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From Thales to Aristotle and Heron of Alexandria: The development of hydrology in the Greek antiquity and its relevance to modern times

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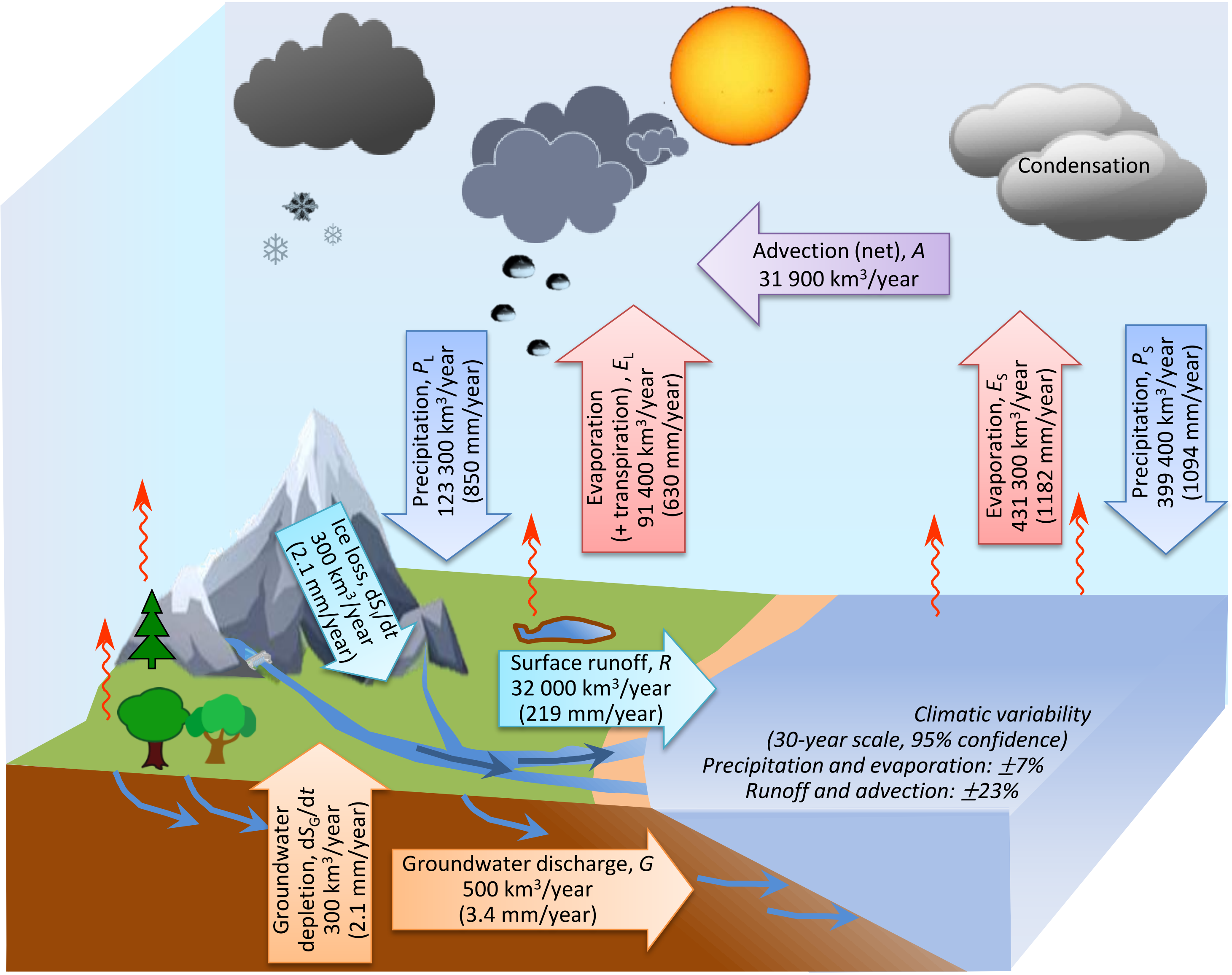
The hydrological cycle as we know it today



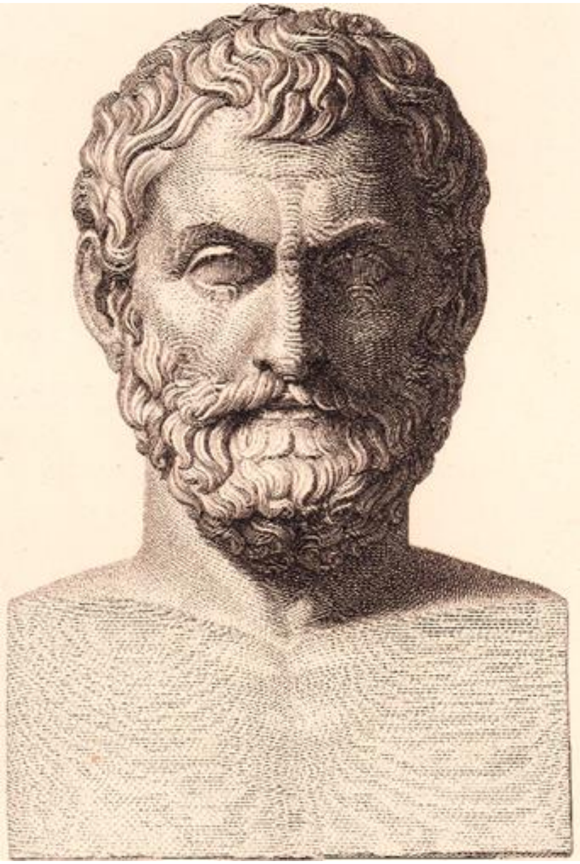
This is the current knowledge (with quantification) about the hydrological cycle (see detailed calculations and results in Koutsoyiannis, 2020).

What did ancient Greeks think about the hydrological cycle and the hydrological processes?

Thales and the birth of science

Thales of Miletus, one of the Seven Sages of Greece, is regarded as the **father of natural philosophy and science**. His contributions cover several fields:

- **Mathematics**. He introduced deduction through theorems; he proved several theorems in geometry, including those bearing his name: the Thales' angle theorem and intercept theorem.
- **Astronomy**. He predicted the solar eclipse in 28 May 585 BC.
- **Physics**. He studied static electricity by experimenting on amber (in Greek ήλεκτρον—electron) as well as magnetism.
- **Surveying engineering**. He measured the heights of pyramids and the distance of ships from the shore.
- **Hydraulic engineering**. He made a diversion of the river Halys for military purposes.



Thales (624–548 BC)
Image source: Visconti (1817)

In addition to his scientific achievements on geometry and astronomy, he dealt with the paradox of the Nile (will be examined below), thus highlighting the importance of hydrology in the birth of science.

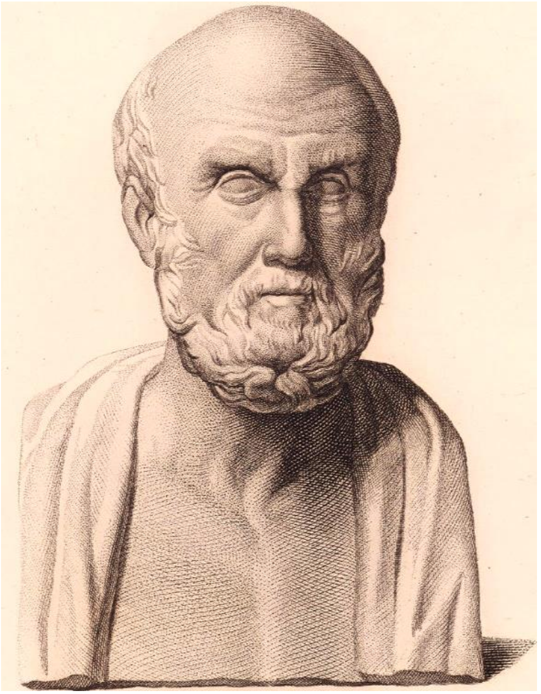
Thales’ successors and the foundation of hydrological cycle

Anaximander of Miletus (610–546 BC) understood the relationship or **rainfall and evaporation**.

Anaximenes of Miletus devised logical explanations for the formation of **wind**, **clouds, rain and hail**.

Xenophanes of Colophon (570–478 BC) understood the presence of fossilized marine organisms at three island locations and developed a theory of alternating periods of flood and drought.
He proclaimed the **sea as the source of clouds, rain water and river flow**.

Hippocrates of Kos (460 – c. 370 BC), the philosopher and most outstanding figure in the history of medicine, studied the relationship of **water and health**. He also contributed to hydrology through his treatise *Airs, Waters, Places*, where he **clearly described the hydrological cycle**, including the fact that the **salt contained in sea water is not evaporated**.



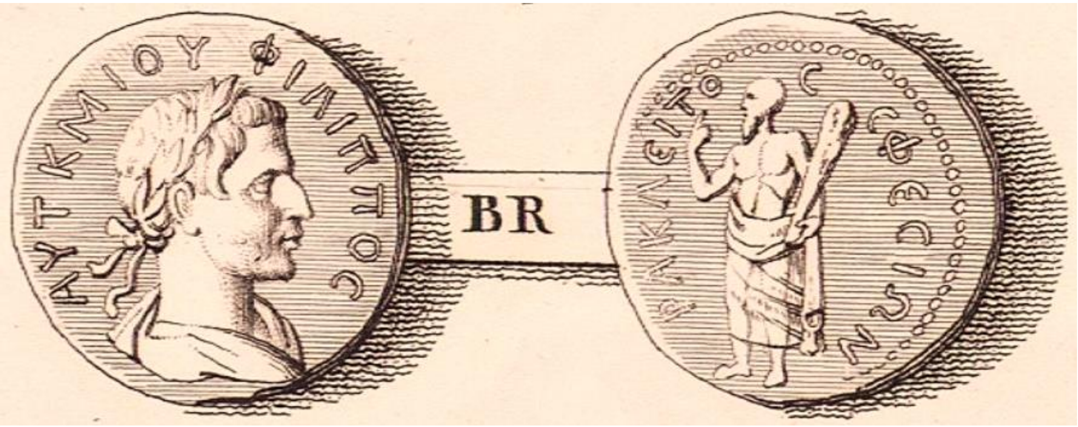
Hippocrates (460 – 370 BC)
Image source: Visconti (1817)

See details in Koutsoyiannis and Mamassis (2021)

Hydrology is the science of change and randomness; Heraclitus described the nature of each in a few words

Heraclitus of Ephesus (535 – 475 BC) was another Ionic philosopher, father of dialectics.

He emphasized the **dominance of change and randomness in Nature**.



Heraclitus of Ephesus (535 –475 BC)
depicted in the back facet of a coin whose front facet shows Philip
Image source: Visconti (1817)

«Πάντα ῥεῖ»
“Everything flows”

(Heraclitus; quoted in Plato’s Cratylus, 339-340)

«Αἰών παῖς ἐστι παίζων πεσσεύων»
“Time is a child playing, throwing dice”

(Heraclitus; Fragment 52)

«Τὸ ἀντίξουν συμφέρον καὶ ἐκ τῶν διαφερόντων καλλίστην ἁρμονίαν καὶ πάντα κατ' ἔριν γίνεσθαι»
“Opposition unites, the finest harmony springs from difference, and all comes about by strife”
(Heraclitus, Fragment B 8)

Aristotle and the phase change of water

Aristotle (384 – 322 BC) taught mostly in Athens, but his theories were influenced by Ionic philosophers. They expand to all aspects of knowledge; in particular his treatise ***Meteorologica*** **offers a great contribution to the explanation of hydrometeorological phenomena**:

«ἔτι δ’ ἡ ὑπὸ τοῦ ἡλίου ἀναγωγὴ τοῦ ὑγροῦ ὁμοία τοῖς θερμαινομένοις ἐστὶν ὕδασιν ὑπὸ πυρός» (Μετεωρολογικά, Β2)

“the sun causes the moisture to rise; this is similar to what happens when water is heated by fire” (Meteorologica, II.2, 355a 15)

Aristotle (384 – 322 BC)
Image source: Visconti (1817)

«συνίσταται πάλιν ἡ ἀτμὶς ψυχομένη διά τε τὴν ἀπόλειψιν τοῦ θερμοῦ καὶ τὸν τόπον, καὶ γίγνεται ὕδωρ ἐξ ἀέρος· γενόμενον δὲ πάλιν φέρεται πρὸς τὴν γῆν. ἔστι δ’ ἡ μὲν ἐξ ὕδατος ἀναθυμίασις ἀτμίς, ἡ δ’ ἐξ ἀέρος εἰς ὕδωρ νέφος»

“the vapour that is cooled, for lack of heat in the area where it lies, condenses and turns from air into water; and after the water has formed in this way it falls down again to the earth; the exhalation of water is vapour; air condensing into water is cloud” (ibid., I.9, 346b 30).

Aristotle and mass conservation

Aristotle recognized **the principle of mass conservation** within the hydrological cycle:

«ὥστε [τὴν θάλατταν] *οὐδέποτε ξηρανεῖται· πάλιν γὰρ ἐκεῖνο φθήσεται καταβὰν εἰς τὴν αὐτὴν τὸ προανελθόν».*

"Thus, [the sea] *will never dry up; for* [the water] *that has gone up beforehand will return to it"* (ibid., II.3, 356b 26).

«κἂν μὴ κατ' ἐνιαυτὸν ἀποδιδῷ καὶ καθ' ἑκάστην ὁμοίως χώραν, ἀλλ' ἔν γέ τισιν τεταγμένοις χρόνοις ἀποδίδωσι πᾶν τὸ ληφθέν».

"Even if the same amount does not come back every year or in a given place, yet in a certain period all quantity that has been abstracted is returned" (ibid., II.2, 355a 26).

Aristotle and Change

Aristotle penetrated into the concept of *change*. He was fully aware that the landscape changes through the ages and that **rivers are formed and disappear in the course of time**:

«ἀλλὰ μὴν εἴπερ καὶ οἱ ποταμοὶ γίγνονται καὶ φθείρονται καὶ μὴ ἀεὶ οἱ αὐτοὶ τόποι τῆς γῆς ἔνυδροι, καὶ τὴν θάλατταν ἀνάγκη μεταβάλλειν ὁμοίως. τῆς δὲ θαλάττης τὰ μὲν ἀπολειπούσης τὰ δ' ἐπιούσης ἀεὶ φανερὸν ὅτι τῆς πάσης γῆς οὐκ ἀεὶ τὰ αὐτὰ τὰ μέν ἐστιν θάλαττα τὰ δ' ἤπειρος, ἀλλὰ μεταβάλλει τῷ χρόνῳ πάντα».

"But if rivers are formed and disappear and the same places were not always covered by water, the sea must change correspondingly. And if the sea is receding in one place and advancing in another it is clear that the same parts of the whole earth are not always either sea or land, but that all changes in course of time" (ibid., I.14, 353a 16).

Aristotle and experimentation

Aristotle also understood **by experiment that salt contained in water is not evaporated**:

«ὅτι δὲ γίγνεται ἀτμίζουσα πότιμος καὶ οὐκ εἰς θάλατταν συγκρίνεται τὸ ἀτμίζον, ὅταν συνιστῆται πάλιν, πεπειραμένοι λέγωμεν»

"Salt water when it turns into vapour becomes drinkable [freshwater] *and the vapour does not form salt water when it condenses again; **this I know by experiment**"* (ibid., II.3, 358b).

This has certainly found technological application in desalination (removal of salt from sea water), useful in a country with scarcity of fresh water and many shores and islands. Thus, we learn from a commentary on Aristotle's Meteorologica II, written by Olympiodorus (the peripatetic philosopher, 495 – 570 AD), that:

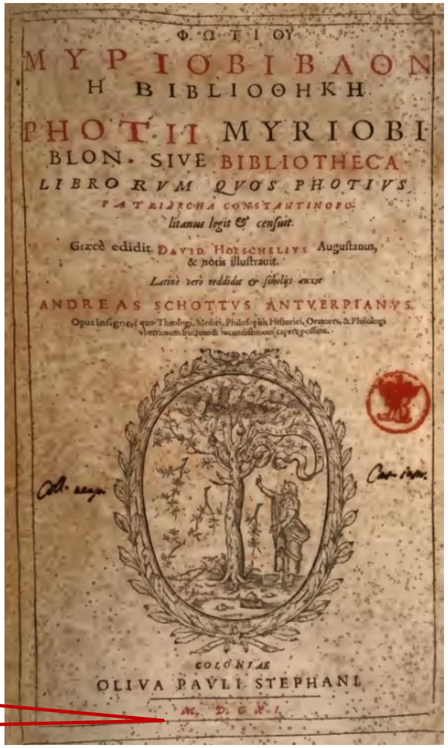
"Sailors, when they labour under a scarcity of fresh water at sea, boil the sea-water, and suspend large sponges from the mouth of a brazen vessel, to imbibe what is evaporated, and in drawing this off from the sponges, they find it to be sweet [fresh] *water"* (Morewood 1838; see also quotation by Alexander of Aphrodisias, peripatetic philosopher, fl. 200 AD, in Forbes, 1970).

Aristotle and the solution of the “Nile paradox”

Most of ancient Greek texts have been lost and information on them is indirectly obtained from references in other books.

An example is Patriarch Photius’s (c. 810/820 – 893) Myriobiblon or Biblioteheca, composed of 279 reviews of books which he had read. This book, perhaps **the first in history collection of book-reviews**, written in Greek, was printed in 1611 with Latin translation.

This gives important information about **Aristotle’s decisive contribution in solving the Nile paradox**.

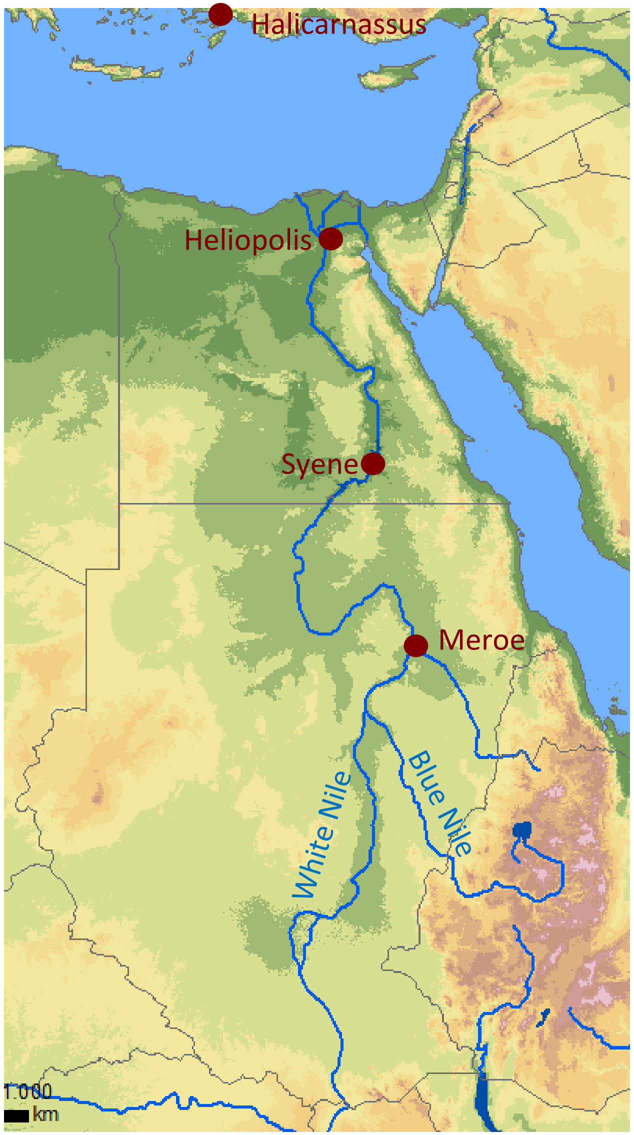


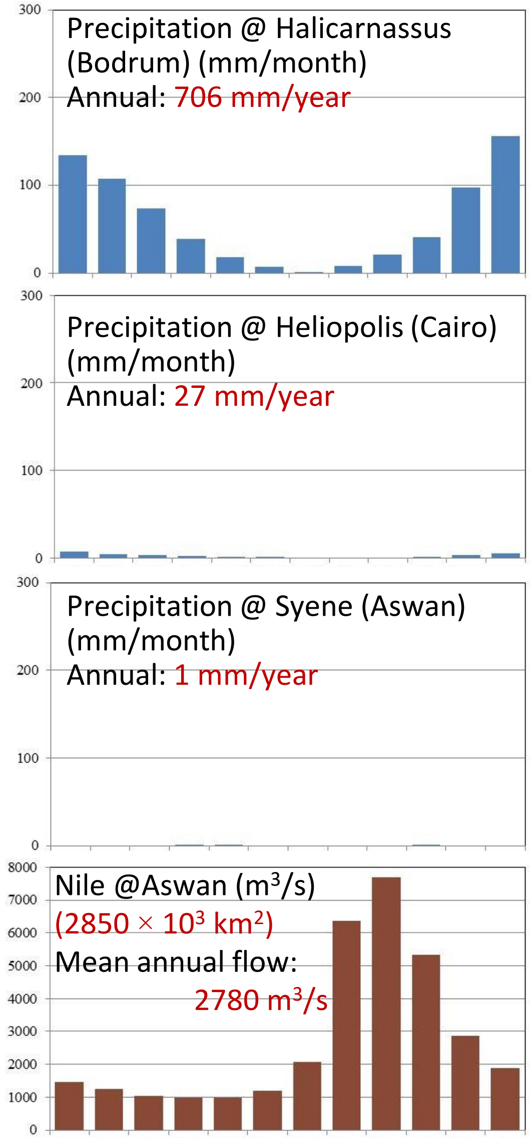
What was the Nile paradox?

The **first great problem related to a natural behaviour** and put in **scientific terms** was the **cause of the Nile floods**. Posed by **Thales**, it was debated for almost **three centuries** (Burstein, 1976).

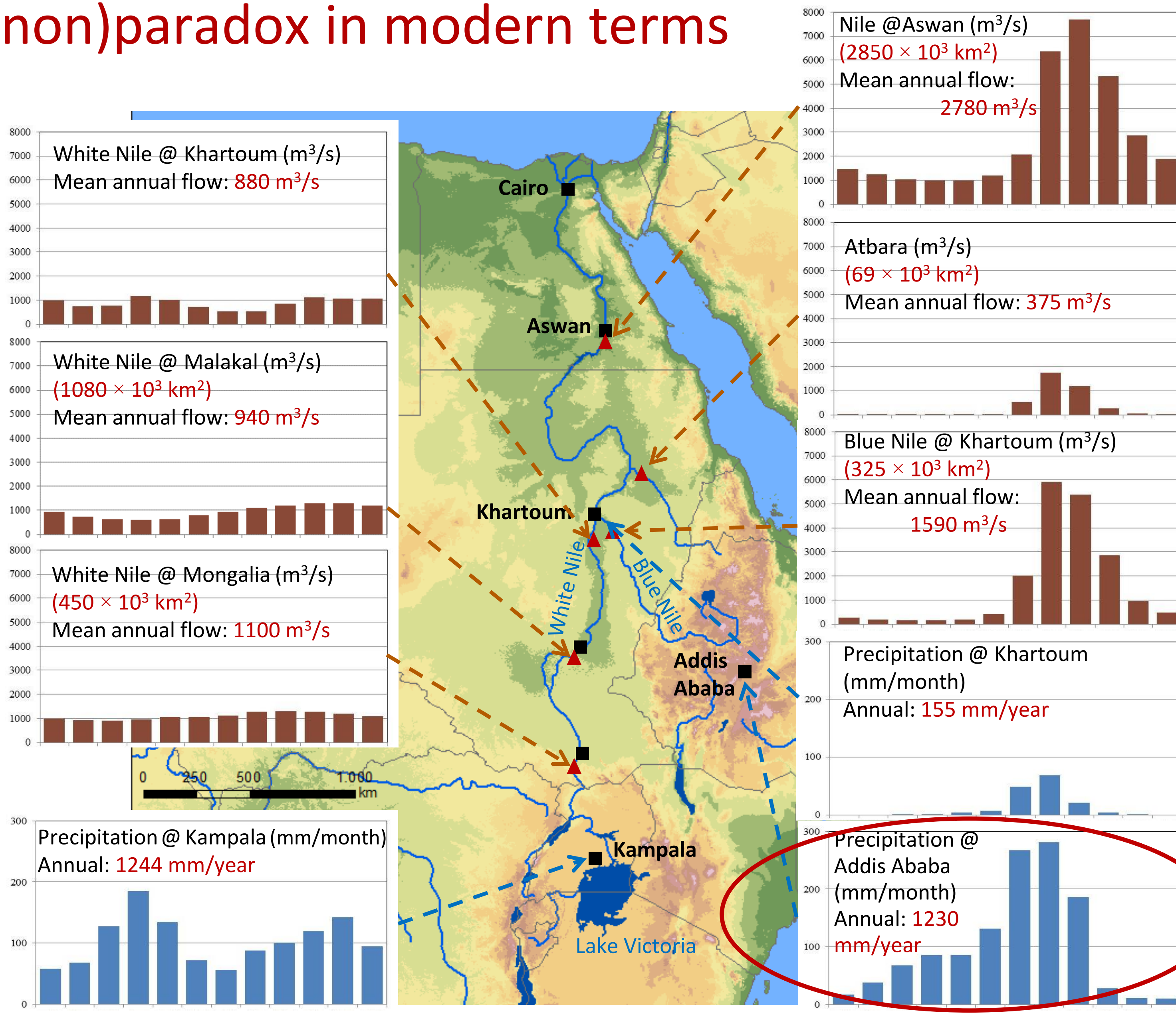
The historian **Herodotus** cites **four different hypotheses** up to his time (one of which is his own).

What puzzled Greek thinkers was the different hydrological regime compared to other Mediterranean rivers: the **Nile floods occur in summer rather than during winter**.





The Nile (non)paradox in modern terms



The solution of the paradox by Aristotle

«Ὅτι οἱ ἐτήσιαι πνέουσι κατὰ τὸν καιρὸν τοῦ ἀκμαιοτάτου θέρους δι΄ αἰτίαν τοιαύτην. Ὁ ἥλιος μετεωρότερος καὶ ἀπὸ τῶν μεσημβρινῶν τόπων ἀρκτικώτερος γινόμενος λύει τὰ ὑγρὰ τὰ ἐν ταῖς ἄρκτοις· λυόμενα δὲ ταῦτα ἐξαεροῦται, ἐξαερούμενα δὲ πνευματοῦται, καὶ ἐκ τούτων γίνονται οἱ ἐτήσιαι ἄνεμοι […]. Ἐκεῖ δὴ ταῦτα ἐκφερόμενα προσπίπτει τοῖς ὑψηλοτάτοις ὄρεσι τῆς Αἰθιοπίας, καὶ πολλὰ καὶ ἀθρόα γινόμενα ἀπεργάζεται ὑετούς· καὶ ἐκ τῶν ὑετῶν τούτων ὁ Νεῖλος πλημμυρεῖ τοῦ θέρους, ἀπὸ τῶν μεσημβρινῶν καὶ ξηρῶν τόπων ῥέων. Καὶ τοῦτο Ἀριστοτέλης ἐπραγματεύσατο· ***αὐτὸς γὰρ ἀπὸ τῆς φύσεως ἔργῳ κατενόησεν, ἀξιώσας πέμψαι Ἀλέξανδρον τὸν Μακεδόνα εἰς ἐκείνους τοὺς τόπους καὶ ὄψει τὴν αἰτίαν τῆς τοῦ Νείλου αὐξήσεως παραλαβεῖν. Διό φησιν ὡς τοῦτο οὐκέτι πρόβλημά ἐστιν· ὤφθη γὰρ φανερῶς ὅτι ἐξ ὑετῶν αὔξει.*** *Καὶ <λύεται> τὸ παράδοξον, <ὅτι> ἐν τοῖς ξηροτάτοις τόποις τῆς Αἰθιοπίας, ἐν οἷς οὔτε χειμὼν οὔτε ὕδωρ ἐστί, ξυμβαίνει τοῦ θέρους πλείστους ὑετοὺς γίνεσθαι»* (Ανώνυμος, Βίος Πυθαγόρου, στο Φωτίου, *Μυριόβιβλον*, Anon, https://el.wikisource.org/wiki/Μαρτυρίαι_(Αριστοτέλης).

“*The Etesian winds* [i.e., monsoons] *blow during the peak of the summer for this reason. The sun, at the zenith passing from south to north, disintegrates the moisture from the arctics and once this moisture is disintegrated, it evaporates and gives rise to monsoons* […] *When they reach the high mountains of Ethiopia and concentrate there, they produce rains. These rains in full summer cause the flood of the Nile and make it overflow, while it flows at the northern arid regions.* ***This was analysed by Aristotle, who, by the superiority of his mind, understood it. He demanded to send Alexander of Macedonia to these regions, and to find, by sight, the cause of the flooding of the Nile. That's why they say there is not a problem anymore.*** *It became apparent by sight that the flow is increased by these rains. And this solved the paradox that in the driest Ethiopian [i.e. African] places where there is no winter nor rain, it happens that in the summer strong rainfalls occur*” (Photios, *Bibliotheca*, Comments on Anonymus, *Life of Pythagoras,* http://remacle.org/bloodwolf/erudits/photius/pythagore.htm)

Aristotle, Alexander and the Hellenistic World

Aristotle, in addition to his many scholarly achievements, was tutor of **Alexander the Great**.

Alexander, during his campaign, in which he conquered big parts of Asia and Africa, was exchanging letters with his tutor (and his mother Olympias), addressing his as professor (καθηγητὴν).

The respect of the student to his mentor* resulted in the **first scientific expedition in history in order to confirm a scientific hypothesis**.

The Hellenistic period, which starts with the death of Alexander in 323 BC and ends with the emergence of the Roman Empire in 31 BC, is marked by the **wide dissemination of the Greek civilization and the flourishing of science**.

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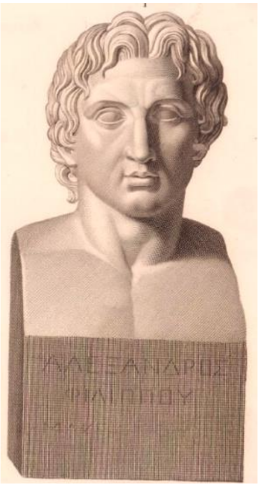
*Note that such respect is not the rule in history: Remarkable counterexample is the conspiration of Kolmogorov, Alexandrov and other students of Luzin, to convict their mentor likely to death—an attempt which was prevented by intervention of Kapitsa and ultimately by a decision of Stalin (Graham and Kantor, 2009).

Aristotle (384 – 322 BC)



Alexander of Macedonia / the Great (356–323 BC)

Source of images: Visconti (1817)

When was Aristotle’s theory accepted?

The **mythological views are more charming than scientific** and, hence, they continued to be popular **during the Roman times**. The Roman epicurean philosopher **Lucretius** (c. 99 – c. 55 BC) and the stoic philosopher **Seneca** (4 BC –65 AD), both of whom wrote about Nile, did not rely on Aristotle’s scientific explanation. Rather, they **were fascinated by the Nile for its mystery, not its demystification**. An excellent summary of the reasons is contained in the following quotation by Merrills (2017):

> *The metaphysical qualities of the Nile—a river that replicated each year the origins of the world, and which overspilled its banks even into the bathhouses and taverns of Pompeii—were essential to its resonance in the Roman world*.

The reference to Pompei encapsulates the archaeological evidence of sacred objects and iconographies for Nile and its waters.

And what about modern times? Were the mythical views abandoned after the first quantification of the hydrological cycle in the 17th century? This question is studied in detail in Koutsoyiannis and Mamassis (2021).

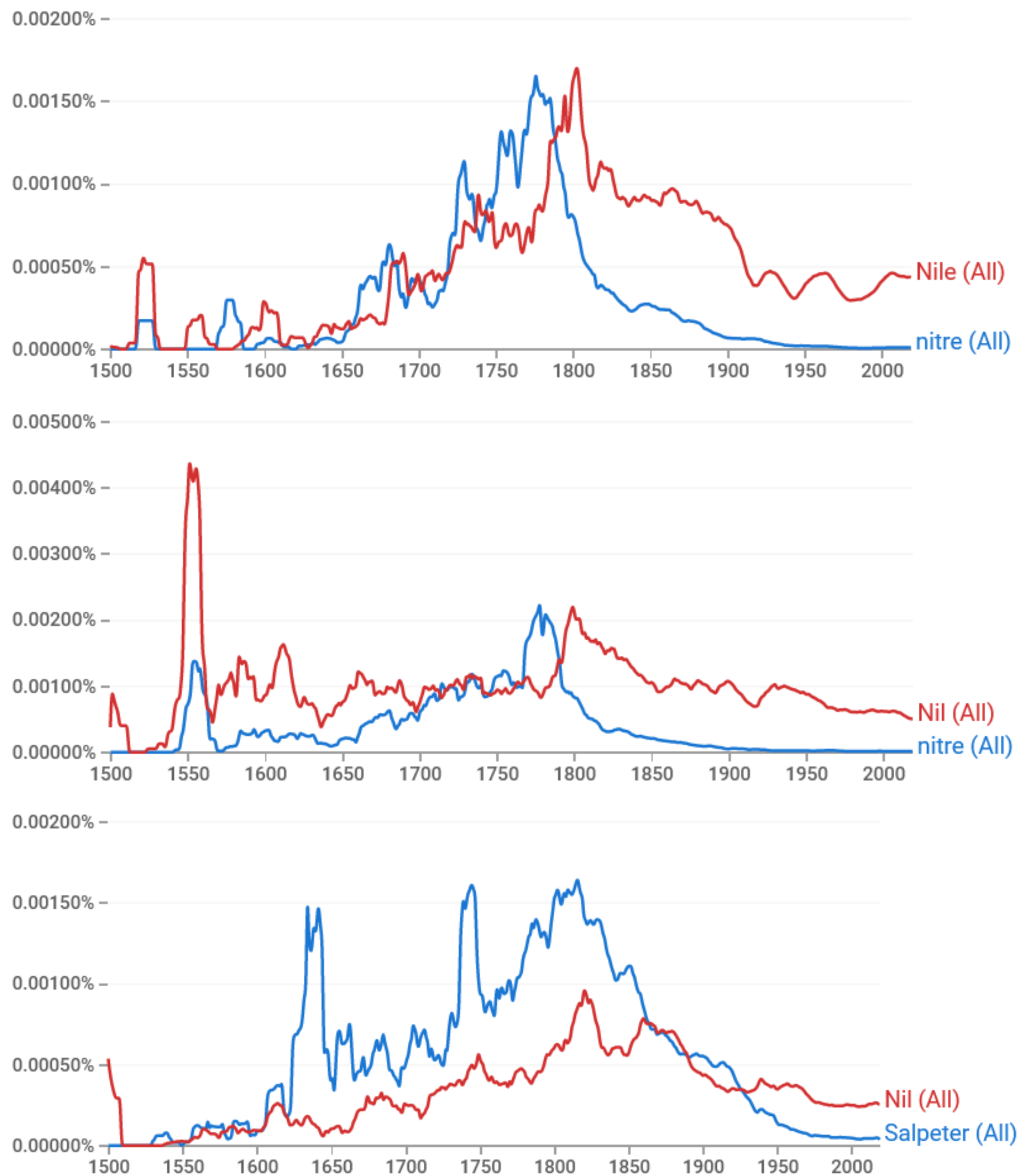
In brief, **the surprising answer is that a new mythology was developed around a “theory” of the “nitre” which was a mythical element that presumably caused the flooding of the Nile**, while rainfall in Ethiopia had a minor role, if any.

Why Aristotle's Nile theory was unpopular?

It took the visit to the origins of the Blue Nile of the Scottish traveller James Bruce and the publication of his book (Bruce, 1813) for the modern mythical theory to cease.

Question (food for thought):

Why Aristotle's incorrect geocentric system was so popular while his correct explanation of the Nile was unpopular?



Frequency of appearance of the indicated words in books hosted in the Google books platform in three languages: (upper) English; (middle) French; (lower) German.

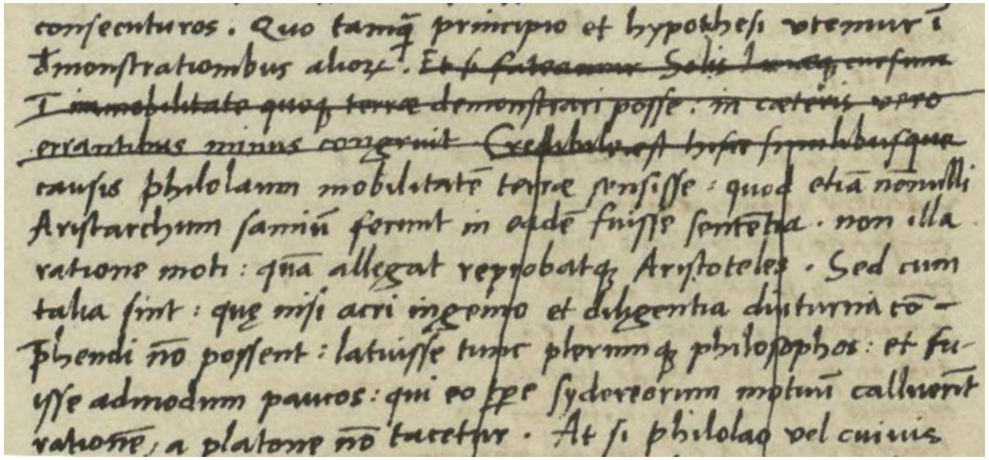
Source: Koutsoyiannis and Mamassis (2021)

Prominent scientists of the Hellenistic period: Aristarchus

Aristarchus of Samos (310 – 230 BC; mathematician and astronomer), **introduced the heliocentric model for the solar system 1800 years before Copernicus**. He also said that the stars were distant suns and made calculations on the relative sizes of the Sun, Earth and Moon. Notably, before him also the Pythagorean philosopher Philolaus (470 – 385 BC) had moved the Earth from the center of the cosmos and made it a planet, but in Philolaus's system Earth does not orbit the Sun but rather a central fire.

Interestingly, **Copernicus in the manuscript of his book *De revolutionibus* included a citation to Philolaus and Aristarchus but he crossed it out before publication**. The point that was crossed out, translated in English (Gingerich, 1973, 1985), reads:

> […] *It is credible that for these and similar causes (and not because of the reasons that Aristotle mentions and rejects), Philolaus believed in the mobility of the Earth and some even say that Aristarchus of Samos was of that opinion. But since such things could not be comprehended except by a keen intellect and continuing diligence, Plato does not conceal the fact that there were very few philosophers in that time who mastered the study of celestial motions.*


consecuturos. Quo tamen principio et hypothesi utemur in
demonstrationibus aliorum. Et si fateamur Solis Lunaeque cursum
in immobilitate quoque terrae demonstrari posse, in caeteris vero
errantibus minus congruit. Credibile est hisce similibusque
causis Philolaum mobilitatem terrae sensisse: quod etiam nonnulli
Aristarchum Samium ferunt in eadem fuisse sententia. non illa
ratione moti: quam allegat reprobatque Aristoteles. Sed cum
talia sint: quae nisi acri ingenio et diligentia diuturna com-
prehendi non possent: latuisse tunc plerosque philosophos: et fu-
isse admodum paucos: qui eo tempore syderorum motuum calluerint
rationem, a Platone non tacetur. At si Philolao vel cuivis

Part of page 22 of Book 1 of Copernicus's manuscript showing the references to Philolaus, Aristarchus and the Greek cosmology, which he crossed out before publication of his book De revolutionibus

Source: http://copernicus.torun.pl/en/archives/De_revolutionibus/1/?view=gallery&file=1&page=22

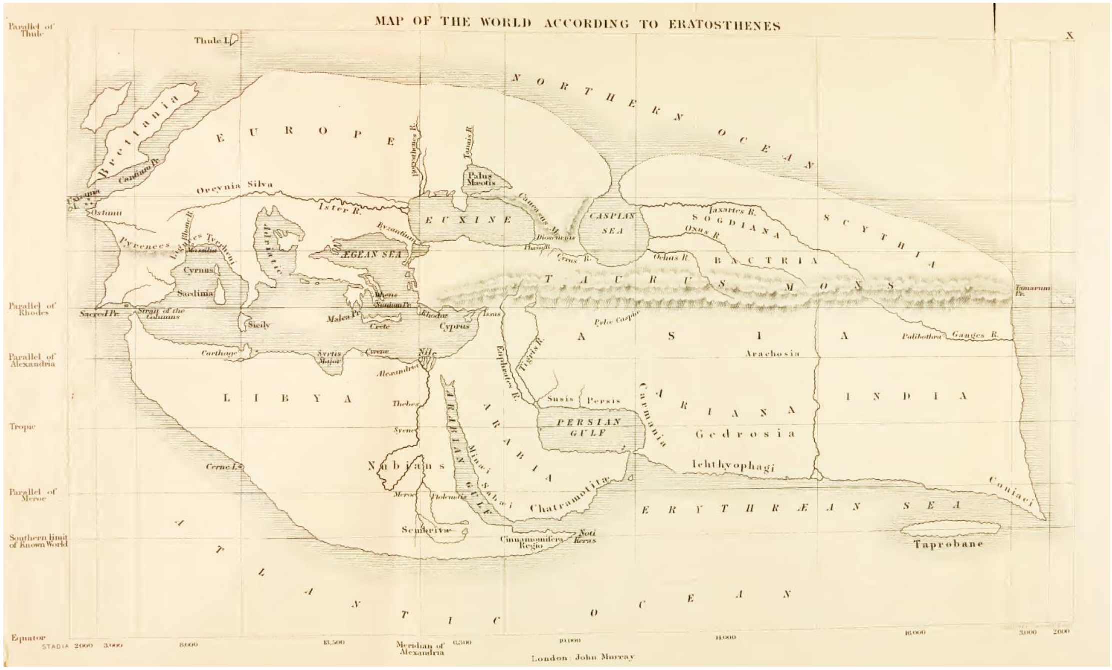
Prominent scientists of the Hellenistic period: Eratosthenes

Eratosthenes (276 – 195 BC; head of the Library at Alexandria, following the windings of the Nile, calculated the distances between several points on the Nile up to Meroe (Strabo, Geography, 17.1.2; Rawlins, 1982). Perhaps because of this, he is often credited by several authors for solving the paradox of the Nile.

However, in view of the information provided here (in particular by Proclus), his achievement seems to be no more than a further verification of Aristotle’s theory. He also seems to have been aware of the earlier expedition to the Nile sources for the purpose of proving Aristotle's theory (Burstein, 1976).

One of his biggest achievements was to **calculate, with remarkable accuracy (<2.5%), the Earth’s circumference** by measuring, at the noon of the day of summer solstice, the shadow cast by a gnomon at Alexandria and the distance between and Alexandria and Syene, where the latter is situated close to the Tropic of Cancer.

Despite the advancements in geography during the Hellenistic period, the achieved geographical representation of the Earth was rather poor.



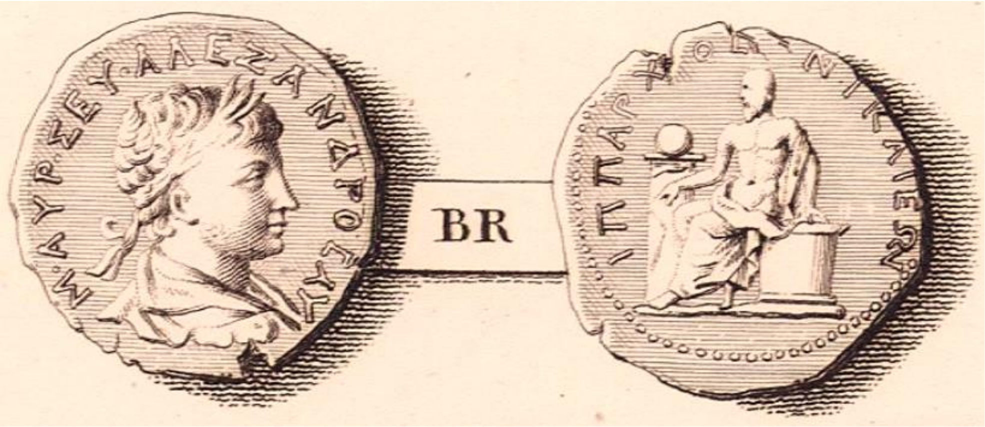
Map of the World according to Eratosthenes
Reproduced by Rhys (1912)

Prominent scientists of the Hellenistic period: Hipparchus

Hipparchus, the Greek astronomer, geographer and mathematician, and founder of trigonometry **introduced the term climate** (κλίμα, pl. κλίματα). Its etymology from the verb κλίνειν (= to incline) expresses the dependence of climate on the seasonal pattern of inclination angles of the incoming sunbeams.

Note that the **notion of climate had been studied earlier by Aristotle, who used another term, crasis** (κρᾶσις = mixture, blend) (see also Koutsoyiannis, 2021,2022).

Perhaps Hipparchus's most remarkable achievement is the **discovery of the precession of the equinoxes, one of the cycles in Earth's motion, with period of about 21 000 years, that determine the long-term changes of the climate. This constitutes one of the several now called Milankovitch cycles.**



Hipparchus of Nicaea (190 – 120 BC), depicted in the back facet of a coin whose front facet shows the Roman emperor Severus Alexander (M. ΑΥΡ. ΣΕΥ. ΑΛΕΞΑΝΔΡΟΣ ΑΥ = Marcus Aurelius Alexandros Augustus)
Image source: Visconti (1817)

Prominent scientists of the Hellenistic period: Archimedes

Archimedes (287 – 212 BC) was the leading scientist (mathematician, physicist, engineer, inventor and astronomer) of the Hellenistic world, and is regarded to be perhaps the greatest mathematician of all time. While Aristarchus's heliocentric system was contrary to "consensus theory" for 1800 years, it is important to notice that it was adopted by Archimedes. In fact, he provides the most precious information about Aristarchus's ideas:

> *It is hypothesized* [by Aristarchus of Samos] *that the fixed stars and the Sun remain unmoved and the Earth revolves about the Sun in the circumference of a circle, with the Sun lying in the middle of the orbit and the sphere of the fixed stars, situated about the same centre as the Sun, is so great that the circle in which the Earth is hypothesized to revolve, bears such a proportion to the distance of the fixed stars as the centre of the sphere bears to its surface* (Archimedes, The Sand Reckoner).

It is well known that Archimedes offered several **important contributions in mathematics, including the concept of infinitesimals and a first version of integral calculus**. From the hydrological perspective, important is the principle named after him and the **foundation of hydrostatics**. From his inventions most relevant to hydrology is **Archimedes' screw, which is still in wide use for pumping**.

The Fields Medal (regarded as the highest honour for mathematicians) depicts Archimedes. The head of Archimedes in the medal is synthesized by the imagination of the artist (Tropp, 1976), as there is no original sign about it, neither in sculpture nor in coins

Image source: https://en.wikipedia.org/wiki/Fields_Medal

Prominent scientists of the Hellenistic period: Heron

The scientist of the Hellenistic period with the greatest contribution to hydrology is **Heron (Hero) of Alexandria** (mathematician and engineer who most likely lived in the 1st century BC or the 1st AD; see Woodcroft, 1851). He studied the notion of pressure and pneumatics and invented a steam machine. He introduced the term hydraulic (organ) for a musical instrument operated by hydraulics (ὑδραυλικὸν ὄργανον), which he describes in his book Pneumatica (Πνευματικὰ; Schmidt, 1899, p. 192, "Ὑδραυλικοῦ ὀργάνου κατασκευὴ"; Woodcroft, 1851, p. 105). **His contribution to hydrology is that he introduced the concept of discharge and its measurement**. Here is the relevant passage from his book Dioptra (Διόπτρα):

Πηγῆς ὑπαρχούσης ἐπισκέψασθαι τὴν ἀπόρρυσιν αὐτῆς, τουτέστι τὴν ἀνάβλυσιν, ὅση ἐστίν. εἰδέναι μέντοι χρὴ ὅτι οὐκ ἀεὶ ἡ ἀνάβλυσις ἡ αὐτὴ διαμένει. ὄμβρων μὲν γὰρ ὄντων ἐπιτείνεται διὰ τὸ ἐπὶ τῶν ὀρῶν τὸ ὕδωρ πλεονάζον βιαιότερον ἐκθλίβεσθαι, αὐχμῶν δὲ ὄντων ἀπολήγει ἡ ῥύσις διὰ τὸ μὴ ἐπιφέρεσθαι πλέον ὕδωρ. αἱ μέντοι γενναῖαι πηγαὶ οὐ παρὰ πολὺ τὴν ἀνάβλυσιν ἴσχουσιν. δεῖ οὖν περιλαβόντα τὸ πᾶν τῆς πηγῆς ὕδωρ, ὥστε μηδαμόθεν ἀπορρεῖν, σωλῆνα τετράγωνον μολιβοῦν ποιῆσαι, στοχασάμενον μᾶλλον μείζονα πολλῷ τῆς ἀποθύσεως· εἶτα δι' ἑνὸς τόπου ἐναρμόσαι αὐτὸν ὥστε δι' αὐτοῦ τὸ ἐν τῇ πηγῇ ὕδωρ ἀπορρεῖν. δεῖ δὲ αὐτὸν κεῖσθαι εἰς τὸν ταπεινότερον τῆς πηγῆς τόπον, ὥστε ἔχειν αὐτὴν ἀπόρρυσιν. τὸν δὲ ταπεινότερον ἐπιγνωσόμεθα τῆς πηγῆς τόπον διὰ τῆς διόπτρας. ἀπολήψεται οὖν τὸ ἀπορρέον διὰ τοῦ σωλῆνος ὕδωρ ἐν τῷ περιστομίῳ τοῦ σωλῆνος· οἷον ἀπολαμβάνει[ν] δακτύλους β· ἐχέτω δὲ καὶ τὸ πλάτος τοῦ περιστομίου τοῦ σωλῆνος δακτύλους ς· ἑξάκις δύο γίνονται ιβ· <ἀποφανούμεθα δὴ τὴν ἀνάβλυσιν τῆς πηγῆς δακτύλων ιβ>. εἰδέναι δὲ χρὴ ὅτι οὐκ ἔστιν αὔταρκες πρὸς τὸ ἐπιγνῶναι, πόσον χορηγεῖ ὕδωρ ἡ πηγή, [ἢ] τὸ εὑρεῖν τὸν ὄγκον τοῦ ῥεύματος, ὃν λέγομεν εἶναι δακτύλων ιβ, ἀλλὰ καὶ τὸ τάχος αὐτοῦ· ταχυτέρας μὲν γὰρ οὔσης τῆς ῥύσεως πλέον ἐπιχορηγεῖ τὸ ὕδωρ, βραδυτέρας δὲ μεῖον. διὸ δεῖ ὑπὸ τὴν τῆς πηγῆς ῥύσιν ὀρύξαντα τάφρον τηρῆσαι ἐξ ἡλιακοῦ ὡροσκοπίου, ἐν τινὶ ὥρᾳ πόσον ἀπορρεῖ ὕδωρ ἐν τῇ τάφρῳ, καὶ οὕτως στοχάσασθαι τὸ ἐπιχορηγούμενον ὕδωρ ἐν τῇ ἡμέρᾳ πόσον ἐστὶν, ὥστ᾽ οὐδὲ ἀναγκαῖόν ἐστι τὸν ὄγκον τῆς ῥύσεως τηρεῖν· διὰ γὰρ τοῦ χρόνου δήλη ἐστὶν ἡ χορηγία. (Ἥρων ο Αλεξανδρεύς, Διόπτρα, Schoenne, 1976)

Prominent scientists of the Hellenistic period: Heron (2)

Translation of the Greek text:

Given a spring, to determine its flow, that is, the quantity of water which it delivers. One must, however, note that the flow does not always remain the same. Thus, when there are rains the flow is increased, for the water on the hills being in excess is more violently squeezed out. But in times of dryness the flow subsides because no additional supply of water comes to the spring. In the case of the best springs, however, the amount of flow does not contract very much. Now it is necessary to block in all the water of the spring so that none of it runs of at any point, and to construct a lead pipe of rectangular cross section. Care should be taken to make the dimensions of the pipe considerably greater than those of the stream of water. The pipe should then be inserted at a place such that the water in the spring will flow out through it. That is, the pipe should be placed at a point below the spring so that it will receive the entire low of water. Such a place below the spring will be determined by means of the dioptra. Now the water that flows through the pipe will cover a portion of the cross-section of the pipe at its mouth. Let this portion be, for example, 2 digits [in height]. *Now suppose that the width of the opening of the pipe is 6 digits. 6 × 2=12. Thus, the flow of the spring is 12* [square] *digits. It is to be noted that in order to know how much water the spring supplies it does not suffice to find the arca of the cross section of the flow which in this case we say is 12 square digits. It is necessary also to find the speed of flow, for the swifter is the flow, the more water the spring supplies, and the slower it is, the less. One should therefore dig a reservoir under the stream and note with the help of a sundial how much water flows into the reservoir in a given time, and thus calculate how much will flow in a day. It is therefore unnecessary to measure the arca of the cross section of the stream. For the amount of water delivered will be clear from the measure of the time.* (Hero, Dioptra, 31, English translation by Cohen, 1958)

Recapitulation and relevance to modern science

1. **Posing scientific questions** (e.g., the Nile paradox) **and seeking scientific explanations** was a crucial historical development, which did not prevail in earlier civilizations, as exemplified by Herodotus's contrast between Greek philosophers and Ancient Egyptian intellectuals (and priests).
2. Science and philosophy were not only invented but also defined, with their meaning clarified to be the **genuine pursuit of truth, independently of other (e.g. economic) interests**.
3. **Science, then called natural philosophy, was developed as part of philosophy**, with other parts thereof, i.e., metaphysics, epistemology, logic and axiology (ethics, aesthetics), being equally developed.
4. The development of (Aristotelian) **logic** offered a powerful instrument for science to distinguish sense from nonsense as well as deduction from induction, and the relative validity of the inference based on each of these two methods.
5. The gradual development of the **scientific method,** which constitutes part of philosophy, by incorporation of observation, experience and, at a later stage, experiment, provided a solid foundation of science.
6. Central in Ancient Greek thought was **reasoning as the main tool for the search for truth**. By no means does this imply that the philosophers of Ancient Greece tended to distrust observations, as incorrectly asserted by some modern scholars (where samples are given in the Introduction). Obviously, if this happened, it would contradict reasoning per se (it is totally unreasonable to dismiss observations).

Recapitulation and relevance to modern science (2)

7. **Clarity (σαφήνεια)** was also a desideratum so strong that Aristotle identified it with truth. This is also related to the accurate accounting of the phenomena and the attainment of accurate scientific knowledge (Lesher, 2010). The introduction of terminology, i.e., of sophisticated terms whose meaning may not be identical to the colloquial one, and their definitions, is another reflection of the clarity desideratum.
8. Formulation of a **plurality of ideas** by different scholars, as well as their **debate**, were vital for the development of science. It is clear from the quotations given above that Ancient Greek scholars cite and discuss each other's ideas and theories, mostly with proper respect and sometimes with moderate irony. Thanks to these discussions, today we are aware of opinions of philosophers whose original works are totally lost.
9. The **plurality of ideas and diversity of opinions**, some of which necessarily were better than other, resulted in an evolutionary process which in turn enabled **scientific progress**. It appears that such recently promoted ideas as that of a "settled science" did not have a place in the ancient environment of scientific inquiry.
10. An important development that expedited scientific progress was the **creation of Philosophical Schools**, functioning as centres of higher-level education and research, similar to modern universities. Plato's Academy, Aristotle's Lyceum (or Peripatetic School), Epicurus's Kepos (meaning garden), Zeno's Stoa (meaning arcade) were some of the most famous. After nine centuries of continuous operation, they were massively closed in 529 AD by an infamous emperor Justinian's edict, which marked a societal paradigm shift and a millennium-long regression in scientific inquiry.

Recapitulation and relevance to modern science (3)

11. The **communication of ideas among philosophers and to the public was organized in the form of books**. Within this practice, a writing style or code was developed, characterized by critical literature review and expression of own thoughts, using a sophisticated language. This writing style is more or less followed even in present day, as can be inferred by inspecting several extracts from Ancient Greek texts given above.
12. According to Plato and Aristotle the motivation of philosophers is their curiosity to explain Nature, but according to Herodotus, it is their ambition to achieve reputation for wisdom. Noting that even this latter does not look an unethical incentive, we may assert that the **development of science complies with the development of axiology and of ethical values, including the promotion of the truth as an ethical value and the modesty of those seeking it**. **Even the term *philosophy* (*φιλοσοφία*) reflects this modesty**. Notably, the term *philosopher* (*φιλόσοφος*) replaced the earlier term *sophos* (*σοφός*, translated in English as *sage* or *wise*, as in the expression "Seven Sages"). According to an Heraclitian aphorism, *wise is only one* (*ἓν τὸ σοφὸν*, meaning something supernatural, i.e. God) and henceforth Pythagoras introduced the term *philosopher*, meaning *lover* (or *friend*) of *wisdom* (*φίλος σοφίας*). This is clarified in the following quotation:

Φιλοσοφίαν δὲ πρῶτος ὠνόμασε Πυθαγόρας καὶ ἑαυτὸν φιλόσοφον […]· *μηδένα γὰρ εἶναι σοφὸν [ἄνθρωπον] ἀλλ' ἢ θεόν* (Διογένης Λαέρτιος, *Βίοι καὶ γνῶμαι τῶν ἐν φιλοσοφίᾳ εὐδοκιμησάντων*, Α.12).

Pythagoras was the first to name it philosophy and himself a philosopher […] *for no man is wise, but God alone.* (Diogenes Laertius, Lives of the Philosophers, 1.12)

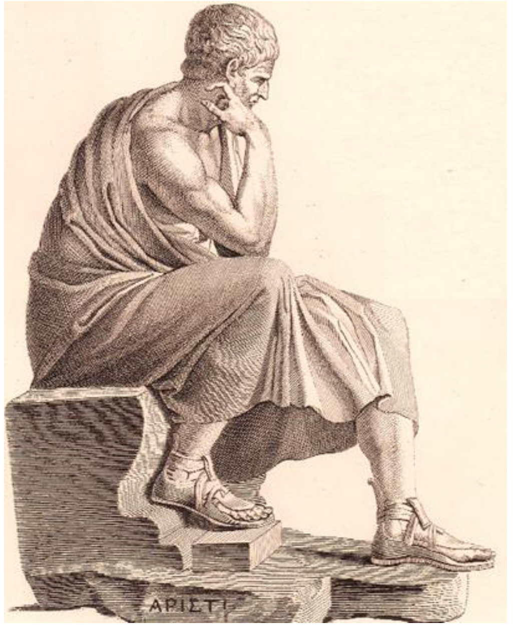
Is modern science consistent with ancient wisdom?

- Modern western societies dislike diversity of opinion and push toward shaping consensus doctrines.
- Adherence to doctrines is preferred over original thinking and scientific enquiry.
- Research funding is directed to what interests political and economic elites.
- Scientific debate on sensitive issues is strongly discouraged and freedom of opinion and expression is suppressed.
- Recycling of stereotypes (e.g. about climate change and sustainable development, which are reiterated in most scientific papers and conferences) has replaced novelty, and this does not lead to progress.
- All these are contrary to the lessons learned from ancient Greeks, who put the emphasis on freedom and unconditional pursuit of truth, and also developed the notion of democracy, which is severely abused in modern societies.
- At the same time, all these are clear signs of substantial decadence of western civilization, with a full collapse being a likely possibility.

Back to Aristotle: importance of seeking the truth

«φίλος μέν Σωκράτης, ἀλλά φιλτάτη ή ἀλήθεια»
(Latin version: “*Amicus Socrates, sed magis amica veritas*”)

“*Socrates is dear* (friend)*, but truth is dearest*” (Ammonius, Life of Aristotle)



Aristotle (384 – 322 BC)
Image source: Visconti (1817)

«δόξειε δ᾽ ἂν ἴσως βέλτιον εἶναι καὶ δεῖν ἐπὶ σωτηρίᾳ γε τῆς ἀληθείας καὶ τὰ οἰκεῖα ἀναιρεῖν, ἄλλως τε καὶ φιλοσόφους ὄντας: ἀμφοῖν γὰρ ὄντοιν φίλοιν ὅσιον προτιμᾶν τὴν ἀλήθειαν»

“*Still perhaps it would appear desirable, and indeed it would seem to be obligatory, especially for a philosopher, to sacrifice even one’s closest personal ties in defense of the truth. Both are dear to us, yet it is our duty to prefer the truth*” (Aristotle, Nicomachean Ethics 1096a11).

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