

The Dickinson Climate Classification: A Taxonomic Thermal-Hydrological Partition of Climate State Space

Caleb Dickinson

Abstract

This paper introduces the Dickinson Climate Classification, a thermodynamically grounded taxonomy that partitions climate state space using invariant thermal and hydrological metrics rather than biological criteria. Unlike widely used frameworks such as the Köppen classification or the UNEP aridity index, which are calibrated to present-day vegetation distributions or land-degradation objectives, the Dickinson system is formulated as a taxonomic division of climates relevant to physically possible life. Cold-month and warm-month thermal zones are defined using evenly spaced climatological temperature intervals, while moisture regimes are determined exclusively by dimensionless precipitation-to-potential evapotranspiration (P/PET) ratios and precipitation seasonality metrics, ensuring invariance under uniform rescaling of hydrological fluxes. The resulting framework provides a stable, internally consistent classification applicable across paleoclimates, present-day conditions, extreme future warming scenarios, and hypothetical climate states without requiring recalibration as biological tolerances evolve. This system is particularly suited for identifying emergent climates with no modern analogues and situating Earth's climates within a broader, formally defined climate state space.

Document Status and Scope

This manuscript presents a formal climate classification framework. It is not a predictive climate model, attribution study, or impact assessment. The system is intended as a taxonomic and analytical tool for comparing climate regimes across paleoclimates, future warming scenarios, and ecologically relevant climatic states that may never be realized on Earth, without requiring revision of thresholds or category definitions. This manuscript is released as a preprint to establish a persistent, citable description of the Dickinson Climate Classification framework, and is distributed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Data and Implementation Notes

All illustrative maps were generated using Google Earth Engine from CHELSA BIOCLIM+ v2.1 1981-2010 climatological normals (Karger et al., 2017; Brun et al., 2022). No new climate model simulations were performed for this work. The classification logic is deterministic and reproducible.

Introduction

The Dickinson Climate Classification differs fundamentally in both purpose and structure from widely used systems. The Köppen system (Köppen, 1884) is explicitly ecological and biogeographic, with classification thresholds calibrated to the present-day distribution of vegetation and climatic analogues on Earth. The UNEP aridity index (UNEP, 1992) is development-oriented, designed primarily to assess land degradation and desertification risk rather than to partition climate space as a whole. In contrast, the Dickinson classification is formulated as a thermodynamic partition of climate state space, independent of biological distributions and socioeconomic objectives.

The Dickinson system conceptualizes Earth’s climates as a subset of a broader, hypothetical climate space. Let \mathcal{C} denote the set of all climate regimes in which life is physically possible. Observed Earth climates occupy a proper subset of \mathcal{C} , but the classification itself is defined over the full domain. This framing does not assert that all regions of climate space described by the system are realizable on Earth; rather, it establishes a formal state space within which Earth’s past, present, and future climates may be situated, compared, and extended under paleoclimatic and projected boundary conditions.

Biological tolerances are not fixed: they shift over evolutionary time as lineages diverge from common ancestors and adapt to changing environmental conditions. Systems calibrated to contemporary species distributions therefore embed historical contingency and lose validity when applied to deep-time climates or extreme future scenarios. Thus, classification thresholds in the Dickinson system are deliberately independent of the present-day distribution limits of biological taxa.

Millimeter-based precipitation thresholds do not represent equivalent hydrological constraints across climates with different thermal regimes: a fixed precipitation total implies fundamentally different surface water availability in cold versus hot environments due to large differences in evaporative demand. For this reason, aridity regimes in the Dickinson system are

defined exclusively using dimensionless ratios of hydrological quantities. No aridity boundary is specified in terms of absolute precipitation totals, absolute evapotranspiration totals, or fixed millimeter thresholds. Instead, aridity classification depends solely on relative water balance and is therefore invariant under uniform rescaling of hydrological fluxes.

The Dickinson classification is intended as a partition of continuous climate space rather than as a definition of habitability limits. It does not attempt to identify the absolute bounds of life. Consequently, climates or microclimates that differ substantially in biological extremity—such as hypothetical thermophile-dominated regimes with $T_{\text{max,mean}} = 55^{\circ}\text{C}$ versus 80°C —may be assigned to the same category if they occupy the same region of thermodynamic climate space. This design choice preserves classification stability across paleoclimatic variability, evolutionary adaptation, and extreme future warming scenarios, without requiring revision in response to newly discovered extremophiles or altered biological tolerances.

Under strong anthropogenic warming, Earth is expected to enter climatic regimes with no present-day analogues, characterized by combinations of thermal and hydrological conditions not historically observed. Classification systems calibrated to modern Earth climate distributions perform well for climates resembling those present at the time of their formulation, but can yield misleading classifications under novel conditions. For example, a hypothetical location with constant rainfall and identical monthly mean temperatures to present-day Phoenix, Arizona would be classified as humid subtropical (Cfa) under Köppen, despite occupying a far more thermodynamically extreme regime than locations such as Tokyo or Atlanta. The Dickinson Climate Classification is designed to address this limitation, providing a framework for tracking climate regime transitions under strong warming, identifying emergent climates with no modern analogues, and comparing paleoclimatic and future states within a single, invariant classification scheme.

Additionally, the structure of this system permits substantially higher spatial and semantic resolution than most legacy climate classification frameworks. Because thermal and hydrological categories are defined using invariant, evenly spaced physical metrics rather than empirically tuned ecological thresholds, the classification can be applied meaningfully at fine spatial scales wherever reliable climatological normals are available. This property makes the framework well suited to resolving sharp climatic gradients, topographic microclimates, and human-relevant thermal regimes without requiring additional calibration or region-specific adjustment.

The system is defined only over the subset of climate space in which life is physically possible. Outside this domain, the classification is not meaningful and no interpretation is implied.

Table 1: Conceptual comparison of major climate classification frameworks, including the Dickinson system, the Köppen classification, the Holdridge bioclimatic life-zone scheme (Holdridge, 1947), and the UNEP aridity index.

Framework	Primary variables	Calibration basis	Applicability
Köppen (1884)	Temperature and precipitation thresholds	Observed vegetation distributions	Present-day Earth climates; limited extrapolation
Holdridge (1947)	Biotemperature, precipitation, P/PET	Plant physiological response	Ecological zoning; biologically contingent
UNEP (1992)	Annual P/PET	Land degradation and desertification risk	Development-oriented; aridity only
Dickinson (this work)	Cold-month T_{\min} , warm-month T_{\max} , P/PET , seasonality	Thermodynamic partition of climate state space	Paleoclimates, future climates, hypothetical states

1 Thermal Metrics and Cold-Month Thermal Zones

Thermal classification in the Dickinson system is based on climatological monthly mean near-surface air temperatures, computed over a standard 30-year normal period. For each location, the coldest-month mean temperature is taken as the minimum of the twelve climatological monthly means, while the warmest-month mean temperature is taken as the maximum.

The cold-month thermal intervals are defined in uniform increments of 10 °C, with 5 °C resolution used for all but one warm-month category; the *hyperthermal summer* category retains 10 °C spacing. These intervals correspond to simple fractional subdivisions of the 100 °C temperature span between the freezing and boiling points of water at standard pressure. The lowest and highest warm-month and cold-month thermal categories are unbounded. This choice provides a transparent and reproducible normalization scale without implying special physical thresholds at category boundaries.

The choice of thermal binning reflects a balance between physical interpretability and classification stability, with asymmetric resolution applied to cold- and warm-month metrics. Cold-month thermal zones are defined using uniform 10 °C intervals, as winter temperature primarily acts as a threshold constraint on surface processes, cryospheric state, and large-scale habitability. Differences smaller than this scale do not typically distinguish fundamentally different winter regimes at the global level, while coarser intervals would collapse thermodynamically distinct cold states.

By contrast, the warm-month thermal axis is partitioned at higher resolution, using 5 °C intervals when a given temperature occurs as a warmest-month mean rather than as a coldest-month mean, across the range of monthly mean temperatures from ≥ 0 to < 40 °C. This reflects the continuous and highly sensitive influence of summer warmth on surface energy balance, evapotranspiration, and heat stress. Accordingly, cold-month thermal classes C, B, A, and Z—defined by their coldest-month means—are each subdivided into paired warm-month categories when their warmest-month means fall within these same numerical temperature intervals (e.g., C into c_1 and c_2 , B into b_1 and b_2 , with analogous subdivisions for A and Z).

This asymmetric treatment follows long-standing precedent in climate classification. In the Köppen system, for example, the temperature spacing between winter-regime isotherms is substantially broader than that separating summer heat regimes (Köppen, 1884). The combined use of uniform 10 °C cold-month bins and finer warm-month subdivisions therefore produces a transparent, scale-consistent partition of climate space that remains robust across paleoclimates, projected future warming scenarios, and hypothetical climate states.

Cold-month thermal zones are assigned using the climatological coldest-month mean temperature ($T_{\min,\text{mean}}$), which provides a robust measure of winter thermal constraint that is insensitive to short- duration extremes. The resulting cold-month thermal zones span the full range of physically plausible climates, from extreme cold environments to hypothetical hyperthermal regimes that may occur under deep-time or future boundary conditions.

Based on $T_{\min,\text{mean}}$, climates are assigned to one of the following cold-month thermal zones:

Hypercanal (H)	$T_{\min,\text{mean}} \geq 50^\circ\text{C}$
Uninhabitable (X)	$40 \leq T_{\min,\text{mean}} < 50^\circ\text{C}$
Hyperequatorial (Z)	$30 \leq T_{\min,\text{mean}} < 40^\circ\text{C}$
Equatorial (A)	$20 \leq T_{\min,\text{mean}} < 30^\circ\text{C}$
Tropical (B)	$10 \leq T_{\min,\text{mean}} < 20^\circ\text{C}$
Subtropical (C)	$0 \leq T_{\min,\text{mean}} < 10^\circ\text{C}$
Temperate (D)	$-10 \leq T_{\min,\text{mean}} < 0^\circ\text{C}$
Continental (E)	$-20 \leq T_{\min,\text{mean}} < -10^\circ\text{C}$
Subarctic (F)	$-30 \leq T_{\min,\text{mean}} < -20^\circ\text{C}$
Arctic (G)	$-40 \leq T_{\min,\text{mean}} < -30^\circ\text{C}$
Superarctic (Y)	$T_{\min,\text{mean}} < -40^\circ\text{C}$

These thresholds are evenly spaced in temperature and are intended to represent thermo-

dynamic regimes rather than ecological boundaries. As a result, the classification remains applicable across paleoclimates, projected future climates, and hypothetical climate states without requiring recalibration to present-day biological distributions.

Note on the term “Uninhabitable”. *Uninhabitable* denotes climates for which the coldest-month climatological mean temperature satisfies $40^{\circ}\text{C} \leq T_{\text{min,mean}} < 50^{\circ}\text{C}$, implying that all monthly means exceed the core body temperature of humans and other large mammals. The term is thermodynamic in scope and does not preclude habitation by organisms with substantially different size, physiology, or thermal regulation strategies than large mammals, nor technologically mediated habitation.

Note on hypercanes. The term *hypercaneal* is used here strictly as a thermal descriptor for extremely hot climatological monthly mean temperatures. Hypercaneal cold-month and/or warm-month thermal zones should be understood as a *necessary but not sufficient* condition for the formation of hypercane vortices (Emanuel, 1988). Hypercane development also depends on additional dynamical and oceanic factors that are not represented in a monthly-mean thermal classification. Accordingly, classification as hypercaneal does not imply the existence, frequency, or persistence of hypercanes.

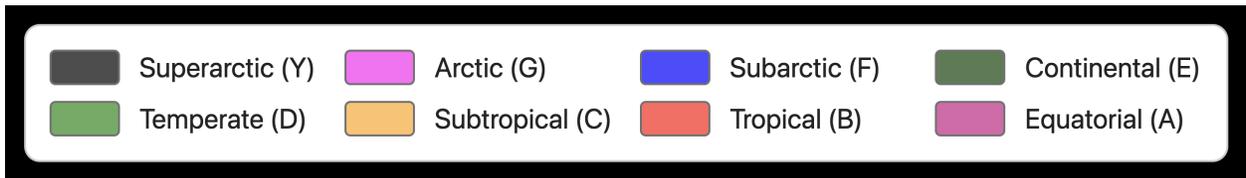
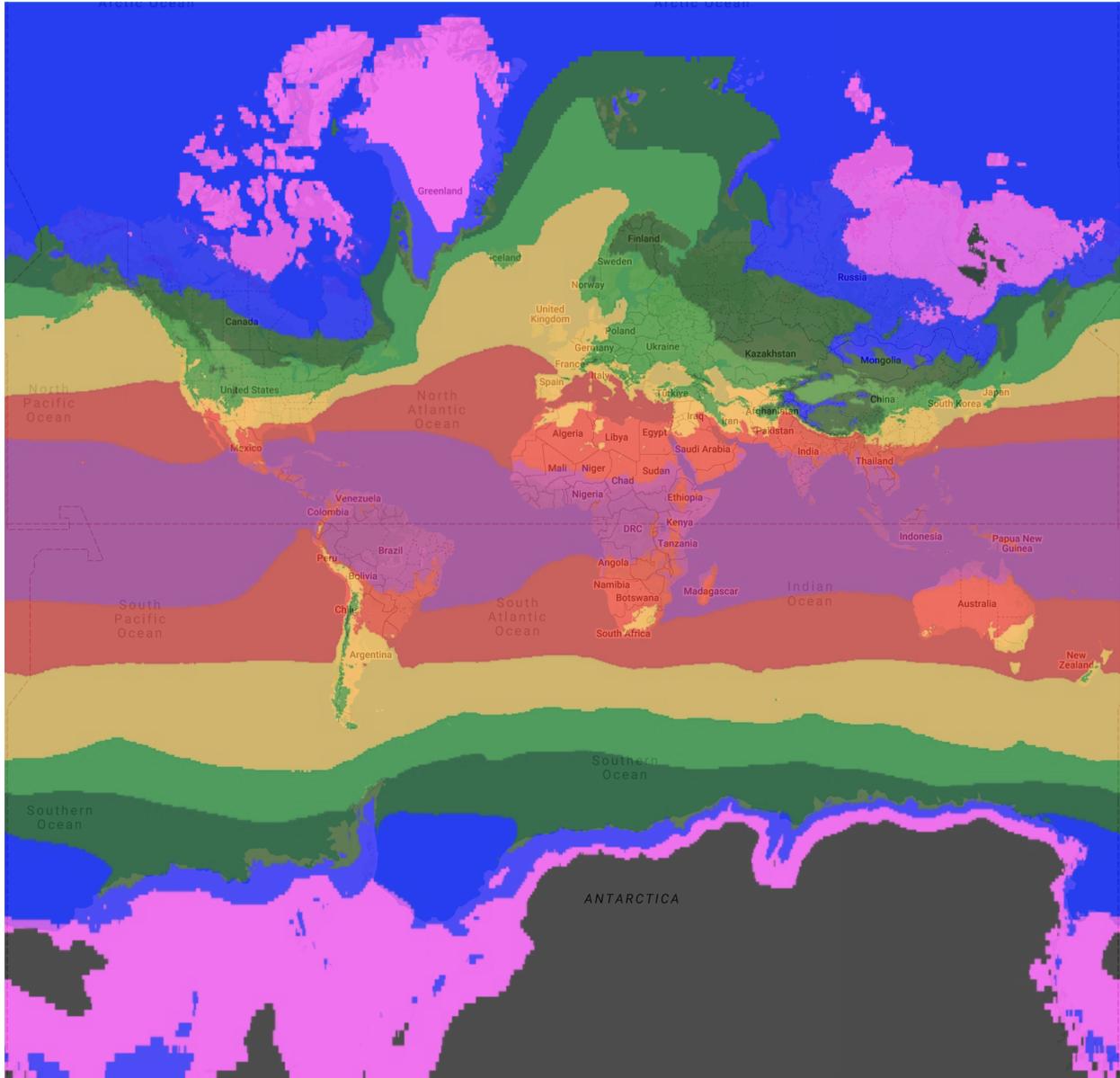


Figure 1: Global distribution of cold-month thermal zones under the Dickinson Climate Classification, based on 1981–2010 climatological normals. Data were processed and plotted in Google Earth Engine (GEE) using CHELSA BIOCLIM+ v2.1 1981-2010 temperature fields (Karger et al., 2017; Brun et al., 2022).

2 Warm-Month Thermal Zones

In addition to cold-season thermal constraints, the Dickinson classification characterizes the intensity of the warm season using the climatological warmest-month mean near-surface air temperature ($T_{\max,\text{mean}}$). This metric provides a stable measure of summer thermal conditions that reflects seasonal energy balance rather than short-lived extreme events.

Warm-month thermal zones are assigned based on $T_{\max,\text{mean}}$ and are intended to distinguish climates with similar winter conditions but substantially different summer heat regimes. The resulting categories span the full range of plausible summer thermal environments, from persistently cold summers to extreme hyperthermal regimes that may occur under deep-time or future warming scenarios.

Based on the warmest-month mean temperature, climates are assigned to one of the following warm-month thermal zones:

Hypercanal Summer (H)	$T_{\max,\text{mean}} \geq 50^{\circ}\text{C}$
Hyperthermal Summer (X)	$40 \leq T_{\max,\text{mean}} < 50^{\circ}\text{C}$
Scorching Summer (z2)	$35 \leq T_{\max,\text{mean}} < 40^{\circ}\text{C}$
Very Hot Summer (z1)	$30 \leq T_{\max,\text{mean}} < 35^{\circ}\text{C}$
Hot Summer (a2)	$25 \leq T_{\max,\text{mean}} < 30^{\circ}\text{C}$
Warm Summer (a1)	$20 \leq T_{\max,\text{mean}} < 25^{\circ}\text{C}$
Cool Summer (b2)	$15 \leq T_{\max,\text{mean}} < 20^{\circ}\text{C}$
Cold Summer (b1)	$10 \leq T_{\max,\text{mean}} < 15^{\circ}\text{C}$
Very Cold Summer (c2)	$5 \leq T_{\max,\text{mean}} < 10^{\circ}\text{C}$
Freezing Summer (c1)	$0 \leq T_{\max,\text{mean}} < 5^{\circ}\text{C}$
Frigid Summer (Y)	$T_{\max,\text{mean}} < 0^{\circ}\text{C}$

As with the cold-month thermal zones, warm-month thresholds are evenly spaced in temperature and are intended to represent thermodynamic regimes rather than biological or impact-based categories. This approach ensures consistency across paleoclimates, present-day climates, and projected future warming scenarios without reliance on species-specific tolerance limits or human comfort thresholds.

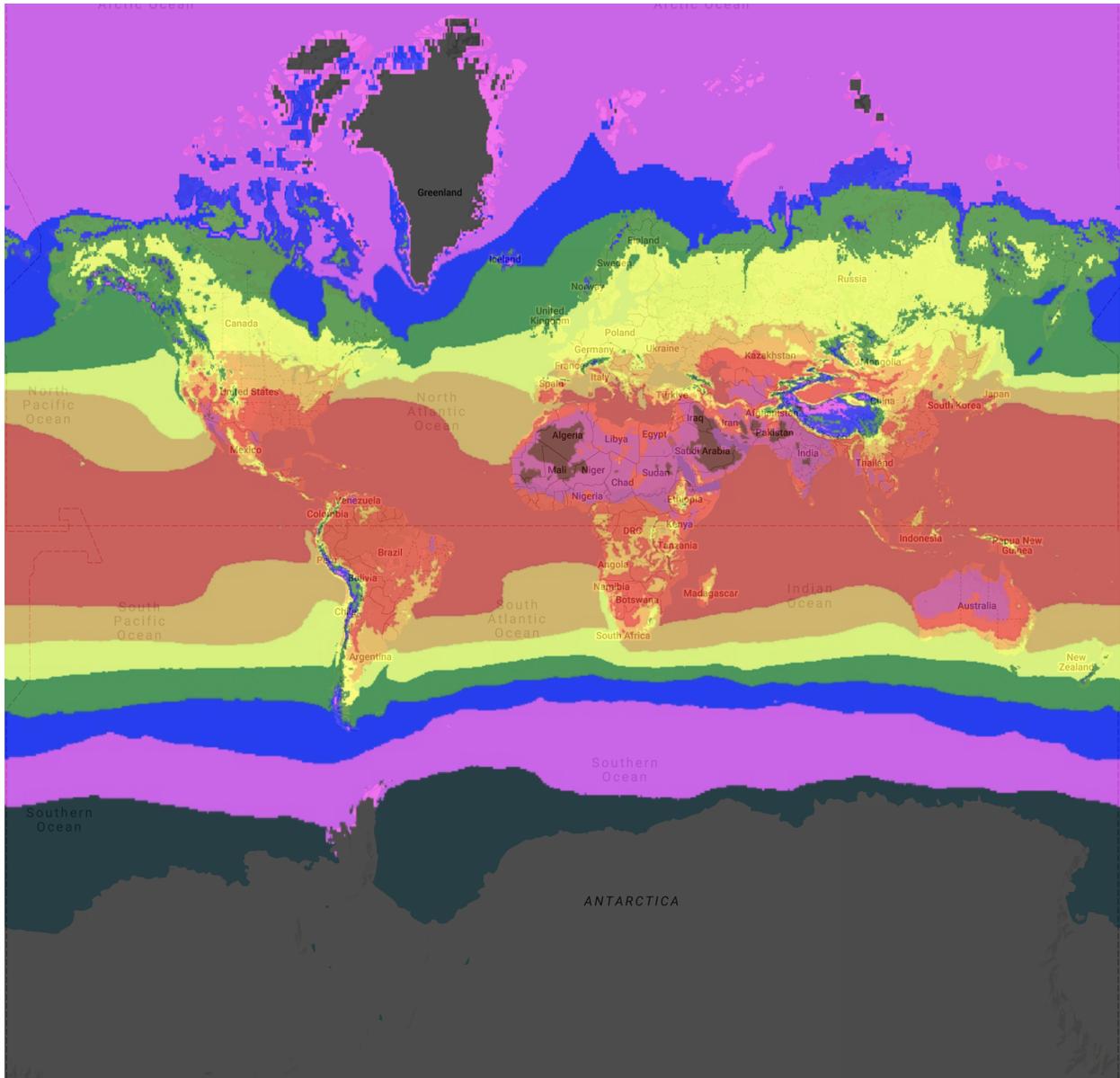


Figure 2: Global distribution of warm-month thermal zones under the Dickinson Climate Classification, based on 1981–2010 climatological normals. Data were processed and plotted in Google Earth Engine (GEE) using CHELSA BIOCLIM+ v2.1 1981-2010 temperature fields (Karger et al., 2017; Brun et al., 2022).

3 Aridity Relevance and Aridity Regimes

Previous climate classification frameworks have implicitly recognized that aridity diagnostics are meaningful only within a limited thermal domain. In the Köppen system (Köppen, 1884), aridity-based categories are restricted to climates whose climatological warmest-month mean temperature exceeds 10 °C, thereby excluding cold-summer and polar regimes in which surface processes are primarily energy-limited rather than moisture-limited. Similarly, the United Nations Environment Programme (UNEP) aridity framework (UNEP, 1992) distinguishes “cold” regions (annual PET < 400 mm) from aridity regimes defined by P/PET ratios, acknowledging that water-balance diagnostics lose interpretive value where evaporative demand is minimal.

Moisture regime classification in the Dickinson system is applied only to climates in which aridity meaningfully structures surface–atmosphere interactions. Specifically, aridity diagnostics are evaluated only at locations where the climatological warmest-month mean temperature is at least 15°C and the climatological coldest-month mean temperature is at least –30°C. Together, these warm- and cold-month constraints define a conservative thermal envelope within which aridity diagnostics exert first-order influence on climate differentiation. Outside this envelope, climates are classified exclusively on thermal grounds.

At locations that do not satisfy these thermal screening criteria, no aridity regime is assigned and the moisture classification is not evaluated within the Dickinson framework.

For climates meeting the aridity relevance criteria, moisture regimes are defined using the annual aridity index

$$AI = \frac{P_{\text{ann}}}{PET_{\text{ann}}},$$

where annual precipitation is computed as the sum of monthly precipitation totals and where PET denotes annual potential evapotranspiration. All aridity regimes are defined using this dimensionless ratio, ensuring invariance under uniform rescaling of hydrological fluxes.

Based on the annual aridity index, climates are assigned to one of four baseline aridity regimes in the Dickinson classification:

Humid (h)	$AI \geq 0.75$
Semihumid (g)	$0.50 \leq AI < 0.75$
Semiarid (s)	$0.25 \leq AI < 0.50$
Arid Desert (d)	$AI < 0.25$

For comparison, the United Nations Environment Programme (UNEP) aridity index defines the following regimes:

Humid	$AI \geq 0.65$
Dry subhumid	$0.50 \leq AI < 0.65$
Semi-arid	$0.20 \leq AI < 0.50$
Arid	$0.05 \leq AI < 0.20$
Hyper-arid	$AI < 0.05$

The Dickinson aridity thresholds are deliberately modified from the UNEP scheme to provide a more uniform partition of climate space. UNEP’s *hyper-arid* and *arid* are incorporated into a single arid category, and each range is repartitioned to produce evenly spaced, analytically comparable moisture regimes. This design choice emphasizes thermodynamic consistency and stability across paleoclimates and future warming scenarios rather than land-degradation or development-focused classification objectives.

Note. Aridity classifications are defined only for terrestrial climates and are not evaluated over the open ocean. Temperature-based classifications, by contrast, are defined globally.

4 Seasonality Diagnostics and Aridity Overrides

In addition to annual water balance, the Dickinson classification incorporates precipitation seasonality diagnostics to distinguish climates with similar aridity indices but fundamentally different seasonal structures. Two complementary diagnostics are used: a high-sun precipitation fraction and a rolling six-month precipitation dominance metric.

The high-sun precipitation fraction (HS) quantifies the proportion of annual precipitation occurring during the six highest-insolation months; April-September in the Northern Hemisphere extratropics, and October-March in the Southern Hemisphere extratropics. Annual precipitation during this period (P_{hs}) is divided by total annual precipitation (P_{ann}) to yield

$$HS = \frac{P_{\text{hs}}}{P_{\text{ann}}}.$$

This diagnostic captures hemispherically asymmetric seasonal regimes, particularly extratropical climates characterized by dry summers and wet winters.

To identify strongly concentrated wet seasons independent of calendar alignment, a rolling six-month precipitation dominance metric is also computed. For each possible six-month

window, cumulative precipitation is evaluated, and the maximum total ($P6$) is normalized by annual precipitation to yield

$$P6_{\text{ratio}} = \frac{P6}{P_{\text{ann}}}.$$

This metric detects monsoonal regimes in which the majority of annual precipitation occurs within a contiguous portion of the year, regardless of its seasonal timing.

These seasonality diagnostics are applied as overrides to the baseline aridity regimes to distinguish Mediterranean and monsoonal climates.

Mediterranean climates are identified as non-arid regimes ($AI \geq 0.25$) exhibiting strong winter precipitation dominance in the extratropics ($HS < 0.4$).

Monsoonal climates are identified using the rolling six-month precipitation dominance metric. Climates in which at least 80% of annual precipitation occurs within any consecutive six-month period ($P6_{\text{ratio}} \geq 0.8$) are classified as monsoonal, excluding climates already classified as arid desert or Mediterranean.

Finally, a temperate rainforest override is applied to prevent Mediterranean classification in climates that remain persistently moist throughout the year. For climates initially identified as Mediterranean, the minimum monthly precipitation (P_{driest}) is compared to annual potential evapotranspiration. If

$$P_{\text{driest}} \geq \frac{PET_{\text{ann}}}{24},$$

the climate is reclassified as humid. This criterion corresponds to a minimum monthly precipitation of at least 50% of mean monthly PET.

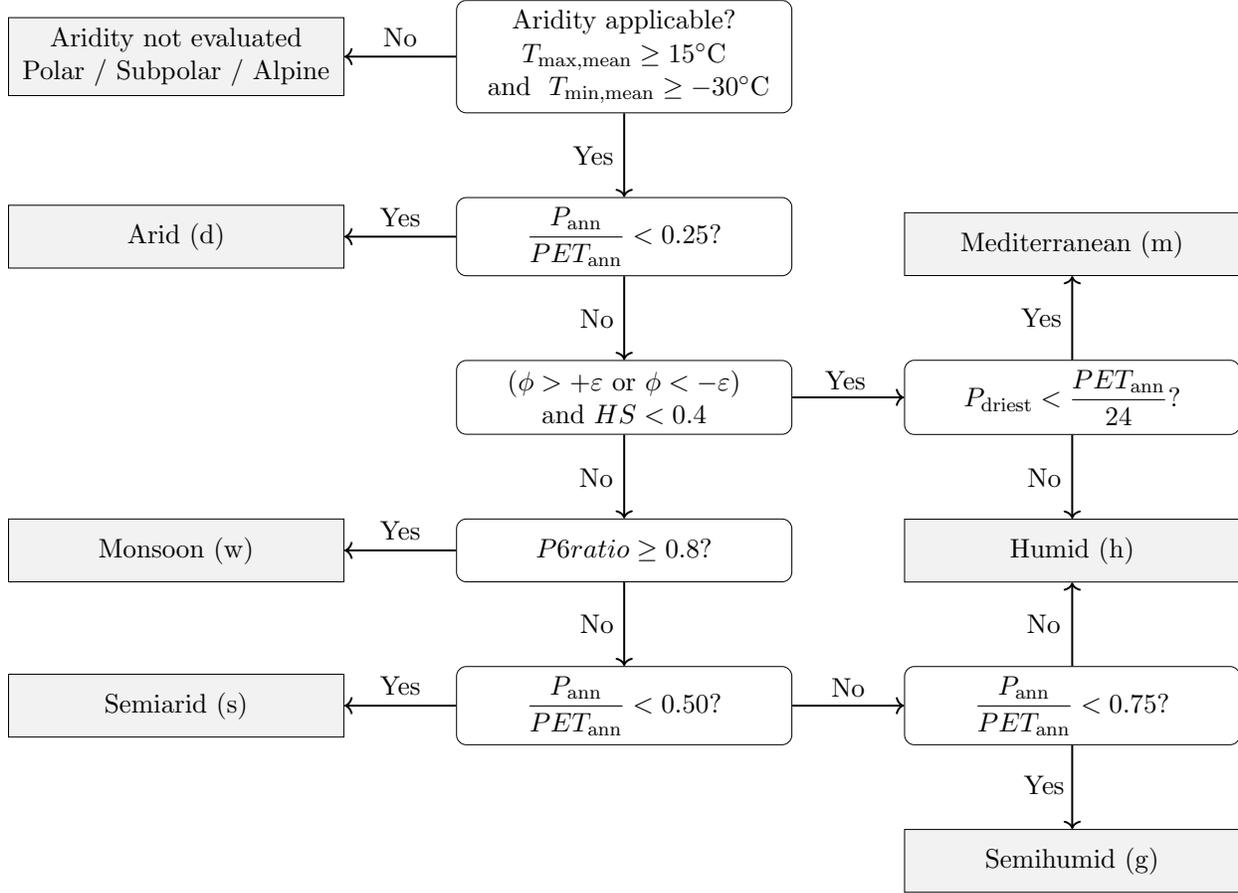


Figure 3: Decision tree for assigning aridity regimes in the Dickinson classification.

Note: ϕ denotes geographic latitude in degrees. ε denotes the Earth’s axial tilt (obliquity), defined as the instantaneous angle between the Earth’s rotational axis and the normal to its orbital plane. For present-day Earth, $\varepsilon \approx 23.44^\circ$, but ε is treated here as a physical parameter rather than a fixed constant, allowing for secular variation over geological timescales. In this context, extratropical locations are defined as latitudes poleward of the astronomical tropics (i.e., $|\phi| > \varepsilon$). Mediterranean seasonality is evaluated only at such locations.

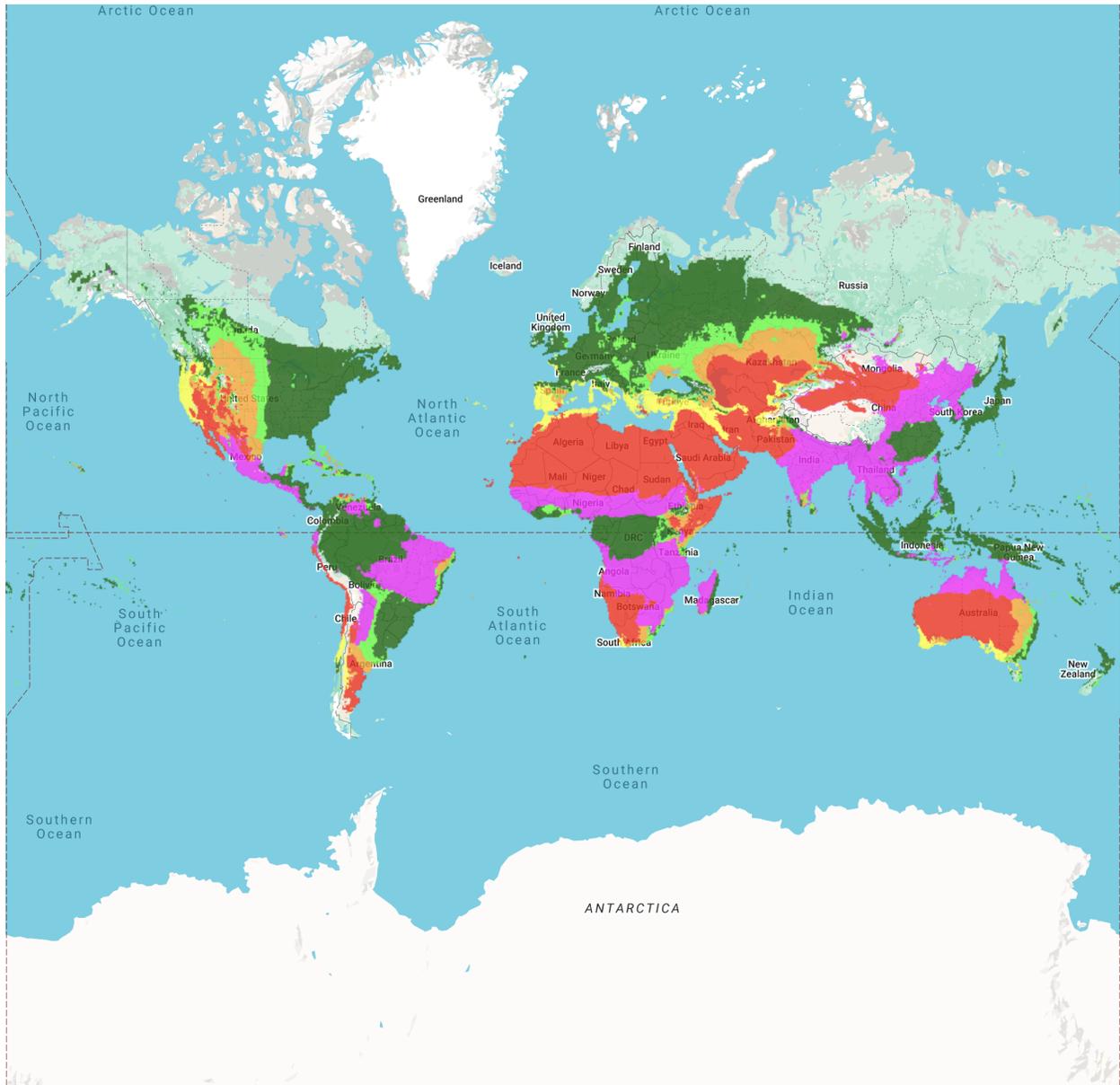


Figure 4: Global distribution of aridity zones under the Dickinson Climate Classification, based on 1981–2010 climatological normals. Data were processed and plotted in Google Earth Engine (GEE) using CHELSA BIOCLIM+ v2.1 1981-2010 precipitation and Penman-Monteith PET fields (Karger et al., 2017; Brun et al., 2022).

5 Illustrative Complete Climate Codes

The following examples demonstrate the semantic interpretation of complete Dickinson climate codes. Each code is composed of a cold-month thermal zone, an aridity regime (where applicable), and a warm-month thermal zone, as defined in the preceding sections. These examples are illustrative only and do not necessarily exist on Earth.

- **YY** — Superarctic with frigid summer (aridity not evaluated).
- **Fa2** — Subarctic with hot summer (aridity not evaluated).
- **Ema1** — Continental Mediterranean with warm summer.
- **CdX** — Subtropical arid with hyperthermal summer.
- **Bb1** — Tropical with cold summer (aridity not evaluated).
- **Bhb2** — Tropical humid with cool summer.
- **Zgz2** — Hyperequatorial semihumid with scorching summer.

Conclusion

The Dickinson Comprehensive Climate Classification provides a complete, thermodynamically grounded partition of climate space without imposing biological assumptions or temporal constraints. By formalizing aridity relevance, seasonality diagnostics, and exception handling, the system remains stable under extreme warming, deep-time climates, and hypothetical planetary environments.

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