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INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

MONAN

Model for Ocean-laNd-Atmosphere predictioN

MONAN 1.0.0 and beyond

Saulo R. Freitas
On behalf of the Scientific Steering Committee

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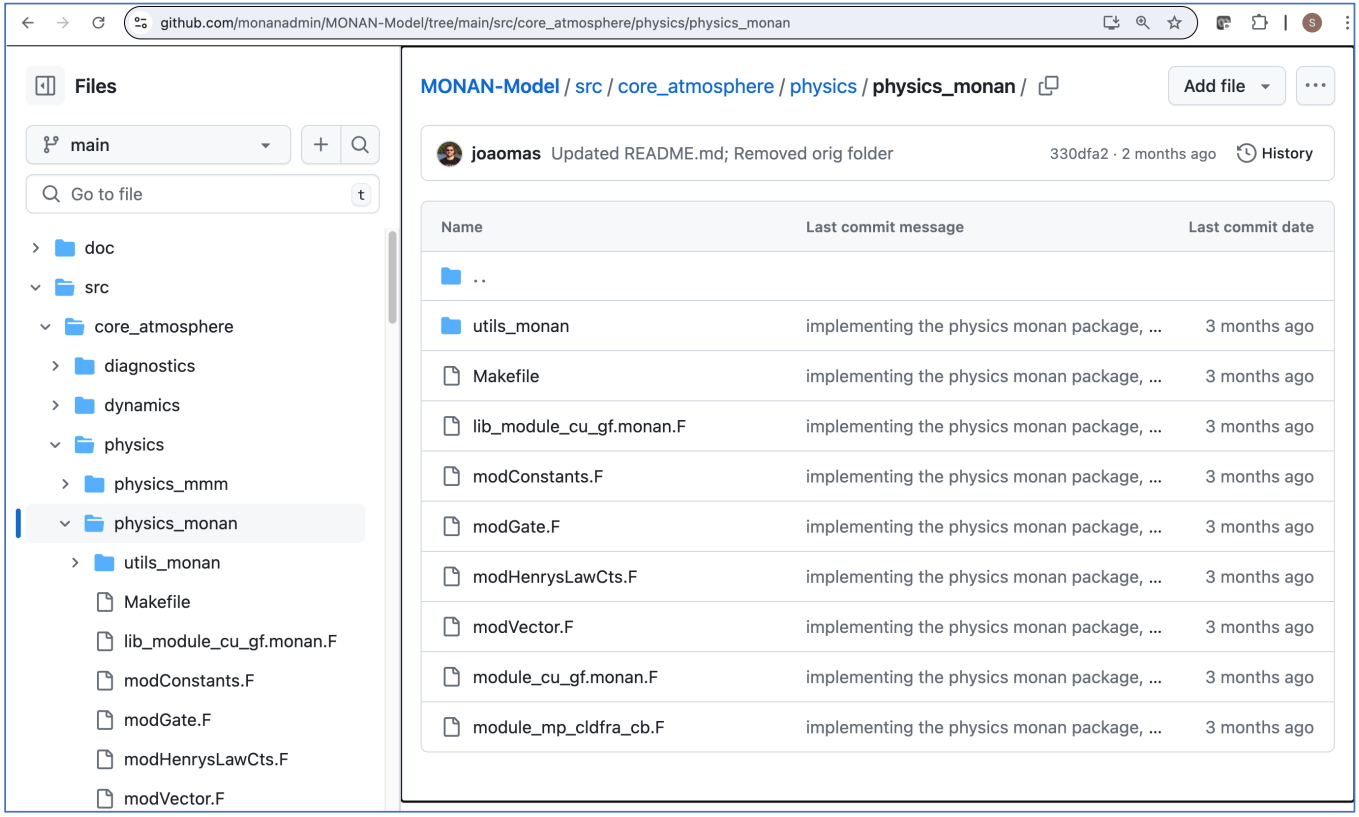
../physics_monan



https://github.com/monanadmin/MONAN-Model/tree/main/src/core_atmosphere/physics/physics_monan

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Physics Developments for MONAN

GF Convection Parameterization

- as in BRAMS/NASA GEOS-5, not the same in WRF or the originally implemented in MPAS by L. Fowler

- ./physics_monan/module_cu_gf.monan.F
- config_physics_suite = 'mesoscale_reference_monan’
- config_physics_suite = convection_pemitting_monan'

Cloud cover fraction CB2002

- as in BRAMS/NASA GEOS-5
- Based on Chaboureau & Bechtold (JAS2002/JGR2005) - diagnostic, includes the updraft mass flux from GF
- ./physics/mpas_atmphys_driver_cloudiness.F
- subroutine “calc_cldfraction_monan”

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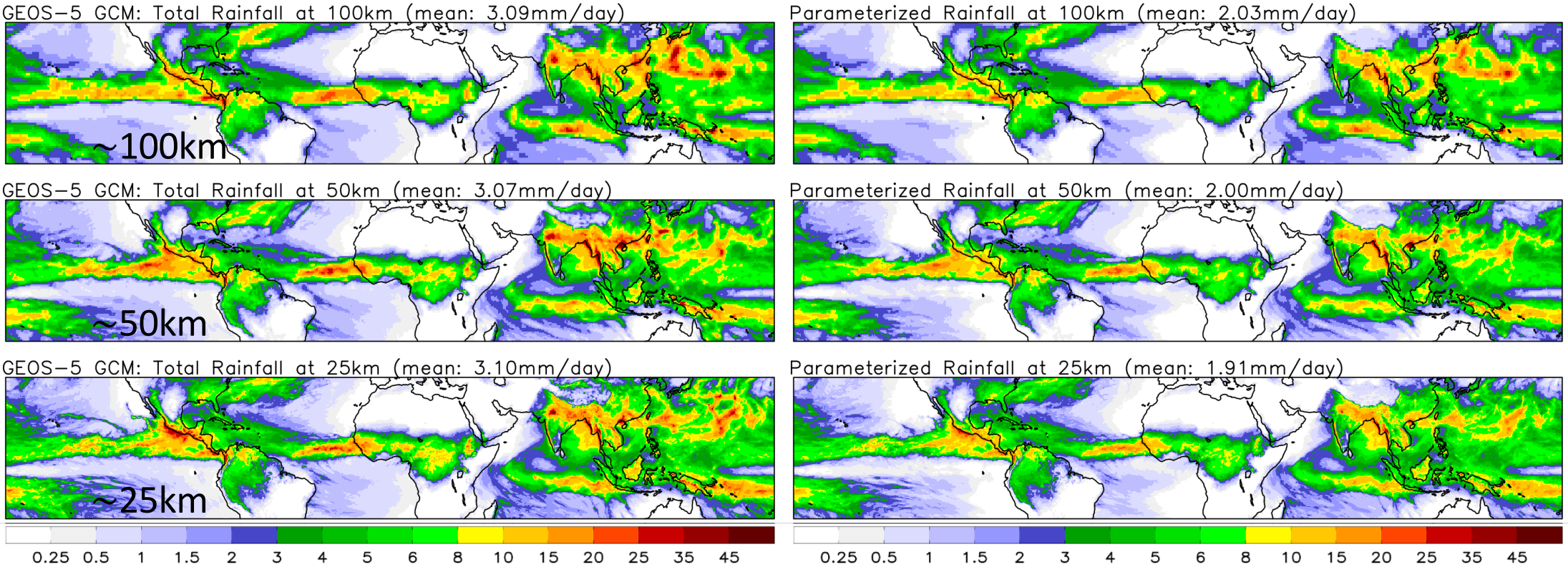
The Grell-Freitas convection parameterization
Some remarks

- Trimodal design: deep, 'congestus' and shallow plumes with an ensemble of closures, including convective scale downdrafts.
- Scale awareness follows Arakawa et al. (2011).
- Aerosol aware following using autoconversion and evaporation dependence on CCN.
- Closure for non-equilibrium convection (diurnal cycle over the land).
- Transport of momentum, tracers, water and moist static energy(MSE),
- In-line scavenging and evaporation for aerosols and trace gases.
- Transport of mass and MSE is conservative, positive definite on machine precision.
- Beta PDFs to emulate the vertical mass flux profiles.
- Lightning parameterization
- Cold Pool Edge effects (convection organization e propagation)

Ref: Grell and Freitas (2014), Freitas et al (2018, 2020, 2021, 2024)

Cascading from 100 km to 3 km
NASA GEOS-5 GCM with GF convection parameterization



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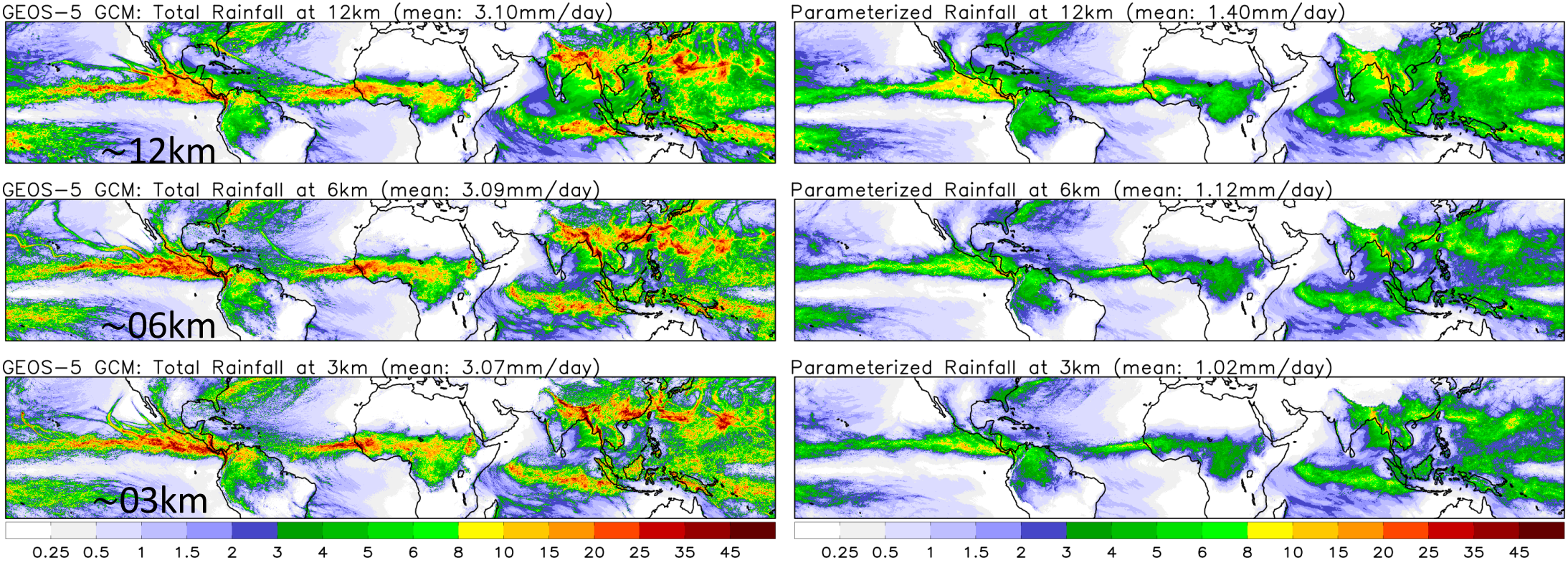
Cascading from 100 km to 3 km
NASA GEOS-5 GCM with GF convection parameterization

The scale-awareness of the deep convection scheme allows for a gradual decrease of the parameterized precip fraction in the gray zone.



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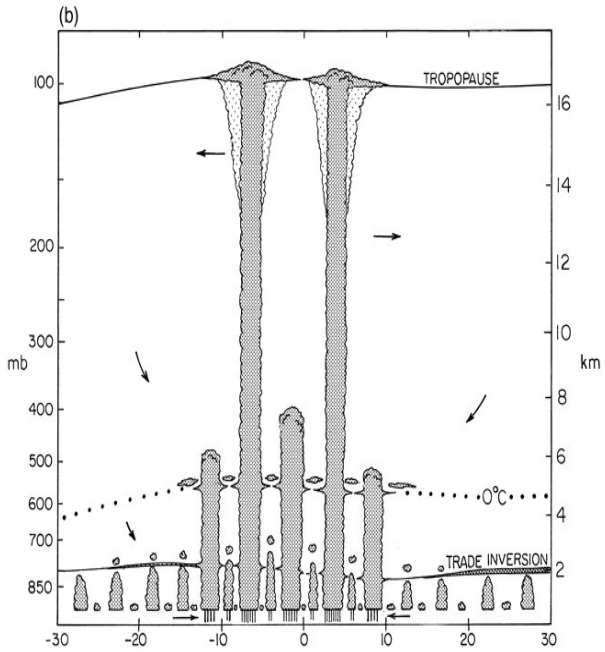
A tri-modal convection parameterization



Johnson et al (1999):
Tri-modal Characteristics of Tropical Convection

The three predominant convective modes:

- shallow limited by the trade inversion,
- congestus by the zero degree inversion layer,
- deep with cloud tops well above.

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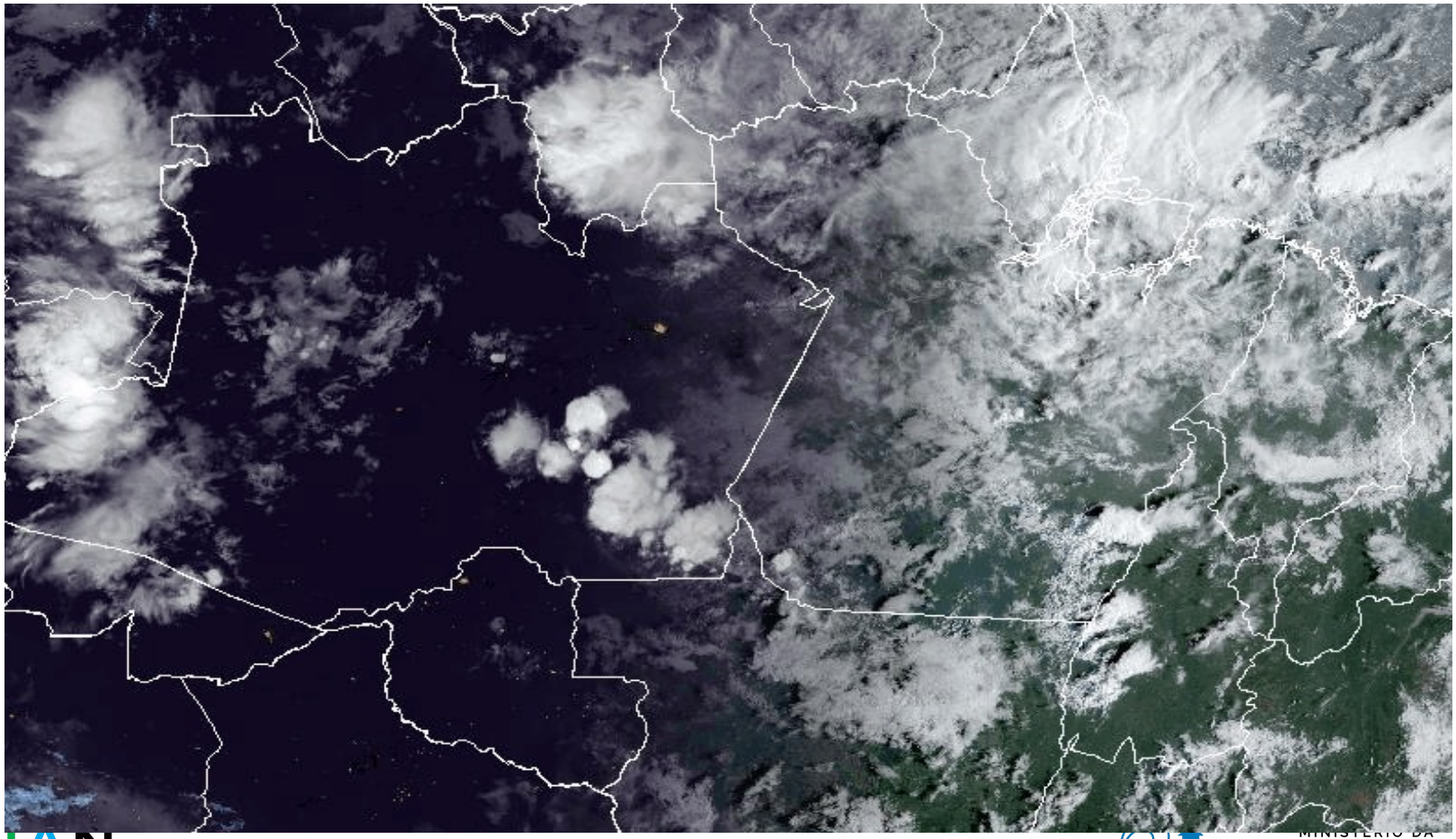
A parameterization for cloud organization and propagation by evaporation-driven cold pool edges



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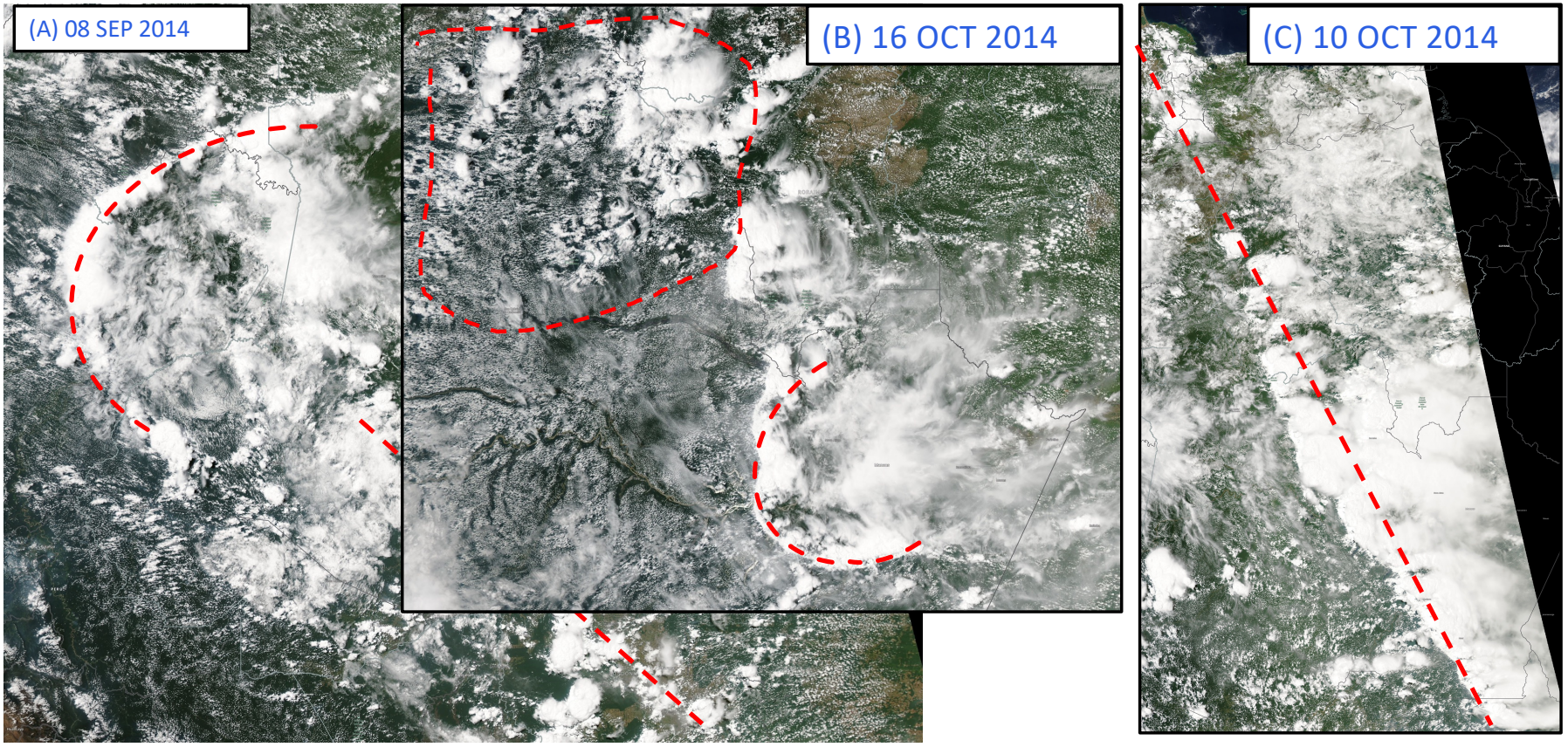
A miscellanea of organized convective systems in the Amazon basin on an ordinary day



Aqua/MODIS true-color images (doi:10.5067/MODIS/MYD02HKM.061)

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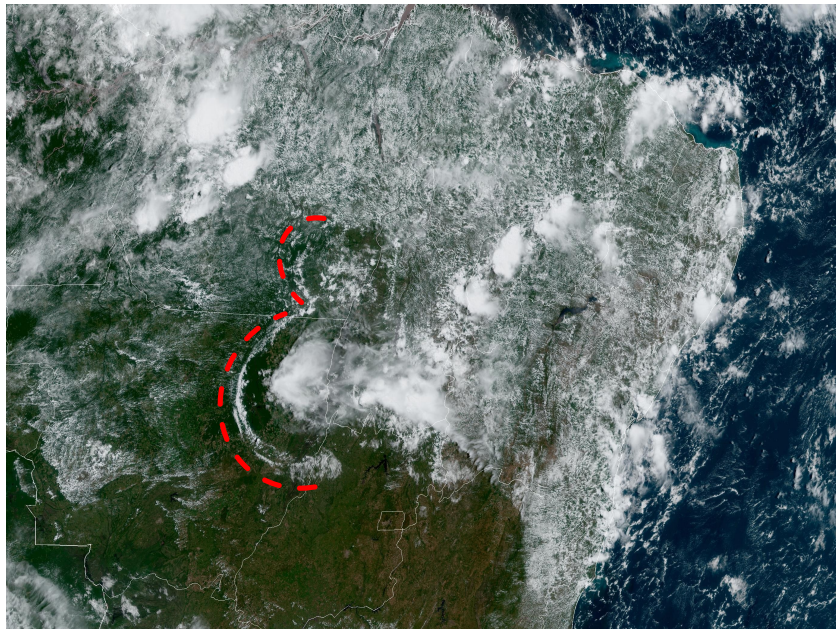
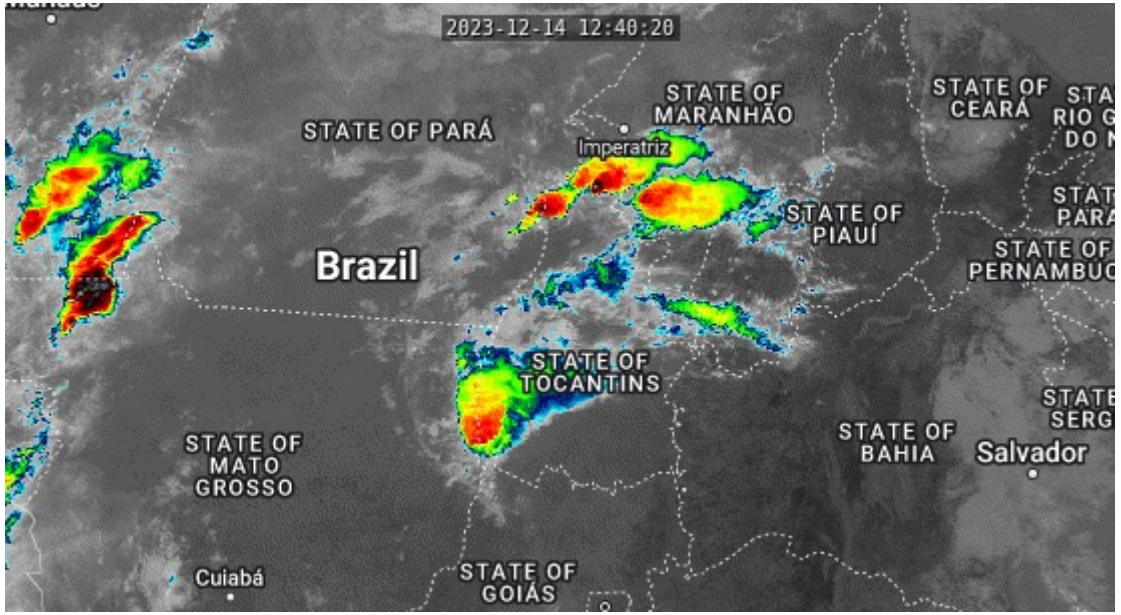
Cold pools over the central part of Brazil





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A parameterization to account for the sub-grid scale effects of the cold pool edges

Definition of Buoyancy-Excess (β_x)
as a measure of the sub-grid scale MSE variability due the presence of the cold pools:

$$\beta_x = -\left(H_d - \tilde{H}\right)$$

a) H_d and $\tilde{H}$ are the downdraft and environment MSE.
b) β_x is 3-D positive-definite prognostic scalar.

The maximum vertical velocity at the leading edge of the cold pc

$$w_{gf} = \kappa \left(\int_0^D \frac{1}{1+\gamma} \frac{\beta_x}{c_p \tilde{T}} \sin^2 \alpha \; g \; dz \right)^{1/2}$$

The gust front horizontal velocity is given by:

$$V_{gf} = \kappa \left(\int_0^D \frac{1}{1+\gamma} \frac{\beta_x}{c_p \tilde{T}} g dz \right)^{1/2}$$

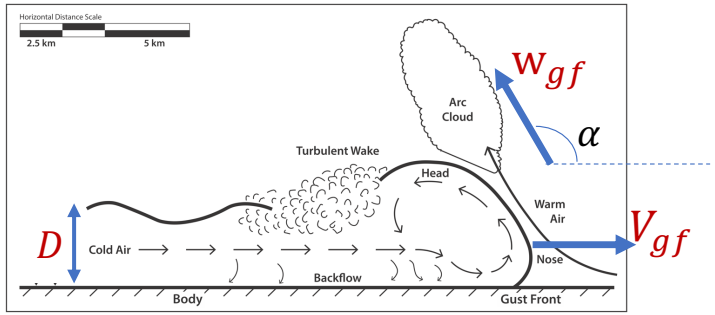

FIG. 1. Conceptual model of a density current. D is the height of the cooler air far behind the head of the density current. Adapted from Droegemeier and Wilhelmson (1987).

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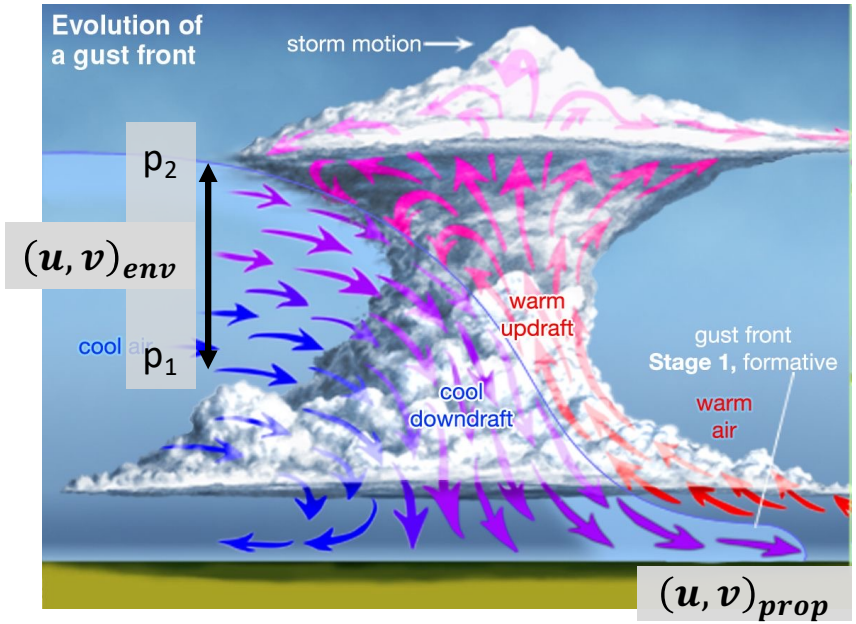
Gust front propagation speed



Definition of the mean cloud layer horizontal speed $(u,v)_{mcl}$:

$$(u,v)_{mcl} = \frac{1}{p_2 - p_1}\int_{p_1}^{p_2}(u,v)_{env}\,dp$$

where p_1= 900 hPa, p_2=600 hPa. $(u,v)_{env}$ is the horizontal environment wind and p is the atmospheric pressure.

The 2-D horizontal propagation velocity of the cold pool:

$$(u,v)_{\text{prop}} = (u,v)_{mcl} + \frac{V_{gf}}{|(u,v)_{mcl}|}(u,v)_{mcl} + 0.6(u,v)_{env}$$

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The proposed prognostic equation for the Buoyancy-Excess (β_x)

In the context of the MPAS/MONAN 1.0.0 model

$$\frac{1}{\tilde{\rho}_d}\frac{\partial \tilde{\rho}_d \beta_x}{\partial t} = \underbrace{-\frac{1}{\tilde{\rho}_d}\nabla \cdot \tilde{\rho}_d \beta_x (u,v)_{prop}}_{\text{2-D advection}} + \underbrace{\frac{1}{\tilde{\rho}_d} DIF_z(\tilde{\rho}_d \beta_x)}_{\text{1-D diffusion}} \underbrace{+ \beta_x \delta_d}_{\text{Source}} \underbrace{- \frac{\beta_x}{\tau}}_{\text{Sink}}$$

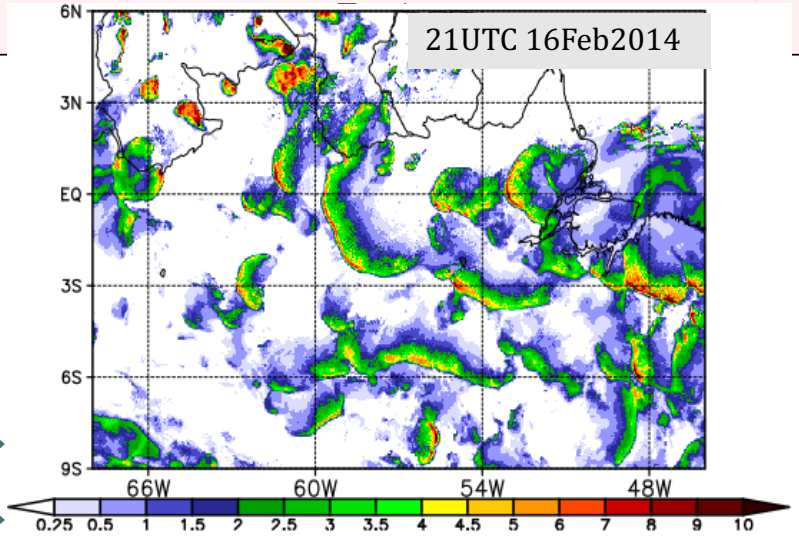
Source

$\boldsymbol{\delta_d}$ is the downdraft detrainment mass-flux given the by the convection parameterization.

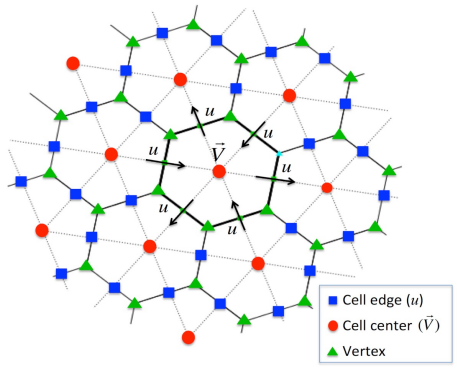
Sink

$\boldsymbol{\tau}$ is the cold pool lifetime. $\boldsymbol{\tau}$ is a tunable parameter in the range of 1–3 hours (currently 2 h everywhere).

Typical model output of the Buoyancy-Excess β_x (kJ/kg)



$\tilde{\rho}_d = \frac{\rho_d}{\xi}$ is the dry air density over the nominal heights



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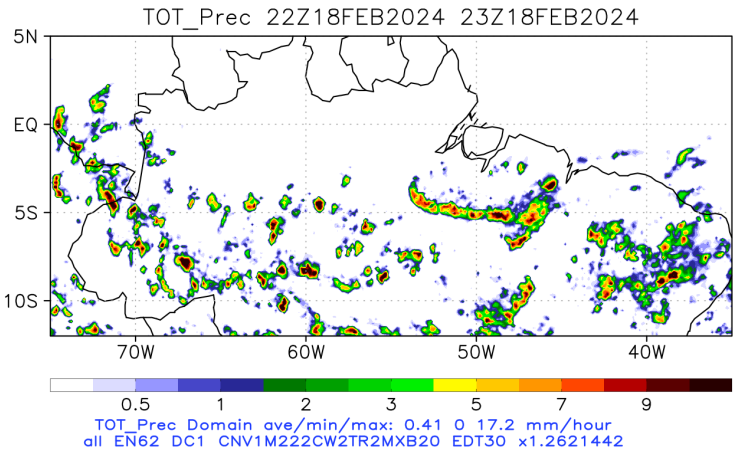
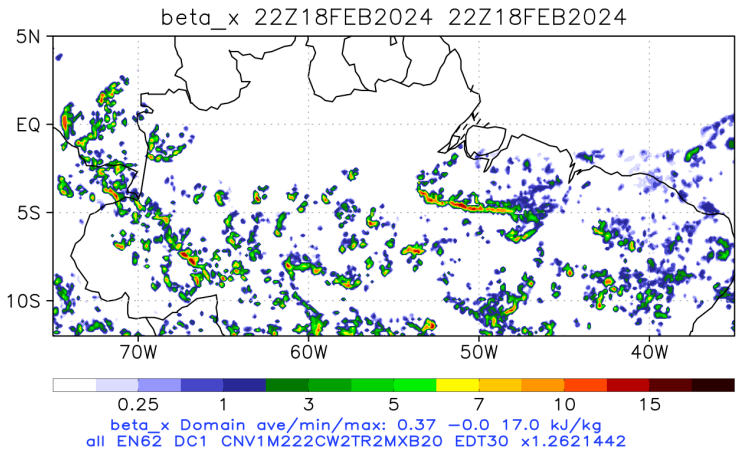
Model results using MPAS/MONAN

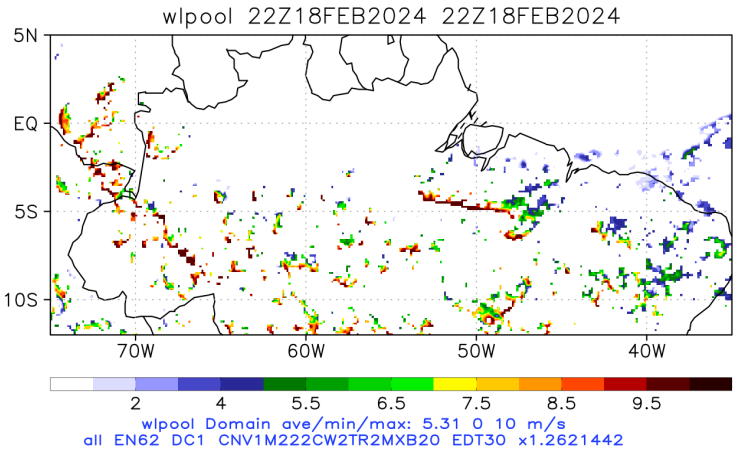
1h accum precipitation (mm)



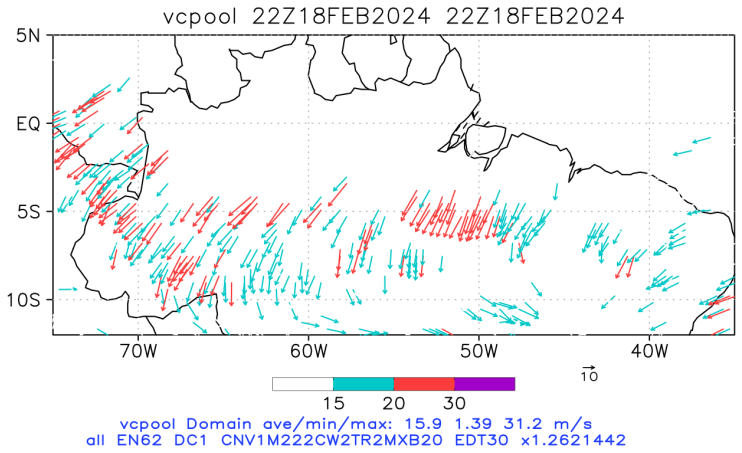
Buoyancy-excess (kJ/kg)



Vertical velocity at the leading edge of the cold pool (m/s)



Terrain-following propagation speed (m/s)



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MPAS Model for Prediction Across Scales

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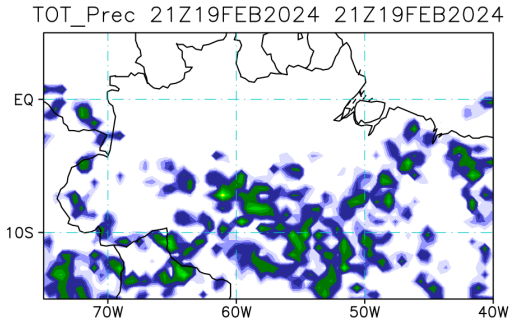
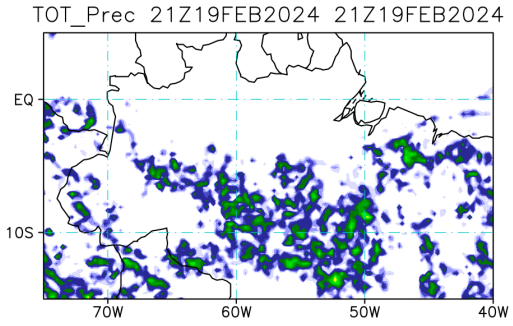
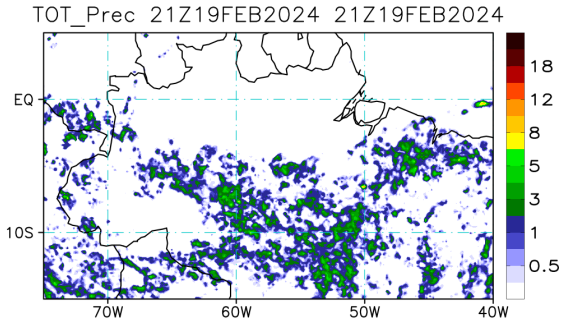
Helps organization in low resolution GCM configuration

	60 km	30 km	15 km
Control	 TOT_Prec Domain ave/min/max: 0.41 0 7.14 mm/hour EN62_DC0_CNV0_EDT30_x1.163842	 TOT_Prec Domain ave/min/max: 0.40 0 7.22 mm/hour EN62_DC0_CNV0_EDT30_x1.655362	 TOT_Prec Domain ave/min/max: 0.42 0 12.8 mm/hour EN62_DC0_CNV0_EDT30_x1.2621442
Cold Pool	TOT_Prec Domain ave/min/max: 0.56 0 8.42 mm/hour EN62_DC1_CNV1M222CW2TR2MXB20_EDT30_x1.163842	TOT_Prec Domain ave/min/max: 0.68 0 16.5 mm/hour EN62_DC1_CNV1M222CW2TR2MXB20_EDT30_x1.655362	TOT_Prec Domain ave/min/max: 0.84 0 27.2 mm/hour EN62_DC1_CNV1M222CW2TR2MXB20_EDT30_x1.2621442

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MPAS Model for Prediction Across Scales

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Hurricane Beryl Hurtles into the Caribbean

The first Atlantic hurricane of 2024 produced dangerous winds and life-threatening storm surge.

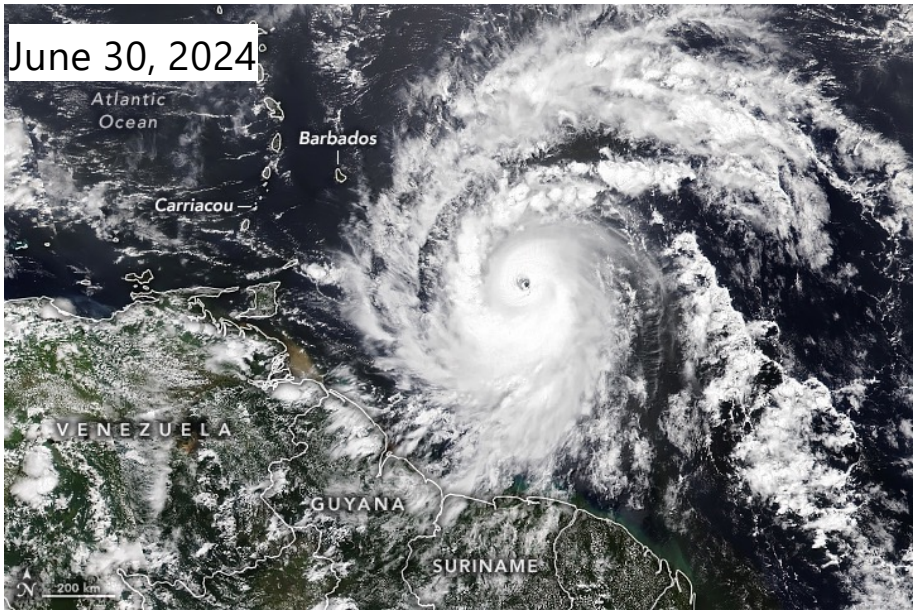
On the morning of July 1, Hurricane Beryl made landfall on Carriacou Island as a Category 4 storm with maximum sustained winds of 150 miles (240 kilometers) per hour.

This image, captured by the VIIRS (Visible Infrared Imaging Radiometer Suite) on NOAA-21, shows Hurricane Beryl at 12:50 p.m. Atlantic Standard Time on June 30, when the eye of the storm was about 300 miles (490 kilometers) southeast of Barbados.

An hour before the image was captured, the National Hurricane Center upgraded Beryl to a Category 4 hurricane with sustained winds of 130 miles per hour.

Beryl formed as a tropical depression in the central tropical Atlantic on June 28 and then became a tropical storm on June 29.

The storm rapidly intensified from a tropical storm to a powerful Category 4 in less than 24 hours. "Rapid intensification" occurs when wind speeds increase by at least 35 miles (56 kilometers) per hour, over 24 hours.



https://earthobservatory.nasa.gov/images/153023/hurricane-beryl-hurtles-into-the-caribbean

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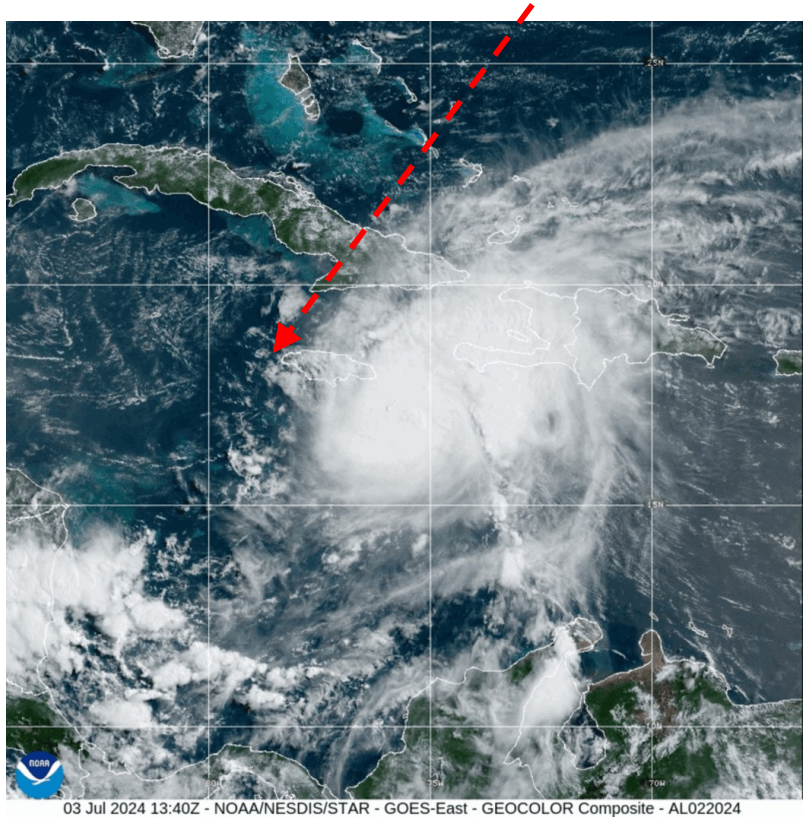
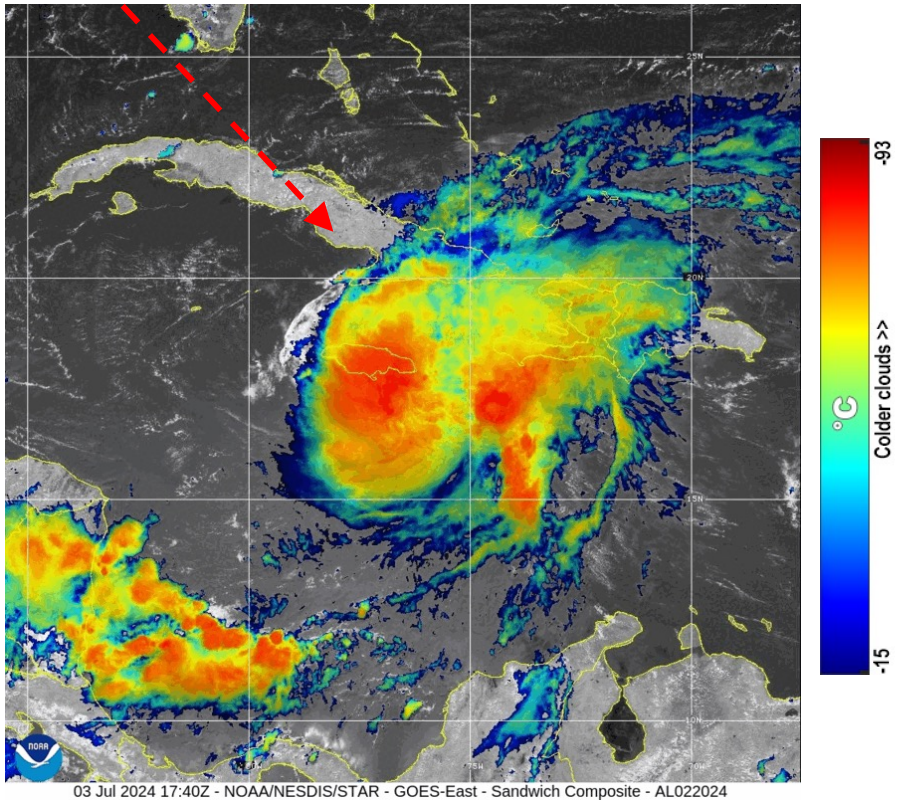
Cold pools and rainband development



03 Jul 2024 13:40Z - NOAA/NESDIS/STAR - GOES-East - GEOCOLOR Composite - AL022024



03 Jul 2024 17:40Z - NOAA/NESDIS/STAR - GOES-East - Sandwich Composite - AL022024

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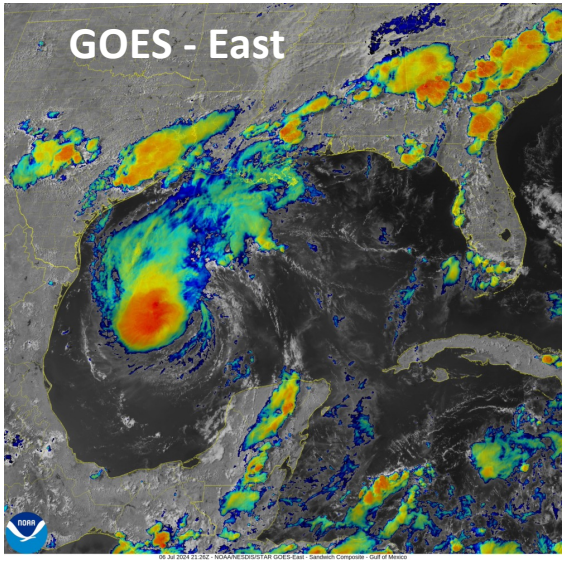
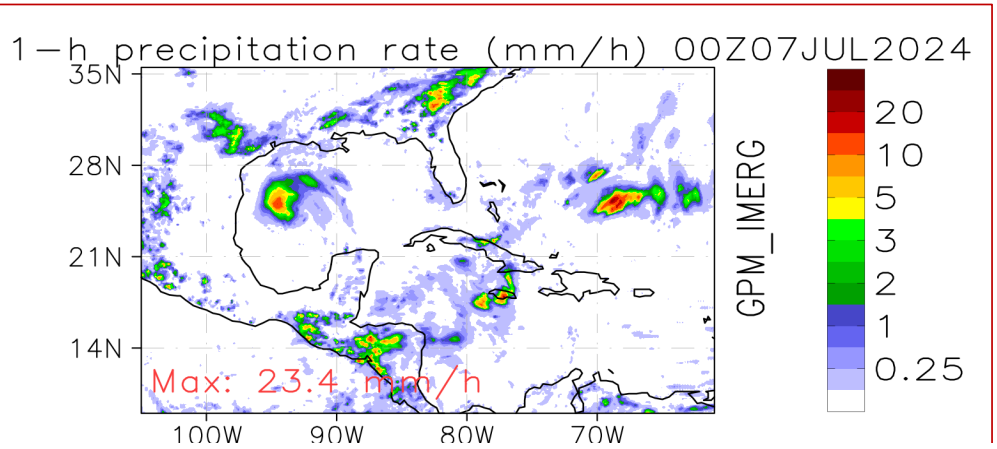
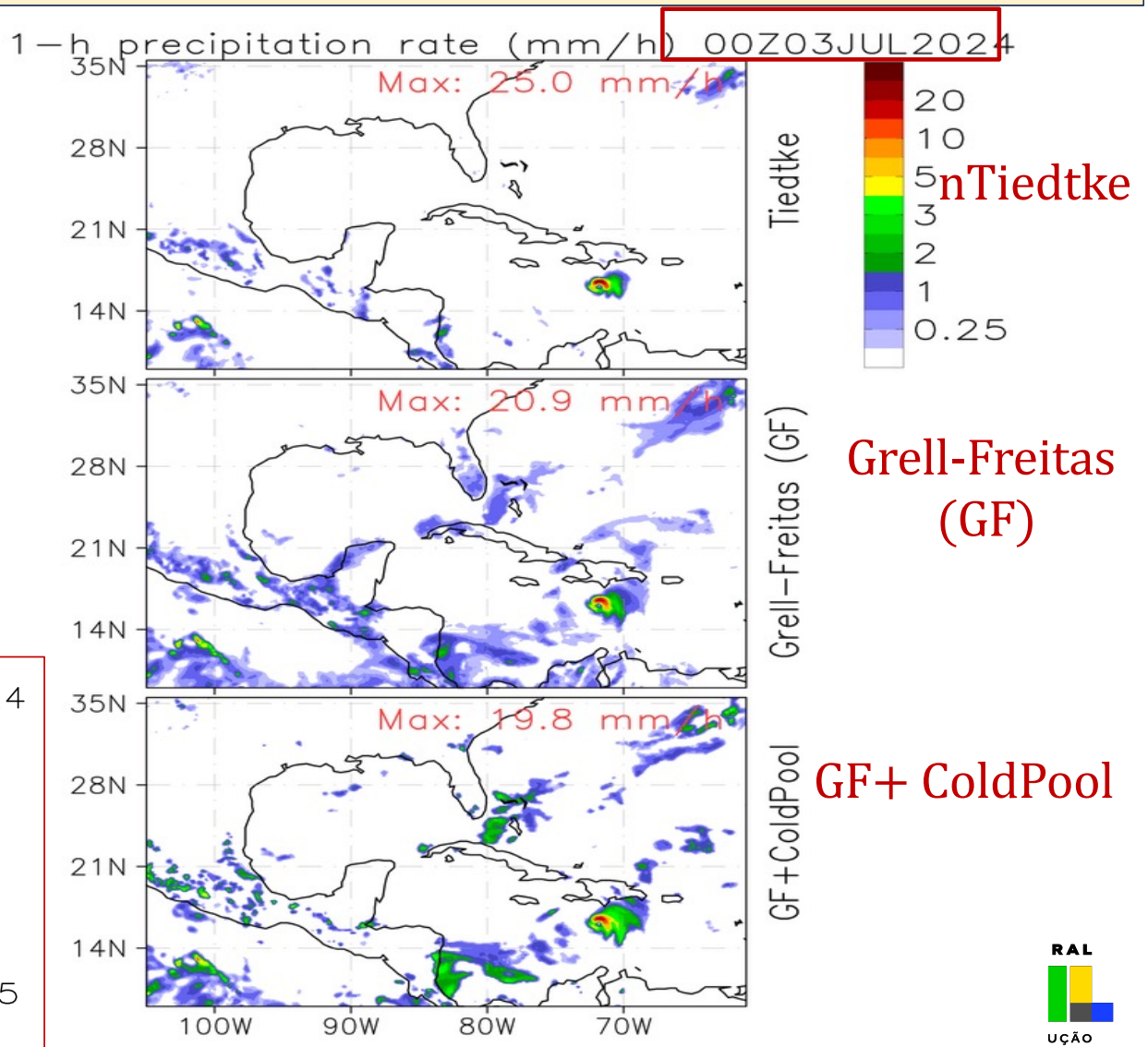
Hurricane Beryl

Horizontal Resolution
x1.2621442 : ~ 15km
00Z03 – 00Z07 July 2024







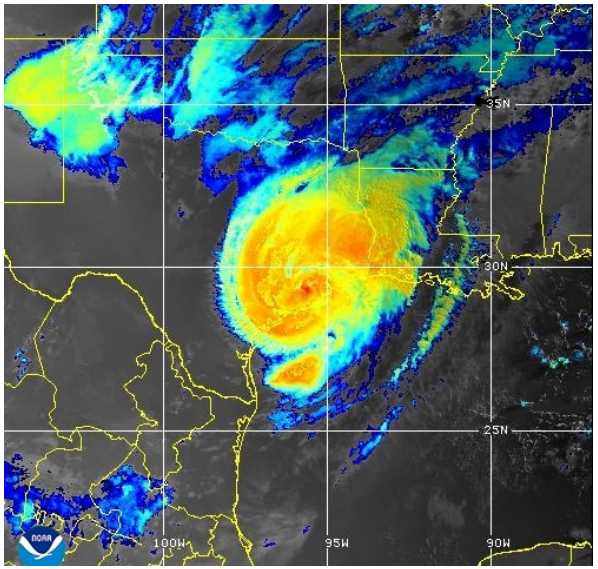
nTiedtke

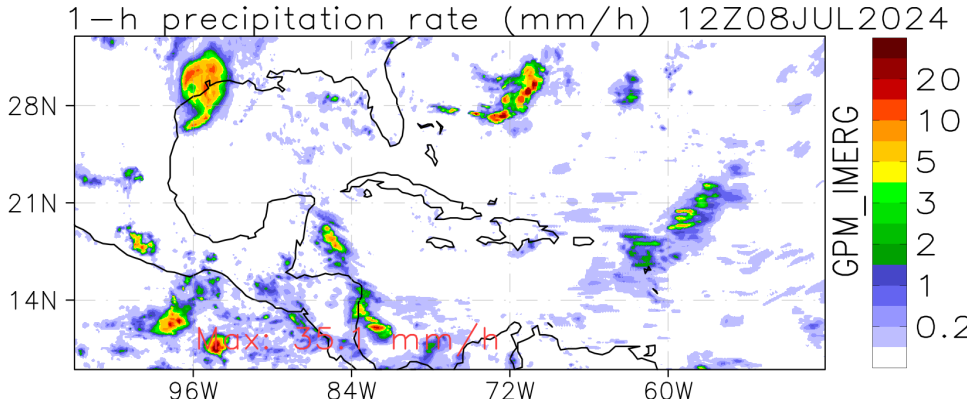
Grell-Freitas (GF)

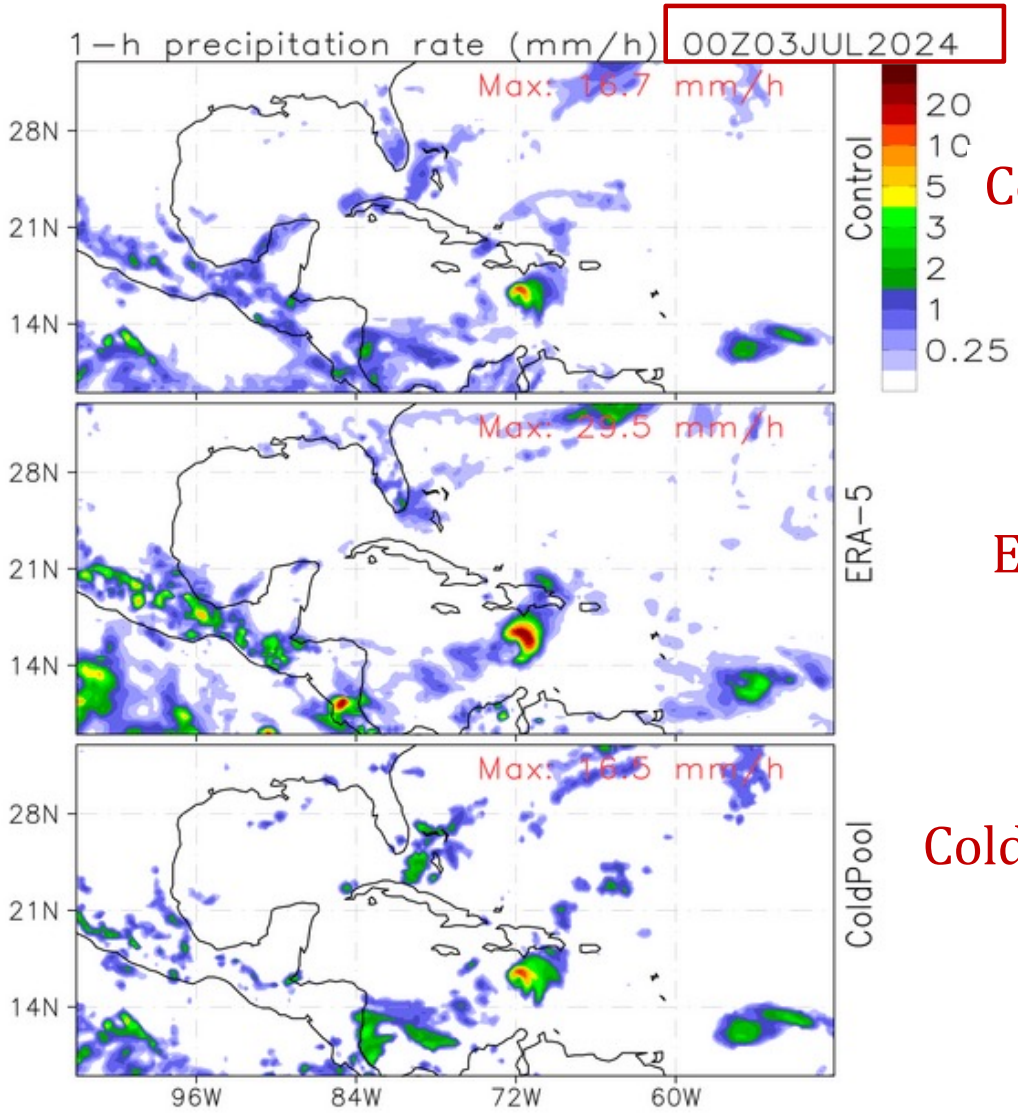
GF+ ColdPool

Horizontal Resolution
x1.655362 : ~ 30km
00Z03 – 12Z08 July 2024

Hurricane Beryl







Control

ERA-5

Cold Pool

What we are doing/planning for the Atmos/Physics component

1. New scare-aware formulation for the GF convection parameterization (3d lateral subsidence spread): INPE + NOAA/GSL
2. WSM6 as the microphysics replacement for the current oversimplified scheme in the GF convection parameterization: S. Freitas
3. PBL dry/moist schemes:
   - Taylor's Theory: Haroldo Campos Velho, P. Kubota
   - Simplified-higher-order-closure–mass-flux (SHOC-MF): Guilherme Machado (PGMET), S. Freitas, P. Kubota
4. EC – Radiation: P. Kubota, R. Souto (LNCC)
5. Physics perturbation methods for ensemble spread : C. Bartarz and J. Gerd
6. Ocean Mixed Layer as in NASA GEOS-5: S. Freitas
7. Biomass Burning + smoke plume rise model: Jaqueline Pereira (PGMET): INPE + NCAR
8. Soil dust aerosols: N. Rosário (UNIFESP), K. Longo (INPE),…
9. Cloud organization + MJO studies: Bianca Fusinato PGMET/ S. Freitas
10. The sensitivity of the hydrological regime simulated by MONAN: Nedilson Ferreira (PGMET), P. Kubota
11. Evaluating the cloud microphysics options in MPAS: Enver
12. Implementing the METplus for model evaluation: Ariane, J. Pablo, Marcelo (INPE)
13. Updating the surface characterization and evaluating surface fluxes over the land: A. Manzi, P. Kubota, J. Gerd
14. Implementing output in GRIB2/3 format: S. Henrique (INPE) F. Li (ECMWF)
15. I probably forgot other initiatives.
16. What is your plan? Let us know if you have plans and if we can help in any way.

More work in being planned

1. Data assimilation with the JEDI framework (DAS Group @ INPE and collaborators)
2. AI/ML (H. Campos Velho, Otávio Medeiros (PGMET), Marcelo Paiva)
3. Ocean/Sea Ice components (Ocean group @ INPE and collaborators)

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Scientific Computing Group [GCC]

GCC – Grupo de Computação Científica (Scientific Computing Group)

DIMNT - Divisão de Modelagem Numérica do Sistema Terrestre (Earth System Numerical Modeling Division)

Carlos Renato, Denis Eiras, Eduardo Khamis, João Messias, Kleucio Claudio, Luiz F. Rodrigues e Marcelo Paiva.

GCC-LNCC – Laboratório Nacional de Computação Científica
(Scientific Computing National Laboratory – GCC Collaborators)

Eduardo (Bidú) e Roberto P. Souto.

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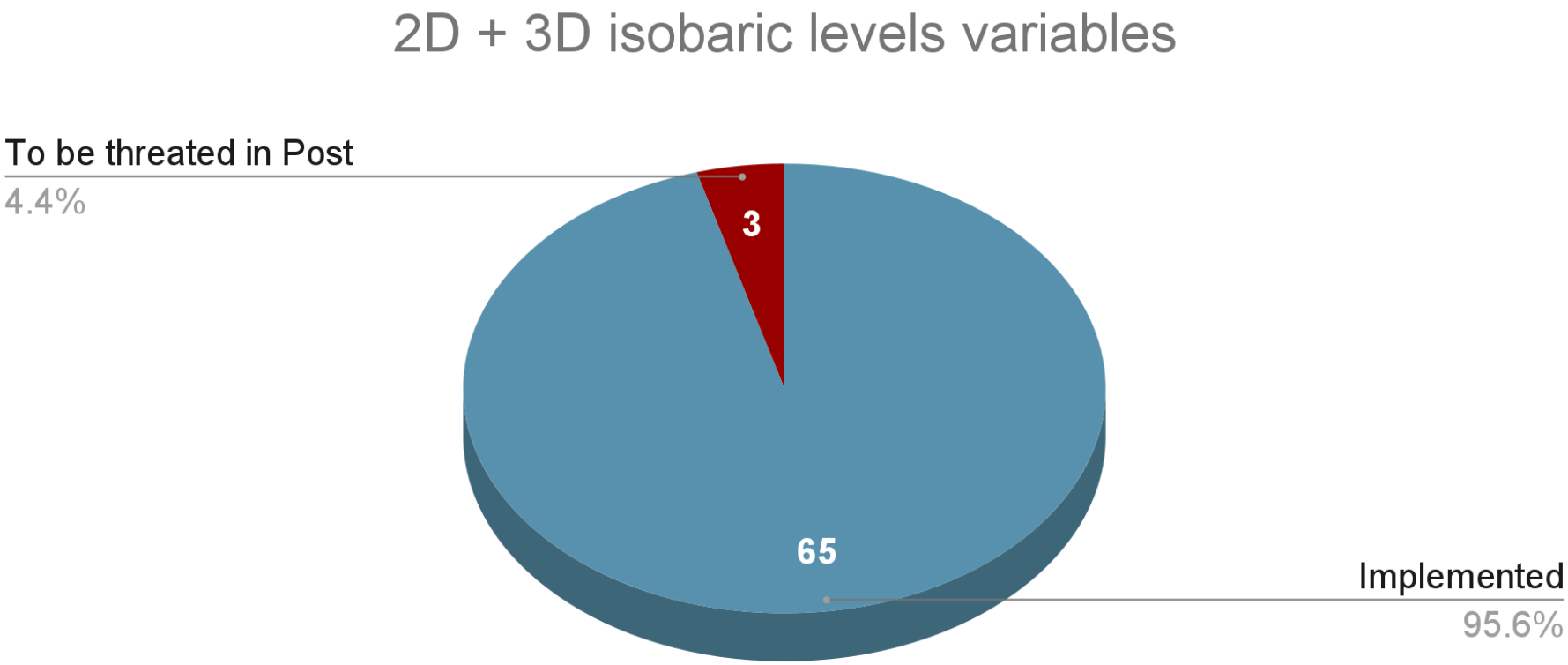
MONAN Versions

- Version 0.1.0 - Initial version structure based on MPAS 8.0.1 Model. [9/out/2023]
- Version 0.2.0 - Included variables and new isobaric levels. [12/mar/2024]
- Version 0.3.0 - Included levels and variables. [5/abr/2024]
- Version 0.4.0 - Included variables; update MPAS-v8.0.2; bug fixes. [19/abr/2024]
- Version 0.5.0 - Included variables. [10/abr/2024]
- Version 0.5.1 - Bug fix: zgeo variable. [17/mai/2024]
- Version 0.6.0 - Update MPAS-V8.1.0. [23/mai/2024]
- **Release 1.0.0** - New GF Parametrization and new cloud fraction scheme [02/jul/2024].

Release 1.0.0 variables



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Release 1.0.0 variables

- 34 – 2D variables
- 31 – 3D variables - now using 22 isobaric levels

src/core_atmosphere/diagnostics/mpas_isobaric_diagnostics.F

…

```
        if (need_t_isobaric) then
            t_iso_levels(:) = (/1500.0, 2000.0, 3000.0, 5000.0, &
                7000.0, 10000.0, 15000.0, 20000.0, &
                25000.0, 30000.0, 40000.0, 50000.0, &
                60000.0, 70000.0, 82500.0, 85000.0, &
                87500.0, 90000.0, 92500.0, 95000.0, &
                97500.0, 100000.0/)
```

Release 1.0.0 variables

src/core_atmosphere/diagnostics/Registry_isobaric.xml

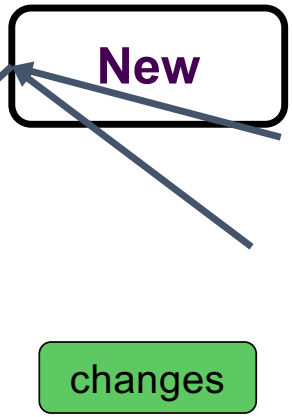
```
        <var name="zgeo_15hPa" type="real" dimensions="nCells Time" units="m"
             description="Geopotential height vertically interpolated to 15 hPa"/>

        <var name="zgeo_20hPa" type="real" dimensions="nCells Time" units="m"
             description="Geopotential height vertically interpolated to 20 hPa"/>

        <var name="zgeo_30hPa" type="real" dimensions="nCells Time" units="m"
             description="Geopotential height vertically interpolated to 30 hPa"/>
```

Release 1.0.0 new parametrizations

config_physics_suite	mesoscale_reference	mesoscale_reference_monan
config_microp_scheme	mp_wsm6	mp_wsm6
config_convection_scheme	cu_ntiedtke	cu_gf_monan
config_pbl_scheme	bl_ysu	bl_mynn
config_gwdo_scheme	bl_ysu_gwdo	bl_ysu_gwdo
config_radt_lw_scheme	rrtmg_lw	rrtmg_lw
config_radt_sw_scheme	rrtmg_sw	rrtmg_sw
config_radt_cld_scheme	cld_fraction	cld_fraction_monan
config_sfclayer_scheme	sf_monin_obukhov	sf_mynn
config_lsm_scheme	sf_noah	sf_noah



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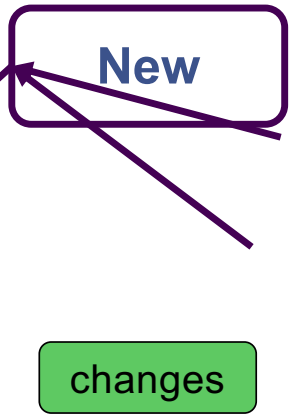
Release 1.0.0 new parametrizations

config_physics_suite	convection_permitting	convection_permitting_monan
config_microp_scheme	mp_thompson	mp_thompson
config_convection_scheme	cu_grell_freitas	cu_gf_monan
config_pbl_scheme	bl_mynn	bl_mynn
config_gwdo_scheme	bl_ysu_gwdo	bl_ysu_gwdo
config_radt_lw_scheme	rrtmg_lw	rrtmg_lw
config_radt_sw_scheme	rrtmg_sw	rrtmg_sw
config_radt_cld_scheme	cld_fraction	cld_fraction_monan
config_sfclayer_scheme	sf_mynn	sf_mynn
config_lsm_scheme	sf_noah	sf_noah



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Post Processing

convert_mpas fork: https://github.com/monanadmin/convert_mpas

- Convert model output to lat lon. Enabled to open in grADS

```
&config_convert_mpas
 verticalCoord = 'MPAS_Model'    !  'MPAS_Model' or 'Pressure '
 nVertLevels = 55
 nOznLevels  = 59
 nMonths     = 12
 nSoilLevels = 4
 nIsobaricLev= 27
/
```

group_levels.py

- Stack all variables on Z dimension (e.g. uzonal_15hPa, uzonal_20hPa)

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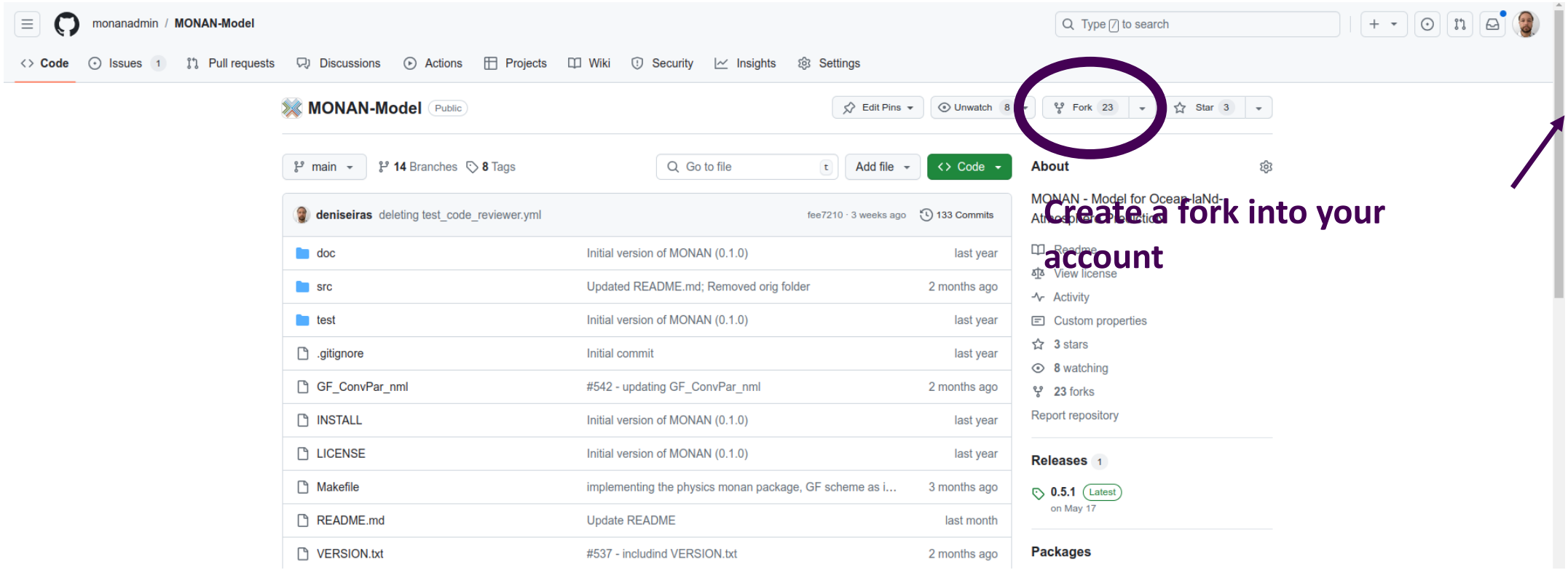
How to contribute to MONAN Model

1. **Fork the MONAN-Model repository to your Github account**
2. Develop, test your code in develop branch
3. Ensure the model works as before when not using your part of the code
4. Synchronize your fork with the oficial repository
5. Commit and push to your fork
6. Create a Pull Request from your account

Contributing to MONAN



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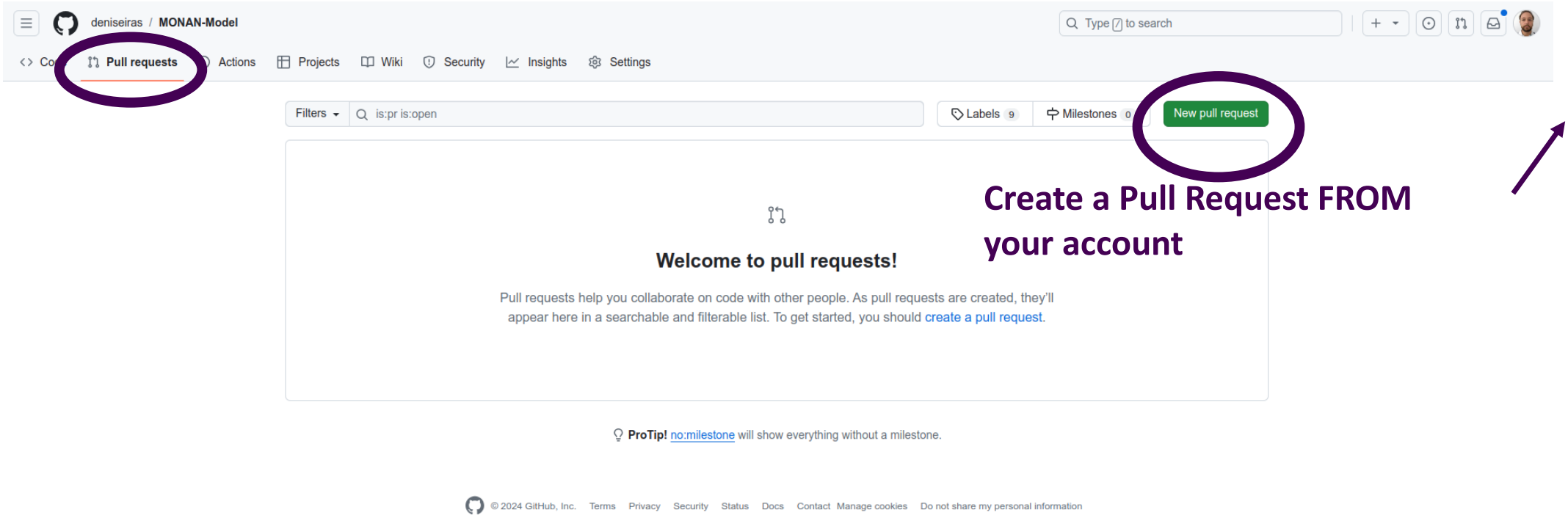

Create a Pull Request FROM your account

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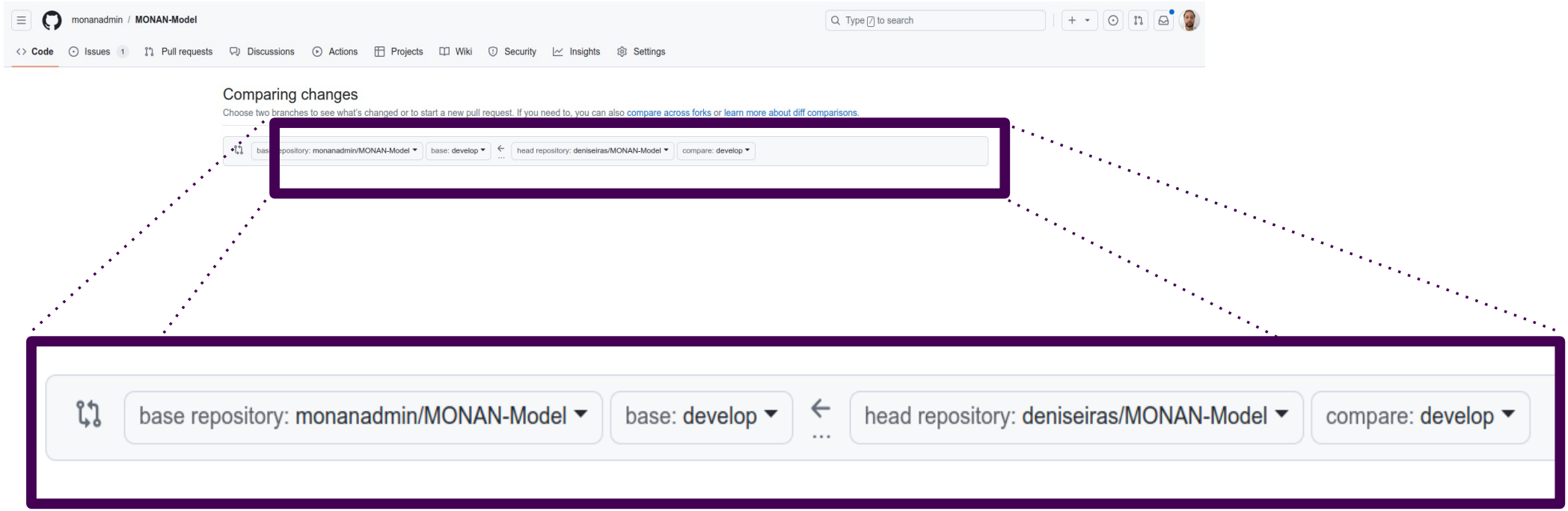

TO develop official repository

FROM your develop branch

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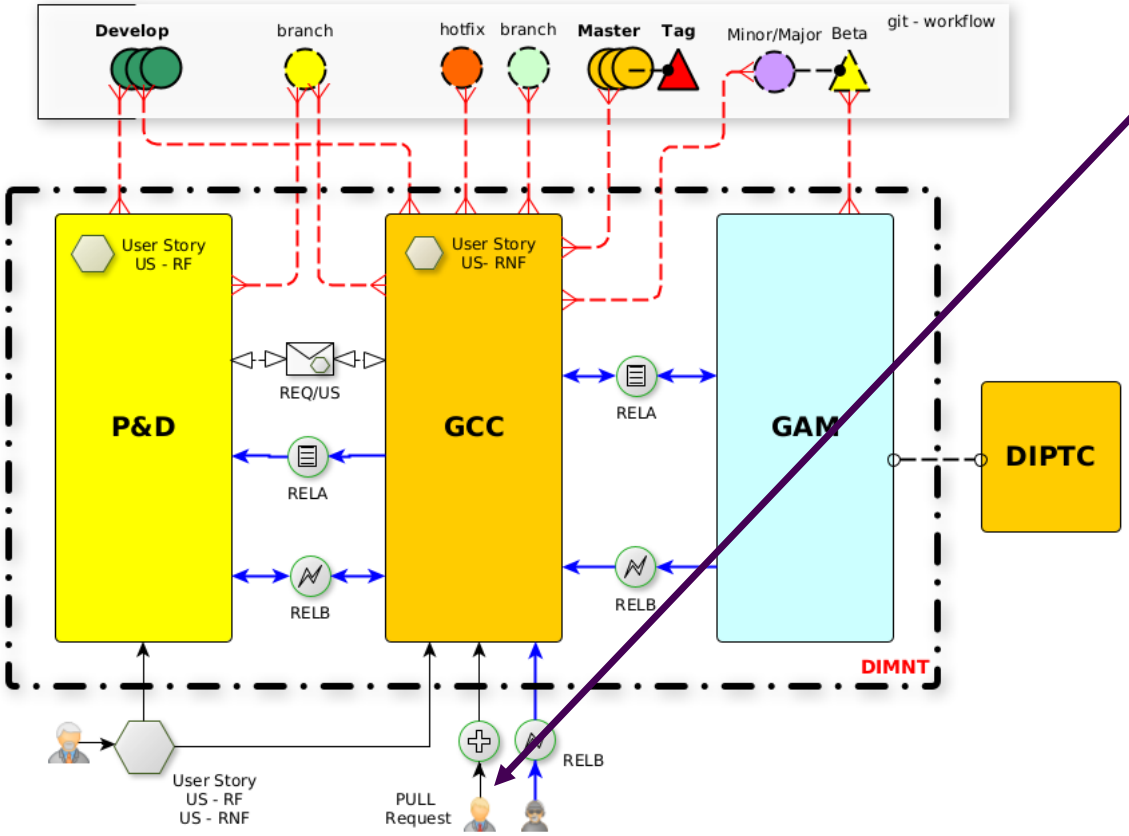

1. **Pull Request from contributor**

2. GCC validation
- Automated and Manual Code Review
- Regression Tests: Why changes ?
- HPC tests and tuning
- Feedback to contributor

1) GAM (Model Evaluation Group)
- Evaluate the new feature
- Feedback to contributor

1. Pull Request accepted

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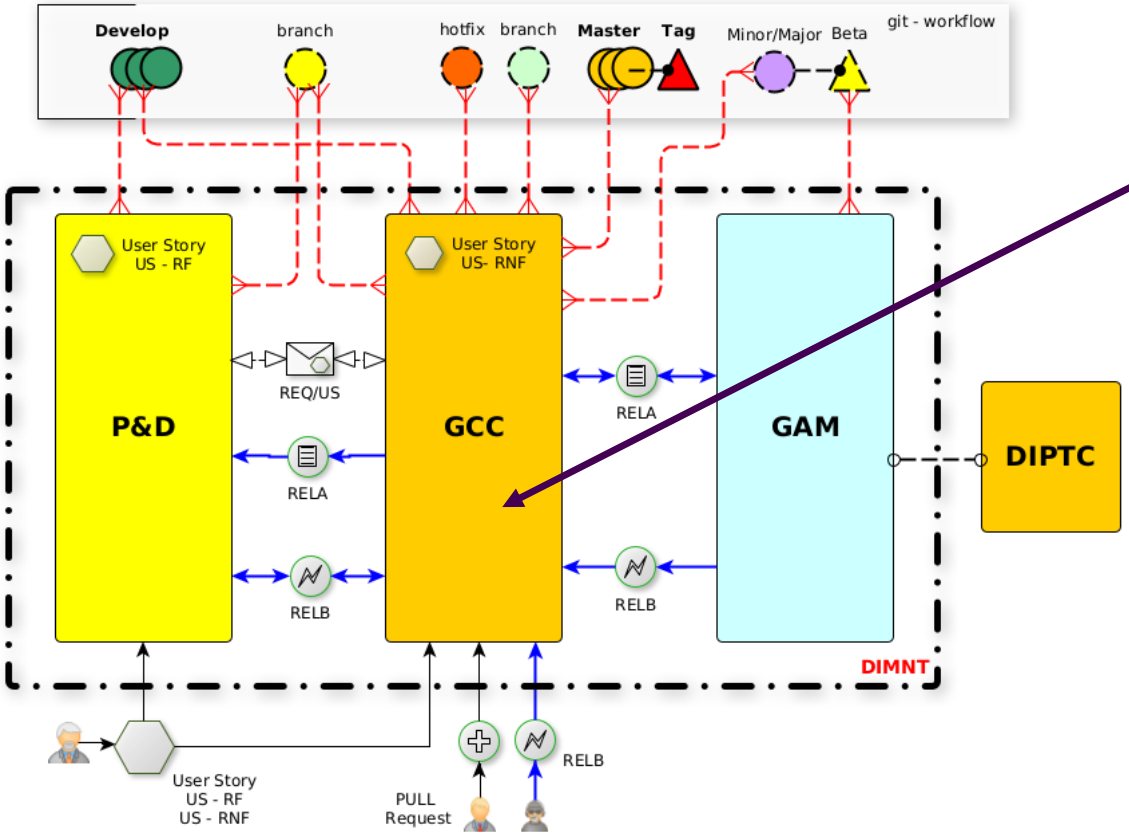

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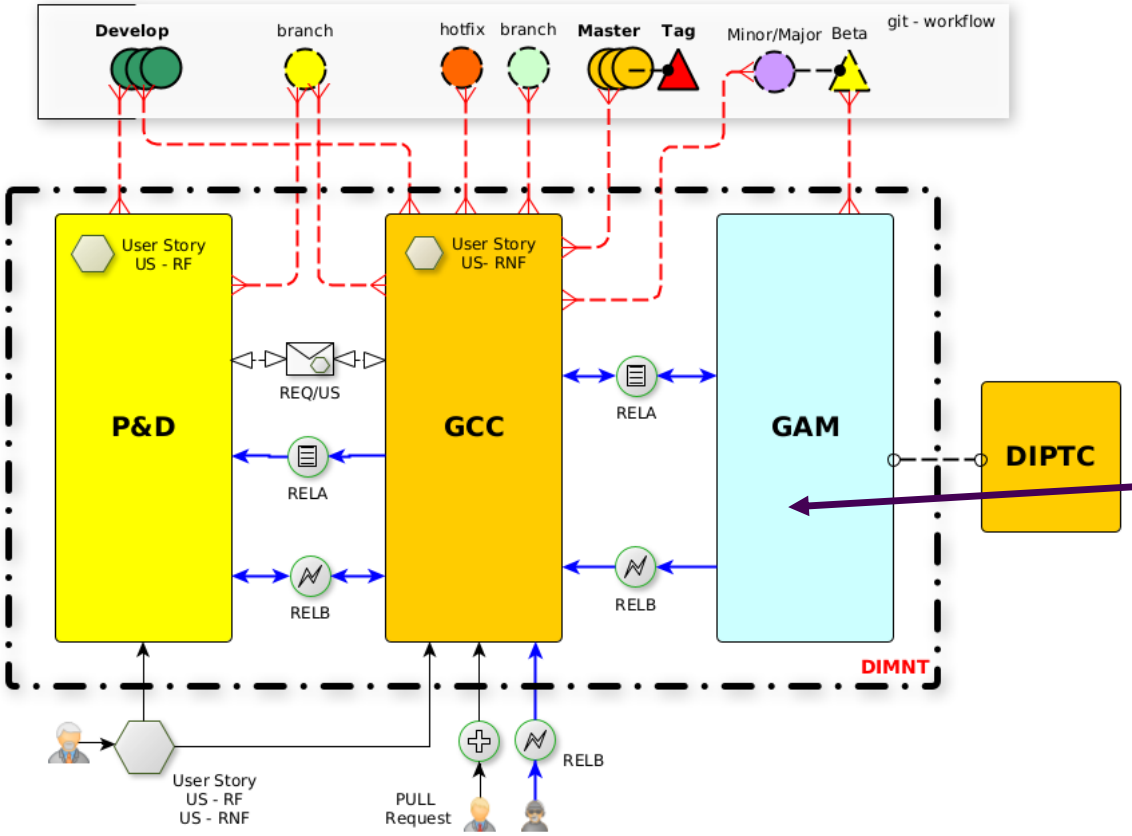

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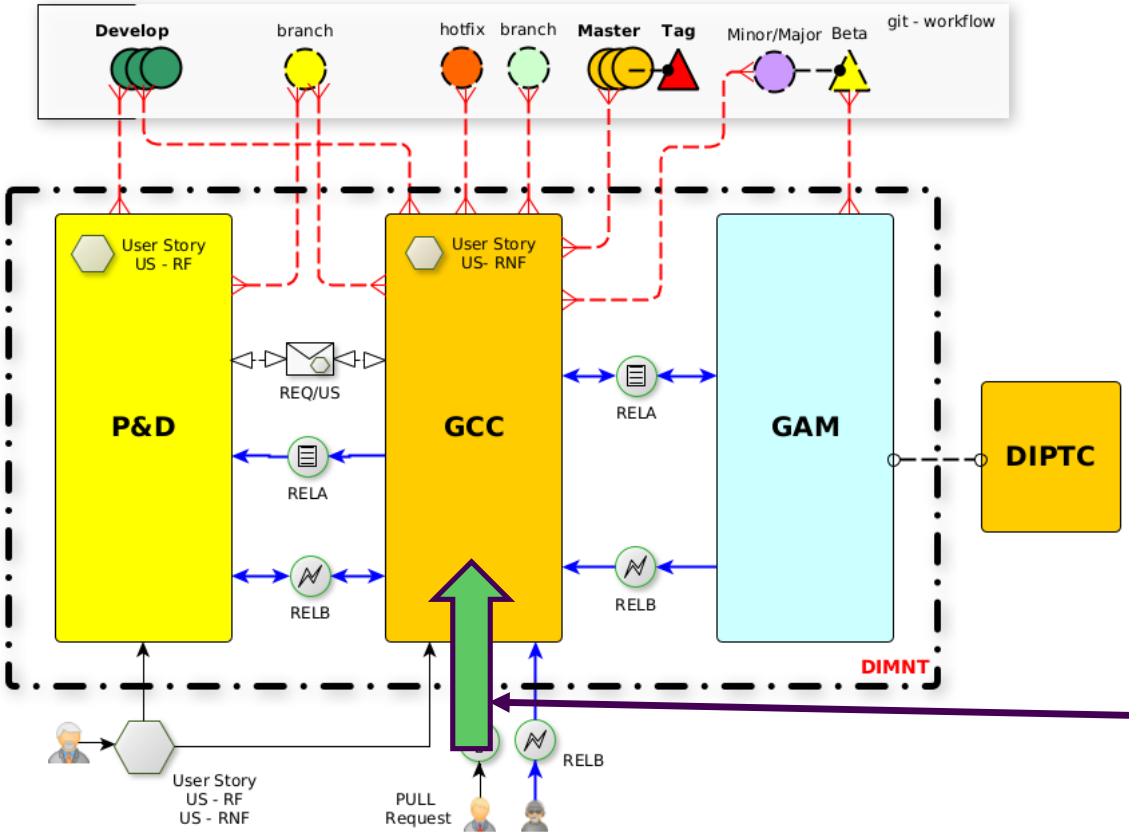

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Continuous Development – Continuous Tests (CD-CT)

Purpose: MONAN continuous evaluation and package distribution to operations

Running @ Egeon cluster

MONAN 1.0.0:	Global forecast 24 Km resolution – GFS data
Compiler:	GNU – O3 optimization
MPI processes:	1024 over 16 nodes (64 cores / node)
10 days prediction:	75 minutes – 8x output / prediction day
Model output:	694 vars 2D (3D vars 22 levels, each level = 1 var) **– 215GB**
Post output:	34 2D vars , 30 3D vars – **55 GB**

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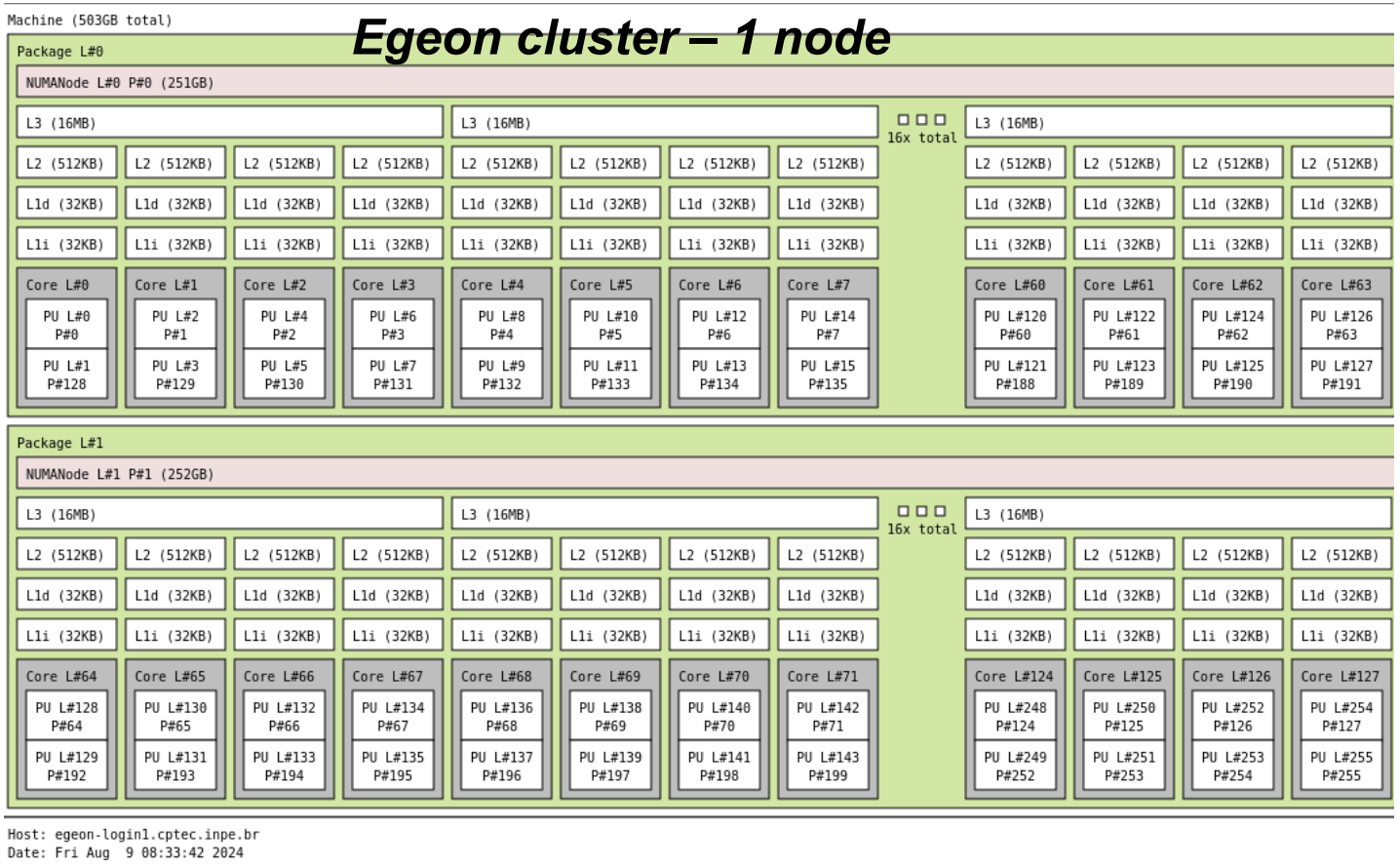

Network: Infiniband

Filesystem: beegfs 466T

32 computation nodes

1 node:

- 2x AMD EPYC 7H12 64 cores
- 503 GB RAM

1 core:

- L1 cache 32KB
- L2 cache 512KB

L3 cache (4 cores) 16MB

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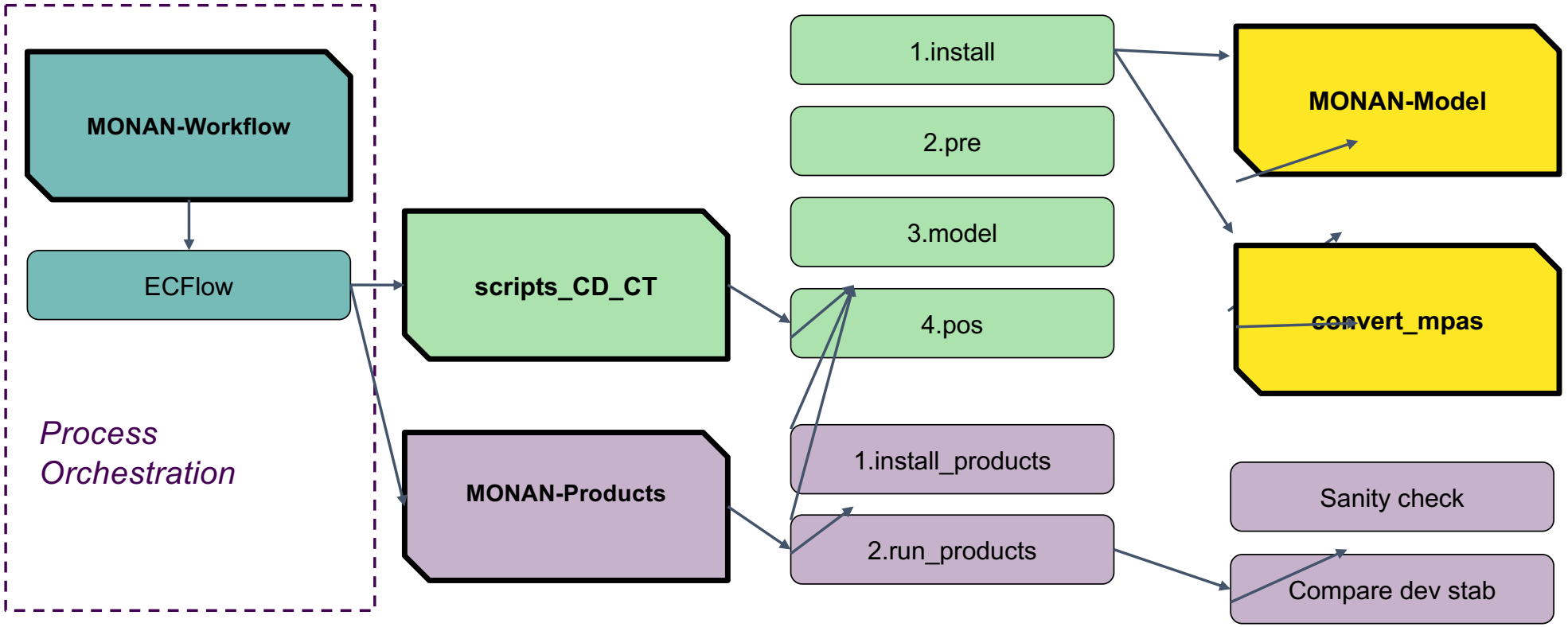

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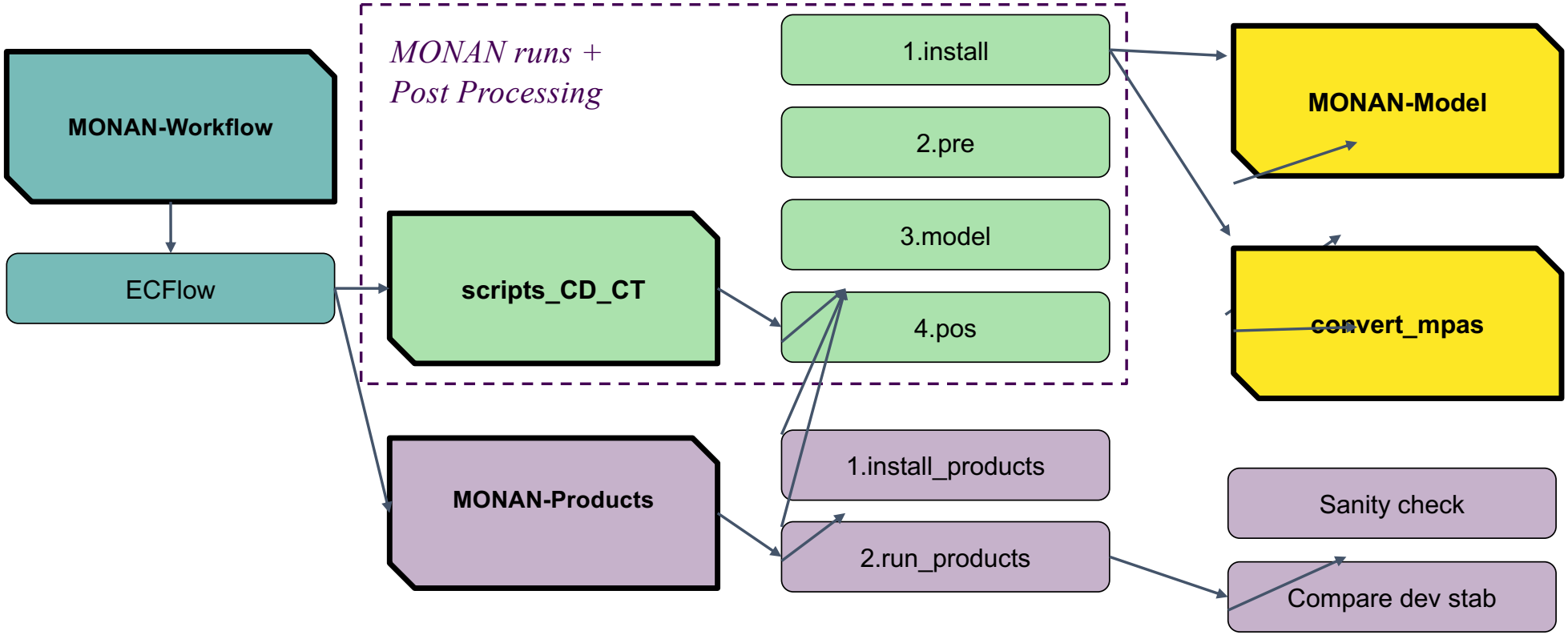

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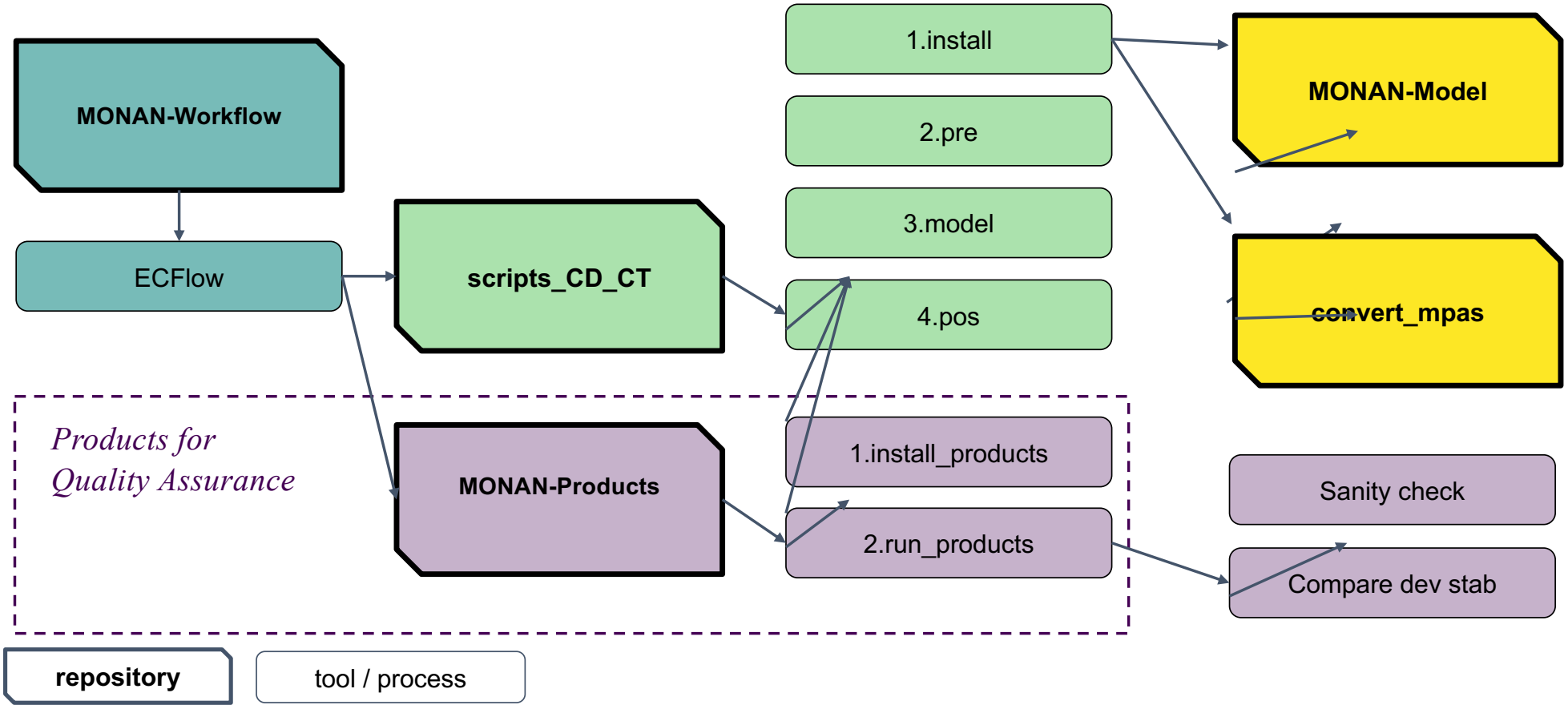

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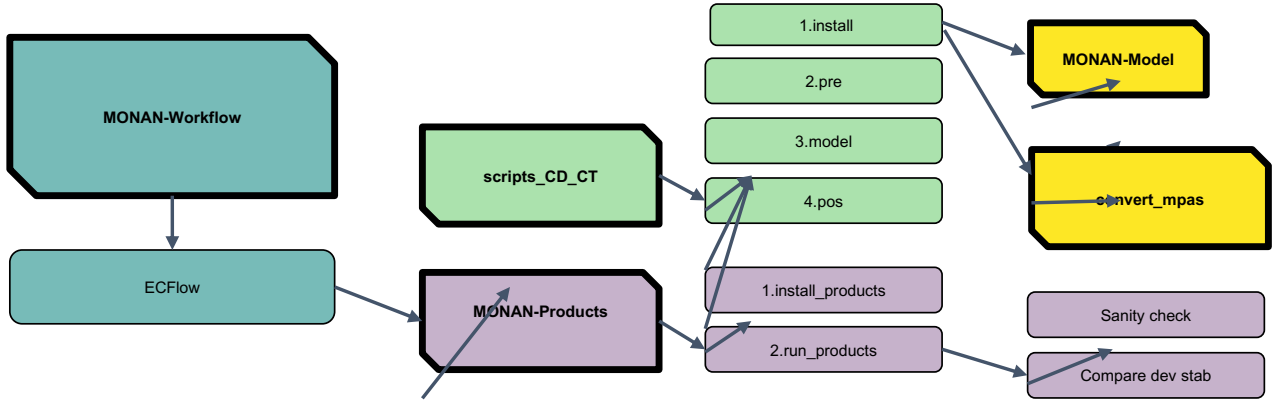

Stage	FCST (h)	MONAN-Workflow	scripts_CD-CT	MONAN-Products	MONAN-Model	convert_mpas (fork)
Stable	240	Develop *ToDo: version*	0.2.1	Develop ToDo: version	1.0.0	1.0.0
Dev	240	Cron *ToDo: develop*	Develop	N/A	Develop	Develop

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Sanity Check

MONAN

Start Date: 07/06/2024

Forecast Date: 08/06/2024

Forecast hour: 09:00

☐ AMS ☐ ERA5

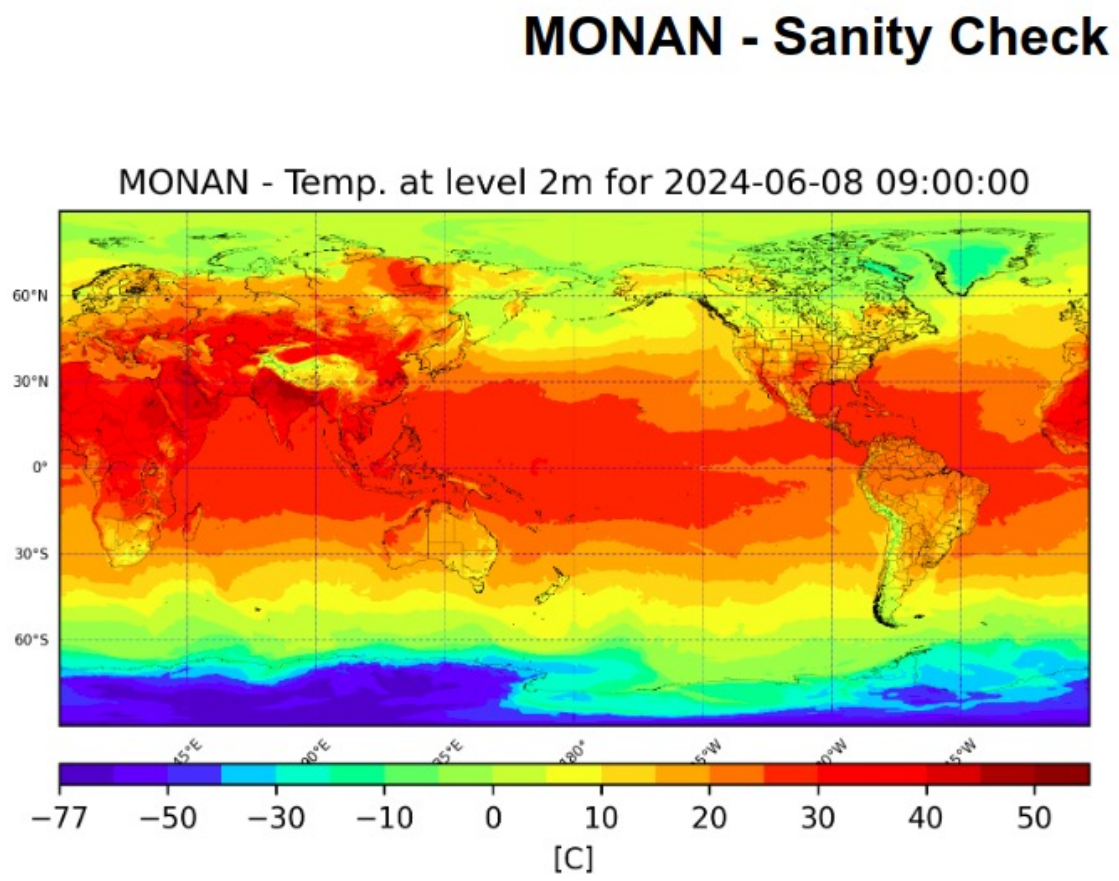
Resolução:
x1024002

Levels Model:
55

Variable:
t2m

Level:
2D

Show



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Compare Dev x Stable

```
7. sst

/mnt/beegfs/eduardo.khamis/issues/511/scripts_CD-CT/dataout/2024020100/Post/MONAN_DIAG_G_POS_GFS_2024020100.00.00.x1024002L55.nc (sst)
  Mean      : 277.84808
  Min,      : 213.74771
  Max.      : 325.1219
  Std. Dev. : 20.605488
  No. elements. : 1297800
/mnt/beegfs/eduardo.khamis/is
  Mean      : 277.84808
  Min,      : 213.74771
  Max.      : 325.1219
  Std. Dev. : 20.605488
  No. elements. : 1297800

/mnt/beegfs/eduardo.khamis/issues/511/scripts_CD-CT/dataout/2024020100/Post/MONAN_DIAG_G_POS_GFS_2024020100.00.00.x1024002L55.nc (sst)
/mnt/beegfs/eduardo.khamis/issues/511/scripts_CD-CT/dataout/2024020100/Post_1.0.0.GF.new/MONAN_DIAG_G_POS_GFS_2024020100.00.00.x1024002L55.nc (sst)
  Difference number of elements     : 1297800
  Difference Mean,Min.,Max.,St. dev : 0.0, 0.0, 0.0, 0.0
```

```
Difference number of elements     : 1297800
Difference Mean,Min.,Max.,St. dev : 0.0, 0.0, 0.0, 0.0
```

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Roadmap

Dev Infrastructure

Operations start

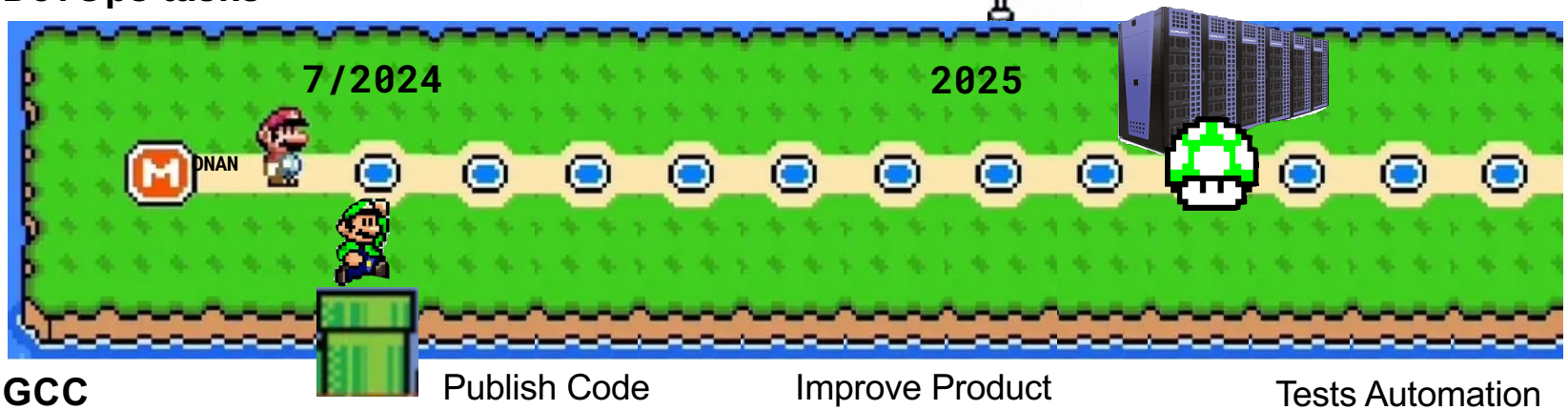
New supercomputer tasks

GCC DevOps tasks

v1.0.0

HPC Tuning

v1.?.?



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GCC Internal tasks

Publish Code Integration Rules

Improve Product Workflow Processes

Tests Automation

Scripts for running (community)

Code Review Automation

Refactoring new features from community

New technologies AI, GPUs …

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That’s All

Thank you !!!

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