Referee Report

Global comment: This paper aims at discussing the influence of ice morphology and disk dynamics on the location of snowlines of main C-, N- and O- bearing species in protoplanetary disks. The authors use static and time-dependent disk models associated with desorption-drift models to depict the fate of ice particles in the disk and to derive the abundance profiles of C, N and O abundances in solids or in the gas phase as a function of the distance to the star. I recommend major revisions before considering the publication of this paper in The Astrophysical Journal. In its present shape, the manuscript poorly addresses the influence of the nature of the ices in the presented results, contrary to the goal announced in the title.

We thank the referee for a thoughtful and detailed report. The global comment concerned the lack of proper morphological data in the paper. First off, the word 'morphology' was a poor choice on our part, as the main focus of our paper is how the composition of the icy particles, not the morphology of the water substrate, affects snowlines. We have replaced the word 'morphology' for composition in the title and throughout the text, except for when we are discussing the effect of the water ice structure, which we do toward the end of section 3.1. Further changes are outlined in the responses below.

Detailed comments:
- Introduction:
1) Titan's atmospheric N_2 is not primordial and probably comes from primordial NH_3 accreted by the satellite (Atreya et al. 1978; Mandt et al. 2014).

We removed the reference to Pluto and Titan when discussing N_2 in the Solar system, since neither provides much constraint on the presence of N_2 in the Solar nebula. We added the suggested comment at the end of the third paragraph of the introduction when we discuss NH_3: "The present day N_2 in Titan's atmosphere, for example, is thought to originate from accretion of primordial NH_3 (Atreya et al. 1978, Mandt et al. 2014)."

2) In the third paragraph, it is stated that N_2 was probably the dominant N_2 form in the protosolar nebula and that the N/O ratio may be enhanced in the outer disk. These statements are at odds with the mention of the N_2 detection in comet 67P/churyumov-Gerasimenko because the abundance of this molecule is very small in the comet.

We removed the reference to comet 67P in the introduction as we discuss the detection of N_2 and the low N_2/CO ratio in 67P in section 4.

3) Sentence "Because of the high volatility of N_2, the N/O ratio in the outer disk should be more enhanced than the C/O ratio..." This argument needs

clarification. The equilibrium curves of pure N2 and CO crystalline ices are very close at nebular conditions. There might be just 2-3 K of difference at low pressure (Fray and Schmitt 2009).

We have revised this statement since the N/O enhancement throughout the outer disk is a result of this study and not immediately obvious. Furthermore, we have added the following explanation: "The C/O ratio in gas cannot exceed unity (i.e., a factor of ~2 enhancement compared to the Solar value) since the major volatile carbon carrier is CO. In contrast, the N/O ratio mainly depends on the relative depletion of N_2 and oxygen carriers, and it will increase as each of the oxygen carrier snowlines (H2O, CO2, CO) is crossed. Beyond the CO snowline, there is no strict upper limit to the N/O ratio. The spatial extent of this latter region depends on the relative bond strengths of CO and N_2 to ice, but may be quite large (see Section 3)."

4) There is no indication of the ice state in this section. I also found nothing in the manuscript. I think that it is a major issue because the results presented by the authors strongly depend on the type of material they consider. From the papers they mention, I found that the authors considered icy grains made of amorphous ice. This should be stated in the paper, as well the corresponding conditions enabling the existence of this type of ice in the disk.

We expanded the fourth paragraph of the introduction to address these concerns. We clarified what we mean by pure and water dominated ices. The CO and N2 binding energies are larger in an amorphous porous water environment than in the amorphous compact case or the crystalline water ice case. The CO and N2 binding energies are lower when they are pure ices than in all water dominated scenarios. We thus consider the pure and amorphous porous water dominated environments as these are the limiting cases (lowest and highest binding energies, respectively), and therefore they allow us to explore the range of distances at which ices with different compositions desorb. We do however return to the case when CO and N2 are bound to a crystalline or more compact amorphous water ice in section 3.1. The conditions in which these types of ices can exist in the disk are discussed in the third paragraph of section 4.

- Section 2:
Eq. 2, please detail T_irr

We redefined T in equation 1 as T_irr and T in equation 2 as T_visc. We agree with the referee that our temperature notation in both equations as T was confusing.

- Section 3.1: This section should include results from different ice morphologies to make more sense. Two extreme cases should be considered: amorphous ice and crystalline ice. The clathrate case could be eventually discussed. All these ices present different condensation/sublimation temperatures and could potentially induce drastic changes of the C/N/O ratios in the disk.

As we note in the introduction, we explore the pure ices and amorphous porous water dominated ices because these are the limiting cases (lowest and highest binding energies). We restate this in section 3.1, i.e. that the results we present in Figure 1 are the extremes and therefore they show the full range of CO and N2 snowline locations in different ice environments. We also quantified the variations in snowline locations for all cases: amorphous porous water ice, amorphous compact water ice, crystalline water ice, and CO and N2 as pure ices. These updates are in the last paragraph of section 3.1. We do not consider clathrates since the formation of clathrates is a very uncertain process in the outer disk, and since at most a small fraction of CO and N2 would be expected to be captured in such structures, i.e. it will not have a significant impact on the gas-phase C/O or N/O ratios.

- Section 3.1: the different snowlines correspond to equilibriums between adsorption/desorption. What are the corresponding temperatures in the disk?

We added the corresponding disk temperatures next to the binding energy values.

- Section 3.2: "In this section we consider pure ices". What does it mean? What is the structure of these ices?

We clarified what we mean by pure ices at the beginning of the section, as well as in the introduction.

- Section 4: please explain what would be the influence of other transport mechanisms such as the "cold finger effect" detailed in Cyr et al. (1999) or Ali-Dib et al. (2014).

Added, and also noted that the influence of other transport mechanisms on snowline locations is described in more detailed in Piso et al. (2015): "Moreover, the diffusion of vapor across the snowlines following the cold finger effect (Stevenson & Lunine 1988, Cyr et al. 1988) will change the shape of the C/O and N/O curves and therefore the magnitude of the C/N/O ratios between different snowlines. The effect of dynamical processes on snowline locations is discussed in more detail in Paper I, Section 5.2."

- Section 5: Last paragraph "Recent measurements... in the gas phase". The N2 (and Ar) depletion measured in 67P may not be a record of the primordial composition. These features may be also due to postformation processes such as radiogenic heating or devolatilization during the orbital history of the comet.

For both this comment and the next one, we note that the referee was referring to the last paragraph of section 4 -- section 5 was probably just a typo. We addressed this concern in the last paragraph of section 4: “However, it is also possible that the measured N$_2$ abundance in 67P may be due to post-formation processes such as radiogenic heating (Rubin et al. 2015) and thus may not reflect the comet's primordial composition.”

- Section 5: Last paragraph "Theoretical models... more detailed modeling is needed". Recent models suggest that JFCs formed between 5 and >30 AU in the protosolar nebula. It is then difficult to rely any N2 measurement in these bodies to the location of the N2 snowline...

We address this concern in the last sentence section 4: “…as well as the uncertainty of the formation zone of Jupiter-family comets (anywhere between 5 and $>$30 AU; Pontoppidan et al. 2014),…”.