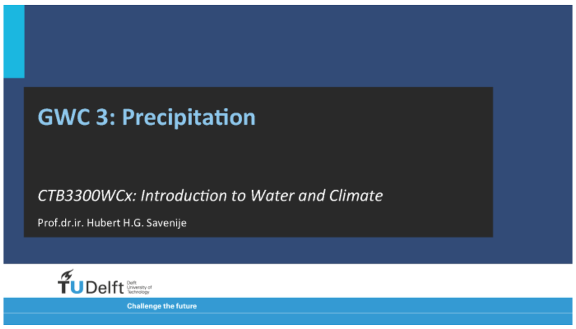
CTB3300WCx – Introduction to Water and Climate

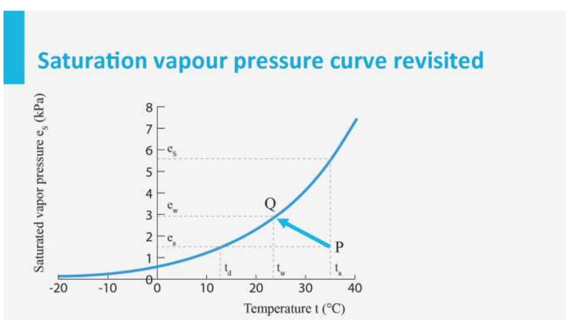
GWC 3 – Precipitation

Hubert Savenije

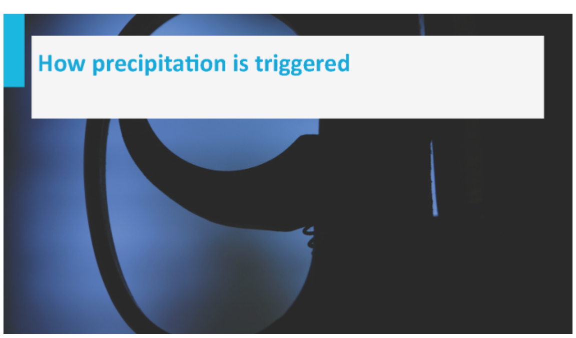


Welcome! My name is Hubert Savenije and I am a hydrologist.

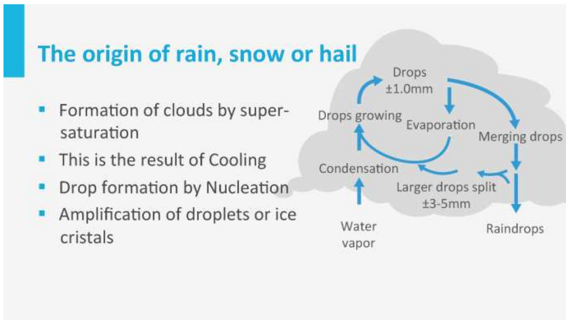
There are many different types of precipitation, besides rainfall. There is of course snow and hail, which is the frozen form of rainfall. Dew is formed by cooling (generally at night as a result of outgoing long wave radiation). While white frost is frozen dew. But there is also glaze ice (or simply glaze), which is undercooled rain that runs into ice as it hits a cold surface. I remember that as a child I could skate on the road.



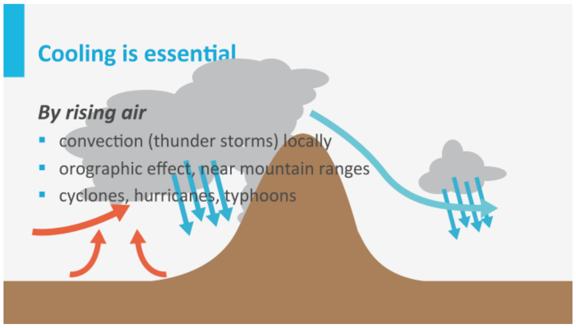
Dew and white frost find their origin in the near ground humidity of the air. It is formed when the Earth's surface cools until the dew point. Just like we saw in the saturation vapor pressure curve in the previous section. But rainfall, snow and hail (as everybody knows) fall from the clouds.



How is this process triggered?

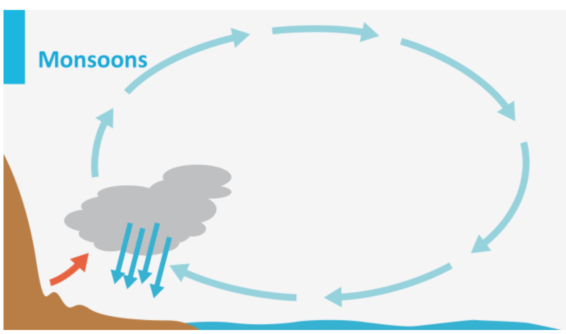


As in the case of dew, droplet formation is governed by the saturation pressure curve. Clouds are formed by super-saturation, which happens when moisture is cooled below the dew point. Cooling is causes by lifting of air:
As a volume of is lifted, the pressure drops, and hence the temperature. The average lapse rate is 6.4^{o}C/km elevation. Condensation requires little crystals or dust particles for nucleation. Turbulence causes the droplets to grow, as drops move up and down, and collide with other droplets until they are too heavy to be sustained by turbulence (or uplift) and drop to the ground.

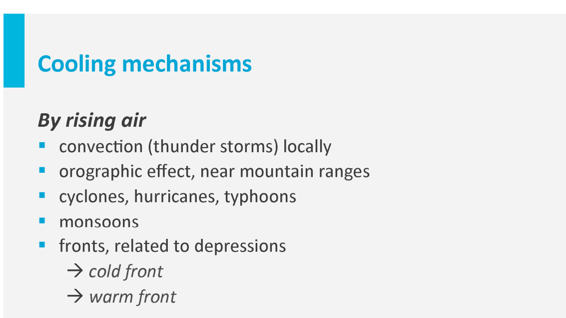


So we see that cooling is essential, and we also noticed that clouds are formed by rising air. What can be the causes of rising air? There can be several; and all of them have different characteristics:
Convection by thunderstorms…
Orographic effects near mountain ranges…
And then we have Tropical cyclones, hurricanes or typhoons. Do you know what the difference is between them?
There is no difference. It is just that their names are linked to different oceans that generate them: the Indian Ocean has cyclones, the Pacific has typhoons, and the Atlantic has hurricanes.

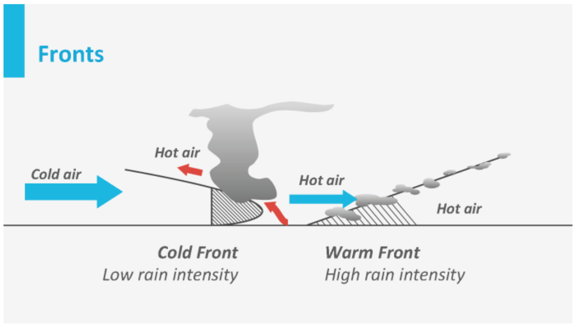
Here you see a movie of the Hurricane Katrina, which caused havoc in New Orleans.



And then there are the monsoons, governed by the difference in cooling between land and ocean in the Tropics, causing see breezes that carry moist air inland.



In temperate areas there are depressions that cause cold and warm fronts to rotate over land.

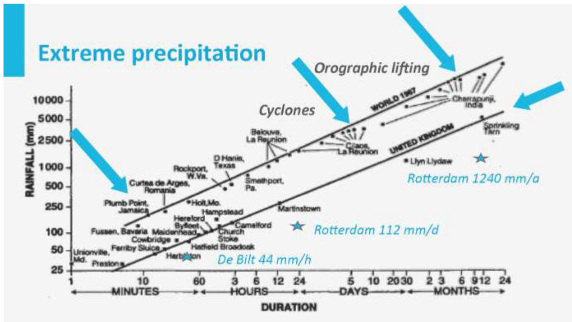


Because cold air is heavier than warm air, a cold front forces itself under warm (and moist) air, causing an uplift, which can trigger heavy thunderstorms. A warm front generally moves over the colder air and triggers less intensive rainfall.

Precipitation world-wide

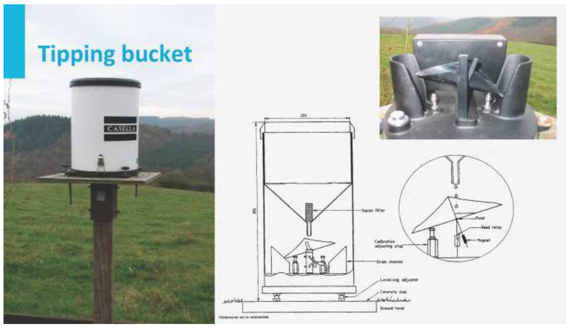
Station	Mean annual Precipitation (mm/yr)
Cherrapoongee (India)	10800
Buenaventure (Colombia)	7130
Singapore	2320
Netherlands	750
Athene	380
Teheran	220
Aden	55

As a result, we see very different amounts of precipitation distributed over the world. From very large amounts in Cherrapoongee, at the foot of the Himalayas, and fed by monsoons, to very small amounts in the arid zones of the Arabian Peninsula.



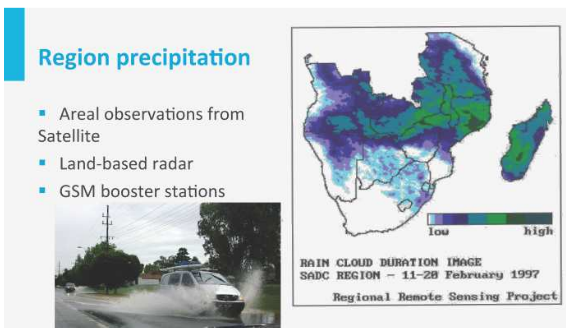
It is fun to look at the world records of precipitation. Here we plot the maximum depths of precipitation recorded in the world as a function of their duration. We see that orographic lifting in the foothills of the Himalayas, under influence of the monsoons triggers the highest amounts of long duration rainfall. A maximum of about 20 m/yr in Cherrapoongee. Just try to imagine how much rainfall that is. The tropical cyclones cause the largest amounts on a daily time scale. In La Reunion (Indian Ocean) we recorded about 2m/day. You could drown by just standing in the rain on a flat terrain! At shorter time scales, we go to the thunderstorms. We have a world record of about 200mm/10 min in South Germany and on Jamaica. Imagine that a bucket standing in the rain would fill up with water in 10 minutes. Of course not all places in the world can have these records. The second line corresponds with the records o UK rainfall. And in the Netherlands, where I am from, we have very modest amounts of rainfall compared to other places in the world, (indicated by the stars) yet I have the feeling that it rains a lot in The Netherlands: we have 180 raindays per year!

How do we measure precipitation? There are many devices. The most traditional is the regular funnel shaped tube which you empty once per day. You read the volume, divide it by the surface areas and record the amount of rainfall per day. Other devices make sure use of weighing, optics, acoustics or tipping device.



This is such a tipping device. When one side is full, it tips and then the other side fills, etc. Be aware, a lot can go wrong. I once had a hornet's nest in it, which blocked the tipping device. But this applies to all the devices mentioned. A lot of things can go wrong, sometimes because they brake down, sometimes because the reader does not know what to do, or sometimes because they are positioned under a tree or in the shade of a house.

Moreover, all the instruments provide point observations in space and we have to be aware that rainfall can very considerably in space.

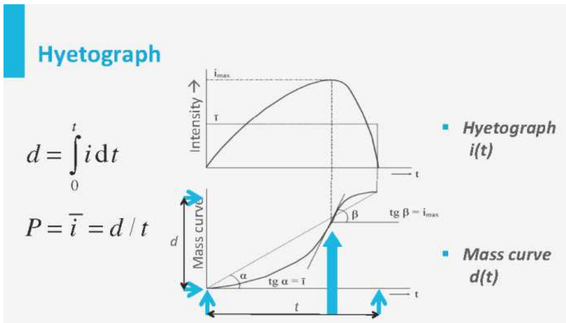


This is an example of the many new remote sensing products that are becoming available. They measure rainfall on the basis of radar, micro-wave and the temperature of clouds. This picture shows how variable the rainfall is and that point observation can give a wrong impression of the average precipitation that fell over a region. There are other new and innovative ways of precipitation measurement: such as land-based radar, information from GSM booster stations and using the speed of cars as a function of the weather, or the speed of screen wipers.

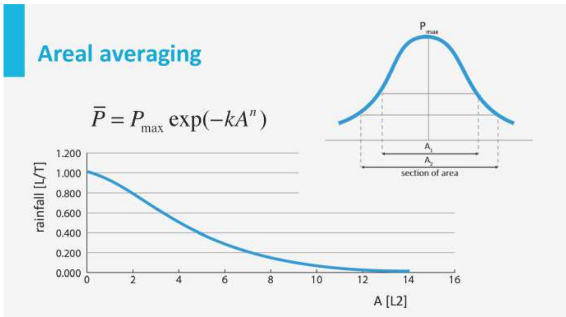
Characteristics of precipitation

- **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* of *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

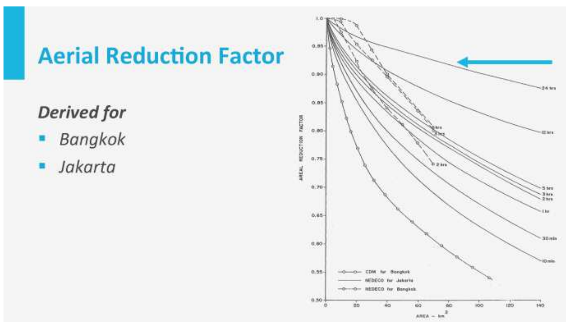
There is still a lot of information around that we can use! Precipitation has a number of characteristics that we have to distinguish very well. Watch out, because not everybody does this. Firstly there is the intensity. Precipitation being a flux, the intensity is the measure of the flux, but it depends on the duration of the rainfall. In general we can say that if the duration is longer, the intensity is lower (we'll come back to that). Second is the depth. This is the integral of the intensity over a certain duration t. It is expressed as a length (e.g. in mm). But be aware, this integral is meaningless without duration, because precipitation is and remains a flux. Many people (even meteorological offices) make mistakes in this regard. For instance they say that the rainfall was 100 mm. But this is meaningless if you don't mention the time over which this 100 mm was accumulated. So always present precipitation as a flux: P=d/t. Then there is the frequency, or the probability of occurrence. A rainfall event always has a probability of occurrence. This is the more important when we speak of extreme precipitation. Finally there is the areal extent of the event. This is extremely important if we want to interpret a point observation of precipitation.



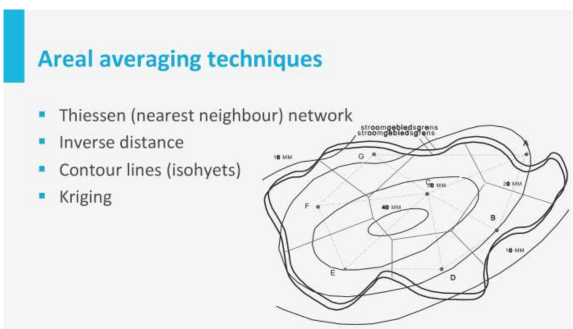
The hyetograph is the Greek word to describe the graph of the rainfall intensity as a function of time. The mass curve is the integral of this curve. And the precipitation over a duration t is found by connecting two points on the curve a distance t apart. The maximum intensity corresponds with the steepest slope of the mass curve.



The areal extent of an event is described by the Areal Reduction curve. If we look at a very extreme precipitation event observed at a certain spot, then we may assume that around it the event was less extreme. Generally it reduces according to some Gaussian distribution, reflecting the size of the event. It can be described by a Gauss-like equation of the maximum intensity Pmax, the area A, and two parameters k and n

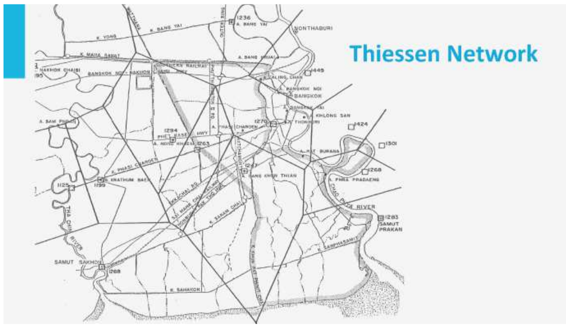


Here I show some of these curves derived by an engineering consultant company for Bangkok and Jakarta. We can see that the distribution is flatter for longer duration events (which seems logical because these are larger systems).

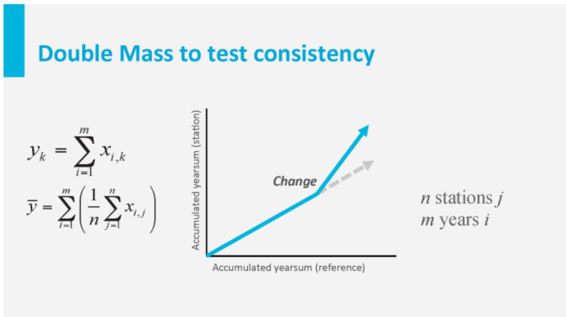


Finally we briefly mention four engineering tools used to average precipitation in space. Most common is the Thiessen network (a way to visualize the nearest neighbour) but another way to favour the nearest neighbor is by inverse distance. A more accurate, but more elaborate, way is using the isohyets (the lines of equal rainfall amounts). But more advances is the use of geo-statistics. The so-called Kriging method.

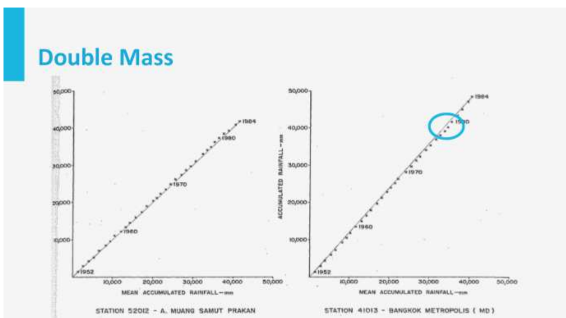
Here we see some isohyets for Thailand.



And a Thiessen network for the city of Bangkok. In the exercise you can see below how these methods are applied in practice.



If you have many point observation data, then it is sometimes hard to assess the consistency of the data. As I said, many things can go wrong in the measurement, collection and the processing of precipitation data. A simple way of identifying stations with problems is to plot double mass curves. In this example on the horizontal axis we see the accumulated means of a number of stations, plotted against the accumulated values of a single station. If something is wrong with that station it may show a haphazard pattern or a kink in the line when something changed around that station.

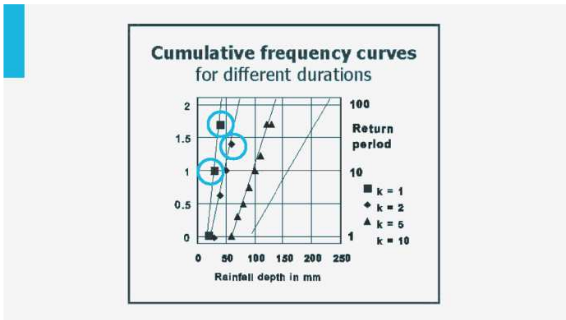


Here you see a few double mass plots of Bangkok again. They look reliable, although the right one had some deviations around 1978.

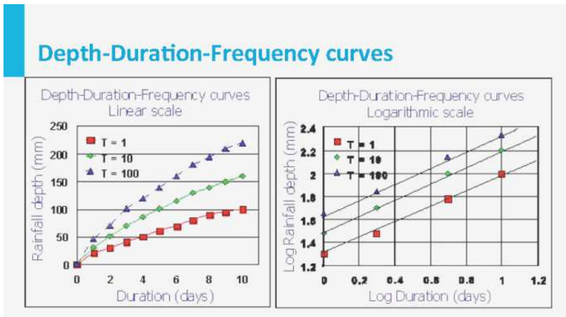
Class interval (mm)	1	2	5	10
0	18262	18261	18258	18253
10	384	432	730	2001
20	48	127	421	1539
30	5	52	243	713
40	1	12	158	493
50		5	83	286
60		2	49	221
70			25	170
80			16	96
90			9	76
100			5	49
110			3	31
120			1	22
130			1	16
140				9
150				7
160				5
170				4
180				2
190				2
200				1

Depth-Duration-Frequency curves

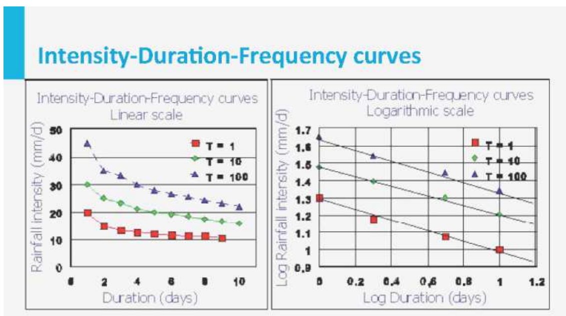
For engineering practices, we to be able to relate precipitation intensity to its duration and frequency, for instance to determine the pumping capacity of a polder, or to find a critical precipitation event to design a bridge or a culvert. For that we follow the following procedure. We have to start with looking at a record of daily rainfall. Assume we have 50 years or records, totaling 365*50=18262 daily values. We then count the number of days with more than 0, 10, 20, 30, etc. mm depth (you can also take smaller classes depending on the purpose). You do the same for amounts fallen in two days, 5 days and 10 days. This results for instance in this Table. We see that only once in 50 years the daily intensity exceeds 40 mm/d, a probability of 2%. Similarly an intensity of 30 mm/d is exceeded 5/50 years, whereby T=10. For the 2 days precipitation 60 mm is exceeded 2 times during 50 years: T=25.



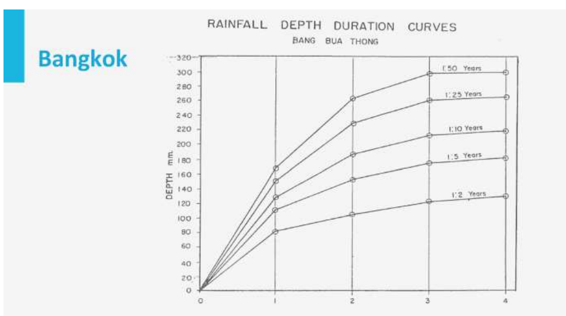
We can plot these data in a graph. On the vertical axis I plotted the logarithm of the Return Period T and horizontally the depth in mm. In the black squares we see the points where an event of 40 mm/d has a return period of 50 years and an event of 30 mm/d a return period of 10 years. Similarly we see the point where 60 mm/2 days has a return period of 25 years.



We can rework these curves in the following graphs. We can plot the depth against the duration for different return periods, on a normal scale (left) or on a log scale (right).



Or we can plot the intensity against the duration for different return periods, also on a normal (left) or on a log scale (right). Such graphs are extremely useful to design the drainage of parking lots, pumping capacities of polders, or design discharge for culverts or bridges.



Here is a graph for Bangkok, which was used to design the drainage of the city on the right bank of the Chao Phya. Now that we have looked into the characteristics of evaporation and precipitation, it is time that we start to look at the third component of the water balance: the runoff. See you later!