Numerical simulation of urban influence on summertime precipitation in Tokyo - How does urban temperature rise affect precipitation?

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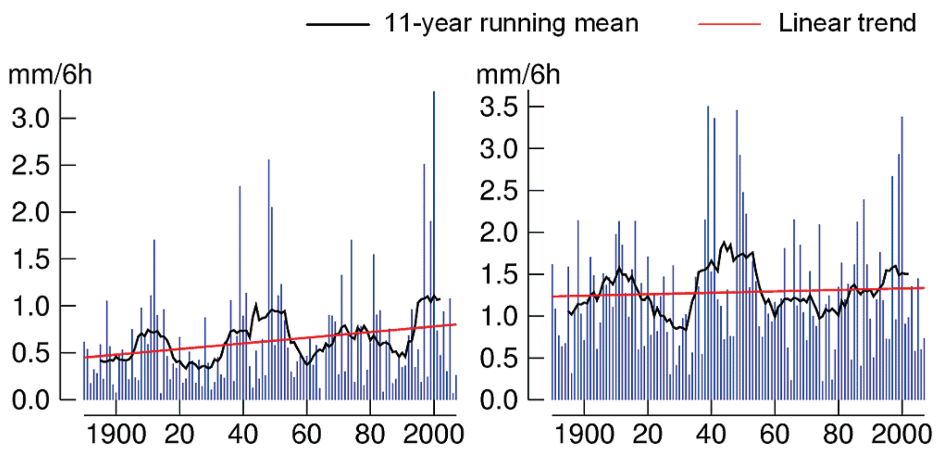
How much is urban impact on rainfall in Tokyo?

Long-term Change and Spatial Anomaly of Warm Season Afternoon Precipitation in Tokyo, Fujibe et al., 2009.



(a) NPP cases (b) All cases

Fig. 1. Six-hourly precipitation amount at Tokyo for 1700–2300 JST from June to August, averaged for NPP and all the cases. Each vertical bar (blue) indicates the value for each year.

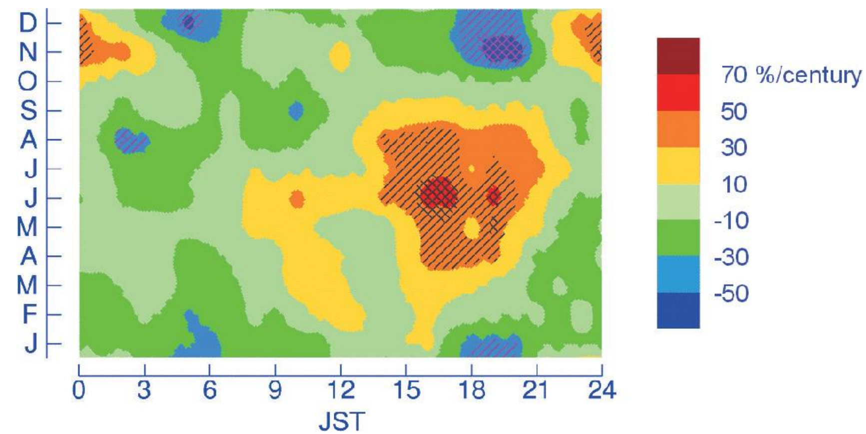
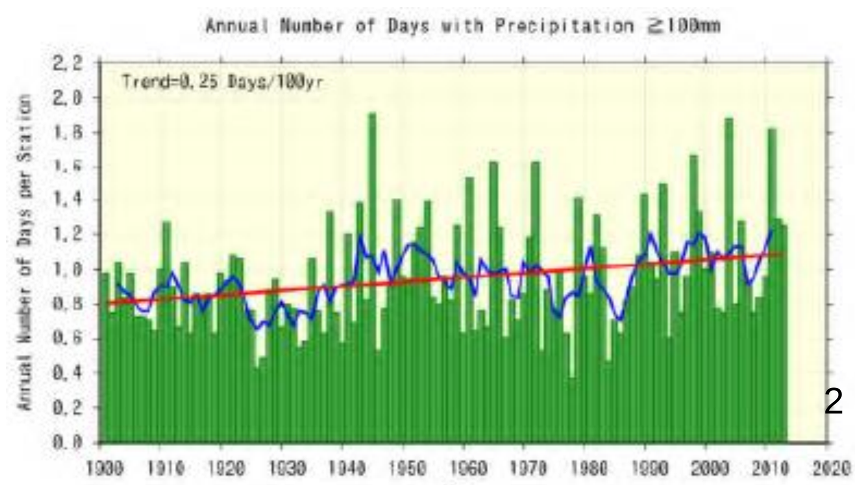


Fig. 2. Linear trend B/A for each time of the day and month for NPP cases. Hatching and double hatching indicate the regions where the trend is significant at the 5% and 1% levels, respectively.

Annual number of days with precipitation >= 100 mm in 51 stations in Japan

Climate change monitoring report (JMA, 2013) →



Aim of this study

・To evaluate the impact of intensified urbanization (temperature rise) in Tokyo on precipitation in its vicinity

- Comparative experiment to examine how urban temperature change in Tokyo affects monthly precipitation in its neighboring area.

Model

Non-Hydrostatic Model of JMA(JMA-NHM) with 2 km grid interval

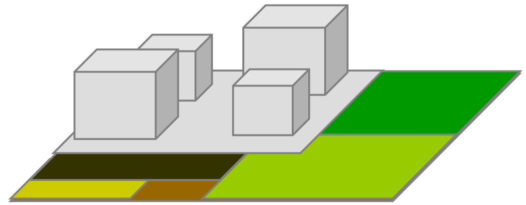
Specifications of NHM (Saito et al., 2006, 2007)

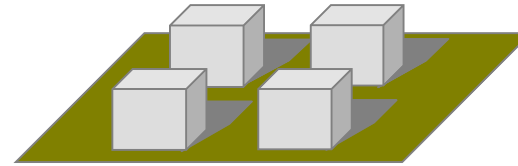
Governing equations	**Fully compressible, non-hydrostatic**
Discretization	**Grid point method, z*-coordinate**
Treatment of advection	**4th order flux form, advection corrected**
Map projection	**Lambert conformal projection**
Topography	**GTOPO30**
Cloud microphysics	**Bulk scheme with ice phase predicting qv, qc, qr, qi, qs, qg**
Cumulus parameterization	**Not used for dx < 4 km**
Turbulent closure	**Improved MY3(Nakanishi & Niino, 2006)**
Cloud radiation	**Kitagawa (2000)**
Clear sky radiation	**Yabu, Murai and Kitagawa (2005)**
Clouds in radiation processes	**Partial condensation scheme**
Surface flux	**Beljaars and Holtslag (1991)**
Urban canopy	**SPUC scheme (Aoyagi and Seino, 2011)**

Square Prism Urban Canopy scheme

SLAB

Grid-averaged surface properties based on 100m-mesh 11 categories land-use data

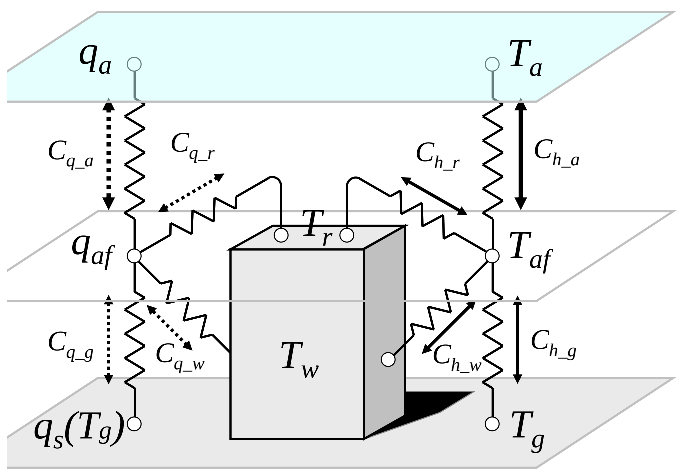




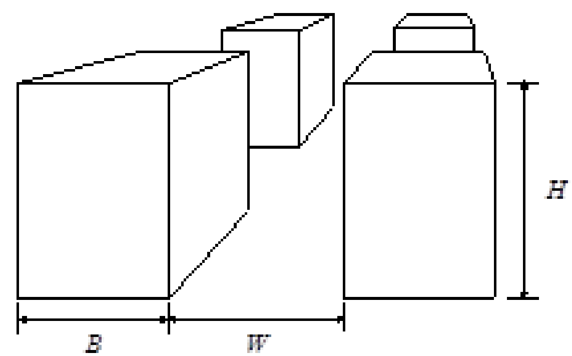
SPUC

Heat, moisture, radiation exchanges between canopy elements and atmosphere are considered

- Regular array of buildings
- Aspect ratio H/B = 0.5 is used
- Precipitation trapping taken into account
- Anthropogenic heating (Senoo et al, 2004)

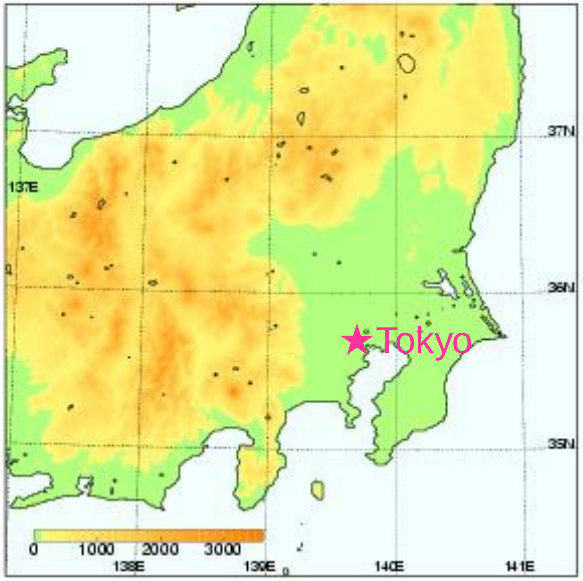


Aoyagi and Seino (2011)

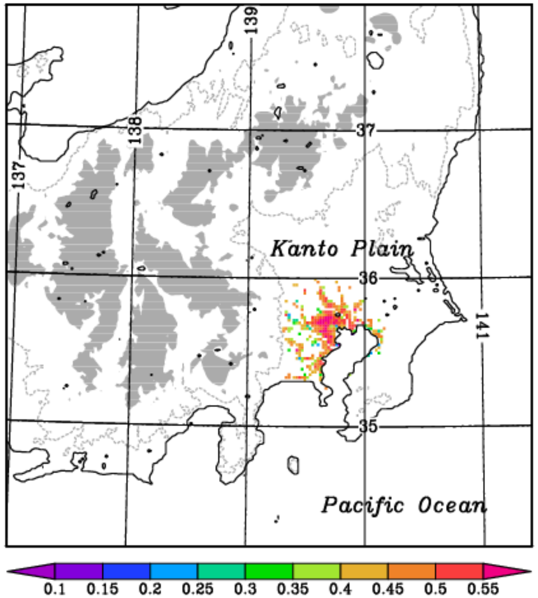


Experimental design

Model: JMA-NHM with/without SPUC
Domain: Central Japan dX=2km 200x200x50 grids
Initial/Boundary conditions: JMA Mesoscale Analyses
Period: August 2006-2013（8 years）
27-hour Integrations starting 21JST everyday



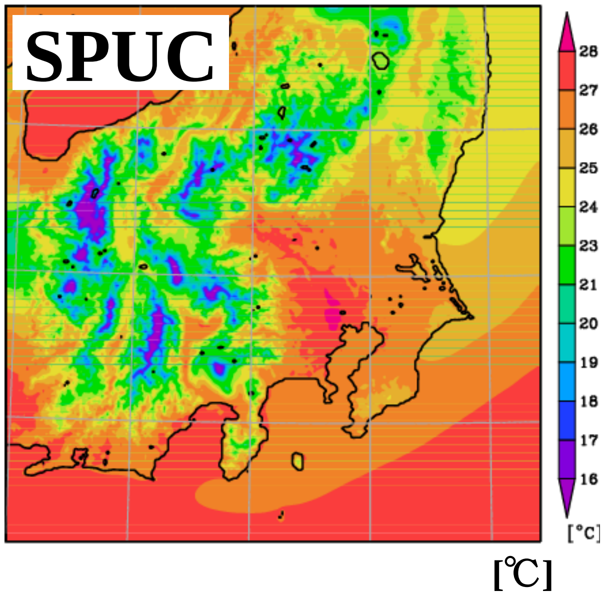
・SPUC is worked at grids where more than 80% of the grid area is occupied with urbanized land use

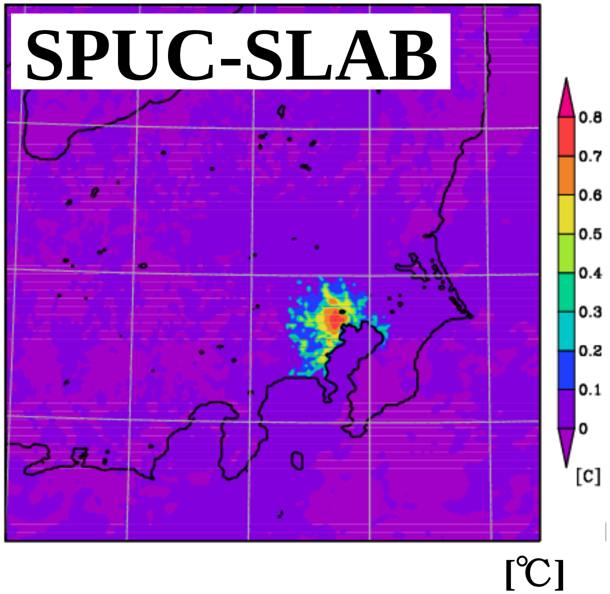


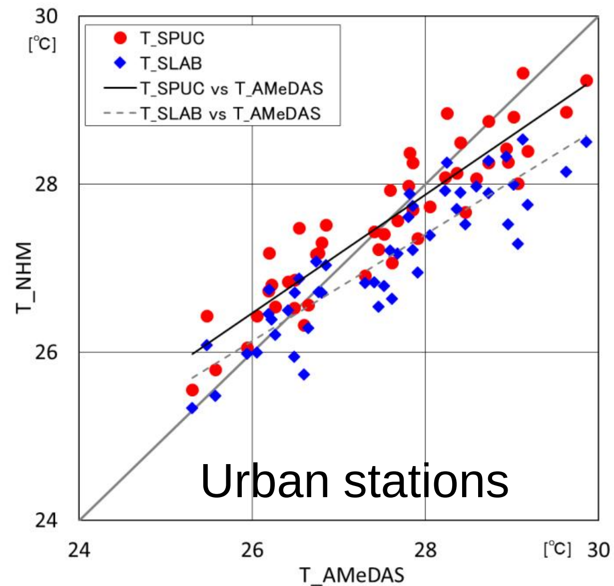
Building area fraction in SPUC-applied grids

Results： Simulated temperature

Monthly mean temperature: 2006-2013 mean





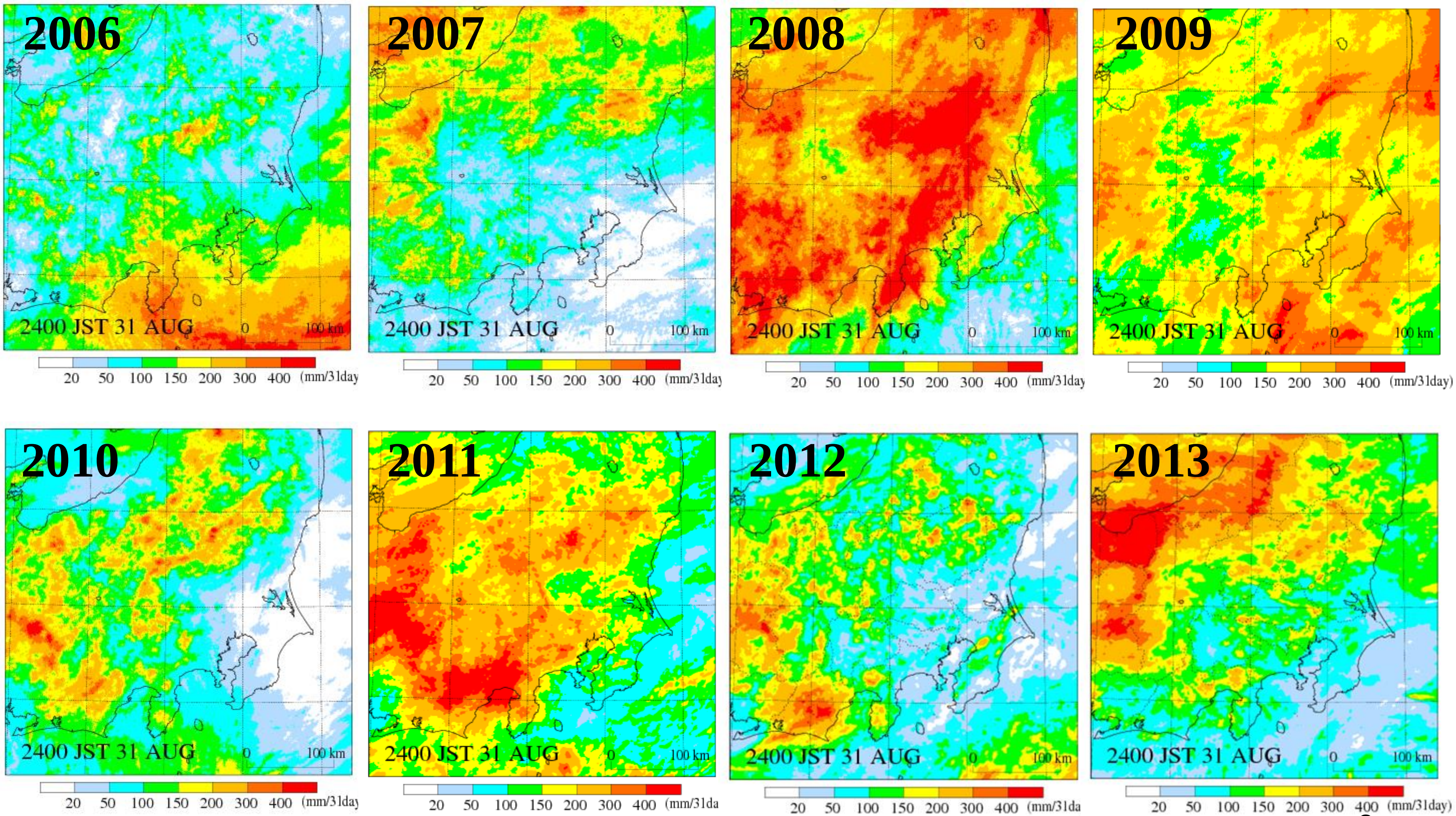


Temperature difference at most one degree existed between SPUC and SLAB simulations in central part of Tokyo

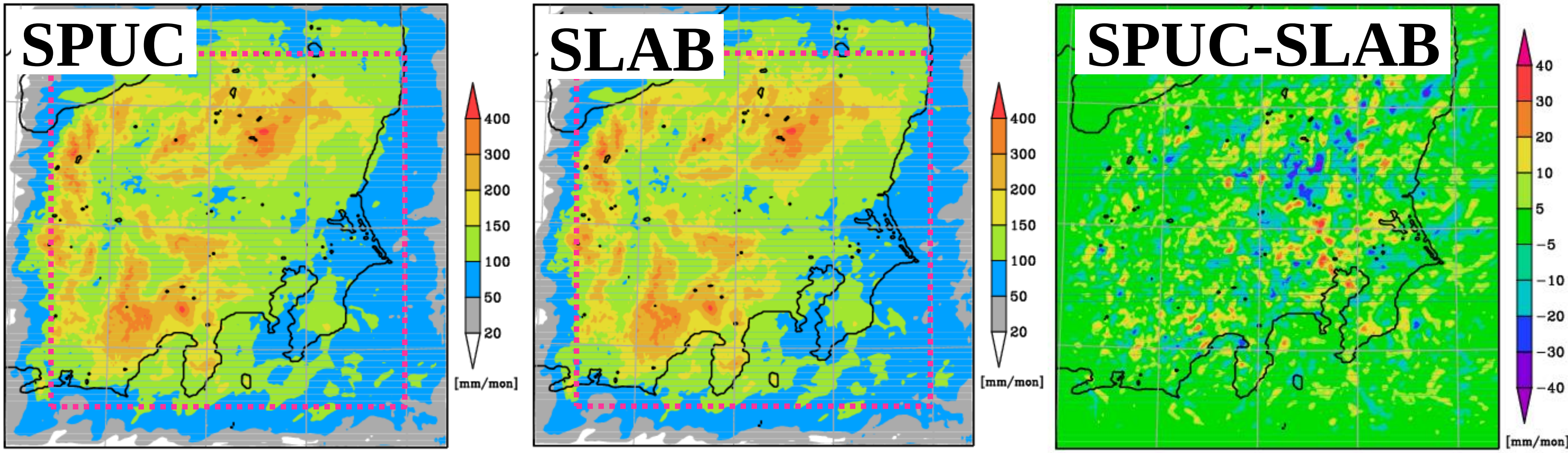
- **SPUC : mean temperatures agree well with observations**
- **SLAB : slightly lower temperatures are simulated**

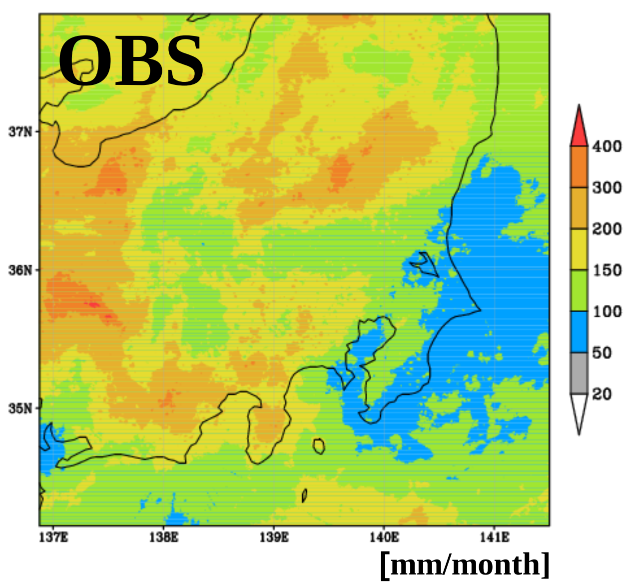
Monthly precipitation: August 2006-2013

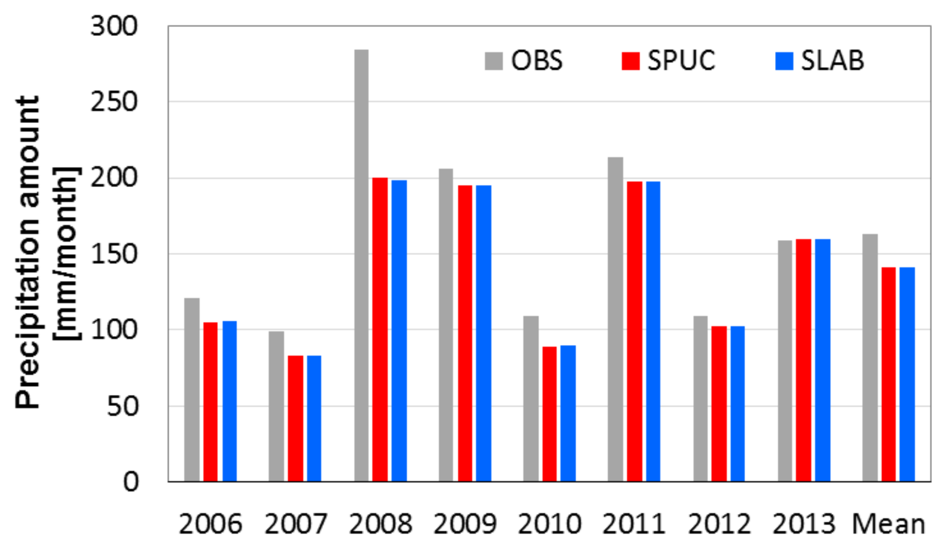
Radar-rain gauge based precipitation amount (JMA)



Monthly precipitation: 2006-2013 mean

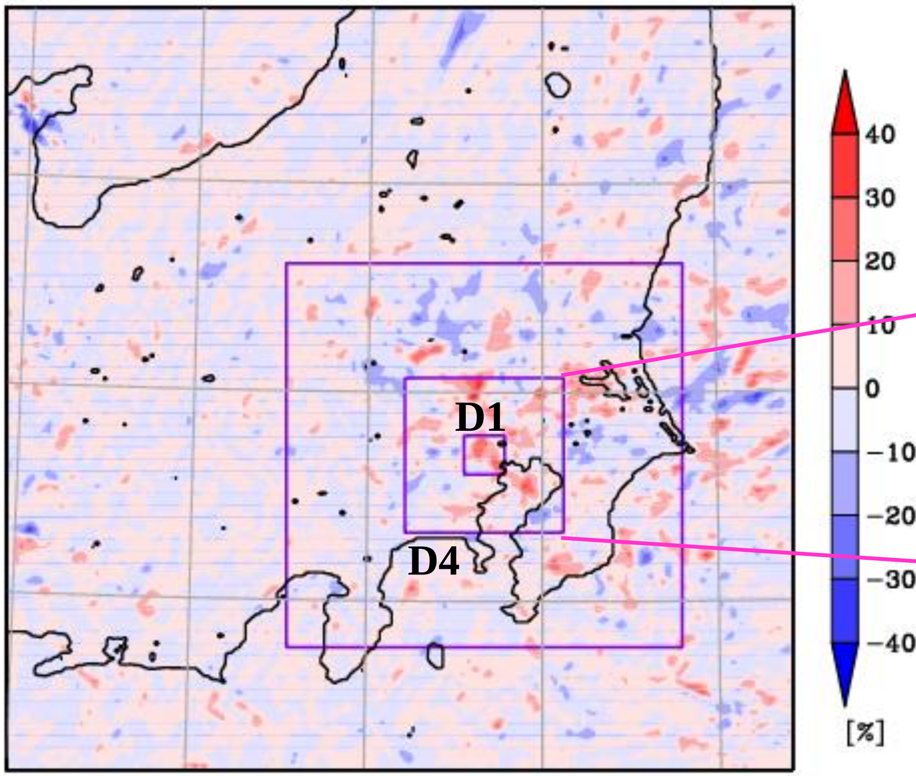


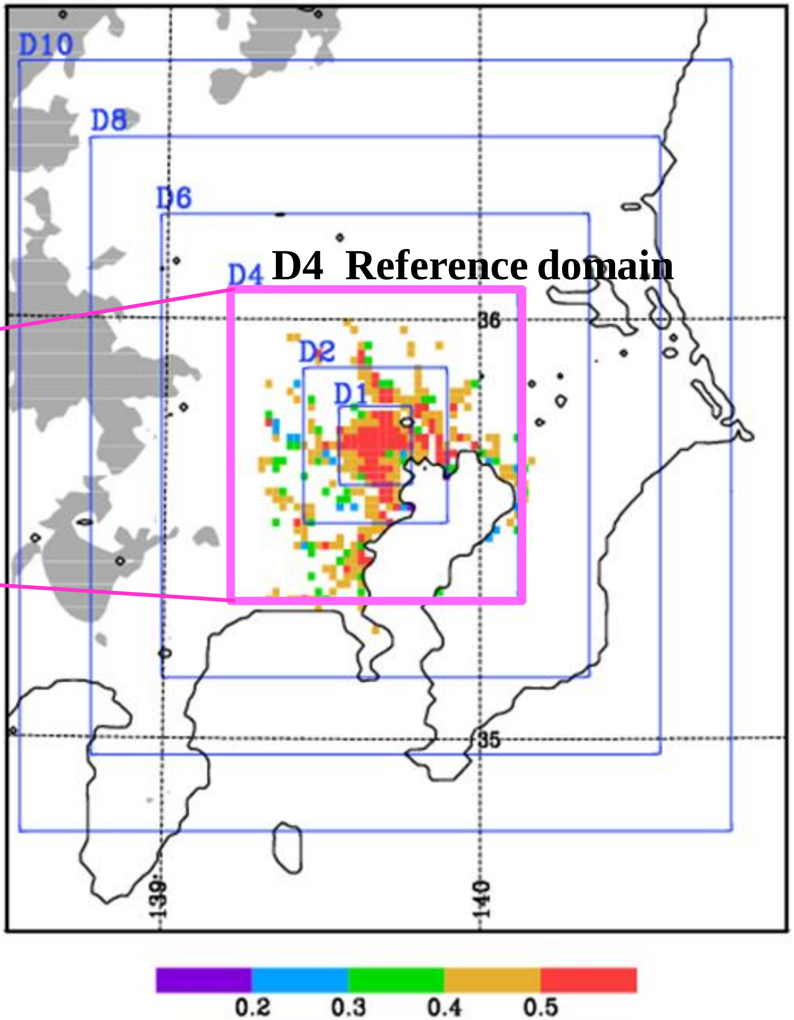




Area-average precipitation

Precipitation increasing rate
(SPUC-SLAB)/SLAB

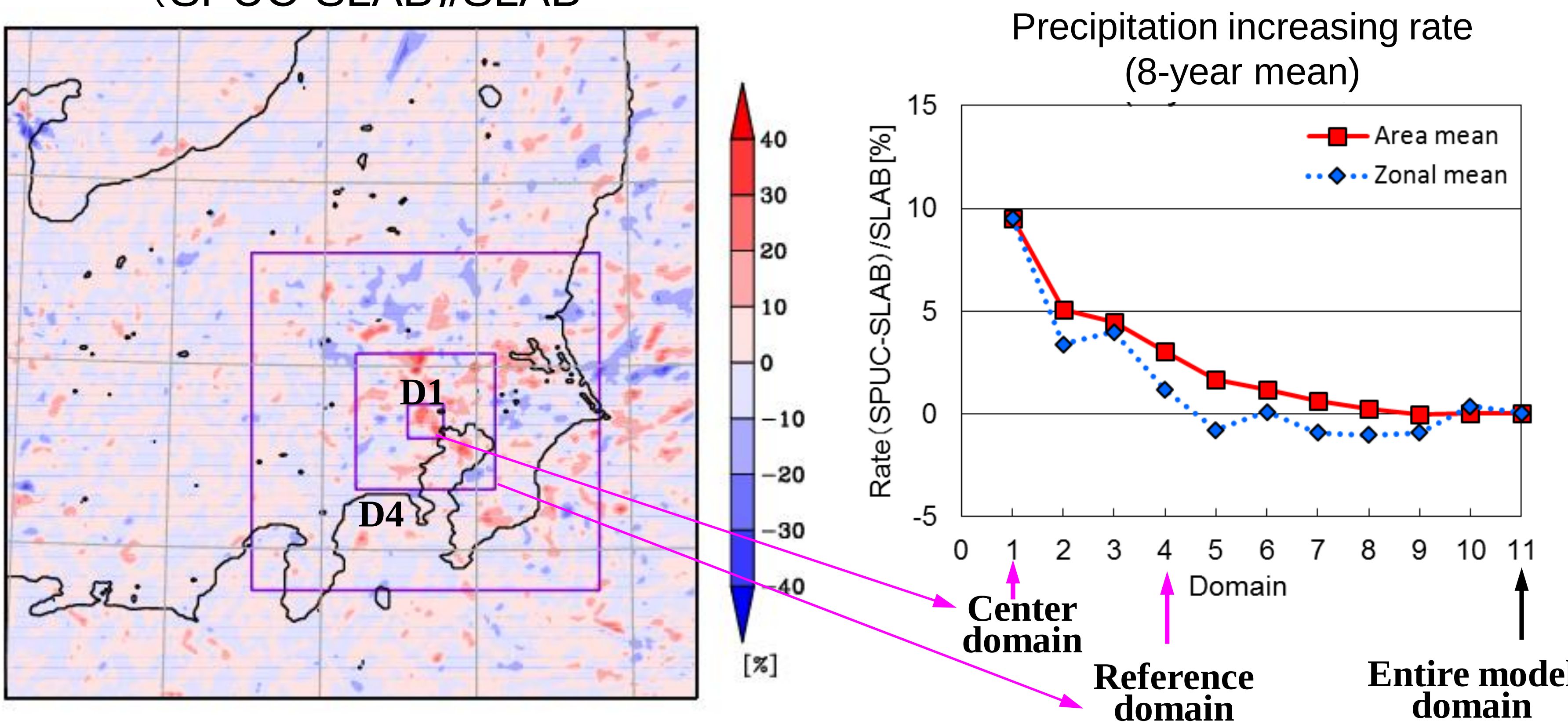




Building area fraction

Area-average precipitation

Precipitation increasing rate
(SPUC-SLAB)/SLAB

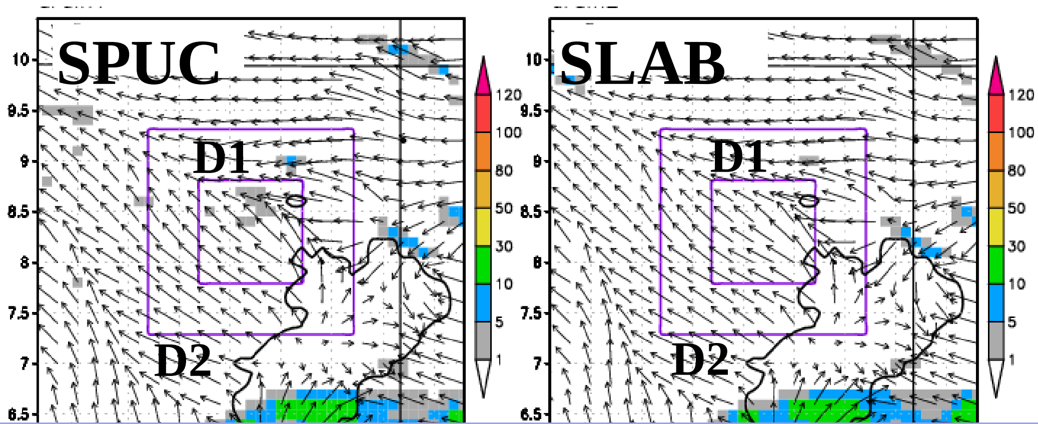


The largest difference, roughly 10 % increase, is found in the center domain D1. Differences gradually decrease as the domain extends

Initiation or enhancement?

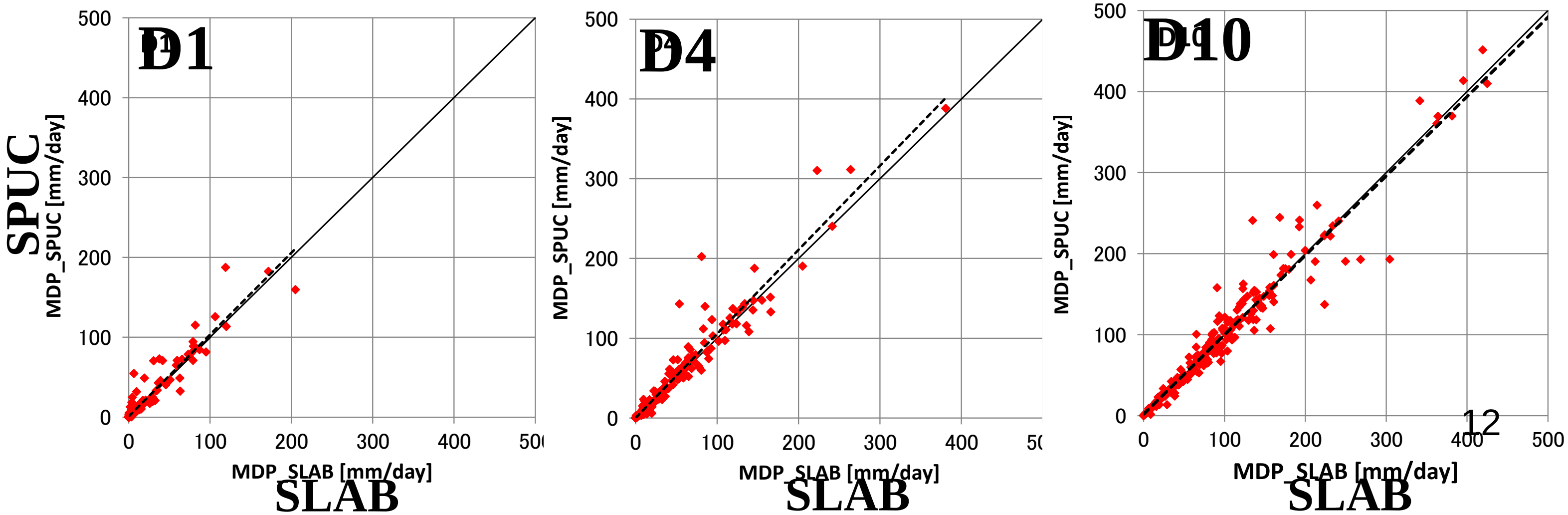
Number of rainy days in the center domain D1

Precipitation occurred only in SPUC(SLAB): 9(3)/105 cases



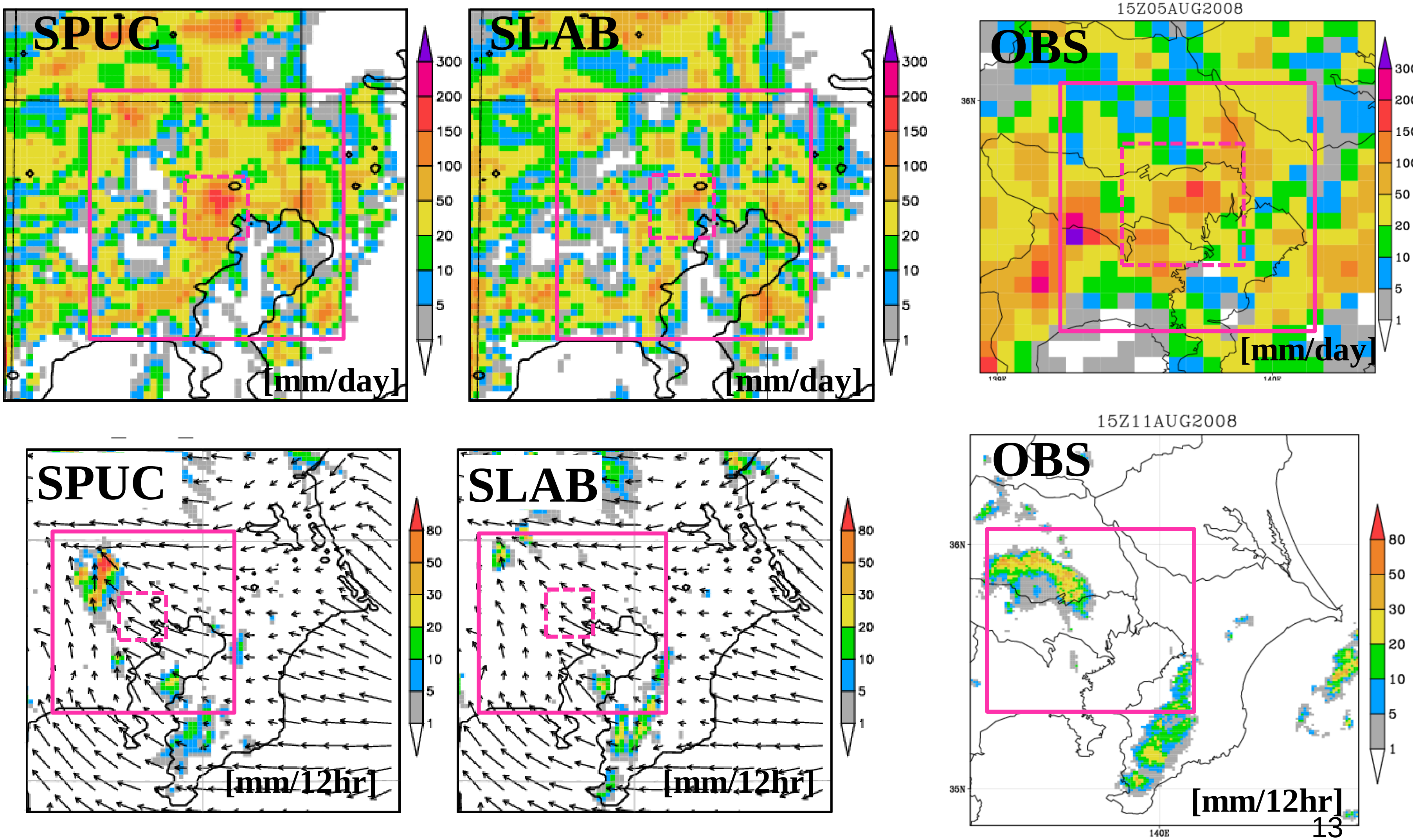
Majority of precipitation increase was attributed to enhancement in remaining cases (within D4)

Area-maximum daily precipitation



Downstream or urban center?

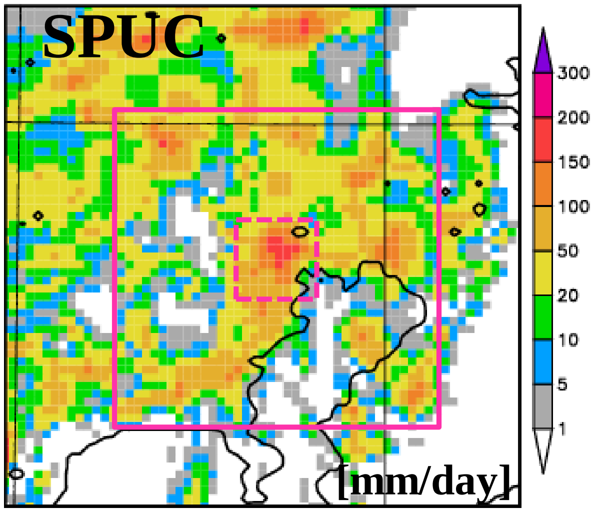
On average largest increase in rainfall appeared in center

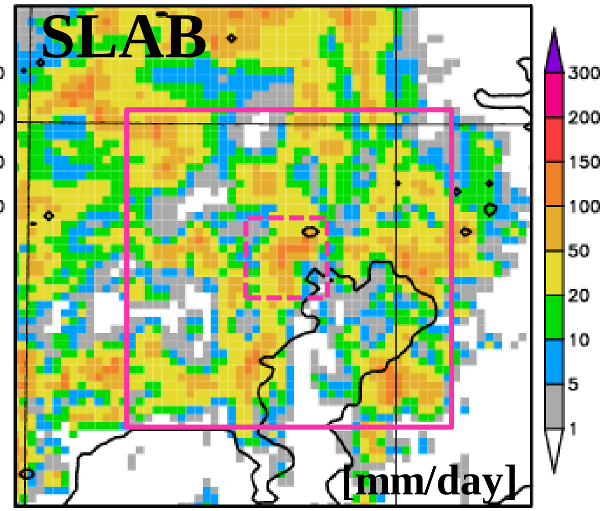


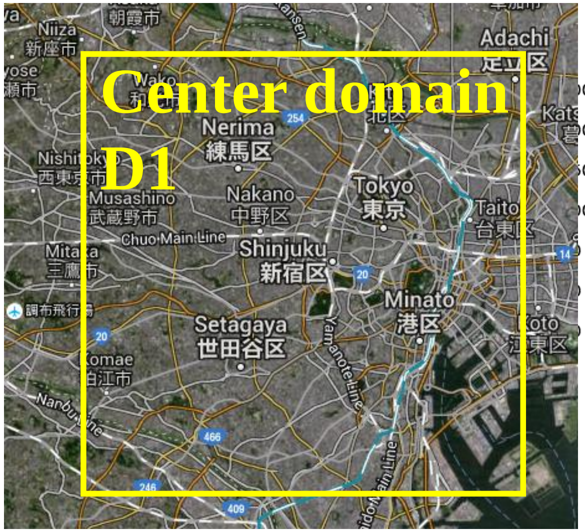
Statistically significant increase in precipitation was found within domain D4

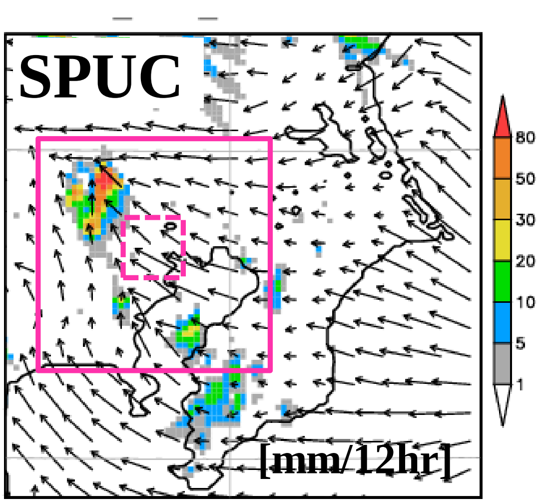
Downstream or urban center?

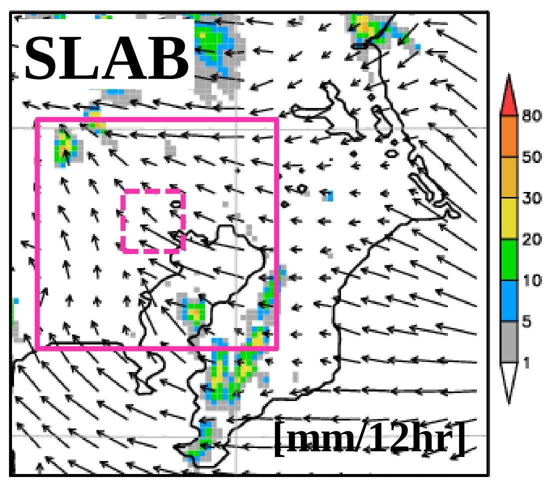
On average largest increase in rainfall appeared in center

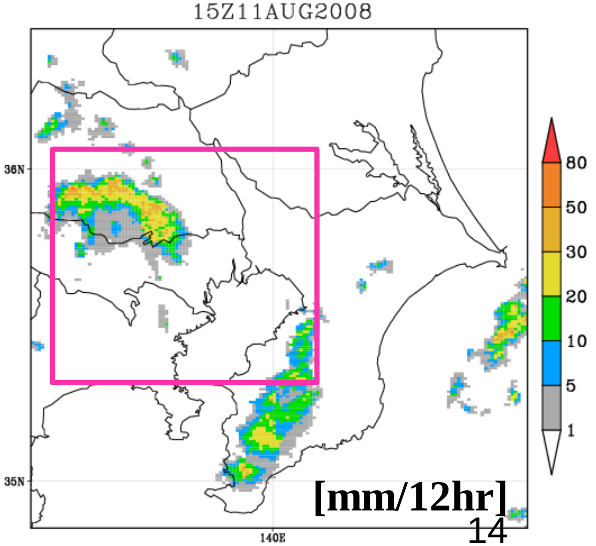












Statistically significant increase in precipitation was found within domain D4

Summary

Comparative simulations for 8-years August suggest

- At most 1 degree mean temperature rise resulted in 10% precipitation increase in central Tokyo with slight (less then 1%) near-surface vapor decrease
- Enhancement of precipitation system rather than initiation is likely to contribute more to the precipitation increase as far as in 2km resolution
- Intensified convergence in urban center (enhanced heat island circulation) plays important role for the mean precipitation increase

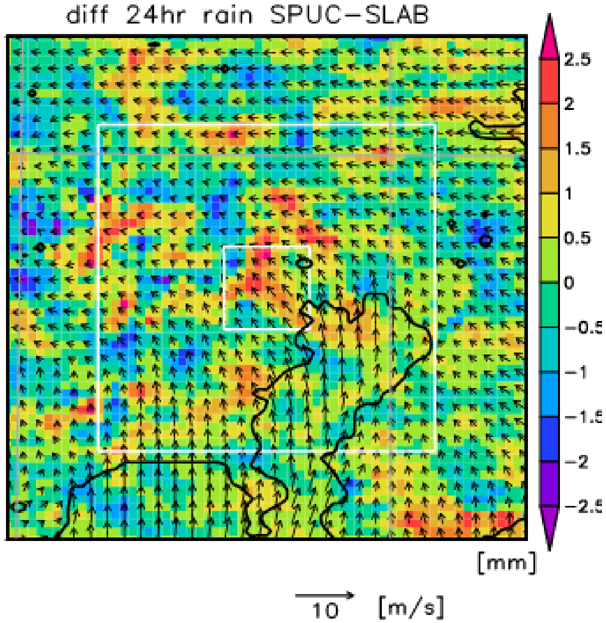
Need for the comparison with observations in heavy rain cases → Next presentation (Belair et al.)

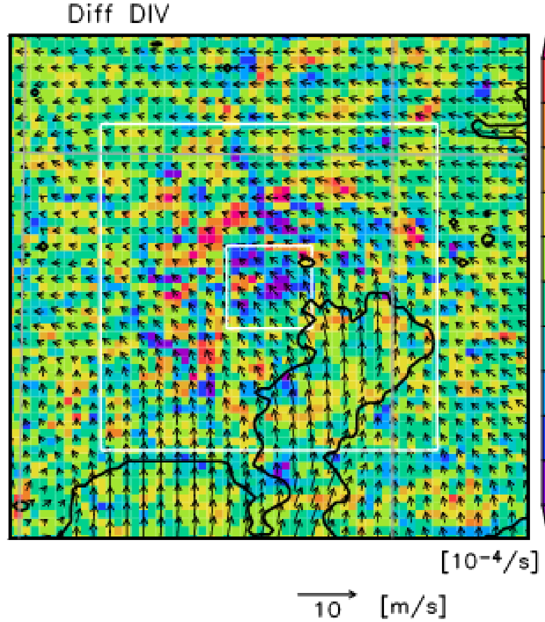
Future works: evaluation of other factors impact

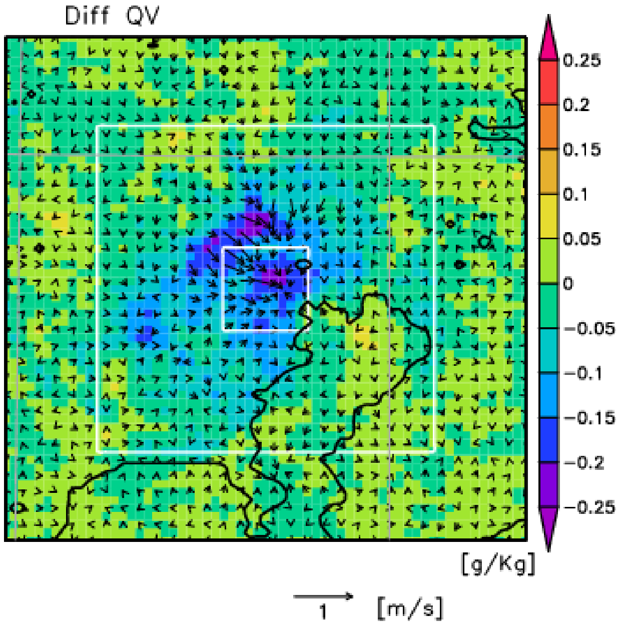

Thank you for
your attention!

Composite for afternoon NPP cases in D1

Composite for 68 afternoon non-preceding precipitation cases in D1







Outline of numerical model

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urban canopy scheme SPUC (Aoyagi & Seino, 2011)
Initial/Boundary condition: JMA Mesoscale Analysis
Domain: Central Japan dX=2km 200x200x50 grids
Cloud microphysics: Bulk scheme with ice phase
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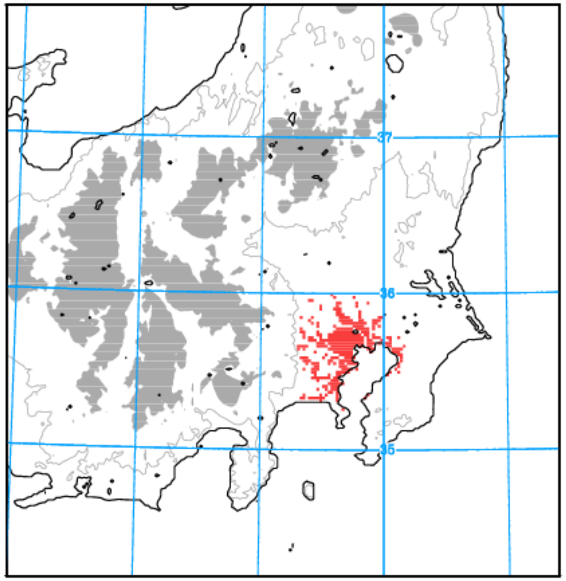
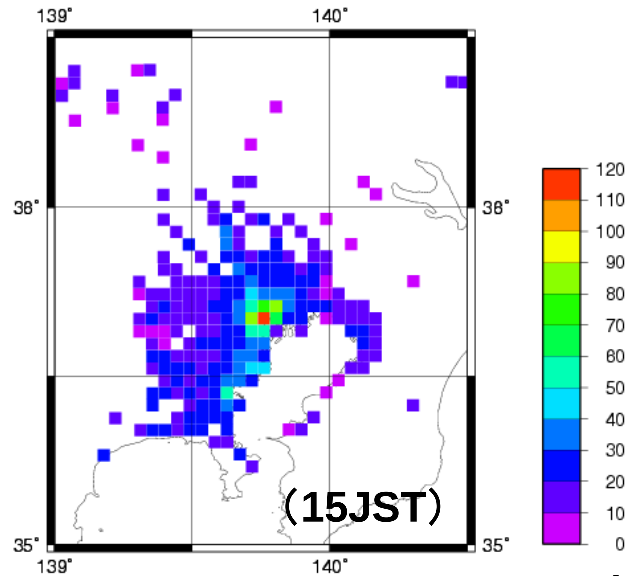


■ : SPUC - applied grid

- SPUC is worked at grids where more than 80% of the grid area is occupied with urbanized land use



$[wm^{-2}]$

Anthropogenic heating (Senoo et al., 2004)

Monthly precipitation: August 2006-2013

Simulation results of SLUC