CHAPTER III

METHOD OF CALCULATION

III.1 The determination of radio wave refractivity.

To make calculation 46 observation stations are chosen to collect the data of atmospheric pressure, temperature, and relative humidity in percent at the surface of the earth. The stations are located at different parts of Thailand as listed below.

Station	Latitude	Longitude	Elevation above MSL (m)
Chiang Rai	19° 55'N	99° 50'E	395.03
Mae Hong Son	19° 18'N	97° 50'E	420.08
Chiang Mai	18° 47'N	98° 59'E	314.12
Mae Sariang	18° 10'N	97° 50'E	211.89
Lampang	18° 15'N	99° 30'E	241.98
Nan	18° 47'N	100° 47'E	201.10
Uttaradit	17° 37'N	100°08' E	64.12
Phrae	18° 10'N	100° 08'E	161.79
Tak	16° 51'N	99° 07'E	116.19
Phitsanulok	16° 50'N	100° 16'E	45.31
Mae Sot	16° 40'N	98° 33'E	211.25
Phetchabun	16° 25'N	101° 08'E	119.24
Phumipol Dam	17° 14'N	99° 03'E	165.90
Loei	17° 32'N	101° 30'E	253.99
Udon Thani	17° 26'N	102° 46'E	182.05
Nakhon Phanom	17° 30'N	104° 20'E	141.00
Sakon Nakhon	17° 10'N	104° 09'E	173.00
Mukdahan	16° 33'N	104° 44'E	139.00
Khon Kaen	16° 20'N	102° 51'E	165.41
Roi Et	16° 03'N	103° 41'E	141.35
Ubon Ratchathani	15° 15'N	104° 53"E	128.40

Station	Latitude	Longitude	Elevation above MSL (m)
Surin	14° 53'N	103° 29'E	146.28
Nakhon Ratchasima	14° 58'N	102° 07'E	189.50
Chaiyaphum	15° 45'N	102° 02'E	183.00
Nakhon Sawan	15° 48'N	100° 10'E	29.50
Lop Buri	14° 48'N	100° 37'E	14.50
Suphanburi	14° 30'N	100° 10'E	7.50
Prachinburi	14° 10'N	101° 10'E	5.99
Kanchanaburi	13° 55'N	100° 36E	12.30
Bangkok	13° 44'N	100° 30'E	12.41
Aranyaprathet	13° 42'N	102° 35'E	48.22
Chon Buri	13° 22'N	100° 59'E	4.22
Sattahip	12° 39'N	100° 53'E	55.67
Chanthaburi	12° 37'N	102° 07'E	5.30
Klong Yai	11° 47'N	102° 53'E	7.20
Ko Sichang	13° 09'N	100° 49'E	26.09
Hua Hin	12° 34'N	99° 48'E	4.50
Prachuap KhiriKhan	11° 48'N	99° 48'E	5.00
Chumphon	10° 27'N	99° 15'E	4.61
Surat Thani	09° 08'N	99° 18'E	11.30
Nakhon Si Thammarat	08° 25'N	99° 58'E	8.14
Songkhla	07° 11'N	100° 37'E	9.62
Narathiwat	06° 26'N	101° 50'E	4.81
Ranong	09° 58'N	98° 38'E	7.50
Phuket	07° 58'N	89° 24'E	3.14
Trang	07° 30'N	99° 40'E	15.66

The climatological data of these stations are collected during the period of 1951-1970. Five to eight observations at intervals of three hours each are taken daily at 01.00, 04.00, 07.00, 10.00, 13.00, 16.00, 19.00, and 22.00 local standard time.

From the available data, the value of the radio wave refractivity at the surface of the earth can be obtained by the following steps.

i) Changing the temperature from degree Celcius(°C)to degree Kelvin (K°) by adding 273 to each value.

ii) From mean temperature, read the value of saturated vapour pressure over water, e_s, from Smithsonian Meteorological Table 94, (APPENDIX III)

iii) The saturated vapour pressure obtained from (ii) is used for the calculation of the vapour pressure using the formula.

$$\text{Vapour pressure (e)} = e_s \times \frac{RH}{100} \text{ mb.}$$

Where RH, is the relative humidity, expressed in per-cent

iv) The radio wave refractivity at the surface of the earth, N_s, in various months are calculated by substituting the values of temperature, and vapour pressure, e (mb) in the formula.

$$N_s = \frac{77.6}{T} \left[P + \frac{4810\, e}{T} \right]$$

For example, the climatological data for the period 1951-1970, at Chiang Rai is shown in Table No.1.

Table No. 1

The climatological data for the period 1951-1970 at Chiang Rai

Month	P mb	T °C	RH (%)
January	1015.28	19.8	78.8
February	1012.40	21.7	71.3
March	1010.04	24.6	66.2
April	1008.23	27.3	65.4
May	1006.41	27.8	75.1
June	1004.99	27.3	81.4
July	1005.01	26.9	82.7
August	1005.32	26.5	85.3
September	1007.54	26.5	83.8
October	1011.93	25.2	82.6
November	1014.43	23.0	81.6
December	1016.01	20.2	81.6
Average	1009.80	24.7	78.0

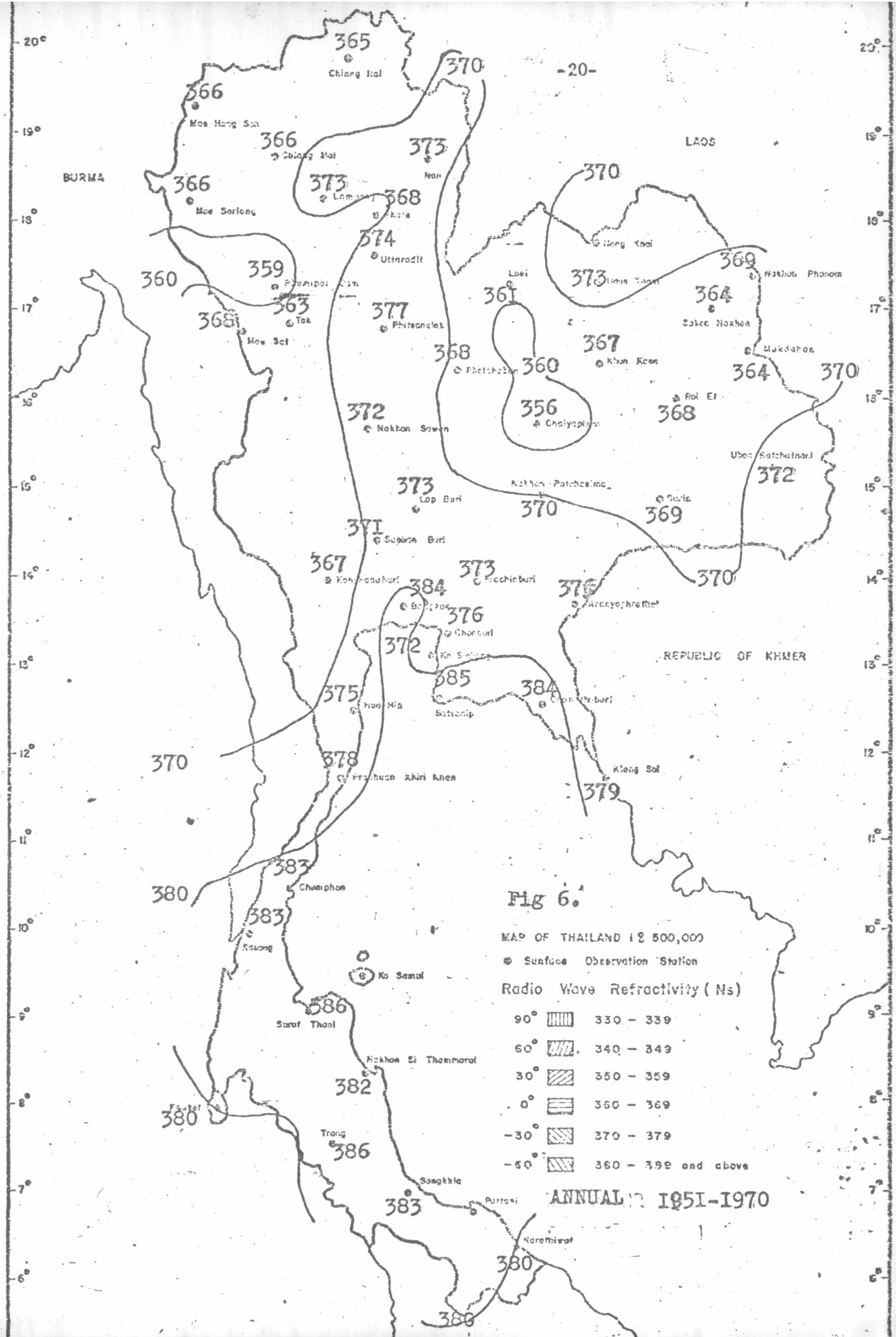
The given procedure of calculation gives the results as tabulated in Table No.2.

Table No. 2

Results calculated from climatological data for the period 1951-1970 at Chiang Rai

Month	T (°K)	e_s (mb)	e (mb)	N_s
January	292.8	23.085	18.191	348.28
February	294.7	25.950	18.483	346.02
March	297.6	30.932	20.471	349.65
April	300.3	36.282	23.728	360.13
May	300.8	37.358	28.056	375.37
June	300.3	36.282	29.534	381.94
July	299.9	35.440	29.309	381.68
August	299.5	34.615	29.527	383.34
September	299.5	34.615	29.007	381.76
October	298.2	32.050	26.473	376.98
November	296.0	28.086	22.918	363.58
December	293.2	23.664	19.310	352.75
Average	297.7	31.109	24.265	365.15

For the other values of the radio wave refractivity in each month of each weather station can be obtained by the same method of calculation. The results for the surface refractivity of the earth from 46 weather stations are shown in the map of Thailand for each month and year, the contour of the iso-refractivity lines are constructed as shown in Fig. 6 to 18. and the seasonal variation in average value N_s ($\overline{N^*_s}$) is shown in Fig. 18.a.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Mukdahan
Khon Kaen
Roi Et
Nakhon Sawan
Ubon Ratchathani
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Surin
Suphan Buri
Prachinburi
Aranyaprathet
Chonburi
Sattahip
Klong Yai
Prachuap Khiri Khan
Chumphon
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Surat Thani
Nakhon Si Thammarat
Trang
Songkhla
Pattani
Narathiwat
MAP OF THAILAND 1:2 500,000
Surface Observation Station
Radio Wave Refractivity (Ns)
90° 330 – 339
60° 340 – 349
30° 350 – 359
0° 360 – 369
-30° 370 – 379
-60° 380 – 399 and above
ANNUAL 1951-1970

Fig 6.

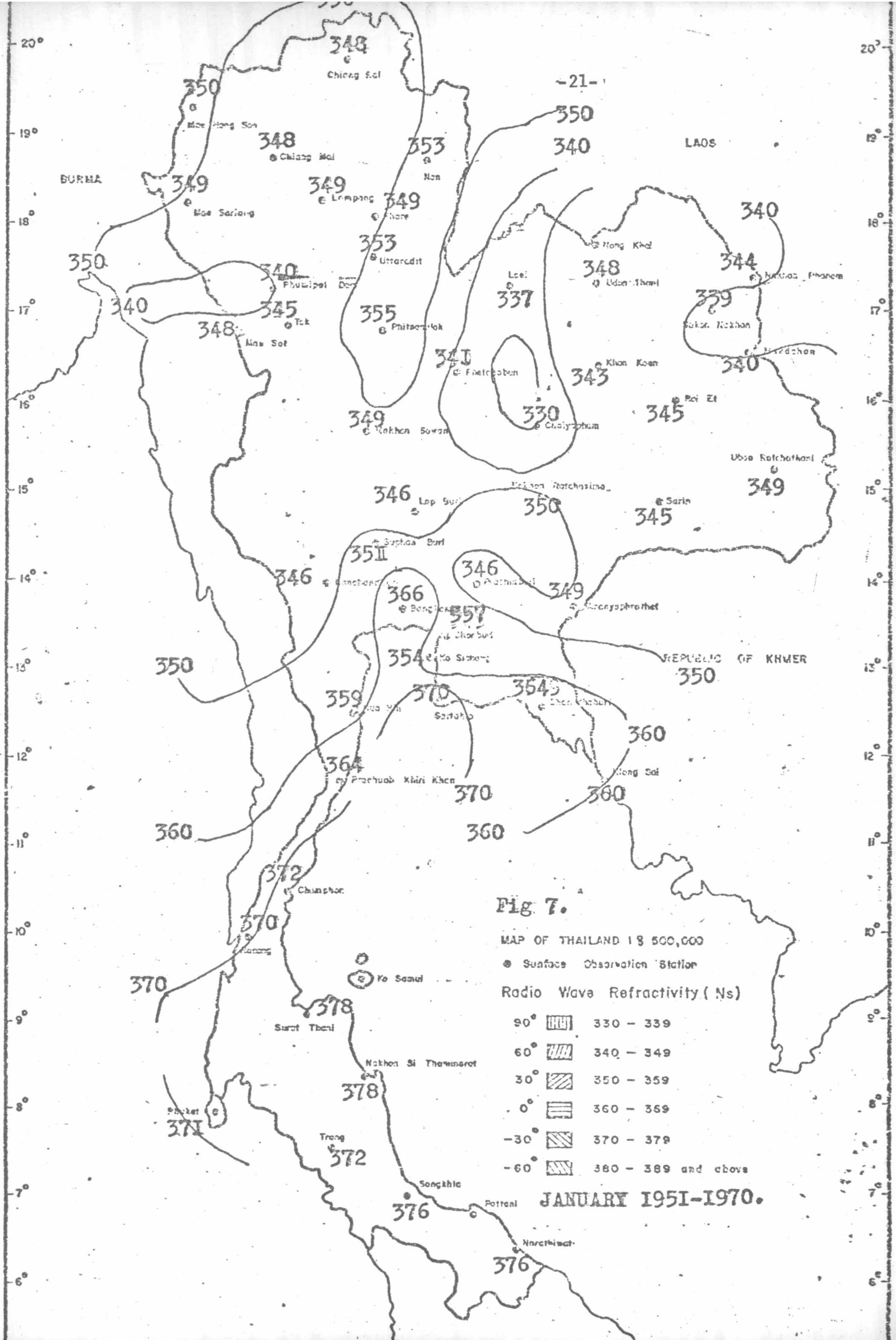


Fig. 7.

MAP OF THAILAND 1:8 500,000

● Surface Observation Station

Radio Wave Refractivity (Ns)

JANUARY 1951–1970.

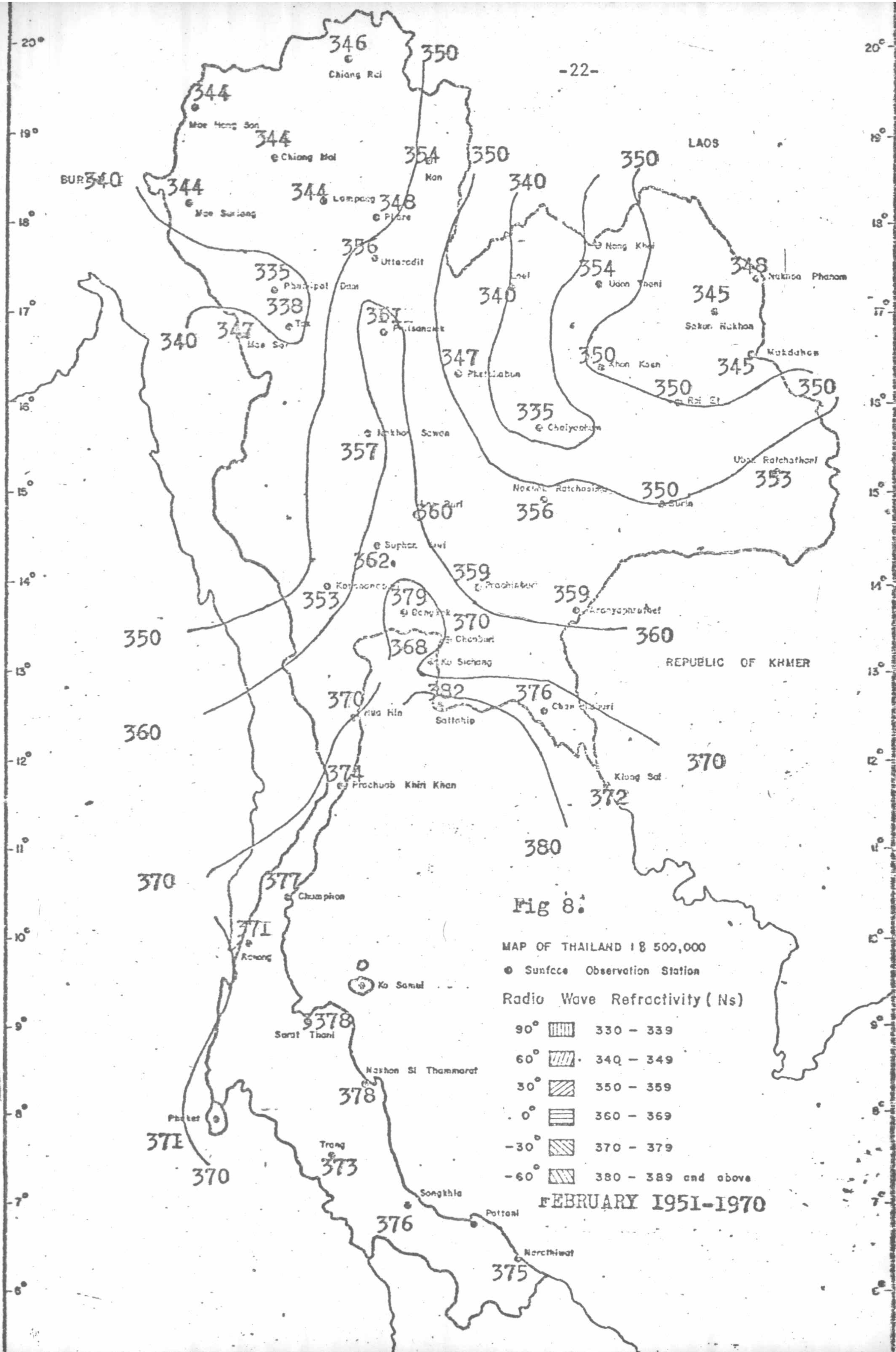
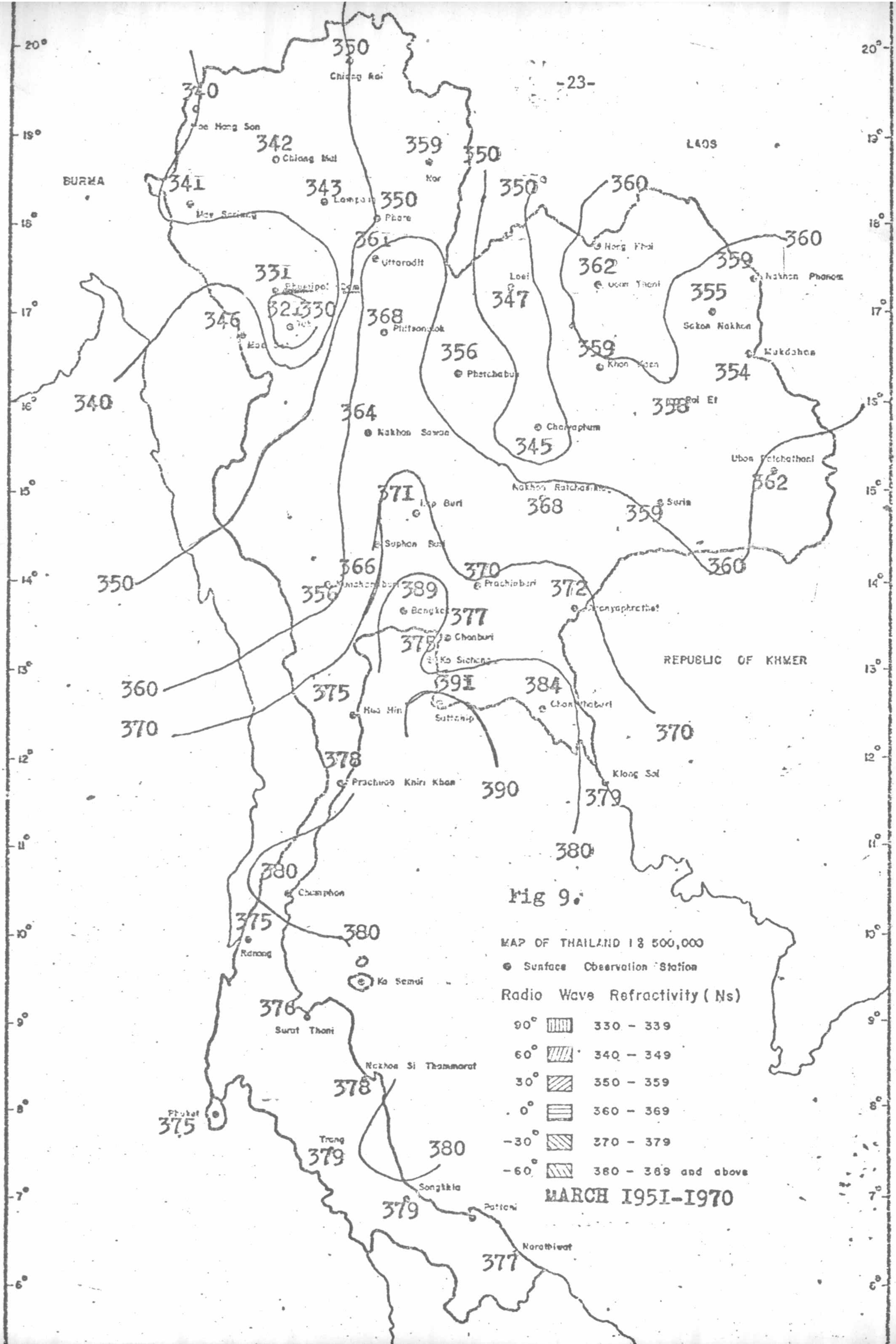


Fig 8.

FEBRUARY 1951-1970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Khon Kaen
Mukdahan
Phetchabun
Chaiyaphum
Nakhon Sawan
Roi Et
Ubon Ratchathani
Nakhon Ratchasima
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Lop Buri
Suphan Buri
Prachinburi
Bangkok
Chonburi
Ko Sichang
Sattahip
Chanthaburi
Klong Yai
Hua Hin
Prachuap Khiri Khan
Chumphon
Ranong
Ko Samui
Surat Thani
Nakhon Si Thammarat
Phuket
Trang
Songkhla
Pattani
Narathiwat
Fig 9.
MAP OF THAILAND 1:8 500,000
Surface Observation Station
Radio Wave Refractivity (Ns)
90° 330 - 339
60° 340 - 349
30° 350 - 359
0° 360 - 369
-30° 370 - 379
-60° 380 - 389 and above
MARCH 1951-1970

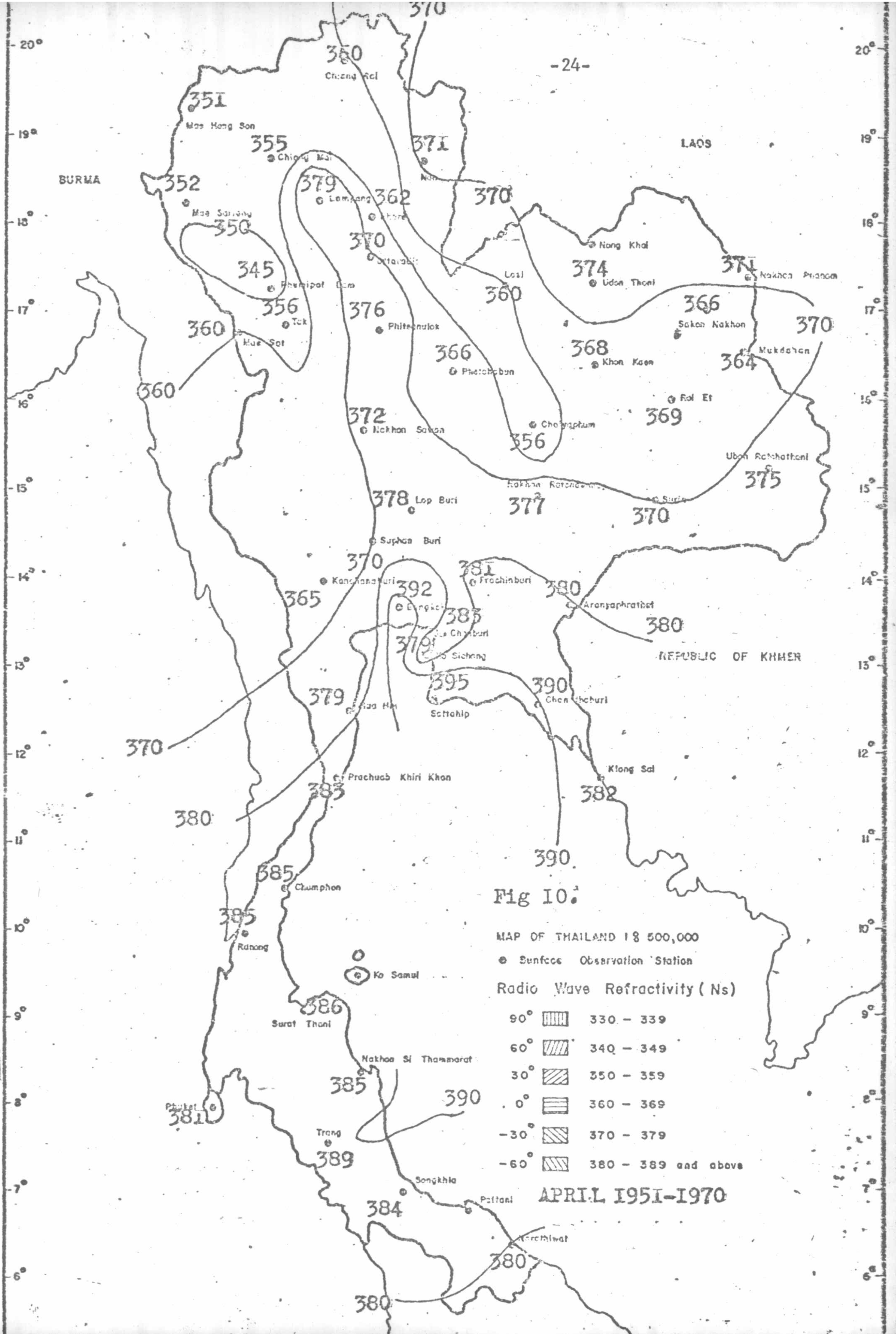


Fig 10.

APRIL 1951-1970

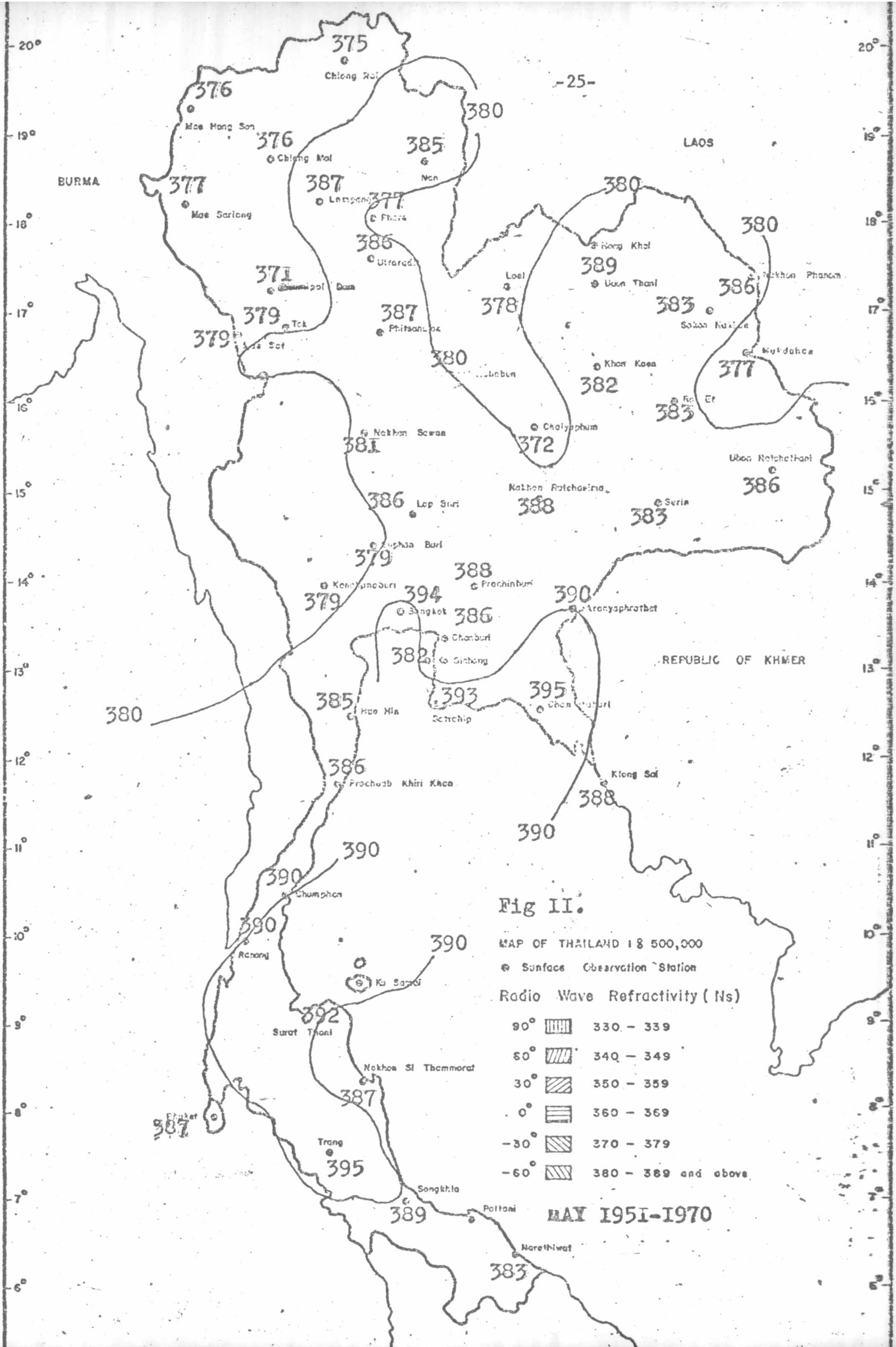


Fig II.

MAP OF THAILAND 1:8 500,000

⊙ Surface Observation Station

Radio Wave Refractivity (Ns)

90°		330 – 339
60°		340 – 349
30°		350 – 359
0°		360 – 369
-30°		370 – 379
-60°		380 – 389 and above

MAY 1951-1970

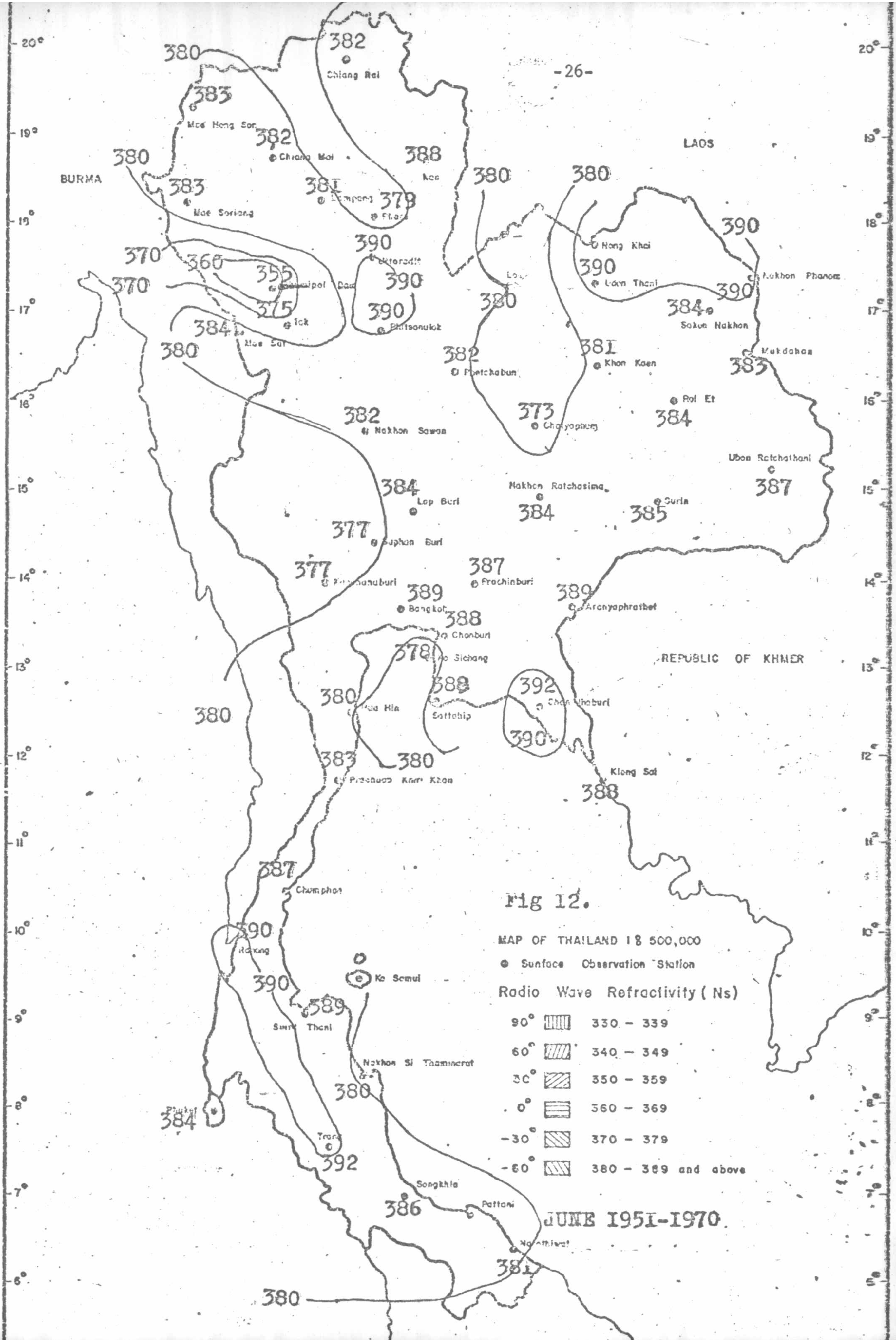


Fig 12.

JUNE 1951-1970.

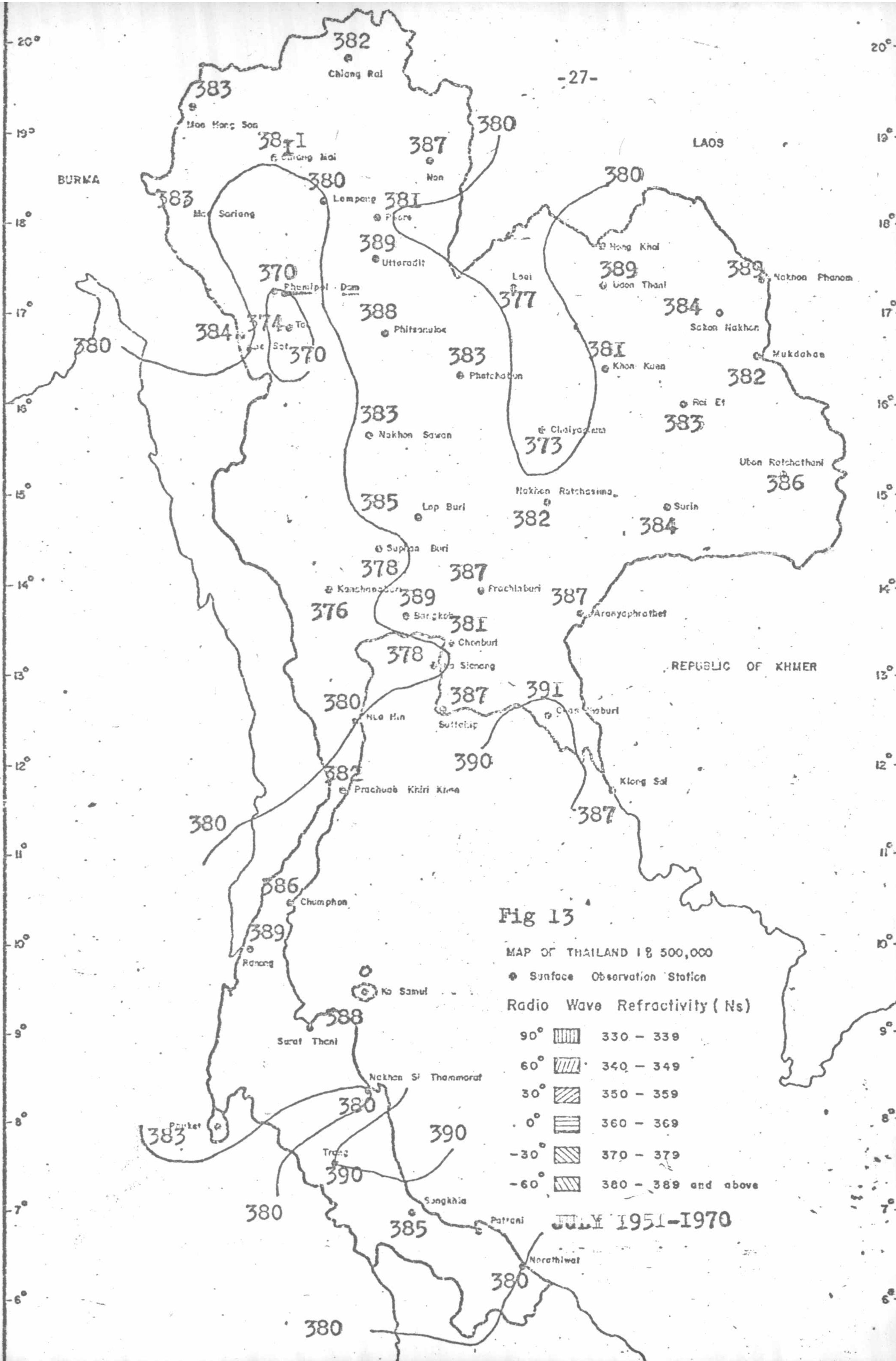


Fig 13

JULY 1951-1970

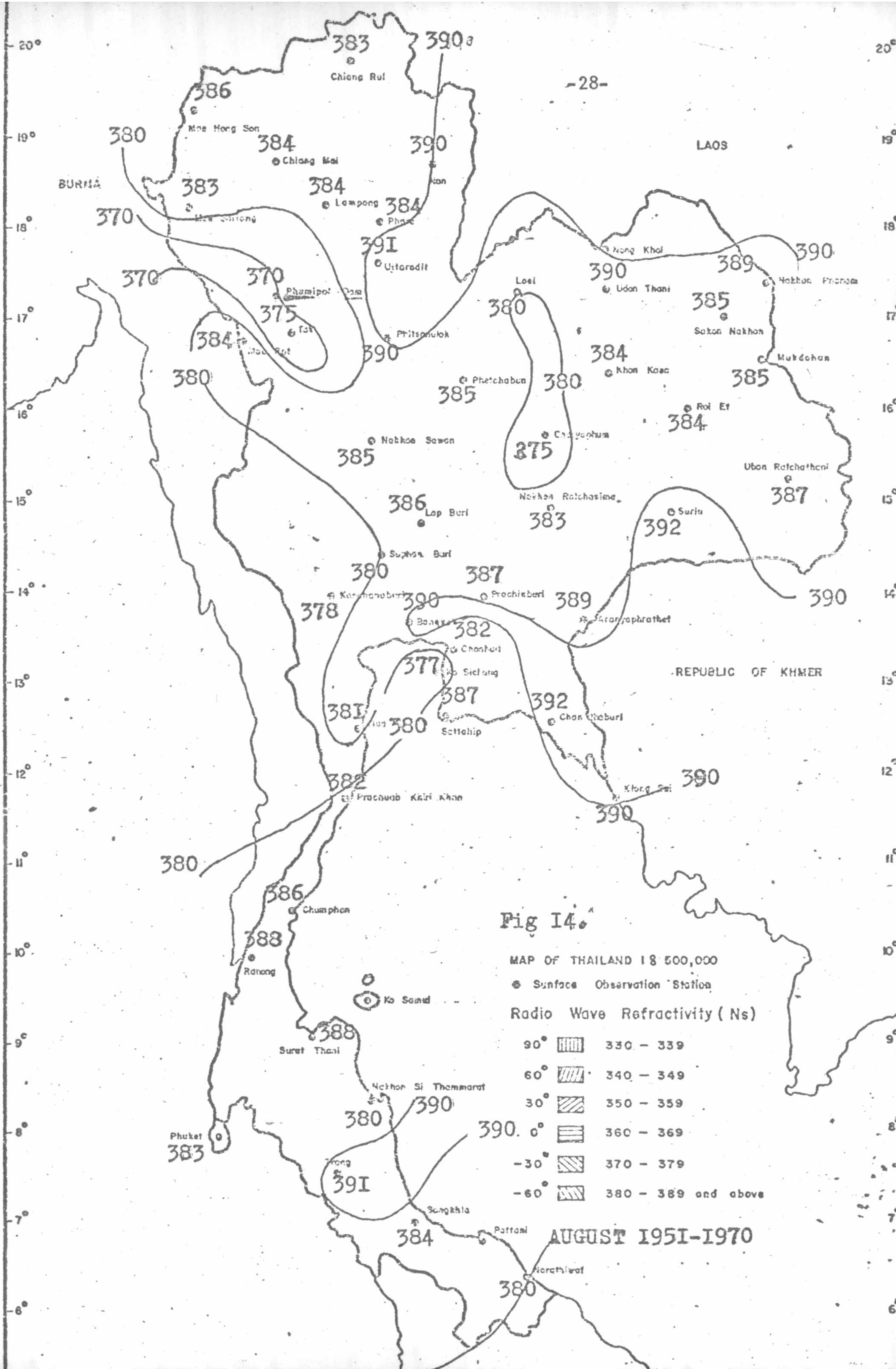
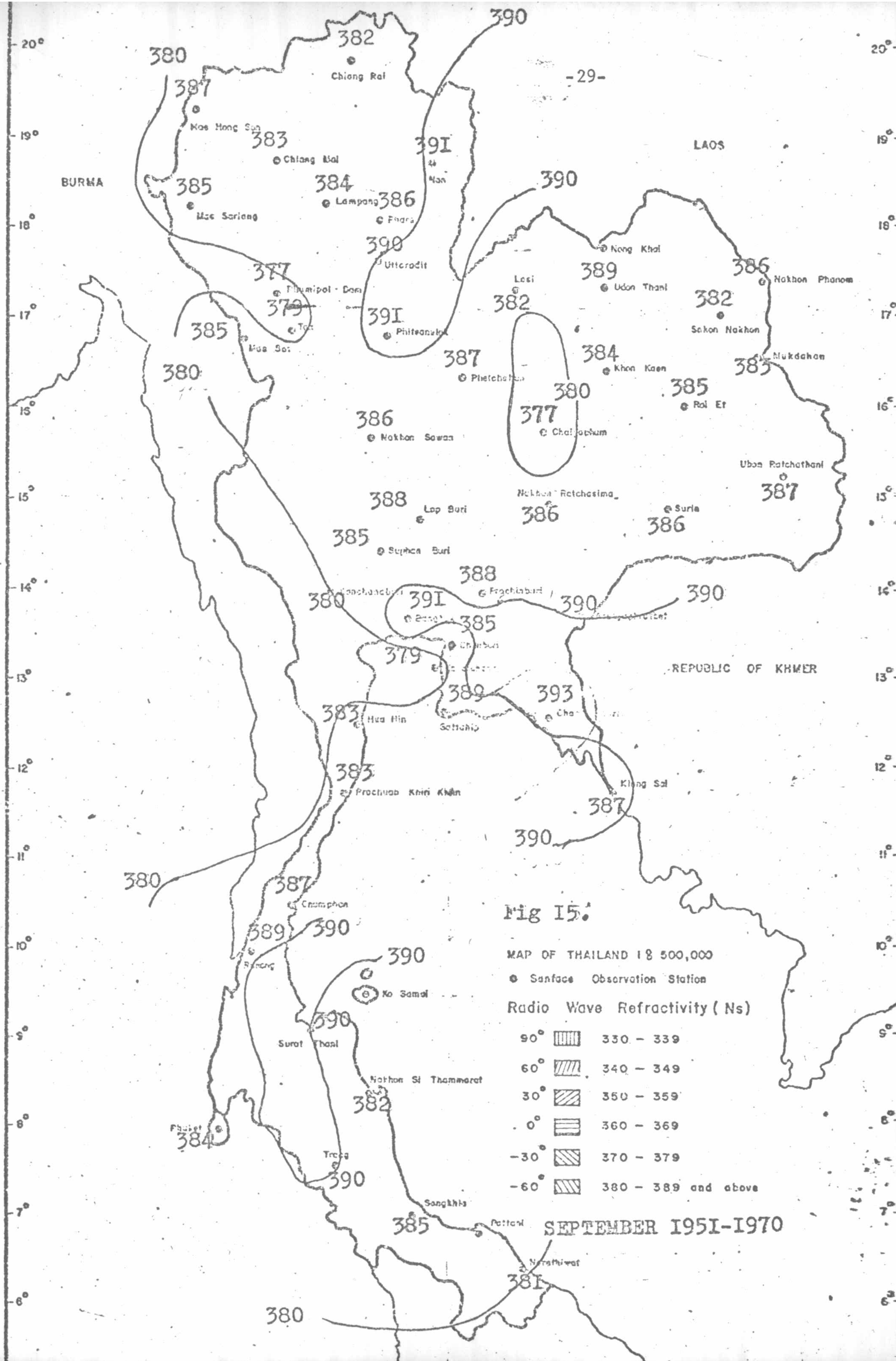


Fig I4.

AUGUST I95I-I970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Mae Sot
Phitsanulok
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Sattahip
Klong Yai
Prachuap Khiri Khan
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MAP OF THAILAND 1:500,000
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Radio Wave Refractivity (Ns)
90° 330 - 339
60° 340 - 349
30° 350 - 359
0° 360 - 369
-30° 370 - 379
-60° 380 - 389 and above
SEPTEMBER 1951-1970
Fig I5.

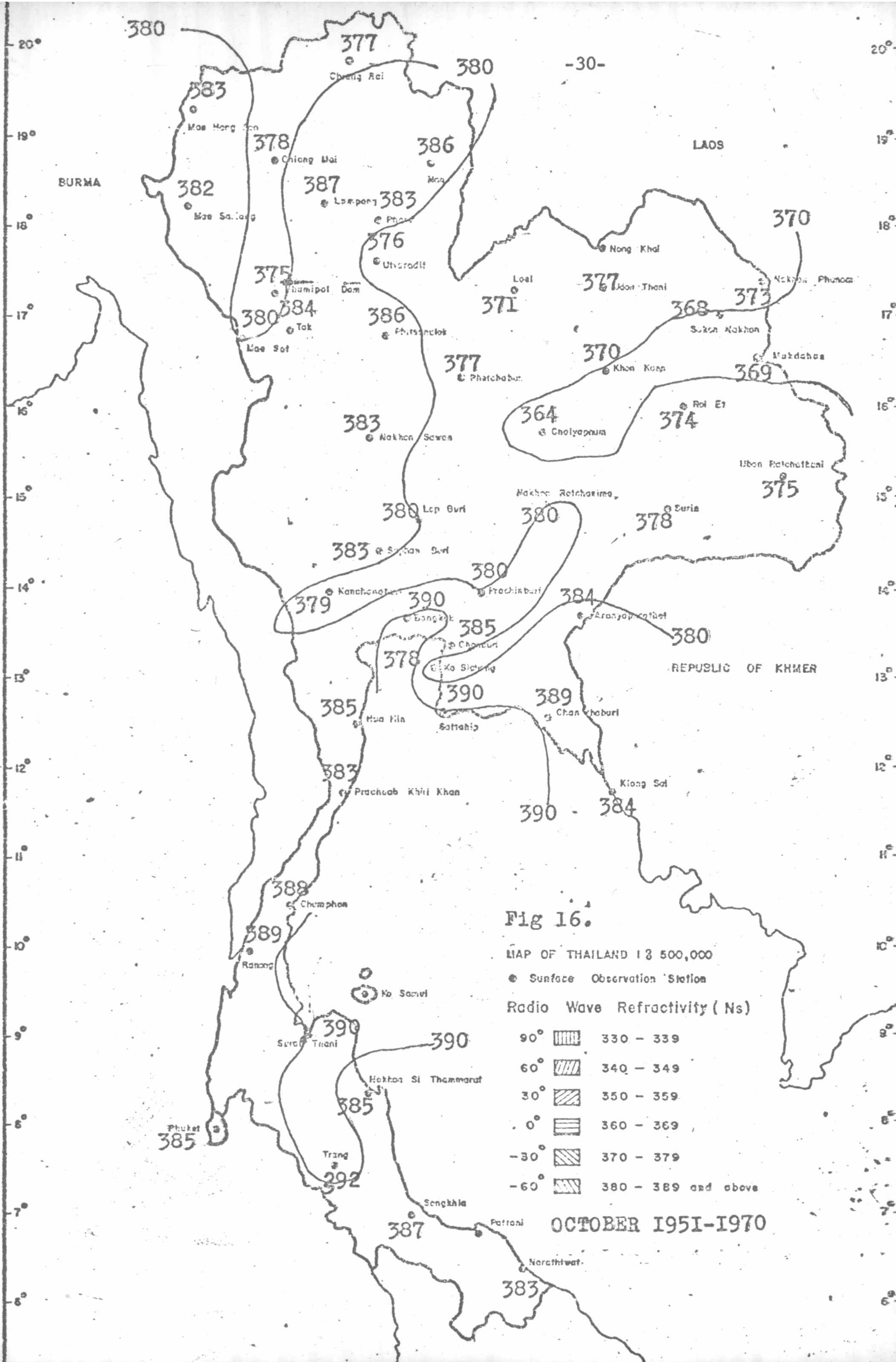


Fig 16.

MAP OF THAILAND 1:3 500,000

⊕ Surface Observation Station

Radio Wave Refractivity (Ns)

90°		330 - 339
60°		340 - 349
30°		350 - 359
0°		360 - 369
-30°		370 - 379
-60°		380 - 389 and above

OCTOBER 1951-1970

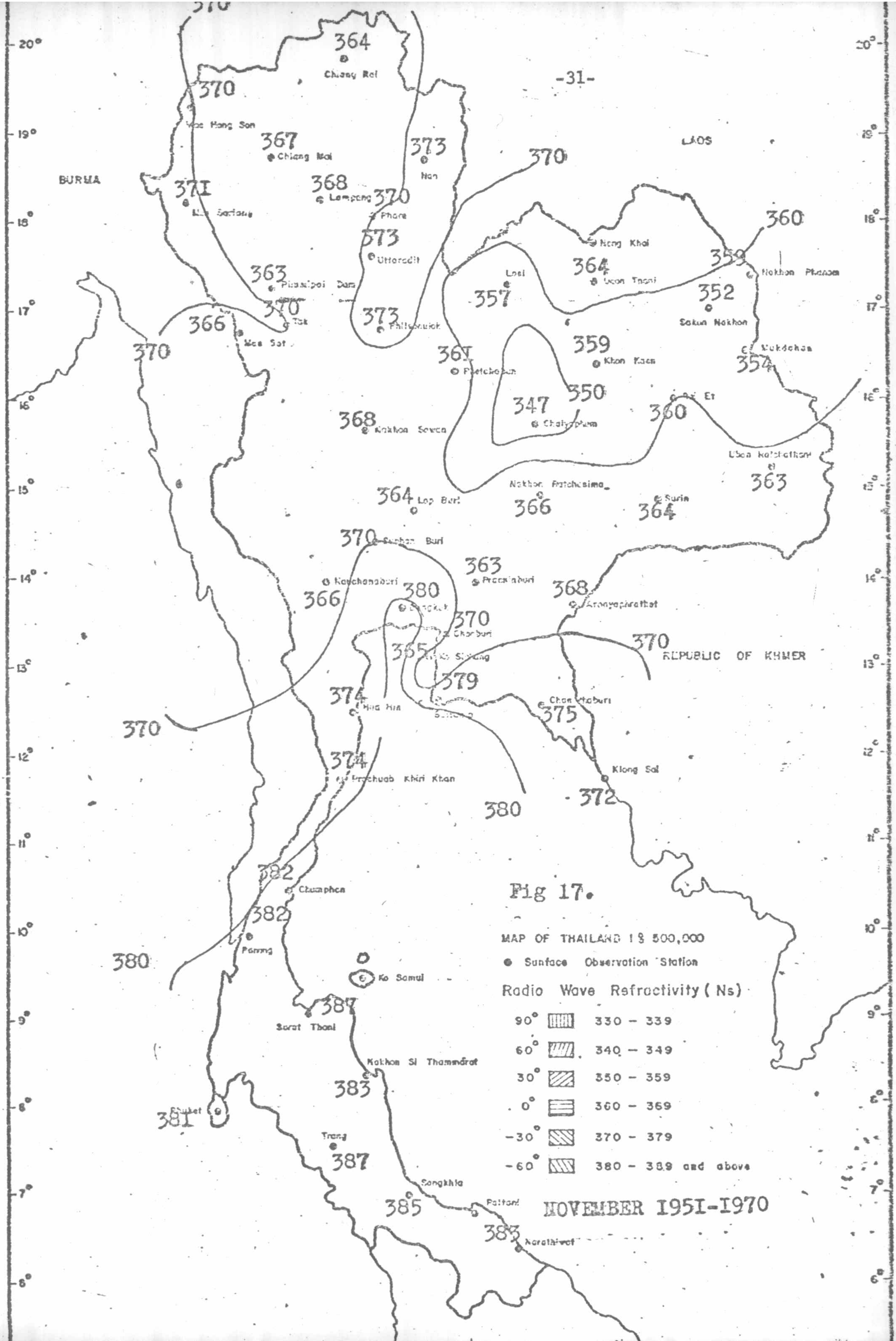
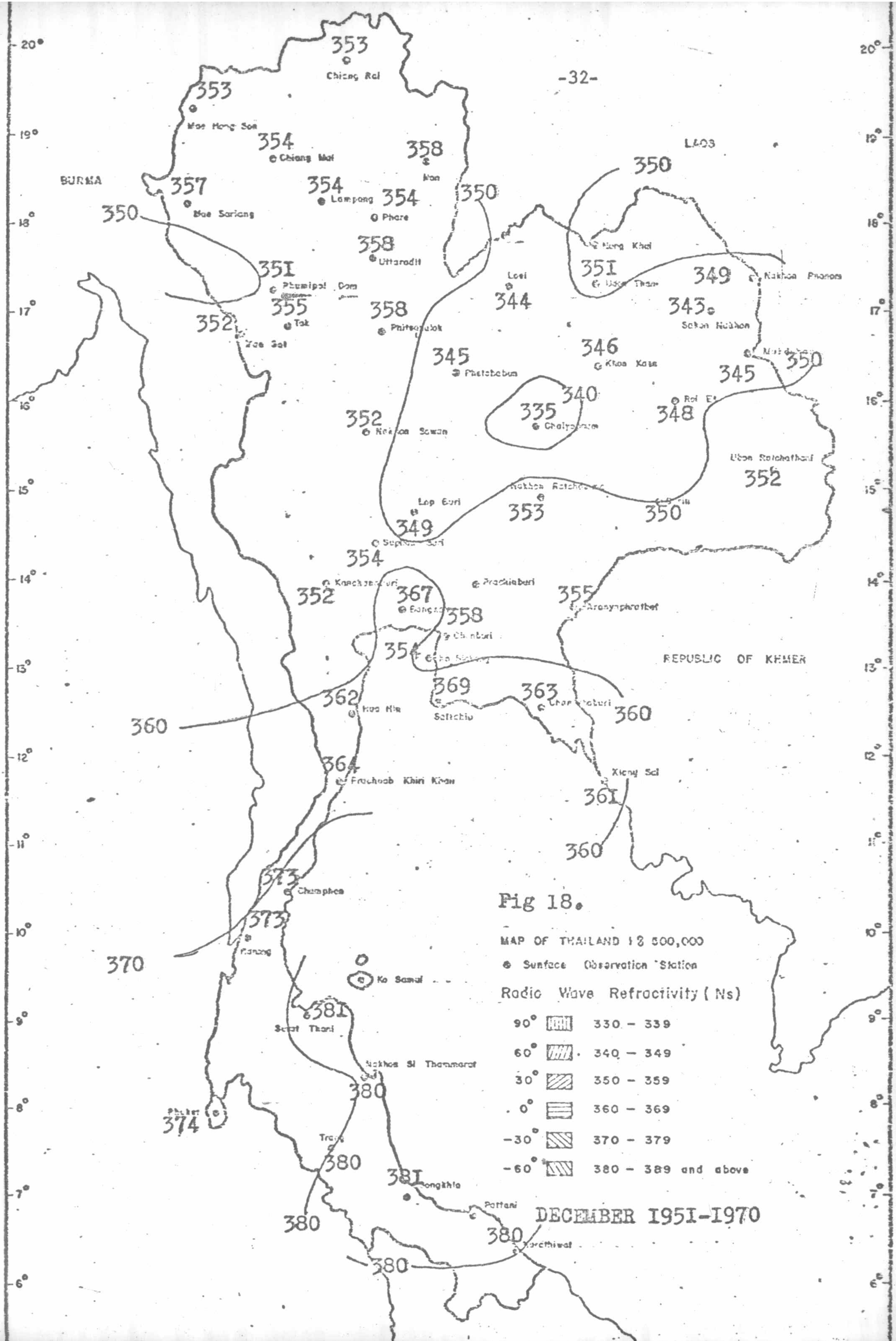


Fig 17.

NOVEMBER 1951-1970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MAP OF THAILAND 1:2 500,000
Surface Observation Station
Radio Wave Refractivity (Ns)
90° 330 – 339
60° 340 – 349
30° 350 – 359
0° 360 – 369
-30° 370 – 379
-60° 380 – 389 and above
DECEMBER 1951-1970
Fig 18.

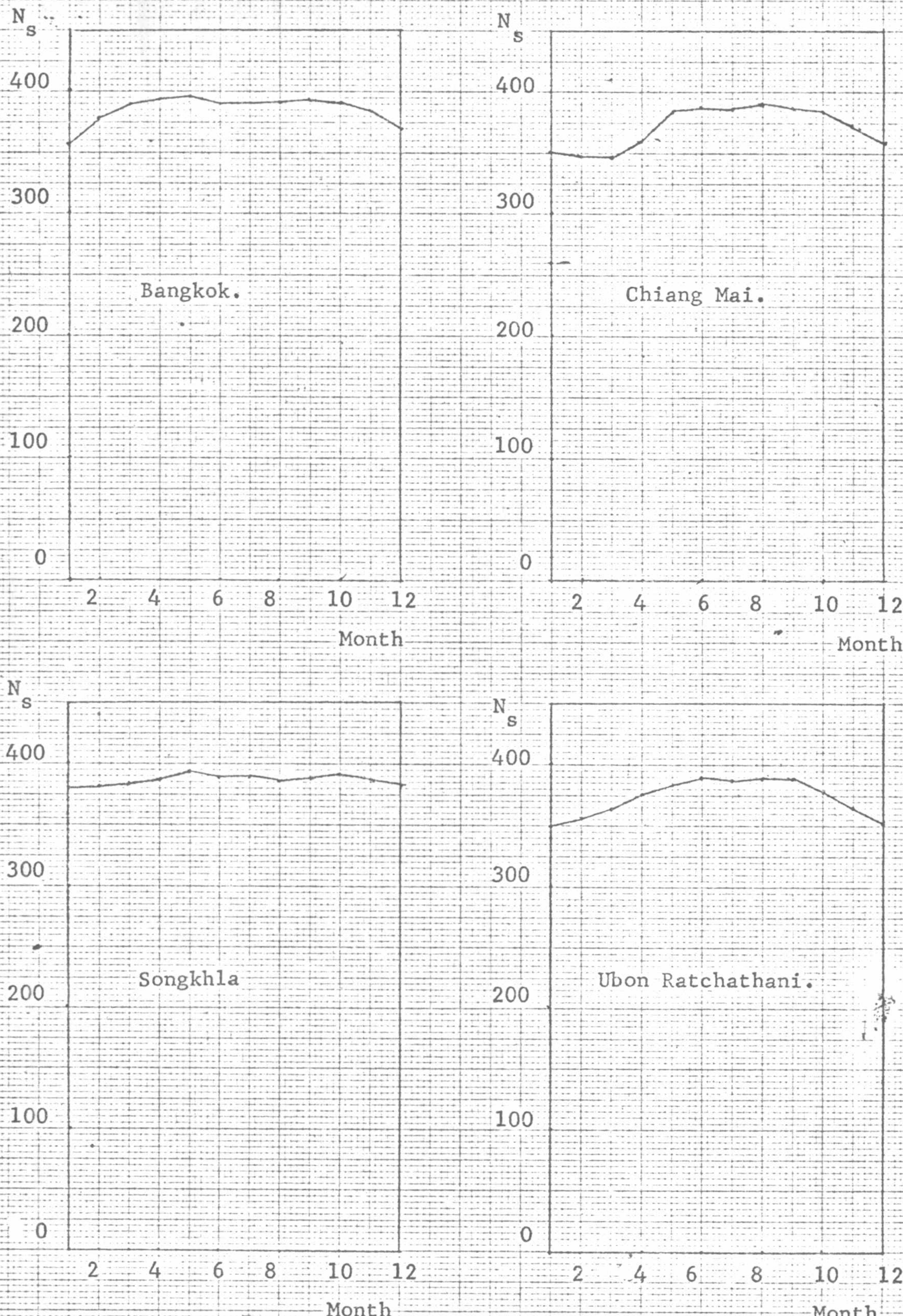


Fig. 18.a. Graph showing the seasonal variations of N_s

III.2 The determination of earth effective radius coefficient

There are four observed stations in Thailand, at Bangkok, Chiang Mai, Songkhla, and Ubon Ratchathani to collect data of atmospheric pressure, temperature, and relative humidity. The geometrical data of these stationsare tabulated below.

Station	Location	Latitude	Longitude	Elevation (m)
Bangkok	Central	13°44' N	100°30' E	13
Chiang Mai	Northern	18°47' N	98°59' E	314
Songkhla	Southern	07°11' N	100°37' E	5
Ubon Ratcha-thani	Northeastern	15°15' N	104°53' E	123

These stations are the only weather stations in Thailand using radiosonde to obtain the data of the atmosphere. A balloon carrying radiosonde equipment is launched every day at 0.00 SMT at each station. It sends down the required data from the ascending balloon to the receiving ground station by radio wave in FM system at frequency of 403 MHz. The ground station will record the data in the form of graph. From the graph the data are converted into discrete height, the corresponding atmospheric temperature, and dew-point temperature at the different atmospheric pressure levels. The data are shown at the durface of the earth and at the pressure level of 1000 mb, 850 mb, 700 mb, 400 mb, 300 mb, 200 mb, 150 mb, 100 mb, 70 mb, 50 mb, 30 mb, and 20 mb, respectively. The balloon carrying radiosonde weighted about 500 grams with ascending rate of 300 meters per minute. before launching, the base line of baroswitch, temperature element and hygrister are checked to make sure that the correct measurement will be obtained.

The data of atmospheric temperature, dew-point temperature and height are recorded daily. Then these data are averaged and published monthly in each five years for distribution to the public. Only the data during the period of 1966 to 1970 for the weather stations at Bangkok, Chiang Mai, Songkhla, and Ubon Ratchathani for recent data are used here.

From the available data, the value of refractivity the gradient of the refractive index, the earth effective radius coefficient and censtant b can be obtained by the following steps.

i) With the aid of a dew point slide rule we can calculate the relative humidity expressed in percent, from the values of dew-point temperature and atmospheric temperature which expressed in degree Celcius.

ii) Calculate the refractivity at different elevation by the same procedure as stated in section III.1.

iii) Plot refractivity, N versus height, H on graph papers. Use H as abscissa and N as ordinate.

vi) Evaluate the gradient of refractivity, $\frac{dN}{dH}$. To the first approximation, this can be done by assuming that $\frac{dN}{dH} = \frac{\Delta N}{\Delta H}$. This assumtion is quite reasonable if the graph is approximately linear in the interval. The values of N_s, H_s and $N_{s + 1\ km}$, $H_{s + 1\ km}$ are the value at the surface of the earth at the height of 1 kilometre above the earth surface respectively. Thus

$$\Delta N = N_s - N_{s + 1\ km}$$

$$\Delta H = H_s - H_{s + 1\ km}$$

since,

$$N = (n - 1) \times 10^{+6}$$

Therefore

$$\frac{dn}{dh} = 10^{-6} \frac{dN}{dH} = 10^{-6} \frac{\Delta N}{\Delta H}$$

v) The value of radio wave propagation constant (K) can be obtained by substution the value of $\frac{dn}{dh}$ to the formula.

$$K = \frac{1}{1 + a \frac{dn}{dh}}$$

vi) Calculate the value of constant b from the formular (1)-(5)

$$N = N_s \left[\exp. (-b) - 1 \right]$$

Sample of calculation, the data of January pressure, atmospheric temperature, and dew-point temperature of Ubon Ratchathani weather station for the period 1966 to 1970 are shown below.

GPM (m)	P (mb)	T (°C)	T_d (°C)
123.00	1014.54	19.10	15.70
1514.00	850.00	15.70	10.30
3141.00	700.00	7.10	-4.20
5851.00	500.00	-6.20	- 20.70
9656.00	300.00	-32.50	- 45.30

By the procedure which is mentioned before, the results calculated from the meteorological data above can be tabulated in Table No. 3.

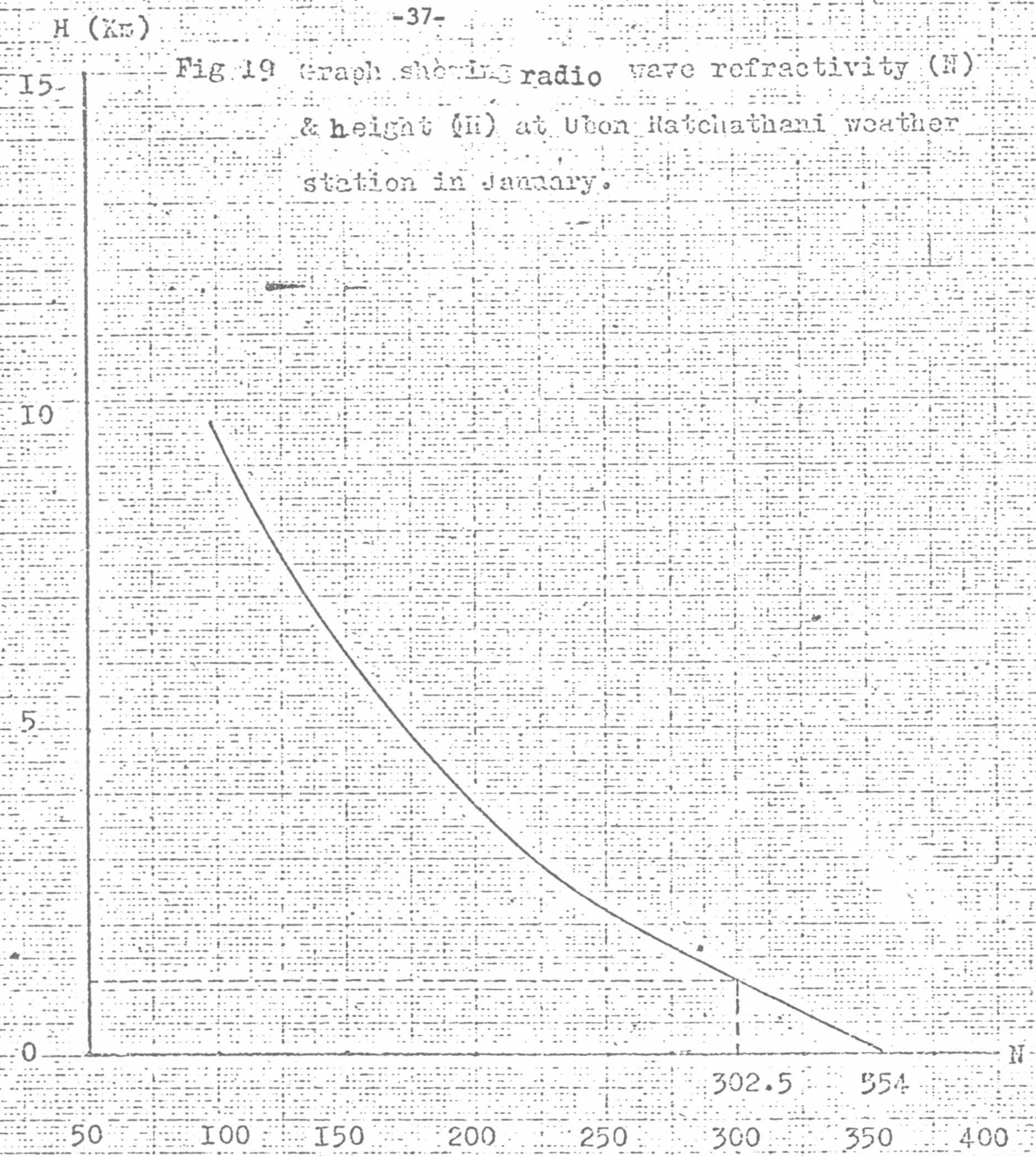
Table No.3

The results calculated from the meteorological data at Ubon Ratchathani weather station for the period 1966 to 1970 in January

H (GPM) (m)	T .C	e_s mb	RH %	e mb	N N-unit
123.00	19.10	22.101	87	19.228	354
1514.00	15.70	17.827	70	12.479	284
3141.00	7.10	10.082	44	4.436	215
5851.00	-6.20	3.622	31	1.123	151
9656.00	-32.50	0.292	27	0.079	97

From Table No. 3, The graph of N and H is obtained, as shown in Fig. 19, the value of K and b are evaluated. The other values of K and b can be evaluated by the same method.

Fig 19 Graph showing radio wave refractivity (N) & height (H) at Ubon Ratchathani weather station in January.



$\Delta N = 51.5$, $\Delta H = -1$ Km.

$$K = \frac{1}{1 + 6370\,(-51.5)\times 10^{-6}} = 1.49$$

$$\exp(-b) = 1 + \frac{51.5}{354} = 1.1455$$

$$b = -0.1358$$

III.3 The Relation between ΔN and N_s

For the relation between ΔN and N_s, the value of K and b that calculated from the radiosondes data is tabulated in Table No.4.

Table No.4

The value of earth effective radius coefficient and constant b.

Station	Bangkok		Chiang Mai		Songkhla		Ubon Ratcha-thani	
month	K	b	K	b	K	b	K	b
January	1.59	-0.1568	1.51	-0.1437	1.64	-0.1488	1.49	-0.1358
February	1.57	-0.1425	1.59	-0.1584	1.72	-0.1598	1.54	-0.1460
March	1.67	-0.1505	1.66	-0.1643	1.87	-0.1766	1.57	-0.1481
April	1.65	-0.1486	1.67	-0.1621	1.86	-0.1725	1.47	-0.1302
May	1.75	-0.1578	1.73	-0.1637	1.72	-0.1579	1.66	-0.1523
June	1.78	-0.1633	1.78	-0.1673	1.78	-0.1648	1.59	-0.1428
July	1.76	-0.1623	1.67	-0.1542	1.72	-0.1579	1.56	-0.1388
August	1.71	-0.1549	1.68	-0.1561	1.76	-0.1634	1.51	-0.1296
September	1.56	-0.1355	1.72	-0.1598	1.52	-0.1332	1.67	-0.1511
October	1.64	-0.1467	1.65	-0.1542	1.67	-0.1523	1.50	-0.1294
November	1.59	-0.1446	1.61	-0.1522	1.62	-0.1448	1.56	-0.1481
December	1.57	-0.1444	1.50	-0.1398	1.63	-0.1485	1.54	-0.1460
Sum	19.84	-1.8029	19.77	-1.8722	20.51	-1.8807	18.66	-1.6982
Average	1.65	-0.1502	1.65	-0.1560	1.71	-0.1567	1.55	-0.1415

The mean value of K, $(\overline{K})$, can be done by $\overline{K} = \Sigma K/n$, n is number of K.

$$\overline{K} = \frac{19.84+19.77+20.51+18.66}{48} = 1.64$$

Then the value of standard deviation, σ, is calculated by the formula

$$\sigma = \sqrt{\frac{\sum(K - \overline{K})^2}{(n - 1)}} = 0.979\times10^{-2}$$

The mean value and the standard deviation for the values of K and b are

$$\bar{K} = 1.64, \qquad \sigma_k = 0.979 \times 10^{-2}.$$

$$\bar{b} = -0.1511 , \qquad \sigma_b = 0.1336 \times 10^{-3}$$

The variation of the mean values of the refractive index of the atmesphere may be approximated by the following exponential formula

$$n(h) = 1 + N_s \exp (0.1511\ h) \times 10^{-6}$$

where

N_s = the radio wave refractivity at the surface of the earth

h = the height above the surface of the earth expressed in kilometres

From the above relation N at a difference height of 1 km above the surface of the earth is determined by

$$\Delta N = N_s \left[\exp (-b) - 1 \right]$$

$$= N_s \left[\exp (-0.1511) - 1 \right]$$

$$= 0.1631\ N_s$$

The value of K is,

$$K = \frac{1}{1 + 6370\ (0.1631 N_s) \times 10^{-6}}$$

$$= \frac{1}{1 + 0.00104\ N_s} = \frac{a_e}{a}$$

and the value of a_e

$$a_e = \frac{6370}{1 + 0.00104\ N_s}$$

The values of N_s in relation to the values of K and a_e at a difference height of 1 km. is tabulated in Table No.5.

Table No.5

The relation between N_s and ΔN , K , a_e .

N_s N-unit	ΔN N-unit	K	ae Km
100	16.31	1.12	7,109
150	24.47	1.19	7,547
200	32.62	1.26	8,043
250	40.78	1.35	8,600
300	48.93	1.45	9,259
350	57.09	1.57	10,016
400	65.42	1.71	10,908
450	73.40	1.88	11,974
500	81.55	2.08	13,250
550	89.71	2.34	14,906
600	97.86	2.66	16,942

The relation between N_s and a_e is plotted in Fig. 20, and the relation between N_s and K is shown in Fig. 21.

The relation between N_s and K in Fig.21 is used to make contour of K in the map of Thailand , and the map of earth effective radius coefficient of Thailand are drawn in Figs. 22 to 34.

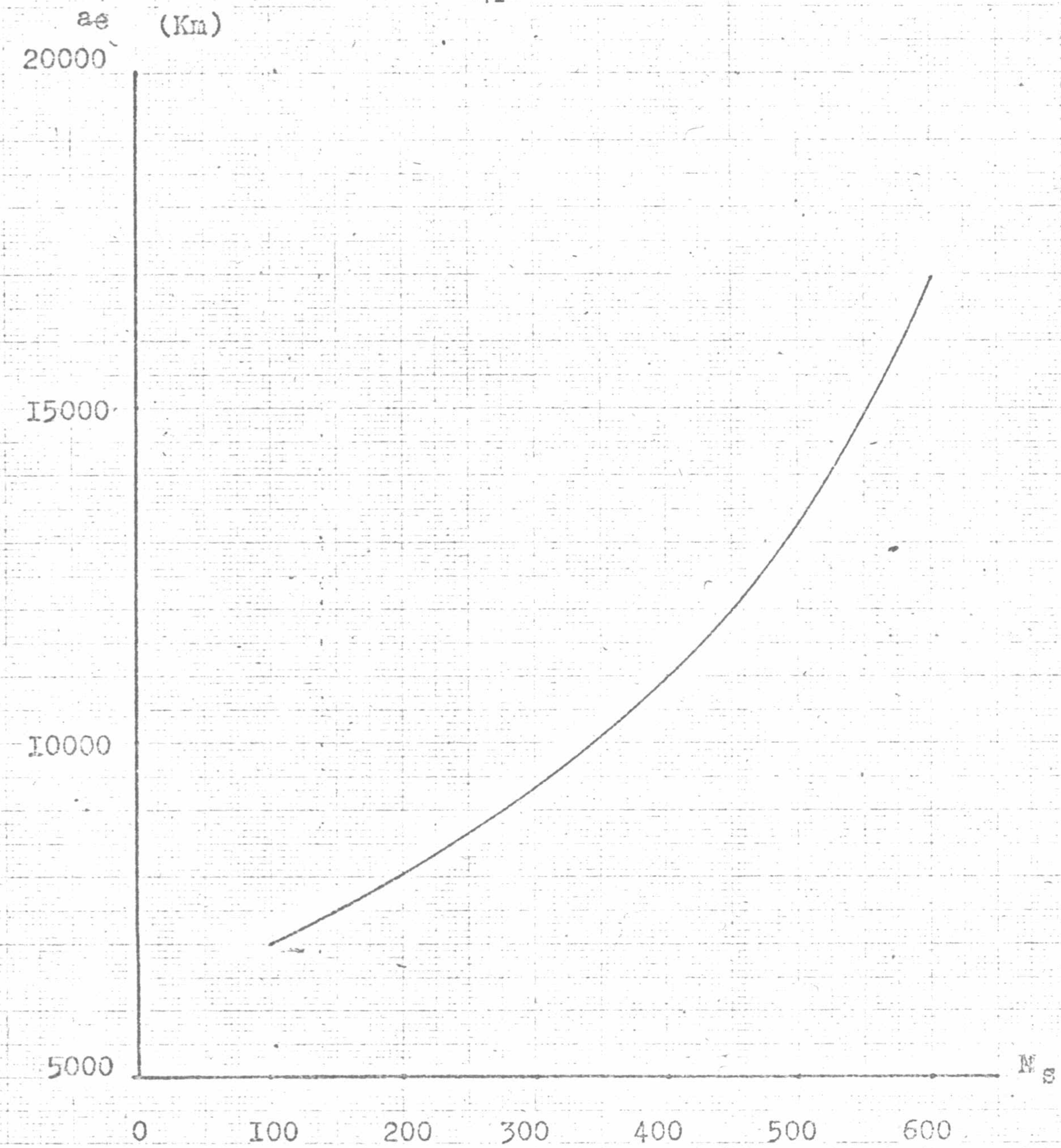


Fig 20 Graph showing the relation between the radio wave refractivity at the surface(N_s) and the earth effective radius (a_e).

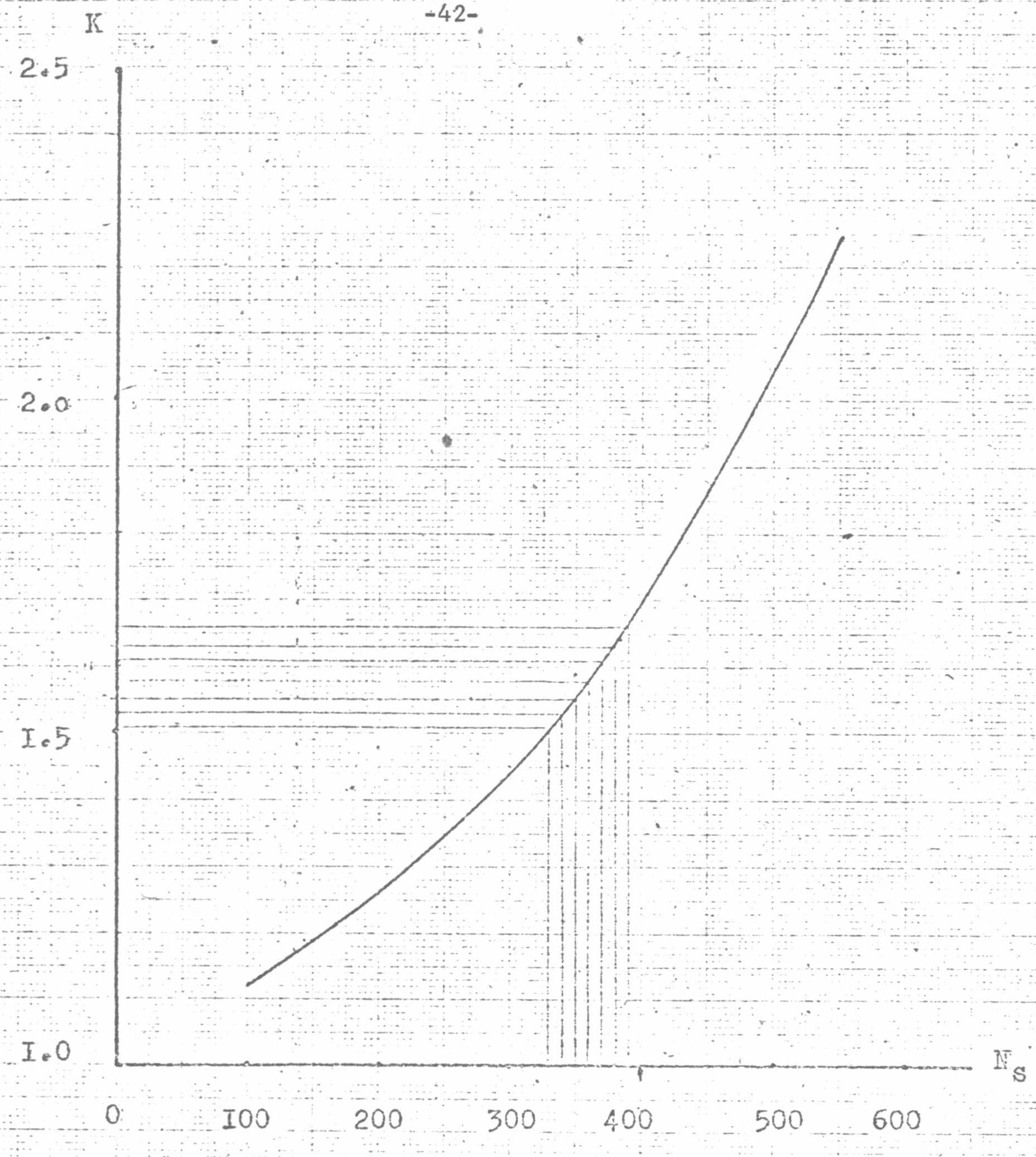


Fig 2I Graph showing the relation between the radio wave refractivity at the surface (N_s) and the radio wave propagation constant (K)

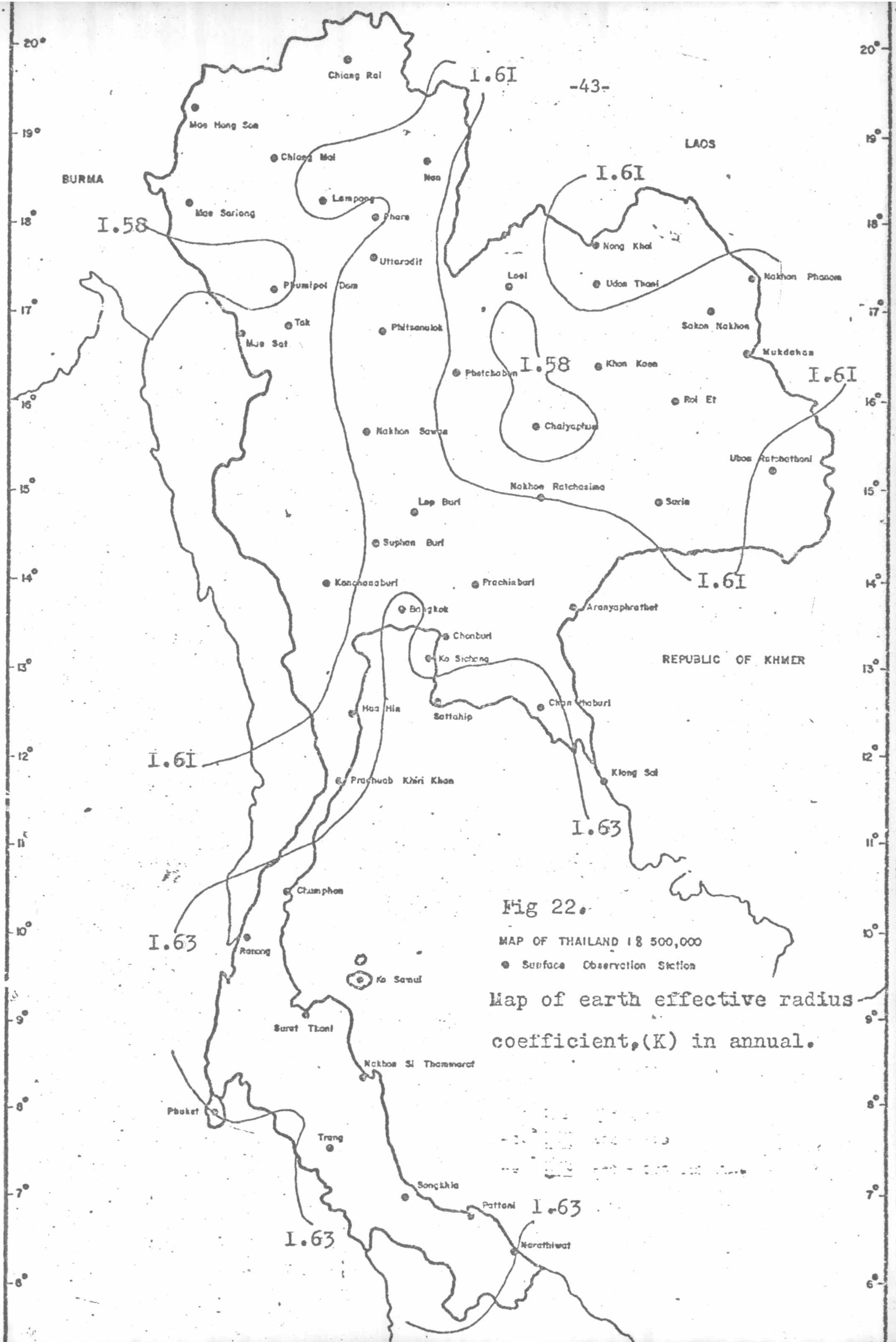


Fig 22.

Map of earth effective radius coefficient,(K) in annual.

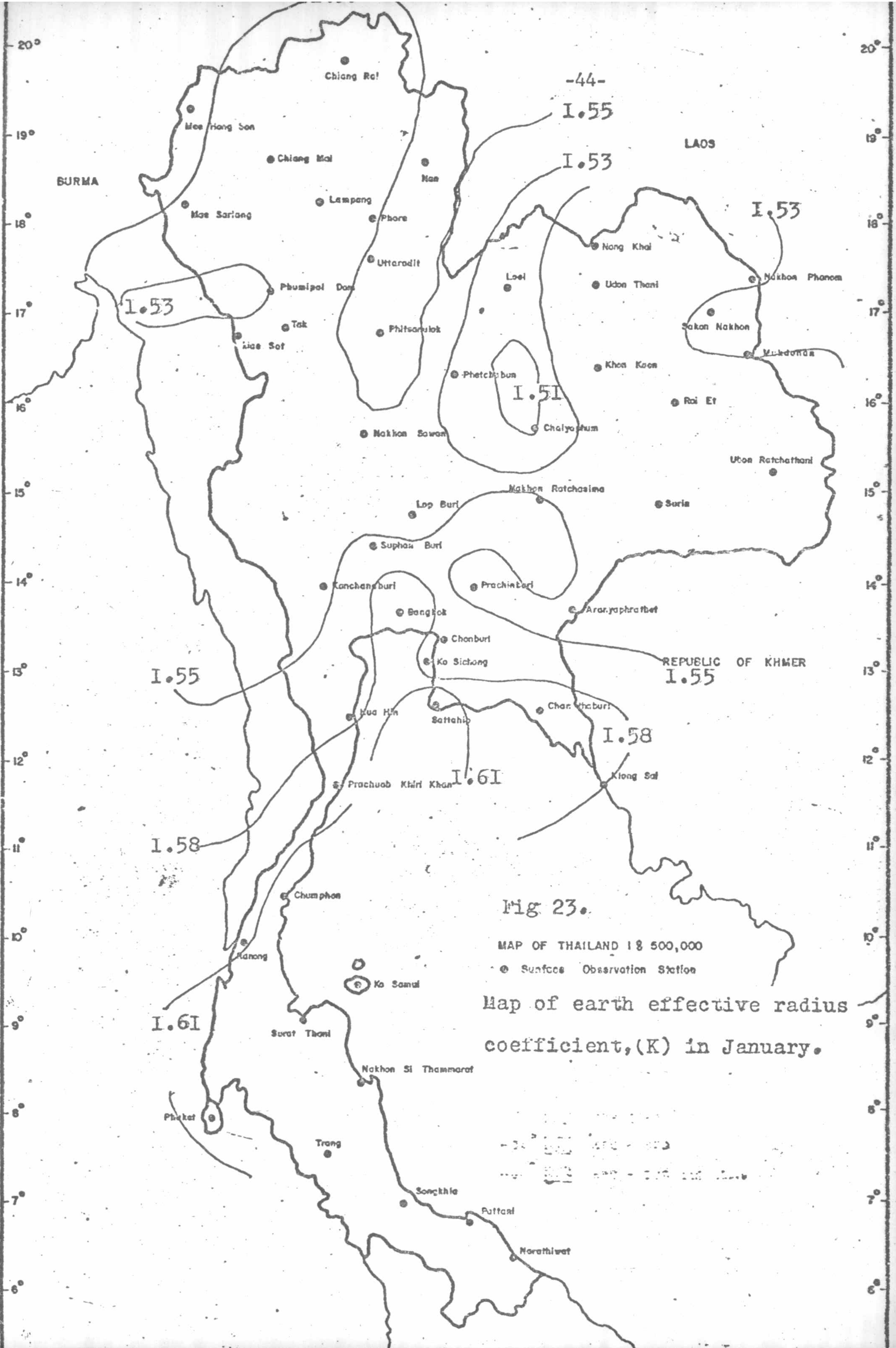


Fig 23.

MAP OF THAILAND 1:8 500,000

⊙ Surface Observation Station

Map of earth effective radius coefficient,(K) in January.

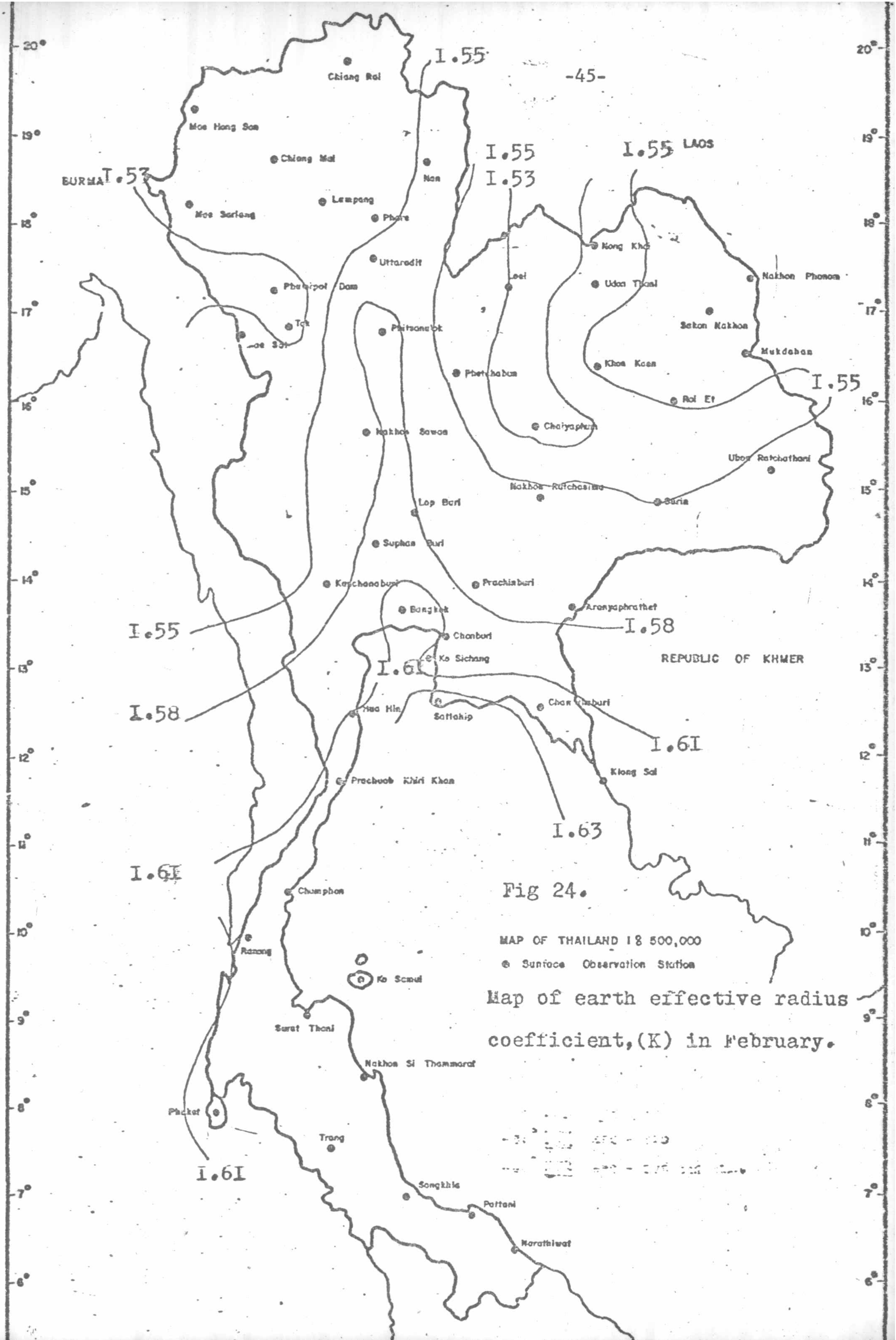


Fig 24.

Map of earth effective radius coefficient,(K) in February.

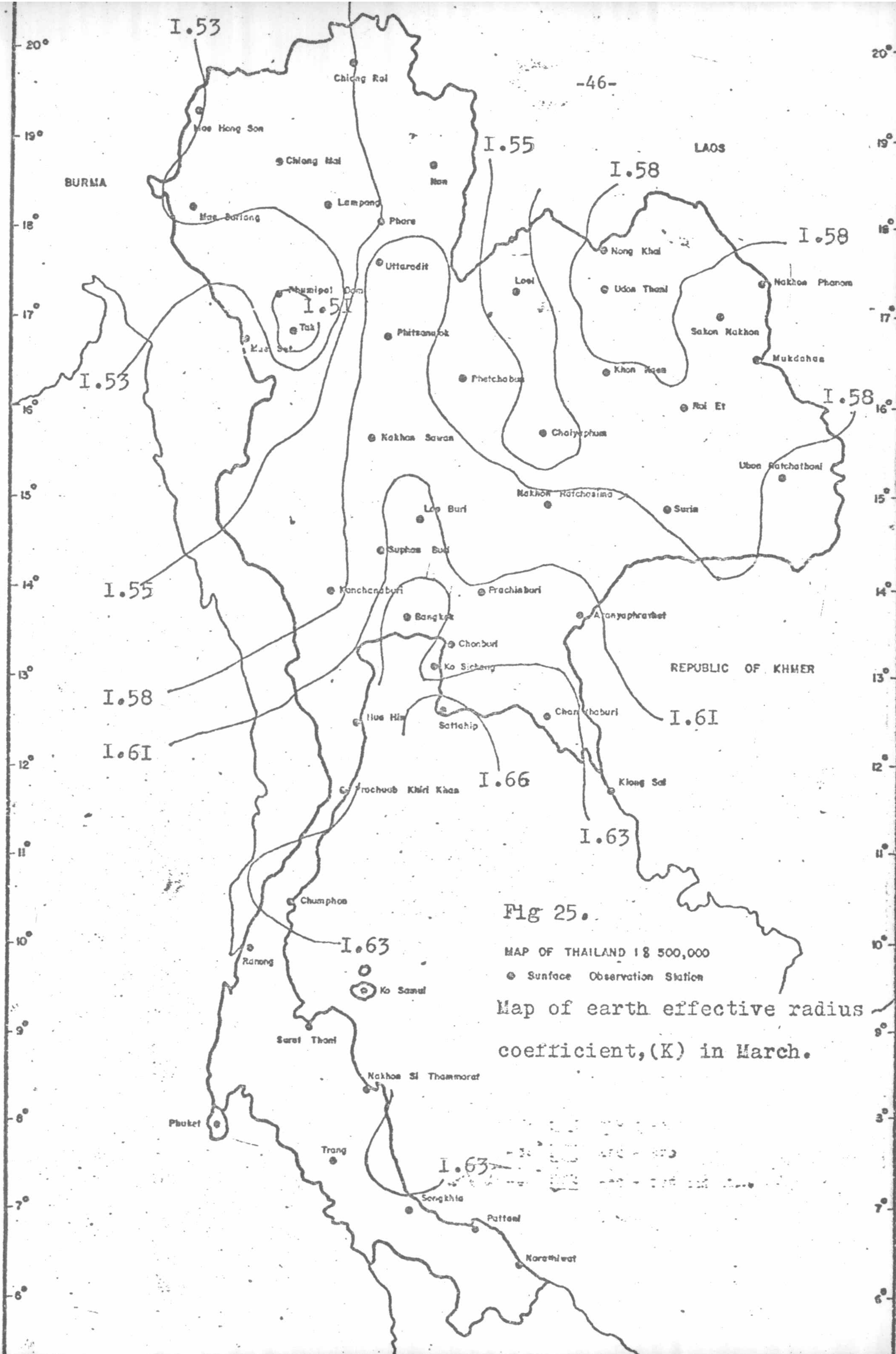


Fig 25.

Map of earth effective radius coefficient, (K) in March.

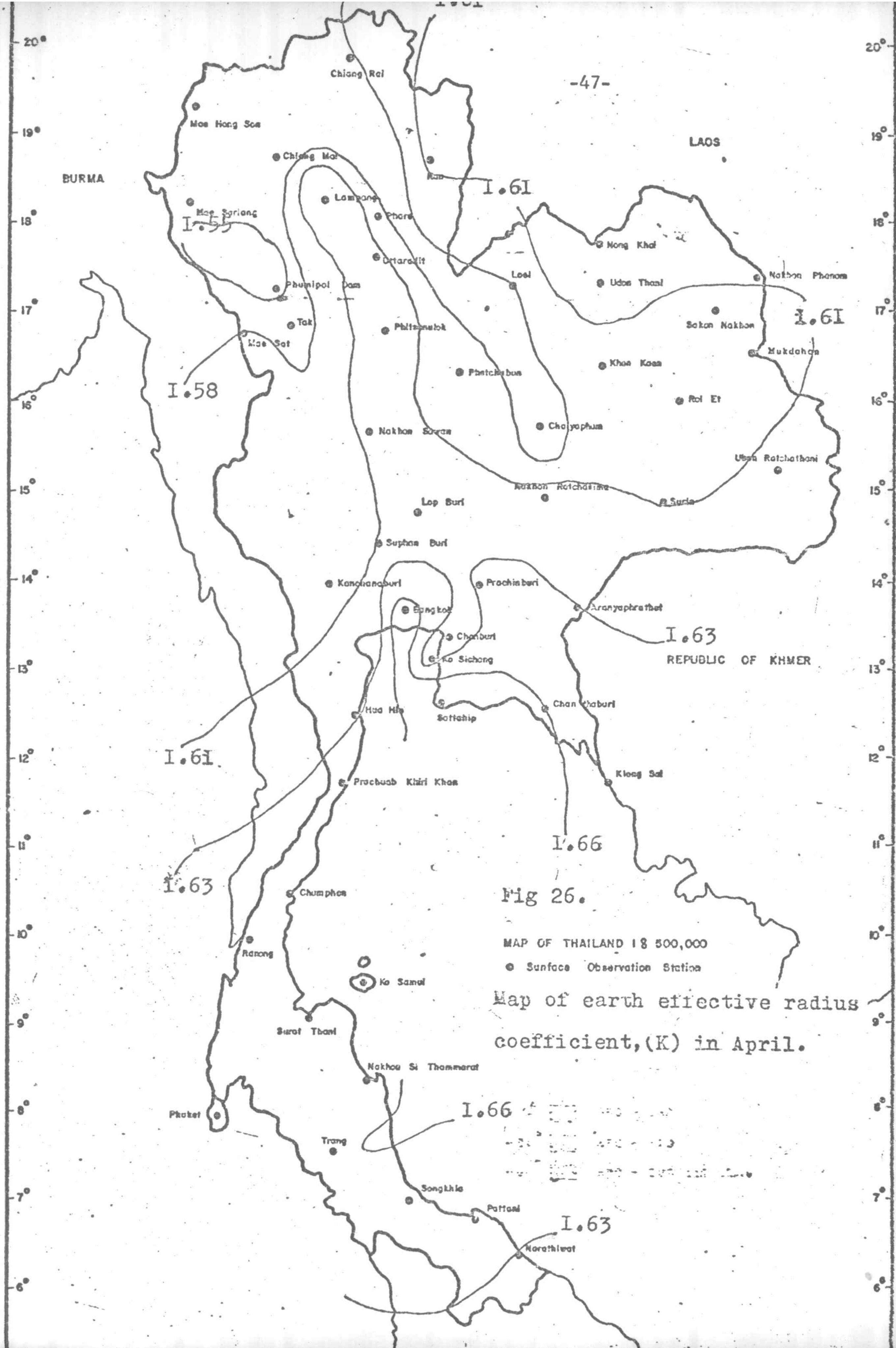


Fig 26.

MAP OF THAILAND 1:8 500,000

● Surface Observation Station

Map of earth effective radius coefficient,(K) in April.

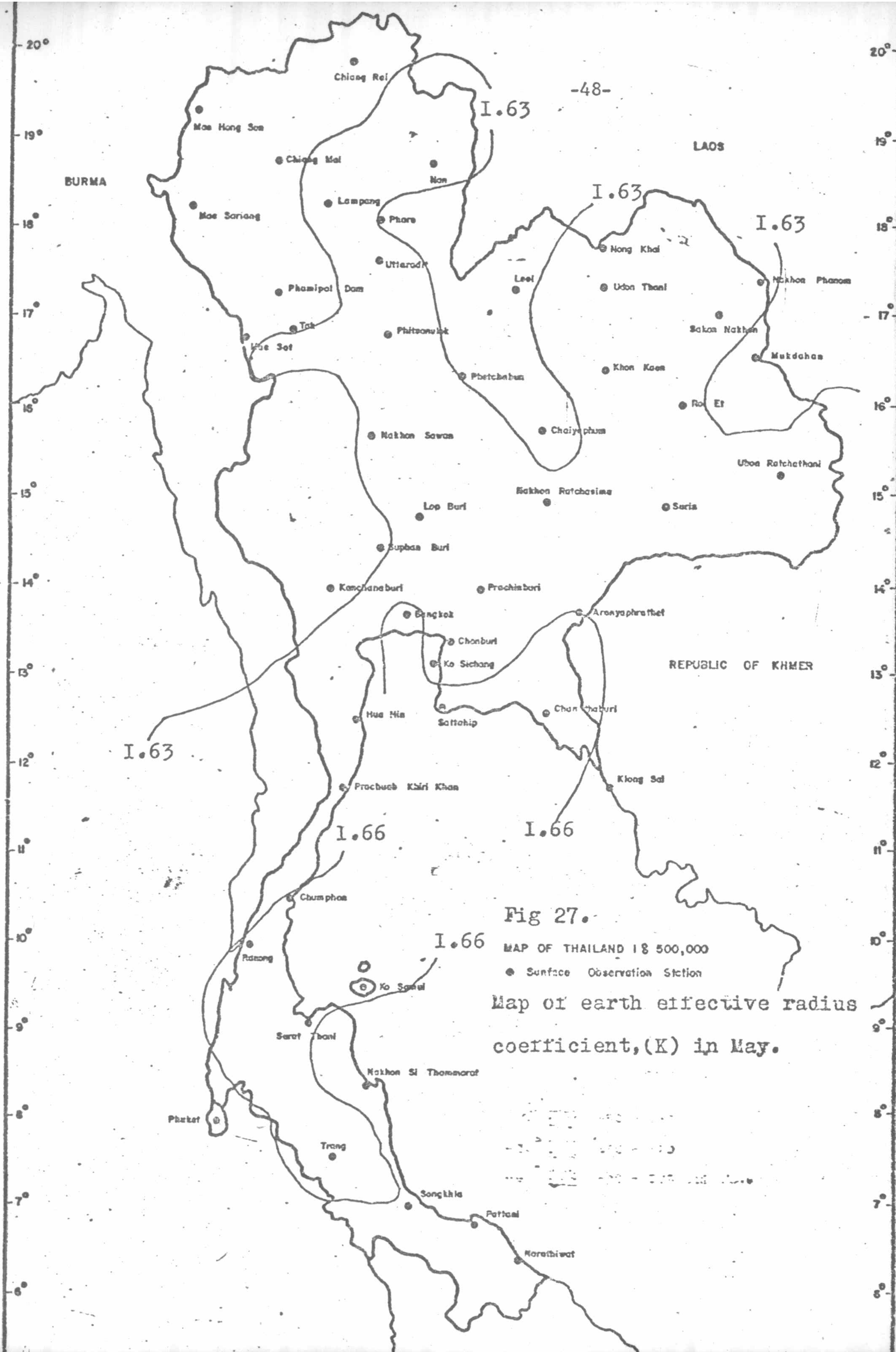


Fig 27.

MAP OF THAILAND 1 : 500,000

● Surface Observation Station

Map of earth effective radius coefficient,(K) in May.

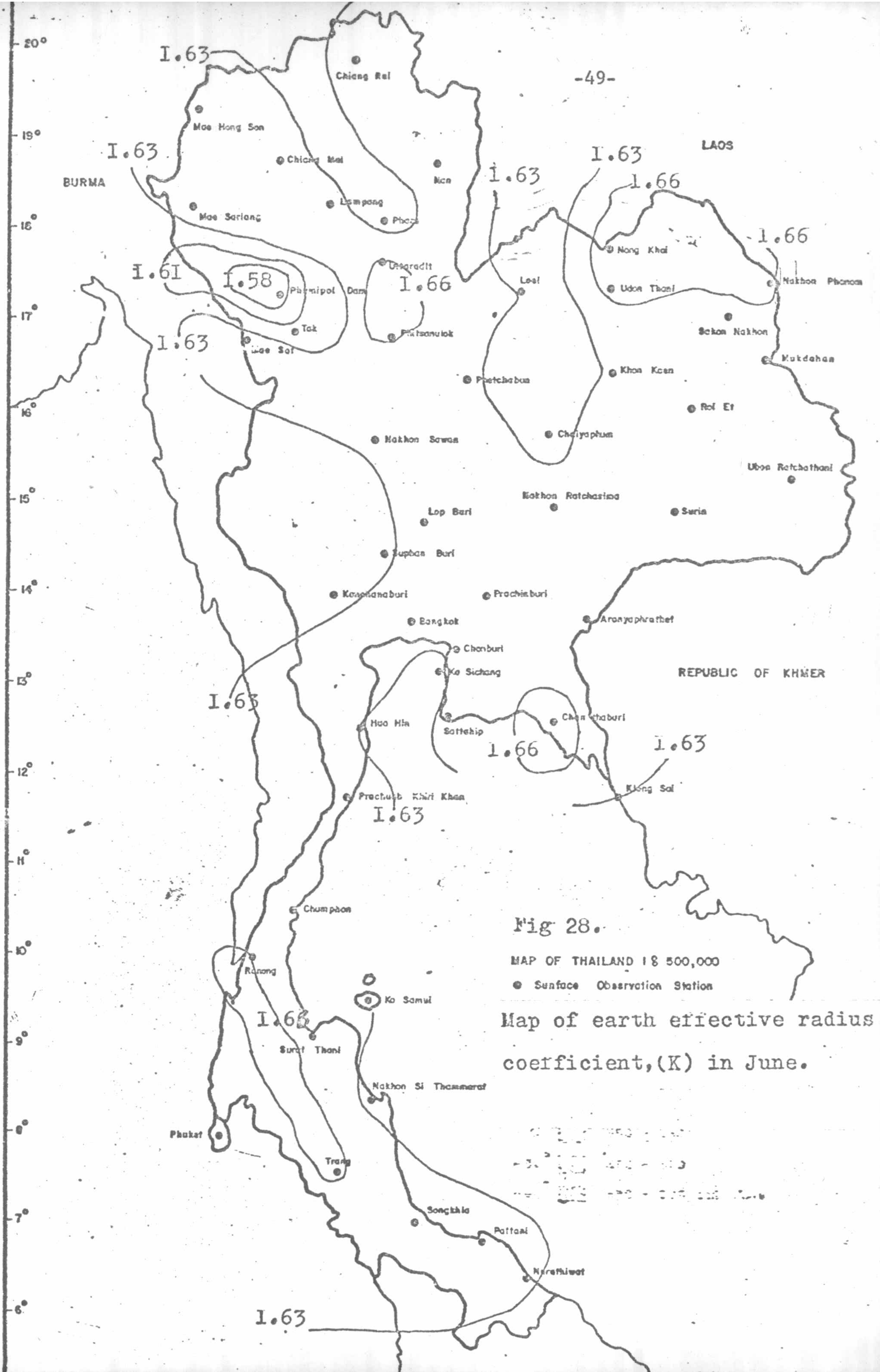


Fig 28.

MAP OF THAILAND 1:8 500,000

● Surface Observation Station

Map of earth effective radius coefficient, (K) in June.

Fig 29.

MAP OF THAILAND 1: 500,000

● Surface Observation Station

Map of earth effective radius coefficient, (K) in July.

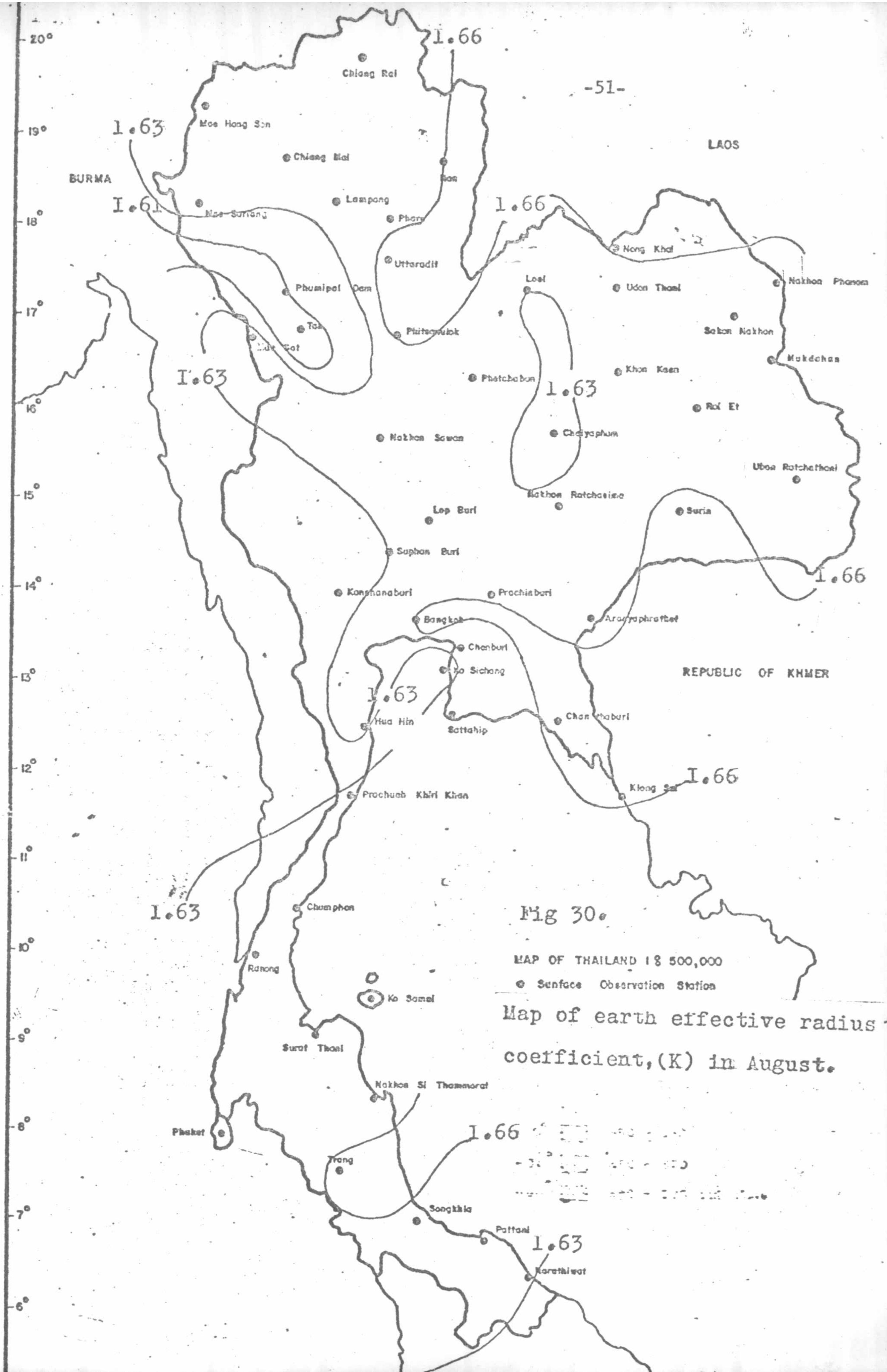
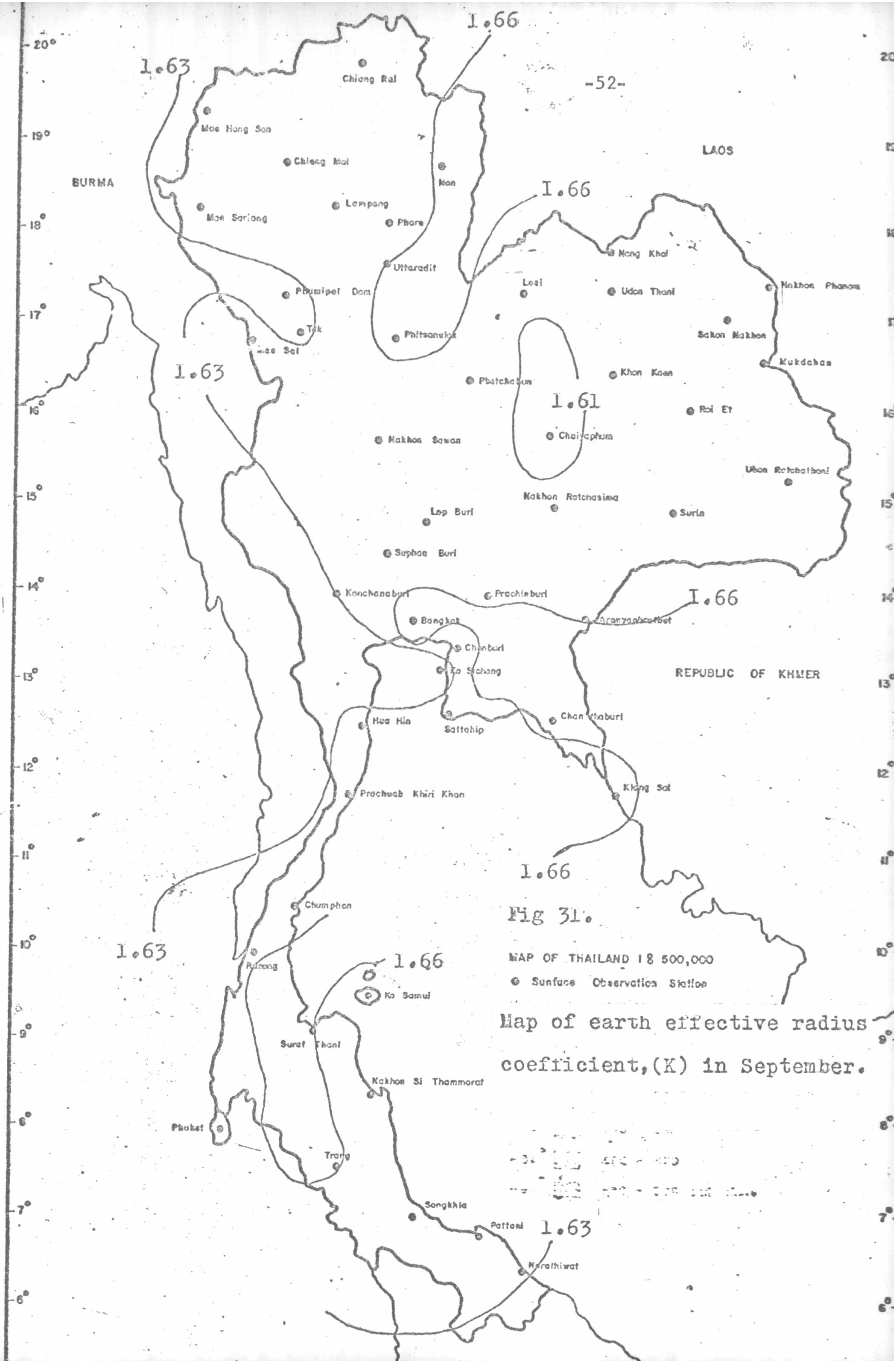


Fig 30.

Map of earth effective radius coefficient, (K) in August.



Map of earth effective radius coefficient, (K) in September.

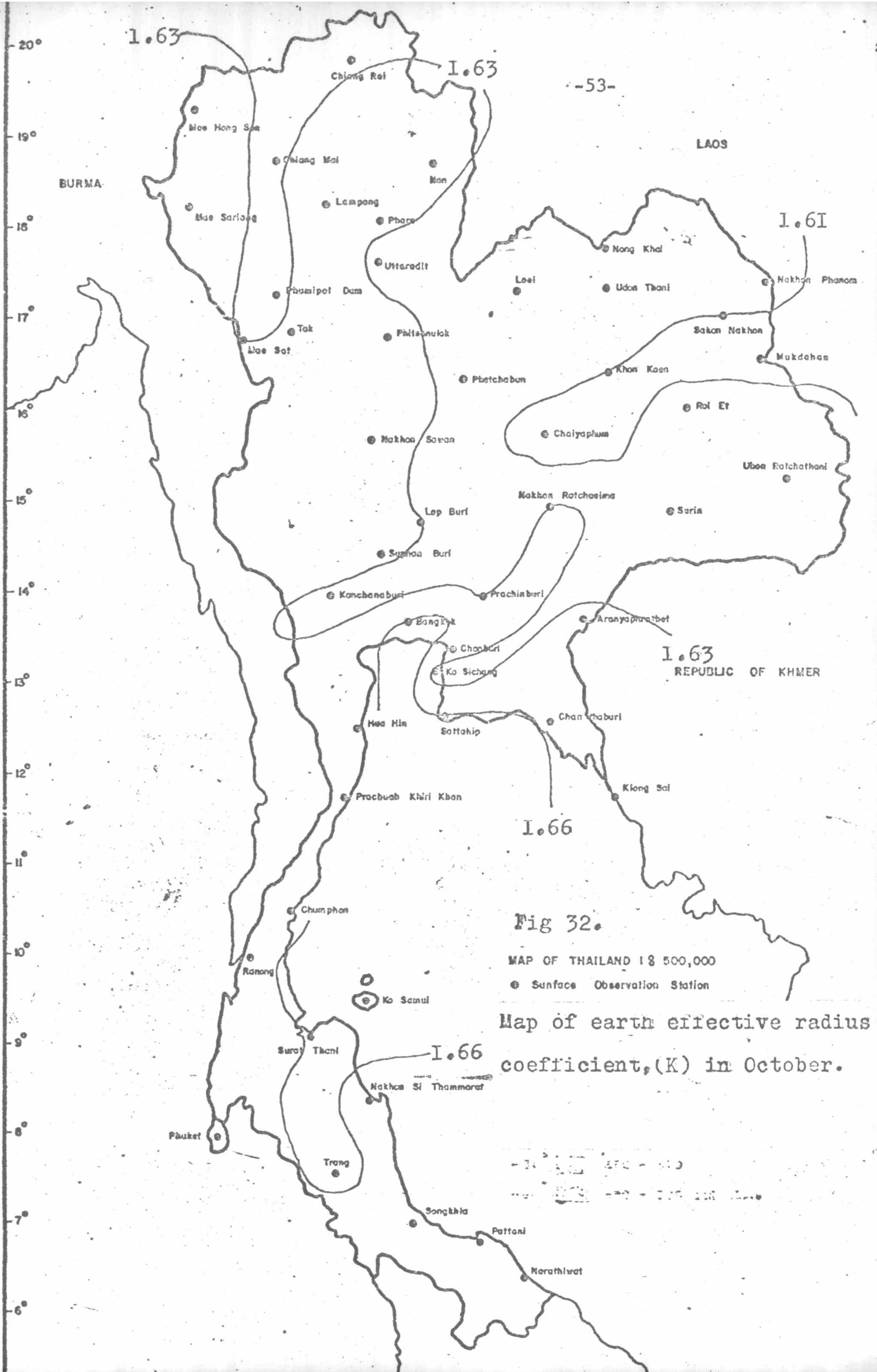


Fig 32.

Map of earth effective radius coefficient,(K) in October.

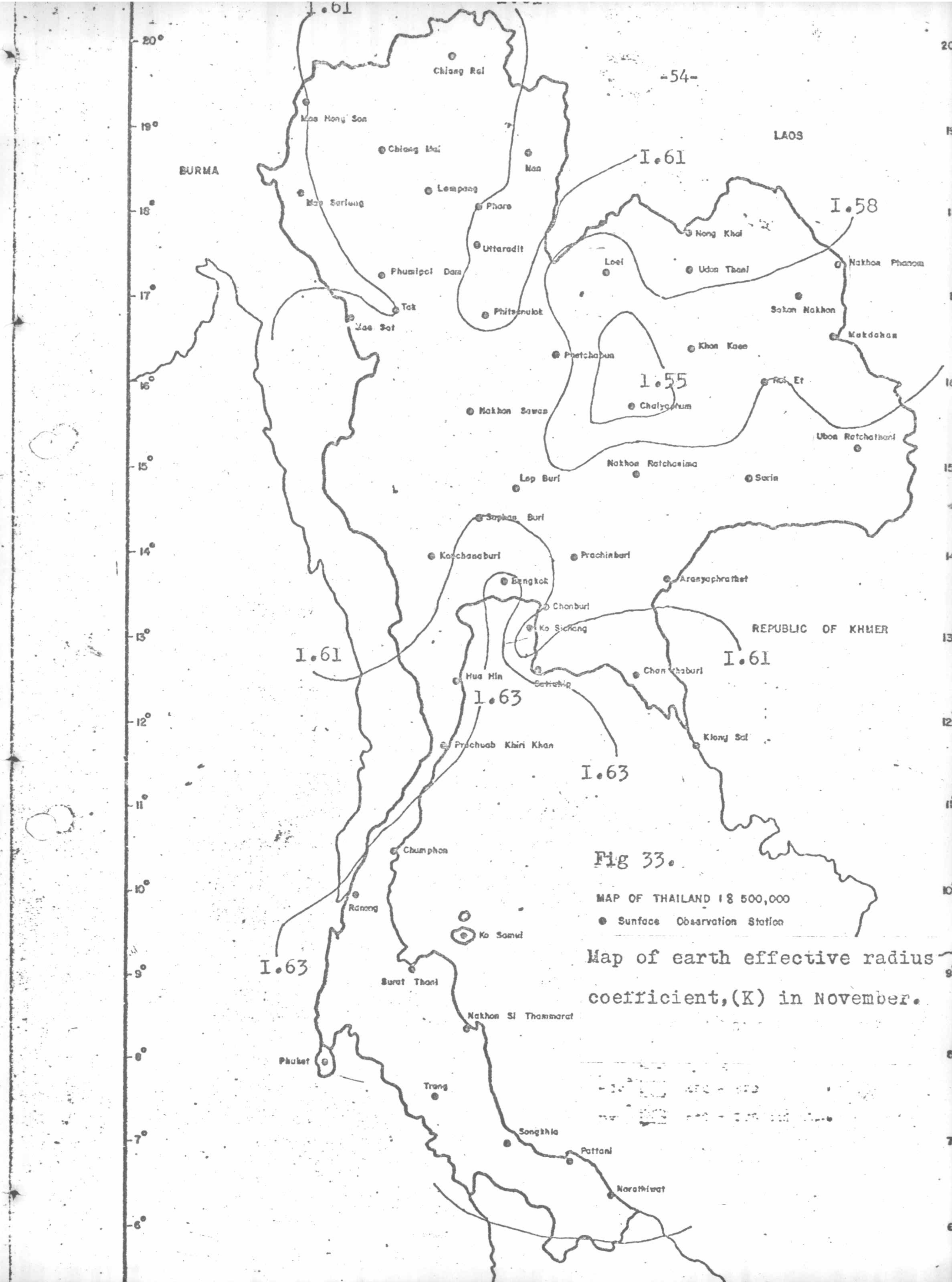


Fig 33.

MAP OF THAILAND 1:8 500,000

● Surface Observation Station

Map of earth effective radius coefficient,(K) in November.

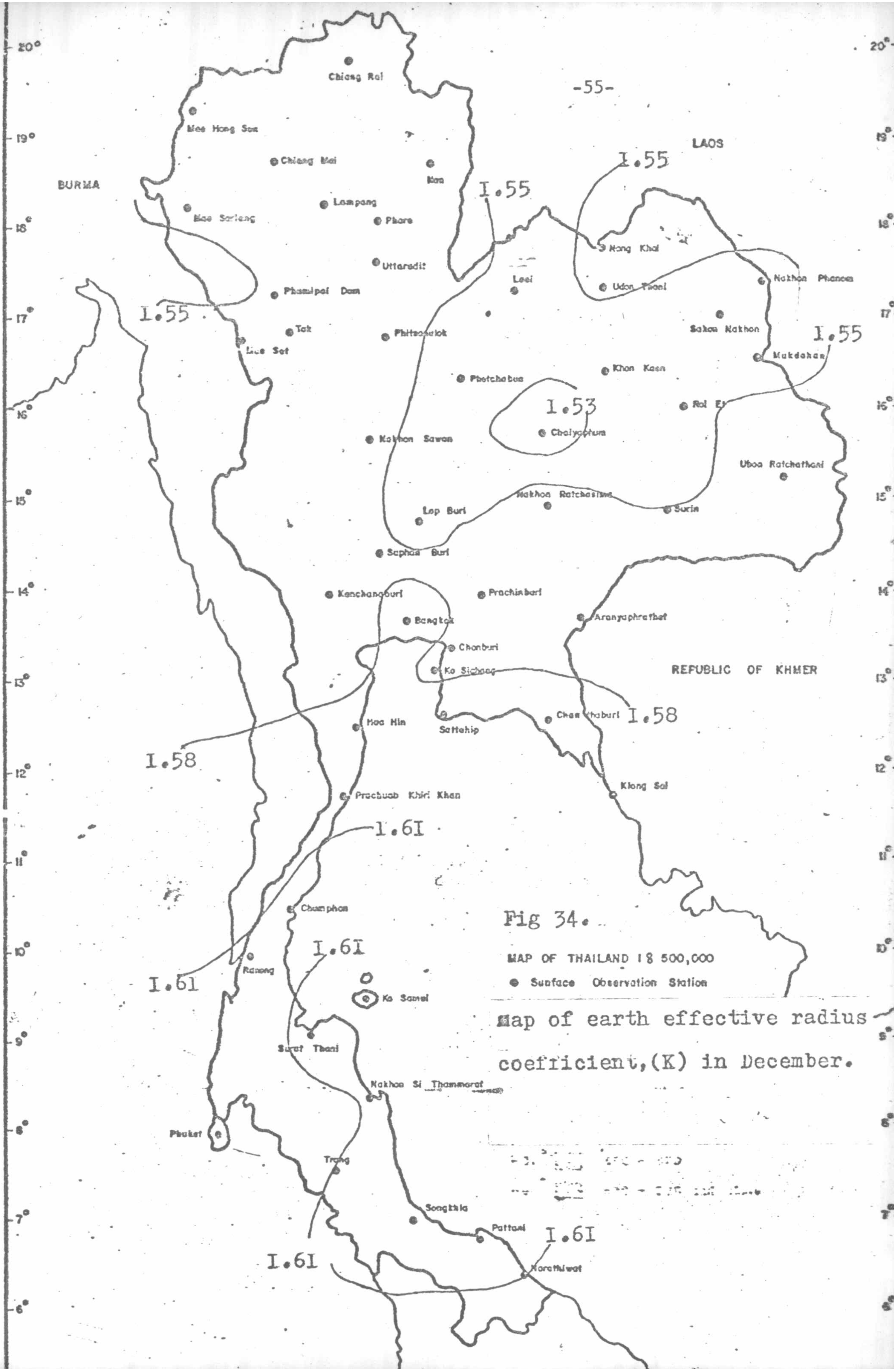


Fig 34.

MAP OF THAILAND 1:8 500,000

● Surface Observation Station

Map of earth effective radius coefficient, (K) in December.