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Impact of global warming on tropical cyclone structure change with a 20-km-mesh high-resolution global model

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Motivation and Review

▪Evaluating changes in tropical cyclone size and structure influenced by global warming is important for projecting socioeconomic damage in the future.

▪However, conducting multi-year climate simulations in order to evaluate these changes costs huge computer resources.

▪Knutson and Tuleya (1999, Climate Dynamics)

=>The 51 tropical cyclones (hereafter TCs) experiments with an 18-km-mesh RCM are conducted over the western North Pacific.

=>The warm core of the TC shifts upward under the warmed environment.

=>The mean horizontal radius of the hurricane-force winds increases 2-3%.

▪Jiang and Perrie(2007, Journal of Climate)

=>A 25-year projection of future environment over the North Atlantic is conducted with a 25-km-mesh RCM.

=>A large increase in wind speed in the upper-level troposphere of the right portion of the storm center is detected.

▪Most studies use a regional model for climate projection.

↓

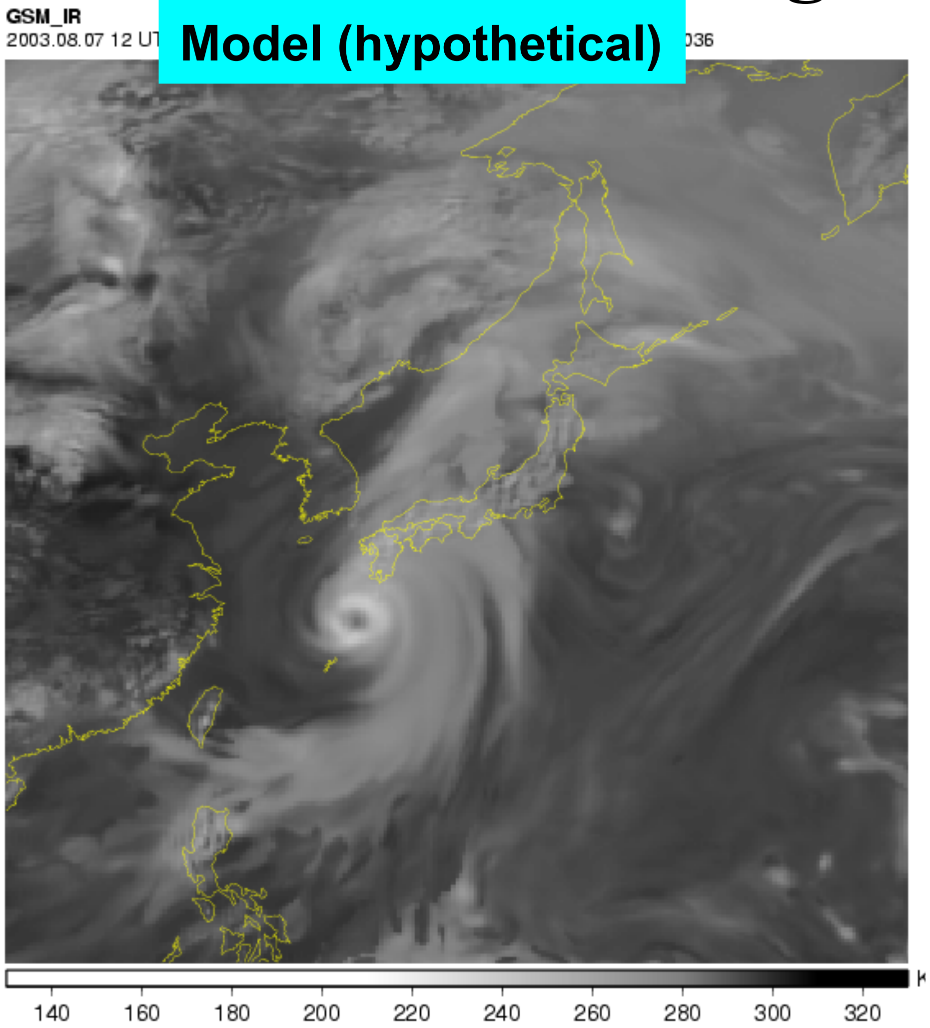
We used a **20-km-mesh Atmospheric Global Circulation Model** in order to evaluate possible changes in tropical cyclone structure affected by global warming.

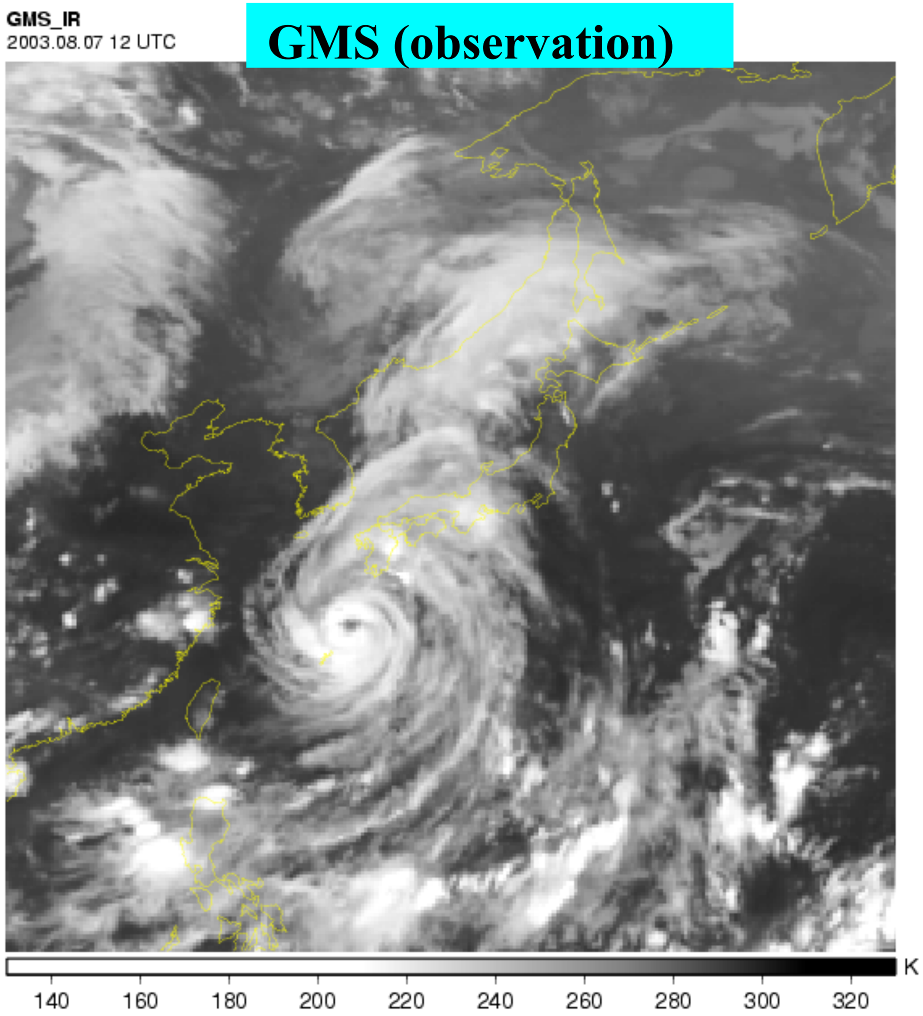
MRI/JMA Atmospheric GCM

- Based on operational JMA-GSM
- Resolution: TL959(20km) with 60 layers
- Time integration: Semi-Lagrangian Scheme (Yoshimura, 2004)
  2 days/1 year integration with DT=6 min and
  30 nodes of Earth Simulator (ES has total 640 nodes)
- Physics
  - Cumulus convection: Prognostic Arakawa-Schubert (Randall and Pan, 1993)
  - SW radiation: Shibata & Uchiyama (1992)
  - LW radiation: Shibata & Aoki (1989)
  - Land hydrology: MJ-SiB: SiB with 4 soil-layers and 3 snow-layers
  - Clouds: large-scale condensation, Cumulus, stratocumulus
  - PBL: Mellor & Yamada (1974,1982) level-2 closure model
  - Gravity wave drag: Iwasaki et al. (1989) + Rayleigh friction

- Japan Meteorological Agency (JMA) :Operational global NWP model
  from Nov 2007
- Meteorological Research Institute (MRI) : Next generation climate model

Sample of a simulated tropical cyclone (Infrared image by model outputs)



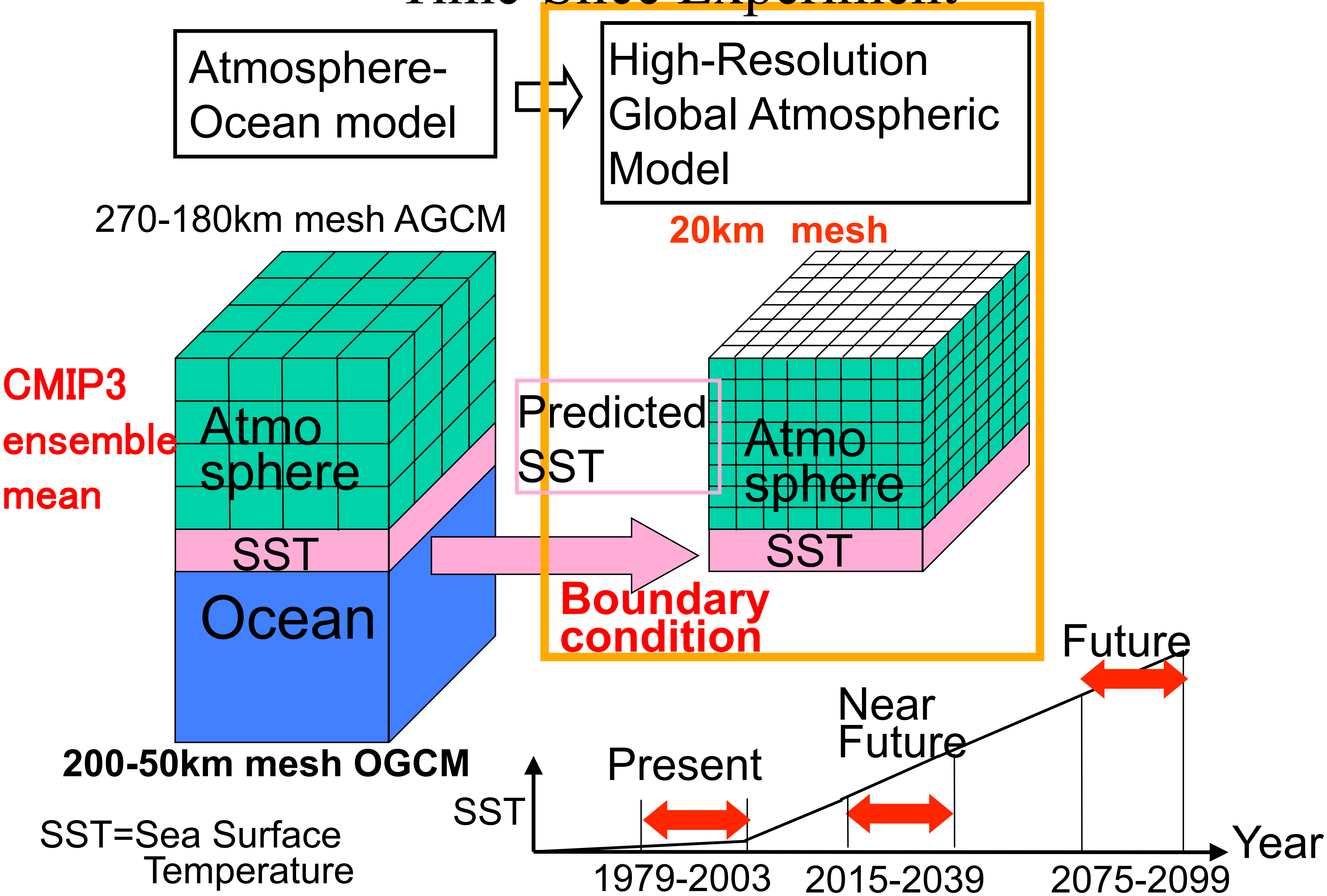


Infrared image

2003 08 07 12 Initial

FT=36

Experimental Design for Climate Simulations; Time-Slice Experiment



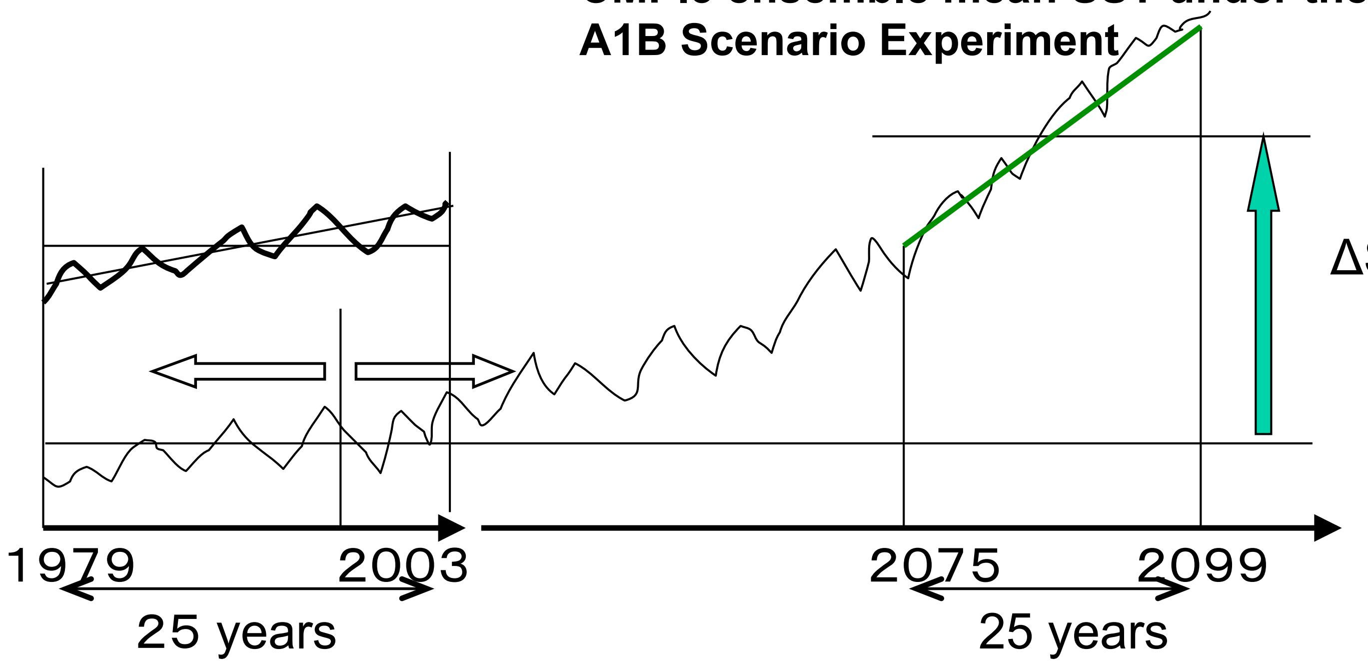
How to determine SST

Mizuta et.al (2008)

Present SST

Observed SST
1979～2003

AR4_20thCentury
Exp. SST -2001



Future SSTA

also applies for 2015-2039

CMIP3 SST change

ΔSST

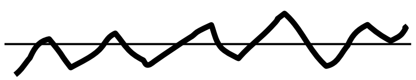
Mean SST(2075-2099) – Mean SST(1979-2003)

+

CMIP3
SST Trend
2075-2099

+

Inter-annual variability
of Observed SST
1979-2003



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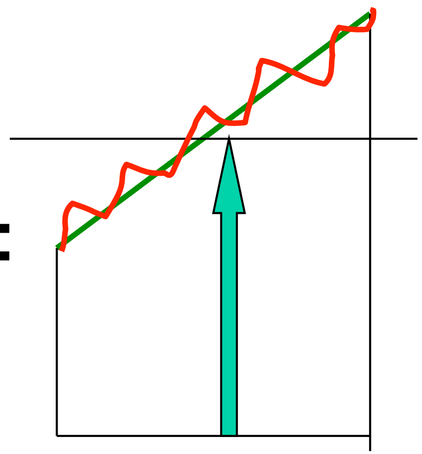
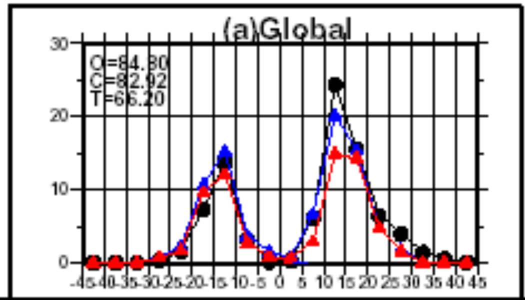
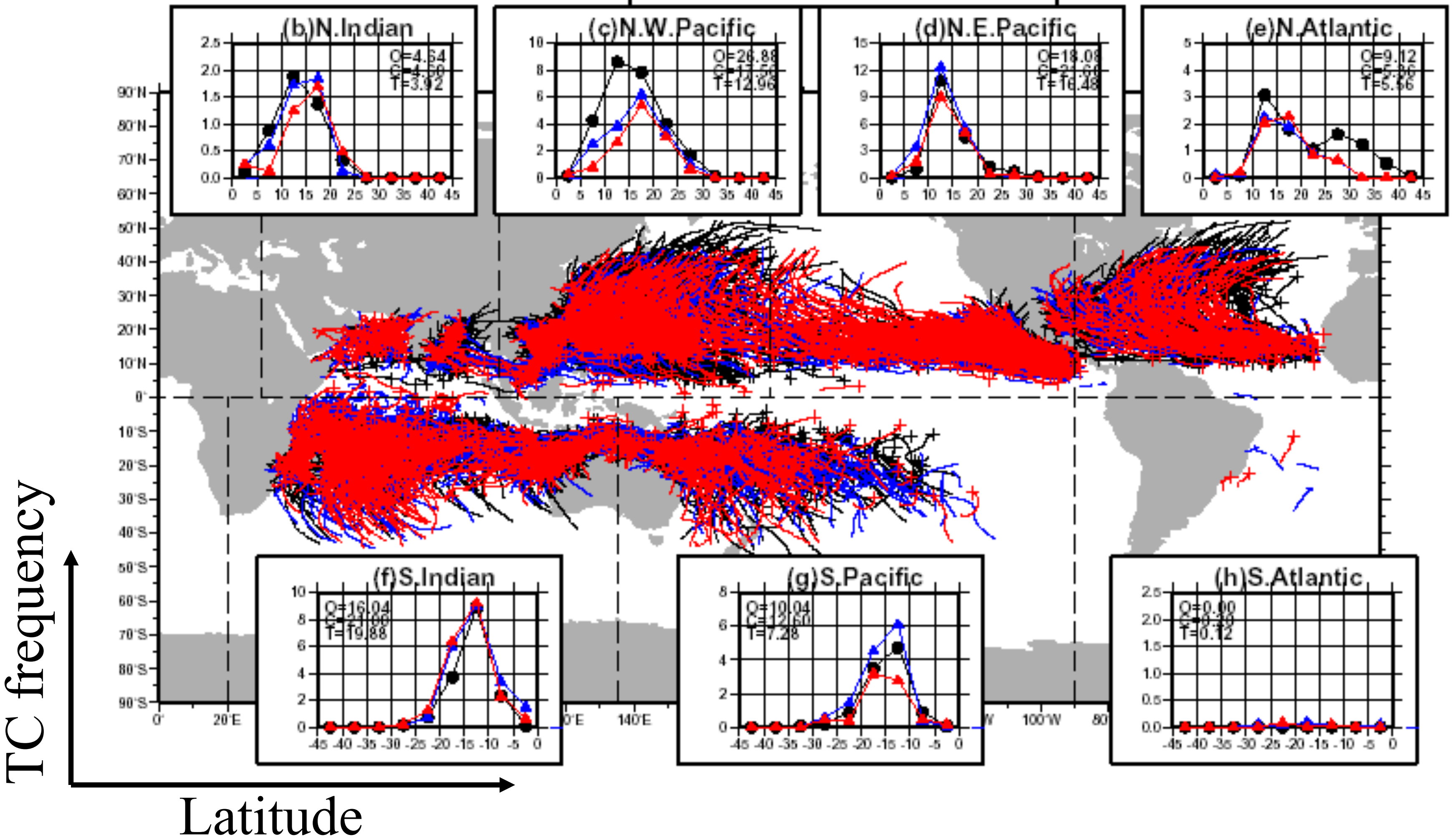


Number of TC Generated in Each Latitude

Annual global average
Present =82 (Observation=84)
Future =66 (20% decrease)

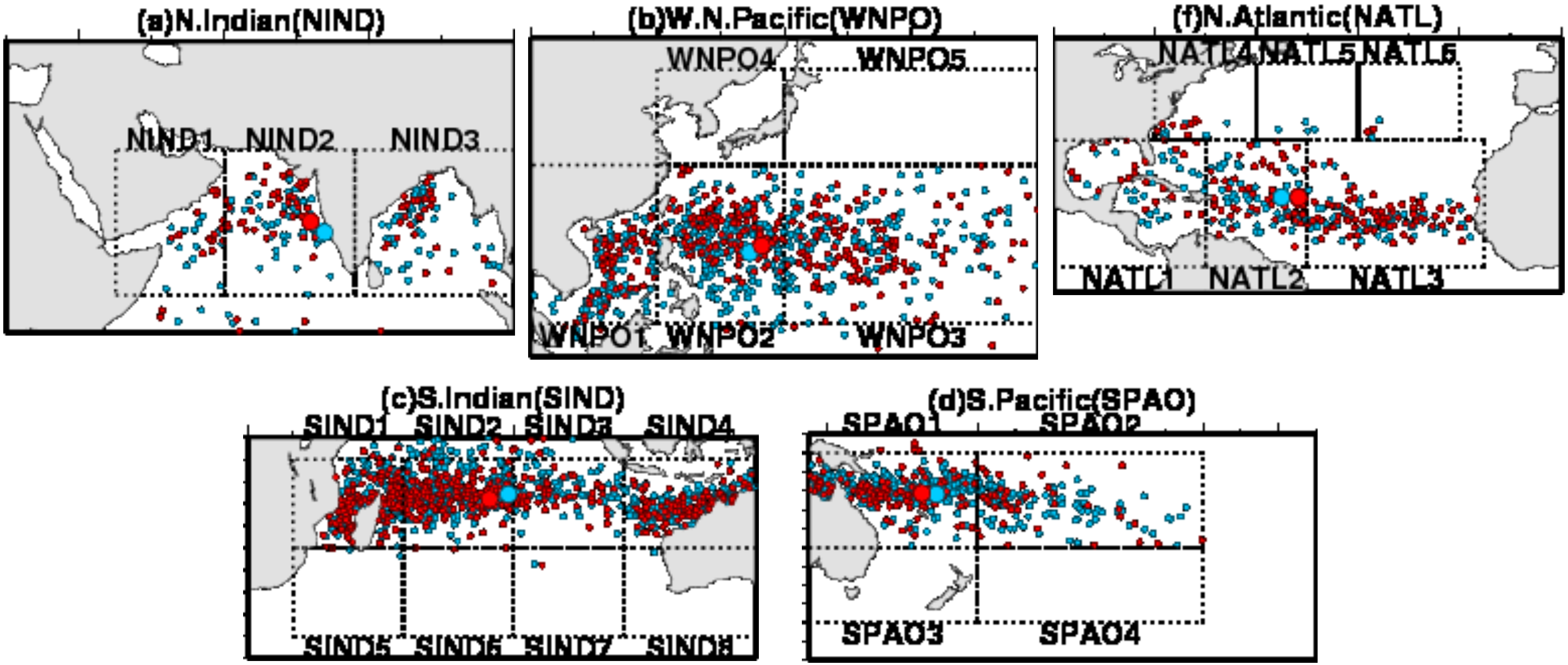


Observation (1979-2003)
Present-day (1979-2003)
Future (2075-2099)



Shift in TC Generated Position

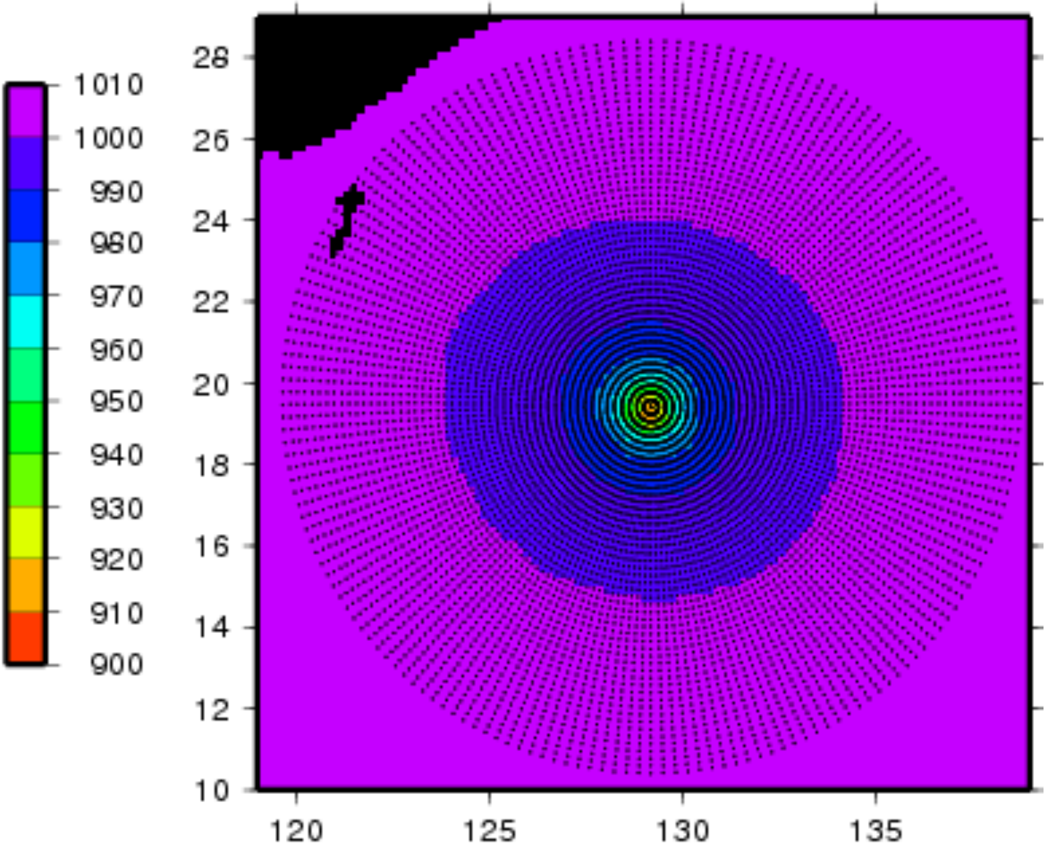
- Averaged TC generated position (present-day simulation)
- Generated position for each TC (present-day simulation)
- Averaged TC generated position (future simulation)
- Generated position for each TC (future simulation)



Methodology - Composite Analysis

Composites here are defined as the average maximum intensity of all storm center's studies

Sample of composition grids

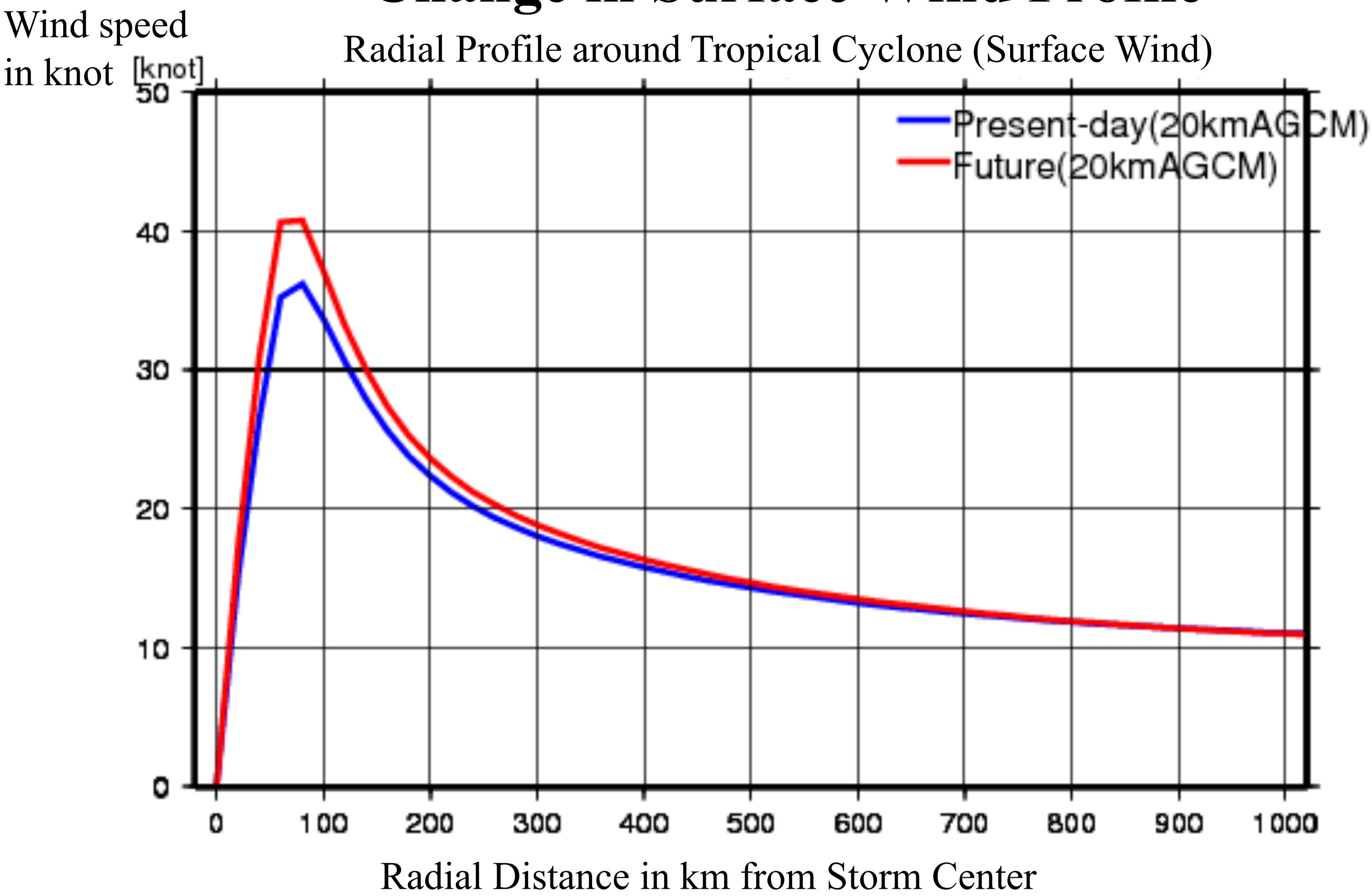


Total TC number (annual average)

Present-day (1979-2003): **2086 (82)**

Future (2075-2099): **1667 (66)**

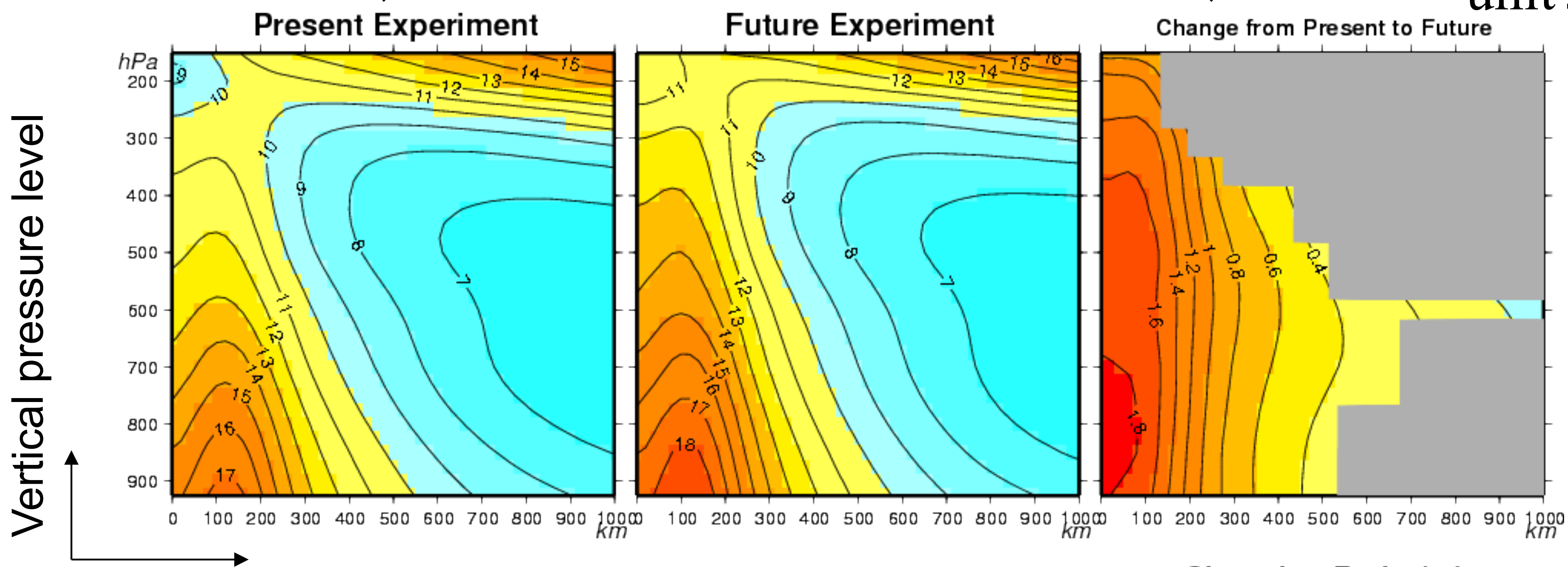
Change in Surface Wind Profile

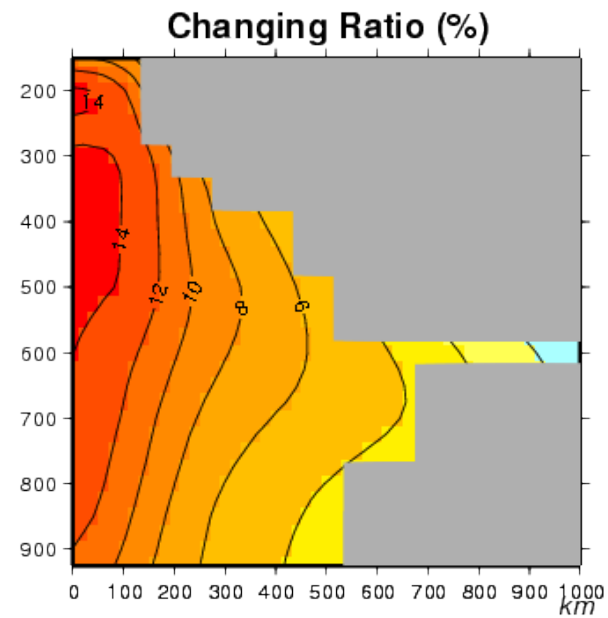


- **Large changes in wind velocity occur near inner-core region.**
- **A surface wind speed increase of more than 4% can be seen up to 500 km from the storm center.**

Change in tangential component of wind（distance and vertical section）

unit：m/s



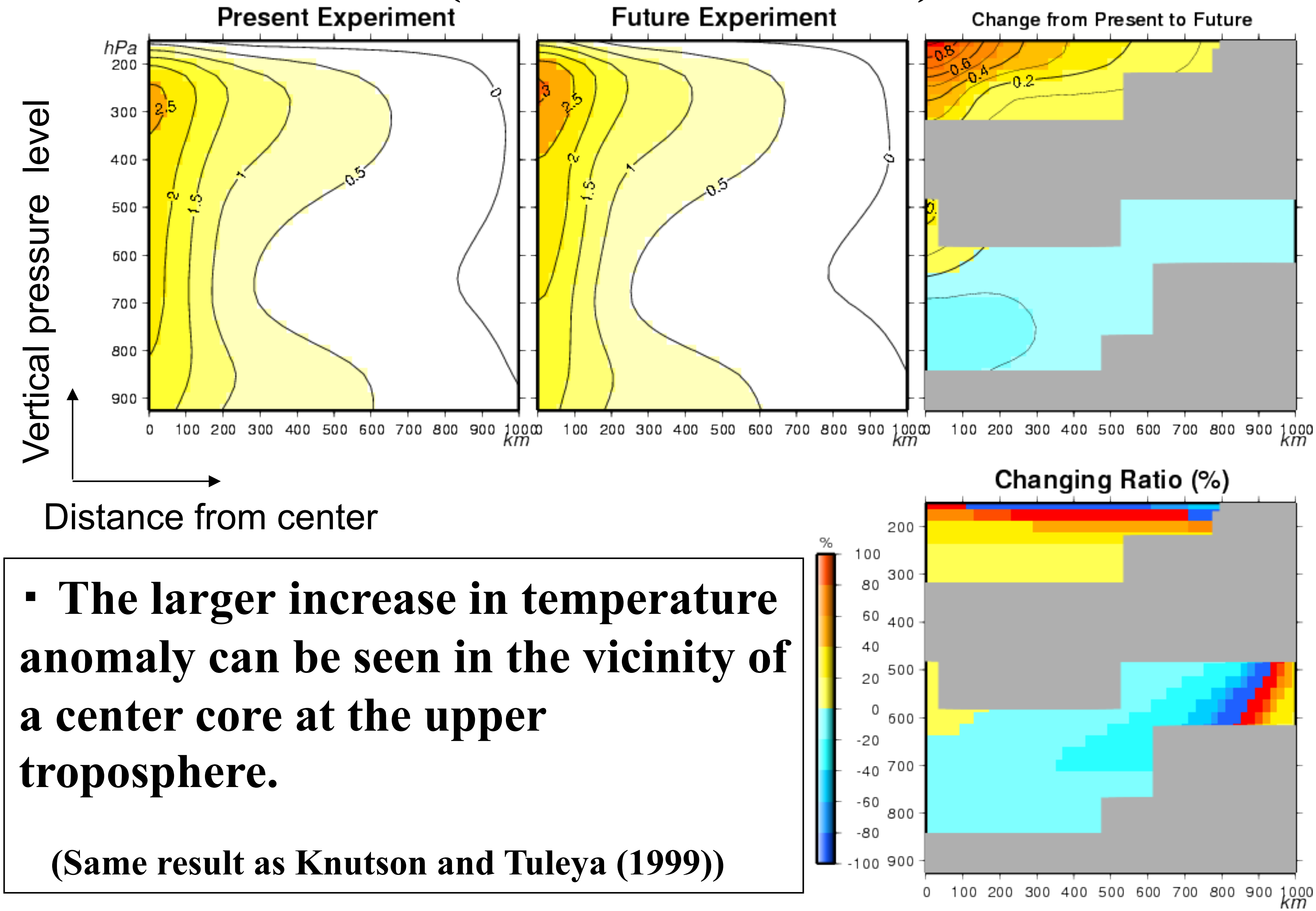


- The large increase in wind velocity (12-15%) occurs at the inner-core side.
- The larger increase in tangential wind occurs at mid level of troposphere.

#gray color=no significant difference

Change in temperature anomaly (distance vs vertical)

unit : K

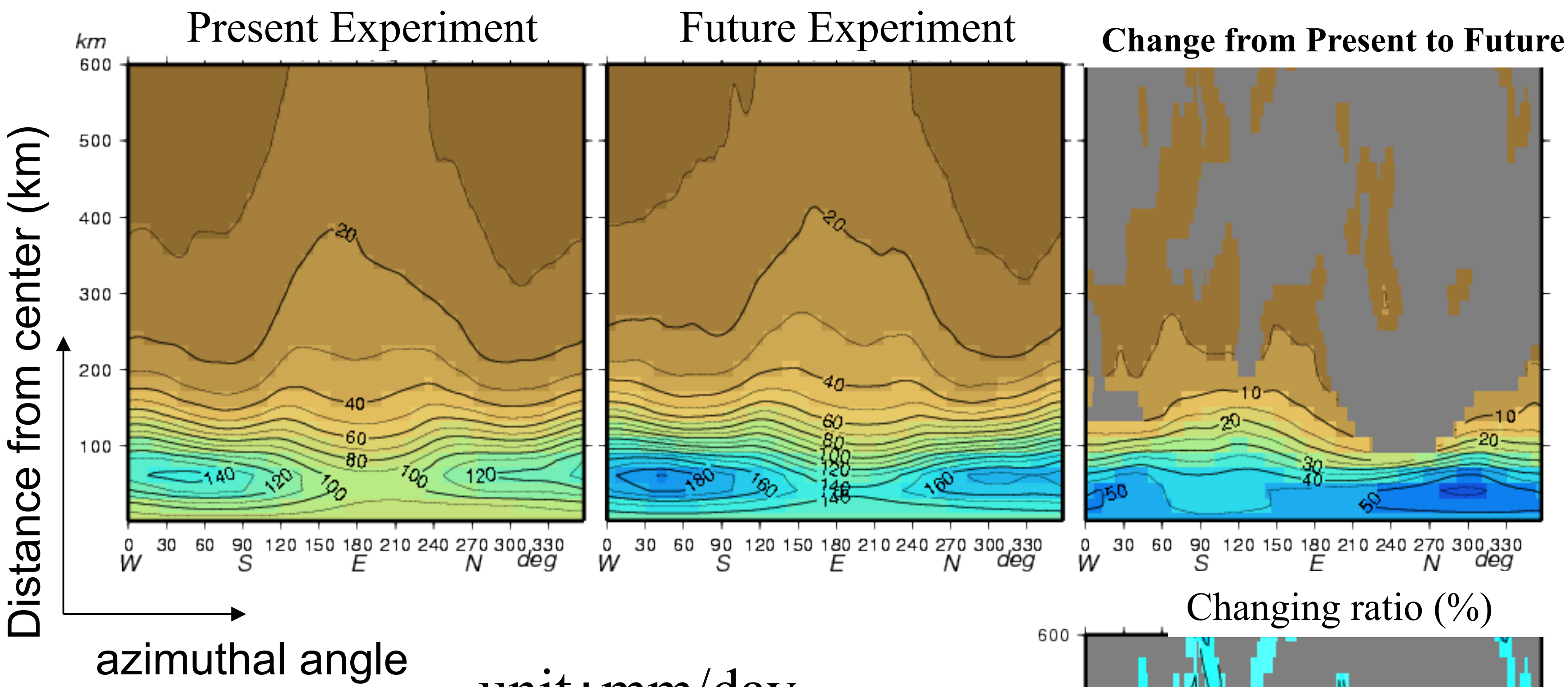


▪ **The larger increase in temperature anomaly can be seen in the vicinity of a center core at the upper troposphere.**

(Same result as Knutson and Tuleya (1999))

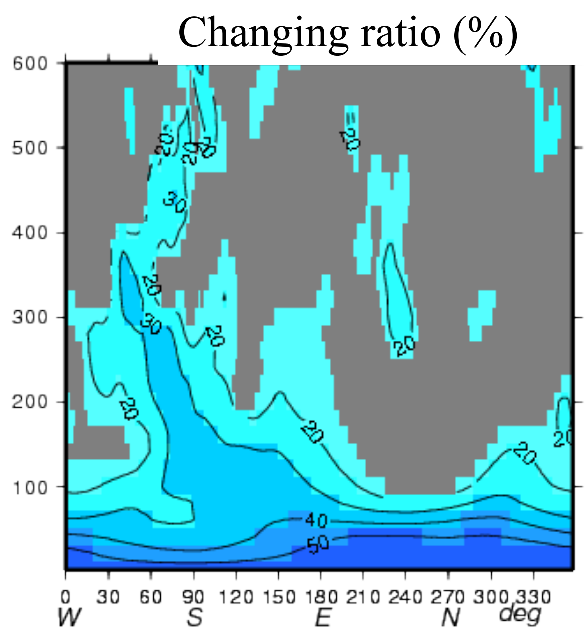
#gray color=no significant difference

Precipitation Change



unit : mm/day

At most a 50% increase in precipitation can be identified in the region up to 100 km from the center.



#gray color=no significant difference

Summary

Consecutive 25-year climate simulations using a 20-km-mesh high-resolution AGCM were conducted to explore structural changes in tropical cyclones due to global warming.
Simulations were conducted for both a present-day and a future warmed environment that is based on an A1B scenario.

- More than a 4% increase in surface wind velocity was identified up to 500 km from storm centers.
- An increase in wind velocity was larger at the middle level of troposphere.
- At most a 50% increase in precipitation was identified in the inner-core region of the TC (at less than 100 km from the center).
- Warm-core enhancement at the upper troposphere leads to an increase in vertical level of TCs.

Change in TC Genesis Frequency and Position