Monsoons in NICAM and challenges ahead

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Yamaura et al. (2013) … Baiu and TC (2012)

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3. **Challenges ahead**

NICAM: Nonhydrostatic Icosahedal Atmospheric Model

http://nicam.jp/hiki/

- Development since 2000

  Tomita and Satoh (2005, *Fluid Dyn. Res.*)

  Satoh et al. (2008, *J. Comp. Phys.*)

- First global dx=3.5km run in 2004

  using the Earth Simulator (JAMSTEC)

  Tomita et al.(2005, *Geophys. Res. Lett.*)

  Miura et al.(2007, Science)

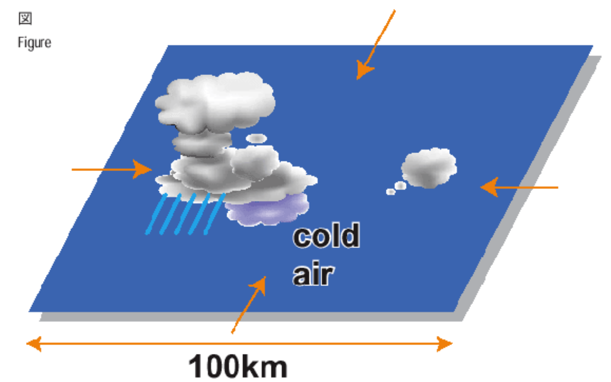
- K computer era (10PF; Kobe,Riken,2012)

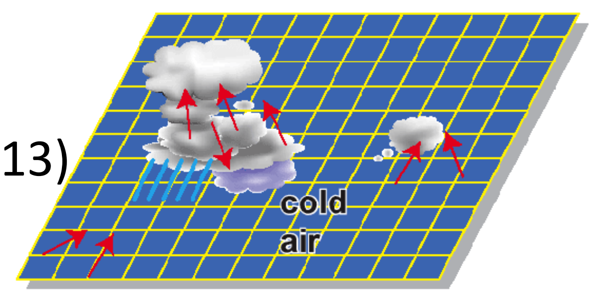
  Toward higher resolution: dx=870m (Miyamoto et al. 2013)

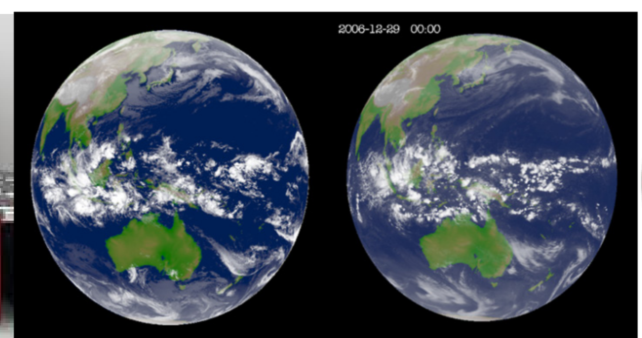
  Multi ensemble simulations

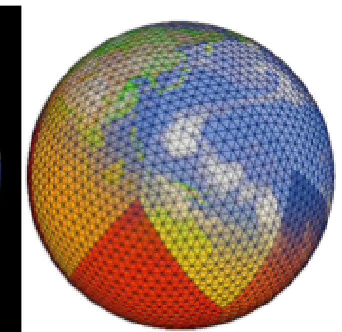
  (Miyakawa et al. 2014 Nat. Comm; Nakano et al. 2015 , *Geophys. Res. Lett.*)

  Multi decadal simulations (Kodama et al. 2015, JMSJ)



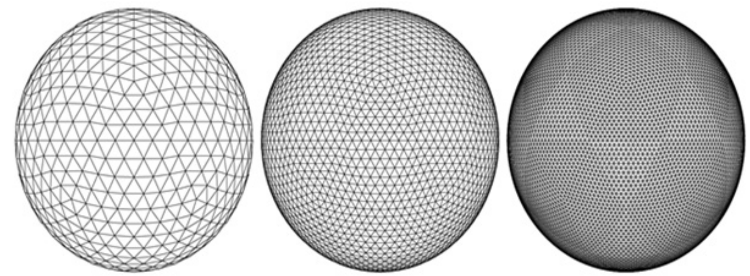


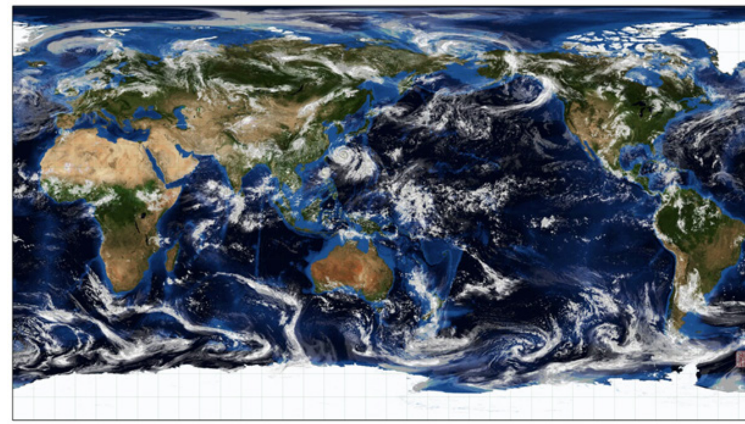




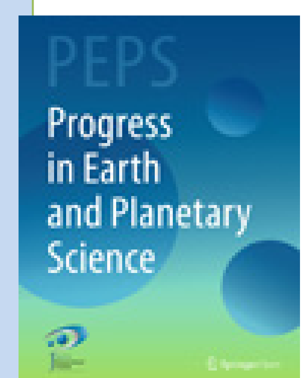
NICAM outcomes: 10-year history and beyond

- Good points of NICAM
  - Realistic meso-scale circulations, e.g. diurnal cycle
  - Multiscale structure of cloud systems
  - Intra-seasonal oscillation: MJO, BSISO (boreal summer ISO)
  - Tropical cyclones
  - Cloud properties with cloud microphysics
  - Collaboration with satellite observation (evaluation, improvements, & assimilation)





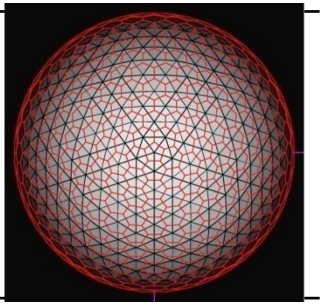
Overview paper:
Satoh, M., Tomita, H., Yashiro, H., Miura, H., Kodama, C., Seiki, T., Noda, A. T., Yamada, Y., Goto, D., Sawada, M., Miyoshi, T., Niwa, Y., Hara, M., Ohno, T., Iga, S., Arakawa, T., Inoue, T., Kubokawa, H. (2014)
The Nonhydrostatic Icosahedral Atmospheric Model: Description and Development.
Progress in Earth and Planetary Science, **1**, 18.
http://dx.doi.org/10.1186/s40645014000181



Nonhydrostatic Icosahedarl Atmospheric Model

Satoh et al. (2014)

■ Dynamics



governing equations	Fully compressible non-hydrostatic system
spatial discretization	Finite Volume Method
horizontal grid configuration	Icosahedral grid (Tomita et al. 2001, 2002)
vertical grid configuration	Lorenz grid
topography	Terrain-following coordinate
conservation	Total mass, total energy Satoh (2002, 2003)
temporal scheme	Slow mode ー explicit scheme （RK2, RK3） Fast mode ー Horizontal Explicit Vertical Implicit scheme

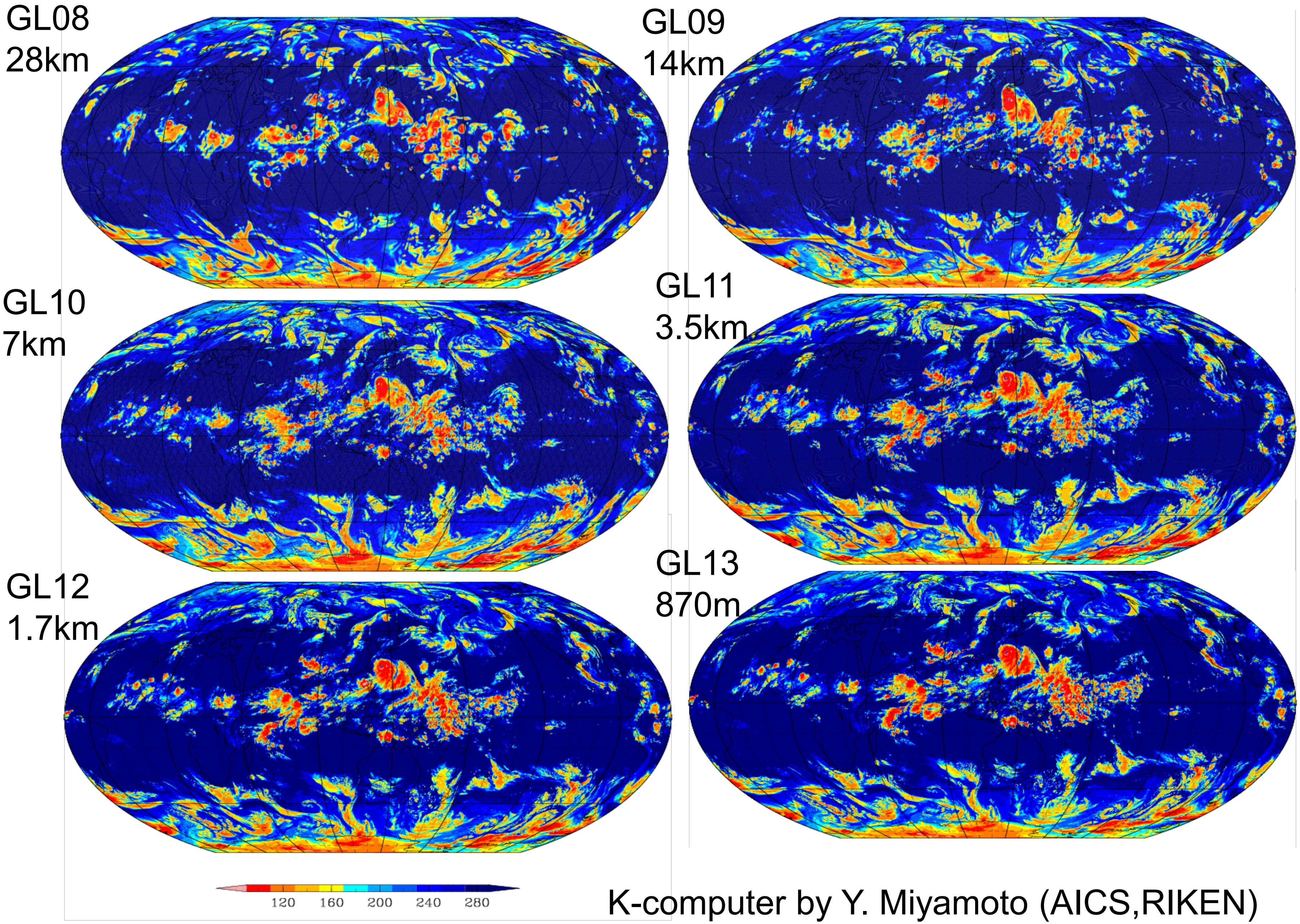
■ Physics

radiation	MSTRNX / MSTRNX-AR5 (Sekiguchi and Nakajima, 2008)
cloud physics	Grabowski(1998); NSW6(Tomita 2008);NDW6(Seiki et al. 2013)
shallow clouds boundary layer	MY level 2 (Mellor and Yamada 1982; Noda et al. 2010) MYNN level 2.5 or 3 (Nakanishi and Niino 2006)
surface flux	Louis(1979), Uno et al.(1995)
surface processes	SST specified & bucket / slab ocean & MATSIRO

NICAM 870m-mesh simulation

- Miyamoto, Y., Kajikawa, Y., Yoshida, R., Yamaura, T., Yashiro, H., and Tomita, H., 2013: Deep moist atmospheric convection in a sub-kilometer global simulation. Geophys. Res. Lett., 40, 4922-4926. DOI:10.1002/grl.50944.
- Miyamoto, Y., R. Yoshida, T. Yamaura, H. Yashiro, H. Tomita and Y. Kajikawa, 2015: Does convection vary in different cloudy disturbances? Atmospheric Science Letters, 16, 305-309, DOI:10.1002/asl2.558.
- Kajikawa, Y., Miyamoto, Y., Yoshida, R., Yamaura, T., Yashiro, H., Tomita, H., 2016: Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing. Progress in Earth and Planetary Science, accepted.

OLR (6UTC, 25 Aug. 2012)

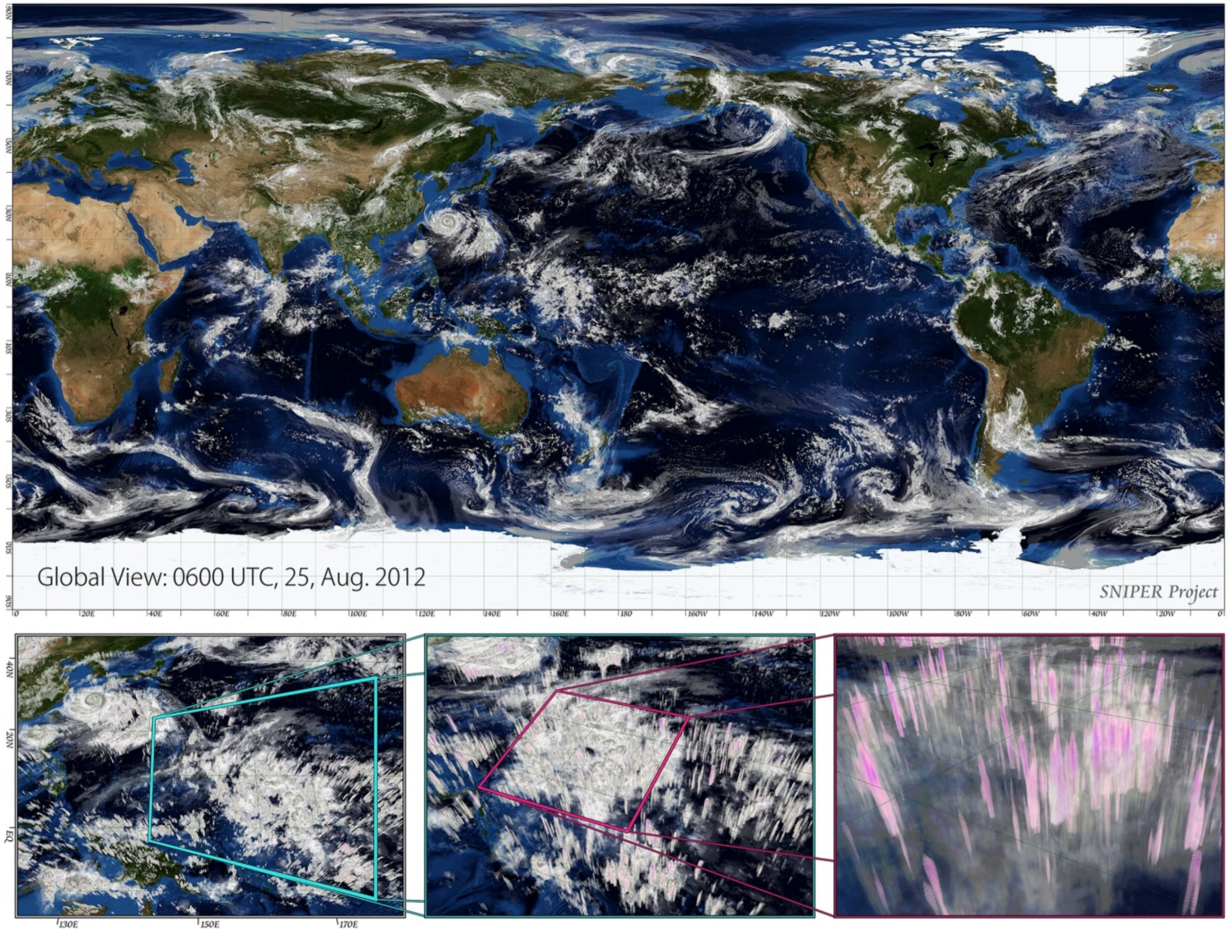


NICAM 870m-mesh simulation

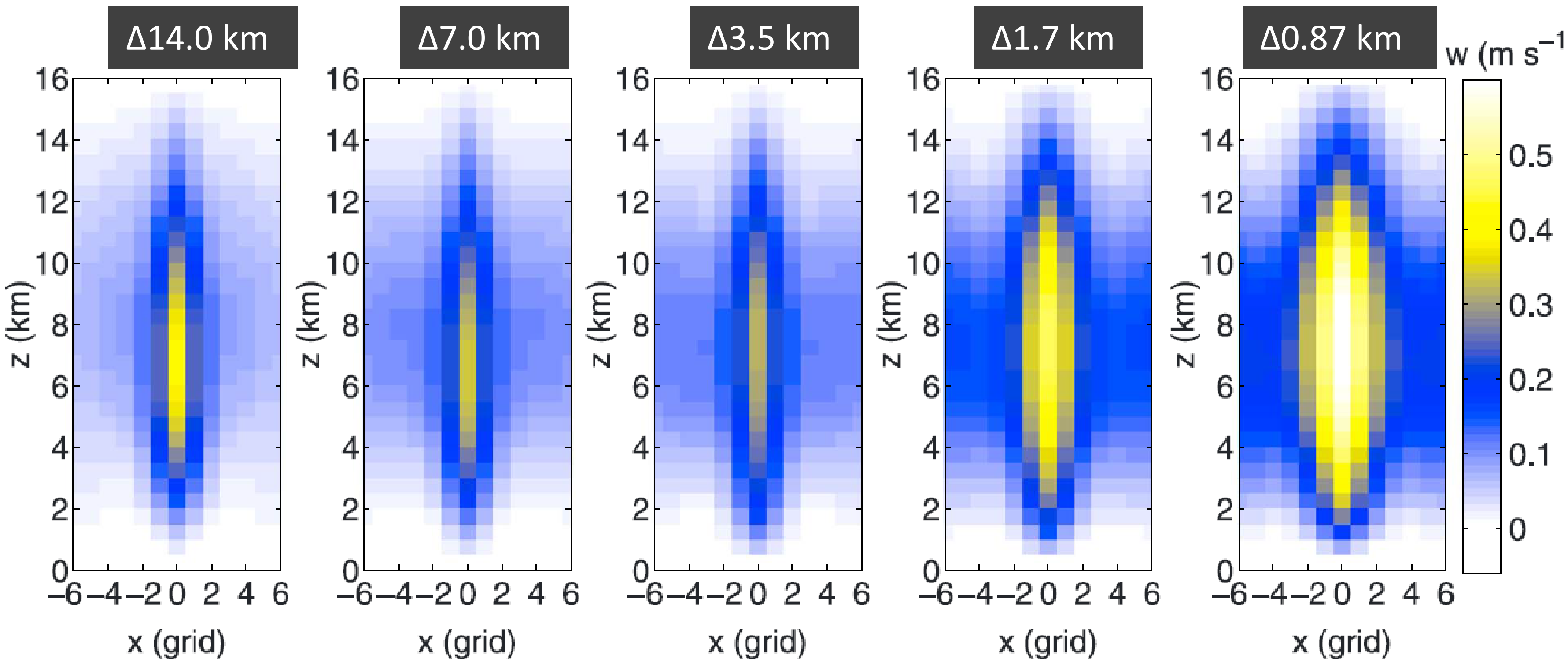
Miyamoto et al. (2013,GRL) using the K computer

dx=870 m

dx=3.5 m



Composite of convection (vertical velocity)



Δx ≧ 3.5 km:

- Convection is represented at <u>1 grid</u>
- Little dependence on resolution

Δx ≦ 1.7 km:

- Convection is represented at <u>multiple grids</u>
- Intensify w/ resolution

※transform the coordinate into the cylindrical around the core grid

mean of all the detected convection

symmetric around the x axis

X axis is normalized by resolution

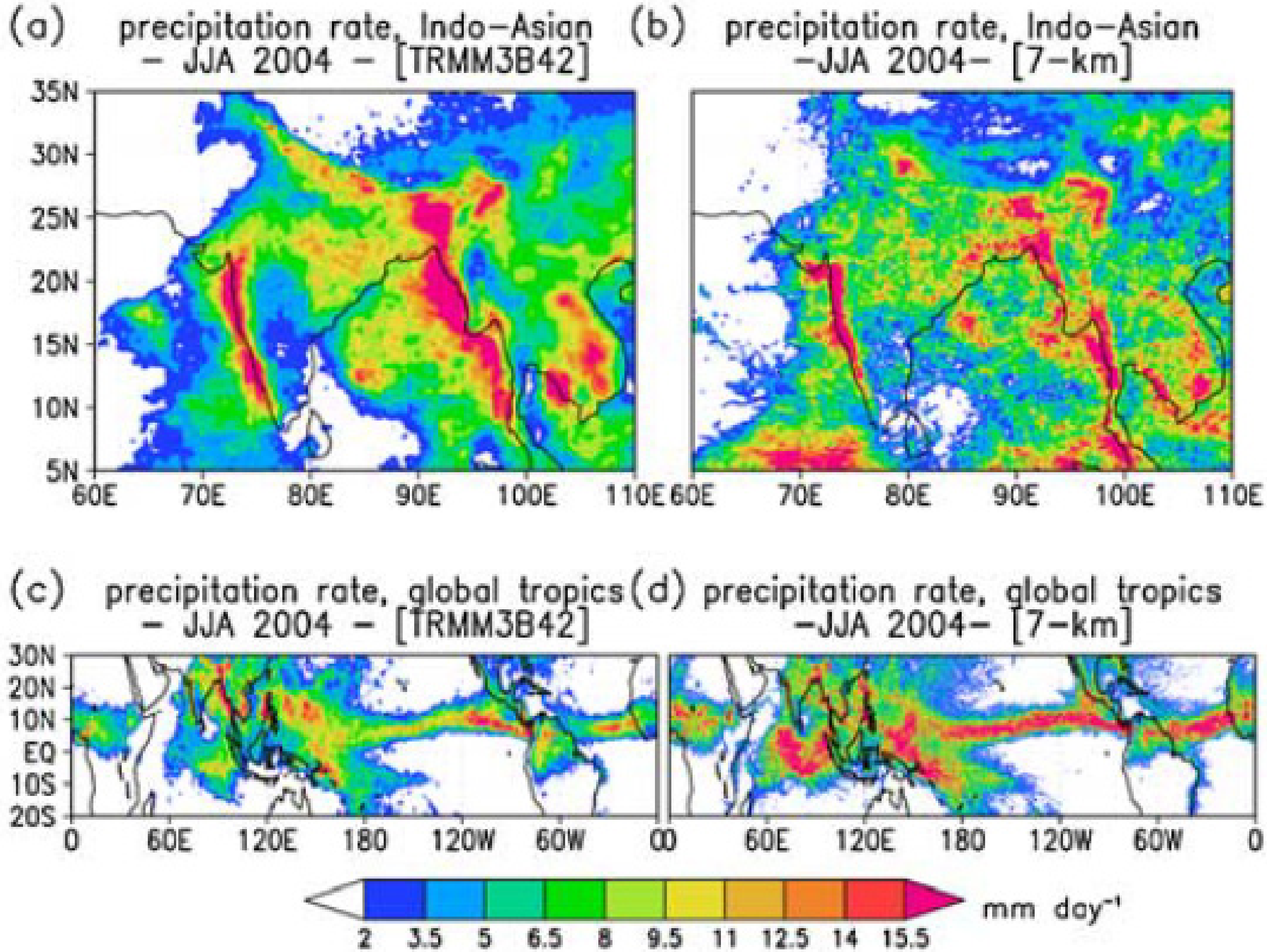
Miyamoto et al. (2013)

2. Monsoon simulations in NICAM

Indo-Asian Summer Monsoon

- Significant seasonal cycle in broad tropical and subtropical domain, affecting world weather and climate (e.g., teleconnection, air-sea interaction)
- Local onset period: late May-early June (south India, SCS), late July (WNP, end of Baiu), Climatologically phase-locked meridional migration (Murakami and Matsumoto 1994; Ueda et al. 1995)
- Multiscale nature: TC activity is closely related to the convective activity associated with monsoon (e.g.,Ueda et al. 1995). Monsoon circulation is a basic background of TC genesis in WNP (Holland 1995).
- Decadal scale modulation in SCS/WNP monsoon onset date associated with SST variability (Kajikawa and Wang 2012; Tomita et al. 2013).

Oouchi et al. (2009, GRL)



2. Monsoon simulations in NICAM
2-1. Indian Summer Monsoon

- Kajikawa, Y., Yamaura, T., Tomita, H., Satoh, M., 2015: Impact of tropical disturbance on the Indian summer monsoon onset simulated by a global cloud-system-resolving model. SOLA, 11, 80-84, doi:10.2151/sola.2015-020.
- Kinter III, J. L., et al., 2013: Revolutionizing Climate Modeling - Project Athena: A Multi-Institutional, International Collaboration. Bull. Am. Meteorol. Soc., 94, 231-245. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-11-00043.1
- Satoh, M, et al., 2012: The Intra-Seasonal Oscillation and its control of tropical cyclones simulated by high-resolution global atmospheric models, Clim. Dyn., 39.2185-2206, DOI 10.1007/s00382-011-1235-6.
- Taniguchi, H., W. Yanase, M. Satoh, 2010: Ensemble simulation of cyclone Nargis by a Global Cloud-system-resolving Model -- modulation of cyclogenesis by the Madden-Julian Oscillation. J. Meteor. Soc. Japan, 88, 571-591.

The Athena Project

Kinter et al.(2013)

Collaborating Groups

- **COLA** - Center for Ocean-Land-Atmosphere Studies, USA
- **ECMWF** - European Center for Medium-range Weather Forecasts, UK
- **JAMSTEC** - Japan Agency for Marine-Earth Science and Technology, Research Institute for Global Change, Japan
- **University of Tokyo**, Japan
- **NICS** - National Institute for Computational Sciences, USA
- **Cray** Inc.

Codes

- **NICAM**: Nonhydrostatic Icosahedral Atmospheric Model
- **IFS**: ECMWF Integrated Forecast System

Super-computers

- **Athena**: Cray XT4 - 4512 quad-core Opteron nodes (18048)
- **Kraken**: Cray XT5 - 8256 dual hex-core Opteron nodes (99072)

Athena Experiments
JJA in 2001-2009 (initialized each year)

Model/Exp.	Resolution	# Cases	Period	Notes
NICAM / Hindcasts	7 km	8	103 days	21 May - 30 Aug 2001 - 2009
IFS / Hindcasts	125 km 39 km 16 km	48	395 days	1 Nov - 30 Nov (following year) 1960 - 2007
IFS / Hindcasts	10 km	20		1 Nov - 30 Nov (following year) 1989 - 2007
IFS / Hindcasts	125 km 39 km 16 km 10 km	9	103 days	21 May - 30 Aug 2001 - 2009 NICAM analogs
IFS / Summer Ensembles	39 km 16 km	6	132 days	21 May - 30 Sep selected years
IFS / Winter Ensembles	39 km 16 km	6	151 days	1 Nov - 31 Mar selected years
IFS / AMIP	39 km 16 km	1	47 years	1961 - 2007
IFS / Time Slice	39 km 16 km	1	47 years	2071 - 2117

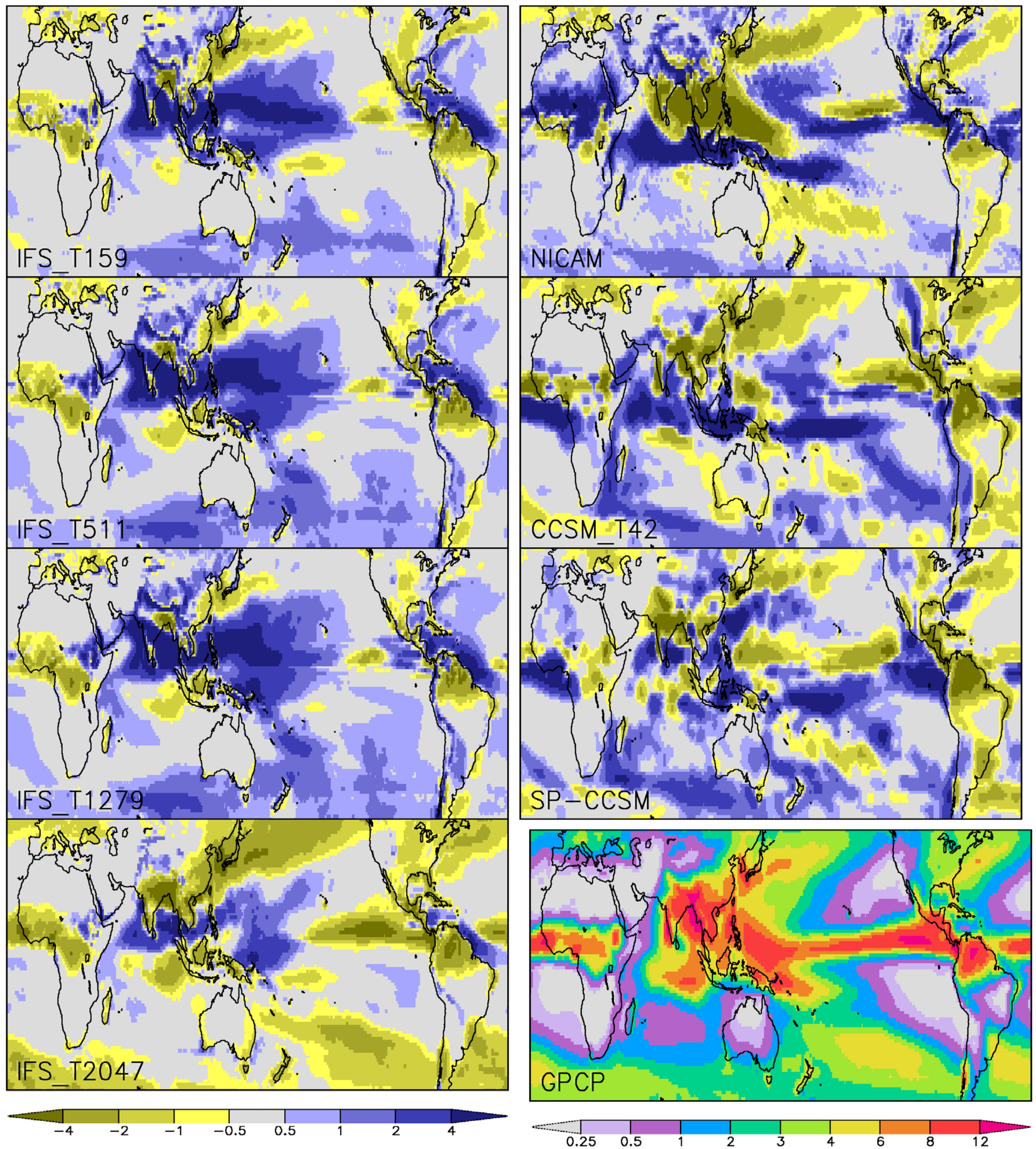
http://wxmaps.org/athena/home/

JJA Precipitation (anomaly from GPCP)

IFS

NICAM

Dirmeyer et al (2012) Clm. Dyn.



GPCP

Satoh et al. (2012)

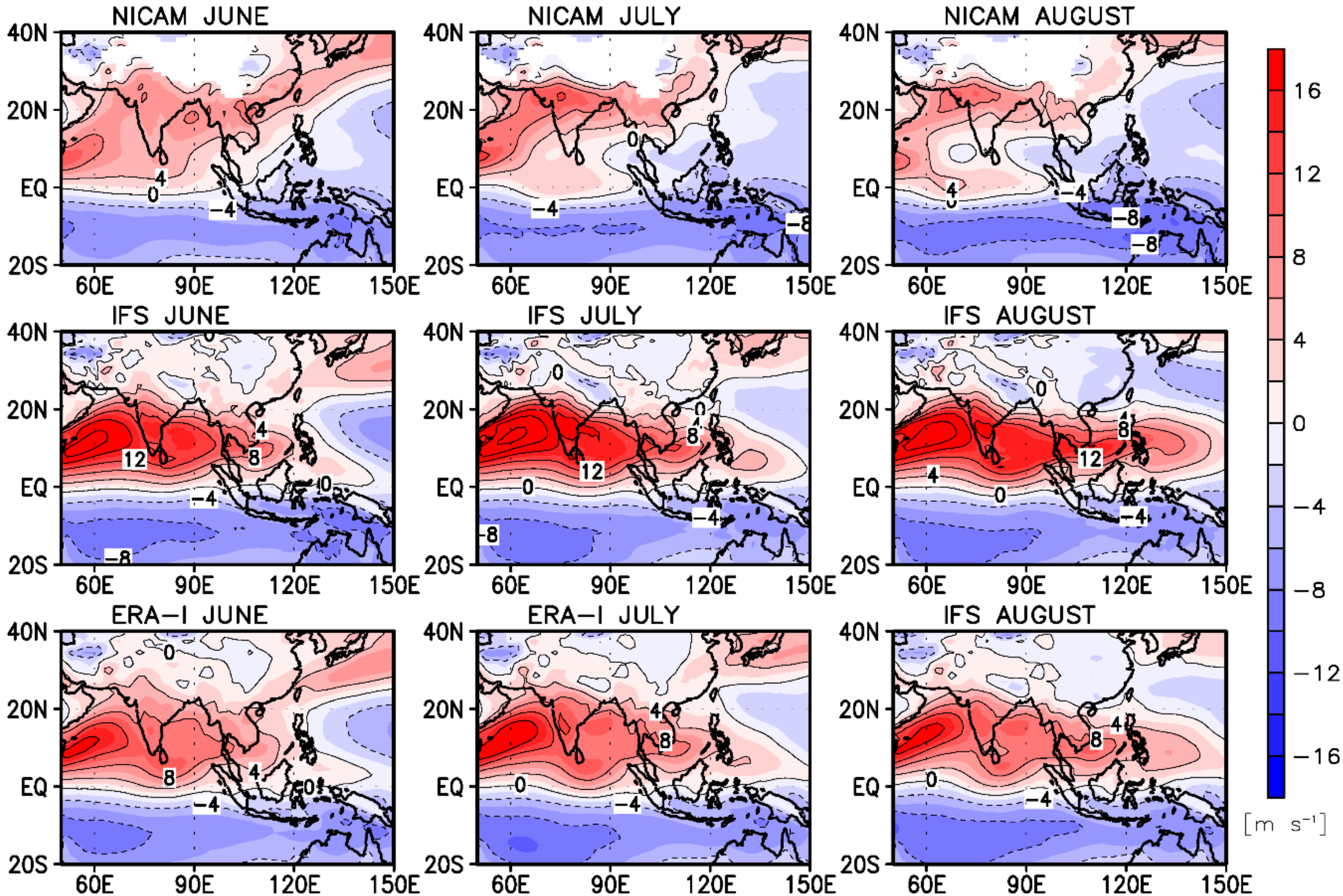
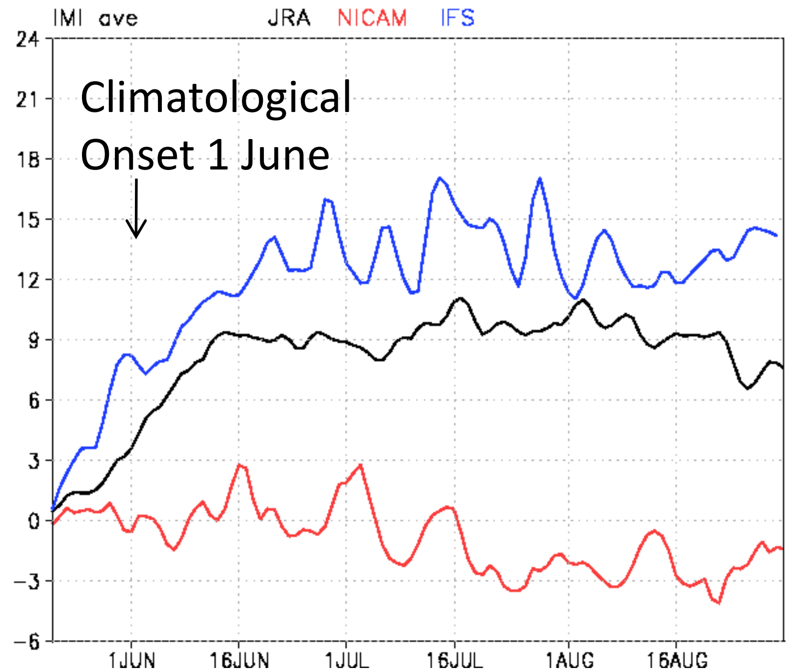


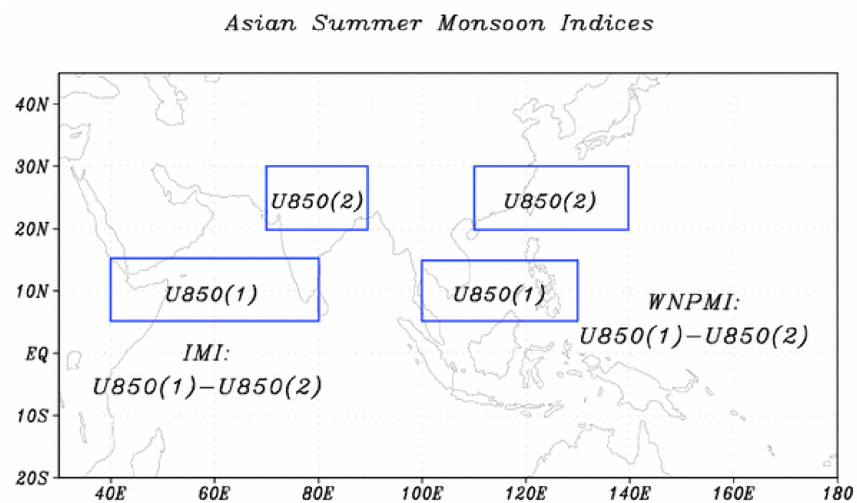
Fig. 1 The 8-year averaged monthly mean zonal wind at 850 hPa in NICAM (top) and IFS (middle) simulations in comparison with ERA–Interim (bottom).

Satoh et al. (2012)

Indian Monsoon Index

JRA（1979-2008）
NICAM(2001-2009)
IFS(2001-2009)





IM Index = U850(40E-80E,5N-15N)-U850(70E-90E,20N-30N)

WNPM Index = U850(100E-130E,5N-15N)-U850(110E-140E,20N-30N)

Satoh et al. (2012)

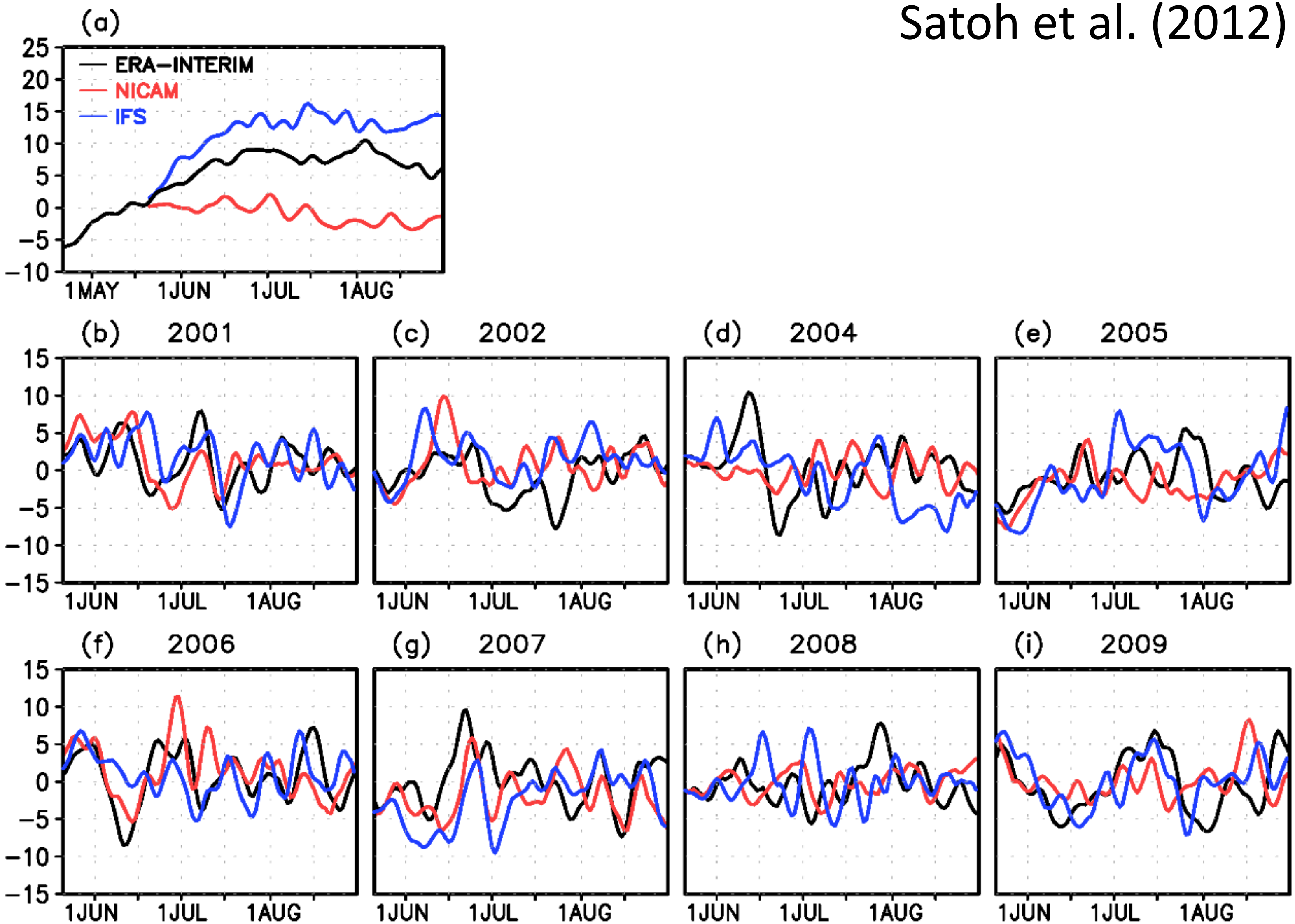


Fig.3 Time series of the Indian Monsoon Index (Wang et al. 2001) for NICAM and IFS simulations and ERA–Interim data. (a) The 8-year average and (b)–(i) anomaly from the average are plotted. 5-day running mean is operated.

Satoh et al. (2012)

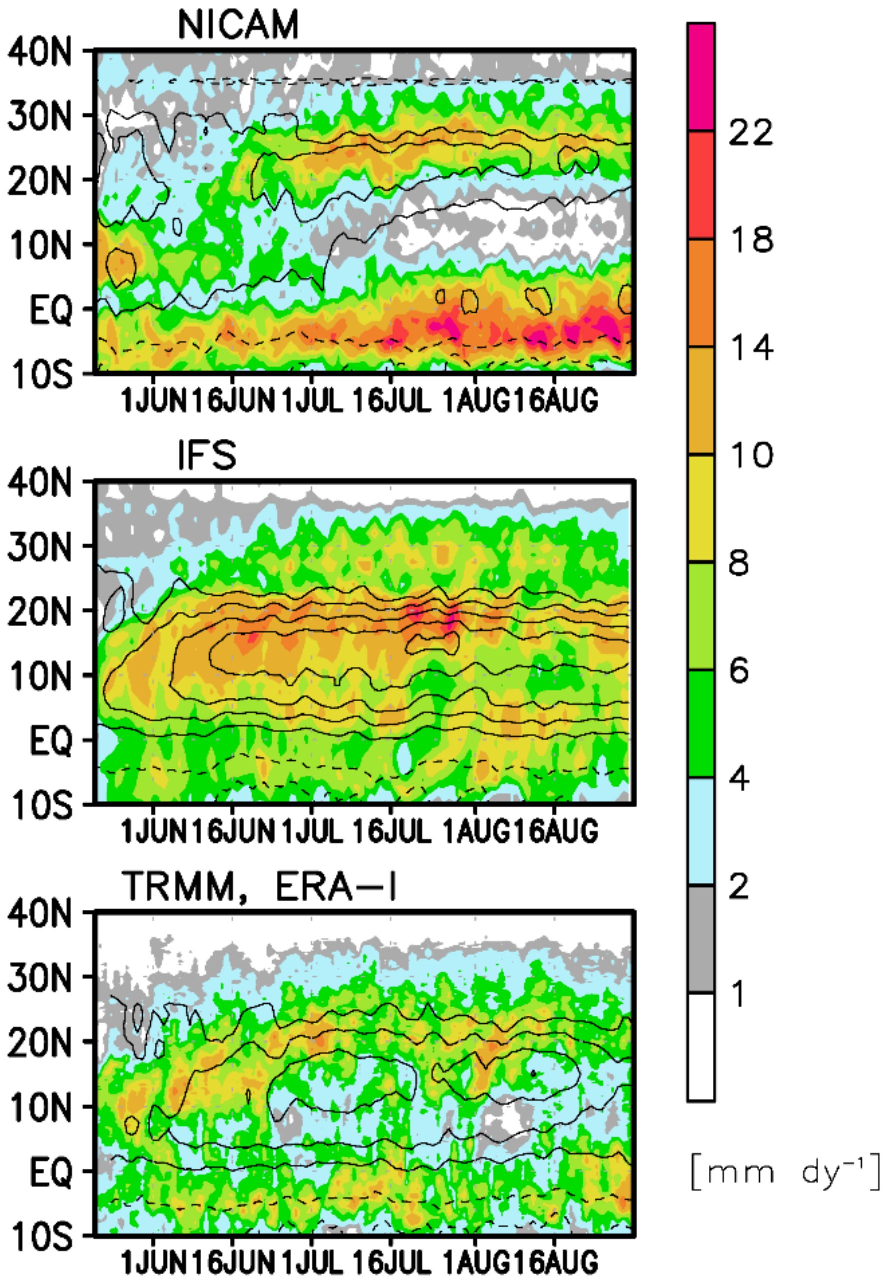
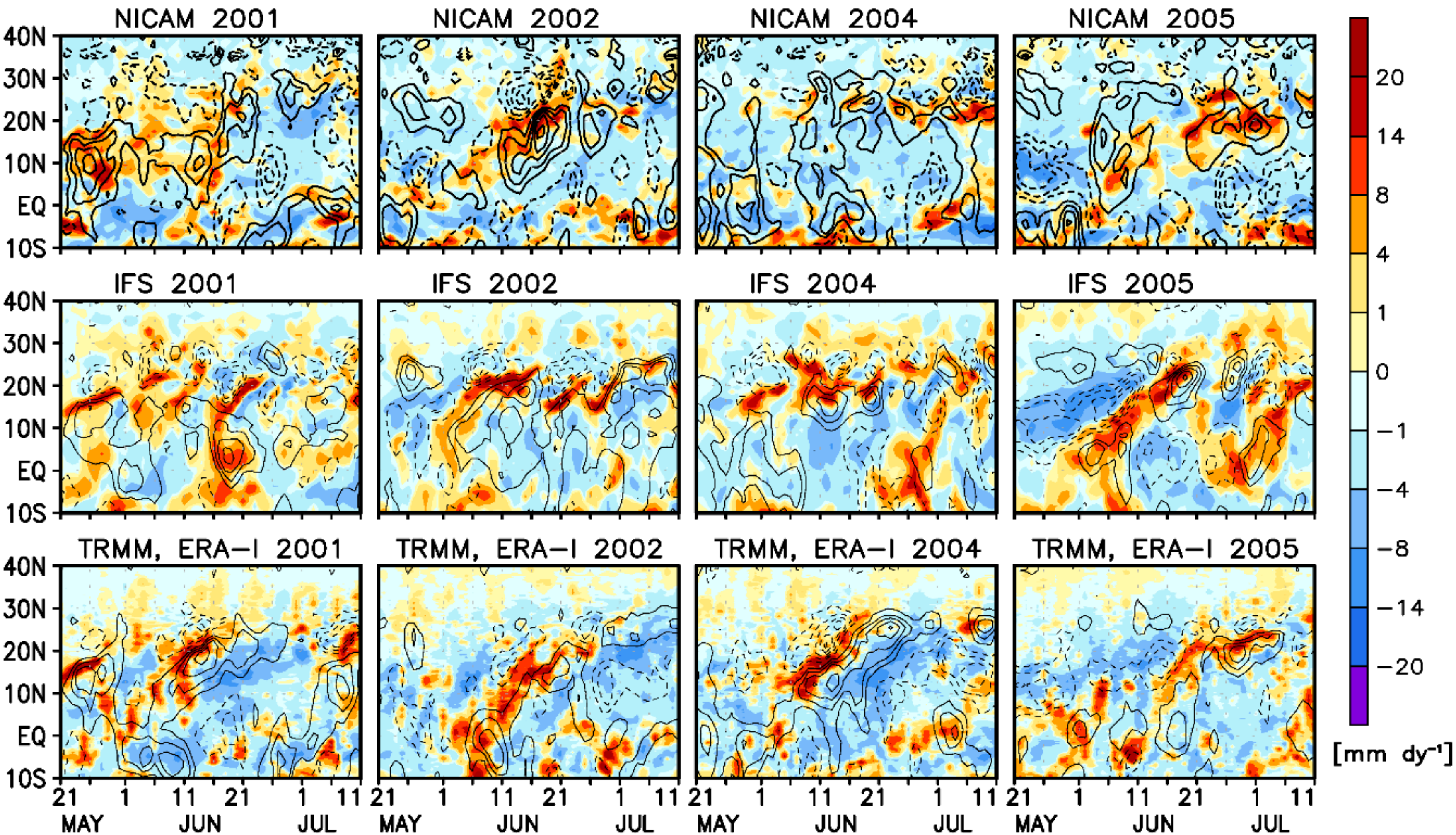
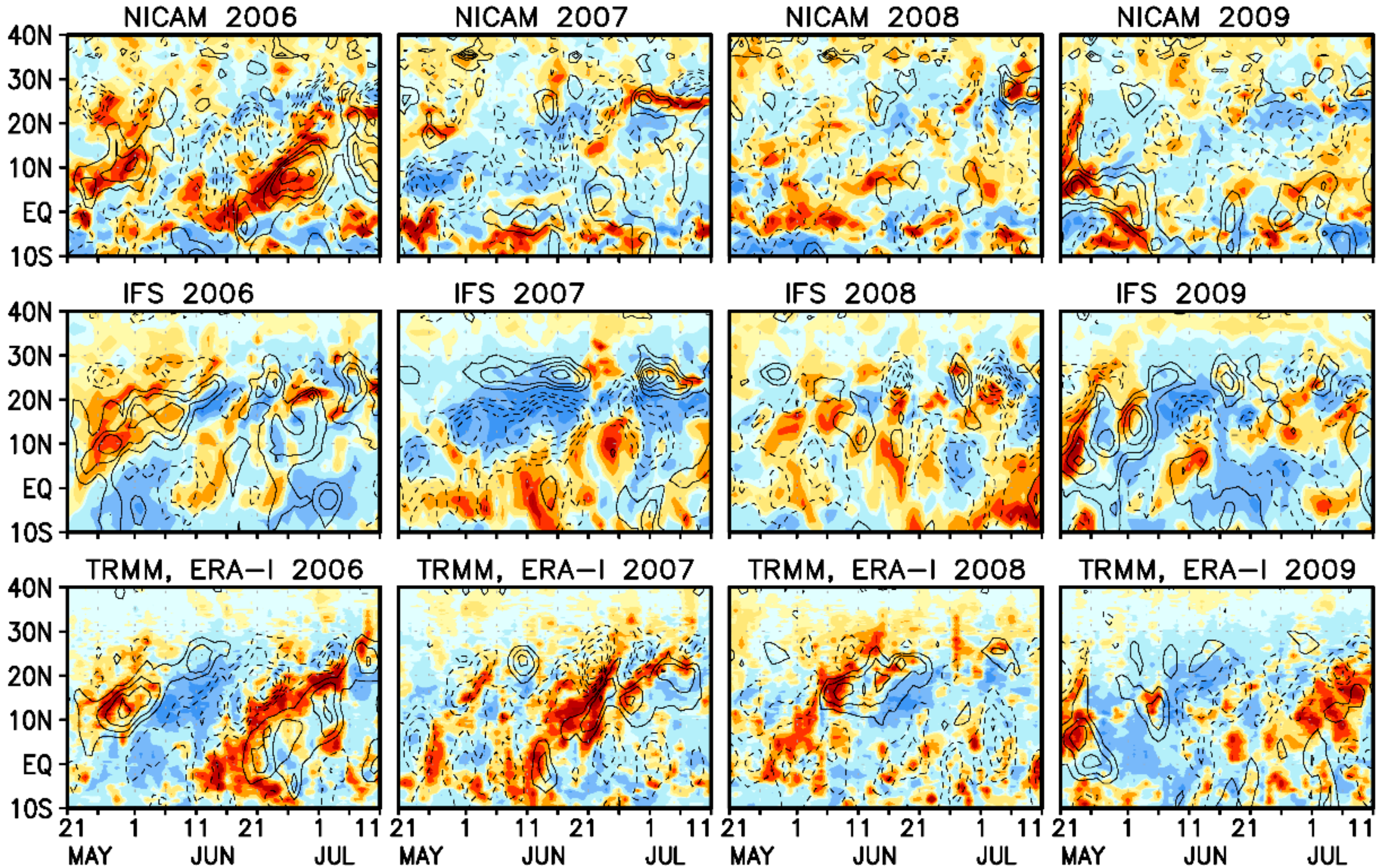


Fig.2 Time-latitude sections of the 8-year 60-90E averaged precipitation (color) and zonal wind at 850 hPa (contour lines) in NICAM (top) and IFS (middle) simulations in comparison with TRMM–3B42 and ERA–Interim and (bottom). Contour intervals for Zonal wind is 4 m s-1 (solid: positive, broken: negative). Zero contour lines are omitted.



Satoh et al. (2012)

Fig.4 Time-latitude sections of anomalous 60-90E average surface precipitation (color) and zonal wind at 850 hPa (contour lines in the initial 52 days of NICAM (top) and IFS (middle) simulations in comparison with TRMM–3B42 and ERA–Interim data (bottom). The anomalies from the 8-year average (Fig. 2) are plotted. Contour intervals for zonal wind are 2 m s^{-1}(solid: positive, broken: negative). Zero contour lines are omitted.



Satoh et al. (2012)

Fig.4 (continue)

Satoh et al. (2012)

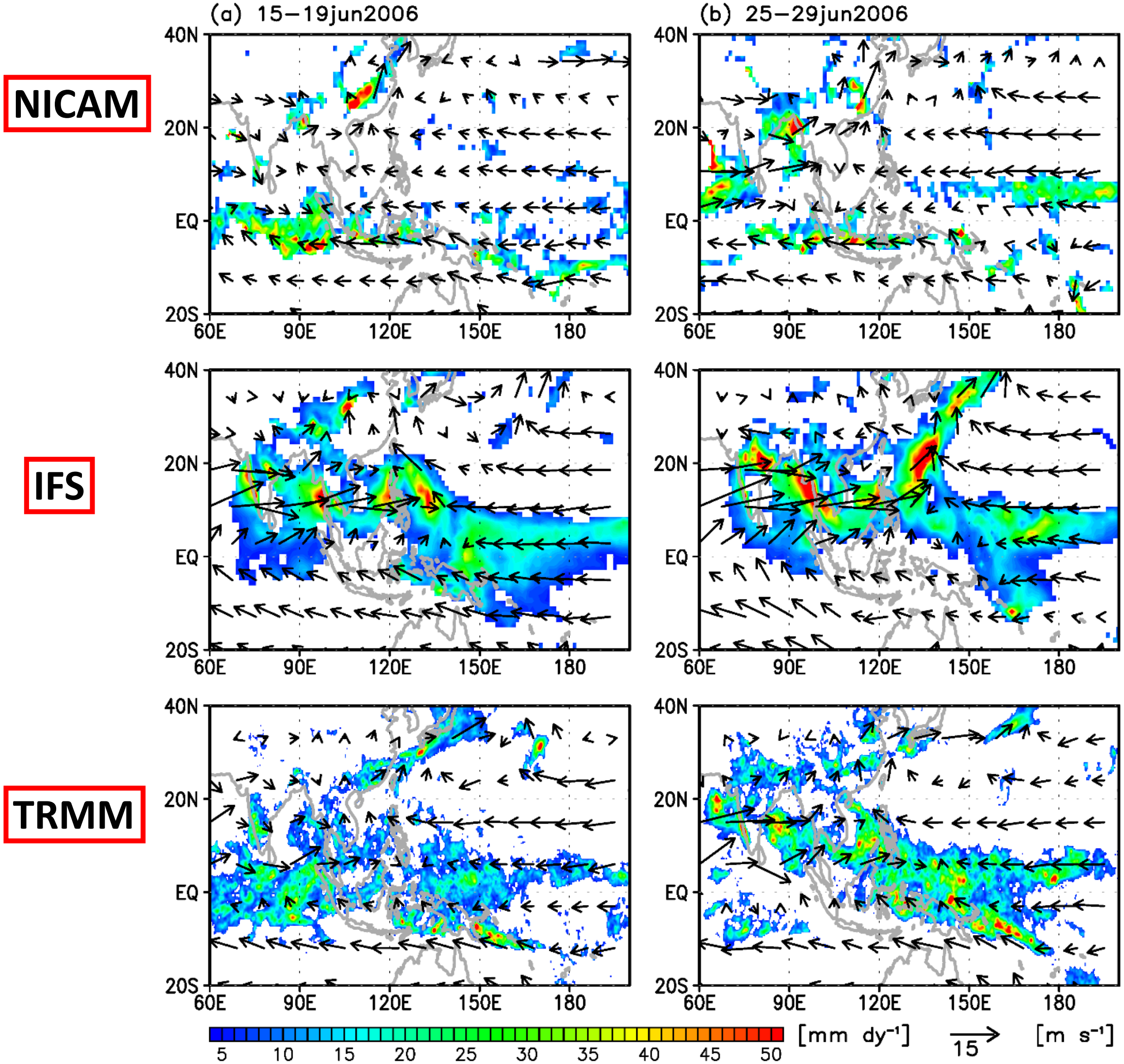
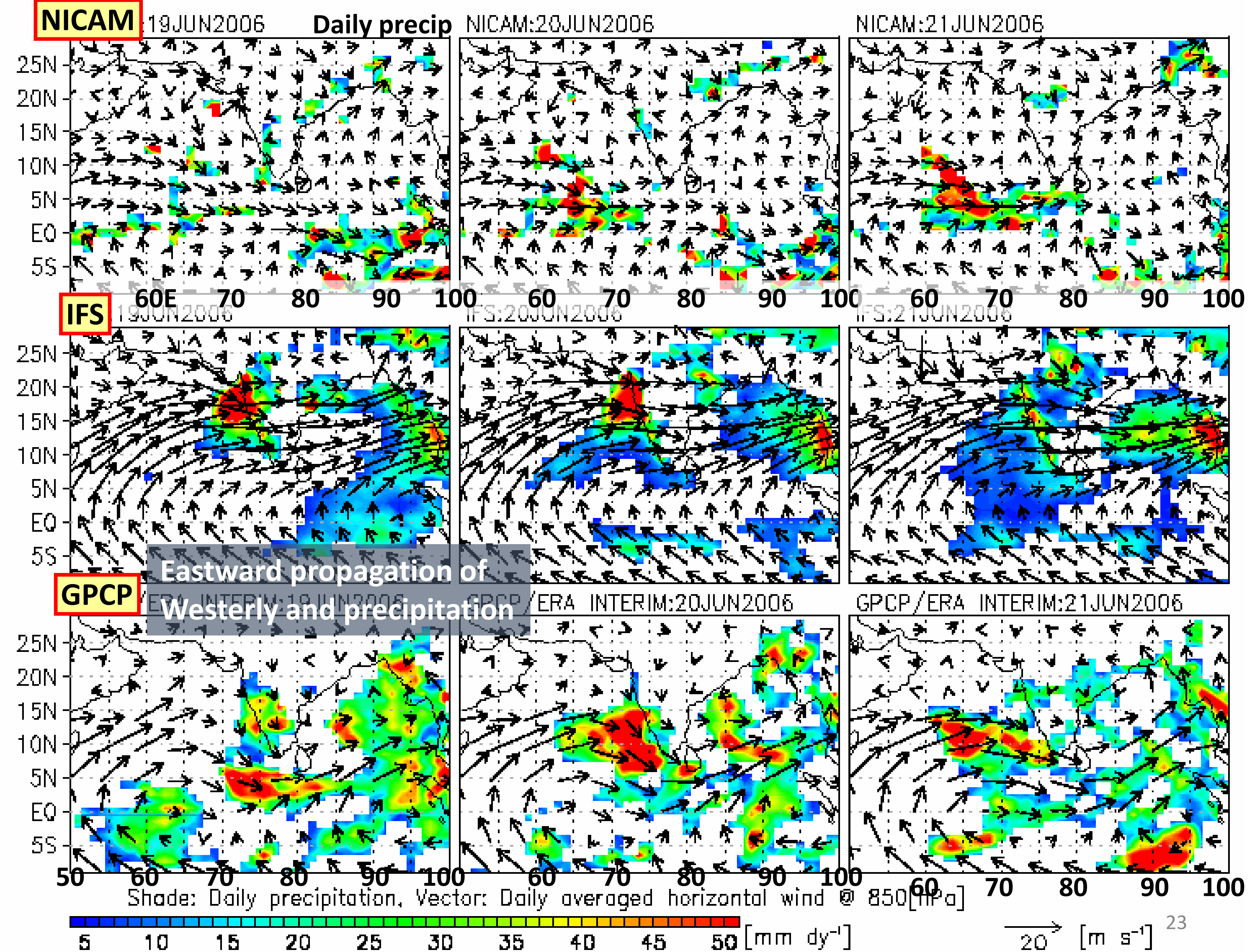
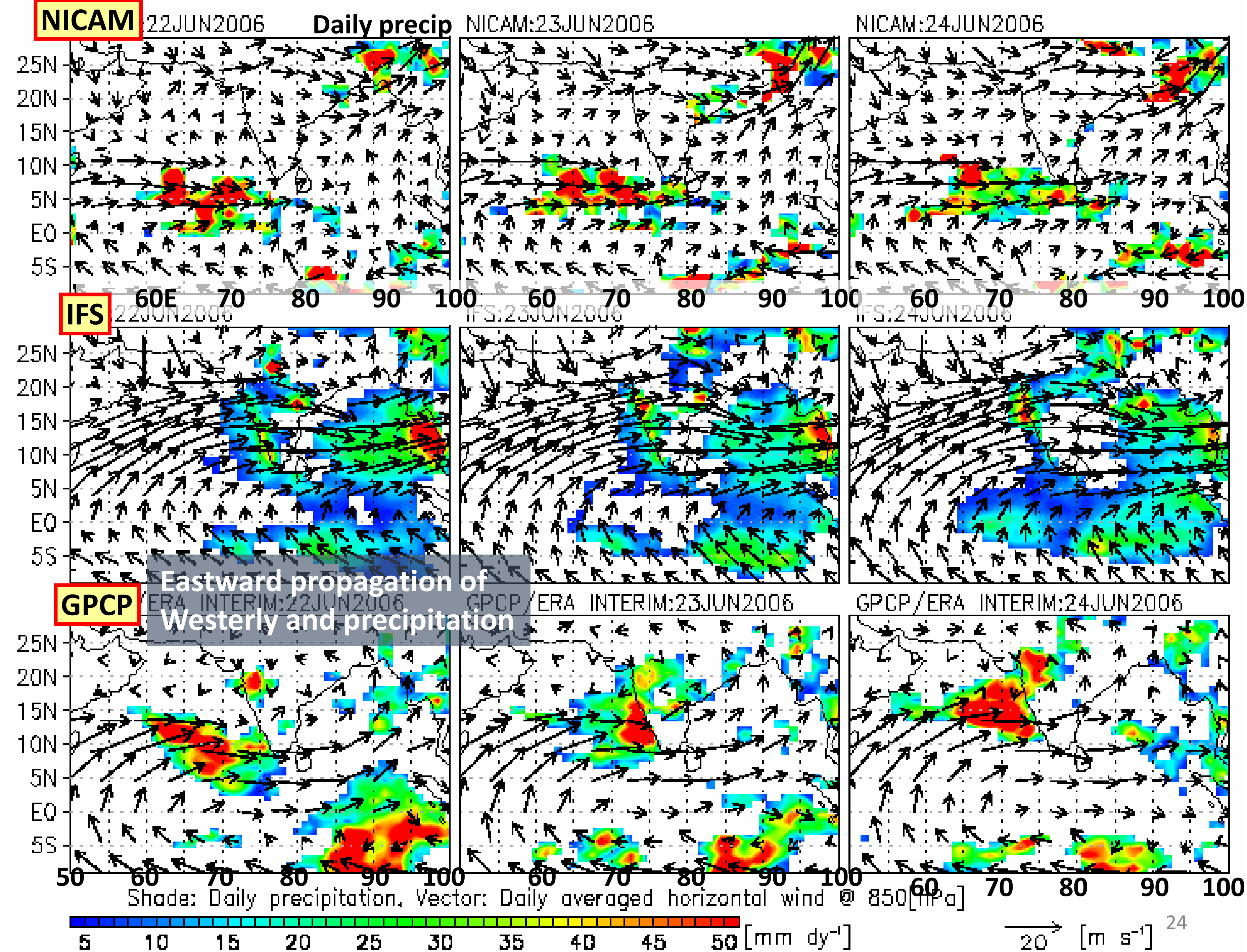


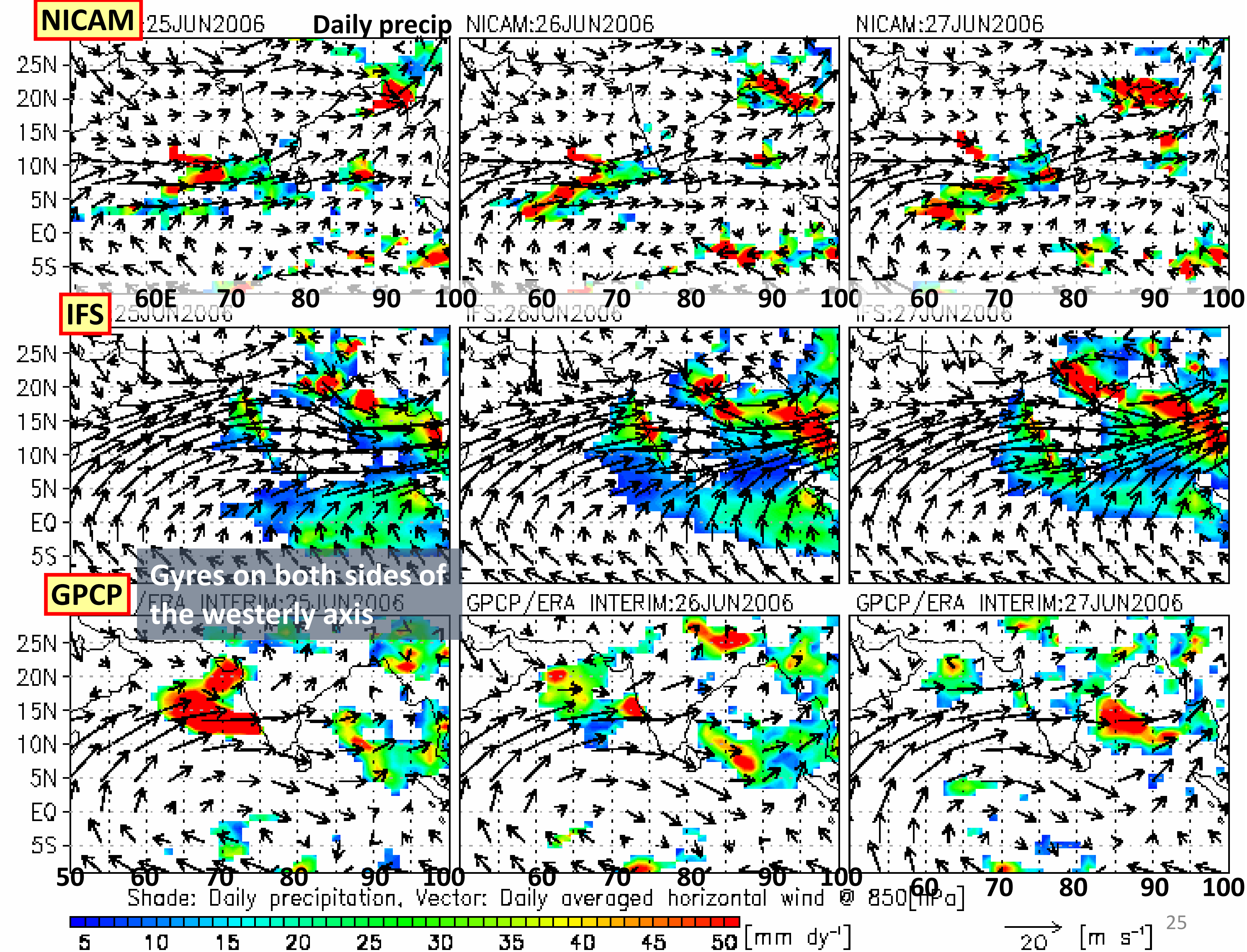
Fig. 5 Pentad-mean surface precipitation and wind vectors at 850 hPa for (a) 15–19 and (b) 25–29 June 2006 for NICAM (top) and IFS (middle) simulations in comparison with TRMM-3B42 and ERA-Interim data (bottom).



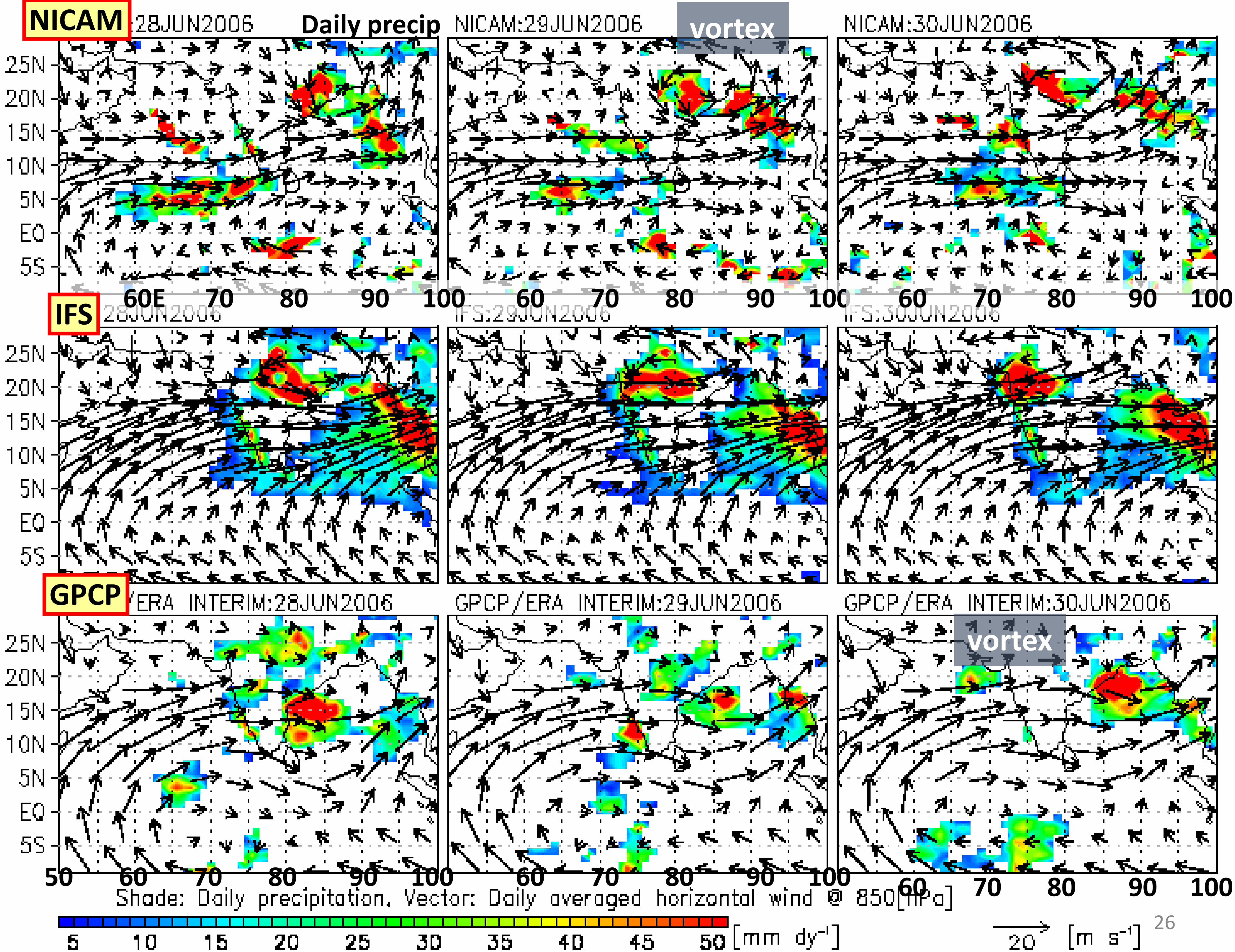
NICAM
Daily precip
NICAM:19JUN2006
NICAM:20JUN2006
NICAM:21JUN2006
IFS
IFS:19JUN2006
IFS:20JUN2006
IFS:21JUN2006
GPCP
GPCP/ERA INTERIM:19JUN2006
GPCP/ERA INTERIM:20JUN2006
GPCP/ERA INTERIM:21JUN2006
Eastward propagation of Westerly and precipitation
25N 20N 15N 10N 5N EQ 5S
60E 70 80 90 100
50 60 70 80 90 100
Shade: Daily precipitation, Vector: Daily averaged horizontal wind @ 850[hPa]
5 10 15 20 25 30 35 40 45 50 [mm dy-1]
20 [m s-1]



NICAM
Daily precip
NICAM:22JUN2006
NICAM:23JUN2006
NICAM:24JUN2006
IFS
IFS:22JUN2006
IFS:23JUN2006
IFS:24JUN2006
GPCP
GPCP/ERA INTERIM:22JUN2006
GPCP/ERA INTERIM:23JUN2006
GPCP/ERA INTERIM:24JUN2006
Eastward propagation of
Westerly and precipitation
25N 20N 15N 10N 5N EQ 5S
50 60E 70 80 90 100
Shade: Daily precipitation, Vector: Daily averaged horizontal wind @ 850[hPa]
5 10 15 20 25 30 35 40 45 50 [mm dy-1]
20 [m s-1]



NICAM
Daily precip
NICAM:25JUN2006
NICAM:26JUN2006
NICAM:27JUN2006
IFS
IFS:25JUN2006
IFS:26JUN2006
IFS:27JUN2006
GPCP
GPCP/ERA INTERIM:25JUN2006
GPCP/ERA INTERIM:26JUN2006
GPCP/ERA INTERIM:27JUN2006
Gyres on both sides of the westerly axis
25N 20N 15N 10N 5N EQ 5S
50 60E 70 80 90 100
Shade: Daily precipitation, Vector: Daily averaged horizontal wind @ 850[hPa]
5 10 15 20 25 30 35 40 45 50 [mm dy-1]
20 [m s-1]

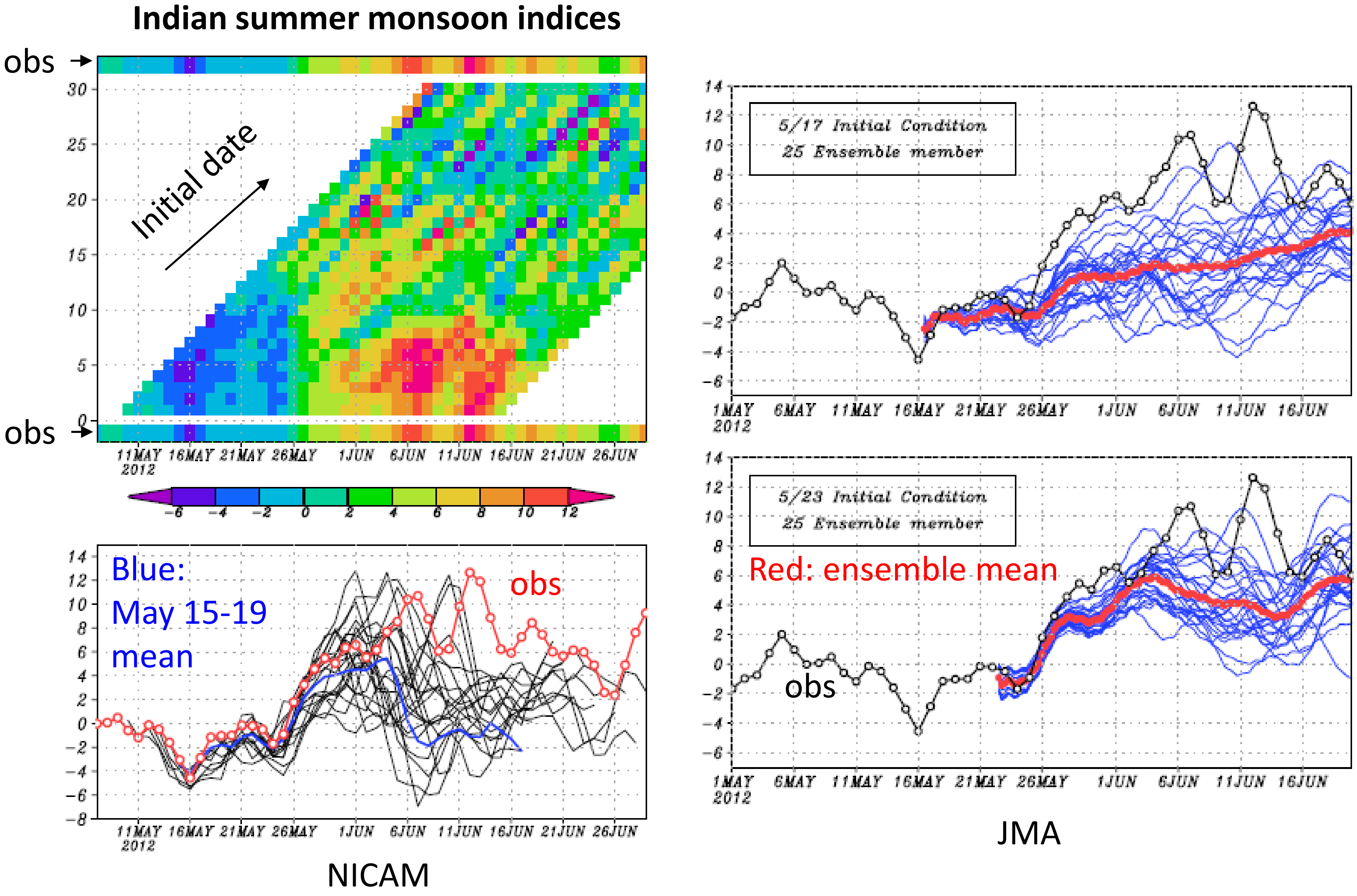


NICAM
:28JUN2006
Daily precip
NICAM:29JUN2006
vortex
NICAM:30JUN2006
IFS
28JUN2006
IFS:29JUN2006
IFS:30JUN2006
GPCP
/ERA INTERIM:28JUN2006
GPCP/ERA INTERIM:29JUN2006
GPCP/ERA INTERIM:30JUN2006
vortex
25N
20N
15N
10N
5N
EQ
5S
50
60E
60
70
80
90
100
Shade: Daily precipitation, Vector: Daily averaged horizontal wind @ 850[hPa]
5 10 15 20 25 30 35 40 45 50 [mm dy-1]
20 [m s-1]

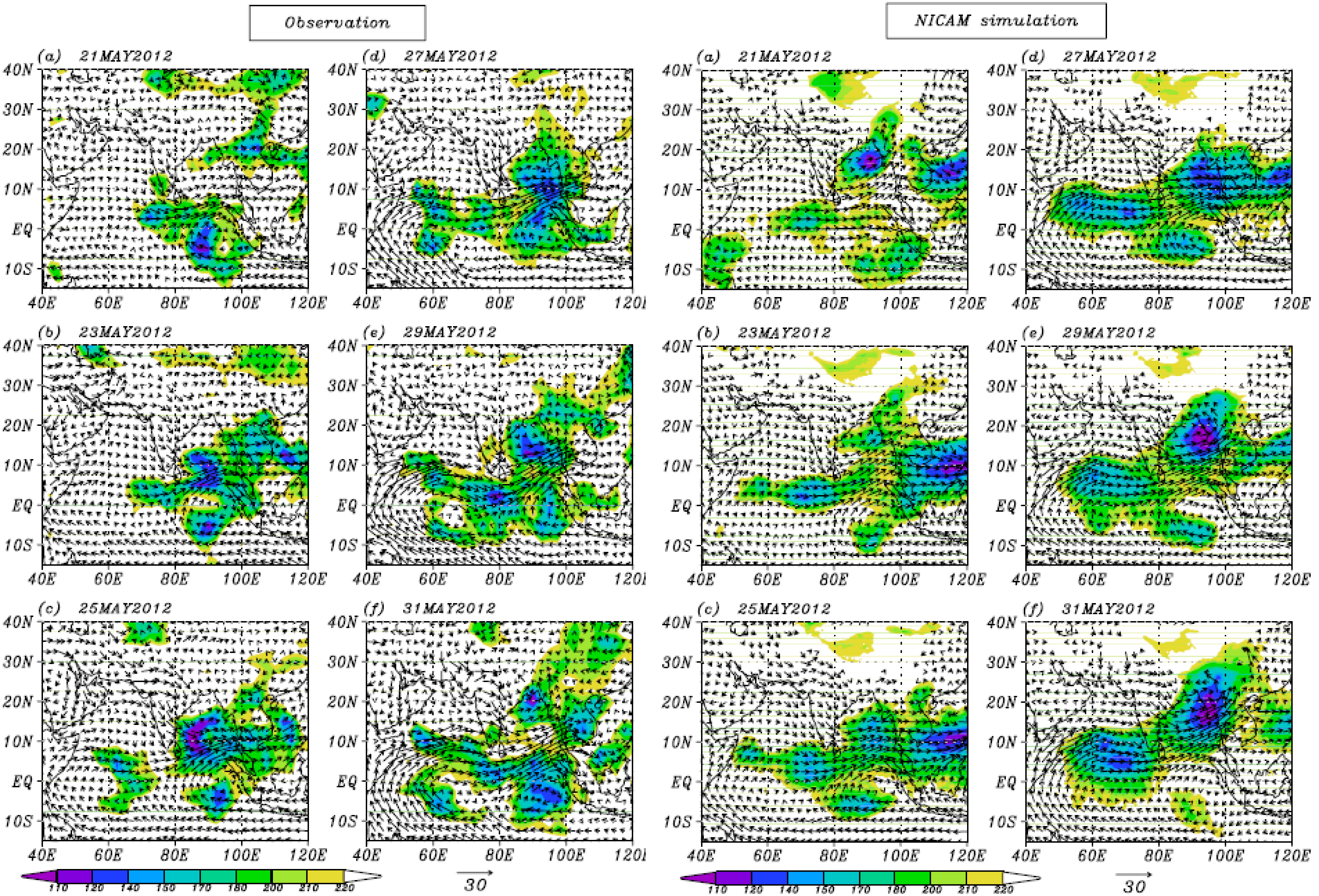
Summary (JJA ensemble simulations; Satoh et al. 2012)

- In the first month of simulation, both models capture the intra-seasonal oscillatory behavior of the Indian monsoon similar to the observed boreal summer ISO in approximately half of the 8-year samples.
- The IFS simulates the NW–SE-oriented rainband and the westerly location better, while NICAM marginally reproduces mesoscale organized convective systems and better simulates the northward migration of the westerly peak and precipitation, particularly in 2006.

Impact of tropical disturbance on the Indian summer monsoon onset in 2012 (Kajikawa et al. 2015)

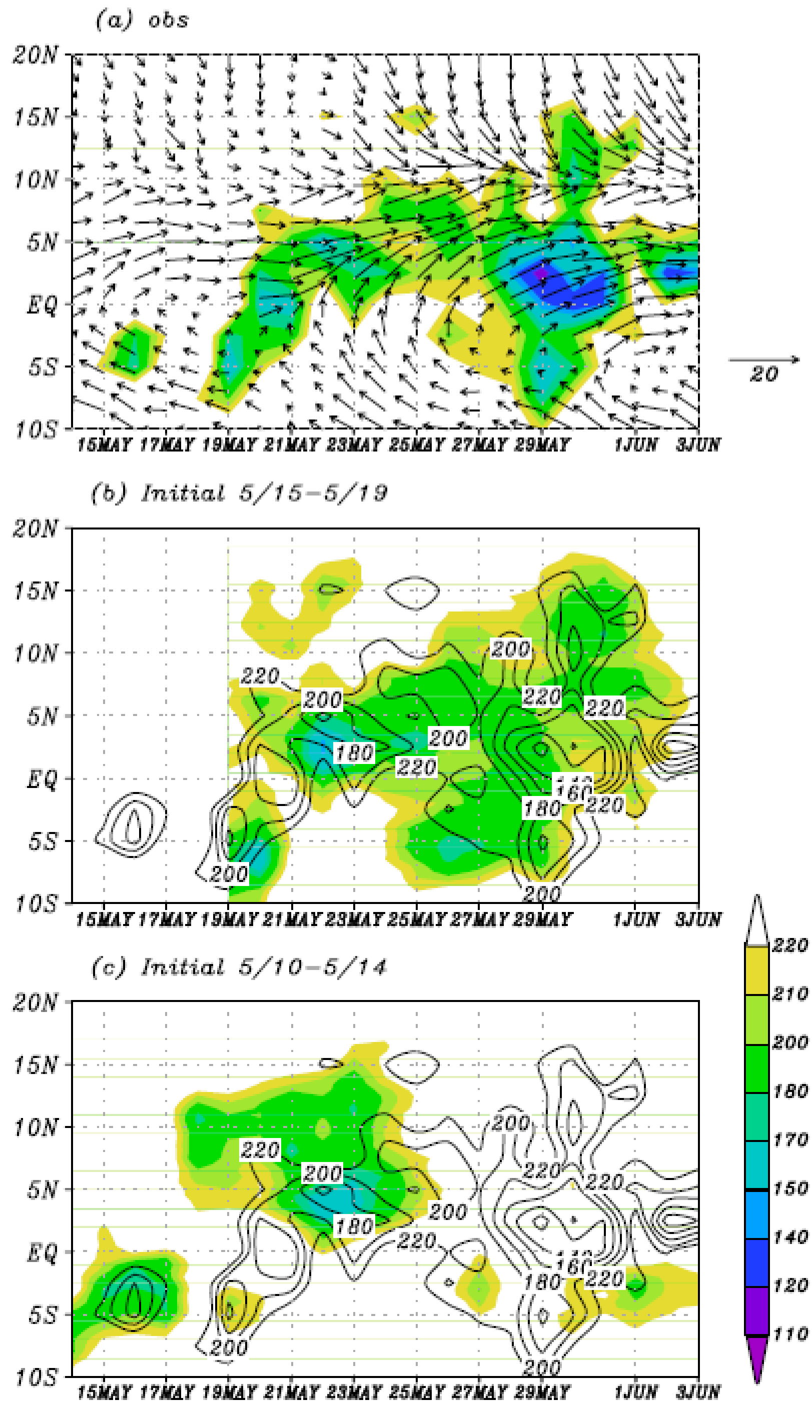


Kajikawa et al. (2015)

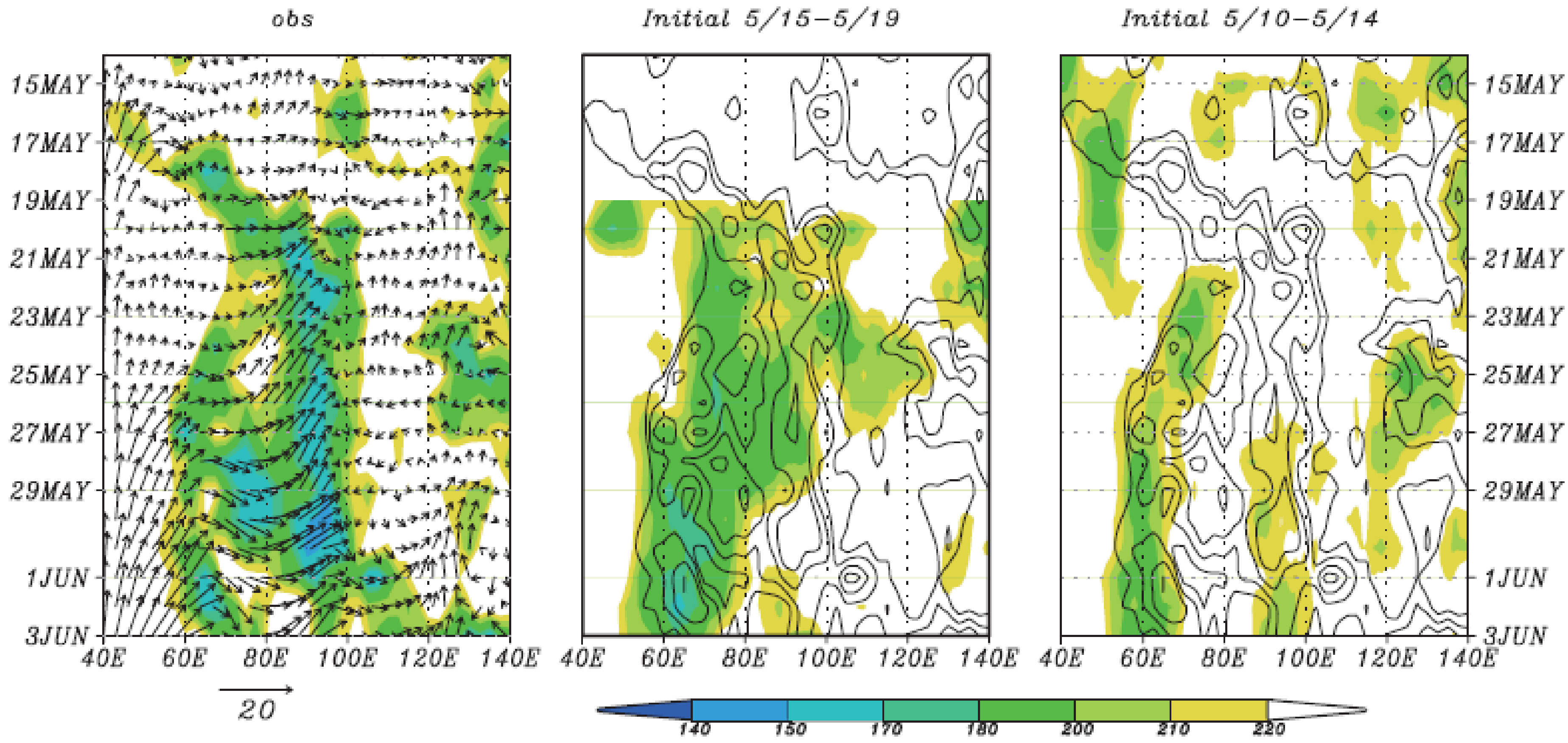


Mean of Exp. with IC at May 15-19

Kajikawa et al. (2015)



Kajikawa et al. (2015)



- Summary (onset of ISM in 2012; Kajikawa et al. 2015)
- Focuses are on the effect of tropical disturbances on ISM onset and considered the potential extension of onset predictability
- A series of 30-day simulations initialized on10 May-10 June show a skill of two weeks predictability of ISM onset.
- The ISM onset was accompanied by northward-migrating tropical disturbances over the Bay of Bengal and the Arabian Sea, which originated in the equatorial Indian Ocean.
- The result suggest that a better representation of tropical disturbances enhances the potential to extend the predictability of the transition phase of the Asian summer monsoon.

2. Monsoon simulations in NICAM
2-2. East Asian Summer Monsoon

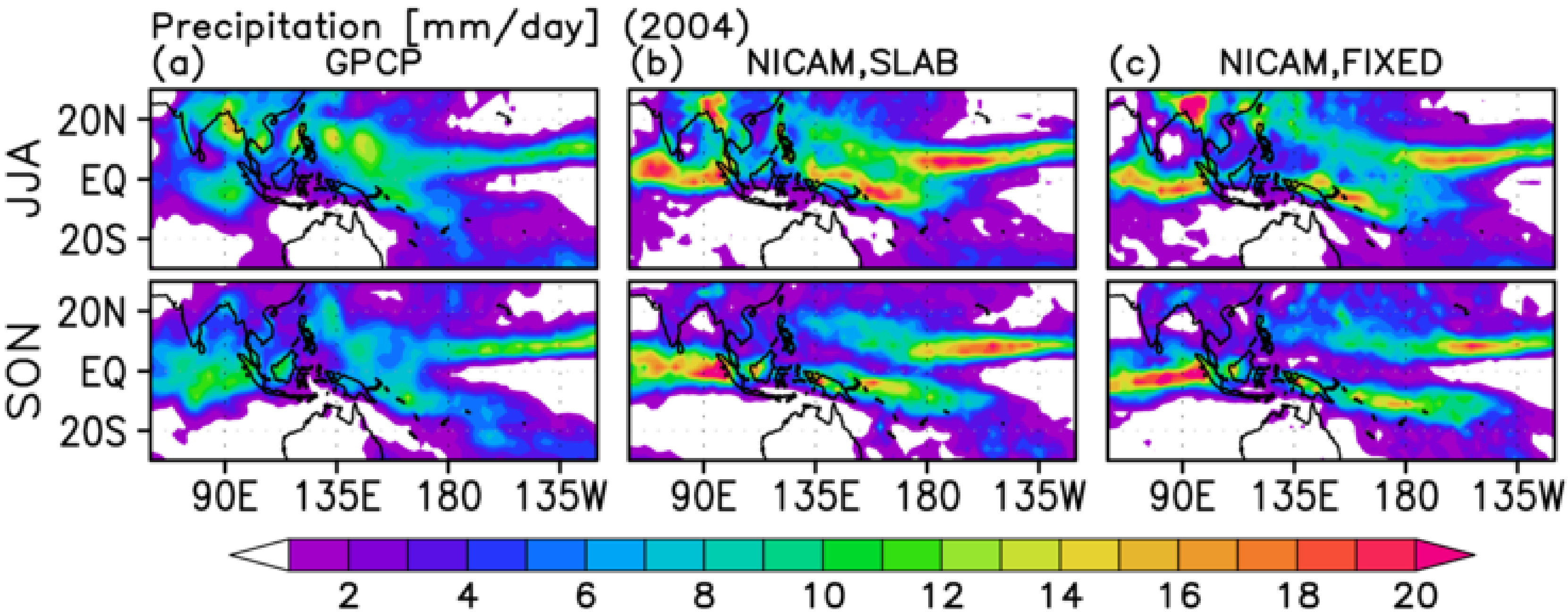
- Kodama, C., Yamada, Y., Noda, A. T., Kikuchi, K., Kajikawa, Y., Nasuno, T., Tomita, T., Yamaura, T., Takahashi, T. G., Hara, M., Kawatani, Y., Satoh, M., Sugi, M.2015: A 20-year climatology of a NICAM AMIP-type simulation. J. Meteor. Soc. Japan, 93, 393-424, doi:10.2151/jmsj.2015-024.
- Yamaura, T., Kajikawa, Y., Tomita, H., Satoh, M., 2013: Possible impact of a tropical cyclone on the northward migration of the baiu frontal zone. SOLA, 9, 89-93. http://dx.doi.org/10.2151/sola.2013-020
-Oouchi, K.,A. T. Noda, M. Satoh, B. Wang, S.-P. Xie, H.G. Takahashi, T. Yasunari (2009): Asian summer monsoon simulated by a global cloud-system-resolving model: Diurnal to intra-seasonal variability. Geophys. Res. Lett.,36, L11815, doi:10.1029/2009GL038271.

NICAM AMIP-type simulations

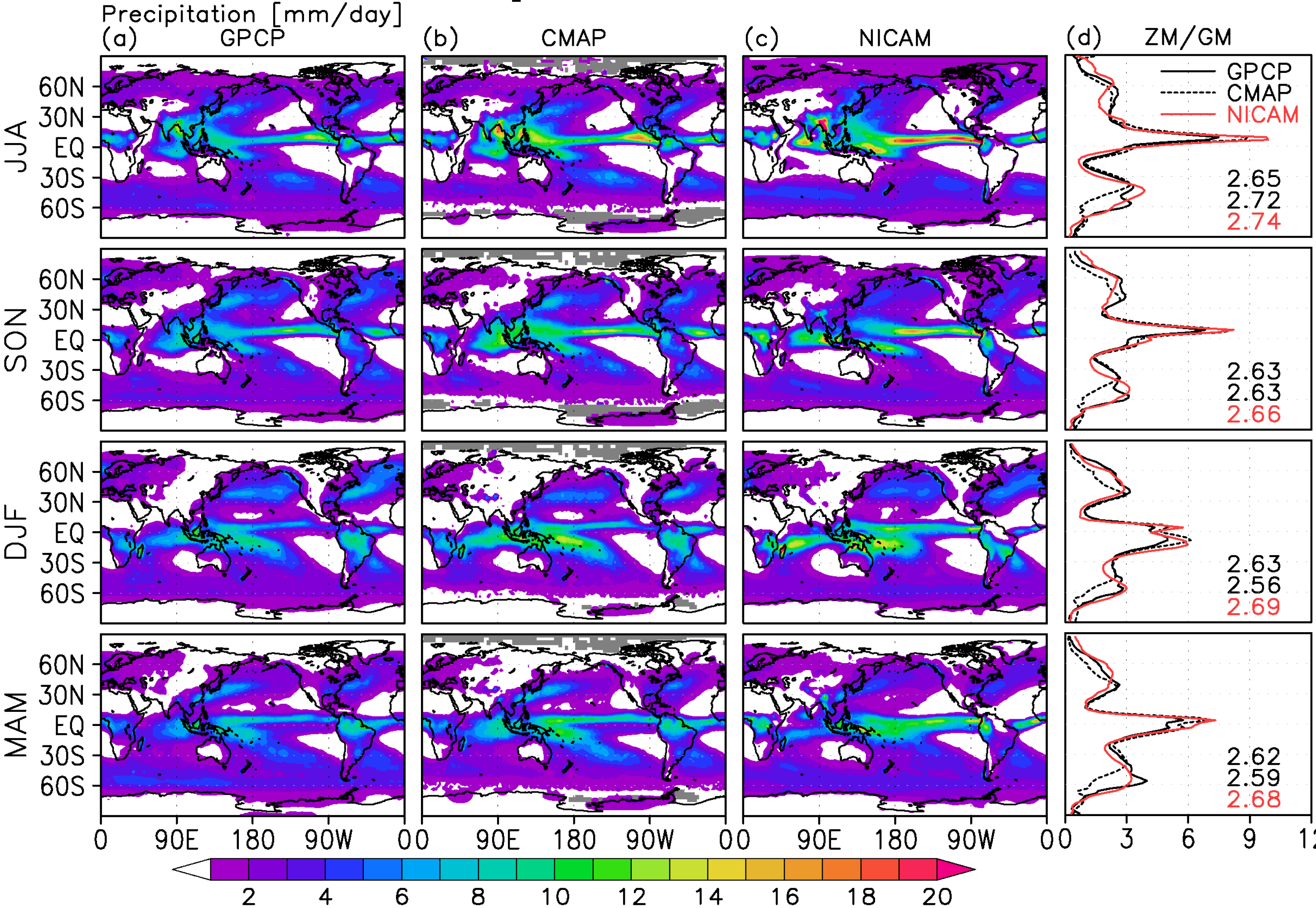
Kodama et al. (2015)

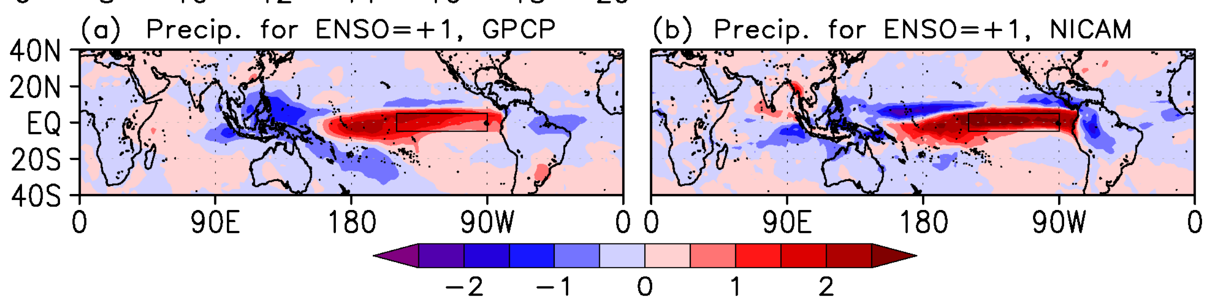
- 14km horizontal mesh and 38 vertical levels up to 40 km.
- 1-moment 6-category bulk cloud microphysics (Tomita 2008).
  - No cumulus convection parameterization
  - parameters tuned by several seasonal-scale experiments
- AMIP configurations except for
  - **slab ocean model** (D=15m & τ=7days) with SST nudging and fixed sea ice
- CNTL run: 1978.06-2009.12
  - monthly mean AMIP2 SST/SSI.
- FUTURE run: 2074.06-2105.12 (A1B scenario)
  - CMIP3 model ensemble dSST = SST(2075-2099) – SST(1979-2003) including trend is added to AMIP2 SST. For sea ice, areal change is considered following Mizuta et al. [2008].

precipitation: SLAB vs. fixed SST



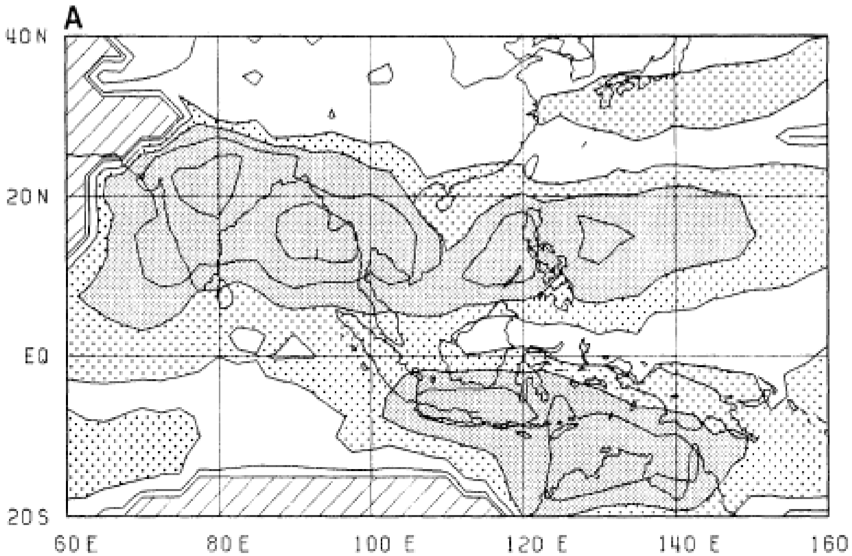
Precipitation rate





Precip. response to ENSO
(ENSO index = +1 anomaly

OLR max-min in annual cycle of 20-yr Climatology



Murakami and Matsumoto (1994)

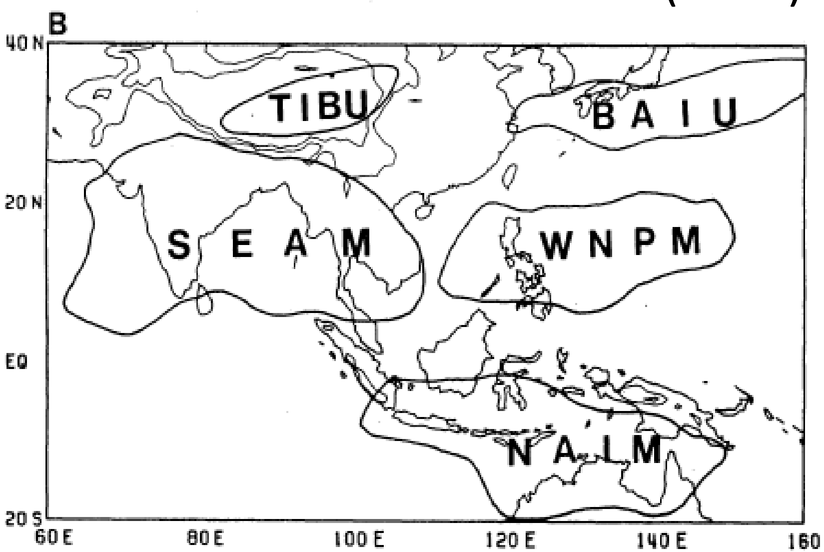
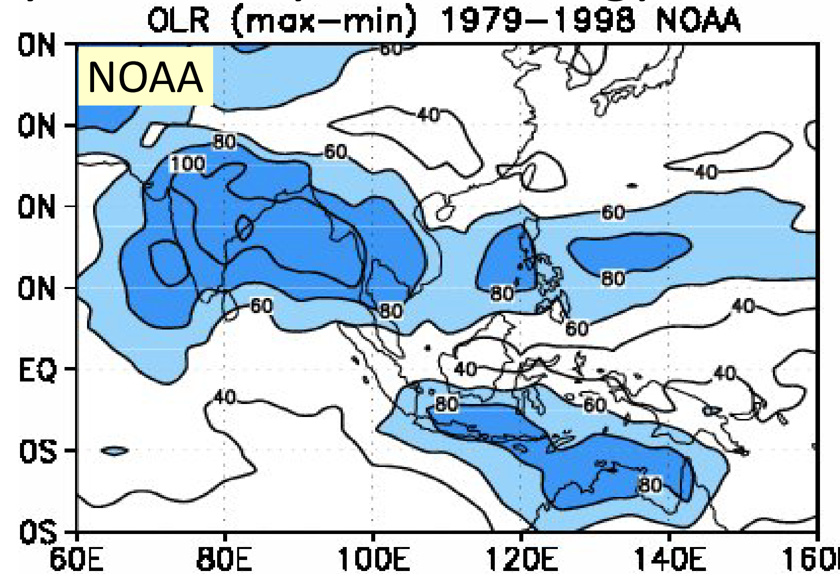
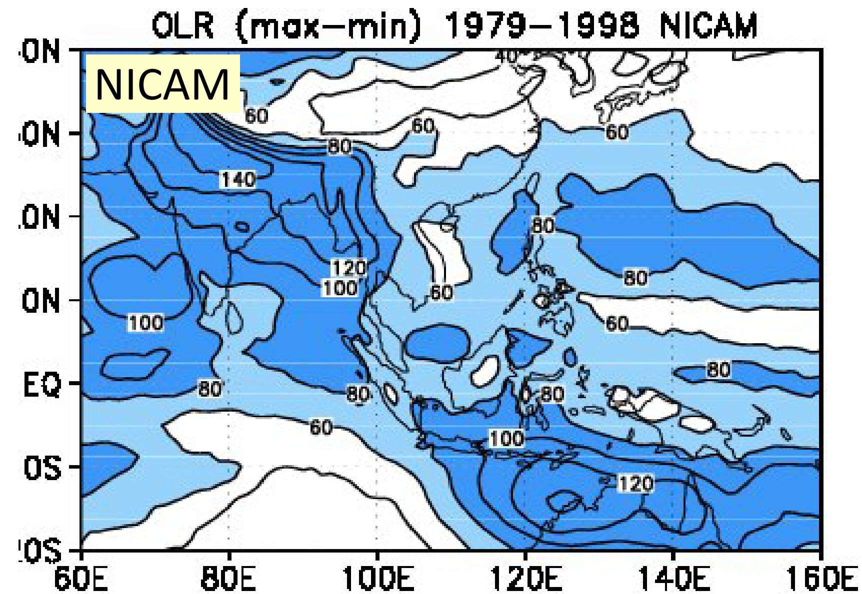


Fig. 1. A: Difference between OLR(max) and OLR(min). Intervals are for 20 Wm^{-2}; hatching denotes OLR(min) greater than 240 Wm^{-2}, while dark (light) shading indicates regions of DD greater than 60 (40) Wm^{-2}. B: The domains of the three monsoon systems SEAM, WNPM and NAIM, as well as two extratropical wet-climate regimes of the TIBU and BAIU. Refer to the text for further information.





Sperber et al. 2013

precipitation JJAS 20-yr Climatology

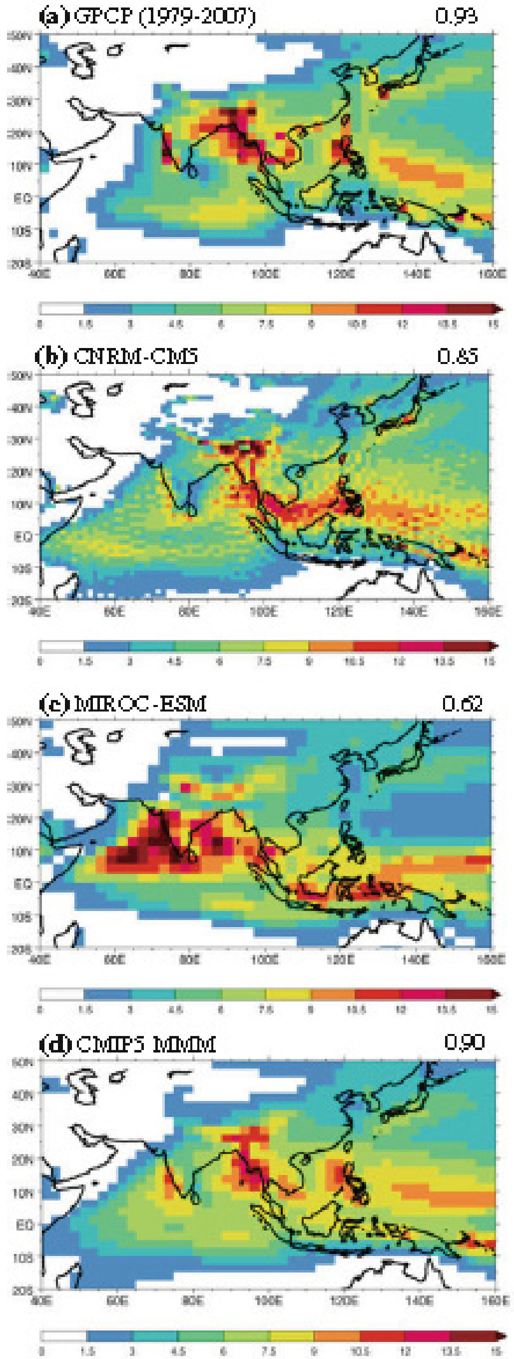
GPCP

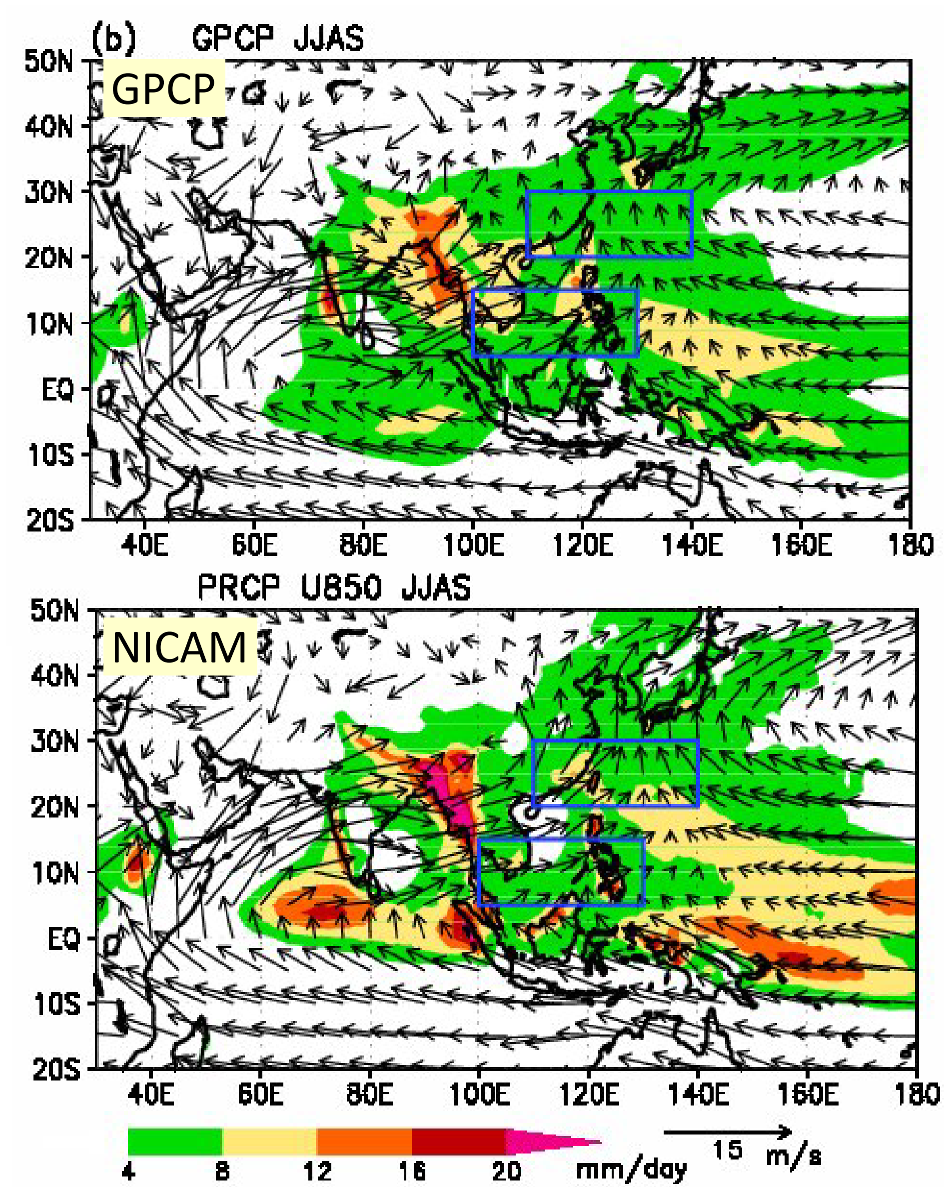
Model: 1961-1999

CNRM-CM5

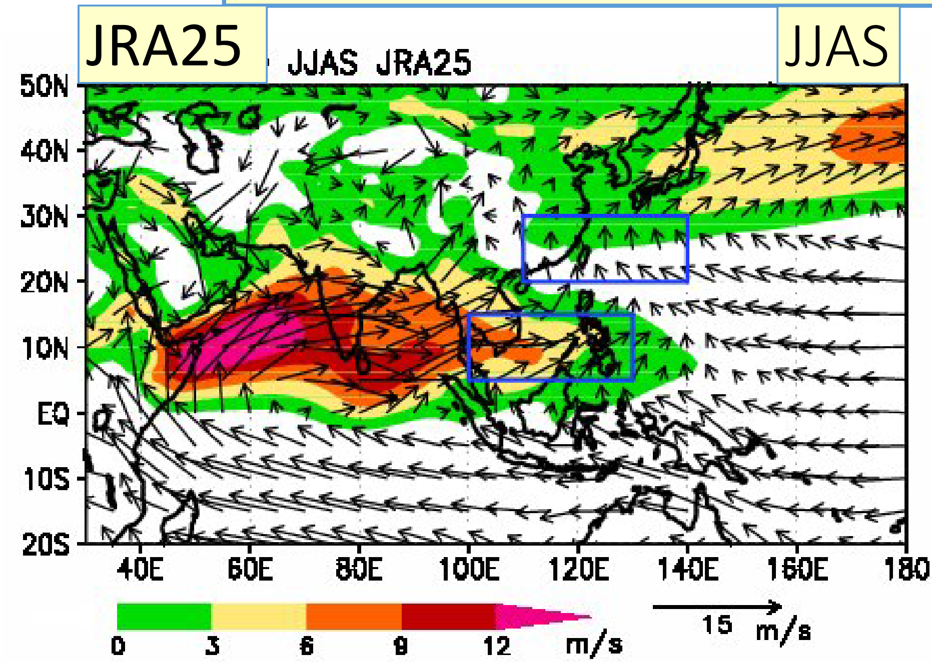
MIROC-ESM

CMIP5-MMM

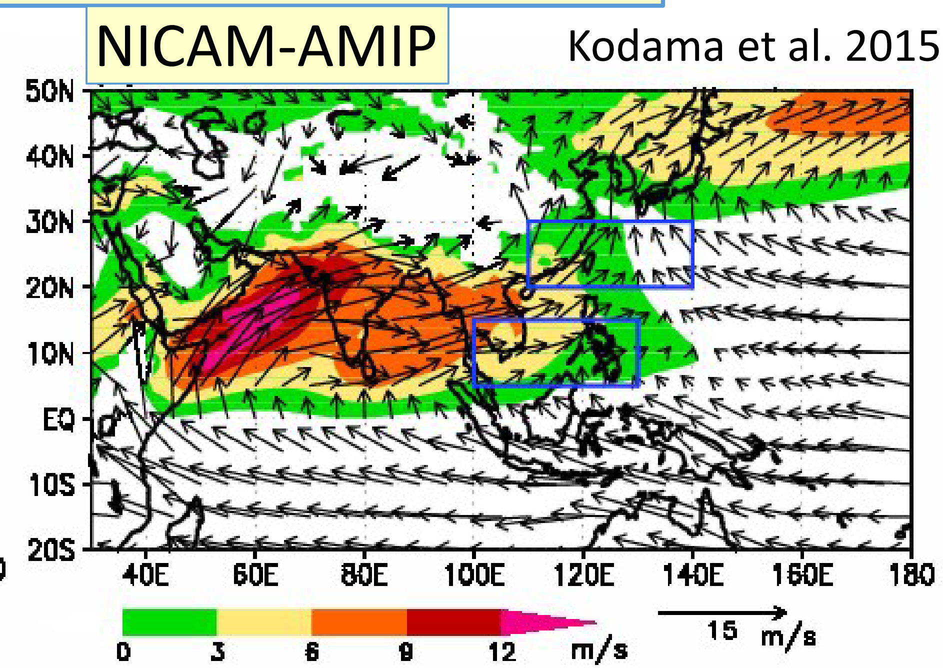


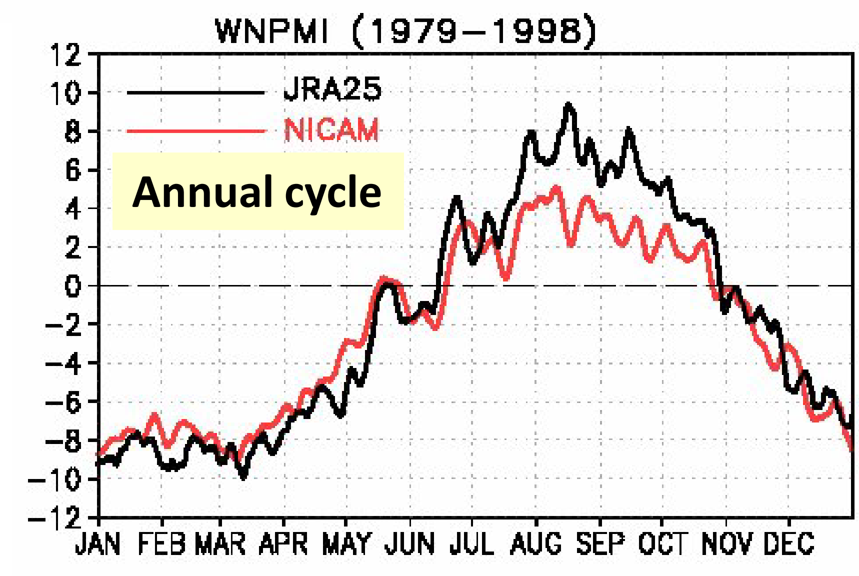


Climatology of Asian monsoon　U850（1979-1998）

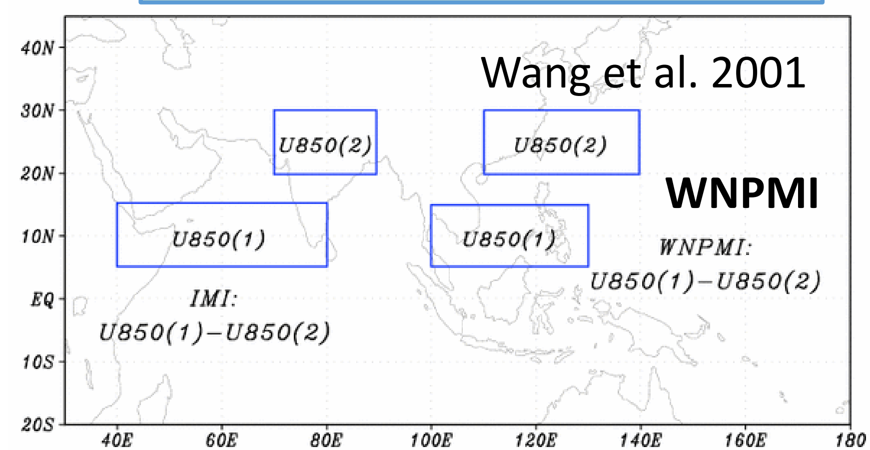


Kodama et al. 2015

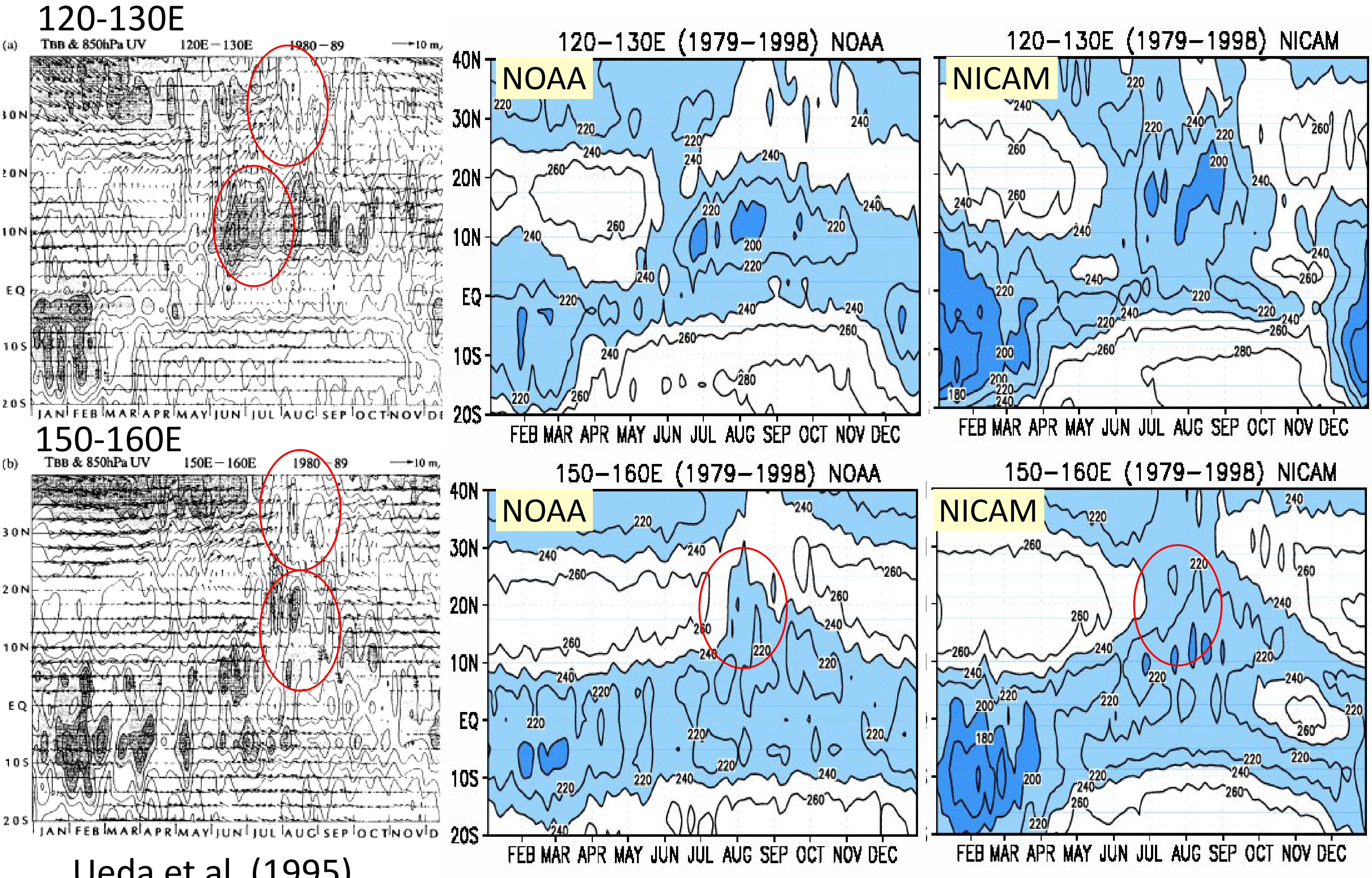




Asian Summer Monsoon Indices

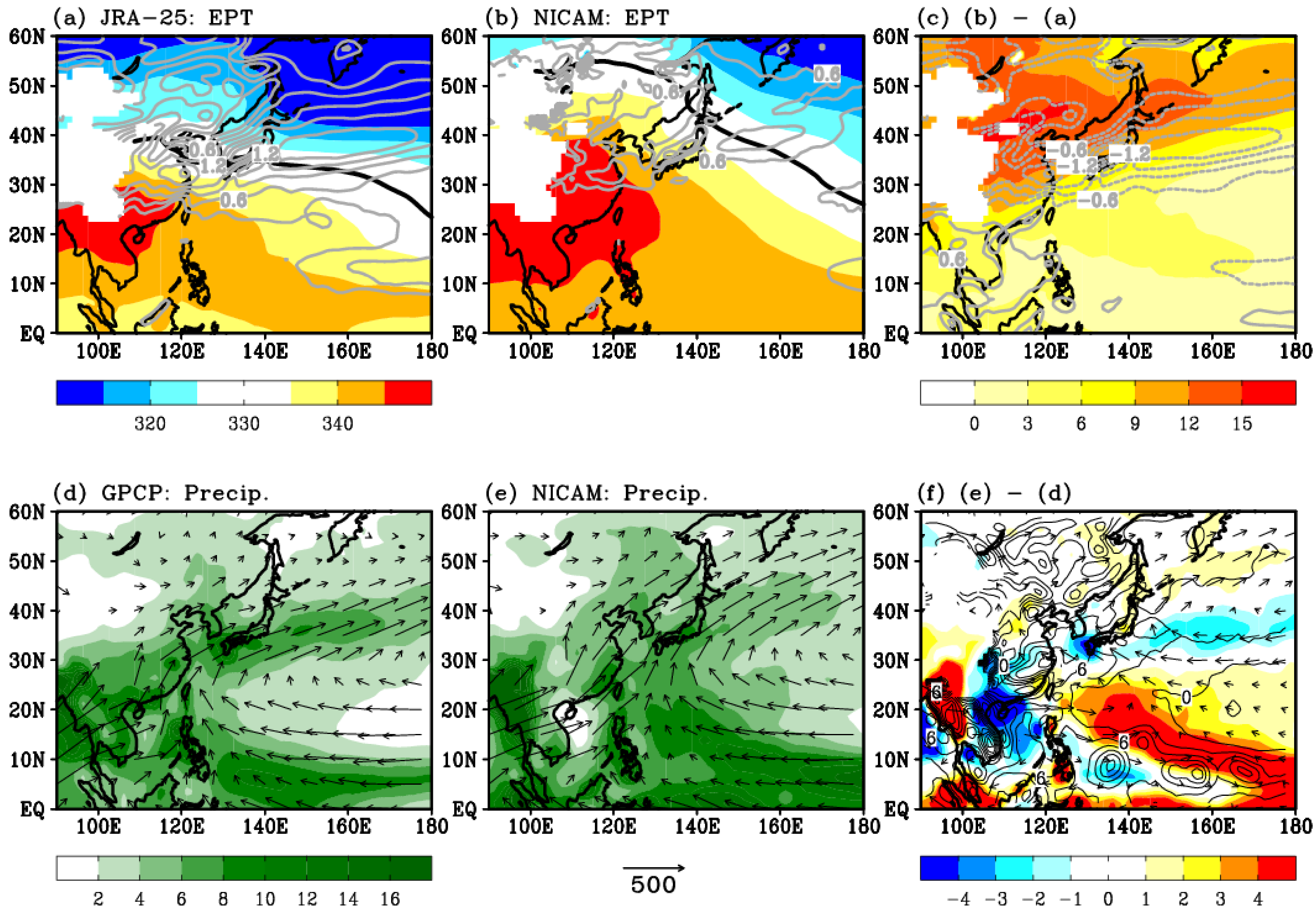


OLR annual cycle of 20-yr Climatology



Ueda et al. (1995)

Kodama et al. (2015, JMSJ)



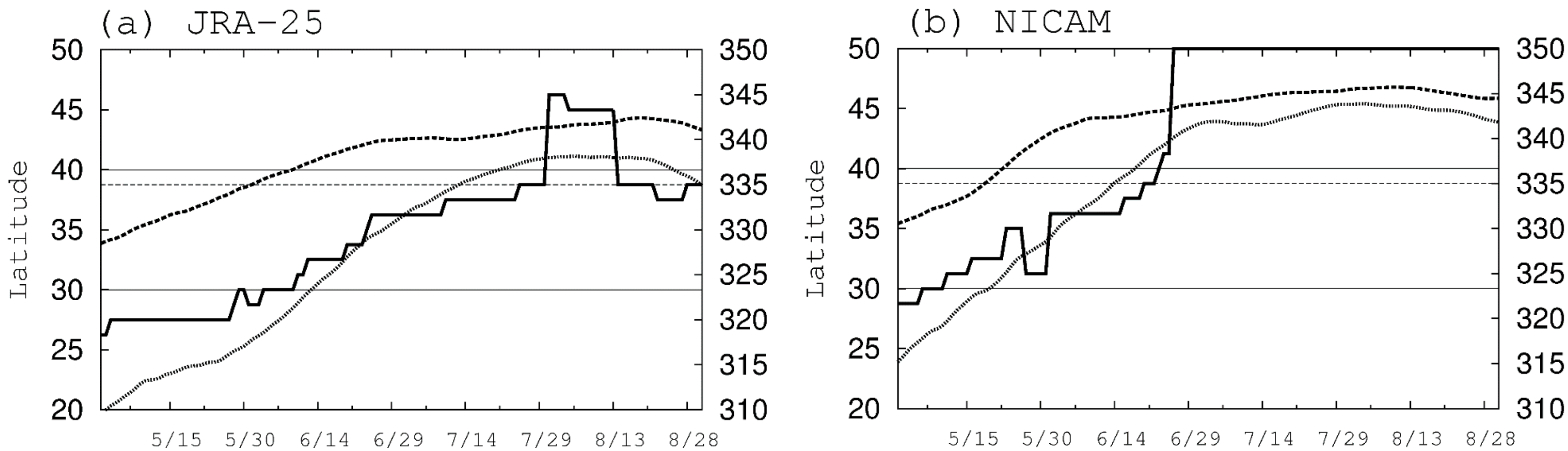
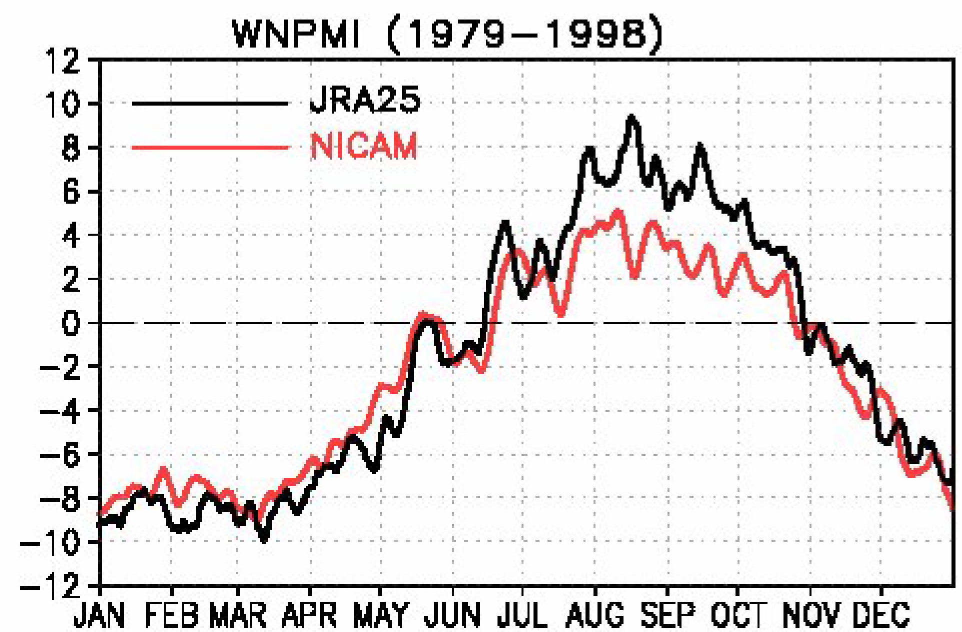
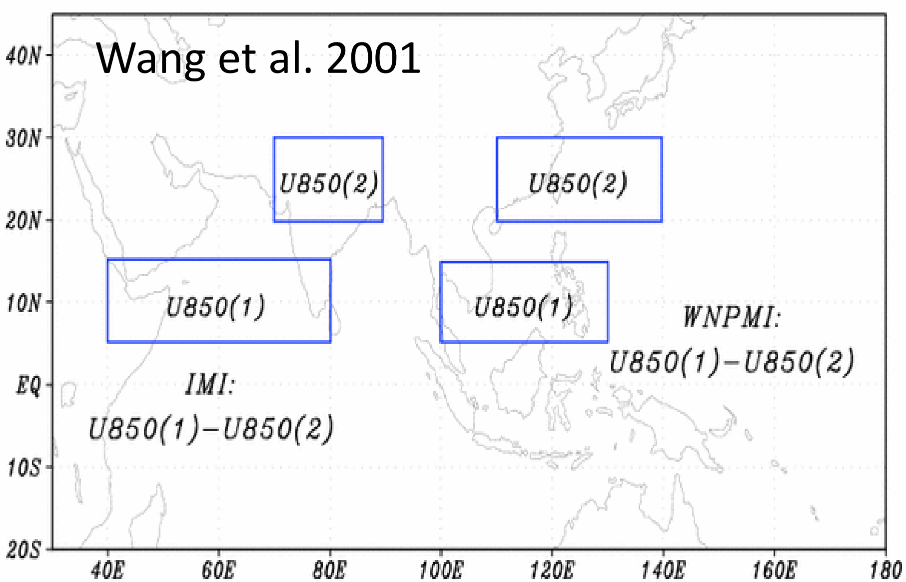


Fig. 17 Climatological mean time series of maximum –∂⟨θe⟩/∂y latitude averaged between 125° and 145° E (stepwise solid line; left axis), ⟨θe⟩ averaged from 125 to 145° E, and 30 to 40° N (smoothed dotted line; right axis), and ⟨θe⟩ averaged from 125 to 145° E, and 20 to 30° N (smoothed dashed line; right axis). JRA-25 results are shown in (a), and NICAM results in (b). Left axis shows maximum –∂⟨θe⟩/∂y latitude in degrees north, and the 30° N and 40° N latitudes are indicated as horizontal solid lines. Right axis shows ⟨θe⟩ in K, and the 335 K ⟨θe⟩ is indicated as horizontal dashed line.

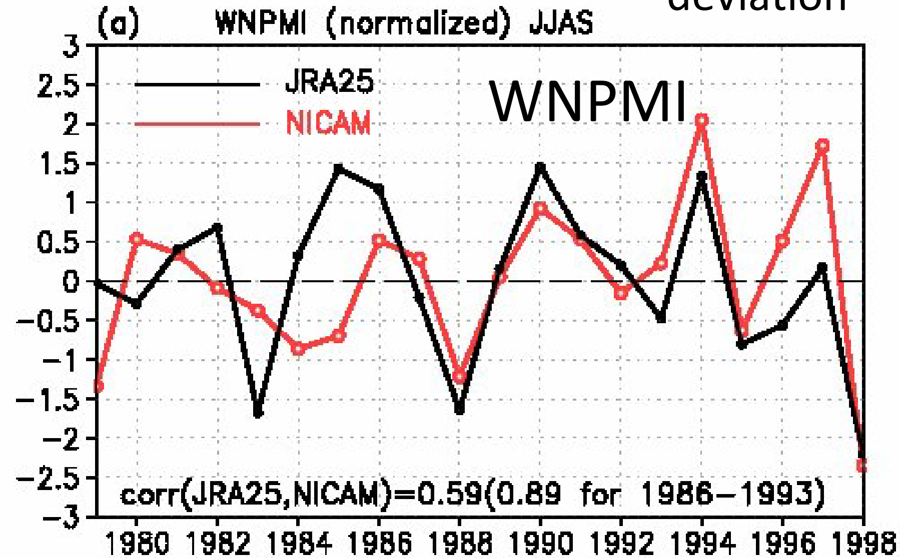
WNPMI JJAS 20-yr Climatology

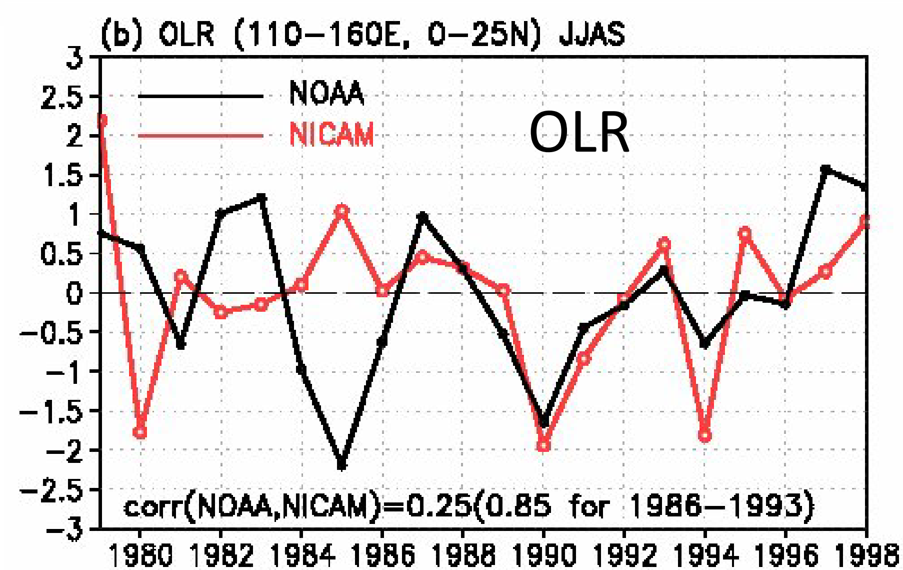




Interannual variation

Normalized by standard deviation





Kodama et al. (2015)

- Summary (AMIP-type simulation; Kodama et al. 2015)
- The 20-yr climatology of the seasonal march of Asian monsoon is reasonably reproduced (much better than the 8-year JJA simulations).
- Biases: northward displacement of westerly axis and subtropical high, which affects monsoon subsystems (e.g., the earlier and shorter Baiu).
- The interannual variability of WNP monsoon circulation (1979-2008) was simulated at correlation coefficient of 0.59 with JRA25). The performance corresponds to that in convection.

3. Challenges ahead

Multi-scale interactions:

- monsoon onset, active/break phase transition
- ISO, Tropical Cyclones

Inter-annual variability:

- ENSO
- Inter-decadal variabilities (PDO, NAO)

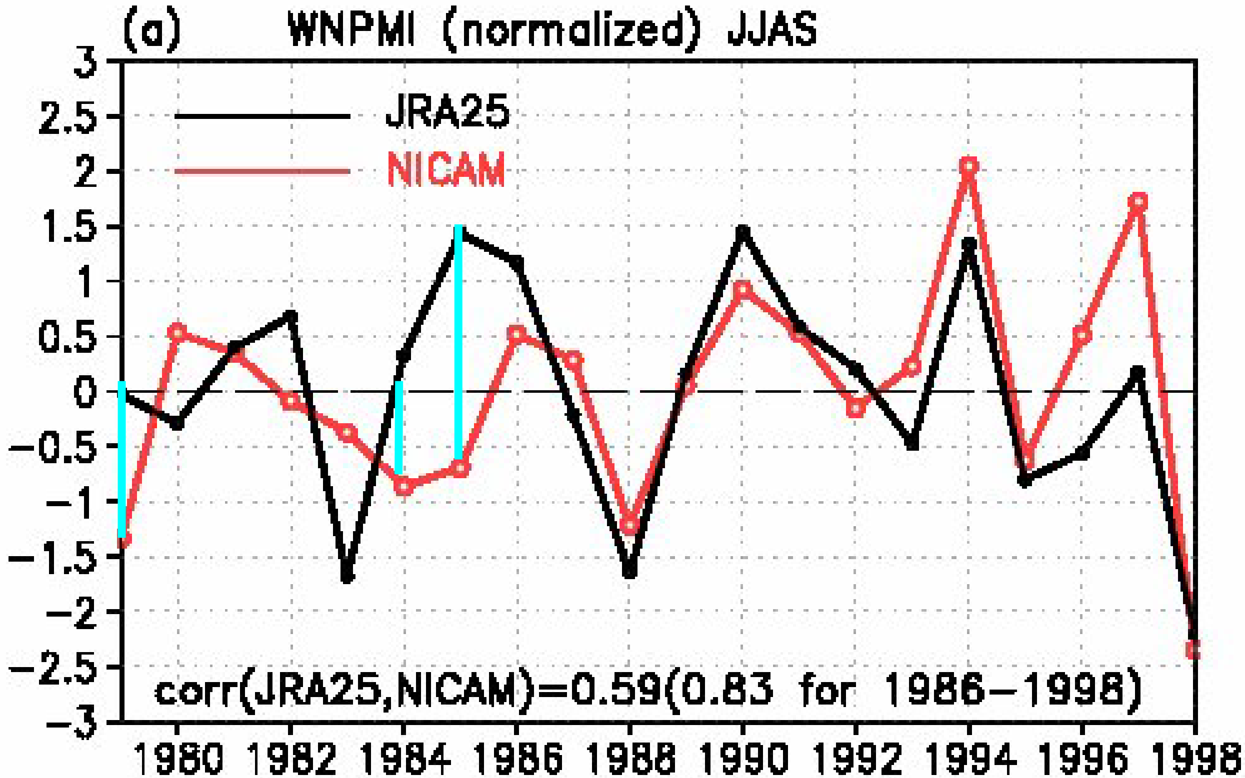
Global monsoons

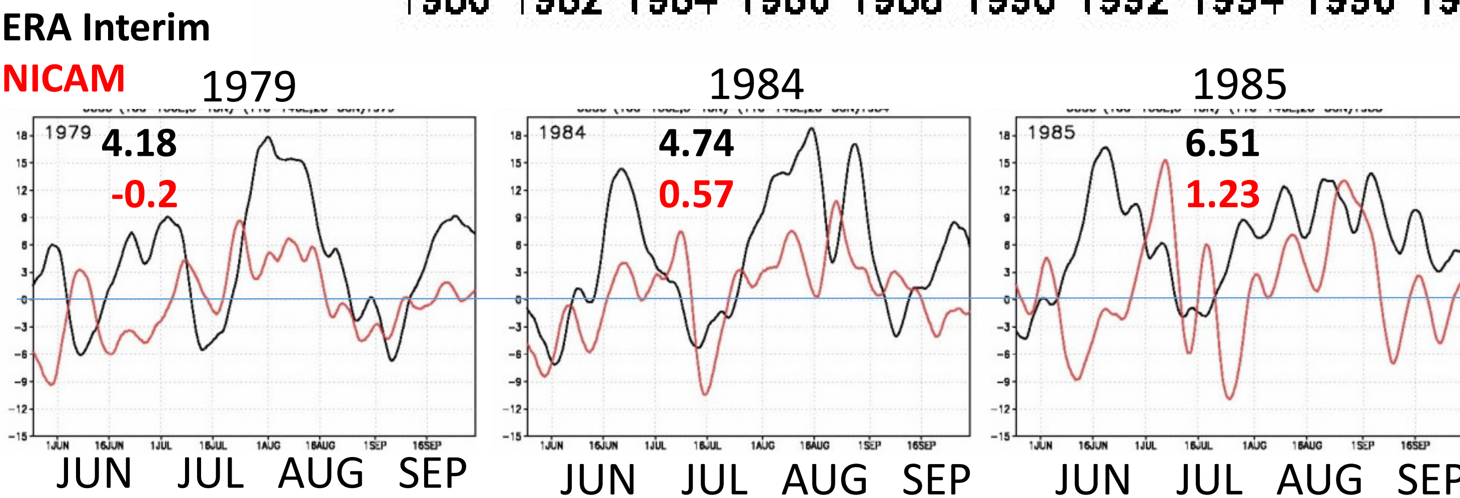
✓Model development (air-sea interactions, land surface processes)

✓Metrics (multi-scale interactions)

✓Model biases (evaluation, understanding)

Inter-annual variability





Wang et al. (2005, GRL)

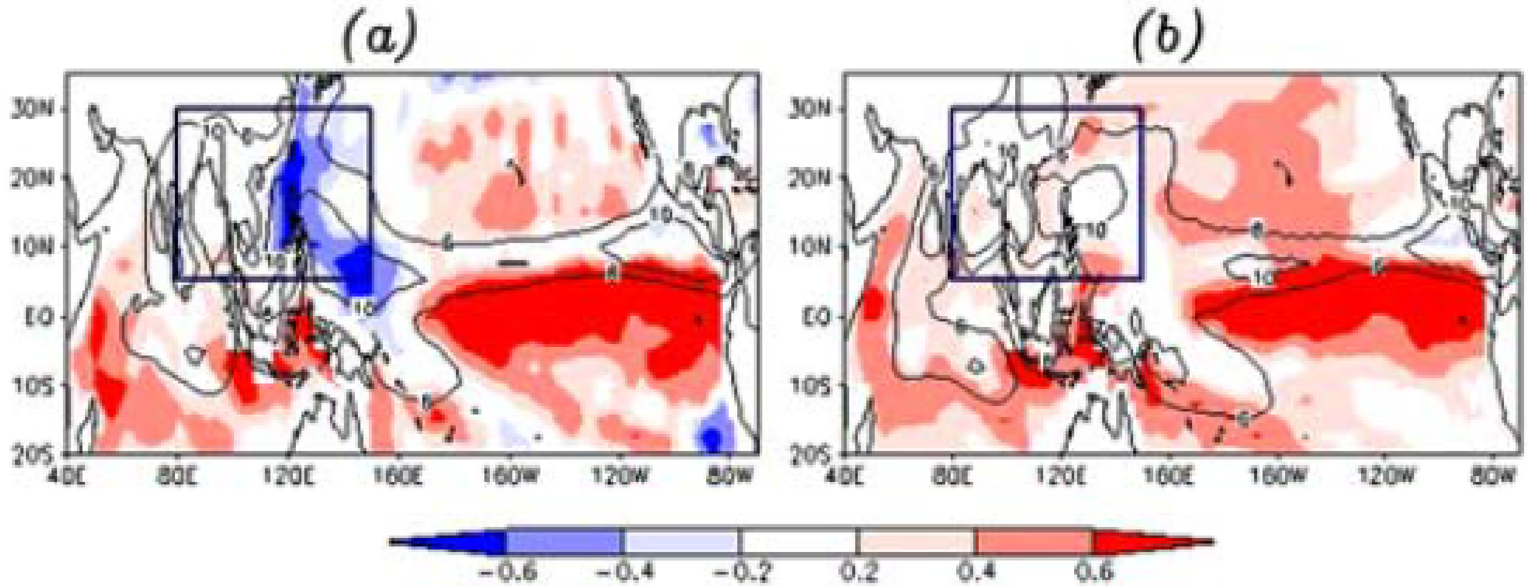
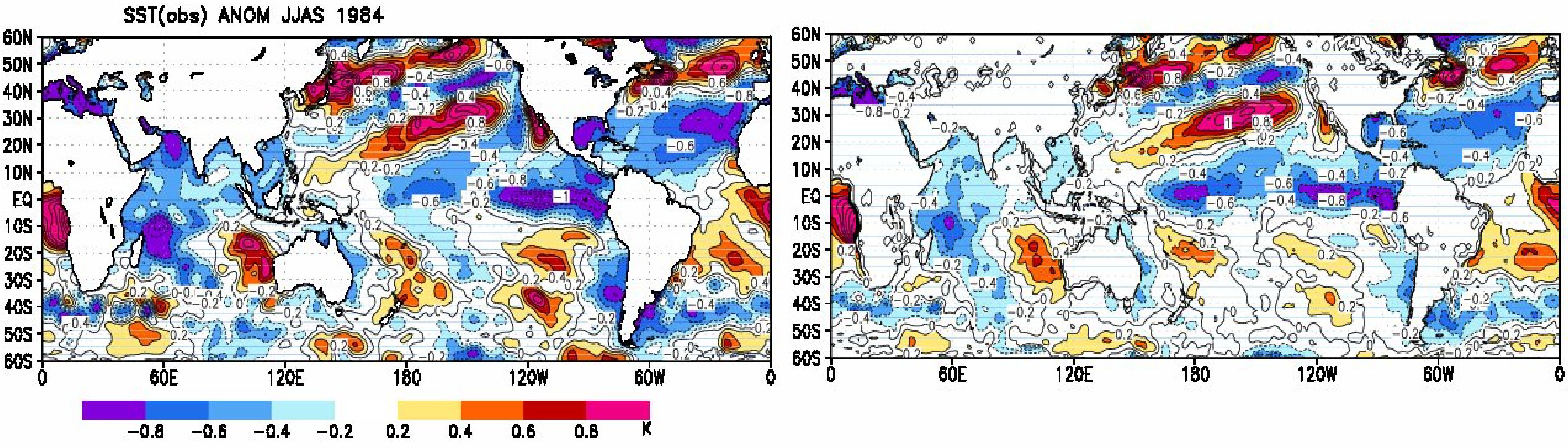
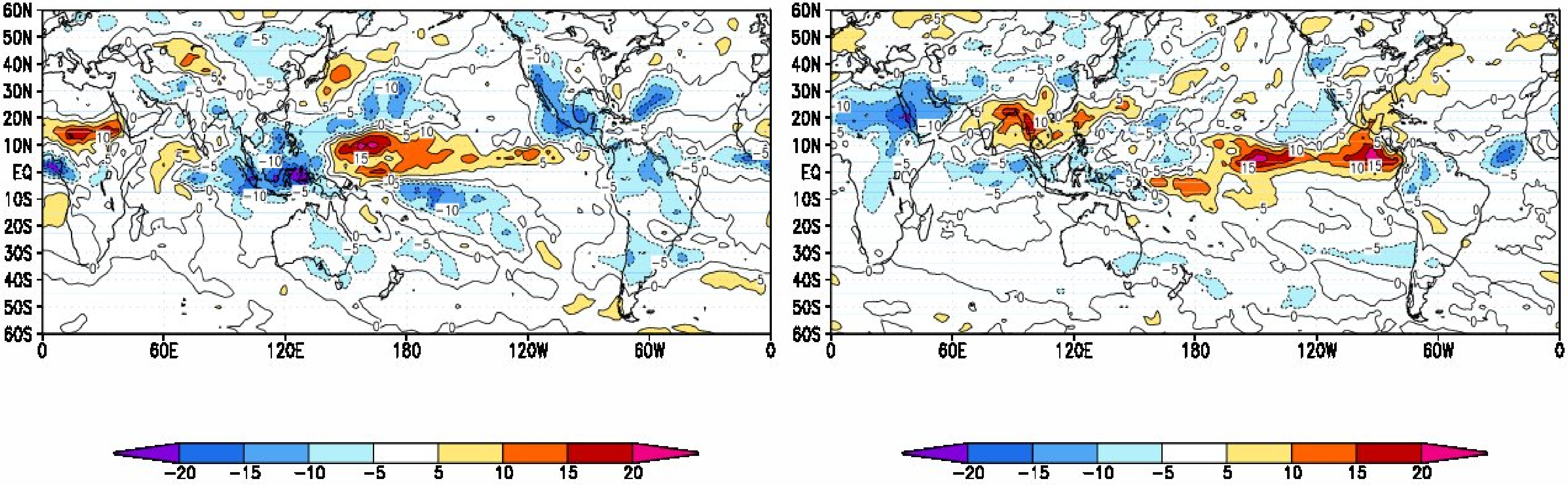


Figure 3. (a) Observed and (b) simulated correlation coefficients between the June–August SST and precipitation anomalies (the color shadings). The contours denote the climatological June–August mean rainfall rate (in units of mm day^{-1}). The observed correlations were computed using 20 years of data (1982–2001) derived from CMAP rainfall and Reynolds SST. The simulated results were made by 5 AGCM's multi-model ensemble simulation.

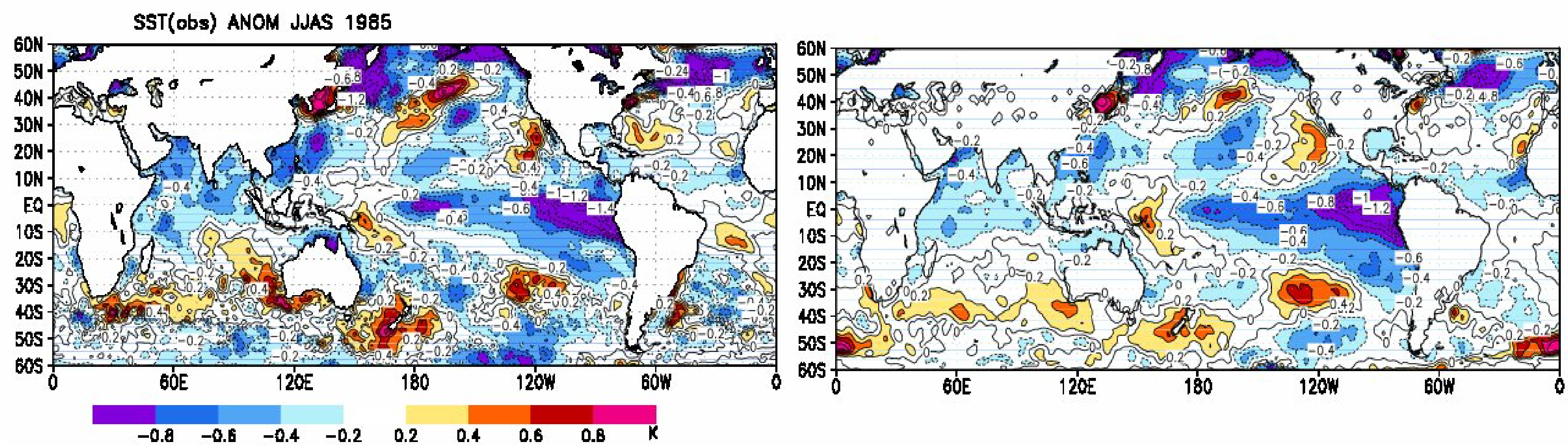
SST anom NOAA 1984 NICAM



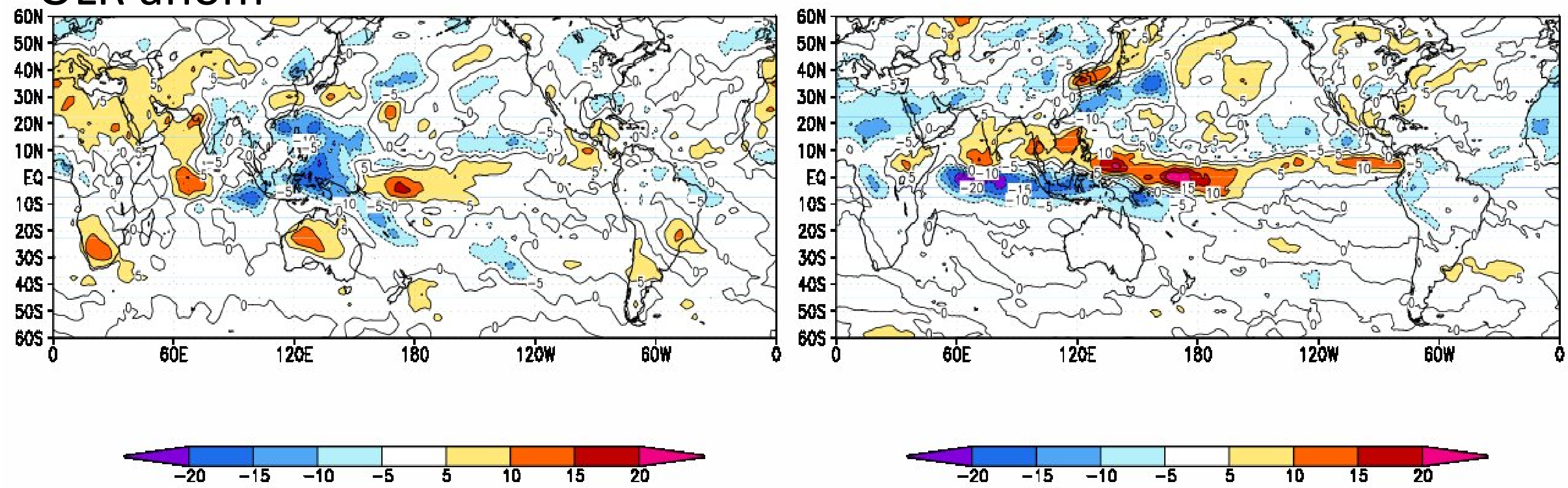
OLR anom



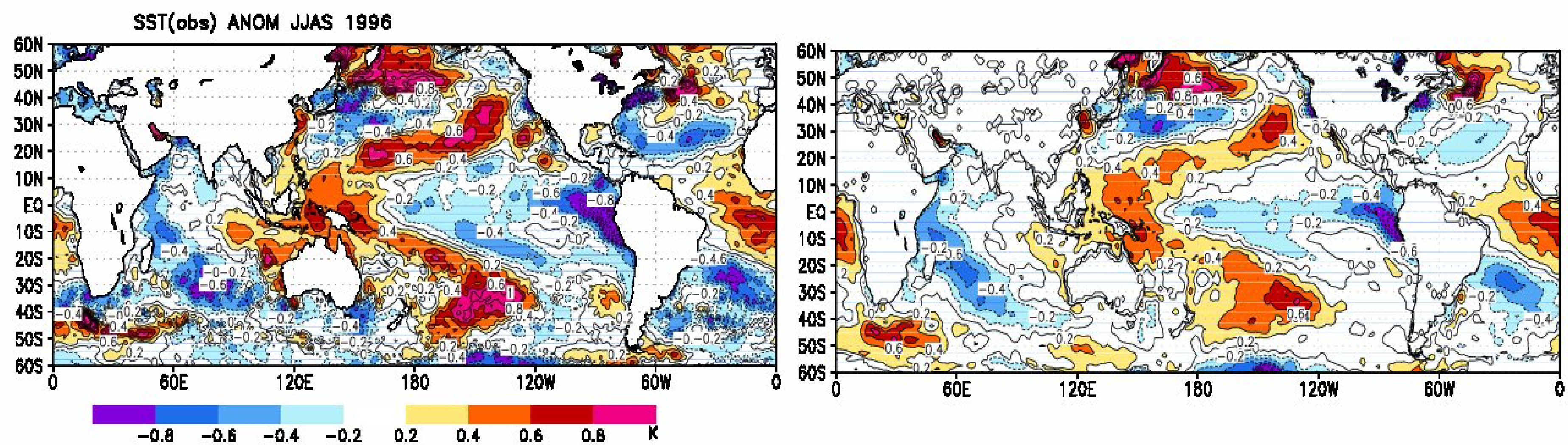
SST anom NOAA 1985 NICAM



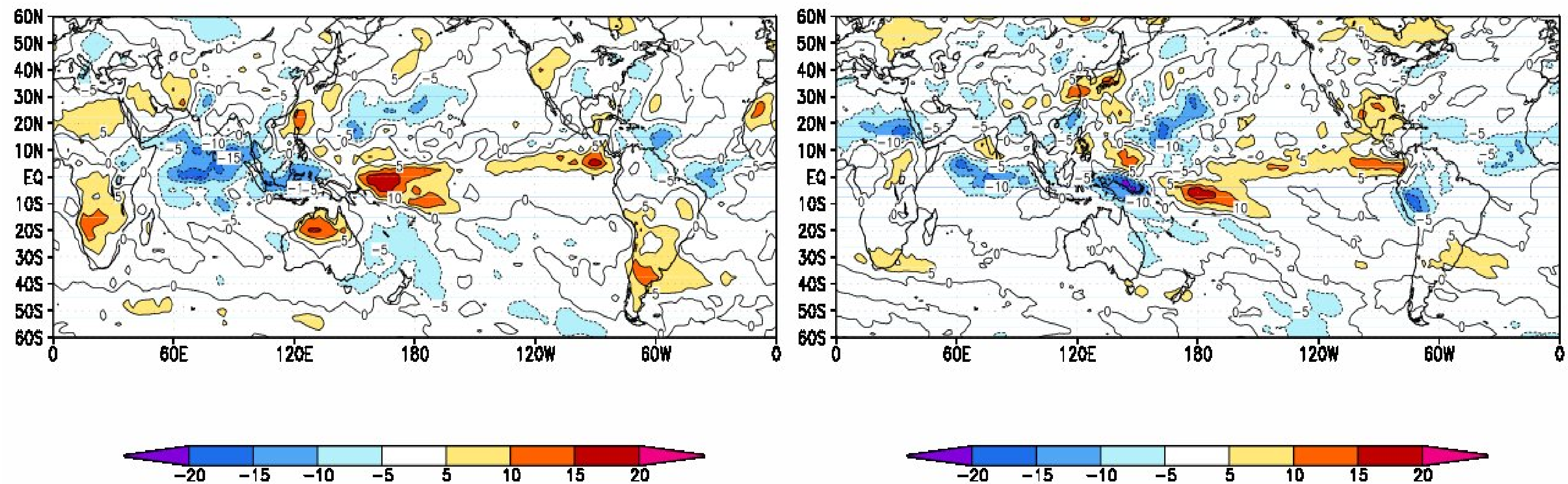
OLR anom



SST anom NOAA 1996 NICAM



OLR anom



SST anom NOAA 1997 NICAM