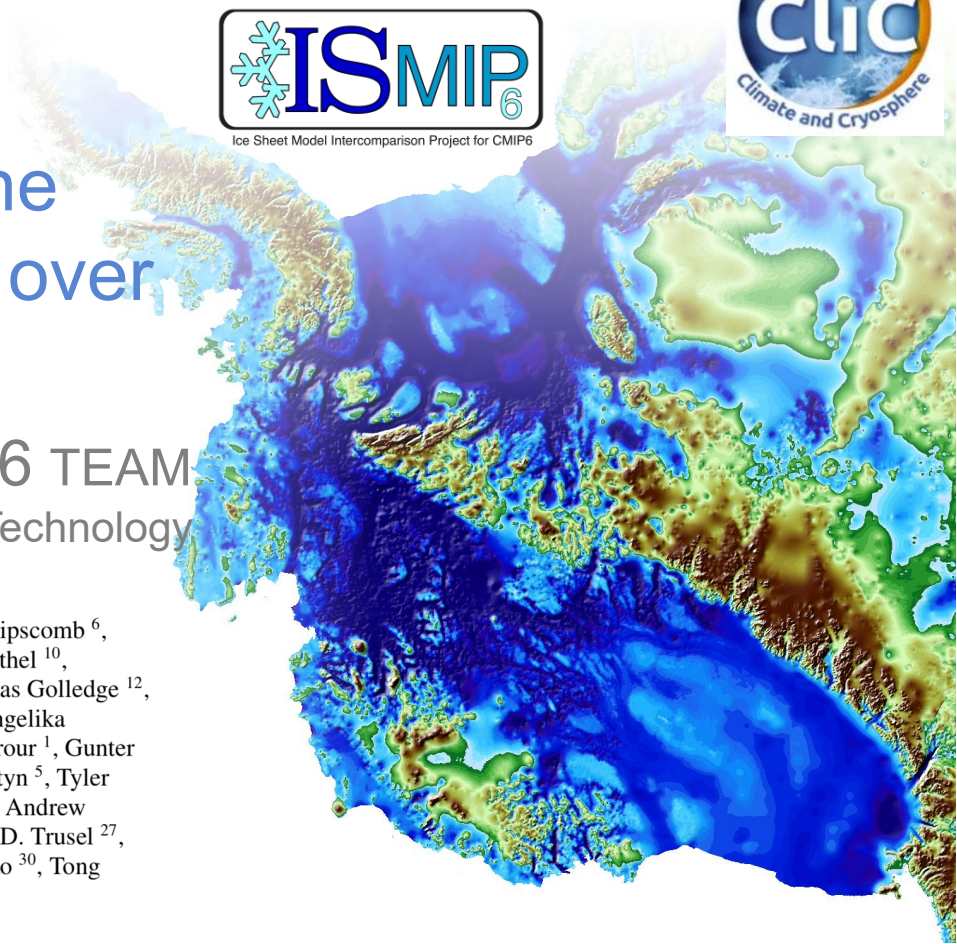
LIWG, Boulder, January 2020

# ISMIP6 Antarctica: a multi-model ensemble of the Antarctic ice sheet evolution over the 21st century



Hélène Seroussi[1] and the ISMIP6 team

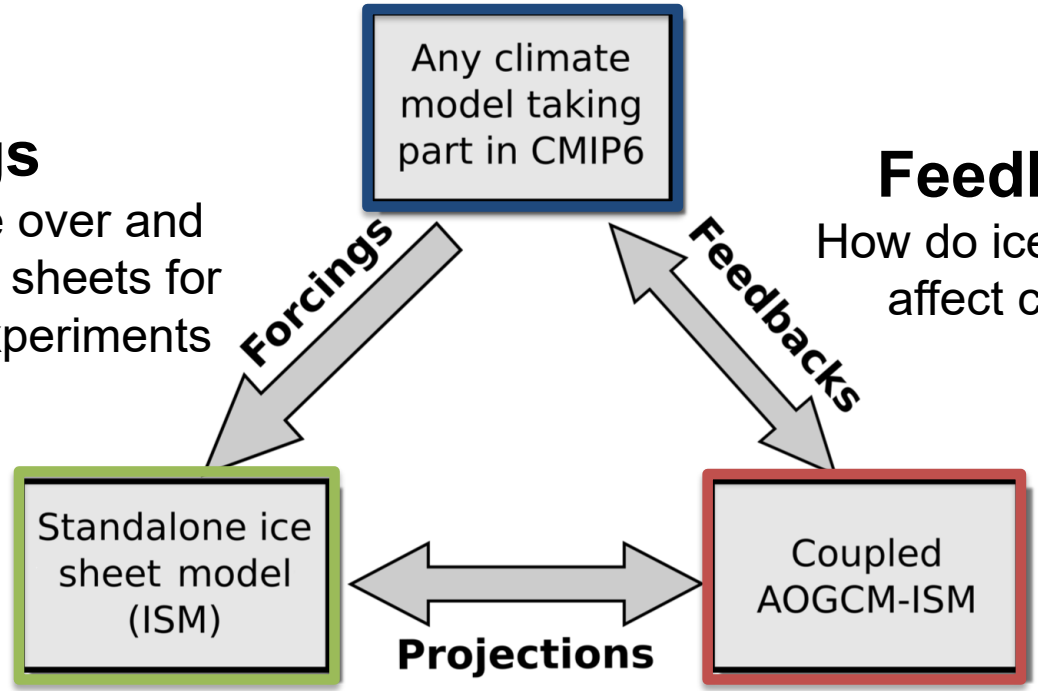
[1] Jet Propulsion Laboratory, California Institute of Technology

Hélène Seroussi [1], Sophie Nowicki [2], Antony J. Payne [3], Heiko Goelzer [4,5], William H. Lipscomb [6], Ayako Abe Ouchi [7], Cécile Agosta [8], Torsten Albrecht [9], Xylar Asay-Davis [10], Alice Barthel [10], Reinhard Calov [9], Richard Cullather [2], Christophe Dumas [8], Rupert Gladstone [11], Nicholas Golledge [12], Jonathan M. Gregory [13,14], Ralf Greve [15], Tore Hatterman [16,17], Matthew J. Hoffman [10], Angelika Humbert [18,19], Philippe Huybrechts [20], Nicolas C. Jourdain [21], Thomas Kleiner [18], Eric Larour [1], Gunter R. Leguy [6], Daniel P. Lowry [22], Chistopher M. Little [23], Mathieu Morlighem [24], Frank Pattyn [5], Tyler Pelle [24], Stephen F. Price [10], Aurélien Quiquet [8], Ronja Reese [9], Nicole-Jeanne Schlegel [1], Andrew Shepherd [25], Erika Simon [2], Robin S. Smith [13], Fiammetta Straneo [26], Sainan Sun [5], Luke D. Trusel [27], Jonas Van Breedam [19], Roderik S. W. van de Wal [4,28], Ricarda Winkelmann [9,29], Chen Zhao [30], Tong Zhang [10], and Thomas Zwinger [31]

# Experimental framework for ISMIP6

## Forcings

Analysis of climate over and surrounding the ice sheets for selected CMIP6 experiments




## Feedbacks

How do ice dynamics affect climate?

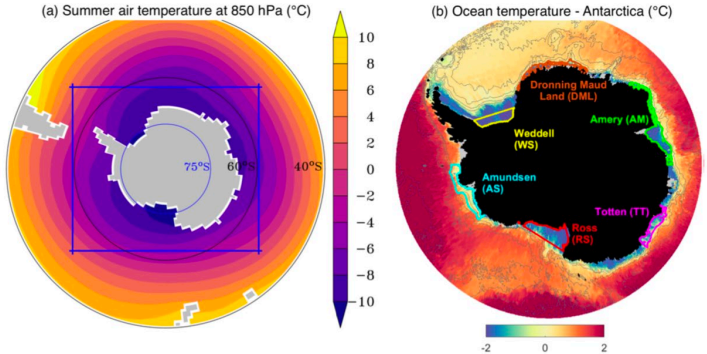
## Projections

Past and future sea level due to ice sheets, along with associated uncertainty due to ice sheets and climate forcing

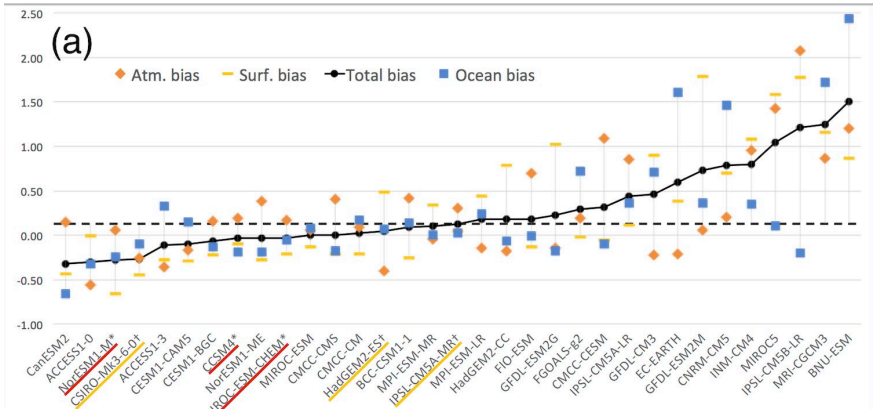
# Forcing selection

Choice of CMIP5 AOGCM (Barthel et al., 2020):

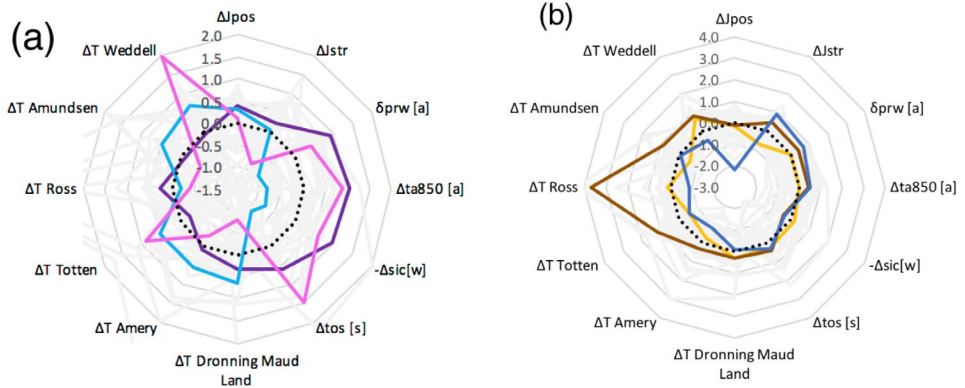
- Good representation of present-day conditions
- Maximize the diversity of climate projections
- Used different cores (ocean, atmosphere, …)




Regions used to compute metrics




Ranking of models according to total bias

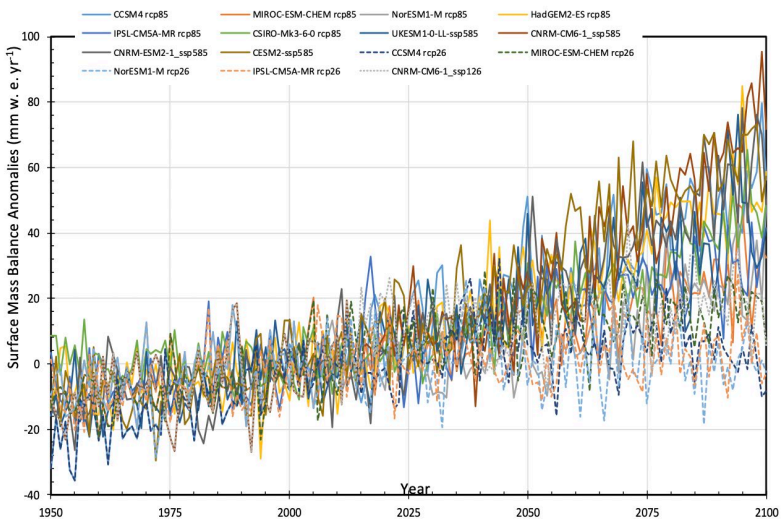



Normalized projected changes by 2100

# External forcings

Ice/atmosphere interface:

- Surface mass balance anomalies
- Surface temperature anomalies
- No regional model to downscale

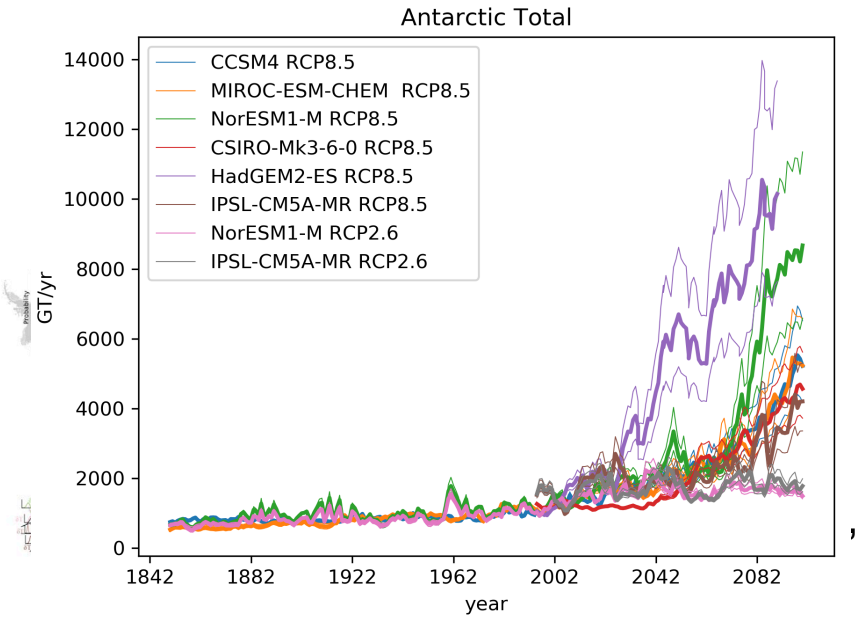



Nowicki et al., in review

Ice/ocean interface:

- Open Melt framework (forcing forcing)
- Standard Melt framework (common melt)

$$m(x,y) = \gamma_0 \times \left(\frac{\rho_{sw} c_{pw}}{\rho_i L_f}\right)^2 \times (TF(x,y,z_{\text{draft}}) + \delta T_{\text{sector}}) \times |\langle TF \rangle_{\text{draft} \in \text{sector}} + \delta T_{\text{sector}}|$$



# Experiments and participants

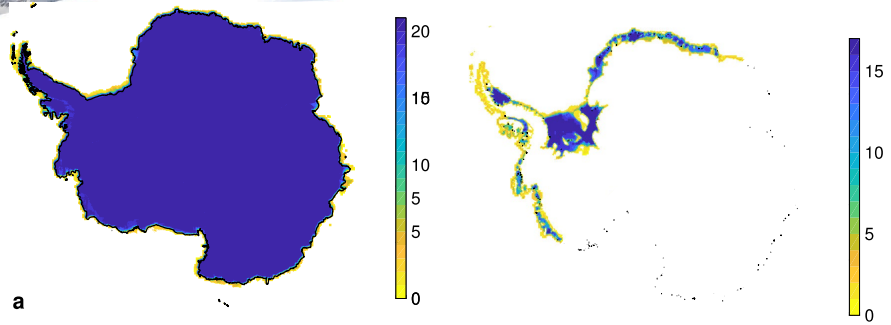
## List of experiments

| Experiment | AOGCM | Scenario | Ocean Forcing | Ocean coefficient | Ice Shelf Fracture | Tier |
|---|---|---|---|---|---|---|
| historical | None | None | Free | Medium | No | Tier 1 (Core) |
| ctrl_proj | None | None | Free | Medium | No | Tier 1 (Core) |
| exp01 | NorESM1-M | RCP8.5 | Open | Medium | No | Tier 1 (Core) |
| exp02 | MIROC-ESM-CHEM | RCP8.5 | Open | Medium | No | Tier 1 (Core) |
| exp03 | NorESM1-M | RCP2.6 | Open | Medium | No | Tier 1 (Core) |
| exp04 | CCSM4 | RCP8.5 | Open | Medium | No | Tier 1 (Core) |
| exp05 | NorESM1-M | RCP8.5 | Standard | Medium | No | Tier 1 (Core) |
| exp06 | MIROC-ESM-CHEM | RCP8.5 | Standard | Medium | No | Tier 1 (Core) |
| exp07 | NorESM1-M | RCP2.6 | Standard | Medium | No | Tier 1 (Core) |
| exp08 | CCSM4 | RCP8.5 | Standard | Medium | No | Tier 1 (Core) |
| exp09 | NorESM1-M | RCP8.5 | Standard | High | No | Tier 1 (Core) |
| exp10 | NorESM1-M | RCP8.5 | Standard | Low | No | Tier 1 (Core) |
| exp11 | CCSM4 | RCP8.5 | Open | Medium | Yes | Tier 1 (Core) |
| exp12 | CCSM4 | RCP8.5 | Standard | Medium | Yes | Tier 1 (Core) |
| exp13 | NorESM1-M | RCP8.5 | Standard | PIGL | No | Tier 1 (Core) |
| expA1 | HadGEM2-RS | RCP8.5 | Open | Medium | No | Tier 2 |
| expA2 | CSIRO-MK3 | RCP8.5 | Open | Medium | No | Tier 2 |
| expA3 | IPSL-CM5A-MR | RCP8.5 | Open | Medium | No | Tier 2 |
| expA4 | IPSL-CM5A-MR | RCP2.6 | Open | Medium | No | Tier 2 |
| expA5 | HadGEM2-RS | RCP8.5 | Standard | Medium | No | Tier 2 |
| expA6 | CSIRO-MK3 | RCP8.5 | Standard | Medium | No | Tier 2 |
| expA7 | IPSL-CM5A-MR | RCP8.5 | Standard | Medium | No | Tier 2 |
| expA8 | IPSL-CM5A-MR | RCP2.6 | Standard | Medium | No | Tier 2 |

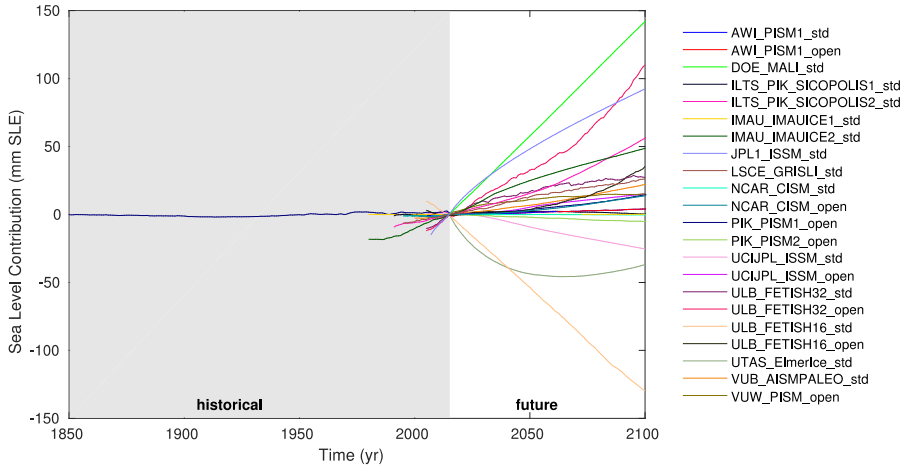
## List of participants and model characteristics

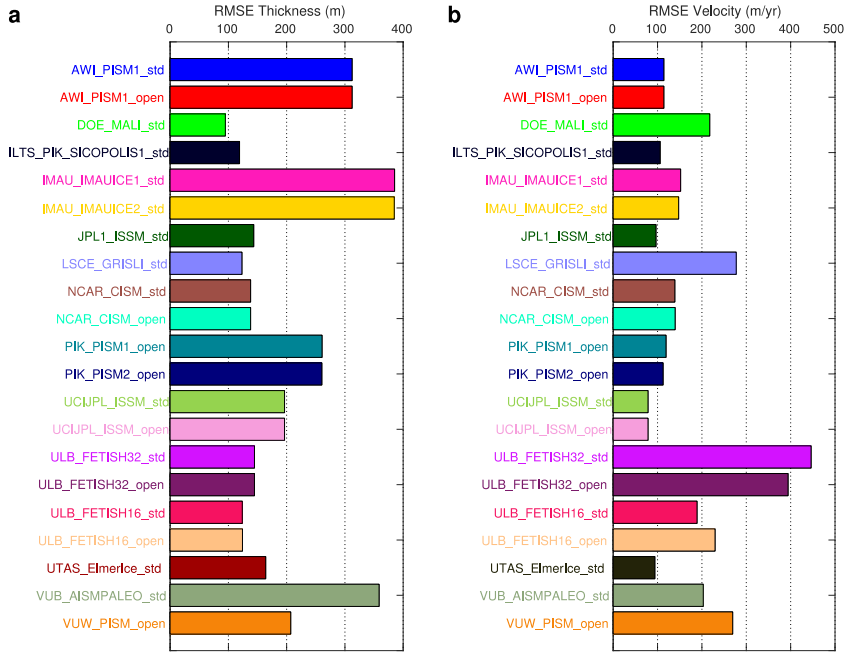
| Model name | Numerics | Stress balance | Resolution (km) | Init. Method | Initial Year | Melt in partially floating cells | Ice Front | Open melt parameterization | Standard melt parameterization |
|---|---|---|---|---|---|---|---|---|---|
| AWI_PISM1 | FD | Hybrid | 16 | Eq | 2005 | No | StR | Quad | NoN-Local |
| DOE_MALI | FE/FV | HO | 2-20 | DA+ | 2015 | Floating condition | Fix | N/A | NoN-Local anom. |
| ILTS_PIK_SICOPOLIS1 | FD | Hybrid | 8 | SP | 1990 | No | MH | N/A | NoN-Local |
| ILTS_PIK_SICOPOLIS2 | FD | Hybrid | 8 | SP | 1990 | No | MH | N/A | NoN-Local |
| IMAU_IMAUICE1 | FD | Hybrid | 32 | Eq | 1978 | No | Fix | N/A | Local anom |
| IMAU_IMAUICE2 | FD | Hybrid | 32 | SP | 1979 | No | Fix | N/A | Local anom |
| JPL1_ISSM | FE | SSA | 2-50 | DA | 2007 | Sub-Grid | Fix | N/A | NoN-Local |
| LSCE_GRISLI | FD | Hybrid | 16 | SP+ | 1995 | N/A | MH | N/A | NoN-Local |
| NCAR_CISM | FE/FV | L1L2 | 4 | SP+ | 1995 | Floating condition | RO | Non-Local + Slope | NoN-Local |
| PIK_PISM1 | FD | Hybrid | 8 | SP+ | 1850 | Sub-Grid | StR | PICO | N/A |
| PIK_PISM2 | FD | Hybrid | 8 | SP+ | 2015 | Sub-Grid | StR | PICO | N/A |
| UCIJPL_ISSM | FE | HO | 3-50 | DA | 2007 | Sub-Grid | Fix | PICOP | NoN-Local |
| ULB_FETISH_16km | FD | Hybrid | 16 | DA* | 2005 | N/A | Div | Plume | NoN-Local |
| ULB_FETISH_32km | FD | Hybrid | 32 | DA* | 2005 | N/A | Div | Plume | NoN-Local |
| UTAS_ElmerIce | FE | Stokes | 4-40 | DA | 2015 | Sub-Grid | Fix | N/A | Local |
| VUB_AISMPALEO | FD | SIA+SSA | 20 | SP | 2000 | N/A | MH | N/A | NoN-Local anom |
| VUW_PISM | FD | Hybrid | 16 | SP | 2015 | No | StR | Lin | N/A |

# Initial conditions




Initial ice extent (a) and floating ice extent (b)

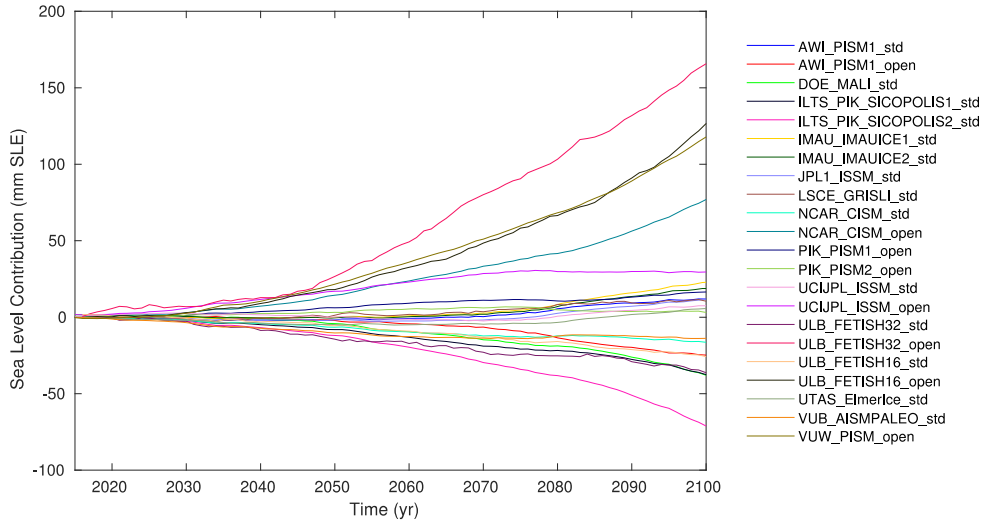


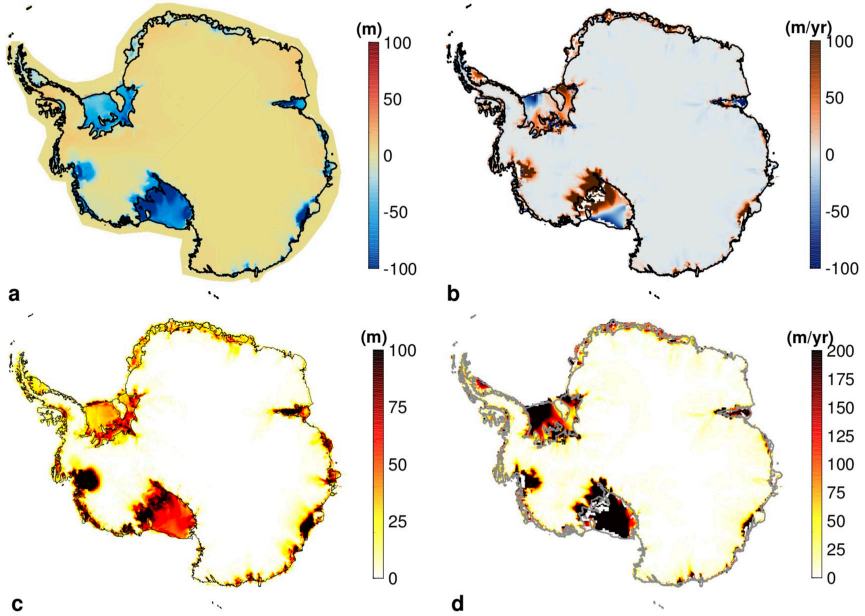




Root Mean Square Error in ice thickness (a, in m) and ice velocity (b, in m/yr) between modeled and observed values at the beginning of experiments

# NorESM1-M RCP 8.5

Evolution of ice volume above floatation relative to control exp.

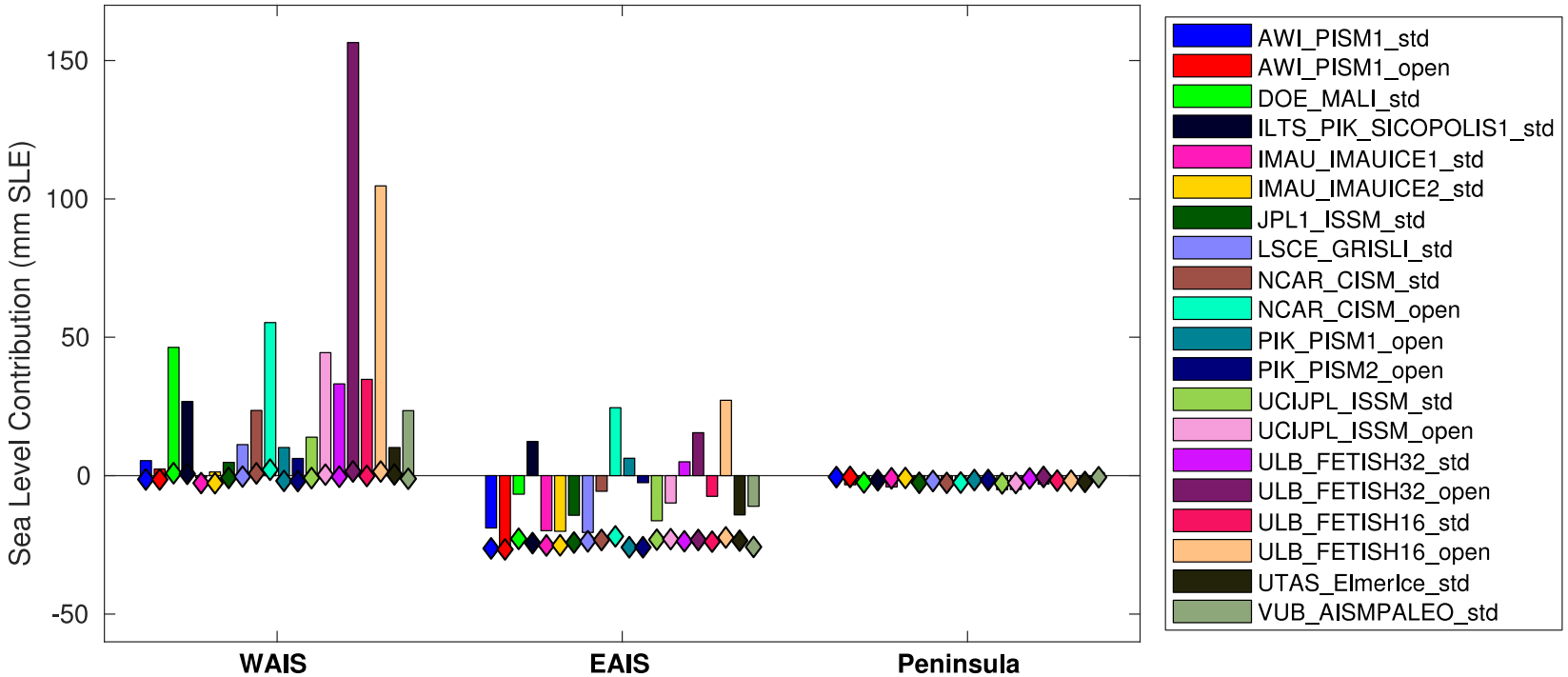


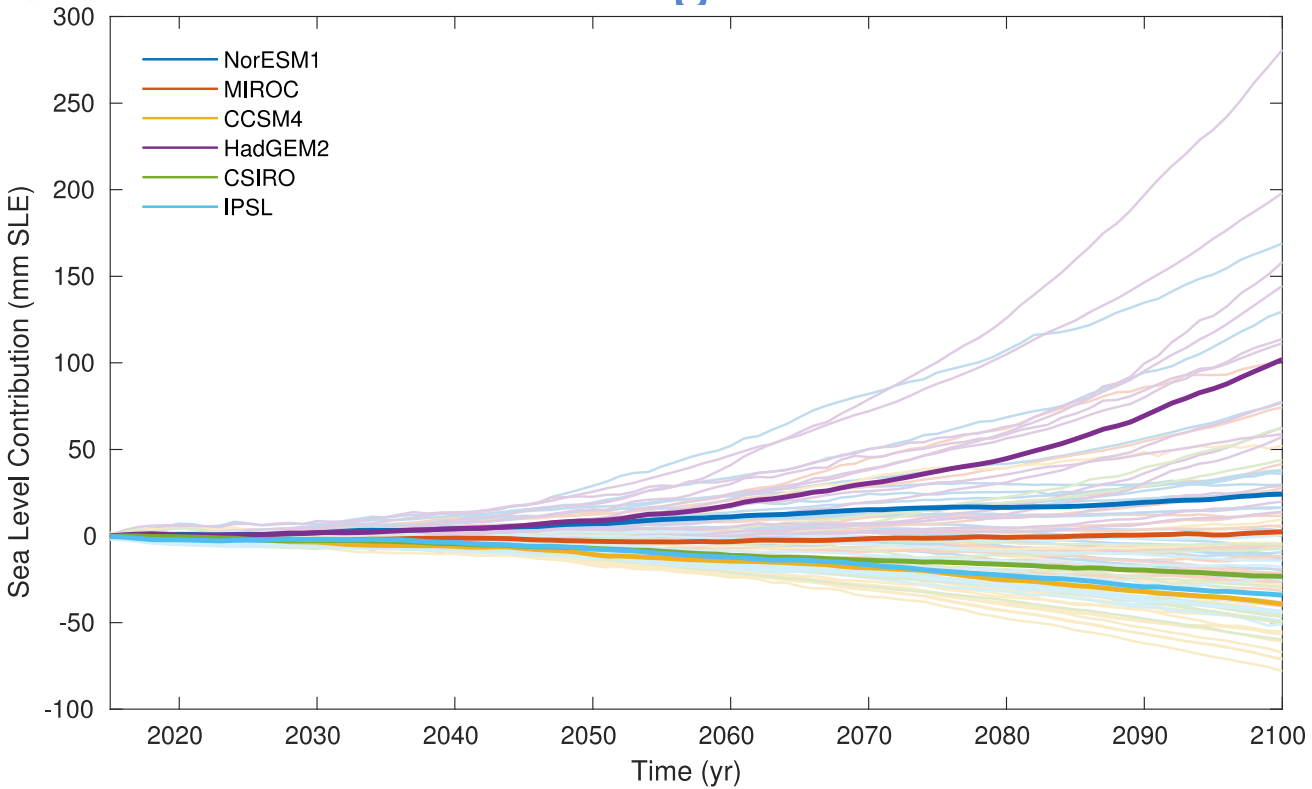

Mean (a and b) and standard deviation (c and d) of simulated thickness change (a and c, in m) and velocity change (b and d, in m/yr) between 2015 and 2100 under medium forcing from NorESM1-M RCP 8.5 scenario relative to ctrl_proj

# NorESM1-M RCP 8.5

Antarctic mass loss for the period 2015-2100 with NorESM1-M RCP 8.5 forcing relative to ctrl_proj by region

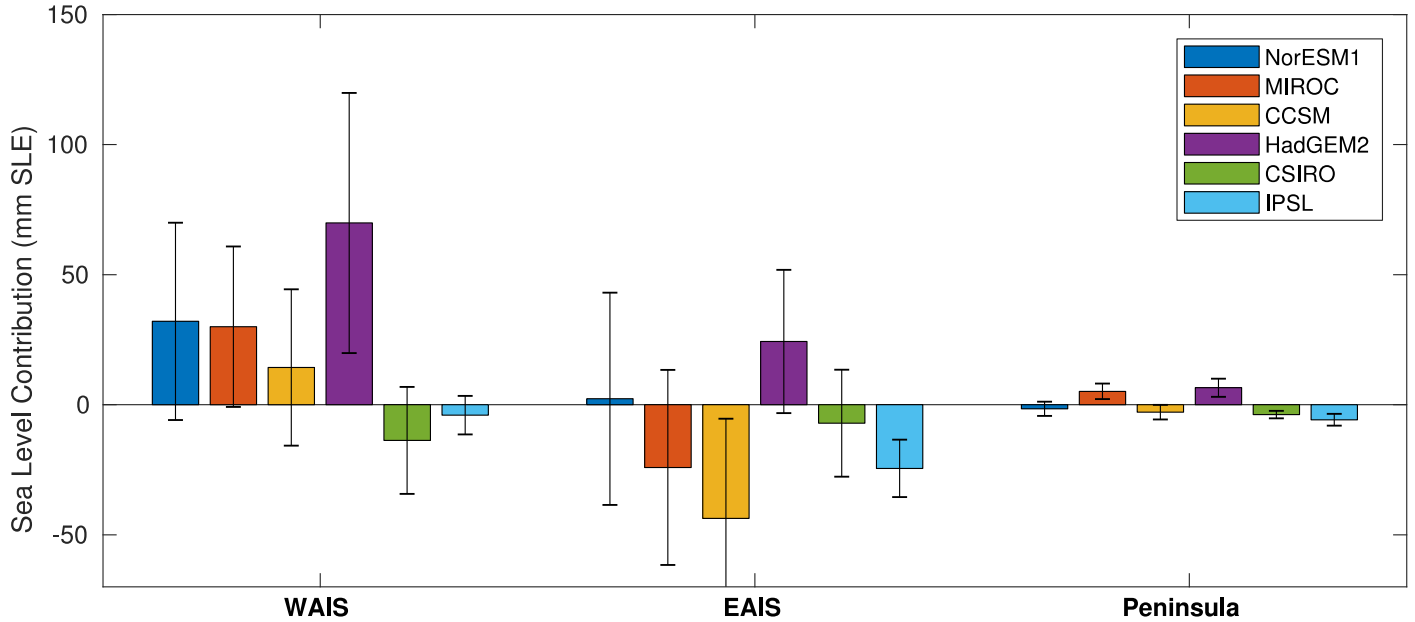


# RCP 8.5 forcing from 6 AOGCMs




Evolution of ice mass loss relative to control exp.: individual models and mean values for the six AOGCMs

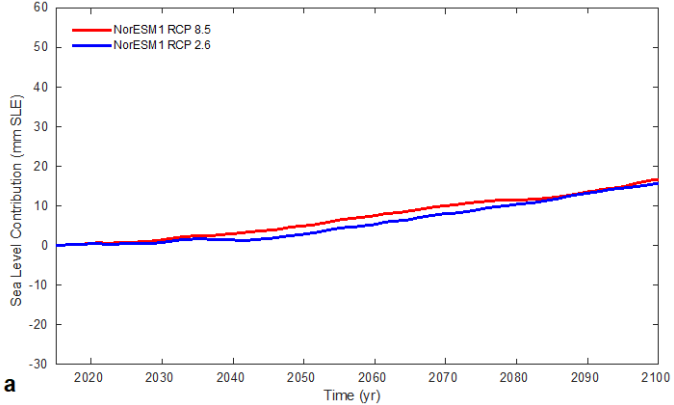
# RCP 8.5 forcing from 6 AOGCMs



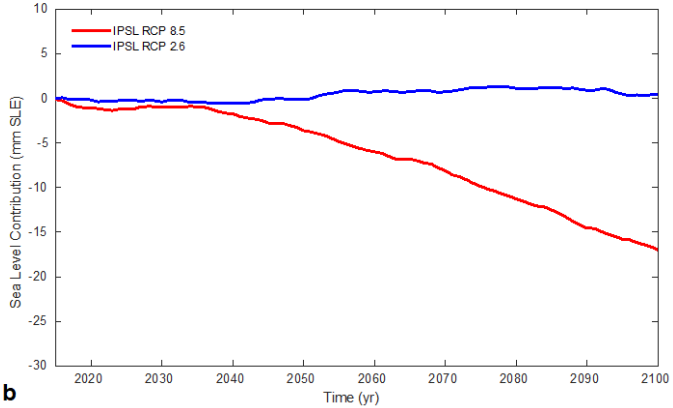

Antarctic mass loss for the period 2015-2100 for the six RCP 8.5 GCM forcing relative to ctrl_proj by region. Mean values and standard deviations (black)

# RCP 8.5 vs RCP 2.6

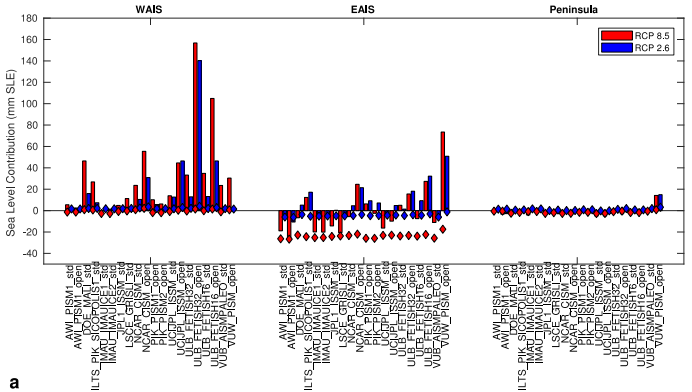
## 2 GCMs (NorESM and IPSL) with RCP 8.5 and RCP 2.6 forcing



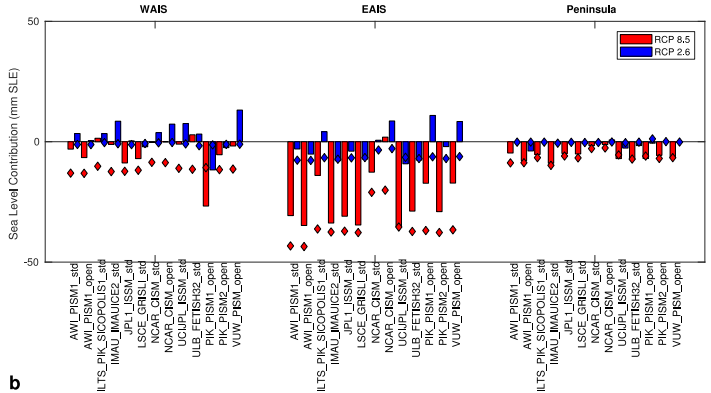

a




b




a

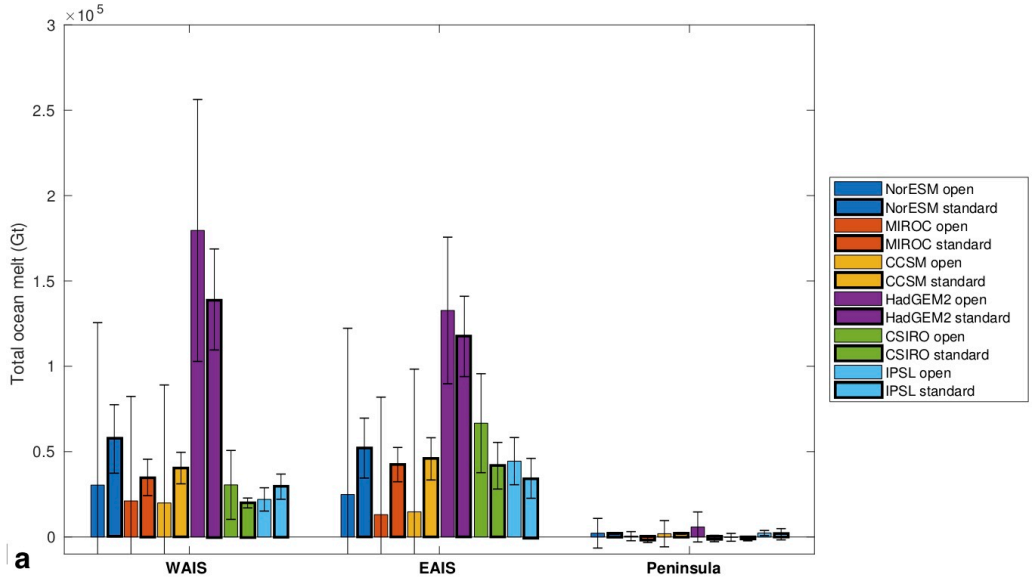



b

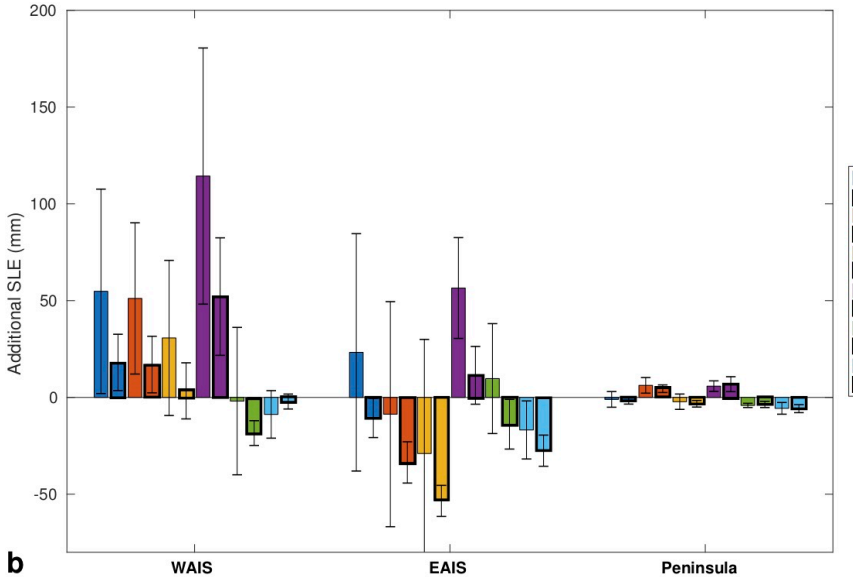
# Uncertainty in melting

Comparison of open and standard melt frameworks

Cumulative basal melt for 2015-2100 period relative to ctrl_proj



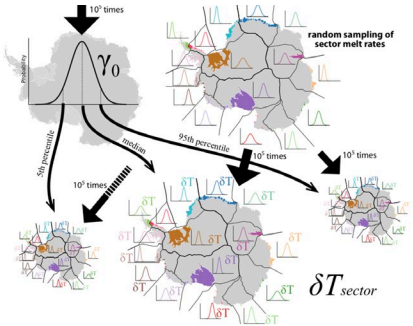

Change in VAF between 2015 and 2100 period relative to ctrl_proj

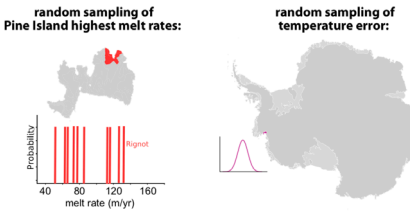


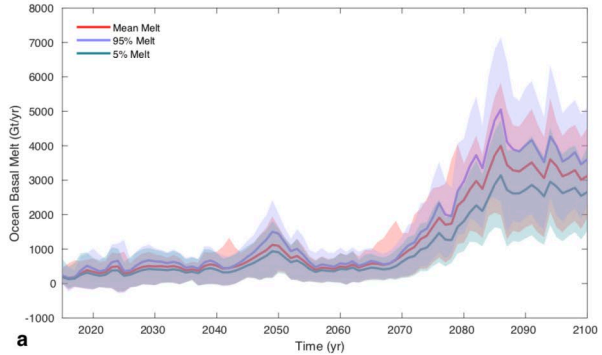

✓ Spatial location of melt is critical

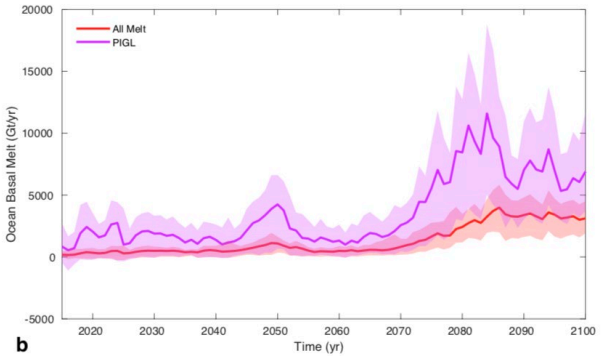
# Uncertainty in melting

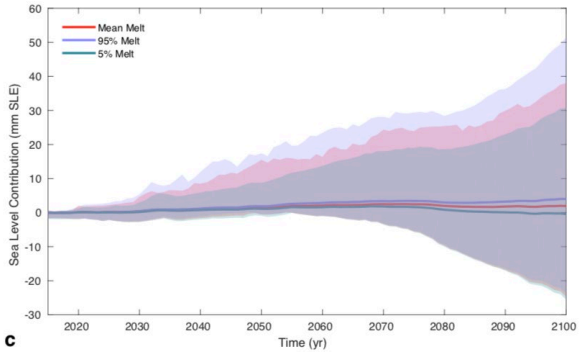
Uncertainty in melt parameterization for the standard melt framework: $\Gamma_o$

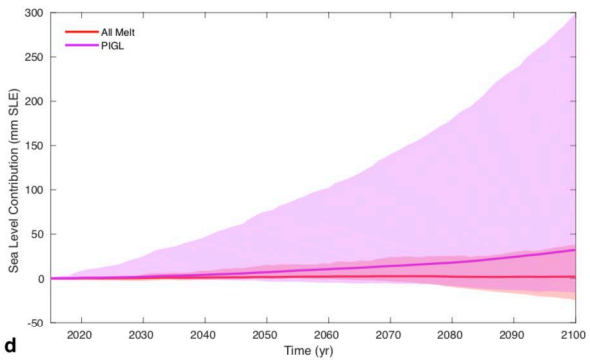


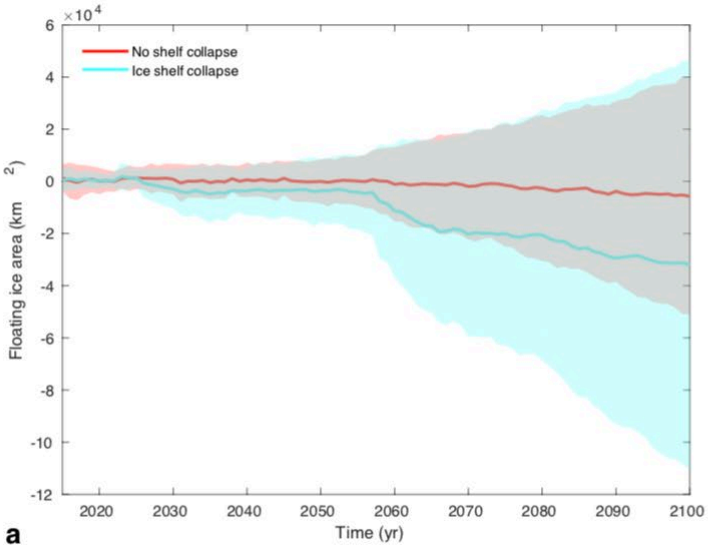

Basal melt

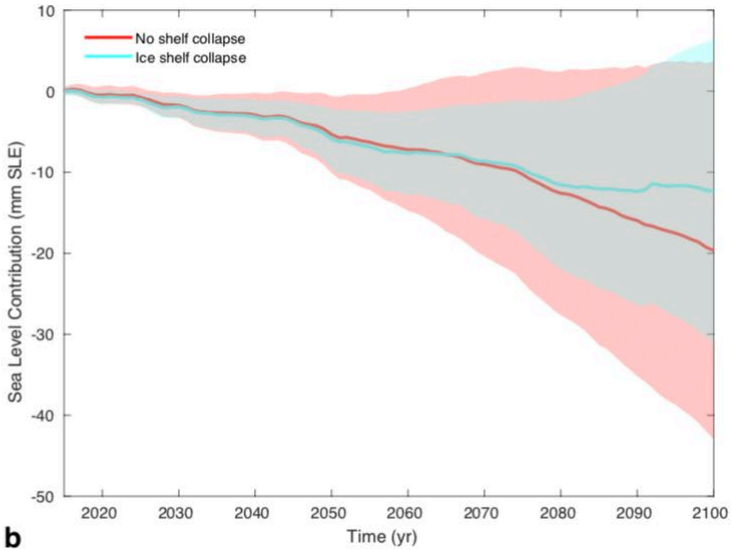
Mass loss

# Impact of ice shelf collapse

Ice shelf collapse if sustained liquid water precipitation at the ice shelf surface (>72.5 cm/yr, Trusel et al., 2015)

Run with CCSM4 with and without ice shelf collapse

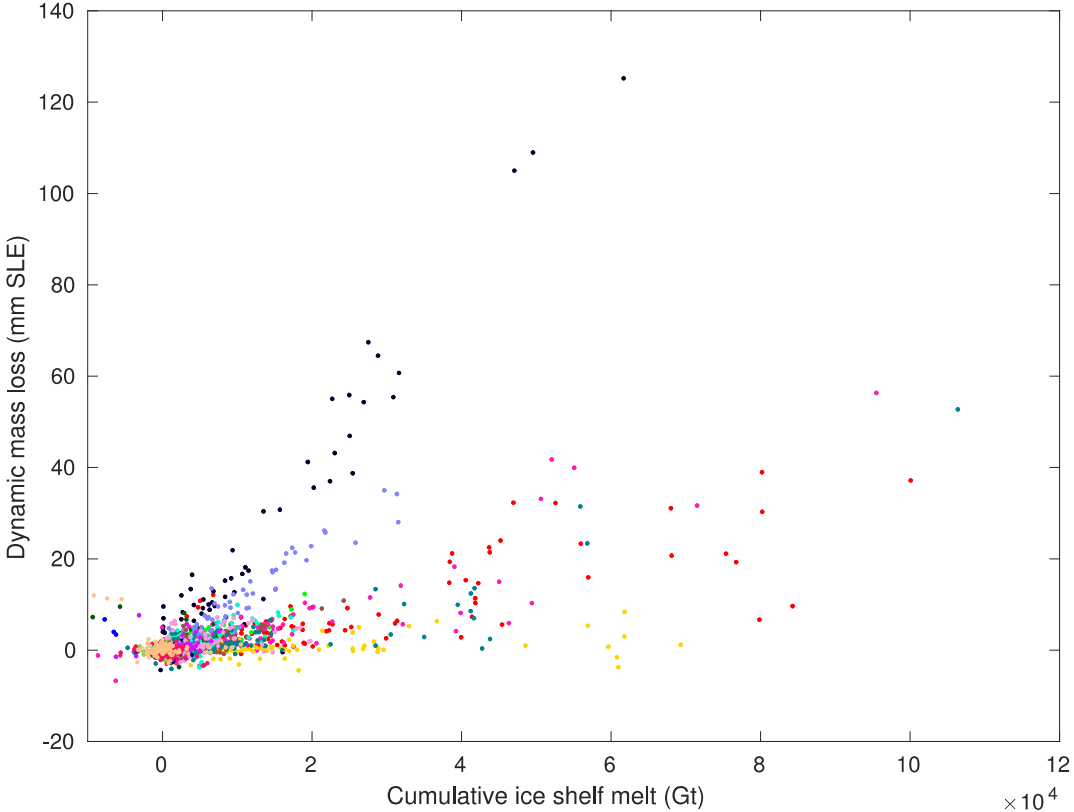


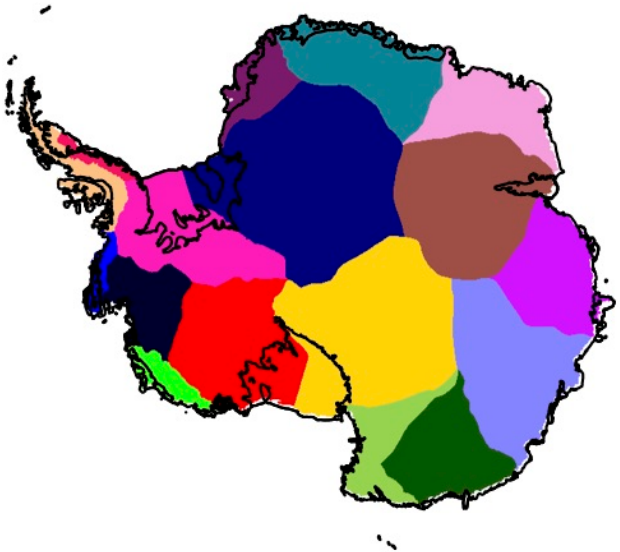




Mean additional mass loss of 10 mm SLE in 2100

# Basins vulnerability

Dynamic mass loss: $DML = \Delta VAF - \Delta SMB$



Antarctic basins

# Conclusions

- Larger uncertainties than Greenland projections with uncertainty from climate models, melt parameterization and ice sheet dynamics

- Significant differences at regional (WAIS, EAIS) and basin scale

- Snowfall in East Antarctica could partially offset the dynamic mass loss caused by warmer ocean waters

- Significant progress since AR5, including realistic forcing and better representation of ice shelves:
  - Interdisciplinary effort with inputs from polar oceanography, atmospheric science, climate models, …
  - Modeling of ice shelves, grounding line migration, ice front (starting), …

- Ice sheet models starting to be used in IPCC

# Questions?

- ISMIP6 web page:
www.climatecryosphere.org/activities/targeted/ismip6

- ISMIP6 wiki page:
www.climatecryosphere.org/wiki/index.php?title=ISMIP6_wiki_page

- Contact the ISMIP6 team
ismip6@gmail.com

ISMIP6

Ice Sheet Model Intercomparison Project for CMIP6

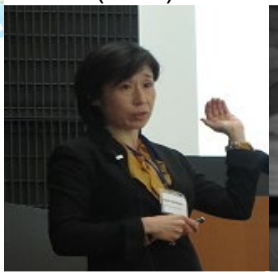
# Ice Sheet Model Intercomparison Project for CMIP6

Goal: Estimate future sea-level contributions from the Greenland and Antarctic ice sheets and associated uncertainties (Nowicki et al., 2016)

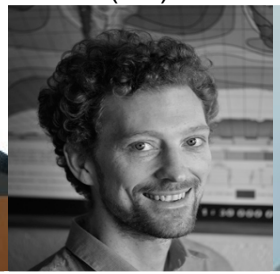
Sophie Nowicki (USA)

Tony Payne (UK)

Eric Larour (USA)



Ayako Abe-Ouchi (JP)

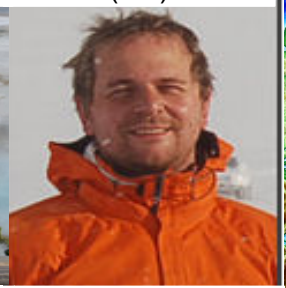


Heiko Goelzer (NL)

Jonathan Gregory (UK)

William Lipscomb (USA)

Helene Seroussi (USA)

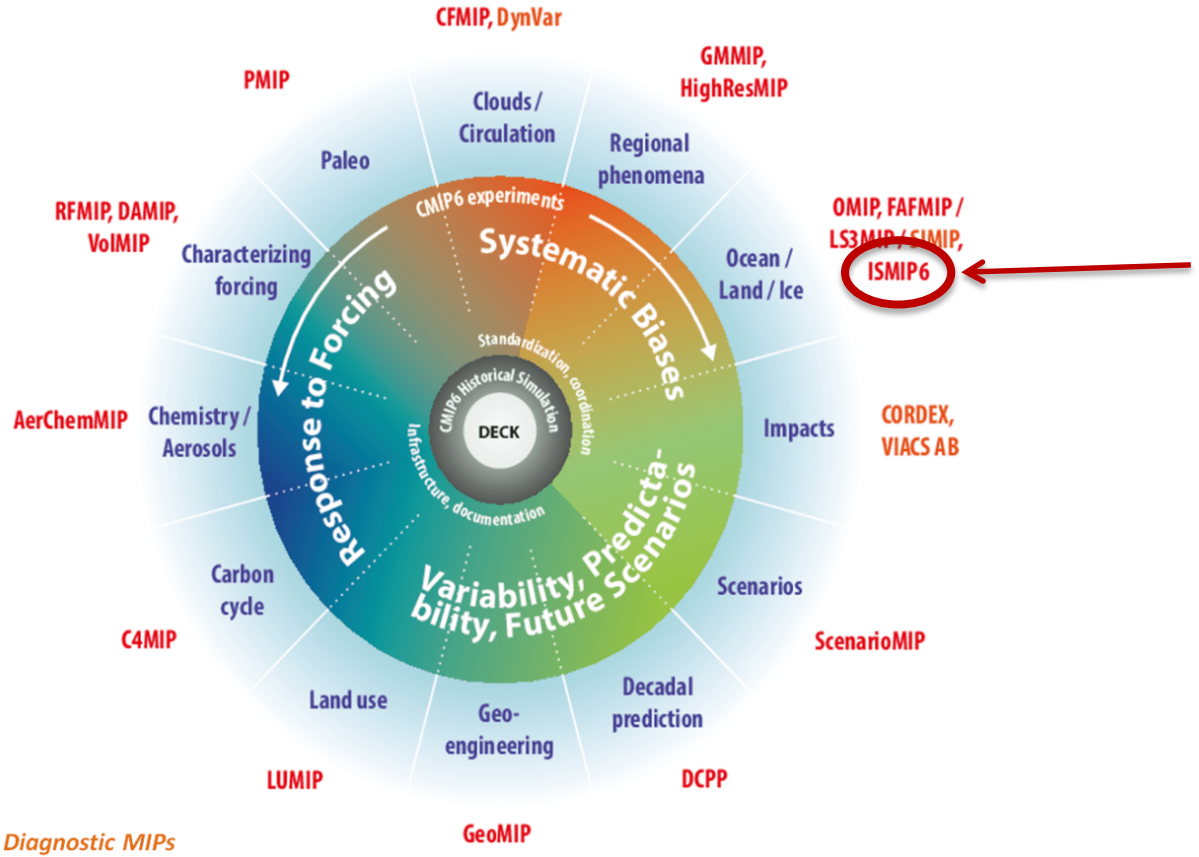


Andrew Shepherd (UK)

CliC Climate and Cryosphere

ISMIP6 Chairs and Steering Committee

# Ice Sheet Model Intercomparison for CMIP6 (ISMIP6)

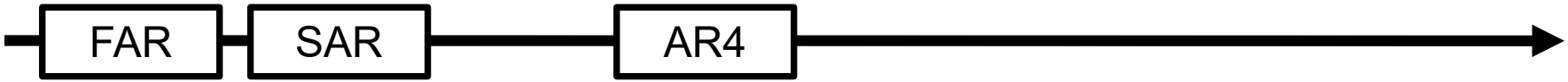


# Ice Sheet & sea level rise within IPCC cycle


- No major dynamic response of the ice sheets was expected during the 21st century
- Main contributor to sea level rise: thermal expansion and melting of glacier

➢ We know everything!

# Ice Sheet & sea level rise within IPCC cycle

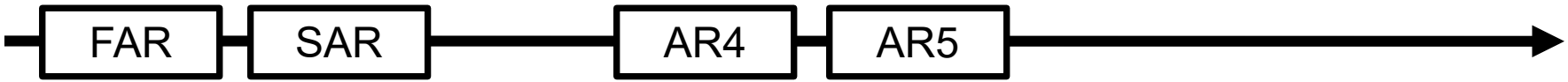



*"understanding of these effects (rapid dynamical changes in ice flow) is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."*

IPCC, 4th Assessment Report (2007)

➢ We know nothing …

# Ice Sheet & sea level rise within IPCC cycle




*"Projection of sea level rise are larger than in the AR4, primarily because of improved modeling of land-ice contribution."*

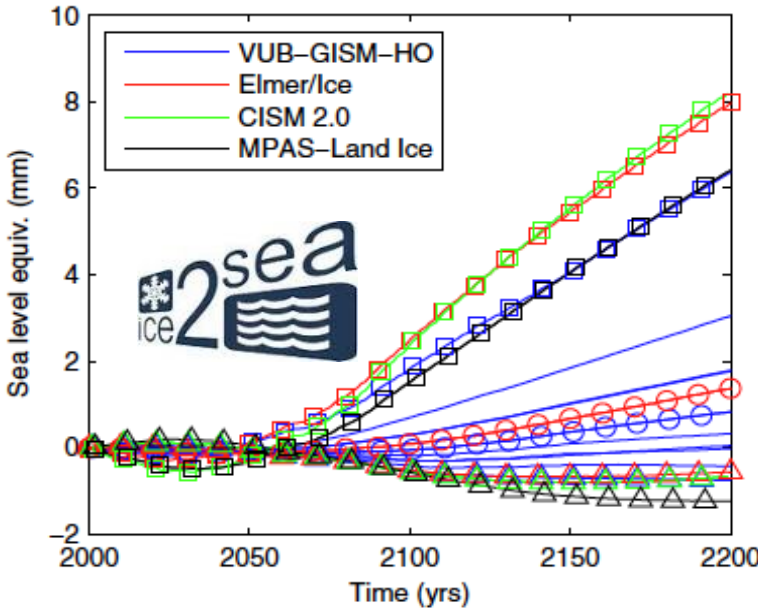
*"significant uncertainties remain, particularly related to the magnitude and rate of the ice-sheet contribution for the 21st century and beyond."*

IPCC, 5th Assessment Report (2013)

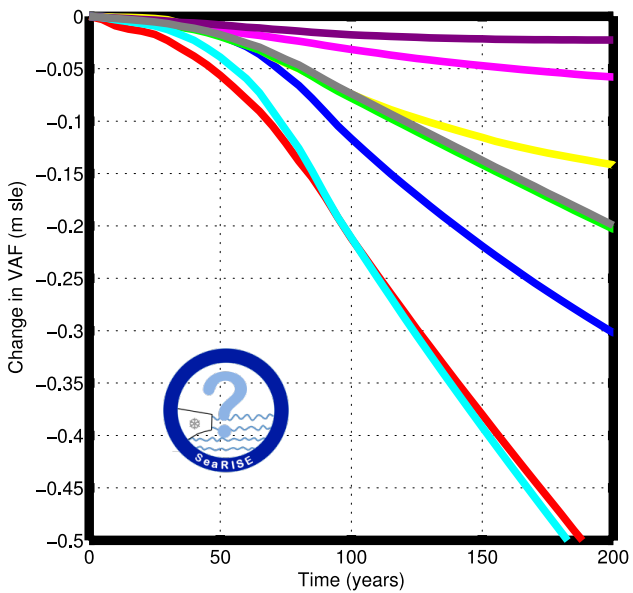
➢ We know something but not enough …

# Ice Sheet & sea level rise within IPCC cycle

FAR → SAR → AR4 → AR5




Shannon et al., 2013




Bindschadler et al., 2013

SeaRISE models
- CISM2
- ISSM
- UMISM
- Elmer/Ice
- SICOPOLIS
- AIF
- IcIES
- PISM