Planetary atmospheric circulation

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1 Atmospheric motions

The long-term global atmospheric circulation (for some years, for example), observable by the motion of clouds and recorded through satellite images of our planet or by telescopes when other planets in our solar system are involved, clearly appears to us as a turbulent motion. From a deterministic (informational) point of view, a turbulent motion can be divided into two types of motions: local and global. As it results from the name of the motion, at the local level (more precisely speaking, regionally) the swirls (circular coherent motions of a limited duration) are characteristic, motions that, as far as our atmosphere is concerned, are called cyclones (anti-cyclones respectively)[1]. Globally, there is a general motion of these cyclones (in the West-East dominant direction for the temperate zone and the East-West direction for the tropical zone), a motion that is the coherent component of the global atmospheric motion. Everything happens similarly to a turbulent flow of a fluid through a pipe where the swirls characterize the local motion, and the displacement of these swirls (the global coherent component) characterizes the overall motion of the fluid mass that determines the flow through the pipe. At the flow through the pipes a theoretical cross-sectional surface S (reference surface) is taken into account with a fixed position relative to the pipe, on which the flow rate distribution is determined. At the atmospheric motion, the theoretical reference surface for global circulation is given by the intersection of the atmospheric layer with a meridian plane (passing through the Earth's axis of rotation). On this reference surface (a circular semi-crown of H thickness, corresponding to the actual thickness of the atmosphere), there will also be a distribution of the air mass motion velocity. The experimental determination of wind speed and direction is a strictly local operation performed by weather stations with fixed and known locations to the terrestrial position reference system. Let θ (latitude to the equator) and φ (longitude to the Greenwich meridian) be the local coordinates of a weather station that makes determinations of wind direction and speed at dt fixed intervals.

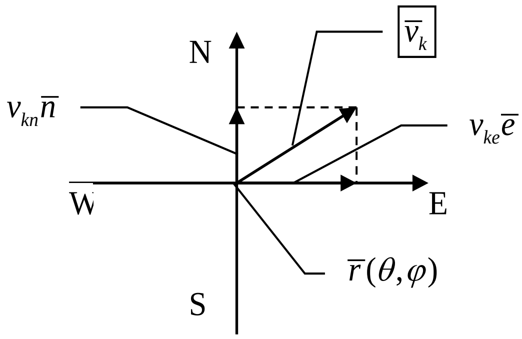

Fig. 1.1

In the medium term Δt (let's say a year), the determinations of this station will be mathematically represented by a set formed of $N_v = \Delta t/dt$ bound vectors $\{\bar{v}_k(e,n,\theta,\varphi,t)\}$ with a fixed application point at the geographic location $\bar{r}(\theta,\varphi)$ of the station (see Fig. 1.1), with the direction equal to the direction of the wind and the module equal to its speed at the

[1] We exclusively refer to the motion of the air masses in the horizontal plane, not to the vertical (convection) motions.

time $t = kdt$ $(k \in \{N\}, k = [1, N_v])$, where *k* is the serial number of the weather data recording in the Δt range, the horizontal axis (abscissa) is the West-East axis with the $\overline{e}$ unit vector positive in the E direction, and the vertical axis (ordinate) is the S-N axis with the $\overline{n}$ unit vector positive in the N direction.

The set of all vectors $\{\overline{v}_k(e,n,\theta,\varphi,t)\}$ determined by all weather stations on Earth at universal time (UT) *t* and at a certain height *h* $(h \in [0, H])$, forms a vector field (a vector space distribution called *Euler distribution* in the objectual philosophy), a field representing the global state of the atmospheric circulation at time *t* and the altitude *h*. To simplify things, we will consider only the data at *h=0* for both the reason that these are the most numerous, easier and more reliable determinations, and especially because the atmospheric circulation at the surface of the terrestrial globe partially influences (by the air-water interaction) the surface hydrosphere (currents) circulation.

As stated above, wind velocity and direction is determined in relation to a local reference system (RS), the measuring devices being fixed to the ground of the station. For the study of global atmospheric circulation as it appears in outer space, one must keep in mind that each measuring point moves with the rotation of the planet. If *R* is the average terrestrial radius, ω is the angular rotation speed of the planet around its own axis, θ is the latitude of the measuring point and $\overline{e}$ is the tangent unit vector at the parallel θ (W-E direction), the local RS will move in the W-E direction with the peripheral velocity of the earth's crust at that point:

$$\overline{v}_\theta = \omega R \cos\theta \, \overline{e} \tag{1.2}$$

For an extra-planetary observatory considered immobile (absolute RS), the atmospheric motions will be correlated with the rotation motion of the planet, and depending on the direction and magnitude of the local wind speed $\overline{v}_k(e,n,\theta,\varphi,t)$ in relation to $\overline{v}_\theta$, the absolute motion will appear *prograde* (the positive $\overline{v}_{ke}$ component) or *retrograde* (the negative $\overline{v}_{ke}$ component). A special mention must be made: the seemingly retrograde motion is absolutely retrograde only on condition:

$$v_{ke} > -v_\theta \tag{1.3}$$

Comment 1.1: As far as Earth is concerned, for R=6378 km and $\omega = 7.29 \times 10^{-5}$ rad/s, it results $v_\theta = 465$ m/s to the equator. In the case of a latitude $\theta = 45°$, this speed is reduced to 329 m/s. The strongest surface wind (a 5th degree tornado) only reaches about 140 m/s, so an absolutely retrograde motion cannot take place.

2 Common components of vector distribution

For each location of a weather station, there should be a temporal distribution at the data collection centre $\{\overline{v}_k(e,n,\theta,\varphi,kdt)\}$ where *k*, as shown in the previous paragraph is the serial number of wind speed and direction determination from the ordered list of these determinations performed at *dt* intervals, on Δt duration ($k=1...N_v$, where N_v is defined above).

As we set out in the par. 1, the set $\{\overline{v}_k(e,n,\theta,\varphi,kdt)\}$ for a certain θ and φ is a set of vectors bound at the same point (the geographic location of the station), which makes it possible to determine a common component (resultant vector) $\overline{v}_c(\theta,\varphi)$ of them for as long as possible. To extract a coherent (global, overall) component from a set of bound vectors, with apparently random directions and modules, we use *objectual analysis*, a method of objectual philosophy. The essence of this method is to divide the properties of a set of objects into two classes: *common properties* belonging to all the objects of the set and *specific* (differential) *properties* that individualize each object in part, making it recognizable to other objects.

According to this classification, if the set of objects consists of the elements of the vector distribution discussed in the previous paragraph, the common components of these vectors will be precisely the common (global) motions of the air masses, maintained over long time ranges Δt. Since vectors are involved and knowing that vectors can only be composed if they have a common reference, we will define the ***common component*** of the set $\{\overline{v}_k(e,n,\theta,\varphi,kdt)\}$ comprised of N_v concurrent vectors, the vector:

$$\overline{v}_c(\theta,\varphi)=\frac{1}{N_v}\sum_{k=1}^{N_v}\overline{v}_k(e,n,\theta,\varphi,kdt)=\frac{1}{N_v}\sum_{k=1}^{N_v}\overline{v}_{kn}(\theta,\varphi,kdt)+\frac{1}{N_v}\sum_{k=1}^{N_v}\overline{v}_{ke}(\theta,\varphi,kdt)= \\ =\overline{v}_{cn}(\theta,\varphi)+\overline{v}_{ce}(\theta,\varphi) \quad (2.1)$$

Because we are only interested in the global motion of air masses, we will neglect the specific components $\overline{v}_{dk}=\overline{v}_k-\overline{v}_c$ of the set $\{\overline{v}_k(e,n,\theta,\varphi,kdt)\}$, and of the components of the common speed we are only interested in the $\overline{v}_{ce}(\theta)$ component characteristic for atmospheric circulation in belts parallel to the equator.

Comment 2.1: The distribution in parallel belts to the equator of the phenomena in the atmosphere of Jupiter or of those in the atmosphere of Saturn is well known. In this article, there are arguments for the existence of an atmospheric motion in belts parallel to the equator for the Earth too, but that can be distinguished only instrumentally and for a long term (decades).

3 Realizable estimates

The method outlined above is safe, scientific, but useful only for those who have access to the world's network of weather stations, funds and a powerful computer with which to process this data. And yet, using only the animated images in the weather bulletins of global coverage TV stations (BBC, CNN, TV5, TVE, etc.), the Discovery documentaries on atmospheric phenomena, scientific journal articles, and public internet data, an estimate can be made of global terrestrial atmospheric circulation, which clearly shows a belt structure. These estimates are based on the following long-term observations:

1. The absence of tropical cyclone nuclei (hurricanes, typhoons, etc.) at latitudes between ±10°.

2. The time-averaged route (over 50 years) of all tropical cyclones in the Atlantic indicates an apparently retrograde motion with a turning point around the 33° N latitude, then returning to the prograde motion before their dissipation.

3. Constant, overall, west-to-east movement of cyclones and anti-cyclones in the temperate zone, a movement observed when looking at the synoptic and animated images of the cloudy formations in the weather bulletins (also for the North Atlantic and Europe areas).

4 Geophysical correlations

The estimated existence of belts with components of the coherent and invariant motion in the long-term terrestrial atmospheric circulation, belts arranged between well-defined latitudes, has a close connection with the layered structure of the planet's interior.

From current estimates of the Earth's internal structure elements[2], we have three large areas: the solid core with a radius of 1220 km, the liquid mantle with a maximum radius of 3480 km and the remainder of the mantle plus the crust. From Fig. 4.1 we see that the solid core has a projection on the terrestrial surface between the latitudes of ±11°, and the liquid mantle has a projection between ±11° and ±33°. But these values are precisely the ones estimated in par. 3 as the boundaries of the belts of global atmospheric circulation, namely the

[2] **William Lowrie** - *Fundamental of Geophysics*, Cambridge University Press 2007

equatorial belt (between the latitudes ±11°) with prograde circulation, the two tropical belts between ±11° and ±33° with an apparent retrograde circulation, and the two temperate belts with a prograde circulation over the latitudes of ±33°. The remarkable coincidence between the projections of the planet's internal areas and the long-term coherent components of global atmospheric circulation estimated in paragraph 3 allows us to formulate the following hypothesis:

Hypothesis 4.1: *Planetary atmospheric circulation has two fundamental components*:

1. turbulent (stochastic) circulation determined mainly by thermodynamic factors (pressure, temperature, density, viscosity, chemical composition, etc.), primarily dependent on the distribution of the solar radiation intensity on the surface of the planet, together with the contribution of the internal heat flow, and

2. laminar (coherent) circulation that is closely correlated with the internal structure of the planet.

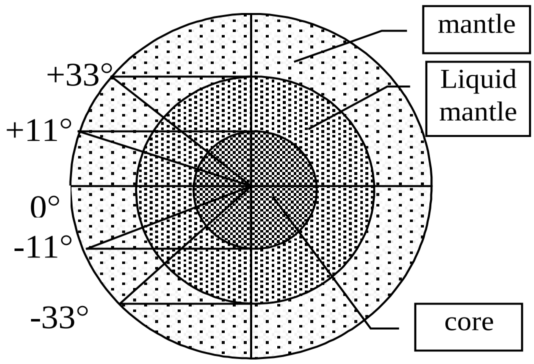

Fig. 4.1

If turbulent circulation has a high degree of randomness in the long term, instead the coherent circulation remains the same indefinitely because the internal structure of the planet is invariant.

5 The Jupiter case

If for Earth we used the hypothesis 4.1 to identify long-term atmospheric circulation belts, the internal structure of the planet being known, in this paragraph we will use the same hypothesis, but in the opposite direction, to estimate the internal structure of the planet Jupiter, Jovian atmospheric circulation belts being known. It should be noted that the structure of these belts is variable in time, but there are common components resulting from the examination of Jovian images on a very long term. The last estimate was made after the infrared image of the Jovian atmosphere provided by the European Space Agency (see Figure 5.1):

- polar radius corresponding to a pressure of 1 bar: 66700 km;
- average equatorial belt: $\pm 6.5°$, to which an average polar radius of approximately 7300 km corresponds;
- average tropical belt from $\pm 6.5°$ to $\pm 18°$ (average polar radius of about 21000 km);
- average temperate belt from $\pm 18°$ to $\pm 28°$ (average polar radius of about 32,000 km);

With these values considered as the projections of the internal Jovian structure, we can reconstruct similarly to the figure 4.1 the hypothetical structure of this planet in fig. 5.2. Note that the drawing is not on scale, and the alignment of the concentric spheres is approximate.

For the purpose of this article, the only important is the order of magnitude and the order in which the inner layers are arranged[3].

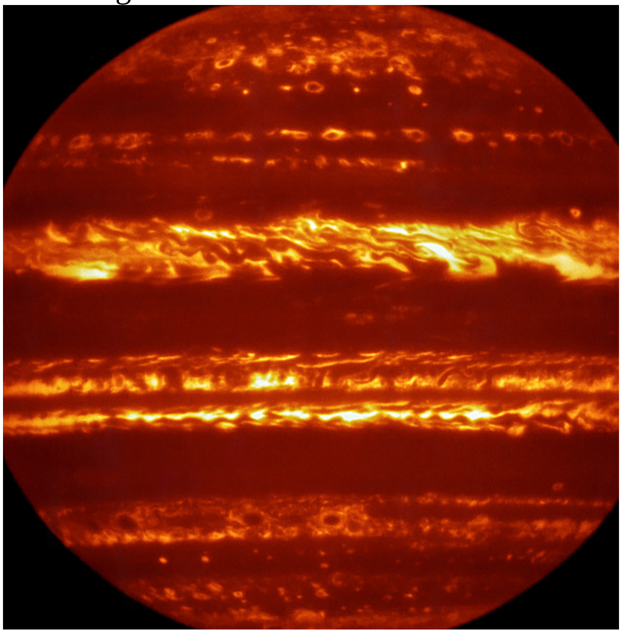

Fig. 5.1 (https://cdn.eso.org/images/screen/eso1623a.jpg)

With these specifications we can analyse the radial distribution of the Jovian interior according to the hypothesis 4.1. The equatorial belt with prograde circulation and reduced turbulence indicates, as in the case of Earth, a solid core of a size slightly larger than Earth. The tropical belt with a seemingly retrograde and intensely turbulent circulation (which includes the permanent cyclone called the red spot) corresponds to a liquid layer (similar to the terrestrial liquid mantle). The temperate belt with prograde and reduced turbulent circulation corresponds to a solid internal layer (equivalent to the terrestrial mantle) with a polar radius of over 32,000 km, from which a gigantic planetary ocean begins (made up of liquefied gases), and at its surface a gigantic atmosphere.

As in the case of Earth, the intensively ionized (incandescent) internal layers contribute to the planetary magnetism (a magnetic field much more intense than the Earth's field), proportional to the dimensions of these mediums and their rotation speed.

The estimation of the internal structure of the planets in our solar system predicted in the current scientific literature is made on purely theoretical basis, with a rather high degree of approximation, and no geophysical measurements are possible as in the case of the Earth. For Jupiter, a layered internal structure is estimated, formed of the following elements:

1. The clouds layer with a thickness of about 50 km at the upper limit of the atmosphere;
2. The actual atmosphere consisting of a mixture of hydrogen and helium initially in gaseous state (up to 1000 km in depth) then liquid with a thickness of about 15000 ... 25000 km, pressure about 2 ... 4 MPa and a temperature of about 15000 K;
3. Mantle made of the same H+He mixture, but in the metallic state (?);
4. The solid core, with a radius of about 13000 km, at a pressure of about 4200 GPa and a temperature of more than 20000 K, consisting of "rocky" (?) in a variant[4], or "rocky and ice" (?) in another variant[5].

[3] Please note once more that the numeric values of the band parameters vary according to the information source, so we are only interested in the average values (the common components). In the future these values can be corrected. There is also a clear asymmetry between the two hemispheres (northern and southern), asymmetry that cannot be explained for the time being, for which reason only average values are taken into account.

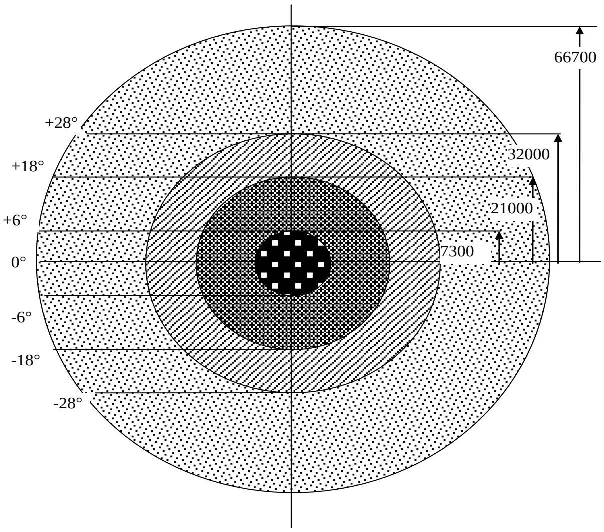

Fig. 5.2

It is noticed that the model according to hypothesis 4.1 is quite close to the current theoretical models, especially with respect to the nucleus, but the major difference is the prediction of a liquid mantle to which the Jovian tropical turbulent belt corresponds.

6 Conclusions

We start from the fundamental observation that any turbulent flow has a coherent (laminar) component with the velocity $\overline{v}_c$ which has as correspondent the speed of transfer of the turbulent medium through a fixed section, normal on the flow rate, a velocity which determines the flow rate of that turbulent medium. In the case of terrestrial atmosphere, we refer to the movement of air masses through a section of circular semi-crown form $\theta \in \left[-\frac{\pi}{2}, +\frac{\pi}{2}\right]$ of H thickness (thickness of troposphere), coplanar with a meridian plane at longitude φ, described at the beginning of this article. The calculation $\overline{v}_c$ according to the relation 2.1 is done starting from the series of experimental determinations of the velocity and direction of the wind $\{\overline{v}_k(e,n,\theta,\varphi,t)\}$ by local weather stations, determinations for as long as possible (decades).

Comment 6.1: Because the common speed $\overline{v}_c$ in the terrestrial case is estimated to be (much) lesser than the local speed $\overline{v}_k$, the condition of the precision of the experimental determinations becomes stringent. For normal practices on weather forecasts, an accuracy too high is not required. The wind direction is usually indicated using the so-called “compass rose”, which implies a tolerance of several angular degrees. The wind speed is in most cases determined with average precision anemometers, sufficient for current requirements. For the rigorous calculation of $\overline{v}_{ce}(\theta)$ and the estimation of atmospheric circulation in belts a greater precision of determinations is required, especially in the wind direction, an accuracy currently provided only by some types of anemometers (such as ultrasonic ones), which means additional costs that can only be justified by the magical phrase - *fundamental research*.

Highlighting a belt circulation for Earth following an objectual analysis of the data $\{\overline{v}_k(e,n,\theta,\varphi,t)\}$ (obtained under conditions mentioned in comment 6.1), belts correlated with the inner structure of our planet, opens the perspective of a more accurate estimation, on geophysical bases, of the internal structure of other planets too, possessing belt circulation atmospheres (Jupiter and Saturn).

[4] **John W. McAnally** - *Jupiter and how to observe it,* Springer 2008
[5] **Linda T. Elkins-Tanton** - *Jupiter and Saturn***,** Chelsea House, 2006

Comment 6.2: There is a planetary atmospheric circulation for Venus also, whose internal structure is supposed to be similar to the terrestrial one, but due to the low rotation speed there is no differentiation of the tropical circulation belt, a belt that would correspond to the planet’s liquid mantle.