Systematic Errors in the Tropics and the Role of Multi-Scale Interactions

Julia Slingo

With thanks to many members of NCAS and the Walker Institute
University of Reading

Climate is a Multi-scale system

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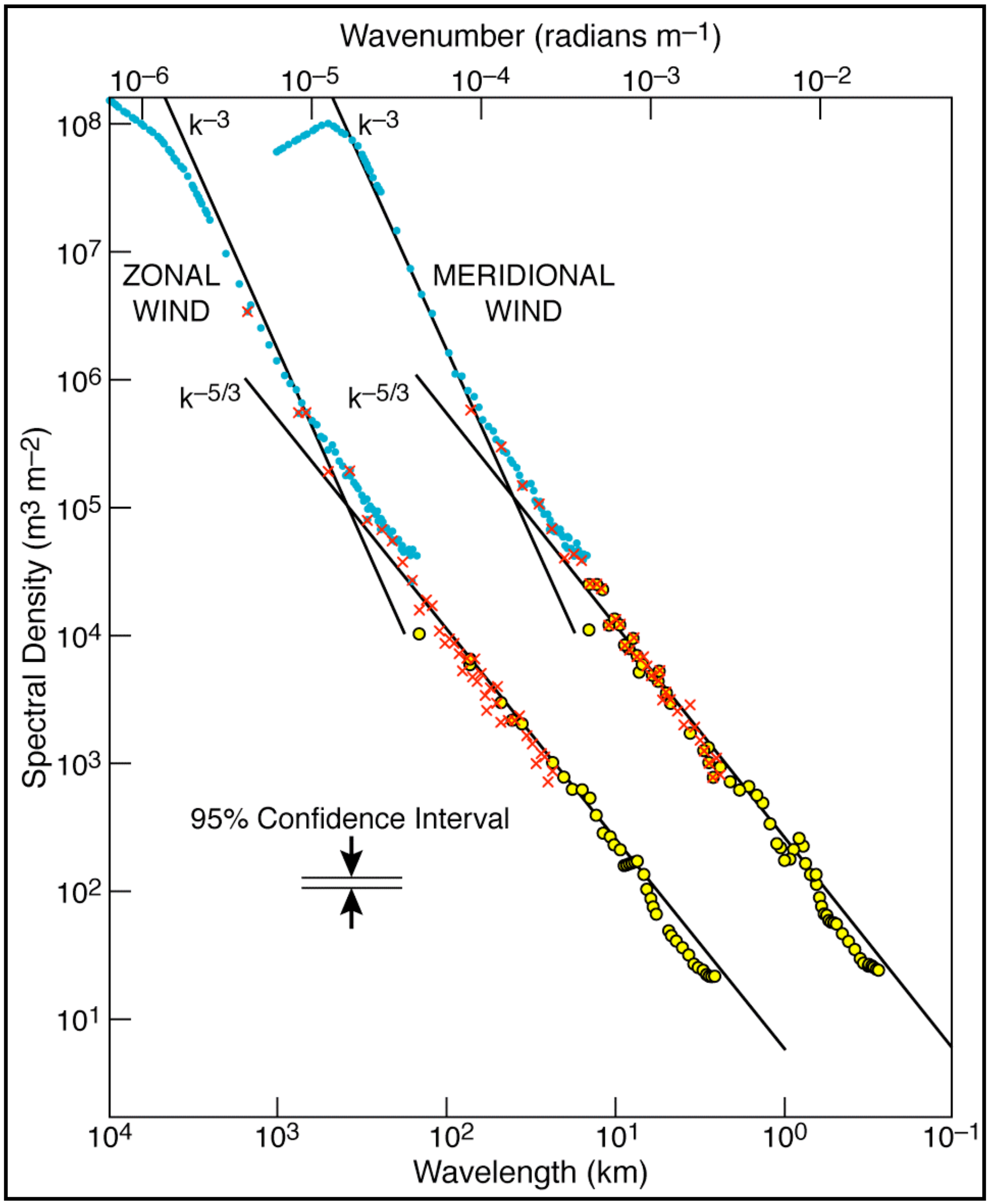

Nastrom and Gage, 1985

- ❖ Climate consists of a continuum of time and spac scales.
- ❖ Traditionally, we have assumed that the effects of unresolved scales can be represented through parametrizations based on b formulae.
- ❖ This inherently assumes t there is no coupling betweer dynamics and physics on the scales.
- ❖ What does this say about upscale energy cascades?

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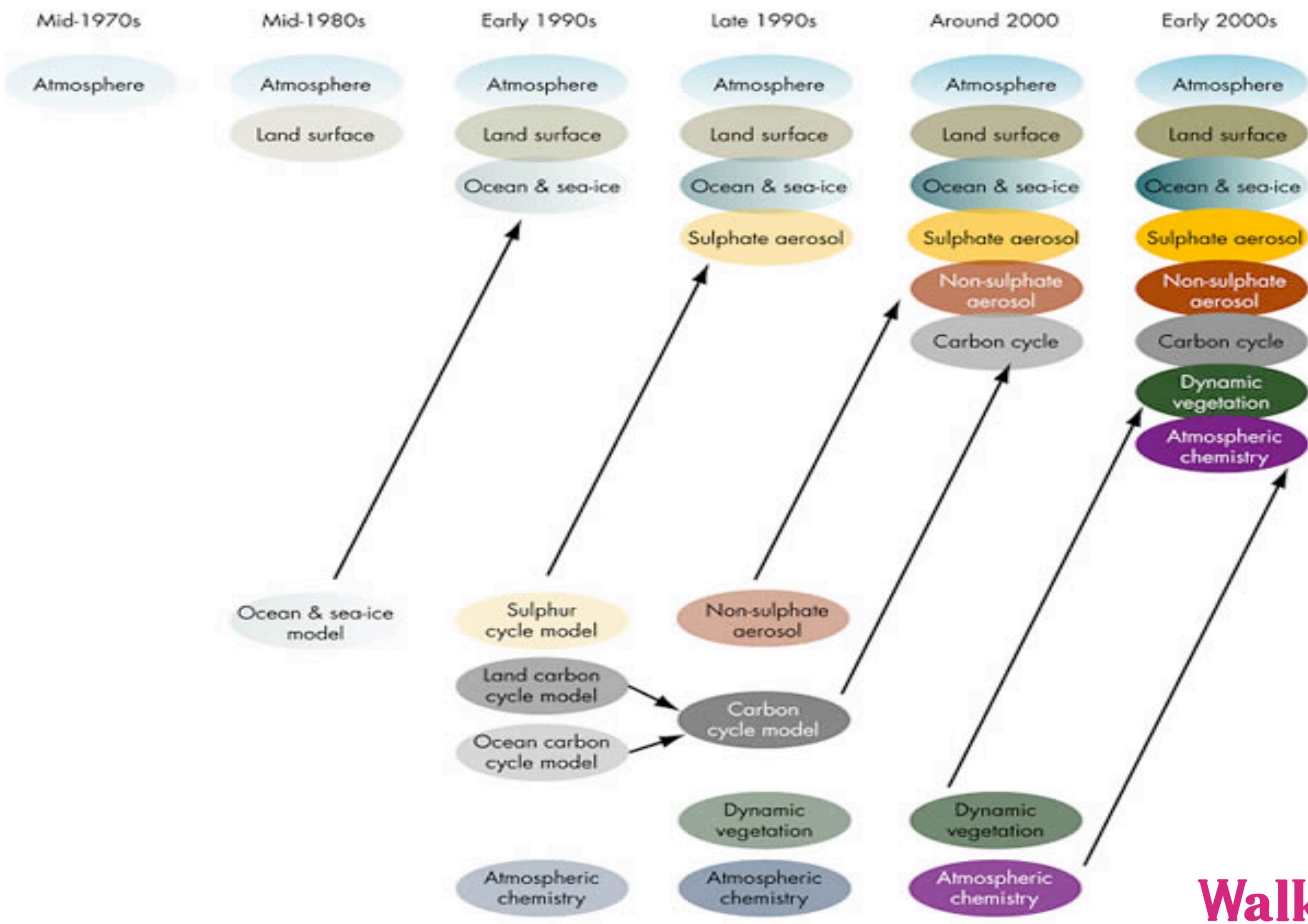
Progression of UK Climate Models

	GATE Tropics 1974	Global 11-level 1980	HadCM2 1994	HadCM3 1998	HadGEM1 2004
Atmosphere	~200km 11 levels	~300km 11 levels	~300km 19 levels	~300km 19 levels	~150km 38 levels
Ocean	-	-	2.5^0 x 3.75^0 20 levels	1.25^0 x 1.25^0 20 levels	1^0 x 1^0 (1/3^0 40 levels
Flux Adjustment?	-	-	Yes	No	No
Computing	?	?	1	4	40

Increasing Complexity in Climate Models



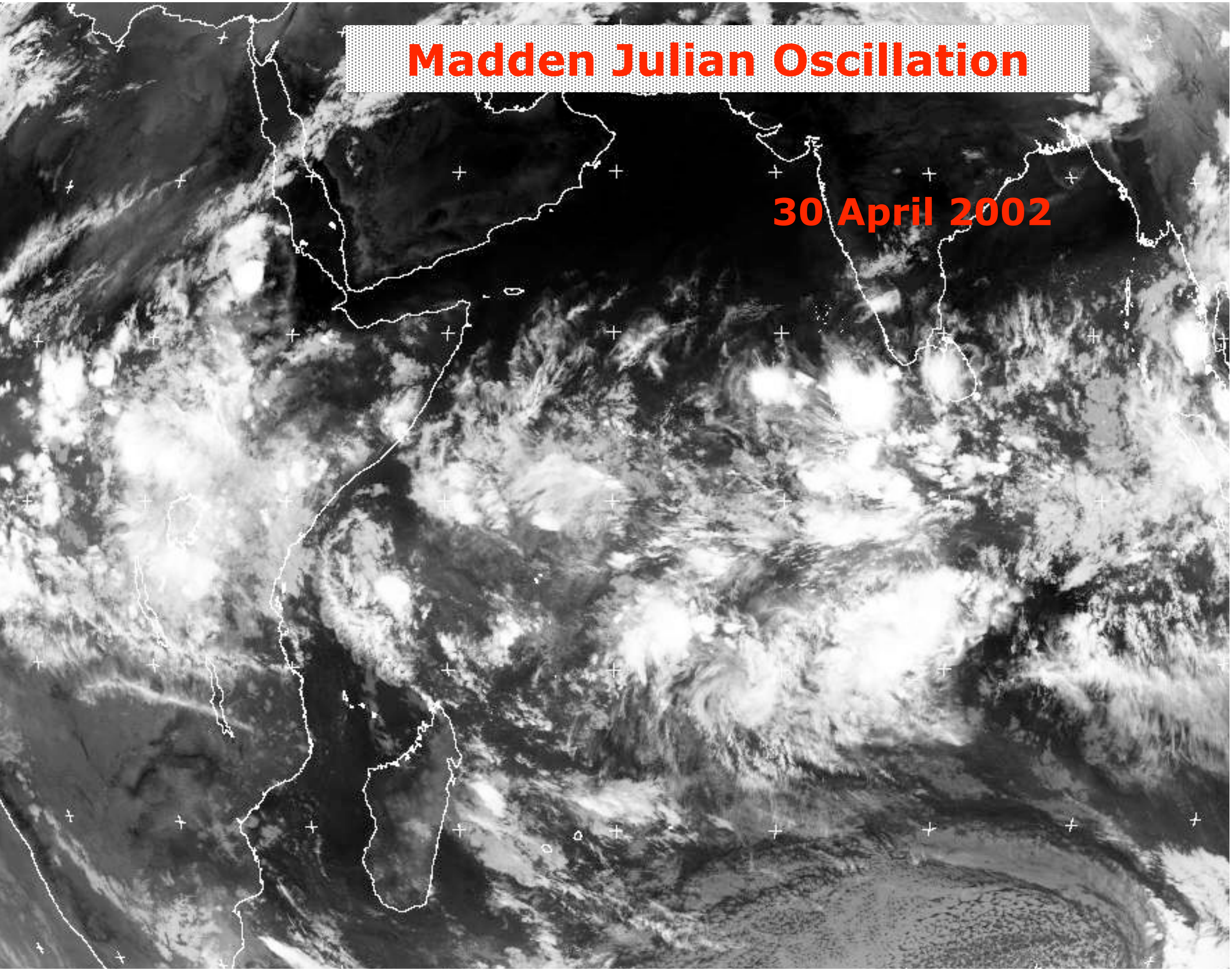
Time to challenge this traditional paradigm for parametrization?

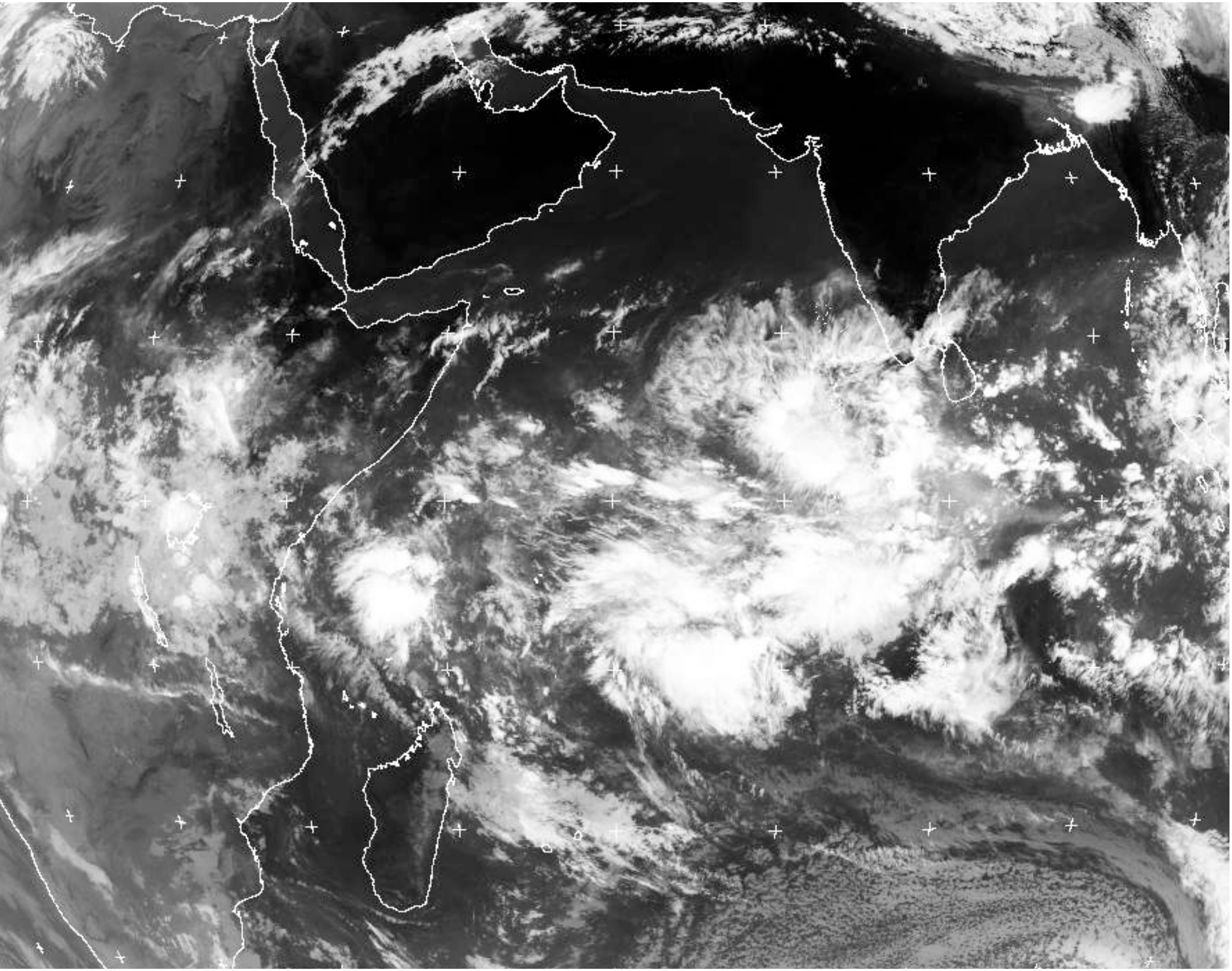
Increasing evidence of multi-scale interactions involving:

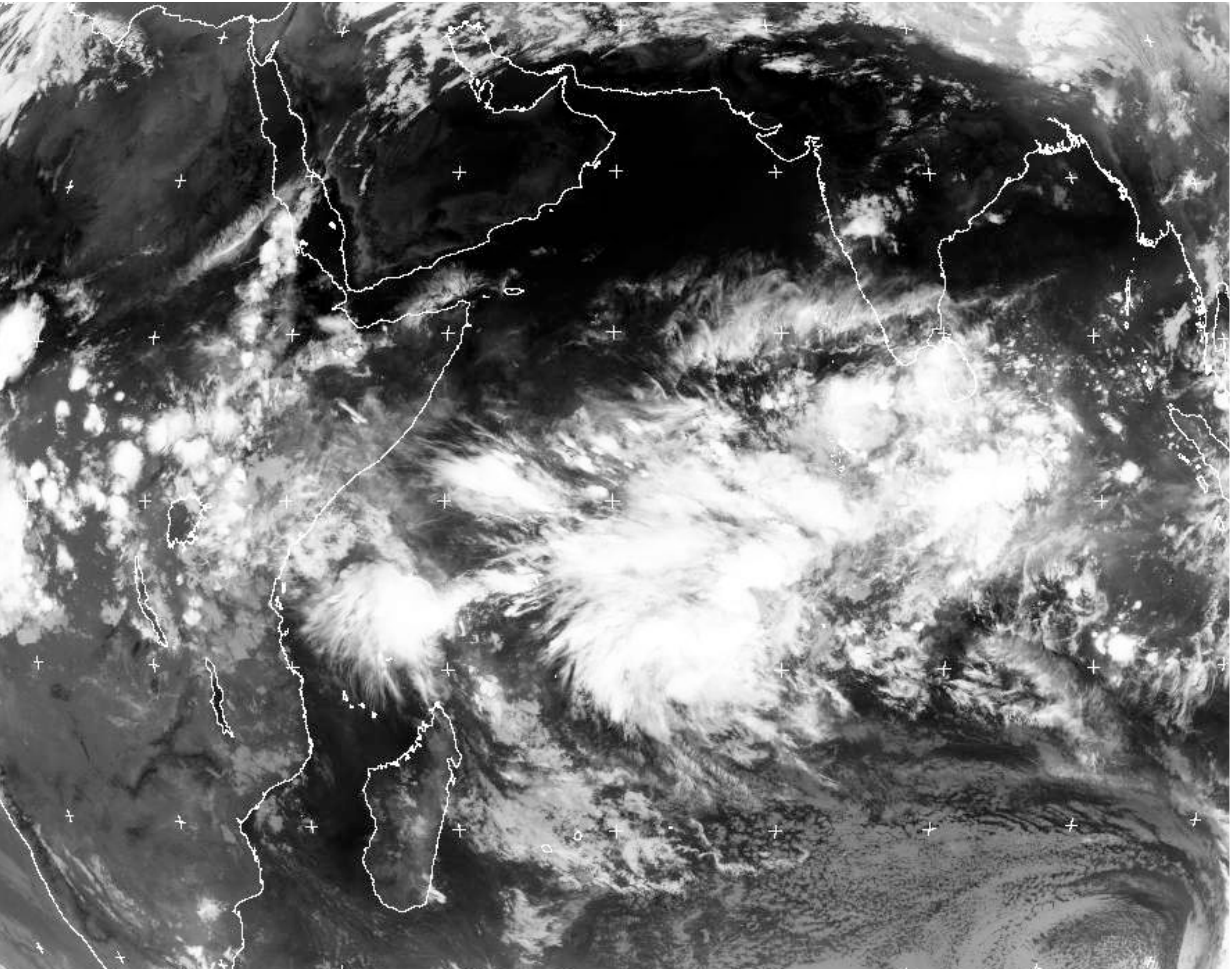
- *Coupling between dynamics and physics on wide range of scales within components of the climate system*
- *Coupling on wide range of scales between components of the climate system*

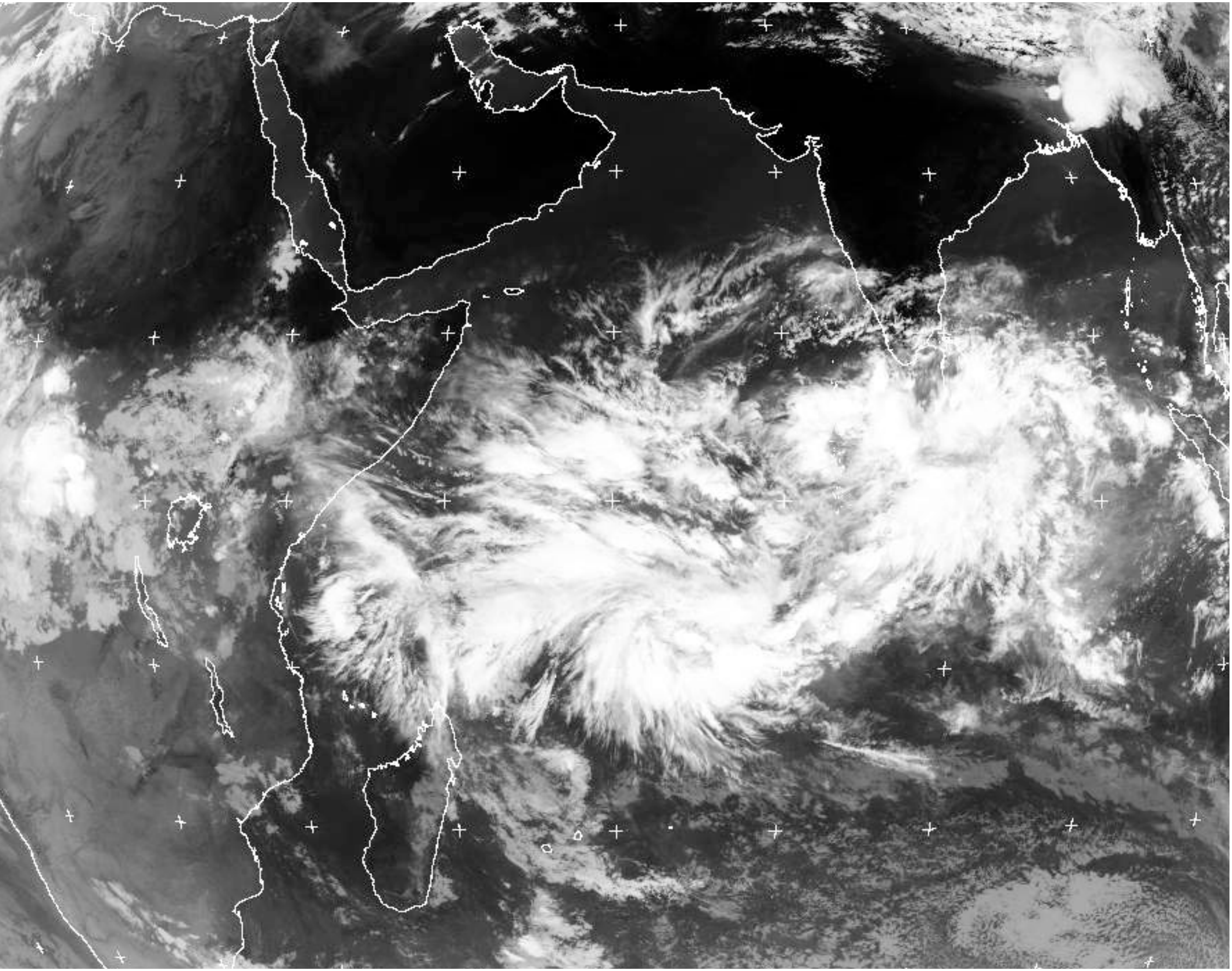
Increasing evidence that multi-scale interactions affect:

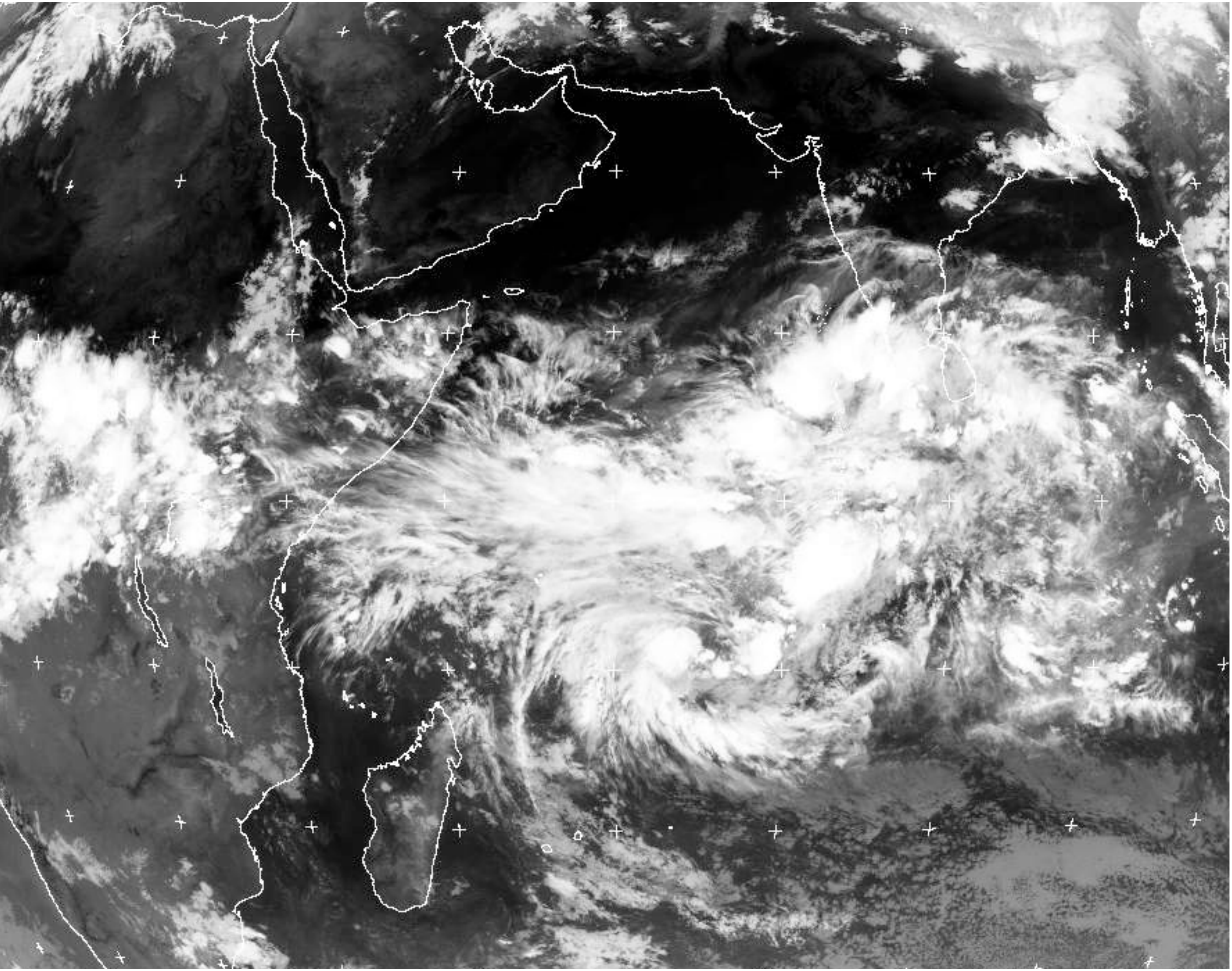
- *Mean state of the climate system*
- *Low frequency variability of the climate system*

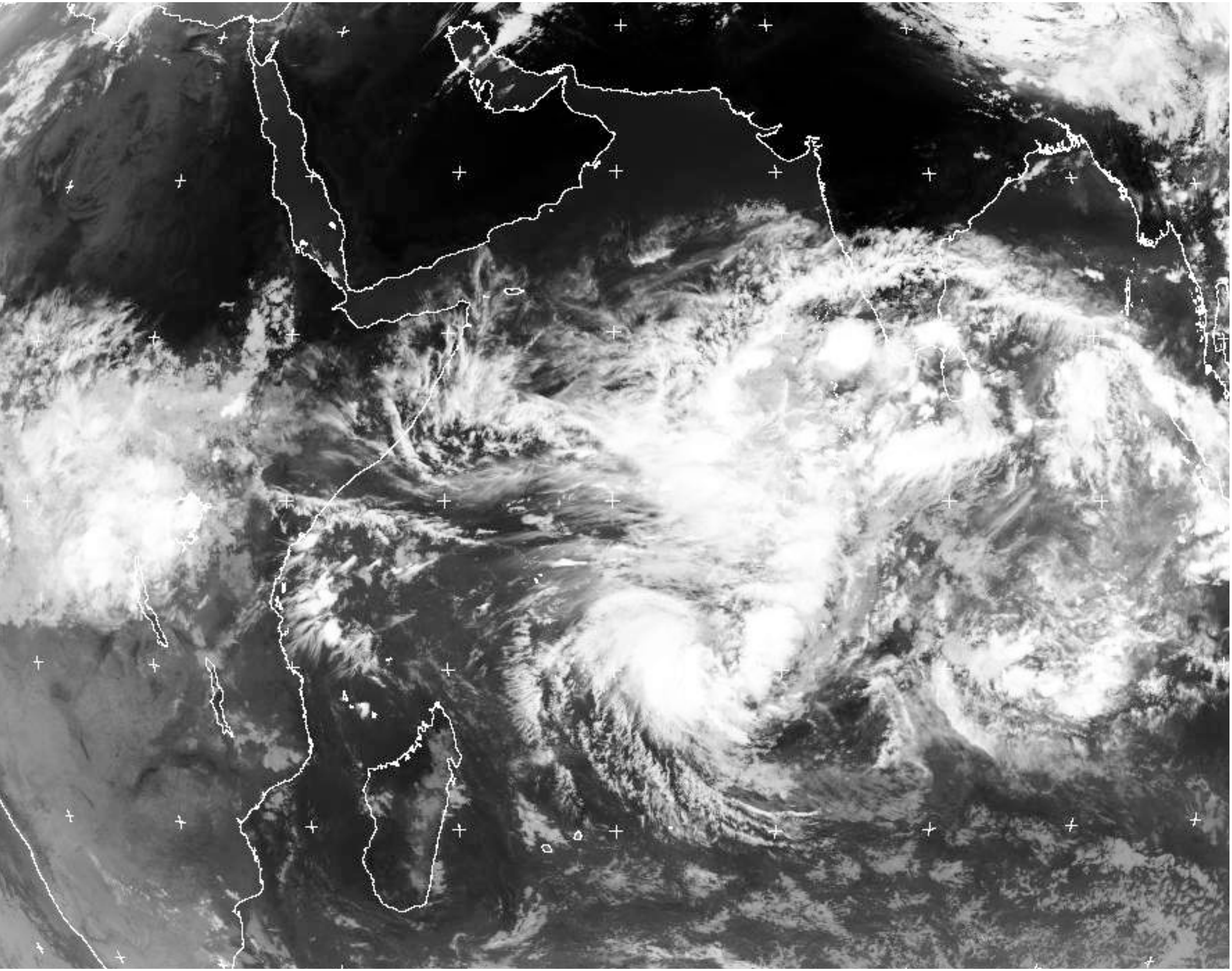

Madden Julian Oscillation
30 April 2002

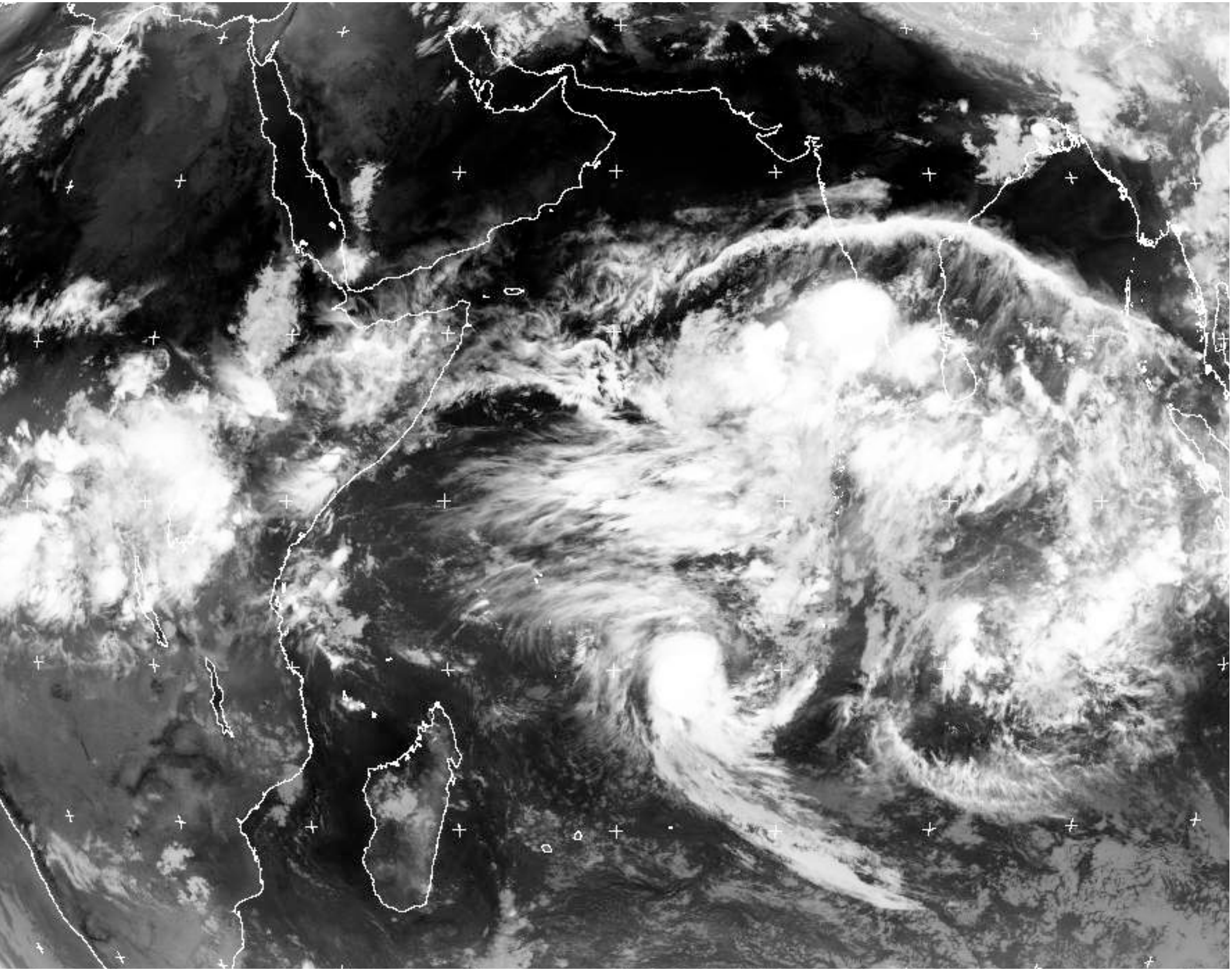


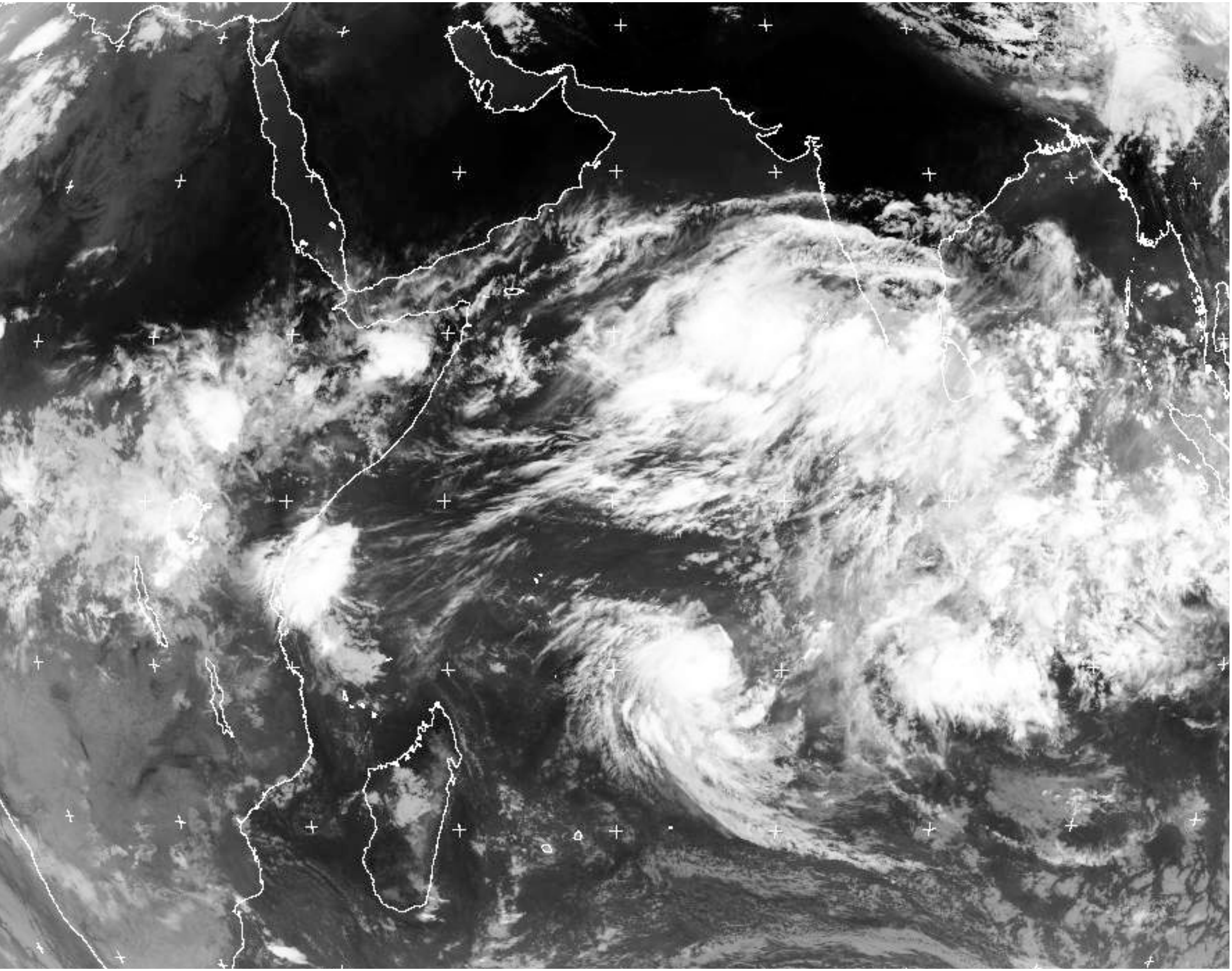


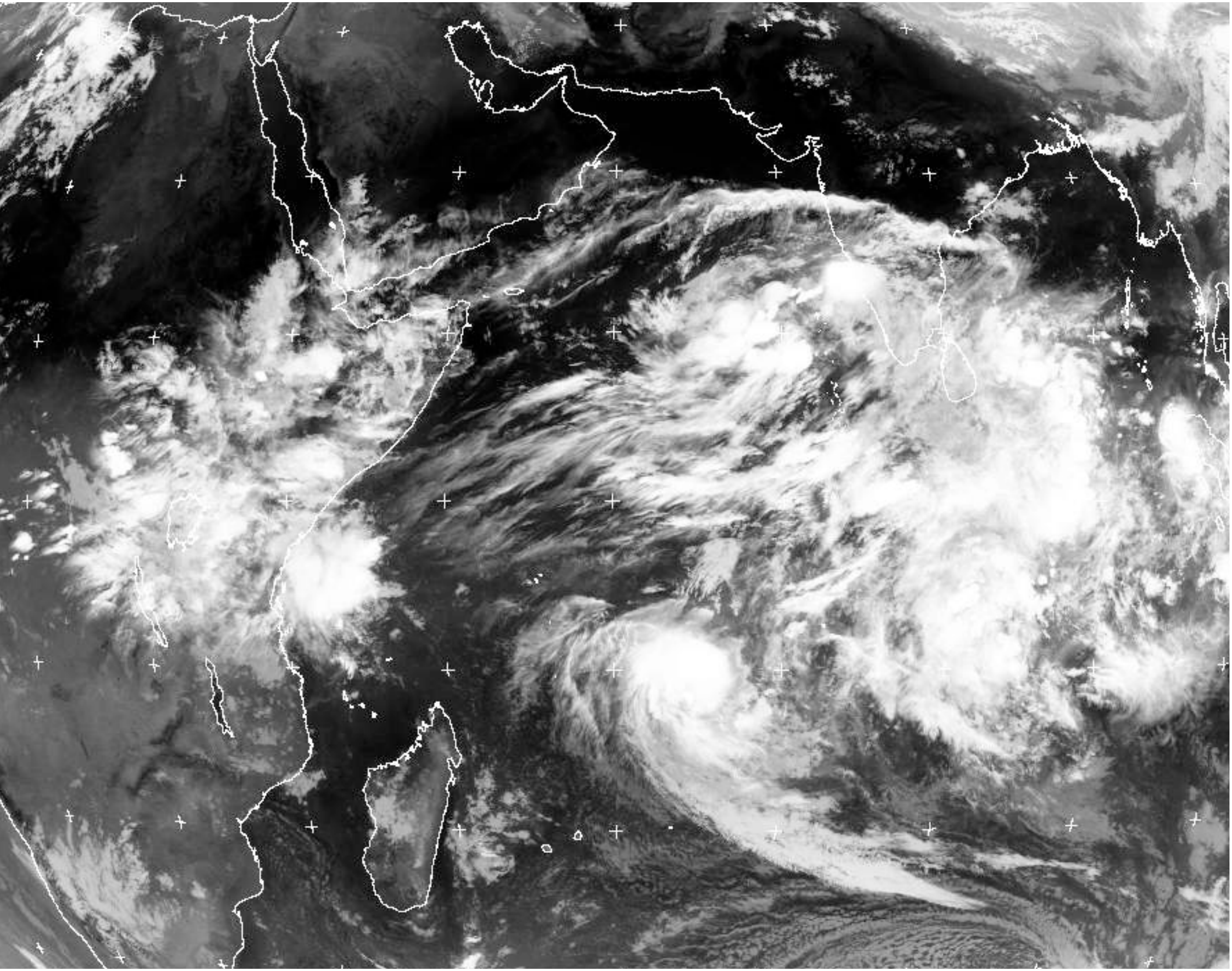


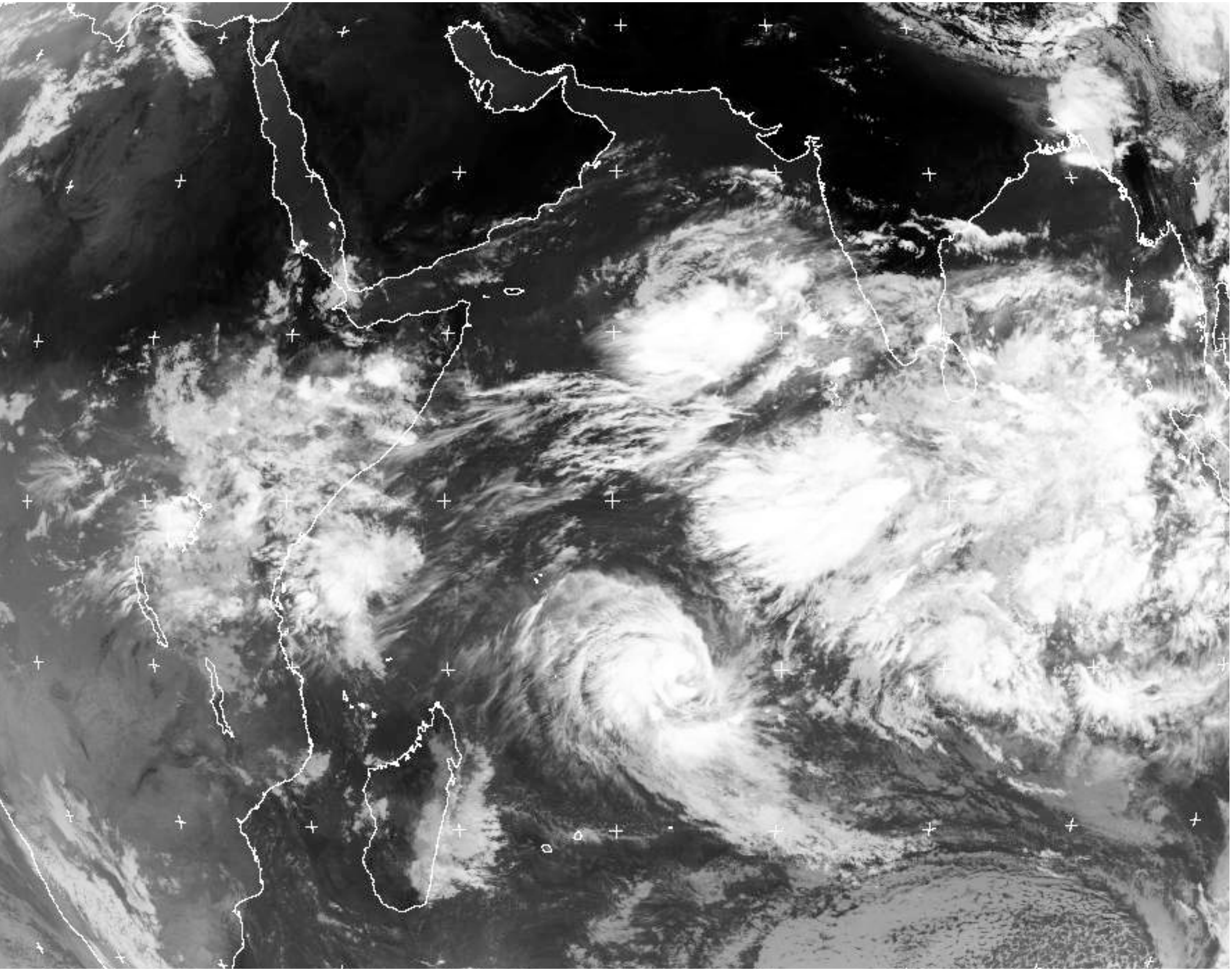


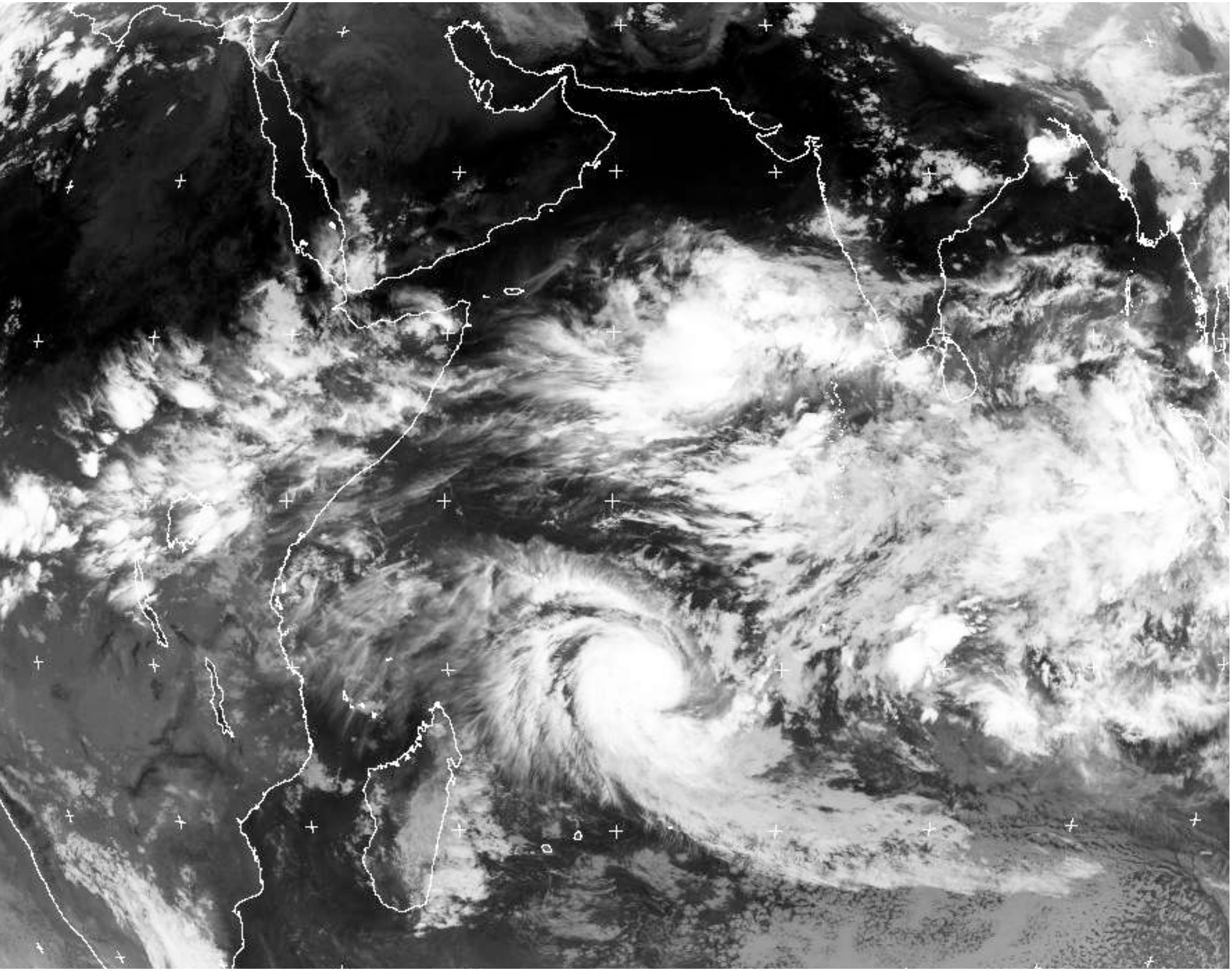


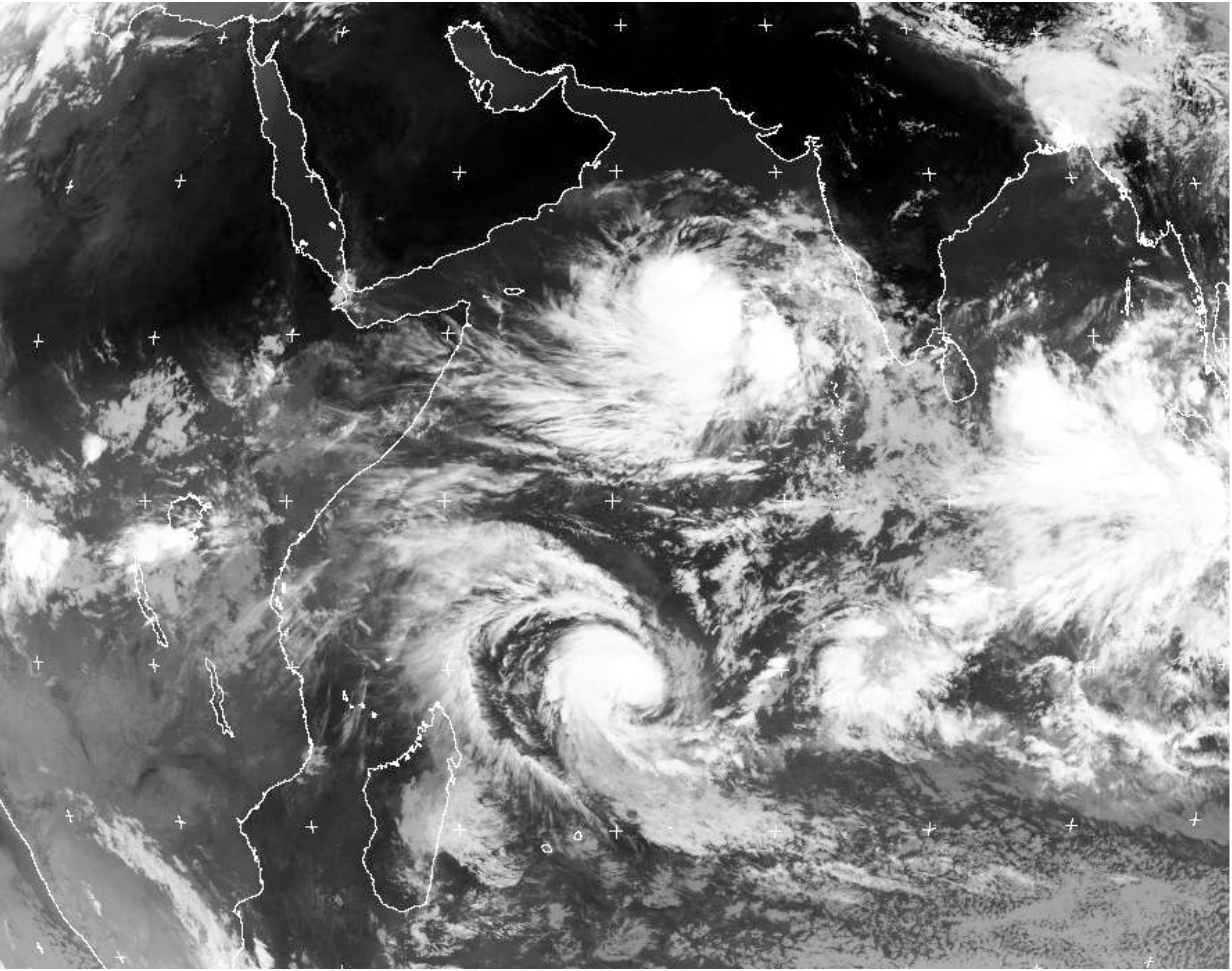


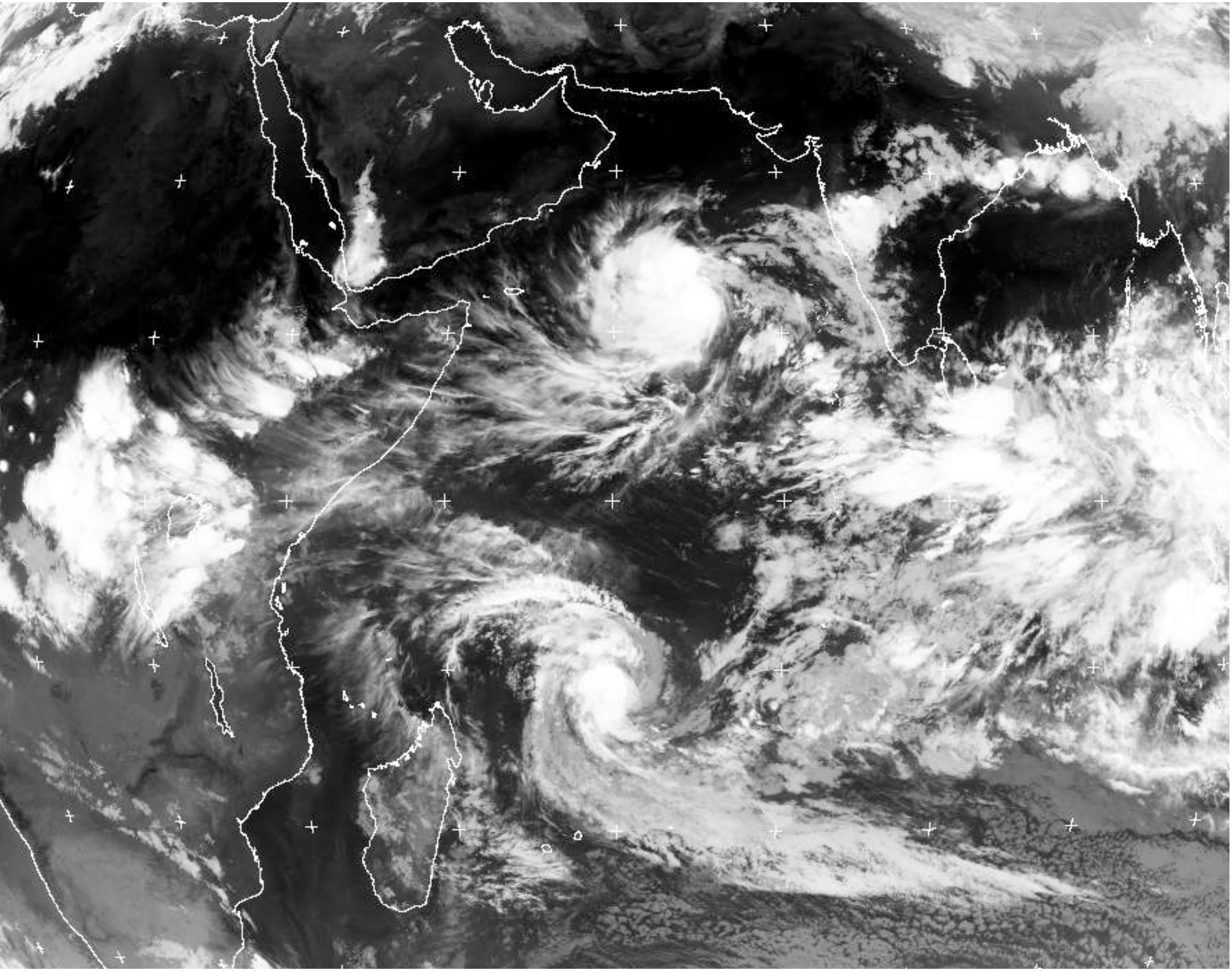


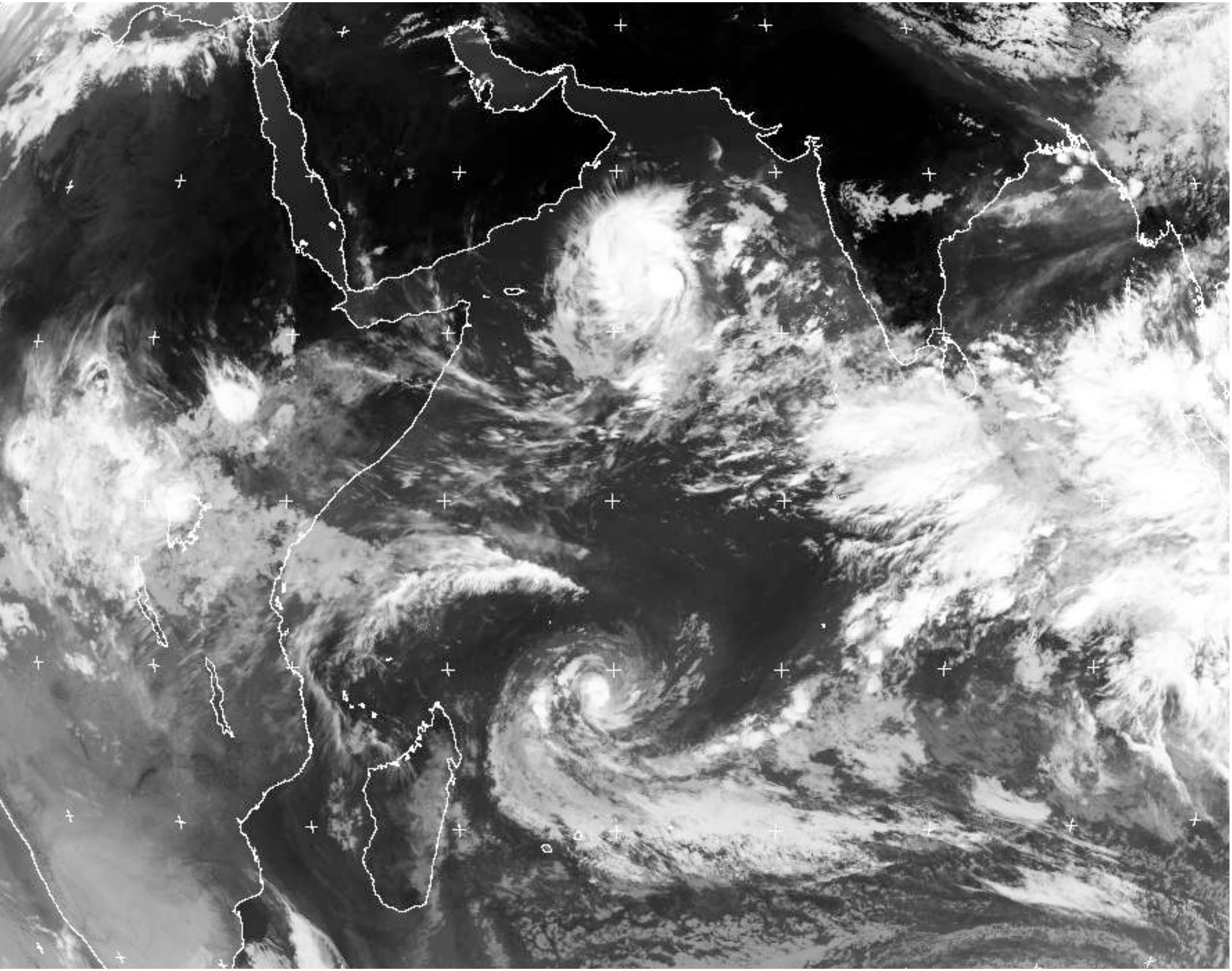


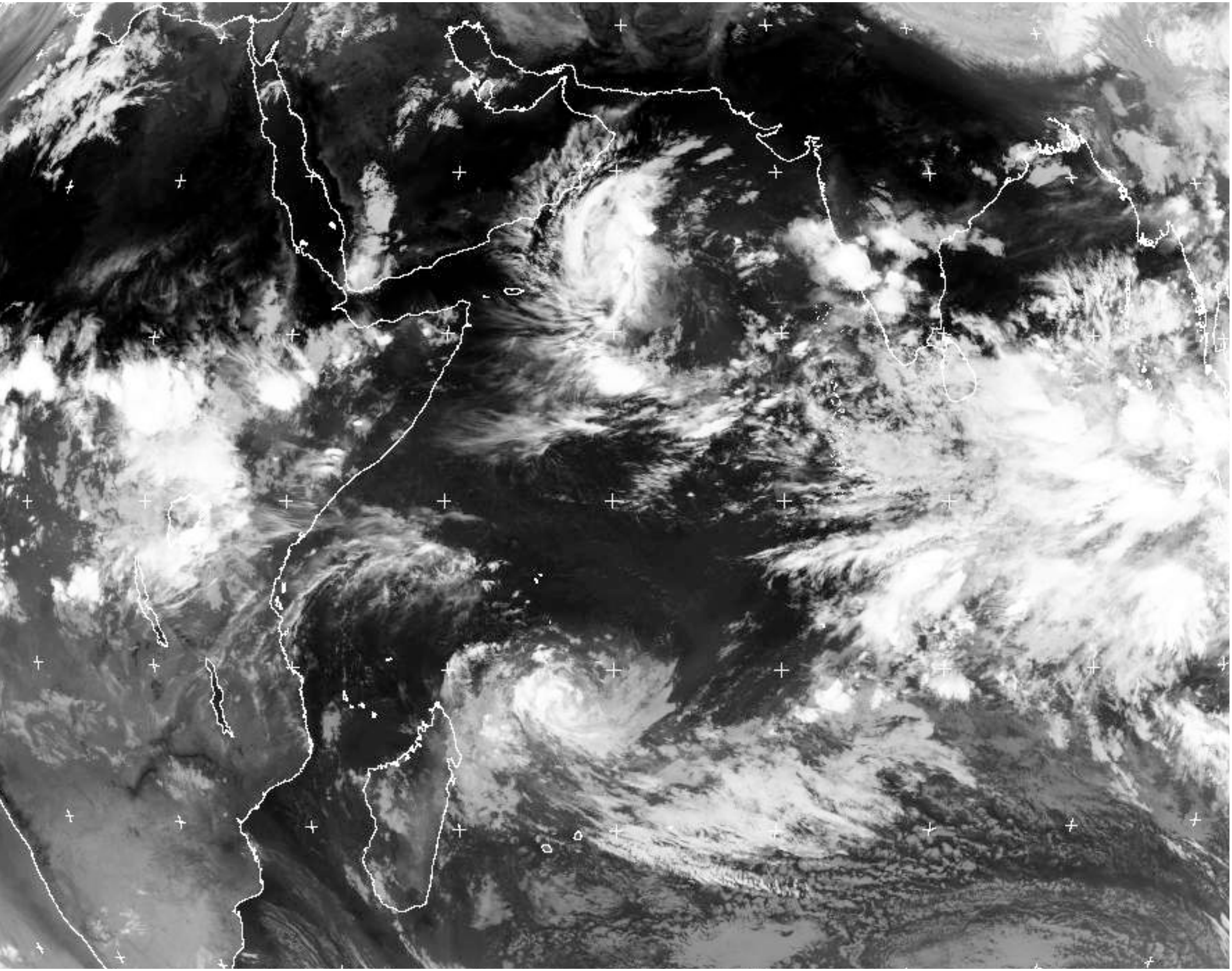


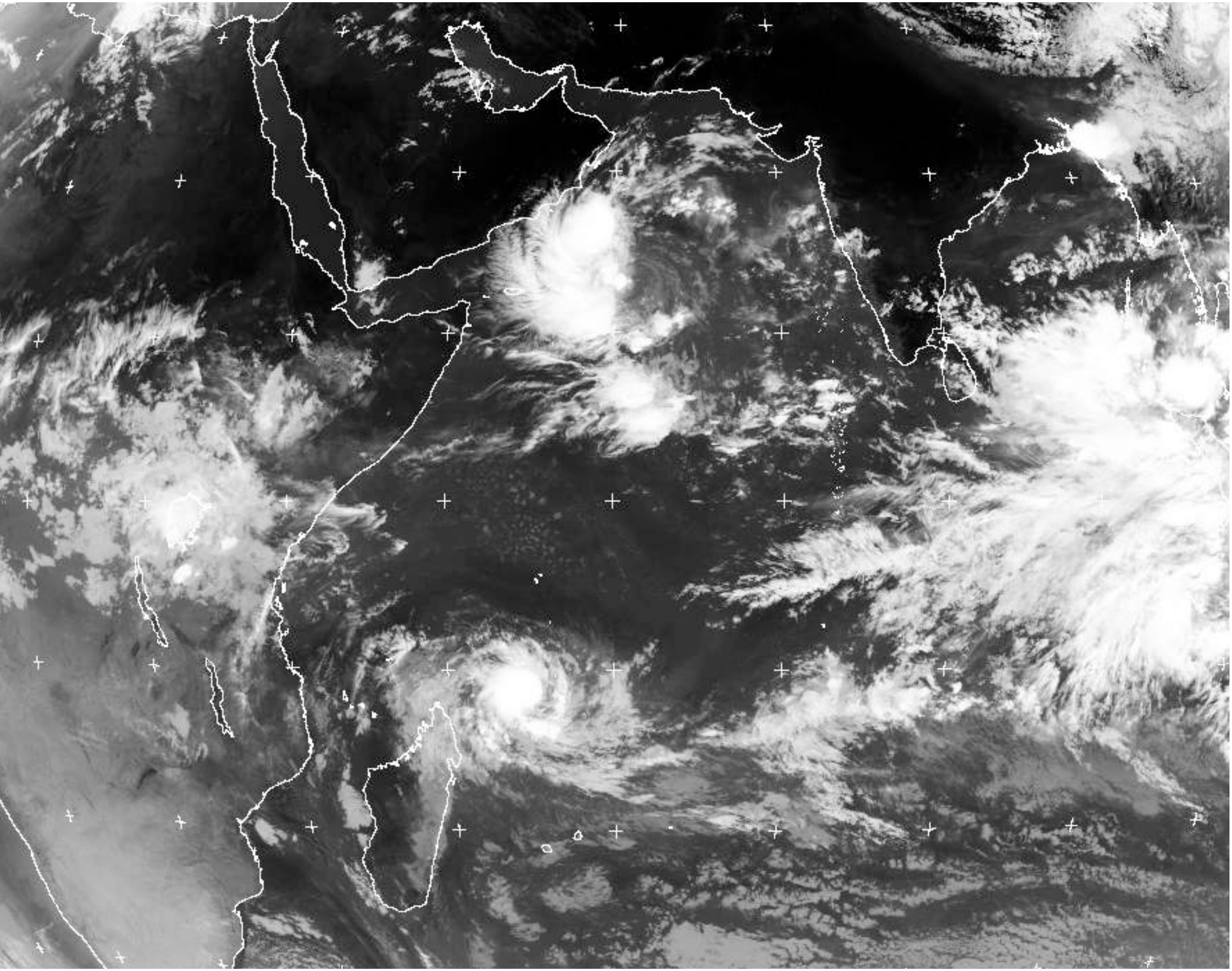


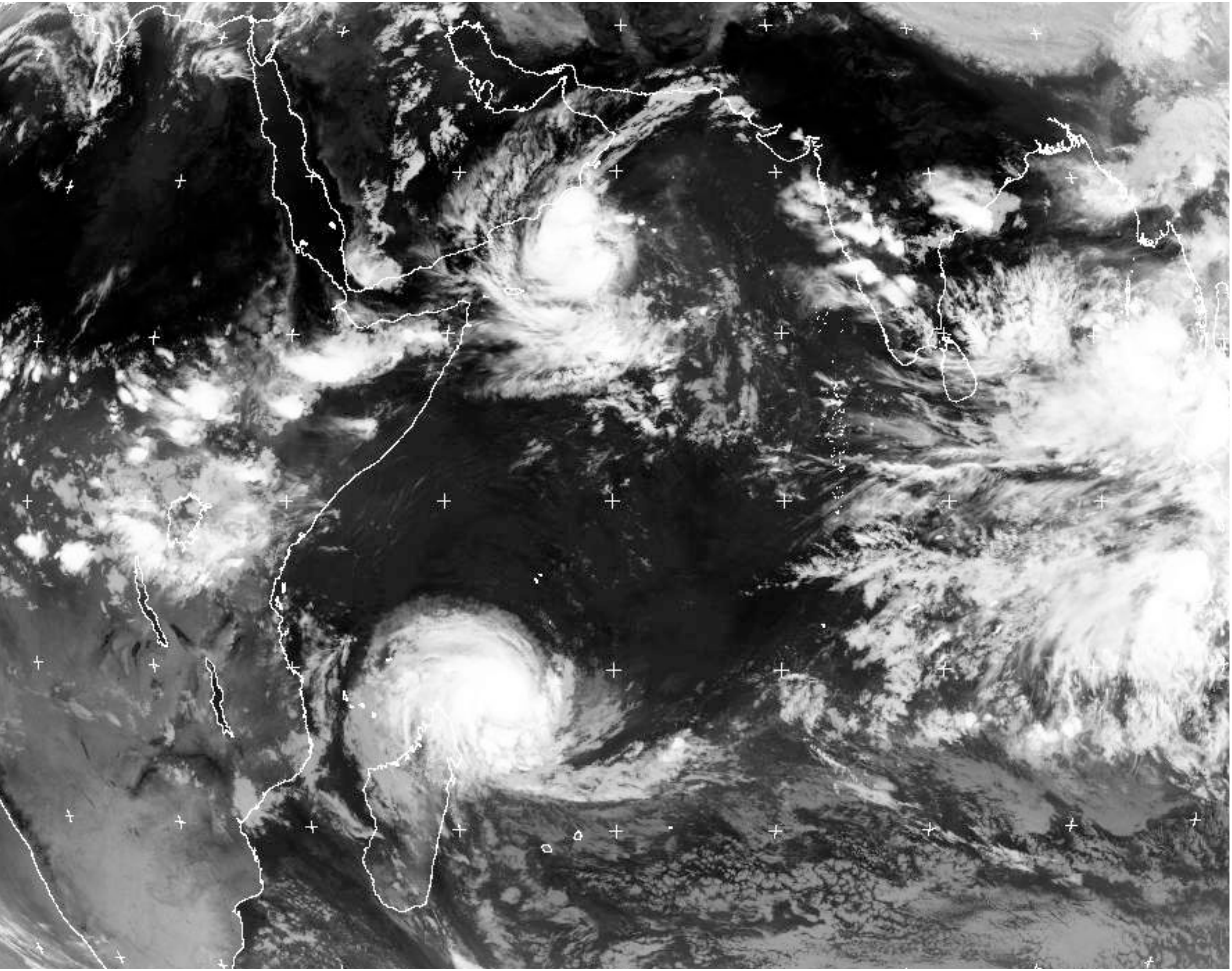


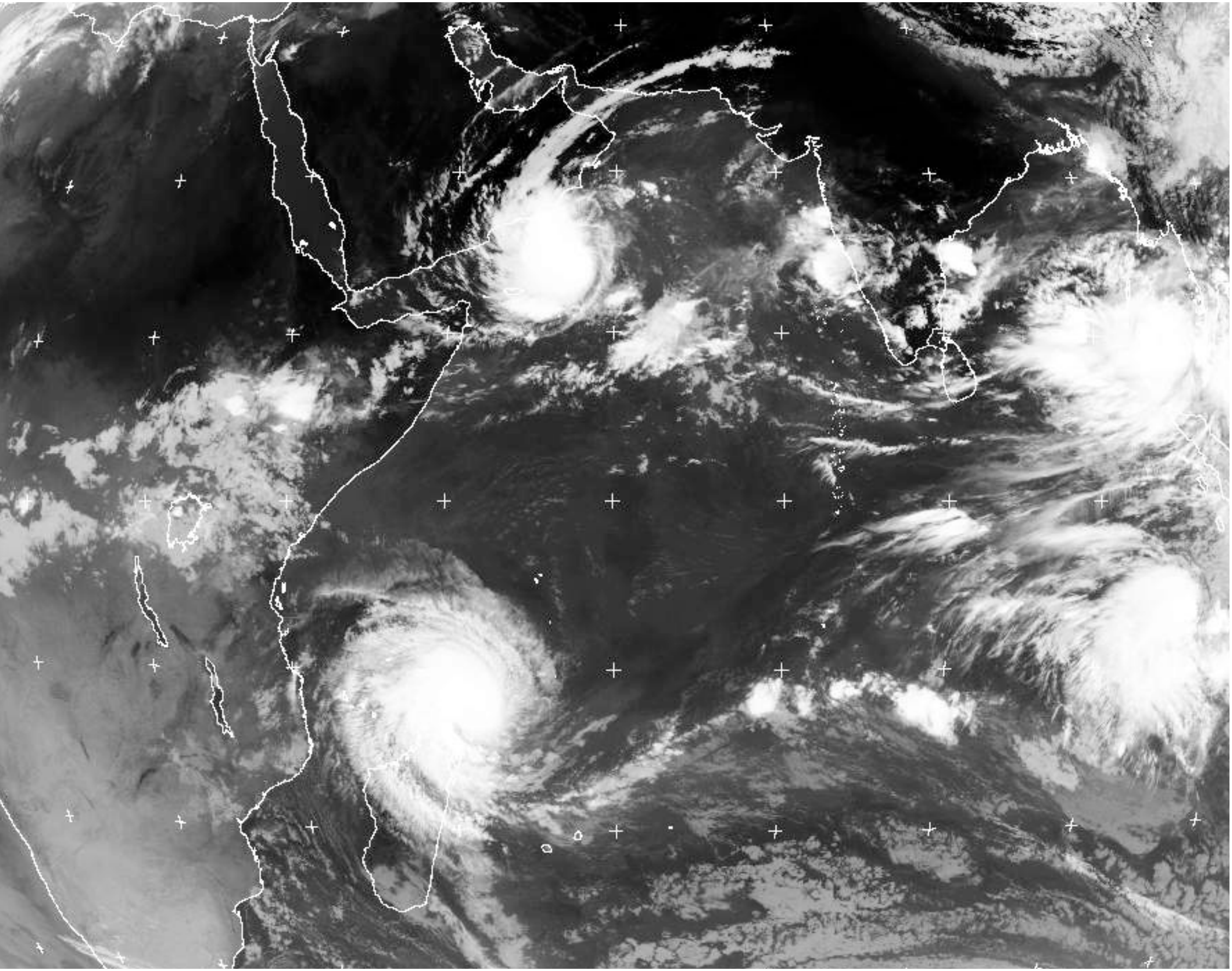


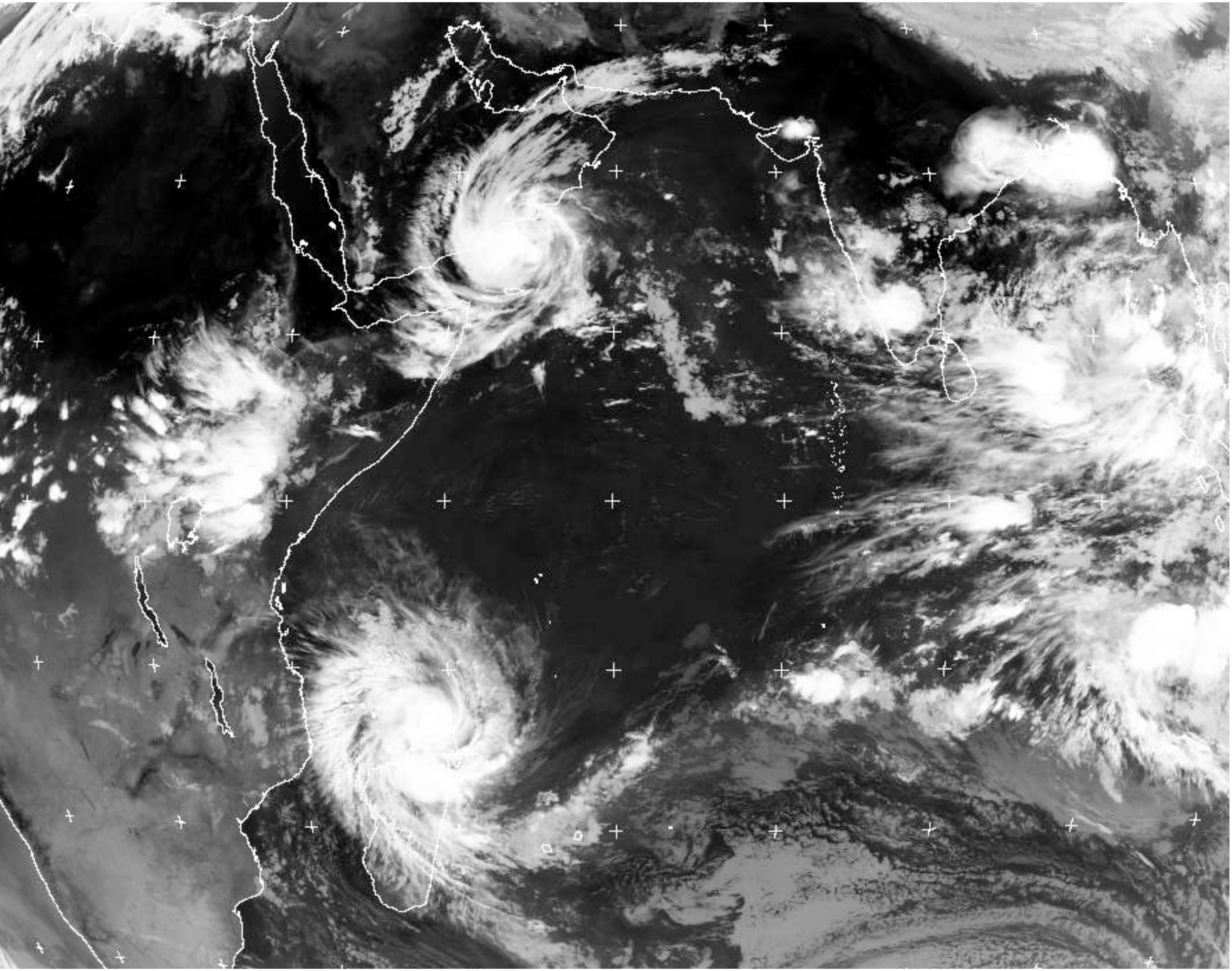


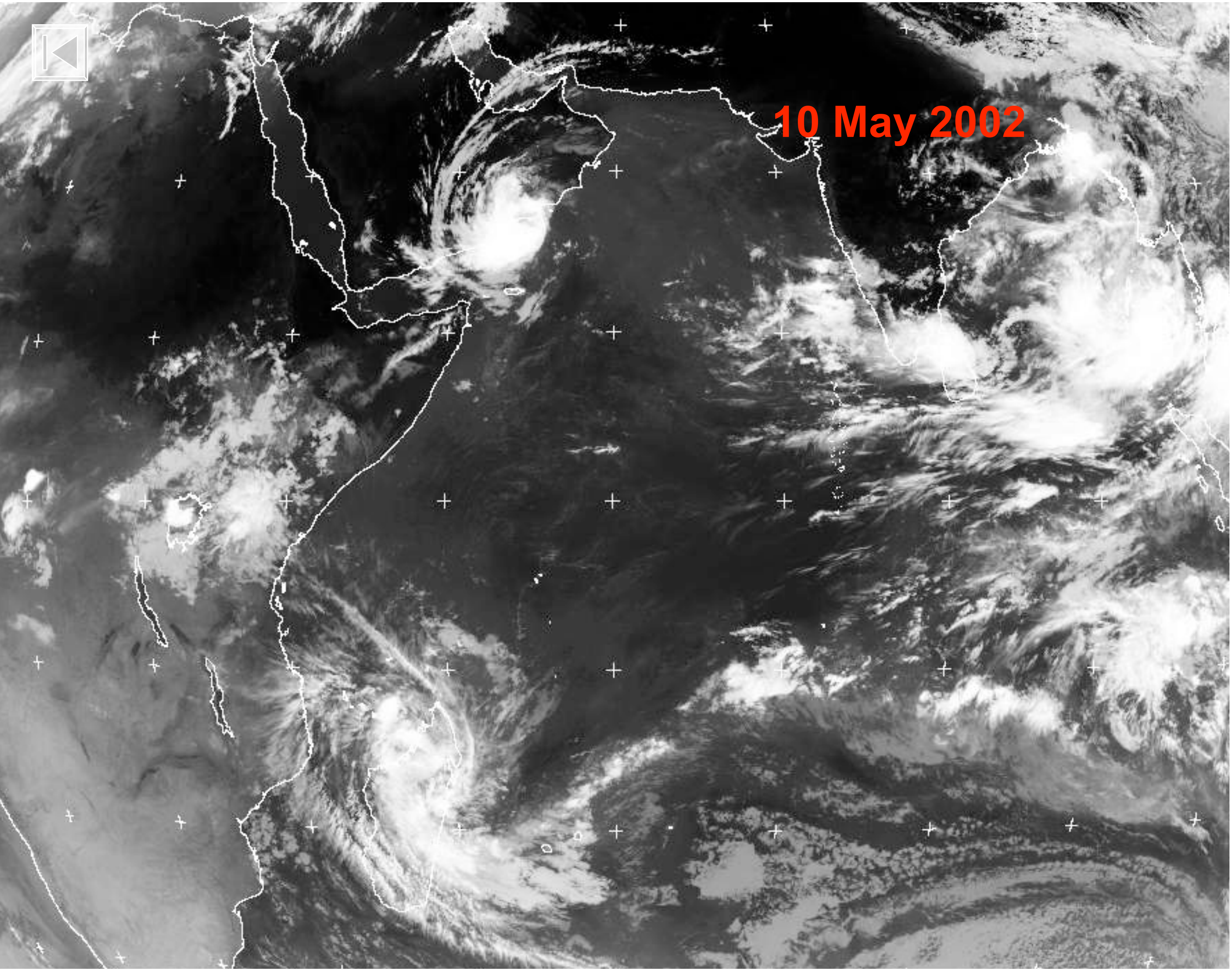











10 May 2002

Equatorial convectively coupled waves

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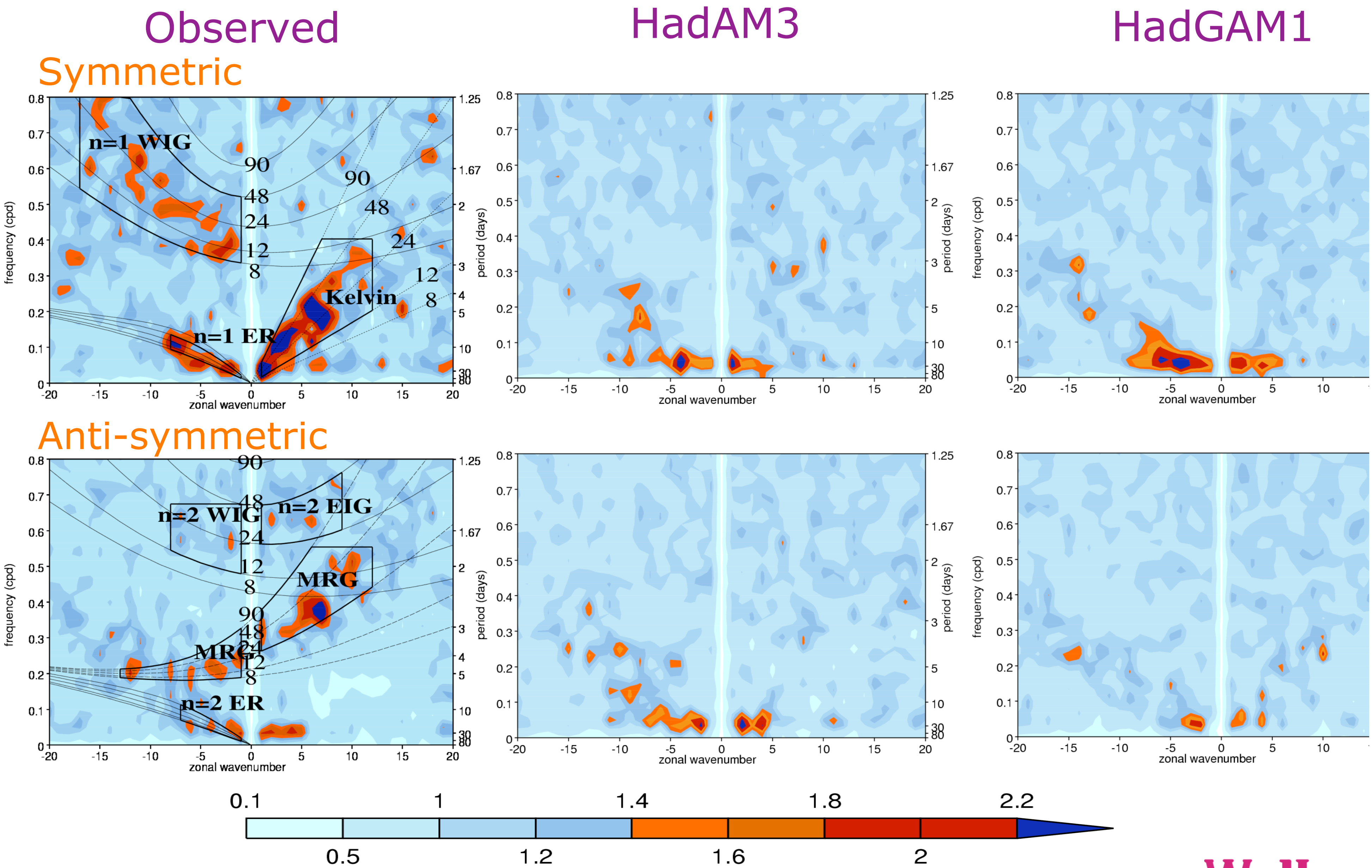

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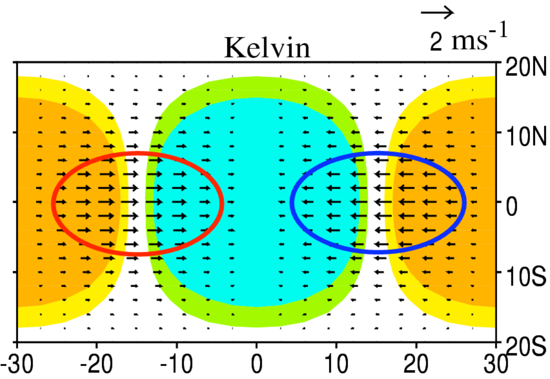
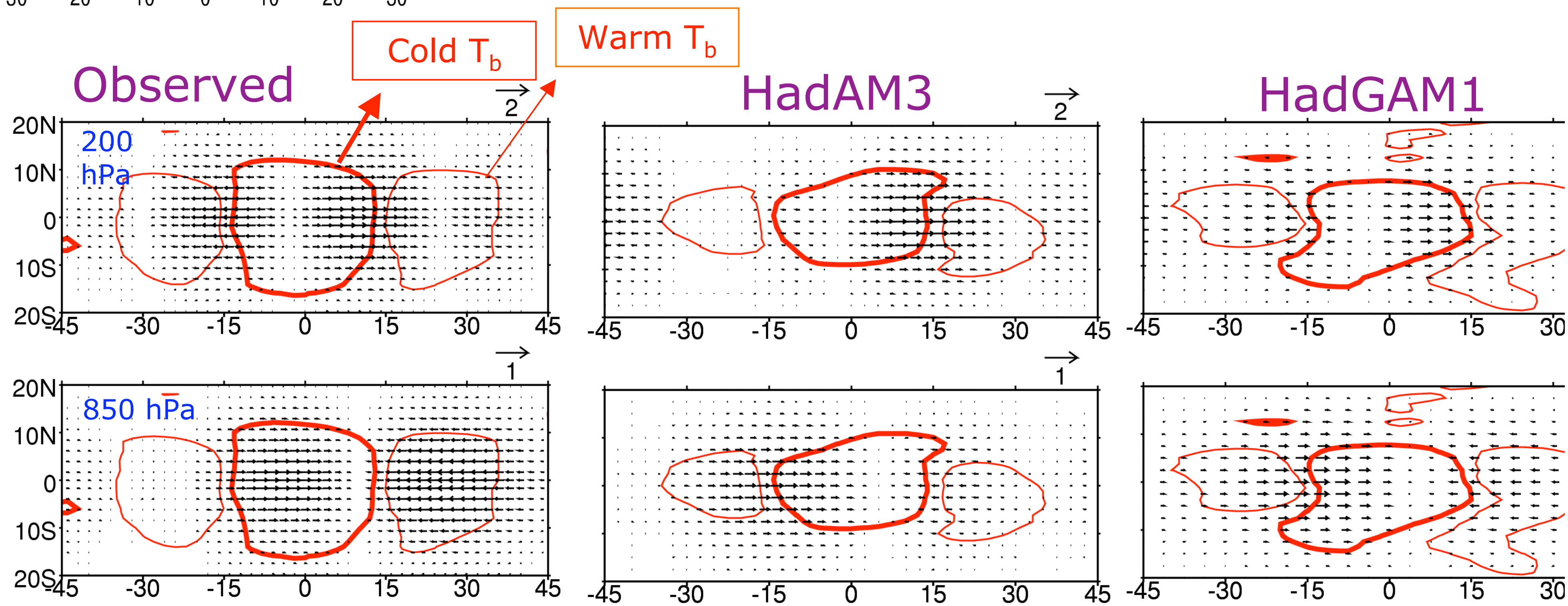
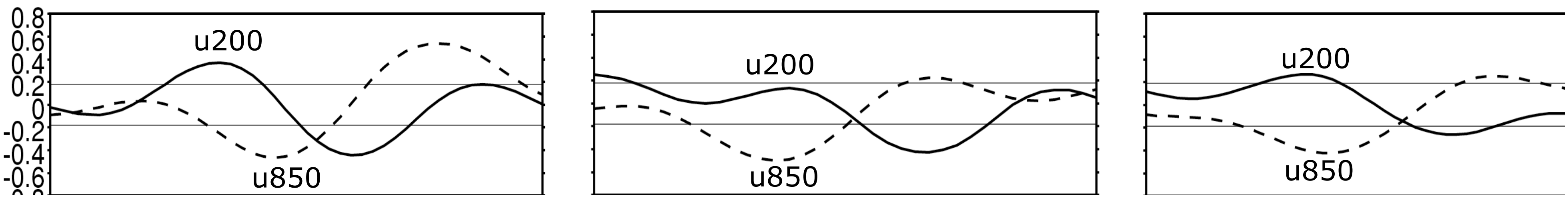
Gui-Ying Yang, Brian Hoskins & Julia Slingo

Kelvin wave structure over the Eastern Hemisphere





Correlation between T_b and *u*



Impact of Westerly Wind Burst on El Niño triggering in HadOPA

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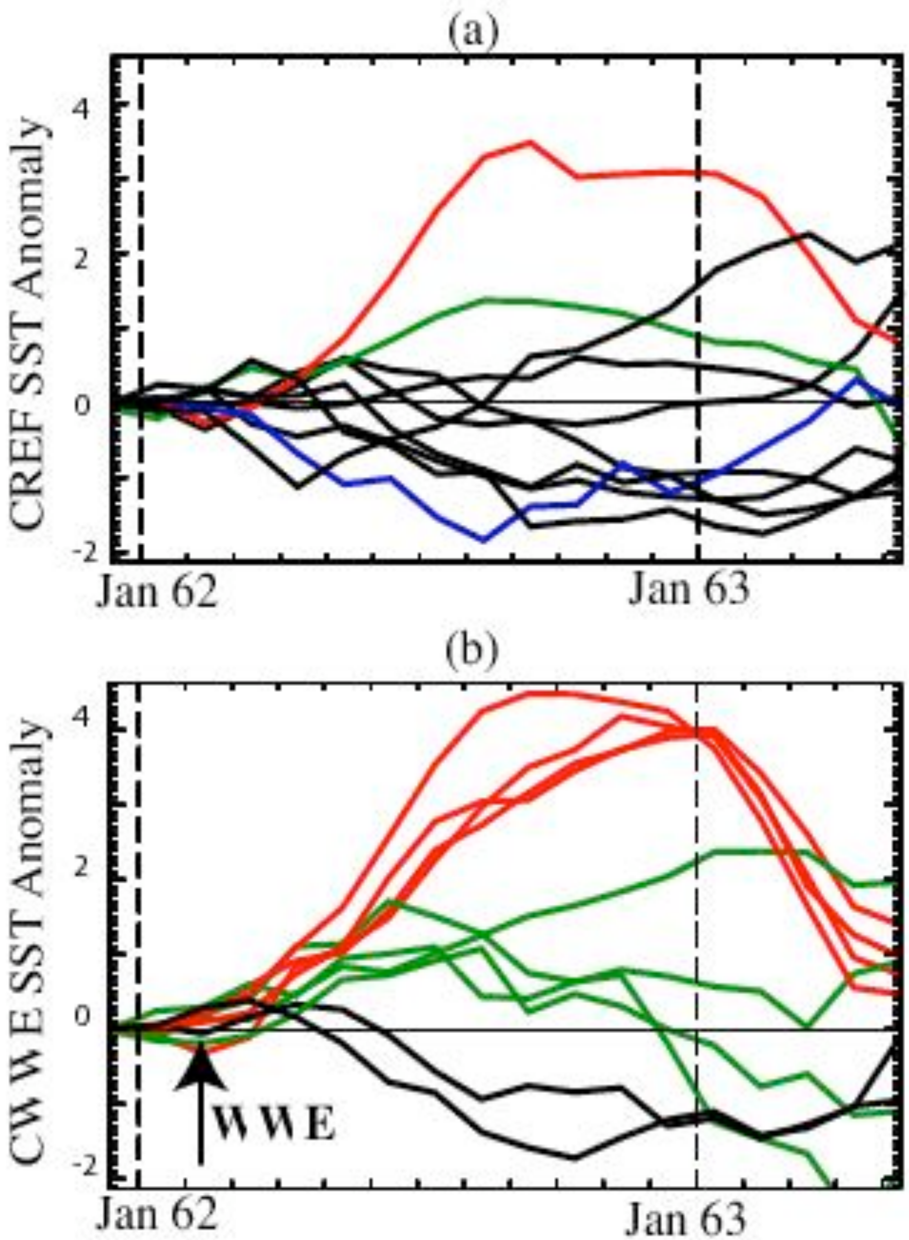

- Identify period when El Ninc inactive and heat content of t West Pacific is near normal i.e neutral conditions
- Initialise 10-member enseml using perturbations to atmospheric initial conditions
- Insert WWE into ocean winc forcing field using magnitude, fetch and duration of March 1997 WWE
- Integrate the model for further 18 months to identify influence of WWE on evolutioi of El Niño

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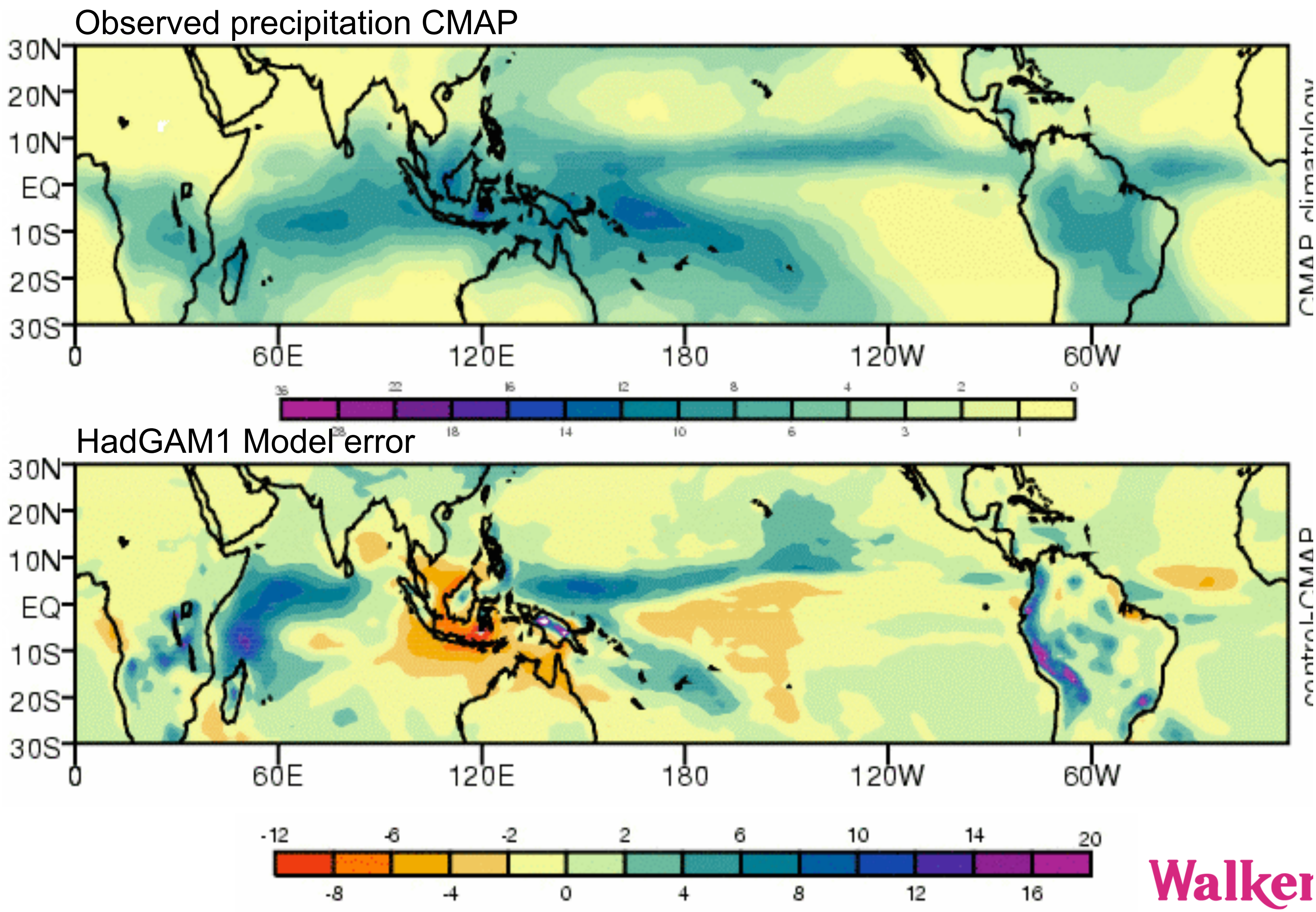
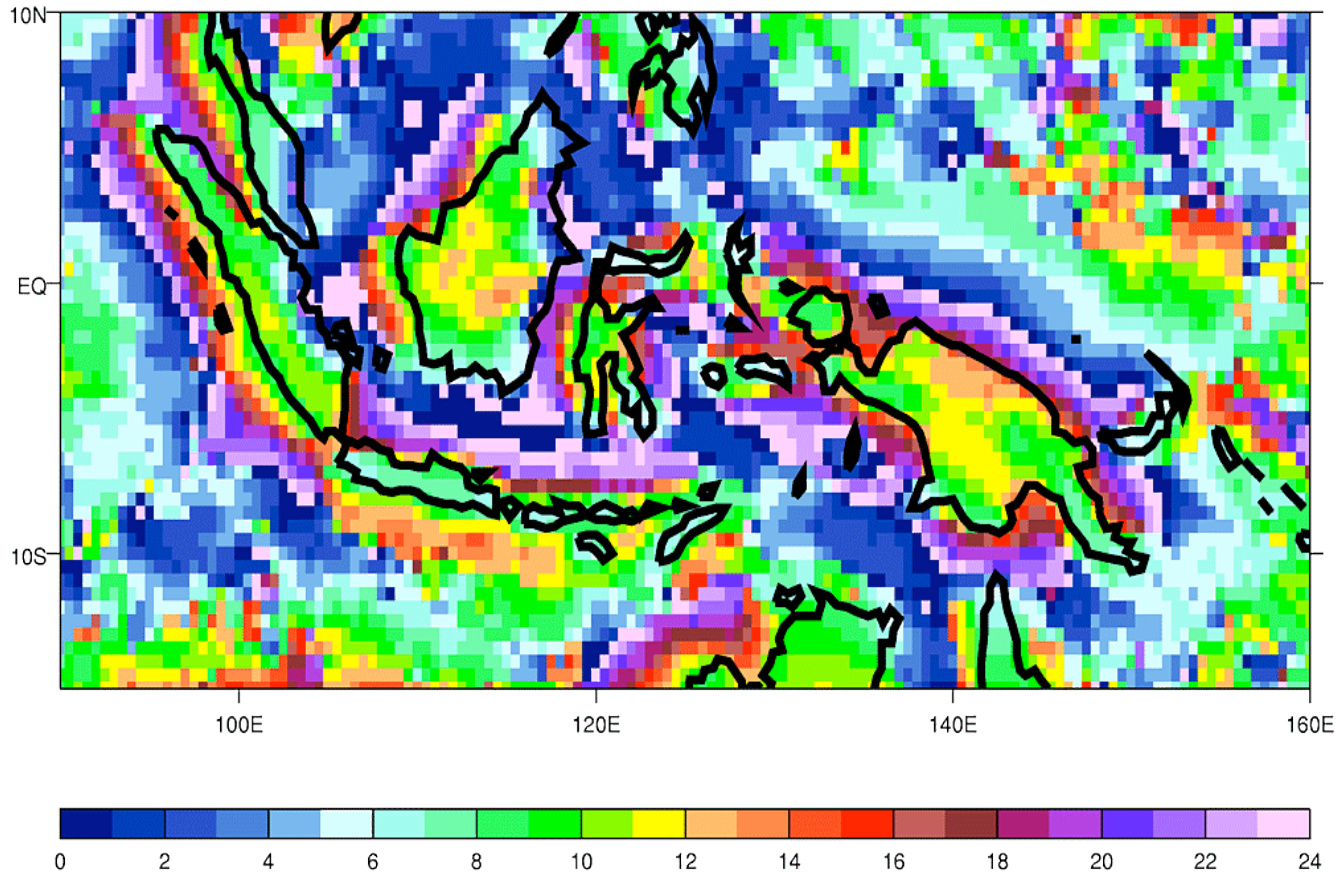
Systematic errors in the mean climate of the Maritime Continent



Phase of diurnal cycle over the Maritime Continent

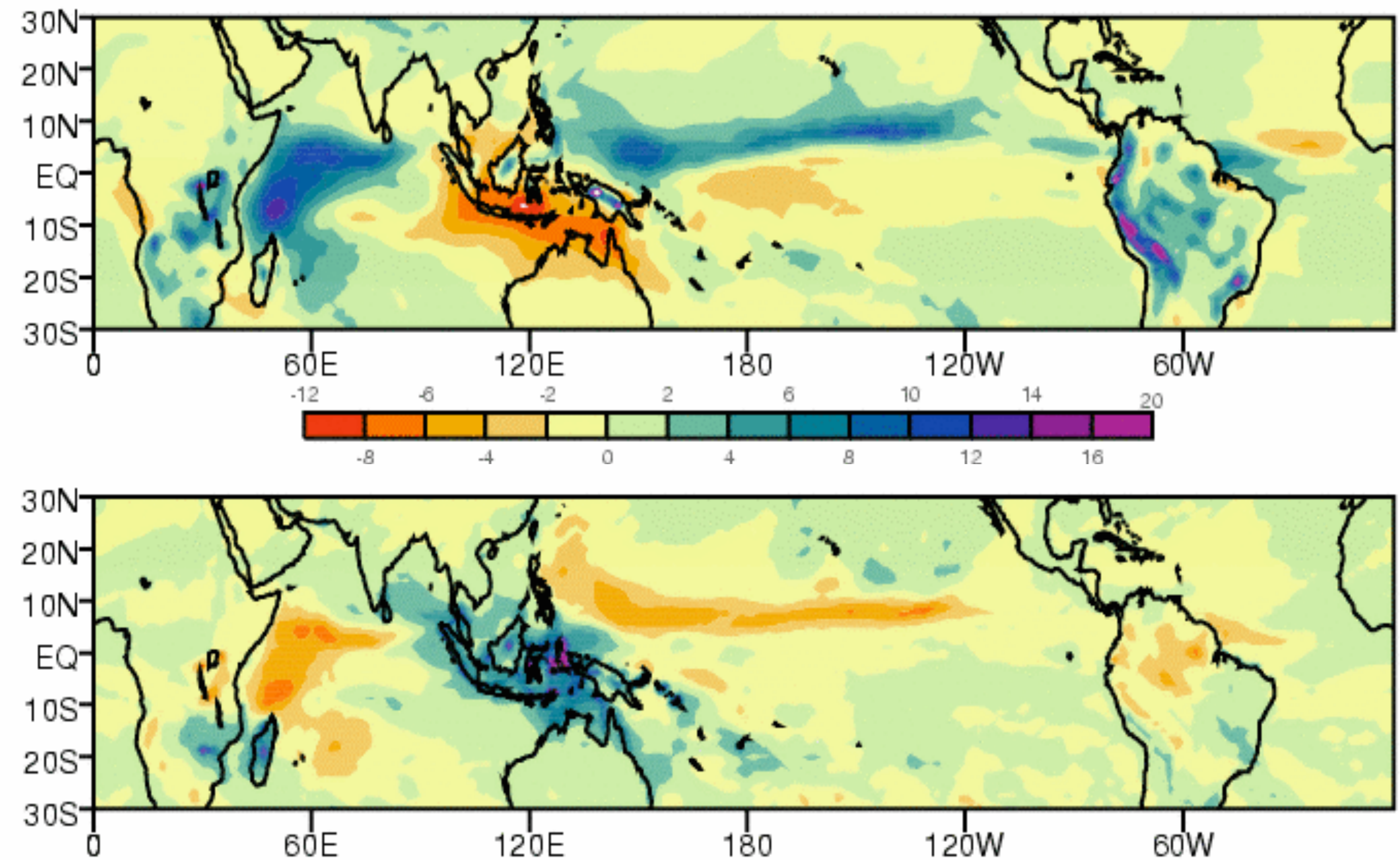


Evidence of complex land/sea breezes
which organize convection for several 100 km

Are sub-gridscale land/sea breezes a crucial component of the energy and hydrological budgets of the Maritime Continent?

Effects of parametrization of coastal effects

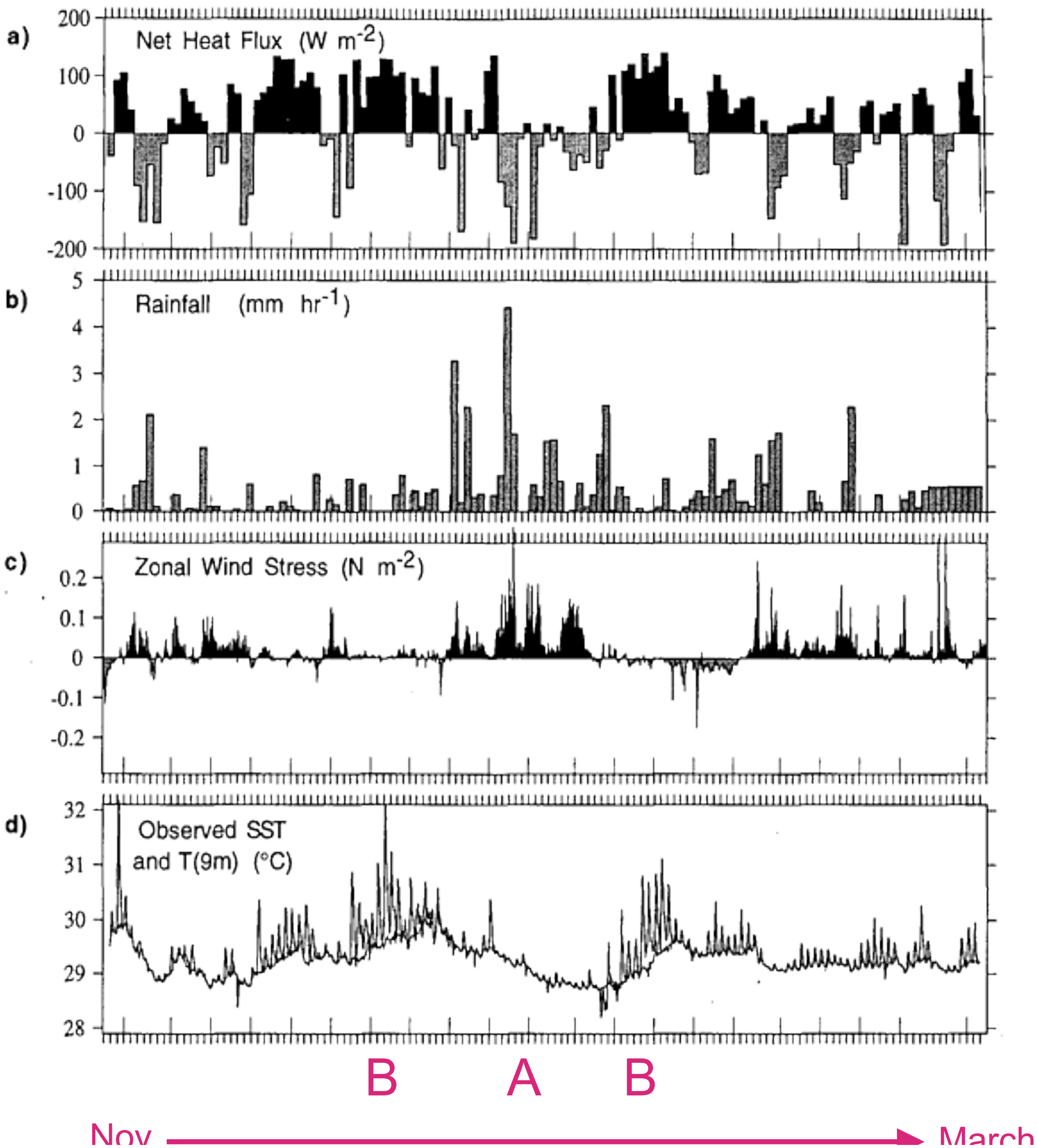
Anomalous DJF precipitation (mm/day) in HadGAM1



Control mi
CMAP

Coastal flu
adjustmer
minus
Control

Coupling with the upper ocean on diurnal to intraseasonal timescales



IMET Buoy data from TOGA-COAI

Note that the diurnal variations occur only during break (B) period

Active (A) periods are preceded by a warming sub-seasonal timescales

(From Anderson et al. 1996, J. Cli

Mixed layer model studies of the diurnal cycle: Sensitivity to vertical resolution

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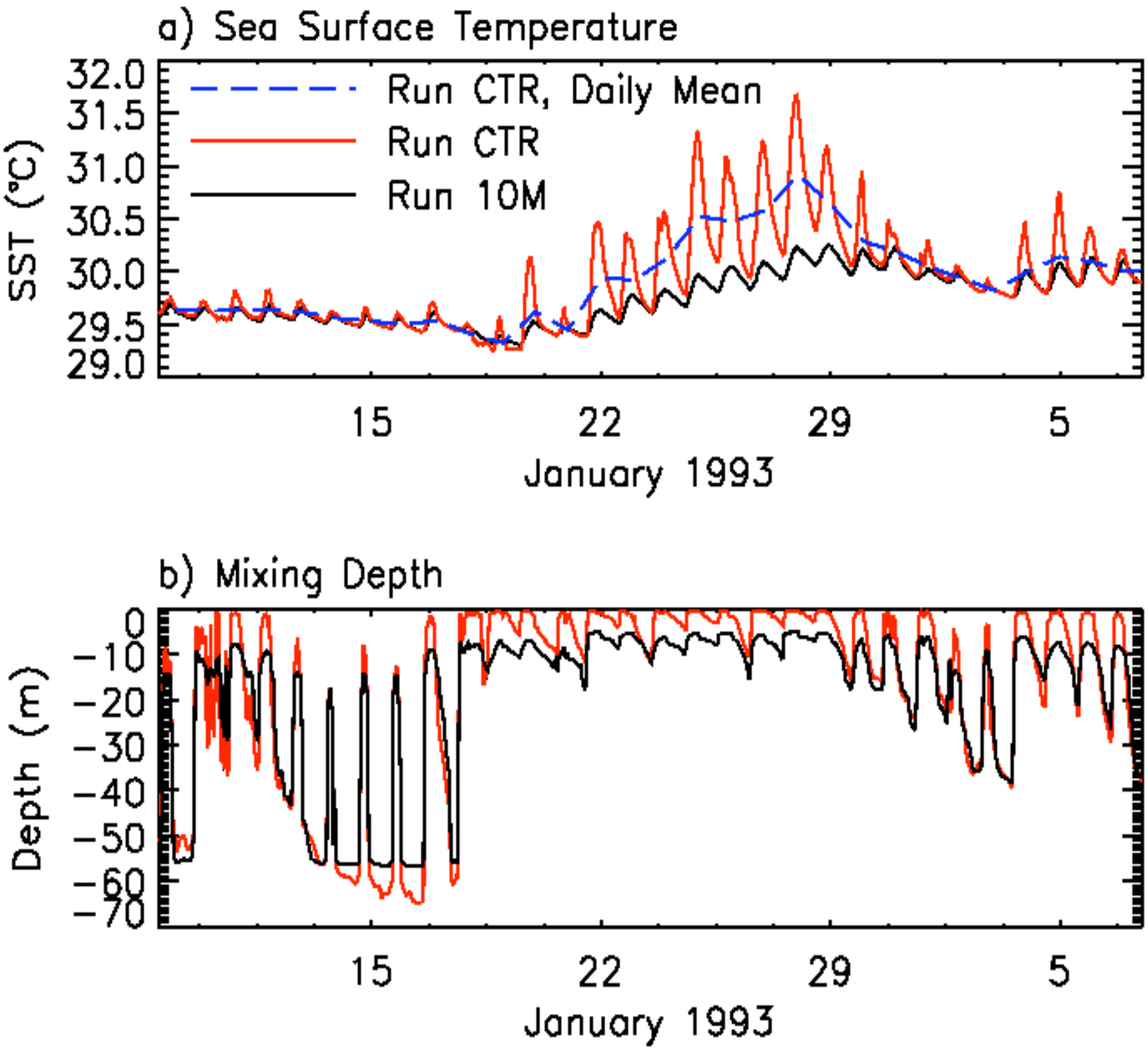

- 1m resolution (CTR gives good simulati diurnal and intrasea variability
- 10m resolution of m ocean models will n resolve diurnal vari of SST
- Intraseasonal varial is ~0.4°C less than
- Implies 40% underestimate of th strength of air-sea coupling

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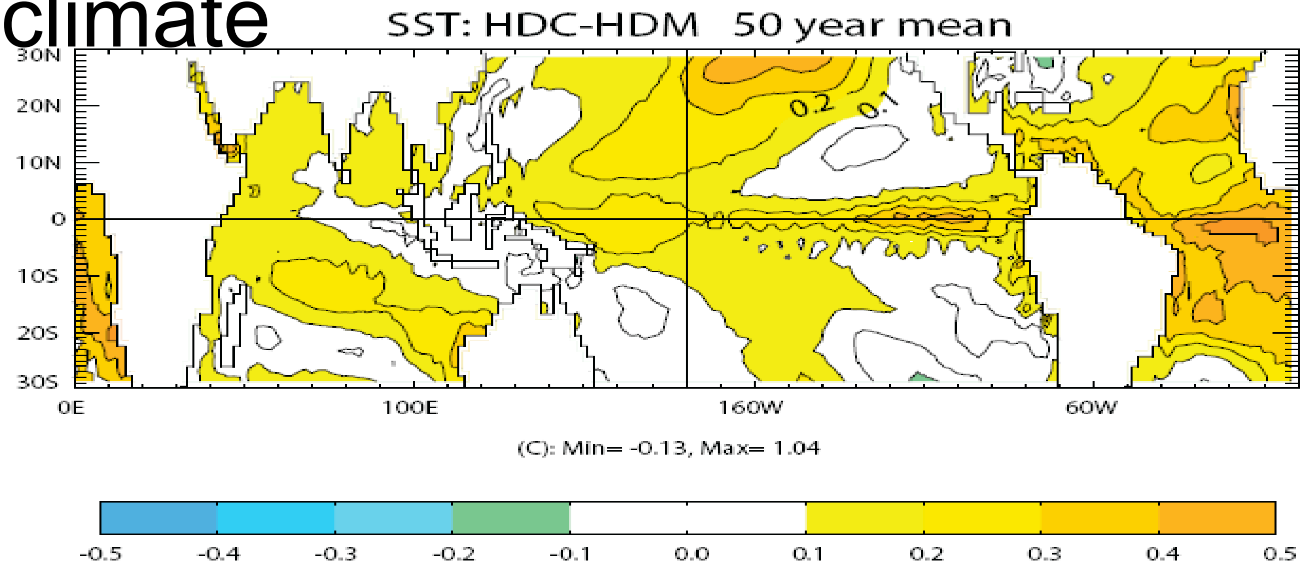
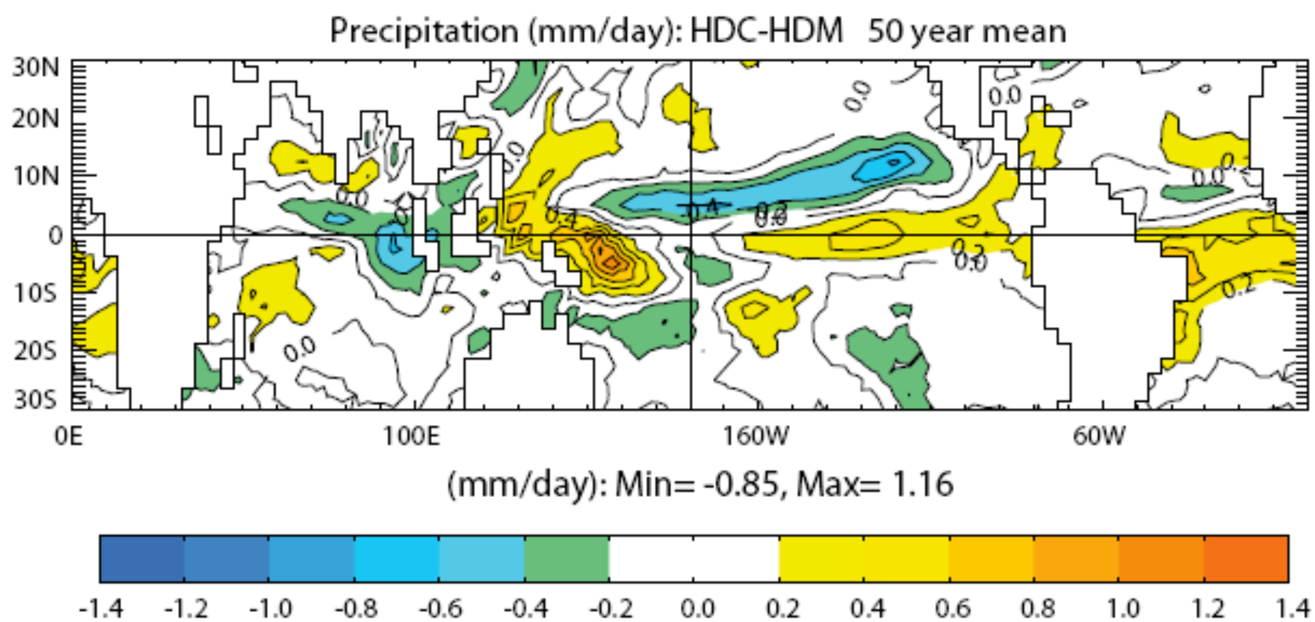
Bernie et al. 2005

Diurnal Coupling with the Ocean: Impact on the annual mean climate





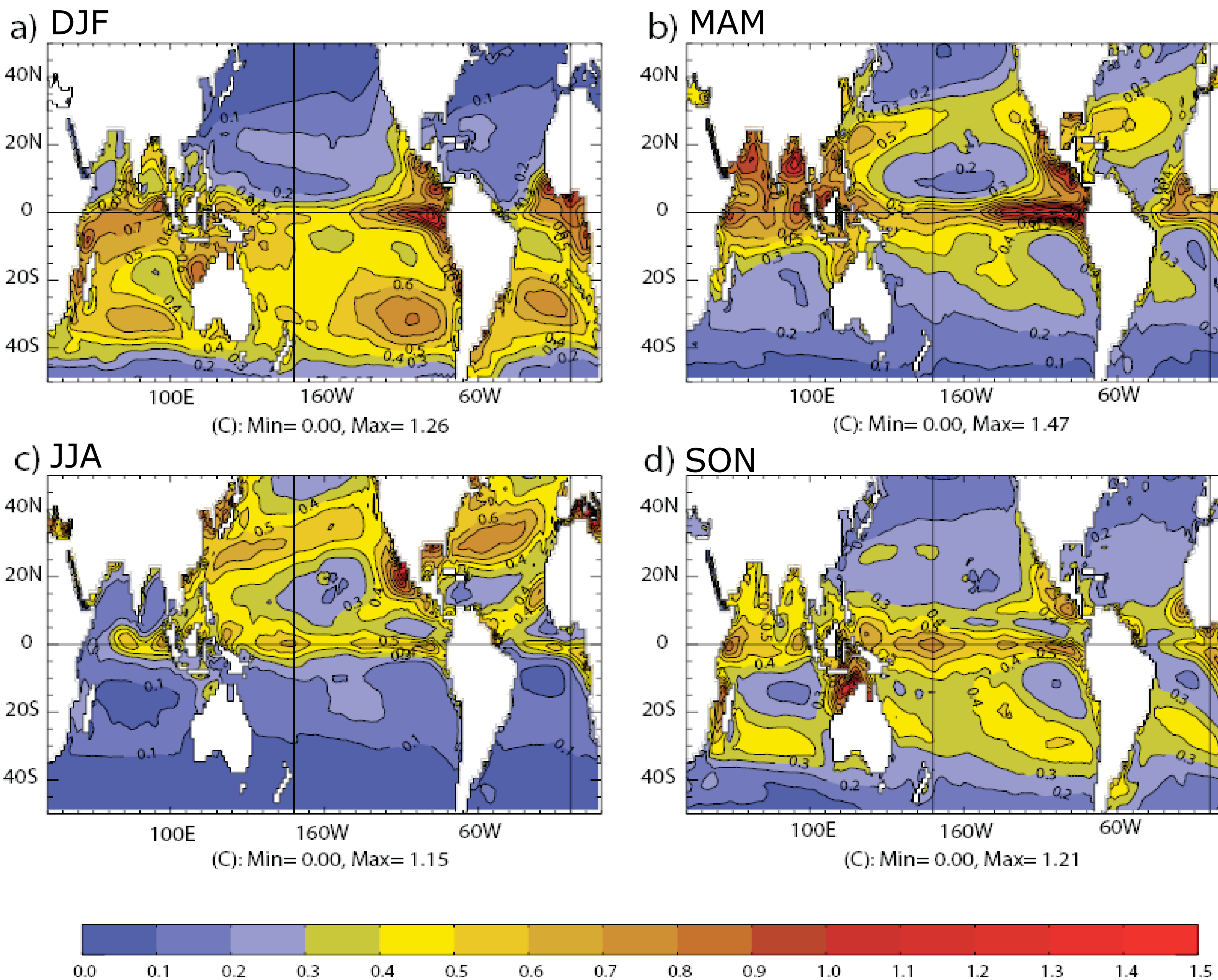
HadAM3 coupled t
OPA with high ver
ocean resolution -
meter in near surf
layer:

HDC: Hourly coup

HDM: Daily coupli

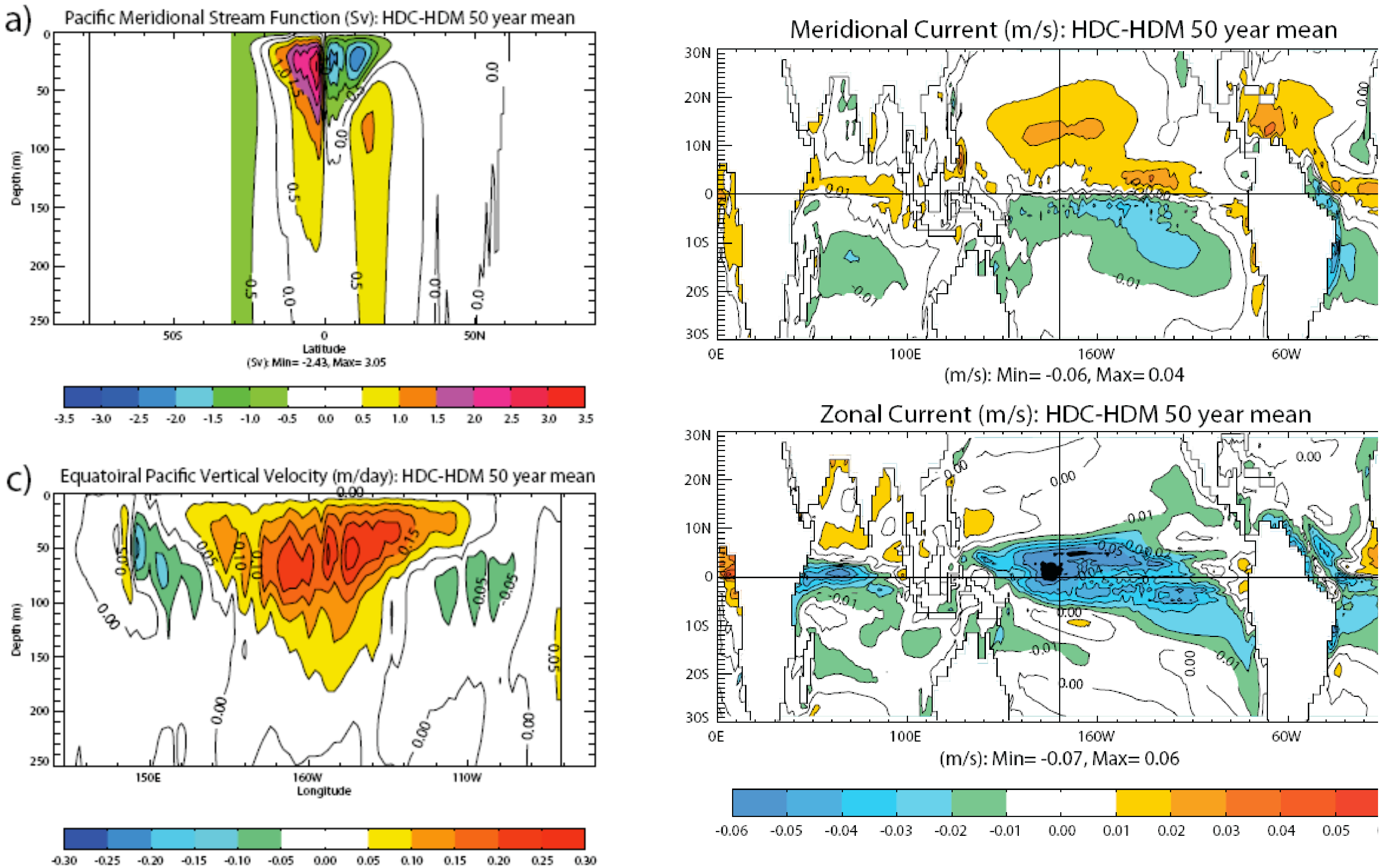
Dan Bernie, Eric Guilvardi, Gurvan Madec, Steve Woolnough & Julia Slingo

Amplitude of SST diurnal cycle in HadOPA (L300)



Dan Bernie, Eric Guilyardi, Gurvan Madec, Steve Woolnough & Julia Slingo

Diurnal Coupling with the Ocean: Impact on the momentum budget



Dan Bernie, Eric Guilvardi, Gurvan Madec, Steve Woolnough & Julia Slingo

Recent developments in UK Climate Models

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	HadCM2 1994	HadCM3 1998	HadGEM1 2004	HiGEM 2005	NUGAM 2006
Atmosphere	~300km 19 levels	~300km 19 levels	~150km 38 levels	~90km 38 levels	~60km 38 levels
Ocean	2.5^0 x 3.75^0 20 levels	1.25^0 x 1.25^0 20 levels	1^0 x 1^0 ($1/3^0$) 40 levels	$1/3^0$ x $1/3^0$ 40 levels	($1/3^0$ x $1/3^0$) (40 levels)
Flux Adjustment?	Yes	No	No	No	(No)
Computing	1	4	40	400	Earth Simulator

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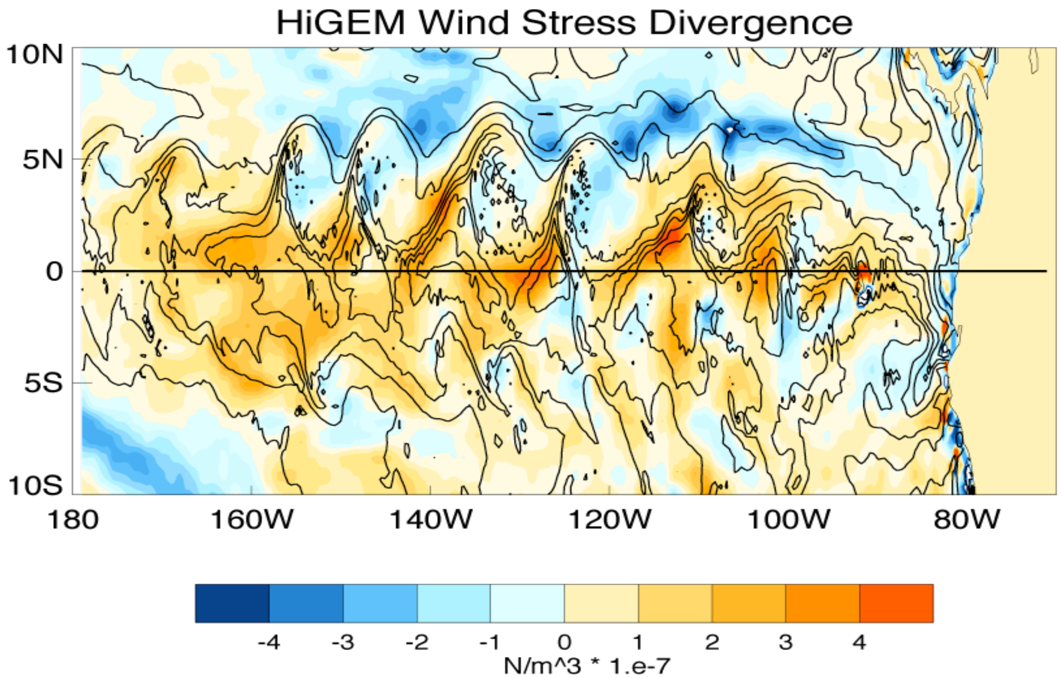

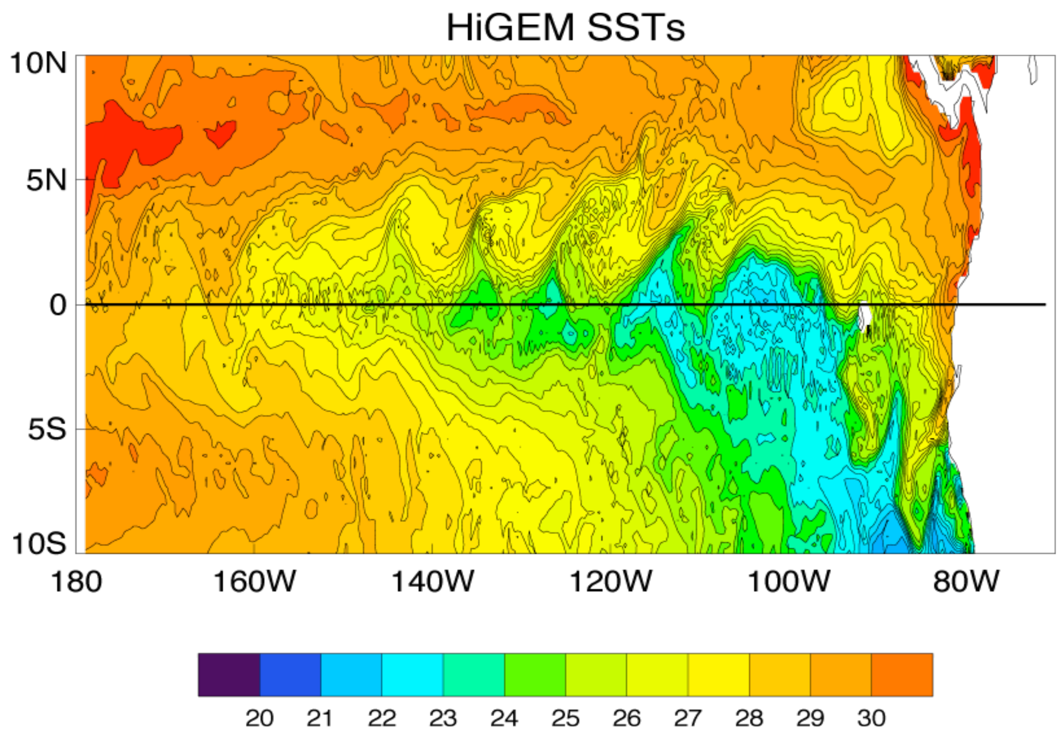

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Tropical Instability Waves in the East Paci

- At higher resolution, waves are more efficient mixing heat into the equatorial cold tongue.
- Crucial component of th heat budget of the equatorial Pacific?
- Evidence of coupling wit the atmosphere

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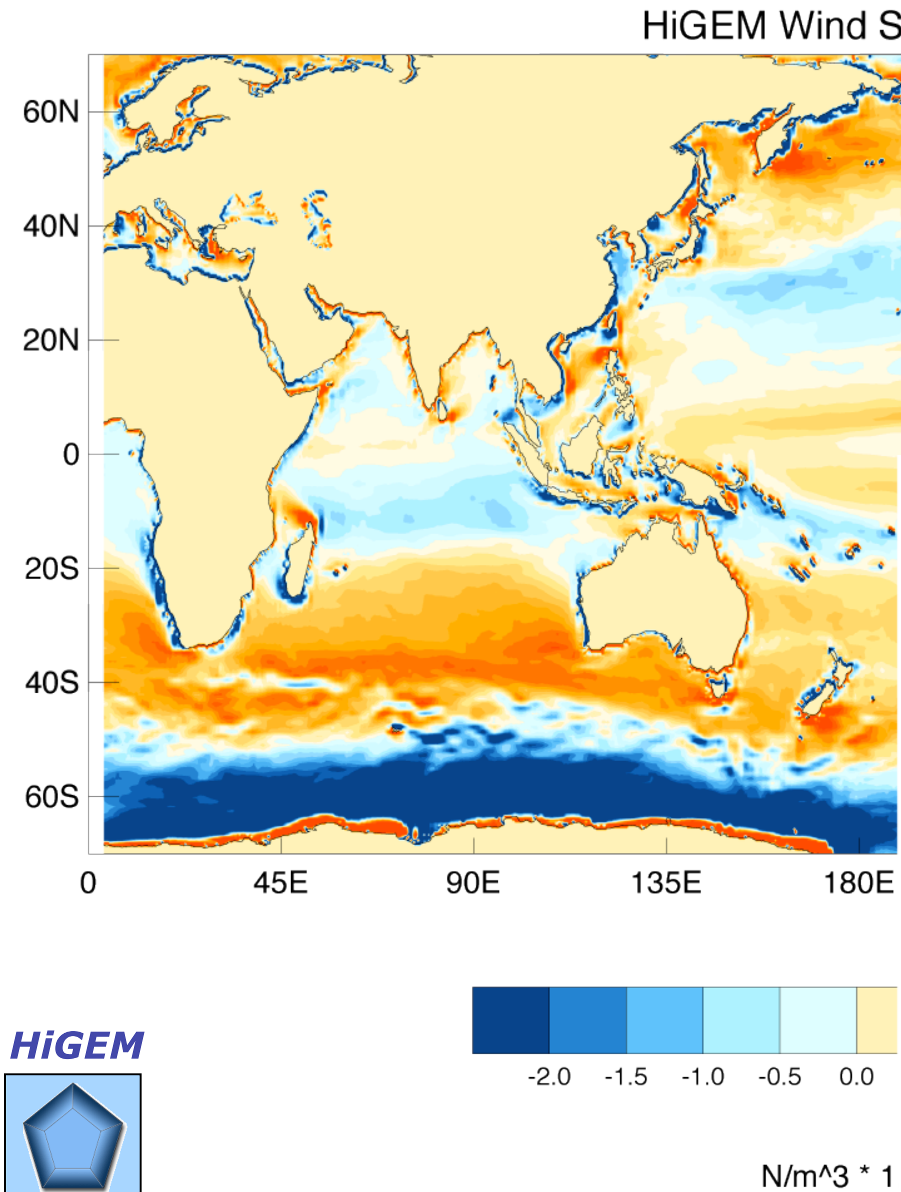
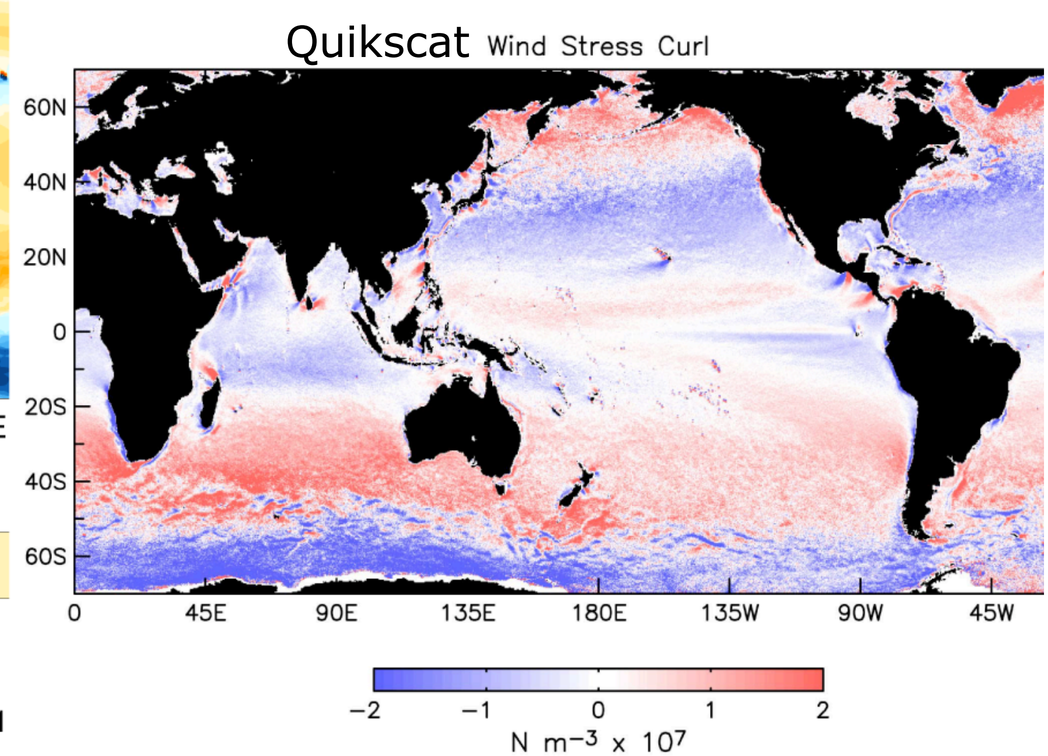
Multi-scale wind forcing of the oceans





HiGEM

Scale interactions in the coupled system: Ocean biology and upwelling

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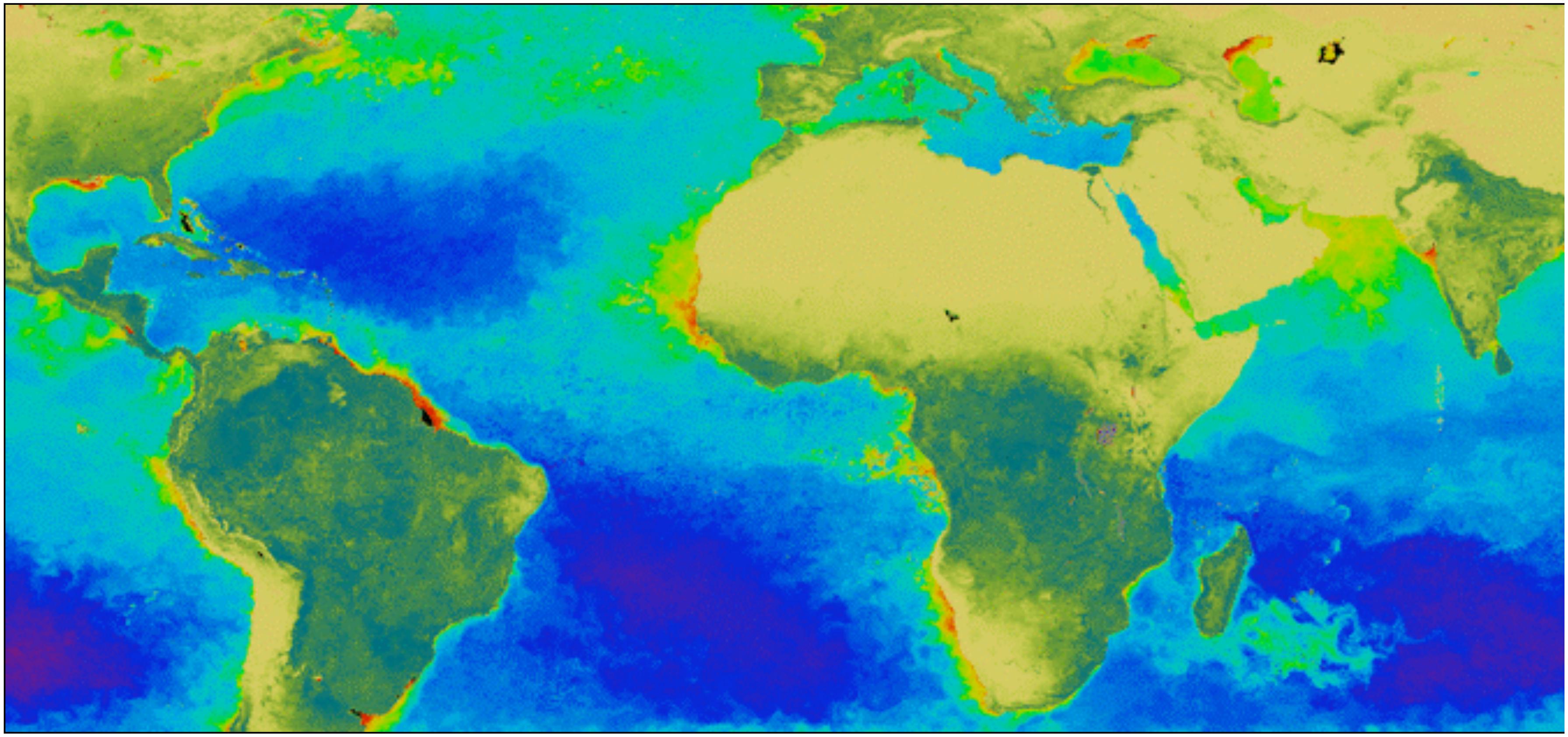

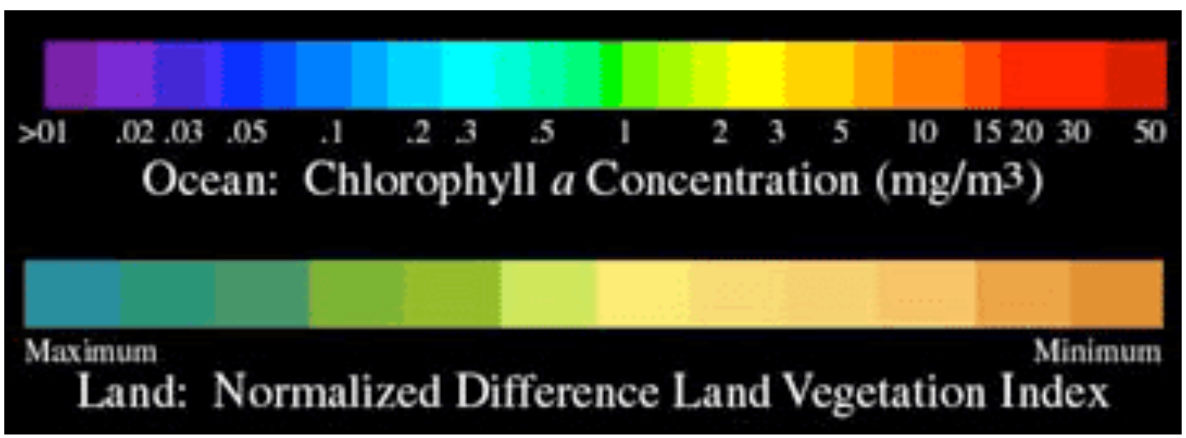

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日英気候共同研究
UK-Japan Climate Collaboration

Climate modelling on the Earth Simulator:

Investigating the role of resolution

Impact of atmosphere and ocean resolution on El Nino

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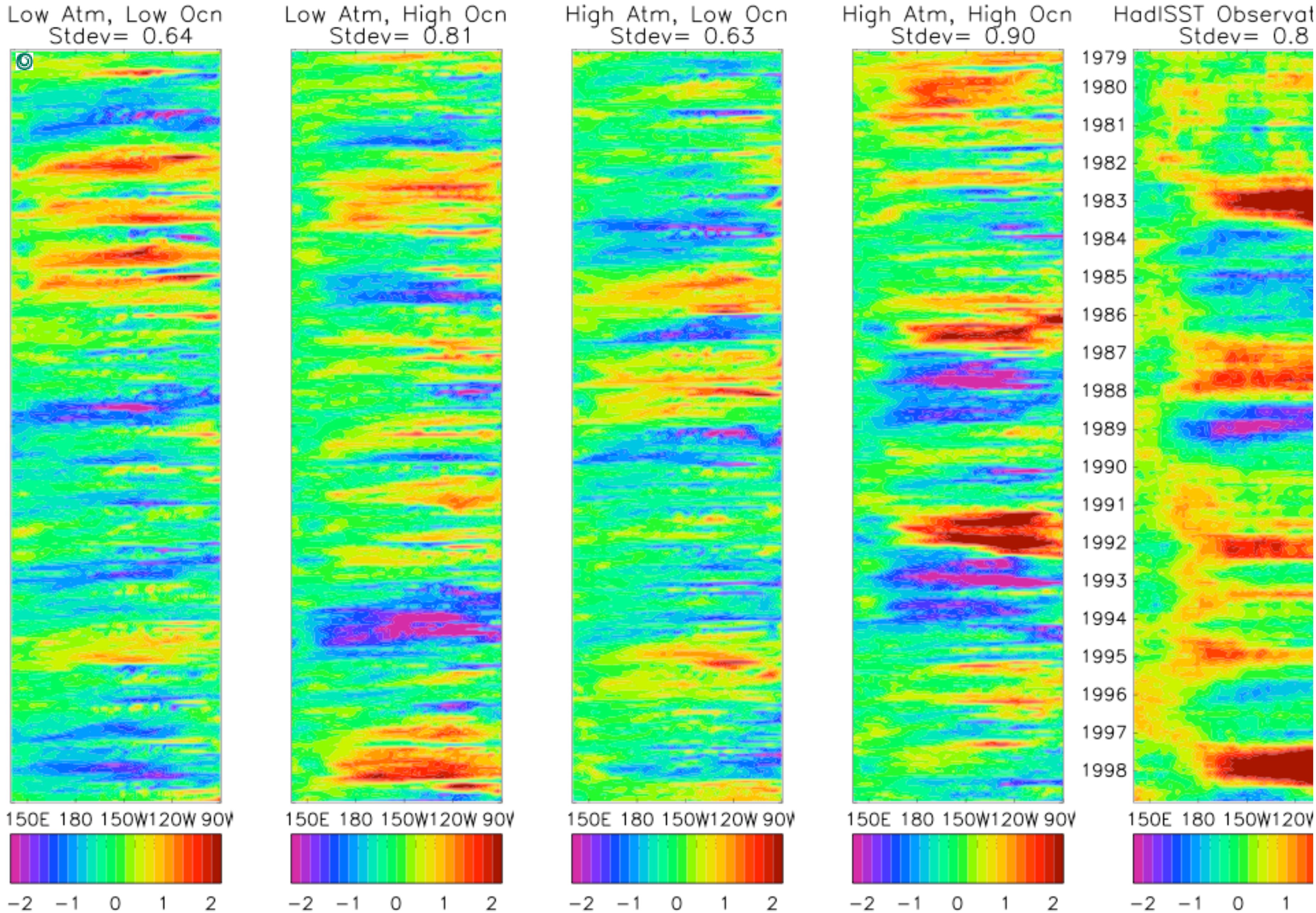
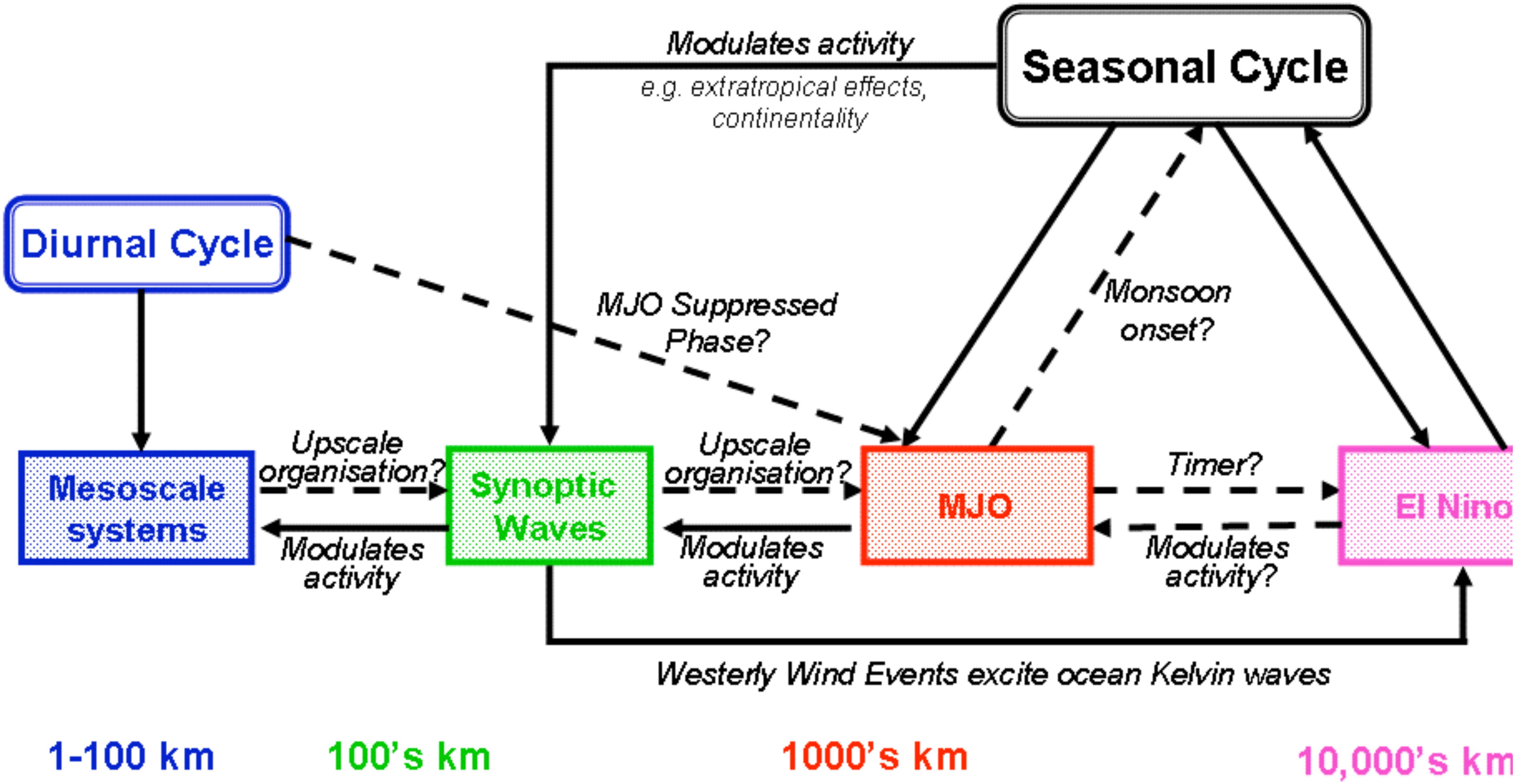


Scale interactions are fundamental to the tropical climate system



From THORPEX/WCRP Workshop on Organised Convection and the MJO

The way forward?

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Organised convection is fundamental to the tropical climate system, yet we do not understand:

- How does convection organise itself across a range of time and space scales?
- How are energy and momentum transferred?
- Why do preferred structures emerge?
- How can these be represented in global models?
- We cannot answer these questions using observations - so we must use models as pseudo 'field experiments'.
- This requires large domains **and** very high resolution so tha the energy spectrum is not compromised.
- Needs very significant computational resource, only just becoming available.

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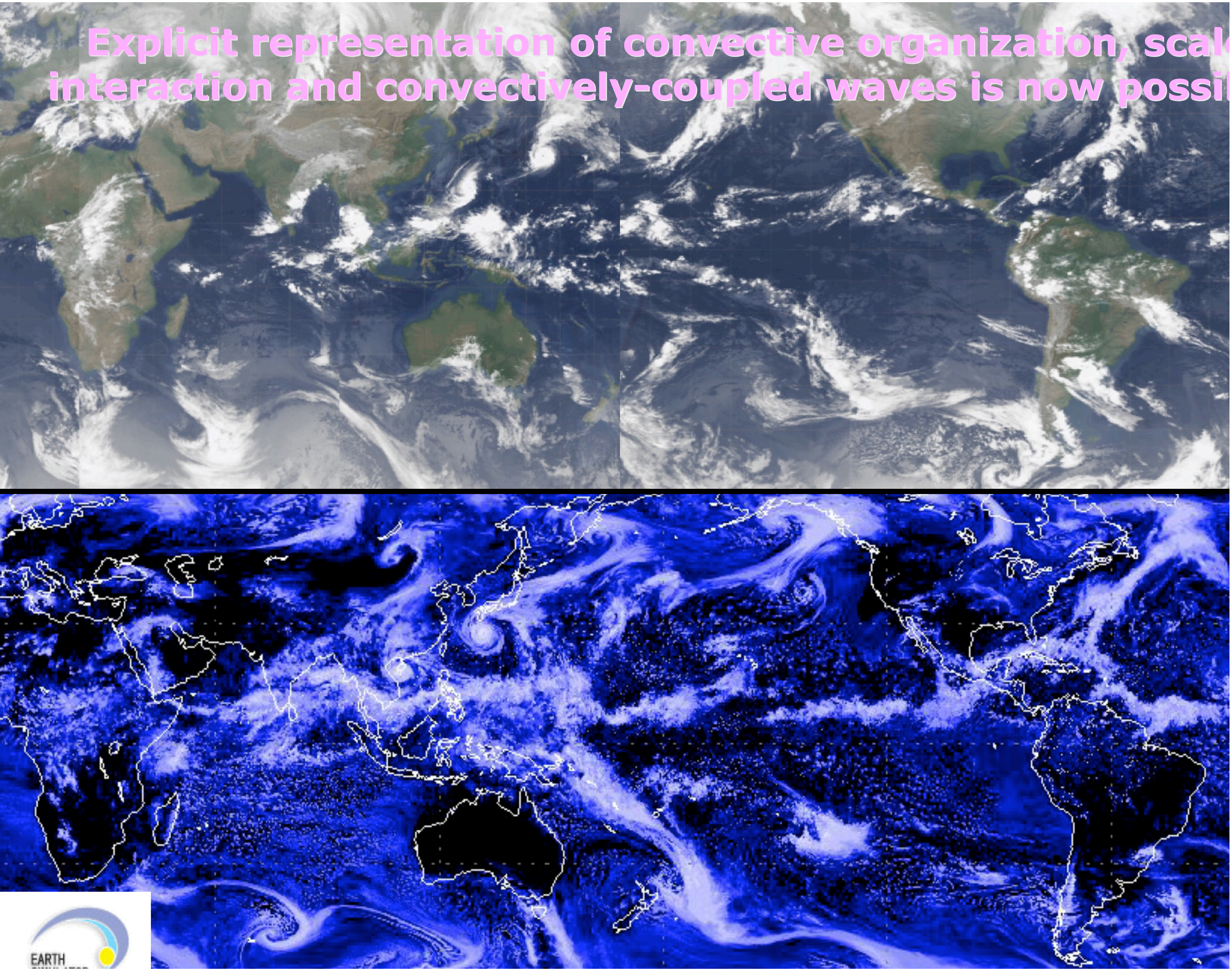
Explicit representation of convective organization, scal interaction and convectively-coupled waves is now possi



Concluding Remarks

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- Increasing evidence from observational and modelling studie that multi-scale interactions are fundamental to the climate system, both *within and between* components of the system
- 'Column' approach to parametrization may not be valid wher there is *strong dynamical-physical coupling* at the sub-gridscale (e.g. organised tropical convection)
- There appear to be *multi-scale coupled* processes that probably cannot be parametrised (e.g. ocean-atmosphere coupling at the ocean eddy scale)
- Is there a *minimum resolution for CGCMs*?
- New opportunities for studying multi-scale interactions provided by *computational 'laboratories'* will be fundamental progress

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