

# GWC 3: Precipitation

*CTB3300WCx: Introduction to Water and Climate*

Prof.dr.ir. Hubert H.G. Savenije



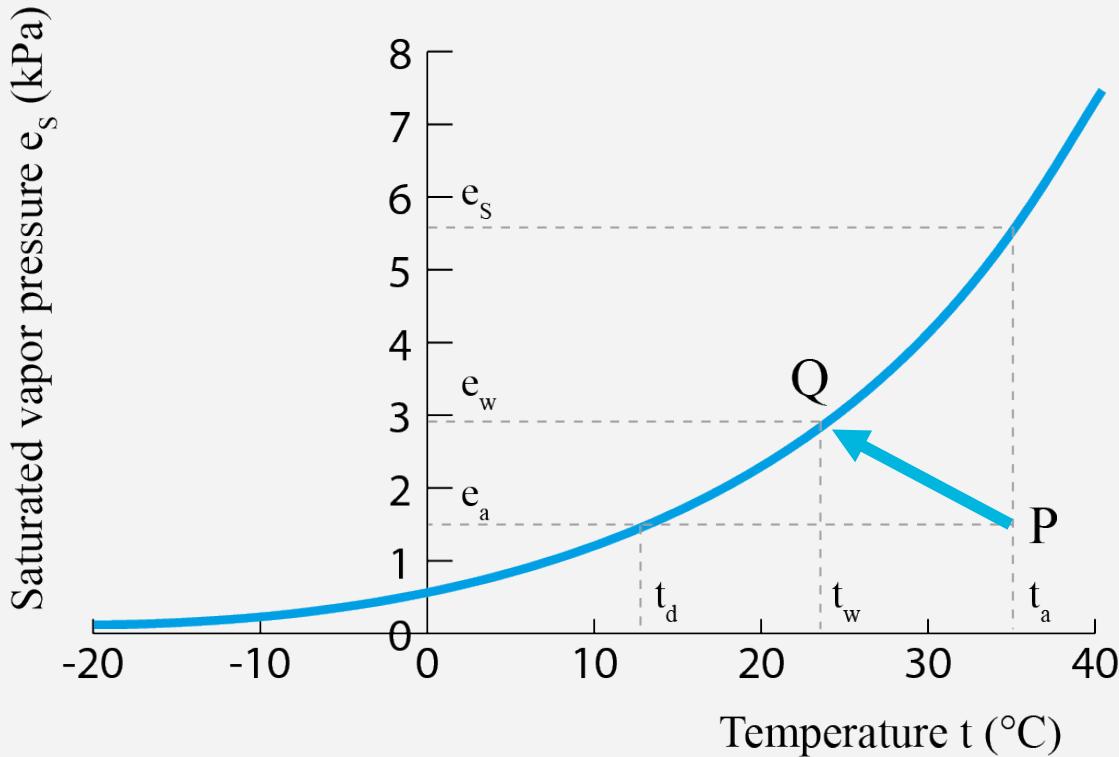
Challenge the future

# Types of precipitation

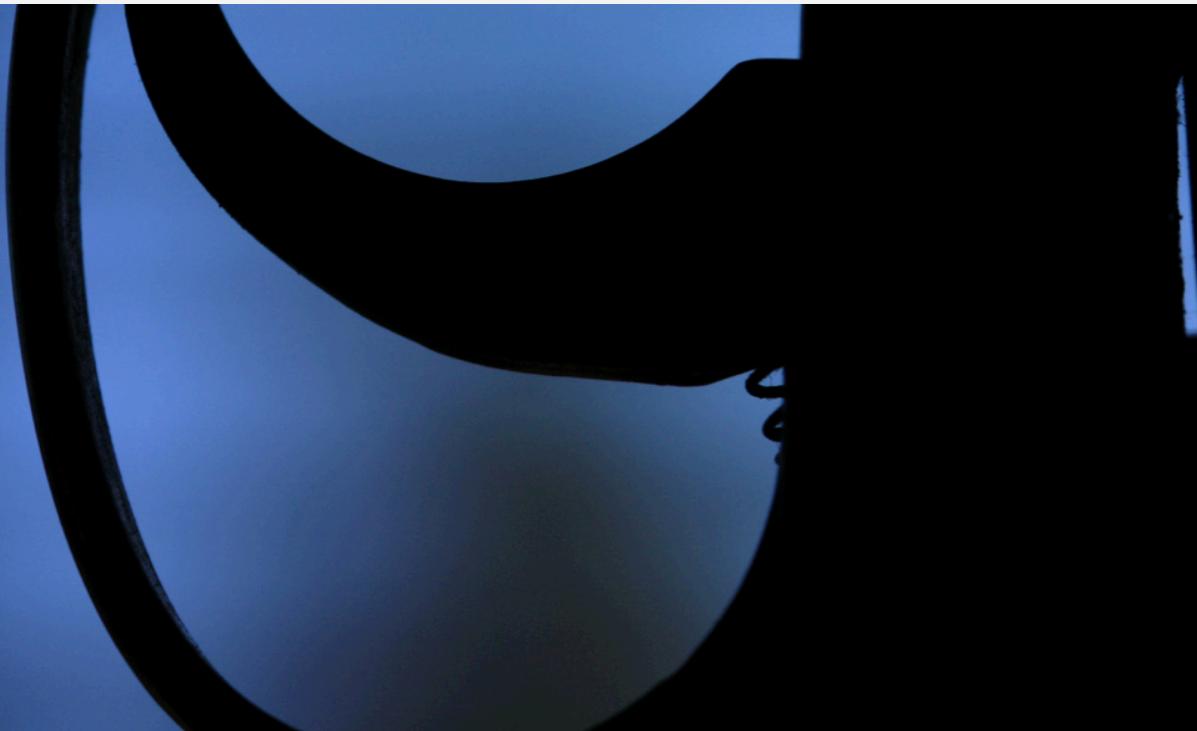
- Rain
- Snow
- Hail
- Glaze ice
- Dew
- White Frost



# Saturation vapour pressure curve revisited

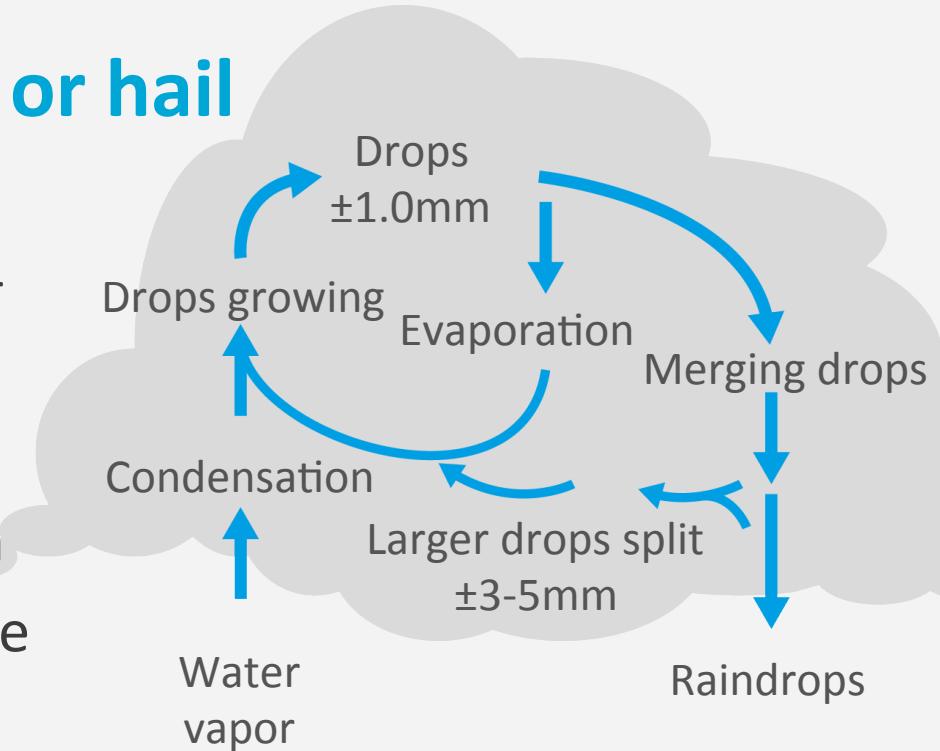


# How precipitation is triggered



# The origin of rain, snow or hail

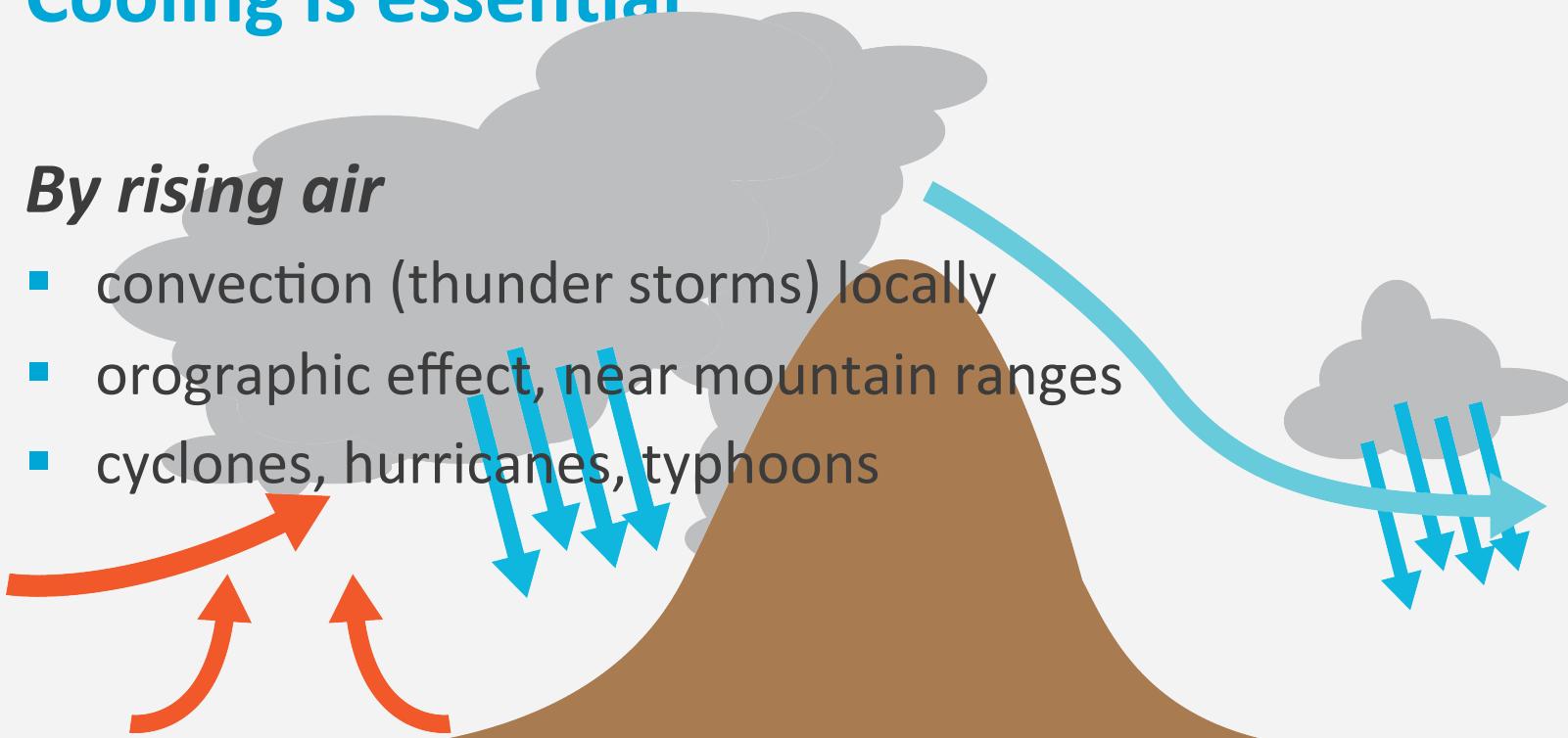
- Formation of clouds by super-saturation
- This is the result of Cooling
- Drop formation by Nucleation
- Amplification of droplets or ice crystals



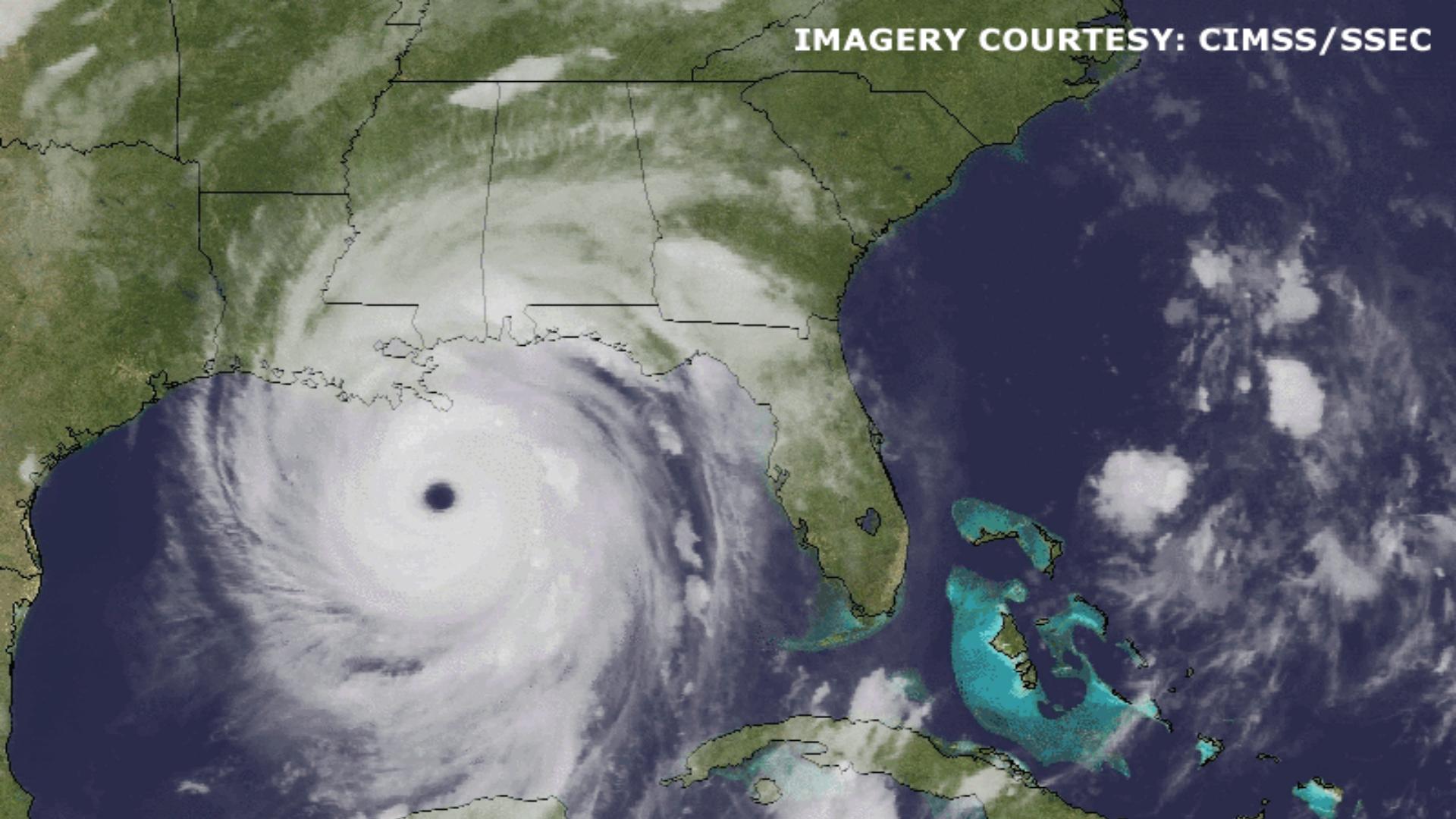
# Cooling is essential

## *By rising air*

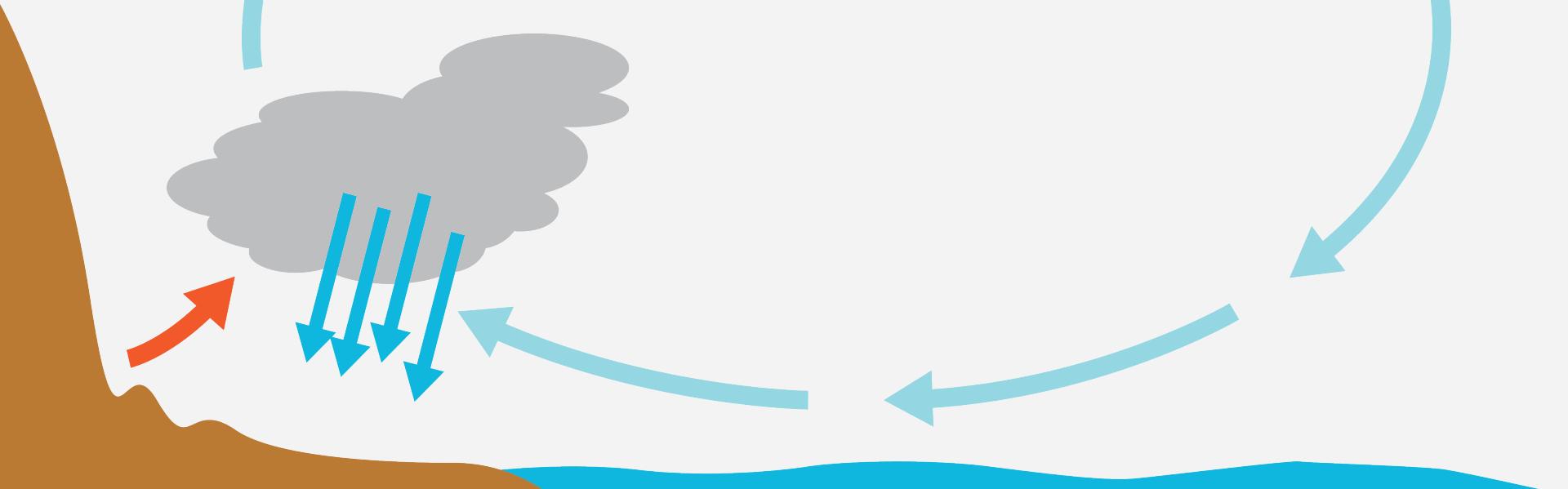
- convection (thunder storms) locally
- orographic effect, near mountain ranges
- cyclones, hurricanes, typhoons



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# Monsoons

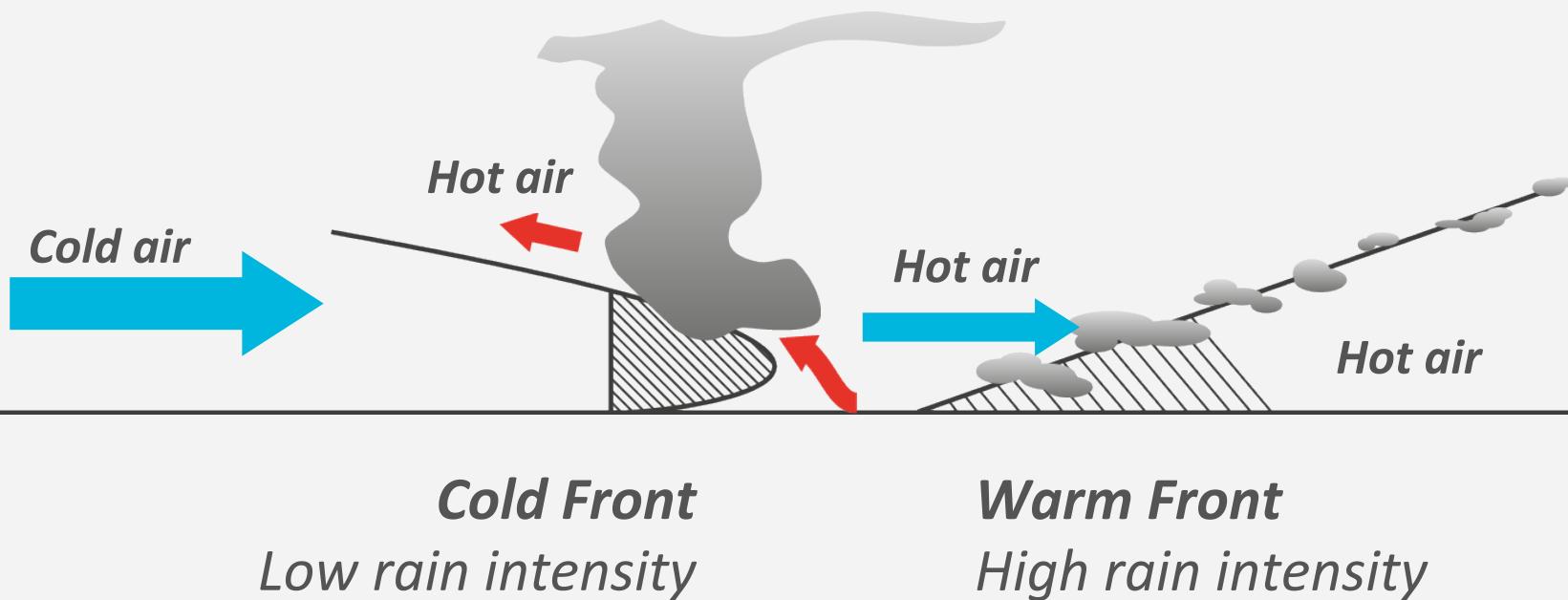


# Cooling mechanisms

## *By rising air*

- convection (thunder storms) locally
- orographic effect, near mountain ranges
- cyclones, hurricanes, typhoons
- monsoons
- fronts, related to depressions
  - *cold front*
  - *warm front*

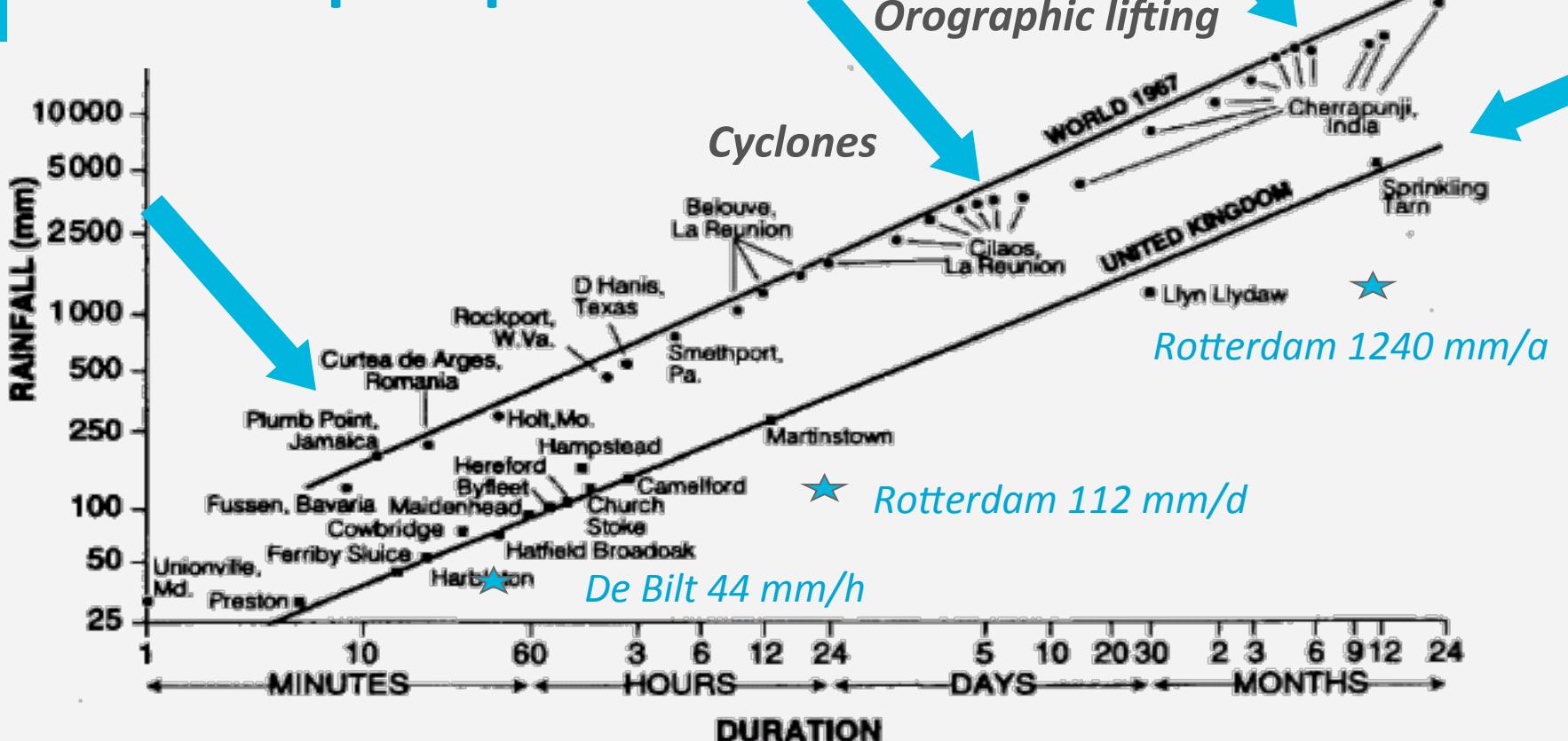
# Fronts



# Precipitation world-wide

Station	Mean annual Precipitation (mm/yr)
Cherrapongee (India)	10800
Buenaventure (Colombia)	7130
Singapore	2320
Netherlands	750
Athene	380
Teheran	220
Aden	55

# Extreme precipitation



# Measuring precipitation



1. Funnel



2. Tipping  
bucket



3. Weighing  
Pluviometer

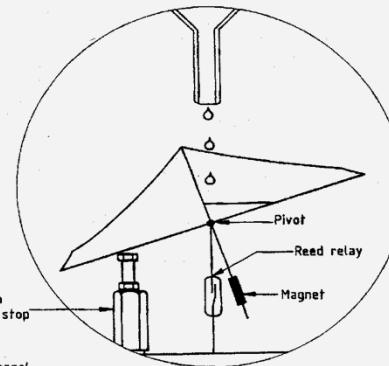
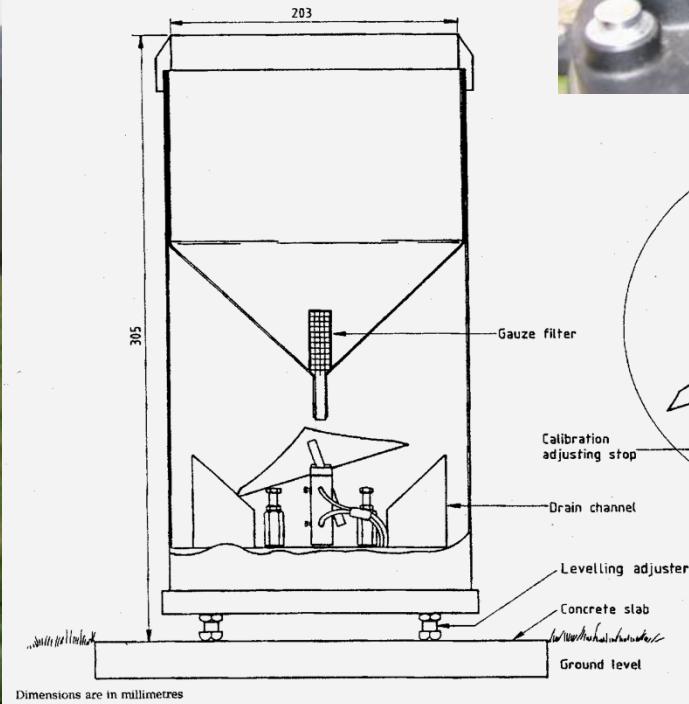


4. Optic  
Pluviometer



5. Acoustic  
Pluviometer

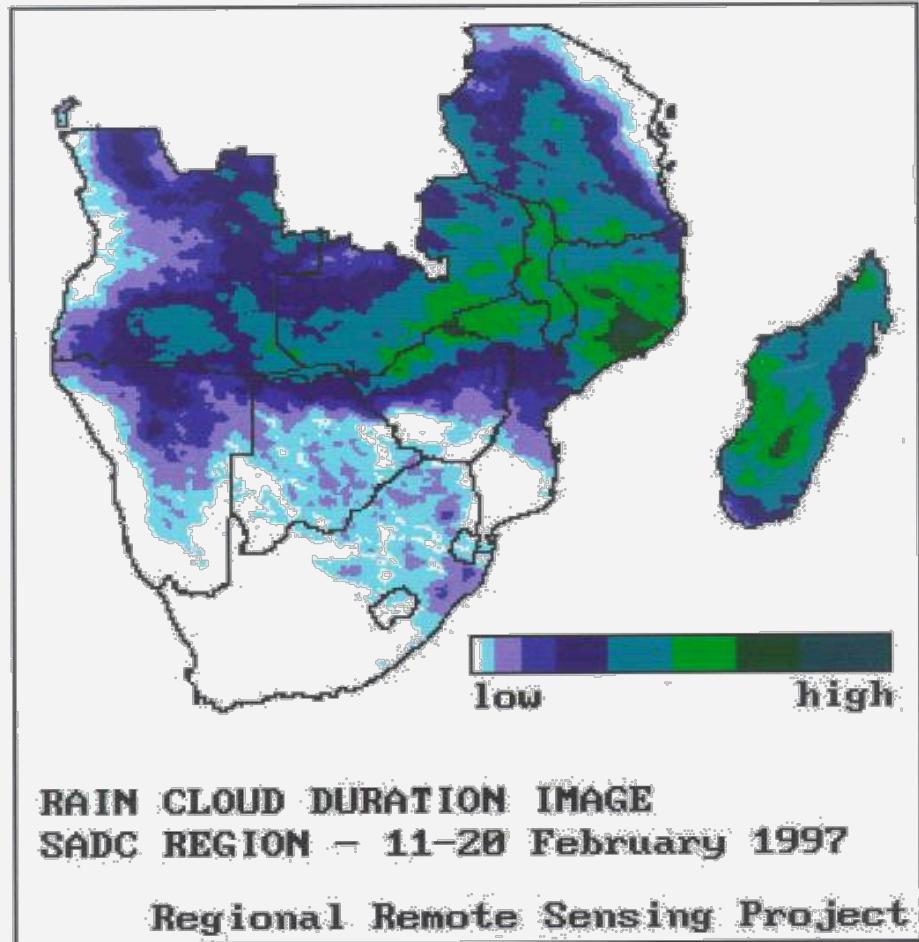
# Tipping bucket





# Region precipitation

- Areal observations from Satellite
- Land-based radar
- GSM booster stations



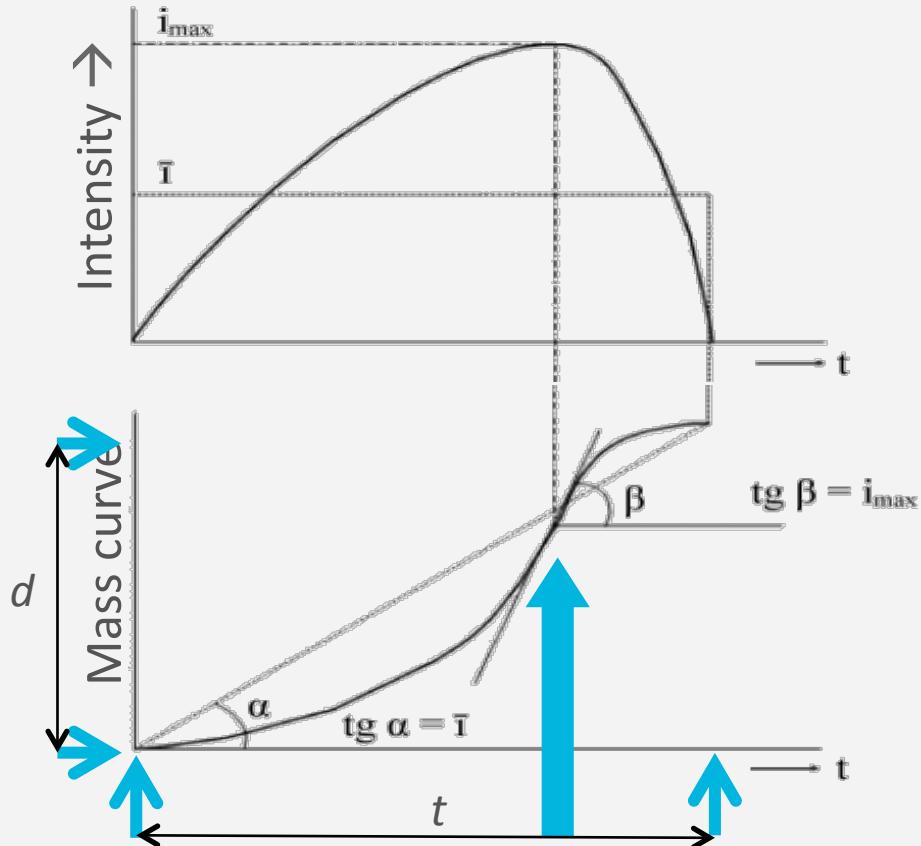
# Characteristics of precipitation

- **Intensity  $I$ ,** the flux per surface area, normally expressed in  $mm/h$ , but also in  $m/s$
- **Depth  $d$ ,** integral of the intensity, in  $mm$  or  $m$  (always associated with a duration  $t$  : the flux  $P=d/t$ )
- **Duration  $t$ ,** duration of the precipitation
- **Frequency  $f$ ,** the probability of occurrence,  $f=1/T$ , whereby  $T$  is the average time between these occurrences
- **Areal extent** of the occurrence, given its intensity, duration and frequency

# Hyetograph

$$d = \int_0^t i dt$$

$$P = \bar{i} = d / t$$

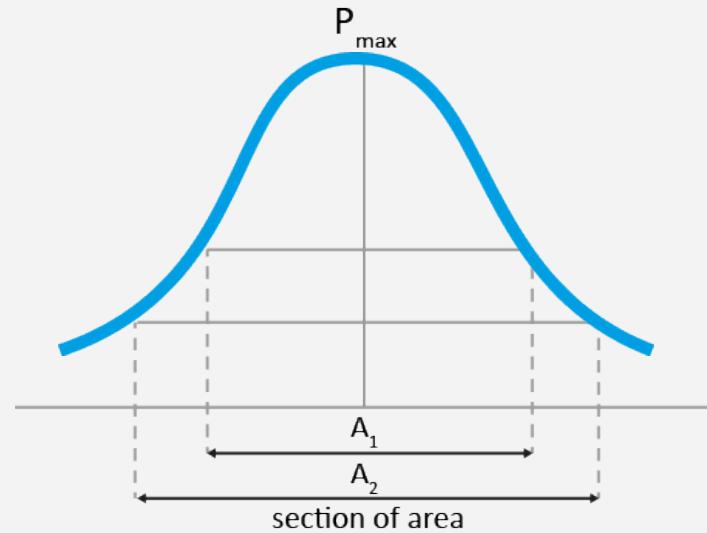
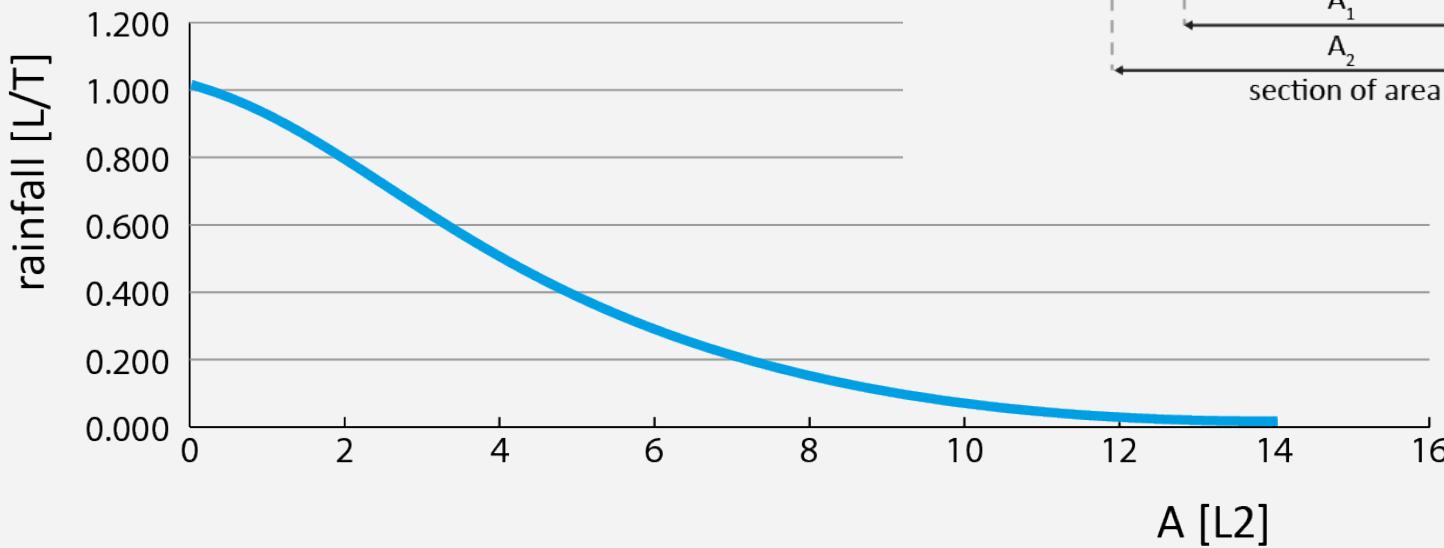


- *Hyetograph*  
 $i(t)$

- *Mass curve*  
 $d(t)$

# Areal averaging

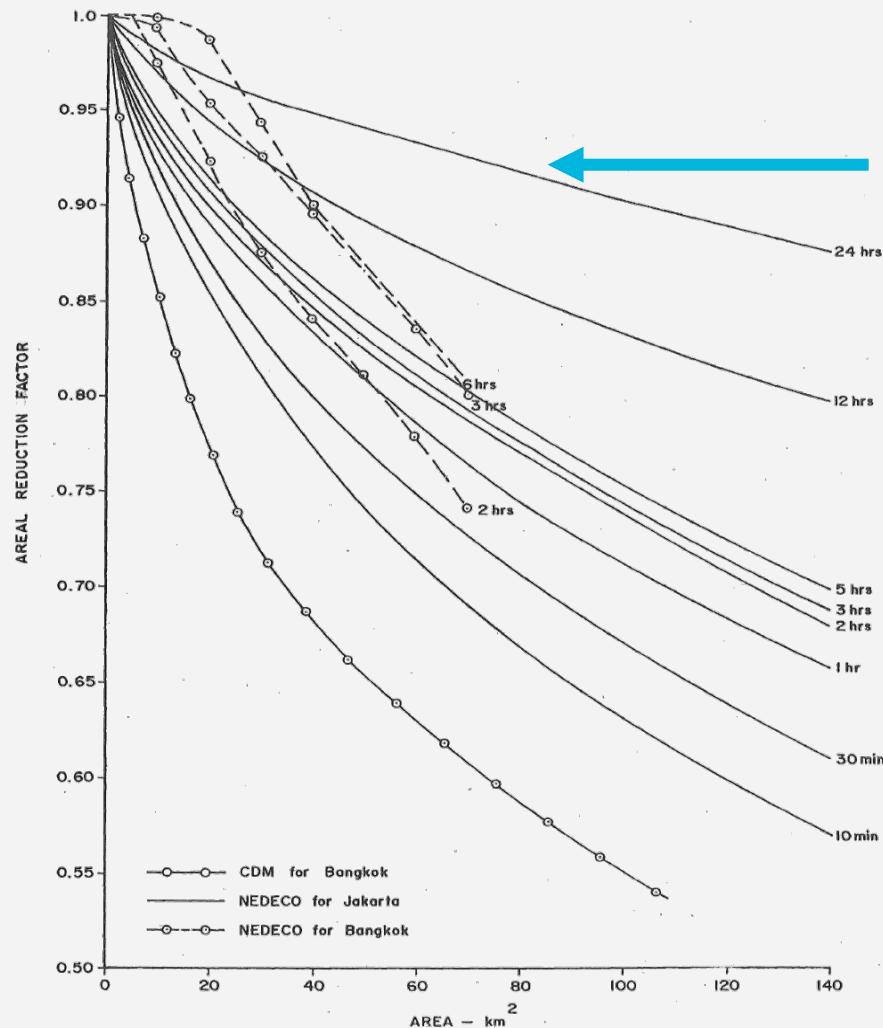
$$\bar{P} = P_{\max} \exp(-kA^n)$$



# Aerial Reduction Factor

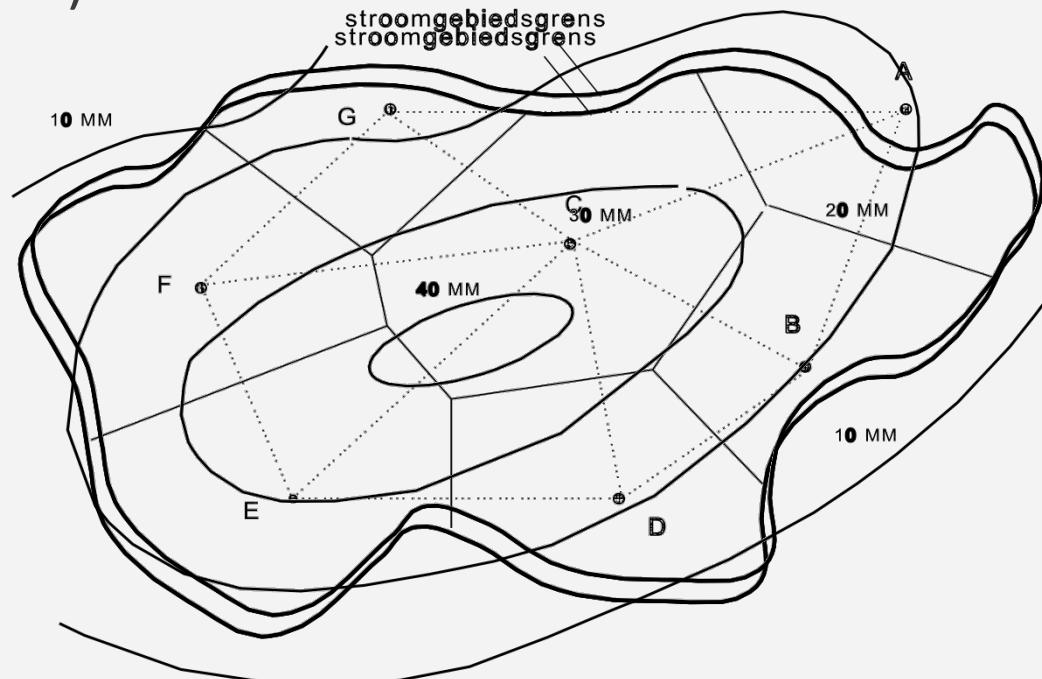
*Derived for*

- Bangkok
- Jakarta

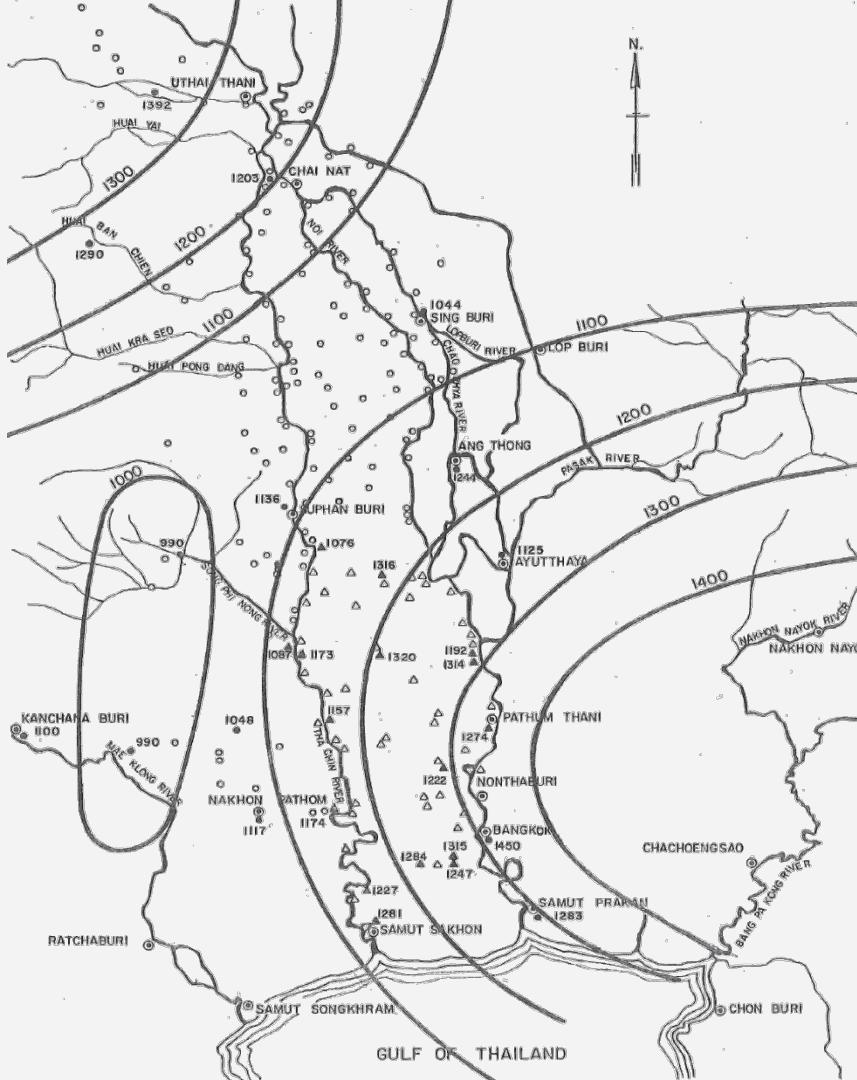
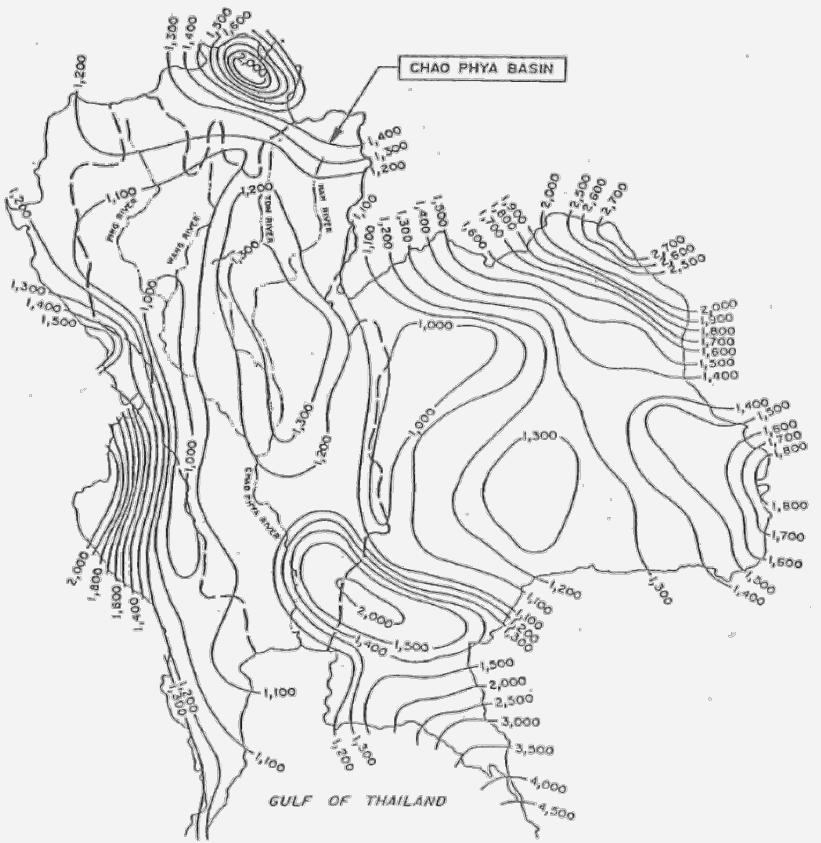


# Areal averaging techniques

- Thiessen (nearest neighbour) network
- Inverse distance
- Contour lines (isohyets)
- Kriging



# Thailand



# Thiessen Network



# Double Mass to test consistency

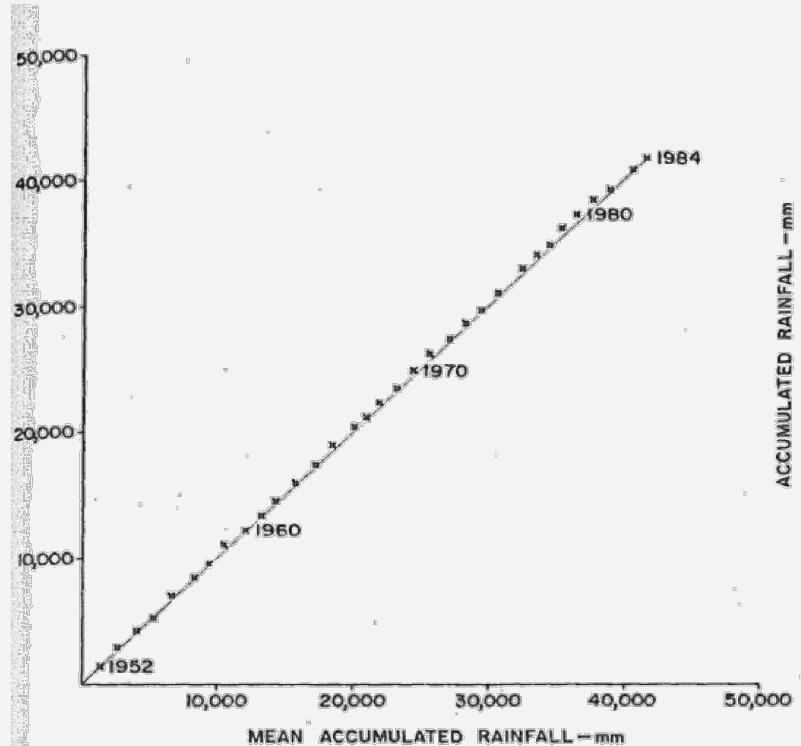
$$y_k = \sum_{i=1}^m x_{i,k}$$

$$\bar{y} = \sum_{i=1}^m \left( \frac{1}{n} \sum_{j=1}^n x_{i,j} \right)$$

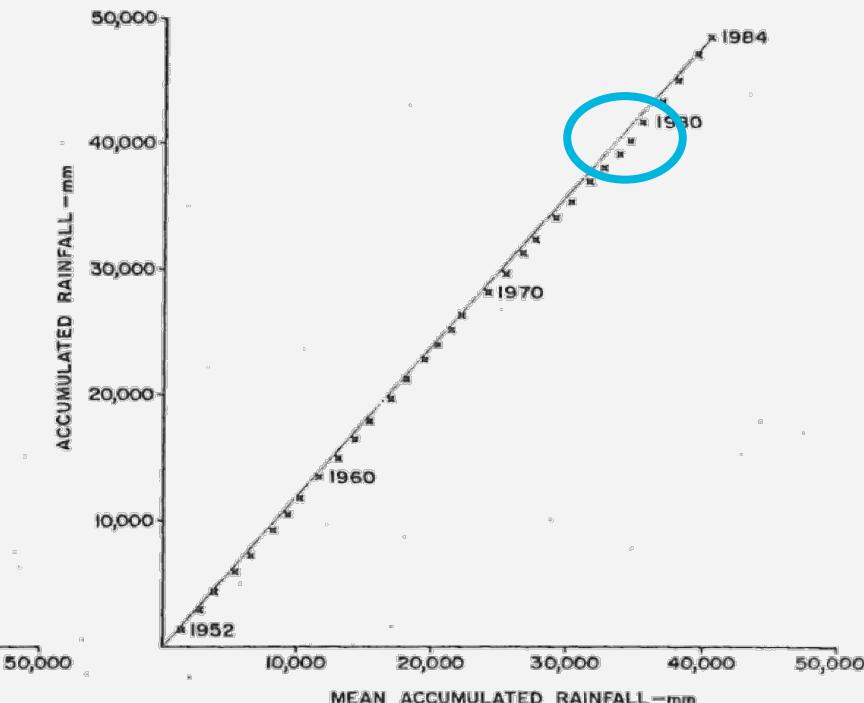


$n$  stations  $j$   
 $m$  years  $i$

# Double Mass



STATION 52012 - A. MUANG SAMUT PRAKAN

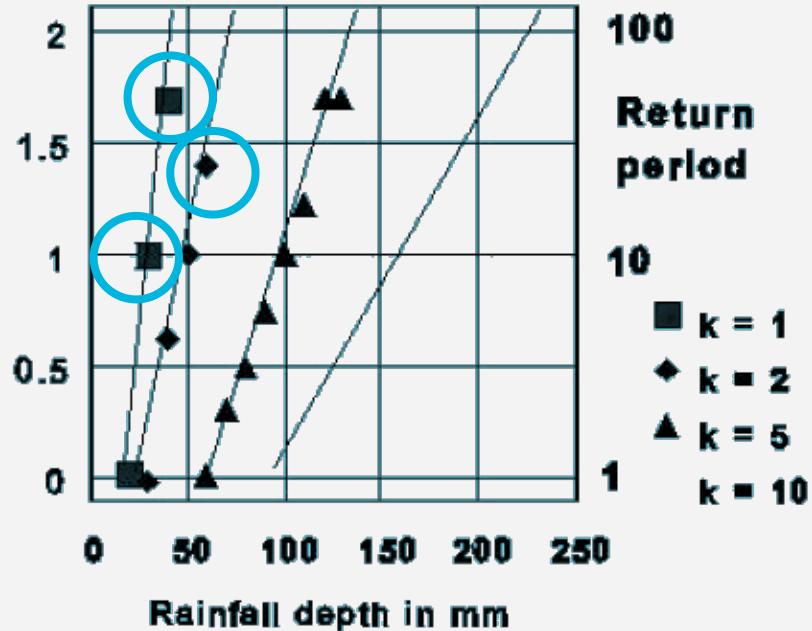


STATION 41013 - BANGKOK METROPOLIS ( MD )

Class interval (mm)	1	2	5	10
0	18262	18261	18258	18253
10	384	432	730	2001
20	48	127	421	1539
30	5	52	243	713
40	1	12	158	493
50		5	83	286
60		2	49	221
70			25	170
80			16	96
90			9	76
100			5	49
110			3	31
120			1	22
130			1	16
140				9
150				7
160				5
170				4
180				2
190				2
200				1

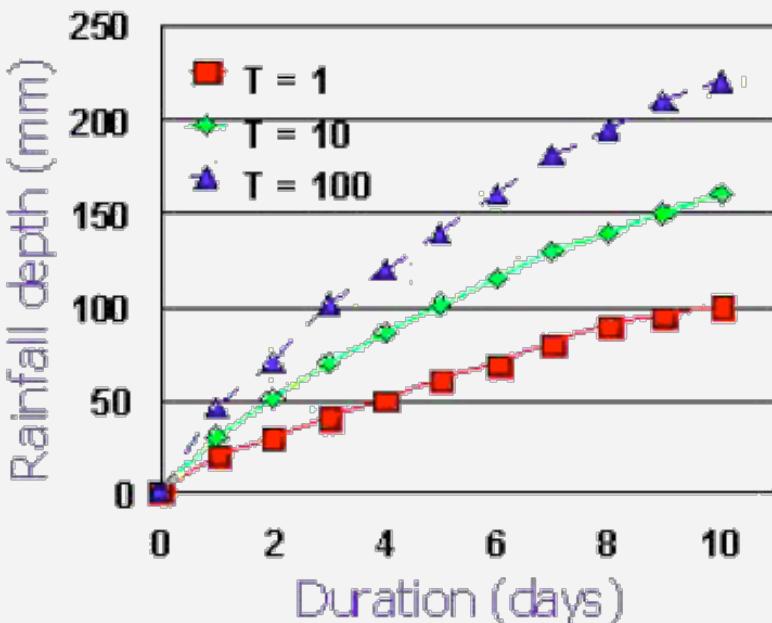
Depth-Duration-Frequency curves

## Cumulative frequency curves for different durations

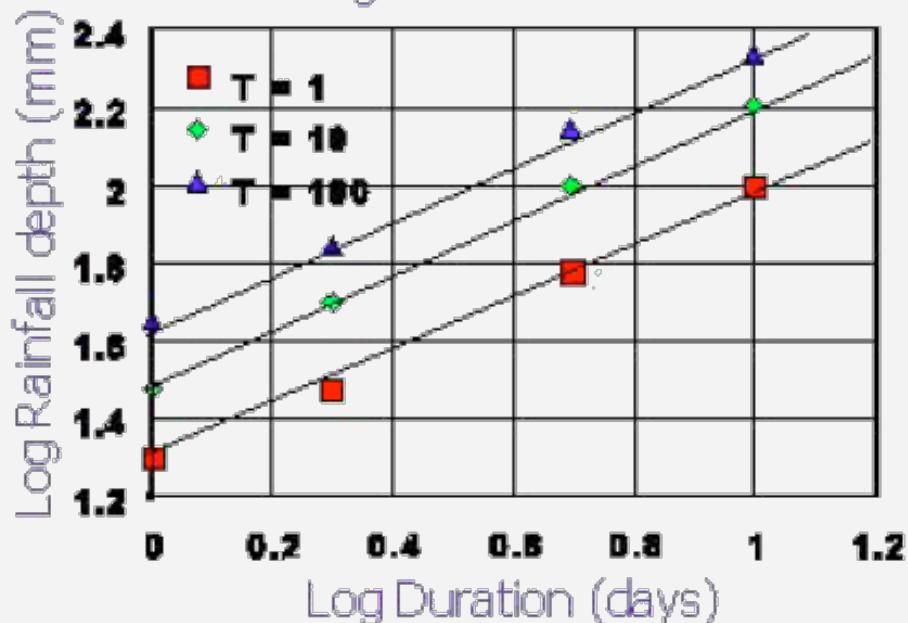


# Depth-Duration-Frequency curves

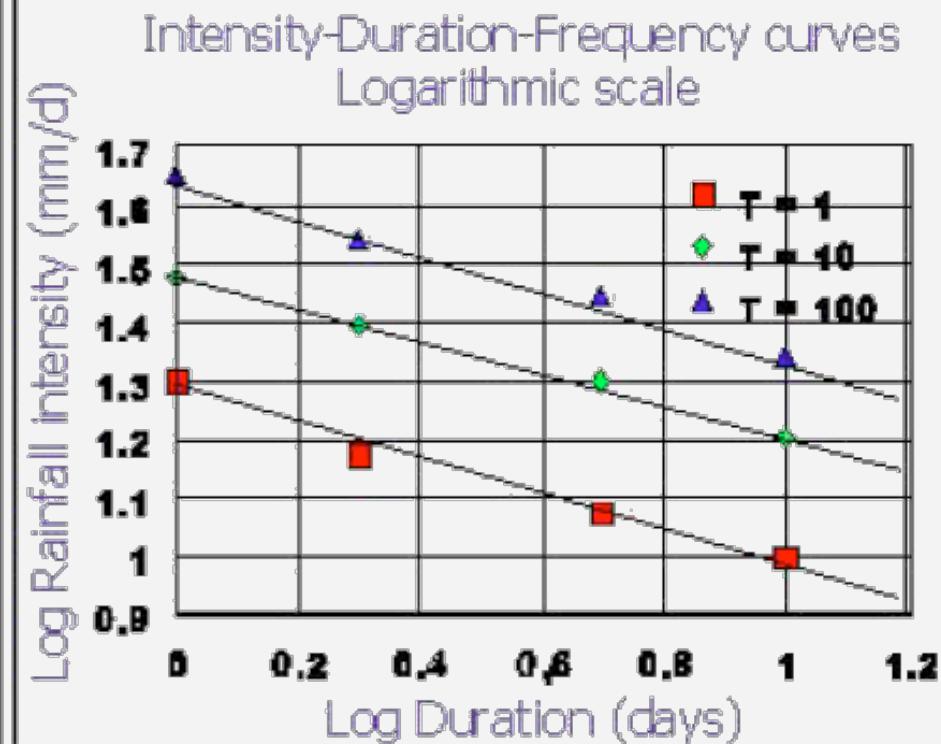
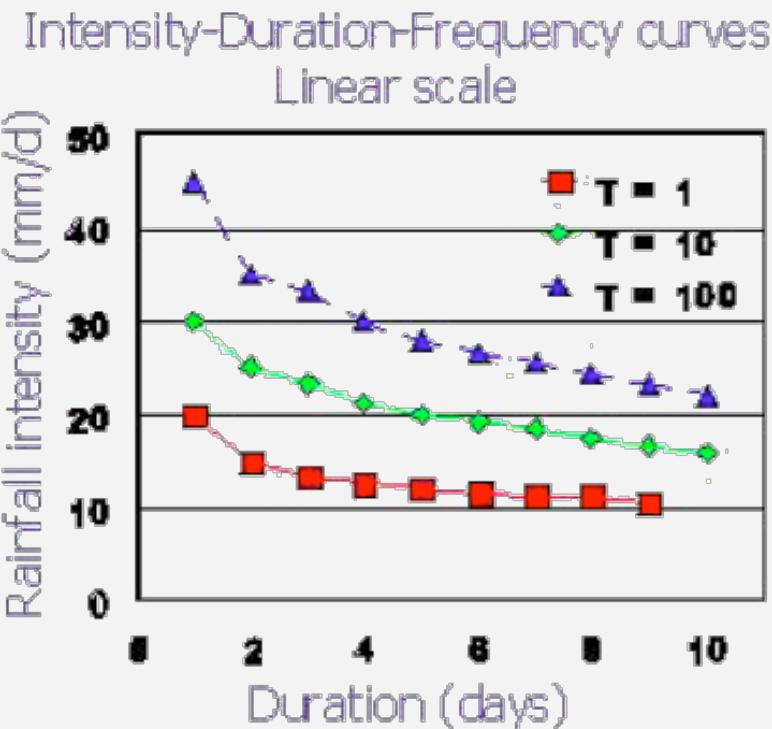
Depth-Duration-Frequency curves  
Linear scale



Depth-Duration-Frequency curves  
Logarithmic scale

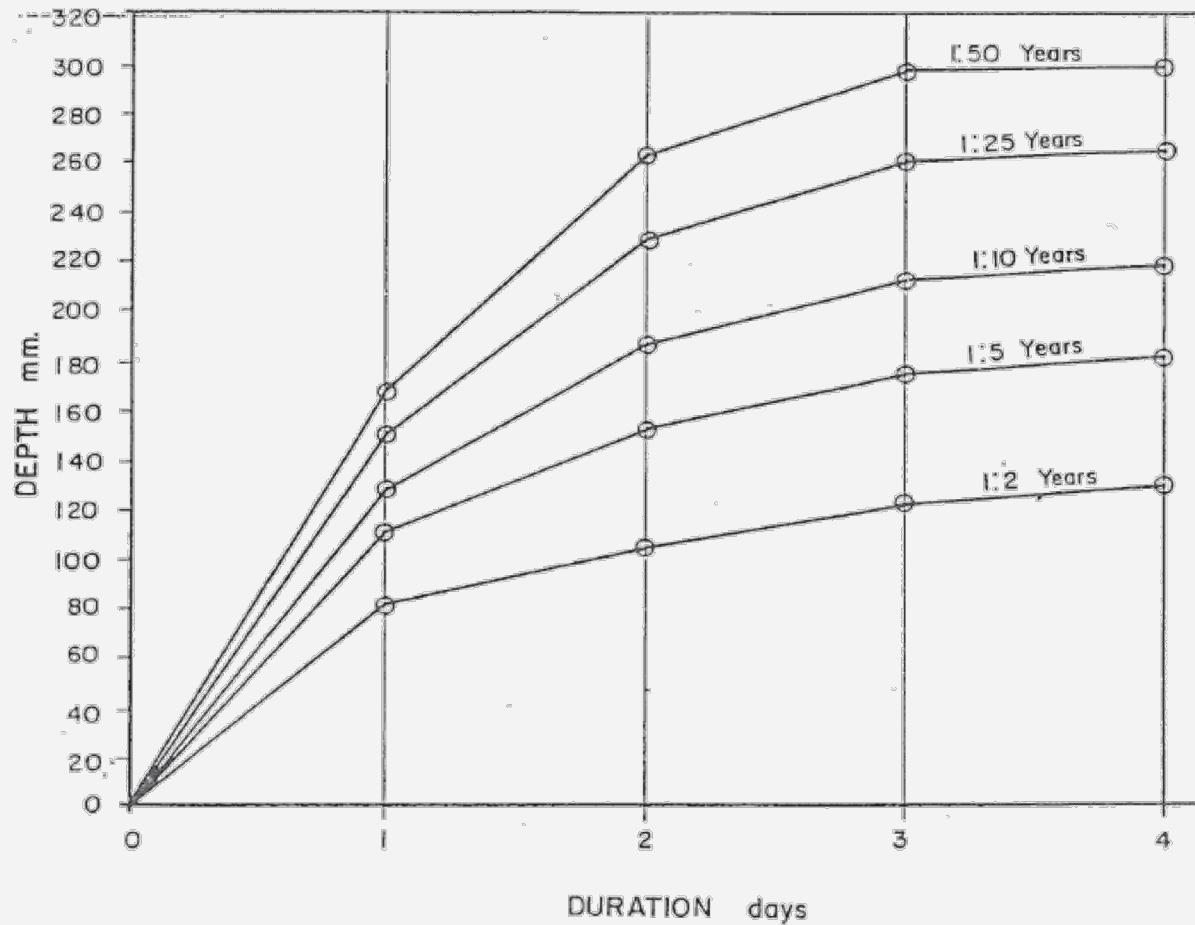


# Intensity-Duration-Frequency curves



# Bangkok

## RAINFALL DEPTH DURATION CURVES BANG BUA THONG



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