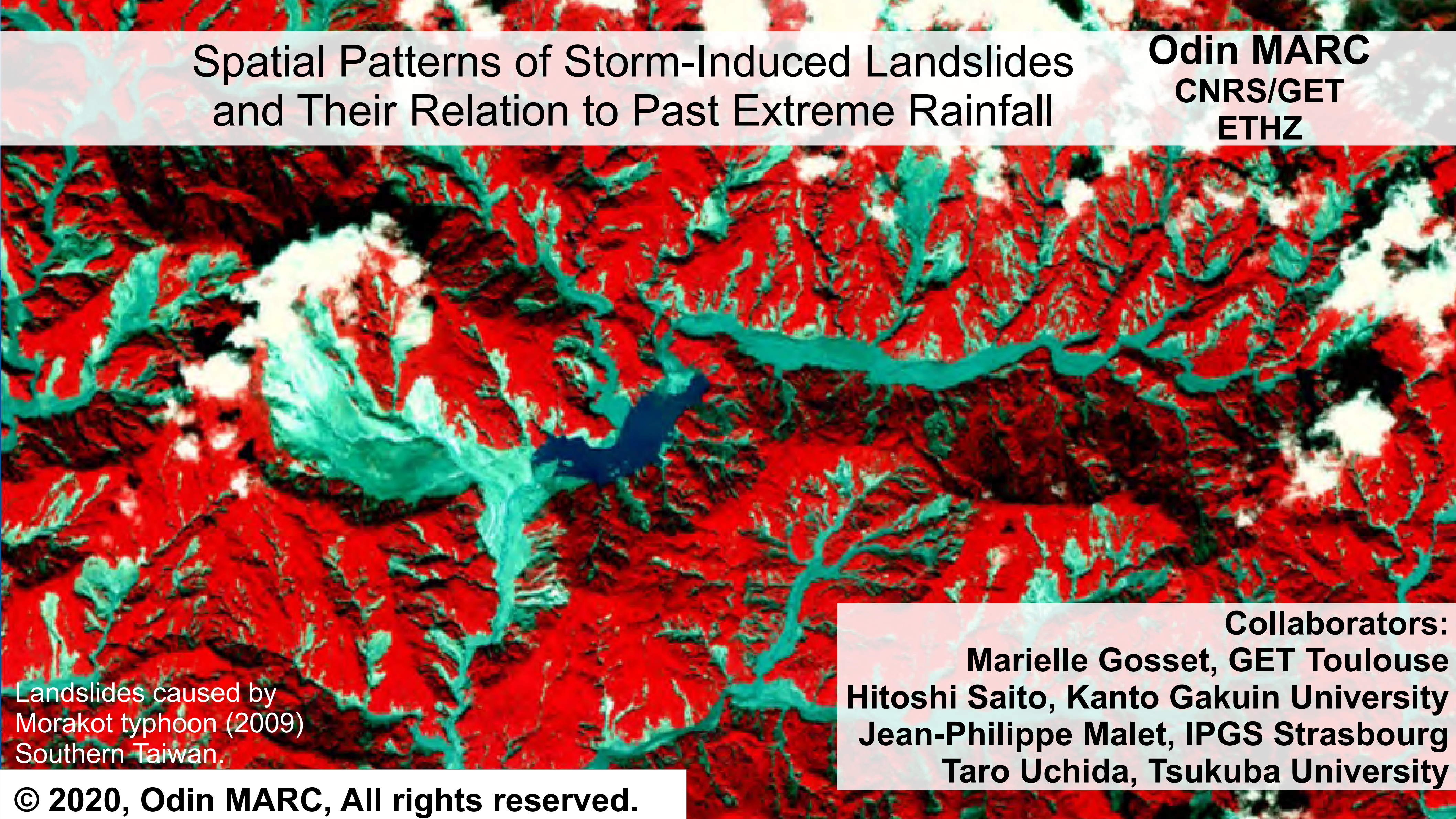
Spatial Patterns of Storm-Induced Landslides and Their Relation to Past Extreme Rainfall

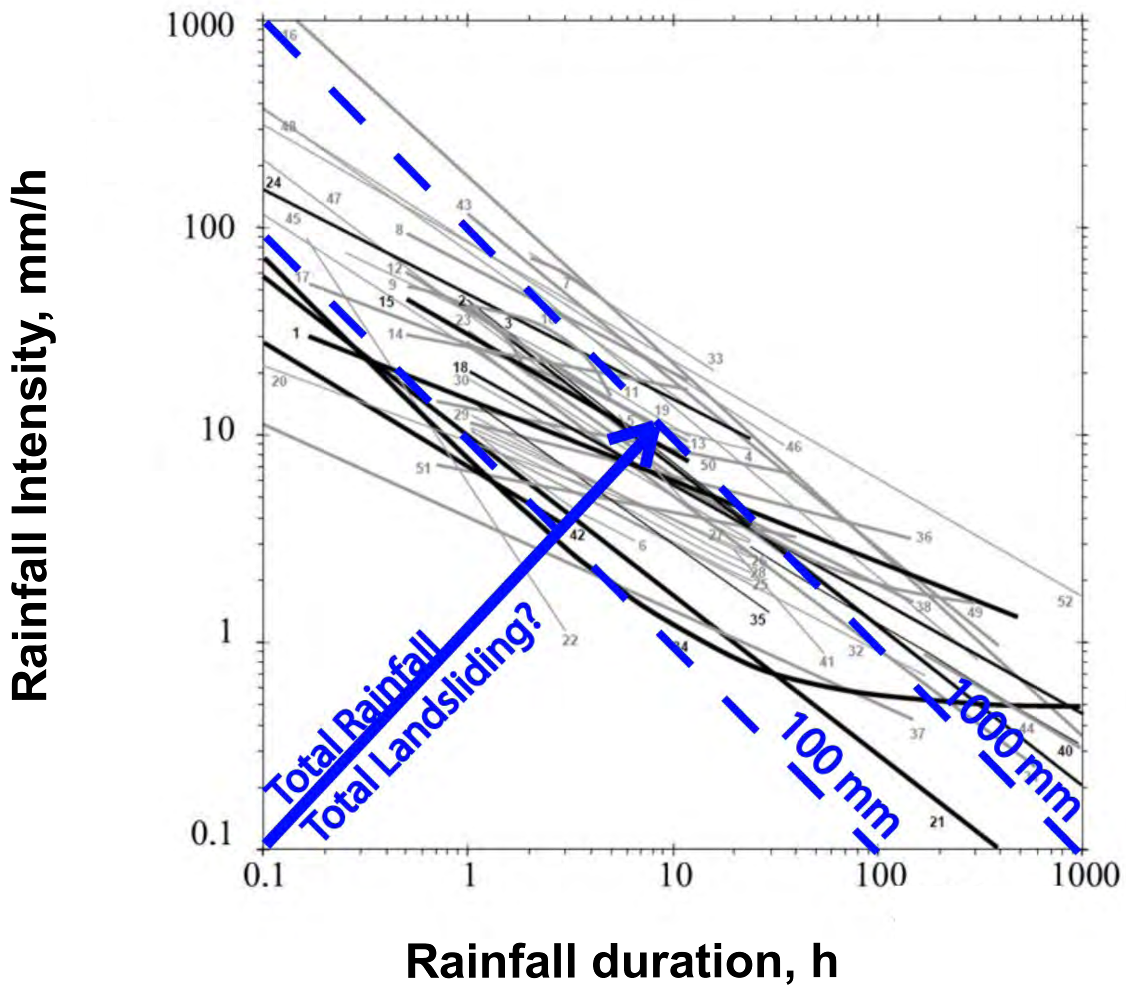
Odin MARC
CNRS/GET
ETHZ



Landslides caused by Morakot typhoon (2009) Southern Taiwan.

Collaborators:
Marielle Gosset, GET Toulouse
Hitoshi Saito, Kanto Gakuin University
Jean-Philippe Malet, IPGS Strasbourg
Taro Uchida, Tsukuba University

Empirical approach: Rainfall threshold



Conventional approach :
→ relate the occurence of a landslide event to local meteorology.

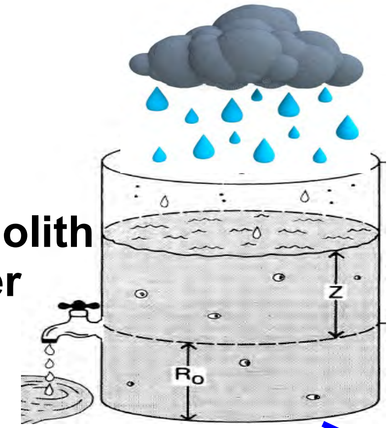
Almost no information on landslide event magnitude (number, sizes...)

→ How does rainfall drive landsliding beyond the threshold ?

Modified from:
Boogard and Greco 2018, NHESS

Many published meteorological thresholds for landslide triggering by rainfall.

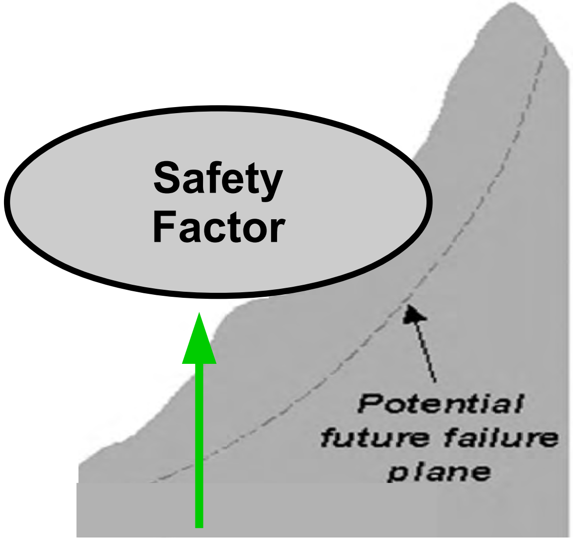
Controls on landsliding



Regolith layer

Pore-Pressure

Total rainfall, intensity, Antecedent moisture,...

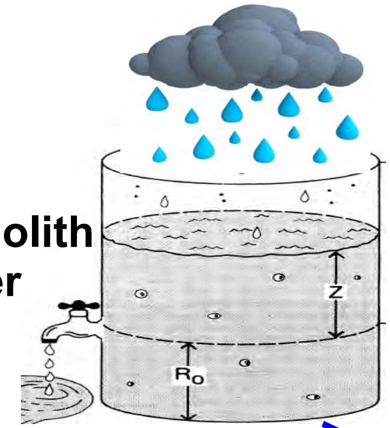


Internal Parameters

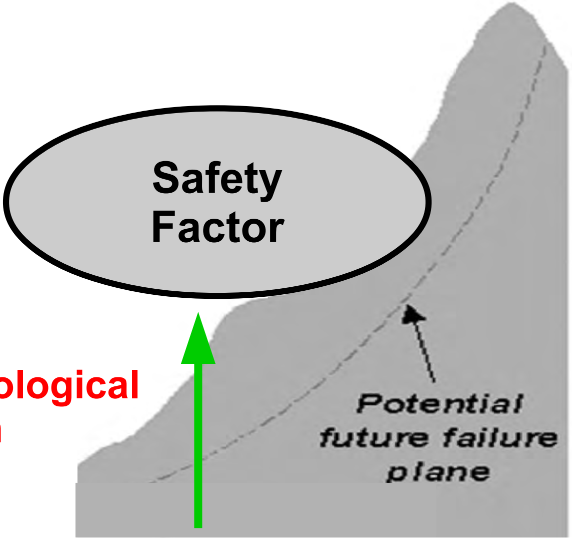
Permeability, Cohesion, Ffriction, slope gradient, ...

Controls on landsliding

Regolith
layer



Pore-Pressure
Total rainfall, intensity,
Antecedent moisture,...



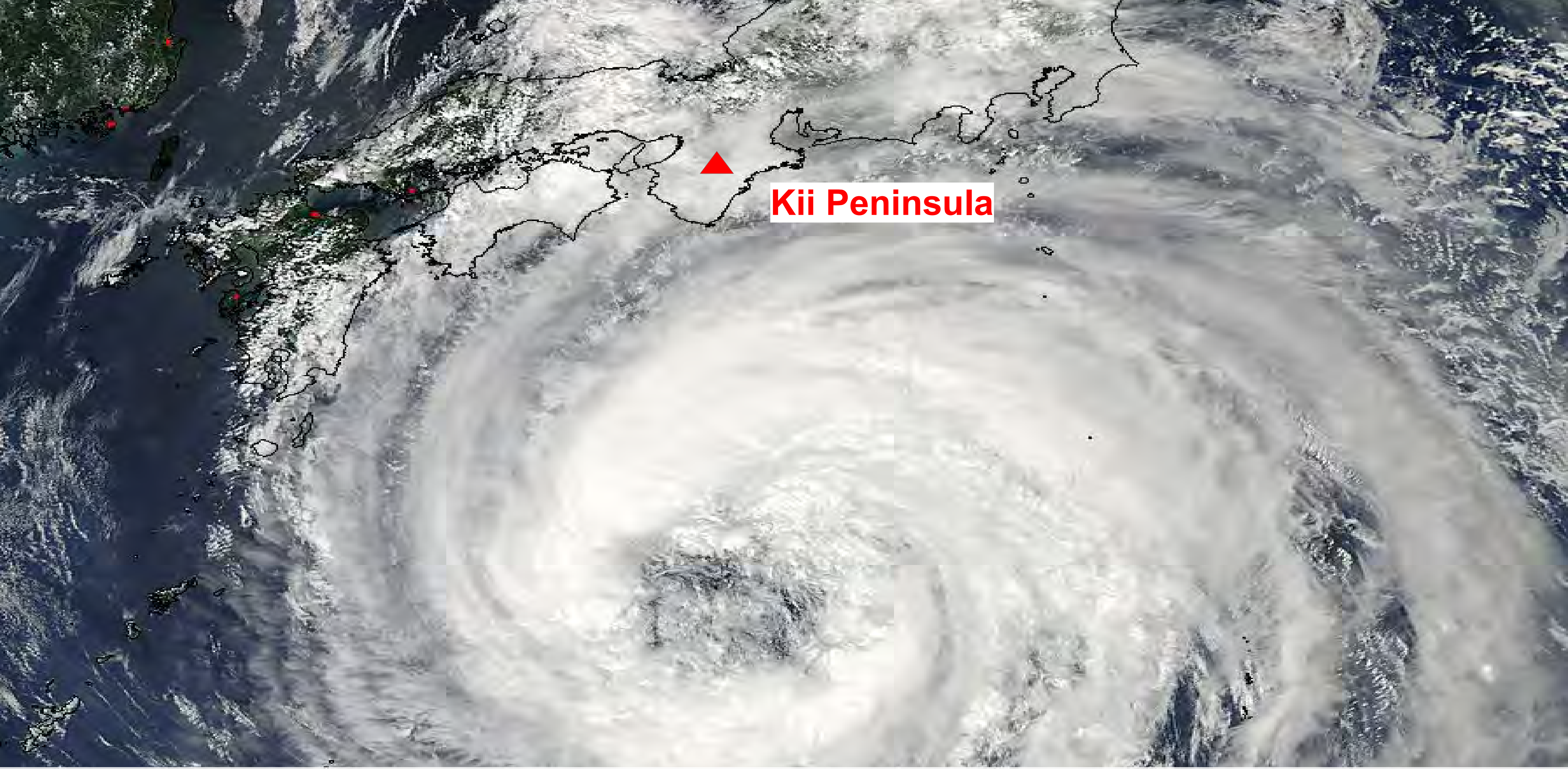
→ **What is the effect of past rainfall extreme on landslide susceptibility ?**

Local hydrological modulation

Landscape evolution by failure of instable slopes?

Internal Parameters

Permeability, Cohesion, Ffriction, slope gradient, ...

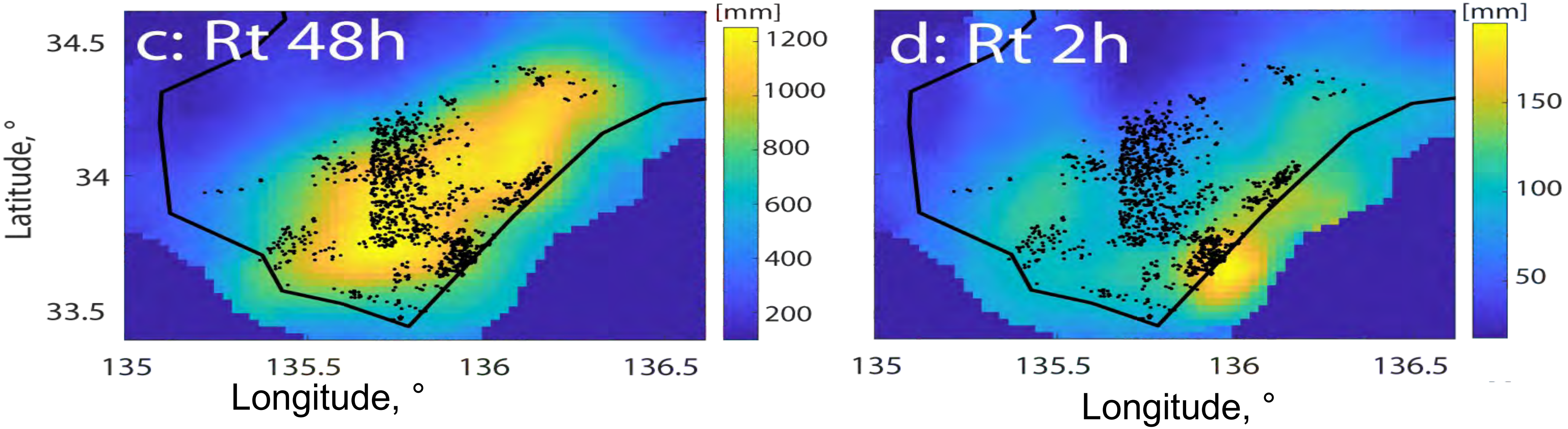


Typhoon Talas in Japan (2011)

Landslide pattern poorly relating to rainfall ?

What could cause disagreement between rainfall and landsliding ?

→ Regional variations in slope gradient ? → DEM
→ Regional variations in regolith strength or hydrological properties ?
→ Almost impossible to measure !!
Potential proxy: Lithological map ? Extreme climatology ?



Rainfall maps (from JMA radars network) during the event with individual landslides in black.
Only landslide attributable to the typhoon, based on pre and post imagery.

Marc et al., GRL, 2019

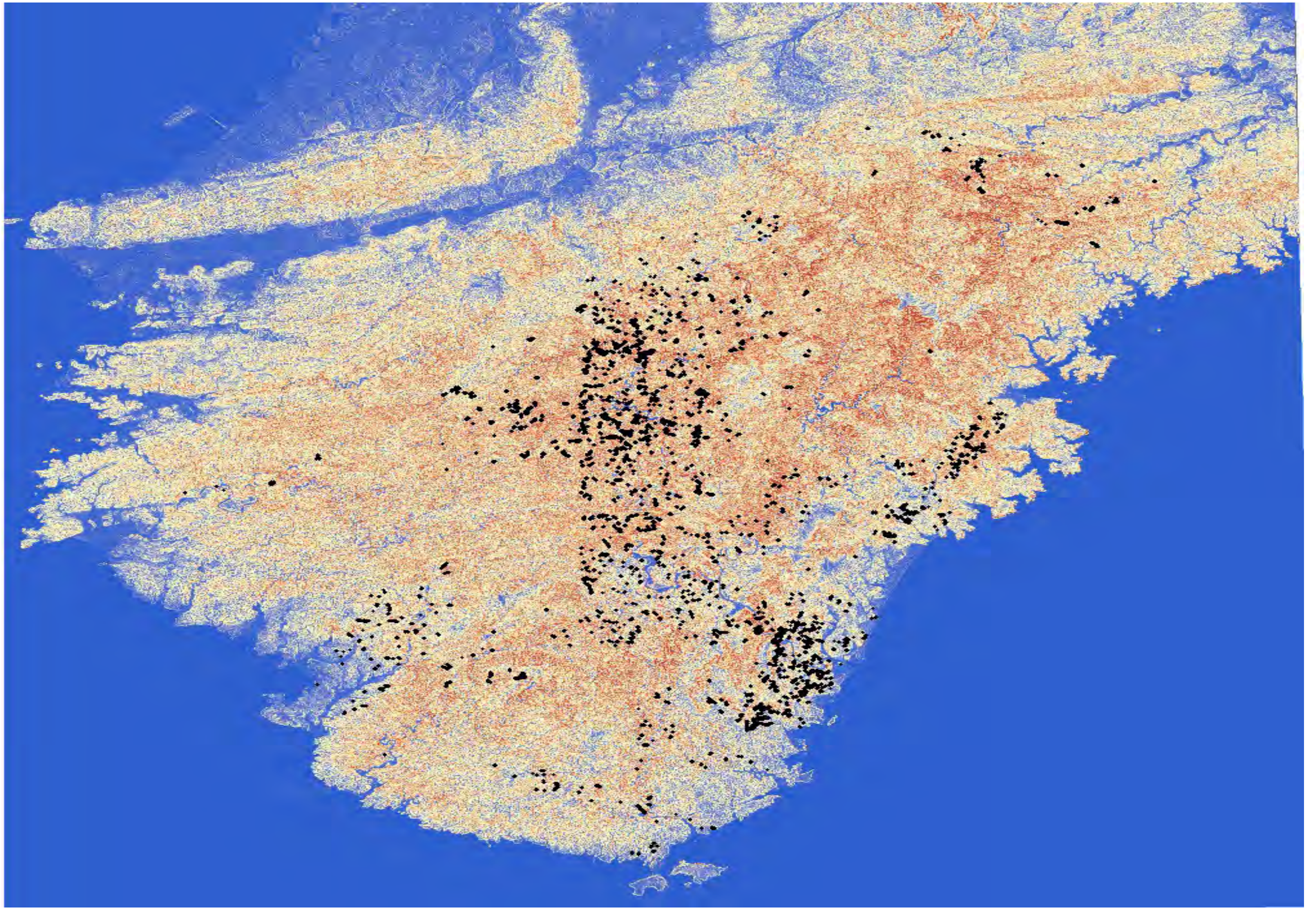
Landslide pattern vs Topography ?

No major difference in slope angles throughout the peninsula.

Slope map from 30m SRTM DEM. Individual landslides caused by Talas typhoon in black.

70°

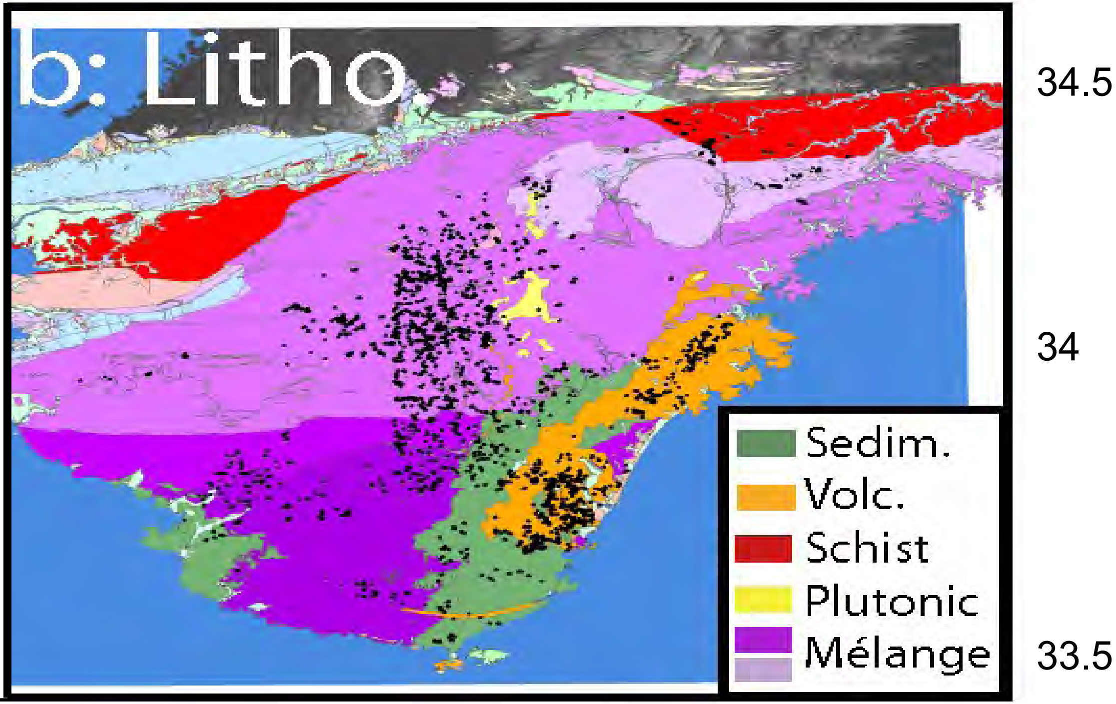
0°



Landslide pattern: Lithology ?

Sharp boundaries of the landslide pattern inland are not lithological.

Simplified lithological map from Geographical Survey of Japan (GSI). Individual landslides caused by Talas typhoon in black.



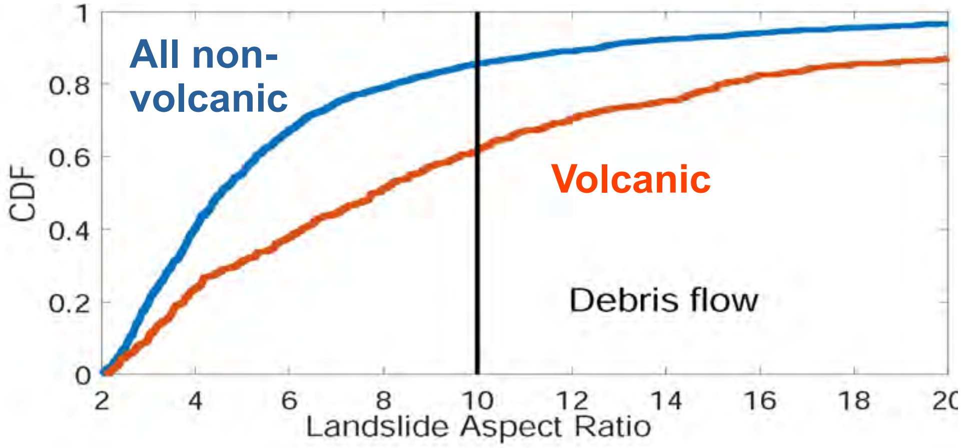
Marc et al., GRL, 2019

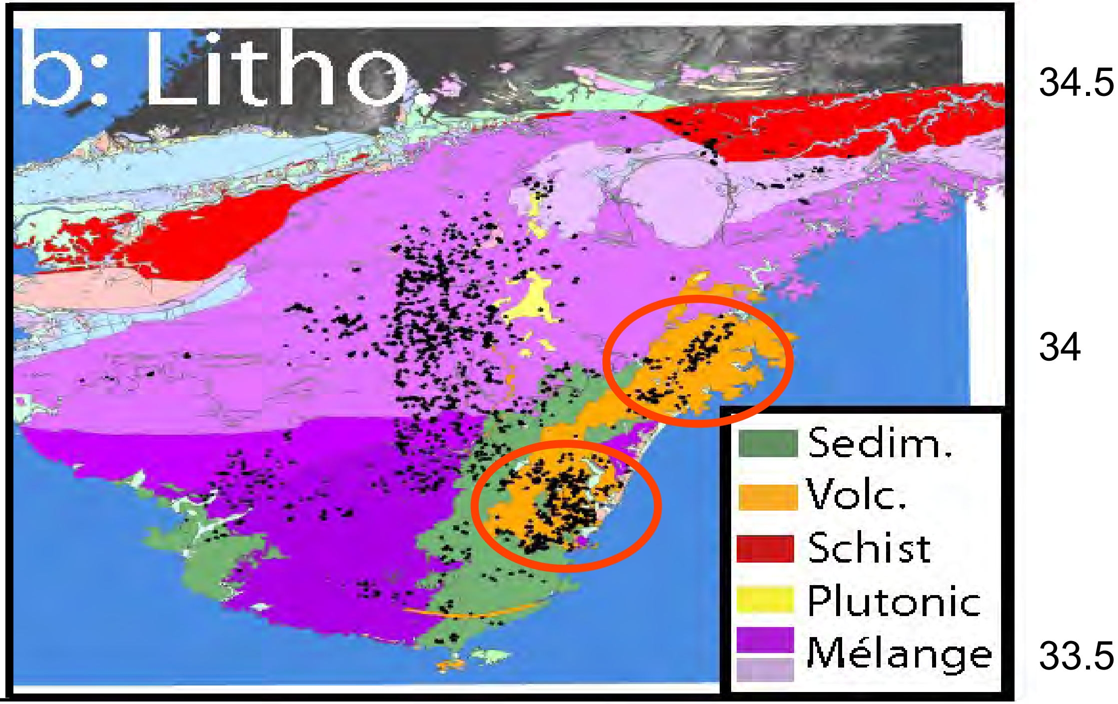
Landslide pattern: Lithology ?

Sharp boundaries of the landslide pattern inland are not lithological.

However, coastal landslide clusters may relate to the volcanic rock formation.

Simplified lithological map from Geographical Survey of Japan (GSI). Individual landslides caused by Talas typhoon in black.

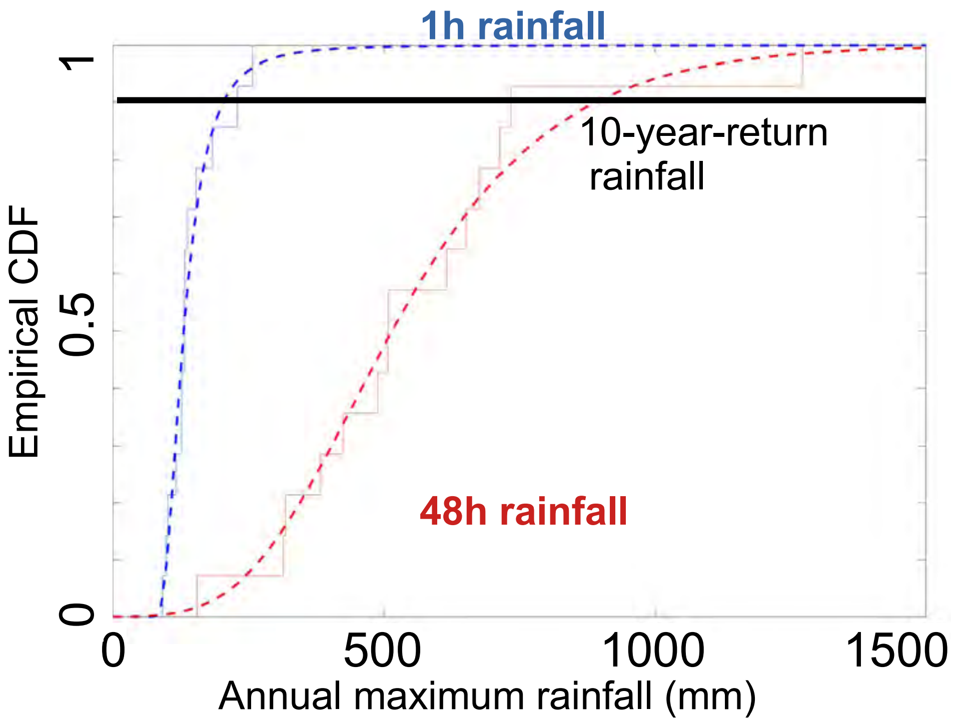




Landslides in the volcanic terrain are geometrically different from the one of other lithologucal units (often more elongated).

Marc et al., GRL, 2019

Extreme rainfall based on long-term statistics of rainfall



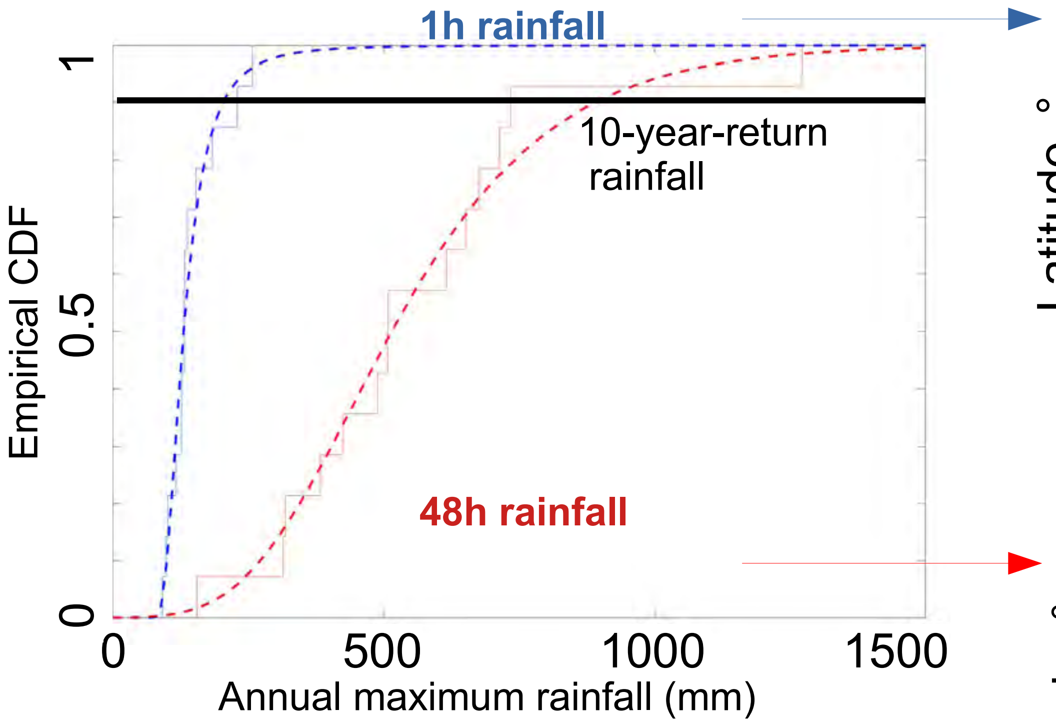
With 26 years of Radar data we compute across the area, the statistics of rainfall over various timescales.

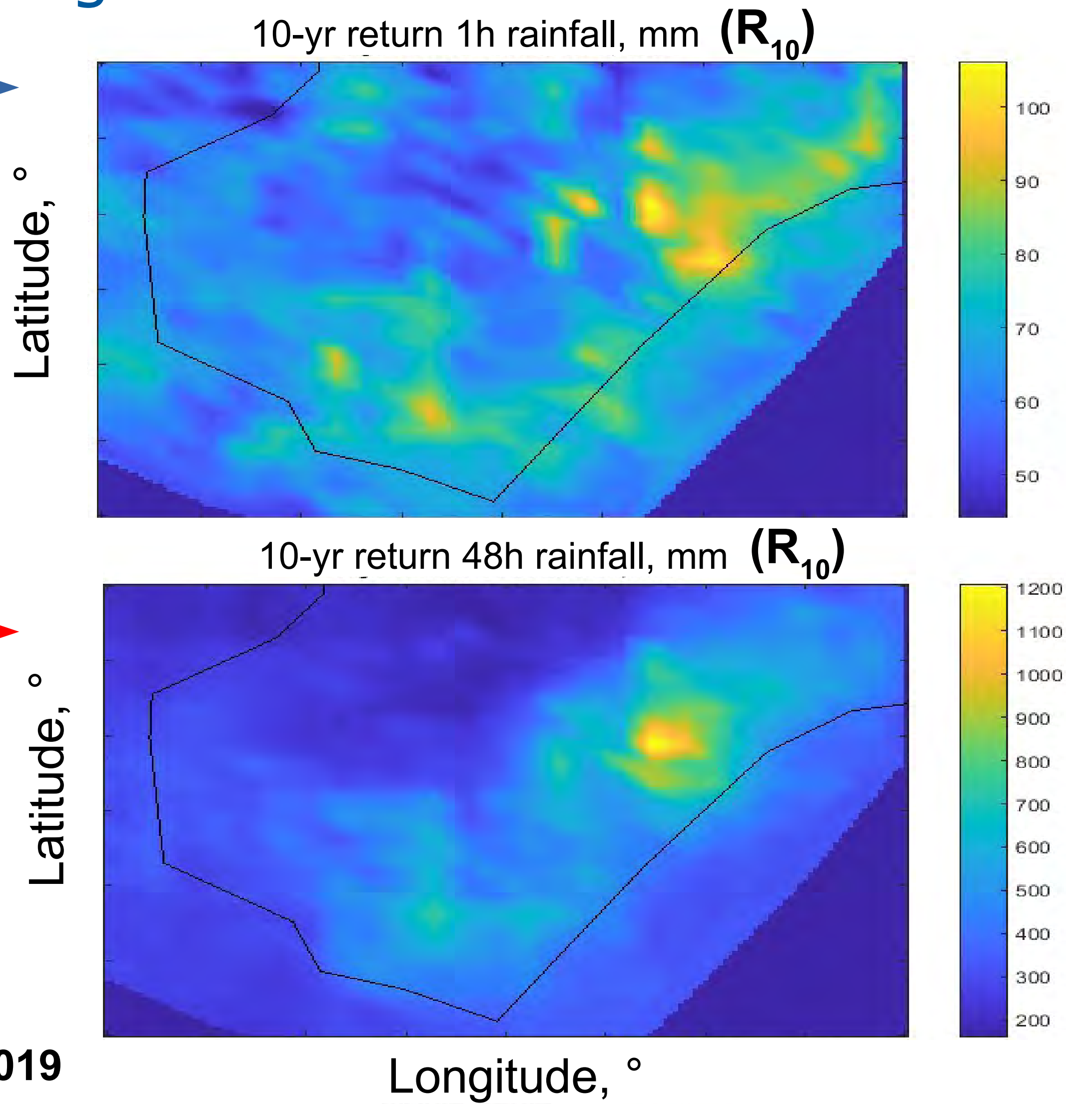
Selecting the annual maxima of a given timescales we fit a Generalized Extreme Value Distribution and estimate the 10-yr return rainfall (R_{10})

NB: Our conclusions stay the same for 20-yr return rainfall. Longer-return become increasingly uncertain.

Marc et al., GRL, 2019

Extreme rainfall based on long-term statistics of rainfall

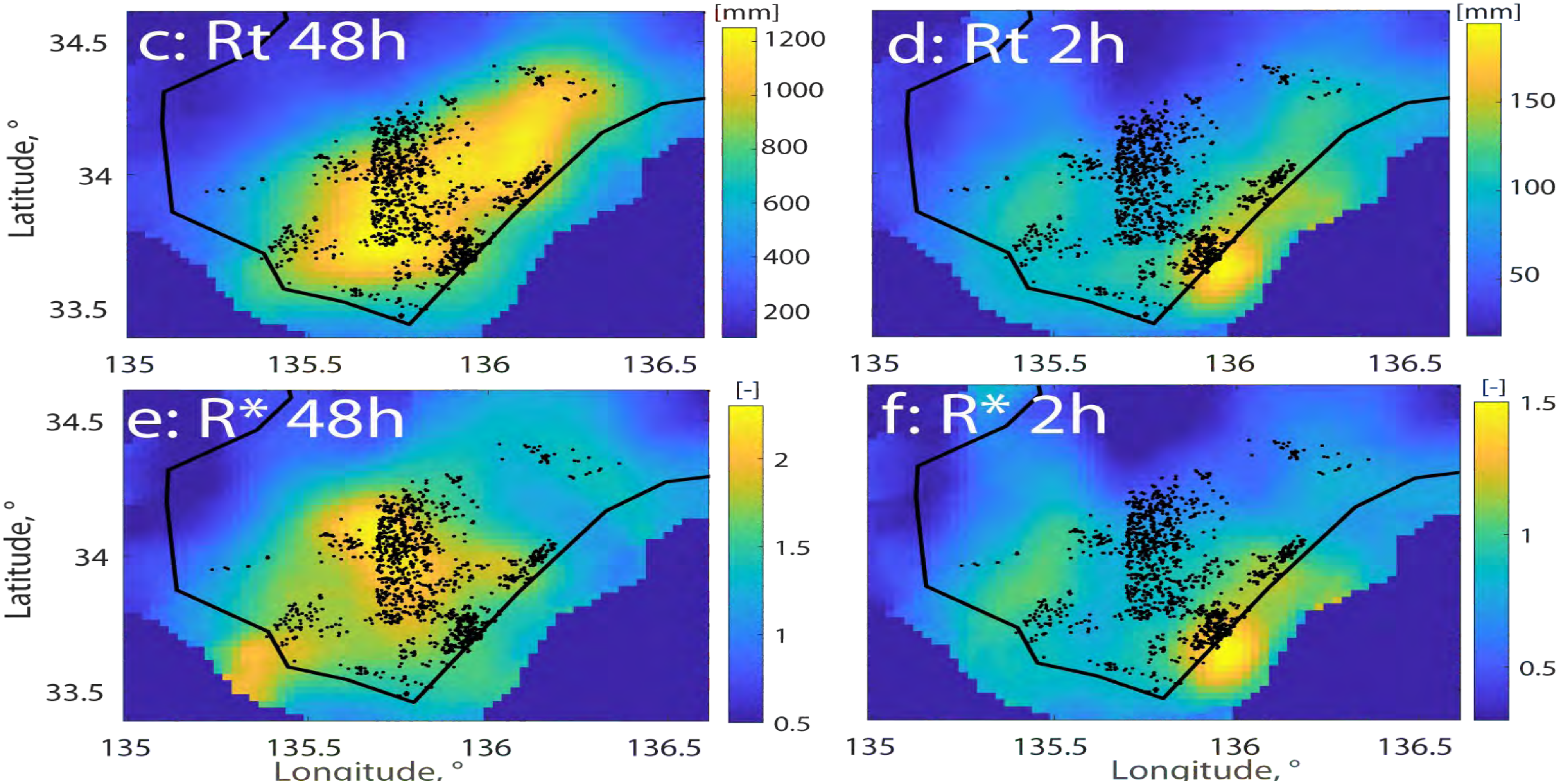




At both timescales, extremes are much larger in the northeastern part of the peninsula than in its center.

Marc et al., GRL, 2019

Landslide pattern matches rainfall anomaly: $R^*=Rt/R_{10}$



Marc et al., GRL, 2019

Empirical prediction of probability and magnitude of landsliding

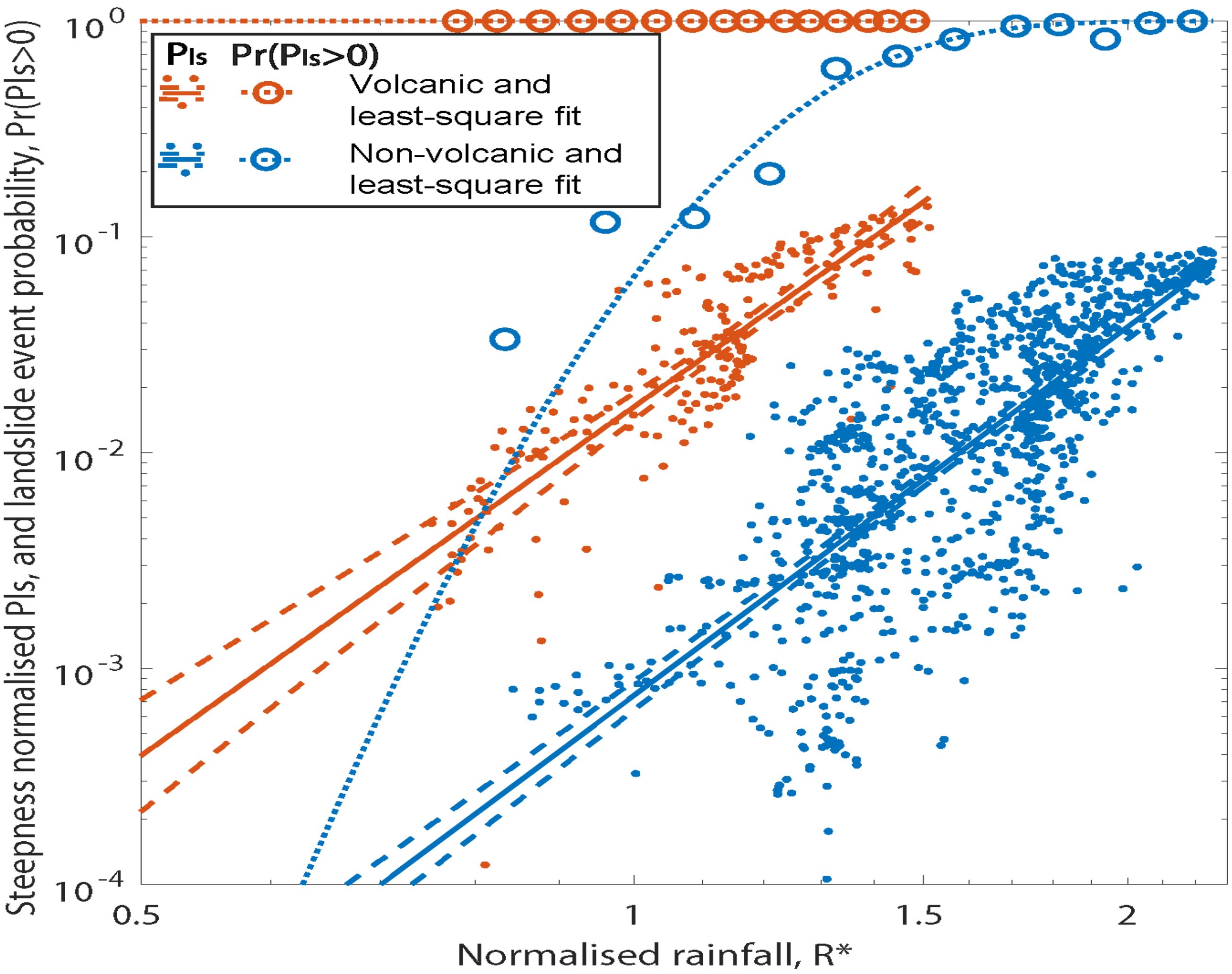
Landslide probability, Pr(P_{ls}>0):
Pr (Rain=X & $\mathbf{L_d}$ >0) / Pr (Rain =X)

Landslide Density, P_{ls}:
Total landslide area / area with S >15°

The two metrics average rainfall and landslide data within ~10km radius.

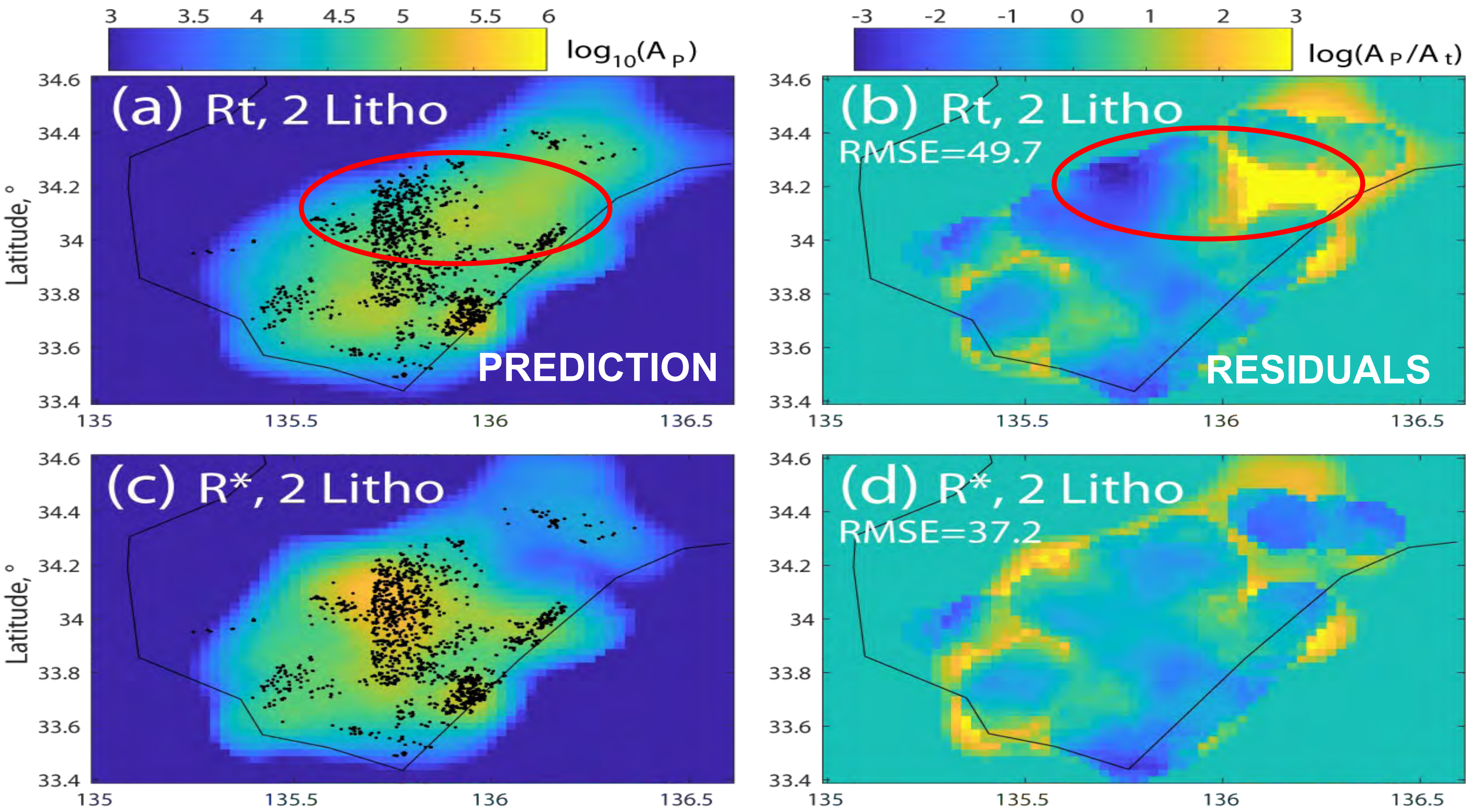
Pr(**P_{ls}>0**) corresponds to a probabilistic rainfall threshold.

But beyond R*~1.5, **Pr**(**P_{ls}>0**) saturates but the density continues to increase.



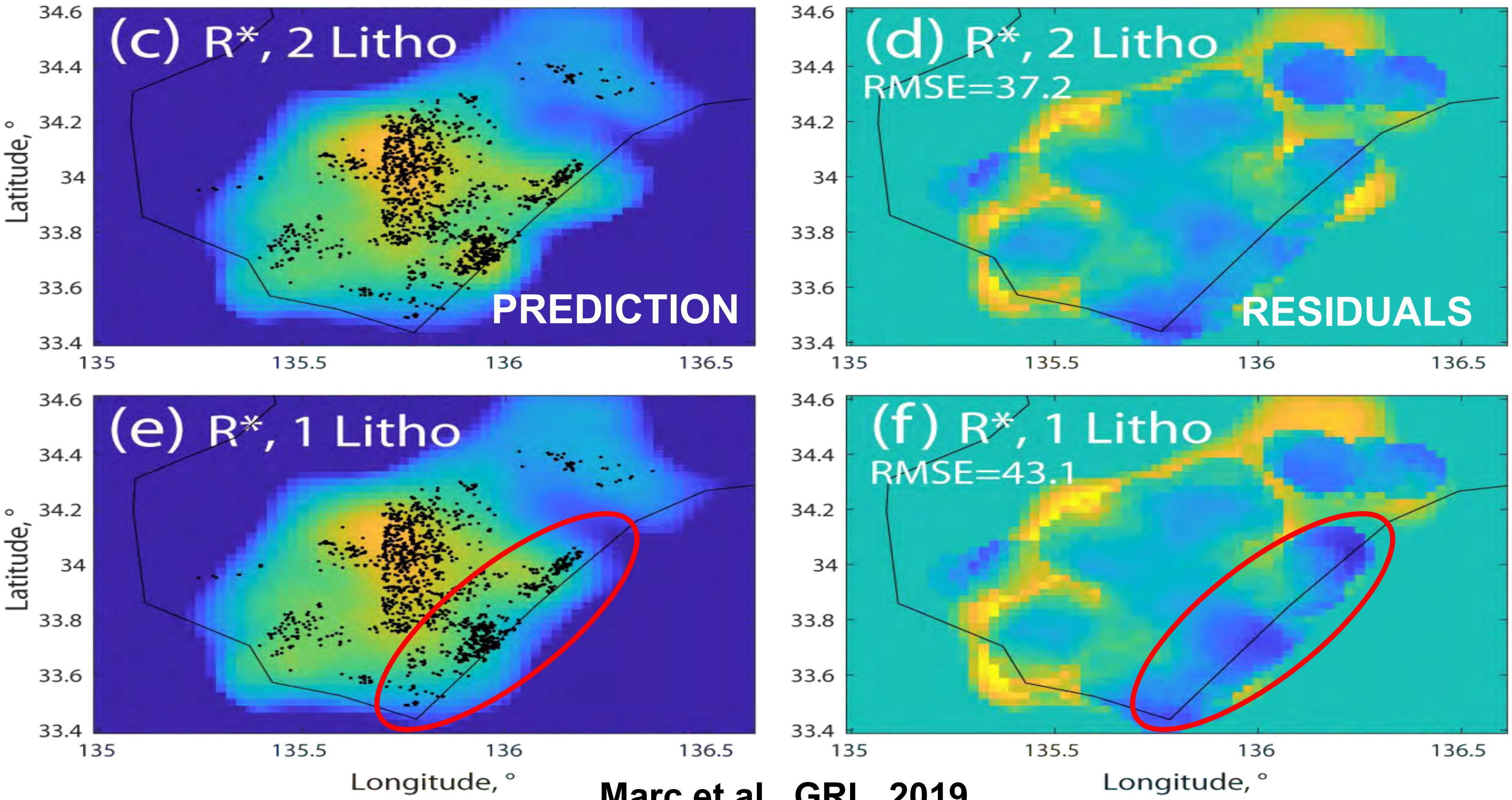
Marc et al., GRL, 2019

Best predictions are based on rainfall anomaly



Marc et al., GRL, 2019

Two lithologies are required to explain coastal clusters



Marc et al., GRL, 2019

Summary and Take-home messages

Can we explain rainfall-induced landsliding with topography and rainfall ?

>> Not in the Kii Peninsula.

>> We must account for regional variations of past extreme rainfall.

Hypothesis:

>> In steep landscapes, landscape and climate evolved to an equilibrium.
There, extreme climatology correlates with hydromechanical properties of the regolith.

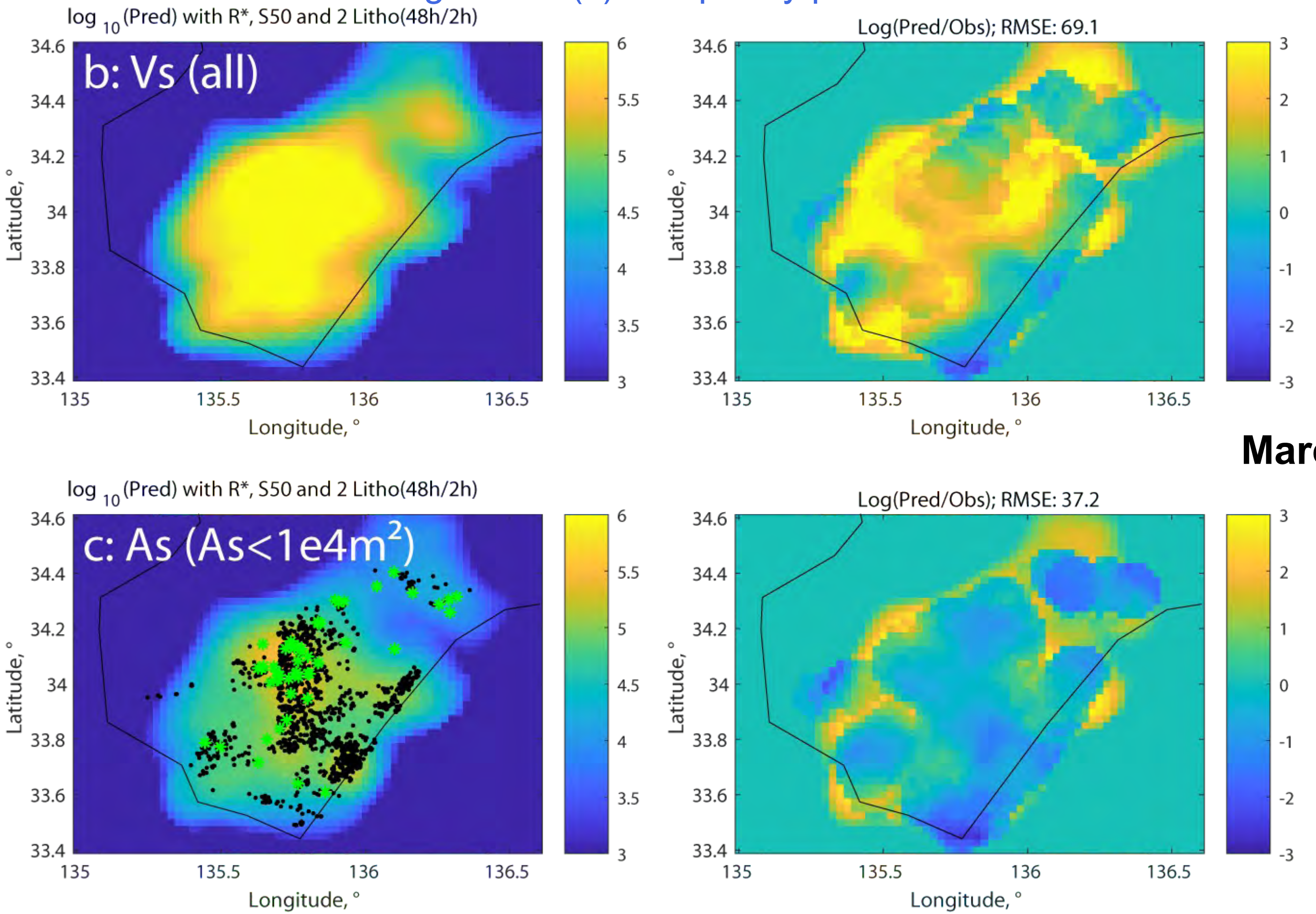
How does rainfall and landsliding scale beyond the threshold for landsliding ?

>> Landslide density increase non-linearly with rainfall anomaly, and continue to increase after landslide probability has saturated (i.e., beyond the threshold).

>> In Japan, different lithologies modulate the response to rainfall and landslide runout.

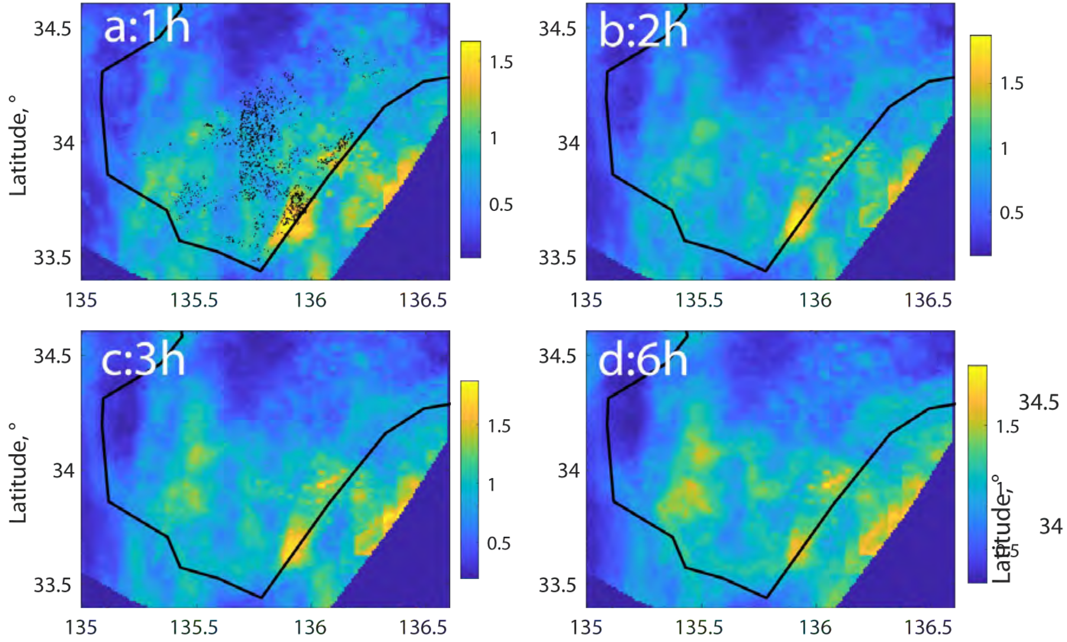
Large landslides (A_s>10,000m²) are poorly predicted

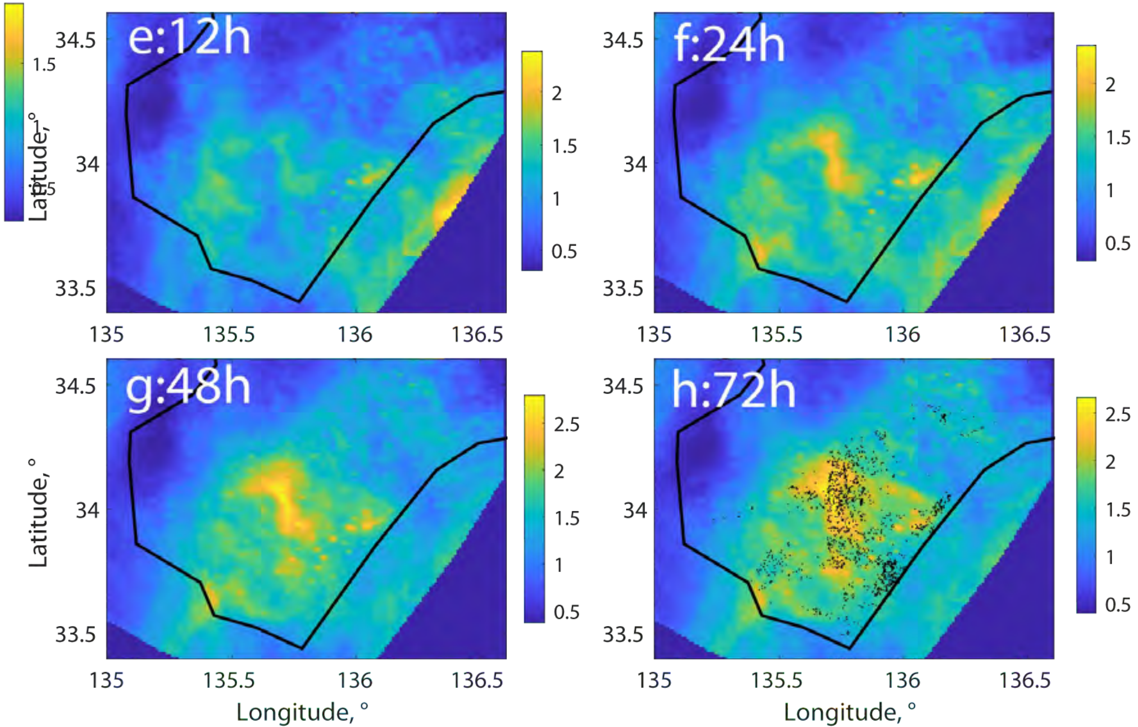
The total volume is dominated by large landslide (defined by scar area A_s>10,000m2) shown in green in (c) and poorly predicted..



Marc et al., GRL, 2019

Rainfall anomaly at every timescale (before smoothing)





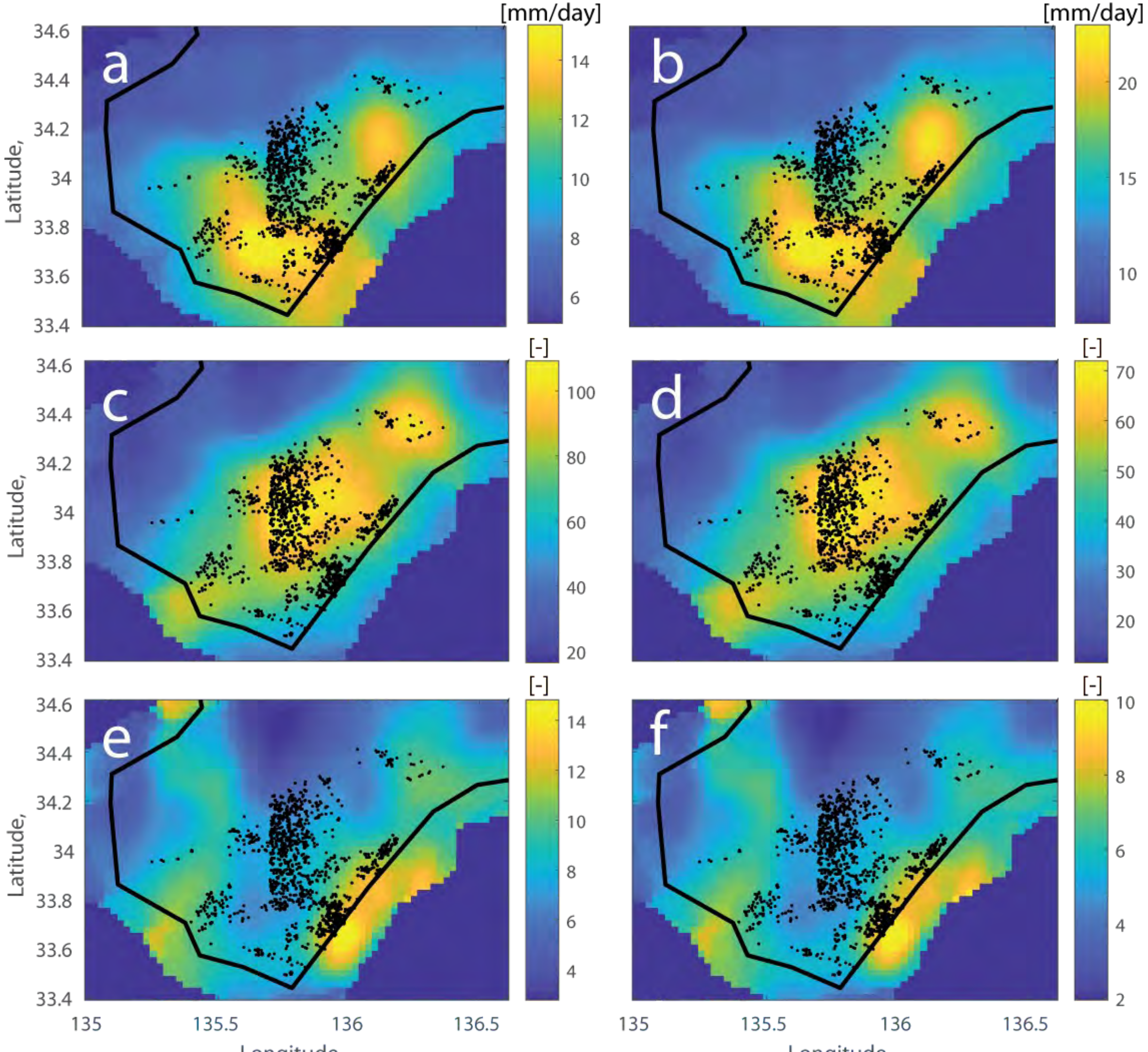
Marc et al., GRL, 2019

Anomaly relative to season rather than past events

Mean Typhoon Season precipitation (MTP)

48h anomaly (Rt_{48h} / MTP)

2h anomaly (Rt_{2h} / MTP)



Mean Annual Precipitation (MAP)

48h anomaly (Rt_{48h} / MAP)

2h anomaly (Rt_{2h} /MAP)

Marc et al., GRL, 2019