HAZARD WARNINGS IN METEOROLOGY: THE IMPORTANCE OF REMOTE SENSING

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Abstract

The prediction of the weather, including extreme events, is now an advanced science whereby observations from a global network are assimilated into complex mathematical models. Forecasters also use the observations to fine-tune the model products and then issue warnings. Satellite-based remote sensing methods, add greatly to our observational database. The most obvious example, and one which saves many hundreds of lives, is the ability to detect and track tropical storms as they develop over the oceans before meeting land. Current remote sensing capabilities are reviewed with examples illustrating their application to different meteorological problems.

1. Introduction

The World Meteorological Organisation (WMO) has recognised the important part the meteorological community has to play in the International Decade for National Disaster Reduction (WMO, 1991). The Meteorological organisations play a leading role in the mitigation and monitoring of natural disasters caused by tropical cyclones, floods, tornadoes and severe thunderstorms, other severe weather (snow, hail and wind storms) and droughts.

Just as the spatial and temporal scale of these disasters can vary substantially, so do the different ways of utilising observation to produce warnings and monitor the disaster. In operational meteorology, a complex infrastructure of data collection and collaboration has built up over many decades. There are two essential types of systems operated by major national meteorological centres·

* Forecasting systems involve the use of a wide range of conventional in-situ observation along with some remote sensing data to define an initial state of the atmosphere. This is then used in a numerical weather prediction model (NWP) to predict the state at sometime in the future, say from 6 hours to 5 days ahead. These models can be run globally at a resolution currently of around 100km or, for the shorter time frames, regionally at higher horizontal resolution, say 15km. A forecaster then takes the product (which may be several hours from data reception) and can compare this with more up-to-date data, particular imagery data from remote sensing satellites or radars. He/she then issues a forecast (or warning) on the basis of the computer model output, or alters that forecast in the light of the new information.

* Nowcasting systems are designed to make extremely timely use of data, principally remotely sensed data, and provide a visual analysis of the situation now, so that a forecaster can provide monitoring information to authorities handling the hazard. An example of such a system is known as FRONTIERS (Conway and Browning, 1988) which combines radar and satellite imagery over the UK to give a visual display of the current rainfall together with a simple extrapolation up to 6 hours ahead. The output from a forecasting system can be used in the nowcasting system, for example a forecast wind can be used to advect precipitation.

2. Types of hazard and the use of remote sensing

Table 1 gives a list of the main hazards for which meteorology has a significant role to play. For each type the scale of the feature (space and time) is identified. For forecasting, this is the scale of the feature to be identified and tracked and for nowcasting it represents the scale of the damage. Remote sensing data which is, or potentially could be, useful in both the forecasting and nowcasting roles is also identified in the table. In the remainder of this paper examples of the use of remote sensing will be discussed for each hazard in turn. Although these categorisations are useful, it is important to appreciate the actual inter-relationships between the phenomena. For example, most of the deaths from hurricane or typhoons result from flooding due to the storm surge and the storm surge can, for example, be responsible for initiating an earthquake. Table 2.2 of Bryant (1993) shows this complex inter-relationship.

Tropical Cyclones (hurricane and typhoon)
Hurricane Andrew was tracked by three geostationary satellites (two operated by EUMETSAT at 0 and 50 W, and the third by NOAA at 140W) as it was initiated over the West African coast on the 12 August 1992, developed and travelled west to reach

Table 1. Remote sensing applied to the forecasting and nowcasting of meteorological hazards

	FORECAST/WARNING		NOWCAST/MONITORING	
HAZARD	Scale	Remote sensing data	Scale	Remote sensing data
Tropical Cyclones	500km 10 days	Imagery Cloud track winds scatterometer	100km 1 day wind 3 day rain	Imagery Radar, Microwave imagery
Floods Coastal	-500km days	Imagery, Scatterometer Altimetry/ Waves, SAR	100-1000km	IR + microwave imagery, SAR
Storm	10-1000km hour-month	As part of WWW SST	10-1000km hour-day	Imagery, Radar, SAR Microwave imagery
Tornadoes	10km hours	As part of WWW	1km 20 mins	Radar Imagery
Snow/Hail/Wind Storms	10-1000km 10 mins-day	As part of WWW including SATOB, SATEM and scatterometer	10-5000km 10 mins-hours	Radar (polarization) Sferics (ground+satellite) IR+Microwave imagery
Drought	1000km months-year	SST scatterometer	1000km months	Multispectral albedo Microwave imagery/ SAR?

Miami on the 24 August and Louisiana on the 26 August. Well over 1000 images of it must have been recorded by just these three satellites. Details of the storm are given by Rappaport (1994); an estimated US$ 25 billion of damage was done, and 65 people lost their lives. In comparison the cyclone that devastated Bangladesh in 1970, caused 500,000 deaths from the resulting storm surge.

Remote sensing data is crucial for forecasting these systems as they develop and travel in regions lacking conventional data. The visual and IR imagery from the polar and geostationary satellites is processed by the satellite operators to give cloud motion wind vectors which can be directly put into the global NWP models. The model cannot resolve the strength of these systems, but fortunately the models are quite accurate at predicting their movement. Other satellite data that can now be directly put into the model are measurements of the surface wind speed from scatterometers. The signal from the scatterometer saturates at about 25m/s; but the centre is accurately pin-pointed by the data. Unfortunately, at the present time the area coverage given by just the one instrument on ERS-1 is not satisfactory, but coverage will improve with more (and double swath width) instruments planned. Tropical Cyclone Centres working mainly from satellite imagery provide the exact position and, from studying the intensity of the circulation, estimate the maximum wind speed. It is these data that can be used by the forecaster to insert extra information (bogus data) into the NWP model run (e.g Hurricane Andrew, Lyne and Radford, 1993).

On approaching land, ground-based radar can be added to the satellite imagery to monitor the progress of the storm and assess the strengths of the wind and rainfall. Microwave imagery is also useful in precipitation monitoring, although only available on polar orbiting satellites, it is likely to be useful in regions lacking radar

Coastal Flood (Storm Surge)

Most of the damage and loss of life from tropical storms results from the storm surge and high waves. Storm surges result from two physical processes. First the water level rises because of the low air pressure (the water is sucked up). Second, the strong winds push the water before them, further raising the water level. Hurricane Andrew caused sea level to rise 4m above the normal height. The lowest recorded central pressure in a storm, 870 hPa, would cause the sea to rise 6.6m. Remote sensing can help forecast the rise in sea level; the strength of the atmospheric circulation can be assessed manually and the calculated winds and central pressure can be used to estimate the strength of the storm surge. Although radar altimeters could measure the surface elevation directly, the instruments have poor spatial coverage and the information is not processed in real time Surface winds can be measured by scatterometers; these measurements are useful for assessing the strength of the circulation.

High sea levels are not the only cause of damage during a storm surge. Surface waves are generated by the wind. Waves generated offshore by severe storms can travel long distances until they reach a coast, where they may steepen as they arrive at the shelving sea bed. Two ERS-1 instruments are useful for observing waves; the radar altimeter and the SAR. Both instruments, however, give only limited coverage. Storm surges and high waves are not only the result of tropical hurricanes; middle latitude depressions can also cause severe flooding, as in the North Sea in 1953

Storm Flood

Flooding of river basins can take place on a number of scales. Small catchment areas can be flooded from single thunderstorm events, flash floods, whereas larger catchment areas such as the Missouri and the Mississippi flooding in 1993, can be caused by a weather pattern, giving prolonged rainfall augment, perhaps, with melting snow. Flash floods are impossible to forecast, other than as a certain low probability given a situation likely to give rise to heavy, but not necessarily exceptional, rainfall. Nowcasting techniques can use a variety of remote sensing data, including a sequence of IR satellite imagery and. or, weather radar imagery; microwave imagery from the polar orbiting satellite could on occasions also be used. Many of the manual techniques rely on recognising certain patterns in the imagery which indicate particular intense or persistent rainfall, see for example Bader *et al.* (1994).

As far as forecasting the longer timescale features NWP methods which use WWW data (world weather watch) relying in part (but not in a dominant way) on remote sensing observations, have some success in forecasting rainfall 24-36 hours ahead, together with temperature (for snow melt models). In the longer time frame, there are certain climatological features that can be recognised through changes in the general circulation, and through sea surface temperature (SST) anomalies, the latter can be best monitored directly by satellite These climatological patterns are discussed later in connection with drought. Monitoring can be achieved with a range of visible imagery from LANDSAT to geostationary satellites depending on the scale. However cloud is a major problem, and SAR offers potential for all weather monitoring.

Tornadoes

Tornadoes are particularly small scale (1km) and short lived (10 minutes) phenomena, with wind strengths in excess of 1300km hr^{-1} (close to the speed of sound). Dopplerised weather radars can monitor these features The precursor to the tornado is a particularly active thunderstorm, which penetrates a strong upper wind. Satellite and radar imagery can be used to monitor thunderstorms and features can be used as indication of likely tornado generations. NWP models, relying in part on remote sensing data, can be used to predict conditions that give rise to tornadoes, but such probabilistic forecasts would apply to vast areas compared to only small areas directly affected.

Other Storms

This is a very wide category and could cover a large number of different situations. Strong winds associated with extra-tropical depressions, are probably by far the most significant The storm of October 1987 (Hill, 1987) is probably most memorable in the minds of those who lived in southern Britain. More recent storms which hit Britain are perhaps less memorable because they did not hit SE England, and they were accurately forecast. The Braer storm that sank the tanker in Shetland, was accurately forecast, down to it's record low pressure centre. The last major event was 3rd February this year, again the storm was accurately forecast, but 32 people lost their lives, 27 in a Maltese carrier and 5 in Britain through strong winds and snow. Mid-latitude storms (particularly in the Northern Hemisphere) are generally well forecast. The role of remote sensing, for example cloud motion wind vectors and satellite temperature sounding data, is difficult to evaluate. Sometimes it may not contribute at all to conventional data, whereas on other occasions it can be demonstrated to have been very significant. Undoubtedly, better use of remote sensing data, particularly cloud imagery, in both forecasting and nowcasting, will pay dividends in improving accuracy. Polar lows are particular small scale features which are often difficult to detect, even on imagery as they form in generally cloudy areas near the sea/ice boundary. Scatterometry is a powerful means of detecting these features and with more scatterometers being flown in the future, greater forecasting accuracy of these features should be achieved, which will improve early warning of many snow fall events. Other features that might be considered are hail, which in a few minutes can devastate crops. There are particular radar techniques that make use of polarization that can detect hail in thunderstorms. Electrical activity can be monitored from ground stations, the UK Met. Office has a system that can detect lightning discharge right across the Atlantic. There are plans to place lightning detection systems on satellites during the next decade, which could provide some additional potential in monitoring thunderstorm activity.

Drought

Some forecasting accuracy at seasonal scales is possible in the southern hemisphere by interpretation of the mean circulation and SST, both of which are best measured with satellites. The ENSO (El Nino Southern Oscillation) (Bryant, 1991) involves changes in atmospheric circulation that change the longitude of the mean ascent areas, so for example, in a normal year, there is general ascent over South Africa, whereas in an ENSO year, the mean vertical motion is downwards and droughts occurs. Monitoring the extent of the drought is best achieved in near arid areas by the extent of vegetation. This can be done by multispectral visible imagery from the polar orbiting satellite. The technique can be calibrated against biomass and give good guidance on extending drought affected areas: in the future it will be possible to do this from geostationary satellites Soil moisture can be directly measured in the microwave region, however, current satellite instruments do not have sufficiently low frequencies (1GHz), and so respond mainly to vegetation. Interpretation of SAR data may provide some information on soil moisture, but this has to be established

3. Summary

Clearly, some remote sensing data are being exploited directly to meet requirements of monitoring hazard. Other remote sensing data are being used operationally as input into global, numerical atmospheric and oceanic models and their impact is crucial in certain areas. Monitoring the oceans certainly relies very heavily on remote sensing data. Operational meteorology already plays an important part in hazard warnings, but there is still further potential for improvements based on better use of remote sensing data in both forecasting and nowcasting systems. Perhaps the bigger challenge for the future is developing mechanisms to make use of the information to minimise damage and loss of life.

4. References

Bader, M. *et al.* (1994) *Images in Weather Forecasting*. Cambridge University Press.

Bryant, E.A. (1991) *Natural Hazards*. Cambridge University Press.

Conway, B.J. and Browning, K.A. (1988) FRONTIERS: Weather forecasting by interactive analysis of radar and satellite imagery. *Phil. Trans. R. Soc London,* **A324**, 299-315.

Hill, G. (1987) *Hurricane Force: The story of the storm of October 1987*, Collins.

Lyne, W.H. and Radford, A.M. (1993) Prediction of exceptionally severe storms, In, *Natural Disasters - protecting vulnerable communities.* 13-15 Oct 1993, Royal Society Meeting, London, Thomas Telford, 184-193.

Rappaport, E.N. (1994) Hurricane Andrew. *Weather,* **49**, 51-61.

WMO (1991) Eleventh World Meteorological Conference, Geneva, 1-23 May 1991, *WMO* No. 756, 123-126.

Discussion

Dr. Foot said that the accuracy of cyclone forecasts as the cyclones approached land was maintained by the forecaster inserting "bogus" data into the model