

Hydrological Measurements

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5. Measuring Evaporation





Measuring evaporation

Evaporation is ...

$$E = E_o + E_t + E_s + E_i$$

- E = total evaporation
- E_o = open water evaporation
- E_t = transpiration
- E_s = soil evaporation
- E_i = interception evaporation

Potential vs Actual

- Potential:
 - No water stress
 - Atmospheric demand for moisture
- Actual:
 - Reality
 - Net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture

Evaporation measurements

	Measurement	E _o	E _t	E _s	E _i
Potential	Class A pan	X			
	Penman (-Monteith)	X			
Actual	Lysimeter		X		
	Sapflow		X		
	Bowen ratio	X			
	Eddy correlation	X			
	Scintillometer	X			
	Energy balance	X			

Potential evaporation measurements

Class A-pan



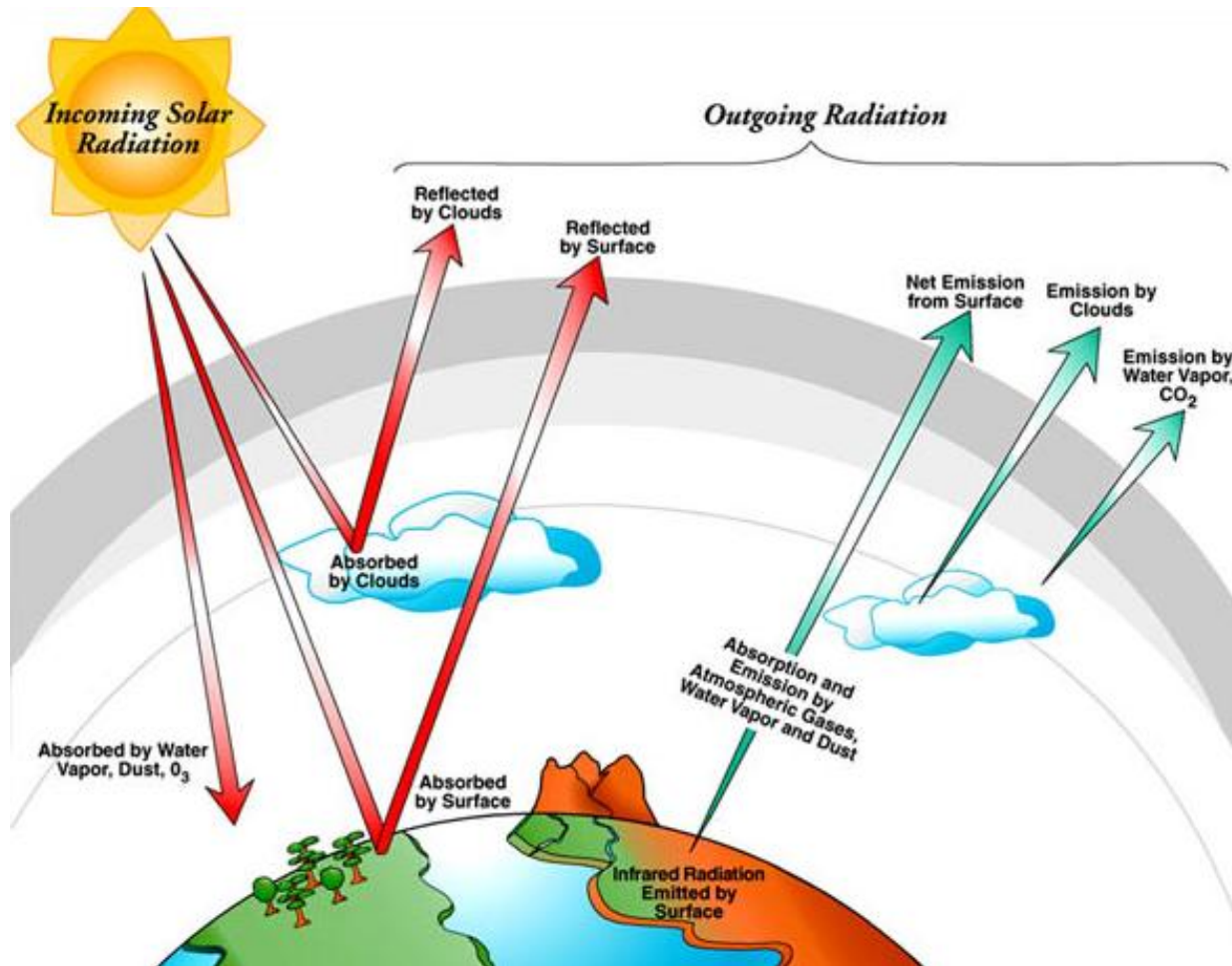
Source Unknown

Penman (-Monteith)

$$\lambda E = \frac{\Delta (R_n - G) + \rho_{\text{air}} c_p \text{vpd} / r_a}{\underbrace{\Delta + \gamma (1 + r_s / r_a)}_{= 0 \text{ for Penman (no vegetation)}}}$$

Radiation

$$R_n = (R_{s,in} - R_{s,out}) - ("R_{l,in}" - R_{l,out})$$



<http://thegreendove.com/2010/05/radiation-flying/>

Radiation – Net radiation



Source Unknown

Cambel-Stokes Sunshine duration recorder

$$R_N = (1-r)R_C - R_B$$

The Netherlands	$R_C = (0.20 + 0.48 n/N)R_A$
Average climate	$R_C = (0.25 + 0.50 n/N)R_A$
New Delhi	$R_C = (0.31 + 0.60 n/N)R_A$
Singapore	$R_C = (0.21 + 0.48 n/N)R_A$

$$R_B = \sigma(273 + t_a)^4 \left(0.47 - 0.21 \sqrt{e_a} \right) \left(0.2 + 0.8 \frac{n}{N} \right)$$

Radiation – Net radiation



Source Unknown

Radiation – Short wave radiation

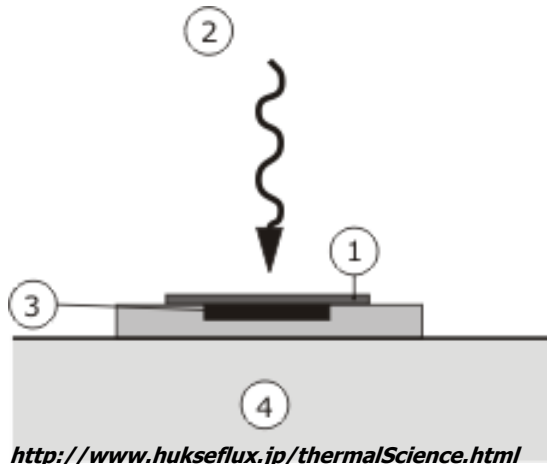


Source Unknown

Hukseflux LP02 (Pyranometer)

LP02 SPECIFICATIONS

ISO classification:	second class
Spectral range:	305 to 2800 nm
Sensitivity (nominal):	15 $\mu\text{V}/\text{Wm}^{-2}$
Temperature range:	-40 to +80 °C
Range :	0 to 2000 Wm^{-2}
Temperature dependence:	< 0.1%/°C
Calibration traceability:	WRR



<http://www.hukseflux.jp/thermalScience.html>

The absorber (1) absorbs radiation (2). The radiation is converted into heat. The heat flux to the heat sink (4) is measured by the thermopile (3).

Radiation – Long wave radiation

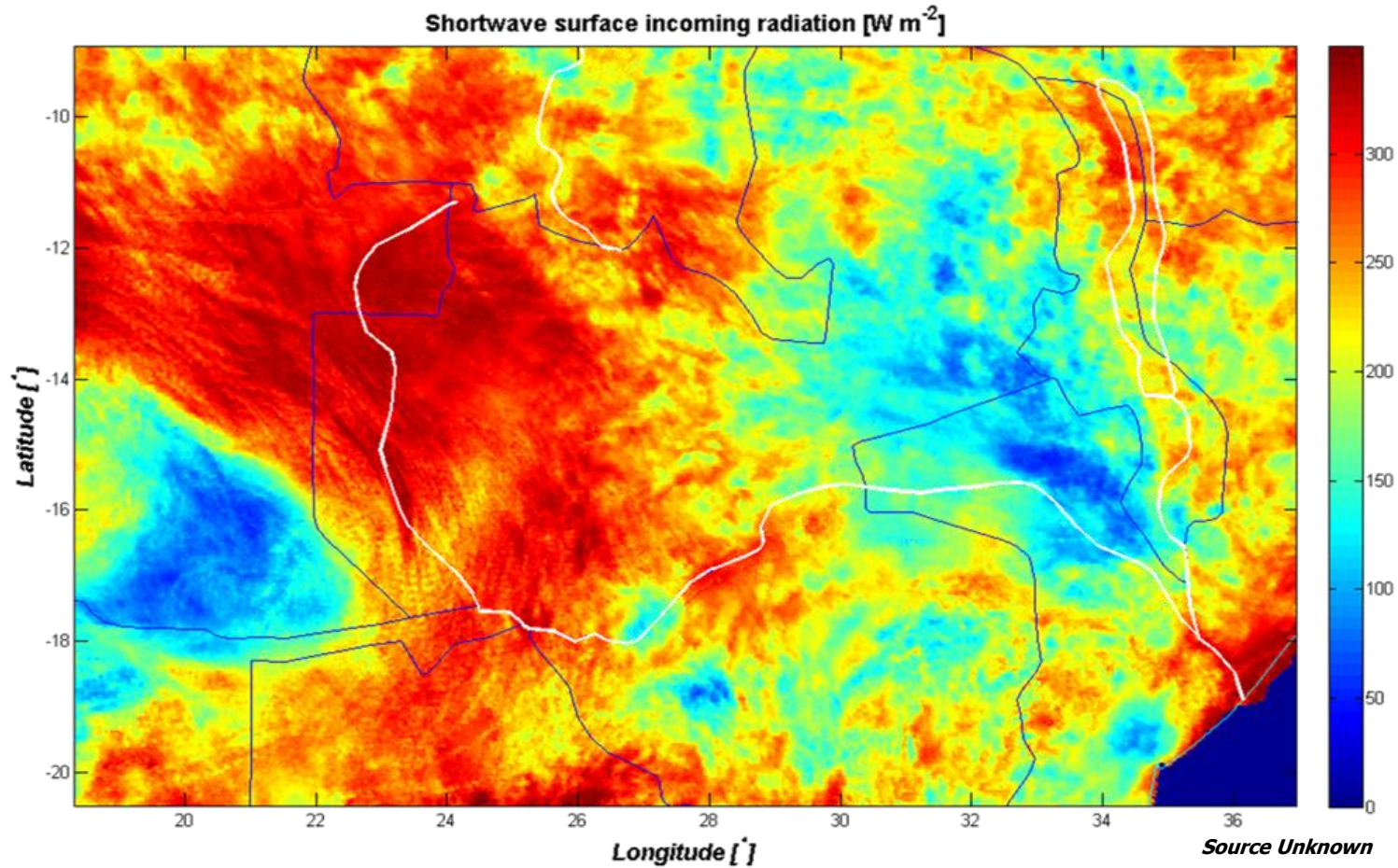


Kipp & Zonen CGR3 Pyrgeometer

Source Unknown

Spectral Range	4.5 to 42 μm (50% points)
Sensitivity (nominal)	5 to 7 $\mu\text{V/W/m}^2$
Response time (63 %)	< 6 s
Response Time (99 %)	<18 s
Temperature Dependence of Sensitivity (–20 to +50 °C)	–10 to +40 °C ± 5 %
Field of View	150°
Irradiance	–250 to +250 W/m ² (net irradiance)
Non stability change / year	< 1%
Temperature sensor	Thermistor (YSI 44031)

Radiation – Remote sensing



Meteosat incoming radiation

Soil heat flux



Source Unknown

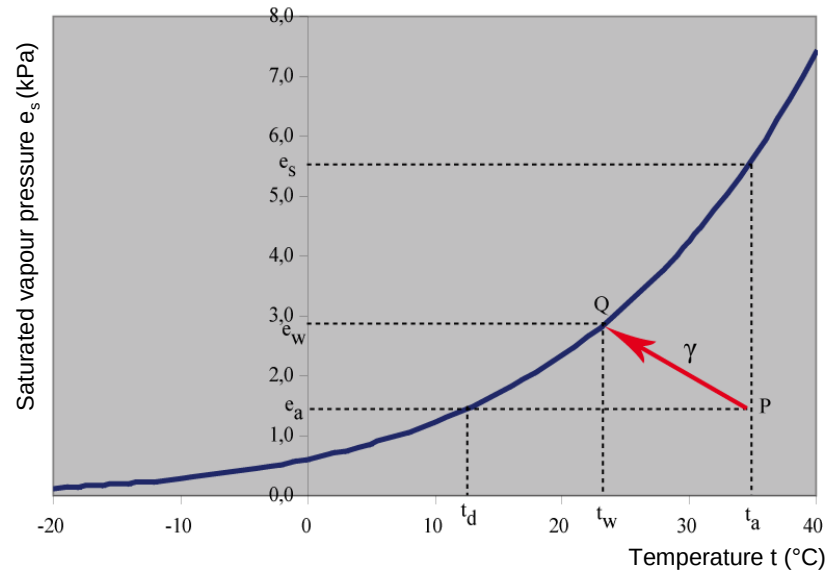
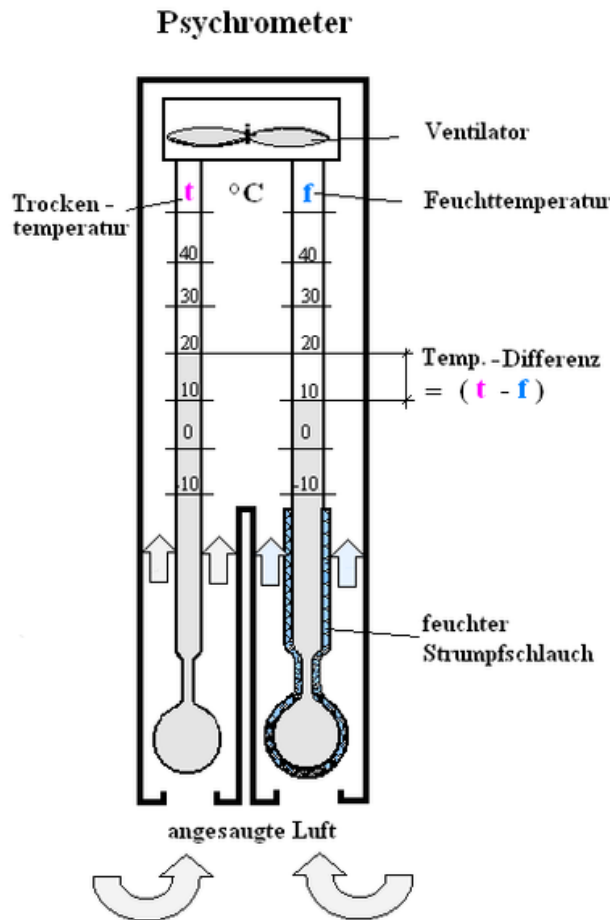
Vapor Pressure Deficit ($e_s - e_a$)

$$e_s(t) = 0.61 \exp \left(\frac{17.3t}{237 + t} \right)$$

$$h = \frac{e_a(t)}{e_s(t)}$$

- Temperature
- Humidity:
 - Psychrometer
 - Humidity sensor

VPD - Psychrometer



$$e_s(t) = 0.61 \exp \left(\frac{17.3t}{237 + t} \right)$$

$$e_a(t_a) = e_s(t_w) - \gamma(t_a - t_w)$$

VPD - Humidity



Source Unknown

Aerodynamic resistance

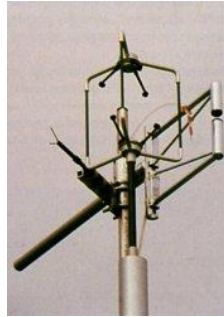


$$r_a = \frac{245}{(0.54u_2 + 0.5)} * \frac{1}{86400}$$

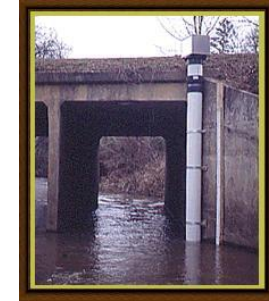
Summary Penman

- Net radiation
- Ground heat flux ($G=0$ on daily time scale)
- Temperature
- Humidity
- Wind

Actual evaporation measurements



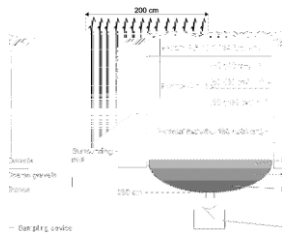
Scintillometer



Water balance

Eddy correlation

Bowen ratio



Lysimeter



1m²

10 ha

500 ha

10,000 ha

Lysimeters



Source Unknown

Lysimeters



Source Unknown

Lysimeters



Source Unknown

Bowen ratio

$$R_n = \rho\lambda E + H + G$$

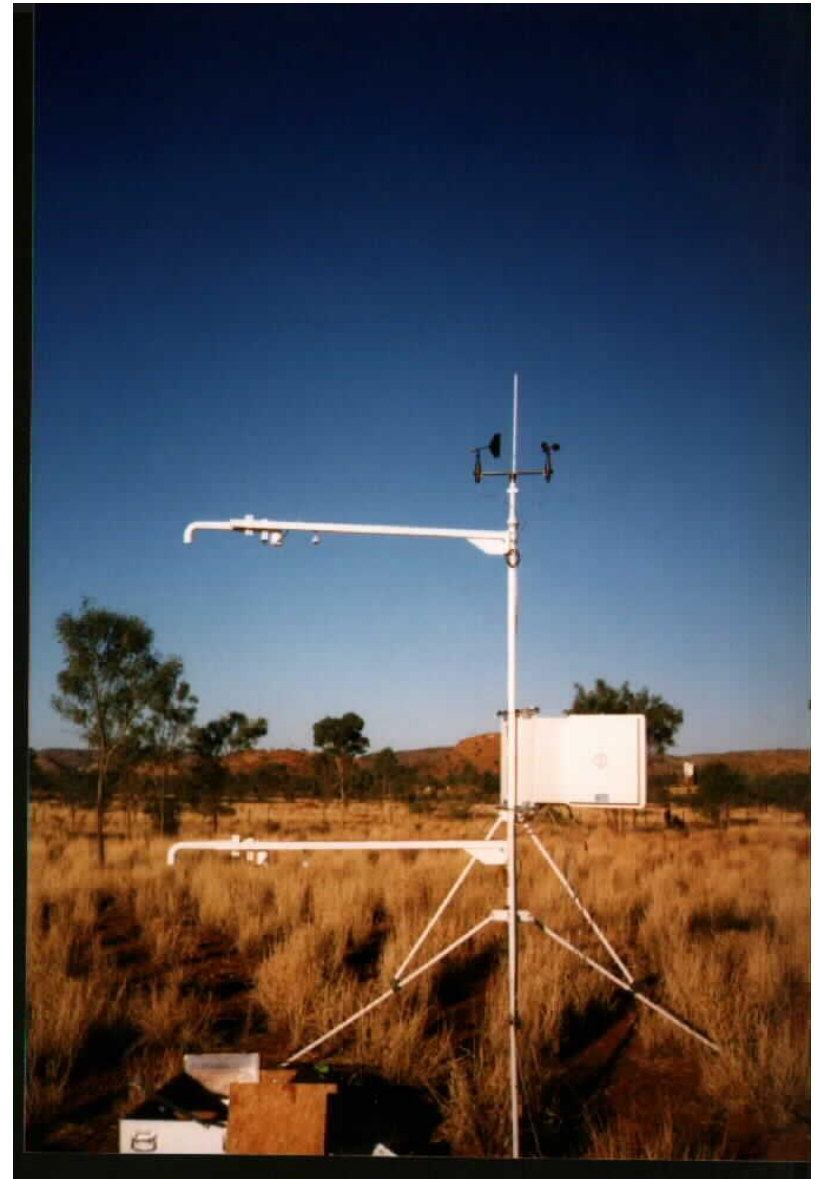
$$\beta = \frac{H}{\rho\lambda E} = \gamma \frac{T_2 - T_1}{e_2 - e_1}$$

Arid: $\beta \gg 1$

Humid: $\beta \ll 1$

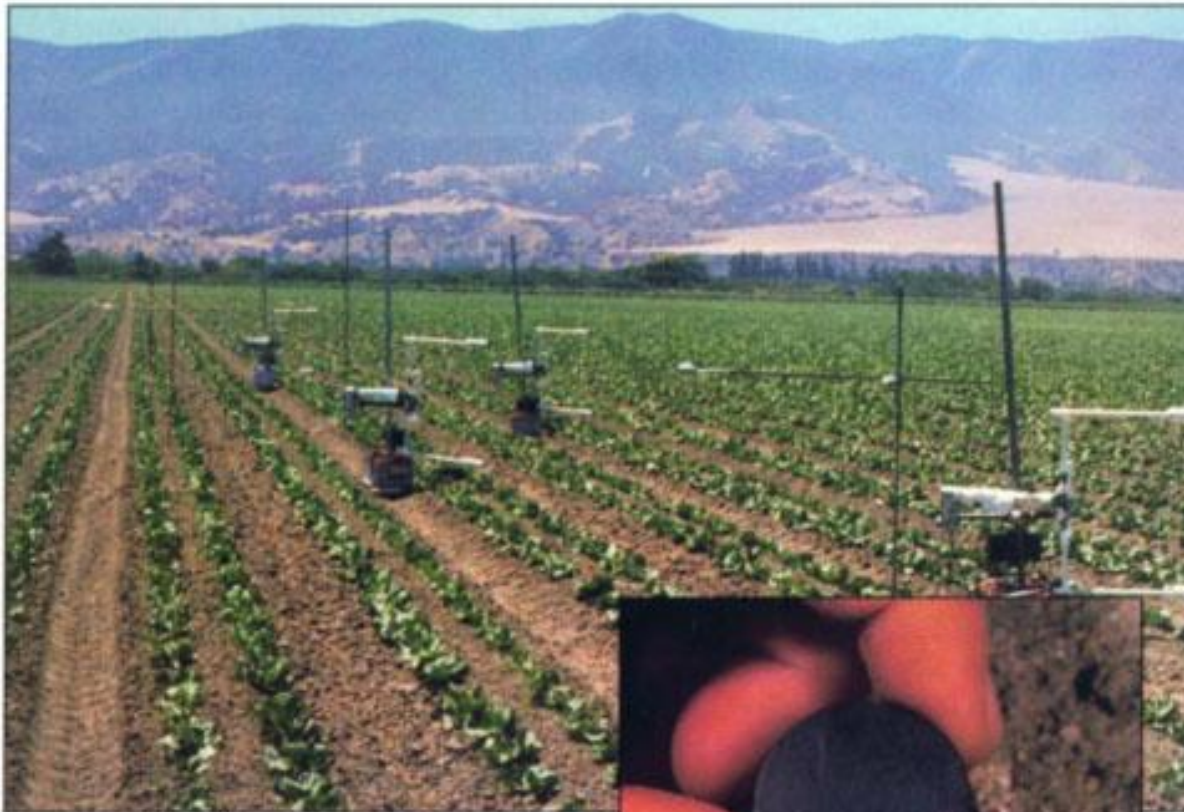
$$E = \frac{R_n}{\rho\lambda(1 + \beta)}$$

Flux tower



<http://www.arts.monash.edu.au/ges/research/climate/cafe.php>

Bowen ratio



Bowen ratio instruments were placed in the field to collect evapotranspiration data. *Inset*, plates were placed just below the soil surface in the plant row, bed shoulder and center of the furrow to measure soil heat flux.

Source Unknown

Bowen ratio with DTS



Eddy covariance



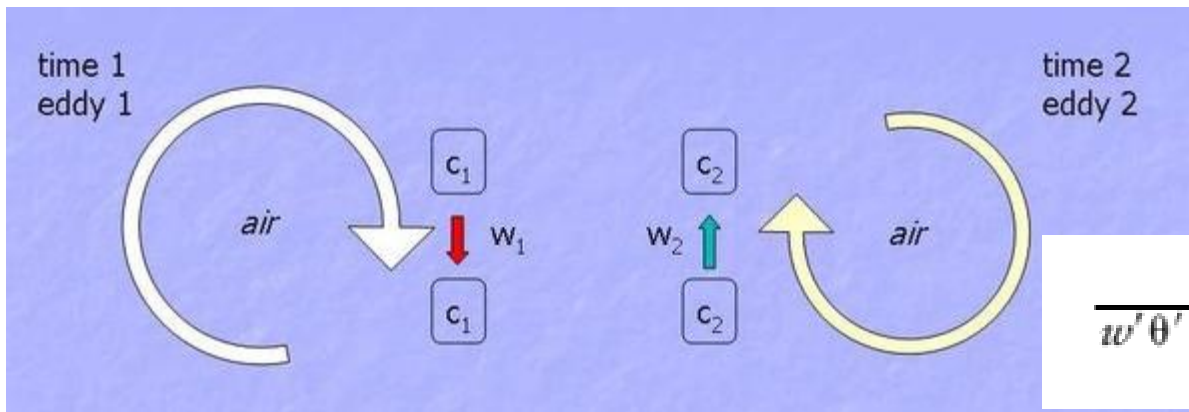
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Principle eddy covariance



Wind
+
Concentration
Temperature (H)
Humidity (λE)

Burba, G.G., and D.J. Anderson, 2010. *A Brief Practical Guide to Eddy Covariance Flux Measurements: Principles and Workflow Examples for Scientific and Industrial Applications*. LI-COR Biosciences, Lincoln, USA, 211 pp.

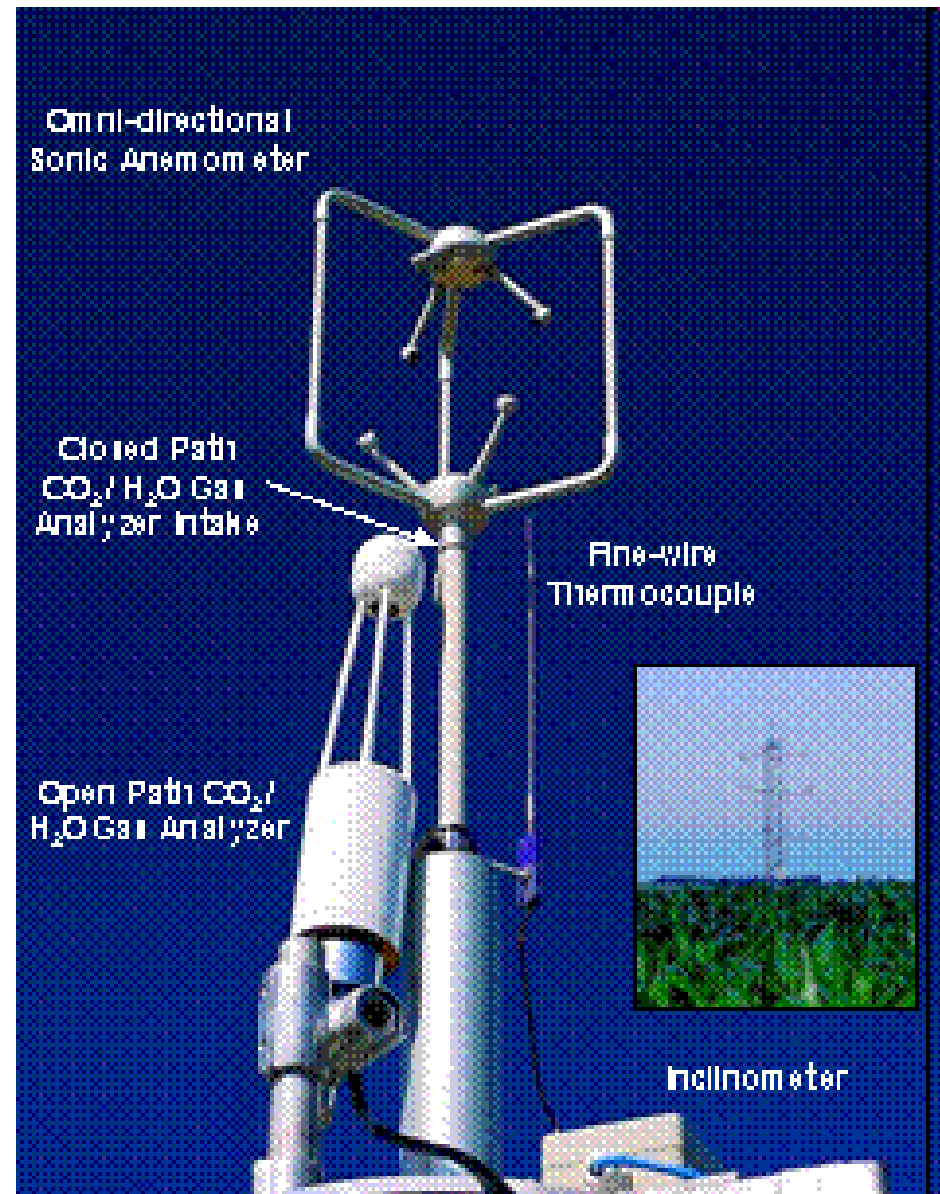


$$\overline{w'\theta'} = \frac{1}{N} \sum_{i=1}^N (w_i - \overline{w})(\theta_i - \overline{\theta})$$

Eddy covariance



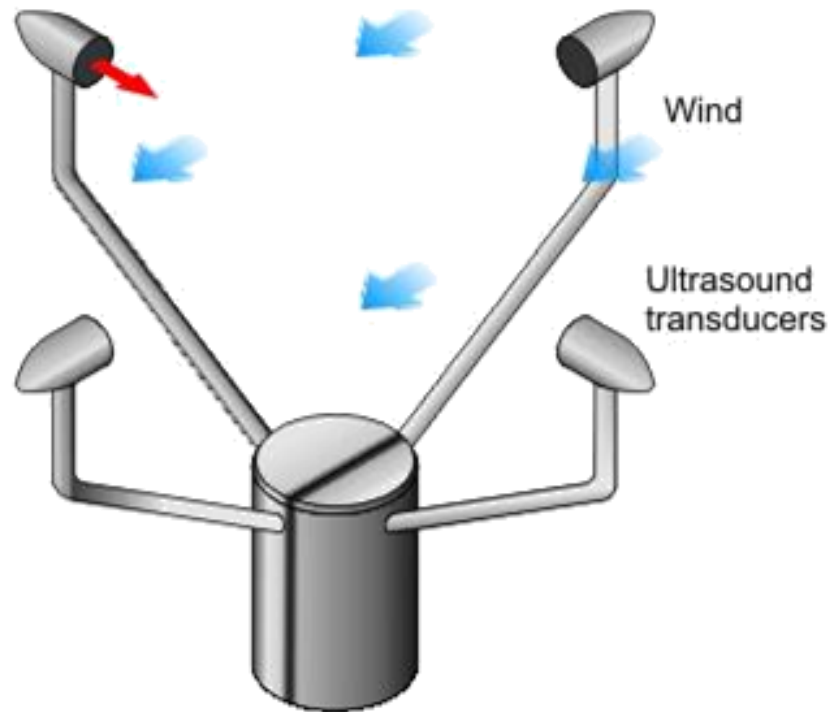
<http://www.campbellsci.com>



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Eddy covariance

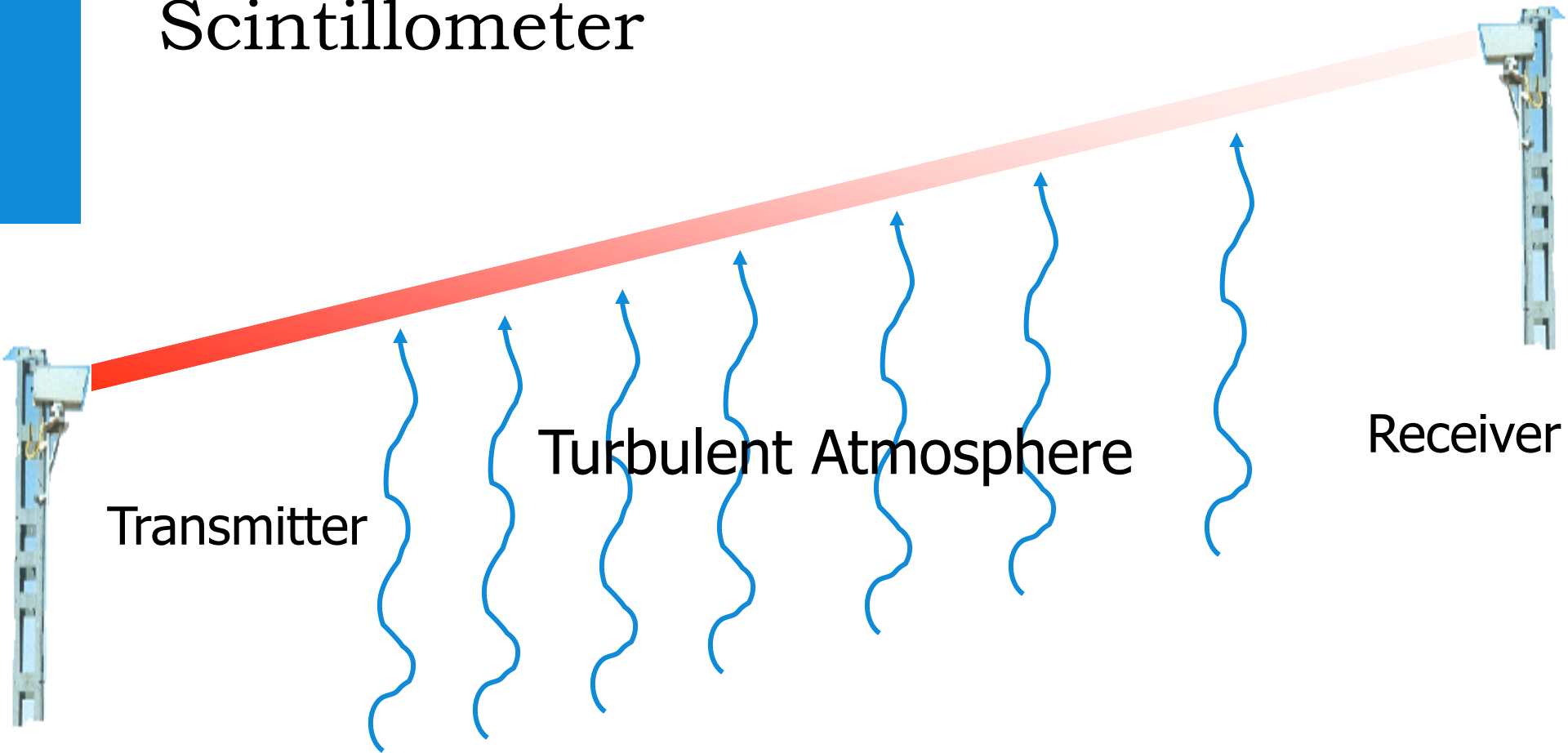
In no wind, or cross wind, the ultrasonic pulse moves at the same speed in each direction



Sonic anemometer

Source Unknown

Scintillometer



Scintillometer



Source Unknown

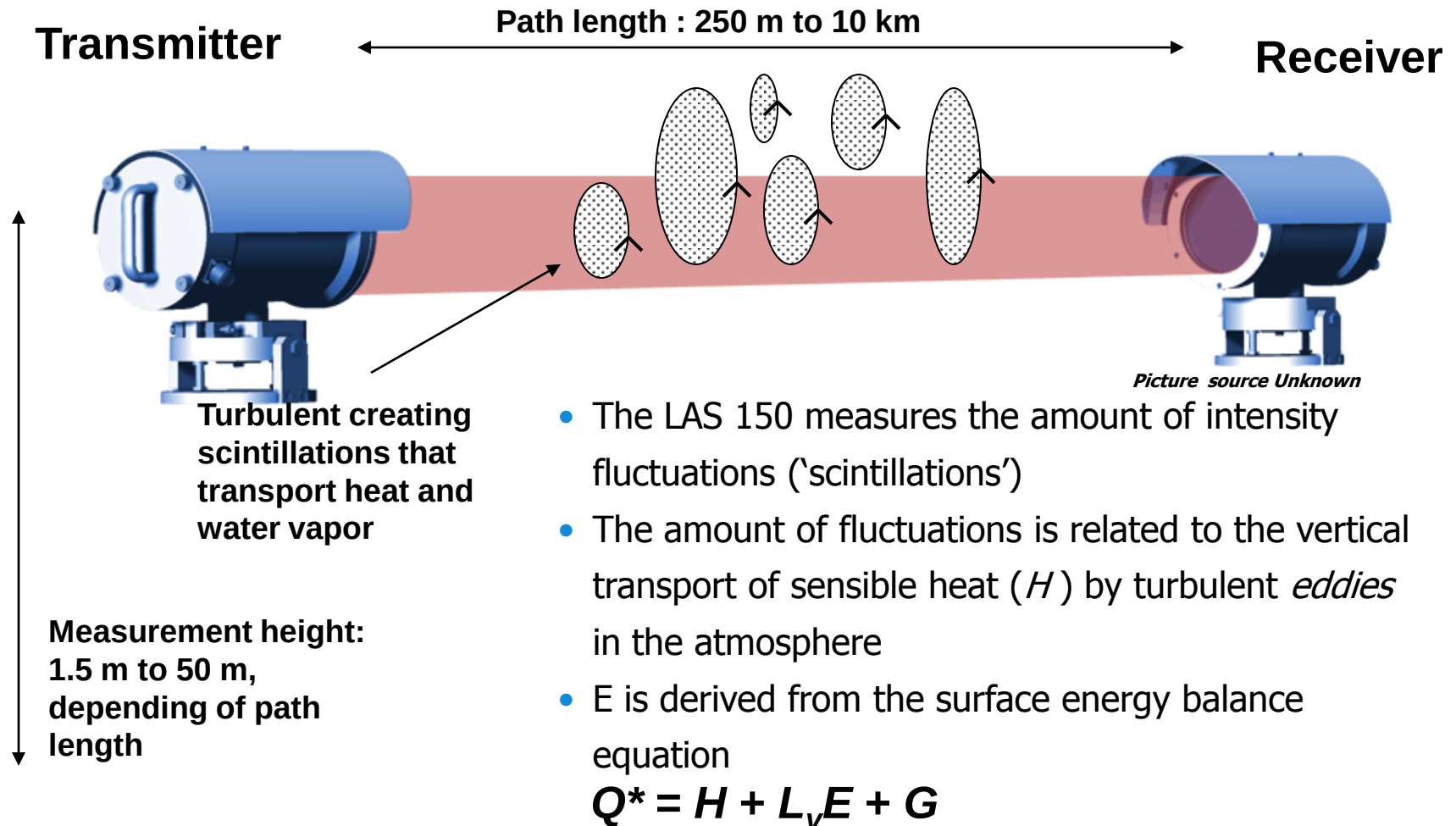
LAS and XLAS transmitter part

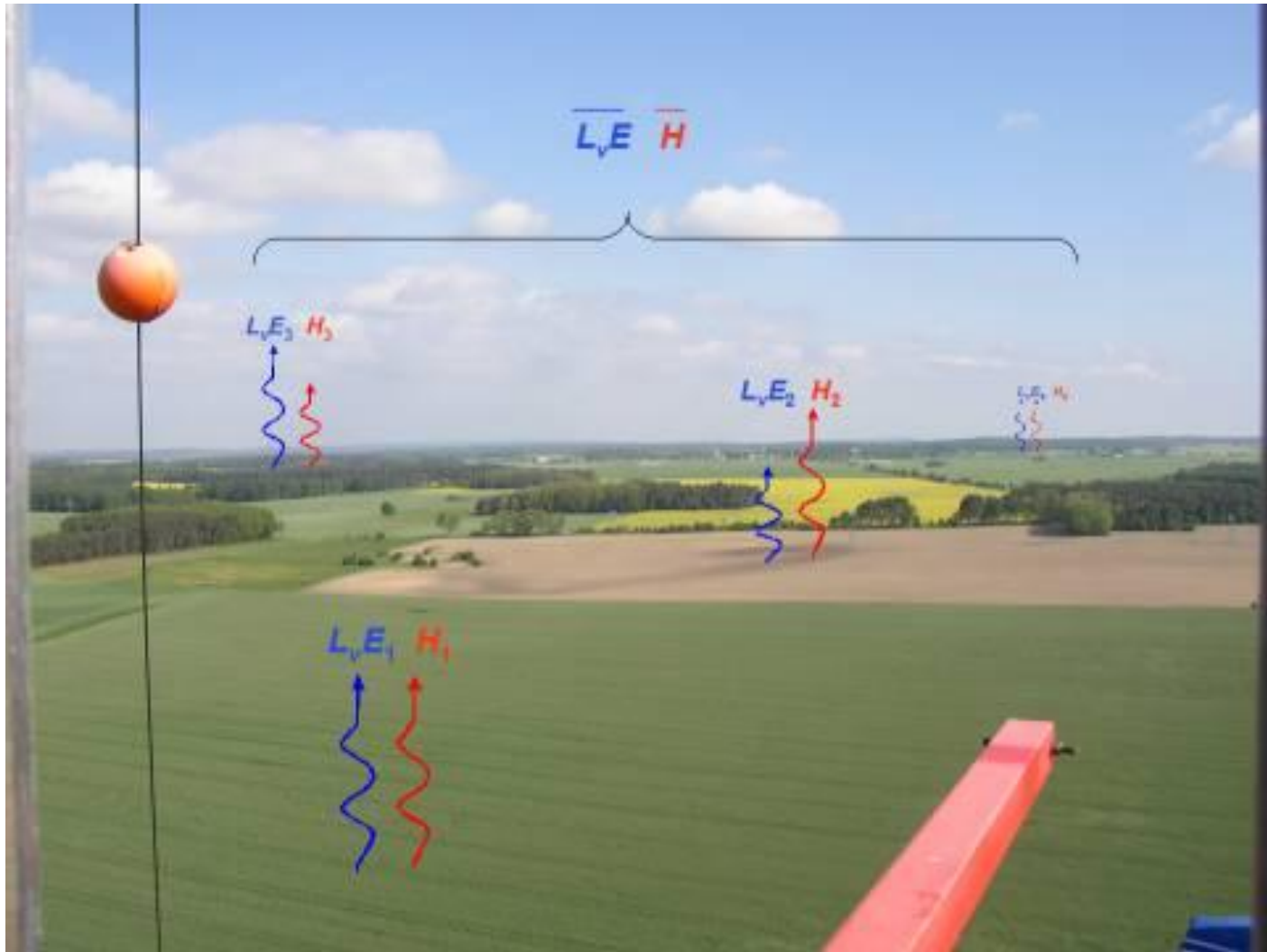


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LAS – Receiver and Transmitter

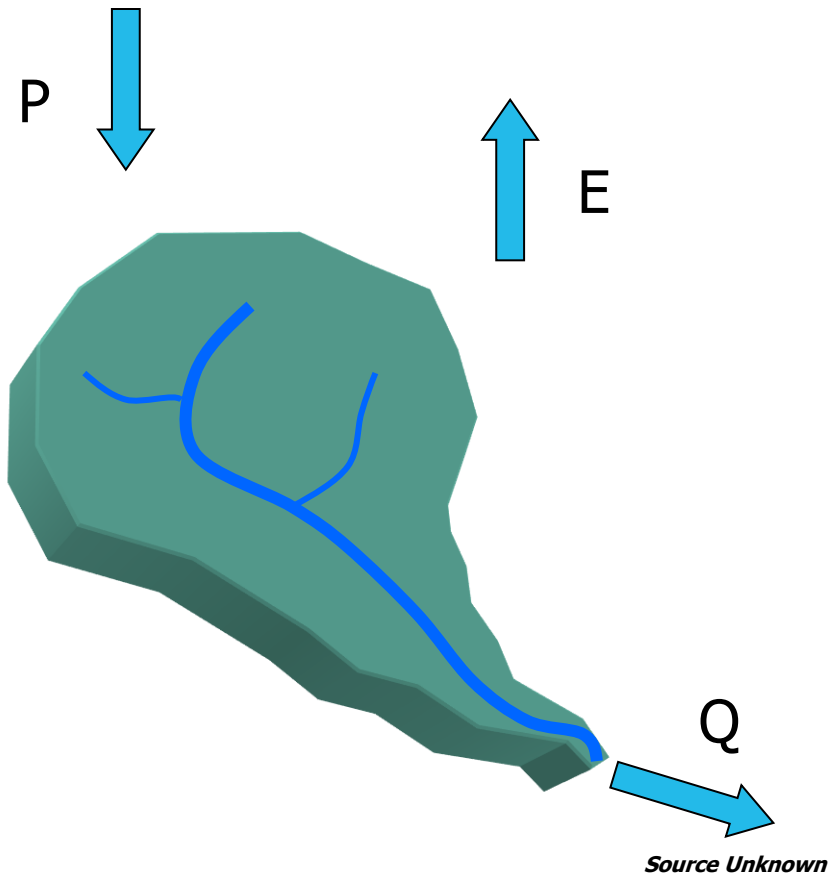
Scintillometer





Source Unknown

Water balance



$$\frac{dS}{dt} = P - E - Q$$

Evaporation measurements summary

	Measurement	E _o	E _t	E _s	E _i
Potential	Class A pan	X			
	Penman (-Monteith)	X			
Actual	Lysimeter		X		
	Sapflow		X		
	Bowen ratio	X			
	Eddy correlation (H & λE)	X			
	Scintillometer (H)	X			
	Energy balance	X			