Modeling Lake Titicaca Daily and Monthly Evaporation

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Answer to Referee 1:

C1: The abstract part should show the essence of the paper, including the significance of this research, methods used and conclusions. However, the authors paid too much attention to the research results while ignoring the data source and the significance of this paper I suggest the authors add the content I mentioned above in the abstract

Answer to comment-C1:

- Yes we will include the recommendations about the significance of this research and as well about the new data used on this paper. Yes the interest of the paper is not only the results, mainly are the models defined for the climate change assessing, on which context with the discussions about the possibility of using, and finally is to show the results and between different time scales.

New abstract

Abstract Lake Titicaca is a crucial water resource in the central part of the Andean Mountain range, which is one of the lakes most affected by climate warming. Since surface evaporation explains most of the lake´s water losses, reliable estimates are paramount for the prediction of global warming impacts on Lake Titicaca and for the region´s water resources planning and adaptation to climate change. Evaporation estimates were done in the past at monthly time steps and using the four methods, as follows: water balance, heat balance, and mass transfer and Penman´s equation. The obtained annual evaporation values showed significant dispersion. This study used new, daily frequency hydro-meteorological measurements. Evaporation losses were calculated following the mentioned methods using both, daily records and their monthly averages, to assess the impact of higher temporal resolution data in the evaporation estimates. Changes in the lake heat storage needed for the heat balance method were estimated based on the morning water surface temperature, because convection during nights results in a well-mixed top layer every morning over a constant temperature depth. We found that the most reliable method for determining the annual lake evaporation was the heat balance approach, although the Penman equation allows an easier implementation based on generally available meteorological parameters. The mean annual lake evaporation was found to be 1700 mm year^{-1}. This value is considered an upper limit of the annual evaporation since the main study period was abnormally warm. The obtained upper limit lowers by 200 mm year^{-1} the highest evaporation estimation obtained previously, thus reducing the uncertainty

in the actual value. Regarding the evaporation estimates using daily and monthly averages, these resulted in minor differences for all methodologies.

Key words: Lake Titicaca, heat balance, water balance, lake evaporation.

C2: The introduction part is basically organized well. However, the methods or the models are ignored in this section, additional information on the theoretical background would be useful here. I suggest moving 3.1 section here

Answer to comment-C2:

- Yes is a good idea to move to this chapter the section 3.1, also beside the theoretical improvement the paper objective also will be refined based on the above background.

1 Introduction

Lake Titicaca, the largest freshwater lake in South America, is located in the endorheic Andean mountain range plateau – Altiplano, straddling the border between Perú and Bolivia (Fig. 1). The lake plays an essential role in shaping the semiarid Altiplano climate, feeds the downstream Desaguadero River and Lake Poopó (Pillco & Bengtsson, 2006; Abarca-del-Río et al., 2012) and supplies the inhabitants with water resources for domestic, agricultural, and industrial use (Revollo, 2001). Anthropogenic pressure on the Altiplano water resources has increased during the last decades due to population growth and increased evapotranspiration losses (FAO, 2011; Canedo et al., 2016; Satgé et al., 2017), as well as due to industrial pollution (UNEP, 1996; CMLT, 2014). The challenge of managing water resources in the Altiplano Basin is further exacerbated by climate conditions: annual rainfall is highly variable (Garreaud et al., 2003), while warming in this region exceeds the average global trend (López-Moreno et al., 2015) which is expected to intensify the evaporation from the lake surface and the evapotranspiration losses from the whole basin. The combine impact of these pressures becomes evident at the downstream end of the system, where Poopó Lake is situated. In recent years this lake suffered extreme water shortages, including its complete drying out in December 2015 (Satgé et al., 2017).

Lake Titicaca has a large surface area of about 8500 km^2 on average. Over a certain water surface level, the lake spills at the South East end and feeds the Desaguadero River. However, the major water output from Lake Titicaca is due to evaporation, which accounts for approximately 90% of the losses (Roche et al., 1992; Pouyaud, 1993; Talbi et al., 1999; Delclaux et al., 2007). In recent years, Lake Titicaca's level dropped below the outlet threshold for some periods. Thus, a small increase in evaporation or decrease in precipitation may turn the lake into a closed system with no outflow.

Since evaporation dominates the water balance in Lake Titicaca, it is essential to improve the knowledge of the lake evaporation. This is especially important in light of anthropogenic pressure and due to evident strong global warming that experiencing this region. Previous studies of Lake Titicaca evaporation have all been based on monthly meteorological observations. Due to the importance of lake evaporation, detailed calculations using daily as well as monthly observations may be necessary. Consequently, this paper investigates different methods for calculating evaporation using both daily and monthly data, in addition we discussed the possibility for the appropriate evaporation models at both time scales to be used on the study the climatic functioning and sensitivity. The main problem with the Lake Titicaca evaporation estimation is the lack of high resolution temporal data. Taking into account only the mass transfer models for different time scale, Singh et al. (1997) calculated monthly evaporation. However, doing the same calculations on a daily basis could give radically different results. For both time scales, the evaporation estimation could be more sensitive to vapor pressure.

On the other hand, random errors in input data could have a significant effect on evaporation estimation at a monthly scale rather than at daily scale (Singh et al., 1997).

The Lake Titicaca surface water is cold with a temperature that remains 12-17 °C throughout the year, and below 40 m depth the temperature is almost constant (Richerson et al., 1977). The water is usually warmer than the air during day time, which means that the air immediately above the lake is unstable. The air temperature shows large diurnal variations, often exceeding 15 °C in summer. At an average terrain elevation above 4000 m.a.s.l. the solar radiation is strong and the atmospheric pressure is low, which means that the ratio between sensible and latent heat flux (Bowen ratio) is lower than at sea level. To determine the evaporation rate using the aerodynamic mass transfer approach, the atmospheric vapor pressure and surface temperature must be known. Furthermore, a wind function must be used because the atmosphere over Lake Titicaca is unstable most of the time. This means that the wind function may be different from the function used for most other lakes.

It can generally be assumed that during a year the lake water temperature returns to the value at the beginning of the year. Thus, for the heat balance, it is sufficient to know the annual net radiation, provided that the sensible heat flux can be estimated from the constant Bowen ratio. When using the method for shorter time periods, the time variation of the lake water temperature profile must be known. The heat balance approach and the aerodynamic method can be combined. The Penman method is such a combined approach. A wind function must be included also in this approach.

C3: Method: In this part, the authors pay too much attention to theoretical background, in my opinion, basic introduction and literature about the Theoretical background should be removed to introduction part

Answer to comment-C3:

- Yes some of the theoretical background will be removed or moved to the upper. Yes the references to the equations will be included.

C4: Four evaporation estimation methods were applied in this study, water balance, energy balance, mass transfer, and the Penman method, I think the authors could add a reference for the equations.

Answer to comment C4:

- Yes the authors of all the equation will added.

On the following section (3 Methods) were answered to comments C3 and C4 and Minor comments:

Answer to comment-5: Final comments.

- Yes, we realized that units must be included, also we will correct the symbols and the reference chapter.

3 Methods

3.1 Lake evaporation models

Four evaporation estimation conventional methods were applied in this study, water balance, energy balance, mass transfer, and the Penman method. These approaches have previously been used by other researchers to estimate Lake Titicaca evaporation at a monthly time step (Carmouze, 1992; Pouyaud, 1993; Delclaux et al., 2007). The methods are briefly described as follows.

Energy balance approach

The energy balance approach (Maidment, 1993) which comes from energy balance equation in term of evaporation and multiply by the coefficient of latent heat to convert it into units of energy is:

$$\lambda E = \frac{R_n - Q_{heat}}{1+\beta}$$

(1)

Where λ is the latent heat vaporization (J Kg^{-1}), E is evaporation rate (mm day^{-1}), R_n is net radiation (w m^{-2}), Q_{heat} is heat storage within the water (W m^{-2}), and β is the Bowen ratio (Bowen, 1926):

$$\beta = \gamma \frac{T_w - T_a}{e_w - e_a}$$

(2)

$$\gamma = \frac{c_p p_a}{0.622\lambda}$$

(3)

where γ is the psychrometric constant (mbar $°C^{-1}$), T_w and T_a are the surface water and air temperature (°C), respectively, e_w and e_a are the water surface and air vapor pressures (Pasc), respectively, c_p is the specific heat capacity (J Kg^{-1} $°C^{-1}$), and Pa is the atmospheric pressure (Kg Pa). The psychrometric constant and thus, also the Bowen ratio, are lower at this high altitude than at sea level. The net radiation is the sum of net short-wave and net long-wave radiation. The net short wave radiation is R_s (1- albedo), where R_s is the solar radiation reaching the lake (W m^{-2}). The atmospheric long-wave radiation as well as the back radiation are computed from the Stefan law. The emissivity of the water is well known, it was set to 0.98 and the emissivity atmosphere must be known. The emissivity of the atmosphere depends on humidity, temperature, and cloudiness. Atmospheric emissivity accounting for clouds was proposed by Crawford and Duchon (1999):

$$\varepsilon_e = (1-s) + s\varepsilon_o(T_a, e_a)$$

(4)

$$s = \frac{R_s}{R_{s,o}}$$

(5)

$$R_{s,0} = R_a e^{\left(\frac{-0.0018 P_a}{K_t \sin\phi_{24}}\right)}$$

(6)

$$\varepsilon_o = 1.18\left(\frac{e_a}{T_a}\right)^{\frac{1}{7}}$$

(7)

Where s is the proxy cloudiness defined as the ratio of measured incoming solar radiation R_s (W m^{-2}) to the solar radiation received for clear sky conditions $R_{s,o}$ (W m^{-2}), ε_0 is the emissivity in clear-sky condition, which is determined from the vapor pressure e_a expressed in hPa and T_a temperature in Kelvin. The Φ_{24} is mean daily sun angle. The constant 1.18 describes the attenuation defined for the region according to Lhome *et al*. (2007). The extraterrestrial solar radiation R_a (W m^2) is determined as function of local latitude and altitude, and time of year using the turbidity coefficient K_t=0.85.

The energy equation is fairly easy to use over a full year, since the lake water usually returns to its initial state when computations were started, or when Q_{heat} equals zero (W m^{-2}). When using the approach over shorter periods the variation of the water temperature in the lake must be accounted for. In Eq. (1), the change of heat storage is included. From temperature water profiling observations, it was assumed that the water temperature below 40 m does not change from month to month. The temperature, T_w, above this mixing depth, h_{mix} (m), changes but remains almost homothermal after convective mixing during night (Richerson et al., 1977), which also is corroborated by our own field investigations. Thus, the change of heat content can be estimated from measured surface temperature:

$$Q_{heat} = \rho c_p \frac{V_{mix}}{A_{lake}} \frac{\partial T_w}{\partial t} \quad (8)$$

Where ρ is density of water (kg m^{-3}), c_p is the specific heat capacity of water, and V_{mix} is the volume above the mixing depth (km^{-3}). Carmouze et al. (1992) introduced the concept of exchange of heat between surface and deep water using the energy balance concept. The results of Carmouze *et al*. (1992) were compared to the calculation results in the present study.

Mass transfer approach

The mass-transfer aerodynamic approach is used in various models based on Dalton's law (Dalton, 1802). The latent heat transfer is related to the vapor pressure deficit. Most often a linear wind function is used (e.g., Carmouze et al., 1992)

$$E = (a + bU)(e_w - e_a) \quad (9)$$

Where E is evaporation rate, U is wind velocity (m s^{-1}), (e_w - e_a) is vapor pressure deficit (mbar). The parameter a accounts for unstable atmospheric conditions. Carmouze *et al*. (1992) used a=0.17 (mm $mbar^{-1}$ day^{-1}) and b=0.30 (mm $mbar^{-1}$ s m^{-1}).

Penman approach

The Penman equation is a combination of energy balance and mass transfer for evaluating open water evaporation (Penman, 1963):

$$E = \frac{\Delta}{\Delta + \gamma} \frac{(R_n - Q_{heat})}{\lambda \rho} + \frac{\gamma}{\Delta + \gamma} c(a' + b'U)(e_s - e_a) \quad (10)$$

Where E is open water evaporation. The slope of the water pressure-temperature curve is denoted by Δ (K Pa s^{-1}), e_s-e_a is the saturation deficit of the air (K Pa), here e_a is dependent on the relative humidity (%). Delclaux et al. (2007) applied the Penman equation to Lake Titicaca using a' = 0.26 and b' = 0.14 and c=1 after optimizing (mm day^{-1} mbar).

Lake water balance model

The water balance approach was applied to calculate water levels in Lake Titicaca in a previous study by Pillco & Bengtsson (2007). The water balance is:

$$A_{lake}\frac{\partial h}{\partial t}=(P-E)A_{lake}+Q_{in}-Q_{out}$$

(11)

Where $\partial h/\partial t$ represents change in water depth, *P* is precipitation on the lake (mm), *E* is evaporation from open water (mm day^{-1}), A_{lake} is water surface of the lake (km^{-2}), which is a function of depth, Q_{in} is inflow to the lake, and Q_{out} represents the outflow from the lake (m^3 s^{-1}). Computations were carried out at a monthly time scale for two periods, one for 1966-2011 also for 2015-2016. As already pointed out, the most reliable method of computing evaporation over long periods is probably the water balance method. However, the computation only can be general, since the inflow to Lake Titicaca is not measured in all rivers.

Possible errors when using monthly averages

The evaporation during individual days is not important for the water balance but only over longer periods as months. However, since the equations for calculating evaporation are not linear, the monthly evaporation computed from monthly mean meteorological data may differ from what is found when data with higher time resolution are used. In the aerodynamic approach the wind speed is multiplied by the vapor deficit. The energy balance approach includes the Bowen ratio, which may differ from day to day and can even be negative for certain periods. If high atmospheric vapor pressure is related to strong winds, the aerodynamic equation using monthly means can yield lower evaporation estimates than when daily values are used. This is further discussed below. The Bowen ratio changes during a month. When the net radiation is large, the air temperature is likely to be rather high but not necessarily related to high vapor pressure. For this situation, the Bowen ratio is relatively high and the computed evaporation higher than it would have been using a constant monthly Bowen ratio. This means that using monthly averages, the computed evaporation will tend to be low.

C5: In the conclusion part, it would be more comprehensive and clear for the authors to conclude the significance as well as the limitation of the research, and with stating the limitations of this research, the suggested research direction for continued studies could be given at the end of this part.

Answer to comment-5: Conclusions

- About the limitations and the advantages about the models used we will describe, especially in respect to models to be used for climate changes assessing at different time scales. Then will have the significance of the study, but also pointing out some recommendations that the models used might improve it in the future using spatial observation data for instance.

6 Conclusions

Due to uncertainty of most observed data such as river inflow to Lake Titicaca, and mainly the discharge data, it might be no easy to improve the water balance results; then it is suggested that the most reliable method of determining the lake evaporation is using the heat balance approach. To estimate the lake evaporation using this method, heat storage changes must be known. Since convection from the surface layer is intense during nights resulting in a well-mixed top layer every morning, it is possible to determine the change of heat storage from the measured morning surface temperature. The lake evaporation is fairly uniformly distributed over the year with lows between July and September. The mean annual evaporation is about 1700 mm year^{-1}, and the mean monthly evaporation is 141.8 mm month^{-1}. When using the mass transfer approach, the required coefficients in the aerodynamic equation was set so that the mean annual evaporation agreed with that obtained from the heat balance calculations. These coefficients were found to be lower than coefficients used in previous studies. Also, when using the mass transfer approach, the evaporation was found to be lowest in July - September.

However, for the climate changes effect on Titicaca Lake evaporation assessment purposes the practical approach rather than the two empirical models might be the Penman equation, one due to available observed data for this lake, and two due to integral behavior of the equation. Also in comparison with the two models proposed in Delclaux et al. (2007) for modeling the lake evaporation, where the first model only depends on the solar radiation data, and the second one depends plus on the air temperature factor; thus both models cannot be applied broadly. The Penman model based on the adjusted wind coefficient, the mean annual evaporation is 1620 mm year^{-1} and the mean monthly is 135 mm month^{-1}. As so far, monthly evaporation computed using daily data and monthly means resulted in minor differences. The most practical model for using at daily scale might be the mass transfer approach and the Penman in comparison to energy balance approach for being high demand observed data. Particularly the Penman equation at daily temporal scale correctly might applied for the climate changes assessment at this altitude. Nonetheless, according to spatial available data from remote sensing, the evaporation equations used at daily and month scales could be applied from now for improving the spatial pattern of the lake evaporation. Since we had really extreme single warmer days during the period 2015-2016 due to El-Niño phenomenon, must be expected to have higher daily rates of evaporation; therefore the application of the models at both time scales for the study period we believe that was found the upper limits of yearly evaporation.

Minor comments:

Answer to comment-5: Final comments.

- Yes, we realized that units must be included, also we will correct the symbols and the reference chapter.

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Answer to Referee 2:

Specific comments:

P2L13: why are daily observations/estimates necessary? It's not clear from the introduction. Please elaborate.

Answer to P2L13:

- Is correct in the Introduction/objective, abstract and in the discussions chapters it was not highlighted in respect to daily evaporation computation. In fact today is necessary to have the models at time scale for testing climate change scenarios outputs. According the previous studies of evaporation (at daily and month scales) depending on model scale used the results obtained might differentiated as well. This aspect will be elaborate in the introduction part definitely.

  Yes, as it was mentioned in above many empirical models were used at month scale for this lake, but still we have the curiosity on computing at daily scale since for first time we have access to high resolution data, second in order to test the climate changes scenarios we will need to have the models at this scale as well. Finally, we think that the results of evaporation might improve from this perspective.

Abstract

Lake Titicaca is a crucial water resource in the central part of the Andean Mountain range, which is one of the lakes most affected by climate warming. Since surface evaporation explains most of the lake´s water losses, reliable estimates are paramount for the prediction of global warming impacts on Lake Titicaca and for the region´s water resources planning and adaptation to climate change. Evaporation estimates were done in the past at monthly time steps and using the four methods, as follows: water balance, heat balance, and mass transfer and Penman´s equation. The obtained annual evaporation values showed significant dispersion. This study used new, daily frequency hydro-meteorological measurements. Evaporation losses were calculated following the mentioned methods using both, daily records and their monthly averages, to assess the impact of higher temporal resolution data in the evaporation estimates. Changes in the lake heat storage needed for the heat balance method were estimated based on the morning water surface temperature, because convection during nights results in a well-mixed top layer every morning over a constant temperature depth. We found that the most reliable method for determining the annual lake evaporation was the heat balance approach, although the Penman equation allows an easier implementation based on generally available meteorological parameters. The mean annual lake evaporation was found to be 1700 mm year^{-1}. This value is considered an upper limit of the annual evaporation since the main study period was abnormally warm. The obtained upper limit lowers by 200 mm year^{-1} the highest evaporation estimation obtained previously, thus reducing the uncertainty in the actual value. Regarding the evaporation estimates using daily and monthly averages, these resulted in minor differences for all methodologies.

Introduction/objectives

Lake Titicaca, the largest freshwater lake in South America, is located in the endorheic Andean mountain range plateau – Altiplano, straddling the border between Perú and Bolivia (Fig. 1). The lake plays an essential role in shaping the semiarid Altiplano climate, feeds the downstream Desaguadero River and Lake Poopó (Pillco & Bengtsson, 2006; Abarca-del-Río et al., 2012) and supplies the inhabitants with water resources for domestic, agricultural, and industrial use (Revollo, 2001). Anthropogenic pressure on the Altiplano water resources has increased during the last decades due to population growth and increased evapotranspiration losses (FAO, 2011; Canedo et al., 2016; Satgé et al., 2017), as well as due to industrial pollution (UNEP, 1996; CMLT, 2014). The challenge of managing water resources in the Altiplano Basin is further exacerbated by climate conditions: annual rainfall is highly variable (Garreaud et al., 2003), while warming in this region exceeds the average global trend (López-Moreno et al., 2015) which is expected to intensify the evaporation from the lake surface and the evapotranspiration losses from the whole basin. The combine impact of these pressures becomes evident at the downstream end of the system, where Poopó Lake is situated. In recent years this lake suffered extreme water shortages, including its complete drying out in December 2015 (Satgé et al., 2017).

Lake Titicaca has a large surface area of about 8500 km^2 on average. Over a certain water surface level, the lake spills at the South East end and feeds the Desaguadero River. However, the major water output from Lake Titicaca is due to evaporation, which accounts for approximately 90% of the losses (Roche et al., 1992; Pouyaud, 1993; Talbi et al., 1999; Delclaux et al., 2007). In recent years, Lake Titicaca's level dropped below the outlet threshold for some periods. Thus, a small increase in evaporation or decrease in precipitation may turn the lake into a closed system with no outflow.

Since evaporation dominates the water balance in Lake Titicaca, it is essential to improve the knowledge of the lake evaporation. This is especially important in light of anthropogenic pressure and due to evident strong global warming that experiencing this region. Previous studies of Lake Titicaca evaporation have all been based on monthly meteorological observations. Due to the importance of lake evaporation, detailed calculations using daily as well as monthly observations may be necessary. Consequently, this paper investigates different methods for calculating evaporation using both daily and monthly data, in addition we discussed the possibility for the appropriate evaporation models at both time scales to be used on the study the climatic functioning and sensitivity. The main problem with the Lake Titicaca evaporation estimation is the lack of high resolution temporal data. Taking into account only the mass transfer models for different time scale, Singh et al. (1997) calculated monthly evaporation. However, doing the same calculations on a daily basis could give radically different results. For both time scales, the evaporation estimation could be more sensitive to vapor pressure. On the other hand, random errors in input data could have a significant effect on evaporation estimation at a monthly scale rather than at daily scale (Singh et al., 1997).

The Lake Titicaca surface water is cold with a temperature that remains 12-17 ^oC throughout the year, and below 40 m depth the temperature is almost constant (Richerson et al., 1977). The water is usually warmer than the air during day time, which means that the air immediately above the lake is unstable. The air temperature shows large diurnal variations, often exceeding 15 °C in summer. At an average terrain elevation above 4000 m.a.s.l. the solar radiation is strong and the atmospheric pressure is low, which means that the ratio between sensible and latent heat flux (Bowen ratio) is lower than at sea level. To determine the evaporation rate using the aerodynamic mass transfer approach, the atmospheric vapor pressure and surface temperature must be known. Furthermore, a wind function must be used because the atmosphere over Lake Titicaca is unstable most of the time. This means that the wind function may be different from the function used for most other lakes.

It can generally be assumed that during a year the lake water temperature returns to the value at the beginning of the year. Thus, for the heat balance, it is sufficient to know the annual net radiation, provided that the sensible heat flux can be estimated from the constant Bowen ratio. When using the method for shorter time periods, the time variation of the lake water temperature profile must be known. The heat balance approach and the aerodynamic method can be combined. The Penman method is such a combined approach. A wind function must be included also in this approach.

P6L16: So you don't trust the precipitation data on shore, so why don't you use e.g., remote sensing data? The lake is big enough, I would say.

Answer to P6L16:

- Regarding the quality precipitation data for the Lake we have considered two rain gauges stations; thus it not might very representative for the entire surface area. Farther more the precipitation could the most uncertainty data, in particular in this region because the long-time period it was measured manually. It seems very good idea to use from remote sensing at least for the two research years (2015-2016), we will compute on this way.

Old versión of Figure 9

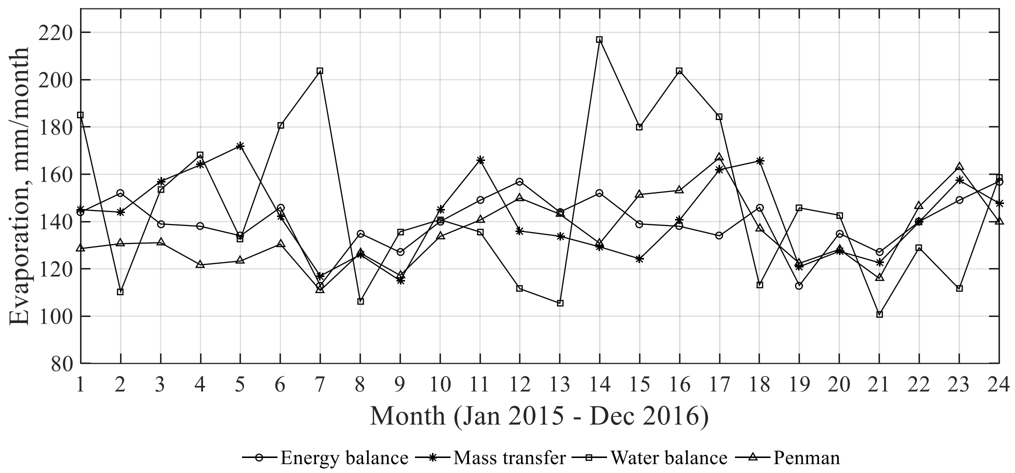

Figure 1. Monthly actual evaporation calculated by the four methods for the period January 2015 to December 2016.

New version of Figure 9

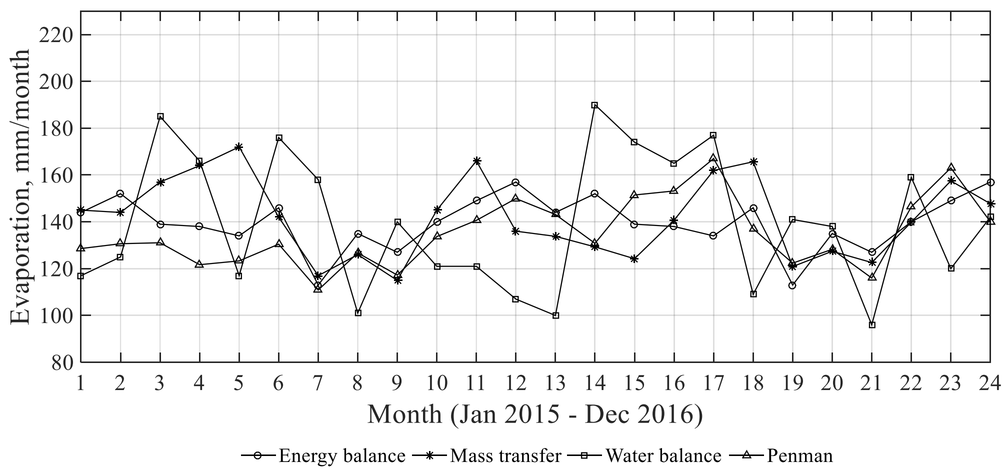

Figure 2. Monthly actual evaporation calculated by the four methods for the period January 2015 to December 2016.

In the Figure 9, the precipitation data the most controversial, it was analysed from other point and neighbour observation, also placed close to the lake shore. Thus the water balance evaporation now gave us a bit different from the previous ones, and it fits better with other three models. For this computation also was analysed the Q-out form the lake; nonetheless some Q data measured for the period 2015-2916 still might be suspicious. The changes of surface water according to water levels dynamics now was taken into the computation, since we have the relation established A=f(h) for the lake. To use the remote sensing data by is considered to be included in another paper; also from the previous works the images used for derivation precipitation data is not necessarily accurate for this lake due to high emissivity.

P8L27: disadvantage of this method is that a and b are empirical numbers. So you can question if these values found in Russia can be used in Lake Titicaca.

Answer to P8L27:

- Yes, the a (mm $mbar^{-1}$ day^{-1}) and b (mm $mbar^{-1}$ s m^{-1}) parameters are empirical values in the mass transfer equation, and by using the previous values found by Carmouze, the evaporation rate was higher to the rest, even significantly higher. Then we lowered those parameters substantially (from a=0.7 and b=0.30 up to a=0.17 and b=0.155). Definitely, Russian values does not mean that can be used for our case, also Russian values cannot be the minimum limits. Since the actual values found almost is the average between the other existing values maybe we do not need to be redundant.

Mass transfer approach

The mass-transfer aerodynamic approach is used in various models based on Dalton's law (Dalton, 1802). The latent heat transfer is related to the vapor pressure deficit. Most often a linear wind function is used (e.g., Carmouze et al., 1992)

$$E = (a + bU)(e_w - e_a) \quad (9)$$

Where *E* is evaporation rate, *U* is wind velocity (m s^{-1}), (e_w - e_a) is vapor pressure deficit (mbar). The parameter *a* accounts for unstable atmospheric conditions. Carmouze *et al*. (1992) used *a*=0.17 (mm $mbar^{-1}$ day^{-1}) and *b*=0.30 (mm $mbar^{-1}$ s m^{-1}).

P8eq11: the surface area A is a function of depth. I assume that the biggest error are caused by this.

Answer to P8eq.11:

- Yes A=f(h), as it was anticipated we used just for A as average value, but since the computation will test by precipitation derived from satellite source, we are able to verify this problem.

The changes of surface water according to water levels dynamics now was taken into the computation, since we have the relation established A=f(h) for the lake

P9L20: I don't understand this sentence. Why is daily evaporation not important for the water balance? you can apply the water balance at any time scale you want.

Answer to P8L20:

- Yes it is correct, we can compute at any time scale the water balance, in case of Titicaca Lake due its size the daily evaporation value should affect very little on the water balance; however the monthly or yearly values might define the lake status. We will analyze more the thinking on the text. However we want to point out that monthly balance modeling is crucial for everything; thus its analysis and accuracy as well.

The evaporation during individual days is not important for the water balance but only over longer periods as months. However, since the equations for calculating evaporation are not linear, the monthly evaporation computed from monthly mean meteorological data may differ from what is found when data with higher time resolution are used. In the aerodynamic approach the wind speed is multiplied by the vapor deficit. The energy balance approach includes the Bowen ratio, which may differ from day to day and can even be negative for certain periods. If high atmospheric vapor pressure is related to strong winds, the aerodynamic equation using monthly means can yield lower evaporation estimates than when daily values are used. This is further discussed below. The Bowen ratio changes during a month. When the net radiation is large, the air temperature is likely to be rather high but not necessarily related to high vapor pressure. For this situation, the Bowen ratio is relatively high and the computed evaporation higher than it would have been using a constant monthly Bowen ratio. This means that using monthly averages, the computed evaporation will tend to be low.

Yes, the last paragraph was analyzed one more time; thus there was not finding any contradiction.

P14section 5.1: be consistent with the naming of your methods. Now the method ’carmouze’ is used, while before it was named mass transfer method. This is confusing for the reader.

Answer to P14section 5.1.

- Ok, the redaction is very easy to correct here.

Detailed energy balance computations over the period 2015-2016 should give good estimates of the total lake evaporation for that period. After 24 months the lake surface temperature at Puno more or less returned to the temperature at the beginning of 2015. Applying this method over the two years of study the mean annual lake evaporation is 1700 mm $year^{-1}$. When computing the evaporation month by month the change of heat storage was considered in the way previously described. The mixing depth was set to 40 m. The change of the heat storage is shown in Fig. 5. The values suggested by Carmouze et al. (1992) are shown for comparison. The calculated monthly heat storage agrees well with the Carmouze estimates.

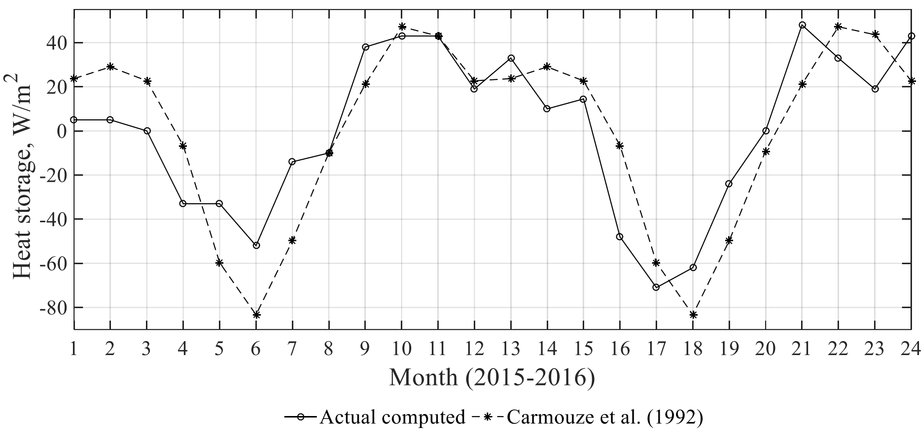

Figure 3. Change of heat storage during 2015-2016.

-P14fig 5: how can you compare evaporation data of two different years? Would be weird if they were the same.

Answer to P14fig 5:

- In the paper we analyzed the full continuous met data gathered during 2015 and 2016 and according to consistent field campaign. By other hand we could not obtain a good experimental evaporation data (tank evaporation data). I fact we are comparing the methods for each year because we need to be sure that methods and the data work, especially for the monthly values like was anticipated. In the same way that the radiative parameters were compared. All the authors have been show until now only the mean month values or yearly.

P16L10: I think the biggest error is not the water level, but the associated wrong estimation of the surface area...

Answer to P16L10:

- This problem will be correct with new computation of water balance as mentioned already.

The new results from the computation is shown in above (Figure 9).

P19L6:?? are you keeping the bowen ratio constant of do you change it day by day? Confusing sentence. Please rewrite.

Answer to P19L6:

- The Bowen ratio changes day by day since we have the observed data at daily.

Minor comments:

-P1L19: ".. using THE heat balance.."
-P1L22: unit of annual evaporation is mm/YEAR
-P3L6,7,8,9,10,11: '-1' should be superscript
-P3L12: unit of annual evaporation is mm/YEAR
-P5L16-18: unit of annual evaporation is mm/YEAR
-P5L24-25: celsius degree symbol is not ok
-P7section3.2.1: add units to all variables.

Answer to minor comments:

- In this regard all the minor comments already have been added in the new manuscript.