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Modeling canopy interception after fog, mixed precipitation and rainfall with the Gash analytical model: possibilities and challenges

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Gash analytical model was designed to model rainfall interception (Gash, 1979), was modified to include sparse vegetation and is used nowadays alone or couple with other models. It has been proved to work well for different forest ecosystems from narrow to broad leaves forest type and even after disruptive events like fires. The special case of water interception in cloud forests presents challenges due to the presence of rainfall only, mixed precipitation (rainfall and fog) and fog events in cloud forest ecosystems. Hereby, the author presents the contribution of the different water inputs to the cloud forest including the influence of wind on the measurements, possibilities and challenges of modeling fog, mixed precipitation and rainfall with the Gash analytical model.
The case study of Jelima (Spain) as located between 1090 and 1300 m elevation was used in this study. Rainfall inputs and fog incidence above the canopy, as well as throughfall were measured using automatic raingauges couple with a fog collector and funnels for one year. The analytical model of rainfall interception advanced by Gash (1979) and revised by Gash et al. (1995) was applied to predict canopy interception during times of rainfall- only and during times of fog-only and mixed precipitation. The model partitions individual events into three stages: wetting up, saturation and evaporation after the event ceases. Thus, the model does rely on the assumption of a dry canopy after the event. To validate this assumption during fog is challenging and therefore mixed precipitation (rainfall and fog occurring the same day) had to be discretized as event. This was possible with high resolution and continuous water-balance calculation. This allowed to determine the dry/wet canopy frequency.
The presently obtained results showed that the analytical model predicted measured amounts of throughfall associated with rainfall-only events quite well. Furthermore, the calibrated model for days with fog-only indicated that actual amounts of fog stripped by the canopy of the ridge-top forest were 13% (on average) of the potential fog deposition as measured above the canopy (DFc) whereas for mixed precipitation events optimized actual amounts of captured fog was 20% of DFc. The possibilities and challenges of modeling fog, mixed precipitation and rainfall with the Gash analytical model will be presented.

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Effect of Dew and Fog Water on Swiss Grassland with Stable Water Isotopes

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Our research investigates how fog and dew affect the water use of representative species at three Swiss grasslands (CH-CHA, CH-FRU, and CH-AWS) along an elevated gradient where long-term half-hourly H_2O flux measurements and meteorological data are available. Dew or fog water has been approved to be essential moisture sources for plants in arid and semi-arid areas (Wen et al., 2012; He & Richards, 2015; Beysens, 2016). However, research so far has rarely focused on the dew or fog water used by plants in temperate ecosystems, although summer drought conditions (e.g. summer 2018 in Europe) may also impose water stress on plants like in semi-arid regions (MeteoSwiss, 2018). Moreover, a very tiny dew yield will have a stronger impact on smaller grasses than trees for which dew contribution is tiny compared to tree's internal water.

To verify the effect of dew or fog formation on plants, stable water isotopes (δ^2H and δ^{18}O) are visited to trace the variability and exchange of H_2O in the Soil-Plant-Atmosphere Continuum (SPAC). The measurements of gaseous and liquid water isotopes (δ^2H and δ^{18}O) at the site CH-CHA were carried out during intensive observation periods of dew and/or fog events in summer 2018. The deuterium excess was calculated as *d-excess*= δ^2H – $8*\delta^{18}O$ to help analyze the variability and exchange of H_2O in the process of dew and/or fog formation. A substantially depleted water tracer was manually sprayed on the leaf surface of selected plants in a dedicated tracer experiment to quantify the share of dew and/or fog water taken up by typical grassland plants. Moreover, leaf water potential and relative water content were measured to verify the effect of fog and dew on grassland plant performance. In 2019 and 2020, the experiment will be carried out at all the three sites (CH-CHA, CH-FRU, and CH-AWS) to investigate the variability of the influence of dew and/or fog formation on plants along an elevated gradient.

With the research in 2018, we test the hypothesis that during summer fair weather and drought periods, downward H_2O flux and d-excess indicated strong dew/ fog deposition that had a measurable and non-negligible quantitative effect on the plant water status of representative Swiss grassland species through foliar water uptake. This caused higher relative water content and leaf water potential of plants before sunrise than that after sunset, but had a more significant effect on *Lolium perenne* than on the other two species (*Taraxacum officinale*, and *Trifolium pratense*) that were investigated.

Our research highlights the importance of dew and fog as a water source in temperate ecosystems during dry summer periods, which are expected to become more frequent with global warming.

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Fog chemistry in southeast Tibet forest ecosystem

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Fog plays an important role in hydrate and nutrient cycle in high attitude forest ecosystems. In southeast Tibet, it is well known that net productivity and carbon sequestration in native forest ecosystems was the highest all around the world. Due to high humidity and large temperature difference between day and night, fog events could be observed frequently in those areas, especially occurred in plant growing season. But fog chemistry has never been reported. Here, we collected fog water samples by Caltech Active Strand Cloudwater Collector (CASCC) at National Forest Ecosystem Observation & Research Station of Tibet Linzhi (29.65N, 94.72E, 3950m, a.s.l.) and determinated cations and anions in 2017 and 2018, meanwhile, rain water samples were collected by rain gauge and analyzed at the same time. The mean concentrations of NH4+, SO42-, K+, Ca2+, Cl-, NO_3- , Mg2+, Na+ were 32.9, 50.0, 29.4, 232.5, 75.8, 20.6, 38.0 and 75.2μeq L-1 in fog water, correspondingly, those values were 7.1, 19.4, 13.1, 122.7, 40.1, 13.9, 28.7 and 58.5μeq L-1 in rain water. Obviously, all ion concentrations in fog water were higher than those in rain water, ignoring fog deposition might lead to an underestimate of total flux, especially for ammonia (4.6 times) and sulfate (2.6 times). Genarally speaking, pH value in the fog was much lower than that in rain water, but minor difference was found in our reasearch (6.38 and 6.21); one explaination was that H+ reacted with NH3 to form NH4+ in fog water, additionally, high NH4+ concentraitons was founded in fog water. Pearson correlation analysis indicated that all ions was significant correlate to Na+ concentrations in fog water, means marine sources contribute largely to local fog ions; 72 hour back-trajectory analysis confirmed that airmass during fog or rain events arrived mainly from the south direction also; it should be point out, High Ca2+ concentration in both rain water and fog water could be explained by that dust pollution derived from the national highway 318. In conclusion, our finding suggested that fog water could be a vital nutrient input to southeast forest ecosystem beside precipitation deposition.

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Spatial delineation of a new fog-driven ecosystem in the tropical lowlands

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A recent review about diversities of epiphytes in tropical forests of the Neotropics revealed an unexpected high diversity at lower elevations in an area in French Guiana where the formation of nocturnal radiation fog, intensified by katabatic drainage flows from the surrounding terrain fosters epiphytic growth. Consequently, the new diversity hotspot has been termed 'Tropical Lowland Cloud Forest‘ (TLCF) in analogy to the well-known Tropical Montane Cloud Forests. In this new project funded by the German Research Foundation, we test the hypothesis that the new forest type is widespread in the Tropics if the local terrain allows the formation of nocturnal radiation fog. For example, tropical lowland forest areas in western Ecuador may serve as an area similar to that in French Guiana for possible TLCF occurrence.
The presented study is based on satellite data because no operational fog measurements from natural rain forests are available. Since fog in TLCFs is a nocturnal / early morning phenomenon, we use all available overflights by the MODIS Aqua platform with 1 km resolution of the MODIS images. Therefore, a new sub-pixel fog classification retrieval is developed in the first part of the project. With use of an affiliated radiative transfer model fog / low stratus contaminated pixels are identified. From 2004 until 2017 fog frequencies will be derived for lowland forest areas in western Ecuador. The Validation of the fog prediction is carried out on the basis of in situ installed fog detectors.
Potential lowland forest areas will be derived from ASTER Global Digital Elevation Model Version 2 and Landsat Vegetation Continous Fields at the target resolution of 30 meters

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Development and evaluation of leaf wetness duration model based on machine learning for orchards in South Korea

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Background: Diseases of plants are depending on many factors including temperature and leaf wetness duration (LWD). While temperature is usually measured at weather stations, LWD sensors frequently are unavailable in weather stations. Even if they are available, observed data are less reliable. Therefore, these properties of LWD observations may act as constraints on the use of disease warning system because LWD is critical in modeling disease. It even lacks of standard protocol (for example, angle, height, and orientation) in measurement (Gleason et al., 2008). The LWD measurement has been often replaced by its estimation used other meteorological variables (Wang et al., 2019).
Aim: In this study, we developed a LWD prediction model based on machine learning method. The model was evaluated by observation datasets and compared with other LWD prediction models.
Method: Deep Neural Network (DNN) modeling was employed for a development of the LWD prediction model as a machine learning method. The Number of Hours of Relative Humidity, Classification And Regression Tree/Stepwise Linear Discriminant (CART/SLD), Penman-Monteith, and DNN models were developed using meteorological observations of temperature, relative humidity, wind speed, short wave radiation, and rainfall at 11 orchards in Jeju, South Korea in 2016. The sensitivity and prediction accuracy of these LWD prediction models were investigated using the observational data in 2017.
Results: The performances of LWD models without rainy days were superior to those of LWD models with rainy days. The seasonal errors of the DNN model ranged similar magnitude (RMSE of ca. 3 hours) among all seasons excluding winter. The other models except DNN had greater magnitude of errors showing the largest (RMSE of ca. 9.6 hours) in summer and the smallest (RMSE of ca 3.3 hours) in winter. Based on the evaluation criteria, the prediction accuracy was best with the DNN model whereas worst with the CART/SLD model.
Conclusion: The DNN-based LWD prediction has a capability to extend spatial coverage with higher accuracy of disease warning systems. It would help better decision making in many agricultural practices.

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Quantification of non-rainfall water for two distinct grassland ecosystems

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Non-rainfall water from dew and hoar frost formation adds in the absence of precipitation water to the soil-plant system. Under arid conditions, non-rainfall events supply a substantial amount of water and are an important ecohydrological component of arid ecosystems, but their role for northern humid ecosystems are largely unknown. Thus, the aim of this work is to quantify the amount and the temporal evolution of dew and hoar frost formation for a low mountain range and alpine grassland ecosystem. In addition there is a general need to estimate the ecological relevance of such non-rainfall water humid grassland ecosystems. Observations from weighable precision lysimeters of two consecutive hydrological years were used to quantify and to better understand the relevance of non-rainfall water for a low mountain range and alpine grassland ecosystems.
Non-rainfall water ranged on a yearly basis between 42.1 mm to 67.7 mm, which corresponds to 4.2 % to 6.0 % of the total annual amount of precipitation. During drier months dew and hoar frost contributed up to 16.1 % of the total monthly precipitation amount. The investigation suggests that dew and hoar frost formation was an ecologically important source of water during droughts as well as cold periods. The seasonal development and the amounts of non-rainfall water could be predicted relatively well with a surface energy balance model (Penman-Monteith), which requires only standard meteorological variables. Our study results reveal that dew and hoar frost formation contribute substantially to the water budgets of a low mountain range and alpine grassland site.

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Radionuclide deposition during fog events

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Fog deposition has been assumed to significantly contribute to the deposition of radionuclides in Japan during the Fukushima accident . Until recently, very little attention had been paid to such meteorological conditions with regard to radioactive contamination. It comes from 1) the lack of relevant field observation since rain gauge network are not able to properly quantify the amount of fogwater, 2) the lack of information about the capability of fog droplets to washout efficiently the atmosphere compare to rain drops, and 3) because of the scarcity of validated modeling scheme for operational models used in emergency situation . It is expected that for a pulse of airborne contaminant, fog deposition could deposit a non-negligible amount of pollutant. Fog contribution to radionuclide deposition on terrestrial ecosystem is thus legitimate, both on a regular basis i.e. during routine situations or after an accident release. This study focuses on radionuclide deposition by fog on different plants. An analysis of the fog water radioactivity levels and a quantification of the fog water deposition have been performed in the north east region of France. In order to quantify the deposition of cloud water, plants are exposed to fog and weighted with a precision balance every ten to twenty minutes. Three main plant species: a small conifer with 3D shape; grasses and leaf-vegetable (cabbage). Results show that the mass of water deposited (0.15 to 4 mL.min-1.m-2 of vegetation cover) is greater on small conifers than on other plants or bare soil. This is consistent with what was expected due to the larger impaction surface of the small conifers and turbulent induced droplet impaction. We also tested different plant densities. As expected high density of plant will compete deposition and lead to an edge (or comb) effect with higher deposition on edge while the deposition is less abundant inside the plant canopy.

During the fog season in continental temperate climate fog water deposition can represent 1 to 2 % of total water deposition (mostly by rain and snow) but corresponds up to 12% of 137Cs or 210Pb deposited amount (in Bq/m2). Apparent deposition velocity are at least those induced by sedimentation for 10 to 20 μm aerosols and at most those assuming and additional contribution by turbulent impaction and deposition. The liquid water content (LWC) can be used to derive the sedimentation deposition velocity (Tav et al. 2018) The LWC is linked to the visibility which can easily be provided by usual sensor even if the use of visibility to derive the LWC leads to a higher uncertainty. An additional simple modelling scheme based on appropriate deposition velocities could partly sort out the problem and improved deposition assessment.

1) Hososhima & Kaneyasu, 2014
2) Katata 2014, 2015

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Phenological response of Tillandsia purpurea in a fog-dependent ecosystem, south of Peru.

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Background.
The present research was developed in the scope of the project "The chilean-peruvian arid coastal fog ecosystems under climate change: understanding biosphere-atmosphere interactions to support biodiversity conservation (2016-2019)", in which it is intended to know and understand the phenological dynamics of Tillandsia purpurea; one of the species that make up the tillandsial communities (Borthagaray et al., 2010; Mostacero et al., 2007), which settle in sectors of the desert coast of Peru and Chile (Pinto, 2005); and to study their relation to the microclimatic variables in which they develop, given that this relationship has an important role for their survival and permanence in these environments, and that until now they have been poorly studied (FontQuer 2000).

Aim. Study the phenological response of Tillandsia purpurea and possible association with environmental variables in a fog-dependent ecosystem

Method.
We studied the phenological response of a T. purpurea, in a tillandsial patch in a sector of the coastal desert of Arequipa, Peru, located 15 km from the coast and 998 m. a.s.l., monthly field visits were made from February to December 2018. The phenological stages (vegetative state, flower buds, flowering, fruiting and dehiscence) of the species were determined, and they were related to microclimatic data on temperature, atmospheric humidity and precipitation, collected with DataLogger Climatological sensors (PCE) and a Rain Collector (DAVIS), installed at the level of the tillandsias, additionally, modified mini fog collector of 0.25 m2 was installed, to obtain data of available fog collection.

Results.
The preliminary analysis shows that T. purpurea, has constant flowering phenological characteristics throughout the months of evaluation, with an increase of fructification between the months of July to September, these characteristics are increased when there is a previous fog or precipitation event . According to the results, the fog collection presents a monthly average of 5 L / 0.25 m2, with an increase during the months of May to October; the precipitation was presented from June to October, with a maximum of 6.6 mm in August. In the relation of the phenological stages applied for this species, it is also shown that dehiscence occurs from February to May. On the variables of temperature and humidity, they do not present an apparent relation of these with the phenological stages, presenting monthly averages of atmospheric humidity of 63% and 18 ° C of environmental temperature.

Conclusions.
T. purpurea presents a positive phenological response by increasing flowering and fruiting events in response to the presence of precipitation and the increase of available fog water. It is important to know and understand the phenological responses of this type of fog-dependent vegetation, since they act directly as indicators of climate change, in the face of possible future scenarios.

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Geographical and Altitudinal Distribution of Tillandsials in Southern Peru, and their Relationship with Topographic Variables: Orientation and Slope

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Context/Purpose:
In the coastal deserts of Peru and Chile, there are ecosystems that survive thanks to the fog coming from the sea. Although the vegetation is mostly annual, there is a perennial formation, which is known as "tillandsial". This xerophilic vegetation does not have functional roots, so water is obtained directly from the humidity coming from the fogs. The tillandsiales can be declared as fragile, since if any change were to happen in their main source of water, the populations would be seriously affected, altering the life of other species that depend on them. It is therefore important to understand the biogeographic patterns that govern the distribution of tillandsials, in order to implement plans for their conservation.

Methods:
Distribution areas were determined using herbarium records and satellite images from Google Earth (with a resolution of 0.6 m). Then, using a 30 m resolution ASTER elevation raster, orientation and slope raster models were produced; then, at the altitude, orientation and slope raster, they were trimmed according to distribution areas and the data were analyzed.

Results:
Distribution maps of tillandsiales in the departments of Arequipa, Moquegua and Tacna were made. The analysis showed that these plant formations have a greater surface area between 800 and 1100 m a.s.l., preferably located towards the SW orientation, and on low slopes (between 0-8°).

Interpretation:
The results show that tillandsiales are located in areas far from the coast, preferably towards the leeward side of the hills, plains or small elevations located behind the coastal mountain range, which indicates that they prefer some range of humidity. On the other hand, the raster analysis showed that tillandsials are located in a range of altitude, according to the layer of clouds coming from the sea; they present an SO orientation, which is related to the direction of the wind and humidity coming from the ocean; and they are located in their majority in low slopes, which could be explained on the basis of their adaptation to take advantage of the humidity of the fogs.

Conclusion:
The distribution patterns of tillandsiales are closely linked to moisture from the sea; altitude, orientation and slope respond to the layer of clouds from the sea. The knowledge generated will provide new knowledge about these exceptional plant formations and will serve as a basis for understanding how they survive such a hostile environment, conservation plans will be guided in a more appropriate way.

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The wisdom of age: how old alpine forests regulate the global hydrological cycle

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The capacity of the hydrological cycle for dampening the increasing radiative forcing due to climate change is challenged in the last years, as an increasing land surface area is becoming water limited. Understanding and quantifying sources of water in terrestrial ecosystems, and the role of the different structural properties of the vegetation canopy in the response to climate forcing is urgently needed. In particular, we were interested in understanding the role of the water intercepted in the canopy of alpine coniferous forests in the water cycle, quantifying it and defining the different constraints influencing direct evaporation from the wet canopy and leaf transpiration.

To this end, we performed a comprehensive research in a subalpine coniferous forest, at the site of Renon, in the Italian Alps, where a dense, old-growth spruce forest is monitored by the eddy covariance technique. We installed 12 sap flow sensors in different trees representative of the forest tree age and diameter distribution. We installed on the meteorological tower a visibility sensor connected with a fog sampler. Through an extensive set of small samplers placed below the canopy, disposed with a stratified strategy as a function of leaf area index, we quantified the relative role of canopy interception as a function of LAI density, precipitation intensity and duration. By inverting the Penman-Monteith equation, we modeled the canopy conductance as a function of main environmental parameters.

We found that at our study site the water intercepted by the canopy represents a large water reservoir, largely decoupled from the ground hydrological cycle. We found also that the dew deposed on the canopy represents a secondary but not negligible addition to canopy water reservoir. Interesting, the amount of leaves are a variable strongly and positively linked to the forest capacity to store canopy water, and it is therefore positively correlated with the capacity of the forest to respond to radiative forcing by increasing emission of latent heat instead of sensible heat. This research gives evidence to the potentially large and yet undetected role of the forest canopy age and structure in the global hydrological cycle.

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Cloud water interception in Hawai‘i: project overview & preliminary results of fog and CWI patterns

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Tropical montane cloud forests (TMCFs) are ecosystems distinguished by their frequent and consistent immersion of clouds at the vegetation level. Cloud water interception (CWI) is an ecohydrological process unique to these fog-affected systems. During CWI, the cloud water droplets moved by wind are intercepted upon impacting the leaf or stem surface of plants and can accumulate in the vegetation canopies. CWI can play an important hydrological role by adding fog water on top of rainfall, thus enhancing below-canopy net precipitation, sometimes to significant amounts.

Although fog has long been recognized as the key factor shaping TMCF ecosystems, our understanding about the influence of fog and CWI on hydrology is still limited. This is mainly because CWI is hard to quantify at scales relevant to most hydrological questions. The controlling factors of CWI, namely the vegetation structural characteristics, fog frequency and density, and wind conditions, are highly variable across space and time so that point measurements are not easily extrapolated. Since the 1960s, CWI research in Hawai‘i has been motivated by the need to better understand the contribution of fog to water resources. Until recently, most studies in Hawai‘i have been done at isolated locations and results have been restricted to relatively small spatial extents, making comparisons and generalization difficult.

The “Cloud Water Interception in Hawai‘i” project is the latest effort aiming to fully characterize the spatial-temporal patterns of fog and the ecohydrological significance of CWI. With the goal of mapping CWI throughout the Hawaiian Islands, we seek to quantify fog patterns, model vegetation controls over CWI, and estimate CWI using an empirical model and spatial datasets. We made ground-based observations of cloud liquid water content (LWC) using fog gauges at five locations spanning a range of elevations on three different islands. These observations are used to validate LWC predicted by the Hawai‘i Regional Climate Model. We then estimate CWI at the same five locations, which also cover the major native ecosystems, using two independent methods: the wet canopy water balance (WCWB) and an empirical model by Katata et al. (2011) driven by the fog gauge-derived LWC observations. The CWI model estimates can then be compared against WCWB to adjust model parameters for the Hawaiian vegetation. Finally, we can use the calibrated empirical model to map CWI using spatial vegetation characteristics data and LWC and wind speed data from the climate model output.

Preliminary analyses revealed large variations in fog frequency (4 - 52% of the hours), the diurnal cycle, and the horizontal fluxes of cloud water (0.2 - 13 mm per hour per unit vertical area) among sites. These patterns do not completely correspond to those of rainfall, suggesting fog might contribute differently from rain to the hydrological regimes.

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Decomposition of plant litter in sea-fog area along pacific coast of Hokkaido, Japan

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Effects of alternation of microclimate which is caused by frequent fog against terrestrial ecosystem is well known as cloud forest at the higher elevation of tropical mountainous areas. However, knowledge on similar effects at along coast line of cold ocean in the higher latitude area, where sea-fog is observed frequently, is limited. Species composition of plants and animals are better known in these areas, and it is being easier to access the geographical distribution of each species throughout the recent development of database, but material cycling is relatively fewer known. Measurement of plant litter, like leaf, twig or wood, in in-situ environment had a fundamental problem of separation on the effect of both environment and quality of material for decomposition, because no plant distributes all over the world, however, a newly developed method, which is called as Tea-Bag Index (TBI), successfully overcame this problem. Then, in this study, relationship between decomposition of plant litter and micro-climate which is created by frequent sea-fog was studied in eastern Hokkaido, Japan. Sea-fog as a typical advection fog is frequently observed in study area during from April to September when the Pacific High-Pressure Cell supplies warm vapor on south wind. This vapor turns into fog at the surface of the Oyashio, a cold ocean current which flows at offshore of Hokkaido, through cooling, and is carried to coastal area. Carried air which include fog is warmed by land and turned into vapor again at the distant area from coastline. Decomposition late was measured by TBI method at three sites, where slope is faces to south direction, in eastern Hokkaido, Japan; 1) Coastal site locates less than 1 km distant from Pacific Ocean 2) highland site locates at 45 km distant from coastline and 600 m in altitude, and 3) inland site locates at 40 km distant from coastline and 100 m in altitude at the middle of the Konsen Plateau. Decomposition late from July 2015 to July 2017 was lower in coastal site than inland and highland site, although in-situ soil temperature during decomposition seasons was similar between coastal and inland sites, and higher than highland site. Slower decomposition in foggy area which followed the prediction of the present study was found, although obtained in-situ soil temperature denied the predicted alternation of microclimate which is caused by frequent sea-fog in coastal area. These findings suggest that some mechanism, which is caused by sea-fog, other than alternation of temperature might more control on decomposition of plant litter.

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In situ observation of tree leaf photosynthesis under foggy condition

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Two mechanisms have been proposed to explain the direct influences of fog on plant photosynthesis: the 'dimming effect' because of the reduced photosynthetically active radiation (PAR), and the 'wetting effect' caused by the blockage of stomata by fog droplets. While the former is easily provable by experiments/observations, the latter is difficult to be observed independently in the field. Modern commercial portable photosynthesis systems require a dry leaf surface for an accurate operation, therefore limit their applicability in this research. Here we present an automated closed leaf chamber system which was designed for continuous field measurement of leaf photosynthesis and respiration. During the measurement, a transparent cover closes the chamber for the measurement of net assimilation rate (An), then a mask covers the chamber and darken the chamber completely, which allows the measurement of dark respiration rate (Rd). The sum of An and Rd, the photosynthetic rate (Ph), can be calculated and then analyzed against visibility and other meteorological parameters, thus enabling us for the analysis of the influence of fog on photosynthesis.
The system with 6 chambers is operating on the canopy of a Chamaecyparis obtusa var. formosana stand at the Chi-Lan Mountain (CLM) site (24°35'N, 121°25'E) in northern Taiwan. The CLM site is characterized by a very high frequency of fog occurrence and receives about 300 mm fog deposition annually. Using the dataset delivered by the chamber system, it becomes possible to explore the effect of fog on leaf-level photosynthesis. For PAR < 200 μmol m-2 s-1, the quantum yield for foggy and non-foggy conditions was 0.02 and 0.023 μmol μmol-1, respectively, indicating that the wetting of Chamaecyparis obtusa var. formosana leaves by fog droplets won't further decrease the photosynthesis rate. The tree species that dominate the cloud forests may have adapted to the foggy environment by keeping a high stomatal conductance at the presence of fog droplets on the leaf surface.

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The light distribution and the canopy leaf characteristics of Chamaecyparis obtusa var. formosana in a subtropical mountainous cloud forest in northeastern Taiwan

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The tree canopy light distribution and leaf acclimation were investigated by canopy positions and leaf ages on 40-year-old Taiwan yellow false cypress (Chamaecyparis obtusa var. formosana) trees in a subtropical mountainous cloud forest. The results showed that the average daily diffuse light was 1.2- to 2.1-fold of direct light above forest canopy. The ecosystem was dominant by diffuse light. The ratio of direct light to diffuse light didn't significant changed along canopy depth. All examined leaf characteristics at the yellow cypress canopy were strongly ontogenetically related to the leaf growth and aging process. Mature leaves show significant higher chlorophyll content and allocated more portion of nitrogen to chlorophyll than other leaf ages, and thus resulted in highest photosynthetic capacity. However, the LMA increased and nitrogen content decreased in leaf life span. The morphological acclimation and resource allocation optimized the photosynthetic ability of whole canopy. The nitrogen content was higher at the high light regime to achieve high Amax and the mass-based (Chlmass) is higher at the low light regime to allow the higher quantum yield (Qy) at the shade bottom canopy. The most light distribution and leaf characteristics were not significantly varied in canopy aspects, only the direct light portion showed higher at the south canopy and the Amax and Qy of leaves at the east canopy were significant higher than other aspects. These findings suggest that frequent fog occurrence and prevailing diffuse light condition result in more even distribution of light within yellow cypress tree canopy and hence reduced the shade stress on the bottom of canopy.

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Decoupled fog and rainfall occurrence at a subtropical rainforest in northern Taiwan

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Fushan Experimental Forest (FEF) of northeastern Taiwan is a subtropical rainforest characterized with frequent rainfall and cloud/fog. The cloud/fog occurrence has been suggested to be a key factor contributing to the very abundant and diverse epiphytes growing at the FEF. However, currently there is no quantitative information of fog frequency and intensity at the FEF. In this study, we collected and monitored fog intensity and frequency using visibility sensor for 2018 at the FEF. The results indicate that fog, defined as when the visibility is less than 1000 m, occurred 234 days. The frequency of very thick fog (visibility < 200 m) comprised 10% (in July) to more than 50% (in March-March) of total foggy period. On a daily basis, fog is least common around noon then and most common near midnight. This pattern was rather consistent throughout the year. There were no significant correlations between 1) monthly rainy days, 2) monthly rainfall and 1) monthly foggy days and 2) monthly foggy hours. Thus, the occurrence of fog and rain seem to be somehow independent. This also suggests that 1) during rainless days, fog could be an important water source for epiphytes and 2) projections on rainfall patterns as a result of climate change may not be a good predictor of fog frequency and intensity patterns. A thorough understanding of the use of fog relative to rain by epiphytes are required to accurately predict how climate change may affect epiphyte survival and growth via changes in rain and fog frequency and intensity.

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Seasonal variation of water inputs for epiphytic plants at a subtropical rainforest, Fu-Shan in northern Taiwan

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Fog water is an important input for arid and semi-arid montane area. Fog is also recognized as the main water source for many forest ecosystems, especially in the dry season. However, the fog water used by epiphytic plants at subtropical rainforest in Taiwan is rarely investigated. This study measured water isotopic compositions of rain and fog in Fu-Shan, northern Taiwan, where the annual precipitation is abundant, 5000 mm/yr. We also measured the water isotopic compositions from leaves epiphytic *Hoya carnosa*, *Pyrrosia lingus* and *Nephrolepis cordifolia* and terrestrial *Nephrolepis cordifolia* between 2016/10-2017/10. The results showed that the average δ^{18}O and δD of rain water were -6.2‰ and -30.8‰ with a significant seasonal variation. δ^{18}O approximated 0.0‰ and -80.0‰ for summer and winter, respectively. The water isotopic signature of fog water echoed with rain water variation and only enriched by 1.0‰ and 12‰ for δ^{18}O of δD, which likely indicated that the fog is mainly from the local or internal circulation. The water isotopic compositions of soil water were comparable with rain water in summer, but were significantly depleted in winter. Moreover, the water isotopic compositions in terrestrial individuals *Nephrolepis cordifolia* followed the variation of soil water, which suggest that soil water was a main source for that species in winter, whereas epiphytic individuals *Nephrolepis cordifolia* showed a more complicated water use. Besides, the isotopic signatures of *Hoya carnosa*, *Pyrrosia lingus* showed a mixture of rain water, fog water and soil water. Despite the abundant precipitation and the complication of cross-species variation, fog water as well as soil water were both important water sources in the dry winter, implying the importance of the two sources during drought events.

Keywords: water isotope, fog water, species selection, and fog forest