05

Extensão de *Águas Superficiais*

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Caracterizar a extensão e variação de corpos de água superficiais e ecossistemas aquáticos, que incluem rios, igarapés, lagos e áreas úmidas como várzeas e igapós, é de importância primordial para o estudo dos ciclos hidrológico, energético e biogeoquímico da bacia Amazônica (Junk, 1997; Melack et al., 2009). Efetivamente, cobrindo cerca de 20% da superfície da bacia e com grande variabilidade temporal, as águas superficiais da Amazônia desempenham um papel fundamental no clima e na manutenção da biodiversidade. As águas superficiais da Amazônia são uma importante fonte e sumidouro de dióxido de carbono (Abril et al., 2014; Amaral et al., 2020; Raymond et al., 2013) 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). Nesse contexto, a compreensão da dinâmica das águas superficiais é de extrema importância para a hidrologia amazônica, para os processos biogeoquímicos e sua ligação com o clima, para uma gestão efetiva dos recursos hídricos e pesqueiros e para uma gestão de desastres para cidades que estão sob risco de inundação (por exemplo, Iquitos, Porto Velho, Rio Branco, Cruzeiro do Sul). Isto é particularmente importante no contexto das atuais mudanças globais que impactam a Amazônia (ver capítulo 12), com intensas secas e inundações, que recentemente afetaram grandes áreas desta região (Davidson et al., 2012; Jiménez-Muñoz et al., 2013; Marengo et al., 2011, 2008). Ademais, o monitoramento das variações das águas superficiais é fundamental para apoiar o desenvolvimento de modelos matemáticos do ciclo hidrológico da Amazônia (ver capítulo 10).

Caracterizar a distribuição e quantificar as variações sazonais e interanuais da extensão de águas superficiais na escala da bacia Amazônica é um desafio, dada sua grande variedade e variabilidade, e presença de cobertura de nuvens e vegetação florestal. As primeiras estimativas da distribuição das águas superficiais para grandes áreas foram baseadas em bancos de dados estáticos de cartas aeronáuticas e fotografias aéreas, que frequentemente refletiam a extensão máxima de águas abertas (Cogley, 2013; Matthews e Fung, 1987) e não forneciam informações sobre suas variações temporais e espaciais. O surgimento das observações por satélite permitiu monitorar a dinâmica em larga escala das águas superficiais, incluindo as da bacia Amazônica (Alsdorf et al., 2007; Prigent et al., 2007), avançando na compreensão dos processos físicos, biogeoquímicos, ambientais e ecológicos associados.

Diferentes técnicas baseadas em SR, utilizando observações feitas em uma ampla gama do espectro eletromagnético (visível, infravermelho e micro-ondas; Melack et al., 2004; Prigent et al., 2016), foram desenvolvidas, com diferentes graus de sucesso, para obter estimativas quantitativas da extensão e da dinâmica das águas superficiais e dos sistemas aquáticos na Amazônia (**Tabela 4**). Essas técnicas abrangem diversas resoluções espaciais e temporais, muitas vezes baseadas em uma análise de custo-benefício entre coberturas temporais e espaciais. Observações com baixa resolução espacial (por exemplo, ~10-50 km dos sensores de micro-ondas passivos) são geralmente limitadas à detecção de áreas relativamente grandes e alagadas, ou regiões onde a área acumulada de pequenas áreas representa uma porção bastante grande da cobertura do satélite. Elas têm a vantagem de cobertura temporal frequente, às vezes diária. As observações de alta resolução (por exemplo, <100 m do SAR, por exemplo) fornecem informações em uma escala espacial fina, mas têm baixa frequência temporal, muitas vezes limitando as observações sobre grandes áreas a algumas vezes por estação do ano. As observações ópticas e infravermelhas oferecem resolução espacial e temporal boas, mas têm capacidades limitadas na região tropical da Amazônia, pois são incapazes de penetrar nas nuvens e na vegetação densa.

Observações de micro-ondas passivos demonstraram sua utilidade para observar as águas superficiais e a extensão de inundações e forneceram algumas das primeiras estimativas por satélite da extensão de águas superficiais da Amazônia (Giddings e Choudhury, 1989), conforme revisado por Kandus et al. (2018). As emissividades

TABELA 4
Abordagens baseadas em SR desenvolvidas para monitorar a extensão de águas superficiais na Amazônia (lista não exaustiva). São mostradas referências, nome do sensor/satélite, nome do produto (quando disponível), área original de estudo, resolução espacial/temporal e período de disponibilidade dos dados.

ABORDAGENS BASEADAS EM SR	REFERÊNCIAS	SATÉLITES/ SENSORES (nome do produto)	ÁREA ORIGINAL DE ESTUDO	RESOLUÇÃO ESPACIAL/ TEMPORAL	PERÍODO DE DISPONIBILIDADE
Micro-ondas Passivos	Giddings e Choudhury (1989)	SMMR no Nimbus 7	4 grandes bacias hidrográficas da SA	~25km / Mensal	1979-1985
	Sippel et al. (1994)	SMMR no Nimbus 7	Amazônia Central e planícies de inundação	~25km / Mensal	1979-1985
	Sippel et al. (1998)	SMMR no Nimbus 7	Rio Amazonas e afluentes	~25km / Mensal	1979-1985 (e 1902-1995 reconstrução)
	Hamilton et al. (2002)	SMMR no Nimbus 7	Quatro grandes bacias hidrográficas sobre a SA	~25km / Mensal	1979-1987
	Brakenridge et al. (2007)	AMSR/E no Aqua	Global	~25km / Diária	2002-2011
	Parrens et al. (2017)	SMOS (SWAF)	Bacia Amazônica	~25-50km / 3-dias	2009-presente

Micro-ondas Ativos	Hess et al. (2003)	SAR no JERS-1	Amazônia central	100m / Set-Out 95 e Maio-Jun 96	Set-Out 95 e Maio-Jun 96
	Bourrel et al. (2009)	SAR no ERS-2 / RADASRAT	Amazônia Boliviana	2 RADASRAT (50m) / 3 imagens ERS (15m)	1996-1998
	Arnesen et al. (2013)	ScanSAR mode no ALOS/PALSAR	Planície de inundação do trecho baixo do rio Amazonas	100m / Doze imagens ScanSAR	2007-2010
	Ferreira-Ferreira et al. (2015)	SAR no ALOS/ PALSAR	Planície de inundação da Amazônia Central	12.5 / 13 ScanSAR fine beam images	2007-2010
	Hess et al. (2015)	SAR no JERS-1	Bacia Amazônica	100m / Set-Out 1995 e Maio-Jun 1996	Set-Out 1995 and Maio-Jun 1996
	Chapman et al. (2015)	Modo ScanSAR no ALOS/PALSAR	Bacia Amazônica	100m / 323 imagens ScanSAR	2007-2010
	Ovando et al. (2018, 2016)	Modo ScanSAR no ALOS/PALSAR e reflectância MODIS	Áreas úmidas Amazônia Boliviana	100m / 45 ScanSAR e 500m / 8-dias / imagens MODIS	2007-2009 e 2001-2014
	Park e Latrubesse (2017)	SAR no ALOS/ PALSAR	Planícies de Inundação da Amazônia (Miratuba)	12-350m / 19 imagens	2006-2008
	Pinel et al. (2019)	SAR no ALOS/PALSAR	Rio Solimões (Janauacá)	30m / 23 imagens	2007-2011
	Resende et al. (2019)	SAR no ALOS/PALSAR	Bacia Amazônica	25m / 56 imagens	2006-2011
	Rosenqvist et al. (2020)	ScanSAR no ALOS-2 PALSAR-2	Bacia Amazônica	50m / Mínimo e Máximo anuais	2014-2017
Óptico e infravermelho	Yamazaki et al. (2015)	Landsat (G3WBM)	Global	90m / 4 cenas de corpo de superfície freq. no intervalo de 5 anos	1990-2010
	Pekel et al. (2016)	Landsat (GSW)	Global	30m / ocorrência de águas superficiais	1984-2015
	Allen e Pavelsky (2018)	Landsat (GRWL)	Global	30m / larguras e áreas estáticas	-
	Souza et al. (2019)	Landsat	Bacia Amazônica	30m / Mudanças da água de superfície	1985-2017
Técnica Multissatélite (Micro-ondas passivos em combinação com outras observações de SR)	Prigent et al. (2020, 2007)	SSMI/AVHRR/ERS (GIEMS)	Global	~25km / mensal	1992-2015
	Schroeder et al. (2015)	SSM/I, SSMIS, ERS, QuikSCAT, ASCAT (SWAMPS)	Global	~25km / mensal / diária	1992-presente
	Aires et al. (2013)	GIEMS/JERS-1 SAR	Amazônia Central	500m / mensal	1993-2007
	Fluet-Chouinard et al. (2015)	GIEMS reduzido (ou GIEMS-D15)	Global	500m / max. / min. / média	1993-2007
	Aires et al. (2017)	GIEMS reduzido (ou GIEMS-D15)	Global	90m / mensal	1993-2007
	Parrens et al. (2019)	SMOS reduzido (ou SWAF-HR)	Bacia Amazônica	1km / 3-dias	2010-2016

(e temperaturas de brilho) são sensíveis à presença de águas na superfície (Choudhury, 1991; Sippel et al., 1994) com uma diminuição da emissividade em ambas as polarizações lineares (horizontal e vertical) e um aumento da diferença de polarização, especialmente em baixas frequências, devido às diferentes propriedades dielétricas entre água, solo e vegetação. As águas superficiais e padrões de inundação nas grandes planícies de inundação da Amazônia central (Hamilton et al., 2002) foram obtidas por meio da análise da diferença de polarização de 37-GHz observada pelo *Scanning Multichannel Microwave Radiometer* (SMMR; satélite Nimbus-7, 1979-1987). Ao desenvolver uma relação entre a área total inundada ao longo do trecho principal do rio Amazonas e as médias mensais do nível da água do rio em Manaus, elas forneceram a primeira reconstrução de 94 anos de áreas inundadas, estimando a média de longo prazo da área inundada ao longo da várzea do rio Amazonas em ~ 47000 km^2. Esses estudos foram seguidos por produtos de águas superficiais derivados de sensores micro-ondas passivos sobre a Amazônia, usando o Sensor Especial de Micro-ondas/Imager (SSM/I), *Advanced Microwave Scanning Radiometer* (AMSR-E; Brakenridge et al., 2007) e, mais recentemente, observações de *Soil Moisture Ocean Salinity* (SMOS) (Parrens et al., 2017). Parrens et al. (2017) utilizaram as observações da banda L do micro-ondas (1,4 GHz) de 2010 a 2017 para mapear a evolução temporal dos corpos de água da Amazônia em resolução espacial grosseira (~50 km) e resolução temporal semanal (produto chamado SWAF) com a capacidade, graças à frequência da banda L, de melhor estimar a água sob densos dosséis. As observações de micro-ondas passivo têm limitações inerentes por causa de sua cobertura da terra, tipicamente na ordem de 25-50 km, e sua resolução espacial relativamente baixa é muitas vezes insuficiente para observar pequenos corpos de água.

Metodologias multissatélites que combinam diferentes tipos de observações para estimar a extensão de águas superficiais e suas dinâmicas expandem as informações fornecidas pelos radiômetros de micro-ondas passivo (**Tabela 4**). Embora projetadas originalmente para aplicações em uma escala global, estas abordagens têm sido avaliadas na bacia Amazônica. As bases de dados *Global Inundation Extent from Multi-Satellite* (GIEMS, Papa et al., 2010; Prigent et al., 2007, 2016, 2020) e *Surface WAter Microwave Product Series* (SWAMPS) *Inundated Area Fraction* (Schroeder et al., 2015) detectam e quantificam a variabilidade multidecadal da extensão de águas superficiais sobre diversos ambientes (Frappart et al., 2008; Papa et al., 2013, 2008). A versão atual do GIEMS está disponível mensalmente, de 1992 a 2015, com uma resolução espacial de ~25 km (GIEMS-2, Prigent et al., 2020, **Figura 6a**), enquanto o

SWAMPS oferece informações atuais e em tempo quase real (Jensen et al., 2018). O uso desses conjuntos de dados provenientes de micro-ondas passivos ajudou a revelar as fontes e características do pulso de inundação e do pulso de inundação anual ao longo do rio Amazonas e seus principais afluentes. Eles contribuíram para mostrar, em escala de bacia, a sazonalidade da extensão de águas superficiais, com a estação de cheias ocorrendo em maio-junho e a de secas em novembro nas planícies de inundação da Amazônia central. Em escala da bacia, a extensão de águas superficiais da Amazônia (**Figura 6b**) varia de ~100 mil km^2 (estação de águas baixas) a quase ~400 mil km^2 (estação de águas altas), mas com uma grande variabilidade interanual, impulsionada principalmente por eventos extremos de secas (1998, 2005, 2010) ou cheias (1997, 2014) (Papa et al., 2010; Prigent et al., 2020). Todavia, as extensões máximas de águas superficiais de GIEMS e SWAMPS são menores do que a das estimativas de SAR (**Figura 6b**).

Prigent et al. (2007) mostraram que as inundações sazonais diferem entre as partes norte e sul da bacia devido a diferenças sazonais na precipitação. Papa et al. (2008) relataram um atraso no período de precipitação, extensão de cheias e picos da vazão em uma escala de bacia, sugerindo, como em Richey et al. (1989), que planícies de inundação em grandes bacias como a amazônica podem armazenar grande volume de água e alterar o transporte de água. Richey et al. (1989) aplicaram um esquema simples de propagação de água e estimaram que até 30% da vazão do rio Amazonas é conduzido através das planícies de inundação. No entanto, estudos como Getirana et al. (2012), baseados em um modelo hidrológico de larga escala que utilizou o GIEMS para avaliar suas simulações de planícies de inundação, sugeriram que o valor real poderia estar abaixo de 5%. Além disso, Sorribas et al. (2020) relataram que a proporção entre o fluxo de água rio-planície e a vazão escoada no rio principal varia entre 5 e 40%, o que é comparável ao intervalo estimado por Richey et al. (1989) e Alsdorf et al. (2010), que usaram métodos gravimétricos e de imagem por satélite para estimar as quantidades de água que enchem e drenam sazonalmente das planícies de inundação amazônicas. Portanto, é necessário entender melhor os processos que controlam as inundações amazônicas para quantificar os vários fluxos em ambientes de planícies de inundação, como é evidente nas aplicações de modelos de inundação em escala regional (Rudorff et al., 2014a).

Radares de abertura sintética são instrumentos ativos que medem o retroespalhamento da superfície observada em um ângulo de incidência (*off-nadir*), independentemente da cobertura das nuvens, permitindo delinear águas abertas e áreas alagadas cobertas por vegetação com uma resolução espacial típica de 10-100 m (Behnamian et al., 2017; Hess et al., 1990; Kasischke et al., 1997). O experimento *Spaceborne Imaging Radar-C* (SIR-C) forneceu dados de alta qualidade, multibanda e multipolarização para a Amazônia que levaram ao desenvolvimento de novas abordagens usando

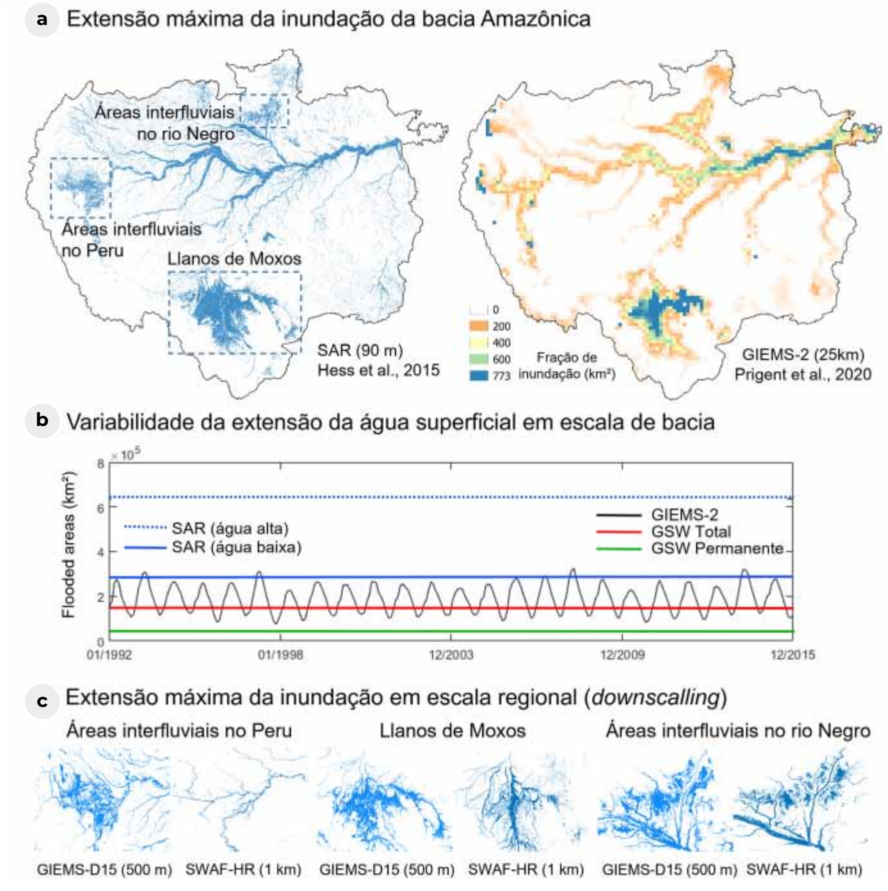

Figura 6: Extensão de águas superficiais da bacia Amazônica. (a) Mapa da extensão máxima de áreas úmidas e águas superficiais (estação de águas altas) do SAR JERS-1 (Hess et al., 2015) e mapa da extensão máxima anual de águas superficiais (fração em km² para cada pixel de 773 km²) com média calculada de 1992 a 2015 do GIEMS2 (Prigent et al., 2020). (b) Variabilidade média mensal da extensão de águas superficiais na escala de bacia para o período 1992- 2015, a partir do GIEMS2 (linha preta sólida), juntamente com estimativas de áreas úmidas derivadas do SAR JERS-1, área inundada para estações de águas altas (linha azul tracejada) e águas baixas (linha azul sólida). Também são mostradas a extensão de águas superficiais permanentes globais (GSW, Pekel et al., 2016) (linha verde, GSW permanente) e a extensão de águas superficiais totais (a permanente mais a temporária) no máximo (linha vermelha, GSW Total). (c) Mapa da extensão máxima de águas superficiais em escala regional (caixas em (a) indicam os locais) do GIEMS-D15 (Fluet-Chouinard et al., 2015) e do SWAF-HR (Parrens et al., 2019).

SAR. Alsdorf et al. (2000) demonstraram a capacidade de análises interferométricas para detectar variações em escala de centímetros na declividade dos rios e planícies de inundação da Amazônia (ver capítulo 4). Hess et al. (1995) desenvolveram algoritmos para detectar inundação e vegetação em áreas úmidas amazônicas, que se beneficiaram da modelagem das interações entre vegetação e radar, incluindo o efeito *double-bounce*. Esta compreensão levou ao uso de dados fornecidos pelo *Japan Earth Resources Satellite-1* (JERS-1) para produzir o primeiro mapa de áreas úmidas de alta resolução para a região central da Amazônia, em períodos de águas baixas e águas altas, a 100 m de resolução (Hess et al., 2003). Esses resultados foram validados com transectos aéreos, de alta resolução e videográficos, em toda a área de imagem (Hess et al., 2003). Hess et al. (2003) descobriram que 17% da área de estudo de 1,77 milhões de km^2 era ocupada por áreas úmidas, das quais 96% eram inundadas em águas altas e 26% em águas baixas. As florestas inundadas representavam quase 70% da área total das áreas úmidas, mas as proporções dos habitats das áreas úmidas apresentaram grandes variações regionais relacionadas à geomorfologia das planícies de inundação. Essas novas estimativas de grandes áreas inundadas foram de grande importância para compreender a emissão de gás metano e dióxido de carbono das áreas úmidas amazônicas (ver capítulo 11).

As estimativas do SAR JERS-1 foram estendidas a todas as áreas úmidas da bacia Amazônica (região <500 m acima do nível do mar) (**Figura 6a**; Hess et al., 2015). Este produto de Hess et al. (2015) é atualmente uma das principais referências para mapeamento destas áreas na região, sendo frequentemente usado em comparações com outros produtos derivados de satélite. Estima-se que a extensão de áreas inundadas (**Figura 6b**) seja de ~285 mil km^2 para a época das águas baixas (outubro-novembro de 1995) e de ~634 mil km^2 para as épocas das águas altas (maio-julho de 1996). Uma comparação interessante foi feita para o corredor central da Amazônia (Prigent et al., 2007) entre o GIEMS e o mosaico da banda L do SAR JERS-1 de 100 m de resolução de Hess et al. (2003) para águas baixas (setembro-outubro de 1995) e altas (maio-junho de 1996). Para ambas as estações do ano, as estruturas espaciais são semelhantes, mas as estimativas da extensão de águas superficiais observadas pelo SAR (118 mil km^2 para a estação de águas baixas, 243 mil km^2 para a estação de águas altas) são maiores que a área estimada pelo GIEMS (105 mil km^2 para a estação de águas baixas, 171 mil km^2 para águas altas). Graças à sua melhor resolução espacial, as estimativas do SAR são capazes de discriminar corpos de água menores que o GIEMS (tipicamente corpos de água menores que 80 km^2, ou seja, 10% de um pixel do GIEMS), especialmente para a estação de águas baixas.

Para toda a bacia Amazônica, as estimativas em sua total amplitude do GIEMS não correspondem às do SAR (**Figura 6a** e **b**), como relatado em Hess et al. (2015), que sugeriu que os conjuntos de dados globais derivados de sensores de menor resolução espacial ou sensores ópticos capturam menos de 25% da área úmida mapeada pelo SAR.

O uso de cobertura multitemporal SAR, como o modo ScanSAR do ALOS/PALSAR, fornece variações de extensão de inundação em escalas mais locais como, por exemplo, a planície de inundação do Lago Grande de Curuai ao longo do baixo rio Amazonas (Arnesen et al., 2013), as várzeas de Mamirauá (Ferreira-Ferreira et al., 2015) ou padrões de inundação na Amazônia central (Pinel et al., 2019; Resende et al., 2019). Rosenqvist et al. (2020) geraram mapas anuais de extensão máxima e mínima de inundação sobre a Amazônia usando o modo ScanSAR do ALOS-2/PALSAR-2, em linha com os mapas de inundação anteriormente gerados com a banda L do JERS-1 e as classificações do radar ALOS/PALSAR (Chapman et al., 2015). Em escala regional, Bourrel et al. (2009) mapearam as inundações na Amazônia Boliviana a partir dos dados da banda C do SAR/Micro-ondas do RADASRAT e do ERS-2. Na mesma região, a dinâmica das águas superficiais das áreas úmidas da Amazônia Boliviana (Ovando et al., 2018), bem como a caracterização de eventos extremos de inundação (Ovando et al., 2016), foram investigados combinando as observações SAR do ALOS/PALSAR com mapas de inundação multitemporais MODIS e variações do nível da água derivadas da altimetria (ENVISAT e SARAL). Outras missões SAR, tais como a do satélite Sentinel-1 do programa Copernicus (lançado em 2014), que oferecem uma revisita global de 6-12 dias, ainda não foram totalmente exploradas na Amazônia e apresentam novas oportunidades para o mapeamento das variações espaciais e temporais das águas superficiais em uma escala espacial fina em ambientes tropicais. O lançamento, no futuro próximo, de novos satélites com tecnologia SAR, como NISAR e SWOT (Prigent et al., 2016), irá oferecer novas oportunidades para monitorar as águas superficiais da Amazônia com sensores especialmente desenvolvidos para estes fins.

As observações de imagens ópticas e infravermelhas (por exemplo, Landsat, SPOT, QuickBird, Ikonos, AVHRR, MODIS, Sentinel 2A/B) oferecem altas resoluções espaciais e temporais (~1-500 m, diárias a semanais), mas geralmente têm uso limitado em ambientes tropicais pela sua incapacidade de penetrar nas nuvens e na vegetação densa. Portanto, continua sendo um desafio monitorar a inundação na Amazônia central durante o período de chuvas, devido à grande cobertura de nuvens

(Asner, 2001; Hess et al., 2015; Klein et al., 2015). Entretanto, a classificação das imagens ópticas usando índices de água e métodos relacionados, conforme revisado por Huang et al. (2018), permite estimar a frequência das inundações com base em mapas temporais da cobertura de águas superficiais, e, apesar das limitações da cobertura vegetal de dosséis e das nuvens, esse tipo de dado pode ser valioso para monitorar águas superficiais abertas. Vários estudos (**Tabela 4**) baseados em observações do Landsat criaram bancos de dados globais da área de rios (*Global River Widths from Landsat* - GRWL; Allen e Pavelsky, 2018) e águas superficiais (Pekel et al., 2016; Yamazaki et al., 2015), que podem ser usados em escala da bacia Amazônica. Com base no monitoramento em uma escala decadal das missões Landsat, o conjunto de dados *Global Surface Water* (GSW, Pekel et al., 2016) usou três milhões de imagens ao longo de 32 anos (de 1984 a 2015) com uma resolução espacial de 30 m para obter um registro mensal da presença de água em cada *pixel* Landsat.

Na bacia Amazônica, as estimativas GSW de extensão de águas superficiais (permanente e total, como a soma dos corpos de água permanentes e temporários) são inferiores àquelas obtidas por outras técnicas baseadas em SR como SAR ou combinação de múltiplos satélites (**Figura 6b**), e a comparação de GSW com GIEMS-D3 (veja mais abaixo) mostrou que corpos de água sazonais em savanas e florestas de inundação não foram detectados corretamente (Aires et al., 2018). Souza et al. (2019) desenvolveram outra classificação Landsat para estimar as mudanças de longo prazo nas águas superficiais da Amazônia revelando o recente aumento nas áreas associadas a lagos de hidrelétricas. Missões recentes de satélites como o Sentinel 2A/B (desde 2015, com resolução espacial de 10 m em intervalos de 5-10 dias; Pham-Duc et al., 2020) ou programas como o RapidEye (desde 2008, com resolução espacial de 5 m e resolução temporal de 1-5,5 dias; Garousi-Nejad et al., 2019) ou o PlanetScope (CubeSats, desde 2014, com resolução espacial de 3-5 m e tempo de revisita diária; Cooley et al., 2019) podem trazer novas oportunidades para estudar a extensão de águas superficiais em escala fina da Amazônia.

Com o objetivo de aproveitar os pontos fortes e complementares de múltiplas observações de satélites, como por exemplo as estimativas de baixa resolução e de longo prazo de micro-ondas passivos versus as observações de alta resolução e limitadas no tempo de observações SAR, foi desenvolvida uma metodologia de *downscaling* por Aires et al. (2013). Esta metodologia combina produtos complementares para estimar inundação mensal na Amazônia central com ~500 m de resolução espacial para o período 1993-2007 (Aires et al., 2013). Vários outros estudos, baseados em abordagens de *downscaling* usando índices de inundação, forneceram mapas de alta resolução da extensão de águas superficiais sobre a Amazônia, tais como GIEMS-D15 (Fluet-Chouinard et al., 2015; ~500 m de resolução espacial e sua adaptação de 1 km como em Reis et al., 2019) e GIEMS-D3 (Aires et al., 2017; 90m). Similarmente, Parrens et al. (2019) propuseram uma metodologia de *downscaling* baseada em múltiplas fontes de SR (SMOS SWAF; combinado com um conjunto global de dados de MDE e GSW) para mapear as águas interiores da Amazônia cobertas por vegetação com ~1 km de resolução espacial, a cada 3 dias, para o período 2010-2016 (denominado SWAF-HR). A **Figura 6c** mostra mapas de extensão máxima de águas superficiais do GIEMS-D15 e SWAF-HR para três regiões, incluindo áreas úmidas interfluviais. Tais observações são valiosas para a tomada de decisão referente à conservação de áreas úmidas, dado que o tempo e a duração da inundação muitas vezes determinam as características ecológicas e a prestação de serviços ecossistêmicos. Reis et al. (2019), por exemplo, classificaram as áreas úmidas da Amazônia de acordo com o tempo e a duração (meses por ano) da inundação detectada com o GIEMS-D15, e o relacioram com os regimes de precipitação. Revelou-se que as áreas úmidas permanentemente inundadas representam a maior área e são principalmente planícies de inundação localizadas nas áreas baixas da bacia Amazônica. As áreas úmidas sazonalmente inundadas variam na duração da inundação, refletindo diferentes regimes pluviométricos e hidrológicos. Essas diferenças regionais nas características da inundação são importantes para o planejamento da conservação e o manejo das áreas úmidas, especialmente no contexto de intervenções humanas, como barragens e construção de hidrovias.

Finalmente, novas técnicas e metodologias de SR continuam a ser desenvolvidas e podem ajudar a monitorar a extensão de águas superficiais da bacia Amazônica. O potencial do Sistema Global de Navegação por Satélite - Reflectometria (GNSS-R) foi explorado (Chew e Small, 2020; Jensen et al., 2018; Rodriguez-Alvarez et al., 2019) usando a constelação de satélites GNSS Cyclone (CYGNSS) e um modelo que demonstra como a refletividade de superfície medida pelo CYGNSS pode capturar a dinâmica de inundação sobre a região.

Na Seção 5.1 *Methods for Measuring Area* em Alsdorf et al. (2007), os autores sugeriram que "talvez a melhor oportunidade nos próximos anos para medições rotineiras da área alagada resulte da missão ALOS da *Japan Aerospace Exploration*

Agency". Mais de uma década depois, vale notar que a extensão e a variabilidade das águas superficiais da Amazônia ainda são uma das variáveis mais estudadas do ciclo hidrológico, no entanto os estudos que utilizam as observações ALOS continuam recentes e limitados. Mais estudos e novas observações são necessários para caracterizar completamente a extensão de águas superficiais da Amazônia e os processos que determinam seus padrões e dinâmica. Em particular, os dados polarimétricos e interferométricos SAR na banda L da próxima missão SAR da NASA/ISRO e as observações feitas na banda Ka do interferômetro SAR (*Radar Interferometer* - KaRIn) da missão SWOT serão capazes de aprimorar o monitoramento da extensão e dinâmica de águas superficiais na Amazônia.

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