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NDVI relationship to monthly evaporation

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Abstract. Normalized difference vegetation indices (NDVI), calculated from Landsat-MSS images, were correlated with monthly total precipitation and estimates of monthly evaporation in a prairie environment. The highest value of the correlation coefficient (r = .80) was obtained between the monthly mean NDVI and estimated evaporation of the preceding month. The de-seasoned NDVI and evaporation values retained a correlation coefficient of .53 corresponding to half of the originally explained variance (r^2=.64) between NDVI and evaporation suggesting that NDVI indices may be useful for estimating regional-scale evaporation in a water-limited environment.

1. Introduction

The normalized difference vegetation index (NDVI) is defined as the ratio of the terms (NIR-Red) and (NIR+Red), where NIR is the spectral response in the near-infrared band (.73-1.1 μm), and Red is the spectral response in the red band (.55-.68 μm) (Tarpley et al., 1984). NDVI was shown to be sensitive to changes in vegetation conditions since it is directly influenced by the chlorophyll's absorption of the sun's radiation (Tucker et al., 1985). Because the chlorophyll status integrates the effects of numerous environmental factors, NDVI has been related to the following components of the water-balance equation for a wide range of spatial and temporal scales: soil moisture (Choudhury and Golus, 1988; Farrar et al., 1994; Nicholson et al., 1996), precipitation (Tucker et al., 1985; Choudhury and Tucker, 1987; Nicholson et al., 1990; Davenport and Nicholson, 1993; Schultz and Halpert, 1993; Di et al., 1994; Nicholson and Farrar, 1994; Grist et al., 1997), and evaporation (Running and Nemani, 1988; Kerr et al., 1989; Cihlar et al., 1991; Gao et al., 1992; Seevers and Ottmann, 1994; Nicholson et al., 1996). Gao et al. (1992) related 6 months of daily NDVI to the evaporative fraction (defined as the ratio of latent heat flux to the sum of latent and sensible heat fluxes) measured by fast response instruments at a single location during the FIFE experiment. Desjardins et al. (1992) related the greenness index (i.e. NIR/Red) of a 225 km^2 area to latent heat fluxes measured by an aircraft for selected days also during the FIFE experiment. Seevers and Ottmann (1994) used bi-weekly values of estimated evaporation and regressed them against the NDVI values of 20 different fields of irrigated crop for selected days. Kerr et al. (1989) and Cihlar et al. (1991) reported an observed time-lag between evaporation and NDVI.

In this study we relate the mean monthly values of NDVI to monthly total precipitation and monthly estimates of evaporation for a 130 km^2 study area with natural prairie vegetation over a 5 year period. A comparable long-term study of NDVI versus concurrent monthly evaporation has been presented by Nicholson et al. (1996) who concluded that with the growing aridity of the environment the NDVI versus evaporation relationship becomes significantly weaker. However, as it is concluded in this recent study, when a time-lag of one month between evaporation and NDVI is taken into consideration, the relationship remains strong even in a water limited environment.

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2. Methodology

NDVI was calculated for thirty scenes of Landsat-MSS imagery for the growing seasons between 1979 and 1983 for the Crescent Lake National Wildlife Refuge in the south-western part of the Sand Hills region of Nebraska. The region consists of undisturbed natural mixed-grass prairie over sandy soils (Bleed and Flowerday, 1990). See Rundquist et al. (1987) and Bleed and Flowerday (1990) for a detailed description of the area. Table 1 presents the calculated NDVI values for the study period obtained by averaging the approximately 500 pixel values covering the 130 km^2 study area. For a detailed description on how these values were derived see Di et al. (1994). The NDVI values for each day of the growing season (starting at Julian day 100 and ending at Julian day 285) were interpolated using a spline algorithm. The derived daily NDVI values were then averaged for each month of the year (see Table 2). Monthly evaporation estimates were obtained by applying the Thornthwaite and Mather (1957) algorithm, as modified by Vorosmarty et al. (1989), based on monthly precipitation and potential evaporation estimated by the Jensen-Haise (1963) method. See Table 3 for the monthly precipitation and estimated evaporation values.

3. Results and conclusions

Figures 1a and 1b display the mean monthly NDVI values versus the monthly total precipitation and monthly evaporation with no time-lag between the monthly values compared. The variation in the NDVI values is only poorly to moderately explained by either variable (r^2=.13 and .30 corresponding to r=.39 and .56, respectively). This latter result is in agreement with Nicholson et al. (1996).

Table 1. NDVI ×100 values for the study area (after Di et al., 1994)

1979		1980		1981		1982		1983	
Julian day	NDVI	Julian day	NDVI	Julian day	NDVI	Julian day	NDVI	Julian day	NDVI
176	21.50	154	16.76	102	0.05	107	2.56	172	19.60
213	23.34	163	14.88	121	7.96	179	18.30	188	19.31
249	14.59	181	19.79	139	12.25	197	23.99	220	12.78
257	13.03	198	12.80	157	16.47	287	3.70	252	7.67
268	6.16	217	10.84	175	16.62			260	6.09
275	5.32	235	6.48	192	13.82				
		262	9.45	211	19.84				
		271	2.09						

Table 2. Calculated monthly mean NDVI ×100 values for the study area

	1979	1980	1981	1982	1983
April	3.99	5.21	3.30	3.14	4.16
May	11.94	13.76	11.18	8.91	12.29
June	19.22	16.79	16.54	15.15	18.53
July	23.75	14.90	15.73	22.32	17.87
August	20.65	8.99	19.41	19.08	12.12
September	12.52	7.89	13.55	11.98	7.09
October	3.95	.72	4.35	4.35	2.23

The relationship significantly improves when the NDVI values are plotted against precipitation and evaporation with a time-lag of one month (Figures 1c and 1d) with explained variation in the NDVI values of .54 and .63 (corresponding to r = .75 and .80), respectively. This is in accordance with the findings of Di et al. (1994) who first pointed out a time-lag between precipitation and NDVI response for the study area using cumulative precipitation with variable accumulation length prior to the NDVI value.

To check that the NDVI versus lagged evaporation relationship is not only an artifact of obvious seasonal effects (i.e. both evaporation and the greening up of vegetation follow a general annual course), one can minimize the seasonal dependence between the two variables by defining the following de-seasoned variables: $E'(m)=E(m)-\langle E(m)\rangle$, and $NDVI'(m)=NDVI(m)-\langle NDVI(m)\rangle$, where E is evaporation, m is month of the year (i.e. April through October), and the brackets designate the 5-year averaged value of the relevant monthly variable. Figure 2 displays a moderate linear relationship between de-seasoned NDVI and one month-shifted de-seasoned evaporation with a correlation coefficient of .53. The same analysis between NDVI and one month-shifted precipitation results in a correlation coefficient value of .41.

Since the evaporation values were estimated using the Thornthwaite and Mather (1957) model, we might expect a stronger relationship between NDVI and evaporation if

Table 3. Monthly total precipitation, P, (mm) and estimated evaporation, E, (mm) for the study area

	1979		1980		1981		1982		1983	
	P	E	P	E	P	E	P	E	P	E
April	39	55	19	42	28	29	18	24	34	37
May	58	82	102	106	118	107	56	63	121	95
June	97	118	58	100	29	38	66	72	89	114
July	127	140	12	44	91	93	70	77	18	76
August	26	50	41	43	30	32	25	28	12	20
September	41	46	7	8	6	7	38	38	11	12
October	47	47	14	14	67	44	34	34	13	13

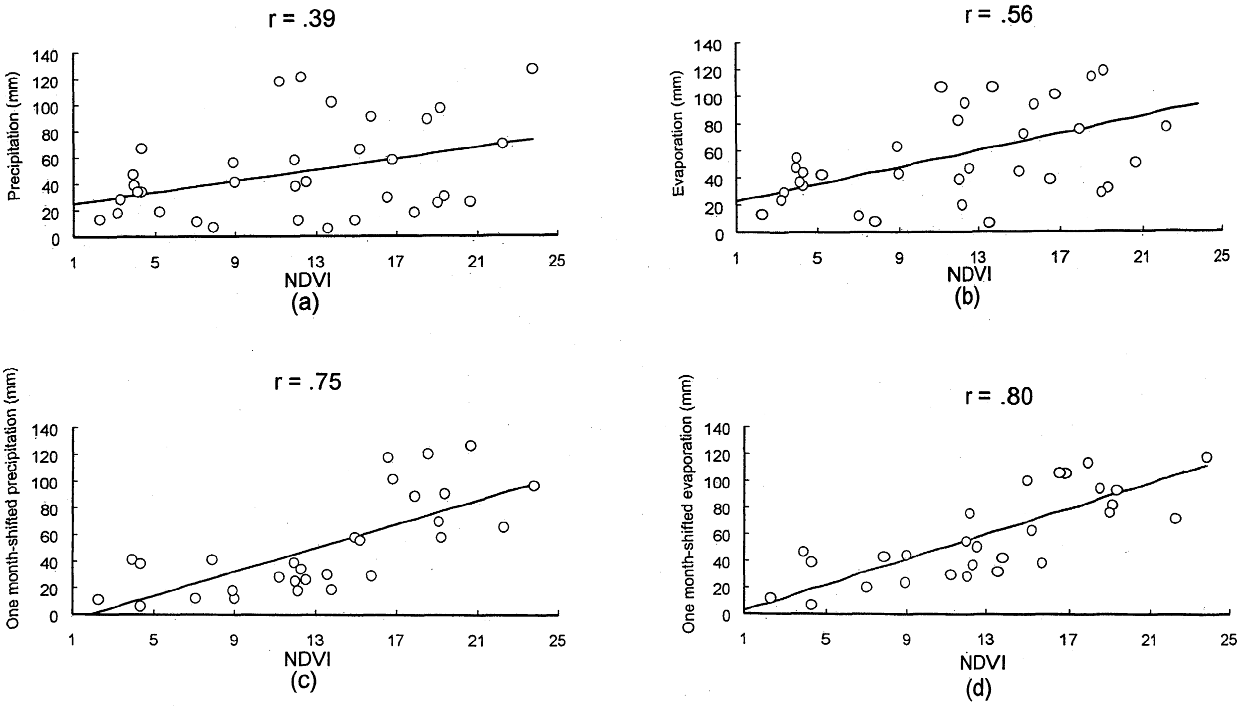

Figure 1. (a) mean monthly NDVI (×100) versus monthly total precipitation; (b) mean monthly NDVI (× 100) versus estimated monthly evaporation; (c) mean monthly NDVI (× 100) versus monthly total precipitation previous to the month with NDVI; (d) mean monthly NDVI (× 100) versus estimated monthly evaporation previous to the month with NDVI.

somehow directly measured values of evaporation were available. Seevers and Ottmann (1994) obtained such a strong relationship between NDVI and estimated evaporation for irrigated crops with unrestricted water availability over a short time period (thus excluding any seasonality effects), where they had accurate measurements of the water volumes irrigated over the fields having more uniform vegetation-soil-topographic conditions than normally found in natural systems. Our study indicates that the NDVI versus evaporation relationship can be strong also for a water-restricted, natural environment with an apparent time-lag between the two variables.

The application of the NDVI index may be a useful tool for estimating evaporation at regional scales for long-term hydrologic budgeting. Also, NDVI may provide further help with model validation by supplying reference values for the modeler against which the model estimated evaporation values can be regressed.

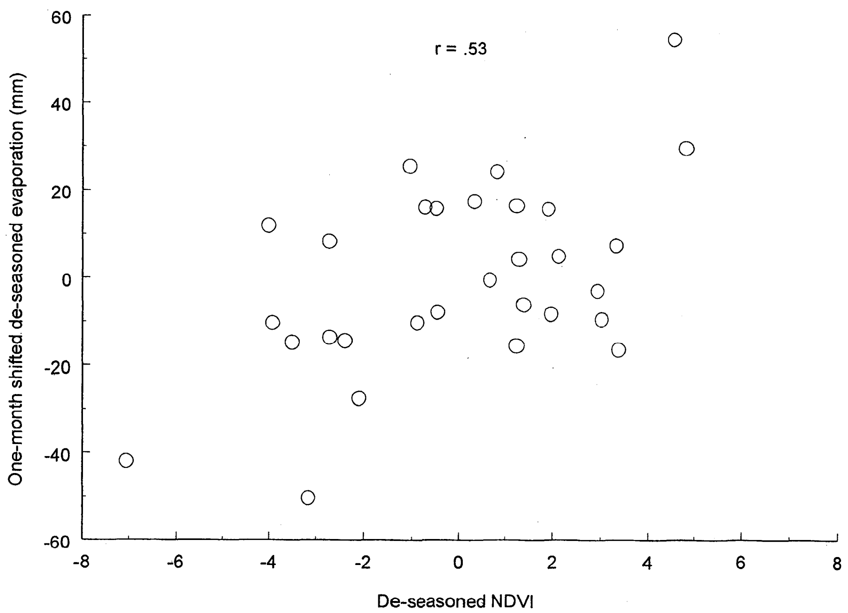

Figure 2. De-seasoned mean monthly NDVI (×100) versus de-seasoned, one month-shifted estimated monthly evaporation.

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