Hadley's Principle:

Part 2 – Hadley rose to fame thanks to the Germans

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My theory has with Hadley's that in common, or rather borrowed from it, that the most important moment is the different rotation velocities at different latitudes… H. W. Dove (1837).

Résumé

Although the English meteorologist George Hadley (1685–1768) was the first to point out the importance of the Earth's rotation for the global atmospheric circulation, in particular the Trade Winds, other scientists, such as Maclaurin, Kant and Laplace, came to the same conclusion later in the eighteenth century, in most cases independently of Hadley. But it would be the Germans who during the first half of the nineteenth century would raise Hadley to fame.

John Dalton, the first to acknowledge Hadley

Among the increasing number of meteorological textbooks in the late eighteenth century was *Idées sur la météorologie*, by the Swiss scientist, Jean-André de Luc (1727–1817). He explained, in the same way as George Hadley, the prevalence of south-westerly and northeasterly winds as a consequence of the Earth's rotation:

> *If the air leaving the equator was calm there, i.e. if its movement is the same as the movement of the surface of the earth, when it arrives at our climate, and if it still has conserved a part of its movement in this sense; then it should go quicker than the surface of the earth in the same meaning being from west to east, and become south-west. The inverse cause changes for us to north-east the winds from north.* (de Luc, 1787.)

It is possible that de Luc, who was a frequent visitor to England, where he held influential contacts, had read or heard about Hadley's 1735 paper. He might also have read Laplace's 1775 articles or have come to think of the mechanism himself.[1] That was, at least, the opinion of another prominent scientist, the English chemist and natural philosopher, John Dalton (1766–1844) who credited de Luc as *the only person, as far as I know, who has suggested the idea of the Earth's rotation altering the direction of the wind,* (Dalton, 1793, 1834).[2]

Although Dalton's fame today rests on his atomic theory, he carried out a wide range of research. In 1787 he began keeping a meteorological journal which he continued all his life. In his 1793 book *Meteorological Observations and Essays* he outlined an explanation of how *the effect of the Earth's rotation to produce, or rather to accelerate, the relative velocity of winds, being as the difference, or more strictly, to the [sine] of the latitude… increase in approaching the poles.* He expressed his surprise and slight irritation that Halley's 1686 theory, in spite of being 'inadequate and immechanical', had become 'almost universally adapted' and could be found in 'several modern productions of great repute' (Dalton, 1793,1834). Only when Dalton's book was in its final stages did he find out that the Trade Winds 'had been explained on the very same principles and in the same manner' by his countryman George Hadley:

> *… On the other hand, G. Hadley Esq, published in a subsequent volume of said Transactions a rational and satisfactory explanation of the trade-winds; but where else shall we find it?*

Dalton's book seems to be the first where George Hadley became explicitly associated with the explanation of the Trade Winds, without being confused with his brother John Hadley or Edmond Halley. When Dalton re-issued his book in 1834 he changed little of its contents and in particular kept his critical comments about the lack of appreciation of Hadley's work.

A few years later, however, on a September day in 1837 when Dalton opened the newly arrived copy of *Philosophical Magazine* he found an article by a German meteorologist H. W. Dove, who in bombastic style, disregarding contributions from anybody else, claimed to have produced the original explanation of the Trade Winds.

Dove's 'Law of Turning'

Heinrich W. Dove (1804–1879), was only 18 years of age when he entered H. W. Brandes' institution at the University of Breslau (Wrocław) in 1822. Heinrich W. Brandes (1777–1834), often regarded as the father of synoptic meteorology, was aware of the role of the Earth's rotation and was close to discovering the geostrophic wind law (Brandes, 1820). In his 1820 textbook he correctly credited Hadley for his 1735 Trade Wind explanation and made clear that he had 'no doubt that this explanation is the right one'. (Brandes, 1820).

After a couple of years, Dove moved to the University of Königsberg to work as a 'Privatdozent'. It is here, in a contribution to the leading German scientific journal *Annalen der Physik,* he presented what would be known alternatively as 'Dove's Law of Turning', 'Dove's Wind Law' or 'The Law of Gyration' (Dove, 1827).

Based on a short series of observations in Königsberg, from 25 September to 6 October 1826, Dove inferred the existence of a 'law-bound', clockwise veering of the wind from east over south to west and then north (Figure1).

To support his theory Dove quoted previously published accounts of seamen, weather amateurs, renowned philosophers and scientists back to the ancient Greeks. According to Dove all wind systems were 'necessary and simple consequences of the same fundamental causes', the effect of the rotation of the Earth. In further papers in *Annalen* Dove explained not only the Trade Winds but also the monsoons and the

[1] A German professor W. A. E. Lampadius (1772–1842) at the University of Freiberg in Saxony acknowledged de Luc together with Immanuel Kant for formulating the basic law of the influence of the rotation of the Earth (Lampadius, 1806).

[2] The chapter reference to de Luc's book *Idées sur la météorologie* provided by Shaw (1926, p.290), based on Dalton (1793, 1843) is wrong.

RMetS Royal Meteorological Society

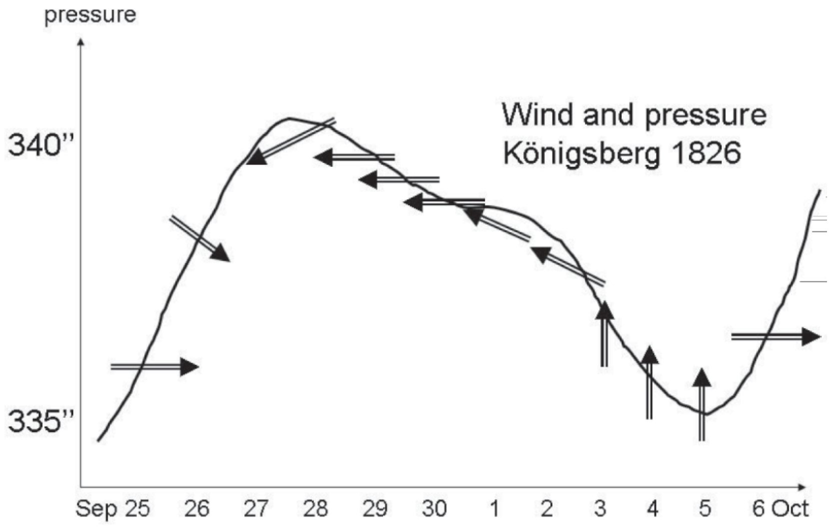

Figure 1. The wind and pressure evolution in Königsberg in the autumn of 1826 when H. W. Dove found his 'Wind Law' according to which the wind follows a clockwise veering. In modern terms the observations indicate at the start of the period northwesterly winds behind a passing low pressure system and the arrival of a high pressure system from west. During the last days of September and the first days of October a new low pressure system is approaching from Central Europe towards the Baltic Sea.

westerlies as consequences of the Earth's rotation (Dove, 1831; 1835).[3]

Dove imagined air parcels lined up in north–south direction. By some impetus they were brought into meridional motion. Air parcels closest to the observer would arrive first and have had least time to be affected by the Earth's rotation; those arriving from further away would have time to be more deflected. Air parcels arriving from the north would gradually arrive from an increasingly northeasterly direction, those from the south from an increasingly southwesterly direction. Air parcels furthest away would arrive as straight east/west winds respectively. This led Dove to postulate two major air flows, one warm southwesterly, one cold and northeasterly.[4] (Figure 2).

Dove's polemic with John Dalton

It was this article, translated from German into English, *The influence of the rotation of the Earth on the currents of its atmosphere; being outlines of a general theory of the winds,* (Dove, 1837a) that appeared in *Philosophical Magazine* in autumn 1837. The passage that upset Dalton most was:

> *…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 immediately wrote a letter to the editor-in-chief of *Philosophical Magazine* (Dalton, 1837) (see box below).

Dalton's letter was published in the next (October) issue of *Philosophical Magazine* and soon reached the editor of *Annalen der Physik* where it was immediately published.

Dalton's letter was followed by a long, rambling reply by Dove, where he wanted to justify himself (Dove, 1837b). He admitted that his explanation had in common with Hadley's, 'or rather borrowed from it', the mechanism of the different rotation velocities at different latitudes. The reason why he had never mentioned his name was, Dove explained, because Hadley was so well-known:

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

He then reminded the readers that neither Hadley nor Dalton's work nor that of

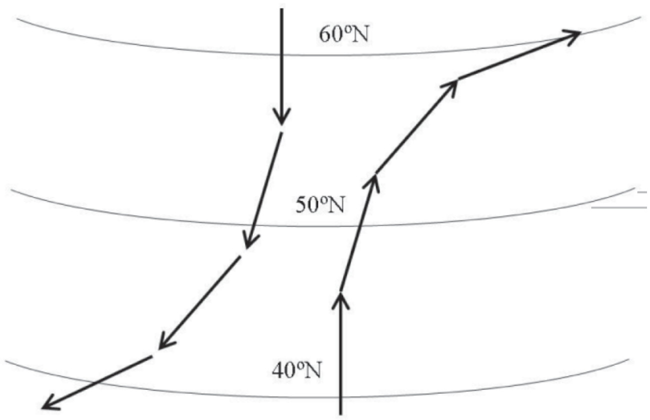

Figure 2. The mechanism of the mid-latitide atmospheric circulation according to H. W. Dove. Air initially moving straight south or north would be increasingly deflected, the air having the most distant origin becoming almost easterly or westerly.

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

[3] Kant's *Anmerkungen* and *Physikalische Geographie* were still available in Königsberg when Dove was at the university in 1825–1827. They contained all the ideas that Dove would promote so forcefully: the typical veering of the wind, the idea about two contesting air masses and the effect of the Earth's rotation. Dove would later claim that his theory was 'partly and briefly hinted at' by Immanuel Kant but denied direct influence (Dove, 1846).

[4] The notion of two contesting air masses is already suggested in an anonymous letter in *Transaction of the Royal Society* in 1735 on pages 519–546 discussing the 'cause of the winds', in a way that more or less pre-dated not only Dove but also the Bergen school frontal theory by almost 200 years.

anybody else, in contrast to his own, contained a 'turning law'. The article ends:

As I am convinced that I have never deliberately kept silent about what others have already published with respect to subjects I have investigated, so I believed I could avert the suspicion that I was seeking to appropriate the intellectual property of a man of such stature that was beyond the reach of my praise or criticism.

In the text Hadley's name was mentioned seven times and from now on Dove never failed to mention Hadley's name in connection with his own Law of Turning.

The 'Dove-Hadley Principle'

About this time, a collection of Dove's most important papers was prepared for the print. It now had an added chapter on the general circulation of the atmosphere with numerous references to Hadley (Dove, 1837c). In 1857 Dove mentioned Hadley several times in a talk to the Berlin Academy of Science and in a paper to the French Academy of Science (Dove, 1857). In his 1861 book *Gesetz der Stürme* (The Law of the Storms), Dove (1861, 1840) duly credited Hadley. Indeed, Dove championed Hadley's Principle so persistently that it gradually became known as the 'Hadley-Dove Principle'.

Dove who, by his contemporaries, was hailed as the 'greatest meteorologist of our time' and 'the Father of present day Meteorology' would, until his death in 1879, remain a dominant personality in European meteorology. He published more than 300 papers, not only in meteorology but also in experimental physics, especially optics and electromagnetism. Professor at the University in Berlin, lecturer at several civilian and military schools, a member of the Prussian Academy of Science and Director of the Prussian Meteorological Institute, he exerted a strong, sometimes dictatorial, influence on the meteorological debate.

Now when Hadley's Principle, or rather the Hadley-Dove Principle, was firmly established in the meteorological community and was applied to well-known phenomena, it started to show its limitations. Indeed, when in the mid-nineteenth century, it was finally realized that the rotation of the Earth exercised a profound influence on the general circulation of the atmosphere, Hadley's Principle came under increasing attacks from both theoretical and practical meteorologists.

Is there a 'Wind Law'?

When observations of the weather became more widely known it appeared that Dove's Law of Turning might have a rather trivial

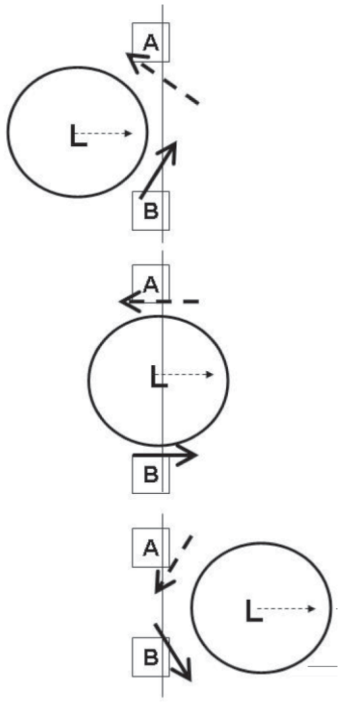

Figure 3. Dove's Wind Law only worked when low pressure systems moved eastward on a track north of the observation site (B). Since this is the case for most of the time for Europe, with the exception of the North Atlantic islands, the north of the British Isles and most of Scandinavia (A), Dove could mobilize considerable statistical evidence to support his hypothesis.

basis. Wasn't it just a reflection of the typical wind changes in the extra-tropical westerlies for locations south of the main cyclone track (Figure 3)? Indeed, it is no coincidence that contradictory evidence came first from the Scandinavian countries located in the middle or north of the storm track. A Danish professor, J F Schouw (1789–1852), who had published a book on the climate of Denmark, expressed doubts about the general validity of Dove's Wind Law. Dove started a vitriolic campaign against Schouw which lasted almost ten years and prompted the poor professor to submit a letter of complaint to *Annalen der Physik* about Dove's 'guerrilla war' (Schouw, 1833).

With the increase in weather observations it became possible to explore a newly discovered phenomenon, the relation between the wind and the pressure distribution. In particular, why did the winds not blow straight into low pressure systems and straight out of high pressure systems?

Buys Ballot's Rule, 1857

C.H.D. Buys Ballot (1817–1890), a Dutch physicist, had started as a devoted follower of Dove's concepts and in 1853 published a paper (in German) supporting Dove's Wind Law (Buys Ballot, 1853). When, some years later, he published a paper (in French) on the relation between the horizontal pressure distribution and the wind direction (Buys Ballot, 1857), it became highly controversial. 'Buys Ballot's Rule' not only challenged Dove's Wind Law, but also questioned the validity of Hadley's Principle. How did the fact that the wind blew about parallel to the isobars, independently of the direction, agree with Hadley's Principle which only allowed north–south winds to be affected?

The British meteorologist William Clement Ley (1840–1896) tried to accommodate this fact with Hadley's Principle and suggested that the inflow to a cyclone from straight east or west, which according to Hadley's Principle was not affected by the Earth's rotation, still had its direction modified thanks to influence from neighbouring portions of the atmosphere with north and south winds (Ley, 1872).

Coriolis rediscovered

In 1851 Jean Bernard Foucault (1819–1868) had conducted his pendulum experiment which unleashed an international scientific discussion about the deflective mechanism of the Earth's rotation, in particular why all directions were affected. In 1859 the French Academy of Science organized a comprehensive debate about the practical consequences of this deflection, primarily on flow in rivers,[5] deflection of artillery gunnery and the balance of railway trains.[6] It now became obvious that the deflective mechanism was equally affecting motions of *all* directions (see Persson, 2005, for detailed references). It was during this debate that Gaspard Gustave Coriolis (1792–1843) and his 1835 work on relative motion in a rotating system was rediscovered.

Coriolis had shown that the inertial (centrifugal) force, until then only considered for objects stationary in the rotating system, had to be extended by an extra force to account for the total inertial force on objects moving relative to the system. It was this extension that later became known as the 'Coriolis Force' (Persson, 2000a).

The debate in France inspired an American mathematician and a Norwegian meteorologist to look deeper into the effects of the Earth's rotation in meteorology.

[5] Since the meandering of the south to north flowing Siberian rivers was regarded as an effect of the Earth's rotation ('von Baer's Law'), the meandering of the east to west flowing Seine river was, by some French scientists, seen as an observational evidence that the Earth's rotation affected all directions.

[6] Inspired by this debate the French scientist Peslin (1836– ?) derived the geostrophic wind equation in 1869. When his paper was rejected by the French Academy of Science he published it in a little-read astronomical publication (Rochas, 2005). Indeed, the French Academy had derived the same equation already in 1859 without realizing its meteorological implications (Persson, 2005).

William Ferrel and the geophysical implications of Foucault's experiment

William Ferrel (1817–1891), a farmer's son from Pennsylvania, was in his late 30s and an unknown schoolteacher in Nashville, Tennessee. In January 1858, after some initial mishaps, he correctly derived expressions for the deflective mechanism in all three dimensions. This would become known as 'Ferrel's Law':

> *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.* (Ferrel, 1858, 1860, 1877)

Ferrel reminded readers that a constant deflection at right angle like this would drive the motion into a circle with a radius V/f, where $f = 2\Omega\sin\varphi$. He was thereby the first scientist to identify the inertia circle motion. The Earth's rotation, therefore, would *constrain* the motion of the air by trying to bring it back from whence it came in an inertial circle motion (Batchelor, 1967; Brunt, 1934, 1944). In other words, the effect of the Earth's rotation is, rather counter-intuitively, to make it difficult for any parcel of air or water to move any considerable distance over its surface.[7]

Henrik Mohn, 1872

The Norwegian meteorologist Henrik Mohn (1835–1916) had followed the debate in the French Academy of Science of 1859, and in particular had been impressed by arguments that the deflective effect worked for all directions of motion. This view was expressed in his *Storm-Atlas* (Mohn, 1872) and two years later in a semi-popular book on *Wind and Weather*. In the preface, Mohn made the readers aware, in a statement that is equally valid today, that dynamic meteorology had entered a period when old traditions were challenged:

> *When there is a disagreement between the old and new opinions, I would advise the reader to consider the basis upon which both are founded and thereafter choose rather than to try to find agreement where there cannot be any.* (Mohn, 1879)

Mohn and Ferrel's works would have a profound effect on the development of dynamic meteorology, in particular in Germany where their articles and books were translated during the 1870s.

The impact of Ferrel's and Mohn's texts in Germany

The 1870s is a very exciting decade in German meteorological history. The old generation is on their way out and the scene is taken by a new. The debate about the effects of the rotation of the Earth divided the scientific community into three camps:

1. Hadley and Dove are right and Ferrel is wrong.
2. Ferrel is right, but Hadley and Dove are not wrong, only incomplete.
3. Hadley and Dove are fundamentally wrong.

Leading theoretical German meteorologists had three major points of criticism of Hadley's Principle. First, it could only be applied to north–south motion, although the deflection occurs for all directions, also for east–west motion (Figure 4). Secondly, the underlying conservation principle should not be one of absolute velocity (absolute *linear* momentum), which only yields ΩV, half of the deflection, but of absolute *angular* momentum, which yields the correct value 2ΩV. Conserving angular momentum implies that the absolute velocity is *not* constant, but *varies*, in conflict with Hadley's Principle (Figure 5).

None of these objections, also mentioned in today's textbooks, are really fatal; being able to account for deflection only of north–south winds can be seen as a step in the right direction. Getting something wrong with a factor 2 does not necessarily mean that it is wrong in principle. So even today there is a widespread notion that Hadley's explanation was not incorrect, only incomplete and a simplified version of the correct one.

But this ignores a third point of criticism: *Hadley's set-up of a mechanical model of the atmosphere was physically wrong*. The assumption about an impulsive force, pushing the air is unrealistic for the atmospheric mechanical system. Unfortunately, very few understood this third point of criticism which turned out to be *the* really fatal objection to the Hadley Principle. We will come back to this in Part 3 when we look at the attitudes to this of the British meteorologists.

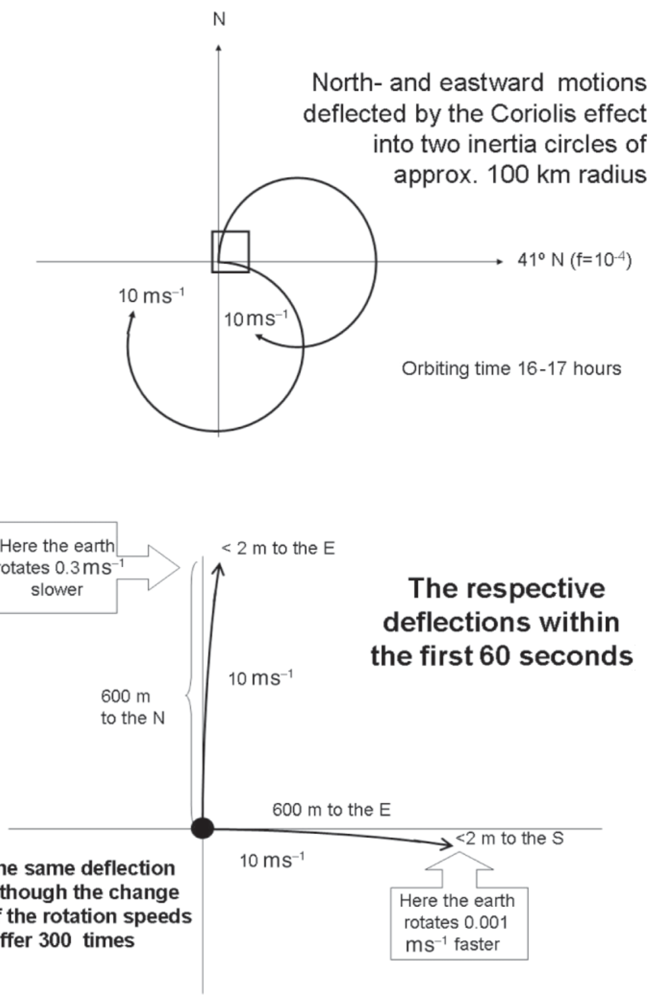

Figure 4. The mathematical formulation of the Coriolis Effect does not contain any reference to any latitudinal variation in the rotational velocity of a latitude circle, RΩcosφ, which does not play any role in the Coriolis Effect.

[7] The global circulation can be seen as an eternal contest between these two tendencies: the pressure gradient force works to *even out* horizontal pressure differences while the Coriolis force tries to *restore* the same differences. At Cambridge University this is called 'Coriolis stiffness' (Michael McIntyre, personal communication 1998). See also Batchelor (1967) and Persson (2000b) for the Taylor Column Effect.

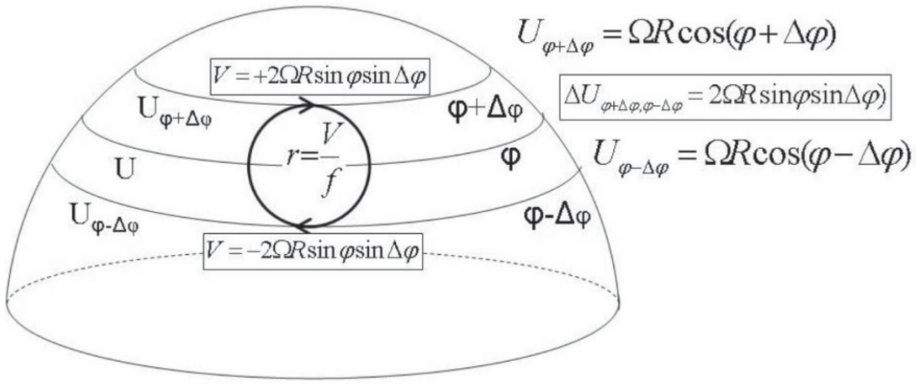

Figure 5. A body set in motion by an impulse will conserve its absolute angular momentum and follow an 'inertia circle' path (with radius $R = V/2\Omega\sin\varphi$) on the Earth's surface. When it, during its circular course, has a direction eastward, with the Earth's rotation, its absolute velocity (absolute linear momentum) will be greater than when it is moving westward, against the Earth's rotation. The basic assumption in Hadley's Principle that the absolute velocity is conserved is not correct.

Because, when the meteorological world turned critical towards Hadley's Principle, one would perhaps assume that his fellow countrymen would come to his defence. On the contrary – *British meteorologists had been the most sceptical from the start*. To them Hadley's Principle, if true, rather suggested that the rotation of the Earth hardly affected the motions of the atmosphere or the oceans at all!

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