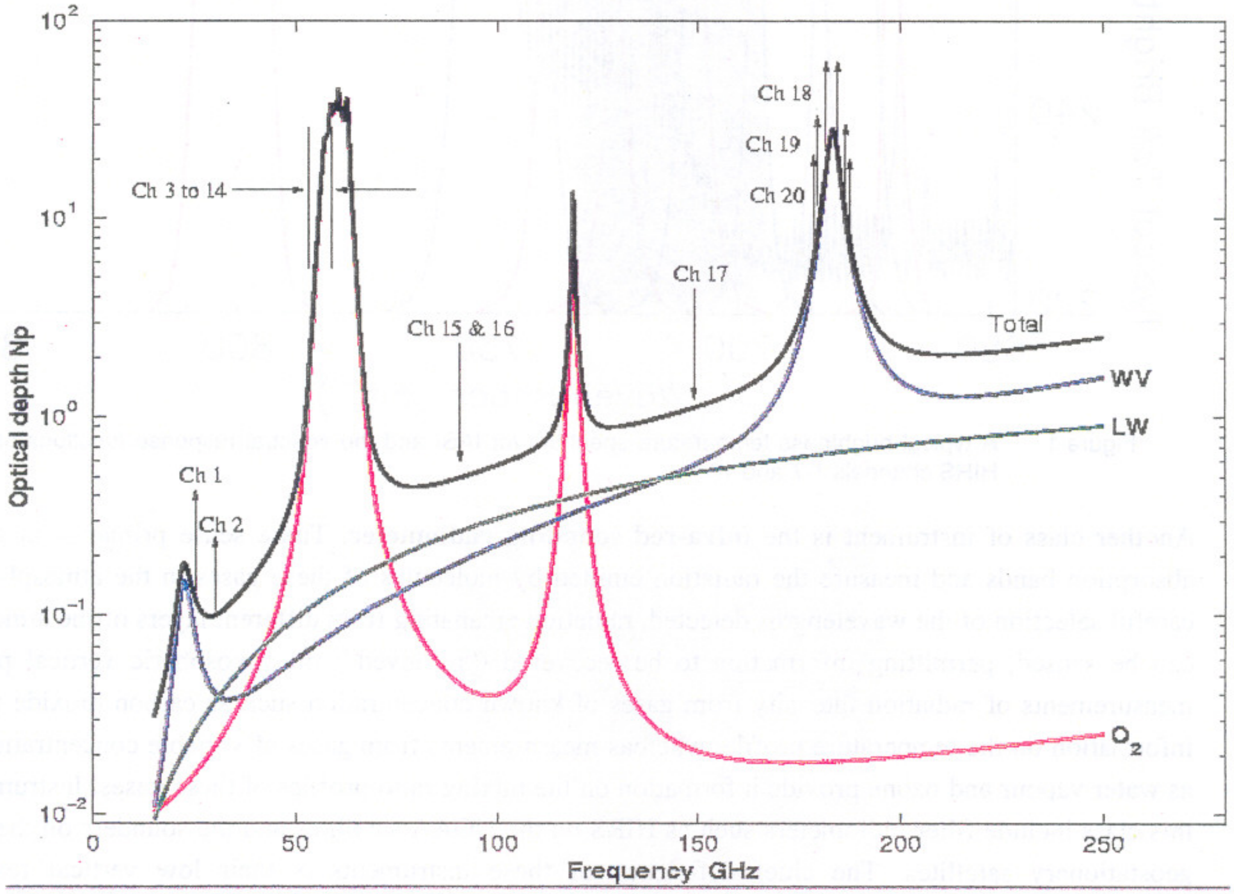

Figure 2 The microwave absorption spectrum for oxygen (O_2), water vapour (WV) and cloud liquid water (LW), and the location of the spectral channels of AMSU.

Microwave imaging radiometers sense radiation mainly in atmospheric "window" regions, emitted mainly by the surface and/or clouds. Over the ocean they provide information on surface wind speed, through its effect on the roughness and hence the emissivity of the sea surface, and on sea-ice cover. Figure 3 shows typical brightness temperatures in one microwave window region as a function of scan angle, polarisation and surface wind speed. They also provide information on cloud liquid water (total column) and precipitation. Also, because the various window channels are differentially contaminated by water vapour absorption, they provide information on water vapour (total column). In fact, over the ocean microwave measurements offer more information on humidity in the lowest levels of the troposphere than do infra-red, because in the microwave region there is a contrast between the emission from warm layers of the atmosphere and emission from the sea surface, which appears much colder because of its low microwave emissivity. Instruments in this class include: SSM/I and SSMIS on current and forthcoming DMSP satellites, and TMI on the TRMM satellite.

The **ultra-violet** region of the spectrum is currently exploited to obtain information on ozone profiles. Ultra-violet radiation from the sun is absorbed and scattered by the atmosphere. Differential absorption over a range of wavelengths can be exploited to retrieved information on the vertical distribution of ozone. Instruments in this class include: SBUV on the NOAA satellites, TOMS on several satellites and GOME on ERS and METOP satellites. Of course, these techniques can only be used in daylight; complementary information (e.g. in the polar winter) is obtained from infra-red sounding instruments.

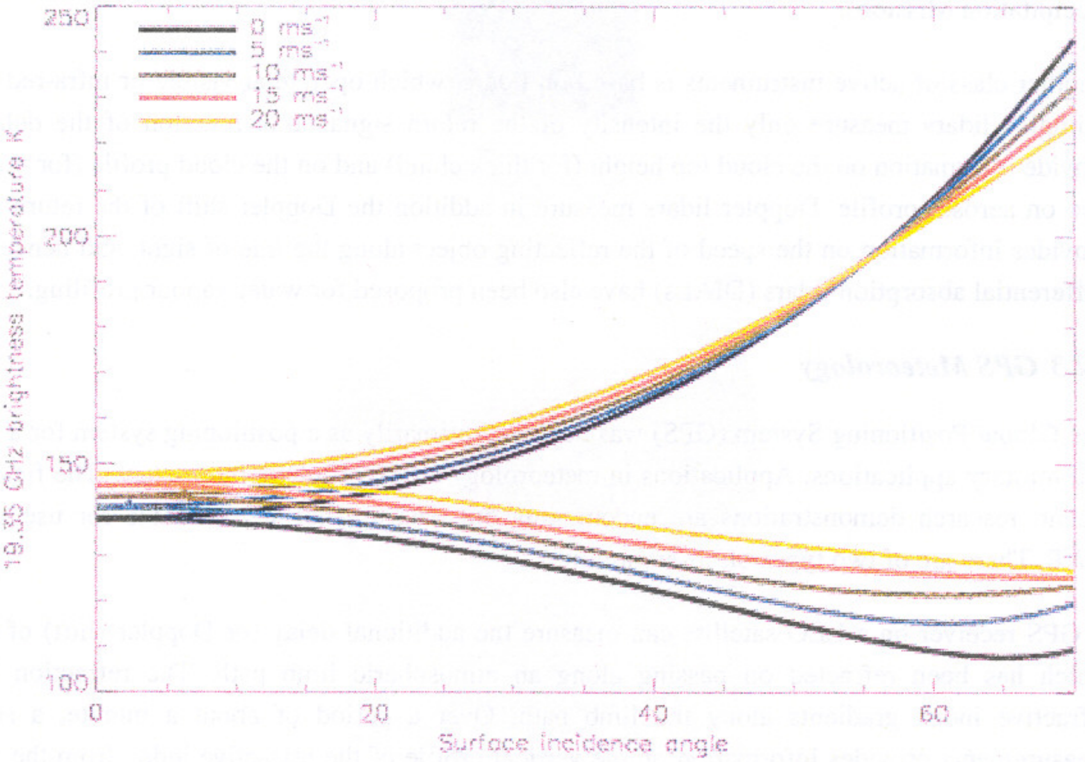

Figure 3 Brightness temperatures to space at 19.35 GHz simulated for a typical atmosphere as a function of surface incidence angle, wind speed and polarisation. The upper and lower groups of lines are for vertical and horizontal polarisation respectively.

2.2.2 *Active remote sensing*

Active instruments are not currently carried on operational meteorological satellites. They have been flown on research satellites, operational demonstration satellites and satellites built primarily for other applications. However, their data are useful in NWP, and some active instruments will fly on operational meteorological satellites in future.

The first broad class of instruments may be called "surface radar", in that they measure radiation emitted by the instrument and reflected back from the Earth's surface. The most widely used of such data in NWP come from scatterometers. These emit microwave radiation and measure the intensity scattered back from the sea surface in a number of directions, which contains information on the sea surface wind speed and direction. Other instruments in this class are: altimeters which, through measurement of the time delay and the shape of the return signal, provide information on the sea surface height, the wave height and the wind; and synthetic aperture radars (SARs), which (among other things) provide information on wave spectra. Altimeter and SAR data are used primarily in ocean and wave models, although altimeter wind speeds have provided valuable validation data for NWP.

The second class of instruments contains cloud and precipitation radars. These emit microwave radiation (at higher frequencies) and measure the backscatter from cloud and precipitation particles. The time delay of the return signal allows information on the profiles of these variables to be retrieved. A precipitation radar was flown on TRMM and other missions have been proposed (e.g. TRMM-2 as part of the Global Precipitation Mission).

Another class of active instruments is based on lidars, which operate at visible or infra-red wavelengths. "Simple" lidars measure only the intensity of the return signal as a function of the delay. They can provide information on the cloud top height (for thick cloud) and on the cloud profile (for thin cloud), and also on aerosol profile. Doppler lidars measure in addition the Doppler shift of the return signal, which provides information on the speed of the reflecting object along the line of sight, and hence on the wind. Differential absorption lidars (DIALs) have also been proposed for water vapour profiling.

2.2.3 *GPS Meteorology*

The Global Positioning System (GPS) was deployed primarily as a positioning system for a range of civil and military applications. Applications in meteorology are a fortuitous by-product. The field is relatively recent; research demonstrations are encouraging but data are not yet available for use in operational NWP. There are of two types of observation:

A GPS receiver on a LEO satellite can measure the additional delay (or Doppler shift) of a GPS signal which has been refracted on passing along an atmospheric limb path. The refraction is caused by refractive index gradients along the limb path. Over a period of about a minute, a series of such measurements provides information on the vertical profile of the refractive index from the surface to the stratopause. The technique is known as radio occultation and provides information, via the retrieved refractivity profile, on the temperature profile (stratosphere and upper troposphere), the humidity profile (lower troposphere) and possibly also the surface pressure. This observation technique has high vertical resolution but low horizontal resolution (due to its limb-sounding geometry). GPS receivers on polar-orbiting satellites can provide global coverage and "all-weather" measurements.

A GPS receiver on the Earth's surface can measure the total delay of GPS signal caused by the atmosphere. This provides information on the total column water vapour above the receiver. It is only a local measurement, but can be made at high temporal frequency, and thus has potential for improving humidity analyses in regional NWP models.

3. OBSERVATIONAL REQUIREMENTS FOR NWP

Accurate forecasts from a NWP system require an accurate description of the initial state of all the important geophysical variables within the domain of the model and at its boundaries. Observational information is required to drive the analysis of these variables. Some variables are more important than others; the main ones are listed below, roughly in order of importance.

Of primary importance are the variables describing the 3D mass and wind fields: the wind (or at least its horizontal component), the temperature and the surface pressure. Next is the 3D humidity field, which affects the evolution of cloud and precipitation in the model, and also has a small effect on the mass field. Variables affecting the surface fluxes are: ice/snow cover, sea surface temperature, vegetation cover, soil moisture, snow depth (water equivalent) and land surface temperature. Of growing importance as initialised variables are cloud and precipitation, particularly for mesoscale NWP and for short-range forecasts. Additional variables that modify atmospheric radiation or act as tracers of motion are: ozone and aerosols.

Observational requirements for all these variables (and others) have been considered in many different fora. The most comprehensive set of observational requirements is maintained by WMO (WMO 2000a, 2000b). It covers a range of user applications encompassed by WMO programmes, including operational NWP.

The observation requirements of NWP are met, to varying degrees, by a range of observing systems, and NWP data assimilation systems are designed to make best use of this diverse range of observations with their various strengths and weaknesses. As discussed in Section 1, satellite systems are playing an important and growing role as part of the composite observing system. The particular strengths of satellite data are their global coverage and generally high horizontal resolution. The role of satellite observations, from current and future systems, in contributing to the analysis of key NWP variables is summarised in Table 1. This table includes instruments on operational meteorological satellites, and also some of the instruments most relevant to NWP on other satellites.

The main deficiencies of the observing system – the present composite system augmented by systems expected to become operational over the decade – for NWP are summarised in Table 2.

	NOW	**FUTURE**
3D Wind	winds - tracking features	GEO radiances in 4D-Var in GEO imagery DWL
3D Temperature	HIRS, MSU, SSU, AMSU	IASI, AIRS, CrIS, SSMIS, ATMS, CMIS, MODIS, GPS-RO
Surface pressure		GPS-RO?
Surface wind	AMIwind, Seawinds SSM/I, TMI	ASCAT SSMIS, CMIS, Windsat
3D Humidity	AMSU, HIRS, SSM/I, TMI	IASI, AIRS, CrIS, SSMIS, MHS, ATMS, CMIS, MODIS, GPS-RO, GPS-WV
Surface		
Temperature (sea, land)	AVHRR, ATSR, TMI	AATSR, VIIRS, MODIS IASI, AIRS, CrIS, AMSR
Ice cover	SSM/I, AMSU, AVHRR	SSMIS, CMIS, ATMS, AMSR, MHS, ASCAT, VIIRS, MODIS
Snow cover	SSM/I, AMSU, AVHRR	SSMIS, CMIS, ATMS, AMSR, VIIRS, MODIS
Vegetation	AVHRR, SSM/I?, AMSU?	MODIS, VIIRS, SSMIS?, CMIS?, ATMS?, AMSR?
Snow depth		AMSR?
Soil moisture		SMOS
Cloud cover	visible/infra-red imagery HIRS, AVHRR	VIIRS, IASI, AIRS, CrIS, MODIS
Cloud water/ice	SSM/I, AMSU	SSMIS, CMIS, MHS, ATMS
Precipitation	visible/infra-red imagery? SSM/I, TMI, TRMM-PR	GPM, including TRMM-2
Ozone	HIRS, SBUV, TOMS	GOME, OMPS, SEVIRI, IASI, AIRS, CrIS, MODIS
Aerosol	AVHRR?, TOMS?	MODIS?, VIIRS?, SEVIRI?

Table 1. SATELLITE DATA IN NWP

Notes: "?" means that the achievable accuracy may be of marginal value for NWP.
See "Acronyms" section for complete instrument names.

Global NWP

wind profiles
surface pressure
snow equivalent water content
precipitation
soil moisture
temperature and humidity profile (vertical resolution in cloudy areas)

and additionally for ...

Mesoscale/regional NWP

wind and humidity profiles, especially in the planetary boundary layer
surface and soil properties (accuracy and frequency)
cloud-base, cloud thickness, cloud properties

(Reference: WMO 2000b)

Table 2. The main deficiencies in planned observing systems for NWP

4. THE NWP MODEL "SEEN" FROM SPACE

4.1 The data assimilation process

Figure 4 shows schematically how observations are assimilated within a NWP data assimilation system. At the bottom we represent the continuous cycle of forecast and assimilation found (in some form) in all assimilation systems. At the top we have the "raw" observations which undergo some pre-processing, of varying degrees of complexity, before presentation to the data assimilation system itself. The NWP fields are interpolated and mapped through an "observation operator" to give what we may call "forecast observations". These are now in the space of the pre-processed observations, with which they can be compared. The difference between the observation and the "forecast observation" — the observation increment — can now be "mapped back" into the space of the model variables, and the process iterated if necessary. The process of "mapping back" involves both the spreading and weighting of observation increments, and it is the main concern of data assimilation theory.

When presented with a new type of observation, we need to learn how to assimilate it effectively. We can use the data assimilation system to help in the learning process in the following way: the new observation is passed through the system illustrated in Fig.4, up to the generation of the observation increment. During the learning period, the new observations are not allowed to affect the analysis (i.e. they are given zero weight). However, the observations increments are stored, and their spatial and statistical properties are studied. From these statistics we can learn not only about the error characteristics of the observation type and its operator, but also about the error characteristics of the NWP fields. In this way, the process of learning how to use the new observations can provide valuable "validation" information on the NWP model itself, particularly concerning its systematic errors.

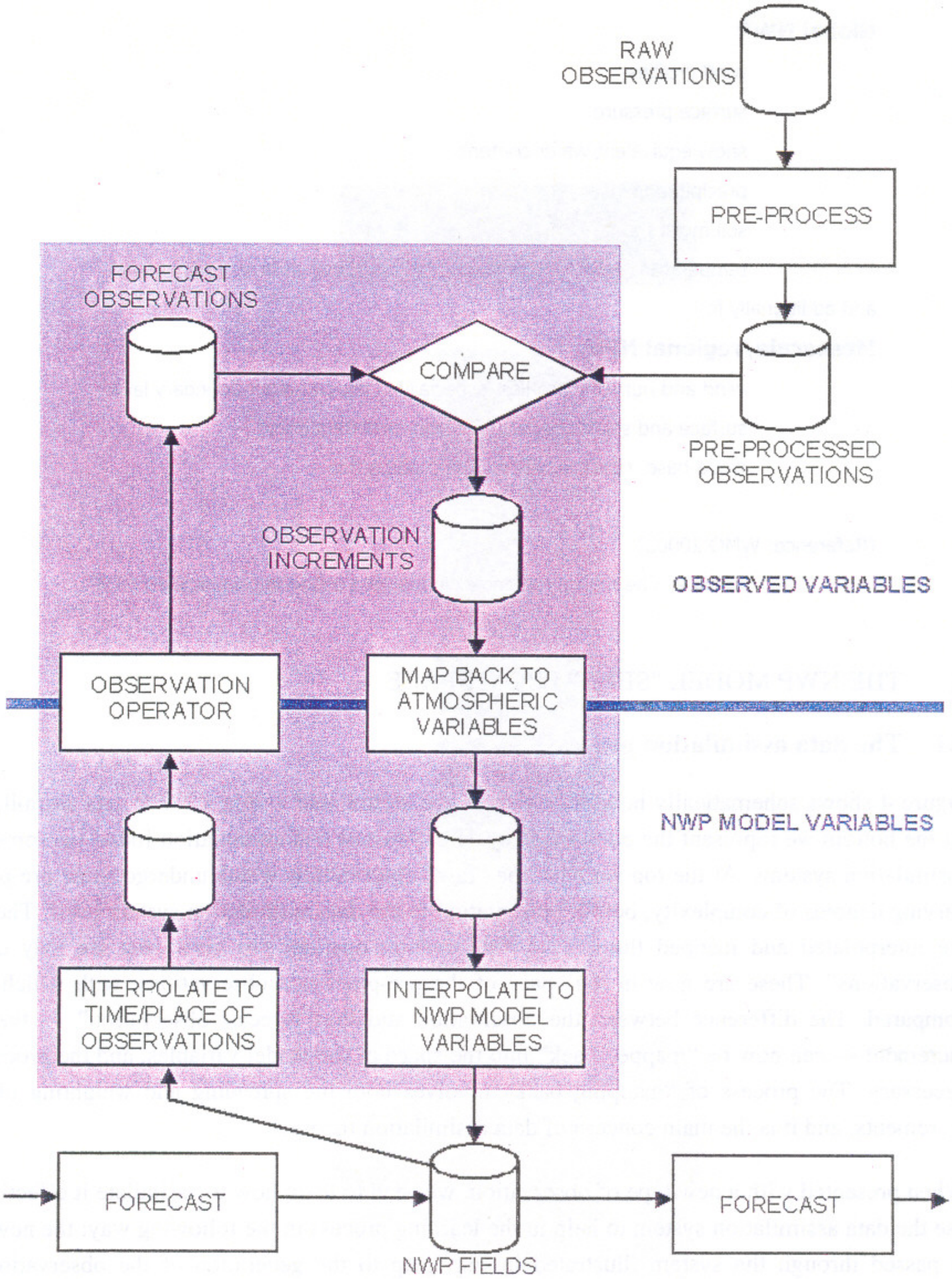

Figure 4 Illustrating schematically the variational assimilation of observations into a NWP model

For each observation type we need an observation operator. In calculating a value for the forecast observation we must simulate accurately the characteristics of the observation at the point that it is presented to the assimilation system. This includes the simulation of any pre-processing that the observation has undergone. It is therefore very important that the observation operator and the pre-processing are correctly matched.

4.2 Signal-to-noise in data assimilation

In general, we need accurate observations to produce an accurate analysis; the lower the observation errors, then the lower the analysis errors. Thus observation errors are important, but we can also see from Fig.4 that errors in the observation operator are equally important; a very accurate observation cannot be used to full effect if the errors in the observation operator are larger.

Fig.4 also provides a framework for understanding the concept of "signal-to-noise" within the data assimilation system. Before the observation is made, the NWP model already "knows" the likely value of the observation to within a certain accuracy. This "prior knowledge" is expressed in a statistical sense through the error covariance of the "background", i.e. the error in the short-range forecast used as a background for the analysis. The optimal weight given to an observation within the data assimilation process should be controlled by the ratio of the background error mapped into observation space and the observation error variance (or, more precisely, the sum of the error variances or the observation and the observation operator). This ratio can be thought of as a "signal-to-noise" ratio for the observation.

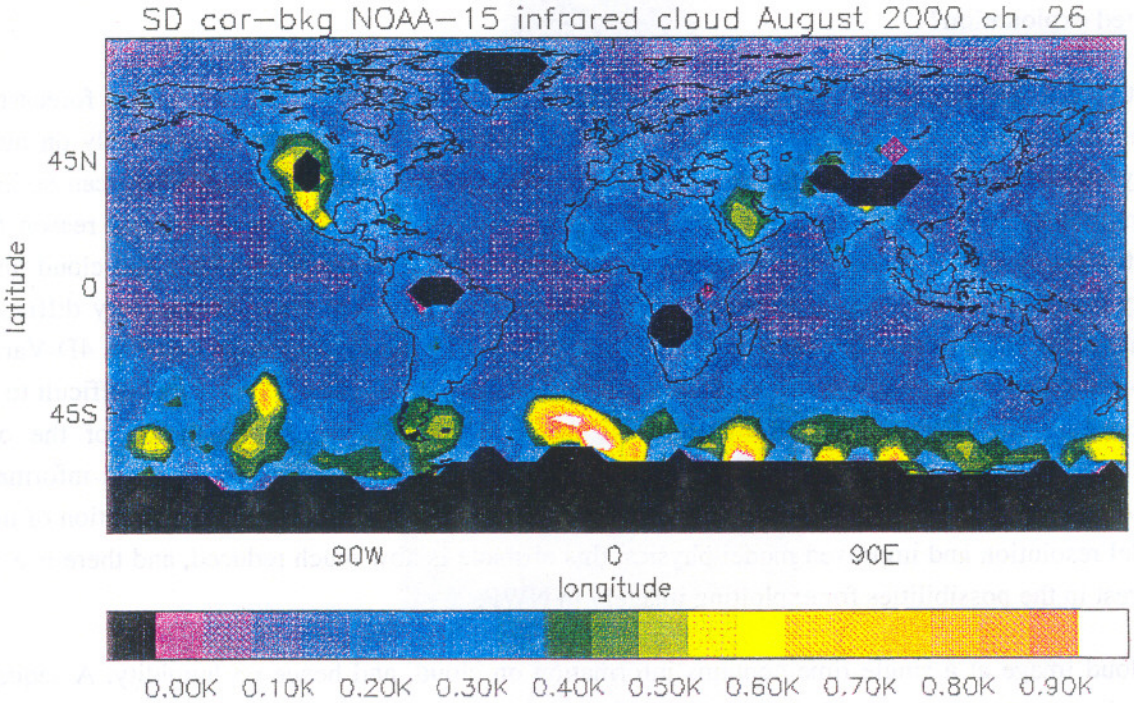

Figure 5 Standard deviations of differences between measured and background (6-hour forecast) brightness temperature for AMSU channel 6 in August 2000.

Fig.5 shows the standard deviation of the observation increments for one type of satellite data – brightness temperatures from channel 6 of AMSU-A on NOAA-15 (a temperature sounding channel with a weighting function peaking at about 400 hPa). Typical values over the ocean are in the range 0.15-0.5 K; this is the accuracy to which the NWP system "knows" the observation of brightness temperature before it is made. It is because this prior uncertainty is so low that we need: observations of low noise, high levels of quality control in the pre-processing of the observations, and low errors in the observation operator.

This is usually true for the use of all observations in NWP (particularly those affecting the mass and wind fields) but it is particularly true for radiance measurements from satellite temperature sounding measurements. This is because not only are typical forecast errors in temperature quite low, but they are also weakly correlated in the vertical. When these vertical structures of forecast temperature error are integrated across the width of a satellite sounding weighting function, the magnitude of the error (now expressed as a brightness temperature error in the observation space) is substantially reduced. The brightness temperature "signal" corresponding to these forecast errors in therefore very low, and the satellite data must be processed and assimilated with great care if they are to have a positive impact on NWP performance.

4.3 Future uses of satellite imagery in NWP

In section 2.2.1, we noted that satellite data from visible and infra-red imaging radiometers are the most widely used in meteorology but they have not been widely exploited in NWP. This is despite the fact that the signal-to-noise ratio of these data (as defined in section 4.2) is very high. What is the reason for their limited exploitation?

Firstly, they are not directly sensitive to the mass and wind variables crucial to accurate forecasts for 24 hours and beyond. They are rich in information on the cloud field (and hence indirectly on humidity). They can therefore be used to improve the initial analysis of cloud and humidity which can be important in improving NWP forecasts in the first few hours. However – and this is the second reason for their limited use to date – it is often not sufficient to improve the analyses of humidity and cloud unless the analyses of mass and wind are adjusted in a dynamically consistent way. This is very difficult to do within a 3D analysis system. The development of truly 4D assimilation systems, such as 4D-Var, is now providing the tools to allow the exploitation of imagery data in this way. Thirdly, it is difficult to use any observation in NWP unless the model itself can make a realistic representation of the observed phenomenon. Until recent years this was a major obstacle to the assimilation of cloud information, as cloud systems were not well represented within the models. However, through a combination of increased model resolution and improved model physics, this obstacle is now much reduced, and there is a growing interest in the possibilities for exploiting imagery in NWP.

A cloud image at a single time contains information on cloud, and hence on humidity. A sequences of such images also contains dynamical information. Information on the **advection** of tracers provides information on the horizontal wind field. Image sequences from GEO satellites are already used in this way by tracking the movement of clouds and water vapour features. Tracer information on dynamical scales resolved by the NWP model can, in principle, be extracted directly from sequences of radiance images within a 4D-Var system, and developments are in progress in this area. However, image sequences also contain information on **dynamical development.** For example, a rapidly developing mid-latitude cyclone has a characteristic signature in a sequence of images, which thus indirectly contain information on fields of 3D wind, potential vorticity, etc. Forecasters already exploit this information to "correct" the output of NWP models (e.g., see Young and Grahame 1999), and so it is clear that the information is present and useful. A challenge for the future is to exploit this information in NWP through the new generation of data assimilation systems.

5. CONCLUDING REMARKS

Satellite observations are playing an increasingly important role in NWP, and they have been responsible for substantial improvements in forecast accuracy in recent years. Advances in satellite instrumentation over the next decade offer the possibility of further improvements in the observations available to NWP. Close collaboration between the providers of these new data and the NWP community will be needed to make effective use of these data.

Moreover, currently available data are far from being exploited to their full potential. At present they are often severely thinned; in future they will be used closer to their full resolution. Where the signal-to-noise of the observations (as defined in this paper) is low, improvements in "forward modelling" will often permit enhanced impact of the observations. Also, sequences of satellite imagery contain dynamical information – both on advection and development – that is currently not exploited in NWP. The new generation of 4D data assimilation systems has the potential to exploit this information in principle. However the links between the observed variables (sequence of radiance images) and the dynamical variables of interest are complicated, and considerable effort will be needed to capture the information potentially available.

Acknowledgements

Many members of the Satellite Applications Section of the Met Office contributed to the material presented in this paper and associated lecture. In particular I would like to thank Andrew Collard, Stephen English, David Offiler, Caroline Poulsen and Roger Saunders.

References

Simmons, A., 2000. Assimilation of satellite data in numerical weather prediction: basic concepts. This volume.

EUMETSAT 1998, CGMS Directory of Meteorological Satellite Applications. Published by EUMETSAT, Darmstadt, Germany; EUM BR 08.

WMO 2000a. Statement of guidance regarding how well satellite capabilities meet WMO user requirements in several application areas. WMO TD No.992 (SAT-22); Geneva, Switzerland.

WMO 2000b. Statement of guidance regarding how well observing system capabilities meet WMO user requirements in several application areas. WMO Report, in preparation; Geneva, Switzerland.

Young, M.V., and N. S. Grahame, 1999. Forecasting the Christmas Eve storm 1997. Weather, 54, 382-391.

List of Acronyms

3D	three dimensional
4D	four dimensional
4D-Var	four-dimensional variational analysis
AIRS	Advanced InfraRed Sounder (instrument on Aqua)
AMIwind	Active Microwave Imager – wind mode (surface wind scatterometer on ERS)
AMSR	Advanced Microwave Scanning Radiometer (instrument on Aqua and ADEOS-2)
AMSU	Advanced Microwave Sounding Unit (instrument on NOAA and METOP)
AATSR	Advanced Along Track Scanning Radiometer (instrument on ENVISAT)
ADEOS	Satellite series of NASDA
Aqua	name of a NASA research satellite in EOS series
ASCAT	Advanced SCATterometer (instrument on METOP)
ATMS	Advanced Technology Microwave Sounder (instrument on NPOESS)
ATSR	Along Track Scanning Radiometer (instrument on ERS)
AVHRR	Advanced Very High Resolution Radiometer (instrument on NOAA and METOP)
CGMS	Co-ordination Group for Meteorological Satellites
CMIS	Conical Microwave Imager/Sounder (instrument on NPOESS)
CrIS	Cross-track Infrared Sounder (instrument on NPOESS)
DIAL	differential absorption lidar
DMSP	Defense Meteorological Satellite Program (of the USA)
DWL	Doppler wind lidar
ECMWF	European Centre for Medium-range Weather Forecasts
ENVISAT	ENVIronmental SATellite (of ESA)
EOS	Earth Observing Satellite (NASA satellite series)
ESA	European Space Agency
ERS	Earth Remote Sensing satellite (ESA satellite series)
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
GEO	geostationary satellite
GOES	Geostationary Operational Environmental Satellite (of NOAA)
GOME	Global Ozone Monitoring Experiment (instrument on ERS and METOP)
GPM	Global Precipitation Mission
GPS	Global Positioning Satellite
GPS-RO	GPS radio occultation (satellite instruments using radio occultation principle)
GPS-WV	GPS water vapour (satellite-to-ground measurements of total column)
HIRS	High-resolution Infrared Radiation Sounder (instrument on METOP and NOAA)
IASI	Infra-red Atmospheric Sounding Interferometer (instrument on METOP)
LEO	low Earth-orbiting satellite
METOP	METeorological OPerational satellite (EUMETSAT satellite series)
MHS	Microwave Humidity Sounder (instrument on METOP and NOAA)

List of Acronyms

MODIS	MODerate-resolution Imaging Spectroradiometer (instrument on EOS)
MSG	Meteosat Second Generation (EUMETSAT geostationary satellite series)
MSU	Microwave Sounding Unit (instrument on NOAA)
NASA	National Aeronautic and Space Administration (of the USA)
NASDA	National Space Development Agency (of Japan)
NH	Northern Hemisphere
NOAA	National Oceanic and Atmospheric Administration (of the USA), and polar-orbiting satellite series of this organisation
NPOESS	National Polar-Orbiting Operational Environmental Satellite System (of the USA)
NWP	numerical weather prediction
OMPS	Ozone Mapper/Profile Suite (instrument on NPOESS)
Quikscat	NASA satellite
SAR	synthetic aperture radar
SBUV	Solar Backscatter Ultra-Violet instrument (instrument on NOAA)
Seawinds	name of polarimetric microwave radiometer for sea surface wind measurement
SEVIRI	Spinning Enhanced Visible Infra-Red Imager (instrument on MSG)
SH	Southern Hemisphere
SMOS	Soil Moisture and Ocean Salinity mission (planned ESA mission)
SSM/I	Special Sensor Microwave / Imager (instrument on DMSP)
SSMIS	Special Sensor Microwave Imager/Sounder (instrument on DMSP)
SSU	Stratospheric Sounding Unit (instrument on NOAA)
TMI	TRMM Microwave Imager
TOMS	Total Ozone Mapping Spectrometer (instrument on several satellite series)
TRMM	Tropical Rainfall Monitoring Mission
TRMM-PR	TRMM Precipitation Radar
VIIRS	Visible/Infrared Imager Radiometer Suite (instrument on NPOESS)
Windsat	name of scatterometer on Quikscat and ADEOS-2
WMO	World Meteorological Organisation