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Water Models as Geographical Chimera: Precipitation Interception Routines as an Example of 'Patchwork Empiricism'

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ABSTRACT: In constructing global 'water worlds', modellers stitch together data and theories from disparate locales, weaving them into seemingly universal hydrological frameworks. This approach offers immense scientific efficiencies, enabling planetary-scale predictions of water availability and related ecological, biogeochemical and atmospheric responses. As this paper shows, however, it risks creating 'geographical chimera' of mismatched empirical parts where, for example, British leaves define rainwater storage, fresh-cut Idaho conifers define snow interception, and blotting-paper bark substitutes for stem evaporation. Each localised study, once transplanted into a global model, can become disconnected from its site-bound context, potentially distorting science, management actions, and policy. Focusing on forest canopy precipitation interception – the first step in the precipitation-to-discharge pathway – this paper reveals how (excellent) decades-old, narrowly framed experiments now anchor universal equations in cutting-edge land surface models. These inherited formulas and parameters risk obscuring local phenomena, devaluing in situ data, and fostering equifinality whereby different configurations yield similar outputs while masking real biophysical processes. In this paper, scientific review is complemented by philosophical critiques, reminding us that abstractions detached from place may become preserved in models through methodological inertia, forming self-justifying 'mathematical mummies'. We need not abandon universality, but this work aims to reinforce the standing call to embed water models in diverse, site-grounded observations, re-examine entrenched analogies, and embrace pluralistic parameter development. A place-sensitive methodology can prevent 'chimeric' routines from eclipsing the hydrological realities they aim to illuminate, enabling models to better reflect the richly varied planet they represent.

KEYWORDS: Hydrological modelling, precipitation partitioning, canopy interception, ecohydrology, empiricism, place, science philosophy

> *Another idiosyncrasy of [thought][*] is no less dangerous: mistaking the last for the first. They place what appears at the end – alas, that it should have come at all! – the 'highest concepts', that is, the model,[+] the final vapor of evaporating reality, at the beginning, as if it were the origin.[1]*

> Nietzsche (1889), "Reason in Philosophy", from *Twilight of the Idols*

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[1] Original German: "Die andre Idiosynkrasie der Philosophen ist nicht weniger gefährlich: sie besteht darin, das Letzte und das Erste zu verwechseln. Sie setzen Das, was am Ende kommt - leider! denn es sollte gar nicht kommen! - die "höchsten Begriffe", das heisst die allgemeinsten, die leersten Begriffe, den letzten Rauch der verdunstenden Realität an den Anfang als Anfang. [*] The original subject of the phrase was 'philosophers'. [+] Edited in translation to show the 'highest concepts' of reality as the 'model'.

INTRODUCTION: MODELLING THE EVAPORATING REALITIES OF WATER

Modelling can profoundly enhance our understanding and management of water; it can offer insights into complex hydrological processes and inform decision-making across scales (Beven, 2019; Maskey, 2022; Alexander et al., 2023; Van Stan and Simmons, 2024a). Models stand upon two fundamental pillars: empirical observation (which anchors models in measurable reality) and imagination (which extends these observations into conceptual frameworks that guide understanding and prediction). Both pillars are grounded in 'place', as the unique characteristics of specific environments shape what we observe and how we imagine. Nietzsche's quotation at the start of this essay cautions against "mistaking the last for the first"; it warns against placing abstracted conclusions at the origin of understanding. This caution is relevant to water modelling, which often integrates findings from diverse geographical locations into unified equations. In doing so, modellers must contend with obscuring the unique phenomena within the ecosystems that inform their models, and the unique phenomenon that define the ecosystems where their models are applied. In the process, there is the danger of elevating the abstract (the last) for the empirical (the first) – what Alfred North Whitehead (1925) calls the "fallacy of misplaced concreteness". Recognising these challenges, the hydrology community has long engaged with this epistemological concern. It has grappled with issues such as conflicting regional conceptual models of water circulation (see discussions of pre-20th century 'hydrology' in Van Stan II and Simmons, 2024b) and the diverse perspectives shaping the field (see the introduction of the pioneering text entitled *Hydrology* by Meinzer, 1942). A danger remains, however, in that modelling offers hydrological science powerful efficiencies in computation, generalisation and decision-making, which can encourage precisely the sort of error that Nietzsche warns us against.

The geographical resolution and scope of empirical observations have expanded through advancements in satellite technology (Beven et al., 2015; van Jaarsveld et al., 2024), global research networks (Arora et al., 2023; Ruddell et al., 2023; Tarboton et al., 2024), and machine learning (Nearing et al., 2021; Kratzert et al., 2022; Shen et al., 2023). These advancements enable more extensive data synthesis across regions, thus fostering imaginative model development and reduced reliance on traditional site-specific studies; however, technological and methodological advancements have not untethered hydrological modelling from place and its history. The empirical basis of hydrology, shaped by the environments and assumptions of research from earlier eras, continues to influence the interpretation of new data and the modelling of processes (Gutmann, 2020; Beven et al., 2021; Horton et al., 2022; Seibert and Bergström, 2022). As a result, evolving models both represent and construct their own geographical 'water worlds', which shape our understanding, management and imagination of water systems (Krueger and Alba, 2022; Klein et al., 2024). These water worlds, especially in large-scale Earth system models, are not geographical in the conventional sense. Each component may instead draw from distinct geographical contexts. A forest's leaves, for example, might be hydrologically represented based on data from southern England (Rutter, 1963; Leyton et al., 1967; Thompson, 1970; Robins, 1974), while those of a grassland may derive from the southwestern United States (Burgy and Pomeroy, 1958; Crouse et al., 1966).

Hydrological processes in global-scale land surface models are, in essence, mosaics of geographically constrained empirical and theoretical frameworks. Parameters and formulas often embed geographically specific values and processes into the models, shaping model outcomes; this risks distorting the hydrological realities of individual locales. These models are composites of disparate parts, much like the mythical Chimera (part lion, part goat, and part serpent), with each part reflecting its own geographical origins. Just as the Chimera's stitched-together form suggests both a marvel and a monstrosity, the geographical chimera of global models reflects an assemblage of empirical discoveries and assumptions that, although powerful and functional, do not always harmonise. The models' structural integrity, while impressive, can produce unintended distortions when these geographically specific components are abstracted into generalised frameworks. In this sense, the geographical chimera becomes a powerful, but potentially dangerous, entity that is capable of both illuminating hydrological processes and obscuring

their local realities. Although various components of water models (and their companion systems) exhibit differing degrees of geographically chimeric character, some are less constrained by the limited geography of their empirical bases; for example, watersheds across a diversity of physical, socio-economic, cultural and political conditions contribute to the empirical foundations of water models (Do et al., 2018; Ghiggi et al., 2019). Moreover, thanks to initiatives such as the International Association of Hydrological Sciences (IAHS) "Prediction in Ungauged Basins" (Hrachowitz et al., 2013), frameworks exist to help make ungauged model applications more 'realistic' (sensu van Emmerik et al., 2015) and less like "mathematical marionettes" (Kirchner, 2006). These kinds of extensive empirical and framework development efforts are lacking (and may not be feasible) for many important parameters and processes in models, and significant gaps thus remain.

These gaps can allow modelling to manifest as a sophism, that is, as a tool that makes a weakly empirical science appear stronger by virtue of "the strength of united effort" (Kierkegaard, 1846) – the united effort of the local data collectors and universalising modellers. Like all sophisms, it "appeals to the non-problematic character of what is manifest and interprets all intellectual interrogation as an attack upon sound common sense and its unhappy susceptibilities" (Heidegger, 1943). In the context of this essay, by asserting that truths derived from one set of phenomena are sufficient to explain others, modelling risks concealing the reality of the second phenomenon, rendering direct study unnecessary and, perhaps more importantly in an economically mindful era, constituting an unnecessary financial cost. Given the perpetual pressure of budget constraints in scientific endeavours, financial expediency generally trumps scientific integrity. Certainly, we accept that it is better to conduct science on a shoestring than to conduct no science at all, but the chimeric danger becomes more acute when these models become stand-ins for empirical science. As an example, this paper aims to demonstrate that this danger is particularly evident in the geographical chimera of forest precipitation interception models. While these models are essential for hydrological research, they risk becoming detached from the realities they seek to represent, thus perpetuating a kind of untruth. As Kierkegaard warns, when such sophistic (modelling) practices are widely accepted, they can, "become the only true point of view" (Kierkegaard, 1846), severing our connection to the natural systems that these models aim to understand and manage. In today's technologically driven (and enabled) era, this risk intensifies, and models can increasingly act as surrogates for phenomena in a process that Rayner (2012) terms "displacement". This shifts our focus from interacting with real phenomena to managing their abstract representations, a tendency that widens the chasm between our lived environmental reality and its numerical representation.

Forest canopy interception is often the first process in the precipitation-to-discharge pathway; thus, our ability to model it influences a range of environmental and hydrological applications (Savenije, 2004, 2018). When precipitation travels through forest canopies, it is stored on surfaces such as leaves, needles, stems and epiphytes, often high above the ground where greater wind speeds can enhance evaporation. Evaporation from canopies can affect regional weather patterns and atmospheric dynamics (der Ent et al., 2014), while locally exerting a cooling effect (Davies-Barnard et al., 2014) – effects that are increasingly variable as climate changes alters rainfall regimes (Lian et al., 2022). Snow intercepted by vegetation introduces additional complexities as it alters the surface energy budget by modifying albedo (Wang et al., 2016; Helbig et al., 2020). Reduced snow cover decreases the land's reflectivity (albedo), which can lead to warming effects that influence the climate (Lundberg and Halldin, 2001; Sturm et al., 2017). Warming also accelerates snowmelt, feeding into a positive snow – albedo feedback loop that intensifies climate warming as snowfall decreases or melts earlier, leaving darker surfaces that absorb more sunlight (Letcher and Minder, 2015). Insights from snow disappearance data across 14 sites in the Pacific Northwest USA (Dickerson-Lange et al., 2017) underscore the need to refine models of forest – snow interactions, as improved understanding of these processes is critical for accurately predicting the effects of forest management and natural disturbances on snowpack and water resources (Lundquist et al., 2021).

This paper anatomises the geographical chimera that constitutes the forest interception component within widely used land surface and hydrologic models, including VIC, PRMS, CLM and Noah-MP. The latter two models (CLM and Noah-MP), in turn, feed boundary conditions to larger-scale models such as CESM and WRF, further amplifying their impact and relevance (Gutmann, 2020). By dissecting the diverse geographical origins of the empirical data and theoretical formulations underpinning these models, we reveal how these chimeras shape our understanding of precipitation interception by forest canopies. This component is not only the first of many geographical chimeras shaping water model worlds; it also plays a pivotal role in determining how much precipitation ultimately reaches terrestrial ecosystems.

METHODS: A GENEALOGICAL 'REVEALING' APPROACH

> *A historical phenomenon, completely understood and reduced to an item of knowledge, is, in relation to the man who knows it, dead (…). History, so far as it serves life, serves an unhistorical power, and thus will never become a pure science like mathematics.*[2]*
>
> Nietzsche (1874), On the Use and Abuse of History for Life from *Untimely Meditations*

Modern review protocols such as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (see Page et al., 2021) aspire to a "purely scientific" standardisation, in tension with the more interpretive, life-oriented function that Nietzsche describes in the quote above. Accordingly, this review intentionally diverges from systematic literature review methodologies like PRISMA. While systematic reviews aim for comprehensive mapping based on strict inclusion/exclusion criteria, our approach is interpretive and critical, focusing on the historical and philosophical underpinnings of canopy interception modelling. Nietzsche's concept of "unhistorical power", for instance, refers to thinkers' capacity to limit or bracket the near-infinite details of the past to reduce the risk of paralysing new insight; without this capacity, excessive historical detail can overwhelm inquiry and stifle new ideas: phenomena (like water storage on leaves or evaporation) risk becoming so 'embalmed' in minutiae that they cease to serve as fertile ground for reinterpretations or innovations. As he once quipped, failing to be selective in this way can lead to a kind of "mental constipation"[3] – that is, an overload of knowledge that stifles rather than stimulates fresh thinking. A genealogical analysis must therefore remain judiciously selective and interpretive to avoid drowning in systematic detail. Thus, our objective was not exhaustive coverage via predefined criteria, but rather a genealogical 'revealing' – Heidegger's Aletheia (ἀλήθεια), or truth-as-uncovering (Heidegger, 1943; Campbell, 2017), which highlights the often-unseen conceptual origins, historical contingencies, and embedded assumptions within the target water modelling routines.

This lens treats the literature not as a linear progression, but rather as a 'geographical chimera' – a patchwork of historically situated insights that call out for Nietzschean-style genealogical scrutiny. This is an approach that traces the historical origins of ideas to reveal how they developed and how they are often shaped by specific interests or contingent events rather than by pure logic (Foucault, 1977; Hoy, 1994). Rather than merely summarising their findings, we sought to understand how certain models and parameters became foundational. Literature identification proceeded through genealogical tracing. We

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[2] Original German: "Ein historisches Phänomen, rein und vollständig erkannt und in ein Erkenntnisphänomen aufgelöst, ist für den, der es erkannt hat, todt... Die Historie, sofern sie im Dienste des Lebens steht, steht im Dienste einer unhistorischen Macht und wird deshalb nie, in dieser Unterordnung, reine Wissenschaft, etwa wie die Mathematik es ist, werden können und sollen". *Authors' note: Nor will it meet Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

[3] "The man in whom this preventative apparatus is damaged and discarded, is to be compared to a dyspeptic, and it is something more than a comparison – he can 'get rid of' nothing (…)". Original German: "(…) Der Mensch, in dem dieser Hemmungsapparat beschädigt wird und aussetzt, ist einem Dyspeptiker zu vergleichen (und nicht nur zu vergleichen —) er wird mit Nichts „fertig"…"; from "'Guilt,' 'Bad Conscience,' and the Like," in *Genealogy of Morals.*

started with seminal works identified through our disciplinary expertise (see Positionality Statement) (e.g.; Rutter et al. (1971), Hedstrom and Pomeroy (1998), and Merriam (1961), and then followed citation lineages backwards, forwards and sideways to identify influential nodes (that is, seminal studies and their interlinked references) and conceptual inheritances and overlooked contexts (including older, non-digitised sources). Strict inclusion/exclusion criteria were thus eschewed in favour of an organic tracing of the development and transmission of key ideas and parameterisations. Identified sources were analysed qualitatively through close reading and annotation; this focused on: (1) the geographical and experimental context of empirical data, (2) underlying conceptual assumptions, (3) cited influences and disciplinary positioning, and (4) rhetorical claims of universality. Our final synthesis is interpretive; it emphasises the contextual nature of model development, and it acknowledges our own 'thrownness' as researchers who are examining these issues from a contemporary perspective that is concerned with model robustness under global change (see discussions of this *Geworfenheit* concept in Sheehan, 2001). This approach aims not only to reveal the 'geographical chimera' inherent in universalising models built from geographically specific empirical parts; it also aims to encourage reflection on how such inherited frameworks might be adapted or revised for contemporary challenges. In some cases, it may be that systematic systems (like PRISMA) would make that reflection harder by enforcing a particular method, one for which minor adjustments may be guaranteed but major reorientation of approaches would be hampered, thus ensuring that what is inherited is embalmed rather than examined.

Positionality statement

Our approach is informed by extensive field experience in vegetated ecosystems during storms, engagement with modern computational modelling techniques between storms, and a deep commitment to phenomenological and hermeneutical inquiry. Our work is driven by a desire to reveal the historically rooted assumptions that underpin global water models, a pursuit that reflects our rigorous scientific training and our philosophical orientation. Drawing on Nietzsche's genealogical methods and Heidegger's insights on unconcealment (Aletheia) and thrownness (Geworfenheit), we distinguish between the 'earth', representing the underlying materiality that remains partly hidden and resistant to full conceptual mastery, and the 'world', the realm of human meanings, interpretations, and cultural practices. Van Stan's disciplinary immersion in canopy interception research meant the 'seminal works' we traced first were those that, during discussion with Simmons, were determined to have shaped (and sometimes constrained) his own practice. Accordingly, the seed set for our genealogical search arose from this lived expertise and dialectical contemplation, and from the interpretive standpoint outlined here. With a touch of humility (and hopefully humour), we note that even our most rigorous critiques are themselves products of a specific historical moment – an idiosyncrasy we share with the very models we interrogate. (After all, even the act of questioning 'global truths' is itself a local, historical product of our satellite-enabled global truth-seeking.) The inquiry contained in the following pages embraces a plurality of perspectives and accepts the provisional nature of scientific 'truths'. In doing so, we aim to foster a deeper, more nuanced understanding of hydrological processes that remains critically engaged with local empirical realities while challenging oversimplified abstractions.

RECONCILING UNIVERSAL MODELS WITH LOCAL REALITIES: A PLACE-CENTRED CRITIQUE OF CANOPY INTERCEPTION MODELS

> *Believe me, friends! It was the modellers[*] who despaired of the Earth – they heard the belly of being speaking to them. Then they wanted to break through the ultimate walls head-first, not only with their heads but also beyond to 'the model-world'. (…)*

however, all being is hard to prove, hard to coax to speech [and hard to model]. Tell me, friends, is not the most wondrous of all things also the best proven? [4]

Nietzsche (1883), "On the Hinterworldly", from *Thus Spoke Zarathustra*

This passage captures a key tension in environmental modelling, which is that in striving to transcend the 'ultimate walls' of our immediate, local and empirical experience, we risk losing sight of the water literally before our senses (or sensors). Building a grand 'model-world' by breaking through these walls 'head-first, not only with their heads' (that is, with our minds and rationalising apparatus) may yield a stunning theoretical construct. Nietzsche questions, however, whether what appears "wondrous" is truly the most well-supported or "best proven". This problem of overshooting the local world did not originate with advanced mathematical models; rather, centuries of philosophical inquiry, from Plato's ideal forms to medieval metaphysics, grappled with the same 'other-worldliness'. For our purposes in this article, a brisk philosophical jump from Nietzsche might begin with Heidegger's *On Being and Time* (1927), which critiques such 'transcendence' as a retreat from the lived world. At the turn of the 21st century, Jeff Malpas builds on Heidegger (and others) to insist that 'place' is foundational to understanding (Malpas, 2010) – a perspective that is relevant to contemporary debate and discussion (Malpas, 2022; Karamercan, 2023). When transposed into hydrology, their combined insight raises a paradox, which is that universalising frameworks can detach us from the distinctly local realities of water in place. This tension manifests starkly in forest hydrology, where researchers across the same time period have struggled to answer a deceptively simple question: how much rain and snow is retained by tree canopies (see Friesen and Van Stan, 2019; Van Stan and Friesen, 2020).

British leaves: The standard for rainwater storage

By the mid-1800s, deforestation and agricultural expansion throughout Europe had taken a heavy hydrological toll (Andréassian, 2004; Van Stan and Friesen, 2020), especially in central European nations (Dove, 1855). Motivated by these concerns, various contemporary researchers from that area (Krutzsch, 1855, 1863; Bühler, 1892; Ney, 1894) began quantifying discrepancies between open-field rainfall (P) and the 'net' rainfall under forest canopies (P_n), attributing the difference to evaporation. With the rise of process-based models in the following century, researchers recognised that they needed a 'storage' parameter (S) – the maximum water held on leaves, bark or epiphytes – for estimating P_n (Merriam, 1961; Rutter, 1963; Rutter et al., 1971). Methodologically, obtaining reliable values for S was (and still is) daunting (Friesen et al., 2015). At the hectare-to-m^2 scale, throughfall (water dripping between leaves) can vary spatially by orders of magnitude, even within a single storm (Zimmermann et al., 2010, 2016), while stemflow (the fraction of rainwater that drains down tree stems) can vary similarly across trees (Metzger et al., 2019; Van Stan et al., 2020). The drivers of this spatiotemporal variability remained shrouded in the difficult-to-access-and-measure canopies tens of metres above their heads; this was noted at the time in nearly all of the early empirical stemflow studies (Riegler, 1881; Bühler, 1892; Ney, 1894; Ebermayer, 1897), as well as in recent work (Wischmeyer et al., 2024). Early empirical methods thus used linear regressions of P and P_n observations across storms, estimating S as the absolute value of the y-intercept (Rutter, 1975):

(1) $P_n = bP - S.$

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[4] Original German: "Glaubt es mir, meine Brüder! Der Leib war's, der an der Erde verzweifelte,—der hörte den Bauch des Seins zu sich reden. Und da wollte er mit dem Kopfe durch die letzten Wände, und nicht nur mit dem Kopfe,—hinüber zu „jener Welt". Aber „jene Welt" ist gut verborgen vor dem Menschen, jene entmenschte unmenschliche Welt, die ein himmlisches Nichts ist; und der Bauch des Seins redet gar nicht zum Menschen, es sei denn als Mensch. Wahrlich, schwer zu beweisen ist alles Sein und schwer zum Reden zu bringen. Sagt mir, ihr Brüder, ist nicht das Wunderlichste aller Dinge noch am besten bewiesen?"
* The original subjects of the phrase have been replaced with 'modellers' and 'model-worlds'.

Here β is the linear regression slope (an estimated fraction of rainfall transmitted) and S (typically a negative value) forms the y-intercept. The observed relationships between P and P_n beneath various canopies, however, were not consistently linear (and were often inconsistent enough for concern), and by the mid-1900s the underlying methodological issues had been well-described (Wilm, 1943; Kimmins, 1973). This drove a search for more direct estimates of S; it also motivated efforts to determine the connection of S to measurable canopy traits that would lend themselves to parametrisation in water models.

The first relationships embraced by the hydrological modelling community came from a grassland study (Merriam, 1961). Inspired by Horton's (1919) idea of estimating the volume of water that could coat leaves as a thin surface film, Merriam (1961) divided S by leaf area to estimate an equivalent film thickness (mm per m^2 of leaf area per m^2 of ground area). This work produced the first range of storage capacity multipliers (0.08 to 0.20). Rutter (1975) synthesised multiple forest, shrub and herbaceous cover studies (Table 1); they confirmed the multiplier values, but Rutter cautioned that, "water on the canopy should not, however, be envisaged as a film of constant thickness over all surfaces", since water clings to plant surfaces in diverse ways, from films to droplets (Holder, 2020), or stored inside porous bark (Ilek and Kucza, 2014; Ilek et al., 2021b); it can even form tiny pools on leaves (phytotelmata) and on stems (dendrotelmata) (Hargis et al., 2019; Mendieta-Leiva et al., 2020). A benchmark paper by Dickinson (1984) on modelling evapotranspiration, however, proposed a durable simplification that determines storage as a function of 'stem and leaf area index' (*SLAI*):

(2) $S = SLAI \times 0.2$

Table 1. Estimates on which current land surface model equations relate leaf and stem area index (LSAI) to canopy rainwater storage capacity (*S*)

Vegetation	*S* [mm]	Location	References
Pinus sylvestris	1.6	51.33393 N, 0.90465 W	Rutter (1963), Crowthorne (UK)
Picea abies	1.5	51.71604 N, 1.26035 W	Leyton et al. (1967), Oxford (UK)
Pseudotsuga menziessii	2.1	51.30582 N, 0.86859 W	Robins (1974), London (UK)
Pinus nigra	1.0	51.30582 N, 0.86859 W	Robins (1974), London (UK)
Carpinus betulus	0.6-1.0	51.71604 N, 1.26035 W	Leyton et al. (1967), Oxford (UK)
Quercus robur	0.4-1.0	51.71604 N, 1.26035 W	Thompson (1970), Oxford (UK)
Calluna vulgaris	2.0	51.71604 N, 1.26035 W	Leyton et al. (1967), Oxford (UK)
Zea mais	0.4-0.7	40.46975 N, 86.99231 W	Stoltenberg and Wilson (1950), Indiana (US)
Mixed grassland	1.0-1.2	Lab (weighing lysimeter)	Burgy and Pomeroy (1958)
Lolium perenne	0.5-2.8	34.18088 N, 117.7685 W	Merriam (1961), California (US)
Molinia caerulea	0.7	51.71604 N, 1.26035 W	Leyton et al. (1967), Oxford (UK)
Pteridium aquilinum	0.9	51.71604 N, 1.26035 W	Leyton et al. (1967), Oxford (UK)

Source: This table is modified from Table 1 of Rutter (1975); due to electronic unavailability of source material, see scan in Supplemental Materials.

Note: These estimates included select trees (top six rows), a low-growing shrub (*Calluna vulgaris*), and some herbaceous covers (bottom five rows).

Dickinson (1984) cited this formula as producing good agreement with Rutter's (1975) review (0.2 – 2 mm). This relationship has endured in many land surface and hydrological models (Gutmann, 2020), producing a range of S that is referenced to this day and has only recently been challenged (Davies-

Barnard et al., 2014; Porada et al., 2018; Van Stan et al., 2023). Like many early data sets, however, its origins are geographically narrow.

The 'water world' of rainwater storage on plant canopies is dominated by measurements from southern England, centering on sites around Oxford and London (Table 1). These classic studies involved species such as *Pinus sylvestris, Picea abies, Quercus robur, Calluna vulgaris* and *Molinia caerulea*, which formed the backbone of widely used canopy interception equations. The few outliers include non-European data such as *Zea mays* in Indiana (Stoltenberg and Wilson, 1950) and *Lolium perenne* in California (Merriam, 1961). Global hydrology models thus carry an Anglocentric bias in their parametrisation of S, which is to say that an empirically thin slice of Earth's diversity is being universally applied. A distinct component of the 'geographical chimera' thus emerges, with canopy rainfall storage capacity being analogous to a British goat or serpent (lions not being native to that soil). In the world of water modelling, the sun never sets on British foliage.[5] This concentration of early research in Britain reflects practical and ecological factors, in that the region's temperate climate and long-standing forestry traditions provided a conducive environment for experimental studies. While this foundation is rooted in excellent science, it raises questions about the geographic generalisability of these parameterisations when applied to ecosystems with vastly different structures and climates.

Such limited diversity might not be glaring if English canopies were biophysically representative of the planet, however the morphologies and climates of, for example, Amazonian rainforests or boreal pine stands differ substantially from those in temperate Britain. As a result, the narrow empirical foundation for S poses at least two serious consequences for science and society. First, applying British-derived parameters to markedly different ecosystems can distort regional evaporation predictions and, by extension, can affect large-scale water budgets. Porada et al. (2018), for example, revised the storage routine, increasing S several times compared to the values determined in Equation 2 (in line with empirical estimates from various regions); this increased global canopy interception evaporation by 10%. Without such adjustments, local processes shaped by unique climates, canopy morphologies or leaf and bark textures are shoehorned into ill-fitting frameworks, amplifying uncertainties that then propagate throughout water models (Savenije, 2004, 2018). When scaled globally, the geographically limited S parametrisation can misrepresent evaporation sources and dynamics (Coenders-Gerrits et al., 2014; Allen et al., 2020; Jiménez-Rodríguez et al., 2021) or related canopy – atmosphere exchanges (Berry et al., 2019; Berry and Goldsmith, 2020), distorting soil moisture and downstream flow forecasts. Notably, sensitivity to such processes varies spatially, and recent continental-scale analyses show that the importance of canopy precipitation interception can shift dramatically depending on place (Mai et al., 2022). Particularly in diverse ecosystems, species-level (or assemblage-level) parameterisation is often impractical and observational setups can be prohibitively complex. In such cases, ecosystem-level proxies (Oliveira et al., 2024) or inferred dynamics from throughfall patterns (Ramírez et al., 2018) offer promising alternatives. Still, such inaccuracies can mask forest stress, as recently demonstrated in the missing interception losses from abundant mistletoe infestations (Klamerus-Iwan and Van Stan, 2023), and inaccuracies can also be compounded in Earth system models; in both cases, local and regional climate forecasts can be affected (Davies-Barnard et al., 2014). The second serious consequence of a narrow empirical foundation for S hinges on the fact that watershed management, reforestation projects and agricultural planning rely increasingly on large-scale model outputs (Bremer et al., 2020; Puy et al., 2022, 2023; Douville et al., 2024), and thus a mismatch between the localised canopy capacities and the

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[5] When frameworks that are developed in one historical–geographical context are uncritically imposed on others, they can perpetuate a form of epistemic dominance that is sometimes critiqued in postcolonial philosophy of science (Harding, 1998; Verran, 2002; Smith, 2012). The British empirical legacy here is emblematic in that, while pioneering local insights, it also established norms that obscure the complexity of non-British ecosystems. The broader impulse to universalise (a hallmark of Enlightenment science) can overshadow place-based knowledge, where distinct climates, ecologies and cultural practices complicate one-size-fits-all assumptions. As direct measurement is difficult or costly, these 'universal' parameters risk flattening hydrological realities that diverge significantly from their British roots.

assumed universal parameter could mislead practitioners into investing in water-related management strategies that are ill-suited to regional ecosystems. This approach may thereby jeopardise biodiversity conservation or crop yields if the water realities diverge from the 'British standard'.

Fresh-cut Idaho conifers: The standard for snow-water storage

Decades of research from cold, conifer-focused experiments in Idaho, Oregon and British Columbia underpin most modern representations of canopy snow interception (Lundquist et al., 2021). The geographical limitation is all the more apparent when considering that the empirical 'world' on which this representation rests is derived from cut Douglas fir or white pine saplings that are weighed after storm events (Satterlund and Haupt, 1967), similarly monitored jack pine and black spruce (Hedstrom and Pomeroy, 1998), or single branches of, for example, Engelmann spruce, subalpine fir or lodgepole pine that are shaken free of snow on steel rods (Schmidt and Gluns, 1991) in outdoor laboratory experiments. Designating single cut trees and branches for study or hanging branches from steel rods allows researchers to isolate causation, which is a strategy with clear analytical value; however, as Cartwright (1983) reminds us, 'laws' often emerge in such idealised conditions precisely because they are abstracted from the messy, interdependent realities of the world. For snow-water storage dynamics, this raises a critical question: do these tightly controlled, geographically narrow experiments yield knowledge that travels well? When reassembled into a global model, this isolated data risks creating a chimeric component that is limited to a specific experimental logic and then knitted into a generalised reconstruction. Imagine a Frankenstein's monster-model: a four-metre Douglas fir that is sporting branches sewn to steel rods and lumbering across a wide range of ecosystems, in each place insisting that it is a real tree, capable of modelling snow-water storage dynamics across all landscapes.

Building on Lundquist et al. (2021), we can trace a 'family tree' of snow interception storage capacity models (I_{max}) from these few trees (and few snowstorms) that converge on a signature equation introduced by Hedstrom and Pomeroy (1998). At its core, the model allows canopy surfaces to collect snow until they can host no more and are saturated; in reality, however, the rate at which snow accumulates on the canopy slows as it nears its maximum snow-holding capacity. Mathematically, this idea is captured in Equation 3, which expresses the rate of interception (how fast snow is caught by the canopy) based on how much space is still left to fill ($I_{max} - I_S$) and how quickly snow is falling (P_S) over a given surface area (C_l) and time step (Δt). In simpler terms: the fuller the canopy gets, the more slowly it can absorb snow. The mathematical representation thus expresses interception rate (dI_S/dt) as a diminishing function of the canopy's I_{max}:

(3) $\quad \frac{dI_S}{dt} = (I_{max} - I_S)(1 - e^{-\frac{C_l P_S \Delta t}{I max}})/\Delta t.$

What makes this framework especially interesting is that even the canopy's maximum snow-holding capacity (I_{max}) is not treated as a fixed number; rather, it changes based on the forest's physical traits and the character of the snow itself. Equations 4 and 5 estimate I_{max} using two key inputs: the leaf area index (LAI in Equation 4), which represents how much surface area is available to catch snow, and the density of fresh snow (ρ_S), which is influenced by air temperature (T_{air}) in Equation 5:

(4) $\quad I_{max} = \propto \left(0.27 + \frac{46}{\rho_S}\right) LAI$

(5) $\quad \rho_S = 67.92 + 51.25 e^{\frac{T_{air}}{2.59}}$

Lighter, fluffier snow tends to accumulate more readily than wet, dense snow, thus as the air gets warmer the snow gets heavier and the canopy holds less of it. Together, these equations build a kind of mechanical imagination of the forest's snowy behaviour. Despite originating in only a handful of winters

at two study sites – one continental (Idaho) and one maritime (Oregon) – this scheme now appears in land surface models such as Noah-MP, CLM and CLASS (Lundquist et al., 2021). As with the British results that define rainwater storage capacity, these tightly bounded observations shape 'global' parameterisations, raising questions as to how well fresh-cut Idaho (and Oregon) conifers can stand in for the world's diverse snow-laden canopies. Here emerges another distinct geographic facet of the water model chimera: snow storage capacity representations materialise as vividly as a serpent head, separate from the British rainwater storage capacity formula and the other elements that together constitute the body of a global water model.

Interestingly, from a hermeneutical – that is, a philosophy of interpretation – standpoint, even research situated in the same general geography (of northwestern North America) arrived at conflicting representations of I_{max} (Friesen et al., 2015; Lundquist et al., 2021). Andreadis et al. (2009) took a notably different path than Hedstrom and Pomeroy (1998), incorporating temperature-dependent snow cohesion that stemmed from winters in the Oregon Cascades, where mid-winter thaw-refreeze cycles more strongly affect canopy retention. As temperatures rise, so does snow cohesion in their formulation, which prolongs or increases interception instead of relying on a static or exponential I_{max} threshold (for more detail, see Lundquist et al., 2021). Despite both approaches sharing coniferous, mountainous origins, they diverge based on continental below-freezing conditions in Idaho versus maritime near-melting regimes in the Cascades. This echoes Malpas' (2022) notion of relational meaning, in which place "opens up a space for relations" that generates new understandings. Even within what might look like a single ecological domain (that is, western North American conifers), subtle differences in climate, terrain and data collection give rise to distinct modelling frameworks and distinct 'water worlds' where one decreases I_{max} in relation to warming temperatures while the other increases it. Neither approach rests on data or imaginative insights from other snowy forested regions such as boreal taiga or monsoonal highlands. Consequently, modern land surface models that adopt one or the other approach may fail to capture interception behaviours in forests with differing canopy architectures, snowfall regimes, or frequent thaw events.

The uncertainty surrounding snow-water storage capacity models has sizable implications, from epistemological challenges in global hydrological modelling to practical risks in forest management and water resource planning (Dickerson-Lange et al., 2021; Lundquist et al., 2021). One stark illustration is the variability in subcanopy snow accumulation ratios, which can differ from open areas by up to 30% due to interception alone (Lundquist et al., 2021). This degree of variation underscores how storage dynamics magnify uncertainties in snow hydrology models, thus complicating our ability not only to simulate present conditions but also to forecast the impacts of forest management practices and temperature change on snow-dominated ecosystems. The problem becomes even more acute in a warming climate, especially in temperate and boreal forests where snow interception storage is highly sensitive to temperature shifts (Lundquist et al., 2021). As air temperatures near the melting point, interception capacity can drop sharply, triggered by faster snow unloading, melt, and more frequent transitions from snowfall to rain. Such temperature-driven processes challenge our ability to predict hydrological responses under future warming; they also add complexity to deeper epistemological issues in snow hydrology modelling. Equifinality (where multiple model configurations yield similar outputs; see Beven, 2006) can mask divergent or oversimplified representations of snow processes. This creates a paradox where the very processes that models aim to represent are simplified or inaccurately parameterised to align with observed outcomes. These simplifications in representing snow-water interactions can be especially misleading under varying climatic conditions, leaving critical gaps in how we anticipate snowpack storage and broader water availability in a changing climate.

Such shortfalls of even a single geographically chimeric element of water models' precipitation interception routines have tangible consequences for adaptive management strategies in forested regions. Common thinning or prescribed fire practices, for example, can alter snow storage in highly site-specific ways, shaped by factors such as wind speed, canopy density and local climate (Dickerson-Lange

et al., 2021). When models abstract from local phenomena or overlook process variability, interventions risk accidentally reducing snow retention rather than enhancing it. This is not merely a matter of adding more process-level detail; increasing model complexity without a firm grounding in appropriate observational data can, in fact, exacerbate uncertainty. As models expand, their internal structure (or their 'effective dimensions') tends to grow; this introduces more influential parameters and higher-order interactions that inflate output variance and may, in the process, reduce a model's usefulness for practical decision-making (Puy et al., 2022). The societal and economic stakes of these missteps are vast; about one-sixth of the global population depends on snowmelt for water supply (Sturm et al., 2017), yet current models often underrepresent critical snow-storage – related processes such as interception and sublimation. Such inaccurate predictions, as with incorrect estimations of rainwater storage capacities, risk exacerbating mismatches between water supply and demand, especially as earlier spring snowmelt timing becomes the norm. Given that the global economic value of snow is estimated in the trillions of dollars (Sturm et al., 2017), the cost of these model-embedded uncertainties cannot be easily dismissed. That said, our call is not for increasingly detailed or 'less certain' models in the conventional sense; rather, it is for more meaningfully situated ones, for models that make their assumptions legible, their limitations visible, and their uncertainties traceable to the data and contexts from which they arise. The usefulness of a model, in this view, lies not in its precision alone, but also in its capacity to make visible the structure of its own abstractions and the local realities it may elide. In sum, the continued reliance on simplified or insufficiently grounded snow-water storage formulas has cascading impacts, not because they fail to produce certainty but because they often fail to expose the contours of their uncertainty. These impacts can ripple from the fundamental pursuit of knowledge, to local forest management, to the global conversations that shape water resource planning.

Bark interception: Just another British leaf, or a piece of blotting paper?

Having anatomised two components of the geographically chimeric interception routine in water models, we now turn to a third: bark. In global models, bark surfaces can represent tens of millions of square kilometres, an area so vast that misrepresenting bark is akin to misrepresenting an entire continent (Van Stan et al., 2021). Many models, nevertheless, treat this 'bark continent' as if it were just another leaf or an extension of leaf surfaces, often adopting a uniform multiplier (such as 0.2 × SLAI) that equates bark's storage per unit surface area to that of leaves (see Section 2.1). In this way, bark is replaced with the British leaf standard already described. Empirical evidence, however, reveals that bark surfaces differ dramatically from foliage, not only in their texture, porosity and capacity to retain or shed water (Ilek and Kucza, 2014; Ilek et al., 2021a; Tonello et al., 2021), but also in their hydrological functionality (Mason Earles et al., 2016; Berry et al., 2021; Ilek et al., 2021b). Variability in such differences influences processes such as the uptake, storage and retention of liquid water (Klamerus-Iwan et al., 2020; Linhoss and Siegert, 2020) and solutes (Oka et al., 2021a, 2021b), the adhesion of solid water such as snow and ice (Ney, 1893; Salamin, 1959), and vapor exchange (Gimeno et al., 2022; Ávila-Lovera and Winter, 2024; Beckett et al., 2024; Jupa et al., 2024).

Some water models do attempt to distinguish bark surfaces from leaves in precipitation interception by introducing bark-specific parameters. In the 'sparse' interception approach, for example (Valente et al., 1997), rainfall is split between an uncovered fraction $(1 - c)$ and a covered fraction (c). Any rain landing on the covered fraction is intercepted by a 'canopy' compartment that is defined via drip-based observations (which implicitly includes small stems or twigs) while a separate 'stem' compartment tracks flow down larger branches and trunks. Within this stem compartment, bark evaporation is frequently represented as a fraction (ε) of potential (or full canopy) evaporation (E_p), such that,

(6) $\quad E_{stem} = \varepsilon \times E_p,$

where ε is a bark-specific multiplier that is meant to capture differences between stem (bark) and the rest of the canopy (leaves and small twigs). In practice, of course, the canopy layer still includes portions of bark on small stems, underscoring how difficult it is to separate 'leaf' from 'bark' in the water world represented by interception models.

This so-called 'bark-specific' parameter, ε, is historically derived from something even less plant-like than leaves: blotting paper. The 'blotting paper evaporimeter' experiment originated in the 19th century and was refined by Renner in the early 20th century (Renner, 1910; Livingston, 1911). It remains the principal empirical basis for estimating bark evaporation in the sparse interception routine (Valente et al., 1997). Other models, however, such as iTree Hydro (Wang et al., 2008; Yang et al., 2011) and the Global Land Evaporation Amsterdam Model (GLEAM) (Miralles et al., 2011; Martens et al., 2017), continue to represent bark evaporation using leaf-analog parameters, effectively maintaining the British leaf standard rather than the blotting paper analogy. Initially designed to approximate leaf evaporation, blotting paper – typically dyed green (see introduction to Monteith, 1965) – was never intended for thicker and more porous, grey-to-brown, irregular bark surfaces; even so, it has been repurposed to estimate bark evaporation as $\varepsilon \approx$ 'negligible' to 5% of E_p (Rutter and Morton, 1977; Gash, 1979; Valente et al., 1997; Linhoss and Siegert, 2016). Although Rutter and Morton (1977) introduced these ε values indirectly from stemflow data (Rutter et al., 1975), no direct bark measurements were used in the works that presented, parametrised or evaluated the model (Rutter et al., 1971, 1975; Rutter, 1975; Rutter and Morton, 1977). The most empirical origin of ε comes from Valente et al. (1997), who placed "small, wet blotting paper samples at canopy and trunk levels" and assumed that the latter represented bark's interception. Key experimental details were unclear, including the exact number and placement of blotting sheets or the microclimate at the trunk, and bark-specific hydrophobicity, albedo or wind effects went unaddressed despite their theoretical impacts on evaporation rates (Van Stan et al., 2017, 2021). In short, this blotting-paper-as-bark analogy has persisted for over a century with minimal validation.

Historically, analogy has played a profound role in scientific discovery (Nappo, 2022). Famous examples include J.C. Maxwell likening electromagnetism to fluid flow (Maxwell and Niven, 2011) and modern physicists comparing black holes to thermodynamic systems (Bekenstein, 1972). In each instance, analogy served as a defeasible yet rational tool for transferring insights from a familiar domain to an unfamiliar one, potentially boosting a hypothesis's probability under the right background conditions (Hesse, 1974; Sober, 2015; Bartha, 2024). Applied to bark, blotting paper is the 'physical analogy' that stands in for unseen (that is, unempirically defined) processes. But when the target domain (bark's hydrologic uniqueness, beyond its geographic setting) is truly not analogous to the source domain (thin, uniform paper), the analogy falters, becoming an idiosyncratic chimeric element within our 'water world' of interception models. It risks undermining, rather than strengthening, our understanding of interception.

The undermining of understanding can be demonstrated by returning to equifinality, whereby narrow parameter ranges such as those determined for ε by analogy can lull modellers into a false confidence. Linhoss and Siegert (2016), for instance, tested interception parameters across the literature (including ε = 0.022 – 0.024) and concluded that ε exerted "relatively low" importance in interception modelling. Such findings feed into a broader complacency, that is, if bark is deemed negligible, why invest in gathering new data? Yet direct measurements suggest otherwise. In situ bark-surface temperature monitoring under rain-saturated conditions indicates that bark evaporation is underestimated by a factor of 2 to 17 when using the blotting paper analogy (Van Stan et al., 2017). The cost is not merely an abstract modelling error; bark's hydrological uniqueness remains overlooked, as does, by extension, entire forest types, especially deciduous forests during leafless conditions. Over decades, these simplifications ossify into global routines: a single, century-old empirical relic, grafted onto sophisticated 21st century models, overshadowing local data. Consequently, bark in land surface models behaves more like a fragment of damp paper than the ecohydrologically active matrix that it is. An immense swath of Earth's vegetation

(the 'bark continent') remains poorly represented in land surface models, underscoring how patchwork empiricism can distort global understandings of canopy interception.

We thus undertake a deeper query, asking from which geography do bark-specific interception parameters truly arise? Do they have real empirical roots, or do our water worlds contain barkless trees cloaked in 'British leaves' or wrapped in blotting paper, all contributing negligible evaporation to the global water cycle? By anchoring a hydrological process in an archaic analogy, the water world of interception routines adopts another idiosyncratic organ, further contributing to its chimeric nature.

CONCLUSIONS

You ask what all idiosyncrasy is in modellers?* (…). For example, their lack of historical sense (…), their Egyptianism [that is, their need to embalm what they value]. They imagine they do honor to a thing by divorcing it from history sub specie æterni[+] – when they make a [mathematical] mummy of it.[6]

Nietzsche (1889), "Reason in Philosophy", from *Twilight of the Idols*

This paper examines the 'water world' of large-scale hydrological models as geographical chimera – a hybrid 'organism' that is a disparate empirical patchwork. It focuses on the precipitation interception routines that initiate the rain-to-runoff pathway. The principal concern is that mosaics of region-specific results, once they are stitched together and elevated to 'global' truths, risk concealing knowledge. From 'British leaves' for rainwater storage, to 'fresh-cut Idaho conifers' for snow interception, to blotting paper bark for stem evaporation, each local study became a presumed universal. Such patchwork-universals risk becoming what Descartes called "true ideas in isolation", decoupled from their original contexts. This disconnect betrays four key risks. These are: first, the risk of neglecting *place*: local canopy-meteorological interactions are subsumed under narrow assumptions, implying that a single site or method can represent Earth's vast hydrological diversity; second, the risk of abusing *analogy*: the powerful cognitive tool that once propelled Darwin, Maxwell and others now collapses essential differences between bark and leaves or between conifer needles and tropical broadleaves; third, the risk of *methodological inertia*: once an equation or parameter (such as the $0.2 \times SLAI$ multiplier for bark or the 2% stem-evaporation factor) enters multiple models, further empirical research is disincentivised; fourth, *equifinality* obscures deeper errors: contradictory parameter sets can yield similar performance metrics, reinforcing an illusion of correctness while sidelining real hydrological processes.

Descartes reminds us that, "When ideas are considered solely in themselves and not taken to be connected to anything else, they can't be false; for whether it is a goat that I am imagining or a chimera, either way it is true that I do imagine it" (as translated by Bennett, 2017). When their empirical elements, severed from specific environmental contexts, amalgamate into a disjointed and bizarre construct, models run the risk of producing a chimera of global environmental representation, and local phenomena risk being 'mummified' into universal formulas. By highlighting these risks, we do not suggest discarding water models; indeed, these chimeras are important, insightful, useful and empowering. These risks, rather, call us to re-embed models in the 'belly of being', that is, in the tangible, place-bound realities

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[6] Original German: "Sie fragen mich, was Alles Idiosynkrasie bei den Philosophen ist?… Zum Beispiel ihr Mangel an historischem Sinn, ihr Hass gegen die Vorstellung selbst des Werdens, ihr Ägypticismus. Sie glauben einer Sache eine Ehre anzuthun, wenn sie dieselbe enthistorisiren, sub specie aetemi, - wenn sie aus ihr eine Mumie machen".

* The original subject of the phrase was "philosophers".

[+]*Sub specie aeternitatis*, Latin for "under the aspect of eternity" is a phrase introduced by Spinoza. It names a standpoint that treats reality as timeless and invariant. Nietzsche redeploys it polemically, warning that when we regard living processes "sub specie æterni" we freeze them into ahistorical abstractions. We use the term in that Nietzschean sense: the ideas embedded in a hydrological model risk becoming "mummified", cut off from the shifting places and times that once animated them.

from and through which water flows. Expanding site-specific field campaigns, revisiting core parameters, and fostering an epistemic openness that includes exploring further parameters and parametrisations can reinforce the links between empirical phenomena and theoretical representation. In short, correcting the chimeric bias means honouring local validations, re-examining legacy analogies, resisting complacency, and embracing more pluralistic methods. Only then can we answer Nietzsche's challenge and ensure that our interception models – and all models – speak from the grounded reality of each forest rather than from the timeless isolation of a mathematical mummy.

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SUPPLEMENTAL MATERIALS

Table S1. Scan of Table 1 from Rutter (1975).

Table I
Interception storage capacities

Vegetation		C, mm	
Coniferous forest			
Pinus sylvestris		1·6	Rutter (1963)
Picea abies		1·5	Leyton *et al.* (1967)
Pseudotsuga menziesii		2·1	Robins (1969)
Pinus nigra		1·0	Robins (1969)
Deciduous forest			
Carpinus betulus	summer	1·0	Leyton *et al.* (1967)
	winter	0·6	
Old *Quercus robur* coppice	summer	1·0	Thompson (1972)
	winter	0·4	
Ericaceous			
Calluna vulgaris		2·0	Leyton *et al.* (1967)
Herbaceous			
Zea mais		0·4–0·7	Stoltenberg and Wilson (1950)
Mixed grasses and legumes		1·0–1·2	Burgy and Pomeroy (1958)
Lolium perenne, 10 cm high		0·5	Merriam (1961)
48 cm high		2·8	Merriam (1961)
Molinia caerulea		0·7	Leyton *et al.* (1967)
Pteridium aquilinum		0·9	Leyton *et al.* (1967)