Model fidelity & Simple energetics based study on Monsoon Lows and Depressions

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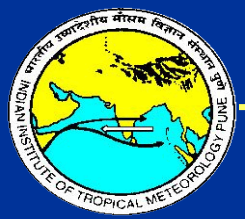
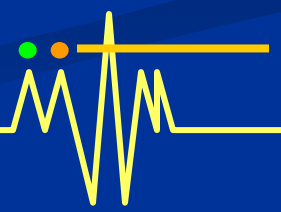
Monsoon Mission meeting 17 December 2019

Outline

- Background
- Monsoon Depressions and Monsoon lows and transition
- Model fidelity
- Conclusion





Tropical Cyclone Hazard to Mumbai in the Recent Historical Climate

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WIKIPEDIA

Bombay Cyclone of 1882 (hoax)

The so-called **Bombay Cyclone of 1882** or **Great Bombay Cyclone** is a hoax (or otherwise fictitious) historical event. Supposedly, the cyclone struck Bombay on 6 June 1882. Though it is widely reported, even in scientific literature, historical research shows that it did not in fact happen.

Example accounts of the supposed event

Reportedly, the earliest mention of the supposed cyclone so far discovered by researchers is in a newspaper called *Telegraph* on 17 September 1947.[1] The cyclone is mentioned in academic literature from at least 1976.[2] Its entry in the 2008 edition of the *Encyclopedia of Hurricanes, Typhoons, and Cyclones* reads:

> **The Great Bombay Cyclone of June 6, 1882:** One of few truly great Indian cyclones to have formed over the Arabian Sea, the Great Bombay Cyclone--engorged with 110-MPH (177-km/h) winds and an 18-foot (6-m) surge--reportedly claimed more than 100,000 lives when it came ashore at Bombay right before daybreak.[3]

A 2014 academic article claims that: 'the deadliest storm surge of Arabian sea was Great Bombay Cyclone, took place in 1882 causing 100,000 causalities [*sic*]. It is one of ten deadliest tropical cyclones of the known history of the world'.[4] Another account, published in 2017, says that

> the city of Bombay was all but destroyed by a monster cyclone that slammed into the Maharashtra region on June 6th 1882. This was one of the few great storms to emerge from the Arabian Sea. The super storm covered an enormous area as it came ashore at dawn bringing with it 110 mile per hour winds and an 18 foot tidal surge that inundated much of the region around Bombay ... The resultant winds, flooding and damage to buildings killed more the 100,000 people.[5]

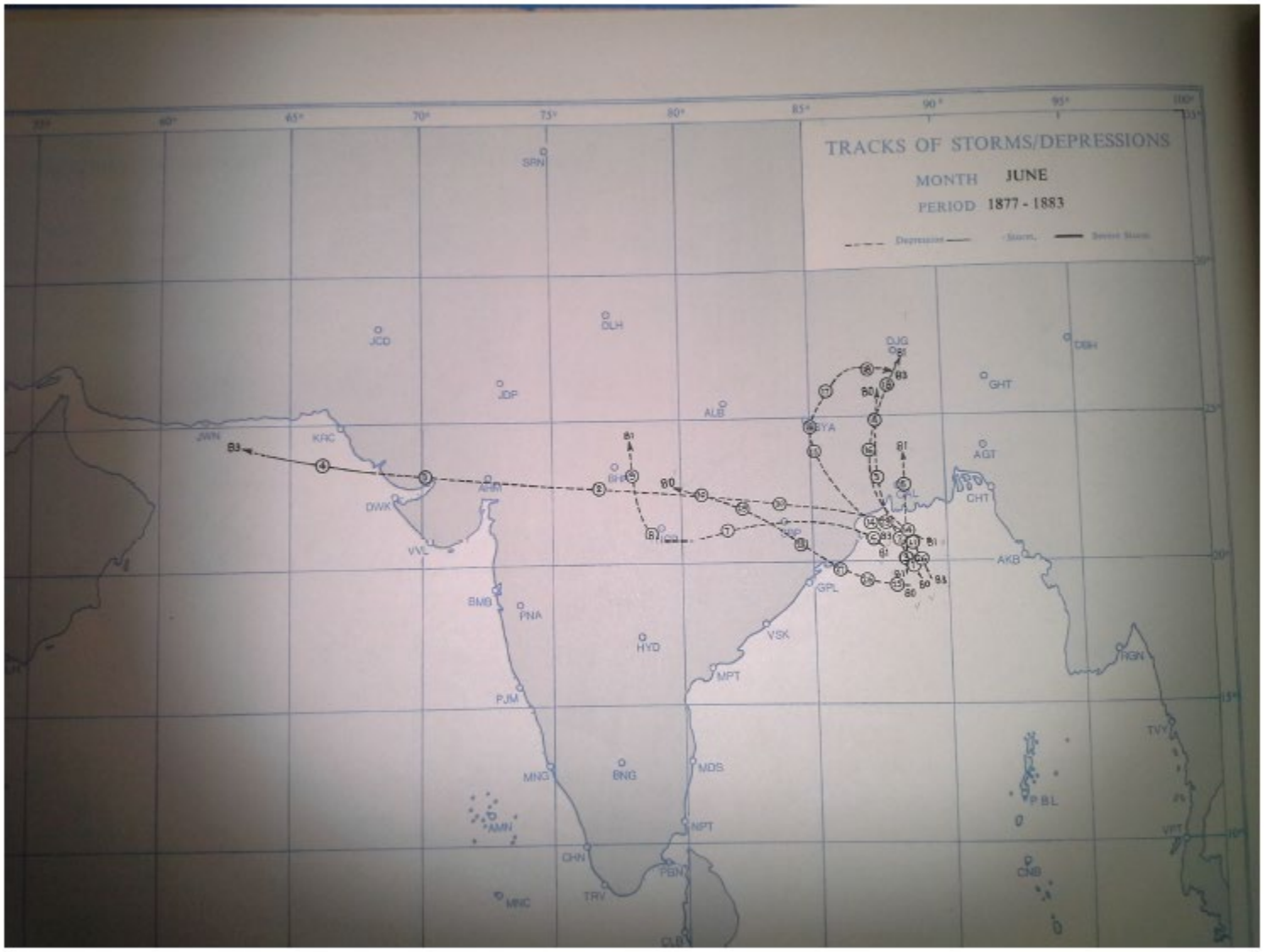
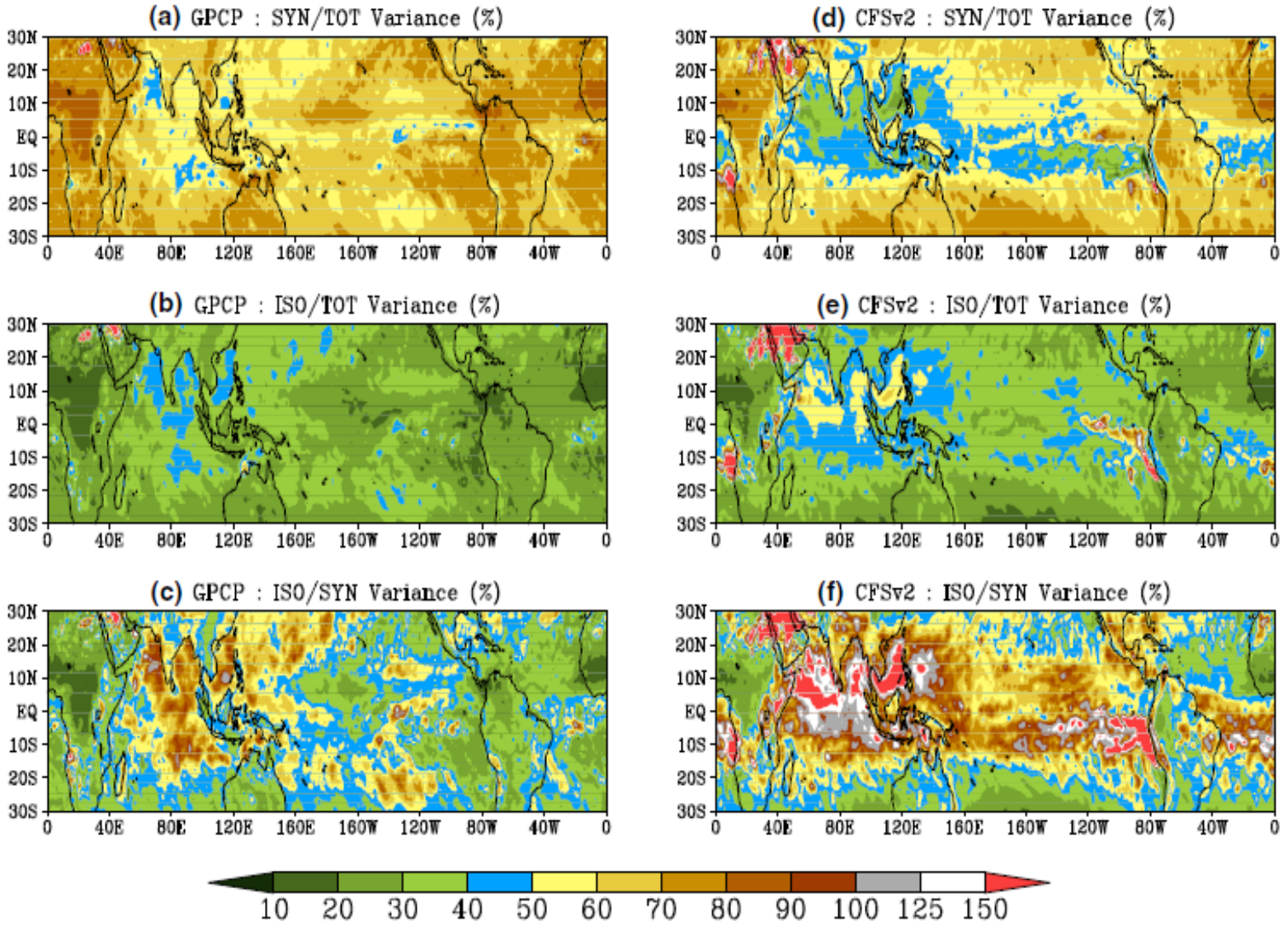


Fig. S1, a)

Sobel et al 2019



Goswami et al. 2014

CFSV2: Less synoptic variance and more ISO variance

a) Ratio of synoptic scale (2-10 day bandpassed) variance to total variance in GPCP; b) ratio of ISO scale (10-90 day bandpassed) variance to total variance in GPCP; c) ratio of ISO scale variance to synoptic scale variance in GPCP; d) ratio of synoptic scale variance to total variance inCFSv2. e) Ratio of ISO scale variance to total variance in CFSv2; f) ratio of ISO scale variance to synoptic scale

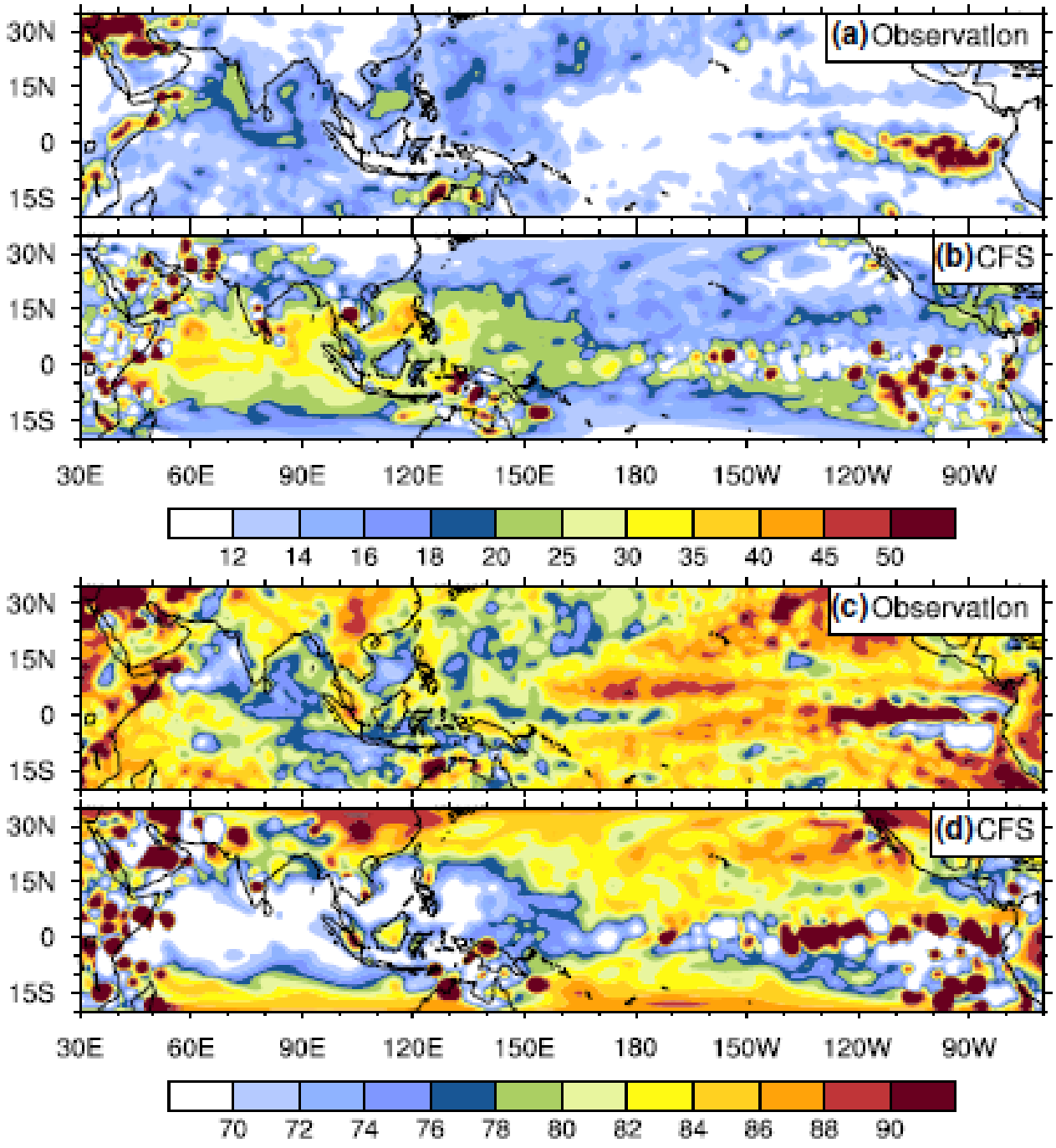
Abhik et al. 2015

CFSv2 T382 ISO 10-90 days variance →

Take away: The CFS shows generally poor variance in synoptic scale

CFSv2 T382 Synoptic variance (2-10 Days) →

- CFSv2 T382 overestimates ISO and underestimates Synoptic variance over tropics



The Global (Ensemble) Forecast Model

Flowchart of GEFS

GDAS

EnKF – GSI Hybrid Data Assimilation System

Analysis (Control)

Ensemble Initialization method: Ensemble Kalman Filter (EnKF) scheme.

The 6-hr forecasts from the previous cycle

20 Perturbed members

Tropical Storm Relocation (if storm is present)

Centering of the perturbations on the ensemble control analysis (Distributes the spread around analysis instead of Ensemble Mean

FORECAST: 21 members runs for 192 hrs (8 days) GFS Semi-Lagrangian T1534 (approx 12 km at equator); L64 vertical resolution.

The stochastic total tendency perturbation (STTP) to enhance model uncertainty

POST PROCESSING

240 hr (10 days) forecast

Resolution: 0.125°x0.125°

6 hr interval

Products: 21 members, Ensemble mean, Ensemble Spread

Flowchart of deterministic GFS

GDAS

EnKF – GSI Hybrid Data Assimilation System

Analysis(Control)

FORECAST: GFS Semi-Lagrangian T1534 (approx 12 km at equator) L64 vertical resolution, runs for 240 hrs (10 days)

POST PROCESSING

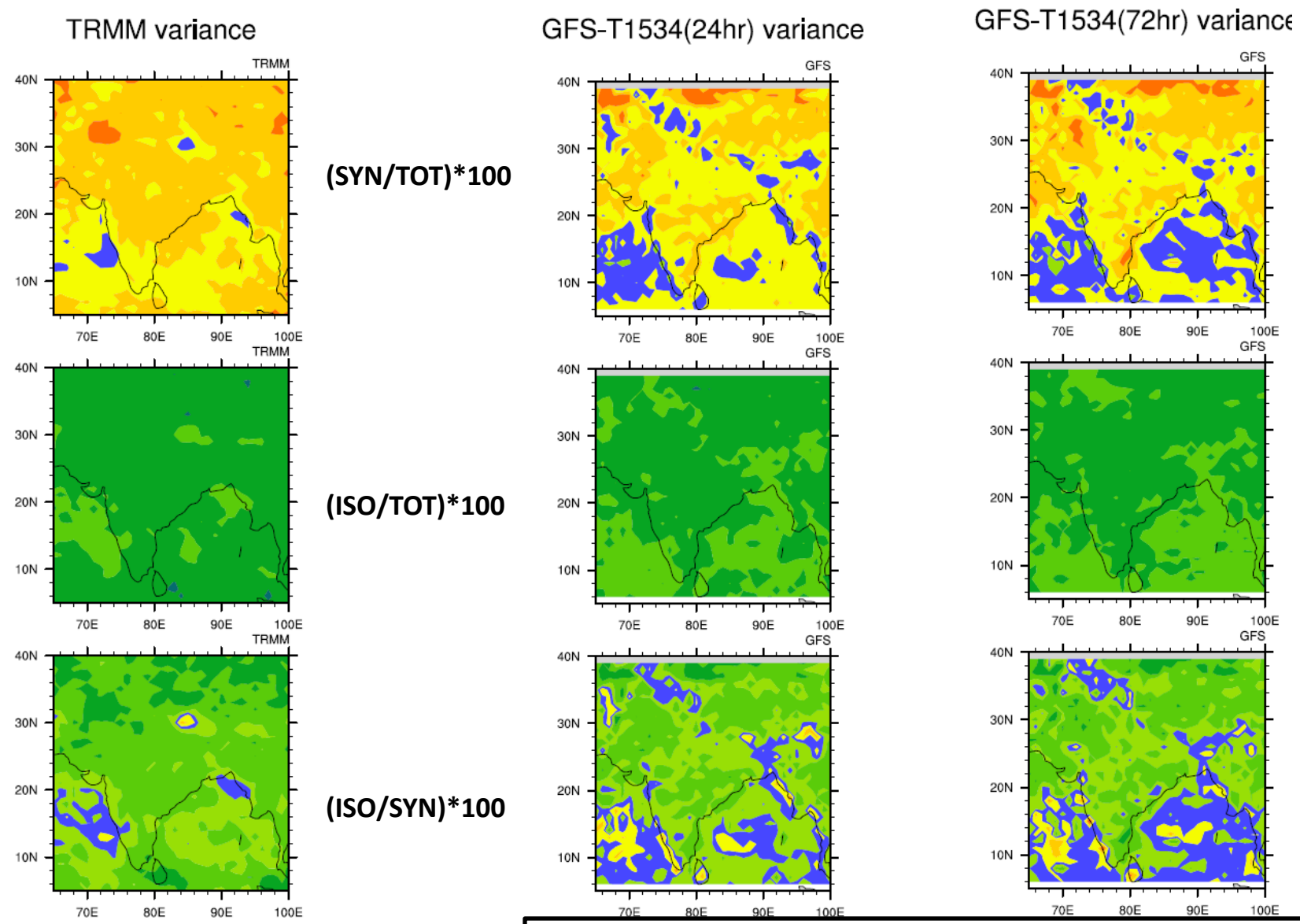
240hr (10 days) forecast

Resolution: Regular grid and Gaussian grid at different resolutions

0.125°x0.125°

What about High Res. GFS (T1534~12.5 km)

Synoptic scale variance



GFS has reasonable fidelity in capturing the synoptic scale variances over Indian region.

Further status of CFS/GFS

CFSv2 T382

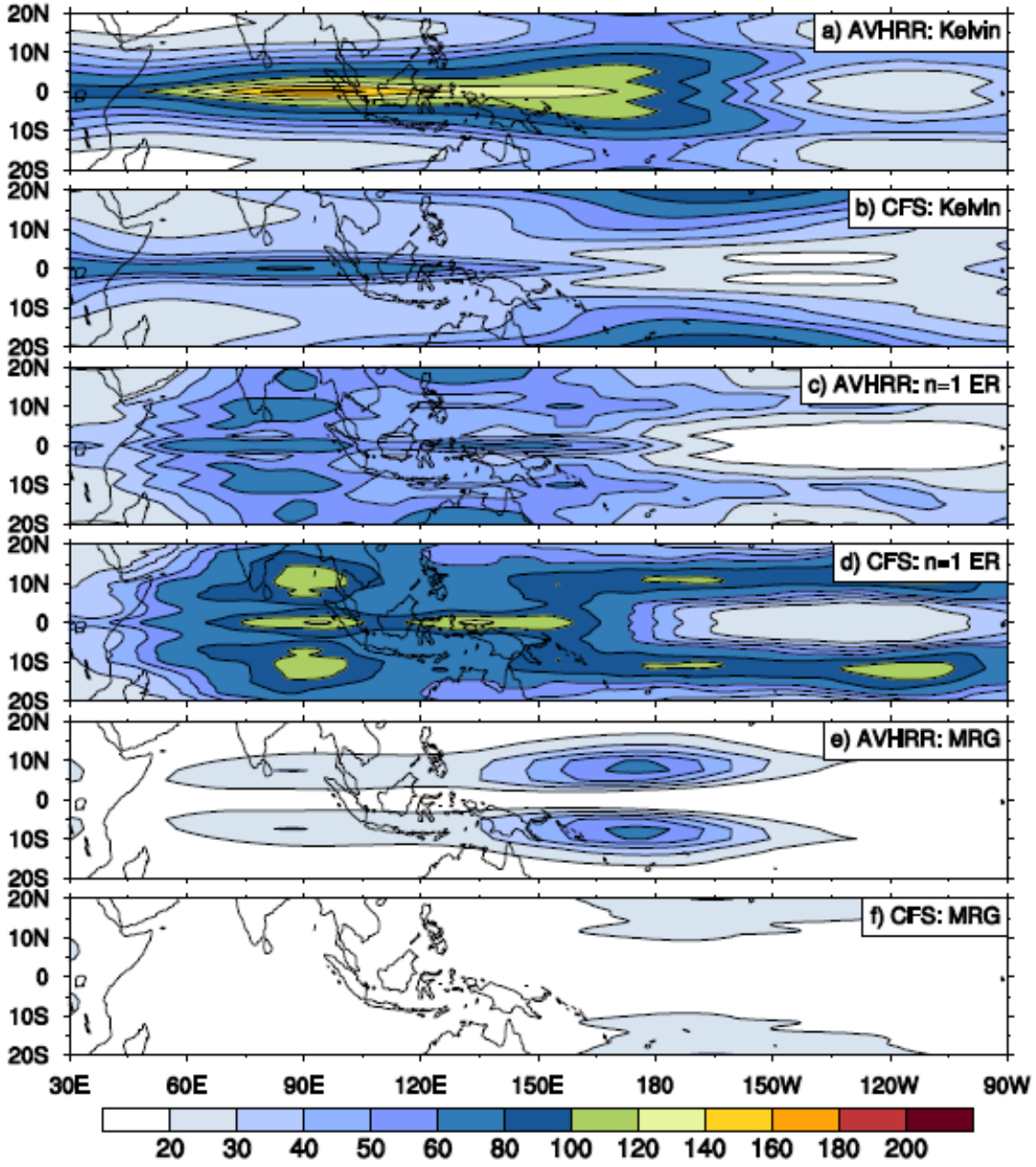


Fig. 13: Distribution of boreal summer time OLR variance (W^2 m^{-4}) of (a), (b) Kelvin; (c), (d) n=1 ER and (e), (f) MRG waves for AVHRR and CFS.

Abhik et al., 2015

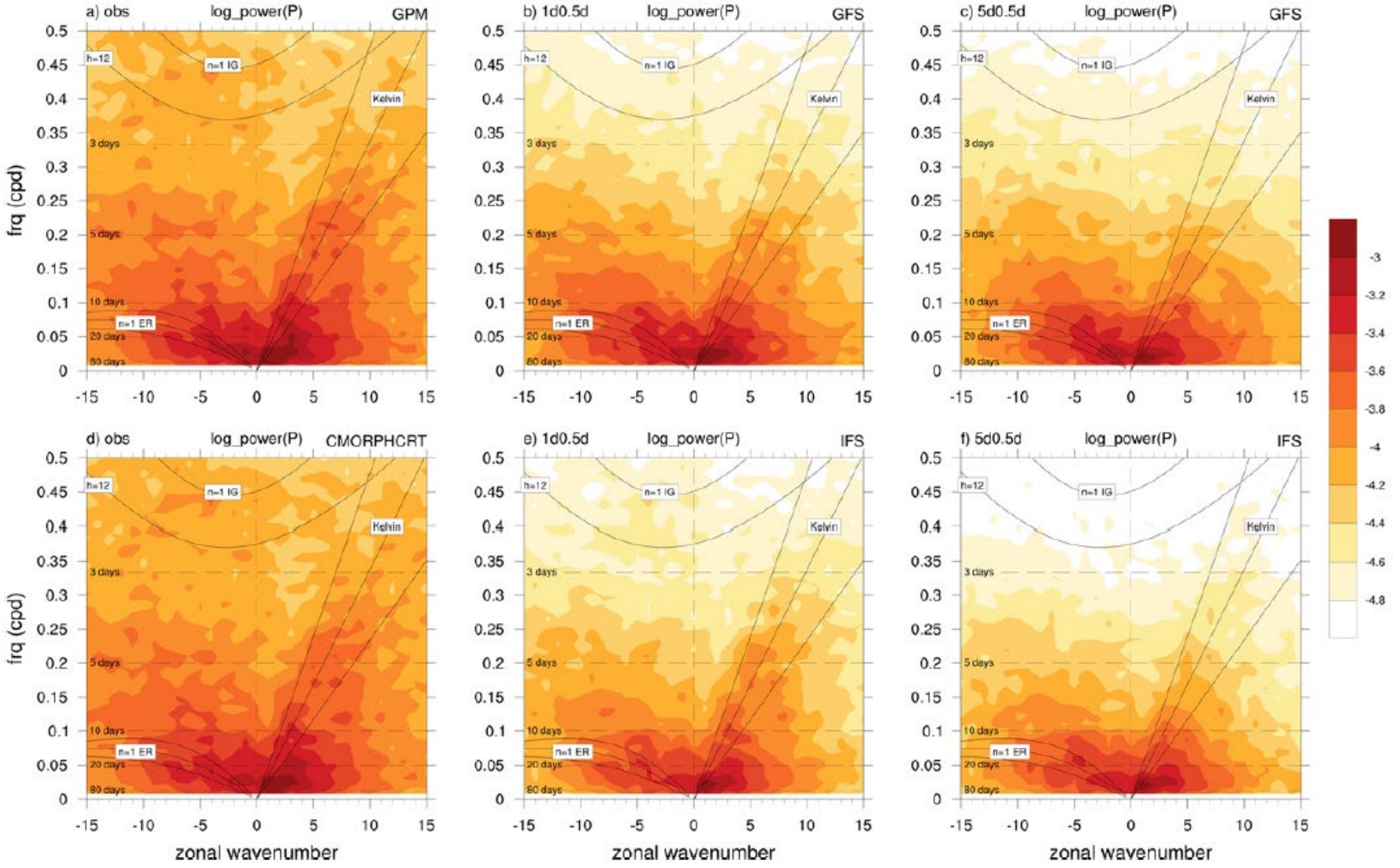


FIG. 9. Zonal wavenumber and frequency power spectra of symmetric rain rates about the equator averaged from 15°S to 15°N for the period January 2015–March 2016 of (a) GPM, (b) GFS 1d0.5d, (c) GFS 5d0.5d, (d) CMORPH, (e) IFS 1d0.5d, and (f) IFS 5d0.5d. Dispersion curves shown are for equatorial waves as in Wheeler and Kiladis (1999), for equivalent depths of 12, 25, and 50 m.

Dais et al. 2018

GFS and IFS

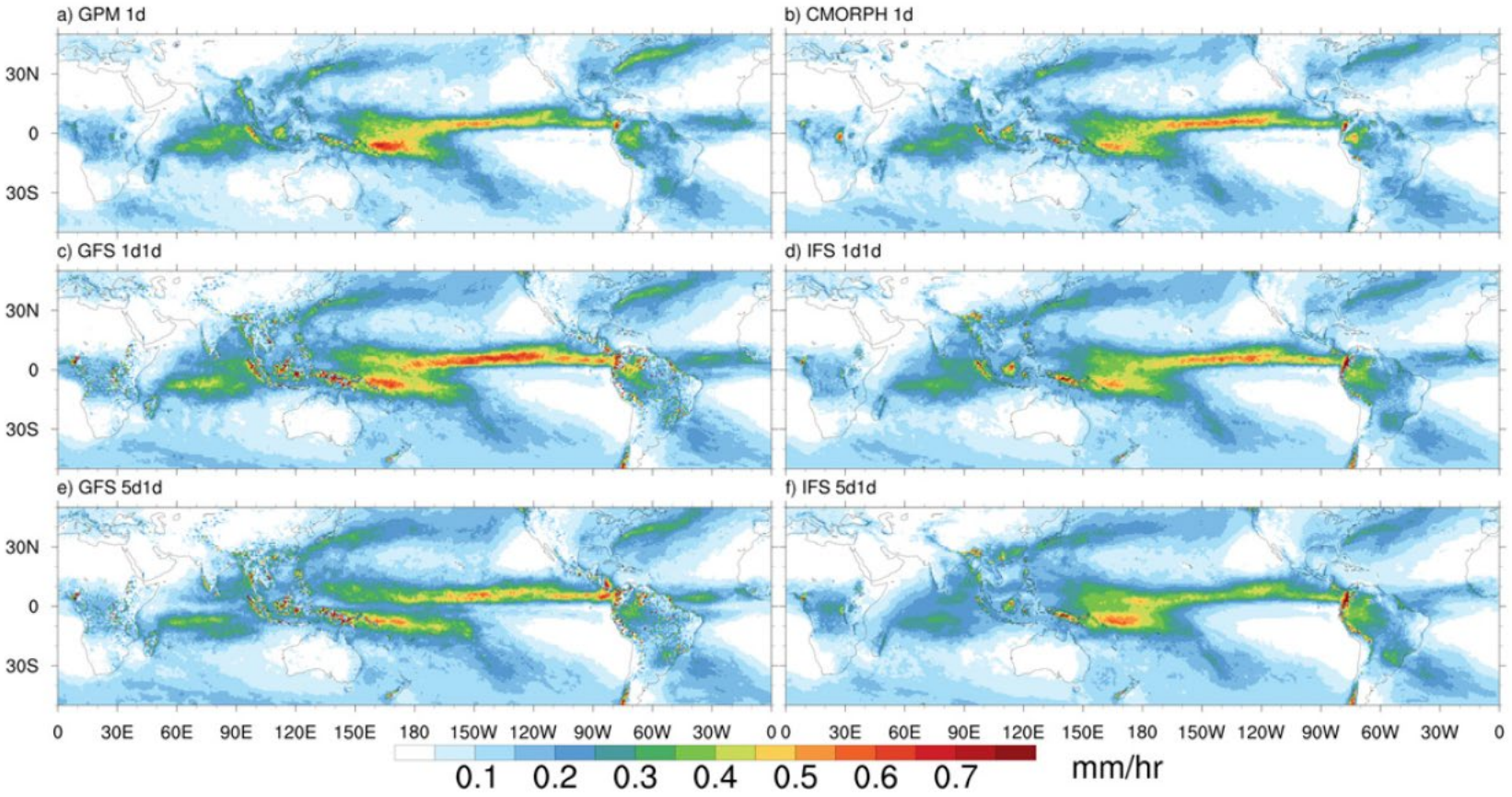


FIG. 3. Mean daily precipitation rate for the period January 2015–March 2016 from the (a) GPM, (b) CMORPH, (c) NCEP GFS day-1 forecast (1d1d), (d) ECMWF IFS day-1 forecast (1d1d), (e) NCEP GFS day-5 forecast (5d1d), and (f) IFS day-5 forecast (5d1d).

Juliana Dias et al. 2018

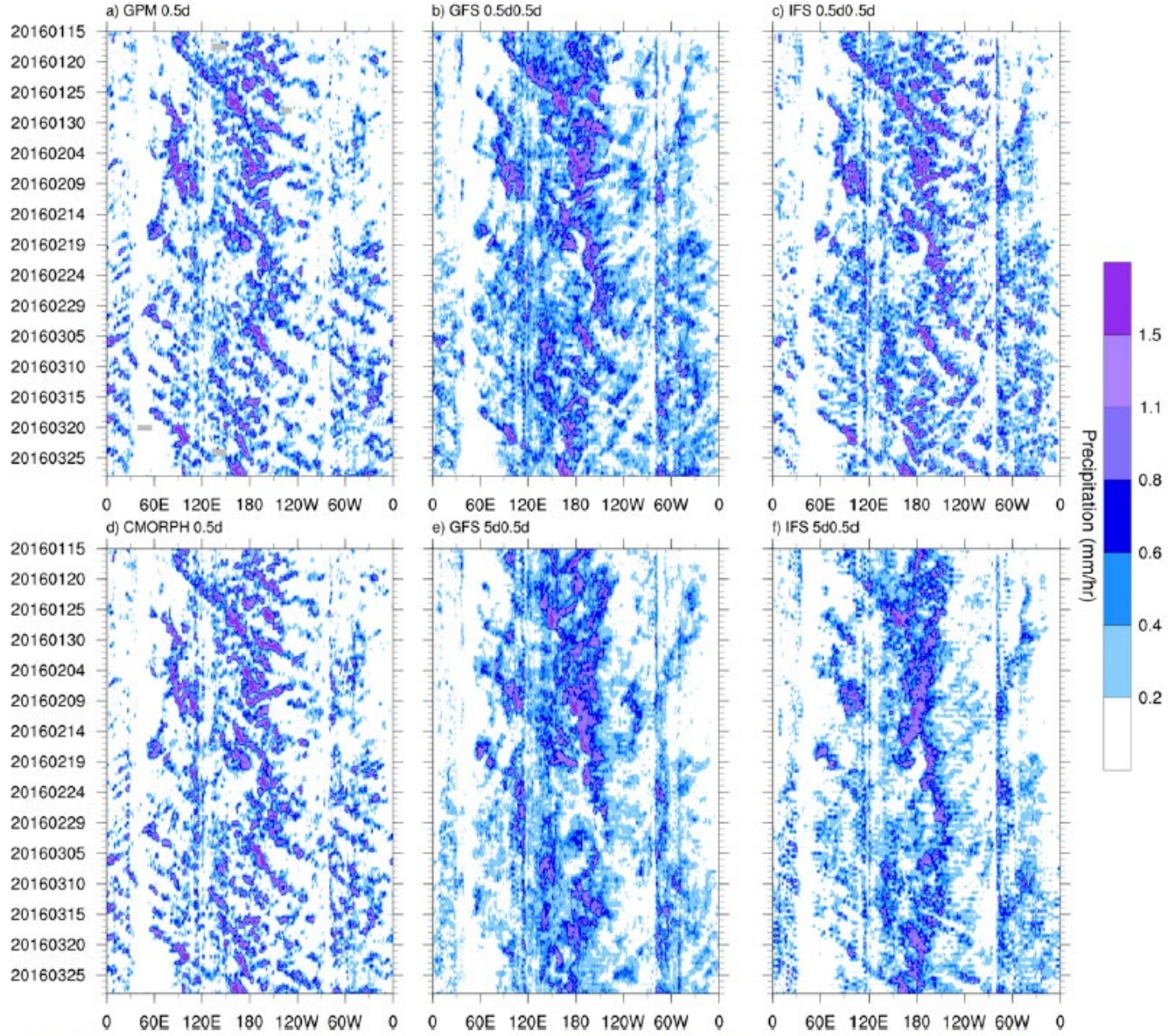


FIG. 1. Time–longitude section of 12-h average rain rates from 15 Jan to 25 Mar 2016 averaged from 5°S to 5°N. Satellite estimates are shown for (a) GPM and (d) CMORPH, and 12-h forecasts are shown for (b) the NCEP GFS and (c) the ECMWF IFS, and 120-h forecasts are shown for (e) the NCEP GFS and (f) the ECMWF IFS.

Diurnal variability

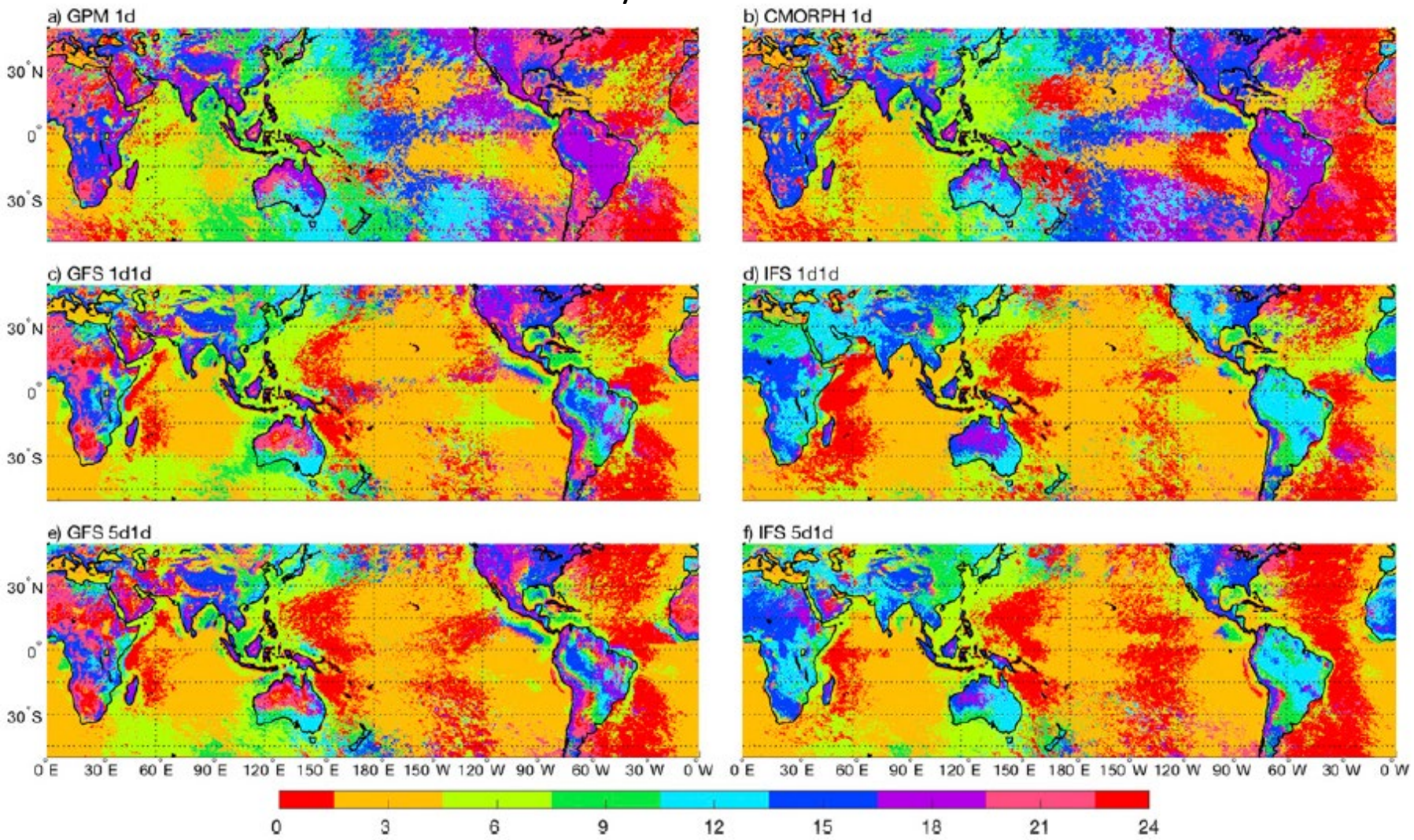
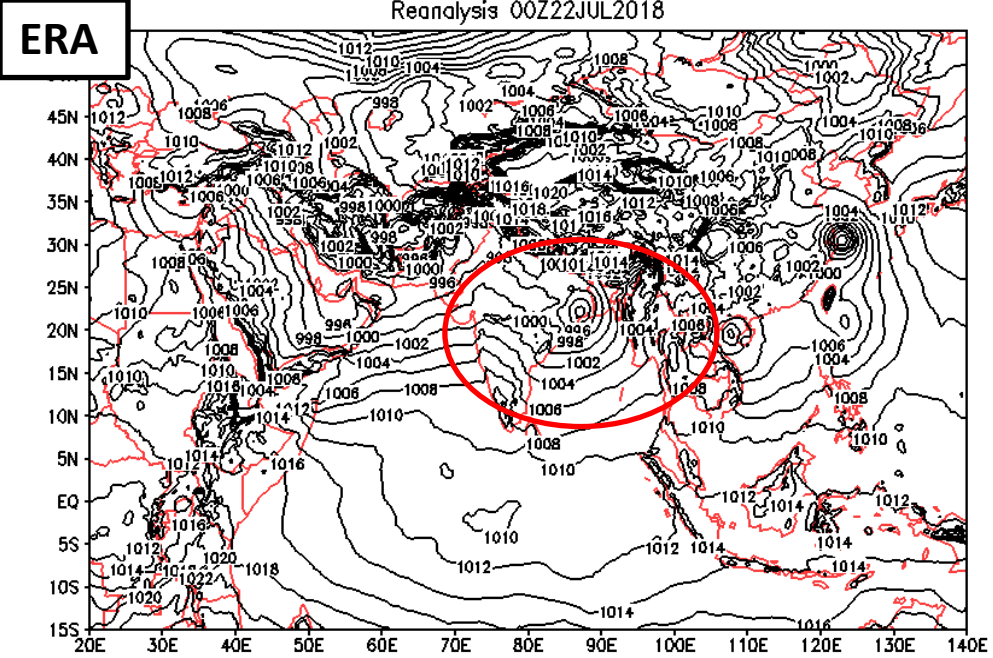


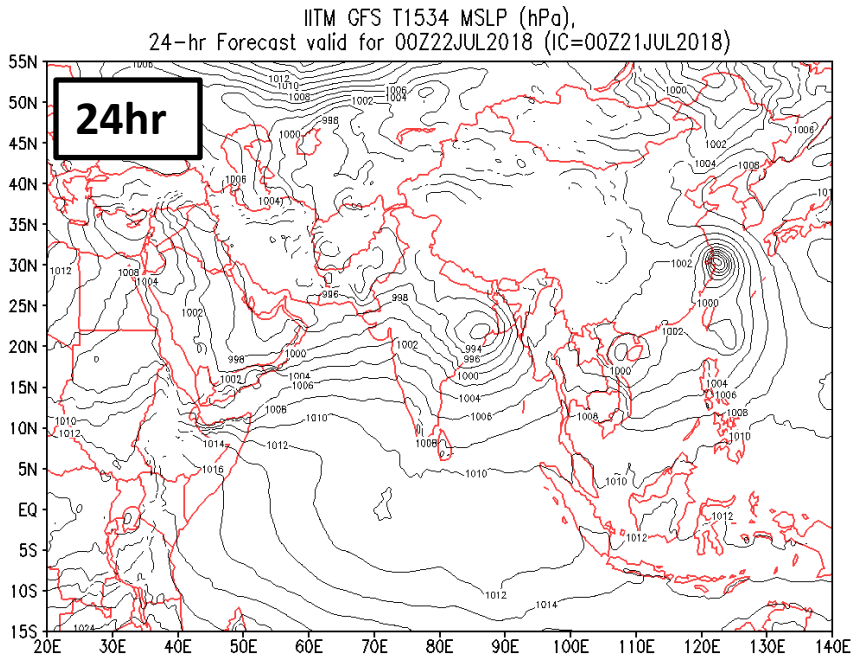
FIG. B1. Panels display the diurnal phase (LST hour of day) of (a) GPM, (b) CMORPH, (c) GFS 1d1d, (d) IFS 1d1d, (e) GFS 5d1d, and (f) IFS 5d1d.

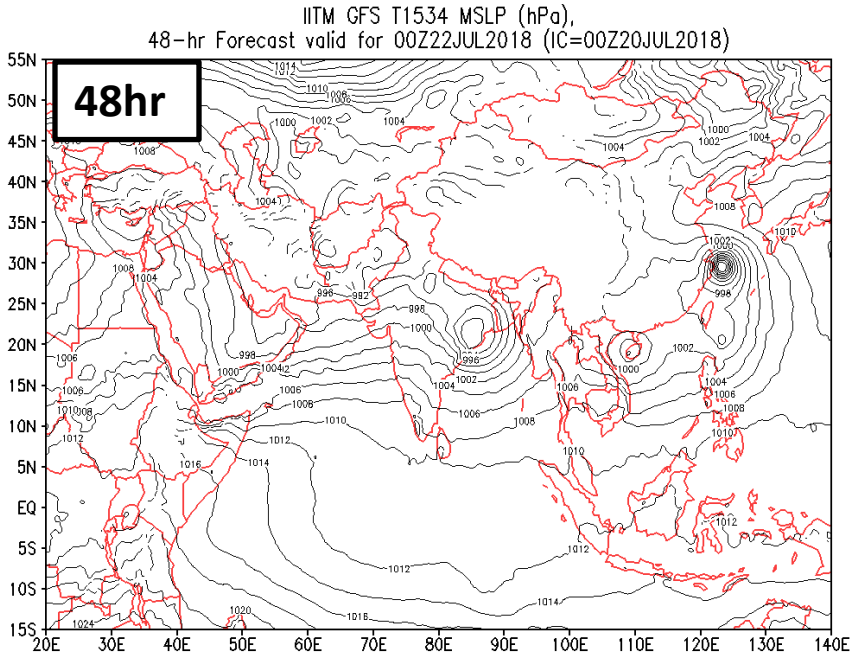
Dais et al. 2018

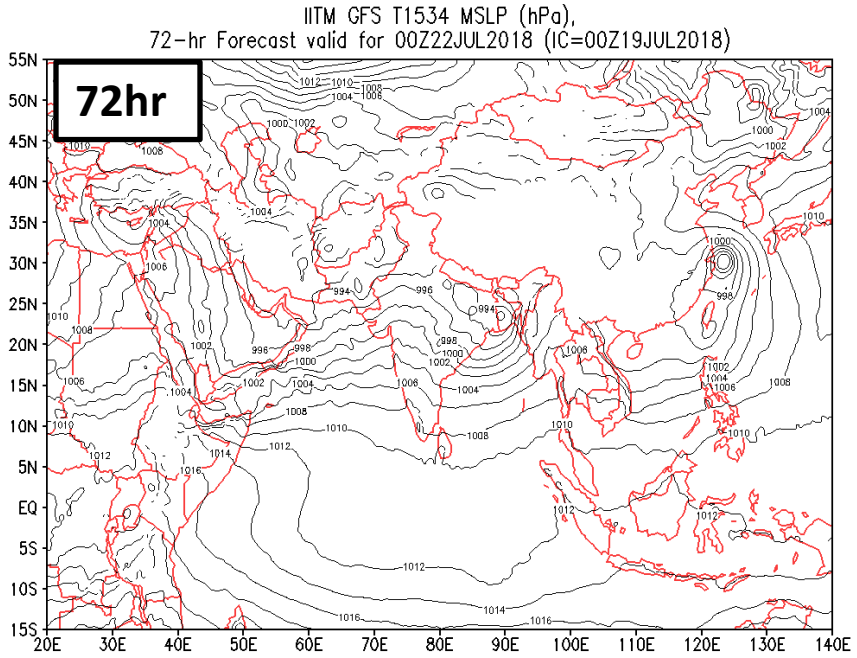
Two questions

- **Whether does the GFS capture the LPS and what lead?**
- **Fidelity to capture Transition from lows to depression**

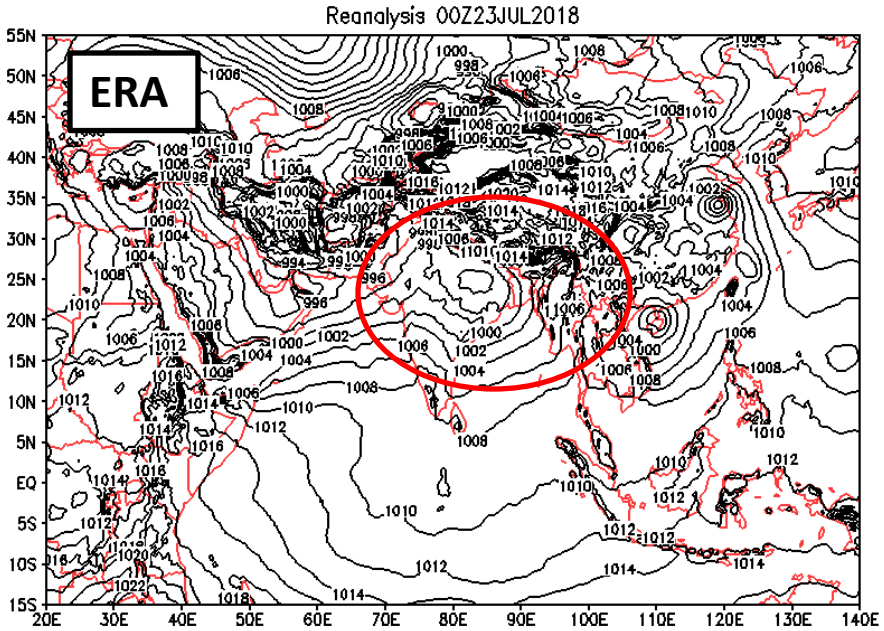


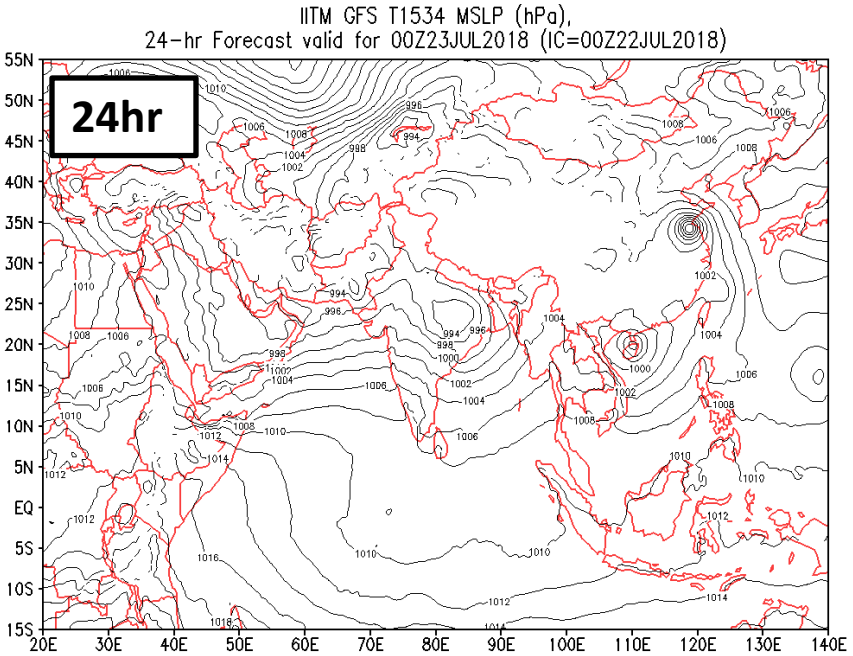


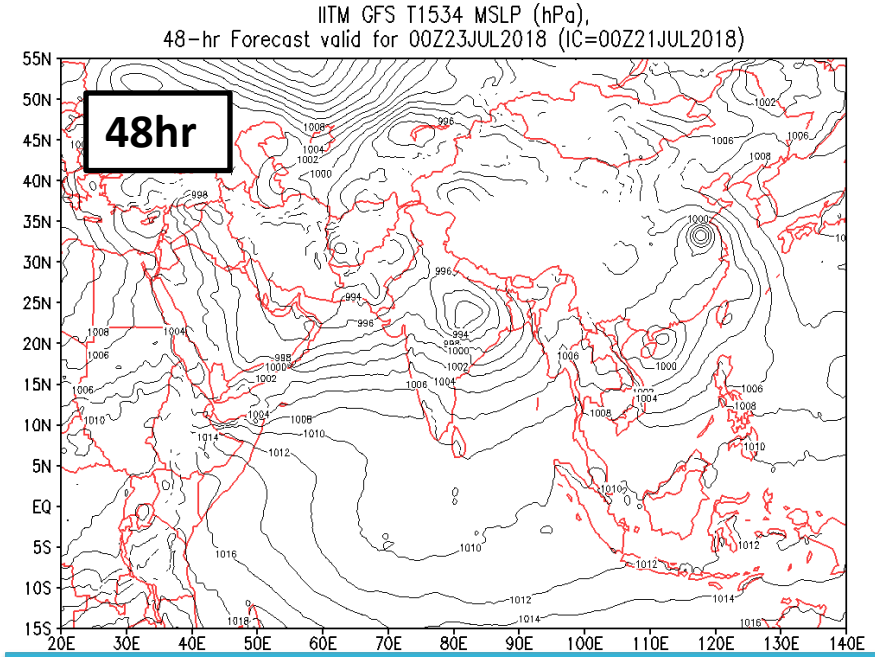


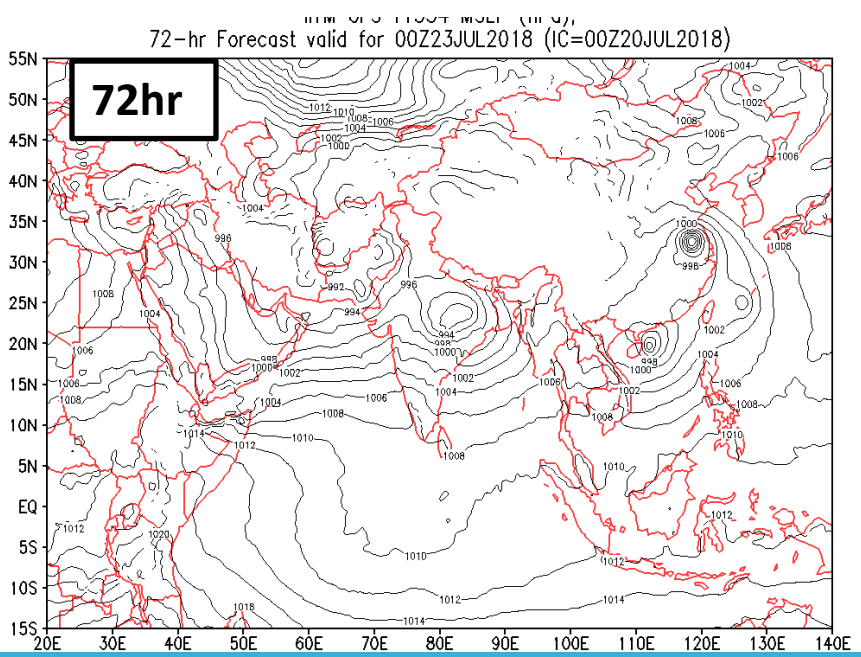


MSLP for depression case:22 July, 2018



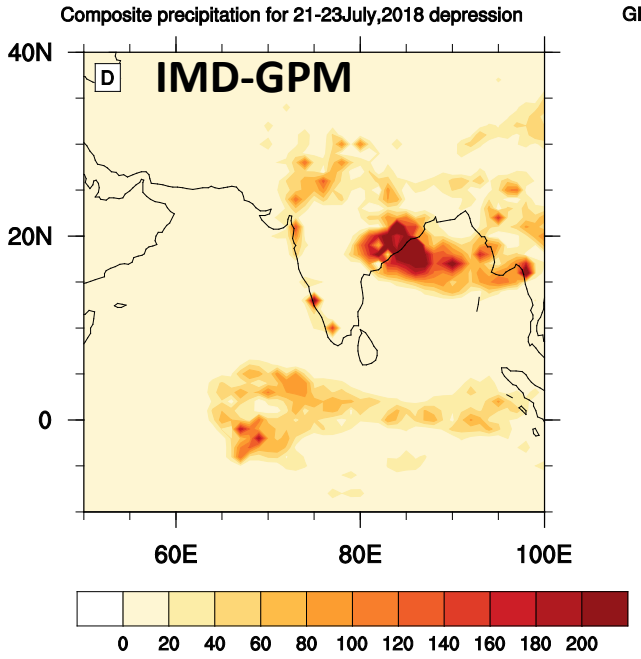


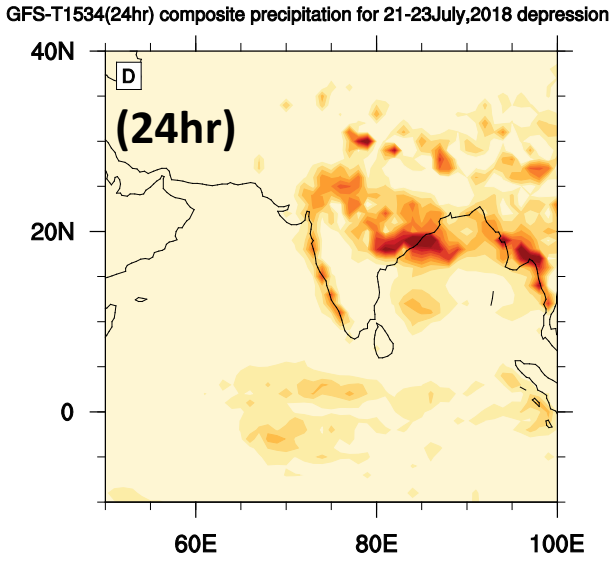


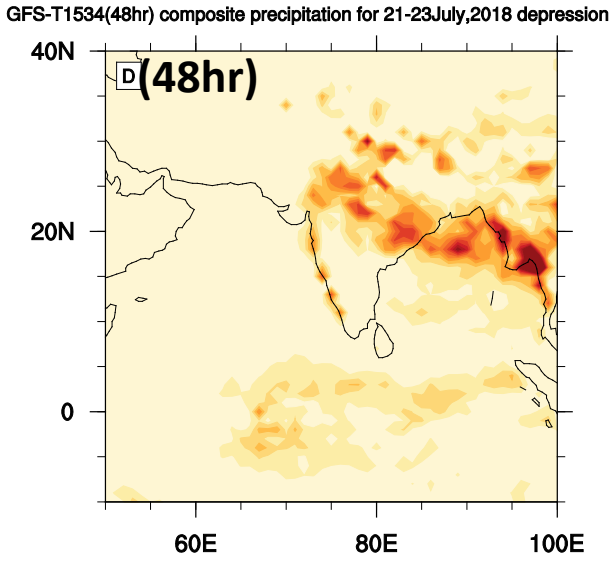


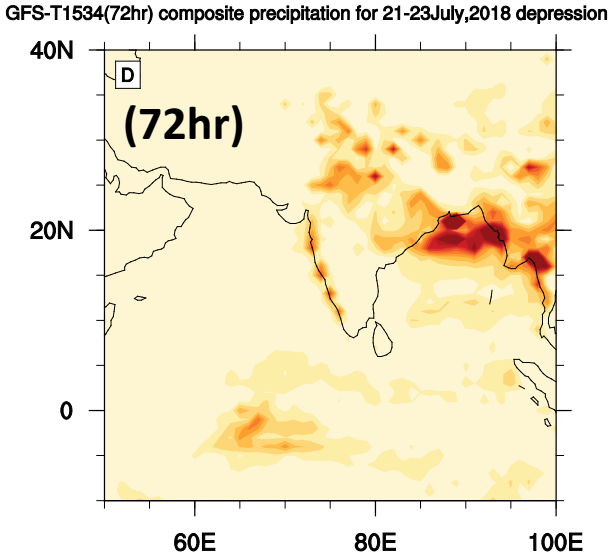
MSLP for depression case:23 July, 2018

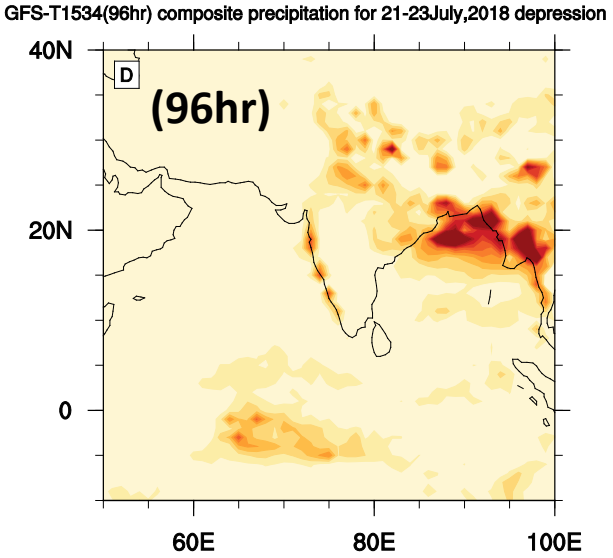
3 day accumulated precipitation based on observation and model



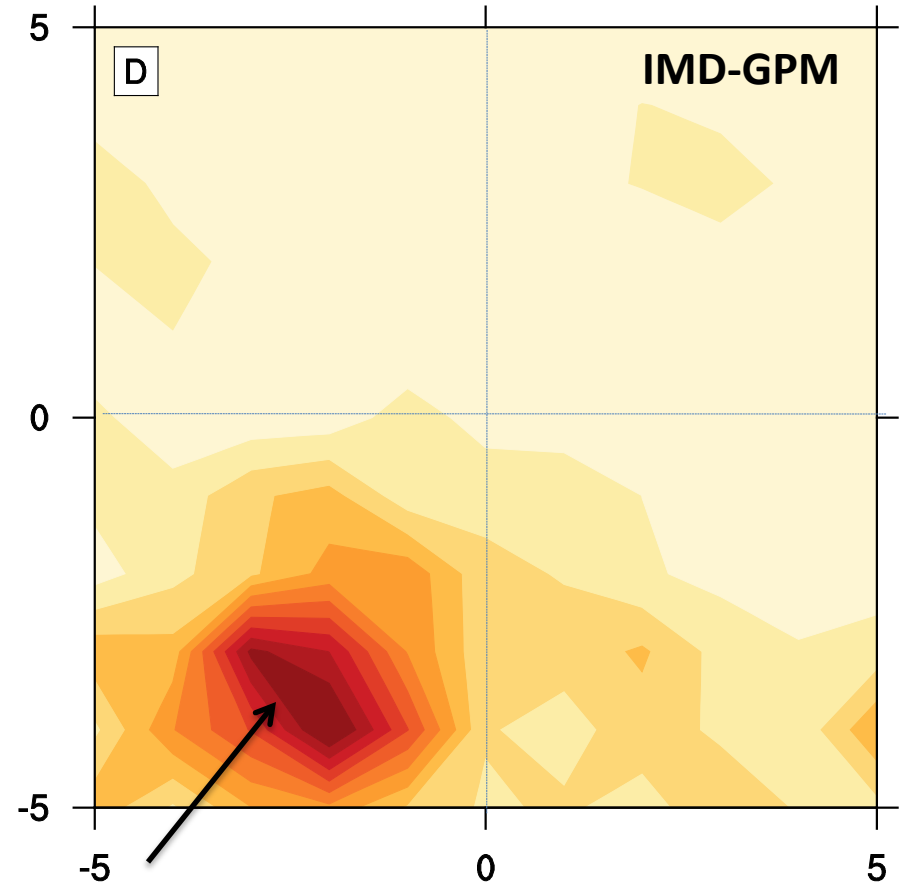


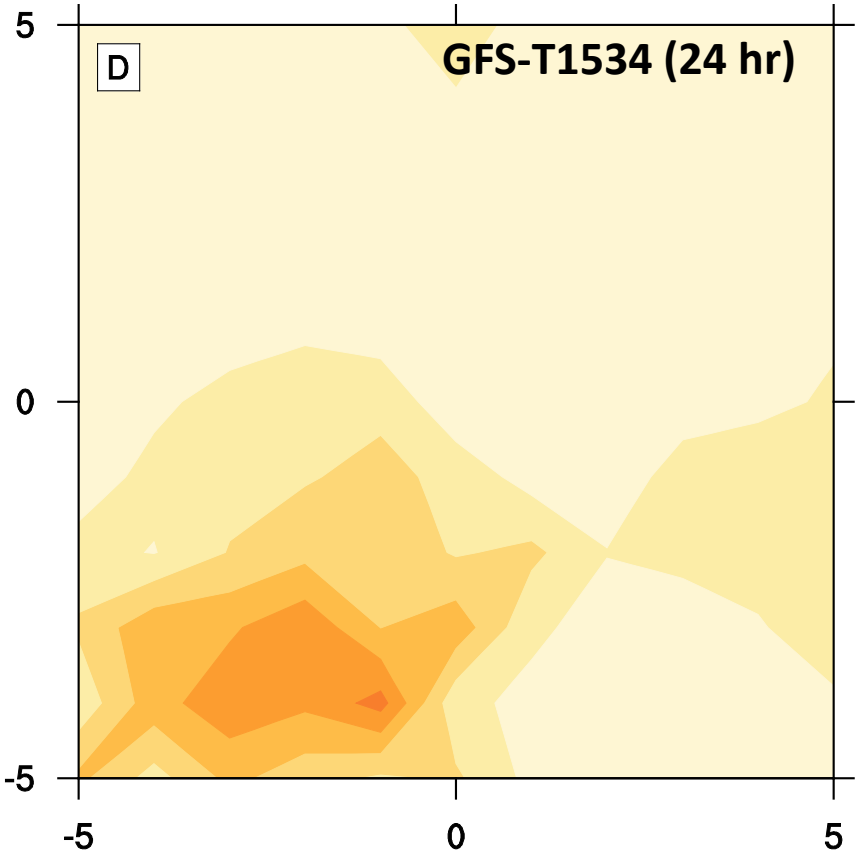






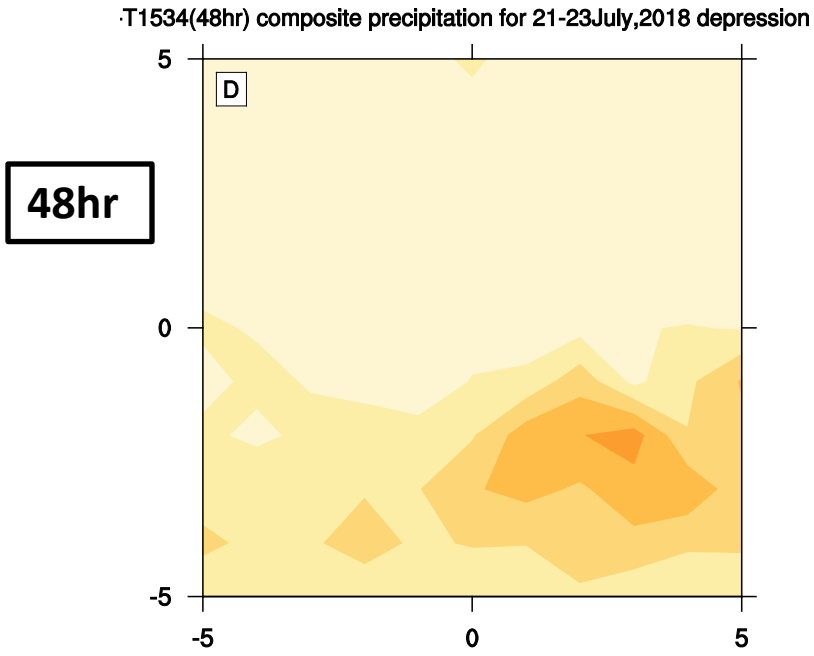
Composite precipitation for 21-23 July,2018 events based on observation and model

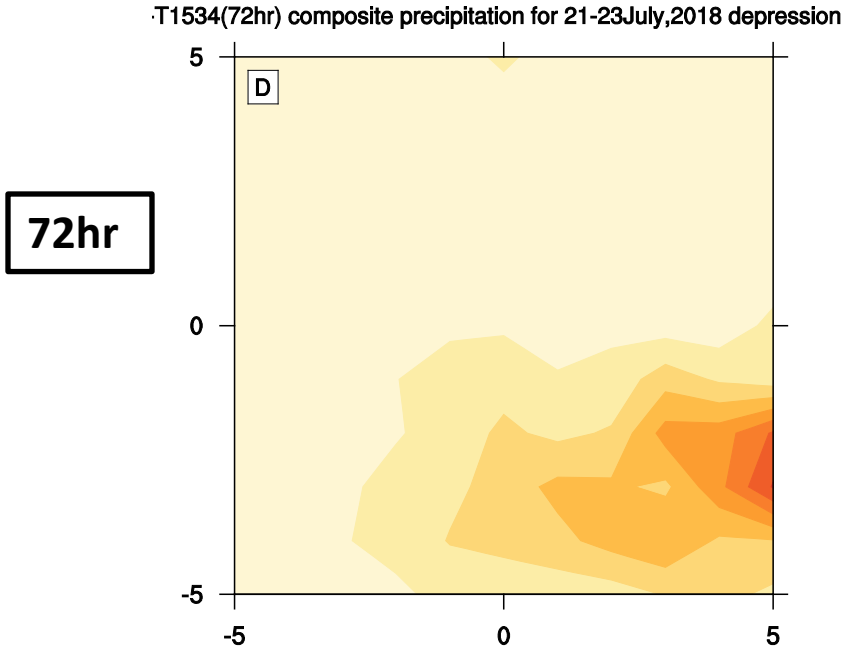


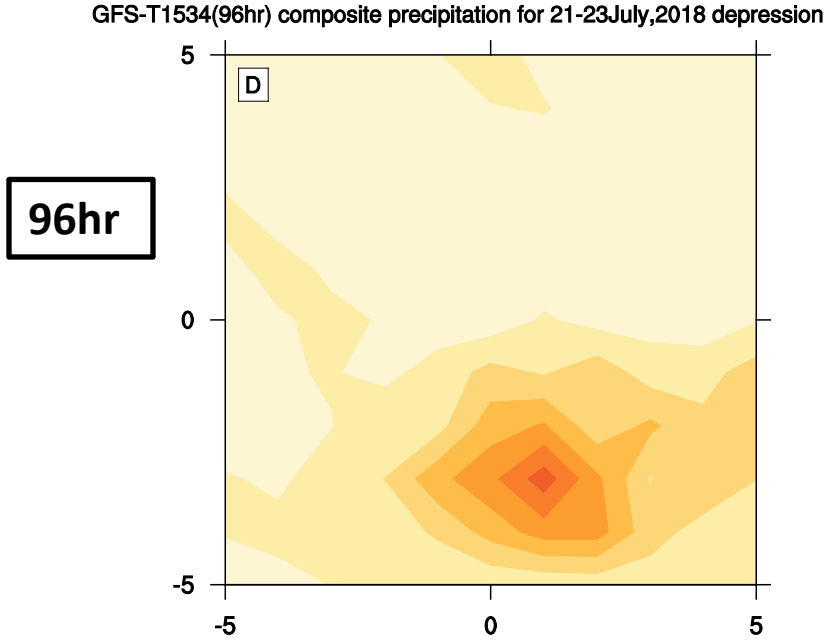


South-west sector

Positive(Negative) in x axis means to the **east/west** from the centre of the system.
Positive(Negative) in y axis means to the **north/south** to the centre of the system


·T1534(48hr) composite precipitation for 21-23July,2018 depression
48hr
D
5
0
-5
-5
0
5


·T1534(72hr) composite precipitation for 21-23July,2018 depression
72hr
D
5
0
-5
-5
0
5


GFS-T1534(96hr) composite precipitation for 21-23July,2018 depression
96hr
D
5
0
-5
-5
0
5


0
20
40
60
80
100
120
140
160
180
200

- One may argue, the case shown earlier may be a random events where the model is able to capture the depression with good lead time.

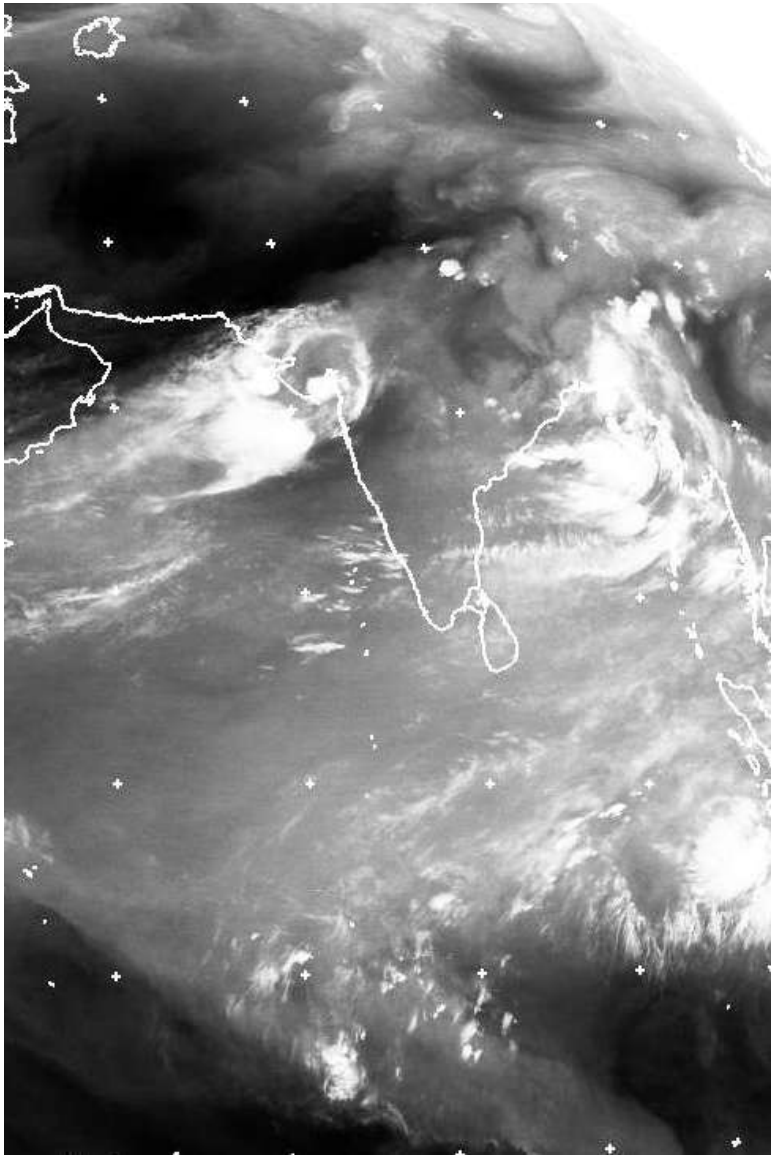
- To see the models systematic performance, we have analyzed data from 2001 to 2010 from observation and as well as from model.

- We have identified 34 cases where low pressure system has intentensified into depressions and 73 cases where low pressure system was not able to intensify. The composite structure of the dynamical parameters based on observation and model are plotted .

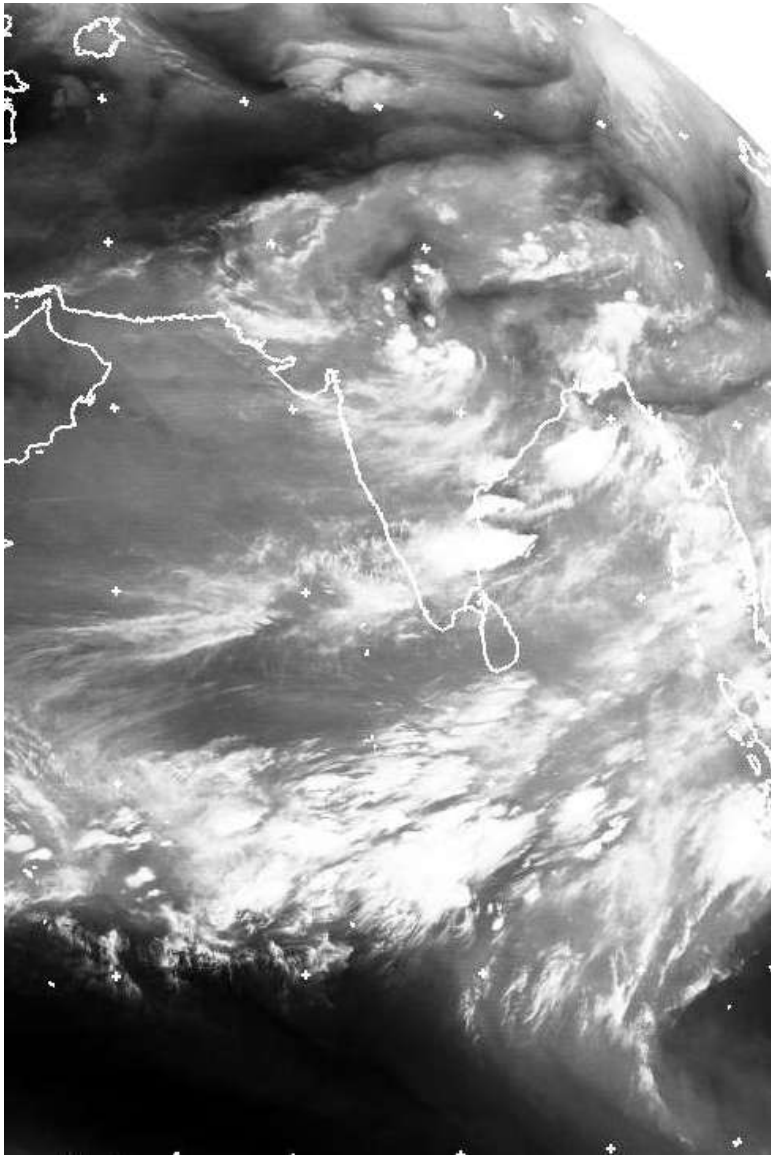
Low to depression

Meteosat VISSR (IODC) 057.0E Image

Low

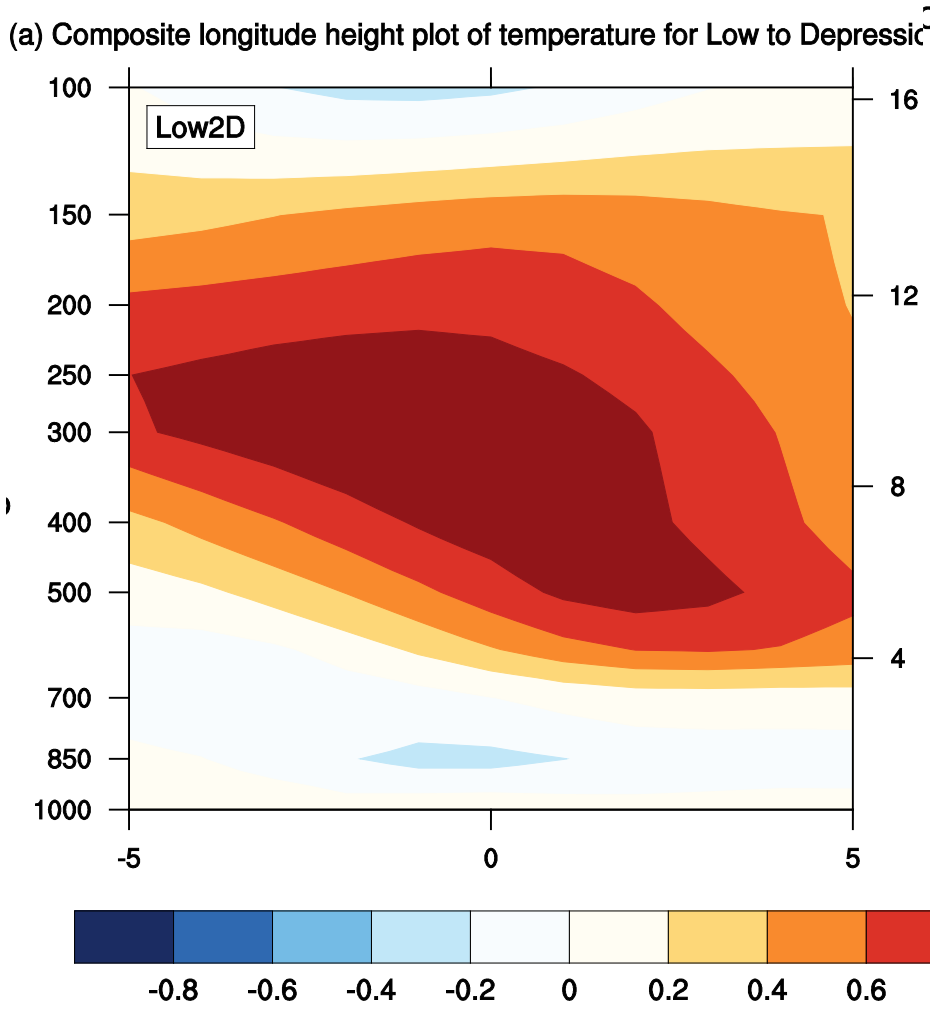


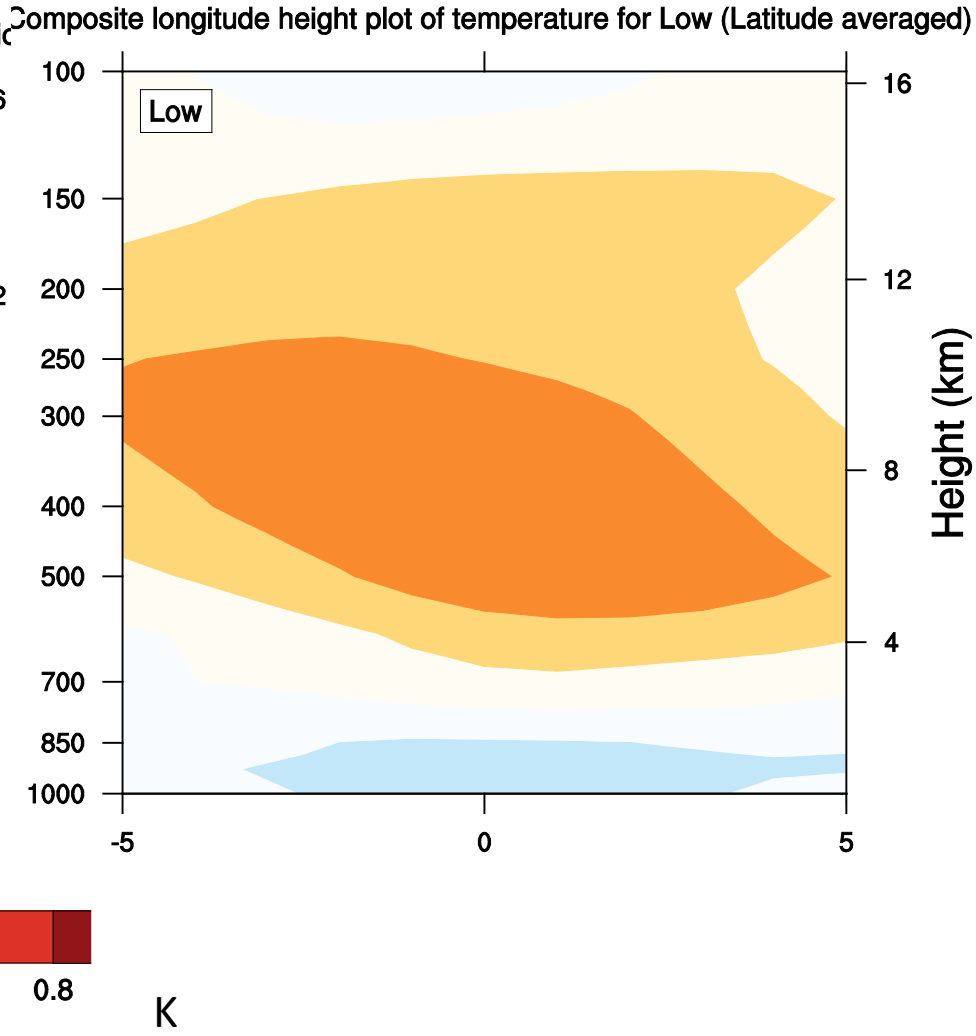
14-18 Sep, 2008



07-12 July, 2008

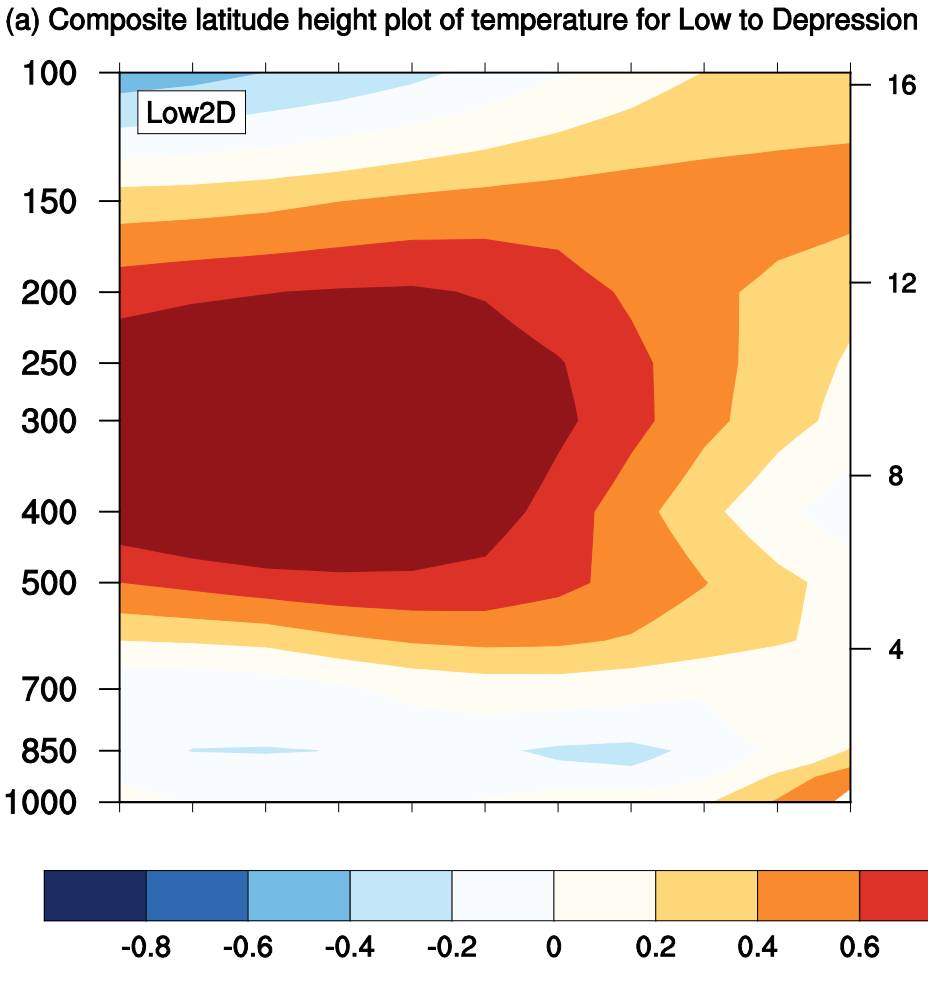
Longitude height plot of anomalous temperature (latitude averaged)

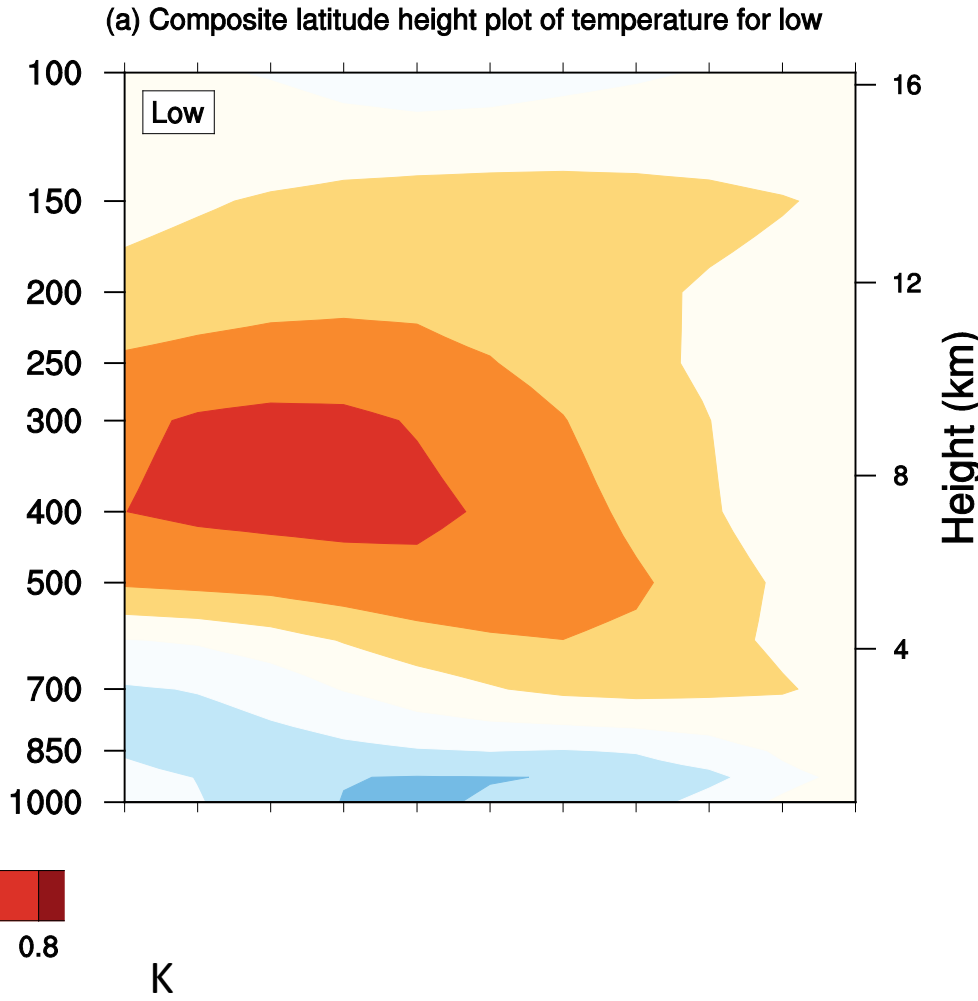




Positive(Negative) in x axis means to the **east/west** from the centre of the system.

Latitude height plot of anomalous temperature (Lon. averaged)

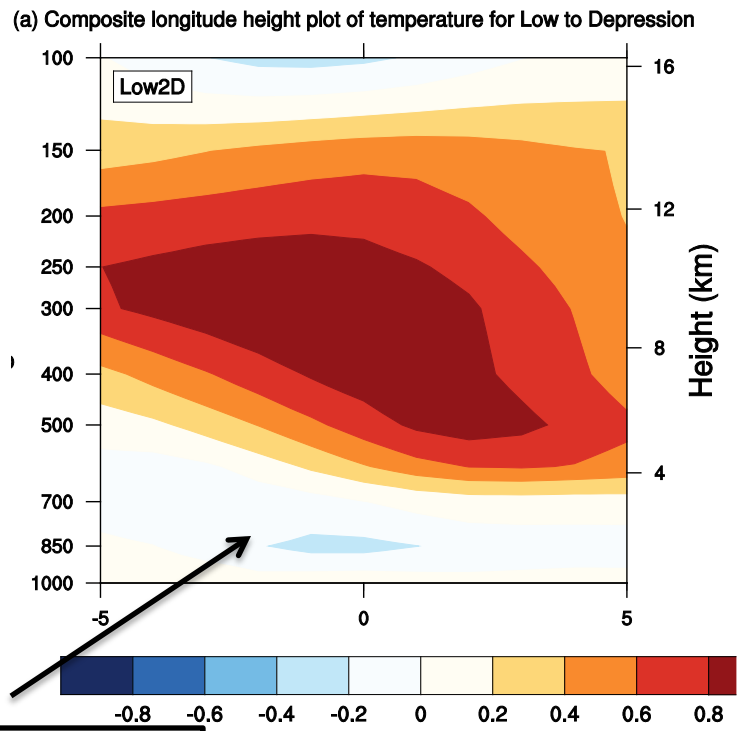




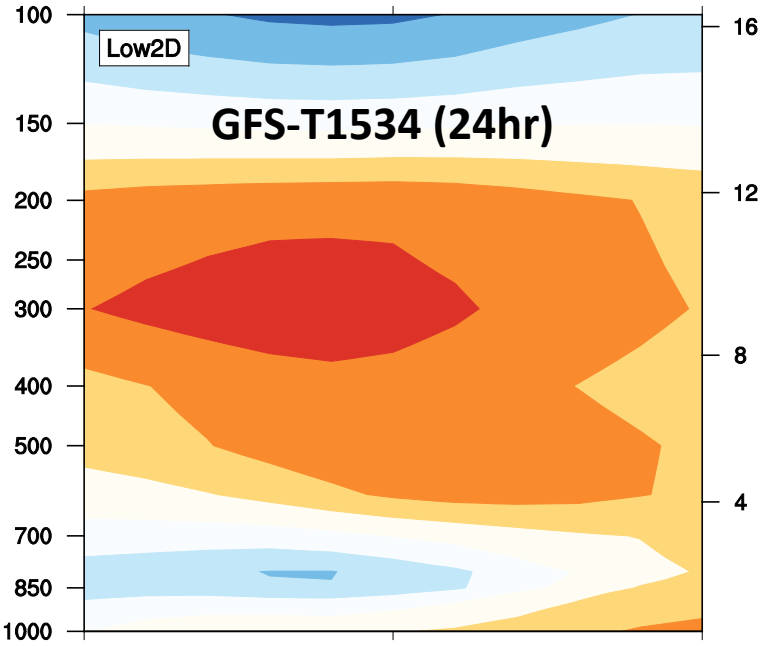
Positive(Negative) in x axis means to the **north/south** to the centre of the system

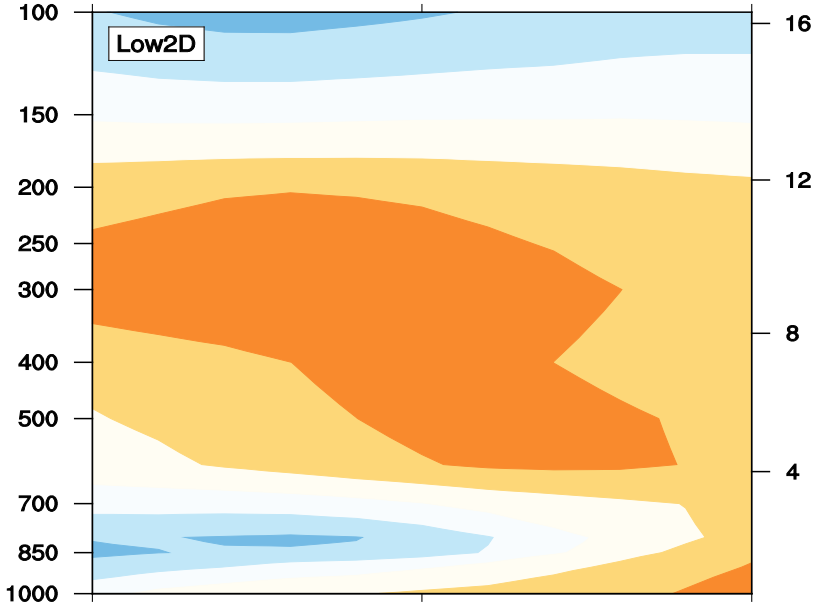
ERA

Longitude height plot of anomalous temperature



Cold Core



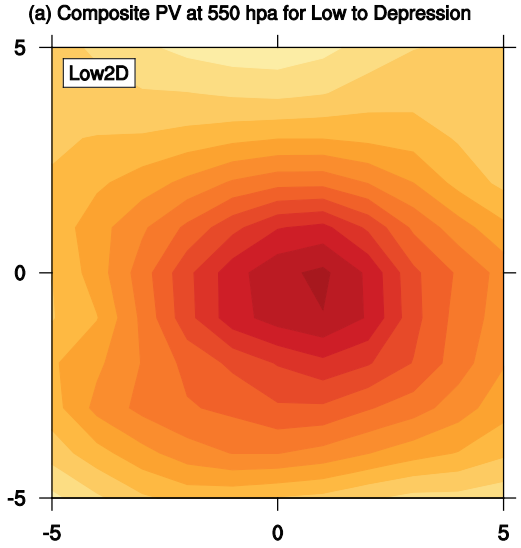


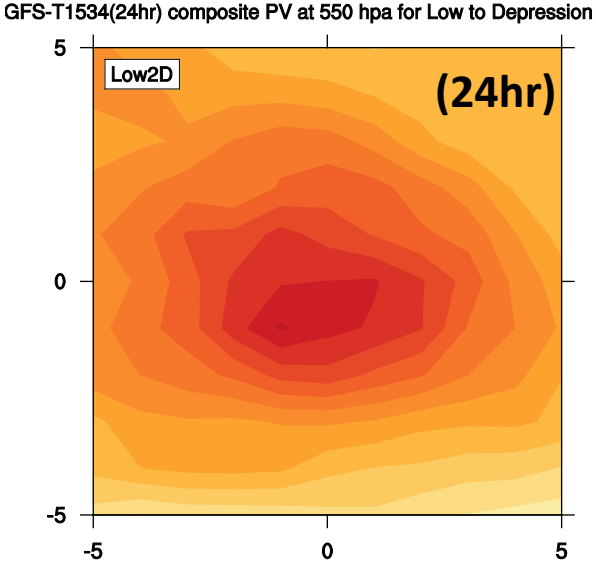
(48hr)

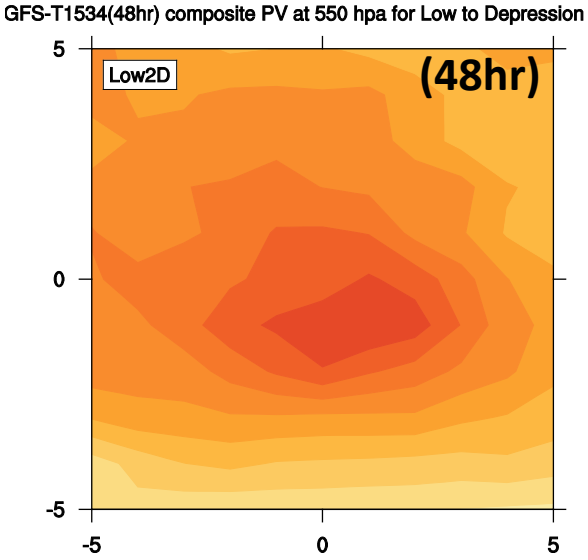
Positive(Negative) in x axis means to the **east/west** from the centre of the system.

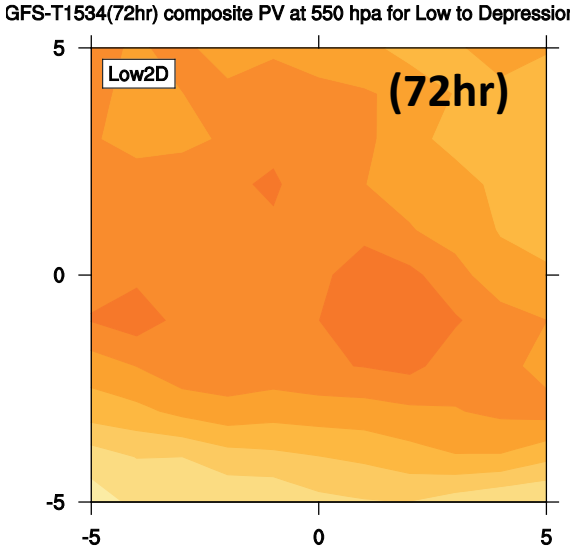
Potential vorticity (low to depression)

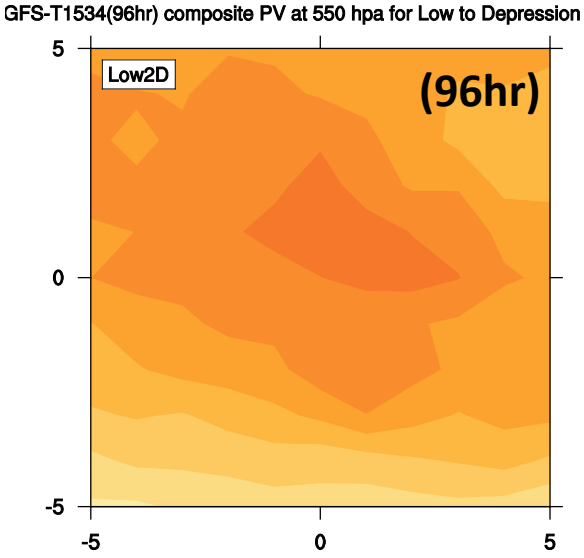
ERA









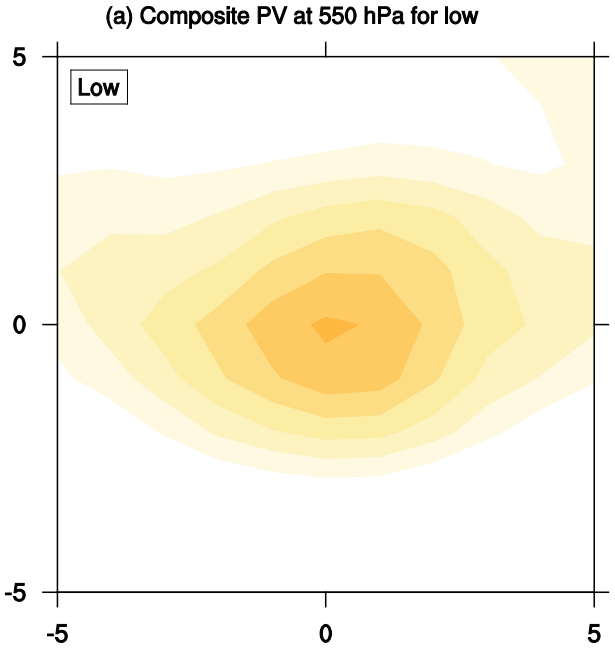


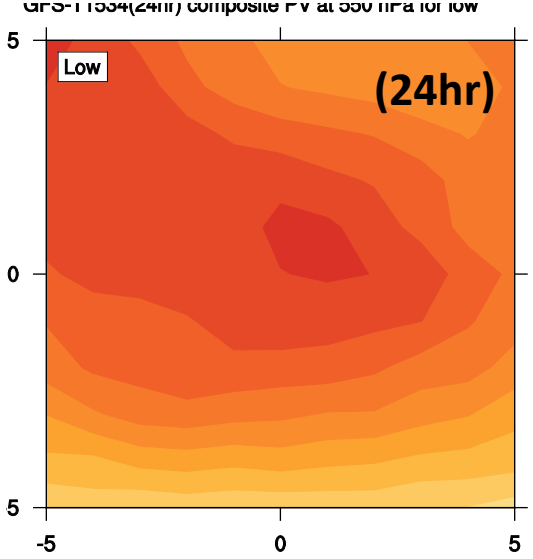
Positive(Negative) in x axis means to the **east/west** from the centre of the system.

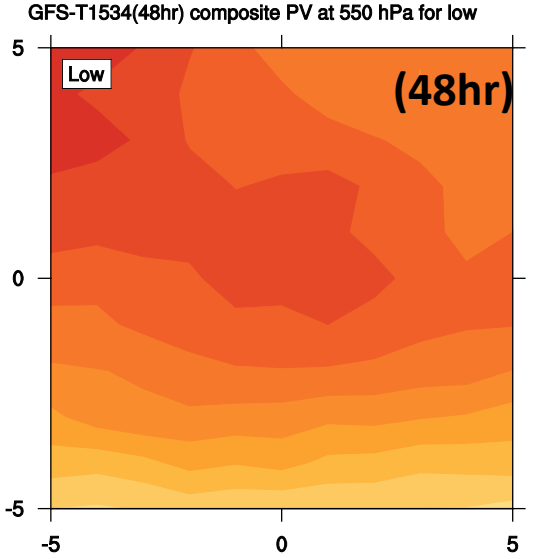
Positive(Negative) in y axis means to the **north/south** to the centre of the system

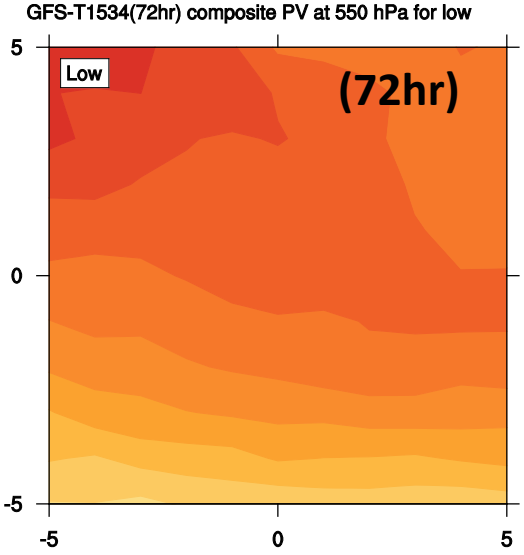
ERA

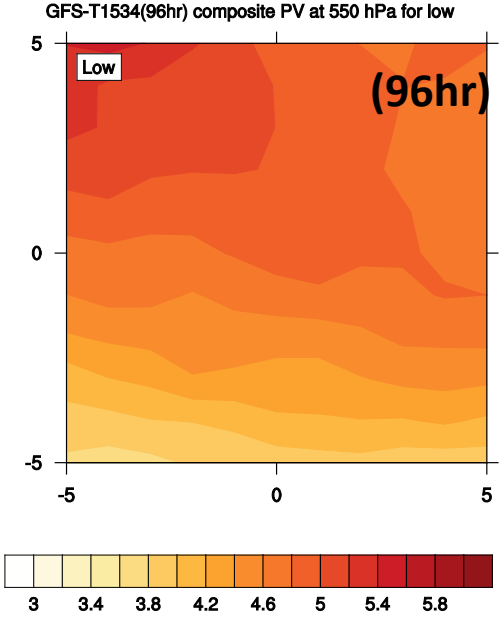
Same for low









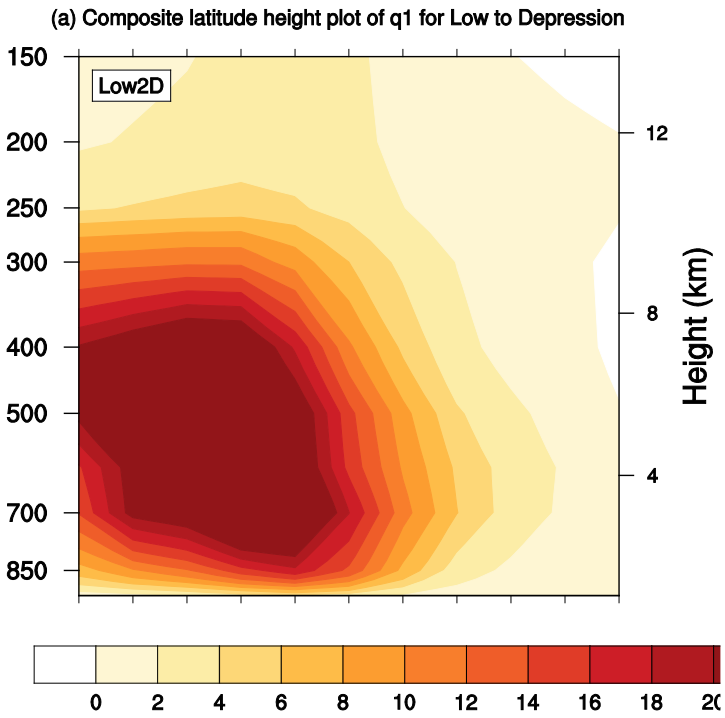


Positive(Negative) in x axis means to the **east/west** from the centre of the system.

Positive(Negative) in y axis means to the **north/south** to the centre of the system

Latitude height plot of heating

ERA



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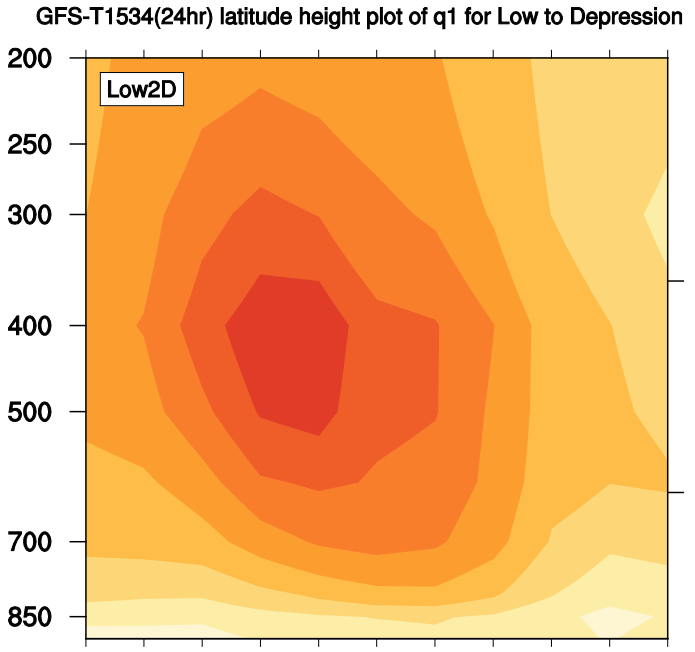
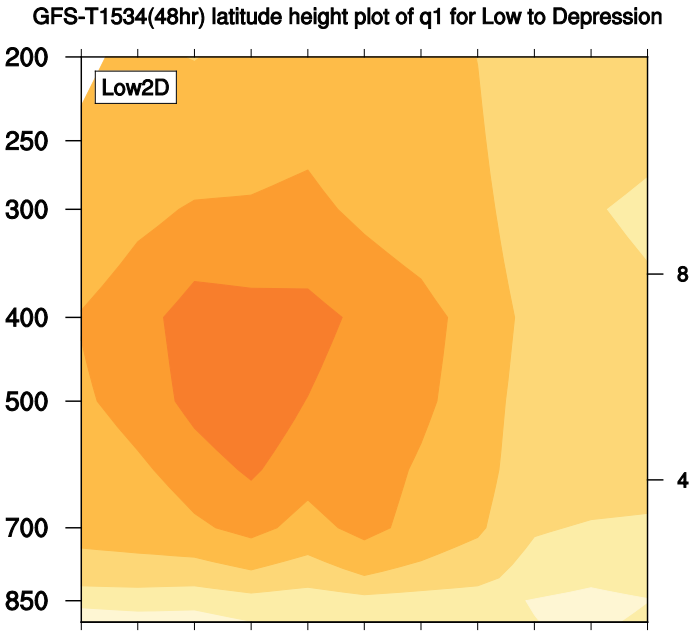


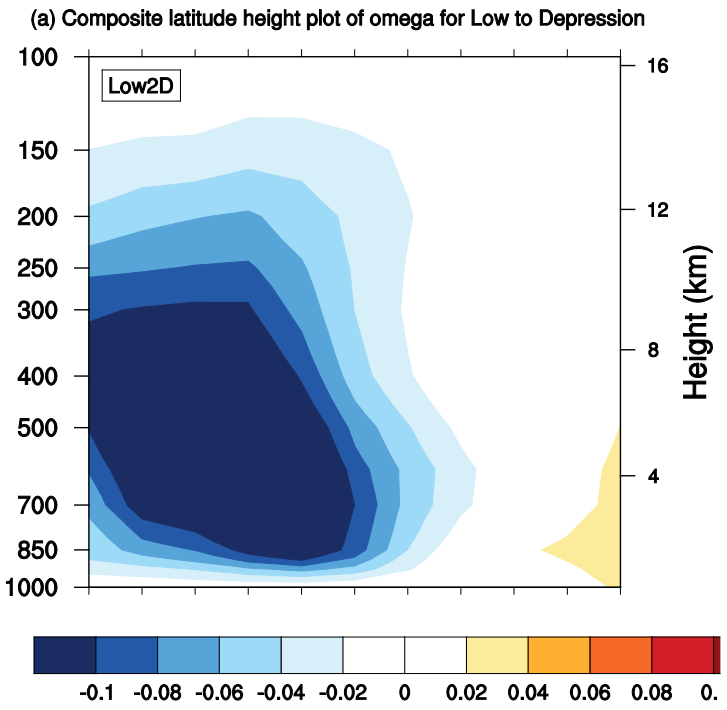
48hr



Positive(Negative) in x axis means to the **north/south** to the centre of the system

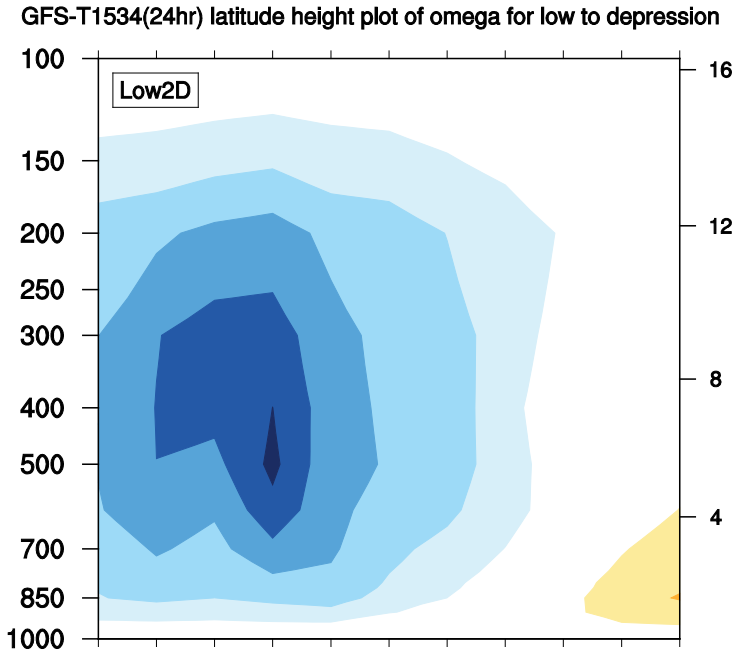
Latitude height plot of omega

ERA



m/s

24hr



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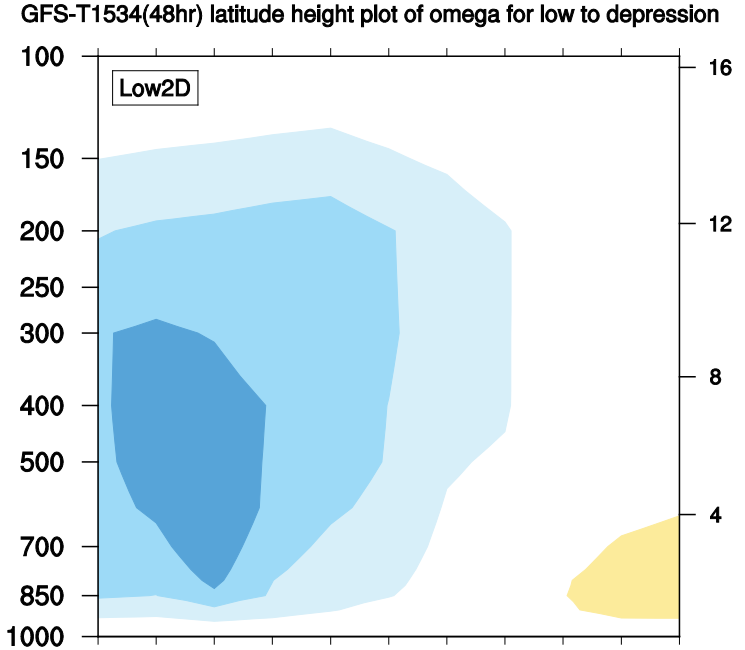
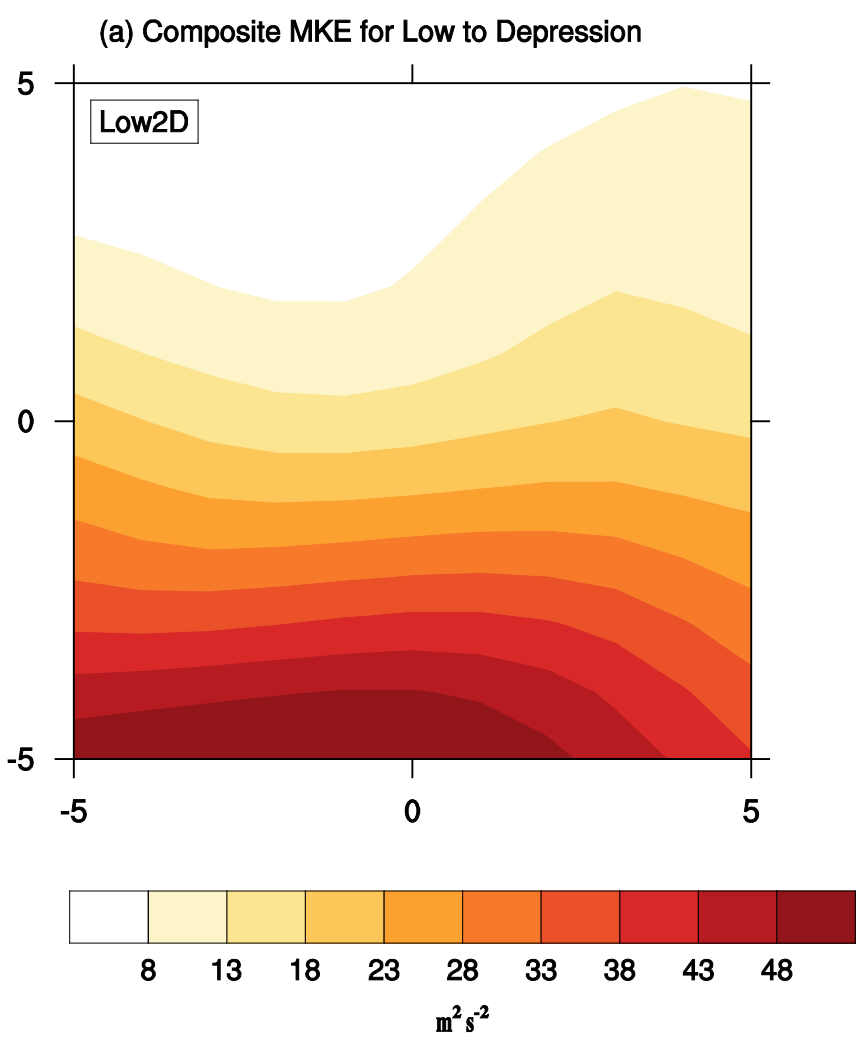
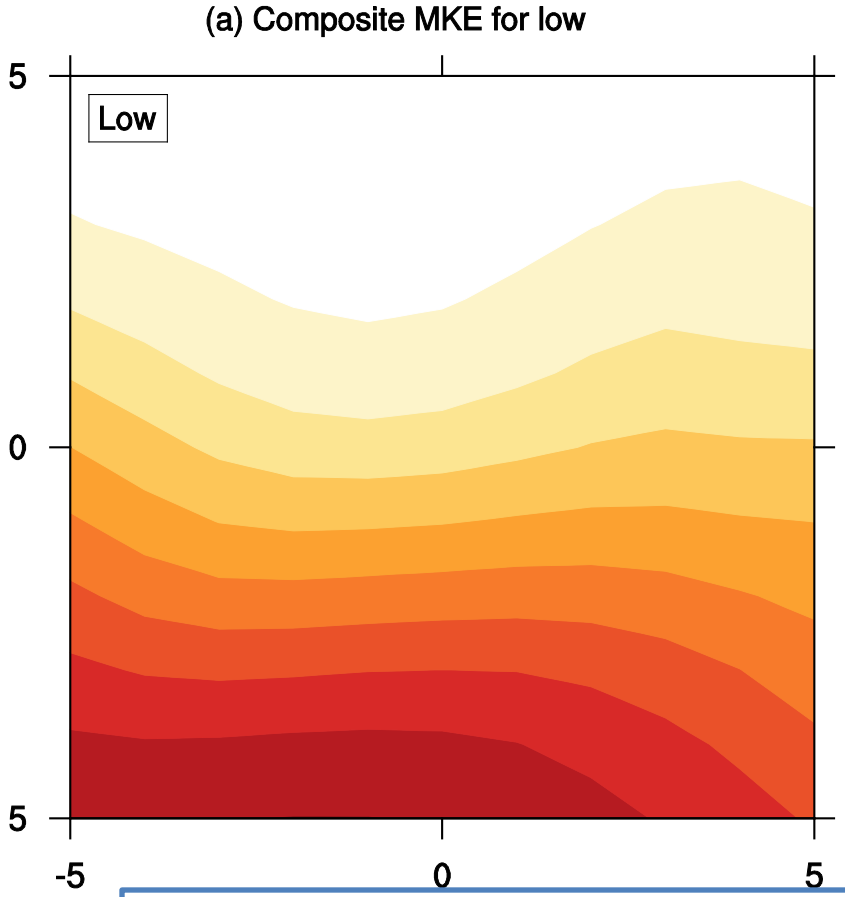


Positive(Negative) in x axis means to the **north/south** to the centre of the system

Energetics analysis for low and depressions study

Mean kinetic energy (MKE) at 850 hpa level





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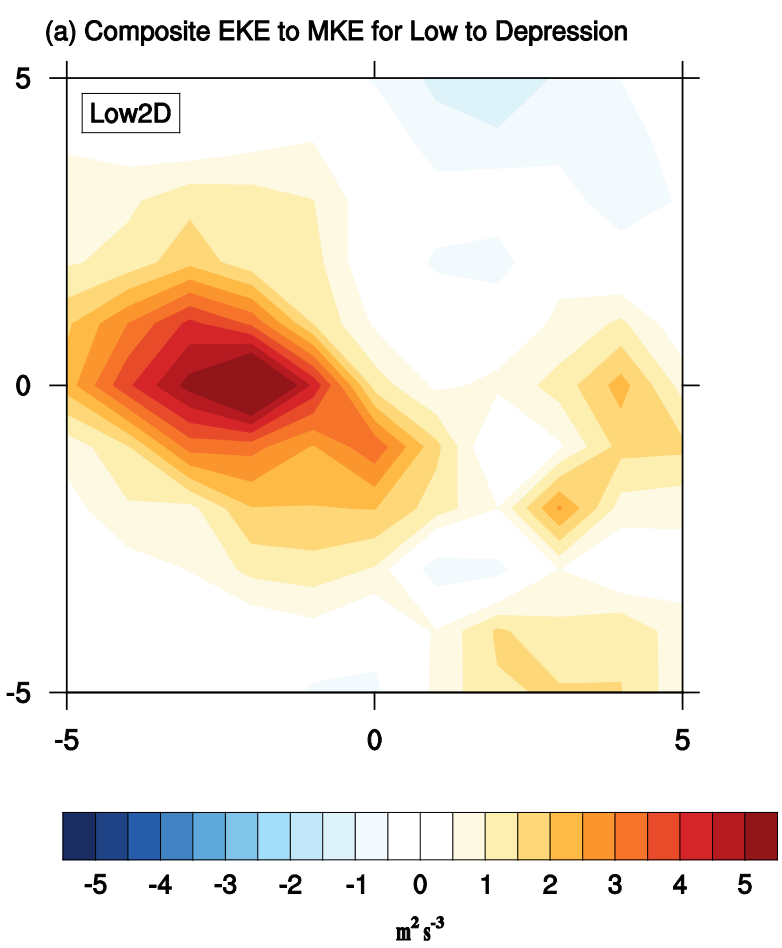
Positive(Negative) in y axis means to the **north/south** to the centre of the system

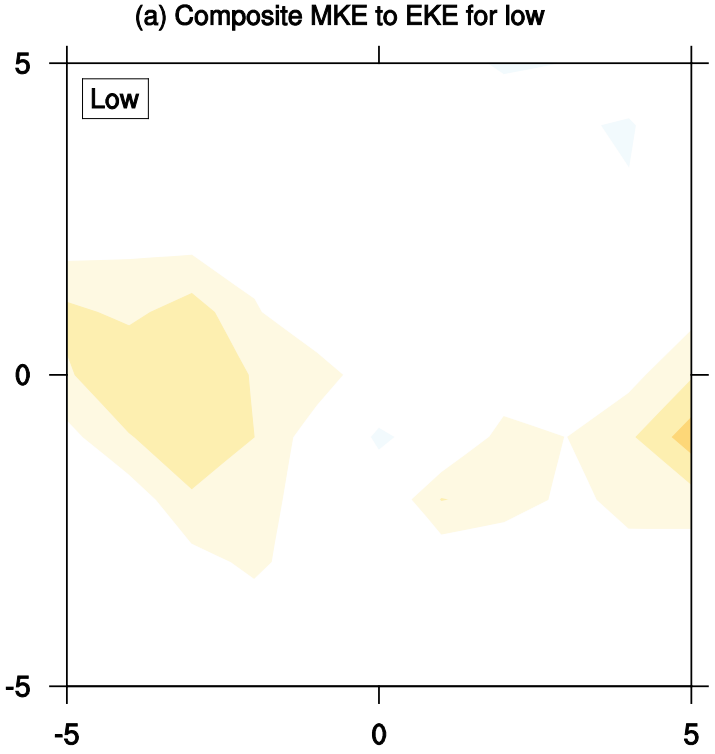
MKE for both the cases looks similar.

Then why for one case the low pressure system is intensifying and other case it fails to intensify ?

MKE to EKE conversion

MKE to EKE conversion is through the interaction between mean flow and high-frequency disturbances. Here EKE contains all the scale less than seasonal mean i.e synoptic scale (2-10 days), ISO scale (10-90 days) and low frequency background state (periods 90 days or longer).





But low and depressions are synoptic scale system, so the energy should come to synoptic scale.

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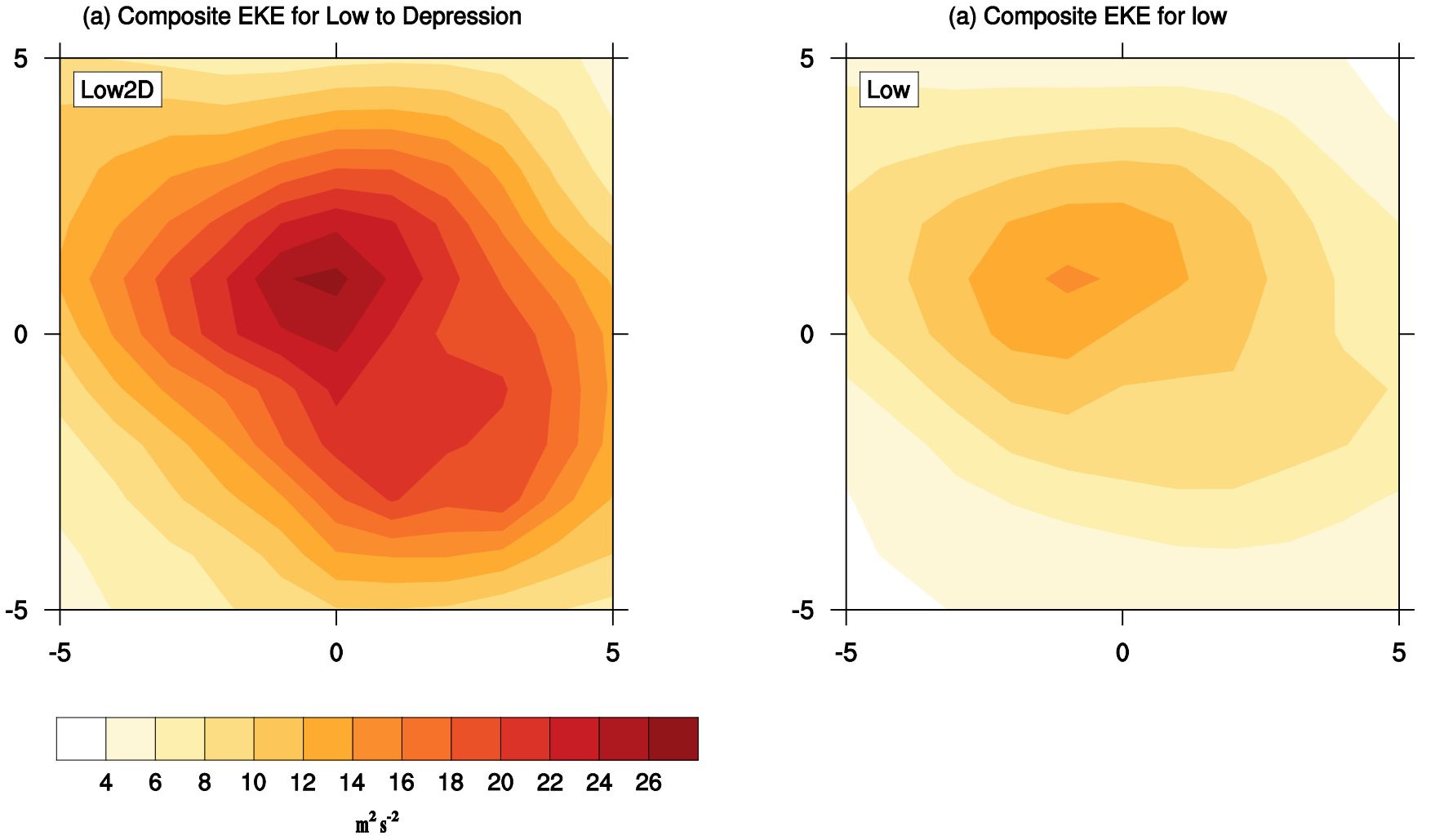
Synoptic scale eddy kinetic energy



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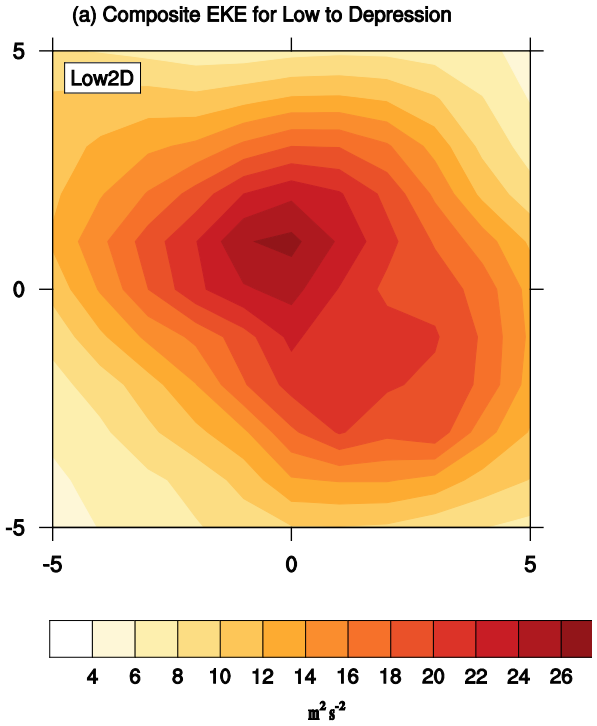
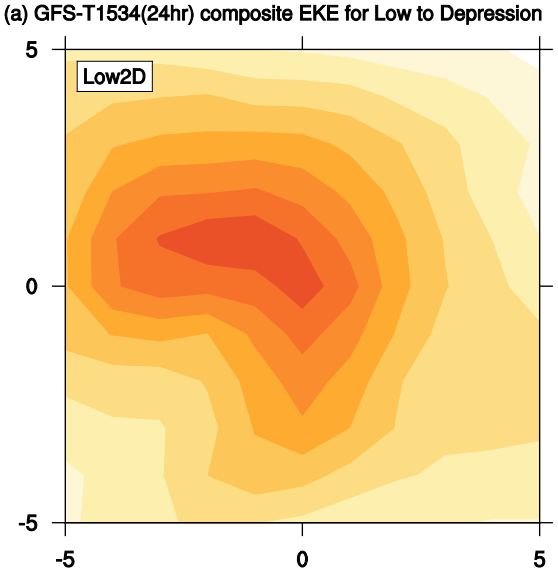
Synoptic scale eddy kinetic energy (low to depression)

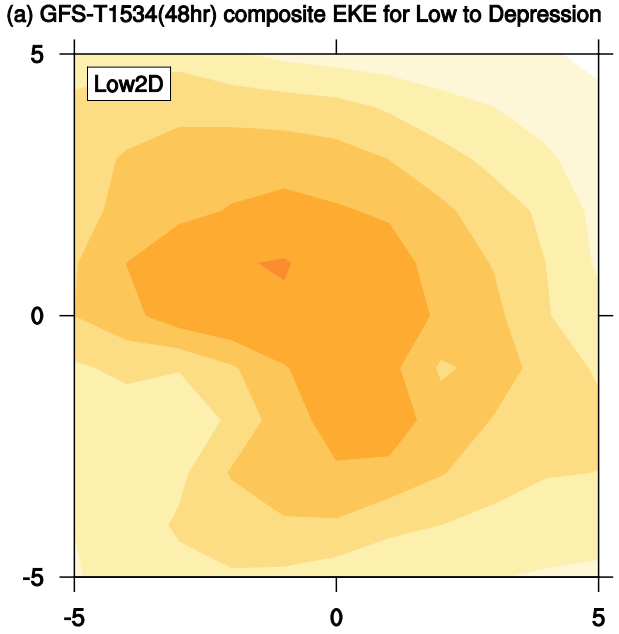
ERA



GFS-T1534 (24hr)



GFS-T1534 (48hr)



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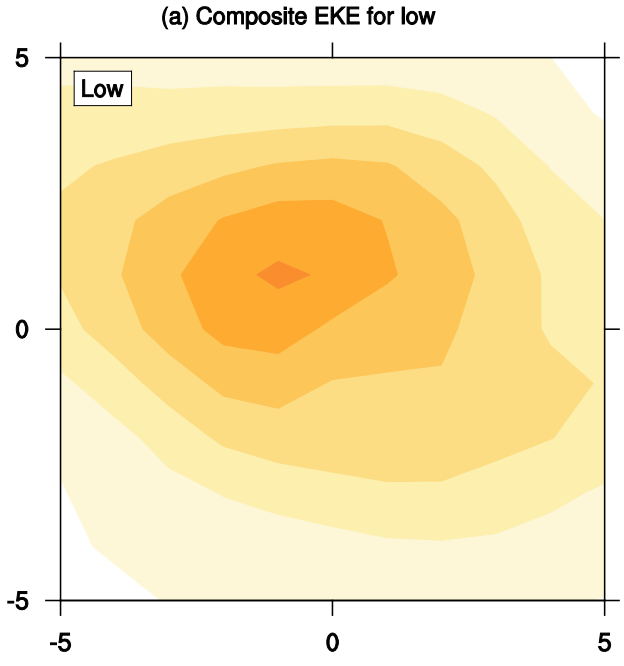
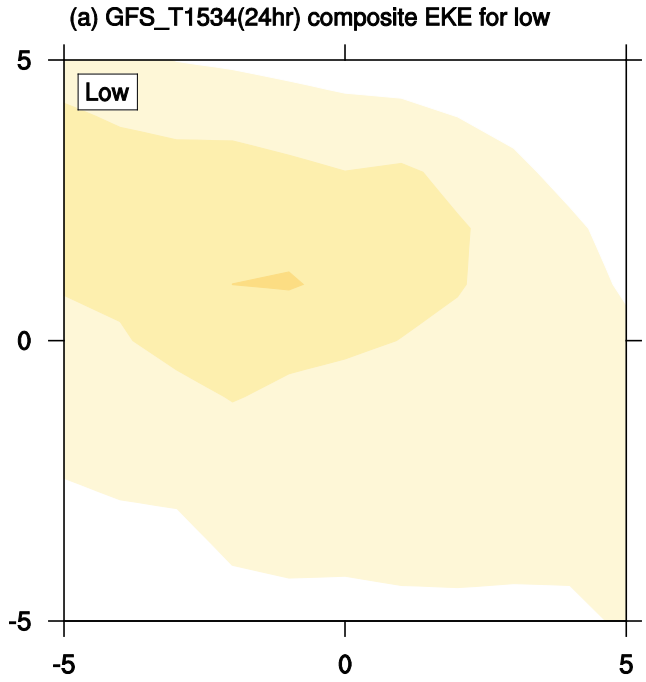
Synoptic scale eddy kinetic energy(low)

ERA



GFS-T1534
(24hr)



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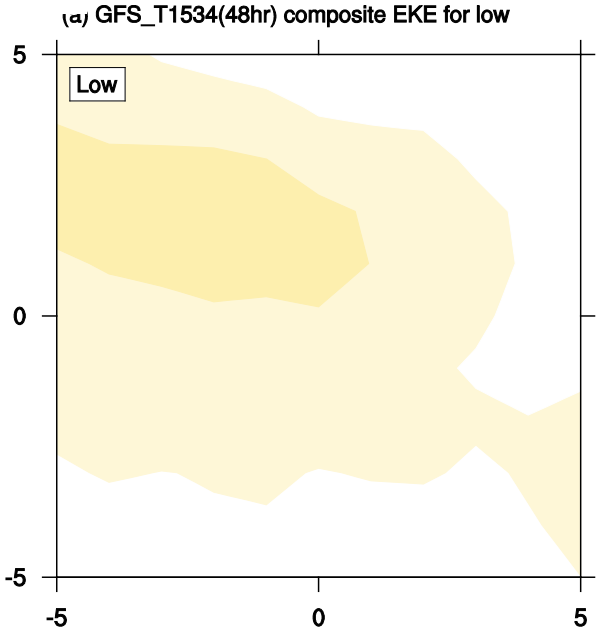
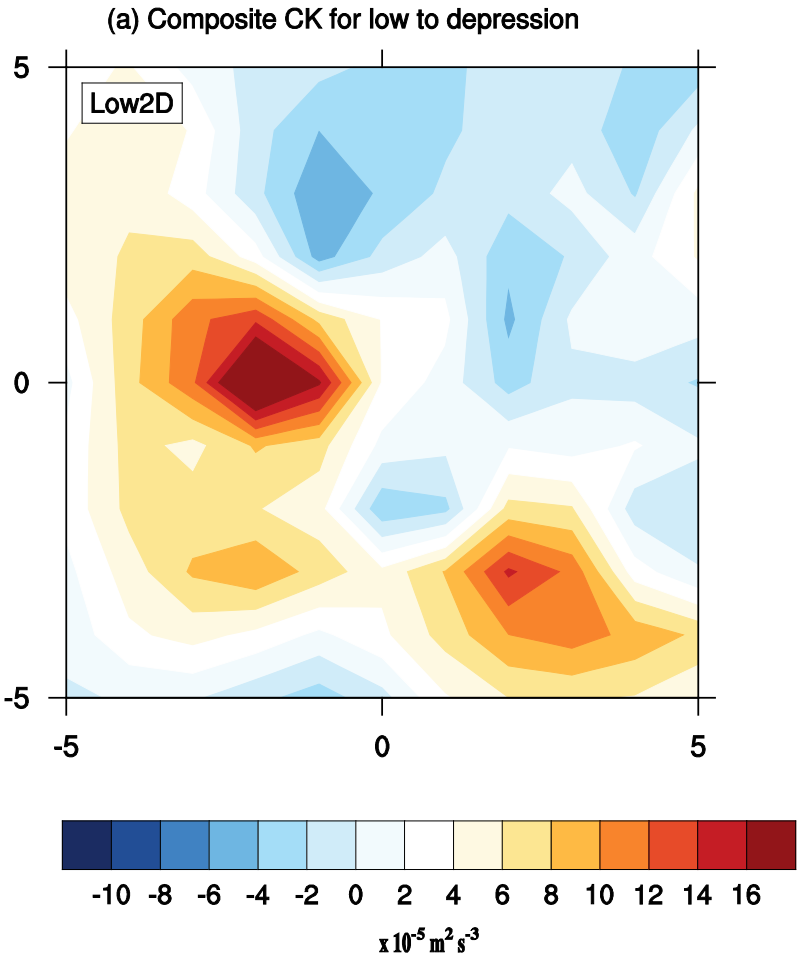
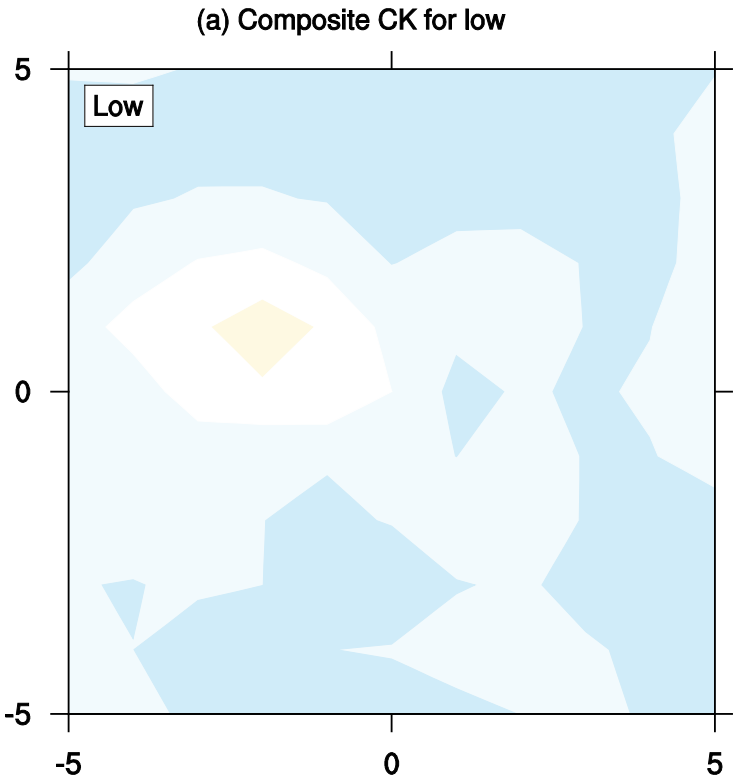
(48hr)



The processes that contribute to synoptic scale EKE

Barotropic energy Conversion from low frequency background state (LFBS) and ISO scale to the synoptic scale





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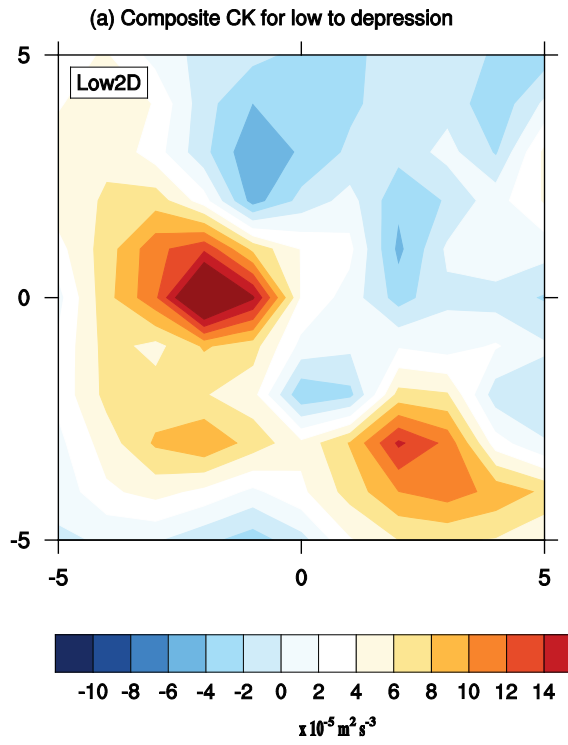
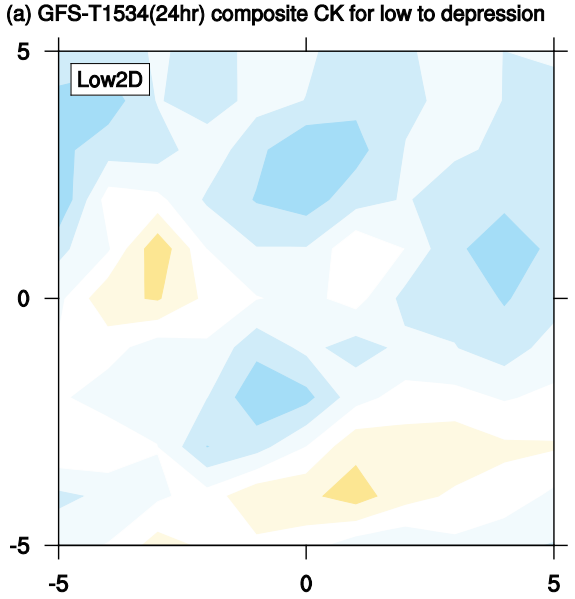
Barotropic energy Conversion from LFBS and ISO scale to the synoptic scale (low to depression)

ERA



GFS-T1534 (24hr)



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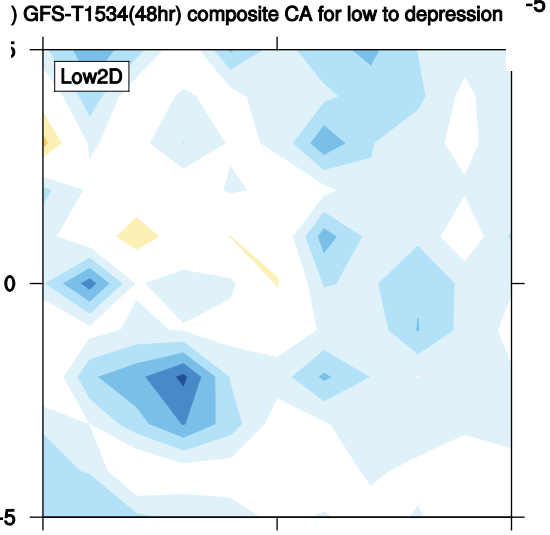

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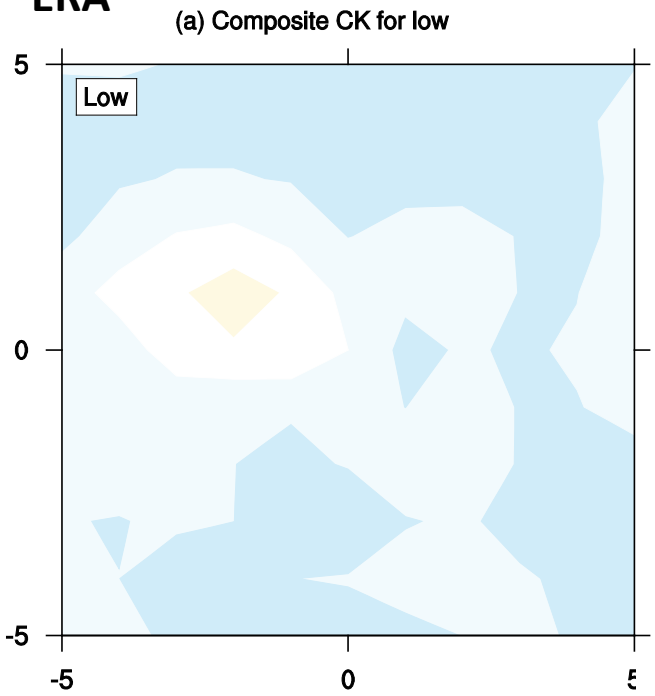
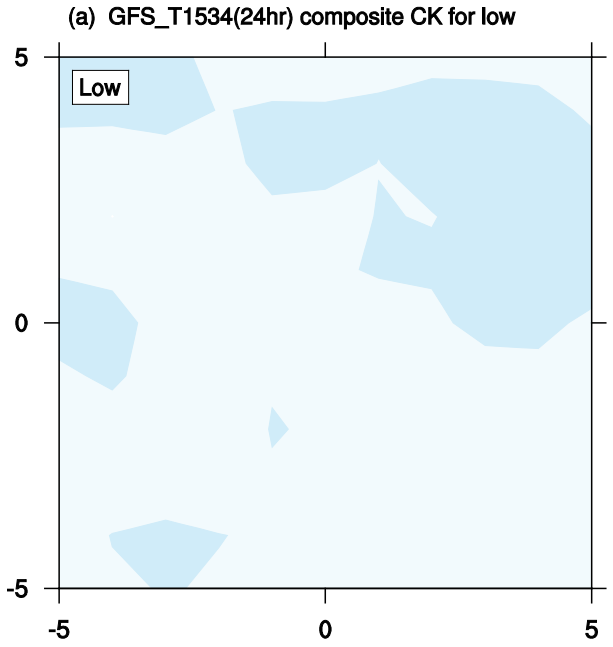
Barotropic energy Conversion from LFBS and ISO scale to the synoptic scale(low)

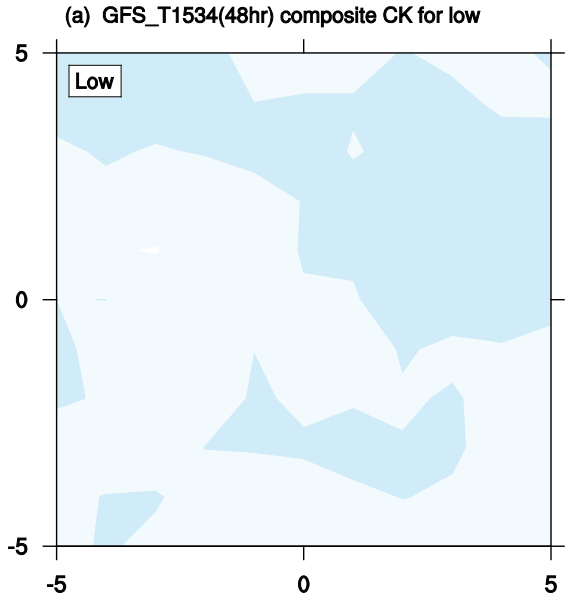
ERA



GFS-T1534
(24hr)

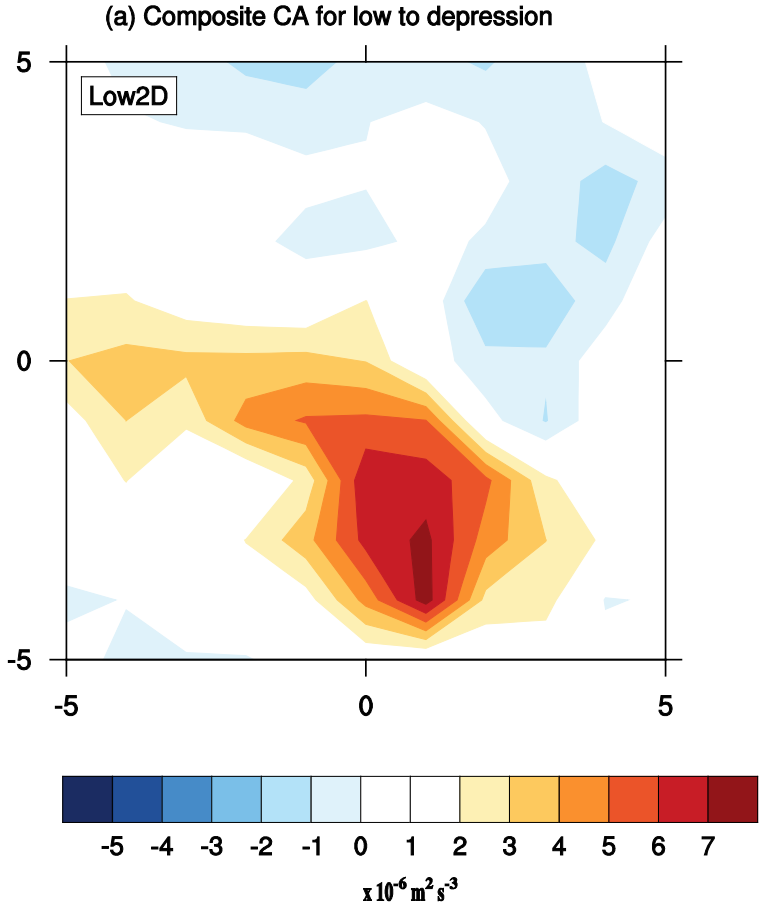


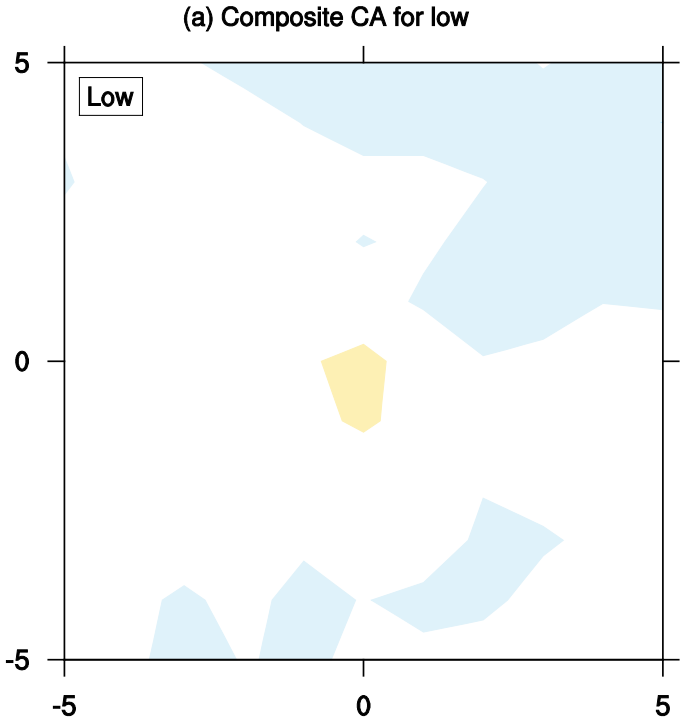
GFS-T1534
(48hr)



Eddy Available potential energy to eddy kinetic energy conversion (CA)

$$CA = -\frac{R}{p}\overline{\omega' T'},$$





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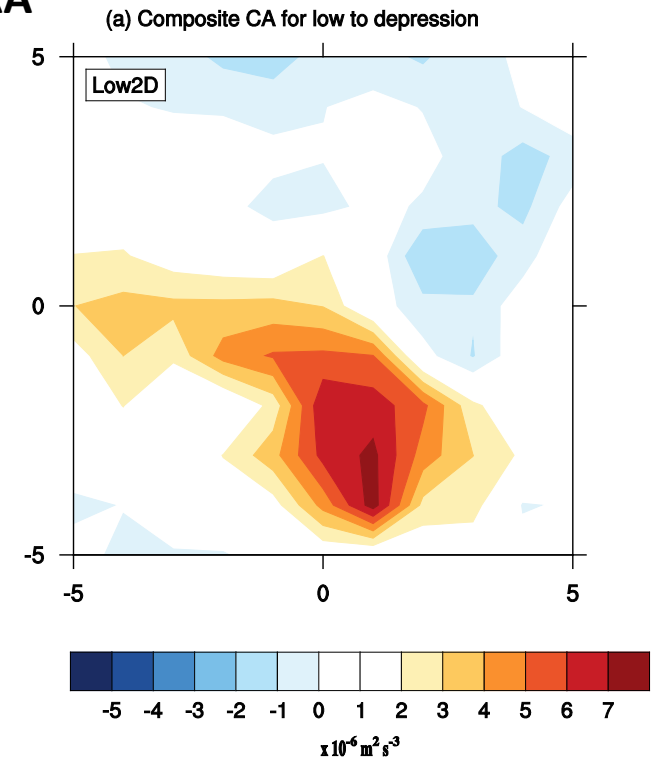
Eddy Available potential energy to eddy kinetic energy conversion

(low to depression)

ERA



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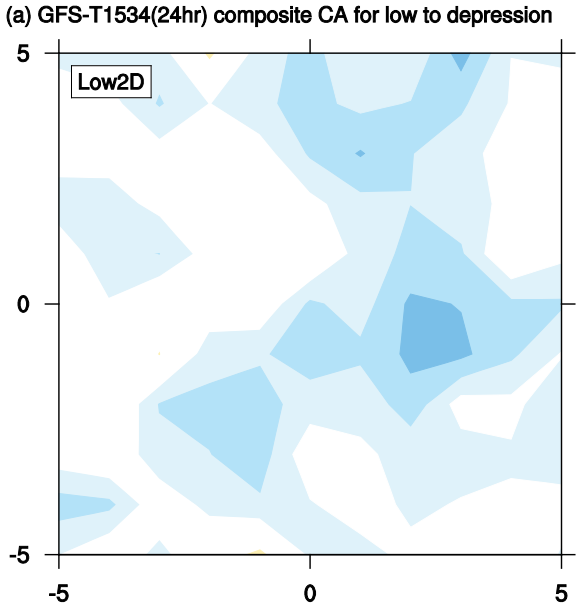

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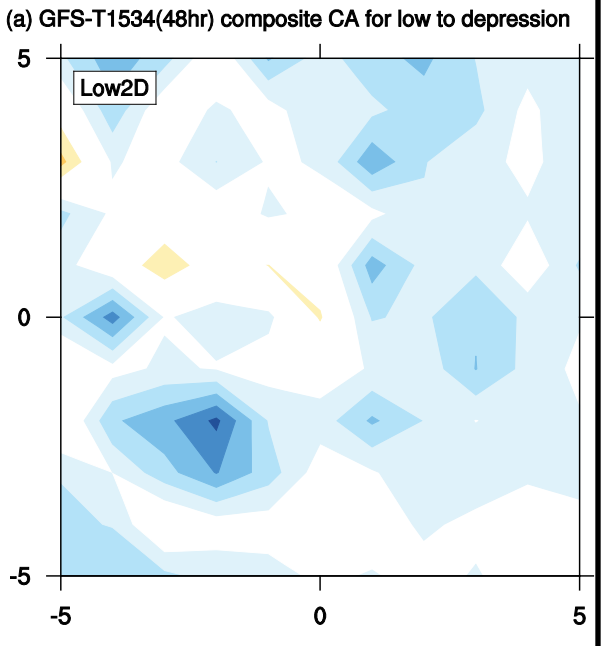

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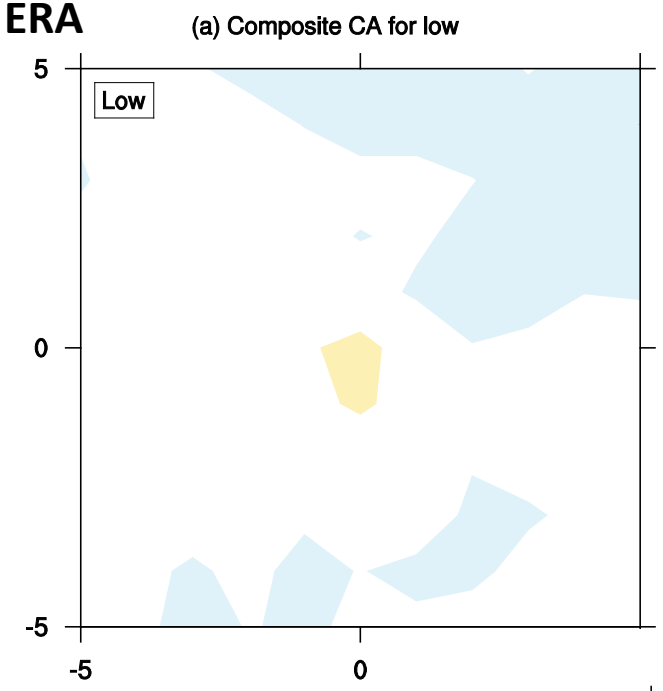
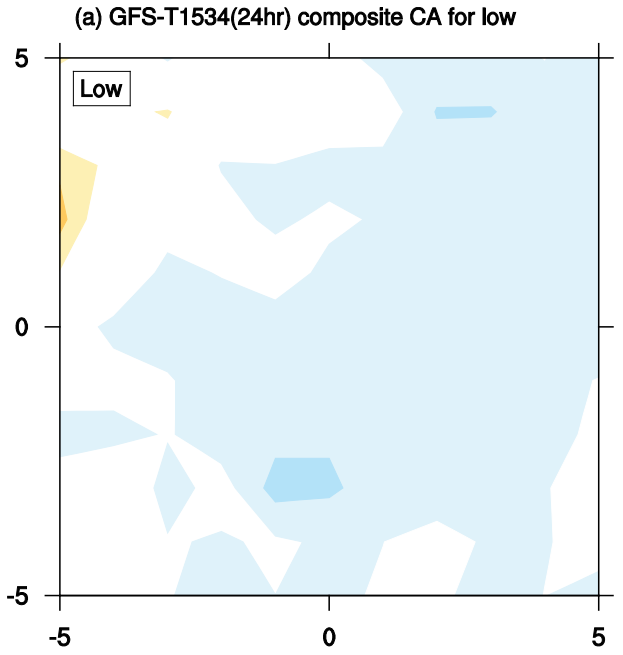
Eddy Available potential energy to eddy kinetic energy conversion(low)

ERA



GFS-T1534
(24hr)



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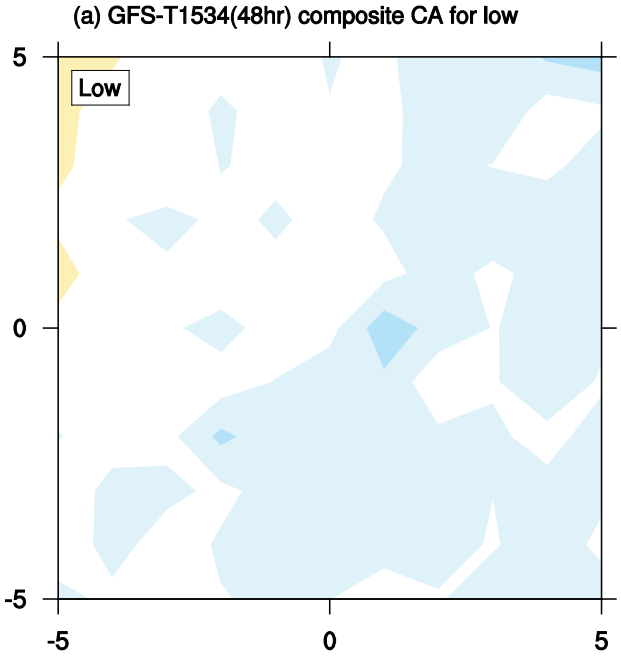
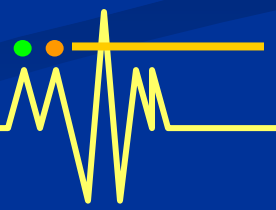
(48hr)



Summary

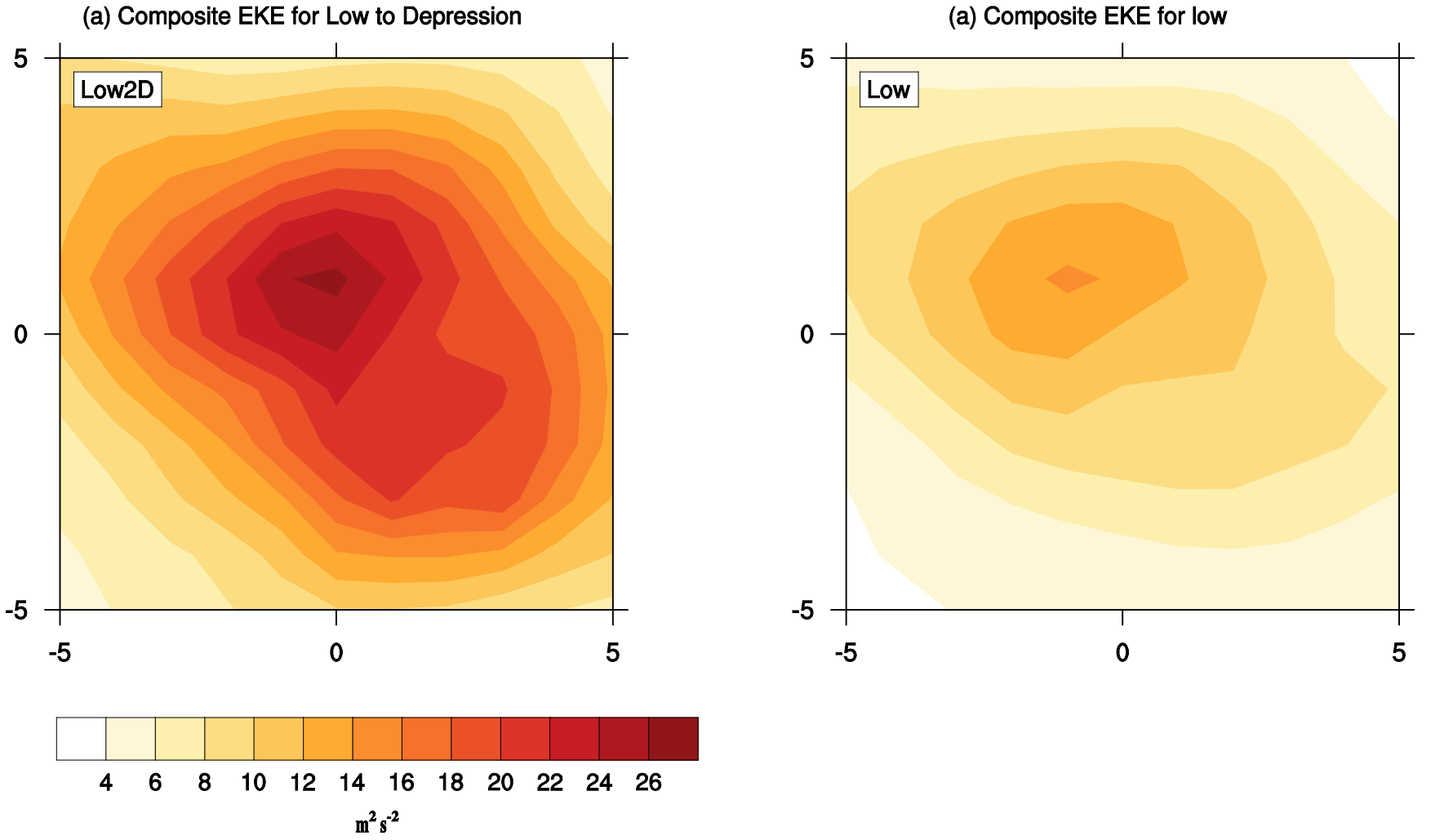
- **Fidelity of model in generating EKE and APE to EKE during Low2Deperession needs further improvement to improve the forecast with longer lead.**
- **Model moist process needs further improvement**
- **Higher resolution has shown improvement.**

Thank You !



Synoptic scale eddy kinetic energy

$[(u'^2 + v'^2)/2]$



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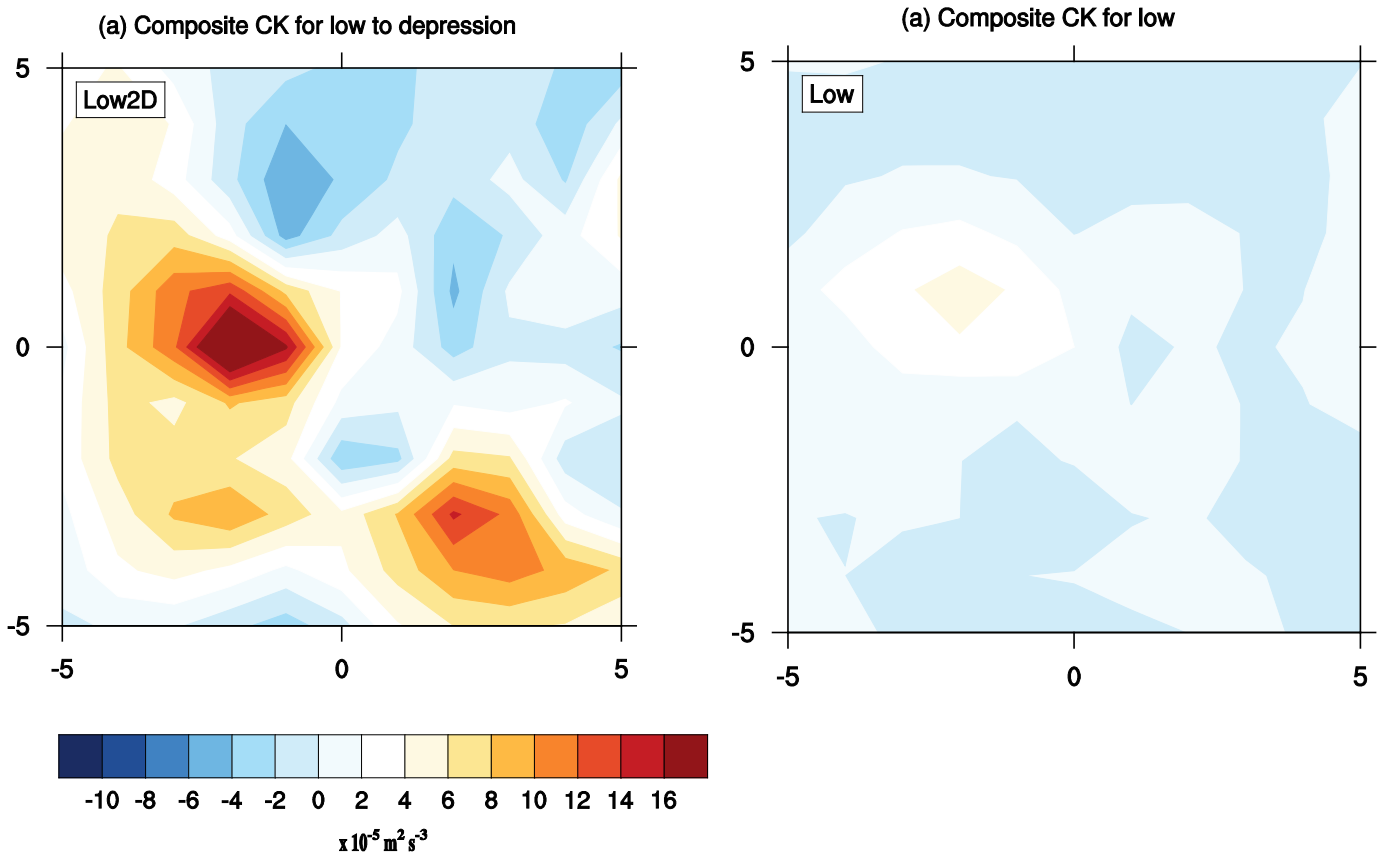
Barotropic energy Conversion from low frequency background state (LFBS) and ISO scale to the synoptic scale

$$\overline{V'.\left[\left(\overline{\overline{\mathbf{V}}}+\tilde{\mathbf{V}}+\mathbf{V}'\right).\nabla\right]\overline{\overline{\mathbf{V}}}} - \overline{V'.\left[\left(\overline{\overline{\mathbf{V}}}+\tilde{\mathbf{V}}+\mathbf{V}'\right).\nabla\right]\tilde{\mathbf{V}}}$$

where double overbar means LFBS field, a tilted overbar means intra-seasonal component and prime means synoptic-scale field.



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A new EKE diagnostic tool for examining the eddy–ISO interaction (Hsu et al. 2011, Sarkar et al. 2018)

A dependent variable is decomposed into three components- the low frequency background state (LFBS) which consist of periods 90 day or longer, intraseasonal component (10-90 days) and synoptic scale component (lower than 10 days). Any variable 'V' can be decomposed as- $V = \bar{\bar{V}} + \tilde{V} + V'$ ------(1) Where double overbar means LFBS field, a tilted overbar means intraseasonal component and prime means synoptic-scale field.

$$\frac{\partial K'}{\partial t} = -u'\left(\frac{\partial \bar{\bar{u}}}{\partial t} + \frac{\partial \tilde{u}}{\partial t}\right) - v'\left(\frac{\partial \bar{\bar{v}}}{\partial t} + \frac{\partial \tilde{v}}{\partial t}\right) - u'(\bar{\bar{u}} + \tilde{u} + u')\left(\frac{\partial \bar{\bar{u}}}{\partial x} + \frac{\partial \tilde{u}}{\partial x} + \frac{\partial u'}{\partial x}\right) - v'(\bar{\bar{u}} + \tilde{u} + u')\left(\frac{\partial \bar{\bar{v}}}{\partial x} + \frac{\partial \tilde{v}}{\partial x} + \frac{\partial v'}{\partial x}\right)$$
$$- u'(\bar{\bar{v}} + \tilde{v} + v')\left(\frac{\partial \bar{\bar{u}}}{\partial y} + \frac{\partial \tilde{u}}{\partial y} + \frac{\partial u'}{\partial y}\right) - v'(\bar{\bar{v}} + \tilde{v} + v')\left(\frac{\partial \bar{\bar{v}}}{\partial y} + \frac{\partial \tilde{v}}{\partial y} + \frac{\partial v'}{\partial y}\right) - u'(\bar{\bar{\omega}} + \tilde{\omega} + \omega')\left(\frac{\partial \bar{\bar{u}}}{\partial p} + \frac{\partial \tilde{u}}{\partial p} + \frac{\partial u'}{\partial p}\right)$$
$$- v'(\bar{\bar{\omega}} + \tilde{\omega} + \omega')\left(\frac{\partial \bar{\bar{v}}}{\partial p} + \frac{\partial \tilde{v}}{\partial p} + \frac{\partial v'}{\partial p}\right) - u'\left(\frac{\partial \bar{\bar{\phi}}}{\partial x} + \frac{\partial \tilde{\phi}}{\partial x} + \frac{\partial \phi'}{\partial x}\right) - v'\left(\frac{\partial \bar{\bar{\phi}}}{\partial y} + \frac{\partial \tilde{\phi}}{\partial y} + \frac{\partial \phi'}{\partial y}\right), \qquad (2)$$

Apply a 10-day low-pass filtering operator (denoted by a single overbar) to the perturbation EKE equation above. The following terms can be dropped:

$$-\overline{u'\left(\frac{\partial \bar{\bar{u}}}{\partial t} + \frac{\partial \tilde{u}}{\partial t}\right)} = -\overline{u'\frac{\partial \bar{\bar{u}}}{\partial t}} = 0,$$
$$-\overline{v'\left(\frac{\partial \bar{\bar{v}}}{\partial t} + \frac{\partial \tilde{v}}{\partial t}\right)} = -\overline{v'\frac{\partial \bar{\bar{v}}}{\partial t}} = 0,$$
$$-\overline{u'\left(\frac{\partial \bar{\bar{\phi}}}{\partial x} + \frac{\partial \tilde{\phi}}{\partial x}\right)} = -\overline{u'\frac{\partial \bar{\bar{\phi}}}{\partial x}} = 0, \quad \text{and}$$
$$-\overline{v'\left(\frac{\partial \bar{\bar{\phi}}}{\partial y} + \frac{\partial \tilde{\phi}}{\partial y}\right)} = -\overline{v'\frac{\partial \bar{\bar{\phi}}}{\partial y}} = 0.$$

Then a low-frequency EKE budget equation may be derived as follows:

$$\frac{\partial \overline{K'}}{\partial t} = \mathrm{CK} + \mathrm{CA} + \mathrm{AM} + \mathrm{AE} + \mathrm{FG} \qquad (3)$$

$$\mathrm{CK} = -\overline{\mathbf{V}' \cdot [(\bar{\bar{\mathbf{V}}}_3 + \tilde{\mathbf{V}}_3 + \mathbf{V}_3') \cdot \nabla_3]\bar{\bar{\mathbf{V}}}} - \overline{\mathbf{V}' \cdot [(\bar{\bar{\mathbf{V}}}_3 + \tilde{\mathbf{V}}_3 + \mathbf{V}_3') \cdot \nabla_3]\tilde{\mathbf{V}}}$$
$$= -\left(\begin{array}{l}
\overline{u'\bar{\bar{u}}\frac{\partial \bar{\bar{u}}}{\partial x}} + \overline{v'\bar{\bar{u}}\frac{\partial \bar{\bar{v}}}{\partial x}} + \overline{u'\bar{\bar{v}}\frac{\partial \bar{\bar{u}}}{\partial y}} + \overline{v'\bar{\bar{v}}\frac{\partial \bar{\bar{v}}}{\partial y}} + \overline{u'\bar{\bar{\omega}}\frac{\partial \bar{\bar{u}}}{\partial p}} + \overline{v'\bar{\bar{\omega}}\frac{\partial \bar{\bar{v}}}{\partial p}} + \overline{u'\tilde{u}\frac{\partial \bar{\bar{u}}}{\partial x}} + \overline{v'\tilde{u}\frac{\partial \bar{\bar{v}}}{\partial x}} + \overline{u'\tilde{v}\frac{\partial \bar{\bar{u}}}{\partial y}} + \overline{v'\tilde{v}\frac{\partial \bar{\bar{v}}}{\partial y}} + \overline{u'\tilde{\omega}\frac{\partial \bar{\bar{u}}}{\partial p}} \\
+ \overline{v'\tilde{\omega}\frac{\partial \bar{\bar{v}}}{\partial p}} + \overline{u'^2\frac{\partial \bar{\bar{u}}}{\partial x}} + \overline{v'u'\frac{\partial \bar{\bar{v}}}{\partial x}} + \overline{u'v'\frac{\partial \bar{\bar{u}}}{\partial y}} + \overline{v'^2\frac{\partial \bar{\bar{v}}}{\partial y}} + \overline{u'\omega'\frac{\partial \bar{\bar{u}}}{\partial p}} + \overline{v'\omega'\frac{\partial \bar{\bar{v}}}{\partial p}} + \overline{u'\bar{\bar{u}}\frac{\partial \tilde{u}}{\partial x}} + \overline{v'\bar{\bar{u}}\frac{\partial \tilde{v}}{\partial x}} + \overline{u'\bar{\bar{v}}\frac{\partial \tilde{u}}{\partial y}} \\
+ \overline{v'\bar{\bar{v}}\frac{\partial \tilde{v}}{\partial y}} + \overline{u'\bar{\bar{\omega}}\frac{\partial \tilde{u}}{\partial p}} + \overline{v'\bar{\bar{\omega}}\frac{\partial \tilde{v}}{\partial p}} + \overline{u'\tilde{u}\frac{\partial \tilde{u}}{\partial x}} + \overline{v'\tilde{u}\frac{\partial \tilde{v}}{\partial x}} + \overline{u'\tilde{v}\frac{\partial \tilde{u}}{\partial y}} + \overline{v'\tilde{v}\frac{\partial \tilde{v}}{\partial y}} + \overline{u'\tilde{\omega}\frac{\partial \tilde{u}}{\partial p}} + \overline{v'\tilde{\omega}\frac{\partial \tilde{v}}{\partial p}} + \overline{u'^2\frac{\partial \tilde{u}}{\partial x}} \\
+ \overline{v'u'\frac{\partial \tilde{v}}{\partial x}} + \overline{u'v'\frac{\partial \tilde{u}}{\partial y}} + \overline{v'^2\frac{\partial \tilde{v}}{\partial y}} + \overline{u'\omega'\frac{\partial \tilde{u}}{\partial p}} + \overline{v'\omega'\frac{\partial \tilde{v}}{\partial p}}
\end{array}\right)$$

$$\mathrm{CA} = -\frac{R}{p}\overline{T'\omega'},$$

$$\mathrm{AM} = \mathrm{AMm} + \mathrm{AMi} = -\overline{\bar{\bar{\mathbf{V}}}_3 \cdot \nabla_3 K'} - \overline{\tilde{\mathbf{V}}_3 \cdot \nabla_3 K'},$$

$$\mathrm{AE} = -\overline{\mathbf{V}_3' \cdot \nabla_3 K'}, \quad \text{and}$$

$$\mathrm{FG} = -\overline{\nabla_3 \cdot (\mathbf{V}_3' \phi')}$$

where a single overbar represents the 10-day low-pass filtering operator, $\overline{K'}$ is the low-frequency EKE (including both the LFBS and ISO components), $\mathbf{V}$ is the horizontal velocity vector, ∇ is the horizontal gradient operator (the subscript 3 represents the three-dimensional components), R is the gas constant for dry air, and T is temperature.

Meaning of Each Term

CK – Conversion from LFBS and ISO scale to synoptic scale system.

CA – Eddy Available potential Energy (EAPE) to Eddy Kinetic energy conversion(EKE).

AM- The advection of EKE by both LFBS and ISO flows.

AE- The advection of EKE by Synoptic scale eddy.

FG- Generation of EKE through convergence of eddy geopotential.

(Sarkar et al. 2018)