Some Historical Remarks on the General Circulation

"Science is done by humans." (starting sentence in Werner Heisenberg's autobiography).

"... at any given time, the most active scientists and technicians – in the rush of new discoveries and inventions, or their sturdy adherence to old methods or their own convictions – will never be sufficiently aware of their one-sidedness. The only possible, but by no means reliable, remedy would be to try to learn from history." (Bergeron, 1959).

Galilei & Kepler (around 1600): absolute eastward motion of the fluid (atmosphere or ocean) independent of latitude → westward (easterly) relative motion near the Equator, eastward (westerly) relative motion in higher latitudes; to both Galilei and Kepler the trade winds were a proof that the Earth rotated

from Persson (2008)

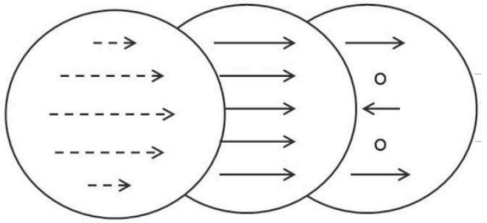
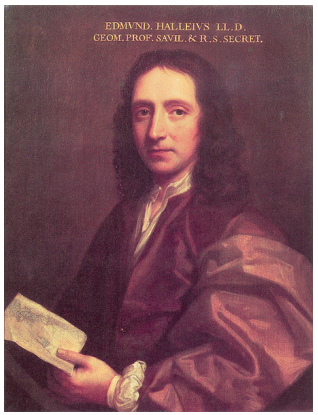


Figure 1. Galileo and Kepler's explanation of the general circulation and, in particular, the easterly Trade Winds. While the velocity of the Earth's surface decreased from the equator (left), the eastward absolute motion of air or water was supposed to be independent of latitude (centre), which would make the flow 'go ahead' at higher latitudes and lag behind around the equator with weak winds in between (right).

Certain Obſervations of the Midland Salt-Springs *of* Worceſter-ſhire, Staford-ſhire *and* Cheſhire.
Of the Crude *Salt, which grows from the* Stone-powder *depoſited by the ſaid* Brines *in Boyling. Of the* Specifick *difference betwixt* Sea *Salt and* Common *Salt.*
A way (*which ſeems to be the true method of Nature*) *of* Diſtilling Sweet *and* Freſh *Water from* Sea *Water, by the* Breath *of* Sea Plants *growing on it.*
That this Breath *probably is the* Material *Cauſe of the* Trade or Tropick Winds. *In a Letter to the Publiſher from the learned* Martin Lifter *Dr. of* Phyſick *of the Univerſity of* Oxon.

Among the known *Sea Plants* the *Sargoſſe* or *Lenticula Marina*, is not to be forgot; this grows in vaſt quantities from 36 to 18 *Degrees Northern Latitude*, and elſewhere upon the deepeſt Seas. And I think (to ſay ſomething by the by of that great *Phenomenon* of the *Winds*) from the daily and conſtant breath of that *Plant*, the *Trade* or *Tropic Winds* do in great part ariſe: becauſe the matter of that *Wind*, coming (as we ſuppoſe) from the breath of only one *Plant*, it muſt needs make it conſtant and uniform: Whereas the great variety of *Plants* and *Trees* at Land muſt needs furniſh a confuſed matter of *Winds*: Again the *Levant Breezes* are briskeſt about *Noon*, the *Sun* quickning the *Plant* moſt then, cauſing it to *breath* faſter, and more vigorouſly; and that *Plants* moſtly languiſh in the *night* is evident from many of them, which contract themſelves and cloſe at that time; alſo from the effects of our *Winters* upon them, which cauſe them to caſt both fruit and leaves too; whereas they are ſaid (the ſame *Plants* for kind) univerſally to flouriſh all the year alike within the *Tropicks*.
As for the *direction* of this *Breeze* from *Eaſt* to *Weſt*, it may be owing to the *General current* of the *Sea*, for a gentle *Air* will ſtill be lead with the *ſtream* of our *Rivers*, for example. Again every *Plant* is in ſome meaſure an *Heliotrop*, and bends it ſelf, and moves after the *Sun*, and conſequently emits its vapours thitherward, and ſo its *direction* is in that reſpect alſo owing in ſome meaſure to the *Courſe* of the *Sun*.

An Hiſtorical Account of the Trade Winds, *and* Monſoons, *obſervable in the Seas between and near the* Tropicks, *with an attempt to aſſign the Phiſical cauſe of the ſaid Winds, by* E. Halley.

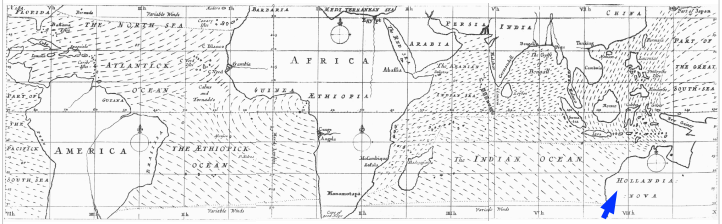


Edmund Halley
(1656–1742), picture around 1687

An Historical Account of the Trade Winds, and Monsoons, observable in the Seas between and near the Tropicks, with an attempt to assign the Physical cause of the said Winds. Philos. Trans. (1686)

Historical side note: Halley was in contact with Newton and convinced him to publish his Principia, which appeared just one year after his trade wind paper, in 1687!

Map from Halley's 1686 paper



"New Holland"

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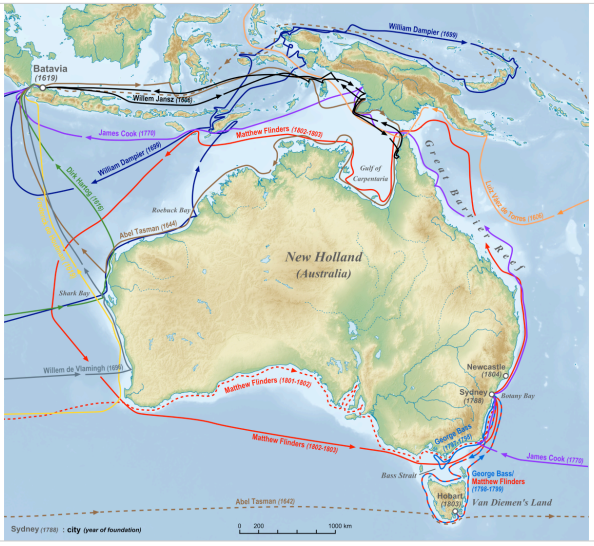
Mercator, 1587, Terra Australis Incognita - "unknown land of the South"



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Halley (1686): solar heating as the driving force behind the trade winds

- causes air to rise near the Equator
- this air has to be replaced from the subtropics
- flow is "pulled" westward by diurnal movement of sun

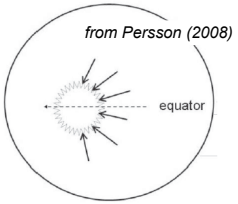
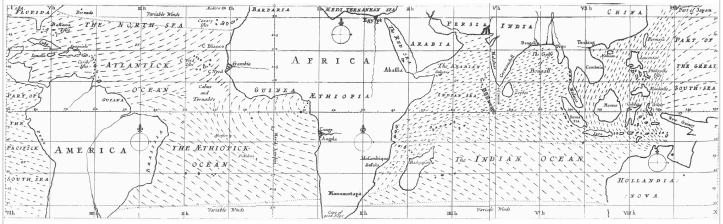


Figure 2. Halley's explanation of the easterly Trade Winds: as the maximum heating of the sun at the Earth's surface during the day moves westward, air will be sucked in from behind and replace the air that has been heated and risen.



George Hadley
(1685–1768)
Concerning the Cause of the General Trade-Winds. Philos. Trans. London (1735).

VI. *Concerning* the Cauſe *of the* General Trade-Winds: *By* Geo. Hadley, *Eſq;* F. R. S.

I Think the Cauſes of the General Trade-Winds have not been fully explained by any of thoſe who have wrote on that Subject, for want of more particularly and diſtinctly conſidering the Share the diurnal Motion of the Earth has in the Production of them: For although this has been [illegible] greater Length than I propoſe. From what has been ſaid it follows:

Crucial role of Earth's rotation

Firſt, That without the Aſſiſtance of the diurnal Motion of the Earth, Navigation, eſpecially Eaſterly and Weſterly, would be very tedious, and to make the whole Circuit of the Earth perhaps impracticable.

Global angular momentum conservation

Secondly, That the N. E. and S. E. Winds within the Tropicks muſt be compenſated by as much N. W. and S. W. in other Parts, and generally all Winds from any one Quarter muſt be compenſated by a contrary Wind ſome where or other; otherwiſe ſome Change muſt be produced in the Motion of the Earth round its Axis.

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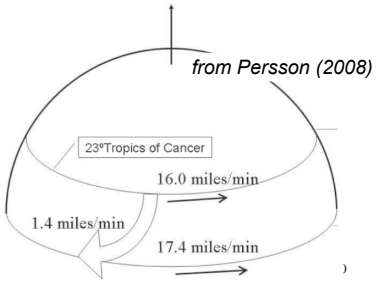
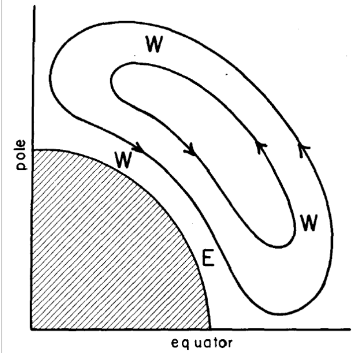
conservation of linear momentum → surface wind of ~40 m/s at the equator

friction slows down wind to observed speeds

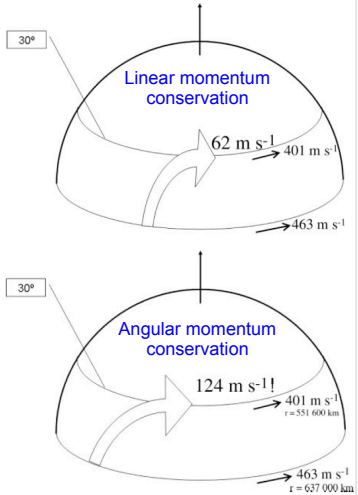
Conservation of angular momentum → ~70 m/s!!



General circulation as envisioned by Hadley



from Lorenz (1983)



from Persson (2009)

- Hadley's work remained largely unnoticed for decades
- Hadley's explanation of the trade winds was rediscovered several times:
  - Immanuel Kant in 1756
  - Pierre Simon de Laplace in 1775, 1796
  - John Dalton in 1793, who while his book was in print found out about Hadley's work and added a comment
  - Heinrich Dove in the 1830's, but later 'Dove-Hadley Principle'
- eventually Ferrel (1856, 1858), who brought in the full Coriolis effect

Dove, 1837: *…it must seem strange that since 1686, in which year Halley published his theory of the trade-winds, consequently for 150 years, not a step has been made towards a general solution of the question.* *from Persson (2009)*

Dalton, 1837:

Notice relative to the Theory of Winds

By John Dalton, D. C. L., F. R. S.

To Richard Taylor, Esq

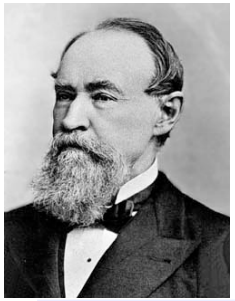
Dear Friend Manchester, Sept 5th 1837

I published a theory of the Trade Winds, &c, as Mr Dove has published, - it was forty-four years ago, as may be seen in my Meteorology, 1793 and 1834. It was first published by G. Hadley, Esq, in 1735, as I afterwards learnt. It is astonishing to find how the true theory should have stood out so long.

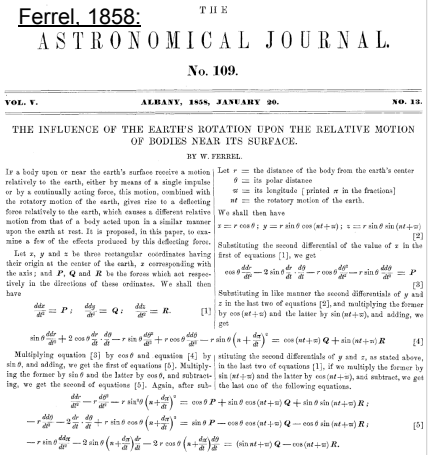
John Dalton

Dove, reply: *It is unnecessary in a scientific journal to mention what everybody already knows and no other theory than his can have been alluded to.*

William Ferrel
(1817–1891)
An essay on the winds and the currents of the ocean. Nashville Journal of Medicine and Surgery (1856).



Ferrel, 1858:



THE
ASTRONOMICAL JOURNAL.

No. 109.

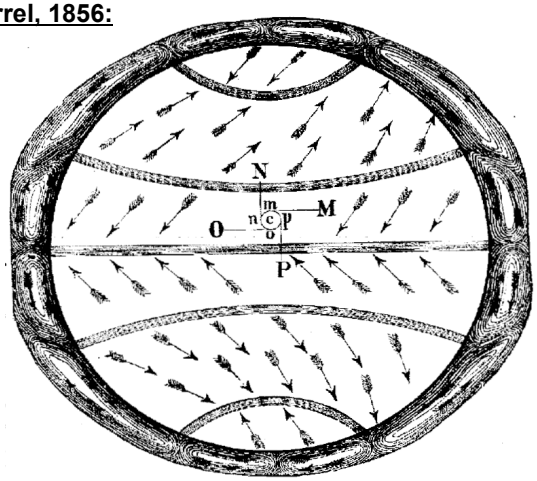
VOL. V. ALBANY, 1858, JANUARY 20. NO. 13.

THE INFLUENCE OF THE EARTH'S ROTATION UPON THE RELATIVE MOTION OF BODIES NEAR ITS SURFACE.

BY W. FERREL.

"If a body is moving in any direction, there is a force arising from the Earth's rotation, which always deflects it to the right in the northern hemisphere, and to the left in the southern hemisphere."

Ferrel, 1856:



From Hann-Süring (Lehrbuch der Meteorologie - "Textbook of Meteorology", 1926): (loosely translated)

"Ferrel's Theory … was first published at places and in such a form, that hampered its distribution and recognition. The mathematical form, in which it appeared, was not very comprehensible to most readers and likewise appeared uninviting to others, due to its lack of elegance."