

# New Interactive Maps of Evapotranspiration, Solar Radiation, and Other Climate Variables

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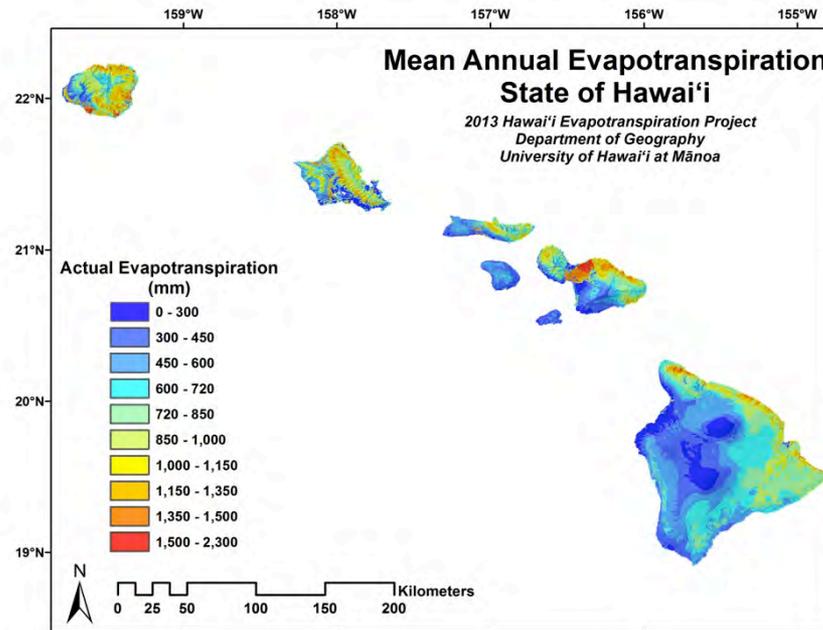
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Commission on Water Resource Management  
20 August 2014

Thomas Giambelluca

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# Rainfall Atlas of Hawai'i

Geography Department - University of Hawai'i at Mānoa



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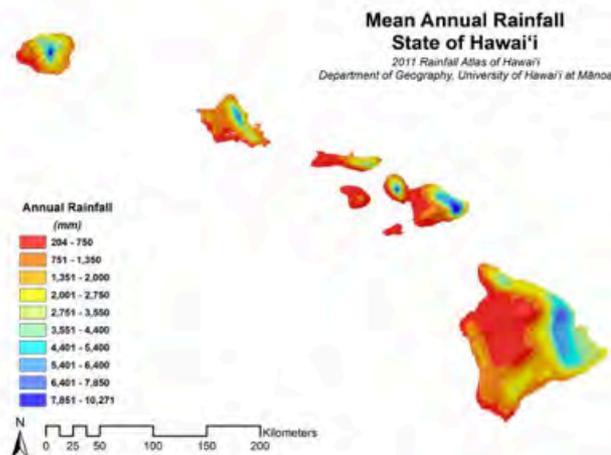
## What is the Rainfall Atlas of Hawai'i?

The Hawaiian Islands have one of the most diverse rainfall patterns on earth. The mountainous terrain, persistent trade winds, heating and cooling of the land, and the regular presence of a stable atmospheric layer at an elevation of around 7,000 ft. interact to produce areas of uplift in distinct spatial patterns anchored to the topography. The resulting clouds and rainfall produced by this uplift lead to dramatic differences in mean rainfall over short distances. Knowledge of the mean rainfall patterns is critically important for a variety of resource management issues, including ground water and surface water development and protection, controlling and eradicating invasive species, protecting and restoring native ecosystems, and planning for the effects of global warming.



*MODIS Image of Hawai'i, NASA Earth Observatory*

Be sure to check out the [interactive map](#)! It may need a few minutes to load on your first visit.



The Rainfall Atlas of Hawai'i is a set of maps of the spatial patterns of rainfall for the major Hawaiian Islands. Maps are available for mean monthly and annual rainfall. The maps represent our best estimates of the mean rainfall for the 30-yr base period 1978–2007. However, for many reasons, it is not possible to determine the exact value of mean rainfall for any location. Therefore, for every map of mean rainfall, we provide a corresponding map of uncertainty. Uncertainty tends to be greatest where we have the poorest information about rainfall, for example in remote locations far from the nearest raingage.

This web site was developed to make the rainfall maps, data, and related information easily accessible. The maps depict rainfall patterns by color and/or by isohyets (lines of equal rainfall). The [interactive map](#) allows users to see the patterns of mean monthly and annual rainfall and corresponding uncertainty, zoom in on areas of particular interest, navigate to specific locations with the help of a choice of different base maps, and click on any location to get the mean annual rainfall and a graph and table of mean monthly rainfall. The locations of stations can also be shown on the interactive map. Clicking on a station gives both station and mapped estimates of monthly rainfall along with station metadata.

# Rainfall Atlas of Hawai'i

Geography Department - University of Hawai'i at Mānoa

HOME

INTERACTIVE MAP

DOWNLOADS

HOW TO CITE

HISTORY

METHODS

RAINFALL

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### Mean Annual Rainfall State of Hawai'i

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## Rainfall Atlas of Hawai'i

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### Mean Monthly Rainfall Index

Rainfall index of mean 2011. Location of mean 2011: Station: KAHU 18 - Unst.

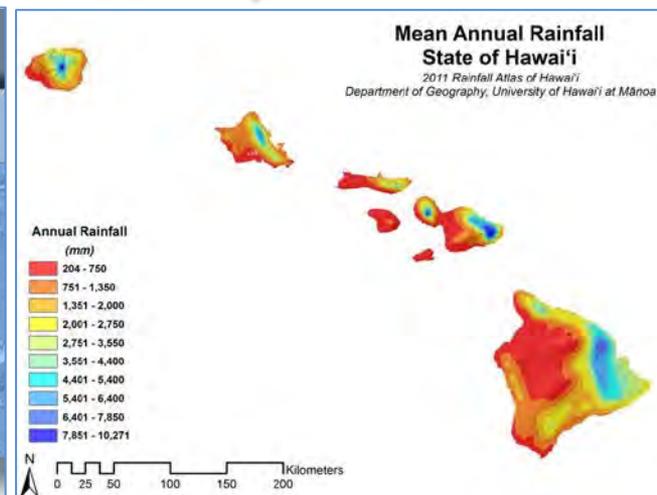
Month	Map	Uncert.	Station	Uncert.
January	248.4	32.2	282.5	35.5
February	189.8	26.1	186.1	28.2
March	262.2	47.4	299.4	40.0
April	233.5	53.3	279.7	32.7
May	178.0	39.0	236.1	38.5
June	232.3	48.4	265.6	39.9
July	234.1	46.0	237.0	29.9
August	193.9	58.1	219.2	34.1
September	194.5	47.0	218.0	28.4
October	239.3	52.9	213.4	38.4
November	230.0	39.7	211.4	48.0
December	277.2	38.5	274.1	35.5
Annual	248.6	34.7	258.6	31.1

### Rainfall Data (mm)

Month	Map	Uncert.	Station	Uncert.
January	248.4	32.2	282.5	35.5
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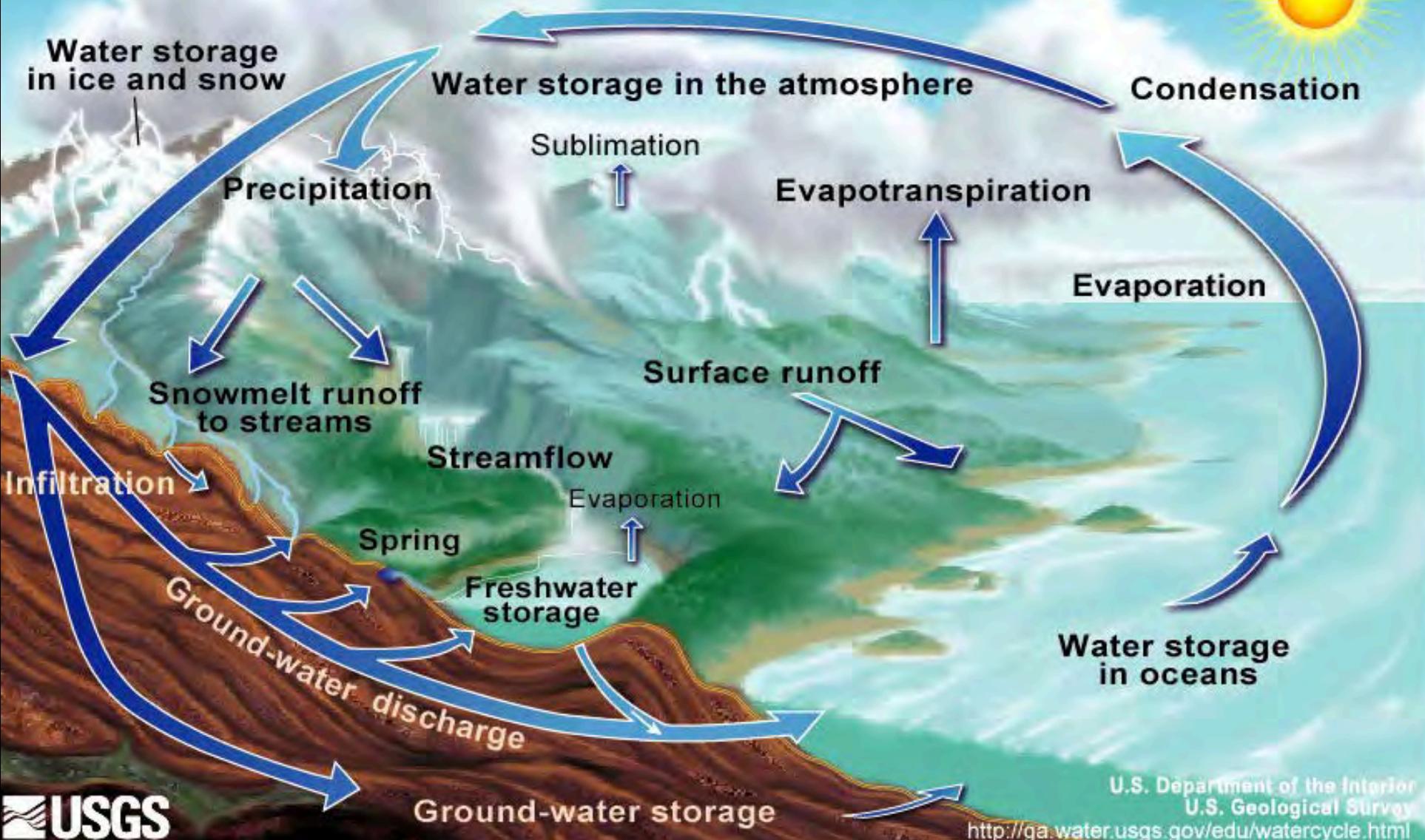
### Station Information

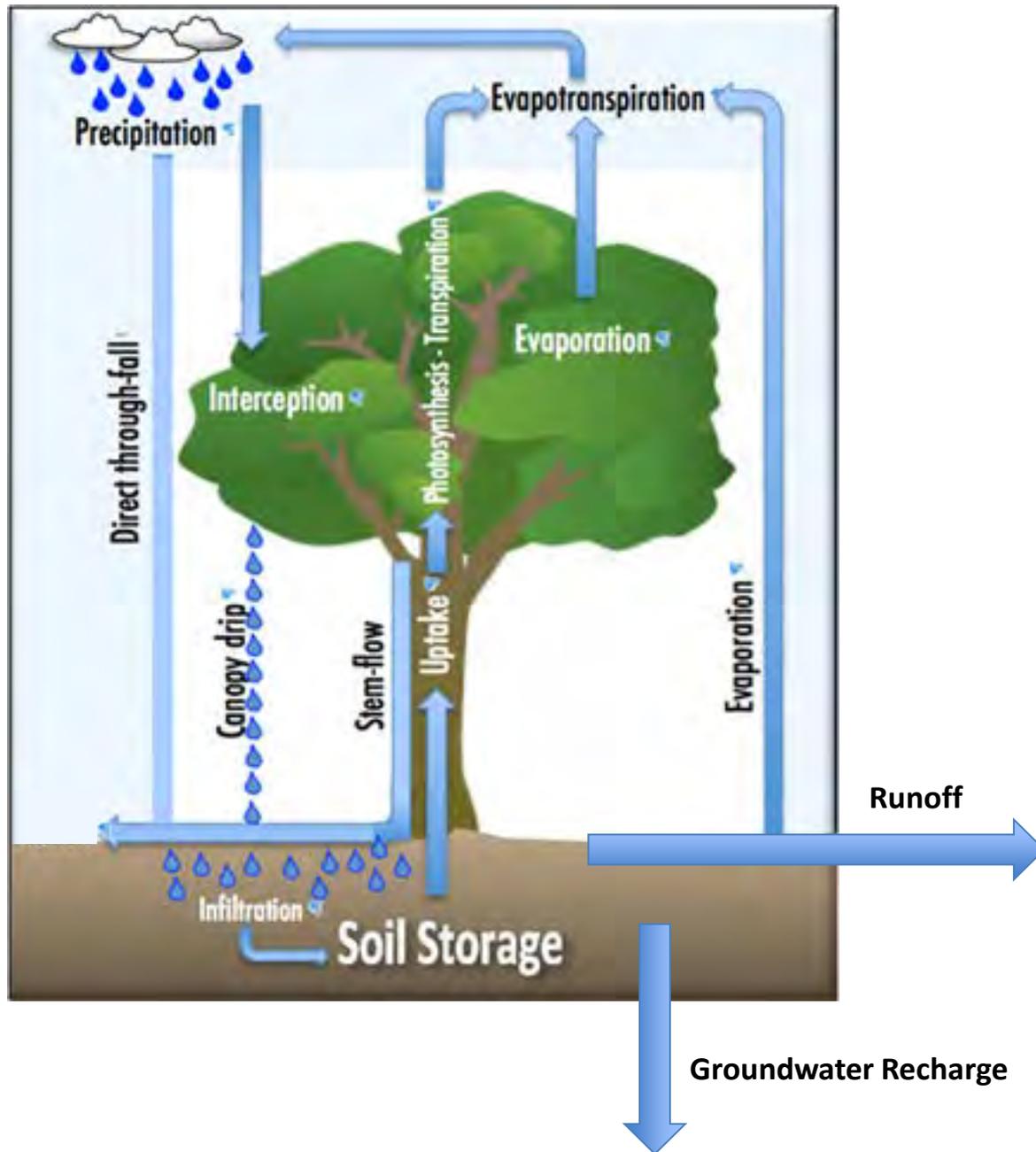
SKN	833
Name	Kahu 18
Observer	US ARMY
Location	Dep: 21.450° N, 157.98° W DM: 21° 27' 03.3" N, 157° 58' 6.7" W UTM Zone #: 60QUR, 2377410 412.1 meters   1352 feet
Elevation	
Record Period	1944 - 1999
Data Source	FIL, NCEP, NARR, Sams, StateMDC



<http://rainfall.geography.hawaii.edu/>

# The Water Cycle





# Evapotranspiration of Hawai'i

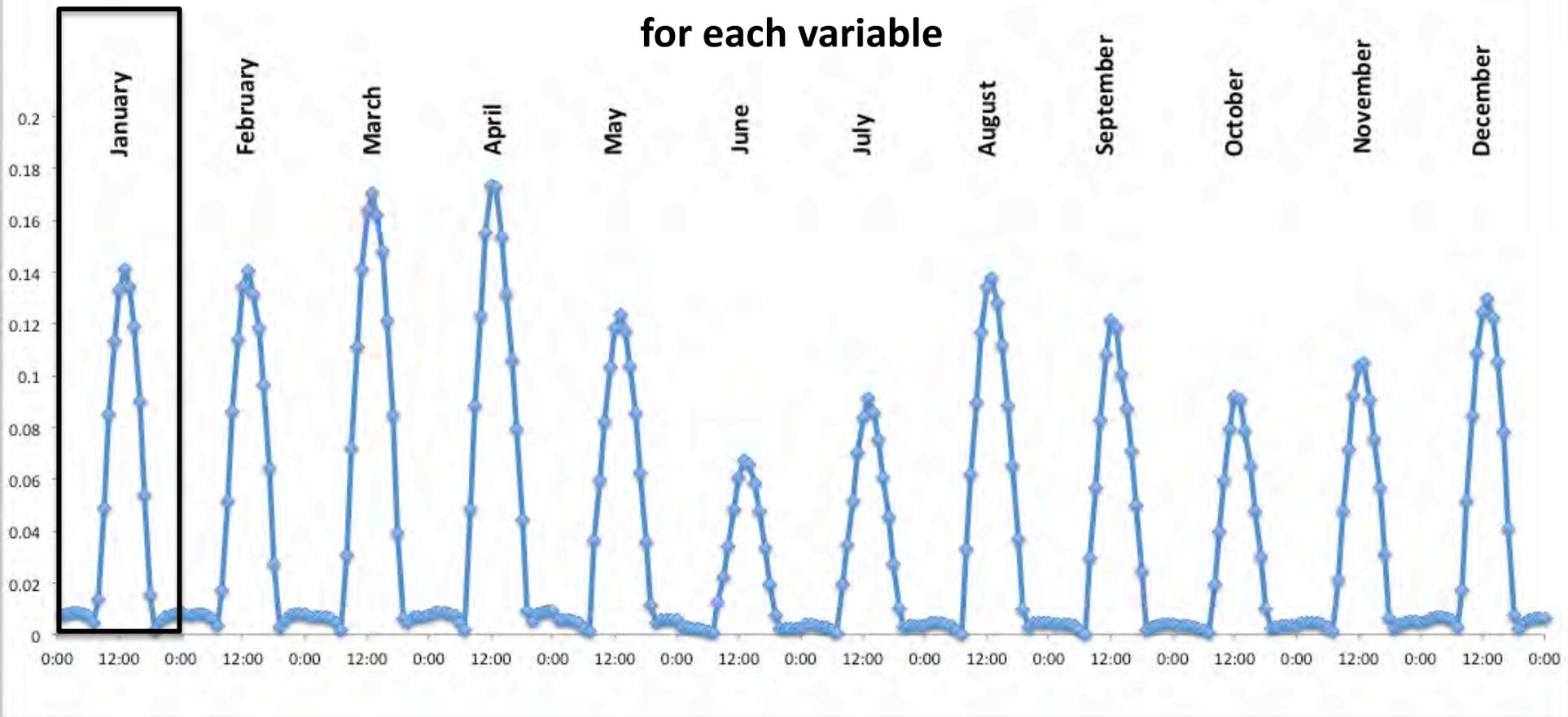
- Many applications of ET information
  - Basic hydrology
  - Water resources assessment and planning
  - Irrigation management
  - Regional climate modeling
  - Terrestrial ecology
- Challenging problem
  - Extreme spatial gradients in ET-relevant variables
  - Need for high spatial resolution results
  - Very few ET measurements

# Strategy

- Map all variables needed to estimate ET
- Develop high resolution maps: spatial units 234 m x 250 m (770 x 820 ft)
- Make maps for each hour of the mean daily cycle of each month

**12 x 24 Hourly Maps + 24 Mean Annual Hourly Maps + 12 Mean Monthly Maps + 1 Annual Map**

**= 325 Maps  
for each variable**



# Penman-Monteith equation

$$\lambda E = \frac{s(R_n - G - Q_A - Q_B) + \rho C_p VPD / r_{aH}}{s + \gamma(r_c + r_{aW}) / r_{aH}}$$

$\lambda E$  = evapotranspiration in energy units

$s$  = slope of saturation vapor press vs. temp. curve

$R_n$  = net radiation

$G$  = soil heat flux

$Q_A$  = sensible heat storage in air layer below ref. ht.

$Q_B$  = sensible heat storage in biomass

$\rho$  = air density

$C_p$  = specific heat of air at constant pressure

$VPD$  = vapor pressure deficit

$\gamma$  = psychrometric constant

$r_{aH}$  = aerodynamic resistance for sensible heat

$r_{aW}$  = aerodynamic resistance for water vapor

$r_c$  = canopy or surface resistance

# ET Estimation Strategy

- Components of ET calculated separately

- **Soil evaporation**

$$\lambda E_{soil}$$

- **Wet-canopy evaporation**

$$\lambda E_{wet\_canopy}$$

- **Transpiration**

$$\lambda E_{transp}$$

- ET = sum of the three components

$$\lambda E_{Total} = \lambda E_{soil} + \lambda E_{wet\_canopy} + \lambda E_{transp}$$

# ET Estimation Strategy

- Soil evaporation

$$\lambda E_{\text{soil}} = \frac{sA + \rho C_p VPD / (r_u + r_{\text{aH}})}{s + \gamma} (1 - f_c) f_{\text{sm}}$$

- Wet-canopy evaporation

$$\lambda E_{\text{wetcanopy}} = \frac{sA_1 + \rho C_p VPD / r_{\text{aH}}}{s + \gamma \left( 1 + \frac{r_{\text{s,water}}}{r_{\text{aH}}} \right)} f_c f_{\text{wet}}$$

- Transpiration

$$\lambda E_{\text{plant}} = \frac{sA_2 + \rho C_p VPD / r_{\text{aH}}}{s + \gamma \left( 1 + \frac{r_c}{r_{\text{aH}}} \right)} f_c (1 - f_{\text{wet}})$$

Available energy

$$A = R_n - G - Q_A - Q_B$$

# VARIABLES MAPPED

## **Radiation Variables**

- Clear sky radiation
- Cloud frequency
- Solar radiation
- Diffuse radiation
- Albedo
- Downwelling longwave radiation
- Upwelling longwave radiation
- Net radiation

## **Heat Storage Variables**

- Soil heat flux
- Biomass heat storage
- Air layer heat storage

## **Other Climate Variables**

- Air Temperature
- Relative Humidity
- Surface Temperature
- Vapor pressure
- Saturation vapor pressure
- Vapor pressure deficit
- Wind speed

## **Land Characteristics**

- Land cover type
- Vegetation height
- Leaf area index
- Vegetation cover fraction
- Canopy wetness fraction
- Soil moisture constraint factor (transpiration)
- Soil moisture constraint factor (soil evaporation)

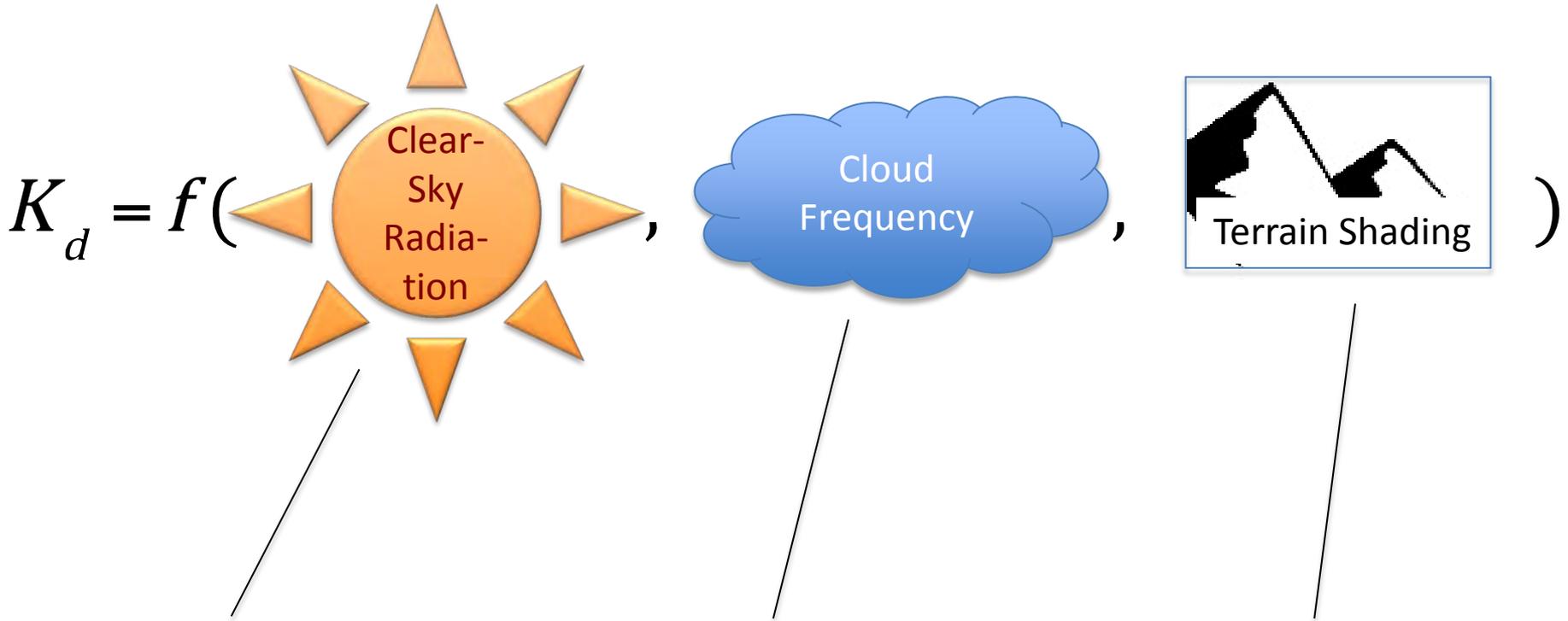
## **Potential Evapotranspiration**

- Potential ET - Priestley Taylor
- Potential ET - Penman-Monteith
- Potential ET - Grass reference surface

## **Evapotranspiration**

- Wet canopy evaporation
- Transpiration
- Soil evaporation
- Evapotranspiration
- Latent energy flux

# Estimating Solar Radiation



Derived from clear-sky model

Derived from satellite imagery

Derived DEM and Sun Angle

159°W

158°W

157°W

156°W

155°W

22°N

21°N

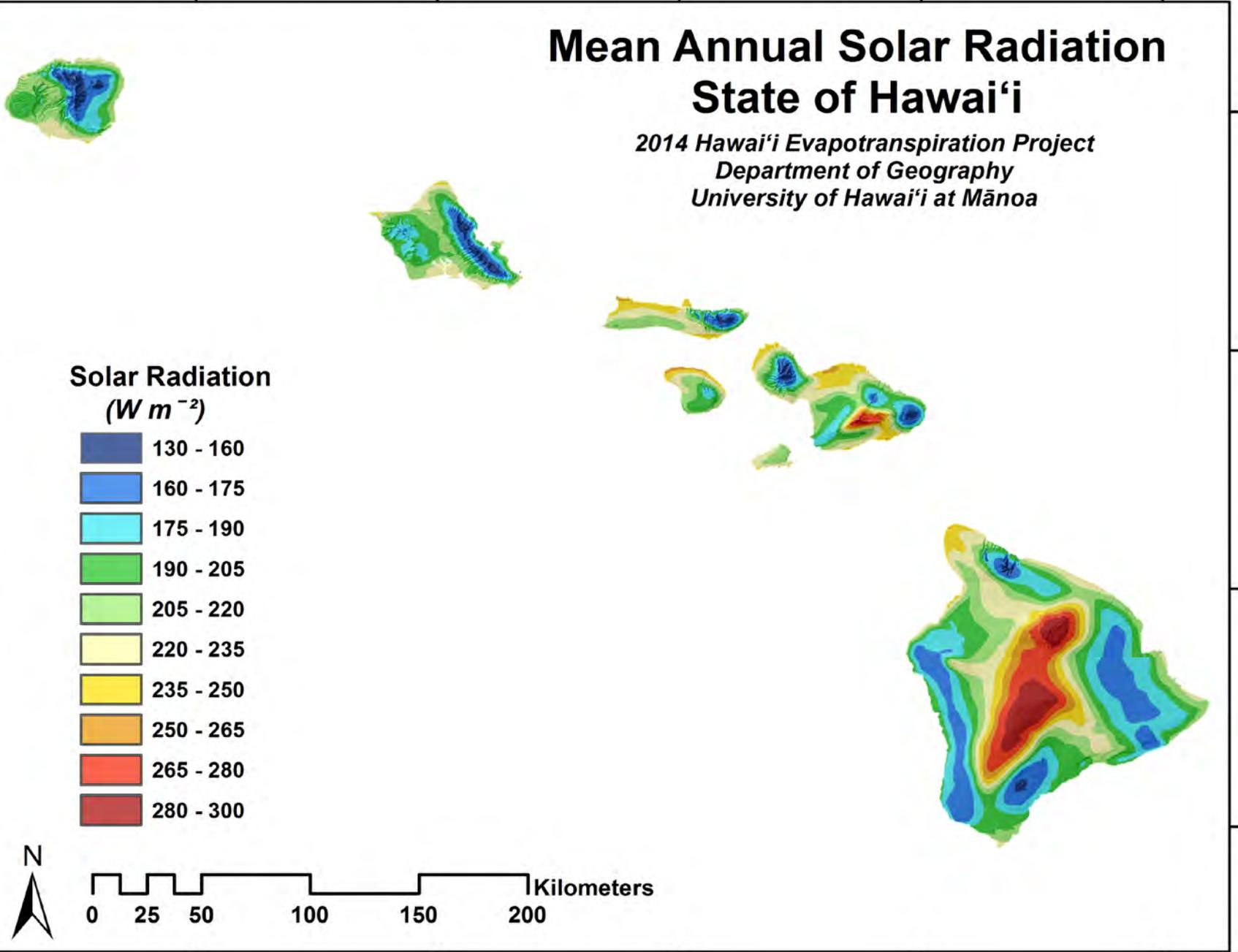
20°N

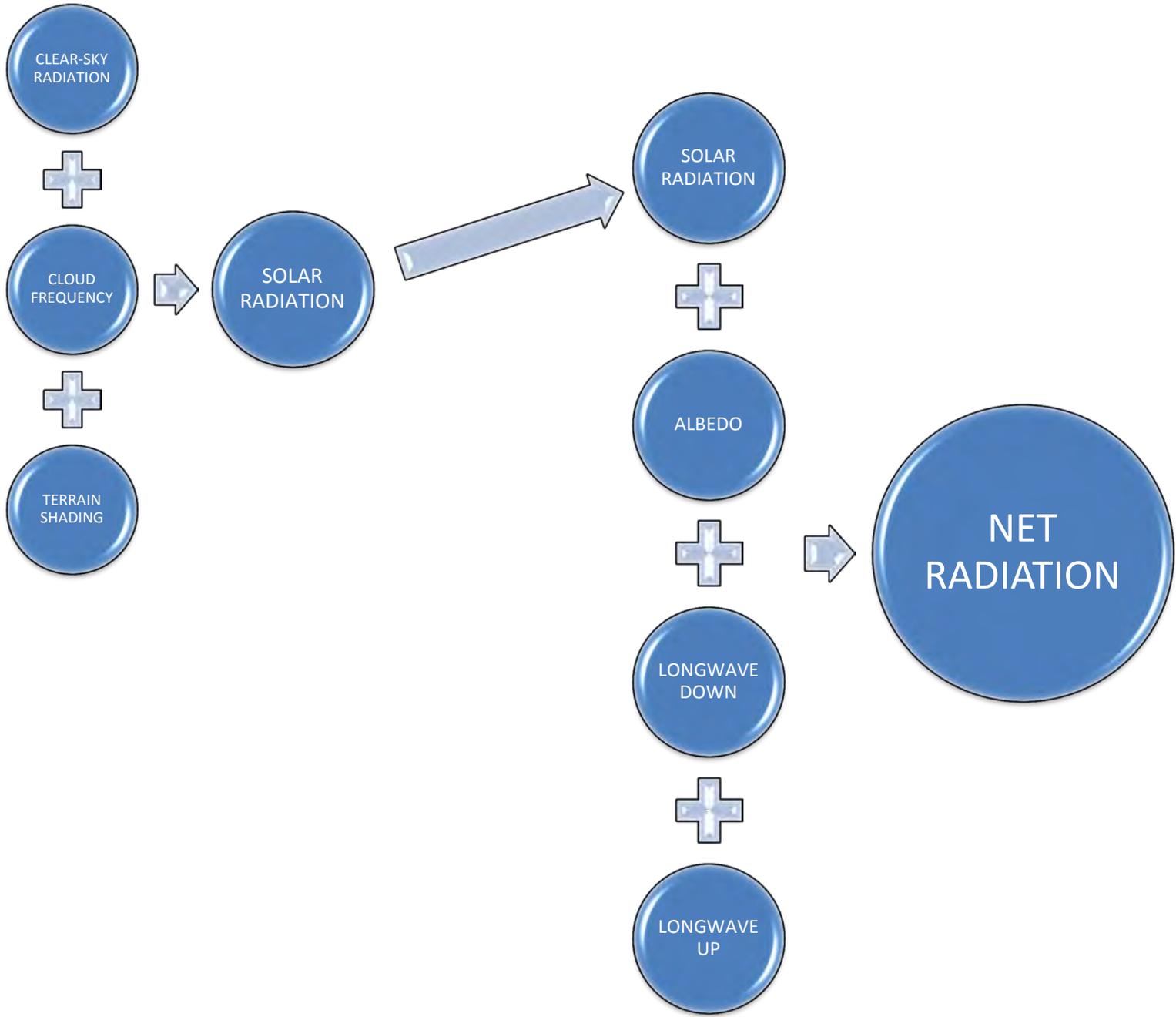
19°N

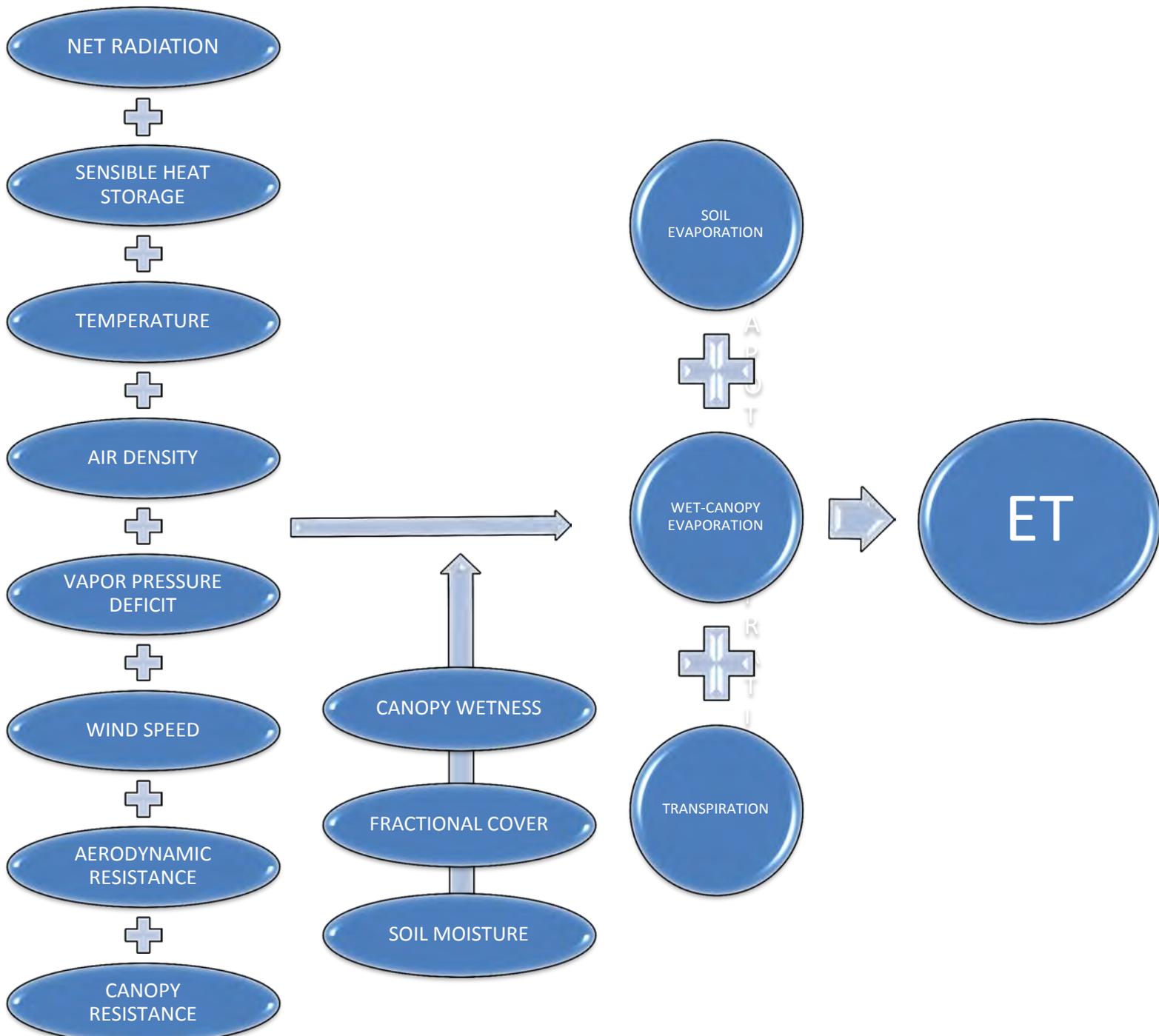
# Mean Annual Solar Radiation State of Hawai'i

*2014 Hawai'i Evapotranspiration Project  
Department of Geography  
University of Hawai'i at Mānoa*

## Solar Radiation ( $W m^{-2}$ )







159°W

158°W

157°W

156°W

155°W

22°N

21°N

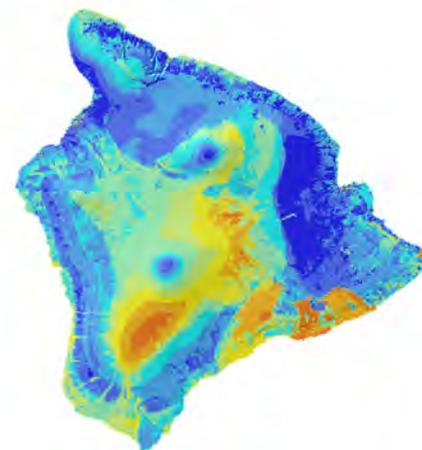
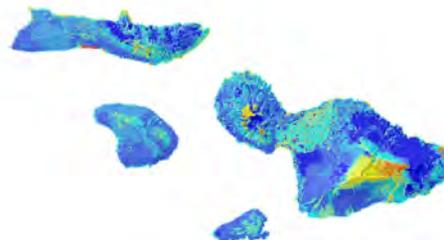
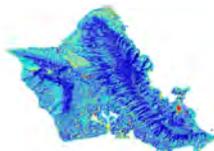
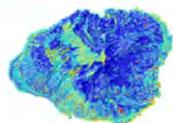
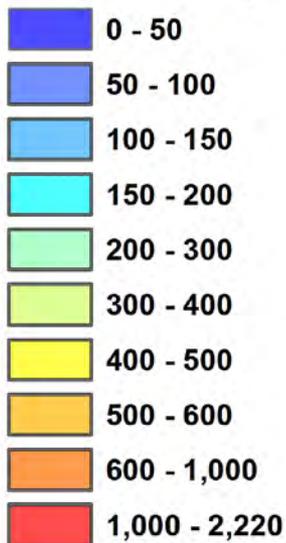
20°N

19°N

# Mean Annual Soil Evaporation State of Hawai'i

*2014 Hawai'i Evapotranspiration Project  
Department of Geography  
University of Hawai'i at Mānoa*

## Soil Evaporation (mm)



159°W

158°W

157°W

156°W

155°W

22°N

21°N

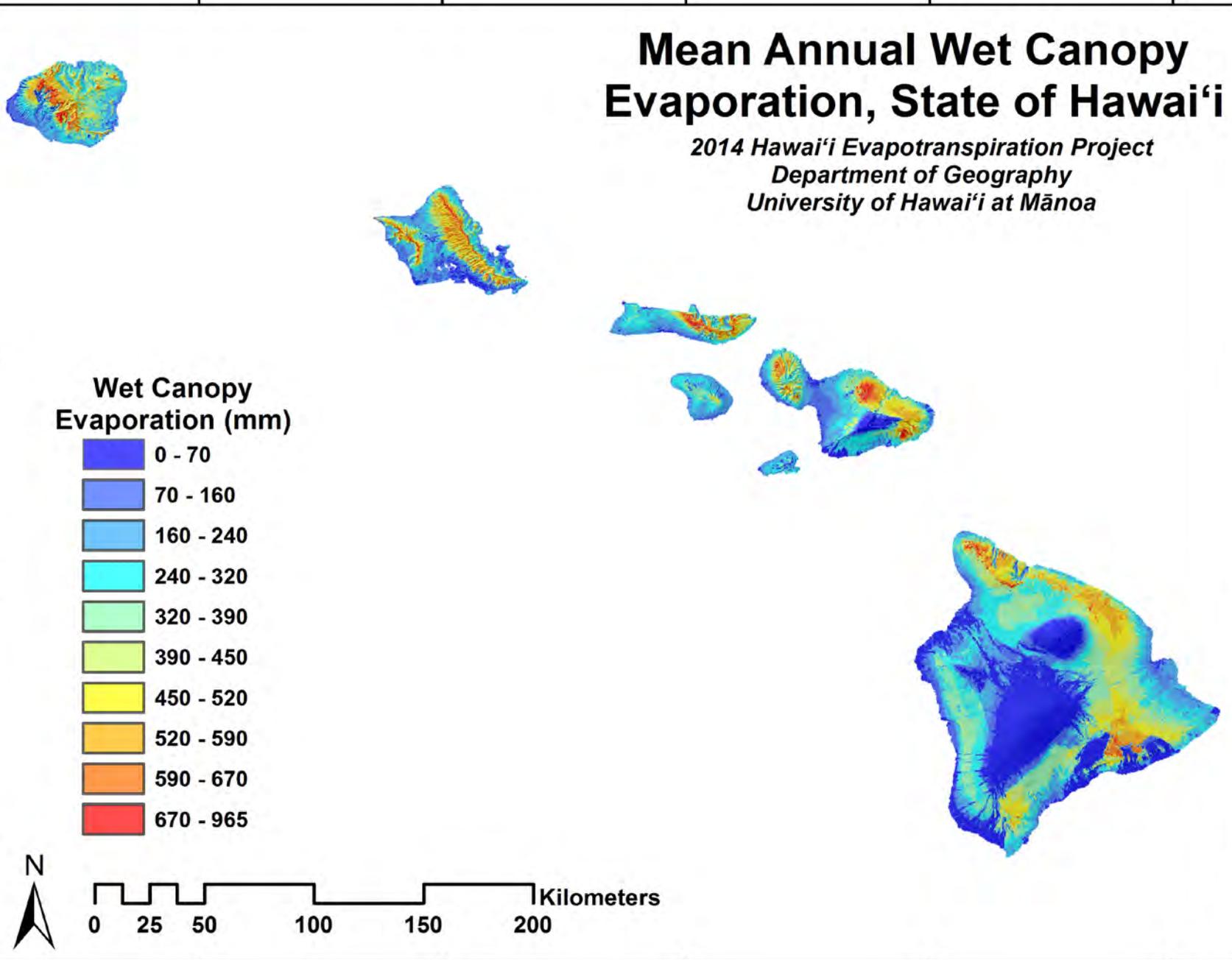
20°N

19°N

# Mean Annual Wet Canopy Evaporation, State of Hawai'i

*2014 Hawai'i Evapotranspiration Project  
Department of Geography  
University of Hawai'i at Mānoa*

## Wet Canopy Evaporation (mm)



159°W

158°W

157°W

156°W

155°W

22°N

21°N

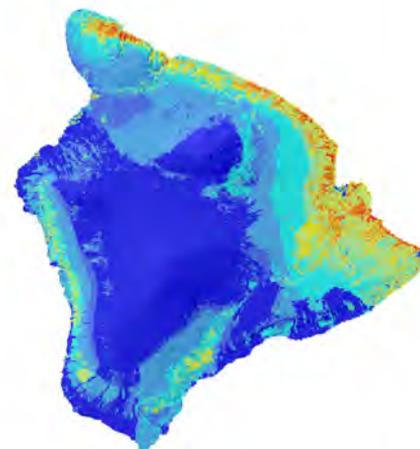
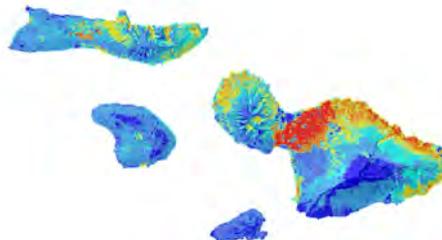
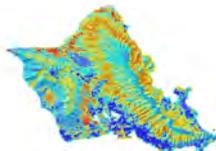
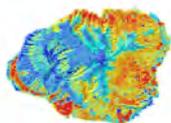
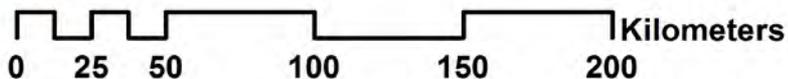
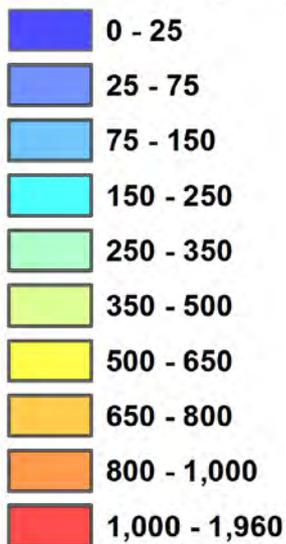
20°N

19°N

# Mean Annual Transpiration State of Hawai'i

*2014 Hawai'i Evapotranspiration Project  
Department of Geography  
University of Hawai'i at Mānoa*

## Transpiration (mm)



159°W

158°W

157°W

156°W

155°W

# Mean Annual Evapotranspiration State of Hawai'i

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Department of Geography  
University of Hawai'i at Mānoa*

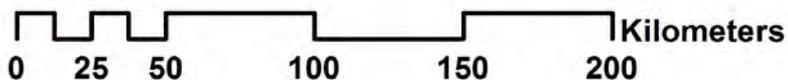
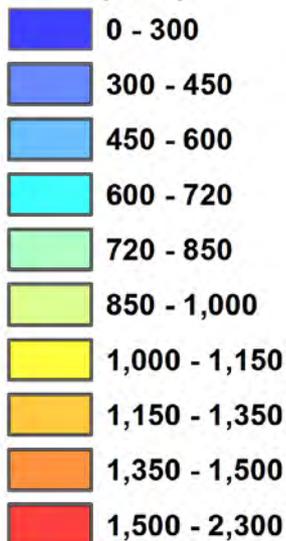
22°N

21°N

20°N

19°N

## Actual Evapotranspiration (mm)



A banner for the Rainfall Atlas of Hawai'i. The background features a landscape with mountains and a blue sky with white clouds. The University of Hawai'i seal is visible in the top right corner.

# Rainfall Atlas of Hawai'i

Geography Department - University of Hawai'i at Mānoa

A banner for the Evapotranspiration of Hawai'i. The background shows a close-up of green leaves with prominent veins. The University of Hawai'i seal is visible in the top right corner.

# Evapotranspiration of Hawai'i

Geography Department - University of Hawai'i at Mānoa

A banner for the Solar Radiation of Hawai'i. The background depicts a bright sun low on the horizon, creating a lens flare effect over a blue sky. The University of Hawai'i seal is visible in the top right corner.

# Solar Radiation of Hawai'i

Geography Department - University of Hawai'i at Mānoa

A banner for the Climate of Hawai'i. The background shows a close-up of a pink and white flower with green leaves. The University of Hawai'i seal is visible in the top right corner.

# Climate of Hawai'i

Geography Department - University of Hawai'i at Mānoa

## URLs

<http://rainfall.geography.hawaii.edu/>

<http://evapotranspiration.geography.hawaii.edu/>

<http://solar.geography.hawaii.edu/>

<http://climate.geography.hawaii.edu/>

# Evapotranspiration of Hawai'i

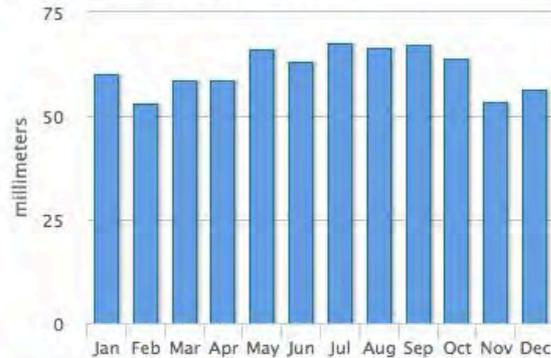
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Graphs Tables

## Evapotranspiration by Month

19.533° N, 155.080° W



## Annual Evapotranspiration by Hour

19.533° N, 155.080° W

Location:

Base Maps

High : 2704.3 mm  
Low : 0.11993 mm

Variable:

Month:  Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

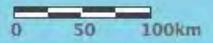
Hour:  01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Units:  other

**Evapotranspiration**

Annual: 733.27 mm

Land Cover: Hawaii Lowland Rainforest





MAHALO

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