High-Resolution Large Ensemble Simulation with an Ocean-Assimilated Climate Model

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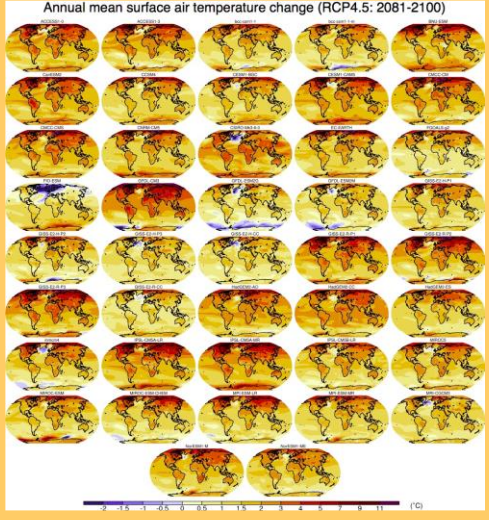
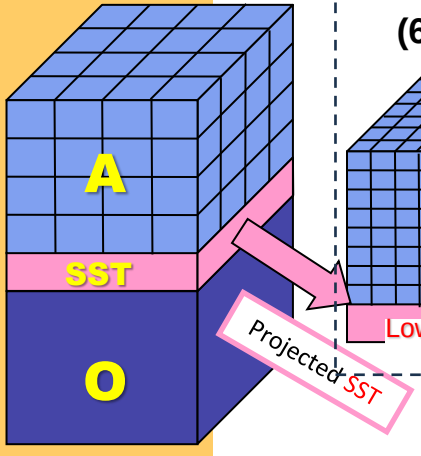
MEXT-Program for The Advanced Studies
of Climate Change Projection(SENTAN)

Climate projections with high-resolution atmosphere MRI models

CMIP Climate Models

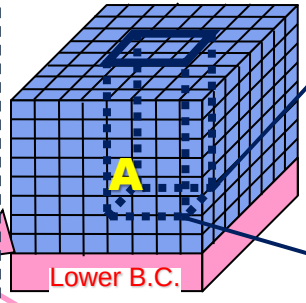


Insufficient resolution for local climate change
(precipitation rather than temperature,
extremes rather than mean climatology)

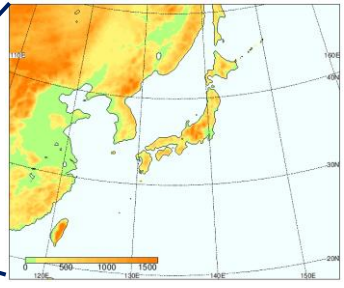


Projected SST

MRI-AGCM
(60km,20km)



NHRCM
(20km,5km,2km)



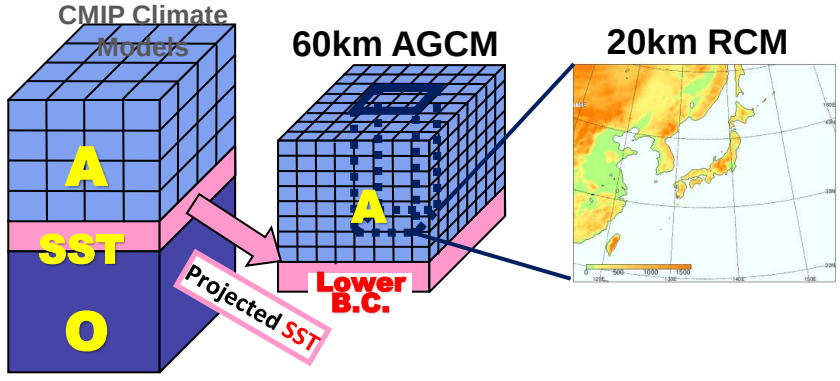
Impact Assessments
Disasters, Agriculture,
Water Resource, Ecosystem,
Human Health, ..

Adaptation Policies
To minimize the loss due to
global warming

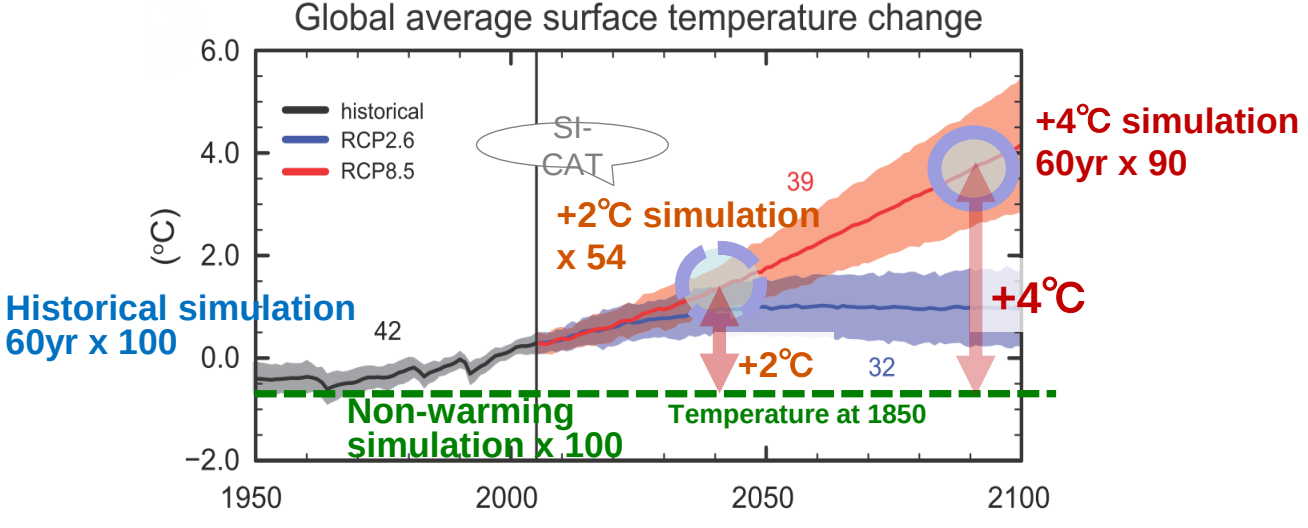
Large ensemble climate simulations with a high-resolution AGCM,RCM

90-100 member ensemble have been conducted to evaluate localized extreme events in the aspects of:

- Probabilistic change of very rare events
- Event attribution
- Uncertainties of the change due to internal variability



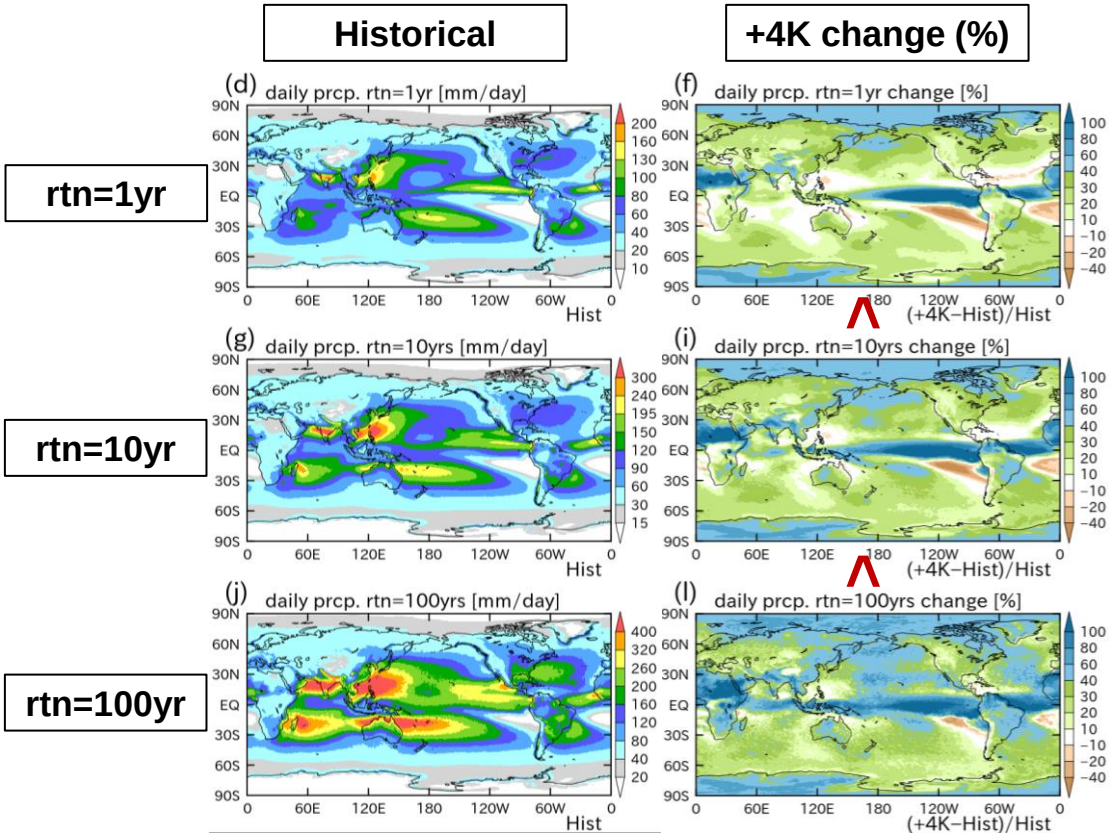
d4PDF
database for Policy Decision making for Future climate change
(Mizuta et al. 2017)

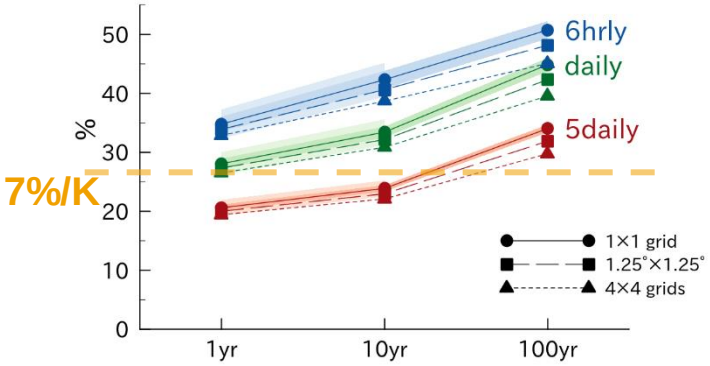


Return values of daily precipitation

Extreme precipitation increases over most parts of the world

Increase is larger for events with longer return periods (= rare, heavy precipitation events)

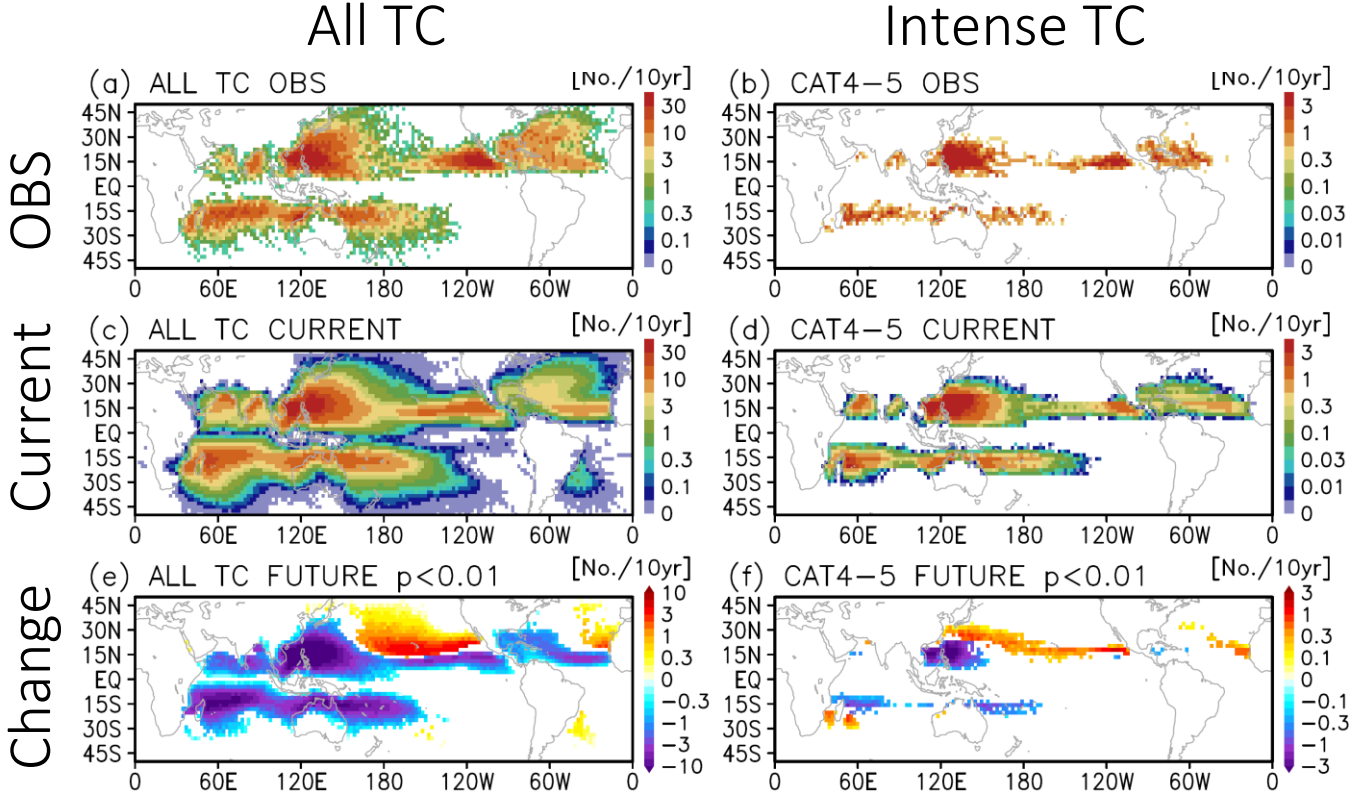




(Mizuta et al. 2020)

Tropical Cyclone Frequencies

- Similar, but smoother distribution compared with the observation
- Intense cyclones increases on N. W. side of Pacific and Atlantic, as well as eastern side.



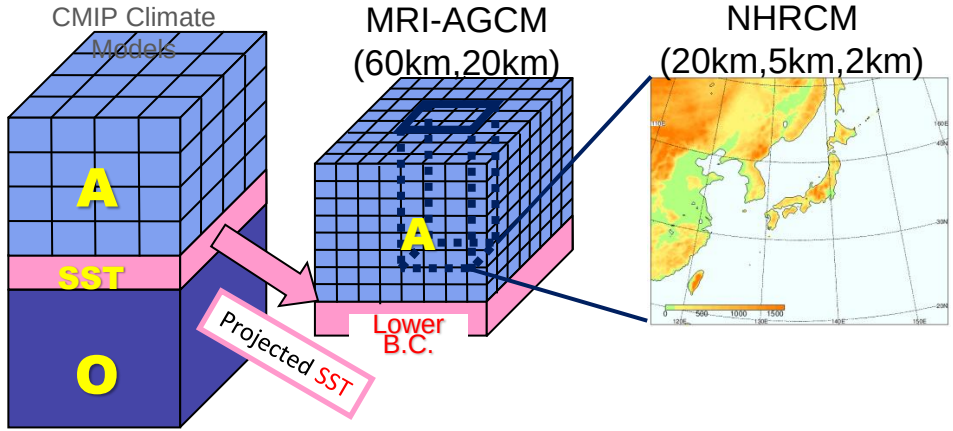
(Yoshida et al. 2017)

Climate projection system including A-O interaction

Previous System

SST is prescribed as
lower boundary condition

→ A-O interaction is not included
(e.g. ocean mixing below tropical cyclones)



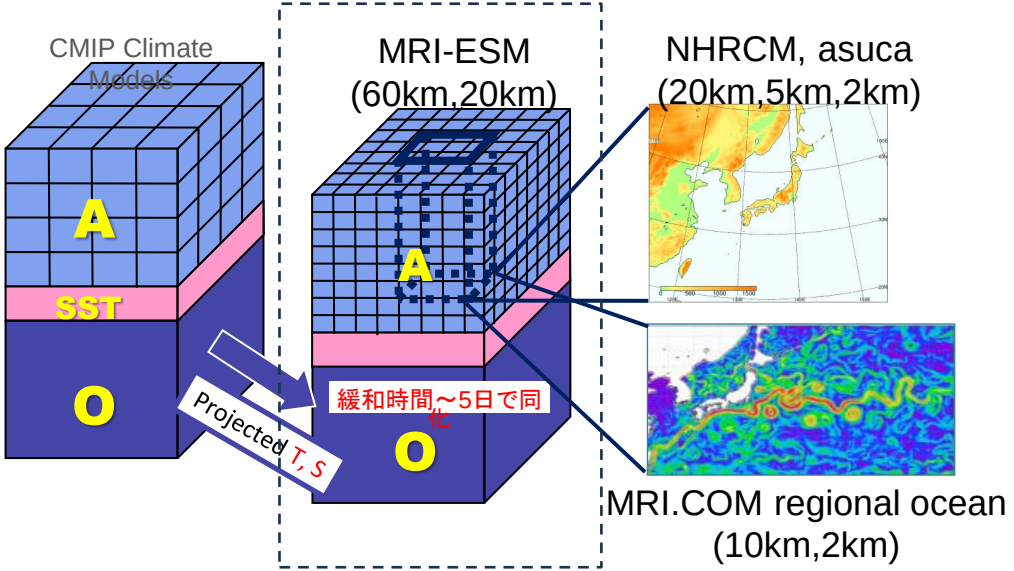
New System

TSE-C (Temporally Sequential Experiments with Coupled model)

Ocean T and S are assimilated
with relaxation time of 5-10 days

Past: Observation T and S
→ simulating realistic regional climate

Future: Obs. + warmings in CMIP models
→ reflecting CMIP projections



Long-term climatology: with assimilated ocean

Surface Temperature

Underestimation of temperature over mid-latitude ocean is reduced with ocean assimilation

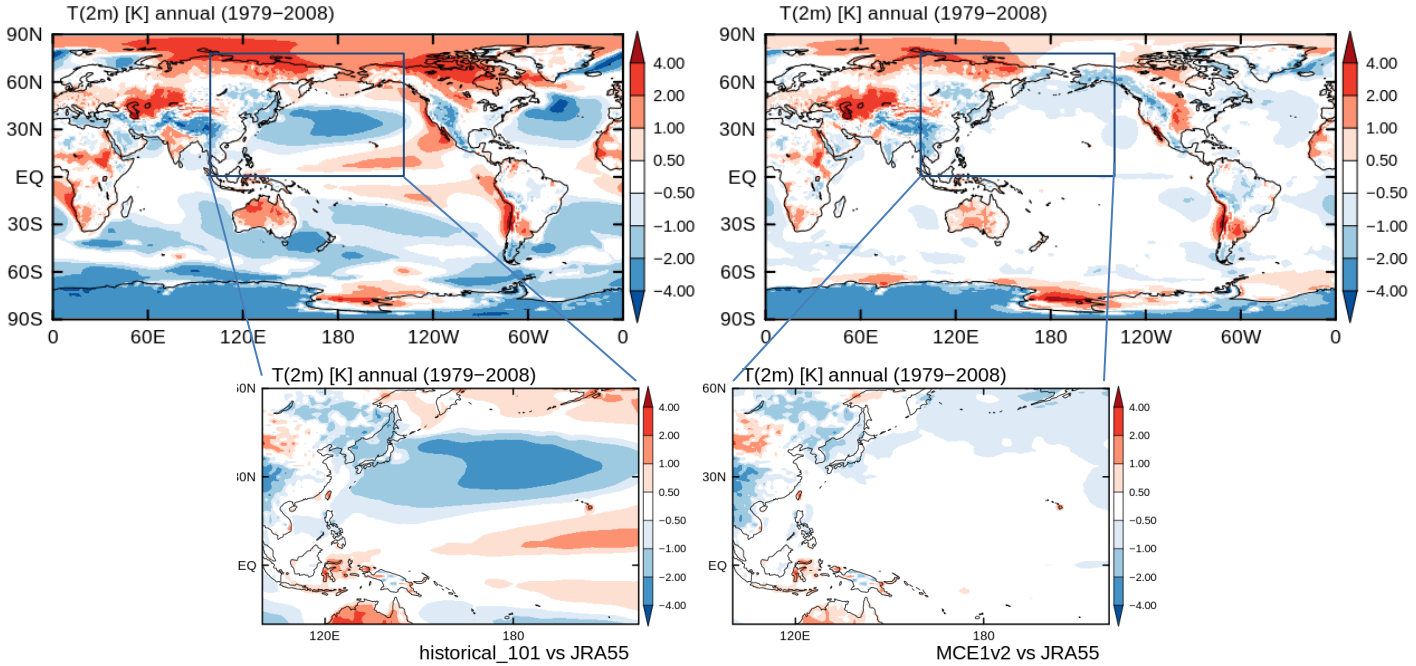
shade: anomaly from JRA-55

MRI-ESM2

fully coupled, CMIP6 model

TSE-C

MRI-ESM2 + assimilated ocean



Long-term climatology: assimilated + higher atmos. resolution

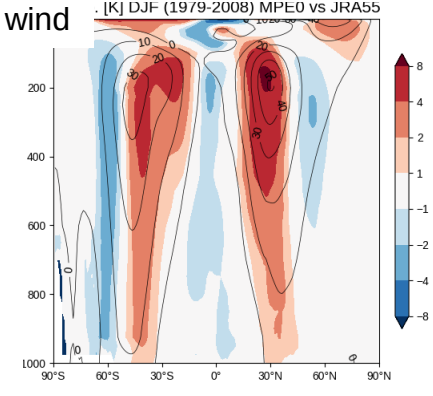
Zonal-mean wind and temperature

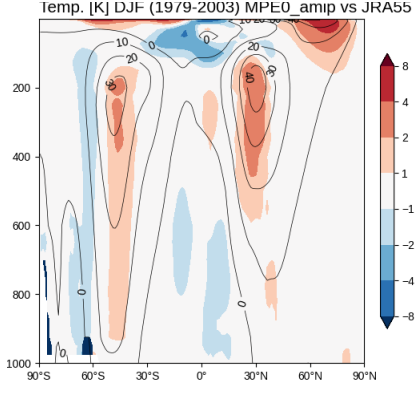
DJF, shade: anomaly from JRA-55

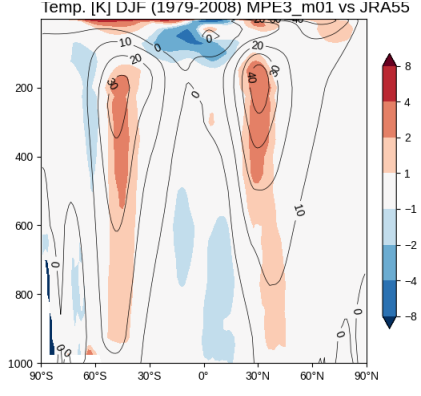
bias with equatorward, stronger jet is reduced as fully-coupled →TSE-C, and 120km→60km

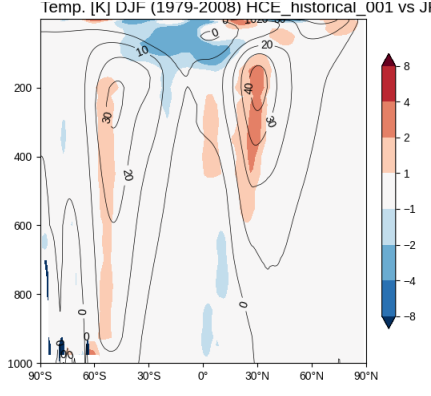
120km fully coupled CMIP6 model | 120km AGCM | 120km TSE-C | 60km TSE-C

Zonal wind

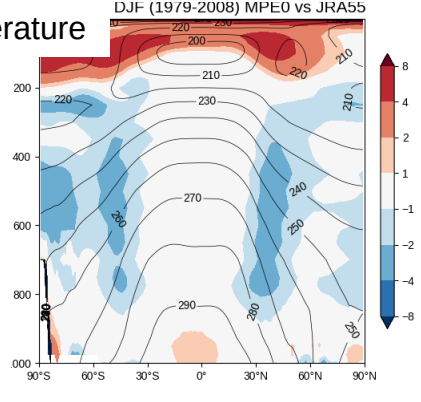


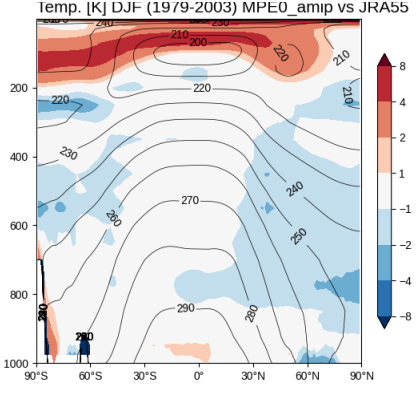


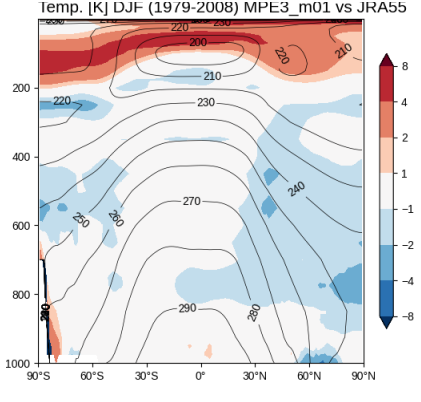


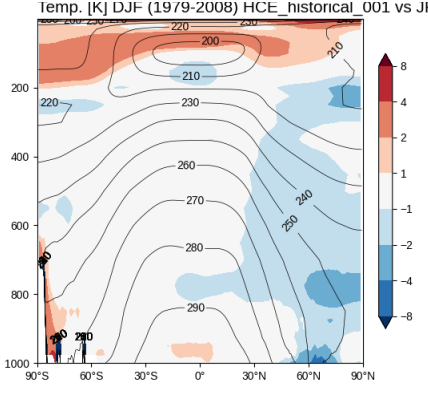


Temperature







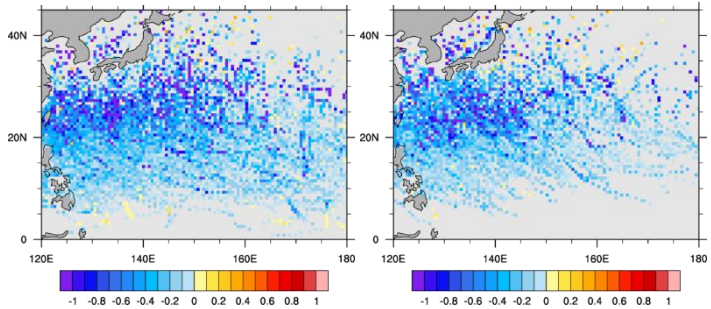


Tropical Cyclones

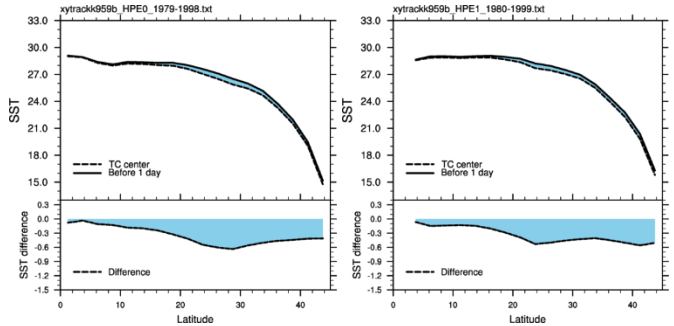
- TSE-C can simulate SST cooling after typhoon passage as well as in fully coupled models.
- Intense TCs at higher latitudes in AGCM can be reduced by introducing short-term A-O coupling.

ESM2 60km fully coupled ESM2 60km TSE-C

SST cooling on the day of typhoon passage [K/day]

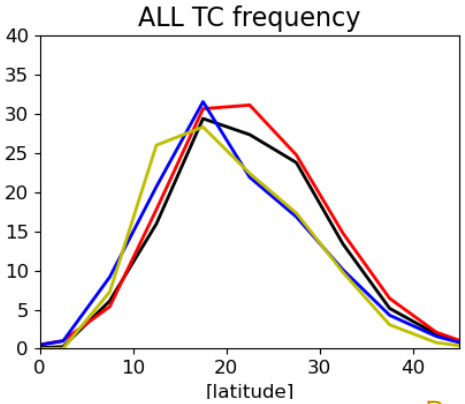


120-180E average of
SST cooling on the day of typhoon passage [K/day]

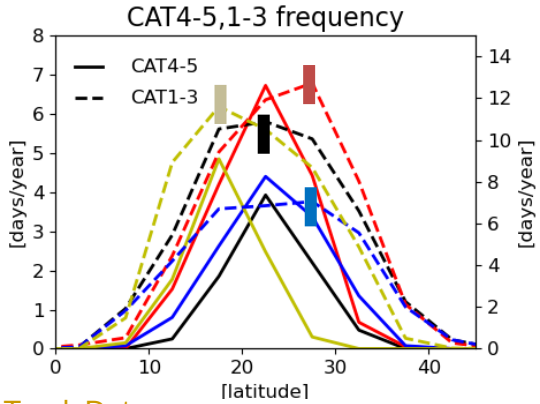


TC frequency over Western North Pacific (120-180E, 0-45N)

All TCs

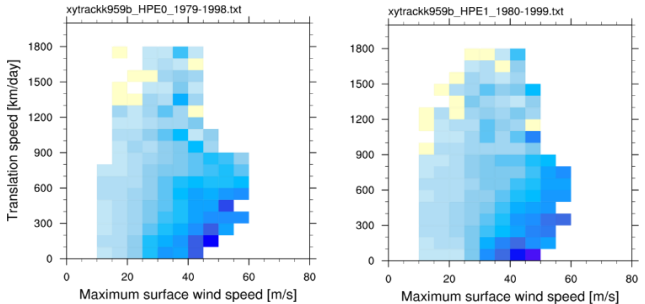


Intense TCs



--- Best Track Data
--- TSE-C 20km
--- ESM2 20km AGCM only
--- MRI-AGCM3.2 20km

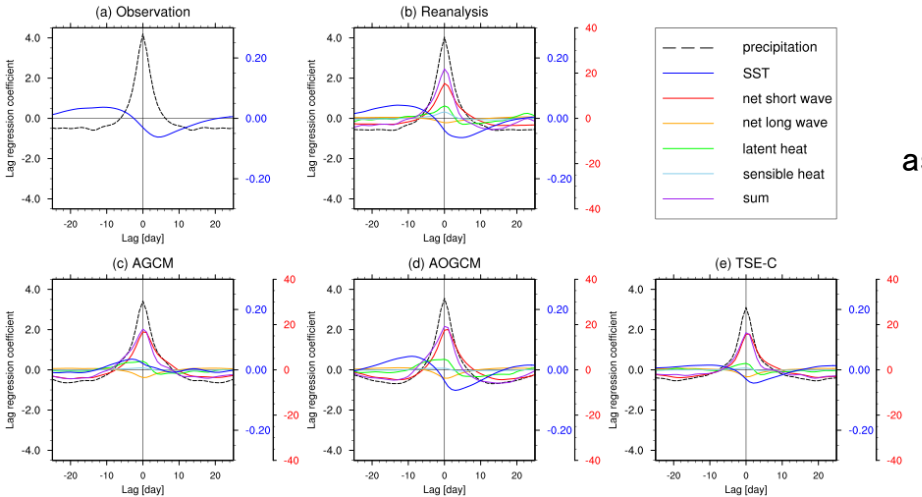
Dependence of SST cooling on max. wind and translation speed (120-180E, 0-45N)



Time lag between SST and precipitation

- Observation shows that precipitation maximum comes about 5-10 days after SST maximum (Arakawa and Kitoh 2004).

- While it is not simulated by AGCM, it is simulated in fully coupled ESM2 and TSE-C experiments.

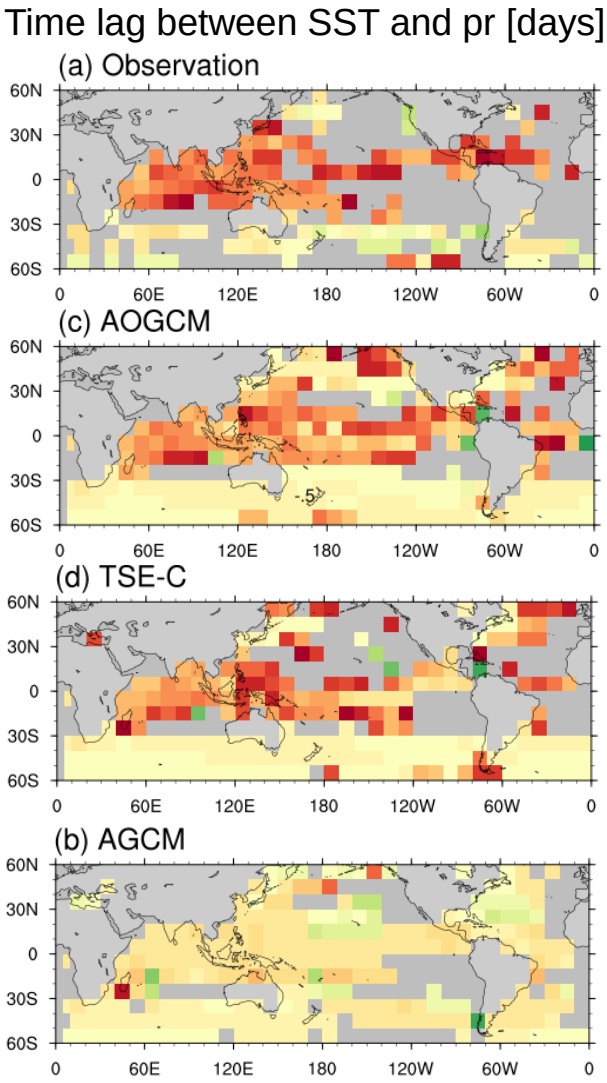


Obs.

MRI-ESM2
fully coupled

TSE-C
assimilated ocean

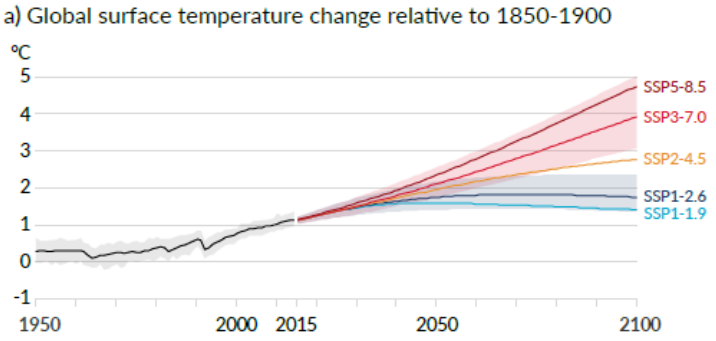
AGCM
prescribed SST



Updated high-res large ensemble

Continuous from 20C to end of 21C

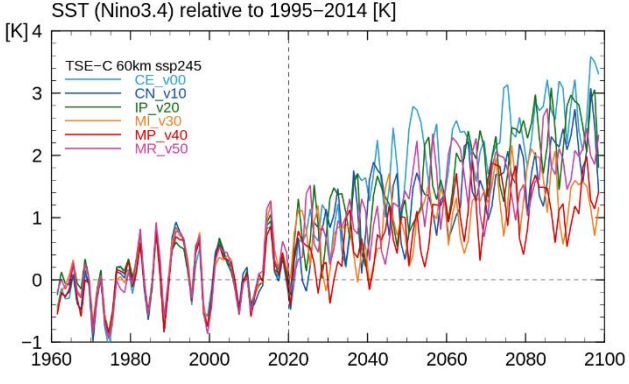
- to investigate gradually emerging climate change around 2040-2060



Considering ensemble methods to evaluate range of uncertainty

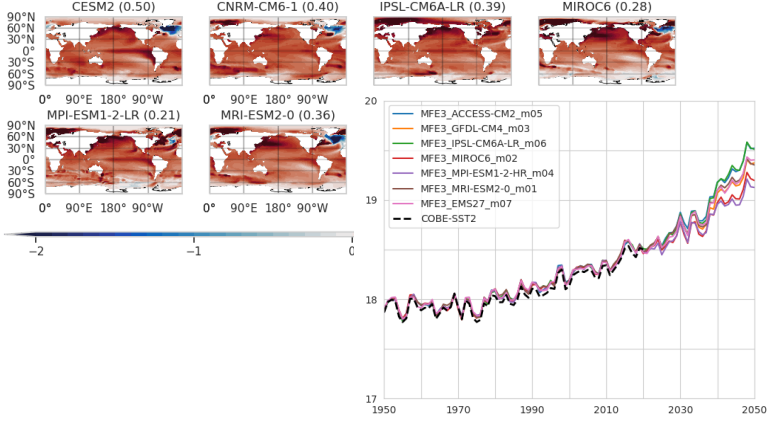
interannual variability phase ensemble

different phase of decadal variability of ocean are forced to ensemble members



forcing model ensemble

different warming patterns of CMIP6 models are forced to ensemble members



Summary

New climate projection system (TSE-C) based on MRI-ESM2

- Ocean T and S are assimilated with relaxation time of 5-10 days, to explicitly simulates short-term A-O interaction without large departure from observed climate.
- It enables regional-scale climate projection with including short-term A-O interaction such as ocean mixing by overpassing tropical cyclones, lag correlation between precipitation and sea-surface temperature, and so on.

Updated high-resolution dataset including a continuous large ensemble

- Continuous from 20C to end of 21C, to investigate gradually emerging regional change around 2040-2060.
- An interannual variability phase ensemble, in which different phase of decadal variability of ocean are forced to ensemble members, is combined with a forcing model ensemble, in which different warming patterns of CMIP6 models are forced to ensemble members.
- The results are also dynamically downscaled to our regional climate model and ocean model with 20km and higher resolution.
- Simulations have just started !

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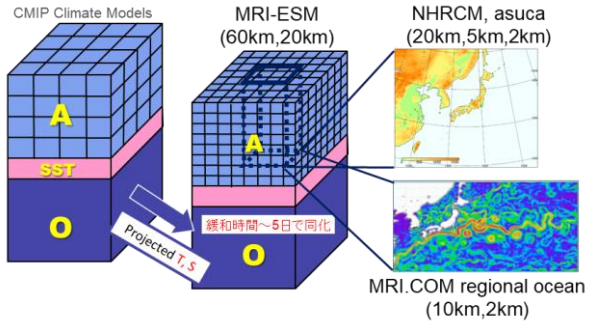
Dataset design with TSE-C system



Continuous, Large-ensemble

(1961-2100, >30 members)

GCM (with A-O coupling): 60 km

→ Regional Atmos.: 20 km → 5 km

→ Regional Ocean: 10 km → 2 km

Initial Conditions

Bias corrections

High-res, Fixed warming level

(20-30 years, ~10 members)

GCM (with A-O coupling): 20 km

→ Regional Atmos.: 5 km → 2 km

Targets:

- Continuous change in the **near-future (around 2050)**
- Contribution to **planning adaptation** depending on scenarios
- **Regional atmos. and ocean models from the same GCM**
  → synthetic comprehension of changes around Japan

Emission scenarios:

based on CMIP6: SSP1-2.6, SSP2-4.5, scaled SSP5-8.5, historical, non-warming

Targets:

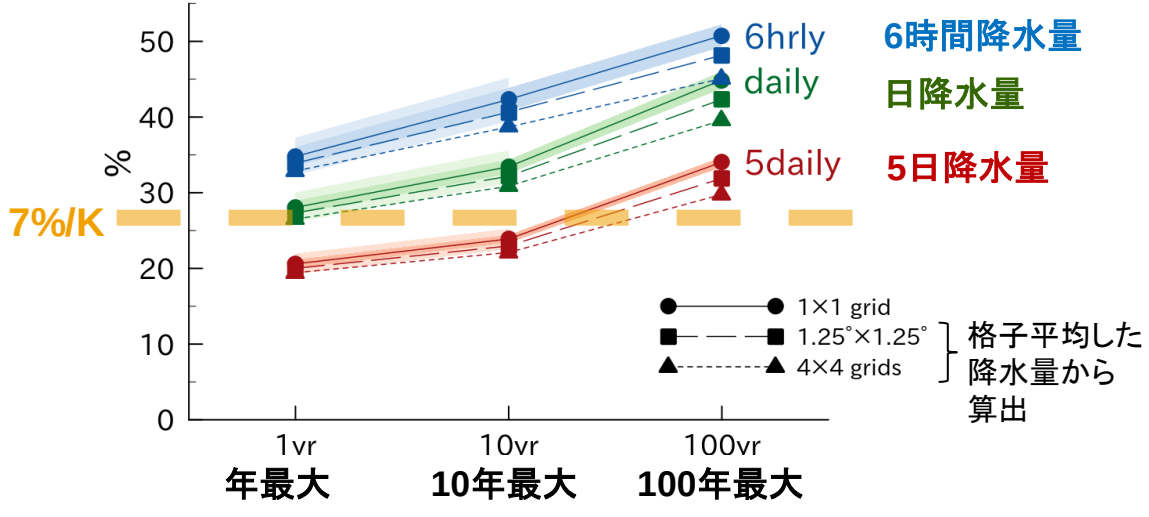
- Extremes by tropical cyclones and Baiu precipitation
- Evaluation of extremes considering **fine topography**
- Time-series of probability of disaster class phenomena (combined with the continuous experiments)

Warming levels:

based on CMIP6: 2°C, 3°C, (4°C,)
historical, non-warming

再現期間・時間スケール・空間スケールによる違い

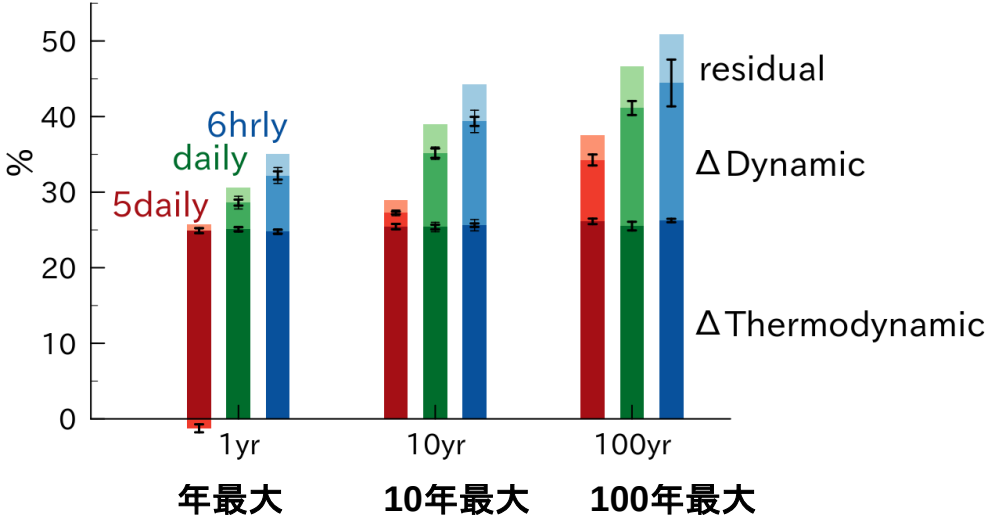
- 極端降水増加率(過去実験→+4K実験)の全球平均値
  - 再現期間の長い (=頻度の小さい、強雨の)事象ほど、増加が大きい。
  - 短時間降水ほど、増加が大きい。
  - 空間スケールの依存性はそれらに比べるとあまり大きくない。
  - 日降水量・6時間降水量については、いずれでも Clausius-Clapeyron での増加(~25-28%)より大きい



再現期間・時間スケールによる寄与の違い

- 気温変化に伴う熱力学的寄与は常にC-Cに近い変化
- 上昇流変化に伴う力学的寄与が、
  再現期間・時間スケールの違いによる増加率の差異に寄与している。

全球平均ΔP_eの熱力学的寄与と力学的寄与



領域課題１、４と共同で実施

先端プロで実施するデータセット2027向け予測実験【全体像】

1961年　1991　2020　2100

過去（気候）再現実験
- [全球60km, 領域20km] 36メンバー（2010年以降100メンバー）
- [領域5km] 6メンバー（1991-2020年は24メンバー）
- [海洋10km, 2km] 36メンバー （2kmは期間・メンバー限定）
- [全球20km] 1979-2020 10メンバー
- [領5km] 4メンバー
- [領2km] 4メンバー

非温暖化実験
- [全球60km, 領域20km] 36-100メンバー
- [領域5km] 6メンバー
- [海洋10km, 2km] 36メンバー （2kmは期間・メンバー限定）
- [全20km] 1979-2020 10メンバー
- [領5km] 4 メンバー

SSP1-2.6
- [全60km, 領20km] 36メンバー
- [領5km] 6メンバー（2070年まで）
- [海10km, 2km] 36メンバー （2kmは期間・メンバー限定）

SSP2-4.5
- [全60km, 領20km] 36メンバー （2050年まで100メンバー）
- [領5km] 6メンバー （2031-2060年は36メンバー）
- [海10km, 2km] 36メンバー （2kmは期間・メンバー限定）

scaled SSP5-8.5
温暖化レベルをマルチモデル平均にスケーリング
多様な温暖化レベル設定実験の初期値作成
- [全60km] 10メンバー
- [海10km, 2km] 10メンバー （2kmは期間・メンバー限定）

- [全20km] 10メンバー
- [領5km] 4メンバー
- [領2km] 4メンバー

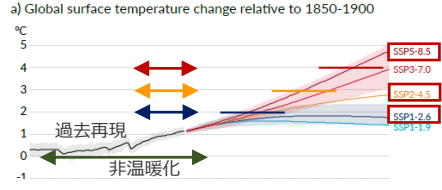
2.0°C レベル

- [全20km] 10メンバー
- [領5km] 4メンバー

3.0°C レベル

4.0°C レベル

温暖化レベル実験
同じ海洋自然変動条件
（1991–2020：30年間）
の下で温暖化影響を比較

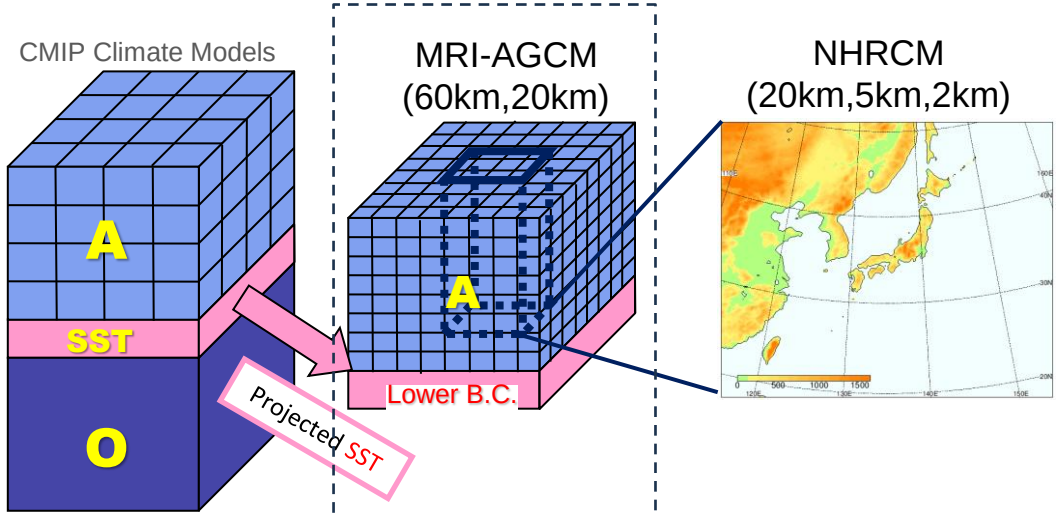


Current system of high-res climate projection

SST is prescribed as
lower boundary condition

Past: Observation SST
→ simulating realistic regional climate

Future: Obs. + warmings in CMIP models
→ reflecting variety of CMIP projections



High-res timeslice exp.	20km (Mizuta et al., 2012)	→	5km, 2km
d4PDF (large ensemble)	60km (Mizuta et al., 2017)	→	20km

Issues

- A-O interaction is not included (e.g. ocean mixing below tropical cyclones)

- Small ensemble members for continuous projections from present to end of 21C

Climate projection system including A-O interaction processes

TSE-C (Temporally Sequential Experiments with Coupled model)

Previous System

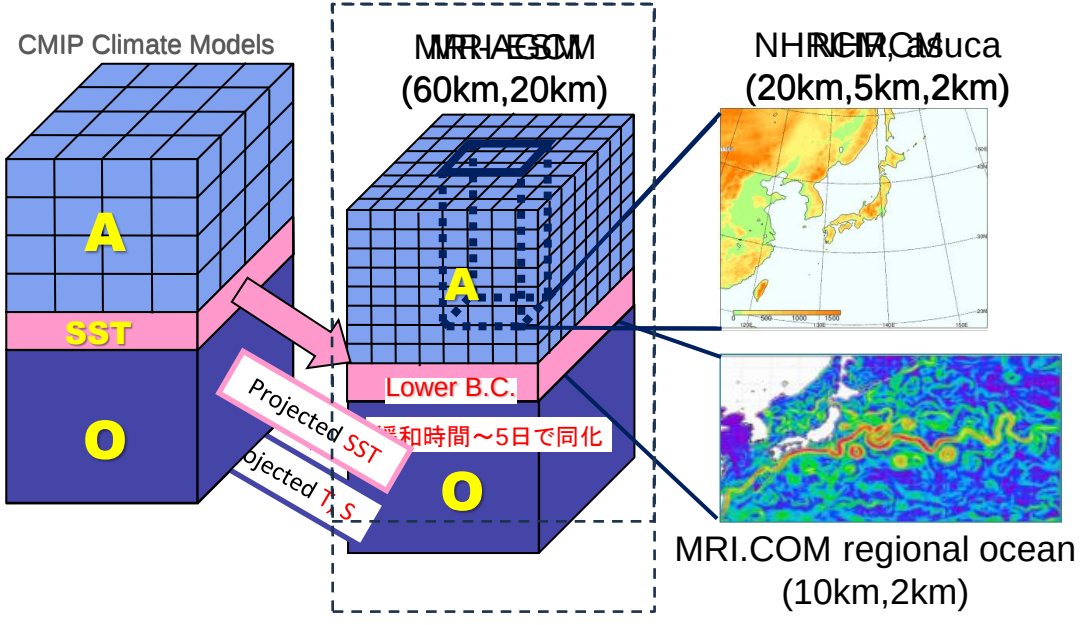
SST is prescribed as lower boundary condition

Past: Observation SST

→ simulating realistic regional climate

Future: Obs. + warmings in CMIP models

→ reflecting variety of CMIP projections

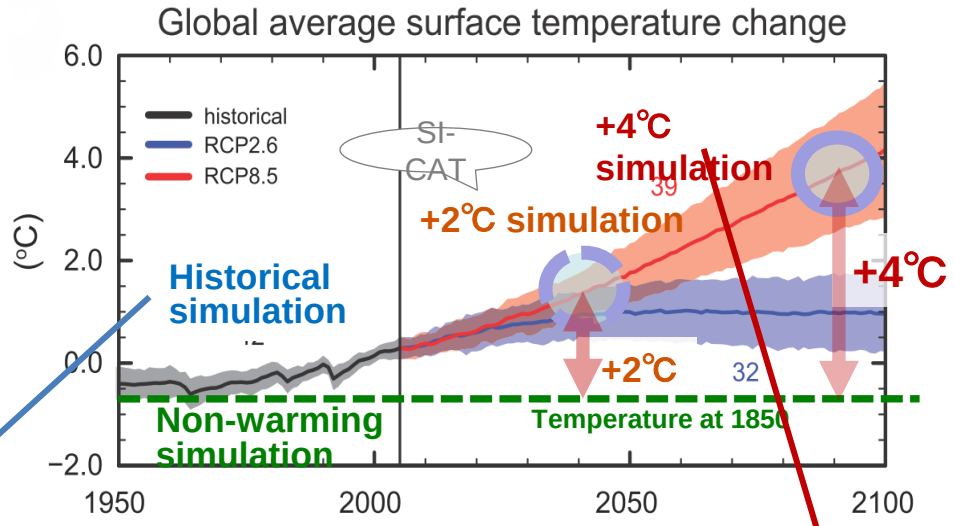


- based on MRI-ESM2 (Yukimoto et al. 2019): CMIP6 coupled model of MRI

- explicitly simulates short-term A-O interaction, while long-term climate is assimilated to the forcing data

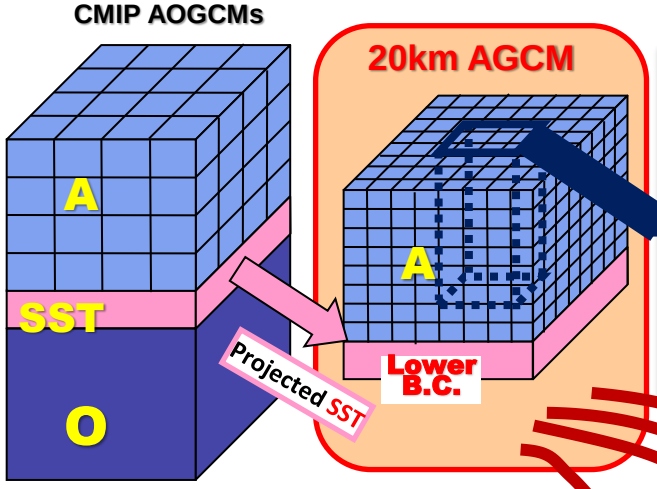
- dynamically downscaled to the regional ocean model (10km over North Pacific, 2km around Japan), in addition to the regional atmospheric model

d4PDF
database for Policy Decision making for Future climate change
(Mizuta et al. 2017)

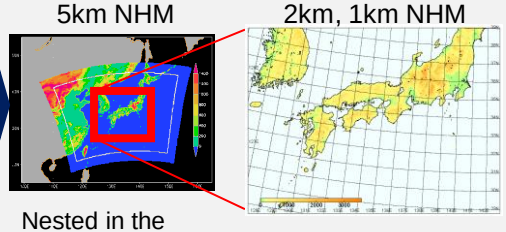


Simulation	Historical	Non-warming	+2℃	+4℃
Duration	60years+ (1951–2010+)	60years+ (1951–2010+)	60years	60years
Ensembles (MRI-AGCM)	100	100	6×9	6×15
Ensembles (NHRCM)	100	100	6×9	6×15
SST	observation	detrended observation	detrended observation + SST warming from CMIP5 models	detrended observation + SST warming from CMIP5 models
GHG etc.	observation	values in 1850	values in 2040	values in 2090

High-resolution time-slice experiments by MRI-AGCM



Dynamical Downscaling by Regional Climate Model



Impact Assessments

- Disasters
- Agriculture
- Water Resources

Study of Future Change in Extreme Events

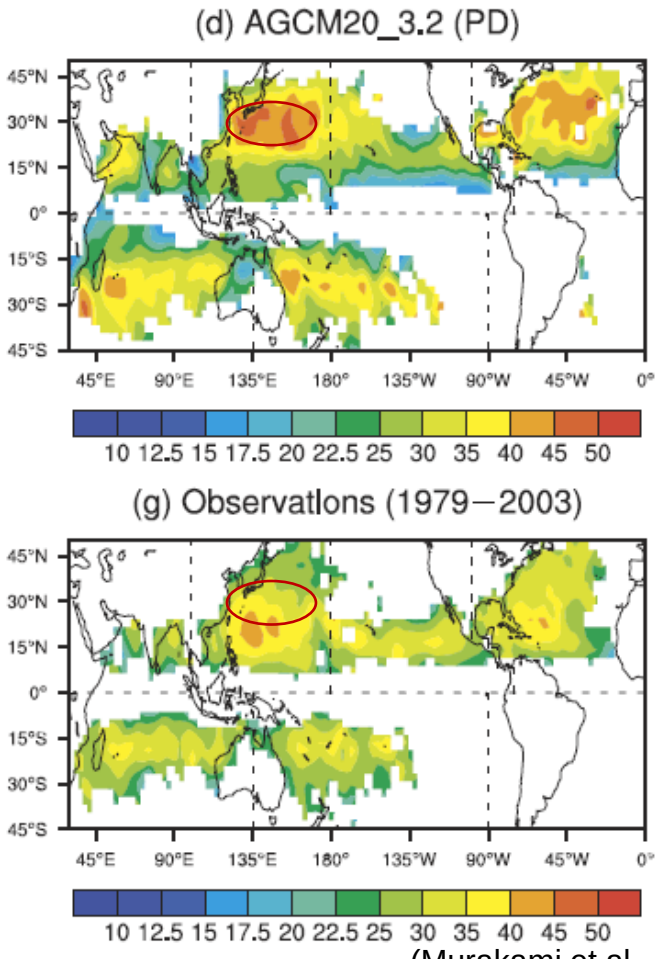
- Tropical Cyclones (e.g. Murakami et al. 2012)
  →less number, more intense
- East Asia Monsoon (e.g. Kusunoki et al.2006)
  →seasonal migration delayed
- Extreme Rainfall (e.g. Kamiguchi et al. 2006)
  →more frequent
- Blockings (e.g. Matsueda et al. 2009)
  →less frequent
- Extratropical Cyclones(e.g. Mizuta et al.2011)

Regional Climate Change

- Outputs provided to researchers of each region
  (Korea, China, Taiwan, Philippines, Thailand, Indonesia, Viet Nam, Bangladesh, India, Israel, Saudi Arabia, Senegal, Spain, Netherland, UK, Ireland, Denmark, Switzerland, Germany, USA, Mexico, Columbia, Barbados, Belize, Bolivia, Peru, Ecuador, Brazil, Argentina, Australia, Papua New Guinea)

A-O interaction on tropical cyclones

Frequency distribution of Intense TCs



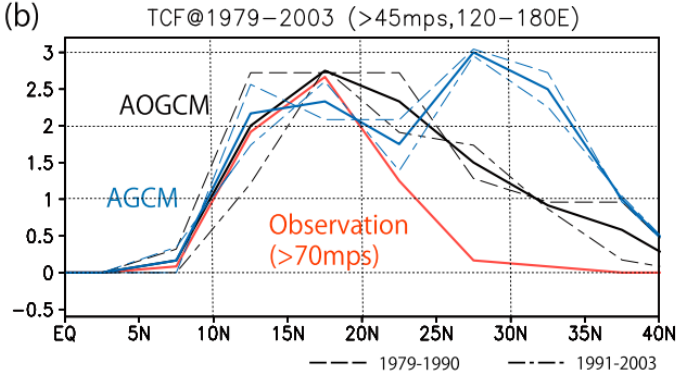
(Murakami et al., 2012)

– Intense TCs at higher latitudes in AGCM than in observation

… SST cooling after typhoon passage are not simulated in AGCM

→ improved by introducing short-term A-O interaction using AOGCM with SST restore

Intense typhoon frequency difference: AGCM - AOGCM



(Ogata et al. 2015)

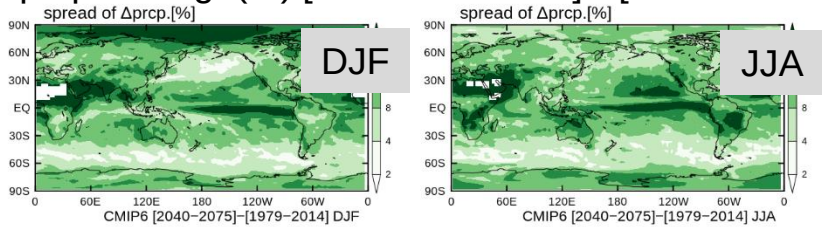
Ensemble methods

Large part of spread between CMIP6 model results can be expressed by TSE-C with a combination of
(1) initial-value ensemble,
(2) interannual variability phase ensemble, and
(3) model ensemble.

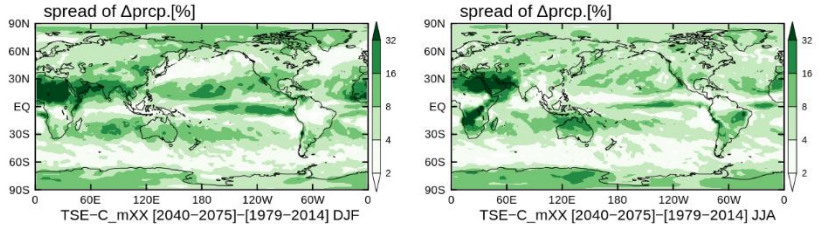
Ensemble spread of prcp. change(%) [ave. 2040-2075]—[ave.1979-2014]

DJF JJA

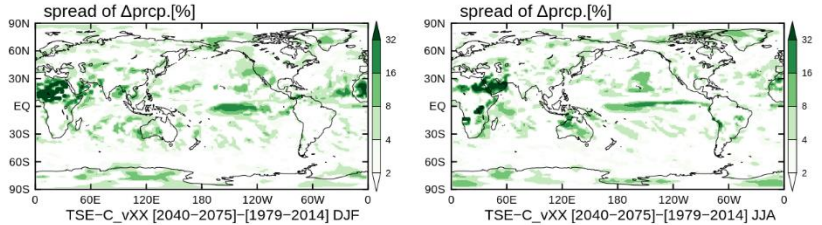
CMIP6 model outputs



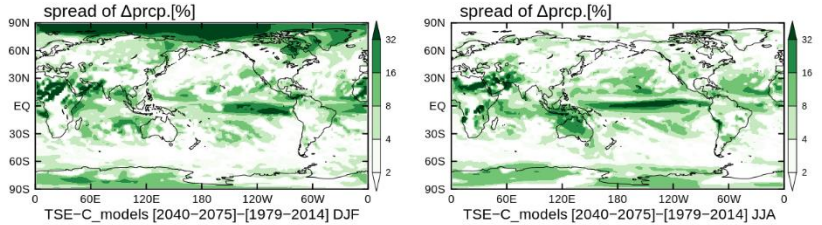
(1) initial-value ensemble



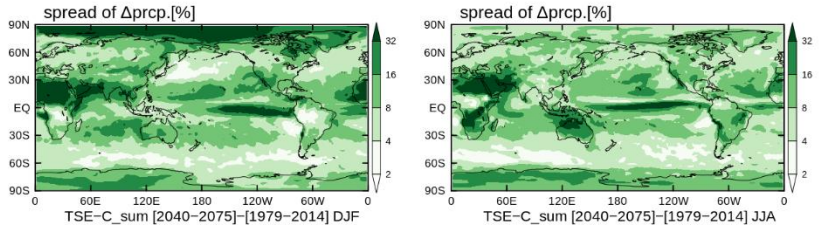
(2) interannual variability phase ensemble
((1) is sustracted)



(3) model ensemble
((1) is sustracted)



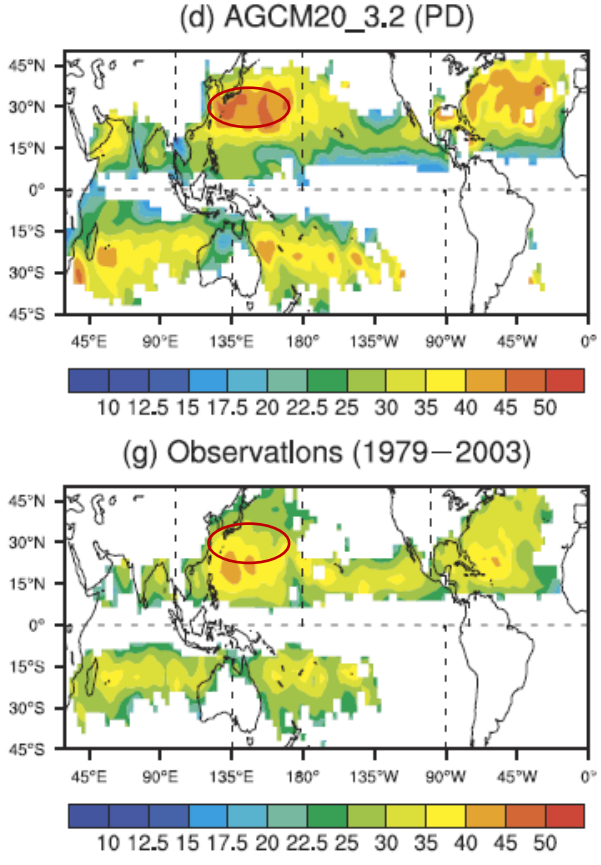
(1) + **(2)** + **(3)**



A-O interaction on tropical cyclones

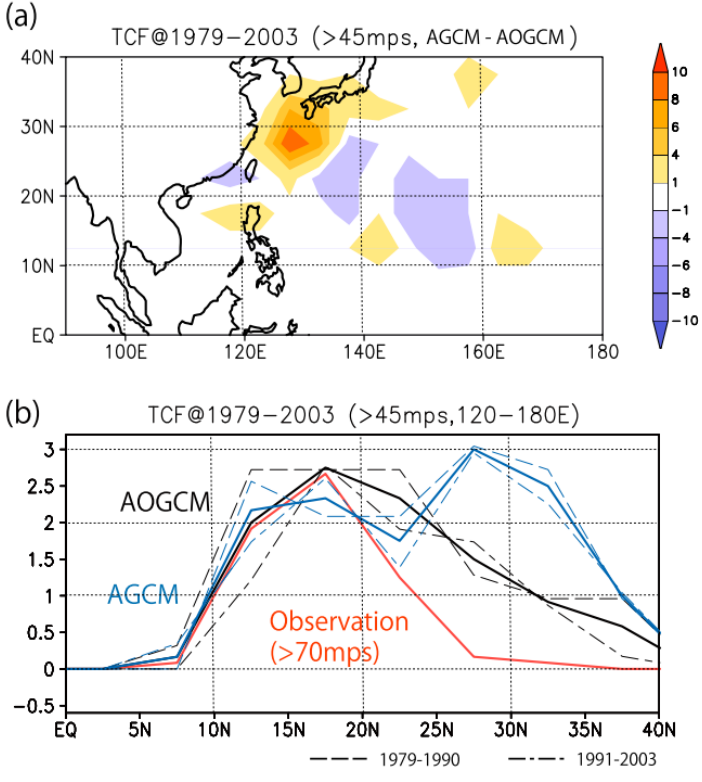
Intense TCs at higher latitudes in AGCM than in observation
→ improved by introducing short-term A-O interaction using AOGCM

Frequency distribution of Intense TCs



(Murakami et al., 2012)

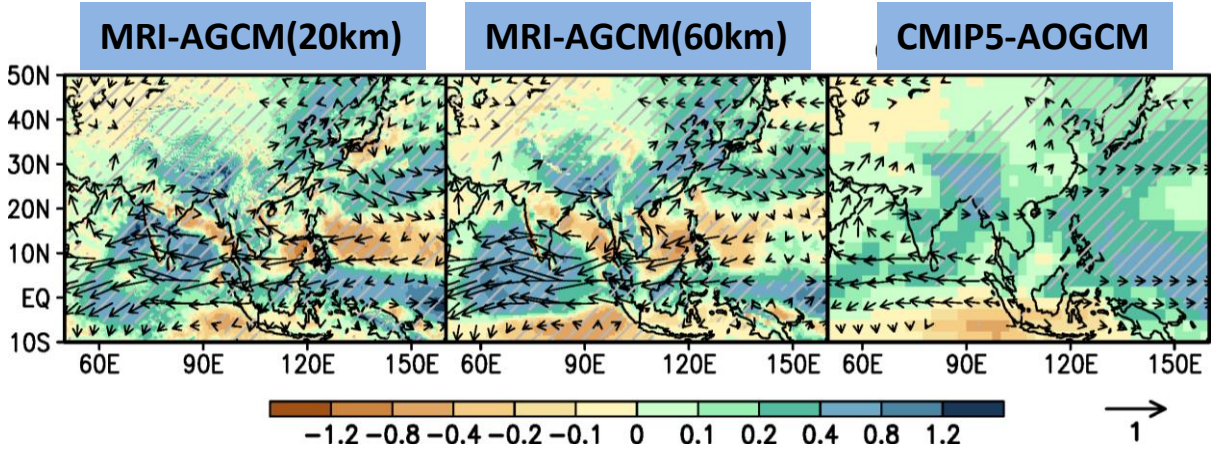
Typhoon frequency difference: AGCM - AOGCM



(Ogata et al. 2015)

大気海洋結合効果（将来予測への影響）

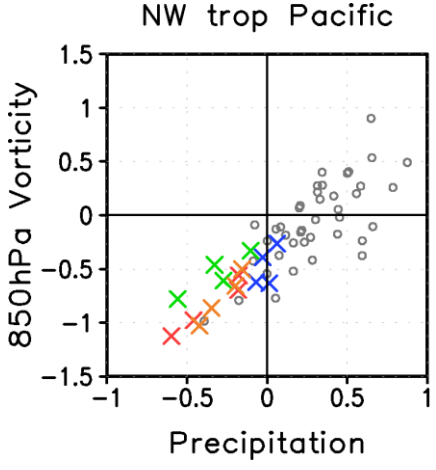
夏季降水量
850hPa風
将来変化



斜線：降水量偏差符号が80%以上メンバーで一致

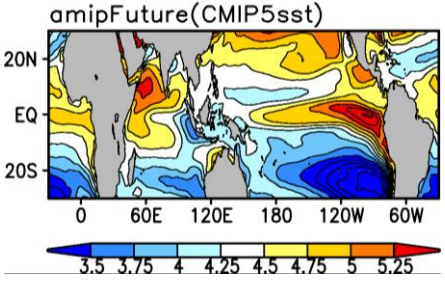
- 熱帯北西太平洋では、MRI-AGCMはCMIP5モデル予測と異なる。
- 日本付近の予測の違いにも関連？

- AGCM降水変化はSSTパターンに過剰に応答？
- 大気海洋結合効果の有無が予測に影響？



10N-20N
110E-140E

MRI−AGCM3.2S(YS)
MRI−AGCM3.2H(YS)
MRI−AGCM3.2H(AS)
MRI−AGCM3.2H(KF)
CMIP5 AOGCM

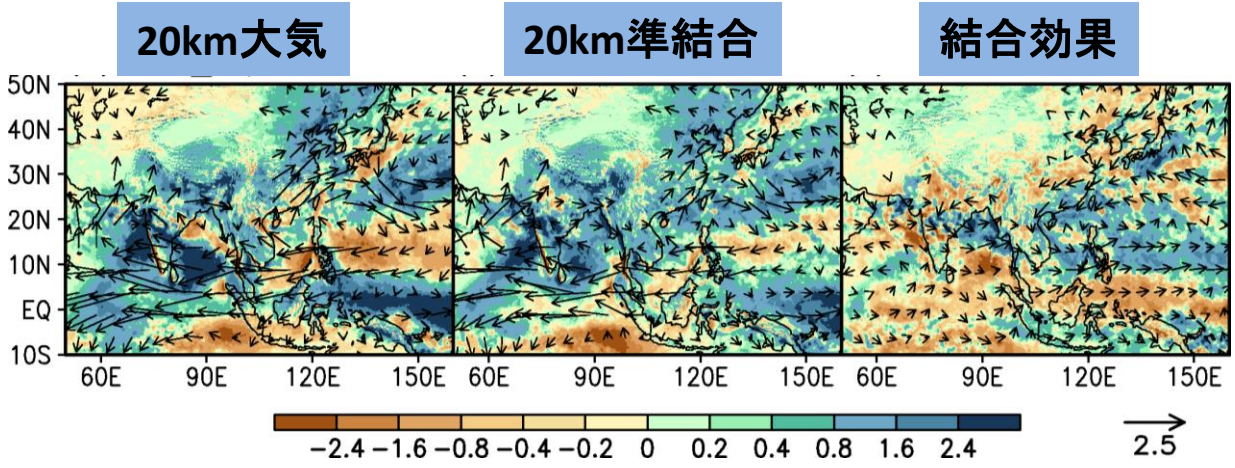


[K]

（熱帯ΔSST=4Kにスケーリング）

大気海洋結合効果（将来予測への影響）

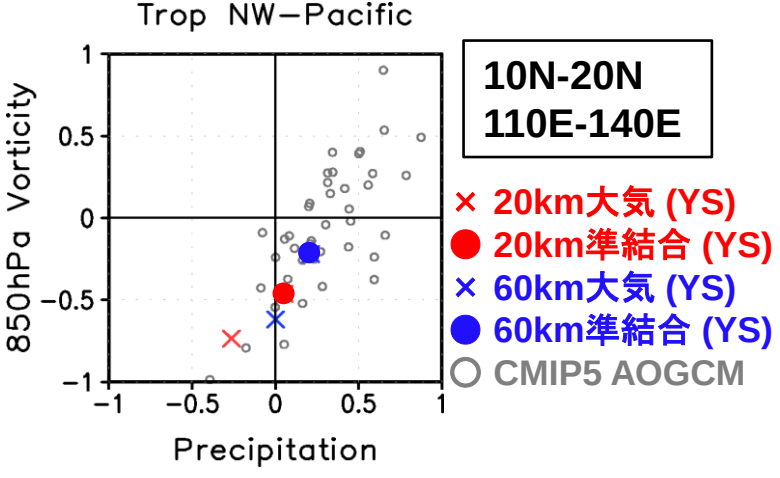
夏季降水量
850hPa風
将来変化



結合効果導入により、

1. 熱帯北西太平洋の降水量増加
2. 日本付近の降水量増加

→ CMIPモデル予測との差異減少



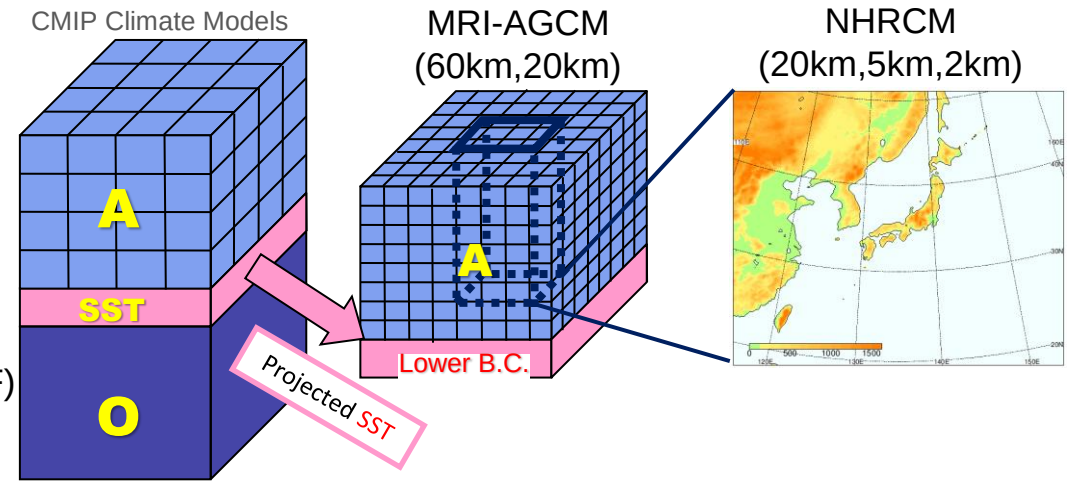
Global and regional projections with A-O interaction

Previous system

SST is prescribed as
lower boundary condition

Past: Observation
Future: Obs. + CMIP warming

Large ensemble time-slice (d4PDF)
and small members of continuous
simulation (HighResMIP)



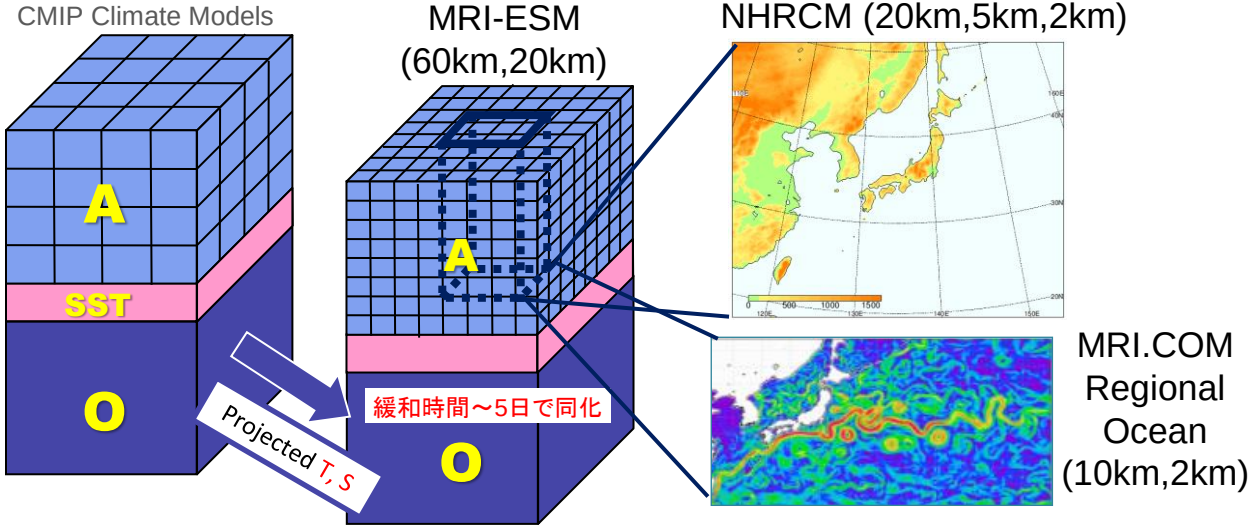
New system

TSE-C (Temporally Sequential Experiments with Coupled model)

Ocean T and S are
assimilated with τ ~ 5days

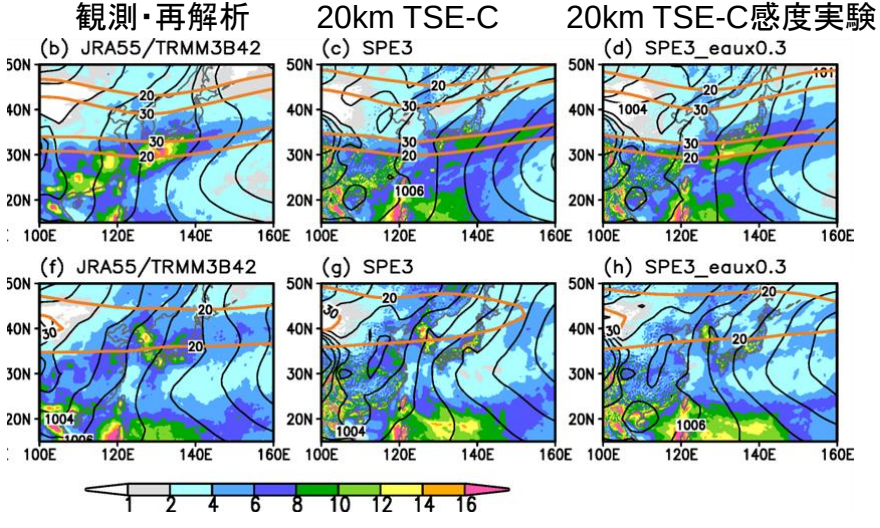
Past: Observation
Future: Obs. + CMIP warming

Large ensemble continuous
simulation

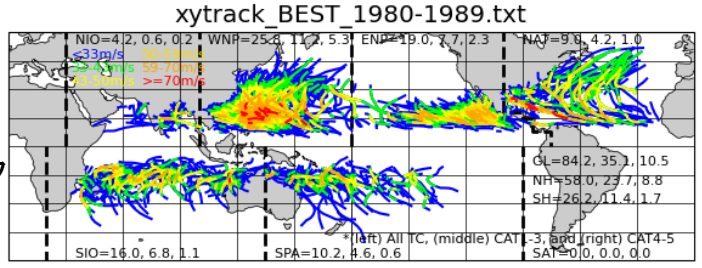


新しい予測システム(TSE-C)の開発・調整

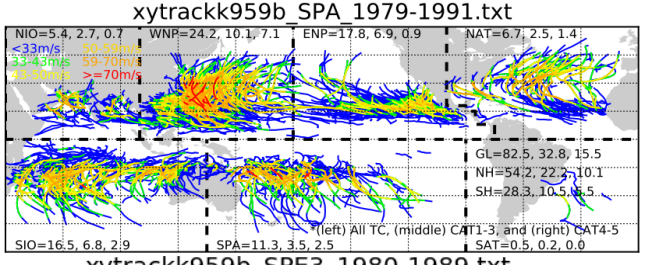
- TSE-C 20kmのテスト実験を行い、気候値再現性能・解像度依存性を確認。設定を変えた感度実験を複数行い、再現性能の向上を調べた。
- 熱帯低気圧の強度分布は再現されている。南半球で過剰といった、地理分布の改善余地がある。
- 梅雨の季節的北上が良く再現できているが、季節進行が早い。
- 冬季に日本周辺で観測より低温になる。



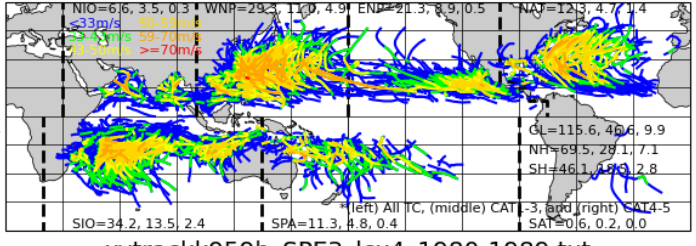
ベストトラック



20km MRI-AGCM3.2



20km TSE-C



20km TSE-C 感度実験