Temperature-dependent projections in FACTS v1.1.1

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FACTS v1.1.1 updates a number of issues in FACTS v1.0 (Kopp et al., 2023):

- FACTS v1.1 preserves a 1:1 mapping between global-mean surface air temperature (GSAT) samples and sea-level samples. In FACTS v1.0, some modules broke this mapping by resampling temperature and ocean-heat content in a random fashion that originally made sense but no longer does. This was not an issue in the application to IPCC AR6, since AR6 was not attempting to preserve traceability of sea level projections to individual temperature samples, but it was a critical issue for some applications (e.g., projection of sea level under probabilistic emissions scenarios).

- FACTS v1.1 introduces a simple interpolation scheme for the two low-confidence ice sheet modules, one of which is based on the Bamber et al. (2019) structured expert judgement study for both ice the Greenland and Antarctic ice sheet (Figure 1 and 2), and one of which uses DeConto et al. (2021) for the Antarctic ice sheet (Figure 3). The interpolation scheme, based on weighting inputted distributions using cumulative global mean surface air temperature in 2100, allows projections from these modules to depend upon temperature inputs. In contrast, in FACTS v1.0, both modules looked up results based on offline calculations and did not depend directly on temperature samples. In FACTS v1.0, the DeConto et al. (2021) module could only provide results for RCP 2.6, 4.5 and 8.5, while the (Bamber et al., 2019) module could only provide results for SSP1-2.6 and SSP5-8.5 (corresponding to 2 C and 5 C warming trajectories in the original paper).

- FACTS v1.1.1 switches the output format for relative sea-level change and global-mean sea-level change from 16-bit integers to 32-bit floating points. We have confirmed that this makes no change at the cm scale, but does enable applications that require finer precision (e.g., calculation of the effects of pulse emissions.)

This technical note documents the relationship between GSAT and sea level in FACTS v1.1. Temperature-dependent results are shown based on binning results from all five SSPs based on 2081–2100 average global-mean surface air temperature (GSAT) in bins with width of 0.5 C (e.g., 1.25–1.75 C, 1.75–2.25 C, etc).

This note also compares SSP-based projections for FACTS v1.1.1 and FACTS v1.0.0 (Table 4). For *medium-confidence* workflows, median and 17th–83rd percentile GMSL agree between the two versions within rounding errors. For *low-confidence* workflows 3e and 3f, which use DeConto et al. (2021) for the Antarctic ice sheet, agreement is good for SSP1-2.6 and SSP5-8.5, but the projection for SSP2-4.5 exhibits greater uncertainty at the high end. This reflects the incorporation of temperature uncertainty in SSP2-4.5 into the projection; the FACTS v1.0.0 considers only the temperature trajectory for SSP2-4.5 in CCSM4. For *low-confidence* workflow 4, which uses Bamber et al. (2019), the projection for SSP1-2.6 is similarly broader at the high end, reflecting temperature uncertainty compared to the 2 C trajectory used for calibration, while the projection for SSP5-8.5 is slightly lower, reflecting that median SSP5-8.5 warming is below the 5 C calibration trajectory.

1 Module-level temperature dependence

Table 1. Component projections for 2100 by SSP

Component	Module	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Glaciers	`emulandice`	0.08 (0.06-0.10)	0.09 (0.07-0.11)	0.12 (0.1-0.14)	0.15 (0.13-0.18)	0.18 (0.15-0.2)
Glaciers	`ipccar5`	0.07 (0.06-0.10)	0.09 (0.07-0.12)	0.11 (0.08-0.15)	0.13 (0.1-0.18)	0.15 (0.11-0.21)
Antarctic	`ipccar5`	0.07 (-0.01-0.14)	0.06 (-0.01-0.13)	0.05 (-0.02-0.13)	0.05 (-0.03-0.12)	0.04 (-0.04-0.11)
Antarctic	`emulandice`	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.08 (0.03-0.14)
Antarctic	`larmip`	0.12 (0.05-0.25)	0.13 (0.05-0.27)	0.14 (0.06-0.29)	0.14 (0.05-0.32)	0.16 (0.06-0.35)
Antarctic	`bamber19`	0.10 (-0.01-0.27)	0.11 (-0.01-0.31)	0.14 (-0.0-0.43)	0.17 (0.01-0.5)	0.19 (0.02-0.55)
Antarctic	`deconto21`	0.09 (0.07-0.12)	0.09 (0.07-0.12)	0.10 (0.07-0.29)	0.22 (0.09-0.47)	0.3 (0.12-0.5)
Greenland	`ipccar5`	0.06 (0.04-0.08)	0.07 (0.05-0.09)	0.09 (0.06-0.11)	0.11 (0.08-0.15)	0.15 (0.11-0.2)
Greenland	`emulandice`	0.04 (-0.0-0.09)	0.05 (0.01-0.10)	0.08 (0.04-0.13)	0.11 (0.06-0.16)	0.12 (0.08-0.18)
Greenland	`FittedISMIP`	0.06 (0.04-0.08)	0.08 (0.06-0.10)	0.10 (0.08-0.12)	0.12 (0.1-0.15)	0.14 (0.11-0.18)
Greenland	`bamber19`	0.13 (0.07-0.32)	0.14 (0.07-0.35)	0.16 (0.08-0.44)	0.19 (0.09-0.53)	0.21 (0.09-0.57)
Sterodynamic	`tlm`	0.11 (0.09-0.14)	0.14 (0.11-0.17)	0.19 (0.16-0.23)	0.24 (0.2-0.29)	0.29 (0.24-0.35)

Median (17th-83rd percentile) projections produced by FACTS modules. All components are in m GMSL contribution relative to a 1995-2014 baseline.

Table 2. Component projections for 2100 by GSAT bin

Component	Module	1.5 C	2.0 C	3.0 C	4.0 C	5.0 C
Glaciers	`emulandice`	0.08 (0.06-0.10)	0.10 (0.08-0.12)	0.14 (0.12-0.16)	0.17 (0.15-0.19)	0.19 (0.17-0.21)
Glaciers	`ipccar5`	0.08 (0.06-0.10)	0.10 (0.08-0.13)	0.12 (0.09-0.16)	0.15 (0.11-0.19)	0.18 (0.13-0.24)
Antarctic	`ipccar5`	0.07 (-0.01-0.14)	0.06 (-0.02-0.13)	0.05 (-0.03-0.12)	0.04 (-0.04-0.11)	0.03 (-0.04-0.11)
Antarctic	`emulandice`	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.08 (0.03-0.14)	0.09 (0.03-0.15)
Antarctic	`larmip`	0.12 (0.05-0.26)	0.13 (0.05-0.28)	0.13 (0.05-0.3)	0.16 (0.06-0.34)	0.17 (0.06-0.37)
Antarctic	`bamber19`	0.10 (-0.01-0.27)	0.12 (-0.01-0.32)	0.14 (0.0-0.45)	0.19 (0.01-0.57)	0.2 (0.04-0.63)
Antarctic	`deconto21`	0.09 (0.07-0.12)	0.09 (0.07-0.12)	0.11 (0.08-0.37)	0.33 (0.17-0.52)	0.34 (0.19-0.52)
Greenland	`ipccar5`	0.07 (0.05-0.08)	0.08 (0.06-0.10)	0.10 (0.07-0.13)	0.13 (0.1-0.17)	0.18 (0.13-0.24)
Greenland	`emulandice`	0.05 (0.00-0.10)	0.06 (0.02-0.11)	0.09 (0.05-0.14)	0.12 (0.08-0.16)	0.13 (0.09-0.18)
Greenland	`FittedISMIP`	0.07 (0.05-0.08)	0.09 (0.07-0.10)	0.11 (0.09-0.13)	0.13 (0.11-0.16)	0.17 (0.13-0.19)
Greenland	`bamber19`	0.13 (0.07-0.32)	0.14 (0.08-0.35)	0.18 (0.08-0.46)	0.22 (0.1-0.56)	0.21 (0.11-0.5)
Sterodynamic	`tlm`	0.13 (0.1-0.15)	0.16 (0.13-0.19)	0.22 (0.18-0.26)	0.27 (0.22-0.32)	0.32 (0.27-0.37)

Median (17th-83rd percentile) projections produced by FACTS modules. All components are in m GMSL contribution relative to a 1995-2014 baseline.

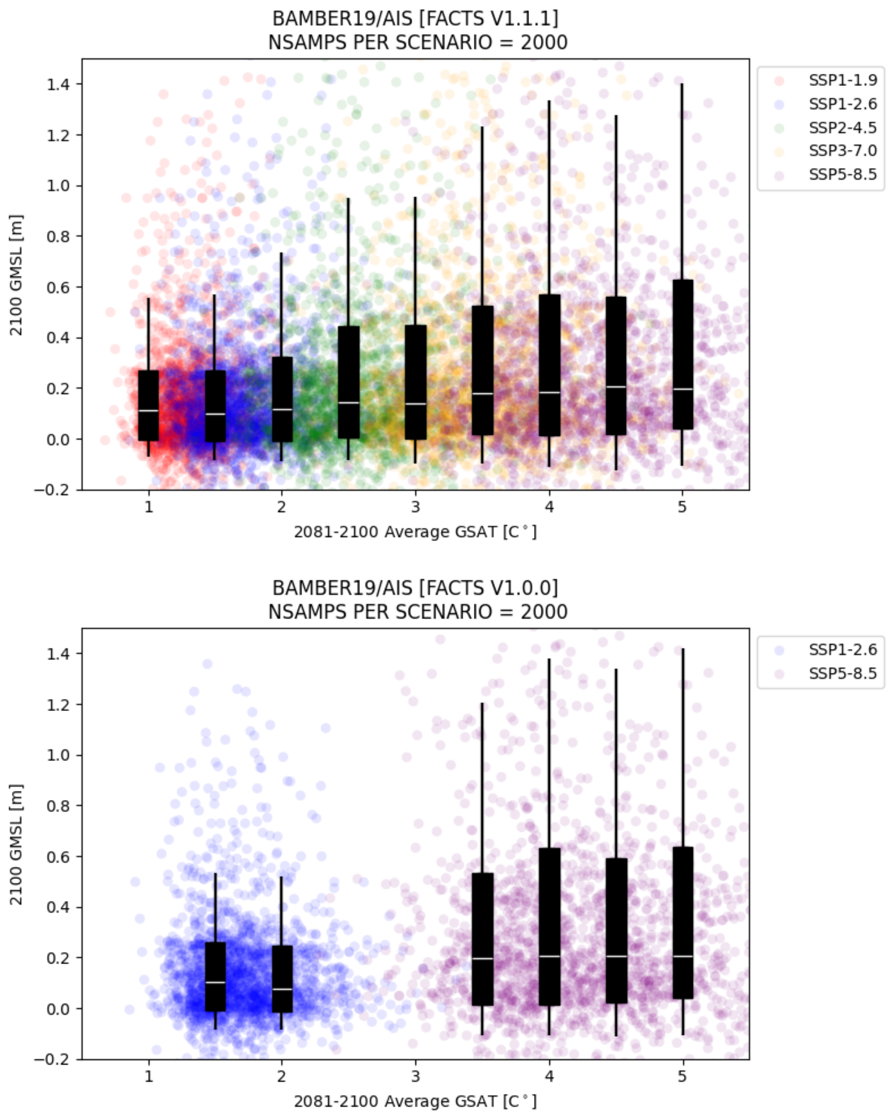


Figure 1. Projections from `bamber19/ais` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT. Dots represent individual projections, colored by SSP. Bars and whiskers represent 17-83rd and 5th-95th percentiles of projections in bins with width of 0.5°C.

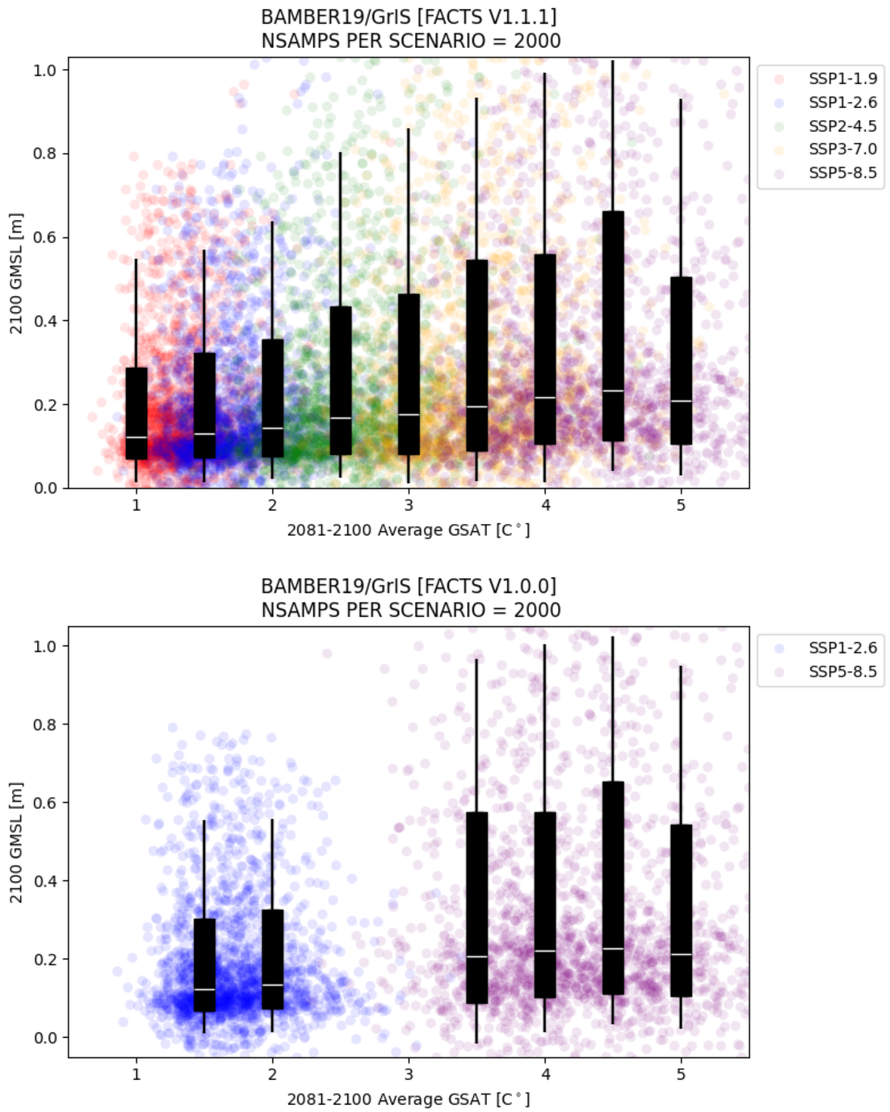


Figure 2. Projections from `bamber19/gris` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

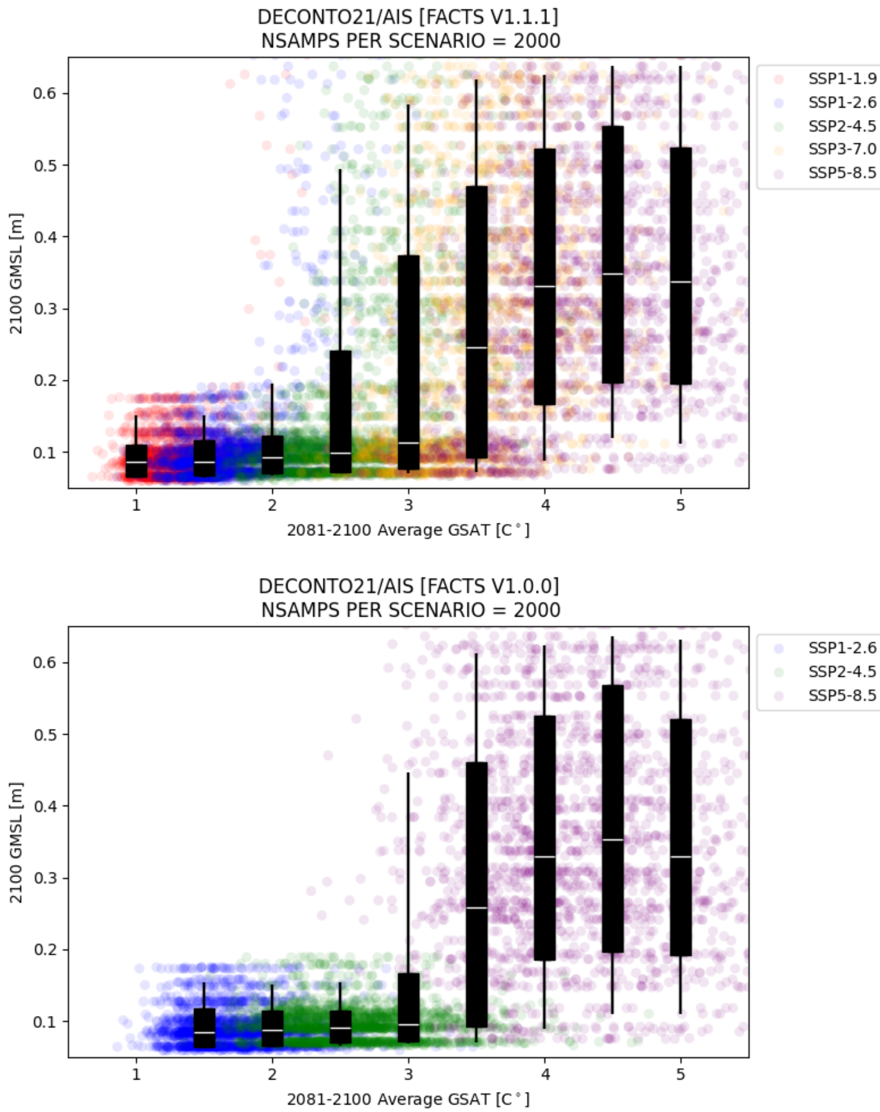


Figure 3. Projections from `deconto21/ais` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

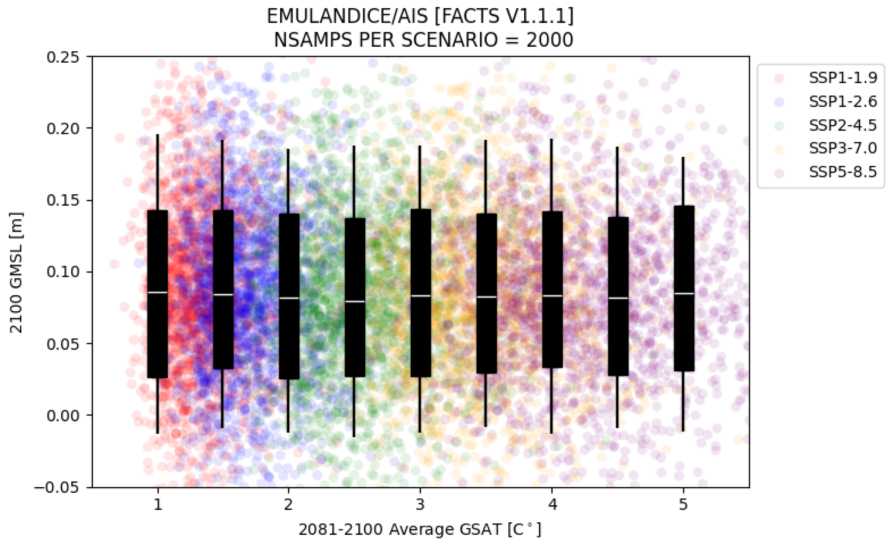


Figure 4. Projections from `emulandice/ais` module in FACTS 1.1 (unchaged from FACTS 1.0) as a function of GSAT.

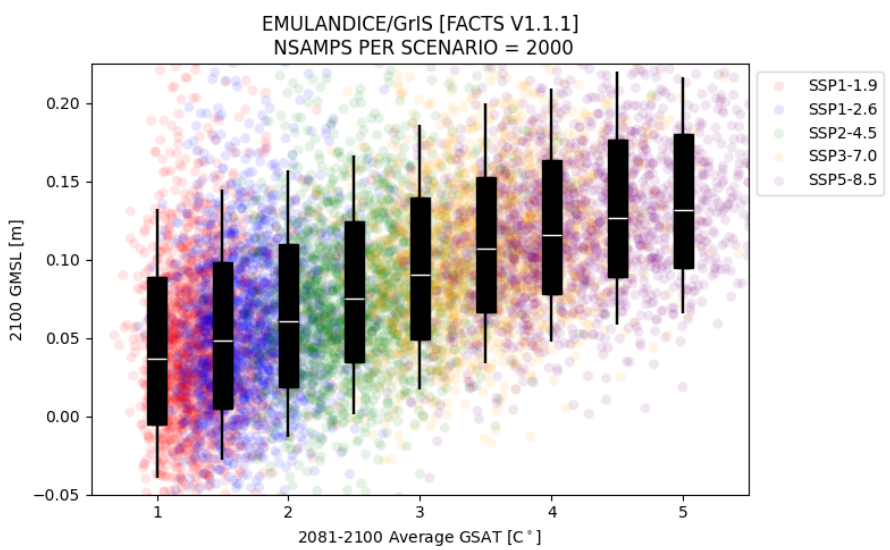


Figure 5. Projections from `emulandice/gris` module in FACTS 1.1 (unchaged from FACTS 1.0) as a function of GSAT.

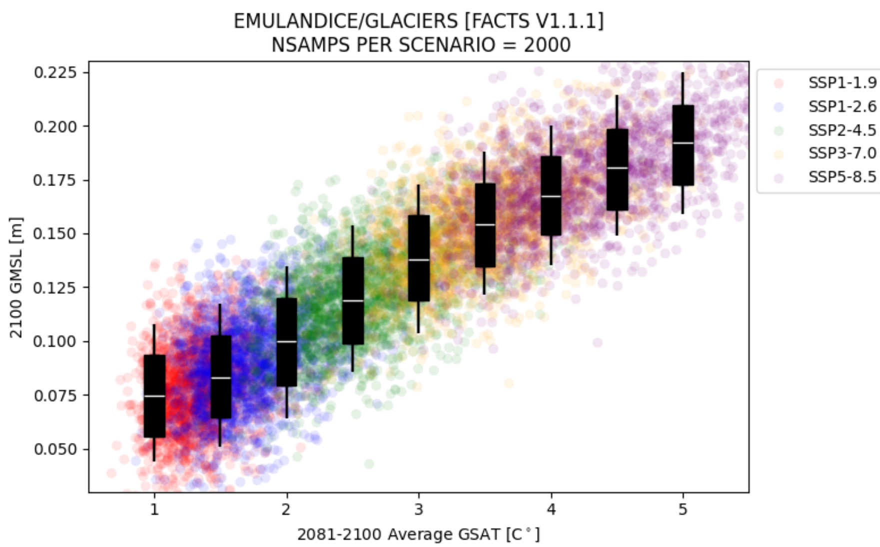


Figure 6. Projections from `emulandice/glaciers` module in FACTS 1.1 (unchaged from FACTS 1.0) as a function of GSAT.

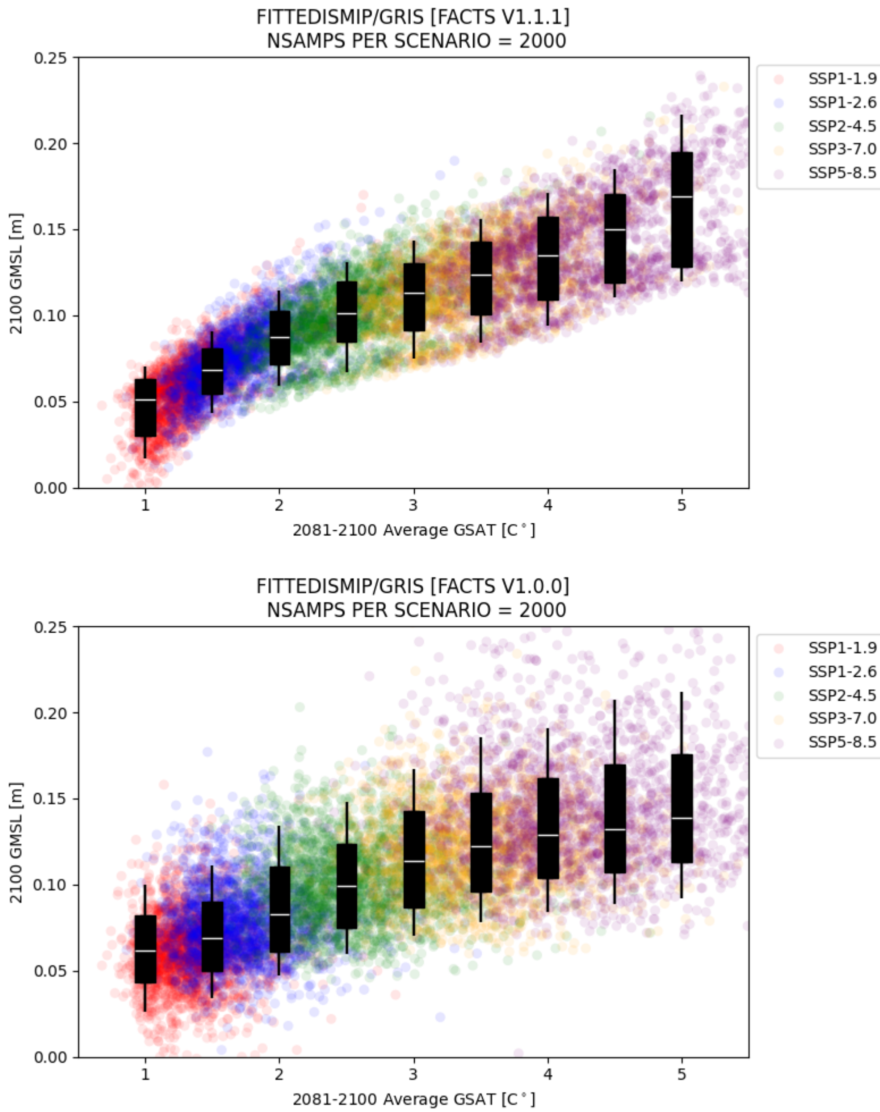


Figure 7. Projections from `fittedismip/gris` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

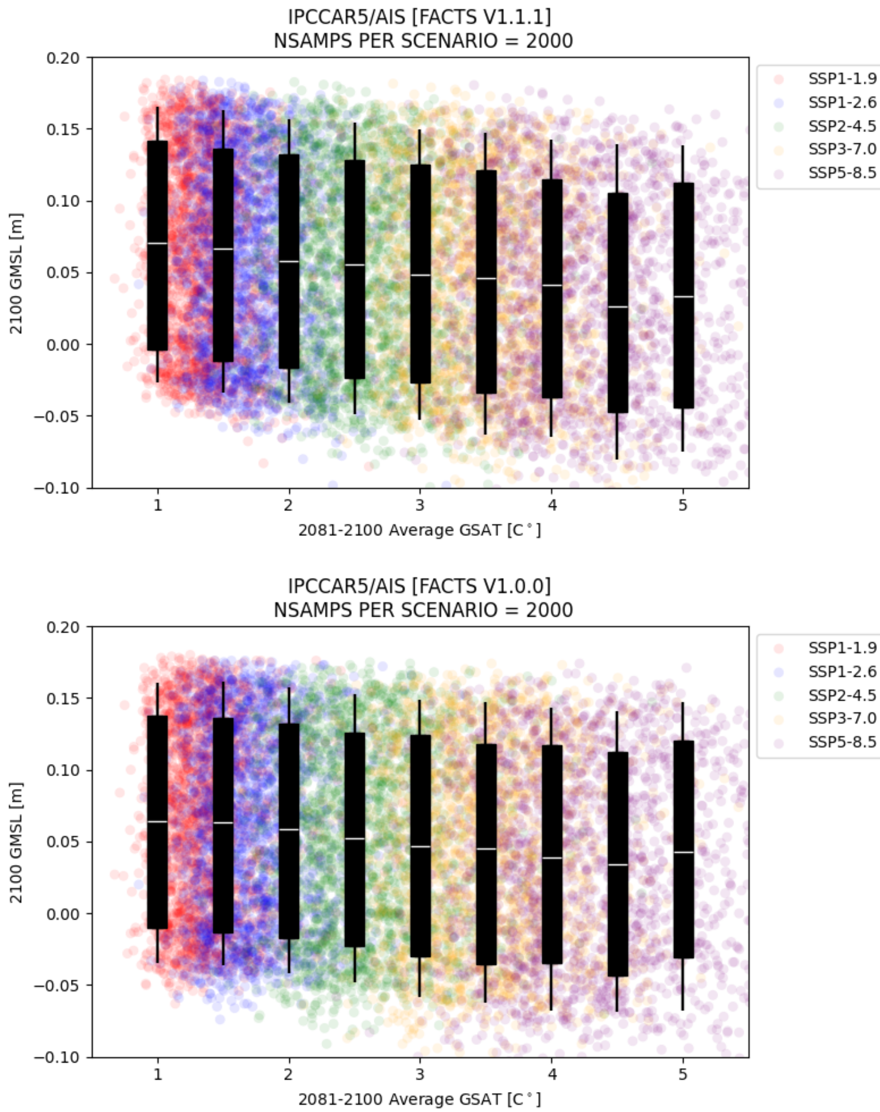
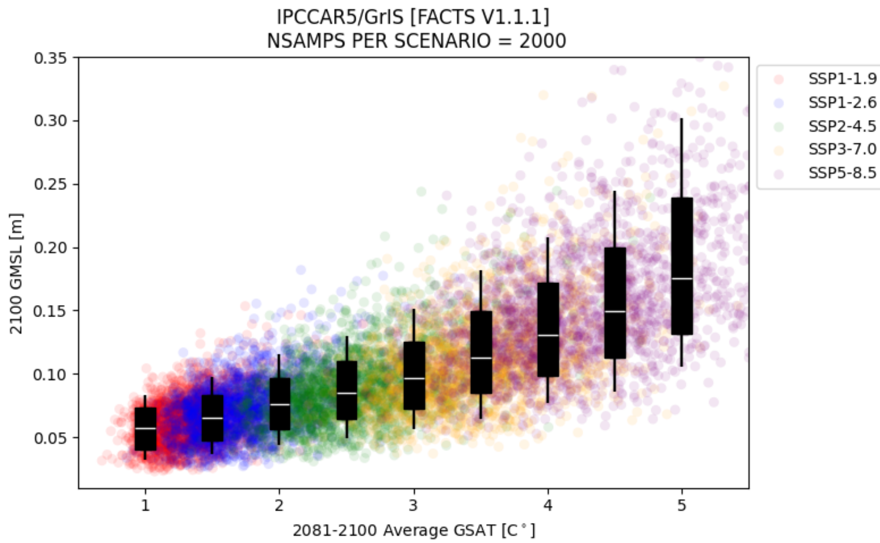


Figure 8. Antarctic ice sheet rojections from `ipccar5/icesheets` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.



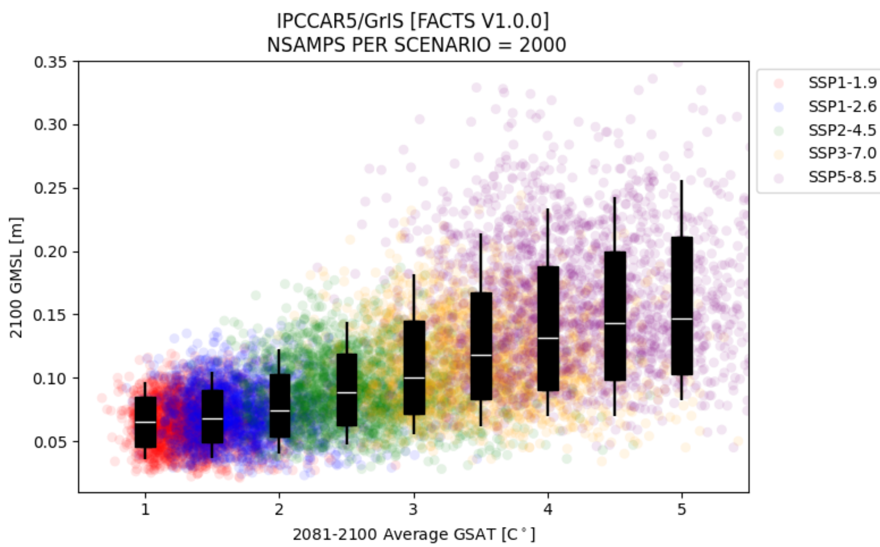


Figure 9. Greenland ice sheet projections from `ipccar5/icesheets` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

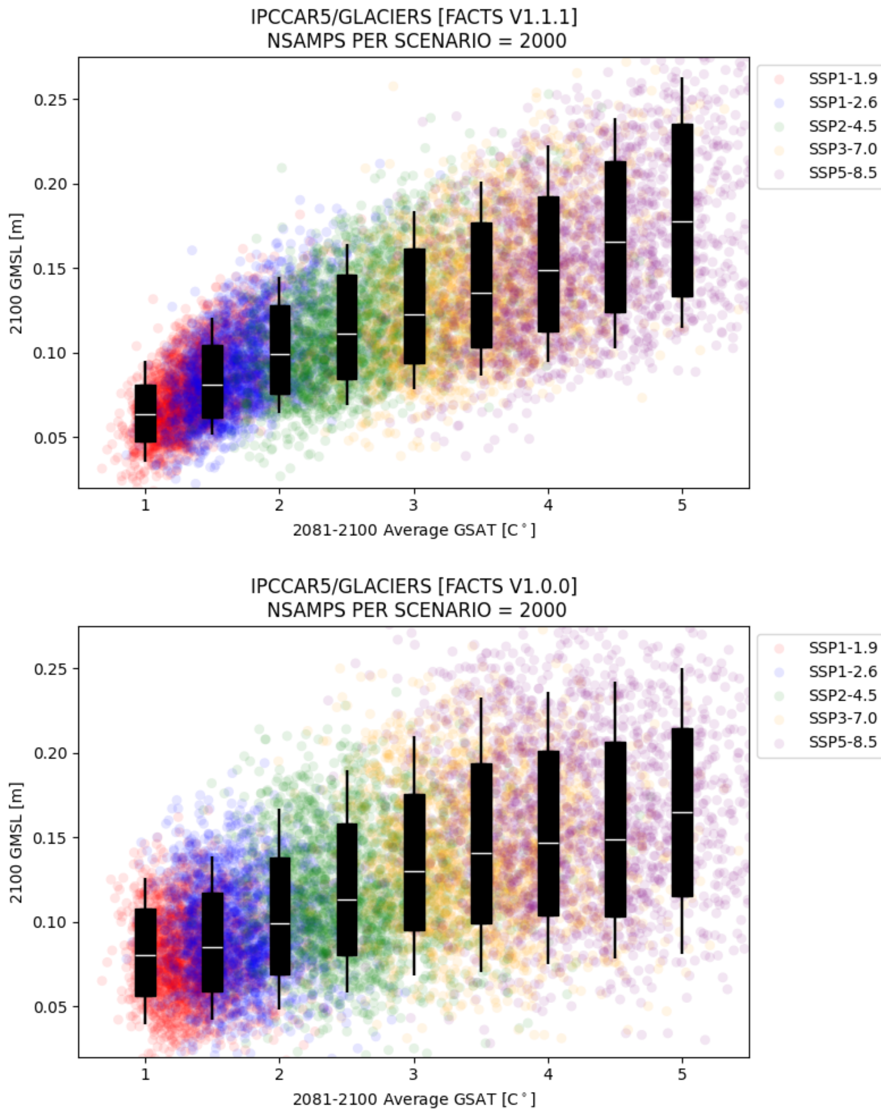


Figure 10. Projections from `ipccar5/glaciers` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

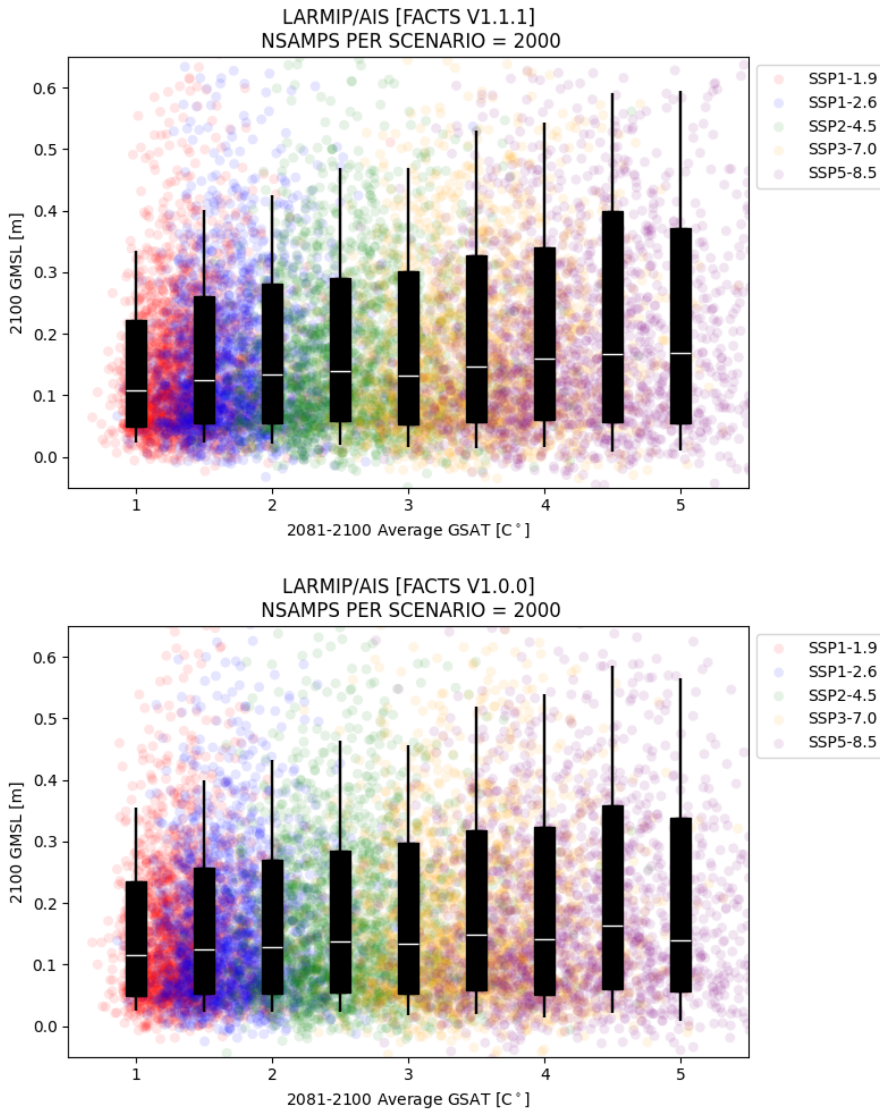


Figure 11. Projections from `larmip/ais` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

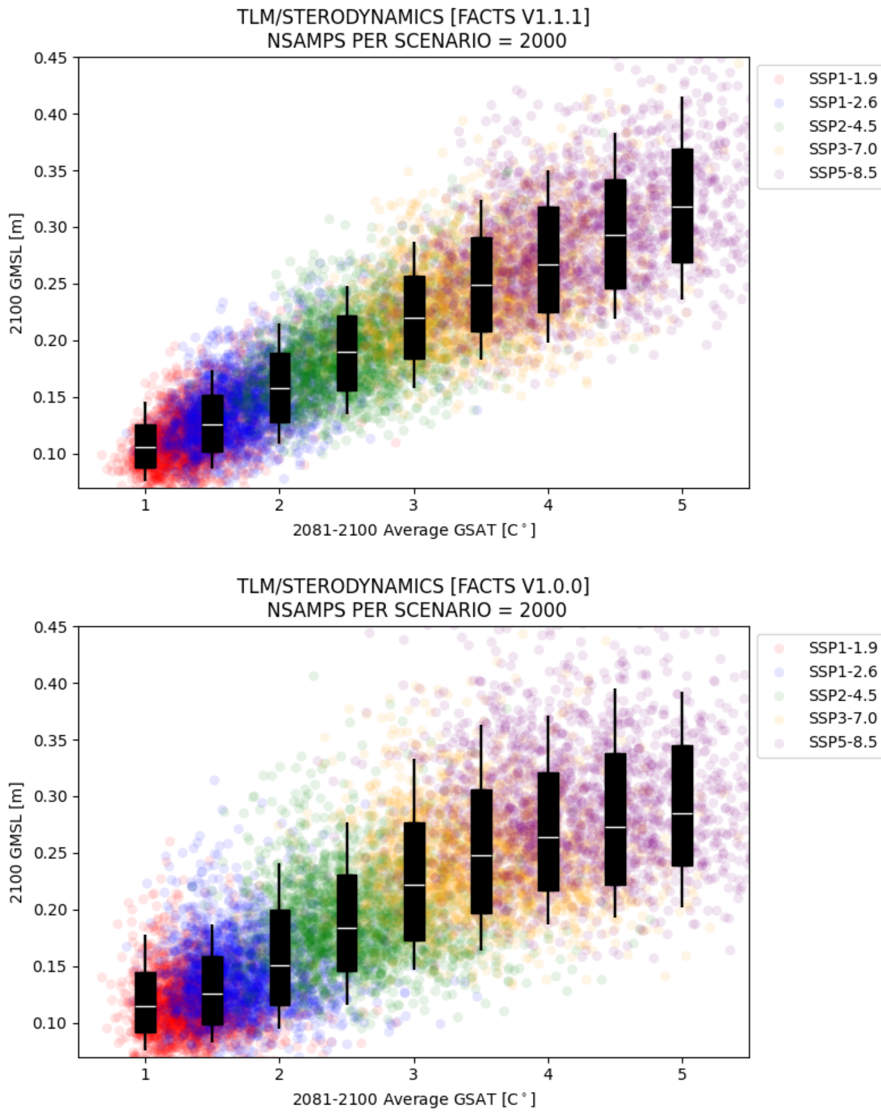


Figure 12. Projections from `tlm/sterodynamics` module in FACTS 1.1 and FACTS 1.0 as a function of GSAT.

2 Workflow-level temperature dependence of GMSL

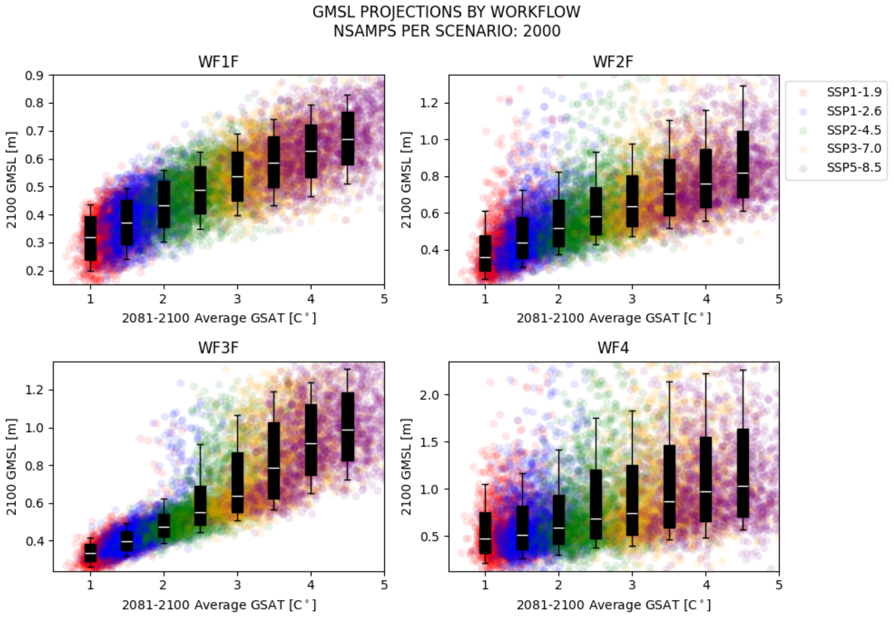


Figure 13. GMSL projections from the four focal FACTS workflows (wf1f, wf2f, wf3f, wf4) as a functions of GSAT.

Table 3. Workflows used in this technical note

Workflow	GrIS	AIS	Glaciers	Land Water	Sterodynamic	VLM
Medium confidence workflows						
1e	`emulandice`	`emulandice`	`emulandice`	`ssp`	`tlm`	`kopp14`
1f	`FittedISMIP`	`ipccar5`	`ipccar5` (GMIP2)	`ssp`	`tlm`	`kopp14`
2e	`emulandice`	`larmip`	`emulandice`	`ssp`	`tlm`	`kopp14`
2f	`FittedISMIP`	`larmip`	`ipccar5` (GMIP2)	`ssp`	`tlm`	`kopp14`
Low confidence workflows						
3e	`emulandice`	`deconto21`	`emulandice`	`ssp`	`tlm`	`kopp14`
3f	`FittedISMIP`	`deconto21`	`ipccar5` (GMIP2)	`ssp`	`tlm`	`kopp14`
4	`bamber19`	`bamber19`	`ipccar5` (GMIP2)	`ssp`	`tlm`	`kopp14`

Table 4. Total GMSL projections for 2100 by SSP, FACTS 1.1.1 vs. FACTS 1.0.0

Workflow	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
1e (1.1.1)	0.36 (0.27–0.45)	0.40 (0.32–0.50)	0.50 (0.41–0.60)	0.62 (0.53–0.73)	0.71 (0.60–0.83)
1e (1.0.0)	0.35 (0.27–0.44)	0.40 (0.32–0.49)	0.50 (0.42–0.60)	0.62 (0.53–0.73)	0.71 (0.61–0.82)
1f (1.1.1)	0.35 (0.26–0.43)	0.40 (0.31–0.49)	0.49 (0.40–0.59)	0.58 (0.48–0.68)	0.66 (0.55–0.78)
1f (1.0.0)	0.35 (0.27–0.44)	0.40 (0.31–0.49)	0.49 (0.40–0.59)	0.58 (0.48–0.68)	0.66 (0.55–0.78)
2e (1.1.1)	0.40 (0.30–0.55)	0.46 (0.35–0.62)	0.57 (0.46–0.75)	0.70 (0.57–0.90)	0.79 (0.65–1.02)
2e (1.0.0)	0.40 (0.30–0.53)	0.46 (0.35–0.60)	0.57 (0.45–0.73)	0.70 (0.57–0.88)	0.80 (0.65–1.00)
2f (1.1.1)	0.41 (0.32–0.56)	0.48 (0.37–0.63)	0.59 (0.47–0.77)	0.70 (0.57–0.89)	0.80 (0.65–1.03)
2f (1.0.0)	0.41 (0.33–0.54)	0.48 (0.38–0.62)	0.59 (0.48–0.74)	0.70 (0.58–0.87)	0.80 (0.66–1.00)
3e (1.1.1)	0.36 (0.30–0.43)	0.41 (0.34–0.50)	0.54 (0.45–0.76)	0.78 (0.59–1.04)	0.94 (0.73–1.16)
3e (1.0.0)	—	0.40 (0.34–0.48)	0.51 (0.45–0.59)	—	0.97 (0.80–1.18)
3f (1.1.1)	0.37 (0.32–0.44)	0.43 (0.37–0.51)	0.55 (0.47–0.78)	0.77 (0.59–1.03)	0.94 (0.72–1.17)
3f (1.0.0)	—	0.43 (0.37–0.49)	0.53 (0.47–0.61)	—	0.97 (0.81–1.17)
4 (1.1.1)	0.49 (0.33–0.80)	0.55 (0.38–0.89)	0.68 (0.46–1.19)	0.84 (0.57–1.42)	0.98 (0.67–1.56)
4 (1.0.0)	—	0.53 (0.37–0.80)	—	—	1.01 (0.69–1.64)

Median (17th-83rd percentile) projections produced by FACTS modules. All results are in m GMSL relative to a 1995-2014 baseline.

Table 5. Total GMSL projections for 2100 by GSAT bin, compared to AR6 warming-level projections

Workflow	1.5 C	2.0 C	3.0 C	4.0 C	5.0 C
1e	0.38 (0.29-0.47)	0.43 (0.35-0.53)	0.57 (0.48-0.66)	0.68 (0.59-0.77)	0.76 (0.67-0.86)
1f	0.37 (0.29-0.45)	0.43 (0.35-0.52)	0.54 (0.45-0.62)	0.63 (0.53-0.72)	0.73 (0.63-0.83)
2e	0.42 (0.33-0.57)	0.49 (0.39-0.66)	0.63 (0.52-0.81)	0.76 (0.63-0.95)	0.86 (0.7-1.08)
2f	0.44 (0.35-0.57)	0.52 (0.42-0.67)	0.64 (0.53-0.8)	0.76 (0.63-0.95)	0.87 (0.72-1.10)
3e	0.38 (0.32-0.45)	0.45 (0.38-0.53)	0.64 (0.54-0.87)	0.92 (0.75-1.13)	1.01 (0.85-1.24)
3f	0.40 (0.35-0.45)	0.47 (0.42-0.54)	0.64 (0.55-0.87)	0.92 (0.75-1.12)	1.03 (0.87-1.24)
4	0.51 (0.35-0.81)	0.59 (0.41-0.93)	0.74 (0.52-1.25)	0.97 (0.65-1.55)	1.05 (0.72-1.61)
AR6	0.44 (0.34–0.59)	0.51 (0.40–0.69)	0.61 (0.50–0.81)	0.70 (0.58–0.92)	0.81 (0.69–1.05)

Median (17th-83rd percentile) projections produced by FACTS modules. All results are in m GMSL contribution relative to a 1995-2014 baseline. AR6 projections are from Fox-Kemper et al. (2021) Table 9.10 and are based on workflows 1e and 2e.

3 Workflow-level temperature dependence of RSL

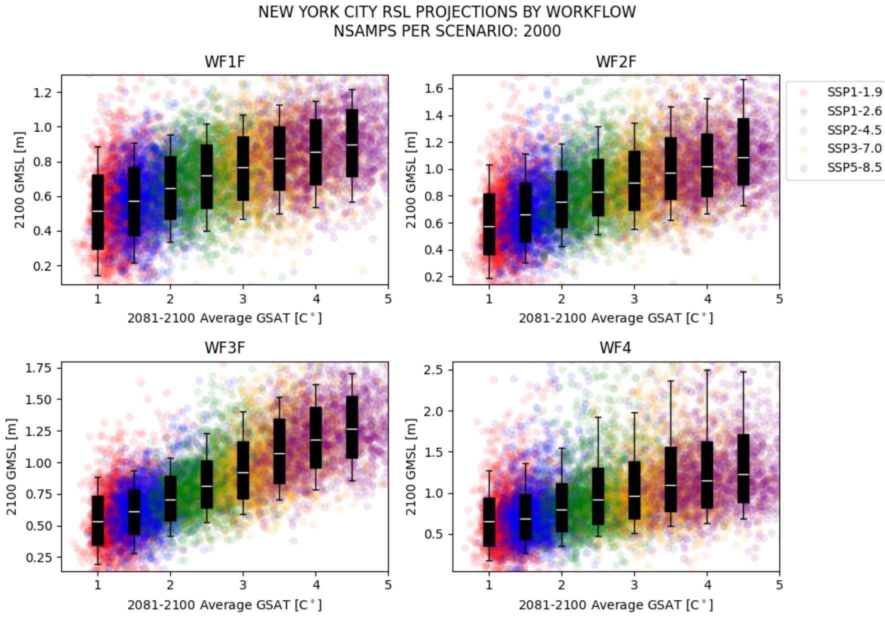


Figure 14. RSL projections from the four focal FACTS workflows (wf1f, wf2f, wf3f, wf4) as a functions of GSAT for New York City.

4 Workflow-level relationship between RSL and GMSL

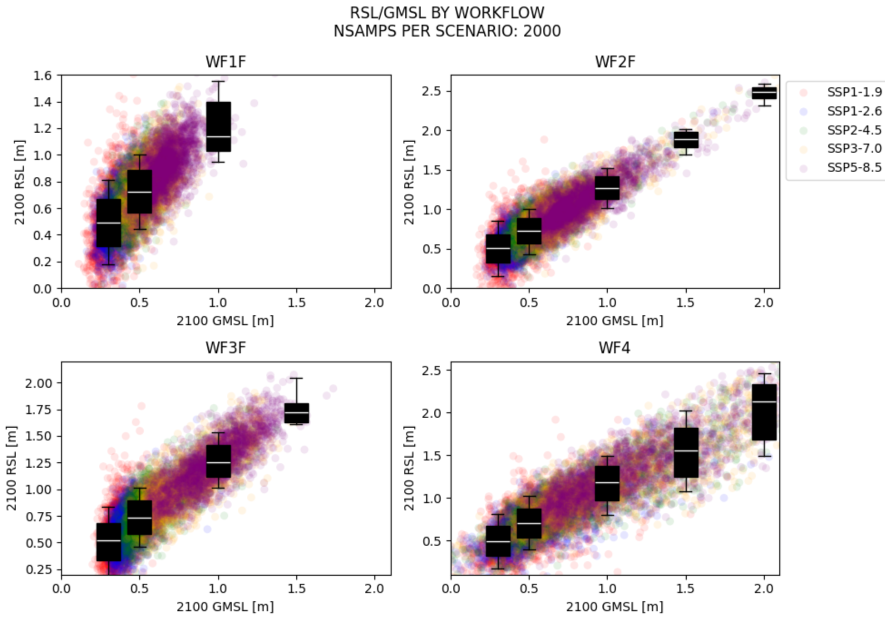


Figure 15. RSL projections from the four focal FACTS workflows (wf1f, wf2f, wf3f, wf4) as a functions of GMSL.

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