**Esos.ISMASS 2012 Workshop - Final Agenda**

**Date and venue:**
The workshop will be held on 14 July 2012, in two sessions, 8:00-13:00 and 14:00-18:00, in Portland, Oregon, USA, in Alexanders Room of Hilton Portland and Executive Tower (921 Southwest 6th Avenue, Portland), venue of the SCAR Open Science Conference.

**Agenda:**

08:00-08:20 – Registration

08:20-08:30 – Workshop presentation

08:30-10:00 – Invited lectures (mass balance from remote sensing; glacial isostatic adjustment)

  08:30-09:00 – “Overview of the Ice Mass Balance Inter-comparison Exercise (IMBIE) project findings” (Erik Ivins, JPL, Caltech, USA, and Ben Smith, APL, University of Washington, USA)

  09:00-09:30 – “What is a GIA model, and why do we need it to determine ice-mass balance?” (Pippa Whitehouse, Durham University, UK)

  09:30-10:00 – “Mass Balance of Antarctic Ice Sheet 1992 to 2008 from ERS and ICESat: Gains Exceed Losses” (Jay Zwally, NASA Goddard, USA)

10:00-10:30 – Coffee break

10:30-12:30 – Invited lectures (modelling of ice-sheet dynamics; contributions to sea level rise from thermal expansion of the oceans; impacts of SLR)

  10:30-11:00 – “Modelling the evolution of Antarctica and Greenland ice sheets: recent improvements and challenges for the future” (Catherine Ritz, LGGE, Grenoble, France)

  11:00-11:30 – “Convergence of Models and Reality? Bothersome Boundary Conditions” (Slawek Tulaczyk, University of California Santa Cruz, USA)

  11:30-12:00 – “Ocean thermal expansion and its contribution to sea-level rise over the past 40 years (1960-present)” (Catia Domingues, ACE CRC, Australia)

12:00-12:30 – “Global impacts of sea-level rise” (Robert Nicholls, University of Southampton, UK)

12:30-13:30 – Buffet lunch offered to Workshop participants

13:30-14:10 – Round table “Ice-sheet mass balance from remote sensing, and GIA”

  Round table moderator: Edward Hanna (University of Sheffield, UK)

  At table: Erik Ivins, Ben Smith, Pippa Whitehouse, Jay Zwally

14:10-14:50 – Round table “Modelling of ice-sheet dynamics”

  Round table moderator: Frank Pattyn (Université Libre de Bruxelles, Belgium)

  At table: Catherine Ritz, Slawek Tulaczyk

14:50-15:30 – Round table “Thermal expansion of the oceans and impacts of sea level rise”

  Round table moderator: Francisco Navarro (Technical University of Madrid, Spain)

  At table: Catia Domingues, Robert Nicholls

15:30-16:00 – Coffee break

16:00-17:30 – ISMASS group organization session

17:30-18:00 – Presentation of draft conclusions and closing
Abstracts of invited lectures

Overview of the Ice Mass Balance Inter-comparison Exercise (IMBIE) project findings
*Erik Ivins, JPL, Caltech, USA, and Ben Smith, APL, University of Washington, USA*

The Ice-sheet Mass Balance Inter-comparison Exercise (IMBIE) is a combined ESA/NASA effort to perform experiments that would allow better understanding of the discrepant results that have arisen concerning the mass balance of the Greenland (GIS) and Antarctic (AIS) ice sheets, including quite different quantitative assessments of east (EAIS) and west (WAIS) for the latter. Three different techniques are inter-compared, with intra-comparison among different groups using the same space data. The techniques are ‘Input-Output Method’ (IOM), radar and laser altimetry (RA and LA), and GRACE gravimetry, and the periods open for experimentation are 1992-2011, with special focus on the period 2003-2008, when direct inter-comparison among techniques is feasible.

A series of experiments established grounds for the inter-comparison. Direct comparisons between RA and IOM for basins within the AIS showed that the two techniques give largely compatible results, with an average difference between the two of 1.4 ± 3.8 Gt yr$^{-1}$ and agreement to within the 2-$\sigma$ errors for 42 of 49 basins. Rates for regions surveyed by RA and not by IOM were small (4.5 ± 6.0 for WAIS and 1.4 ± 1.7 Gt yr$^{-1}$ for EAIS) demonstrating that direct IOM measurements capture nearly all significant mass loss in Antarctica. Likewise, comparisons between modeled SMB (as used for IOM), RA, and GRACE measurements during an exceptional 2009 EAIS snowfall event showed close agreement between the magnitude and spatial pattern of the resulting mass anomaly.

The different techniques then were used to establish mass-rate estimates suitable for comparison and for the establishment of reconciled estimates. IMBIE IOM results include updated error estimates, but exclude heuristic scaling between measured and unmeasured areas that have been used in other publications, giving somewhat less negative results than have been reported elsewhere. RA gave estimates of WAIS and EAIS elevation rates north of 86 S. For regions where ice dynamics suggest changes in discharge, the volume estimate was scaled by the density of ice. Where as, elsewhere it was scaled by the density of snow to produce mass-change estimates. Laser altimetry data were analyzed by four separate groups using different techniques to interpolate between measurements, and two sets of techniques to correct for instrumental biases and to scale between volume and mass changes; these results were limited to 2003-08, but covered as far north and south as 86 degrees. Different LA groups found significantly different mean rates of mass change, chiefly in East Antarctica where correction magnitudes are large compared to elevation-change signals. An additional area of debate is over the role of the glacial isostatic adjustment (GIA), as it has an important influence on GRACE results reported for Antarctica. Largely due to maturation of two ancillary data sets (Whitehouse – this session), two new GIA (nGIA) models can be folded into our analyses to replace two older models. Use of nGIA improves our understanding of GRACE’s constraint on AIS. Combining mass-change estimates for the 2003-08 period showed all three techniques agreeing for all of the regions to within estimated errors, except for LA on the EAIS where corrections tended to dominate the signal. Combined AIS and GIS IMBIE time series give an accelerating rate of loss, with mass rates of $-102 \pm 118$ between 1992 and 2000, $-292 \pm 75$ between 2000 and 2012, and $-343 \pm 62$ Gt yr$^{-1}$ between 2005 and 2012.

The optimum target period for GRACE intra-comparison among six research groups was 2003-2010. The results, with nGIA models used for Antarctica, gave WAIS = $-108 \pm 26$, EAIS = $+57 \pm 35$ and AIS = $-81 \pm 35$ Gt yr$^{-1}$, while for Greenland the loss determined in the experiment is much larger: GIS = $-229 \pm 27$ Gt yr$^{-1}$. Clear acceleration of loss in WAIS and GIS, and a gain in EAIS, over the target time period is identified for the intra-comparison.
**What is a GIA model, and why do we need it to determine ice-mass balance?**

*Pippa Whitehouse, Durham University, UK*

Glacial Isostatic Adjustment (GIA) is the response of the Earth system to changes in the distribution of glacial and oceanic surface masses during a glacial cycle. A GIA model consists of a series of predictions relating to the temporally- and spatially-varying changes in relative sea level, geoid height, and solid Earth deformation arising due to GIA processes. Such a model is constructed from two key inputs: the global ice-loading history, and the rheological properties of the Earth.

Due to the viscous nature of the Earth’s mantle, the solid Earth response to surface loading continues for several thousand years following the cessation of load changes. In the polar regions, the dominant GIA signal is one of uplift, in response to the decrease in the mass of the Greenland and Antarctic ice sheets following the Last Glacial Maximum (LGM). However, in some areas, such as East Antarctica, the ice sheet is thought to have grown since the LGM, and these regions will therefore currently be experiencing solid Earth subsidence.

This spatially-varying uplift signal contaminates observations of ice mass change in two ways. Firstly, any solid Earth deformation will be included in altimetry observations, and should be subtracted in order to determine the change in ice surface elevation purely due to changes in the thickness of the ice sheet. Secondly, the gravitational signature of GIA will contaminate GRACE gravimetry observations, and, similarly, the GIA component must therefore be subtracted to reveal the gravitational signature of present-day ice mass change. In this latter case, the GIA signal in Antarctica is approximately equal and opposite to the gravitational signal of present-day ice mass loss, and therefore, correctly determining the GIA signal is critical to determining the magnitude and distribution of present-day ice mass change using the GRACE data.

**Mass Balance of Antarctic Ice Sheet 1992 to 2008 from ERS and ICESat: Gains Exceed Losses**

*Jay Zwally, NASA Goddard, USA*

During 2003-2008, the mass gain of the Antarctic ice sheet from snow accumulation exceeded the loss from ice discharge by 43 ± 16 Gt yr$^{-1}$ (2.3% of input), as derived from ICESat laser altimetry. The 101 Gt/yr gain in East Antarctica (EA) and the 68 G yr$^{-1}$ gain in four drainage systems (DS) of West Antarctic (WA2) exceeded combined losses of 98 Gt yr$^{-1}$ from three coastal DS of West Antarctic (WA1) and 28 Gt yr$^{-1}$ from the Antarctic Peninsula (AP). Re-analysis of ERS radar-altimeter data, including a new post-glacial-rebound correction, indicates an even larger gain of 120 ± 50 Gt yr$^{-1}$ during 1992-2001. In WA2 and EA, persistent dynamic thickening (excess of long-term accumulation over ice flux) contributed more than 170 Gt yr$^{-1}$ to the net positive balance in both periods. Consistent with observed outlet-glacier accelerations, a loss increase of 66 Gt yr$^{-1}$ in WA1 and AP from dynamic thinning dominated a gain increase of 9 Gt yr$^{-1}$ from positive accumulation anomalies, accounting for most of the 77 Gt yr$^{-1}$ decrease in the overall gain in the later period. During both periods, regional changes driven by short-term accumulation variations are small compared to dynamic changes. Although recent increases in dynamic thinning in WA1 and AP have been partially offset by accumulation increases, continuation at similar rates would initiate small Antarctic contributions to sea-level rise within a decade.

**Modelling the evolution of Antarctica and Greenland ice sheets: recent improvements and challenges for the future**

*Catherine Ritz, LGGE, Grenoble, France*

Ice sheet modelling is a precious tool to understand the evolution of ice sheets in response to climate change. Models were first developed to simulate the behaviour of ice sheets during the glacial interglacial cycles but they are more and more used to evaluate the potential contribution
to sea level rise in the context of global warming. The initial models had some limitations that made this task difficult but during the last years substantial work has been done. In this presentation, the most significant improvements are presented. i) The mechanical equations used are more rigorous with a variety of higher order approximations and some models are even designed to solve the complete set of “full Stokes” equations. ii) For the Antarctic ice sheet, the volume is governed by the dynamic of the grounding line. Theoretical and numerical works have shown that a potential dynamic instability could occur and make this ice sheet contribute to a sea level rise. However, these works have also demonstrated that a grid resolution down to 100 m is necessary to model this process. This raises difficulties to simulate the whole ice sheet and several strategies have been proposed from parameterisations to multigrid or unstructured grid approaches. iii) Finally, inverse approaches begin to be used. One example is the calibration of models by inferring bedrock properties from surface velocity observations. We will also present an approach based on ensemble simulations to quantify the possible range of contribution to sea level related to the grounding line retreat in Antarctica. Challenges for the future will be the continuation of the works mentioned above with at least two other crucial topics: modelling the calving and understanding how basal properties evolve with time.

Convergence of Models and Reality? Bothersome Boundary Conditions
Slawek Tulaczyk, University of California Santa Cruz, USA

This abstract will be made available through the Workshop website http://www.climate-cryosphere.org/en/events/2012/ISMASS/Home.html

Ocean thermal expansion and its contribution to sea-level rise over the past 40 years (1960-present)
Catia Domingues, ACE CRC, Australia

One of the key indicators of changes in the earth's energy and sea level budgets is the amount of heat stored in the ocean. The heat content of the ocean has markedly increased and accounts for about 90% of the total heat accumulated in our climate system since the 1970s. Warmer subsurface temperatures raise the volume of the ocean (thermal expansion) and causes sea level to rise. Thermosteric sea level (ThSL) is one of the major factors contributing to the global mean sea-level (GMSL) rise observed during the second half of the 20th century and early 21st century, and is also expected to continue to be one of the largest contributing factors along the 21st century. This is not surprising given the ocean’s massive thermal inertia and enormous capacity to store heat. In this talk, we first provide an overview of the challenges in estimating near-global ThSL in the top 700 m of the ocean, from sparse and unevenly distributed subsurface ocean temperature data, measured by a large mix of instruments. We illustrate the impact of different instrumental bias corrections and mapping approaches on the global evolution and spatio-temporal variability of ThSL estimates. We also explain how our ThSL estimate is reconstructed and assess its contribution to the observed GMSL rise over successive trend periods, from 1960 onwards, and compare these results with ThSL estimates from another two groups, Levitus et al. and Ishii and Kimoto. Overall, all these estimates indicate a multi-decadal ThSL rise in the upper 700 m of the ocean, with contributions to GMSL varying from 20% to 35%. Finally, based on a detection and attribution (D&A) analysis, we assessed the causes of the multi-decadal ocean warming, leading to the observed ThSL rise, in the context of structural uncertainties in the underlying ocean data sets and in a large set of climate models from 13 major modeling groups. An anthropogenic fingerprint, driven by global mean and basin-scale pattern changes, is detected since 1980 (at 1% significance level), confirming the results of earlier studies. This detection is robust to a number of observational, model and methodological or structural uncertainties.
Global impacts of sea-level rise

Robert Nicholls, University of Southampton, UK

Coastal areas constitute important habitats, and they contain a large and growing population, much of it located in economic centers such as London, New York, Tokyo, Shanghai, Mumbai, and Lagos. The range of coastal hazards includes climate-induced sea level rise, a long-term threat that demands broad response. Global sea levels rose 17 cm through the twentieth century, and are likely to rise more rapidly through the twenty-first century when a rise of more than 1 m is possible. In some locations, these changes may be exacerbated by (1) increases in storminess due to climate change, although this scenario is less certain, and (2) widespread human-induced subsidence due to ground fluid withdrawal from, and drainage of, susceptible soils, especially in deltas. Relative sea level rise has a range of potential impacts, including higher extreme sea levels (and flooding), coastal erosion, salinization of surface and ground waters, and degradation of coastal habitats such as wetlands. Without adaptation, large land areas and millions of people could be displaced by sea-level rise. Appropriate responses include climate mitigation (a global response) and/or adaptation (a local response). A combination of these strategies appears to be the most appropriate approach to sea level rise regardless of the uncertainty. Adaptation responses can be characterized as (1) protect, (2) accommodate, or (3) retreat. While these adaptation responses could reduce impacts significantly, they will need to be consistent with responses to all coastal hazards, as well as with wider societal and development objectives; hence, an integrated coastal management philosophy is required. In some developed countries, including England and the Netherlands, proactive adaptation plans are already being formulated. Coastal cities worldwide will be a major focus for adaptation efforts because of their concentrations of people and assets. Developing countries will pose adaptation challenges, especially in deltaic areas and small islands, which are the most vulnerable settings.