DROUGHTS & FLOODS ASSESSMENT AND MONITORING USING REMOTE SENSING AND GIS

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Abstract : Space technology has made substantial contribution in all the three phases such as preparedness, prevention and relief phases of drought and flood disaster management. The Earth Observation satellites which include both geostationary and polar orbiting satellites provide comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals and 'thus' - have become valuable for continuous monitoring of atmospheric as well as surface parameters related to droughts and floods. Geo-stationary satellites provide continuous and synoptic observations over large areas on weather including cyclone monitoring. Polar orbiting satellites have the advantage of providing much higher resolution imageries, even though at low temporal frequency, which could be used for detailed monitoring, damage assessment and long-term relief management. Advancements in the remote sensing technology and the Geographic Information Systems help in real time monitoring, early warning and quick damage assessment of both drought and flood disasters. In this lecture the use of remote sensing and GIS and the global scenario for the drought and flood disaster management is discussed.

INTRODUCTION

Droughts and floods are water-related natural disasters which affect a wide range of environmental factors and activities related to agriculture, vegetation, human and wild life and local economies. Drought is the single most important weather-related natural disaster often aggravated by human action, since it affects very large areas for months and years and thus has a serious impact on regional food production, life expectancy for entire populations and economic performance of large regions or several countries. During 1967-1991, droughts

Satellite Remote Sensing and GIS Applications in Agricultural Meteorology
pp. 291-313

have affected 50 per cent of the 2.8 billion people who suffered from all natural disasters and killed 35 per cent of the 3.5 million people who lost their lives. In the recent years large-scale intensive droughts have been observed in all continents leading to huge economic losses, destruction of ecological resources, food shortages and starvation of millions people. Floods are among the most devastating natural hazards in the world, claiming more lives and causing more property damage than any other natural phenomena.

Several users such as top level policy makers at the national and international organisations, researchers, middle level policy makers at the state, province and local levels consultants, relief agencies and local producers including farmers, suppliers, traders and water managers are interested in reliable and accurate drought and flood information for effective management. The disaster management activities can be grouped into three major phases: The Preparedness phase where activities such as prediction and risk zone identification are taken up long before the event occurs; the Prevention phase where activities such as Early warning/Forecasting, monitoring and preparation of contingency plans are taken up just before or during the event; and the Response/Mitigation phase where activities are undertaken just after the event which include damage assessment and relief management.

Remote sensing techniques make it possible to obtain and distribute information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. A satellite, which orbits the Earth, is able to explore the whole surface in a few days and repeat the survey of the same area at regular intervals, whilst an aircraft can give a more detailed analysis of a smaller area, if a specific need occurs. The spectral bands used by these sensors cover the whole range between visible and microwaves. Rapid developments in computer technology and the Geographical Information Systems (GIS) help to process Remote Sensing (RS) observations from satellites in a spatial format of maps - both individually and along with tabular data and “crunch” them together to provide a new perception - the spatial visualisation of information of natural resources. The integration of information derived from RS techniques with other datasets - both in spatial and non-spatial formats provides tremendous potential for identification, monitoring and assessment of droughts and floods.

REMOTE SENSING FOR DROUGHTS

Monitoring and assessment of drought through remote sensing and GIS depend on the factors that cause drought and the factors of drought impact.

Based on the causative factors, drought can be classified into Meteorological, Hydrological and Agricultural droughts. An extensive survey of the definition of droughts by WMO found that droughts are classified on the basis of: (i) rainfall, (ii) combinations of rainfall with temperature, humidity and or evaporation, (iii) soil moisture and crop parameter, (iv) climatic indices and estimates of evapotranspiration, and finally (v) the general definitions and statements.

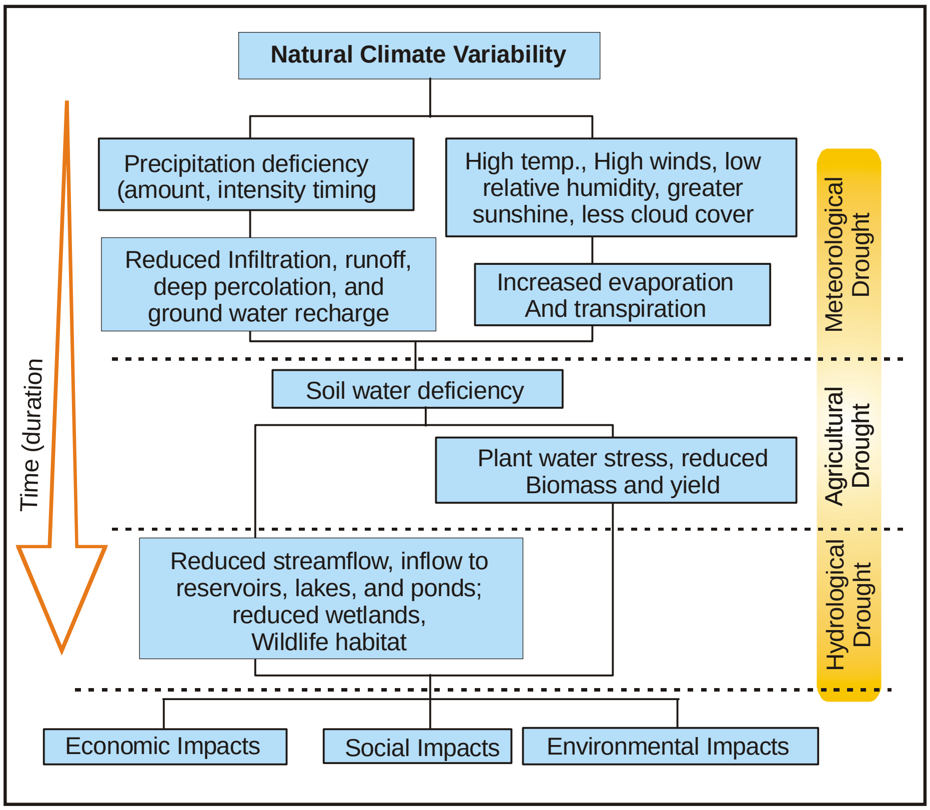

Figure 1: Sequence of Drought impacts

Drought is a normal, recurrent feature of climate and occurs in all climatic zones, although its characteristics vary significantly from one region to another. Drought produces a complex web of impacts that span many sectors of the economy and reach well beyond the area experiencing physical drought. Drought impacts are commonly referred to as direct or indirect. Reduced crop, rangeland, and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates; and damage to wildlife and fish habitat are a few examples of direct impacts. The consequences of these impacts illustrate indirect impacts. The remote sensing and GIS technology significantly contributes to all the activities of drought management.

Drought Preparedness Phase

Long before the drought event occurs, the preparedness in terms of identifying the drought prone / risk zone area and the prediction of drought and its intensity is essential.

Drought Prone/Risk zone identification

The drought prone area or risk zone identification is usually carried out on the basis of historic data analysis of rainfall or rainfall and evaporation and the area of irrigation support. The conventional methods lack identification of spatial variation and do not cover man's influence such as land use changes like irrigated area developed and the area affected due to water logging and salinity. The remote-sensing based method for identification of drought prone areas (Jeyaseelan *et al.*, 2002) uses historical vegetation index data derived from NOAA satellite series and provides spatial information on drought prone area depending on the trend in vegetation development, frequency of low development and their standard deviations.

Drought prediction

The remote sensing use for drought prediction can benefit from climate variability predictions using coupled ocean/atmosphere models, survey of snow packs, persistent anomalous circulation patterns in the ocean and atmosphere, initial soil moisture, assimilation of remotely sensed data into numerical prediction models and amount of water available for irrigation. Nearly-global seasonal climate anomaly predictions are possible due to the successful combination of observational satellite networks for operational meteorological, oceanographic and hydrological observations. Improved coupled models and near-real time evaluation of *in situ* and remote sensing data - allows for the first time physically-based drought warnings several months in advance, to which a growing number of countries already relate their policies in agriculture, fisheries and distribution of goods.

The quality of seasonal predictions of temperature and precipitation anomalies by various centres such as the National Climate Research Centre

(NCRC) of United States, the European Centre for Medium Range Weather Forecasts (ECMWF), the India Meteorological Department (IMD), the National Centre for Medium Range Weather Forecast of India (NCMRWF) is a function of the quality and amount of satellite data assimilated into the starting fields (e.g., SST from AVHRR and profiles from TOVS on NOAA satellites, ERS-2 scatterometer winds, SSM/I on DMSP satellites and all geostationary weather satellites: Geostationary Operational Environmental Satellites (GOES), i.e. GOES-East, GOES-West of USA, METeorological SATellite (METEOSAT) of Europe, Geostationary Meteorological Satellites (GMS) of Japan, Indian National Satellites (INSAT) of India etc.). The new assimilation techniques have produced a stronger impact of space data on the quality of weather and seasonal climate predictions.

The potential contribution by existing satellites is by far not fully exploited, since neither the synergy gained by the combination of satellite sensors is used nor all the satellite data are distributed internationally. For example, better information flow is needed from satellite data producers to the intermediary services such as CLIPS (Climate Information and Prediction Services) project of World Meteorological Organisation (WMO), and prediction centres including the European Centre for Medium Range Weather Forecasts (ECMWF), National Centres for Environmental Predictions (NCEP), Japan Meteorological Agency (JMA), India Meteorological Department (IMD), National Centre for Medium Range Weather Forecast, India (NCMRWF) etc. to local services and ultimately to end users. Further the drought predictions need to be improved with El Niño predictions and should be brought down to larger scales.

Drought Prevention Phase

Drought Monitoring and Early Warning

Drought monitoring mechanism exists in most of the countries based on ground based information on drought related parameters such as rainfall, weather, crop condition and water availability, etc. Earth observations from satellite are highly complementary to those collected by *in-situ* systems. Satellites are often necessary for the provision of synoptic, wide-area coverage and frequent information required for spatial monitoring of drought conditions. The present state of remotely sensed data for drought monitoring and early warning is based on rainfall, surface wetness, temperature and vegetation monitoring.

Currently, multi channel and multi sensor data sources from geostationary platforms such as GOES, METEOSAT, INSAT and GMS and polar orbiting satellites such as National Oceanic Atmospheric and Administration (NOAA), EOS-Terra, Defense Meteorological Satellite Program (DMSP) and Indian Remote Sensing Satellites (IRS) have been used or planned to be used for meteorological parameter evaluation, interpretation, validation and integration. These data are used to estimate precipitation intensity, amount, and coverage, and to determine ground effects such as surface (soil) wetness.

Rainfall Monitoring

Rain is the major causative factor for drought. As the conventional method is based on the point information with limited network of observations, the remote sensing based method provides better spatial estimates. Though the satellite based rainfall estimation procedure is still experimental, the methods can be grouped into 3 types namely Visible and Infrared (VIS and IR) technique, passive microwave technique and active microwave technique.

VIS and IR technique: VIS and IR techniques were the first to be conceived and are rather simple to apply while at the same time they show a relatively low degree of accuracy. A complete overview of the early work and physical premises of VIS and thermal IR (10.5 – 12.5 μm) techniques is provided by Barrett and Martin (1981) and Kidder and Vonder Haar (1995). The Rainfall estimation methods can be divided into the following categories: cloud-indexing, bi-spectral, life history and cloud model. Each of the categories stresses a particular aspect of cloud physics properties using satellite imagery.

Cloud indexing techniques assign a rain rate level to each cloud type identified in the satellite imagery. The simplest and perhaps most widely used is the one developed by Arkin (1979). A family of cloud indexing algorithms was developed at the University of Bristol, originally for polar orbiting NOAA satellites and recently adapted to geostationary satellite imagery. "Rain Days" are identified from the occurrence of IR brightness temperatures (TB) below a threshold.

Bi-spectral methods are based on the very simple, although not always true, relationship between cold and bright clouds and high probability of precipitation, this is characteristic of Cumulonimbus. Lower probabilities are associated with cold but dull clouds (thin cirrus) or bright but warm (stratus) clouds. O'Sullivan *et al.* (1990) used brightness and textural characteristics during daytime and IR temperature patterns to estimate rainfall over a 10 × 10 pixel array in three categories: no rain, light rain, and moderate/heavy rain. A family of techniques that specifically require geostationary satellite imagery are the life-history methods that rely upon a detailed analysis of the cloud's life cycle, which is particularly relevant for convective clouds. An example is the Griffith-Woodley technique (Griffith *et al.*, 1978). Cloud model techniques aim at introducing the cloud physics into the retrieval process for a quantitative improvement deriving from the overall better physical description of the rain formation processes. Gruber (1973) first introduced a cumulus convection parameterization to relate fractional cloud cover to rain rate. A one-dimensional cloud model relates cloud top temperature to rain rate and rain area in the Convective Stratiform Technique (CST) (Adler and Negri, 1988; Anagnostou *et al.*, 1999).

Passive microwave technique: Clouds are opaque in the VIS and IR spectral range and precipitation is inferred from cloud top structure. At passive MW frequencies, precipitation particles are the main source of attenuation of the upwelling radiation. MW techniques are thus physically more direct than those based on VIS/IR radiation. The emission of radiation from atmospheric particles results in an increase of the signal received by the satellite sensor while at the same time the scattering due to hydrometeors reduce the radiation stream. Type and size of the detected hydrometeors depends upon the frequency of the upwelling radiation. Above 60 GHz ice scattering dominates and the radiometers can only sense ice while rain is not detected. Below about 22 GHz absorption is the primary mechanism affecting the transfer of MW radiation and ice above the rain layer is virtually transparent. Between 19.3 and 85.5 GHz, frequency range radiation interacts with the main types of hydrometeors, water particles or droplets (liquid or frozen). Scattering and emission happen at the same time with radiation undergoing multiple transformations within the cloud column in the sensor's field of view (FOV). The biggest disadvantage is the poor spatial and temporal resolution, the first due to diffraction, which limits the ground resolution for a given satellite MW antenna, and the latter to the fact that MW sensors are consequently only mounted on polar orbiters. The matter is further complicated by the different radiative characteristics of sea and land surfaces underneath. The major instruments used for MW-based rainfall estimations are the SSM/I, a scanning-type instrument that measures MW radiation over a 1400-km wide swath at four separate frequencies, 19.35, 22.235, 37.0 and 85.5 GHz, the latter extending the spectral range of previous instruments into the strong scattering regime (as regards to precipitation-size particles).

Active microwave: The most important precipitation measuring instruments from space is the PR, precipitation radar operating at 13.8 GHz on board TRMM, the first of its kind to be flown on board a spacecraft. The instrument aims at providing the vertical distribution of rainfall for the investigation of its three-dimensional structure, obtaining quantitative measurements over land and oceans, and improving the overall retrieval accuracy by the combined use of the radar, and the TMI and VIRS instruments.

Surface Temperature Estimation

The estimation of water stress in crop/ vegetation or low rate of evapotranspiration from crop is another indicator of drought. As water stress increases the canopy resistance for vapor transport results in canopy temperature rise in order to dissipate the additional sensible heat. Sensible heat transport (ET) between the canopy (Ts) and the air (Ta) is proportional to the temperature difference (Ts-Ta). Therefore the satellite based surface temperature estimation is one of the indicators for drought monitoring since it is related to the energy balance between soil and plants on the one hand and atmosphere and energy balance on the other in which evapotranspiration plays an important role. Surface temperature could be quite complementary to vegetation indices derived from the combination of optical bands. Water-stress, for example, should be noticed first by an increase in the brightness surface temperature and, if it affects the plant canopy, there will be changes in the optical properties.

During the past decade, significant progress has been made in the estimation of land-surface emissivity and temperature from airborne TIR data. Kahle *et al.* (1980) developed a technique to estimate the surface temperature based on an assumed constant emissivity in one channel and previously determined atmospheric parameters. This temperature was then used to estimate the emissivity in other channels (Kahle, 1986). Other techniques such as thermal log residuals and alpha residuals have been developed to extract emissivity from multi-spectral thermal infrared data (Hook *et al.*, 1992). Based on these techniques and an empirical relationship between the minimum emissivity and the spectral contrast in band emissivities, a Temperature Emissivity Separation (TES) method has been recently developed for one of the ASTER (Advance Space borne Thermal Emission and Reflection Radiometer) products (ATBD-AST-03, 1996).

In addition, three types of methods have been developed to estimate LST from space: the single infrared channel method, the split window method which is used in various multi-channel sea-surface temperature (SST) algorithms, and a new day/night MODIS LST method which is designed to take advantage of the unique capability of the MODIS instrument. The first method requires surface emissivity and an accurate radiative transfer model and atmospheric profiles which must be given by either satellite soundings or conventional radiosonde data. The second method makes corrections for the atmospheric and surface emissivity effects with surface emissivity as an input based on the differential absorption in a split window. The third method uses day/night pairs of TIR data in seven MODIS bands for simultaneously retrieving surface temperatures and band-averaged emissivities without knowing atmospheric temperature and water vapor profiles to high accuracy. This method improves upon the Li and Becker's method (1993), which estimates both land surface emissivity and LST by the use of pairs of day/night co-registered AVHRR images from the concept of the temperature independent spectral index (TISI) in thermal infrared bands and based on assumed knowledge of surface TIR BRDF (Bi-directional Reflectance Distribution Function) and atmospheric profiles.

Because of the difficulties in correcting both atmospheric effects and surface emissivity effects, the development of accurate LST algorithms is not easy. The accuracy of atmospheric corrections is limited by radiative transfer methods and uncertainties in atmospheric molecular (especially, water vapor) absorption coefficients and aerosol absorption/scattering coefficients and uncertainties in atmospheric profiles as inputs to radiative transfer models. Atmospheric transmittance/radiance codes LOWTRAN6 (Kneizys *et al.*, 1983), LOWTRAN7 (Kneizys *et al.*, 1988), MODTRAN (Berk *et al.*, 1989), and MOSART (Cornette *et al.*, 1994) have been widely used in development of SST and LST algorithms and the relation between NDVI and emissivities are used.

Soil Moisture Estimation

Soil moisture in the root zone is a key parameter for early warning of agricultural drought. The significance of soil moisture is its role in the partitioning of the energy at the ground surface into sensible and latent (evapotranspiration) heat exchange with the atmosphere, and the partitioning of precipitation into infiltration and runoff.

Soil moisture can be estimated from : (i) point measurements, (ii) soil moisture models and (iii) remote sensing. Traditional techniques for soil moisture estimation/ observation are based on point basis, which do not always represent the spatial distribution. The alternative has been to estimate the spatial distribution of soil moisture using a distributed hydrologic model. However, these estimates are generally poor, due to the fact that soil moisture exhibits large spatial and temporal variation as a result of inhomogeneities in soil properties, vegetation and precipitation. Remote sensing can be used to collect spatial data over large areas on routine basis, providing a capability to make frequent and spatially comprehensive measurements of the near surface soil moisture. However, problems with these data include satellite repeat time and depth over which soil moisture estimates are valid, consisting of the top few centimetres at most. These upper few centimetres of the soil is the most exposed to the atmosphere, and their soil moisture varies rapidly in response to rainfall and evaporation. Thus to be useful for hydrologic, climatic and agricultural studies, such observations of surface soil moisture must be related to the complete soil moisture profile in the unsaturated zone. The problem of relating soil moisture content at the surface to that of the profile as a whole has been studied for the past two decades. The results of the study indicated following four approaches : (i) regression, (ii) knowledge based, (iii) inversion and (iv) combinations of remotely sensed data with soil water balance models.

Passive microwave sensing (radiometry) has shown the greatest potential among remote sensing methods for the soil moisture measurement. Measurements at 1 to 3 GHz are directly sensitive to changes in surface soil moisture, are little affected by clouds, and can penetrate moderate amounts of vegetation. They can also sense moisture in the surface layer to depths of 2 to 5 cm (depending on wavelength and soil wetness). With radiometry, the effect of soil moisture on the measured signal dominates over that of surface roughness (whereas the converse is true for radar). Higher frequency Earth-imaging microwave radiometers, including the Scanning Multichannel Microwave Radiometer (lowest frequency 6.6 GHz) launched on the Seasat (1978) and Nimbus-7 (1978-87) satellites, and the Special Sensor Microwave Imager (lowest frequency 19.35 GHz) launched on the DMSP satellite series have been utilized in soil moisture studies with some limited success. The capabilities of these higher frequency instruments are limited to soil moisture measurements over predominantly bare soil and in a very shallow surface layer (<5 cm). At its lowest frequency of 19.35 GHz the SSM/I is highly sensitive to even small amounts of vegetation, which obscures the underlying soil. Large variations in soil moisture (e.g., flood/no-flood) in sparsely vegetated regions and qualitative river flooding indices, are all that have been shown feasible using the SSM/I.

Vegetation Monitoring

The vegetation condition reflects the overall effect of rainfall, soil moisture, weather and agricultural practices and the satellite based monitoring of vegetation plays an important role in drought monitoring and early warning. Many studies have shown the relationships of red and near-infrared (NIR) reflected energy to the amount of vegetation present on the ground (Colwell, 1974). Reflected red energy decreases with plant development due to chlorophyll absorption in the photosynthetic leaves. Reflected NIR energy, on the other hand, will increase with plant development through scattering processes (reflection and transmission) in healthy, turgid leaves. Unfortunately, because the amount of red and NIR radiation reflected from a plant canopy and reaching a satellite sensor varies with solar irradiance, atmospheric conditions, canopy background, and canopy structure/ and composition, one cannot use a simple measure of reflected energy to quantify plant biophysical parameters nor monitor vegetation on a global, operational basis. This is made difficult due to the intricate radiant transfer processes at both the leaf level (cell constituents, leaf morphology) and canopy level (leaf elements, orientation, non-photosynthetic vegetation (NPV), and background). This problem has been circumvented somewhat by combining two or more bands into an equation or 'vegetation index' (VI). The simple ratio (SR) was the first index to be used (Jordan, 1969), formed by dividing the NIR response by the corresponding 'red' band output. For densely vegetated areas, the amount of red light reflected approaches very small values and this ratio, consequently, increases without bounds. Deering (1978) normalized this ratio from -1 to +1, with the normalized difference vegetation index (NDVI), by taking the ratio between the difference between the NIR and red bands and their sum. Global-based operational applications of the NDVI have utilized digital counts, at-sensor radiances, 'normalized' reflectances (top of the atmosphere), and more recently, partially atmospheric corrected (ozone absorption and molecular scattering) reflectances. Thus, the NDVI has evolved with improvements in measurement inputs. Currently, a partial atmospheric correction for Raleigh scattering and ozone absorption is used operationally for the generation of the Advanced Very High Resolution Radiometer. The NDVI is currently the only operational, global-based vegetation index utilized. This is in part, due to its 'ratioing' properties, which enable the NDVI to cancel out a large proportion of signal variations attributed to calibration, noise, and changing irradiance conditions that accompany changing sun angles, topography, clouds/shadow and atmospheric conditions. Many studies have shown the NDVI to be related to leaf area index (LAI), green biomass, percent green cover, and fraction of absorbed photo synthetically active radiation (fAPAR). Relationships between fAPAR and NDVI have been shown to be near linear in contrast to the non-linearity experienced in LAI – NDVI relationships with saturation problems at LAI values over 2. Other studies have shown the NDVI to be related to carbon-fixation, canopy resistance, and potential evapotranspiration allowing its use as effective tool for drought monitoring.

Response/Mitigation phase

Assessment of Drought impact

Remote sensing use for drought impact assessment involves assessment of following themes such as land use, persistence of stressed conditions on an intra-season and inter-season time scale, demographics and infrastructure around the impacted area, intensity and extent, agricultural yield, impact associated with disease, pests, and potable water availability and quality etc. High resolution satellite sensors from LANDSAT, SPOT, IRS, etc. are being used.

Decision support for Relief Management

Remote sensing use for drought response study involves decision support for water management, crop management and for mitigation and alternative strategies. High resolution satellite sensors from LANDSAT, SPOT, IRS, etc. are being used. In India, for long term drought management, action plan maps are being generated at watershed level for implementation.

Global scenario on Remote Sensing use

The normalised difference vegetation index (NDVI) and temperature condition index (TCI) derived from the satellite data are accepted world-wide for regional monitoring.

The ongoing program on Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO and uses METEOSAT rainfall estimates and AVHRR NDVI values for Africa.

The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall map, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.

Joint Research Centre (JRC) of European Commission (EC) issues periodical bulletin on agricultural conditions under MARS-STAT (Application of Remote sensing to Agricultural statistics) project which uses vegetation index, thermal based evapotranspiration and microwave based indicators. Agricultural Division of Statistics, Canada issues weekly crop condition reports based on NOAA AVHRR based NDVI along with agro meteorological statistics. National Remote Sensing Agency, Department of Space issues biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS) which uses NOAA AVHRR and IRS WiFS based NDVI with ground based weather reports. Similar programme is followed in many countries world-wide.

REMOTE SENSING FOR FLOODS

Floods are among the most devastating natural hazards in the world, claiming more lives and causing more property damage than any other natural phenomena. As a result, floods are one of the greatest challenges to weather prediction. A flood can be defined as any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream. When a bank is overtopped, the water spreads over the flood plain and generally becomes a hazard to society. When extreme meteorological events occur in areas characterized by a high degree of urbanization, the flooding can be extensive, resulting in a great amount of damage and loss of life. Heavy rain, snowmelt, or dam failures cause floods. The events deriving from slope dynamics (gravitational phenomena) and fluvial dynamics (floods) are commonly triggered by the same factor: heavy rainfall. Especially in mountainous areas, analyzing flood risk is often impossible without considering all of the other phenomena associated with slope dynamics (erosion, slides, sediment transport, etc.) whereas in plains damages are caused by flood phenomena mainly controlled by water flow.

Forms of Floods: River Floods form from winter and spring rains, coupled with snow melt, and torrential rains from decaying tropical storms and monsoons; Coastal Floods are generated by winds from intense off-shore storms and Tsunamis; Urban Floods, as urbanization increases runoff two to six times what would occur on natural terrain; Flash Floods can occur within minutes or hours of excessive rainfall or a dam or levee failure, or a sudden release of water.

Flood Preparedness Phase

Flood Prone/Risk zone identification

The flood information (data) and experience (intuition) developed during the earlier floods may help in future events. The primary method for enhancing our knowledge of a particular flood event is through flood disaster surveys, where results such as damage assessment, lessons learned and recommendations are documented in a report (see the Natural Disaster Survey Report on "The Great Flood of 1993," Scofield and Achutuni, 1994). Flood risk zone map is of two types: (1) A detailed mapping approach, that is required for the production of hazard assessment for updating (and sometimes creating) risk maps. The maps contribute to the hazard and vulnerability aspects of flooding. (2) A larger scale approach that explores the general flood situation within a river catchment or coastal belt, with the aim of identifying areas that have greatest risk. In this case, remote sensing may contribute to mapping of inundated areas, mainly at the regional level.

Flood Prevention Phase

Flood Monitoring

Though flood monitoring can be carried out through remote sensing from global scale to storm scale, it is mostly used in the storm scale using hydrodynamic models (Figure 2) by monitoring the intensity, movement, and propagation of the precipitation system to determine how much, when, and where the heavy precipitation is going to move during the next zero to three hours (called NOWCASTING). Meteorological satellites (both GOES and POES) detect various aspects of the hydrological cycle —precipitation (rate and accumulations), moisture transport, and surface/ soil wetness (Scofield and Achutuni, 1996). Satellite optical observations of floods have been hampered by the presence of clouds that resulted in the lack of near real-time data acquisitions. Synthetic Aperture Radar (SAR) can achieve regular observation of the earth's surface, even in the presence of thick cloud cover. NOAA AHVRR allows for a family of satellites upon which flood monitoring and mapping can almost always be done in near real time. High-resolution infrared (10.7 micron) and visible are the principal data sets used in this diagnosis. The wetness of the soil due to a heavy rainfall event or snowmelt is extremely useful information for flood (flash flood) guidance. SSM/I data from the DMSP are the data sets used in this analysis. IRS, SAR, SPOT, and to some extent high resolution

NOAA images can be used to determine flood extent and areal coverage. Various precipitable water (PW) products have been developed and are available operationally for assessing the state of the atmosphere with respect to the magnitude of the moisture and its transport. These products include satellite derived PW from GOES (Holt *et al.*, 1998) and SSM/I (Ferraro *et al.*, 1996), and a composite that includes a combination of GOES + SSM/I + model data (Scofield *et al.*, 1996, 1995).

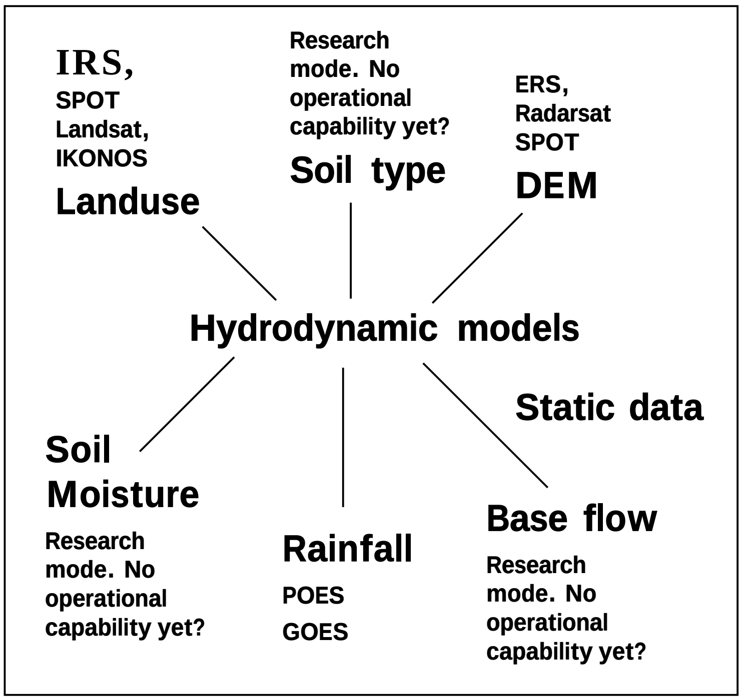

Figure 2: Remote sensing capabilities in Hydrodynamic models of flood

Flood Forecasting

Hydrologic models play a major role in assessing and forecasting flood risk. The hydrologic models require several types of data as input, such as land use, soil type, soil moisture, stream/river base flow, rainfall amount/intensity, snow pack characterization, digital elevation model (DEM) data, and static data (such as drainage basin size). Model predictions of potential flood extent can help emergency managers develop contingency plans well in advance of an actual event to help facilitate a more efficient and effective response. Flood forecast can be issued over the areas in which remote sensing is complementary to direct precipitation and stream flow measurements, and those areas that are not instrumentally monitored (or the instruments are not working or are in error). In this second category, remote sensing provides an essential tool.

Quantitative Precipitation Estimates (QPE) and Forecasts (QPF) use satellite data as one source of information to facilitate flood forecasts. New algorithms are being developed that integrate GOES precipitation estimates, with the more physically based POES microwave estimates. An improvement in rainfall spatial distribution measurements is being achieved by integrating radar, rain gauges and remote sensing techniques to improve real time flood forecasting (Vicente and Scofield, 1998). For regional forecast, the essential input data are geomorphology, hydrological analysis, and historical investigation of past events and climatology. GOES and POES weather satellites can provide climatological information on precipitation especially for those areas not instrumentally monitored.

Forecast on the local scale requires topography, hydraulic data, riverbed roughness, sediment grain size, hydraulic calculations, land cover, and surface roughness. Remote sensing may contribute to mapping topography (generation of DEMs) and in defining surface roughness and land cover. In this case, remote sensing may contribute to updating cartography for land use and DEM. Complex terrain and land use in many areas result in a requirement for very high spatial resolution data over very large areas, which can only be practically obtained by remote sensing systems. There is also a need to develop and implement distributed hydrological models, in order to fully exploit remotely sensed data and forecast and simulate stream flow (Leconte and Pultz, 1990 and Jobin and Pultz, 1996). Data from satellites such as ERS, RADARSAT, SPOT and IRS can provide DEM data at resolutions of about 3 to 10 meters. Land use information can be determined through the use of AVHRR, Landsat, SPOT and IRS data. The rainfall component can be determined through the use of existing POES and GOES platforms. Although there are no operational data sources for estimating soil type, soil moisture, snow water equivalent and stream/river base flow, there has been considerable research on the extraction of these parameters from existing optical and microwave polar orbiting satellites.

Models can also assist in the mitigation of coastal flooding. Wave run-up simulations can help planners determine the degree of coastal inundation to be expected under different, user-specified storm conditions. These types of models require detailed near-shore bathymetry for accurate wave effect predictions. While airborne sensors provide the best resolution data at present, this data source can be potentially cost-prohibitive when trying to assess large areas of coastline. In addition to DEM data, satellite based SAR can also be used to derive near-shore bathymetry for input into wave run-up models on a more cost-effective basis.

Response Phase

Assessment of Flood Damage (immediately during Flood)

The response category can also be called "relief," and refers to actions taken during and immediately following a disaster. During floods, timely and detailed situation reports are required by the authorities to locate and identify the affected areas and to implement corresponding damage mitigation. It is essential that information be accurate and timely, in order to address emergency situations (for example, dealing with diversion of flood water, evacuation, rescue, resettlement, water pollution, health hazards, and handling the interruption of utilities etc.). For remote sensing, this often takes the form of damage assessment. This is the most delicate management category since it involves rescue operations and the safety of people and property.

The following lists information used and analyzed in real time: flood extent mapping and real time monitoring (satellite, airborne, and direct survey), damage to buildings (remote sensing and direct inspections), damage to infrastructure (remote sensing and direct inspection), meteorological NOWCASTS (important real-time input from remote sensing data to show intensity/estimates, movement, and expected duration of rainfall for the next 0 - 3 hours), and evaluation of secondary disasters, such as waste pollution, to be detected and assessed during the crisis (remote sensing and others). In this category, communication is also important to speedy delivery.

Relief (after the Flood)

In this stage, re-building destroyed or damaged facilities and adjustments of the existing infrastructure will occur. At the same time, insurance companies require up-to-date information to settle claims. The time factor is not as critical as in the last stage. Nevertheless, both medium and high-resolution remote sensing images, together with an operational geographic information system, can help to plan many tasks. The medium resolution data can establish the extent of the flood damages and can be used to establish new flood boundaries. They can also locate landslides and pollution due to discharge and sediments. High-resolution data are suitable for pinpointing locations and the degree of damages. They can also be used as reference maps to rebuild bridges, washed-out roads, homes and facilities.

Global scenario on Remote Sensing use

There have been many demonstrations of the operational use of these satellites for detailed monitoring and mapping of floods and post-flood damage assessment. Remote Sensing information derived from different sensors and platforms (satellite, airplane, and ground etc.) are used for monitoring floods in China. A special geographical information system, flood analysis damage information system was developed for estimation of real time flood damages (Chen Xiuwan). Besides mapping the flood and damage assessment, high-resolution satellite data were operationally used for mapping post flood river configuration, flood control works, drainage-congested areas, bank erosion and developing flood hazard zone maps (Rao *et al.*, 1998). A variety of satellite images of the 1993 flooding in the St. Louis area were evaluated and combined into timely data sets. The resulting maps were valuable for a variety of users to quickly locate both natural and man-made features, accurately and quantitatively determine the extent of the flooding, characterize flood effects and flood dynamics. (Petrie *et al.*, 1993). Satellite optical observations of floods have been hampered by the presence of clouds that resulted in the lack of near real-time data acquisitions. Synthetic Aperture Radar (SAR) can achieve regular observation of the earth's surface, even in the presence of thick cloud cover. Therefore, applications such as those in hydrology, which require a regularly acquired image for monitoring purposes, are able to meet their data requirements. SAR data are not restricted to flood mapping but can also be useful to the estimation of a number of hydrological parameters (Pultz *et al.*, 1996). SAR data were used for estimation of soil moisture, which was used as an input in the TR20 model for flood forecasting (Heike Bach, 2000). Floods in Northern Italy, Switzerland, France and England during October 2000 were studied using ERS-SAR data. Using information gathered by the European Space Agency's Earth Observation satellites, scientists are now able to study, map and predict the consequences of flooding with unprecedented accuracy. SAR images are also particularly good at identifying open water - which looks black in most images. When combined with optical and infra-red photography from other satellites, an extremely accurate and detailed digital map can be created. Quantitative Precipitation Estimates (QPE) and Forecasts (QPF) use satellite data as one source of information to facilitate flood and flash flood forecasts in order to provide early warnings of flood hazard to communities. New algorithms are being developed that integrate the less direct but higher resolution (space and time) images. An improvement in rainfall spatial distribution measurements is being achieved by integrating radar, rain gauges and remote sensing techniques to improve real time flood forecasting (Vicente and Scofield, 1998). Potential gains from using weather radar in flood forecasting have been studied. (U.S. National Report to International Union of Geodesy and Geophysics 1991-1994). A distributed rainfall-runoff model was applied to a 785 km basin equipped with two rain gauges and covered by radar. Data recorded during a past storm provided inputs for computing three flood hydrographs from rainfall recorded by rain gauges, radar estimates of rainfall, and combined rain gauge measurements and radar estimates. The hydrograph computed from the combined input was the closest to the observed hydrograph. There has been considerable work devoted to developing the approach needed to integrate these remotely sensed estimates and in situ data into hydrological models for flood forecasting. A large-scale flood risk assessment model was developed for the River Thames for insurance industry. The model is based upon airborne Synthetic Aperture Radar data and was built using commonly used Geographic Information Systems and image processing tools. From the Ortho-rectified Images a land cover map was produced (Hélène M. Galy, 2000).

CONCLUSIONS

Droughts and Floods are among the most devastating natural hazards in the world, claiming more lives and causing extensive damage to agriculture, vegetation, human and wild life and local economies. The remote sensing and GIS technology significantly contributes in the activities of all the three major phases of drought and flood management namely, 1. Preparedness Phase where activities such as prediction and risk zone identification are taken up long before the event occurs. 2. Prevention Phase where activities such as Early warning/ Forecasting, monitoring and preparation of contingency plans are taken up just before or during the event and 3. Response/Mitigation Phase where activities just after the event includes damage assessment and relief management. In this lecture, brief review of remote sensing and GIS methods and its utilization for drought and flood management are discussed.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. R.R. Navalgund, Director, Dr. A. Bhattacharya, Deputy Director (RS &GIS) and Dr. L. Venkataratnam, Group Director (A&SG) of NRSA for nominating the author to present the lecture in the WMO Sponsored Training/Workshop on Remote sensing data interpretation for Application in Agricultural Meteorology.

REFERENCES

Adler, R.F. and A.J. Negri, 1988. A satellite infrared technique to estimate tropical convective and stratiform rainfall. J. Appl. Meteorol., 27: 30-51.

Anagnostou, E.N., A.J. Negri and R.F. Adler, 1999. A satellite infrared technique for diurnal rainfall variability studies. J. Geophy. Res., 104: 31477-31488.

Arkin, P.A. 1979. The relationship between fractional coverage of high cloud and rainfall accumulations during GATE over the B-scale array. Mon. Wea. Rev., 106: 1153-1171.

ATBD-AST-03, 1996. Advance Space borne Thermal Emission and Reflection Radiometer (ASTER) products.

Barret, E.C. and D.W. Martin, 1981. The use of satellite data in rainfall monitoring. Academic Press, 340 pp.

Becker, F. 1987. The impact of spectral emissivity on the measurement of land surface temperature from a satellite. Int. J. Remote Sens. 11: 369-394.

Becker, F. and Z.L. Li 1990. Toward a local split window method over land surface. Int. J. Remote Sens. 11: 369-393.

Berk, A., L.S. Bemstein and D.C. Robertson, 1989. MODTRAN: A moderate resolution model for LOWTRAN 7. Rep. GLTR-89-0122, Burlington, MA: Spectral Sciences, Inc.

Chen Xiuwan. Flood Damage Real-Time Estimation-Model based on remote sensing and GIS. Institute of Remote Sensing and GIS, Peking University, Beijing, China. http://incede.iis.u-tokyo.ac.jp/reports/Report_11/Chen.pdf

Colwell, J.E. 1974. Vegetation canopy reflectance. Remote Sens. Environ., 3: 175-183.

Cornette, W.M., P.K. Acharya, D.C. Robertson and G.P. Anderson 1994. Moderate spectral atmospheric radiance and transmittance code (MOSART). Rep. R-057-94(11-30), La Jolla, CA: Photon Research Associates, Inc.

Ferraro, R.R., Weng, F., Grody, N.C. and Basist, A., 1996. An eight year (1987-94) climatology of rainfall, clouds, water vapor, snowcover, and sea-ice derived from SSM/I measurements. Bull. of Amer. Meteor. Soc., 77: 891-905.

Griffith, C.G., W.L. Woodley, P.G. Grube, D.W. Martin, J. Stout and D.N. Sikdar 1978. Rain estimation from geosynchronous satellite imagery- Visible and infrared studies. Mon.Wea. Rev., 106: 1153-1171.

Gruber, A. 1973. Estimating rainfall in regions of active convection. J. Appl. Meteorol., 12: 110-118.

Heike Bach. An Integrated Flood Forecast System Based on Remote Sensing Data, VISTA-Remote sensing applications in Geosciences.

Hélène M. Galy, Richard A. Sanders Willis, London, UK RGS-IBG Annual Conference, University of Sussex, January 4^{th} – 7^{th} 2000.

Holt, F.C., W.P. Menzel, D.G. Gray and T.J. Schmit 1998. Geostationary satellite soundings: new observations for forecasters. US Department of Commerce, NOAA, NESDIS, 30 pp.

Hook, S.J., A.R. Gabell, A.A. Green and P.S. Kealy 1992. A comparison of techniques for extracting emissivity information from thermal infrared data for geological studies. Remote Sens. Environ., 42: 123-135.

Jeyaseelan, A.T. and Chandrasekar, K. 2002. Satellite based identification for updation of Drought prone area in India. ISPRS-TC-VII, International Symposium on Resource and Environmental Monitoring, Hyderabad.

Jobin, D.I. and T.J. Pultz, 1996. Assessment of three distributed hydrological models for use with remotely sensed inputs. Third International Workshop on Applications of Remote Sensing in Hydrology, Greenbelt, MD, October 16-18, pp. 100-130.

Jordan, C.F. 1969. Derivation of leaf area index from quality of light on the forest floor. Ecology, 50: 663-666.

Kahle, A.B. 1986. Surface emittance, temperature and thermal inertia derived from Thermal infrared multispectral scanner (TIMS) data for Death Valley, California. Geophysics, 52 (7): 858-874.

Kahle, A.B., D.P. Madura and J.M. Soha, 1980. Middle infrared multispectral aircraft scanner data: analysis of geological applications. Appl. Optics, 19: 2279-2290.

Kerr, Y.H., J.P. Lagouarde and J. Imbernon, 1992. Accurate land surface temperature retrieval from AVHRR data with use of an improved split window algorithm. Remote Sens. Environ., 41(2-3): 197-209.

Kidder, S.Q. and T.H. Vonder Harr, 1995. Satellite Meteorology: An Introduction. Academic Press, 466 pp.

Kneizys, F.X., E.P. Shettle, L.W. Abreu, J.H. Chetwynd, G.P. Anderson, W.O. Gallery, J.E. A. Selby and S.A. Clough 1988. Users guide to LOWTRAN7. Rep. AFGL-TR-88-0177, Bedford, MA: Air Force Geophys. Lab.

Kneizys, F.X., E.P. Shettle, W.O. Gallery, J.H. Chetwynd, L.W. Abreu, J.E.A. Selby, S.A. Clough and R.W. Fenn, 1983. Atmospheric transmittance/Radiance: Computer code LOWTRAN 6. Rep. AFGL-TR-83-0187, Bedford, MA: Air Force Geophys. Lab.

Leconte, R. and T.J. Pultz, 1990. Utilization of SAR data in the monitoring of snowpack, wetlands, and river ice conditions. Workshop on Applications of Remote Sensing in Hydrology, Saskatoon, Saskatchewan, February 13-14, 1990, pp. 233-247.

Li, Z.L. and F. Becker, 1993. Feasibility of land surface temperature and emissivity determination from AVHRR data. Remote Sens. Environ, 43: 67-85.

O'Sullivan, F., C.H. Wash, M. Stewart and C.E. Motell, 1990. Rain estimation from infrared and visible GOES satellite data. J. Appl. Meteorol., 29: 209-223.

Ottle, C. and M. Stoll, 1993. Effect of atmospheric absorption and surface emissivity on the determination of land temperature from infrared satellite data. Int. J. Remote Sens., 14(10): 2025-2037.

Petrie, G.M., G.E. Wukelic, C.S. Kimball, K.L. Steinmaus and D.E. Evaluating 1993. Mississippi River Flood Developments Using ERS-1 SAR, Landsat, and Spot Digital Data. Beaver Pacific Northwest Laboratory, Richland, Washington http://www.odyssey.maine.edu/gisweb/spatdb/acsm/ac94108.html

Prata, A.J. 1994. Land surface temperatures derived from the advanced very high resolution radiometer and the along track scanning radiometer 2. Expeimental results and validation of AVHRR algorithm. J. Geophys. Res., 99(D6): 13025-13058.

Price, J.C. 1984. Land surface temperature measurements from the split window channels of the NOAA-7/AVHRR. J. Geophys. Res., 89: 7231-7237.

Pultz, T.J. and Yves Crevier, 1996. Early demonstration of RADARSAT for applications in hydrology. Third International Workshop on Applications of Remote Sensing in Hydrology, Greenbelt, MD, October 16-18, 1996, pp. 271-282.

Rao, D.P., V. Bhanumurthy and G.S. Rao, 1998. Remote Sensing and GIS in Flood Management in India. Memoir Geological Society of India, No. 41, 1998. pp. 195-218.

Scofield, R.A. and R. Achutuni, 1994. Use of satellite data during the great flood of 1993. Appendix C of the natural disaster survey report on The Great Flood of 1993, NOAA/NWS Report, U.S. Department of Commerce, Silver Spring, MD, C-1 — C-18.

Scofield, R.A. and R. Achutuni, 1996. The satellite forecasting funnel approach for predicting flash floods. Remote Sensing Reviews, 14: 251-282.

Scofield, R.A., D. Zaras, S. Kusselson and R. Rabin, 1996. A remote sensing precipitable water product for use in heavy precipitation forecasting. Proceedings of the 8th Conference on Satellite Meteorology and Oceanography, Atlanta, GA, 29 January - 2 February, 1996, AMS, Boston, MA, pp. 74- 78.

Scofield, R.A., S. Kusselson, D. Olander, and J. Robinson, 1995. Combining GOES, microwave, and raw insonde moisture data for improving heavy precipitation estimates and forecasts. Proceedings of the 14th Conference on Weather Analysis and Forecasting, Dallas, TX, 15 – 20 January, 1995, AMS, Boston, MA, (J4) 1 - (J4) 6.

Sobrino, J.A. and V. Caselles, 1991. A methodology for obtaining the crop temperature from NOAA-9 AVHRR data. Int. J. Remote Sens., 38: 19-34.

Vicente, G. and R.A. Scofield, 1998. The operational GOES infrared rainfall estimation technique. Bulletin of the American Meteorological Society, September 1998.

Vidal, A. 1991. Atmospheric and emissivity correction of land surface temperature measured from satellite using ground measurements or satellite data. Int. J. Remote Sens., 12(12): 2449-2460.

Wan, Z. and J. Dozier 1996. A generalized split-window algorithm for retrieving land-surface temperature from space. IEEE Trans. Geosci. Remote Sens., 34: 892-905.

Wan, Z. and Z.L. Li, 1997. A physics based algorithm for retrieving land-surface emissivity and temperature from EOS/MODIS data. IEEE Trans. Geosci. Remot. Sens., 27(3): 268-278.