The Brazilian developments on the Regional Atmospheric Modeling System

Unified Version (5.2)

- **Atmos. Chemistry, Physical and Dynamics Aspects,**
- **Operational Products and Evaluation,**
- **Report of 13 years at CPTEC/INPE.**

S. R. Freitas, K. M. Longo, L. F. Rodrigues
A. Santos, C. Santos e Silva, C. Pavani, D. França, D. Moreira, F. Batista,
F. Cavalcante, G. Pereira, G. Ferrada, G. Camponogara, I. Menezes, J. Larise, M. Gácita,
M. Alonso, M. Zarzur, N. Rosário, R. Fonseca, R. Stockler, R. Siqueira, R. Braz, V. Oliveira.

http://meioambiente.cptec.inpe.br

INPE

CPTEC

MGMAI
Grupo de Modelagem da Atmosfera e Interfaces

Outline

- Operational products and evaluation of previous version (5.0) and of the new version (5.2)
- Some physical and dynamics aspects of version 5.2
- Brief report of 13 years at CPTEC/INPE
- Network of collaborators and developers

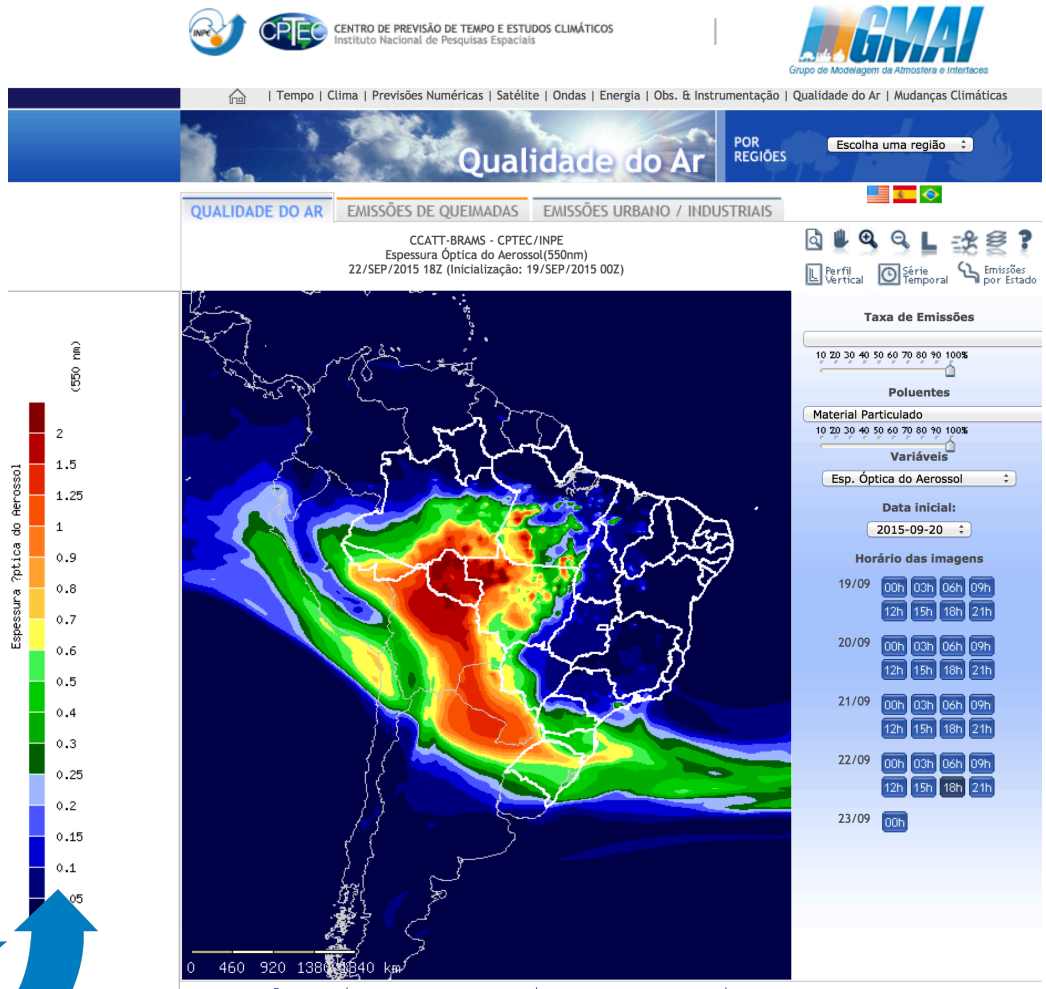
Operational Integrated Air Quality and Weather Forecasts

Since March 2003

BRAMS
RELEASE
BRAMS + CCATT + JULES

AOD @ 550 nm

Forecast valid for 18 UTC 22 SEP 2015



http://meioambiente.cptec.inpe.br

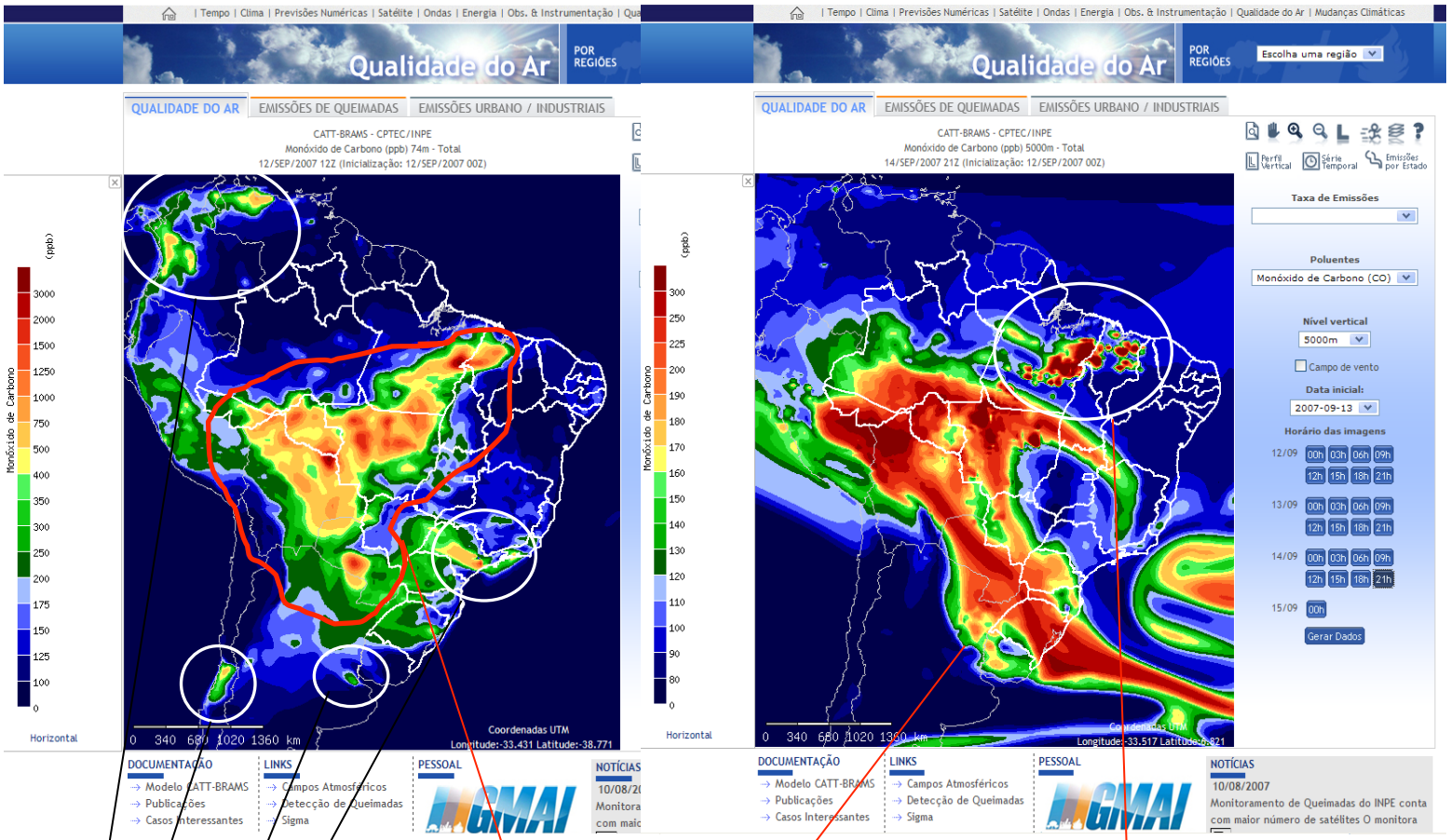
Provides:

- ✓ Weather+air quality FCT
- ✓ (CO, NOx, O3, PM2.5, AOD)
- ✓ 24 h + 72h fct
- ✓ 25 km grid spacing

INPE

Real Time Air Quality and Weather Forecasts for South America
Since March 2003

Surface level CO (ppbv) 12Z-12SEP2007 500 hPa CO (ppbv)



Mega Cities pollution

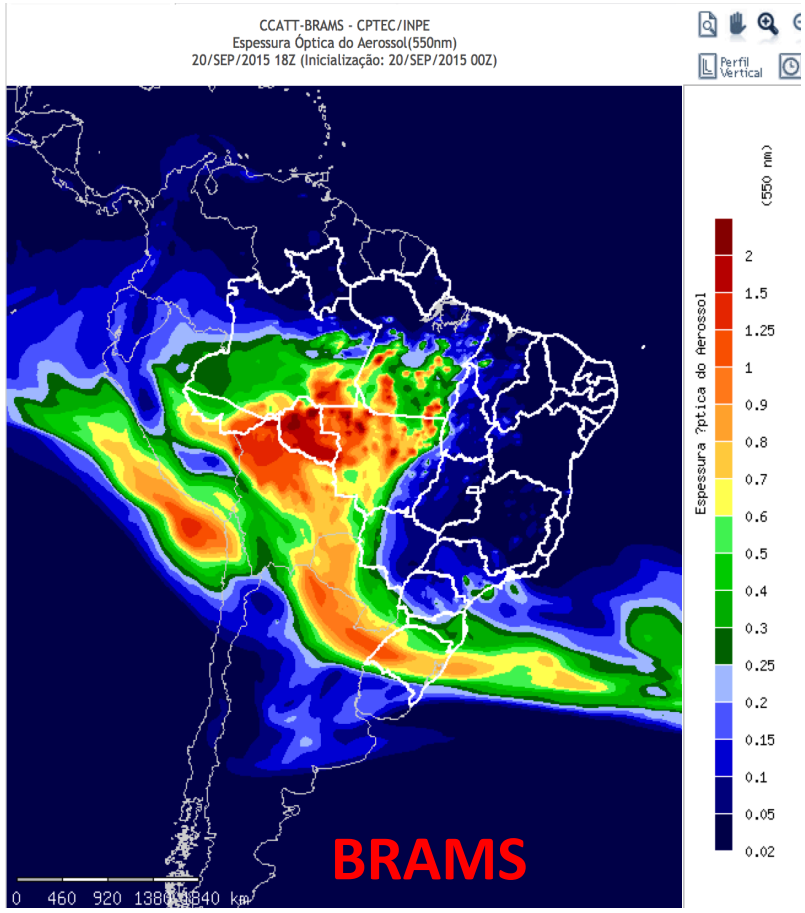
Old biomass burning pollution plumes

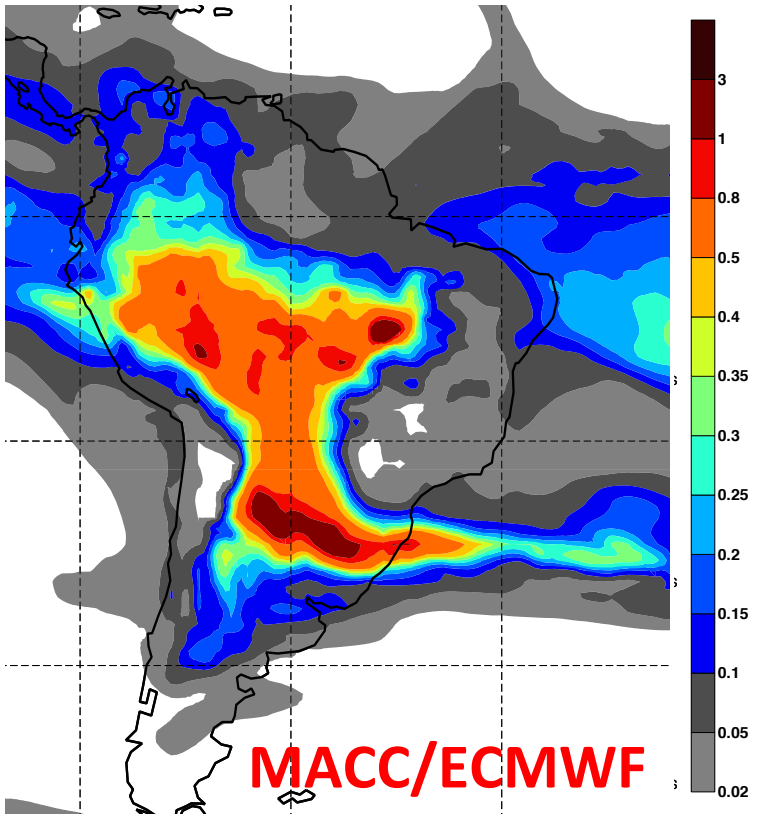
new fresh plumes injected by pyrocumulus

A visual comparison between BRAMS and MACC/ECMWF forecast

AOD at 550nm

Init: 00UTC 20SEP2015 – FCT 18UTC 20SEP2015





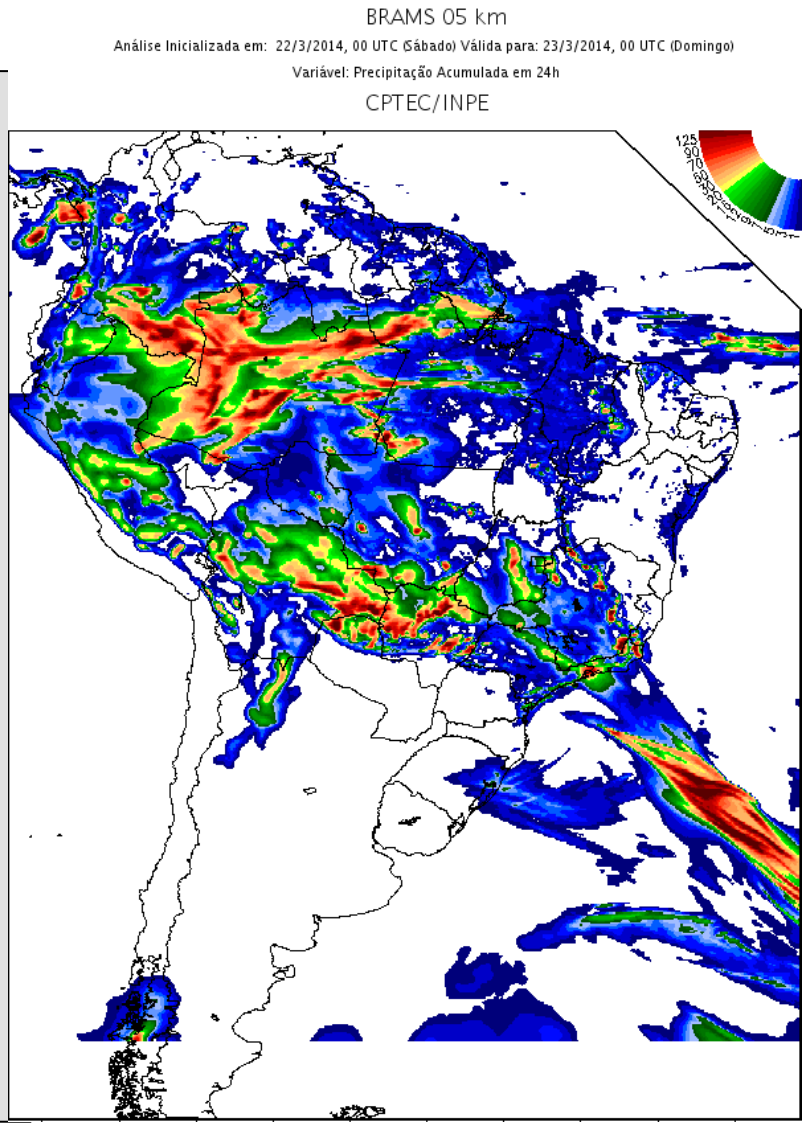
(Color scales are not the same)

http://meioambiente.cptec.inpe.br/ http://www.gmes-atmosphere.eu

Regional weather forecast for South America on 5km grid spacing with BRAMS: Since January 2013

- Grid spacing:
  - Horizontal: 5 km x 5 km.
  - Vertical: 50 to 800 meters
- Time step: 15 seconds

- Model domain:
  - # grid points: 1360 x 1489 x 55 ~ 100 x 10^6
  - Model top at 21 km height ASL
- Forecast length:
  - 3 ½ days, starting at 00, 12 UTC.
- Execution time :
  - 20 mn on 9600 cores produces 1 day forecast
  - I/O is the biggest bottleneck.
- Physics:
  - MY 2.5 turbulence scheme
  - 2-moments cloud microphysics with 7 water species.
  - CARMA long/short wave radiation scheme
  - Grell and Freitas convective parameterization
  - JULES surface scheme
  - IC/BC from interpolation of GFS model forecast.

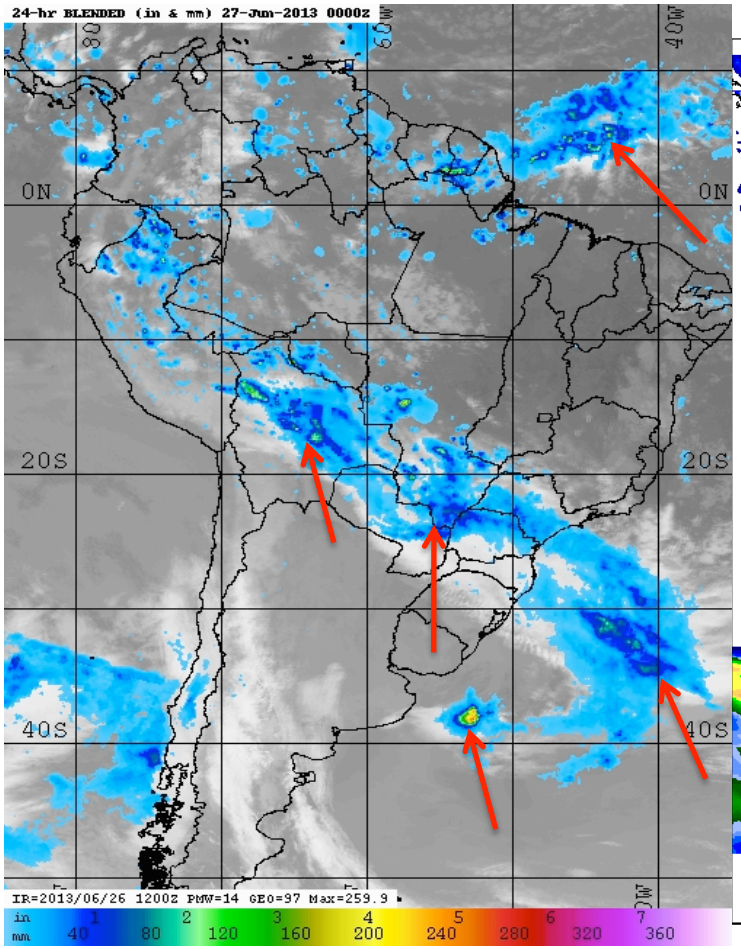


An example of visual comparison of the 24-h accum. rainfall TRMM x BRAMS 5 km

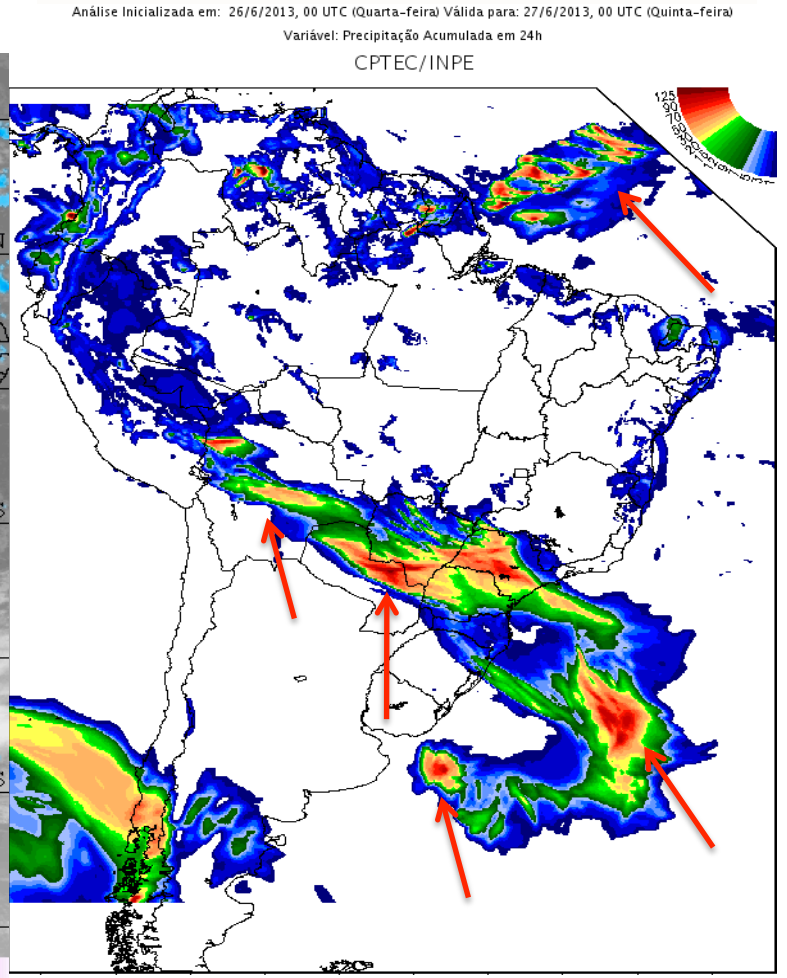
Real-time forecast for 00 UTC 27JUN2013

BRAMS
RELEASE
BRAMS + CCATT + JULES

Rainfall estimated by TRMM



BRAMS 5 km Forecast

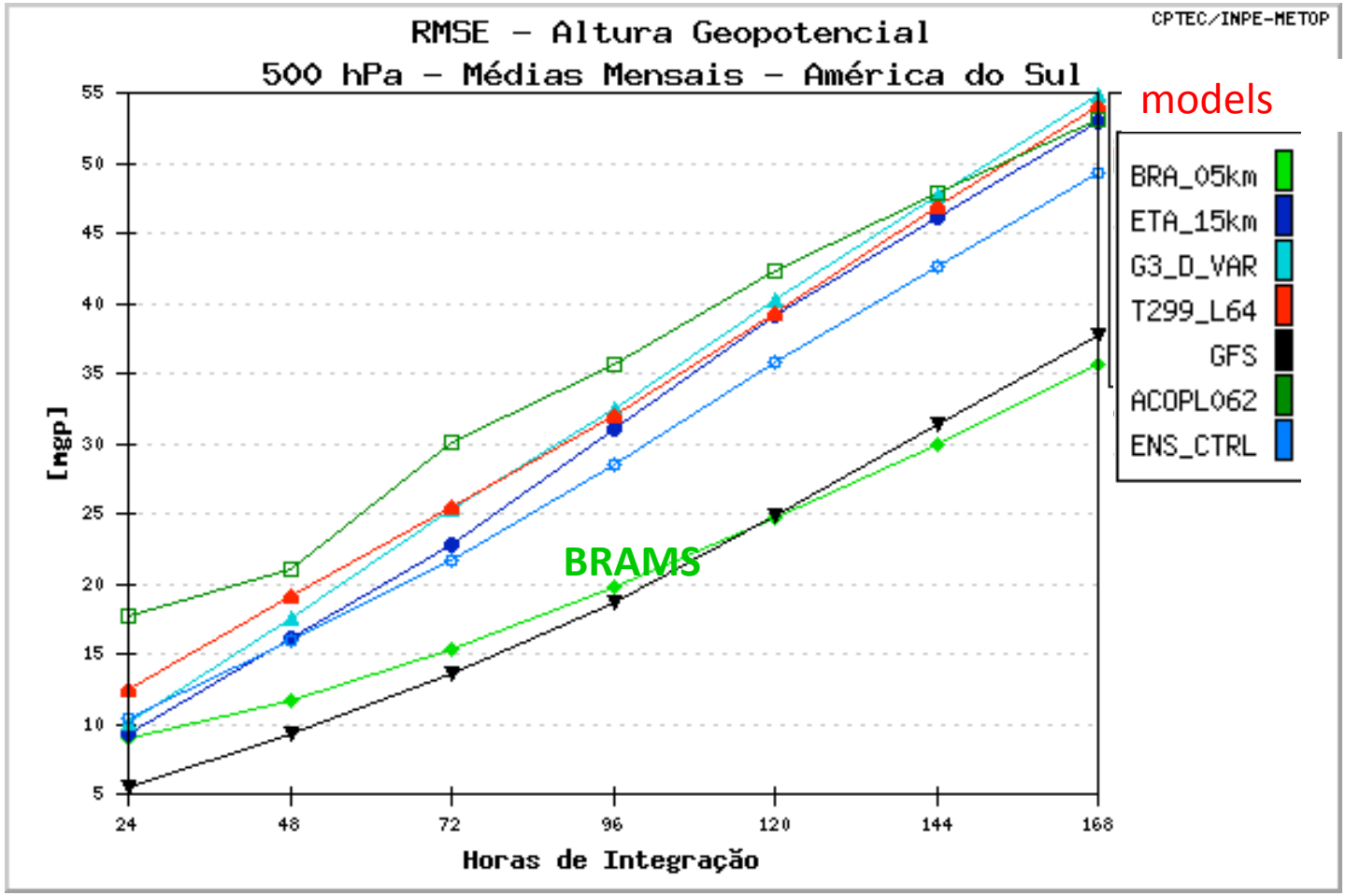


INPE

Quantitative Evaluation of BRAMS version 5.0

(Operational implementation in January 2013)

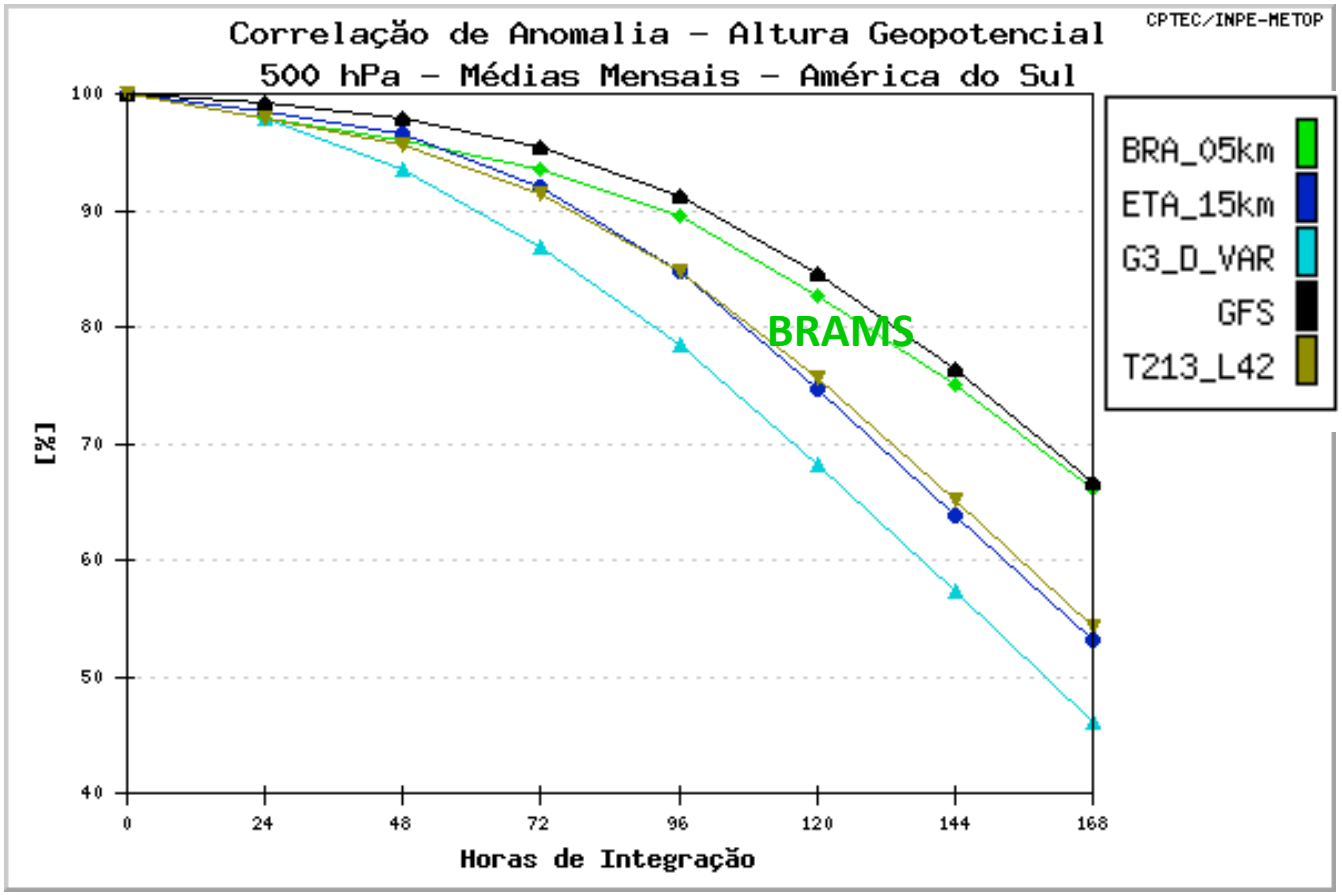
RMSE
Geopotential Height at 500 hPa



Dados de 2013 a 2015 às 00 e 12 UTC

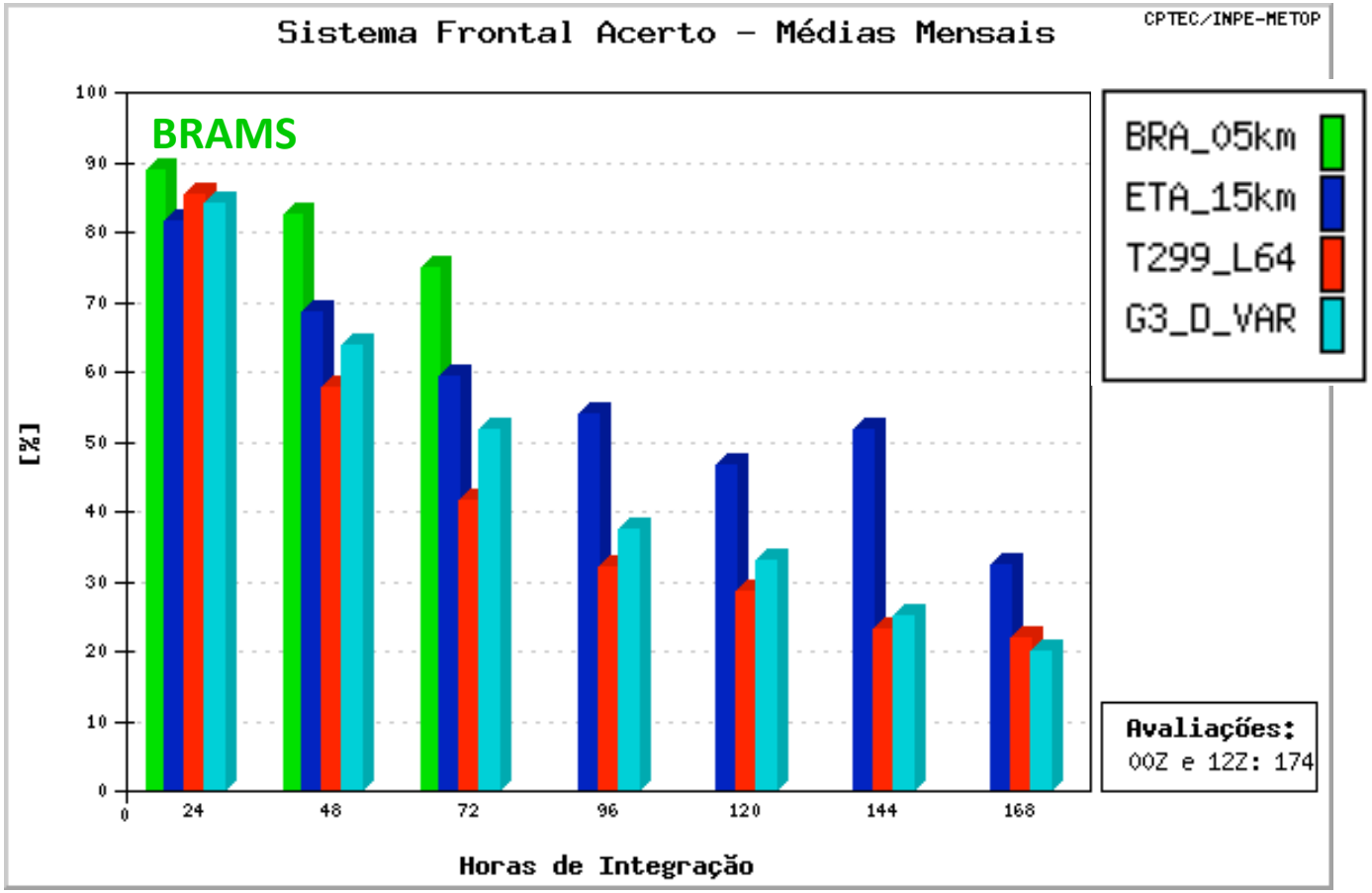
Avaliação Evaluation from CPTEC/DOP:
avaliacaodemodelos.cptec.inpe.br/anl/skill_regioes/mensal/phps/index.php

Anomaly correlation of geopotential height at 500 hPa



Data from Aug/2013 to July/2015 on 00 and 12 UTC
Avalaible at:
http://avaliacaodemodelos.cptec.inpe.br/anl/skill_regioes/mensal/phps/index.php

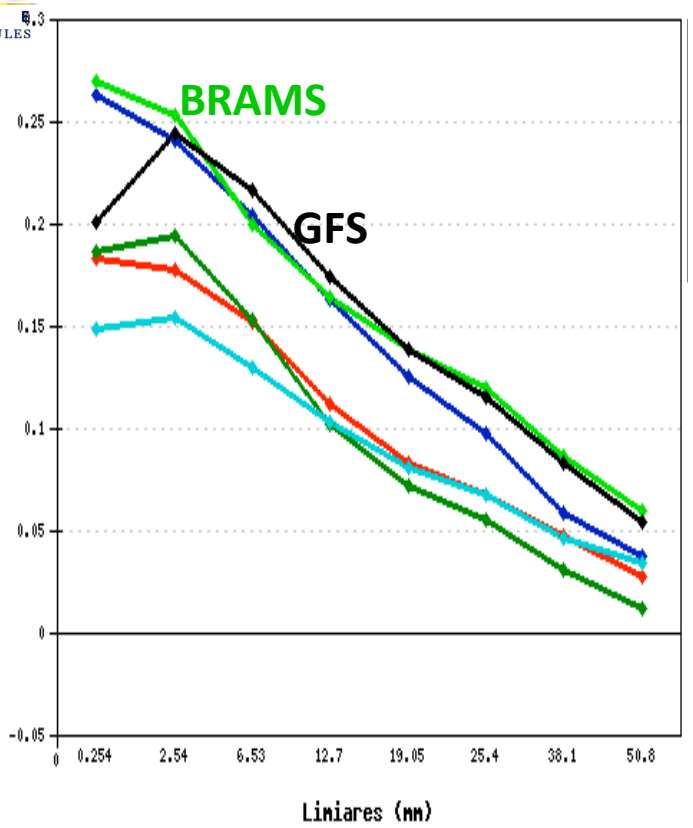
Semi-Objective Evaluation
Position of Cold-Fronts



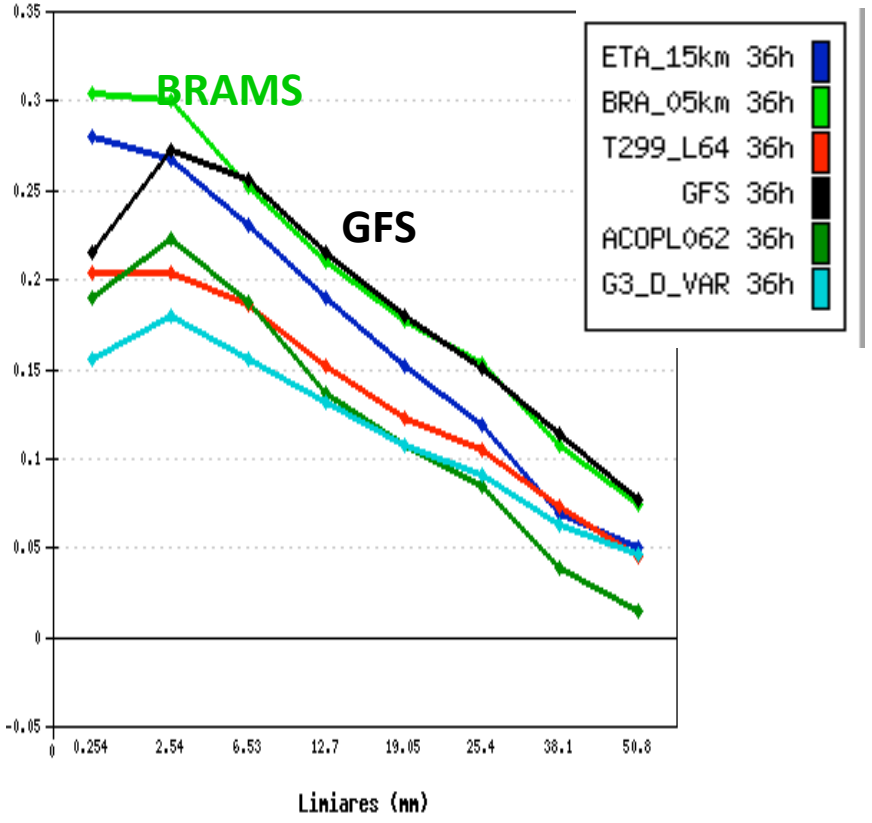
http://avaliacaodemodelos.cptec.inpe.br/anl/subjet/phps/index.php

ETS : RAINFALL
36-hour Forecast – Monthly Average

South America



South-Southeast Region of Brazil



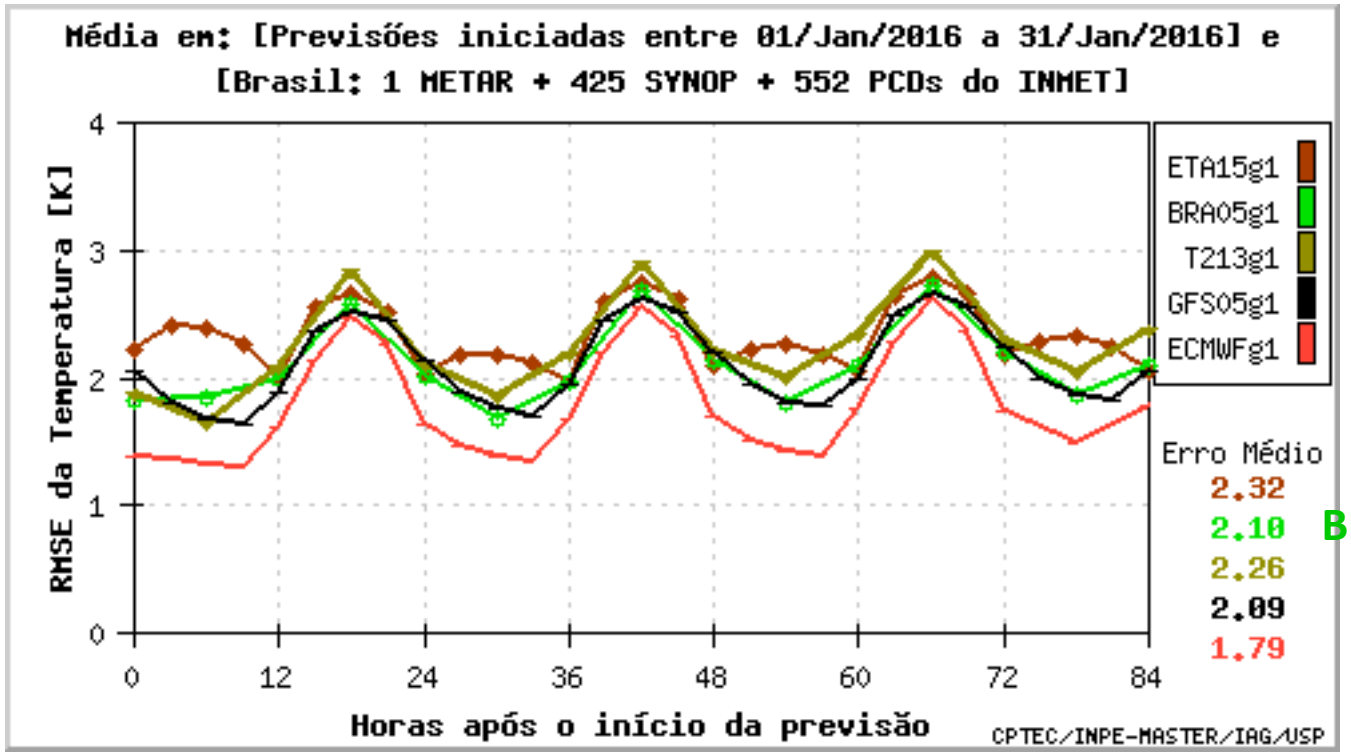
DOP/CPTEC Evaluation

Data from Aug-2013 to July-2015 (2 years) and available at:

http://avaliacaodemodelos.cptec.inpe.br/obs/qpf/phps/index.php

2-meter Temperature
84-hour Forecast – Monthly Average for Jan/2016

Evaluation domain: Brazil



DOP/CPTEC Evaluation
Data from Jan/2016 and available at:
http://intercomparacaodemodelos.cptec.inpe.br/phps

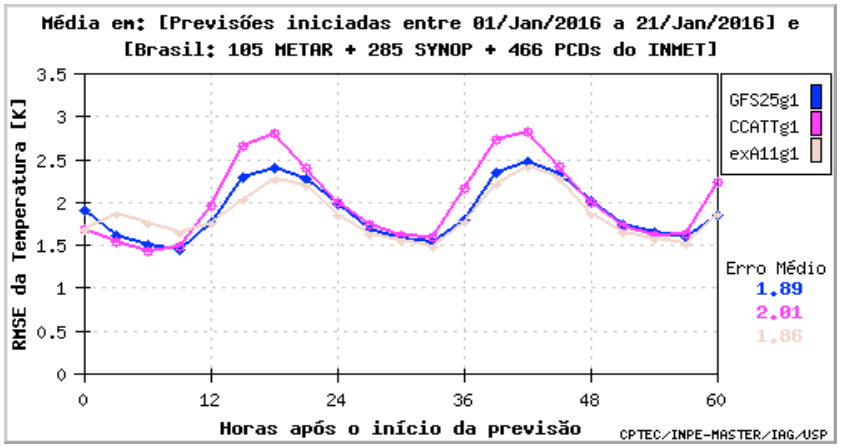
- Now the evaluation of 5.2 for the new operational air quality and weather forecast on 20 km at CPTEC/INPE.

Evaluation of version 5.2 for the new operational air quality and weather forecasts on 20 km

BRAMS RELEASE
BRAMS + CCATT + JULES

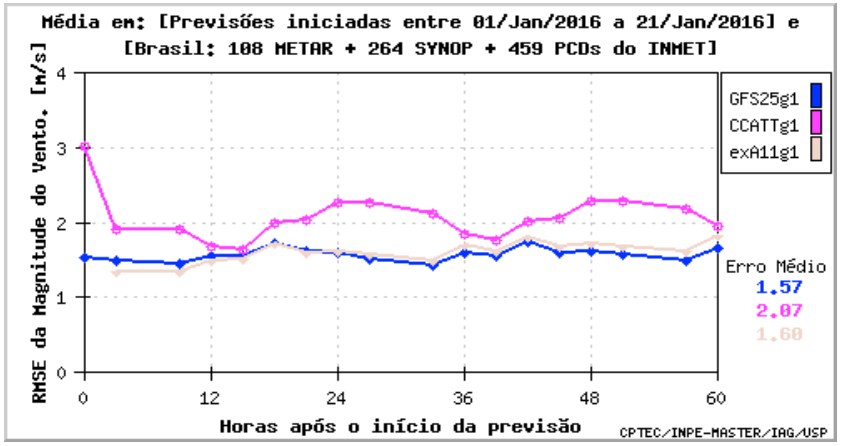
GFS25g1
v. 4.3
v. 5.2

RMSE of 2-m temperature



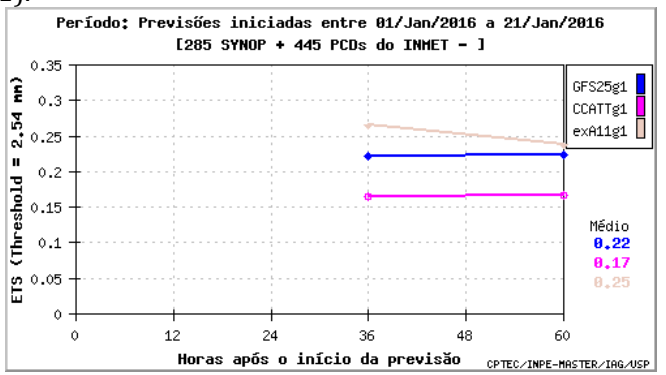
1.86

RMSE of 10-m wind magnitude

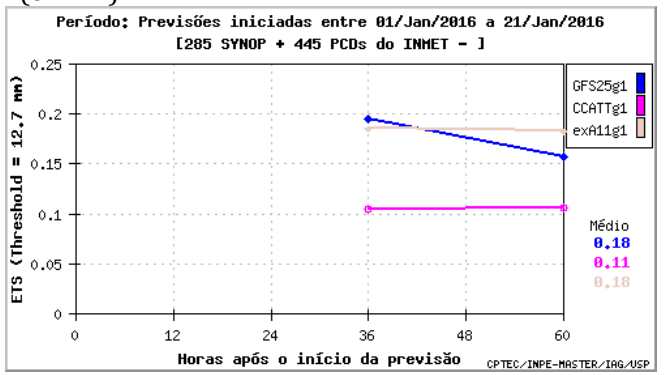


1.60

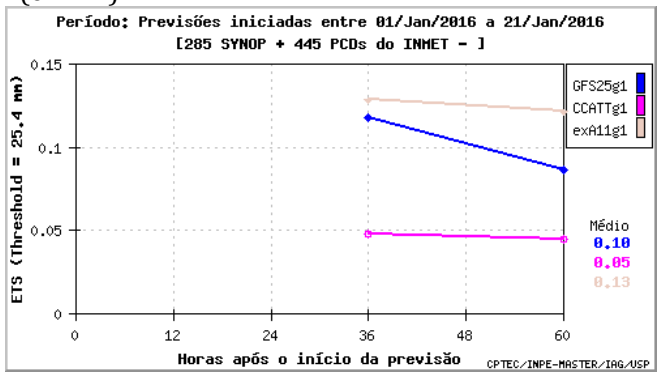
ETS of Rainfall



ção para o limiar de 2.54 mm. Modelos envolvidos GFS
.2 (exA11).



ção para o limiar de 12.7 mm. Modelos envolvidos GFS
.2 (exA11).



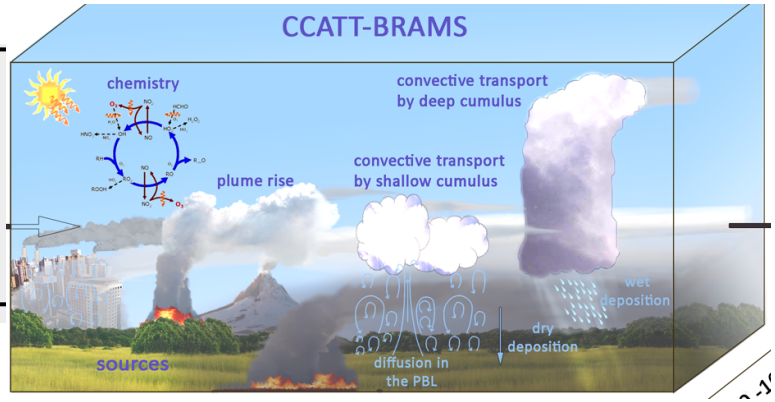
ção para o limiar de 25.4 mm. Modelos envolvidos GFS

Some aspects of atmospheric chemistry in BRAMS model

Version 5.2

Mass continuity equation in BRAMS

$$\underbrace{\frac{\partial \overline{s}}{\partial t}}_{\text{mixing ratio tendency}} + \underbrace{\overline{u}_i \frac{\partial \overline{s}}{\partial x_i}}_{\text{grid-scale advection term}} = \underbrace{-\frac{1}{\rho_0}\left(\frac{\partial \rho_0 \overline{u_i' s'}}{\partial x_i}\right)}_{\text{sub-grid transport by the un-resolved flow}} + \underbrace{\overline{Q_s}}_{\text{forcing}}$$



$$Q_s = \left(\frac{\partial \overline{s}}{\partial t}\right)_{chem} + W + R + Q$$

Q: emissions (biomass burning, urban-industrial processes, biogenic, etc…)

W: wet removal

R: dry removal

Solver for chemistry: based on the Rosenbrock's methods with dynamic timestep selection based on prescribed error tolerance and of 2nd and 3rd orders.

PREP-CHEM-SRC

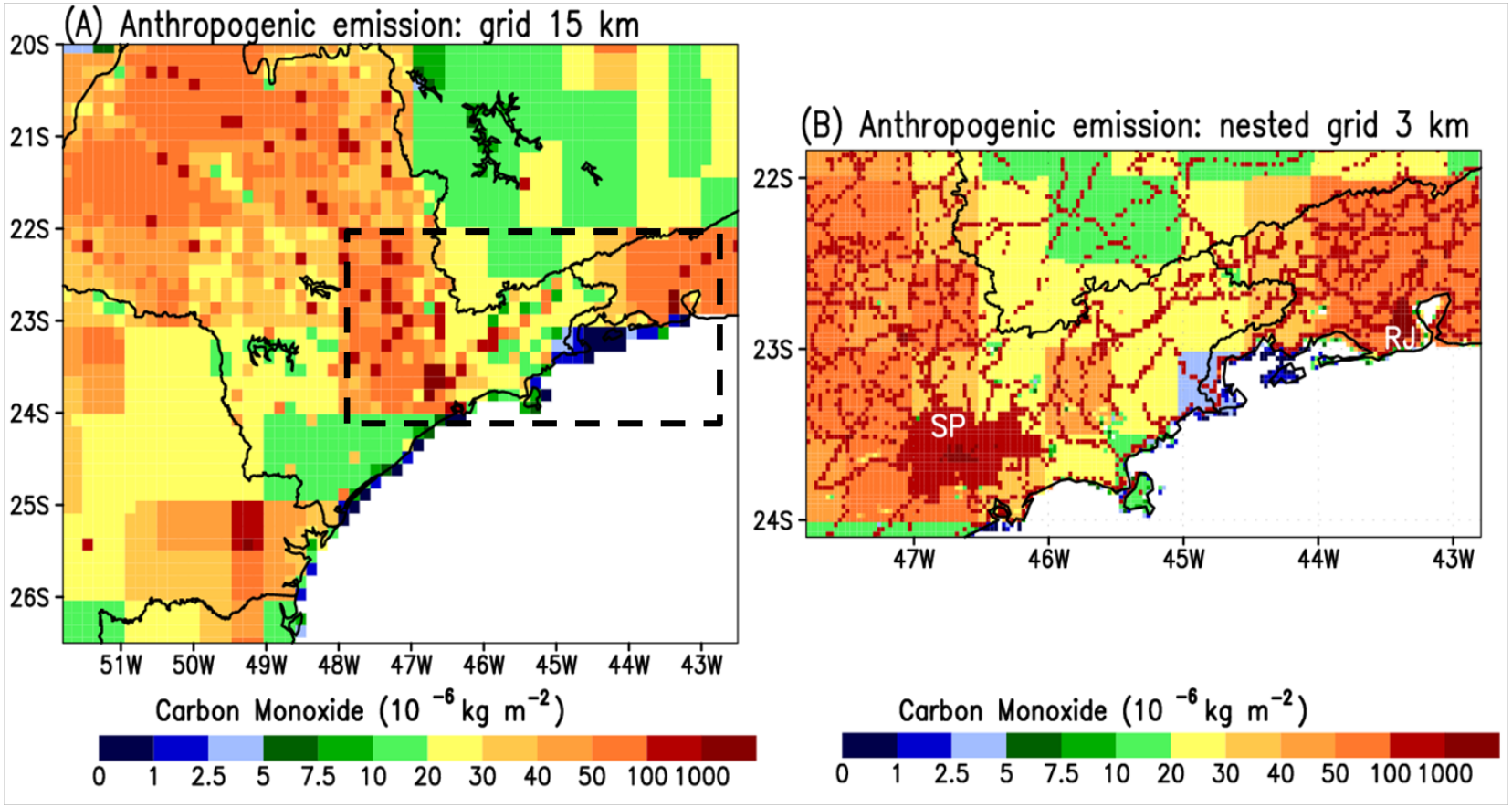
A preprocessor of trace gas and aerosol emissions fields

Source	Database	Resolution	Species
Urban Industrial transportation	RETRO	0.5° x 0.5°, monthly	26 chemical species
	EDGARv4.2 , EDGAR-HTAP	0.1° x 0.1°, monthly	CH4, NMVOC, CO, SO2, NOx, NH3, PM10, PM2.5, BC and OC
	S. America inventory by Alonso et al., 2011	Model resolution, monthly	CO, NO_x
Biogenic	GEIA	1° x 1°, monthlly	Acetone, C2H4, C2H6, C3H6, C3H8, CO, CH3OH, DMS, NO, isoprene, terpenes and NVOC
	MEGAN (Guenther et al., 2006)	0.5° x 0.5°, monthly	CO, CH4, C2H4, C2H6, C3H6, C3H8, CH3OH, formaldehyde, acetaldehyde, acetone, other ketones, toluene, isoprene, monoterpenes and sesquiterpenes
Biomass Burning	3BEM (Freitas et al., 2005; Longo et al., 2009) 3BEM FRE (Pereira et al., 2009)	Model resolution, daily	110 chemical species (Andreae & Merlet)
	GFED (Giglio et al. (2006) and van der Werf et al. (2006)	1° x 1°, 8 days/ monthly	110 chemical species (Andreae & Merlet)
Volcanoes	Mastin et al. (2009)	Pontual (1535 volcanoes)	Ash
	AEROCON (Diehl, 2009; Diehl et al., 2011)		SO_2
Biofuel use, charcoal prod. and burning of agricultural waste	Yevich and Logan (2003)	1° x 1°, annually	110 chemical species (Andreae & Merlet)

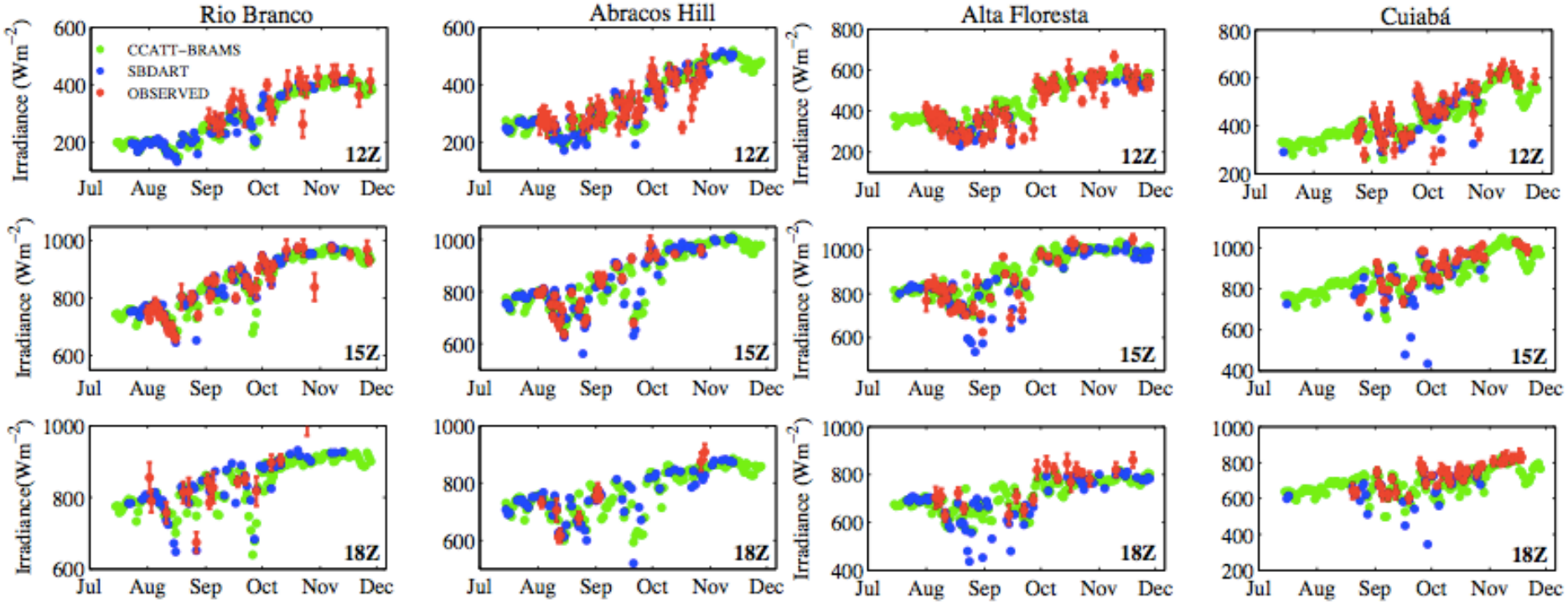
For regional and global models: BRAMS, WRF-Chem (including NASA-Unified WRF), FIM.
Also emission fields on polar-stereo, Lambert-conformal, Mercator, lat-lon, gaussian grids.

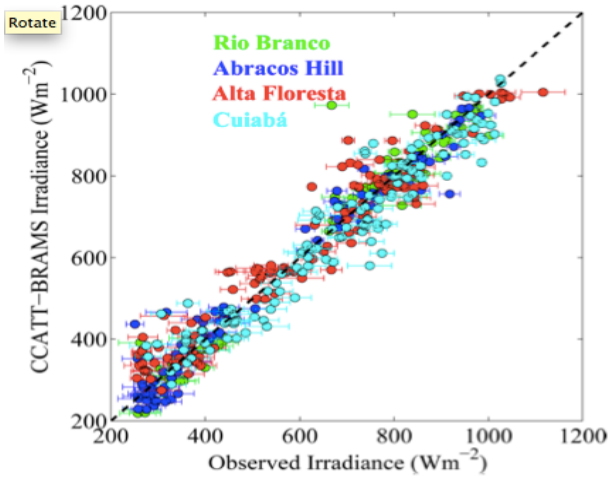
Freitas et al., GMD 2011

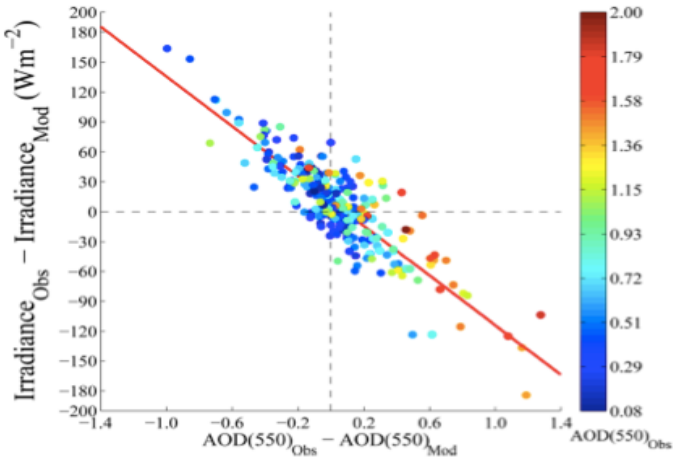
Global - Regional – Local Emissions Inventories



Solar flux model x observation





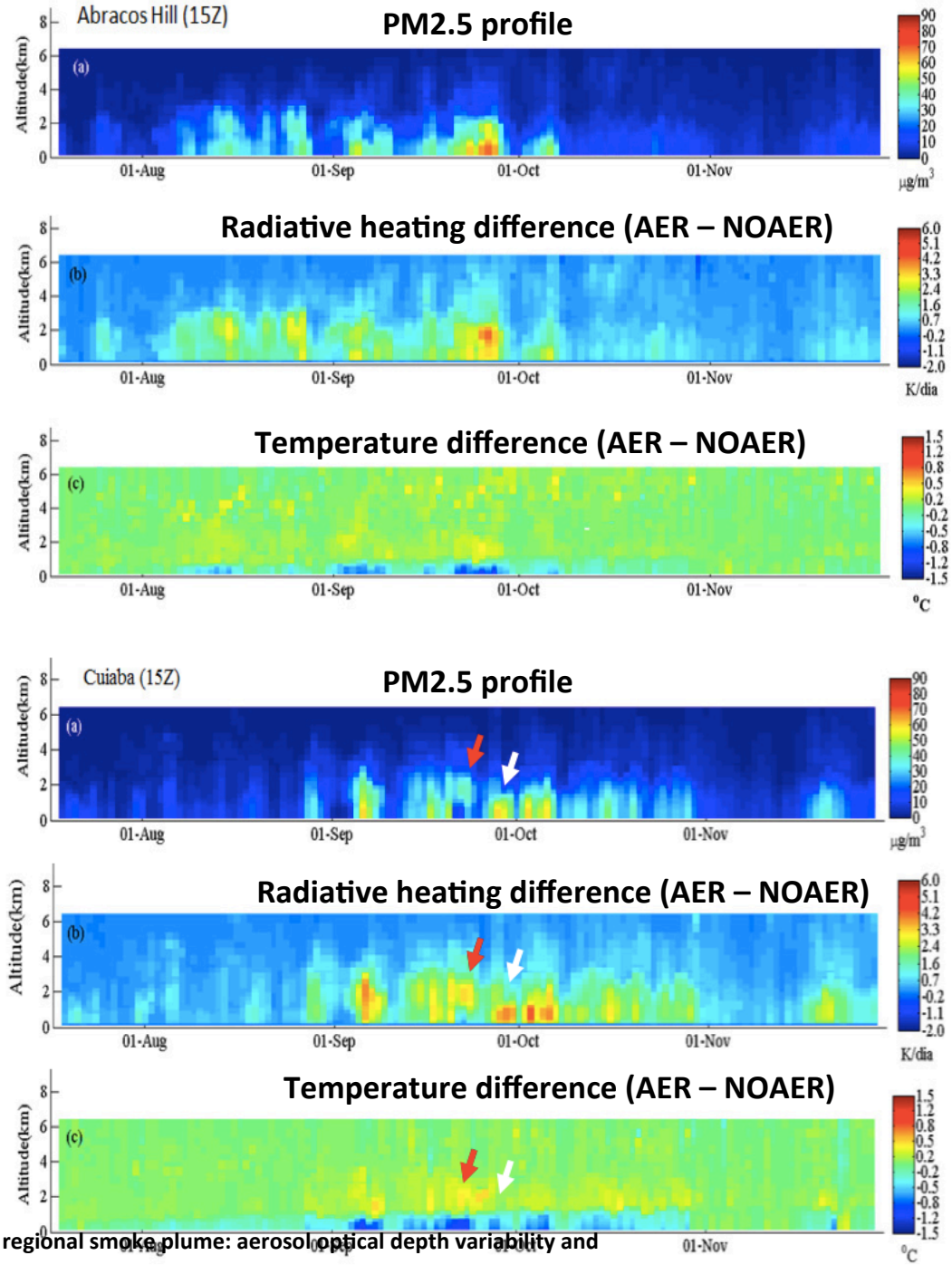


Aerosol optical depth is the major source of uncertainty when it comes to modeling of solar irradiance at the surface

Rosário, N. E., Longo, K. M., Freitas, S. R., et al.: Modeling South America regional smoke plume: aerosol optical depth variability and shortwave surface forcing. Atmos. Chem. Phys. 13, 2923, 2013.

BRAMS
RELEASE
BRAMS + CCATT + JULES

Aerosols Direct Radiative Effect: impact of vertical distribution



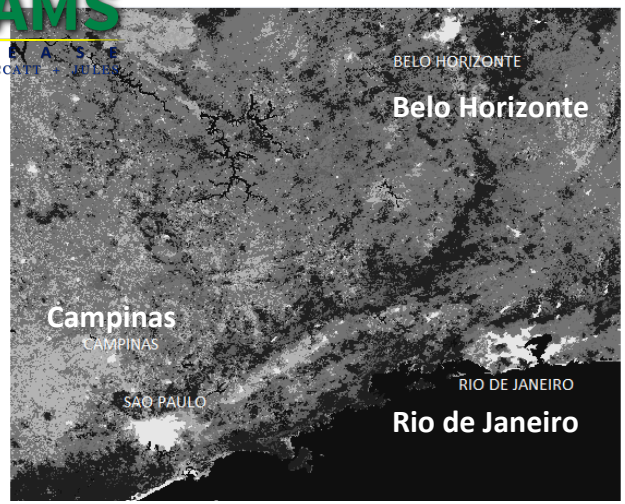
Top PBL: +0.5 °C
Near surface:
- (0.5 to 1.5) °C

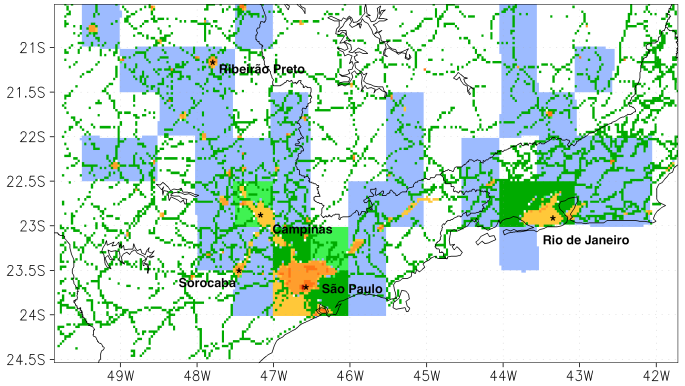
Top PBL: +0.5 °C
Near surface:
- (1.5) °C

Top PBL: +0.3
Near surface:
- (0.5) °C

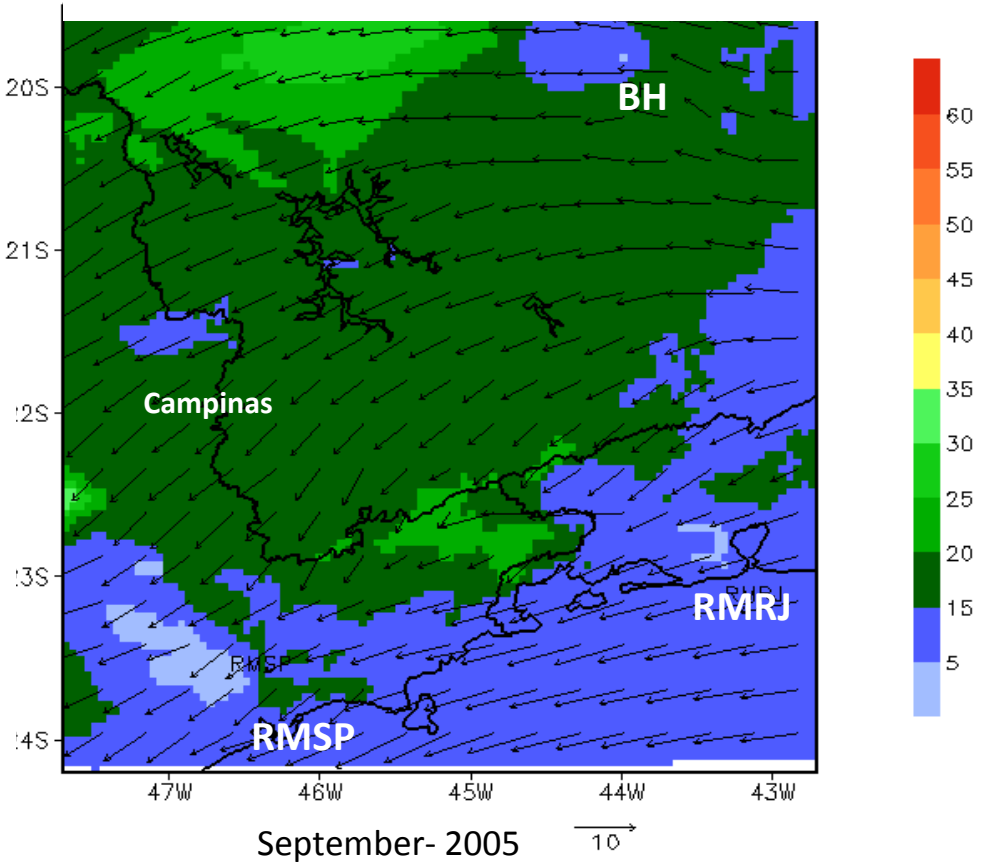
Rosário, N. E., Longo, K. M., Freitas, S. R., et al.: Modeling South America regional smoke plume: aerosol optical depth variability and shortwave surface forcing. Atmos. Chem. Phys. 13, 2923, 2013.

High resolution air quality forecast for the main urban areas of Brazil



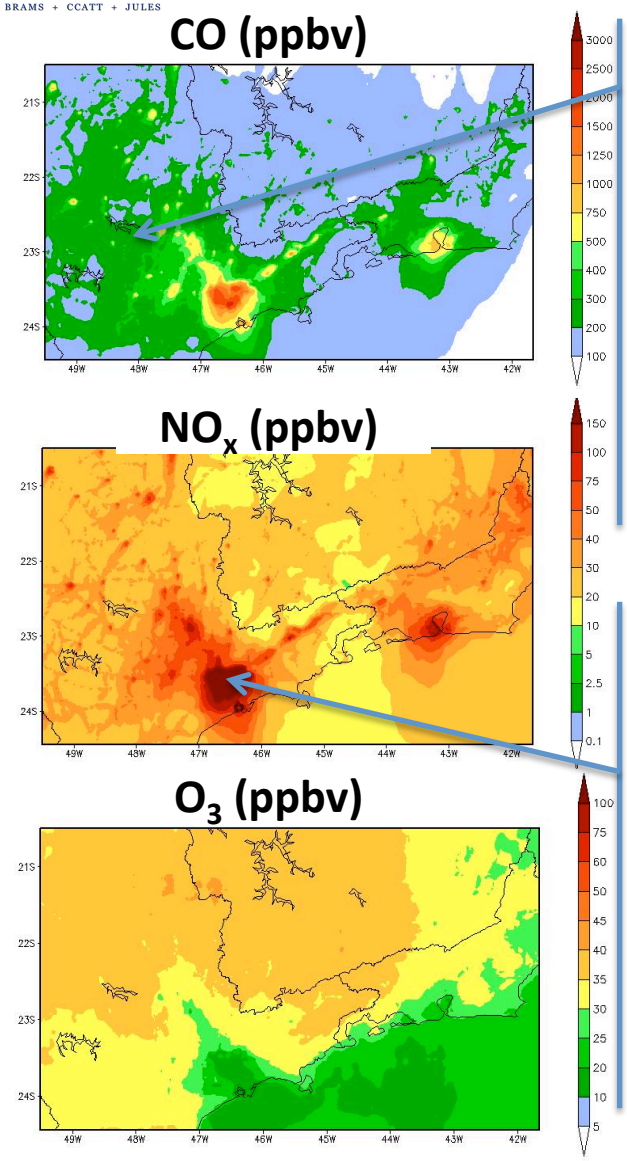


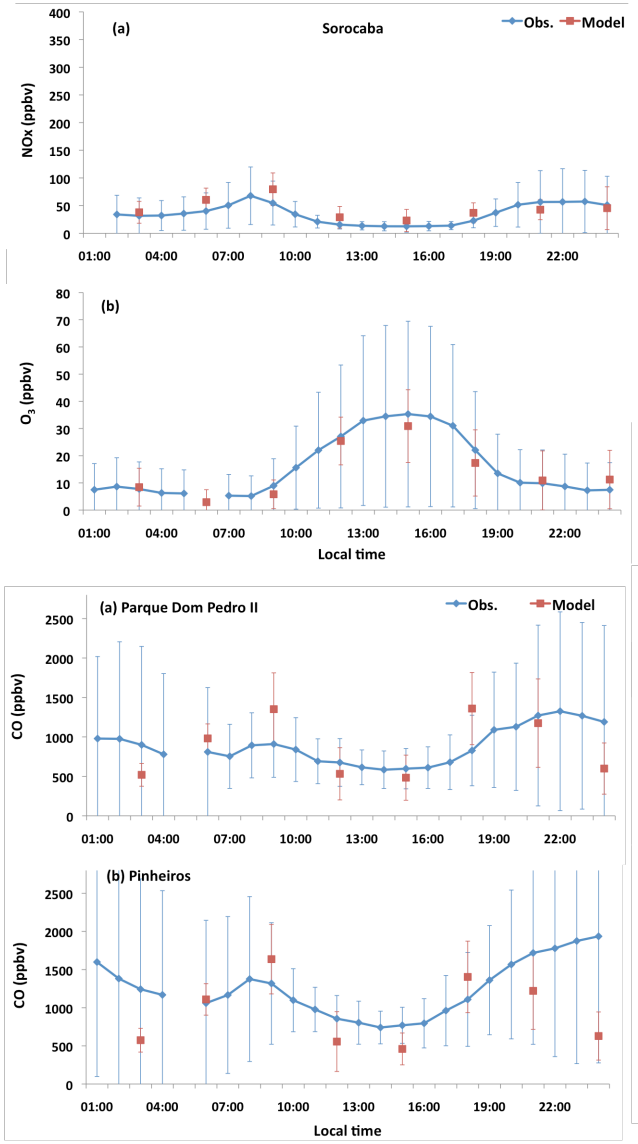
Near surface Ozone (ppbv)

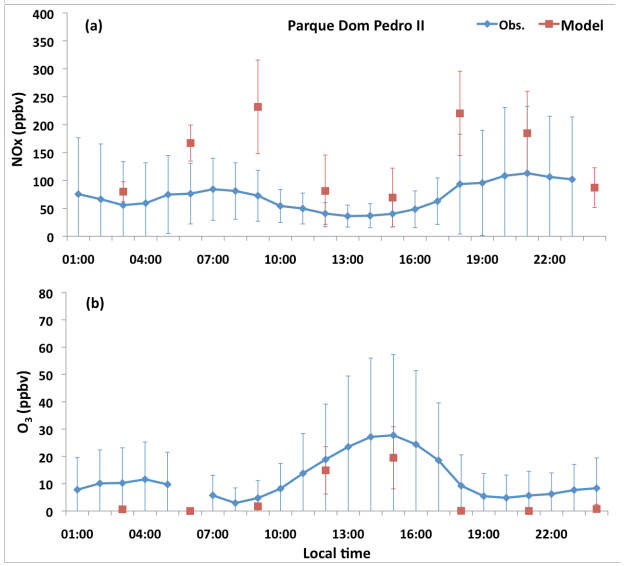


September- 2005

High resolution urban air quality forecast

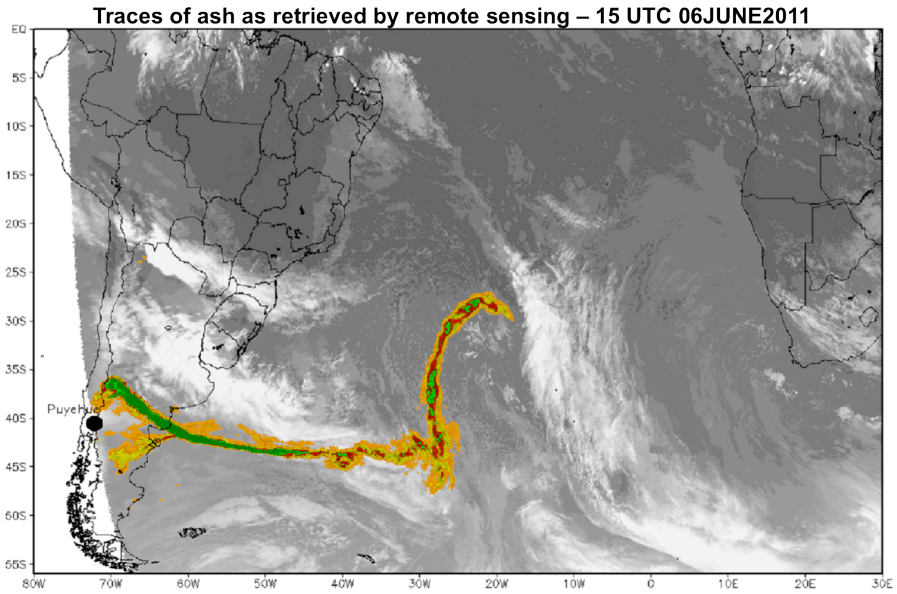


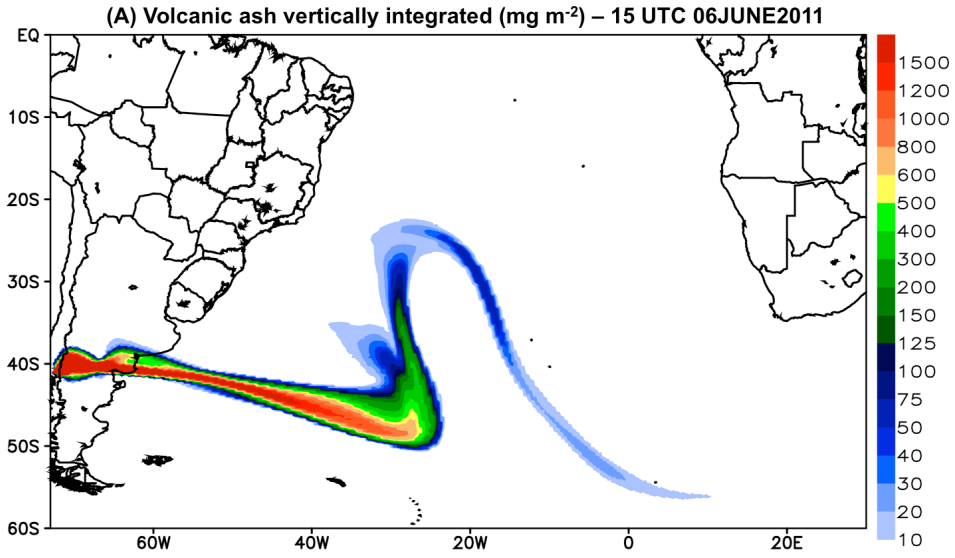


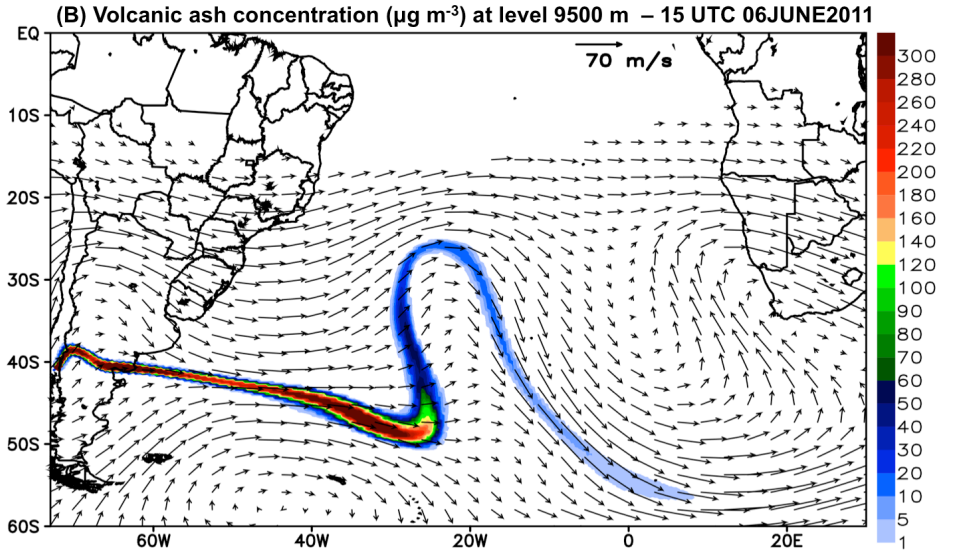


Longo, K M., S. R. Freitas, M. Pirre, et al. The chemistry CATT-BRAMS model (CCATT-BRAMS 4.5): a regional atmospheric model system for integrated air quality and weather forecasting and research. Geosci. Model Dev., 6, 1389-1405, 2013.

Monitoring the transport and dispersion of volcanic ash







Some aspects of physical parameterizations and dynamics of BRAMS model

Version 5.2

This version of BRAMS contains the additional following physical parameterizations

1. Radiation:
   - CARMA (Toon et al., 1988, Rosário et al 2013) and RRTMG (Iacono et al., 2008) schemes for long- and short-wave, including aerosols effects and coupled with microphysics and convection schemes.
2. Microphysics:
   - a double moment from RAMS CSU version,
   - Thompson single moment in cloud liquid water and
   - Thompson double moment in cloud liquid water and aerosol aware (Thompson and Eidhammer, 2014).
3. Convection schemes:
   - Souza (1999) for shallow convection,
   - Grell and Deveny (2002) for deep convection and
   - Grell and Freitas (2014) scale and aerosol aware for deep and shallow convection including convective transport and wet removal of tracers.
4. Turbulence parameterizations:
   - Nakanishi & Nino (2004) TKE based formulation,
   - Taylor's theory based formulation (Campos Velho, 1998)

Scale-Aware Physics

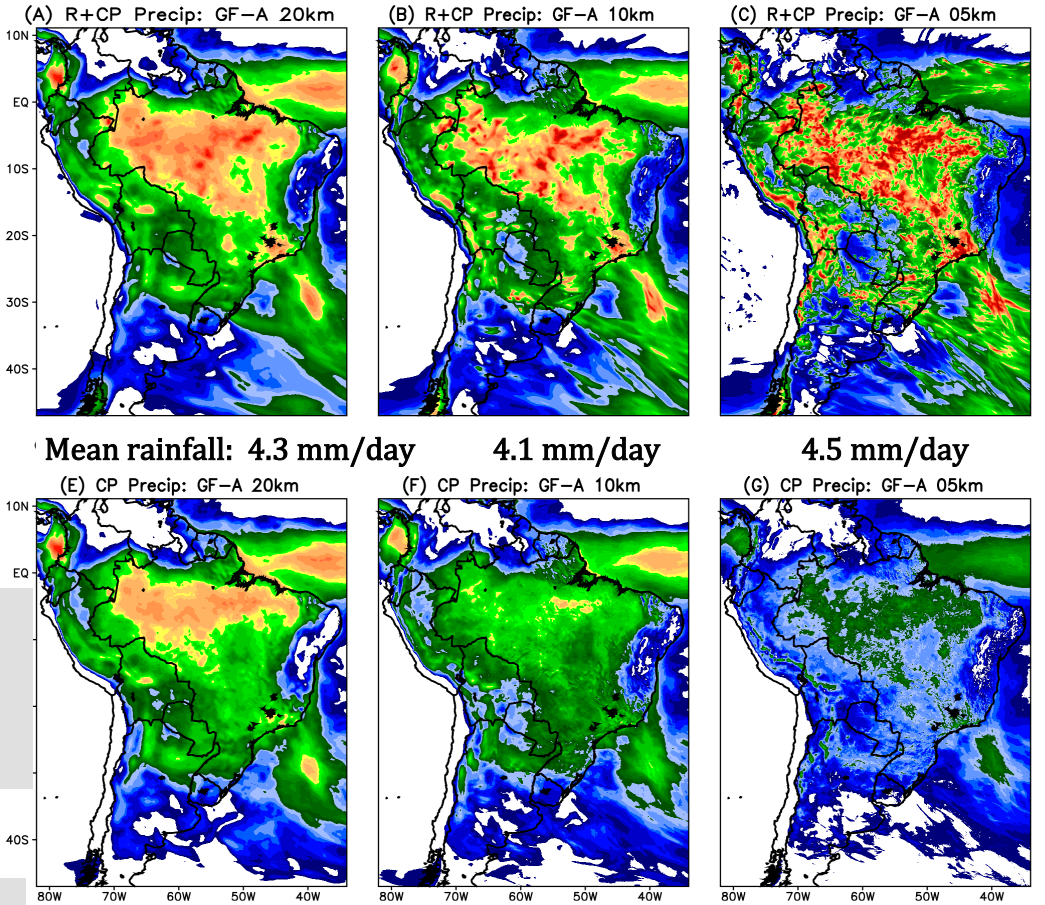
Addressing the grey-zone problem for deep convection

BRAMS Simulations on 20, 10 and 5 km grid spacing

Total 24h rainfall: resolved + from the convective parameterization

24 h Rainfall: only from the convective parameterization

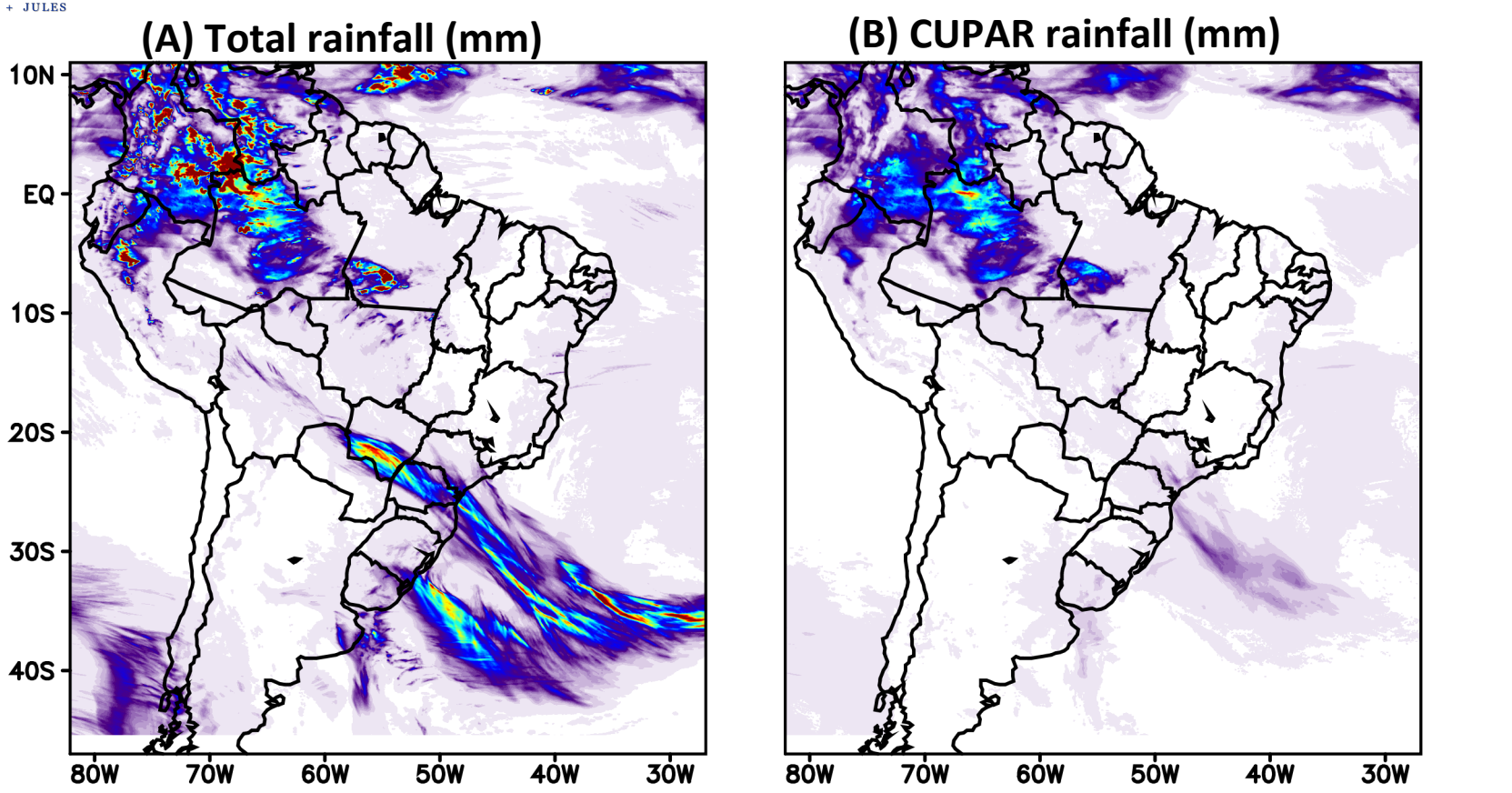
Results are model average for Jan 2013 - 15 days w/ 36horas FCT



(Grell and Freitas, 2014, ACP)

An example of real-time performance of BRAMS 5.2

5 km grid spacing
24-hour accumulated rainfall for 12 October 2015

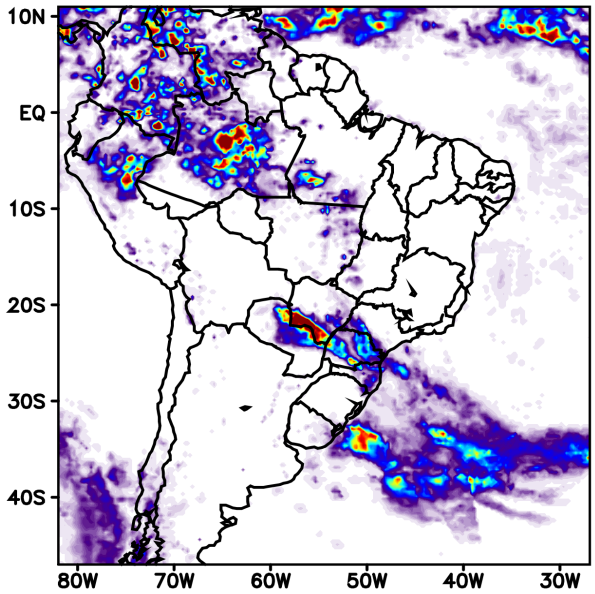


Freitas et al. (2016, GMD)

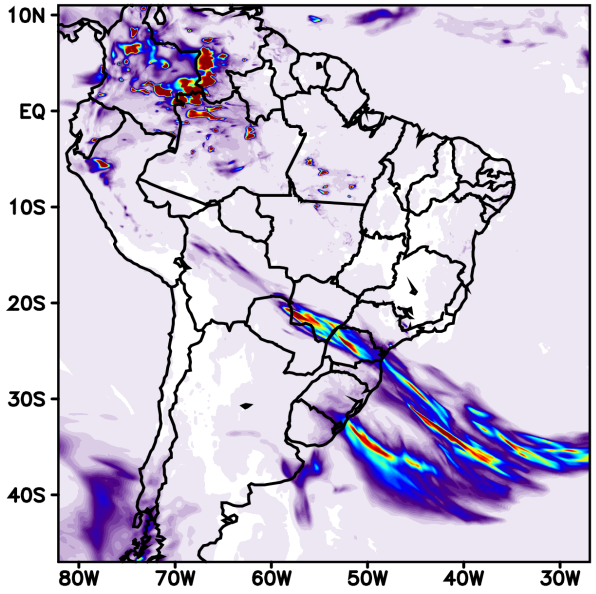
An example of the model performance for the new operation at 5 km grid spacing

BRAMS model forecast of 24-hour accumulated precipitation for 12 October 2015 and on 5 km grid spacing.

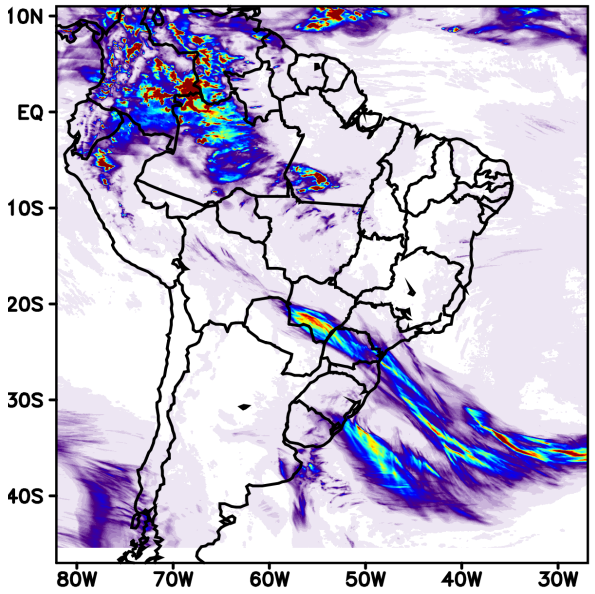
(A) TRMM rainfall (mm)

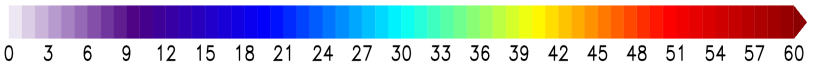


(B) Model rainfall (mm) 2014 GF scheme



(C) Model rainfall (mm) NEW GF scheme





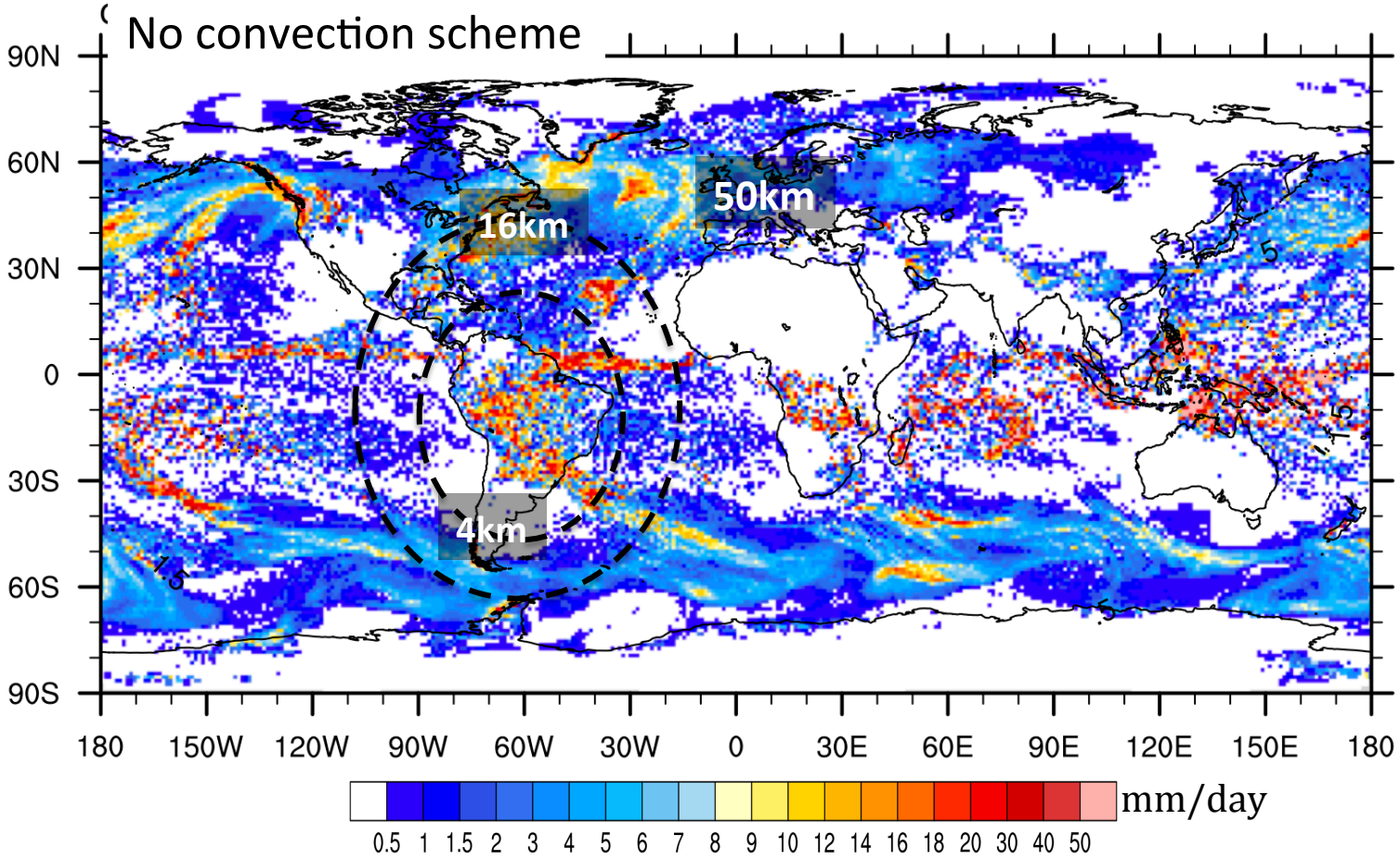
Application of Grell-Freitas scheme in global simulations with variable resolution:

MPAS model

Simulated total precipitation

50 – 3 km variable resolution mesh – 3 days FCT

No convection : only cloud microphysics
Convection scheme : GF with and without scale dependence



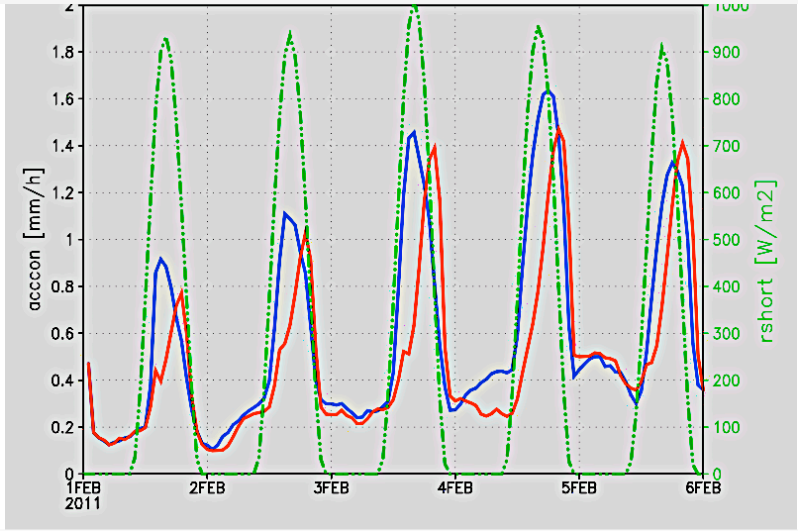
Accumulated precipitation from 00 UTC 11 and 00 UTC 14 January 2014

L. Fowler et al. (MWR, in press)

Improved diurnal cycle of deep convection over the Amazonia:
Applying the new closure from P. Bechtold for non-equilibrium convection

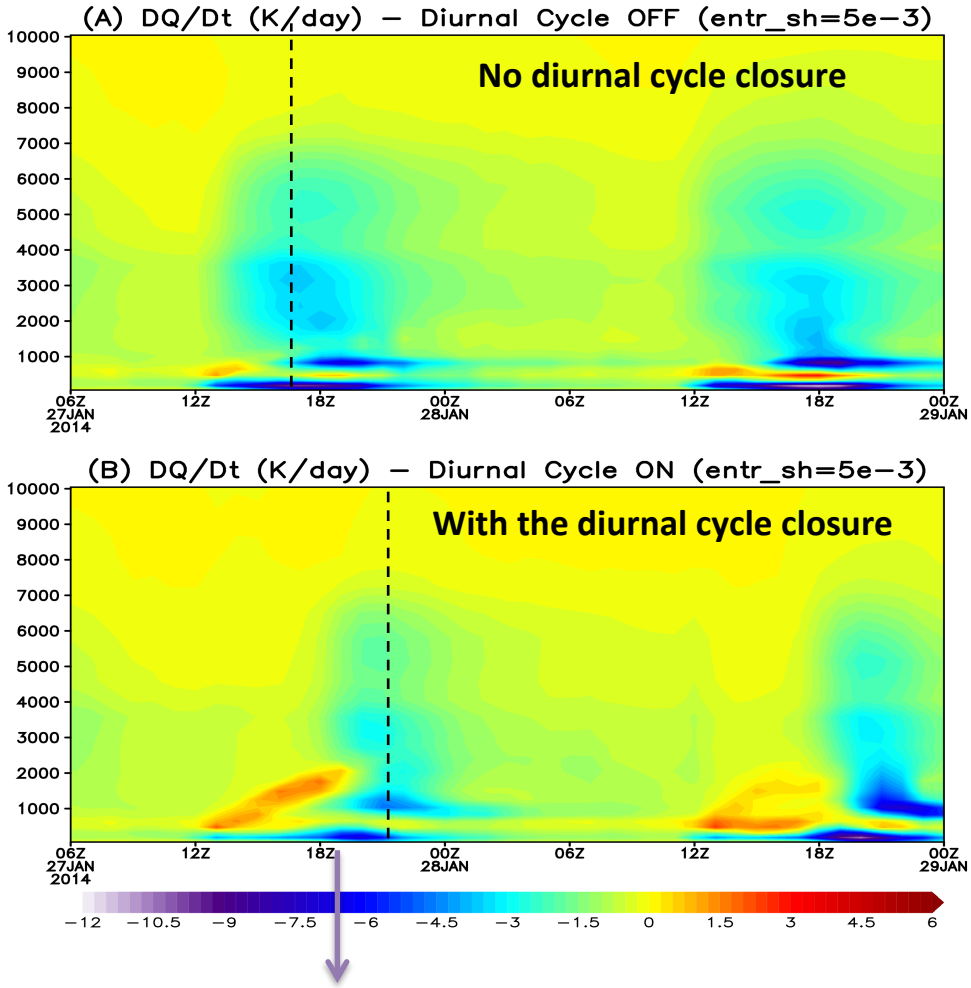
BRAMS
RELEASE
BRAMS + CCATT + JULES

Convective Precipitation (mm/h)



- 5 days forecast of CUPAR precipitation
- Model grid spacing: 27 km
- Area average over Amazon Basin
- BLUE = diurnal cycle closure OFF
- RED = diurnal cycle closure ON
- GREEN= surface solar radiation

water vapor tendency (K/day)



Better transition from shallow to deep convection regimes

Bechtold et al., 2014; Freitas and Grell, in prep.

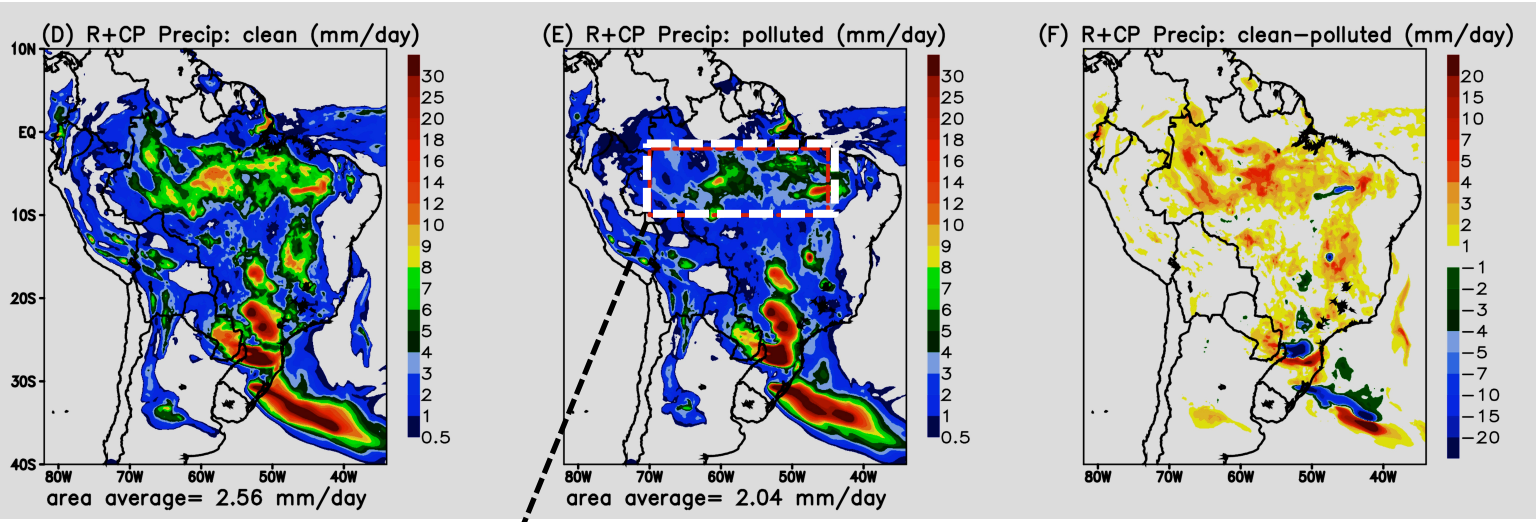
Including aerosol indirect effects in convective parameterization

clean / polluted – dx 20 km – 24h accumulated (mm)

total rainfall: clean

total rainfall: polluted

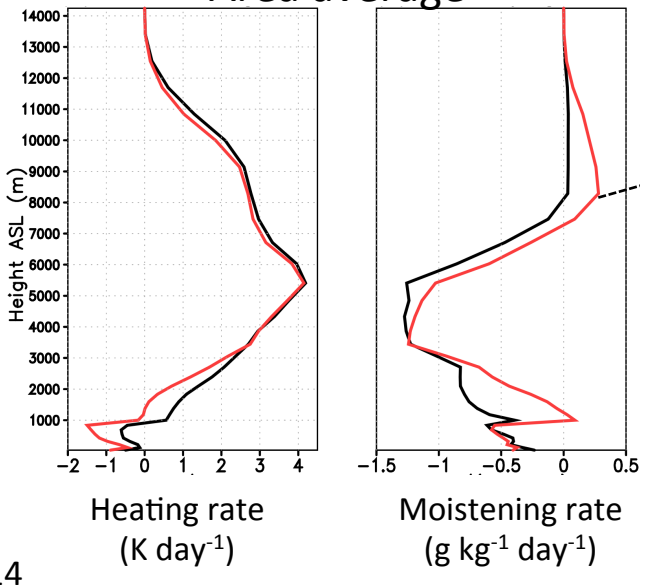
clean - polluted



Area average

Clean:
CCN 150 cm^{-3}

Polluted
CCN 3000 cm^{-3}



Grell and Freitas, ACP 2014

Resolved Precipitation simulation applying more accurate transport schemes: Monotonic, low numerical diffusion advection scheme

a) Monotonic (positive-definite, non-oscillatory, no under- or overshoots)

b) Mass conservative

c) Low numerical diffusion

d) Also improves the preservation of non-linear tracers correlation of the original RAMS advection scheme

e) multi-component mass conservation.

Freitas et al., 2012 JAMES/AGU

- Current/planned developments and research

New time integration schemes and high order advection operators for BRAMS model

- Currently, BRAMS employs the horizontally-explicit /vertically-implicit technique to integrate in time its dynamic core
- Additionally, split-explicit time scheme is used to integrate the slow and fast modes.
- BRAMS applies the leapfrog time scheme with Asselin filter which allied with the 2nd order advection scheme, gives a 1st order global accuracy.
- The objective of this work is to implement an additional time integration scheme and advection operator which gives at least 2nd order global accuracy.

Time integration	Status	Advection operator	Status
RK3: Runge-Kutta (Wicker and Skamarock,2002; Baldauf, 2008, 2010)	Serial run only	The polynomial flux specification (Wicker and Skamarock,2002,) with 3rd and 5th order of spatial approximations. Additionally, the *Flux Correct Transport* (FCT, Skamarock, 2006)	Serial run only
ABM3: Adams-Bashforth-Moulton 3rd order (Wicker, 2009)	Serial run only	Weight Essentially Non-Oscillatory (WENO, Jiang and Shu, 1996; Baba and Takahashi, 2013)	Not yet
ABM3+RK2 (Freitas, in prep.)	Not yet	Suresh and Huynh (1997). This scheme is similar to piecewise parabolic method with a limiting approach which preserves both monotonicity and accuracy.	Not yet
SSP-RK (Durran, 2010)	Not yet	-	-

S. Freitas and R. Mello (CPTEC), H. Campos Velho (LAC/INPE), J. Panetta (ITA) and M. Baldauf (DWD/Germany)

Data Assimilation

- 3D-VAR Global Statistical Interpolation
- Participants:
  - E. Vendrasco, L. Sapucci, C. Pavani (GDAD/CPTEC)
  - P. Silva Dias (USP)
  - M. Pagowski (ESRL/NOAA)
  - H. Campos Velho (LAC/INPE, to be invited)
  - S. Freitas (INPE - NASA)

Fire Spreading model

- Ph.D. thesis of Isilda Menezes (Univ. Évora), 2016
- In collaboration with ICAAM / Portugal

MATRIX Aerosol Model

- K. Longo, A. Santos, L. Flávio, M. Sanchez and S. Freitas

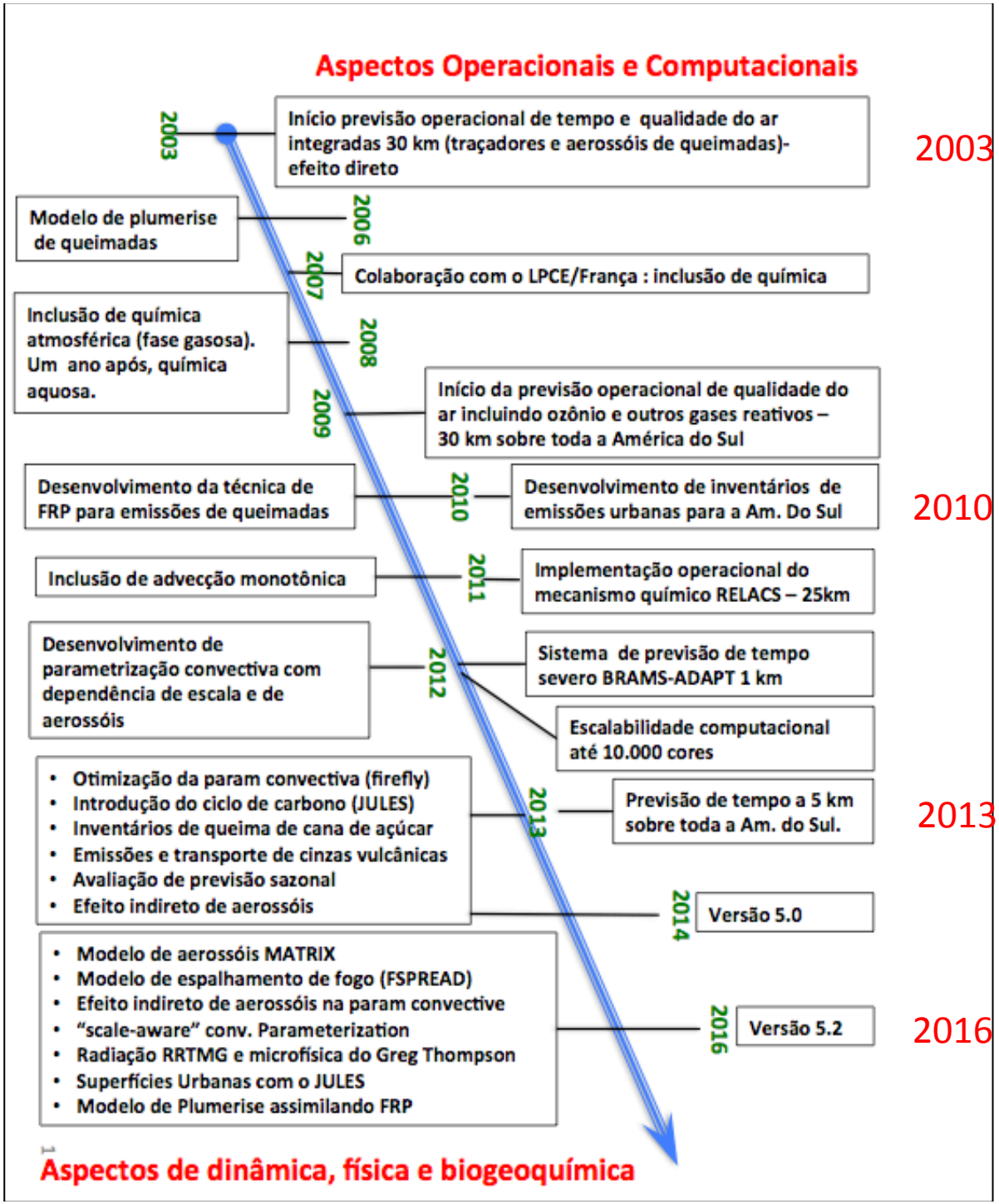
BRAMS at CPTEC/INPE:

a 13 years history

BRAMS
RELEASE
BRAMS + CCATT + JULES

BRAMS developments and implementations at CPTEC/INPE:

a 13 years history



INPE

Funding Agencies and Companies which contributed for the development of the BRAMS System in CPTEC/INPE

- Petrobras
- CNPq (*projetos regulares, bolsas*)
- Capes (*bolsas*)
- FAPESP (*projetos regulares, bolsas*)
- Min. da Saúde
- IBAMA
- IAI
- COPEL
- INTEL

Publications, capacity building, operational products: period 2003 - 2016

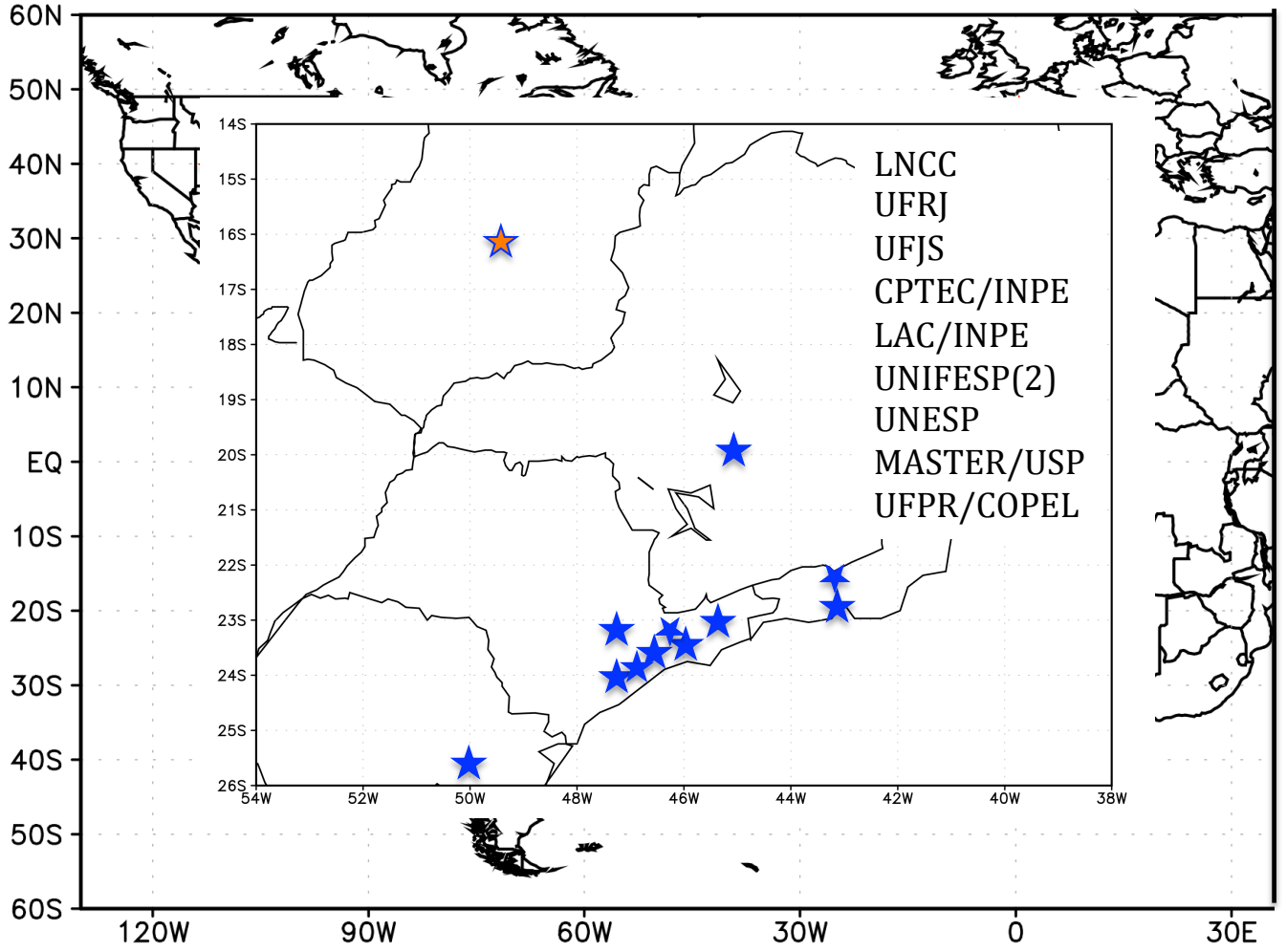
Index	Quantity
Journal Papers	> 100
Workshop Papers	> 200
Master theses	13 / 1
Doctorate theses	13 / 5
Operational products	• Global soil moisture • Air quality and weather forecast (20 km) • Weather forecast (5km) • Severe weather forecast (adaptive grid - 1km)
Special operational products for field campaigns	• BARCA, SAMBBA, GoAmazon, CHUVA
Training	• Four BRAMS tutorials

Current collaborations

- NOAA/ESRL: physical parameterizations, data assimilation, fire emissions and plumerise
- DWD/Germany: new dynamic core
- KIT/Germany: fire emissions and plumerise
- NASA/Goddard: fire emissions and plumerise
- SENAMHI/PERU: air quality forecast
- CNEA/Argentina: Emissions and air quality research
- LNCC, USP, UFRJ, UFCG, UNIFESP(2), UFRN, SISAM, UFPEL, UNESP,
- Several computer companies (SGI, INTEL…)

Institutions which are currently applying BRAMS for research and real-time forecast

USA
France
Portugal
Colombia (3)
Peru
Argentina (2)
Brazil:
- UFAP
- SISAM
- UEA
- UFPA
- UFPEL
- UFRS
- FUNCEME
- UFCG
- UFRN



Networking BRAMS, CCATT-BRAMS, RAMS

Obrigado !