Modeling the glacial-interglacial impact of the Pacific Trade Wind Inversion on the geomorphology and hydrology of the Big Island of Hawaii

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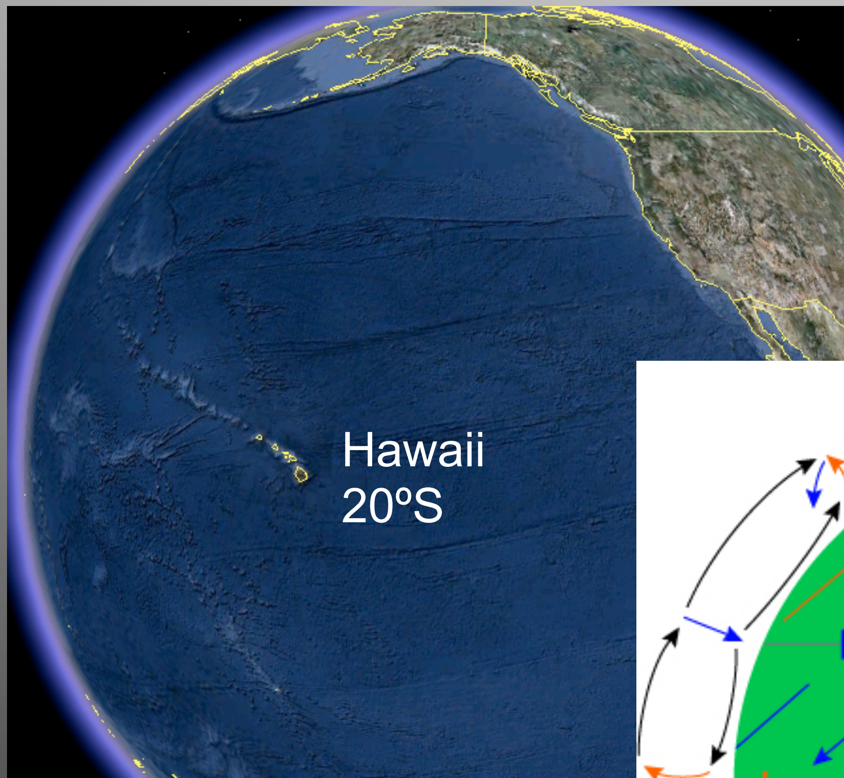
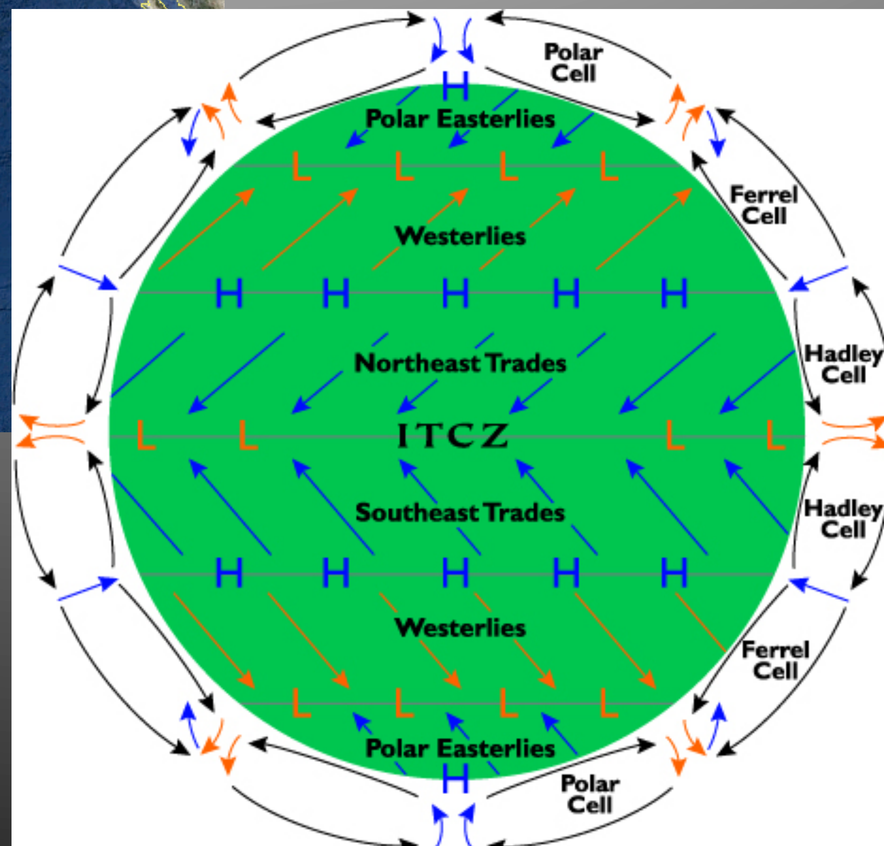
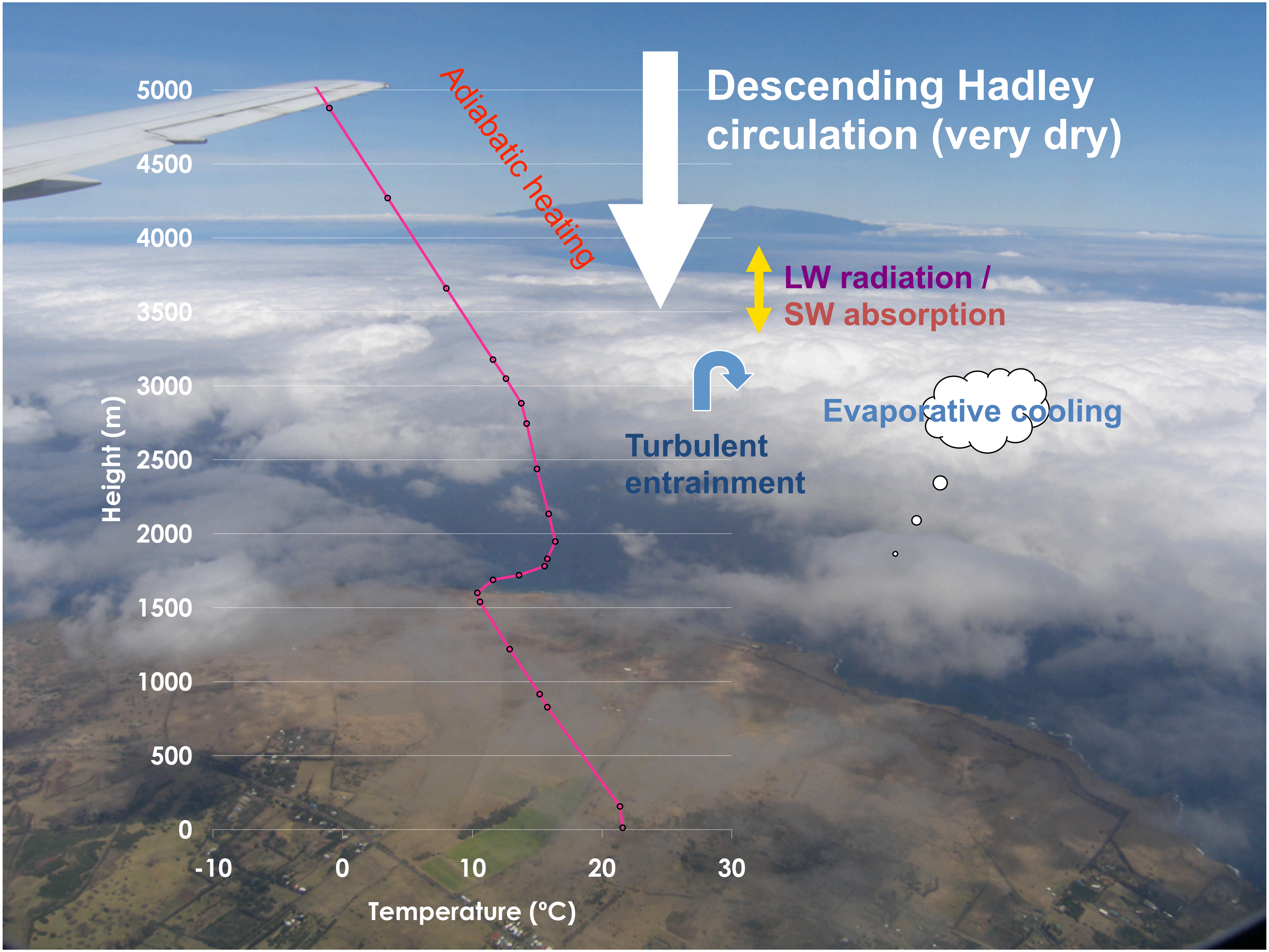
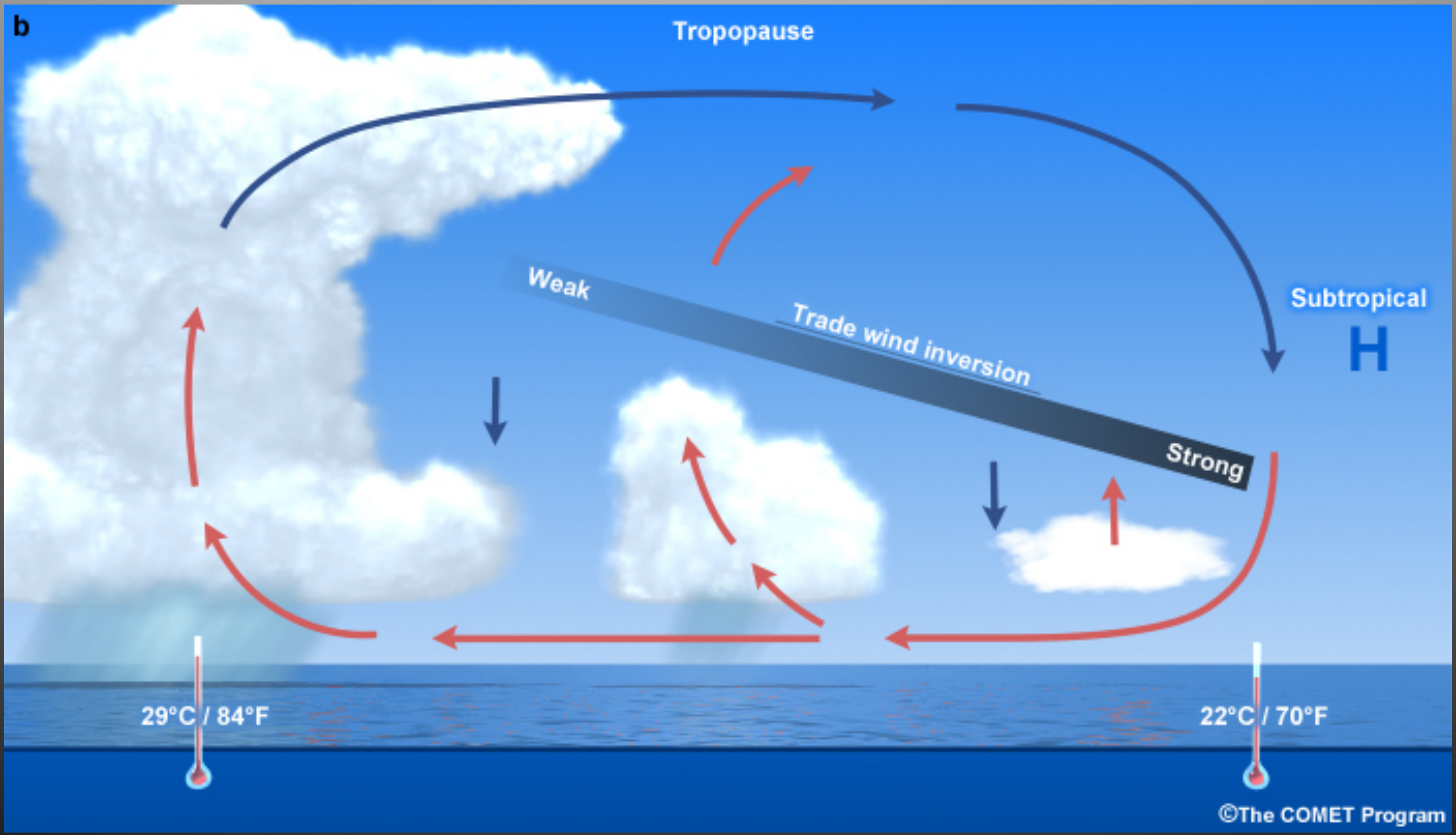




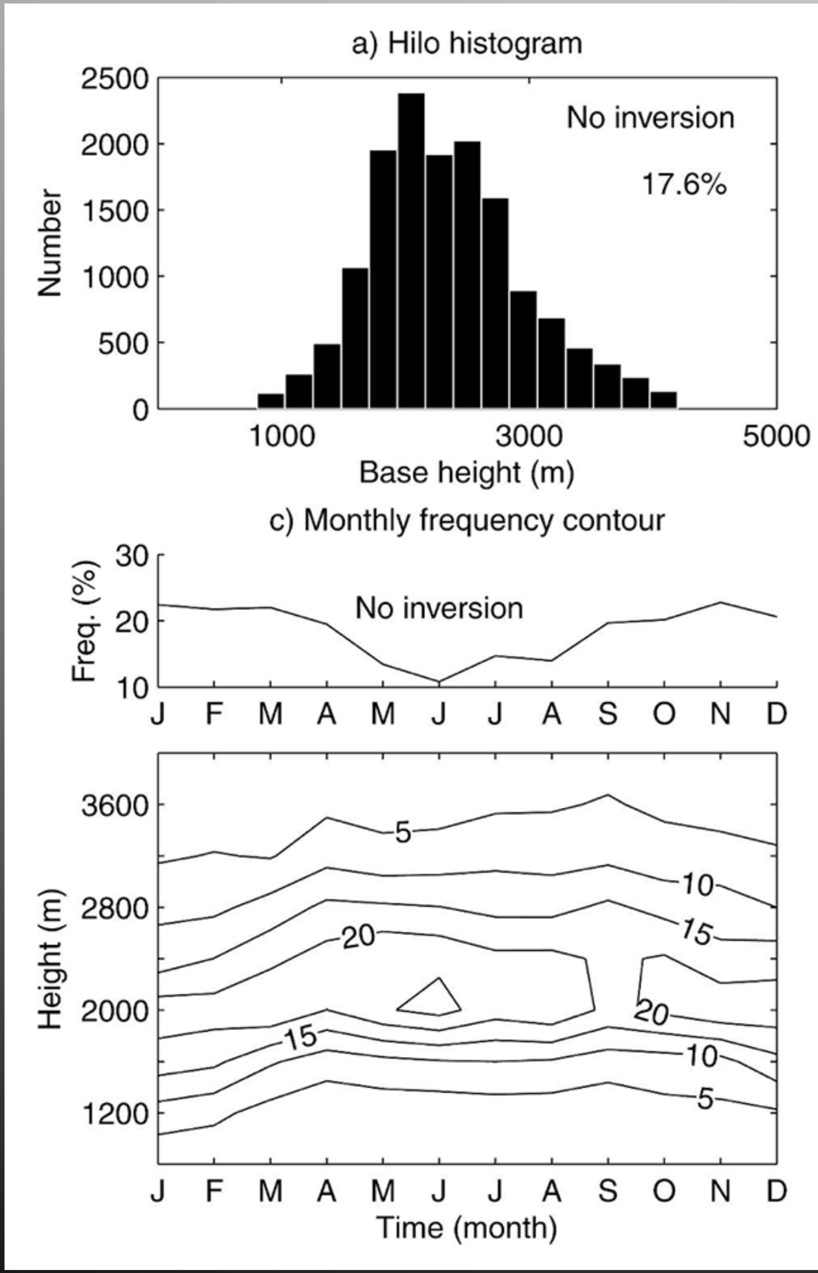
Diana Engle,
Data Discovery
Hurricane Science Center


Descending Hadley circulation (very dry)
Adiabatic heating
LW radiation /
SW absorption
Turbulent entrainment
Evaporative cooling
Height (m)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-10
0
10
20
30
Temperature (°C)

Trade Wind Inversion



www.meted.ucar.edu

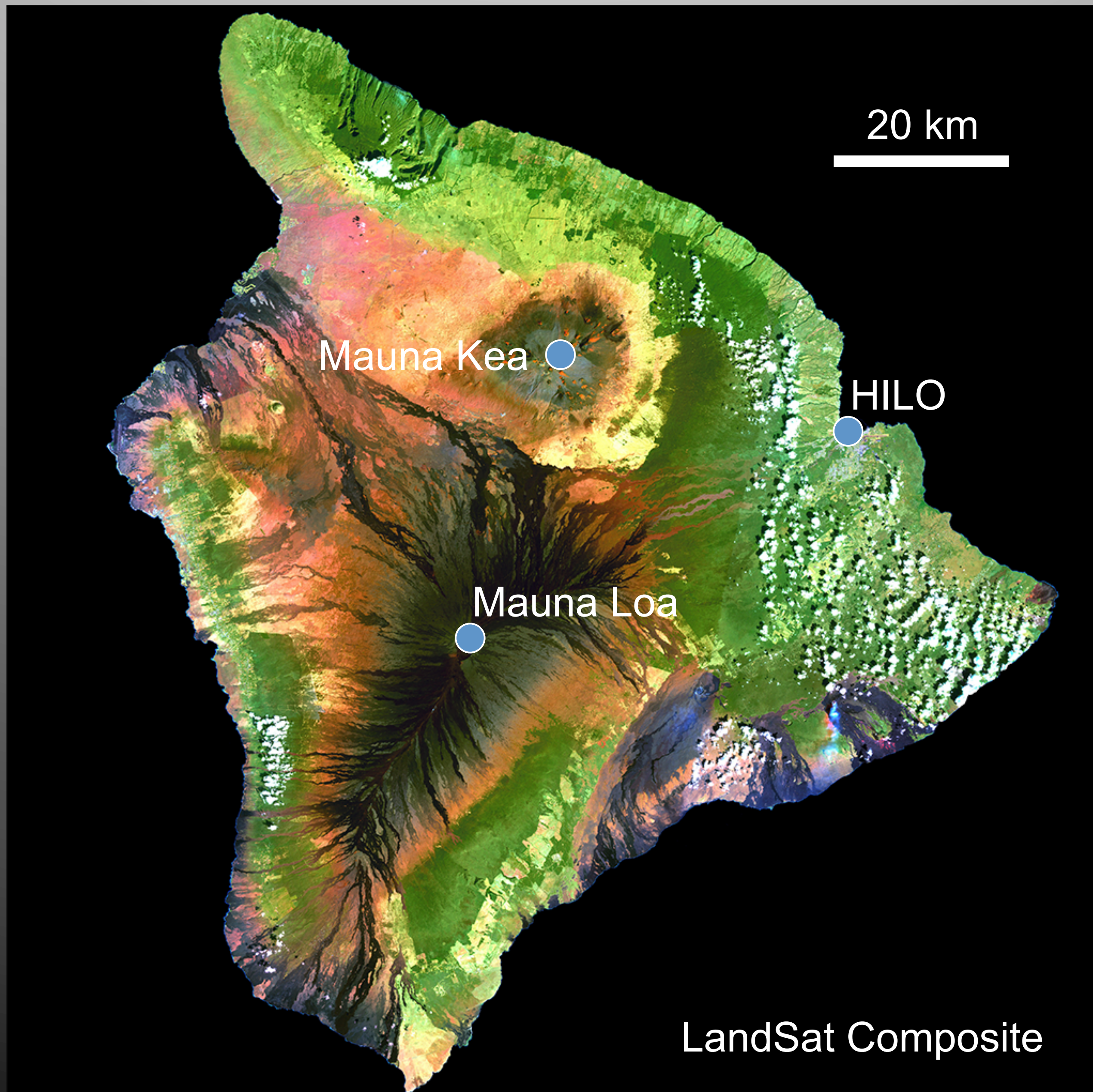


Inversion height stats are well-characterized

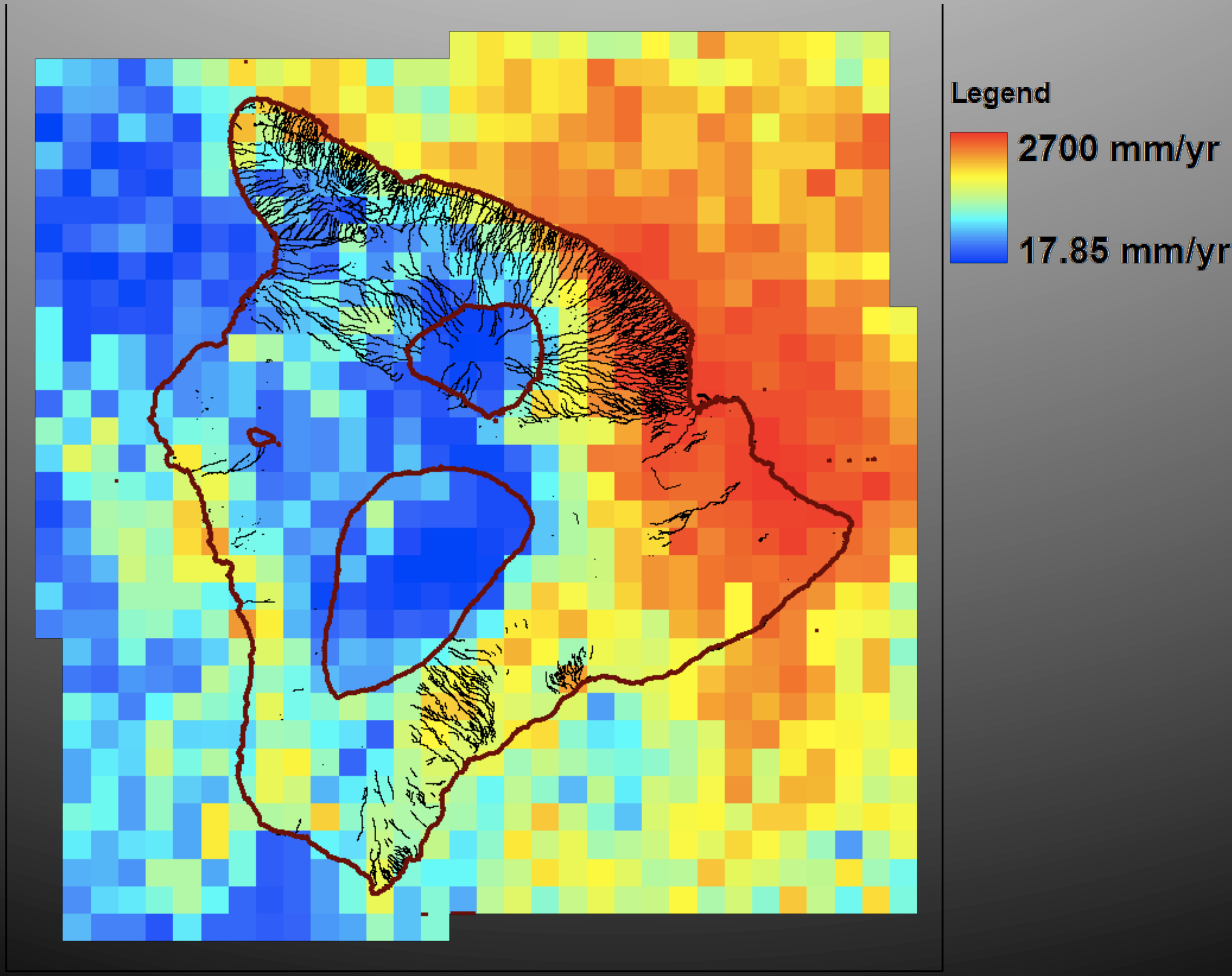
Both height distribution and time statistics are constraint on a climate model

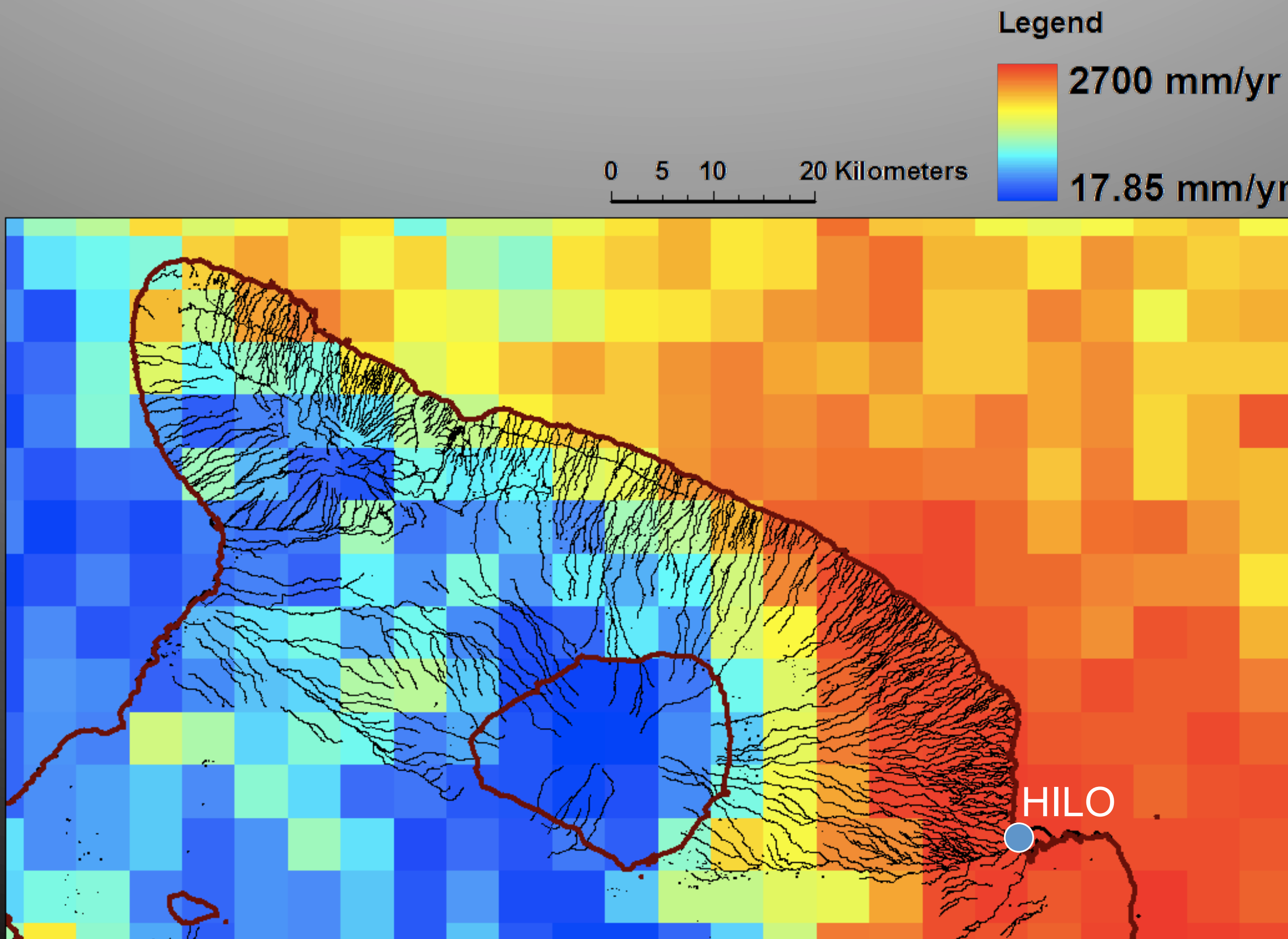
LGM conditions probably modified these, but how?

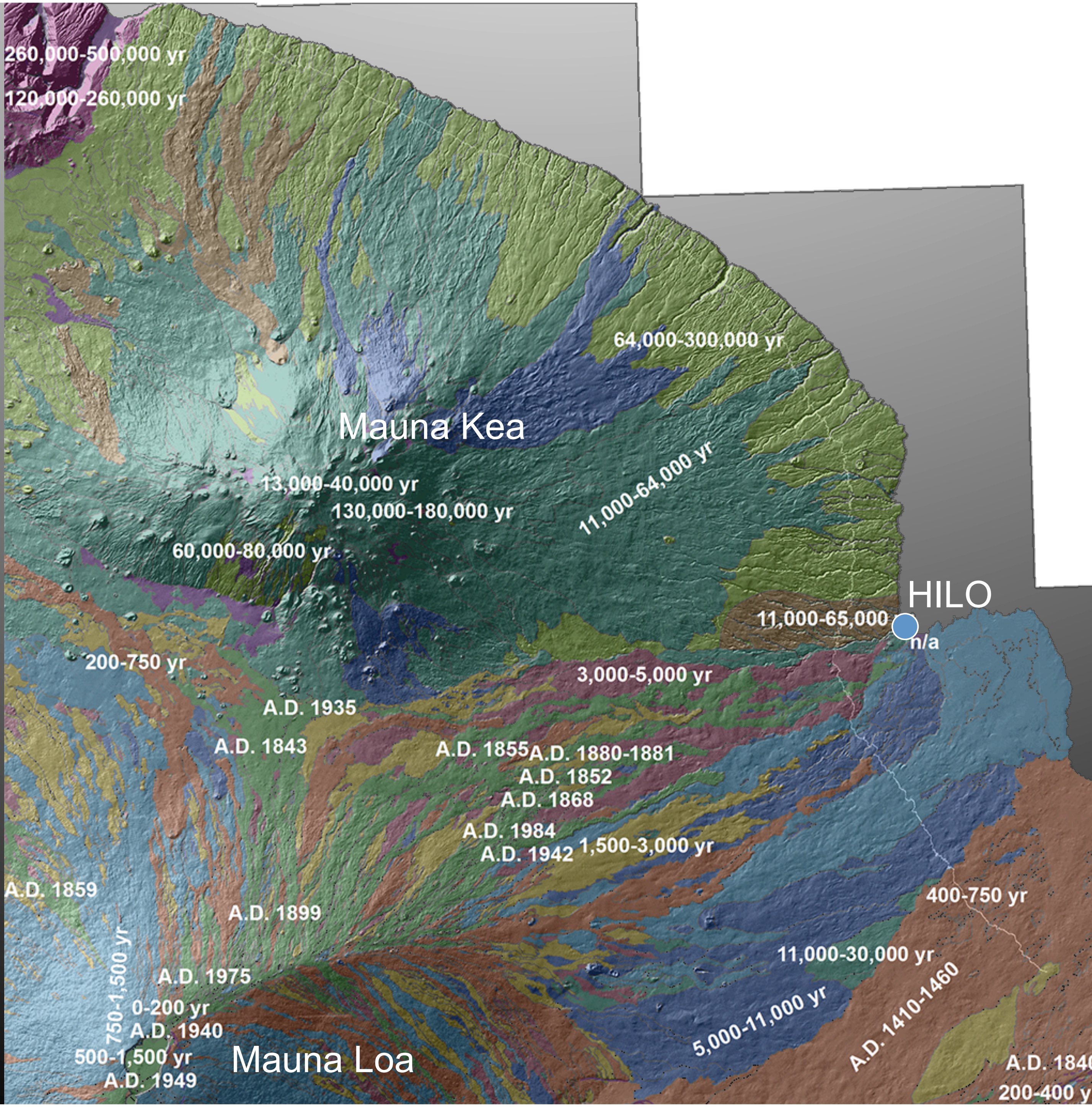
Cao et al., 2007
J. Climate

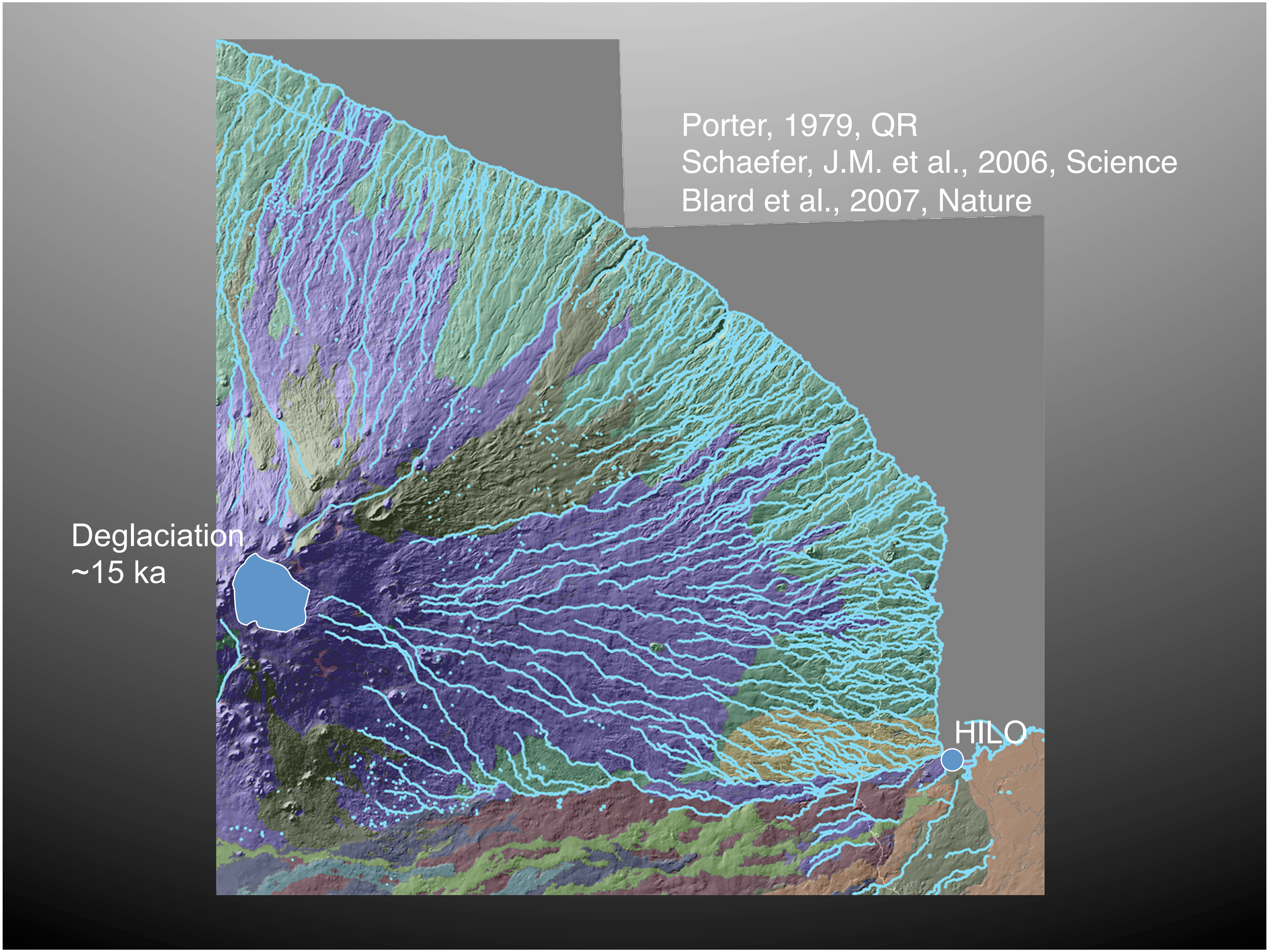

20 km
Mauna Kea
HILO
Mauna Loa
LandSat Composite

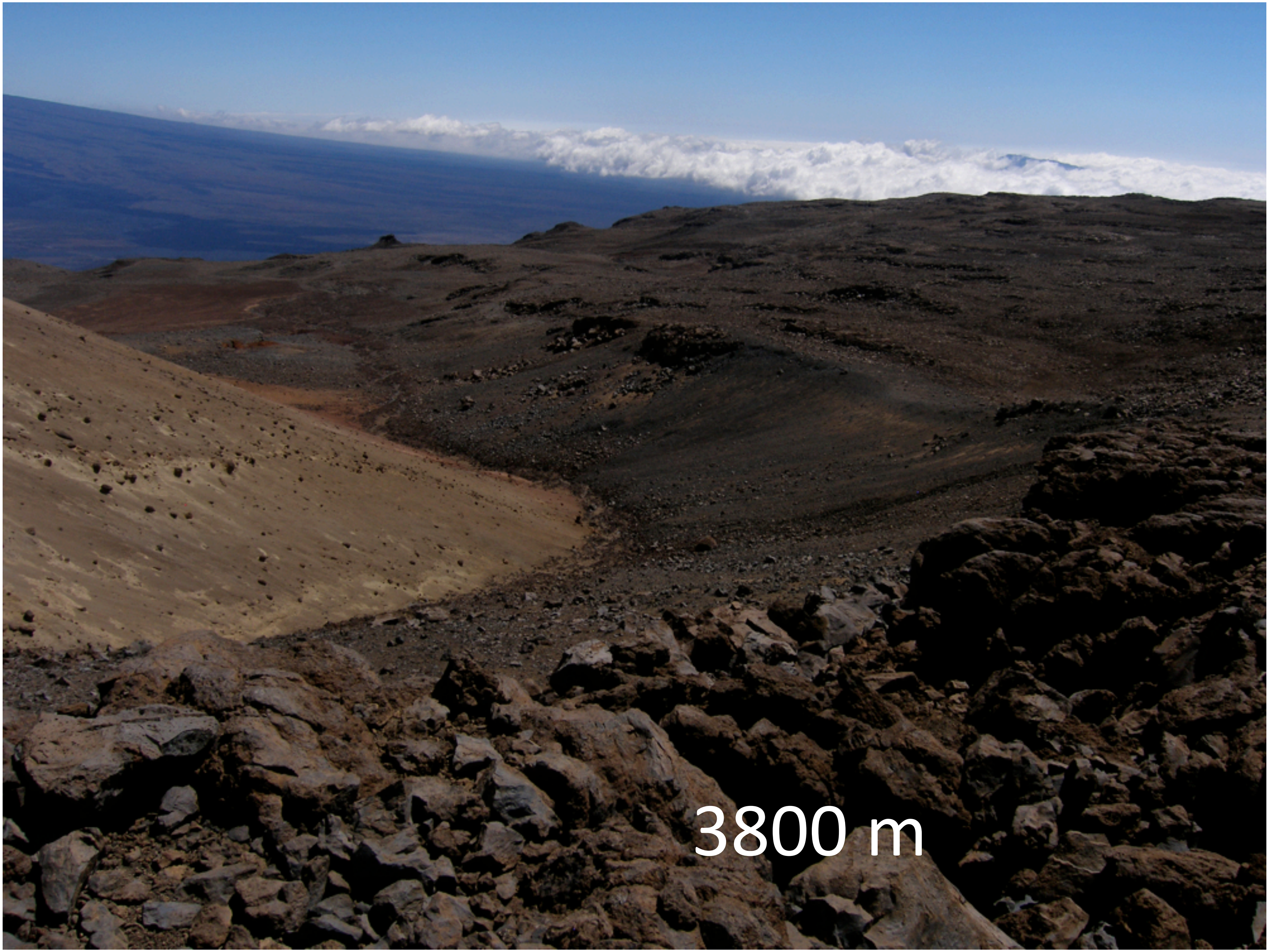
TRMM Data, 1998-2008




Legend
2700 mm/yr
17.85 mm/yr
0 5 10 20 Kilometers
HILO


260,000-500,000 yr
120,000-260,000 yr
64,000-300,000 yr
Mauna Kea
11,000-64,000 yr
13,000-40,000 yr
130,000-180,000 yr
60,000-80,000 yr
HILO
11,000-65,000
n/a
200-750 yr
3,000-5,000 yr
A.D. 1935
A.D. 1843
A.D. 1855
A.D. 1880-1881
A.D. 1852
A.D. 1868
A.D. 1984
A.D. 1942
1,500-3,000 yr
A.D. 1859
A.D. 1899
400-750 yr
750-1,500 yr
11,000-30,000 yr
A.D. 1975
A.D. 1410-1460
0-200 yr
A.D. 1940
5,000-11,000 yr
500-1,500 yr
Mauna Loa
A.D. 1949
A.D. 1840
200-400 yr


Porter, 1979, QR
Schaefer, J.M. et al., 2006, Science
Blard et al., 2007, Nature
Deglaciation
~15 ka
HILO

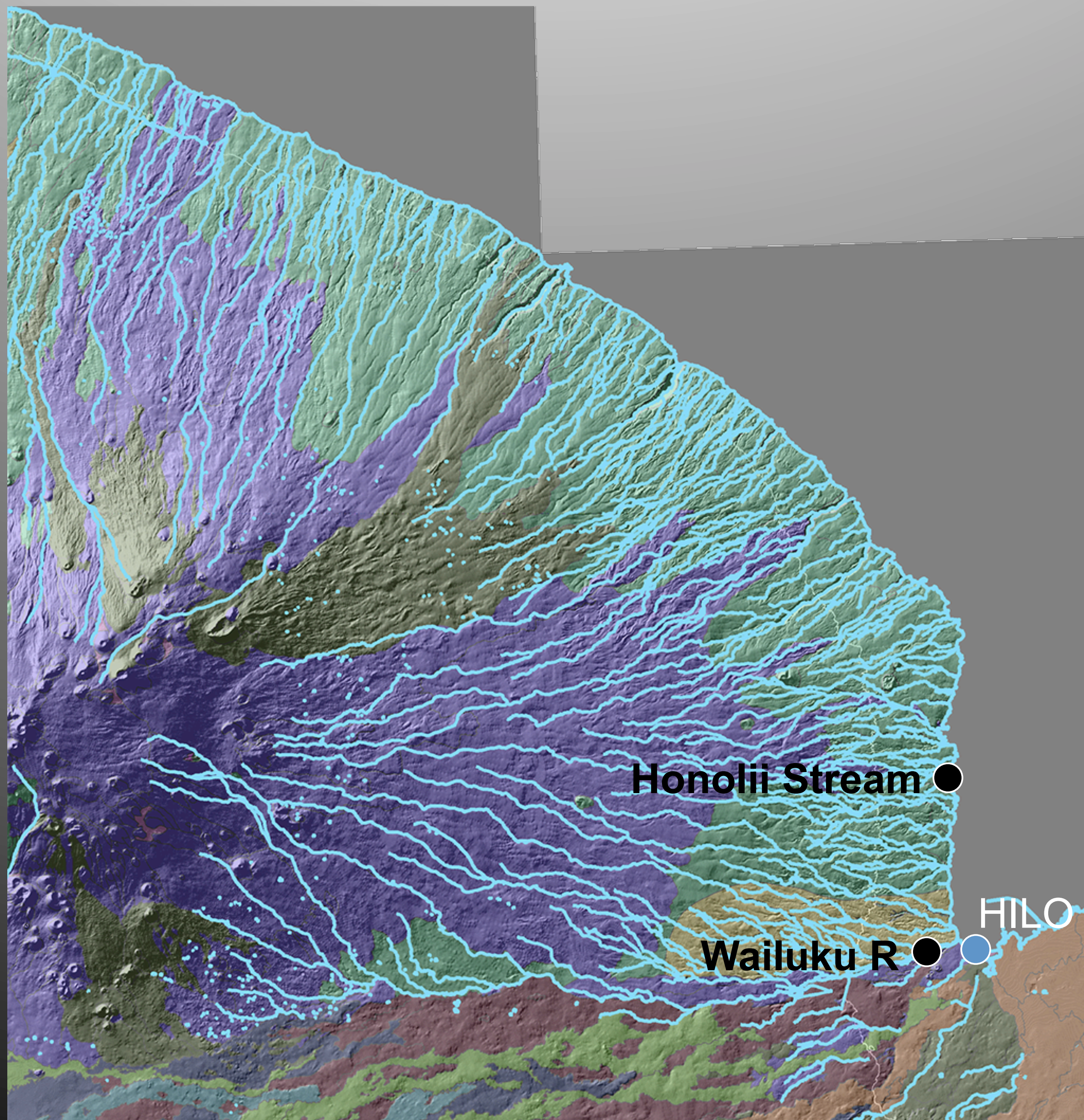

3800 m

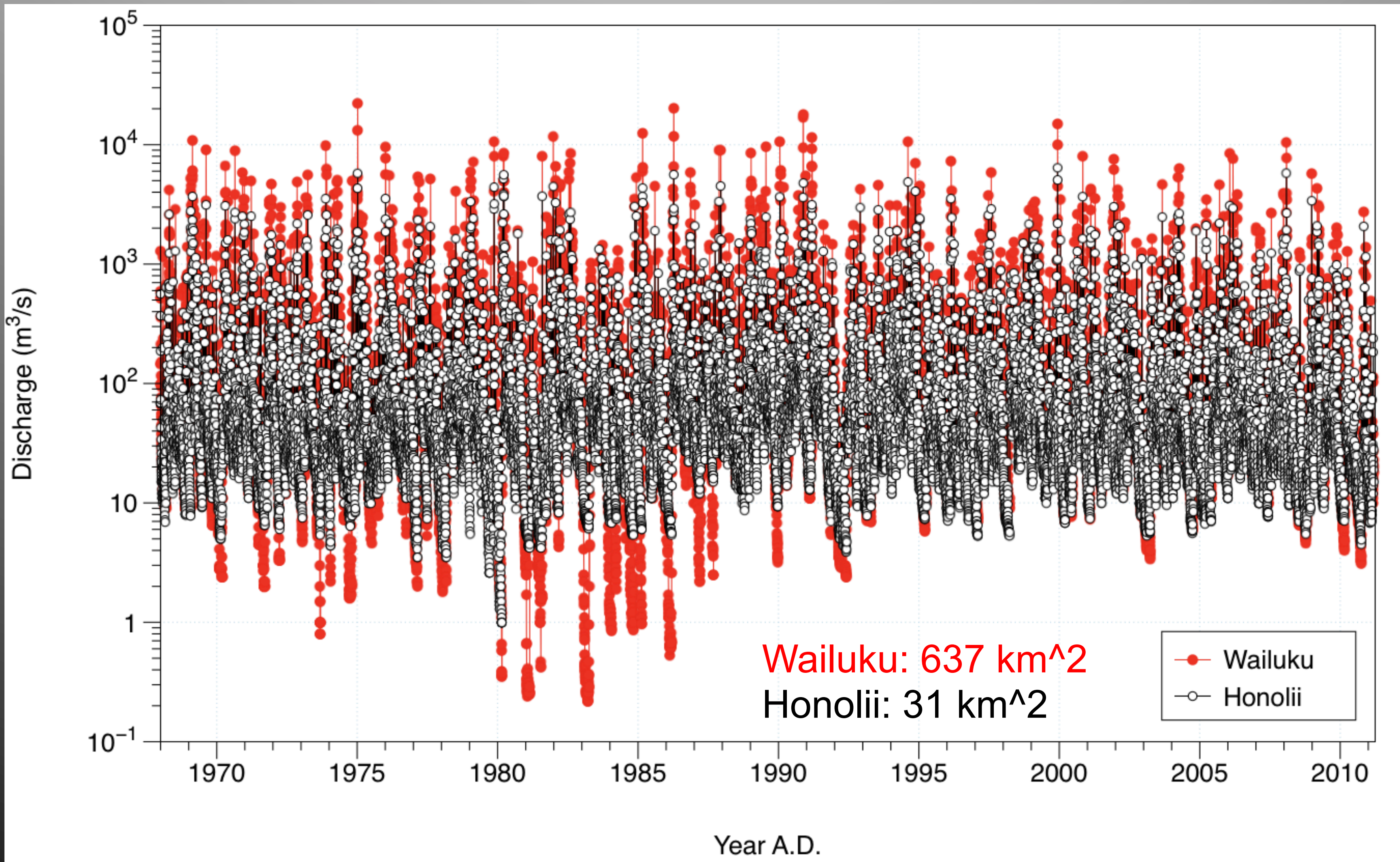
3000 m

2000 m

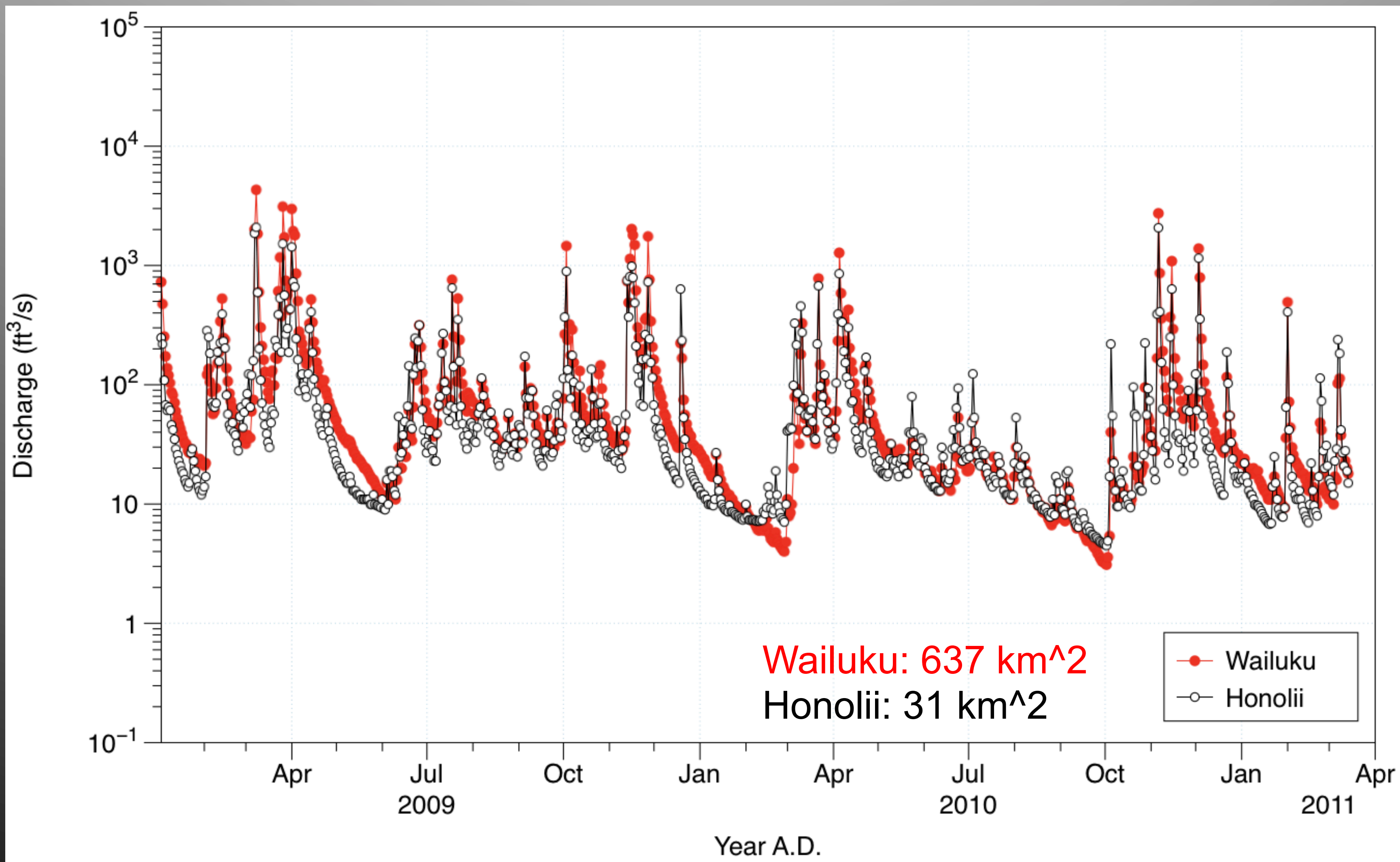
1100 m

100 m



Honolii Stream
HILO
Wailuku R



Discharge (m^3/s)
10^5
10^4
10^3
10^2
10
1
10^-1
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year A.D.
Wailuku: 637 km^2
Honolii: 31 km^2
Wailuku
Honolii


Wailuku: 637 km^2
Honolii: 31 km^2
Wailuku
Honolii
Discharge (ft^3/s)
Year A.D.
Apr
Jul
Oct
Jan
2009
2010
2011

Scientific questions (a few)

To what extent does discharge variability impact the fluvial erosion rates above and below the inversion layer?

Was the LGM fluvial system more top-heavy due to the presence of an ice cap? Did this impact erosion rates?

How does the delivery of sediment to the channels by hillslopes impact fluvial erosion rates above and below the inversion layer?

Are the positions of the large knickpoints better explained by stream discharge or by a stochastic history of landsliding at the coast?

Modeling Goals

- Simulate modern precipitation climatology at relevant scales

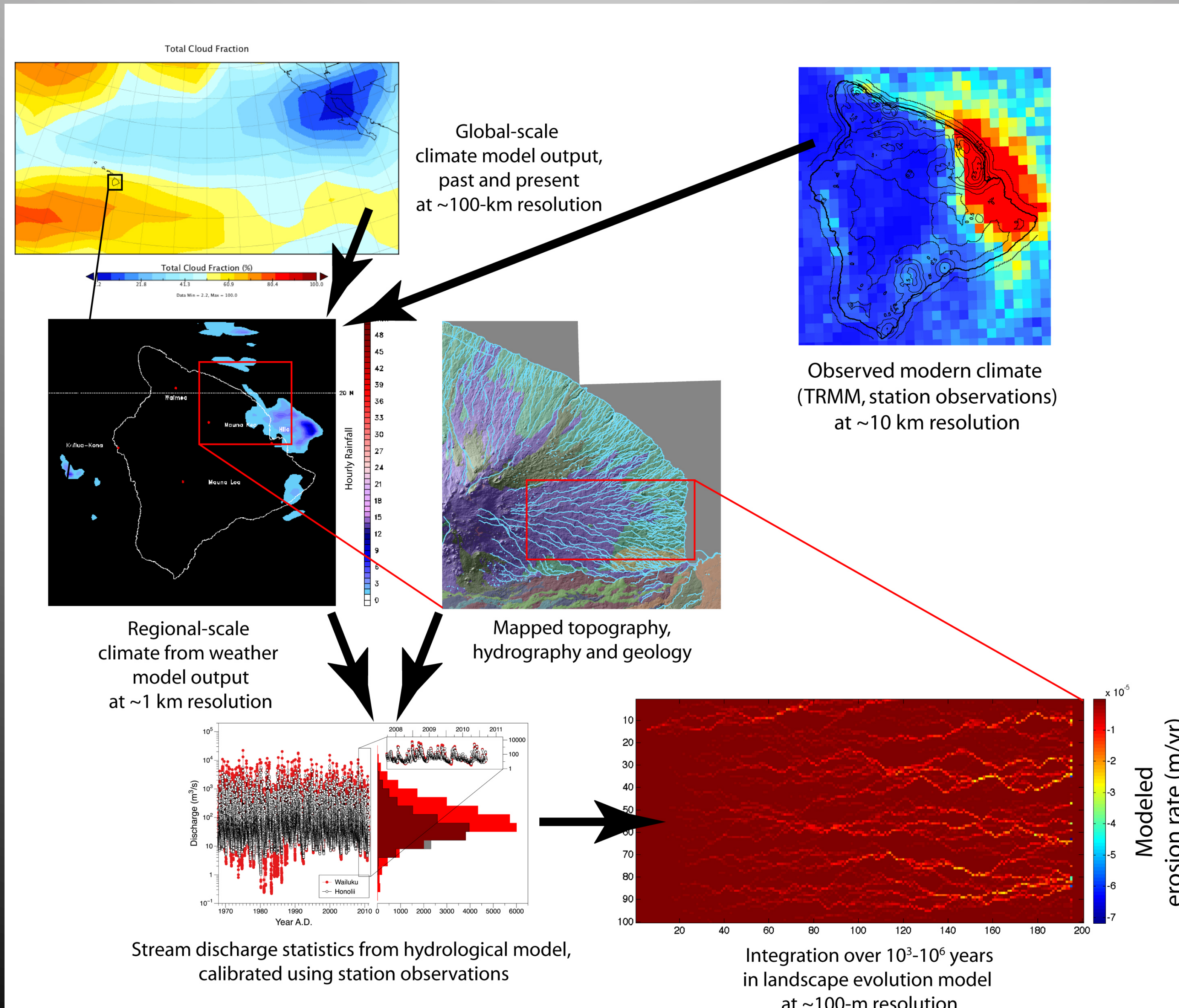
  Need: a regional climate model (RCM) and data to drive it

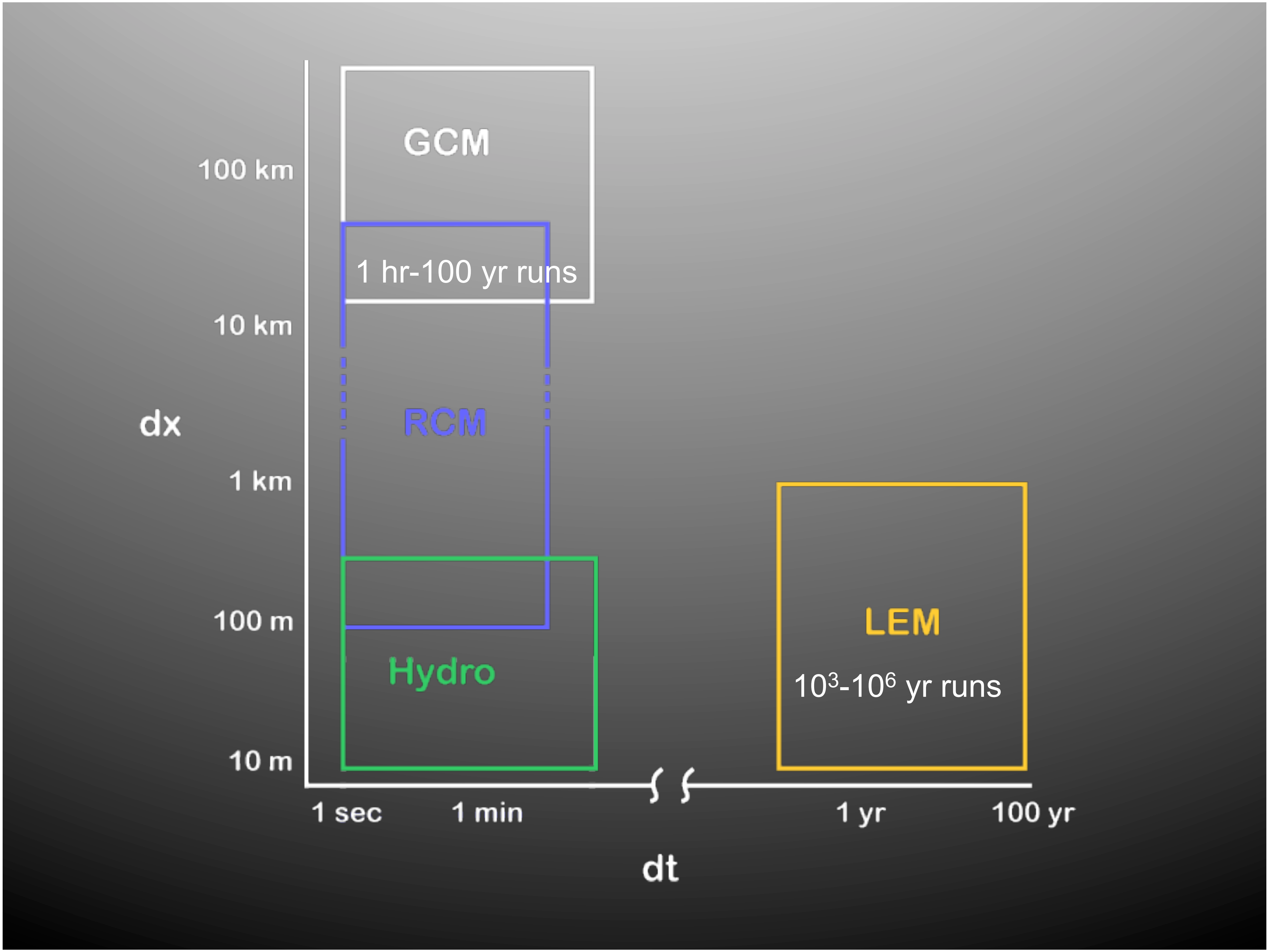
- Characterize glacial-interglacial changes to inversion height, storm frequency, temperature, hydrology …

  Need: data to drive RCM with LGM boundary conditions, e.g., GCM output

- Incorporate these changes into a LEM to model forward to narrow down viable hypotheses before spending time and money on field efforts

  Need: hydrologic simulation that captures daily to seasonal hydrograph, glacial-interglacial precipitation changes, and responds to channel network evolution over ~10^5 yr timescales


Total Cloud Fraction
Total Cloud Fraction (%)
Global-scale
climate model output,
past and present
at ~100-km resolution
Observed modern climate
(TRMM, station observations)
at ~10 km resolution
Waimea
Kailua-Kona
Mauna Kea
Hilo
Mauna Loa
20 N
Hourly Rainfall
Regional-scale
climate from weather
model output
at ~1 km resolution
Mapped topography,
hydrography and geology
Discharge (m³/s)
Year A.D.
Wailuku
Honolii
Stream discharge statistics from hydrological model,
calibrated using station observations
x 10⁻⁵
Modeled
erosion rate (m/yr)
Integration over 10³-10⁶ years
in landscape evolution model
at ~100-m resolution

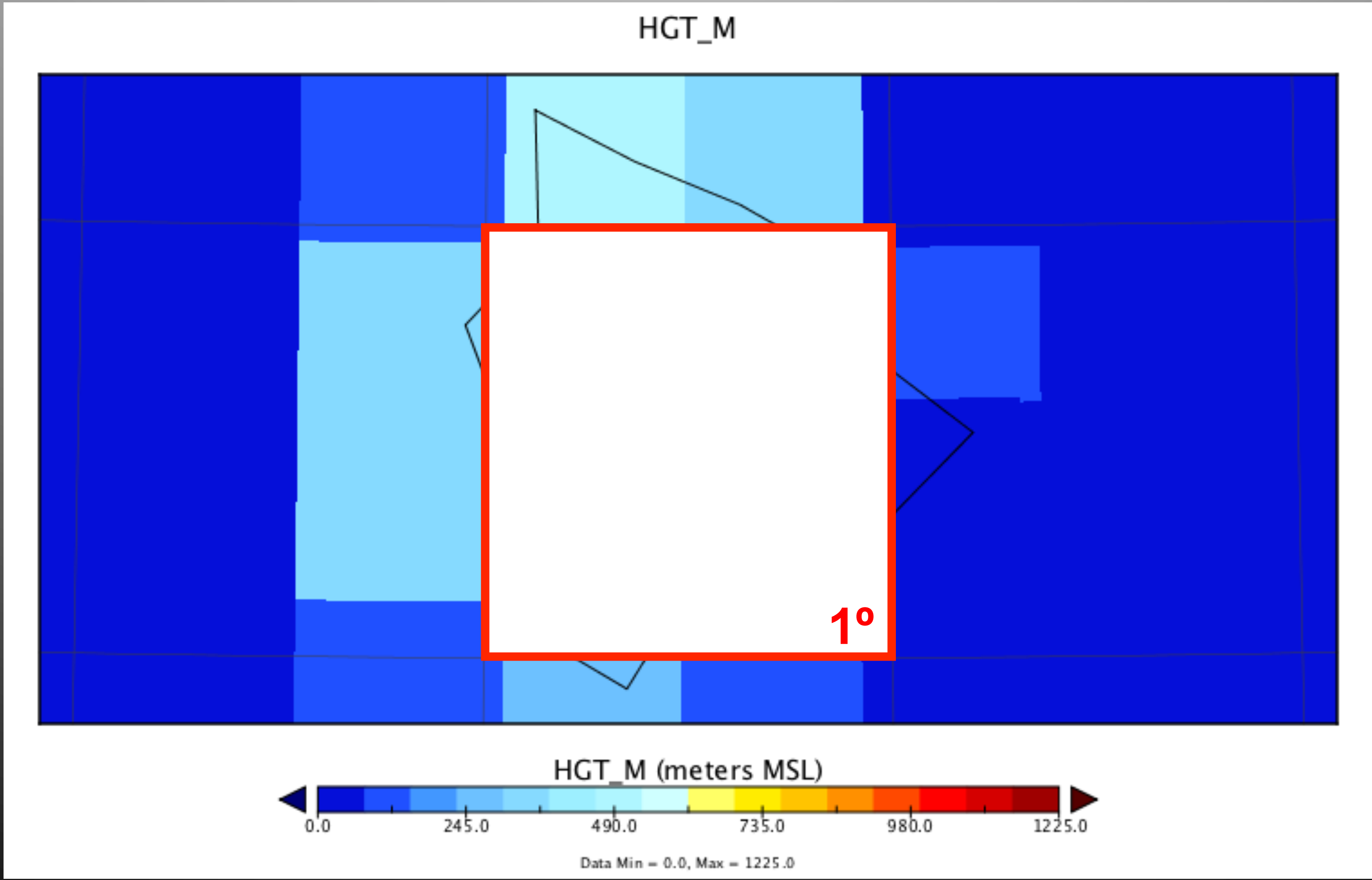


GCM
1 hr-100 yr runs
RCM
Hydro
LEM
10^3-10^6 yr runs
100 km
10 km
dx
1 km
100 m
10 m
1 sec
1 min
1 yr
100 yr
dt

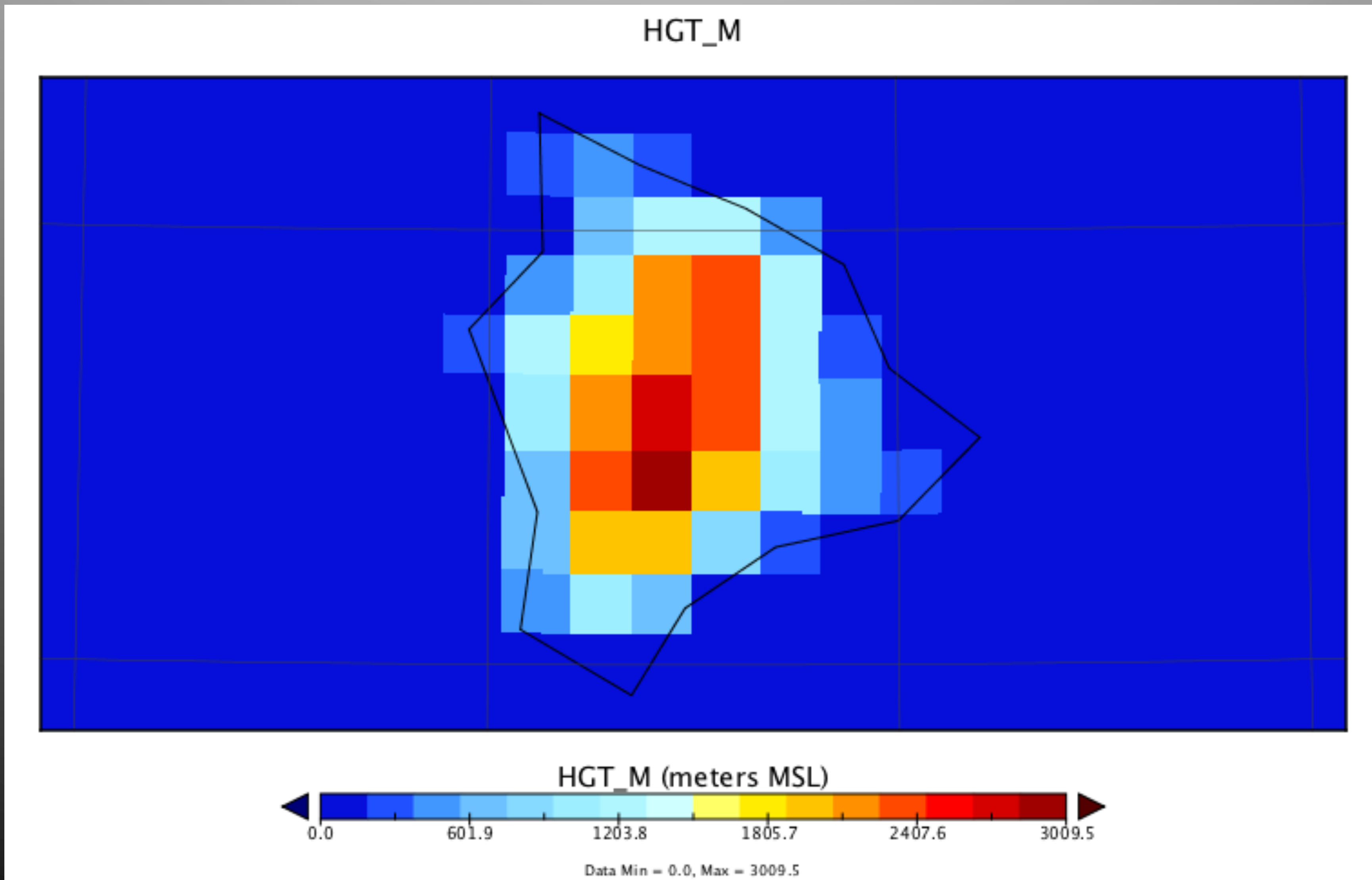
NCAR Weather Research and Forecasting (WRF) model

- Fully-compressible, non-hydrostatic atmospheric climate simulation
- Domain nesting for high spatial resolution driven by outer domain simulation
- Can ingest climate model output, reanalysis data, station observations
- CCSM output for LGM and 20th century recently available at the needed 6-hourly output

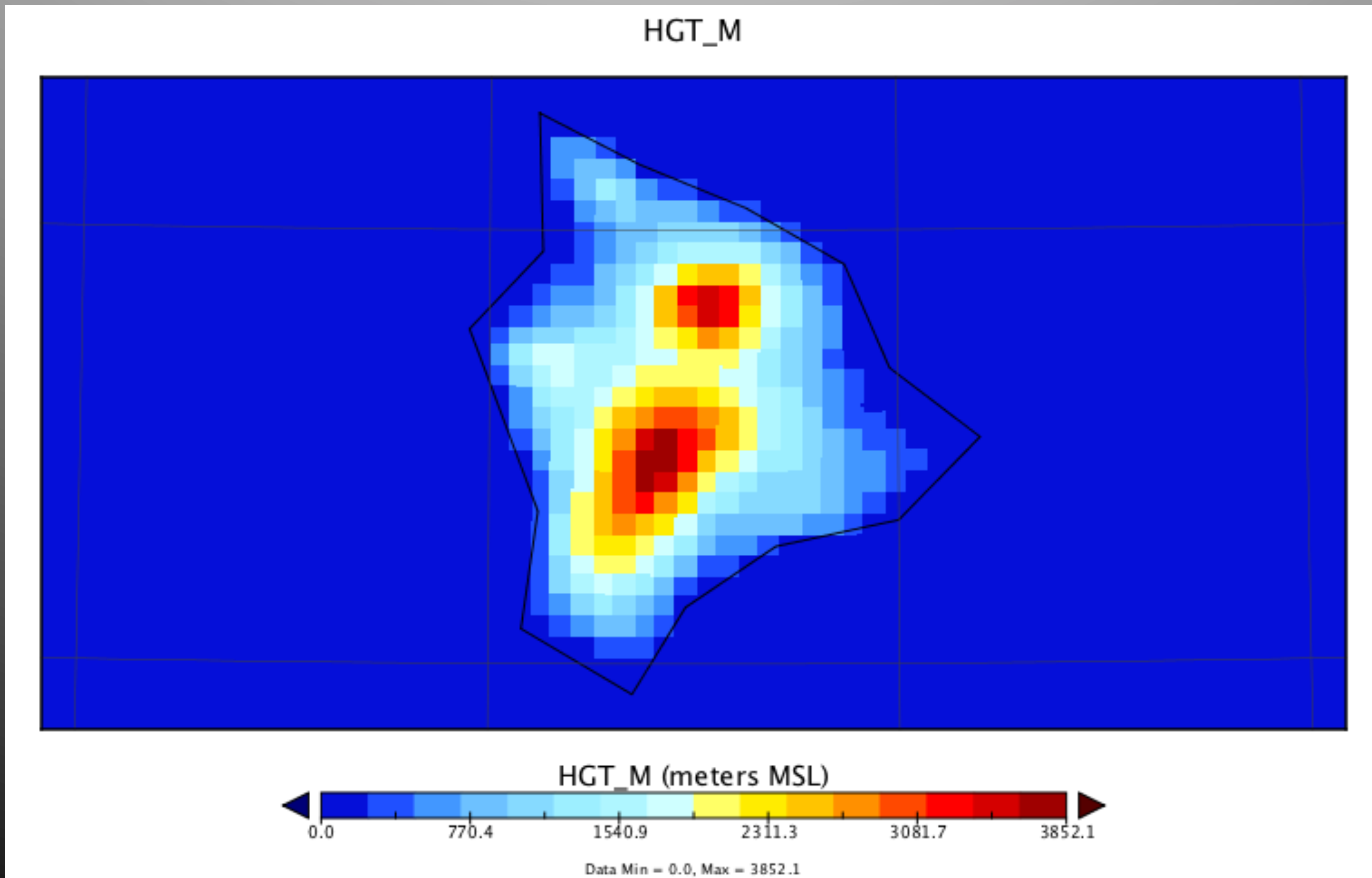
Topography: dx = 48 km



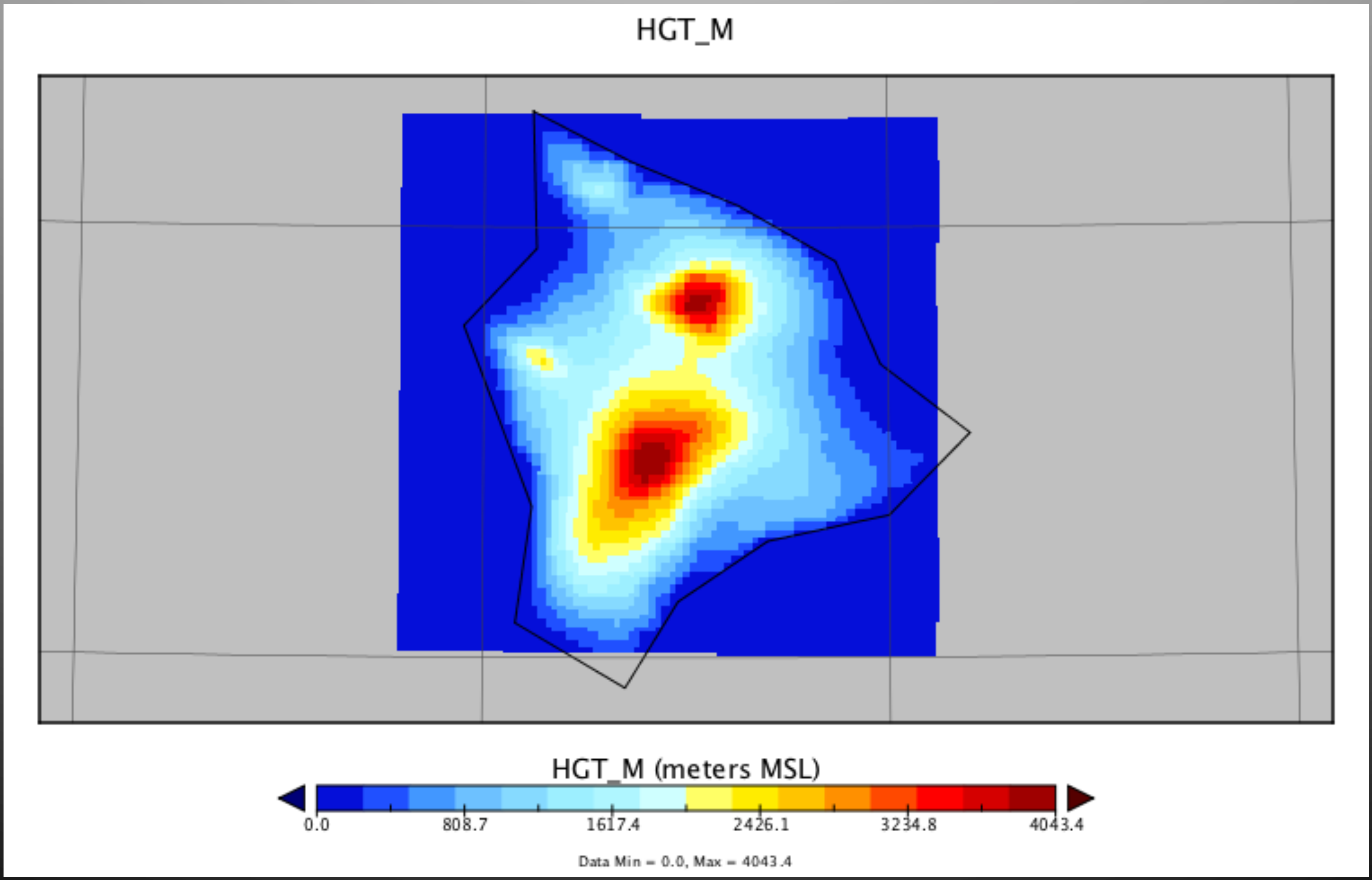
Topography: dx = 16 km



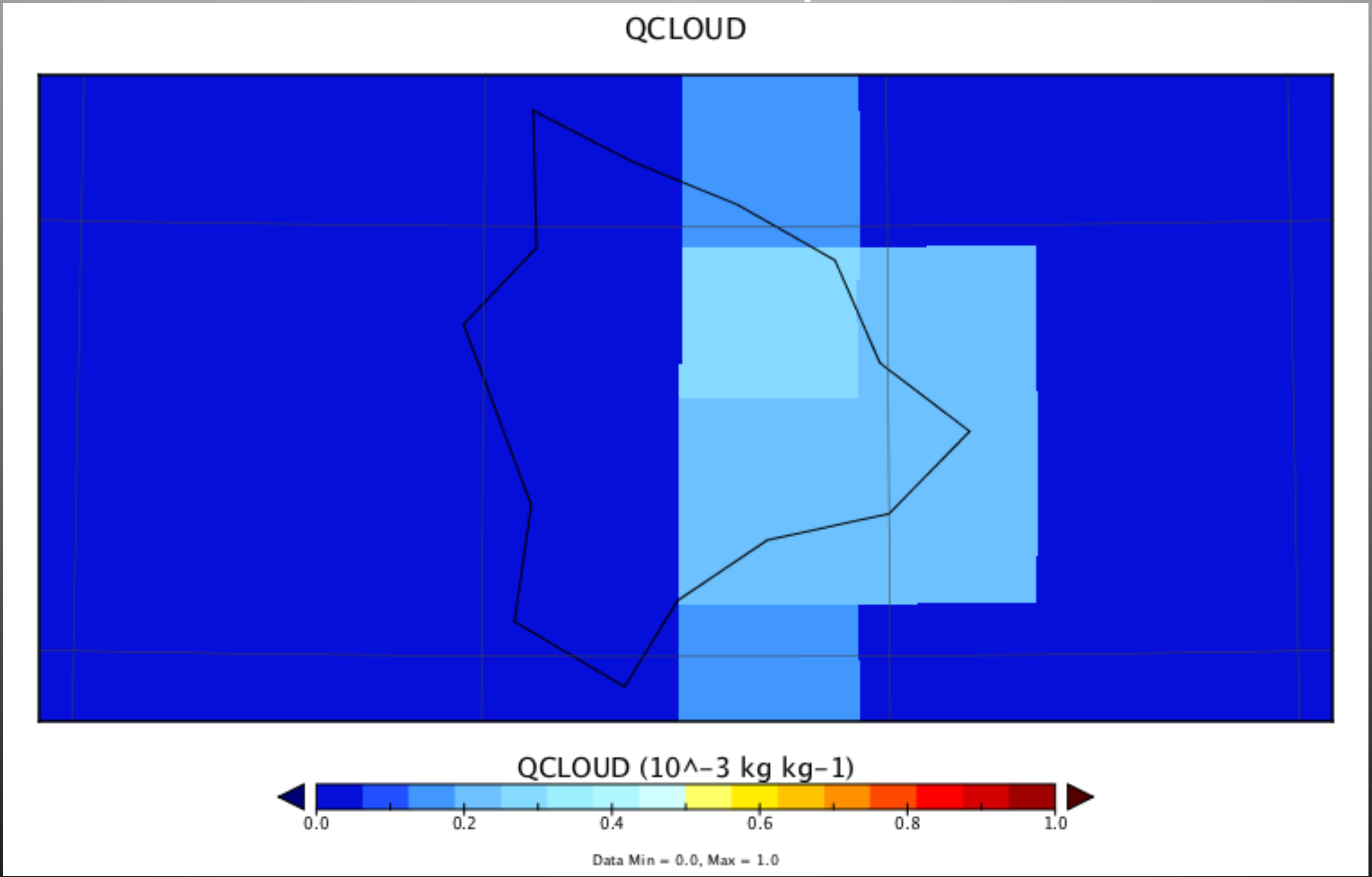
Topography: dx = 5.33 km



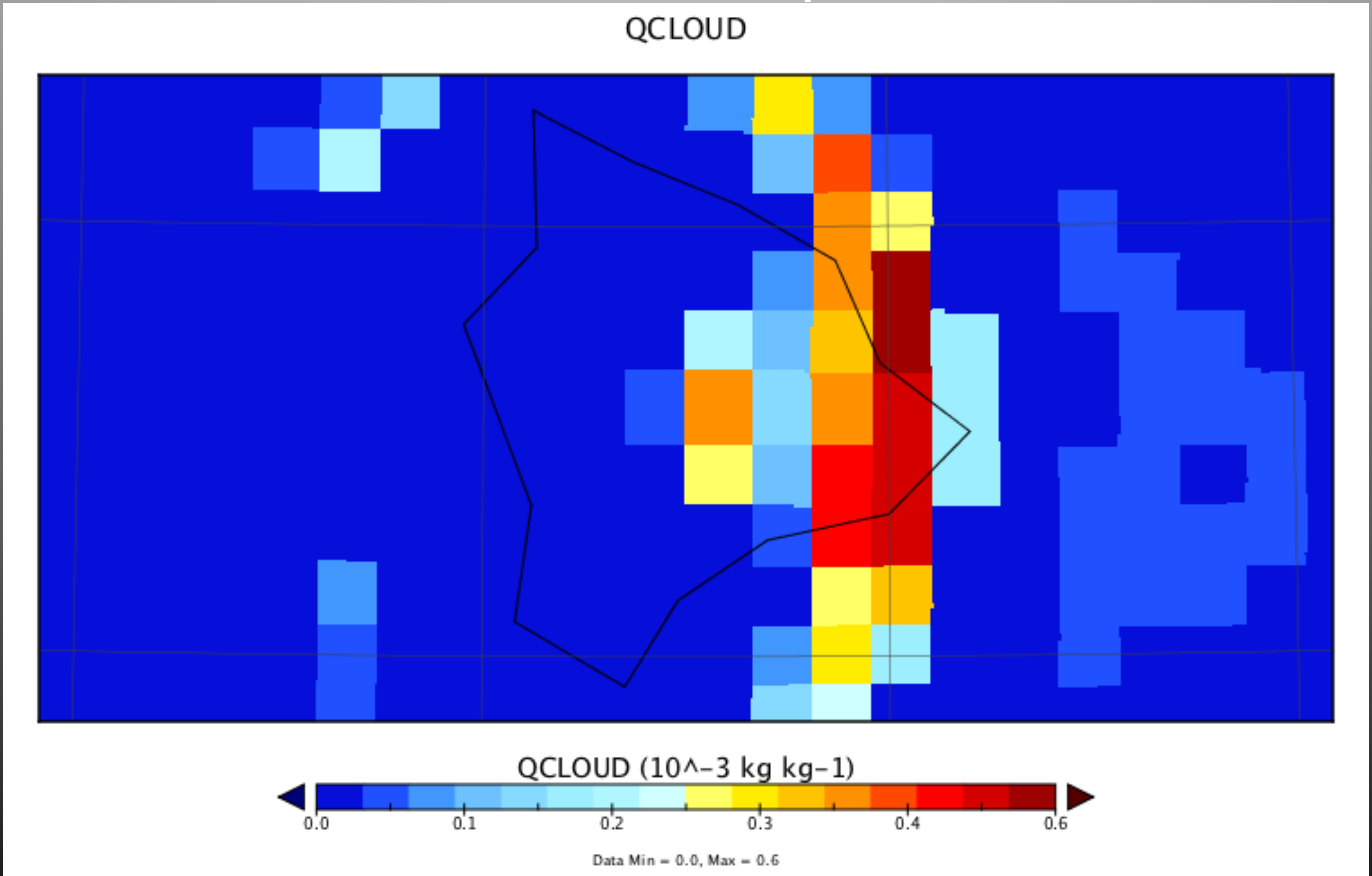
Topography: dx = 1.77 km



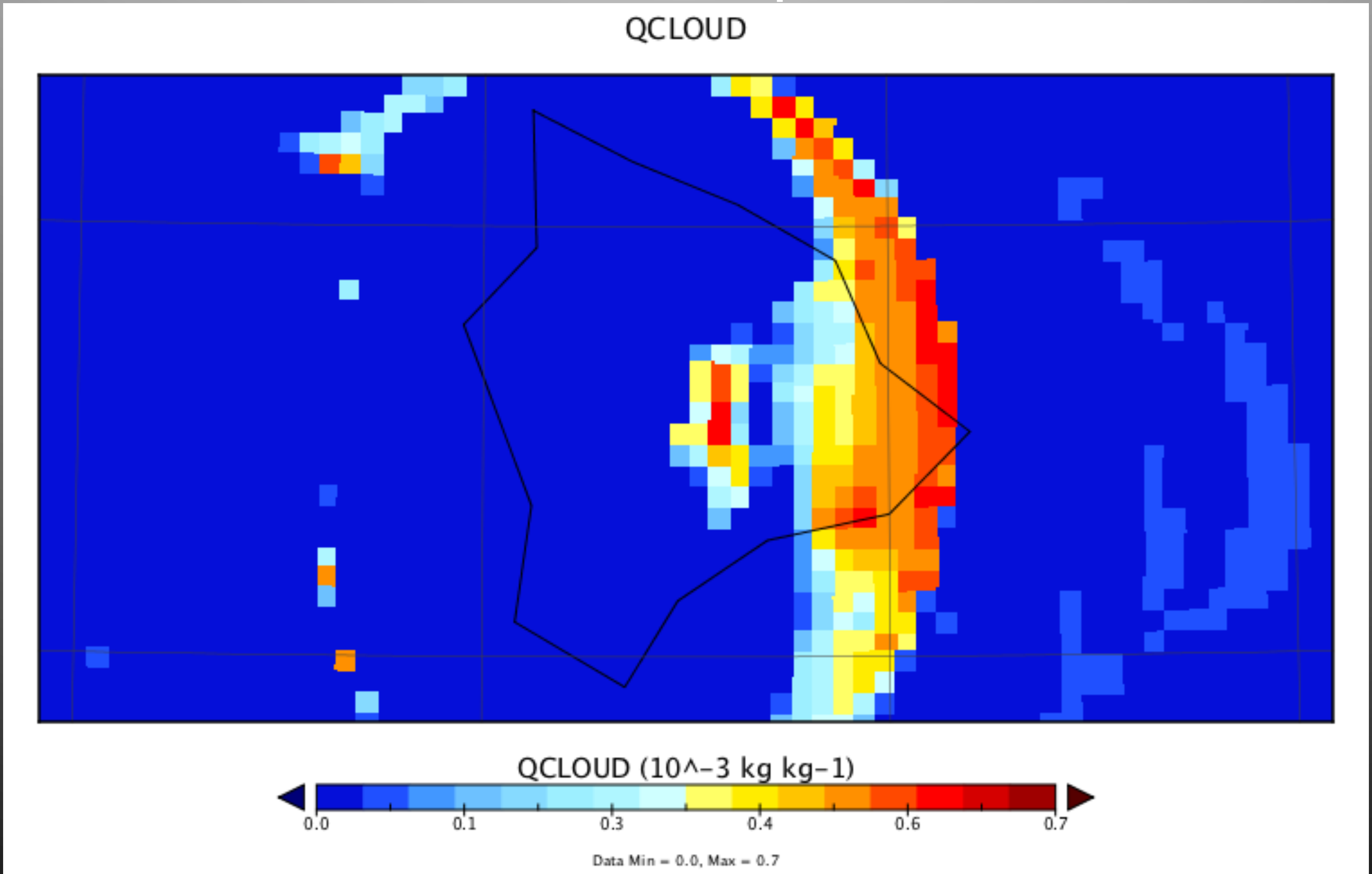
Downscaled CCSM output: dx = 48 km



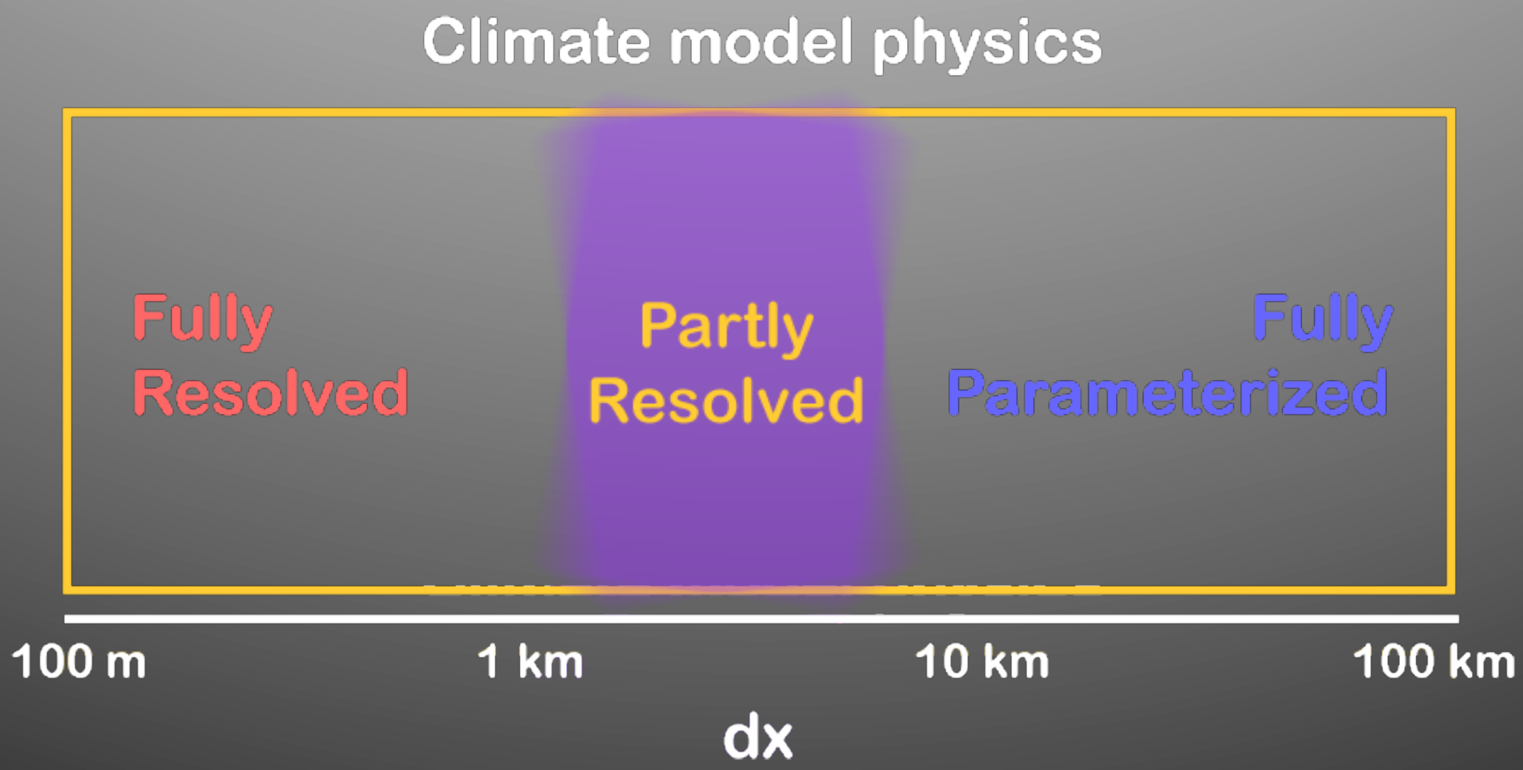
Downscaled CCSM output: dx = 16 km

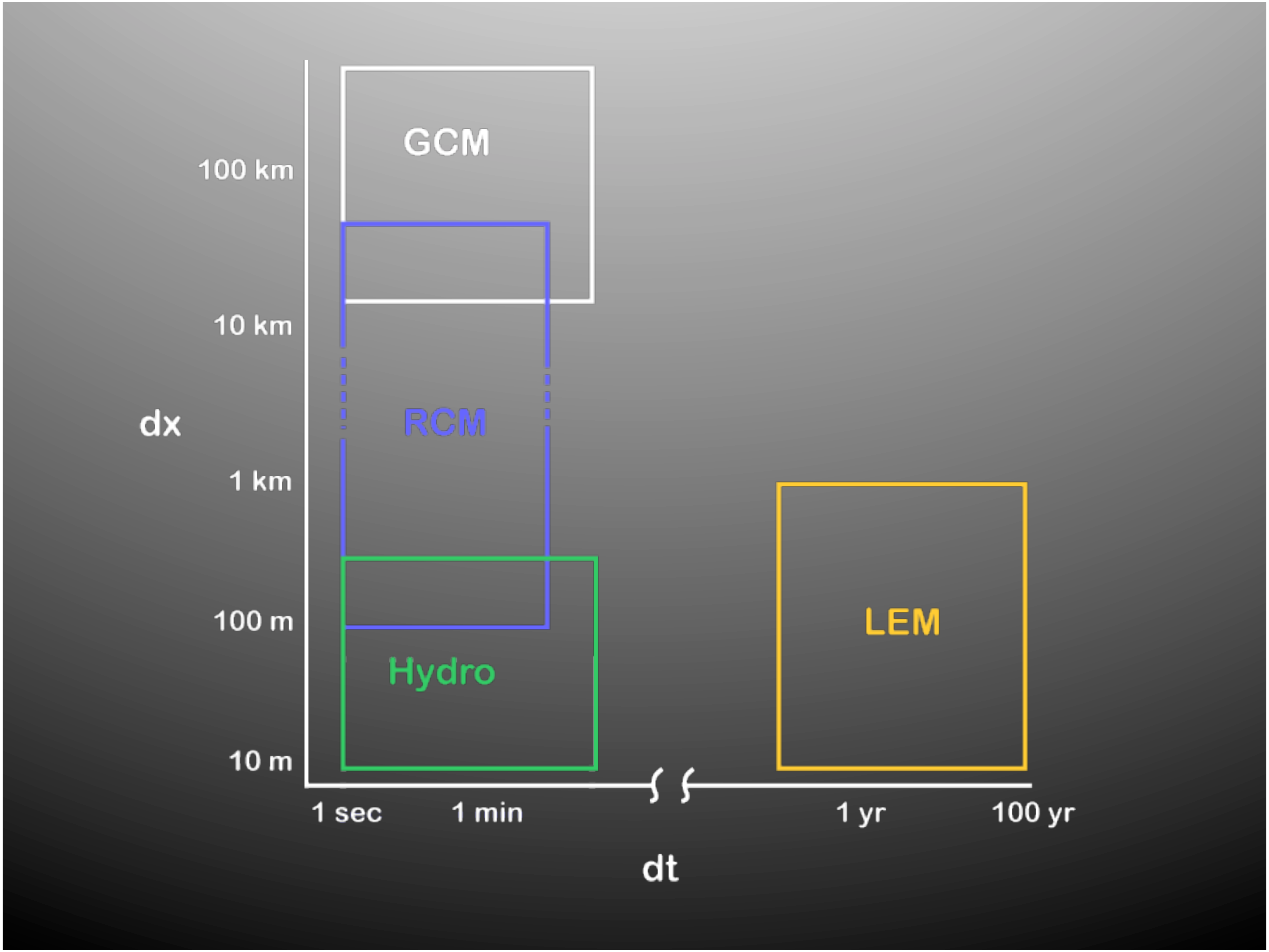


Downscaled CCSM output: dx = 5.33 km



Climate model scale gap




GCM
RCM
Hydro
LEM
100 km
10 km
1 km
100 m
10 m
dx
1 sec
1 min
1 yr
100 yr
dt

The hydrology gap

Statistics of flow are important because big events do the most work. Assuming a steady flow proportional to drainage area gives different results than a stochastically forced runoff.

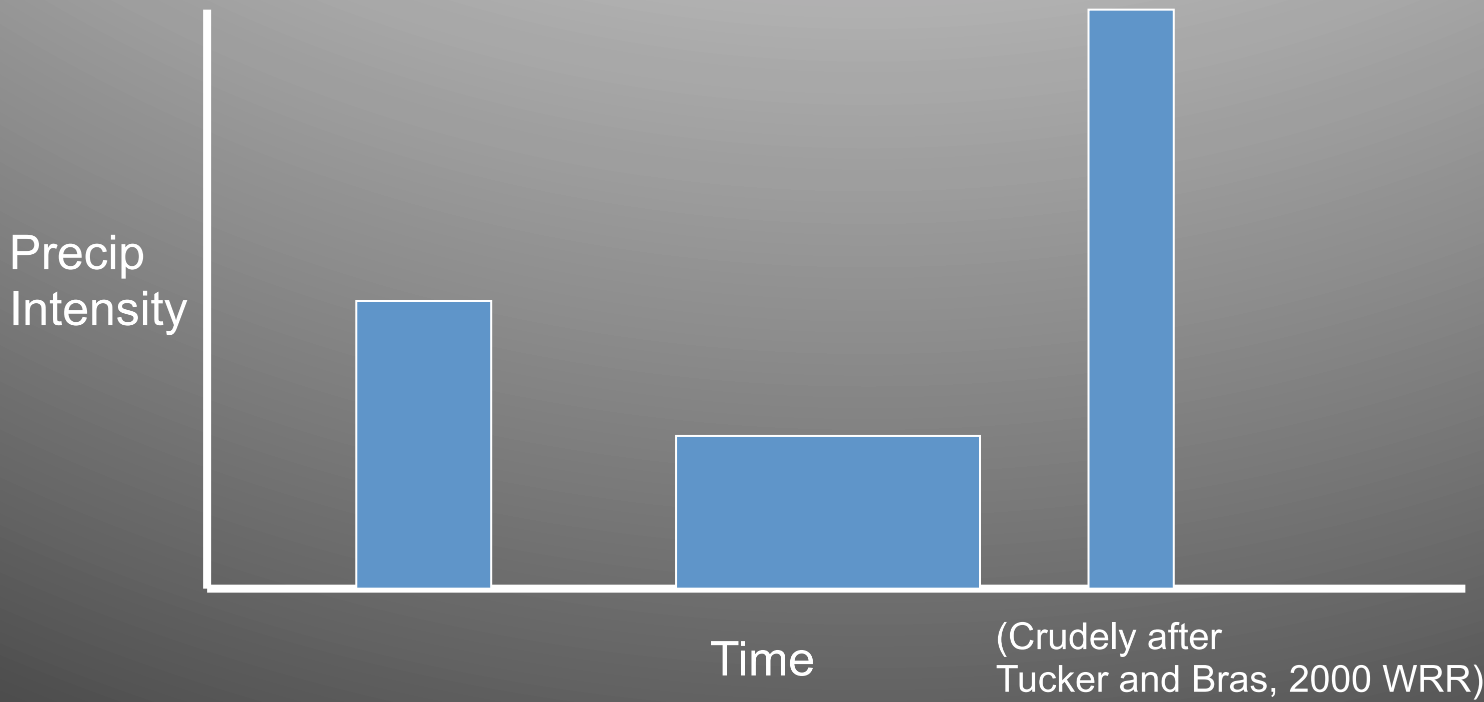
LEMs have basic hydrology, but given the same input precipitation distributions may not properly reproduce the hydrograph - all the water runs off instantly.

Hydrologic models can do well at the hydrograph, but run at too low a timestep to be reasonably integrated in an LEM - more compatible with coupling to RCM.

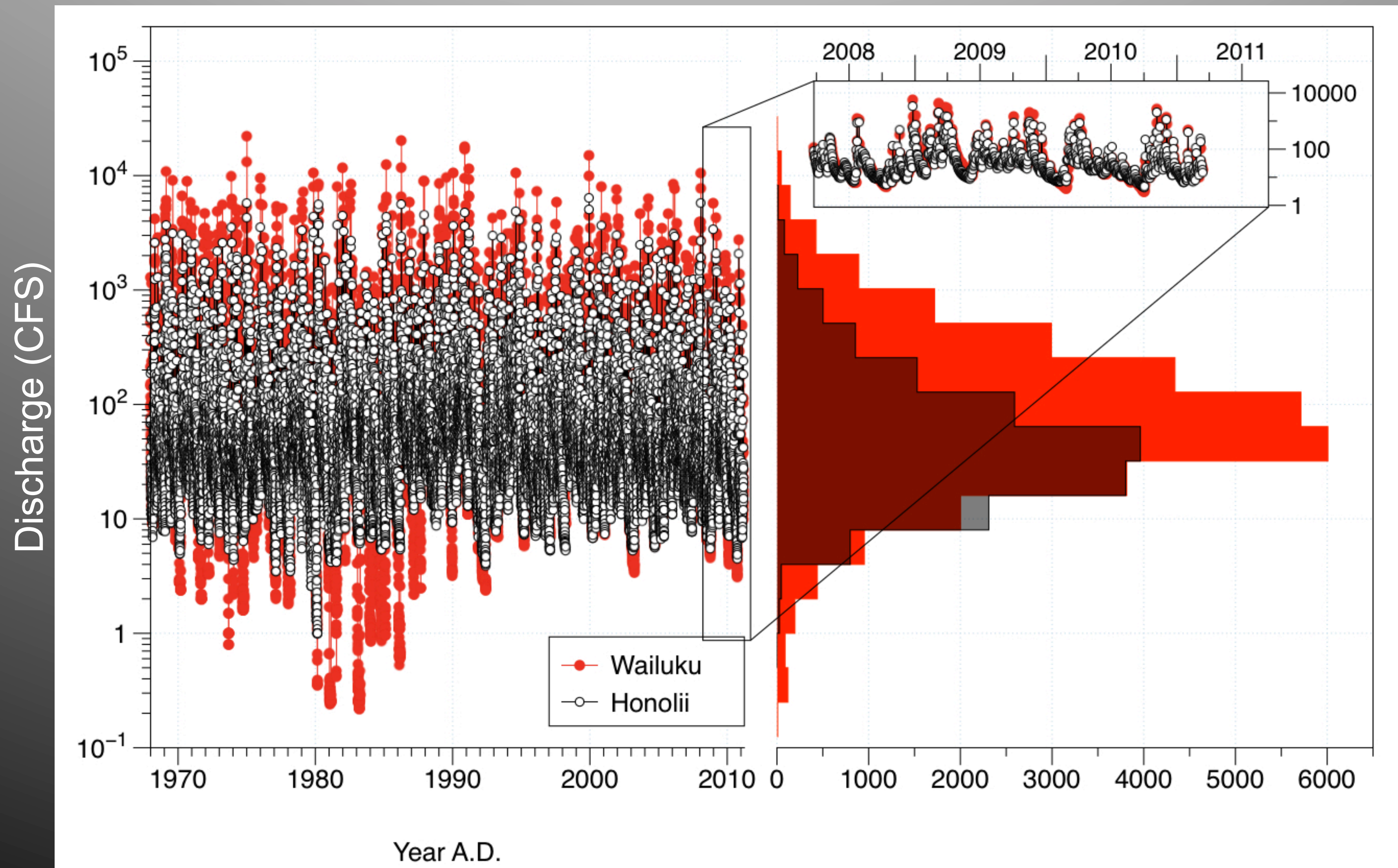
But drainage areas change as channels move over long timescales in LEM, so a static discharge map won't do any good.

We're going to need a statistical approach - statistics know nothing about time.

Stochastic rainfall approach

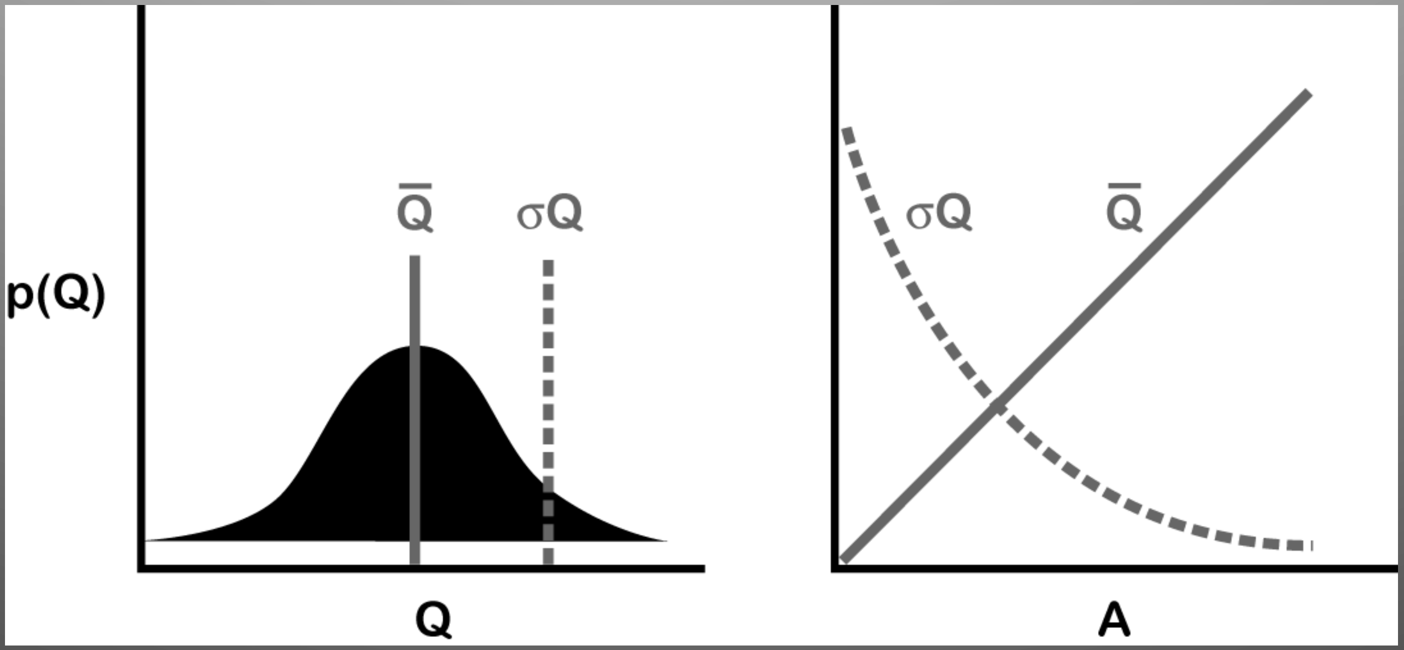


The hydrographs this approach generates may or may not be realistic for a given setting, especially when spatial variability is important.

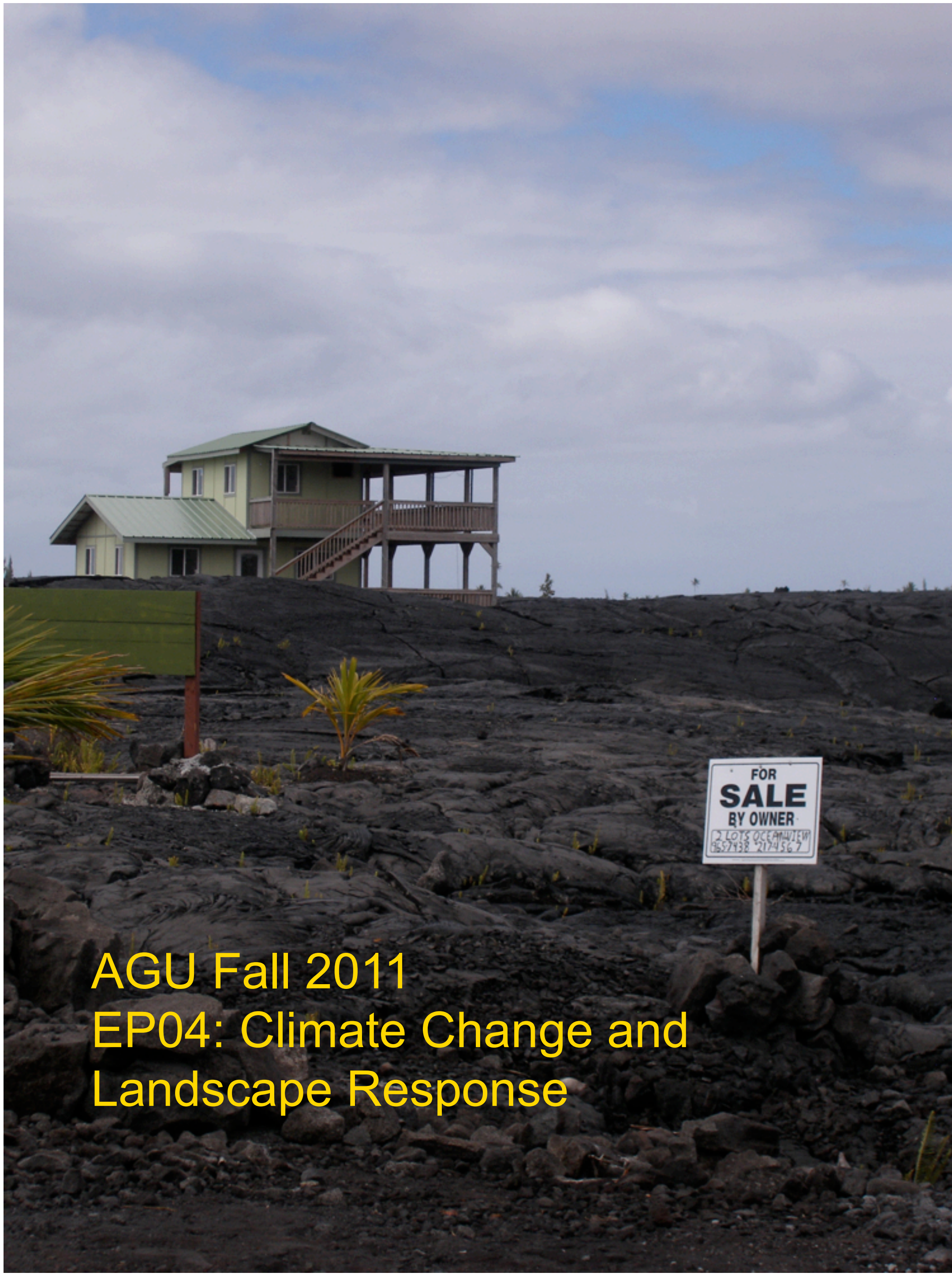


Discharge (CFS)
10^5
10^4
10^3
10^2
10
1
10^−1
1970
1980
1990
2000
2010
Year A.D.
Wailuku
Honolii
0
1000
2000
3000
4000
5000
6000
2008
2009
2010
2011
10000
100
1

Statistical discharge mapping



Cleverly map hydro model discharge (Q) statistics into channel network based on nominal drainage area (A), or use with transport/erosion laws that explicitly incorporate discharge statistics.



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Conclusions

New CCSM output for LGM and 20th century allows rigorous dynamical downscaling with WRF: geomorphic investigations can acknowledge explicit differences between glacial and interglacial climates

- BUT -

Important scale gaps exist between climate models, landscape models and hydrological models

Until computing power allows 10^4-10^6 yr coupled runs at climate-model timesteps, bridging these gaps will involve some form of statistical mapping