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THE USE OF SATELLITE DERIVED METEOROLOGICAL DATA IN WATER BUDGET ANALYSES

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ABSTRACT: *In recent years, satellite derived meteorological data have started to replace measured station meteorological data for use in climate models. However, satellite derived data may not necessarily be compatible with certain models. This study illustrates the effect of using satellite derived data in a climatic water budget model designed for use with measured station data. The satellite derived data, when used in the water budget, provide unreliable estimates of surplus, and hence streamflow, as well as deficit, or irrigation requirements for the majority of the United States.*

INTRODUCTION

In the past few years, satellite derived meteorological data have started to replace measured station meteorological data for use in climatological models. Some of the advantages of the satellite derived data are evident: people are not required to make the observations; processing of the data can be accomplished automatically; measurements can be obtained in unpopulated regions; and with the exception of an equipment failure, complete spatial and temporal data collection is achieved. The high expense of the satellite and of obtaining the data for processing are limitations. However, the advantages of satellite derived data may outweigh the limitations since the use of satellite derived data is increasing. The use of satellite derived data may not be appropriate for all models though. Many climate models, developed before the satellite age using measured station data, are important climatological tools today. In this study, temperature and precipitation data for the years 1985 through 1988, obtained from satellite derived estimates and from measured station data, are compared in a water budget analysis of the United States.

DATA

The satellite derived meteorological data were obtained from the NASA Goddard Space Flight Center ftp site, sponsored by the Mission to Planet Earth program. The satellite derived meteorological estimates used in this study were produced by the Goddard Space Flight Center, using an algorithm developed by Joel Susskind, and have a spatial resolution of one degree latitude by one degree longitude and a monthly temporal resolution. The original satellite values were acquired by NASA from the television, infrared observation system, operational vertical sounder (TOVS) onboard the National Oceanic and Atmospheric Administration's NOAA-9 and NOAA-10 satellites.

Measured station meteorological data came from a yearly compilation of monthly average temperature and total monthly precipitation from 344 first order National Weather Service stations across the United States. While data for the last 100 years are available, only the years 1985 through 1988, which coincided with the available satellite derived data, were used. These measured station data were interpolated, using an inverse distance weighting function, to the same one degree latitude by one degree longitude grid as the satellite derived data, in order to permit direct comparisons.

METHODS

The Thornthwaite-Mather Climatic Water Budget (Thornthwaite and Mather, 1955) is a convenient method of accounting for the climatic demand for water, or potential evapotranspiration (PE), and the climatic supply of water, or precipitation (P). The inputs to the water budget are temperature, precipitation, and an estimate of the water holding capacity of the soil or field capacity. For this study it is assumed that the water holding capacity of the soil across the United States is a uniform 150mm. According to Thornthwaite and Mather (1955) and Willmott et al. (1985) this is a legitimate assumption as it is representative of various vegetation and soil types.

In the water budget, temperature is used to calculate PE using the Thornthwaite method (Thornthwaite and Mather, 1955). Thornthwaite's method was chosen because researchers worldwide have shown that the Thornthwaite-Mather water budget approach provides reasonable results when measured station data are used in the analyses (Mather, 1978; 1979; Carter, 1956; 1958). Once PE is determined, it is compared to precipitation on a monthly basis. If precipitation is greater than PE, the actual evapotranspiration from a location takes place at the PE rate. If PE exceeds precipitation, additional water is drawn from the soil in an attempt to achieve the PE rate. Often, the amount of moisture drawn from the soil is less than the difference between PE and precipitation and actual evapotranspiration occurs at a rate lower than the PE rate.

Surplus is one useful output from the water budget. In areas where it is moist (P>PE), the surplus is the excess water not needed to achieve the PE rate or recharge the soil moisture. This water moves through the soil and eventually becomes streamflow. Surplus can only occur when the soil is at field capacity. If moisture has been drawn from the soil in a dry time, it must be replenished, during a wet time, before there can be a surplus.

Soil moisture storage is another useful output from the water budget. Soil moisture storage indicates the amount of moisture that is available to vegetation, in addition to precipitation. As soil dries, however, the ratio of the amount of moisture supplied by the soil to the amount of moisture required by vegetation to meet the PE rate decreases. Stated more simply, as soil dries it is less willing to give up its moisture. Even if there is a large amount of water in the soil, the vegetation may not be able to withdraw all that is required to achieve the PE rate.

The third important output from the water budget is deficit. Deficit is the amount of moisture that the vegetation requires to achieve the PE rate but does not receive. Therefore, deficit can be used as an estimate of the amount of irrigation required for optimum vegetation development.

DISCUSSION

Once the data were obtained, the satellite derived data and the measured station data were input into the water budget model and the results of the four, yearly water budgets were averaged for both data sets for each grid cell. These results were input into the ARC/INFO geographic information system. Maps of the inputs and outputs from both sets of water budget computations, as well as maps of the differences between the measured station data and the satellite derived data, were generated. The results of the comparison between the satellite derived data and the measured data are discussed below.

Figure 1(a through e) shows graphs of the four-year average input (temperature and precipitation) and output (PE, surplus, and deficit) data. The temperature data, derived from the satellite, show a smaller yearly range than the measured station temperature data (Figure 1a). In addition, the maximum and minimum temperatures in the satellite derived data lag one month behind the measured station temperature data. Figures 2a through 2c show the four year average temperature across the U.S. using the measured station and the satellite derived data sources as well as the difference between the two sources (measured station temperature minus satellite derived temperature). In Figure 2, as in all following figures, the same scale applies to maps a and b while map c has its own scale. With the exception of the

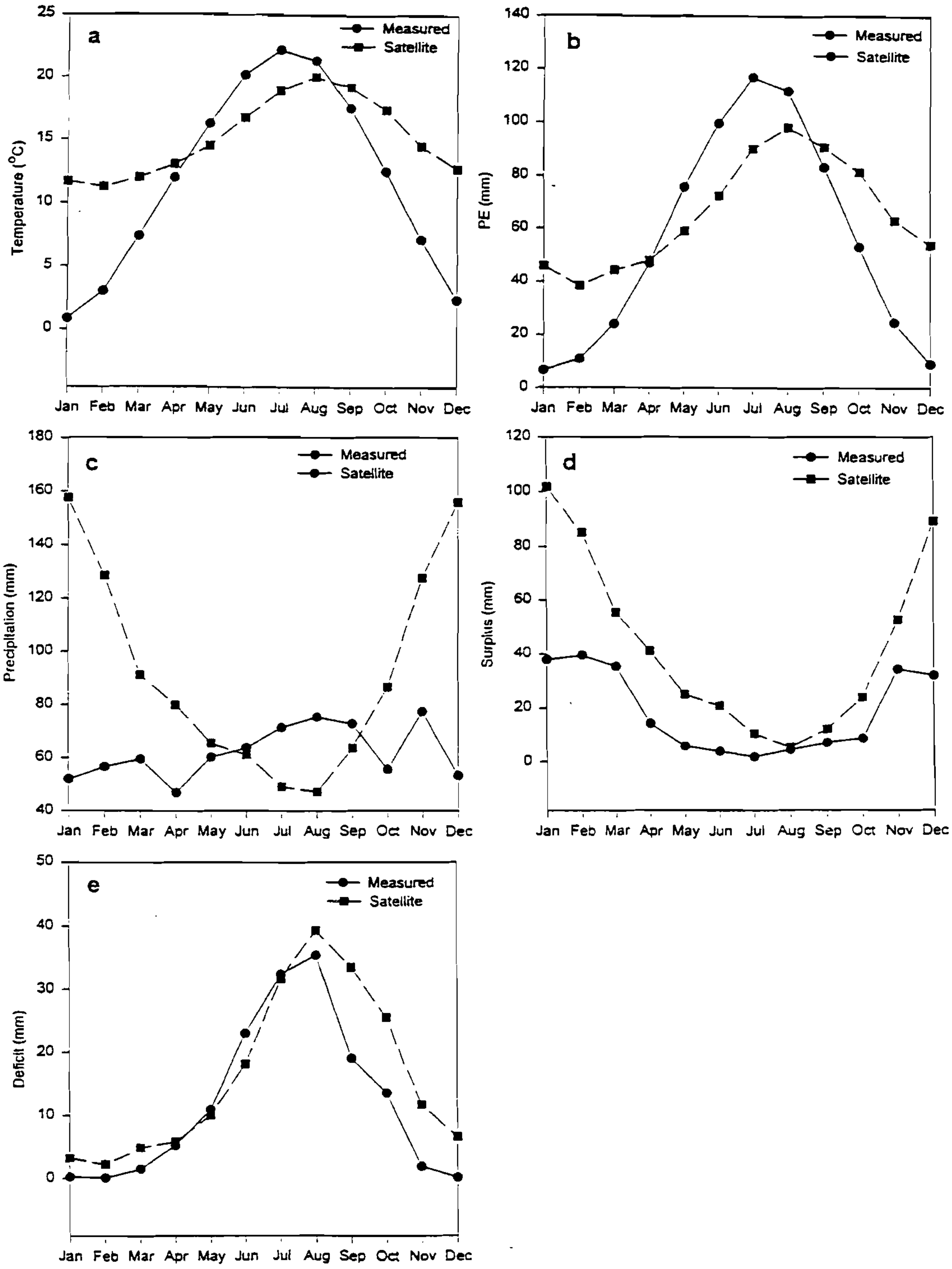


Figure 1 Four year averaged monthly values for: a) temperature, b) PE, c) precipitation, d) surplus, e) deficit.

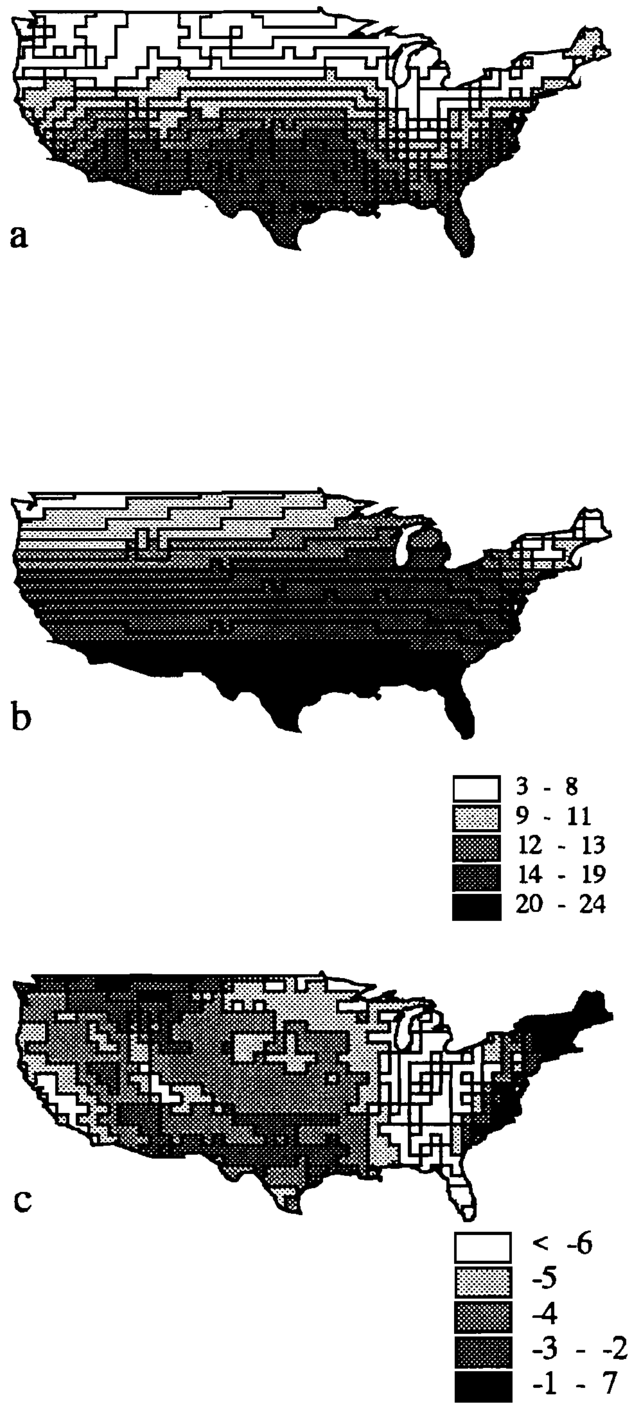


Figure 2 Four year average temperature in °C:
a) measured, b) satellite, c) a - b.

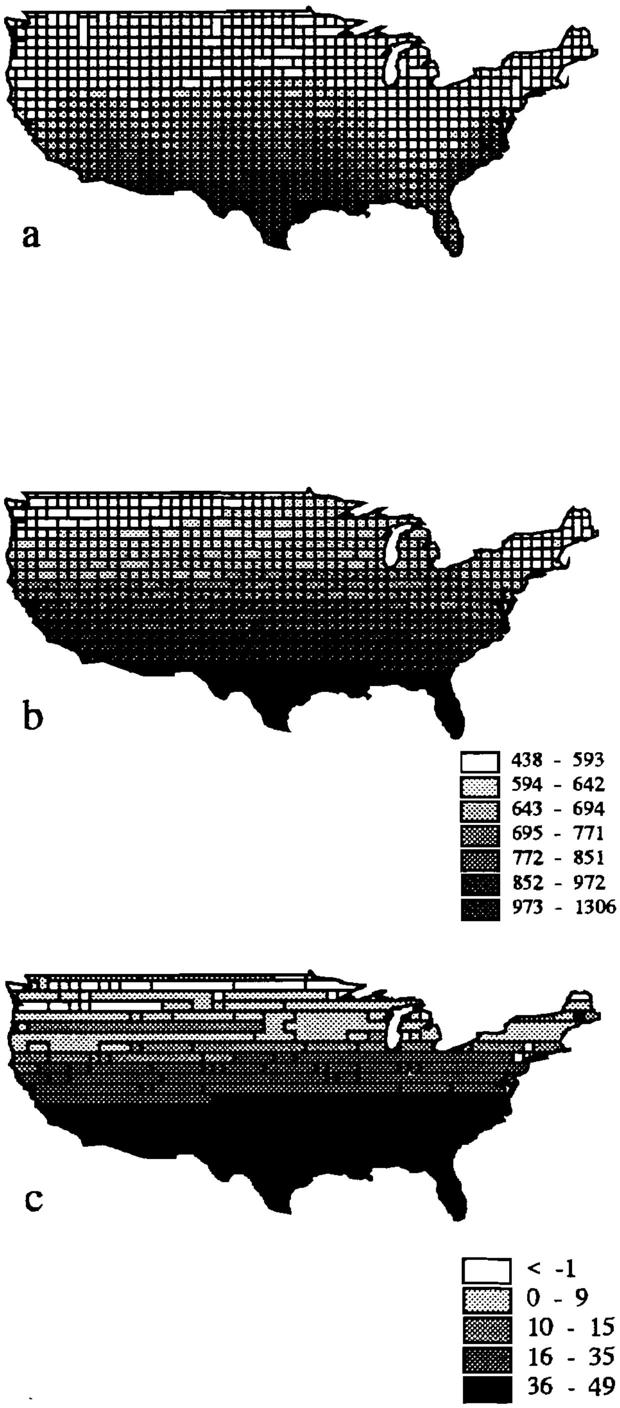


Figure 3 Four year average PE in mm:
a) measured, b) satellite, c) a - b.

northeast, part of the Atlantic coast and a small area in the northwest, the satellite derived data provide higher average temperature estimates than the measured station temperature data.

Similarly, the higher satellite derived temperature estimates influence the PE (Figure 1b), since PE is a function of temperature. The PE estimates from the satellite derived temperature data show a smaller range than do the PE estimates from the measured station temperature data. Figures 3a through 3c again show that, with the exception of areas in the north and parts of the Northeast, the satellite derived temperature data provide higher estimates of PE than do the measured station temperature data. The maximum difference in PE is less than 50mm.

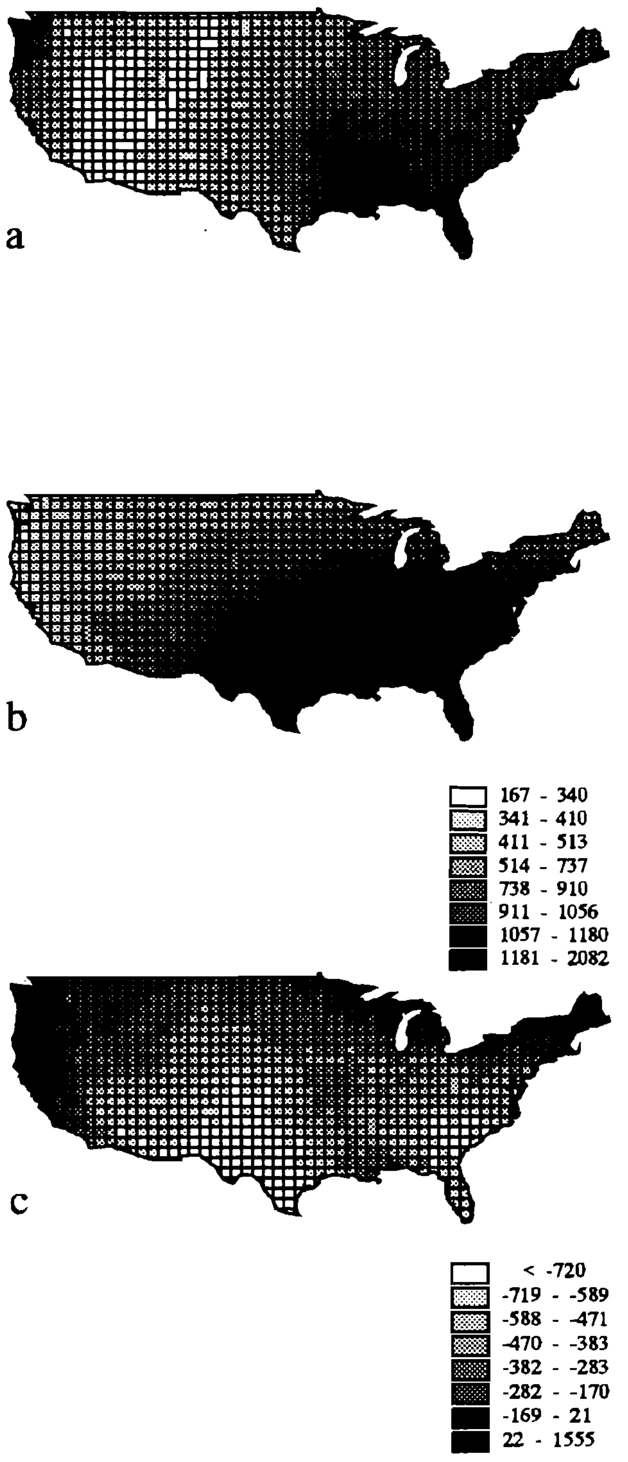
Currently, satellite estimates of precipitation are inadequate. While the averaged measured station precipitation shows a fairly even distribution through the year, the satellite derived precipitation data overestimates the observed winter season precipitation and underestimates the observed summer season precipitation significantly (Figure 1c). Figures 4a through 4c illustrate that the satellite derived precipitation estimates are higher than the measured station precipitation totals by a significant margin (up to 720mm). Exceptions to this pattern occur in the northeast, on the west coast, and in small areas in the north.

Despite increased PE estimates, monthly surpluses are vastly exaggerated when satellite derived temperature and precipitation estimates are combined in the water budget (Figures 1d and 5a through c). This is probably a function of the overestimate of precipitation from the satellite derived data. In each month, surplus is overestimated when compared to surplus calculated using measured station data. This overestimate encompasses most of the country, with the largest overestimation taking place in the desert southwest and the region leeward of the Rocky Mountains. This surplus estimate could lead to exaggerated streamflow estimates for most of the country, leading to potential concern with flooding and flood prevention, as well as misappropriation of water resources.

Deficit is more closely predicted using satellite derived data, when compared to the deficit estimated from the measured station data, than most of the other water budget quantities. Deficit was only encountered, in any significant degree, in the summer months (Figure 1e). During the summer, the satellite derived data estimated less precipitation than was actually measured. In addition, summer temperatures, and hence PE, were underestimated by the satellite derived data. These two occurrences combined to yield average four-year deficits which closely approximated the deficit computed from the measured station data. Figures 6a through 6c, illustrate that only in the lower peninsula of Florida and in the extreme north do the deficit results derived from the satellite data compare poorly with the deficit estimates from the measured station data. Still, this slight increase in the deficit estimates, calculated from satellite derived data, could lead to an exaggerated concern for irrigation water throughout the entire country.

CONCLUSIONS

The climatic water budget was used in this study to provide an example of the potential outcome when satellite derived temperature and precipitation data are used in a model developed and based on measured station data. Water budget calculations derived from satellite derived data provide unreliable PE, surplus, and deficit estimates because of the often exaggerated temperature and precipitation input estimates. Therefore, care must be taken when models fit to station data are combined with satellite derived data. This is not, however, meant to dissuade the use of satellite derived data. A water budget model modified for use with satellite derived data would possibly yield unreliable results when used with measured station data. Determining which data were used to develop a model can help limit the misuse of the model.



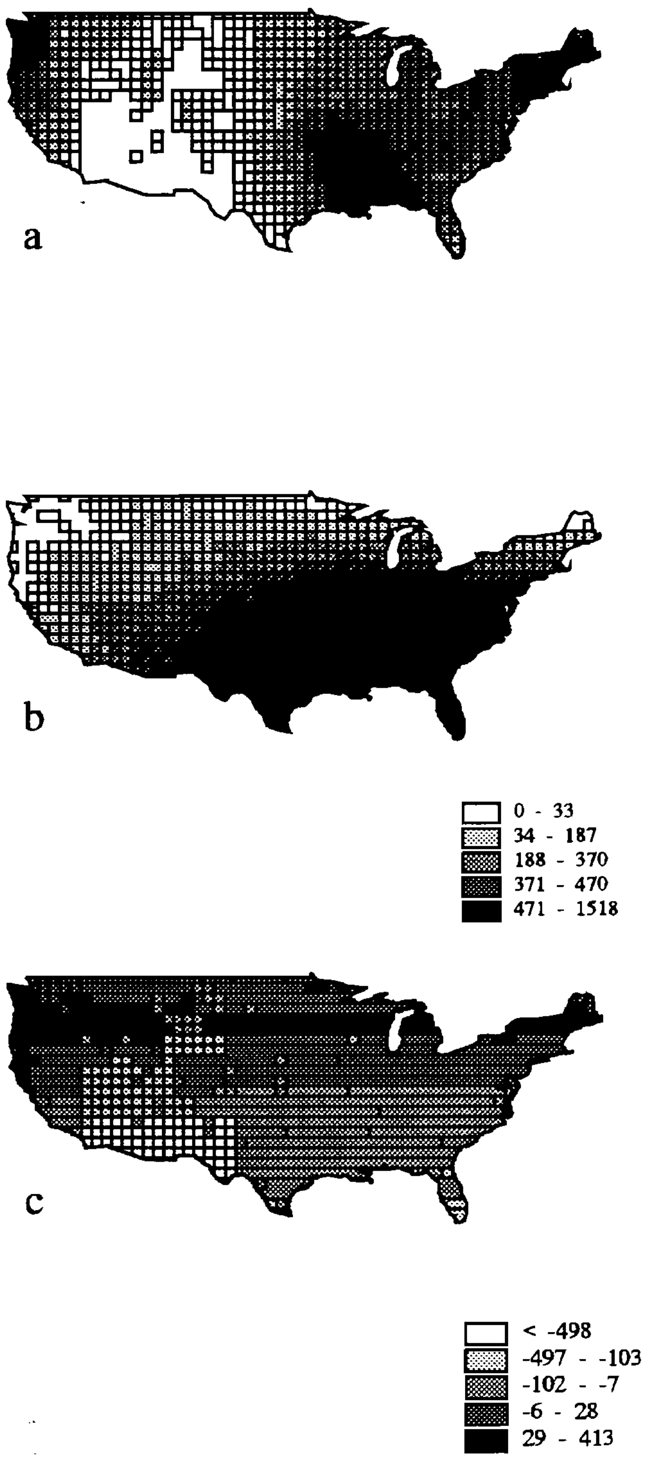


Figure 4 Four year average precipitation in mm: a) measured, b) satellite, c) a - b.

Figure 5 Four year average surplus in mm: a) measured, b) satellite, c) a - b.

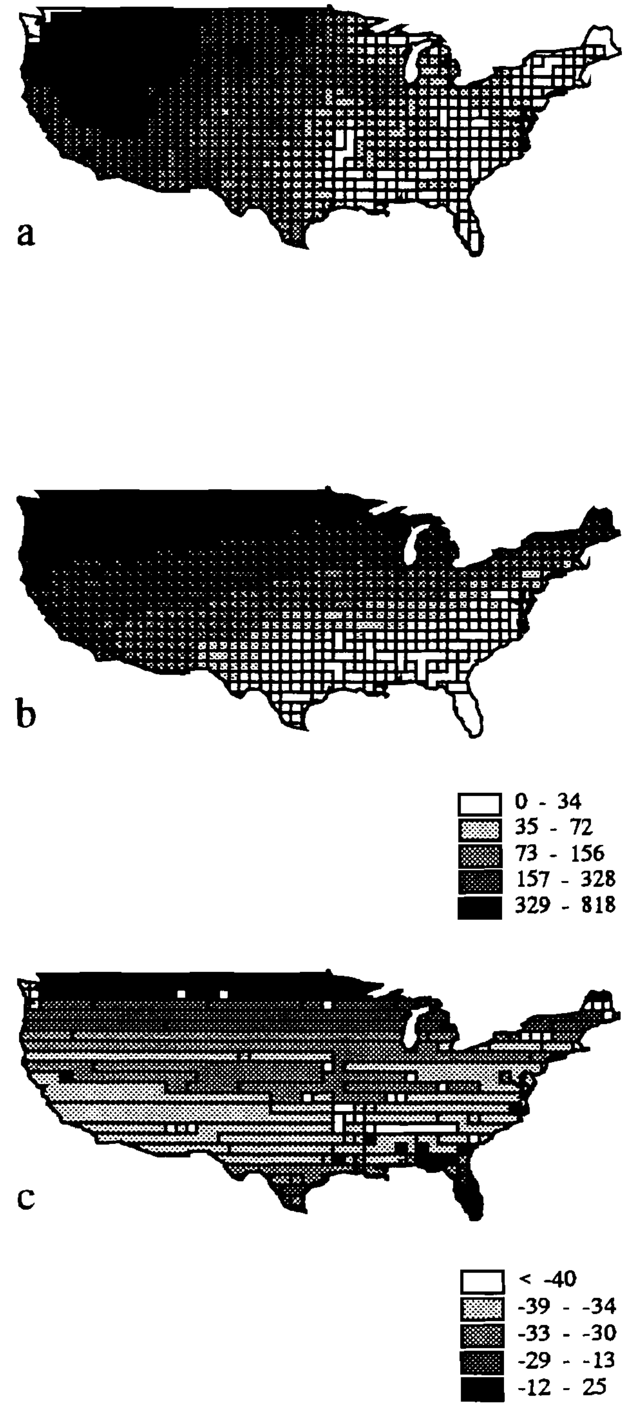


Figure 6 Four year average deficit in mm:
a) measured, b) satellite, c) a - b.

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