Supplementary information for

# How much water vapour does the Tibetan Plateau release into the atmosphere?

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**S1. Detailed descriptions of each ET products.**

**ETMonitor ET product.** ETMonitor estimated plant transpiration and soil evaporation in soil-vegetation canopy system using Shuttleworth–Wallace two-source scheme (Shuttleworth and Wallace, 1985) combined with a Jarvis-type method to estimate canopy resistance to transpiration, where the minimum canopy resistance is regulated by soil moisture and other environmental variables (Jarvis, 1976, Steward, 1988). Canopy interception loss is estimated using a revised Gash model (Gash et al., 1995, Zheng and Jia, 2020). For the water or snow/ice surface, the water evaporation and snow/ice sublimation are estimated by Penman combination equation. Meanwhile, following improvements are conducted for ET estimation: estimate daily mean soil heat flux by building a machine learning method; apply the downscaled 1-km soil moisture to the calculation of canopy surface and soil surface resistances; using daily water body area data to adjust the land cover to consider the impact of rapid change in water body area and snow cover; the model parameters are optimized using flux measurements from global flux tower sites(Zheng et al., 2022).

**MOD16 ET product**. MOD16 ET is based on the Penman–Monteith equation, which includes MODIS remotely sensed data (e.g., vegetation, surface albedo, and land cover classification) and daily meteorological reanalysis (Mu et al., 2011). The MOD16 algorithm is initially built by Cleugh et al. (2007) and later updated by Mu et al. (2007) and Mu et al. (2011). ET is estimated as the sum of water vapor fluxes from soil evaporation, wet canopy evaporation and plant transpiration at dry canopy surface. Canopy conductance for plant transpiration is calculated by using LAI to scale stomatal conductance up to canopy level, while leaf stomatal conductance is regulated by vapor pressure deficit and air temperature and the Biome-Property-Look-Up-Table (BPLUT) is adopted to assign the parameter for a given biome type. MOD16 ET product provided ET data for the vegetation-cover regions, while other non-vegetation pixels are filled as missing value.

**MOD16-STM ET product.** MOD16-STM ET product is obtained using an improved MOD16 algorithm proposed for the cold, arid, and semiarid regions of the Tibetan Plateau (Yuan et al., 2021). The nonlinear relationships between the soil surface resistance and soil surface hydration state in different soil textures were redefined by using five flux tower measurements over the TP. The value of the mean potential stomatal conductance per unit leaf area used for transpiration calculation in grasslands was optimized.

**PMLV2 ET product.** The Penman–Monteith–Leuning Version 2 (PMLV2) is water-carbon coupled model that estimates ET components separately including transpiration, soil evaporation, and interception loss (Zhang et al., 2019). In PMLV2, transpiration is estimated using Penman–Menteith equation with modified canopy conductance by Leuning et al. (2008) that derive canopy conductance based on GPP. Interception loss is estimated using a modified version of the widely adopted rainfall interception model of Gash. The PMLV2 ET products from 2000 to 2019 with 500m resolution are obtained from GEE platform using the code: ee.ImageCollection("CAS/IGSNRR/PML/V2_v017")).

**PMLV2-Tibet ET products.** PMLV2-Tibet ET is estimated using PMLV2 model driven by the regional meteorological data from China Meteorological Forcing Dataset (CMFD, He et al., 2020). Meanwhile, PMLV2-Tibet ET uses ground observation data from 14 eddy-covariance flux towers in TP to calibrate the model parameters (Ma and Zhang., 2021).

**SSEBop ET product.** The operational Simplified Surface Energy Balance (SSEBop) model is based on the Simplified Surface Energy Balance (SSEB) approach with a parameterization for operational applications (Senay et al., 2020). It estimates ET fractions based on remotely sensed MODIS land surface temperature (LST) using thermal index approach, and temporally upscaled to 10 days with reference ET from global weather datasets. The SSEBop uses predefined, seasonally dynamic, boundary conditions that are unique to each pixel for the hot and cold reference points. SSEBop estimates are from 2002 at 1 km spatial resolution and a 10-days temporal resolution. Data were provided by the Early Warning and Environmental Monitoring Program via the United States Geological Survey and can be downloaded from the following website https://earlywarning.usgs.gov (last access: 21 January 2021).

**BESSv2 ET product.** The BESSv2 ET is obtained using the quadratic form of the Penman-Monteith equation incorporated in the process-based model (Breathing Earth System Simulator version 2) that integrates key physical and biochemical processes related to land–atmosphere flux exchange (Li et al., 2023). Comparing with first version of BESS, the BESSv2 integrated a newly developed ecosystem respiration module, an optimality-based maximum carboxylation rate model, and extended the temporal coverage of flux datasets from 1982 to 2019(Li et al., 2023).

**GLASS ET product.** GLASS ET product algorithm is based on the multi-model ensemble method, that is the Bayesian model averaging (BMA) method which merges five process-based ET algorithms to estimate ET (Yao et al., 2014). The five process-based ET algorithms include the MOD16 LE product algorithm, the revised remote-sensing-based Penman-Monteith LE algorithm, the Priestley-Taylor-based LE algorithm, the modified satellite-based Priestley-Taylor LE algorithm, and the semi-empirical Penman LE algorithm.

**SynthesisET ET product.** The synthesized ET product is obtained by synthesis ET from different sources with the high-performing products were selected based on site-pixel evaluation against the flux eddy covariance covering the entire globe.

Five ET products were used to create the synthesized ET set including PMLV2, SSEBop, MODIS, and NTSG (the Numerical Terradynamic Simulation Group) ET products. The synthesized ET product is with a 1km spatial resolution and monthly temporal resolution from 1982 to 2019 (Elnashar et al., 2021). The synthesized ET data are available on the GEE platform.

**EB ET product.** EB ET product is obtained by a thermal energy balance (EB) model using a column canopy-air turbulent heat diffusion method developed to depict dynamic changes more realistically in aerodynamic resistance (Chen et al., 2021). MODIS Aqua and Terra land surface temperature fields were combined and a nearest-evaporative-fraction gap-filling method was merged into the EB model to generate a global ET product covering the period 2003–2017 with daily 5km resolution.

**GLEAM ET product.** The Global Land Evaporation Amsterdam Model (GLEAM) is physically based on an algorithm that estimates ET components separately including transpiration, interception loss, bare soil evaporation, snow sublimation, and open-water evaporation (Miralles et al., 2011). In GLEAM, transpiration and bare soil evaporation are estimated using Priestley–Taylor equation with stress functions based on microwave vegetation optical depth and simulated root-zone soil moisture calculated from a multilayer water balance model. Interception loss is estimated using Gash model. The open-water evaporation and snow sublimation are also estimated using Priestley–Taylor equation. In this study, both GLEAM version3.5a and GLEAM version3.5b are adopted, while GLEAMv3.5a is based on satellite and reanalysis data with long-term coverage (from 1982~2020) and GLEAMv35.b is based on solely satellite data with short-term coverage (from 2003~2020) (Martens et al. 2017).

**FLUXCOM ET product.** FLUXCOM represents a state-of-the-art ML-based upscaling of EC-measured surface fluxes where data from 224 flux towers around the world were used to train multiple (i.e., three to nine) ML methods (Jung et al., 2019). The FLUXCOM-RS product employed only remote sensing data (i.e., MODIS) to estimate ET for the period of 2001–2015, while the FLUXCOM-RS-METEO products used both gridded meteorological forcing and MODIS data for extended temporal coverages.

**CR ET products**. CR ET product is obtained using the calibration-free complementary relationship model (Ma et al., 2021). CR builds upon the dynamic feedbacks between the land-atmosphere interface without the need of any soil and vegetation status or precipitation information while requiring only a minimal number of meteorological variables in a calibration-free mode.

**TerraClimate ET product.** TerraClimate ET is estimated based on a modified Thornthwaite-Mather climatic water-balance model for global terrestrial surfaces, which incorporates evapotranspiration, precipitation, temperature, and interpolated plant extractable soil water capacity (Abatzoglou et al., 2018). The water balance model is very simple and does not account for heterogeneity in vegetation types or their physiological responses to changing environmental conditions. TerraClimate estimates are provided at a monthly temporal resolution from 1958 to 2018 and 5 km grid cells.

**GLDAS ET products.** GLDAS ET products are obtained under the NASA Global Land Data Assimilation System (GLDAS), which aims to generate optimal fields of land surface states and fluxes, by ingesting satellite- and ground-based observational data products, using advanced land surface modeling and data assimilation techniques (Rodell et al., 2004). Depending on the adopted land surface model, three major data were adopted in this study: the **GLDAS-VIC** ET product based on VIC model, the **GLDAS- Noah** ET product based on Noah model, the **GLDAS-SLSM** ET product based on Catchment-LSM (B. Li et al., 2019).

**MERRA2 ET product.** MERRA-2 is the atmospheric reanalysis produced with the NASA Goddard Earth Observing System Model, version 5 (GEOS-5), modeling and data assimilation system and were designed to provide historical analyses of the hydrological cycle across a broad range of climate time scales (Gelaro et al., 2017).

**ERA5** and **ERA5-Land ET products.** ERA5 is the latest generation of reanalysis data created by the ECMWF (Hersbach et al., 2020). ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. ERA5-Land uses the Carbon Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land (CHTESSEL) as a land surface model. This model also has major updates in its model structure in the form of improved climatological seasonality of vegetation and new parameterization to calculate bare soil evaporation, which leads to a better representation of evapotranspiration over the land (Munoz-Sabater et al., 2021).

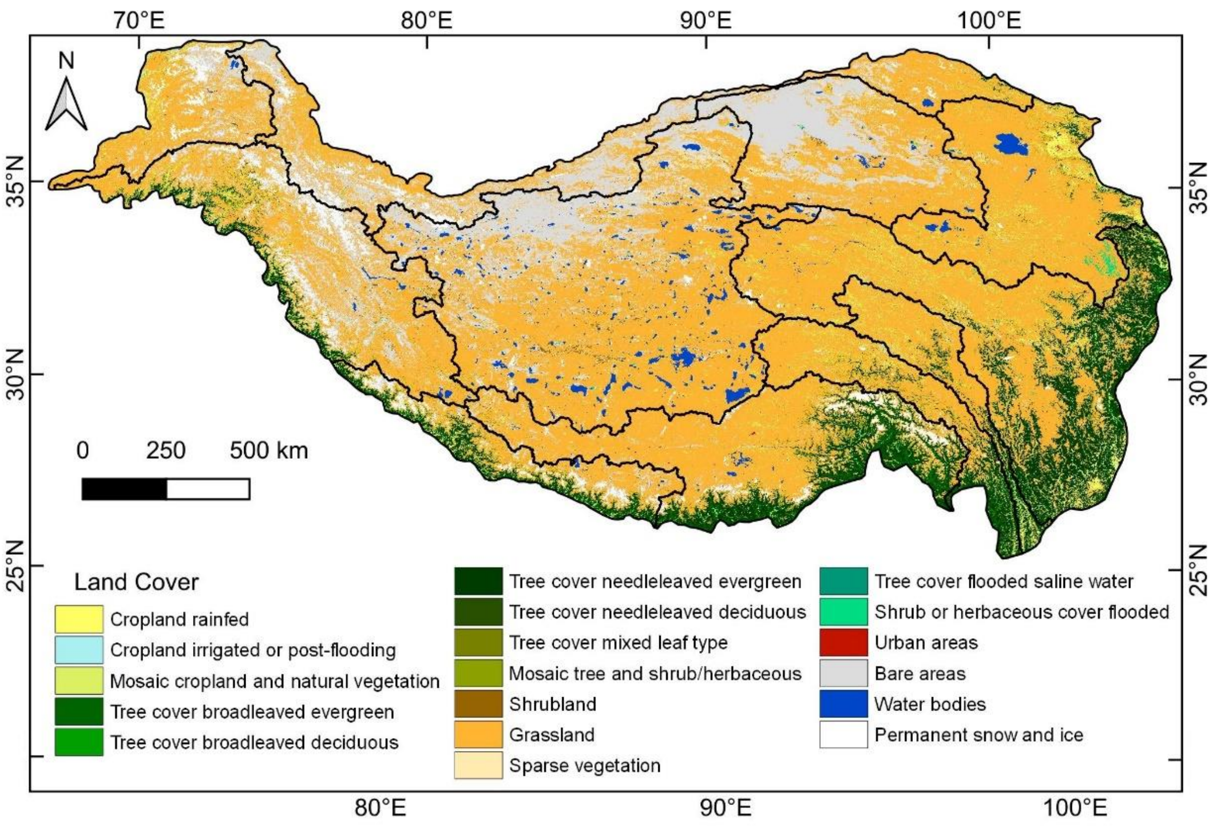


**Figure S1. Land cover map of the Tibetan Plateau, example of 2015 by ESA CCI.**

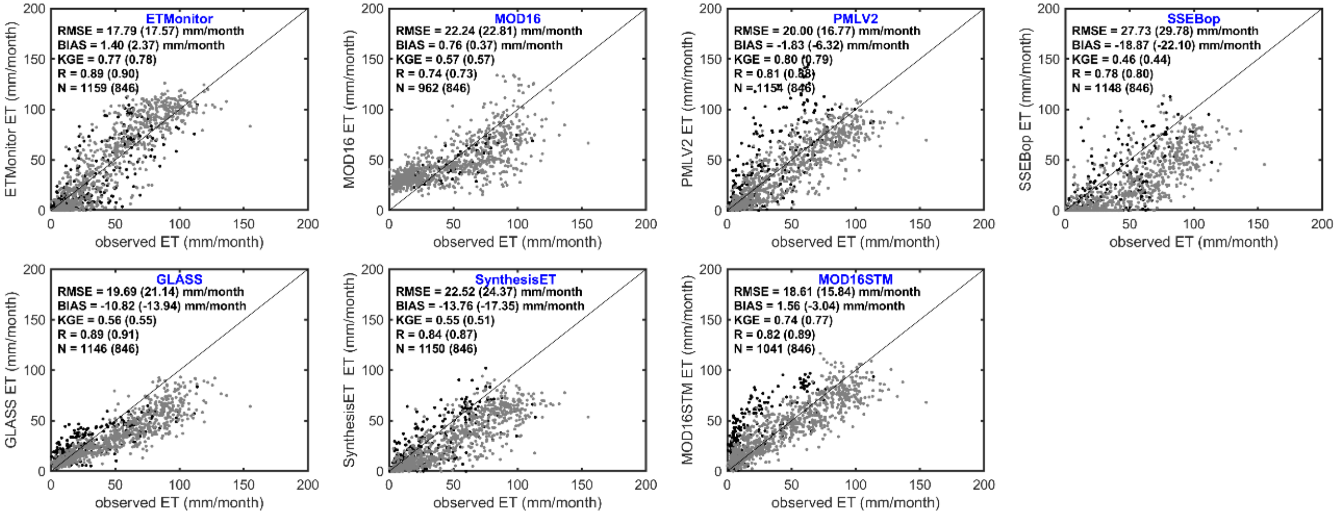


**Figure S2. Validation results of high-resolution ET products against flux tower measurements. Values outside of the brackets are the validation results obtained based on different samples depending on the availability of each product, while values in the brackets represent the validation results obtained based on same sample (gray dots) numbers for every product (mainly vegetation covered sites during 2001~2018).**

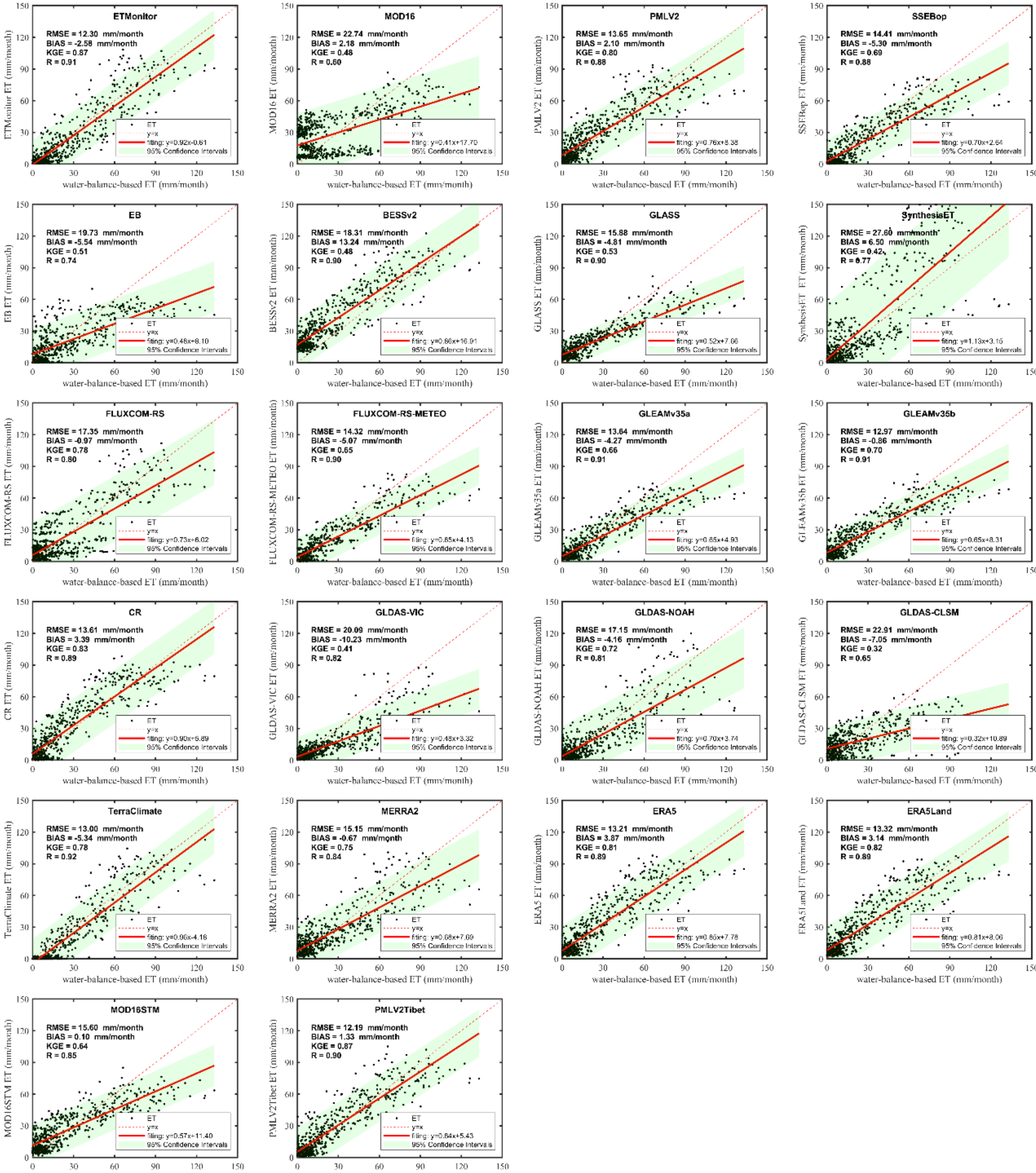


**Figure S3. Validation of ET products against water balance-based ET at basin-scale based on water balance modelling.**

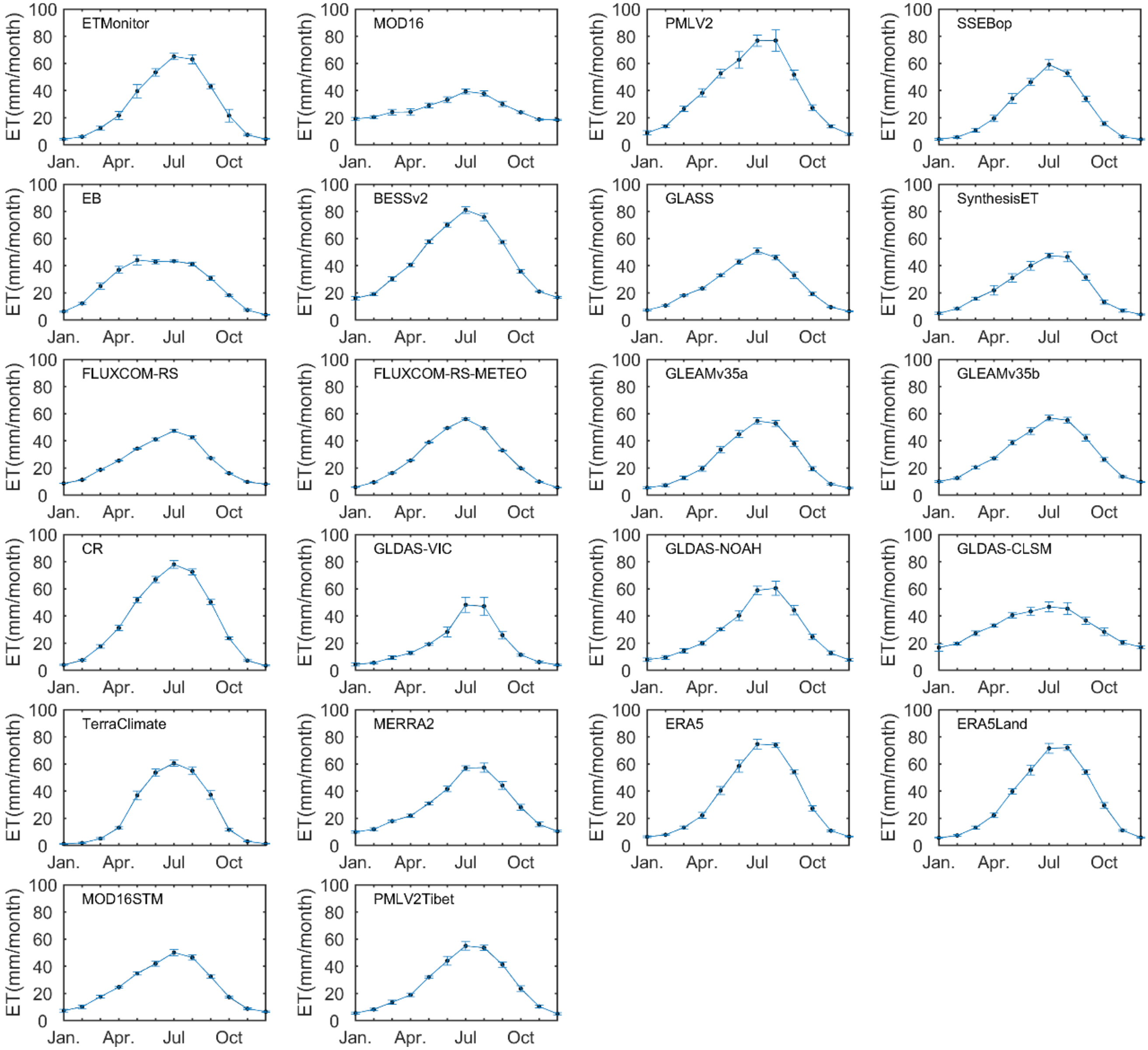


**Figure S4. Seasonal cycle of ET in Tibetan Plateau by different products. Each point in the figure represents the multi-year averaged ET of that month, while the bar is the standard deviation.**

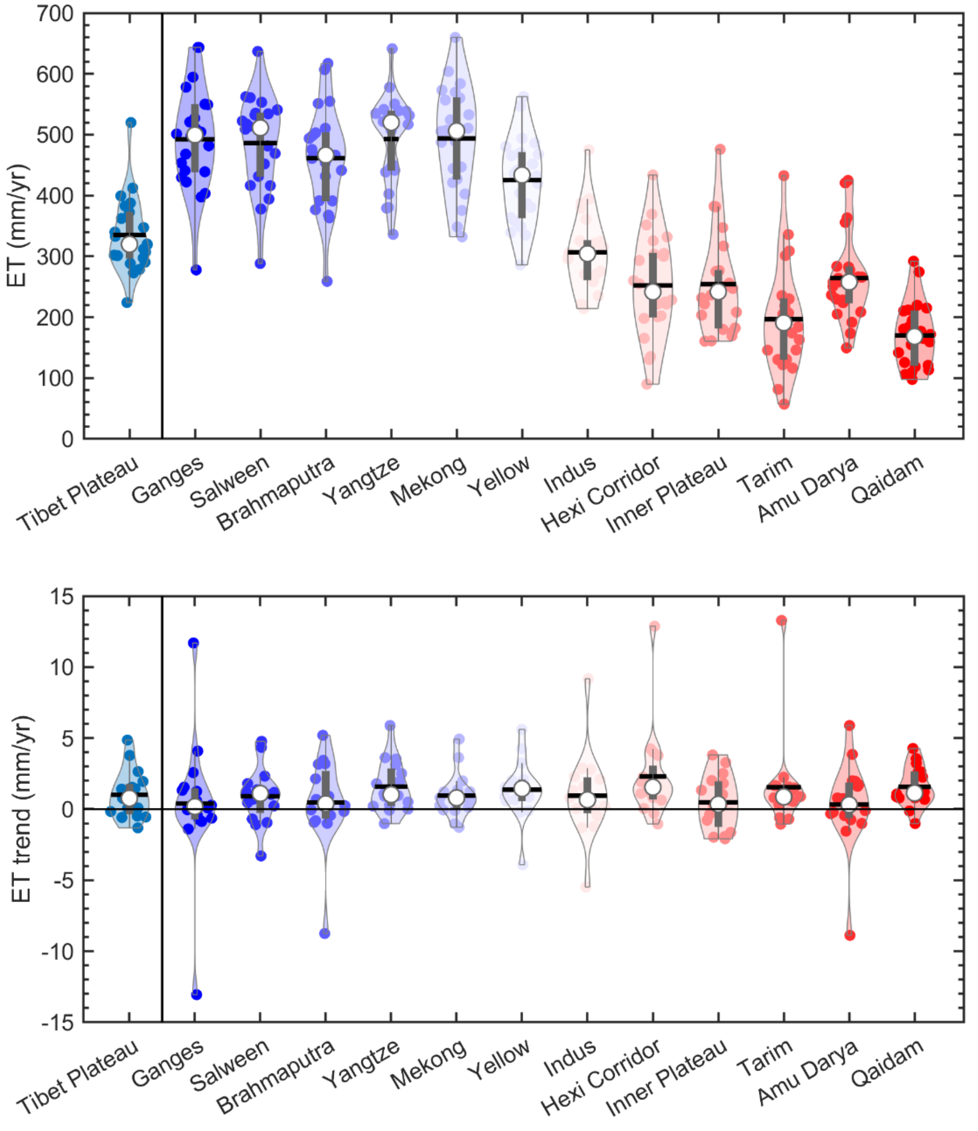


**Figure S5. Violin plots of annual ET amount (top panel) and trend (bottom panel) by different products in Tibetan Plateau and the different basins from 2000 to 2020 (for those products with less than 21years, the statistic values were calculated based on its own period as shown in Figure 2). The open dot represents the median value, and the upper and lower of the vertical thick gray lines indicate the 75th and 25th percentile respectively. The horizontal black solid line is averaged value.**

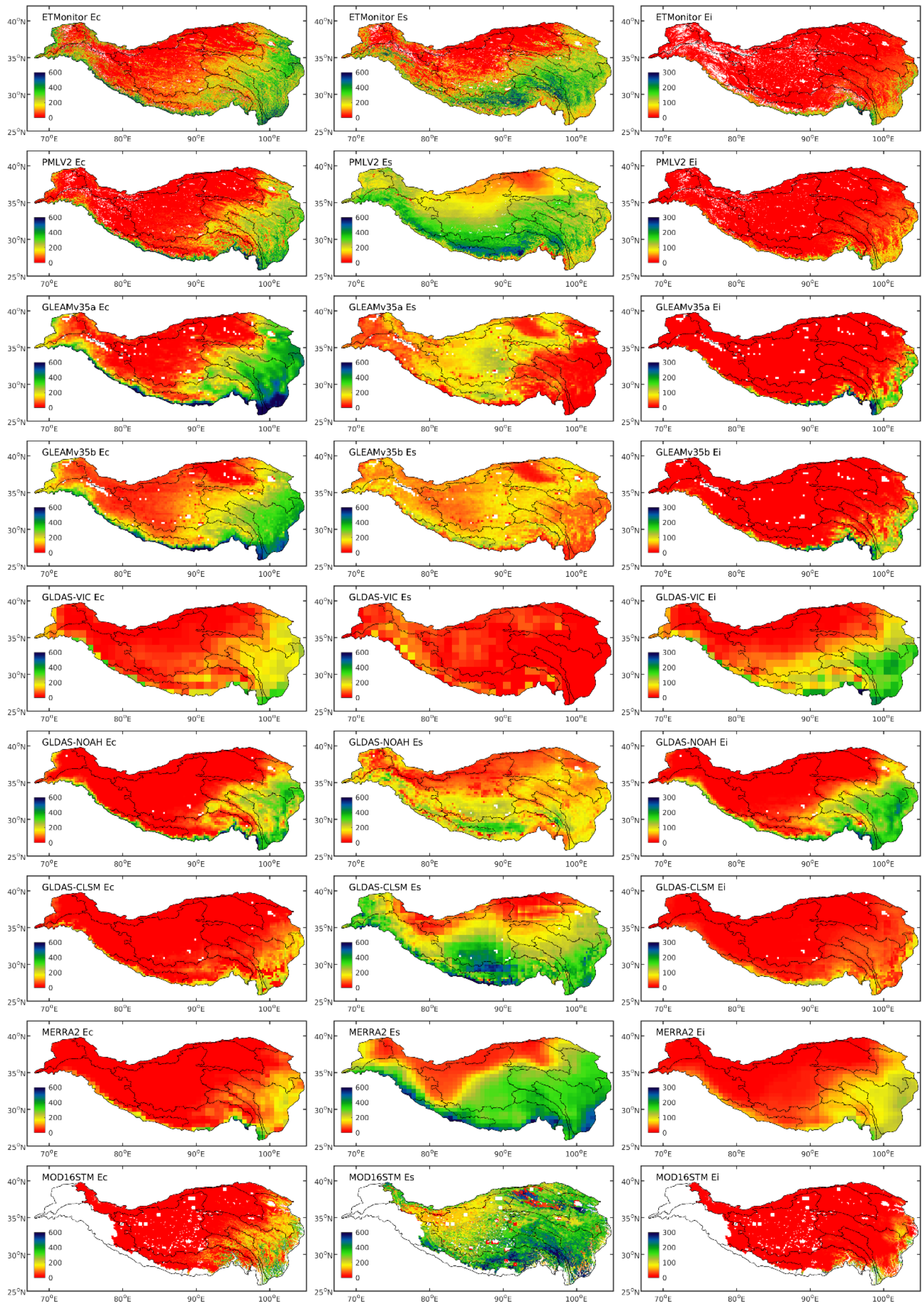


**Figure S6. Spatial variability of ET components in the Tibetan Plateau as estimated with different products during their overlap period (2001~2018).**

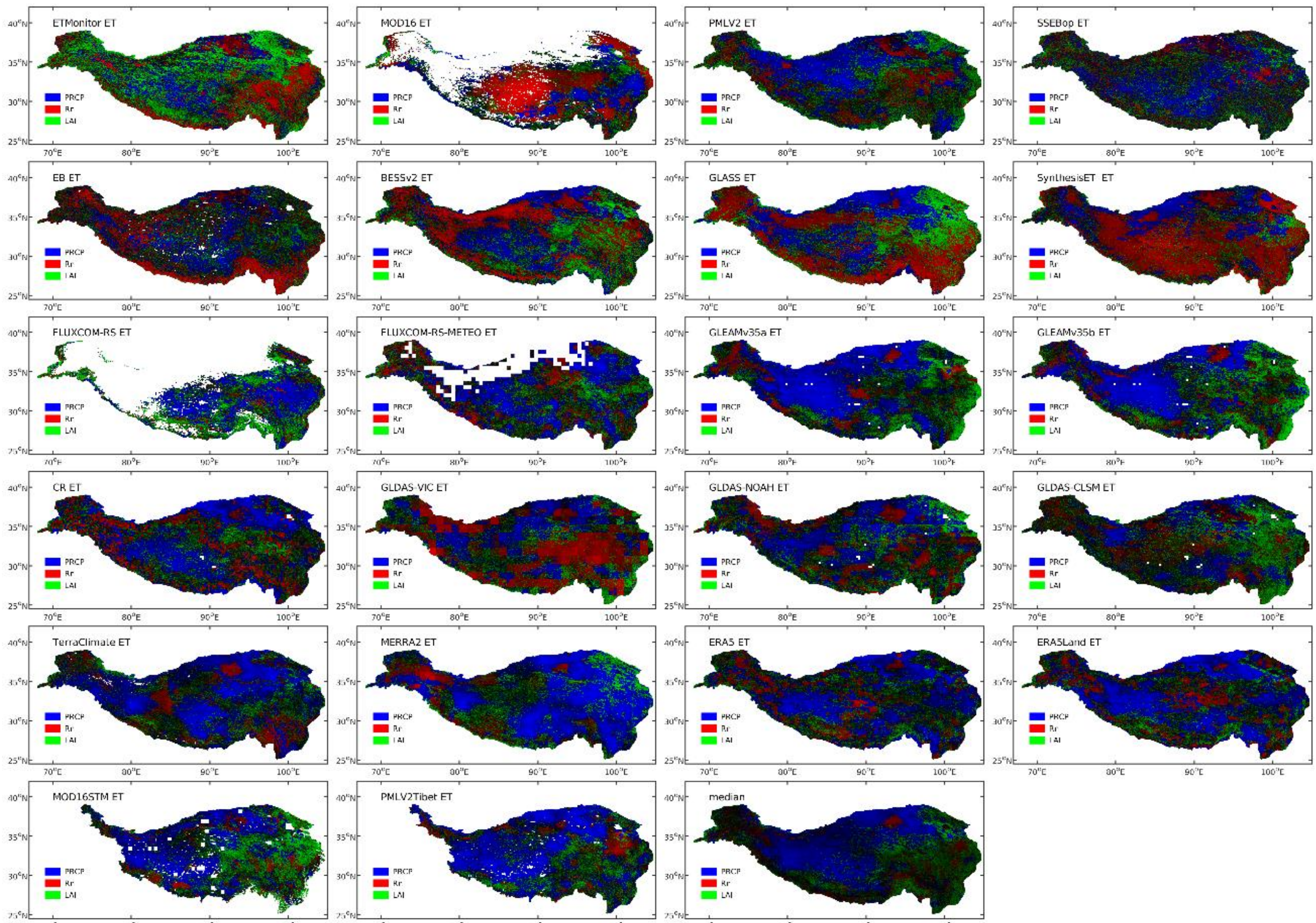


**Figure S7: False color composite maps to visualize the relative magnitudes of the correlation coefficient of ET with precipitation, Rn, and LAI.**

**Table S1. Multiple year (2003-2013) averaged ET in the Tibetan Plateau and sub-basins by different products.**

| Products Name | Tibetan Plateau | Yellow | Yangtze | Qaidam | Inner Plateau | Hexi Corridor | Tarim | Mekong | Salween | Indus | Ganges | Brahma-putra | Amu Darya |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ETMonitor** | **339.83** | **486.10** | **538.52** | **105.94** | **176.08** | **228.32** | **116.37** | **603.90** | **562.34** | **275.81** | **481.71** | **502.96** | **228.37** |
| MOD16 | (320.17) | 494.03 | 534.77 | (194.40) | (255.95) | (331.95) | (206.99) | 507.02 | 535.38 | 325.14 | 594.52 | 554.75 | 283.48 |
| **PMLV2** | **382.90** | **451.77** | **541.48** | **154.80** | **251.58** | **198.06** | **174.04** | **573.21** | **560.84** | **387.91** | **578.08** | **551.23** | **257.96** |
| SSEBop | 288.19 | 339.24 | 379.22 | 164.90 | 208.28 | 221.45 | 230.12 | 332.12 | 377.81 | 258.67 | 429.68 | 367.72 | 250.85 |
| EB | 311.78 | 357.47 | 507.51 | 97.63 | 182.31 | 202.27 | 130.29 | 510.62 | 508.92 | 220.91 | 520.77 | 469.35 | 208.60 |
| BESSv2 | 519.88 | 562.44 | 641.30 | 274.47 | 475.91 | 433.74 | 432.61 | 659.77 | 636.77 | 474.98 | 643.40 | 606.94 | 420.63 |
| GLASS | 301.09 | 363.48 | 402.51 | 171.76 | 221.68 | 221.48 | 184.01 | 402.51 | 416.22 | 271.34 | 422.18 | 391.33 | 229.91 |
| SynthesisET | 272.78 | 335.04 | 380.30 | 113.46 | 169.31 | 165.38 | 145.80 | 375.46 | 394.17 | 270.25 | 438.98 | 391.16 | 204.98 |
| FLUXCOM-RS | (290.38) | 546.80 | 577.82 | (183.72) | (276.65) | (293.37) | (202.86) | 583.88 | 532.20 | (296.15) | (504.29) | (475.80) | (263.84) |
| FLUXCOM-RSM | (319.55) | 380.56 | 444.84 | (211.91) | (231.67) | (260.08) | (235.53) | 444.20 | 451.87 | (379.27) | (501.12) | (431.67) | (355.76) |
| **GLEAMv35a** | **301.95** | **386.37** | **441.55** | **159.46** | **236.44** | **254.85** | **162.96** | **421.32** | **416.49** | **220.94** | **397.57** | **376.70** | **191.63** |
| **GLEAMv35b** | **362.21** | **441.30** | **518.51** | **180.35** | **247.29** | **303.45** | **197.59** | **487.52** | **513.69** | **324.72** | **549.27** | **466.66** | **277.66** |
| CR | 412.15 | 435.67 | 524.93 | 210.17 | 347.25 | 325.57 | 335.89 | 524.24 | 522.40 | 394.34 | 526.98 | 510.43 | 363.36 |
| GLDAS-VIC | 224.08 | 286.00 | 336.17 | 118.55 | 160.53 | 135.13 | 130.67 | 348.30 | 288.27 | 214.13 | 277.69 | 258.86 | 149.51 |
| GLDAS-NOAH | 332.85 | 419.64 | 531.69 | 120.74 | 179.94 | 130.44 | 146.05 | 569.74 | 517.42 | 325.53 | 453.45 | 460.87 | 257.56 |
| GLDAS-CLSM | 372.48 | 348.32 | 450.05 | 109.00 | 316.95 | 89.84 | 121.74 | 446.95 | 469.18 | 361.12 | 643.41 | 617.08 | 424.76 |
| **Terra Climate** | **278.45** | **403.97** | **438.57** | **125.49** | **161.07** | **224.89** | **57.01** | **426.88** | **431.55** | **234.89** | **403.35** | **363.32** | **236.44** |
| MERRA2 | 347.38 | 470.32 | 550.37 | 141.75 | 203.35 | 200.67 | 81.38 | 532.89 | 540.81 | 315.29 | 550.09 | 493.85 | 173.24 |
| **ERA5** | **399.40** | **467.84** | **525.20** | **215.11** | **381.45** | **369.26** | **301.36** | **505.30** | **481.43** | **303.55** | **467.97** | **454.26** | **282.44** |
| **ERA5Land** | **387.65** | **465.49** | **516.91** | **219.71** | **382.20** | **351.63** | **308.74** | **489.06** | **452.50** | **261.86** | **440.98** | **441.40** | **223.75** |
| MOD16STM | (297.33) | 431.80 | 521.68 | 291.94 | 250.58 | 299.98 | 218.42 | 560.22 | 553.22 | (321.76) | (509.59) | (498.48) | - |
| PMLV2Tibet | (307.21) | 480.38 | 539.28 | 176.84 | 275.13 | 304.81 | 205.25 | 556.90 | 534.23 | (305.34) | (497.86) | (466.36) | - |
| **Median value** | 362.21 | 441.30 | 524.93 | 159.46 | 247.29 | 254.85 | 174.04 | 505.30 | 513.69 | 303.55 | 481.71 | 466.66 | 257.96 |
| **Average value** | 350.34 | 439.00 | 504.11 | 164.47 | 257.31 | 272.06 | 192.17 | 506.05 | 498.39 | 306.02 | 486.42 | 460.79 | 262.55 |
| **Standard deviation** | 42.46 | 32.13 | 41.19 | 37.74 | 75.53 | 57.58 | 90.87 | 63.48 | 53.80 | 63.33 | 64.54 | 64.44 | 50.27 |
| **Uncertainty *** | 0.12 | 0.07 | 0.08 | 0.23 | 0.29 | 0.21 | 0.47 | 0.13 | 0.11 | 0.21 | 0.13 | 0.14 | 0.19 |

* uncertainty is expressed as the ratio of standard deviation to average ET values by different products. Also note that those basins with large portion of missing values were shown with brackets and were not accounted in the statistics.