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Hydrology
Precipitation

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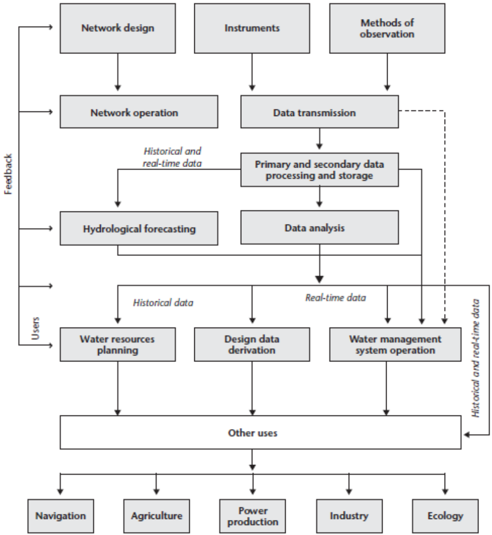
Content & Structure

You are going to learn

Measure precipitation and analyse rainfall data ...

- Monitoring
- Rainfall gauges
- Maximum rainfall
- Rainfall amount and intensity
- Double mass curve
- Rainfall probability
- Interpolation

Monitoring



Monitoring networks. Source WMO report 168 (2008, p. I.1-3)

Precipitation (amount and form)	3–7%
Rainfall intensity	1 mm h^{-1}
Snow depth (point)	1 cm below 20 cm or 10% above 20 cm
Water content of snow	2.5–10%
Evaporation (point)	2–5%, 0.5 mm
Wind speed	0.5 m s^{-1}
Water level	10–20 min
Wave height	10%
Water depth	0.1 m, 2%
Width of water surface	0.5%
Velocity of flow	2–5%
Discharge	5%
Suspended sediment concentration	10%
Suspended sediment transport	10%
Bed-load transport	25%
Water temperature	0.1–0.5°C
Dissolved oxygen (water temperature is more than 10°C)	3%
Turbidity	5–10%
Colour	5%
pH	0.05–0.1 pH unit
Electrical conductivity	5%
Ice thickness	1–2 cm, 5%
Ice coverage	5% for $\geq$ 20 kg m^{-3}
Soil moisture	1 kg m^{-3} $\geq$ 20 kg m^{-3}

Measurement errors. Source WMO report 168 (2008, p. I.1-2-18)

Station Network

Density

Recommended minimum densities of stations (area in km² per station)

Physiographic unit	*Precipitation*		*Evaporation*	*Streamflow*	*Sediments*	*Water quality*
	Non-recording	*Recording*				
Coastal	900	9 000	50 000	2 750	18 300	55 000
Mountains	250	2 500	50 000	1 000	6 700	20 000
Interior plains	575	5 750	5 000	1 875	12 500	37 500
Hilly/undulating	575	5 750	50 000	1 875	12 500	47 500
Small islands	25	250	50 000	300	2 000	6 000
Urban areas	–	10–20	–	–	–	–
Polar/arid	10 000	100 000	100 000	20 000	200 000	200 000

Figure: Density of precipitation network. WMO report 168, p. I-2-24

Rain Gauge

Location

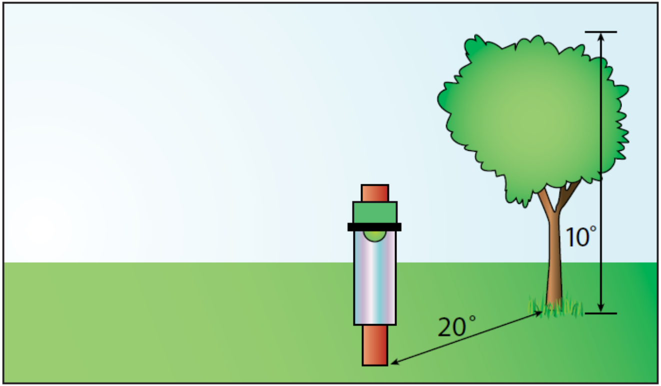
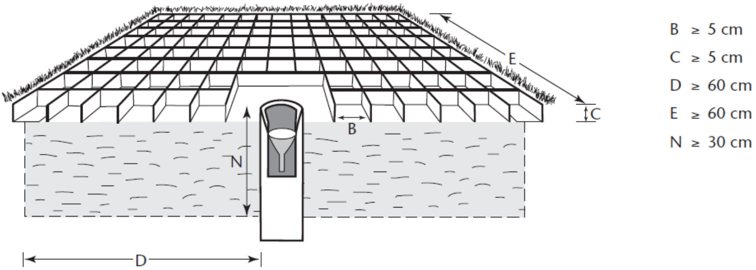


Figure: Localisation of rain gauges. WMO report 168, p. I-3-1

Rainfall measurement

Pit gauge



Pit gauge for the measurement of liquid precipitation

Figure: Pit gauge to measure rainfall at ground. WMO rep. 168, I-3-2

Main components of the systematic error in precipitation measurement and their meteorological and instrumental factors listed in order of general importance

$$P_k = kP_c = k(P_g + \Delta P_1 + \Delta P_2 + \Delta P_3 \pm \Delta P_4 - \Delta P_5)$$

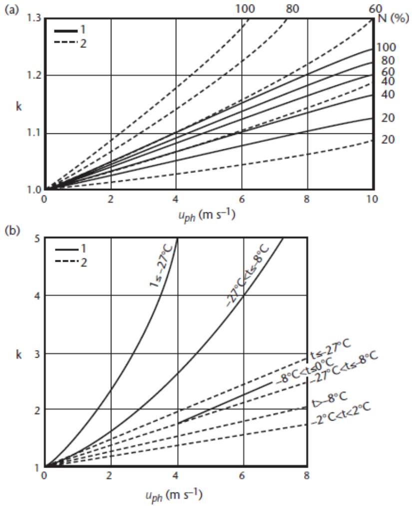
where P_k is the adjusted precipitation amount, k is the correction factor, P_c is the precipitation caught by the gauge collector, P_g is the measured precipitation in the gauge, and P_1 to P_5 are corrections for components of systematic error as defined below:

Symbol	*Component of error*	*Magnitude*	*Meteorological factors*	*Instrumental factors*
k	Loss due to wind field deformation above the gauge orifice	2–10% 10–50%[a]	Wind speed at the gauge rim during precipitation and the structure of precipitation	The shape, orifice area and depth of both the gauge rim and collector
$\Delta P_1 + \Delta P_2$	Losses from wetting on internal walls of the collector and in the container when it is emptied	2–10%	Frequency, type and amount of precipitation, the drying time of the gauge and the frequency of emptying the container	The same as above and, in addition, the material, colour and age of both the gauge collector and container
ΔP_3	Loss due to evaporation from the container	0–4%	Type of precipitation, saturation deficit and wind speed at the level of the gauge rim during the interval between the end of precipitation and its measurement	The orifice area and the isolation of the container, the colour and, in some cases, the age of the collector, or the type of funnel (rigid or removable)
ΔP_4	Splash-out and splash-in	1–2%	Rainfall intensity and wind speed	The shape and depth of the gauge collector and the kind of gauge installation
ΔP_5	Blowing and drifting snow		Intensity and duration of snow storm, wind speed and the state of snow cover	The shape, orifice area and depth of both the gauge rim and the collector

[a] Snow

Source: Measurement errors. Source WMO report 168 (2008, p. I.1-3-5)

Wetting loss



- wetting loss
- k is correction factor
- wind speed u_{ph}
- rainfall N with intensity < 0.3 mm/h
- Temperature T

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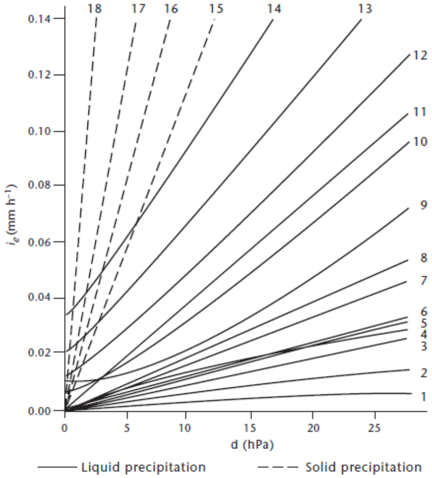
Evaporation loss



- evaporation loss
- depends on saturation deficit *d* (hPa)
- Temperature

Note: Intensity of evaporation (i_e) for various gauges: (a) Liquid precipitation: (i) Australian standard gauge 1, 2, 7, 11 for $P \leq 1$ mm; 1.1 to 20 mm; > 20 mm (all for wind speeds, $u_e > 4$ m s^{-1}), and for $u_e \geq 4$ m s^{-1}, respectively; (ii) Snowdon gauge in a pit 3, 6, 8 for $P \leq 1$ mm, 1.1 to 10 mm and ≥ 10 mm, respectively; (iii) Hellmann gauge 4; (iv) Polish standard gauge 5; (v) Hungarian standard gauge 9; (vi) Tretyakov gauge 10, 12, 13, 14 for wind speeds at the level of the gauge rim of 0 to 2, 2 to 4, 4 to 6 and 6 to 8 m s^{-1}, respectively; (b) Solid precipitation: Tretyakov gauge 15, 16, 17, 18 for wind speeds 0 to 2, 2 to 4, 4 to 6 and 6 to 8 m s^{-1}, respectively, where i_e is the intensity of evaporation in mm h^{-1} and τ_e is the time elapsed between the end of the precipitation and the measurement of precipitation.

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Radar measurement

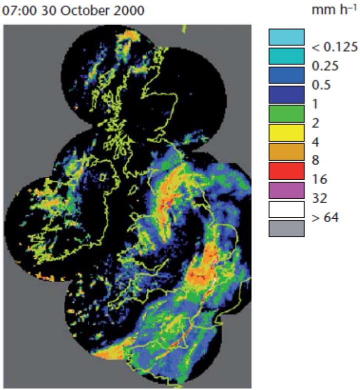


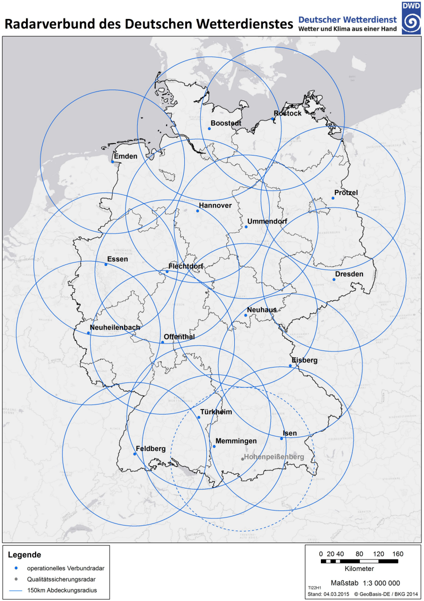
Figure I.3.10. United Kingdom radar network image comprising radar data from the United Kingdom and Ireland at 0700 UTC on 30 October 2000. The different colours represent different rainfall rates in mm h^{-1} as shown. The coastline is shown. (Courtesy Met Office, United Kingdom)

- radar produces maps
- cover and intensity
- in Europe good cover
- complex transfer signal to amount
- drop spectrum

Radar measurement

Radar station on Hohen Peißenberg, Germany

Radarverbund des Deutschen Wetterdienstes



Radar signal

Radar signal attenuation due to precipitation (dB km^{-1})

Rate of rainfall (mm h^{-1})	*Wavelength (m)*			
	0.1	0.057	0.032	0.009
1.0	0.0003	0.002	0.007	0.22
5.0	0.0015	0.015	0.061	1.1
10.0	0.003	0.033	0.151	2.2
50.0	0.015	0.215	1.25	11.0
100.0	0.015	0.481	3.08	22.0

Distance (km) over which precipitation at a given rate of rainfall must extend to give an attenuation of 10 dB at various wavelengths

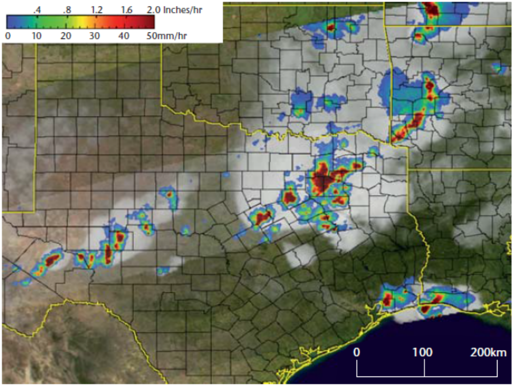
WMO report 168 (2008): Radar signal and factors

$$P_r = P_t \pi^3 G^2 \theta.\phi.h K^2 Z / 512(2 \ln 2) R^2 \lambda^2$$

where P_r is the average power in watts received from a series of reflected pulses, P_t is the peak power transmitted in watts, G is the antenna gain, θ and ϕ are the horizontal and vertical beam widths, h is the pulse length in metres, R is the range in metres, λ is the wavelength in metres, K^2 is the refractive index term of rain (0.9313 for 10-cm radar equipment assuming a temperature of 10°C), and Z is the reflectivity.

TRMM

Satellite measurement

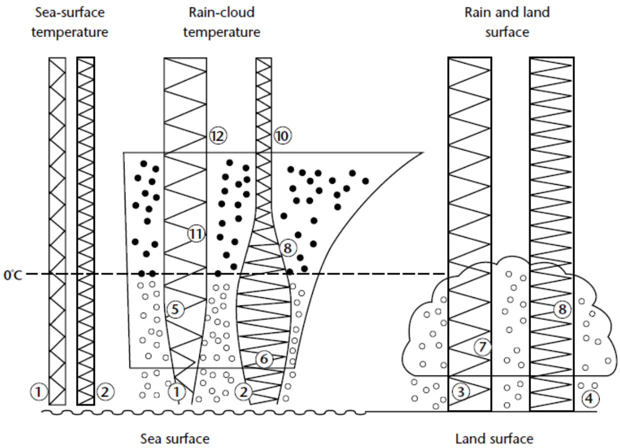


Heavy rainfall over Texas derived from the TRMM Microwave Imager and Precipitation Radar on the TRMM satellite at 0439 UTC 1 May 2004 (Courtesy NASA)

Source: TRMM measurement of rainfall. Source WMO report 168 (2008, p. I.1-3-24)

TRMM

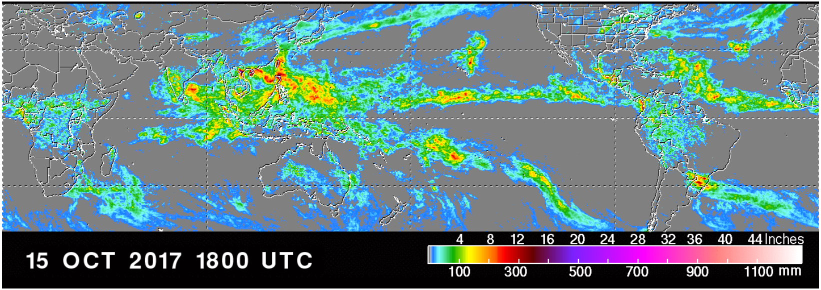
Satellite measurement



Source: TRMM measurement of rainfall. Source WMO report 168 (2008, p. I.1-3-24)

TRMM

Satellite measurement



Source: TRMM measurement of on 15.10.2017. Link: https://trmm.gsfc.nasa.gov/

Data sources

Precipitation

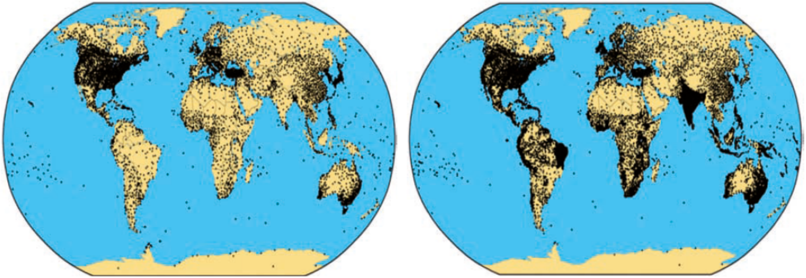
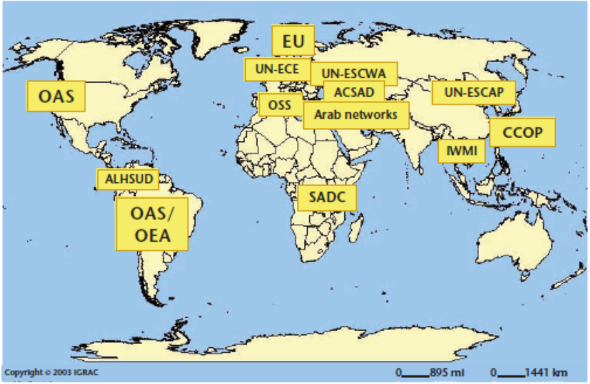


Figure 4.1. GHCN air temperature network (left) and GHCN precipitation network (right); available online at http://www.ncdc.noaa.gov/ghcnm/

Source: Data sources for rainfall data. Source WMO report 1095 (2012, p. 22)

Regional Precipitation Data



ACSAD	Arab Centre for the Study of Arid Zones and Dry Lands	OEA	Organización de los Estados Americanos
ALHSUD	Latin American Association of Groundwater Hydrology for Development	OSS	Sahara and Sahel Observatory
CCOP	Coordinating Committee for Geoscience Programmes in East and Southeast Asia	SADC	Southern African Development Community
EU	European Union	UN-ECE	United Nations Economic Commission for Europe
IWMI	International Water Management Institute	UN-ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
OAS	Organization of American States	UN-ESCWA	United Nations Economic and Social Commission for Western Asia

Source: Data sources for rainfall data. Source WMO report 1095 (2012, p. 33)

Online Data Sources

Datasets *Categories of information*	*Centre/providing company*	*Current Internet link*
1. Biophysical data		
AQUASTAT – Land use and population – Climate and water resources – Water use, by sector and by source – Irrigation and drainage development – Environment and health	**FAO** Food and Agriculture Organization of the United Nations	http://www.fao.org/AG/AGL/aglw/aquastat/main/index.stm
FAOSTAT – Land use and irrigation, fertilizer and pesticides statistics	**FAO** Food and Agriculture Organization of the United Nations	http://faostat.fao.org/
– Land cover – Population density – Biodiversity for 154 basins and sub-basins around the world	**IUCN** water atlas World Conservation Union	http://www.waterandnature.org/en/resources/publications/thematic-collection/facts-figures/watersheds-world
Gridded population of the world	**SEDAC** Socioeconomic Data and Applications Centre	http://sedac.ciesin.columbia.edu/gpw/

Data sources by international organizations. Source WMO report 1095 (2012)

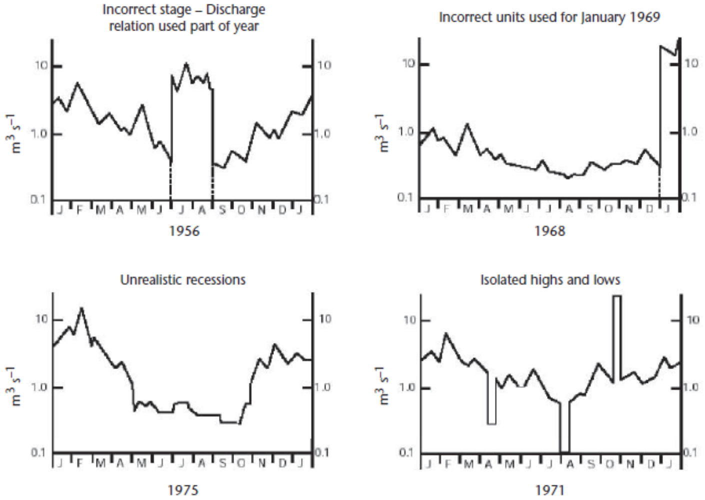
Online Data Sources

2. Topographic data		
TOPO30 **STRM** – Elevation data (land) **HYDRO1k** – Streams, drainage basins	**USGS** United States Geological Survey	http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/Elevation_Products
ETOPO5 and ETOPO2 – Global relief (land and oceans)	**NGDC** National Geophysical Data Center	http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html
3. Climate data		
– Precipitation, temperatures, pressure...	**CRU** Climatic Research Unit	http://www.cru.uea.ac.uk/
Global precipitation analysis	**GPCC** Global Precipitation Climatology Centre	http://gpcc.dwd.de
4. River flow data		
– Water fluxes into the oceans – Discharge statistics – Composite runoff fields – Global Terrestrial Network for River Discharge (GTN-R) ...	**GRDC** Global Runoff Data Centre	http://grdc.bafg.de

Data sources by international organizations. Source WMO report 1095 (2012)

Analysis

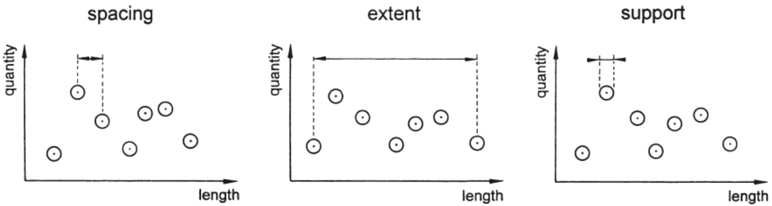
Check data for consistency



Data quality. Source WMO report 168 (2008)

Sampling theory

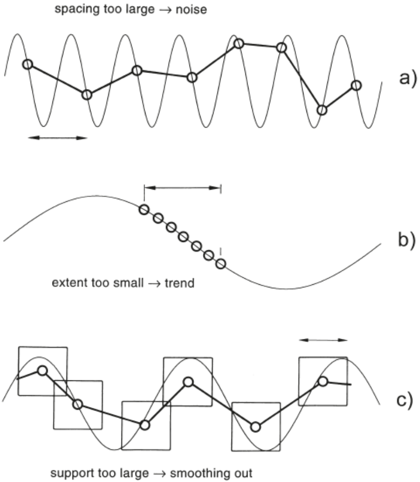
Triplets



Definition of the scale triplet (spacing, extent and support). This scale triplet can apply to samples (i.e. measurement scale) or to a model (i.e. modelling scale). (Redrawn from Blöschl and Sivapalan, 1995; reproduced with permission.)

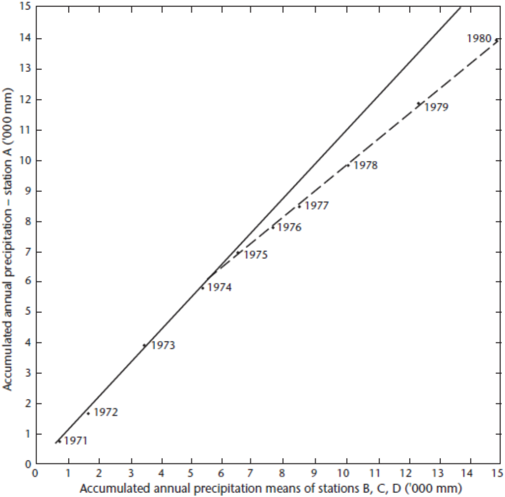
Bloeschl & Grayson (2000)

Sampling theory



Bloeschl & Grayson (2000)

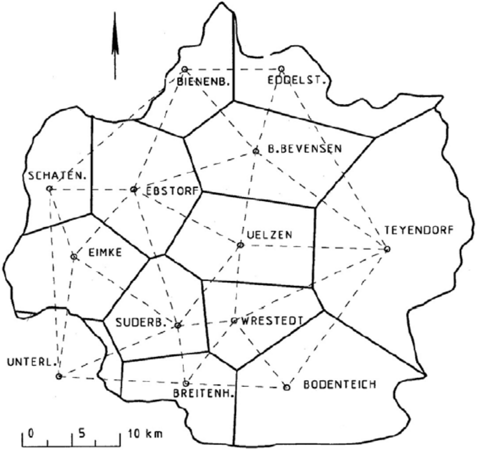
Compare two stations



- take 2 station series
- plot pairs $(P_1; P_2)$
- deviation from 45 degree line
- detect trends, systematic errors
- changes in station environment

From point data to maps

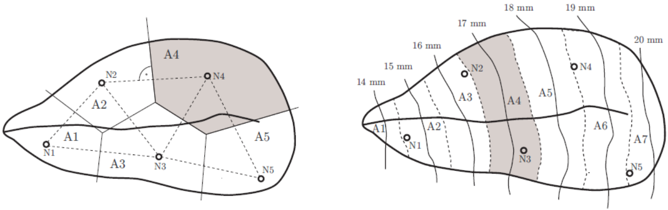
Thiessen Polygone



- objective method
- area weight
- analog & digital

Isoline Method

$$N_m = \frac{\sum (N_i \cdot A_i)}{\sum A_i}$$

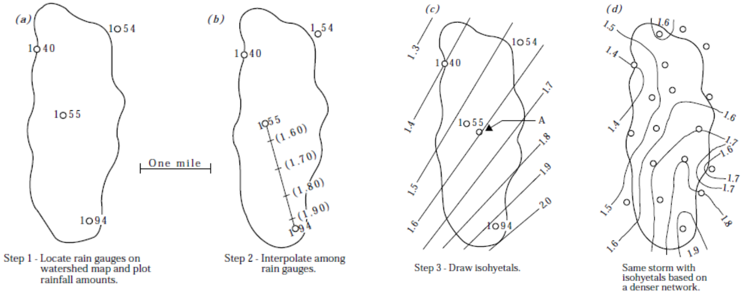


(a) Thiessen-Polygon (b) Isohyete

Ostrowski, 2017

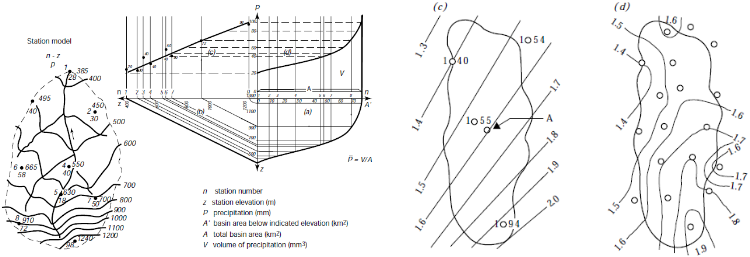
- subjective unless applied with triangular linear interpolation
- assumption of linear changes between changes
- analog & digital

Isoline Method Construction



USDA (United States Department of Agriculture, Stormwater in Urban Basins

Isoline Method Construction



Hypsometric method.

Step 3 - Draw isohyetals.

Same storm with isohyetals based on a denser network.

USDA (United States Department of Agriculture, Stormwater in Urban Basins

Guide-to-Hydrological-Practice-1994-p429-Hypsometric.png

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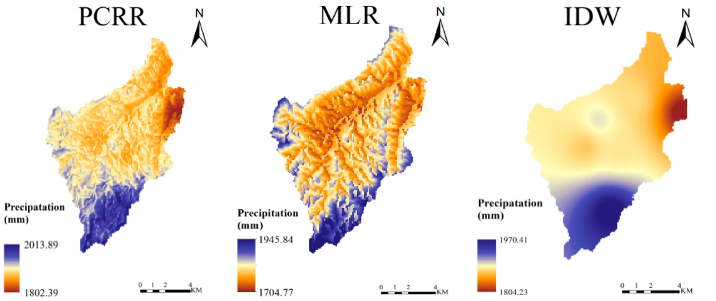
Interpolation algorithms



- Inverse Distance Method (IDW)
- PCRR principal component linear regression (PCLR)
- multiple linear regression (MLR)

Interpolation algorithms

Interpolation models	Interpolation functions	Weight vector(W)	Constant (m)	Parameter Specification
IDW, Inverse Distance Weighted	$Z_p = \sum_{i=1}^{n} w_i Z_i$	$w_i = \frac{d_i^{-k}}{\sum_{i=1}^{n} d_i^{-k}}$	0	d_i : the distance between P_0 and P_i; k : a power parameter
Kriging	$Z_p = \sum_{i=1}^{n} w_i [z_i - m] + m$	w_i	$m(1 - \sum_{i=1}^{n} w_i)$	
MC, Minimum Curvature	$Z_p = \sum_{i=1}^{n} w_i R(d_i) + T(x,y)$	w_i	$T(x,y)$	d_i : the distance between P_0 and P_i; $R(d_i)$: the principal curvature function; $T(x,y)$: a 'trend' function

Liu, 2007

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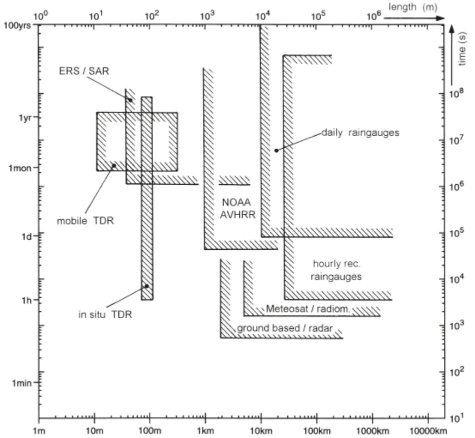
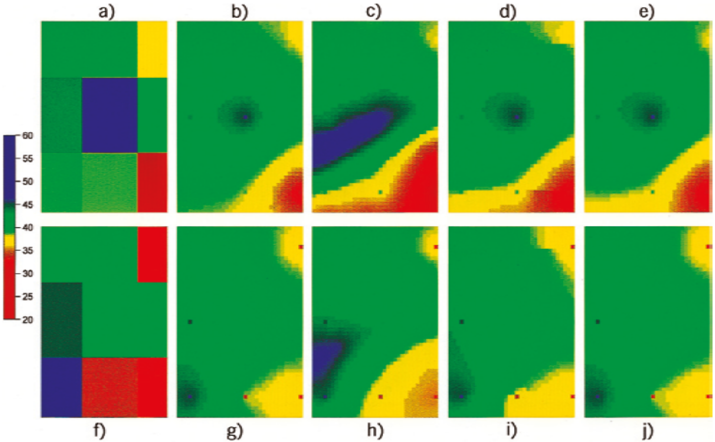
Scales



Space and timescales of rainfall and soil moisture variability that can be captured by different instruments represented as the domain between spacing and extent of the measurements.

Bloeschl & Grayson, 2000

Scales

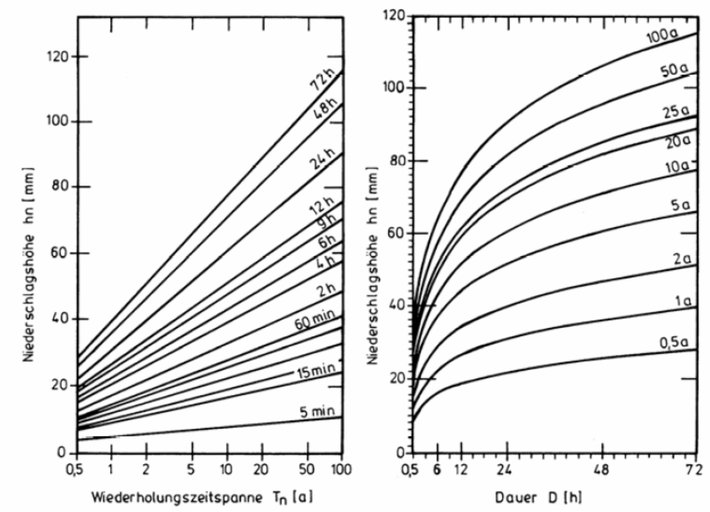


Interpolation methods applied to nine sample points on a 30 × 40 m spacing. (a) to (e) are based on nine samples from Figure 2.7(a); (a) Thiessen method; (b) ordinary kriging; (c) External Drift kriging with the radiation weighted wetness index; (d) External Drift kriging with topographic aspect index; (e) as for (d) but with a larger search radius; (f) to (j) are based on nine samples from Figure 2.7(c); (f) Thiessen method; (g) ordinary kriging; (h) External Drift kriging with the radiation weighted wetness index; (i) External Drift kriging with topographic aspect index; (j) as for (i) but with a larger search radius.

Bloeschl & Grayson, 2000

Frequency of rainfall and statistics (to be continued ...)

Time-Depth vs. Time-Intensity



Maniak, 2016