Cyclogensis Monitoring & Forecast by RSMC New Delhi

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## Evolution of Cyclonic disturbances Over the Indian Seas

<table>
<thead>
<tr>
<th>System</th>
<th>Pressure deficit (hPa) at the centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1.0</td>
</tr>
<tr>
<td>Depression</td>
<td>1.0 - 3.0</td>
</tr>
<tr>
<td>Deep Depression</td>
<td>3.0 - 4.5</td>
</tr>
<tr>
<td>Cyclone</td>
<td>4.5-8.5</td>
</tr>
<tr>
<td>Severe Cyclone</td>
<td>8.5-15.5</td>
</tr>
<tr>
<td>Very Severe Cyclone</td>
<td>15.5-65.6</td>
</tr>
<tr>
<td>Super Cyclone</td>
<td>&gt;65.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low pressure system</th>
<th>Maximum sustained winds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 17 knots</td>
</tr>
<tr>
<td>Depression</td>
<td>17 – 27 kts</td>
</tr>
<tr>
<td>Deep Depression</td>
<td>28 – 33 kts</td>
</tr>
<tr>
<td>Cyclone</td>
<td>34 – 47 kts</td>
</tr>
<tr>
<td>Severe Cyclone</td>
<td>48 – 63 kts</td>
</tr>
<tr>
<td>Very Severe Cyclone</td>
<td>64 – 89 kts</td>
</tr>
<tr>
<td>Extremely Severe Cyclonic Storm</td>
<td>90-119 kts</td>
</tr>
<tr>
<td>Super Cyclone</td>
<td>120 kts &amp; above</td>
</tr>
</tbody>
</table>
Cyclone Forecasting and Warning Process

- 15 days Extended Range Outlook for cyclogenesis issued every Thursday
- 5 days Probabilistic Cyclogenesis Forecast issued daily
- Track, intensity and structure forecast upto 5 days issued every six hours from depression stage and every three hrs during cyclone stage
- Impact based heavy rainfall, wind, wave & storm surge warning for 5 days with advice for action issued every 6 or 3 hrs
- Hourly update 12 hrs prior to landfall

Four Stages of Warning System

- Pre-cyclone watch (Yellow) – 72 hrs in advance
- Cyclone Alert (Orange) – 48 hrs in advance
- Cyclone warning (Red) – 24 hrs in advance
- Post-Landfall Outlook – 12 hrs before landfall
- De-Warning – When Cyclone weakens

Warning Products

- Four stage cyclone warning
- Sea area bulletin
- Coastal weather bulletin
- Bulletins for Indian navy
- Fisheries warnings
- Port warnings
- Aviation warning
- Bulletin-for AIR/TV/ press
- Warnings for registered users.
**Genesis Forecast**

<table>
<thead>
<tr>
<th>Seasonal</th>
<th>Extended Range</th>
<th>Short to medium Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Issued</td>
<td>22nd April, 2018, Every Thursday</td>
<td>June, 2014 for 72 hours April, 2018 for 120 hours Issued Daily based on 03Z observations</td>
</tr>
</tbody>
</table>

- Insufficient data
- Large interannual and intra-seasonal variability
- Low skill

**Valid for next 15 days with quantitative forecast of cyclogenesis as LOW (0-33%), MOD (34-67%), HIGH (68-100%)**

**Valid for next 5 days with cyclogenesis forecast as LOW NIL (0%), LOW(1-33%), MODERATE (34-67%), HIGH (68-100%)**

**Utility:** Suitable for forecasters to improve monitoring & forecasting in medium range based on extended range prediction. Help in planning & preparedness with longer lead period.
Extended Range Forecast (Consensus approach)

Large scale Processes
- MJO
- MISO
- Monsoon gyre
- Cyclogenesis over NW Pacific

Synoptic scale processes
- Genesis Parameters (low level vorticity & convergence, upper level divergence)
- Ocean State (SST, OTE)
- 10 m winds
- MSLP

Deterministic Global models (10 days forecast)
- IMD GFS
- NCUM
- NCEP-GFS
- ECMWF (MSLP, 10m wind, Genesis parameters)

Ensemble Models 10-15 days
- NEPS
- GEFS
- ECMWF Ensemble

ERF Models 4 weeks
- MME
- CFS V-2
- CFS
- NCMRWF

Genesi Potential parameter
- Global Cyclogenesis from CIRA (48 hours)
- IMD GPP (7 days)
- Global Tropics Hazards Outlook by NOAA (2 weeks)

METEOROLOGICAL DEPARTMENT
Extended Range Forecast (Consensus approach)

(i) Madden Julian Oscillation (MJO) phase and amplitude following Mohapatra and Adhikary (2011)

(ii) The mean sea level pressure (MSLP) and 10 m wind fields from various global models including IMD-GFS, NCEP-GFS, NCUM, ECMWF, IMD-GEFS, NEPS following the criteria for genesis (IMD, 2013)

(iii) IITM/IMD CFSv-2 cyclogenesis probability, MSLP & 850 hpa winds forecast for 4 weeks (Pattanaik and Mohapatra, 2016)

(iv) IMD’s Genesis Potential Parameter (Kotal and Bhattacharya, 2011)

(v) 30 days cyclogenesis forecast from
(http://www.atmos.albany.edu/facstaff/roundy/tcforecast/tcforecast.html)

(vi) Tropical cyclone formation product probability by RAMMB, CIRA for next 48 hours
(http://rammb.cira.colostate.edu/projects/gparm/)

(vii) Global Tropics Hazards and Benefits Outlook by NOAA for next two weeks
(http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ghazards/)

(viii) NINO 3.4 values for El-Nino or La-Nina conditions and dipole index for Indian Ocean Dipole (IOD) from Bureau of Meteorology (www.bom.gov.au)
Extended range outlook dated 6th May indicated development of depression over southeast Arabian Sea and adjoining Lakshdweep during 14th-16th May.

Depression formed over Lakshdweep on 14th May.

Extended range outlook dated 13th May indicated HIGH probability of cyclogenesis and movement of system towards Gujarat coast parallel to West coast of India during 14-20 May.

Tauktae moved parallel to West coast of India and crossed south Gujarat coast on 18th May.
GENESIS PROBABILITY: SHORT TO MEDIUM RANGE FORECAST

Consensus Approach

- Sea conditions (SST, OTE, Depth of 26°C isotherm)
- Conditional Instability (Deep and Middle layer)
- Pre existing disturbance
- Environmental conditions vertical (wind shear, low level vorticity, upper level divergence etc)

Numerical Models

Dynamical Statistical Models

Statistical Models

Genesis Forecast (Nil, Low, Mod, High)

Day-1
Day-2
Day-3
Day-4
Day-5
TYPICAL EXAMPLE OF MEDIUM RANGE FORECAST

TROPICAL WEATHER OUTLOOK FOR NORTH INDIAN OCEAN (THE BAY OF BENGA AND ARABIAN SEA) VALID FOR NEXT 120 HOURS ISSUED AT 0600 UTC OF 10.05.2021 BASED ON 0000 UTC OF 10.05.2021.

BAY OF BENGA:
Scattered low and medium clouds with embedded moderate to intense convection lay over southwest bay of Bengal off Sri Lanka coast also over southeast bay of Bengal & north bay of Bengal.

PROBABILITY OF CYCLOGENESIS/FORMATION OF DEPRESSION DURING NEXT 120 HRS:

<table>
<thead>
<tr>
<th></th>
<th>24 HRS</th>
<th>48-72 HOURS</th>
<th>72-96 HOURS</th>
<th>96-120 HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARABIAN SEA:</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
</tr>
<tr>
<td>PROBABILITY OF CYCLOGENESIS/FORMATION OF DEPRESSION DURING NEXT 120 HRS :</td>
<td>24 HRS</td>
<td>48-72 HOURS</td>
<td>72-96 HOURS</td>
<td>96-120 HOURS</td>
</tr>
<tr>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>LOW</td>
<td></td>
</tr>
</tbody>
</table>

REMARKS:
Madden Julian Oscillation (MJO) currently lies in phase 4 with amplitude close to one. It is likely to continue in the same phase for the next 4-5 days with gradual reduction in amplitude. The phase of MJO is conducive for enhanced convection over the Arabian Sea & Bay of Bengal during the forecast period. The area of convection developed over southwest Arabian Sea & adjoining

TWO issued on 10th indicated formation of LPA southeast Arabian Sea around 14th May likely intensification into a cyclone. (about 4 days prior to formation of cyclonic storm on 14th May). Even before formation of LPA on 13th May.
Genesis: Monitoring and prediction

- Analysis of all synoptic, satellite and NWP model products for genesis, intensity and track monitoring and prediction
- Development of an objective conceptual model
- Daily Watch is essential for issue of tropical weather outlook for genesis
- Check list
- Road Map /Methodology
Factors Affecting Genesis and intensification of Cyclone (Gray’s Parameter)

Formative Stage covers the period from the genesis of a cyclonic circulation to the cyclonic storm stage through low pressure, depression and deep depression stages. Following factors are considered favourable for cyclogenesis.

i. Coriolis Parameter
ii. Low level positive vorticity
iii. Weak vertical wind shear of horizontal winds
iv. Warm Sea surface temperature (> 26.5° Celsius)
v. Large convective instability
vi. Large relative humidity at lower and middle troposphere (CISK)
vii. Pre-existing disturbance

Broad scale features:
1. Madden Julian Oscillation
2. Equatorial Rosby waves
3. Kelvin waves
4. Inter Tropical Convergence Zone
5. LaNina conditions
6. Indian Ocean Dipole
Factors Affecting Genesis and intensification of Cyclone (Gray’s Parameter)

(i) High SSTs exceeding 26°C and a deep thermocline

(ii) Large values of low-level positive relative vorticity

(iii) Weak vertical shear of the horizontal winds

(iv) Conditional instability through a deep atmospheric layer

(v) Large values of relative humidity in the lower and middle troposphere

(vi) Mesoscale Vortex

(Heavily dependent on Ocean observations)
Factors Affecting Genesis and intensification of Cyclone (Broad Scale features)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Bay of Bengal</th>
<th>Arabian Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>El-Nino Year (East Pacific warmer)</td>
<td>Less cyclones over BoB</td>
<td>No impact</td>
</tr>
<tr>
<td>La Nina Year (West Pacific warmer)</td>
<td>More cyclones over BoB (BoB warmer, more remnants from west Pacific)</td>
<td>No impact</td>
</tr>
<tr>
<td>Indian Ocean Dipole (SST West Indian Ocean – SST East Indian Ocean)</td>
<td>-ve IOD conditions favourable</td>
<td>+ve IOD conditions favourable</td>
</tr>
<tr>
<td>Madden Julian Oscillation (West to east propagating waves of enhanced &amp; suppressed phase of convection). 30-40 days cycle. Movement: (5 0 /day towards east and 1 0 /day towards north)</td>
<td>Phase 3,4,5</td>
<td>Phase 2,3</td>
</tr>
<tr>
<td>Impact: Increase RH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rossby waves (east to west propagating waves). Develop due to rotation of earth and meander due to variation in coriolis effect with latitude. Impact: Increase vorticity</td>
<td>Presence support vorticity and hence convective activity. Most favourable for cyclogenesis after MJO</td>
<td></td>
</tr>
<tr>
<td>Kelvin waves (west to east propagating waves). These waves are trapped to coastlines and at equator. Their amplitude is highest at coast and decays exponentially with off shore distance (polewards).</td>
<td>Support MJO activity. Not much impact is seen directly over cyclogenesis.</td>
<td></td>
</tr>
</tbody>
</table>
Simultaneously propagating multiple waves are favourable for genesis of TC category storms over the BoB & AS in different seasons instead of single waves passing over the region.

Simultaneous occurrence of MJO, ER & KW being most effective and that of LW+KW being least effective for genesis of TC category of storms.

There is no preferred association of any convectively coupled equatorial waves for genesis of depression over the BoB and AS.
Tools to use for tropical activity daily watch

❖ Vis and IR geostationnary animation over the last 24 hours
  ▪ Superimposed with EIR in Dvorak colors
  ▪ Observations data

❖ Analysis of available numerical models guidance
  ▪ SLP (sea level pressure)
  ▪ Relative Vorticity at 850 hPa: measures the rotation of air over itself. A maximum of 850 hPa vorticity shows deep convection organizing with circulation.
  ▪ Low level winds (Favorable low level surges, or inflows, with trade wind or monsoon wind)
  ▪ Upper level winds (200 hPa), threshold at 20 kt: upper level outflows, high or ridges favorable for good divergence, vertical wind sheared areas
Digital Forecasting System is very helpful for tropical daily weather watch.
In addition, forecaster should consult data from internet sources

Internet data:

- Scatterometry data
- Micro-wave imagery for developing lows
- CIMSS maps (vertical wind shear, upper level divergence)
- MJO/OLR dry or enhanced convection phases.

Digital Forecasting System is not sufficient
Tropical Cyclone Module is not sufficient
Data and products from various national and international agencies need to be tapped through website. A few are given below

<table>
<thead>
<tr>
<th>Track and intensity forecast Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>MONTEREY Tropical Cyclones</td>
</tr>
<tr>
<td>CIMSS Tropical Cyclones</td>
</tr>
<tr>
<td>ECMWF-Latest Tropical Cyclones</td>
</tr>
<tr>
<td>TIGGI,</td>
</tr>
<tr>
<td>Tropical cyclone prediction centres</td>
</tr>
<tr>
<td>WMO site</td>
</tr>
</tbody>
</table>

- Satellite imageries and products
  - Monterey
  - CIMSS Tropical Cyclones
  - TPC POLAR ORBITING SATELLITE DATA LINKS
    - TRMM

- Interactive Weather Satellite Imagery Viewers from NASA GHCC
- Satellite INSAT
- Geostationaries from DUNDEE
- FNMOC Satellite Data Tropical Cyclone Homepage
- RSS / Tropical Cyclone Microwave Data Archive
- AMSU-A NASAAMSU-A NASA, AMSU

- SST and Heat Content
  - NOAA SST & Tropical Cyclone Heat Potential
  - Anomalies in SST (Nesdis_Noaa)
  - Anomalies in SST (FNMOC)

- Large scale features
  - OLR, MJO map- BOM
  - CPC - Climate Weather Linkage: MJO
  - OLR animations NOAA
  - CDC Map Room Climate Products
  - Probability of a Tropical Cyclone
Flow chart for genesis monitoring

**Level 1**
- Rapid Analysis of Tropical Convection
  - N
  - Moderate/Strong Convection
    - N
    - Area of Convection ≥ 5°
      - N
      - Depth of Convection based on CTT ≤ 4° C
        - N
        - No. of convective cloud clusters ≤ 3
          - N
          - Distance between clusters ≤ 3° lat/long (distance between lowest CTT)
            - N
            - No Genesis
              - No Genesis
              - Tropical Weather Outlook
                - Level-1
    - Y
    - Area of Convection increasing
      - N
      - Depth of Convection decreasing or CTT decreasing
        - N
        - Organisation of convection increasing with formation of LLCC/Vortex
          - N
          - Distance between clusters decreasing
            - N
            - No Genesis
              - Tropical Weather Outlook
                - Level-1
            - Y
            - Find centre of LLCC
              - Find associated MSW
                - Level-4
                - Level-5
        - Y
        - Area of Convection ≥ 5°
          - N
          - Depth of Convection decreasing or CTT decreasing
            - N
            - Organisation of convection increasing with formation of LLCC/Vortex
              - N
              - Distance between clusters decreasing
                - N
                - No Genesis
                  - Tropical Weather Outlook
                    - Level-1
                - Y
                - Find centre of LLCC
                  - Find associated MSW
                    - Level-4
                    - Level-5
            - Y
            - No Genesis
              - Tropical Weather Outlook
                - Level-1
          - Y
          - 24-Hr animation of satellite imagery
            - Y
            - Area of Convection increasing
              - N
              - Area of Convection ≥ 5°
                - N
                - Depth of Convection decreasing or CTT decreasing
                  - N
                  - Organisation of convection increasing with formation of LLCC/Vortex
                    - N
                    - Distance between clusters decreasing
                      - N
                      - No Genesis
                        - Find centre of LLCC
                          - Find associated MSW
                            - Level-4
                            - Level-5
                    - Y
                    - Distance between clusters decreasing
                      - Y
                      - Find centre of LLCC
                        - Find associated MSW
                          - Level-4
                          - Level-5
                - Y
                - Low Level Cyclonic Circulation (LLCC)
                  - N
                  - LLCC Multiple
                    - Y
                    - Find centre of all LLCCs and associated MSW for each LLCC
                      - Level-4
                      - Level-5
                  - Y
                  - No Genesis
                    - Tropical Weather Outlook
                      - Level-3
                      - Level-4
                      - Level-5
    - Y
    - Analysis of (LLCC)
      - N
      - LLCC Single
        - Y
        - Find centre of LLCC
          - Find associated MSW
            - Level-4
            - Level-5
    - Y
    - Find centre of all LLCCs and associated MSW for each LLCC
      - Whether No. of LLCCs decreasing
        - Y
        - Find centre of LLCC
          - Find associated MSW
            - Level-4
            - Level-5
        - N
        - Whether distance between LLCCs decreasing
          - Y
          - Find centre of LLCC
            - Find associated MSW
              - Level-4
              - Level-5
          - N
          - Find centre of LLCC
            - Find associated MSW
              - Level-4
              - Level-5
      - Whether distance between LLCCs decreasing
        - Y
        - Find centre of LLCC
          - Find associated MSW
            - Level-4
            - Level-5
        - N
        - Find centre of LLCC
          - Find associated MSW
            - Level-4
            - Level-5
Flow chart for genesis monitoring

Level 6
- LLCC Within/outside convection
  - LLCC within convection
    - Organisation Curved Band
      - Apply logarithmic spiral to find T No. as per Dvorak’s technique
        - T not defined/ T1.0
          - LPA/ WML
            - Depression
  - LLCC within convection
  - Organisation Shear Pattern
    - Find difference between centre of LLCC and sharp edge of convective cloud in IR imagery following Dvorak’s Technique
      - T = 1.5
        - LPA/ WML
          - Depression
    - Find T No. following Dvorak’s Technique
      - T not defined/ T1.0
        - LPA/ WML
          - Depression
  - Find MSW from T No. following Dvorak’s Technique
    - Find MSW associated with LLCC from Scatterometer, Ships, buoys, coastal & Island Stations
      - Optimise observed wind speed to determine MSW
        - MSW < 17 kt, > 17-27 kt
          - Compare MSW with T No. based MSW to find C.I.
    - Examining MSLP based on available data from Buoy, Ship, Coastal inland station around LLCC
      - Analysis MSLP by drawing isobars at 2 hpa interval,
      - Find no. of closed isobars (circular/elliptical) and size of LPS and R17
      - Define LPA/WML/Depression
        - Define ΔP, ECP, MSW, CI, LPA/ WML/Depression, shape & size (ROCI and R17) after optimization and consistency check

Level 1
- Level 7
- Level 8
- Level 9

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First step: Rapid analysis of the tropical convective activity

- Is it poor, moderate, strong?
- What is its evolution during the last 24 hours?
  ✓ The deep convection has intensified or not (in geographical extension, in intensity – coldness of Cb’s top –, in cyclonic organization)?
  ✓ Comparison must be done with the days before at the same hours, to avoid to be influenced by the diurnal effect: over ocean, deep convection naturally intensifies (depth and extension) during the night, between 18 UTC and 02 UTC (maximum of deep convective activity at the end of the night, near 23 UTC-01UTC).
### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Area</td>
<td>(i) $&gt; 5 \times 5^\circ$</td>
<td>INSAT 3D/3DR</td>
<td>Visible imagery</td>
</tr>
<tr>
<td>(ii) Depth</td>
<td>(ii) Reflectivity &gt; X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iii) Number of clusters with reflectivity &gt; X</td>
<td>(iii) Number of clusters with reflectivity &gt; X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iv) Clusters organisation</td>
<td>(iv) Organized if associated with low level circulation centre</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Parameters

<table>
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<th>Parameters</th>
<th>Criteria</th>
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</tr>
</thead>
<tbody>
<tr>
<td>(i) Area</td>
<td>(i) $&gt; 5 \times 5^\circ$</td>
<td>INSAT 3D/3DR Meteosat</td>
<td>IR imagery</td>
</tr>
<tr>
<td>(ii) Depth</td>
<td>(ii) CTT $&lt;-40^\circ$C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iii) No. of clusters with CTT $&lt;-40^\circ$</td>
<td>(iii) No. of clusters with CTT $&lt;-40^\circ$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td>Criteria</td>
<td>Source</td>
<td>Product</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>--------</td>
<td>---------</td>
</tr>
</tbody>
</table>
| Persistence of convective clusters during past 24 hrs | (i) Is it persisting for more than 24 hrs  
(ii) Increase or decrease in area  
(iii) Increase/decrease in depth  
(iv) Increase in organisation/scattering  
(v) Increase/decrease in number of clusters  
(vi) Clusters coming closer or going away from each other | INSAT 3D/3DR | IR imagery |
## MONITORING OF LLCC MICROWAVE PRODUCTS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) single or multiple LLCC</td>
<td>(i) Associated wind speed = 17 kt or more</td>
<td>Multiplatform Satellite Surface Wind Analysis - CIRA, Colorado State Univ</td>
<td></td>
</tr>
<tr>
<td>(ii) cyclonic circulation</td>
<td>(ii) Centre location well defined</td>
<td><a href="http://rammb.cira.colostate.edu/products/tc_realtime/image_mpsatwnd.asp">http://rammb.cira.colostate.edu/products/tc_realtime/image_mpsatwnd.asp</a></td>
<td></td>
</tr>
<tr>
<td>(iii) Outer wind field structure</td>
<td>(iii) Storm size extends up to extent of circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iv) Storm size information</td>
<td>(iv) If multiple LLCC → They are coming together or away</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(v)</td>
<td>(v) Within deep convective cluster or exposed LLCC (outside deep convection)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3. ENVIRONMENTAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) SST</td>
<td>SST &gt; 26.5°C</td>
<td>TMI, AMSRE, Windsat) [<a href="http://www.aoml.noaa.gov/phod/data">http://www.aoml.noaa.gov/phod/data</a> phod1/work/HHP/](<a href="http://www.aoml.noaa.gov/phod/data">http://www.aoml.noaa.gov/phod/data</a> phod1/work/HHP/)</td>
<td>Data and analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INSAT 3D imd.gov.in</td>
<td>Data and analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GODAS INCOIS</td>
<td>Data and analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ROMS INCOIS</td>
<td>Data and analysis</td>
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</tbody>
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<th>Product</th>
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</thead>
<tbody>
<tr>
<td>(b) Tropical Cyclone Heat Potential (TCHP)/ Ocean heat content (OHC)</td>
<td>&gt;50 KJ/cm²</td>
<td><a href="http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/">http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/</a></td>
<td>Data and Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://rammb.cira.colostate.edu/products/tc_realtime/products/storms/">http://rammb.cira.colostate.edu/products/tc_realtime/products/storms/</a></td>
<td>Data and Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCOIS</td>
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</table>
### Parameters

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</thead>
<tbody>
<tr>
<td>(c) Depth of 26 deg. Isotherm</td>
<td>Threshold : &gt; 50 metre</td>
<td><a href="http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/NEW/">http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/NEW/</a></td>
<td></td>
</tr>
<tr>
<td>(d) Sea height anomaly</td>
<td>Threshold: &gt; 10 centimetre</td>
<td><a href="http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/">http://www.aoml.noaa.gov/phod/dataphod1/work/HHP/</a></td>
<td>INCOIS</td>
</tr>
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<tbody>
<tr>
<td>(e) Mid-tropospheric relative humidity</td>
<td>Threshold : &gt; 50%</td>
<td>IMD (NWP)</td>
<td>Model analyses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NCMRWF</td>
<td>Actual observation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IMD (GTS)</td>
<td>Moisture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microwave satellite</td>
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<th>Parameters</th>
<th>Criteria</th>
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</tr>
</thead>
<tbody>
<tr>
<td>(f) Upper level wind</td>
<td>• Upper level outflow region</td>
<td>CIMSS</td>
<td>Satellite based wind (300-100 hPa)</td>
</tr>
<tr>
<td></td>
<td>• Location of trough</td>
<td><a href="http://tropic.ssec.wisc.edu/real-time/windmain.php?&amp;basin=ndian&amp;sat=wm5&amp;prod=w...">http://tropic.ssec.wisc.edu/real-time/windmain.php?&amp;basin=ndian&amp;sat=wm5&amp;prod=w...</a></td>
<td>Satellite based wind (300-100 hPa)</td>
</tr>
<tr>
<td></td>
<td>• Location of ridge</td>
<td>IMD/SAC-ISRO</td>
<td>Wind Observation</td>
</tr>
<tr>
<td></td>
<td>• Jet region and strength</td>
<td>IMD</td>
<td>Radar based upper wind</td>
</tr>
<tr>
<td></td>
<td>• Steering current</td>
<td>IMD (Radar Lab), New Delhi, imd.gov.in</td>
<td></td>
</tr>
</tbody>
</table>
### 3. ENVIRONMENTAL PARAMETERS

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<th>Product</th>
</tr>
</thead>
</table>
| (g) Lower level winds | - Lower level inflow  
|                  | - LLCC and intensity (outer layer)  
|                  | - Outer storm size                      | CIMSS  
|                  | Comparison with actual wind  
|                  | Determination of the model with best initial condition | IMD/SAC-ISRO  
|                  | Satellite based wind (850-700 hPa) | IMD  
|                  | Satellite based wind (850-700 hPa) | IMD (Radar Lab), New Delhi, imd.gov.in  
|                  | Wind observations | IMD (NWP)  
|                  | Radar based wind over Radar station | Model Analysis |
## 3. ENVIRONMENTAL PARAMETERS

<table>
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<tr>
<th>Parameters</th>
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<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h) Vertical Wind shear</td>
<td></td>
<td>CIMSS</td>
<td>Wind shear (200-850 hPa level)</td>
</tr>
<tr>
<td></td>
<td>10-20 kt – Moderate wind shear</td>
<td>CIMSS</td>
<td>Area Averaged wind shears and Layer means</td>
</tr>
<tr>
<td></td>
<td>&gt;20  kt- high wind shear</td>
<td>AMSU <a href="http://rammb.cira.colostate.edu/products/tc_realtime/products/storms/">http://rammb.cira.colostate.edu/products/tc_realtime/products/storms/</a></td>
<td></td>
</tr>
<tr>
<td>Threshold:</td>
<td>low to moderate wind shear</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low to moderate wind shear</td>
<td></td>
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<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h) Vertical Wind shear tendency</td>
<td>Decrease/increase- intensification/weakening</td>
<td>CIMSS <a href="http://tropic.ssec.wisc.edu/real-time/windmain.php">http://tropic.ssec.wisc.edu/real-time/windmain.php</a></td>
<td>24 hr tendency in wind shear</td>
</tr>
<tr>
<td>(i) Upper level divergence</td>
<td>TC secondary circulation Convective updraft Outflow Storm development Threshold: $&gt;10 \times 10^{-5}$ sec$^{-1}$</td>
<td>CIMSS <a href="http://tropic.ssec.wisc.edu/real-time/windmain.php">http://tropic.ssec.wisc.edu/real-time/windmain.php</a></td>
<td>Satellite based analysis 300-100 hPa level</td>
</tr>
<tr>
<td>(i) Lower level convergence</td>
<td>Entrainment of dry air Low level inflow Threshold: $&gt;10 \times 10^{-5}$ sec$^{-1}$</td>
<td>CIMSS <a href="http://tropic.ssec.wisc.edu/real-time/windmain.php">http://tropic.ssec.wisc.edu/real-time/windmain.php</a></td>
<td>Satellite based analysis 850 hPa analysis</td>
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<table>
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<tr>
<th>Parameters</th>
<th>Criteria</th>
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<th>Product</th>
</tr>
</thead>
</table>
| (k) Lower level vorticity | • Measure of rotation  
• Positive: Cyclonic  
• Negative: Anti-cyclonic  
• Increasing/decreasing – Strengthening/weakening of TC  
• Merging of vorticity centres leads to intensification and vice versa  
Threshold: $> 10 \times 10^{-5}$ sec$^{-1}$ | [http://tropic.ssec.wisc.edu/real-time/windmain.php](http://tropic.ssec.wisc.edu/real-time/windmain.php) | Satellite based  
850 hPa vorticity  
Satellite based  
700 hPa vorticity  
Satellite based  
500 hPa vorticity |
## 3. ENVIRONMENTAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m) OLR</td>
<td>Convection monitoring through animation, Diurnal variation Location and intensity of convection Threshold:&lt;200watt/m²</td>
<td><a href="http://www.cpc.ncep.noaa.gov/products/precip/Cwlink/MJO/CLIVAR/clivar_w.shtml">http://www.cpc.ncep.noaa.gov/products/precip/Cwlink/MJO/CLIVAR/clivar_w.shtml</a></td>
<td>Phase and amplitude of MJO and its Dynamical forecast</td>
</tr>
<tr>
<td>IMD</td>
<td>(TIR1, TIR2, WV)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## 4. GENESIS PROBABILITY BY DYNAMICAL STATISTICAL MODEL

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genesis Probability by statistical models</td>
<td>Above normal probability</td>
<td>CIRA</td>
<td>Daily probability for 2 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://rammb.cira.colostate.edu/projects/gparm/">http://rammb.cira.colostate.edu/projects/gparm/</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOAA</td>
<td>Daily probability for 2 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Climatological probability</td>
</tr>
</tbody>
</table>
## 4. GENESIS PROBABILITY BY DYNAMICAL STATISTICAL MODEL

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genesis probability by statistical models</td>
<td>IMD-GPP (grid) $&gt;30$</td>
<td>IMD(NWP)</td>
<td>Daily probability for 7 days</td>
</tr>
<tr>
<td></td>
<td>IMD-Average GPP $&gt;08$</td>
<td>IMD(NWP)</td>
<td>Daily probability for 3 days</td>
</tr>
<tr>
<td></td>
<td>Above normal Probability</td>
<td>ISRO Sriharikota, ISRO, Ahmedabad</td>
<td>Daily probability for 7 days Based on scatterometer pass</td>
</tr>
</tbody>
</table>
### 4. GENESIS PROBABILITY BY DYNAMICAL STATISTICAL MODEL

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Genesis</td>
<td>Probability: above normal</td>
<td>JTWC</td>
<td>Probability of genesis in the week</td>
</tr>
<tr>
<td>Probability by statistical models</td>
<td>Probability of genesis over a grid</td>
<td>Cyclone eAtlas-IMD</td>
<td>Climatology of genesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://www.rmcchennaieatlas.tn.nic.in">www.rmcchennaieatlas.tn.nic.in</a></td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td>Criteria</td>
<td>Source</td>
<td>Product</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Monitoring and prediction of genesis   | • two closed isobars with interval of two hPa is considered as cyclogenesis (formation of depression)  
• In case of wind field, threshold cyclonic wind is 17 knots or more  
• Location of centre is the location of lowest pressure | IMD (NWP)     | WRF Model analysis and forecast                                                                                                                                                                 |
|                                        |                                                                                                                                                                                                                                                                                                                                         | IAF           | WRF Model analysis and forecast                                                                                                                                                                 |
|                                        |                                                                                                                                                                                                                                                                                                                                         | NCMRWF        | NCUM-R Model analysis and forecast                                                                                                                                                              |
### 5. GENESIS MONITORING AND PREDICTION BY NWP

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring and prediction of genesis</td>
<td>- two closed isobars with interval of two hPa is considered as cyclogenesis (formation of depression)</td>
<td>NCMRWF</td>
<td>NCUM Model analysis and forecast</td>
</tr>
<tr>
<td></td>
<td>- In case of wind field, threshold cyclonic wind is 17 knots or more</td>
<td>GTS</td>
<td>JMA Model analysis and forecast</td>
</tr>
<tr>
<td></td>
<td>- Location of centre is the location of lowest pressure</td>
<td>ECMWF</td>
<td>ARP Model analysis and forecast</td>
</tr>
</tbody>
</table>

**Source & Product**
- NCMRWF: NCMRWF Analysis and Forecast
- GTS: GTS Analysis and Forecast
- ECMWF: ECMWF Analysis and Forecast
- JMA: JMA Model Analysis and Forecast
- ARP: ARP Model Analysis and Forecast

**In case of wind field, threshold cyclonic wind is 17 knots or more.**

**Location of centre is the location of lowest pressure.**
6. OFFICIAL MONITORING AND FORECAST

<table>
<thead>
<tr>
<th>Parameters</th>
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<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) NWP Models</td>
<td></td>
<td></td>
<td>Number of closed isobars and associated</td>
</tr>
<tr>
<td></td>
<td>two closed isobars with interval of two hPa is considered as cyclogenesis (formation of depression)</td>
<td>Model products of IMD/NCMRWF/NCEP/JMA/ECMWF/ARP etc.</td>
<td>surface wind speed</td>
</tr>
<tr>
<td></td>
<td>In case of wind field, threshold cyclonic wind is 17 knots or more</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Location of centre is the location of lowest pressure</td>
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### 6. OFFICIAL MONITORING AND FORECAST

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<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) Statistical models</td>
<td>Location of centre is the location of lowest pressure</td>
<td>CIRA / NOAA / IMD-GPP / ISRO / JTWC</td>
<td>Probability of genesis</td>
</tr>
<tr>
<td>(c) Radar</td>
<td>Reflectivity / Radial Velocity</td>
<td>RADAR Lab, IMD</td>
<td>Wind speed / Vertical extension of convective clouds</td>
</tr>
<tr>
<td>(d) Satellite observations</td>
<td>Intensity estimation</td>
<td>INSAT-3D / 3DR</td>
<td>T number based on Dvorak technique</td>
</tr>
</tbody>
</table>
### 6. OFFICIAL MONITORING AND FORECAST

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<th>Criteria</th>
<th>Source</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e) Synoptic observations</td>
<td>- two closed isobars with interval of two hPa is considered as cyclogenesis (formation of depression)</td>
<td>GTS / INCOIS</td>
<td>Number of closed isobars and associated surface wind speed</td>
</tr>
<tr>
<td></td>
<td>- In case of wind field, threshold cyclonic wind is 17 knots or more</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Location of centre is the location of lowest pressure</td>
<td>INCOIS / NRL / CIRA</td>
<td>Conditions for genesis, intensification and movement</td>
</tr>
<tr>
<td>(f) Environmental parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Check list for the north Indian Ocean

Dated  
**Time**

1. **Mean sea level pressure (MSLP)**  
   Central pressure:
   Outer most closed isobar Pressure:
   Radius of outermost closed isobar  
   Pressure deficit :
   No. of closed isobar (within 6 deg):
   Shape of isobar (circular/elliptical)  
   Size of the system (lat./long.)

2. **Number of days the low pressure area is persisting :**

3. **Region of occurrence of low pressure area :**
4. **24 hrs pressure change**
   a. General description :
   b. Maximum fall and station/buoy :

5. **Pressure departure from normal**
   a. General description :
   b. Maximum negative departure and station :

6. **Circulation:**
   a. Vertical extension :
   b. Tilting
   c. Wind speed (sector): west/ east/ north/ south   Surface
   0.9 km
   1.5 km
   d. Maximum wind (Magnitude, Region of occurrence and Distance of maximum wind from centre of circulation at surface level)
7. **Lower level convergence**:
   a. Maximum value and region of occurrence:
   b. Convergence in forward sector
   c. Tendency during past 06/12/24 hrs

8. **Upper level divergence**:
   a. Maximum value and region of occurrence:
   b. Divergence in forward sector
   c. Tendency during past 06/12/24 hrs

9. **Lower level vorticity**
   a. Maximum value and region of occurrence:
   b. Vorticity in forward sector
   c. Tendency during past 06/12/24 hrs

10. **Vertical wind shear**
    a. Minimum value and region of occurrence:
    b. Wind shear in forward sector

11. **Wind shear tendency**
    a. Minimum value and region of occurrence:
    b. Wind shear tendency in forward sector:
Check list for the north Indian Ocean

12. QPE
   a. QPE during past 12 hrs (Maximum value and region of occurrence) :
   b. QPE during past 24 hrs (Maximum value and region of occurrence) :
   c. Tendency (Increasing/decreasing) :

12. OLR :
   a. Daily mean (Maximum value and region of occurrence) :
   b. 3 hourly mean (Maximum value and region of occurrence) :
   c. Tendency (Increasing/decreasing) :

13. SST
   a. Maximum SST and region of occurrence
   b. SST in forward sector
   c. Tendency in SST

14. Location and intensity from other sources
   a. NOAA SSD
   b. JTWC
Check list for the north Indian Ocean

Radar features:
1. Pattern: Line curve/Spiral band/Eye
2. Line Curve (Number and tendency, associated maximum reflectivity and its place of occurrence)
3. Characteristics of spiral bands (Number and tendency, Maximum reflectivity and its place of occurrence)
4. Eye characteristics:
   (i) Visible/Invisible width Tendency
   (ii) Open/ closed, If open how much and tendency
   (iii) Circular/elliptical
5. Characteristics of eye wall
   (i) Maximum reflectivity and its place of occurrence and tendency
   (ii) Single eye wall/ double eye wall
   (iii) Size of eye and eye wall (Diameter/radius)
6. Pre-cyclone squall lines (Region of occurrence, time of occurrence)
7. Precipitation characteristics (Place and time of occurrence of maximum precipitation)
8. Radius of maximum reflectivity (in different quadrants)
9. Radius of maximum wind (in different quadrants)
10. Vertical extension of convective clouds
11. Radar estimated location of centre with confidence (Multiple centres in case of multiple radars) and intensity with confidence
Based on all the inputs as discussed in check list derived by following the sequential steps as given in the roadmap, forecaster will be able to take a judicious decision in the probabilistic/deterministic term.
Case Study

(To prepare extended range & short to medium range forecast bulletin based on 0300 UTC of 7th April, 2022)
Step 1: Broad scale features (MJO)

MJO in phase 4 with amplitude less than 1 on 7th April. To move eastwards into phase 5 during first half of week 1. Thereafter, will move across phases 6 & 7 during remaining part of the forecast period. Favourable for enhancement of convective activity over NIO during first half of week 1.
Step 1: Broad scale features (Equatorial waves)

**Week 1 (first half):**
3-5 mps easterly waves over central BoB, 3-5 mps westerly waves over EIO & adj. south BoB, Kelvin waves over south AS, low frequency background waves over EIO & adj. south BoB and Rossby waves over southwest BoB

**Week 1 (later half):**
Easterlies disappeared. Westerly flow more towards SIO. Kelvin waves over BoB & adj. EIO. And Rosby waves over SIO & adjoining Malay peninsula
Step 1: Broad scale features (Equatorial waves)

Week 2 (first half):
No easterly flow, westerly waves strong (3-5) over south AS and westerly flow over EIO & adj. south BoB, Kelvin waves over south AS and south BoB, low frequency background waves over EIO & adj. south BoB & adj. south BoB.

Week 2 (later half):
Easterlies 1-3 mps over central BoB. Westerly flow over EIO & adj. south BoB. Kelvin waves over BoB & adj. EIO. And Rosby waves over SIO.
Step 2: Synoptic scale features

- SST is around 29-30degC over south & adj. westcentral BoB and adj. southeast AS.
- OHC is >100 KJ/cm² over south Andaman Sea and adjoining SE BoB with gradually decreasing trend, becoming 60-80 KJ/cm² over remaining parts of south & major parts of adjoining central BoB and Andaman Sea. Over the AS, OHC is >100 KJ/cm² over southeast & adj. EC AS.
- Depth of 26 deg isotherm around 100 m over major parts of south BoB & AS.

https://www.aoml.noaa.gov/phod/cyculture/data/ni.php
Step 2: Synoptic scale features

Cyclonic circulation over south Andaman Sea
Fig. 1: Tracks of (a) cyclonic disturbances (MSW ≥ 17 kt) and (b) cyclonic storms (MSW ≥ 34 kt) in the month of April during the period 1891-2020
Step 3: Model guidance

Most of the models including IMD GFS, GEFS, NCUM, NEPS, ECMWF, ECMM, JMA etc. are indicating that there is no likelihood of formation of depression over NIO during next 2 weeks. IMD GPP is indicating a potential zone of cyclogenesis over southeast BoB on 8th with west-northwestwards movement. However, models like GFS, NCUM, ECMWF etc. are indicating that the existing cyclonic circulation over south Andaman Sea would move west-northwestwards towards TamilNadu coast.

Conclusion:
In view of all the above,

- Probability of cyclogenesis for next 120 hours is taken as NIL.
- Probability of cyclogenesis during next 2 weeks is taken as NIL.

However, the cyclonic circulation over south Andaman Sea would move west-northwestwards.
Thank you