Precipitation

GG22A: GEOSPHERE & HYDROSPHERE
Hydrology

Precipitation studies

- The hydrological aspects of precipitation studies are concerned with:
  - The *form* of Precipitation.
  - Its *variation*.
  - The *interpretation* of measured rainfall data.

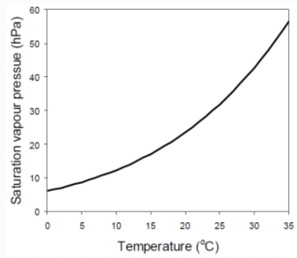
Precipitation

- Types of precipitation:
  - Rain
  - Snow
  - Hail
  - Fog
  - Dew

Generation of precipitation

- Condensation
- Coalescence
- Cooling

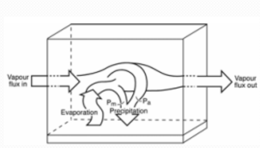
Warm air is able to hold more water than cool air.
The dew point is the temperature to which a parcel of air must be cooled in order to become saturated.



Cooling of air

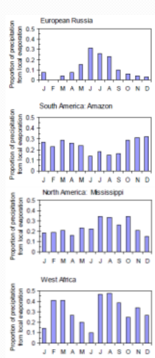
- *Conductive* cooling:
  - air comes into contact with a colder surface, such as if it is blown from a liquid water surface onto cooler land
- *Radiational* cooling:
  - emission of infrared from air or surface
- *Evaporative* cooling:
  - addition of moisture to air cools or saturates it.
- *Adiabatic* cooling:
  - air is forced to rise.

Evaporative cooling



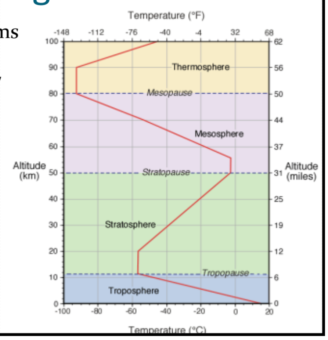
% of rainfall from local evaporation

Trenberth (1999)

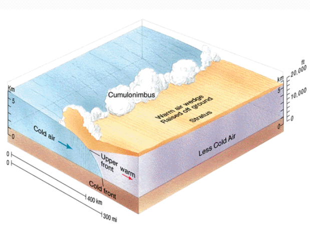


Adiabatic cooling

- Three main mechanisms for air to rise:
  - Convergence (frontal/ non-frontal)
  - Convection
  - Orographic uplift

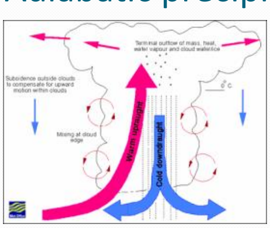


Adiabatic precipitation



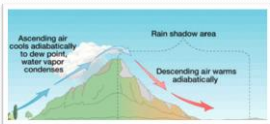
- Cyclonic:
  - Frontal: when warm moist air is forced to rise over a wedge of denser cold air.
  - Non-Frontal: convergence and uplift in an area of low pressure (tropical wave, low pressure system in the westerlies).

Adiabatic precipitation



- Convectional:
  - Heating of the ground surface causing convectional currents of thermally unstable air.
  - Produces intense rainfall of limited duration and areal extent.

Adiabatic precipitation

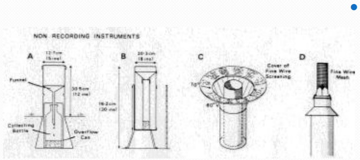


- Orographic:
  - Mechanical uplift or forcing of moist air over barriers (mountains, islands in oceans).
  - Lifting may produce convectional instability which actually produces the rainfall rather than the orographic uplift.
  - The intensity of precipitation increases with the depth of the uplifted layer of moist air.

Precipitation measurement

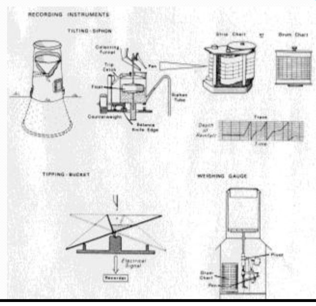
- Point measurement
  - Raingauges/ snowgauges
- Areal estimation (over a catchment)
  - Interpolation of point measurements
  - Radar and satellite

Measurement of rainfall



- Point measurements:
  - Rain Gauge:
    - Non-Recording Rain Gauges

Measurement of rainfall



- Point measurements:
  - Rain Gauge:
    - Recording Rain Gauges:
      - Siphon-Gauge
      - Tipping Bucket Gauge
      - Weighing Gauge

Rain gauges

- Standard Rain Gauge:
  - collects rainfall and is periodically emptied when the precipitation amounts are recorded manually.
  - *Different countries have different standards*

- Tipping Bucket Rain Gauge: automatically records increments of rainfall (typically 0.1-0.5mm) on a strip chart or digitally.

Rain gauges

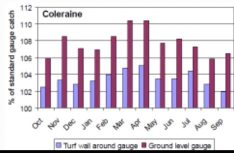
Tipping Bucket Rain Gauge:

- Closed

- Opened to show tipping mechanism

Gauge error

- Accuracy problems
  - Wind turbulence: leads to underestimates.
    - More significant the higher that the rim of the rain gauge is above the ground.
    - Gauge can also act as an obstacle to wind flow which means rainfall is deflected and carried downwind.



Bias in rainfall measurement
Essery & Wilcock (1991)

Gauge error

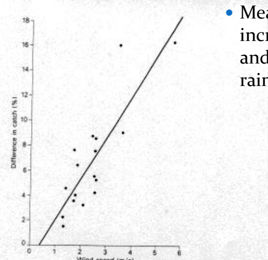


Figure 2.3 *Relation between average wind speed and difference in catch between standard and ground-level raingauges at 17 long-term sites in Britain. (Reprinted with permission from* Atmospheric Environment, *vol. 20, J. C. Rodda and S. W. Smith, The significance of the systematic error in rainfall measurement for assessing atmospheric deposition, © 1986 Pergamon Journals Ltd.)*

- Measurement errors increase with windspeed and with reduced raindrop size.

Gauge error

- Rain gauges do not accurately record extreme rainfall events or high intensity rain, due to splash.

Gauges can be designed to minimise errors from splash

Gauge error

- Extreme rainfall may:
  - be beyond the capacity of storage gauges
  - cause recording gauges to malfunction,
  - cause recording gauges to lose accuracy due to the time it takes for them to tip or siphon empty.
- Extreme events may also be localized and not be recorded by a single rain gauge, or may pass between gauges in a network.

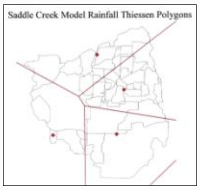
Areal estimates

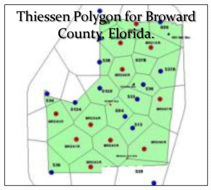
- Achieved by a network of gauges or by using additional radar and satellite information.
- Standard WMO guidelines for the density of rain gauge networks depending on the environment.

Areal estimates from point data

- Point measurements must be in representative locations.
- Rainfall can be estimated at unmeasured locations:
  - Weighted average
    - Thiessen polygons
  - Interpolation
    - isohyets
    - inverse-square distance
    - kriging

Areal estimates from point data



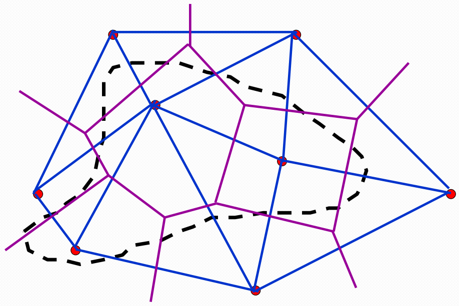


- Thiessen polygons for estimating mean catchment rainfall
  - Weights the catches at each gauge by the proportion of the catchment area that is nearest to that gauge.

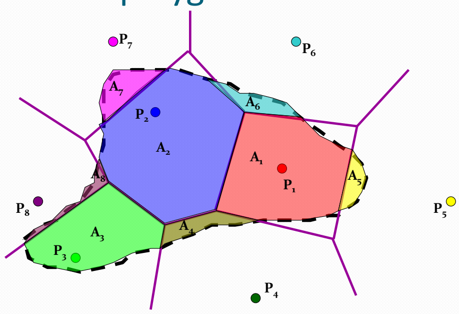
Thiessen polygon method

- Consists of attributing to each station an influence zone in which it is considered that the rainfall is equivalent to that of the station.
  - The influence zones are represented by convex polygons.
  - Polygons are obtained using the mediators of the segments which link each station to the closest neighbouring stations

Thiessen polygon method



Thiessen polygon method



Thiessen polygon method

Mean catchment rainfall, $\overline{P}$:

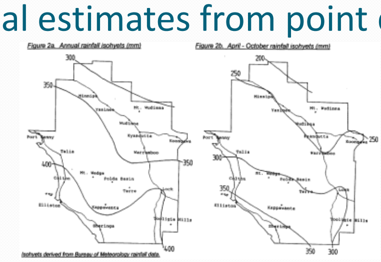
$$\overline{P} = \frac{P_1A_1 + P_2A_2 + \ldots.. + P_mA_m}{(A_1 + A_2 + \ldots.. + A_m)}$$

Generally, across M stations:

$$\overline{P} = \frac{\sum_{i=1}^{M} P_iA_i}{A_{total}} = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$

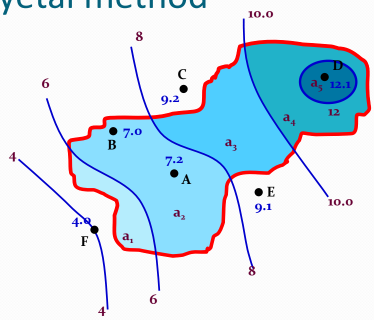
The ratio $\frac{A_i}{A}$ is called the weighting factor of station i

Areal estimates from point data



- The isohyetal method
  - Isohyets are lines of equal rainfall
  - They are drawn between rain gauges, then the areas between the isohyets are calculated.

Isohyetal method



Isohyetal method

$$\overline{P} = \frac{a_1\left(\frac{P_1+P_2}{2}\right) + a_2\left(\frac{P_2+P_3}{2}\right) + \ldots + a_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A}$$

$\overline{P}$ = mean precipitation over the catchment

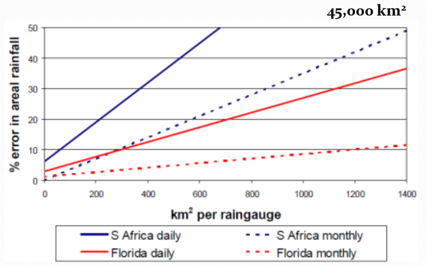
$P_1, P_2, P_3, \ldots, P_n$ = values of the isohytes

$a_1, a_2, a_3, \ldots, a_4$ = inter isohytes areas

A = catchment total area

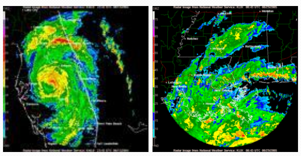
Accuracy of areal estimates from point data

45,000 km²



Seed & Austin (1990)

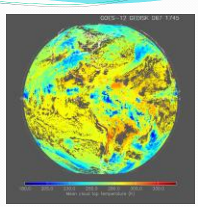
Areal estimates

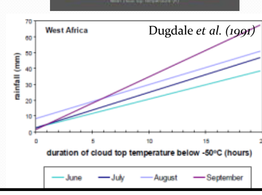


- Weather Radar and satellites
  - Radar reflectivity is used to calculate rainfall totals, while the radar is often calibrated with rain gauge data.
  - Errors can result from:
    - Insects and birds
    - Ground/ sea clutter
    - Wind turbines

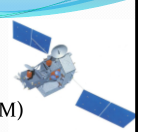
Areal estimates

- Satellite measurements:
  - Cloud top temperature
  - Could top brightness



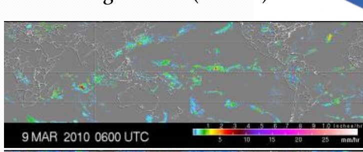


Areal estimates

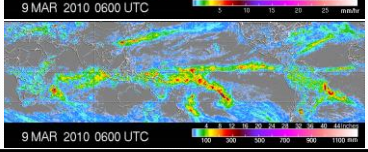


- Tropical Rainfall Measuring Mission (TRMM)

3 hourly data



7 day accumulation



http://trmm.gsfc.nasa.gov/

Analysis of precipitation data

- Estimates of the average rainfall of an area.
  - E.g. catchment rainfall
- Patterns and movements of individual storms.
- The occurrence of rainfall of different magnitudes. Estimation of the Probable Maximum Precipitation.

Temporal variations in precipitation records

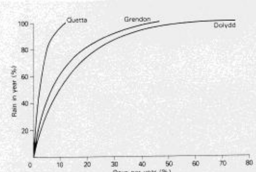


Figure 2.6 *Percentage of annual rainfall occurring in a given percentage of the time for Dolydd (mid-Wales, 1780 mm/yr) and Grendon (southern England, 630 mm/yr) (based on data for 1969–81 from the Institute of Hydrology); and Quetta (northern Pakistan, 205 mm/yr) (data from Packman, 1987).*

- Stochastic Variations: random nature of precipitation.
  - Total precipitation can be dominated by only a few storms or rain days.

Temporal variations in precipitation records

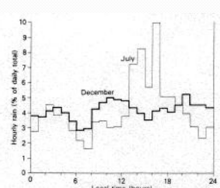


Figure 2.8 *Average diurnal variations of rainfall at Concord, New Hampshire, in July and December, over a 26-year period (from Foster, 1948).*

- Periodic Variations: related to diurnal or annual cycles.
  - Diurnal variations are greatest where the rainfall is derived from convective storms.
  - The annual cycle is more obvious across most of the globe.

Occurrence of rainfall of different magnitudes

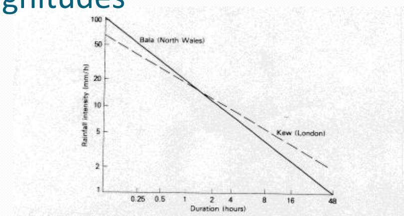


Figure 2.11 *Rainfall intensity duration curves for a five-year return period for two areas with contrasting rainfall regimes. (From Keers and Westcott, 1977. By permission of the Controller of Her Majesty's Stationery Office.)*

- Rainfall intensity-duration curves

Occurrence of rainfall of different magnitudes

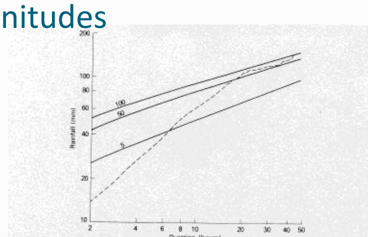


Figure 2.12 *Depth–duration frequency curves of 5, 50 and 100 year return periods based on NERC (1975) for a site in South Wales, together with the profile of a large storm on 26–27 December 1979 in South Wales (from Jack, 1981).*

- Depth-duration frequency curves

Occurrence of rainfall of different magnitudes

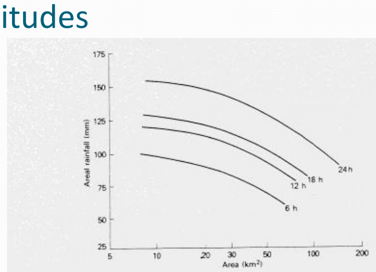


Figure 2.13 *Typical depth–area–duration curves (from Shaw, 1988).*

- Depth-area duration curves

Probable maximum precipitation

- The physical upper limit to the amount of precipitation on a given area over a given time.
- The theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year.

Probable maximum precipitation

- Methodology:

1. Maximization and transposition of real or modelled storms.
2. Plot maximum precipitation intensities by duration of actual recorded storms across the globe.

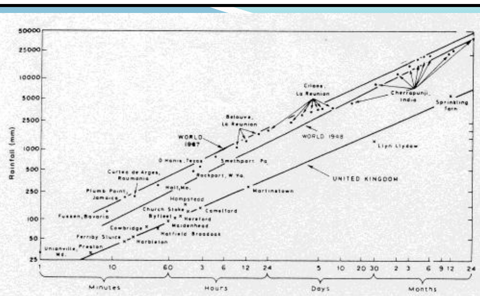


Figure 2.15 *Magnitude–duration relationship for the world and the United Kingdom extreme rainfalls (redrawn after a diagram by Rodda, 1970), based on data from various sources and showing envelope curves for the world maxima recorded prior to 1948 and prior to 1967.*

- 1948 Curve is approximated as $P = 255D^{0.5}$
- 1967 Curve is approximated as $P = 420D^{0.475}$
- P = Precipitation in mm. D = Rainfall Duration in hrs.

Summary

- Generation of precipitation
  - Cooling of air: Conductive, Radiational, Evaporative, Adiabatic (cyclonic, convectional, orographic).
- Measurement and estimation:
  - Rain guages; gauge errors; Thiessen polygons; Isohyets
  - Weather Radar; satellite measurements; TRMM
- Analysis of rainfall:
  - Temporal variations; rainfall magnitudes; probable maximum precipitation.