The global response to the Madden-Julian Oscillation

The long arm of the MJO: You can run but you can't hide

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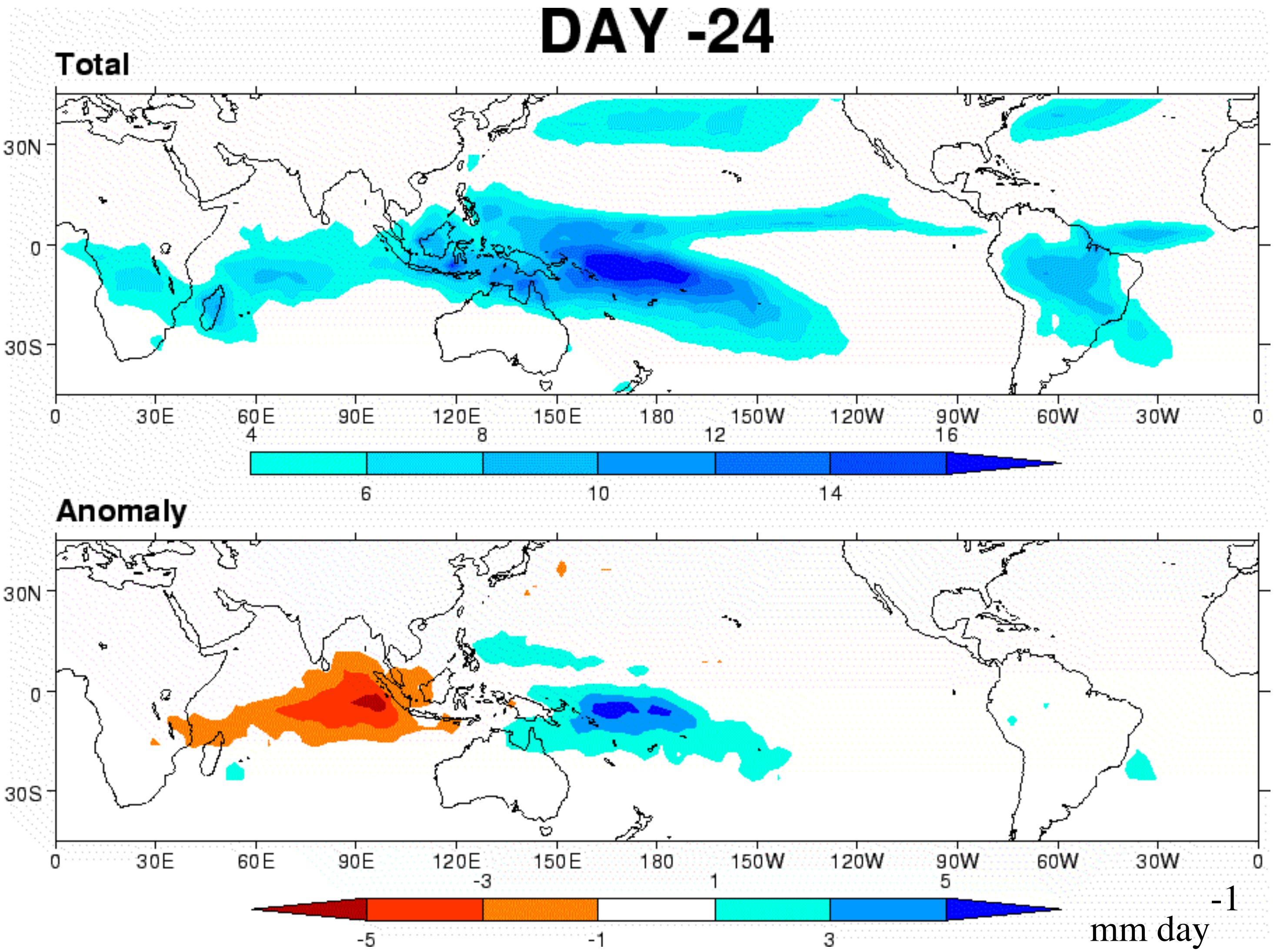
Outline

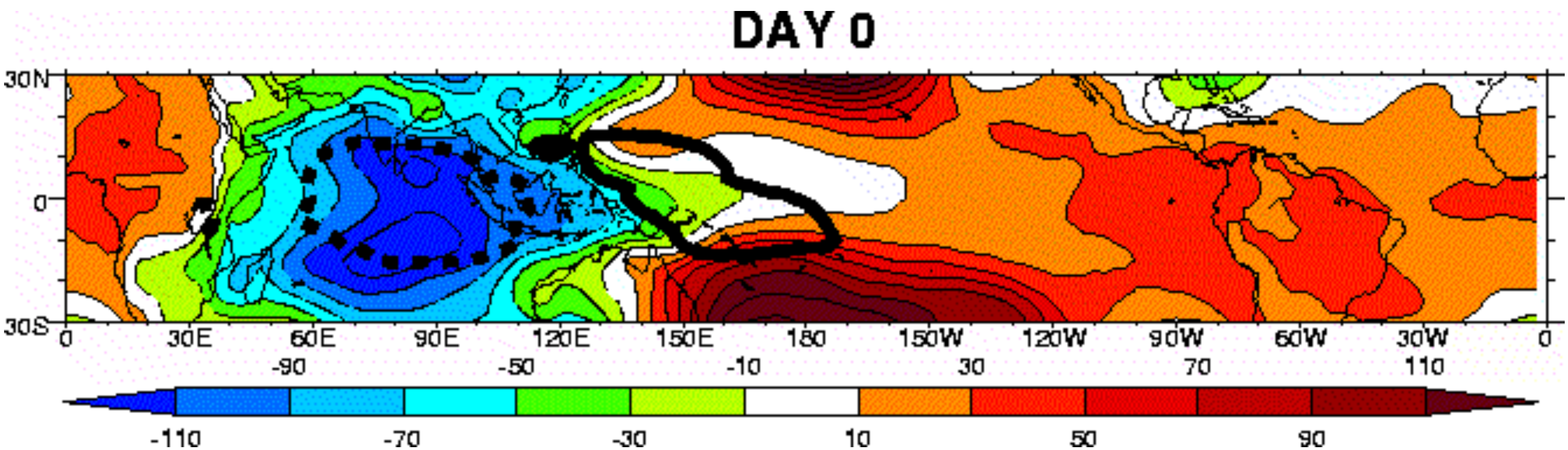
- Tropical response to MJO
  - West African monsoon
- Extratropical response to MJO
  - Direct response: Rossby wave dispersion
  - Indirect response: Modulation of internal extratropical modes
  - High-latitude deep ocean response
- Tropical dynamical ocean response
  - Pacific: El Ninõ and deep ocean
  - Indian Ocean: dynamical ocean feedback mechanism

MJO core region: tropical warm pool
MJO cycle: rainfall rate (DJF)



MJO tropical teleconnections: equatorial wave dynamics

MJO cycle: sea level pressure



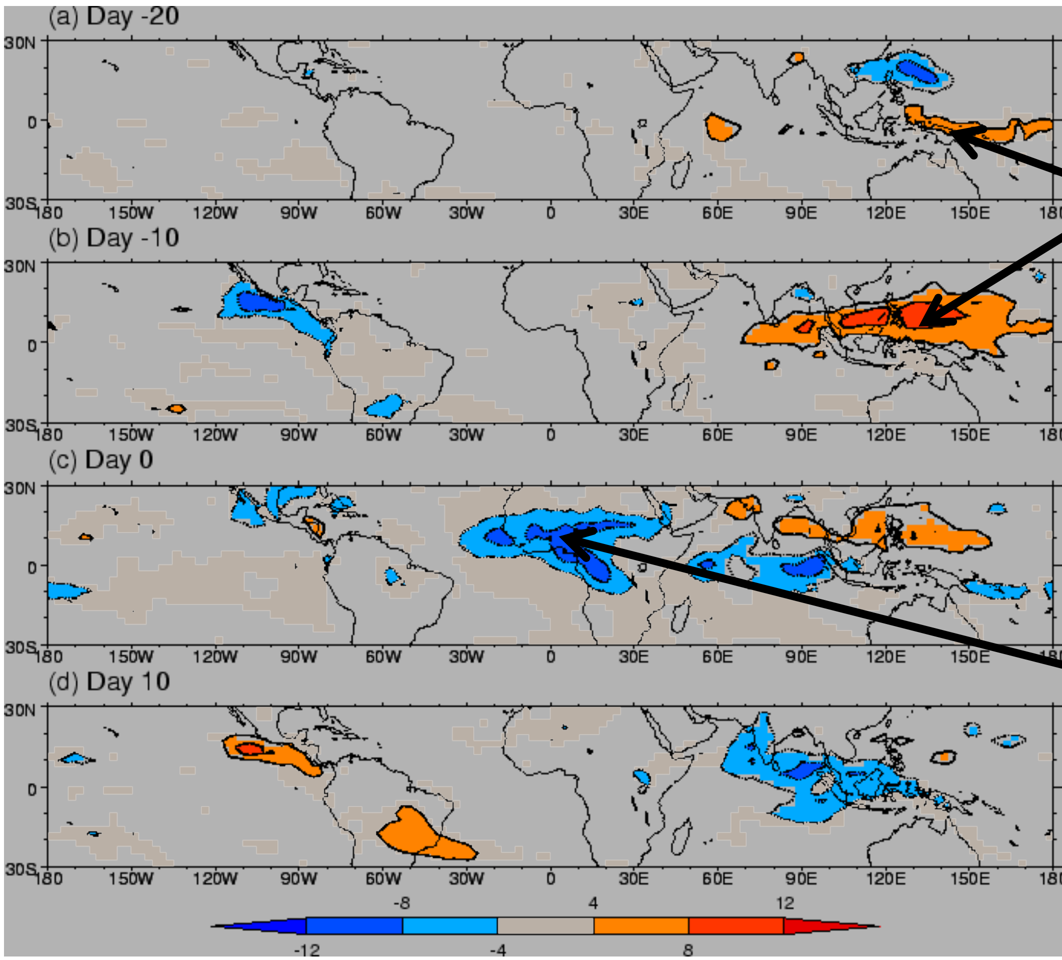
SLP anomaly: Pa

OLR contours

-10 W m^{-2} Enhanced convection

+10 W m^{-2} Suppressed convection

Response of the West African monsoon to the MJO
Observed OLR: JJAS



MJO: reduced convection over warm pool 10-20 days earlier

Leads to enhancement of convection over West Africa

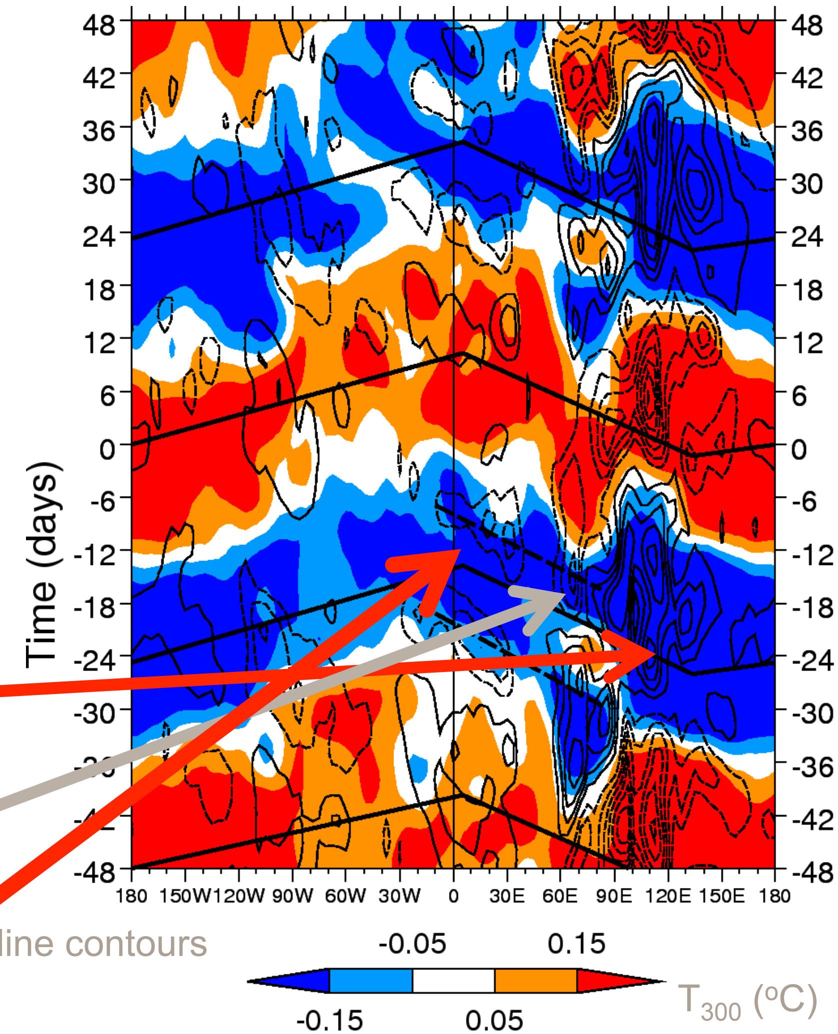
Matthews AJ, 2004: Intraseasonal variability over tropical Africa during northern summer. *J. Climate,* **17,** 2427-2440

Response of the West African monsoon to the MJO

Model: Equatorial wave teleconnections

- Mechanism: "Cold" equatorial Kelvin and Rossby waves propagate from Indian Ocean to Africa and trigger convection

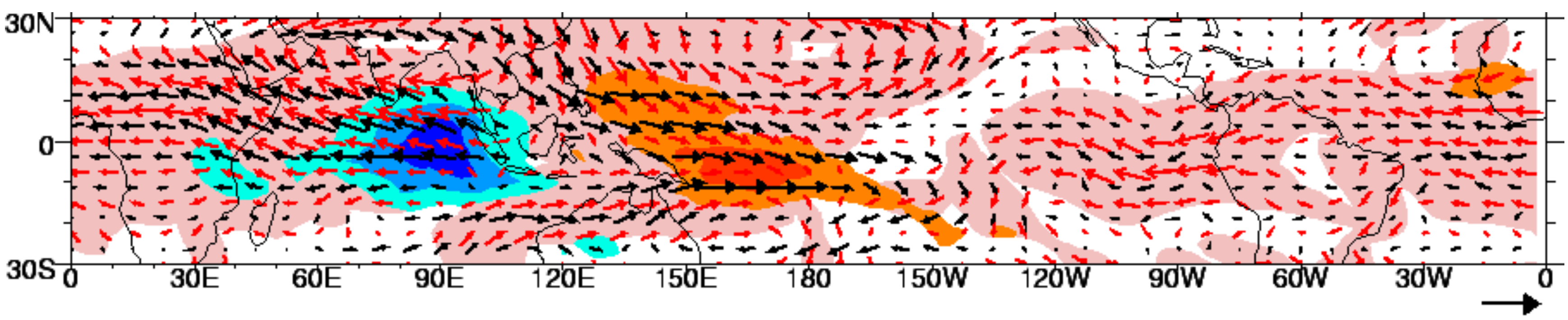
- Atmospheric GCM: HadAM3.
  - Externally forced MJO over warm pool
  - Suppressed MJO convection gives cold equatorial Rossby wave
  - Enhanced African convection



Lavender SL, Matthews AJ, 2009: Response of the West African monsoon to the Madden-Julian Oscillation. *J. Climate,* **22,** 4097-4116

Tropical response to MJO heating
Dry atmospheric model (IGCM1)

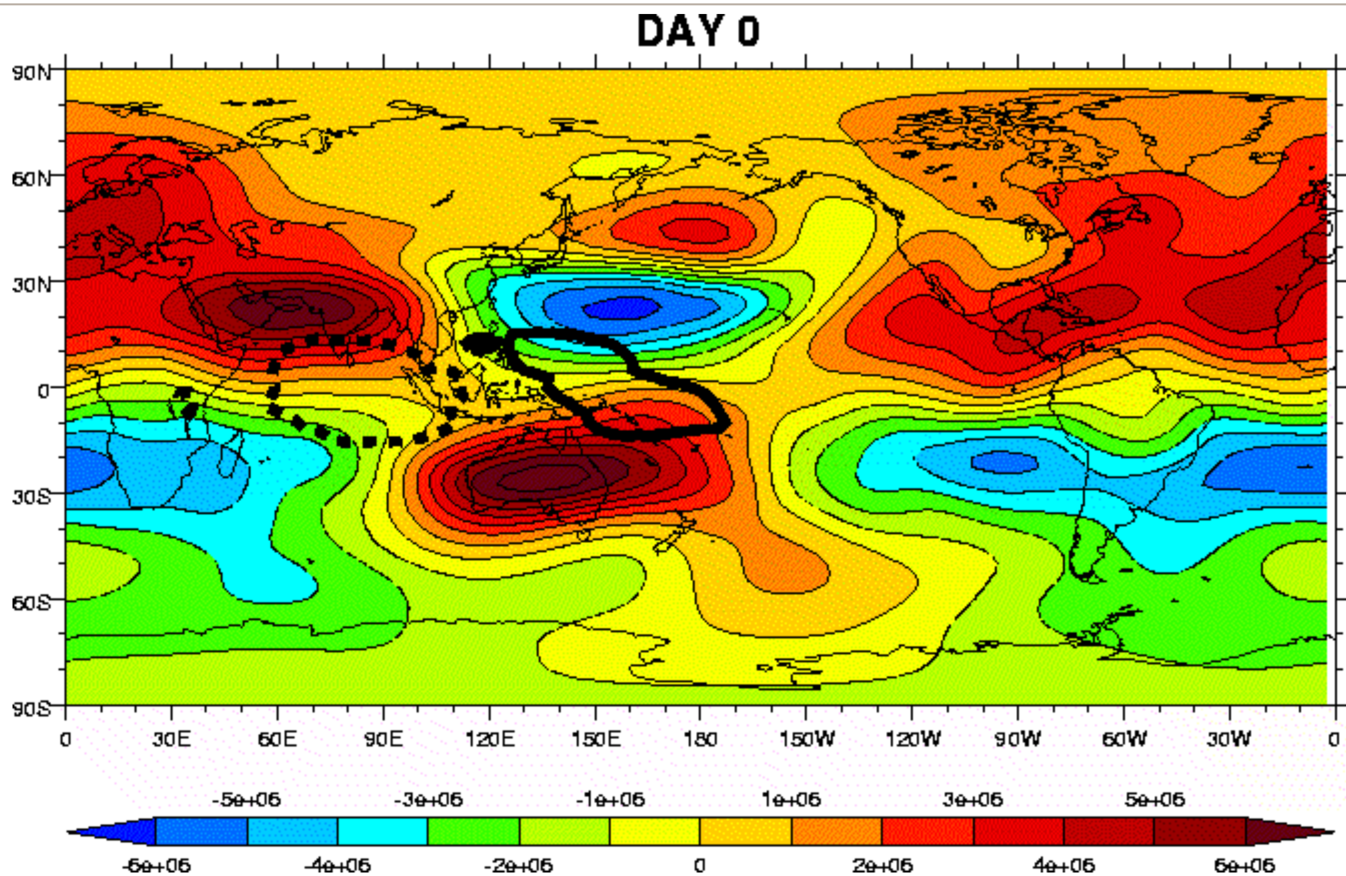
- Model linearised about observed 3-D DJF flow
- Added observed time-dependent MJO heating
- Equatorial Kelvin/Rossby wave response
- 200-hPa wind vector anomalies
  - Red vectors = observed
  - Shading: u or v wind locally significant at 95% level
  - Black vectors = model
  - Pattern correlation coefficient r=0.82



Matthews AJ, Hoskins BJ, Masutani M, 2004: The global response to tropical heating in the Madden-Julian Oscillation during northern winter. *Quart. J. Roy. Meteorol. Soc.,* **130,**1991-2011.

Global structure of MJO

MJO cycle: 200-hPa streamfunction



200-hPa NCEP reanalysis streamfunction anomaly ($m^2 s^{-1}$)

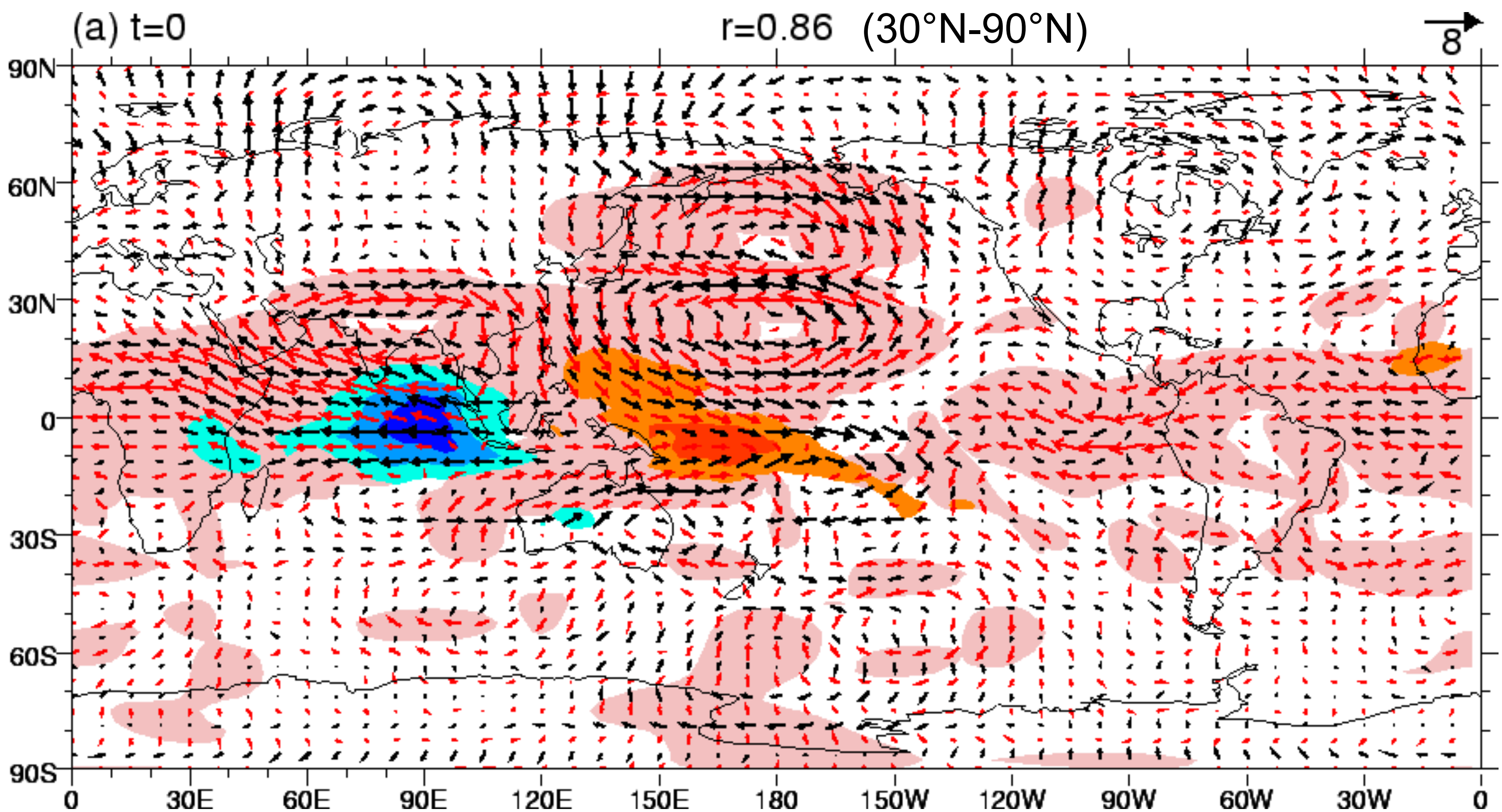
OLR contours

-10 $W m^{-2}$ Enhanced convection

+10 $W m^{-2}$ Suppressed convection

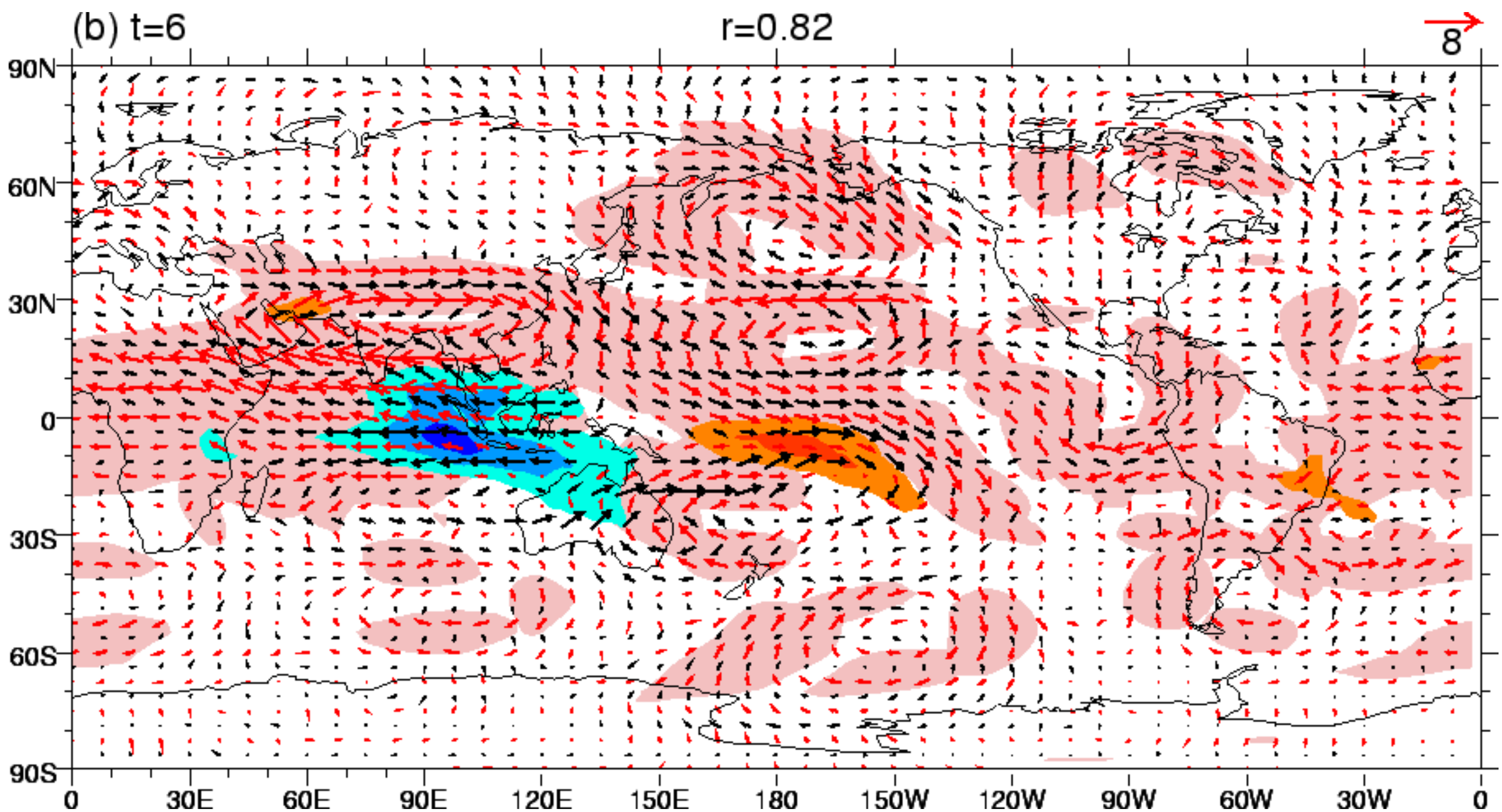
Global response to MJO heating

Dry dynamical model (IGCM1) t=0 days



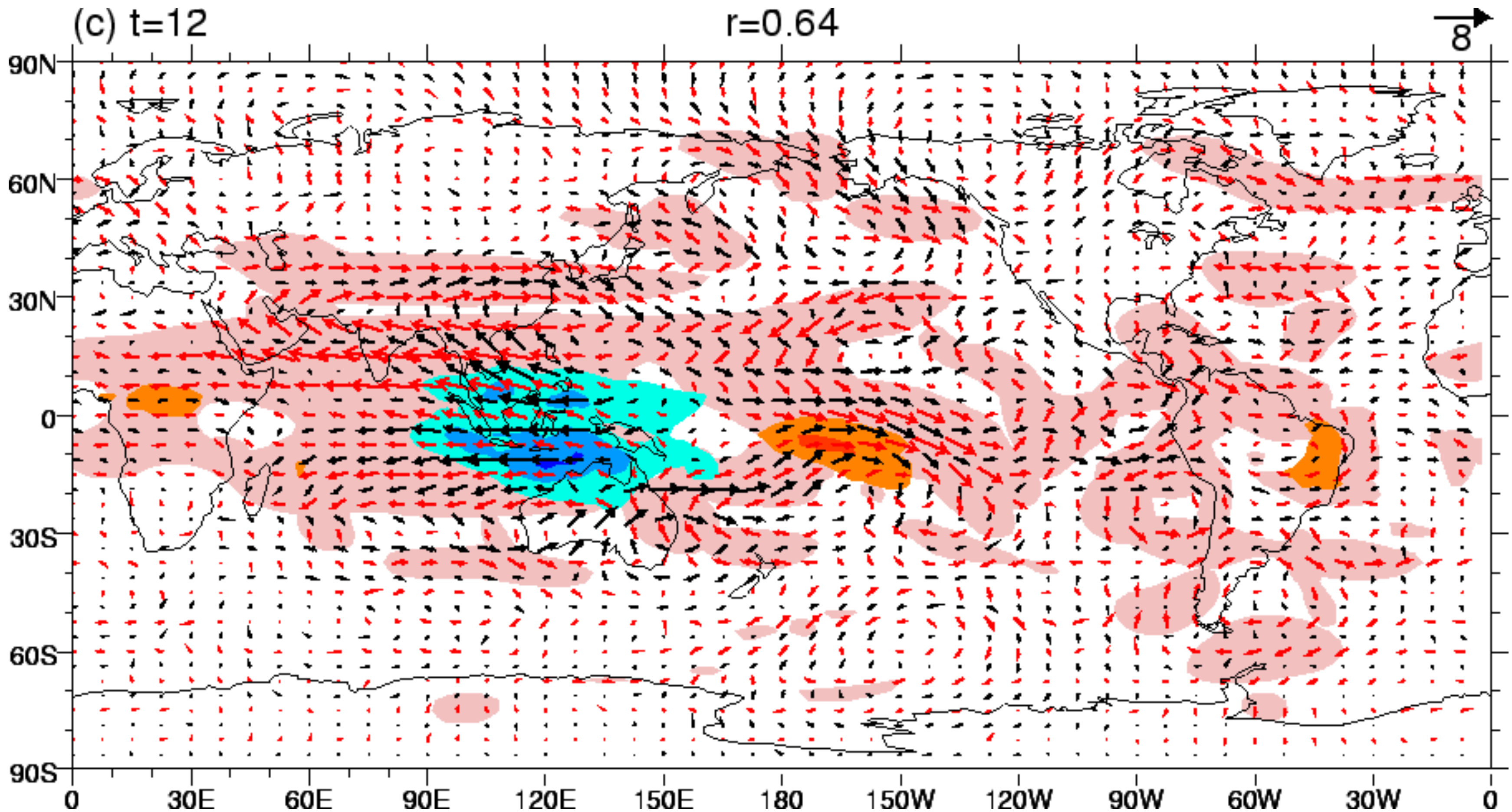
Global response to MJO heating

Dry dynamical model (IGCM1) t=6 days



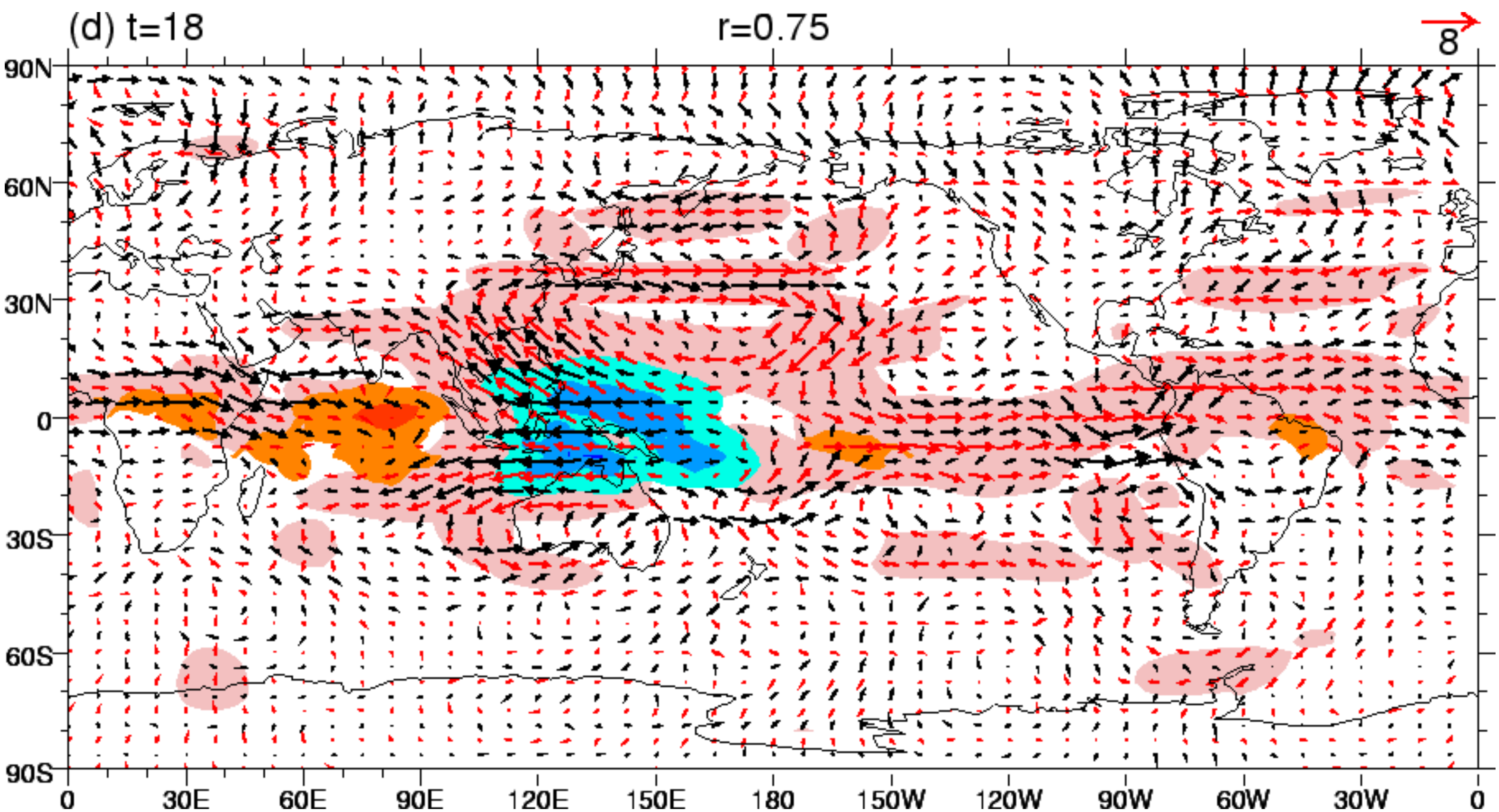
Global response to MJO heating

Dry dynamical model (IGCM1) t=12 days



Global response to MJO heating

Dry dynamical model (IGCM1) t=18 days



Direct response to MJO heating

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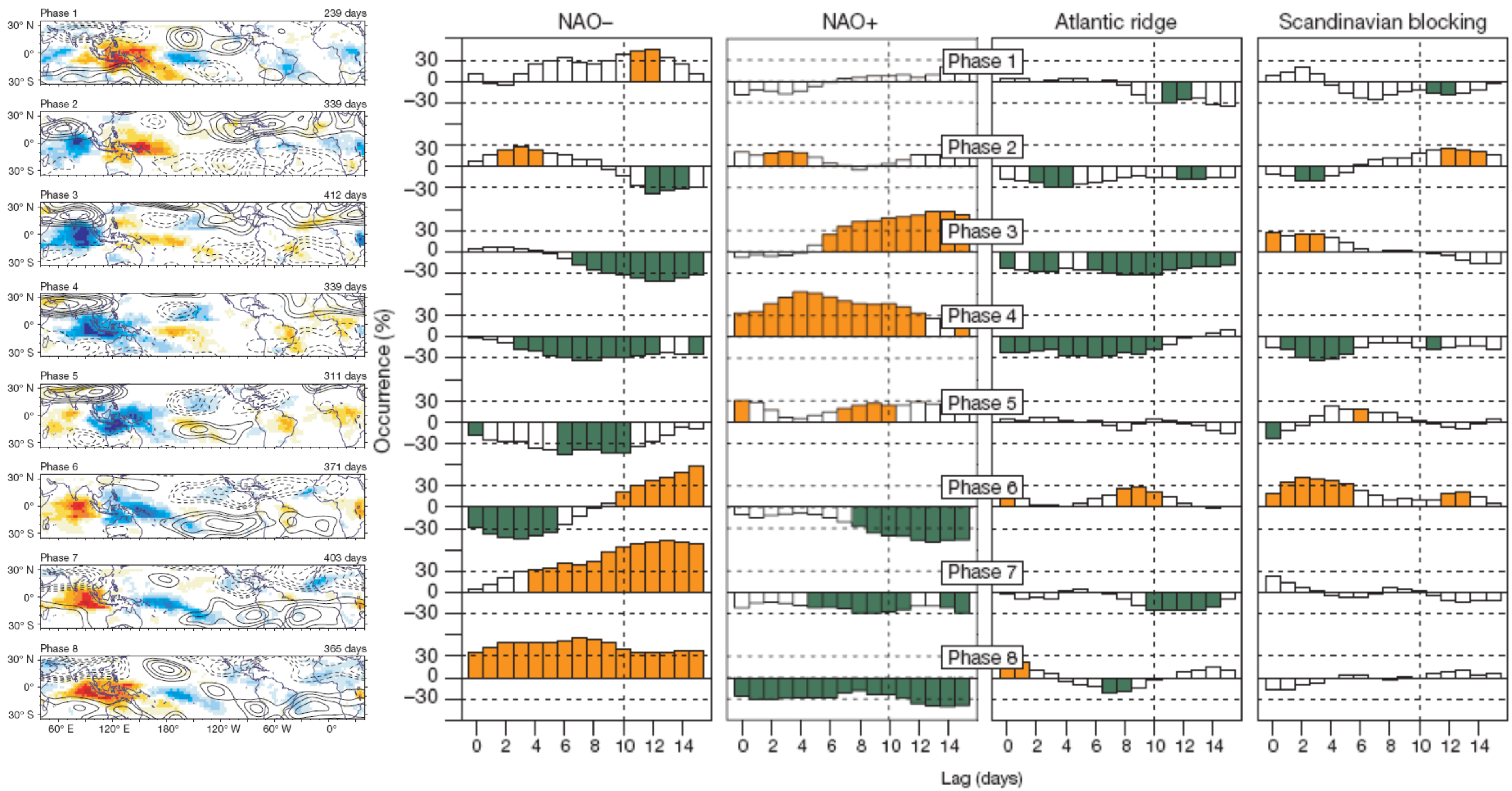
- Tropical response
  - Equatorial Kelvin/Rossby wave response
  - Established in few days
- Extratropical response
  - Model simulation accurate (high pattern correlations) over Pacific and North America
  - Interpreted as direct Rossby wave response on 3-D flow
  - Established in two weeks
  - MJO heating changes substantially in this time

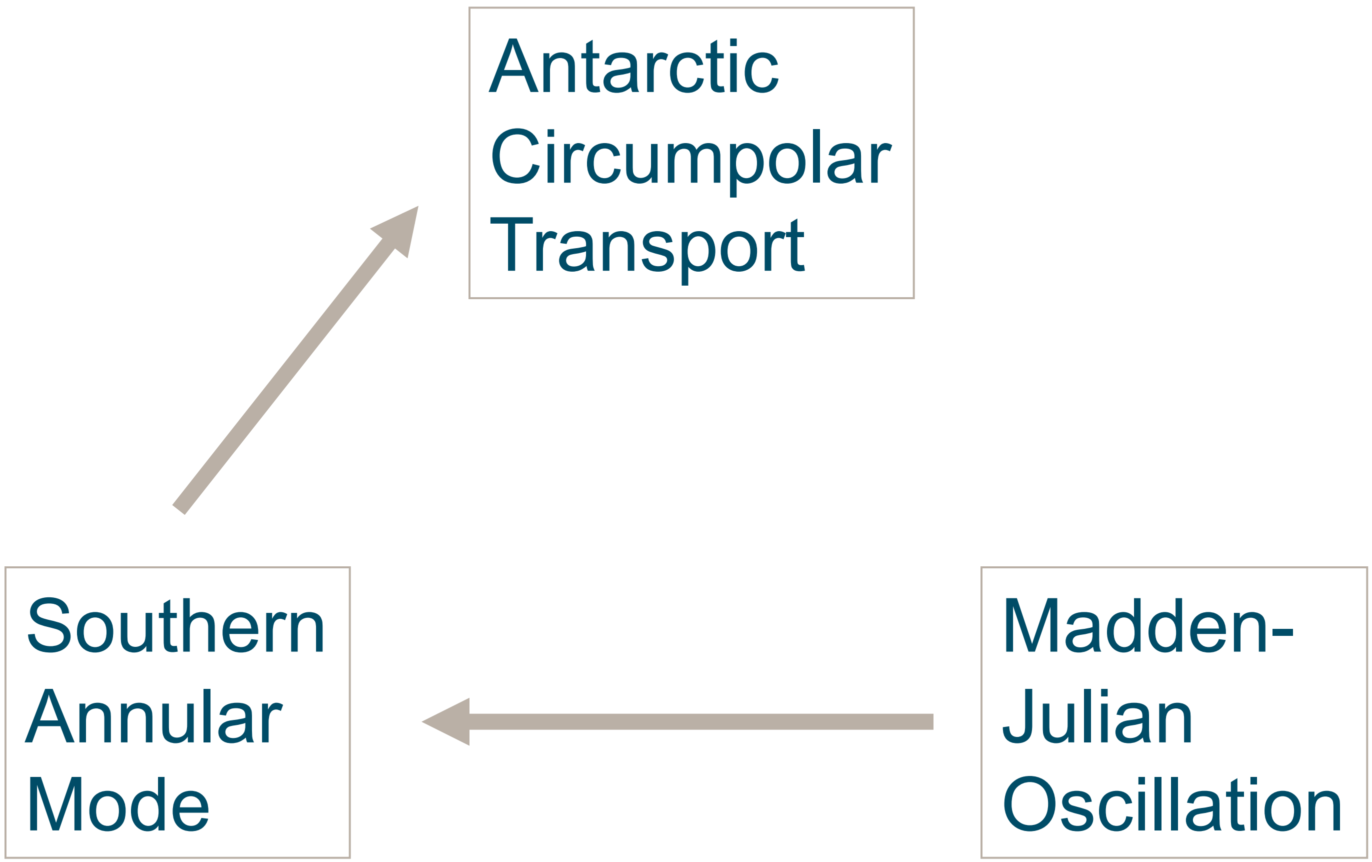
Indirect response to MJO heating

MJO and extratropical regimes (NAO)



Cassou C,2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. *Nature,* **455,** 523-527.

MJO and southern hemisphere extratropics



Matthews AJ, Meredith MP, 2004: Variability of Antarctic circumpolar transport and the southern annular mode associated with the Madden-Julian oscillation. *Geophys. Res. Lett.*, **31,** L24312, doi:10.1029/2004GL021666.

Ocean bottom pressure recorders
~10 year daily mean time series

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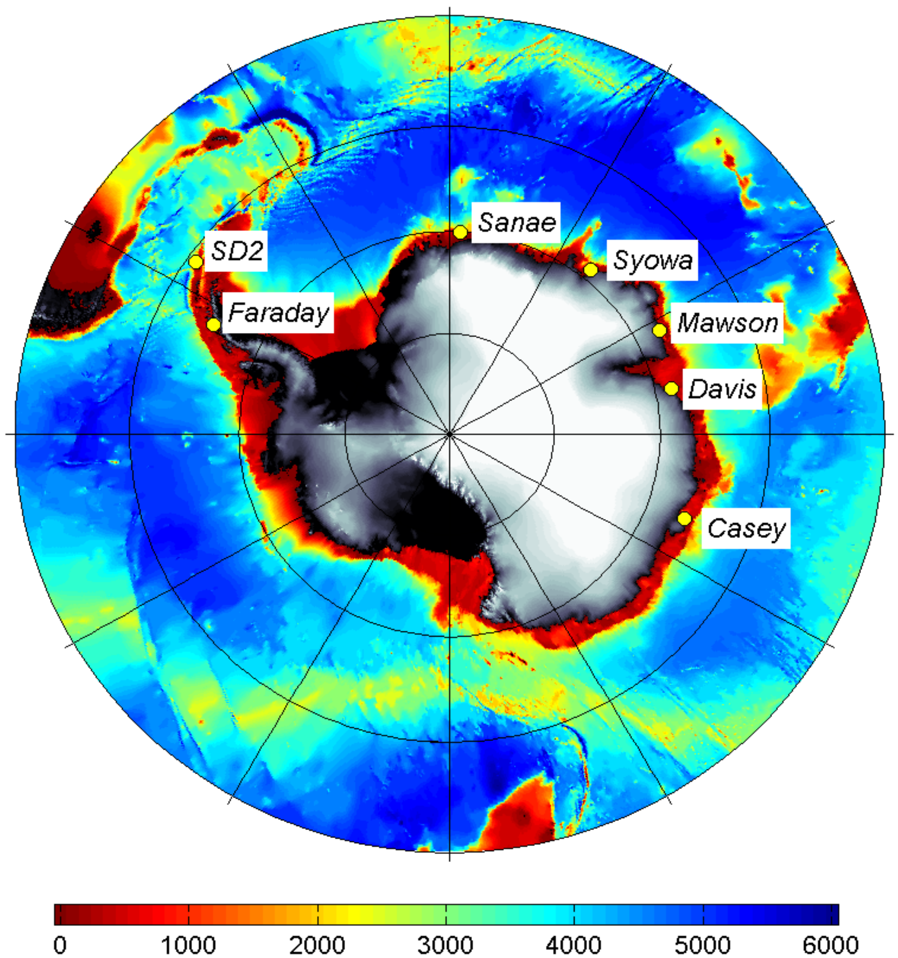
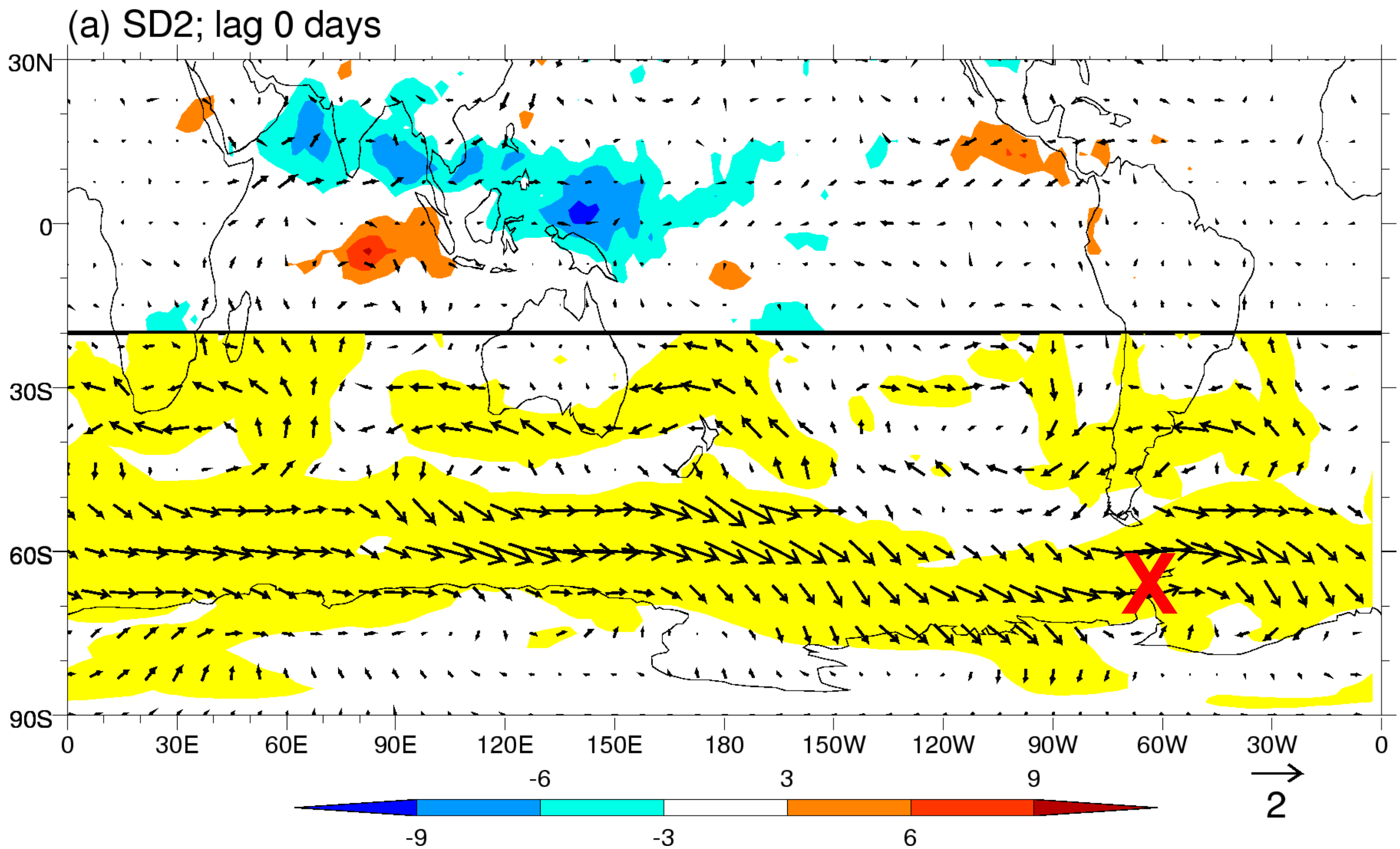


OLR, 1000-hPa wind regressed onto –SD2 (X) bottom pressure

May-October



Mechanism: Upper tropospheric Rossby wave propagation

Day -10

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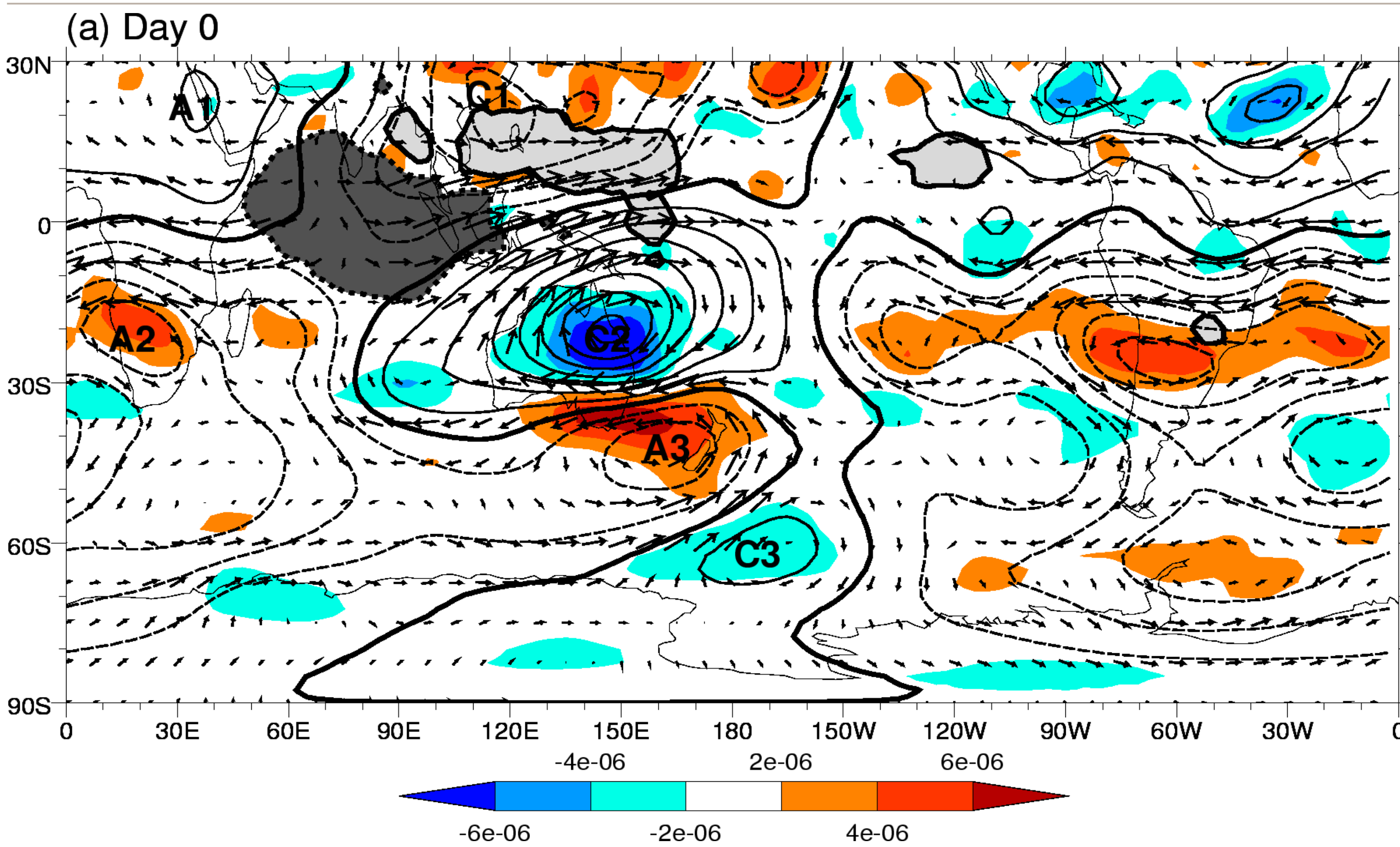
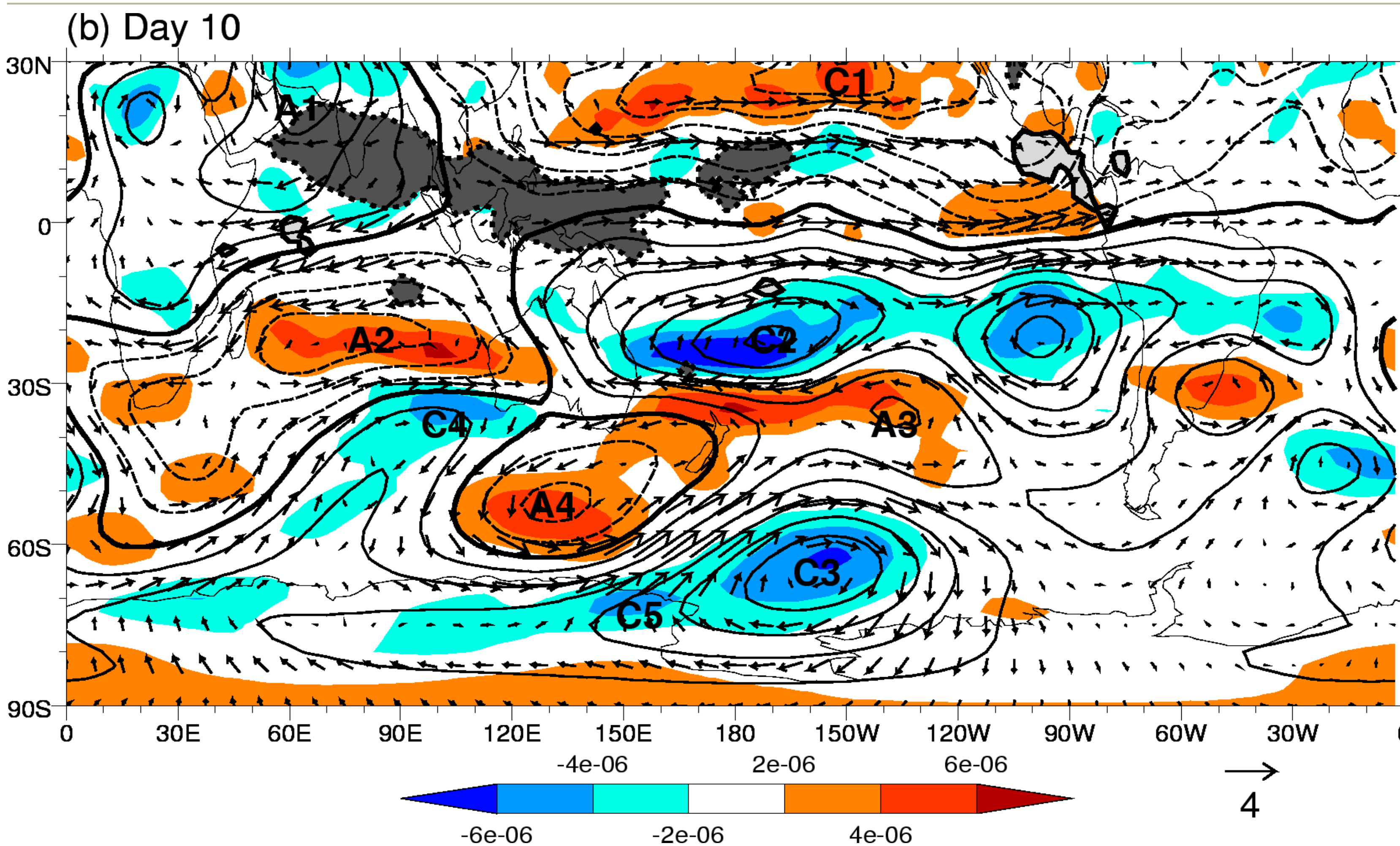


OLR (grey shading).

200-hPa vorticity (colour shading), streamfunction (line contours), wind (vectors)

Mechanism: Upper tropospheric Rossby wave propagation

Day 0

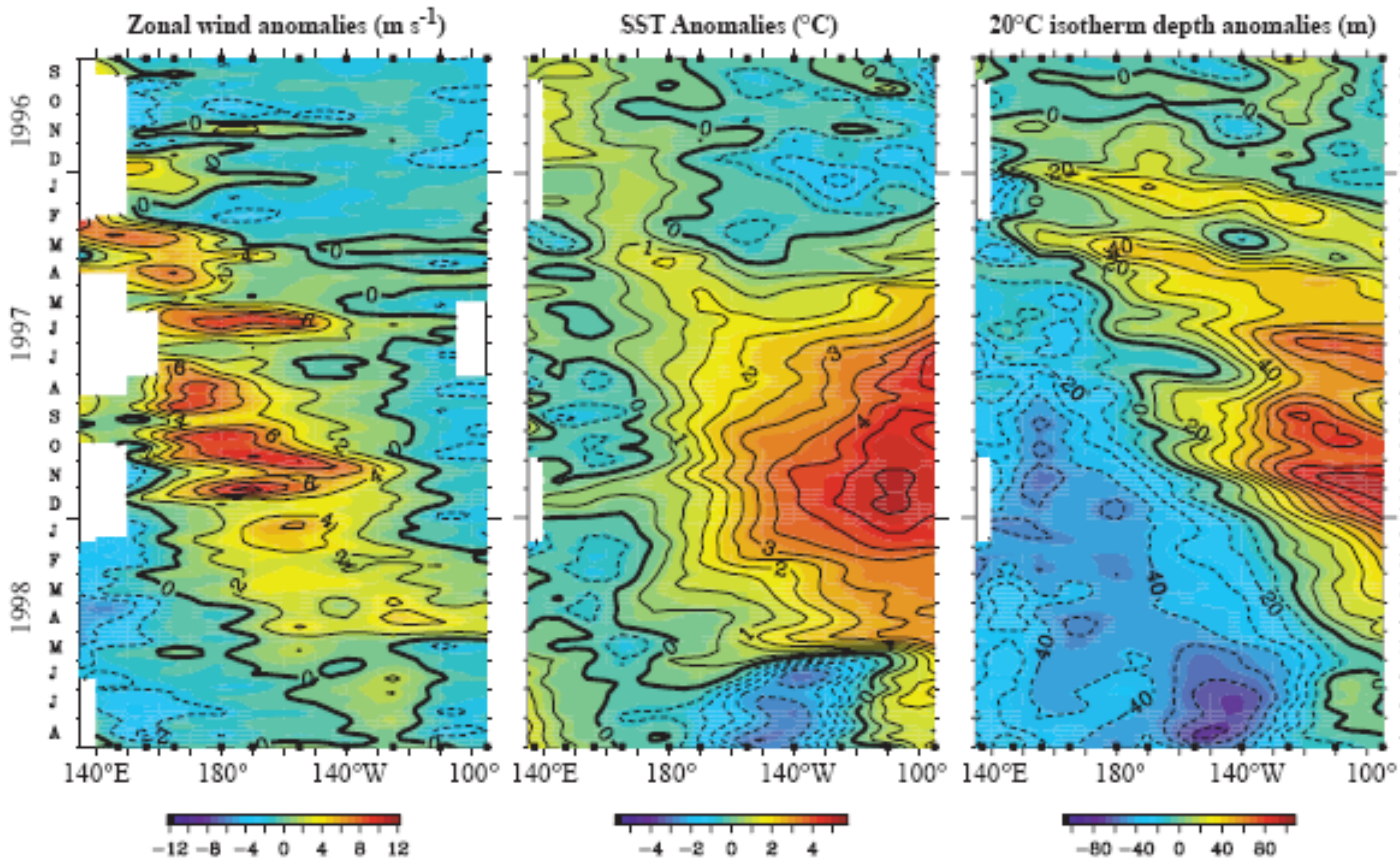


OLR (grey shading).

200-hPa vorticity (colour shading), streamfunction (line contours), wind (vectors)

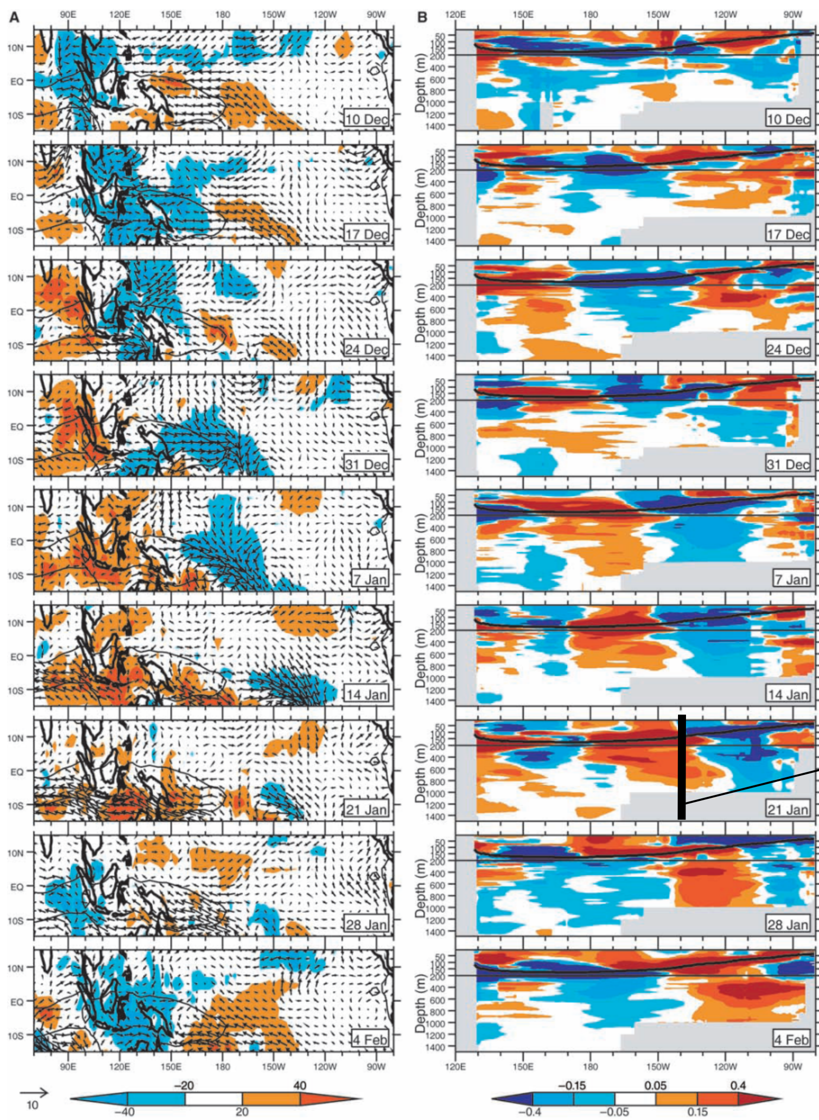
Ocean MJO dynamical teleconnections

MJO-forced oceanic equatorial Kelvin waves trigger El Niño

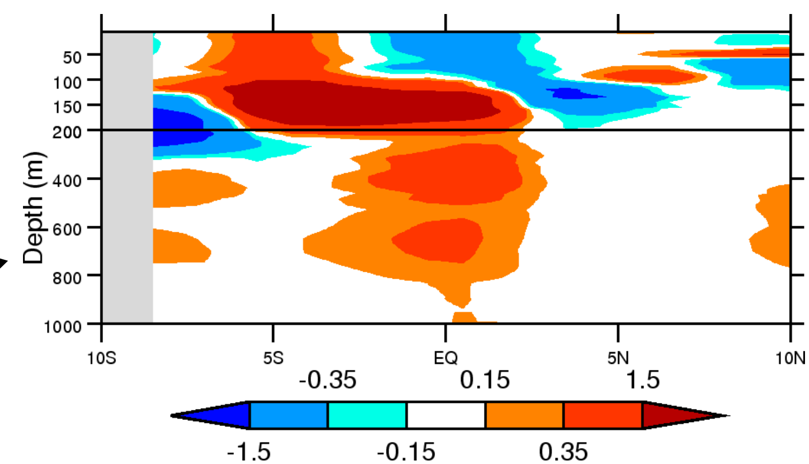


McPhaden MJ, 1999: Genesis and evolution of the 1997-98 El Nino. *Science*, **283,** 950-954.

Dynamical ocean MJO component
Deep oceanic Kelvin wave

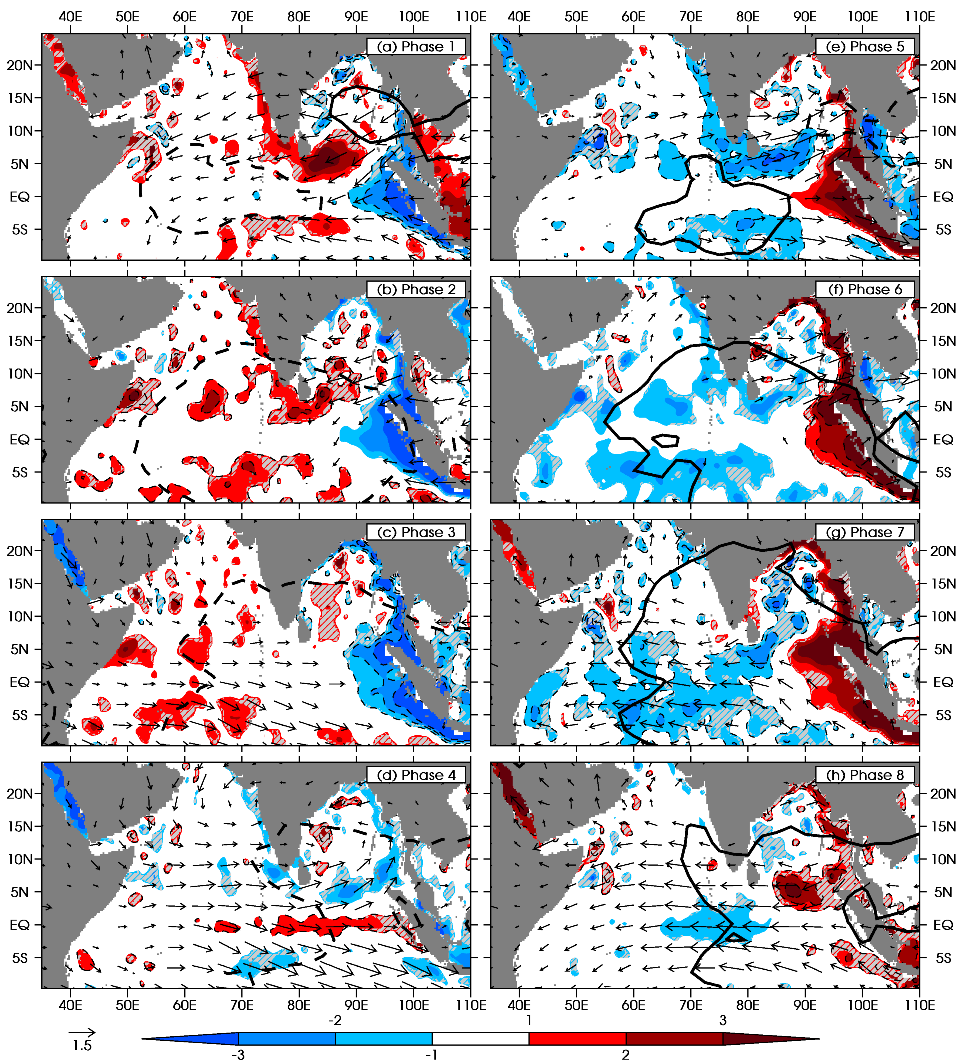


- Deep structure measured by Argo floats
- Oceanic equatorial Kelvin wave forced by MJO wind stress
- Extends down to at least 1000 m



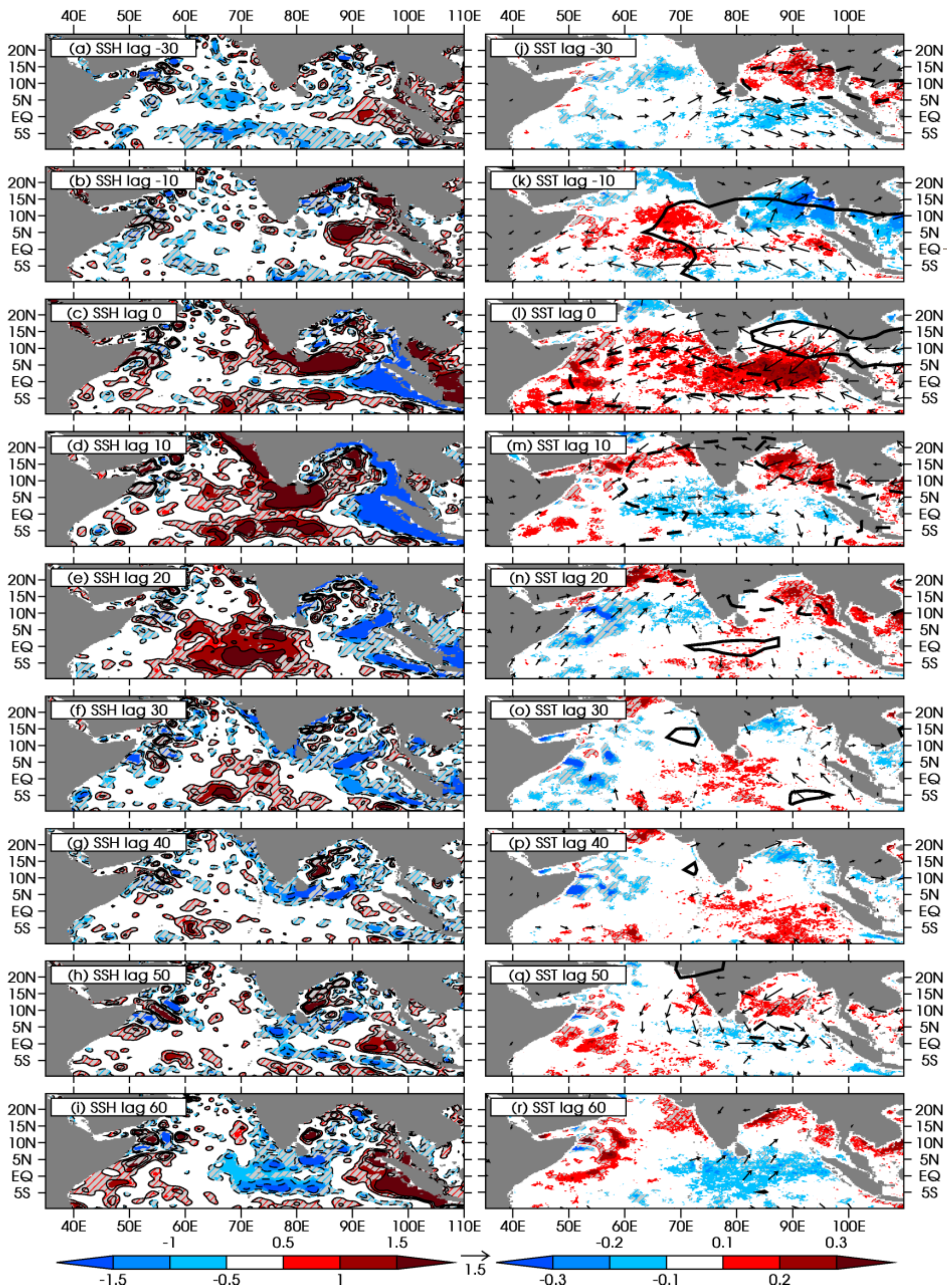
Matthews AJ, Singhruck P, Heywood KJ, 2007: Deep ocean impact of a Madden-Julian Oscillation observed by Argo floats. *Science,* **318,** 1765-1769.

Ocean-atmosphere dynamical teleconnection feedback mechanism for the MJO



- ✦ MJO defined by Wheeler-Hendon index
- ✦ Composite satellite sea surface height (SSH) anomalies
- ✦ Equatorial Kelvin wave
- ✦ Reflects into equatorial Rossby wave at Sumatra
- ✦ Coastal Kelvin wave
- ✦ Aliasing: MJO time scale < ocean wave time scale

Webber, BGM, Matthews AJ, Heywood KJ, 2010: A dynamical ocean feedback mechanism for the Madden-Julian Oscillation. *Quart. J. Roy. Meteorol. Soc.*, **136,** 740-754.



- Time-lagged composites, with respect to Wheeler-Hendon phase 1
- Day -30: downwelling Kelvin wave in east Indian Ocean
- Day -10: reflects into westward-propagating downwelling Rossby wave
- Day 60: reaches west Indian Ocean, induces positive SST anomaly

Equatorial Rossby wave propagation

Hovmoller diagrams (2-4N, 2-4S)

Northern summer (May-October)

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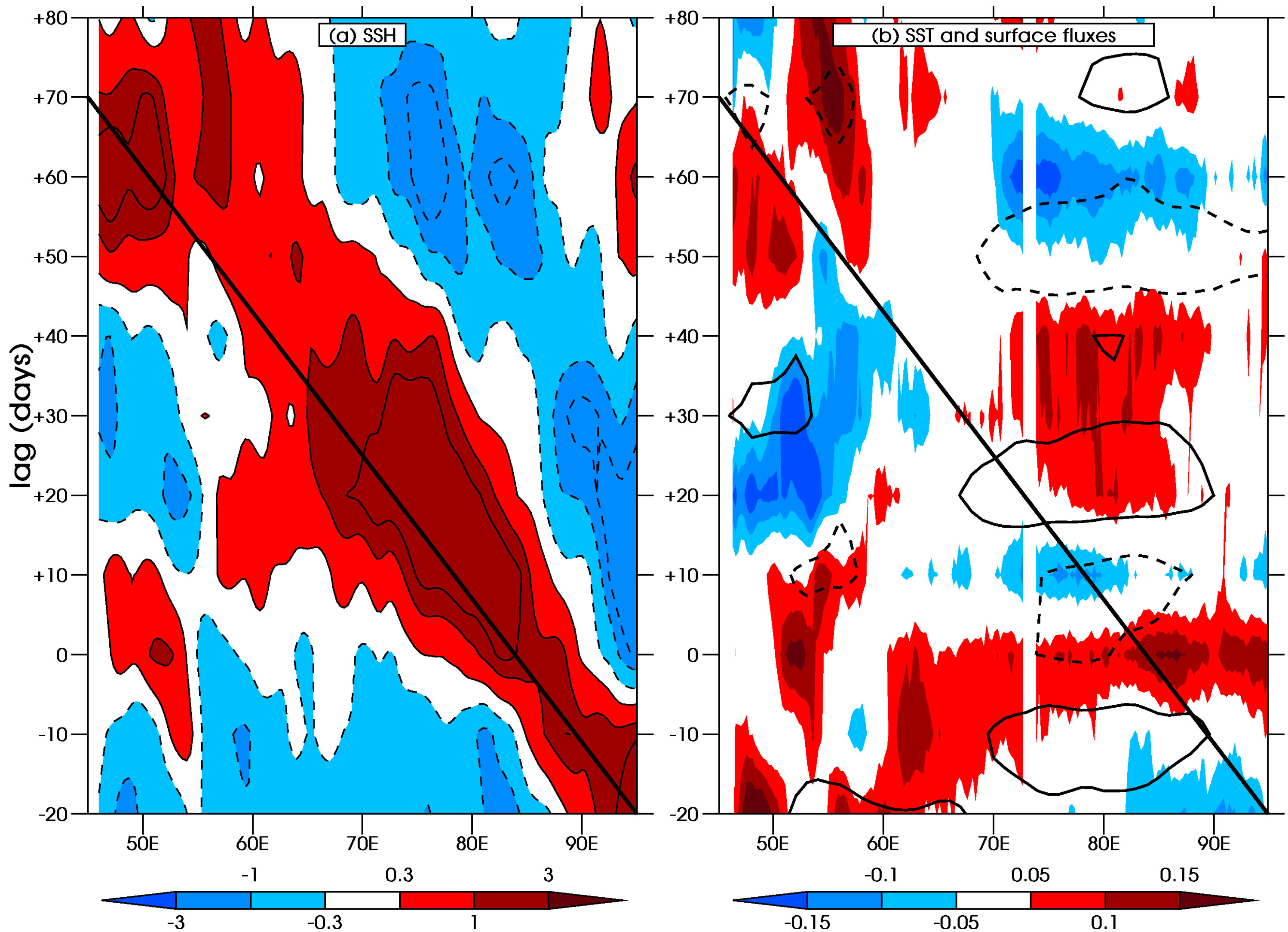
SSH

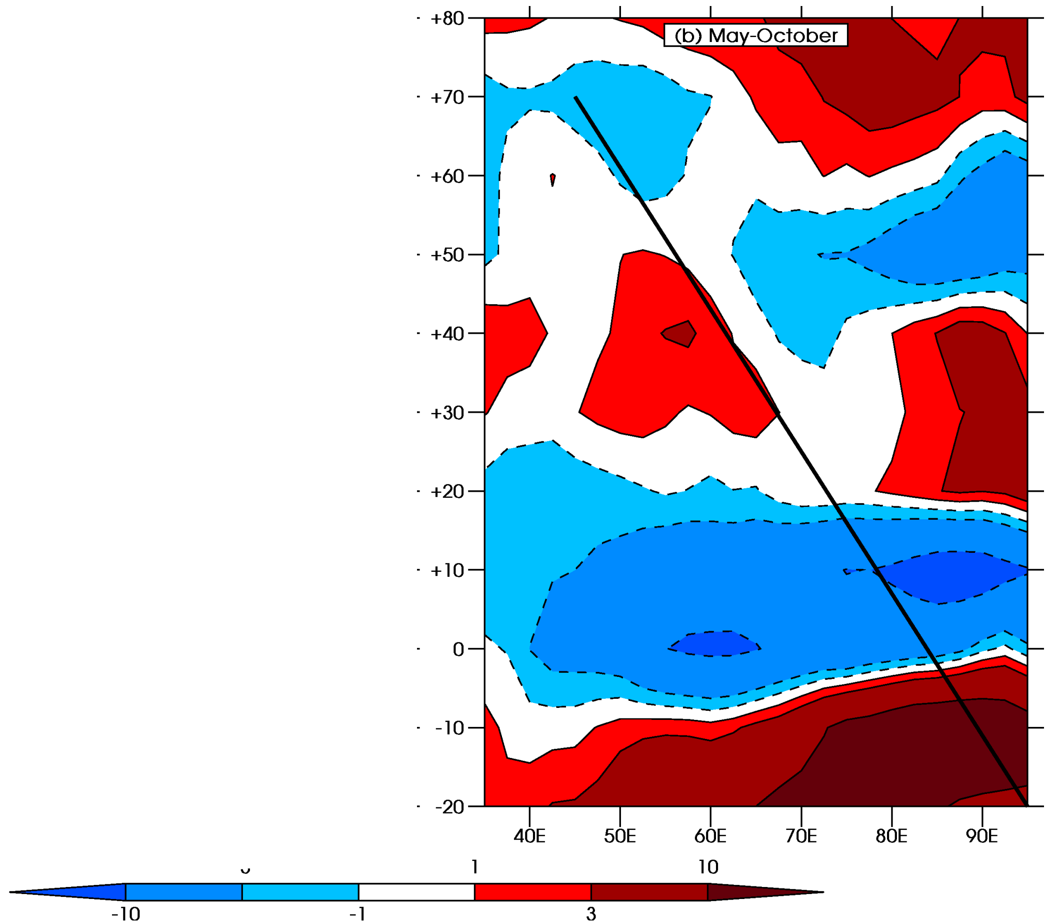


SST, surface flux

Triggering of convection by ocean Rossby wave

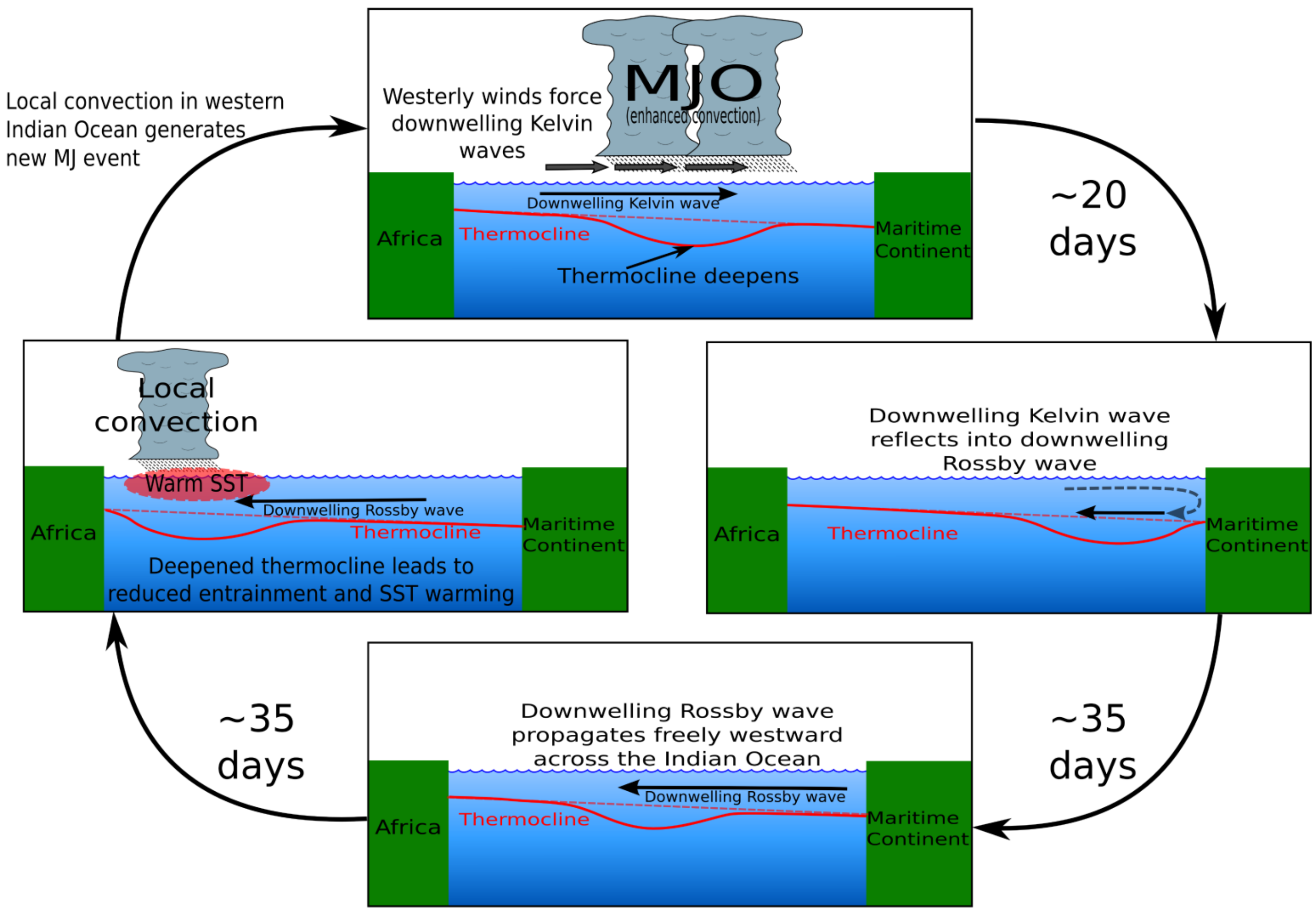
Hovmoller OLR (5S-5N)

May-October



Ocean teleconnection feedback mechanism for MJO

Triggering the next-but-one MJO



Conclusions

Effect of MJO heating in core region of tropical warm pool

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- Excites atmospheric equatorial Kelvin and Rossby waves
  - Established in a few days
  - Can destabilise and trigger convection over west African monsoon
- Excites atmospheric extratropical Rossby waves
  - Established in two weeks
  - Can be simulated accurately if MJO heating and basic state correct
  - Affects occurrence of internal midlatitude modes (e.g., NAO)
  - Affects high latitude ocean circulation through surface wind anomalies
- Excites oceanic equatorial Kelvin and Rossby waves
  - Deep Kelvin waves in Pacific
  - Delayed oscillator type mechanism in Indian Ocean feeds back onto MJO (next-but-one event or low-frequency tail)

Mechanism: Upper tropospheric winds extend to surface

Zonal wind section at 150°E

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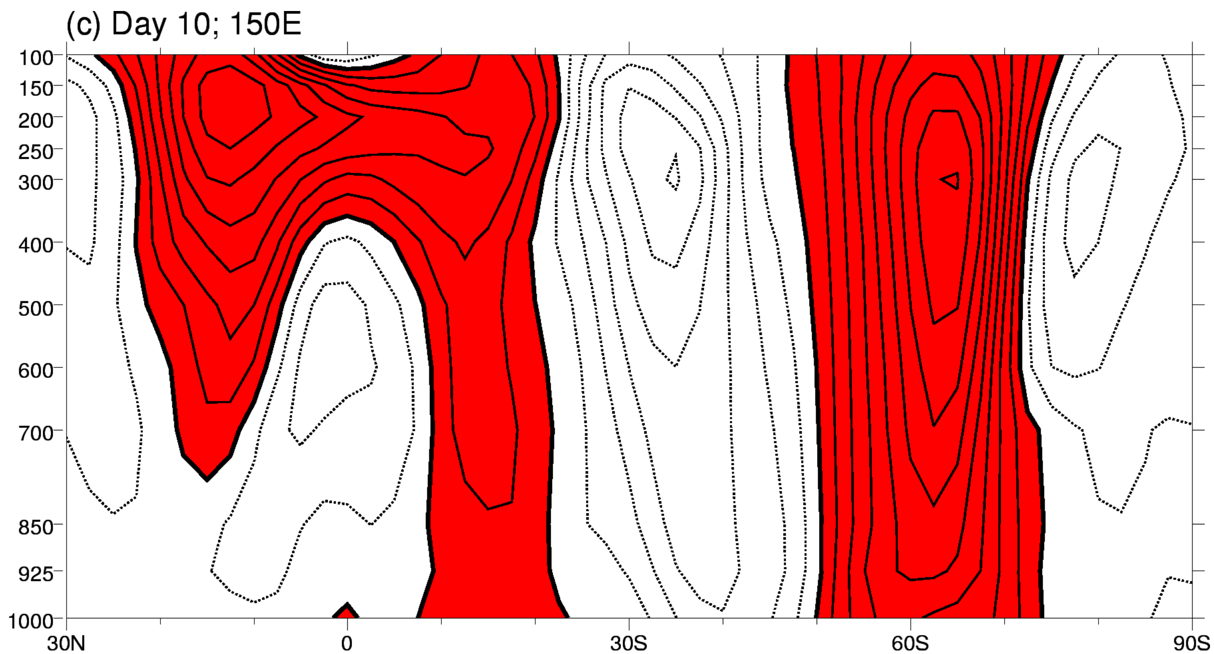
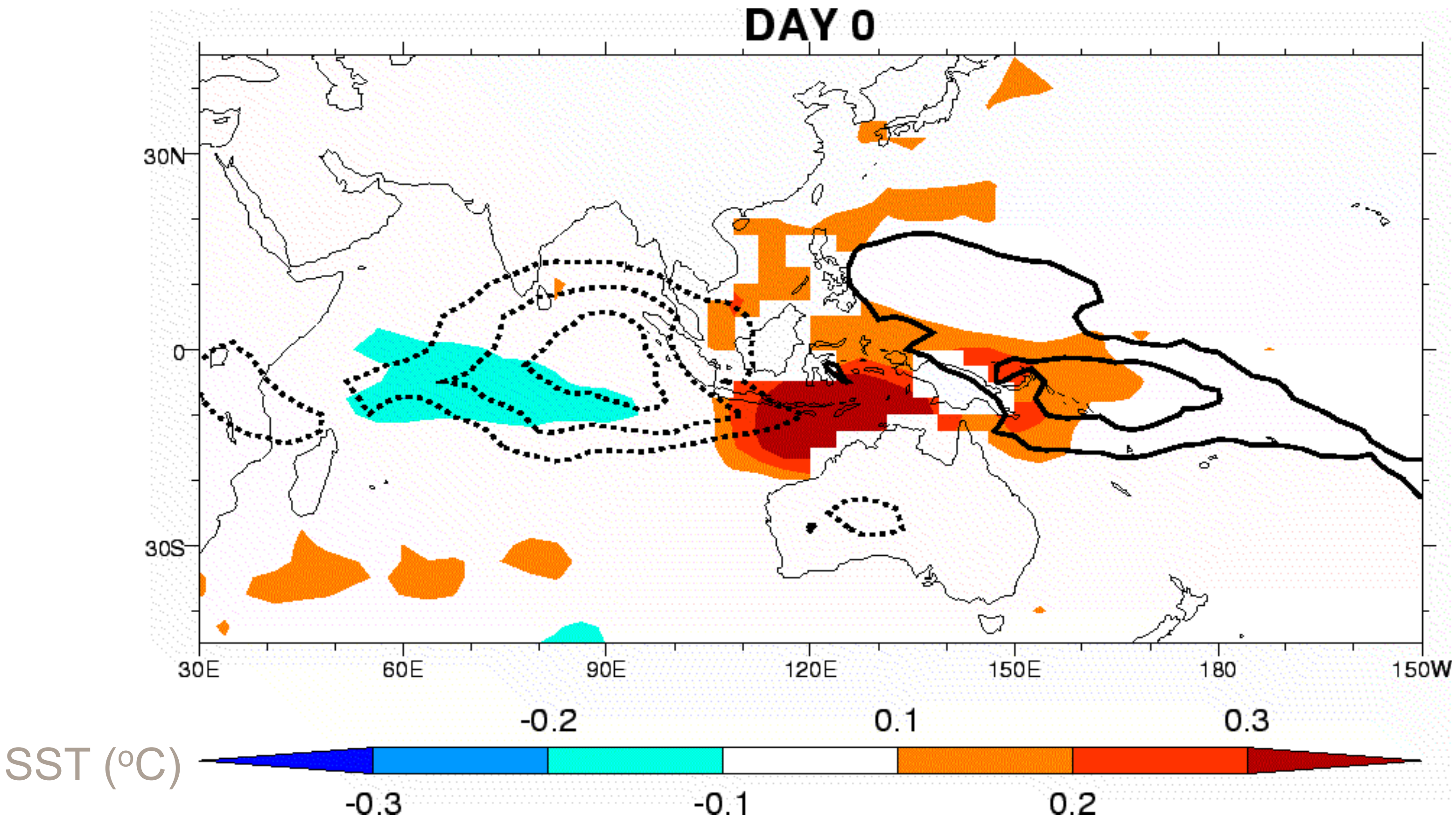


- Tropical anomalies are baroclinic: opposite sign between upper and lower troposphere
- Extratropical anomalies are barotropic: upper tropospheric anomalies extend down to surface

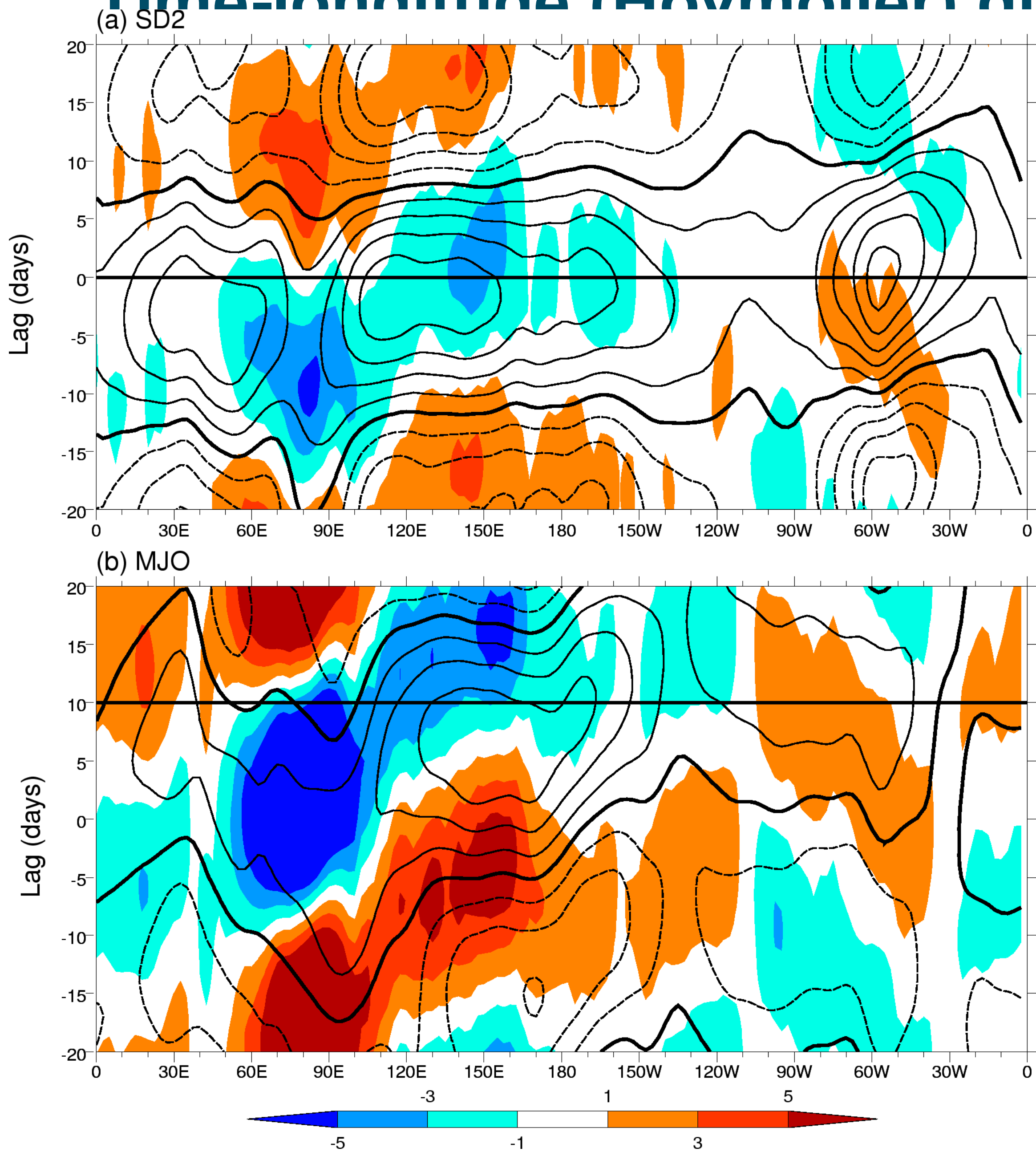
Ocean component of MJO

MJO cycle: sea surface temperature



OLR line contours: solid = positive, dotted = negative

Time-longitude (Hovmoller) diagram



- OLR anomalies (20°S-20°N) coloured
- Zonal wind anomalies at 60°S, line contours

Heading

- Some text