Response to Anonymous Referee #1 (Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, C126-C131, 2009)

We would like to thank the anonymous referee #1 for his thorough review and for his relevant remarks, which will certainly contribute to improve our submitted manuscript.
In this author comment, the comments made by the referee will be referred as RC; the authors' comments and answers as Reply.

RC1: This paper considers the effect of spatial resolution on ET derived from remote sensing data over a Chinese oases area using Landsat and Modis data. Generally, this paper covers a very interesting and scientifically relevant topic, but needs many improvements both literary (a native English speaker should check the text) as well as on the presentation of the used methodologies. To my opinion, the authors try to work out too many objectives in a rather small study analysis. In fact, this paper touches so many items, but none of them are provided with an in-depth analysis. In the end, this paper suffers from an accumulation of shallow analyses.

Reply: We gratefully acknowledge this valuable comment. In the revised manuscript we shall improve readability and provide a more clear interpretation of the used methodologies. In addition, we shall present an intensive statistic analysis of the effect of spatial resolution on ET derived from remote sensing data.

RC2: Up-scaling ground observation and remote sensing data is a real discipline itself. Yet, little considerations are given on existing up-scaling techniques from the literature. This seems to be a general flaw of the manuscript. The authors clearly fail in situating their study in a larger framework and proper credits on literature reports is lacking throughout the manuscript. For instance no discussion or situation of the results with respect to published international papers is given. And since the literature on modelling ET is enormous, it is not difficult to find related papers (even papers on ET modelling across different scales).

Reply: Many thanks for the constructive comments. We shall add a literature review of existing methods/studies on modeling ET in the introduction and discussion sections and update our reference list in the revised manuscript.

RC3: 1) Another major drawback of this manuscript is that the authors do not demonstrate the added value of their proposed methodology by using more Landsat images. At this stage, only one image has been used. Hence, to my opinion, conclusions are drawn based on a too few amount of results (for instance evaluating LST values only using 6 numbers). 2) This manuscript also contains poorly explained methods (as indicated below). Sometimes, I really do not understand what the authors mean, or equations are presented without providing the proper context. 3) Also the use of the evaporative fraction for temporal up-scaling is presented in a very confusing way as indicated below. The authors should clearly explain why this method is used,

the made assumptions of this technique, and why its implementation is justified. 4) Also the procedure of collecting ground reference data for surface temperature is lacking. How many measurements per location were collected? Etc.

Reply: Thanks for the great comments. We now answer above comments by point to point:

1) This question really touches on a major limitation of our original submitted manuscript, namely our validation was insufficient. As there were only two eddy covariance systems placed in the JTEX2004 study area, they provided the only in-situ ET data available for the direct validation of our remotely sensed derived results. Unfortunately, there was only a cloud-free Landsat-5 TM imagery during the whole experimental period of JTEX2004. Several Landsat-7 ETM+ SLC-off (gap-filled) imageries inconvenienced the practical applications of them to analysis of scale effect. In order to overcome this data scarce, we shall use more Landsat and Modis images to assess the effect of spatial resolution on remotely sensed derived ET if one assumes that ET derived from remote sensing data are accurate. Therefore, in the revised manuscript results will be extended as you suggest. Of course, we can only combine remote sensing data with routine meteorological data to estimate ET across different scales in the absence of in-situ water vapor flux observations.

2) We shall provide a more clear interpretation of the used methods/equations in the revised manuscript.

3) Please see our response to RC28 as given below.

4) In the revised manuscript, the description of the deployed equipments and a list of the available data in our study will be provided in a newly added table, which will give more information about the procedure of data collection.

RC4: -This title is too long: consider next suggestion “The effect of spatial resolution on remotely sensed derived evapotranspiration of an oasis area in Northwestern China;

Reply: A good suggestion. We shall accept it.

RC5: -As a non-native English speaker, I feel that the grammar needs improvements; For instance on the use of the article “the”. Sometimes the authors should leave it, sometimes they should add it: p1322, L3 “… western China by using the Landsat-Tm and Modis data” or p1322, L10: “of 250 m resolution was syncretized into THE MODIS LST retrieval algorithm”; Is “syncretized” a proper English word? Etc (too many to mention them all). Some paragraphs are well written, other paragraphs are very not tidy;

Reply: The authors admit that our original submitted manuscript is not well written and

the grammar needs improvements. We shall try our best to make it easy to read. And we surely feel that "syncretized" is not a proper word for expression of our intent and it will be replaced with "incorporated" in the revised manuscript.

RC6: -P1322, L3-4: "A relatively high consistency was observed between the TM-based latent heat flux and daily ET estimates **AT ONE HAND** and in-situ measurements **AT THE OTHER HAND**, with relative errors of 9.7% and 8.8%, respectively."

Reply: Thanks! We shall reword the sentence as you suggest.

RC7: -P1322,L13-17: this is not a well written sentence… Etc.

Reply: The authors agree with the referee's comment and we shall rewrite this sentence in the revised manuscript.
The existing text will be amended to read, "Our results indicate that MODIS data may result in a rough estimate of ET over an inhomogeneous landscape, compared to that derived from TM data. But when used in conjunction with in situ meteorological forcing data the MODIS-based ET estimate can effectively depict the basic spatial distribution trend of ET process."

RC8: For the readers comfort, please stick to ET. Do not use ET and latent heat flux together.

Reply: Yes, the authors acknowledge that there is a confused usage of terminology in our original manuscript and we shall replace "latent heat flux" with "instant ET" in the revised manuscript.

RC9: -P1323, L10: this is a very limited amount of references! As the literature on RS based ET is huge, you should at least provide some more references, and perhaps also some review papers?

Reply: We agree with the point and we shall provide more references in the revised manuscript.

RC10: - This list of objectives is not well formulated. It should be "Deriving different spatial resolution…" and "Introducing a simple method…" and "Verifying …" and "Deriving and validating remotely sensed ET from LANDSAT and MODIS against eddy covariance measurements…" etc. To my opinion the use the word "authentic" is not right.

Reply: The authors agree with the comment. We shall delete the 1^{st}, 2^{nd}, 3^{rd}, 5^{th} items from the list in accordance with RC1 since it is impossible to work out too many objectives in this paper due to the limitation of paper length.

RC11: -P1325, L5: "…the middle reaches of the Hei river basin where is an arid inland river basin in the…"; there is something wrong with the sentence;

Reply: Thanks! This sentence will be amended to read, "…the middle reaches of an inland river in the…"

RC12: -P1325, L20: "The Terra-MODIS images used in this study were at 10:30 LT"; there is something wrong with the sentence;

Reply: The authors admit that there is an expression error in the sentence. The sentence will be amended to read, "The AM Terra-MODIS overpass was around 10:30 local time over the study area."

RC13: - Include references on how the LANDSAT image was atmospherically corrected!

Reply: We atmospherically corrected that cloud-free Landsat-5 TM imagery using 6S model (Vermote, E.F. et al., 1997a; Vermote, E. et al., 1997b) in our original manuscript. When 6S model (FORTRAN code) was used, its main parameters were set as follows:
Satellite spectral bands = 25, 27, 28, 29, 30 corresponding with bands 1, 3, 4, 5 and 7 of landsat5 TM image.
Atmospheric model = midlatitude summer, but the default value of the total atmospheric water content (2.93g/cm2) was replaced with 0.95 g/cm2, i.e. the spatial mean value of the remotely sensed water content over the Jinta oasis by using MODIS data from Eq. (10).
Aerosol model = continental aerosol
The meteorological visibility = 15 km.
Directional surface effects were considered and Roujean's BRDF model was adopted (Roujean et al., 1992).
The AC-Fig. 1 below shows atmospheric transmittances for Landsat-7 ETM+ bands 1, 2, 3, 4, 5 and 7 from an overpass on August the 20th 2004 at 11:50 am BST. The atmospheric path is between the land surface target and satellite sensor. Here the solar zenith angle was 34.78°and the atmospheric water content was 1.0 g/cm^2 and total ozone content was 0.30 cm-atm. The path radiances for bands 1, 2, 3, 4, 5 and 7 are 27.80 , 17.20 , 11.20 , 5.12 , 0.30 and 0.05 W m^{-2} sr^{-1} μ m^{-1}, respectively.

AC-Fig. 1

RC14: -P1326, L 17: "component L↓ can take ground observed values"; there is something wrong with the sentence; "component L↓ can be taken from ground observations"?

Reply: We admit that the sentence contains an expression error, and we shall accept the referee's suggestion in the revised manuscript. As solar radiation observations are not always available for our study area, the radiation can be estimated based on Motran4.0 model.

RC15: -P1327, L 6: "Model and its application"; I do not understand why you bring forward its application. This is not the right place.

Reply: Yes, it is ill-considered to mention the model's application here. The word "application" will be removed from our revised manuscript.

RC16: Equation 4: why using the square?

Reply: Choudhury et al. (1994) found that the relationship between NDVI and fractional cover can often be expressed as

$$P_v = 1 - \left(\frac{NDVI_{\max} - NDVI}{NDVI_{\max} - NDVI_{\min}}\right)^p$$

Where NDVImax is the NDVI for complete vegetation cover and NDVImin is NDVI for bare soil. The coefficient p is a function of leaf orientation distribution within the canopy, where erectophile to planophile canopies have values between 0.6 and 1.25. But in practical applications the parameter p is often appointed arbitrarily by users instead of depending on observations. Carlson and Ripley (1997) and Gillies et al. (1997) proposed a different relationship as follows

$$P_v = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}}\right)^2$$

This relationship has a fixed form and it is easy to use. Thus we adopted it in our study.

RC17: what interpolation method? Please briefly describe!

Reply: This interpolation method was proposed by Ding et al (1989) and Wu et al (1993) and applied by Ma (2001) in Hei river basin of Northwestern China to derive the regional distribution of air temperature at reference height:
Remotely sensed derived LST is taken as initial temperature field and the value at pixel (i,j) is smoothed by the smoothing method of nine points

$$T^*_{sfc(i,j)} = \begin{bmatrix} 4T_{sfc(i,j)} + 2(T_{sfc(i+1,j)} + T_{sfc(i-1,j)} + T_{sfc(i,j+1)} + T_{sfc(i,j-1)}) \\ + T_{sfc(i+1,j+1)} + T_{sfc(i-1,j+1)} + T_{sfc(i+1,j-1)} + T_{sfc(i-1,j-1)} \end{bmatrix} / 16$$

When there are n observation sites in a study region, the difference between the smoothed LST field and the air temperature $T_{a(k)}$ on the number k (k=1,2,…,n) site

is

$$dT_{a(k)} = T^{*}_{sfc(k)} - T_{a(k)}$$

If all the differences $dT_{a(k)}$ $(k = 1,2,...,n)$ are known, the difference at pixel (i,j) is derived as following

$$dT_{a(i,j)} = \sum_{k=1}^{n} [r_k^{-2} \cdot dT_{a(k)}] / \sum_{k=1}^{n} r_k^{-2}$$

Where r_k is the distance between the pixel (i,j) and the number *k* (*k*=1,2,…,*n*) site. Then the regional distribution of air temperature can be obtained

$$T_{a(i,j)} = T^{*}_{sfc(i,j)} - dT_{a(i,j)}$$

RC18: Is the soil heat flux equation origination from Ma et al (in Chinese)? Perhaps he parameterized it differently, but I did not know that he derived the equation.

Reply: Yes, the equation was not derived by Ma et al but proposed by Menenti et al (1991) and Bastiaanssen (1995).
Because Ma et al have applied successfully this soil heat flux equation in the Hei river basin in 1990s, so we indirectly introduced the equation from Ma's paper (in Chinese). Of course, we shall indicate the original literatures of this soil heat flux equation in our revised manuscript.

RC19: -P1327, L13-21: To my opinion this is not the right place. This is a discussion.

Reply: The authors accept this opinion and we shall place this part in sect. 1 in our revised manuscript.

RC20: -P1328, L1: Section 3.2.: better "Spatial upscaling of the TM estimates to the MODIS grids".

Reply: We deem that this new subtitle is better than the original one, so we will accept it.

RC21: -P1328, L1-12: very sloppy formulation! Contains spoken language,typos,etc. I do not understand what the authors are trying to tell. How can you use VIS and NIR from TM with ground measured TIR in combination with Modis?

Reply: Since this paragraph deviates from the motif of our paper, we decide to delete it in our revised manuscript. As regard how we use VIS and NIR information from TM with ground measured TIR temperatures to get 30 m resolution LST, more explanation will be given in our response to RC23.

RC22: -Why did the authors use TM and Modis imagery from different dates? Since Modis has a daily coverage, the same day could be used…

Reply: In our study it is assumed that the regional distribution of both NDVI and albedo over the study area keep invariant during several days. So the 30 m resolution fractional vegetation cover P_v derived from VIR (band 3) and NIR (band 4) of TM imagery is able to be used to derive another day's 30 m resolution LST using Eq. (7). In addition, the 1 km resolution Terra-Modis LST product imagery (available from NASA's official site) for the overpass on 10:30am LT, 3 July 2004 over the JTEX2004 area contains many invalid values, so we had to select the MODIS-LST imagery in another day.

RC23: -Equation 7. Since LST is used in the fourth power, there is no linear relation and thus it is mathematically incorrect to split it in the way you do! Consequently, the authors can not use this as such since some assumptions are involved;

Reply: We disagree in this point. In our study, mean surface temperature of this 30 m mixed-pixel (note that it is not the TM TIR resolution), according to Eq. (7), is derived as

$$\overline{T} = \sqrt[1/4]{[(1-P_v)\cdot\varepsilon_{soil}\cdot T_{soil}^4 + P_v\cdot\varepsilon_{veg}\cdot T_{veg}^4]/\overline{\varepsilon}}$$

Where T_{veg} and T_{soil} are the ground-measured surface temperatures for full vegetation surface and full bare soil surface, respectively. P_v is 30 m resolution vegetation cover fraction derived from TM-NDVI and it keeps invariant during several days. ε_{soil} and ε_{veg} are broadband emissivities for soil and vegetation surfaces, respectively, and they can be estimated as follows

$$\varepsilon_{broadband} = \frac{\int_0^\infty \varepsilon(\lambda)B(\lambda,T)d\lambda}{\sigma T^4}$$

Where $\varepsilon(\lambda)$ is the spectrum of surface emissivity and in calculation the 3.5 μm to 14.5 μm spectral range is enough. $B(\lambda,T)$ is plunk function. According to the landcover map of the JTEX2004 area, we select the emissivity spectrums of five materials from MODIS/ASTER emissivity spectral libray (available at: http://www.icess.ucsb.edu/modis/EMIS/html/em.html and http://speclib.jpl.nasa.gov/) to depict the spatial distribution of land surface emissivity:
Sandy soil stands for bare soil surface.

Dune sand stands for desert surface.
Green grass stands for grassland surface.
Leaf-1 stands for cropland surface and leaf-2 stands for woodland surface.

AC-Fig. 2

$\bar{\varepsilon}$ is the mean emissivity for this 30 m mixed-pixel and it is derived from Eq. (3). For P_v=1.0, $\bar{\varepsilon}$ is equal to ε_{veg}, and for P_v=0.0, $\bar{\varepsilon}$ is equal to ε_{soil}.

RC24: -Equation 8. In fact you assume a linear mix. Can this be justified? –P1329, L22: the authors mean brightness temperature?

Reply: The authors agree that Eq. (8) gives a linear mix in fact. But at present there is no better or widely accepted method depicting this relationship between different scales, so we can use an approximate method as Eq. (8) to get mixed-pixel mean properties.
-P1329, L22: Thanks! "bright" should be corrected as "brightness".

RC25: -Equation 10. How sensitive are the results on LST if slight different alpha and beta coefficients are used?

Reply: We selected a Terra-MODIS imagery covering the JTEX2004 area with overpass on 10:00 LT 8 August 2004 and derived the regional distribution of LST using different alpha and beta values. The figures below show that Eq. (10) is sensitive to beta coefficient but not sensitive to alpha coefficient.

AC-Fig. 3a

AC-Fig. 3b

RC26: -P1330 L7-11: the authors proportionally resize the LST using NDVI? Or what did the authors? This is not very clear.

Reply: No, we did not proportionally resize the LST using NDVI. In our study, we resized the spatial size of MODIS bands 31 and 32 to 250 m equivalent to the spatial size of MODIS VIS and NIR bands, thus land surface VIS and NIR information can be utilized in LST retrieval while land surface TIR information kept invariant. So we obtained the pseudo 250 m resolution LST from Eq. (9) and (10).

RC27: -P1330, L12: here the authors should better stress that TM produceds instantaneous ET, and that this value should be converted to daily values.

Reply: We accept this opinion. In our revised manuscript, such emphasis will be included.

RC28: -Equation 11. This Eq needs clarification: what is ETref here? Is that the potential reference crop ET, or something else? In that case ETact/ETpot,ref equals the crop factor K0. Or do the authors want to use the fact that the Evaporative Fraction (EF) (which is by definition LE/(LE+H)) more or less is conservative during the day and use that to convert instantaneous values to daily values? I think it is the last case, but then this should be clearly mentioned and proper reference should be given to this statement! It is common knowledge that this conservation of EF during daytime is only an approximation, and as such the authors should clearly state why for their case the assumption can be made!

Reply: Actually, we think the referee did not fully understand our temporal up-scaling method partly because of being not good for our writing.
In our manuscript, ETref is the potential reference crop ET and it is computed using FAO56 Penman-Monteith Equation:

$$ET_{ref} = \frac{0.408\Delta(R_n - G) + r\dfrac{900}{T+273}U\ (e_s - e_a)}{\Delta + r(1 + 0.34U\ )}$$

Therefore, EFref (the reference evapotranspiration fraction) here is equivalent to crop factor K0 and it is not LE/(LE+H). Both Fig. 3 in our original submitted manuscript and newly added figure (Please see our response to RC37) show that EFref keeps invariant during daytime (local time) and it has the conservation property similar to the ratio LE/(LE+H) or LE/(Rn-G0) , so we can use Eq. (11) to convert instant ET to daily ET. Moreover, many daytime above-canopy sensible heat flux values collected from eddy covariance system at the central oasis (site #5) during the JTEX2004 experimental period were negative while only a few of daytime sensible heat flux values collected at the east edge of Jinta oasis (site #1) were negative, which makes the ratio LE/(LE+H) difficult to be utilized in our study. Further, both radiant and aerodynamic effects are included in EFref coefficient due to the physical meanings of FAO56 Penman-Monteith Equation. Therefore, we think that the EFref method is better than the LE/(LE+H) method for our study.

RC29: -P1330, L22: from this I interpret that the authors are using ET pot for a reference crop? Or is it actual evapotranspiration?

Reply: No, ETref,day is not ET pot measured by evaporation pan or actual ET. It is daily potential reference crop ET computed from routine meteorological data using FAO56 Penman-Monteith Equation.

RC30: -P1332, L4: use “reference data” in stead of “ground truth”.

Reply: It should be in P1331,L4.
Good suggestion. We accept it.

RC31: -P1332, L7: smallest instead of least ?; “almost twice As high as …”.

Reply: It should be in P1331, L4.
Thanks! We will rectify these grammar errors.

RC32 : -P1332, L10-13: this is not clearly phrased!

Reply: It should be in P1331, L10-13.
Thanks! We will rephrase this part as follows:
“It is evident that the RMSE for 1 km MODIS LST varies over different land surface types. Since LST is the key input data for our ET model, a variation in the accuracy of LST retrieval may result in the variation in the precision of ET prediction over different land surface types.”

RC33: -P1332, L10-14: “it is OBSERVED”, in stead of “seen” (also in L25); un-proper use of the word “factually”.

Reply: It should be P1331, L14.
Thanks! The authors accept the comment; and the word “factually” will be replaced with “better” in our revised manuscript.

RC34: -P1332, L17: “lightly changed”? the authors mean “slightly”?

Reply: It should be P1331, L17.
Thanks! “lightly” should be corrected as “slightly”

RC35: -P1333, L19: “can suffer less”? This is not the right expression.

Reply: We accept the referee’s comment. This sentence will be rectified in our revised manuscript.

RC36: -Fig.2.: what about the other sites? Which sampling scheme was used to collect reference LST values at each site? Why are there different amount of sites in both figures?

Reply: During the JTEX2004 experimental period, LST was continuously measured by Infrared Radiometer at 10 m height on 1# (oasis surface), 3# (desert surface), 4# (bare sandy soil surface) and 8# (oasis surface) observation sites and reference LST data were automatically recorded once every ten minutes.
On other sites land surface temperature was only irregularly observed by holding type

portable Infrared radiometer at overpass times of Landsat-TM and Terra-MODIS.
We will supplement the 3# site data in Fig. 2a in our revised manuscript.

AC-Fig. 4. The new Fig. 2a in our revised manuscript.

RC37: -Fig. 3: what about the EF of the other observation sites? Include them in the figure.

Reply: During the JTEX2004 experimental period, two eddy covariance flux systems were deployed on #1 and #5 observation sites. The EFref for 1# site had the diurnal variation characteristic similar to that for 5# site. Please see the figure below:

AC-Fig. 5.

RC38: -Fig. 4.: to my opion, the use of 6 values is far too low for drawing conclusion on the implemented methodology. What is "RE" in the legend of subfigures? Latent heat fluxes are instantaneous values? Why including such a large range in the figures, if for instance LST values range from 25 to 35℃ (the authors give a range from 0-100 ℃)?

Reply: We admit that the use of 6 values is low for drawing conclusion on our used methodology. However, there was only a cloud-free Landsat-5 TM imagery available for our study during the JTEX2004 experimental period. Several Landsat-7 ETM+ SLC-off (gap-filled) imageries inconvenienced the practical applications of them to analysis of scale effect. In order to overcome this data scarce, we shall use more Landsat and Modis images to assess the effect of spatial resolution on remotely sensed derived ET if one assumes that ET derived from remote sensing data are accurate.
"RE" in the legend means the relative error of estimates.
Latent heat fluxes are instantaneous observation values from eddy covariance system.
With regard to the range in the figures, the authors' original intention is that a large range can make readers easier to understand the results of this investigation. In view of the referee's opinion, we would like to modify the figures to a more appropriate display range for readers comfort.

RC39: -Fig.5: what are the R^2 and the slope and intercept of the regression?

Reply: With regard to Fig. 5, the R^2 (determiant coefficient or interpretative variance) is 0.36 and the correlation coefficient is 0.60. The slope and intercept are 0.51 and 156.7, respectively.

RC40: -Fig.6. Include units!

Reply: Units have been inside the figure. We will modify legends to a appropriate size for readers comfort.

RC41: -Fig.8. “Fine days”? What do the authors mean? What is the purpose of this figure?

Reply: “Fine days” means clear-sky condition. In view of the perplexity of this expression, we will rectify the expression.
The purpose of fig.8 is to show that the advantage of the moderate resolution remote sensing data at ET mapping on a large scale. According to this comment we shall remove it from our revised manuscript since this figure deviates from the motif of our paper.

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