**Critical Roles of Wetlands in Methane Emission and Terrestrial Water Storage in a Changing Climate**

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**1. Key Science and Application Challenges**

Wetland dynamics is crucial to changes in both *atmospheric methane* and *terrestrial water storage*, which are directly relevant to *global water and energy cycle sciences*. The IPCC Fifth Assessment Report (IPCC AR5) highlights the role of wetlands as a key driver of methane (CH4) emission, which is more than one order of magnitude stronger than carbon dioxide as a greenhouse gas in the centennial time scale. In the multitude of methane emission sources (hydrates, livestock, rice cultivation, freshwaters, landfills and waste, fossil fuels, biomass burning, termites, geological sources, and oxidations in soils), wetlands constitute the largest contributor with the widest uncertainty range of 177-284 Tg(CH4) yr–1 according to the IPCC estimate [*IPCC*, 2013].

In the global water and energy cycles, it is critical to identify and understand interrelations of hydrological cycles involving precipitations, soil moisture change, inundation, stream flow and runoff with wetlands dynamics and cycles of CH4 emission change. Pertaining to CH4 production and emission is the anaerobic metabolism for which inundated wetlands are directly relevant. As such there is a close connectivity in water and methane cycles. As the water cycle accelerates and intensifies in a changing climate [*Syed et al*., 2010; *Durack et al*., 2012], impacts on wetlands and thus CH4 emission are expected, but quantitative assessments require quantitative characterization of wetland dynamics at various time scales (seasonal, annual, interannual, to decadal scales).

Wetlands are highly susceptible to climate change that might lead to wetland collapse. Such wetland destruction would decrease the terrestrial water storage capacity and thus contribute to sea level rise, consequently exacerbating coastal flooding problems. For both CH4 change and water storage change, wetland dynamics is a crucial factor with the largest uncertainty. The increase or decrease in wetland extent is dependent on the regional wetland hydrology that can be significantly impacted by changes in temperature and precipitation. Consequently, the complex changes inflict a low confidence in quantitative projections of wetland CH4 emission from models and ecosystem warming experiments. And yet, both spatial distribution and temporal variability of wetlands remain highly unconstrained despite the existence of remote sensing products [*Papa et al*., 2010; *IPCC*, 2013].

This wetland information gap has long been recognized in the International Geosphere Biosphere Programme Global Analysis, Integration and Modelling (IGBP-GAIM) report, stating “Wetland extent: The largest gap in wetland characterization is the size of wetlands themselves, both in space and time. The level of flooding and the areal extent of wetlands is the largest uncertainty in applying models of wetland function to models of the global system. Both the temporal and areal extent of wetland flooding should be characterized in terms of ha-days. An additional factor is the phasing of flooding (i.e., continuous or intermittent). These issues are not adequately addressed in land cover compilations and terrestrial ecosystem models” [*IGBP-GAIM*, 1996].

Regarding the importance of wetlands to societal benefits, the Ramsar Convention [2015], an international treaty for the conservation and sustainable utilization of wetlands, articulates that “wetlands are vital for human survival. They are among the world’s most productive environments; cradles of biological diversity that provide the water and productivity upon which countless species of plants and animals depend for survival. Wetlands are indispensable for the countless benefits or “ecosystem services” that they provide humanity, ranging from freshwater supply, food and building materials, and biodiversity, to flood control, groundwater recharge, and climate change mitigation.”

As a key community of practice, the Ramsar Convention provides the single most global framework for intergovernmental cooperation on wetland issues, and a platform for collaboration between governments, experts, international NGOs, local communities and private companies and for promotion of scientific and technical cooperation and exchange of knowledge.

**2. Urgency and Timeliness**

Compounding the difficulties in discerning CH4 change, its growth in the Earth atmosphere has varied peculiarly in recent decades, demanding an urgent and significant advance in wetland monitoring capability to timely capture and understand such changes. Whereas CH4 concentration was stable for a decade since the late 1990s, CH4 emission has increased again since 2007 after a decade of ‘methane hiatus’ in 1990s-2000s [*IPCC*, 2013] to closely observe the renewed increase in a timely manner as CH4 emission changes along a new phase, whose cause is yet to be found, and establish whether it is a part of a new decadal cycle or a shift into a new regime of CH4 emission. While the exact drivers of such renewed growth is still unclear, a bottom-up estimation [*IPCC*, 2013] suggests that climate-driven fluctuations of methane emissions from natural wetlands are the main drivers of the global interannual variability of CH4 emissions. While IGBP-GAIM report highlighted the progress made in the 1980s leading to the classic global digital dataset of wetlands [*Matthews and Fung*, 1987], it also noted the deficiency and insufficiency in wetland characterizations. Such limitation remains [*Papa et al*., 2010; *IPCC*, 2013] as there has been no break-through in global wetland mapping.

Moreover, the urgent need of global data to monitor wetlands is emphasized by the rapid rate of wetland loss (~64 % of the world’s wetlands have disappeared since 1900) [*Ramsar Fact Sheet 3*, 2015]. In parallel, the populations of freshwater species declined by 76% between 1970 and 2010 according to World Wildlife Fund’s Living Planet Index [*WWF*, 2015]. These astounding deterioration rates need to be verified, captured, and monitored globally to determine whether such changes decelerate or even accelerate faster. Beyond science research, such wetland information is important to the community of practice (stakeholders, city planners, decision makers, local and state agencies, etc.) for societal benefit applications in an array of ecosystem functions where wetlands must be preserved or restored [*LMU*, 2015]. Recognizing the urgent need for a complete and consistent map of global wetlands, the Ramsar Convention [2015] calls for a wetlands inventory and impact assessment.

**3. Space-Based Observations and Potential Break-Through**

Space-based observations are fundamentally imperative for global monitoring of wetlands in time and in space routinely over the global coverage, while in-situ data can be collected over small areas for local applications and for validations of satellite algorithms.

The IGBP-GAIM report [*IGBP-GAIM*, 1996] reviewed and provided a great evaluation of advantages and limitations of various remote-sensing methods for wetland mapping. These include an array of different instruments systematically grouped into six categories: optical coarse resolution, optical fine resolution, optical/hyperspectral, passive microwave, active microwave, and synthetic aperture radar sensors. Since the late 1990s, numerous satellite sensors have been launched and/operated, from which datasets have been applied to map wetlands and observe their changes. A recent method based on polarization-ratio anomalies using satellite data from a Ku-band scanning scatterometer successfully demonstrates that weekly monitoring of wetland can delineate the terrestrial water storage capacity of the Mississippi wetlands in holding and later releasing water into the river system. Despite of these past methods and recent advances, a consistent global characterization, for both spatial distribution and temporal variability of wetlands, remains deficient [*IPCC*, 2013]. This demands new break-through methods to advance the capability to monitor global wetland dynamics in synergy with present and future satellite sensors/constellations.

The abundance of current and future Global Navigation Satellite Systems (GNSS) may offer a potential break-through for wetland dynamic monitoring, which necessitates a demonstration that GNSS reflectometry (GNSS-R) can distinctively identify wetlands. Initial results from the Catalonia (Spain) aircraft field campaign and TechDemoSat-1 satellite observations over known wetland areas have indicated the capability of GNSS-R to detect wetlands [*Zuffada et al*., 2015]. Although limited in lower latitudes, the Cyclone Global Navigation Satellite System mission will provide much more extensive satellite data for GNSS-R wetland algorithms development and verifications for use with future global GNSS-R measurements. GNSS-R advantages include: (1) Frequent and global coverage from multiple constellations, (2) long-term GNSS transmitters to be continued decades into the far future, (3) low-cost small-size receivers and antennas, (4) low frequencies unaffected by clouds or rains and less obscurity by vegetation cover, and (5) strong coherent forward reflection signatures in the bistatic geometry over inundated wetlands.

**4. Wetlands Science, Applications, and Technology Communities**

The wetlands science community across a wide range of expertise and disciplines, including the IGBP-GAIM, engaged and contributed significantly to the IPCC AR5, which highlights to critical roles on wetlands in methane emissions and water storage in a changing climate [*IPCC*, 2013]. The Ramsar Convention represents a key community of practice across the world for wetlands science and applications, together with local wetlands authorities and stakeholders. In writing this white paper, key findings from IGBP-GAIM, IPCC AR5, and the Ramsar Convention have been included, and interactions with airborne-satellite technology communities have been involved. These science and applications communities demand advances in wetlands observations from satellites to fill the critical and urgent gap of knowledge of global wetland dynamics from now to future decades.

**References:** Available upon request to Son.V.Nghiem@jpl.nasa.gov