Dear editor,

We are very thankful the editor and referees for helpful and constructive comments and recommendations. We have revised the paper in accordance with reviewer suggestions to produce an improved version of our manuscript. In particular, the method chapter included more detailed description of our experimental site, eddy-covariance flux measurements, data post processing and used approaches for statistical analysis. The result and discussion chapters were also extended. Additional references were given.

Detailed response to comments of both referees was presented in BG interactive discussions (AC C1761, AC C2067).

According to associated editor suggestions we made in the revised manuscript an additional explanation for use of smoothed times series. To justify the main conclusions (as asked editor) the statistical analysis of time series was also extended.

The smoothing procedure for data analysis was applied in order to filter the high-frequency oscillations in time-series of monthly atmospheric characteristics and NEE, GPP, RE, ET values.

It is well known that the typical timescale of ENSO is estimated to be about 48-52 months (e.g. Setoh et al 1999) whereas the timescale of the main meteorological parameters (global solar radiation, precipitation amount, air temperature) patterns is characterized by much higher month-to-month variability even after annual trend filtering (local and regional circulation processes, the Madden–Julian oscillation, etc.). For smoothing procedure the simple unweighted moving average method was applied.

In addition to simple correlation statistics that was used to analyze the relationships between ENSO activity and changes of meteorological variables and fluxes, we estimated the cross-correlation functions that allow to find similarity of two series as a function of the time lag of one relative to the other (Chatfield 2004). Results of statistical analysis of our time series show that the maximal deviations of meteorological parameters and characteristics from mean values and ENSO culminations have the different time lags. In particular the maximal deviations of e.g. global solar radiation and GPP are occurred prior to ENSO culmination. Maximal negative deviation of precipitation from the mean values is observed 8 months prior to El Niño culmination whereas maximal positive deviation - 5 months after that. Maximal deviations of evapotranspiration and NEE are observed simultaneously with maximal or minimal values of SST in Nino4 and Nino3.4 regions. The reasons of the observed positive and negative time shifts can be obviously explained by both global and regional atmospheric processes. One of the possible trigger for ENSO is stochastic forcing such as westerly wind bursts and Madden-Julian Oscillation events (Wang et al 2012) . Other hypothesis explains the warm episode of ENSO by a rapid collapse of the easterly trade winds (Wyrtki 1975). This event results in moving the accumulated warm water from the western Pacific eastward in the form of equatorial down welling Kelvin waves and initialisation of El Niño event. Shift of warm water from the region of Indonesia to Central Pacific result in shift the corresponding zone of deep convection and in decrease of the cloud amount in the western Pacific (increase of global solar radiation). These processes can actually explain the reasons why the minimal clouds amount and maximal solar radiation are observed prior maximal SST anomalies (ENSO culmination). It is obvious in this case that applied ENSO indexes are not suitable in forecasting of these parameters. It makes difficult also an adequate application of the different causality tests such as the Granger causality test, etc.

Answers to comments of reviewer 1

We thank the anonymous reviewer (REV1) for his timely comments on our manuscript, which gives us the opportunity for interactive discussion. This is highly appreciated.

Comment: "However, my major concern is that this manuscript is quite limited in scope, due to the fact that the El Niño response is only studied on a single site. In my opinion the paper would benefit from adding additional sites from the same region (Indonesia, South-East Asia, or North Australia) to study if the observed El Niño effects on surface fluxes can be generalized. Such findings would be of high value for modelling work. Nevertheless, even with only one site included, this is a well presented study for a region that is relatively data-poor."

Answer: We absolutely agree with reviewer on the importance of the consideration of the regional patterns of ecosystem responses to ENSO events in SEA and that an analysis of additional sites from ENSO influenced regions, as named by reviewer, will extend the scope of the analysis to a wider perspective. However, as the reviewer correctly mentioned, the region is relatively data poor and, therefore, we focused our manuscript on a single case study, with long-term series of thoroughly measured fluxes in a pristine mountainous tropical rainforest growing in Central Sulawesi, Indonesia. The investigated ecosystem type (mountainous rain forest) constitutes the main remaining parts of the tropical rain forests in Sulawesi and equatorial regions of SEA and we found it suitable to start investigating the ENSO effects with this important ecosystem type. As commented by the reviewer: this single case study enriches the data basis for the region.

Comment: "However, I was confused by the way the two steps in the analysis are presented on page 4413. The first step is described as a correlation analysis between "NEE, GPP, … and SST-anomalies". But are you correlating flux (e.g. NEE)-anomalies with SST-anomalies or monthly absolute flux values (e.g. NEE) with SST anomalies in this first step? The second step is presented as a "more accurate analysis" where absolute deviations of monthly fluxes from the average are calculated. In fact, these 'absolute deviations' are flux-anomalies according to me. In addition, I suggest describing in more detail what is meant by a 'more accurate analysis'. (Is this really the good wording?)."

Answer: 1) In the first step that were the absolute values. We will add this information to the manuscript as: "In the first step to assess the possible impact of ENSO events on CO_2 and H_2O fluxes the possible correlation between the **absolute values** of monthly NEE, GPP, RE, ET and SST anomalies in Nino4 and Nino3.4 regions (Nino4 and Nino3.4 indexes) were analyzed".

2) We agree also that the phrase "more accurate analysis" is not quite correct and we will rephrase this in the revised manuscript as:
“In the second step of data analysis we analyzed the correlation between the deviations of monthly flux values from monthly averages over the entire measuring period and the Nino4/Nino3.4 indexes. The deviation in the case of GPP (ΔGPP) was estimated as

$$\Delta GPP_{Month,Year} = GPP_{Month,Year} - \frac{1}{N}\sum_{Year=2004}^{2008} GPP_{Month,Year}$$

where $GPP_{Month,Year}$ is total monthly GPP for a particular month (January to December) and corresponding year (2004 to 2008), $\frac{1}{N}\sum_{Year=2004}^{2008} GPP_{Month,Year}$ is monthly GPP for this particular month averaged for the entire measuring period (2004 to 2008); N is number of years…”

We accept the suggestions given in comments 1-3.
1) We will use “rainforest” everywhere in text;
2) the study of Malhi et al 1999 was conducted in Amazon region – we will add this information to the text;
3) we will use “intra-annual” instead of “annual” in text, where it is necessary.

We thank REV1 especially for his/her comment 4 on Figure 4. From this we noticed that during the editing and re-coloring processes the graph for the global radiation (G) trend was accidentally replaced by the graph for GPP. Both graphs for GPP and for G have actually similar shapes. The corrected figure is given below.

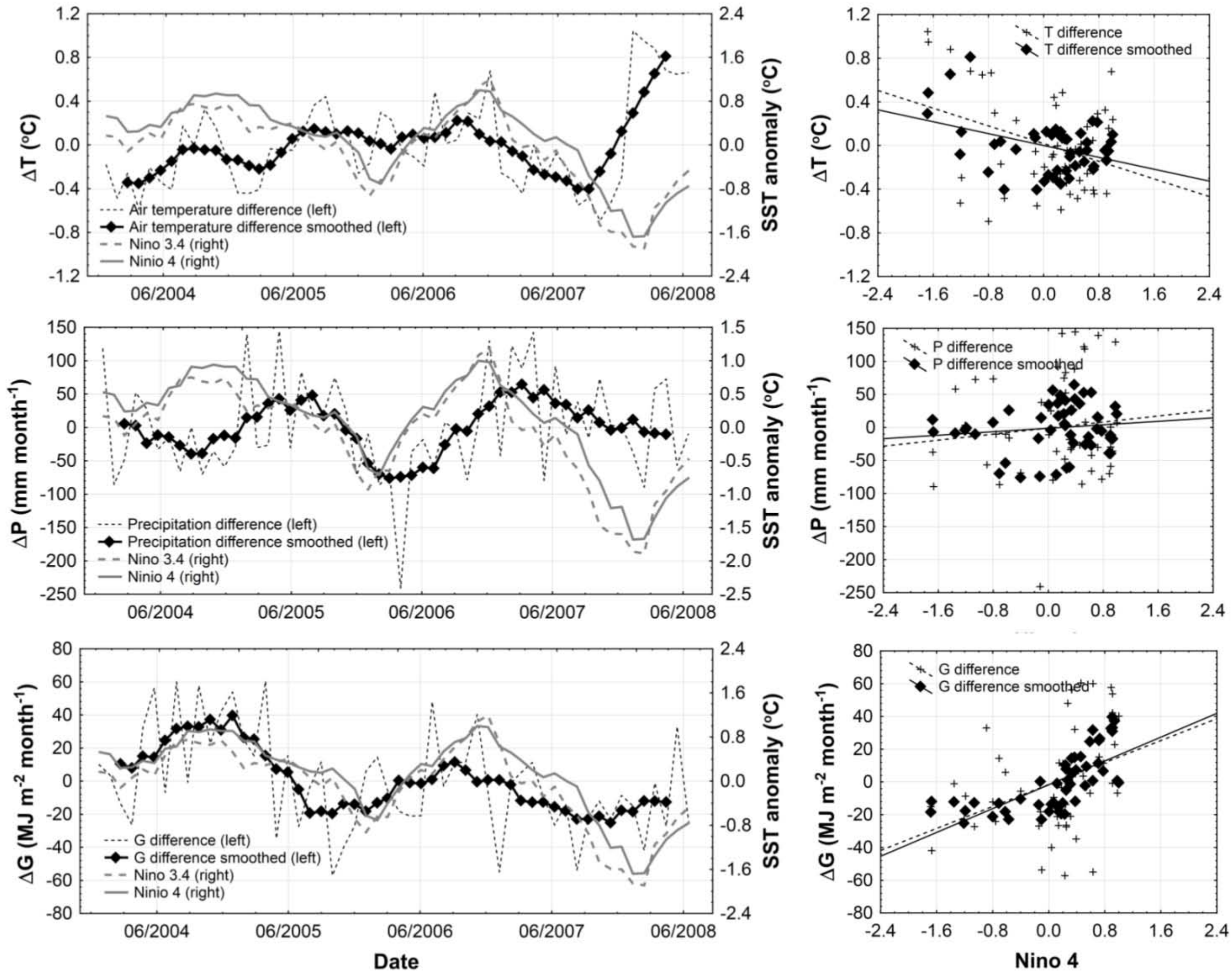

Figure 4. Comparisons of inter-annual patterns of Nino4 and Nino3.4 indexes with variability of both deviations and 6 months running mean deviations of monthly air temperature (*T*), precipitation (*P*) and global radiation (*G*) values from mean monthly values of *T*, *P* and *G* averaged over the entire measuring period from 2004 to 2008.

Answers to comments of reviewer 2

We would like to thank the anonymous reviewer (Reviewer 2) for the critical, but nevertheless very helpful comments on our manuscript. (1) they made us clear that our site description was misleading given the incorrect impression that our site is on a steep slope in mountainous area. It is rather on a fairly large plateau at high elevation. (2) the comments inspired us to new analysis that provided clear evidence about the robustness of our results. We will first address these two points and then respond to the specific comments.

(1) The Bariri flux tower site is located at high elevation (1430 m a.s.l.), on a large plateau surrounded by mountains. To illustrate the size of the plateau - the village Bariri is on the same plateau and about 7 km away. The area directly surrounding the flux tower has a gentle slope. The wind field measured with a 3D sonic anonemeter shows that the slope is about 3° (Fig. 1). Such slope is typical for many sites within FLUXNET and clearly gentler than at some of the FLUXNET-sites that neverthelss regularly publish their results in peer-reviewed journal incl. global syntheses, e.g. Renon (IT), Lägeren (CH), Niwot Ridge (USA), Griffin (UK).

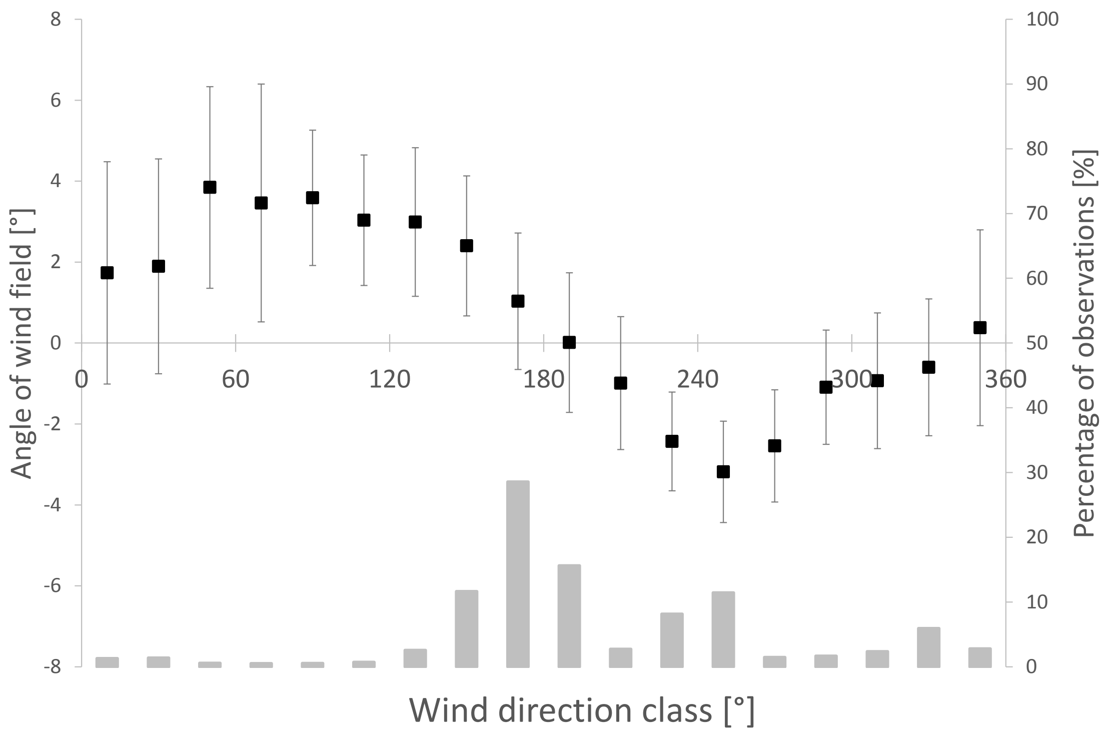

Fig. 1: Angle of wind field and percentage of 30 min observations for different wind direction classes for the Bariri flux tower.

While we agree that hilly terrain poses additionally challenges to eddy covariance measurements, we don't see supported by the literature that eddy covariance measurements are not possible at sites with gentle slopes similar to our site (about 3°).

We are on the contrary convinced that the reservations of Reviewer 2 are too strict and conservative. Asking for ideal measurement conditions would render virtually all real site conditions insufficient for the application of the method. Literature shows that this position is not shared among the bulk of micrometeorologists. At first glance, it is obvious to request exact realization of the requirements that arise from theory, in praxis the question is rather to which degree is the data quality affected by non-ideal site conditions? And here the existing experiences with the method have led to clear recommendation as to how to select and process the raw data in order to minimize the effects, e.g. on annual flux sums. We refer to the latest set of recommendations that have been published recently (Aubinet et al., 2012), with some contributions by authors of this manuscript.

All field data in our study have been selected and post-processed strictly according to the established recommendations for eddy covariance flux measurements. The raw data were screened for outliers and either corrected or rejected. The raw data screening identified clearly the data that were affected by rain, a known phenomenon when using an open-path sensor. The spectra of the remaining data represented the expected features in the inertial subrange well. The night-time fluxes showed a clear dependency on the development of turbulence. When the friction velocity (u_*) fell below 0.25 m s^{-1} the average CO_2 flux was significantly lower than at $u_* > 0.25$, beyond which no further u_* dependency was observed. This result confirms the reservations of Reviewer 2, but restricts its effect to certain meteorological conditions, i.e. mainly at stable atmospheric stratification and low turbulence. At the same time the clear observed dependency gave a handle to avoid the effects by only including flux values that were measured at $u^* > 0.25$ m s^{-1}. In our manuscript, we mentioned the data processing and data quality assessment only briefly to avoid distraction of the readers focus from the main findings, i.e. the relationships between the CO_2 exchange processes, GPP and RE and climate anomalies. We will provide a more detailed description of the method in the revised manuscript.

Nevertheless, we are aware that even with all precautions taken, a slope may still result in an systematic underestimation of the night time fluxes. That is the reason, why we limit our analysis to monthly anomalies to further reduce a potential bias in our data.

(2) One may argue that even the monthly anomalies of NEE, RE and GPP might be biased by a night-time underestimation of fluxes, particularly if the underestimation of the night time fluxes itself would somehow be related to ENSO. As a consequence, we examined midday NEE, which are typically

dominated by GPP and not by RE. As midday NEE data are direct measurements typically with turbulent conditions and thus without an extrapolation from nighttime data, they should be unaffected by potentially flawed data due to a slope or night time problem. Our new analysis based on midday NEE shows a similar clear relationship between monthly midday NEE and the ENSO index (Fig. 2) with an R^2 = 0.59. This analysis confirms our main results indicating that our analysis is in fact robust.

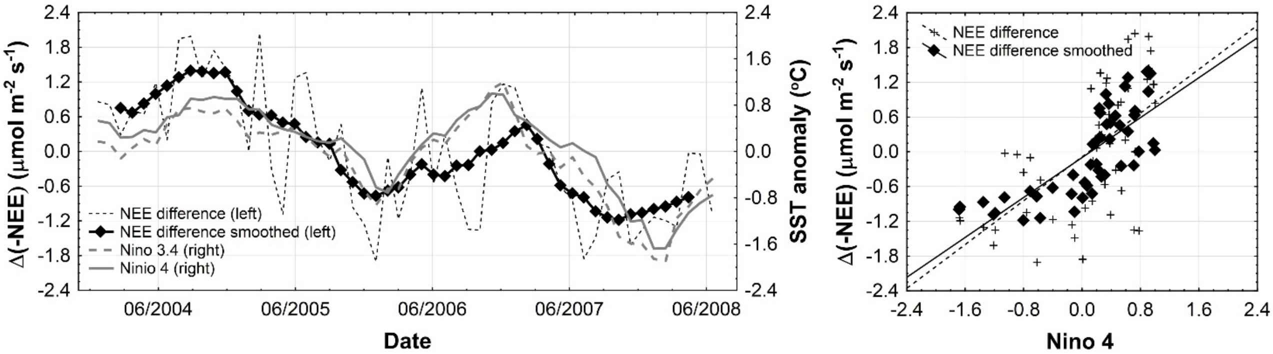

Fig. 2: Monthly averages of midday NEE (10:00-14:00) and Nino 3.4 and Nino 4 showing a strong relationship (R^2 = 0.59).

Direct response to the comments

Comment 4409 " Already here the paper fails to justify the choice of the eddy covariance method to measure fluxes in a mountain forest, given that, according to the theory, the method is restricted to flat, homogeneous terrain. This problem becomes even more important in the following sections"

Comments 4410/4411

A slope of 5 degrees is quite a lot when it comes to turbulence measurements above tall forest canopies. Even gentler slopes have been reported to create massive advective problems, not only during nighttime with respect to a downhill flow of respired CO2 but also induced by perturbations in airflow patterns (see e.g. the paper by Katul et al. (2006) in BLM about "the influence of hilly terrain on canopy-atmosphere CO2 exchange"). A realistic account of the uncertainty of the data caused by systematic errors due to the poor suitability of the site for eddy covariance measurements would be indispensible before interpreting any small variations in gap-filled monthly flux totals.

Answer: Addressed already above

Comment to P. 4410/4411

"It does not help that the authors apparently chose to hide the annual sums of net carbon uptake (and presented only monthly totals instead), as this would have

revealed at once how unrealistic the order of magnitude is. Looking at the monthly NEE totals shown in Fig. 2 it seems likely that the average annual total must have been something close to 1000 g C per m2 (or 10 t per ha), which is far outside any plausibility range, for example when comparing it to the Nature paper by Luyssaert et al. (2007) about the carbon budget of old-growth forests. The big question is thus how robust and certain the data in the present study are. Was perhaps a large part of soil respiration not seen due to advection? Or did the position of the tower in relation to the hill top create a problem like that described by Katul et al. (see above) that would depend on the prevailing wind direction and thus probably on ENSO as well? "

Answer: We would like to point out that our reported GPP values (3150 gCm^{-2} y^{-1}) are reasonably close to the average for tropical forests (3551 +/- 160 g C m^{-2} y^{-1}) as reported in Luyssaert et al. (2007). Additionally, we focus on anomalies where systematic errors (e.g. a potential cold air drainage causes a systematic underestimation of RE) are mostly removed.

Furthermore, our site is located at 1430 m elevation, where temperatures are much lower while insolation and water availability are still high. We can now compare our high elevation forest in Sulawesi with as example Tapajos National Forest (TNF) in Brazil in Southern America (http://daac.ornl.gov/LBA/guides/CD32_Brazil_Flux_Network.html). Both sites have similar location near the equator, they are characterized by very high annual insolation and precipitation. However, both sites have a different elevation and of course the different temperature conditions.
Taking into account the elevation and temperature differences (about 1430 meters, 5-6°C for air and upper soil layer) we can use a simple approach describing RE as a function of temperature (Q10 or Arrhenius function) and estimate a significant difference in RE values between the two sites. GPP in both sites is quite the same taking into account similar insolation conditions (3260 g C $m^{-2}y^{-1}$ in TNF against 3150 g C m^{-2} y^{-1} in Bariri). Similar results for GPP can be obtained for major sites located in lowlands in SEA region (http://asiaflux.net/). RE due to higher temperature (by 4-7 °C) for forests with similar biomass and lower content of organic matter in soil significantly exceed the RE at our site (about 3100 g C $m^{-2}y^{-1}$ in TNF (Miller et al. 2011) against 2250 g C m^{-2} y^{-1} in Bariri).

Comments P. 4412 " *Understandably (since due to practical reasons in terms of power supply) an open-path gas analyser was used to measure the high frequency fluctuations of the CO2 and H2O concentrations. The point is however, that this sensor cannot measure in the rain. Due to the climatic conditions at the research site this must mean that there are data gaps during substantial parts of the investigation period. Filling these gaps with the algorithms described in the paper fails to* *acknowledge that the relation of ET to environmental factors depends on the wetness of the surface. In other words, when the good data are restricted to dry periods only, these cannot be used to fill the gaps during rainy periods without introducing a serious bias in the water fluxes (see e.g. the study by Ringgaard et al. 2014 in AgrForMet). The method is therefore unsuitable to detect possible ENSO effects (due to interannual variations in rainfall regimes) on ET, and even the gap filled CO2 fluxes remain questionable given that the gaps are not distributed randomly across the variable space."*

Answer: We agree that open-path sensors are limited in their ability to measure under rainy or dew conditions. As done in virtually all similar studies, we rejected such data. The remaining data fullfilled all spectral and integral data quality criteria. However, in our study we did not use measurements made during dry periods for gap filling in wet periods, to avoid biases from statistical extrapolation from dry to wet meteorological conditions. Instead, we used a process-based model that considered e.g. evaporation from wet leaf surface, i.e. the Mixfor-SVAT model (Olchev et al., 2002; 2008). The model was validated using measured fluxes at various experimental sites (e.g. Olchev et al 2002, 2008), took part in model comparisons (Falge et al 2005) and showed a good performance to describe the temporal variability of fluxes even under wet rainy conditions. The model is also able to predict dew generation and evaporation. Based on this approach, we are confident that our gap filled ET and CO2 flux data do not suffer from respective systematic errors caused by the use of an open-path sensor. In our revised manuscript, we will describe the gap-filling approach and the model in more detail.

Comment: "*In addition, the OP sensor is prone to sensor heating in the sun, for which various correction schemes have been suggested (e.g. the so-called Burba-correction). We would need to know how exactly the data were analysed (in terms of the corrections that were applied), rather than just being told that everything "followed existing rules" – of which there are many.*".

Answer: Burba et al. 2008, pointed out that the suggested correction mainly applies in cold environments. Reverter et al. 2011 showed that the effect decreases with increasing mean annual temperature. While this suggests that the effect will be small at our site and will probably not bias our finding, we will nevertheless use one of the proposed methods to correct for this effect and mention the results in the revised manuscript.

Comments P. 4415 " *This is the direct result of the aforementioned problem: ET must inevitably be lower during rainy periods because gaps were filled with response functions derived from data measured under dry conditions!"*

Answer: As it was already mentioned we didn't use the method suggested by Reviewer 2 for gap filling. On the other hand , precipitation is not the key factor that is responsible for evapotranspiration rate in most biomes, excluding of course the very arid areas. The rate of evapotranspiration is governed by available energy, temperature, water vapour deficit, wind speed, ecophysiological properties of vegetation, etc.. Tropical rainforest grow in a climate where precipitation significantly exceeds potential evaporation values, in some years even during relatively dry seasons.

The discussion about data uncertainty will be added to the revised version of the manuscript.

Comments P. 4413 " *What does "mobile station" mean – did it not remain at the same place during the course of the study?*"

Answer: The "Mobile station" is an autonomic meteorological station for continuous measurements of the main meteorological parameters (air temperature, humidity, precipitation, global and reflected solar radiation, soil temperature, wind speed and direction) outside the forest. We will rephrase the term.

Comments P. 4414 *" The signs of the deviations from the average monthly values are confusing. The signs of all fluxes considered should be explained somewhere earlier in the paper."*

Answer: The signs will be explained in the final manuscript version.

References

Aubinet, M., Vesala, T. and Papale, D. (Editors), 2012. Eddy Covariance: A Practical Guide to Measurement and Data Analysis. Springer Atmospheric Sciences.

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Falge E., Reth S., Brüggemann N, Butterbach-Bahl K., Goldberg V., Oltchev A., Schaaf S., Spindler G., Stiller B., Queck R., Köstner B., Bernhofer C. 2005. Comparison of surface energy exchange models with eddy flux data in forest and grassland ecosystems of Germany. J. Ecological Modelling, 188 (2-4), pp.174-216

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1. Olchev A, Ibrom A., Ross T., Falk U., Rakkibu G., Radler K., Grote S., Kreilein H., Gravenhorst G. 2008 A modelling approach for simulation of water and

carbon dioxide exchange between multi-species tropical rain forest and the atmosphere. J. Ecological Modelling 212, pp. 122–130

Reverter B.R., A. Carrara, A. Fernández, C. Gimeno, M.J. Sanz, P. Serrano-Ortiz, E.P. Sánchez-Cañete, A. Were, F. Domingo, V. Resco, G.G. Burba, A.S. Kowalski, Adjustment of annual NEE and ET for the open-path IRGA self-heating correction: Magnitude and approximation over a range of climate, Agricultural and Forest Meteorology, Volume 151, Issue 12, 15 December 2011, Pages 1856-1861, ISSN 0168-1923, http://dx.doi.org/10.1016/j.agrformet.2011.06.001.

List of made changes and corrections

Abstract.

Page 4406
Lines 1-5. Sentences were revised.

The possible impact of El Niño-Southern Oscillation (ENSO) events on the main components of CO_2 and H_2O fluxes between tropical rainforest and atmosphere is investigated. The fluxes were continuously measured in a pristine mountainous tropical rainforest growing in Central Sulawesi in Indonesia using the eddy covariance method for the period from January 2004 to June 2008.

Introduction

Page 4409
Lines 10-13 Sentence was clarified.

In particular, Malhi et al. (1999) reported that for Amazon region in the South America El Niño periods are strongly associated with enhanced dry seasons that probably result in increased carbon loss, either through water stress causing reduced photosynthesis or increased tree mortality.

Method . Experimental site description.

Page 4410-11
Lines 24-26
Sentences were revised.

The site is located on a large plateau of several kilometres in size at about 1,430 m above sea level surrounded by mountain chains surmounting the plane by another 300 m to 400 m. Within 500 m around the tower the elevation varies between 1,390 and 1,430 metres. Wind field measurement with a sonic anemometer indicate a slope of around 2-3°, which is similar to many Fluxnet sites. About 1,000 m to the east from the experimental site, the forest is replaced by a meadow; in all other directions the forest extends several kilometres.(Ibrom et al., 2007).

2.3 Flux measurements

Page 4412
Line 10-15
Additional description was included.

Post-field data processing on eddy covariance flux estimates was carried out strictly according to the established recommendations for data analysis (Aubinet et al., 2012). In addition to the procedures described in Falk et al. (2005) and Ibrom et al. (2007), we corrected the flux data for CO_2 or H_2O density fluctuations due to heat conduction from the open-path sensor (Burba et al., 2008; Järvi et al. 2009) using finally the suggested method as described in Reverter et al. (2011).
The system operated at ca. 70% of the time. Ca. 30% of the measured flux data were negatively affected by rain and other unfavourable conditions and removed. From night time ecosystem respiration data a friction velocity (u_*) threshold value of 0.25 m s^{-1} was estimated (Aubinet et al., 2000), i.e. at u_* values above this threshold the measured night time flux became independent from u_*. Night time flux values that were measured at $u_* < 0.25$ m s^{-1} were removed, which left 15% of the measured night time flux data in the data set.

2.4 Micrometeorological measurements

Page 4413
Line 2-5 Sentence was clarified.

To fill the gaps in measuring records the meteorological data from an autonomic meteorological station, situated about 900 m away from the tower outside the forest on a nearby meadow, were used.

2.5 Data analysis

Page 4413-4414
Paragraph was revised. Smoothing procedure was explained.

Page 4413, Line 12-20

In the first step to assess the possible impact of ENSO events on meteorological parameters (global solar radiation (G), precipitation amount (P), air temperature (T) and CO_2 and H_2O fluxes, the correlation between the absolute values of monthly G, P, T, NEE, GPP, RE, ET and monthly SST-anomalies in Nino4 and Nino3.4 regions (Nino4 and Nino3.4 indexes) were analysed.
In the second step we analyzed the correlation between the deviations of monthly meteorological parameter and flux values from their monthly averages over the entire measuring period and the Nino4/Nino3.4 indexes..

Page4414, Line 1-6

The typical timescale of full ENSO cycle is estimated to be about 48-52 months (Setoh et al 1999) whereas the timescale of the main meteorological parameters (global solar radiation (G), precipitation amount (P), air temperature (T)) is characterized by much higher month-to-month variability even after annual trend filtering. In order to filter the high-frequency oscillation in the time-series of atmospheric characteristics and monthly NEE, GPP, RE, ET anomalies the simple centered moving average smoothing procedure was applied. The moving averages (MA) of variables were calculated over 7 months (centered value ±3 months).
Statistical analysis included both simple correlation and cross-correlation analysis. Cross-correlation analysis was used to take into account the possible forward and backward time shifts of maximal anomalies of meteorological parameters and CO_2 and H_2O fluxes in respect to time of the ENSO culmination. To describe the relationships between atmospheric fluxes and meteorological parameters the monthly non-smoothed values were used.

Results

Page 4414
Line 13
"Annual" was replaced by "intra-annual"
The same changes in line page 4415, Line 10

Page 4415
Line 18-30
Paragraph was revised.

Analysis of the temporal variability of the centered moving average values of ΔGPP (ΔGPP_{MA}) (Figure 3) in contrast to comparisons of absolute monthly GPP indicates a relatively high

correlation between ΔGPP_{MA} and both Nino4 ($r^2=0.52$, $p<0.05$) and Nino3.4 ($r^2=0.60$, $p<0.05$) indexes. Close correlation between the intensity of ENSO events and ΔGPP_{MA} can be explained by the influence of ENSO initiating processes and ENSO itself on total cloud amount in the region and, as a result, on monthly sums of incoming G (Figure 4). Variability of G (ΔG_{MA}) is very closely correlated with Nino4 and Nino3.4 indexes ($r^2=0.48$, $p<0.05$ for both indexes) (Figure 4) and it can explain 69% of variability of GPP ($r^2=0.69$, $p<0.05$). The maximal deviations of ΔGPP_{MA} and ΔG_{MA} from mean values (averaged for the entire measuring period) are occurring 2-3 months before the peak phase of the ENSO events (Figure 5). The maximal cross-correlation coefficients in this period reached 0.76 for ΔG_{MA}, and 0.86 - for ΔGPP_{MA}. The effect of T changes (ΔT) on ΔGPP is very low ($r^2=0.01$, $p>0.05$).
The correlation between ΔT_{MA} and Nino4, Nino3.4 indexes are relatively low ($r^2=0.15$, $p>0.05$ for Nino4 and $r^2=0.05$, $p>0.05$ for Nino3.4) and it can explain the very weak correlations between ΔRE_{MA} and ENSO indexes ($r^2=0.10$, $p<0.05$ for Nino4 and $r^2=0.04$, $p>0.05$ for Nino3.4) (Figures 3-4). The maximal deviations of T_{MA} and RE_{MA} from mean values (averaged for the entire measuring period) are occurring 2 months after the peak phase of the ENSO events and it has negative sign (Figure 5). The cross-correlation coefficient in this period is -0.53 ($p<0.05$).

Page 4416
Lines 13-23
Paragraph was revised.

Taking into account that the monthly anomalies of NEE might be biased by a still unaccounted advection effects at night-time, despite u_* filtering, , we additionally examined NEE at midday (10:00-14:00), when turbulent mixing is typically well developed. Data analysis based on midday NEE shows a similar clear relationship with the ENSO index (Figure 6) with $r^2 = 0.59$ under $p<0.05$. The maximal deviations of both NEE_{MA} and midday NEE_{MA} from the their mean values occurred simultaneously within the peak phase of the ENSO events (Figure 5).
Analysis of the temporal variability of the moving average values of monthly ET (ΔET_{MA}) showed a high correlation to ENSO activity as well: $r^2 = 0.72$, $p<0.05$ for Nino4 and $r^2 = 0.70$, $p<0.05$ for Nino3.4 (Figure 7), probably also triggered by G_{MA}, which in turn correlated strongly with both the Nino4 and the Nino3.4 index. Periods of extreme ΔET_{MA} values and maximal ENSO intensity occurred simultaneously (Figure 5). Correlations between ΔET and ΔT, as well as between ΔET and ΔP, are insignificant - $r^2=0.09$ ($p>0.05$) and $r^2=0.01$ ($p>0.05$), respectively. However, figures 4 and 5 clearly show a time delay in ΔP_{MA} oscillation, relative to Nino4 and Nino3.4 patterns. The maximal negative deviations of ΔP_{MA} are observed about eight months before,(cross-correlation between ΔP_{MA} and Nino 4 index 0.72, $p<0.05$) and maximal positive deviation of ΔP_{MA} - about four-five months after the peak phases of ENSO (cross-correlation between ΔP_{MA} and Nino 4 index - 0.40, $p<0.05$), respectively.

4. Discussion
Page 4418
Lines 1-13 Paragraphs were revised.

Application of the centered moving average smoothing procedure allows us to filter the high-frequency month-to-month oscillations in the time-series of atmospheric characteristics caused by local and regional circulation processes that are not directly connected with ENSO activity. The relationships between ΔGPP_{MA}, ΔET_{MA} and Nino4 and Nino3.4 indexes are mainly governed on the one hand by the dependency of the incoming solar radiation on ENSO development – surface water warming in Nino 3.4 and 4 regions generally results in a decrease of cloudiness above the study region and thus – in increase of incoming solar radiation. On the other hand there are many data about a high correlation between monthly GPP and ET rates and incoming and absorbed solar radiation (e.g. Ibrom et al., 2008). The effects of monthly air temperature and precipitation changes on ΔGPP and

ΔET variability are relatively poor, mainly due to the low correlations between ΔT_{MA}, ΔP_{MA} and ENSO intensity.
The cross-correlation analysis (Fig. 5) shows that the ΔGPP_{MA} and ΔG_{MA} have a small 2-3 month backward shift relatively to the course of Nino4 SST, i.e. the maxima in GPP_{MA} occur earlier than ENSO culmination in the central Pacific (Nino4 SST anomaly). The maximal values of ΔE_{MA} occurred simultaneously with El Niño and La Niña culminations.

Page 4419
Line 2 Additional sentence was added..

The lower panels of Figure 4 indicate however, that the decrease of radiation due to increase of cloudiness does not depend linearly on La Nina intensity, reaching a saturation state at approximately -20..-30 MJ m^{-2} $month^{-1}$.

Line 10 Additional sentence was added..

As is was already mentioned even during the El Niño culmination in 2005-2006 the ET/PET did not decrease below 0.74, $(ET/PET)_{MA}$>0.81, and the relative soil water content of the upper 30 cm horizon was always higher than 80%.

Lines 21-23 sentence was revised.

Interestingly the radiation dependent GPP (as represented by smoothed 7 month mean) does not demonstrate any prolonged constant period during La Nina phases though the radiation does. During the first cold event the GPP-reduction is not as strong as during the second one, although the G-reductions are nearly of same strength. It could be assumed that in the first case the effect of radiation decrease on GPP was compensated by other factors like slight increase of air temperature.

5. Conclusion
Conclusion was revised. Sentences were clarified.

CO_2 and H_2O fluxes in the mountainous tropical rainforest in Central Sulawesi in Indonesia showed a high sensitivity of monthly GPP and ET to ENSO intensity for the period from January 2004 to June 2008. This was mainly governed by the high dependency of incoming solar radiation (*G*) to Nino4 and Nino3.4 SST changes and the strong sensitivity of GPP and ET on *G*.
Interestingly, we observed time shifts between the SST anomalies and smoothed GPP anomalies driven by radiation anomalies. The maximal deviations of GPP and G from their mean values occurred 2-3 months before the peak phase of the ENSO events. The effect of ENSO intensity on RE was relatively low, mainly due to its weak effect on air temperature. Anyway, the small cross-correlation between RE and ENSO intensity had a compensatory effect on the timing of NEE, which thus was - like evapotranspiration - in synchrony with El Niño culminations. Unlike the observations in other tropical sites, precipitation variations had no influence on the CO_2 and H_2O fluxes at study site, mainly due to the permanently sufficient soil moisture condition in the study area.Other climatic anomalies in the Western Pacific region, such as the Indian Ocean Dipole and the Madden–Julian oscillation, did not show any significant effect on neither the meteorological conditions nor the CO_2 and H_2O fluxes in the investigated mountainous tropical rainforest in Central Sulawesi.
It is important to emphasise that the considered observation period does not cover a period with extreme El Niño events, such as, e.g., the 1982-83 and 1997-98 events, when the anomaly of Nino3.4 SST, during several months, exceeded 2.6°C and more significant changes of surface water availability were observed. Also, in lowland parts of Sulawesi, characterised by higher temperatures

and lower precipitation, the vegetation response to ENSO events is likely to be different and more pronounced (Erasmi et al., 2009).
All observed ENSO events during the selected period are classified as Central Pacific type. Recently, Yeh et al. (2009) showed that under projected climate change the proportion of Central Pacific ENSO events might increase. Furthermore, Cai et al. (2014, 2015) showed that current projections of climate change for the 21^{st} century suggest an increased future likelihood of both El Niño and La Niña events. Based on the results of our study, potential increases in ENSO activity would results in an increased variability of the CO_2 and H_2O exchange between atmosphere and the tropical rainforests in such regions.

Reference
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Additional references were added.

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Figures
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The error in Figure 4 illustrating comparisons of inter-annual pattern of SST anomalies in Nino4 and Nino3.4 zones of equatorial Pacific with variability of both deviations and 7 month (±3 months) moving average deviations of monthly global radiation (G) values from mean monthly values of G averaged over the entire measuring period from 2004 to 2008 was corrected.

Additional figure (figure 5) was added. It shows cross-correlation functions between ΔG_{MA}, ΔT_{MA}, ΔP_{MA}, ΔE_{MA}, ΔGPP_{MA}, ΔRE_{MA}, ΔNEE_{MA} and midday ΔNEE_{MA} values and SST anomalies in Nino4 zone of equatorial Pacific. Filled symbols are corresponded to p-value <0.05 and non-filled symbols - to p>0.05. Lag step is 1 month.

Response of CO_2 and H_2O fluxes of a mountainous tropical rain~~-~~forest in equatorial Indonesia to El Niño events

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Abstract

The possible impact of El Niño-Southern Oscillation (ENSO) events on the main components of CO_2 and H_2O fluxes between tropical rainforest and atmosphere is investigated. ~~in a pristine mountainous tropical rainforest growing in Central Sulawesi in Indonesia is described.~~ The fluxes were continuously measured in a pristine mountainous tropical rainforest growing in Central Sulawesi in Indonesia ~~is described.~~ using the eddy covariance method for the period from January 2004 to June 2008. During this period, two episodes of El Niño and one episode of La Niña were observed. All these ENSO episodes had moderate intensity and were of Central Pacific type. The temporal variability analysis of the main meteorological parameters and components of CO_2 and H_2O exchange showed a ~~very~~ high sensitivity of Evapotranspiration (ET) and Gross Primary Production (GPP) of the tropical rain~~-~~forest to meteorological variations caused by both El Niño and

La Niña episodes. Incoming solar radiation is the main governing factor that is responsible for ET and GPP variability. Ecosystem Respiration (RE) dynamics depend mainly on the air temperature changes and are almost insensitive to ENSO. Changes of precipitation due to moderate ENSO events did not cause any notable effect on ET and GPP, mainly because of sufficient soil moisture conditions even in periods of anomalous reduction of precipitation in the region.

1. Introduction

The contribution of tropical rainforests to the global budget of greenhouse gases, their possible impact on the climatic system, and their sensitivity to climatic changes are key topics of numerous theoretical and experimental studies (Clark and Clark, 1994; Grace et al., 1995, 1996; Malhi et al., 1999; Ciais et al., 2009; Lewis et al., 2009; Phillips et al., 2009; Malhi, 2010; Fisher et al., 2013; Moser et al., 2014). The area covered by tropical rainforests was drastically reduced during the last century, mainly due to human activities and presently there are less than 11.0 million km^2 remaining (Malhi, 2010). While deforestation rates in the tropical forests of Brazil are now declining, countries in South-East Asia, particularly Indonesia, show globally the largest increase in forest loss (Hansen et al., 2013), resulting in major changes in carbon and water fluxes between the land surface and the atmosphere. Therefore, during the last decade the tropical forest ecosystems of South-East Asia and especially Indonesia are the focus area of intensive studies of biogeochemical cycle and land surface - atmosphere interactions. On the one hand, it is necessary to know how these tropical forests influence the global and regional climate, and on the other hand, how they respond to changes of regional climatic conditions.

Climate and weather conditions in the equatorial Pacific and South-Eastern part of Asia are mainly influenced by the Intertropical Convergence Zone (ITCZ) which is seasonally positioned north and south of the equator. Another very important factor affecting the climate of South-East Asia is the well-known coupled oceanic and atmospheric phenomenon, El Niño-Southern Oscillation (ENSO). During the warm phase of ENSO, termed "El Niño", sea surface temperature (SST) in the central and eastern parts of the equatorial Pacific sharply increases, and during a cold phase of the phenomenon, termed "La Niña", the SST in these areas is lower than usual. Both phenomena, El Niño and La Niña, lead to essential changes of pressure distribution and atmospheric circulation and, as a result, to anomalous changes of precipitation amount, solar radiation, and temperature fields, both in the regions of sea surface temperature anomalies and in a wide range of remote areas through the mechanism of atmospheric bridges (Wang, 2002; Graf and Zanchettin, 2012). Typically, in Indonesia El Niño results in dryer conditions and La Niña results in wetter conditions, potentially impacting the land vegetation (Erasmi et al., 2009). ENSO events are irregular, characterised by different intensity and, are usually observed at intervals of 2-7 years.

To describe the possible effects of ENSO events on CO_2 and H_2O exchange between land surface and the atmosphere, many studies for different Western Pacific regions were carried out during recent decades (Feely et al., 1998; Malhi et al., 1999; Rayner and Law, 1999; Aiba and Kitayama, 2002; Hirano et al., 2007; Erasmi et al., 2008; Gerold and Leemhuis, 2010). They are mainly based on the results of modelling experiments and remote sensing data (Rayner and Law, 1999). Experimental results based on direct measurements of CO_2 and H_2O fluxes, which allow studying the response of individual terrestrial ecosystems to anomalous weather conditions, are still very limited (e.g. Hirano et al., 2007; Moser et al., 2014). Existing monitoring networks in equatorial regions of the Western Pacific are associated mainly with lowland areas and do not cover mountainous rainforest regions, even though mountainous regions cover some of the last remaining undisturbed rainforest in South-East Asia. Most attention in former studies was paid to the description of plant response to anomalously dry and warm weather during El Niño events (Aiba and Kitayama, 2002; Hirano et al., 2007; Moser et al., 2014). The possible changes in plant functioning during La Niña events are still not clarified. In particular, Malhi et al. (1999) reported that for Amazon region in the South America El Niño periods are strongly associated with enhanced dry seasons that probably result in increased carbon loss, either through water stress causing reduced photosynthesis or increased tree mortality. Aiba and Kitayama (2002) examined the effects of the 1997–98 El Niño drought on nine rainforests of Mount Kinabalu in Borneo using forest inventory and showed that El Niño increased the tree mortality for lowland forests. However, it did not affect the growth rate of the trees of upland forests (higher than 1,700 m) where mortality was restricted by some understorey species only. Eddy covariance measurements of the CO_2 fluxes in a tropical peat swamp forest in Central Kalimantan, Indonesia, for the period from 2002 to 2004, provided by Hirano et al. (2007), showed that during the El Niño event in the period November-December 2002 the ~~net~~ annual net CO_2 release reached maximal values, mainly due to strong decrease of GPP in the late dry season, because of dense smoke emitted from large-scale fires. Effects of El Niño on annual RE in 2002 were insignificant.

There is a ~~great~~ lack of experimental data on CO_2 and H_2O fluxes in mountainous rainforests in equatorial regions of the Western Pacific, and on their response to ENSO. Hence, the main objective of this study was to evaluate and quantify the impact of ENSO events on the main components of CO_2 and H_2O fluxes in a pristine mountainous tropical rainforest growing in Central Sulawesi, Indonesia. The methodology used was analysis of long-term eddy covariance flux measurement data.

2. Materials and Methods

2.1 El Niño's types and intensity

Nowadays, two types of ENSO can be distinguished: 1) the canonical or conventional El Niño, which is characterised by SST anomalies located in the eastern Pacific near the South American coast (Rasmusson and Carpenter, 1982) and 2) the Central Pacific El Niño or El Niño Modoki (Larkin and Harrison, 2005; Ashok et al., 2007; Kug et al., 2009; Ashok and Yamagata, 2009; Gushchina and Dewitte, 2012). In 2003, the new definition of the conventional El Niño was accepted by the National Oceanic and Atmospheric Administration (NOAA) of the USA, in referring to the warming of the Pacific region between 5°N - 5°S and 170° - 120°W. According to Ashok et al. (2007) the Central Pacific El Niño/El Niño Modoki - i.e. unusually high SST - occurs roughly in the region between 160°E - 140°W and 10°N - 10°S.

As criteria to assess the intensity of ENSO events, a wide range of indexes based on different combinations of sea level pressure and SST data in various areas of the Pacific are used. For diagnostics of the central Pacific El Niño, the SST anomalies (in °C) in Nino4 region (5°N - 5°S and 160°E - 150°W) are broadly used (Figure 1). The monthly SST anomalies (in °C) in Nino3.4 region (5°N - 5°S and 170° - 120°W) are used to diagnose both types of El Niño phenomenon: canonical and Central Pacific (Download Climate Timeseries, 2013).

2.2 Experimental site

The tropical rainforest selected for the study is situated near the village Bariri in the southern part of the Lore Lindu National Park of Central Sulawesi in Indonesia (1°39.47'S and 120°10.409'E or UTM 51S 185482 m east and 9816523 m north) (Figure 1). The site is located on a large plateau of several kilometres in size at ~~It lies on a small plateau (~~about 1,430 m above sea level~~)~~ surrounded by mountain chains surmounting the plane by another 300 m to 400 m. Within 500 m around the tower the elevation varies between 1,390 and 1,430 metres. Wind field measurement with a sonic anemometer indicate a slope of around 2-3°, which is similar to many Fluxnet sites. ~~Thus, the ground surface has a gentle westward inclination that does not exceed 5°.~~ About 1,000 m to the east from the experimental site, the forest is replaced by a meadow; in all other directions the forest extends several kilometres. (Ibrom et al., 2007).

According to the Köppen climate classification the study area relates to tropical rainforest climate (*Af*) (Chen D. and Chen H.W., 2013). Weather conditions of the region are mainly influenced by the ITCZ. During the wet season (typically, from November to April) the area is influenced by very moist northeast monsoons coming from the Pacific. Maximum precipitation during the observation period from January 2004 to July 2008 ~~is~~ was observed in April - with

258.0±148.0 mm month^{-1}. The drier season usually lasts from May to October. The precipitation minimum is was observed in September with 195.0±48.0 mm month^{-1}. The September-October period is was also characterised by maximal incoming solar radiation, up to 650±47.0 MJ m^{-2} month^{-1}, mainly because of a significant decrease of convective clouds, due to the reversing of oceanic northeast monsoon to a southeast monsoon blowing from the Australian continent. The mean annual precipitation amount exceedededs 2000 mm. The mean monthly air temperature varies between 19.4 and 19.7 °C. The mean annual air temperature is was 19.5 °C (Falk et al., 2005; Ibrom et al., 2007).

The vegetation at the experimental site is very diverse and represented by more than 88 different tree species per hectare. Among the dominant species are *Castanopsis accuminatissima* BL. (29%), *Canarium vulgare* Leenh. (18%) and *Ficus spec.* (9.5%). The density of trees, with diameter at breast height larger than 0.1 m, is 550 trees per ha. In addition, there is more than a 10-fold larger number of smaller trees per hectare with stem diameter lower than 0.1 m. The total basal area of trees reached 53 m^2 per ha. One-sided Leaf lLeaf area index (LAI) is about 7.2 m^2 m^{-2}. LAI has been estimated using an indirect hemispherical photography approach with a correction for leaf clumping effects. The height of the trees, with diameters at breast height larger than 0.1 m, varies between the lowest at 12 m and the highest at 36 m. The mean tree height is 21 m (Ibrom et al., 2007).

2.3 Flux measurements

CO_2 and H_2O fluxes were measured from 2004 to 2008 within the framework of the STORMA project (Stability of Rainforest Margins in Indonesia, SFB 552), supported by the German Science Foundation (DFG). The eddy covariance equipment for flux measurement was installed on a meteorological tower of 70 m height at the 48 m level, i.e. ca. 12 m higher than the maximal tree height. The measuring system consists of a three-dimensional sonic anemometer (USA-1, Metek, Germany) and an open--path CO_2 and H_2O infrared gas analyzer (IRGA, LI-7500, Li-Cor, USA) (Falk et al., 2005;; Ibrom et al., 2007; Panferov et al., 2009). The open-path IRGA was calibrated with calibration gases two times per year and showed no considerable sensitivity drift within one year of operation. Turbulence datawere are sampled at 10 Hz and stored as raw data on an industrial mini PC (Kontron, Germany). All instruments were are powered by batteries, which were are charged by solar panels, mounted on the tower. The system is entirely self-sustaining and has been proven to run unattended over a period of several months. Post-field data processing on eddy covariance flux estimates was provided carried out strictly according to the established recommendationsto existing rules for data analysis (Aubinet et al., 2012). The raw data were

~~screened for outliers and either corrected or rejected.~~ In addition to the procedures described in Falk et al. (2005) and Ibrom et al. (2007), we corrected the flux data for CO_2 or H_2O density fluctuations due to heat conduction from the open-path sensor (Burba et al., 2008~~,~~; Järvi et al. 2009) using finally the suggested method as described in Reverter et al. (2011).

The system operated at ca. 70% of the time. Ca. 30% of the measured flux data were negatively affected by rain and other unfavourable conditions and removed. From night time ecosystem respiration data a friction velocity (u_*) threshold value of 0.25 m s^{-1} was estimated (Aubinet et al., 2000), i.e. at u_* values above this threshold the measured night time flux became independent from u_*. Night time ~~F~~flux values that were measured at $u_* < 0.25$ m s^{-1} ~~at night time~~ were removed, which left 15% of the measured night time flux data in the data set. For filling the gaps in the measured Net Ecosystem Exchange (NEE) data, as well as the gaps in net radiation, sensible and latent heat flux records ~~of~~ the process-based Mixfor-SVAT model (Olchev et al., 2002; 2008) were applied. The Mixfor-SVAT model was also used to quantify RE and forest canopy transpiration. The model was validated using long-term data records obtained for the tropical rain~~-~~forest in Bariri under well-developed turbulent conditions. The results of model validation showed a good agreement of model calculations with field observations for a broad spectrum of weather and soil moisture conditions (Falk et al., 2005; Falge et al., 2005; Olchev et al., 2008). GPP of the tropical rainforest was derived as a difference between measured NEE and RE.

2.4 Micrometeorological measurements

Air temperature, relative humidity and horizontal wind speed were measured at 4 levels above~~,~~ and at 2 levels inside~~,~~ the forest canopy using ventilated and sheltered thermo-hygrometers and cup anemometers (Friedrichs Co., Germany) installed on the tower. Short- and long-wave radiation components were measured below and above the canopy with CM6B and CG1 sensors (Kipp & Zonen, The Netherlands). Rainfall intensity was measured on top of the tower with a tipping bucket in a Hellman-type rain gauge. To fill the gaps in measuring records the meteorological data from an autonomic meteorological~~mobile automatic~~ station, situated about 900 m away from the tower outside the forest on a nearby meadow, were used. For the analysis, the monthly mean values of air temperature and monthly sums of precipitation and solar energy were calculated.

2.5 Data analysis

To estimate the possible impact of ENSO events on CO_2 and H_2O fluxes in the tropical rainforest at Bariri the temporal variability of monthly NEE, GPP, RE and ET in periods with different ENSO intensity was analysed. To quantify the ENSO impacts on meteorological parameters and fluxes and to distinguish them from effects caused by the seasonal migration of the ITCZ, the intra-annual patterns of CO_2 and H_2O fluxes as well as meteorological conditions during the measuring period were also evaluated.

In the first step to assess the possible impact of ENSO events on meteorological parameters (global solar radiation (G), precipitation amount (P), air temperature (T) and CO_2 and H_2O fluxes, the ~~possible~~ correlation between the absolute values of monthly G, P, T, NEE, GPP, RE, ET and monthly SST-anomalies in Nino4 and Nino3.4 regions (Nino4 and Nino3.4 indexes) were analysed.

In the second step we analyzed the correlation between the deviations of monthly meteorological parameter and flux values from their monthly averages over the entire measuring period and the Nino4/Nino3.4 indexes.~~, for a more accurate analysis of possible responses of H_2O and CO_2 fluxes in the tropical rain forest to ENSO forcing and to distinguish from their annual cycle, the absolute deviations of monthly flux values from monthly averages over the entire measuring period were calculated~~. The deviation in the case of GPP (ΔGPP) was estimated as

$$\Delta GPP_{Month,Year} = GPP_{Month,Year} - \frac{1}{N}\sum_{Year=2004}^{2008} GPP_{Month,Year}$$

where $GPP_{Month,Year}$ is total monthly GPP for a particular month (January to December) and corresponding year (2004 to 2008), $\frac{1}{N}\sum_{Year=2004}^{2008} GPP_{Month,Year}$ is monthly GPP for this particular month averaged for the entire measuring period (2004 to 2008); N is number of years. ~~The temporal variability of deviations was then compared to Nino3.4 and Nino4 indexes.~~ Positive values in ΔGPP, ΔRE, and ΔNEE indicate GPP, RE higher and NEE (carbon uptake) lower than average.

The typical timescale of full ENSO cycle is estimated to be about 48-52 months (Setoh et al 1999) whereas the timescale of the main meteorological parameters (global solar radiation (G), precipitation amount (P), air temperature (~~E~~T)) is characterized by much higher month-to-month variability even after annual trend filtering. In order to filter the high-frequency oscillation in the time-series of atmospheric characteristics and monthly NEE, GPP, RE, ET anomalies the~~sliding~~ simple ~~central~~centered moving -average smoothing procedure was applied.~~In order to avoid any possible influence of short-term month-to-month flux fluctuations,~~ The ~~smoothed central~~ moving averages (MA) of variables ~~parameters~~ were calculated~~curves of flux deviations were analysed. For the smoothing procedure,~~ over ~~the~~ 7 months (centered~~ral~~ value ±3 months)~~ running means was used.~~.

Statistical analysis included both simple correlation and cross-correlation analysis. Cross-correlation analysis was used to take into account the possible forward and backward time shifts of maximal anomalies of meteorological parameters and CO_2 and H_2O fluxes in respect to time of the ENSO culmination. To describe the relationships between atmospheric fluxes and meteorological parameters the monthly non-smoothed values were used.Similar deviations were calculated also for mean monthly air temperature (T), global solar radiation (G) and precipitation amount (P).The temporal variability of deviations was then compared to Nino3.4 and Nino4 indexes.

3. Results

During the measuring period, two El Niño (August 2004 - March 2005 and October 2006 - January 2007) and one La Niña (November 2007 - April 2008) phenomena were observed. All events had moderate intensity. Both warm events could be classified as the Central Pacific or Modoki type, according to Ashok et al. (2007), since the SST-anomalies were centred in Nino3.4 and Nino4 regions (Figure 1).

Analysis of the intra-annual pattern of CO_2 and H_2O fluxes shows a relatively weak seasonal variability (Figure 2). The maximal values of GPP were obtained during the second part of the drier season - from August to October (278±13 gC m^{-2} $month^{-1}$) - which is also characterised by maximal values of incoming solar radiation. The mean monthly air temperature in the period varied from minimal values in August (19.2±0.2 °C) to maximal values in October (19.8±0.2 °C). The minimal GPP values were obtained in transition periods between more wet and dry seasons - in May - June and November - December (240±15 and 249±21 gC m^{-2} $month^{-1}$, respectively). These periods are also characterised by minimal amounts of incoming solar radiation (512±40 MJ m^{-2} $month^{-1}$). Maximal RE (206±10 gC m^{-2} $month^{-1}$) and values were obtained in October, which corresponds to the period of maximal air temperature and insolation. The local maximum of RE in April - May (199±4 gC m^{-2} $month^{-1}$) is also well correlated with a small increase of the air temperature in these months. The minimal RE was observed in February and June-August (174±10 and 187±15 gC m^{-2} $month^{-1}$, respectively). The intra-annual pattern of ET was closely related to the seasonal variability of GPP. The maximum values of ET were also observed in October (136±4 mm), in the month of maximal incoming solar radiation and highest values of air temperature. In spite of a large amount of precipitation and a high air temperature during the period from March to June, ET in this period was much lower than in September and October (e.g. 105±8 mm in April).

Comparisons of monthly NEE, GPP, RE, ET and SST-anomalies in Nino4 and Nino3.4 regions (Nino4 and Nino3.4 indexes) indicate relatively low correlations. Changes of the Nino4 index can explain about 12% of the observed variability in GPP (coefficient of determination, r^2=0.12 under significance level, $p<0.05$), 9% of RE (r^2=0.09, $p<0.05$), 9% of NEE (r^2=0.09, $p>0.05$), 6% of ET (r^2=0.06, $p<0.05$) and only about 1% of transpiration (TR) (r^2=0.01, $p>0.05$).

Similar values were obtained in correlation analysis for the Nino3.4 index. In the period of El Niño peak phases (September 2004 - January 2005 and October 2006 - January 2007) the values ET and GPP tend to increase in the study area. An increase of RE was indicated only during the second El Niño event from October 2006 to January 2007. The effect of El Niño on NEE was insignificant. The effect of La Niña on CO_2 and H_2O flux components was very small and manifested only in a slight increase of NEE.

Analysis of the temporal variability of the centered moving average values of ΔGPP (ΔGPP_{MA}) (Figure 3) in contrast to comparisons of absolute monthly GPP indicates a relatively high correlation between ΔGPP_{MA} and both Nino4 (r^2=0.52, $p<0.05$) and Nino3.4 (r^2=0.60, $p<0.05$) indexes. Close correlation between the intensity of ENSO events and ΔGPP_{MA} can be explained by the influence of ENSO initiating processes and ENSO itself on total cloud amount in the region and, as a result, on monthly sums of incoming G (Figure 4). Variability of G (ΔG_{MA}) is very closely correlated with Nino4 and Nino3.4 indexes (r^2=0.48, $p<0.05$ for both indexes) (Figure 4) and it can explain 69% of variability of GPP (r^2=0.69, $p<0.05$). The maximal deviations of ΔGPP_{MA} and ΔG_{MA} from mean values (averaged for the entire measuring period) are occurring ~~a few~~2-3 months before the peak phase of the ENSO events (Figure 5). The maximal cross-correlation coefficients in this period reached 0.76 for ΔG_{MA}, and 0.86 - for ΔGPP_{MA}. The effect of T changes (ΔT) on ΔGPP_{MA} is very low (r^2=0.01, $p>0.05$).

The correlation between ΔT_{MA} and Nino4, Nino3.4 indexes are ~~also very~~relatively low (r^2=0.15, $p>0.05$ for Nino4 and r^2=0.05, $p>0.05$ for Nino3.4) and it can explain the very weak correlations between ΔRE_{MA} and ENSO indexes (r^2=0.10, $p<0.05$ for Nino4 and r^2=0.04, $p>0.05$ for Nino3.4) (Figures 3-4). The maximal deviations of T_{MA} and RE_{MA} from mean values (averaged for the entire measuring period) are occurring 2 months after the peak phase of the ENSO events and it has negative sign (Figure 5). The cross-correlation coefficient in this period is -0.53 ($p<0.05$).

Despite the relatively close dependence of ΔGPP_{MA} on ENSO intensity, the correlations between ΔNEE_{MA} and Nino4, Nino3.4 indexes are lower (r^2 = 0.31, $p<0.05$ for Nino4 and r^2 = 0.37, $p<0.05$ for Nino3.4), mainly because of their very low correlation during the first part of the measuring period (before December 2005). During the second part of the considered period (from June 2006 to June 2008) with one strong El Niño (October 2006 - January 2007) and one La Niña (November 2004 - April 2008)~~,~~ events ΔNEE_{MA} and Nino4, Nino3.4 indexes are correlated much better. ~~Such a trend~~It can be explained by the influence of ΔRE_{MA} on ΔNEE_{MA} dynamics that is mainly governed by temperature variability and which is, as already mentioned, very poorly correlated with Nino4/Nino3.4 indexes (Figures 3-4).

Taking into account that the monthly anomalies of NEE might be biased by a still unaccounted advection effects at night-time, despite u_* filtering, ~~night-time underestimation of CO_2~~

~~fluxes~~ , we additionally examined ~~averaged~~ NEE ~~-~~at midday ~~NEE~~ (10:00-14:00), when turbulent mixing is typically well developed.~~, which are mainly governed by GPP and not by RE. As midday NEE data are direct measurements typically with turbulent conditions they should be unaffected by potentially flawed data due to a slope or night time problem.~~ Data analysis based on midday NEE shows a similar clear relationship ~~between monthly mean (?) ofaveraged midday NEE and the~~ with the ENSO index (Figure 6) with $r^2 = 0.59$ under $p<0.05$. The maximal deviations of both NEE_{MA} and ~~averaged~~ midday NEE_{MA} from the their mean values ~~are~~ occurred simultaneously within the peak phase of the ENSO events (Figure 5).

Analysis of the temporal variability of the moving average values of monthly ~~Δ~~ET~~ET~~ (ΔET_{MA} ~~variability~~) showed a ~~well response~~ high correlation to ENSO activity as well: ~~-~~$r^2 = 0.72$, $p<0.05$ for Nino4 and $r^2 = 0.70$, $p<0.05$ for Nino3.4 (Figure ~~5~~7), probably also triggered by ~~the~~ G_{MA}, which in turn ~~very high correlation~~ correlated strongly with ~~between ΔG_{MA} and~~ both the Nino4 and~~,~~ the Nino3.4 index~~es and ΔG_{MA} and ΔET_{MA}~~. ~~Interestingly, a small backward phase shift is observed betweenP~~ periods of extreme ΔET_{MA} values and maximal ~~intensity of~~ ENSO intensity ~~are~~ occurred ~~also quite~~ simultaneously (Figure 5). Correlations between ΔET_{MA} and ΔT_{MA}, as well as between ΔET_{MA} and ΔP_{MA}, are insignificant - r^2=0.09 ($p>0.05$) and r^2=0.01 ($p>0.05$), respectively. However, ~~f~~Figures 4 and ~~4~~ 5 clearly show~~s~~ a ~~manifested~~ time delay in ΔP_{MA} oscillation, relative to Nino4 and Nino3.4 patterns~~, -~~. ~~when~~ The maximal ~~positive or~~ negative deviations of ΔP_{MA} are ~~indicated~~ observed about ~~five~~ eight months ~~after~~ before~~peak phases of ENSO~~,(cross-correlation between ΔP_{MA} and Nino 4 index ~~-~~-0.72, $p<0.05$) and maximal positive deviation of ΔP_{MA} - about four-five months after the peak phases of ENSO (cross-correlation between ΔP_{MA} and Nino 4 index - 0.40, $p<0.05$), respectively. ~~The best correlation between the time-shifted time series of ΔP_{MA} from ENSO index patterns is much higher ($r^2 = 0.32$, $p<0.05$ for Nino4 and $r^2 = 0.28$, $p<0.05$ for Nino3.4).~~

To explain a very low sensitivity of ET to P changes, we analysed the intra-annual variability of the ratio between ET and potential evaporation (PET), as well as between ET and P. PET was derived using the well-known Priestley and Taylor (1972) approach and it is equal to evaporation from wet ground or open water surface.

The mean annual ET during the measuring period is considerably lower than P (ET/P=0.742). Over the annual course, the ratio varied between 0.58 (in March and November) to 1.85 (in August and October). During dry periods before the positive phase of ENSO, the mean values of the ET/P ratio grow up to 1.9-2.1. During the periods of negative Nino4 and Nino3.4 anomalies the mean monthly ET/P ratio fell, in some months, down to 0.3. Correlation analysis of temporal variability of $\Delta(ET/P)$ and $\Delta(ET/P)_{MA}$ ratios and Nino4 and Nino3.4 indexes (Figure ~~5~~7) did not show any statistically significant relationships. However, it should be mentioned that the temporal pattern of $\Delta(ET/P)$ and $\Delta(ET/P)_{MA}$ is characterised by two peaks that were observed in July of 2005 and April 2007, about 6-8 months prior to the El Niño culmination (Figure 57).

The monthly mean ET/PET ratio has a feeble intra-annual trend course with maximum in June (0.93±0.03) and with minimminima um in February and October (0.84±0.06). The averaged annual ET/PET ratio for the entire measuring period was 0.880±0.055. The minimal values of $\Delta(ET/PET)_{MA}$ ($\Delta(ET/PET)_{MA}$=0.81) were observed during the El Niño culmination in 2005-2006, and the maximal values, during the period of maximal intensity of La Niña in 2008 ($\Delta(ET/PET)_{MA}$=0.93). Thus, monthly ET rates are relatively close to PET values during the whole year including the periods of maximal ENSO activity. The relative soil water content of the upper 30 cm horizon calculated using the Mixfor-SVAT model during the entire period of the field measurements, including the periods with maximal values of the ET/P ratio, was always higher than 80%. This, together with the ET/PET ratio, is a clear indicator of permanently sufficient soil moisture conditions in the study area, including periods of El Niño and La Niña culminations, explaining the very low sensitivity of ΔET to ΔP.

4. Discussion

The provided analysis of the temporal variability for the main components of carbon and water balances in the tropical rainforest showed a very high correlation between Nino4 and Nino3.4 SST anomalies, characterising the ENSO intensity with ΔGPP_{MA} and ΔET_{MA} deviations from monthly averages over the entire measuring period. Application of the centered moving average smoothing procedure allows us to filter the high-frequency month-to-month oscillations in the time-series of atmospheric characteristics caused by local and regional circulation processes that are not directly connected with ENSO activity. These relationships between ΔGPP_{MA}, ΔET_{MA} and Nino4 and Nino3.4 indexes are mainly governed on the one hand by the strong dependency of the incoming solar radiation on ENSO intensity development – surface water warming ofin Nino 3.4 and 4 regions generally results in a decrease of cloudiness above the study region and thus – in increase of incoming solar radiation. and On the other hand there isare many data about a high correlation between monthly GPP and ET rates and incoming and incomingabsorbed solar radiation absorbed by the ground surface (e.g. Ibrom et al., 2008). The effects of monthly air temperature and precipitation changes on ΔGPP and ΔET variability are relatively poor, mainly due to the low correlations between ΔT_{MA}, ΔP_{MA} and ENSO intensity. The maximal intensity of ENSO events is usually observed in the period of December to February.

~~During the year, the intensity of ENSO associated anomalies changed drastically, including the change of anomaly sign. As a result, the effect of ENSO in annual values of both meteorological parameters and fluxes is very poorly manifested.~~

The cross-correlation analysis (Fig. 5) shows that the~~The patterns of~~ ΔGPP_{MA}~~, ΔET_{MA}~~ and ΔG_{MA} have a ~~clearly manifested~~small ~~1~~2-3 month backward shift relatively to the course of Nino4 SST, i.e. the maxima in GPP_{MA} ~~and ET~~ occur earlier than ENSO culmination in the central Pacific (Nino4 SST anomaly). The maximal values of ΔE_{MA} ~~were~~ occurred ~~quite~~ simultaneously with El Niño and La Niña culminations. Such an effect of El Niño episodes on ~~the seasonality of~~ G can be explained, as mentioned above, by a decrease of the cloud amount in the region of Indonesia, due to the El Niño-associated shift of the Walker circulation cell, and corresponding zone of deep convection, from the maritime continent of Indonesia toward the dateline following SST anomalies displacement. El Nino usually begins in April, and toward August-September the ascending branch of the Walker cell leaves Indonesia and migrates eastward to the Pacific. Therefore, 3-4 months before the El Niño culmination in December-January, a decrease in cloud amount is observed over Indonesia. Weakening of El Niño, in turn, leads to a backward shift of intensive convection zone westward. It can result in increasing precipitation amounts in the region during the second half of the wet period after passing the maximal El Niño activity~~,~~ and also the gradual increase of the cloudiness and decrease of incoming solar radiation. The opposite effect takes place during the La Niña with similar phase shift: simultaneously, with the spreading of a negative SST anomaly over the Pacific, the increasing of deep convection over Indonesia occurs, which results in an increase of cloudiness and precipitation, being more pronounced as it falls into the dry period of the year. The lower panels of Fig~~.~~ure 4 indicate however, that the decrease of radiation due to increase of cloudiness does not depend linearly on La Nina intensity, reaching a saturation state at approximately -20..-30 MJ m^{-2} $month^{-1}$.

A relatively poor correlation between ΔT_{MA} patterns and ENSO activity and an insignificant influence of ΔT on ΔGPP and ΔET can be mainly explained by the small intra-annual amplitude of the air temperature in the study area not exceeding 1.0 °C, as well as by the low dependence of the air temperature on incoming solar radiation. The mean monthly temperatures ranged in the intra-annual course between 19.5 °C and 20.5 °C. Maximal air temperatures do not exceed 28.5 °C, even on sunny days. Such optimal thermal conditions with high precipitation amount provide sufficient soil moistening and relatively comfortable conditions for tree growth during the whole year. As is was already mentioned even during the El Niño culmination in 2005-2006 the ET/PET ~~doesn't~~ did not decrease~~d~~ below 0.74, ~~(~~ $(ET/PET)_{MA}$>0.81, ~~)~~ and the relative soil water content of the upper 30 cm horizon was always higher than 80%.

The analysis of absolute and relative changes of GPP and ET during the periods of maximal El Niño and La Niña ~~activity~~ activities showed that GPP during the El Niño culminations of 2005 and 2007 increased by about 20 gC m^{-2} month^{-1} (6-7%). ΔGPP_{MA} was about 9 gC m^{-2} month^{-1} (2-3%), ΔET - about 40 mm month^{-1} (about 30%) and ΔET_{MA} - about 10 mm month^{-1} (6-7%). Thus, the maximal ΔGPP was two times lower than the mean annual amplitude of GPP (Figure 2). The maximal ΔET was equal to the annual amplitude of ET (Figure 2). During the La Niña culmination of 2008 the maximal relative changes of GPP were higher than the relative changes observed during El Niño events: ΔGPP was about -22 gC m^{-2} month^{-1} (8%), ΔGPP_{MA} - about -12 gC m^{-2} month^{-1} (4%). The maximal decrease of ΔET in the period was relatively small: ΔET - about -12 mm month^{-1} (10%) and ΔET_{MA} - about -5 mm month^{-1} (4%). ΔET was about 3 times lower than the mean annual amplitude of ET. Interestingly the radiation dependent GPP (as represented by smoothed 7 month mean) does not demonstrate any ~~saturation states~~prolonged constant period during La Nina phases though the radiation does. During the first cold event the GPP-reduction is not as strong as during the second one, although the G-reductions are nearly of same strength. It could be assumed that in the first case the effect of radiation decrease on GPP was compensated by other factors like slight increase of air temperature~~(?)~~.

~~It can be expected that more intensive ENSO events can result in much larger changes of GPP and ET.~~

Additionally, we investigated the influence of other climatic anomalies in the region on CO_2 and H_2O fluxes of the tropical rain~~-~~forest, such as the Madden–Julian oscillation (MJO) and the Indian Ocean Dipole (IOD). The MJO is characterised by an eastward propagation of large regions of enhanced and suppressed deep convection from the Indian ocean toward central Pacific (Zhang, 2005). Each MJO cycle lasts approximately 30–60 days and includes wetter (positive) and drier (negative) phases. As an estimation of deep convection intensity in the tropics, the outgoing long-wave radiation (OLR) measured at the top of the atmosphere is commonly used. It was recently shown that 6-12 months prior to the onset of an El Niño episode a drastic intensification of the MJO occurs in the Western Pacific (Zhang and Gottschalck, 2002; Lau, 2005; Hendon et al., 2007; Gushchina and Dewitte, 2011). Furthermore, MJO behaviour varies significantly during the ENSO cycle: it is significantly decreased during the maxima of conventional El Niño episodes, while it is still active during the peak phase of central Pacific events. MJO rarely occurs during La Niña episodes (Gushchina and Dewitte, 2012). As MJO is strongly responsible for intra-seasonal variation of precipitation in the study region, the occurrence of MJO events was compared to the significant anomalies of ET/P ratio and of key meteorological variables. No evidence of MJO influence is observed: the positive and negative anomalies of ET/P ratio are associated to positive, negative and zero anomalies of OLR, filtered in the MJO interval. Also, no significant relation emerged from the correlation analysis.

Correlations between MJO index (Wheeler and Kiladis, 1999; Gushchina and Dewitte, 2011), and the deviations of key meteorological parameters from monthly averages during the study period were very low: $r^2 = 0.03$ for T, $r^2 = 0.03$ for P and $r^2 = 0.01$ for G ($p>0.05$, in both cases).

The Indian Ocean Dipole (IOD) is characterised by changes of the SST in the western Indian Ocean, resulting in intensive rainfall in the western part of Indonesia during the positive phase and corresponding precipitation reduction during the negative phase (Saji et al., 1999). To find a possible influence of IOD events on temporal variability of meteorological parameters and CO_2 and H_2O fluxes, the monthly mean IOD index (Dipole Mode Index, DMI) was used. Results showed that with respect to the western part of Indonesia situated close to Indian Ocean the IOD phenomenon has no significant impact on meteorological conditions and fluxes of the area of Central Sulawesi.

5. Conclusions

CO_2 and H_2O fluxes~~,~~ in the mountainous tropical rain~~–~~forest in Central Sulawesi in Indonesia~~,~~ showed a ~~very~~ high sensitivity of monthly GPP and ET to ENSO intensity for the period from January 2004 to June 2008. ~~It~~ This ~~is~~ was mainly governed by ~~a~~ the high dependency ~~sensitivity~~ of incoming solar radiation (*G*) to Nino4 and Nino3.4 SST changes and the stro~~i~~ng sensitivity of GPP and ET on ~~influence of *incoming solar radiation*~~ *G*~~-~~.~~on GPP and ET.~~
Interestingly, we observed lag effects between the fluxes and ~~the climate anomaly~~ENSO. The maximal deviations of ~~Δ~~GPP_{MA} and ~~Δ~~G_{MA} from their mean values (ΔGPP_{MA} and ΔG_{MA}) ~~were~~ occurred 2-3 months before the peak phase of the ENSO events whereas the maximal values of ΔE_{MA} and ΔNEE_{MA} ~~were~~ occurred at the same time as the peak~~quite simultaneously with El Niño events~~~~and La Niña culminations~~. The ~~E~~effect of ENSO intensity ~~activity~~ on RE ~~is~~was relatively low mainly due to its ~~only~~ weak ~~sensitivity~~ effect on ~~of~~ ~~In contrast, RE pattern is mainly influenced by the~~ air temperature~~ variation, which is however not significantly influenced by ENSO activity. Thus, there is no significant relationship between to Nino4 and Nino3.4 SST dynamics and RE pattern~~. Anyway, the~~is~~ small cross-correlation between RE and ENSO intensity ~~dices~~ had a compensatory effect on the timing of NEE that did not show any lag effects to the ENSO dynamics, contrary to the lagged effect of ENSO on *G* and GPP~~as observed with GPP and G~~~~Correlation between ENSO intensity and variation of monthly mean NEE values is also relatively low~~ whereas ~~the correlation between monthly averaged midday NEE and ENSO intensity is much higher mainly due to high correlation between midday NEE and GPP~~. ~~The maximal values of~~ ΔNEE_{MA} ~~and~~

~~monthly averaged midday $ANEE_{MA}$ are occurred simultaneously with the peak phases of ENSO~~. Other than observed in other tropical sites, ~~Precipitation~~ precipitation variation ~~has~~ had no influence on the CO_2 and H_2O fluxes at this site, mainly due to the permanently sufficient soil moisture condition in the study area.

Other climatic ~~anomalous events~~anomalies in the Western Pacific region, such as the Indian Ocean Dipole and the Madden–Julian oscillation, ~~-~~did not show any significant effect on neither the meteorological conditions nor the CO_2 and H_2O fluxes in the investigated mountainous tropical rain forest in Central Sulawesi.

It is important to emphasise that the considered observation period does not cover a~~the~~ period with extreme El Niño events, such as, e.g., the 1982-83 and 1997-98 events, when the anomaly of Nino3.4 SST, during several months, exceeded 2.6°C and more significant changes of surface water availability were~~moistening conditions could~~ ~~be~~ observed. Also, i~~It can be also expected that i~~n lowland parts of Sulawesi, characterised by higher temperatures and lower precipitation, the vegetation response to ENSO events is likely to be ~~can be also~~ different and more pronounced (Erasmi et al., 2009).

All observed ENSO events during the selected period are classified as Central Pacific type. Recently, Yeh et al. (2009) showed that under projected climate change the proportion of Central Pacific ENSO events might increase. Furthermore, Cai et al. (2014, 2015) showed that current projections of climate change for the 21st century suggest~~are associated with~~ an increased future likelihood ~~general increase~~ of both El Niño and La Niña events. Based on the results of our study, potential increases in ENSO activity would results in ~~Taking this into account the results of the present study indicate possible substantial~~an increased variability of ~~variations of~~ the CO_2 and H_2O exchange between atmosphere and the tropical rain~~-~~forests in such regions~~Indonesia under future climatic conditions~~.

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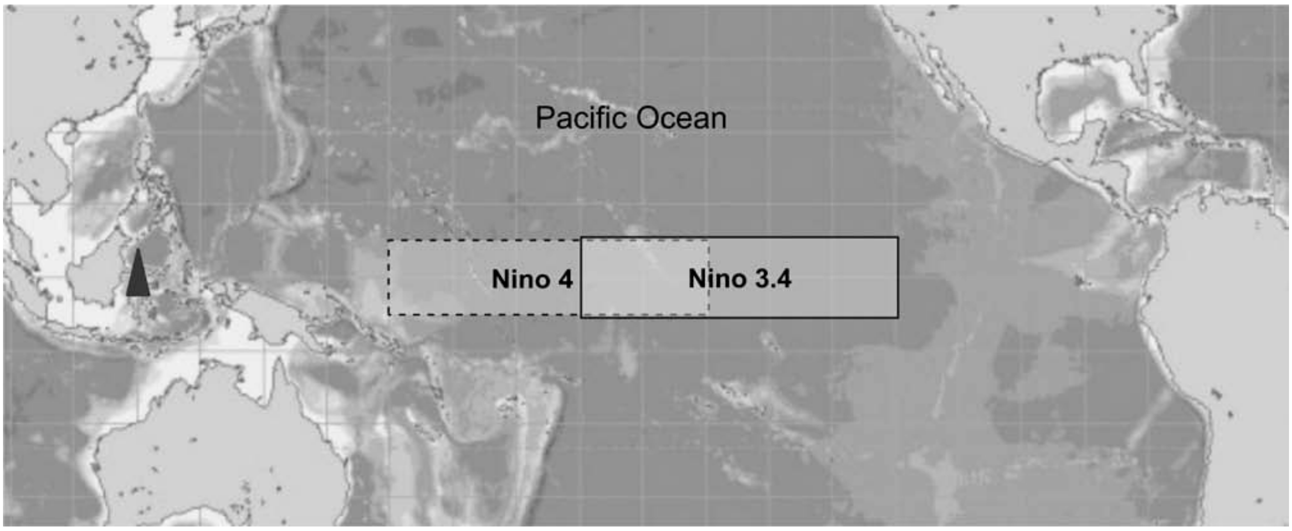

Figure 1. Geographical location of a study area (marked by black triangle) in tropical rain forest in Central Sulawesi (Indonesia) and Nino4 and Nino3.4 regions.

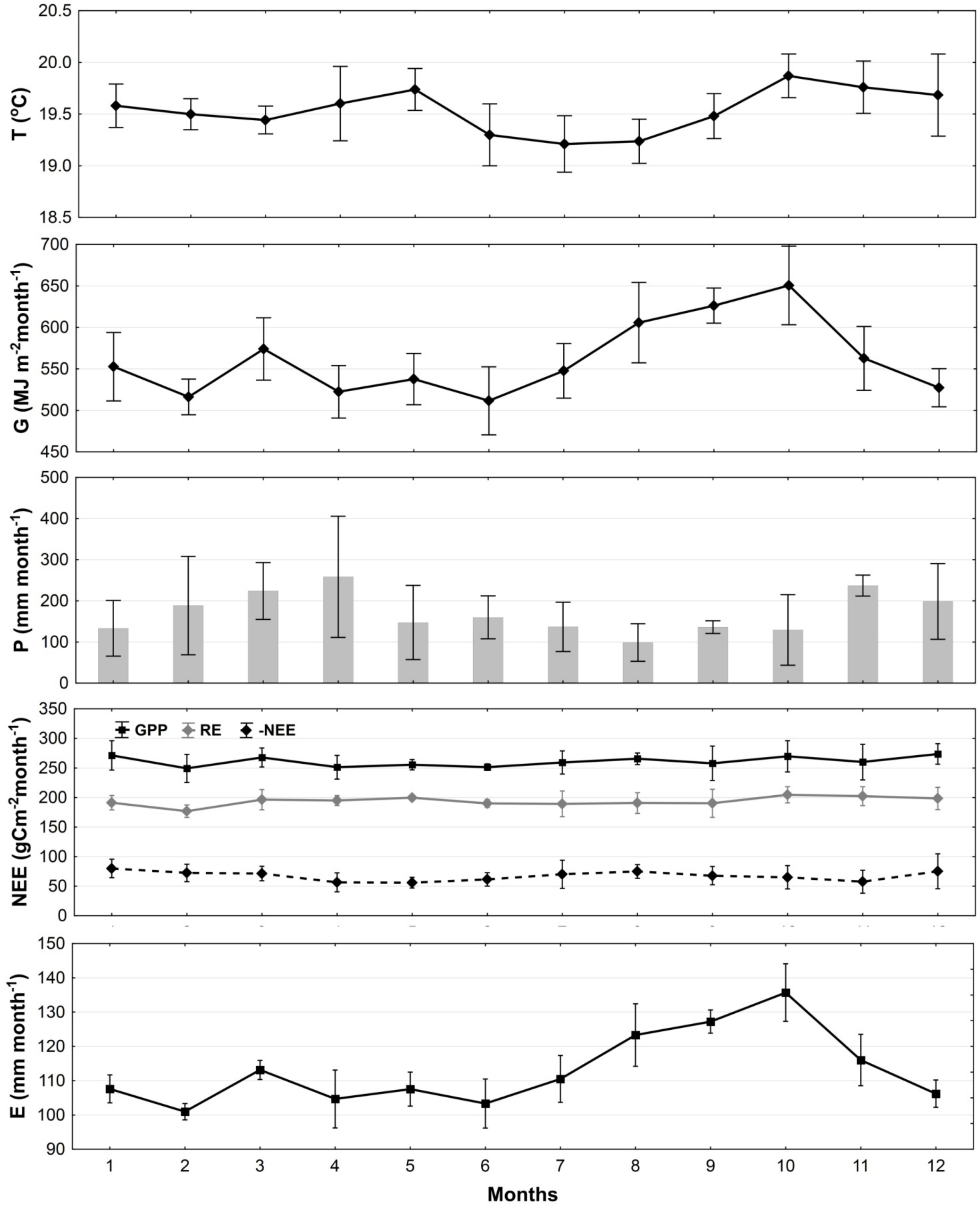

Figure 2. Mean intra-annual ~~trends~~courses of air temperature (T), global solar radiation (G), precipitation (P), NEE, GPP, RE and ET for the tropical rain forest in Bariri. Vertical whiskers indicate standard deviations (SD).

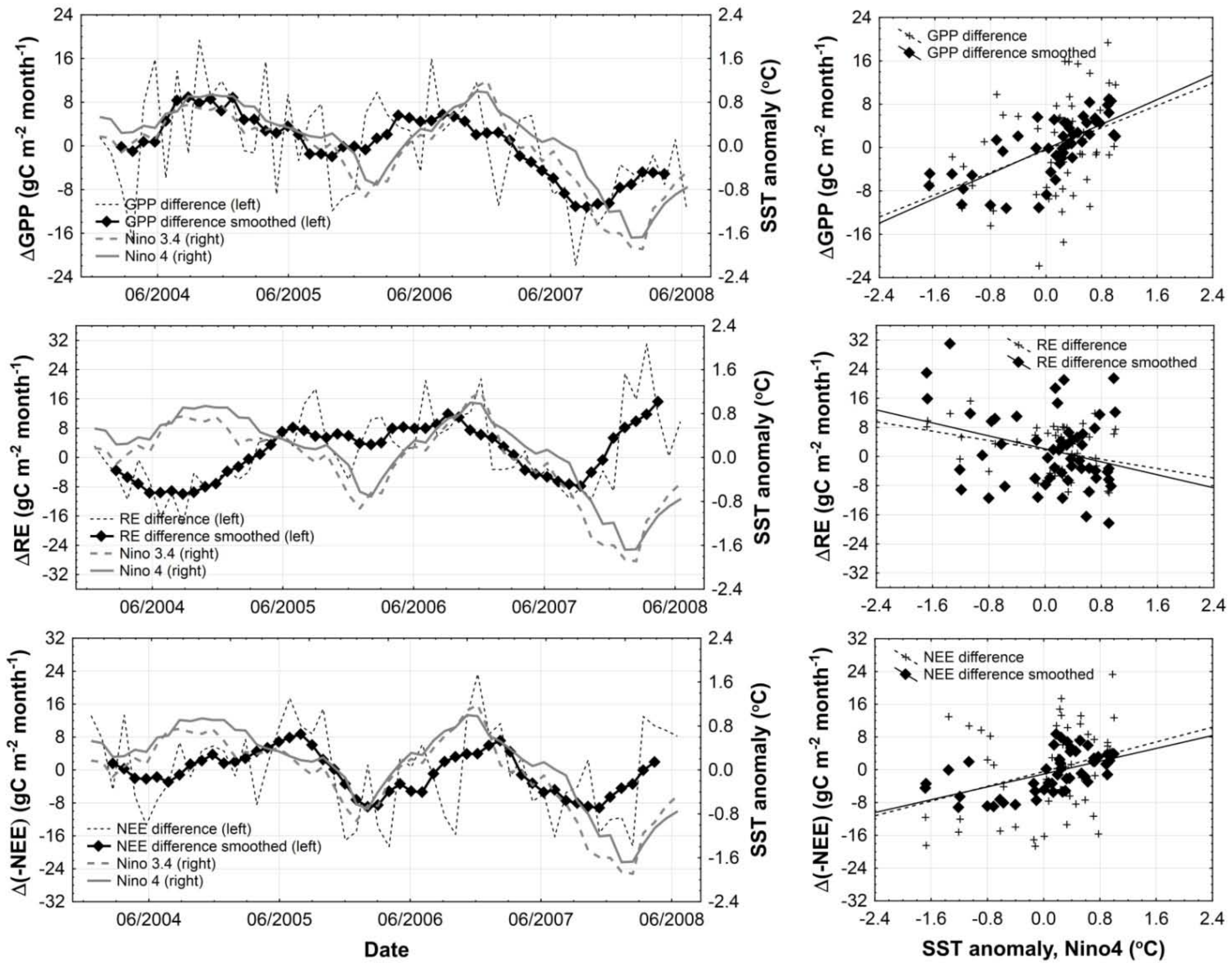

Figure 3. Comparisons of inter-annual pattern of SST anomalies in Nino4 and Nino3.4 zones of equatorial Pacific with variability of both deviations and ~~6~~ 7 month (±3 months)~~s~~ ~~running meancentral~~ moving average deviations of monthly GPP, RE and NEE values from mean monthly values of GPP, RE and NEE averaged over the entire measuring period from 2004 to 2008.

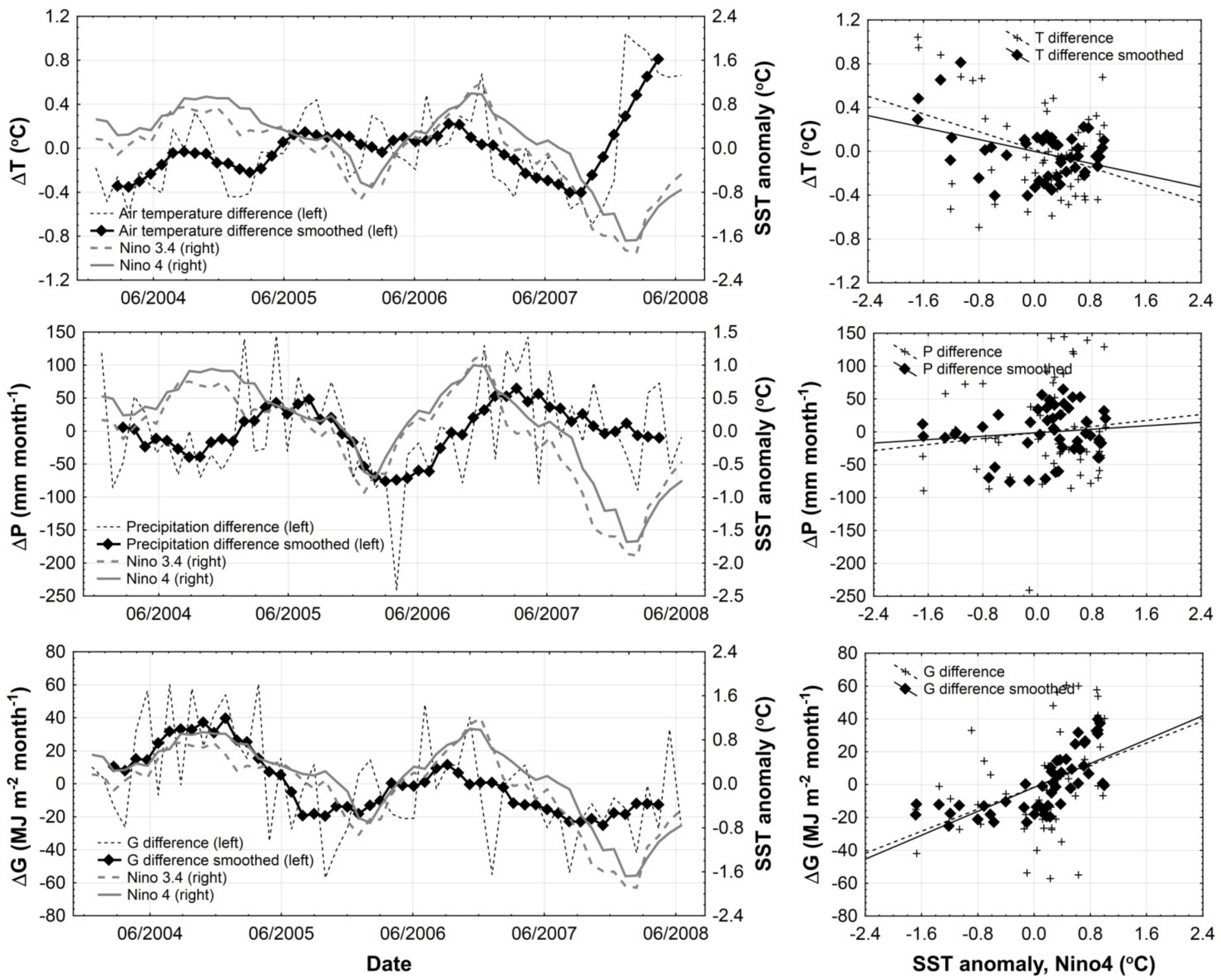

Figure 4. Comparisons of inter-annual pattern of SST anomalies in Nino4 and Nino3.4 zones of equatorial Pacific with variability of both deviations and ~~6~~ 7 month (±3 months)~~s~~ moving average~~running mean~~ deviations of monthly air temperature (T), precipitation (P) and global radiation (G) values from mean monthly values of T, P and G averaged over the entire measuring period from 2004 to 2008.

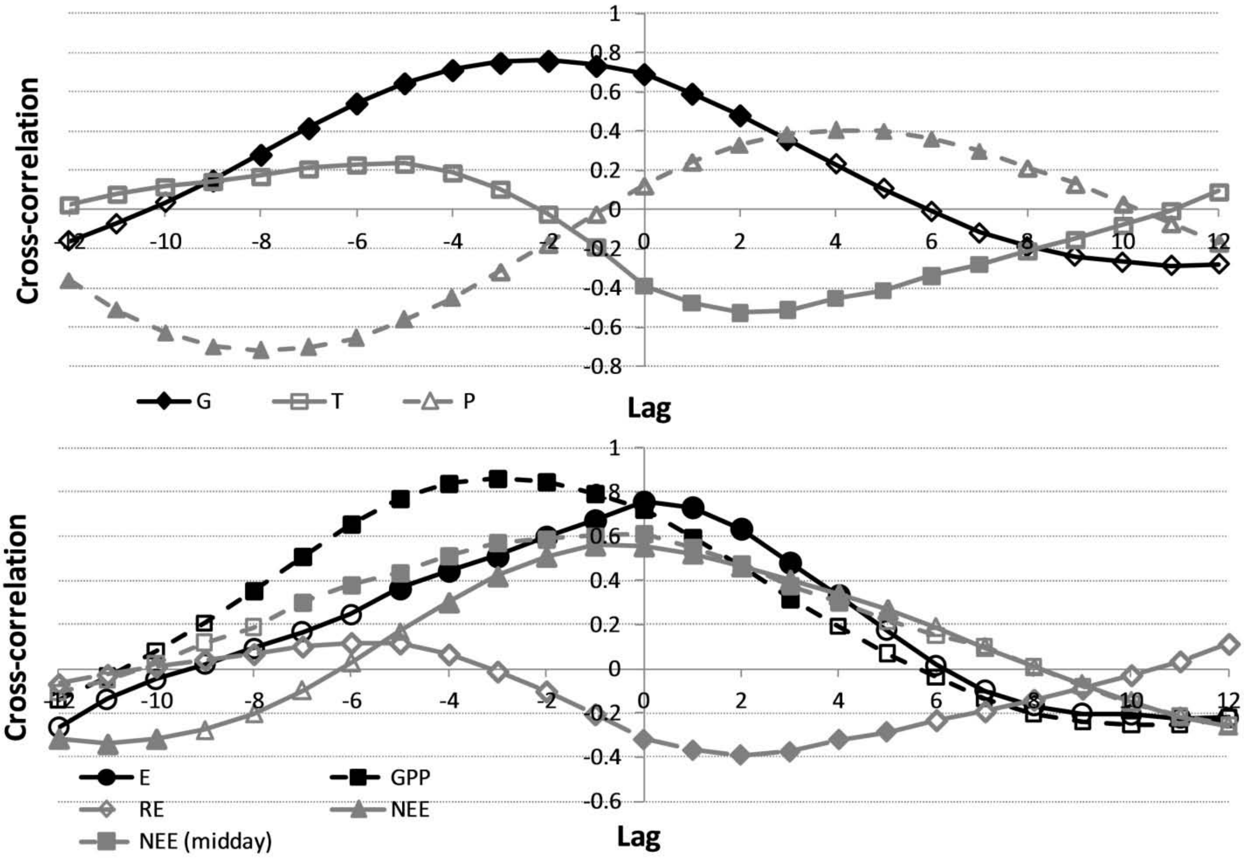

Figure 5. Cross-correlation functions between ΔG_{MA}, ΔT_{MA}, ΔP_{MA}, ΔE_{MA}, ΔGPP_{MA}, ΔRE_{MA}, ΔNEE_{MA} and midday ΔNEE_{MA} values and SST anomalies in Nino4 zone of equatorial Pacific. Filled symbols are corresponded to p-value <0.05 and non-filled symbols - to $p>0.05$. Lag step is 1 month.

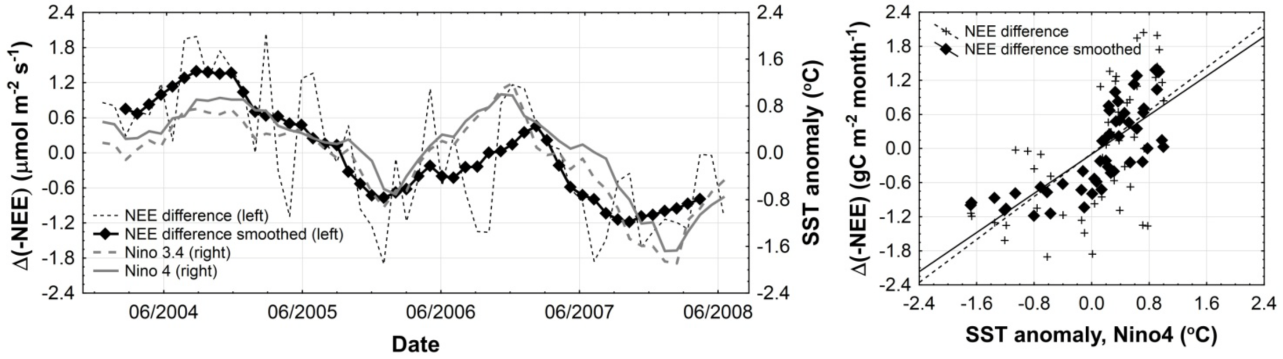

Figure 6. Comparisons of inter-annual pattern of SST anomalies in Nino4 and Nino3.4 zones of equatorial Pacific with variability of both deviations and 7 month (±3 months) moving average deviations of midday NEE (10:00-14:00) values from mean monthly midday values of NEE averaged over the entire measuring period from 2004 to 2008.

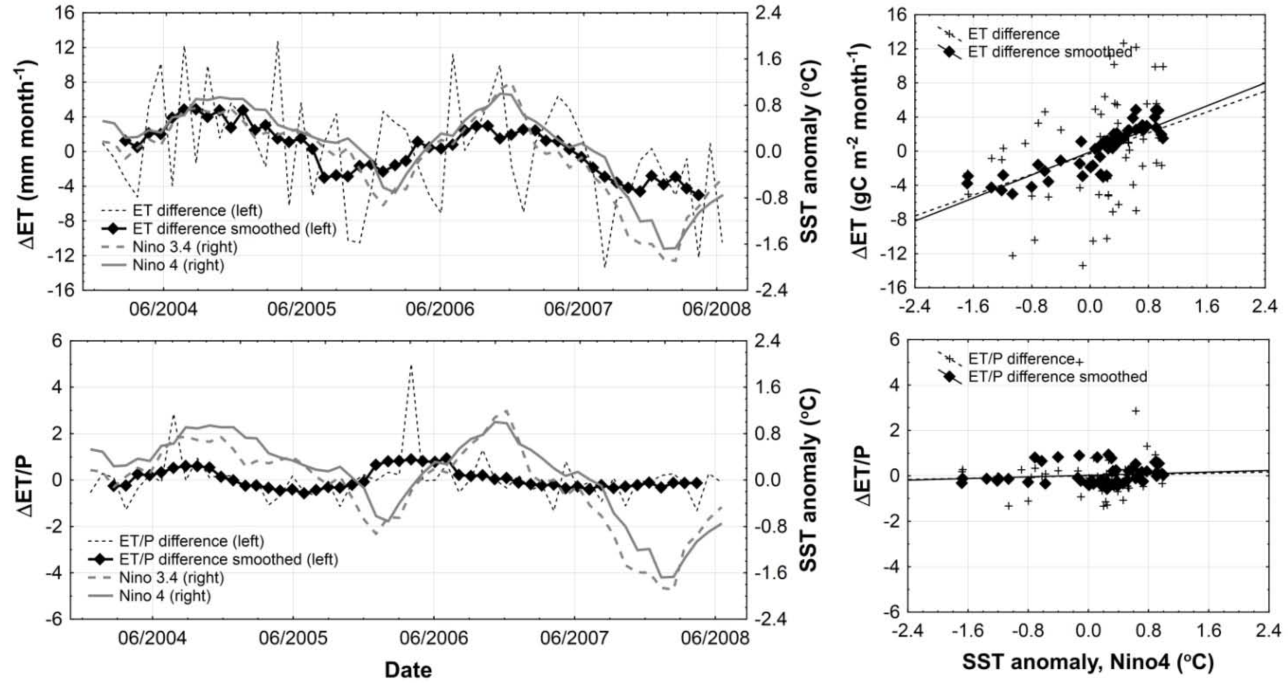

Figure 675. -Comparisons of inter-annual pattern of SST anomalies in Nino4 and Nino3.4 zones of equatorial Pacific with variability of both deviations and 6 7 month (±3 months)s moving averagemoving average frunning mean deviations of monthly ET rate and ratio ET/P from mean monthly ET rate and ET/P averaged over the entire measuring period from 2004 to 2008.