Editorial – The IGBP Synthesis - Celebrating three decades of Earth System Science

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Space is often quoted as being the “*final frontier*”, but in some senses we have been undertaking a journey just as challenging on our own planet. The ability to treat Earth and its various components (ocean, land and atmosphere) as a whole system and recognize the interaction of the physical, chemical and biological processes that regulate the Earth system was a critical step in researching this “*final frontier*”. This research was largely catalyzed by action of the International Geosphere-Biosphere Program (IGBP) and its constituent projects. This special issue celebrates three decades of IGBP leading Earth system science and contains a set of papers that details the program-level, science and policy support successes. IGBP as a program came to a formal end in December 2015. This collection of papers signposts a fraction of what has been achieved in fostering international collaborative research and synthesis on global change research.

As a program, IGBP has been on a voyage of discovery that has passed through three broad phases as detailed in the opening overview paper (Seitzinger et al. (2016)). The first, an explore and discovery phase, set out to understand and map the individual components of the Earth system. It was followed by a rationalize and model phase that joined the system together and began to incorporate humans as part of the system. In this phase, the now famous term “*Anthropocene*” was coined and the great acceleration was demonstrated (Steffen et al., 2015). The final phase pushed towards sustainability, an attribute and predict phase that had an increased emphasis on applicability and relevance of knowledge.

A key characteristic, strength and delivery vehicle of IGBP has been its core-projects, which have undoubtedly journeyed from strong disciplinary bases to create whole new communities in science, e.g. science at the interfaces in the Earth system. As detailed in Seitzinger et al. (2016) the core projects over the period of IGBP have waxed and waned as the understanding of Earth system science grew and required the formation of different science groupings and disciplines to meet new challenges.

Within this special issue the current core-projects that represent the compartments of the Earth system in terms of atmosphere (IGAC, International Global Atmospheric Chemistry (Melamed et al., 2016)), land (Global Land Project, (Verburg et al., 2016)) and ocean (IMBER, Integrated Marine Biogeochemistry and Ecosystem Research (Hofmann et al., 2016)), as well as the requisite links atmosphere-ocean (SOLAS, (Brévière et al., 2016)), atmosphere-land (iLEAPS, Integrated Land Ecosystem-Atmosphere Processes Study (Sun et al., 2016)) and land-ocean (LOICZ, Land-Ocean Interactions in the Coastal Zone (Ramesh et al., 2016)) are detailed. IGBP made a bold effort in

AIMES (Analysis, Integration and Modelling the Earth system (Schimel et al., 2016)) to integrate the understanding towards a more quantitative understanding of the Earth's biogeochemical cycles and their coupling with the physical climate system – an early and valiant effort to forge Earth system modelling. PAGES (Past Global Changes) looks to past changes in the Earth's physical climate system, biogeochemical cycles, ecosystem processes, biodiversity, and human dimensions in order to make predictions for the future.

On reading this special issue it remains clear that the challenge of Earth System Science remains, after three decades of scientific endeavor, we continue to work toward a truly integrated system view of the Earth that can deal with humans as part of the forcing and feedbacks. Much of that baton has now been picked up by Future Earth (Rockström, 2016), which pushes forward on global environmental change and sustainability research.

The central challenge remains as captured by Kenneth E. Boulding - *'We have to visualise the Earth as a small, rather crowded spaceship, destination unknown, in which humans have to find a slender thread of a way of life in the midst of a continuous cycle of material transformations. It is clear on our 'spaceship' there are no inputs or outputs, we must circulate the resources that we rely on such as water, food and air continuously'*

References

- Brévière, E.H.G., Bakker, D.C.E., Bange, H.W., Bates, T.S., Bell, T.G., Boyd, P.W., Duce, R.A., Garçon, V., Johnson, M.T., Law, C.S., Marandino, C.A., Olsen, A., Quack, B., Quinn, P.K., Sabine, C.L., Saltzman, E.S., 2016. Surface ocean-lower atmosphere study: Scientific synthesis and contribution to Earth system science. *Anthropocene*.
- Hofmann, E., Bundy, A., Drinkwater, K., Piola, A.R., Avril, B., Robinson, C., Murphy, E., Maddison, L., Svendsen, E., Hall, J., Xu, Y., 2016. IMBER – Research for marine sustainability: Synthesis and the way forward. *Anthropocene*.
- Melamed, M.L., Monks, P.S., Goldstein, A.H., Lawrence, M.G., Jennings, J., 2016. The international global atmospheric chemistry (IGAC) project: Facilitating atmospheric chemistry research for 25 years. *Anthropocene*.
- Ramesh, R., Chen, Z., Cummins, V., Day, J., D'Elia, C., Dennison, B., Forbes, D.L., Glaeser, B., Glaser, M., Glavovic, B., Kremer, H., Lange, M., Larsen, J.N., Tissier, M.L., Newton, A., Pelling, M., Purvaja, R., Wolanski, E., 2016. Land–Ocean Interactions in the Coastal Zone: Past, present & future. *Anthropocene*.
- Rockström, J., 2016. Future Earth. *Science* 351, 319-319.
- Seitzinger, S.P., Gaffney, O., Brasseur, G., Broadgate, W., Ciais, P., Claussen, M., Erisman, J.W., Kiefer, T., Lancelot, C., Monks, P.S., Smyth, K., Syvitski, J., Uematsu, M., 2016. International Geosphere–Biosphere Programme and Earth system science: Three decades of co-evolution. *Anthropocene*.
- Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C., 2015. The trajectory of the Anthropocene: The Great Acceleration. *Anthropocene Review* 2, 81-98.
- Suni, T., Guenther, A., Hansson, H.C., Kulmala, M., Andreae, M.O., Arneth, A., Artaxo, P., Blyth, E., Brus, M., Ganzeveld, L., Kabat, P., de. Noblet-Ducoudré, N., Reichstein, M., Reissell, A., Rosenfeld, D., Seneviratne, S., 2016. The significance of land-atmosphere interactions in the Earth system—iLEAPS achievements and perspectives. *Anthropocene*.
- Verbarg, P.H., Crossman, N., Ellis, E.C., Heinemann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K.-H., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D.C., Chowdhury,

R.R., Shibata, H., Thomson, A., Zhen, L., 2016. Land system science and sustainable development of the earth system: A global land project perspective. *Anthropocene*.