DESCRIBING THE COMPONENTS OF THE WATER TRANSPORT IN THE MARTIAN ATMOSPHERE.. F. Montmessin, R. M. Haberle, *NASA Ames Research Center - Moffett Field*, F. Forget, *Laboratoire de Meteorologie Dynamique-France*, P. Rannou, M. Cabane, *Service d'Aeronomie-France*.

Introduction: In this paper, we examine the meteorological components driving water transport in the Martian atmosphere. A particular emphasis is given to the role of residual mean circulation and water ice clouds in determining the geographical partitioning of water vapor and frost.

Model description: For our simulations, we use the General Circulation Model (GCM) developped at Laboratoire de Meteorologie Dynamique (Paris/France) [1] to simulate Martian hydrological cycle for various orbital configurations. The model includes usual representations of processes like surface sublmation, cloud formation and sedimentation (with predicted cloud particle sizes) [2]. Most of our simulations

Water cycle and circulation: Using the same decomposition as that found in [3], it is possible to recast the water transport in terms of circulation components. Indeed, it is staightforward to demonstrate that the total meridional transport of a tracer species includes the contribution of the mean meridional circulation, that of transient eddies and that of stationary waves.
Following this approach, we express the total transport of water vapor at a given latitude and at a given height as $[\bar{qv}]$, where the $\bar{qv}$ symbol denotes the time average and [] symbols denotes the zonal mean of the product qv, q being the mass mixing ratio of water and v the meridional wind. According to [3], $[\bar{qv}]$ can be written as:

$$[\bar{qv}] = [\bar{q}][\bar{v}] + [\bar{q'v'}] + [\bar{q^*v^*}] \quad (1)$$

with the prime symbol $'$ expressing the departure from the time average ($q' = q - \bar{q}$ and $v' = v - \bar{v}$) whereas the star symbol being related to the departure from the zonal average ($q^* = q - [q]$ and $v^* = v - [v]$).
In short, total water transport $[\bar{qv}]$ is the sum of the mean meridional circulation component $[\bar{q}][\bar{v}]$, that of transient eddies $[\bar{q'v'}]$ and that of non-travelling waves $[\bar{q^*v^*}]$. Eq. (1) can be integrated over height to yield

$$\int_{p_s}^{0}[\bar{qv}]\frac{dp}{g} = \int_{p_s}^{0}[\bar{q}][\bar{v}]\frac{dp}{g} + \int_{p_s}^{0}[\bar{q'v'}]\frac{dp}{g} + \int_{p_s}^{0}[\bar{q^*v^*}]\frac{dp}{g} \quad (2)$$

The latter equation, akin to a zonal- and vertical-mean expression of the water meridional transport, synthetizes the general behavior of the meridional flux fields. Given that q is the sum of both atmospheric water vapor and water ice (clouds), eqs. (1) and (2) can be further recasted to yield the respective contributions of vapor and clouds. Most of the water cycle studies to date [4,5] have focused on the sole role of the Hadley cell in cross-equtorial flows of moisture. However, [4] and [5] have shown that baroclinic activity plays a key role in cycling water in and out the north residual cap. Indeed, [6] concluded that the observed extraction of water from the north polar cap can not be reproduced with a two-dimensionnal circulation model. According to [5], horizontal mixing of moisture between high and mid-latitudes precedes the incorporation of water within the ascending branch of the Hadley cell in the northern tropics. Likewise, the mechanism by which water returns to the north residual cap includes water trapping in the seasonal CO_2 cap, thanks to an intense mixing of air masses across the cap edge. During the recession of the cap, seasonal water frost is carried poleward by a succession of sublimation/recondensation processes occuring within poleward warm fronts and equatorial cold fronts.
With this in mind, describing water transport in terms of its meteorological components becomes a necessary task in order to fully appreciate the mechanisms controlling the Martian water cycle stability.
Results of our analysis on an annual average and at specific seasons will thus be presented.

Water cycle and clouds: Following their first observation of what has been since called the "Aphelion cloud belt", i.e. a cloudy structure encircling the equator during northern spring and summer, [7] proposed a mechanism, involving clouds, to predict preferred storage location of water with changes of perihelion date. The so-called *Clancy effect* comes from the potential ability of clouds to sequester water below the returning branch of the equinoctial Hadley cell if the latter is synchronized with the aphelion season. In practice, aphelion season implies decreasing atmospheric temperatures in the tropics and thus lower levels of condensation/precipitation. Perihelion season, on the contrary, comes with enhanced solar forcing and warmer temperatures which allow water to be carried by the Hadley cell towards the winter hemisphere without experiencing the effects of cloud sedimentation.
On an annual average, [7] suggests a net flux of water towards the hemisphere for which summer is timing with aphelion. Whereas the current orbital configuration should therefore favor the northern hemisphere, it also implies that this situation is reversed when the perihelion is shifted of 180^o.
[7] even suggested that the current position of the permanent water ice cap is a consequence of this effect. Accordingly, the permanent water ice cap should move to the south pole when aphelion occurs during southern summer.
On the other hand, [8] showed that, regardless of excentricity and aphelion date, the south to north topographic slope applies a major component to the general circulation biasing cross-equatorial mass flows towards the north hemisphere.
The purpose of our study is to confront the *Clancy effect* to that induced by topographic forcing within the context of GCM simulations. Ultimately, we will discuss the stability of a permanent cap in the south pole that recent observations may confirm [9].

Reference

[1] F. Forget et al., *JGR* **104**, 24155 (1999)
[2] F. Montmessin et al., *proceedings of the mars VI conference*, Pasadena (2003)

[3] J. P. Peixoto and A. Oort, *Physics of Climate*, Amer. Inst. of Physics (1992)
[4] H. Houben et al., *JGR* **102**, 9069 (1997)
[5] M. Richardson and J. Wilson, *JGR* **107**, 10.129/2001JE001536 (2002)
[6] R. Haberle et B. Jakosky, *JGR* **95**, 1423 (1992)
[7] T. Clancy et al., *Icarus* **122**, 36 (1996)
[8] M. Richardson and J. Wilson, *Nature* **416**, 298 (2002)
[9] T. Titus et al., *Science* **299**, 1048 (2003)