GLEAM4.1 Datasets

1. – GENERAL

The Global Land Evaporation Amsterdam Model[1,2] (GLEAM) is a set of algorithms that separately estimate the different components of terrestrial evaporation (i.e. '*evapotranspiration*') based on satellite observations: transpiration (*Et*), interception loss (*Ei*), bare-soil evaporation (*Eb*), snow sublimation (*Es*) and open-water evaporation (*Ew*). Intermediate outputs of the model include potential evaporation (*Ep*), root-zone soil moisture (*SMrz*), surface soil moisture (*SMs*), evaporative stress (*S*), and surface sensible heat flux (*H*). The rationale of the method is to maximize the recovery of information about evaporation contained in the available data stack of climatic and environmental observations from space.

Penman's equation calculates *Ep* based on observations of surface net radiation, near-surface air temperature, wind speed, vegetation height, and vapour pressure deficit[3]. Potential evaporation estimates are converted into actual evaporation based on the multiplicative, evaporative stress factor *S*. The derivation of *S* is based on microwave vegetation optical depth (used as a proxy for the vegetation water content), vapour pressure deficit, incoming solar radiation, air temperature, CO_2 concentration, wind, leaf area index, fraction of absorbed photosynthetically active radiation, and estimates of root-zone soil moisture[4]. The latter is calculated using a multi-layer running water balance that describes the infiltration of observed precipitation through the vertical soil profile, including a linear reservoir model to account for plant access to groundwater[5]. To correct for random forcing errors, microwave observations of surface soil moisture are assimilated into the soil profile. Interception loss is calculated based on an observation-constrained version of the van Dijk-Bruijnzeel model of rainfall interception driven by precipitation and vegetation characteristics[6]. Estimates of actual evaporation for regions covered by ice and/or snow are derived using the Penman equation adapted for ice and super-cooled waters. For a detailed description, the reader is directed to Miralles *et al.* (*in review*)[7].

Compared to previous GLEAM versions, GLEAM4 includes the following updates:

1. Hybrid learning of evaporative stress from eddy-covariance and sapflow data[4]
2. Improved representation of interception, including short vegetation[6]
3. Potential evaporation based on Penman's[3] instead of Priestley and Taylor's equation
4. Explicit consideration of plant access to groundwater[5]
5. Higher spatial resolution (0.1°) and longer record (1980–2023)

Two datasets are being produced using **GLEAM4**: **GLEAM4.1a** and **GLEAM4.1b**. The former is already available via www.gleam.eu, and the latter will be available in short time.

2. – DATA CHARACTERISTICS

The two datasets available on this server differ only in their forcing and temporal coverage:

1. **GLEAM4.1a**: a global dataset spanning the 44-year period 1980–2023. The dataset is based on reanalysis radiation and air temperature, a combination of gauge-based, reanalysis and satellite-based precipitation, and satellite-based vegetation optical depth (see Table 1).
2. **GLEAM4.1b**: a global dataset spanning the 21-year period 2003–2023. The dataset is (mostly) driven by satellite data (see Table 1).

Table 1 provides more information on the forcing variables used to produce these datasets. All GLEAM4 datasets are provided on a 0.1° x 0.1° latitude–longitude grid and with a daily temporal resolution.

Table 1: Overview of forcing datasets.

Variable	GLEAM4.1a	GLEAM4.1b
Net radiation	MSWX[8]	CERES[9]
Shortwave incoming	MSWX[8]	CERES[9]
Air temperature	MSWX[8]	AIRS[10]
Precipitation	MSWEP[11]	IMERG[12]
Wind speed	ERA5[13]	ERA5[13]
Vapor pressure deficit	MSWX[8]	AIRS[10]
Carbon dioxide concentration	CAMS[14]	CAMS[14]
Snow water equivalent	GlobSnow[15]/NSIDC[16]	GlobSnow[15]/NSIDC[16]
Surface soil moisture	ESA CCI[17]	ESA CCI[17]
Vegetation optical depth	VODCA[18]	VODCA[18]
Fraction of absorbed photosynthetically active radiation	MOD15A2H[19]	MOD15A2H[19]
Leaf area index	MOD15A2H[19]	MOD15A2H[19]
Vegetation height	GEDI/Landsat[20]	GEDI/Landsat[20]
Land cover fractions	MEaSURES[21]/MOD44B[22]	MEaSURES[21]/MOD44B[22]
Soil properties	SoilGrids[23]	SoilGrids[23]

3. – FILE ORGANISATION

Datasets are organised in netCDF files. There is one netCDF file per variable and per year, and they are stored as a **3D array with dimensions *n-days* x 1800 x 3600** (*n-days* is the number of days in the corresponding year). Therefore, the first cell corresponds to the 1st of January of the corresponding year, and it is centered at latitude 89.95 and longitude –179.95. The following variables are available:

1. ***E*** - Actual evaporation [mm/day]
2. ***Ep*** - Potential evaporation [mm/day]
3. ***Ei*** - Interception loss [mm/day]

4. ***Eb*** - Bare-soil evaporation [mm/day]
5. ***Es*** - Snow sublimation [mm/day]
6. ***Et*** - Transpiration [mm/day]
7. ***Ew*** - Open-water evaporation [mm/day]
8. ***Ec*** - Surface condensation [mm/day]
9. ***S*** - Evaporative stress factor [-]
10. ***SMrz*** - Root-zone soil moisture [m^3/m^3]
11. ***SMs*** - Surface soil moisture [m^3/m^3]
12. ***H*** - Sensible heat flux [W/m^2]

Note that by definition: ***E = Et + Eb + Ew + Ei + Es + Ec*** and ***S = E/Ep***. Missing values in the files are masked with –999. **Some NaN values can be found in deserts for both Et and Eb, which will be set to zero in future updates*.

Next to the daily data, temporally aggregated files (monthly and yearly) are also available. There is one netcdf file per variable with the entire record at either monthly (dimensions ***n-days* x 1800 x 3600**), or yearly (dimensions ***n-days* x 1800 x 3600**) temporal resolution, date stamps are set to roughly the end (i.e. the end of the aggregation period) of the month or year, respectively.

4. – DATA POLICY

Datasets are freely available and can be downloaded from this server. Whenever GLEAM4 datasets are used in a scientific publication, the following references should be cited:

a. **GLEAM**: Miralles, D.G., Holmes, T.R.H., de Jeu, R.A.M., Gash, J.H., Meesters, A.G.C.A., Dolman, A.J. Global land-surface evaporation estimated from satellite-based observations, Hydrology and Earth System Sciences, 15, 453–469, doi: 10.5194/hess-15-453-2011, 2011.
b. **GLEAM4 datasets**: Miralles, D.G., Koppa, A., Baez-Villanueva, O.M., Tronquo, E., Bonte, O., Zhong, F., Beck, H.E., Hulsman, P., Haghdoost, S., Dorigo, W.A. GLEAM4: global evaporation and soil moisture datasets at 0.1° resolution from 1980 to near present, in review.
c. **Interception module**: Zhong, F., Jiang, S., Dijk, A.I.J.M. van, Ren, L., Schellekens, J., Miralles, D.G. Revisiting large-scale interception patterns constrained by a synthesis of global experimental data, Hydrology and Earth System Sciences, 26, 5647–5667, 2022.
d. **Soil module**: Hulsman, P., Keune, J., Koppa, A., Schellekens, J. & Miralles, D. G. Incorporating Plant Access to Groundwater in Existing Global, Satellite-Based Evaporation Estimates, Water Resources Research, 59, 2023.
e. **Stress module**: Koppa, A., Rains, D., Hulsman, P., Poyatos, R., Miralles, D.G. A deep learning-based hybrid model of global terrestrial evaporation, Nature Communications, 13, 1912, 2022.

5. – FINAL REMARKS

The reader is referred to the **references above for more detailed information** about the model, and to the FAQ section at www.gleam.eu. Any feedback about the datasets and/or website is highly appreciated and can be sent through email to info@gleam.eu.

6. – REFERENCES

1. Miralles, D.G., Holmes, T.R.H., de Jeu, R.A.M., Gash, J.H., Meesters, A.G.C.A. and Dolman, A.J.: Global land-surface evaporation estimated from satellite-based observations, Hydrology and Earth System Sciences, 15, 453–469, doi: 10.5194/hess-15-453-2011 (2011a).
2. Miralles, D.G., de Jeu, R.A.M., Gash, J.H., Holmes, T.R.H. and Dolman, A.J.: Magnitude and variability of land evaporation and its components at the global scale, Hydrology and Earth System Sciences, 15, 967–981, doi: 10.5194/hess-15-967-2011 (2011b).
3. Penman, H. L. Natural evaporation from open water, bare soil and grass. Proc. Royal Soc. Lond. Ser. A-Mathematical Phys. Sci. 193, 120–145 (1948).
4. Koppa, A., Rains, D., Hulsman, P., Poyatos, R. & Miralles, D. G. A deep learning-based hybrid model of global terrestrial evaporation. Nat. Commun. 13, 1912, 10.1038/s41467-022-29543-7 (2022).
5. Hulsman, P., Keune, J., Koppa, A., Schellekens, J. & Miralles, D. G. Incorporating Plant Access to Groundwater in Existing Global, Satellite-Based Evaporation Estimates, Water Resources Research, 59 (2023).
6. Zhong, F., Jiang, S., Dijk, A.I.J.M. van, Ren, L., Schellekens, J., Miralles, D.G. Revisiting large-scale interception patterns constrained by a synthesis of global experimental data, Hydrology and Earth System Sciences, 26, 5647–5667 (2022).
7. Miralles, D.G., Koppa, A., Baez-Villanueva, O.M., Tronquo, E., Bonte, O., Zhong, F., Beck, H.E., Hulsman, P., Haghdoost, S., Dorigo, W.A. GLEAM4: global evaporation and soil moisture datasets at 0.1° resolution from 1980 to near present (in review).
8. Beck, H. E., van Dijk, A. I. J. M., Larraondo, P. R., McVicar, T. R., Pan, M., Dutra, E., & Miralles, D. G.. MSWX: Global 3-Hourly 0.1° Bias-Corrected Meteorological Data Including Near-Real-Time Updates and Forecast Ensembles, Bulletin of the American Meteorological Society, 103(3), E710-E732. Retrieved from http://www.gloh2o.org/mswx/ (2022).
9. Wielicki, B.A.: Clouds and the Earth's Radiant Energy System (CERES): An earth observing system experiment, Bulletin of the American Meteorological Society, 77, 853–868 (1996).
10. Aumann, H.H., Chahine, M.T., Gautier, C., Goldberg, M.D., Kalnay, E., McMillin, L.M., Revercomb, H., Rosenkranz, P.W., Smith,W.L., Staelin, D.H., Strow, L.L., and Susskind, J.: AIRS/AMSU/HSB on the Aqua mission: design, science objectives, data products, and processing systems, IEEE Transactions on Geoscience and Remote Sensing, 41, 253–264, doi: 10.1109/TGRS.2002.808356 (2003).
11. Beck, H.E., van Dijk, A.I.J.M., Levizzani, V., Schellekens, J., Miralles, D.G., Martens, B. and de Roo, A.: MSWEP: 3-hourly 0.25° global gridded precipitation (1979–2015) by merging gauge, satellite and reanalysis data, Hydrology and Earth System Sciences, 21, 589–615, doi: 10.5194/hess-21-589-2017 (2017).
12. Hou, A. Y. et al. The global precipitation measurement mission. Bull. Am. Meteorol. Soc. 95, 701–722, 10.1175/bams-d-13-00164.1 (2014).
13. Hersbach, H. et al. The ERA5 global reanalysis. Q. J. Royal Meteorol. Soc. 146, 1999–2049, 10.1002/qj.3803 (2020).

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14. Inness, A. Cams global reanalysis (eac4). copernicus atmosphere monitoring service (cams) atmosphere data store (ads).305 (2019).
15. Luojus, K., Pulliainen, J., Takala, M., Lemmetyinen, J., Kangwa, M., Smolander, T., and Derksen, C.: Global snow monitoring for climate research: Algorithm theoretical basis document (ATBD) - SWE-algorithm, Tech. Rep. Version/Revision 1.0/02 (2013).
16. Armstrong, R., Brodzik, M., Knowles, K., and Savoie, M.: Global Monthly EASE-Grid Snow Water Equivalent Climatology, Version 1, doi: http://dx.doi.org/10.5067/KJVERY3MIBPS (2005).
17. Dorigo, W.A., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E.,Hamer, D. P. Hirschi, M., Ikonen, J., De Jeu, R. Kidd, R. Lahoz, W., Liu, Y.Y., Miralles, D., Lecomte, P. ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions, Remote Sensing of Environment, 185–215, doi: https://doi.org/10.1016/j.rse.2017.07.001 (2017).
18. Moesinger, L., Dorigo, W., Jeu, R. D., Schalie, R. V. D., Scanlon, T., Teubner, I., & Forkel, M. The global long-term microwave vegetation optical depth climate archive (VODCA). Earth System Science Data, 12(1), 177-196. doi: 10.5194/essd-12-177-2020 (2020).
19. Yan, K. et al. Evaluation of modis lai/fpar product collection 6. part 2: Validation and intercomparison. Remote. Sens. 8,10.3390/rs8060460 (2016).
20. Potapov, P. et al. Mapping global forest canopy height through integration of gedi and landsat data. Remote. Sens. Environ. 253, 112165, 10.1016/j.rse.2020.112165 (2021).
21. Hansen, M., Song, X.P.: Vegetation Continuous Fields (VCF) yearly global 0.05 deg, NASA EOSDIS Land Processes DAAC, doi: 10.5067/MEaSUREs/VCF/VCF5KYR.001 (2018).
22. DiMiceli, C., Carroll, M., Sohlberg, R., Kim, D., Kelly, M., Townshend, J. MOD44B MODIS/Terra Vegetation Continuous Fields Yearly L3 Global 250m SIN Grid V006 [Data set]. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/MODIS/MOD44B.006 (2015).
23. Hengl, T. et al. Soilgrids250m: Global gridded soil information based on machine learning. PLOS ONE 12, 1–40,10.1371/journal.pone.0169748 (2017).