Climatic, hydrological and karst geological controls on groundwater recharge: the view from an Australian vadose zone cave observatory

Andy Baker, Romane Berthelin, Pauline Treble, Yan Liu, Andreas Hartmann

UNSW SYDNEY

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AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

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Emmy Noether-Programm

DFG Deutsche Forschungsgemeinschaft

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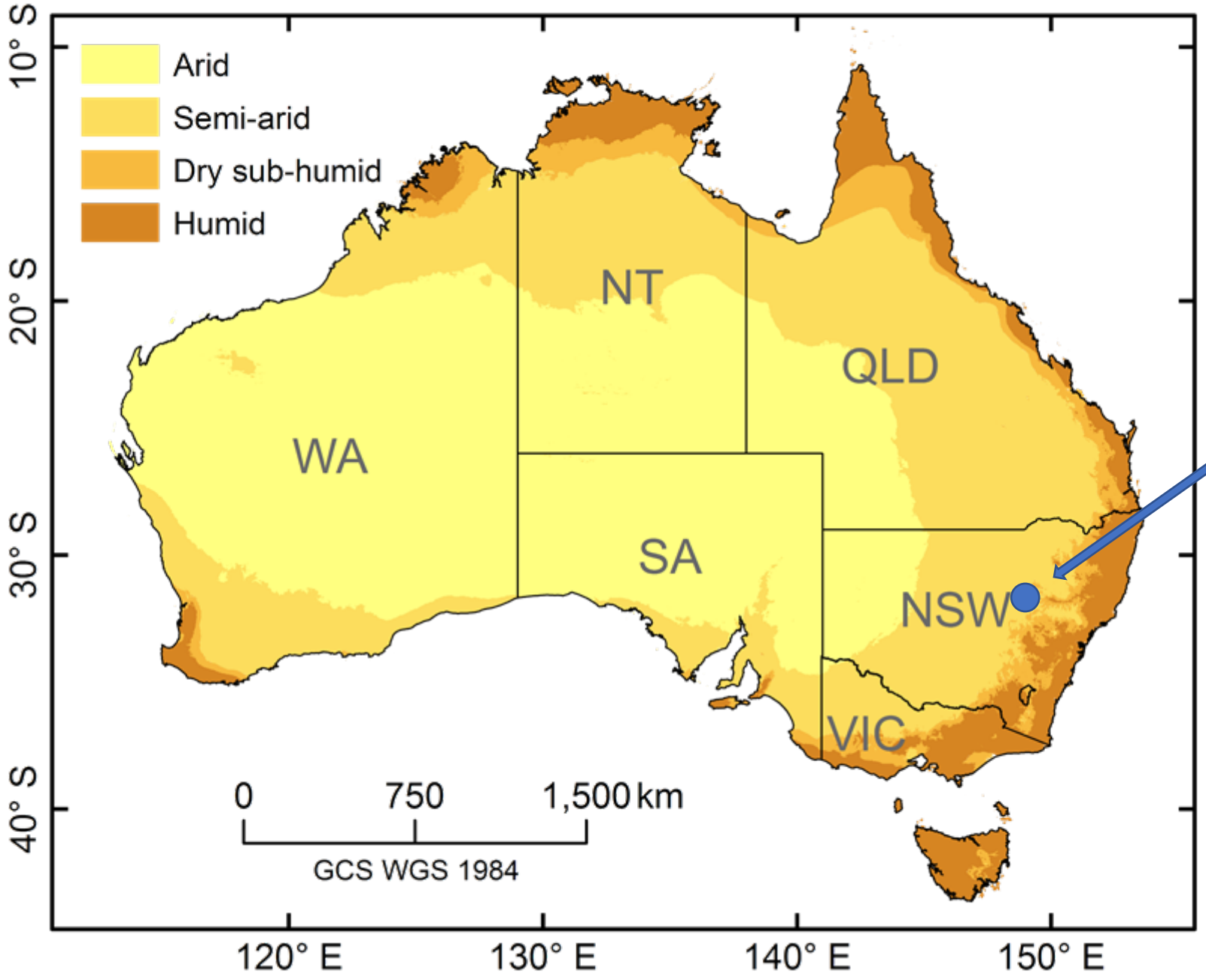
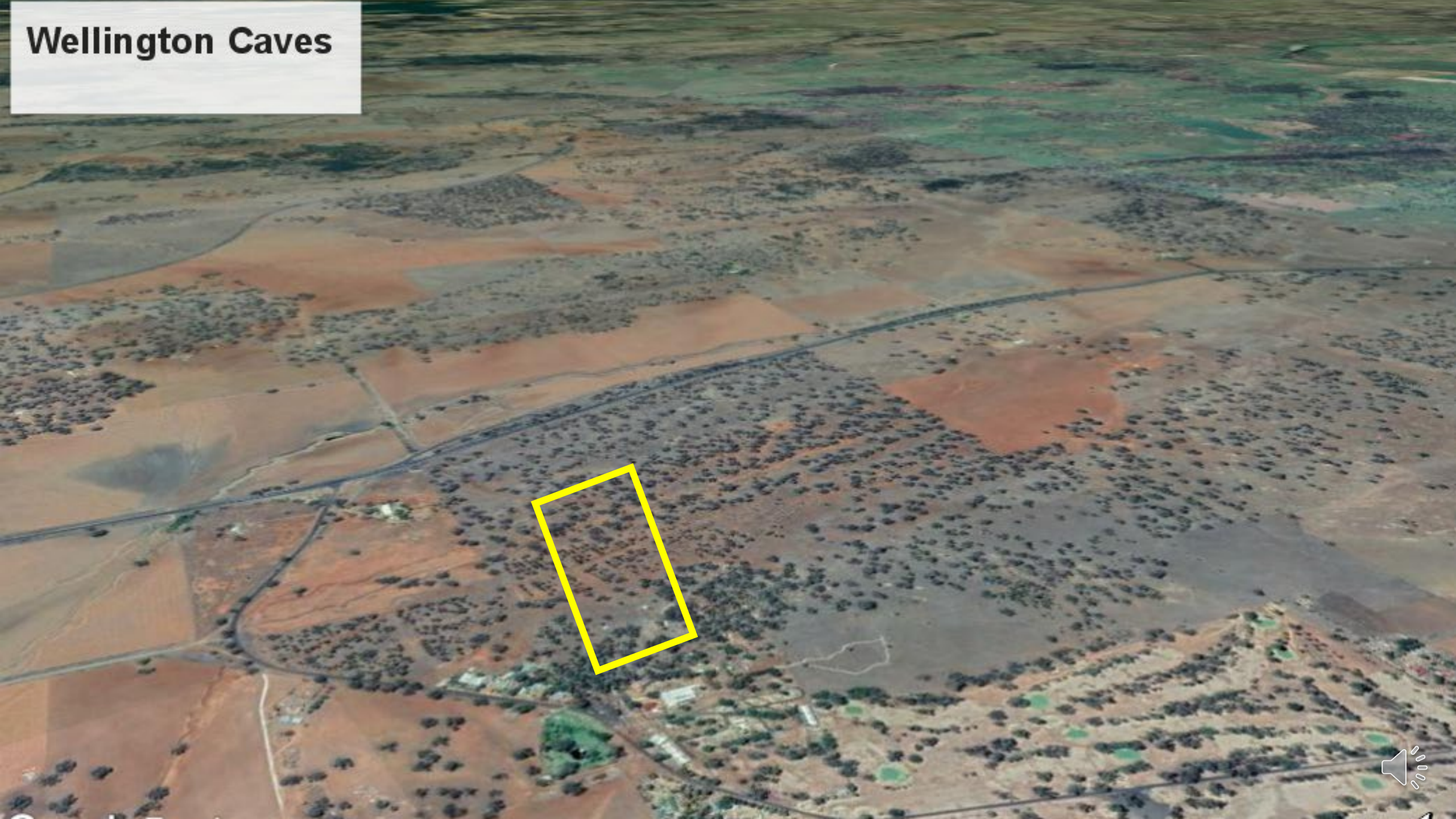
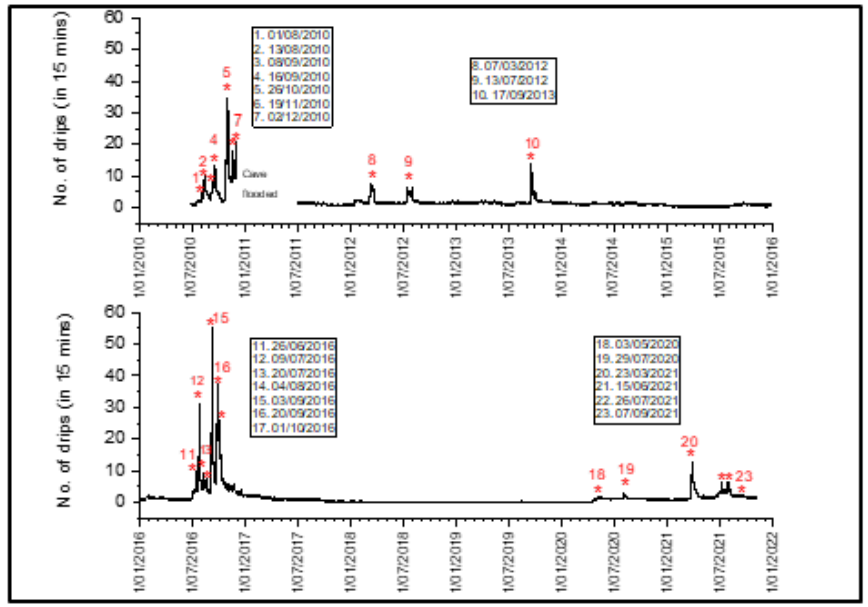
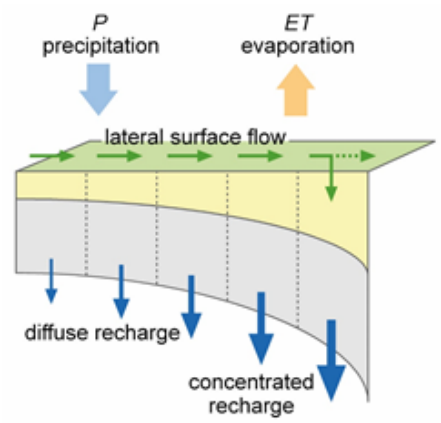


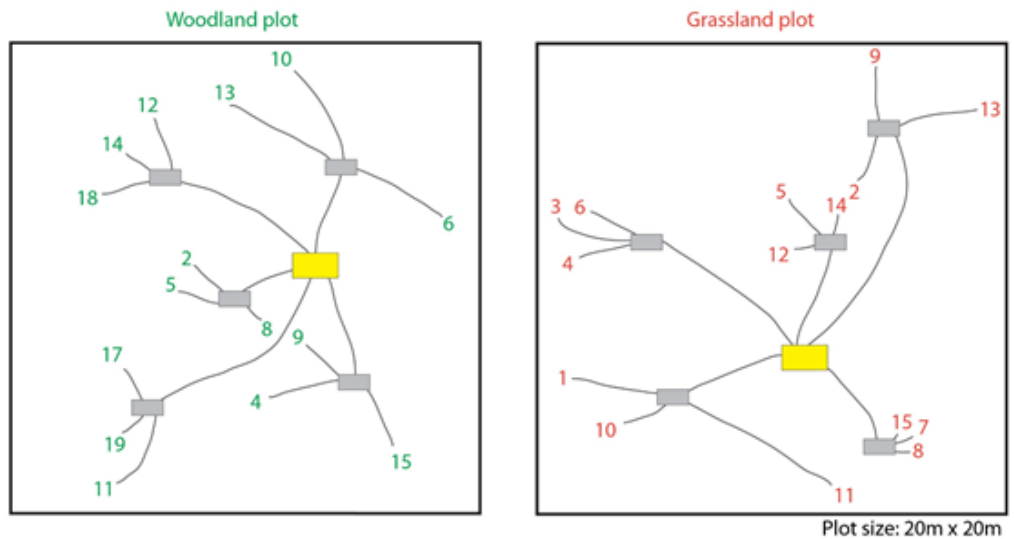
Wellington Caves,
New South Wales,
AUSTRALIA


Wellington Caves


No. of drips (in 15 mins)
1. 01/08/2010
2. 13/08/2010
3. 08/09/2010
4. 16/09/2010
5. 26/10/2010
6. 19/11/2010
7. 02/12/2010
8. 07/03/2012
9. 13/07/2012
10. 17/09/2013
Cave flooded
11. 26/06/2016
12. 09/07/2016
13. 20/07/2016
14. 04/08/2016
15. 03/09/2016
16. 20/09/2016
17. 01/10/2016
18. 03/05/2020
19. 29/07/2020
20. 23/03/2021
21. 15/06/2021
22. 26/07/2021
23. 07/09/2021


Google Earth
200 m
N


P
precipitation
ET
evaporation
lateral surface flow
diffuse recharge
concentrated
recharge


Woodland plot
Grassland plot
Plot size: 20m x 20m
Data logger
Distributor
Connection cable

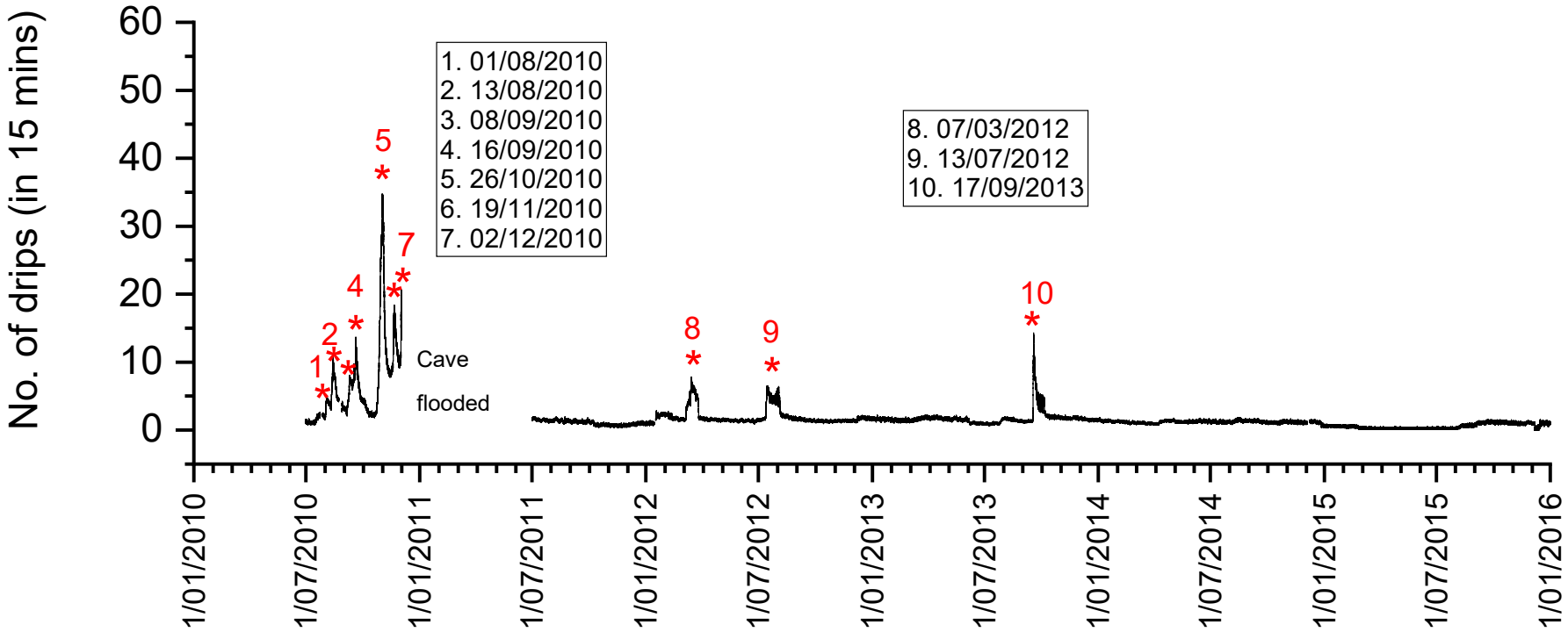
Cathedral Cave

South Passage.

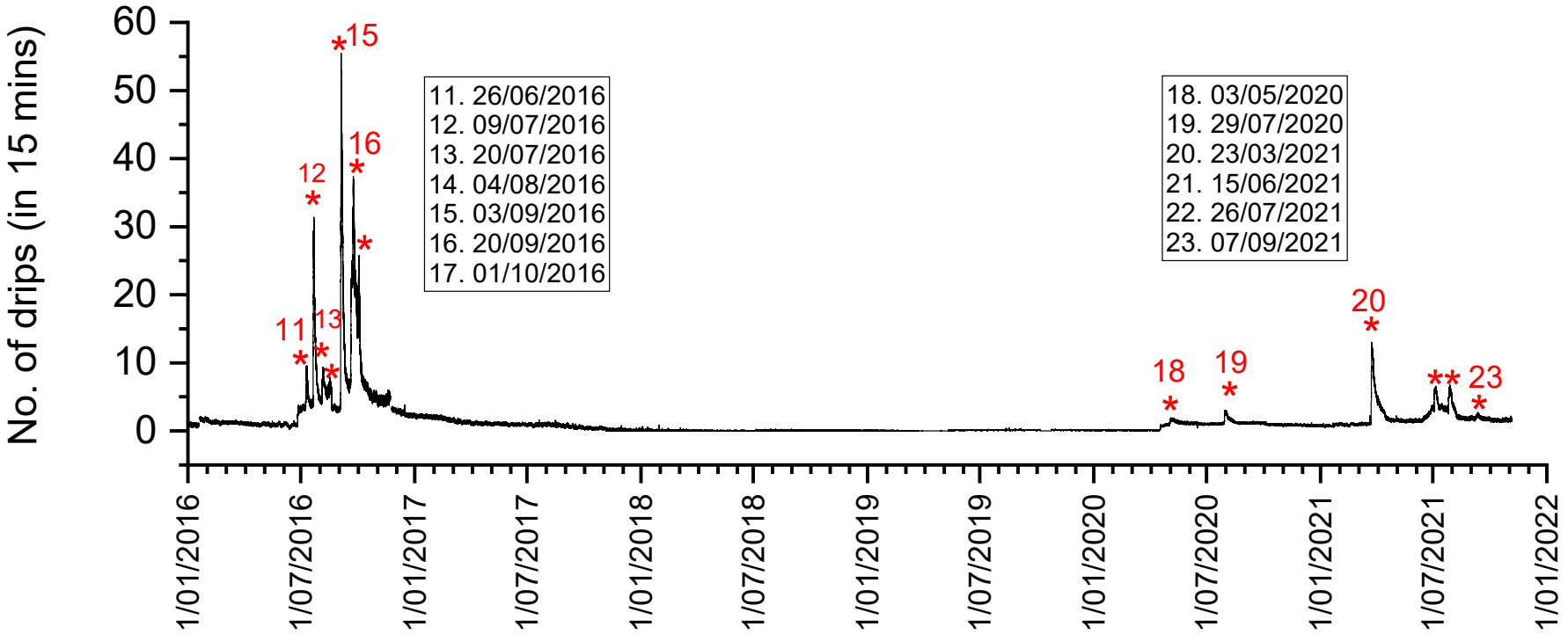
25 m below the surface.

Just above the water table.

Cave recharge (2010-2015)



Cave recharge (2016-2021)

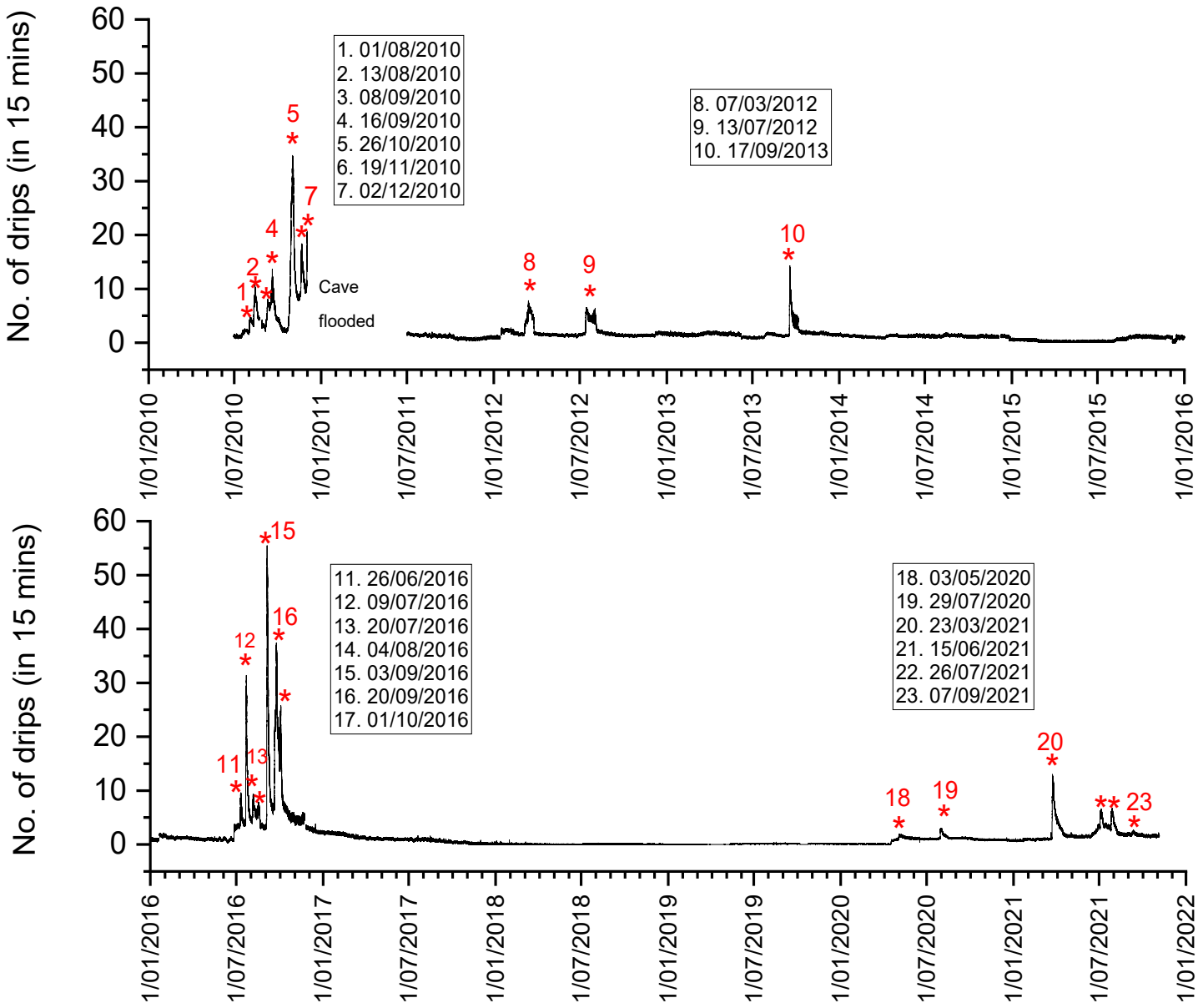


Climatology

23 recharge events in 12 years

Annual precipitation: ~615 mm

Annual potential evapotranspiration: ~1679 mm



How much rainfall is needed for groundwater to be recharged?

("rainfall recharge thresholds")

Median 14-day precipitation: 67.1 mm

Minimum 14-day precipitation: 30.8 mm

Event number	Date of recharge increase	14-day antecedent precipitation (mm)
1	1/08/2010	52.4
2	13/08/2010	58.9
3	8/09/2010	41.2
4	16/09/2010	72.0
5	26/10/2010	75.0
6	19/11/2010	89.6
7	2/12/2010	131.4
8	7/03/2012	120.0
9	13/07/2012	53.4
10	17/09/2013	62.2
11	26/06/2016	80.4
12	9/07/2016	46.6
13	20/07/2016	78.2
14	4/08/2016	41.4
15	3/09/2016	94.4
16	20/09/2016	61.1
17	1/10/2016	83.2
18	3/5/2020	62.2
19	29/7/2020	43.6
20	23/03/2021	120.4
21	15/06/2021	85.2
22	26/07/2021	31.8
23	07/09/2021	30.8
MEDIAN		67.1
MINIMUM		30.8

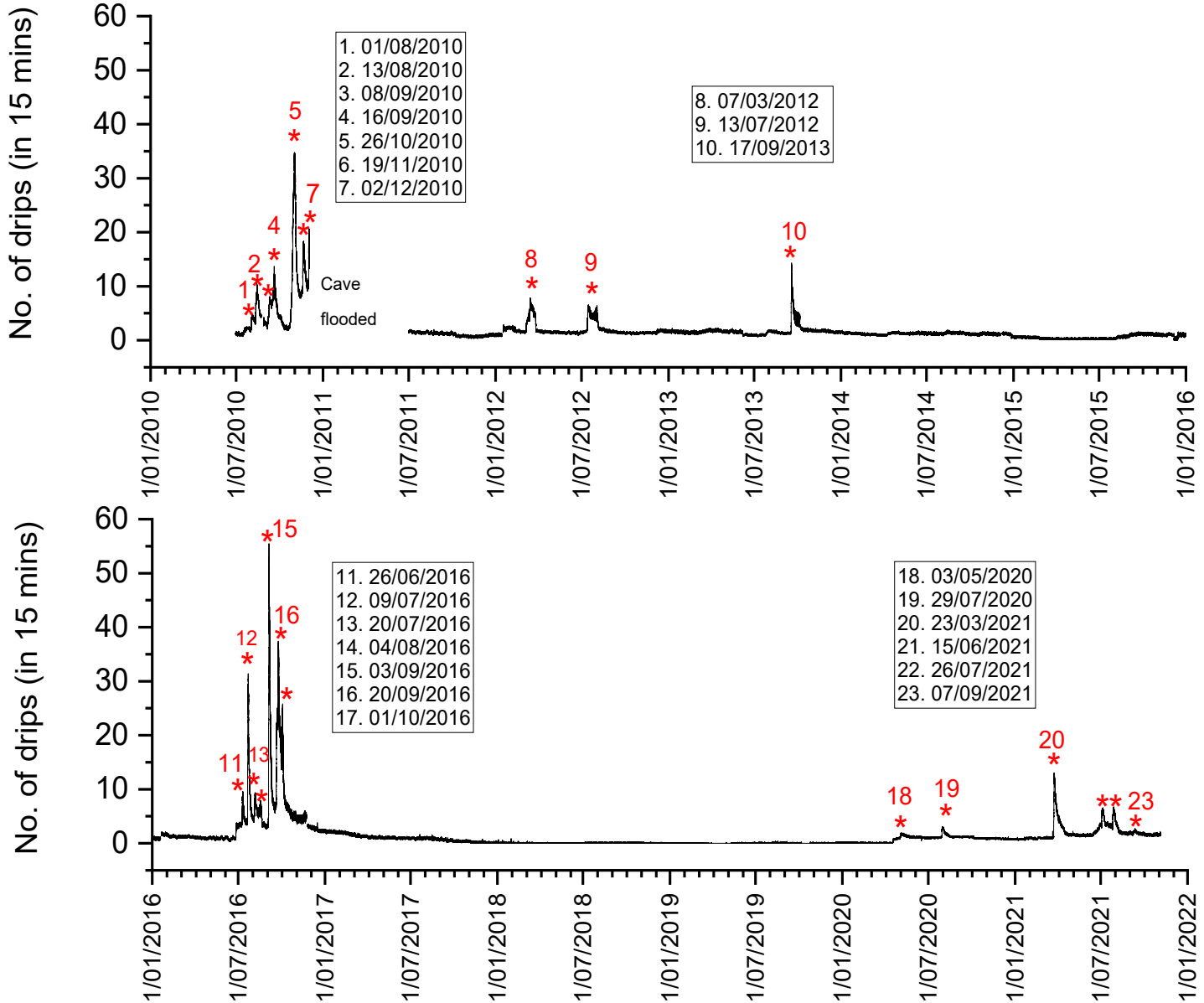
In which month is groundwater recharge most likely? How much rain is needed?

Recharge most likely in the Austral winter (July-September), and rainfall recharge thresholds are lower.

	Minimum 14-day antecedent precipitation (mm)
January	> ~112 (No recharge events)
February	> ~115 (No recharge events)
March	120.0 (2 events)
April	> ~130 (No recharge events)
May	62.2
June	80.4 (2 events)
July	31.8 (5 events)
August	41.4 (3 events)
September	30.8 (6 events)
October	75.0 (2 events)
November	89.6
December	131.4

Climatology

Seven events between August & December 2010 during a La Niña (enhanced spring rainfall is typical in eastern Australia)

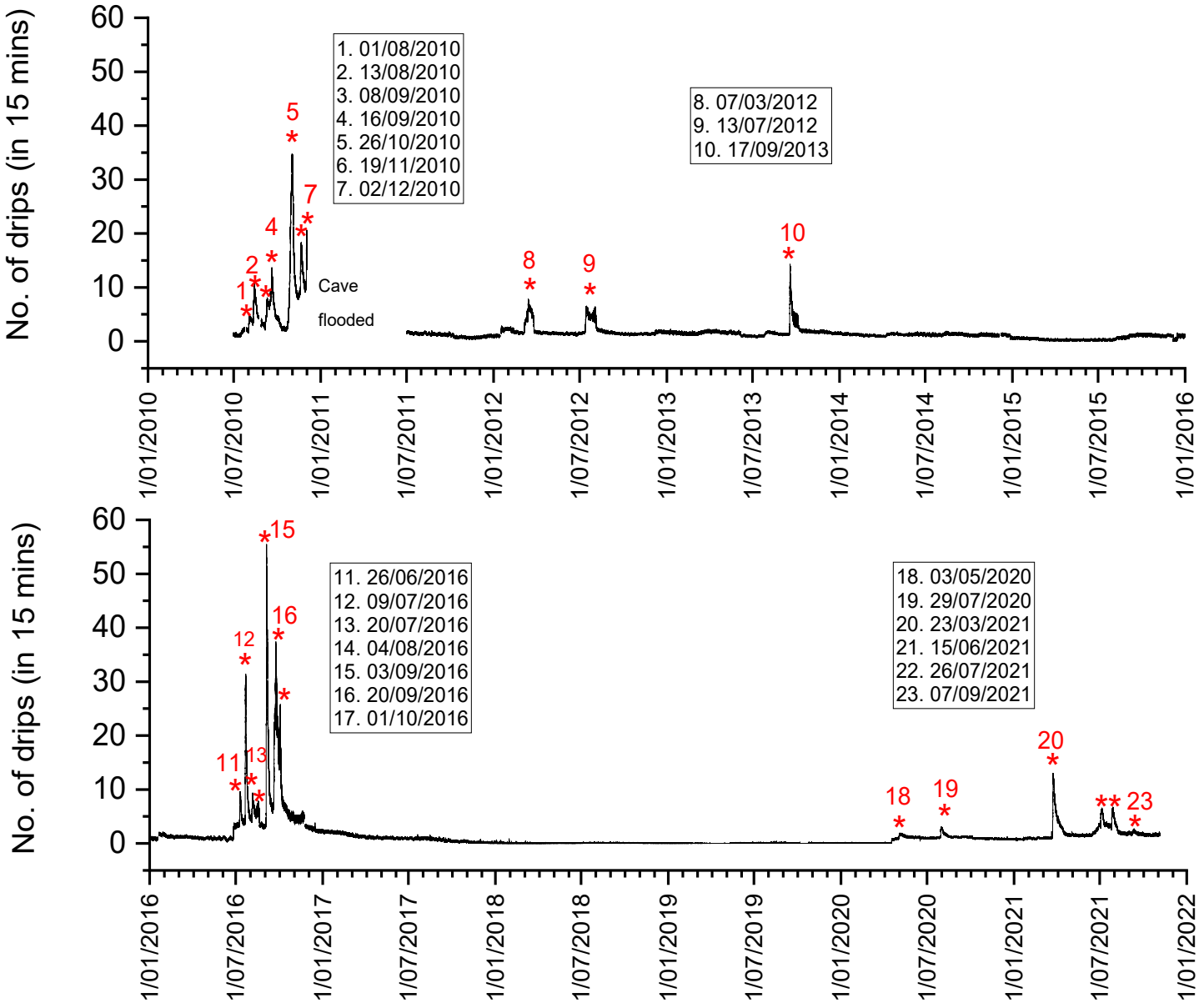


Climatology

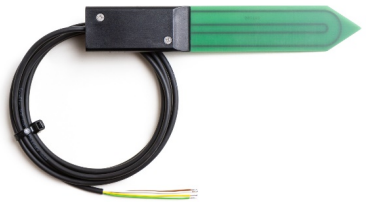
Seven events between June & October 2016

Three events between June and September 2021

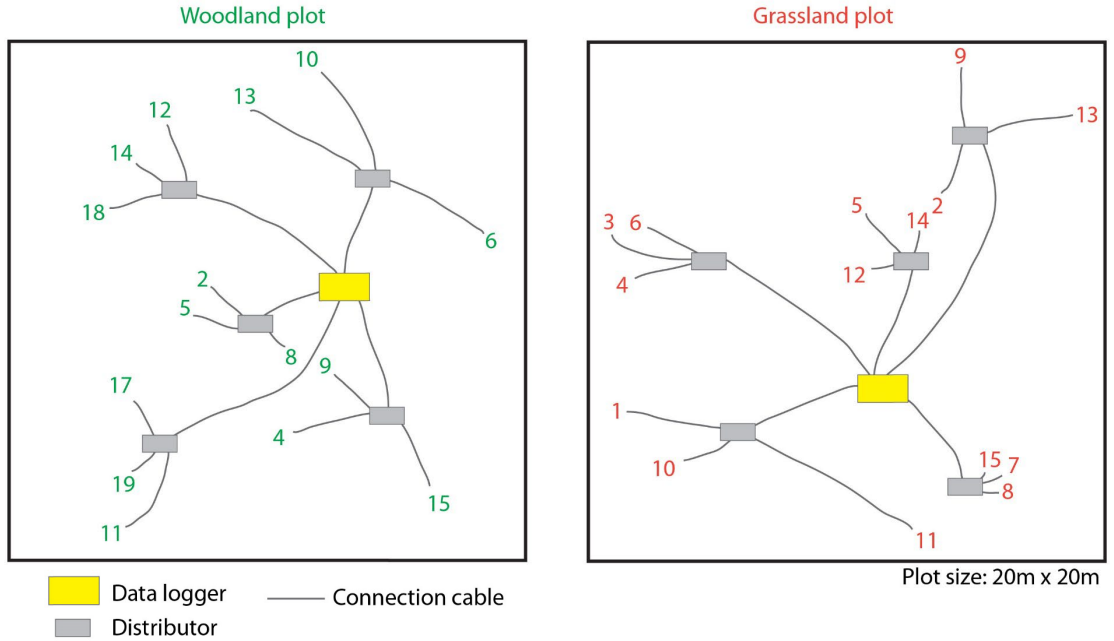
Both associated with a negative Indian Ocean Dipole (which is associated with wet winters and springs in southern Australia).



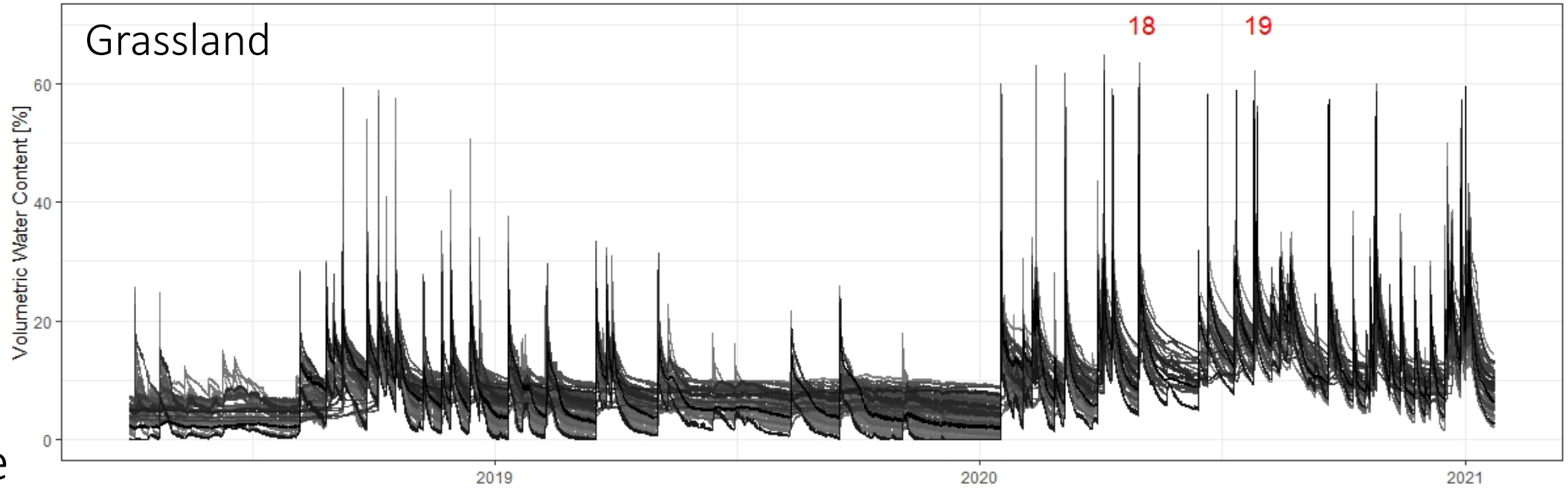
Soil moisture monitoring network (2018-2021)

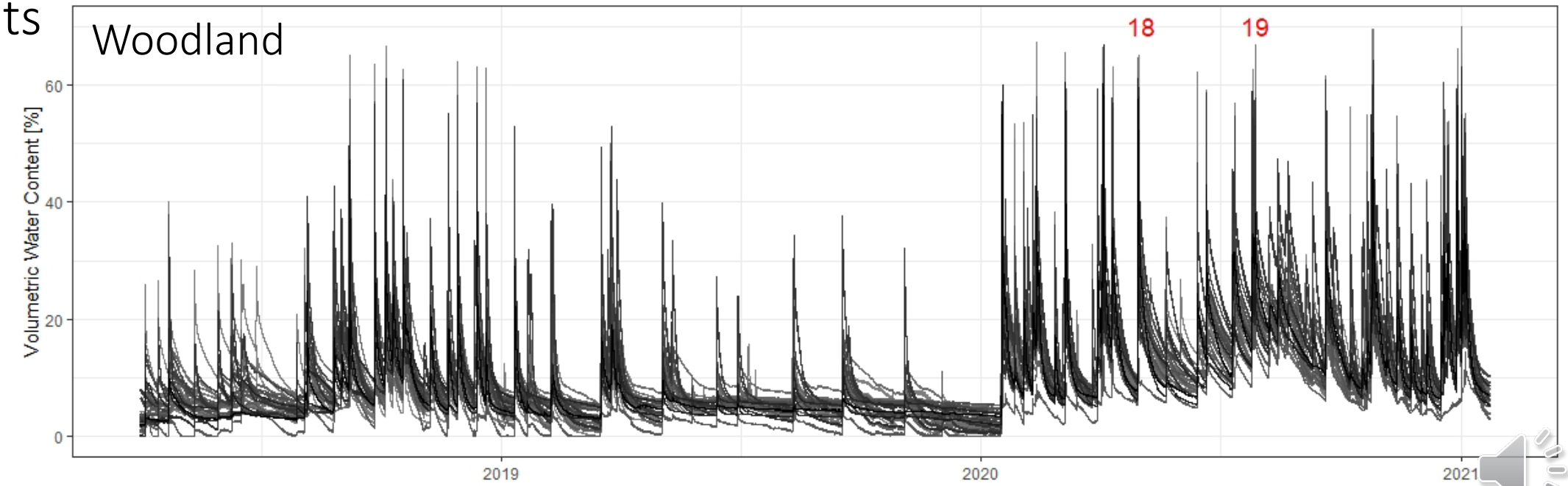


- 30 profiles
- 3 depths: 5, 10 cm, and at the limit with the rock
- 15 min temporal resolution

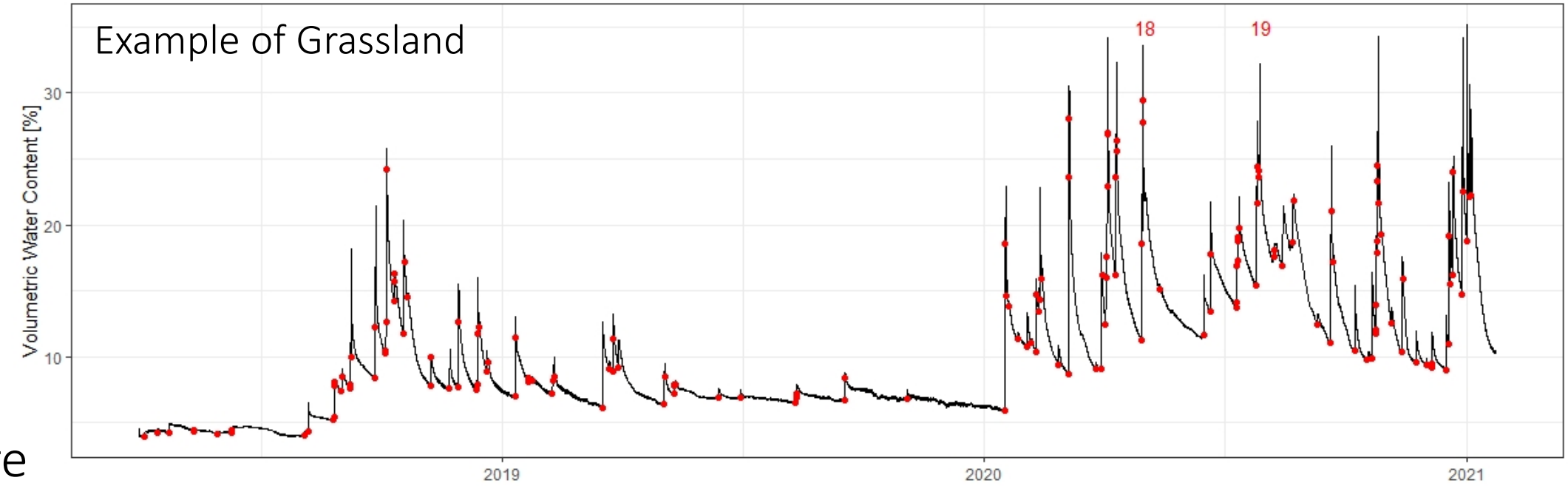


Soil moisture measurements





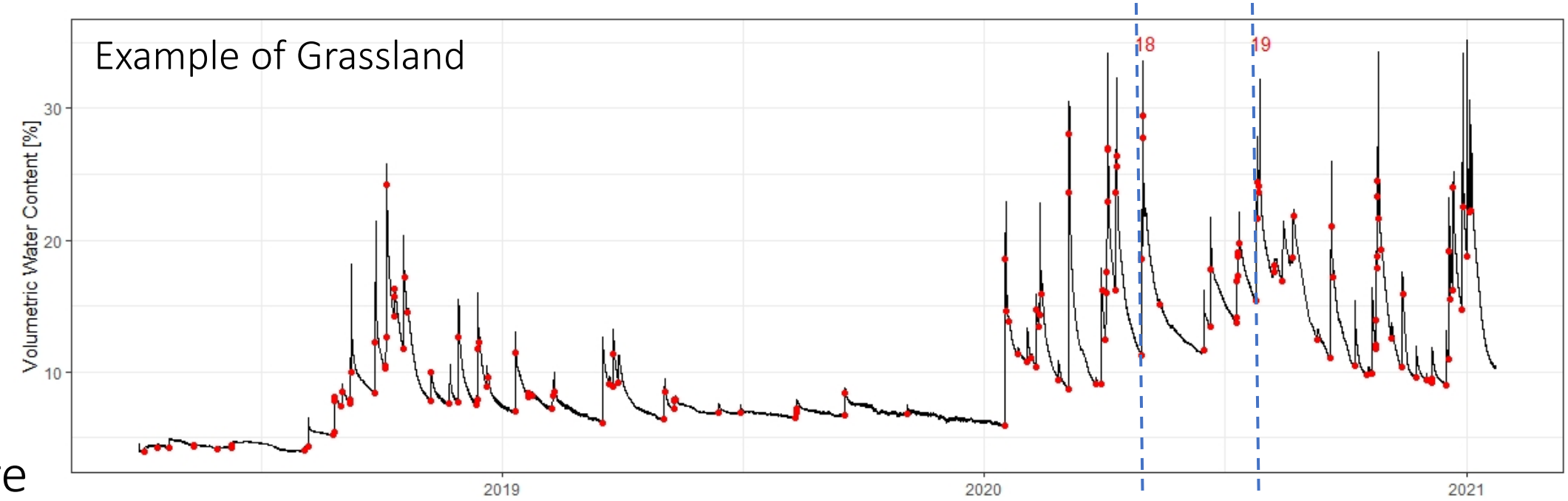
Soil moisture events



- Automatic extraction of soil moisture events (relative increase of 1%)
- Applied to the averaged time series of soil moisture measurements conducted with the deepest probes
- Extraction of different metrics: antecedent, average, peak, and amplitude response of soil moisture during each event

  - 160 events extracted in Grassland
  - 208 events extracted in Woodland

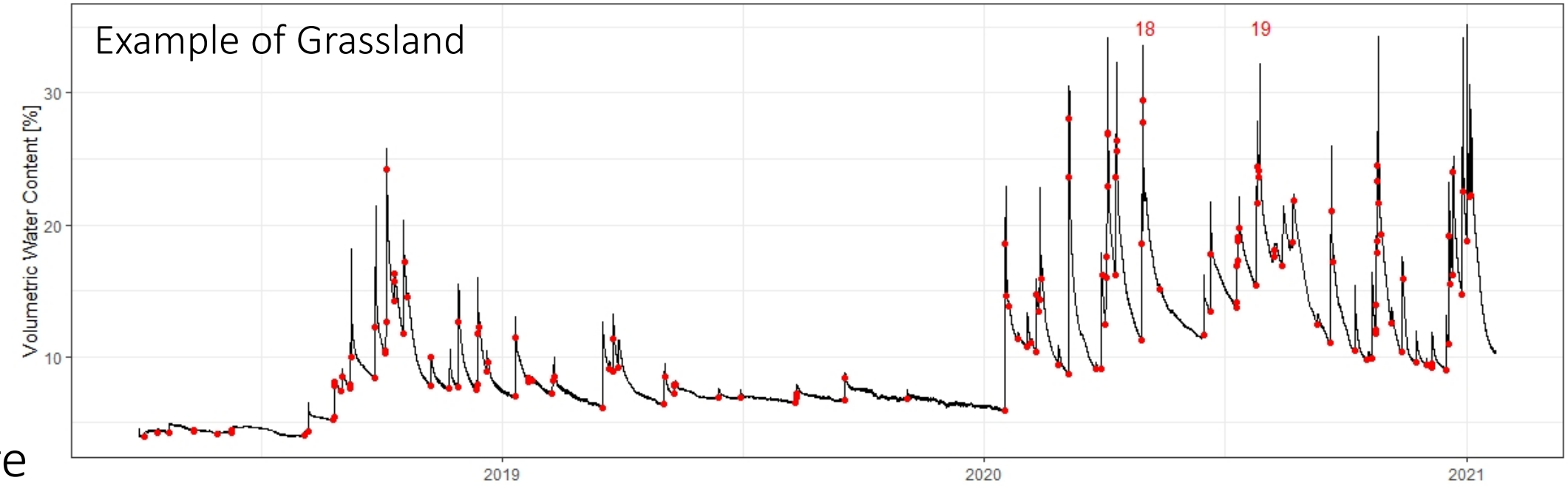
Soil moisture events

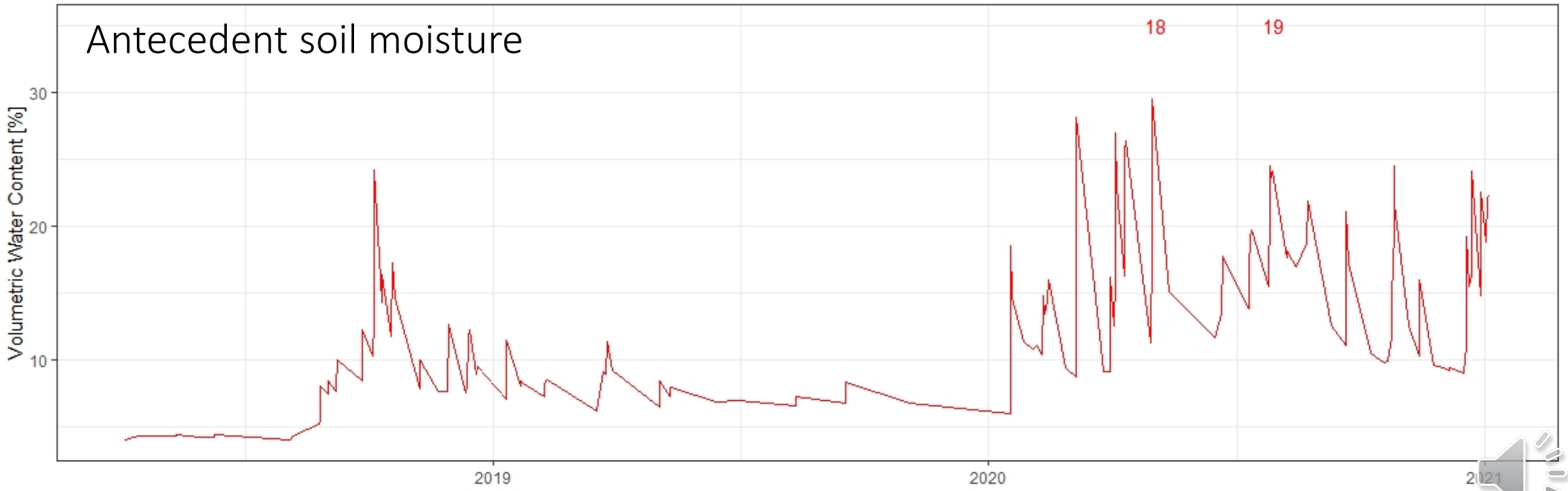


Soil moisture event that is happening before recharge

	Grassland			Woodland		
Volumetric water content	All SM events	Recharge event 18	Recharge event 19	All SM events	Recharge event 18	Recharge event 19
Averaged [%]	14	24	25	14	28	28
Peak [%]	16	34	32	19	42	36
Amplitude [%]	3	22	17	5	33	20

Soil moisture events





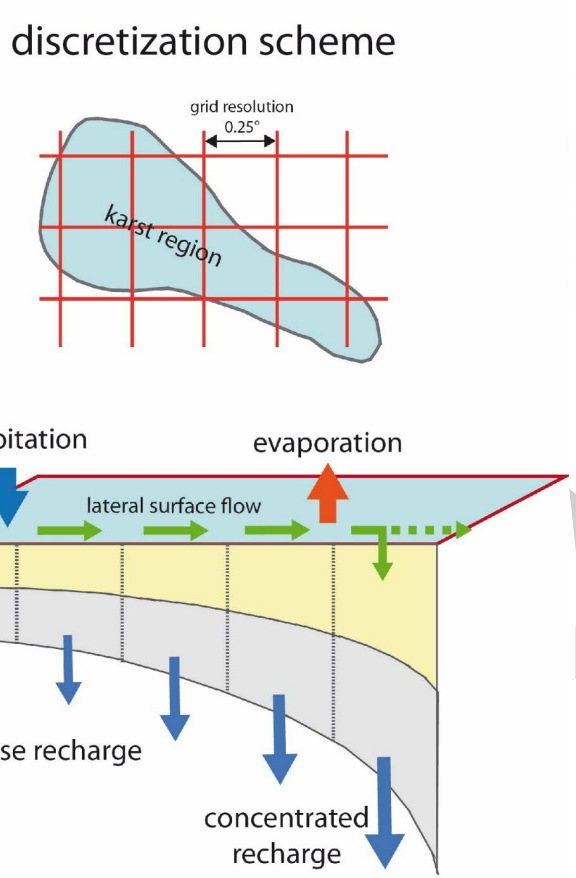
Karst recharge model

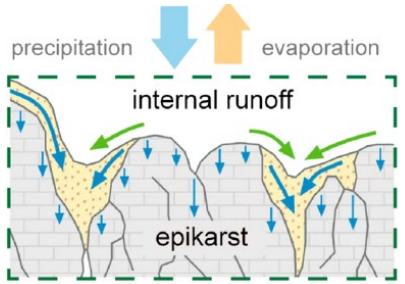
Model:

- Based on conceptual understanding
- Grid over all karst regions across the globe
- Evaluation with observed recharge and observed soil moisture

Observed soil moisture data:

- Normalization of the soil moisture measurements to approximate the soil saturation
- Average of the soil saturation for each depth
- Monthly average of the time series



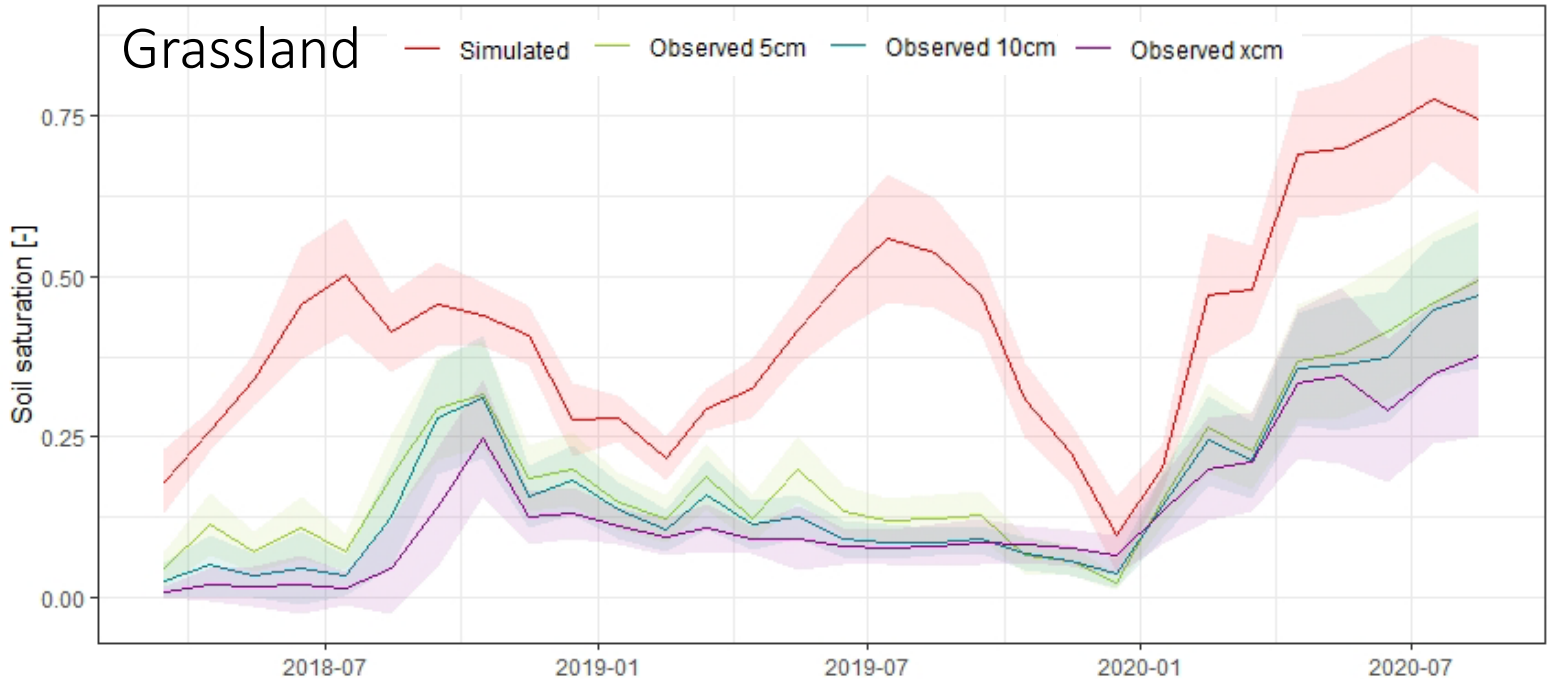


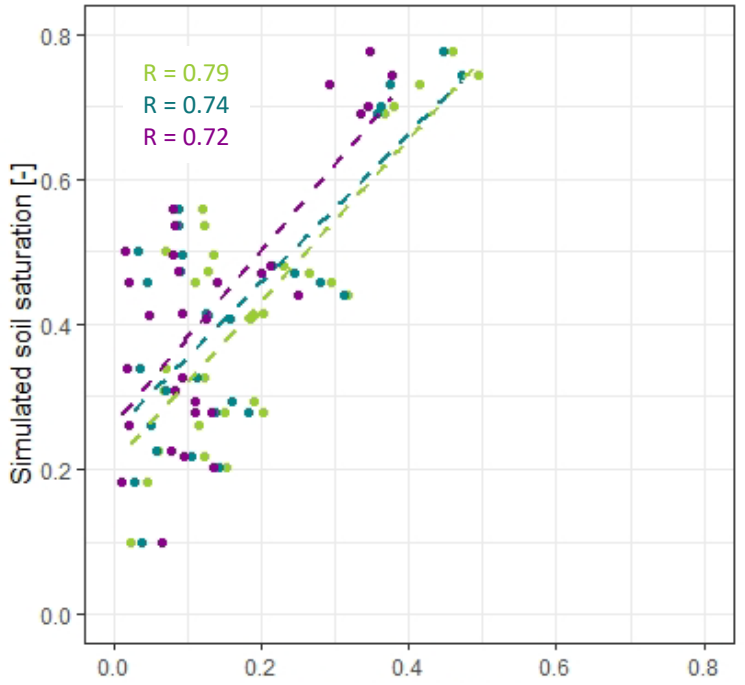
Output:

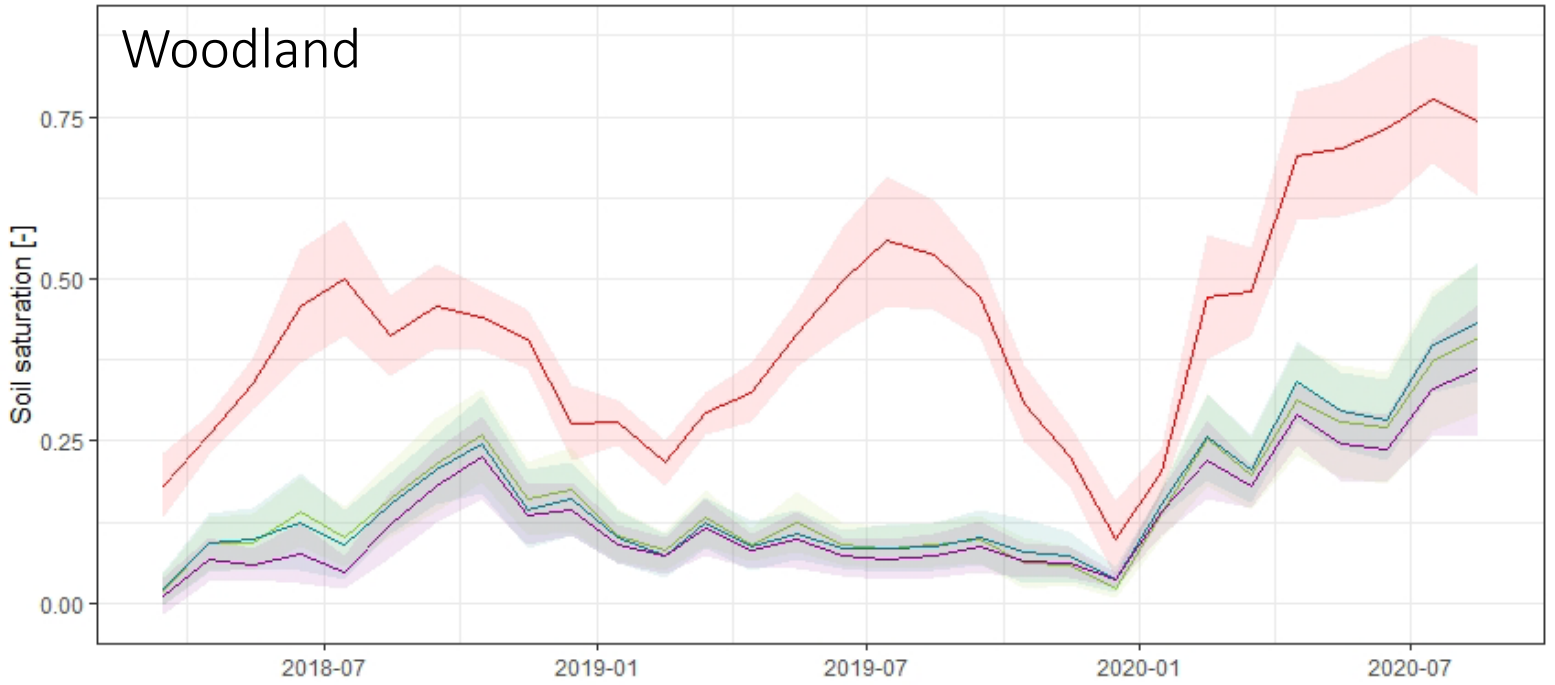
Recharge [mm/month]

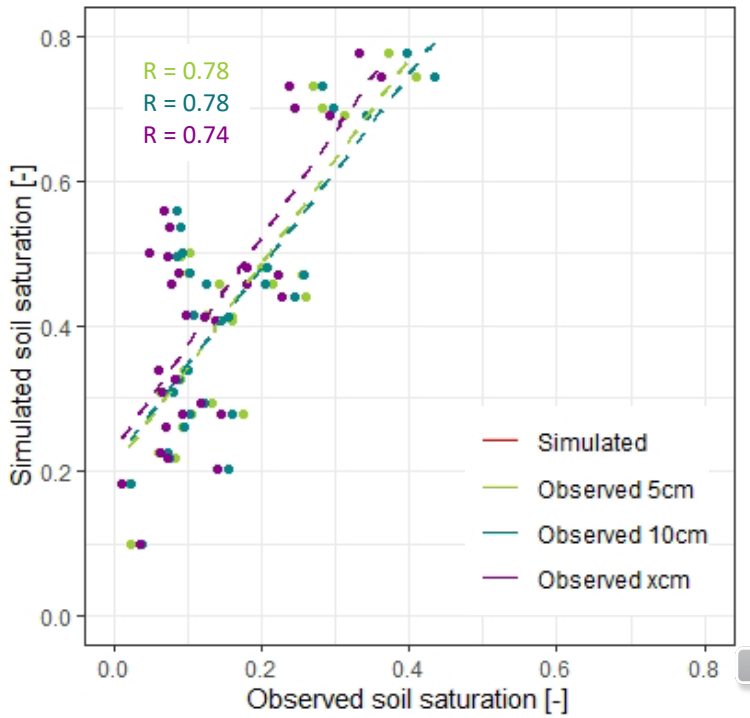
Soil Saturation [-/month]

(Hartmann et al., 2014, Geoscientific Model Development)

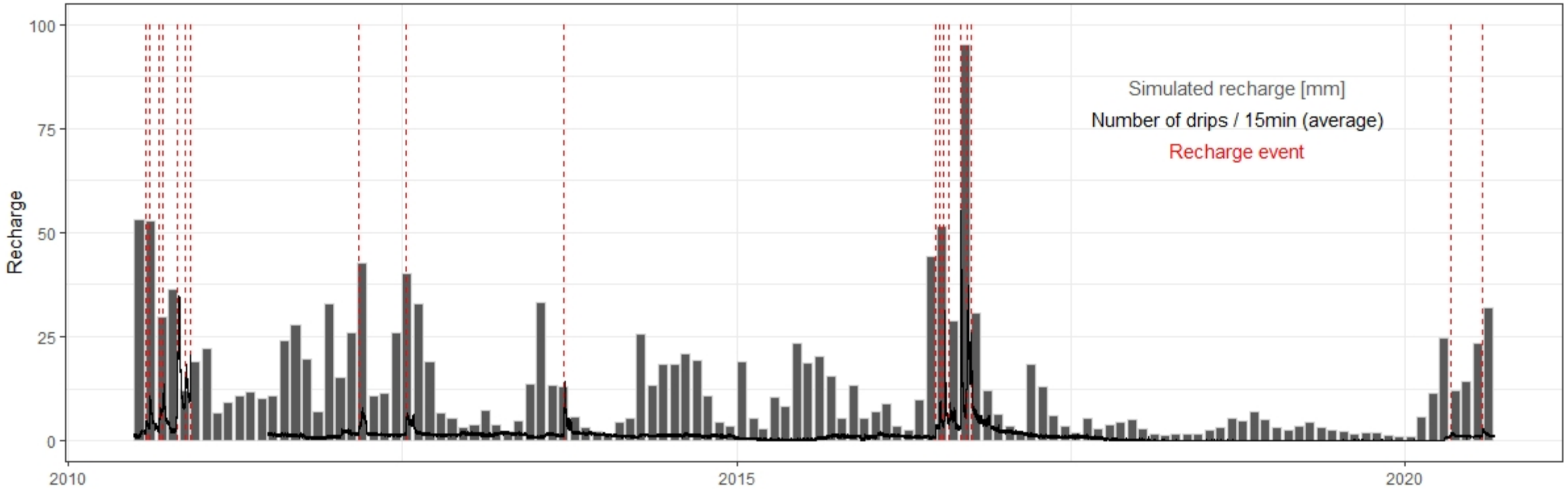

Grassland
Simulated
Observed 5cm
Observed 10cm
Observed xcm
Soil saturation [-]
0.00
0.25
0.50
0.75
2018-07
2019-01
2019-07
2020-01
2020-07


R = 0.79
R = 0.74
R = 0.72
Simulated soil saturation [-]
0.0
0.2
0.4
0.6
0.8


Woodland
Soil saturation [-]
0.00
0.25
0.50
0.75
2018-07
2019-01
2019-07
2020-01
2020-07


R = 0.78
R = 0.78
R = 0.74
Simulated soil saturation [-]
Observed soil saturation [-]
Simulated
Observed 5cm
Observed 10cm
Observed xcm
0.0
0.2
0.4
0.6
0.8

Simulated Recharge



Conclusions

- The cave observatory allows the direct measurement of the timing of recharge, and the determination of rainfall recharge thresholds at an event scale.

- The soil moisture observations can help in the prediction of recharge, using a threshold of antecedent soil moisture. This needs to be confirmed with additional observations (data collection continues).

- The karst recharge model has a high potential to be used to predict recharge, with some modifications identifed by our integrated approach.