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THE ARIDITY COEFFICIENT AND ITS APPLICATION TO CALIFORNIA

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"In climatology, as in other sciences, we should try to find an exact physical meaning of each of our surrounding natural phenomena. This, being so for all climatic elements, must likewise be true for the aridity."

La Jolla, California. November 1, 1939

"Although it may seem as though the climate is changing, there is no evidence that the trend will continue in the same direction."

Dr. G. F. McEwen in Science News Letter
for February 17, 1940

I N T R O D U C T I O N

I am very much obliged to Dr. Sverdrup for the opportunity of spending some months at the Scripps Institution in order to prepare some climatic comparisons between California and sunny regions of Europe and Africa. My sincere thanks are also due to Dr. McEwen for his kind invitation to present today in this seminar before the Scientific Staff of the Scripps some preliminary results of my climatic campaign in this Country.

The Scripps Institution of the University of California is certainly well known the world over, but I was very agreeably surprised to find here such great scientific activity together with a perfect organization and American efficiency. I appreciate very much the opportunity and honor of giving a climatic talk before you all in this not only scientific but highly sympathetic environment.

After having spent the last fifteen years in various sunny regions throughout the world for my solar radiation and climatic studies, I feel the necessity of comparing my results obtained on different European Rivieras and in some remote oasis of the Sahara Desert, with corresponding sunny regions in America. Having already visited this country some years ago, I have always been in touch with the specialists of U.S. Weather Bureau in Washington and of Blue Hill Observatory of Harvard University in order to organize some climatic comparisons between sunshine conditions of the Old and New Worlds. A good chance came to me when a big Assembly of the International Union of Geodesy and Geophysics was held in Washington last September. I was sent as delegate to the capital of U.S.A. by the Polish Academy of Sciences in order to participate in the International Meeting and, afterwards, to spend some months in California collecting data and becoming familiar with its climates.

But the war came and forced me to extend my sojourn. While here I try to emulate the great scientific activity of you all and, in order to give you a real evidence of this fact, I am going to present to you some preliminary results of my climatic studies made at the Scripps Institution since the end of last November.

Sunshine and Aridity - Dominant Features of California Climate

Among the few privileged areas with good sunshine and weather, belonging to the so-called Mediterranean type of climate, nobody could deny that California represents one of the very best. To pretend it to be the absolutely best climate of the whole world, as we find in some descriptions for tourist use, would probably find little echo by the scientists. The climatologists would present many scientific arguments that the European and North African Rivieras, the southwest corner of Australia and around Cape Town, the restricted areas of South America and Asia, and several places conveniently located in some tropical mountains, although belonging to the same Mediterranean climatic type, may have some peculiar advantages and disadvantages.

But probably none of the climatologists will deny that California represents a unique field, very good, if not absolutely the best, for climatic studies. Such rapid passage from coastal plains of California, with sunshine and mild temperature, to the other side of the surrounding mountains with a desert type of weather and such a variety of local climates upon the hills, in dry areas and beyond the mountains could be only exceptionally found in other regions of the world.

For the studies of California climates, two problems are predominant, the sunny character of weather and the aridity problem as a function of precipitation and temperature. All our activity, all human and animal life, all character of soils and vegetation, depend above all on sunshine and aridity conditions.

E X A M P L E

for computing the aridity coefficient.

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The aridity coefficient is obtained from the ordinary rainfall temperature records by the simple multiplication of three factors:

(Latitude Factor) x (Temperature Range) x (Precipitation Ratio)

La Jolla, California. (Scripps Pier)
The Scripps Institution of Oceanography, University of California
Geographic latitude 32° 52' North, longitude 117° 15' W. Greenwich.

I. Latitude Factor.
For La Jolla the latitude factor is 0.34, according to the table:

VALUES OF COSECANT OF THE GEOGRAPHIC LATITUDE (NORTH OR SOUTH)
DIVIDED BY 5.4 (3 times 1.8, one-third being the proportionality factor)
FOR USE WITH THE FAHRENHEIT SCALE (1.8°F.= 1.0°C)

Lat.	+0	+1	+2	+3	+4	+5	+6	+ 7	+8	+9
0	(3.0)	(3.0)	(3.0)	(3.0)	(3.0)	2.12	1.77	1.52	1.33	1.18
10	1.07	.970	.891	.825	.766	.716	.672	.633	.599	.569
20	.542	.517	.494	.474	.455	.438	.423	.408	.395	.382
30	.370	.360	.350	.341	.332	.323	.315	.307	.300	.294
40	.288	.282	.277	.272	.267	.262	.258	.254	.250	.246
50	.243	.239	.235	.232	.229	.226	.223	.221	.219	.217
60	.215	.212	.210	.208	.206	.204	.203	.201	.200	.198
70	.197	.196	.195	.194	.193	.192	.191	.190	.189	.189
80	.188	.188	.187	.187	.186	.186	.186	.185	.185	.185
90	.185									

In the vicinity of the equator: 4 North - 0 - 4 South, for climatic reasons, a uniform value 3.0 is used.

II. RANGE OF TEMPERATURE °F. LENGTH OF RECORD - 15 YEARS
AVERAGES FOR THE PERIOD: 1925 - 1939

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
54.9x	55.3	56.6	58.1	60.3	62.5	66.4	67.4	65.9	63.2	60.7	57.5	60.7
REDUCTIONS TO FIFTY YEARS USING SAN DIEGO SERIES												
-.6	-.8	-1.2	-1.5	-1.5	-.6	-1.1	-.7	-.6	-.9	-1.4	-1.2	-1.0
REDUCED AVERAGES FOR FIFTY YEARS (1881 - 1930)												
54.3x	54.5	55.4	56.6	58.8	61.9	65.3	66.7	65.3	62.3	59.3	56.3	59.7

RANGE: FOR 15 YEARS 67.4 - 54.9 = 12°.5; 50 YEARS 66.7 - 54.3 = 12°.4 F

III. PRECIPITATION RATIO

YEAR	INCHES	YEAR	INCHES
1925	10.8	1933	7.7
1926	10.9	1934	10.4
1927	14.5	1935	13.4
1928	6.4	1936	13.8
1929	3.4x	1937	10.4
1930	12.1	1938	13.3
1931	16.1	1939	7.3
1932	11.5		

ANNUAL TOTALS IN INCHES FOR 15 YEARS

AVERAGE FOR 15 YEARS - - - - - - 10.8 INCHES
MAXIMA - - ABS. 16.1 - 14.5 - 13.8 MEAN 14.8
MINIMA - - ABS. 3.4 - 7.3 - 7.7 MEAN 6.1

PRECIPITATION RATIO FOR 15 YEARS
ABS. - - - - - - - - - - (16.1 - 3.4):10.8 = 1.2
THREE - - - - - - - - - (14.8 - 6.1):10.8 = 0.8

PRECIPITATION RATIO REDUCED TO FIFTY YEARS (USING McEWEN'S REDUCTIONS)
FROM ABS. - - - - - - - - - - 1.2 (36%) 1.6 THREE - 0.8 (36%) 1.1 (24%) 1.35

(I)x(II)x(III) ARIDITY COEFFICIENT

(Latitude Factor) x (Range of Temperature) x (Precipitation Ratio)

FROM ONE ABSOLUTE MAX. AND MIN. - - - - - - - - - - - - 0.34 X 12.4 X 1.6 = 6.7%
AS A MEAN FOR THREE - - - - - - - - - - - - - - - - - - 0.34 X 12.4 X 1.35= 5.5%

OR IN ROUND FIGURES - - - - 6%

REDUCTION VALUES (M^cEWEN'S FACTORS)

in order to reduce the precipitation ratio to a uniform period of 50 years

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PERCENTAGES TO BE ALWAYS ADDED IF the length of rainfall records of a station is under 50 years

YEARS:	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
10	55	50	46	42	39	36	33	30	28	26
20	24	23	22	21	20	19	18	16	15	14
30	13	12	11	10	9	9	8	8	7	7
40	6	5	5	4	3	3	2	1	1	0

ADDITIONAL PERCENTAGES TO BE ADDED ONLY in case the precipitation ratio is computed as a difference between the mean of three highest and three lowest annual rainfall totals, divided by corresponding average.

YEARS:	6	8	10	12	14	16	18	20	25	30	35	40	45
% - -	59	41	33	28	25	23	21	20	18	16	15	14	14

YEARS:	46 - 57	58 - 74	75 - 95	over 95
% - -	13%	12%	11%	10%

These additional percentages must be applied, even if the series of rainfall records exceed 50 years provided that the precipitation ratio is computed as a mean from three maxima and minima instead of one absolute maximum and minimum.

AVERAGE VALUES OF ARIDITY COEFFICIENT

UNITED STATES, CANADA AND GREENLAND - - - - - - - -	15%
NORTH MEXICO TO 20° NORTH - - - - - - - - - - - - -	20%
SOUTH MEXICO, WEST INDIES, CENTRAL AMERICA - - -	7½%
AVERAGE FOR NORTH AMERICA - - - - about	15%
AVERAGE FOR SO. CALIF., NEVADA AND ARIZONA - - -	25%
SOUTHERN CALIFORNIA ONLY - - - - - - - - - - - - -	30%
COASTAL PLAINS AND MOUNTAINS - - - - - - - - - - -	12%
DESERT AREAS -	40%
HIGHEST ARIDITY COEFFICIENT - BAGDAD, CAL.	70%

ARIDITY INCREASES ABRUPTLY FROM COAST TO DESERT

SAN DIEGO REGION	10%	HILLS AND MTS.	15%	YUMA AND CALEXICO	40%
SAN PEDRO	6%	LOS ANGELES	13%	MT. WILSON	20%
MOJAVE	42%	GRAY MTS.	27%	SAN BERNARDINO	14%
BARSTOW	44%	BAGDAD	70%		

PACIFIC SHORES:		ATLANTIC SHORES:	
SANTA BARBARA	7%	KEY WEST, FLA.	6%
SAN FRANCISCO	4%	MIAMI, FLA.	6%
EUREKA	2%	NEW YORK, N.Y.	7%
TATOOSH ISLAND	2%	BLOCK ISLAND, R.I.	9%

AS SOON AS WE GO FROM THE SHORES TO DESERT PLACES, THE ARIDITY INCREASES VERY ABRUPTLY.
AVALON (CATALINA ISLAND) 5%, SAN PEDRO 6%, CALEXICO AND YUMA over 40%, GREENLAND RANCH (DEATH VALLEY) 57%; BAGDAD, CALIF. 70%.

The so-called Mojave and Colorado Desert, between Death Valley and Mexico, has the highest averages not only for the United States, but also for the whole North American Continent. Bagdad, California, situated on the highway from Los Angeles to Needles and Arizona, has 70% aridity coefficient as compared with 100% (middle part of Sahara), 80% in Arabian and 60% in Australian Desert.

SOME AVERAGES AND MAXIMA OF ARIDITY COEFFICIENT

NORTH AMERICA: AVERAGE ABOUT 15, MAX. 70 BAGDAD, CALIF.
OTHER MAXIMA (U.S.A.): GREENLAND RANCH (DEATH VALLEY) 57, YUMA 41
MEXICO: NORTHERN PART (-20 NORTH) AVERAGE 20
MAXIMA: MULEGE, BAJA CALIF. 50, CASAS GRANDES, CHIHUAHUA 32
SOUTH MEXICO, WEST INDIES, CENTRAL AMERICA 7½

SOUTHERN CALIFORNIA: AVERAGE 30, MAX. 70
DESERT AREAS 40, COASTAL PLAINS AND MOUNTAINS 12
AVERAGE FOR SOUTHERN CALIFORNIA, NEVADA AND ARIZONA 25

OTHER CONTINENTS:
NORTH AFRICA: SAHARA 100 SOUTH AFRICA: KALAHARI 60
ASIA: ARABIA 80 AUSTRALIAN DESERT 60
SOUTH AMERICA: AVERAGE 10, MAX. 50 PERU, CHILE
TROPICAL ZONE (EQU. - 20 SOUTH) ONLY 6 AS AN AVERAGE
EUROPE: AVERAGE LESS THAN 10
MAX. ARIDITY: 15 MURCIA, CARTAGENA (EASTERN SHORES OF SPAIN)
POLAND: AVERAGE 10 GDYNIA, BALTIC SHORES 7, WARSAW 10, CARPATHIAN MOUNTAINS 12
IRELAND: WESTERN PART OF GREAT BRITAIN, 5 AS AN AVERAGE

OCEANIC SHORES:
PACIFIC: LA PAZ 28, ENSENADA 12, SAN DIEGO 11, SAN PEDRO 6, SAN FRANCISCO 4, EUREKA 2, TATOOSH ISLAND 2
ATLANTIC: KEY WEST 6, MIAMI 6, NEW YORK 7, BLOCK ISLAND, R.I. 9

INCREASE FROM PACIFIC SHORES TO MOJAVE AND COLORADO DESERT:
SAN PEDRO 6, LOS ANGELES 13, SAN BERNARDINO 14, GRAY MOUNTAINS 27, MOJAVE 42, BARSTOW 44, BAGDAD 70, NEEDLES 42

As soon as we go from the Pacific shores to the surrounding hills and mountains, the aridity increases, as may be seen from comparing the data of Avalon (Catalina Island) and San Pedro on Pacific shores (both 6% aridity) with Los Angeles metropolitan areas (13%) distant some 15-20 miles from the ocean. The hills and intermediate mountains around the Los Angeles region have as an average nearly the same value as the extended metropolitan area. But the aridity coefficient increases very rapidly toward the surrounding dry areas, as may be seen from the following data:

Miles from shore	Elevation in feet	Observing station	Aridity Coefficient
First Series			
0	10	San Pedro	6%
15	338	Los Angeles	13%
40	5850	Mount Wilson	20%
90	2751	Mojave	42%
Second Series			
60	1054	San Bernardino	14%
90	3000	Gray Mountains	27%
100	2105	Barstow	44%
150	700	Bagdad	70%

The mileage is only approximately given from the Pacific shores (S. Pedro) in air line. To express the distances in kilometers, we have to multiply it by 1.6.

In the dry areas surrounding the coastal plains and mountains of Southern California, the aridity coefficient is high and may be estimated as about 40% in the so-called Mojave and Colorado Deserts between Death Valley and the international boundary line separating California from Mexico. Comparing with an average for coastal plains and mountains (nearly 12% ranging mostly between 5 and 15%), we may state that the Southern portion of California has the highest average not only for the United States, but also for the whole North American continent.

Conclusion

The idea of a new aridity coefficient, which represents a combined effect of temperature range as a measure of continentality and a precipitation ratio as an adequate expression of rainfall variability very suitable for dry areas, was born in Poland some twenty years ago. Immediately after publishing my first papers on thermal continentality, I charged one of my young assistants, the late Paul Rychlinski, with preparing some maps of the precipitation ratio throughout the world. Unfortunately my assistant with pulmonary disease died after collecting only a small amount of data for some desert stations in Australia.

In the period between 1923 and 1936, I made extensive studies chiefly on solar radiation and of the climates of the European and North-African Rivieras. After coming to the United States in the late summer of 1939, I had the opportunity of visiting Florida last October, and also spent some time in Arizona before coming to Southern California at the end of last November. Some reporters have interviewed me at Phoenix and Tucson asking as to comparisons of the so-called Arizona Desert with the Sahara and Arabia. I have been several times in some French, Egyptian and Arabian oases and have had the opportunity of spending in 1925 five months in the Oasis of Ouargla, French Sahara on the route Algiers-Biskra-Touggourt to Insalah and Tamanrasset in the Ahaggar Mountains located in the middle of the Sahara.

By crossing the so-called Desert of Arizona, very different, of course, to the real Desert of Sahara with its immense moving sand dunes and rocky hammadas without any vegetation during long distances, my former idea of the aridity coefficient has revived in me and I have promised myself to recommence the study of the whole aridity problem. For a scientific worker in the field of climatology it is always very fascinating to be able to give a mathematical expression for our surrounding natural phenomena.

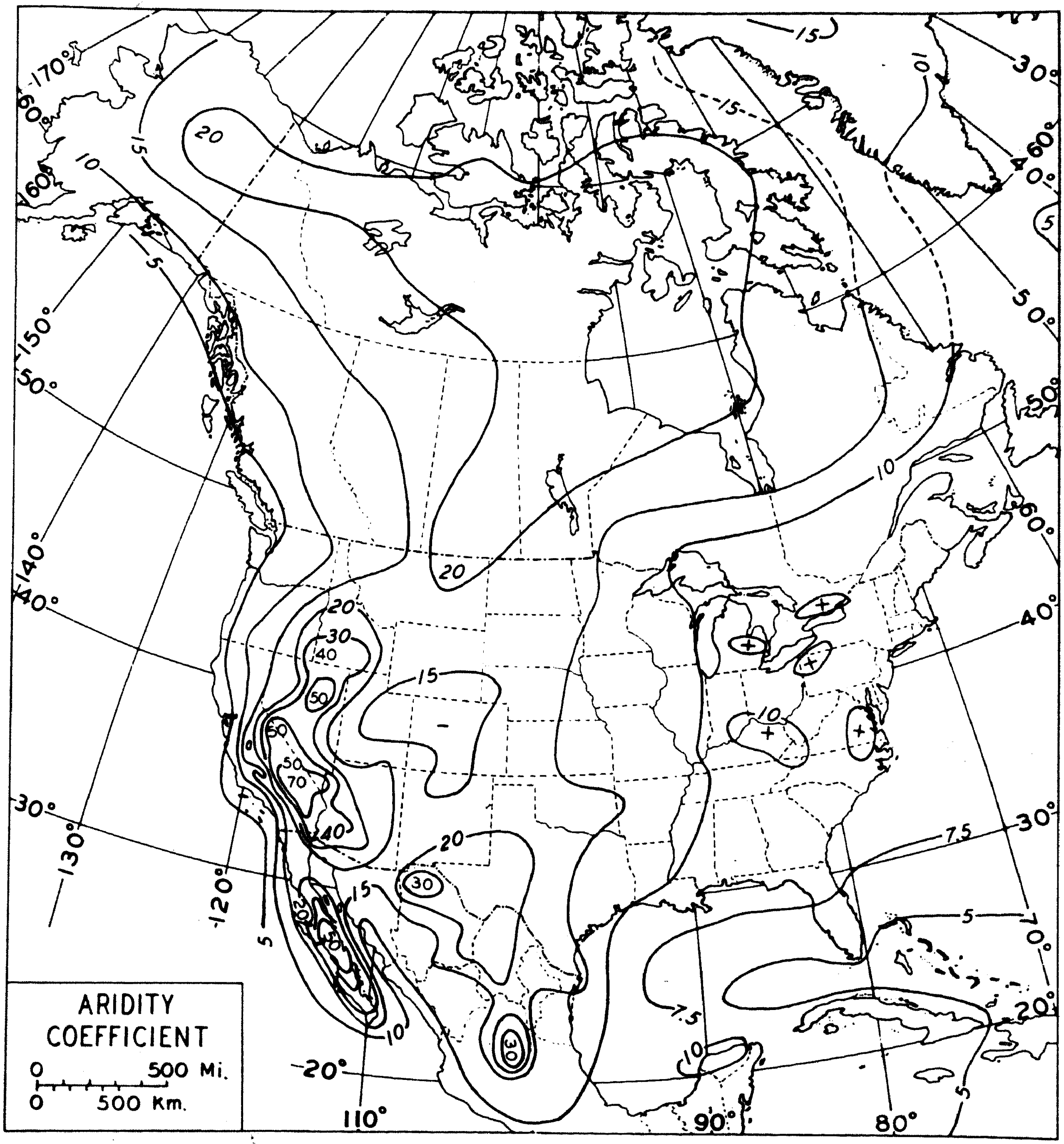
Instead of vague formulation that the dry areas of Arizona, the Mojave and Colorado Deserts have different climatic aspects, it is far better to be able to state that the Mojave and Colorado Deserts represent the driest area in North America; Bagdad, California, has 70% aridity coefficient, Yuma 42%, Phoenix 28%, and Tucson 22% as compared with the middle of the Sahara approaching 100%.

The possibility of expressing climatic elements in numbers having a physical meaning is certainly a very fascinating study for every scientific mind. But, as the Polish proverb says, the whole hell is tapestried with good ideas, or, in the English version, the road to hell is paved with good resolutions. Each sound idea should be realized; the first country known not only in Poland but throughout the world as highly efficient is the United States of America. So my European idea of aridity coefficient, born in Poland, revived in Arizona, is now in process of being realized at the Scripps Institution of Oceanography under the auspices of the University of California. Here at La Jolla, this lovely place, located on the Pacific shore in the San Diego region, I hope to be able to finish and publish some papers concerning the aridity problem and climatic comparisons between California and other Rivieras.

The aridity problem is very important not only for climatic and other scientific studies, but for many practical purposes. The irrigation work depends on it and so the whole population of any dry area must be interested in meteorological records.

I do not claim that every climatologist using the aridity coefficient should afterwards know all about climate. I do not think that every person, like farmer or horticulturist operating in dry areas, would have an immediate benefit if aridity coefficient were computed for their estates or areas. But I believe in having some good scientific reasons to claim:

1. that each climatic and other scientific description, especially for dry regions, has a real gain in introducing and using some convenient numerical expression for aridity;
2. that the aridity coefficients are useful not only in science but for planning and operation of irrigation work and dry farming.


ARIDITY
COEFFICIENT
0 500 Mi.
0 500 Km.