Modeling groundwater head declines in major cities of the world: current situation & future projection

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Edwin H. Sutanudjaja – e.h.sutanudjaja@uu.nl
https://www.uu.nl/staff/EHSutanudjaja



Utrecht University



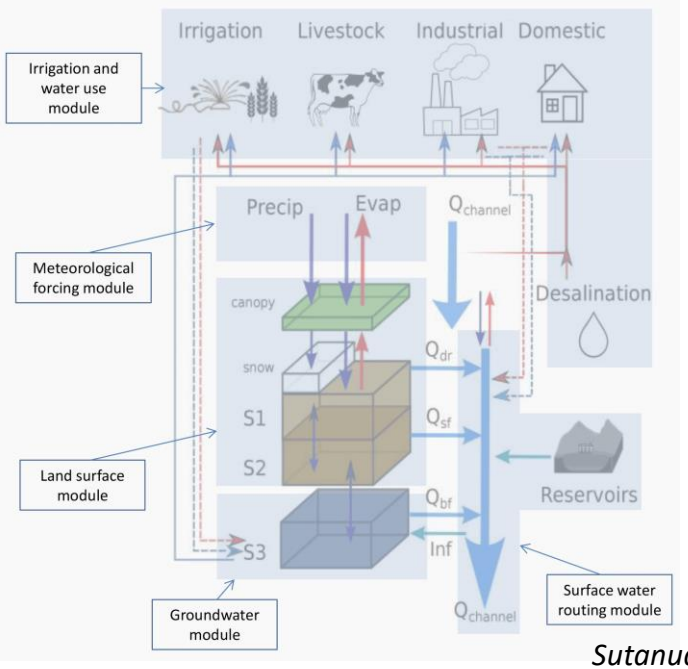
Highlights / Outline

- I am currently further developing PCR-GLOBWB (global hydrological model) and GM-GLOB (MODFLOW-based groundwater model) for modeling current/historical and future global groundwater head changes **with focus on cities/urban areas**.

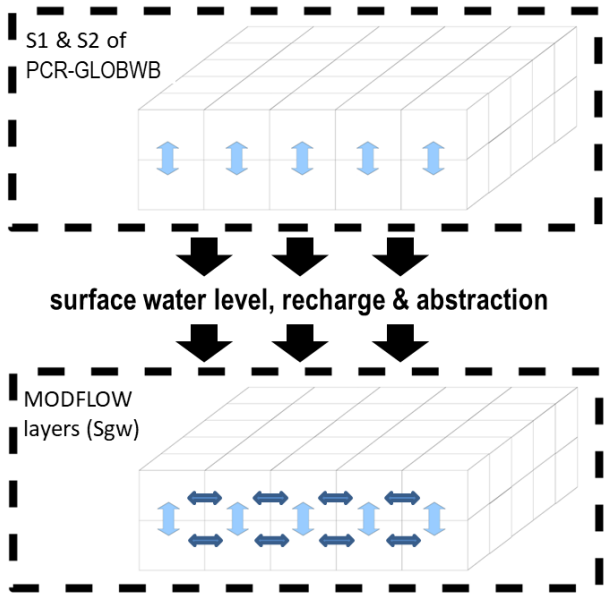
- The slides 7-13 show maps of rates of groundwater head declines, i.e. current (historical): 1971-2010 (left maps) and future (RCP 4.5, SSP2): 2011-2050 (right maps), for various locations (with focus on cities).
  - The spatial resolution of the model is 5 arcmin (~10 km at the equator).

- New and more areas, including cities, with falling groundwater head problems would occur, not only due to climate change (i.e. in areas that become dryer), but also due to increasing population and expansion of urban areas.

PCR-GLOBWB (hydrology) & GM-GLOB (modflow, groundwater)



Sutanudjaja et al., 2018



Sutanudjaja et al., 2011, 2014;
de Graaf et al., 2015, 2017, 2019

- **Spatial resolution: 5 arcmin (~10 km at the equator)**
- The improved versions of PCR-GLOBWB and GM-GLOB (MODFLOW) are currently developed in this study. List of improvements (not exhaustive):
  - Improving rules in allocating desalinated, ground-, and surface water to satisfy water demand, i.e. based on literature studies and inventory data of water infrastructures, e.g. from the City Water Map (McDonald et al., 2014), UNEP, UNDP and World Bank.
  - Improving MODFLOW schematization (e.g. varying cell areas across latitudes).

Scenario (assumptions):

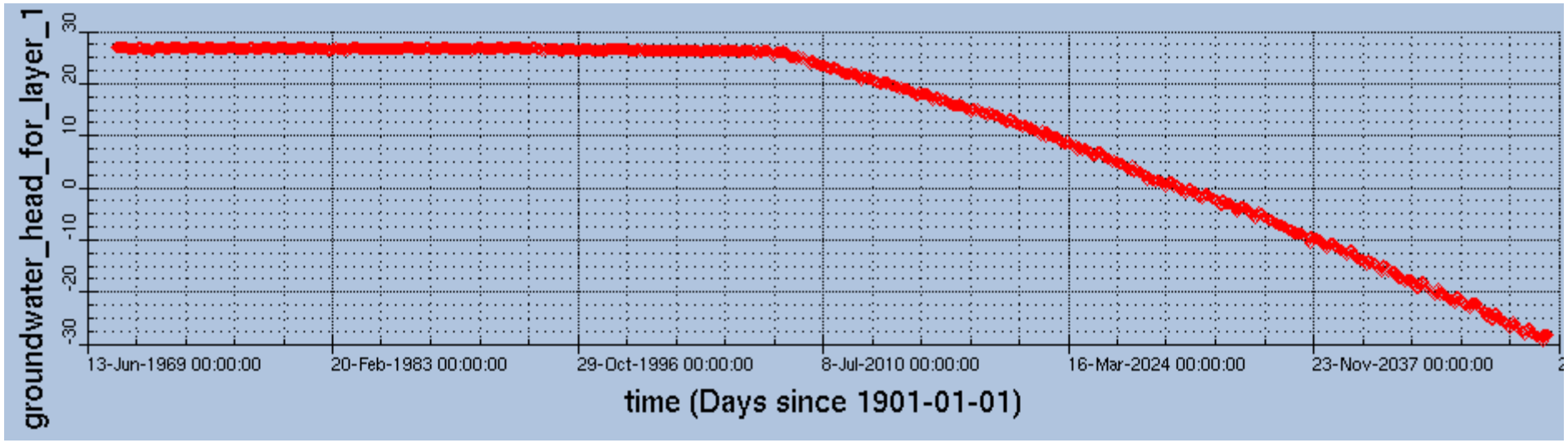
- Current (historical): 1971-2010
  - Forcing: CRU-ERA
  - Historical domestic and industrial water demand data.
  - Historical development/expansion of urban areas.
  - Historical development/expansion of irrigated areas.

- Future projection (**RCP 4.5, SSP2**): 2011-2050
  - Forcing: RCP 4.5, HadGEM2-ES, from ISI-MIP CMIP5 (Hempel et al. 2013), and bias corrected to CRU-ERA
  - **Domestic & industrial demands follow SSP2** based on the IMAGE model prediction of urban areas and population density (van Vuuren et al., 2017)
  - **Expansion of urban area follows SSP2 of the IMAGE model**
  - **Fixed irrigation area extent is assumed after 2010. Yet, areas that become drier (due to climate change) would require higher irrigation supply.**

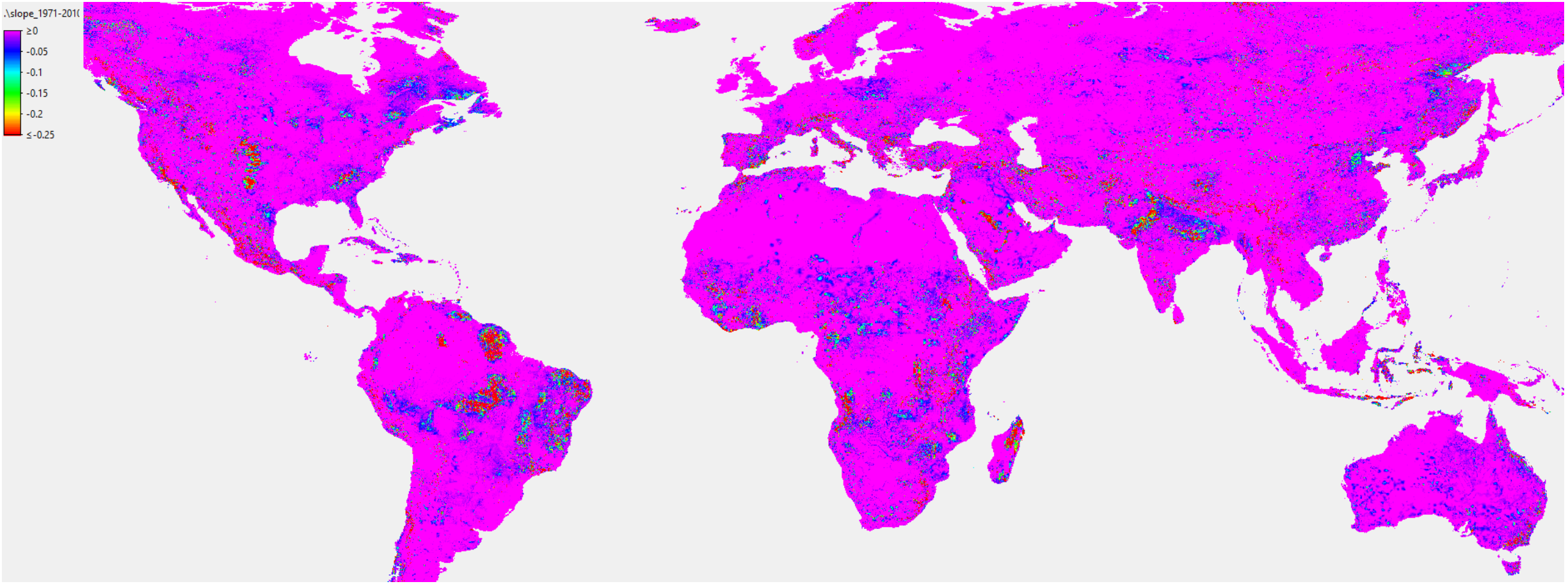
- Both current and future runs/scenarios use the same rule for allocating desalinated, ground-, and surface water to meet water demands.
  - Basically, this means that water infrastructure/network extents/coverages stay the same for the current and future runs.

Illustration: simulated groundwater head time series

- Monthly time series of groundwater heads for the period 1971-2050.
- For this pixel, groundwater abstraction just started in 2011 (most likely, due to urban area expansion)



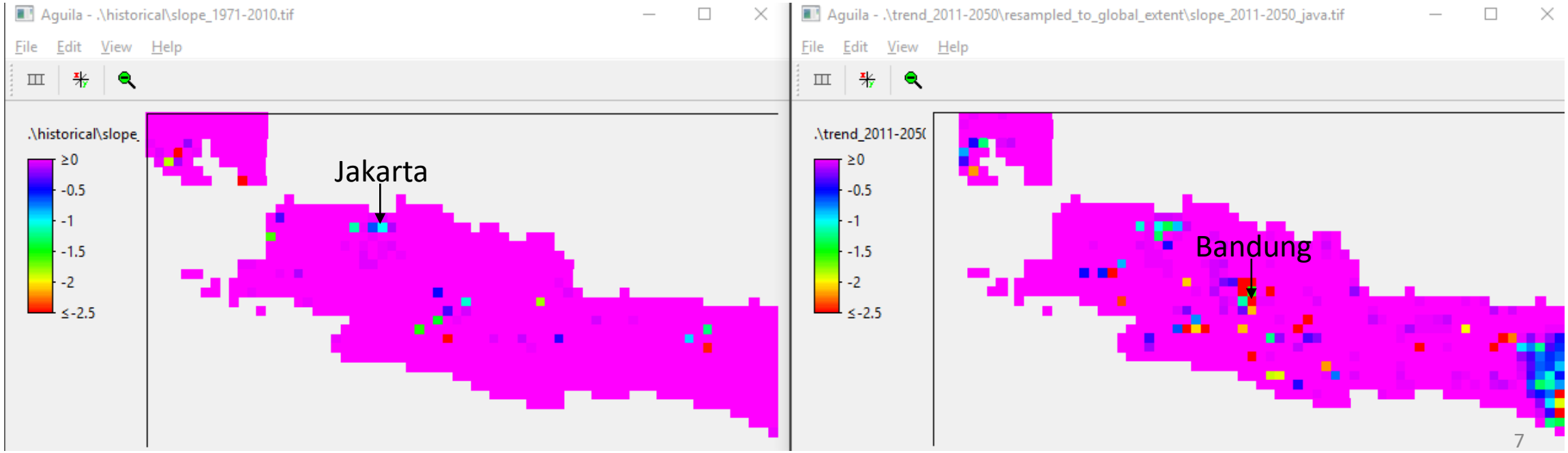
Rates (m/yr) of groundwater head declines, 1971-2010



- Irrigated areas depleting groundwater can be seen.
- Yet, to identify cities with groundwater decline problems, we have to zoom in.

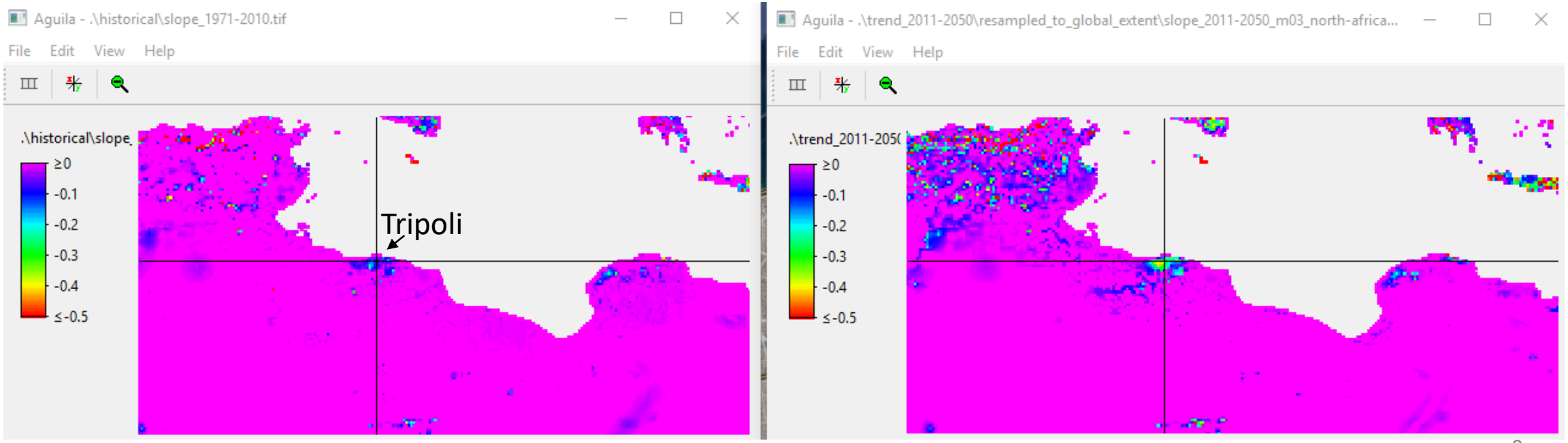
Java Island, Indonesia

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050
- The spatial resolution of the model is 5 arcmin (~10 km at the equator).
- Negative values indicating declines.
- Jakarta (1971-2010: -1.00 m/yr; 2011-2050: -1.35 m/yr), Bandung (-1.00; -2.00)



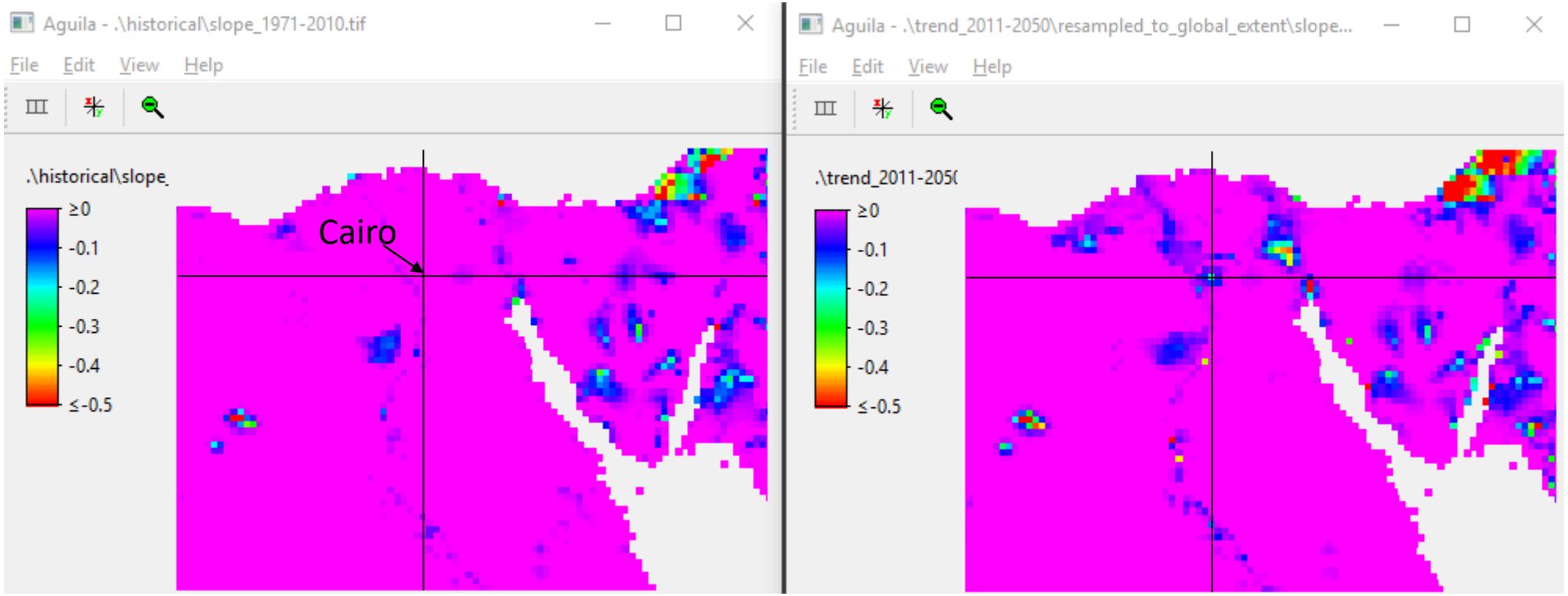
North Africa

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050
- Tripoli, Libya (1971-2010: -0.09 m.year-1; 2011-2050: -0.31 m.year-1)



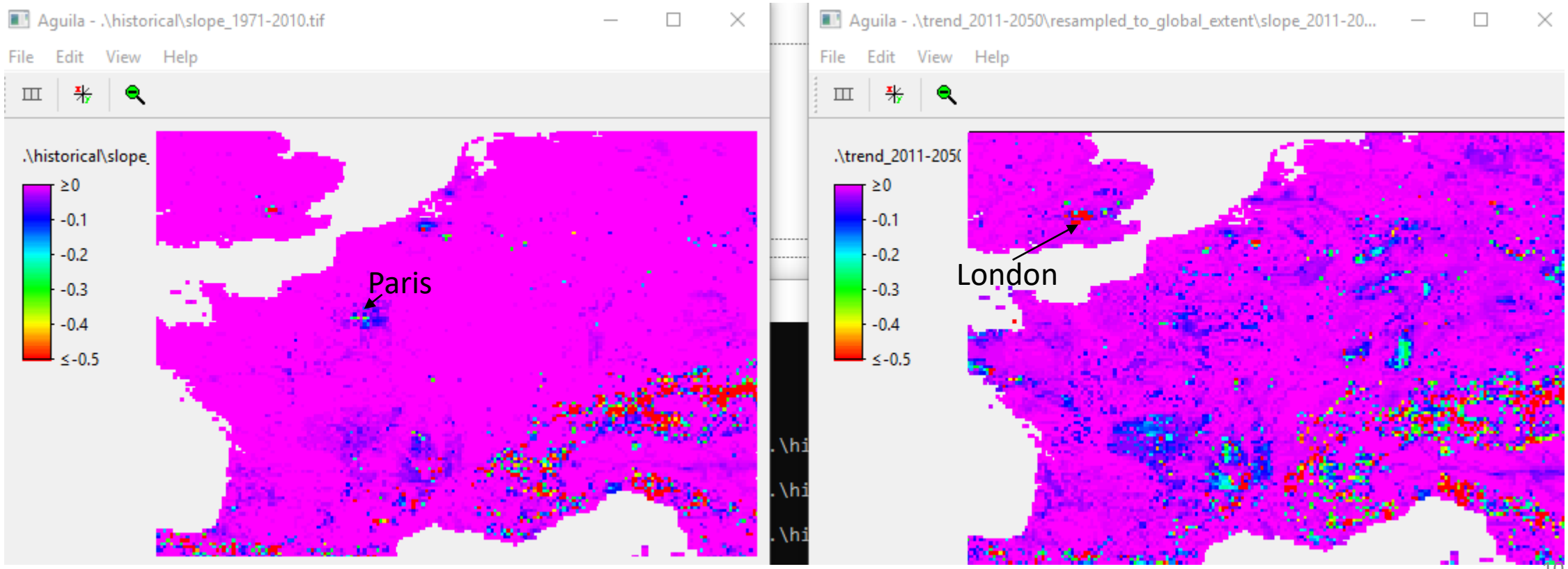
Egypt

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050
- Cairo (1971-2010: 0.07 m.year-1; 2011-2050: -0.23 m.year-1)



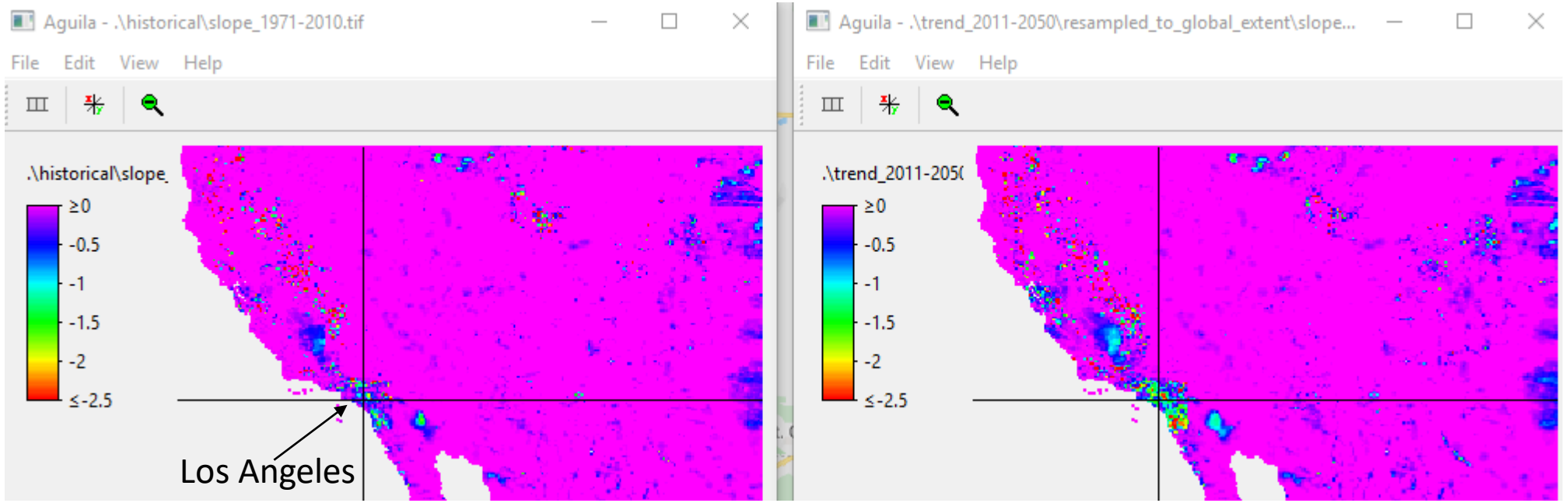
Europe

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050



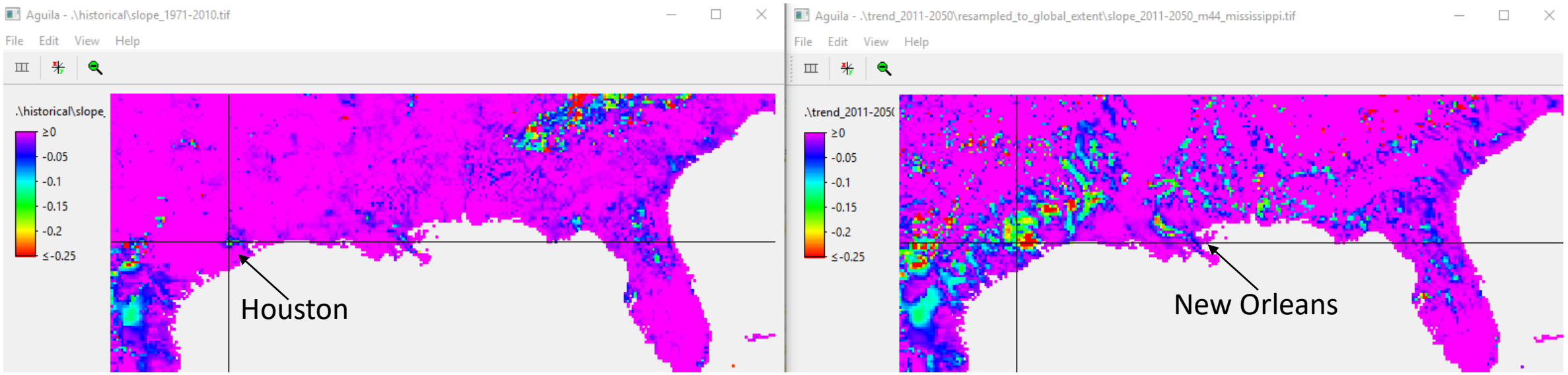
California, US

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050



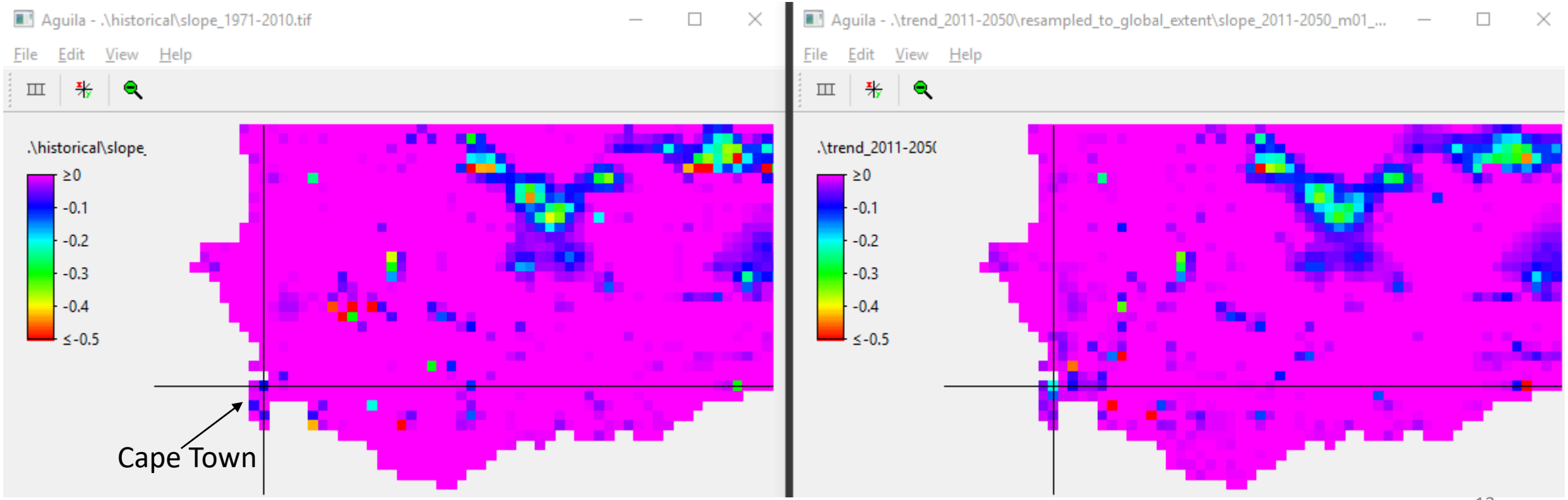
US (Houston, New Orleans, Florida)

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050



Cape Town, South Africa

- Maps showing rates (m.year-1) of declines, left: 1971-2010; right: 2011-2050
- Cape Town (1971-2010: -0.09 m.year-1; 2011-2050: -0.21 m.year-1)



Conclusion:

- New and more areas, including cities, with falling groundwater head problems would occur, not only due to climate change (i.e. in areas that become dryer), but also due to increasing population and expansion of urban areas.

Ongoing/future works:

- Validating the historical run to observation data and independent studies
- Include more GCMs
- Include more RCPs and SSPs

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