7.3 USING NDVI AND ELEVATION TO IMPROVE PRECIPITATION MAPPING

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1. INTRODUCTION

The spatial resolution of a precipitation map is limited by the spacing of the point data used to construct the map. Consequently, the spatial resolution is poor for global maps that only use station information in data sparse areas. In order to improve analyses in these data sparse areas, a model was developed to estimate the spatial trend of precipitation from remotely sensed vegetation and elevation information. The spatial trend model is based on the hypothesis that topography produces spatial trends of precipitation, and spatial trends of precipitation produce corresponding spatial trends in vegetation. In this way, the model is different than a model that only correlates NDVI to precipitation.

A Geographic Information System (GIS) was used to combine topography and Normalized Difference Vegetation Index (NDVI) data in order to define 'topographic' areas in which the spatial trend of precipitation could be modeled. This spatial trend information was used in conjunction with station precipitation data to produce monthly maps for precipitation statistics for global land areas.

2. DATA

Data consist of global topography, NDVI, and observed station precipitation. The global topography is a 3x3 grid cell average of the US Geological Survey GTOPO30 data set which has a resolution of approximately 1 kilometer (USGS, 1999). The NDVI is an Advanced Very High Resolution Radiometer (AVHRR) derived product produced by the NOAA National Geophysical Data Center and contains monthly NDVI averages for the discontinuous five-year time period of April 1985 - December 1987 and January 1989 - March 1991 (NOAA, 1997). The NDVI are presented on a grid with a horizontal resolution of approximately 15 kilometers.

Precipitation data were derived from two data sets. Daily precipitation totals for the United States were obtained from the National Climatic Data Center (NCDC) Cooperative Summary of the Day data set (NOAA, 1999). Precipitation data from outside of the United States were obtained from the Air Force Combat Climatology Center (AFCCC) hourly DATSAV3 data set (USAF, 2000) and converted into daily values. Data were obtained for approximately 6,400 USA stations and 3,400 international stations for the 24 - year period of 1975 - 1998.

3. STATISTICS MAPPED

Monthly maps were produced for the 10th, 50th, 90th, and extreme (100th) percentiles for 14 precipitation statistics. Table 1 lists the statistics. Each of the 14 monthly statistics was calculated from daily data within a month. That is, each statistic is a representation of one month and does not include data from neighboring months. For example, greatest 15-day precipitation and the greatest number of consecutive wet days refer to a single month. Statistics were not calculated for months with more than four missing daily values. Percentiles were not calculated if more than 10 monthly values were missing (i.e., percentiles are based on 14 to 24 monthly values). Missing data in some areas reduced the number of stations used to calculate percentiles by as much as 25 percent.

The data were divided into five regions for data manageability: North America, South America, Africa, Australia, and Eurasia. Islands associated

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with and in close proximity to a region were included with the region. Isolated islands were not included in the map analyses (although station statistics were calculated for such islands). A total of 3,360 precipitation statistics maps were produced (12 months x 14 statistics x 4 percentiles x 5 regions).

Seven of the 14 statistics are related to the amount of precipitation in a period. These statistics are referred to as ‘amount’ statistics. The remaining seven statistics are referred to as ‘number of days’ statistics. Amount statistics were mapped using the ‘Augmented Inverse Distance Weighting ’ (AugIDW) method described below. The number of days statistics were mapped using a simple Inverse Distance Weighting (IDW) method.

Table 1. Precipitation Statistics.

Statistic (units)	**Method**
Total Monthly Precipitation (inches)	AugIDW
Average Wet Day Precipitation (inches)	AugIDW
Greatest 1-Day Precipitation (inches)	AugIDW
Greatest 5-Day Precipitation (inches)	AugIDW
Greatest 10-Day Precipitation (inches)	AugIDW
Greatest 15-Day Precipitation (inches)	AugIDW
Greatest Consecutive Wet Day Total (inches)	AugIDW
Greatest Number of Consecutive Wet Days (days)	IDW
Greatest Number of Consecutive Dry Days (days)	IDW
Number of Days $ 0.5 Inches (days)	IDW
Number of Days $1.0 Inches (days)	IDW
Number of Days $ 2.0 Inches (days)	IDW
Number of Days $ 3.0 Inches (days)	IDW
Total Number of Wet Days (days)	IDW

4. MODEL

Equations 1-3 define the Augmented Inverse Distance Weighting model used to interpolate the seven amount type of point precipitation statistics to grid cell values for subsequent mapping.

$$P(x) = PT(x) + p(x) \tag{1}$$

$$\begin{aligned} PT[x(\text{topo})] &= A + B * \text{NDVI} \\ PT[x(\text{flat})] &= PT[x(\text{nearest topo})] \end{aligned} \tag{2}$$

$$p(x) = \text{Inverse Distance Weighting estimate of } [P(I) - PT(I)] \text{ point residuals} \tag{3}$$

where

P = a precipitation statistic (e.g., monthly total, number of days greater than 1“, etc.)
PT = spatial trend of P
p = residual P - PT
x refers to grid cell quantities
x(topo) refers to grid cell quantities within topographic areas
x(flat) refers to grid cell quantities between topographic areas
x(nearest topo) refers to the nearest grid cell within a topographic area
I refers to point values of P

‘Topographic areas’ are polygons in which the direction of the elevation gradient is nearly parallel (within +/- 15 degrees) of the direction of the NDVI gradient (see Figure 1). These polygons represent areas in which the average vegetation (as represented by the 5-year monthly average NDVI) is responding to an underlying spatial trend of precipitation due to spatial gradients of elevation. The model parameters (A and B, equation 2) were calculated via a least squares fit for each statistic, percentile, and month from the dense Contiguous-US precipitation data. The resulting parameters were then used for all global land areas.

The mapping error for the AugIDW model was estimated for all statistics for all months as a linear function of the distance of a grid cell to the nearest station. A set of about 260 US stations (arranged in a variable spaced lattice) were used to calibrate the error model by comparing the 6,140 held-back stations to the maps produced from the 260 stations.

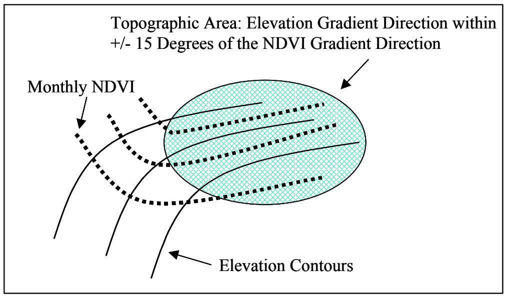

Figure 1. Topographic Areas.

The AugIDW method reduces to a simple IDW method when no vegetation and elevation information are available. Consequently, the value of the AugIDW method was investigated by comparing the method's error estimates to IDW error estimates. The same small set of 260 US stations was used to produce both error estimates.

The error comparison showed that augmenting the station data with NDVI and elevation information reduced the errors for amount type statistics for February through November in the Northern Hemisphere. Therefore, the final mapping program augments station data with NDVI and elevation information for amount type statistics during February through November. The mapping program does not augment the station data for number of day type statistics and for the months of December and January in the Northern Hemisphere. In the Southern Hemisphere the February through November period is replaced by the months of August through May.

5. MAPS

The appropriate AugIDW or IDW analysis was applied to entire continental regions to produce monthly precipitation statistics maps for each region. The level of realistic detail in a map varied considerably between continents and seasons.

Most of the detail present in both the AugIDW and simple IDW based maps for the North American continent is due to the very large number of stations (6,400) that went into the analysis. Both methods constrain the map values to closely approximate individual station values.

The level of realistic detail in amount type of statistics for August through May is enhanced by topographic and vegetation information in the data sparse Amazon region of South America. Patterns in this area for number of day type statistics (which are analyzed via the IDW method) generally contain less detail because no auxiliary information is added to the widely spaced station data.

Maps for the African continent show the least level of detail for two reasons. First, the data sparse regions are very extensive. Consequently, no information is available to indicate any local detail in maps produced by the IDW method. Second, the maps produced by the AugIDW method are confounded by the lack of information contained in the NDVI and elevation fields. The data sparse regions are generally areas where the NDVI is low and has little spatial variation that corresponds to elevation gradients. Consequently the precipitation trend fields are mostly flat and produce little variation in the final maps. Additional detail is present, however, in the areas such as the Horn of Africa where a coordinated elevation and vegetation signal exists.

The maps for all continental areas display statistic patterns that are meteorologically reasonable. However, no direct comparison with maps produced by other methods was made because of differences in time periods, type of statistic, and stations used by the other methods.

6. CONCLUSIONS

A set of 3,360 monthly precipitation statistics maps plus an equal number of error maps were produced for global land areas. Maps for the seven 'number of days' type of statistics were produced by Inverse Distance Weighting of station data. Maps for the seven 'amount' type of statistics for February through November (August through May in the Southern Hemisphere) were enhanced by using an Augmented Inverse Distance Weighting mapping method to combine station data with spatial trends estimated from NDVI and elevation data.

The success of the enhancement depends on the relevant information contained in the NDVI and elevation fields. Additional realistic detail is added to data sparse areas when the gradients of the NDVI are large and correspond to elevation gradients. If either the NDVI or the elevation are flat, no additional detail is produced in the precipitation maps.

Future work is to develop a mapping method that is not restricted to vegetated areas during specific months.

7. ACKNOWLEDGMENTS

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