Assessment of dynamical downscaling in Japan

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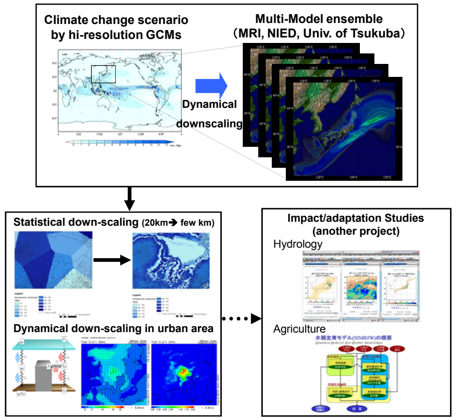
Getting a 'Feel' for Future Climate Change!

Abstract

The responses of the climate system to increases in carbon dioxide concentrations and to changes in land use/land cover and the subsequent impacts of climatic variability on humans and natural ecosystems are of fundamental concern. Because regional responses of surface hydrological and biogeochemical changes are particularly complex, it is necessary to add spatial resolution to accurately assess critical interactions within the regional climate system for climate change impacts assessments. We quantified the confidence and uncertainties of Type II dynamical downscaling where the lateral and bottom boundary conditions were obtained from Japanese 25-year ReAnalysis (JRA-25) and assessed the value (skill) added by the downscaling to a climate simulation in Japan. We conducted the sensitivity study of domain size and nudging scheme using a regional climate model (NIED-RAMS). The Meteorological Research Institute Nonhydrostatic Model (MRI-NHM) and the University of Tsukuba Weather Research and Forecasting Model (T-WRF) were also used for the comparison. Two key variables for impact studies, surface air temperature and precipitation, were investigated using the Japanese high-resolution surface observation, Automated Meteorological Data Acquisition System (AMeDAS) on 78 river basins. RAMS shows the cool and low pressure biases. In the period (JJA) when the control of lateral boundary condition is relatively weak, the RCM solution in the interior of the domain was much deteriorated in the larger domain. In the larger domain, spectral nudging reduced the mean biases. However, in other seasons when the influence of synoptic scale disturbances is strong, spectral nudging had insignificant impacts. Except for the 2mT in JJA, dynamical downscaling could add value to the forcing data beyond what is achieved by interpolating global reanalysis. Wave model bias was reduced by using multi-model forcing. The multi-model ensemble approach promises to increase the credibility of impact studies.

Multi-ensemble downscaling Project (S5-3)

Combination of dynamical and statistical downscaling



Spectral nudging scheme

Model Variables

$$\frac{dQ}{dt} = \sum_{|n|\le N}\sum_{|m|\le M} \frac{dQ_{mn}}{dt}\cdot e^{ik_m x}\cdot e^{ik_n y}$$

$$= L(Q) - \sum_{|n|\le N}\sum_{|m|\le M} K_{mn}\cdot\left(Q_{mn} - Q_{omn}\right)\cdot e^{ik_m x}\cdot e^{ik_n y}$$

Model Operator — Spectral Nudging Coefficient (depend on height) — Observations

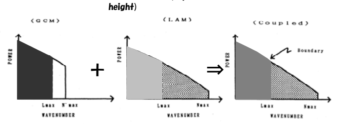
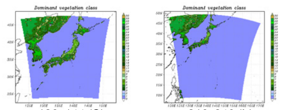


Fig. 3. A schematic illustration of the conceptual explanation of spectral coupling. N_{max} and N'_{max} are the maximum wavenumbers of the LAM and the GCM, respectively. L_{max} is the boundary wavenumber of the large-scale and small-scale parts. These wavenumbers are defined with respect to the LAM's domain. The shaded parts of the spectral of the GCM and LAM are combined in one way.
(Kida et al., 1991)

1. Sensitivities of domain size and nudging scheme on dynamical downscaling skill (mean bias in river basins)

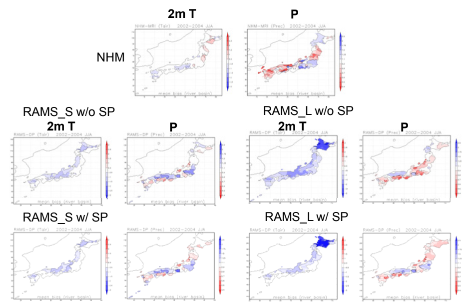
1A. Experimental Setup

- Horizontal grid space: 20km, Vertical layers:27(〜21km), Soil layers:10
- Physics: Cumulus: Kain-Fritsch scheme, Bulk-microphysics, Radiation: Chen & Cotton, PBL: Mellor-Yamada level 2.5, Land surface: Leaf2 + GEMTM + river routing scheme
- Nudging scheme: Davies / Spectral nudging
- Initial & Boundary Condition (Lateral & SST): JRA25 (T106), 6 hourly (Nudging 5 grids)
- Integrated period: 2002 to 2004, 3 months spin-up in Jan2002
- Obs data: AMeDAS (Automated Meteorological Data Acquisition System) operated by Japan Meteorological Agency. About 1300 stations in Japan.



128x144 (S) 216x240 (L)

1B. Mean model bias of sensitivity experiments and NHM (JJA)



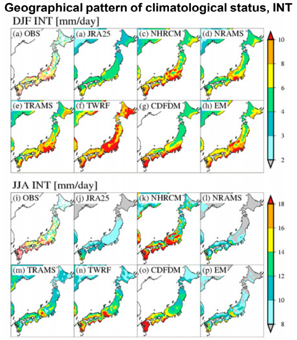
Bias of 2m air temperature (2mT) was much deteriorated in larger domain. The bias of precipitation (P) was also strongly influenced by the domain size. In the period (JJA), influence of synoptic-scale disturbances is relatively weak to control the RCM solution in the interior of the domain. Spectral nudging has some impacts on reducing the mean biases (2mT and P). On the other hand, the influence of synoptic scale disturbances in winter is strong and spectral nudging has little impacts.

2. Can dynamical downscaling add the value to forcing data?

2A. Comparison between dynamical downscaling and statistical downscaling

As a test for predictability, statistical downscaling from the parent model in a hindcast mode (Type 2) should be used as the benchmark (control) with which dynamic downscaling would have to improve on.

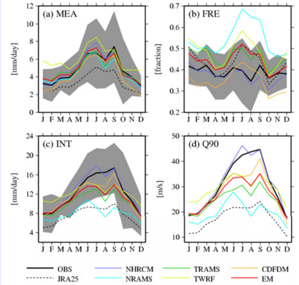
Geographical pattern of climatological status, INT



Mean intensity in DJF and JJA. In DJF, precipitation of forcing data JRA25 is not in good agreement with obs. WRF model overestimate the precipitation intensity. Other results including SD are comparable.

In JJA, NHRCM shows good skill in mean intensity. But other models underestimate the precipitation intensity.

Seasonal Change of Mean precipitation (MEA), Number of wet days (FRE), Mean intensity (INT), 90th percentile (Q90)



Seasonal change in 4 statistics of Obs, JRA25, and models. Even though the mean precipitation is relatively well reproduced, wet days and intensity is not well reproduced in most of the models. Only NHRCM which is used for operational weather forecast in Japan can demonstrate good skill. Reason of the frequent weak precipitation in summer in RAMS is mainly attributed to not well-tuned convective parameterization.

Through the intercomparison, we highlighted the respective strengths and weaknesses of the models and assessed the value added to the reanalysis data by dynamical downscaling methods to regional climate simulation over and beyond what is achieved by the bias-correction-type statistical downscaling method of reanalysis data.

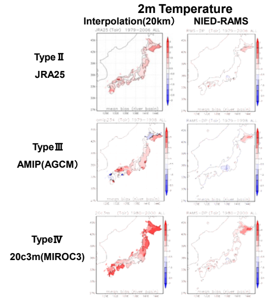
- ✓All downscaling models successfully improve the quality of daily precipitation data relative to reanalysis
- ✓No best downscaling model for all aspects exist (though NHRCM is close to the best in Japan)
- ✓Each downscaling models have own strengths and weaknesses

2B. Comparison between TypeⅡ, TypeⅢ, TypeⅣ

Downscaling Categories (Castro et al., JGR, 2005)

- ✓Type 1 (Weather prediction)
  Day-to-day weather prediction: real world observed initial conditions
- ✓Type 2 (Hindcast using Reanalysis)
  Seasonal weather simulation: real world observed lateral boundary conditions
- ✓Type 3 (AGCM: Seasonal Forecast, AMIP run)
  Season weather prediction: observed sea surface temperatures;
- ✓Type 4 (AOGCM or ESM: CMIP run)
  Multiyear climate prediction

From top to bottom: more constraints to fewer; greater predictive skill to less. Skill of predictability in Type 2 can be considered as upper limit of Type 3 and 4.

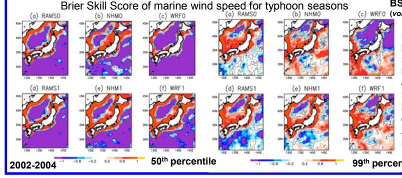


✓Downscaling could add values (improve the skills) to all the forcing data (TypeⅡ, TypeⅢ, TypeⅣ)
✓Skills of 2m temperature of forcing data were degraded as observational constraints are fewer.
✓Spatial pattern of orographic precipitation in winter is improved by downscaling. However, added-value to mean bias of precipitation is not obvious. Main source of bias can be physics parameterization.
✓ Downscaling skill of TypeⅢ and Ⅳ were not much worse than that of TypeⅡ.

3. Can dynamical downscaling add the value (skill) to extreme events?

3A. Multi-model comparison of surface winds

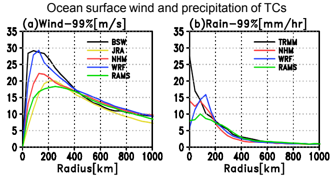
Brier Skill Score of marine wind speed for typhoon seasons BSS= $1-\sigma^2_{RCM}\sigma^{-2}_{JRA}$ (von Storch and Zwiers, 1999)



BSS varies between −∞ to +1
Positive values: better performance of RCM
Negative values: better performance of JRA25
Zero: performance is comparable

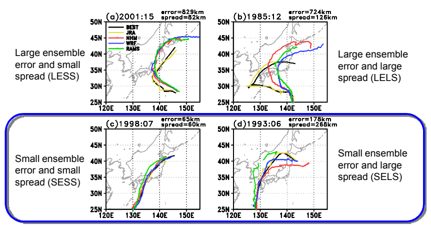
3B. Multi-model comparison of tropical cyclones

Ocean surface wind and precipitation of TCs



✓WRF simulated surface wind associated with TCs well.
✓None of the RCMs reasonably simulated the intense precipitation in the vicinity of the TC center. But large observational uncertainty of extreme events by satellite observation

Examples of Tropical cyclone tracks



Large ensemble error and small spread (LESS)
Large ensemble error and large spread (LELS)
Small ensemble error and small spread (SESS)
Small ensemble error and large spread (SELS)

✓No clear correlation between ensemble mean RMSE and spread.
✓Multi-model ensemble approach reduced TC track errors for about 60% of the TCs classified into the SESS and SELS categories.
✓However, not for remaining TCs of LESS and LELS.

Conclusions

1.

- In the period (JJA) when the control of lateral boundary condition is relatively weak, the RCM solution in the interior of the domain (bias of 2m air temperature(2mT) and precipitation (P)) was much deteriorated in larger domain.
- In larger domain, spectral nudging had some effects on reducing the mean biases (2mT and P). However, in other seasons when the influence of synoptic scale disturbances is strong, spectral nudging had insignificant impacts. Because Japan is surrounded by the sea, SST also should play a significant role (nudging effect) as a boundary condition.

2.

- Through the intercomparison, we assessed the added value by dynamical downscaling over and beyond what is achieved by the bias-correction-type statistical downscaling.
- Each downscaling models have own strengths and weaknesses. No best downscaling model for all aspects exist (though NHRCM is close to the best in Japan for the metrics of precipitation).
- Downscaling could add values (improve the skills) to all the forcing data (TypeⅡ、TypeⅢ、TypeⅣ)
  Downscaling skill of TypeⅢ and Ⅳ were not much worse than that of TypeⅡ for mean P and 2mT.

3.

- RCMs could add value for marine wind in coastal areas of Japan
- RCM does not add any values to W_{50} in open ocean (W_{99} is much better than W_{50})
- RCMs reasonably simulate the 40 % of TC tracks.
- Multi-model ensemble approach contributes to reduce TC track errors.
- None of RCMs reasonably simulate the intense precipitation in the vicinity of the TC center. Current RCMs have limited ability.

References

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