

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS



MONAN

Model for Ocean-laNd-Atmosphere predictioN

The pressing climate emergency and the imperative to advance climate modeling

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Outline

a) Climate change and adverse phenomena in South America.

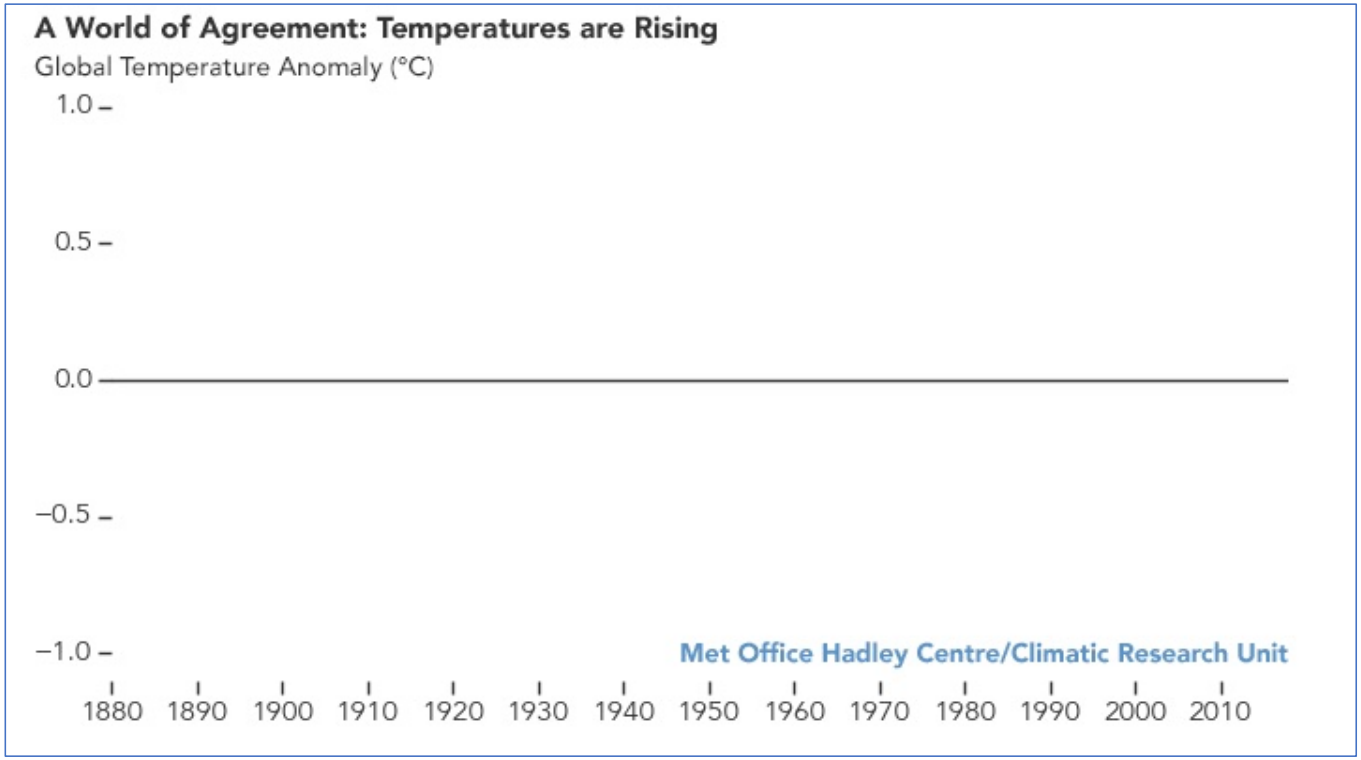
b) Aspects of climate modeling.

c) The emergence of data-driven models.

d) We are working to develop the next generation of weather and climate information for South America

The Climate Change and the Climate Emergency

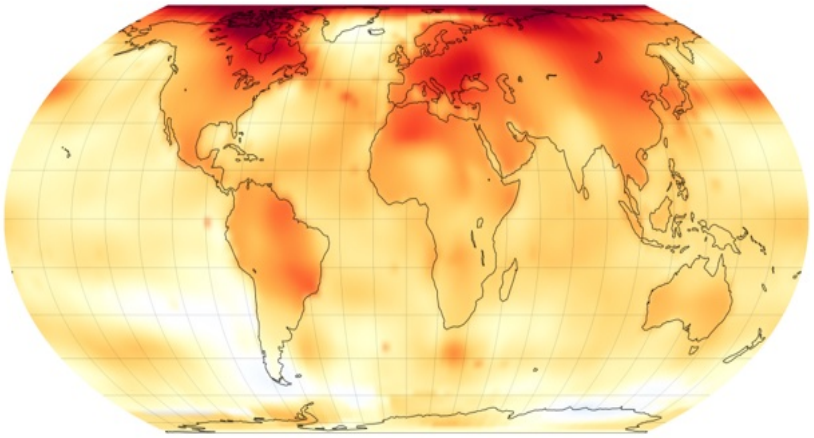
The global warming



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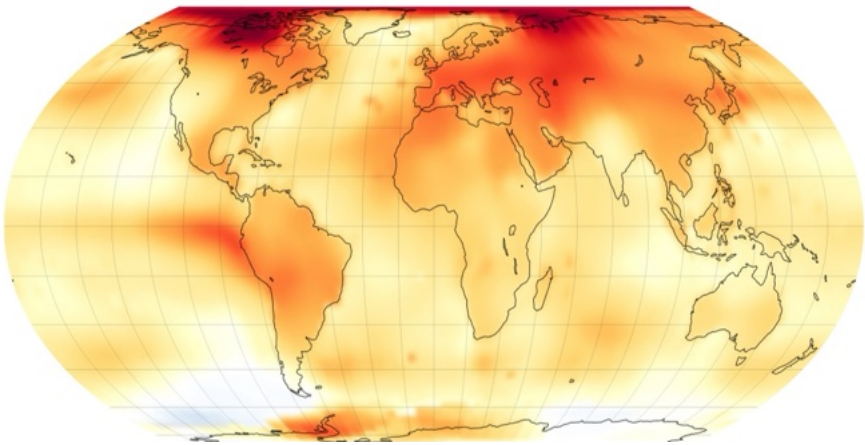
NASA announced that 2023/4 was the hottest year on record

2023

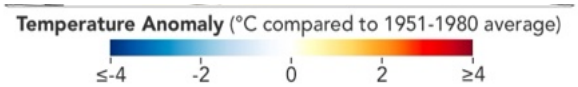


https://earthobservatory.nasa.gov/images/152313/five-factors-to-explain-the-record-heat-in-2023

2024



https://earthobservatory.nasa.gov/images/153806/2024-was-the-warmest-year-on-record

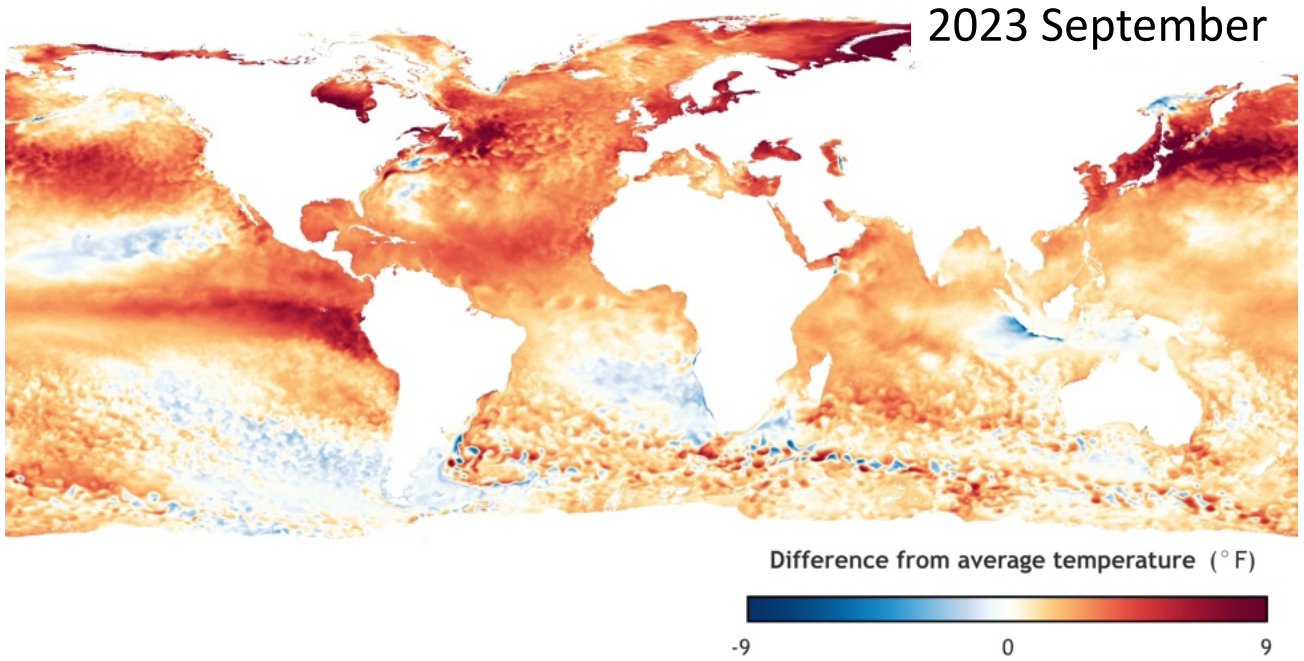


Temperature-Anomaly

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El Niño in 1997 and 2023

SST - Global, Monthly Difference from Average



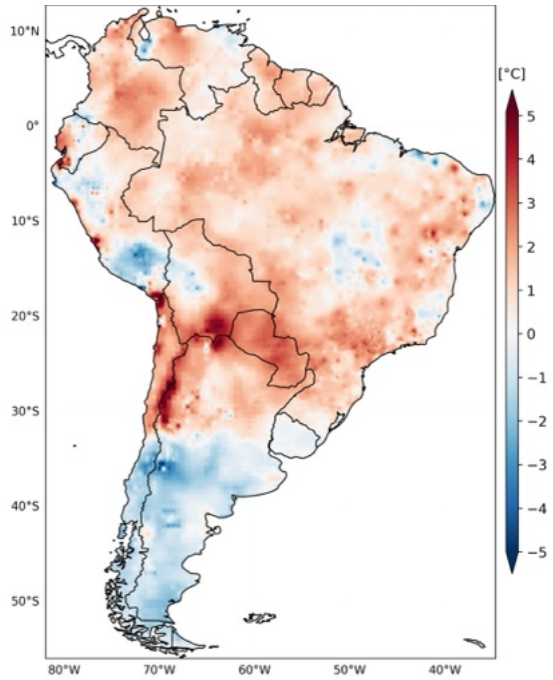
AVERAGE FROM 1985-1993

https://www.climate.gov

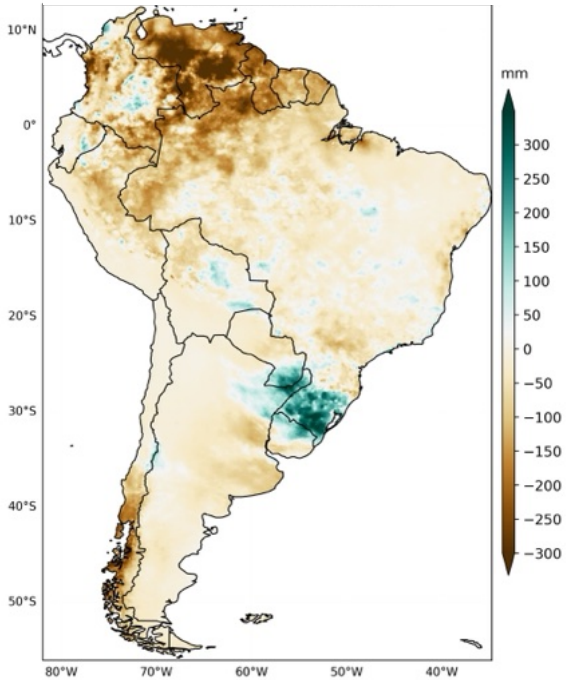
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The synergy between El Niño in 2023 and the global warming

Daily Maximum Temp Anomaly [C]



Precipitation Anomaly [mm]

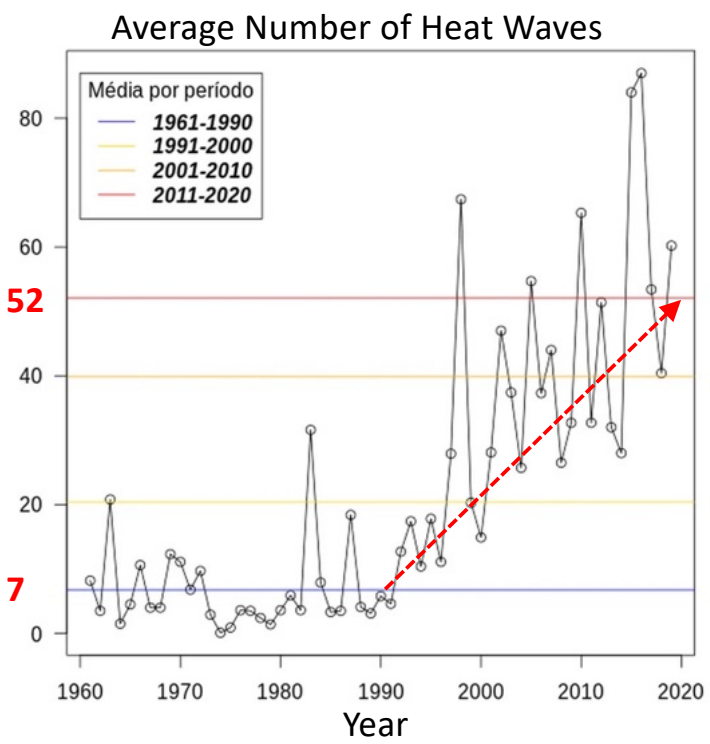


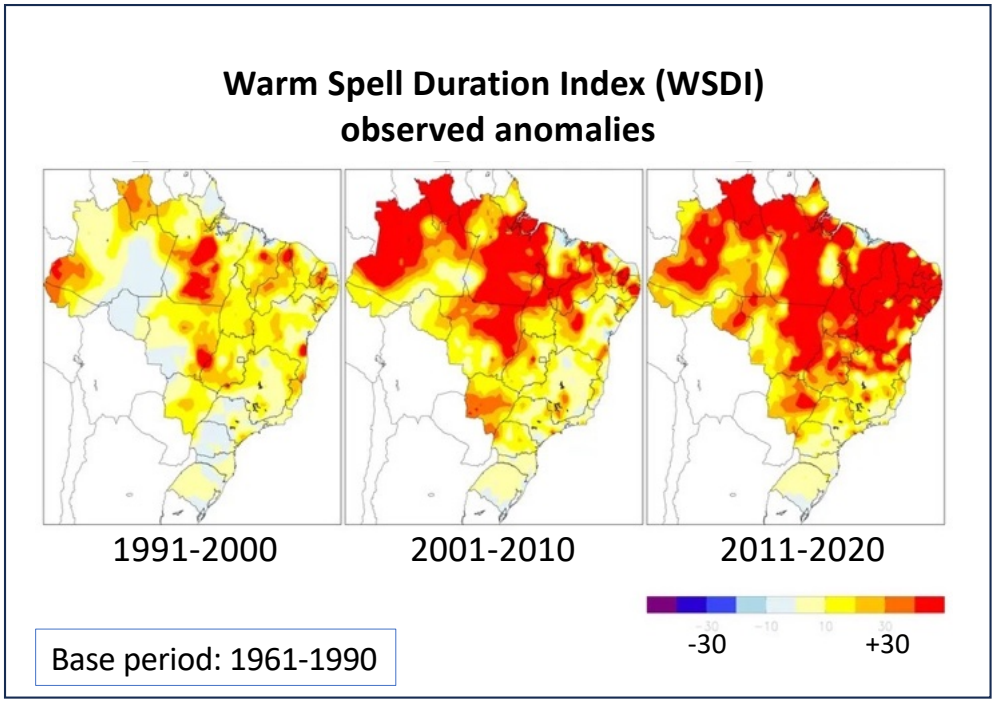
Anomalies for Aug-Sep 2023
Reference data: 2000-2022

Figures provided by J. Rozante (2023) DIPTC/INI

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In 30 years, heat waves in Brazil have increased from 7 to 52 days a year





In 2023, more than 100 million people (about 50% of the population) in Brazil were affected by a heat wave.

Source: L. Alves (2023) MCTI/INPE

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“Extreme events cause record rains and hundreds of deaths in Brazil”



Bahia – 27 mortes Dez/2021



M. Gerais – 19 mortes JAN/2022



Petrópolis (RJ) - 230 mortes Jan/2022



S. Paulo – 34 mortes Fev/2022



Pernambuco – 128 mortes Maio/2022



Litoral Norte de SP ~ 60 mortes Fev/2023

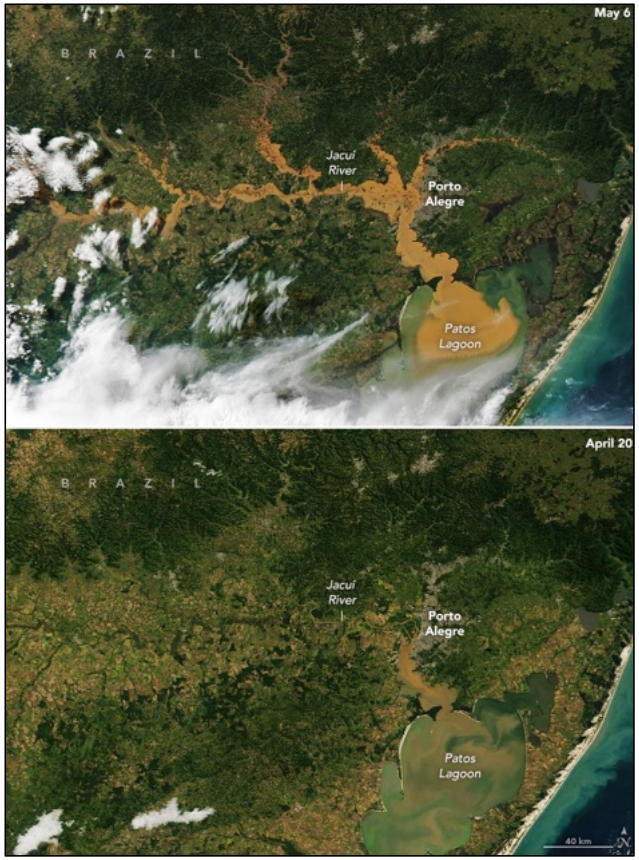
Recent Extreme Weather Events @ South of Brazil
May 2024

600 thousand people displaced, more than 2 million affected



More than 90% of the *Rio Grande do Sul* state being affected by flooding.





Historical perspective of the costs of environmental disasters in Brazil

R$ 150 bilhões: Custo de desastres com chuvas no país salta 41% em 10 anos

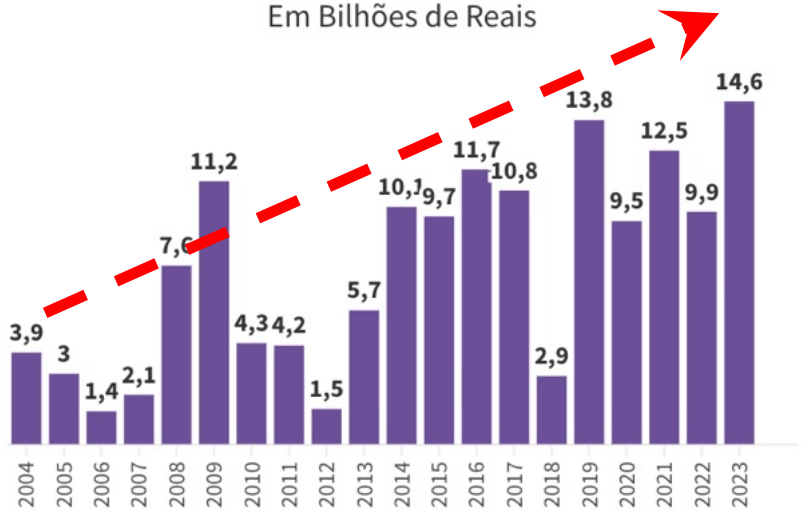
Wanderley Preite Sobrinho • Do UOL, em São Paulo
25/05/2024 04h00



Ruas alagadas na cidade de Canoas, no Rio Grande do Sul
Imagem: Wesley Santos

Prejuízos em desastres com chuva* disparam no Brasil

Em Bilhões de Reais

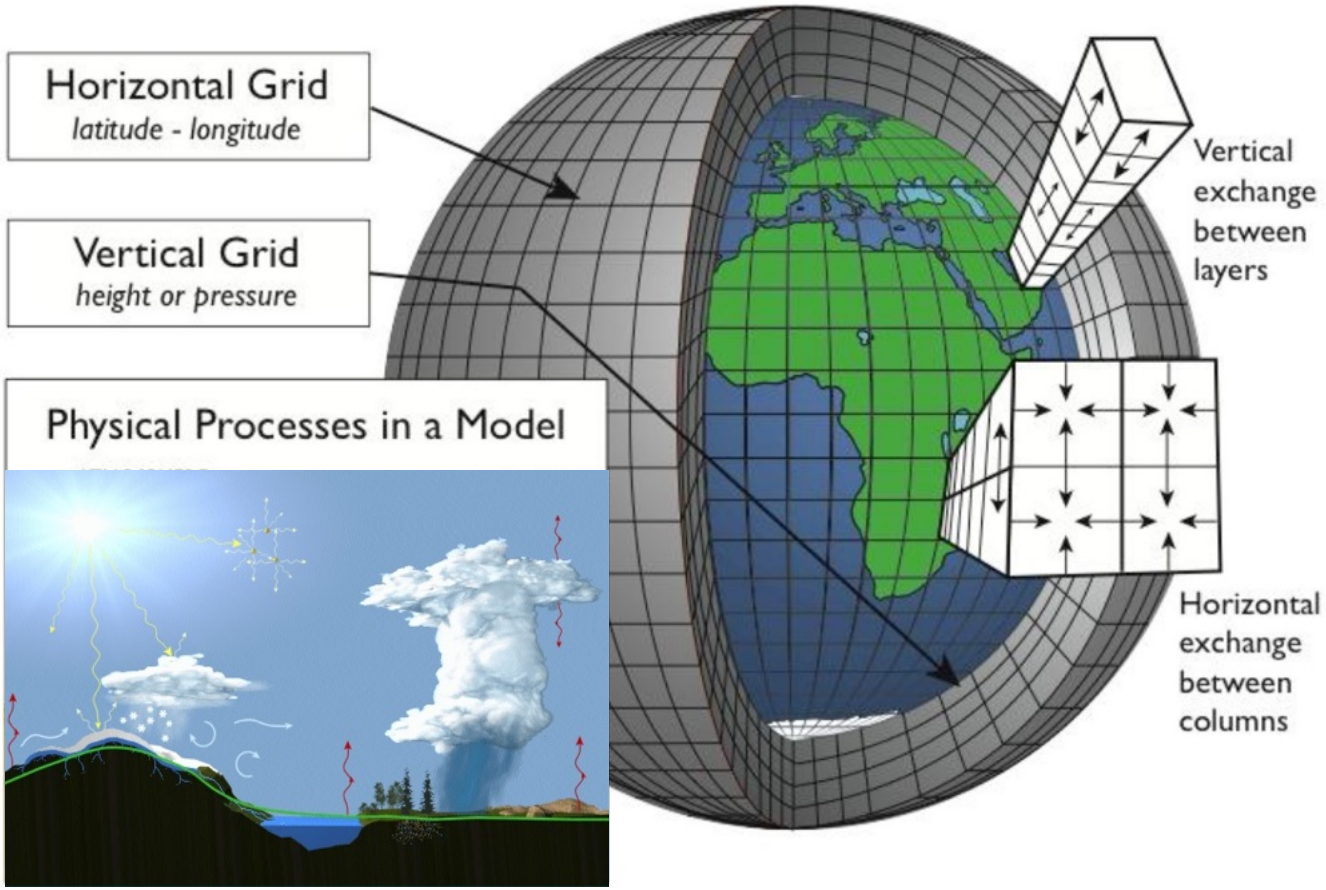


Fonte: Atlas Digital de Desastres no Brasil (Ministério do Desenvolvimento Regional),

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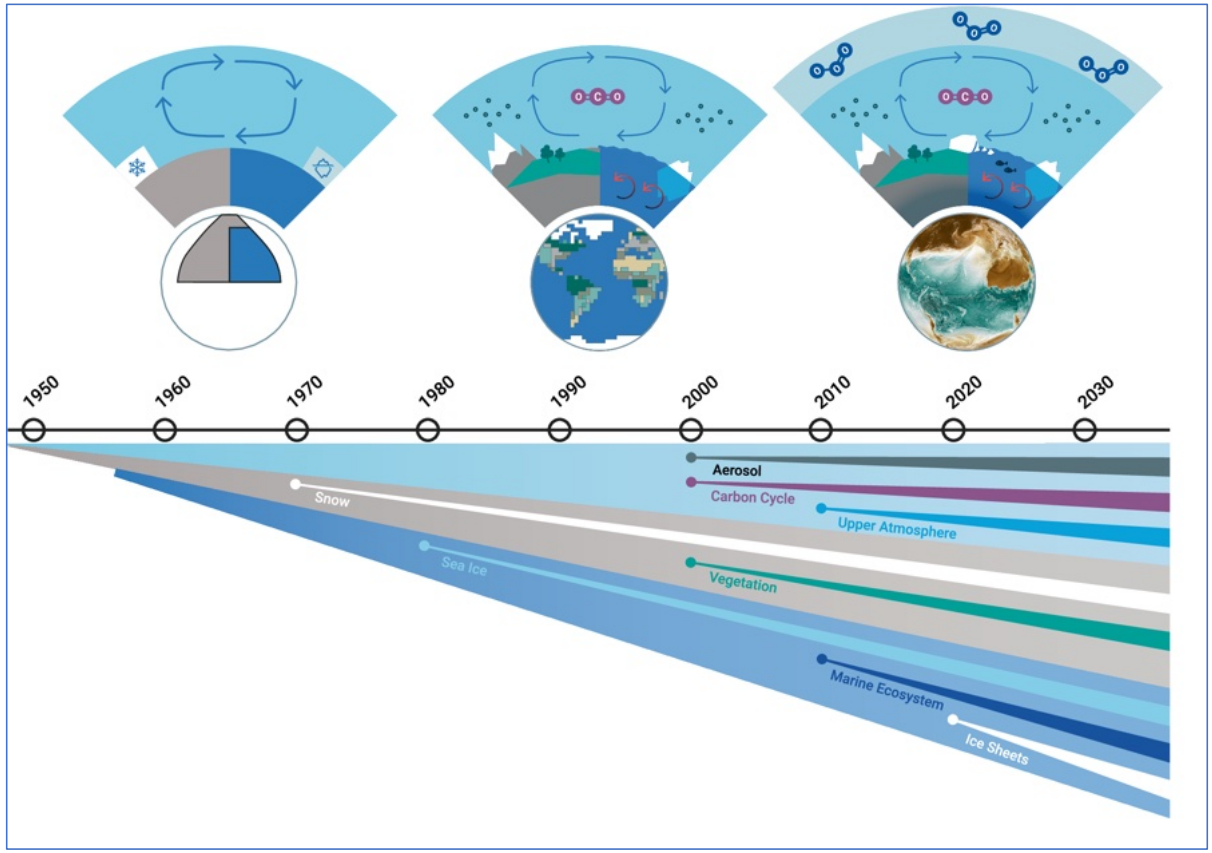
Earth System Models

Traditional Methods



Timeline of climate model complexity.

Progression of model components from early climate models to the latest Earth System Models.

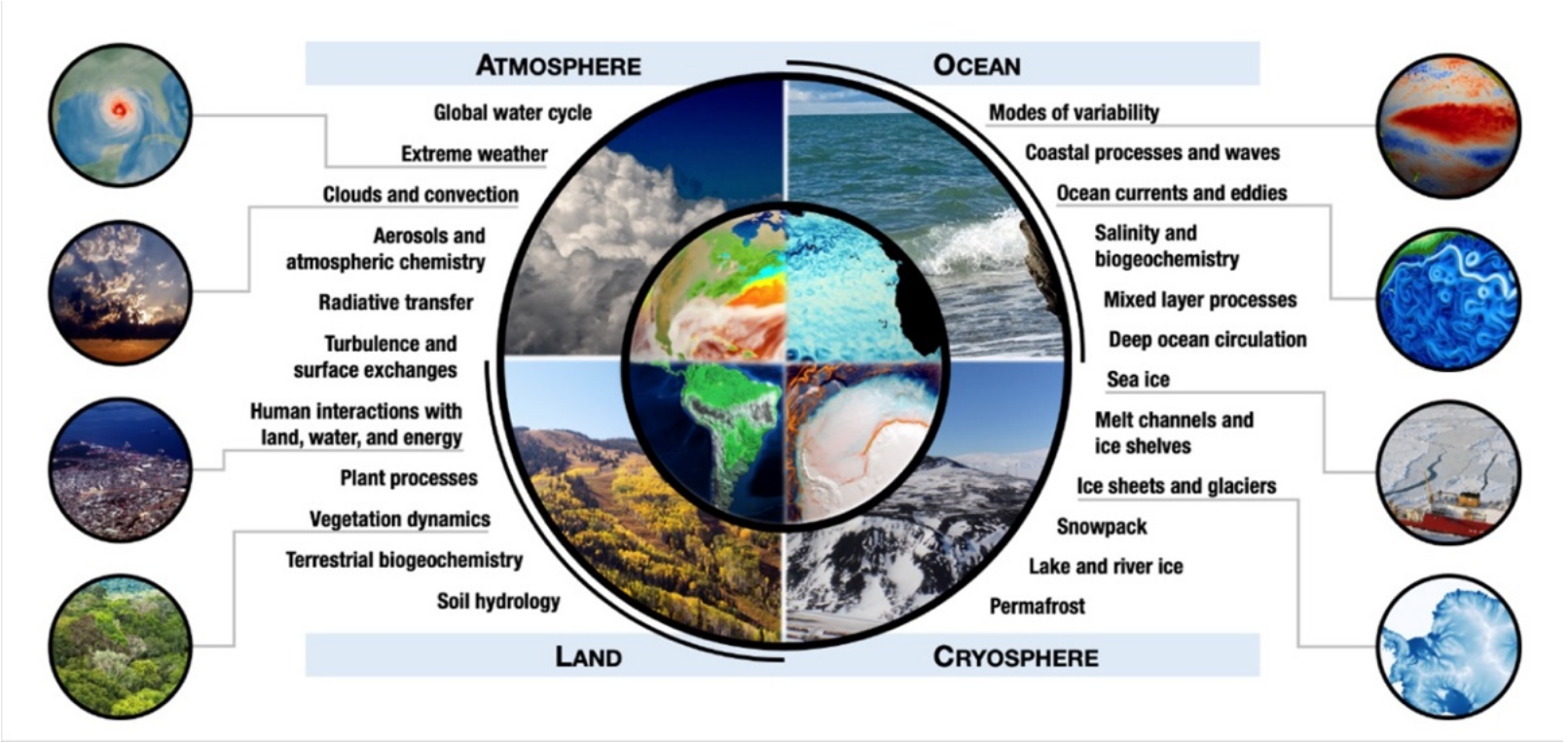


npj Climate and Atmospheric Science, 2025
https://doi.org/10.1038/s41612-025-00955-8

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The physical components of an Earth System model



https://www.energy.gov/science/doe-explainsearth-system-and-climate-models

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Weather Forecast Routine in Operational Centers

Initial Condition



Observation
+
Data Assimilation

Physical model and its numerical discretization

$$\frac{\partial \vec{v}}{\partial t} = -\vec{v}\cdot\nabla\vec{v} - \frac{1}{\rho_a}\nabla p - g\vec{k} - 2\vec{\Omega}\times\vec{v} + \vec{F}_{visc}$$

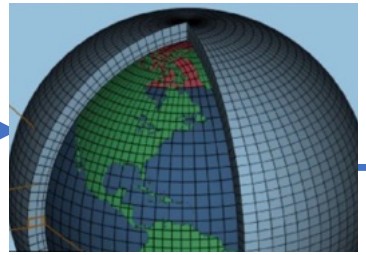
$$\frac{\partial \rho_a}{\partial t} = -\nabla\cdot\rho_a\vec{v}$$

$$\frac{\partial \theta}{\partial t} = -\vec{v}\cdot\nabla\theta + Q_\theta$$

$$\frac{\partial r_n}{\partial t} = -\vec{v}\cdot\nabla r_n + Q_r$$

$$\frac{\partial s_{n,i}}{\partial t} = -\vec{v}\cdot\nabla s_{n,i} + Q_{s_{n,i}}$$

Navier-Stokes Eq. +
Conservation Laws

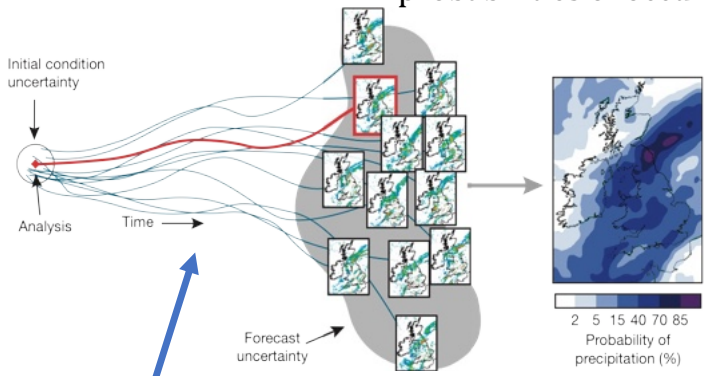


Numerical system
with approximations



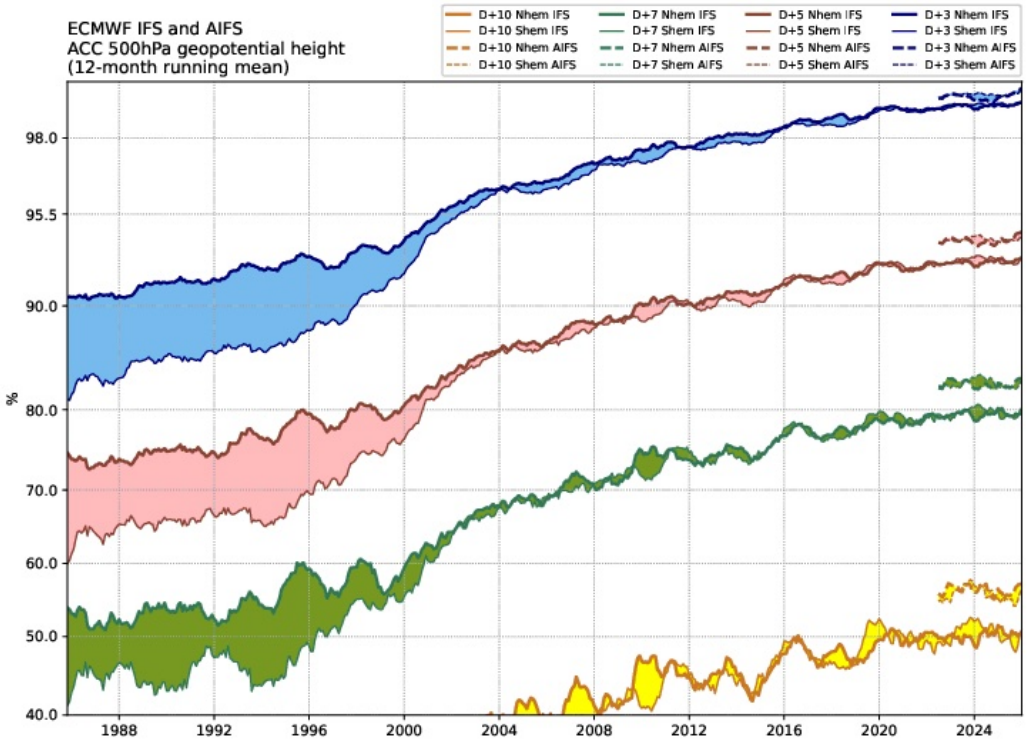
Numerical solution
with supercomputers

Ensemble Forecast providing
probabilities of occurrence

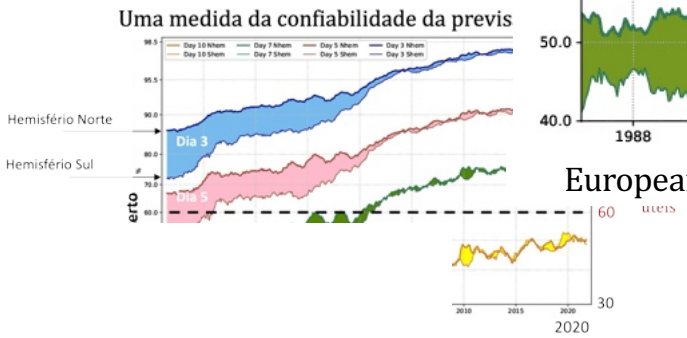


The temporal evolution of the skill of the ECMWF model

Anomaly correlation coefficient of 500hPa Geopotential Height



European Center for Medium-Range Forecasts (ECMWF) global model



The emergence of data-driven models

Nowadays, the number of new tools for climate and weather prediction based on Data and AI methods is vast.





The new ECMWF weather forecasting system

a. The ECMWF has always (in 50 years) been the leader in the world for medium-range (up to 15 days) forecasts on a global scale.

b. The forecasts are produced using a physically based global numerical model called the Integrated Forecast System (IFS).

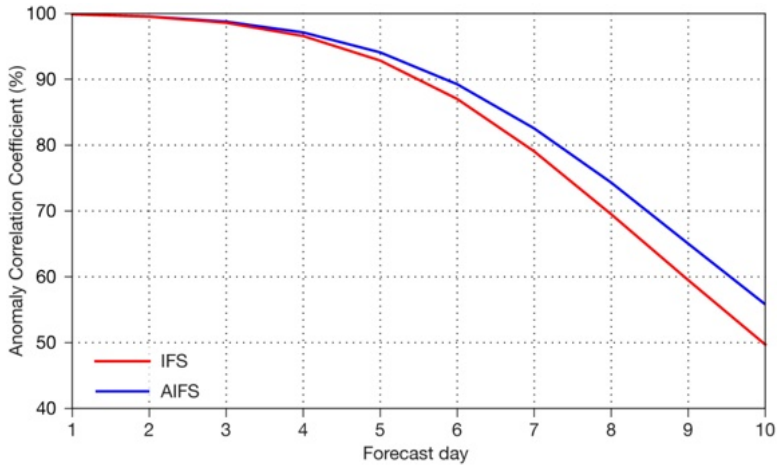
c. In Jan 2024, was launched the machine learning 'version' of IFS: Artificial Intelligence/Integrated Forecasting System (AIFS)

d. AIFS was trained on
   a. a subset of the ERA5 reanalysis for 1979–2018
   b. and fine-tuned on operational IFS data from 2019 to 2020.

AIFS training data.

Field	Level type	Input/Output
Geopotential, U component of wind, V component of wind, vertical velocity, specific humidity, temperature	Pressure level: 50, 100, 150, 200, 250, 300, 400, 500, 600, 700, 850, 925, 1000	Both
Surface pressure, mean sea-level pressure, sea-surface temperature, 2 m temperature, 2 m dewpoint temperature, 10 m U component of wind, 10 m V component of wind	Surface	Both
Land-sea mask, orography, standard deviation of sub-grid orography, slope of sub-gridscale orography, insolation, latitude/longitude, time of day/day of year	Surface	Input

AIFS forecast skill: NH Anomaly Correlation Coefficient for geopotential height at 500 hPa for 2022.



The new-new ECMWF weather forecasting system

Artificial Intelligence–Direct Observation Prediction (AI–DOP).

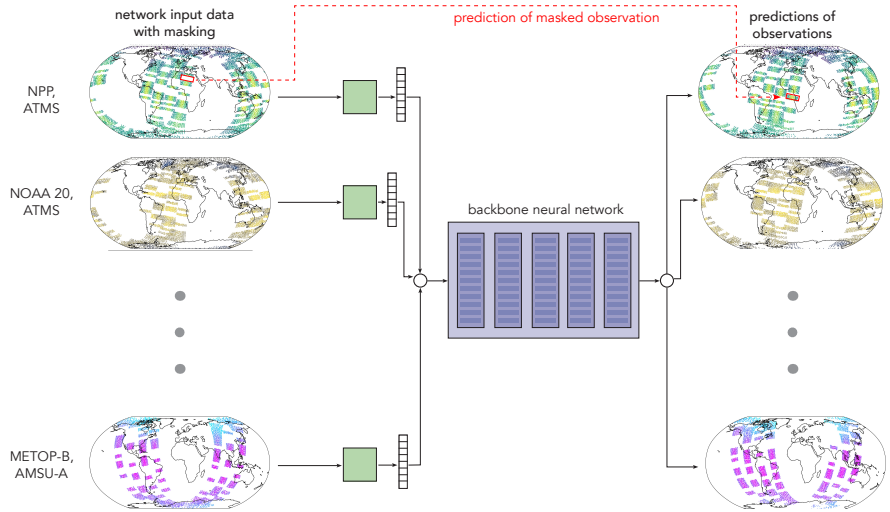


Figure 2: A schematic representation of the transformer neural network used in the prototype experiments. On the left we see portions of the satellite observations being randomly masked, and during training the network being challenged to predict the values of the masked data.

McNally, et al., 2024b: Data driven weather forecasts trained and initialised directly from observations. https://doi.org/10.48550/arXiv.2407.15586

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What is the Brazilian community working on to advance the accuracy of climate and weather information for society?

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How can the numerical forecast of the atmosphere and its interfaces be advanced effectively?

We need focus in all three directions:

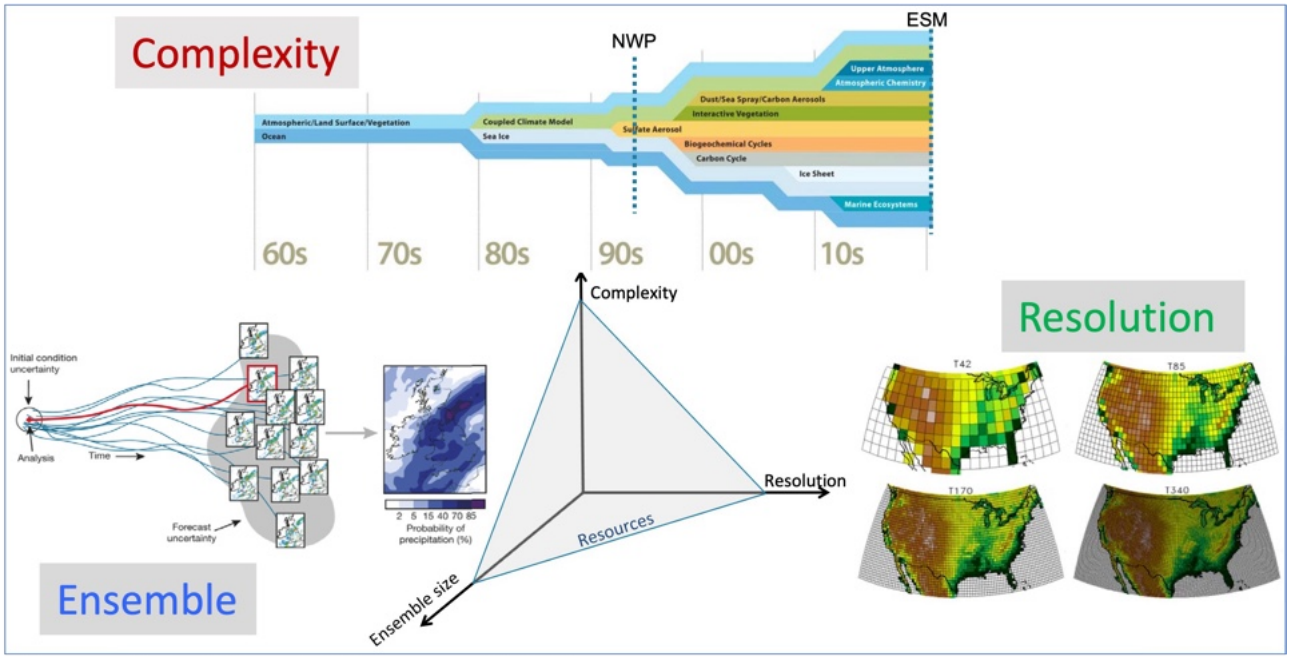


Figure adapted from J.-F. Lamarque (NCAR)

This entire framework assisted by:

- Access, treatment, and storage of observational data;
- Data assimilation at different levels of complexity;
- High-performance computing service, management of complex software (codes with millions of lines);
- Analysis and quantitative evaluation of model results;
- Post-processing, use of IA, interpretation, publication of forecasts;
- Methodologic management of activities, processes, and routines;
- Efficient and transparent communication with society and stakeholders.

Models of the Earth System

Diversity is key

"Scientists advocate for an integrative approach that recognizes the interdependence of different approaches and tools and explores the synergies between them."

"In other words, the researchers suggest embracing diversity — including people — as this will help the field address the complex challenges it faces."

npj Climate and Atmospheric Science, 2025
https://doi.org/10.1038/s41612-025-00955-8



"Embracing different approaches, including hierarchical modeling, machine learning, and high-resolution modeling, will ultimately lead to improved climate projections." Bordoni et al (2025)

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Model for Ocean-laNd-Atmosphere predictioN

What was proposed in 2022, and what are we working on?

A new paradigm of focus and organization for advancing the numerical weather, climate, and environmental forecasting in South America.

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In the **MONAN work plan,** we adopt a unified and community Earth System model

We all work on a single modeling system, a single computational code

1. **It involves the most relevant Earth System components:**
   a) Atmosphere, biosphere and continental soils, cryosphere, oceans, upper space.
   b) Anthropogenic disturbances relevant to the dynamics of the natural system (anthroposphere).
2. **Unified/Multiscale Physics:**
   a) Suitable for spatial scales of atmospheric phenomena on the order of 10^2 m to 10^3 km.
   b) Suitable for temporal scales of now-casting, weather, sub-seasonal, seasonal and climate change.
3. **Accurate:**
   a) Reduced number of approximations and use of state-of-the-art numerical methods for solving equations in supercomputers.
   b) Anchored in a robust Data Assimilation System using remote sensing and local observations.
   c) Enhanced with Artificial Intelligence/Machine Learning techniques.
4. **Community model:**
   a) Open source with free and public access.
   b) Workshops and training for the community.
5. Multi-Institutional Governance:
   a) Scientific steering committee formed by representatives of operational and research centers, academy and stakeholders.

How do we organize ourselves for this project?

Scientific Steering Committee of the Earth System Community Model

- Created on April 8, 2021 by the Director of INPE (Dr. Clezio De Nardin)
- Participating Institutions: INPE, INMET, LNCC, INPA, CENSIPAM, DECEA, Army Forces and several Universities

Current Members of SSC

Membros internos ao INPE:

1. Saulo R. Freitas
2. Antonio Ocimar Manzi
3. Caio Coelho
4. Carlos Bastarz
5. Chou Sin Chan
6. Renato Galante
7. Haroldo Fraga de Campos Velho
8. João Gerd
9. Joaquim Eduardo Rezende Costa
10. Jorge Luis Gomes
11. Karla Longo
12. Luciano Pezzi
13. Luiz Flávio Rodrigues
14. Paulo Kubota
15. Ronald Buss de Souza
16. Celso Luiz Mendes

Membros externos:

1. Pedro Dias (IAG/USP)
2. Afonso Paiva (COPPE-UFRJ)
3. Enio Pereira de Souza (UFCG)
4. Flávia Rodrigues Pinheiro (Marinha do Brasil)
5. Gilberto Bonatti (INMET)
6. Hélio Abreu Nogueira (FAB)
7. Ivan Saraiva (CENSIPAM)
8. Julia Cohen (UFPA)
9. Luiz Cândido (INPA)
10. Luiz Cláudio Oliveira Andrade (Exército)
11. Marcia Yamasoe (IAG/USP)
12. Fabrício Harter (UFPel)
13. Pedro Peixoto (IME/USP)
14. Ricardo de Camargo (IAG/USP)
15. Roberto P. Souto (LNCC)
16. Vinícius Capistrano (UFMS)
17. Francisco C. Vasconcelos Jr (FUNCEME)
18. Yanina Skabar (SMN Argentina)
19. Marlos Guimarães (Eletrobrás)

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Institutions Participants in the MONAN Project– August 2026

































































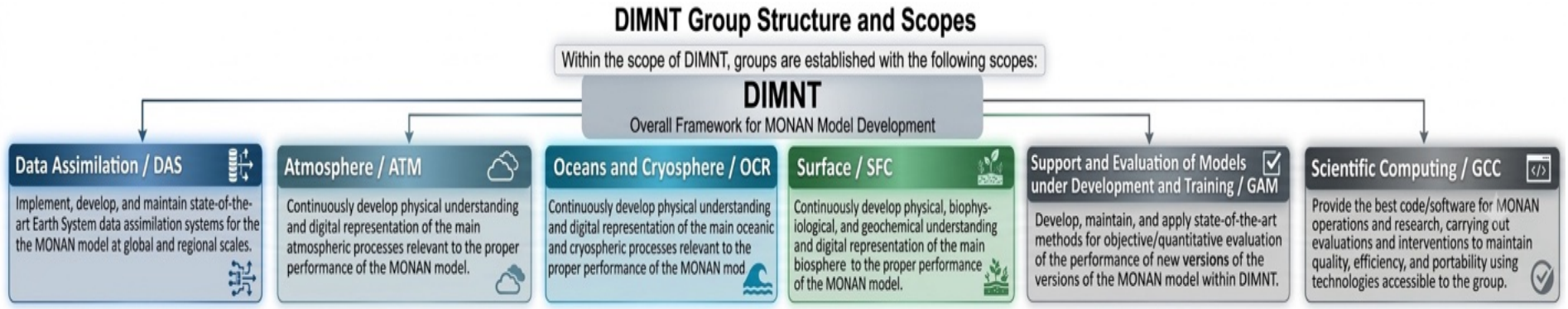








Our (INPE) institutional reorganization



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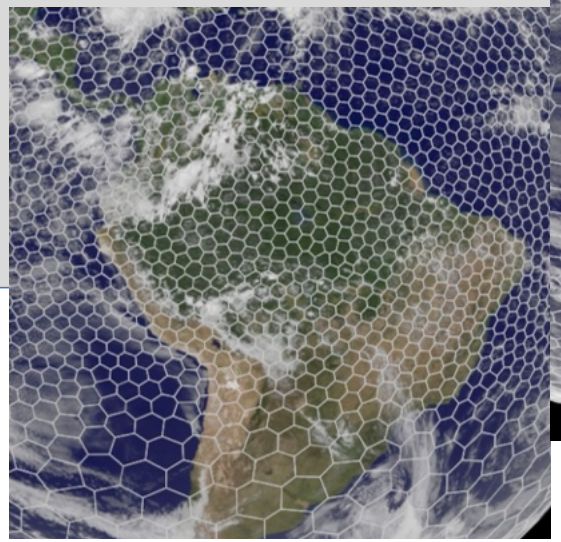
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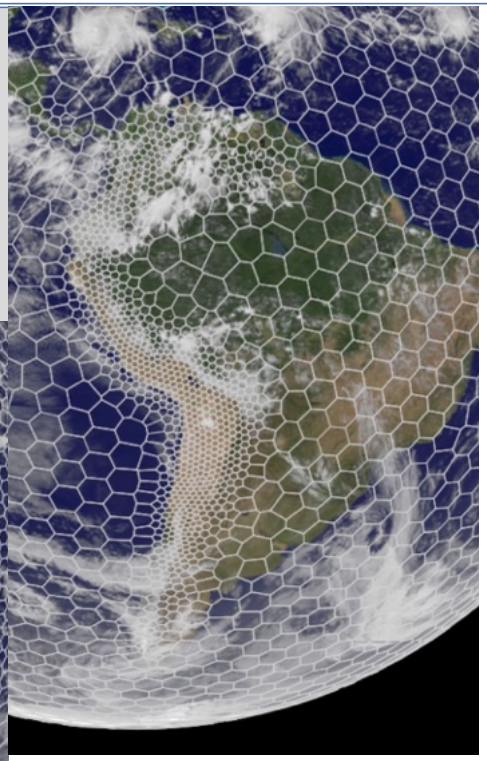
The Atmospheric Component of MONAN

The MPAS-A was officially recommended by the working group at INPE, mostly due to

- ✓ Software design with modern Fortran features.
- ✓ Portability for GPU.
- ✓ The WRF legacy 1: the most successful regional model developed in the world.
- ✓ The WRF legacy 2: applied by a large part of the South America community
- ✓ Successful application in convection-allowing scales.

On 03 August 2023, the Scientific Committee of MONAN approved the recommendation.



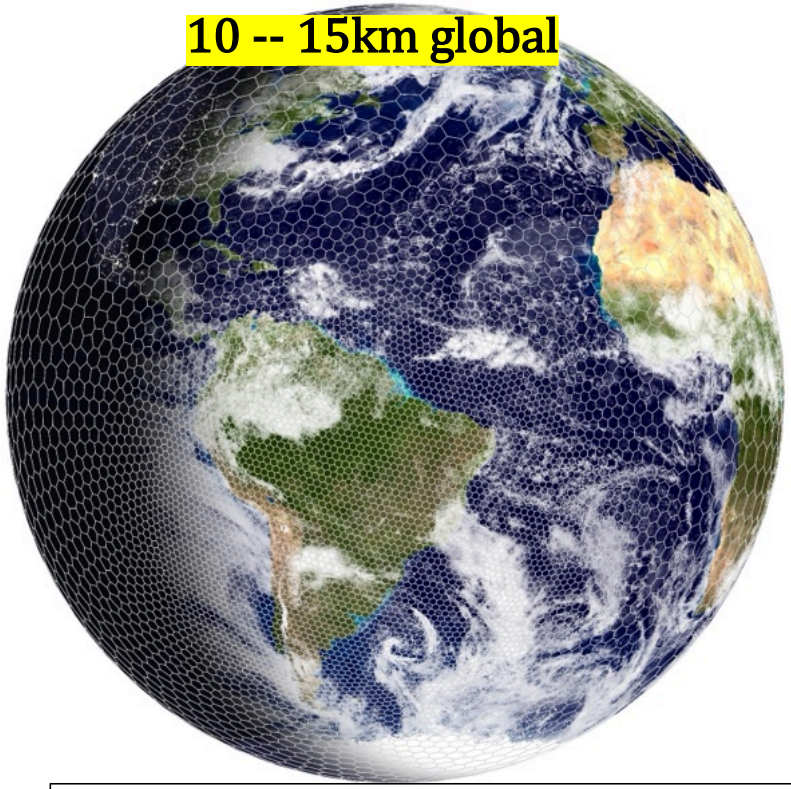


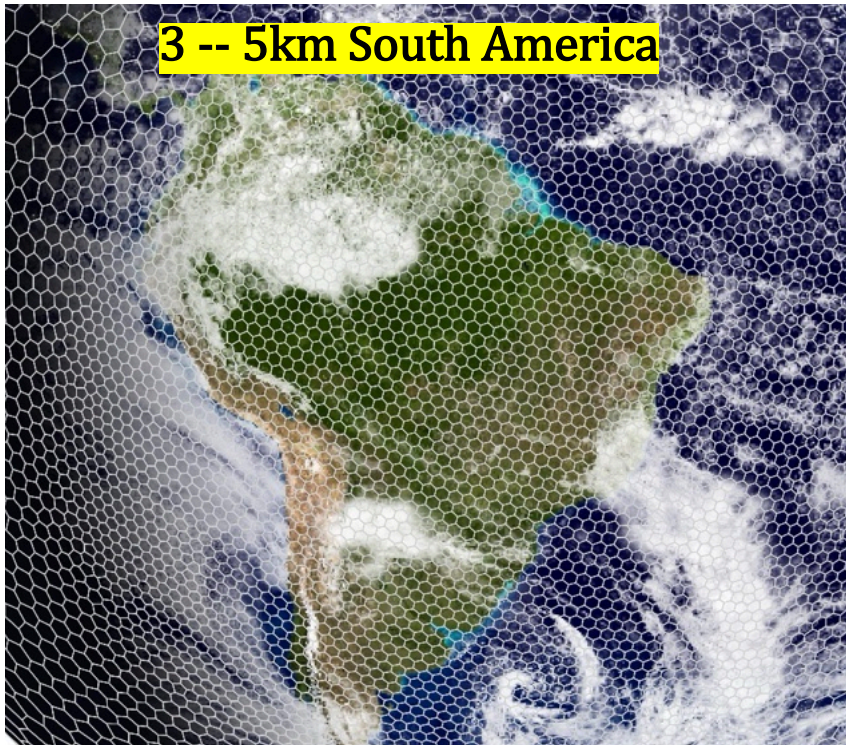
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Modeling in non-structured computational meshes.





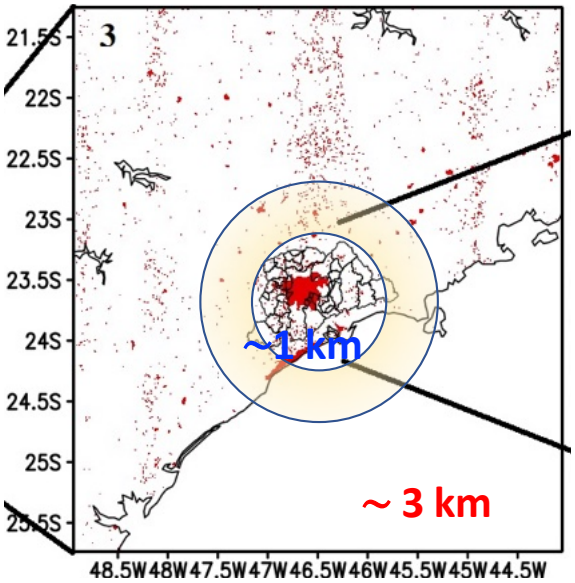
Allows for local refinement: a “single” model for regional and global scales.

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Interlocution with the Latin-America Meteorology Network and Regional Centers (operational and academic)

Environmental Prediction on a Regional/Local Scale



Example for the Metropolitan Region of São Paulo for implementation by regional centers

- Methods:
  - Initial and boundary conditions with analysis/forecasts produced with CPTEC/INPE's global **MONAN**;
  - Addition of weather radar data assimilation for nowcasting with the regional configuration of **MONAN.**
- Products:
  - Weather products (including severe weather);
  - Air quality and public health;
  - Biometeorology (thermal comfort indicators, heat waves, UV radiation);
  - Forecast of energy production (solar, wind);
  - Ocean waves;
  - ?

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MONAN/MPAS – Atmos+Land
Latest version 1.4.3-rc

https://github.com/monanadmin/MONAN-Model

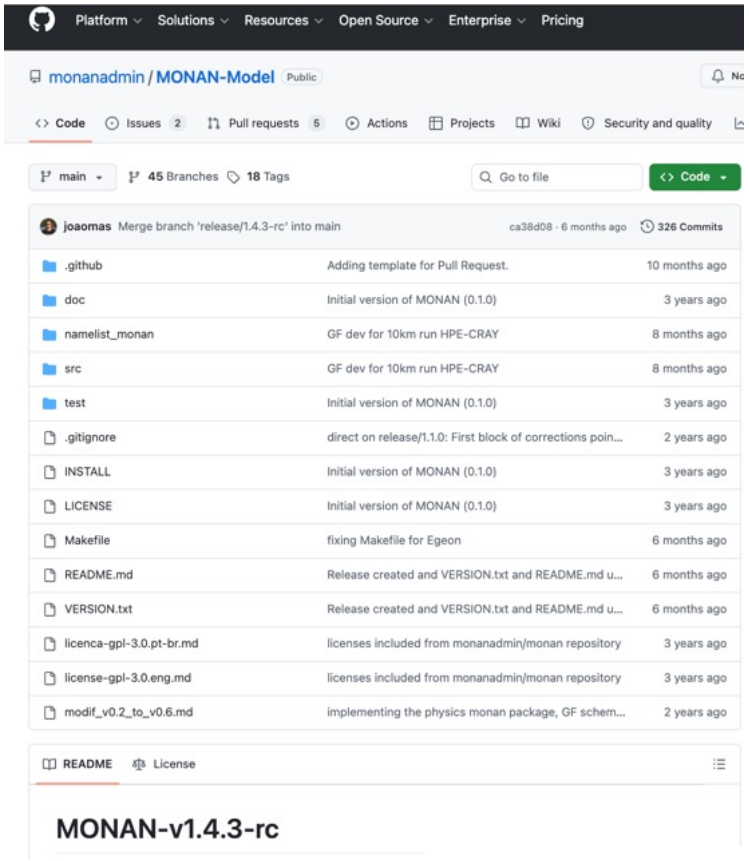
This version is being tested as a candidate for the next medium-range global forecast at INPE:

- IC from GFS-FV3 at 00 UTC and 12 UTC
- Deterministic
- 11 – days
- 10 km

```
----- Setting up physics suite 'mesoscale_reference_monan' -----

    config_microp_scheme        = mp_wsm6
    config_convection_scheme    = cu_gf_monan
    config_pbl_scheme           = bl_mynn
    config_gwdo_scheme          = bl_ysu_gwdo
    config_radt_cld_scheme      = cld_fraction_monan
    config_radt_lw_scheme       = rrtmg_lw
    config_radt_sw_scheme       = rrtmg_sw
    config_sfclayer_scheme      = sf_mynn
    config_lsm_scheme           = sf_noah
```

(*) in-house developments



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MONAN/MPAS execution in the new supercomputer Jaci

Jaci Supercomputer (HPE/Cray):

- 104 compute nodes, each featuring dual AMD EPYC 9745 CPUs 2400 MHz (256 cores/node), 768 GB RAM, 17 PB ClusterStor (Lustre) and Slingshot interconnect.

Operational deployment:

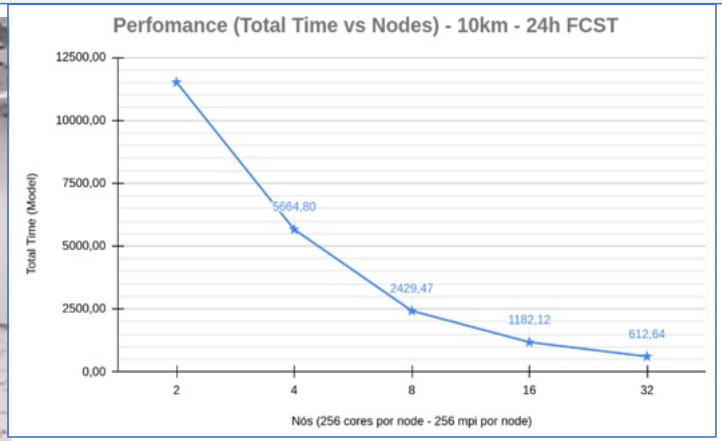
- MONAN v1.4.3-rc simulations on a 10 km quasi-uniform mesh (5,898,242 horizontal grid cells) were performed from 23 Jan to 22 Feb 2026, with daily 00Z (264 h) and 12Z (120 h) forecast cycles, using 32 compute nodes (256 cores/node) and the Intel compiler. Average execution times were 6,263.56 s (~1h44min24 s) and 2,877.09 s (~47 min 57 s), respectively.

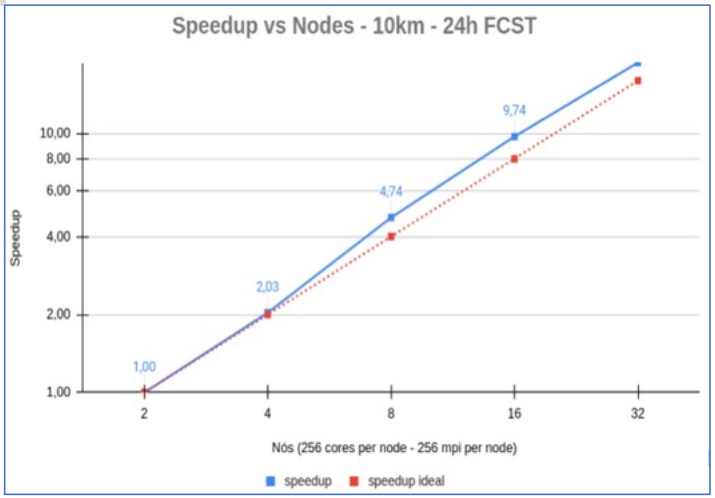
Performance, Speedup and Parallel Efficiency Analysis:

- A strong-scaling assessment of MONAN v1.4.3-rc on the Jaci supercomputer (10 km quasi-uniform mesh) demonstrated excellent scalability from 2 to 32 compute nodes, achieving the best performance with 32 nodes and 8,192 MPI processes. Speedup followed or exceeded the ideal trend, with parallel efficiency reaching 121.8%, indicating superlinear scaling.

MONAN
Model for Ocean-laNd-Atmosphere predictioN



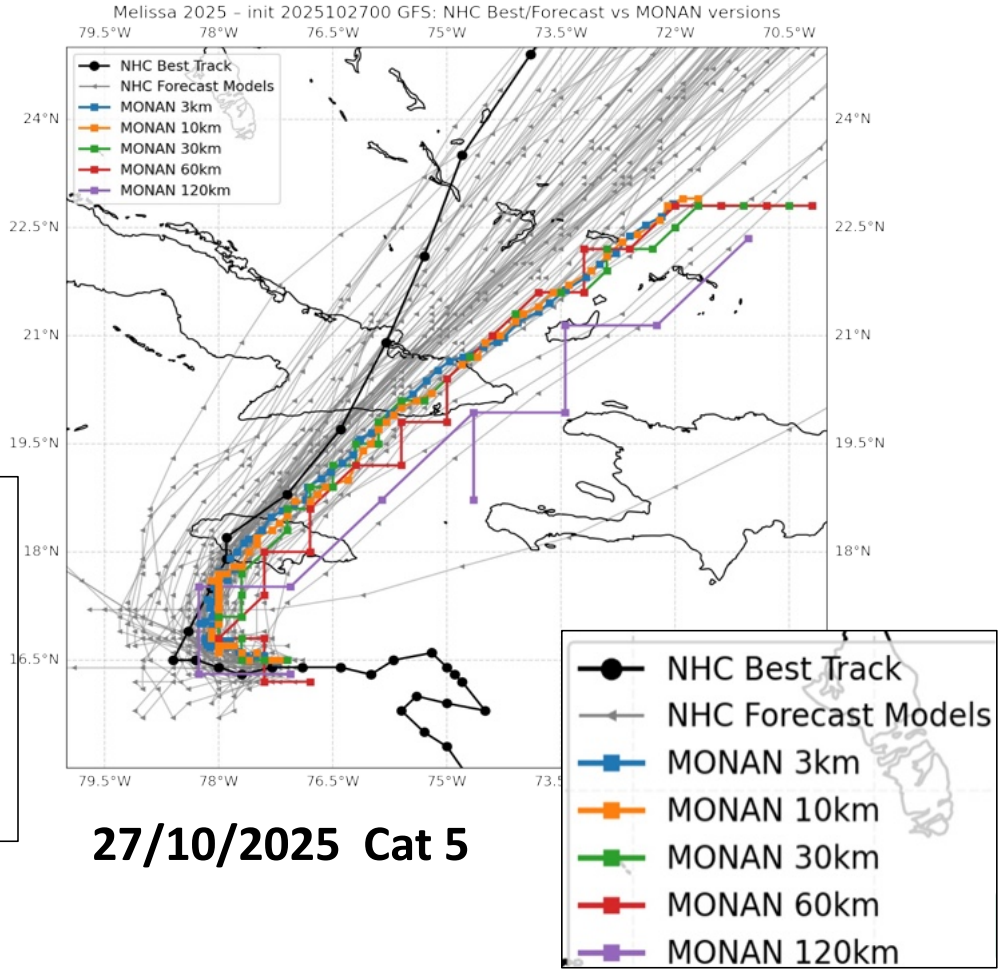




Hurr Melissa 2025 Case-Study

- **MONAN-Model:** 1.4.2-rc
- **Runs:** 25/10/2025 and 27/10/2025
- **Output freq:** 1h
- **Forecast length:** 72h
- **Initial condition:** GFS and ERA5
- **Resolution:** 120km, 60km, 30km, 10km, 3km
- **HPC:** Jaci Supercomputer

- The trajectory is consistent with the ensemble, reflecting varying degrees of uncertainty depending on the hurricane's stage of development.
- Higher resolution leads to improved trajectory representation.
- The noCV test shows a slightly improved trajectory, although it is unclear whether this result is robust.

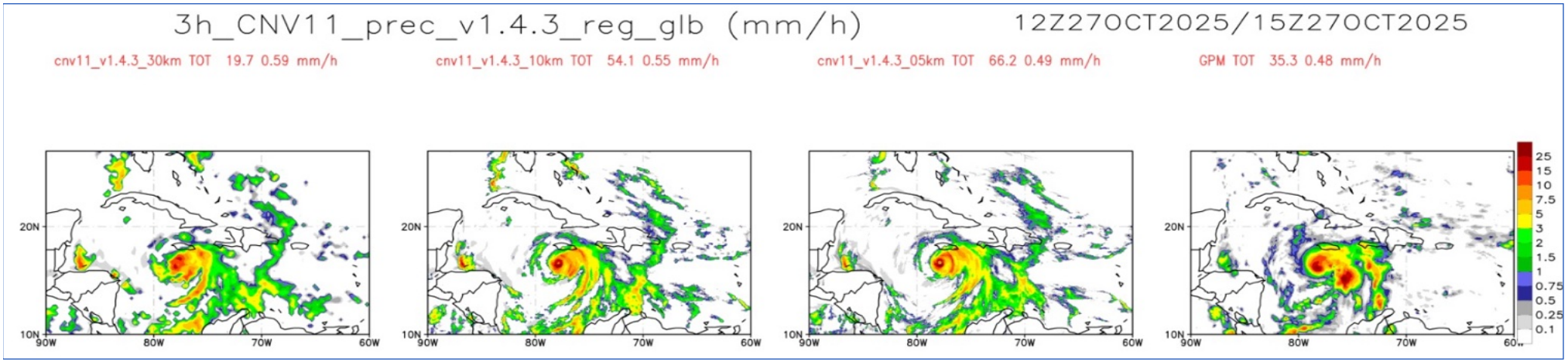


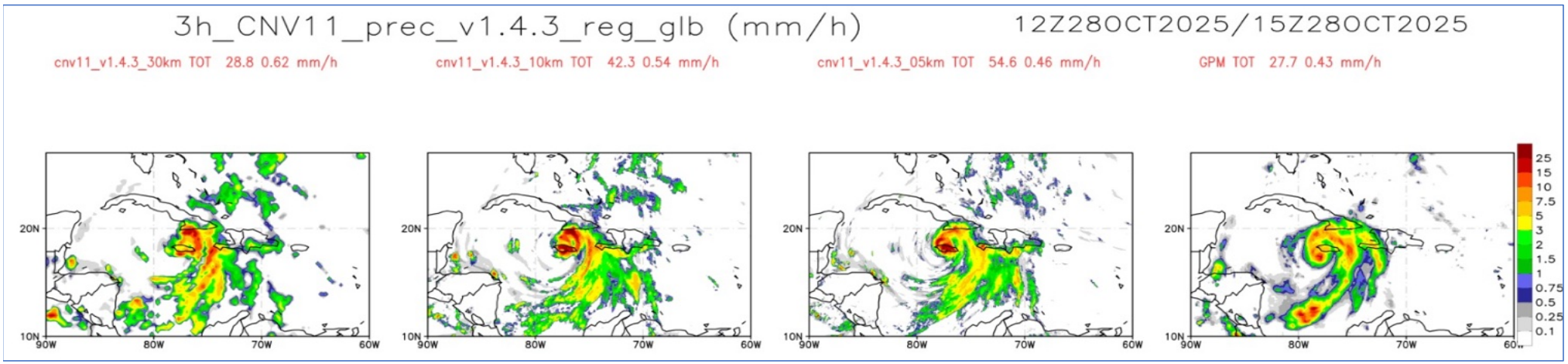
27/10/2025 Cat 5

MONAN
Model for Ocean-laNd-Atmosphere predictioN

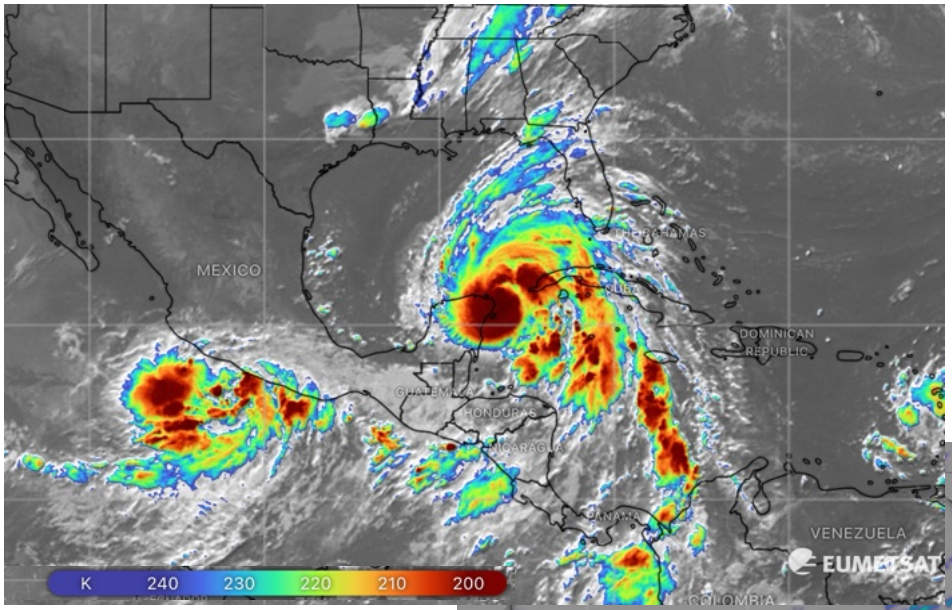
MONAN versão 1.4.3-rc Melissa Trop Cyclone (3 h)

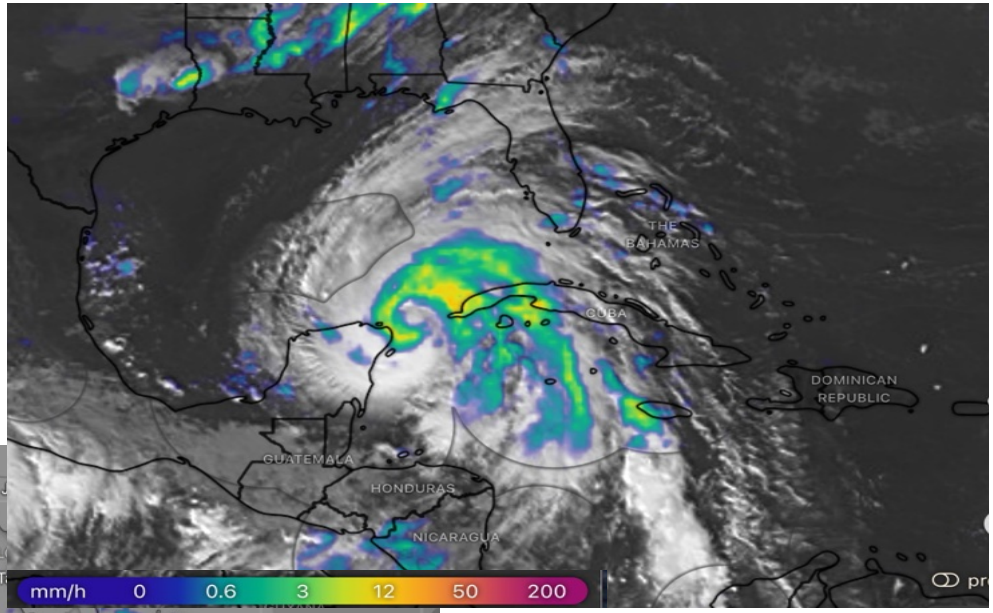
MONAN 30km	MONAN 10km	MONAN 05km	GPM

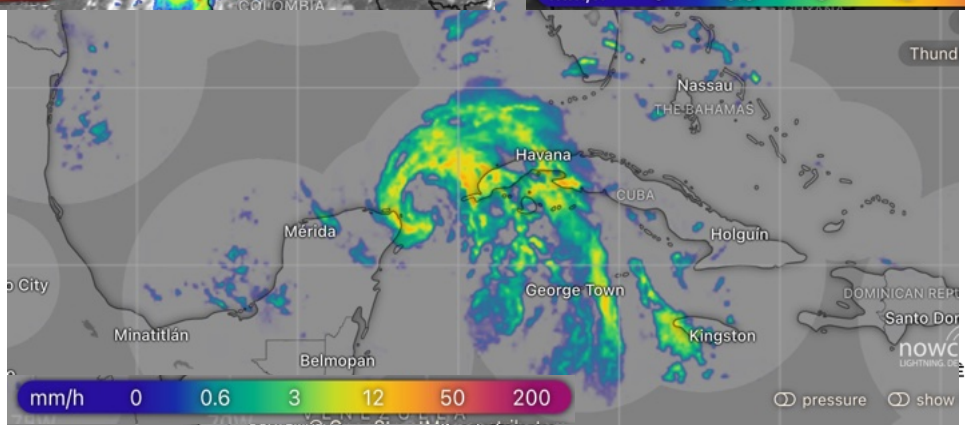




Hurricane Helene 12UTC 25SEP2024





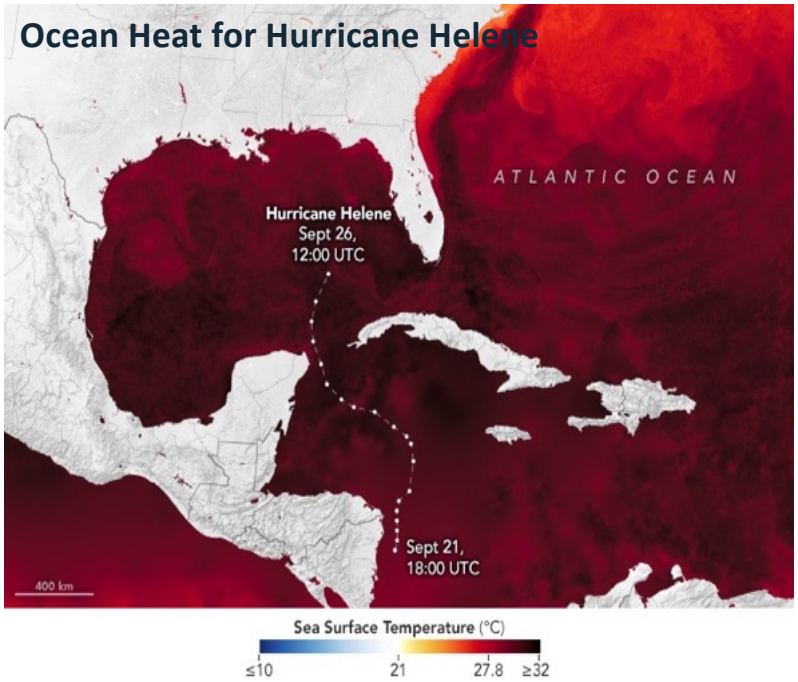


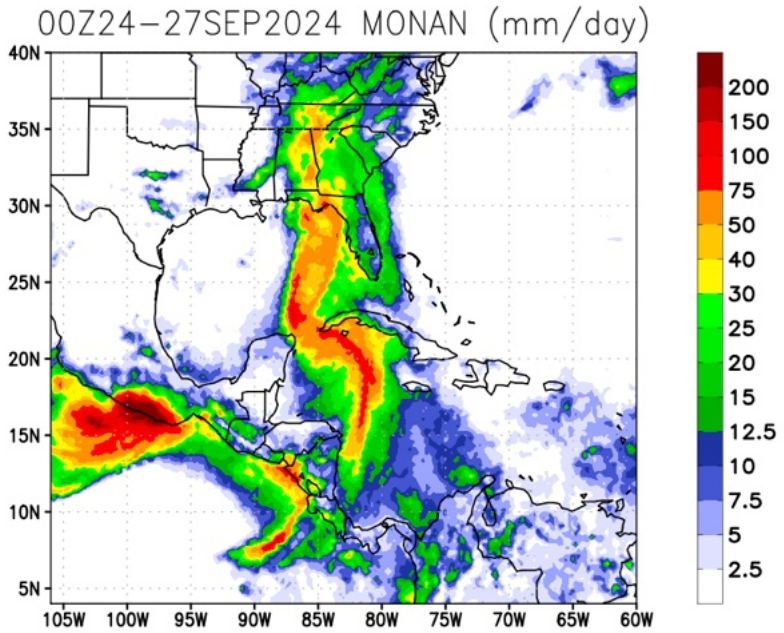
MONAN
Model for Ocean-laNd-Atmosphere predictioN

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

Helene 21 – 26 SEP2024





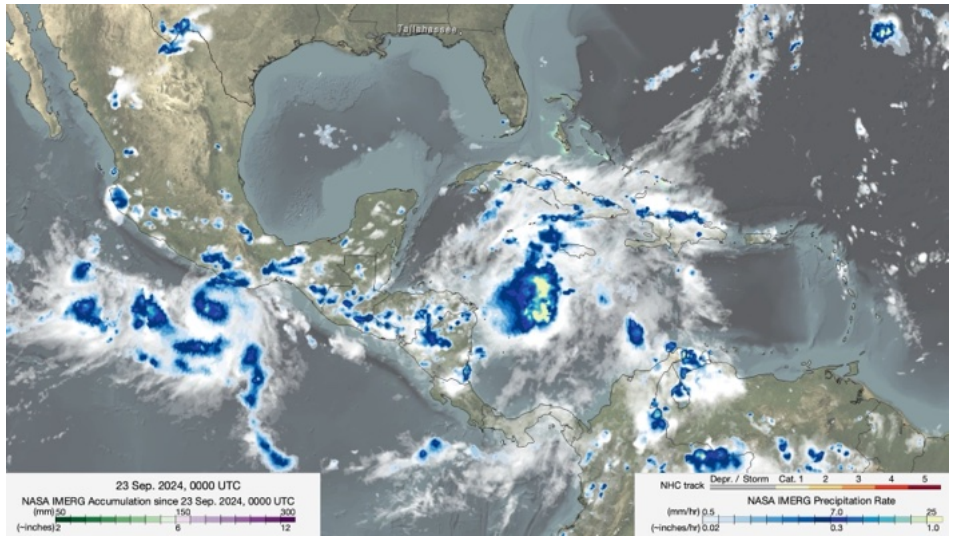
MONAN
Model for Ocean-laNd-Atmosphere predictioN

INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

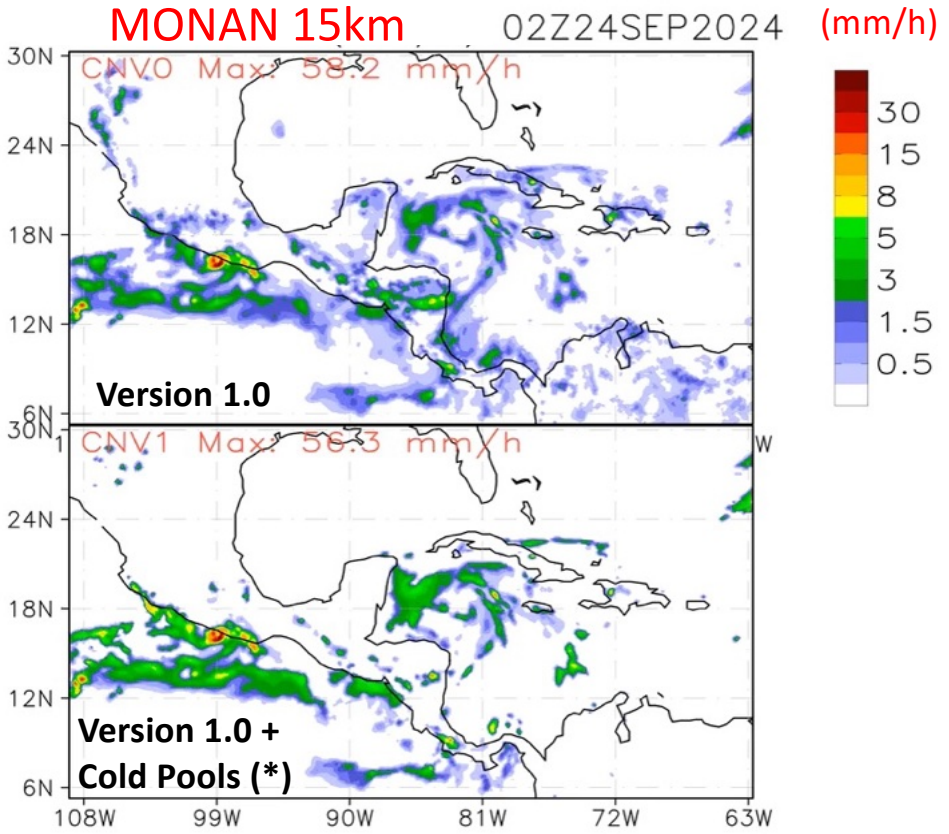
GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

Helene 24 – 28 SEP2024

GPM – IMERG V06



MONAN 15km



MONAN
Model for Ocean-laNd-Atmosphere predictioN

(*) Freitas et al., 2024 AGU/JAMES

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

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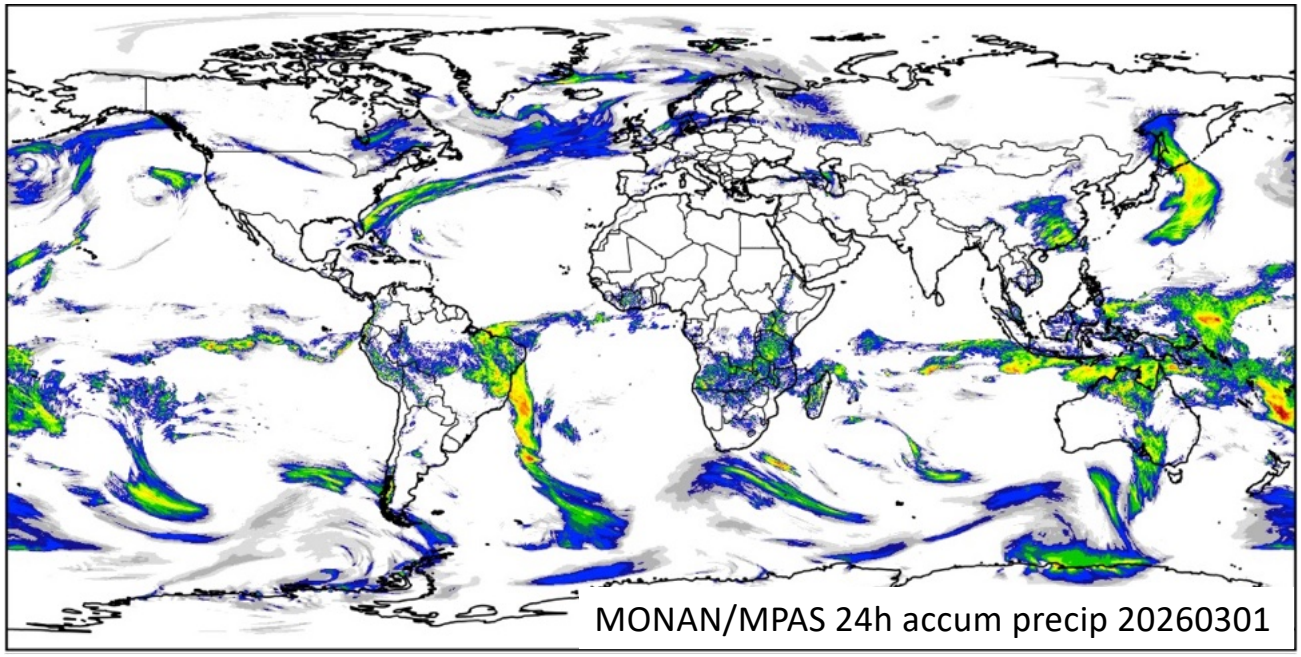
Examples of model performance in terms of precipitation forecasting

Real-time global scale at 10 km

MONAN
Model for Ocean-laNd-Atmosphere predictioN

INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

Recent intense precipitation over the Northeast/Brazil



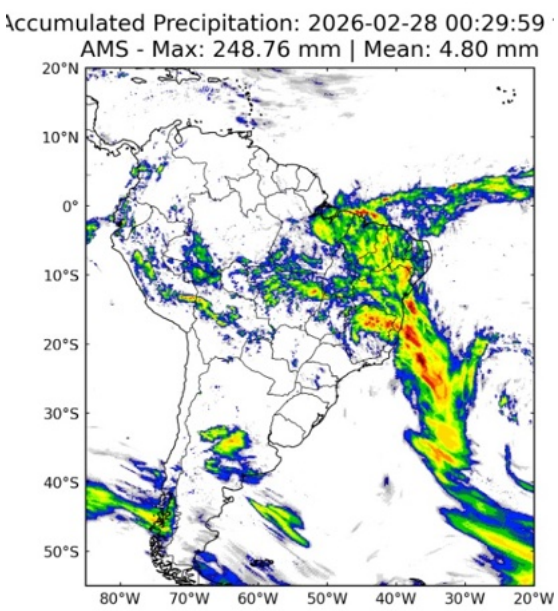
GPM – IMERG 0.1 dg	max 343 mm	Mean 2.86 mm
MONAN/MPAS 10km	max 222 mm	Mean 2.85 mm

MONAN
Model for Ocean-laNd-Atmosphere predictioN

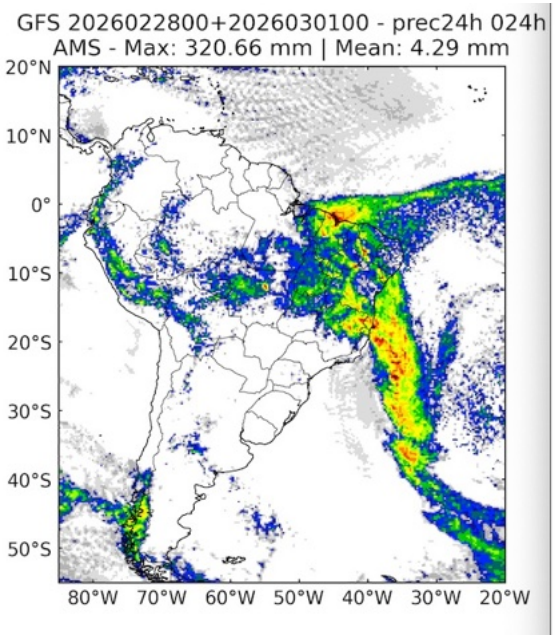
INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

Recent intense precipitation over the Northeast

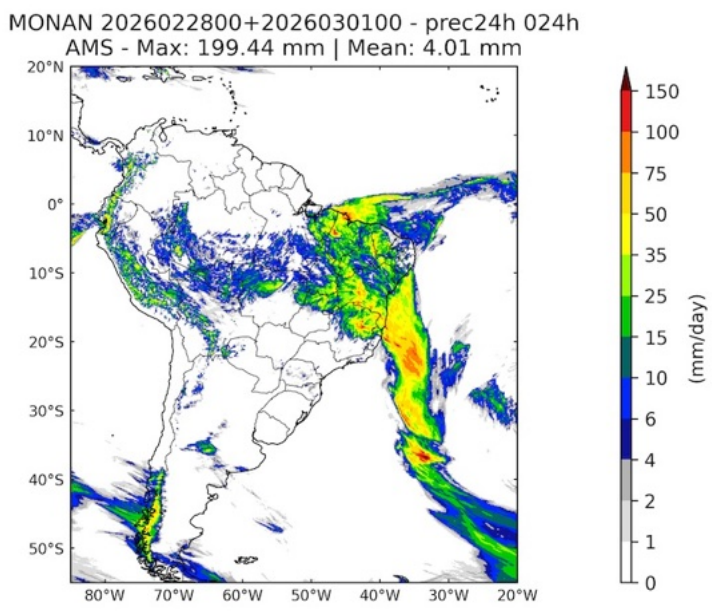
GPM-IMERG



GFS / FV3



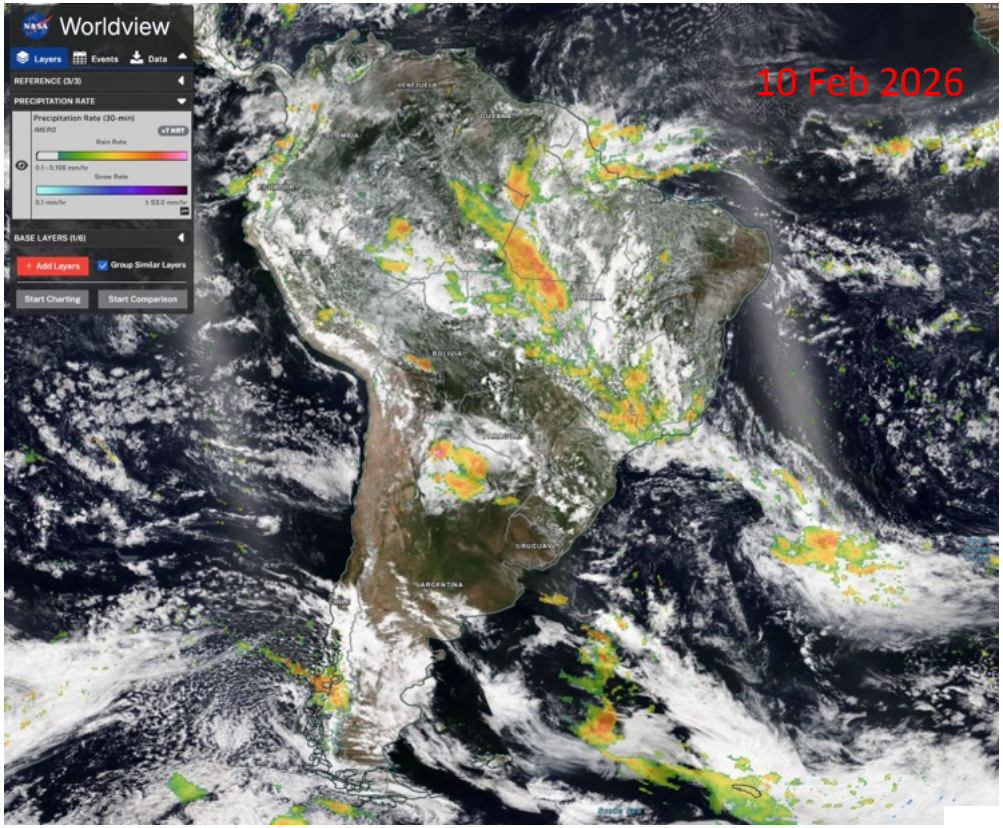
MONAN / MPAS



MONAN
Model for Ocean-laNd-Atmosphere predictioN

INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

A recurrent precipitation system over S. America
The “South Atlantic Convergence Zone”

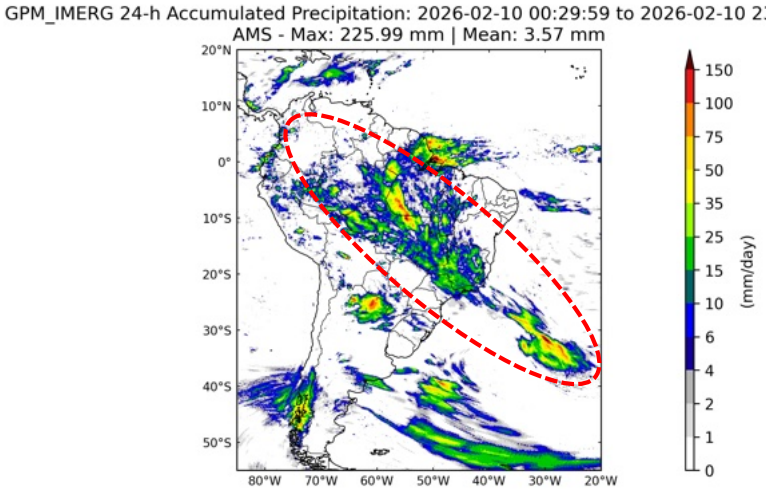


MONAN
Model for Ocean-laNd-Atmosphere predictioN

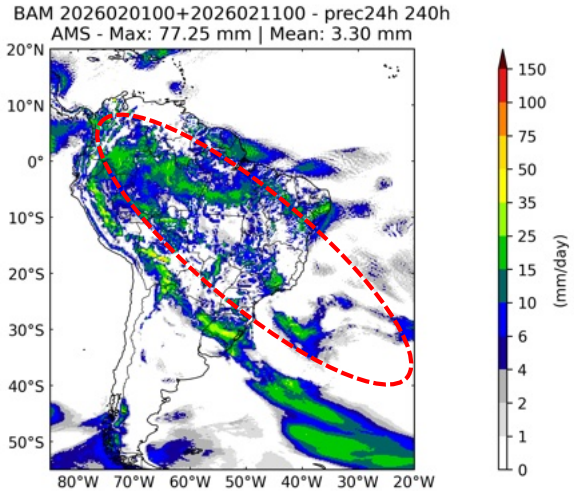
MINISTÉRIO DA
CIÊNCIA, TECNOLOGIA
E INOVAÇÃO

Real-Time Forecasts for day 10 Feb 2026

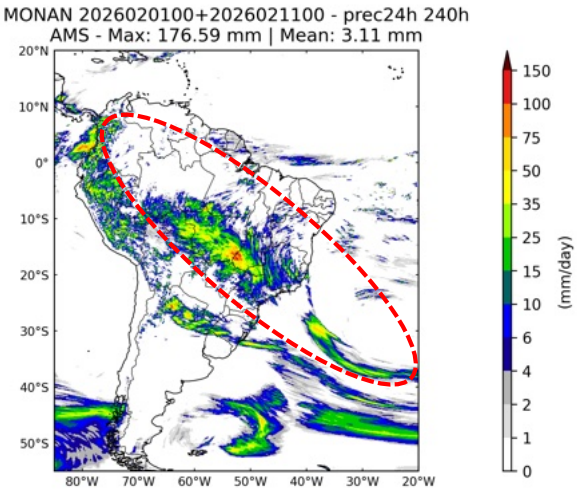
Starting at 00UTC 01 to 10 Feb 2026



GPM-IMERG



BAM/INPE



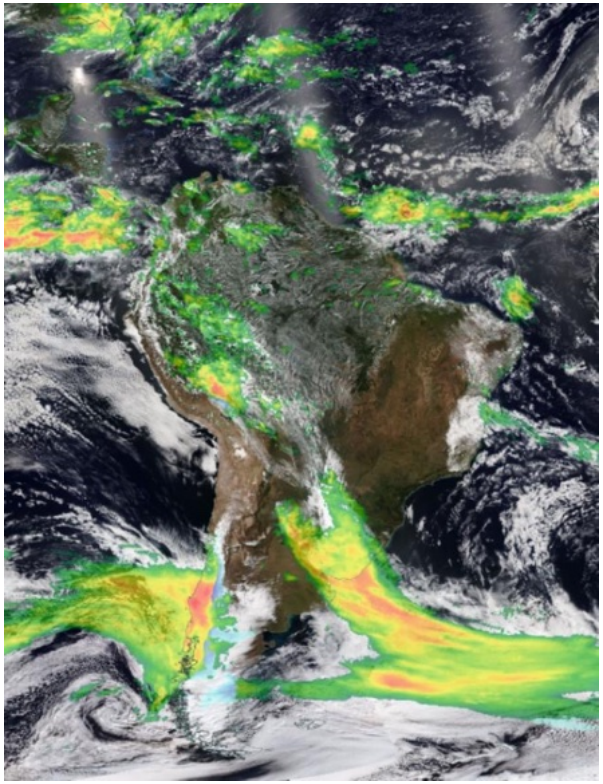
MONAN-MPAS/INPE

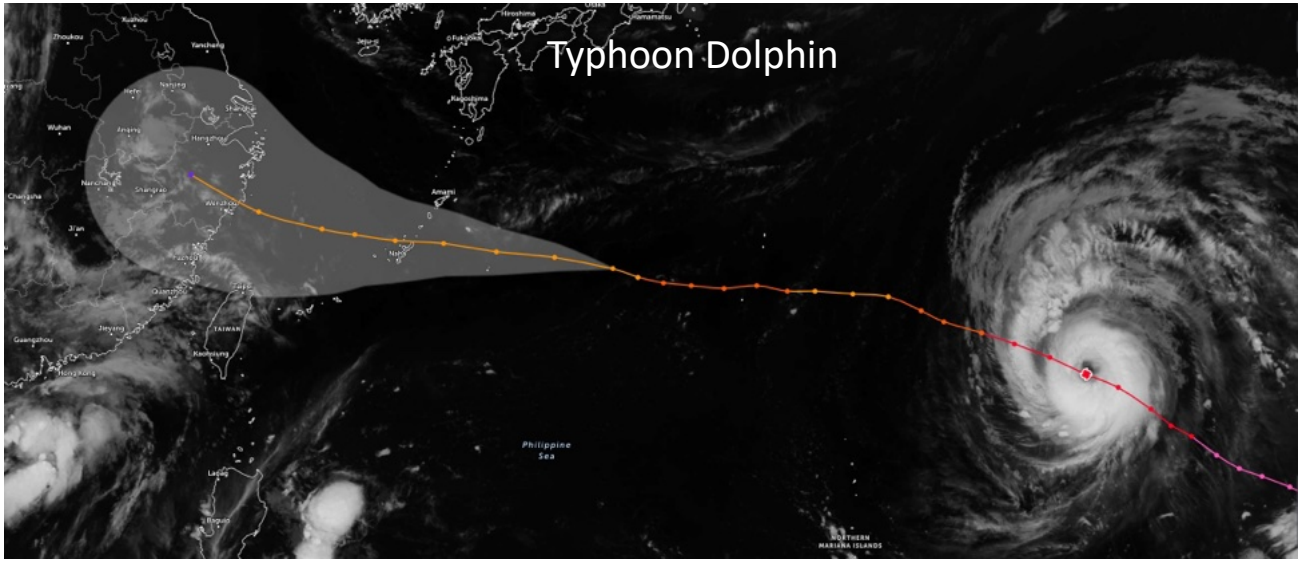
24-h accum rainfall for day 10 Aug

MONAN
Model for Ocean-laNd-Atmosphere predictioN

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

Real-time forecasting of two severe weather features
1 August 2026

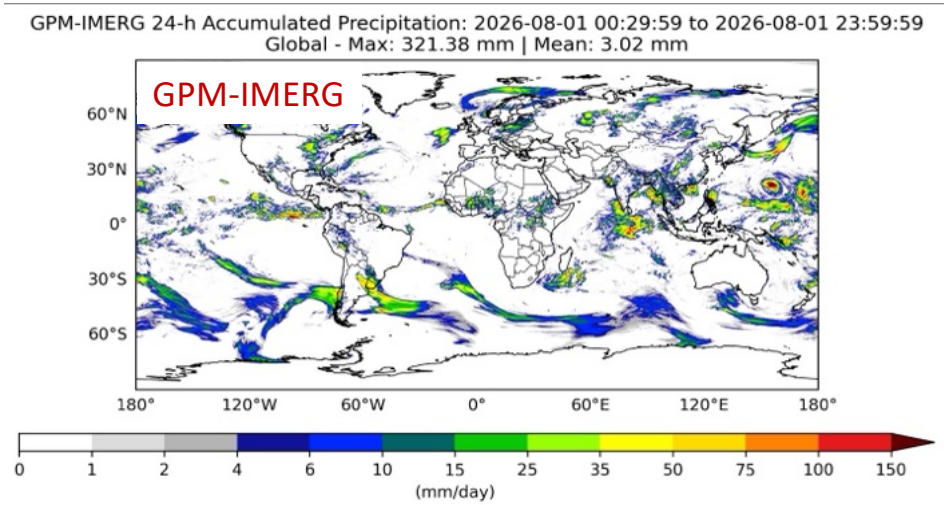


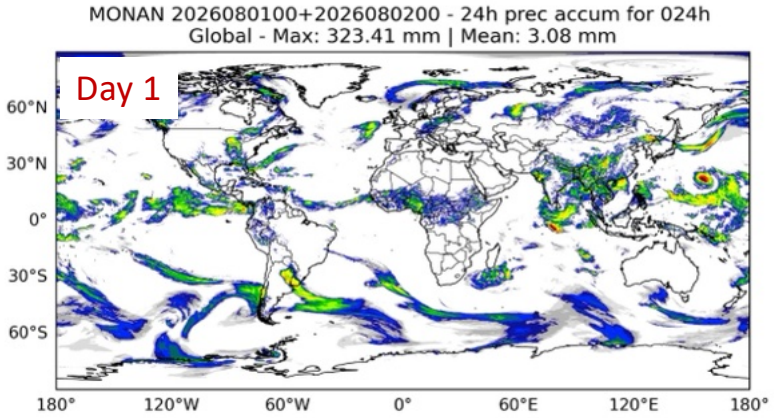


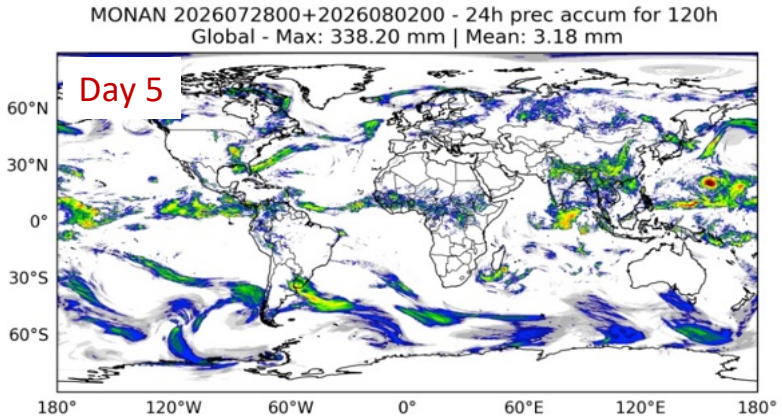
MONAN
Model for Ocean-laNd-Atmosphere predictioN

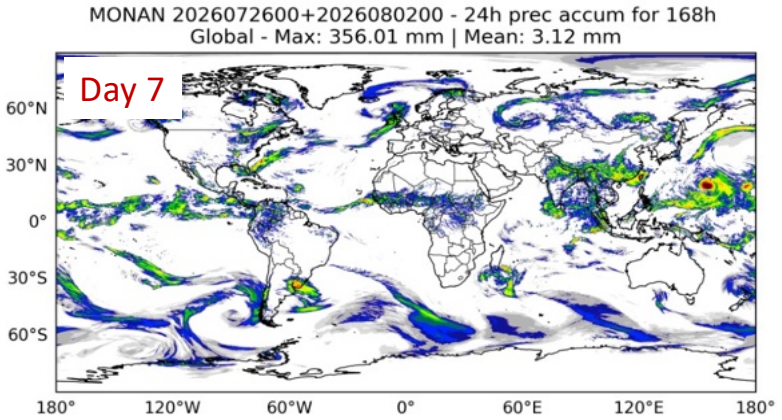
INPE
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

MONAN – 24h Precipitation Forecast day 1, 5 and 7



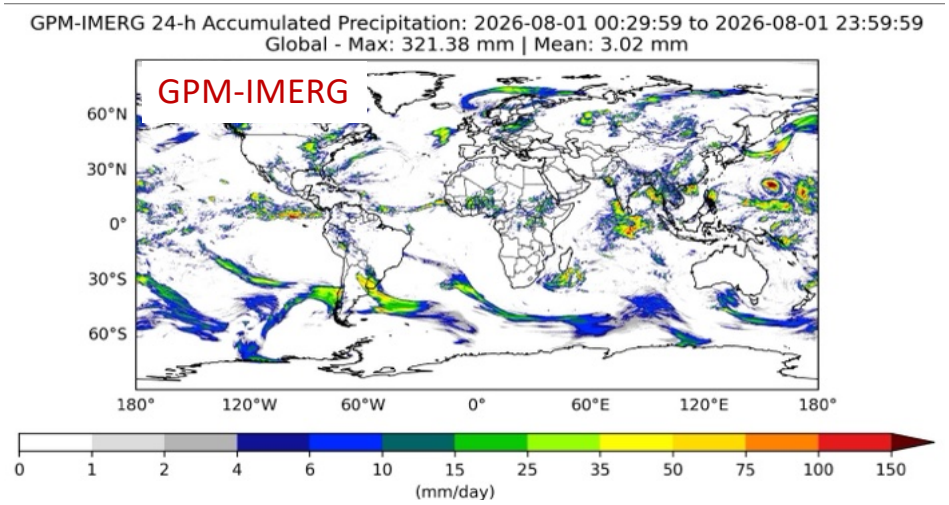


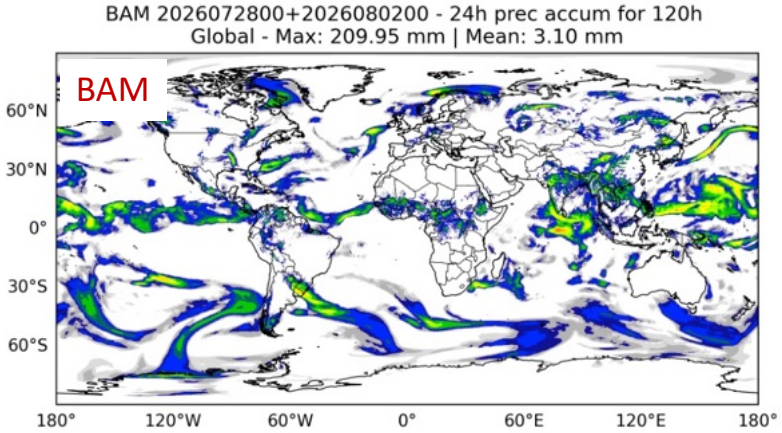


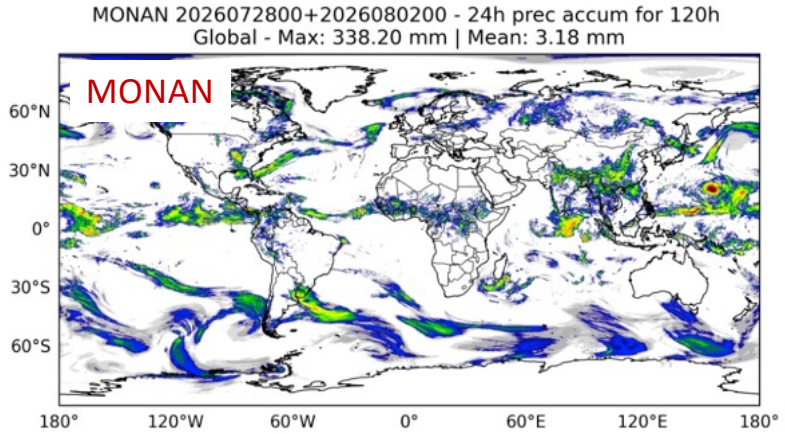


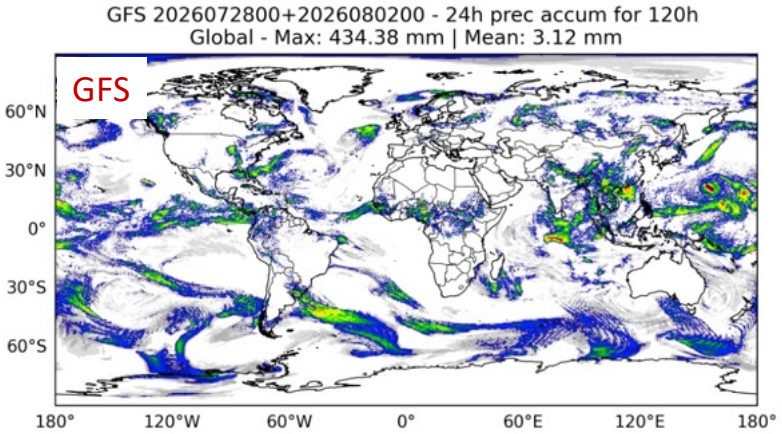
Precipitation Forecast day 5

Evaluation together with MONAN, BAM, and GFS

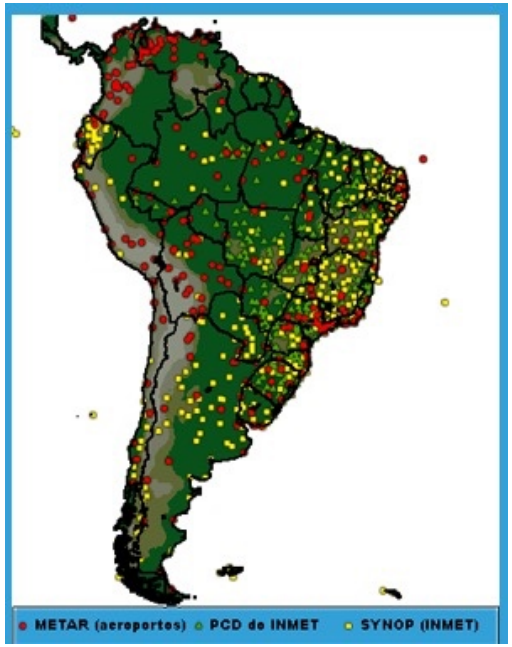




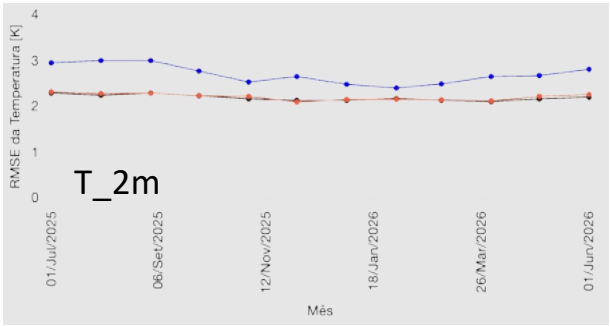


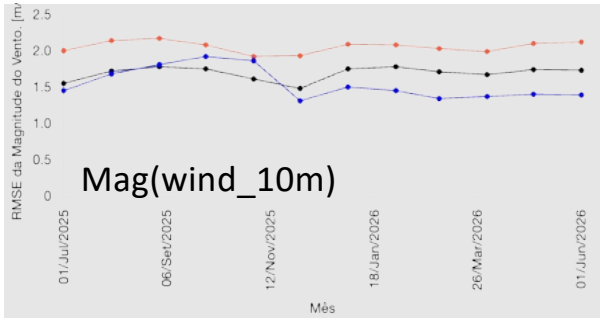


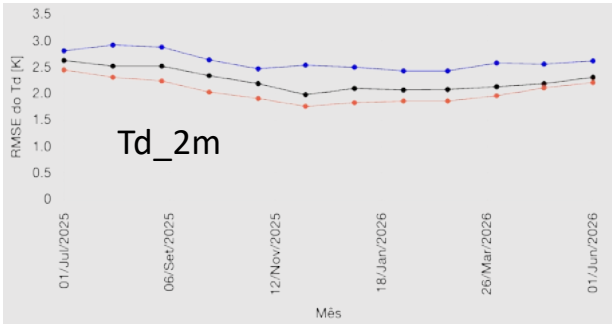
Near-surface evaluation for July 2025 – June 2026
South America



Weather stations: ~970
201 METAR
271 SYNOP
501 PCDs do INMET







BAM MONAN GFS

Modelos	Viés* [K]	RMSE* [K]
GFS: 0.25°	-0.26	2.24
MONAN: 1.4.3rc	-0.25	2.25
BAM	-0.50	2.75

MONAN
Model for Ocean-laNd-Atmosphere predictioN

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

Precipitation bias (DJF 2026)

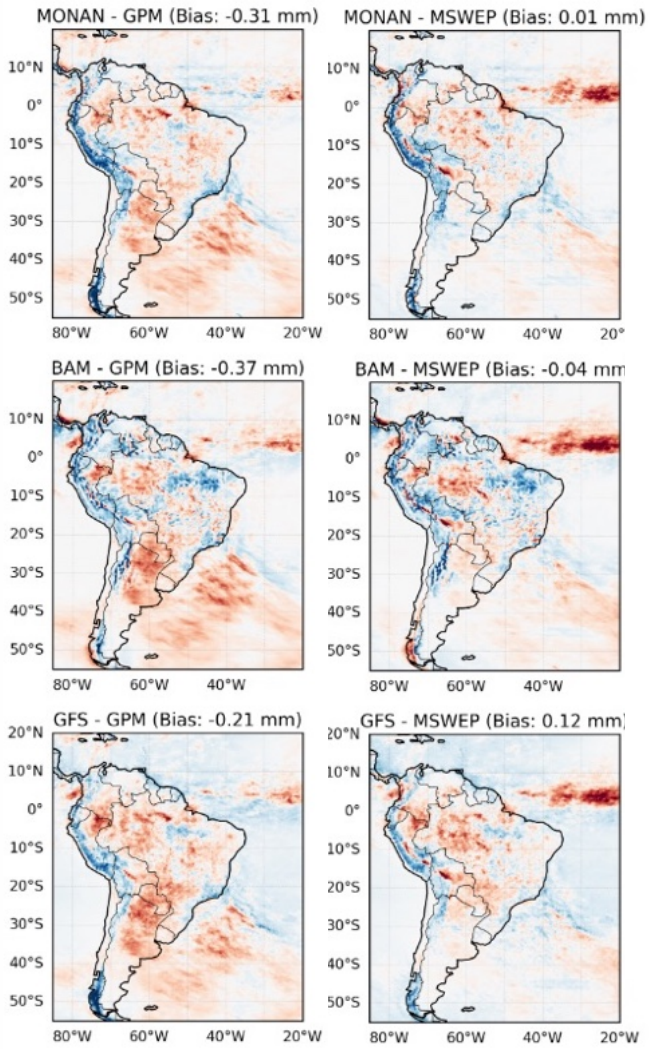
24 h

GPM-IMERG MSWEP

MONAN/MPAS

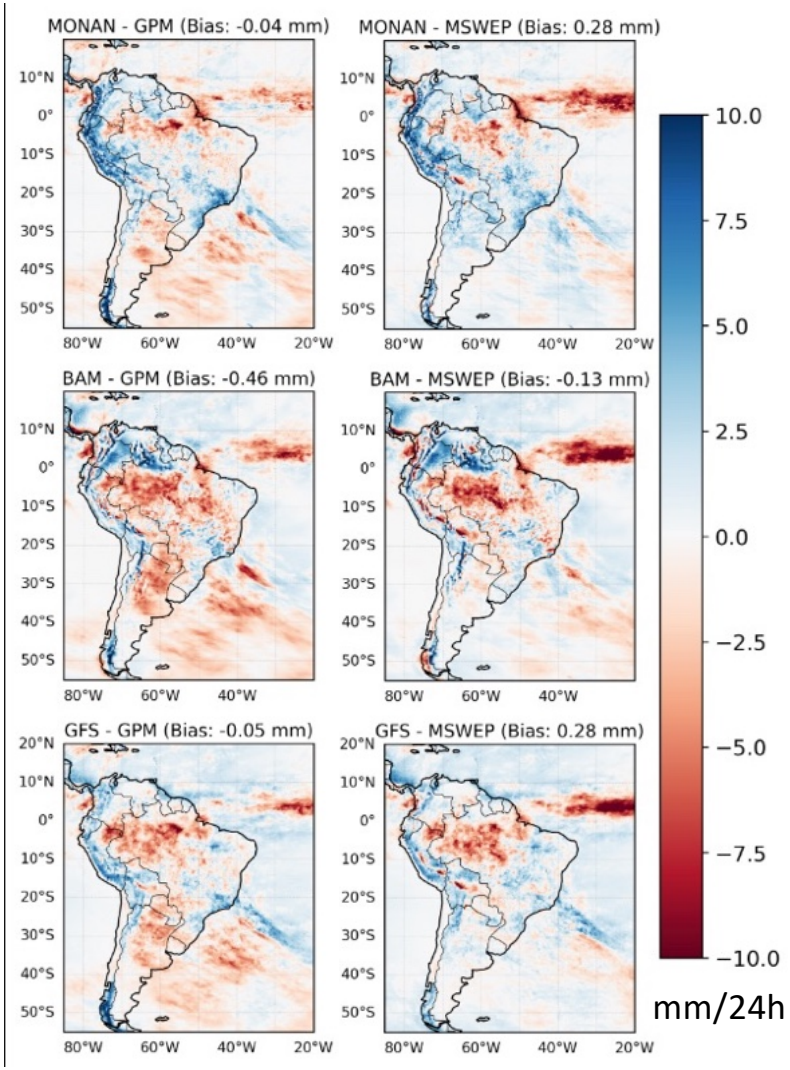
BAM

GFS



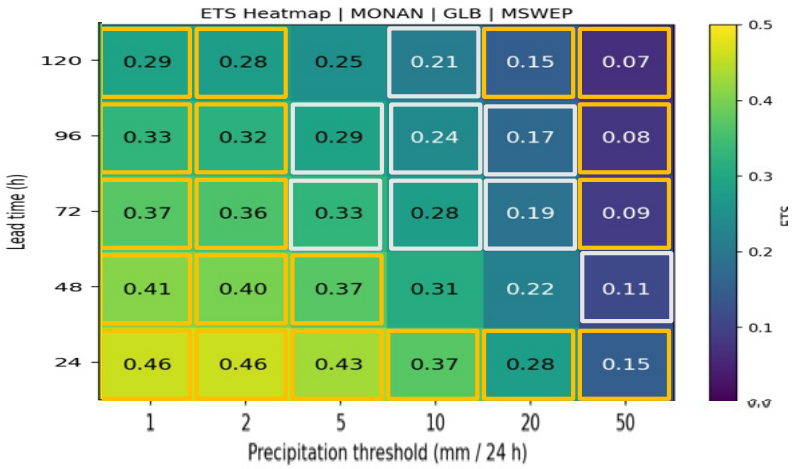
120 h

GPM-IMERG MSWEP

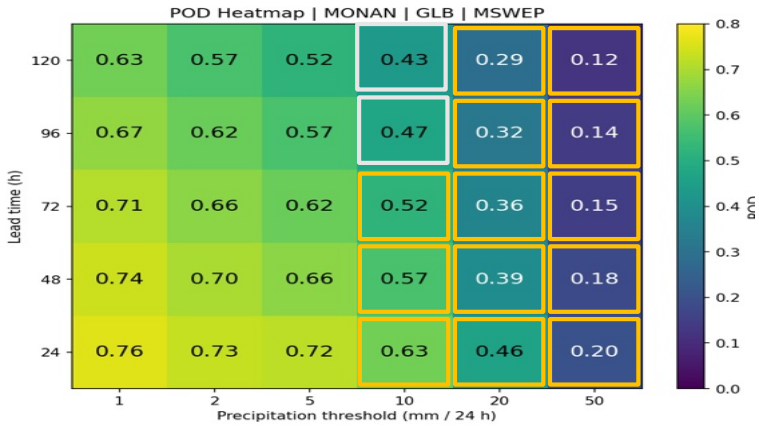


Precipitation Skill Heatmaps, Global, JFM 2026
MONAN/MPAS x GFS

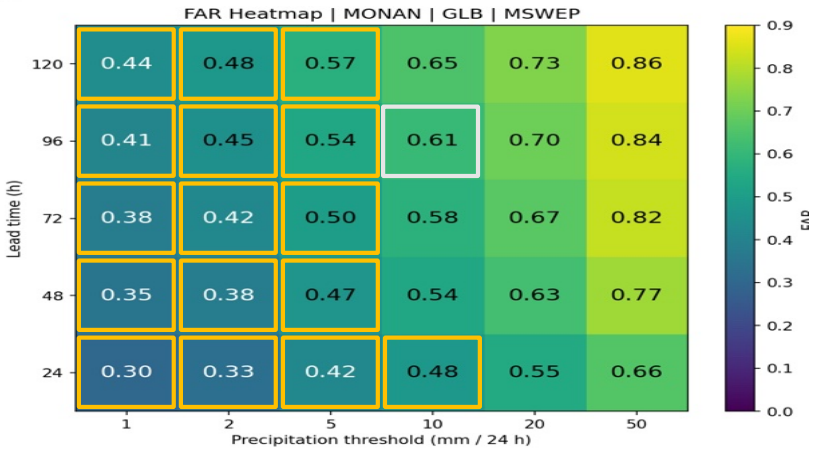
ETS



POD



FAR



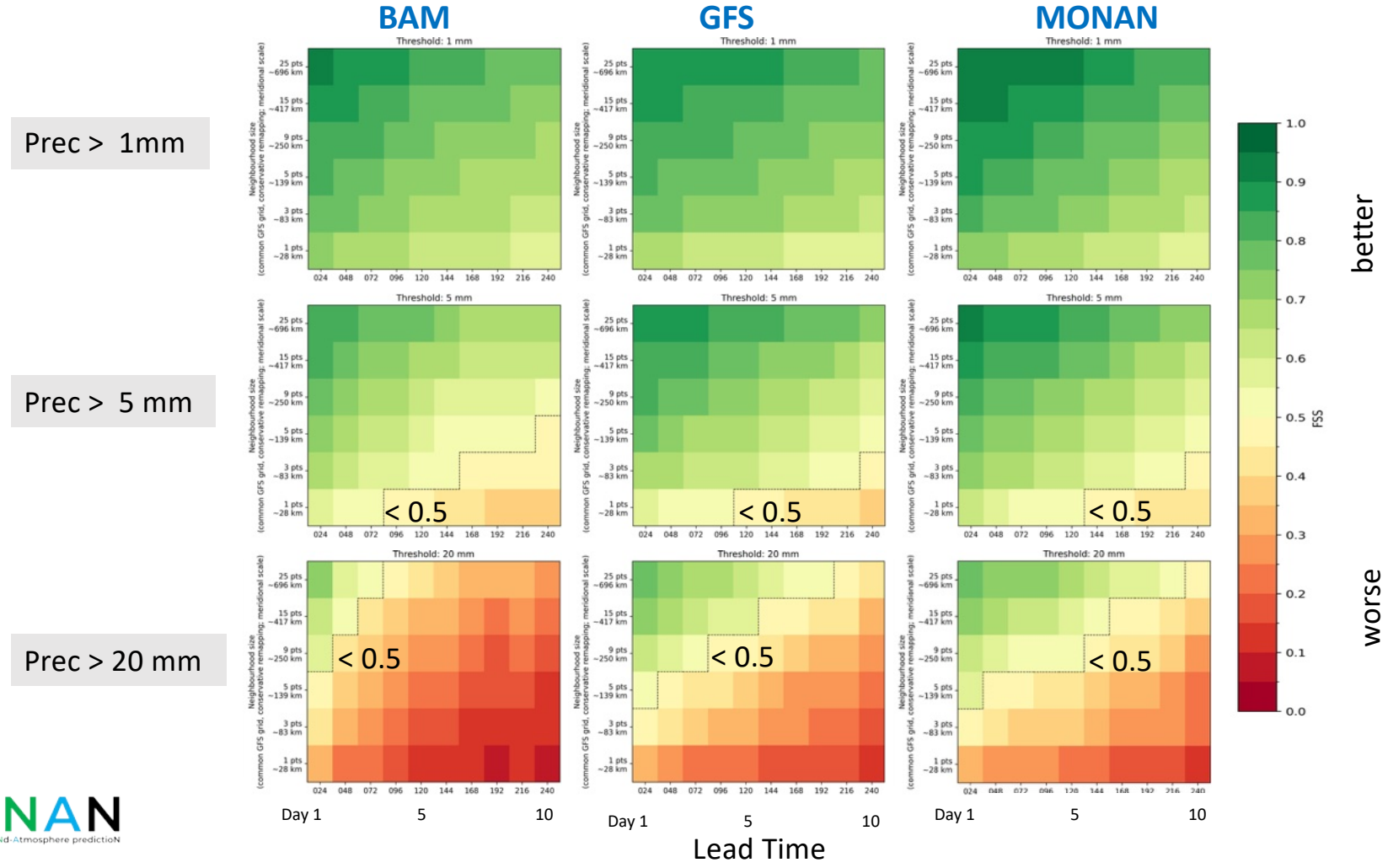
MONAN/MPAS is better than GFS

MONAN/MPAS is equal to GFS

ETS ↑ better | FAR ↓ better | POD ↑ bette

✶ **MSWEP** is used as the observational referenc

Scale-dependent verification of precipitation using the fraction skill score

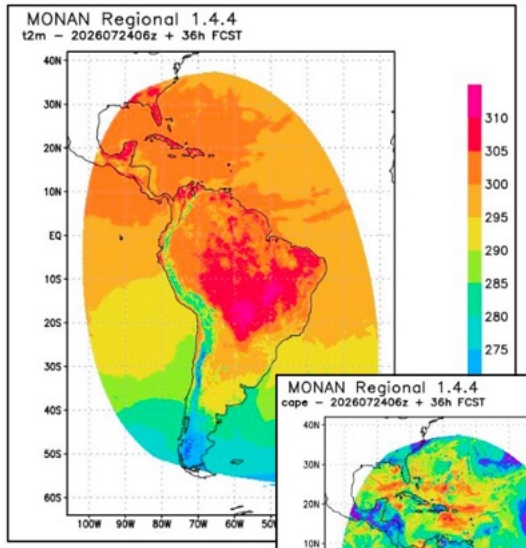


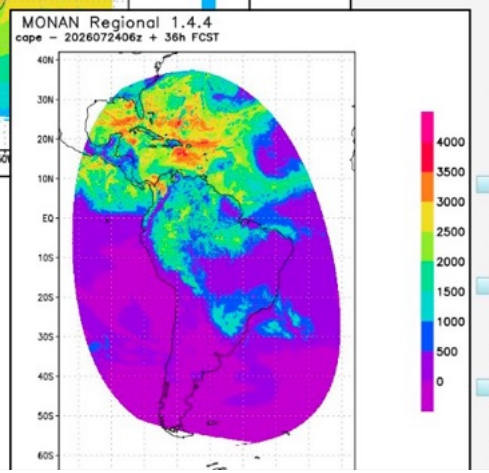
MONAN
Model for Ocean-laNd-Atmosphere predictioN

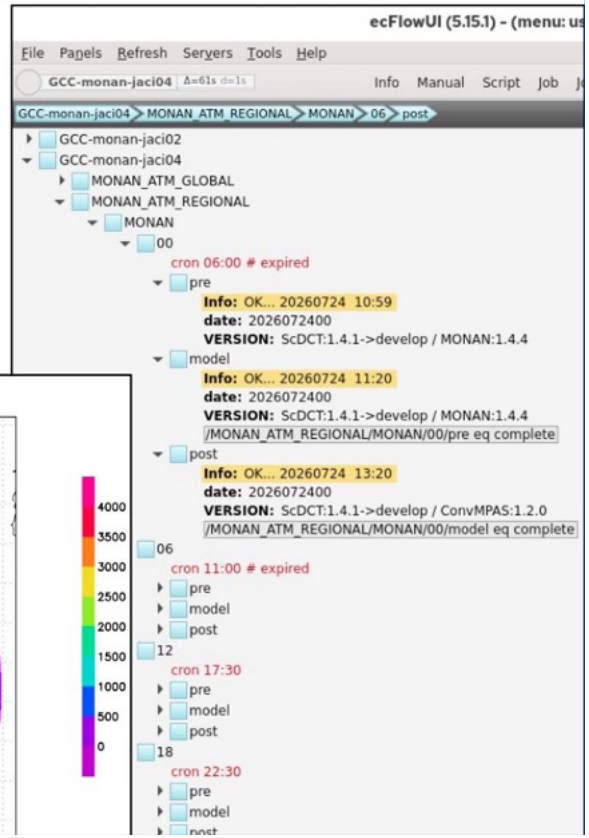
Recent Implementation - Regional Forecasting (5 x 5 km^2)

2. MONAN 1.4.4 Regional na Jaci (GCC)

- **4** Rodadas diárias GCC ("não operacional"):
  - **00z** com FCST 120h;
  - **12z** com FCST 72h;
  - **06z** com FCST 36h;
  - **18z** com FCST 36h.
- 16 nodes e 256 cpn.
- **CI**: GFS (3h LBC interval)
- **Output**:
  "/p/projetos/monan_adm/monan/ecf_GCC/
  MONAN-WorkFlow-OPER/
  MONAN_ATM_REGIONAL/
  flushout_regional"
- **P1** (20/04/2024 a 01/05/2024) em:
  "/p/projetos/monan_adm/monan/tc/1.4.4/
  P1_5km_regional_AMS_CAR/"
- **Mesh:** AMS_CAR.
- **Resolução** : 5 x 5 km^2 ~ 24 millions horizontal grid cells

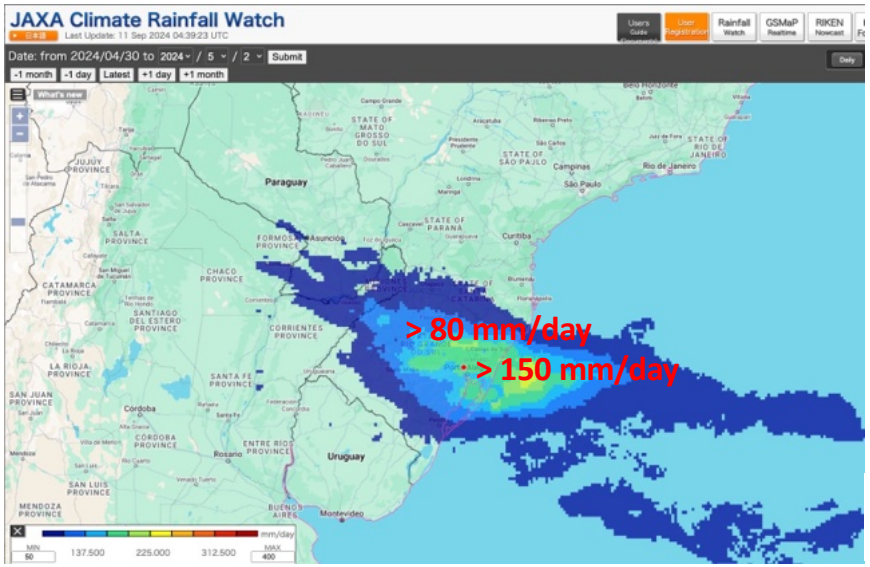






Flooding in RS /Brazil
3-day accumulated precipitation: 30/04 – 02/05 2024

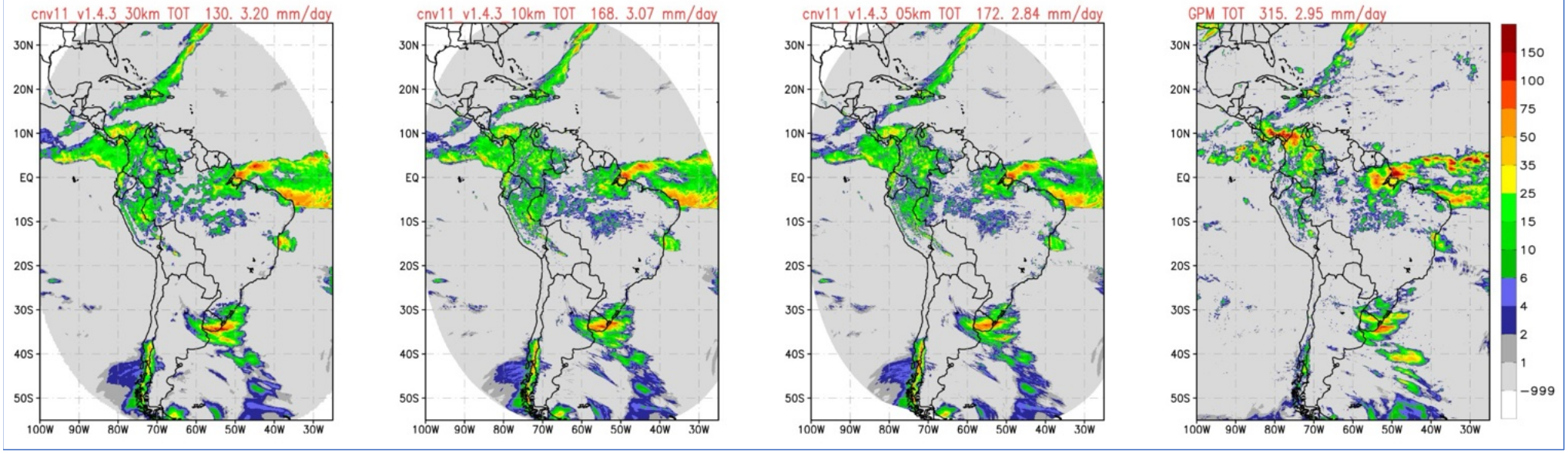




MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

MONAN versão 1.4.3-rc CASO RS (24 h accum 26-27/04)

MONAN 30km | MONAN 10km | MONAN 05km | GPM



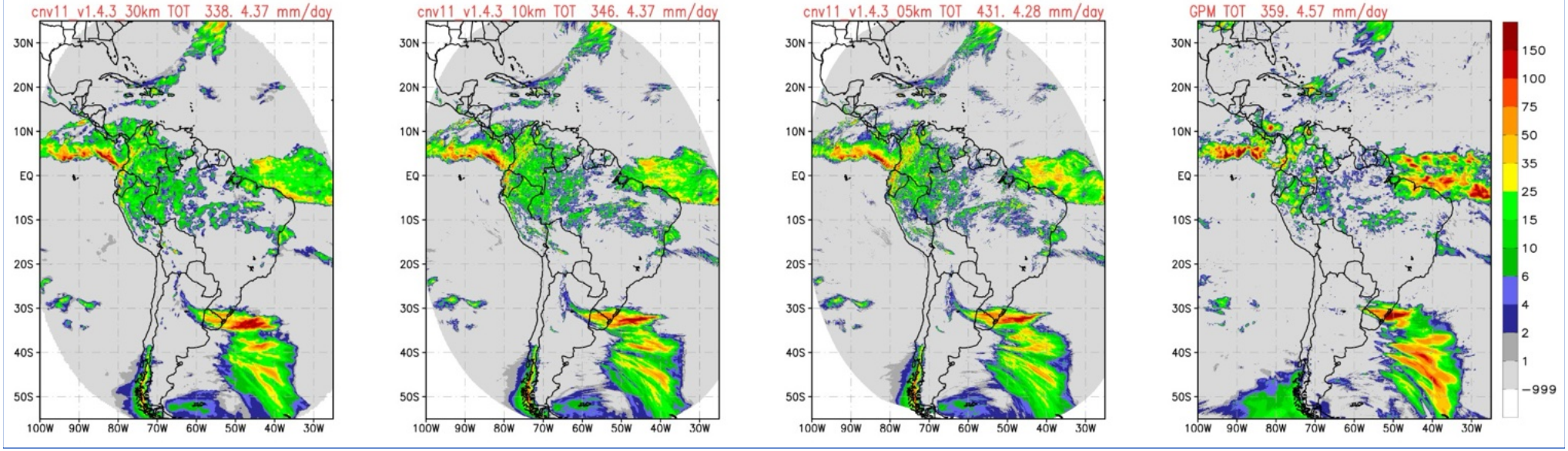
Regional Grid for Latin-Am and Caribean areas

MONAN
Model for Ocean-laNd-Atmosphere predictioN

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

MONAN versão 1.4.3-rc CASO RS (24 h 27-28/04)

MONAN 30km | MONAN 10km | MONAN 05km | GPM



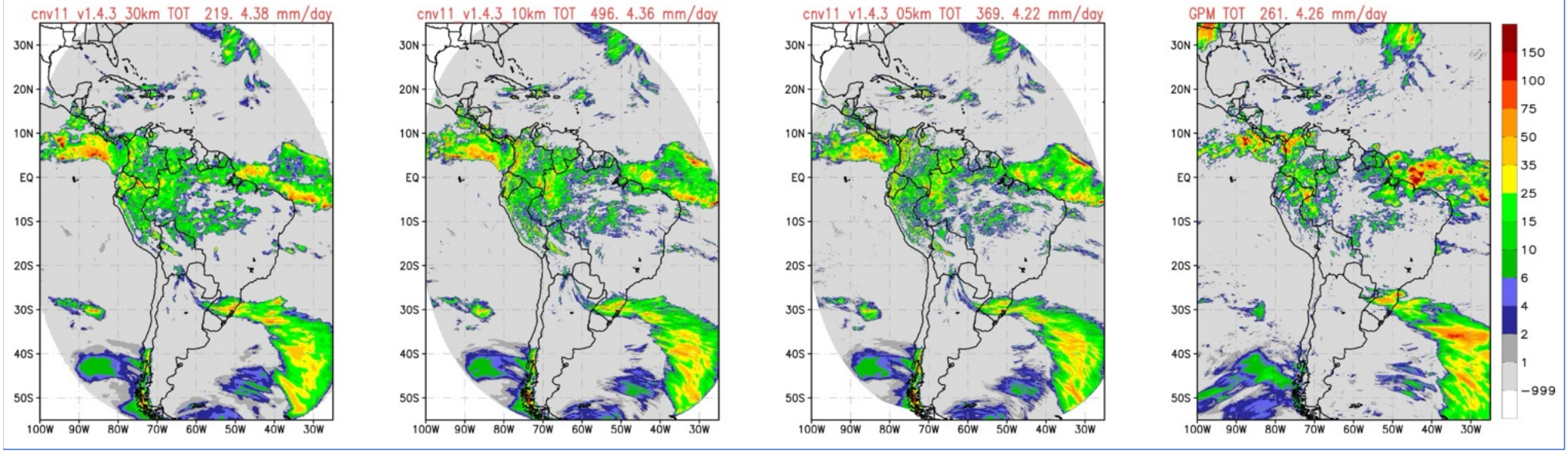
Regional Grid for Latin-Am and Caribean areas

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MONAN versão 1.4.3-rc CASO RS (24 h 28-29/04)

MONAN 30km | MONAN 10km | MONAN 05km | GPM



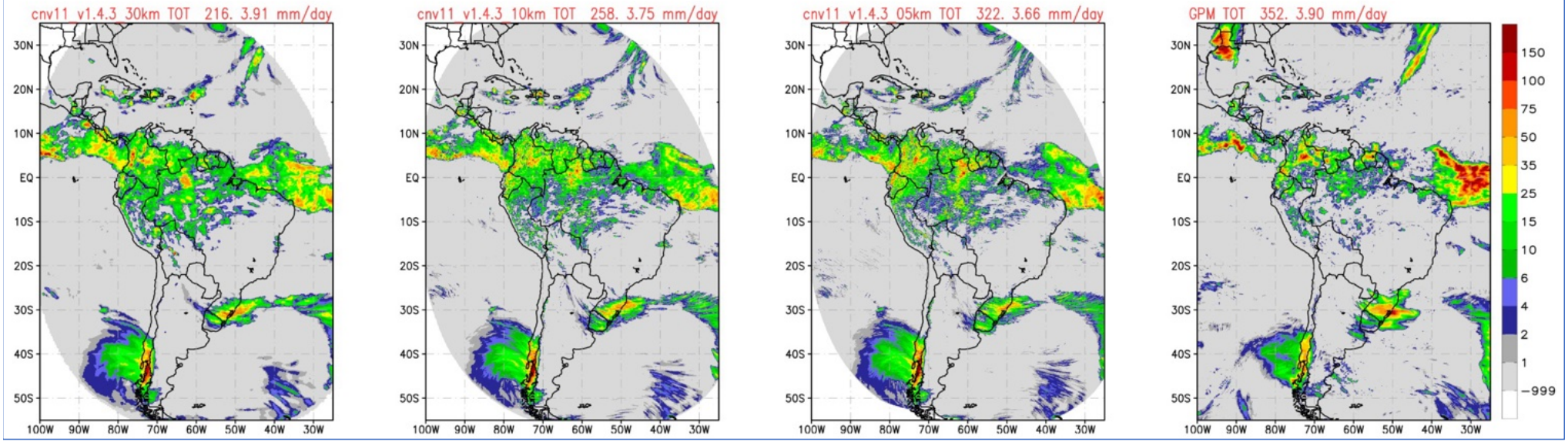
Regional Grid for Latin-Am and Caribean areas

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MONAN versão 1.4.3-rc CASO RS (24 h 29-30/04)

MONAN 30km | MONAN 10km | MONAN 05km | GPM



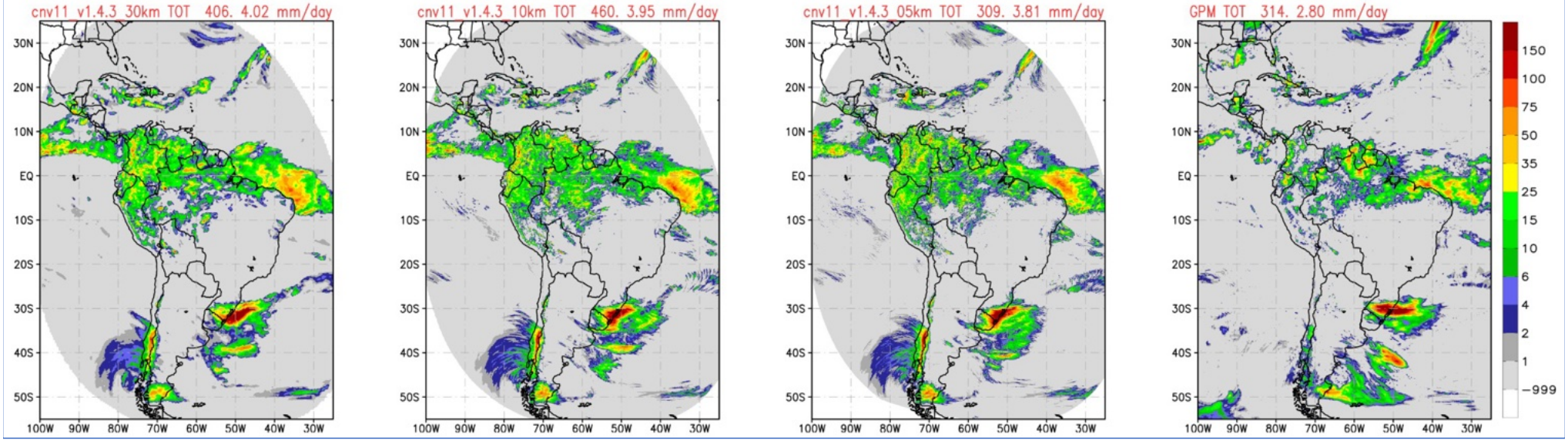
Regional Grid for Latin-Am and Caribean areas

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MONAN versão 1.4.3-rc CASO RS (24 h 30/04 - 01/05)

MONAN 30km | MONAN 10km | MONAN 05km | GPM



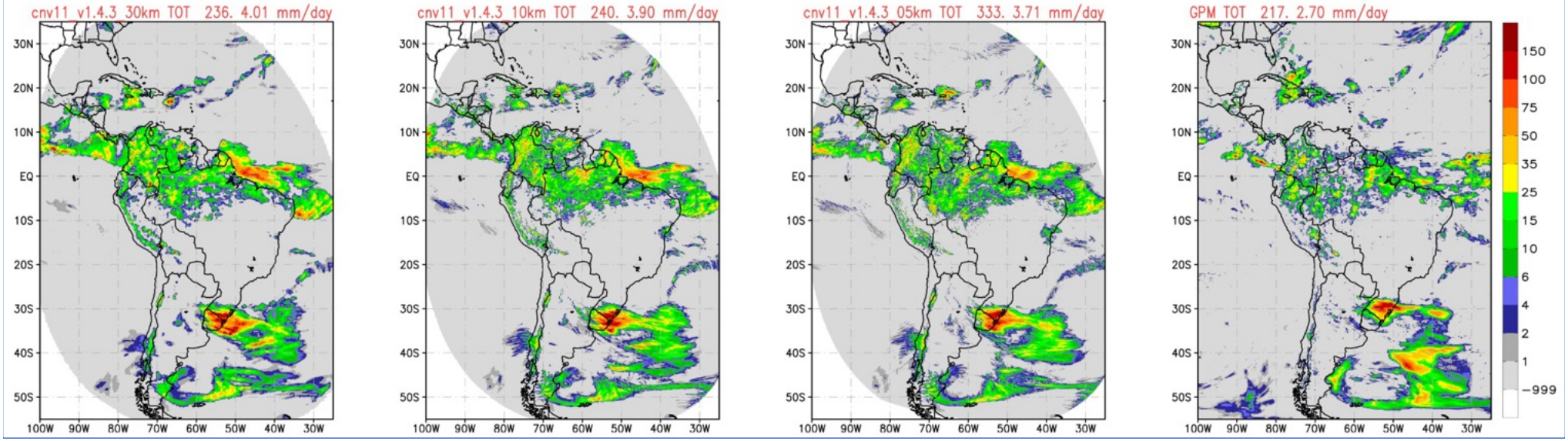
Regional Grid for Latin-Am and Caribean areas

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MONAN v1.4.3-rc CASO RS (24 h 01-02/05/2024)

MONAN 30km	MONAN 10km	MONAN 05km	GPM



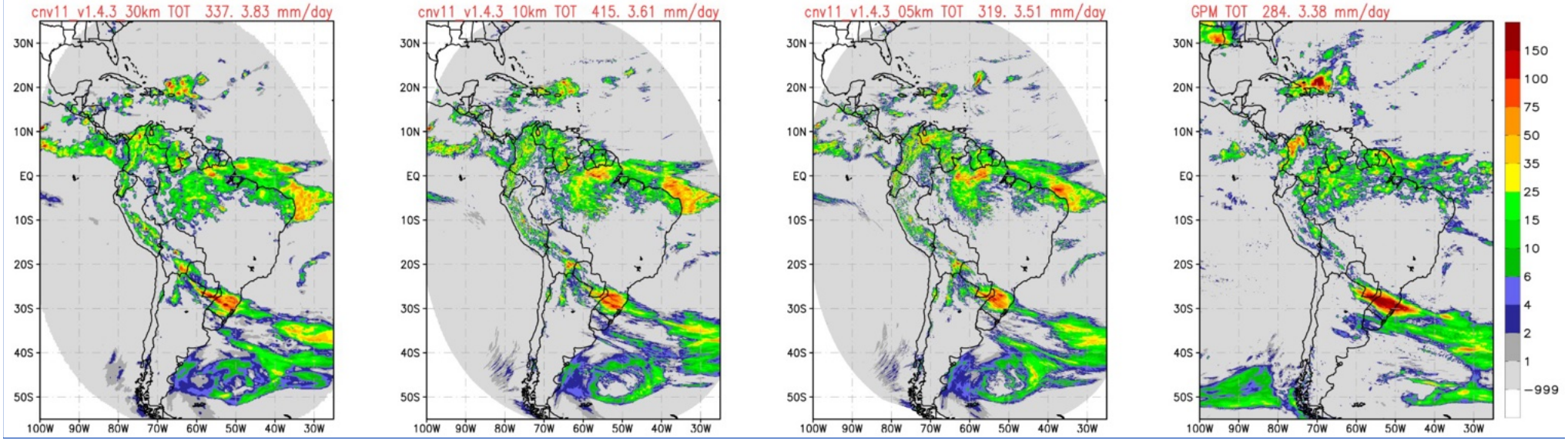
Regional Grid for Latin-Am and Caribean areas

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MONAN versão 1.4.3-rc CASO RS (24 h 02-03/05)

MONAN 30km | MONAN 10km | MONAN 05km | GPM

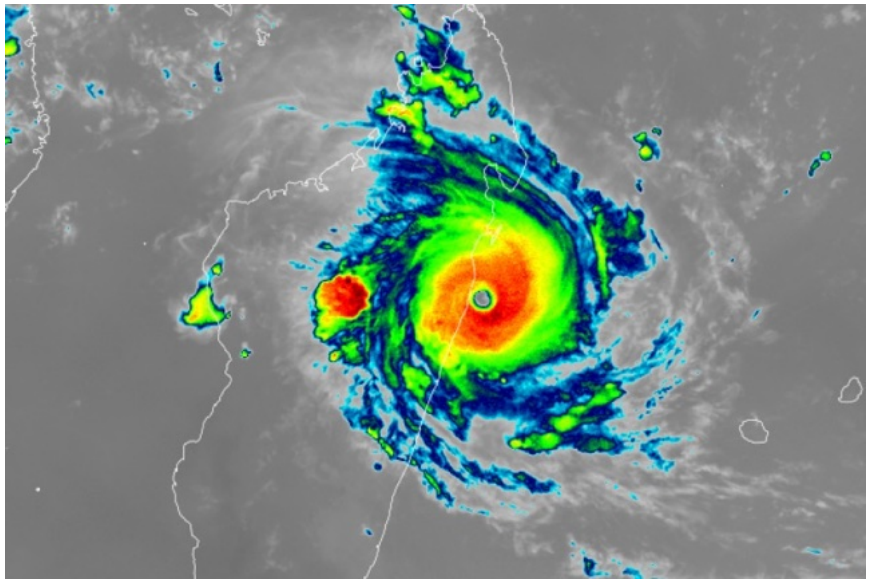


Regional Grid for Latin-Am and Caribean areas

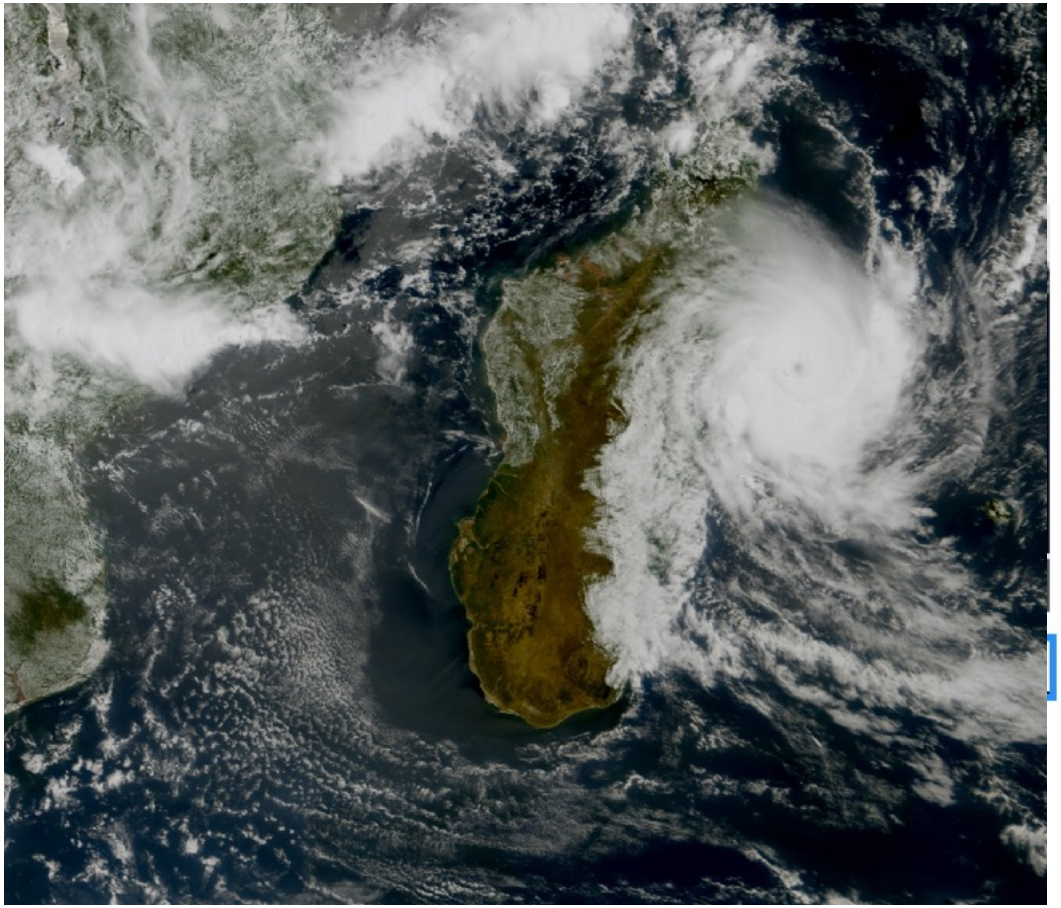
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“Tropical cyclone Gezani hits Madagascar”



Intense Tropical Gezani, 10 Feb 2026, 1500 UTC, just before landfall on Toamasina, Madagascar (*Meteosat 9)*



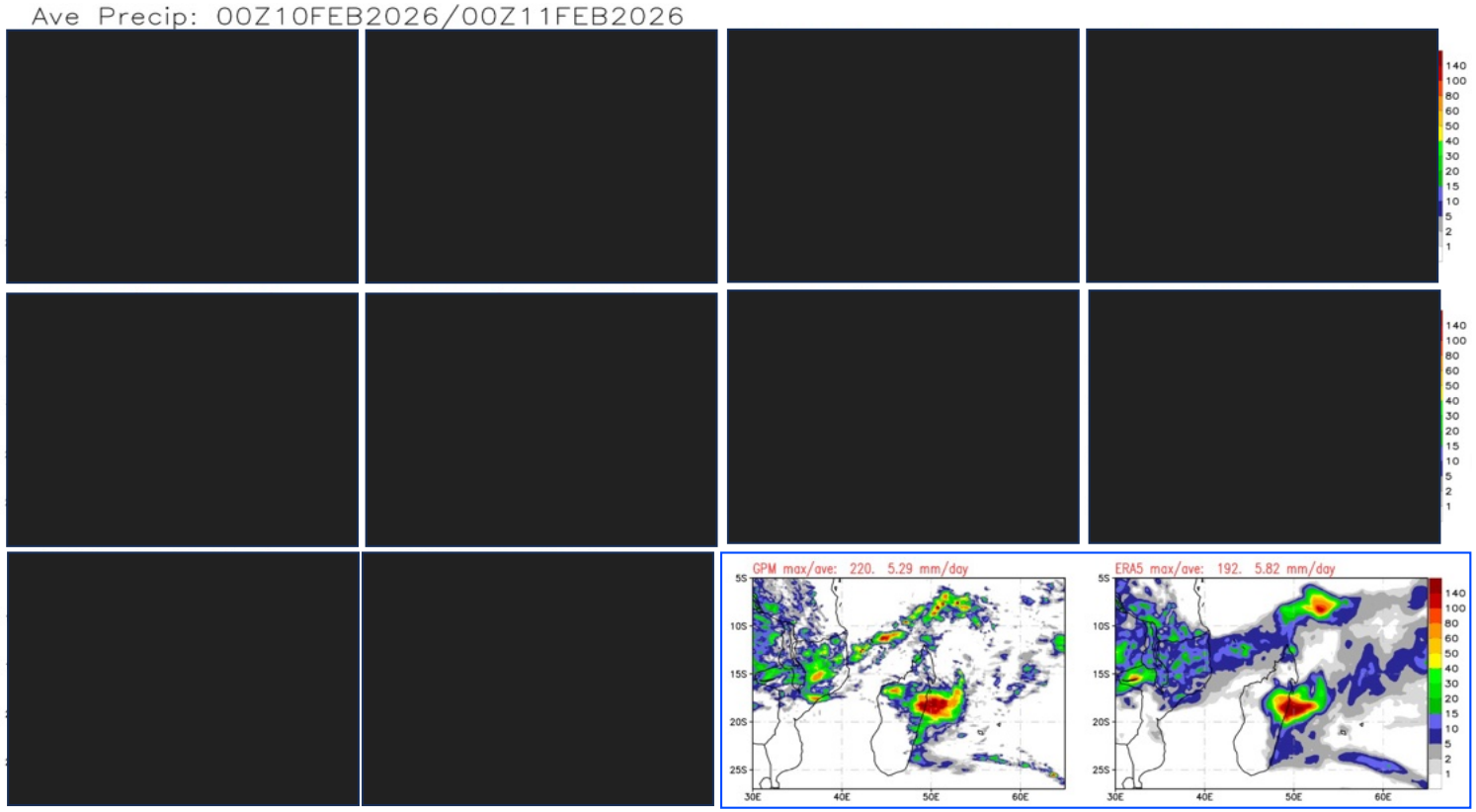
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GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

Tropical Cyclone Gezani – Real-Time MONAN Forecasts for day 10/02
Starting at 00UTC from day 1 to 10/02

MONAN
FCST_DAY



GPM_IMERG ERA-5

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The 1st MONAN training workshop for the South American Community

Participaram do treinamento 30 pesquisadores, professores ou tecnologistas:

- MCTI, USP, UFRJ, CEMPA, UFRN, UFBA, UNESP, UFCG, UFPel, Marinha Brasileira, FUNCEME, UFMS, FURG, CENSIPAM, Força Aérea Brasileira, UFAL, UNIFESP, UFPA e LNCC.
- Instituto de Geofísica e SENAMHI do Peru
- Serviço Meteorológico da Argentina





12-16 de Agosto 2024
CPTEC/INPE de Cachoeira Paulista, Brazil

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WORLD METEOROLOGICAL ORGANIZATION

International Weather Forecast Course brings together representatives from 15 countries at INPE

17-28 Nov 2025 - Cachoeira Paulista / Brazil





Participants: Argentina (SMN), Bolivia (NAABOL), Brazil (INMET), Chile (METEOCHILE), Colombia (IDEAM), Cuba (INSMET), Costa Rica (IMN), El Salvador (MARN), Ecuador (INAMHI), Mexico (SMN), Panama (IMHPA), Paraguay (DINAC), Peru (SENAMHI), the Dominican Republic (ONAMET), and Uruguay (INUMET).

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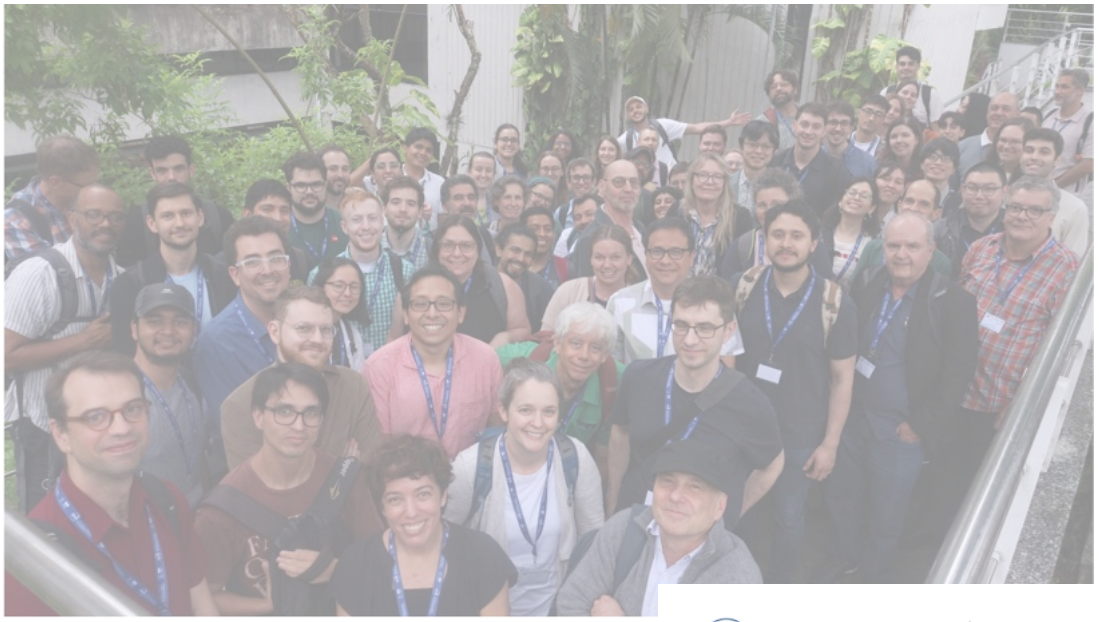
5th Workshop on Convective Organization (WCO5)

Organized convective systems are often responsible for high impact precipitation extremes, and changes in convective organization have the potential to amplify or dampen future climate change. Following on from the highly successful previous conferences WCO, WCO2, WCO3 and WCO4 this conference will examine our present knowledge of convective organization in models and observations.

Sessions:

- Extreme precipitation events
- Convective organization over land
- Organization of convection on global k-scale models
- Artificial intelligence applied to convective organization
- Cold-pool driven convective organization
- Shallow and congestus convective organization (over ocean and land)
- Convective organization feedback on climate
- Convective organization and tropical waves





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Current developments

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MONAN-JEDI: VALIDATED JACI BASELINE FOR JEDI-BASED DA

The MONAN-JEDI effort has moved from environment preparation to a functional and validated baseline on JACI.

BUILD ENVIRONMENT

spack-stack-inpe

Compilers, MPI, system libraries, and unified JEDI ecosystem dependencies.

↓

COMPILED CORE

MONAN-JEDI

Project-controlled operational JEDI bundle & compiled Data Assimilation executables.

↓

ORCHESTRATION LAYER

MONAN-JEDI-workflow

Highly portable, reproducible automated forecast and DA cyclic workflow system.

Validated Technical Baseline

- **JACI environment consolidated** for MPAS-JEDI/MONAN-JEDI stack.
- **MAPS-JEDI successfully built** and verified locally on JACI hardware.
- **Full CTest verification suite** passed with 100% correctness.
- **Real tutorial experiments** actively running on JACI node architecture.
- **Onboarding and documentation** fully consolidated for new team members.

Oceanic and Cryosphere Models

Evaluation done with MOM6 and HYCOM systems

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MOM6 vs HyCOM

Feature	HYCOM	MOM6
Philosophy	Consolidated Engineering	Flexible Evolution
Vertical Grid	Set Rules *(Hybrid Classic approach)* - It sets rules for specific zones: isopycnals for the deep, sigma for coasts, and z-levels for the top.	General Platform *(ALE Framework)* - It works like a shapeshifter, adapting its vertical grid to the physics of the water automatically.
Software Style	Traditional Code	Modern and Scalable
Best Use Case	Real-time Forecasting Navy models and offshore industry. It is fast and integrates with real data perfectly.	Long-term Research New standard for NOAA and CMIP. It provides superior stability and math for long-term predictions.
Community	Deep roots in Naval history.	Rapidly growing with modern developers and open-source support. Broad interest in use, application and research.

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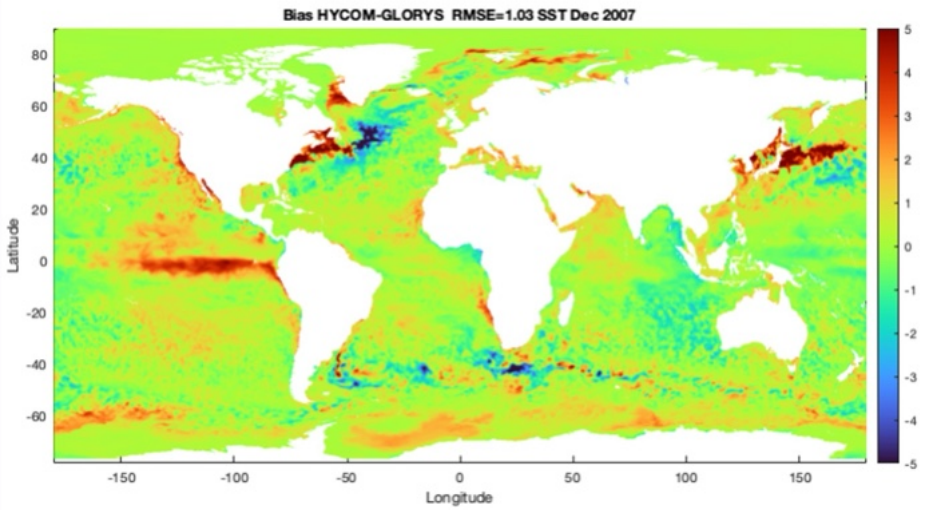
MONAN Ocean Component: HYCOM vs MOM6

Global Model Evaluation —

PARTNERSHIP	GRID RESOLUTION	FORCING & PERIOD	INITIAL CONDITION	HPC PLATFORM
COPPE/UFRJ (Prof. A. Paiva)	Global — 25 km	ERA5 / Long run 21 yr (2004–2024)	Daily GLORYS (Copernicus)	JACI Supercomputer (INPE)

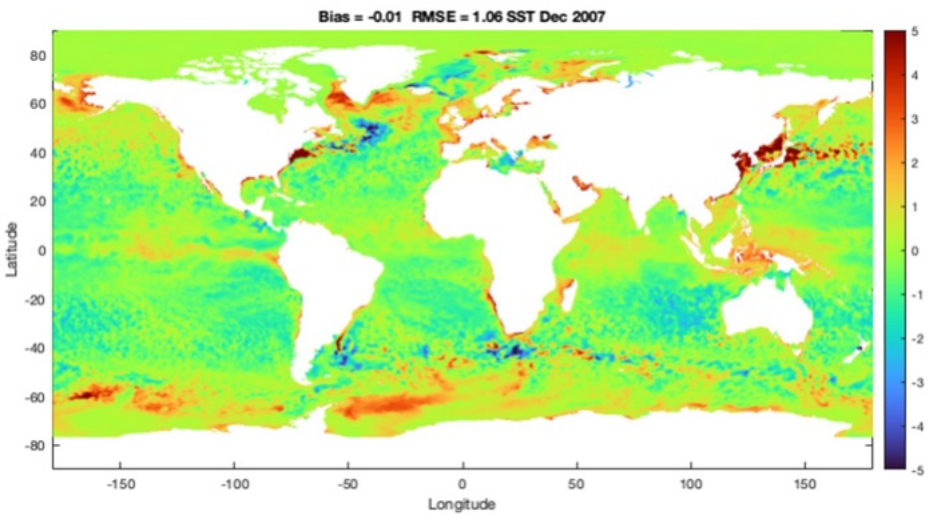
HYCOM Model vs GLORYS Reanalysis

Dec 2007 SST

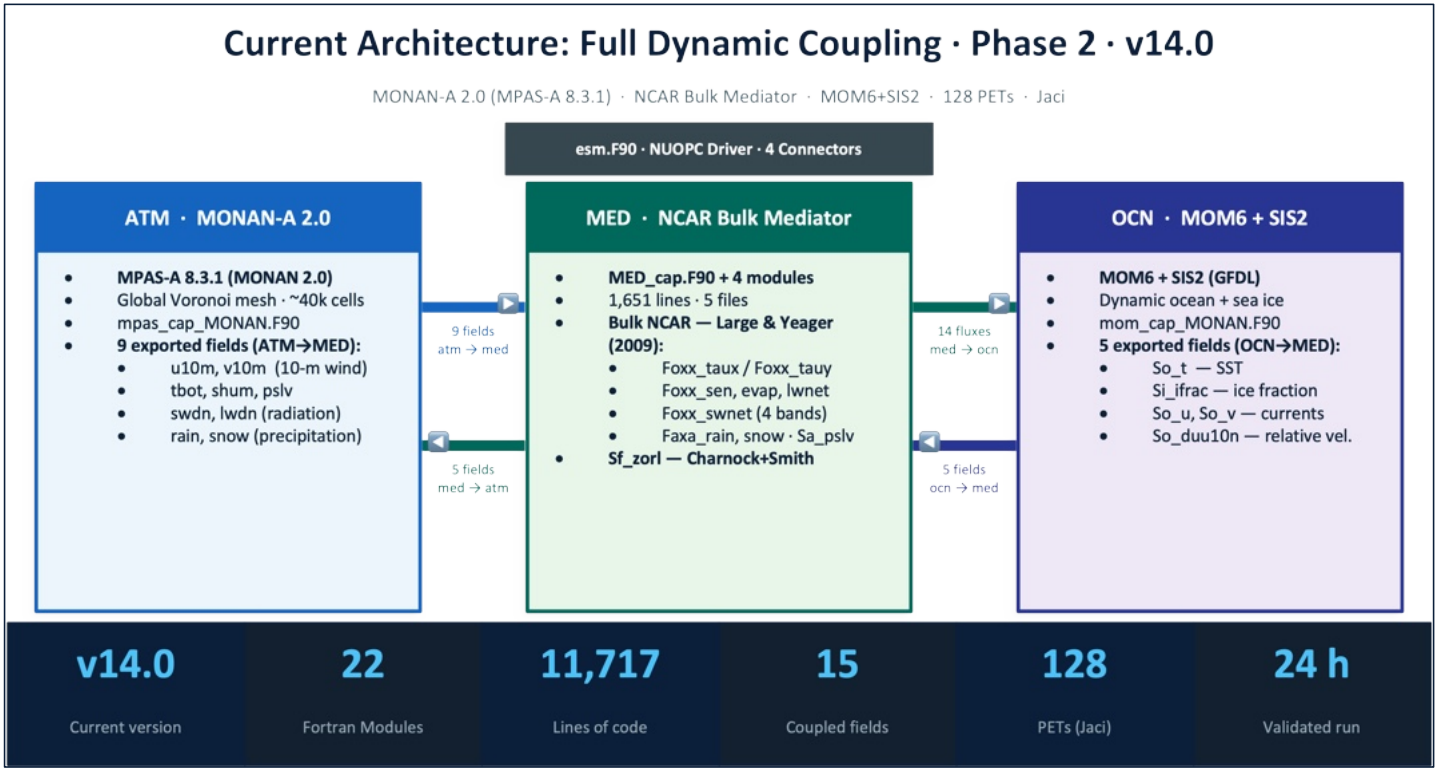


MOM6 Model vs GLORYS Reanalysis

Dec 2007 SST



MONAN/MPAS ----- MediadorBulk NCAR ----- MOM6+SIS2



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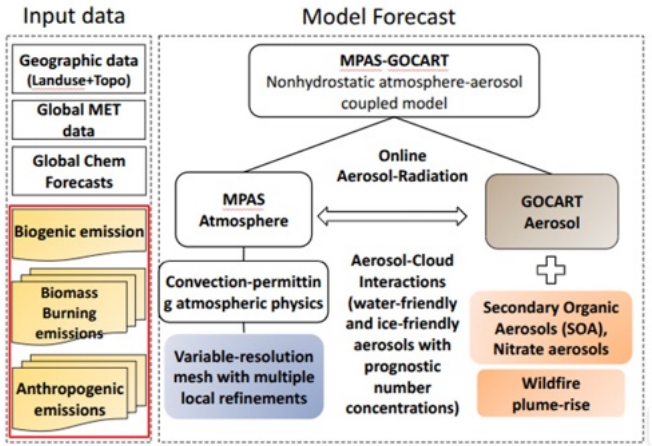
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Implementation of Wildfire Smoke Plume Rise Model in the MPAS-GOCART2G

MPAS-GOCART2G
Nonhydrostatic atmosphere-aerosol coupled model → MPAS-Atmosphere → chemistry

GOCART2G

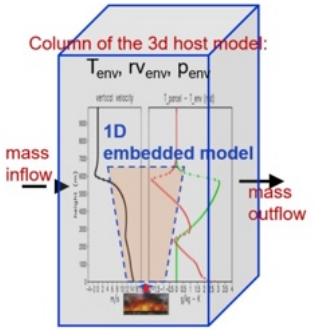
Plume Rise Model



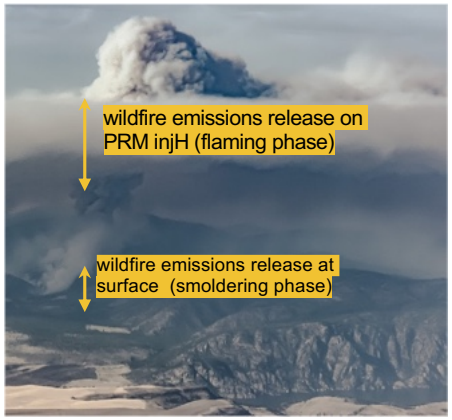
PARAMETRIZATION TO ESTIMATE WILDFIRES SMOKE PLUME INJECTION HEIGHT

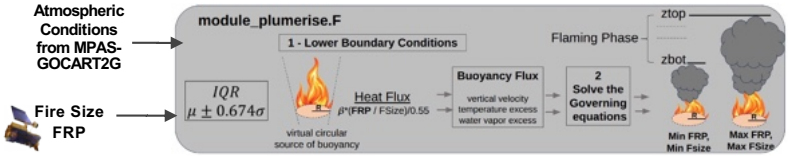
1-D time-dependent cloud-resolving model (Freitas et al. 2007, 2010)

- Based on microphysics and entrainment;
- Solves the vertical momentum, first law of thermodynamics and the continuity equation for water phases;
- Takes in fire information (active fire size and heat flux), besides the atmospheric environment condition;
- The plume-top height: height for which the vertical velocity of the in-plume air parcel is less than 1 ms^{-1}.



$$\left(\frac{\partial \bar{s}}{\partial t}\right)_{em} = \bar{E}_\eta(k,t) = \begin{cases} (1-\lambda)\dfrac{F_\eta}{\bar{\rho}_{dry\,air}(k)\Delta z_k}, k = 1\,(surface) \\ \lambda\dfrac{F_\eta}{\bar{\rho}_{dry\,air}(k)\Delta z_k}, k = k_{zbot}, k_{ztop}\,(PRM\ injection\ height) \end{cases}$$

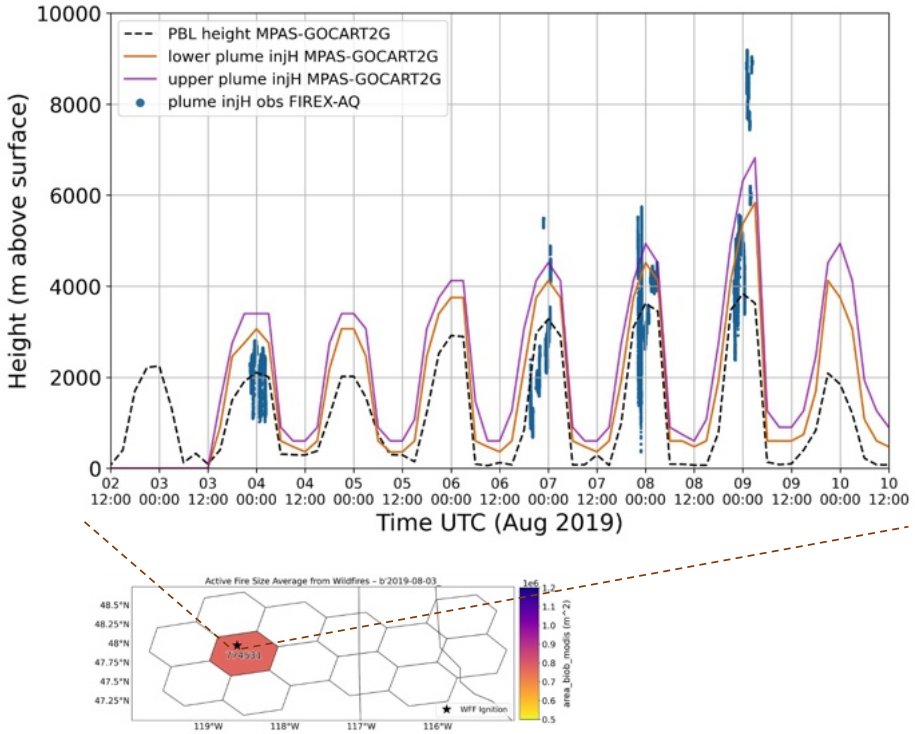


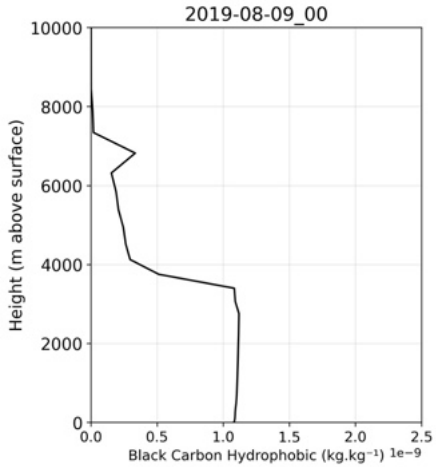


Jaqueline Pereira, M.Sc.
PhD Candidate in Meteorology
National Institute for Space Research (INPE)
jaqueline.pereira@inpe.br

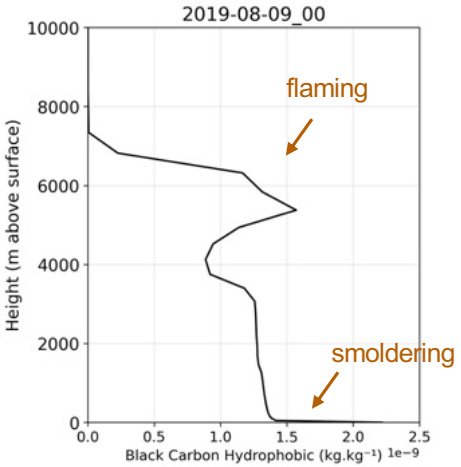
Implementation of Wildfire Smoke Plume Rise Model in the MPAS-GOCART2G

Case Study: Williams Flats Fire 2019
August 02 - 10, 2019





PRM = False

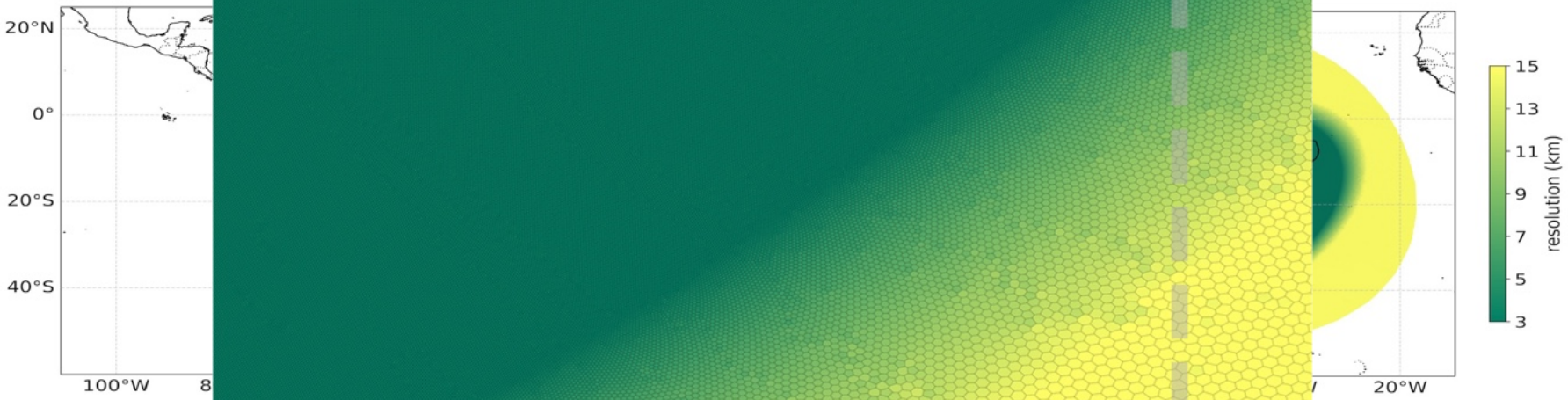


PRM = True
Vegetation category = **Boreal Forest**
45% release on flaming phase
heat flux min and max = **30 - 80 kWm^{-2}**

This work has been supported by the following Brazilian research agencies: CAPES (88887.937568/2024-00) and CNPq (140137/2022-0).
This work is supported by the NASA PACE Science and Applications Team (Grant No. 80NSSC24K1786).

Regional grids for nowcasting

1) Elliptical g cells)



We are developing a t , based on

- vtx-mpas-meshe
  MPAS-BR (https ow
- jigsaw (https:// imization
- MPAS-Limited-A d cutting regional grid

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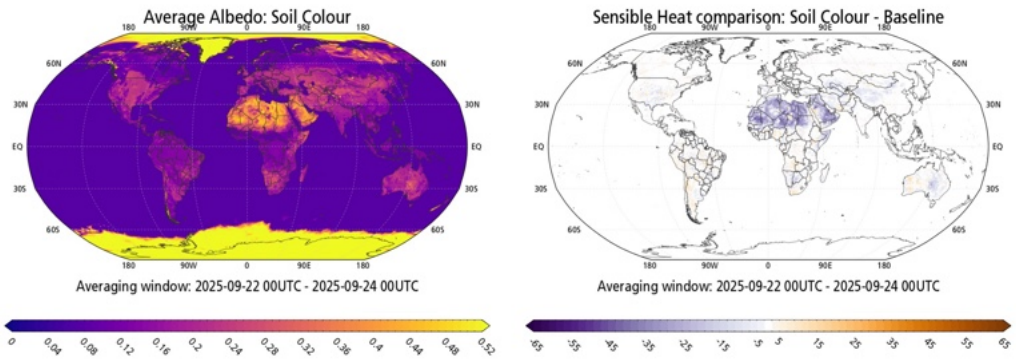
New developments on MONAN land surface models

Spatially heterogeneous soil colour (Noah-MP)

Motivation. Improve spatial representation of albedo

Implementation. CLM-5 map and parameters

Impact. Marked shifts in fluxes across major deserts



More info. https://github.com/monanadmin/MONAN-Model/pull/19

Cumulative sfc fluxes (Noah)

Motivation. Facilitate comparison with flux towers (hourly averages)

Implementation. Built on existing cumulative radiative flux logic

More info. https://github.com/monanadmin/MONAN-Model/pull/29

Flexible soil depth grid (Both)

Motivation. 2-m soils are too shallow for tropical moist forests (rooting depths ~ 10m)

Implementation. Namelist variables for top soil thickness and expansion for deeper soils

Status. Ongoing tests. Cryptic bug fixes submitted to MONAN and MPAS

More info. https://github.com/monanadmin/MONAN-Model/pull/33

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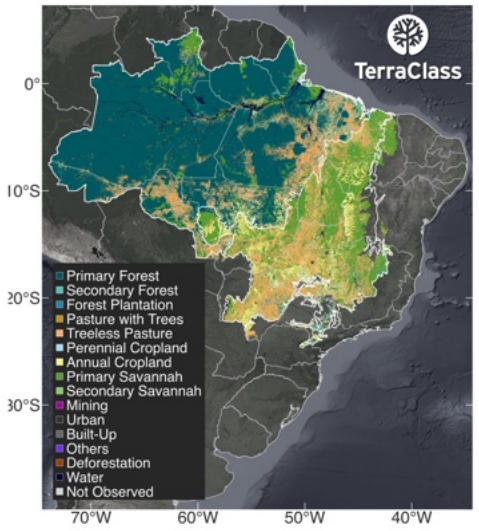
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New developments on MONAN land surface models

Vegetation map revision

Goal: Leverage INPE's monitoring of land use and land cover

New vegetation classes: secondary tropical forests, C3/C4 grasses

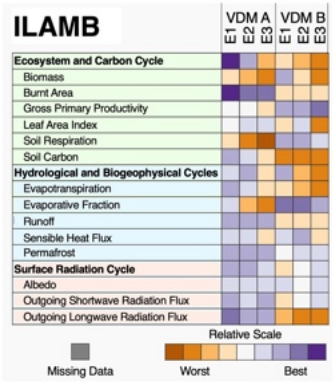


Demography-MIP

Goal: Select DGVM (preferably demographic) for climate-scale runs

Models: ED2, CLM-FATES, JULES

Criteria: Accuracy ▪ Governance ▪ Interoperability ▪ Accessibility

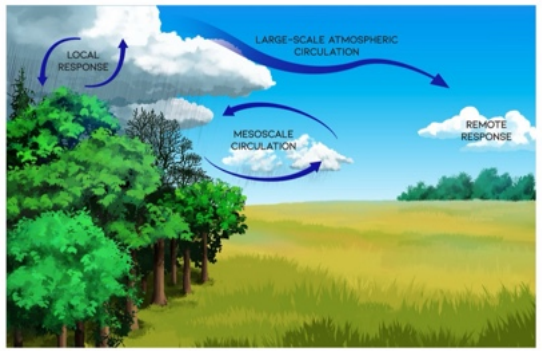


Collier et al. (2018) *JAMES*

ESM-MONAN

Long-term goal: Feedbacks between degradation/regeneration and climate

Opportunities: Integration of novel remote sensing data (GEDI, EMIT, EDGE, EAGLE) to MONAN



Bonan et al. (2024) *JAMES*

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MONAN
Planned Subsequent Deliverables

- Coupling with Atmospheric DA using the JEDI Framework (2025-2027)
  a. Ensemble forecast for medium range (up to 15 days)
  b. Nowcasting for severe storms (up to 6 hours)
  c. Air pollution forecasting (up to 7 days)
- Coupling with oceanic and cryosphere models (2025-2028)
  a. Sub-seasonal prediction (up to 30 days)
  b. Seasonal prediction (3-month ahead)
- Coupling with the anthroposphere (2027-2030)
- Climate change scenarios (2030-2031)
- Fully developed **MONAN** South America, Earth System Community Model (2031)

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The acronym and symbol of MONAN

Monan is a Tupi-Guarani (native people of S. America) word that means "land without evils", where they live with their ancestors and Gods, without war, starvation, or any human diseases.



Thanks for your attention!

MONAN
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