Tropical cyclone and multi-scale precipitation events in the summer seasonal simulations and global warming experiments with NICAM

K.Oouchi[1], M. Satoh[1,2], Y. Yamada[1], A. Noda[1], H. Tomita[1], W. Yanase[3], and NICAM team

1. Research Institute for Global Change (FRCGC), JAMSTEC
2. Center for Climate System Research, The University of Tokyo
3. Ocean Research Institute, The University of Tokyo

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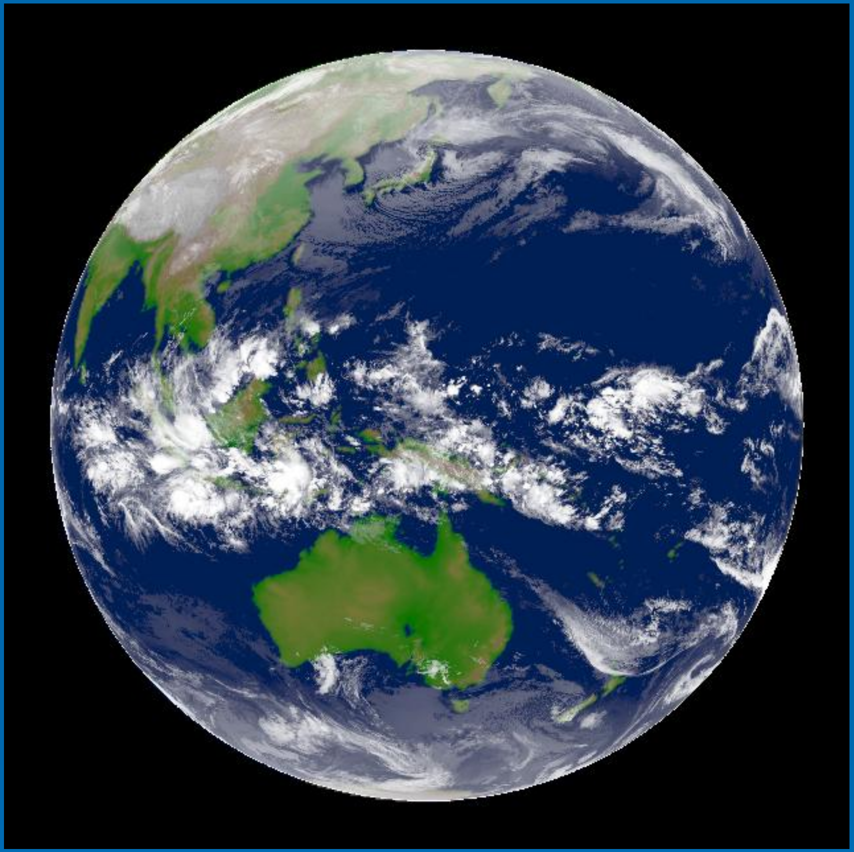
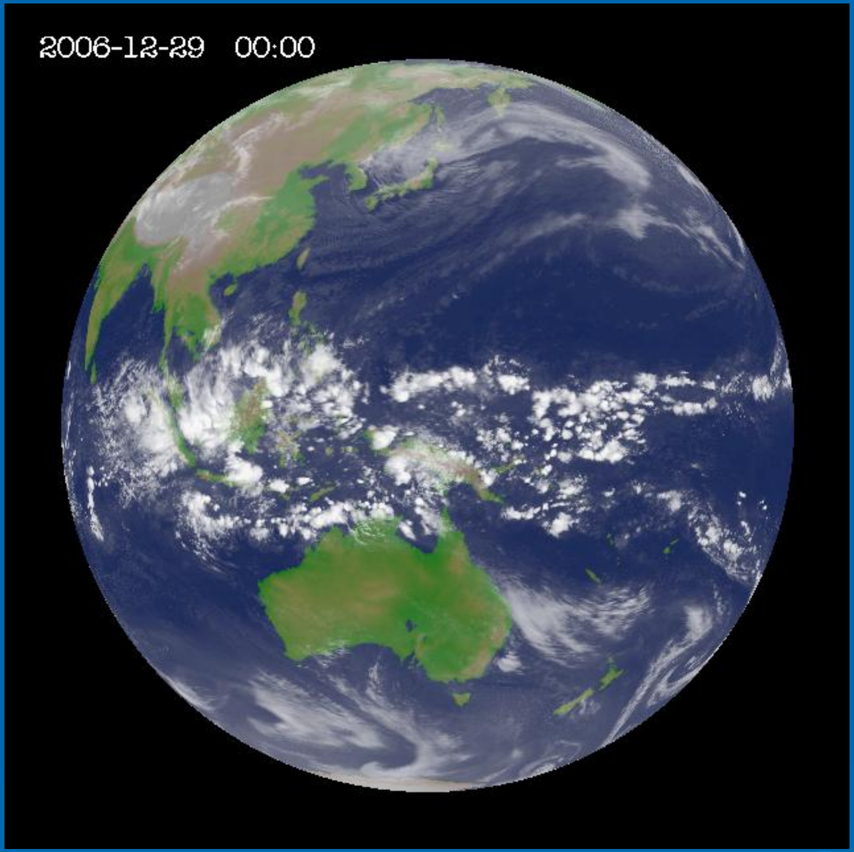
10-14 August, 2009, ICTP, Trieste

JAMSTEC

EARTH SIMULATOR



MTSAT-1R

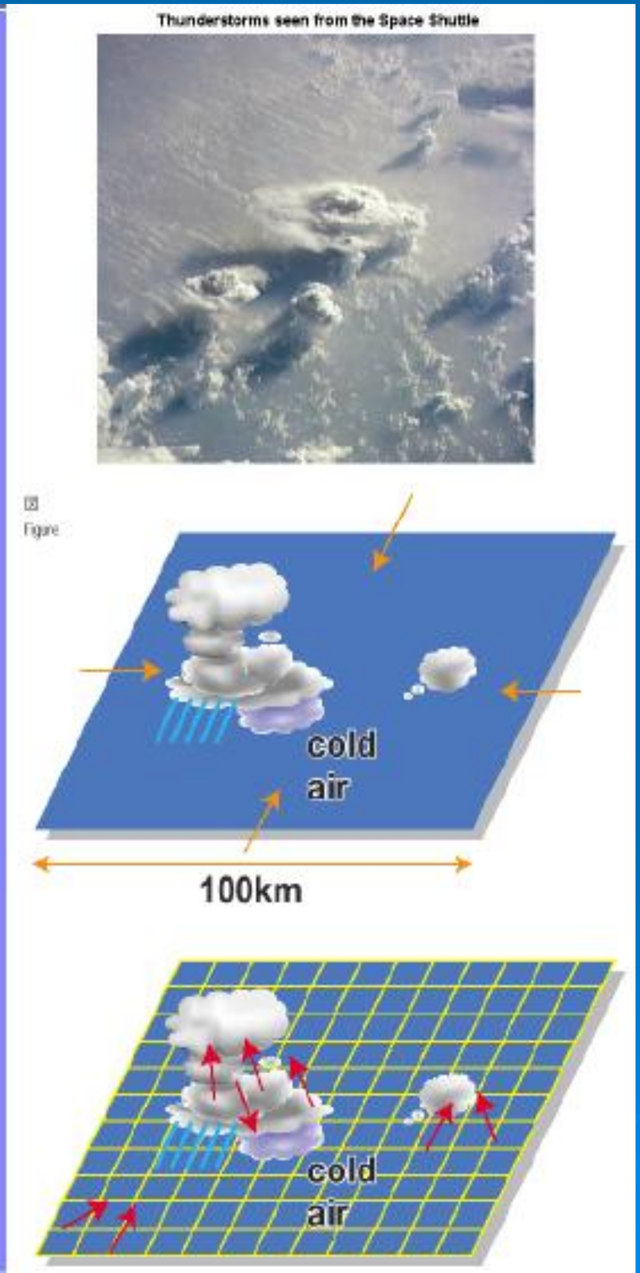


NICAM

Boreal winter simulation (snapshot at Day 10)

Miura et al. (2007,Science)

Why global-cloud-resolving model ?



Issues:

- how much the resolution should be fine to capture typhoon dynamics and discuss its climatology such as future change

- A high-resolution GCM study (Oouchi et al. 2006) argued that "gross feature" of TC is represented in the 20-km mesh GCM. Is this really so ?

- Tropical cyclone climatology is an ensemble effect of meso-scale process

Thunderstorms seen from the Space Shuttle

Contents:

Highlight of the results from recent two NICAM runs:

- global warming experiment

- boreal summer seasonal experiment

New perspectives in recent NICAM runs:

What is different from the previous NICAM runs:

- time range is extended to seasonal length while best exploiting the strength of the global cloud-system resolving (7-km and 14-km mesh) framework

- "climate issues *on seasonal time scale*" are brought to more serious attention – but in a way different from conventional climate models: vast range of hierarchy from mesoscale to synoptic/planetary scale

How to take advantage of the model strength ?

global cloud-resolving, high resolution,…

A rationale: high-resolution is necessary for future climate modeling

STRATEGIES

REVOLUTION IN CLIMATE PREDICTION IS BOTH NECESSARY AND POSSIBLE

A Declaration at the World Modelling Summit for Climate Prediction

Scientific viewpoints to be explored:

-High-resolution model is capable of representing cloud cluster and mesoscale convection that are fundamental elements in organized convection under latent instability condition

- It is a challenging new pathway to connect mesoscale cloud-system modeling with comprehensive weather-climate modeling

The Japanese experience of simulating global climate with horizontal resolution of 3.5–10 km has established the basis for wider experimentation with—and application of—very high-resolution models. Thus, the experts at the summit concluded that climate modeling will need—and is ready—to move to fundamentally new high-resolution approaches to capitalize on the seamlessness of the weather–climate continuum.

Much higher resolution of the major model components (e.g., atmosphere, ocean, and land) is a fundamental prerequisite for a more realistic representation of the climate system and more relevant predictions (e.g., extremes, convection, and tropical variability), and thus regional and local applications. Improving the basic model physics is also important, whether through observationally inspired development, much higher resolutions, or stochastic concepts. Among the many advantages of very high-resolution studies is the improvement of the prediction of the tropical climate and its variability. This would dramatically improve predictions for some of the most populated and poorest areas of the globe.

Shukla et al. (2009,BAMS)

global warming experiment

(Yamada et al. 2009, to be submitted)

Aim of the talk ; *before exploring detailed genesis process study*

- to discuss results on the *general* features of TCs in GCRM run, as a 1st step

basic statistics of future change

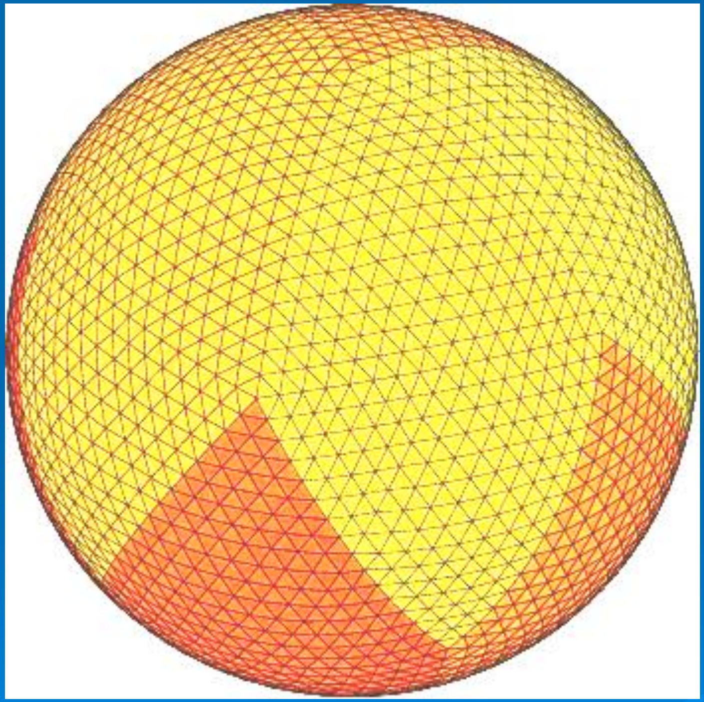
track, frequency, intensity

regional difference of the change

large-scale environmental factors

Note: statistical assessment is compromised by the limited sampling number in this case study approach

Nonhydrostatic ICosahedral Atmospheric Model (NICAM)



- conserve total mass and energy
  (Satoh, 2002,2003)

- Boundary layer scheme:
  MYNN (Niino and Nakanishi,2004;
  Noda et al. 2009)

- Cloud Microphysics: 2 solid categories
  (Grabowski, 1998)

- Radiation scheme: MSTRNX
  (Sekiguchi and Nakajima, 2008)

- This study: 14-km mesh

Satoh et al. (2008) Tomita et al. (2004)

Design of the global warming experiment

CMIP3 multi model ensemble: 18 members

sea surface temperature

- present SST: control case (Reynolds OI SST for 2004)
- future SST :

  control case SST + CMIP3-based ΔSST (future-present)

Important climate change forcing

future : ensemble average for the period 2075 - 2099
present : ensemble average for the period 1979 – 2003

sea ice concentration

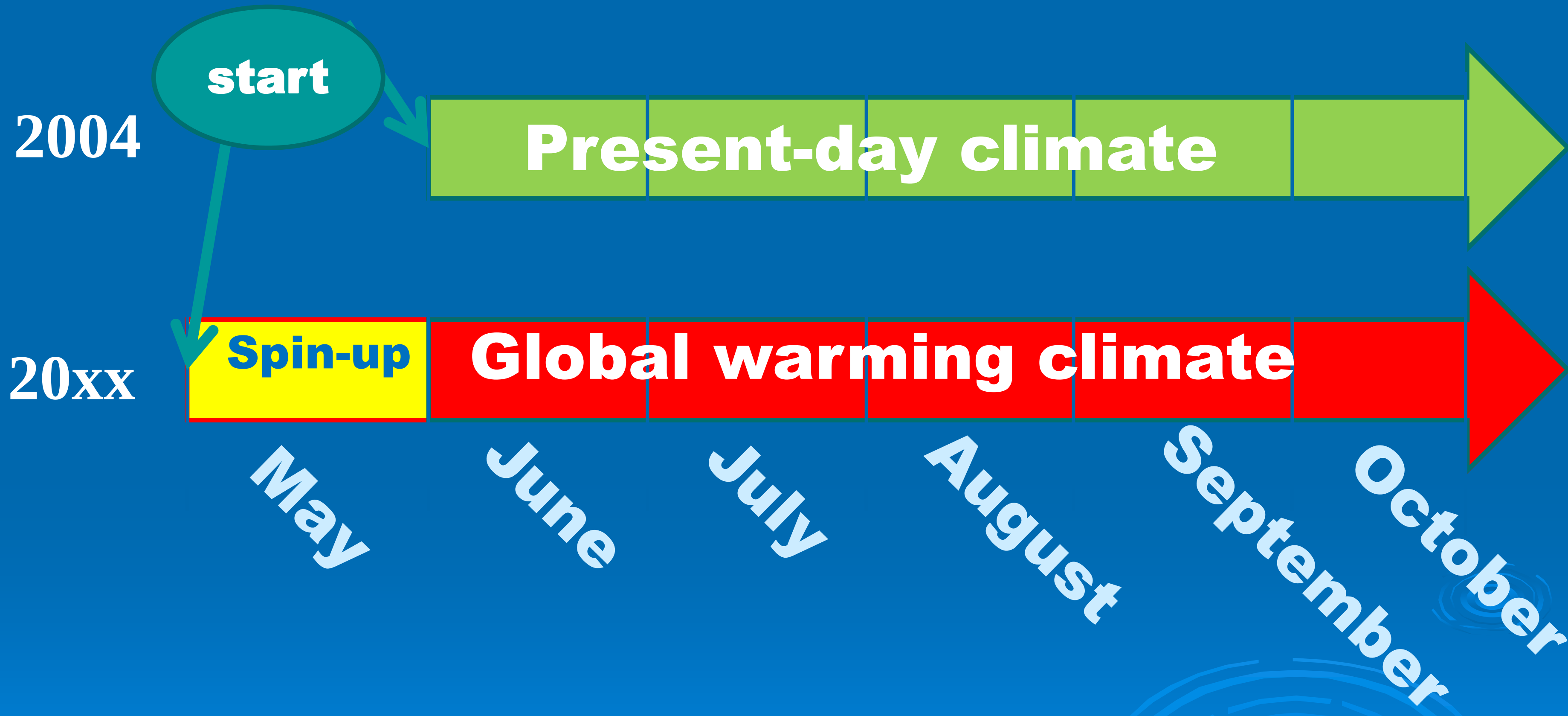
- give a difference between future and present 25years average

(Mizuta et al, 2008)

greenhouse gases (SRES A1B scenario)

- CO_2 doubled – 100 years later
- ozone, other gases : the same as the control (2004)

Thanks to Climate Research Division/MRI for the sea ice dataset and processing codes (Drs. Akio Kitoh, Ryo Mizuta and Yukimasa Adachi)


start
2004
Present-day climate
20xx
Spin-up
Global warming climate
May
June
July
August
September
October

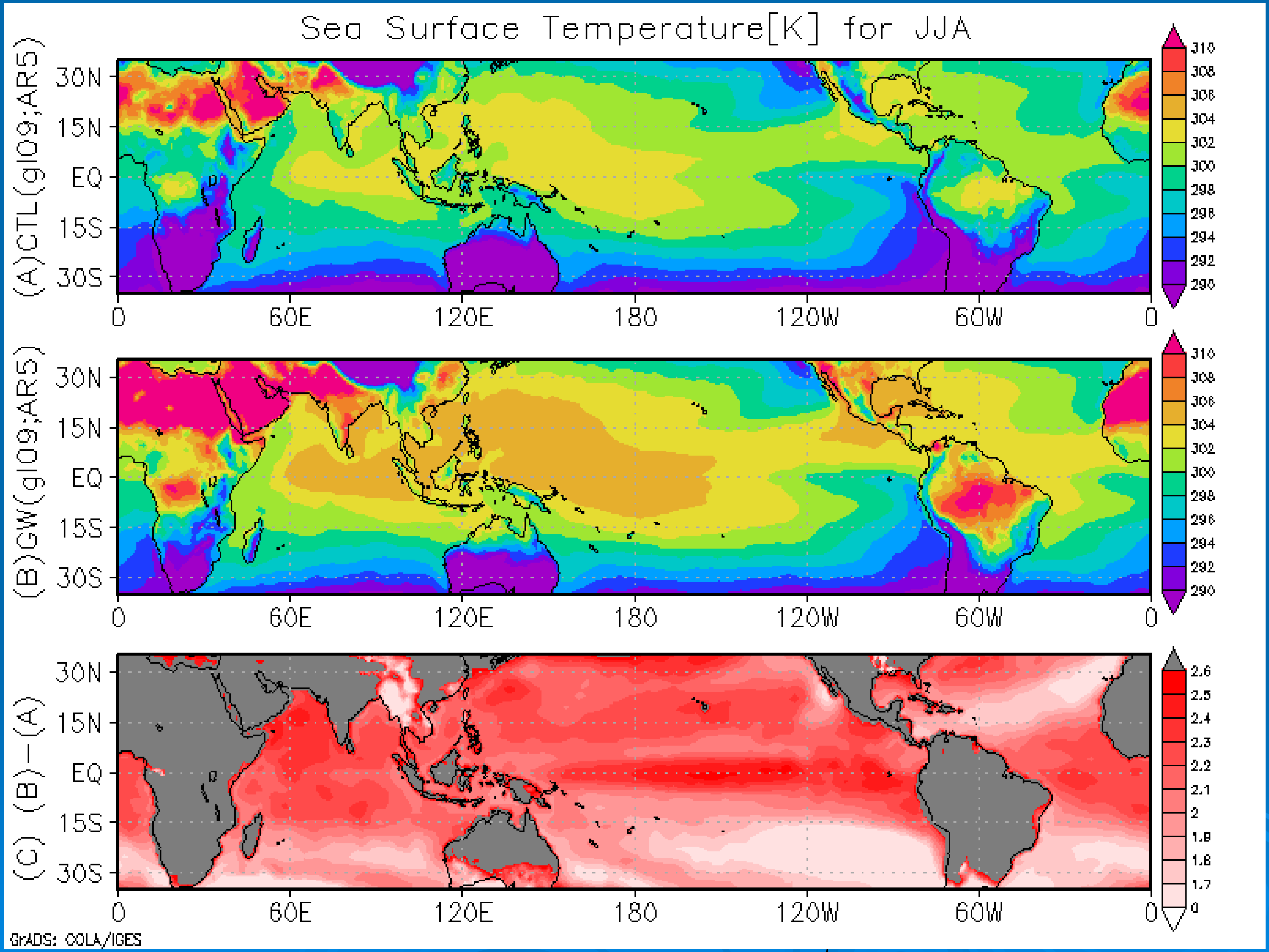
Results

SST forcing

CTL

GW

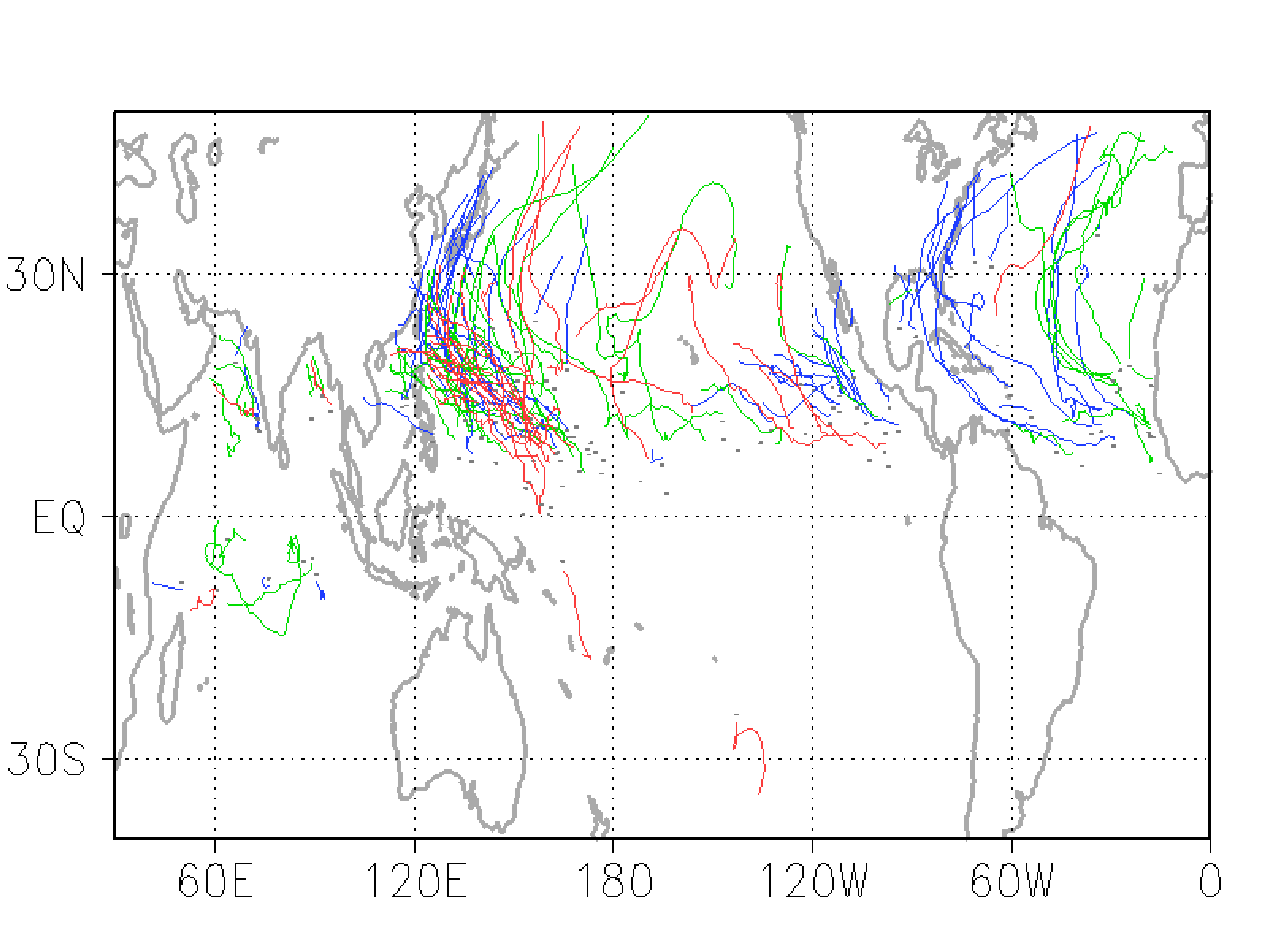
GW - CTL



El Nino

Global frequency and distribution of tropical cyclone

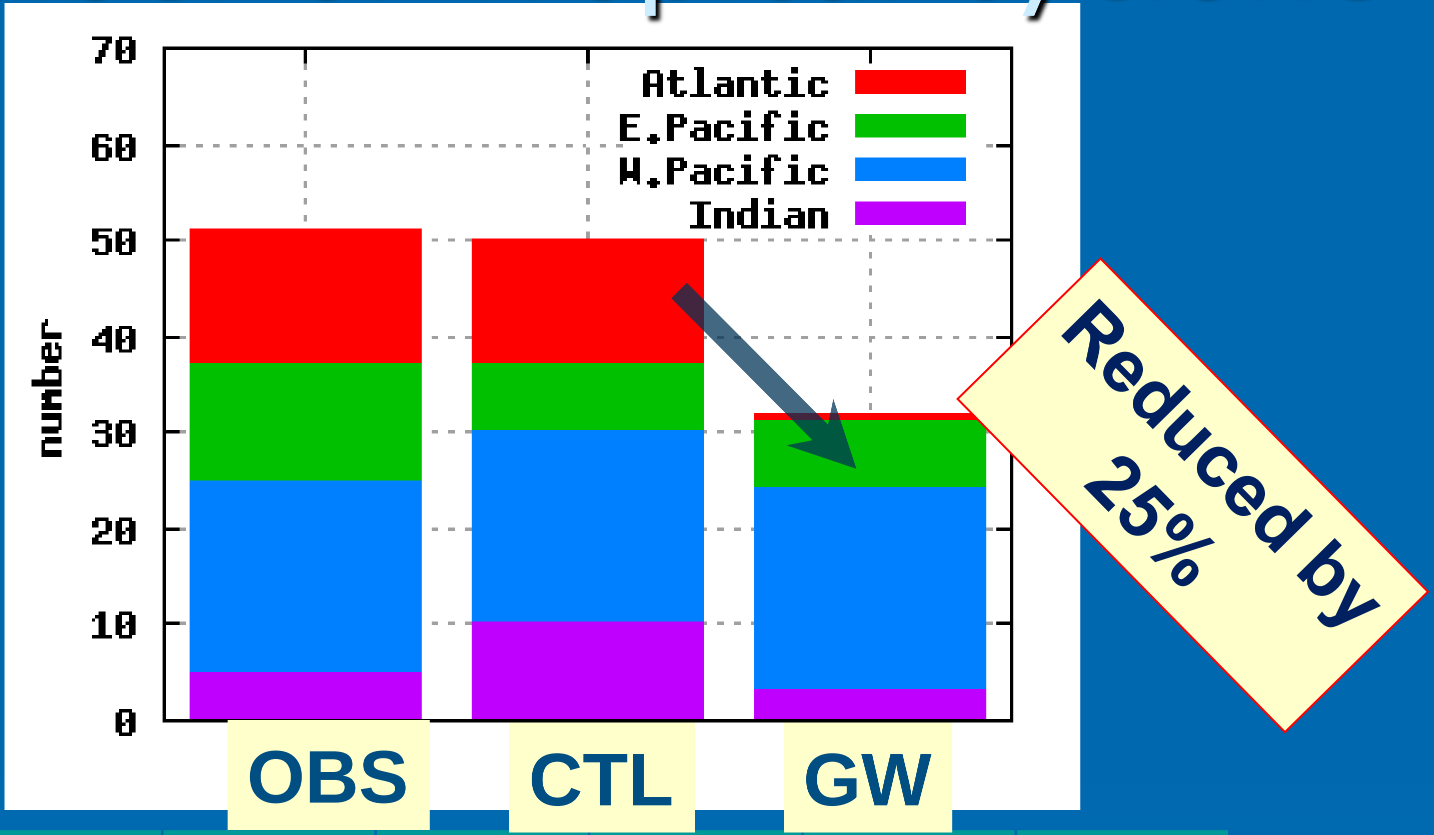
JJASO



OBS
CTL
GW

Number of Tropical cyclone

JJASO



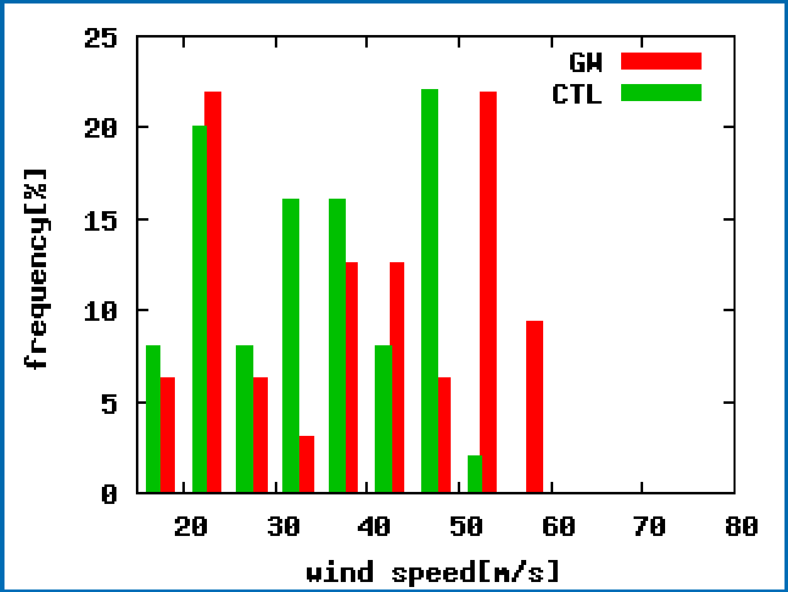
basin	Indian	westen Pacific	eastern Pacific	Atlantic	Globe
range	30E-100E	100E-180	180-90W	90W-0	-----
OBS	5	20	12	14	51
CTL	10	20	7	13	50
GW	3	21	7	1	32

OBS： Unisys. Best Track

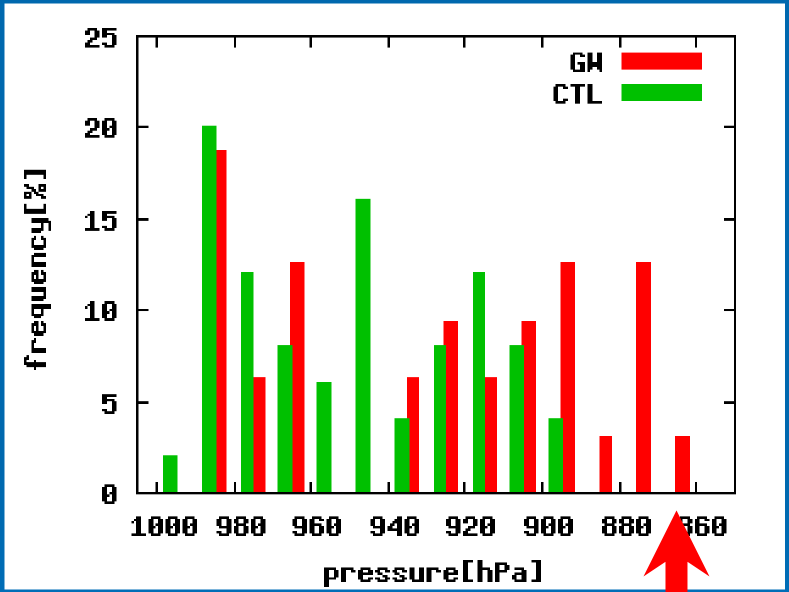
Possible change of the intensity

JJASO

max surface wind



min surface pressure



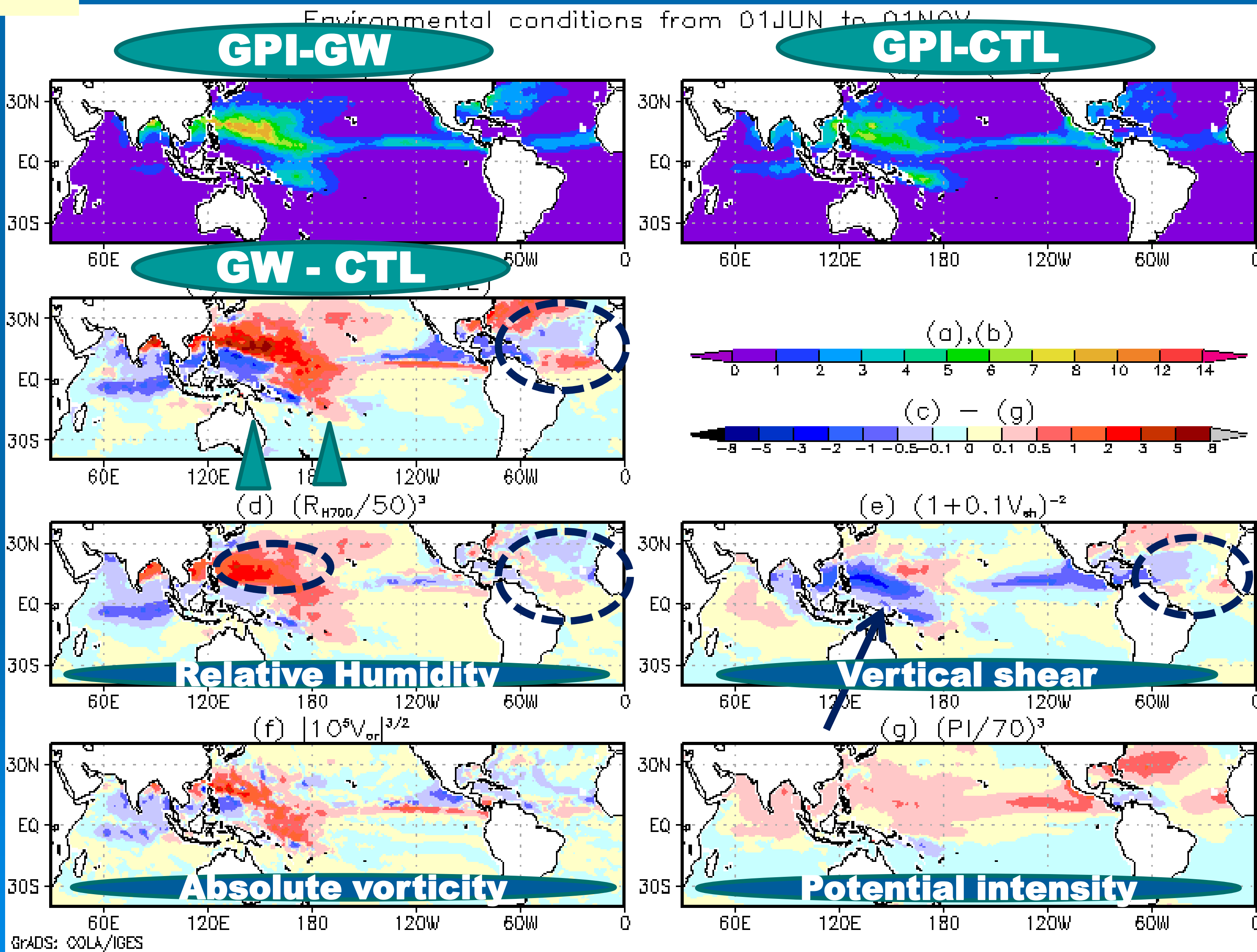
The most intense TC: 871 hPa

Under GW condition climate,
we can see the intensification of wind speed and minimum pressure.

Environmental influence (GPI)

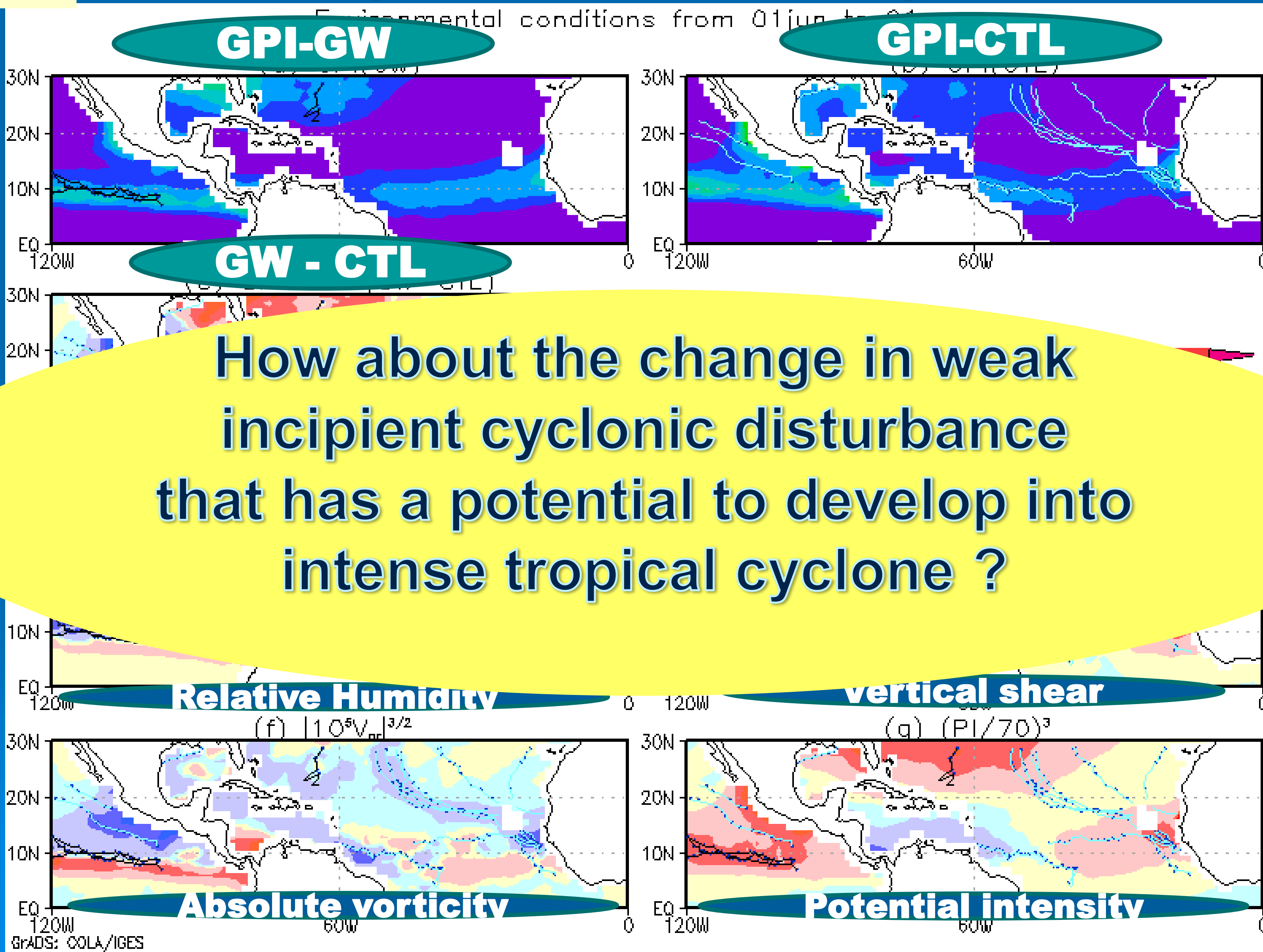
Emanuel and Nolan (2004), Camargo et al. (2007)

JJASO



Environmental influence (GPI : Atlantic)

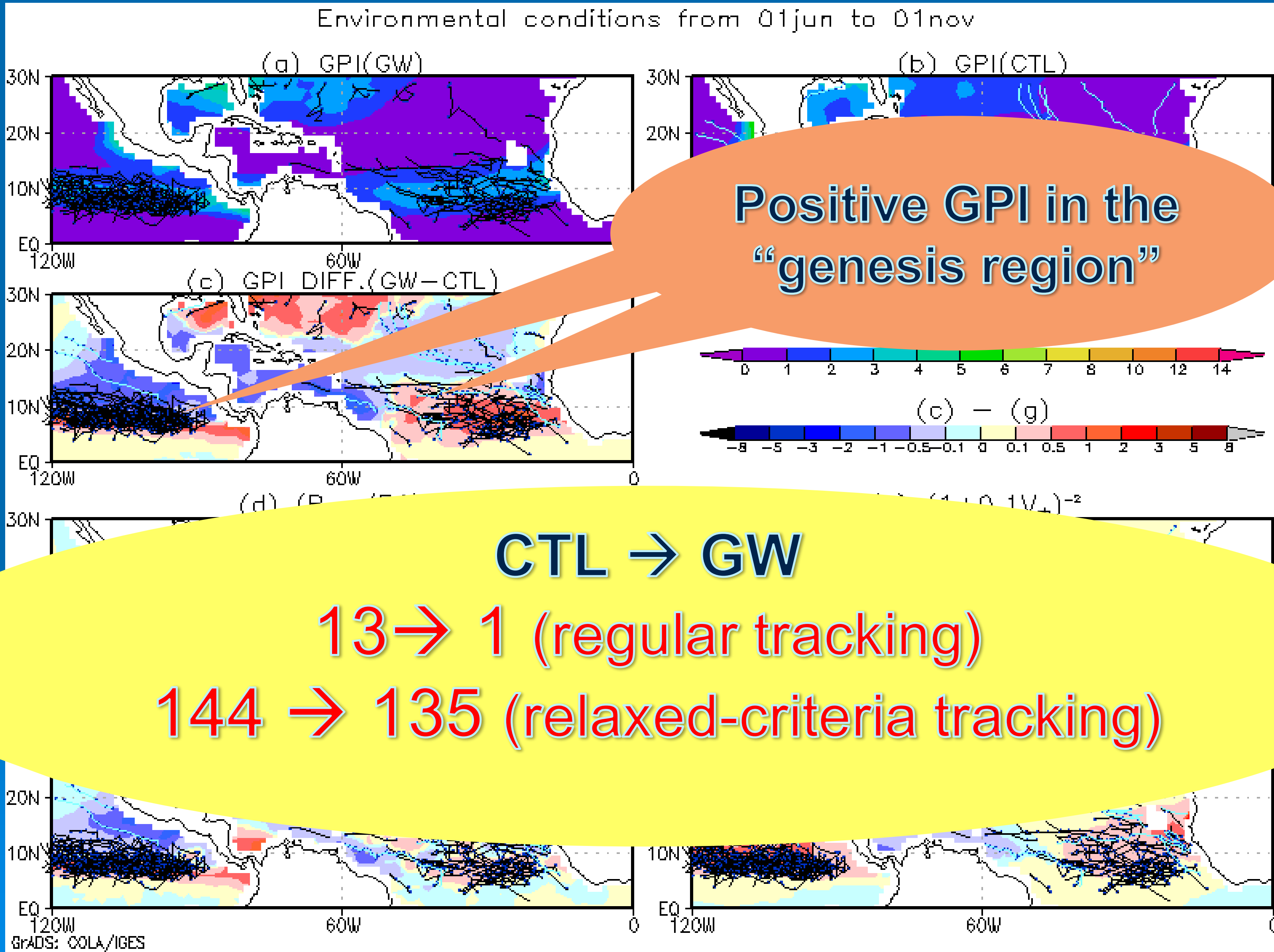
JJASO



How about the change in weak incipient cyclonic disturbance that has a potential to develop into intense tropical cyclone ?

Environmental influence

(warm-core, wind speed criteria relaxed)



Positive GPI in the “genesis region”

CTL → GW

13→ 1 (regular tracking)

144 → 135 (relaxed-criteria tracking)

GPI-analysis summary

- GPI distribution is consistent with the genesis location; useful metrics for capturing large-scale genesis control

- Over the western Pacific, eastward shift in the increased GPI region is evident, suggesting eastward shift in the genesis region

- Over the North Atlantic, the GPI shows bi-modal characteristics; increases in the genesis region and decreases in the development region

  (Vecchi and Soden, 2007)

- Frequency is sensitive to tracking threshold; "weak vortices" do not reduce significantly (Atlantic)

Summary large-scale characteristics of TC change

The GCRM global-warming experiment suggests

- Increased intensity and decreased frequency in the globe
  - in consistent with the statement in IPCC AR4

- Decreased frequency in the Atlantic more significantly, compared to the other oceanic basins

  - GPI increases in the genesis region, but does not in the development region – vertical shear is the key factor

  - Frequency of weak incipient disturbance (including TD) almost remains unchanged (~ 5 % reduction)

  - Large-scale control is likely to govern the frequency of vortex disturbances of enough strength (such as TCs) but is not for weak or seeding vortices

Future works　focus on the genesis stage and triggering mechanism (stochastic process)

- to understand the change in stochastic processes including triggering disturbances, such as MJO and tropical waves

- to understand the change in the mesoscale processes and structure in the genesis and evolution of TCs

The boreal summer experiment (2004)

- 1 June – 31 August, 2004
- 14- and 7- km mesh runs

What is new in the experiment

- The first longer-term (3 or 5 months) boreal summer run using GCRM

  → capable of exploring **MJO "cycles" and associated tropical cyclogenesis**

  → include mature **Asian monsoon** period

Target of the analyses

1. MJO (cycle)
2. tropical cyclone (typhoon)
3. Asian monsoon

1,2

Preconditioning of a tropical cyclogenesis simulated in association with a propagation of an MJO of enough strength about 25-30 days after the time integration starts – beyond the usual predictability time range (10 ~20 days; Vitart, 2003) in NWP models (Oouchi et al. 2009; SOLA)

3

Multi-scale variability in precipitation and circulation in the Asian monsoon (Oouchi et al. 2009; GRL)

other notable results

improvement in simulating low clouds in offshore regions of subtropical continents (Noda et al. 2009; Atmos. Res.)

Theme in monsoon study

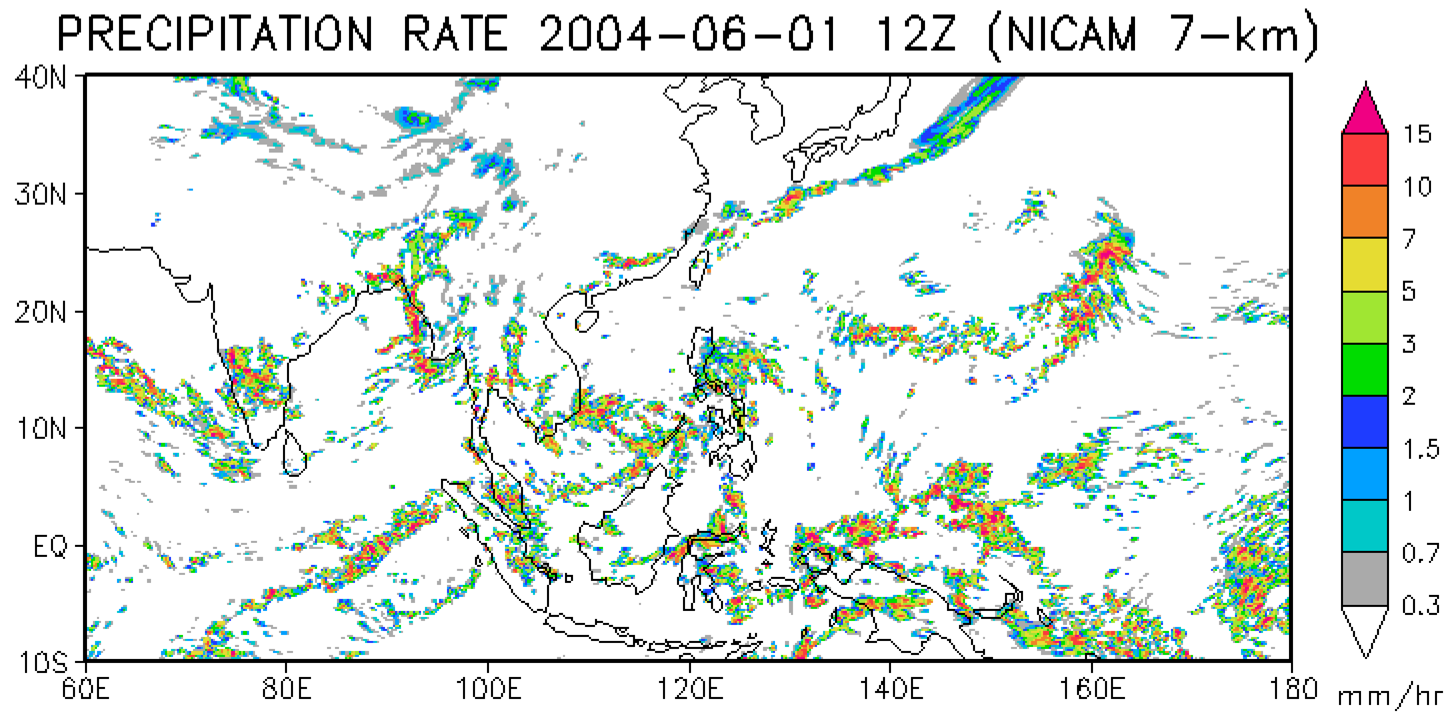
Multi-scale aspects of monsoon simulated in global-cloud-system resolving model

how well NICAM captures

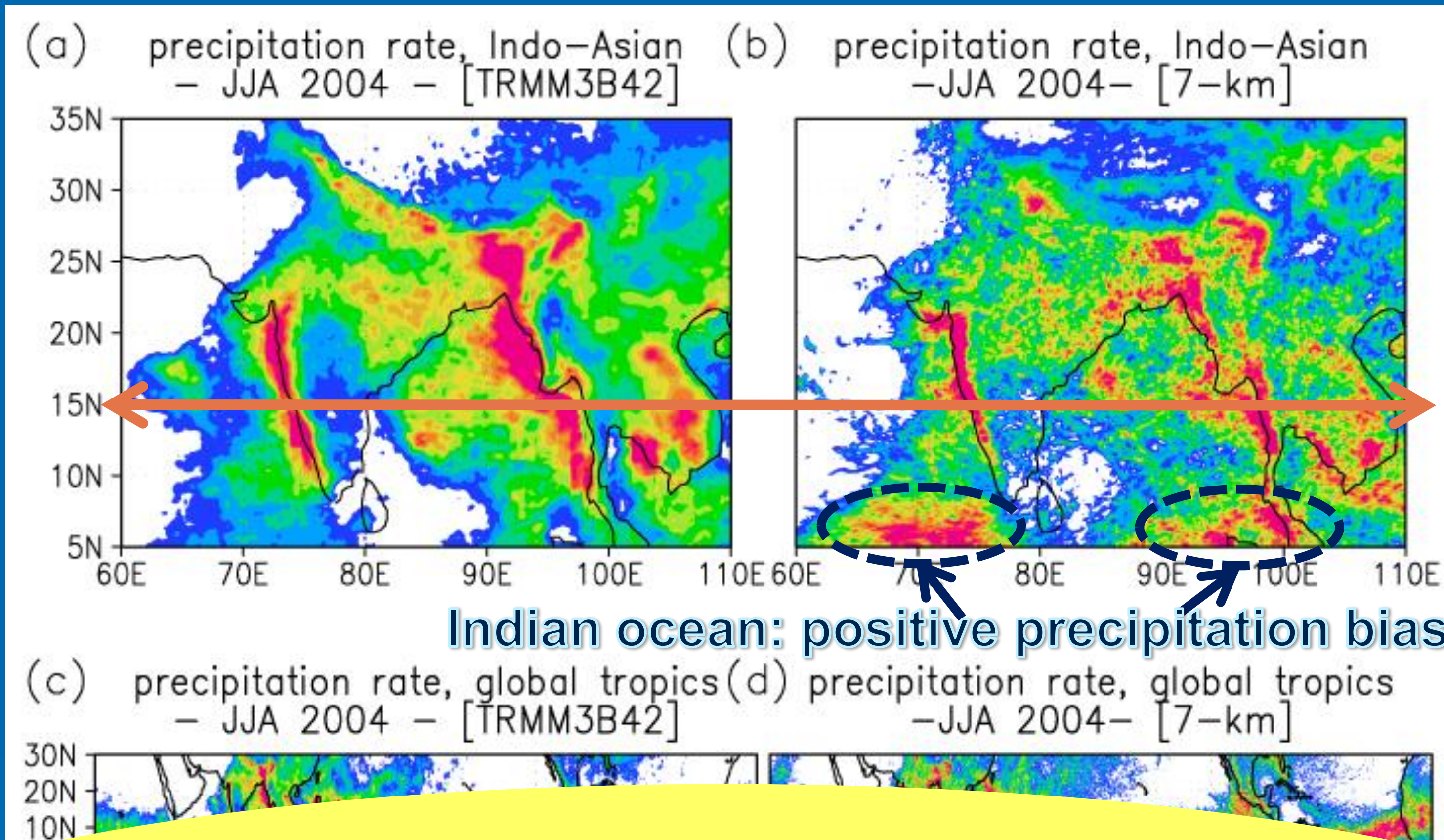
- seasonal mean local precipitation across the Indian subcontinent including mountain ranges

- diurnal to intra-seasonal precipitation features embedded in monsoon circulation

(Oouchi et al. 2009, GRL)

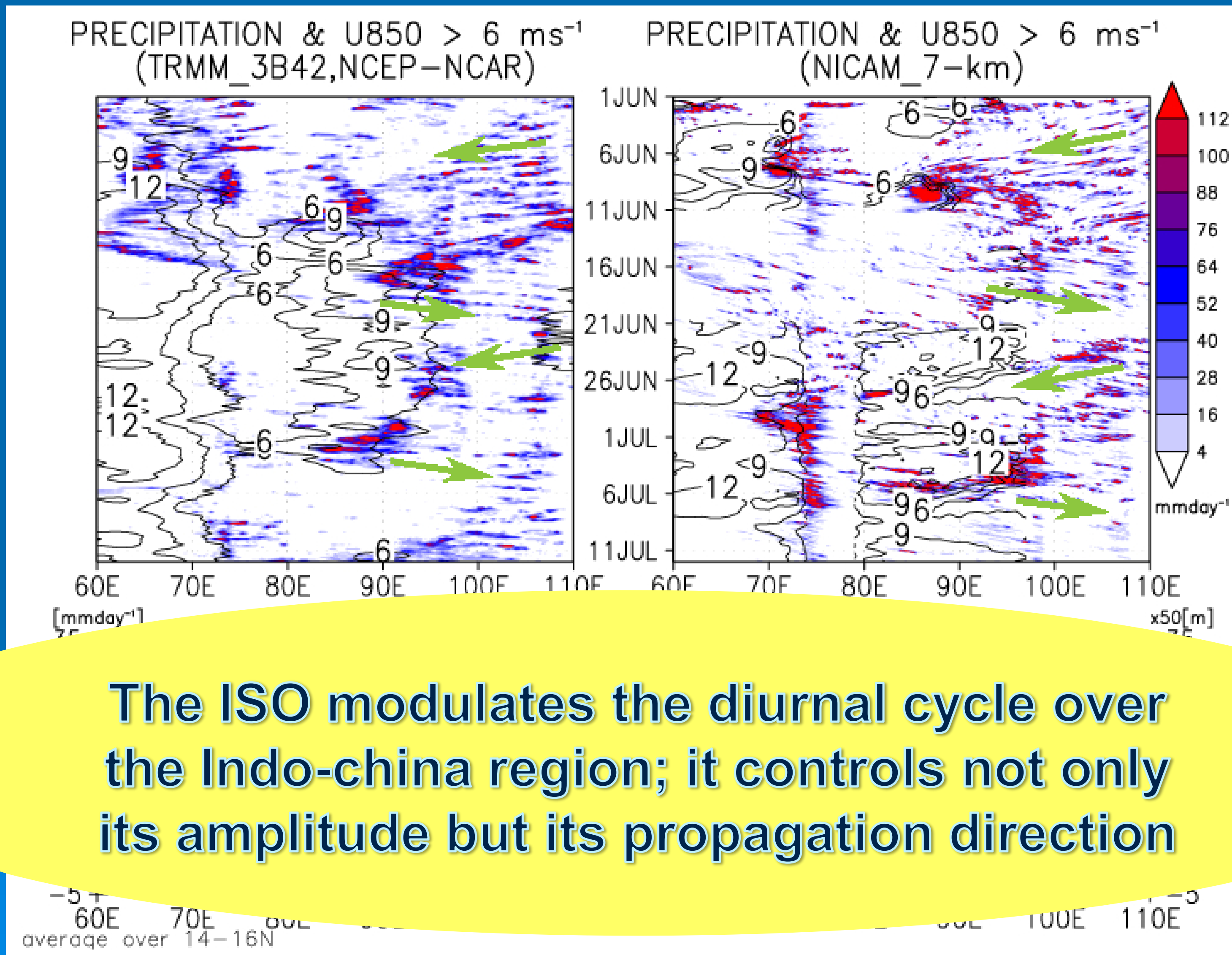

PRECIPITATION RATE 2004-06-01 12Z (NICAM 7-km)
40N
30N
20N
10N
EQ
10S
60E
80E
100E
120E
140E
160E
180
15
10
7
5
3
2
1.5
1
0.7
0.3
mm/hr

Mean precipitation (JJA 2004)



These orography-induced precipitation features significantly regulate the wet and dry phases of local monsoon

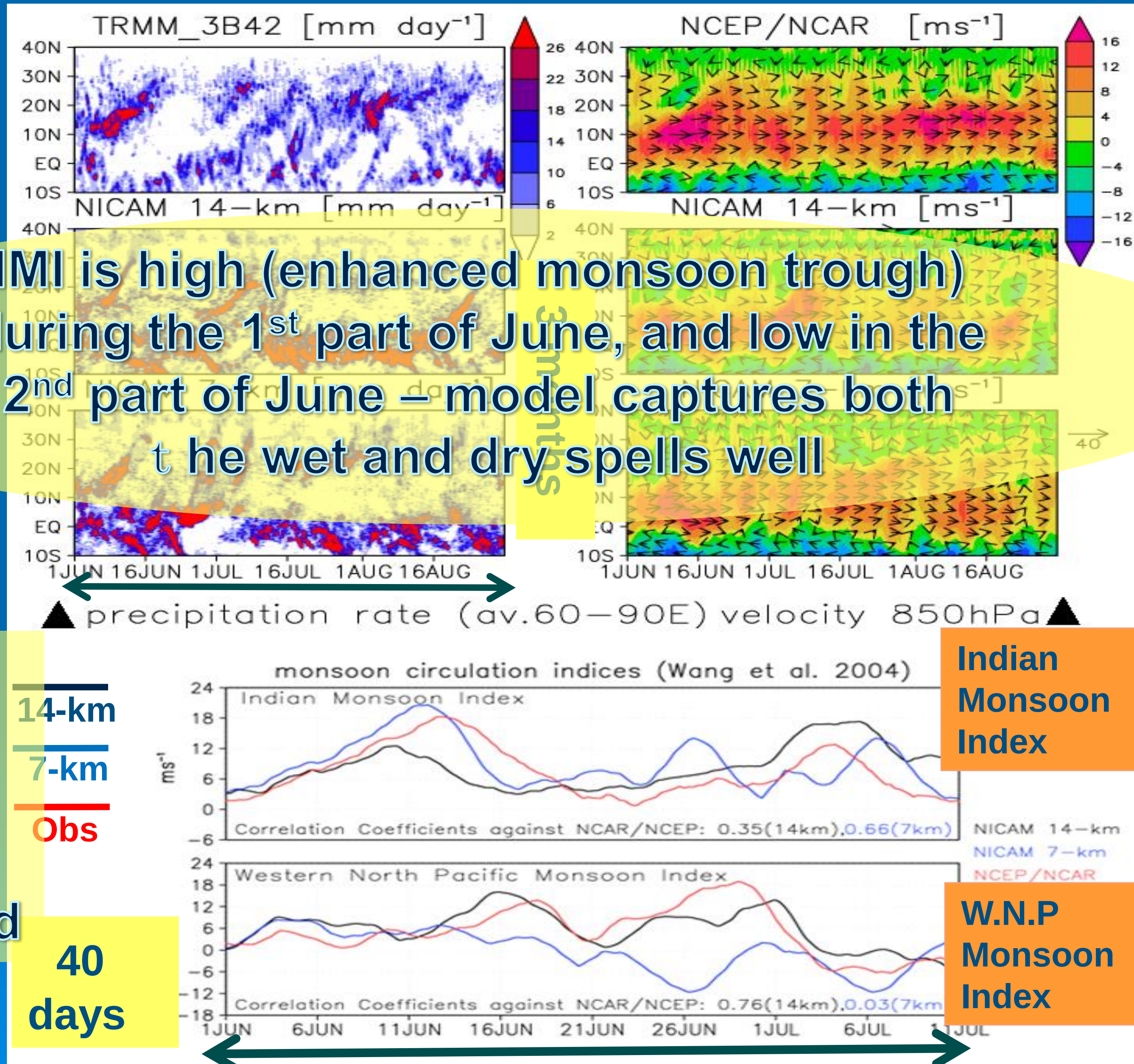
Precipitation hierarchy in Indian subcontinent (14-16N)



The ISO modulates the diurnal cycle over the Indo-china region; it controls not only its amplitude but its propagation direction

Evolution of Precipitation and 850 hPa velocity

IMI is high (enhanced monsoon trough) during the 1st part of June, and low in the 2nd part of June – model captures both the wet and dry spells well



Predicted reasonably monsoon variability 40 days forward

Summary Asian monsoon simulated in GCRM

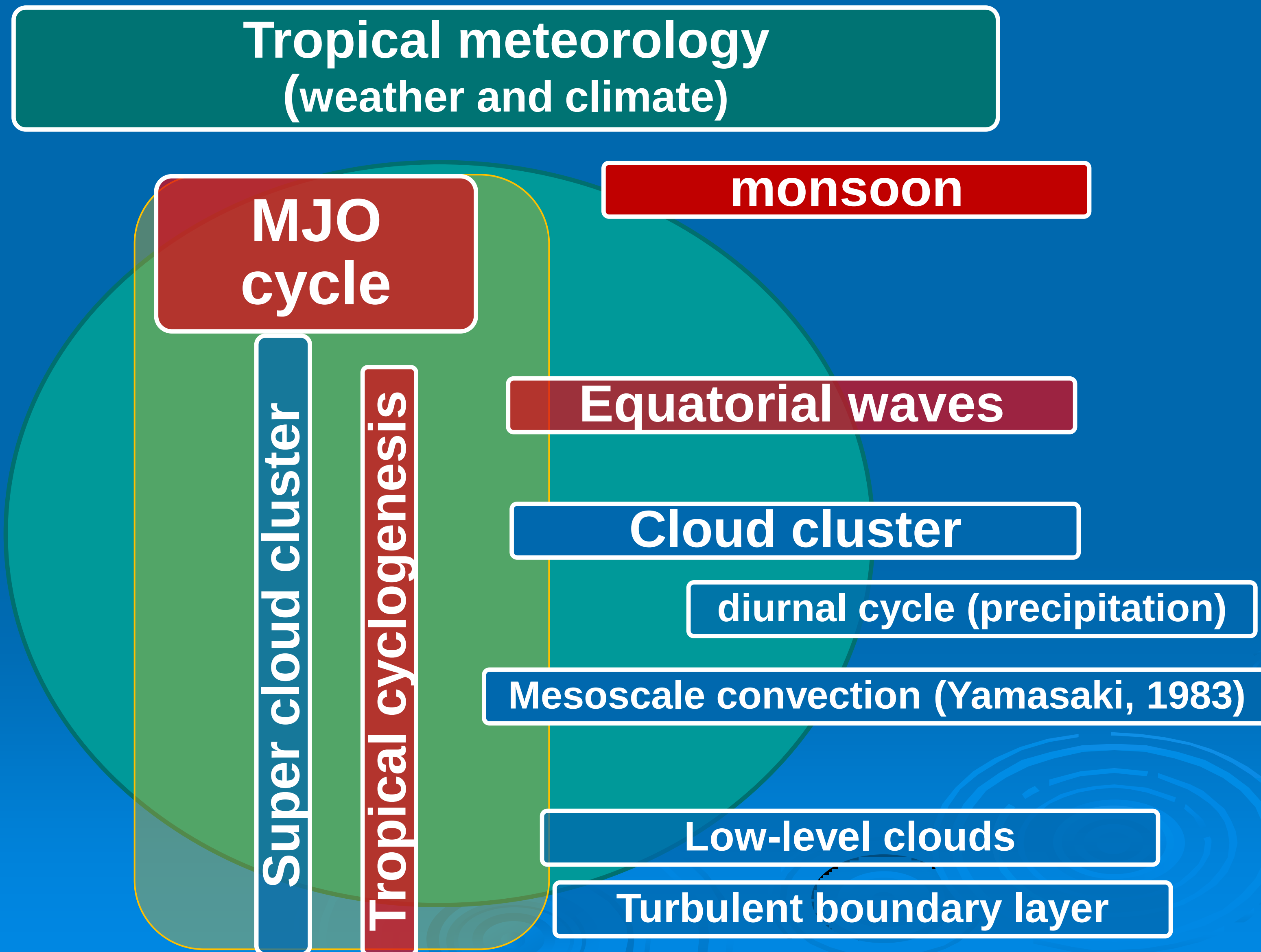
- Hierarchical precipitation features ranging from diurnal to intraseasonal scales are captured well, in particular in land area
  - precipitation in the local mountain ranges, northwestward migration of cyclones…
- Indian Monsoon Index shows encouraging skill of GCRM in predicting activity of a monsoon cycle (activity of monsoon trough) for about 30 – 40 days
- GGRM tends to overpredict precipitation over the Indian Ocean (2.7 mm/day vs. 1.8 mm/day; for 60-90E mean)

Future works interactions in the hierarchical monsoon system

- to understand the interactions and the mechanisms in the hierarchical monsoon system (e.g., cloud disturbances from mesoscale – synoptic – planetary scale)

- to understand a possible link between the monsoon and tropical disturbances such as MJO

Tropical cloud-resolving studies using NICAM
- boreal summer experiment -



Supplementary slides

Pros and cons: global warming study using GCRM

Pros

- The use of **global cloud-resolving model** (GCRM) is a reliable way of getting around the uncertainty in cumulus convection scheme inherent to conventional climate models (Satoh et al. 2008)
- It allows to discuss change in "structure of tropical cyclone" by resolving **cloud cluster of O (100 km) scale**, and marginally resolving **mesoscale convection of O (10km) scale**; and to **derive more reliable estimate of future changes**
- It is in harmony with the expected "**revolution in climate prediction**" endorsed in the Climate Summit Declaration (Shukla et al., 2009 BAMS) and high-end computing

Pros and cons: global warming study using GCRM

Cons

- **GCRM experiment is computationally demanding, with the forced compromise of short time integration and small sampling number, and unable to derive climate statistics**

  => but this is OK as the purpose is different

- **On-going research strategy:**
  to argue changes in tropical cyclogenesis process, cloud structure, and triggering disturbances (MJO, easterly wave…) as GCRM has a promising skill in simulating these triggering disturbances and cloud processes and therefore should be more credible in projecting future changes of these events

[References: NICAM hindcast runs]

- MJO and TC genesis process study (Miura et al. 2007; Fudeyasu et al. 2008)

- TC genesis preconditioning by MJO (Fudeyasu et al. 2008; Oouchi et al. 2009a)

Experimental Design

Initialization	**NCEP Global analysis on 00Z Jun 01, 2004**
Nudging	**None**
Bottom boundary	**Bucket model and Weekly Reynolds SST**
Horizontal resolution	**14km (7km)**
Vertical resolution	**40 levels (0 – 38,000 m; interval; 80 m - 2.9km)**
Cloud	**Cloud microphysics by Grabowski (1998)**
Turbulence **(improvement by Dr. A.T. Noda)**	**Improved version of Mellor-Yamada Level 2 (e.g., Nakanishi & Niino 2004; Mellor and Yamada 1982) ※partial cloud not treated**
Surface flux	**Bulk parameterization by Louis (1979)**
Radiation	**MSTRNX (Sekiguchi et al. 2008)**
Integration period	**2004 experiment:** **14-km: June - October (~ 5 months)** **7-km: June - August (~3 months)pan**

NICAM development phase

1 Inclusion of moist processes and performance test as a global cloud-resolving model (15-30 day run)

Aqua-planet experiment

Tomita et al. (2005) , Miura et al. (2005) , Nasuno et al. (2007), Iga et al. (2007)

2 Inclusion of realistic components (seasonal run)

boreal winter experiment (~30days):

Miura et al. (2007) , Fudeyasu et al. (2008) Nasuno et al. (2009) Sato et al (2009)

boreal summer experiment (3-5months):

Noda et al. (2009) – low-level cloud

Oouchi et al. (2009a,b) – triggering of TC by MJO / Asian monsoon

3 Global-warming experiment *This study*

changes from the present-day simulation are discussed, with the seasonal run + improved radiation scheme being the control case

TC genesis potential index (GPI) (Camargo et al 2007)

$$GP = \left|10^5 \eta\right|^{\frac{2}{3}} \left(\frac{\mathrm{H}}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2}$$

η : the_absolute_vorticity

H : the_relative_humidit y

V_{pot} : the_potential_intens ity

V_{shear} : the_vertical_wind_shear