CHAPTER-3

PRECIPITATION

Review of Precipitation

- Definition
- Forms of Precipitation
- Mechanism to form precipitation
- Classification/Types of Precipitation
- Measurement of Precipitation
- Missing Precipitation Data
- Double Mass Analysis
- Averaging Precipitation over an area

Precipitation for present course

- Artificially induced Precipitation
- Radar Measurement of Precipitation
- Satellite estimates for Precipitation
- Adequacy of Rain gauge network
- Presentation of Rainfall data
- Frequency of Point Rainfall
- Intensity Duration Frequency Relationship
- Probable Maximum Precipitation
- World Greatest observed Rainfall
- Rainfall distribution map for Pakistan
- Global Rainfall distribution

Precipitation

Definition:

All types of moistures reaching to the surface of earth from atmosphere.

Forms of Precipitation:

- Drizzle (tiny liquid droplets, 0.1-0.5 mm, intensity < 1mm/hr)
- Rainfall (Liquid drops dia > 0.5 mm, intensity > 2.5 mm/hr)
- Snowfall (Ice crystals at elevation > 3000 m, G = 0.1)
- Sleet (Mixture of rainfall and snowfall)
- Glaze (Ice coating on surface)
- Hail (Ice balls,5-125 mm dia)
- Fogs (Weak cloud colone reaching to the surface)
- Frost (Freezing of dew drops)
- Trace (when amount of ppt. < 0.125 mm)

Necessary Conditions / Mechanism to form Precipitation

(1) Lifting Mechanism to cool the air

(2) Formation of Cloud droplets / Ice crystals

(3) Growth of Cloud Droplets / Ice crystals

(4) Sufficient accumulation of moisture

(1) Lifting Mechanism to cool the air

(i) Convections

(ii) Orographic barriers

(iii) Cyclones

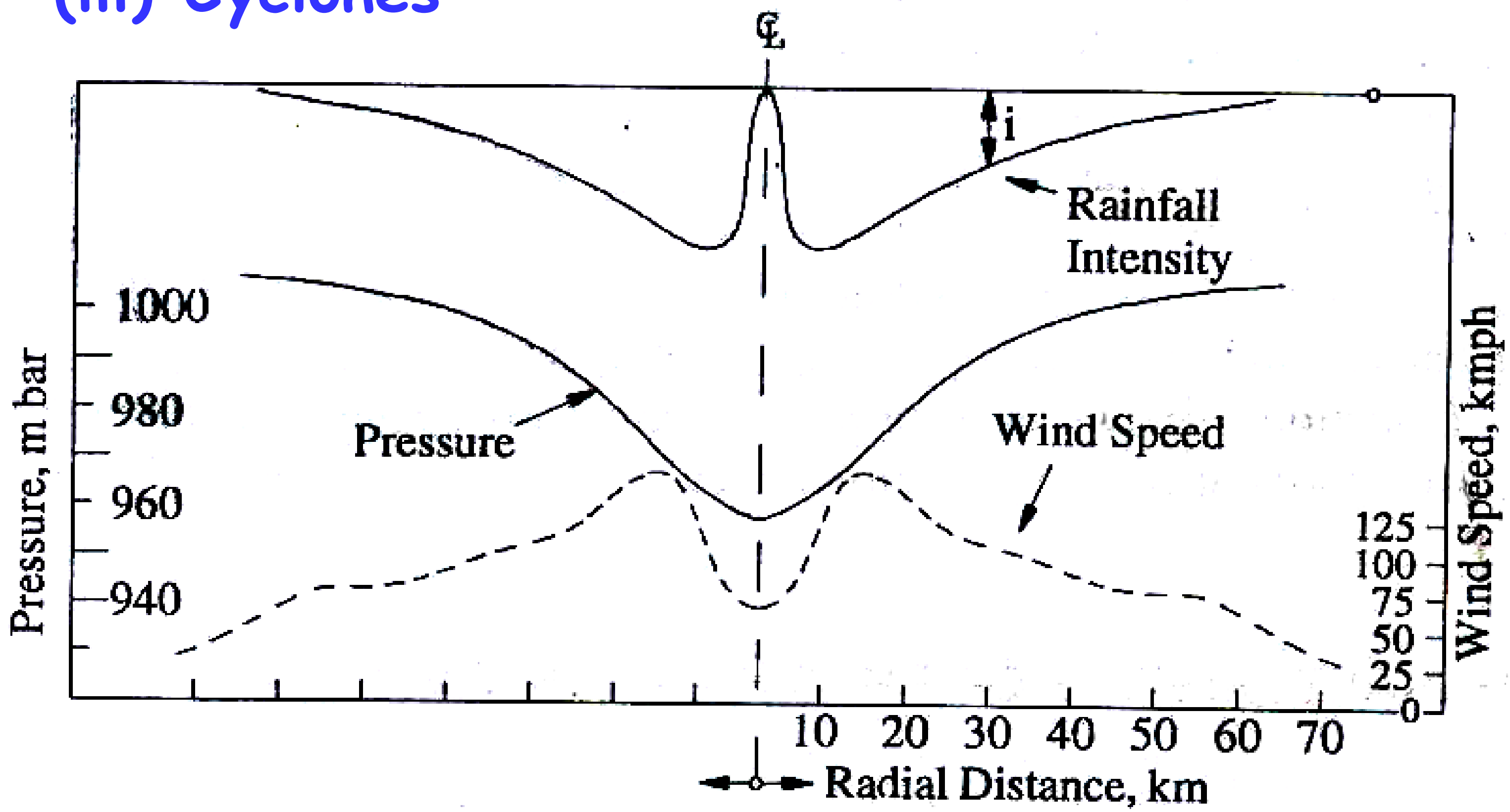
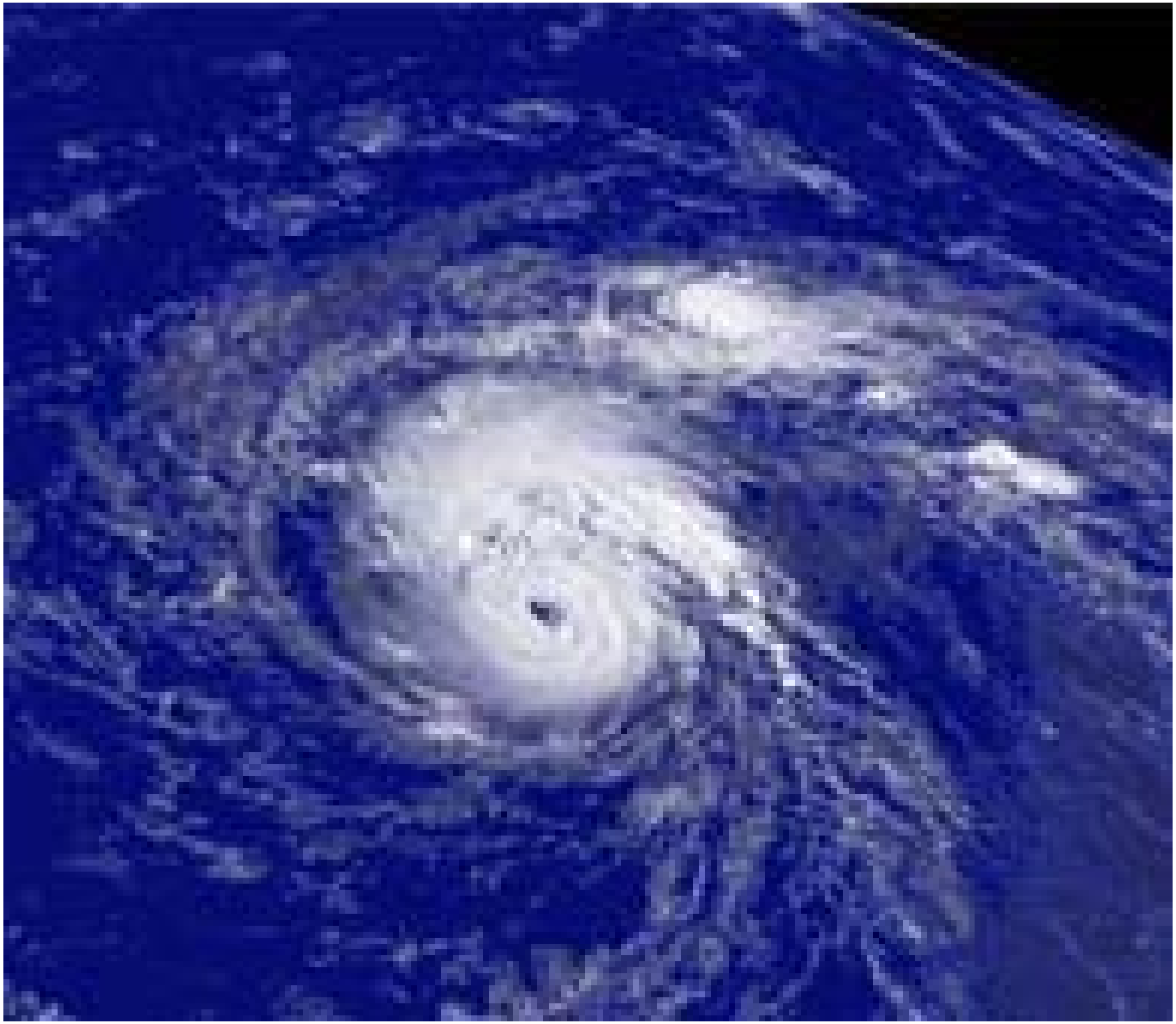


Fig. 2.1 Schematic section of a tropical cyclone



Cyclonic Precipitation

Cyclonic Precipitation

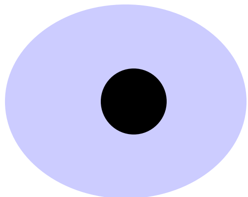
(2) Formation of Cloud droplet / Ice Crystals

Seeds:

(1) Hygroscopic nuclei or Condensation Nuclei

(0.1-10 μm in dia)

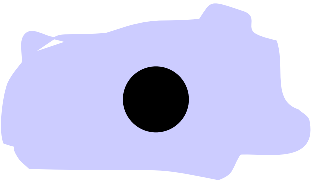
Particles of sea salt, Products of sulfurous & Nitrous acids



Cloud droplet

(2) Freezing Nuclei

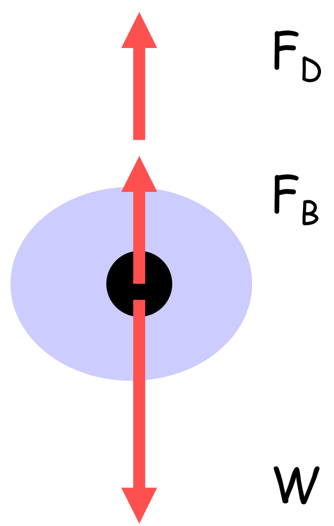
Clay Mineral (Kaolin)



Ice Crystal

(3) Growth of Cloud Droplets / Ice Crystal

- Cloud elements are generally smaller than 50 μm (0.05 mm).
- Non precipitating droplets have diameter < 10 μm for 5 mm/s updraft.
- To grow cloud droplet, two Processes take place:
  (1) Coalescence (about 7 collisions/ km fall)
  (2) Co-existence of Ice crystals and water droplets (Bergeron's effect)



(4) Sufficient Accumulation of Moisture

Some time there are clouds!!!,

but no there is no rainfall ???

Classification / Type of Precipitation

Precipitation is classified based on the moisture Lifting Mechanism

(1) Convectional Precipitation
(2) Orographic Precipitation
(3) Cyclonic Precipitation

Measurement of Precipitation

What to measure?

(1) Amount of Precipitation (mm)

(2) Duration of rainfall (beginning & ending) (hrs)

(3) Intensity of ppt.(mm/hr)

(4) Areal extent of ppt. (km^2)

Main Approaches:

(1) Rain gauges / Ground Measurement

(2) Using Radars

(3) Satellite Estimates

Rain Gauges

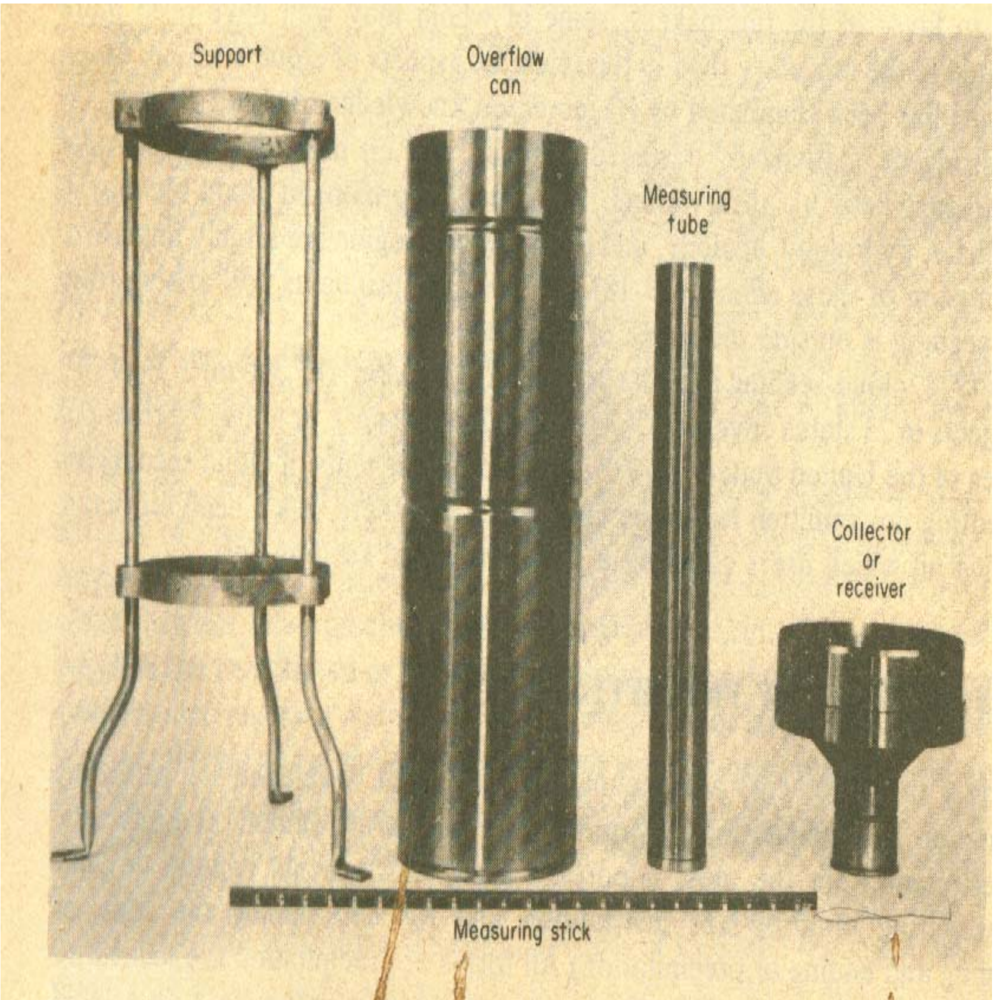
(1) Non Recording Rain gauge

Standard Rain gauge / U.S. National Weather Rain gauge

(2) Recording Rain gauges

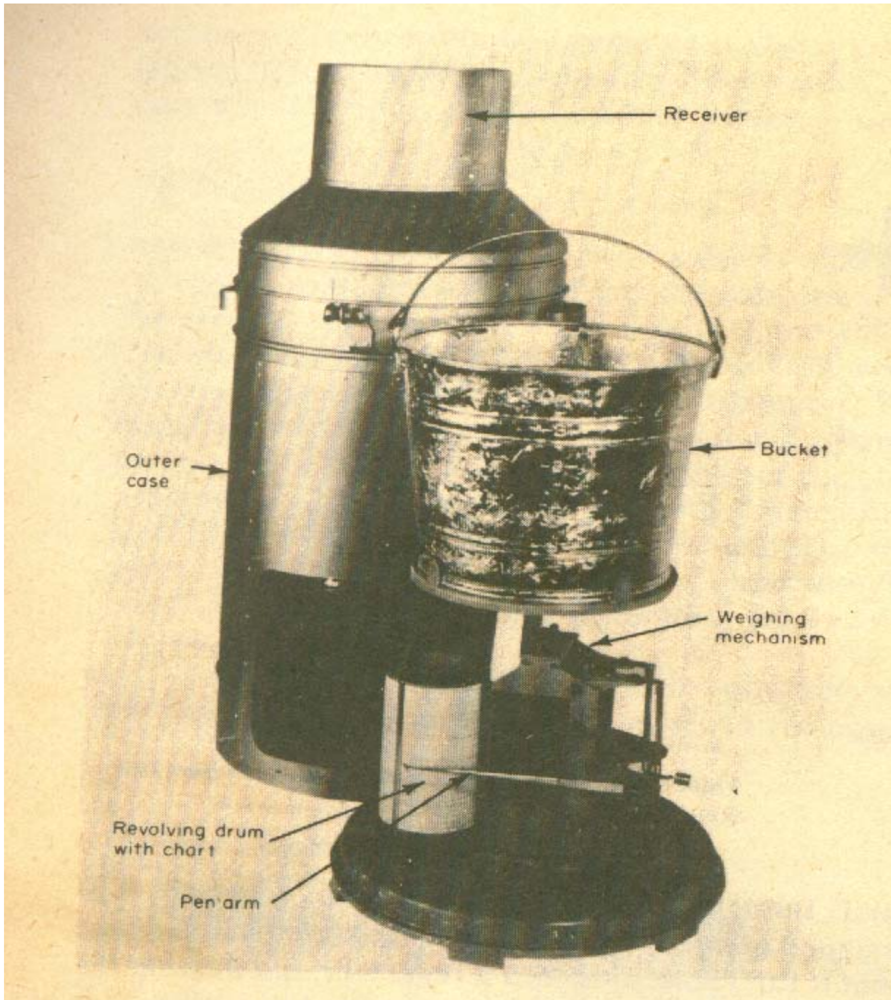
(1) Float Type Rain gauge
(2) Tipping Bucket Type Rain gauge
(3) Weighing Type Rain gauge

Standard Rain gauge



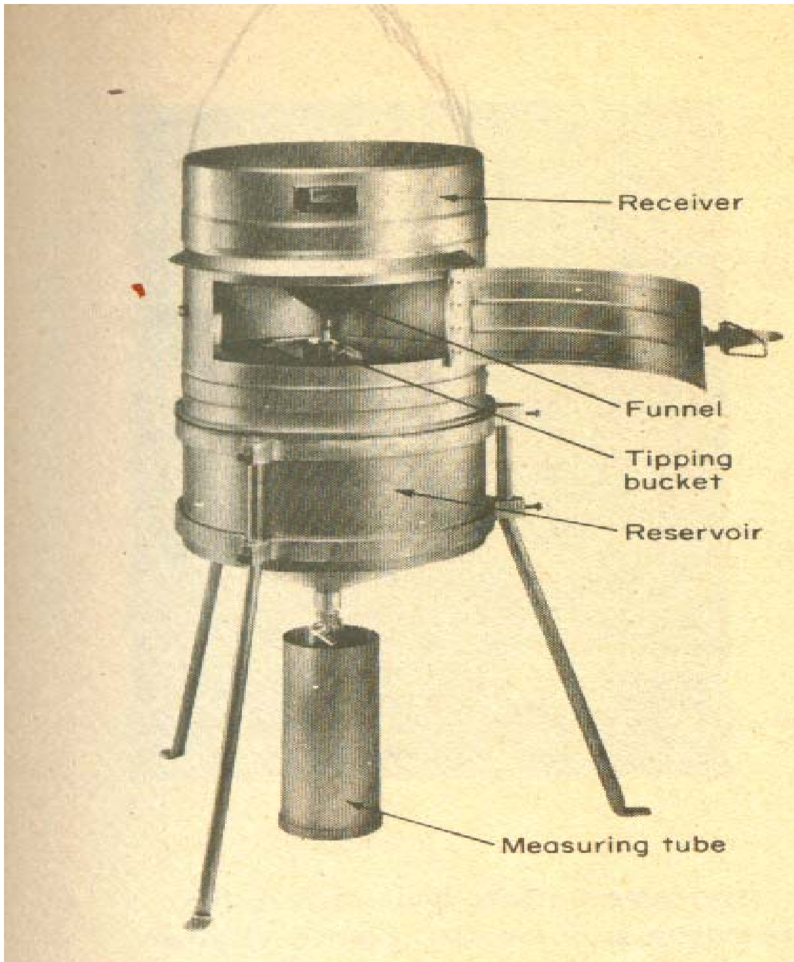
Rain passes from the collector (dia= 20.3cm) into a cylindrical measuring tube having X-sectional Area= 1/10th of the collector so that 0.1 inch rainfall will fill the tube to a depth of 1inch.

Weighing Type Rain gauge



It weighs the rain or snow which falls into a bucket set on the platform of a spring or level balance. The increasing weight of the bucket and its contents is recorded on a chart (Record shows accumulation)

Tipping Bucket Type Rain gauge



The designed quantity of rainfall will fill the one compartment and overbalance the bucket so that it tips, emptying into a reservoir and moving the second compartment into place beneath the funnel & actuates the electric circuit.

(unsuitable for snow measurement)

Artificially Induced Precipitation

- Attempts to increase the precipitation, suppress the hail & lighting, mitigate hurricane, dissipate fog, prevent frost, alter radiation balance is called as , "Weather Modifications"

What Could be done??

- If moisture is available in upper atmosphere, but no seeds!

  Seeds can be spread (Chemicals)

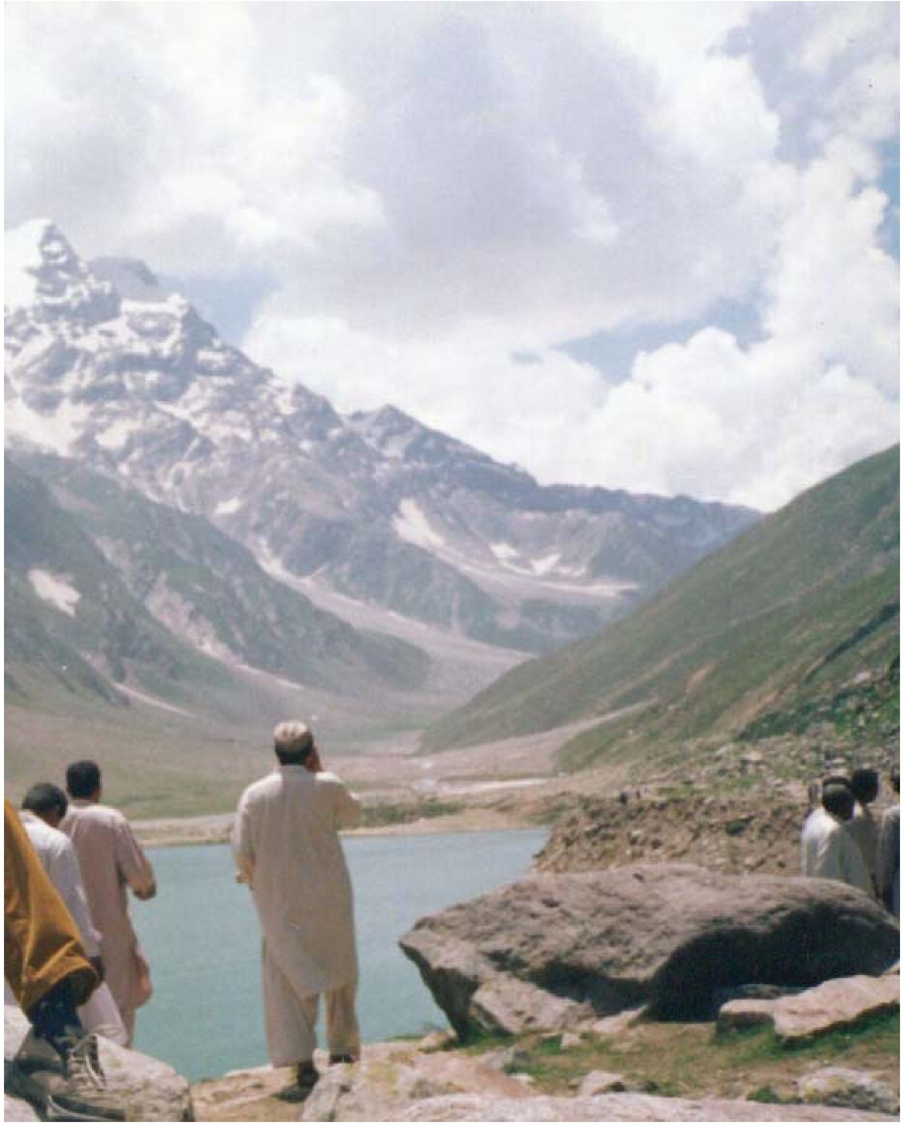
- If Clouds are there, but no rainfall!

  Chemicals on the top of clouds can be spread to grow the size of cloud droplets (Salts / Chemicals)

Does these Chemicals have environmental impacts?

Answer: Yes

Artificially Induced Precipitation (cond.)



- 1-It was demonstrated in 1946, that Dry Ice can cause precipitation in a cloud containing the certain salts.
- 2-Salts in supercooled clouds,(temp. -4°C) can initiate rainfall immediately.

Silver Iodide (AgI) is found to be one of the most effective salt for artificial rain.

(Cloud Seeding)

CLOUD SEEDING DEPENDS ON

- Height of cloud base & top (Thickness).
- Difference between density inside the cloud and outside the cloud.(buoyancy)
- Updraft velocity distribution.
- Concentration & Distribution of freezing nuclei added artificially.

THEORIES OF CLOUD SEEDING

- **STATIC APPROACH.**
- It is based on introducing about one artificial nucleus per litre (61 cubic inch) of the cloud air, to produce ice crystals which through diffusion and accretion, eventually grow into precipitation particles.

- **DYNAMIC APPROACH.**
- It involves massive seeding about 100 to 1000 nuclei per liter of cloud air of cumulus clouds to stimulate, through release of heat of fusion.
- It also raises cloud tops with about 3 Km to 5 Km within few minute & increases the probability of natural rain fall.

REMARKS

- Dynamic approach is particularly useful in lower latitudes, where tops of the cumuli are often below the -25°C Seeding clouds results in long-lasting rains

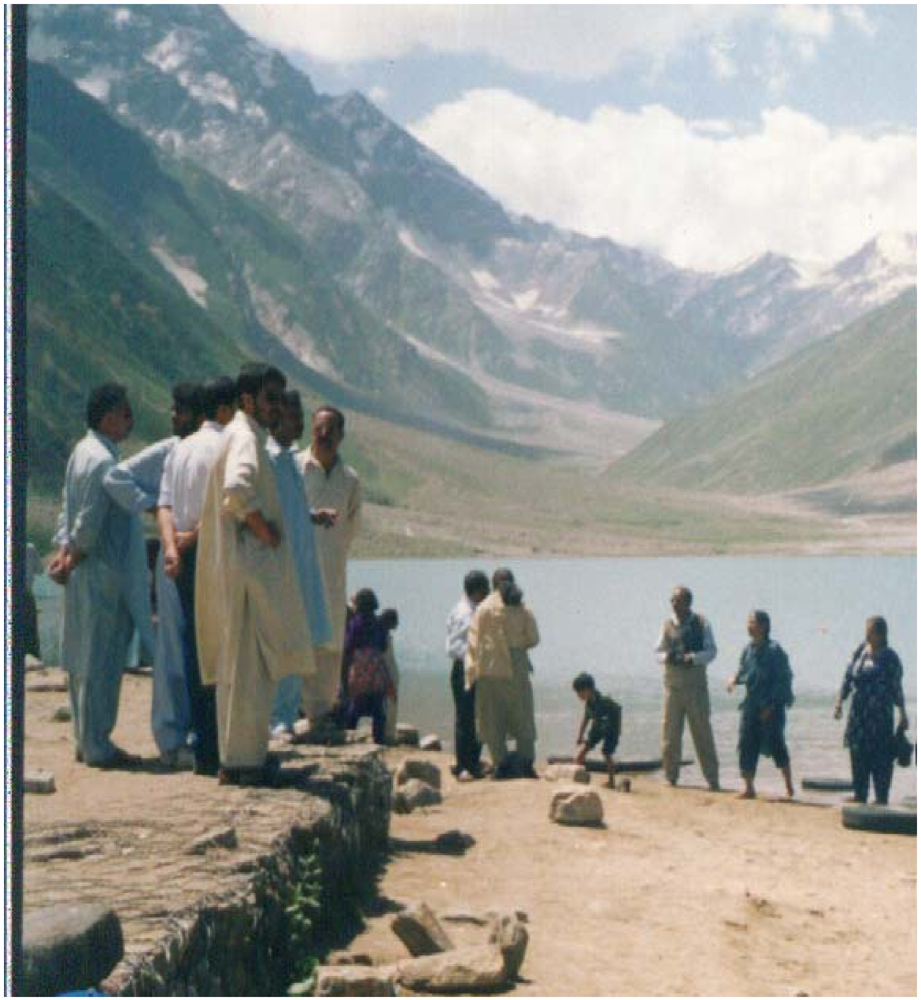
(MET-Dept.USA Florida)

REMARKS

- Stratus clouds offer poor prospectus for effective seeding with the purpose of increasing rainfall. The moisture content is relatively low and atmospheric conditions attending such clouds are too stable. Seeding results in weak turbulence which distributes the ice nuclei so that they cloud may be dissipated with or no precipitation.

- Seeding of "Orographic" clouds under a favorable conditions has been fairly effective.

REMARKS



- Seeding with freezing nuclei is ineffective in warm clouds because of the absence of supercooled droplets.

Artificial Rainfall

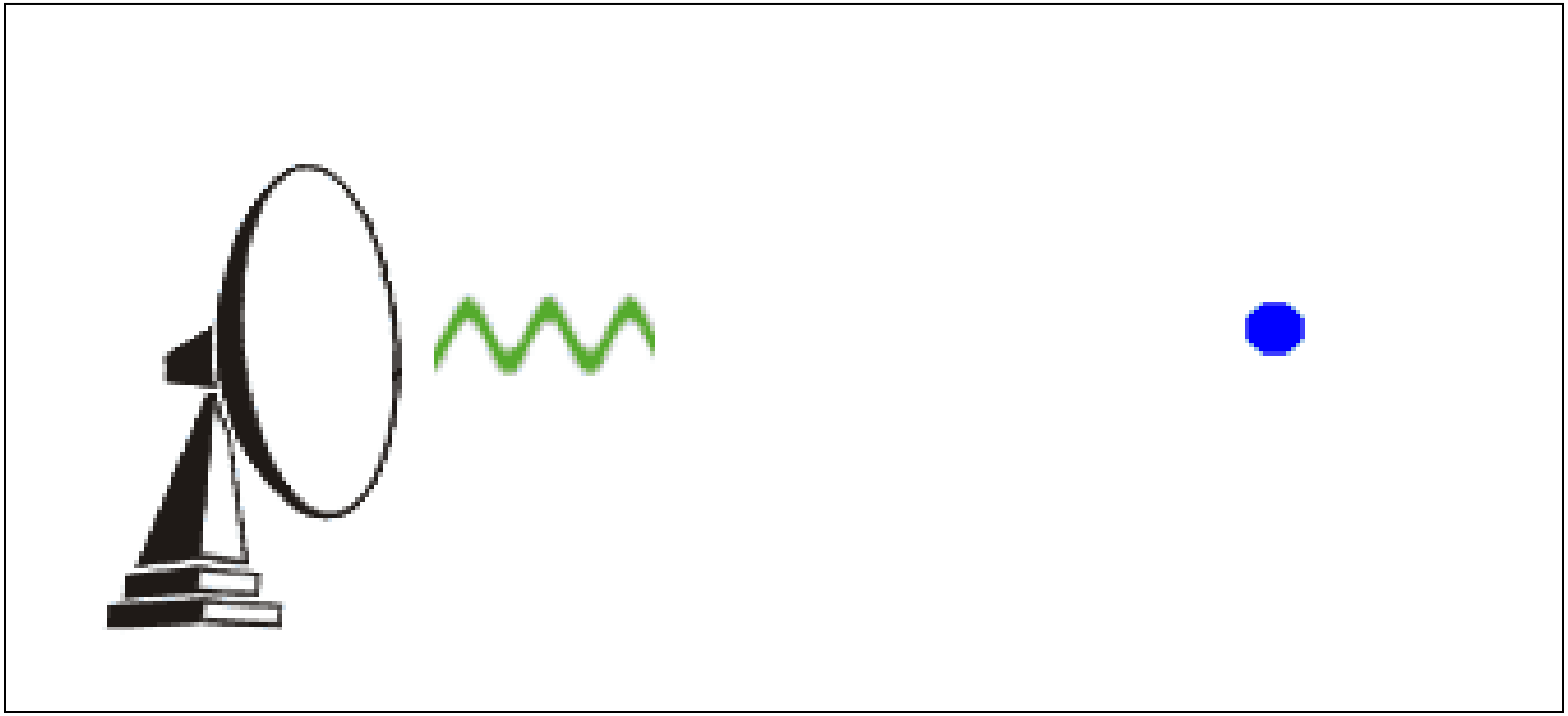
Done By The Meteorological Department At The National Centre Of Meteorology And Seismology (Ncms) To Remove The Air Pollution On Dubai's Atmosphere.

It Is Called 'Cloud Seeding' A Latest Technology To Customise Weather..Cloud Seeding, A Form Of Weather Modification, Is The Attempt To Change The Amount Or Type Of Precipitation That Falls From Clouds, By Dispersing Substances Into The Air That Serve As Cloud Condensation Or Ice Nuclei.

The Usual Intent Is To Increase Precipitation, But Hail Suppression Is Also Widely Practiced. Silver Iodide And Dry Ice Are The Most Commonly Used Substances In Cloud Seeding .
Technology

AN AIRCRAFT IS PUTTING DRY ICE ON CLOUDS WHICH MAKES ARTIFICIAL RAIN

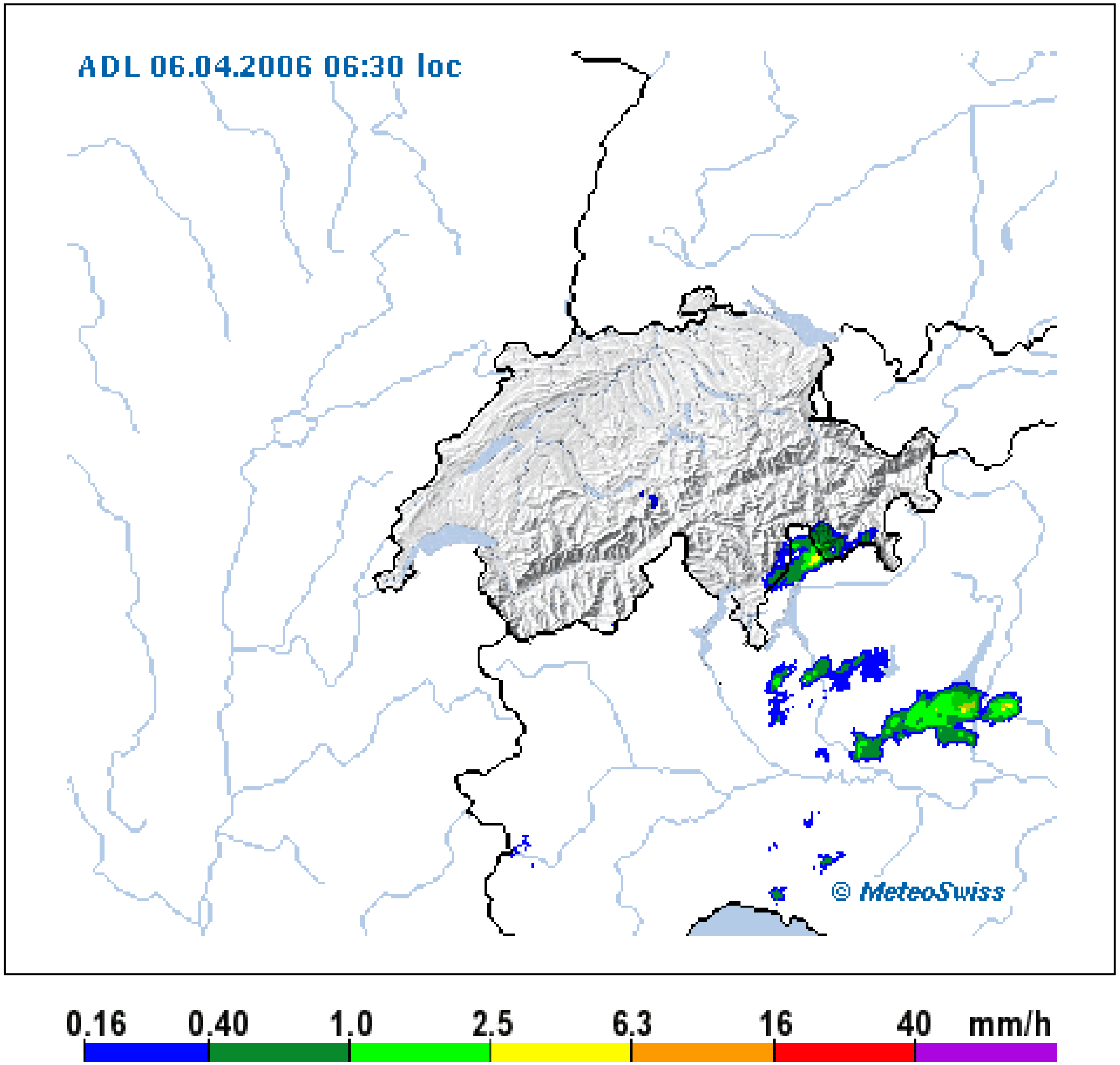
Radar Measurement of Precipitation



Radar Measurement of Precipitation

What we can measure?

(1) Intensity of ppt.
(2) Duration of ppt.
(3) Amount of ppt.
(4) Areal extent
(5) Movement of rainstorm



Radar Measurement of Precipitation

- Radar transmits pulses of electromagnetic energy as a beam in the direction of the moveable antena.

- The radiated wave, which travels at the speed of light, is partially absorbed, scattered and reflected by ppt. Particles & return to the radar, which is received by the same antena.

Target Signal
Energy returned to the radar

Returned Power
Amount of energy returned to the radar.

Echo Intensity
Brightness of an echo, indication of the magnitude of returned power or radar reflectivity.

Reflectivity of a group of hydrometeors depends on:
(1) Drop size distribution
(2) Number of particles / volume
(3) Physical state (solid or liquid)
(4) Shape of the individual particles

Greater reflectivity means higher intensity of ppt.

Radar Measurement of Precipitation

Attenuation

Loss of radar energy due to passage through ppt. Part of the loss results from scattering and part from absorption.

The larger the rain and snow dia to wave length ratios, the greater is the attenuation.

$$Attenuation \ \alpha \left(\frac{d}{L}\right)$$

Thus for a short wave length the total energy may be greatly diminished by penetration into the storm.

Wave lengths less than 5 cm are considered unsuitable for measuring ppt. Howerer, these may be useful for detecting very light rainfall at short distances (drizzling).

Wave lengths 5-10 cm with beam width < 2 degrees are recommended for ppt. measurement.

Average Return Power

It is the measure of radar Reflectivity of all particles at range r intercepting the radiated beam.

$$P_r = \frac{c}{r^2} z \quad (1)$$

$$z = \sum d^6 \quad (2)$$

$$z = a R^b \quad (3)$$

$$P_r = \frac{c}{r^2} a R^b \quad (4)$$

$$R = \left(\frac{P_r r^2}{c a} \right)^{1/b} \quad (5)$$

Where

Pr = Average Return Power

C = coefficient (function of wave length, beam shape and width, pulse length)

a = coefficient (15-1100)

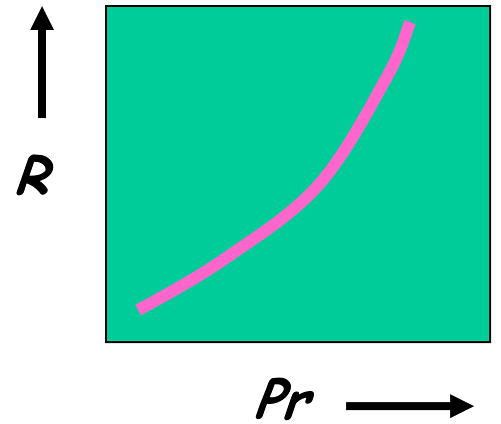
b = coefficient (1.2-3.2)

are determined by calibration

r = radius

R = rainfall rate (mm/hr)

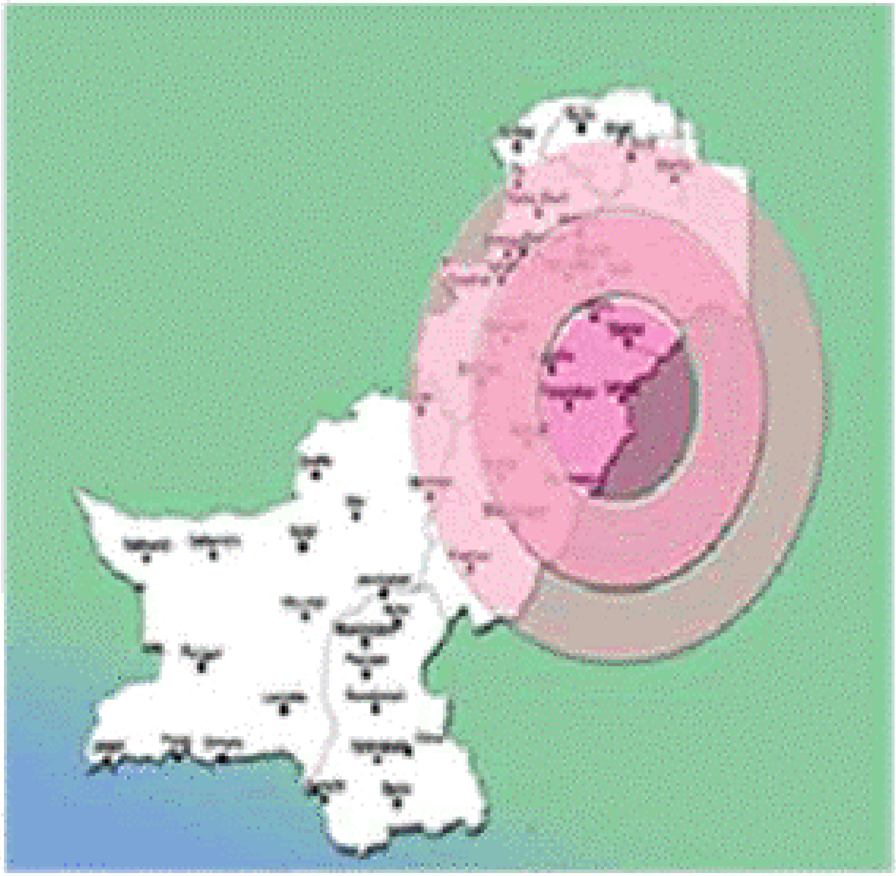
d = diameter of individual raindrop



Radar Beam

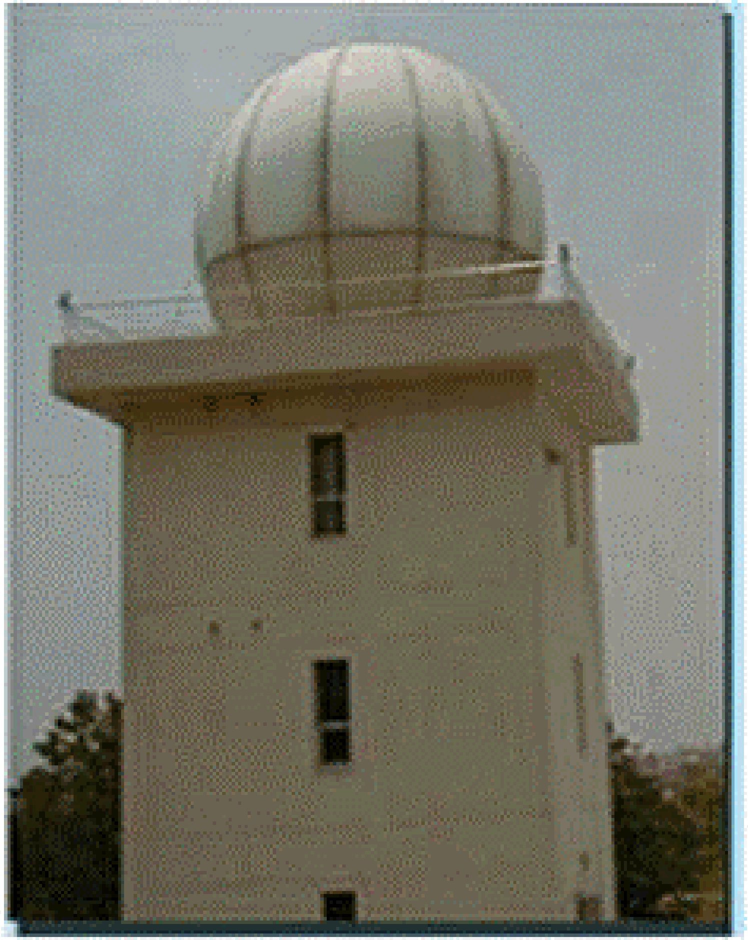
- In order to avoid interference from hills, trees, buildings, the radar beam is directed upward at an angle of 0.5 to 1^{o} above the horizontal.
- Height of beam increases with distance.
- Precipitating particles may not reach up to the ground and may evaporate in atmosphere.
- Measured amount of ppt. is greater than actual.
- Radars over estimate the PPT.

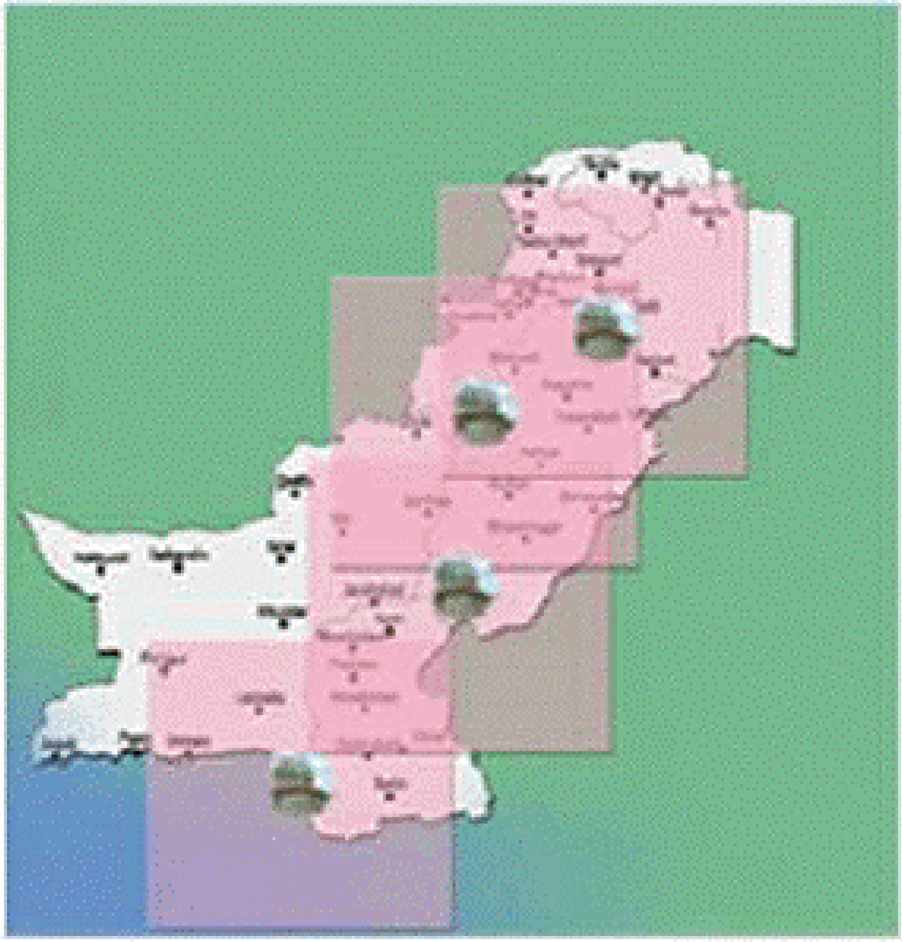
3 GHz DOPPLER RADAR LAHORE



RANGE 450 KMS

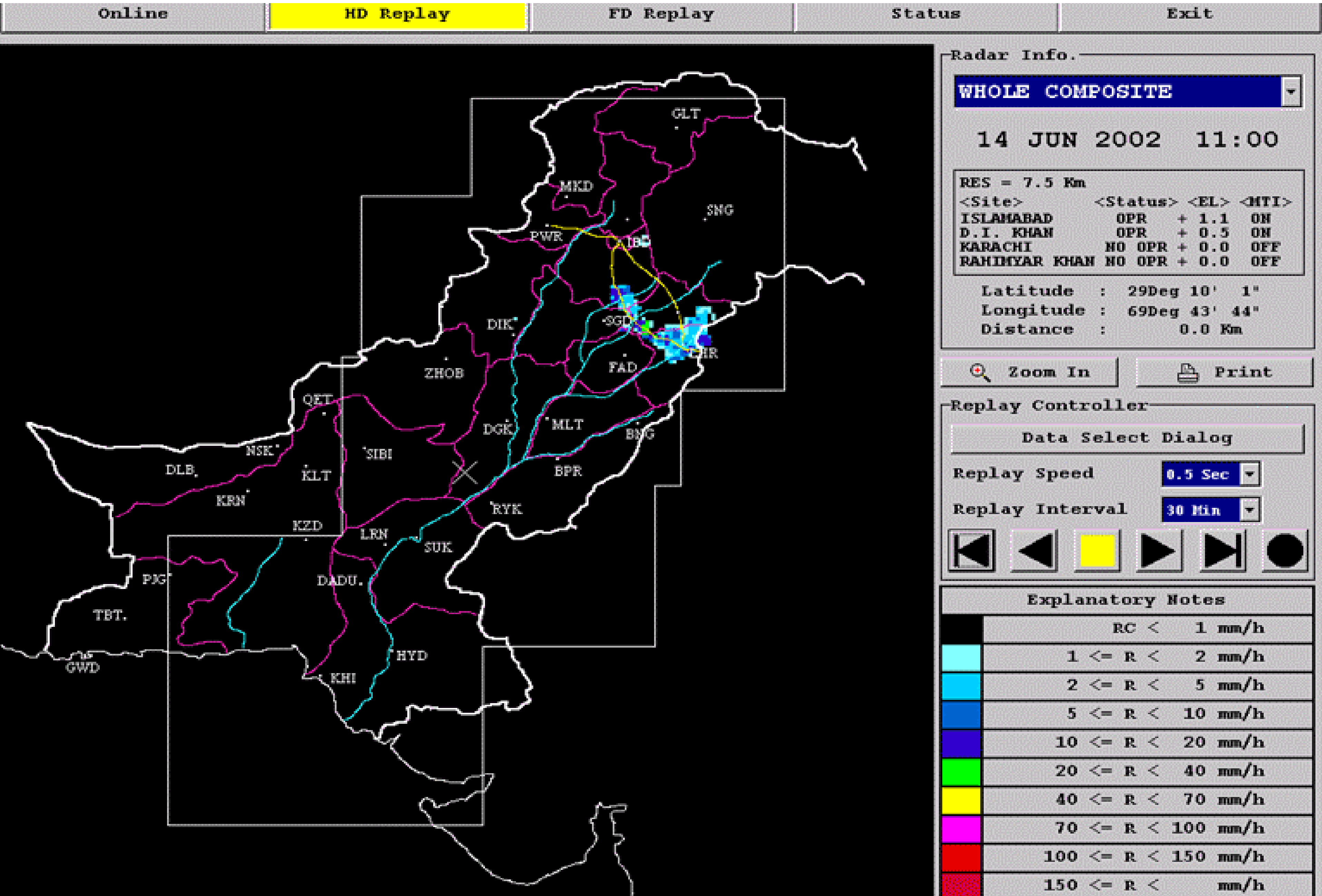
COUNTRY WIDE INTEGRATED 5 GHz RADAR NETWORK





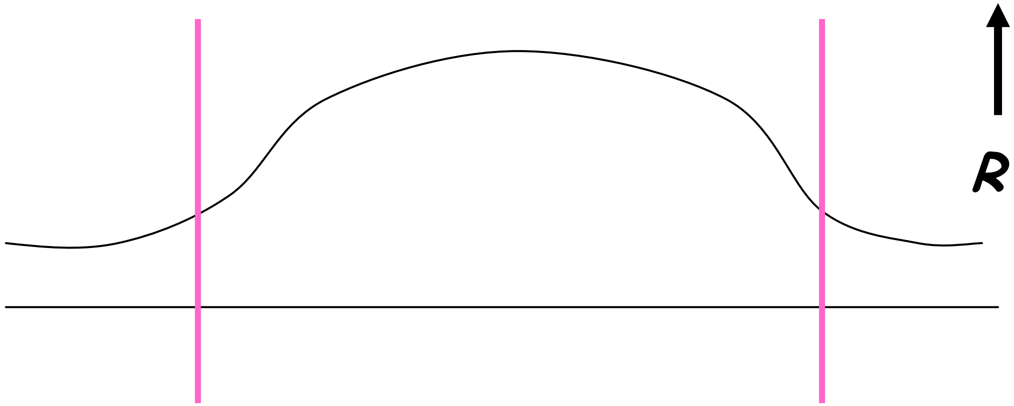
RANGE 250 KMS

AREA COVERED THROUGH RADAR NETWORK

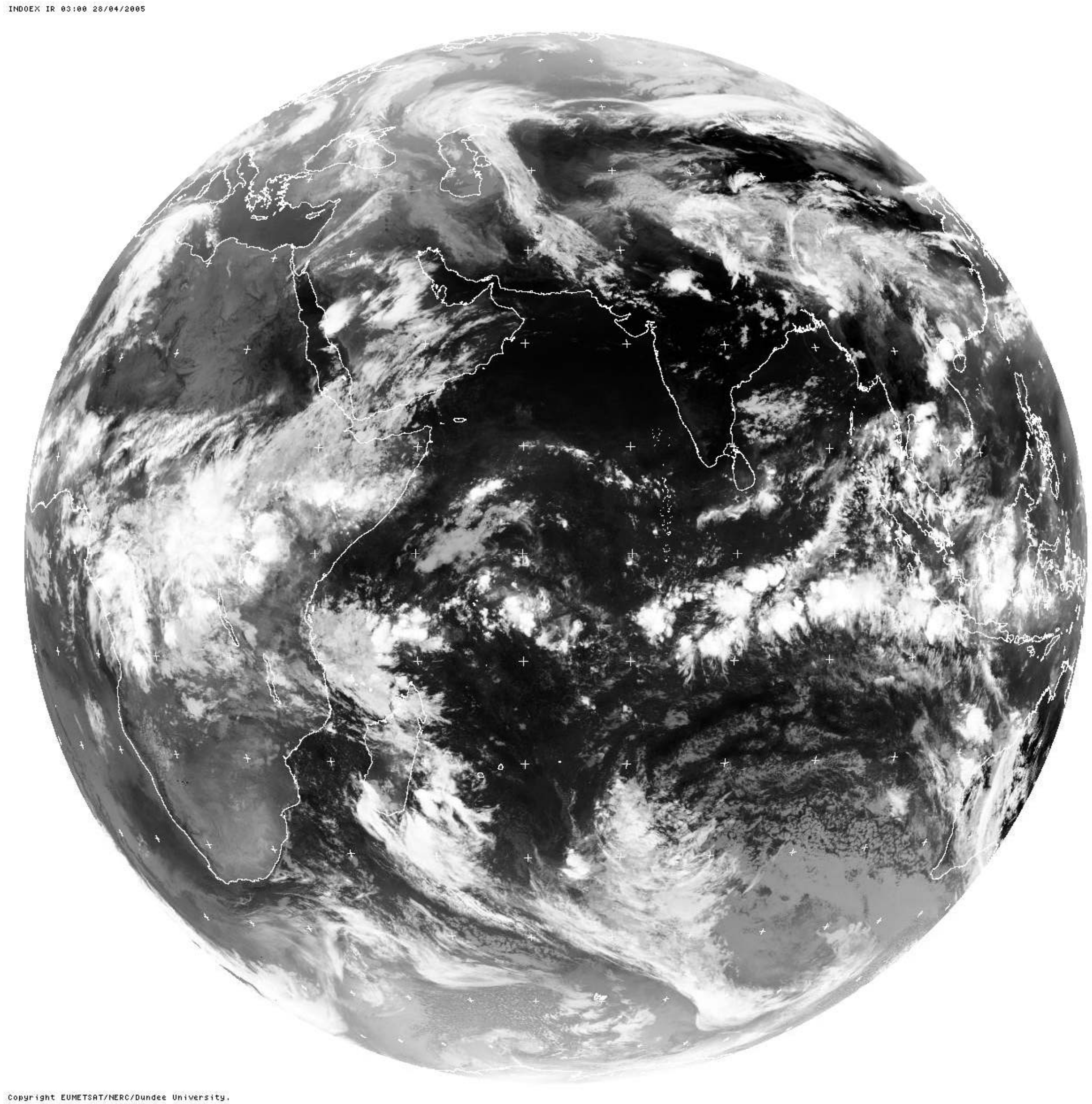


Satellite Estimates of Precipitation

- Satellites cannot measure ppt directly.
- Images are taken from the satellites
- Brightness of cloud photograph is related with ppt. Intensity.
- Brighter the image, more thicker are the clouds
- The tallest and densest cloud produces the heaviest ppt.
- The relation between rain intensity and cloud brightness is developed with gauge and radar measurements at a place.
- Some time, photographs do not reveal precipitation-producing clouds.
- Satellite images help in assessing the direction and avg speed of cyclones.
- Used for precipitation measurement over oceans



IR IMAGE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Copyright EUMETSAT/NERC/Dundee University.

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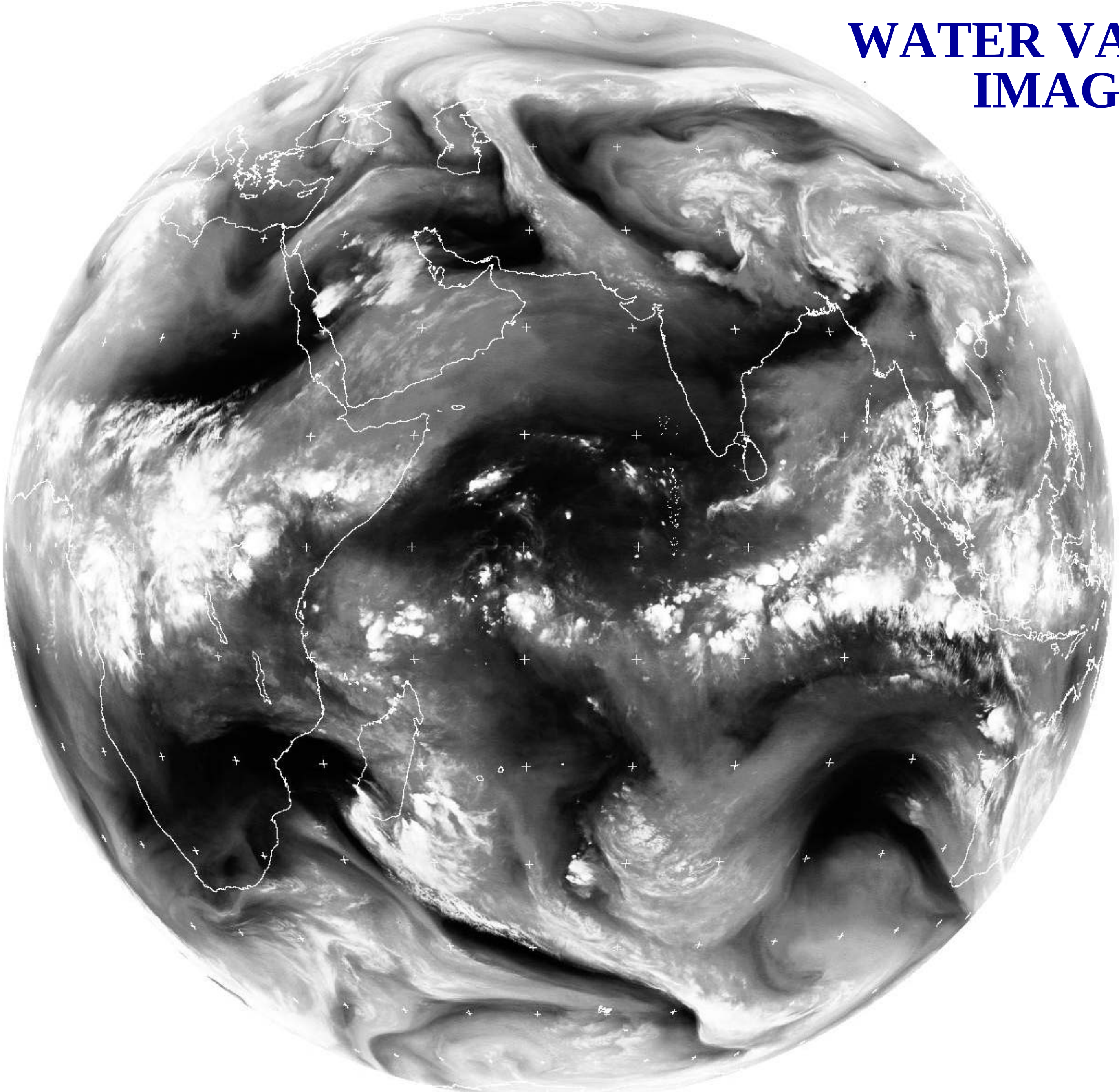
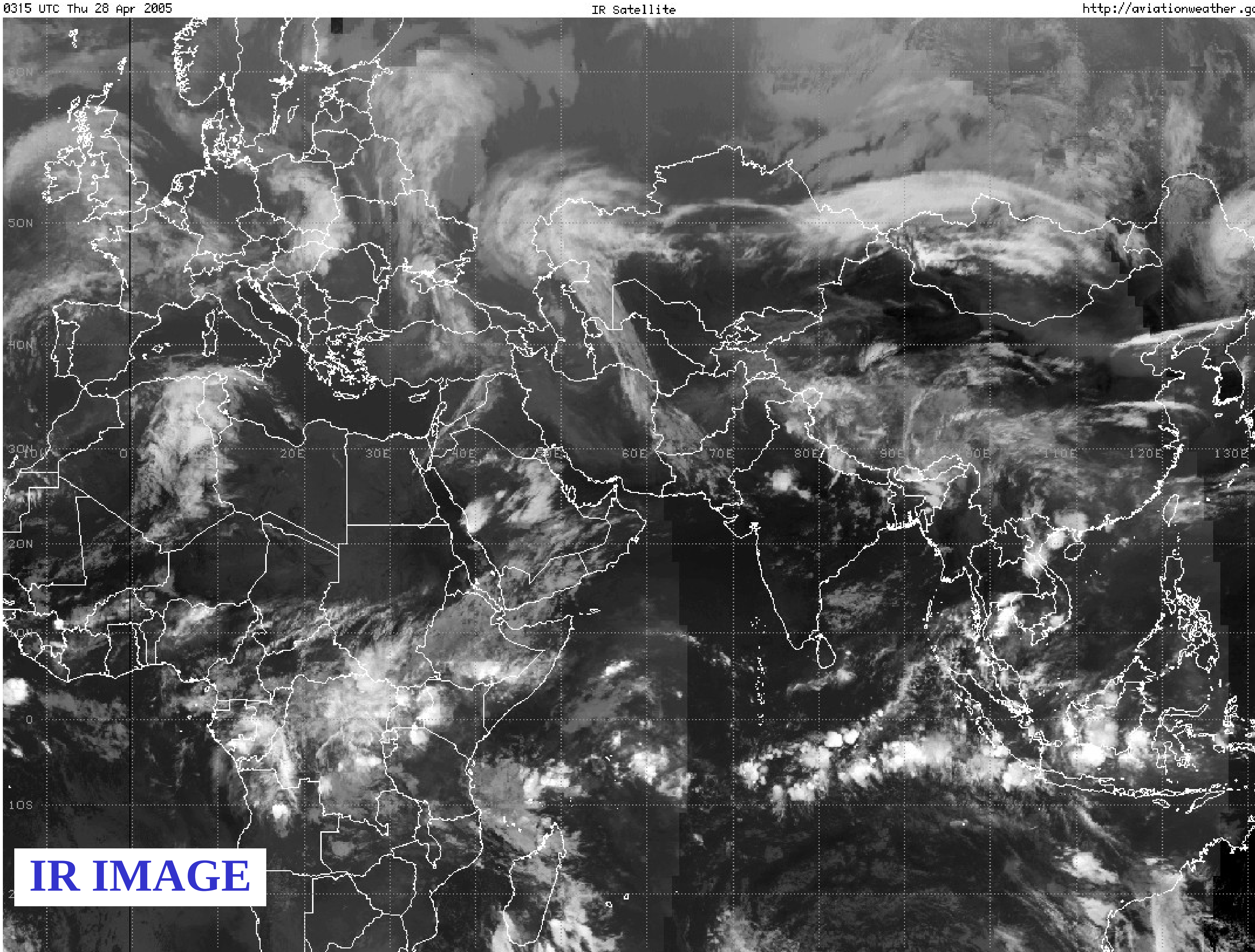
WATER VAPOUR IMAGE




0315 UTC Thu 28 Apr 2005
IR Satellite
http://aviationweather.gov
50N
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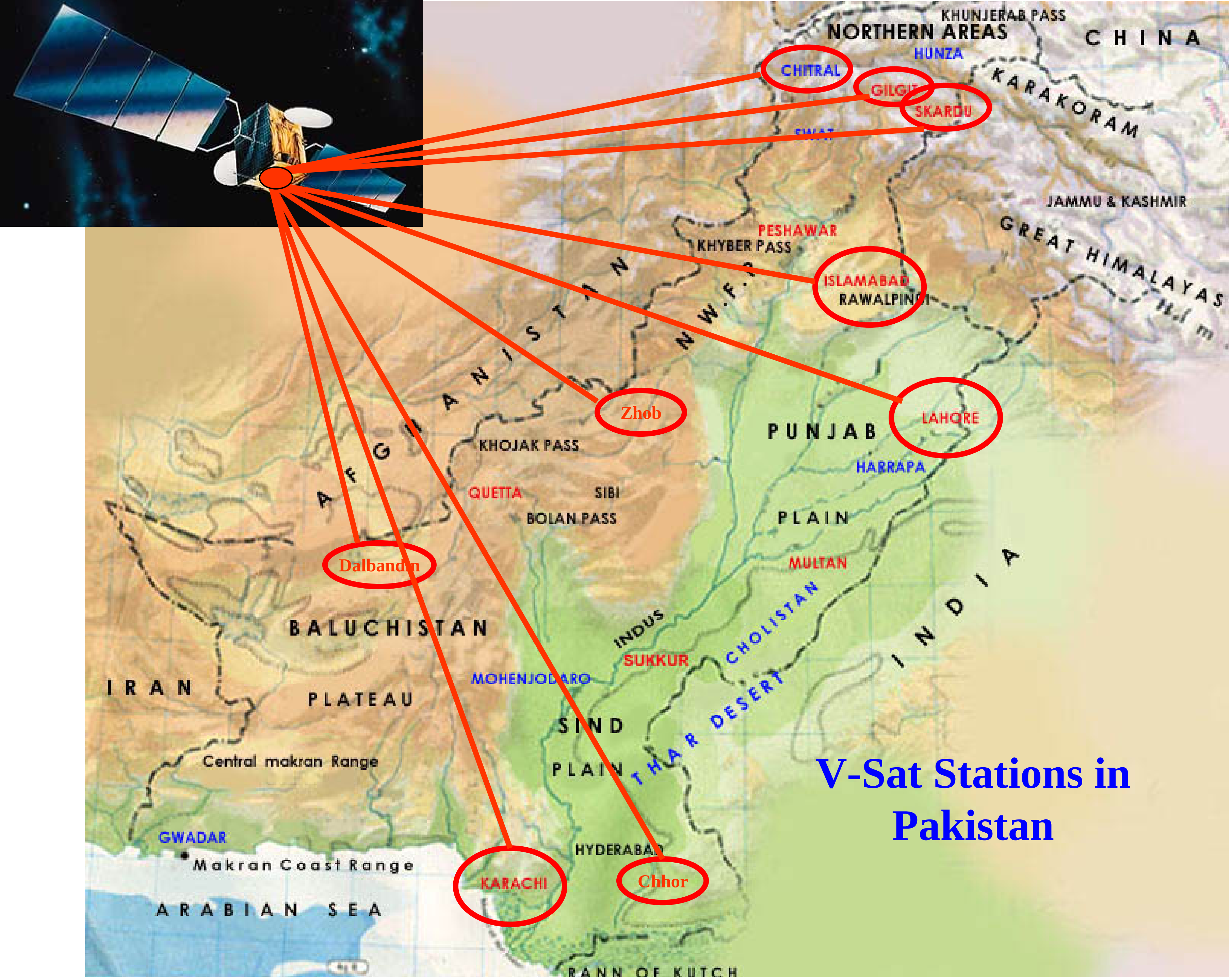
IR IMAGE



V-Sat Stations in Pakistan
KHUNJERAB PASS
NORTHERN AREAS
CHINA
HUNZA
CHITRAL
GILGIT
SKARDU
KARAKORAM
JAMMU & KASHMIR
GREAT HIMALAYAS
PESHAWAR
KHYBER PASS
ISLAMABAD
RAWALPINDI
N.W.F.P.
AFGHANISTAN
Zhob
LAHORE
PUNJAB
KHOJAK PASS
HARRAPA
QUETTA
SIBI
BOLAN PASS
PLAIN
MULTAN
INDIA
BALUCHISTAN
INDUS
SUKKUR
CHOLISTAN
IRAN
PLATEAU
MOHENJODARO
THAR DESERT
SIND
PLAIN
Central makran Range
GWADAR
Makran Coast Range
HYDERABAD
KARACHI
Chhor
ARABIAN SEA
RANN OF KUTCH

Gauge Density

No. of rain gauging stations serving per unit area

WMO Recommended minimum densities of PPT. Stns (Stations / 10^6 km^2)

Area	Non Recording	Recording
Coastal	1,111	111
Mountainous	4,000	400
Interior plains	1,740	174
Hilly / Undulating	1,740	174
Small Islands	40,000	4,000
Urban Areas		50,000-100,000
Polar / arid	100	10

Source: Guide to Hydrological Practices by WMO, 1994

Adequacy of rain gauge stations

- The optimal number of stations that should exist to have an assigned %age error in the estimation of mean rainfall can be obtained by statistical analysis as:

$$N = \left[\frac{C_v}{\varepsilon}\right]^2$$

$$C_v = \left(\frac{\sigma_{m-1}}{\overline{P}}\right) X\ 100$$

$$\sigma_{m-1} = \sqrt{\left[\frac{\sum_1^m \left(P_i - \overline{P}\right)^2}{m-1}\right]}$$

$$\overline{P} = \frac{1}{m}\left[\sum_1^m P_i\right]$$

Where

N = Optimal number of stations

ε = Allowable degree of error in the estimation of mean rainfall (%)

C_v = coefficient of variation of rainfall at existing m stations (%)

m = Already rain gauge stns in the catchment

σ_{m-1} = standard deviation

P_i = ppt magnitude in the ith station

Presentation of Rainfall data

(1) Mass Curve of Rainfall

(2) Rain Hyetographs

(3) Point Rainfall

(4) Average ppt. over an area

(5) Depth Area Duration (DAD) Relationships

(6) Maximum Depth Area Duration (DAD) Curves

(7) Frequency of Point Rainfall

(8) Intensity Duration Frequency Relationships (IDF) curves

(9) Probable Maximum Precipitation (PMP)

Mass Curve of Rainfall

- It is a plot of the accumulated precipitation against time, plotted in chronological order.
- All recording rain gauges provide daily or weekly rain charts (Mass curve of rainfall)
- Mass curve of rainfall is very useful in extracting the information on:

(1) No. of rainstorms (for daily, weekly, monthly & annual)

(2) Amount of rainfall in each rainstorm

(3) Duration of each rainstorm

(4) Intensity of rainfall in the rainstorm

(5) Total amount of rainfall (daily, weekly, monthly & annual)

Mass Curve of Rainfall

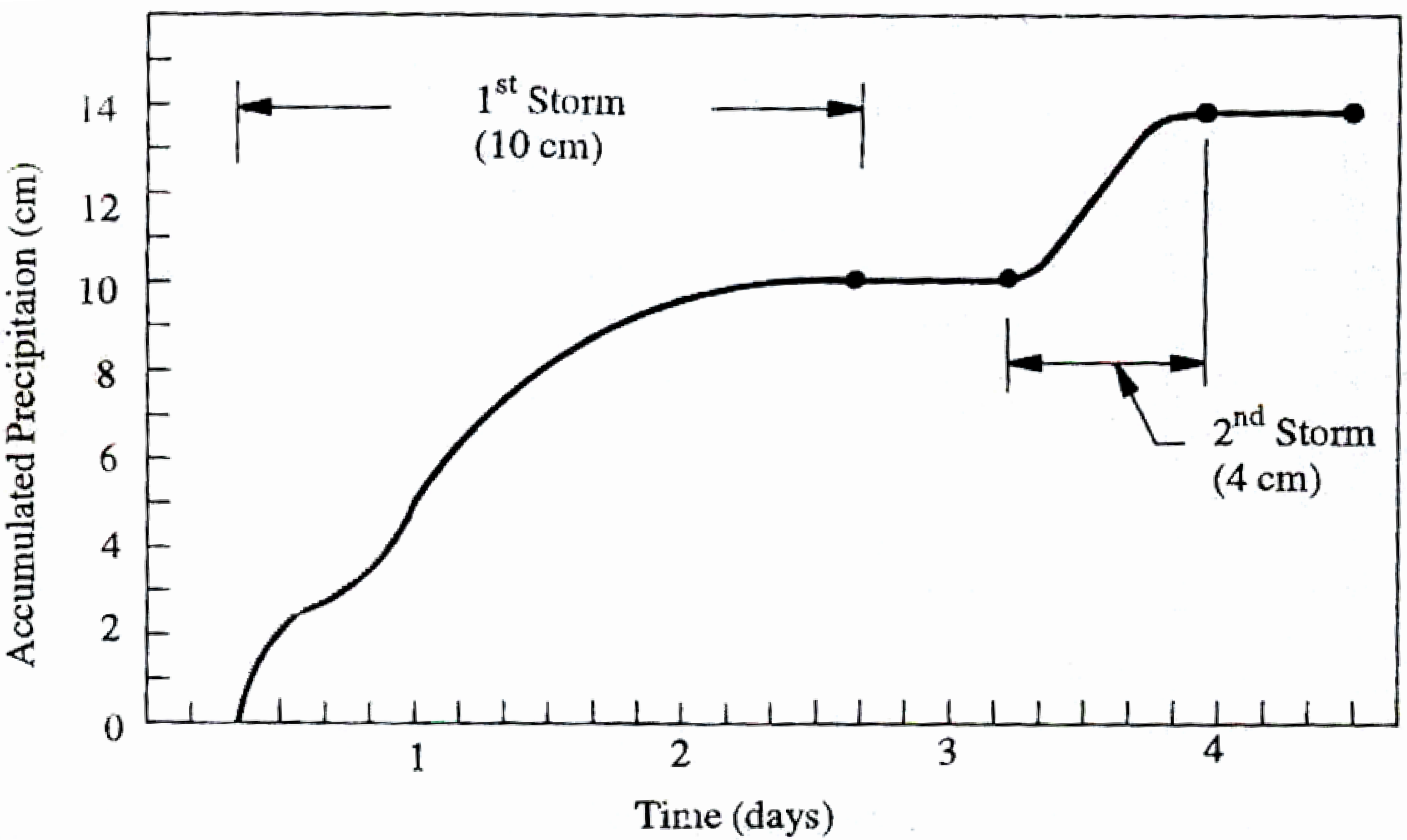


Fig. 2.8 Mass curve of rainfall

Rain Hyetograph

- It is a plot of the intensity of rainfall against the time interval and is represented as a bar chart.
- The hyetograph is derived from the mass curve
- It is a convenient way of representing the characteristics of a storm.
- The area under the hyetograph presents the total precipitation received in the period.
- The time interval depends on the purpose

Rain Hyetograph

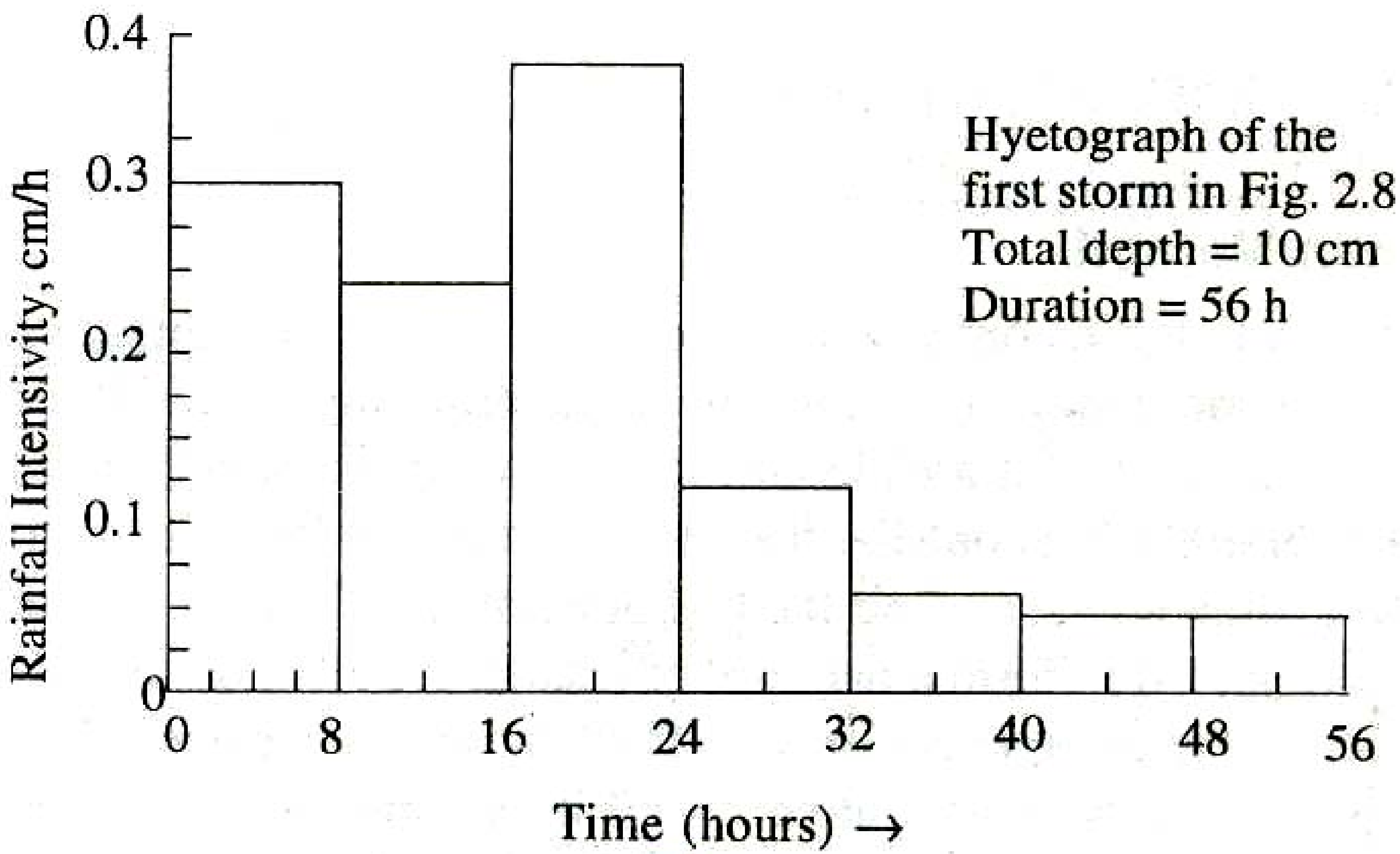
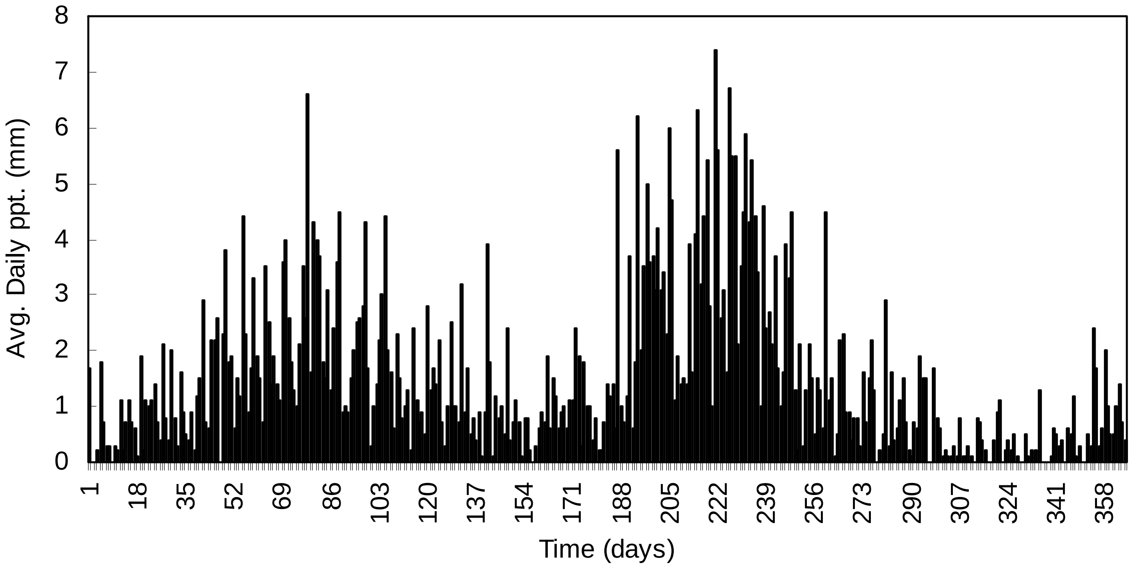
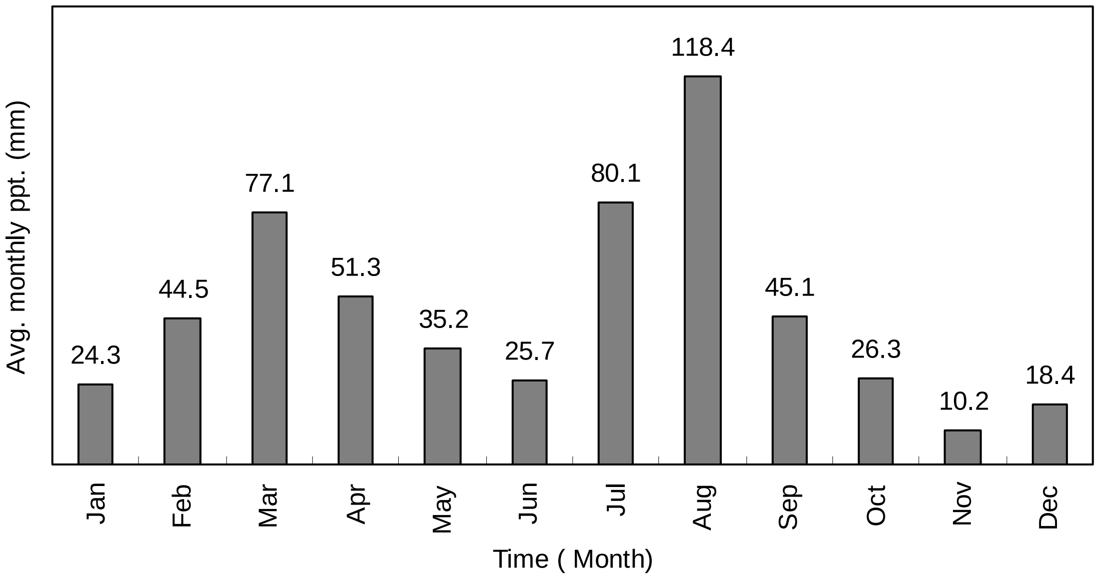


Fig. 2.9 Hyetograph of a storm

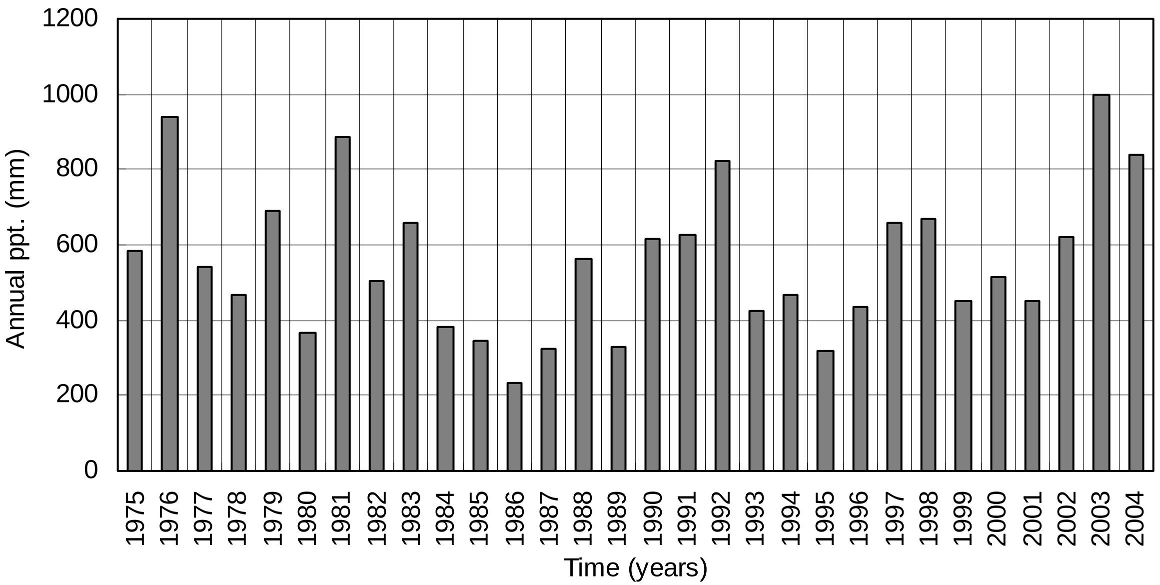
Point Rainfall / Station Rainfall





Point Rainfall / Station Rainfall

- Graphically rain data (hourly, daily, weekly, monthly, annual) are represented as plots of magnitudes vs chronological time in the form of a bar diagram.
- Gives no rainfall trends as rapid variations.
- 3 to 5 points moving average can smooth out the variations and bring out some trend.



Depth Area (DA) Relationship

- Gives areal distribution characteristics of a rainstorm
- Used for the estimation of severe floods
- For a rainfall of a given duration, the average depth decreases with the increase in area as an exponential fashion given by

$$\overline{P} = P_o \; \exp\left(-K \; A^n\right)$$

Where

$\overline{P}$ = average depth in cm over a area A (km^2)

A = rainstorm area

P_o = highest amount of rainfall (cm) at the storm centre (for larger catchments, highest average depth over an area of 25 km^2).

K & n are constants for a region

Depth Area Duration (DAD) Curves

- Gives areal distribution characteristics of a rainstorm
- Used for the estimation of severe floods
- Important aspect of hydro-metereological study

Procedure to prepare DAD curves

(1) Severe most rainstorms in the region are considered

(2) Isohyetal maps and mass curves of the storms are compiled

(3) From the mass curve, various durations and their respective maximum depths of rainfalls are noted.

(4) A depth area curve for a given duration of rainfall is prepared

(5) The procedure is then repeated for different durations.

Depth Area Duration (DAD) Curves

- Maximum depth for a given storm decreases with the area, for a given area the maximum depth increases with the duration.
- DAD curves are essential to develop design storms to compute design floods for major hydraulic structures (dams).

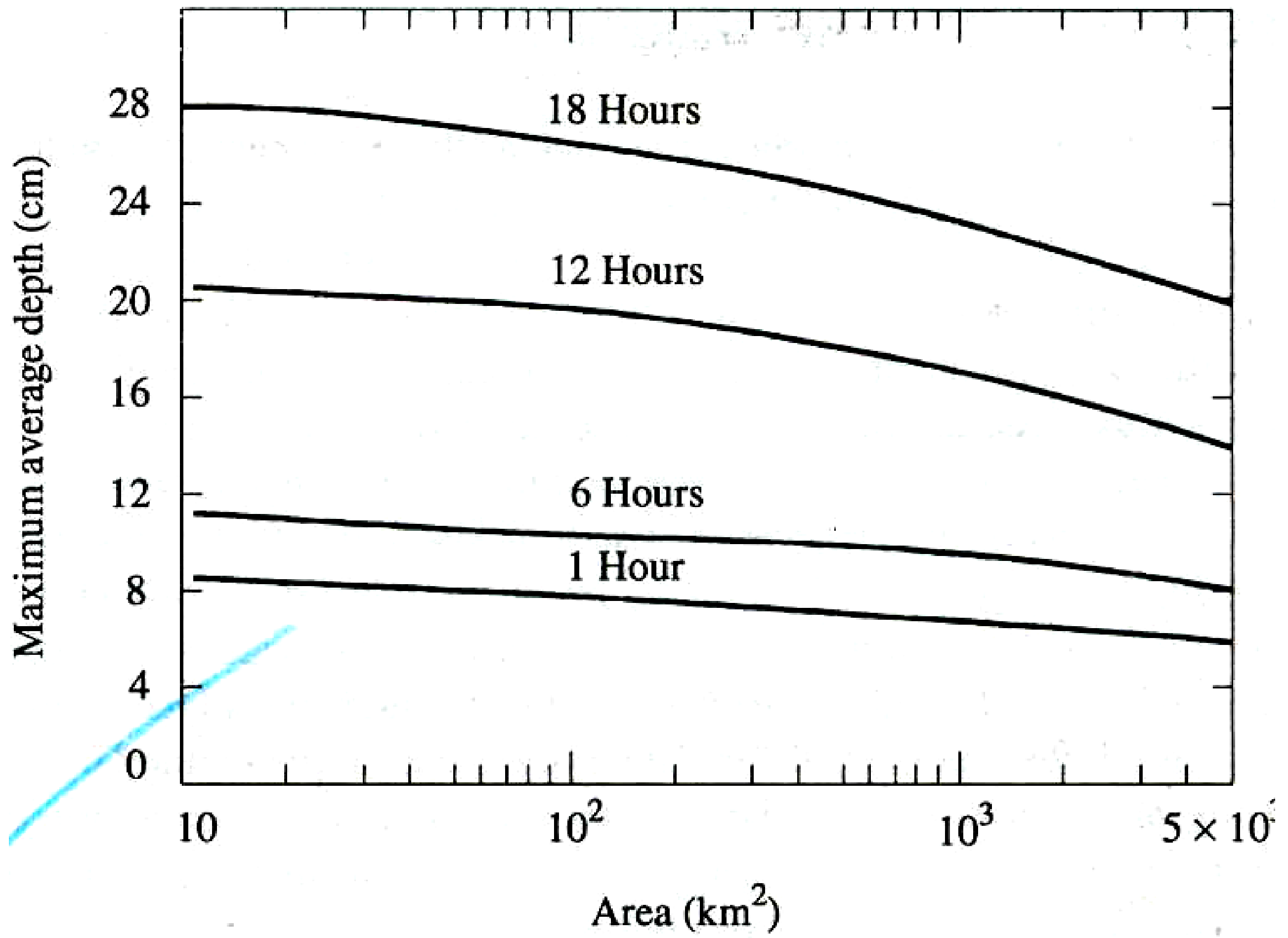


Fig 2.13 Typical DAD curves

Frequency of Point Rainfall

- The rainfall at a place is a random hydrologic process
- Statistical approach to compute rainfall for a given return period based on past data available.
- Methods for compiling rainfall data are two

(1) The Annual Series [only the max rain in each year is taken]

(2) Partial duration Series [all rains above a specified threshold are taken]

Return Period / Recurrence Interval (T)

It is the average number of years during which a rainfall of a given magnitude will be equaled or exceeded once.

Or

The time interval after which a similar rainfall can be expected

Computation of Return Period (T)

- Methods for computation of return periopds

(1) Empirical Approach [for short extrapolations, up to twice]

(2) Analytical Approach [for long extrapolations]

m/N	c
1	1
0.9	0.95
0.8	0.88
0.7	0.845
0.6	0.78
0.5	0.73
0.4	0.66
0.3	0.59
0.2	0.52
0.1	0.40
0.08	0.38
0.04	0.28

- Empirical Approaches

(1) California Method $$T = \frac{N}{m}$$

(2) Allen Hazen Method $$T = \frac{N}{m - 0.5}$$

(3) Weibull Method $$T = \frac{N+1}{m}$$

(4) Gumbel's Method $$T = \frac{N}{m + c - 1}$$

(5) Blom Method $$T = \frac{(N + 0.12)}{(m - 0.44)}$$

(6) Gringorten Method $$T = \frac{(N + 0.25)}{\left(m - \frac{3}{8}\right)}$$

Where

m is the order number when arranged in descending order and *N* total number of records

Probability of exceedence or occurrence (P)

It is the %age of chance of its occurrence in any one year i.e. Frequency.

$$P = \frac{1}{T} X 100$$

Probability of Non exceedence or non occurrence (q)

The probability that it will not occur in a given year. It is denoted by *q*.

$$q = (1 - P)$$

Plotting Position

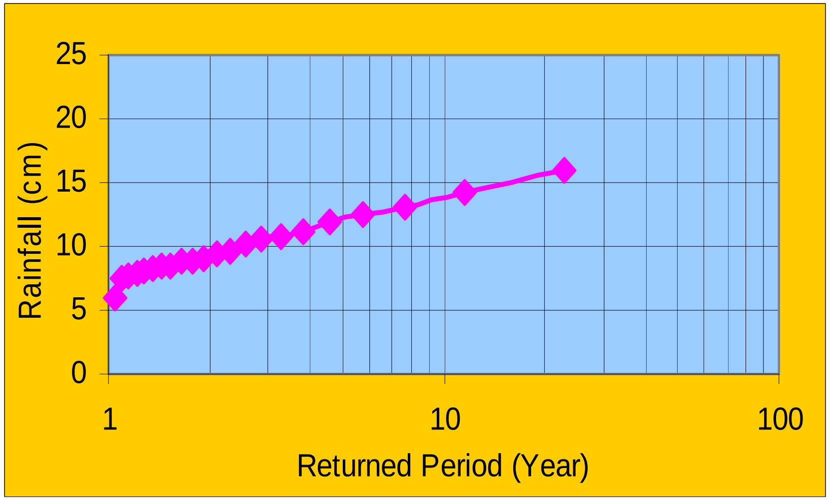
The exceedance probability of the event obtained by the use of an empirical formula is called plotting position.

$$P = \left[\frac{m}{N+1} \right]$$

Purpose of Frequency analysis of an annual series is to obtain a relation between the magnitude of the event & its probability of exceedance.

A simple empirical technique is to arrange the given annual extreme series in descending order of magnitude and to assign an order number *m*.

- Gives good results for small extrapolations
- Error increases with the amount of extrapolation
- For accurate work, use analytical methods



Intensity Duration Frequency Relationship (IDF Curves)

Graphical relationship between avg max intensity and duration of rainfall for various return periods at a place.

- The intensity of storm decreases with the increase in storm duration.
- A storm of any given duration will have a larger intensity if its return period is large.
- For watershed management, it is necessary to know the rainfall intensities at different durations for different return periods.
- A general intensity duration frequency relationship is given below:

$$i = \frac{c}{T_d^e + f}$$

Where

i = intensity of rainfall (cm/hr)

T_d = duration of rainfall (hr)

C, e & f are constants

IDF CURVES

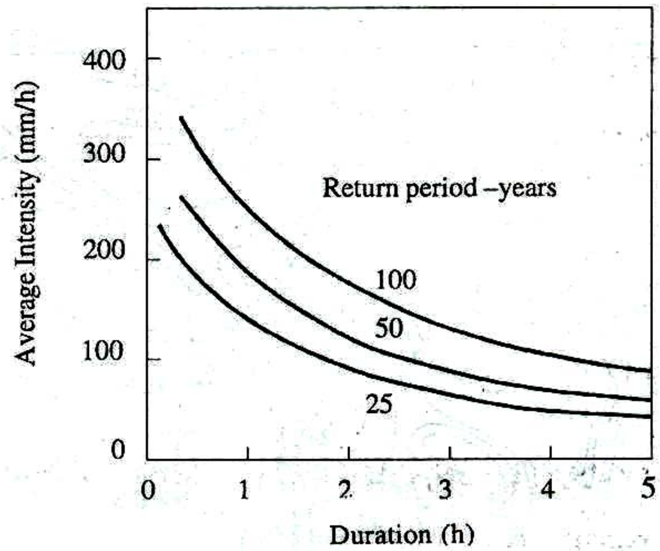


Fig. 2.15 (a) Intensity–duration–frequency curves

DDF CURVES

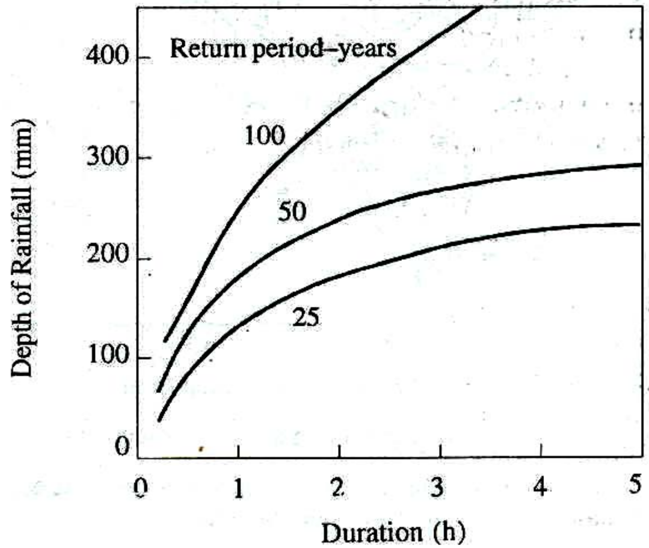


Fig. 2.15 (b) Depth–duration–frequency curves.

TABLE 14.2.3
Constants for rainfall equation (14.2.2) for 10-year return period storm intensities at various locations

Location	c	e	f
Atlanta	97.5	0.83	6.88
Chicago	94.9	0.88	9.04
Cleveland	73.7	0.86	8.25
Denver	96.6	0.97	13.90
Houston	97.4	0.77	4.80
Los Angeles	20.3	0.63	2.06
Miami	124.2	0.81	6.19
New York	78.1	0.82	6.57
Santa Fe	62.5	0.89	9.10
St. Louis	104.7	0.89	9.44

Constants correspond to i in inches per hour and T_d in minutes. *Source*: Wenzel, 1982, Copyright by the American Geophysical Union.

Procedure to prepare IDF curves for an area

(1) Mass curves of the storms are compiled.

(2) Severe most rainstorms in the region are considered (one per year).

(3) From the severe storms, various durations and their respective maximum depths of rainfalls are noted.

(4) Compute cumulative rainfall depths for each duration.

(5) Determine avg intensity of precipitation for each duration.

(6) Carry out Frequency analysis (Gumbel Distribution) and determine intensities for various return periods (2, 5, 10, 50, 100 years).

(7) Determine avg ppt, standard deviation and frequency factors for each return period to carryout frequency analysis.

(8) Adjust computed values with factors of 0.88, 0.96 and 0.99 for 2, 5 and 10 years return periods, respectively.

(9) Plot IDF curves for each return period

$$x_T = \bar{x} + K_T \, \sigma$$

$$K_T = \frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\frac{T}{T-1}\right)\right]$$

TABLE 14.2.2
Annual exceedence series of rainfall data for Coshocton, Ohio

Rank	Return period (yr)	Maximum depth (in) and date for duration shown			
		15 min	30 min	60 min	120 min
1	25.00	1.423 6/12/57	2.625 6/12/57	3.220 6/12/57	3.421 6/12/57
2	12.50	0.940 7/11/51	1.326 7/24/68	1.830 6/27/75	1.900 7/27/69
3	8.33	0.920 6/12/59	1.238 5/13/64	1.756 7/27/69	1.883 8/21/60
4	6.25	0.910 5/13/64	1.177 6/23/52	1.510 8/21/60	1.792 7/4/69
5	5.00	0.890 6/27/75	1.170 7/22/58	1.431 7/24/68	1.733 7/24/68
6	4.17	0.884 6/23/52	1.167 6/27/75	1.375 7/22/58	1.703 8/4/59
7	3.57	0.860 8/14/73	1.149 6/17/70	1.313 6/17/70	1.623 6/12/59
8	3.13	0.810 7/27/69	1.087 6/15/75	1.306 5/13/64	1.609 6/28/57
9	2.78	0.805 6/22/51	1.063 8/22/51	1.290 6/23/52	1.604 6/13/72
10	2.50	0.783 6/24/56	1.060 7/11/51	1.269 4/25/61	1.600 7/28/61
11	2.27	0.770 8/15/75	1.040 6/12/59	1.225 6/12/59	1.570 4/25/61
12	2.08	0.770 7/22/58	1.037 7/19/67	1.213 7/4/69	1.482 7/22/58
13	1.92	0.750 7/10/73	1.027 9/5/75	1.204 6/13/72	1.393 8/11/64
14	1.79	0.750 6/17/70	1.023 7/10/73	1.203 8/11/64	1.353 5/13/64
15	1.67	0.733 7/19/67	1.000 7/10/55	1.200 8/3/63	1.351 9/24/70
16	1.56	0.732 7/30/58	0.975 7/27/69	1.194 8/2/64	1.335 6/23/69
17	1.47	0.710 7/3/52	0.972 7/30/58	1.192 9/12/57	1.310 8/14/57
18	1.39	0.707 8/3/63	0.934 8/27/74	1.174 7/28/61	1.305 6/24/57
19	1.32	0.700 7/24/68	0.919 7/28/61	1.143 6/22/51	1.300 6/11/60
20	1.25	0.700 6/4/63	0.907 9/12/57	1.130 9/24/70	1.300 6/23/52
21	1.19	0.700 6/22/60	0.890 8/14/73	1.130 7/19/67	1.290 8/2/64
22	1.14	0.692 4/3/74	0.880 6/24/56	1.109 9/5/75	1.274 9/12/57
23	1.09	0.688 8/27/74	0.873 6/11/60	1.095 7/6/58	1.230 7/3/52
24	1.04	0.687 9/12/57	0.869 7/4/69	1.094 6/28/57	1.220 7/6/58
25	1.00	0.670 4/13/55	0.850 8/11/64	1.063 8/27/74	1.200 9/5/75

Source: Wenzel, 1982, Copyright by the American Geophysical Union.

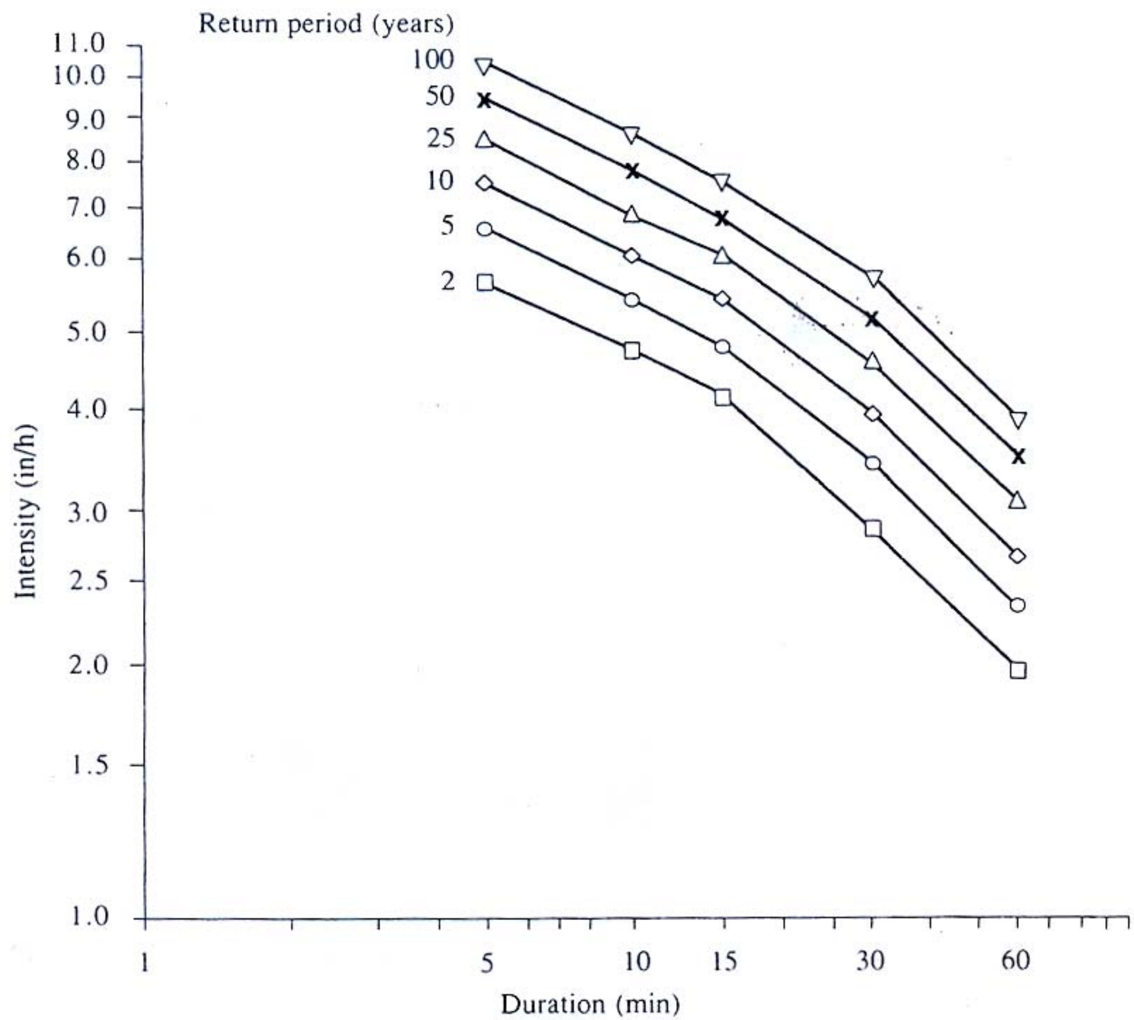


FIGURE 14.2.2
Intensity-duration-frequency curves for Oklahoma City (Example 14.2.1).

Probable Maximum Precipitation (PMP)

Extreme / greatest rainfall for a given duration that is physically possible over a station or basin due to extreme meteorological combinations..

Or

That rainfall over a basin which would produce a flood flow with virtually no risk of being exceeded.

To keep the failure probability for a hydraulic structure as low as possible, virtually zero.

Procedure to develop PMP

(1) Meteorological Method

(2) Statistical study of rainfall data

Using Statistical Studies

$$PMP = \overline{P} + k\,\sigma$$

K depends on (Consult Manual):

(1) Statistical distribution of series
(2) Number of years of the record
(3) Return Period

Where

$\overline{P}$ = mean of annual maximum rainfall series

σ = Standard deviation of series

k = Frequency factor

according to WMO, 1983, PMP can have return period as long as 500,000,000 years, so *k* is app. = 15

PMP is calculated by using the Hershfield method (1961) using frequency equation:

$$PMP = (K_x X_n) + K_m (K_s S_n)$$

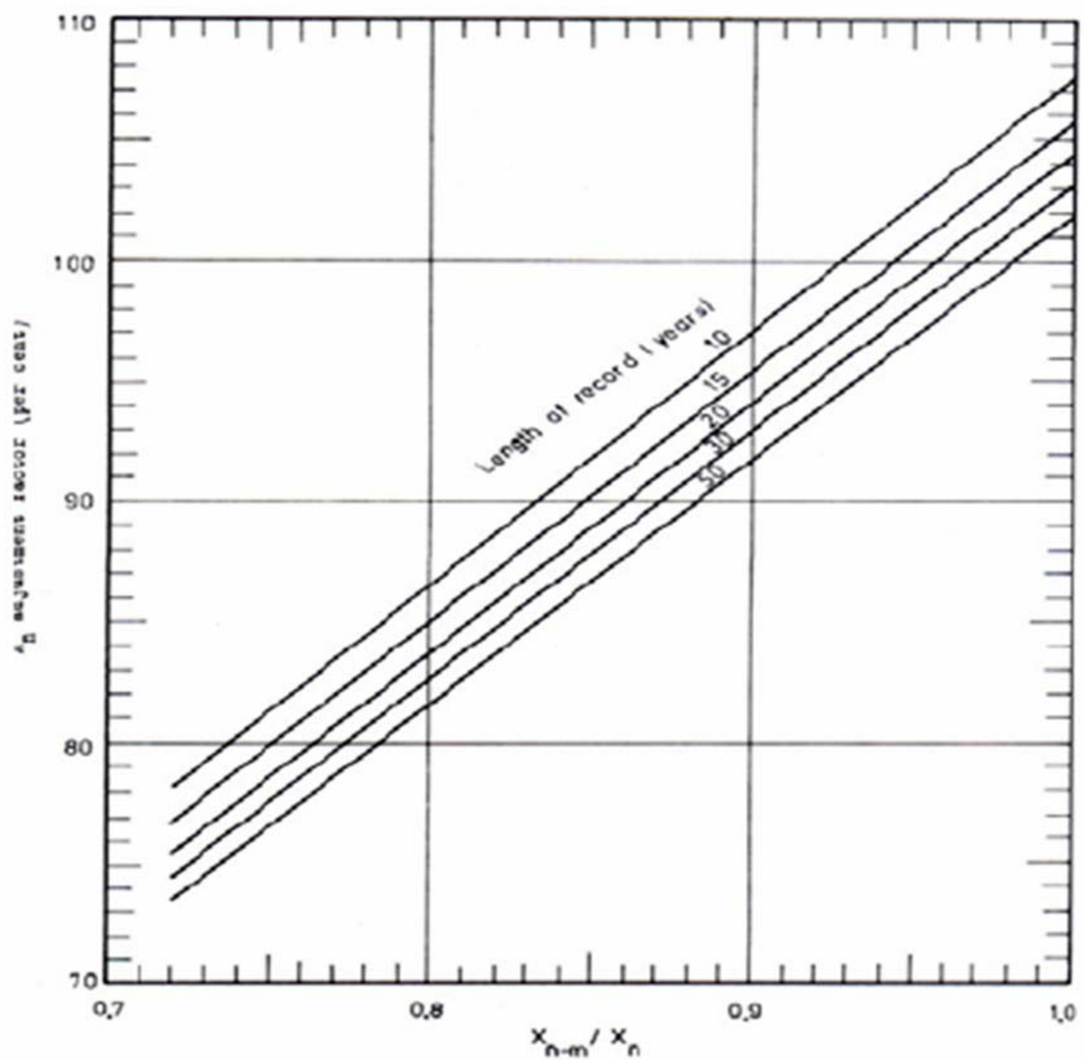
Where Xn and Sn are mean and standard deviation of a series of n annual maxima and Kx & Ks are adjustment factors.

Km is frequency factor and its value corresponding to adjusted values of Xn by means of Figure

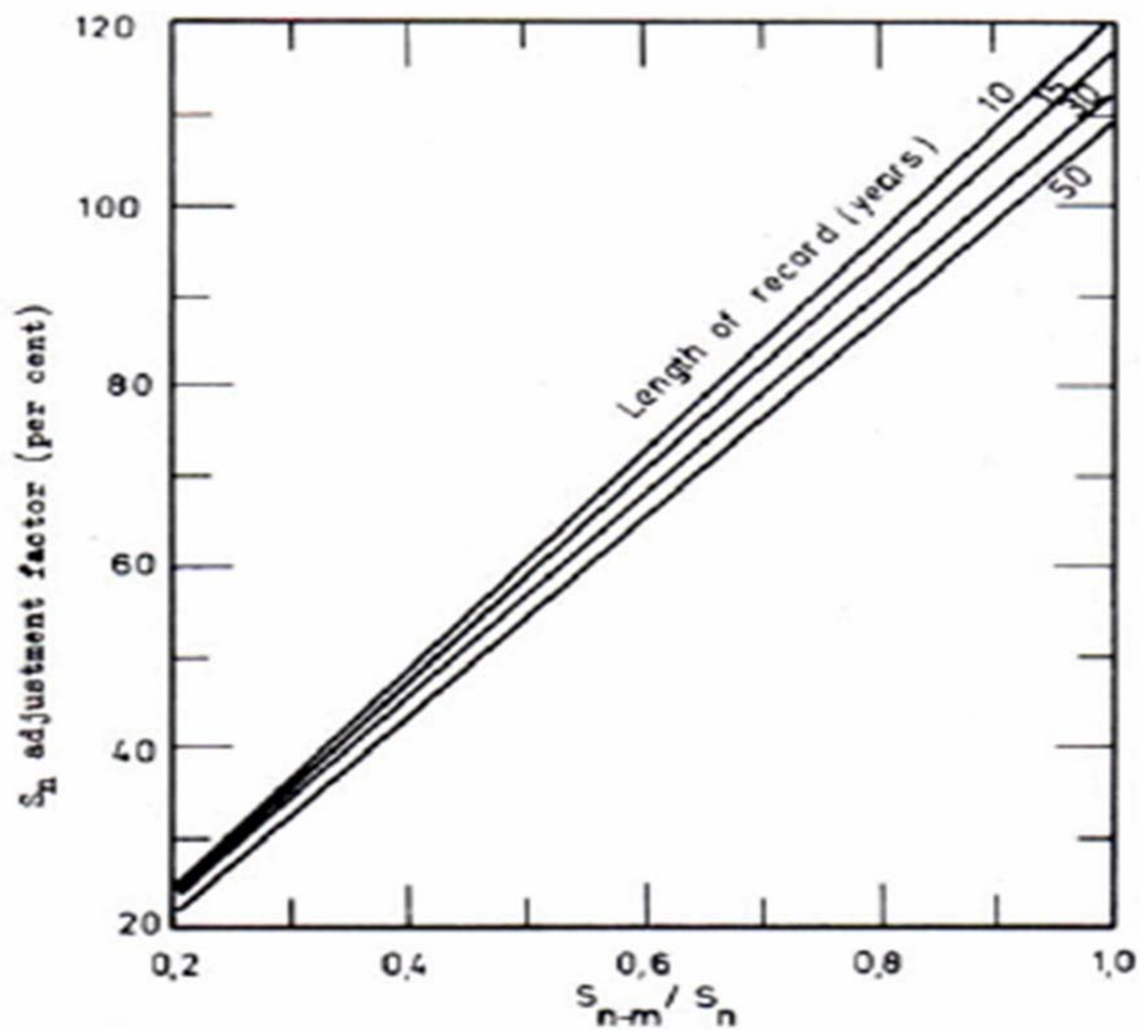
Or using following Hershfield Equation.

$$K_m = \left(\frac{X_m - X_{n-1}}{S_{n-1}} \right)$$

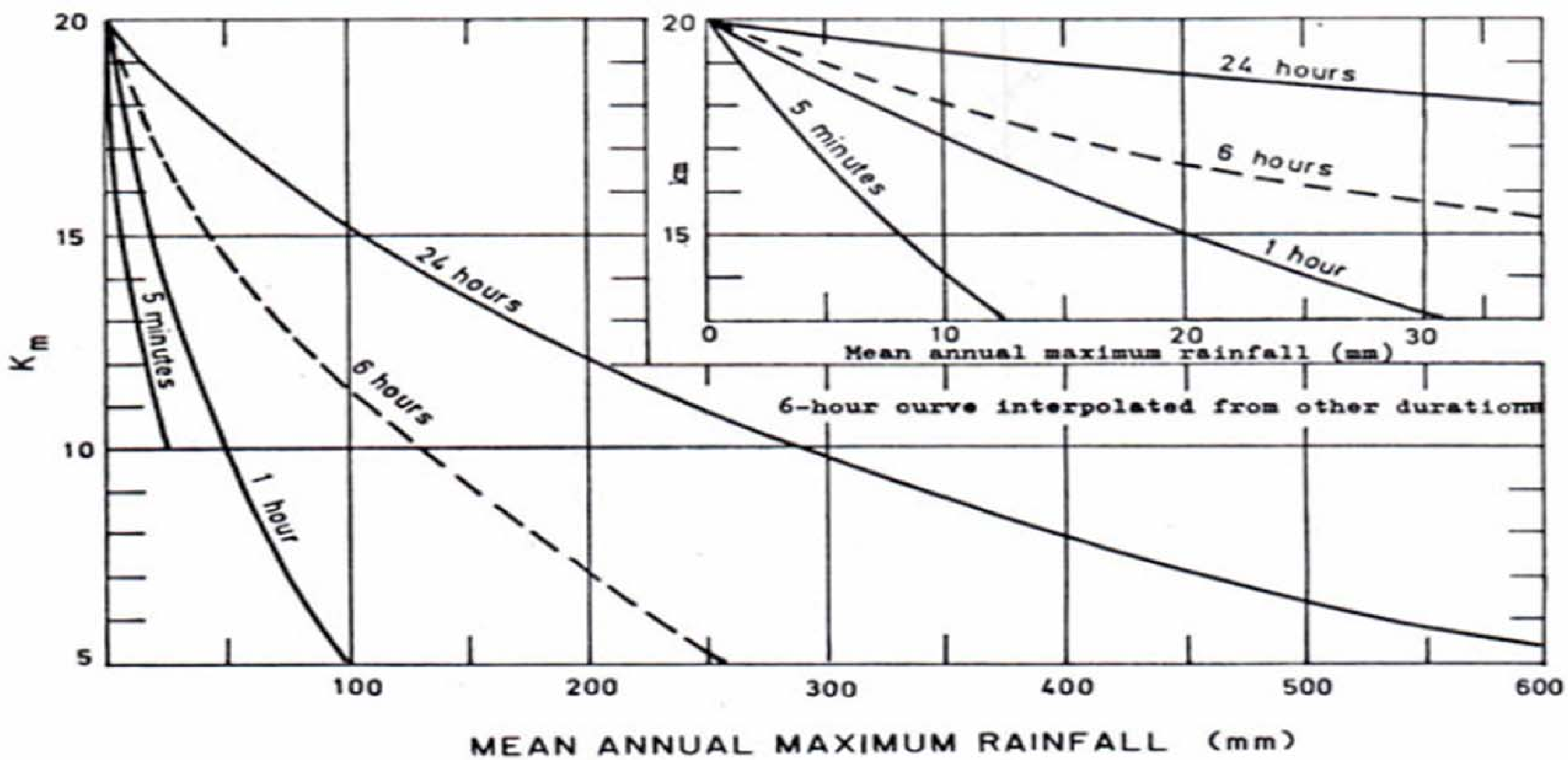
ADJUSTMENT OF MEAN PRECIPITATION



ADJUSTMENT OF STANDARD DEVIATION

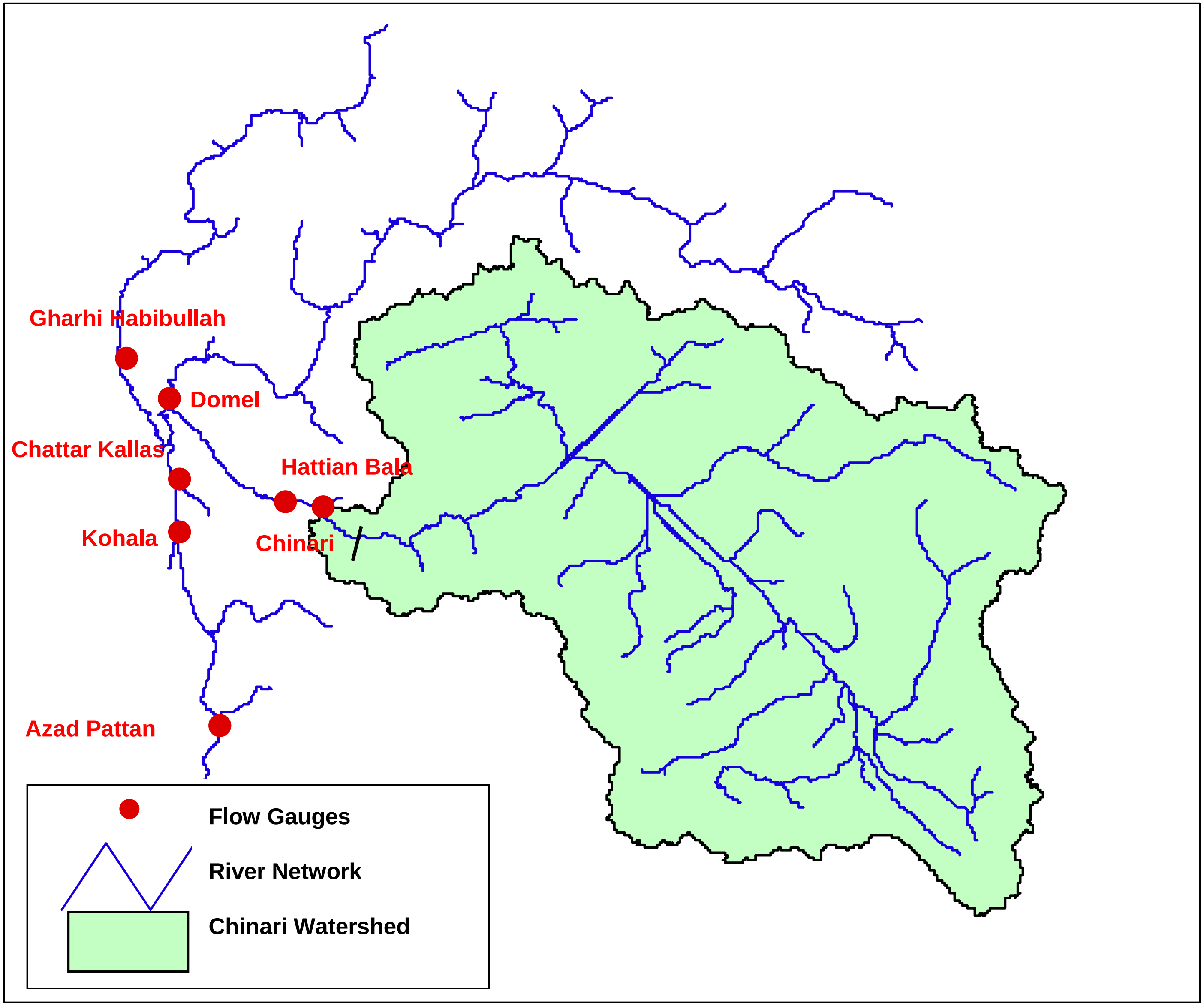


DETERMINATION OF FREQUENCY FACTOR (K_m)

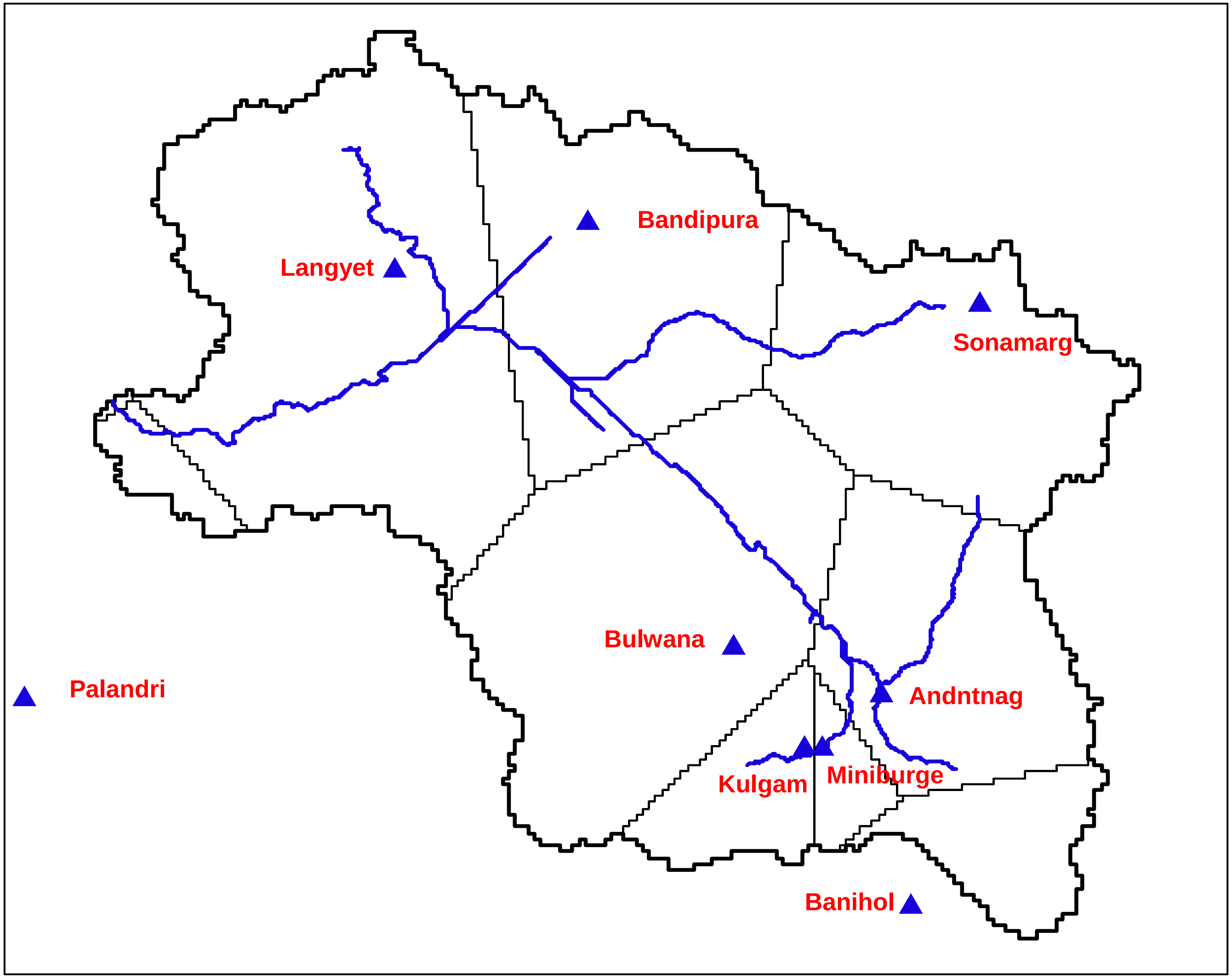


Meteorological / Physically Based Method for PMP

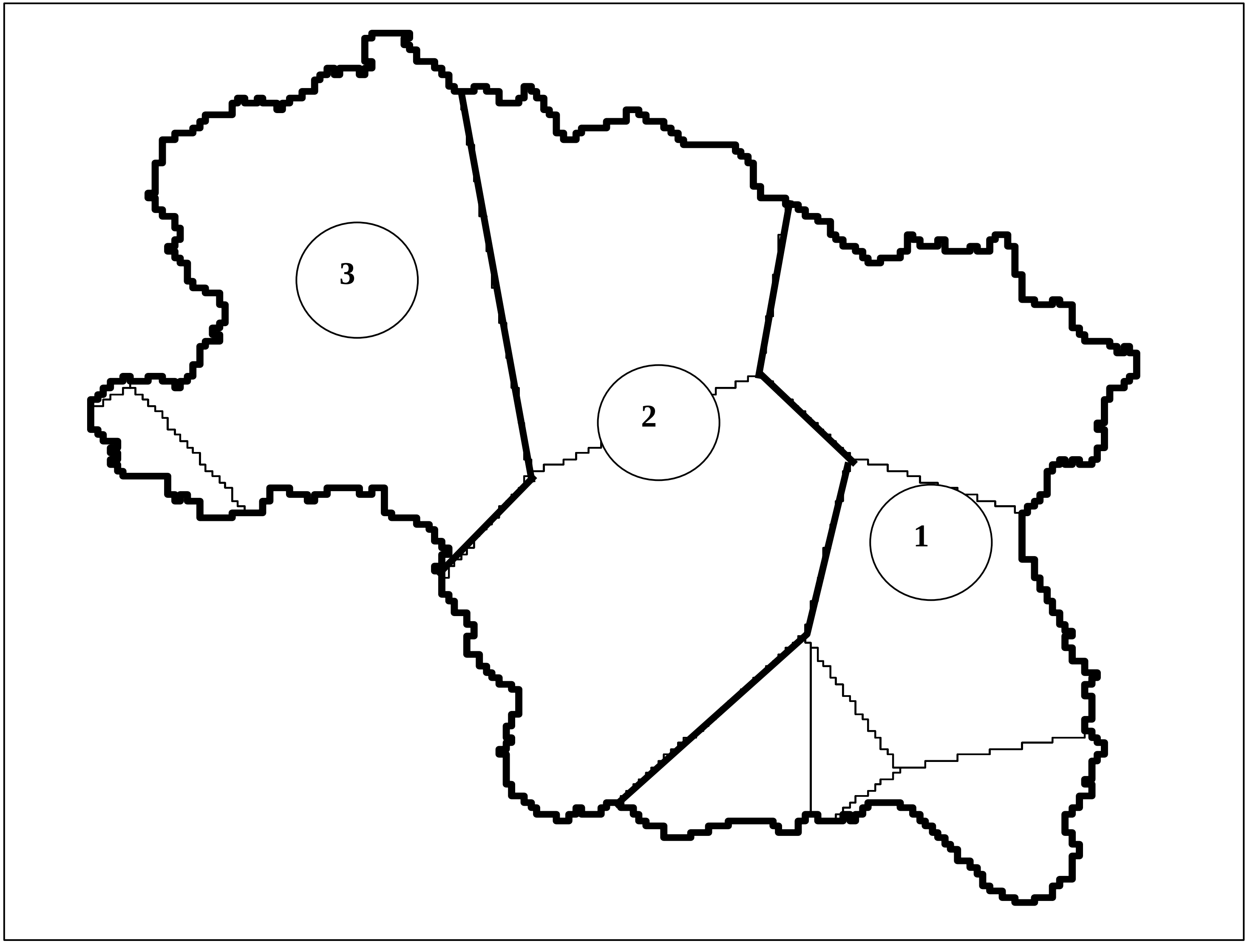
- Data Collection (severe most rainstorm's hourly data)
- Delineation of watershed boundary for the dam site.
- Divide watershed in segments based on similar Metreological characteristics
- Generate Rain gauge point coverage
- Find highest Instantaneous maximum discharge year at the stream gauging station till recent.
- Select Probable Maximum Storm (PMS) based on past data
- Compute Average precipitation over the segments of WS for PMS.
- Compute 'Moisture Maximization Factor'.
- Compute PMP for each segment.
- Compute weighted average PMP for whole watershed.
- Consider possibility of antecedent rainstorm



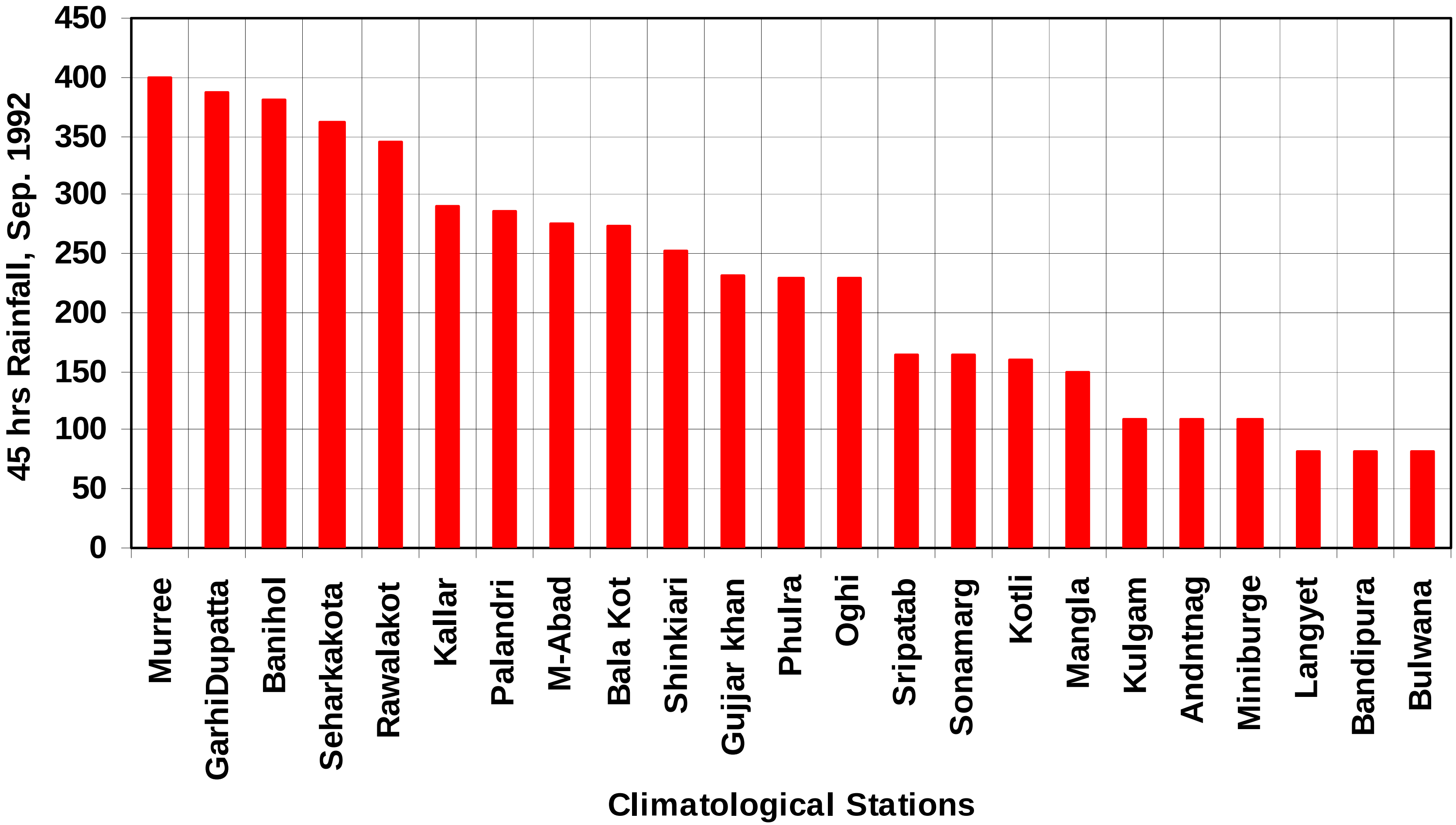
Gharhi Habibullah
Domel
Chattar Kallas
Hattian Bala
Kohala
Chinari
Azad Pattan
Flow Gauges
River Network
Chinari Watershed



Bandipura
Langyet
Sonamarg
Bulwana
Palandri
Andntnag
Kulgam
Miniburge
Banihol


3
2
1

Rainfall Amounts at various locations in 1992 (45 hours)



Moisture Maximization Factor

$$r_m = \left(\frac{W_m}{W_s} \right)$$

W_m is the maximum precipitable water indicated for the storm reference location

W_s is the precipitable water estimated for the storm.

These are for a moisture column with the base at ground and the top at 300 m Bar.

Data Required

12 hr Storm dewpoint temp.	T_s	22.8	^oC
Max. 12hr persistant dewpoint temp.	T_p	28.2	^oC
Storm elevation (Pressure)	P	930	milli Bar
Pressure at Top Layer	P_u	300	milli Bar
Temperature Lapse Rate	α	6.5	$^oC/km$
Gas constant for air	R_a	287	j / kg.^oK

$$\Delta M = (Avg\ \ Humidity)\ (Avg\ \ Air\ \ Density)\ (Area)\ (thickness)$$

$$q_y = 0.622\left(\frac{e}{p}\right)$$

Precipitable water for Dew Point Temp. of 22.8 oC, and Pressure of 930 mBar

Pressure	z	dZ	T	T	Pressure	Air Density	Avg. Density	Vap. Press. e.	Sp. Humidity q_v	Avg Humidity	Incremental Mass δM	Incremental Precipitation mm	%age of Total
m Bar	km	m	oC	oK	kPa	kg/m^3	kg/m^3	kPa	kg/kg	kg/kg	kg	mm	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
930	0		**22.8**	295.8	93.00	1.10		2.78	0.0186				
827	1	1000	16.3	289.3	82.74	1.00	1.05	1.85	0.0139	0.0163	17.00	17.00	35.3
734	2	1000	9.8	282.8	73.42	0.90	0.95	1.21	0.0103	0.0121	11.50	11.50	23.9
650	3	1000	3.3	276.3	64.97	0.82	0.86	0.77	0.0074	0.0088	7.62	7.62	15.8
573	4	1000	-3.2	269.8	57.33	0.74	0.78	0.48	0.0052	0.0063	4.93	4.93	10.2
504	5	1000	-9.7	263.3	50.43	0.67	0.70	0.29	0.0036	0.0044	3.11	3.11	6.5
442	6	1000	-16.2	256.8	44.22	0.60	0.63	0.17	0.0024	0.0030	1.91	1.91	4.0
386	7	1000	-22.7	250.3	38.64	0.54	0.57	0.10	0.0016	0.0020	1.14	1.14	2.4
336	8	1000	-29.2	243.8	33.65	0.48	0.51	0.05	0.0010	0.0013	0.66	0.66	1.4
300	8.82	820	-34.53	238.47	29.95	0.44	0.46	0.03	0.0007	0.0008	0.31	0.31	0.7

Precipitable Water during Storm mm = W_s = 48.20

Precipitable water for Dew Point Temp. of 28.2 oC, and Pressure of 930 mBar

Pressure	z	dZ	T	T	Pressure	Air Density	Avg. Density	Vap. Press. e.	Sp. Humidity q_v	Avg. Humidity	Incremental Mass ηM	Incremental Precipitation mm	%age of Total
m Bar	km	m	oC	oK	kPa	kg/m^3	kg/m^3	kPa	kg/kg	kg/kg	kg	mm	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
930	0		**28.2**	301.2	93.00	1.08		3.83	0.0256				
829	1	1000	21.7	294.7	82.92	0.98	1.03	2.60	0.0195	0.0225	23.17	23.17	48.1
737	2	1000	15.2	288.2	73.74	0.89	0.94	1.73	0.0146	0.0170	15.94	15.94	33.1
654	3	1000	8.7	281.7	65.41	0.81	0.85	1.13	0.0107	0.0126	10.75	10.75	22.3
579	4	1000	2.2	275.2	57.85	0.73	0.77	0.72	0.0077	0.0092	7.09	7.09	14.7
510	5	1000	-4.3	268.7	51.02	0.66	0.70	0.44	0.0054	0.0066	4.57	4.57	9.5
449	6	1000	-10.8	262.2	44.85	0.60	0.63	0.27	0.0037	0.0046	2.87	2.87	6.0
393	7	1000	-17.3	255.7	39.31	0.54	0.57	0.16	0.0025	0.0031	1.76	1.76	3.6
343	8	1000	-23.8	249.2	34.33	0.48	0.51	0.09	0.0016	0.0021	1.04	1.04	2.2
300	8.97	970	-30.105	242.895	30.00	0.43	0.46	0.05	0.0010	0.0013	0.58	0.58	1.2

Maximum Precipitable Water mm = W_m = 67.77

World's Greatest Observed Rainfall

Based on the rainfall records available over the world, following relationship is established:

$$P_m = 422 \; D^{0.475}$$

Where

P_m = Extreme rainfall depth in mm

D = Duration in hours

Note: PMP may be obtained from this equation

World's Greatest Observed Rainfall

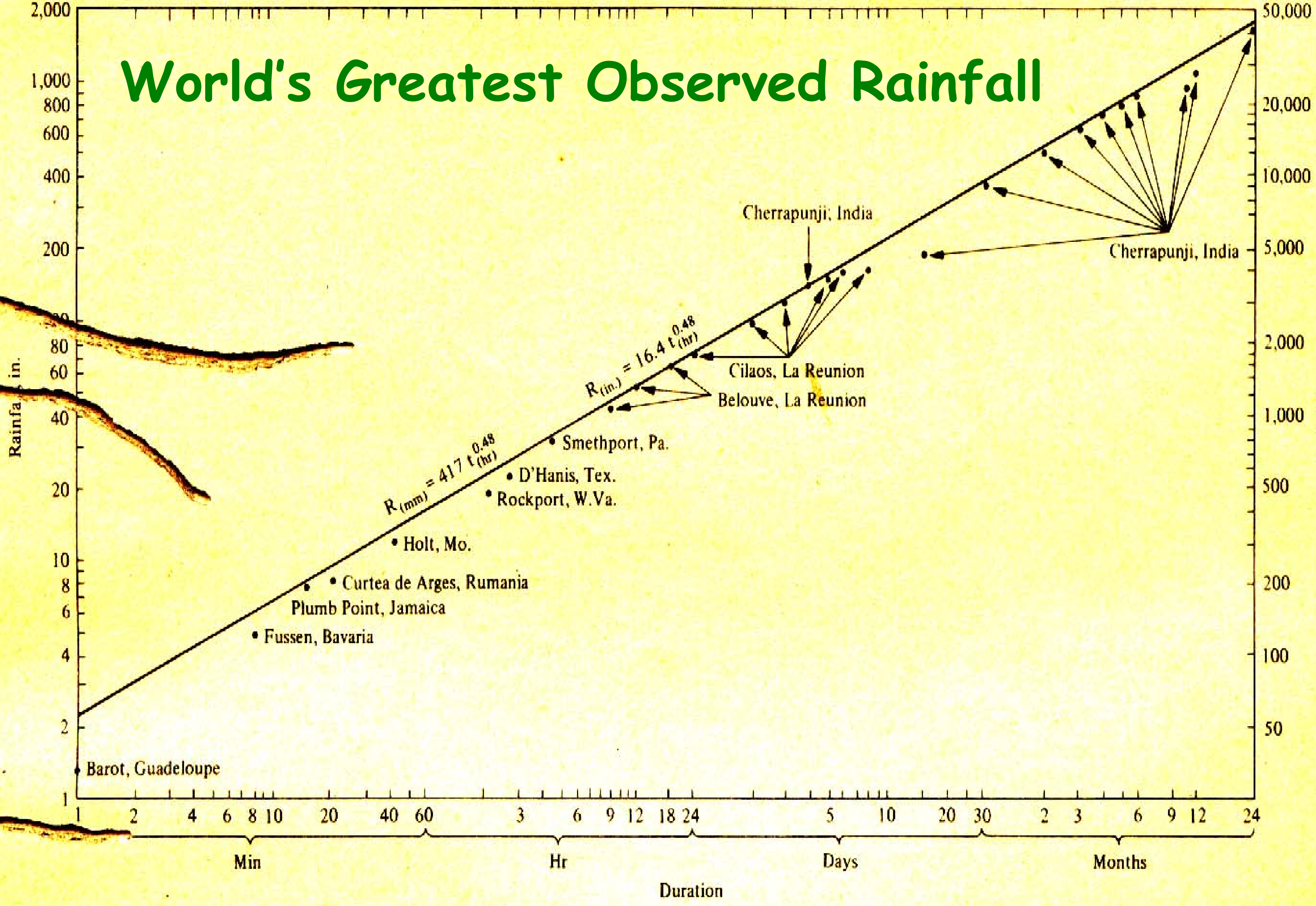


Figure 3-16 World's greatest observed point rainfalls.

Rainfall Distribution Map for Pakistan

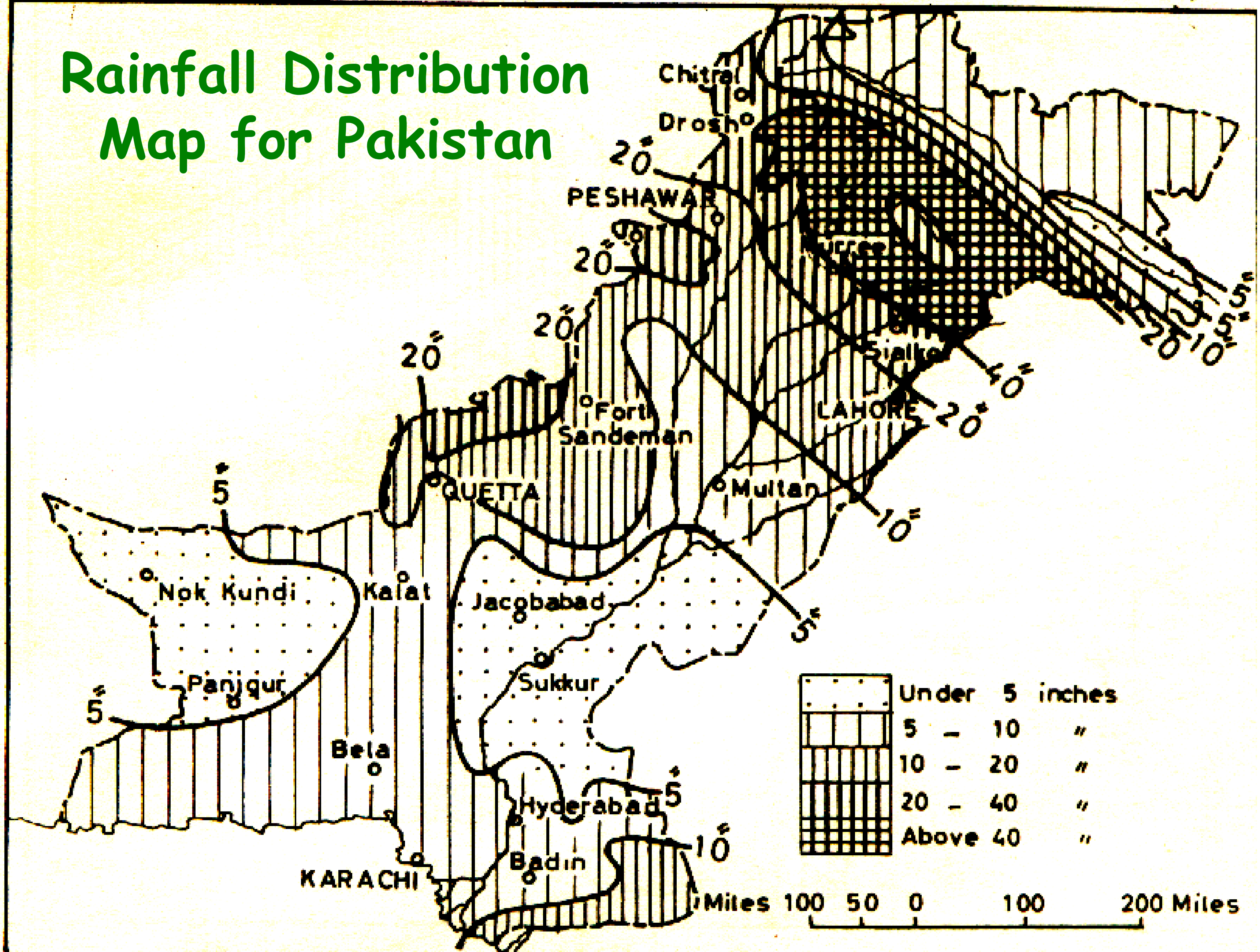
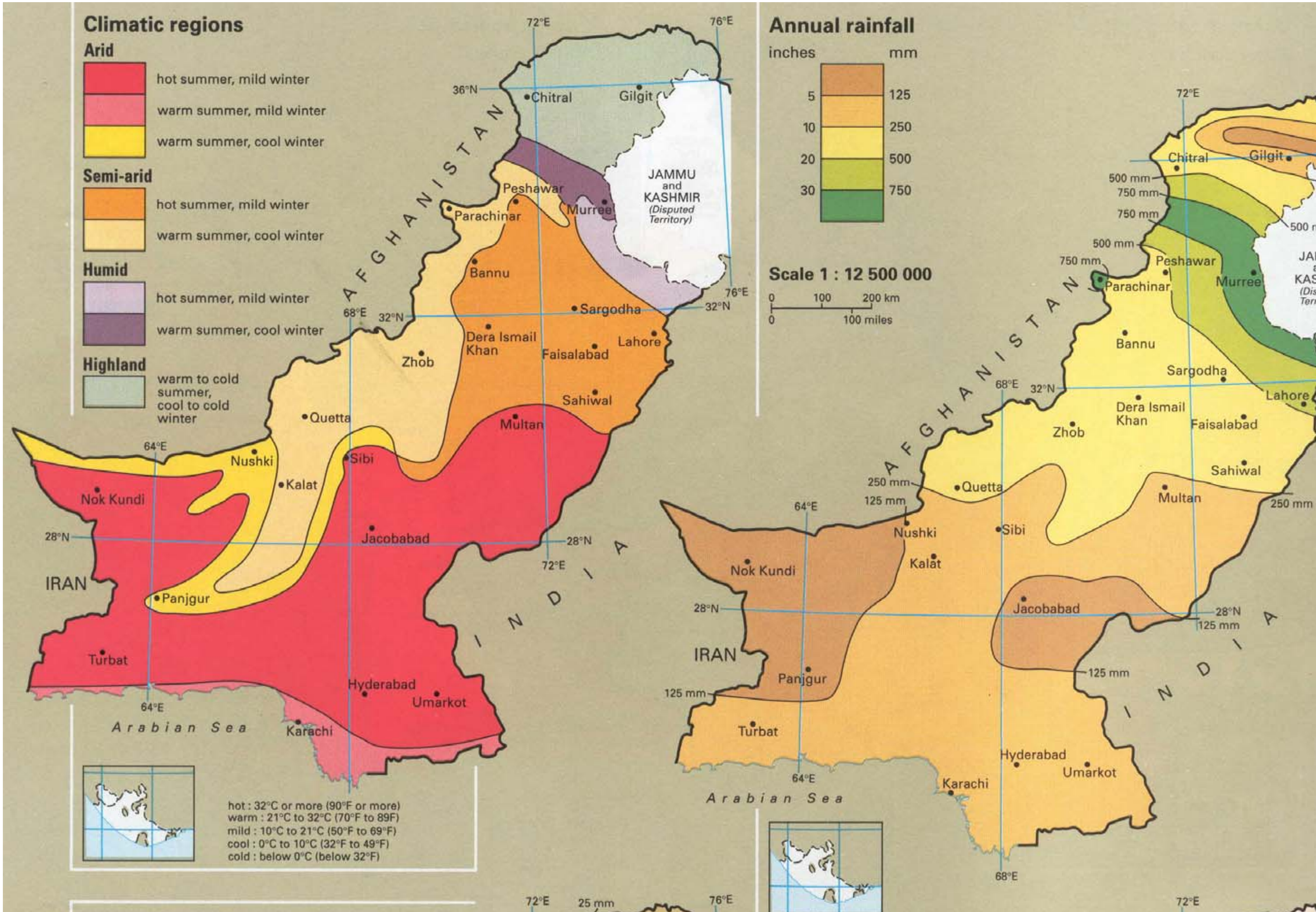


Fig. 19 Pakistan: Mean annual rainfall

Climate & Rainfall Distribution Maps for Pakistan



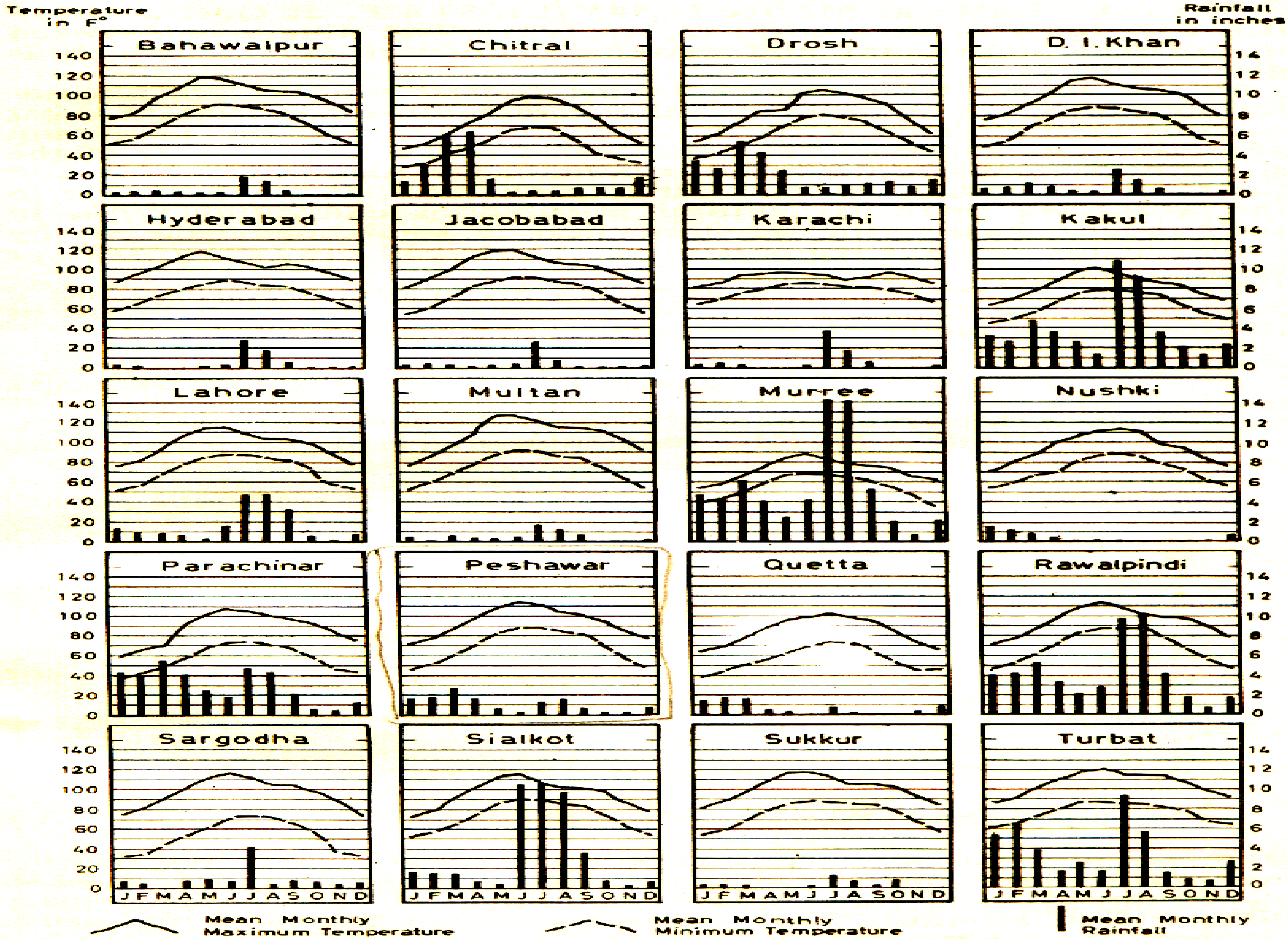
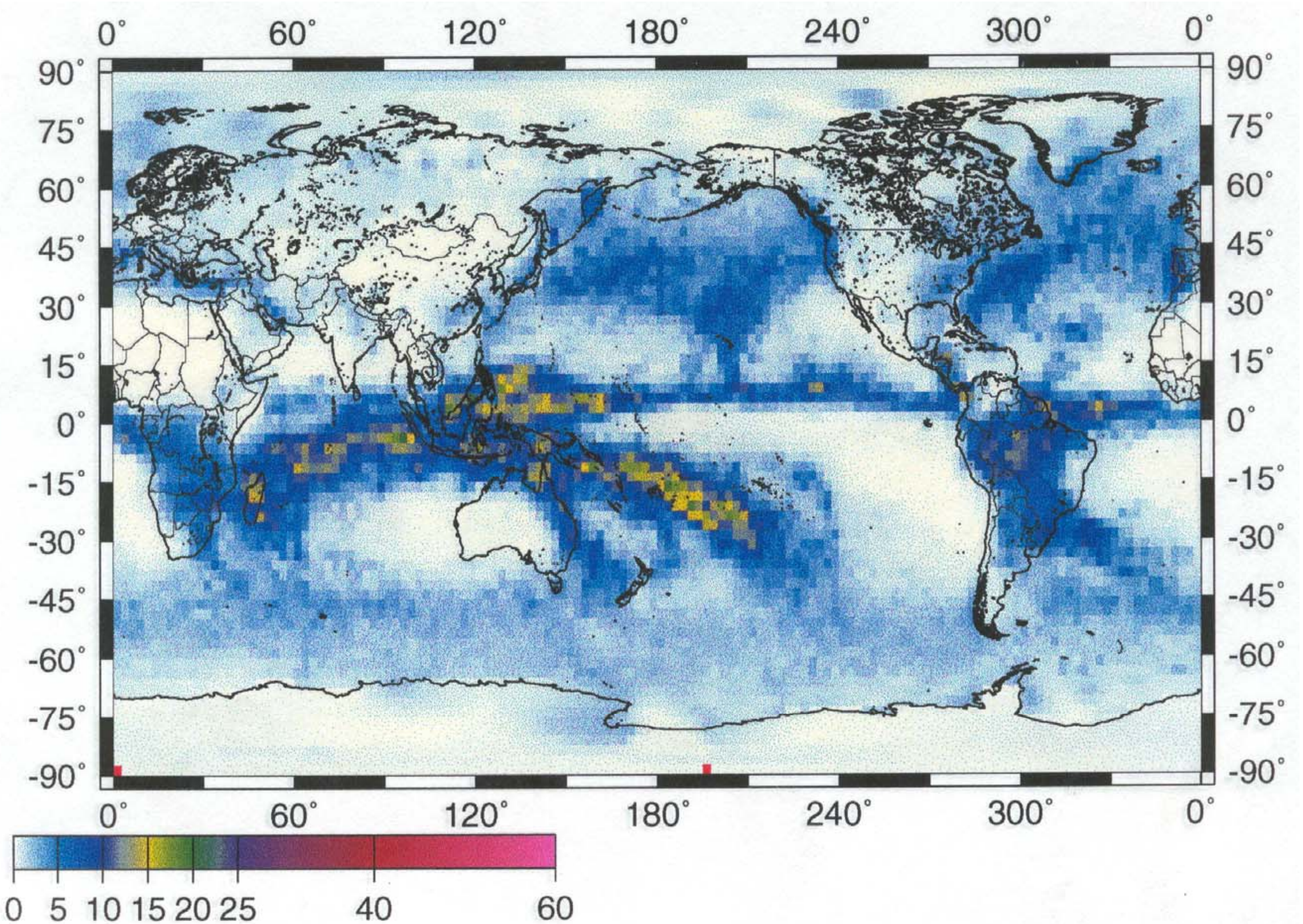
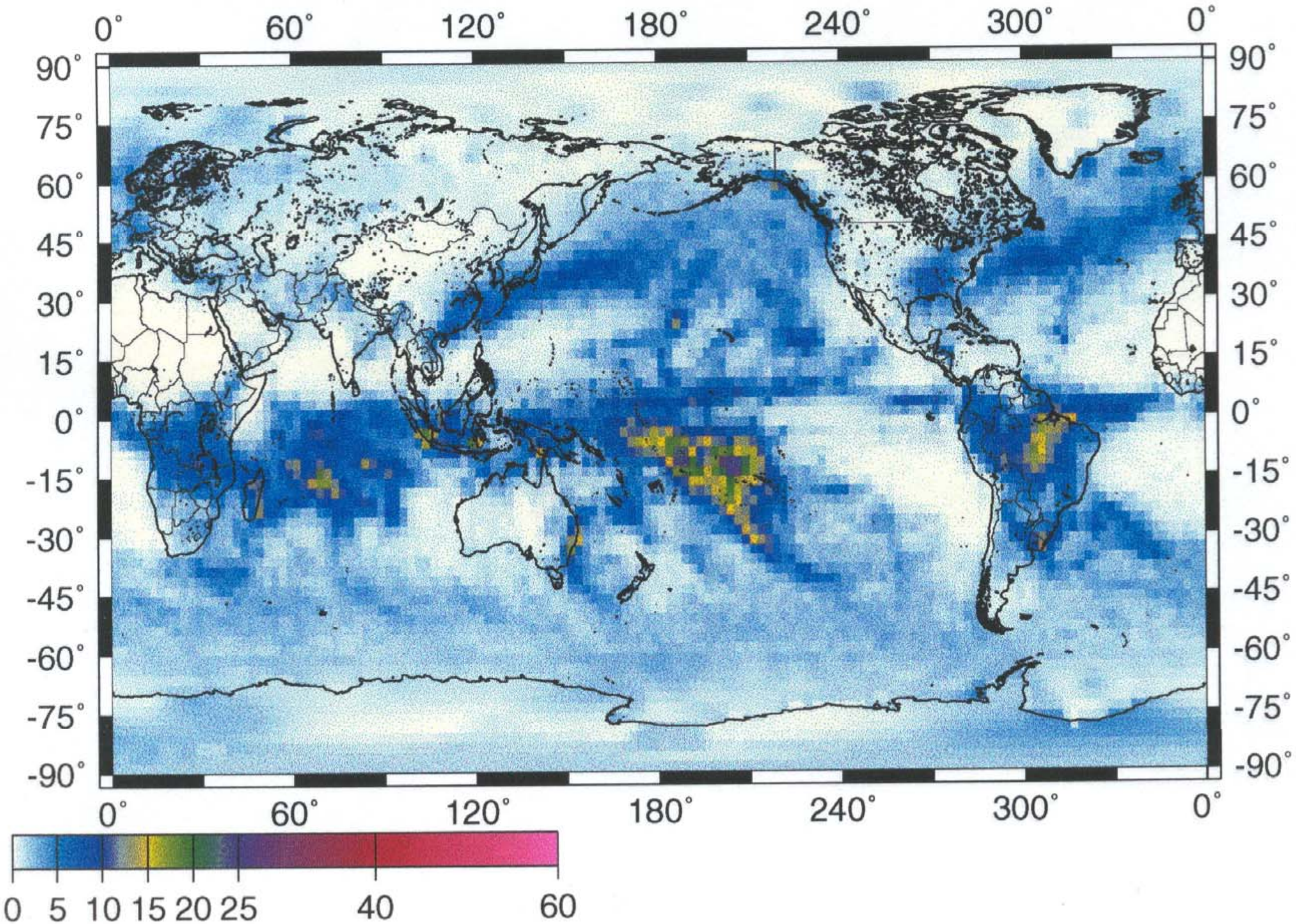


Fig. 16 Pakistan: Rainfall and Temperature

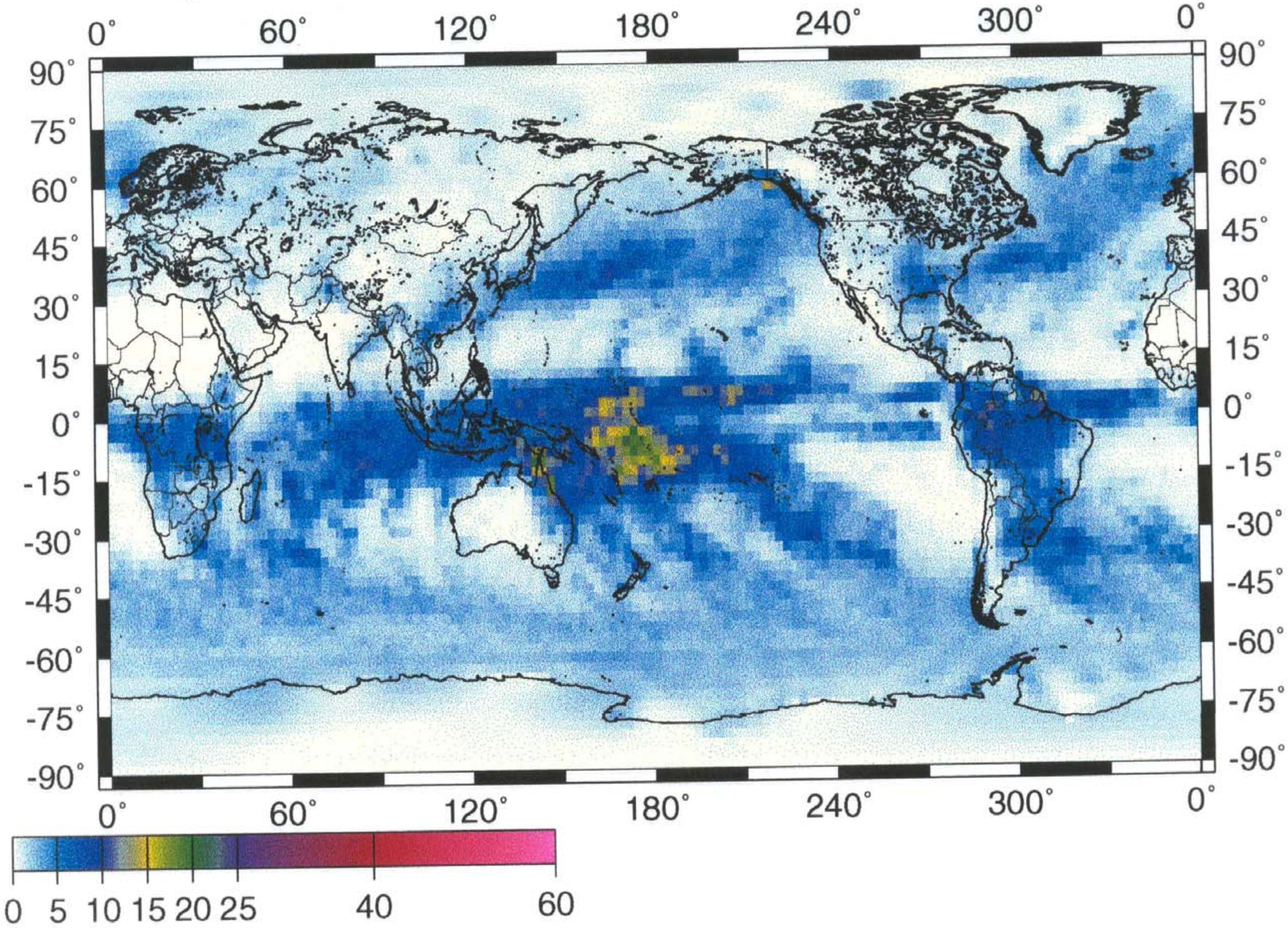
GLOBAL MONTHLY PPT. IN JAN, 1990



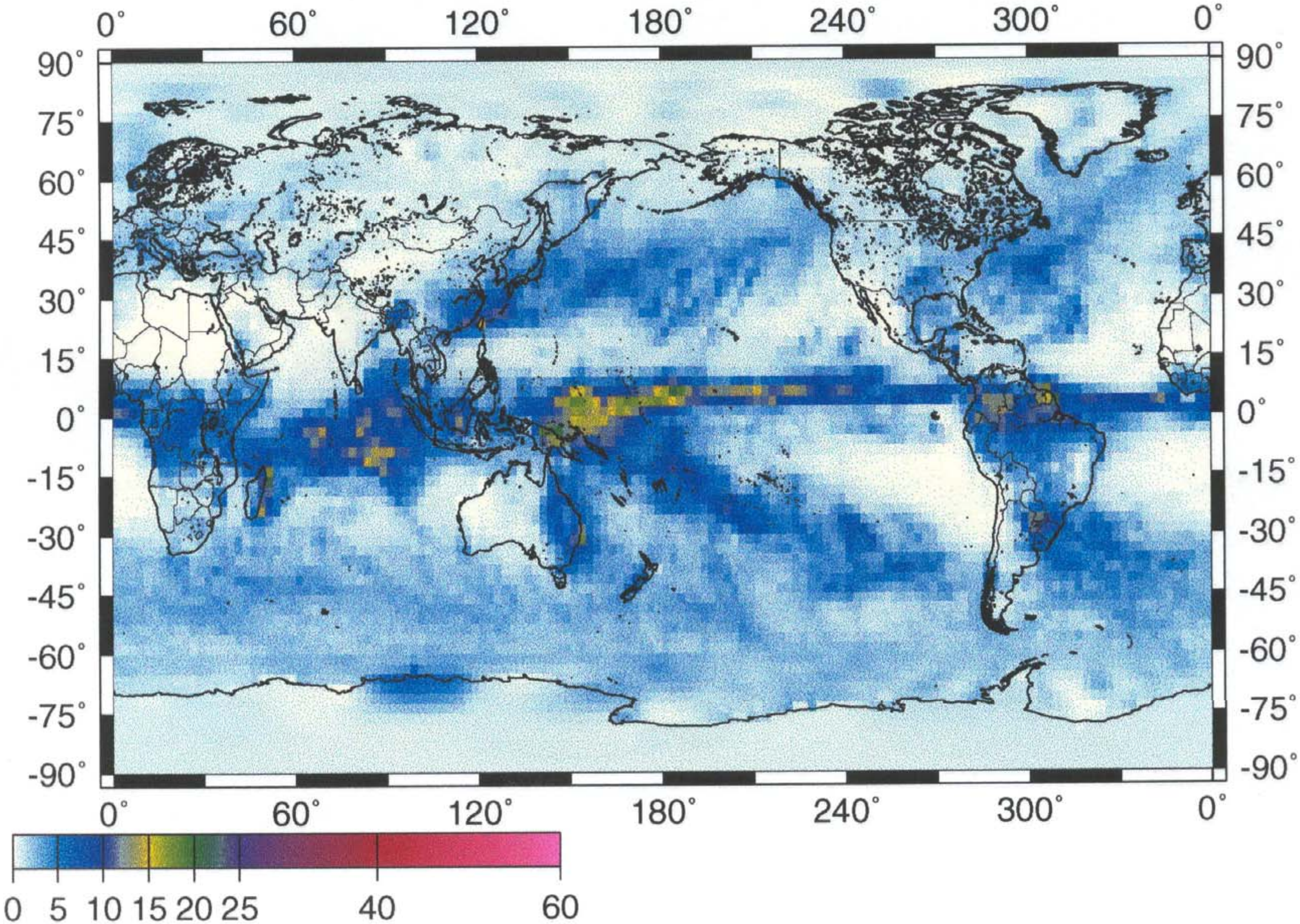
GLOBAL MONTHLY PPT. IN FEB, 1990



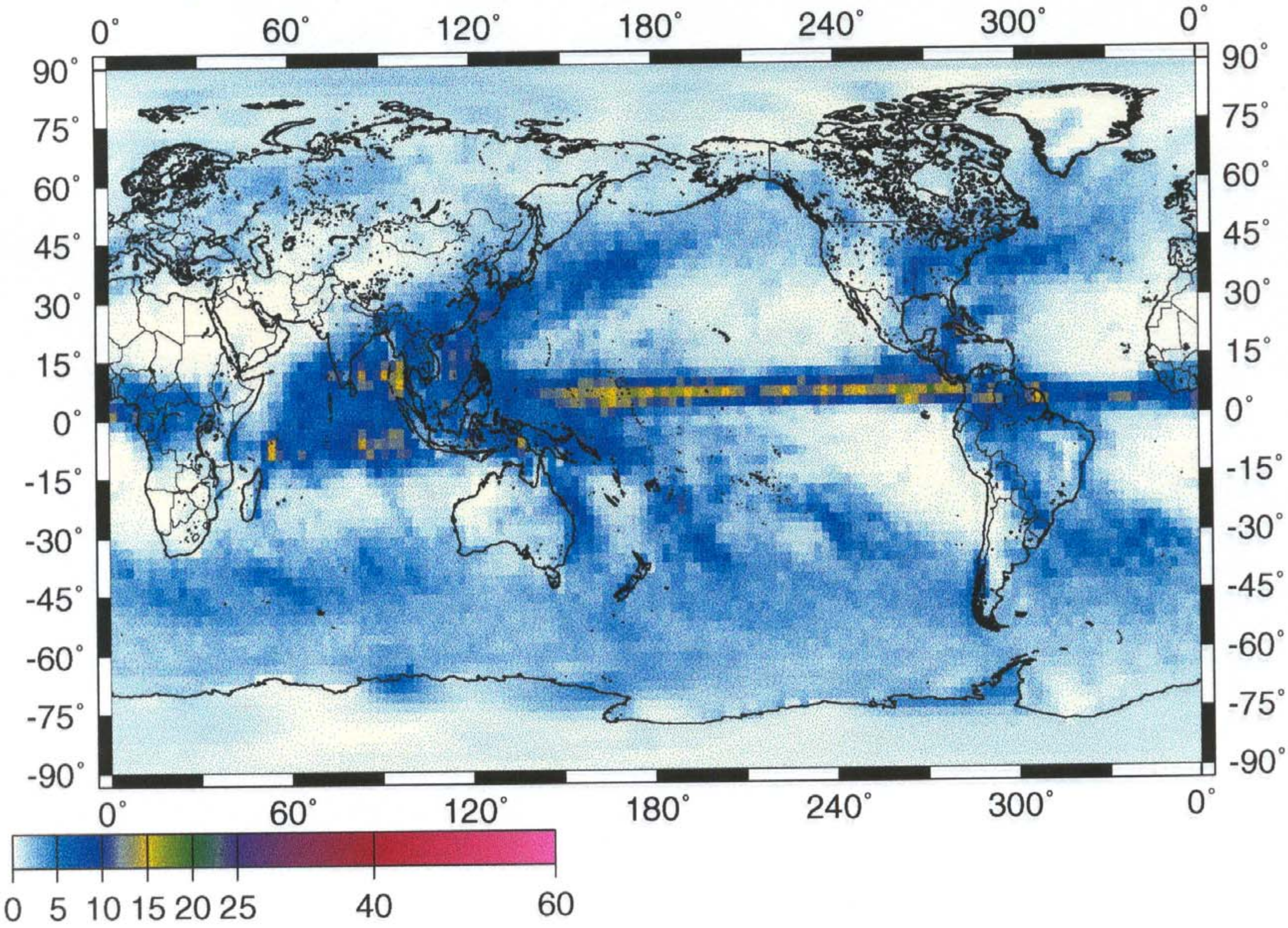
GLOBAL MONTHLY PPT. IN MAR, 1990



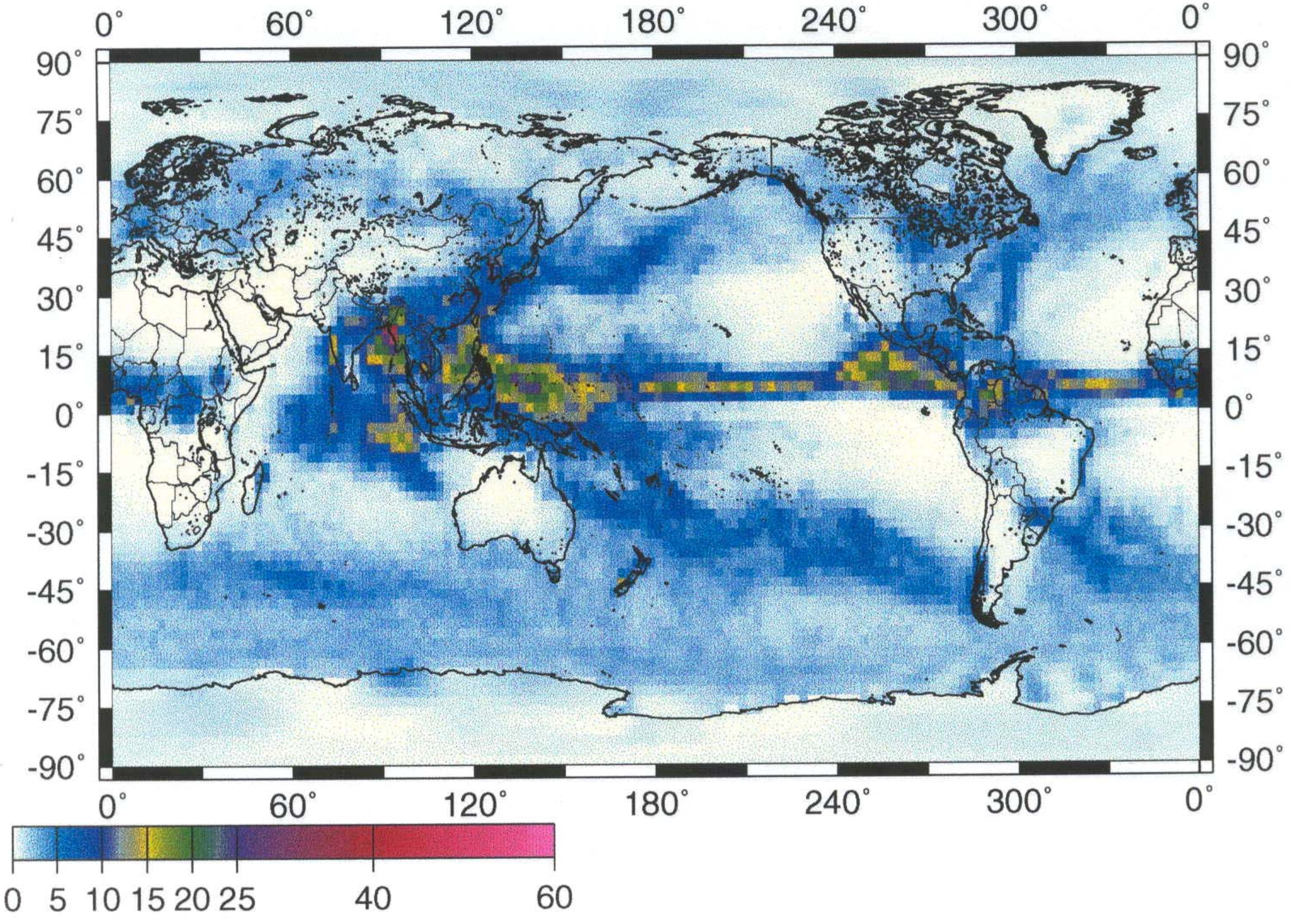
GLOBAL MONTHLY PPT. IN APR, 1990



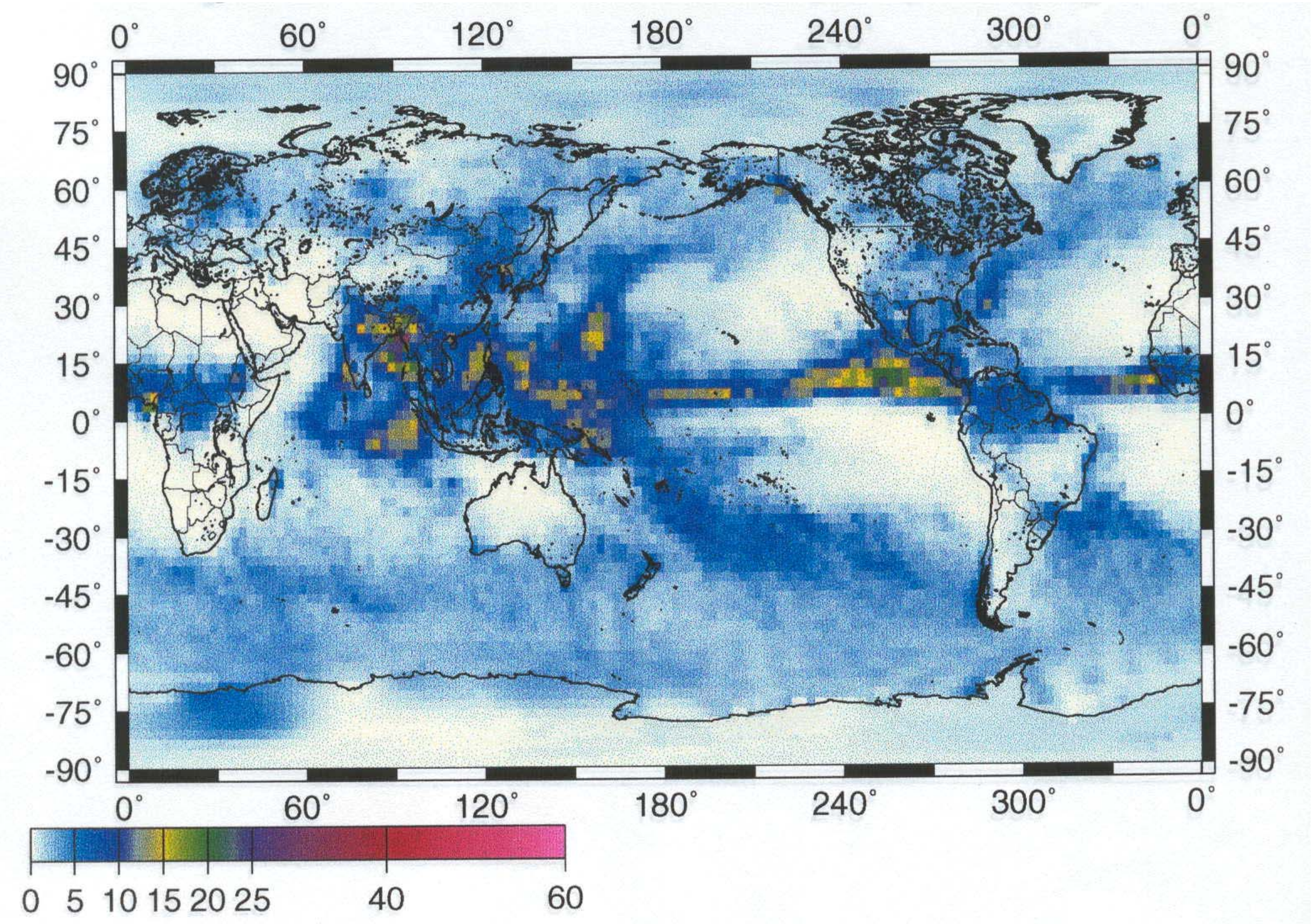
GLOBAL MONTHLY PPT. IN MAY, 1990



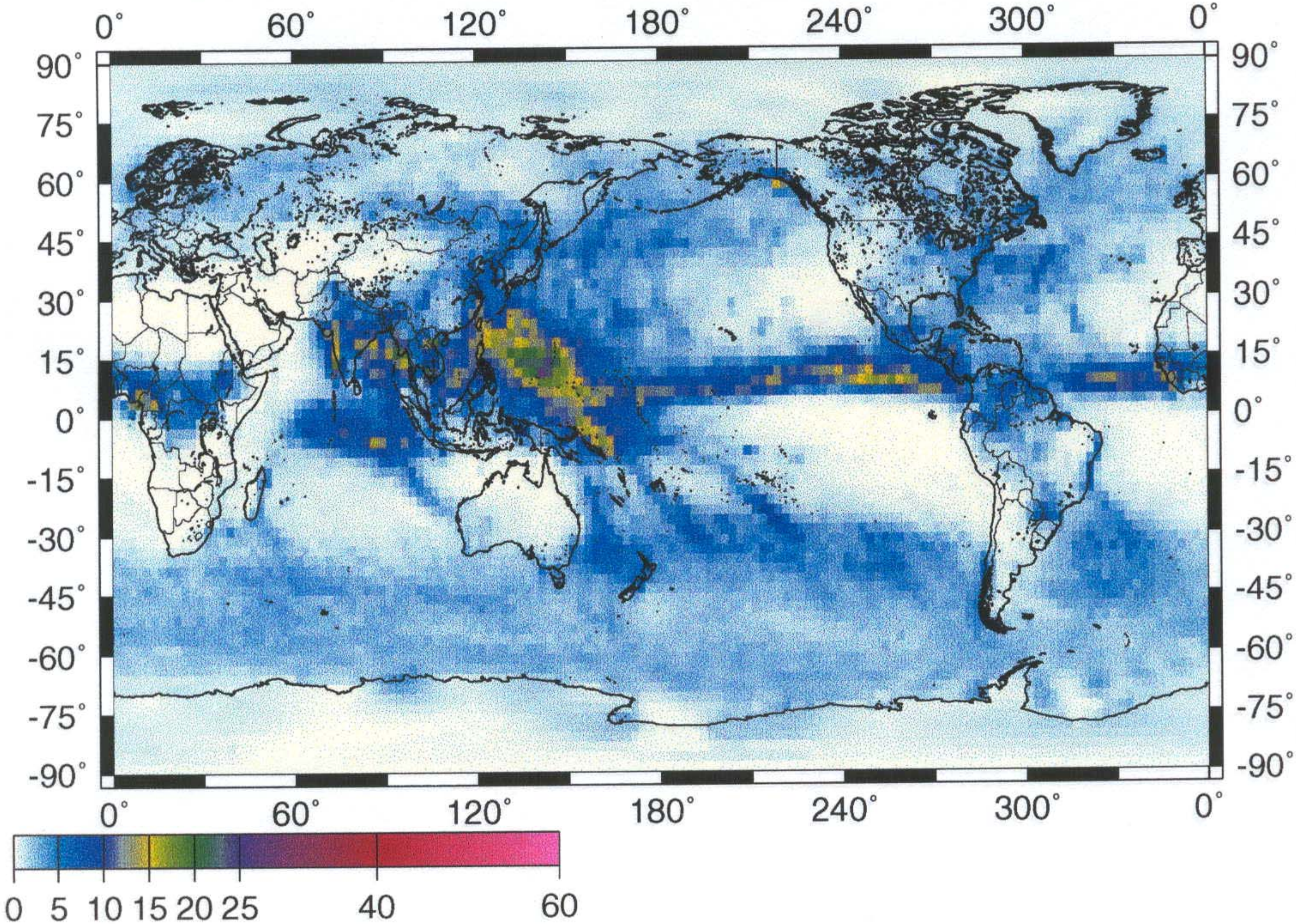
GLOBAL MONTHLY PPT. IN JUN, 1990



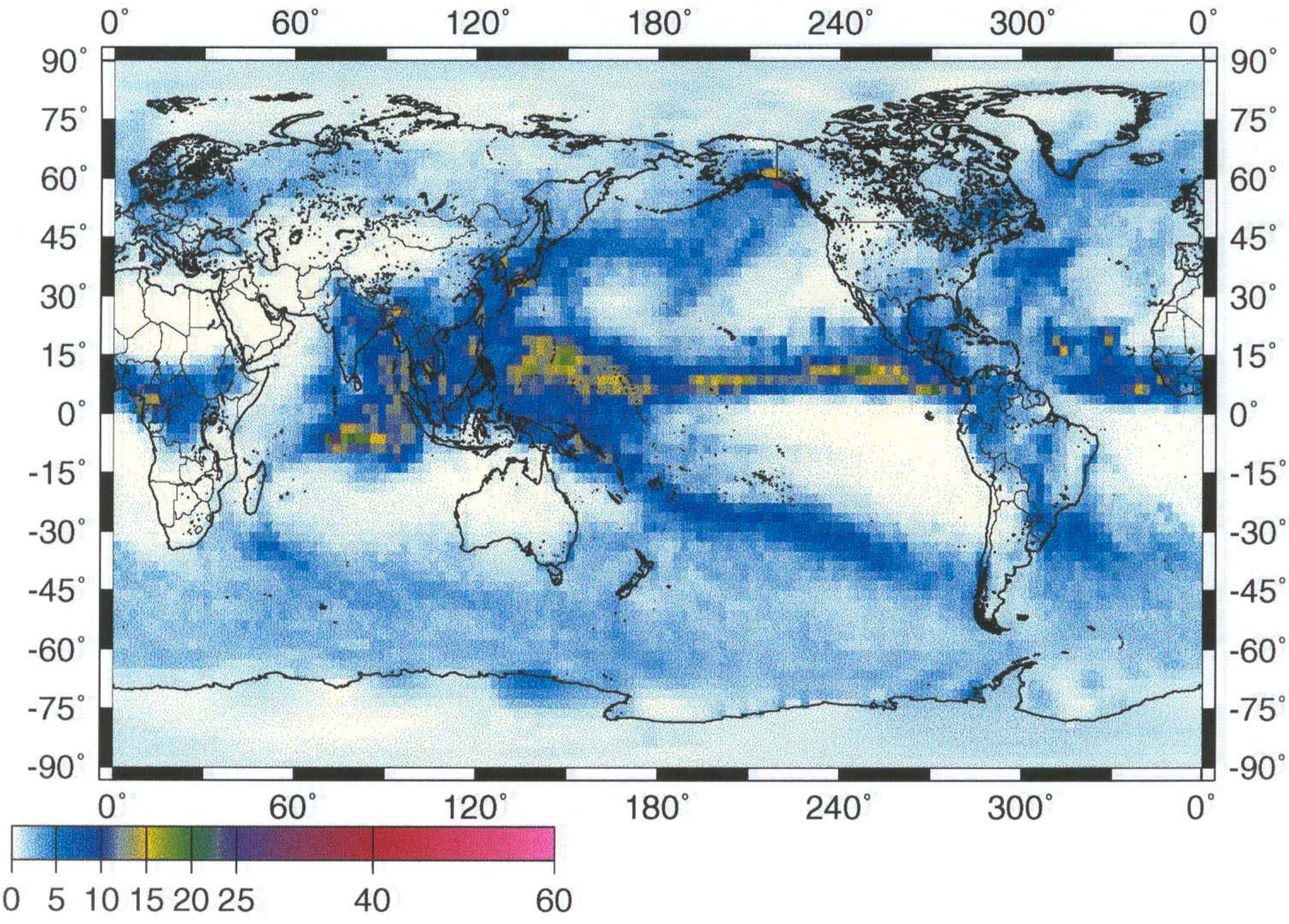
GLOBAL MONTHLY PPT. IN JUL, 1990



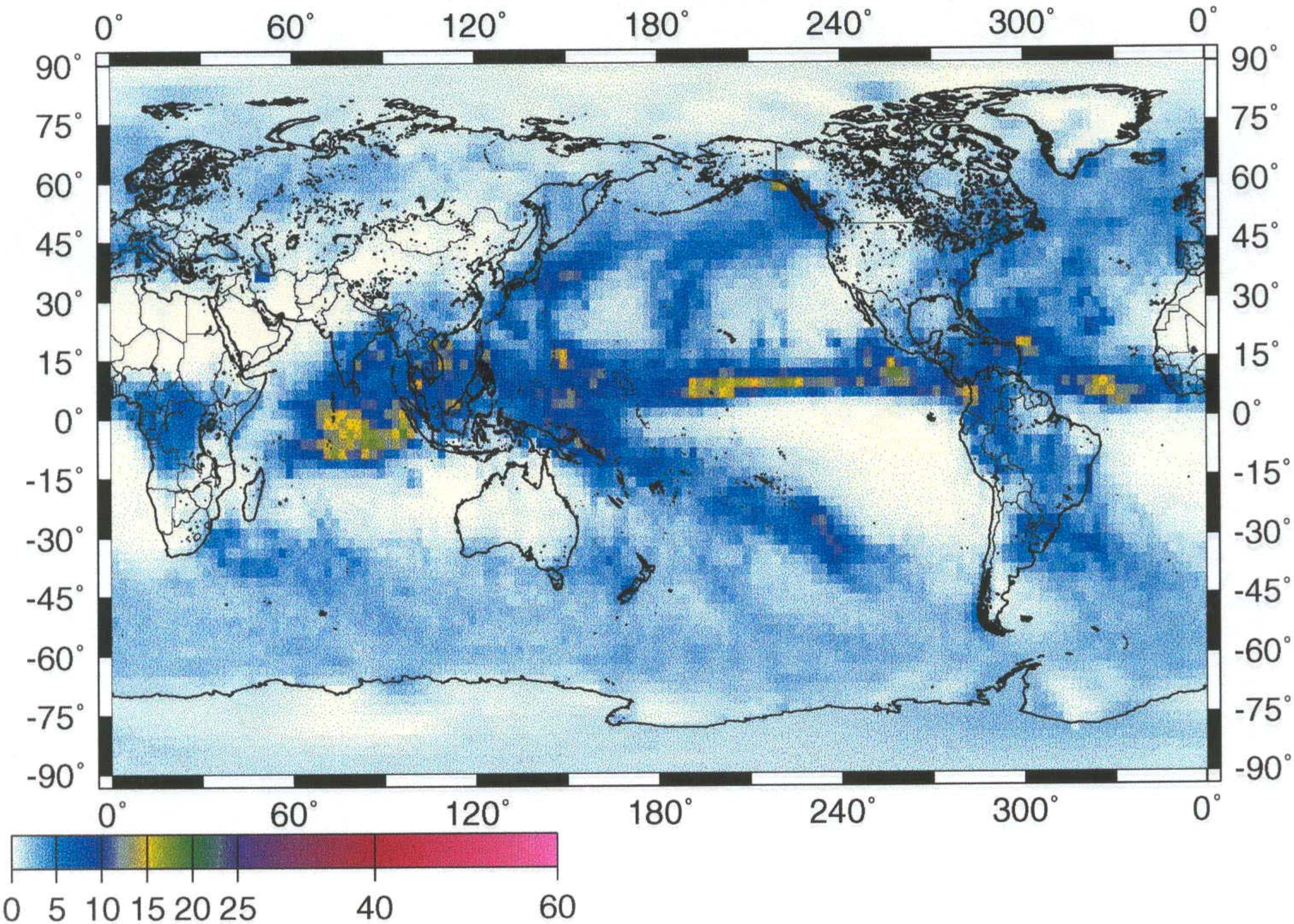
GLOBAL MONTHLY PPT. IN AUG, 1990



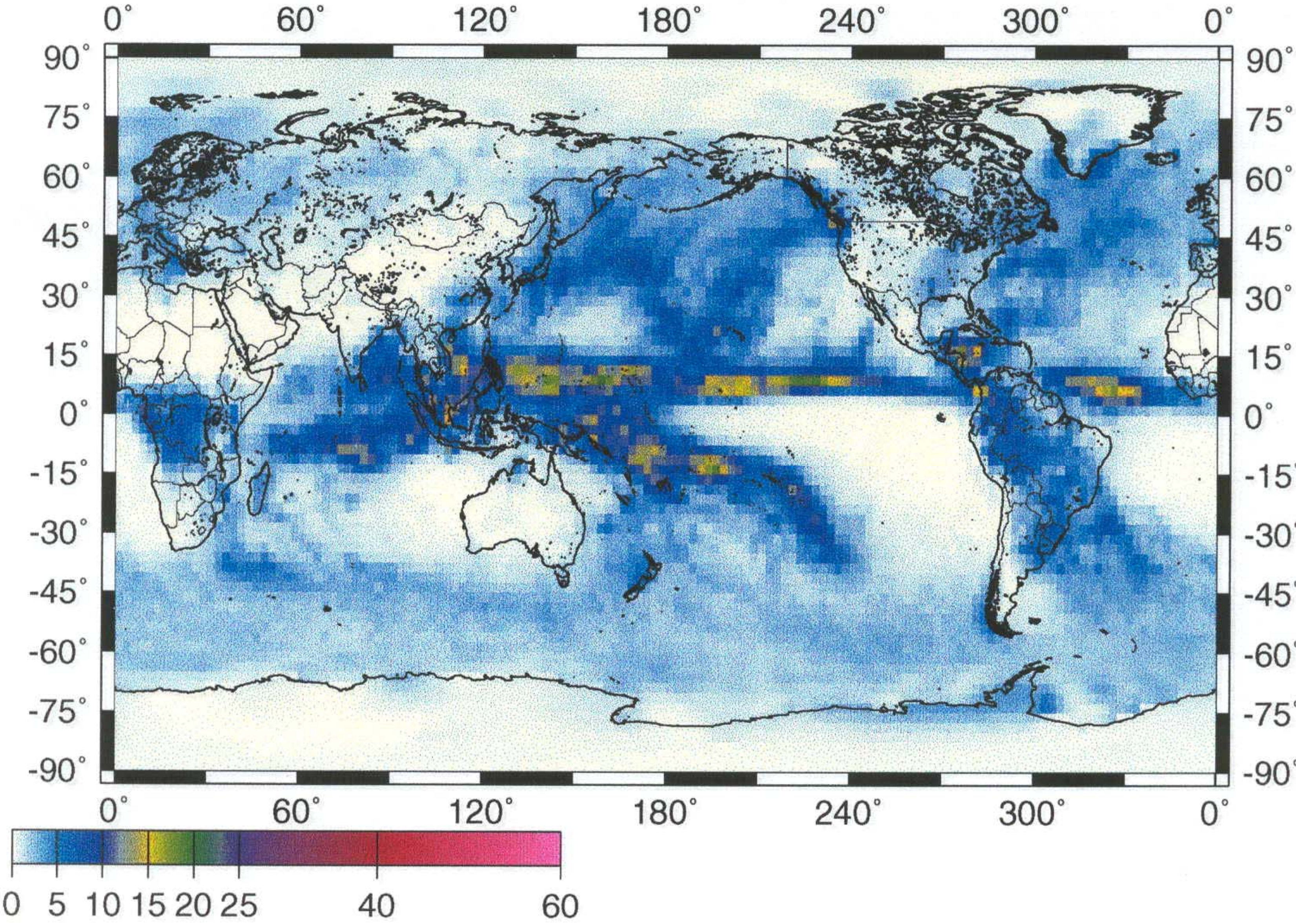
GLOBAL MONTHLY PPT. IN SEP, 1990



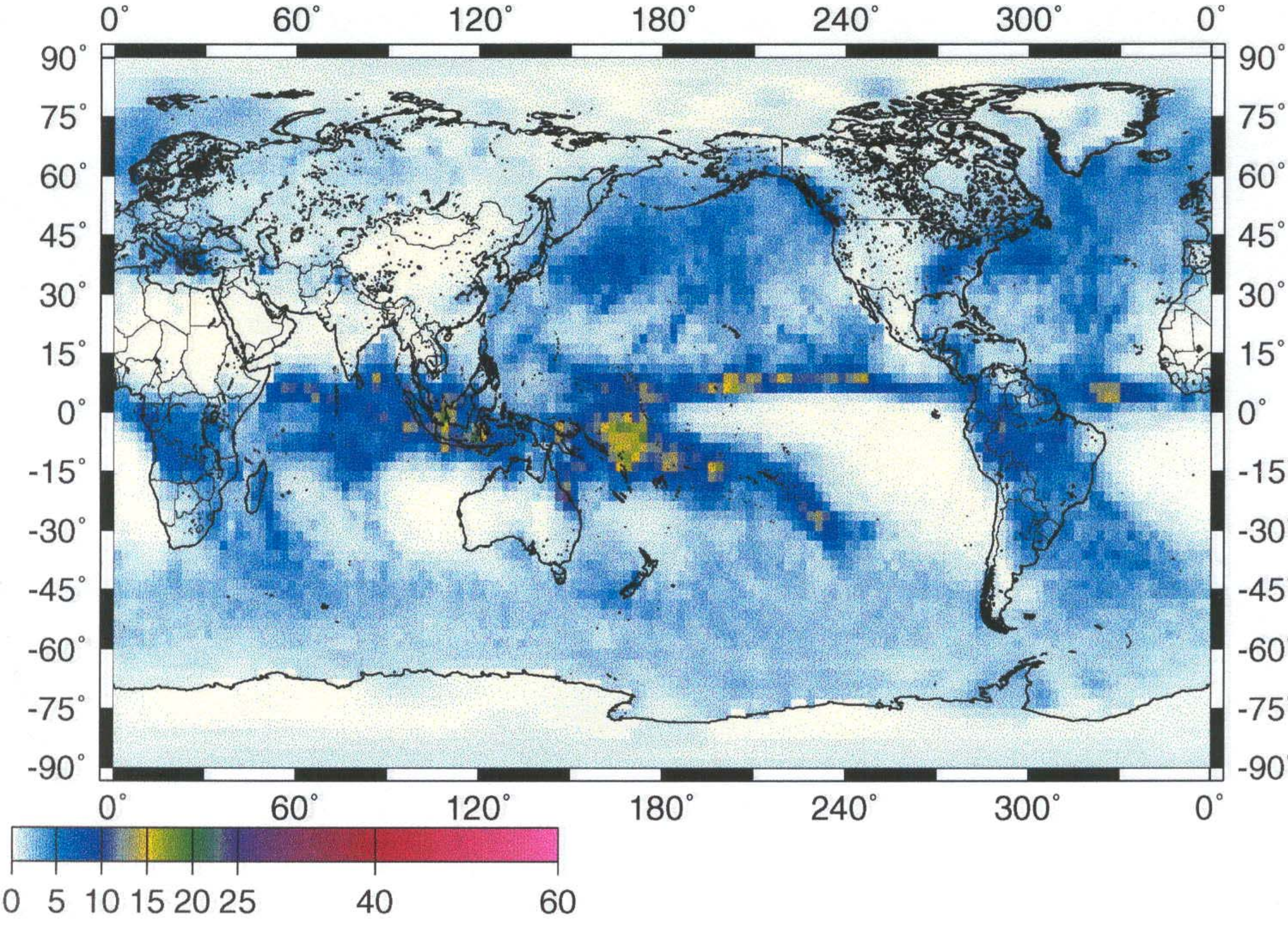
GLOBAL MONTHLY PPT. IN OCT, 1990



GLOBAL MONTHLY PPT. IN NOV, 1990



GLOBAL MONTHLY PPT. IN DEC, 1990



Thanks