PRELIMINARY DATA REQUIREMENTS FOR A FEASIBILITY STUDY OF THE SOLAR OPTION IN THE RHONE-ALPES REGION OF FRANCE

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Preface

This paper is one of a series describing a multidisciplinary IIASA research program on Integrated Energy System Modelling and Policy Analysis. The initial phase of this research program is focused on the energy systems of three regions: the State of Wisconsin in the U.S.A.; the German Democratic Republic; and the Rhône-Alpes Region in France. The primary purposes of the study are at least three-fold:

(1) To identify existing patterns of regional energy use and supply at appropriate levels of disaggregation.

(2) To compare alternative methodologies for regional energy forecasting, planning, and policy development.

(3) To use the above methodologies to examine alternate energy policy strategies for each of the regions, to explore their implications from various perspectives using sets of indicators related to environmental impacts, energy use efficiency, etc., and to evaluate the adequacy of the alternative methodologies as policy tools.

Out of these above three items should evolve improved methodologies for energy systems research and policy analysis. The comparative method, intersecting the different disciplines and nations which would be involved in this project, should serve as a powerful tool to the mutual benefit to the participating nations as well as to other countries facing similar energy problems. It could also serve as a prototype for similar studies on other resources such as materials, water, air, i.e. as a vehicle for development of an approach for improved resource management.

W.K. Foell

Papers in the series describing this research program are:

(1) Foell, W.K. "Integrated Energy System Modelling and Policy Analysis: A Description of an IIASA Research Program" IIASA Working Paper WP-75-38, April 1975.

(2) Dennis, R.L. and Ito, K. "An Initial Framework for Describing Regional Pollution Emissions in the IIASA Integrated Energy System Research Program" IIASA Working Paper WP-75-61, June 1975.

(3) Weingart, Jerome, "Preliminary Data Requirements for a Feasibility Study of the Solar Option in the Rhône-Alpes Region of France" IIASA Working Paper, June 1975.

(4) Hölzl, A. and Foell, W.K. "A Brief Overview of Demographic, Geographic, and Energy Characteristics of the German Democratic Republic, Rhône-Alpes, and Wisconsin" IIASA Working Paper, June 1975.

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I. Introduction

The solar "option" consists of a number of possible energy systems options including or incorporating various types of solar conversion elements. Options include systems to produce heat, electricity, synthetic fuels and shaft horsepower.

In order to evaluate the potential role of some menu of solar options within an evolving energy system "mix" in a region, it is necessary to be able to answer to some reasonable degree the following questions:

1) What solar systems options are in principle available and what would their technical, economic and industrial characteristics be?
2) What are the timetables for development, commercial introduction and diffusion for these options?
3) What are the regional patterns of sunlight and weather and how will these influence the "mix" of potentially interesting solar technologies?
4) What are the likely impacts on energy supply and installed energy conversion facilities of other kinds in an integrated energy system?
5) Assuming some number of these technologies (e.g. solar thermal electric power generation in units of 100 Mwe average output) would be both commercially available and economically interesting, is there available suitable land? What are the detailed problems related to land availability, acquisition and use for such solar technologies and how do such problems compare with siting

and land use issues raised by use of alternative (non-solar) systems?

6) What would be a reasonable initial area in which to begin development, installation and evaluation of a solar option for a region (e.g. solar water heating for houses, small solar thermal electric power stations on the order of 25 Mwe average, etc.)? How would one go about it (CNRS solar program in France, for example)?

7) How does one integrate the examination of a solar option into the total examination of alternative futures for a region? Which methodological tools are useful and how would they actually be used in such an examination?

Questions 1, 2, and 7 would be addressed primarily by IIASA, whereas questions 3, 4, 5, and 6 would require cooperation directly with a specific region such as Rhône-Alpes. In addition, the solar research program of CNRS would presumably be an important source of information in elaboration of 1 and 2.

An initial and very preliminary examination of the potential for use of solar conversion systems in a region could be carried out after some initial data on patterns of sunlight, land use and topography, and the structure of the regional energy system, including demand patterns, were available.

The following pages contain an outline of some of the material which I feel would be useful in carrying out such a preliminary assessment. These are certainly not the final requirements; we would expect to better define the detail and scope of required data as these evaluations are carried out in greater and greater detail.

II. Some Preliminary Data Requirements

In order to begin a preliminary sketch of the feasibility of some solar options making an eventual contribution to the energy system of the Rhône-Alpes region, it will be necessary to have some preliminary data in an organized form. Some of this is available now within IIASA, other data will be fairly easy to collect, and other data will be more difficult to get. The required data fall into the following categories:

Land Use and Physical Characteristics of the Region

Physical geography

Climatology

Insolation patterns (direct and diffuse radiation)

Topography

Ecology

Water flows

Categories of land use (forests, meadows, agriculture of various types, "wasteland", etc.)

Man-made Features - the Built Environment

Urban and suburban regions

Industry

Transportation intrastructure (roads, railways, etc.)

Energy Systems Structure

Primary conversion facilities (power plants of various types, heating plants, etc.)

Energy storage (primarily hydro; coal and oil storage, etc.)

Energy transport (transmission lines, pipelines, energy corridors, trucks, trains, etc. for fuels)

Power conditioning (substations, switchyards, etc.)

Demand Patterns

By source (Electricity demand as a function of time over a year, with breakdown of supply for each major generating facility, natural gas and oil for industrial, residential and commercial processes, etc.)

By end use (domestic hot water, space heating and air conditioning, commercial and institutional building requirements, transportation, etc.)

III. Land Use and Facility Siting Data

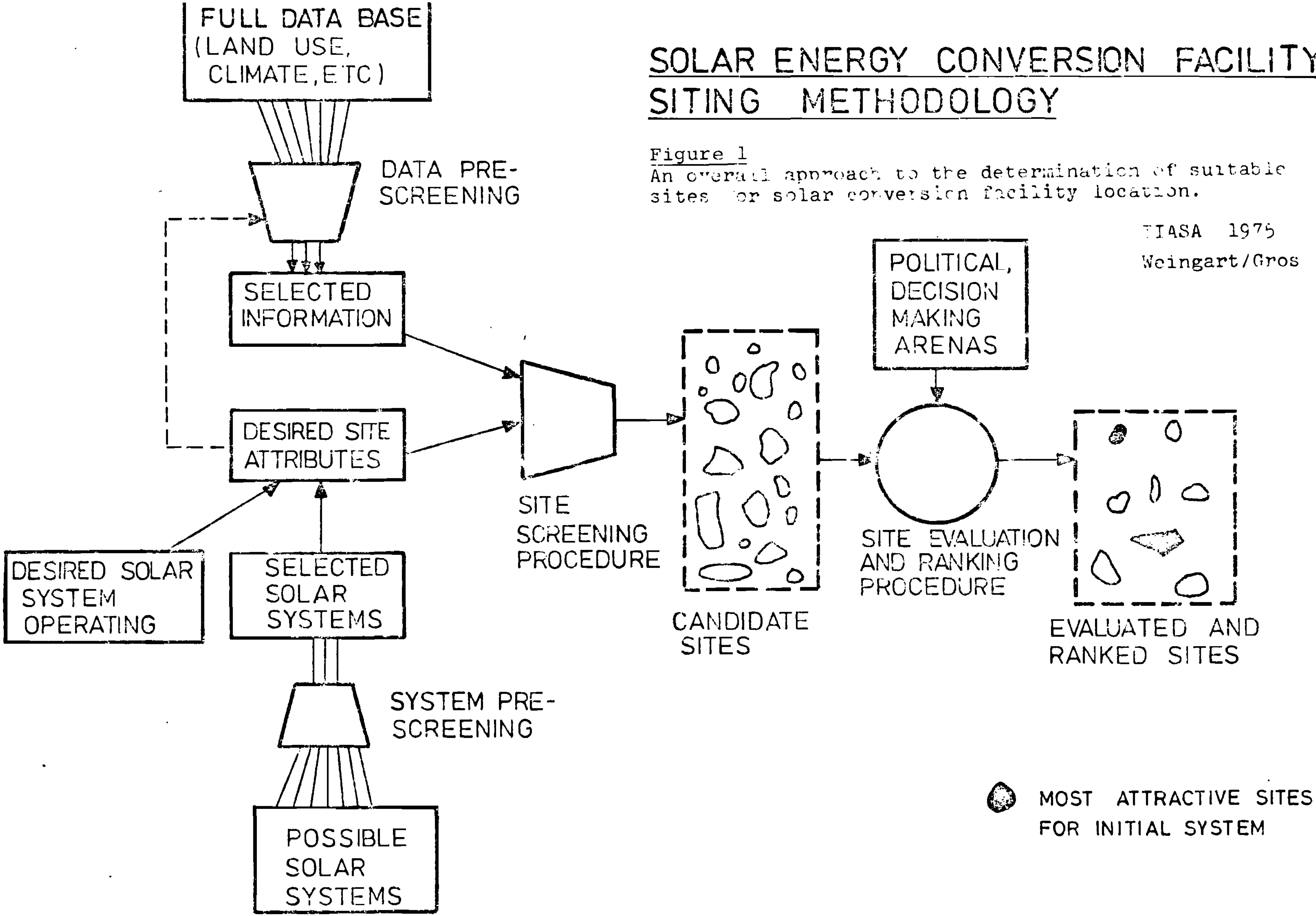
The identification of suitable locations for various types of solar facilities is a crucial component of any preliminary evaluation of the ultimate potential significance of some solar system options in any region. Figure 1 outlines the main steps involved in a complete analysis of this kind. The specification of the crucial information related to the local characteristics of a region in terms of climatology, topography, physical geography, meteorology, land use and costs etc., is an important component of this process since it is possible to drown in available data without a procedure for careful data prespecification and screening.

There is currently an effort underway to perform such a preliminary piece of work for Austria, including the identification of a few candidate sites for the initial installation of a prototype electric power generation system (either photovoltaic or solar thermal electric or both). A preliminary copy of this will be provided to the Grenoble group and we will later complete a specification of the types of data required

SOLAR ENERGY CONVERSION FACILITY SITING METHODOLOGY

Figure 1
An overall approach to the determination of suitable sites for solar conversion facility location.

IIASA 1975
Weingart/Gros



and a clear description of how we have proceded in Austria.

As an example of a truncated procedure to immediately get a rough idea of the possibilites, we examined former agricultural land now no longer farmed due to economic constraints (land made unuseable for farming during the WW II, land of low productivity, etc.). Some 1000 square kilometers of this type of land, primarily flat and generally as sunny as any large area of Austria, currently exist and would in principle be available for solar system siting. The actual suitability of such land must be judged by application of screening criteria including proximity to load centers, availability of water, access to energy corridors and transportation (for heavy equipment during construction), soil stability, maximum winds, and so forth. A similar rough estimate may be possible by the Grenoble group as part of a preliminary look at land availability and suitability.

An important aspect of the siting evaluation work for Europe will be the need for examination of land at the microscale (100 ha area plots) including considerable use of local experts to identify where such places exist, since there are no equivalents (in terms of large, flat sunny land) of Arizona to be found in Europe. Hence our strategy must permit the screening of large areas of land, with the possibility of doing so with a " mesh" of 100 ha size in candidate regions (such as agricultural land), which may be attractive in general for solar systems.

The land area of the Rhône-Alpes region is roughly 40,000 km^2. If fifteen percent of the incident global solar radiation was converted into electricity, it would require about one percent of the land area of 400 km^2 to provide, <u>on the average</u>, the electrical demand of the region in 1974. Of course, the variation over the year in available sunlight raises serious questions about the use of solar energy conversion unless suitable storage means are found. The only available technology currently is pumped hydrostorage; other technologies may well become both technically and economically feasible over the coming several decades.

In any case it would require some three to four decades before solar energy conversion could provide a substantial portion (> 15%) of any large region's electrical or total energy requirements. However, this indicates in a rough way the order of magnitude of land requirements. A synopsis of the estimate is shown below:

<u>Rough Estimate of Land Areas Required to Provide Electricity and Other Energy from Solar Conversion</u>

Assume Population = 5×10^6 10,000 Mwe

Elec/capita = 2 kwe

Conversion efficiency = 0.15 for solar to electric, complete utilization of all solar-produced electricity

Insolation = 4 kwh/m^2-day

Required area is approximately 400 km^2 or one percent of total land in region (40,000 km^2).

A set of solar "land area indices" has been computed for France, the FRG and Italy to illustrate further the land requirements for solar energy conversion on a large scale (Table 1). These indices are computed assuming that solar energy conversion provides, on the average, the total electrical energy demand or the total primary energy demand (exclusive of electric power generation) with an average conversion and delivery efficiency of fifteen percent. These issues will be elaborated on in working papers currently in preparation.

The following is a brief summary of preliminary land use data and related information which we would hope to obtain soon.

Data Desired

Gross Breakdown of Land Use

Category	Area (km^2)	% total
France		
Rhone-Alpes region		
Arable in use		
Arable resting		
Arable not in use any longer - not "good"		
Forest		
Meadow, grazing		
Wasteland		
Mountainous		
Other that seem relevant and important		
(i.e., large industrial areas, military reservations, etc.)		

Maps Desired

The French National Atlas

Map of land use distribution in the region

Map showing solar insolation or related quantities (i.e. total sunshine hours per month or season or year - monthly is best)

COUNTRY	POPULATION ($x 10^6$)	AREA $1000km^2$	ENERGY CONSUMPTION (kwht)	ELECTRICITY DEMAND (kwhe)	INSTALLED CAPACITY (Gwe)	NATIONAL LOAD FACTOR	SOLAR LAND INDICES (km^2), %	TRANSMISSION LINE CORRIDORS
FRG	62	250	2.61 E12	2.54 E11	54	0.54	(1) 9000 (3.6) (2) 1200 (0.5)	1160 km^2
FRANCE	51	550	1.73 E12	1.49 E11	38.8	0.44	6800 (1.2) 1550 (0.3)	1130 km^2
ITALY	54	300	1.14 E12	1.35 E11	36.05	0.43	3300 (1.1) 1130 (0.4)	685 km^2

Assumptions: Specified average insolation
0.15 net conversion efficiency
1.0 use factor for solar produced energy
4.0 kwh/m^2-day

(1) for all primary energy demand other than generation of electricity

(2) for all electricity demand

* Wisconsin right of way land area values used

Table 1 Land area required to provide total primary energy demand and total electrical energy demand, by country, through solar energy conversion systems. All data for 1971.

IV. Solar Radiation Data Desired; Data Currently Available At IIASA

Sunlight Characteristics, Measurements

Solar radiation at the surface of the earth can be described in terms of the spatial, temporal and spectral distribution of the diffuse (scattered) and direct (beam) radiation components. Usually, measurements made at weather stations or similar installations will integrate over the spectral distribution. The most common measurements are of the total global radiation (direct plus diffuse) incident on a horizontal surface, and measurements are typically reported on an hourly basis. Some installations also measure the normal incidence using a tracking sensor. The units of measurement and reporting are most typically in Langleys (calories per square cm per day) and less commonly in joules per square cm per day (typical of French work) or in BTU per square foot per hour. Other units include kilowatt hours per square meter per hour (or per day) or incident power expressed in watts or incident radiation. An empirical "cloud cover modifier" is also sometimes reported and can be used to estimate values of direct sunlight from total insolation measurements.

Desired Data

The most desirable data would be in the form of incident energy measured on an hourly basis for both total radiation and the direct component (either at normal or horizontal incidence). In the absence of the direct measurements, the total global radiation can be used to make reasonable computations of direct radiation.

Typical data are reported for Austria on an hourly basis for a number of stations. The data at each station are given in Langleys for each hour of sunlight during the year. Some typical data has been plotted at IIASA for the purpose of visually showing the range in variation in sunlight patterns over a month and throughout the year. Similar plots can be generated to show the direct and diffuse radiation incident on a surface of arbitrary orientation at any time during the year by well known computational techniques. Such data are really necessary to say anything specific about the behavior of a particular solar conversion system over a year.

A list of specific items desired for the Rhône-Alpes region is found in Table 2.

Table 3 is a brief summary of a possible format for information and data related to solar energy in and near the Rhône-Alpes region and is provided as a guide for the Institut Economique et Jurdique de l'Energie at the University of Grenoble.

Information on Hand At IIASA

Information on hand includes Solar Radiation and Radiation Balance Data (daily average insolation) for 1968, 1969, and 1970 and World Distribution of Solar Radiation (long term averages of monthly averaged daily radiation for a period prior to 1966). We do not have any detailed hourly data for France comparable to the available data for Austria.

The data on hand are summarized for the Rhone-Alpes and nearby regions in Table 4. The monthly averages of measurements at Macon and Carpentras are shown, along with calculated monthly averages for Dijon, Tarare, Lyon, Bescancon and

Table 2 First Round Data Requirements - Rhone-Alpes Region*

(1) Insolation Data

a. sunlight hours

monthly

annually

b. radiation

	global	direct	cloud cover
hourly			
daily			
monthly			
annually			

(2) General Weather Conditions

a. snowfall

b. rainfall

c. hail conditions

d. wind conditions

e. maximum and minimum temperatures, mean temperature

(3) Electricity Demand (monthly, daily kwhe, hourly for entire region (present and projected) for a year

(4) Electricity System Map, including information on pumped storage facilities (EDF should have all of this including perhaps a book describing the pumped stoarage and other hydro facilities).

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* An example of the level of detail used in a preliminary site evaluation for the proposed prototype ten megawatt electric solar thermal electric power plant in the United States is available at IIASA for solar radiation values, sunshine hours, mean sky cover, wind histories, and supplementary weather data related to temperature extremes, annual snowfall, wind and thunderstorms. (Ref: Aerospace Corporation, Solar Thermal Conversion Central Receiver Pilot Plant Siting, 1975). Once sites are established through an examination of sunlight maps, agricultural and other land data, and other maps, the more detailed climatological factors can be examined. For the level of detail required in the first round, something akin to the climatological maps of the Austrian Atlas would be suitable.

Table 3 Solar Radiation and Measurement Data Desired For the Rhône-Alpes Region

Measurement Station

(1) Name and location, including latitude, longitude and altitude

(2) Type of measuring equipment*

(3) Location of measuring equipment relative to things which may make data difficult to generalize under some conditions (i.e., located in valley, near industrial air pollution sources, etc.)*

(4) Date of establishment of station*

(5) Key person in charge of data management*

Measurements

(1) Type of measurements (i.e., global radiation only, global plus normal incident direct, global plus normal incident horizontal, direct radiation only; cloud cover modifers)

(2) Time interval of measurements (e.g. 1 hour, 3 hours)

(3) Reporting interval (1 hour, 3 hours, daily averages, etc.)

Data Format

(1) Printed tables and lists

(2) Maps (insolation or sunshine hours or probability of maximum possible sunshine)

(3) Computer compatible format (punched cards, paper tape, magnetic tape)

(4) How it can be obtained

The two measurement stations of relevence to the Rhone-Alpes region (to the knowledge of the author) are located at Macon and Carpentras.

* optional if the relevant data can be obtained without these.

Table 4

COMPUTED AND MEASURED GLOBAL SOLAR RADIATION
IN OR NEAR THE RHÔNES-ALPES REGION OF FRANCE(1)

Calories per cm^2-day (monthly averages)

MEASUREMENT STATION (1)	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Macon	75	115	240	330	490	510	490	410	350	160	120	73
Carpentras	**	**	315	500	600	595	660	545	440	270	180	130
COMPUTATION LOCATION(2)												
Dijon	90	160	300	400	470	530	540	460	340	220	110	70
Tarare	100	160	280	380	440	510	540	450	340	220	120	80
Lyon	100	160	310	420	490	540	570	480	350	220	110	80
Bescancon	90	150	290	380	460	520	530	450	330	220	110	70
Montelimar	150	230	300	420	480	600	640	490	380	240	170	120
SELECTED COMPARISONS (3)												
Phoenix, Ariz.	297	408	521	643	724	740	652	612	568	452	339	280
Vienna, AUSTRIA	69	131	221	331	432	456	453	389	276	159	78	51

Montelimar. Vienna, Austria and Phoenix, Arizona (USA) are shown for comparisons. Table 5 shows the location for the measured and computed values of insolation. It is not obvious without some understanding of the local meteorology and topography that one can extend these values into the region east of Lyon (5 deg. east).

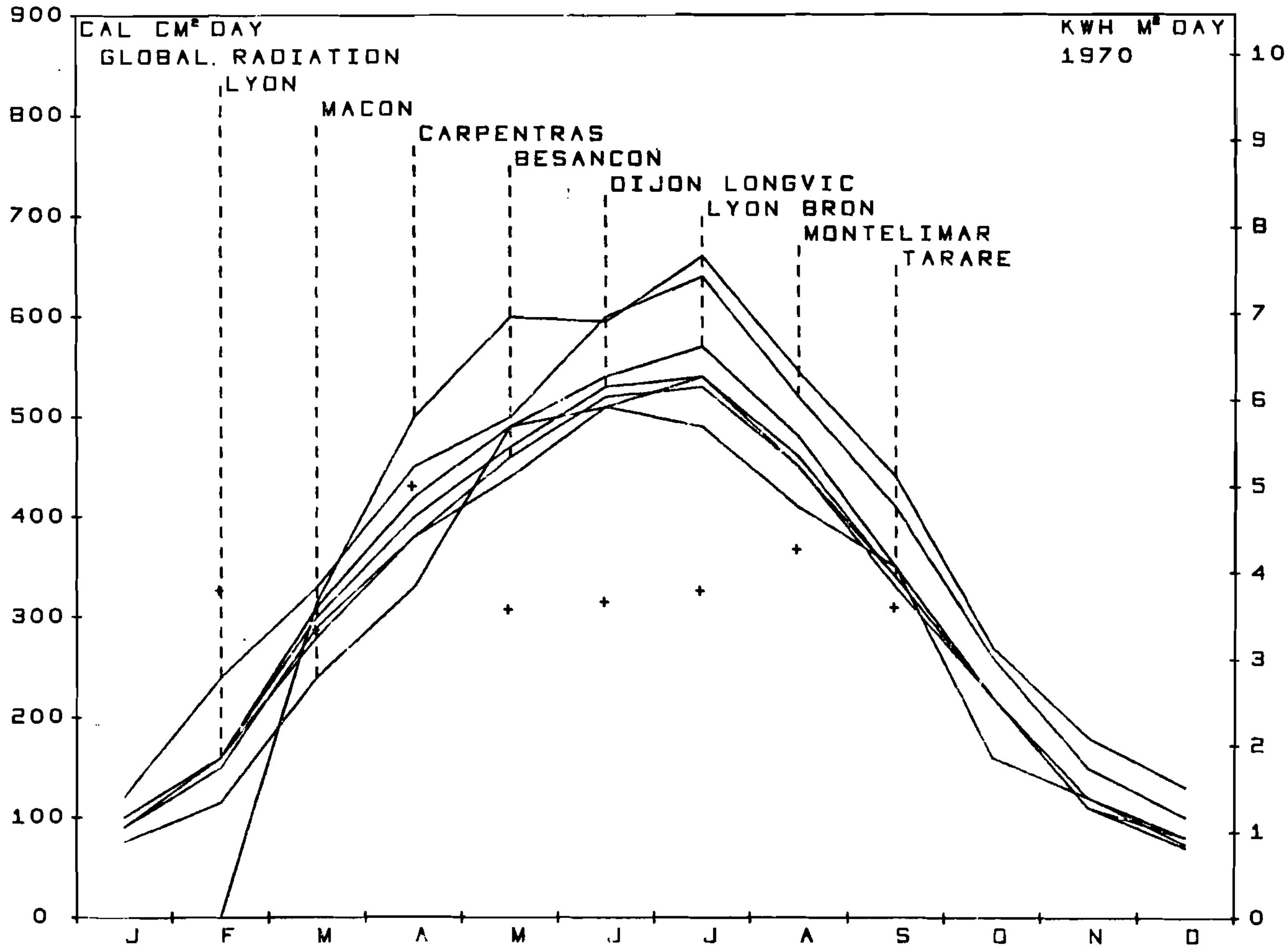
Table 5 Average Insolation Characteristics in the Rhône-Alpes Region

Location	Annualized Average Daily Insolation
Macon	280 Langleys S.D. = 170
	3.25 khw/m^2-day
Carpentras	423 Langleys S.D. = 188 Mar.-Dec.
	4.91 kwh/m^2-day
	(361 L with 100 L estimate for Jan. and Feb.)
	4.29 kwh/m^2-day
Dijon	308 L 3.60 kwh/m^2-day
Tarare	302 L
Lyon	319 L
Bescancon	300 L
Montelimar	360 L
	318 L (average) S.D. = 25
	3.70 kwh/m^2-day

REGIONS ET DEPARTEMENTS

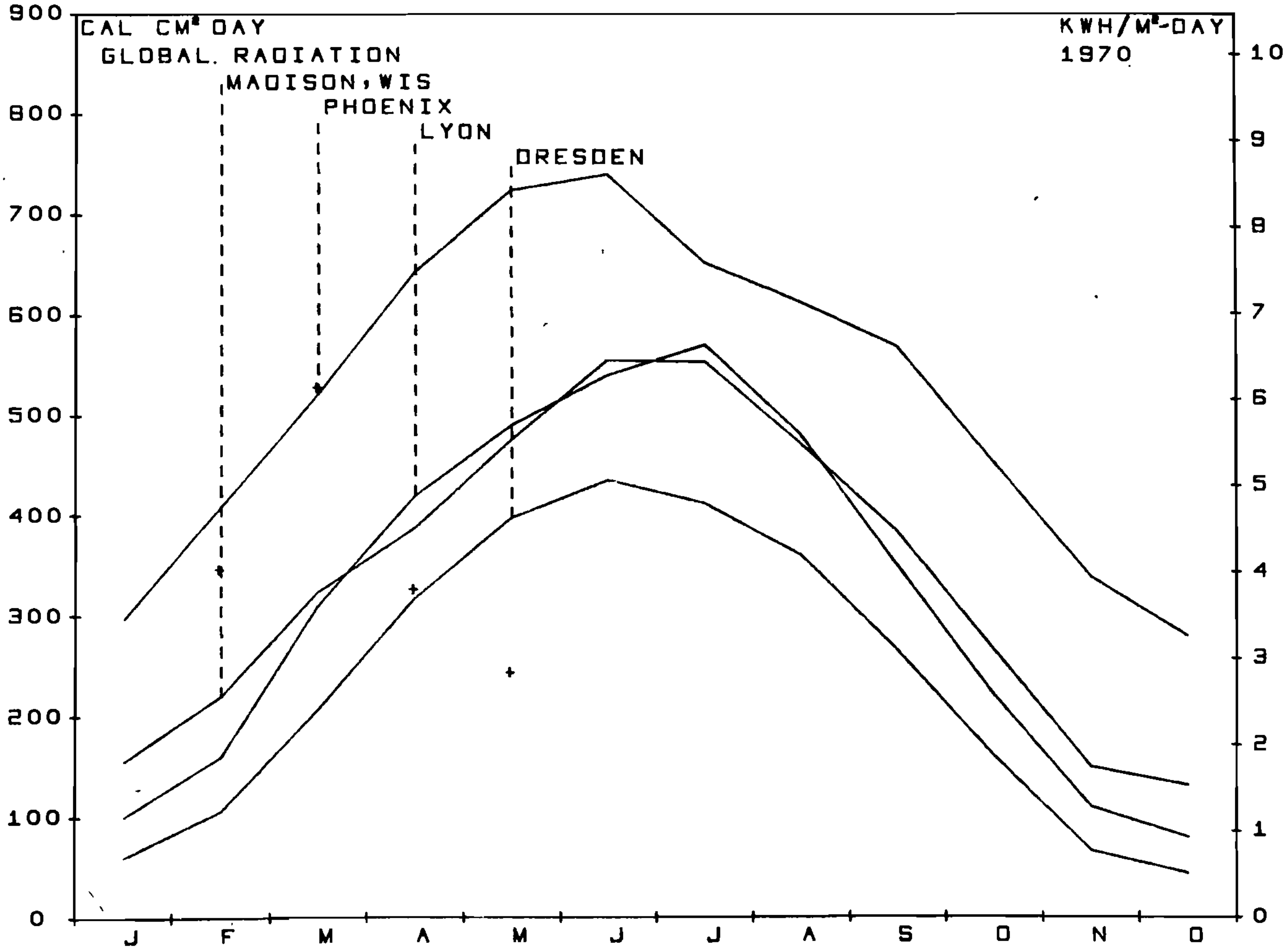
Regions and Departments in France

Figure 2



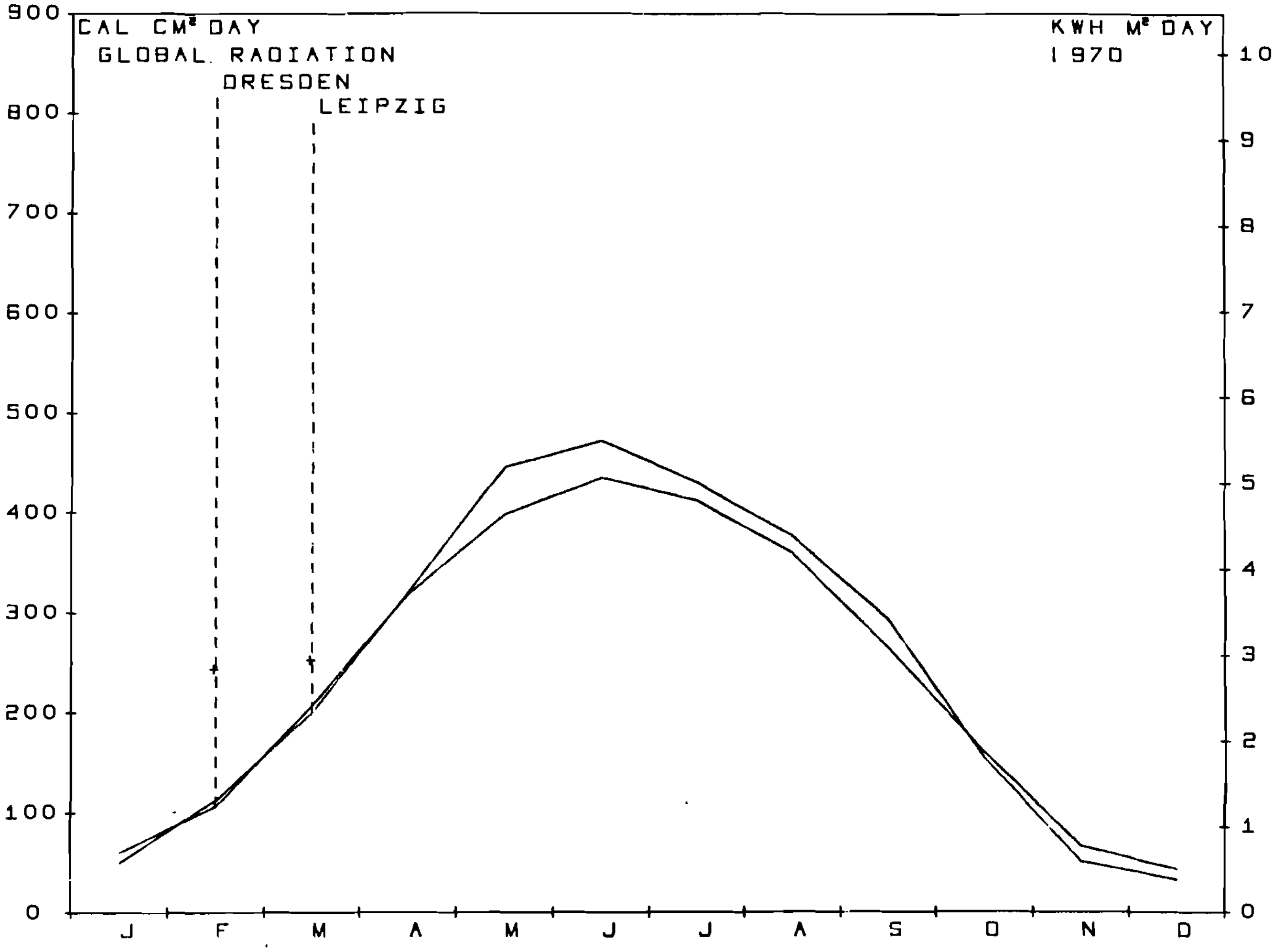
Measured or Calculated Global
Radiation in France Near the
Rhone-Alpes Region. (Ref.1, 2)

Figure 3



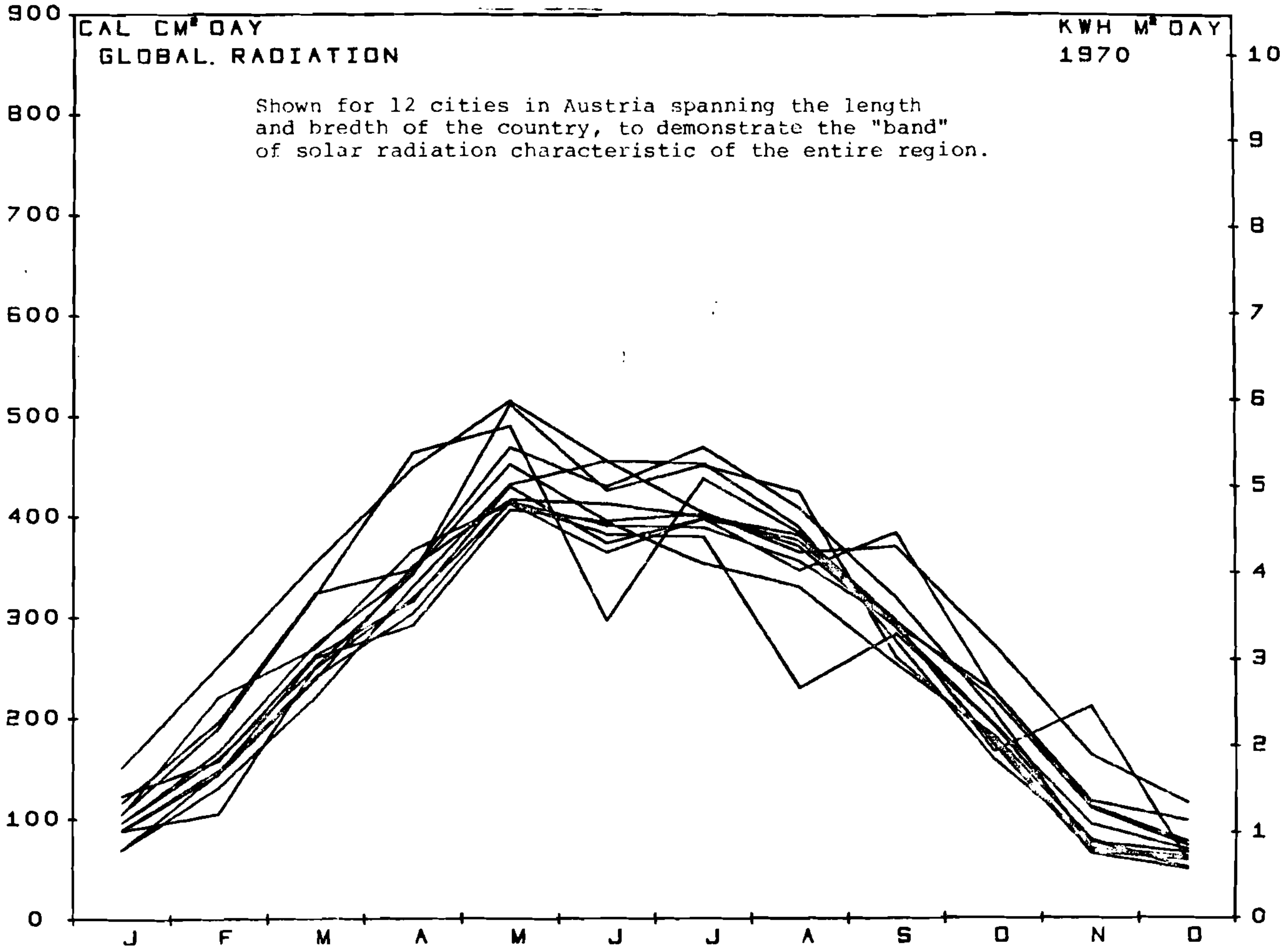
Global Radiation at Madison, Phoenix,
Lyon and Dresden (Ref.1, 2)

Figure 4



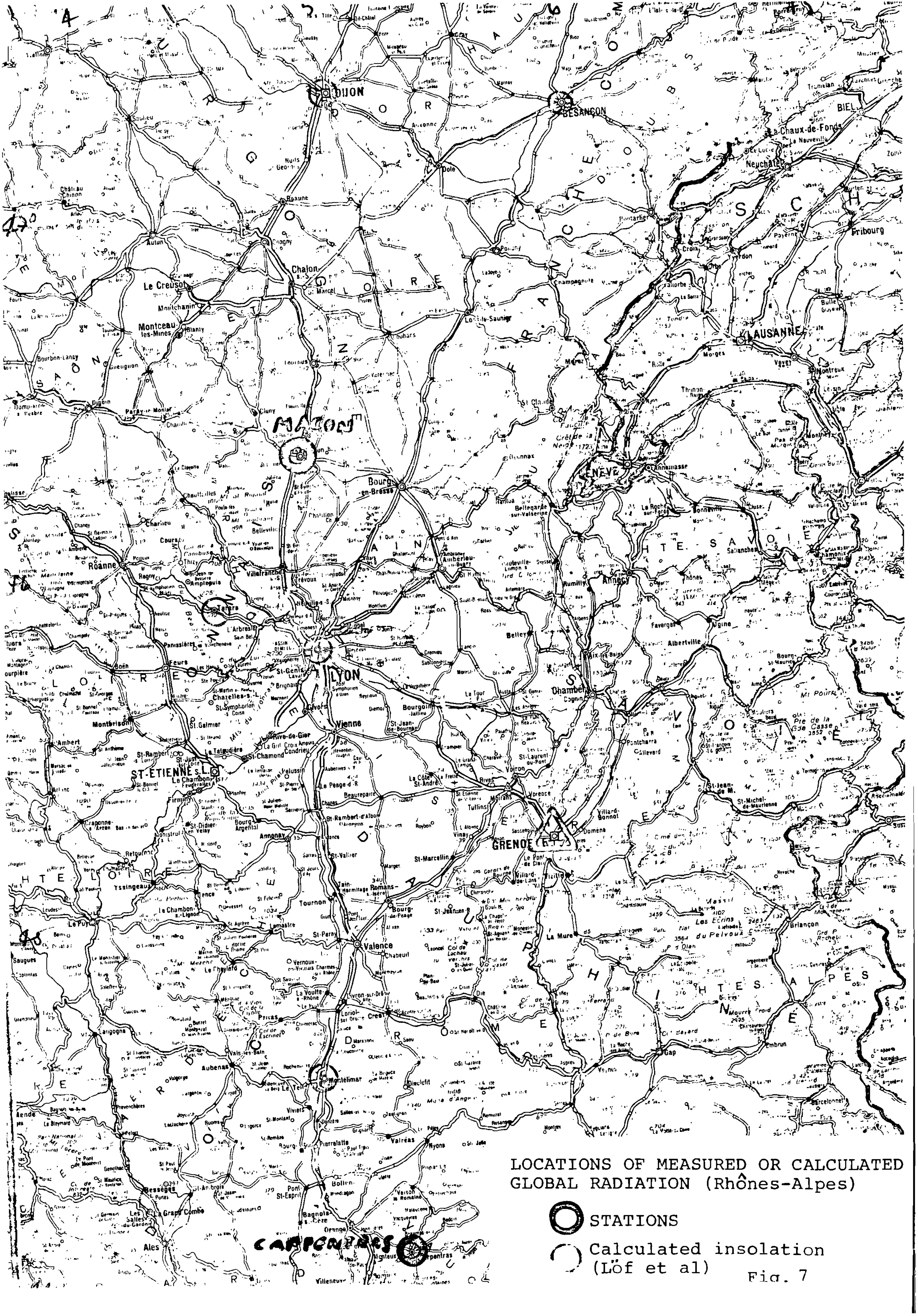
Global Radiation at Dresden add
Leipzig for 1970. (Ref. 1)

Figure 5



Global Radiation for 12 Locations Throughout Austria. (Ref.1, 2)

Figure 6



LOCATIONS OF MEASURED OR CALCULATED GLOBAL RADIATION (Rhônes-Alpes)

STATIONS

Calculated insolation (Löf et al)

Fig. 7

Footnotes

(1) Measurements are monthly averages of total global radiation (horizontal surface) measured in 1970 and tabulated in the series Solar Radiation and Radiation Balance Data. Data for France is presented in the reference in the form (joules per cm^2) and was converted to (calories per cm^2) for comparison with the other computed and measured data. Conversion factor: 1 joule is approximately 0.24 calories.

Calculated by Löf et al, World Distribution of Solar Radiation and presented in (calories per cm^2), daily insolation from monthly averages.

Comparisons also from Löf et al.

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(1) Löf, George, John Duffie, and Clayton Smith, "World Distribution of Solar Radiation". College of Engineering, University of Wisconsin Engineering Experiment Station Report No. 21, July 1966.

(2) "Solar Radiation and Radiation Balance Data". USSR Chief Administration of the Hydro-Meteorological Service, A.I. Voeikov Main Geophysical Observatory, Leingrad, Dec. 1970.

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