Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

AWE-GEN-2d

A new gridded stochastic weather generator

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Peter Molnar, Paolo Burlando

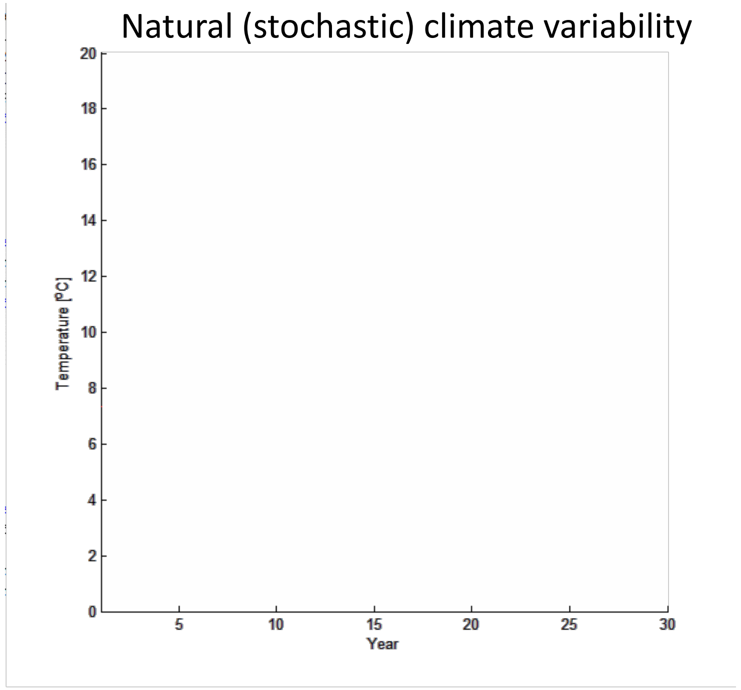
15th Swiss Geoscience Meeting
Davos, November 2017

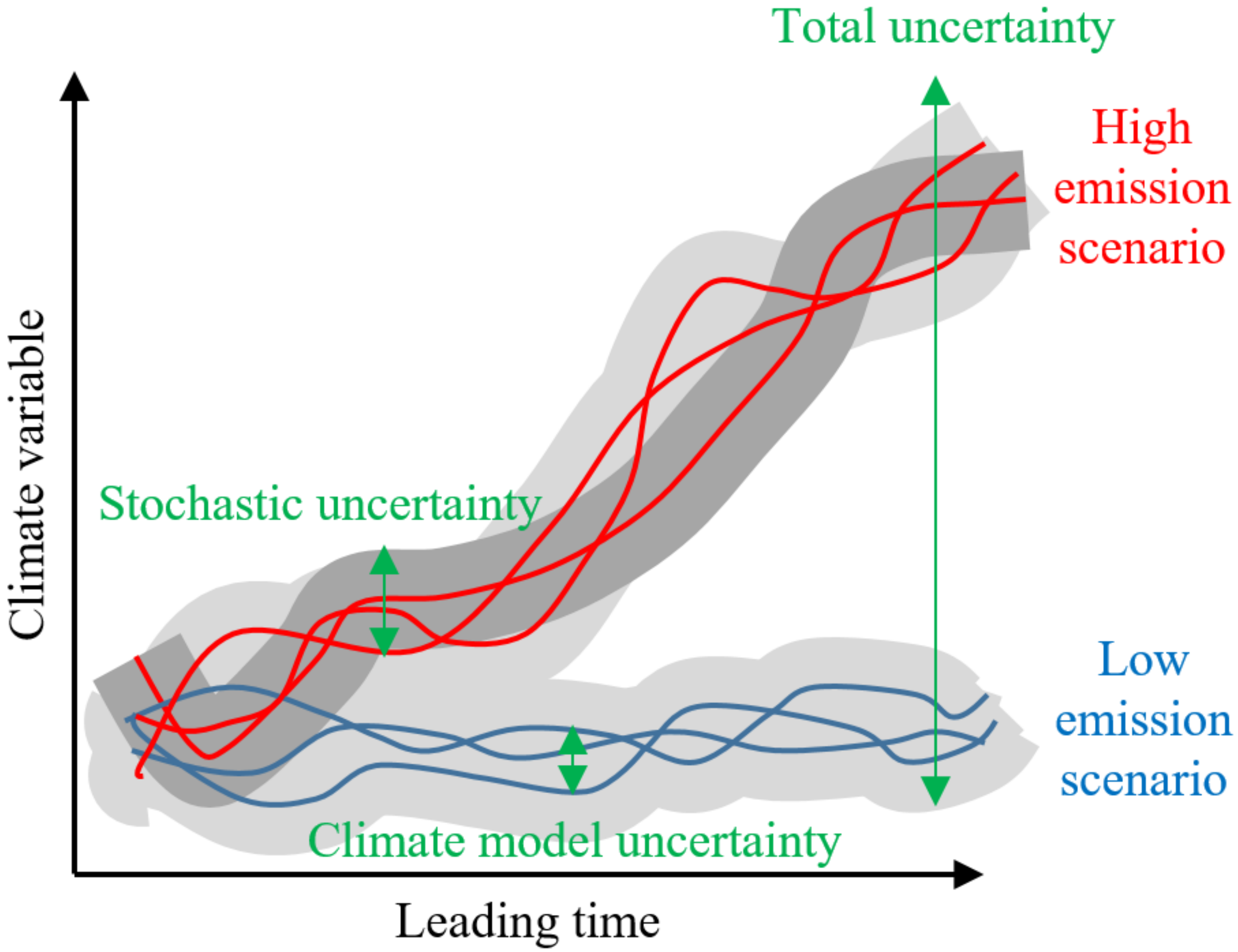
Outline

1. Motivation
   - Why do we need a weather generator?
   - What is a weather generator?
2. AWE-GEN-2d
   - Model structure
   - Validation
3. Case study
   High spatio-temporal resolution climate scenarios for snowmelt modelling in small alpine catchments

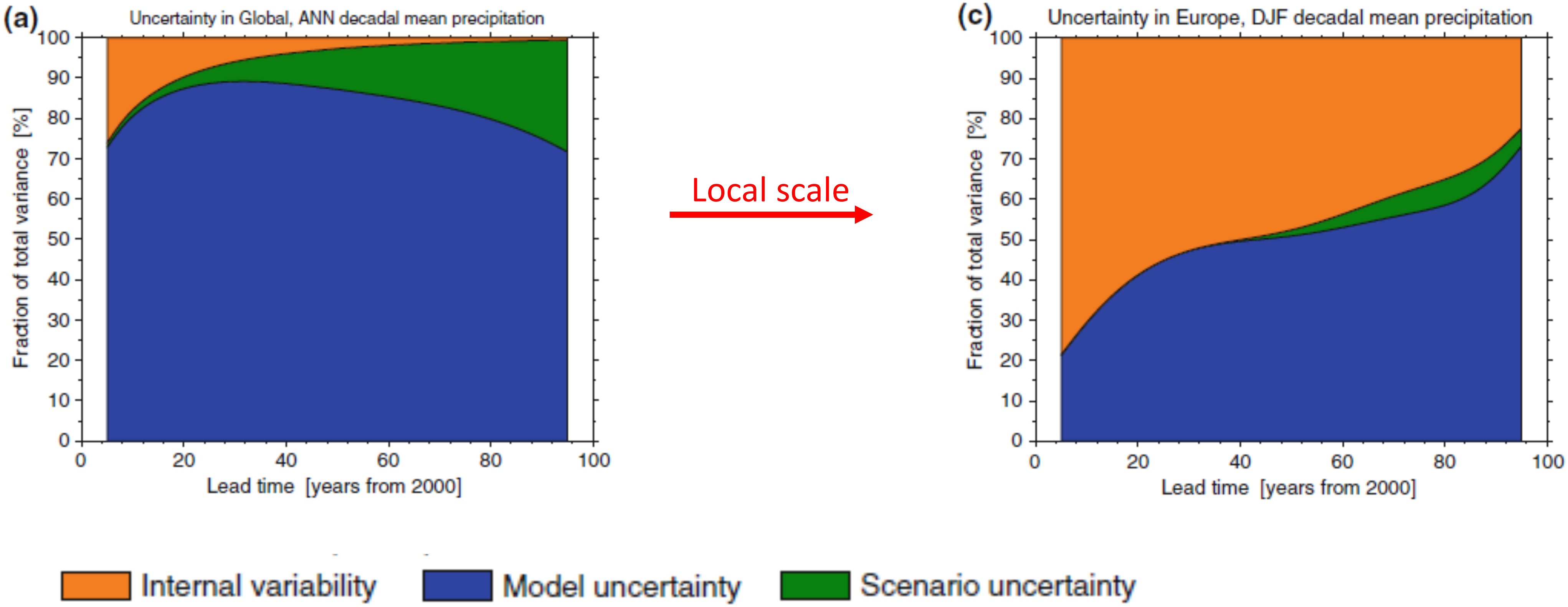
Climate uncertainties

1. Emission scenario uncertainty
2. Climate model uncertainty
3. Internal climate variability





Climate uncertainties

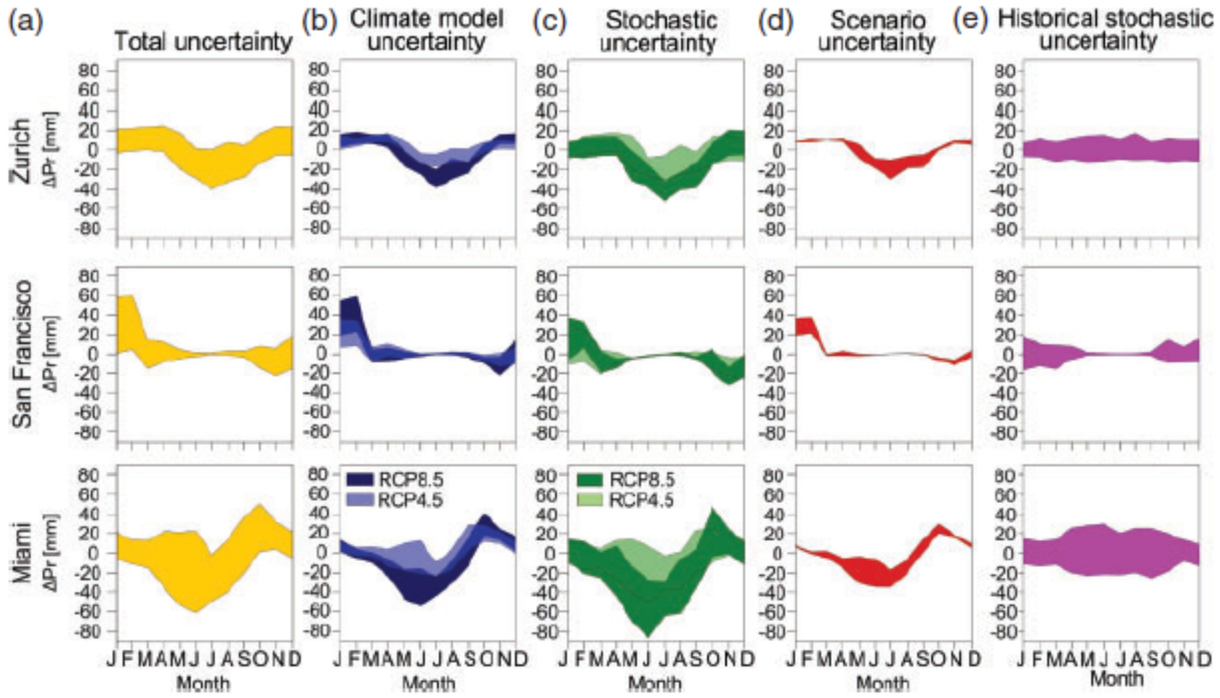


Local scale

Hawkins and Sutton (2011)

Climate uncertainties

Local scale



Natural climate variability is important at small- local-scales!

Fatichi et al. (2016)

How one can simulate multiple climate realizations?

Dynamic approach

- Physically based, numerical-deterministic model
- F… resolution, nesting is

ti

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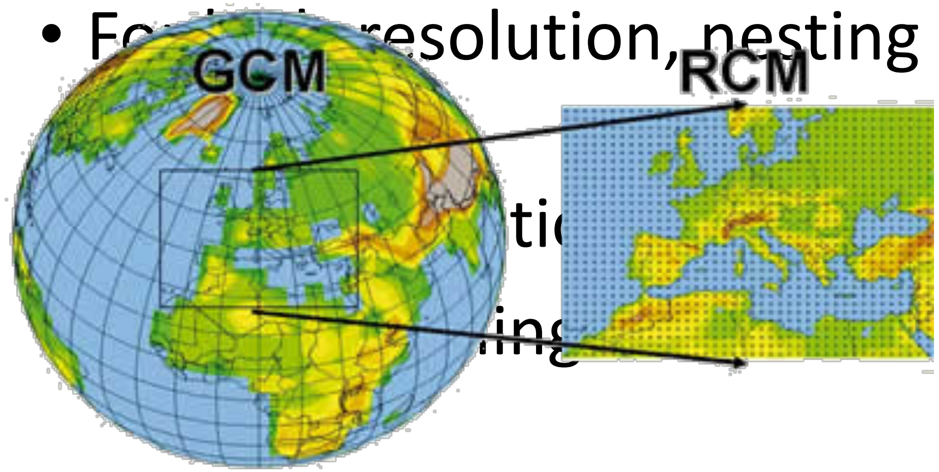
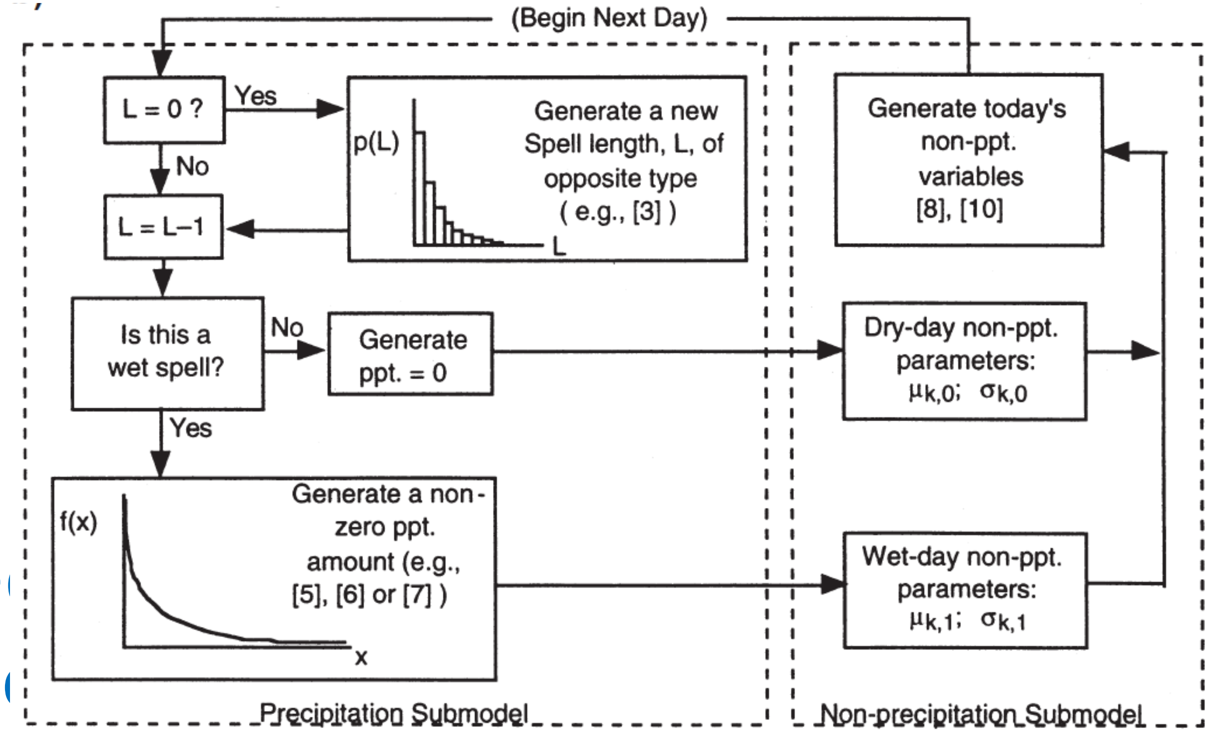


Stochastic approach

- Empirical-statistical based (weather generator)



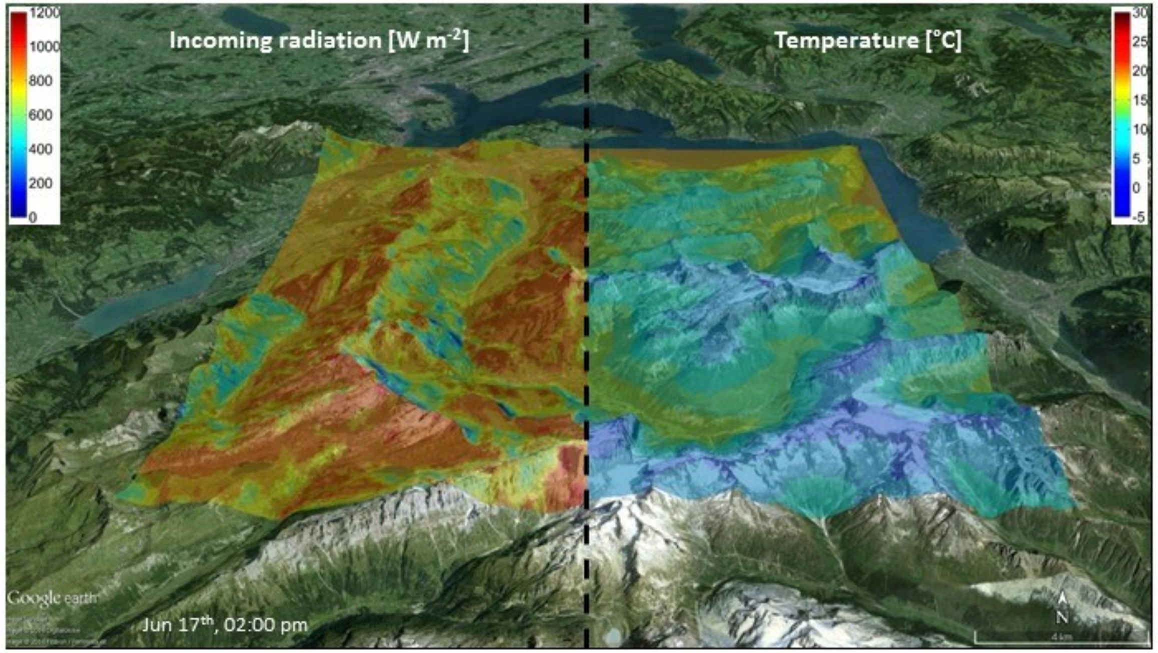
Wilks and Wilby (1999)

Gap to the best of our knowle…

stochastic weath…

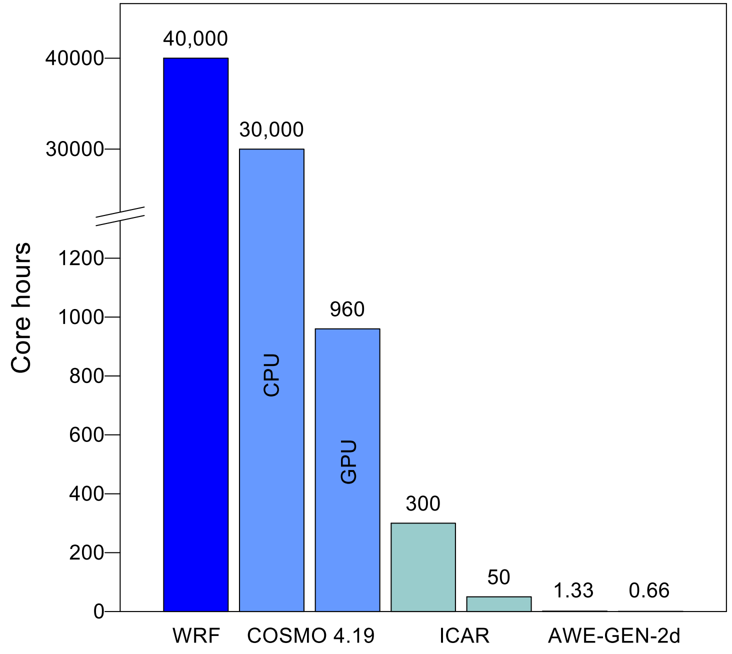
AWE-GEN-2d in a nutshell

- AWE-GEN-2d (**A**dvanced **WE**ather **GEN**erator for **2-D**imensional grid) follows the philosophy of combining physical and stochastic approaches to generate gridded climate variables in a high spatial and temporal resolution.

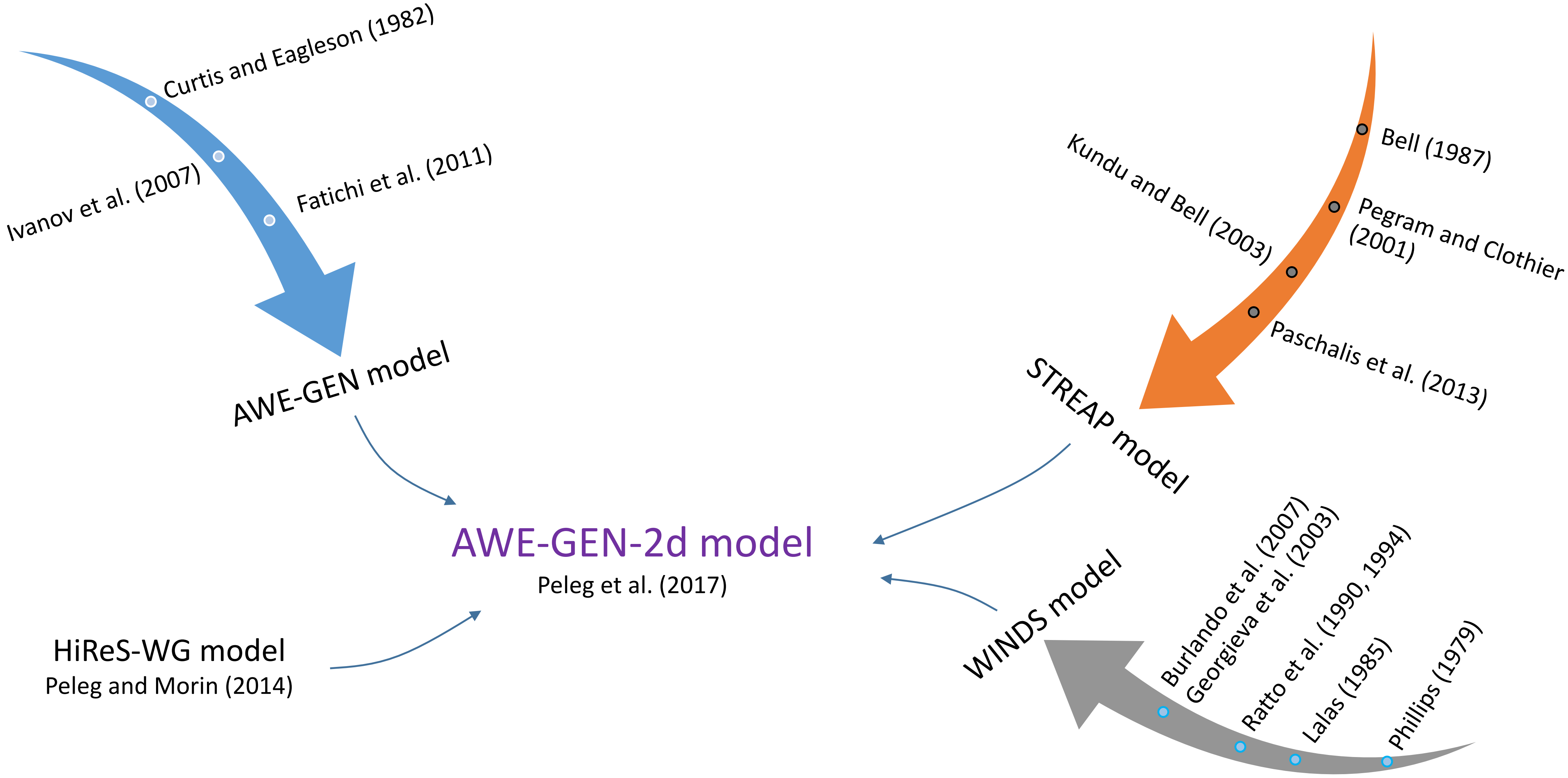


AWE-GEN-2d in a nutshell

- AWE-GEN-2d (**A**dvanced **WE**ather **GEN**erator for **2-D**imensional grid) follows the philosophy of combining physical and stochastic approaches to generate gridded climate variables in a high spatial and temporal resolution.
- It is relatively fast and efficient in terms of computational demand.
- It allows generating many stochastic realizations of present and future climates.

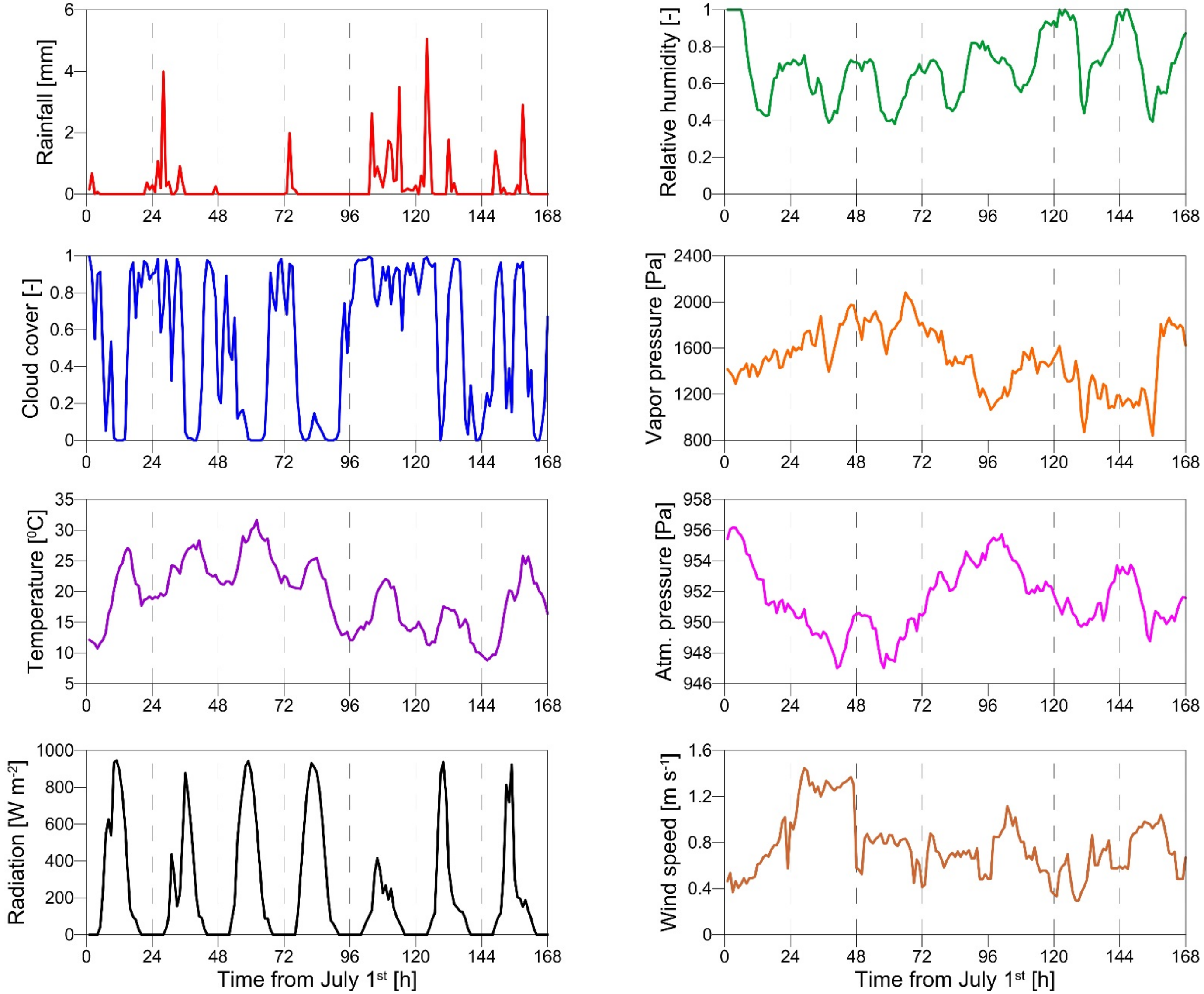


Ancestors


Curtis and Eagleson (1982)
Ivanov et al. (2007)
Fatichi et al. (2011)
AWE-GEN model
Bell (1987)
Kundu and Bell (2003)
Pegram and Clothier (2001)
Paschalis et al. (2013)
STREAP model
AWE-GEN-2d model
Peleg et al. (2017)
HiReS-WG model
Peleg and Morin (2014)
WINDS model
Burlando et al. (2007)
Georgieva et al. (2003)
Ratto et al. (1990, 1994)
Lalas (1985)
Phillips (1979)

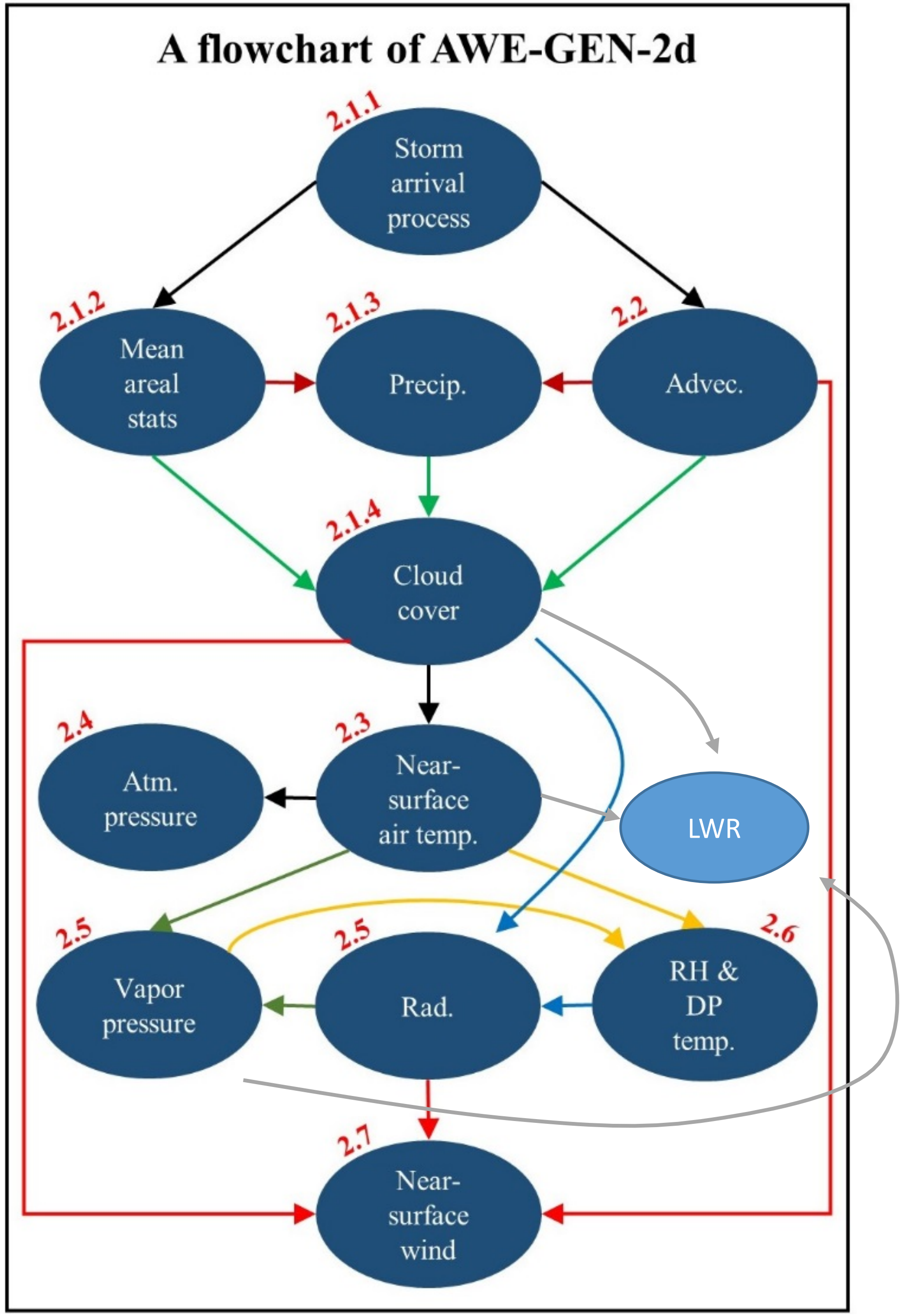
Climate variables

- Sub-daily temporal resolution.
- Similar output as of GCM/RCM:
  - Precipitation
  - Cloud cover
  - Temperature
  - Radiation (longwave, shortwave, diffusive)
  - Relative humidity
  - Vapor pressure
  - Atmospheric pressure
  - Wind speed

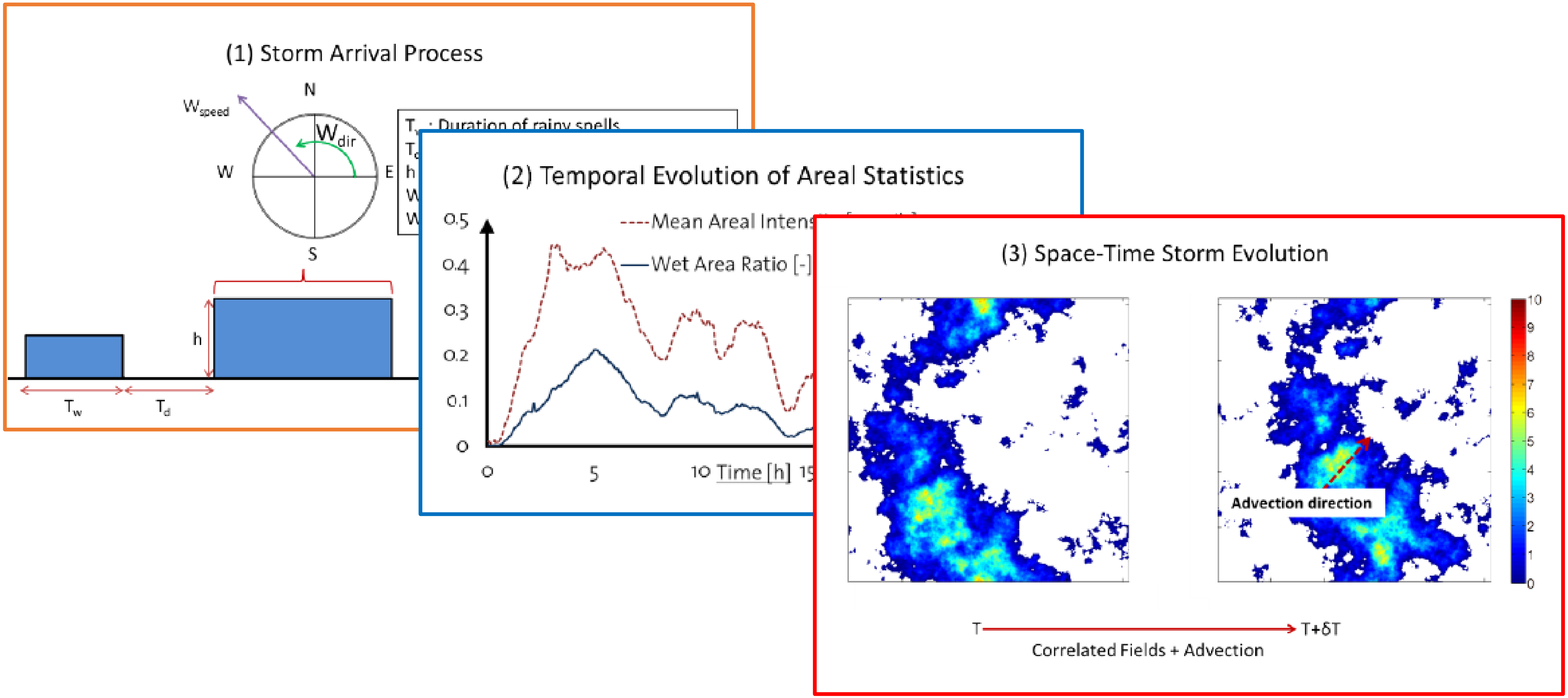


Model structure

- Composed of eight modules.
- There is dependency between most, but not all, meteorological variables.



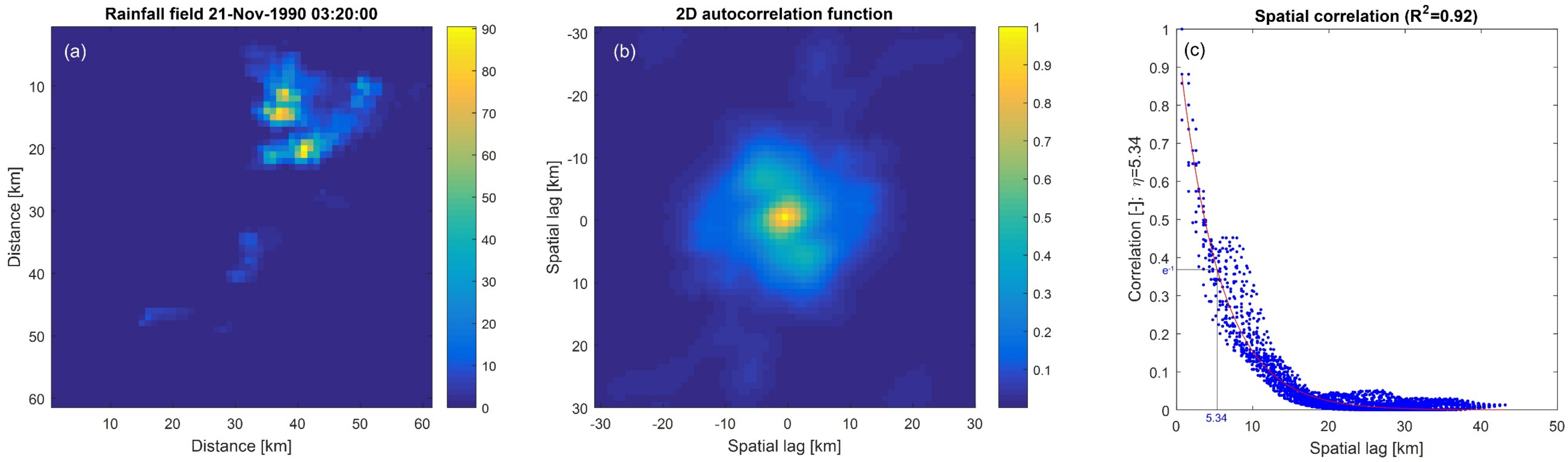
Precipitation



Paschalis et al. (2013)

Space-time storm evolution

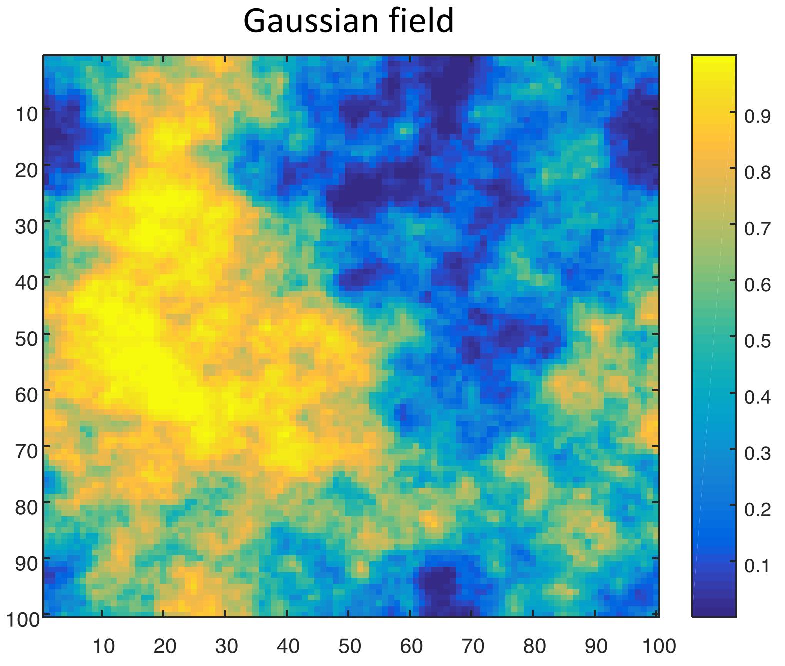
- The fields takes into account the exponential decay of the spatial autocorrelation (spectral density analysis) and the ARMA process (temporal correlation).



Peleg et al. (2017)

Space-time storm evolution

- The simulated WAR and IMF time series for each storm are transformed into the space-time evolution of the precipitation fields using latent Gaussian fields (simulated using 2-D FFT method).



WAR = 35%

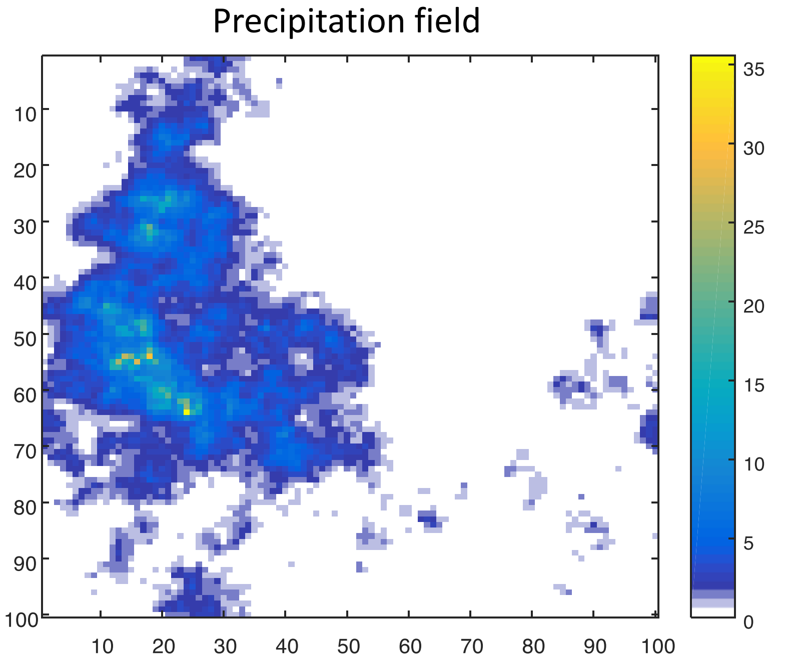
IMF = 1 mm h^{-1}

CV=1

$$R(x,y,t) = LN^{-1}(U[G(x,y,t)],\mu,\sigma)$$

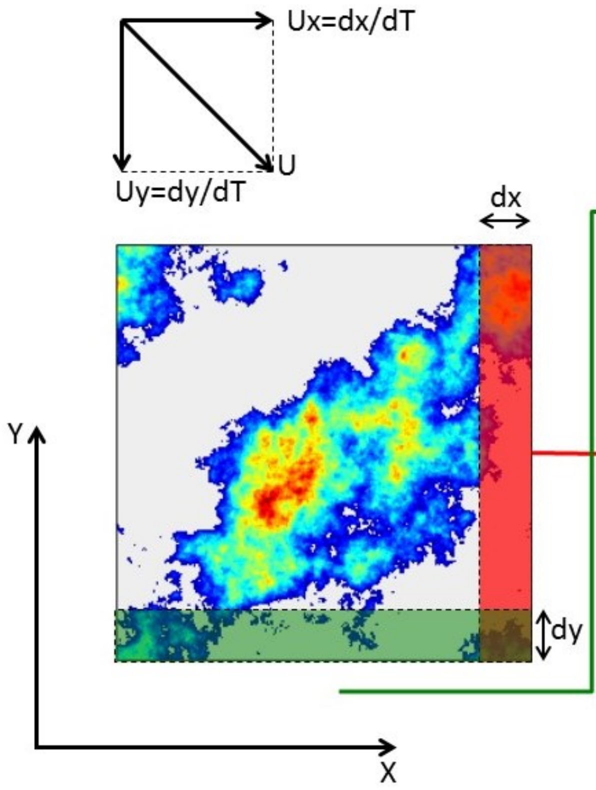
$$\mu = log\left(\frac{IMF(t)}{WAR(t)\sqrt{CV^2+1}}\right)$$

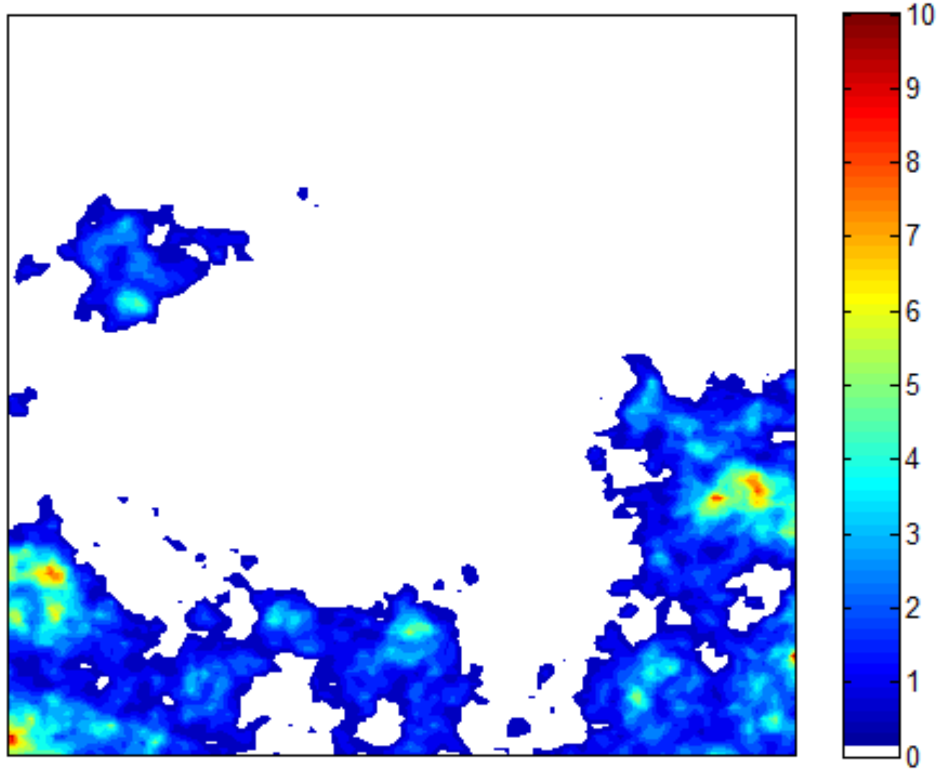
$$\sigma = \sqrt{log(CV^2+1)}$$



Space-time storm evolution

- Due to the symmetries of the fast Fourier transform the generated fields can be folded.





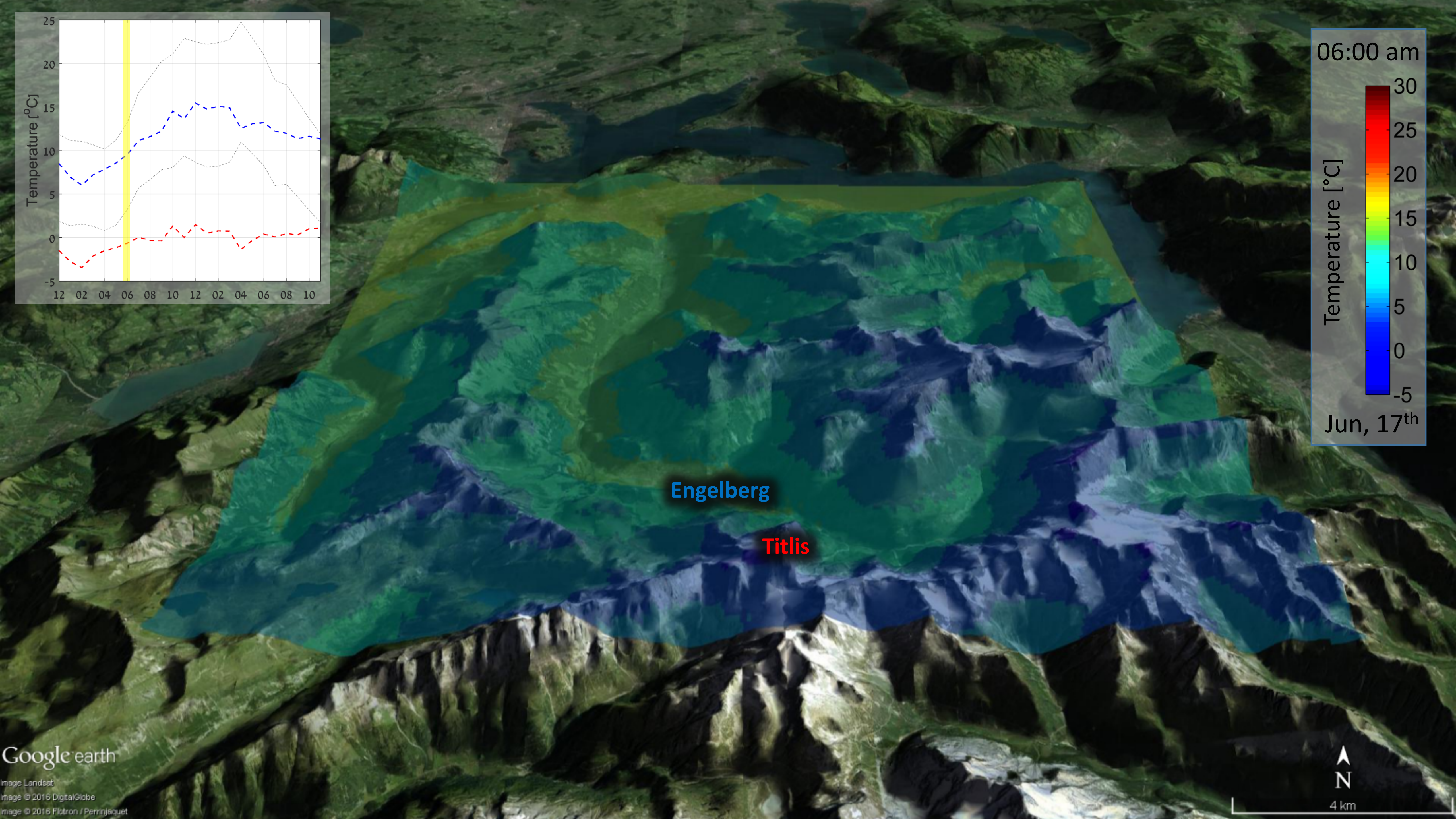
Paschalis et al. (2013)

Cloud cover

- During the intra-storm period, the cloudiness and rainfall fields are cross-correlated and cloud cover has always an equal or larger extent than the precipitation field.
- During an inter-storm period, the existence of a ‘‘fair weather’’ region is assumed, meaning that the cloudiness decreases as a function of the time passed since the end of the previous storm and increases toward the beginning of the next storm, using a two term exponential function.
- The stochastic component of the cloud cover series during an inter-storm period is simulated through an ARMA model.

Near-surface air temperature

- Air temperature is generated with an hourly time step first for a given reference level and then spatially extrapolated to all grid cells using a stochastic lapse rate.
- The deterministic temperature component is assumed to be directly related to the incoming longwave radiation and to the hourly position of the Sun and site geographic location.
- The stochastic temperature component is estimated through an autoregressive model AR(1).
- The air temperature at a given reference level can be generated with or without considering the shading effect of the terrain. The shadow effect is calculated as a binary coefficient: the sloping surface is shadowed by neighboring terrain (==0) when the horizon angle is lower than the zenith angle for a given solar azimuth.



Temperature [°C]
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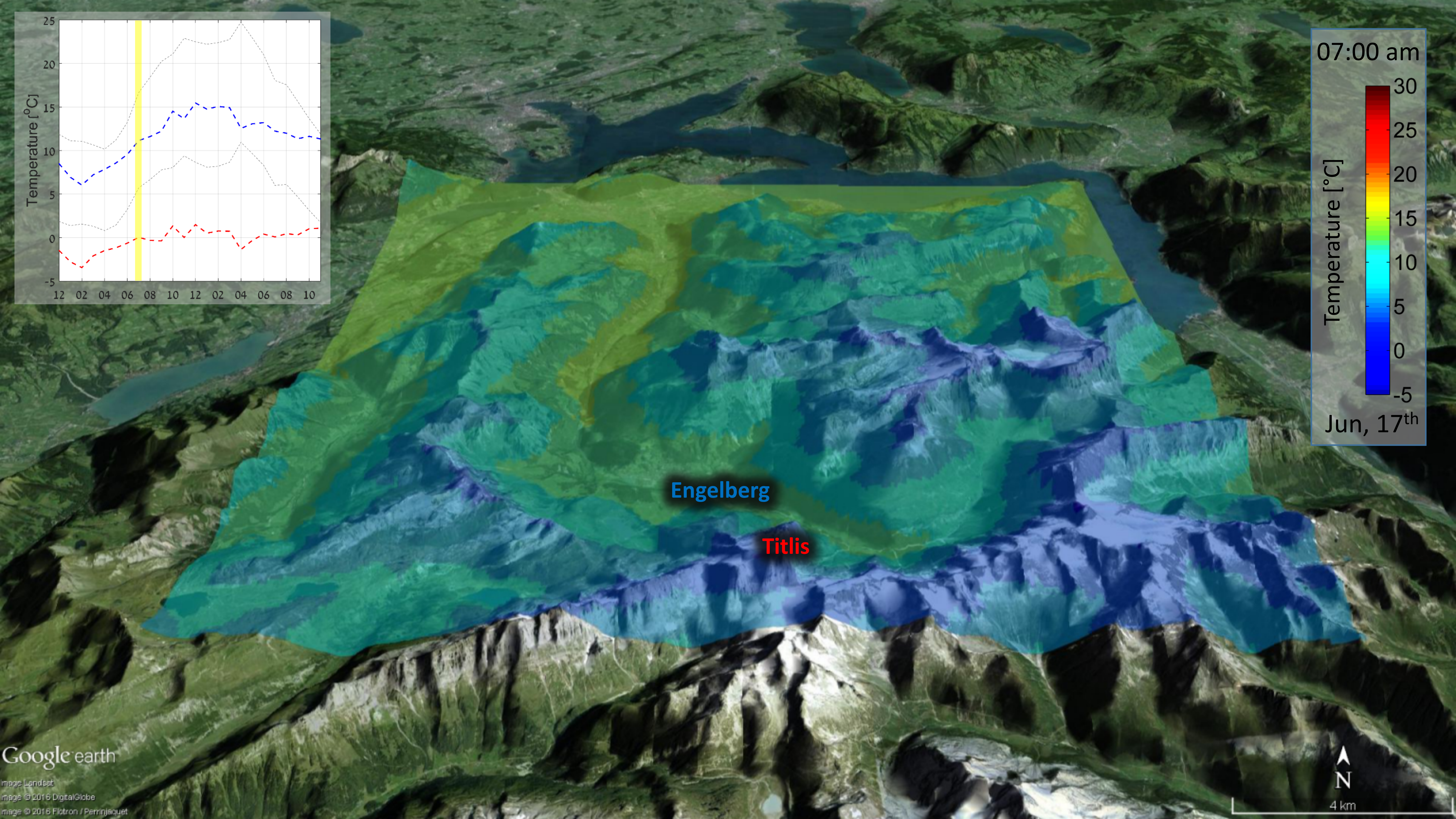
Temperature [°C]
Jun, 17th
Engelberg
Titlis
Google earth
Image Landsat
Image © 2016 DigitalGlobe
Image © 2016 Flotron / Perrinjaquet
N
4 km



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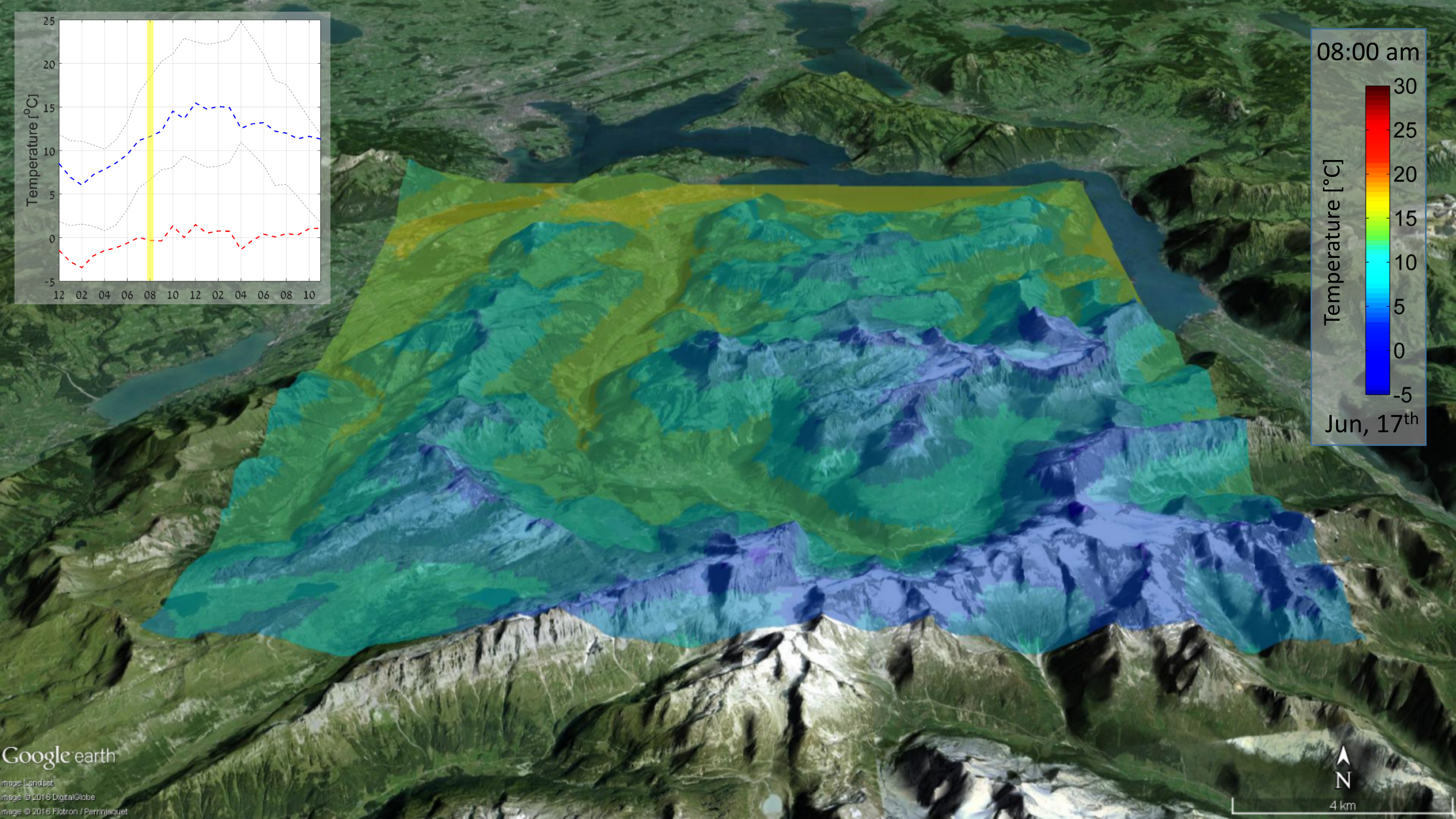

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Temperature [°C]
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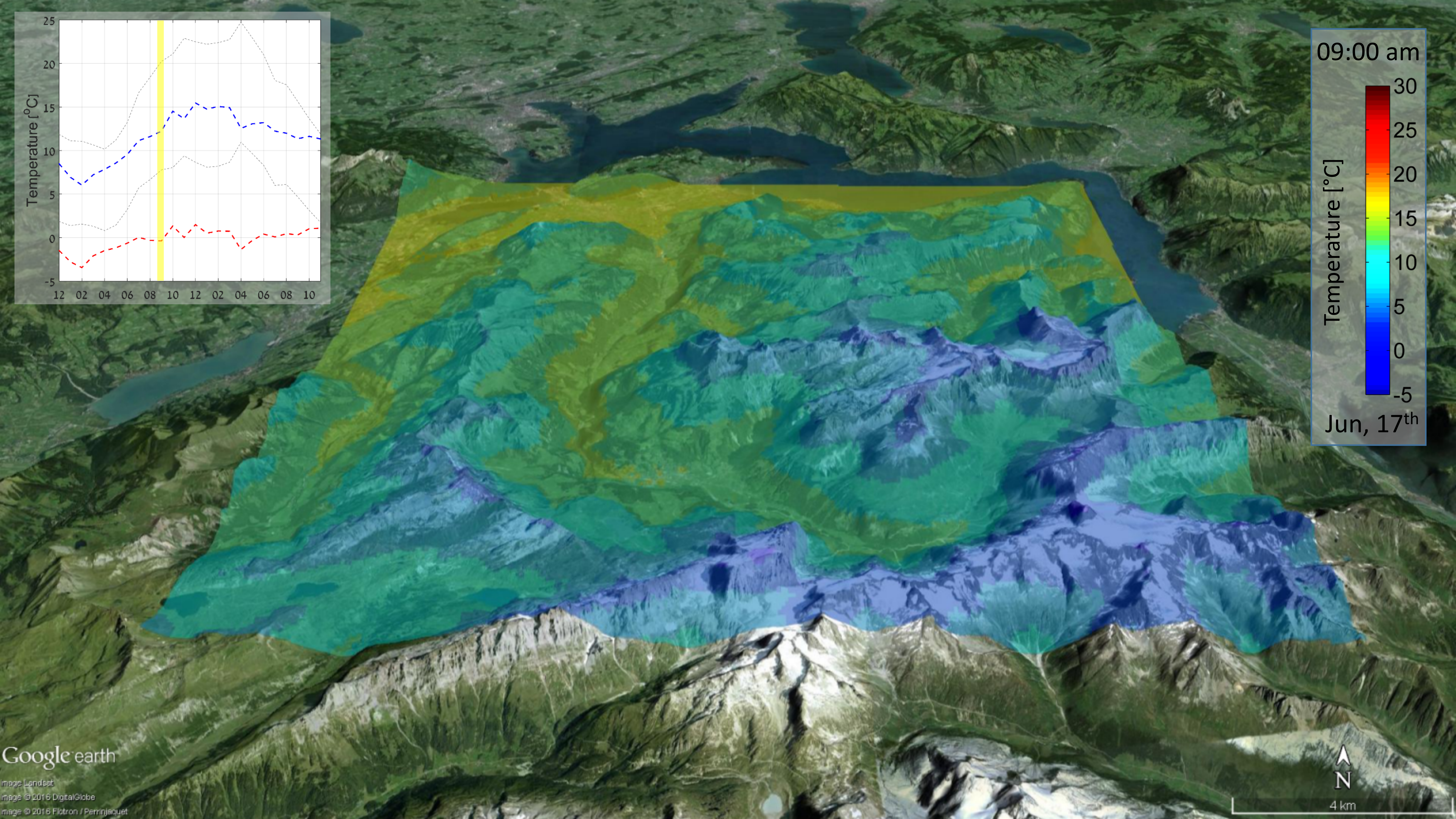

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Temperature [°C]
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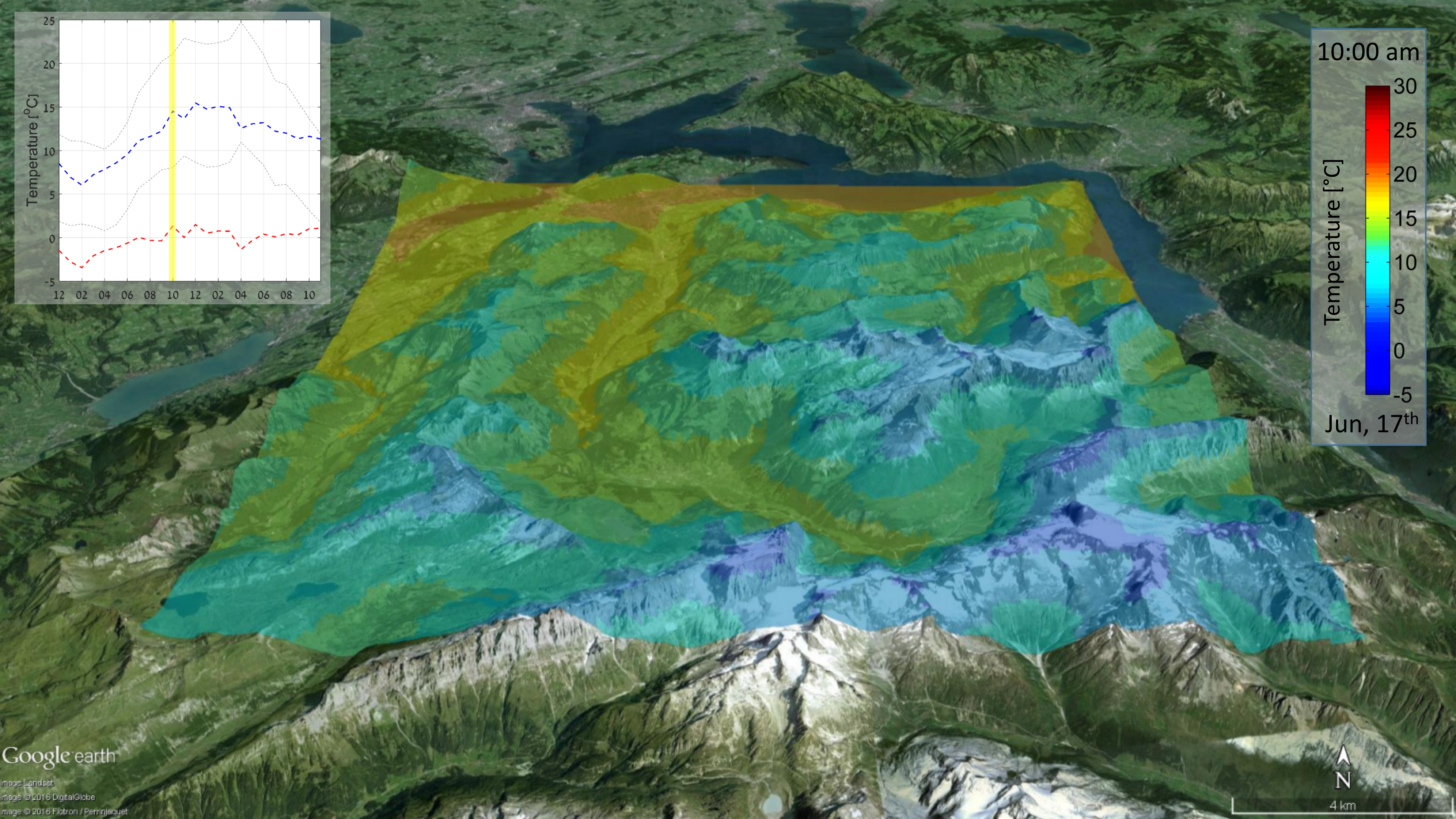

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Temperature [°C]
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Image Landsat
Image © 2016 DigitalGlobe
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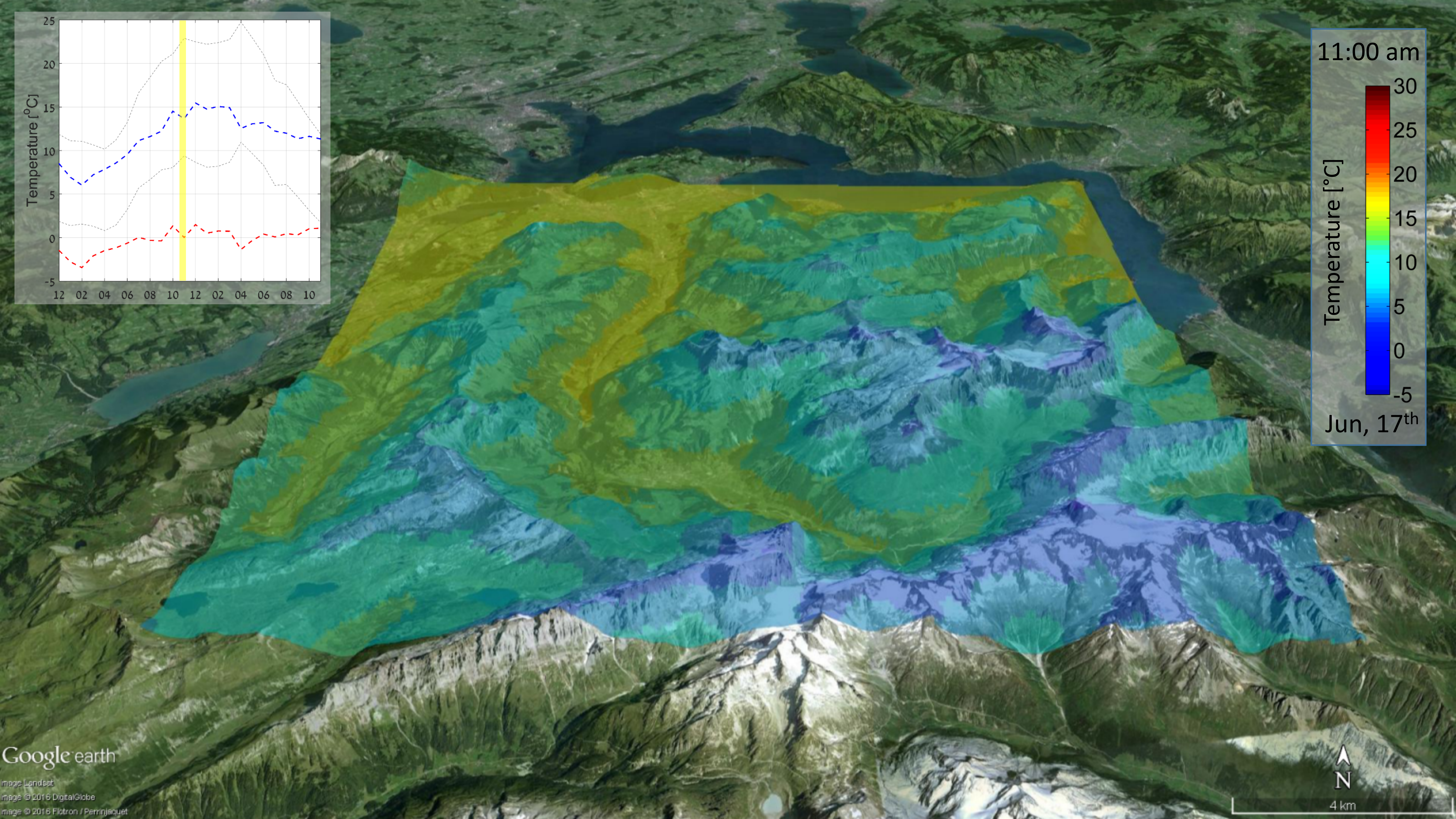

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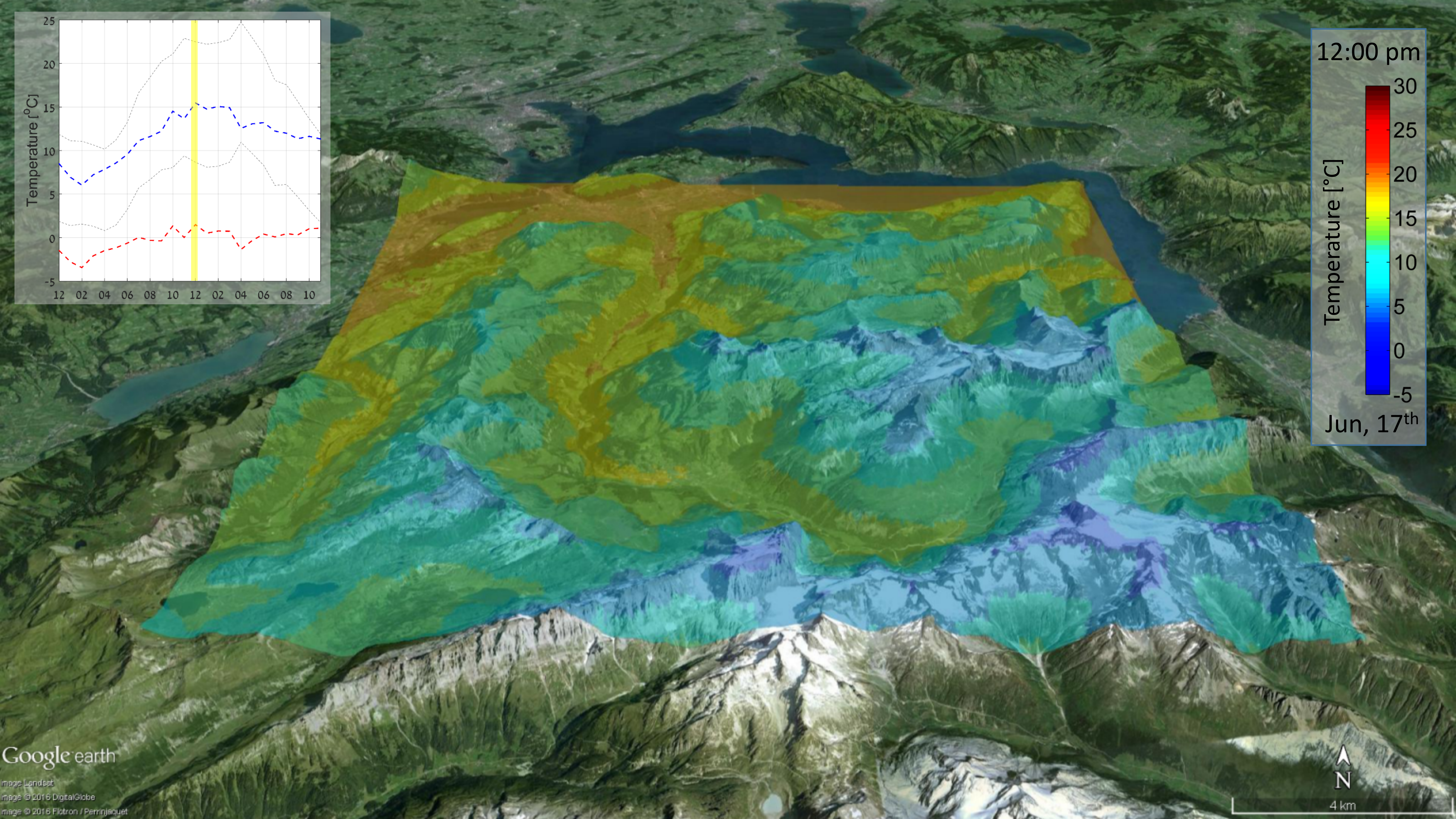

Temperature [°C]
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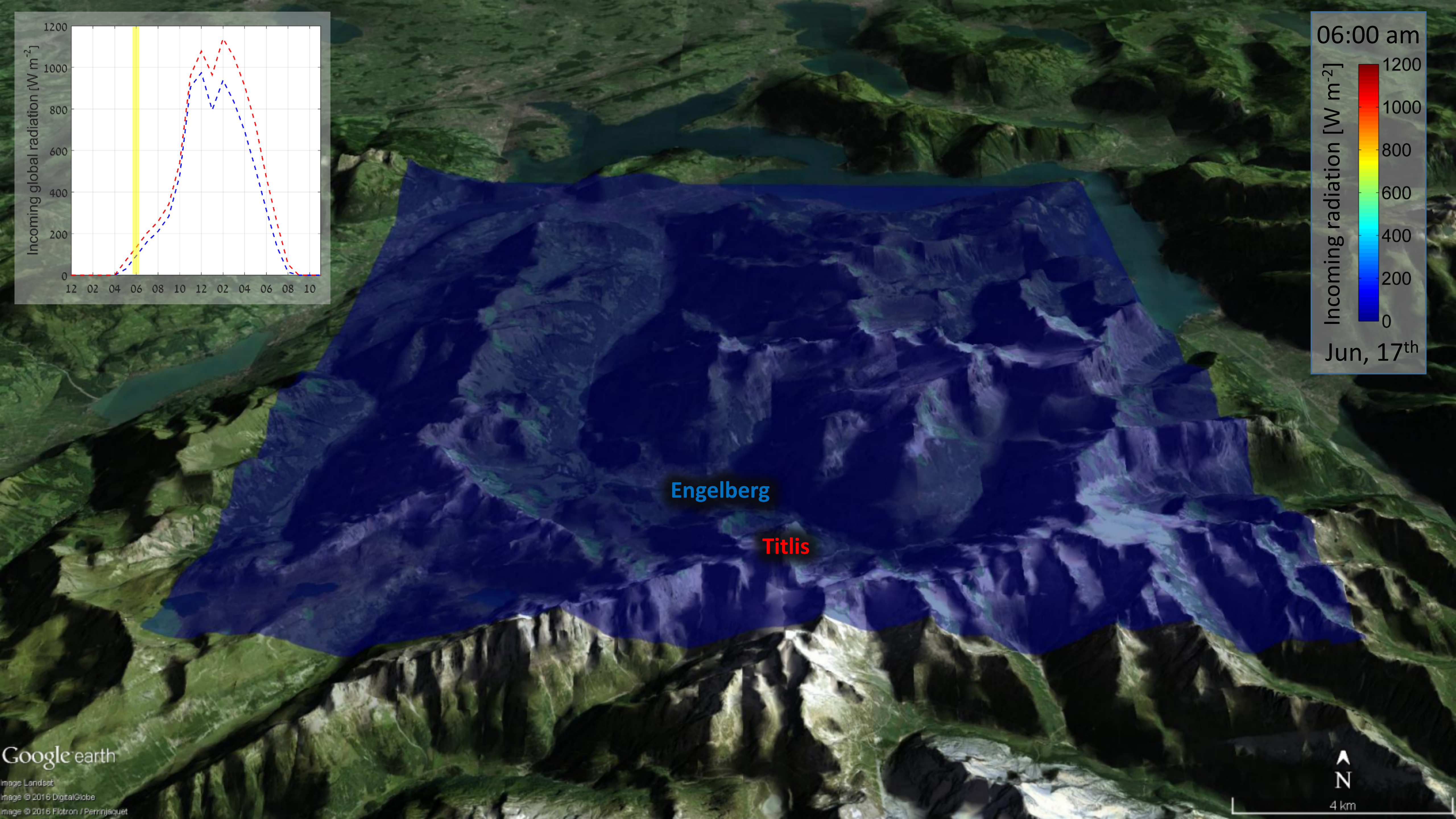
Temperature [°C]
Jun, 17th
Google earth
4 km
N

Shortwave incoming radiation

- The atmospheric radiation transfer is computed for clear-sky conditions and for cloudy conditions (direct and diffusive transmittance terms).
- The clear-sky radiation component considers two bands: the ultraviolet/visible band with wavelengths [0.29–0.70 μm] and the near infrared band with wavelengths [0.70–4.0 μm].
- Instantaneous values of the Sun (e.g. altitude, azimuth and declination) are considered.
- O_3 and the NO_2 amounts in the atmospheric column, the single scattering albedos, the surrounding ground albedo and the Angstrom turbidity (to calculate the spectral aerosol optical depth) are required.
- Radiative properties of clouds are computed as a function of the total vertical liquid water path (LWP).
- The spatial distribution of solar radiation over a domain is computed as a function of the local topography and of the surrounding terrain through the sky view factor, shadow effect and terrain configuration factor.



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Incoming global radiation [W m-2]
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Incoming radiation [W m-2]
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Image Landsat
Image © 2016 DigitalGlobe
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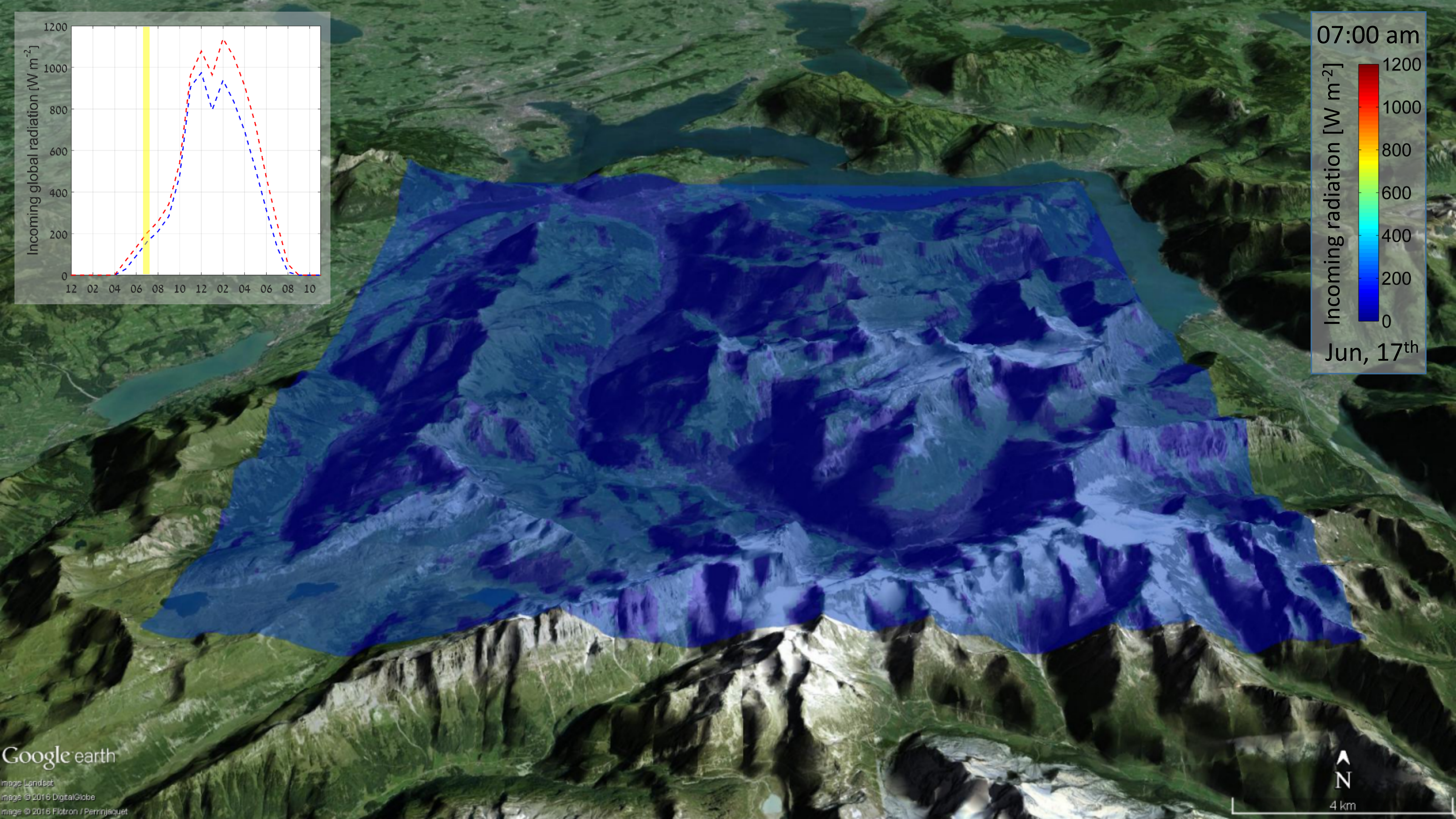

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Incoming radiation [W m^-2]
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Google earth
Image Landsat
Image © 2016 DigitalGlobe
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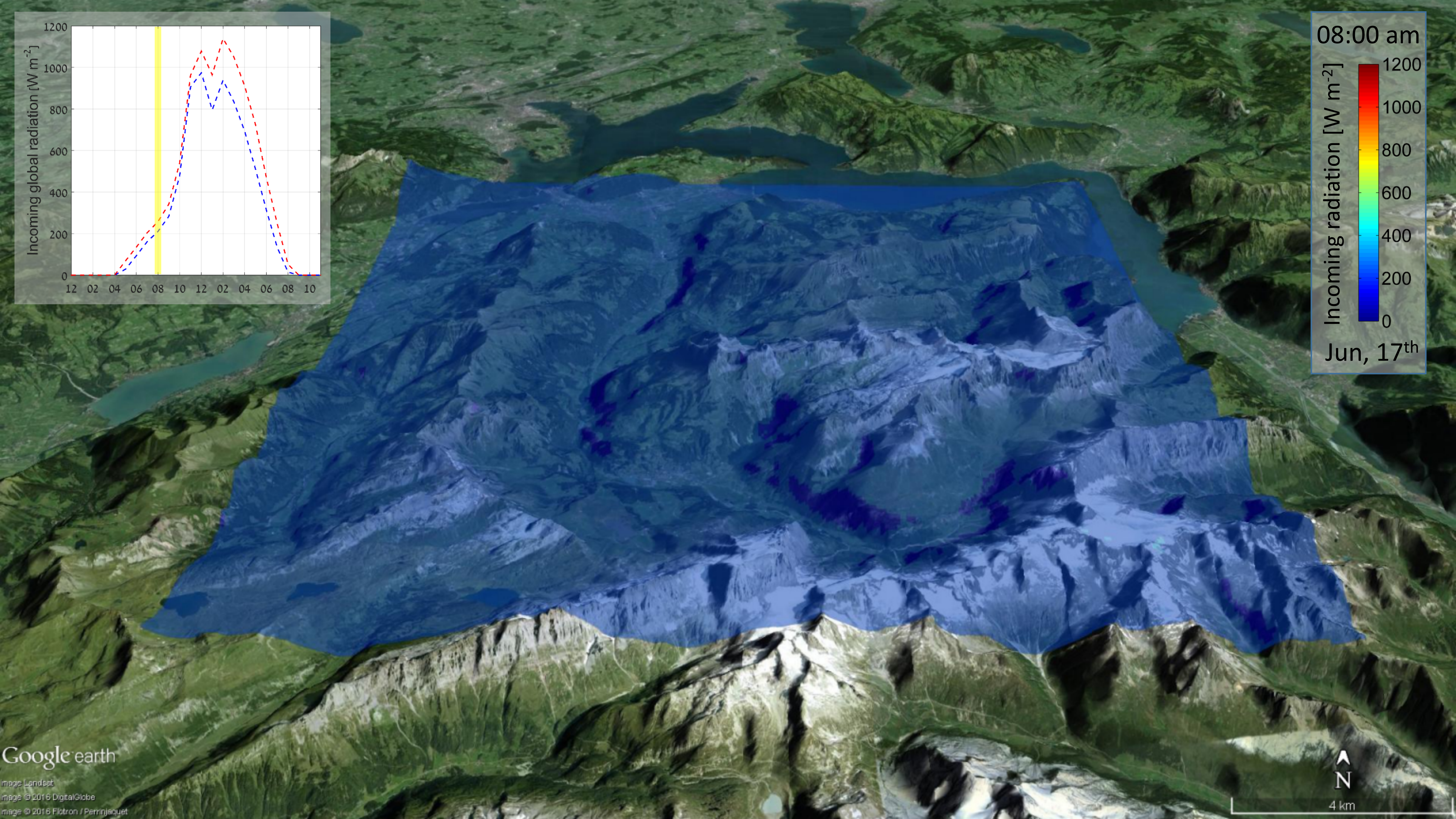

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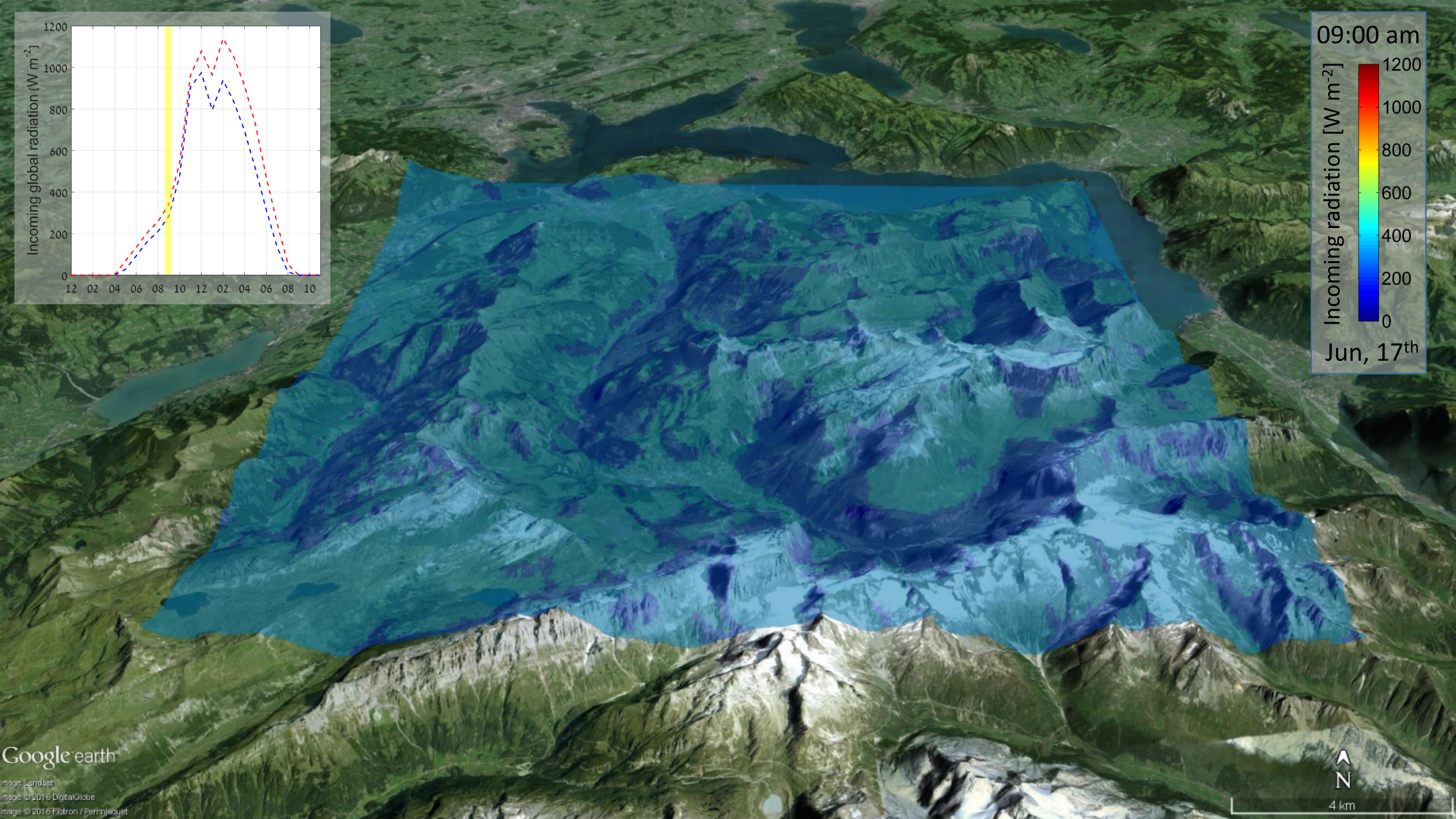

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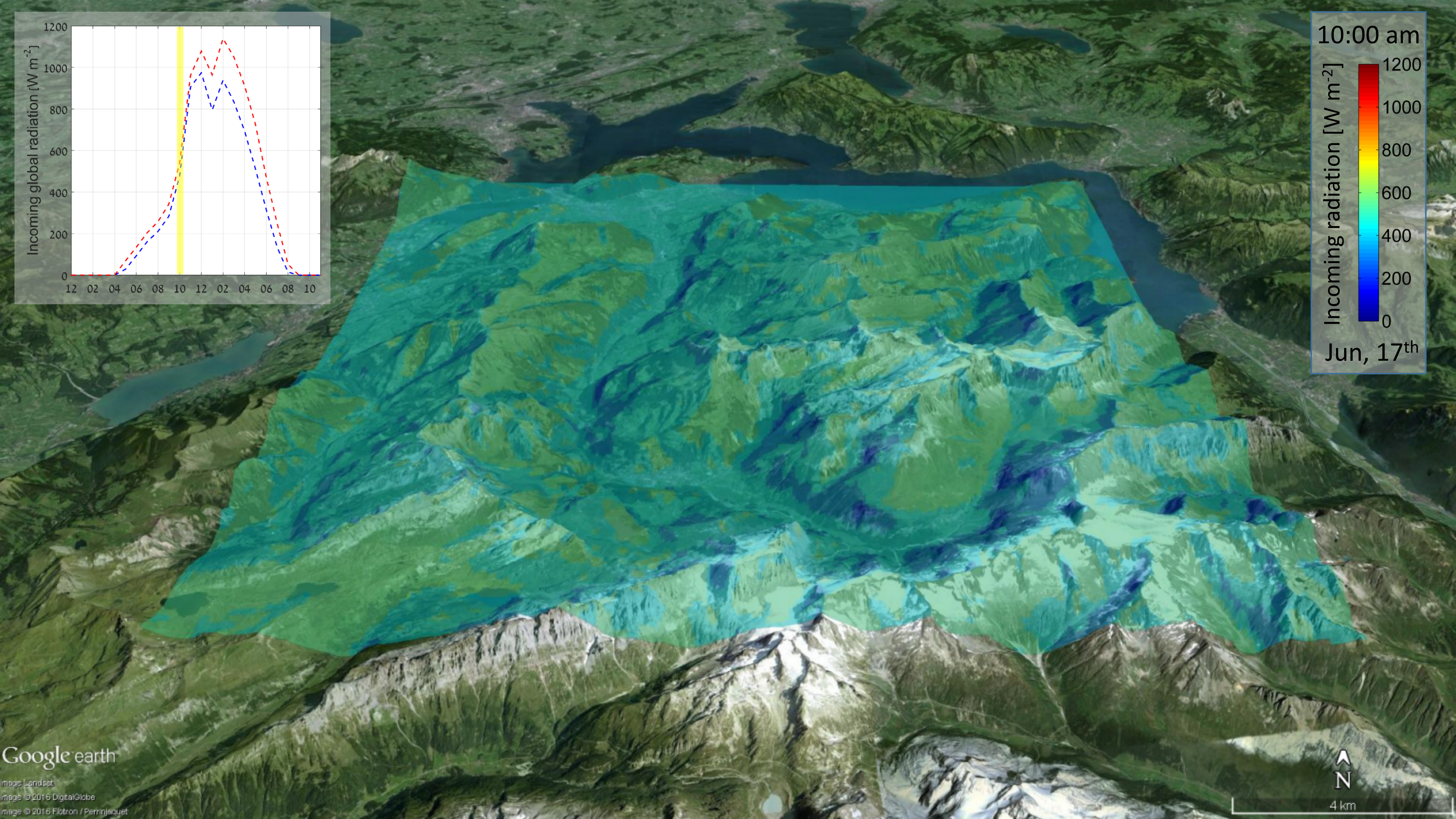

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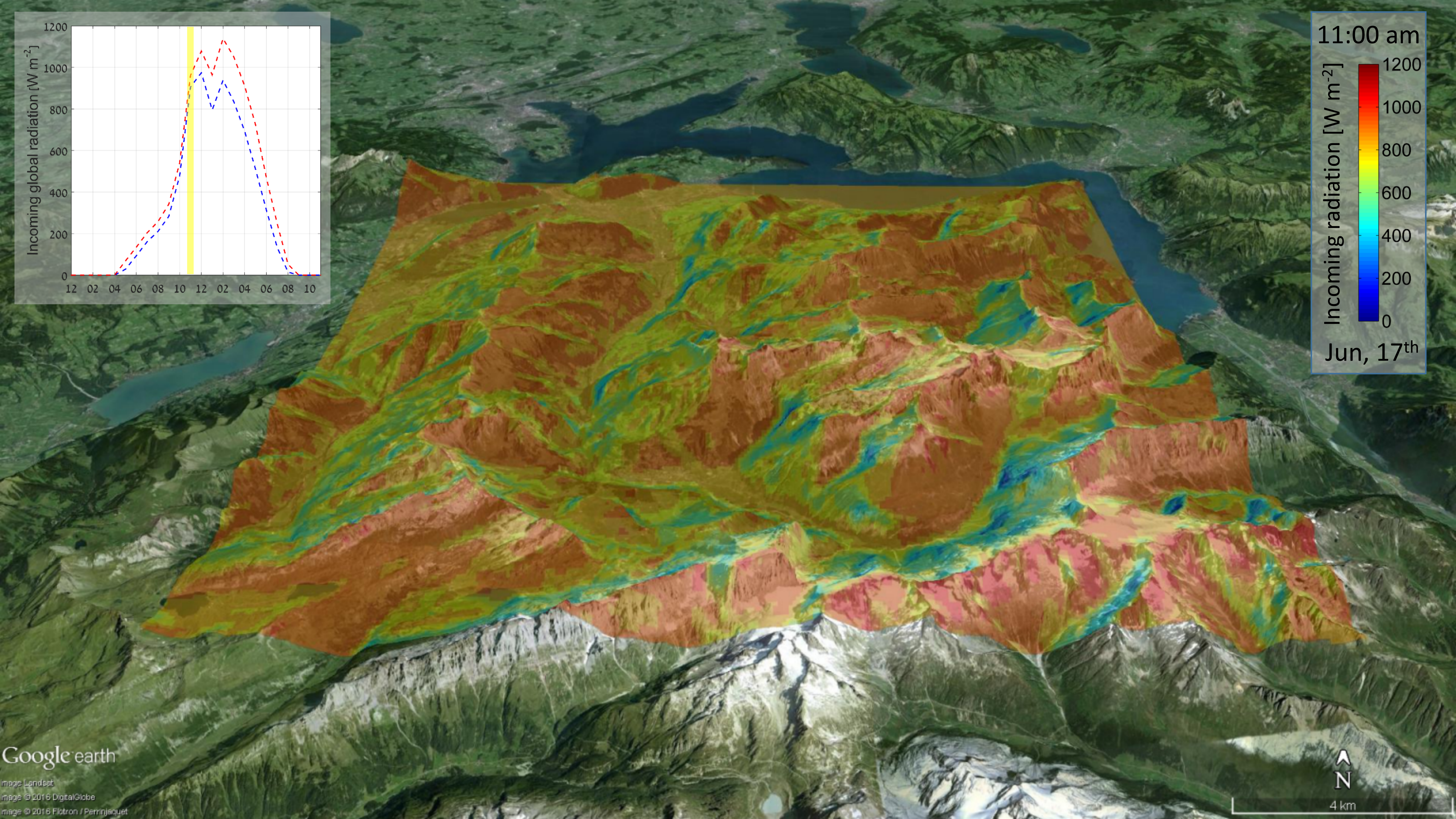

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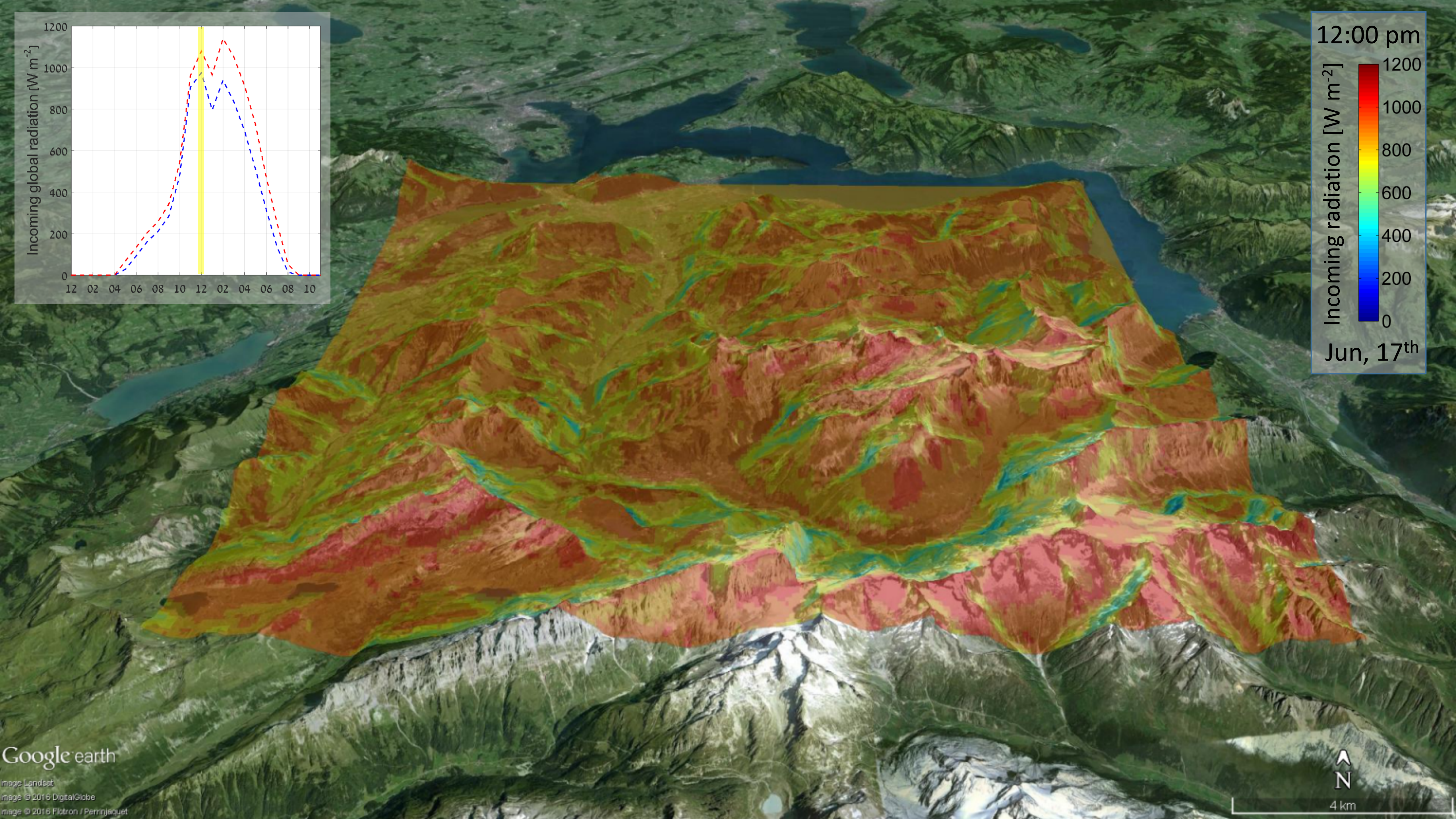

Incoming global radiation [W m-2]
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Incoming radiation [W m-2]
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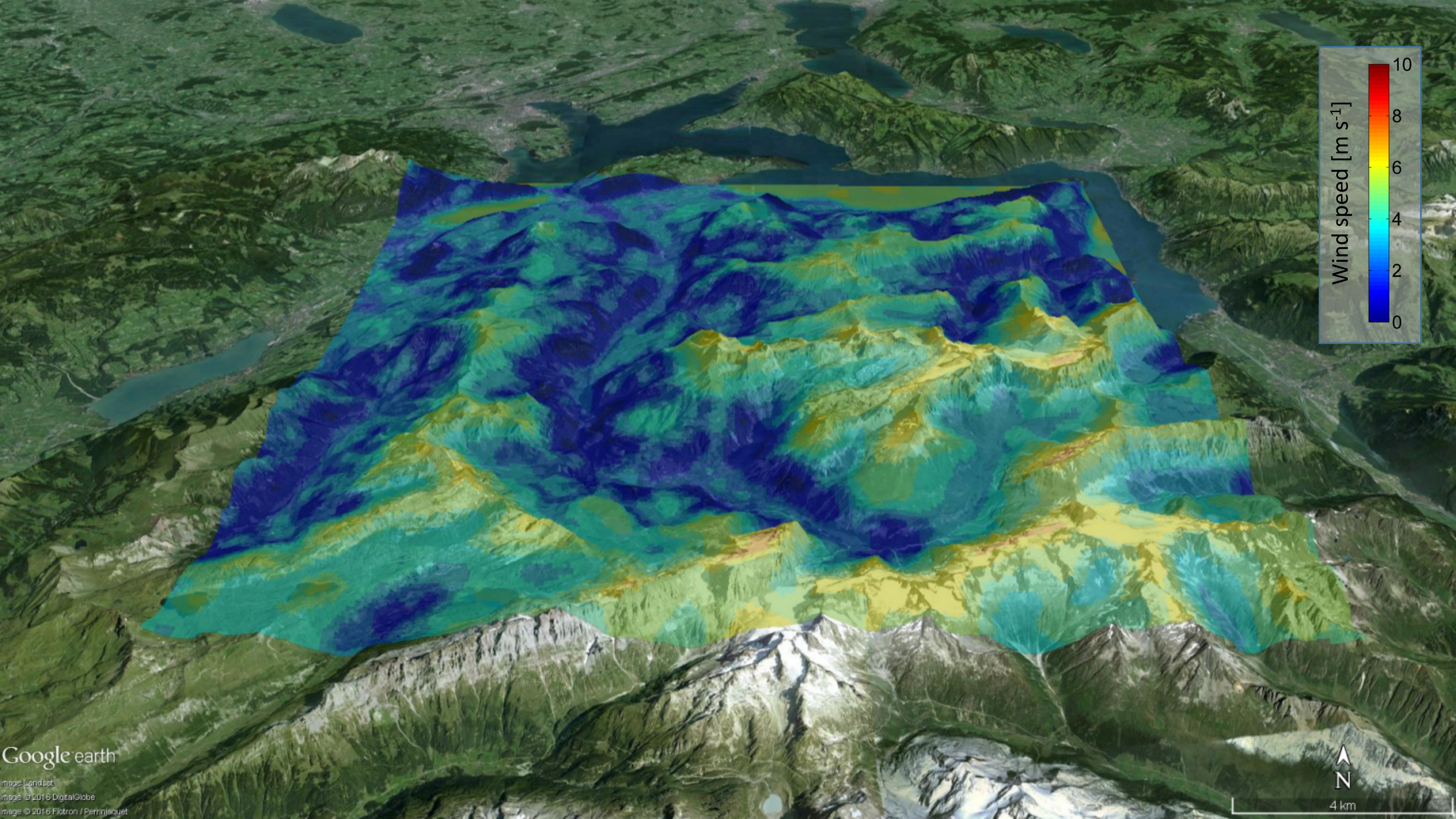
Jun, 17th
Google earth
Image Landsat
Image © 2016 DigitalGlobe
Image © 2016 Flotron / Perrinjaquet
N
4 km

Near-surface wind speed

- Near-surface wind speed is computed from the geostrophic wind speed.
- The near-surface wind speed is calculated using the geostrophic drag law (mass conservation component is not implemented), which requires a simplified computation of the Monin-Obukhov length, the friction velocity per grid cell, and the PBL height.
- The atmospheric stability is determined through the Pasquill stability classes (from extreme unstable to very stable atmospheric conditions), which is determined based on the shortwave incoming solar radiation and the cloud cover.
- Topographically driven wind correction is applied (optional).



Wind speed [m s-1]
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Google earth
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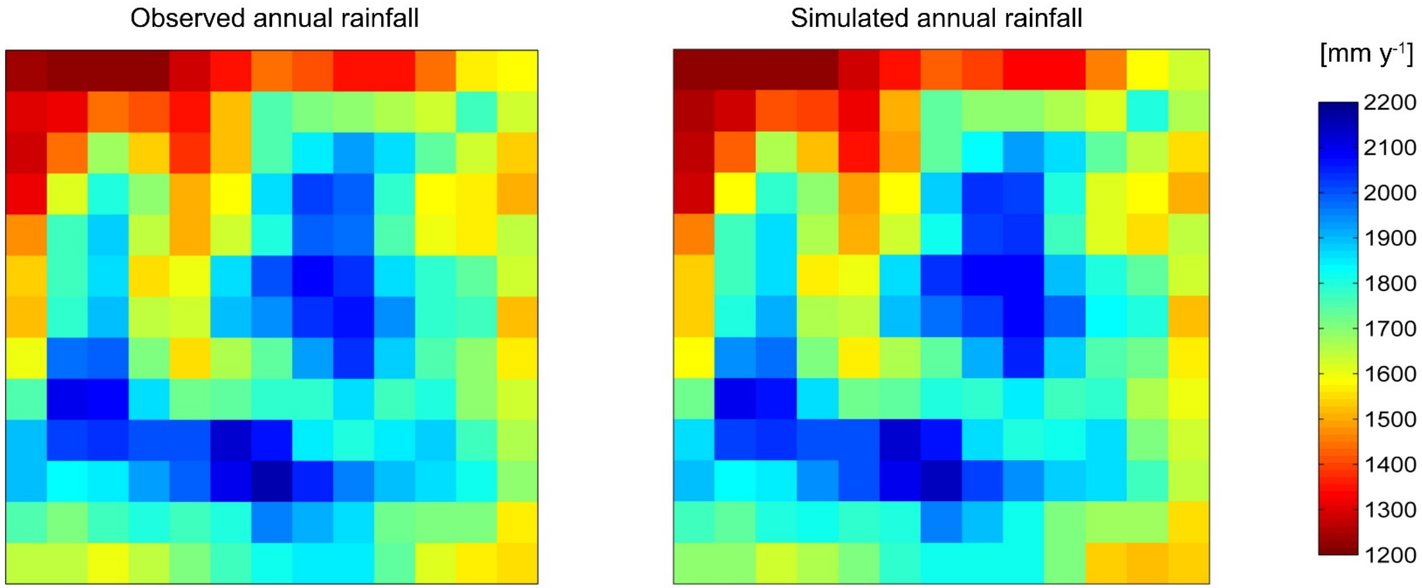
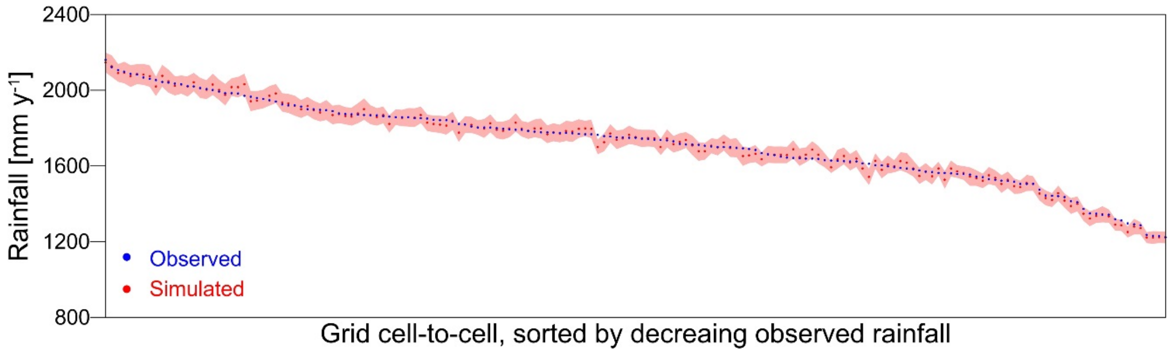
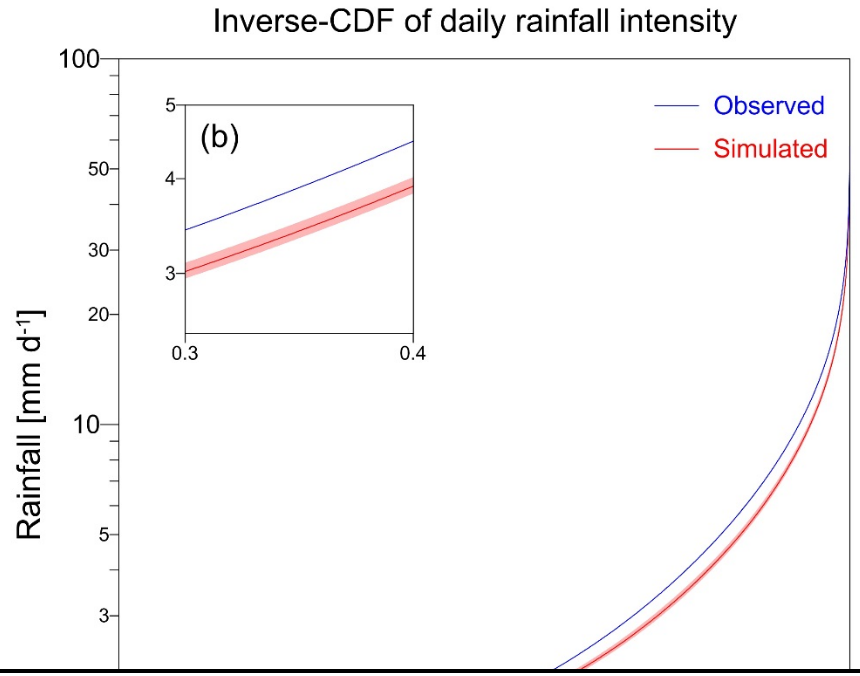
Model validation

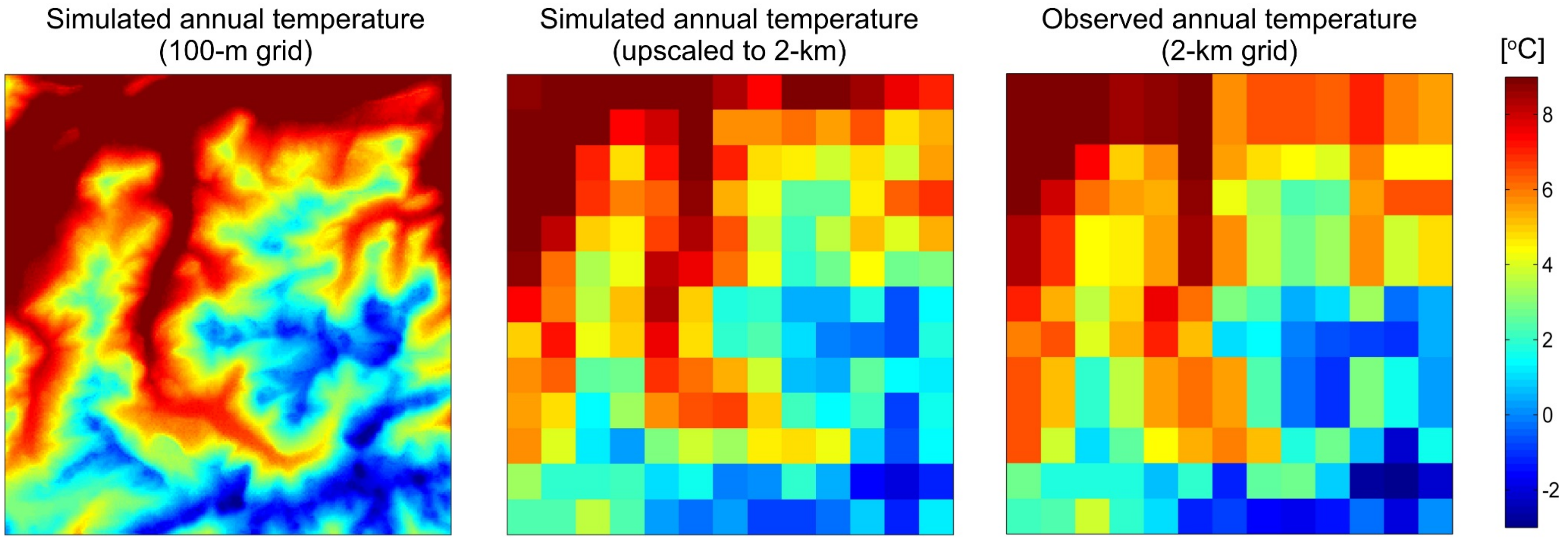


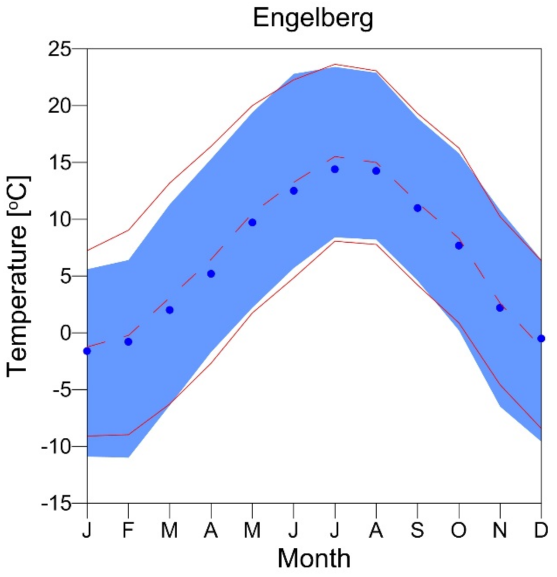


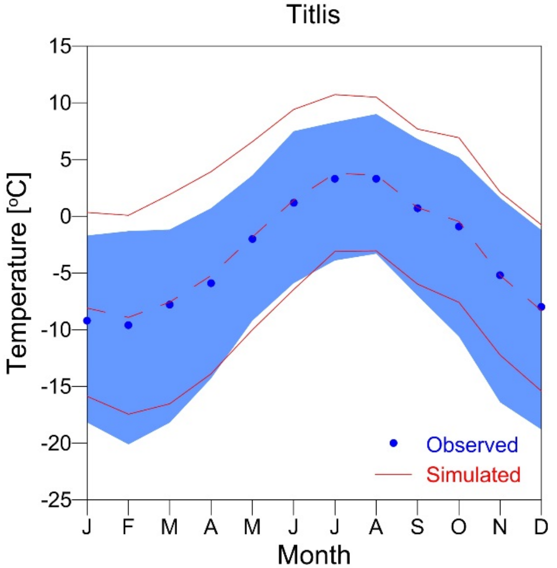


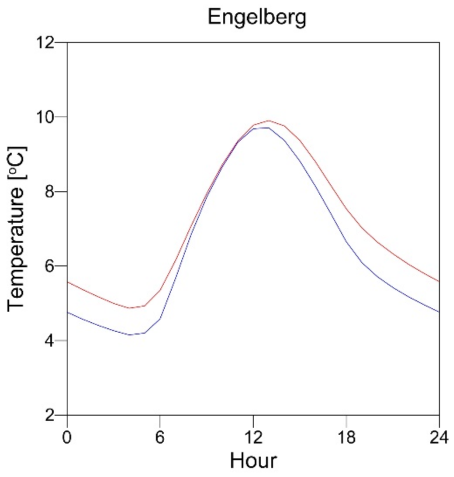
- Obs.: 30 years of data
- Sim.: 50 realizations, each of 30 years

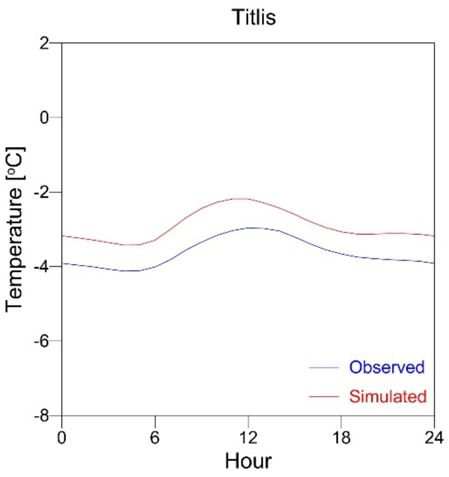
Temperature



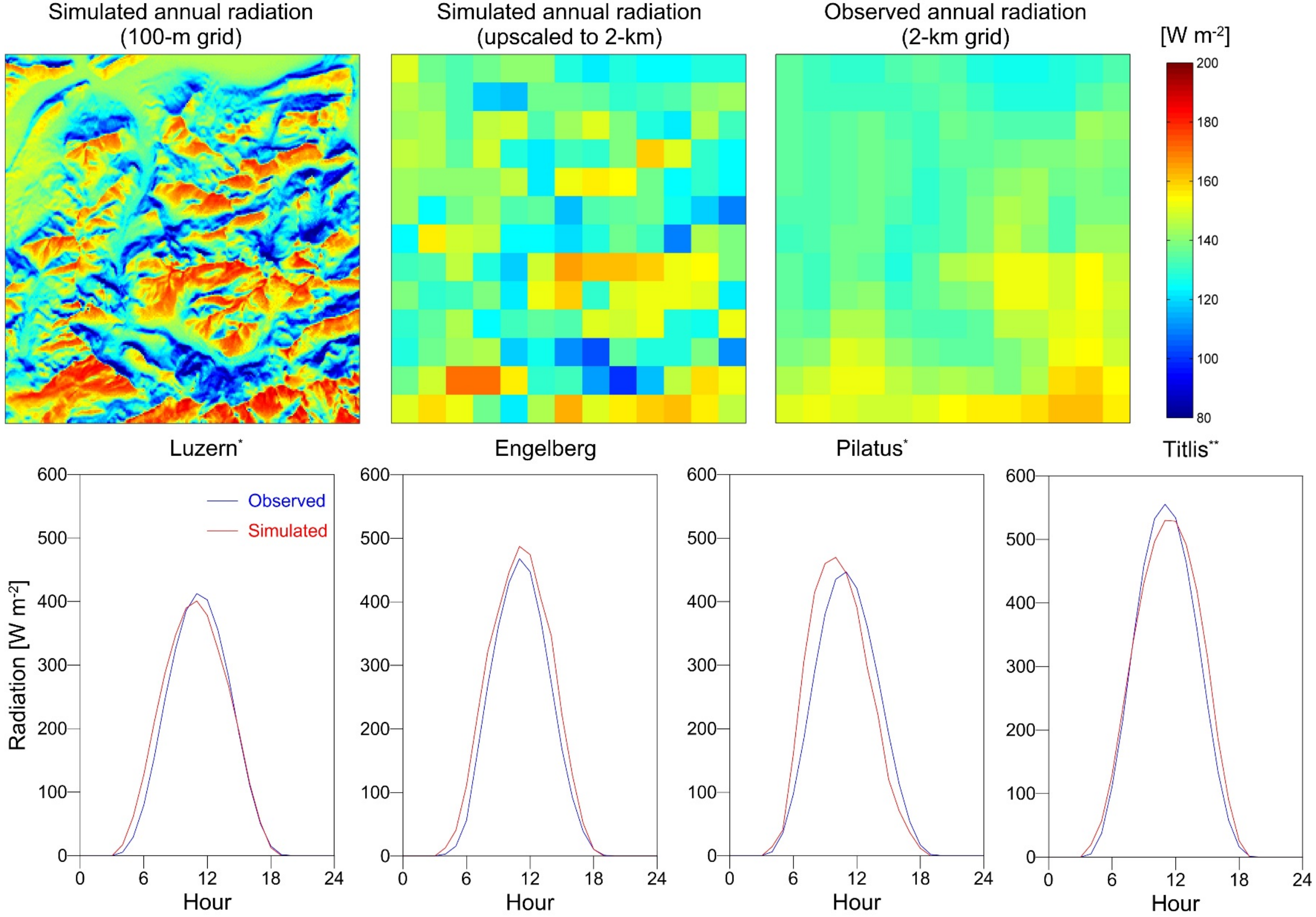


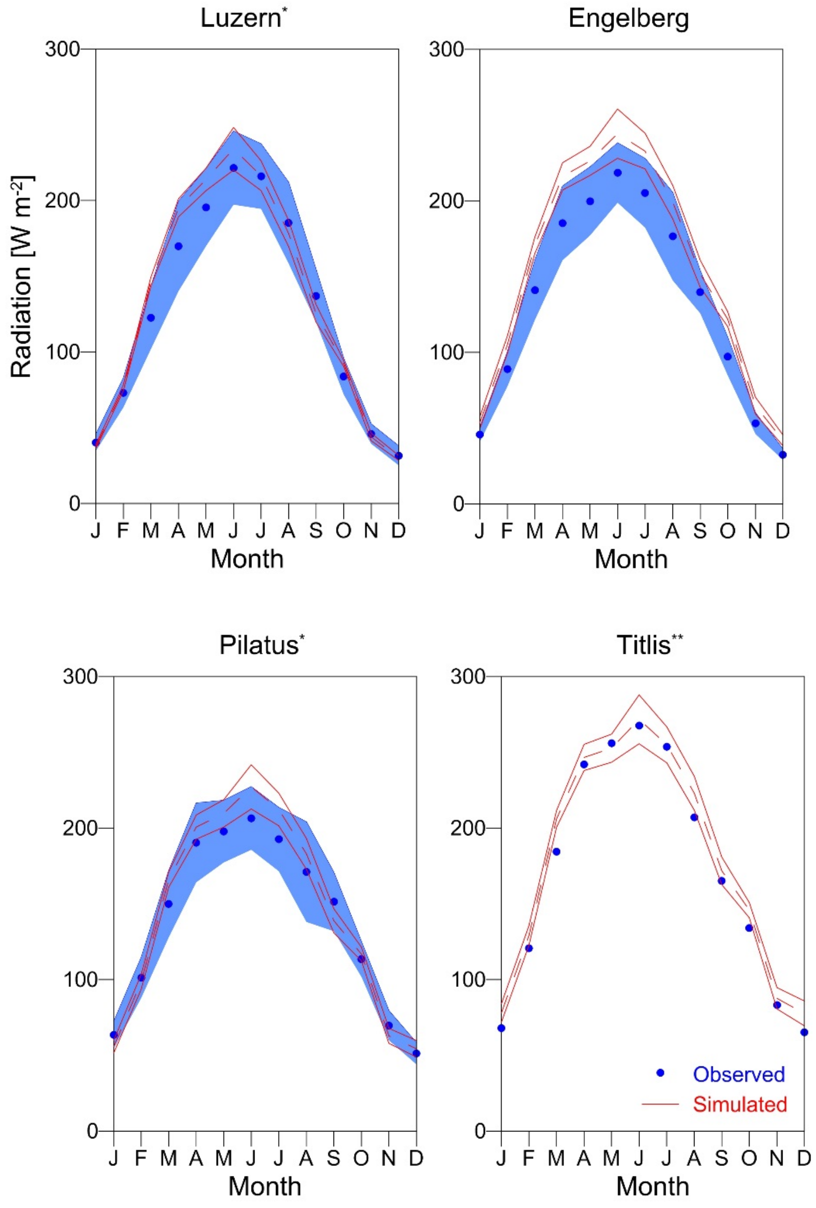




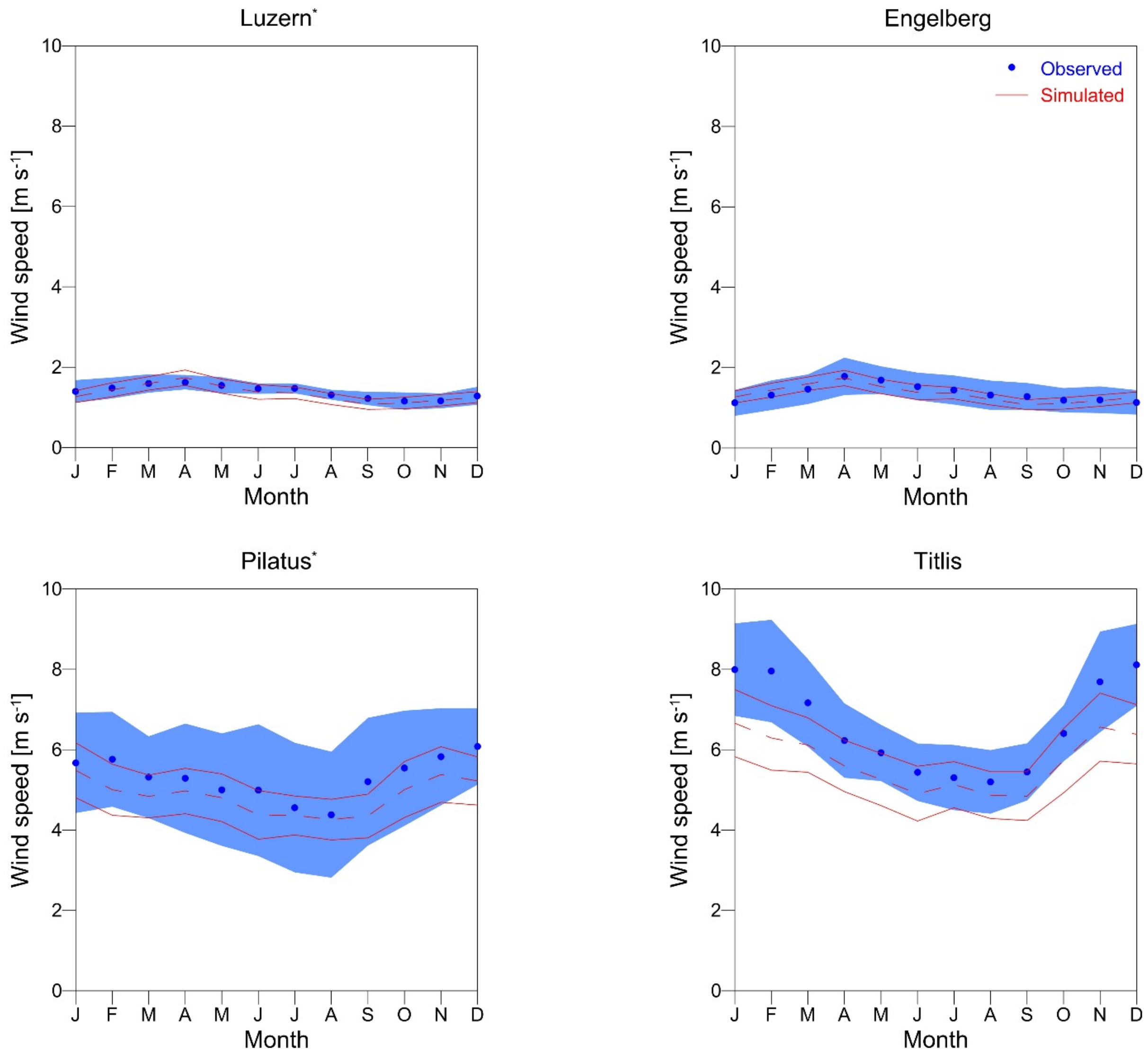


Shortwave radiation





Wind speed


Luzern*
Engelberg
Observed
Simulated
Pilatus*
Titlis
Wind speed [m s-1]
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J F M A M J J A S O N D
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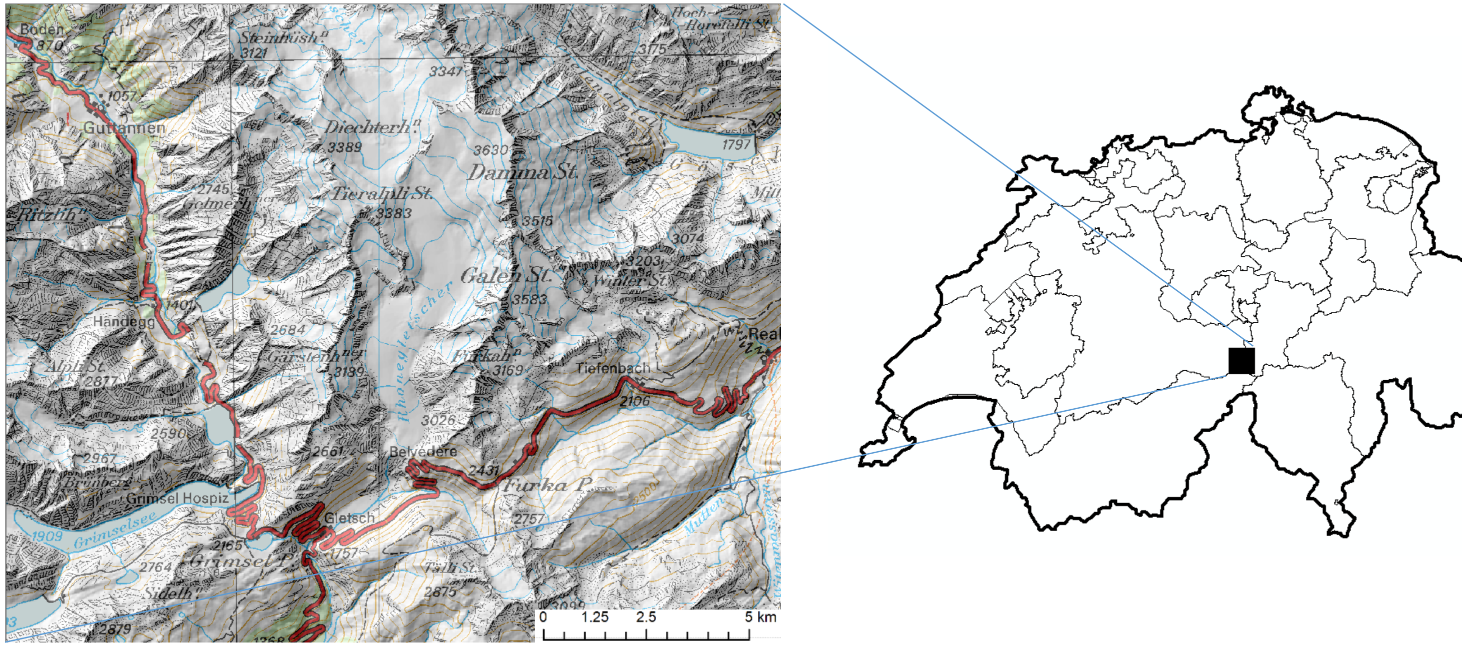
High spatio-temporal resolution climate scenarios for snowmelt modelling in small alpine catchments

- This project aim to support economic risk assessments of long-term investments for small hydropower plant operations.

- The impact of climate change on distribution and frequency of snowmelt is examined using AWE-GEN-2d and a high-resolution energy balance snow cover model (JIM/FSM).

Gletsch



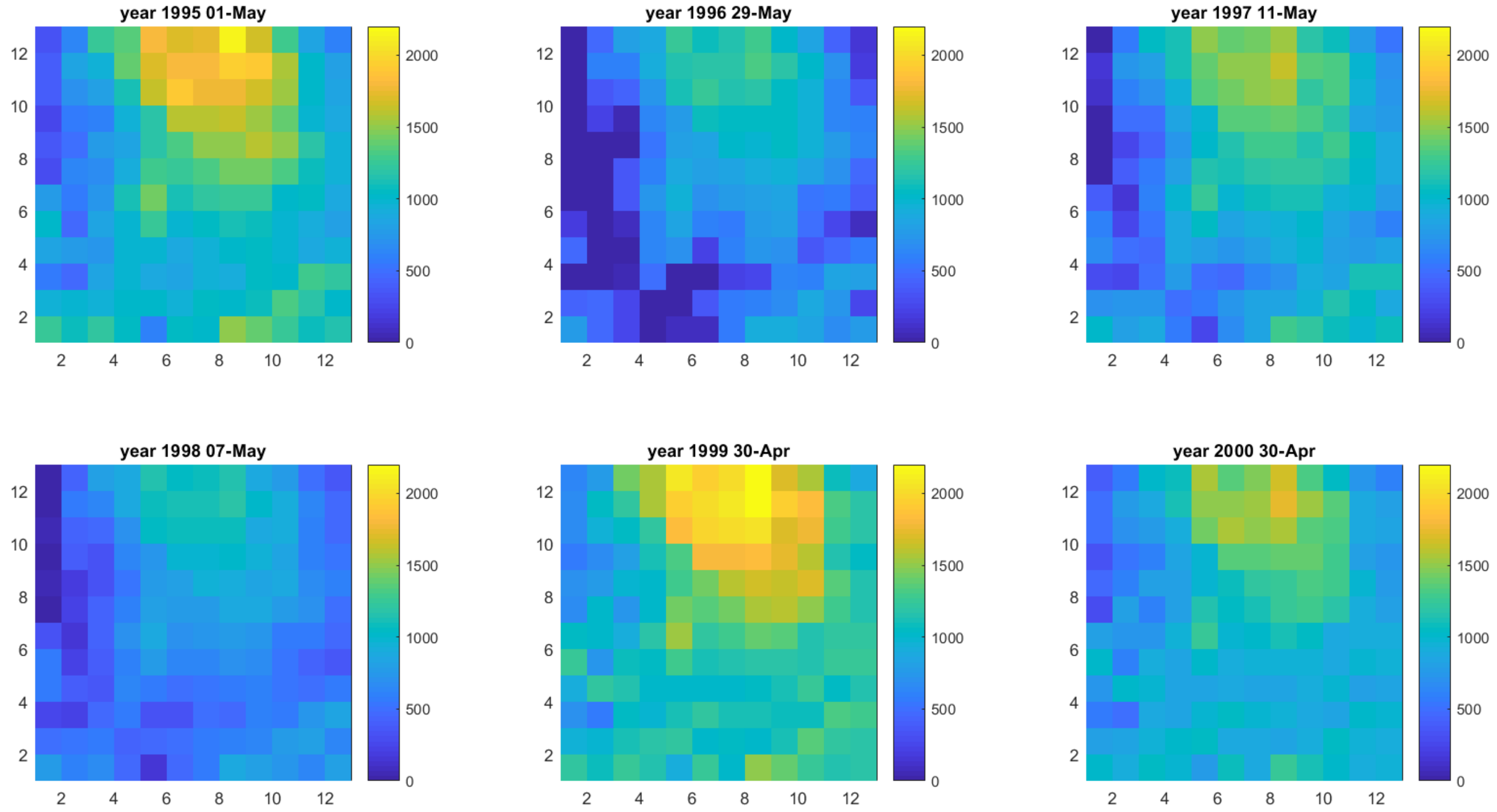
Area: 39.8 km^2
Glaciation: 52%
Mean elevation: 2719 m a.s.l.

Schirmer, Burlando, Jonas

High spatio-temporal resolution climate scenarios for snowmelt modelling in small alpine catchments

Snow Water Equivalent

- SWE in mm at peak of the season
- 10 years available / 4 realization of 30 years
- 1 km resolution / 100m resolution



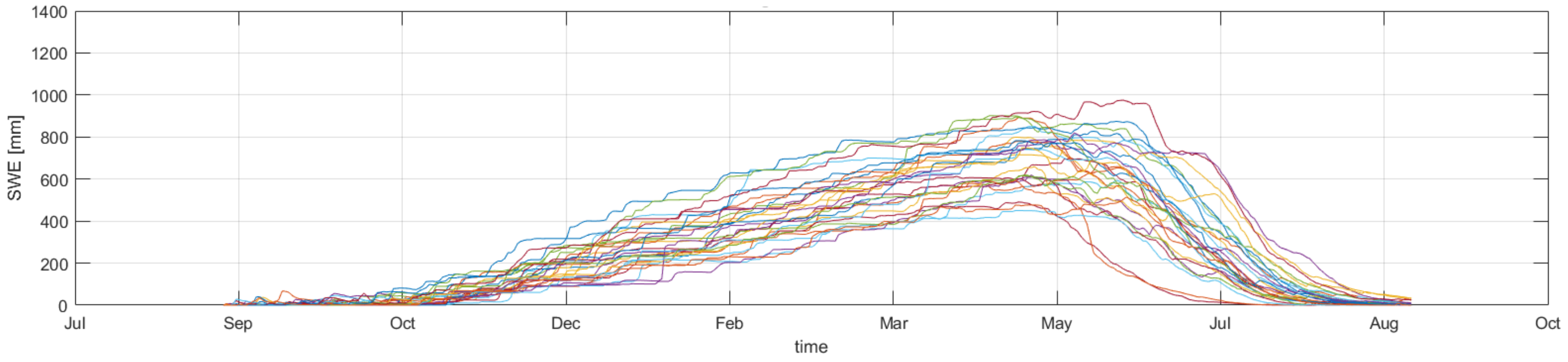
Schirmer, Burlando, Jonas

High spatio-temporal resolution climate scenarios for snowmelt modelling in small alpine catchments

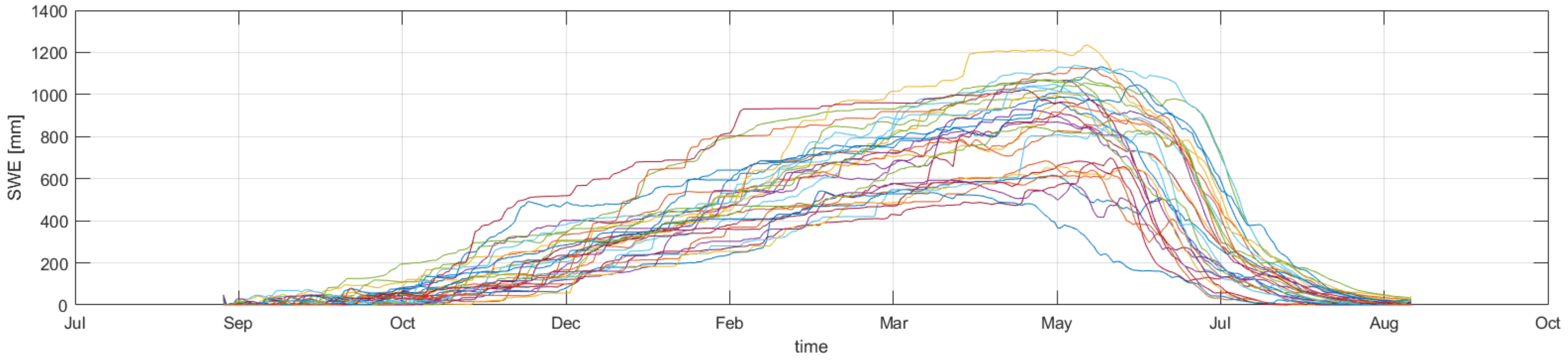
Snow Water Equivalent

- Temporal SWE
- Dynamics are well preserved
- Work in progress…

Simulated



Observed



Schirmer, Burlando, Jonas

Thank you for your attention!

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AWE-GEN-2d paper:

Peleg, N., Fatichi, S., Paschalis, A., Molnar, P., and Burlando, P. (2017): **An advanced stochastic weather generator for simulating 2-D high resolution climate variables**. *Journal of Advances in Modeling Earth Systems*, 9, p. 1595-1627.