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Progress in Simulating Intraseasonal Variability in Climate Models

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PCMDI

Program for Climate Model Diagnosis and Intercomparison

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Outline

- Observations and Models Used
- Literature/Results Used
- Boreal Winter Madden-Julian Oscillation
  - Dominated by eastward propagation of enhanced convection
- Boreal Summer Intraseasonal Variability
  - Eastward and northward propagation of enhanced convection
- Preliminary Conclusions/Ongoing Work

Observations, CMIP5, and CMIP3 Models

- Observations
  - CMAP, GOES Precipitation Index, GPCP, AVHRR OLR
- CMIP5 (27 models overall)
  - BCC-CSM1.1, CanCM4, CanESM2, CCSM4, CMCC-CM, CMCC-CMS, CNRM-CM5, CSIRO-Mk3.6.0, FGOALS-s2, GFDL-CM3, GFDL-ESM2G, GISS-E2-R, HadCM3, HadGEM2-CC, HadGEM2-ES, INM CM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC-ESM, MIROC-ESM-CHEM, MIROC4h, MIROC5, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M
- CMIP3 (20 models overall)
  - bccr_bcm2.0, cccma cgcm3.1, cccma cgcm3.1 t63, ccsm3.0, cnrm cm3, csiro mk3.0, csiro mk3.5, gfdl cm2.0, gfdl cm2.1, giss aom, fgoals 1.0g, ingv-sxg, inmcm3.0, hadcm3, ipsl cm4, miroc 3.2 (hi-res), miroc 3.2 (med-res), miub echo-g, echam5/mpi-om, and mri cgcm2.3.2a
- CMIP5 Historical vs. CMIP3 20c3m simulations
  - Modeling groups best estimates of natural and anthropogenic forcing
  - CMIP5 has higher horizontal resolution (most ~1^{o} vs. ~2.5^{o})
  - CMIP5 has more complete representation of the Earth system and improved parameterizations

Literature/Results Used

Boreal Winter Madden-Julian Oscillation

Sperber, K. R., and D. Kim (2012) Simplified metrics for identification of the Madden-Julian oscillation. *Atmos. Sci. Lett.*, **13**, 187-193. doi: 10.1002/asl.378

Hung, M.-P., J.-L. Lin, W. Wang, D. Kim, T. Shinoda, and S. J. Weaver (2012) MJO and Convectively Coupled Equatorial Waves Simulated by IPCC AR5 Climate Models. *J. Climate* (in revision)

Kim, D., Sperber, K. R., and Co-authors (2009) Application of MJO simulation diagnostics to climate models. *J. Climate*, **22**, 6413-6436. doi: 10.1175/2009JCLI3063.1

CLIVAR MJO Working Group (2009) MJO simulation diagnostics. *J. Climate*, **22**, 3006-303. doi: 10.1175/2008JCLI2731.1

Lin, J.-L., and Co-authors, 2006: Tropical intraseasonal variability in 14 IPCC AR4 models. Part I: Convective signals. *J. Climate,* **19**, 2665–2690.

Sperber, K. R. (2003) Propagation and the vertical structure of the Madden-Julian oscillation. *Mon. Wea. Rev.*, **131**, 3018-3037.

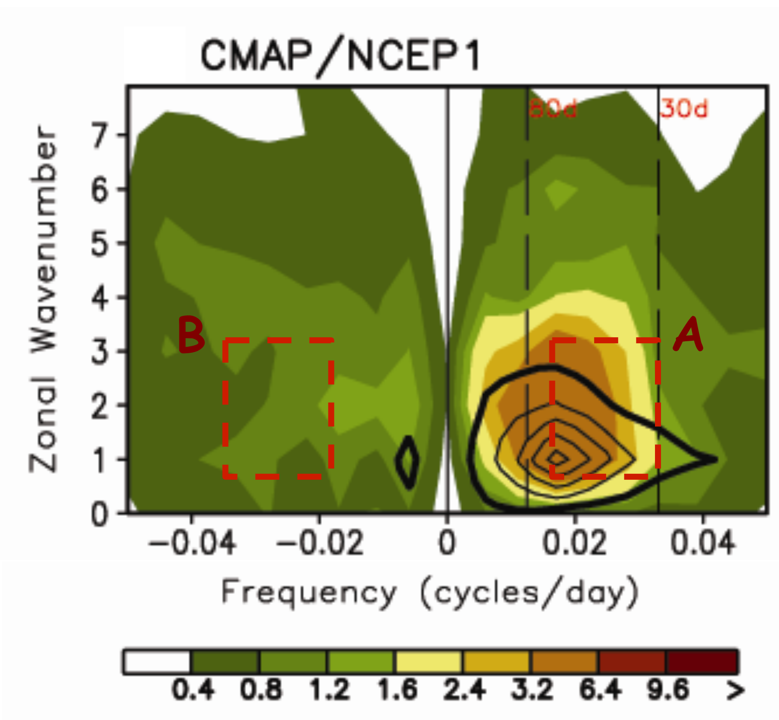
Boreal Summer Intraseasonal Variability

Sperber, K. R., H. Annamalai, I.-S. Kang, A. Kitoh, A. Moise, A. Turner, B. Wang, and T. Zhou (2012) The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. *Climate Dynamics* (in press)

Sperber, K. R., and H. Annamalai (2008) Coupled model simulations of boreal summer intraseasonal (30-50 day) variability, part 1: systematic errors and caution on use of metrics. *Climate Dynamics*, **31**, 345-372. doi:10.1007/s00382-008-0367-9

Annamalai, H., and K. R. Sperber (2005) Regional heat sources and the active and break phases of boreal summer intraseasonal (30-50 day) variability. *J. Atmos. Sci.*, **62**, 2726-2748.

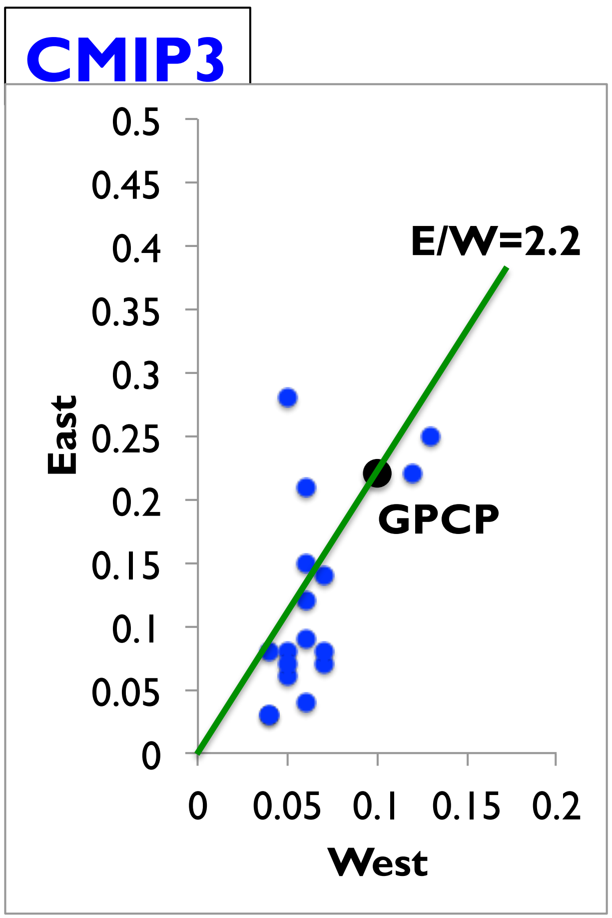
Boreal Winter Madden-Julian Oscillation: Precipitation Wavenumber-Frequency Power Spectrum

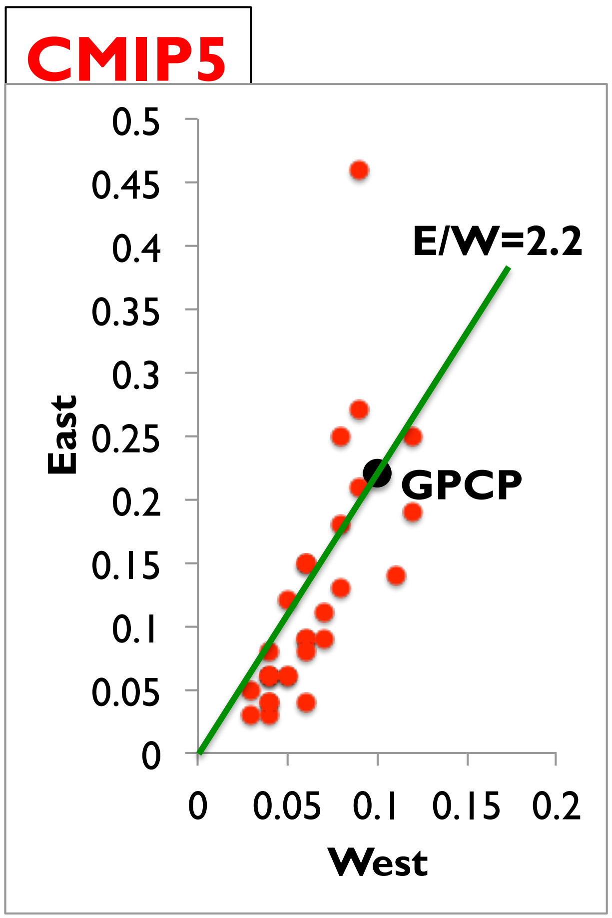


- Diagnostic promoted by the CLIVAR MJO Working Group (CLIVAR MJOWG 2009, Kim et al. 2009)
- East (West)
  sum of spectral power within box A
  (sum of spectral power within box B)
- E/W: East/West
- Wavenumbers 1-3, period 30-60 days
- Model data is interpolated into 2.5 x 2.5 degree resolution
- 20-year (1979-1998) period from CMIP3 and CMIP5
- GPCP data for 1997-2008 is used as reference

Boreal Winter Madden-Julian Oscillation: Precipitation Wavenumber-Frequency East Power vs. West Power

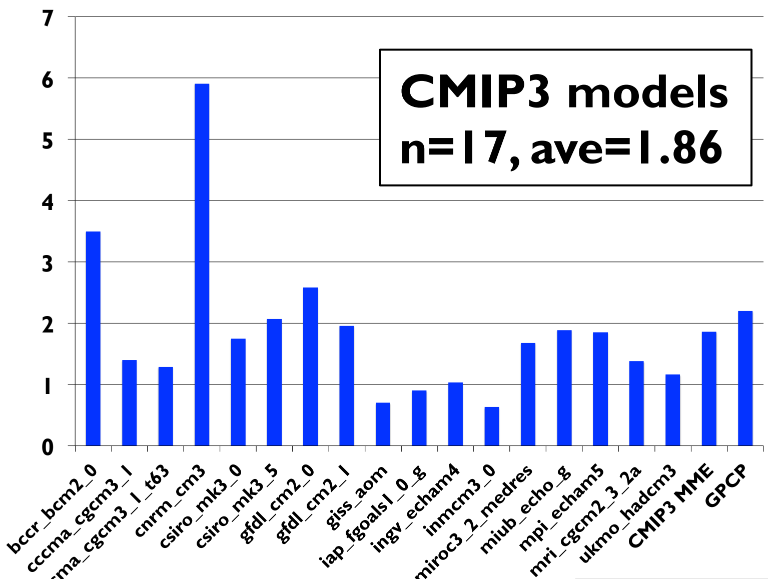
- Wavenumbers 1-3, period 30-60 days
  - The majority of models have weak intraseasonal variance
  - The majority of models have eastward power that is underestimated relative to the westward power

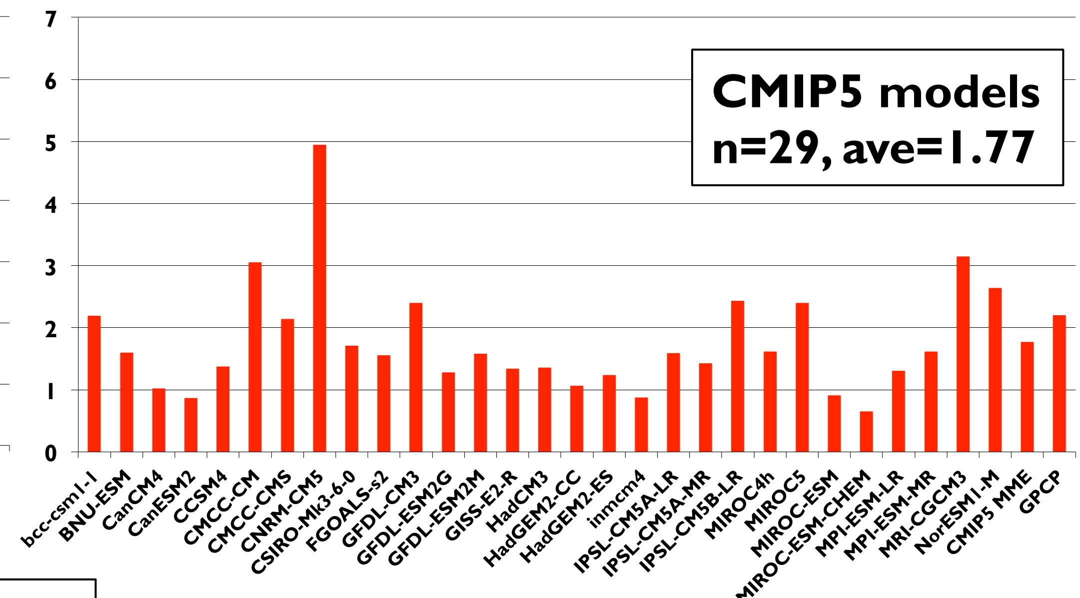




Boreal Winter Madden-Julian Oscillation: Precipitation Wavenumber-Frequency East/West Ratio

- Wavenumbers 1-3, period 30-60 days
  - CMIP5: more models have a realistic East/West Ratio in the MJO band
    - 9/29 (31%) CMIP5 models have an E/W ratio >2, compared to 4/17 (24%) of the CMIP3 models

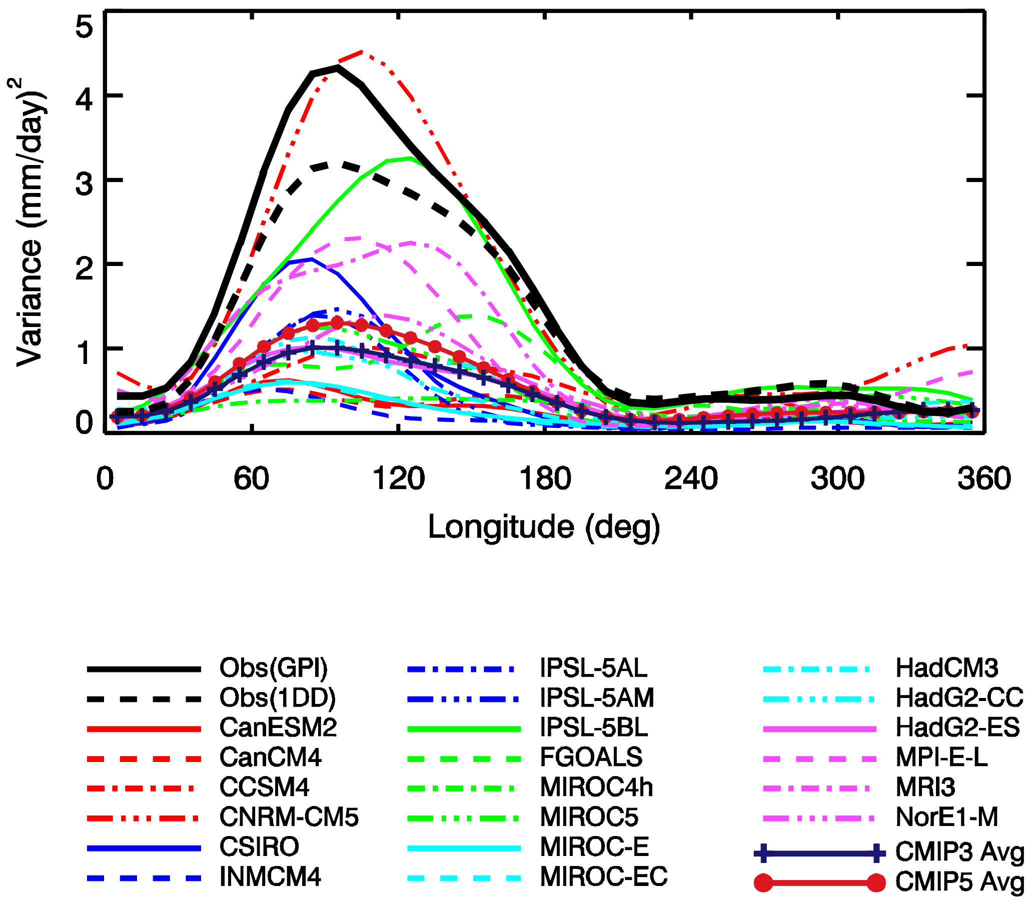




GPCP=2.2

Boreal Winter Madden-Julian Oscillation Precipitation Variance (5ºN-5ºS average)

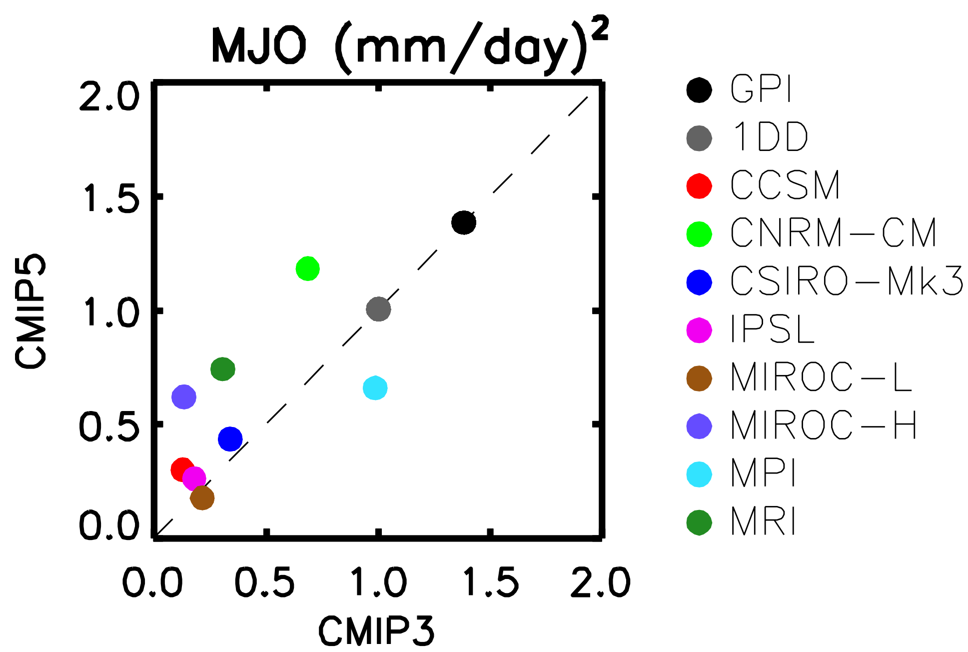
- Wavenumber 1-6, period 30-70 days
  - The majority of models underestimate MJO variance
  - The CMIP5 average is improved relative to the CMIP3 average



Boreal Winter Madden-Julian Oscillation Precipitation Variance (15°N-15°S, 65°E-185°E average): CMIP5 vs. CMIP3

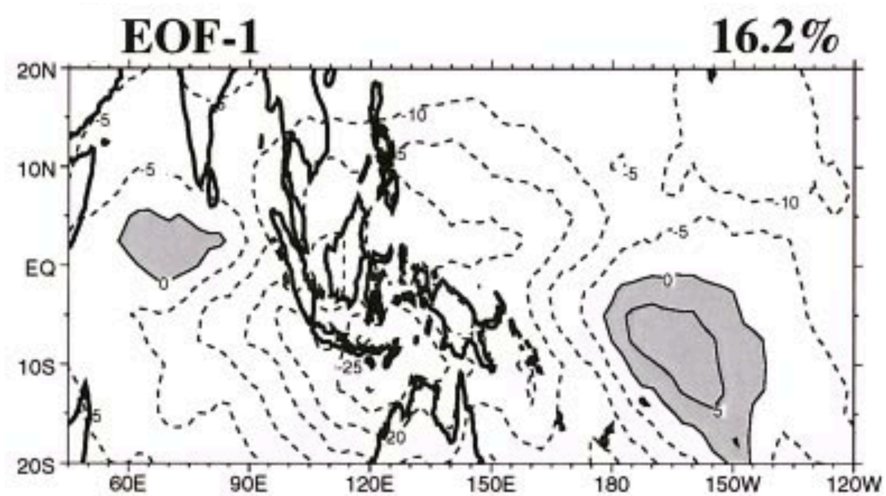
- Wavenumber 1-6, period 30-70 days
  - Paired CMIP5 and CMIP3 models
  - Most CMIP5 counterparts have improved their MJO variance

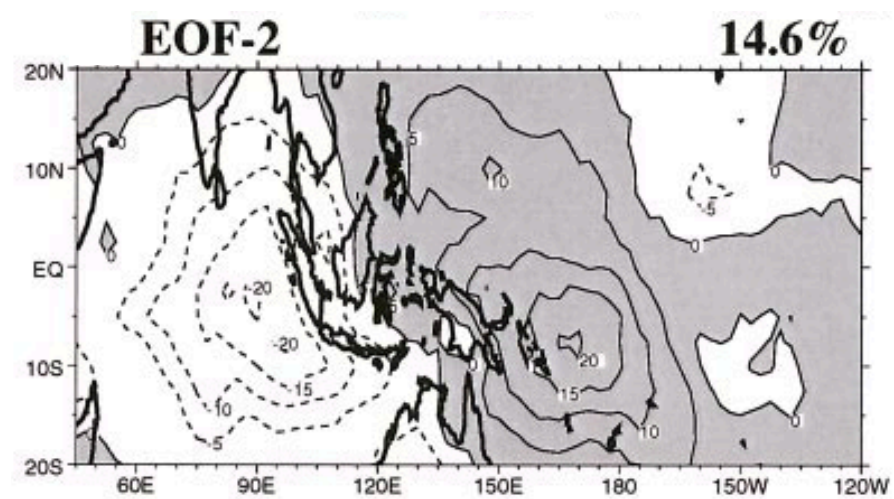
CMIP3	CMIP5
CCSM3	CCSM4
CNRM-CM3	CNRM-CM5
CSIRO-Mk3.0	CSIRO-Mk3.6.0
IPSL-CM4	IPSL-CM5A-MR
MIROC3.2 medres	MIROC4h
MIROC3.2 hires	MIROC5
MPI-OM	MPI-ESM-LR
MRI-CGCM2.3.2	MRI-CGCM3



Boreal Winter Madden-Julian Oscillation: Outgoing Longwave Radiation (Wm^{-2})

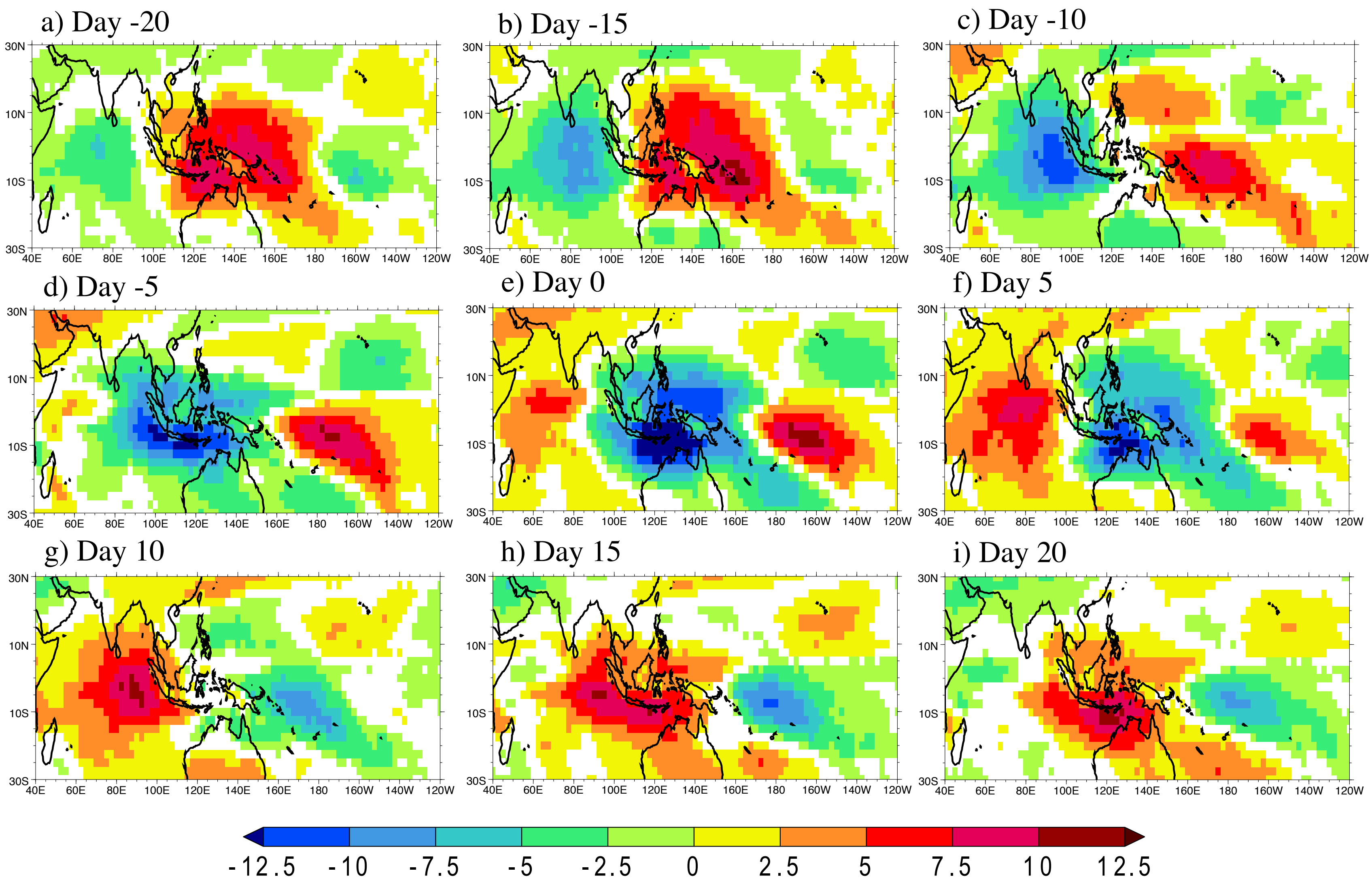
- Unified Approach to Model Diagnosis
  - Regrid model data to AVHRR OLR grid, and apply 20-100 day bandpass filter
  - Project model filtered OLR onto the leading MJO EOF’s obtained from 20-100 day filtered AVHRR OLR (Sperber 2003, *Mon. Wea. Rev.*, **131**, 3018-3037)
  - The resulting PC’s are used for lag regression to reconstruct the MJO Life-Cycle (the regression fit is for 1 standard deviation of the PC)





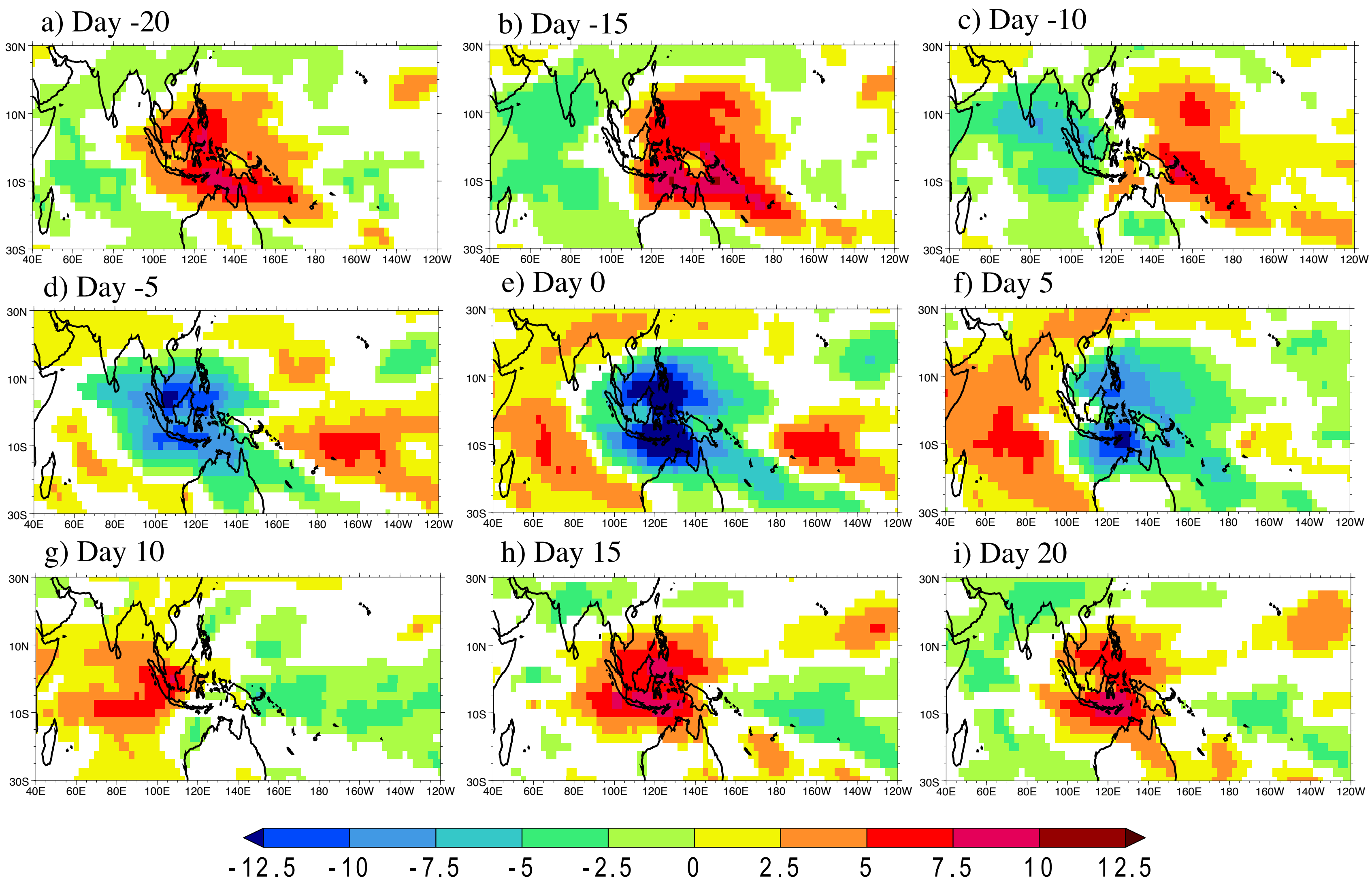
Boreal Winter Madden-Julian Oscillation using 20-100 day Filtered OLR (Wm^{-2}): AVHRR Observations

- Eastward propagation of convective anomalies from the Indian Ocean to the Central Pacific Ocean



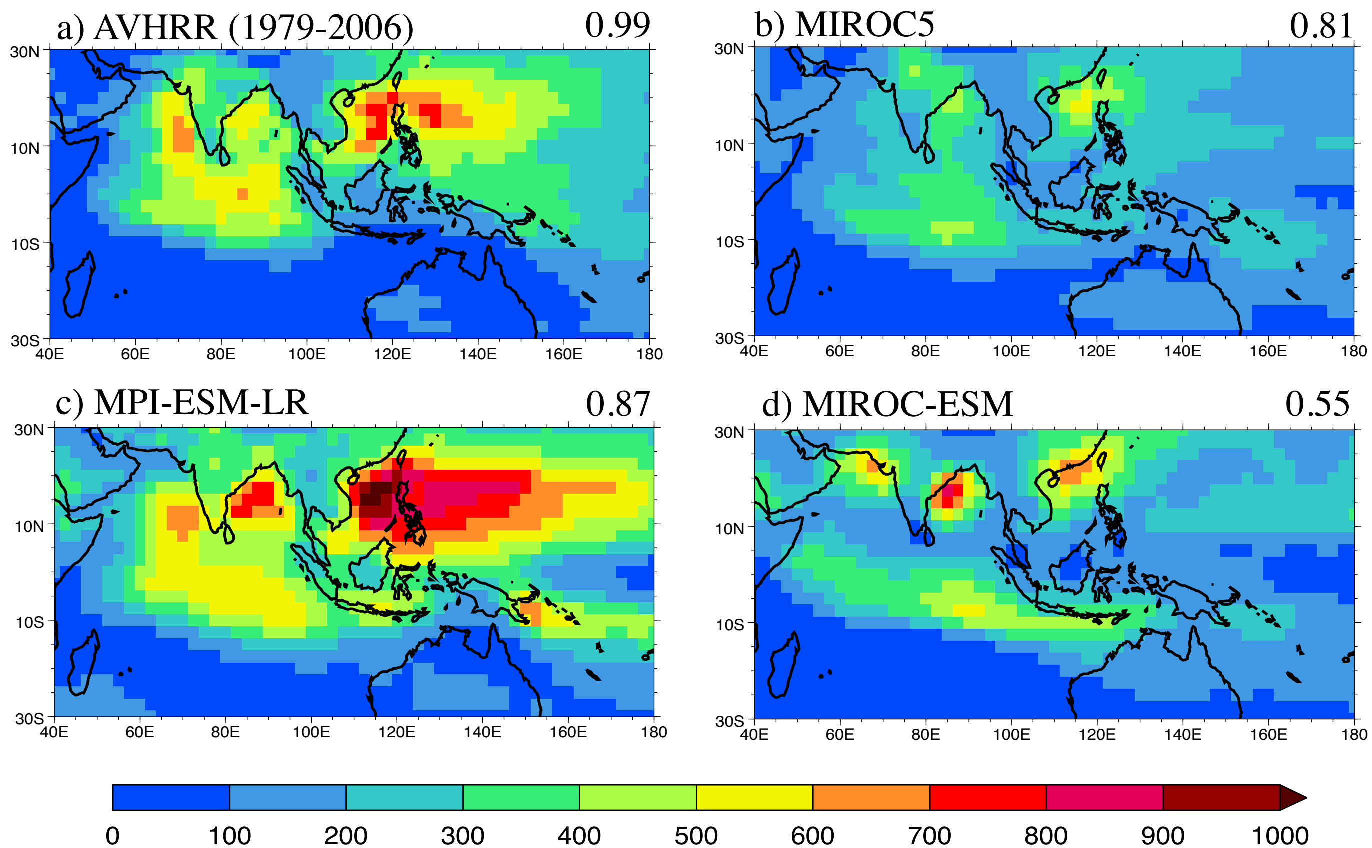
Boreal Winter Madden-Julian Oscillation using 20-100 day Filtered OLR (Wm^{-2}): NorESM1-M

- Eastward propagation of convective anomalies from the Indian Ocean to the Central Pacific Ocean (curiously, during boreal summer this model is dominated by westward propagation!)



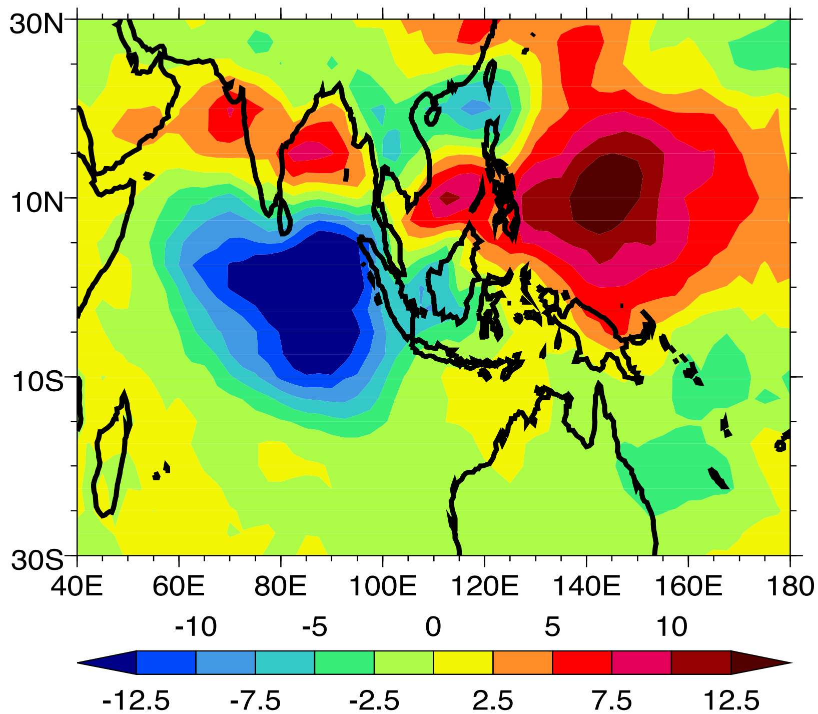
Boreal Summer Intraseasonal Variability (BSISV): 20-100 day Variance $(Wm^{-2})^2$

- CMIP3 and CMIP2+ discussed in detail in Sperber and Annamalai (2008)
  - Only 1 model, ECHAM4/OPYC, gave a high-quality representation of the BSISV
- Variance of 20-100 day bandpass filtered OLR (JJAS)
  - Includes propagating and standing components of intraseasonal variability



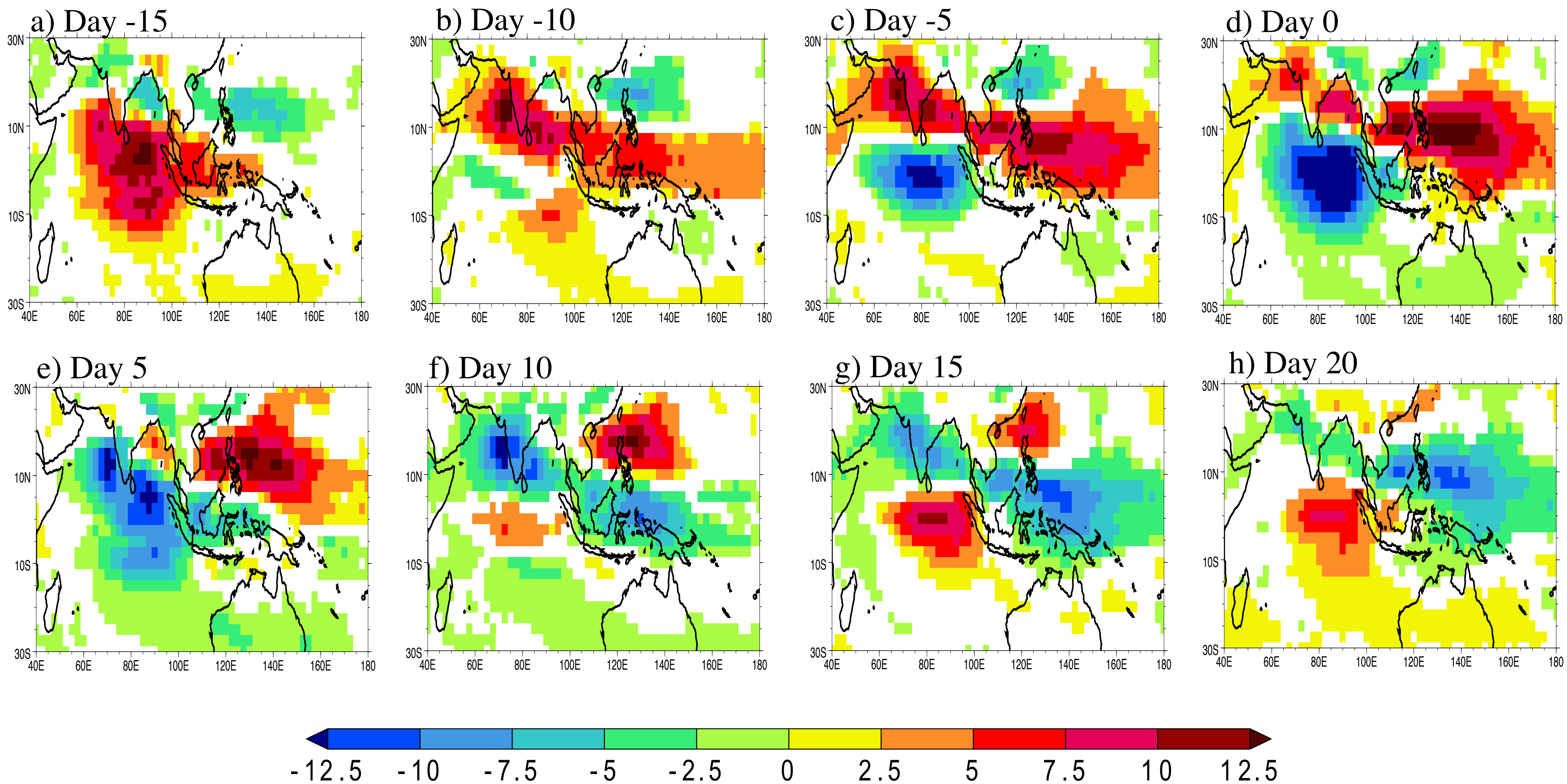
BSISV Life-Cycle: Outgoing Longwave Radiation (Wm^{-2})

- Unified Approach to Model Diagnosis
  - Regrid model data to AVHRR OLR grid, and apply 20-100 day bandpass filter
  - Project model filtered OLR onto the Day 0 Cyclostationary EOF pattern obtained from 20-100 day filtered AVHRR OLR (Annamalai and Sperber 2005, *JAS*, 62, 2726-2748)
  - The resulting PC is used for lag regression to reconstruct the BSISV Life-Cycle (the regression fit is for 1 standard deviation of the PC)



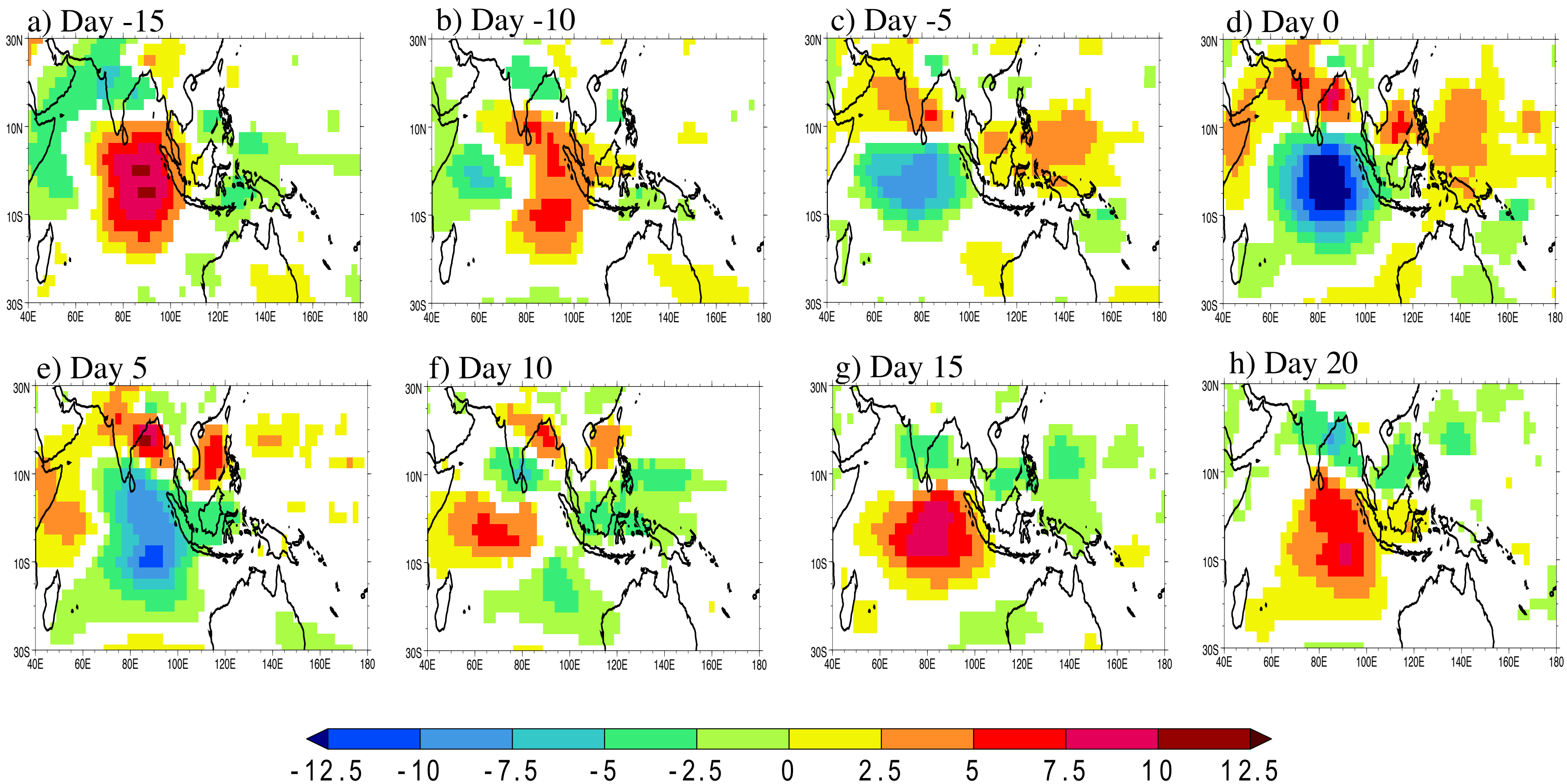
BSISV Life-Cycle using 20-100 day Filtered OLR (Wm^{-2}): AVHRR Observations

- Eastward and northward propagating OLR anomalies (Annamalai and Sperber 2005, *JAS*, 62, 2726-2748)
- The Day 10 tilted rainband is a key component of the BSISV



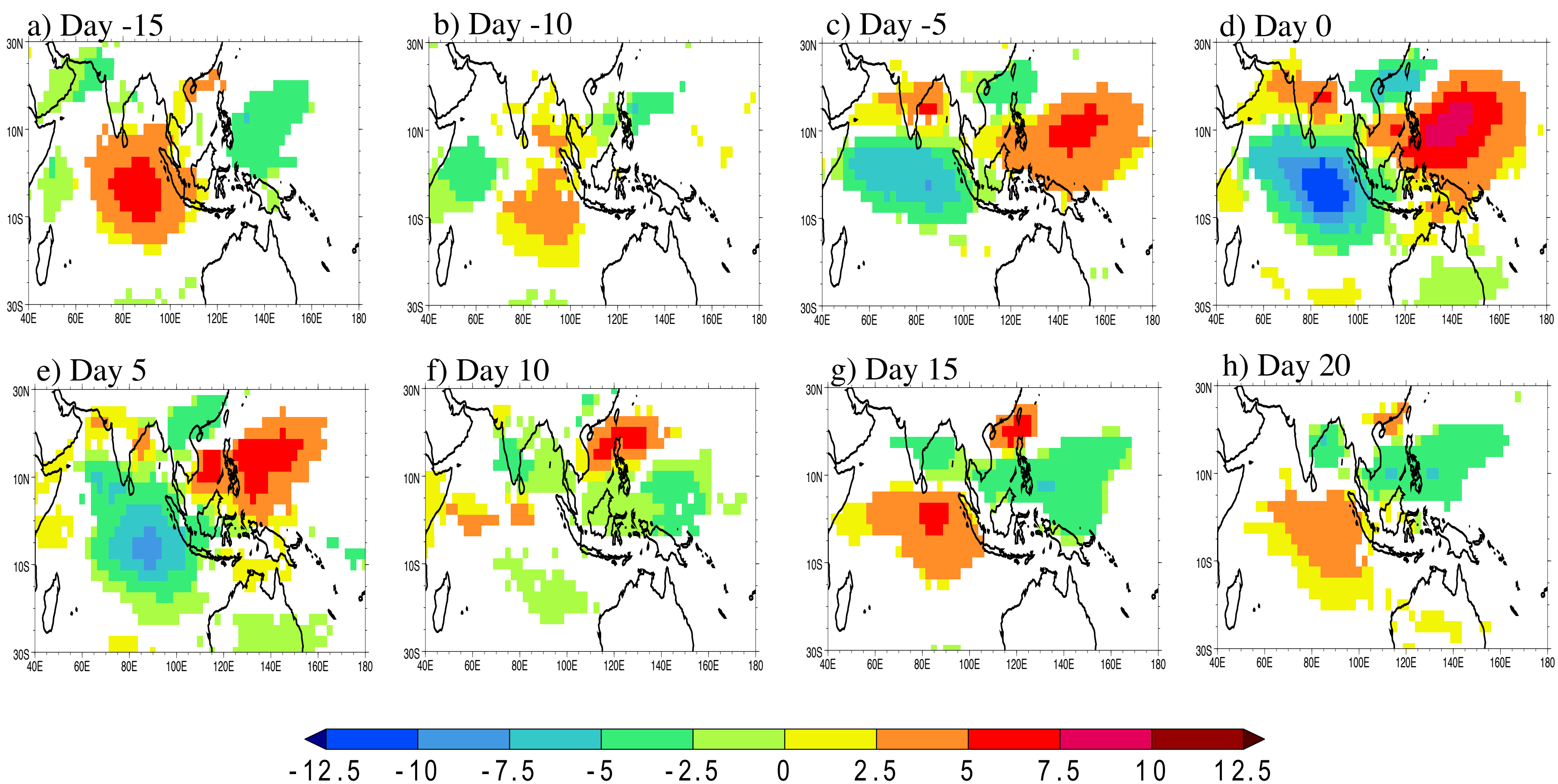
BSISV Life-Cycle using 20-100 day Filtered AVHRR OLR (Wm^{-2}): MIROC5

- Similar evolution as observed, but the anomalies are weaker
- Only non-ECHAM-4 based model to "reasonably" simulate BSISV
  - MRI-CGCM3, and to a lesser extent GFDL-ESM2G, have the tilted rainband



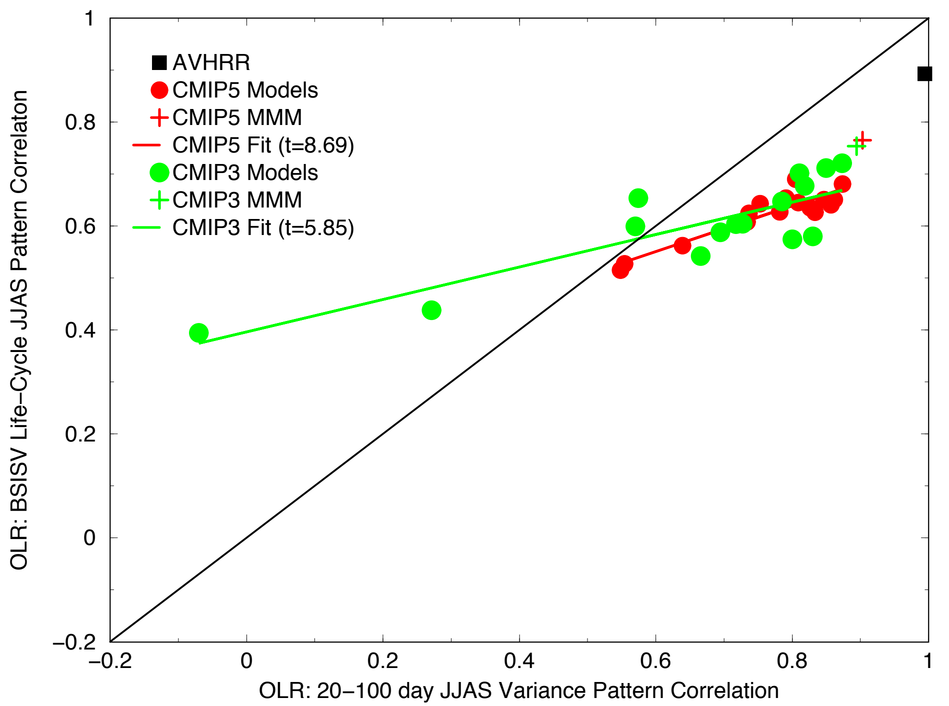
BSISV Life-Cycle using 20-100 day Filtered AVHRR OLR (Wm^{-2}): CMIP5 Multi-Model Mean

- Despite the poor simulation of the BSISV by the vast majority of models, the MMM gives a good representation of the BSISV life-cycle, and the MMM's exceed that skill of the individual models



Skill: 20-100 day Variance vs. BSISV Life-Cycle

- For both CMIP3 and CMIP5, the BSISV is better simulated in models that have a better pattern correlation in their simulation of the 20-100 day filtered variance (the linear regression fits are significant at better than the 1% level)
- This suggests that the location and strength of the filtered variance maxima are largely determined by the propagating BSISV



Preliminary Conclusions/Ongoing Work

- MJO/BSISV: Signal in OLR better represented than that in precipitation
- MJO/BSISV: Intraseasonal variance improved in CMIP5 compared to CMIP3, though most models still underestimate the observed magnitude
- MJO/BSISV: Most models simulate near-equatorial eastward propagation from the Indian Ocean to the Maritime Continent, but have difficulty in exhibiting eastward propagation over the Pacific Ocean
- BSISV: MIROC5 (and to a lesser extent MRI-CGCM3 and GFDL-ESM2G) exhibit northward propagation. This is the first time that non-ECHAM4 based models have shown this capability
- MJO/BSISV: Improvement suggests possible importance of diluted convective updrafts, convective momentum transport (CMT), and moisture-convergence-type convective closure/trigger
- MJO/BSISV: The CMIP5 multi-model mean (MMM) gives a good representation of the life-cycle of the MJO, suggesting a multi-model approach to forecasting the intraseasonal variability could be fruitful
- MJO: The Year of Tropical Convection (YOTC) MJO Task Force is applying MJO process-oriented diagnostics and the CLIVAR MJO Working Group diagnostics to develop a more complete investigation of MJO skill in the CMIP5 models