SISAL

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Speleothems from the Middle East: An Example of Water Limited Environments in the SISAL Database

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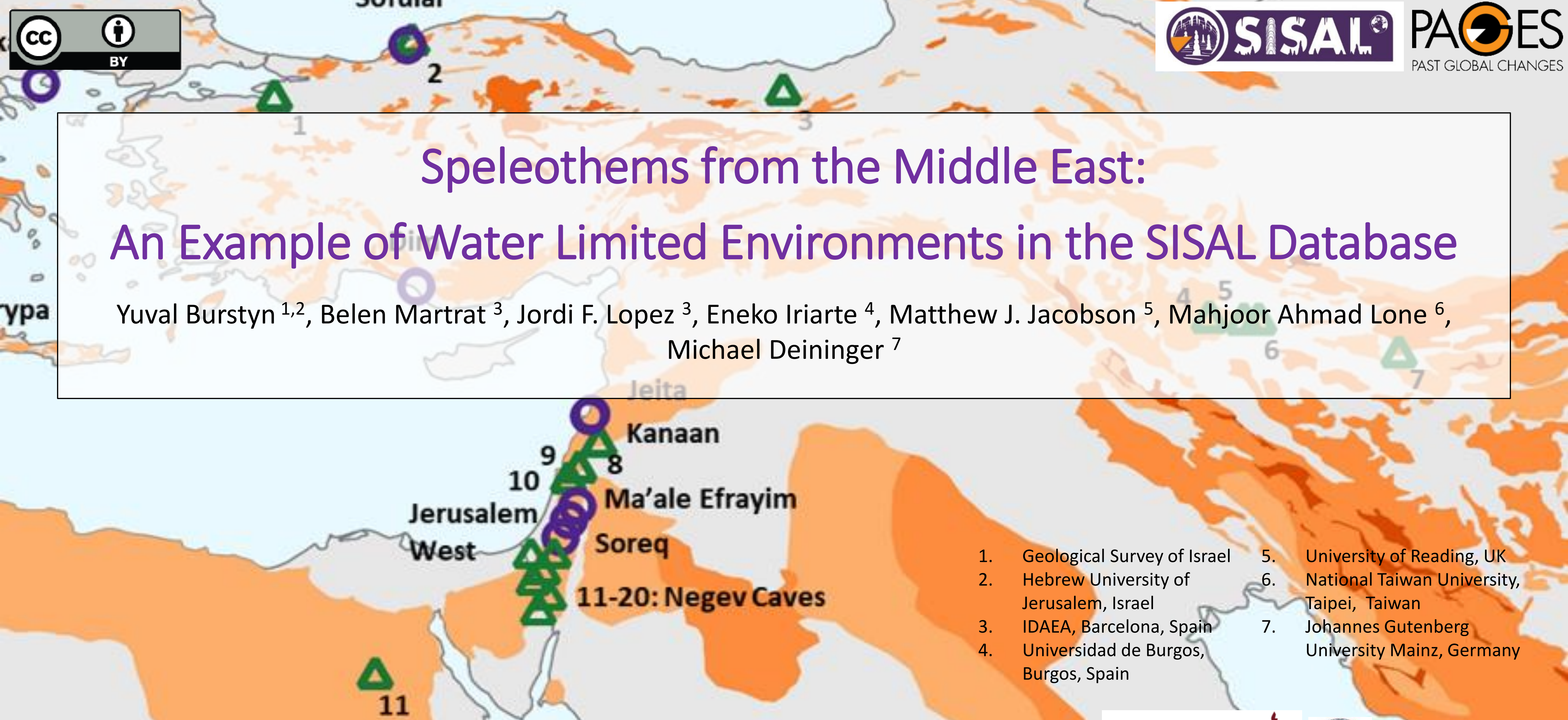

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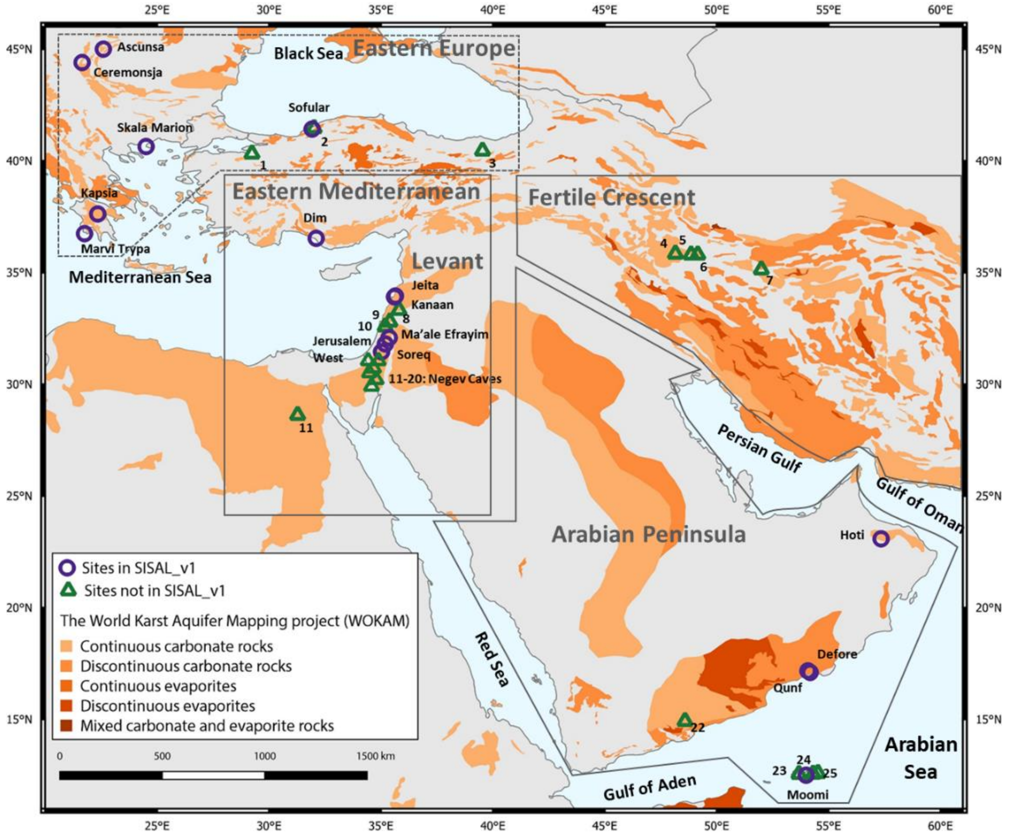
Overview | Regional Climate | Spatial/Temporal Settings | ME Time-Series | ME Composite | SISAL DB

Speleothems from the Middle East

The ME is divided to three sub-regions:

- Levant/Eastern Mediterranean
- Fertile Crescent (FC)
- Arabian Peninsula (AP) – see Scroxton et al.



Importance of the Middle East

- **Climatic Heterogeneity:** The transition between temperate Mediterranean climates (Levant) to hyper-arid sub-tropical deserts in the southern part of the AP.
- **Water-limited:** climate projections predict severe drying, making it important to understand the controls of hydro-climate perturbations in the region.
- **Quaternary archeological records:** bottle-neck for early hominin dispersion out of Africa, "Neolithic Revolution", expansion and subsequent collapse of civilizations in the past.

Speleothems from the Middle East

Goals

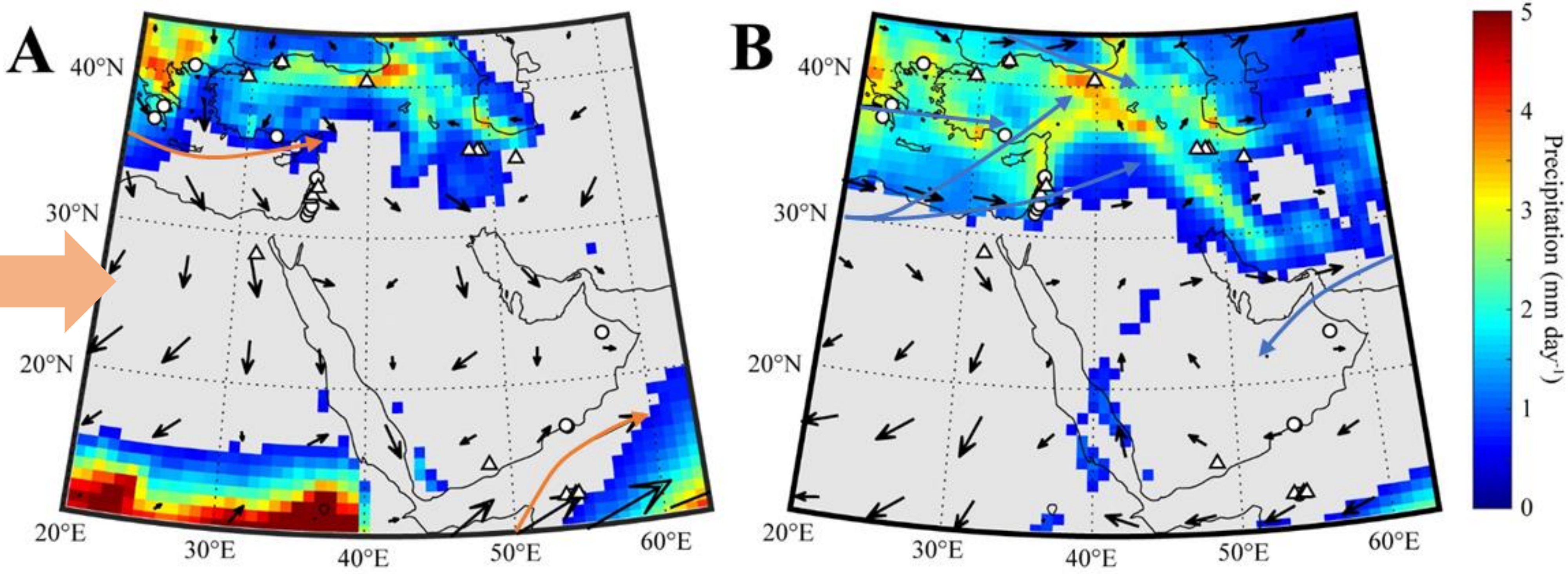
- Highlight the applicability of speleothems from the Middle East (ME) to resolve regional-scale consistencies and inconsistencies between sub-regions (see map).
- Test for spatial coherency between ME speleothems and additional climate recorders (i.e. Arctic ice sheets and Mediterranean surface temperatures).
- the spatial distribution of carbonate bedrock is not continuous, so without regional continuity, improved entity density would improve regional analysis coherency.

Results

- High coverage since LGM, highest in Holocene. Median age resolution is ~7 years, varies from seasonal to centennial.
- Proxy sensitivity for the Levant is highest in Soreq Cave. Deglaciation timing is not spatially coherent. Holocene values in almost all Levant entities converge, and they coherently record centennial to millennial perturbation.
- Regional composite reduces timing and trend uncertainties inherent to the SISAL database but it suffers from gaps in the Holocene entities which could be improved with the upload of new records from FC.

Speleothems from the Middle East

The ME is located within the subtropical high-pressure belt associated with dry climates (i.e. the global desert belt).



JJAS

DJFM

Speleothems from the Middle East

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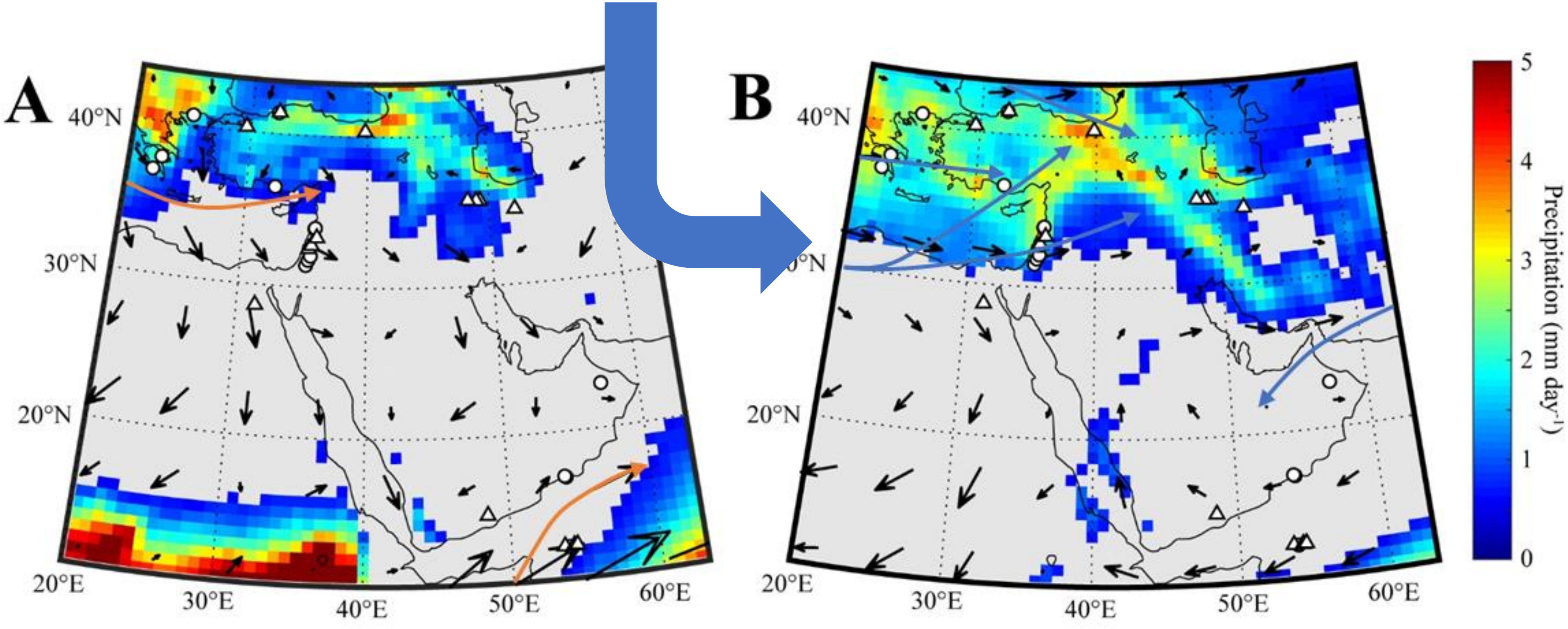
Modern climate of the Levant is **less arid** and much milder than would be expected from its location.
This is due to Mediterranean winter cyclones delivering over >95% of precipitation to the Levant, Fertile Crescent (FC) and on rare instances the Arabian Peninsula (AP)



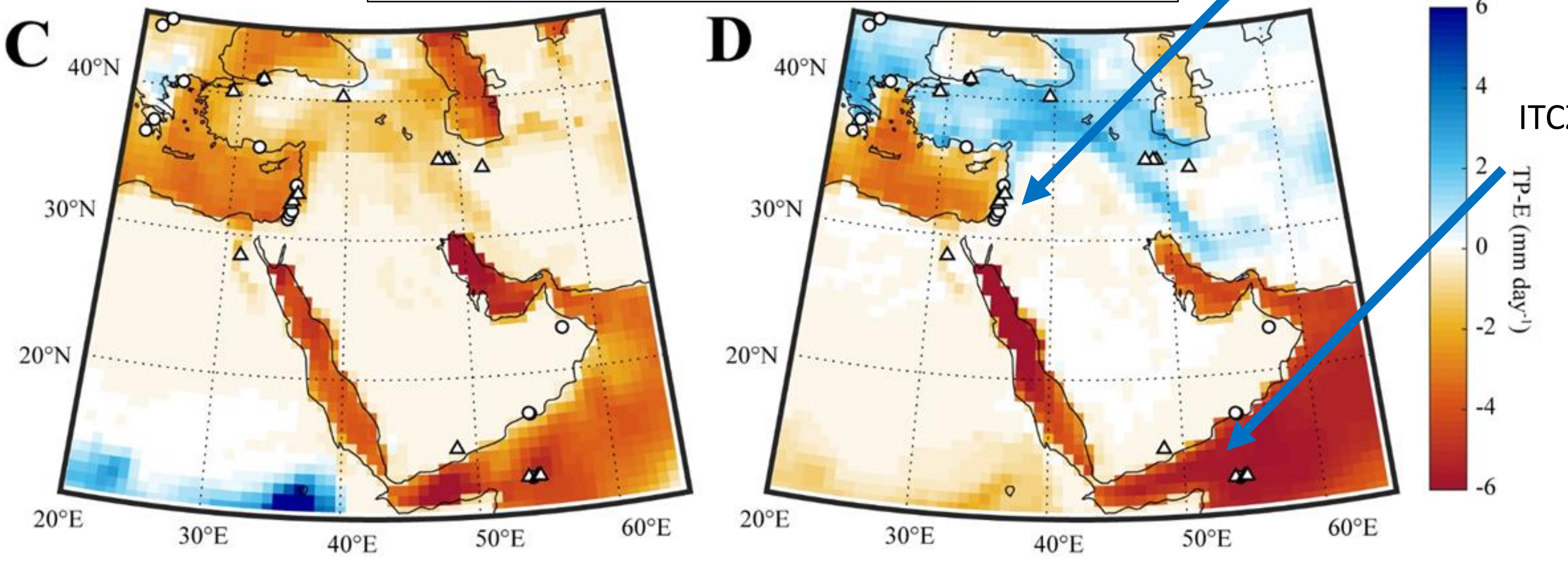
JJAS DJFM

Speleothems from the Middle East

The ME water-balance plays an important role in the development of cave records in the region.

Dry summers with negative winter balance throughout the ME

Effective infiltration = Rainfall - evaporation



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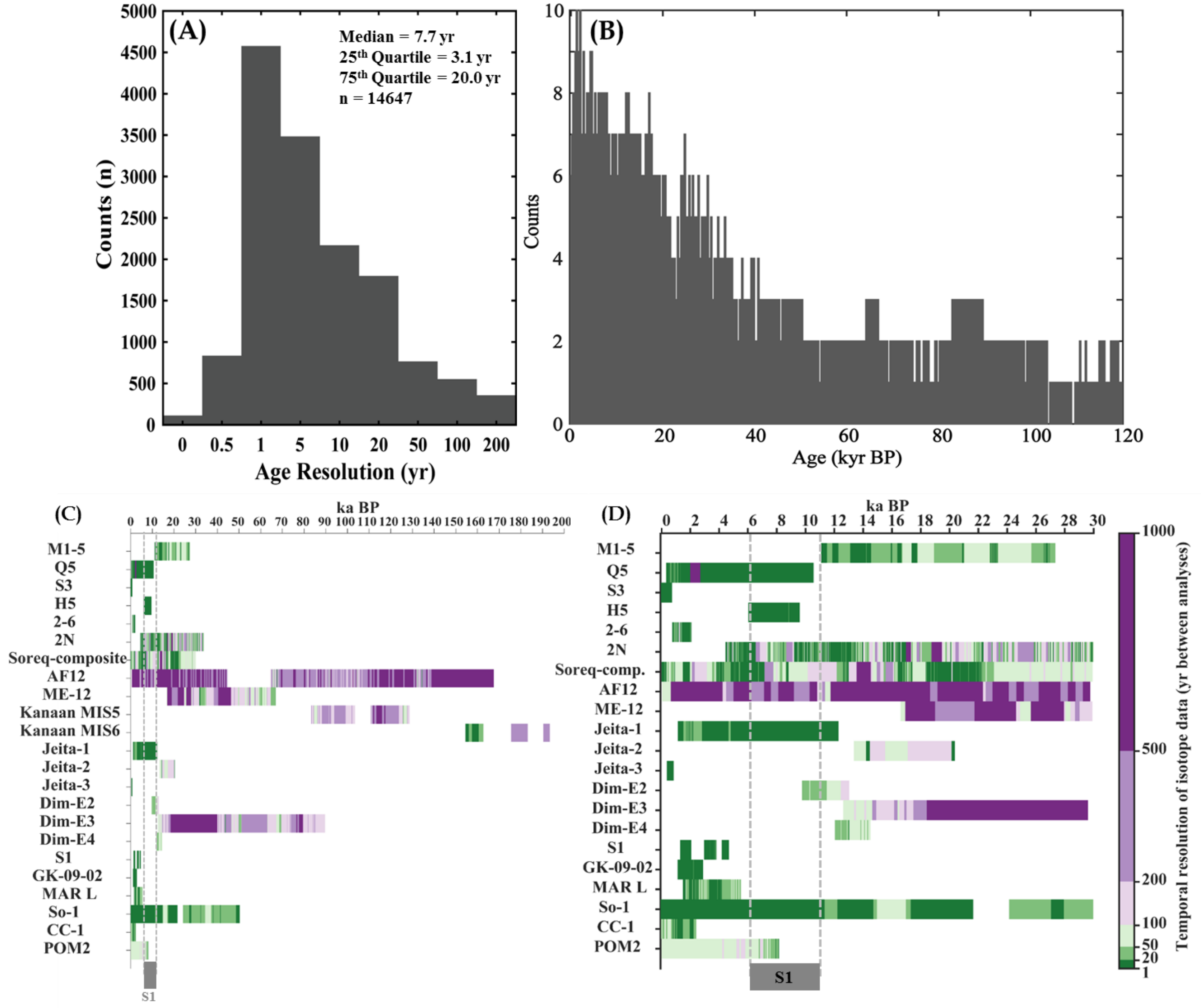
ITCZ sensitivity

Speleothems from the Middle East

(A) Age-resolution of the ME entities – **between 3 and 20 years**

(B) Speleothem records during the last 120 kyr subdivided in 250-year bins-
Most records are <40 ka BP, with peak values after LGM

(C and D) Temporal coverage and temporal difference of studied entities covering the pre-Holocene time periods: up to 200 ka BP, and last 30 ka BP.



Sapropel 1 period is bracketed by the dashed lines in C and D

Spatial/Temporal Resolution

Speleothems from the Middle East

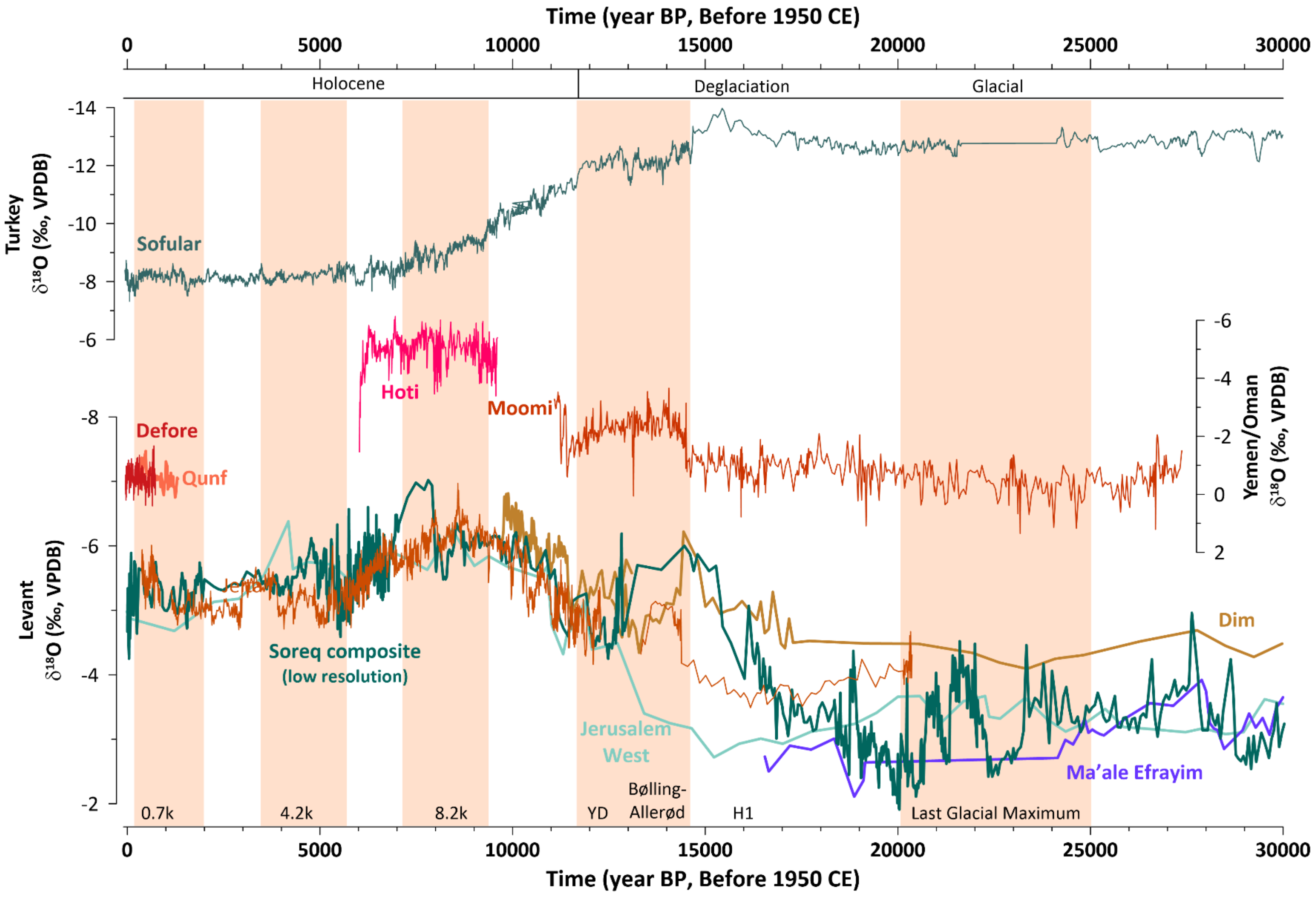
Entities reviewed here are (see list):

17 ME speleothem stable oxygen isotope ($\delta^{18}O_{cc}$) records from 10 sites from the SISAL_v1 database.

These entities provide a record of past hydro-climatic variability for the last 300 ka.

The review focuses on the last ~22 ka BP since the Last Glacial Maximum, with emphasis on Holocene major climate events – 8.2ka, 4.2ka and 0.7ka.

Additional six sites from Eastern Europe and Northern Turkey (see Kern et al. 2019) are included here, as these sites are along the dominant Eastern Mediterranean Sea (EM) storm tracks.



ME Entities Time-Series (1/3)

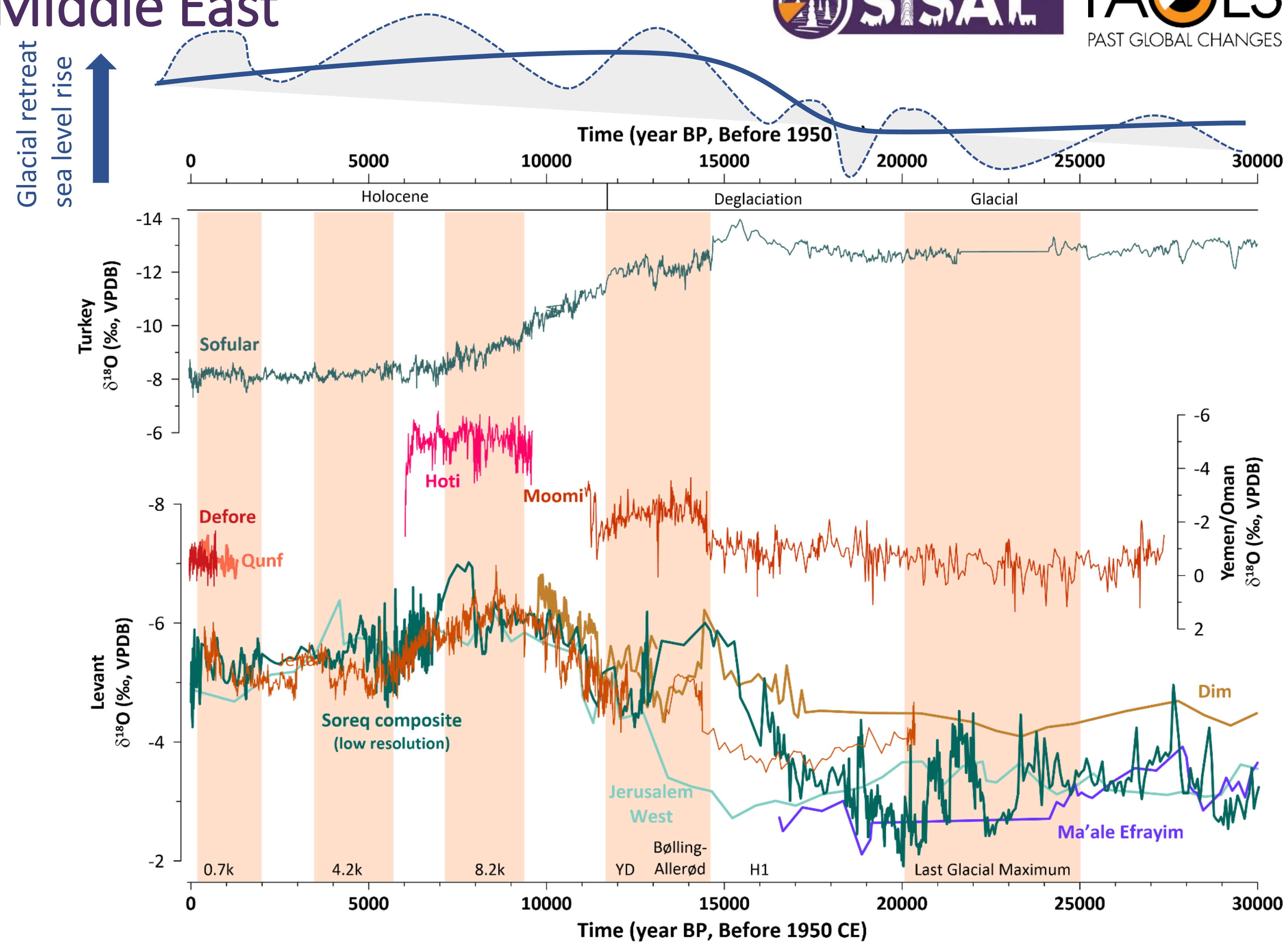
Speleothems from the Middle East

Controls on δ¹⁸Occ

- Millennial/glacial scale variability in δ¹⁸Occ (long wavelength) is linked to the Mediterranean vapor source ("source effect", compared to marine δ¹⁸O).

- Centennial / decadal (medium wavelength) variability is linked to the change in rainfall amount (high effective rainfall = low δ¹⁸Occ) superimposed on small scale changes in EM surface water (e.g. increased Nile flux)

- Seasonal (where available) – evidence of mixing between light δ¹⁸O winter influx and the pore reservoir.



Speleothems from the Middle East

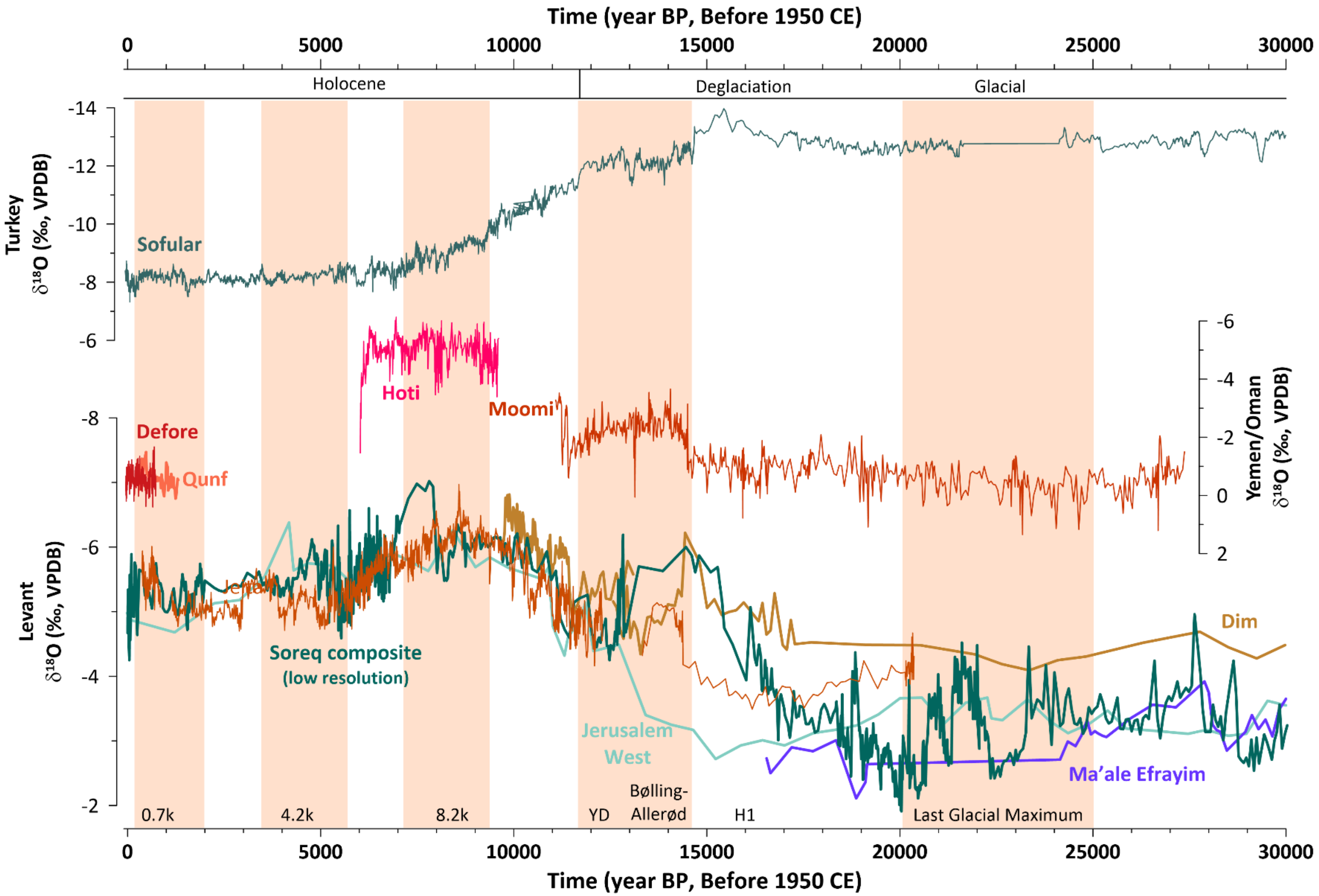
Observations

LGM and deglaciation

- <u>Sensitivity</u>: Soreq is the only Levant Cave which records variations between 30 ka and BA. Other records have lower temporal resolution.
- <u>Proxy signature</u>: During the glacial absolute $\delta^{18}Occ$ varies ~2‰ between sites and entities.
- <u>Deglaciation</u>: The deglaciation slope is different between the various Levant records
  The deglaciation starts early in Soreq, and last in JWC which shows the sharpest slope.

Holocene

- <u>Sensitivity</u>: Most records resolve millennial to centennial events at a similar tempo and amplitude.
- <u>Proxy signature</u>: Post-YD, the absolute $\delta^{18}Occ$ of Levant records is remarkably similar.



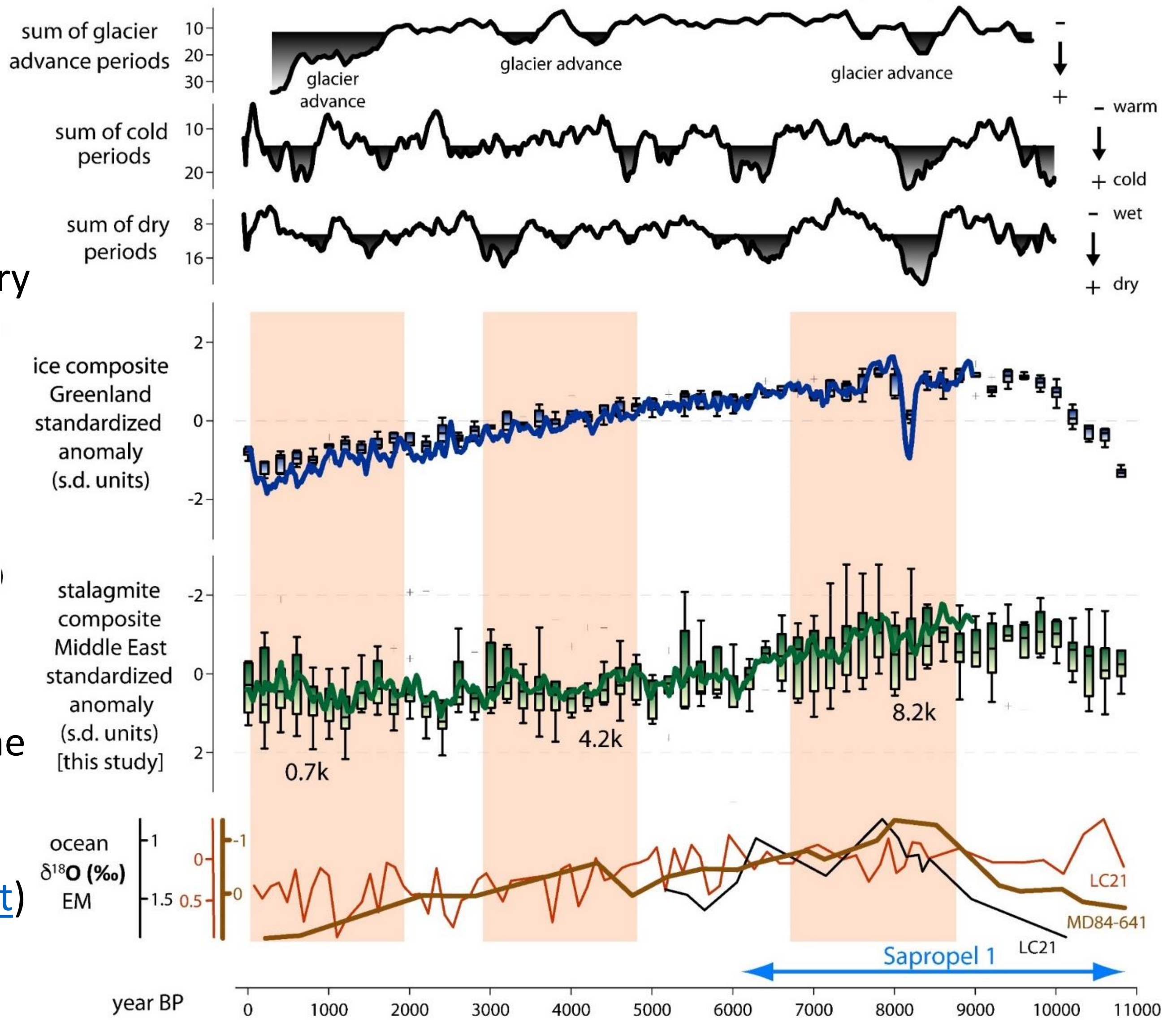
ME Entities Time-Series (3/3)

Speleothems from the Middle East

The 12 ka Composite:
200y-bin (box plot) / 25y-bin (running mean line)

8.2 ka
- Timing: the event in the composite is in agreement with NGIP composite, peak δ^{18}O of EM marine record, sum of dry and cold periods and a minor glacial advance.
- Amplitude: minimal in the composite – due to spatial coherence between samples evident from the large normalized-SD boxes.
- Post-event 25y trendline suggests regional drying – in agreement with the end of sapropel 1 and the African humid period.

4.2 ka
- Convergence: the signal appears as a coherent trough in the composite defining a maximum regional drying. Caution is required as multiple entities show gaps during this period.
- Could be resolved in by adding FC records (see idenified list)



ME STD Means Composite (1/2)

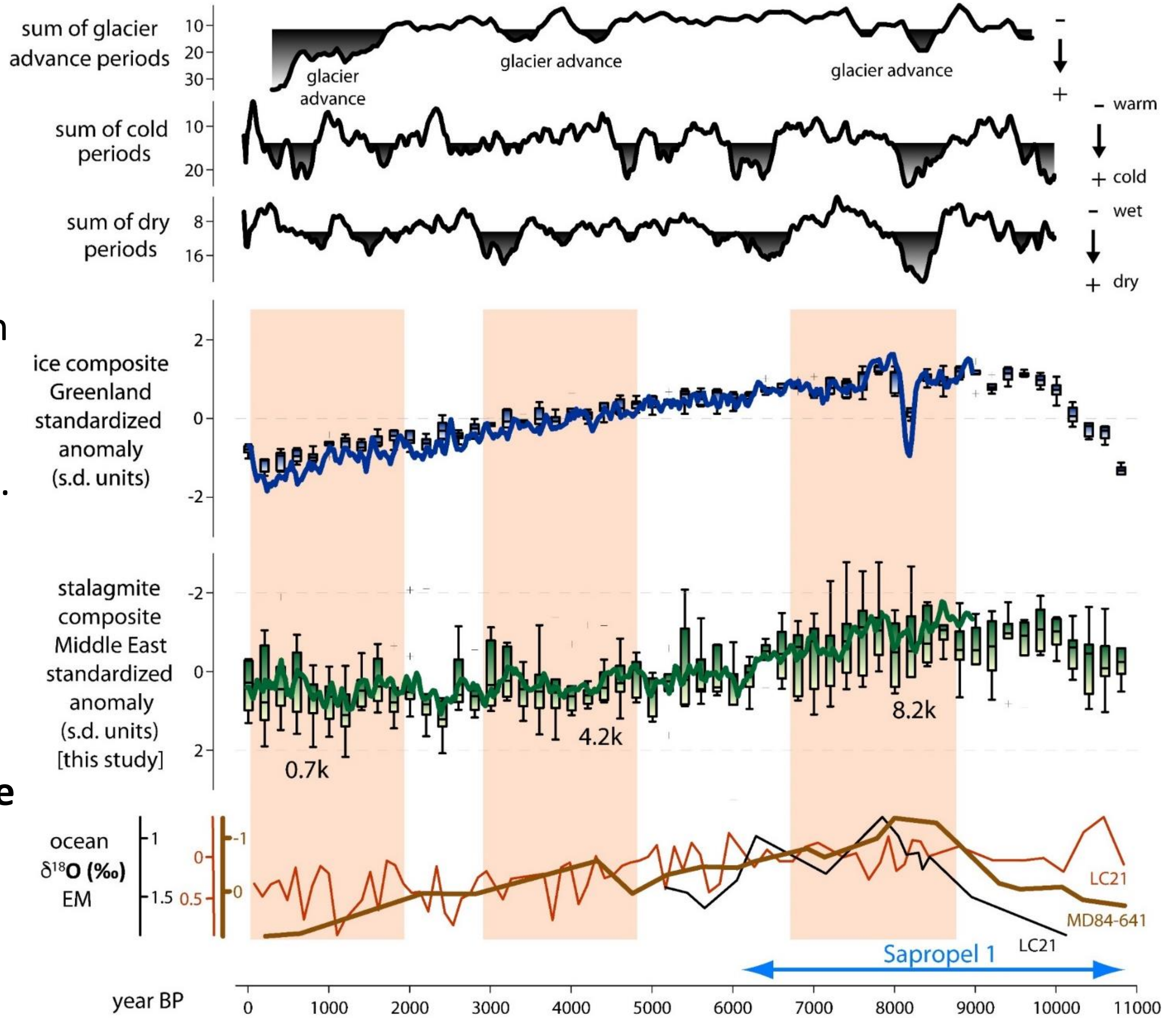
Speleothems from the Middle East

The 12 ka Composite:
200y-bin (box plot) / 25y-bin (running mean line)

2 ka (Late-Holocene cycles and Little Ice Age)

- Overall: Suggest leveling or change in the drying trend prevalent since 8.2 ka in the speleothem composite.
- Timing: A long-term wet-dry cycle from ~2.5 ka is visible on the 25y mean, with a wet peak identifying the LIA.
- Industrial: Large variability between records, minor drying trend since LIA → “too soon to tell” in 200y/25y resolution.
- FC entities: Will help increase fidelity of the regional trend (e.g. Flohr et al., 2017).

From a Holocene point of view - The speleothem composite provides a sensitive outlook on the last millennia (25y), while highlighting the regional heterogeneity (200y).



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Emphasis for future speleothem research in the Middle East

- Increase spatial coverage in the region.

Specifically in the Fertile Crescent, Arabian Peninsula and Saharan belt where current site density is considerably lower than the Levant and the interplay of Atlantic-Mediterranean vs. ITCZ requires further investigation.

- Increase the temporal coverage and generate longer time-series from the region.

As most of the records cover only the last 40-30 ka

- Application of high temporal-resolution analysis methodologies.

To increase the resolution and resolve seasonal bias of the available geological paleorecords

SISAL outlook for the Middle East

Numerous identified entities, which are still not incorporated in SISAL, suggest an excellent opportunity for the database.

Current efforts to upload new time-series would improve on existing application of tempo-spatial statistical analyses.

E.g. synthesis and standardization techniques and Monte Carlo Principal Component coherence analysis (Deininger et al., 2016)

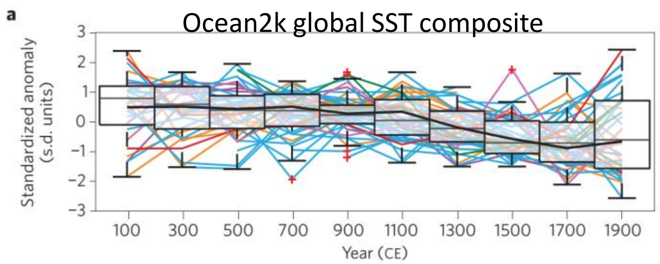
Speleothems from the Middle East

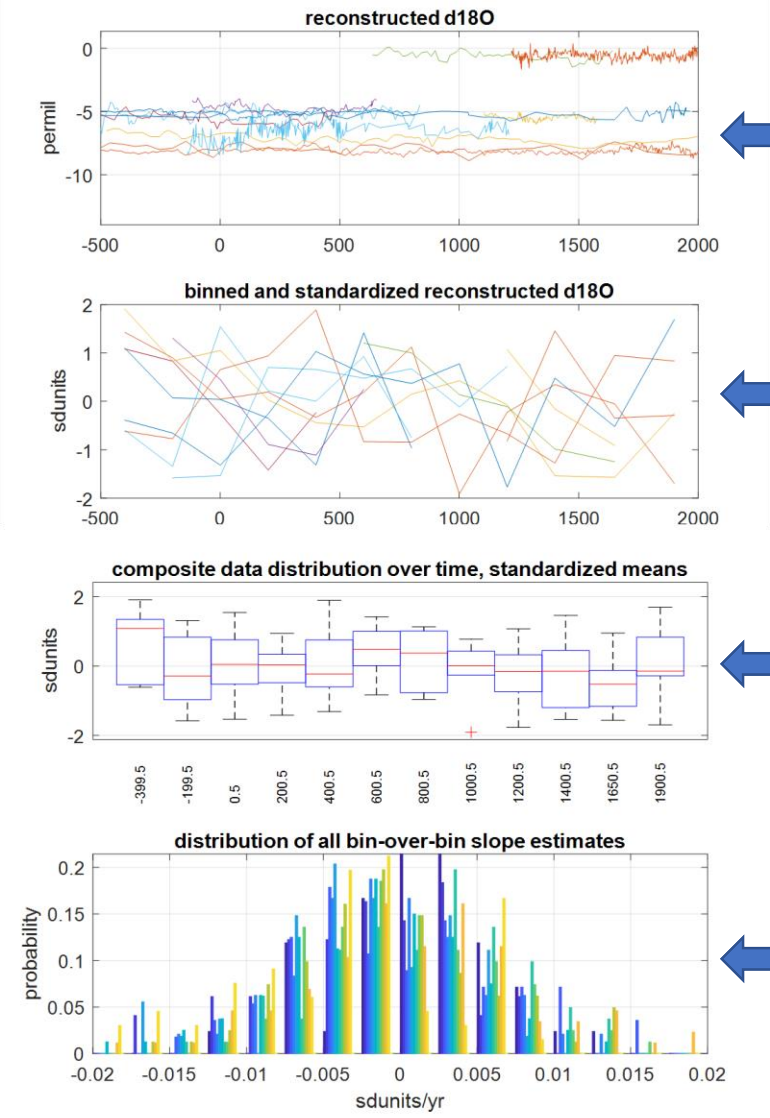
The Regional Multi-Record δ^{18}Occ Composite

The available speleothem stable oxygen isotope ratio.

Holocene time-series are investigated via binning and normalizing (providing median, the 25th and 75th quantiles of the data) at 25-year and 200-year time windows.

This methodology was previously used in the context of the PAGES 2k databases.
(Helen V. McGregor et al, 2015, Nature Geoscience)





The original Time-Series (TS)

TS standardized in N-year bins

TS standardized means

SD/bin-year slope

Home

Standardized Means Methodology

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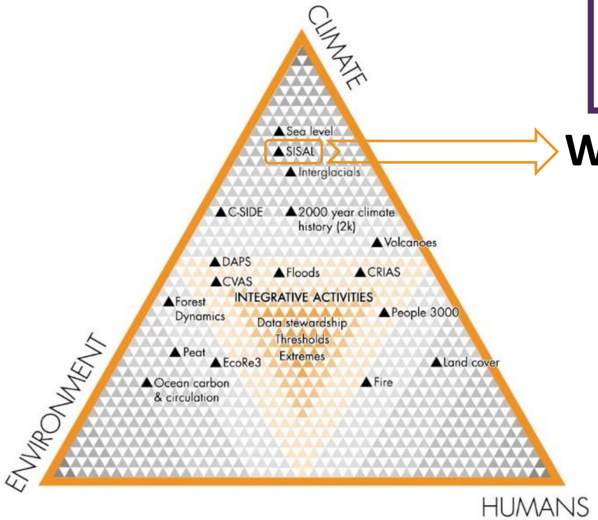
PAGES' Working Groups are temporary organizations that bring paleo-scientists together to target specific aspects of PAGES scientific agenda that cannot be addressed by a single team.



SISAL

Specific objectives

- Identify the current status of speleothem-based palaeoclimate reconstructions globally.
- Generate global-scale database available to the palaeoclimate community.
- Provide data to evaluate the CMIP6-CMIP4 simulations using isotope-enabled climate models.
- Formulate recommendations for future speleothem research.

Why speleothems?

- Good temporal coverage (U/Th up to c. 600.000 years) → Potential to cover PMIP4 key periods.
- Well distributed globally.
- Suitability for accurate age determination
  (non dependent on calibration)

The SISAL database: http://pastglobalchanges.org/ini/wg/sisal

Earth System Science Data
Open Access

The SISAL database: a global resource to document oxygen and carbon isotope records from speleothems

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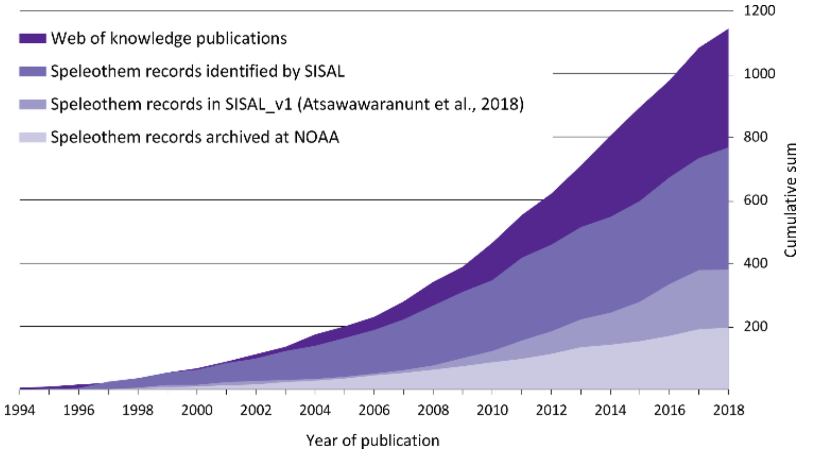
https://www.earth-syst-sci-data.net/10/1687/2018/

SISAL v1 (381 records from 174 sites)
SISAL identified sites (913 sites)



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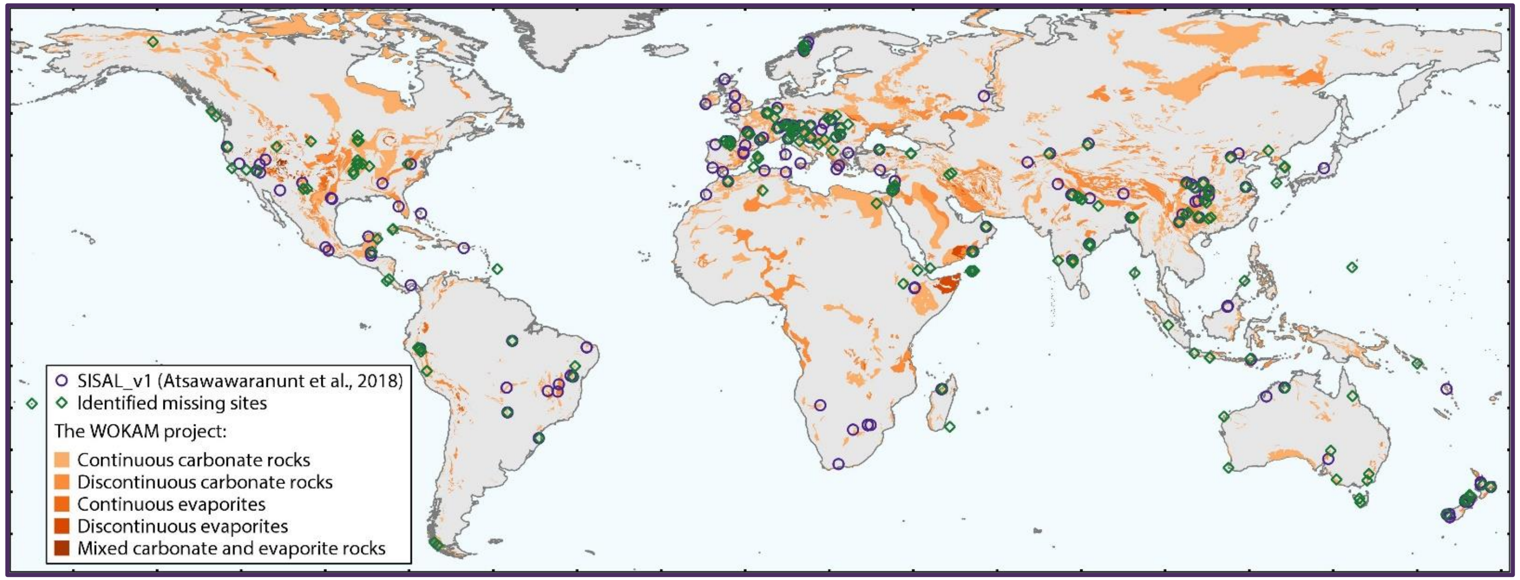
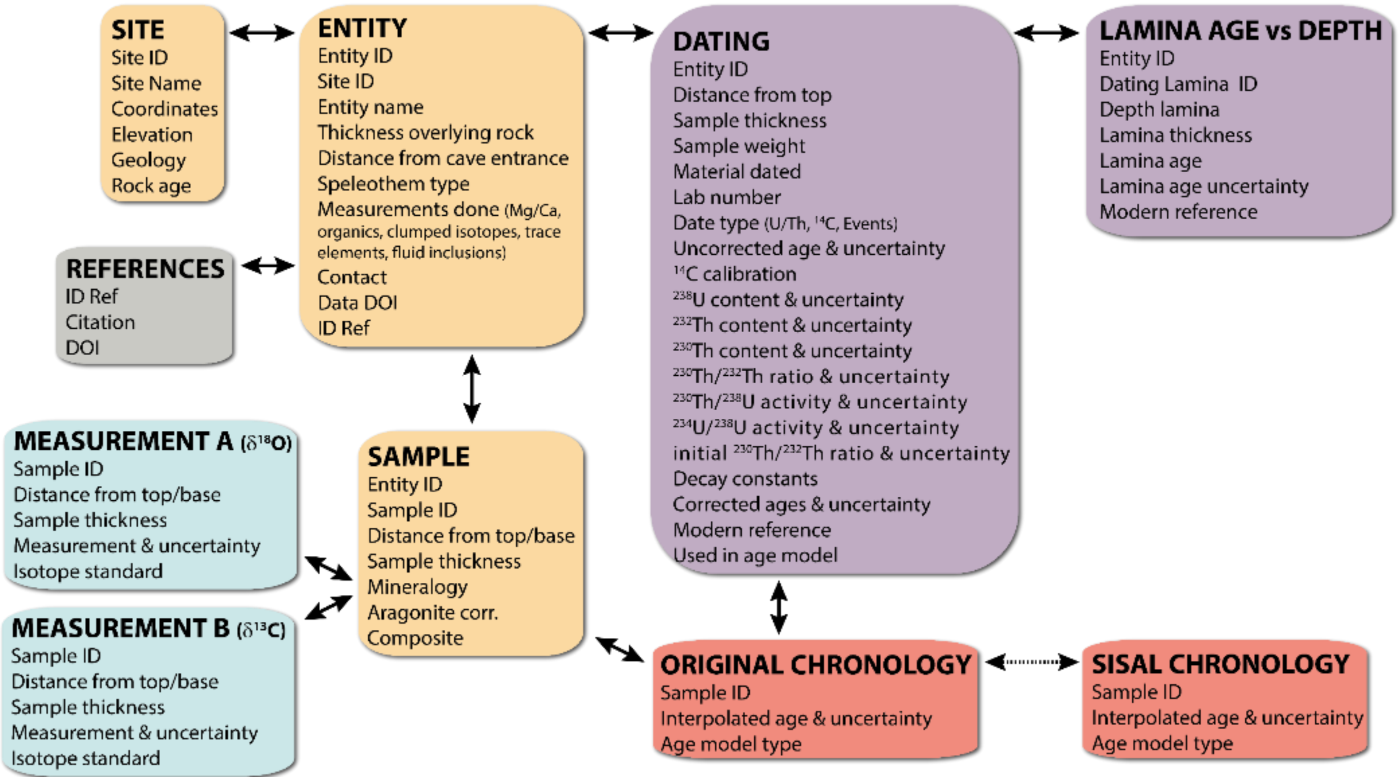


This product is designed for:

- Exploring regional and global – scale past changes in the hydrological cycle.
- Evaluating isotope-enabled climate simulations of the past.

The SISAL database: http://pastglobalchanges.org/ini/wg/sisal

- Extensive **metadata** fields for quality control (including dating information)
- SISAL will standardise the age models
- It includes records not available in public repositories
- First global compilation done by speleothem researchers



The SISAL database: http://pastglobalchanges.org/ini/wg/sisal

site_name	*Site _id*	**Location**	*latitude* °N	*longitude* °E	**elevation (m AMSL)**	*entity _name*	*entity _id*	**Min. Age (yrs BP)**	**Max. Age (yrs BP)**	**Ref.**
Ascunsa	72	Romania	45.00	22.60	1050	POM-2	161	-32	8169	[46]
Ceremosjna	76	Serbia	44.40	21.65	530	CC-1	165	-48	2426	[47]
Defore	170	Oman	17.17	54.08	150	S3	366	-46	731	[48]
						S4		9095	10,693	[49]
Dim	79	Turkey	36.53	32.11	232	Dim-E2	168	9738	13,094	[50]
						Dim-E3	169	12,575	89,714	
						Dim-E4	170	12,020	14,555	
Hoti	152	Oman	23.08	57.35	800	H5	327	6026	9607	[49,51
						H1 H2 H3 H4 H10 H11 H12 H13 H14 flowstone		78,000 ~present ~present 117,000 6,200 6,200 164 117,000 180,000 300,000 6,200 117,000	82,000 5,000 5,000 130,000 10,500 10,500 6277 130,000 210,000 325,000 10,500 130,000	[49,52
Jeita	11	Lebanon	33.95	35.65	100	Jeita-1	58	1137	12,288	[53,54
						Jeita-2	59	13,330	20,367	
						Jeita-3	60	372	847	
						JeG-Stm-1		1100	11,900	[54]
Jerusalem West	68	Israel	31.80	35.20	700	AF-12	152	-16	168,714	[55]
Kanaan	19	Lebanon	33.91	35.61	98	Kanaan_ MIS5	81	83,125	128,847	[56]
						Kanaan_ MIS6	82	154,455	193,498	
Kapsia	44	Greece	37.62	22.35	700	GK-09-02	120	1115	2904	[57]
Ma'ale Efrayim	110	West Bank	32.08	35.37	250	ME-12	218	16,548	66,948	[18]
						36 samples				
Mavri Trypa	156	Greece	36.74	21.76	70	S1	347	1296	4687	[58]
Moomi	138	Yemen	12.50	54.00	400	M1-5	293	11,086	27,370	[59]
						M1-2		40,000	53,000	[59]
Qunf	159	Oman	17.10	54.18	650	Q5	351	308	10,558	[49]
Skala Marion	56	Greece	40.64	24.51	41	MAR_L	136	1481	5534	[60]
Sofular	141	Turkey	41.42	31.93	700	SO-1	305	-56	50,275	[61]
						SO-2 SO-4 SO-6 SO-10 SO-14B SO-17A		-60 1080 93572 ~present 475,910 86,190	59,510 307,030 133,200 2,200 670,000 122,930	[62,63
Soreq	160	Israel	31.45	35.03	400	Soreq composite	354	~present	30,031	[64]
						2N	353	4440	33,804	[31]
						2 – 6	352	743	2086	[14]
						Numerous samples		~present	250,000	[13,28 65–72

List of SISAL_v1 Entities

Sites identified but currently not in SISAL_v1 (see Figure 1)

Cave Name	Figure 1 id	Country	latitude (N)	longitude (E)	elevation (masl)	*Identified speleothems*		Min. Age	Max. Age	Ref.
Ashalim	11	Israel	30.94	34.74	400		-	116,700	>U/Th	[73]
Akcakale	3	Turkey	40.45	39.54		2p	-	-55	189	[74]
Casecas	24	Yemen	12.56	54.31		STM5	-	12	856	[75]
Dimarshim	23	Yemen	12.55	53.68		D1	-	~present	4530	[49]
Even Sid	12	Israel	30.64	34.81	800		-	87,700	>U/Th	[73]
Gejkar	6	Iraq	35.80	49.16		Gej-1	-	-63	2380	[29]
Gol-e Zard	7	Iran	35.13	52.00	2530	-	-	3700	5100	[76]
Hol-Zakh	13	Israel	31.16	35.20	150			111,700	349,100	[73]
Hoq	25	Yemen	12.59	54.53		Hq1 STM1 STM6	-	-50 -53 -56	6900 5600 4500	[75]
Izzim	14	Israel	31.14	35.06	500		-	372,600	500,100	[73]
Karaca	1	Turkey	40.32	29.24		K1	-	6000	77,300	[77]
Kataleh Khor	4	Iran	35.84	48.16		(2 samples)	-	214,000	500,000	[78]
Ma’ale ha-Meyshar	15	Israel	30.49	34.93	450		-	110,600	>U/Th	[73]
Ma’ale Dragot	16	Israel	31.4	35.00	300	MD (6 samples)		<500	426,440	[79]
Makhtesh ha-Qatan	17	Israel	30.95	35.22	-20		-	140,000	>U/Th	[73]
Mitzpe Shlagim	8	Israel/Syria	33.32	35.81	2224	MS-1 MS-2 MS-3	-	4300 8800 8500	88,000 89,000 49,100	[80]
Mukalla Cave	22	Yemen	14.92	48.59	1500	Y99 Y97-4 Y97-5	- - -	119,141 5630 8790	358,887 185,600 233,300	[16]
Ovacik	2	Turkey	41.46	32.02		O-1	-	4472	9796	[61]
Peqiin	9	Israel	32.58	35.19	650	PEK-5 PEK-6 PEK-9 PEK-10	-	5620 24,710 47,810 55,630	6780 223,700 283,650 288,160	[72]
Qal'e Kord	5	Iran	35.80	48.86		QK 8 QK 14	-	78,104 6581	99,182 127,012	[78,81
Shizafon mini-caves	18	Israel	30.04	35.00	400		-	333,400	>U/Th	[73]
Tzavoa	19	Israel	31.20	35.20	550	TZ (15 samples)		14,400	204,760	[79]
Wadi Lotz	20	Israel	30.47	34.58	900	LOTS-3	-	?	>U/Th	[73]
Wadi Sannur	21	Egypt	28.62	31.28		WSS 1 to 6	-	136,460	188,120	[82]
Zalmon	10	Israel	32.80	35.40		ZAL-1 to ZAL-7 and ZAL-11	-	5100	165,000	[83]

List of Identified Entities