Response to the Dr. Wagreich's comments

General comment: The submitted paper gives evidence for changes in atmospheric circulation during the Cretaceous Greenhouse period. Data is based on distribution of climate-sensitive sediments, i.e. desert sediments. Deserts are then interpreted as proxies to descending parts of ancient Hadley cell positions. As the distribution and extend of deserts are minimal during mid-Cretaceous supergreenhouse, the authors interpreted that as evidence for shrinkage of Hadley cells during these times. All in all this is a nice and provocative paper that will stimulate discussion and research in the investigated field – more a pioneer paper than a concise review. There remain a lot of data to be integrated and a much higher time resolution can be achieved in the future. But the paper is good and should be published with minor modifications.

Detailed Review: Cretaceous eolian sandstones are the main feature of interest, and the main area of investigation of the authors seems to be the large land mass of Asia. The main arguments of the authors are put forward clearly. Shrinking of Hadley cells during warmer periods is a plausible theory.

The data base has errors of +/– 5 to 10° on paleolatitudes – the authors should discuss this in the light of significance of their conclusions then – see also p.124, line 15 and following.

As was pointed out by referee, better discussion of the paleolatitudes shifts in the light of the rather large error bars is required. Thus, we revised the several sentences to demonstrate much clearer explanation of the significance of the latitudinal shifts of eolian sandstone distributions and paleo-wind directions. The revised and added sentences are as follows. First, we added sentences in Page 4, Line 10–13 in revised manuscript as follow, "Latitudinal differences of the studied basins are large (**Table 1**), and no substantial changes in their relative positions have occurred during the Cretaceous (e.g., Li, 1994; Meng and Zhang, 1999). Thus, changes in the latitudinal distribution of the eolian sandstone deposits exhibit the absolute latitudinal shifts of desert climatic zone.". Then, we added and revised several sentences in Page 4, Line 24–31 in revised manuscript as follow, "Paleolatitude of the studied basins are the critical basis for the present study which demonstrate that the location of the subtropical high-pressure belt changed significantly during the Cretaceous. The reconstructed paleolatitudes of the studied basins have errors of less than ±5˚ (between ±1.1˚ and ±4.2˚), which stem from the paleomagnetic data (**Table 1**). Although the reconstructed paleolatitudes of the basins have relatively large error bars, both eolian sandstone distribution and paleo-wind direction data suggest that marked latitudinal shifts of the subtropical high-pressure belt have occurred during the Cretaceous (**Figs.1B, 2**), as described below.". In addition, we revised several sentences in Page 5, Line 19–27 in revised manuscript as follow, "Although the reconstructed magnitude of the latitudinal shifts have relatively large error bars, which stem from uncertainty in the paleomagnetic data, it is noteworthy that the southern margin of the desert zone was located in the Tarim basin (N36.3˚ ± 3.3˚) during the early Cretaceous, whereas its northern margin was shifted to Sichuan basin (N27.5˚ ± 2.0˚) during the mid-Cretaceous. Thus, there was not only no overlap in the distributions of desert zone between the early and mid-Cretaceous time, but also a marked latitudinal gap (8.8˚ ± 5.3˚) between its southern and northern margins had existed between the early and mid-Cretaceous (**Figs. 1B, 2**). Therefore, the large-scale latitudinal shifts of the climate zones (ca. 13.8˚–15.4˚ in mean values) have occurred in Asia during the Cretaceous.”.

However, I find it hard to follow the arguments in chapter 3.5, where the consequences for ocean circulation are discussed. There exist other models (e.g. Hay, 2011) and the effects are not straightforward.

As was pointed out by referee, we agreed that the previous version of chapter 3.5 include unconvincing argument, particularly regarded to the causal linkage of changes in deep ocean circulation and changes in Hadley circulation width. Thus, we largely revised several sentences, and notified the importance of the coincidence of switches of both oceanic and atmospheric circulation system between the mid- and late Cretaceous time. In addition, we demonstrated the several scenarios of the possible causal linkage of changes in ocean and atmospheric circulation system. This argument is described from Page 14, Line 29 to Page 15, Line 17 in the revised manuscript, “The approximately synchronous occurrences of the changes in the deep-ocean circulation and the width of the Hadley circulation during the mid- to late Cretaceous indicate a possible linkage in the ocean and atmosphere circulation system during the Cretaceous “greenhouse” period (**Fig. 4**). Although the causal relationship between the changes of Hadley circulation width and deep ocean circulation during the Cretaceous is currently unclear, we infer following possible scenarios. Poleward shifts of the subtropical high-pressure belt during the late Cretaceous could have resulted in the formation of more saline surface water in higher latitude that possibly promoted the onset of deep-ocean circulation in higher latitude ocean. On the other hand, during the mid-Cretaceous, equatorward shift of the subtropical high-pressure belt and increased humidity in the mid-latitude extratropics could have resulted in the formation of saline water in lower latitude and development of less saline water in higher latitude so that the deep water formations in higher latitude oceans were suppressed (weaker deep-ocean circulation). Alternatively, enhanced ocean vertical mixing (upwelling) by wind-driven turbulent in mid- to high latitude oceans, due to the enhanced extratropical cyclone activity in in the mid-Cretaceous (**Fig. 4D**), could have resulted in weaker (more local and chaotic) deep water formations in higher latitude oceans (resemble to the “eddy-filled ocean”; Hay, 2008). The other alternative scenario is both the changes of ocean and atmospheric circulation systems were triggered by the changes of meridional temperature gradients and atmospheric CO_2 level. Conclusively, although further work is needed to address their possible causal linkage, it is noteworthy that there is temporal synchronicity in the switches of the ocean and atmospheric circulation system during the mid- to late Cretaceous (**Fig. 4**).”.

In addition, as is pointed out by referee, there exist other models on the Cretaceous oceanic circulation (e.g. Hay, 2011). Thus, we also slightly revised the several sentences (introductory part of the chapter 3.5) from Page 12, Line 31 to Page 13, Line 6 in revised manuscript as follows “It is well-established that the wind-driven circulation drove the surface currents in the ocean gyres, whereas the deep ocean circulation ventilated the interior with cold and relatively saline water from the poles (thermohaline circulation). Increasing evidence also suggested that wind-driven turbulent mixing is also an important factor for ocean circulation (e.g., Kuhlbrodt et al., 2007; Toggweiler and Russell, 2008). Thus, changes in the width of the Hadley circulation system during the Cretaceous could have been related with the changes of the ocean circulation system such as latitudinal shifts of the subtropical gyre circulation and/or possible development of the "eddy-filled ocean" as is proposed by Hay (2008, 2011).".

References I miss are the work by Floegel and Beckmann on ITCZ and African climate variability. Cite that and discuss significance for your study.

Beckmann, B., Flögel, S., Hofmann, P., Schulz, M., and Wagner, T., 2005a, Orbital forcing of Cretaceous river discharge in tropical Africa and ocean response: Nature, v. 437/8, p. 241-244.

Beckmann, B., Wagner, T., and Hofmann, P., 2005b, Linking Coniacian - Santonian (OAE3) black - shale deposition to African climate variability: a reference section from the eastern tropical Atlantic at orbital time scales (ODP site 959, off Ivory Coast and Ghana) *in* Harris, N.B., ed., The Deposition of Organic - Carbon - Rich Sediments: Models, Mechanisms, and Consequences, SEPM Society for Sedimentary Geology Special Publication, v. 82, p. 125-143.

Floegel, S., and Wagner, T., 2006, Insolation - control on the Late Cretaceous hydrological cycle and tropical African climate – global climate modelling linked to marine climate records: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 235, p. 288 - 304.

Flögel, S., Beckmann, B., Hofmann, P., Bornemann, A., Westerhold, T., Norris, R. D., and Wagner, T. (2008): Evolution of tropical watersheds and continental hydrology during the Late Cretaceous greenhouse; impact on marine carbon burial and possible implications for the future. Earth and Planetary Science Letters, doi: 10.1016/j.epsl.2008.06.011.

According to the referee's comments, we cited the works by Beckmann et al. (2005), Flögel and Wagner (2006), Flögel et al. (2008), and Hoffmann et al. (2003) to indicate the supporting evidence of the enhancement of the hydrological cycles in tropics and mid-latitude extratropics during the climatically warm interval of Coniacian-Santonian OAE-3.

Revised sentences are from Lines 10 to 26 in Page 12 of revised manuscript as follows, "Research results of the high resolution proxy data and paleoclimatic simulations of the Upper Cretaceous deposits in equatorial Atlantic of coastal Africa (Hofmann et al., 2003; Beckmann et al., 2005; Flögel and Wagner, 2006) and coastal South America (Flögel et al., 2008) also suggested the enhanced hydrological cycle in the tropics during the climatically warm interval of the Coniacian–Santonian Ocean Anoxic Event 3 (OAE-3). Firstly, Hoffman et al. (2003) presented the orbital-scale variations of the organic carbon burials and river discharges from the African continents. They suggested that ocean anoxia and organic carbon burials were triggered by the increased humidity and enhanced river discharge, which could be caused by the latitudinal shifts of the ITCZ. Then, paleoclimatic simulation results (Flögel and Wagner, 2006) further suggested that the enhanced hydrological cycles in the African tropics during the climatically warm intervals were ultimately triggered by increased humidity in the mid-latitude extratropics, instead of the latitudinal movement of ITCZ. Thus, although the results of Flögel and Wagner (2006) are not the direct evidence of the changes of Hadley circulation width, and their time-scales of climate changes are different from our results, the enhanced hydrological cycle in both the tropics and the mid-latitude extratropics during the climatically warm interval of Coniacian–Santonian OAE-3 are indicated, which are trend consistent with our results.".

Other minor changes are as follows:

p.121, line 6: delete /so:

"/so" has been deleted as suggested (Page 2, Line 21 in the revised manuscript).

p.122, line 21: delete been:

"been" has been deleted as suggested (Page 3, Line 30 in the revised manuscript).

p.122, line 25: delete the:

"the" has been deleted as suggested (Page 4, Line 2 in the revised manuscript).

p.124, line 7: Late Cretaceous (and later in manuscript, also Early Cretaceous):

The reason why we used the terms "late Cretaceous" and "early Cretaceous" is because we would like to distinguish the paleoclimatologicaly important time-period of the "mid-Cretaceous" interval from the general categories of the Early and Late Cretaceous (e.g., GTS, 2009). Thus, we didn't change the "early Cretaceous" and "late Cretaceous" as Early and Late Cretaceous.

p.146, Fig. 1: I don't recognized the notion of the significance of red bed deposition in that respect.:

As is pointed out by the referee, the notion of the "Red beds" is not obviously related with the respect of desert distribution changes. However, the "Red beds" is thought to be present in alternating dry and wet seasons, and/so we used the distributions of its deposits as a supporting evidence (proxy) of the distribution of semi-arid climatic zone. Although we did not emphasized the spatio-temporal changes of the red bed distributions, **Fig. 1** revealed that some differences exist between the early and late Cretaceous (i.e., low latitude area was slightly drier in the late Cretaceous than that of early Cretaceous time). Thus, we thought it is important to provide the original data-sets of the spatio-temporal changes of the red bed distribution in **Fig. 1**, although we did not include such discussions in this paper.

p.148, Fig. 3: Write out Alb, Tur, Camp, Maas or explain abbreviations.:

As is pointed out by the referee, we did not explain the abbreviation in **Fig. 3**. It is also similar to the **Fig. 1**. Thus, we added a sentence explaining its abbreviations as follow "Abbreviated stage names are as follows: Ber = Berriasian; Vlg = Valanginian; Hau = Hauterivian; Bar = Barremian; Apt = Aptian; Alb = Albian; Cen = Cenomanian; Tur = Turonian; Co = Coniacian; Sa = Santonian; Camp = Campanian; Maast = Maastrichtian" in the caption of **Fig. 1**.

Fig. 3: Is see some desert islands swimming in the Tethys during Cmp - Maa - is there really evidence for that (I don't think so)?:

The yellow color zone in **Fig.3** represents the distribution of subtropical arid zone, and it is different from the location of desert record indicated as (also) yellow color area. To clearly demonstrate the difference between the location of desert record and the distribution of subtropical arid zone, we revised the **Fig.3**. Pink, yellow, light green and dark green zones, which represent the distribution of tropical humid, subtropical arid, mid-latitude warm humid, and high-latitude temperate zones, respectively, are all indicated in the caption of the **Fig.3**.

In addition, there is an evidence of the presence of eolian sandstone deposits in an isolated island in the Tethys during the Albian–Turonian [e.g., (7): Iberia basin in southern Spain]. Thus, there could be also some evidence of eolian sandstone records in isolated island in the Tethys during the Cretaceous.

p.149, Fig. 4: Very good compilation, but I won't call Coniacian to Maastrichtian as "cool", its still greenhouse climate ("moderate greenhouse").:

The reason why we used the term "cool" in **Fig.4** is to indicate the differences of climate mode between the extremely warm climate of the mid-Cretaceous and relatively cool (even though it is moderately warm) climate of the early and late Cretaceous periods. According to the referee's comments, we added a sentence explaining this differences of climate mode in the caption as follows "**(F)** Inferred climate mode in the early, mid- and late Cretaceous. The mid-Cretaceous is characterized by extremely warm "supergreenhouse" mode, while the early and late Cretaceous are characterized by relatively cool (moderately warm) "greenhouse" mode".

p.151, Fig. 5: Highly speculative and provocative.:

We agreed that **Fig. 5** is highly speculative and provocative figure. But we draw this figure to clearly demonstrate the conceptual scheme of our results of the drastic shrinkage of the width of the Hadley circulation. In addition, we illustrated this figure to indicate the possible presence of the threshold in atmospheric CO_2 level and non-linear response of atmospheric circulation to atmospheric CO_2 increase and/or global warming. Thus, although the **Fig. 5** is maybe highly speculative and provocative figure, we would like to use this figure to demonstrate the conceptual scheme of our results, and to indicate the possible presence of the threshold and non-linear response of atmospheric circulation system, which are the main conclusion of this paper.