HOLSEA

Geographic variability of Holocene sea level

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EGU 2020

INQUA Founded 1928

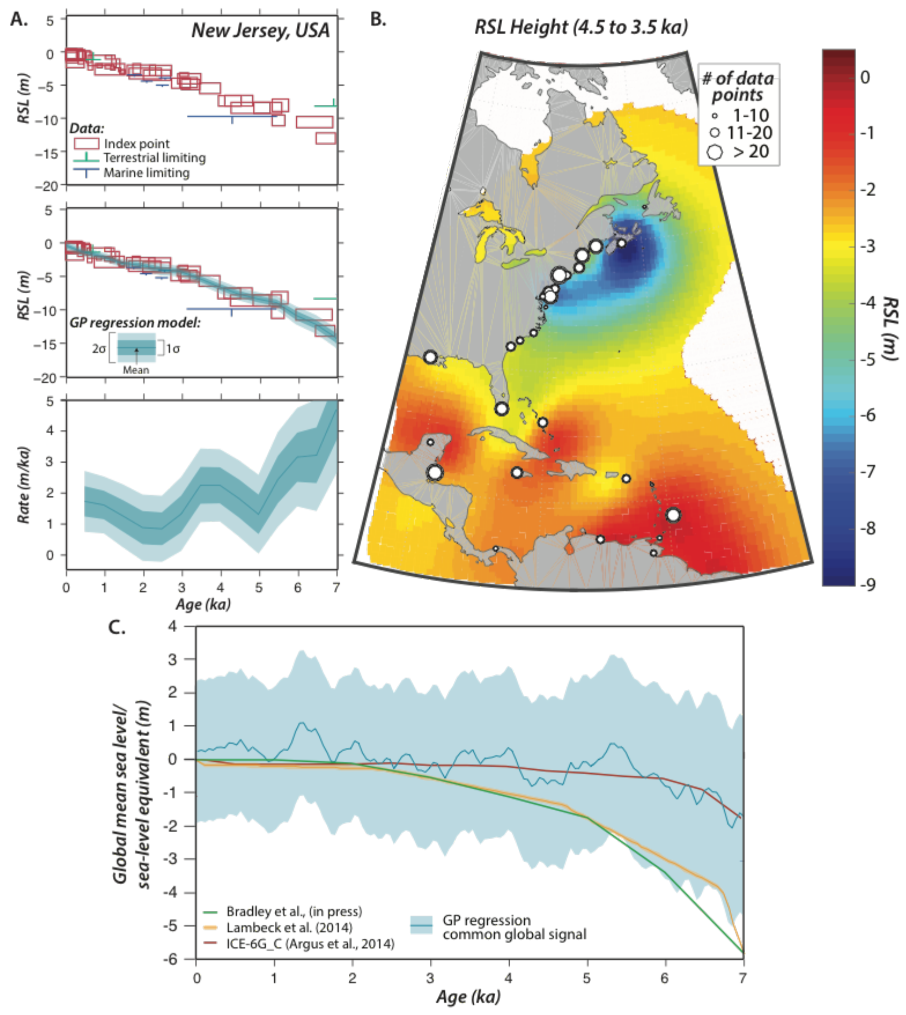
PALSEA

IGCP Project 639

OVERARCHING GOALS

- Produce a standardized global synthesis of Holocene relative sea-level data to:
  1) Estimate the magnitudes and rates of global mean sea-level change based on proxy data
  2) Identify trends in spatial variability and better understand the processes responsible for geographic differences in relative sea-level change

- Requires data from disparate geographic locations and different proxies to be broadly comparable



PROJECT OBJECTIVES
PART I: DATA SYNTHESIS

Identify data currently available to synthesize

- Includes data sent in prior to last HOLSEA meeting, additional published studies to 'easily' collate to fill in gaps, and submissions to QSR special issue

Identify the most commonly used indicators across regions and define their indicative meanings

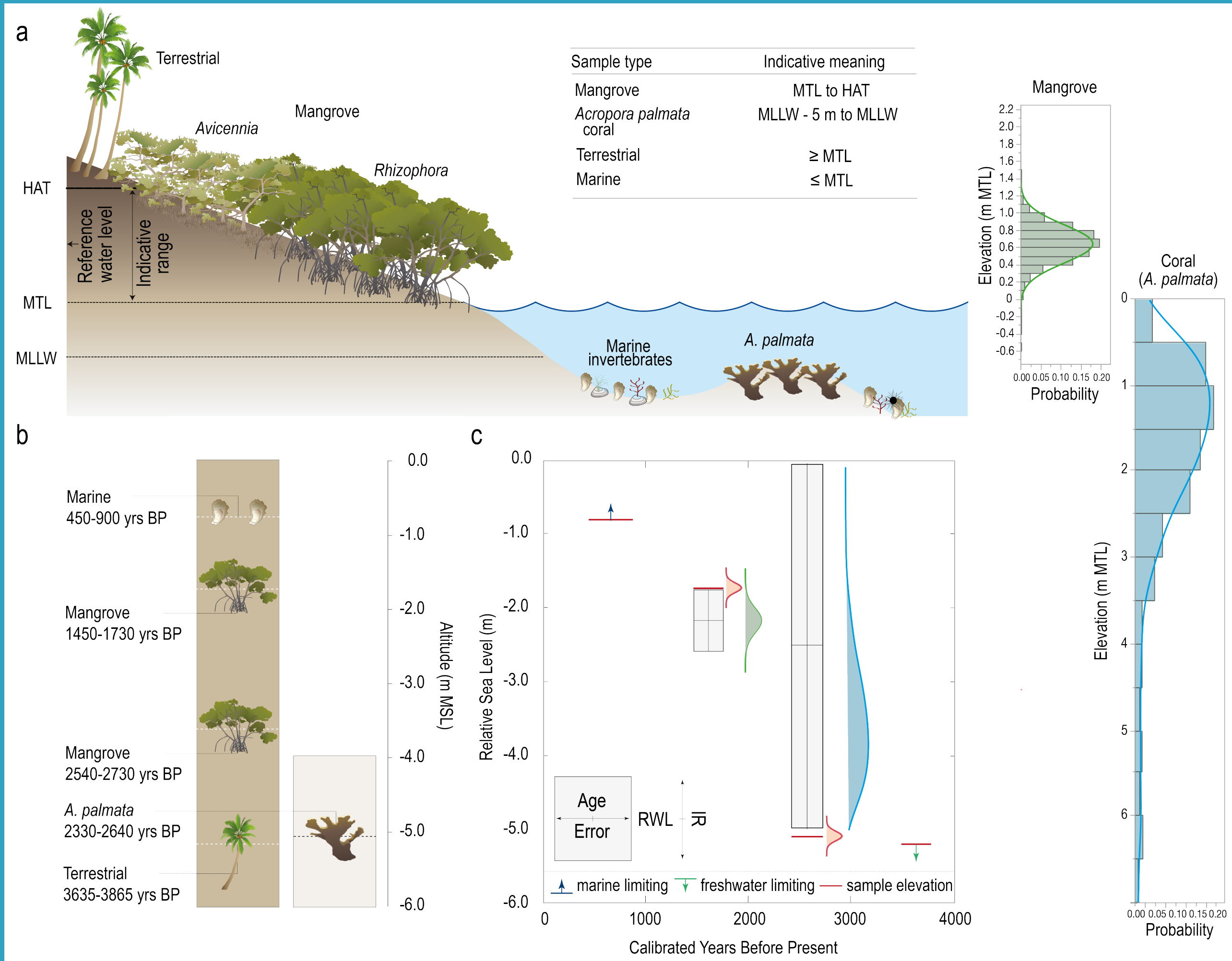
- Ecological, physiological or physical controls on distribution of indicators
- Does this definition vary by region or with local conditions?

Ensure steps are taken to appropriately calibrate/calculate age of indicators and fully incorporate age uncertainties

Define best practices for archiving sea-level data

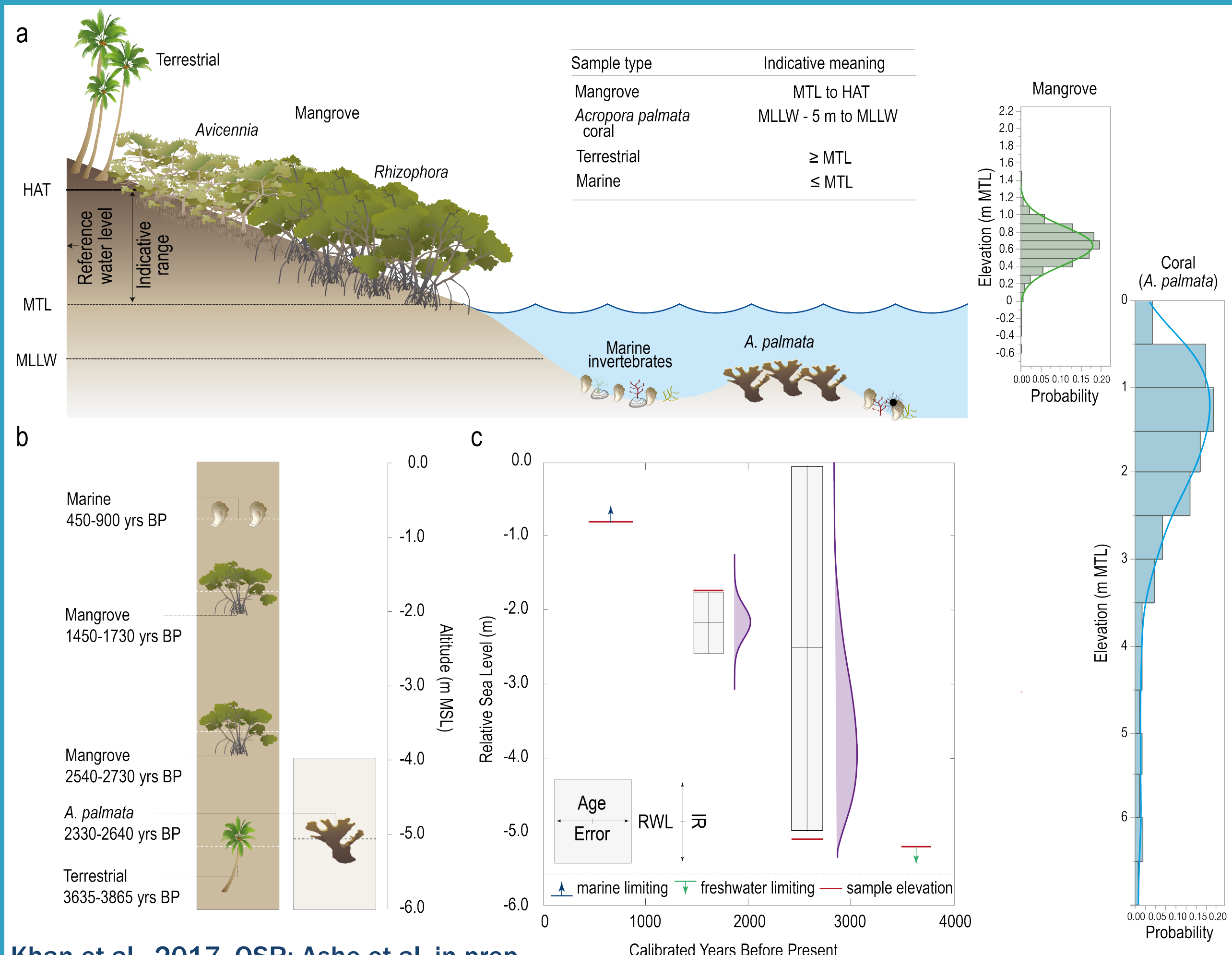
- Interpretation and estimation of measurement error
- Format of a global database

RECONSTRUCTION OF RELATIVE SEA LEVEL: INTERPRETATION AND MEASUREMENT UNCERTAINTIES



- Sea-level indicator
  - Systematic and quantifiable relationship to elevation with respect to the tidal frame
- Indicative meaning
  - Describes the contemporary relationship of an indicator to sea level relative to tidal datums to account for local variation among sites

RECONSTRUCTION OF RELATIVE SEA LEVEL: INTERPRETATION AND MEASUREMENT UNCERTAINTIES



Khan et al., 2017, QSR; Ashe et al. in prep

RSL = A – RWL

- Index points: define the position of RSL over space and time
- Limiting data: provide upper (terrestrial) or lower (marine) bound on the position of RSL over space and time
- Horizontal uncertainties related to dating method
- Vertical uncertainties related to indicative meaning and measurement uncertainties

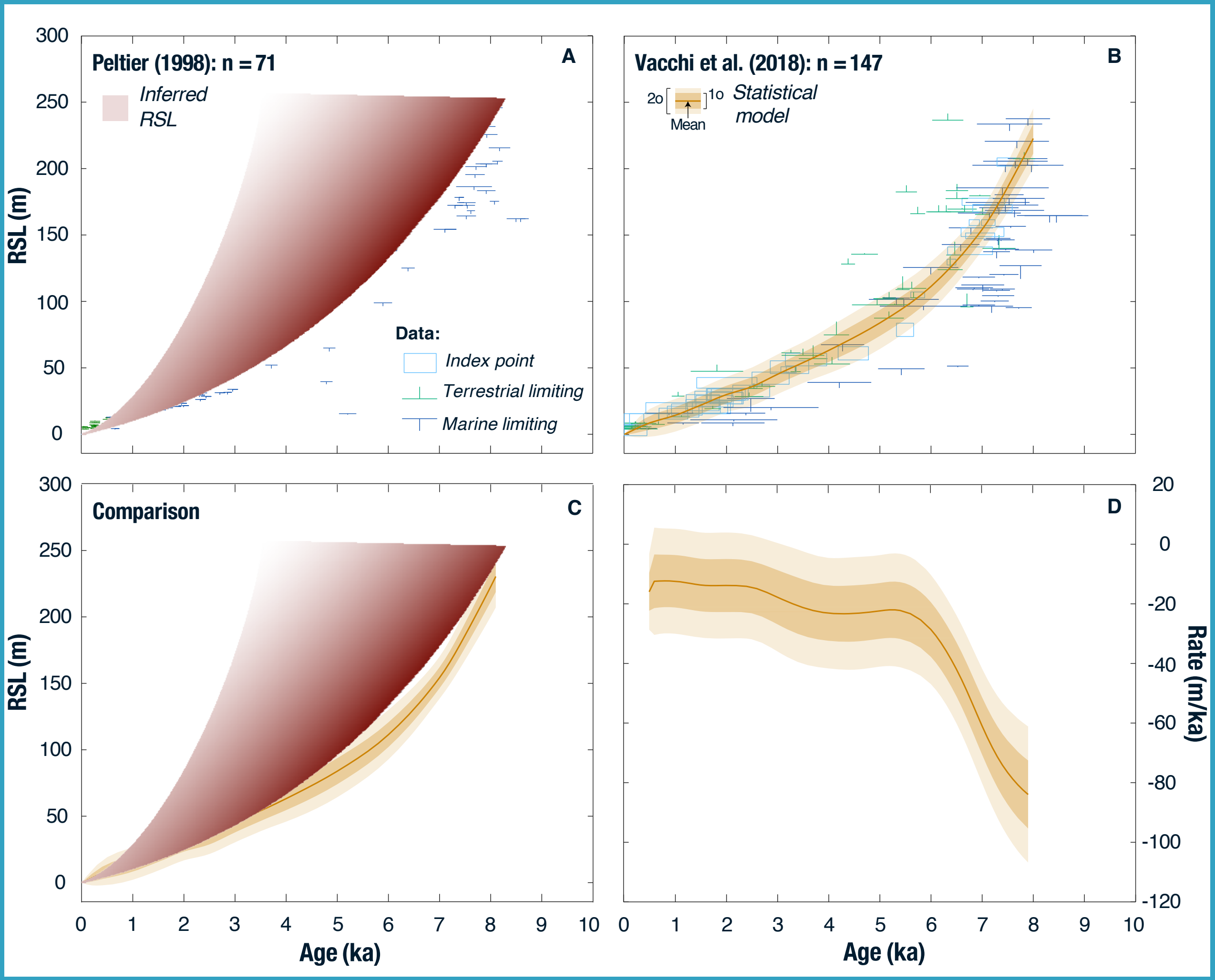
PROJECT OBJECTIVES
PART II: DATA ANALYSIS

- What are the current limitations with respect to HOLSEA objectives (i.e., determining sensitivity of ice sheets during past warm periods, understanding of the driving mechanisms of sea-level change, enhancing predictions of 21st century sea-level rise)?
- Are there any key regions where Holocene data might help improve models or overcome these limitations (e.g., locations where models are sensitive to Greenland ice melt or lithospheric thickness, etc.)?
- Different approaches to combining GIA modeling and sea-level data
- Useful formatting or information to accompany sea-level data for use in models

PROGRESS TO DATE

- 4 workshops
  - 2016: PALSEA meeting, Mt. Hood, Oregon
  - 2017: IGCP639 meeting, Durban, South Africa
  - 2018: IGCP639/Medflood, Sicily, Italy
  - 2019: PALSEA meeting, Dublin, Ireland
- Developed a template for archiving sea-level data in the global database (Khan et al. 2019, QSR)
- Created a website: www.holsea.org
- Established a preliminary global database through special issue in QSR: "Inception of a global atlas of sea levels since the Last Glacial Maximum"
  - 13 submissions + introduction

IMPORTANCE OF UPDATING DATABASES



- New data
- Updated interpretations/ calibration datasets
- Methodological advances allow probabilistic analysis of past RSL and its rates

DATABASE FORMAT

Category	#	Column heading	Data, interpretation, comment	Units
A. Identifier/original citation	1	Unique sample ID	Data	n/a
	2	Reference	Data	n/a
B. Fields related to geographic location	3	Region code	Interpretation	n/a
	4	Sub-region	Interpretation	n/a
	5	Latitude	Data	degrees
	6	Longitude	Data	degrees
C. Fields related to horizontal position of RSL	7	Dating method	Data	n/a
	8	Corrected age	Data	^{14}C a B
	9	Corrected age uncertainty	Data	^{14}C a
	10	Age	Interpretation	cal a BP
	11	Age 2σ Uncertainty +	Interpretation	cal a
	12	Age 2σ Uncertainty -	Interpretation	cal a
D.1 Fields related to stratigraphy from which the sample was obtained	13	Dated facies	Interpretation	n/a
	14	Overburden facies (nearest layer)	Interpretation	n/a
	15	Underlying facies (nearest layer)	Interpretation	n/a
	16	Tendency	Interpretation	n/a
	17	Sample depth/Overburden thickness	Data	m
	18	Depth to consolidated substrate	Data	m
	19	Intercalated	Data	yes/no
D.2 Fields related to uncertainties in determining the depth of a sample in a core or section	20	Sampling method	Data	n/a
	21	Sample thickness	Data	m
	22	Sample thickness type	Comment	n/a
	23	Corrected sample thickness	Interpretation	m
	24	Sample thickness uncertainty	Interpretation	m
	25	Sampling uncertainty	Interpretation	m
	26	Core shortening/stretching uncertainty	Interpretation	m
	27	Non-vertical drilling uncertainty	Interpretation	m
D.3 Fields related to uncertainties in determining the absolute elevation of a core or section	28	Tidal uncertainty	Interpretation	m
	29	Water depth uncertainty	Interpretation	m
	30	Leveling uncertainty	Interpretation	m
	31	(d)GPS or RTK uncertainty	Interpretation	m
	32	Benchmark uncertainty	Interpretation	m
	33	Vegetation zone uncertainty	Interpretation	m
	34	Map uncertainty	Interpretation	m
	35	DEM uncertainty	Interpretation	m
	36	Orthometric sample elevation	Data	m
	37	Orthometric datum or MSL epoch	Data	n/a
	38	Sample elevation	Data	m MSL
	39	Sample elevation type	Comment	n/a
	40	Sample elevation uncertainty +	Interpretation	m
	41	Sample elevation uncertainty -	Interpretation	m

- Important distinction made between raw data and interpretations

Category	#	Column heading	Data, interpretation, comment	Units
D.4 Tidal datums	42	MLWS	Interpretation	m MSL
	43	MLWN	Interpretation	m MSL
	44	MLLW	Interpretation	m MSL
	45	MLW	Interpretation	m MSL
	46	MTL	Interpretation	m MSL
	47	MHW	Interpretation	m MSL
	48	MHHW	Interpretation	m MSL
	49	MHWN	Interpretation	m MSL
	50	MHWS	Interpretation	m MSL
	51	HAT	Interpretation	m MSL
D.5 Fields related to uncertainties associate with the sample's indicative meaning	52	Type	Interpretation	n/a
	53	Primary indicator type	Interpretation	n/a
	54	Secondary indicator type	Interpretation	n/a
	55	Supporting evidence	Interpretation	n/a
	56	Sample indicative meaning	Interpretation	n/a
	57	Reference water level	Interpretation	m MSL
	58	Indicative range uncertainty	Interpretation	m
	59	RWL modeling uncertainty	Interpretation	m
	60	IR modeling uncertainty	Interpretation	m
	61	Paleotide-corrected RWL (if any)	Interpretation	m MSL
	62	Paleotide-corrected indicative range (if any)	Interpretation	m
	63	Paleo indicative range change uncertainty (if any)	Interpretation	m
D.6 Fields used to account for effects of sediment compaction and tectonics on sample elevation	64	Compaction correction (if any)	Interpretation	n/a
	65	Compaction correction uncertainty (if any)	Interpretation	n/a
	66	Tectonic correction (if any)	Interpretation	m/ka
	67	Tectonic correction uncertainty (if any)	Interpretation	m/ka
D.7 Fields use to calculate the past position and uncertainty of RSL from each sample	68	RSL 2σ Uncertainty +	Interpretation	m
	69	RSL 2σ Uncertainty +	Interpretation	m
	70	RSL 2σ Uncertainty -	Interpretation	m
	71	Corrected RSL (if any)	Interpretation	m
	72	Corrected RSL uncertainty + (if any)	Interpretation	m
	73	Corrected RSL uncertainty - (if any)	Interpretation	m
	74	Correction type (if any)	Interpretation	n/a
E. Additional notes	75	Reject	Interpretation	n/a
	76	Why rejected?	Comment	n/a
	77	Notes	Comment	n/a

- 77 fields to archive the geographic and vertical position of data points
- Additional 18 (radiocarbon) to 20 (U-series) fields to archive age attribute of data points

SEA-LEVEL INDICATORS

2016:

```
Console ~/Documents/HOLSEA/Data/
[1600] "wood fragmsents"
[1601] "Wood from mangroves"
[1602] "Wood from peat"
[1603] "Wood from upper part of organic silt layer"
[1604] "Wood in estuarine mud "
[1605] "wood in intertidal silt"
[1606] "Wood in marine sand"
[1607] "wood in peat"
[1608] "Wood Peat"
[1609] "wood, 4m slice"
[1610] "Wood, Freshwater Mariscus-Nymphaea peat"
[1611] "wood, peat"
[1612] "Wood, Peat"
[1613] "Wood, Plant matter"
[1614] "Wood, Rangia sp."
[1615] "Wood, Root?"
[1616] "Wood, Sand"
[1617] "Wood, Wood"
[1618] "Wood/plant, Nuculana sp."
[1619] "Wood/plant, Rangia sp."
[1620] "Wood/plant, Wood/plant"
[1621] "Wooden artifact"
[1622] "Wooden plank"
[1623] "Woody Carr Peat"
[1624] "Woody Herbaceous Peat"
[1625] "Woody material"
[1626] "Woody matter, Wood"
[1627] "Woody org sed, Organic sediments"
[1628] "Woody org sed, Wood"
[1629] "Woody org sed, Woody org sed"
[1630] "Woody Peat"
[1631] "Woody peat    "
[1632] "Woody peat, Woody peat"
[1633] "Yoldia hyperborea (h up to -20m)"
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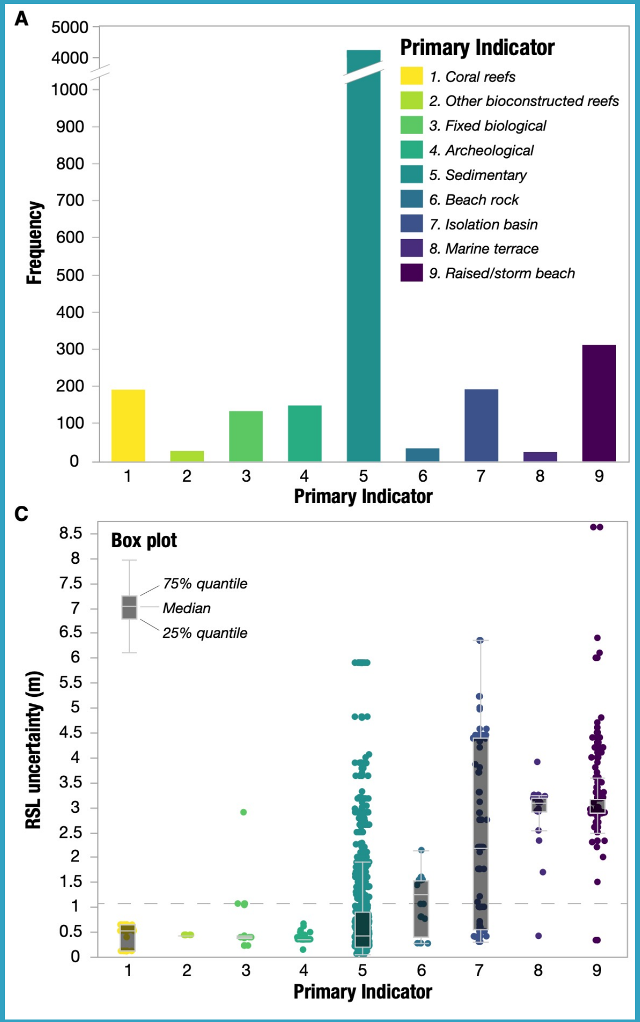
- 1633 unique sea-level indicators in initial data compilation in 2016
- Developed standardized groupings of indicators

SEA-LEVEL INDICATORS

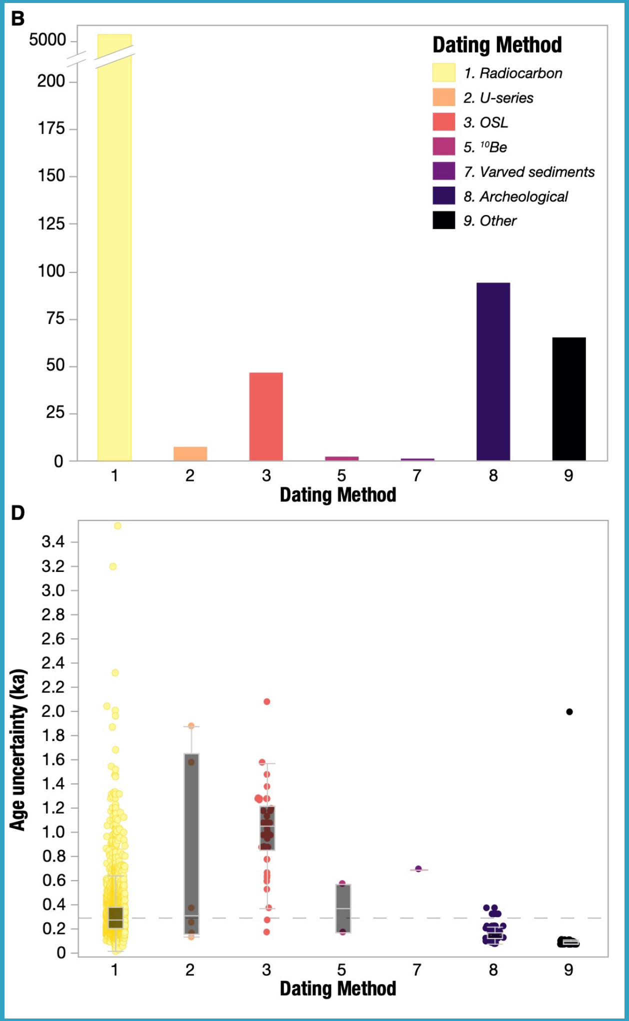


Secondary indicator and supporting evidence:

Sample Type	Evidence	Reference Water Level	Indicative Range
Index Points			
Undifferentiated salt-marsh environment	Intertidal sediments with unnamed salt-marsh plant macrofossils or identification only to genus level (e.g., Shaw and Ceman, 1999; Gehrels et al., 2004; Daly et al., 2007; Shaw et al., 2010). Foraminiferal assemblages dominated by high and low marsh taxa (e.g., Scott and Greenberg, 1983; Scott et al., 1981, 1995; Gehrels et al., 2005; Barnett et al., 2016; Kemp et al., 2017).	(HAT to MTL)/2	HAT to MTL
Higher high marsh environment	Intertidal sediments with higher high marsh plant macrofossils (e.g. Shaw and Ceman, 1999; Shaw et al., 2010). Foraminiferal assemblages dominated by higher high marsh taxa (e.g., Shaw and Ceman, 1999; Barnett et al., 2016)	(HAT to MHHW)/2	HAT to MHHW
High marsh environment	Intertidal sediments with high marsh plant macrofossils (e.g. Shaw and Ceman, 1999; Gehrels et al., 2004; Daly et al., 2007; Shaw et al., 2010). Foraminiferal and diatom assemblages dominated by high marsh taxa (e.g., Scott and Greenberg, 1983; Scott et al., 1995; Gehrels et al., 2005; Barnett et al., 2016; Kemp et al., 2017)	(HAT to MHW)/2	HAT to MHW
Low marsh environment	In tertidal sediments with low marsh plant macrofossils (e.g. Shaw and Ceman, 1999; Patterson et al., 2004; Daly et al., 2007; Shaw et al., 2010). Foraminiferal assemblages dominated by low marsh taxa (e.g., Scott and Greenberg, 1983; Scott et al., 1981, 1995; Gehrels et al., 2005; Barnett et al., 2016; Kemp et al., 2017).	(MHW to MTL)/2	MHW to MTL
Shorre environment	Intertidal sediments with plant macrofossils and faunal assemblages typical of the *shorre* facies (e.g. Dionne, 1996, 1997; 1999; Dionne and Coll, 1995; Dionne et al., 2004).	(MTL to MLLW)/2	MTL to MLLW
Lower *shorre* to *slikke* environment	Intertidal sediments with plant macrofossils and faunal assemblages typical of the lower portion of the *shorre* facies and of the *slikke* facies (e.g. Dionne, 1996, 1997; 1999; Dionne and Coll, 1995; Dionne et al., 2004).	(MHW to MLLW)/2	MHW to MLLW
Slikke environment	Intertidal sediments with plant macrofossils and faunal assemblages typical of the *slikke* facies (e.g. Dionne, 1996, 1997; 1999; Dionne and Coll, 1995; Dionne et al., 2004).	(MTL to MLLW)/2	MTL to MLLW
Isolation Basin	Sediments recording the switch between freshwater and brackish/marine sediments that are supported by changing diatoms or macrofossil assemblages (e.g., Pienitz et al., 1991; Miousse et al., 2003; Glaser et al., 2004; Pendea et al., 2010).	(HAT to MTL)/2	HAT to MTL
Beach ridges	Gravelly to boulder beach deposits with macrofossil faunal assemblages dominated by *Mytilus edulis* shells (e.g., Allard and Tremblay, 1983; Lavoie et al., 2012; Tamura, 2012; Billy et al., 2015)	(3 + HAT to MLLW)/2	3 + HAT to MLLW
Beach deposits	Sandy to gravelly found mid to lower beach stratigraphic context (e.g., planar or cross-bedded lamination, e.g., Fraser et al., 2005; Lavoie et al., 2012) and with macrofossil faunal assemblages dominated by intertidal to shallow subtidal shells (e.g., *M. edulis*; *Mya arenaria*; *Nucella lapillus*, Matthiessen, 1960; Powers et al., 2006) or in-situ mussel banks of *M. edulis* shells.	(MHW to MLLW)/2	MHW to MLLW
Limiting Points			
Marine limiting	Identifiable in-situ marine shells found in marine and glacio-marine deposits (e.g., Hillaire-Marcel, 1976; Gray et al., 1993; Gray and Lauriol, 1985; Bell et al., 2005). Foraminiferal assemblages dominated by marine taxa (e.g., Cronin, 1979; Scott et al., 1987). Isolation basin sediments with marine diatoms and marine shell assemblages (e.g. Pienitz et al., 1991; Shaw et al., 2009).	MTL	Below MTL
Freshwater limiting	In-situ tree stumps (e.g., Catto et al., 2000; Dionne, 2001) Peat that does not meet the above requirements to be classified as an index point. Freshwater isolation basin sediments (lacustrine gyttja) dominated by freshwater diatoms and freshwater shells assemblages (e.g. Glaser et al., 2004; Pendea et al., 2010). Coastal archaeological settlements (e.g., Fitzhugh, 1977; Martindale et al., 2016)	MTL	Above MTL

Vacchi et al., 2018, QSR

DATING METHODS

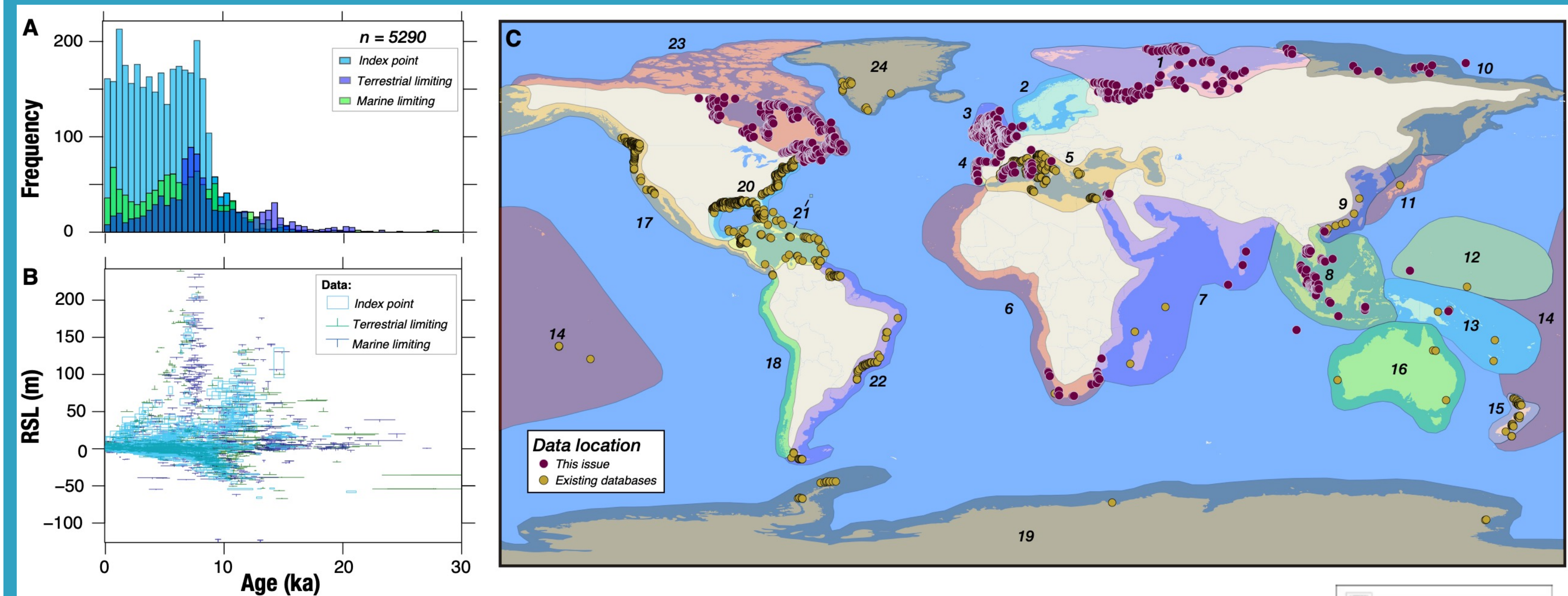


- Vast majority of samples dated using radiocarbon

- Other dating methods predominantly from age-depth models derived from Pb-210 and other recent age markers, or banding on coral microatolls

- Data template requires users to provide raw laboratory measurements as well as details about how ages were calibrated/calculated

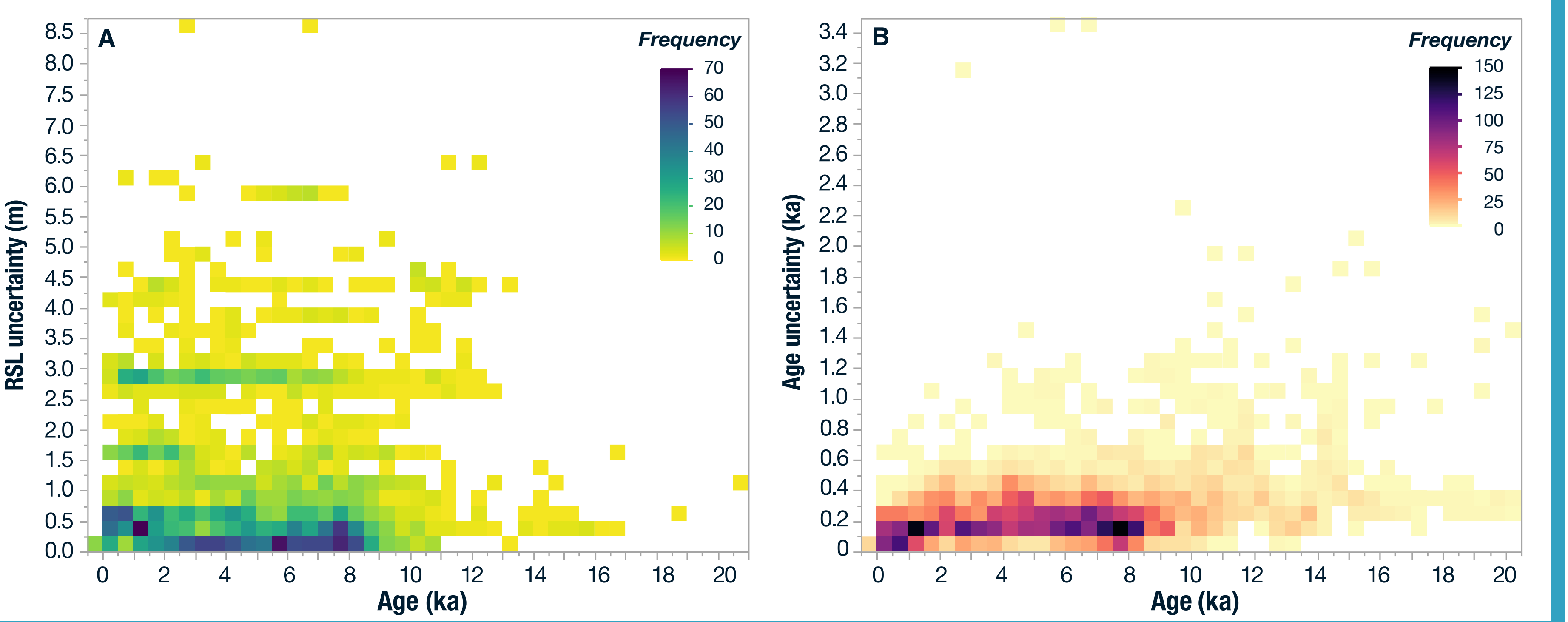
AVAILABLE DATA



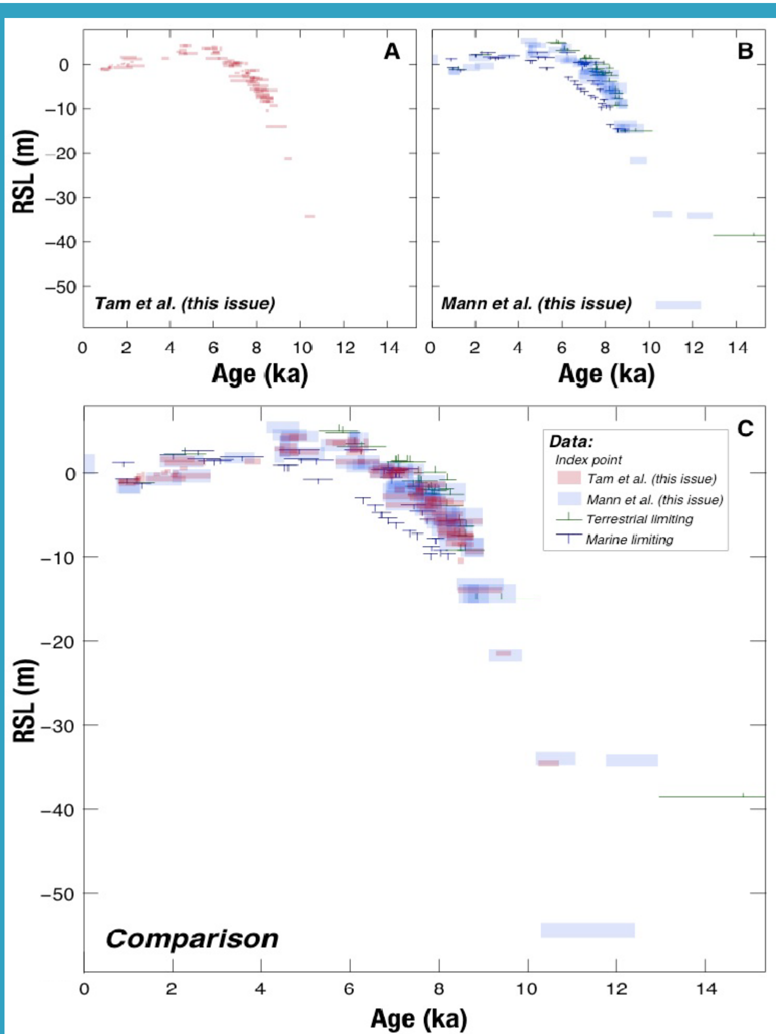
- 5290 valid data points (3202 index points, 2088 limiting points) in special issue
- >13,000 data points when existing robust databases combined

Khan et al., 2019, QSR

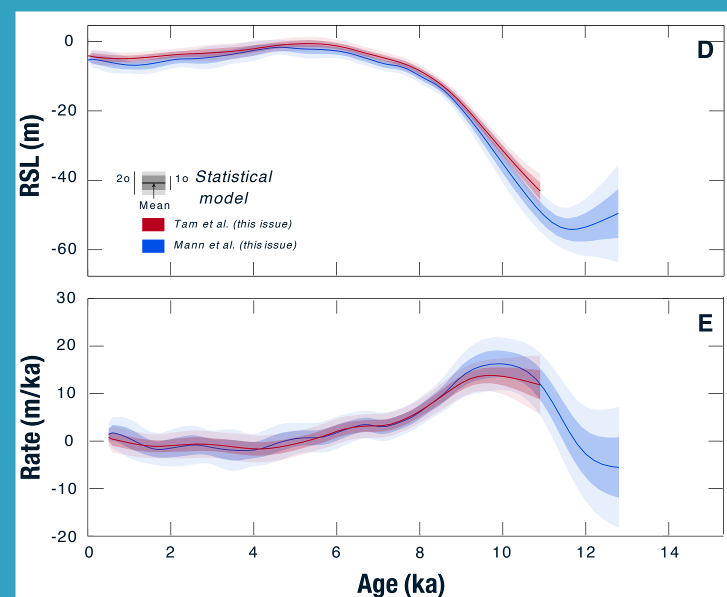
RESOLUTION OF DATA THROUGH TIME



REPLICATION OF SEA-LEVEL DATA



- Different approaches based on the objectives of their study
- Easy to understand differences in interpretation when using HOLSEA template
- How to handle samples with multiple interpretations in the database?



APPLICATION OF THE DATABASE

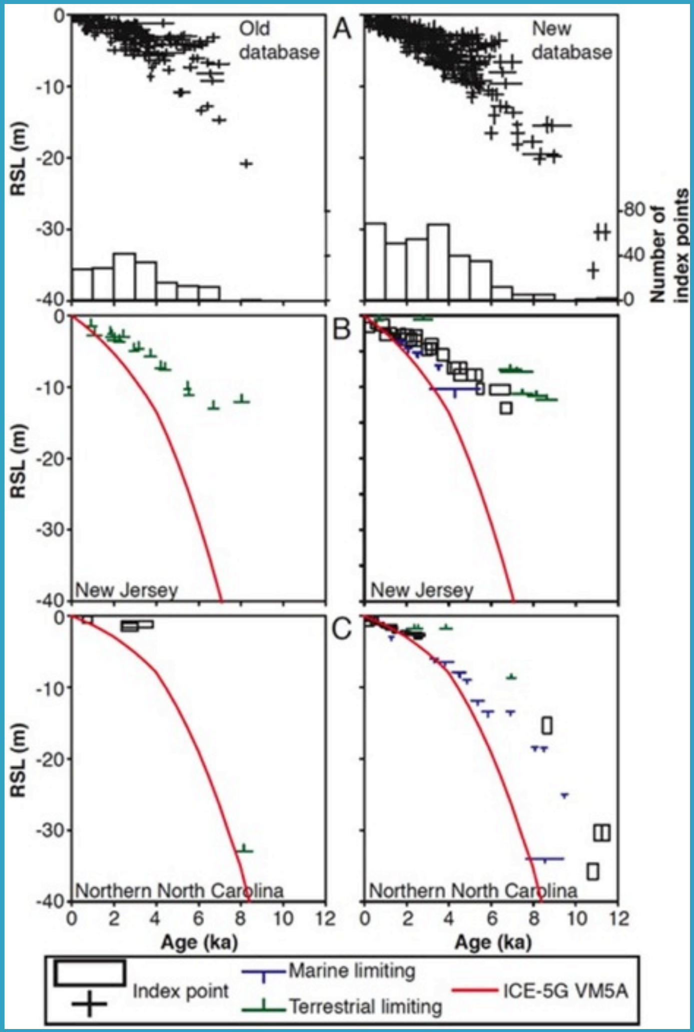
Produce a standardized global synthesis of Holocene relative sea-level data to:

1) Provide a high-quality standard to the GIA community for model tuning
2) Estimate the magnitudes and rates of GMSL change
3) Examine regional variability of RSL, its rates, and its driving mechanisms
4) Guide research questions to inform RSL projections

IMPORTANCE FOR GIA MODELS

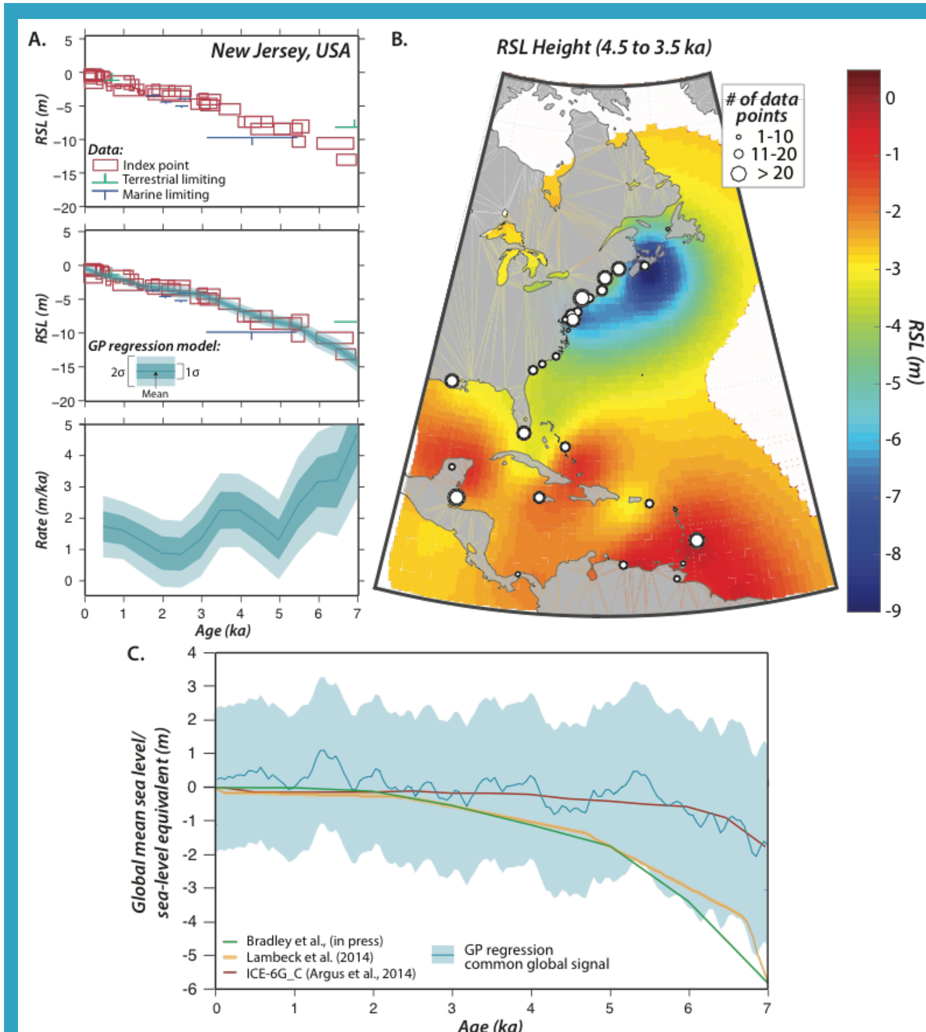
1. Increased number (>650 data points) compared to Peltier (1996)
2. Understanding of the indicative meaning
3. Elevation uncertainties

Certain locations may require 3D viscosity structure to fit RSL data



Engelhart et al. (2011)

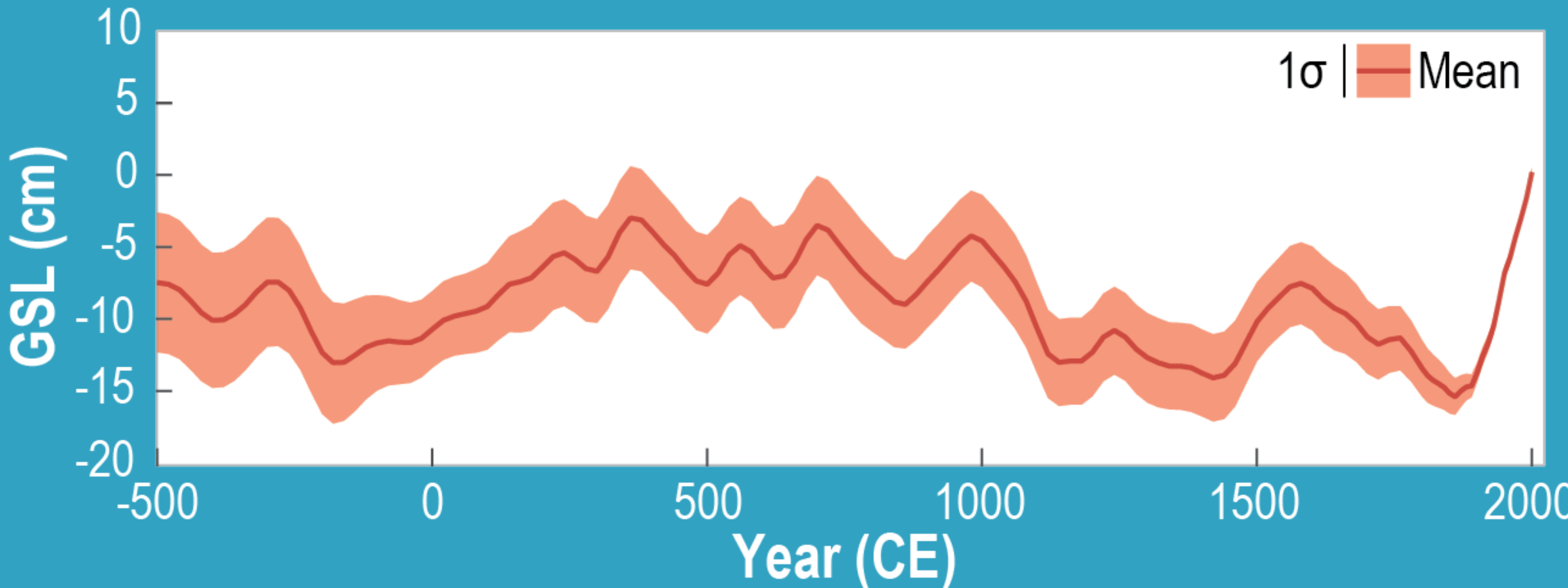
STATISTICAL ANALYSIS OF SEA-LEVEL DATA



Advances in statistical modeling of RSL data enables us to expand our knowledge of past sea levels beyond inferences from discrete index points to developing probabilistic estimates of its past position and rates of change on local (A), regional (B), and global (C) scales.

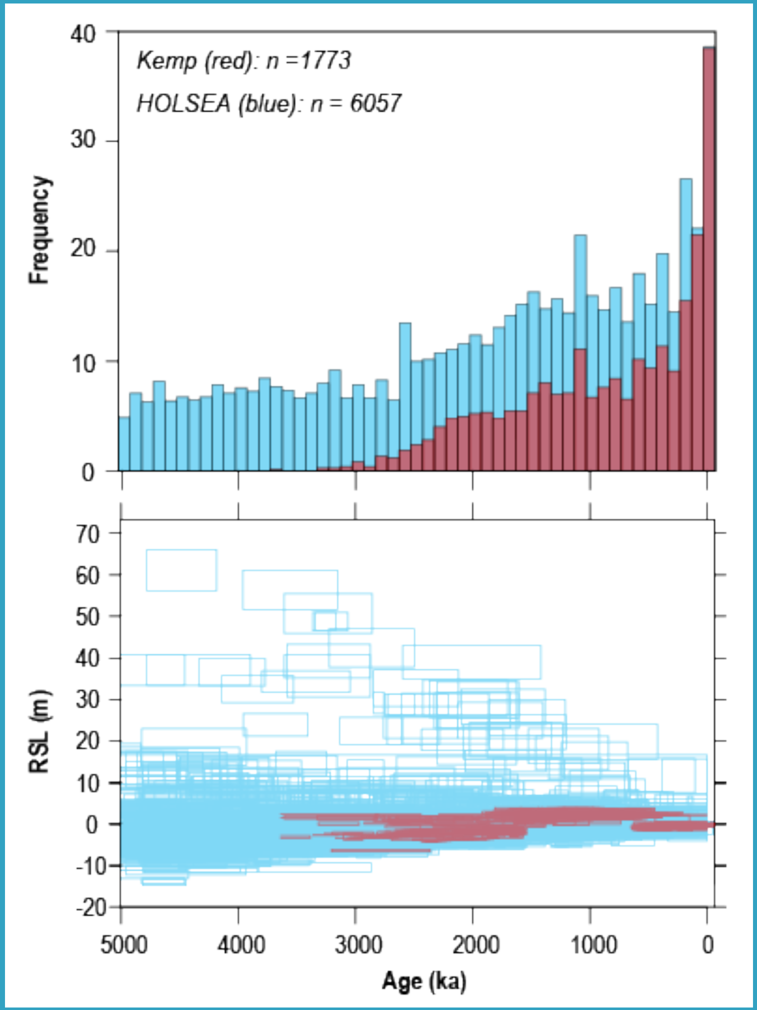
Ashe et al. (2019), QSR

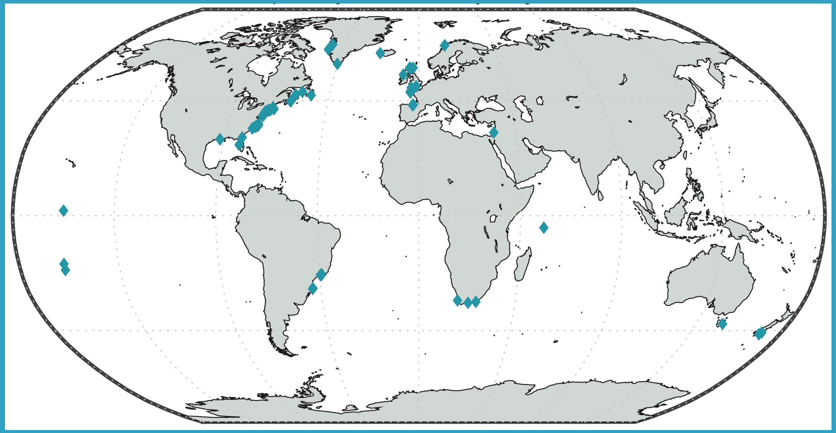
UPDATING GLOBAL MEAN SEA-LEVEL RECONSTRUCTIONS



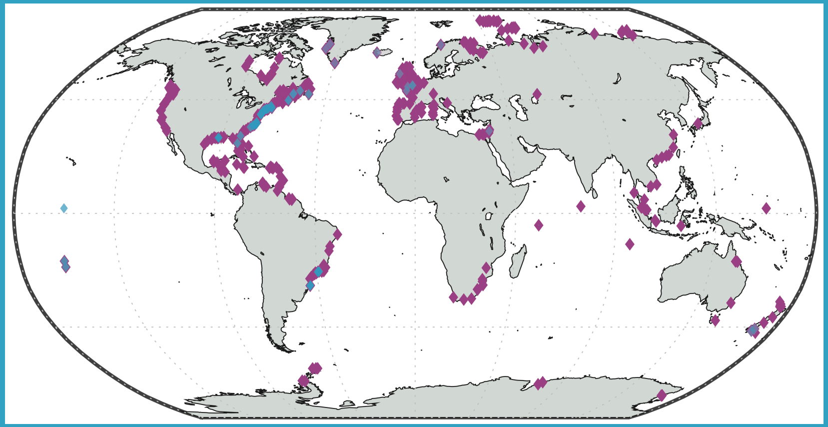
Kopp et al., 2016, PNAS

UPDATING GLOBAL MEAN SEA-LEVEL RECONSTRUCTIONS





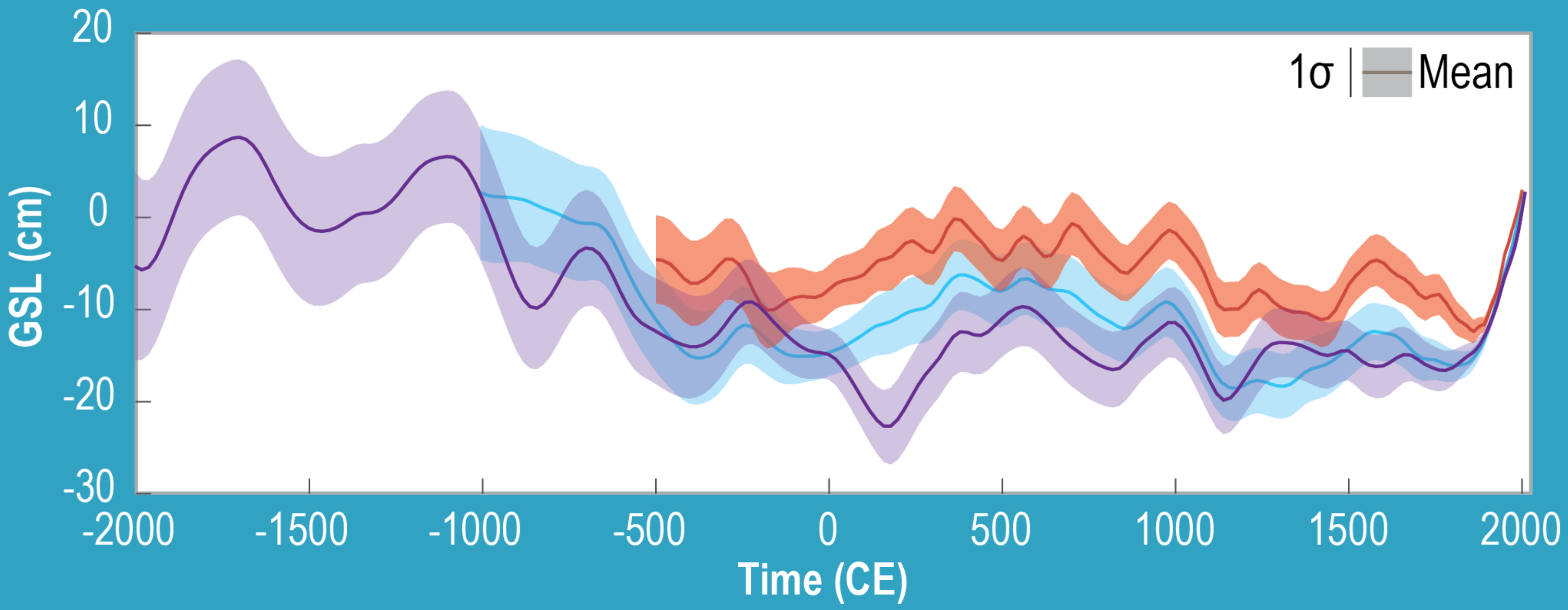
Kemp et al. (2018) proxy dataset



Expanded HOLSEA proxy dataset

UPDATING GLOBAL MEAN SEA-LEVEL RECONSTRUCTIONS

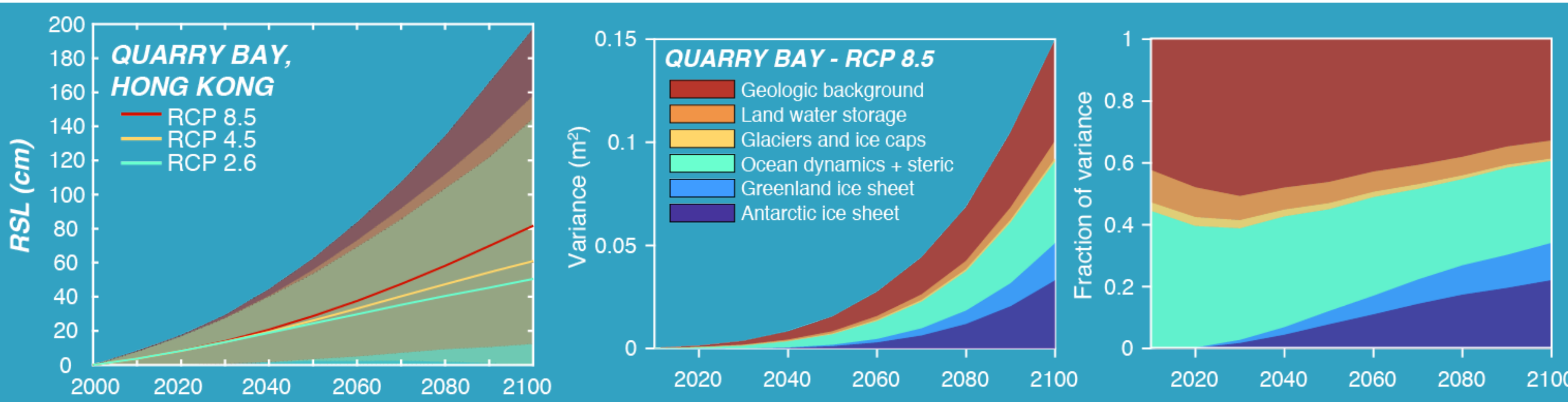
PRELIMINARY ANALYSIS!

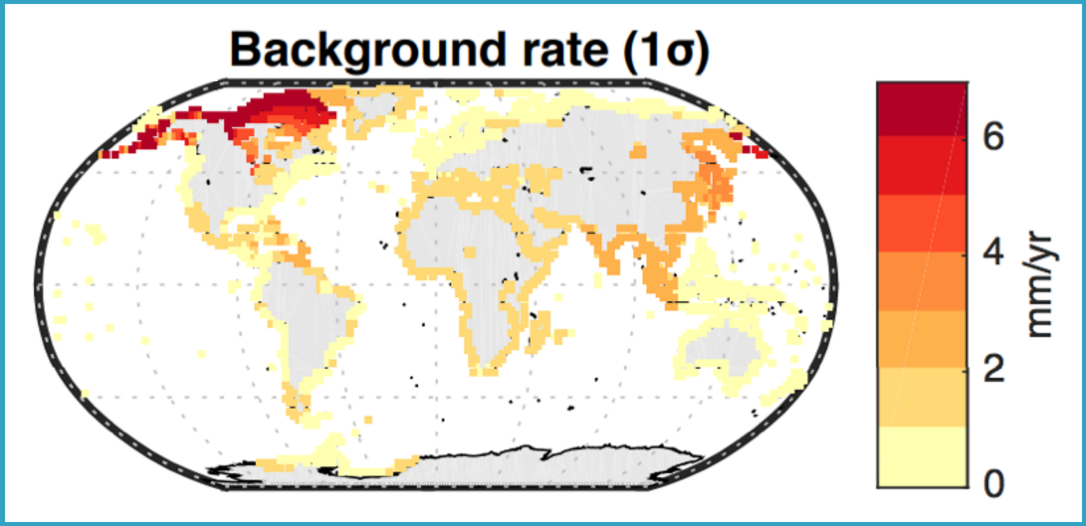


Sensitivity tests :

- Examine robustness of jumps in new curve from -1500 to -500 CE
- Understand lowering of GSL estimates with increased amount of data

RSL PROJECTION UNCERTAINTY





- Relatively high uncertainties on background geologic component of predictions across many coastlines

- Can we reduce these uncertainties by increasing the number of sea-level studies in these region?

Kopp et al., 2014, 2017 Earth's Future; Horton et al., 2018, Annual Reviews

FOR FURTHER DETAILS

- Khan, N.S., Horton, B.P., Engelhart, S., Rovere, A., Vacchi, M., Ashe, E.L., Törnqvist, T.E., Dutton, A., Hijma, M.P. and Shennan, I., 2019. Inception of a global atlas of sea levels since the Last Glacial Maximum. *Quaternary Science Reviews*, *220*, pp.359-371.
- QSR Special Issue: https://www.sciencedirect.com/journal/quaternary-science-reviews/special-issue/10JP1J08X2H
- www.holsea.org