Framework Description Document

(FDD)

IMBIE II

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Acronyms and Abbreviations

APIS	Antarctic Peninsula Ice Sheet
EAIS	East Antarctic Ice Sheet
GIA	Glacial isostatic Adjustment
GrIS	Greenland Ice Sheet
IMBIE	Ice Sheet Mass Balance Intercomparison Exercise
SMB	Surface Mass Balance
WAIS	West Antarctic Ice Sheet

1. Introduction

1.1 Purpose and Scope

The purpose of this report is to describe the assessment process for phase 2 of the Ice Sheet Mass Balance Intercomparison Exercise (IMBIE-II). It includes the agreed rules for participant datasets, an overview of the assessment schedule and processing, and a descriptions of the spatial domains to be adopted by participants.

1.2 Structure

This document is structured as follows:

- Section 2 describes the agreed rules for participant datasets
- Section 3 provides and overview of the assessment schedule and processing
- Section 4 outlines the spatial domains to be used by participants

2 Rules for Participant Datasets

The following rules for participants were the culmination of discussions held amongst the executive committee, at the Executive Committee Meeting in New York City, December 2015, and thereafter. A strict set of conditions were decided upon so as to ensure that individual datasets met certain data quality standards and also to ease the assimilation of datasets for intercomparison and reconciliation. Conditions were outlined to participants at the stage of registration, with registrants having to fill out a questionnaire to ensure they were aware of the terms, and to provide the project and group leaders with an indication of the expected data submissions. Upon submission, a further questionnaire had to be filled out to ensure that all conditions were met. The conditions are outlined in Section 2.1 below. In addition, we also stipulated requirements for file formats that are described in Section 2.2.

2.1 Participant Conditions

We stipulated that to participate in IMBIE, a person or team was to contribute a unique dataset to one of the five experimental data groups (altimetry, mass budget, gravimetry, SMB, or GIA). It was only possible to submit one data set to each experimental group. The methods employed and the errors must have been fully described in an international peer-reviewed journal, or in exceptional circumstances, we would accept an accompanying document that was to be subject to peer-review by the IMBIE executive committee. It was also stated that participants were expected to play an active role in the exercise, remaining in timely correspondence with project coordinators when required.

The conditions varied by experiment group and each are outlined in the following sections.

2.1.1 Altimetry

The IMBIE altimetry experiment group is led by Ben Smith, to whom all correspondence was to be addressed, with one of the project leaders in copy. To participate in the IMBIE altimetry experiment group,

it was required that participants contribute either (i) a time-series of ice sheet regional mass change and its associated uncertainty or (ii) a constant rate of mass change and its associated uncertainty. The contributions were required to be computed within one or more of the drainage basins we defined (i.e. Zwally *et al.,* 2012 or Rignot *et al.,* 2016). It was made clear that time-series of mass change were preferred, where possible encompassing the period 2003 to 2008 to aid comparison with results from other techniques. There were additional optional experiments which participants could choose to participate in, and it was made clear that these would require contribution of additional data.

In registration and data submission, the following was required from the participants:

- Personal details, including name, affiliation, email, and telephone number
- Personal account name and password
- Confirmation that they accept general conditions to remain in timely correspondence with the experiment group leaser, and that they understand that only submissions received before the submission closing data will be included in the assessment.
- Indication of the regions (AP, WAIS, EAIS, GrIS) for which they intended to/ did supply time series and/or mean rates of mass change, and uncertainty estimates.
- Information on which altimetry missions were employed in the mass balance calculations (i.e. ERS-1, ERS-2, EnviSat, ICESat, CryoSat-2, Altika, Sentinel-3, Airborne, Other).
- Information on which methods were used to compute elevation changes (i.e. Cross-overs, Repeat track, plane fit, other)
- Information on the general methods used to estimate elevation changes in unobserved regions. (i.e. area scaling, interpolation, specific value assignment, other).
- Information on any independent observations used to evaluate altimetry elevation rates (i.e. airborne, ground-based, independent satellite, other).
- Whether or not a GIA correction had been applied, and if so, what the name of the model was and a citation to prove that it was published (i.e. peer-reviewed).
- In the case of ICESat data, which methods were used to correct for inter-campaign biases.

- The methods used to convert from volume to mass change
- Whether the mass balance methods of the participant were already published and if so, provide the reference in which the methods were described.
- Indication of whether or not they intended to participate in any additional experiments.

2.1.2 Gravimetry

The IMBIE gravimetry experiment group is led by Isabella Velicogna, to whom all correspondence was to be addressed, with one of the project leaders in copy. To participate in the IMBIE gravimetry experiment group, participants were required to contribute a time-series of ice sheet regional mass change and its associated uncertainty, and must be willing to perform a set of basic experiments to assess the accuracy of their mass balance calculation. It was made clear that time-series of mass change were preferred, where possible encompassing the period 2003 to 2008 to aid comparison with results from other techniques. For data submissions where a spherical harmonics approach is taken, it was stipulated that RL05-compatible Level-2 data was to be used. The participants contributions were required to be computed within one or more of a pre-defined set of ice sheet sectors (i.e. Zwally *et al.,* (2012), Rignot *et al.,* (2016)).

In registration and data submission, the following was required from the participants:

- Personal details, including name, affiliation, email, and telephone number
- Personal account name and password
- Confirmation that they accept general conditions to remain in timely correspondence with the experiment group leaser, that they understand that only submissions received before the submission closing data will be included in the assessment, and to perform a set of basic experiments using defined synthetic data, defined epochs, a defined suite of GIA models and, if a spherical harmonic approach is employed, defined solutions for C20 and degree 1 terms, to assess the sensitivity of my gravimetry mass balance calculations.

- Indication of the regions (AP, WAIS, EAIS, GrIS) for which they intended to/ did supply time series of mass change and uncertainty computed using either/or spherical harmonics or mascons, with and without corrections for glacial isostatic adjustment and, including estimates of leakage effects from different sources. In the case of estimates using spherical harmonics, the degree 1 and C20 coefficients used in the calculation were also required.
- Information on the general methods used (i.e. Spherical Harmonics, MASCONS or other).
- Information on the independent observations used to evaluate the gravimetry data set (i.e. none, airborne, ground-based, independent satellite, or other).
- Information on the model used to account for GIA – including description and doi.
- Information on the model used to account for hydrology leakage – including descriptions and doi.
- Information on whether or not a model had been used to account for ocean leakage, and if so, the name of the model used.
- Description of any additional sources of leakage accounted for.
- Identification of the degree 1 coefficients used in the mass balance calculation – Swenson *et al.,* (2008) was recommended.
- Identification of the C20 coefficients used in the mass balance calculation – Cheng *et al.,* (2013) was recommended.
- Identification on whether or not the methods employed has already been published and if so, where.
- Indication of whether or not, and which additional experiments participants would participate in.

2.1.3 Mass Budget

The IMBIE mass budget experiment group is led by Eric Rignot, to whom all correspondence was to be addressed, with one of the project leaders in copy. To participate in the IMBIE mass budget experiment group, participants were required to contribute either (i) a time-series of ice sheet regional mass change and its associated uncertainty or (ii) a constant rate of mass change and its associated uncertainty. The contributions were required to be computed within one or more of the drainage basins defined by IMBIE. Time-series of mass change were preferred, where possible encompassing the period 2003 to 2008 to aid

comparison with results from other techniques. Participants were made aware that there were additional optional experiments which they may choose to participate in, though they would require the contribution of additional data.

In registration and data submission, the following was required from the participants:

- Personal details, including name, affiliation, email, and telephone number
- Personal account name and password
- Confirmation that they accept general conditions to remain in timely correspondence with the experiment group leaser, and that they understand that only submissions received before the submission closing data will be included in the assessment.
- Indication of the regions (AP, WAIS, EAIS, GrIS) for which they intended to/ did supply time series and/or mean rates of ice discharge and net inland accumulation, and uncertainty estimates, plus the coordinated of the flux gates through which ice discharge was calculated.
- Indication of the missions employed in the ice velocity calculation (i.e. ERS-1, ERS-2 EnviSat, ALOS PALSAR, TerraSAR-X, COSMO SkyMed, RADARSAT-1/-2, Sentinel-1/-2, Landsat-8 or other).
- Indication of methods employed to compute ice velocity (i.e. intensity feature tracking, coherent feature tracking, interferometric phase or other).
- Indication of any datasets used to compute ice thickness (i.e. gridded observations, airborne profiles, ground-based observations, mass conservation model, other).
- Indication of whether the ice thickness dataset employed is available for distribution among the experiment group.
- Information on the dataset that was used to compute snow accumulation, including a doi of the publication where the dataset is described
- Information on the dataset used to compute runoff, including a doi of the publication where the dataset is described.
- Information on the general method used to estimate mass balance in unobserved regions.
- Information on independent observations used to evaluate ice velocity measurements (i.e. airborne, ground-based, independent satellite).

- Information on whether the mass budget methods used are published or not, and if so, where the methods are published.
- Information on whether the ice velocity, snow accumulation and runoff measurement errors has been fully described in a publication or not, and if so, where.
- Indication of whether or not they are intending to participate in the additional experiments to investigate methodological differences in more detail, and if so, for which region.

2.1.4 SMB

The IMBIE surface mass balance (SMB) experiment group is led by Michiel van den Broeke, to whom participants are required to that all correspondence should be addressed, with one of the project leaders in copy. To participate in the IMBIE SMB experiment group, participants are required to contribute time-series of ice sheet surface mass balance and its associated uncertainty. Participant contributions must be computed within one or more of the drainage basins defined by IMBIE (i.e. Zwally *et al.,* 2012; Rignot *et al.,* 2016). Each time series must be sampled at monthly intervals or shorter, and should ideally encompass the period 1992 to 2015 to aid comparison with satellite data sets. An SMB data set is required to be derived from a model that (i) assimilates meteorological observations, (ii) performs continuous runs, and (iii) includes a treatment of snow, surface melting, and refreezing processes. There are additional optional experiments that participants may choose to participate in, it is made clear that these will require contribution of additional data.

In registration and data submission, the following was required from the participants:

- Personal details, including name, affiliation, email, and telephone number
- Personal account name and password

- Confirmation that they accept general conditions to remain in timely correspondence with the experiment group leaser, and that they understand that only submissions received before the submission closing data will be included in the assessment.
- Indication of the regions (AP, WAIS, EAIS, GrIS) for which they intended to/ did supply time series and/or gridded time series of surface mass balance, and uncertainty estimates.
- Information on which meteorological data was used to force the boundaries of the SMB data.
- Indication of which observations were used to constrain the SMB model (i.e. airborne, ice cores, snow pits, AWS, Manned weather stations, stakes or other).
- Indication of the independent observations used to evaluate the SMB model output (i.e. airborne, ice cores, snow pits, AWS, manned weather stations, stakes or other).
- Confirmation on whether or not the SMB model methods and errors have been published, and if so, provide the published version of the paper.
- Indication on participation in additional experiments to investigate the methodological differences between models in more details.

2.1.5 GIA

The IMBIE glacial isostatic adjustment (GIA) experiment group is led by Pippa Whitehouse, to whom participants are required to address all correspondence to, with one of the project leaders in copy. The role of the GIA experiment group is to assess GIA solutions and their impact on estimates of ice sheet mass balance. It was outlined to participants that this activity takes place in parallel with the first annual update on ice mass balance derived from satellite data, and based on this assessment, the group will then make recommendations on GIA solutions for future IMBIE assessments. To participate in the IMBIE GIA experiment group, participants are required to contribute uplift rates and Stokes coefficients calculated using a GIA 'forward' model, and an assessment of their associated uncertainties. Participants uplift rates should be computed on a 0.5 degree grid, and Stokes coefficients should be provided at least up to degree and order 90. The GIA solutions must have been compared, quantitatively, with rebound data, and must utilise an ice history model that is guided by geological constraints. To participate, participants are required to have created either the ice history or Earth model that forms the basis of their GIA solution,

and they may submit only one GIA estimate to this exercise for each ice sheet.

In registration and data submission, the following was required from the participants:

- Personal details, including name, affiliation, email, and telephone number
- Personal account name and password
- Confirmation that they accept general conditions to remain in timely correspondence with the experiment group leaser, and that they understand that only submissions received before the submission closing data will be included in the assessment.
- Indication of the regions (AP, WAIS, EAIS, GrIS) for which they intended to/ did supply uplift rates and associated uncertainties, distributed on a 0.5 degree grid.
- Indication of whether they will provide Stokes coefficients at least up to degree and order 90.
- Information on the aspects of the GIA solution that the participant created (i.e. the ice history model, the earth model, approach to sea-level loading and self-gravitation).
- Information on the ice history model that has been employed in the GIA solution (including far field ice) (i.e. own model, other – giving doi).
- Information on the Earth model that was employed in the GIA solution (i.e. own model, other – giving doi).
- Information on the code used to produce the GIA solution (i.e. own code, other – giving doi).
- Information on the rebound data (e.g. GPS or relative sea level, giving details of publications or online dataset) that were used to evaluate the GIA solution.
- Information on other types of data that were used to constrain the GIA solution.
- Indication on whether or not the GIA model and errors had been published and if so, provide a version of the published paper.

2.2 File Formats

We defined standard file formats to simplify data collection. If there was a standard format for a basic or optional experiment, participants were required to only submit data using this format. We warned that data submitted using other formats would not be accepted.

2.2.1 Time-series of mass change

The file format prescribed was comma separated, ASCII.

We asked that the file contain nine columns of information, each row detailing the *Participant Surname*, the *Experiment Group* name (Altimetry, Gravimetry, or Mass Budget), the *Drainage Region Se*t employed (Rignot or Zwally), the *Drainage Region ID* (see below), the *Drainage Region Area* (in square kilometers), the *Drainage Region Area Observed* by the satellite dataset (in square kilometers), the *Date* for each entry in the time series (in decimal years), the *Relative Mass Change* for each entry in the time series (in gigatons), and the *Relative Mass Change Uncertainty* for each entry in the time series (in gigatons).

For the Zwally drainage region set, ID's are numeric in the range 1 to 27 (Antarctica) and 1.1 to 8.2 (Greenland). For the Rignot drainage region set, ID's are alphabetical in the range "A-Ap" to "K-A" (Antarctica) and "CW" to SW" (Greenland). Results computed within ice sheet boundaries were to be labelled "APIS" (Antarctic Peninsula", "EAIS" (East Antarctica), "WAIS" (West Antarctica), and "GRIS" (Greenland).

If results were submitted for multiple drainage sets, drainage basin, or ice sheet areas, these were to be concatenated into a single file.

An example dataset was provided on the website.

2.2.2 Rates of mass change

The file format is comma separated, ascii.

The file was to contain ten columns of information, each row detailing the *Participant Surname*, the *Experiment Group* name (Altimetry, Gravimetry, or Mass Budget), the *Drainage Region Set* employed

(Rignot or Zwally), the *Drainage Region ID* (see below), the *Drainage Region Area* (in square kilometres), the *Drainage Region Area Observed* by the satellite dataset (in square kilometres), the *Start Date* for each of interval in the mass trend time series (in decimal years), the *End Date* for each interval in the mass trend time series (in decimal years), the *Rate of Mass Change* for each interval in the mass trend time series (in gigatons per year), and the *Rate of Mass Change Uncertainty* for each interval in the mass trend time series (in gigatons per year).

For the Zwally drainage region set, ID's are numeric in the range 1 to 27 (Antarctica) and 1.1 to 8.2 (Greenland). For the Rignot drainage region set, ID's are alphabetical in the range "A-Ap" to "K-A" (Antarctica) and "CW" to SW" (Greenland). Results computed within ice sheet boundaries should be labelled "APIS" (Antarctic Peninsula", "EAIS" (East Antarctica), "WAIS" (West Antarctica), and "GRIS" (Greenland).

If participants were submitting results for multiple drainage sets, drainage basin, or ice sheet areas, they were asked to concatenate these into a single file.

An example data set was provided on the website.

3 Assessment Schedule and Processing

The schedule for IMBIE II in 2016/2017 is as follows:

Event	Date
Participant Registration Deadline	12th August
Data Submissions Open	18th October
Data Submissions Closed	1st November
Data Processing by Isardsat	November/December
Executive Committee Discussion of Results	11th December
Presentation of Initial Results to Participants	11th December
Completion of assessment	1st March

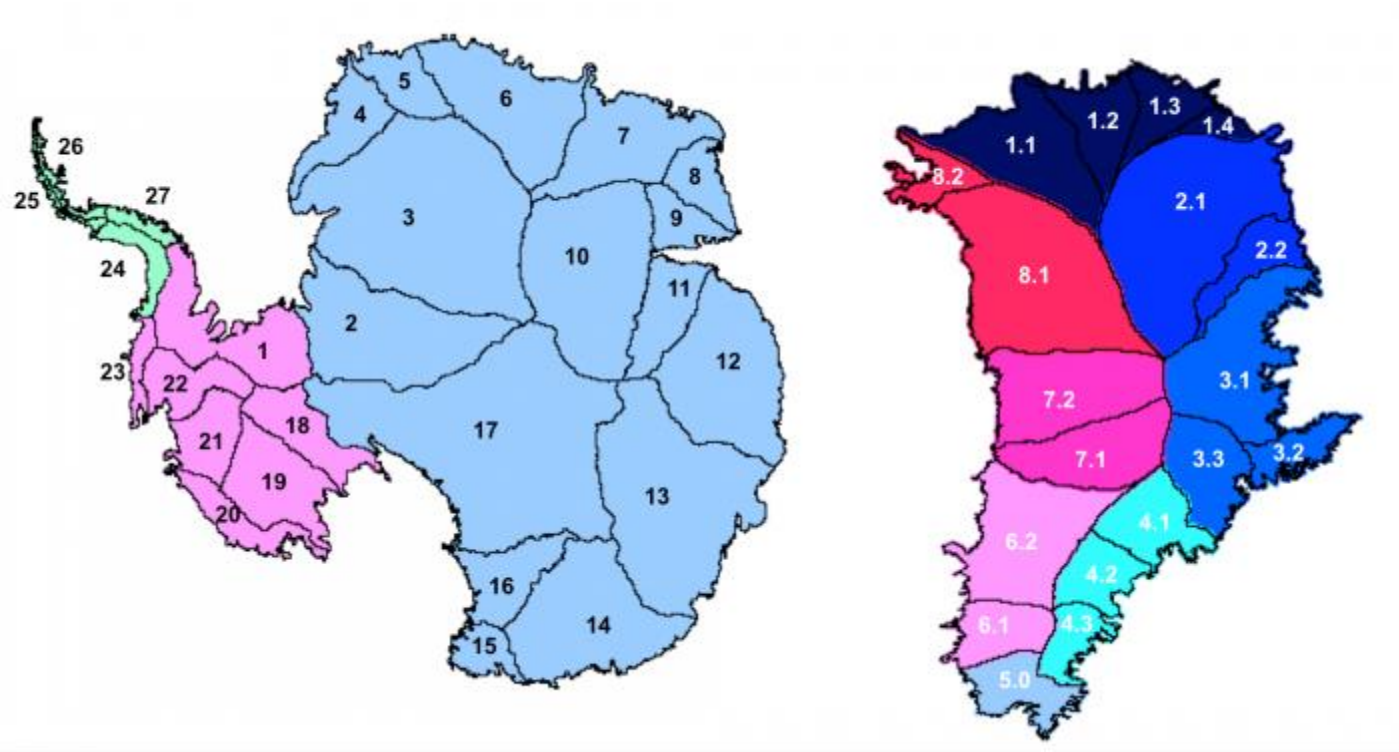
4 Adopted Spatial Domains

IMBIE II is using two sets of grounded ice area and drainage basin definitions for Antarctica and Greenland. The first set, mapped by Zwally et al., (2012), were used in IMBIE 2012 and are retained for consistency. The second set, mapped by Rignot et al. (2016), are an updated definition introduced here for the first time. In 2016, participants posted their results at least one of these sets of drainage basins.

4.1 Zwally Basins

The maps were created using surface elevation data derived from ICESat, with the drainage basins delineated based on ice provenance. The definitions include 27 basins in Antarctica and 19 basins in Greenland that cover areas of 12,377,790 km² and 1.722.572 km², respectively. In Antarctica, the East and West Antarctic Ice Sheets (EAIS and WAIS, respectively) are separated approximately along the Trans-Antarctic Mountains, with the EAIS divided into 16 basins, the WAIS into seven and the Antarctic Peninsula into four. The 19 basins in Greenland are grouped into eight separate regions (1=North, 2=North-East, 3=East, 4=South-East, 5=South, 6=South-West, 7=West, 8=North-West). These delineations are shown in the figures below.

Drainage basin and ice sheet outlines in lat/lon vector format can be downloaded from the the IMBIE website.



Antarctica (left) and Greenland (right) drainage basin and ice sheet definitions, produced by Zwally *et al.,* (2012) and used by IMBIE 2016

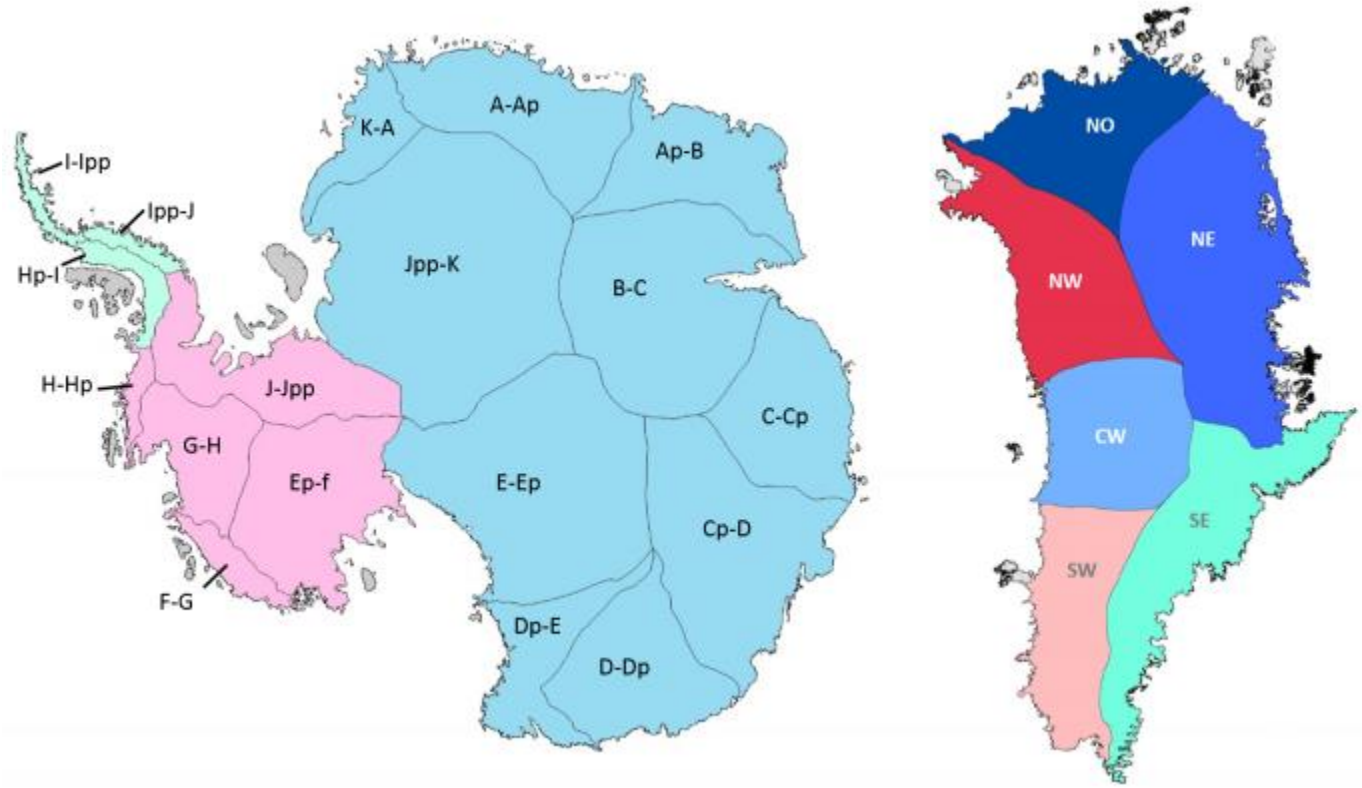
4.2 Rignot Basins

Antarctica is separated into WAIS, EAIS and AP based on historical definitions plus information from modern-day DEM and ice velocity data. AP is limited by Ronne to the east and George VI to the west. WAIS and EAIS are divided along the Transantarctic range; WAIS drains into Ronne, EAIS drains into Filchner. The basin boundaries are defined with a posting of ~ 150m. Within these three ice sheet regions, subregions A, B, C, Cp, etc. are defined based on historical nomenclature (Giovinetto and Zwally, 2000) plus modern DEM and ice velocity data, and adjusted to match the drainage boundaries of the major ice shelves. Grounding lines, area, ice fronts of all ice shelves are based on (Rignot *et al.*, 2013). The interior basins rely on an ERS/ICESat DEM in the interior and the 2011 velocity mosaic (flow direction) near the coast. The basins are close to an earlier definition (Rignot *et al.*, 2011a) where no area is left out, and hence can be used for altimetry, gravity and mass-budget alike. Grounding lines are InSAR 2011 (NSIDC).

Surrounding glaciers and ice caps are in one separate shape file. Sub-sub-divisions are not included at this stage.

Greenland ice drainage units are based on historical usage (Rignot et al., 2011b). The regions are separated based on glacier regime (marine-terminating dominance versus land-terminating) and SMB (dry vs wet). NW and CW has a clear basin boundary near Rinks. CW to SW marks the transition from tidewater to land-terminating. SE vs NE is at a major transition in SMB with a well-defined divide inland. Our delineation uses the GIMP DEM, and an ice velocity data set (Rignot and Mouginot, 2012). All surrounding ice caps and glaciers are in one shape file “islands”. Ice margin is from GIMP. Sub-sub-divisions are not included.

The basins are available on the IMBIE website.



Antarctica (left) and Greenland (right) drainage basin and ice sheet definitions, produced by E. Rignot and J. Mouginot and used by IMBIE 2016.

5 References

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