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Introdução

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A bacia do rio Amazonas é um importante sistema hidrológico (~6 milhões de km^2 de área de drenagem) com diversos rios, várzeas e áreas alagáveis (Junk et al., 2011; Reis et al., 2019; **Figura 1**). Ela abrange sete países e abriga quatro dos dez maiores rios do mundo, a saber, os rios Solimões-Amazonas*, Madeira, Negro e Japurá (**Figura 2**), recebendo alta precipitação anual (~2200 mm por ano, Builes-Jaramillo e Poveda, 2018; Espinoza et al., 2009). Cerca de 30-40% da precipitação na bacia é reciclada pela evapotranspiração local (Eltahir e Bras, 1994; Salati et al., 1979; Satyamurty et al., 2013a), fornecendo umidade a partes do sul da América do Sul. O rio Amazonas flui para o Oceano Atlântico com uma vazão média anual de 206000 m^{3}s^{-1} (Callède et al., 2010), totalizando quase 20% do total da água doce global que chega ao oceano anualmente e exporta uma grande quantidade de sedimentos para o oceano (1,1 bilhão de toneladas por ano; Armijos et al., 2020).

As altas taxas de precipitação, evapotranspiração e grandes variações no armazenamento de água doce e vazão fazem da bacia Amazônica uma peça-chave no sistema climático global, com grandes contribuições para os ciclos da água, energia e carbono (Gash et al., 2013; Gatti et al., 2021; Nagy et al., 2016). As águas superficiais da Amazônia, por exemplo, são uma importante fonte e sumidouro de dióxido de carbono (Abril et al., 2014; Amaral et al., 2020; Guilhen et al., 2020; Raymond et al., 2013; Richey et al., 2002) e a maior fonte natural de metano nos trópicos (Kirschke et al., 2013; Melack et al., 2004; Pangala et al., 2017; Pison et al., 2013). As variações sazonais da água contribuem para a formação de florestas tropicais (Leite et al., 2012), mantêm alta produtividade aquática (Melack e Forsberg, 2001) e biodiversidade (Junk, 1997; Junk et al., 2010), e influenciam a distribuição dos peixes e a produção pesqueira (Junk et al., 2010; Lobón-Cerviá et al., 2015; **Figura 1**). A bacia abriga ~40% da floresta tropical mundial e ~15% da biodiversidade terrestre global (Marengo et al., 2018), e é também lar das populações humanas ribeirinhas que dependem dos rios para transporte e utilizam esses ambientes para sua subsistência (Anderson et al., 1991; Campos-Silva et al., 2020; Endo et al., 2016). A Amazônia também atende à população sul-americana em geral em termos de energia, alimentos e outros produtos florestais, além da manutenção de processos climáticos.

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*O rio Solimões-Amazonas é chamado rio Solimões antes da confluência com o rio Negro, a partir do qual é chamado rio Amazonas até o oceano.


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Figura 1: Diversidade da bacia do rio Amazonas. (a) Imagem da missão espacial MODIS da parte central da bacia, caracterizada por grandes planícies aluviais (Fonte: catálogo da *National Aeronautics and Space Administration* - NASA; *https://visibleearth.nasa.gov/images/62101/the-amazon-Brasil/62104l*); (b) Imagem da missão espacial Sentinel-1 dos rios e lagos do alto rio Solimões (Fonte: catálogo da ESA; *https://www.esa.int/ESA_Multimedia/Images/2020/09/Amazon_River*); (c) Imagem MODIS mostrando a reduzida cobertura de nuvens sobre corpos de água (Fonte: catálogo da NASA; *https://earthobservatory.nasa.gov/images/145649/mapping-the-amazon*); (d) Vista aérea do rio Branco (Foto de Thiago Laranjeira); (e) Planície de inundação durante a época de águas altas (Foto de João Paulo Borges Pedro); (f) Canal de várzea na Reserva de Desenvolvimento Sustentável Mamirauá (Foto de Jefferson Ferreira-Ferreira); (g) Comunidade na margem do rio (Foto de Thiago Laranjeira); (h) Manatins ou Peixe-boi (Foto de Amanda Lelis); (i) Pirarucu, o maior peixe de água doce com escamas do mundo (Foto de Bernardo Oliveira).

A região tem enfrentado múltiplos riscos devido às mudanças climáticas e antropogênicas, e as mudanças na hidrologia amazônica podem ter impactos substanciais a nível global (Jimenez et al., 2019). Nas últimas décadas, a bacia sofreu vários eventos climáticos intensos, como secas e enchentes extremas, sem equivalente nos últimos 100 anos (Barichivich et al., 2018; Marengo e Espinoza, 2016). Secas severas podem levar a perturbações ambientais, desde o aumento da ocorrência de incêndios (Zeng et al., 2008) até mudanças abruptas nos cardumes de peixes (Röpke et al., 2017). Além disso, os impactos negativos acumulados do aumento das intervenções humanas em toda a região, como barragens (Forsberg et al., 2017; Latrubesse et al., 2017), desmatamento (Arias et al., 2020; Coe et al., 2009; Gutierrez-Cori et al., 2021; Leite-Filho et al., 2020; Leite et al., 2012), incêndios (Aragão et al., 2008; Libonati et al., 2021; Xu et al., 2020; Zeng et al., 2008), e mineração (Abe et al., 2019; Lobo et al., 2015), possivelmente desencadearão grandes modificações que podem afetar o ciclo hidrológico da Amazônia.

A caracterização e compreensão do ciclo da água na Amazônia é primordial para as pesquisas climática e ecológica e para a gestão dos recursos hídricos. Consequentemente, é necessário um monitoramento abrangente da dinâmica espaço-temporal dos componentes do ciclo da água e de como eles interagem com a variabilidade climática e as pressões antropogênicas. Em bacias hidrográficas tropicais grandes e remotas como a Amazônica, as redes de observações *in situ* são difíceis de operar e manter, e as observações de sensoriamento remoto trouxeram grandes oportunidades para o monitoramento dos diversos componentes do ciclo da água, embora muitos desafios técnicos ainda precisem ser superados.

Durante as últimas décadas, enquanto a bacia Amazônica esteve no centro das discussões científicas internacionais, o entendimento da hidrologia amazônica coevoluiu com outro campo inovador: o sensoriamento remoto (SR) do ciclo da água terrestre. Nesse contexto, a bacia Amazônica tem sido um laboratório natural ideal para o desenvolvimento seminal de técnicas de SR com o advento da observação da Terra por satélites. Esses avanços têm fomentado a compreensão científica da hidrologia amazônica, dos ecossistemas e das mudanças ambientais em curso. Por exemplo, as primeiras aplicações dos satélites altimétricos e gravimétricos para caracterizar, respectivamente, a elevação das águas superficiais (Guzkowska et al., 1990) e as variações totais de armazenamento de água (Tapley et al., 2004) foram realizadas na bacia devido à largura do rio e às grandes mudanças espaciais e temporais da água doce. As aplicações pioneiras de SR também incluem micro-ondas, radar de abertura sintética e mapeamento interferométrico de inundações em grande escala e caracterização da dinâmica de sedimentos (Alsdorf et al., 2000; Hess et al., 2003; Mertes et al., 1993; Sippel et al., 1994). Desde então, várias aplicações usando dados de SR foram realizadas em outras bacias em todo o mundo (por exemplo, Alsdorf et al., 2021). Todos esses avanços importantes foram conquistados por uma comunidade diversificada de cientistas com diferentes interesses e visões sobre o ciclo da água Amazônica e, surpreendentemente, até a presente data não havia uma revisão abrangente que analisasse o crescimento contínuo de publicações que fazem uso de observações de SR para estudar a hidrologia da região.

Neste livro, apresentamos uma extensa revisão das conquistas de mais de três décadas de avanços científicos sobre a hidrologia da bacia Amazônica utilizando SR (**Figura 2**). Apresentamos também perspectivas, atualmente propiciadas por uma disponibilidade sem precedentes de observações da Terra e o lançamento iminente de satélites dedicados à hidrologia, tais como o SWOT (*Surface Water and Ocean Topography*) e a missão NASA-ISRO SAR (NISAR). Este trabalho reuniu especialistas em SR de diferentes processos hidrológicos da bacia Amazônica para rever tópicos específicos e discutir caminhos para os avanços científicos, assim como as oportunidades que moldam essa área para as próximas décadas. As revisões levaram em conta variáveis do ciclo hidrológico, como precipitação, evapotranspiração, elevação e extensão de águas superficiais, topografia da planície de inundação e dos canais fluviais, qualidade da água (por exemplo, estimativa de sedimentos, clorofila e matéria orgânica dissolvida), armazenamento total de água e de águas subterrâneas, que são apresentados em capítulos separados (**Figura 2**). Cada capítulo descreve como a variável é estimada por meio do SR, apresenta os avanços científicos que foram alcançados a partir dessas informações, bem como várias aplicações desenvolvidas para a bacia, discutindo os desafios futuros. Em seguida, quatro capítulos são dedicados à integração de dados de SR nas seguintes áreas: análise de balanço hídrico, modelagem hidrológica e hidráulica, ecossistemas aquáticos e mudanças ambientais na Amazônia. O capítulo 13 resume os avanços científicos, as lacunas de conhecimento e as oportunidades de pesquisa sobre a hidrologia e os ecossistemas da Amazônia, incluindo as próximas missões de observação da Terra. Este capítulo também aborda como as lições aprendidas com as experiências na Amazônia estão beneficiando outras grandes bacias hidrográficas em todo o mundo. O final do capítulo 13 discute como ir dos avanços científicos desenvolvidos para um planejamento efetivo de recursos hídricos em escala de bacia, bem como as novas ferramentas de monitoramento ambiental disponíveis, destacando nossas recomendações para a agenda de pesquisa da hidrologia amazônica a partir do espaço para a próxima década.

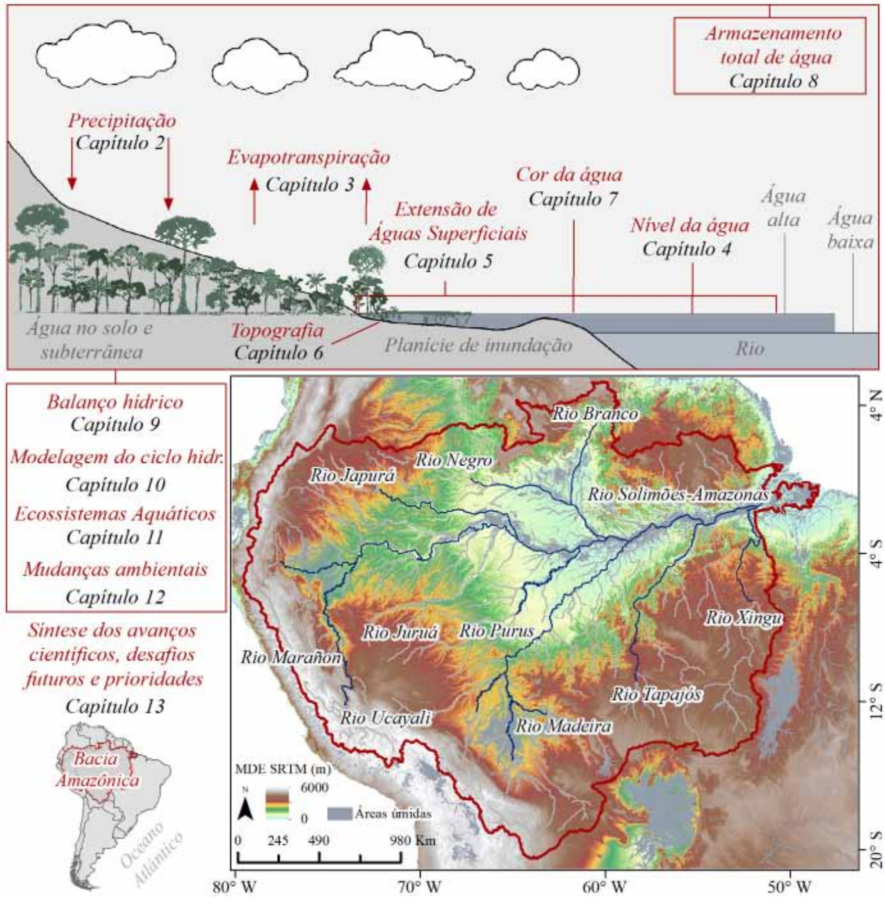

Figura 2: Localização da bacia Amazônica na América do Sul e representação das variáveis hidrológicas observadas pelas técnicas de SR, com os respectivos números dos capítulos deste livro.

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