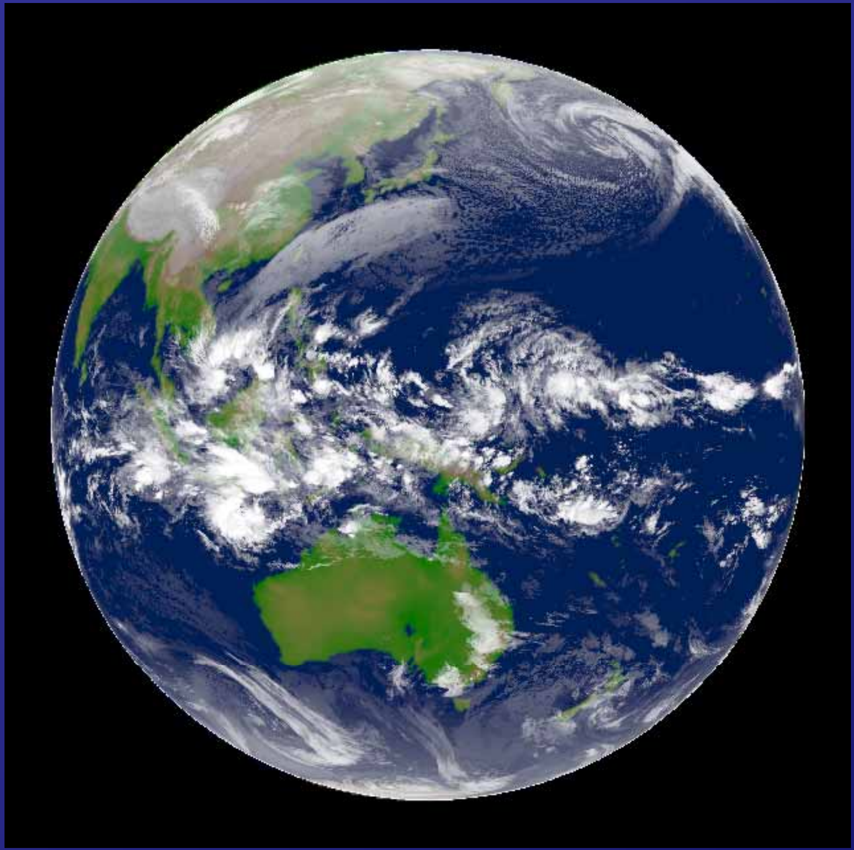
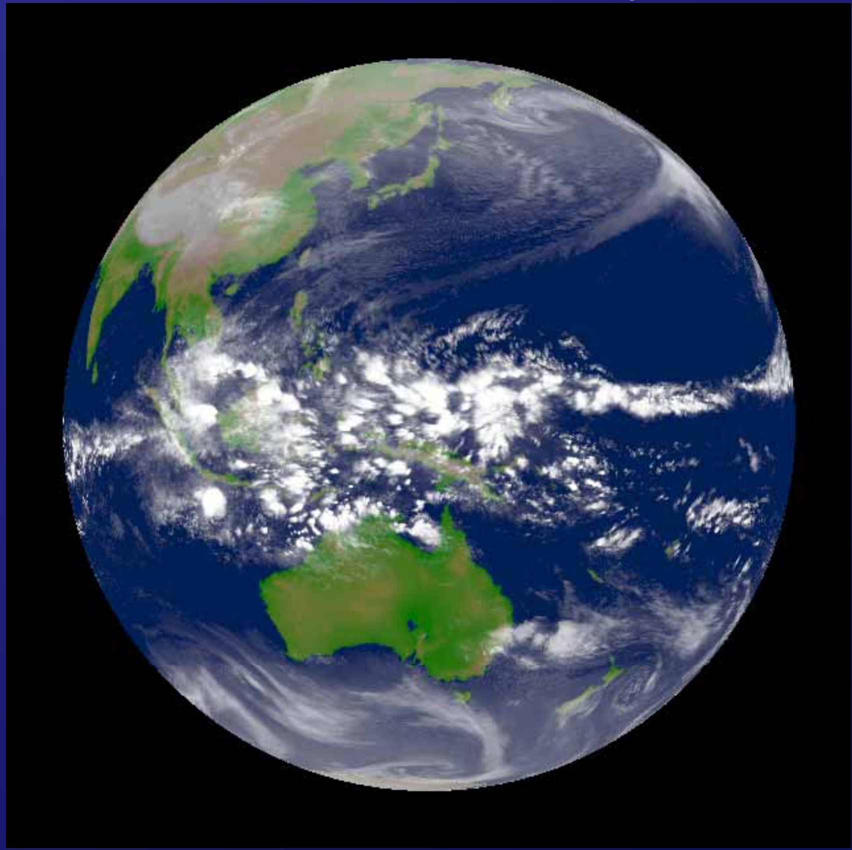
Global cloud-resolving simulations of MJO events in November 2006-January 2007: A brief introduction

Observation: TBB from MTSAT-1R



Simulation: OLR from a 3.5-km grid run



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Contents

- **Why global cloud-resolving models (CRMs)?**
- **A global CRM development activity in Japan**
- **A Madden-Julian Oscillation (MJO) simulation**
  - **December 2006-January 2007**
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- **A simulation of the MISMO case**
  - **November 2006**
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  - **Sensitivity to the zonal SST gradient**

CRMs over the globe

Major issues of current AGCMs are

- ambiguities in cloud parameterizations, and
- the lack of direct interactions between physical processes.

(Randall et al. 2003, BAMS)

CRMs may help studies on intraseasonal variations.

CRMs will reduce uncertainties in climate simulations.

Strategy-A

Multi-scale Modeling Framework (or super-parameterization)

- Statistical forcing from embedded CRMs is used instead of parameterized forcing.

Strategy-B

Global cloud-resolving model

- Clouds are explicitly computed.

Global CRM activities in FRCGC

OCT 1997 start-up of FRSGC directed by T. Matsuno

2000 Development of a high resolution model started.

Main members: Masaki Satoh, Hirofumi Tomita, Koji Goto

2000-2001

- A SWM on the spherical geodesic grid (A-grid): Tomita et al. (2001 JCP)
- A discrete set of the full compressible equations (Lorenz grid): Satoh (2002 MWR, 2003 MWR)

2002

- Development of a 3-D global dynamical core: H. Tomita, K. Goto

MAR 2002 The Earth Simulator started operation.

2003

- Physics parameterizations: H. Tomita, M. Satoh
- The model was named as Nonhydrostatic Icosahedral Atmosphere Model (NICAM).

APR 2004 I took a position in FRSGC.

2004-2005

- Implementation of the topography (terrain following vertical coordinate, z*): H. Tomita
- An upwind-biased advection scheme: Miura et al. (2007, MWR)
- An aqua-planet simulation: Tomita et al. (2005, GRL), Miura et al. (2005, GRL), Nasuno et al. (2007, JAS)

2006

- A typhoon simulation with a land and sea: Miura et al. (2007, GRL)

2007

- One month MJO simulations: Miura et al. (2007, Science)

2007-2008

- 3-5 months simulation (MJO, typhoon): A. Noda, K. Oouchi

Model configuration

Non-hydrostatic ICosahedral Atmosphere Model (NICAM): Satoh et al. (2007, JCP)

• Dynamics (grid-scale)	
Governing equations	**Full compressible non-hydrostatic system**
Spatial discretization	**2^{nd}-order centered scheme (Tomita et al., 2001 JCP)** **2^{nd}-order upwind biased scheme (Miura, 2007 MWR)**
Horizontal grid	**Spherical geodesic grids (Tomita et al., 2001 JCP)**
Vertical grid	**Lorenz grid** **Terrain-following coordinate**
Conservation	**mass, tracers, total energy (Satoh, 2003 MWR)**
Temporal scheme	**Slow mode — explicit scheme (2^{nd}-order Runge-Kutta)** **Fast mode — horizontal explicit-vertical implicit scheme**
• Physics (subgrid-scale)	
Turbulence / surface flux	**Yamada and Mellor (1979) / Louis(1979), Uno et al.(1995)**
Radiation	**Sekiguchi and Nakajima (2008)**
Cloud microphysics	**Grabowsky(1998)**
Cloud parameterization	**no**
Shallow clouds	**no**
Land process	**Mixed layer/bucket**

An MJO simulation

Miura et al. (2007, *Science*).

Initial conditions:

Interpolated from NCEP tropospheric analyses (6 hourly, 1.0x1.0 degree grids)

Initial time:

14-km run and 7-km run: 2006-12-15 00:00:00

3.5-km run: 2006-12-25 00:00:00

Boundary conditions:

Reynolds SST, Sea ICE (weekly data)

ETOPO-5 topography, Matthews vegetation

UGAMP ozone climatology (for AMPI2)

Horizontal grid intervals:

14 km, 7 km, 3.5 km

Vertical domain:

0 m ~ 38,000 m

40-levels (stretching grid)

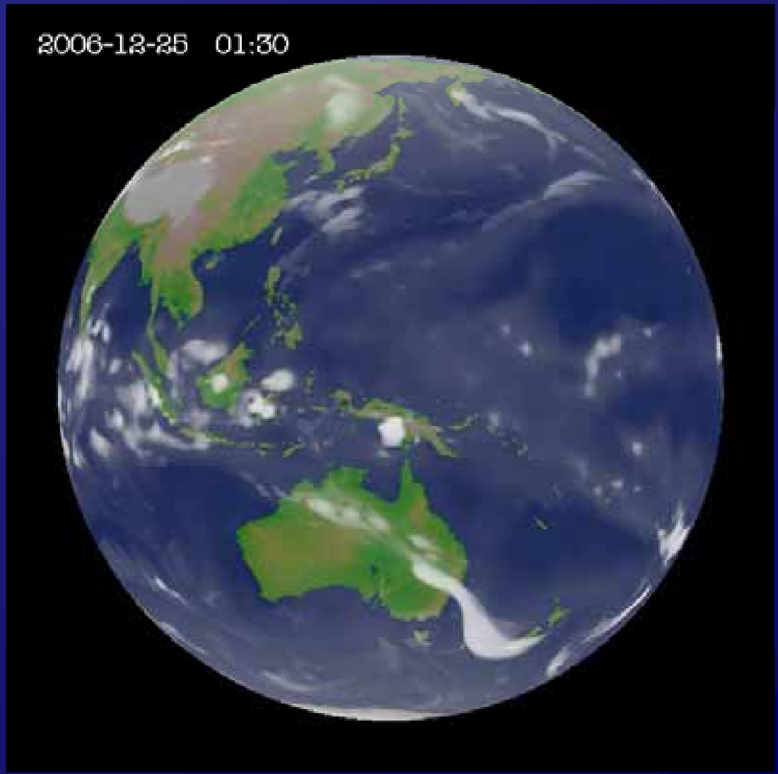
Duration:

14-km run: 30 days (dt = 30s)

7-km run: 30 days (dt = 30s)

3.5-km run: 7 days (dt = 15s)

OLR from 3.5-km grid run

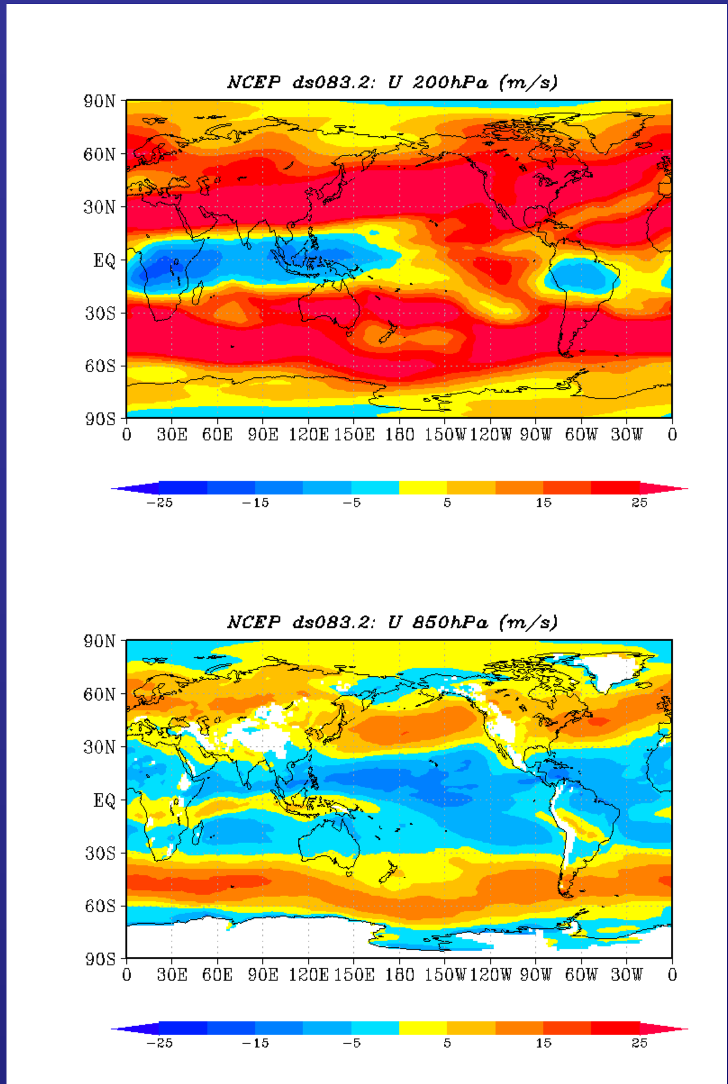


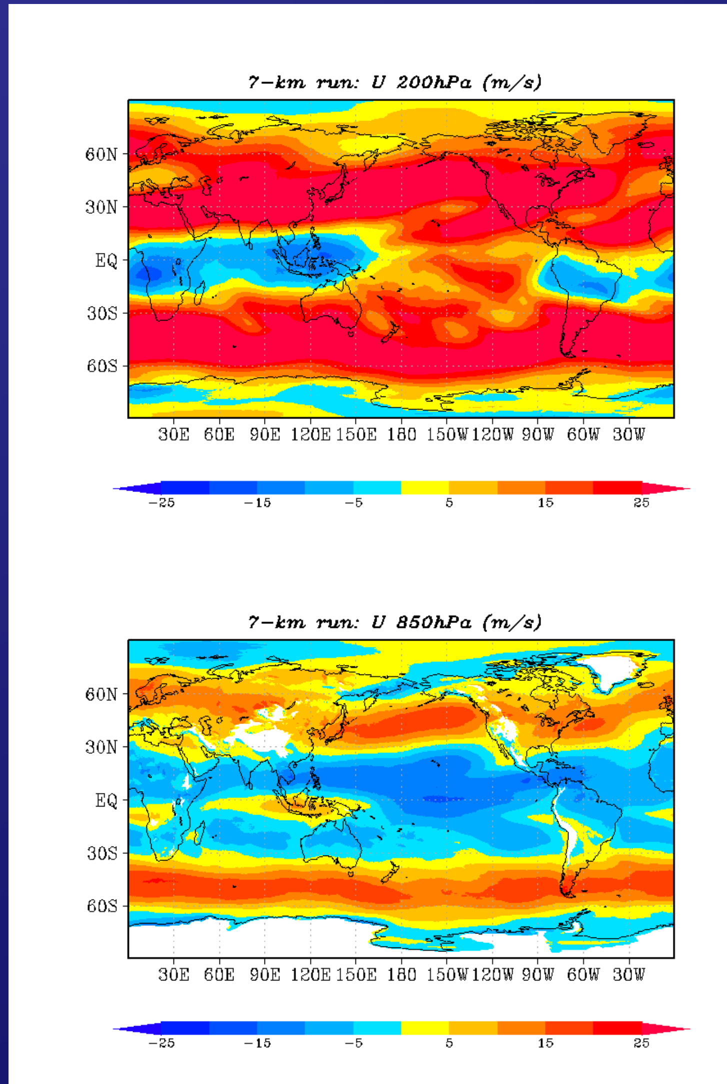
30-day mean: zonal wind

NCEP | 7-km grid run

200 hPa

850 hPa

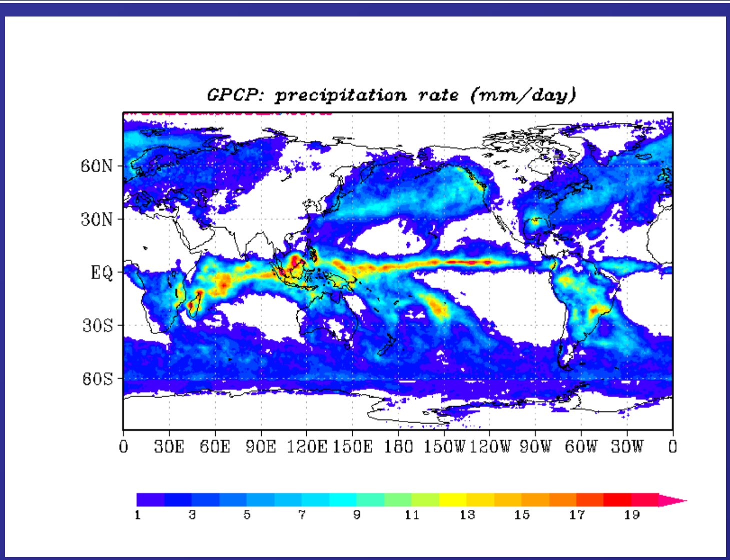




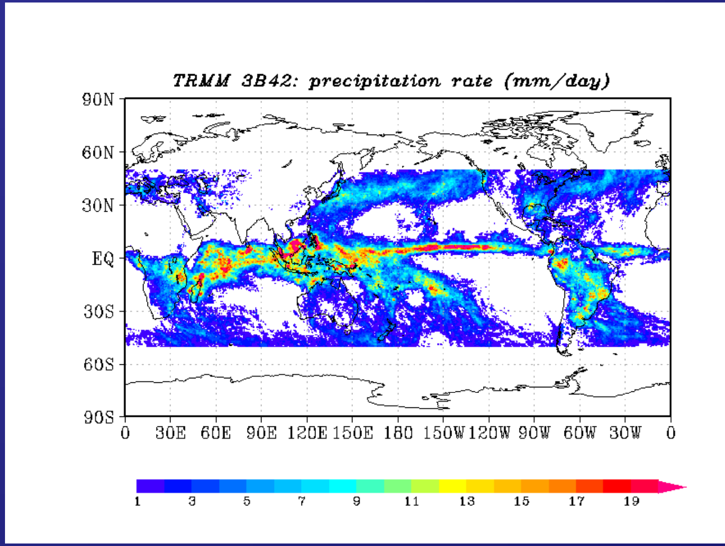
- The spatial structure was simulated well.
- The wind velocity was overestimated.

30-day mean: precipitation

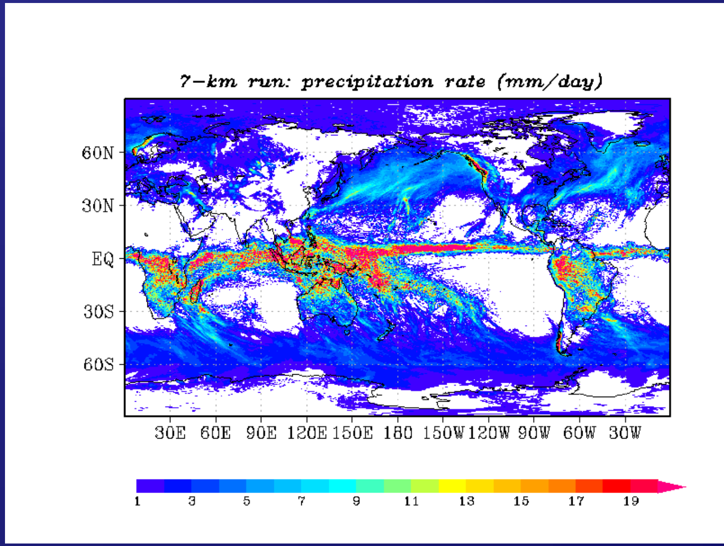
GPCP



TRMM 3B42



7-km grid run

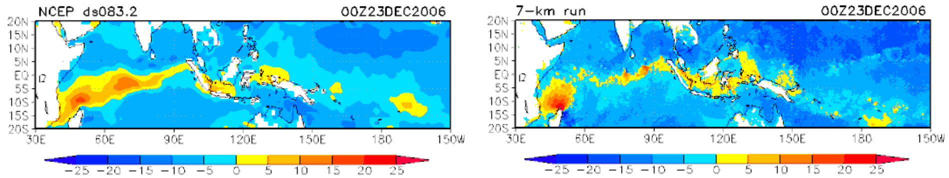


- The spatial structure was reproduced well.
- The precipitation rate was overestimated in the tropics.

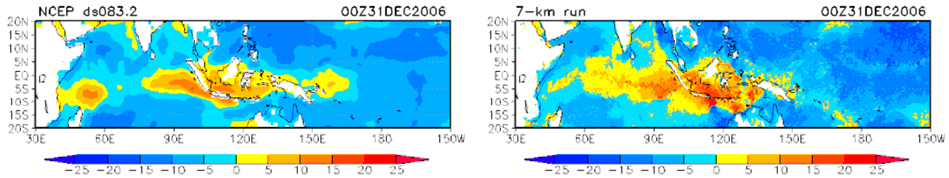
Time change in zonal wind

NCEP: p=975 hPa | 7-km run: z=249 m | NCEP: lat=0 | 7-km run: lat=0

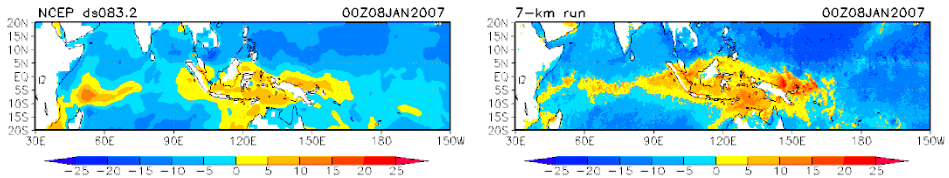
2006-12-23

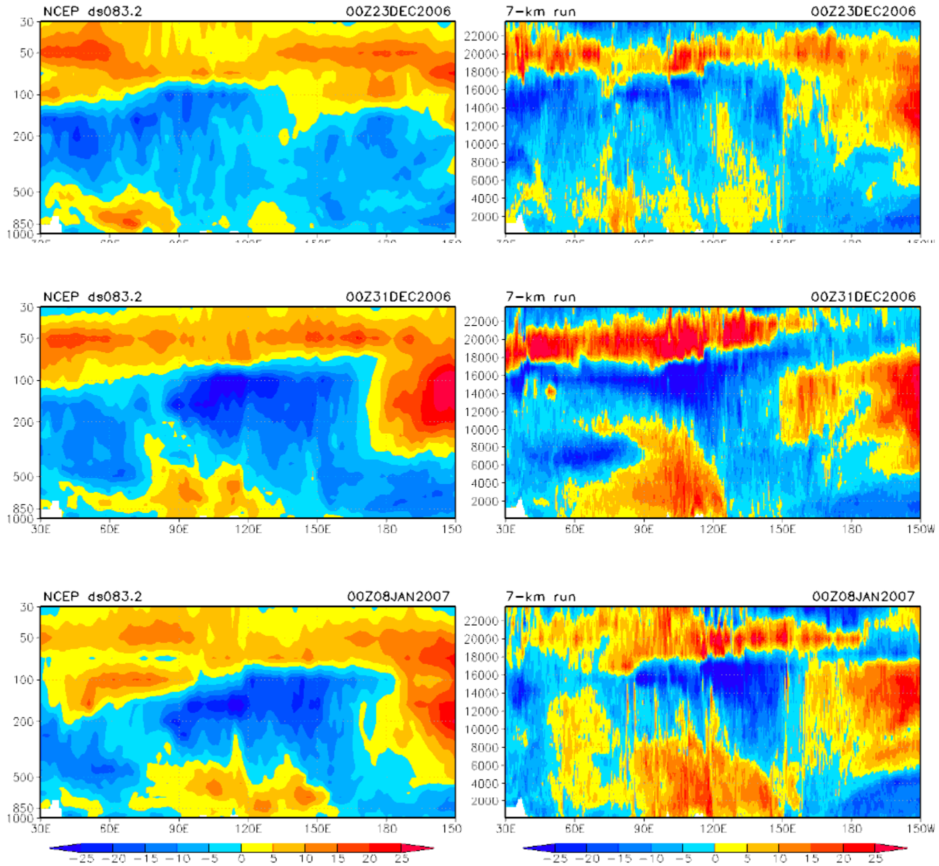


2006-12-31



2007-01-08



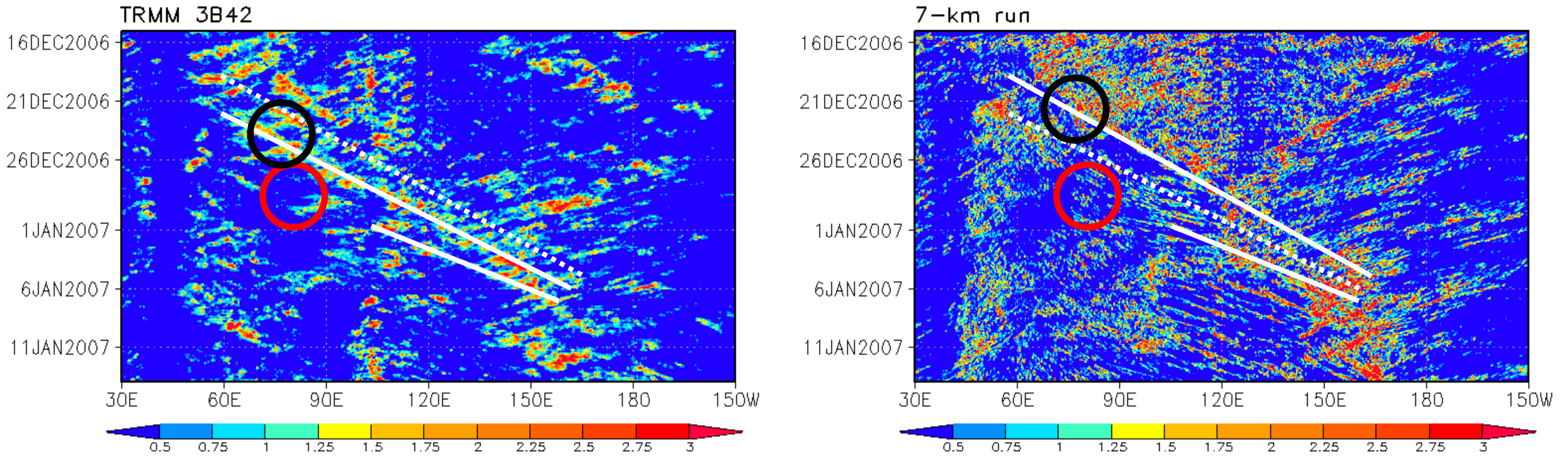


- The westerly region prevailed eastward slowly.
- Both the strength and the depth of the westerly winds were overestimated.

Hovmöller diagrams: precipitation

TRMM 3B42: average from 5S to 5N

7-km run: average from 5S to 5N



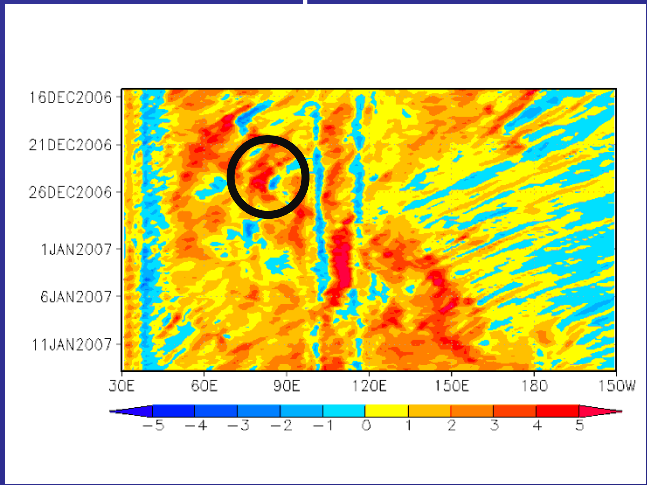
- Convective activity was enhanced over the maritime continents when a strong eastward propagating signal arrived.
- The generation of the strong eastward propagating signal was about 2 days earlier in the 7-km grid run than in the observation.
- The convective center shifted to the SPCZ after 6 January 2007.

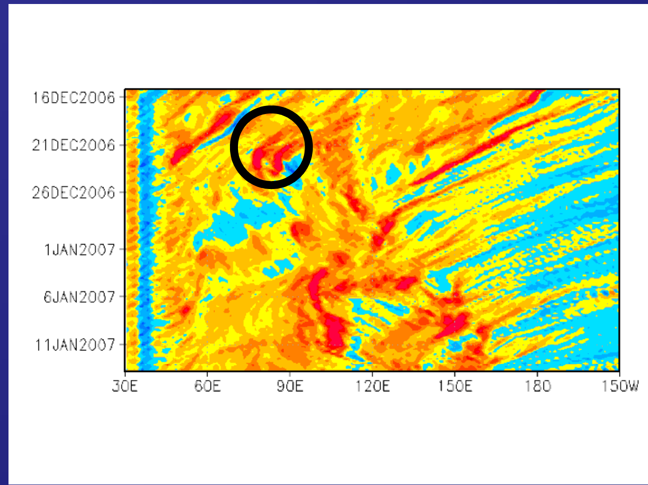
Hovmöller diagrams: vorticity

NCEP: p=850 hPa

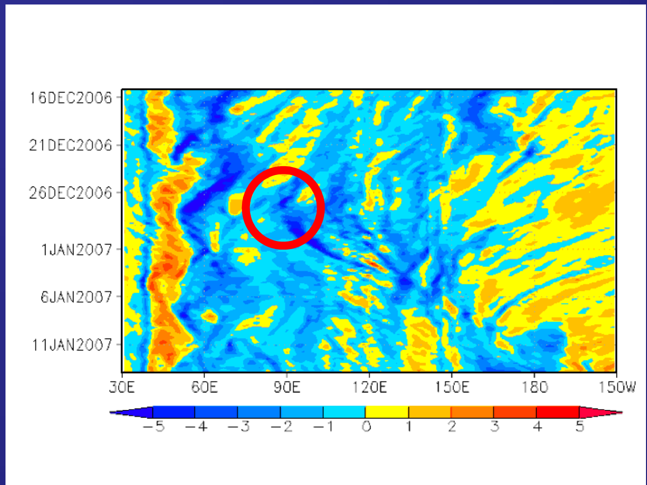
7-km run: p=850 hPa

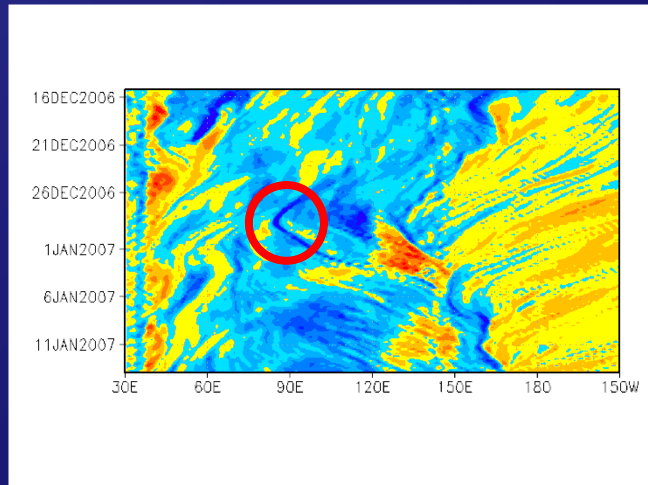
0-5N





10S-5S



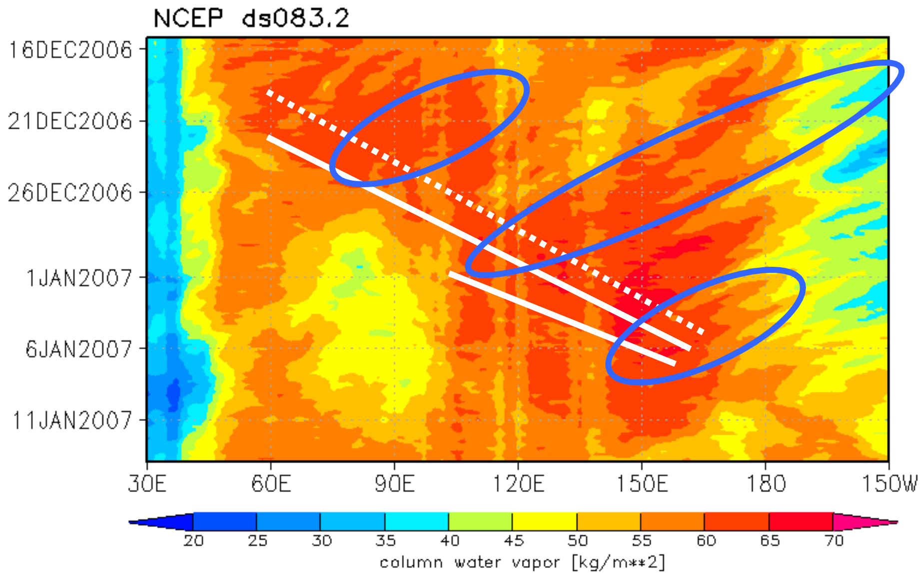


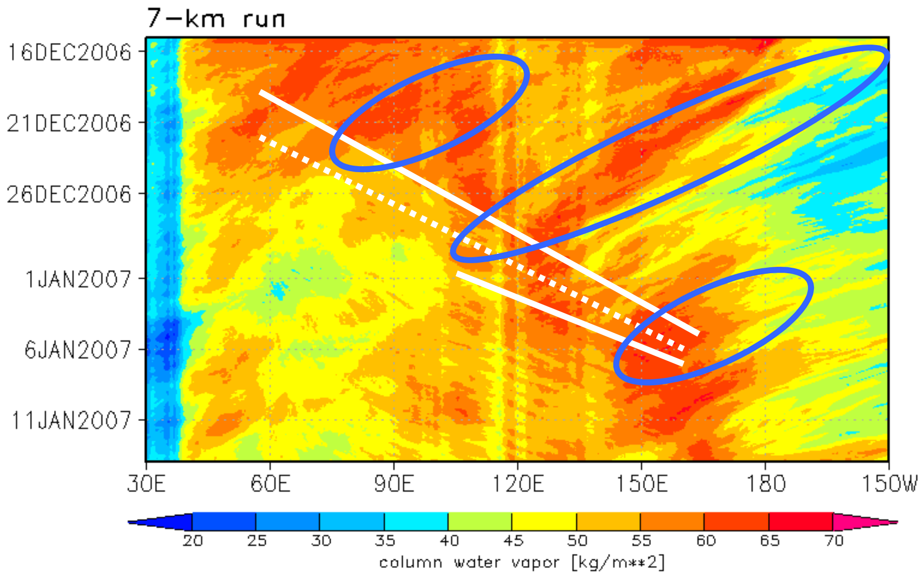
- The positive (0-5N) and negative (10S-5N) vorticites changed their direction from westward to eastward.

Hovmöller diagrams: precipitable water

NCEP ds083.2: average from 5S to 5N

7-km run: average from 5S to 5N



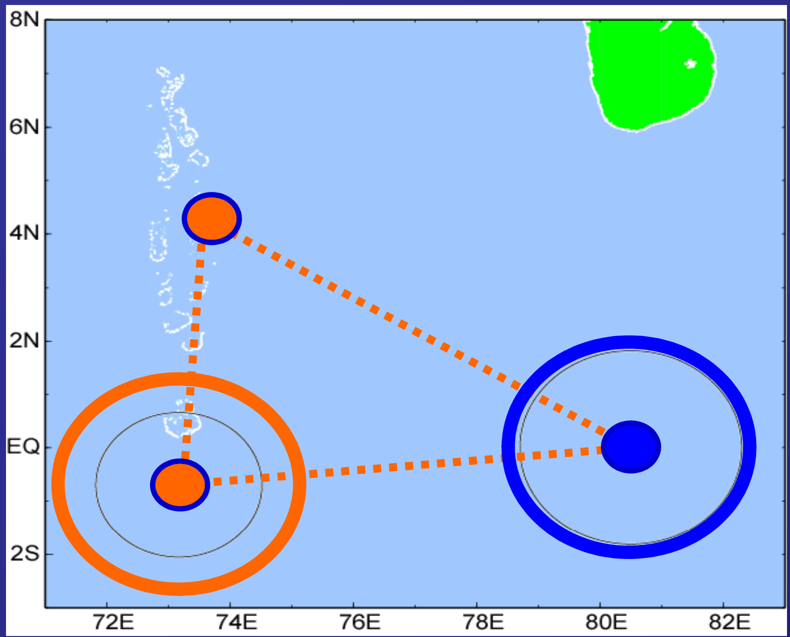


- Eastward propagating signals moved low-level convergence zone to the east.
- Moisture was transported from the east of the convective center.
- Moist phases seemed to relate to the eastward shift of the convective center.
- Moistening might not be the sufficient condition for the eastward shift. (e.g. 1/1~1/5 in NCEP)

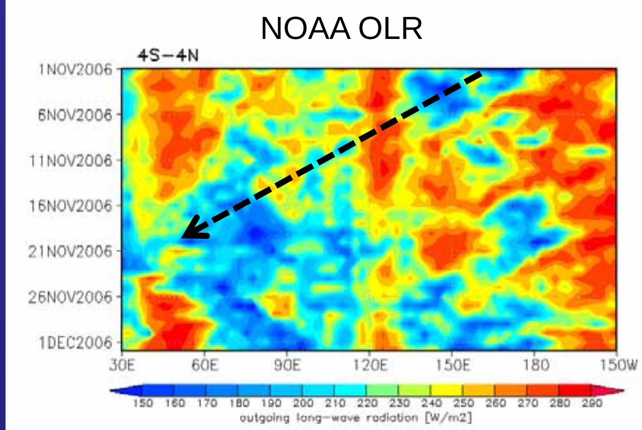
Simulation of the MISMO case

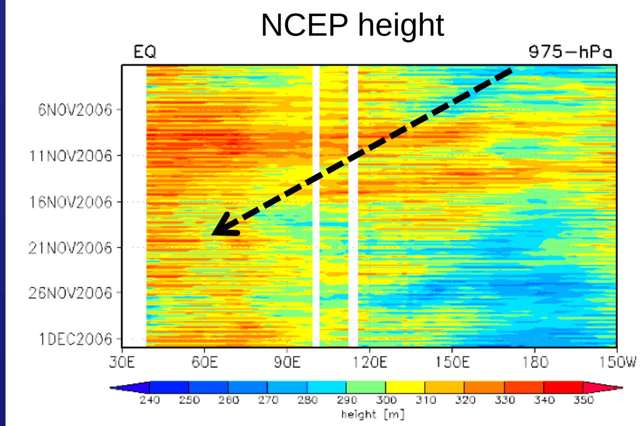
MISMO

October 31 to November 26



(figure rom Dr. Katsumata)





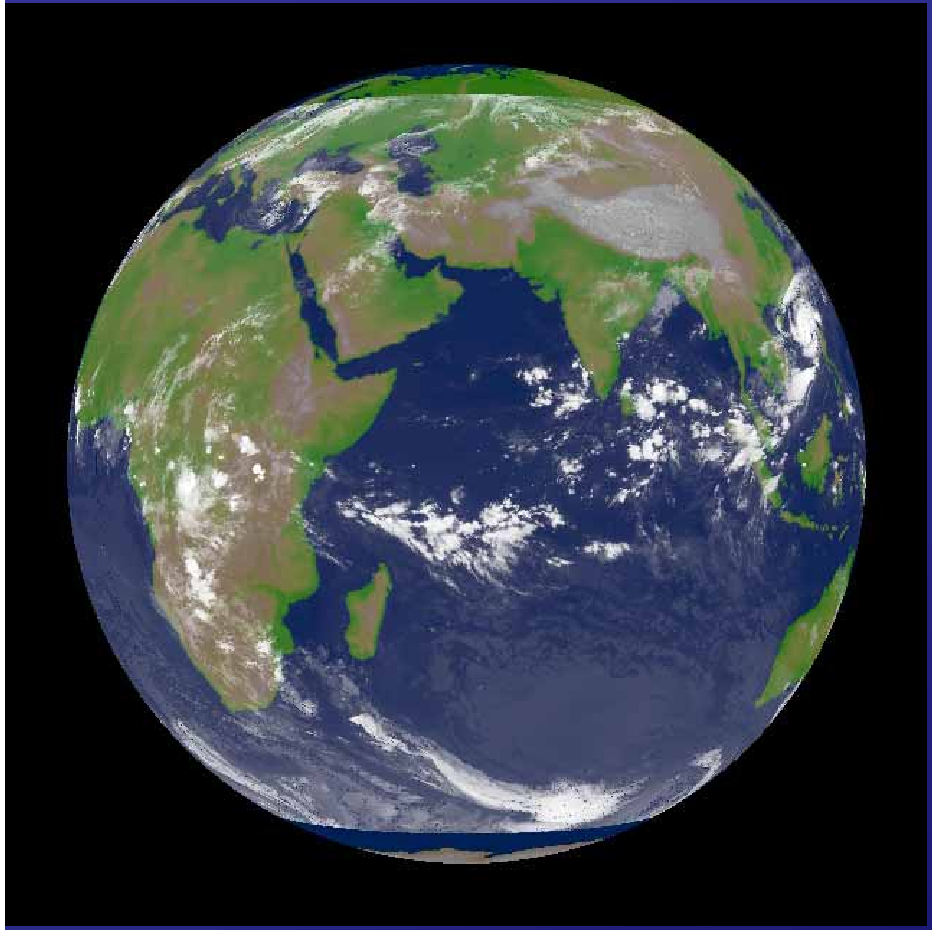
A claim from Sperber et al. (Science, 2 May 2008)

"Spontaneous generation of MJOs was not demonstrated."

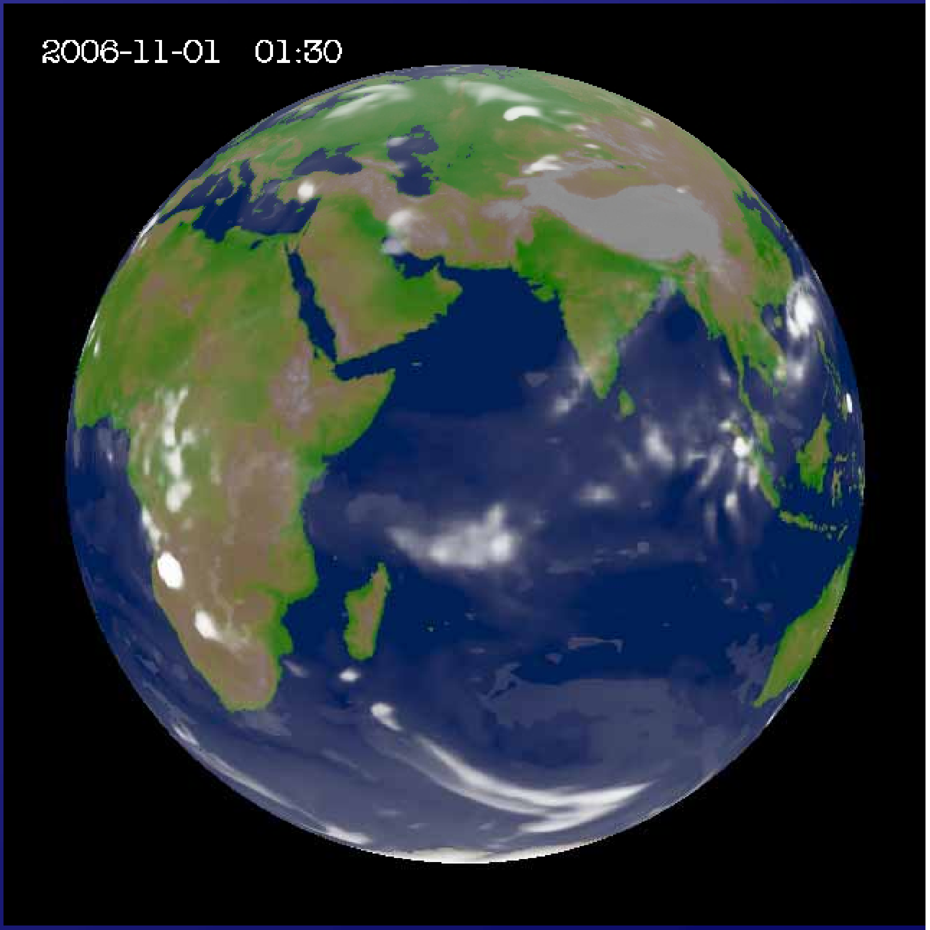
- Initial date: November 1, 2006
- 7-km grid (32 days)

Cloud images: 2006-11-01

NCEP full resolution IR data

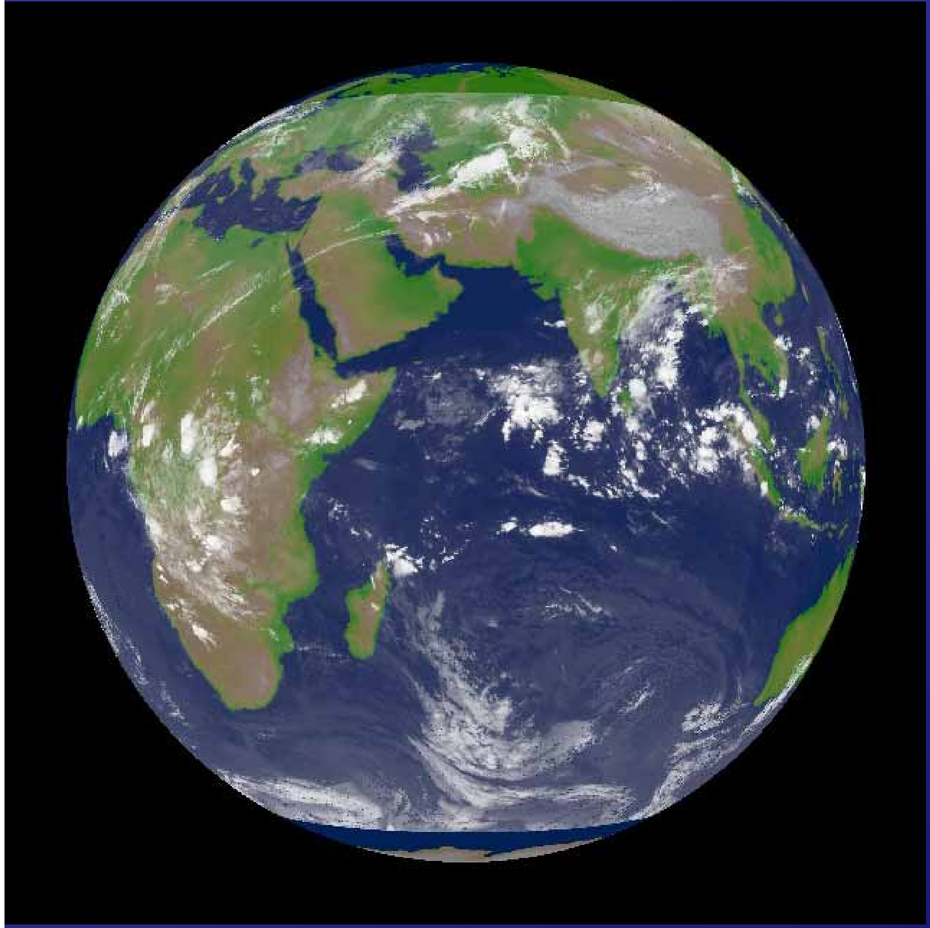


OLR: 7-km grid run

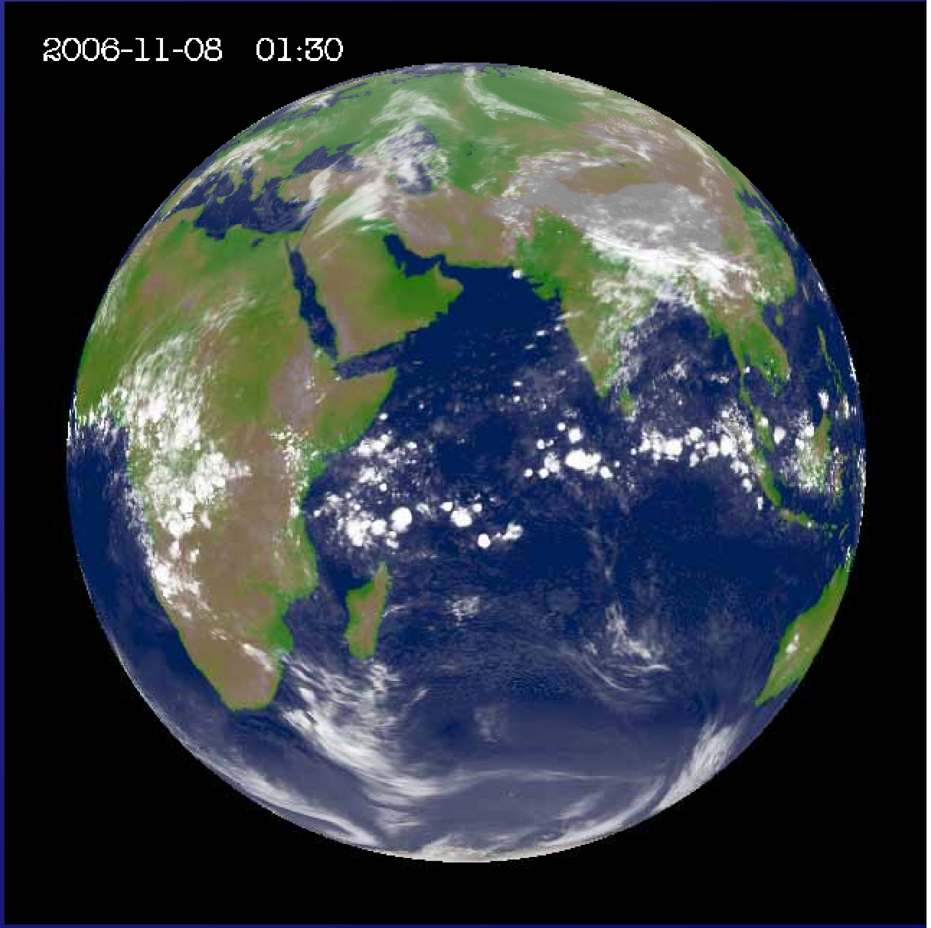


Cloud images: 2006-11-08

NCEP full resolution IR data

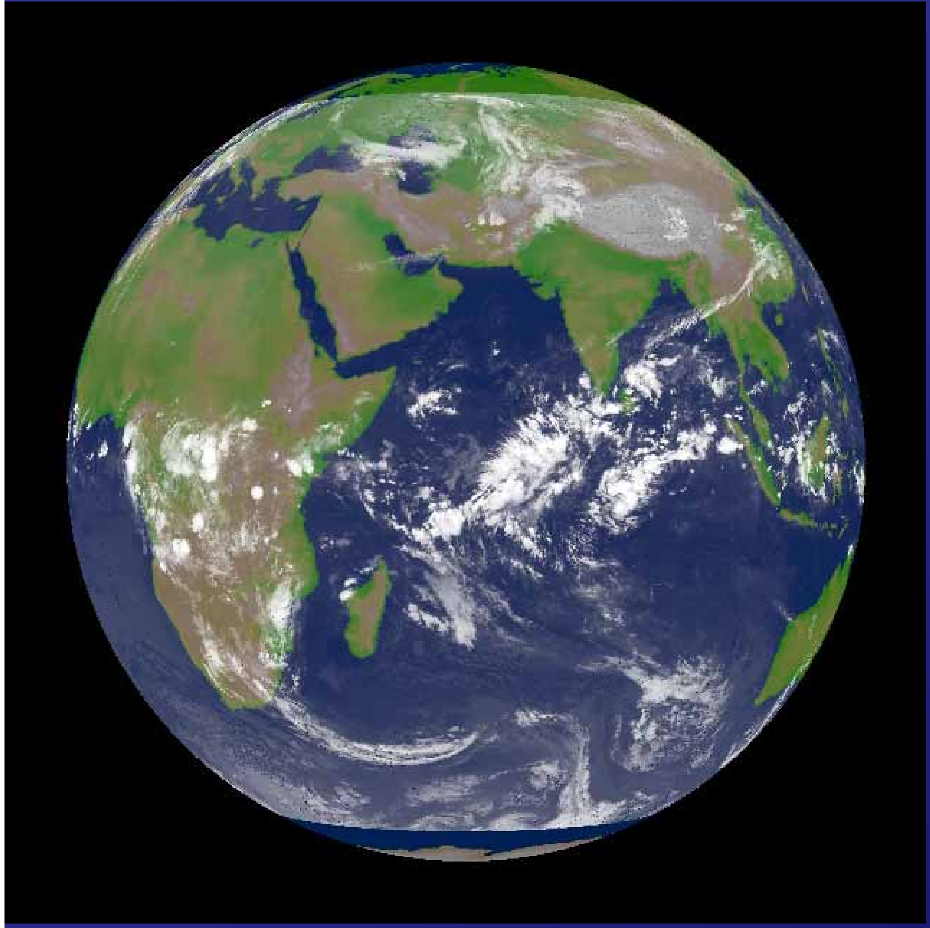


OLR: 7-km grid run

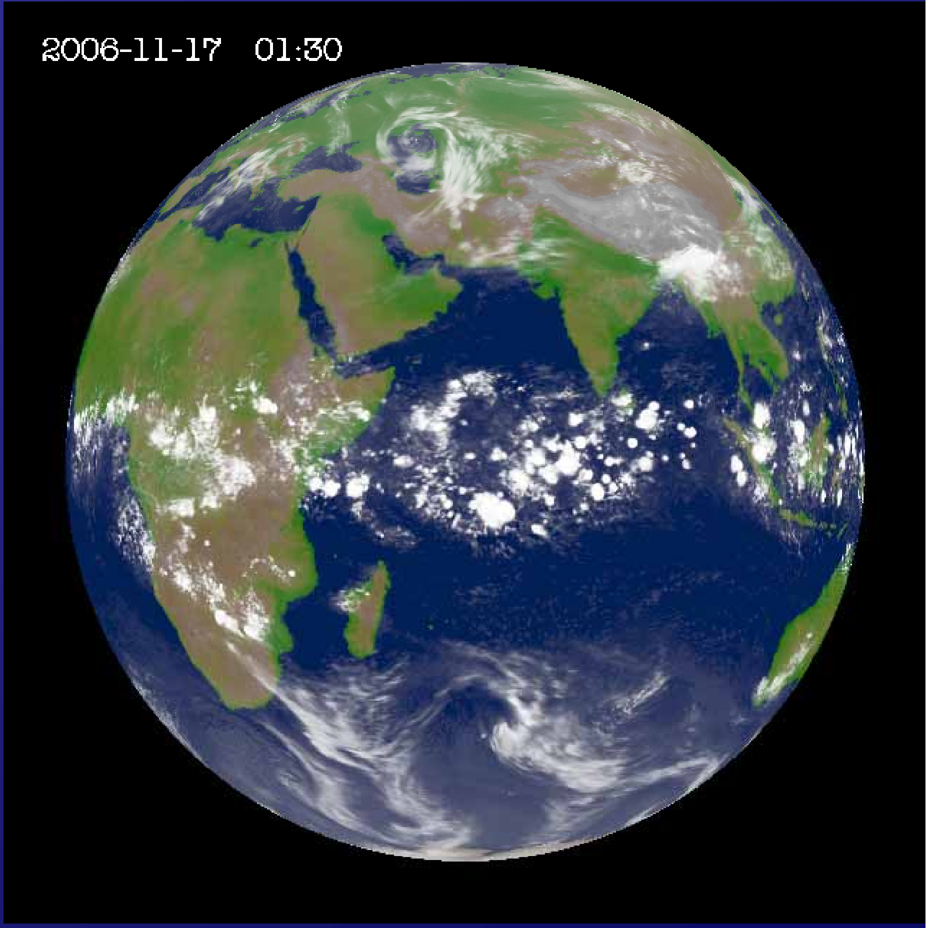


Cloud images: 2006-11-17

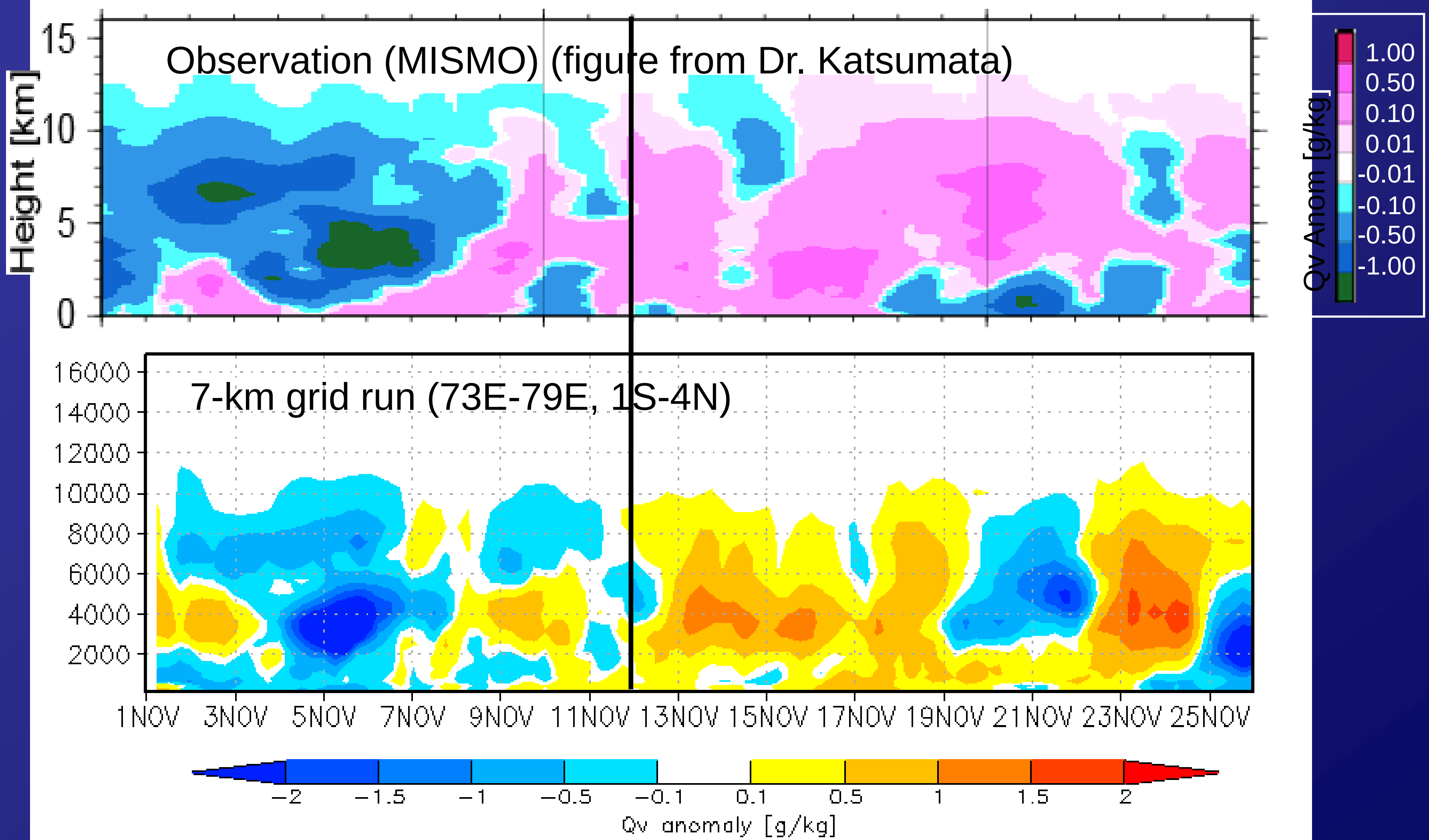
NCEP full resolution IR data



OLR: 7-km grid run



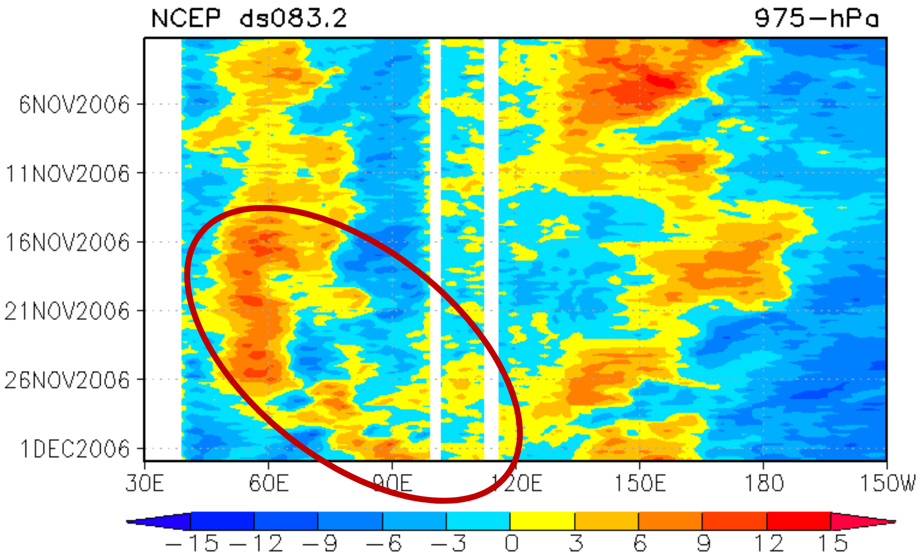
Vapor mixing ratio anomaly from 26 or 27 day mean

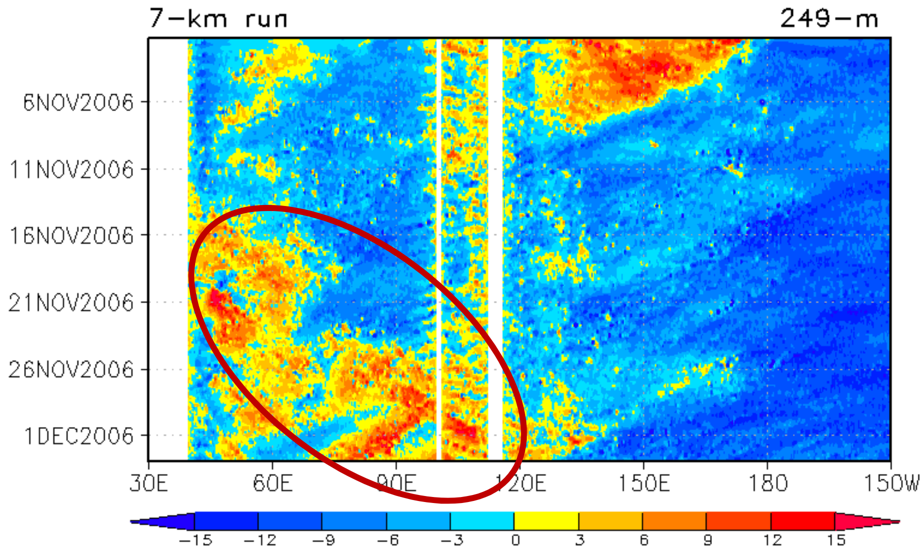


Hovmöller diagrams: zonal wind

NCEP: p=975 hPa, lat=0

7-km run: z=249 m, lat=0

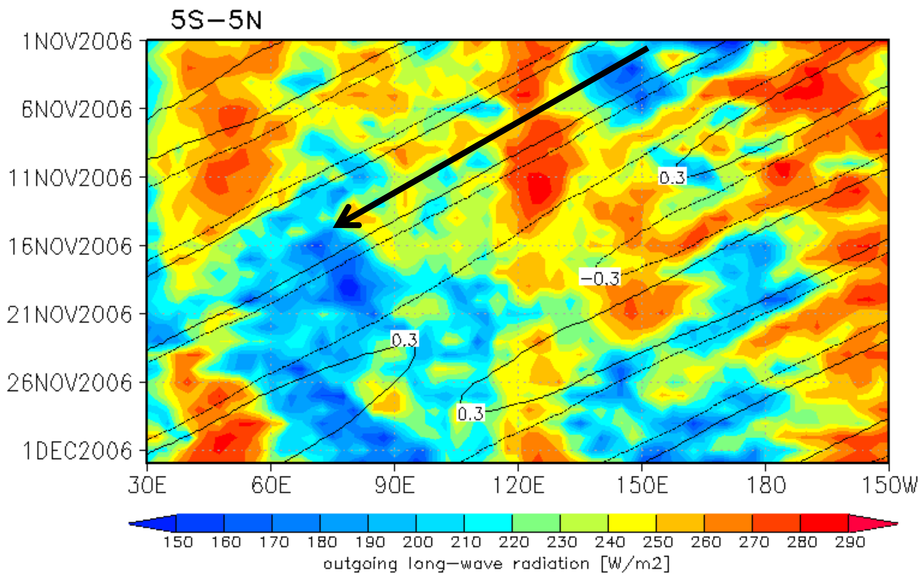


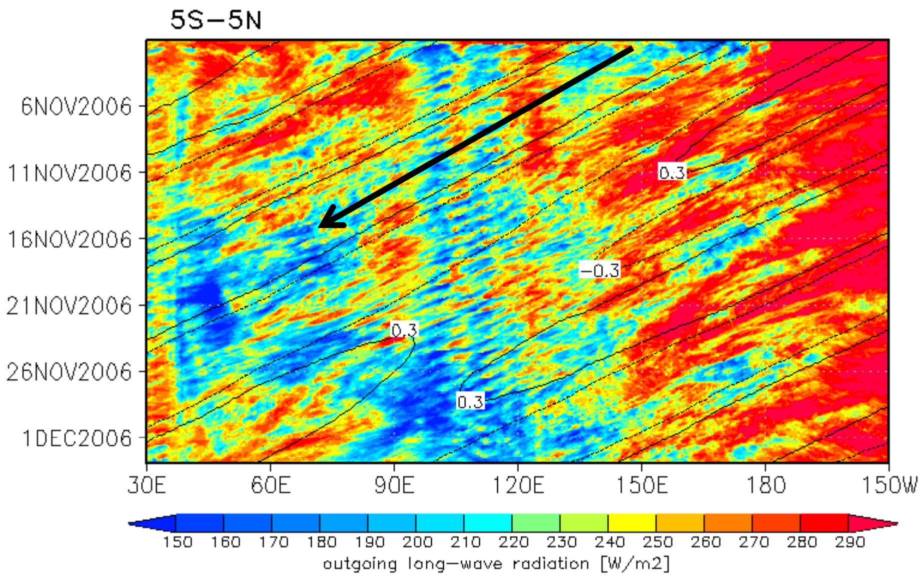


- Easterly winds were stronger in the 7-km grid run than in the NCEP data.
- Westerly winds were intensified after about November 16.
- The westerly region moved eastward slowly.
- Eastward-propagating smaller-scale signals were not clear when the background wind was easterly.

Hovmöller diagrams: OLR

NOAA	7-km grid run





The black lines are the zonal wind anomaly obtained by applying a Rossby wave filter (Wheeler and Kiladis 1999, JAS) to the zonal wind of NCEP ds083.2 data on the equator. The zonal wave numbers from 3 to 6 and the equivalent depth between 80 m and 160 m (c~30-40 m/s) were assumed to include an estimate of 160 m (Numaguti 1995, JMSJ) .

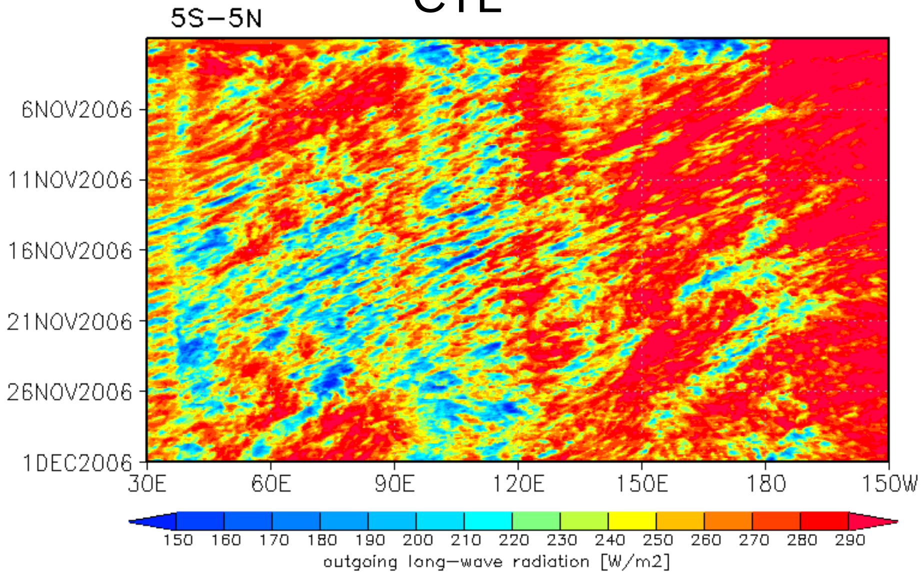
- Convective activities were enhanced along the boundaries between the westerly and the easterly anomalies of the equatorial Rossby wave, suggesting an importance of zonal or meridional mixing of air masses.
- The MJO event appeared to start when a westerly anomaly reached over the Indian Ocean, where the zonal SST gradient existed.

Sensitivity to the zonal SST gradient

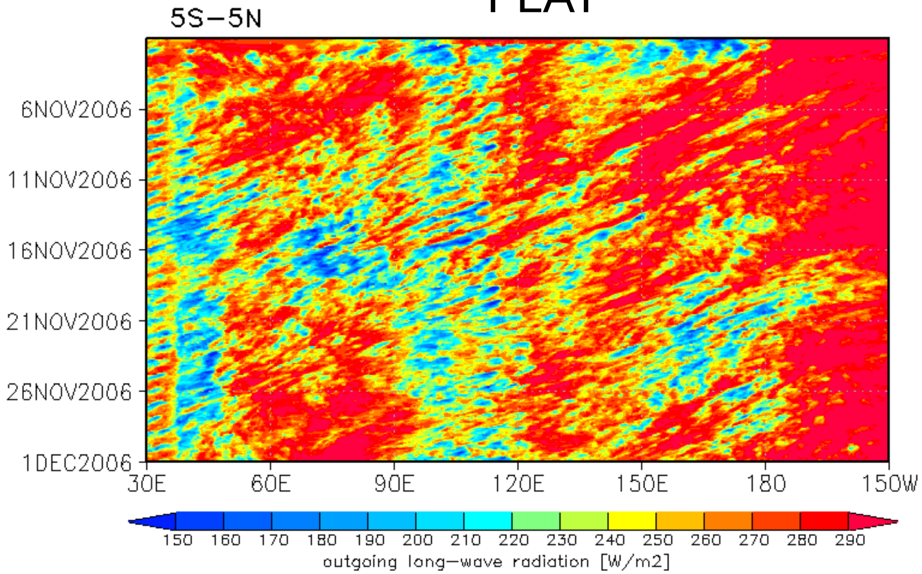
CTL: 14-km grid, the same settings as the 7-km grid run

FLAT: SST of 70.5E was used in the western Indian Ocean

CTL



FLAT

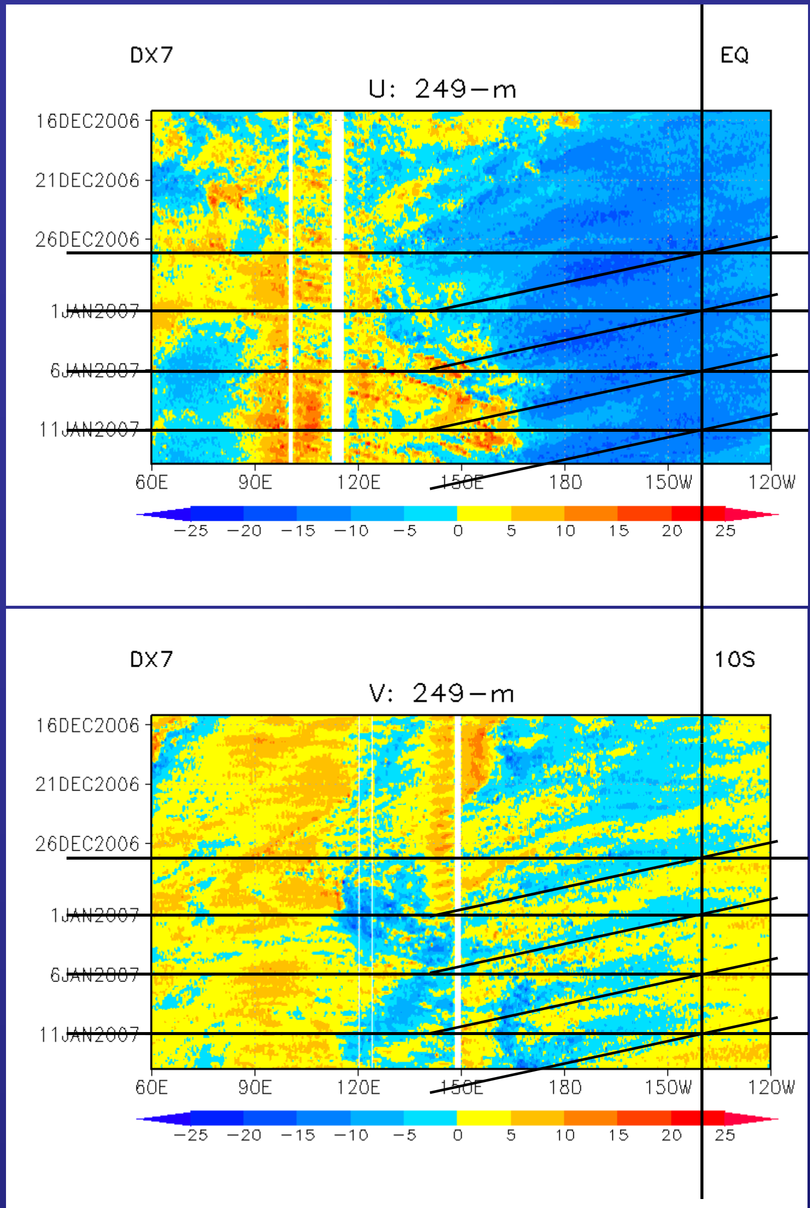


- The time evolutions were very similar before November 16.
- Convection was enhanced over the eastern part of the Indian Ocean.
- Convection disappeared over the Indian Ocean without the zonal SST gradient .

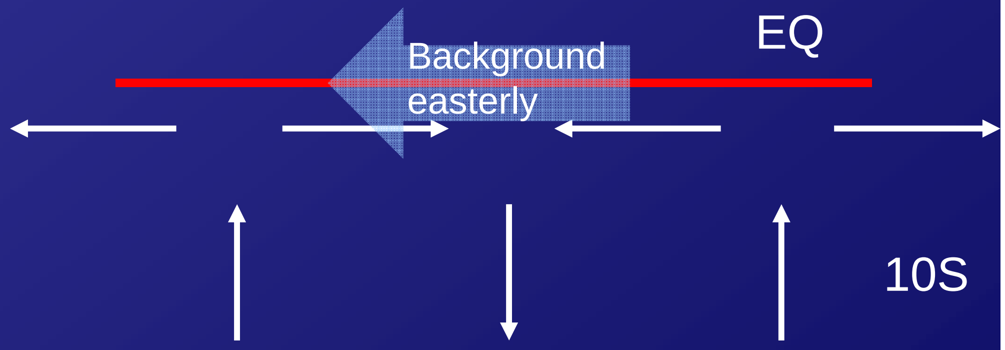
Summary

- **We are just beginning to evaluate what km-scale global CRMs can do or cannot do.**
- **A global CRM can simulate a spontaneous generation and a slow eastward movement of the MJO.**
  - The next would be the 30-60 day cycle of the MJO (Dr. Oouchi , FRCGC).
  - Simulated tropical cyclones are being validated (Dr. Fudeyasu, U. Hawaii).
  - Simulated eastward-moving signals are being studied (Dr. Nasuno, FRCGC).
- **The reason why a global CRM can simulate two MJO events is possibly that cloud systems are triggered by the equatorial waves and some external forcing accordingly in the model.**
  - The equatorial Rossby wave may control the large-scale environment.
  - Zonal SST contrasts may enable the uplift of warmer air by colder air.
  - The equatorial Kelvin wave may trigger strong convective systems inside the MJO.

Equatorial Rossby wave (subjective lines)?



Zonal wind:
z=249 m, lat=0



Meridional wind:
z=249 m, lat=10S

- The moist and dry phases were likely associated with equatorial Rossby waves.