Badlands of Rio Grande do Norte, in the drought-stricken Brazilian Northeast (August, 1993).

# THE DROUGHT TOOLBOX

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**ABSTRACT.** Droughts are a pervasive and recurrent element of Nature, surely a reality that developed human societies must contend with. This article describes a drought toolbox, formulated using sound principles of climatology and hydrology. The objective is to provide clear, easy-to-follow relations to enhance the understanding of droughts, their intensity, duration, and frequency throughout the defined climatic spectrum. This endeavor should help in assessing the impact of global climate change on drought phenomena. The overall aim is to develop improved strategies to cope with droughts under the contemporary reality of climate change.

## 1. INTRODUCTION

A drought is a period of little precipitation in a specific place or region of the Earth, when compared to the normal amount. It may last days, months, or years. The cause of droughts may be attributed to the cybernetic behavior of the Earth, where droughts follow floods, and floods follow droughts

(Lovelock, 1979; **Ponce, 1995**). A drought *intensity* (how severe is a drought?), *duration* (how long will it last?), and *frequency* (how often does it recur?) remain to be determined by further analysis.

The socioeconomic effects of droughts depend largely on the prevailing climate. This is because the population of the Earth is not evenly distributed. In general, semiarid and subhumid regions tend to have larger concentrations of population, while arid and humid regions tend to have smaller concentrations. Toward the climatic extremes, in *superarid* and *superhumid* regions, human populations are even more scant. In the arid extreme (on the dry side), comparatively fewer people are affected by a drought, while in the humid extreme (on the wet side), droughts are naturally milder, shorter, and/or of a much lower frequency.

It is clear that drought analysis, control, and policy depend largely on the prevailing climate and on the locally affected populations. There is not one rule that relates to droughts; the multiplicity of rules is related to the varying climate. In this article, we contribute to the knowledge of droughts by defining the *climatic spectrum* with a specific focus on subtropical and midlatitudinal regions. The resulting climate classification underlies the structure of a *tool box* designed to further the understanding of drought properties. The overall aim is to relate drought phenomena to the contemporary climate change experience.

## 2. THE CLIMATIC SPECTRUM

We characterize the climatic spectrum solely in terms of *mean annual precipitation*, an approach which appears to be useful, as a first approximation, for subtropical and midlatitudinal regions. The factors affecting mean annual precipitation are listed in **Box A**.

**Box A.** Factors affecting mean annual precipitation (**Ponce, 2014**).

1. Latitude.
2. Orographic factor: The presence of mountains in the vicinity.
3. Mesoscale ocean curents.
4. Atmospheric wind circulation.
5. Proximity to oceans and other large bodies of water.
6. Atmospheric pressure.
7. Character of the Earth's surface, including color and texture, which affect albedo (**Ponce and others, 1997**).
8. Presence of atmospheric particulates, both natural and human-induced.

Around the world, mean annual precipitation varies widely. It has been documented to vary between the low value of 15 mm in the Atacama desert, in Northern Chile (Wikipedia: **Atacama Desert**), and the high value of 11,872 mm in Mawsynram, Meghalaya, Eastern India (Wikipedia: **Mawsynram**).

We characterize the climatic spectrum in terms of the ratio of mean annual precipitation $P_{ma}$ to annual global terrestrial precipitation $P_{agt}$ . Following **Ponce and others (2000)**, we assume $P_{agt}$ = 800 mm.

Globally, the middle of the climatic spectrum, i.e., the division between semiarid and subhumid climates, corresponds to $P_{ma} / P_{agt} = 1$. Regions with $P_{ma} / P_{agt} < 1$ have less-than-average moisture; conversely, regions with $P_{ma} / P_{agt} > 1$ have greater-than-average moisture. Mean annual precipitation varies typically in the range of 100-6400 mm, with a few isolated cases falling outside of this range. This variation enables the division of the climatic spectrum into the eight types listed in **Box B**.

**Box B.** Division of the climatic spectrum into eight subclimates.

1. *Superarid:* $P_{ma} / P_{agt} < 0.125$
2. *Hyperarid:* $0.125 \le P_{ma} / P_{agt} < 0.25$
3. *Arid:* $0.25 \le P_{ma} / P_{agt} < 0.5$
4. *Semiarid:* $0.5 \le P_{ma} / P_{agt} < 1$
5. *Subhumid:* $1 \le P_{ma} / P_{agt} < 2$
6. *Humid:* $2 \le P_{ma} / P_{agt} < 4$
7. *Hyperhumid:* $4 \le P_{ma} / P_{agt} < 8$
8. *Superhumid:* $P_{ma} / P_{agt} \ge 8$

## 3. THE DROUGHT TOOLBOX

Table 1 shows the conceptual model of drought characterization of **Ponce and others (2000)**, referred to in this article as the *drought toolbox*. This table summarizes **intensity - duration - recurrence interval** relations, in other words, the IDF relations for droughts. **Box C** summarizes the rationale behind the entries of Table 1.

**TABLE 1. Conceptual model of drought characterization across the climatic spectrum.**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| **Climatic Spectrum** | | | | | | | | |
| **Climatic type** | Super-arid ← | Hyper-arid → | Arid → | Semi-arid → | Sub-humid → | Humid → | Hyper-humid → | Super-humid → |
| **Mean annual precipitation $P_{ma}$ (mm)** | | 100 | 200 | 400 | 800 | 1600 | 3200 | 6400 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $P_{ma}/P_{agt}$ | | 0.125 | 0.25 | 0.5 | **1** | 2 | 4 | 8 |
| **Annual potential evapotranspiration $E_{ap}$ (mm)** | | 3000 | 2400 | 2000 | **1600** | 1200 | 1200 | 1200 |
| $E_{ap}/P_{ma}$ | | 30 | 12 | 5 | **2** | 0.75 | 0.375 | 0.1875 |
| **Length of rainy season $L$ (mo)** | | 1 | 2 | 3 | **4** | 6 | 9 | 12 |
| **Drought Characteristics** | | | | | | | | |
| **Intensity $I$ (dimensionless)** | ***Moderate*** | 0.25 | 0.5 | 1.0 | **1.5** | 1.0 | 0.5 | 0.25 |
| | ***Severe*** | 0.5 | 1.0 | 2.0 | **3.0** | 2.0 | 1.0 | 0.5 |
| | ***Extreme*** | 0.75 | 1.5 | 3.0 | **4.5** | 3.0 | 1.5 | 0.75 |
| **Duration $D$ (yr)** | | 1 | 2 | 4 | **6** | 4 | 2 | 1 |
| **Recurrence interval $T$ (yr)** | | 2 | 3 | 6 | **12** | 25 | 50 | 100 |

***Note:*** $P_{ma}$ = mean annual precipitation; $P_{agt}$ = annual global terrestrial precipitation; $E_{ap}$ = annual potential evapotranspiration.

**Box C.** Rationale behind the entries of Table 1.

1. A superarid climate corresponds to $P_{ma}$ < 100 mm; hyperarid between 100 and 200 mm; and so on... up to superhumid > 6,400 mm.
2. The ratio $P_{ma}/P_{agt}$ is 0.125 at the limit between superarid and hyperarid climates, and doubles moving to the right, for every climate class, up to $P_{ma}/P_{agt}$ > 8 for superhumid climates.
3. $E_{ap}$ is about 3,000 mm at the limit between superarid and hyperarid climates.
4. $E_{ap}$ is about 1,600 mm at the middle of the climatic spectrum, at $P_{ma}$ = 800 mm.
5. $E_{ap}$ is about 1,200 mm and remains approximately constant in the humid side of the climatic spectrum.
6. The length $L$ of the rainy season varies between 1 month at the limit between superarid and hyperarid climates, and 12 months for superhumid climates.
7. A *moderate* drought intensity represents an annual deficit of 25% from the mean; a *severe* drought intensity an annual deficit of 50% from the mean; an *extreme* drought intensity an annual deficit of 75% from the mean.
8. **Drought intensity *I*** varies from moderate (1.5) to severe (4.5) at the middle of the climatic

spectrum.

9. By definition: $T > D$; therefore, this justifies the values of $D < T$ on the dry side of the climatic spectrum. For superhumid climates, $D$ is estimated as 1 year, confirming the fact that droughts are hardly present in superhumid climates.

10. **Drought duration *D*** reaches a maximum of 6 years at the middle of the climatic spectrum.

11. **Drought recurrence interval *T*** increases from very short, as short as 2 years, in superarid climates, to very long, approaching 100 years, in superhumid climates.

12. Drought recurrence interval $T$ is about 12 years at the middle of the climatic spectrum.

## 4. CLOSING STATEMENT

Droughts are a pervasive and recurrent element of Nature, surely a reality that developed human societies must contend with. This article describes a **drought toolbox**, formulated using sound principles of climatology and hydrology. The objective is to provide clear, easy-to-follow relations to enhance the understanding of droughts, their intensity, duration, and frequency throughout the defined climatic spectrum. This endeavor should help in assessing the impact of global climate change on drought phenomena. The overall aim is to develop improved strategies to cope with droughts under the contemporary reality of climate change.

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