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STUDY OF SENSITIVITY OF EVAPOTRANSPIRATION TO EXPECTED CLIMATIC CHANGES

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PREFACE

The global warming due to enhanced greenhouse effect is expected to cause major changes in various climate variables as absolute humidity and precipitation, annual rainfall regime, and net terrestrial and global solar radiations etc. This, in turn, would also have profound impact on various hydrological parameters, viz. runoff, evapotranspiration, soil moisture, ground water. Evapotranspiration, a major component of water cycle would also be affected but in a more complicated manner than generally expected.

The National Institute of Hydrology established the Atmospheric Land Surface Modelling Division with the major objective of carrying out studies and research on coupled atmosphere land surface processes. In the present report an attempt has been made to study the sensitivity of evapotranspiration to expected climatic change.

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ABSTRACT

Global warming due to increasing concentrations of greenhouse gases is likely to have profound impact on meteorological parameters. The changes in meteorological parameters would lead to alterations in hydrological cycle. Evapotranspiration, a major component of water cycle would also be affected but in a more complicated manner than generally expected.

An attempt has been made in the present study to see the sensitivity of evapotranspiration to expected climatic changes, using the meteorological data for Roorkee. Preliminary studies illustrate that the future changes in solar radiation and humidity need to be considered together with the temperature in determining the future changes in evapotranspiration.

1.0 INTRODUCTION

The rising concentrations of carbon dioxide and other greenhouse gases as methane, nitrous oxide, chlorofluorocarbons and the rising temperature of the globe in the recent years has been a matter of major concern to the scientific workers as well as the policy makers. Though, there are still uncertainties to relate the two, the magnitude of warming has been compatible with that expected to have resulted from the greenhouse effect (WMO, 1987). Climate Modellers have also found that the doubling of carbon dioxide in the atmosphere would result in temperature increase of between 1.5-4.5°C (Hansen et al., 1984; Washington and Meehl, 1984).

Greenhouse gases produced by human activities allow the solar energy to pass through while absorb and re-radiate to the earth the long wave terrestrial radiation, thus maintaining the temperature of the earth and keeping it warm. However, with steady increase in concentration of these gases, the temperature is expected to rise considerably and global warming to occur.

The global warming is expected to cause major changes in various meteorological parameters as absolute humidity and precipitation, annual rainfall regime and net terrestrial and global solar radiation etc. Table 1.1 lists some of the changes in different climate parameters under the hypothesis of a doubling of the atmospheric carbon dioxide concentration as studied by different workers.

Table 1.1 - Specific changes in climate under the hypothesis of a doubling of the atmospheric CO_2 concentration (Bultot et al.,1988)

	Decrease	Increase	Sources
Net terrestrial radiation	3.1 Wm^{-2}		Chou et.al., 1982
Global solar radiation	2.5 Wm^{-2}		Chou et.al., 1982
Flux of sensible heat	8%		Manabe and Wetherald, 1975
Flux of latent heat of evaporation.		7%	Manabe and Wetherald, 1975
Cloudiness		1.5%	Washington and Meehl,1984
Air temperature		See below	Manabe and Stouffer, 1980
Water vapour pressure		Linked to air temperature, the relative humidities being assumed invariant.	Manabe and Wetherald, 1975 Washington and Meehl, 1984
Precipitation, P	See blow	see below	Manabe et.al. 1981 Washington and Meehl,1984

Monthly increments

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Air temperature (deg K)	+3.1	+3.4	+3.4	+3.1	+2.8	+2.7	+2.5	+2.3	+2.3	+2.7	+2.8	3.2	2.86
Precipitation (mm/month)	+9.3	+10.5	+9.9	+10.2	-1.2	-2.7	-1.6	-2.2	0.0	+5.3	+8.1	+8.7	54.3

The contribution to greenhouse effect from India is only about 4% (Hai et al, 1990). Hingane et al. (1985), while analyzing the mean annual temperature for India during the period 1901-1980 have found a trend of about 0.4°C warming during recent 8 decades. The precipitation pattern, however, has not shown any significant periodicity or long term increasing or decreasing trends (Mooley et al, 1981).

1.1 Climate Change and Water Resources

The global warming due to increasing concentrations of greenhouse gases has also attracted the policy makers Many important economic and social decisions are being made today on long term projects - major water resource management activities such as irrigation and hydropower, drought relief, agricultural land use, structural designs and coastal engineering projects, and energy planning all based on the assumption that past climatic data, without modification, are a reliable guide to the future. However, this is no longer a good assumption since the global warming could modify the future climate conditions.

As a consequence of changes in meteorological parameters due to enhanced greenhouse effect significant impact on hydrological parameters viz. run off, evapotranspiration, soil moisture, ground water etc., is expected (Nemec and Schaake, 1982; Cohen, 1986; Gleick, 1986, 1987; Bultot et al., 1988; Waggoner, 1990 and others).

Table 1.2 shows the results obtained by different

Table 1.2 - Effects of climate changes on runoff (Gleick, 1986)

Author*	Region	Scale (km^2)	Climatic change	%Change in runoff (annual average)
Stockton and Boggess (1979)	Average for seven western U.S.regions	10^5	+2C;-10% precip.	-40 to -76
Nemec and Schaake(1982)	Arid basin	10^4	+1C +10% precip.	+50
			+1C;-10% precip.	-50
	Humid basin	10^3	+1C;+10% precip.	+25
			+1C; -10% precip.	-25
Revelle and Waggoner (1983)	Colorado river basin	10^5	+2C;+10% precip.	-18
			+2C;-10% precip.	-40 ± 7.4
Idso and Brazel(1984)	12 drainage basins of Arizona	__	+2C;-10% precip.	+40 to +60
Flaschka (1984)	Great Basin	10^5	+2C;-10% precip.	-17 to -38
U.S. EPA (1984)	Central U.S.	10^5	Doubled atmospheric carbon dioxide	-26
	NW U.S.	10^5		+20 to +60

* Each assessment uses different method, hence the direct comparison of results is not possible.

Table 1.3 - Case studies of impact of climate change on hydrology for critical or sensitive environments

Critical or sensitive environment	Region	Future changes	Remarks
Large water bodies	Great Lakes basin(US/ Canada)	decrease in precipitation	lake levels expected to be lower and hence navigation would be affected.
		decrease in runoff	
	The Caspian Sea	The dynamics of the sea would change in 15 - 20 years	
Critical agricultural regions	South Platte river basin	less certain consequences of global warming, increases or very large decreases in precipitation.	
	Murray-Darling basin	precipitation increases in spring autumn and summer.	slight reduction in demand for irrigation water
Intensivly urbanised areas	Delaware river basin, USA	Probability of occurrence of drought	
Regions of snowmelt generated runoff	The Sacramento-San Joaquin River basin (USA)	Total annual runoff to remain near current levels or to increase	
		Higher runoff in winter months and considerably less in the spring snowmelt - runoff season.	

workers on changes in runoff due to changes in temperature and precipitation. Linz et al. (1990) have reviewed the studies of impact of climate change on hydrology for critical or sensitive environments, which is given in tabular form in Table 1.3.

Warming speeds up drying and the capacity of air for evaporated water rises about 6% per °C. Thus, a warmer earth would have faster evaporation. But, as the atmospheric capacity to store water is less, the precipitation on earth would be more in a warmer world. The floods and droughts would be more severe than they are now in some places, while these would be less severe in others (Waggoner, 1990). However, the regional distribution of precipitation is still not certain.

1.2 Need of Study of Sensitivity of Evapotranspiration to Expected Climate Changes

Evapotranspiration (ET) is the major component of the water budget after precipitation. The water resources of runoff are the net of precipitation minus evaporation. Thus, future water resources can not be known until changes in future evaporation are also known together with the changes in precipitation.

There are three necessary prerequisites for the evapotranspiration to occur. These are a source of water, energy to drive the phase change and a sink for water or the moisture deficit in the air above ground. The question of how climate change may alter ET is rather complicated. This is because the greenhouse warming is accompanied by changes in cloudiness, windiness, radiation and humidity which affect the above three prerequisites. The climatic changes may alter the plant growth, plant cover of the ground and also the deeper or shallower rooting, which in turn also affects ET. Thus, for further evapotranspiration calculations in a warmer world, one needs to consider the simultaneous changes in the above mentioned climate parameters together with the expected rise in temperature.

Different workers have carried out evapotranspiration studies as a consequence of climatic changes. In some of the works it has been considered as a function of temperature (Revelle and Waggoner, 1983; Gleick, 1987), while Idso and Brazel (1984) have taken ET as a function of the carbon dioxide effects on plant resistance. Martin et al. (1989) studied the sensitivity of evapotranspiration in a wheat field, a forest and a grassland to change in climate and direct effects of carbon dioxide. They used the Penman Monteith equation (Monteith, 1965) to estimate evapotranspiration, which has been successfully used to evaluate the ET from crops and forests by Rosenberg et al. (1989). The P-M approach incorporates micrometeorological and physiological parameters and is best used at local level and with the time scales of the order of a day. It has been found suitable for simulation studies as well (Stewart, 1984).

2.0 METHODOLOGY OF THE PRESENT PROBLEM

Following the approach of Martin et al. (1989), an attempt to study the sensitivity of evapotranspiration to expected climatic change using the data for Roorkee has been made.

The Penman formula for evapotranspiration has been used for sensitivity study. The advantage of Penman's equation is that it is based on sound theoretical reasoning and is obtained by a combination of the energy balance and mass transfer approach. It has been widely used for potential evapotranspiration studies in India (Rao et al, 1971 and others). Moreover, it also has the advantage that the computations can be made using meteorological parameters which are generally available and thus, the sensitivity of evapotranspiration to expected changes in climate parameters can be easily studied. According to Penman, potential evapotranspiration is the amount of water transpired in unit time by a short green crop. completely shading the ground of uniform height and never short of water.

A standard formulation of Penman's equation, incorporating some of the modifications suggested by other investigations is

$$PET = \frac{A\ Hn + Ea\ \gamma}{A + \gamma} \qquad (2.1)$$

where PET is the daily potential evapotranspiration in mm per day, A and γ are the derivatives of saturation vapour pressure with respect to temperature and the psychrometric constant (= 0.49) respectively both in mm of mercury per °C. Hn is net radiation in mm of evaporable water per day and Ea is the parameter including wind velocity and saturation deficit.

The net radiation and the parameter Ea are estimated by the following equations.

$$Hn = Ha\ (1-r)\ (a + b\ \ n/N) - \sigma\ Ta^{4}\ \ (0.56 - 0.092\ \ \sqrt{ea}\ )\ x \quad (0.10 + 0.90\ n/N) \qquad (2.2)$$

$$Ea = 0.35\ (\ 1 + u2\ /100).\ (\ ew - ea) \qquad (2.3)$$

where,

Hn is the incident radiation outside the atmosphere on a horizontal surface expressed in mm of evaporable water per day, r is the albedo, a the constant depending upon the latitude ϕ, and is given by 0.29 cos ϕ, b the constant with an average value of 0.52, n and N the actual and possible hours of bright sunshine, σ the Stefan Boltzman constant equal to 2.01 x 10^{-9} mm/day, Ta the mean air temperature in K, ea the actual mean vapour pressure of air in mm of Hg , u2 the mean wind speed at 2m above ground in km/day, ew the saturation vapour pressure at mean air temperature in mm of Hg.

The value of saturation vapour pressure as is obtained using the equation (Martin et al, 1989)

$$\log\ (es(Ta)\ 10^{-2}) = 23.95717 - 2954.98/Ta - 5.07026\ \log\ (Ta) \qquad (2.4)$$

where Ta is the temperature in K as defined above, A is given by equation (Martin et al., 1989)

$$A(Ta) = 1/Ta\ (\ 6804.10/Ta\ \ - 5.07026)\ es$$

3.0 DATA AVAILABILITY

Roorkee lies in the moist sub humid region at a latitude of 29°51'. Parameters were calculated for Roorkee for the days with maximum and minimum Pan evaporation values in each month of 1986 (for which all the meteorological data were available) as an initial study. The meteorological parameters viz., Ta, u2, ea and n are the observed values, whereas the values of Ha, a and N which are the function of latitude of the station (ϕ = 29° 51' for Roorkee) were obtained from the standard tables (Subramanya, 1984). The value of the r was taken to be 0.25, which is for close ground green crops.

4.0 EXPECTED CHANGES IN CLIMATE

To evaluate the hydrological effects of expected climatic changes, one needs the predictions/ forecasts of changes in climatological parameters. As the scenario of regional climatic changes and trends over different regions of India are still not available, the sensitivity of hydrological parameters to expected changes in climate has to be studied by considering the range of possible changes in meteorological parameters based on literature review. We have considered the following changes in these parameters based on the literature review and as used by other workers (Schneider et al 1989; Martin et al, 1989).

Temperature changes : +10K to -10K
Changes in solar radiation : +20 to -20%
Changes in vapour pressure : +20 to -20%

Changes in wind speed : +20 to -20%

Although changes in precipitation are not considered directly by the Penman's equation, their effects are included via their effect on atmospheric humidity.

Firstly, the calculations for potential evapotranspiration were performed using actual meteorological parameters (i.e. temperature, solar radiation, actual vapor pressure and wind speed). Then, each factor was changed one at a time so that the sensitivity of PET to each individual climate parameter could be tested. Next, the sensitivity of PET to multiple climate parameter changes was tested, taking two and three parameters simultaneously.

5.0 RESULTS AND DISCUSSION

Corresponding to representative winter, summer, monsoon and post monsoon months results have been presented for high flux days (Jan 28, April 16, July 13 and Oct 18) and low flux days(Jan 20, April 5, July 27 and October 31) in January, April, July and October. Figure 5.1 shows the sensitivity of potential evapotranspiration estimates by Penman's equation to temperature changes in the range from -10 to 10K for days of high flux (Jan.28 and Oct. 18) and low flux (Jan 20 and Oct 31) for January and October months of 1986. With increase in temperature, PET also increases. If all other factors remain the same, warming should cause drier air and hence more rapid ET. The sensitivity of evapotranspiration to other meteorological parameters are shown in the Figs. 5.2 (a,b,c,d). PET increases with increase

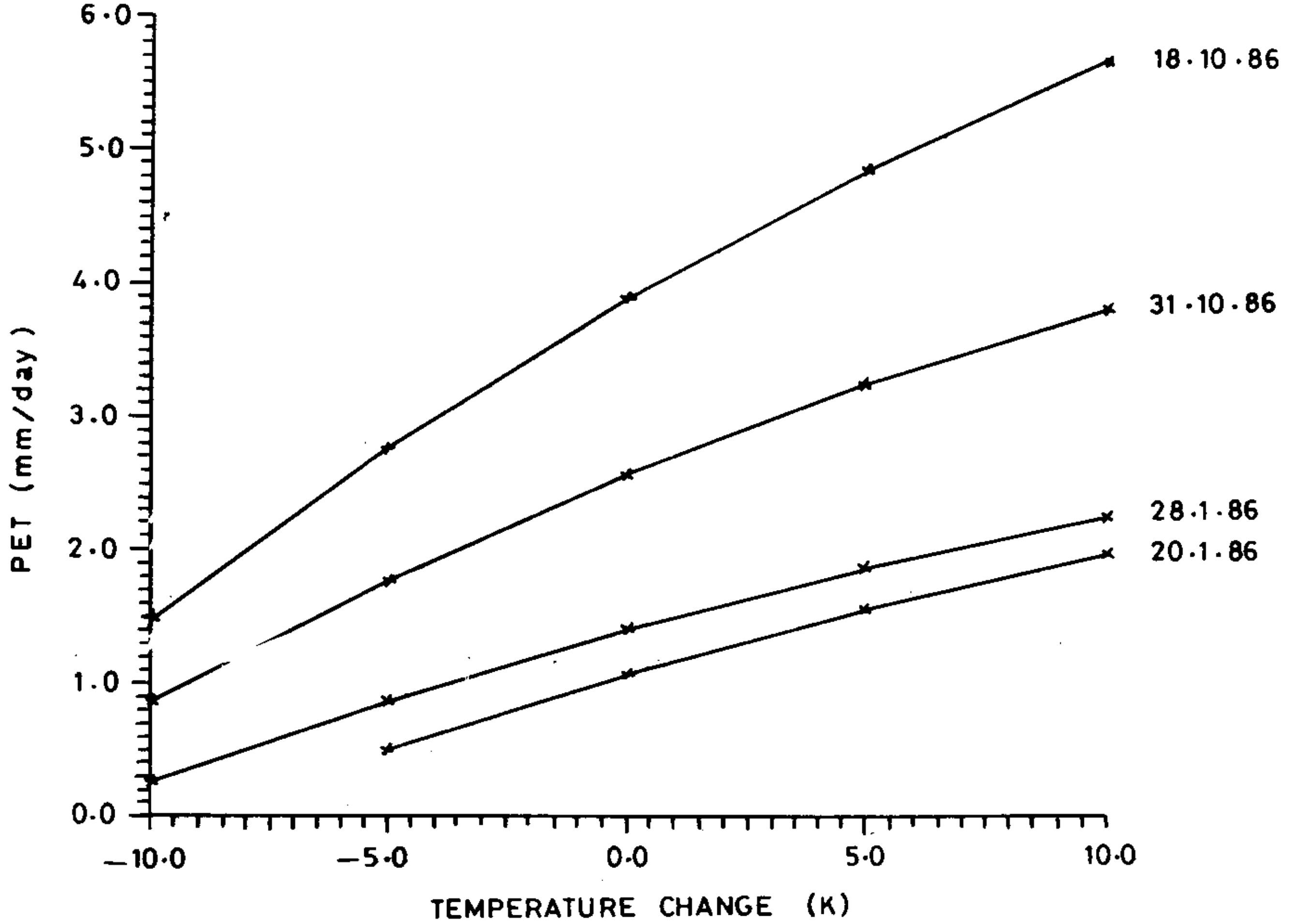

FIG.5·1 SENSITIVITY OF PET ESTIMATES TO TEMPERATURE CHANGES

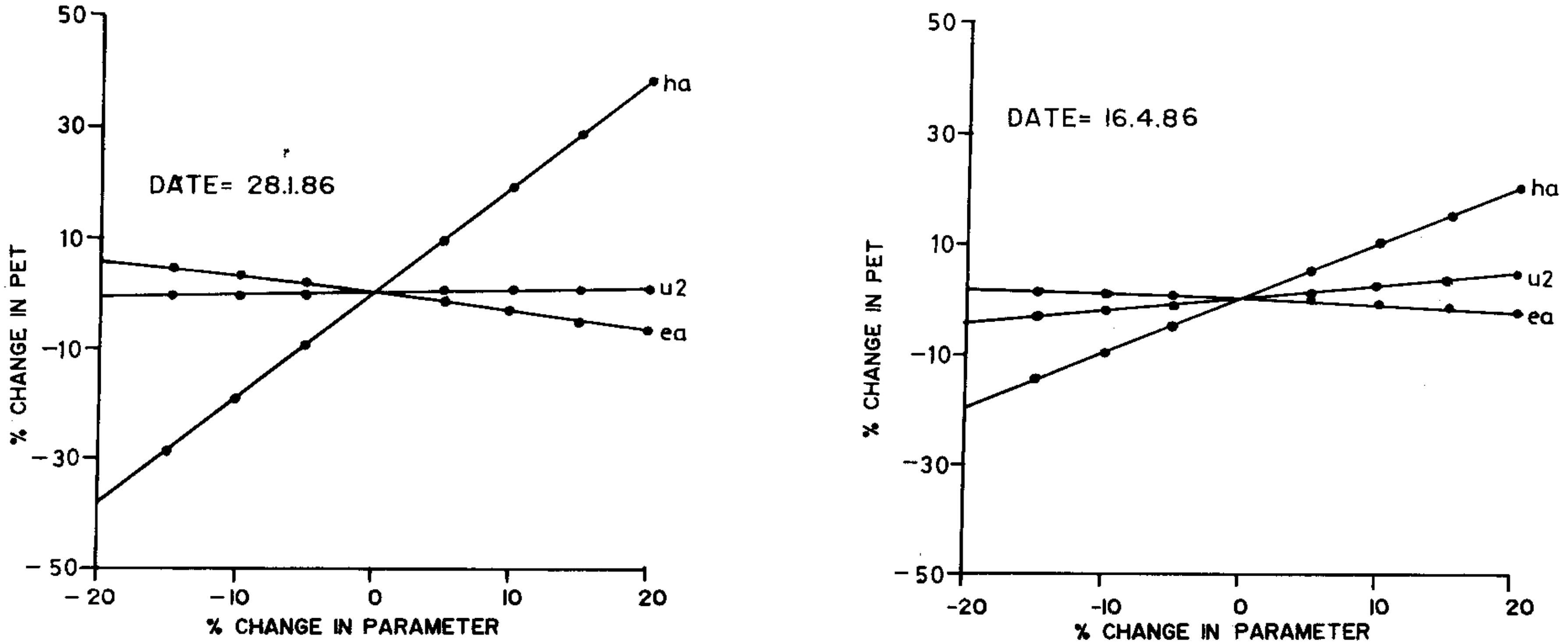

FIG.5·2(a)-SENSITIVITY OF PET ESTIMATES TO SOLAR RADIATION (ha), VAPOUR PRESSURE (ea) AND WIND SPEED (u2) FOR HIGH FLUX DAYS IN JANUARY AND APRIL

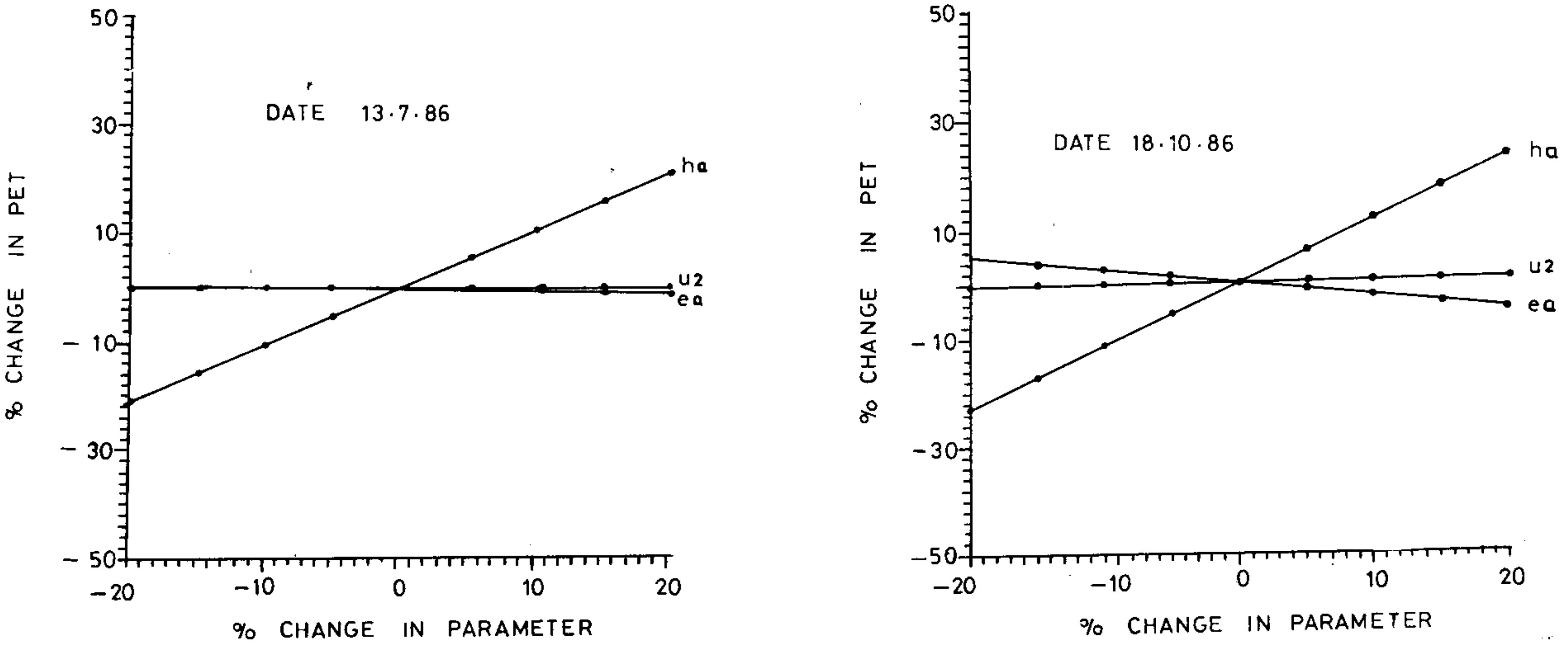

FIG. 5.2 (b)-SENSITIVITY OF PET ESTIMATES TO SOLAR RADIATION (ha), VAPOUR PRESSURE (ea) AND WIND SPEED (u2) FOR HIGH FLUX DAYS IN JULY AND OCTOBER

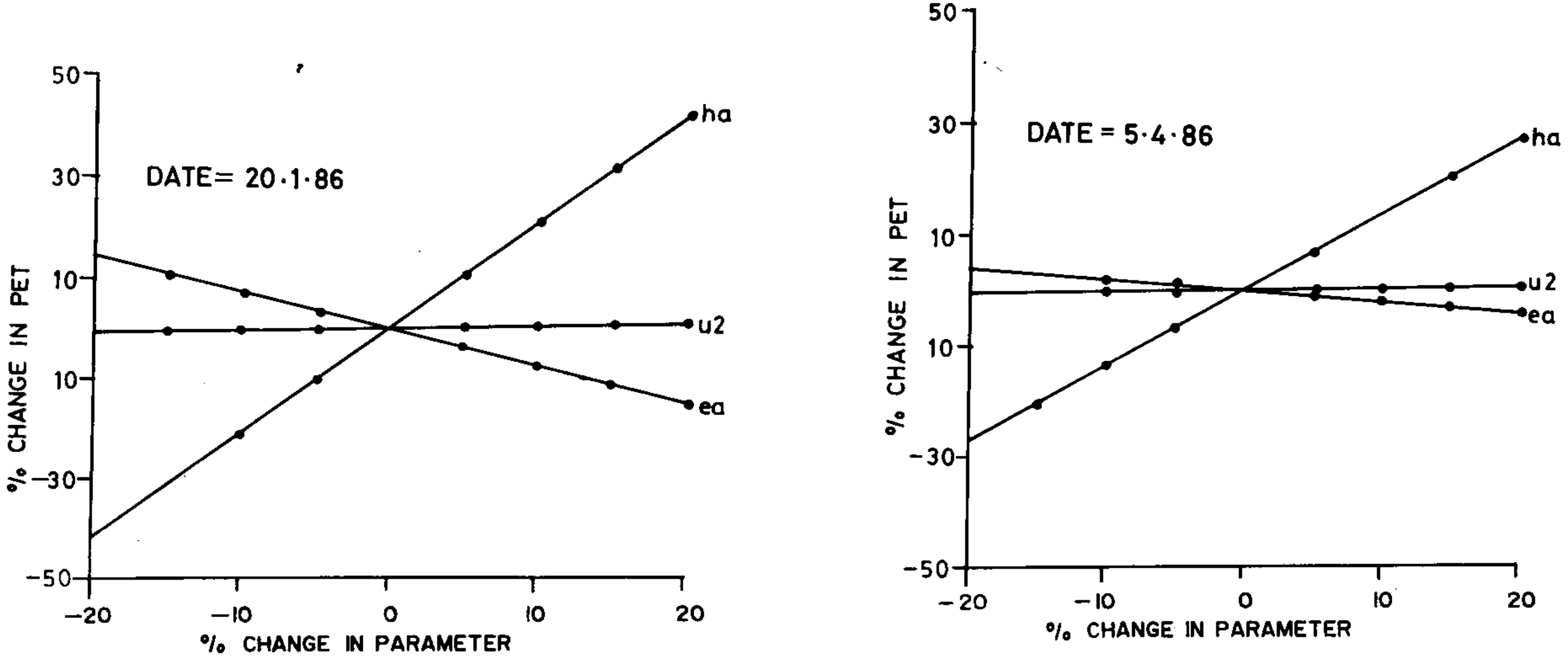

FIG.5.2 (c)–SENSITIVITY OF PET ESTIMATES TO SOLAR RADIATION (ha), VAPOUR PRESSURE (ea) AND WIND SPEED (u2) FOR LOW FLUX DAYS IN JANUARY AND APRIL

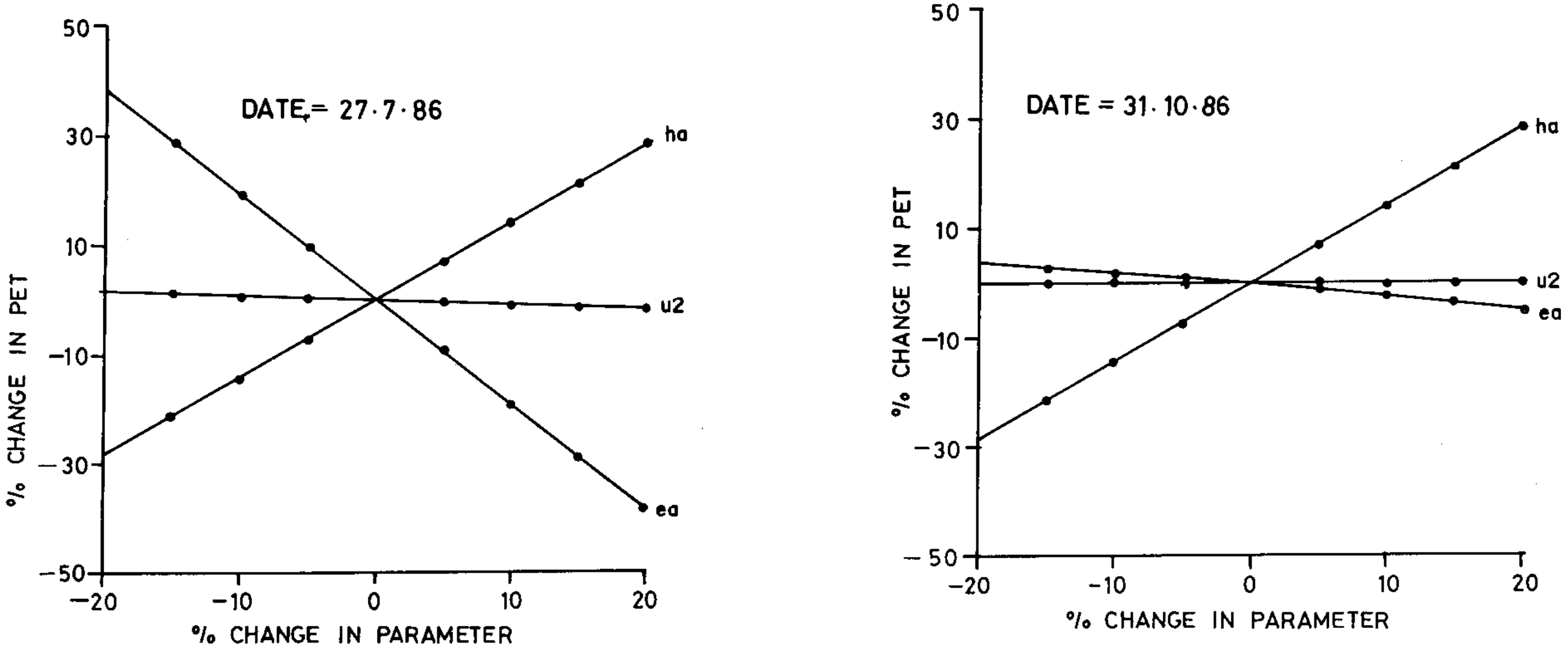

FIG. 5·2(d)-SENSITIVITY OF PET ESTIMATES TO SOLAR RADIATION (ha), VAPOUR PRESSURE (ea) AND WIND SPEED (u2) FOR LOW FLUX DAYS IN JULY AND OCTOBER

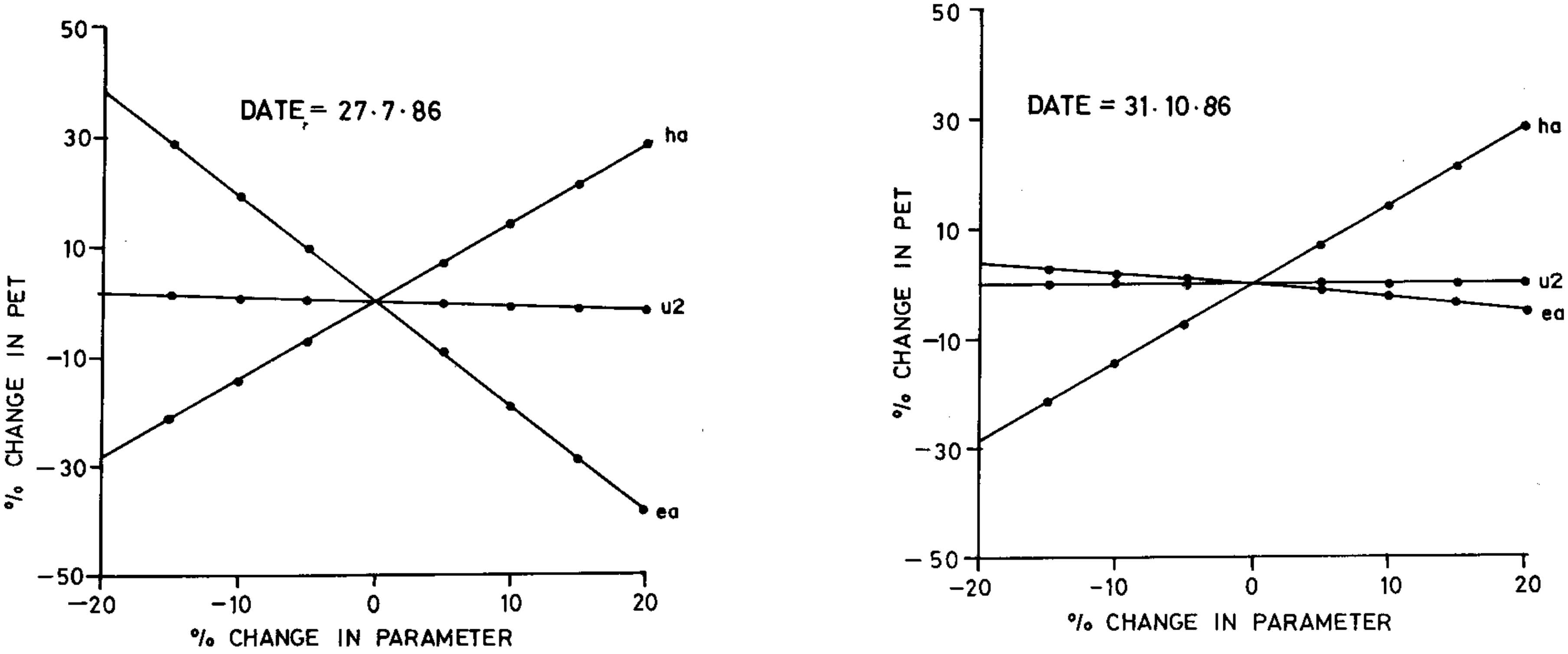

FIG. 5·2(d)–SENSITIVITY OF PET ESTIMATES TO SOLAR RADIATION (ha), VAPOUR PRESSURE (ea) AND WIND SPEED (u2) FOR LOW FLUX DAYS IN JULY AND OCTOBER

Table 5.1 - Sensitivity of potential evapotranspiration to expected climatic changes

Changes in climatic parameters	Month	Temp. change in K	%change in Ha	%change in ea	High Flux day		Low Flux day	
					PET	%change	PET	%change
1. No climatic change	Jan.	0	0	0	1.41	-	1.07	-
2. Temperature increase only		3	0	0	1.7	21	1.38	29
3. Single factor changes		0	10	0	1.68	19	1.3	21
		0	-10	0	1.14	-19	0.85	-21
		0	0	10	1.36	- 3	0.99	- 7
		0	0	-10	1.45	3	1.15	7
4. Temperature and net radiation change		3	10	0	1.98	40	1.62	51
		3	-10	0	1.42	1	1.14	6
5. Temperature, net radiation and vapour pressure change		3	10	10	1.96	39	1.56	46
		3	10	-10	2.00	42	1.67	56
		3	-10	10	1.39	- 2	1.08	1
		3	-10	-10	1.43	2	1.2	12

Changes in climatic parameters	Month	Temp. change in K	%change in Ha	%change in ea	High Flux day		Low Flux day	
					PET	%change	PET	%change
1. No climatic change	April	0	0	0	5.84	-	3.94	-
2. Temperature increase only		3	0	0	6.40	10	4.5	14
3. Single factor changes		0	10	0	6.42	10	4.47	13
		0	-10	0	5.26	-10	3.41	-13
		0	0	10	5.77	- 1	3.86	- 2
		0	0	-10	5.89	1	4.02	2
4. Temperature, and net radiation change		3	10	0	7	20	5.05	28
		3	-10	0	5.8	- 1	3.94	0
5. Temperature, net radiation and vapour pressure change		3	10	10	6.97	19	5.01	27
		3	10	-10	7.02	20	5.09	29
		3	-10	10	5.78	- 1	3.9	- 1
		3	-10	-10	5.82	-0.3	3.97	1

Changes in climatic parameters	Month	Temp. change in K	%change in Ha	%change in ea	High Flux day		Low Flux day	
					PET	%change	PET	%change
1.No climatic change	July	0	0	0	6.26	-	1.64	-
2.Temperature increase only		3	0	0	6.94	11	2.27	38
3.Single factor changes		0	10	0	6.93	11	1.87	14
		0	-10	0	5.6	-11	1.41	-14
		0	0	10	6.24	- 0.3	1.32	-19
		0	0	-10	6.27	0.2	1.95	19
4.Temperature and net radiation change		3	10	0	7.62	22	2.51	53
		3	-10	0	6.26	0	2.03	24
5.Temperature net radiation and vapour pressure change		3	10	10	7.66	22	2.23	36
		3	10	-10	7.57	21	2.78	69
		3	-10	10	6.29	0.5	1.76	7
		3	-10	-10	6.21	- 1	2.30	40

Changes in climatic parameters	Month	Temp. change in K	%change in Ha	%change in ea	High Flux day		Low Flux day	
					PET	%change	PET	%change
1.No climatic change	Oct.	0	0	0	3.19	-	2.57	-
2.Temperature increase only		0	0	0	3.76	18	2.99	16
3.Single factor changes		0	10	0	3.57	12	2.93	14
		0	-10	0	2.82	-12	2.20	-14
		0	0	10	3.09	- 3	2.51	- 2
		0	0	-10	3.29	3	2.62	2
4.Temperature and net radiation change		3	10	0	4.15	30	3.37	31
		3	-10	0	3.37	6	2.61	2
5.Temperature, net radiation and vapour pressure change		3	10	10	4.09	28	3.34	30
		3	10	-10	4.2	32	3.38	32
		3	-10	10	3.32	4	2.59	1
		3	-10	-10	3.42	7	2.63	2

in solar radiation and decreases with increasing vapour pressure. The effect of wind speed is negligible on PET and hence it was not taken into account for studying two anc multiple factor changes.

Table 5.1 lists the range of climatic changes and sensitivity of PET to these changes. A 3° C warming increases the PET in the range 10-38% when changes in other factors are not considered. The effects of a 3° C warming and a ± 10% changes in net radiation are additive in all the eight cases. Also a 3°C temperature rise and the change in net radiation and vapour pressure by ± 10% diminish for increase PET additively. With a 'drying' climate i.e. with a 10% increase in solar radiation and 10% decrease in vapour pressure, the increase in PET are maximum. Both the changes in this scenario emphasize the condition where changes in all climate variable act to increase the evaporative demand. In another scenario, the impact of increased temperature on PET is partially offset by changes in solar radiation and vapour pressure. This case (10% decrease in solar radiation and 10% increase in vapour pressure) corresponds to cloudier and more humid atmosphere . The change in PET in this case is considerably low as compared to the previous case.

The above mentioned results clearly depend upon the model employed. Hence we have chosen a model whose data demands are met with actual field observation.

6.0 CONCLUSION AND REMARKS

The above analyses illustrate the danger of assuming that evapotranspiration would increase with global warming. It would however, also depend upon the changes in other climatic parameters as well. Therefore, the formulation of evapotranspiration need to be done not only in terms of temperature, but also in terms of other meteorological parameters as well.

It is to be noted that climatic changes may cause changes in soil moisture and thus the amount of water available to the plant roots and the amount which could be transpired. Further more, one of the major greenhouse gases, carbon dioxide affects the plants physiological conditions specially the plan growth and the resistance to the passage of water to the atmosphere through plant. Thus, the expected changes in plant physiological parameters need to be considered together with the expected climatic changes. We propose to consider these parameters also in future studies for sites in different agroclimatic zones of the country.

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