Introduction:
Structured expert judgment is an accepted tool in risk analysis for supplementing data shortfalls, quantifying uncertainty and building rational consensus. A panel of experts quantifies uncertainty with regard to variables of interest and calibration variables from the subject area. Experts are treated as statistical hypotheses and combined so as to maximize the statistical accuracy and informativeness of the "decision maker". Expert names are preserved to enable competent peer review, but are not associated with responses in any open documentation. Expert reasoning is captured during the elicitation and becomes, where indicated, part of the published record. Elicitation is done by specifying percentiles of uncertain quantities, as illustrated below. Equally weighted combinations are also enabled.

Elicitation Format
You are presented with an uncertain quantity
How many sq km were impacted by the Sept 15 2017 melt event in Greenland

___________	___________	___________
5%	**50%**	**95%**

You are asked to quantify your uncertainty by specifying percentiles of your subjective uncertainty:
The 50%-tile is that number for which you judge the chance ½ that the true value is above or below
The 5%-tile is that number for which the chance that the TRUE VALUE IS BELOW IS 0.05.
ALWAYS: 5%-tile ≤ 50%-tile ≤ 95%-tile

Suppose you respond as shown below:

__100,000__	**__150,000___**	**_220,000__**
5%	**50%**	**95%**

This means that the true value is equally likely to be above or below 150,000 sq km, and a 90% chance that it lies between 100,000 and 220,000. The true value in this case is 263,000, which falls above the 95 percentile. If the expert is **statistically accurate**, 5% of the values should, in the long run, fall above their associated 95 percentiles.

A ***good probability assessor*** is one whose assessments capture the true values with the (long run) correct relative frequencies (**statistically accurate)**, with distributions which are as narrow as possible (**informative).** Informativeness is gauged by 'how far apart the percentiles are' relative to an appropriate background (Shannon relative information).

In gauging overall performance, statistical accuracy is more important than informativeness. Non-informative but statistically accurate assessments are useful, as they sensitize us to how large the uncertainties may be; highly informative but statistically very inaccurate assessments are not useful. Do not shy away from wide distributions if that reflects your real uncertainty.

Dependence Elicitation

Expert uncertainties may not be independent. It may be that two or more variables may co-vary. We distinguish two types of co-variation; **Overall Dependedence** and **Tail Dependence.** Overall dependence is indicated when knowledge that one variable is above its median raises belief that another variable is above or below its median. Overall dependence can be positive (above - above) or negative (above-below). Taill dependence is indicated when the association between two variables is concentrated in the upper or lower tails. Tail dependence ranges from 0 (tail independence) to 1 (complete tail dependence).

We gauge expert dependence by asking for exceedence probabilities.

An example for capturing overall dependence is:

> For the Greenland Ice Sheet in 2100 with 4°C global surface warming wrt pre-industrial:
> *Given **runoff** ≥ your 50% value, **probability** that **accumulation** also ≥ your 50% =* __________

- if runoff and accumulation are completely **positively** dependent, then this **probability = 1**
- if runoff and accumulation are **independent,** then **this probability = 1/2**
- if runoff and accumulation are completely **negatively** dependent, then this **probability = 0**

Many distributions, includian the Normal distribution are **Tail Independent.** Ignoring taill dependence when it is present can produce large errors when variables are summed. This has been credited for contributing to the 2008 financial crisis.

An example for capturing tail dependence is:

> For the Greenland Ice Sheet in 2100 with 4°C global surface warming wrt pre-industrial
> *Given **runoff** ≥ your 95% value, probability that **accumulation** also ≥ your 95% =* __________

- if runnoff and accumulation are tail independent, this **probability = 0.05**
- if runnoff and accumulation are completely tail dependent, this **probability = 1**

(Tail dependence is a property characterizing association as values go to their highest or lowest extremes. As the 95%-tile increases toward 100%, the lower limit goes to zero.)

Dependence is potentially very complex. In this study dependence is elicited only for selected pairs of variables for year 2100 with 4°C global surface warming . The same dependence structure will be used for other years.

This sheet contains 16 questions. Three distinct and ascending values are required for each question, please.

1 According to Kopp et al (2016), over the 2,000 years prior to the industrial era, Global Mean Sea Level (GMSL) exhibited small fluctuations of about ±8 cm. What was the decline in GMSL in cm between the years 1000 and 1400 CE?

Kopp, R.E., et al. (2016). Temperature-driven global sea-level variability in the Common Era. PNAS, 113, E1434-E1441. [10.1073/pnas.1517056113]

5%	50%	95%

2 Chuter et al (2017) compared two different indicators of ice thickness along the grounding line of the Abbot ice shelf in Antarctica, using data derived from CryoSat-2 and Bedmap2. What was the largest thickness difference in meters (if CS2 > Bedmap2, the difference is positive)?

Chuter, S. J., et al. (2017), Mass balance reassessment of glaciers draining into the Abbot and Getz Ice Shelves of West Antarctica, Geophys. Res. Lett., 44, 7328–7337, doi:10.1002/2017GL073087

5%	50%	95%

3 Totten Glacier is the highest flux outlet in East Antarctica. Based on ICESat laser altimetry, as of 2009 what was its thinning rate over areas of fast flow, in m/yr?

Pritchard HD et al (2009) Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets. Nature (online 29 Sep 2009).

5%	50%	95%

4 Based on (roughly monthly) GRACE measurements of mass changes from April 2002 through 2016, Antarctic ice sheets lost mass at a rate of 138 Gt/year, and the Greenland ice sheet lost mass at a rate of 269 Gt/year. The "May-Sep anomaly" (*for anomaly read difference*) in any given year is the mass in September minus the mass in May [in Gt]. Over the period 2002 – 2016, what was the average Greenland “May – Sep anomaly” (i.e. mass difference), in Gt?

Wiese, D. N., et al. (2016) JPL GRACE Mascon Ocean, Ice, and Hydrology Equivalent Water Height RL05M.1 CRI Filtered Version 2., Ver. 2., PO.DAAC, CA, USA. Dataset accessed [2017-12-12] at http://dx.doi.org/10.5067/TEMSC-2LCR5. [https://grace.jpl.nasa.gov/resources/31/]

5%	50%	95%

5 As per last question: The "Dec-Mar anomaly" is the mass in March of the following year minus the mass in the preceding December [in Gt]. What was the average Antarctica “Dec - Mar anomaly” (i.e. mass difference) over the period 2002 – 2016, in Gt?

Wiese, D. N., et al. (2016) JPL GRACE Mascon Ocean, Ice, and Hydrology Equivalent Water Height RL05M.1 CRI Filtered Version 2., Ver. 2., PO.DAAC, CA, USA. Dataset accessed [2017-12-12] at http://dx.doi.org/10.5067/TEMSC-2LCR5. [https://grace.jpl.nasa.gov/resources/31/]

5%	50%	95%

6 The Marguerite Bay palaeo ice-stream in the northern Antarctic Peninsula reaches the sea as a submarine trough flowband that is ~700km long. The final 230km of the trough, before the sea, forms a reverse slope bed. Jamieson et al. (2012) developed a dynamic simulation of ice-stream retreat since the Last Glacial Maximum, constrained by geophysical data consistent with the geomorphological record. On the basis of a steady state flow mass balance flux, their model considered initial flow velocities at the sea, V_S, and at the start of the reverse slope, V_{RS}. What was the difference in these velocities, in m/year (positive if $V_S > V_{RS}$)?

Jamieson, S. S. R., et al. (2012). Ice-stream stability on a reverse bed slope. Nature Geoscience 5: 799-802. doi:10.1038/ngeo1600

5%	50%	95%

7 Lambeck et al (2014) list 968 measurements of past relative sea level (RSL) [m] relative to present with associated ages (ka BPE) between 0.073 and 34.8 ka. Negative values for RSL denote values lower than present. There are 14 sediment measurements from Western Australia (ages 15 - 30 ka), and 16 coral measurements from the Caribbean (ages 17 ka - 20 ka). What is the difference between these regional RSL [m] medians (positive for W Australia RSL higher than Caribbean, negative otherwise)?

Lambeck, K., et al. (2014). Sea level and global ice volumes from the Last Glacial, Maximum to the Holocene. PNAS, 111, 15296-15303. www.pnas.org/cgi/doi/10.1073/pnas.1411762111

5%	50%	95%

8 Paolo et al (2015) made estimates of thickness-change rates (m/yr) in the Antarctic ice shelves for the period 1994-2012, using radar altimetry data. Radar height changes were converted to thickness changes and rates. For the individual ice shelves, what is the span of percentage thickness change from the shelf with greatest reduction to that with highest gain (e.g. -25% → +25% = 50%) ?

Paolo, F.S. et al (2015) Volume loss from Antarctic ice shelves is accelerating. Science DOI: 10.1126/science.aaa0940

5%	50%	95%

9 Using aerial imagery from the 1980s alongside altimetry for later periods, Kjeldsen et al. (2015) estimated the total ice mass loss per year around the entire Greenland Ice Sheet since for three periods: 1900-1983; 1983-2003; ad 2002-2010. What was the difference between estimated total ice mass loss in Gt/yr for the first period and that for the third period (in Gt/yr, positive if Period 3 > Period 1, otherwise negative)?

Kjeldsen, K. K., et al. (2015). Spatial and temporal distribution of mass loss from the Greenland Ice Sheet since AD 1900. Nature 528(7582): 396-400. doi:10.1038/nature16183

5%	50%	95%

5%	50%	95%

10 Wang et al. (2017) considered four sub-regions comprising the West Antarctic Ice Sheet. According to them, snow accumulation on the Antarctic Peninsula (AP) exhibited the greatest increase in the 20th century. What was the overall percentage increase of snow accumulation on AP between 1950 to 2010 CE?

Wang, Y., et al. (2017). Snow accumulation variability over the West Antarctic Ice Sheet since 1900: a comparison of ice core records with ERA-20C reanalysis. Geophysical Research Letters, 44. https://doi.org/10.1002/2017GL075135

A study by Miles et al (Nature, 2013) examined the terminus position of 175 Pacific Ocean-terminating outlet glaciers in East Antarctica using satellite imagery and, for comparison, 46 glaciers facing the Ross Sea. They examined three epochs 1974-1990, 1990-2000 and 2000-2010.
Miles, B. W. J., et al., (2013), Rapid, climate-driven changes in outlet glaciers on the Pacific coast of East Antarctica, Nature, 500(7464), 563-566,

11 What was the mean terminus change rate for Pacific-facing outlet glaciers in the third epoch, in m/yr (positive for advance, negative for retreat)?

5%	50%	95%

12 Of the 46 glacier outlets facing the Ross Sea for which measured widths are reported by Miles et al., what is the average width (km)?

5%	50%	95%

13 Of these same Ross Sea outlets which have measured widths greater than the average for all 46, and for which measured velocities are reported, what is the average velocity (m/y)?

5%	50%	95%

14 In Pfeffer et al (2008), thirty-three Greenland drainage basins had a median width at gate of 10.4 km. For those with reported widths greater than the median value of 10.4 km, what is the average velocity at gate (m/y)?

5%	50%	95%

Pfeffer, W.T., et al. (2008). Kinematic constraints on glacier contributions to 21st-Century sea-level rise. Science 321, 1340; DOI: 10.1126/science.1159099

15 Mitrovica et al. (2001) presented numerical predictions of gravitationally consistent patterns of relative sea-level change following variations in either the Antarctic or Greenland ice sheets. The predictions, which were normalized by the equivalent global-mean sea-level change for each mass flux event, characterize geometrically distinct patterns on a global scale. If a melting event in Greenland contributes a net 1mm/yr of relative sea-level rise at Newlyn (50.1°N, 5.5°W) in southwest England, according to this modelling what would be the contribution to relative sea-level rise at the point from a similar melting event in West Antarctica?

5%	50%	95%

Mitrovica, J.X., et al. (2001). Recent mass balance of polar ice sheets inferred from patterns of global sea-level change. Nature 409, 1026-1029.

16 During the last deglaciation, the largest and most rapid melting episode was Meltwater Pulse1A [MWP-1A], which occurred about 14,500 years ago, with rates of sea-level rise reaching approximately 4m per century (various sources cited by Liu et al., 2015). Liu et al. used a glacial isostatic adjustment (GIA) sea-level model to calculate global sea-level changes for a range of ice histories, corrected to remove the effect of pre-MWP1a ice changes, so that the difference among the sites depends on static-equilibrium gravitational, rotational and deformational effects. They compared these sea-level estimates with coral and/or mangrove paleo-sea-level indicators from three locations: Barbados, Sunda Shelf and Tahiti. What was their model-corrected upper bound estimate of MWP-1A amplitude for the coral indicators of Barbados, in m?

5%	50%	95%

Liu J et al. (2015) Sea-level constraints on the amplitude and source distribution of Meltwater Pulse 1A. Nature Geoscience, (advance online publication doi:10.1038/NGEO2616).

1

exp1 *A positive accumulation change will results in a negative sea level contribution.*

exp1 SLR = “mm global-mean sea-level equivalent" = Runoff+ Discharge - Accumulation

Three distinct and ascending values are required for each question, please.

Greenland

2050

Greenland, for a global mean SAT rise of **1.5`°C** by **2050** WRT pre-industrial what will be the **integrated contribution,** in **mm SLR** relative to 2000-2010 of the following:

We are asking you to consider two trajectories of global mean SAT. In the first trajectory, GMST rises to 1.5°C above pre-industrial (defined here as 1850-1900) by 2050, then to 2.0°C by 2100, and stabilizes at 2.0°C through 2300. In the second trajectory, GMST rises to 2.0°C above pre-industrial by 2050, then to 5.0°C by 2100, and stabilizes at 5.0°C through 2300. In the 21st century, the first response is consistent with Representative Concentration Pathway 2.6, and the second response consistent with Representative Concentration Pathway 8.5. After 2100, we are attempting to capture your understanding of the dynamic response of the ice sheets in a stabilized global climate.

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

Idem, 2°C by 2050

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

2100

Greenland, for a global mean SAT rise of **2°C** by **2100** WRT pre-industrial what will be the **integrated contribution,** in **mm SLR** relative to 2000-2010 of the following:

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

Idem, 5°C by 2100

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

2200

Greenland, for a global mean SAT rise of **2°C** by **2200** WRT pre-industrial what will be the **integrated contribution,** in **mm SLR** relative to 2000-2010 of the following:

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

Idem, 5°C by 2200

Accumulation	**5%**	**50%**	**95%**
Runoff	**5%**	**50%**	**95%**
Discharge (grounding line flux)	**5%**	**50%**	**95%**

2300

Greenland, for a global mean SAT rise of **2°C** by **2300** WRT pre-industrial what will be the **integrated contribution,** in **mm SLR** relative to 2000-2010 of the following:

Accumulation	**5%**	**50%**	**95%**

Accumulation			
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2300

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

West Antarctica

2050

West Antarctica, for a global mean SAT rise of **1.5°C** by **2050** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 2°C by 2050

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2100

West Antarctica, for a global mean SAT rise of **2°C** by **2100** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5C by 2100

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2200

West Antarctica, for a global mean SAT rise of **2°C** by **2200** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2200

Accumulation	5%	50%	95%

Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2300

West Antarctica, for a global mean SAT rise of **2°C** by **2300** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2300

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

East Antarctica

2050

East Antarctica, for a global mean SAT rise of **1.5°C** by **2050** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 2°C by 2050

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2100

East Antarctica, for a global mean SAT rise of **2°C** by **2100** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2100

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2200

East Antarctica, for a global mean SAT rise of **2°C** by **2200** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%

Accumulation			
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2200

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

2300

East Antarctica, for a global mean SAT rise of **2°C** by **2300** WRT pre-industrial what will be the integrated contribution, in mm SLR relative to 2000-2010 of the following:

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Idem, 5°C by 2300

Accumulation	5%	50%	95%
Runoff	5%	50%	95%
Discharge (grounding line flux)	5%	50%	95%

Median exceedance *[if these uncertainties are independent, the probability is 0.5; probabilities greater than 0.5 indicate positive association, less than 0.5 indicate negative association.]*

95% -tile exceedance *[if these uncertainties are independent, the probability is 0.05; probabilities greater than 0.05 indicate positive association.]*

warming is with respect to Pre Industrial global mean temperature

Greenland Ice Sheet, 2100 5°C Warming

Given ***runoff*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***discharge*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***runoff*** *≥ your 50% value, probability that* ***discharge*** *also ≥ your 50% =*

Given ***runoff*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***discharge*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***runoff*** *≥ your 95% value, probability that* ***discharge*** *also ≥ your 95% =*

West Antarctica Ice Sheet, 2100, 5°C warming

Given ***runoff*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***discharge*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***runoff*** *≥ your 50% value, probability that* ***discharge*** *also ≥ your 50% =*

Given ***runoff*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***discharge*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***runoff*** *≥ your 95% value, probability that* ***discharge*** *also ≥ your 95% =*

East Antarctica Ice Sheet, 2100; 5°C warming

Given ***runoff*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***discharge*** *≥ your 50% value, probability that* ***accumulation*** *also ≥ your 50% =*
Given ***runoff*** *≥ your 50% value, probability that* ***discharge*** *also ≥ your 50% =*

Given ***runoff*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***discharge*** *≥ your 95% value, probability that* ***accumulation*** *also ≥ your 95% =*
Given ***runoff*** *≥ your 95% value, probability that* ***discharge*** *also ≥ your 95%*

Discharge GrIS, WAIS, EAIS, 2100, 5°C warming

Given GrIS ***discharge*** *≥ your 50% value, probability WAIS* ***discharge*** *≥ 50% value =*
Given GrIS ***discharge*** *≥ your 50% value, probability EAIS* ***discharge*** *≥ 50% value =*
Given EAIS ***discharge*** *≥ your 50% value, probability WAIS* ***discharge*** *≥ 50% value =*

Given GrIS ***discharge*** *≥ your 95% value, probability WAIS* ***discharge*** *≥ 95% value =*
Given GrIS ***discharge*** *≥ your 95% value, probability EAIS* ***discharge*** *≥ 95% value =*
Given EAIS ***discharge*** *≥ your 95% value, probability WAIS* ***discharge*** *≥ 95% value =*