**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)
- Halley (1686)
- Hadley (1735)
- Kant (1756)
- Laplace (1775, 1796)
- Dalton (1793, 1837)
- Dove (1830's)
- Ferrel (1856, 1858)
- Thomson (1857, 1892)

- Defant (1921)
- Jeffreys (1926)

- Modern Era: Rossby, Palmen, Charney, Eady, Phillips, Lorenz, Green (not naming anybody still alive)

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**Lorenz (1983):**

The prevailing ideas have evolved in a manner that appears to be far from random. Indeed, to a present-day dynamic meteorologist, an account of the development of these ideas is suggestive of a giant stepwise numerical integration, with time steps of half a century or longer. At the beginning of each step, certain ideas appear more or less as established facts in the standard texts, but are questioned by the avant-garde. Within each step there occurs a formulation of new theoretical ideas, an interval in which these ideas are rejected or simply ignored, an interval of fairly general acceptance, a more or less concurrent discovery of observational facts that contradict the new theory, an interval in which these observations are ignored or questioned, and a final acceptance of the new observations and a rejection of the theory by the new avant-garde. To many readers, our time steps will be more suggestive of innings.

**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)*

![Diagram](image)
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!
Wednesday AM, General Circulation History

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

George Hadley (1685–1768)
Crucial role of Earth's rotation
Global angular momentum conservation

VI. Concerning the Cause of the General Trade-Winds: By Geo. Hadley, Esqr. 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,

VII. From what has been said it follows:

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

Secondly, That the N.E. and S.E. Winds within the Tropics 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.

From Persson (2008)

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!!
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

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**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.

**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.

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**William Ferrel** (1817–1891)


**Ferrel, 1858:**

"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."
Wednesday AM, General Circulation History

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.”


“Hadley's theory in its main features ... must be substantially true, and must ... form the basis of any tenable theory that could be devised.”

The fundamental Flaw of Hadley’s Model

“In practice the motion of a mass of air through a large range of latitude, while retaining its original angular momentum about the axis of the Earth, can never arise.” (Brunt, 1934, 1944)

from Persson (2009)