14th Southwest Indian Ocean Seasonal Climate Outlook Forum

Performance Evaluation of ECMWF Atmospheric Model Forecast

Assessment of Wet Seasons of 2023-24 Over Madagascar, Mauritius & Seychelles

Regional Integrated Multi-Hazard Early Warning System for Africa and Asia

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Objectives of the Study

The study focused on,

• The study evaluates the first five days (120 hours) forecasts over the Madagascar, Mauritius, and Seychelles during the wet season (ONDJFMA) of 2023-24.
• The study also analyzed the rainfall responsible for extreme events such as cyclonic storm, flood, landslide, very heavy rainfall cases occurred in wet 2023-24 at these countries.

Data Used

Table 1: Data selected for the country-specific monsoon season of 2023

| Input data	Period of record	Time (IC)	Domain Grid	Horizontal Grid Resolution	Variable (Unit)
SET-1 HRES[1]	1 October 2023 to 4 May 2024	00UTC	4°S – 26°S; 42°E - 58°E	0.2° x 0.2° or (~20km x ~20km)	Precipitation (mm)
GPM IMERG[2]	1 October 2023 to 4 May 2024	00UTC	4°S – 26°S; 42°E - 58°E	10 x 10 km	precipitation (mm/day)

Tools Used

- **Climate Data Operator (CDO)**
- **ecCodes**
- **Python**
- **R programming**

Study Area

Table 2: The months considered for the evaluation and main rainfall season of each country. This period contributes the highest percentage of the overall rain for each country.

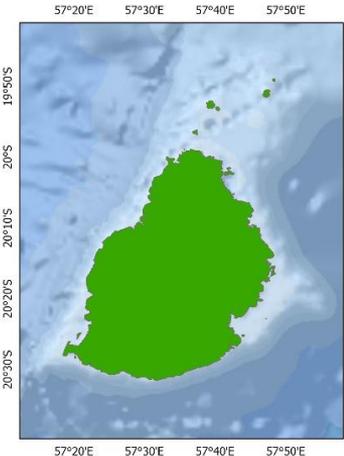| Country	Wet/Rainy Season	Reason/Monsoon/Climate System
Region D: Southeast-Africa		
Madagascar	ONDJFMA	Indian Monsoon
Mauritius	ONDJFMA	Mild tropical maritime
Seychelles	ONDJFMA	Trade Winds
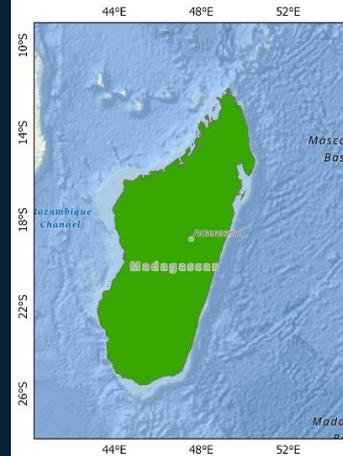
Madagascar   Seychelles   Mauritius
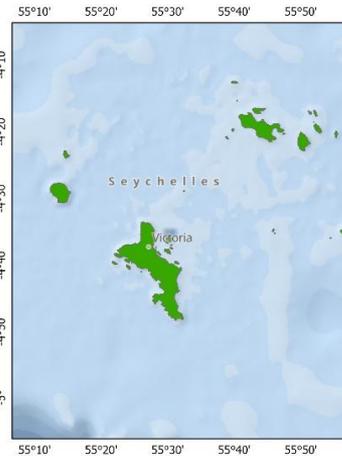
Verification Methods

Table 3: Binary verification Indicators

| Indices	Statistical Equation	Perfect score
Probability of Detection (POD) also known as hit rate	$POD \lor HR = \dfrac{hits}{hits + misses}$	The perfect score is 1
Hanssen and Kuipers' discriminant (HK/KSS) or true skill statistic (TSS) or Peirce's skill score (PSS)	$HK = \dfrac{hits}{hits + misses} - \dfrac{false\ alarms}{false\ alarms + correct\ negatives}$	The perfect score is 1
False Alarm ratio (FAR)	$FAR = \dfrac{false\ alarms}{hits + false\ alarms}$	The perfect score is 0
Threat score (TS) or critical success index (CSI)	$TS\ or\ CSI = \dfrac{hits}{hits + misses + false\ alarms}$	The perfect score is 1

Total precipitation (mm)
ONDJFMA 2023-24
as of GPM IMERG
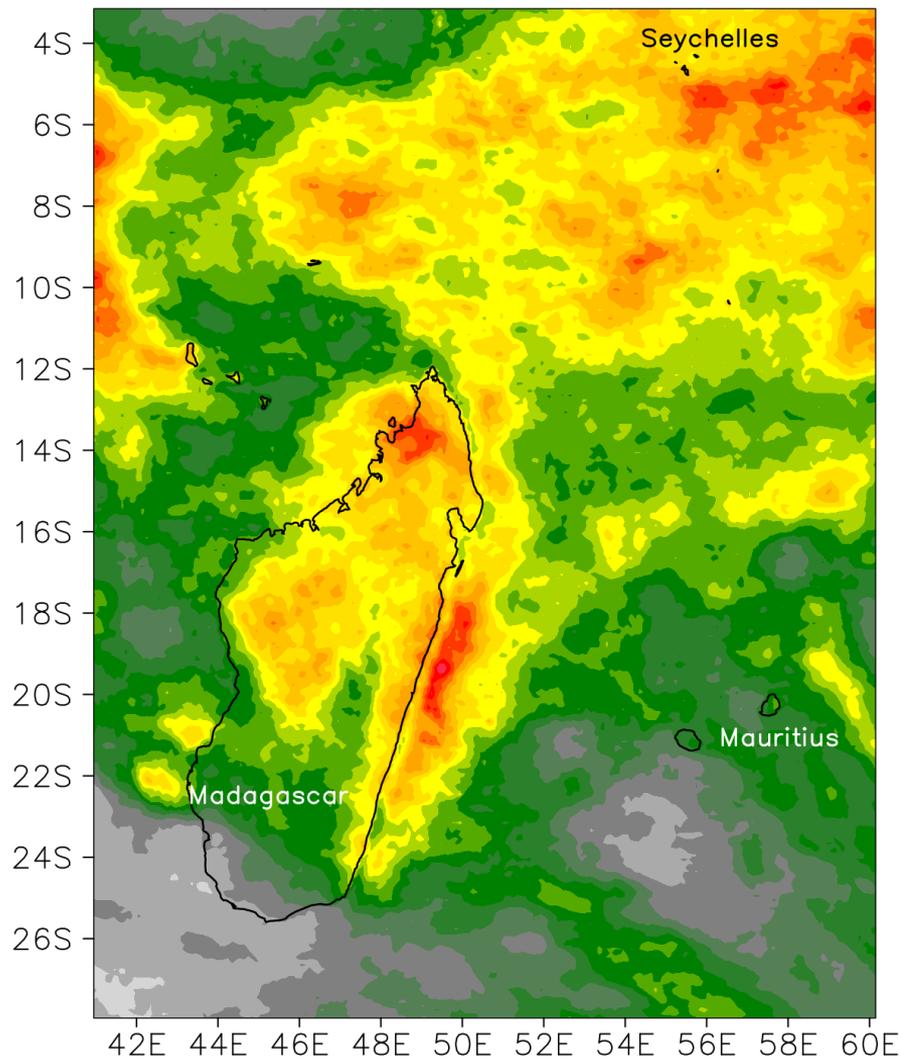
Results

Country A: Madagascar

- During the day 1 to 5, the northern Madagascar exhibit higher RMSE values, indicating lower accuracy. However, by day five, RMSE values have significantly increased across the northern and eastern parts of the country.
- Correlation coefficients are significantly higher during day 1 to day 3 forecasts. But, during the day 4 to 5, low correlation coefficients are observed across many regions of Madagascar. As the lead time extends to day five, the correlation coefficients decrease notably, especially in regions such as central Madagascar.
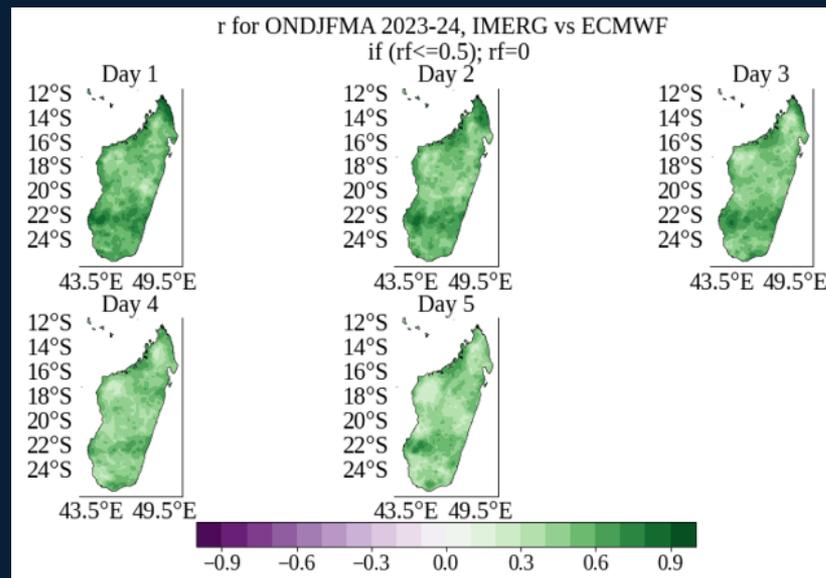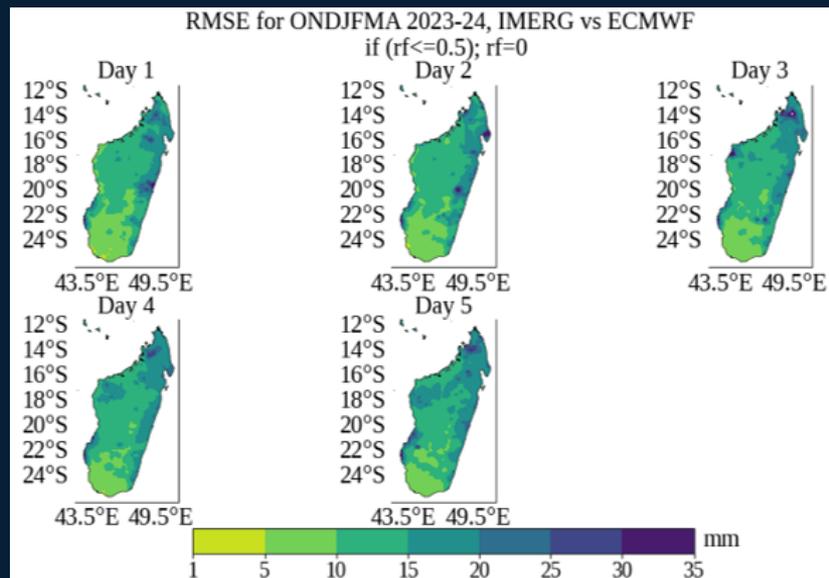
Country A: Madagascar

- **Medium HK values are evident in almost all areas over Madagascar showing good forecast discrimination between rainy and non-rainy periods during day 1 to 5.**
- **However, as the forecast lead time increases to day four, HK values decline, indicating reduced forecast skill in distinguishing between events and non-events.**
- **For example, southern Madagascar exhibit very low HK scores throughout the forecast period.**
- **The eastern coastal region exhibits very good HK scores whereas the mountainous central and western dry regions exhibit moderate scores.**

HK (rf>=2.5mm) for ONDJFMA 2023-24, IMERG vs ECMWF if (rf<=0.5); rf=0
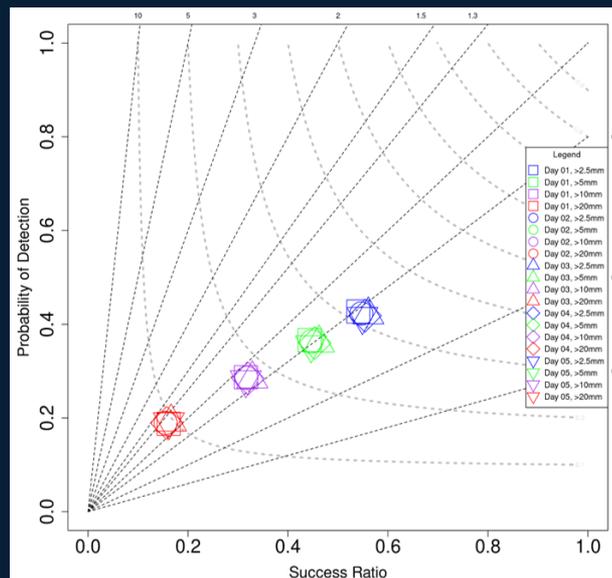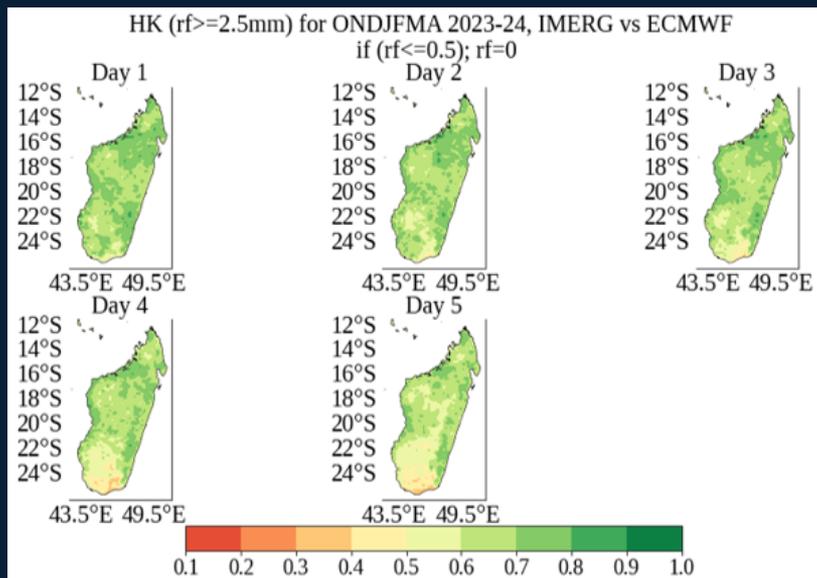
Extreme Event Analysis: Tropical Cyclone ALVARO

Tropical cyclone ALVARO made landfall over the southwestern-central coast of Madagascar on 1 January, 2024 and crossed the southern-central regions on 2 January.
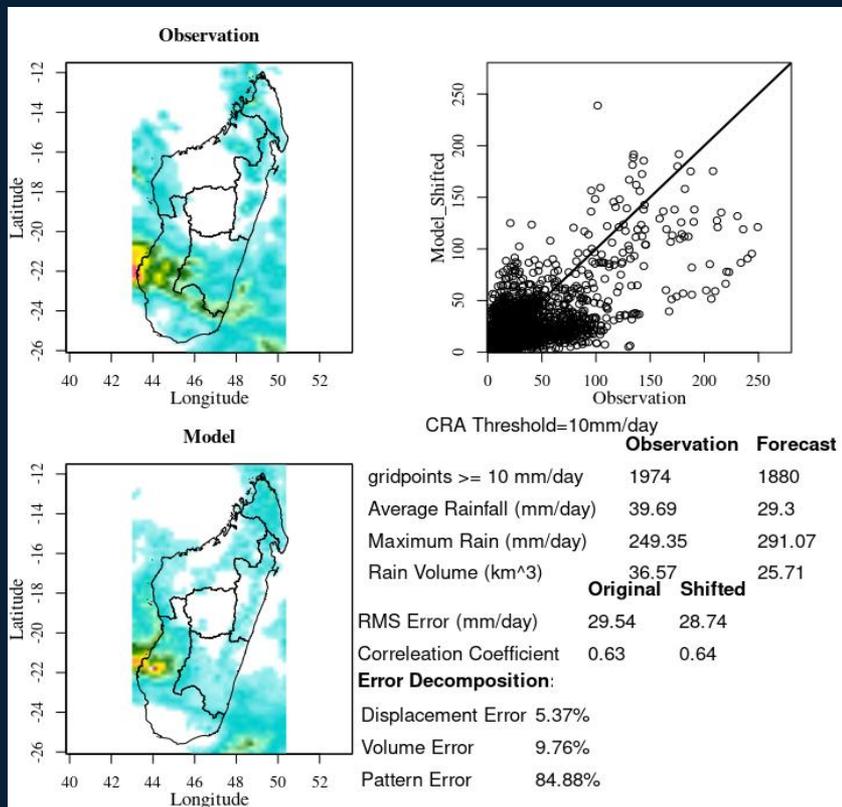
Extreme Event Analysis: Tropical Cyclone Freddy

Tropical Cyclone Freddy was one of the longest-lived systems in the Southern Hemisphere. Freddy formed off the coast of Indonesia in early February 2023 and crossed the southern Indian Ocean, making landfall on the east coast of Madagascar on 21 February 2023.
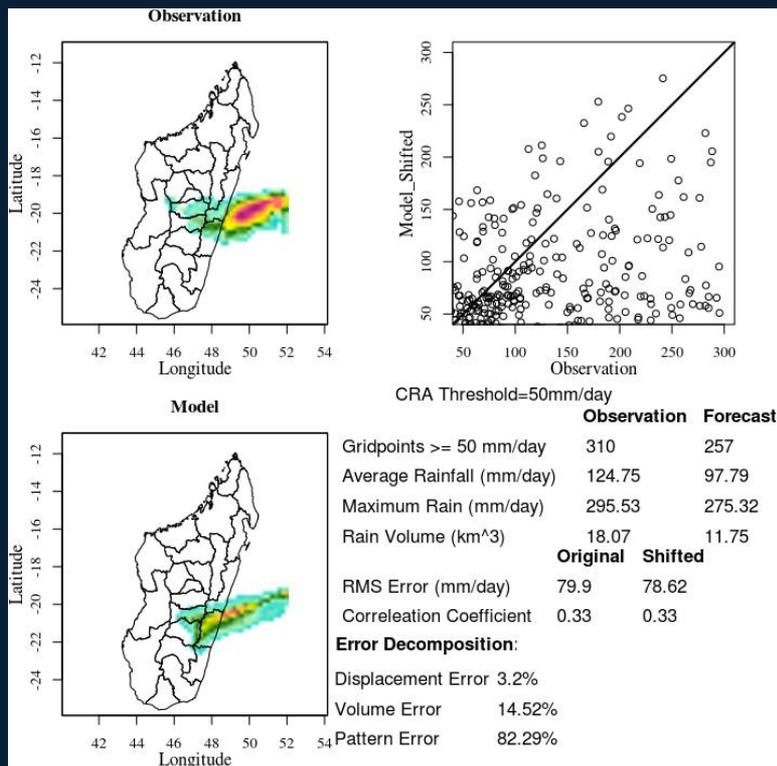
Country B: Mauritius

- During the day 1 to 5, the eastern Mauritius exhibit higher RMSE values. By day 4, RMSE values have significantly increased across the southern and eastern parts of the country.
- During the day 4 to 5, low correlation coefficients are observed across the Mauritius.
- As the lead time extends to day five, the correlation coefficients decrease notably, especially in regions such as southern Mauritius.
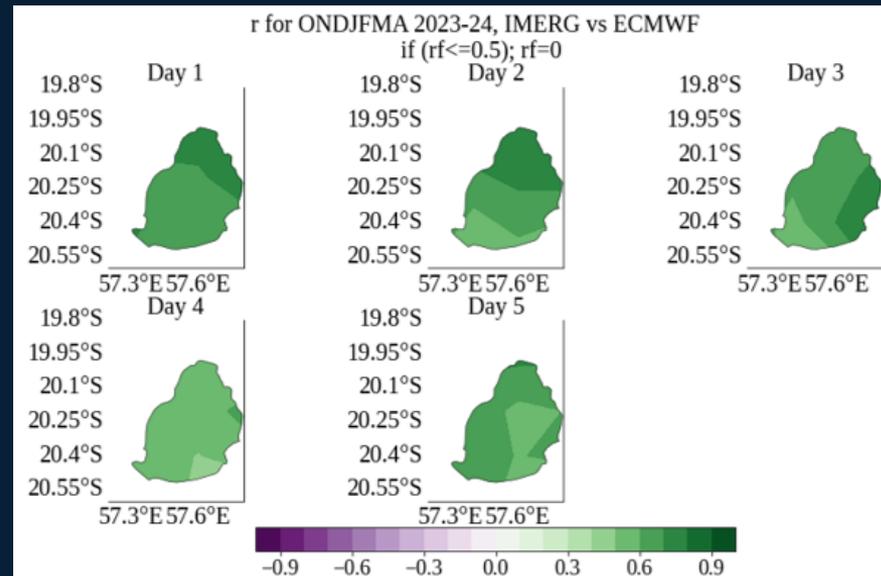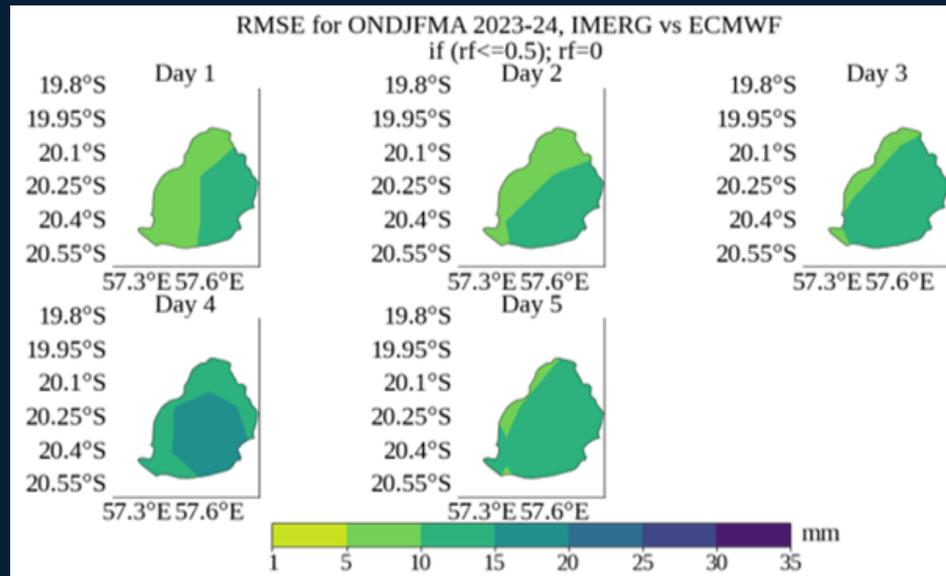
Country A: Mauritius

- Medium HK values are evident in almost all areas over Mauritius.
- As the forecast lead time increases to day 5, HK values decline, indicating reduced forecast skill in distinguishing between events and non-events.
- Central Mauritius exhibit very low HK scores throughout the forecast period. However, the skills start deteriorating significantly for Day 5 forecasts. The eastern region exhibits low HK scores.

HK (rf>=2.5mm) for ONDJFMA 2023-24, IMERG vs ECMWF if (rf<=0.5); rf=0
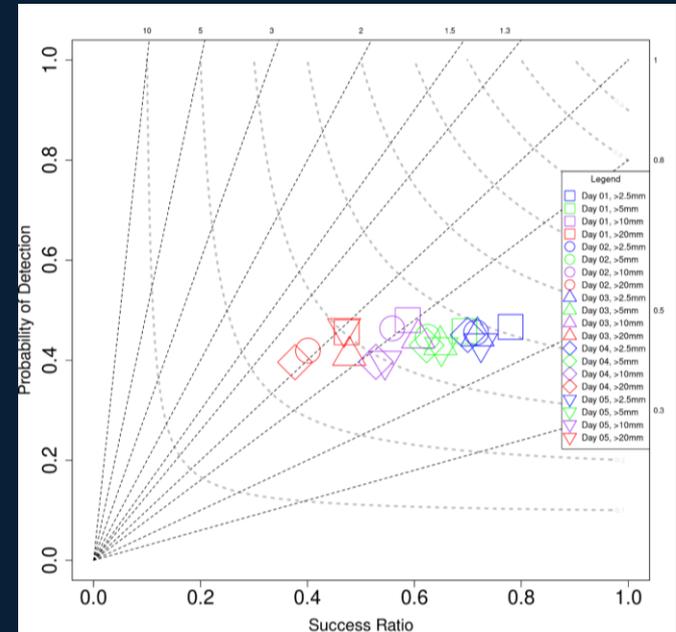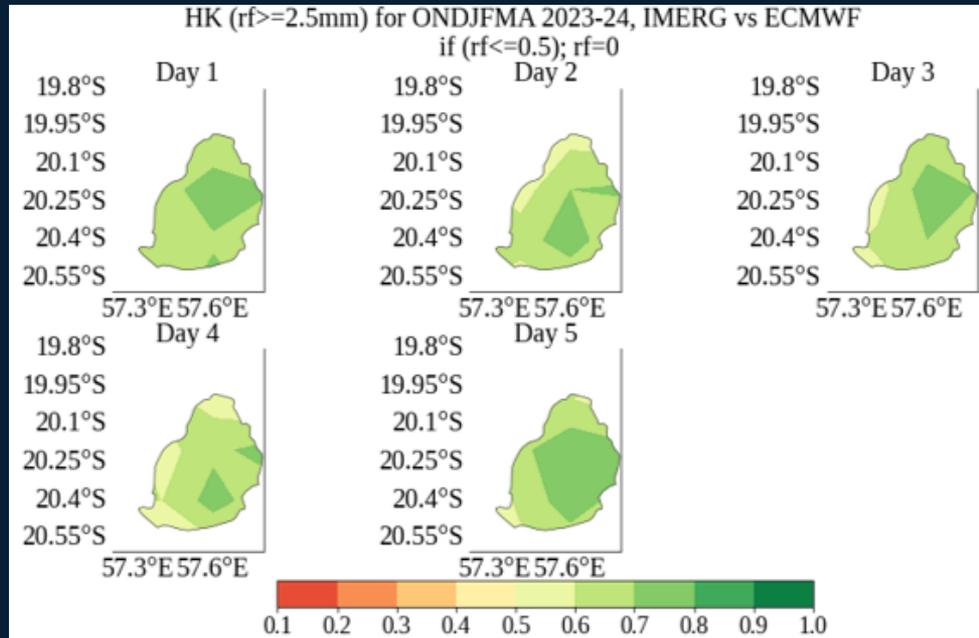
Extreme Event Analysis: Tropical Cyclone Belal

In January 2024, Tropical Cyclone Belal lashed Réunion and Mauritius, islands in the southwest Indian Ocean east of Madagascar. The storm strengthened on January 14 to the equivalent of a category-2 hurricane, Belal made landfall over northwestern Réunion on the morning of January 15.

CRA Threshold=10mm/day

	Observation	Forecast
gridpoints >= 10 mm/day	20	20
Average Rainfall (mm/day)	56.74	78.04
Maximum Rain (mm/day)	110.16	115.86
Rain Volume (km^3)	0.52	0.72

	Original	Shifted
RMS Error (mm/day)	33.35	33.35
Correleation Coefficient	0.03	0.03

Error Decomposition:

Displacement Error	0%
Volume Error	40.77%
Pattern Error	59.23%

Country C: Seychelles

- **During the 3 to day 5, the southern Seychelles exhibit higher RMSE values.**
- **However, by day five, RMSE values have significantly increased across the southern and eastern parts of the country.**
- **As the lead time extends to day five, the correlation coefficients decrease notably, especially in regions such as northern Seychelles.**
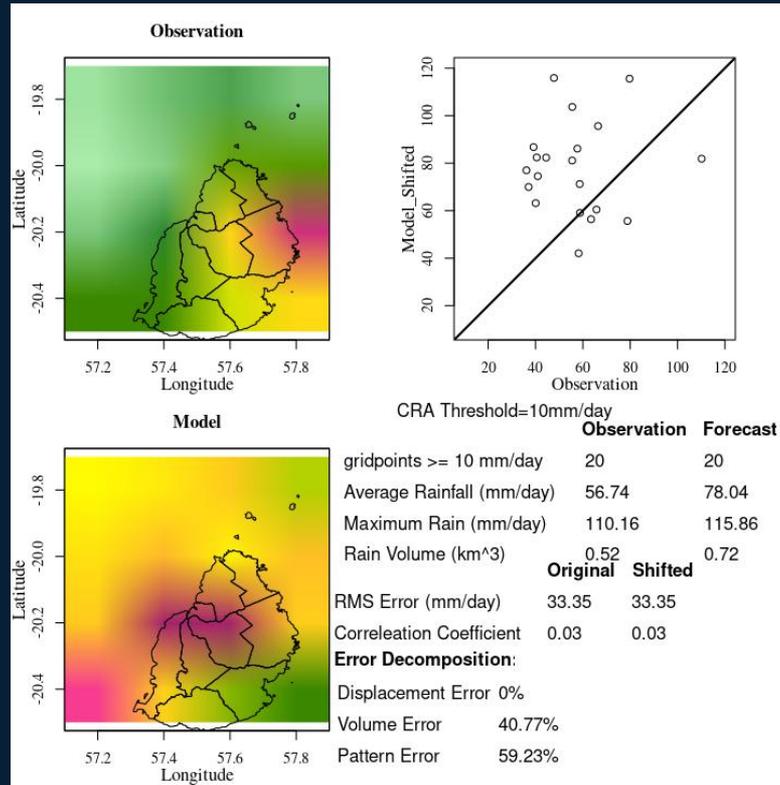

RMSE for ONDJFMA 2023-24, IMERG vs ECMWF
if (rf<=0.5); rf=0
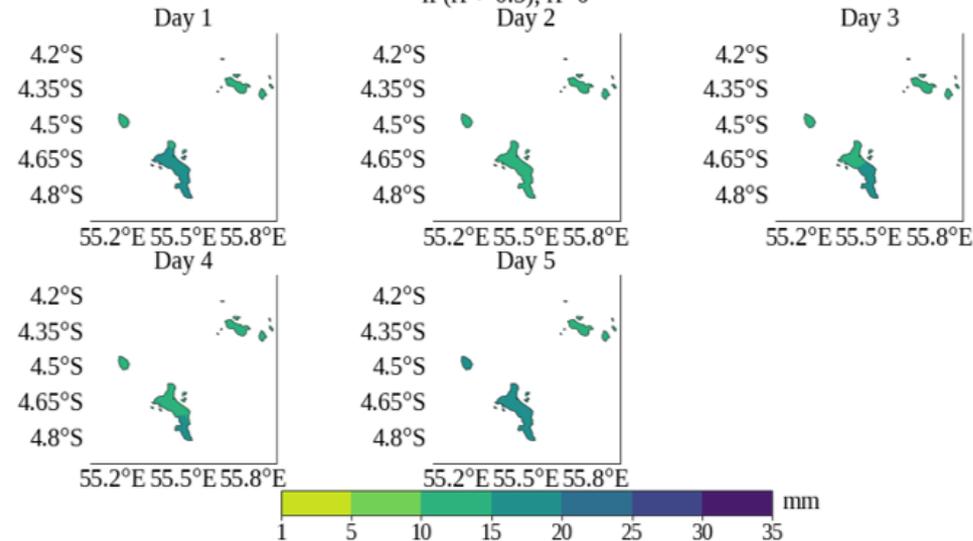
r for ONDJFMA 2023-24, IMERG vs ECMWF
if (rf<=0.5); rf=0
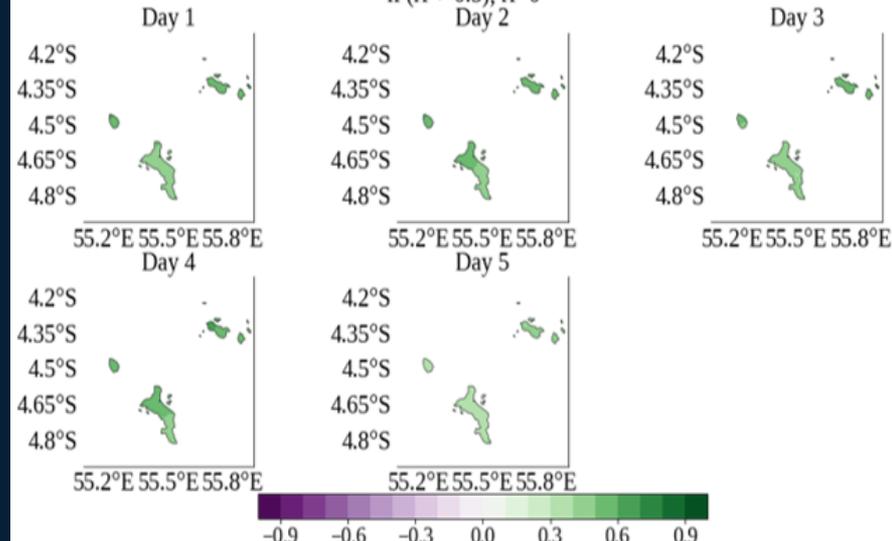
Country C: Seychelles

- **Medium HK values are evident in almost all areas over Seychelles showing good forecast discrimination between rainy and non-rainy periods during day 1 to 5.**
- **For example, southern and eastern Seychelles exhibit very low HK scores throughout the forecast period.**
- **However, the skills start deteriorating significantly for Day 4 to Day 5 forecasts. The northern region exhibits very good HK scores.**

HK (rf>=2.5mm) for ONDJFMA 2023-24, IMERG vs ECMWF if (rf<=0.5); rf=0
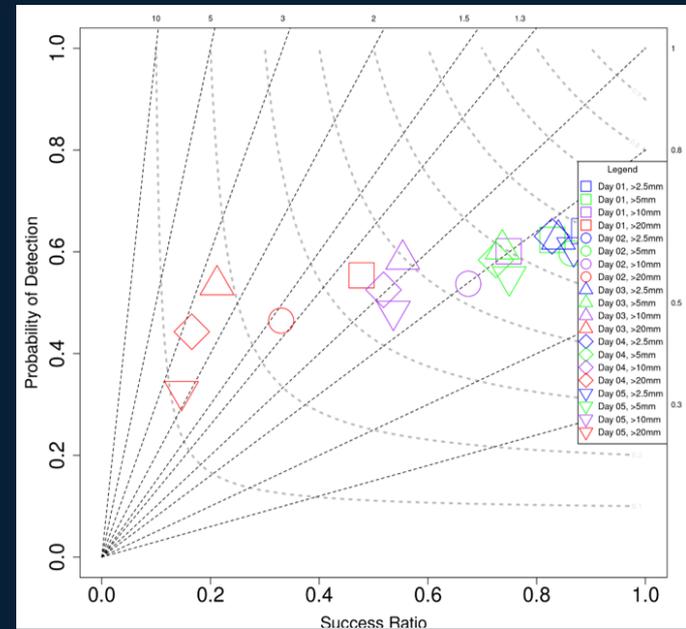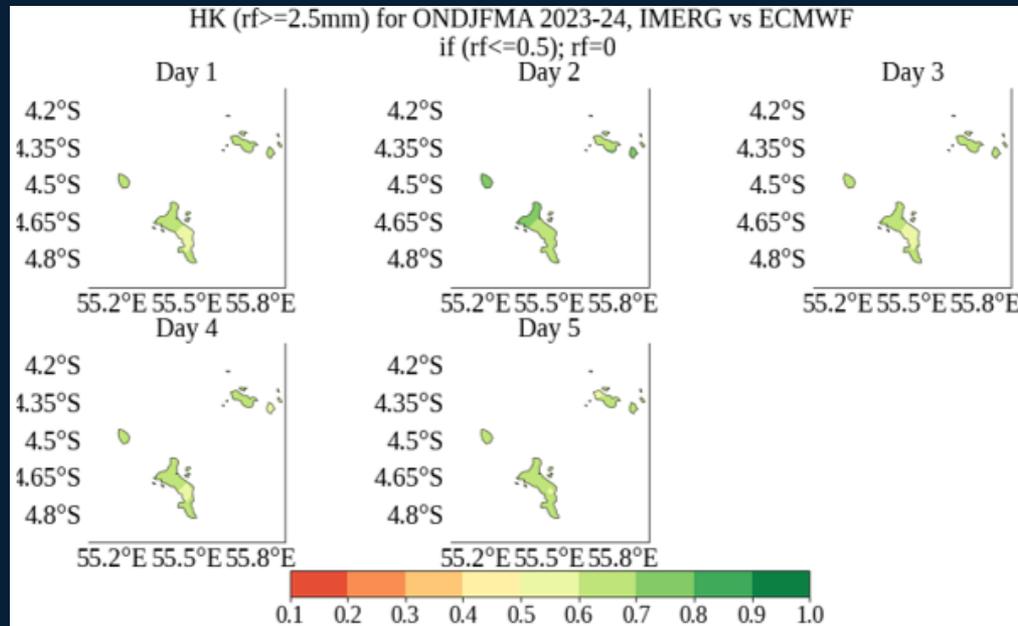
Extreme Event Analysis: Flood and Landslide

Heavy rainfall has been affecting the Seychelles since 6 December 2023, causing flooding and landslides that have resulted in casualties and damage. Media report, as of 8 December, three fatalities in the northern part of Mahe Island due to floods.

CRA Threshold=10mm/day

	Observation	Forecast
gridpoints >= 10 mm/day	22	23
Average Rainfall (mm/day)	19.41	17.23
Maximum Rain (mm/day)	30.68	24.97
Rain Volume (km^3)	0.21	0.19

	Original	Shifted
RMS Error (mm/day)	8.79	8.79
Correleation Coefficient	0.03	0.03

Error Decomposition:

Displacement Error	0%
Volume Error	1.93%
Pattern Error	98.07%
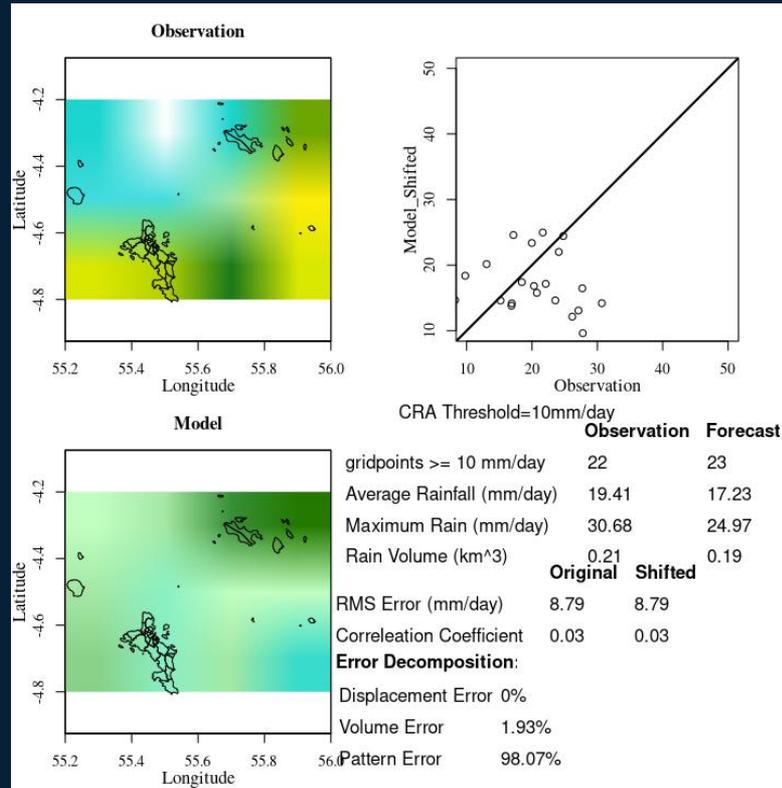
Conclusion

- Across all three countries, RMSE values increased and correlation coefficients decreased especially beyond day 3.
- HK scores declined significantly by day 4 and 5.
- Performance diagrams highlighted that forecast skill decreased more sharply with increasing rainfall thresholds than with increasing lead time. In particular, Frequency Bias (FBIAS) tended to be high and CSI lower at thresholds above 20 mm/day.
- In Madagascar, forecasts captured spatial rainfall patterns reasonably well, although forecast skill was notably lower in northern and eastern regions by day 5. For Cyclones Alvaro (January 2024) and Freddy (February 2023), the model showed good spatial agreement with observed heavy rainfall, with low displacement and volume errors (~2–10%).
- In Mauritius, forecast skill degraded more noticeably, particularly in central and eastern areas. During Cyclone Belal (January 2024), the model reasonably predicted heavy rainfall but with overestimation in central/western regions, leading to a volume error of ~41% and pattern error of ~60%.
- In Seychelles, forecasts initially performed well but deteriorated significantly in the southern and eastern regions by days 4-5. For the December 2023 flood and landslide event, the model overestimated rainfall, showing a high pattern error (~98%) but a low volume error (~2%).
- These findings suggest that ECMWF forecasts provide moderate to high skill up to 3 days in advance, especially at lower rainfall thresholds.
- Further analysis shall be carried out to evaluate the performance of the Day 6 to 10 HRES products and also the ensemble products over the region, especially on their recent performance for the prediction of probabilistic forecasts.

Thank You