CENTER FOR WEATHER FORECASTS AND CLIMATE STUDIES
CPTEC/INPE - BRAZIL

Update of CPTEC activities - 2012

by

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Outline

- Recent developments on:
  - Regional Atmospheric Modeling
  - Global Atmospheric Modeling
  - Data Assimilation
  - Ensemble Prediction
- Recent Activities

Plans of 2011: Current models resolution and expected for the next year

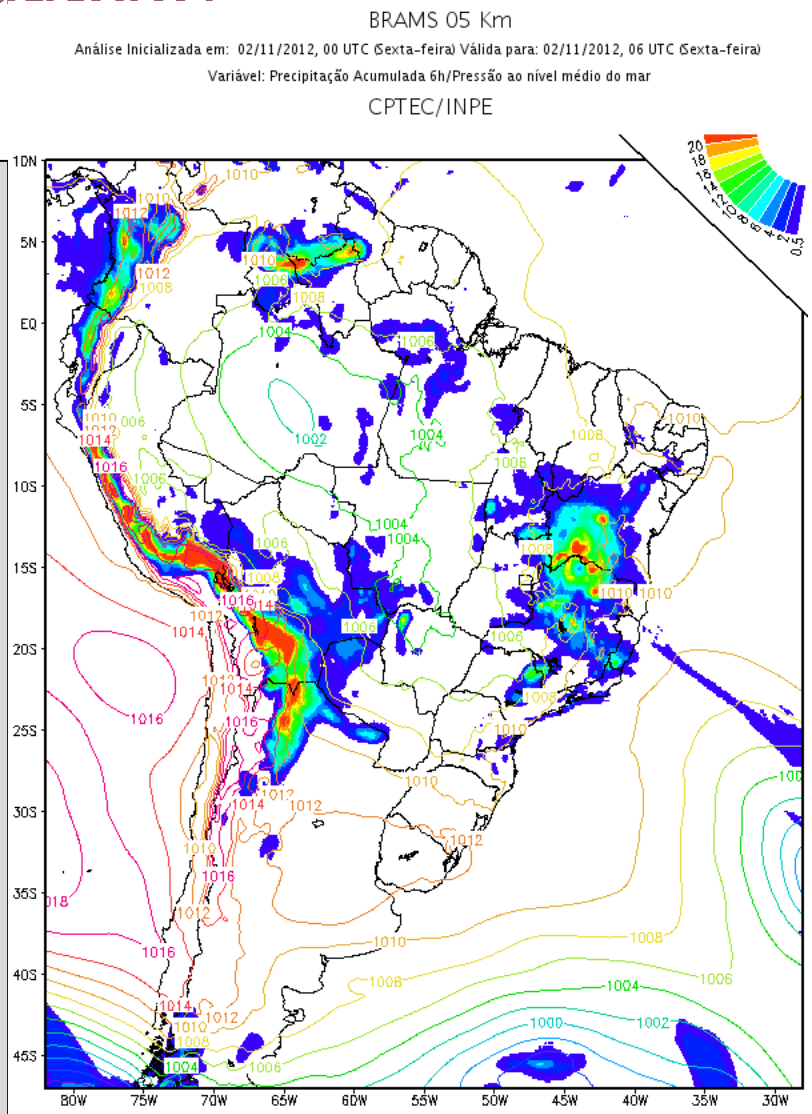
MODEL – FOCUS - DOMAIN – FORECAST TIME LENGHT	Current 2011	Next Year 2012
BRAMS – Severe Weather – 500x500 kmˆ2 over South America – 1 to 1 ½ day	1 km – under evaluation	1 km- available for the Operational FCT Division ✔
Eta - Severe Weather – Southeast Brazil – 3 days	5 km	2 km
Eta - Weather – S. America - 7 days	15 km	5 km
BRAMS – Weather– S. America – 7 days	20 km	5 km- under evaluation ✔
CCATT – Weather + Air Quality (on-line) – S. America – 3 days	25 km	15 km
AGCM with NCEP – Weather – Global – 7 days	63 km / L 42 45 km / L 64	20 km / L 96
AGCM with LETKF– Weather – Global- 7days	----------	45 km / L 64
OA-GCM– 30 days– Global	105 km / L 28	80 km / L 42
Eta – seasonal climate – S. America	40 km	10 km

BRAMS - Brazilian developments on the Regional Atmospheric Modeling System: recent developments < 2 years

- Ensemble version of convective parameterization G3d appropriated for high resolutions simulations (deltax < 10 km), that including also aerosol indirect effects.
- Nakanishi and Nino turbulence scheme
- JULES Surface scheme with fully coupled carbon cycle
- UK-Met Office Radiation Scheme (fully coupled with aerosols, cloud microphysics)
- Updated cloud microphysics from CSU with input of CCN field (ready for inclusion of aerosol indirect effects)
- Digital Filter for model initialization
- Monotonic advection for scalars (theta, tke, hydrometeors, tracers, aerosols, ..)
- Adams-Bashforth (2^{nd}, 3^{rd} and 4^{th} orders) for time integration : but not fully successful, planning to include Adams-Bashforth–Moulton (Wicker, 2009) or Runge Kutta (Skamarock et co-authors, 200X)
- Huge improvements in the code scalability (thousands of processors), parallel I/O and memory usage.

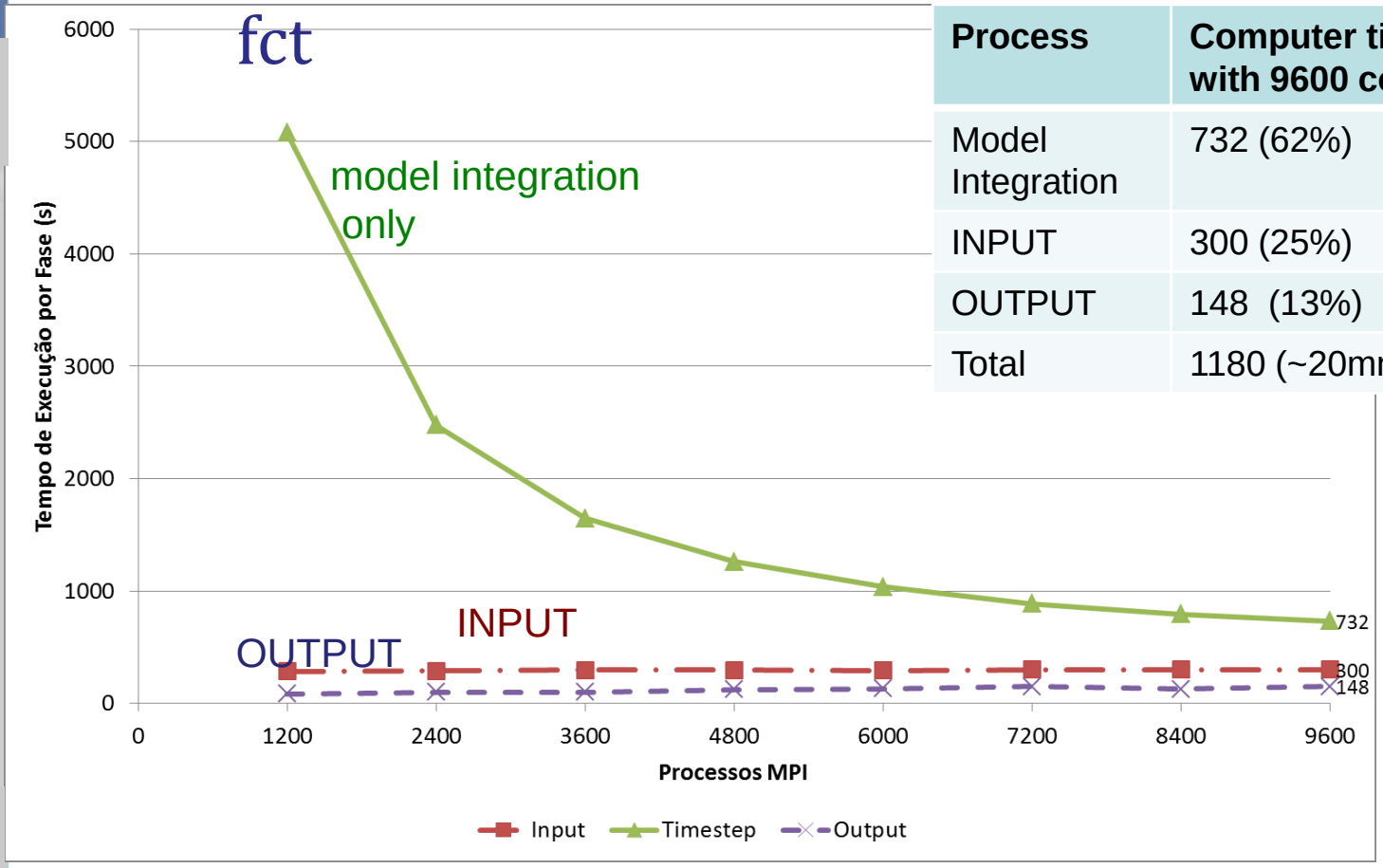
New regional weather forecast for South America on 5km resolution (under evaluation)

- Grid spacing:
  - Horizontal: 5 km x 5 km.
  - Vertical: 50 to 800 meters
- Time step: 15 seconds
- Model domain:
  - # grid points: 1360x1489x55 ~ 100 x 10^6
  - Model top @ 21 km
- Forecast length:
  - 5 days, starting at 00 UTC, (near future will be implemented at 12 UTC).
- Execution time :
  - 1h 40 mn on 9600 cores produces 5 days forecast (I/O is the bigger bottleneck)



BRAMS 5 km
Some computational aspects

Elapsed time for 1 day fct



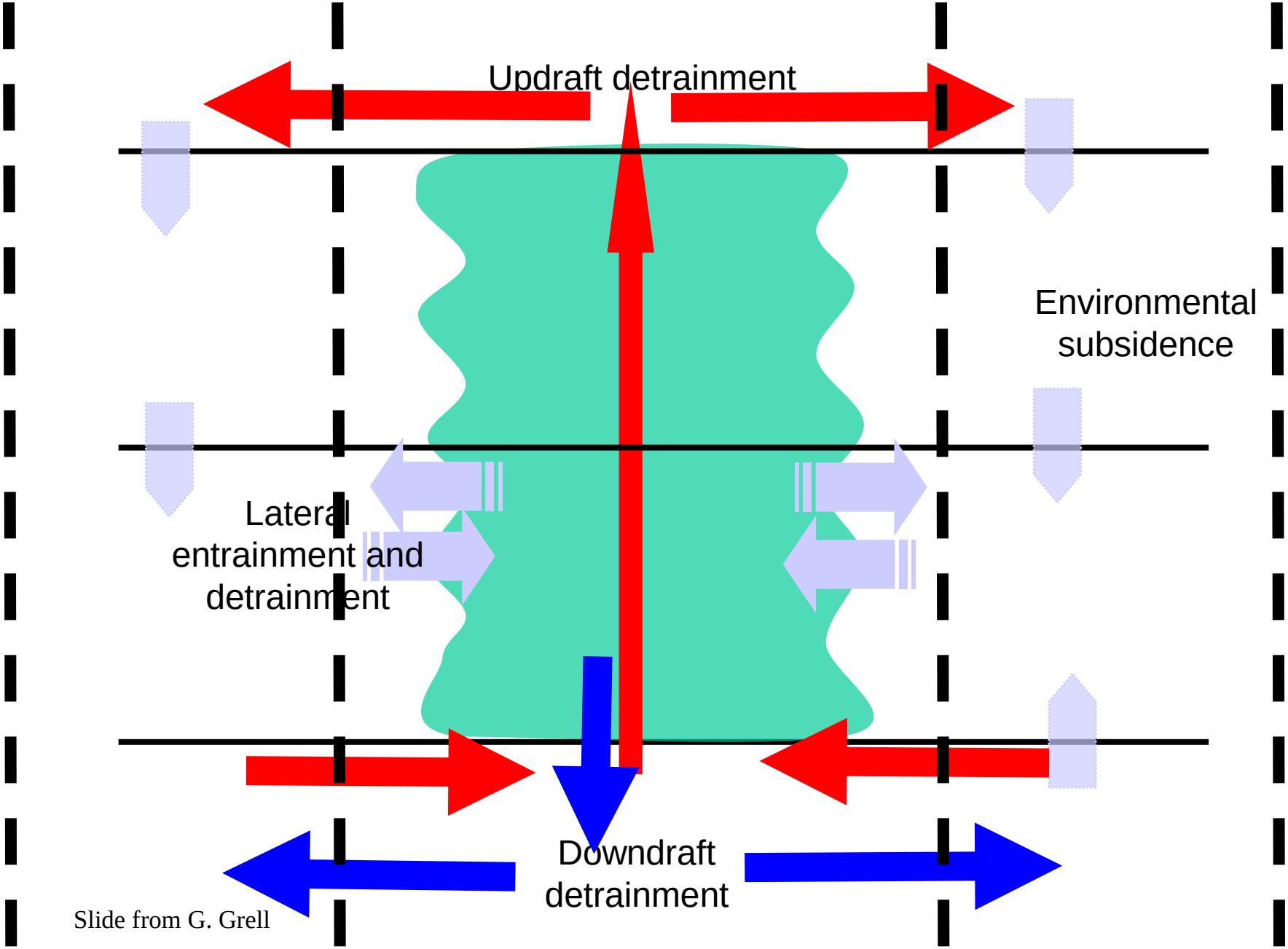
Process	Computer time (s) with 9600 cores
Model Integration	732 (62%)
INPUT	300 (25%)
OUTPUT	148 (13%)
Total	1180 (~20mn/day)

To allow for a smooth transition on “gray” scales, where more and more of the convection is resolved:

We apply the new Grell’s cumulus scheme: G3d

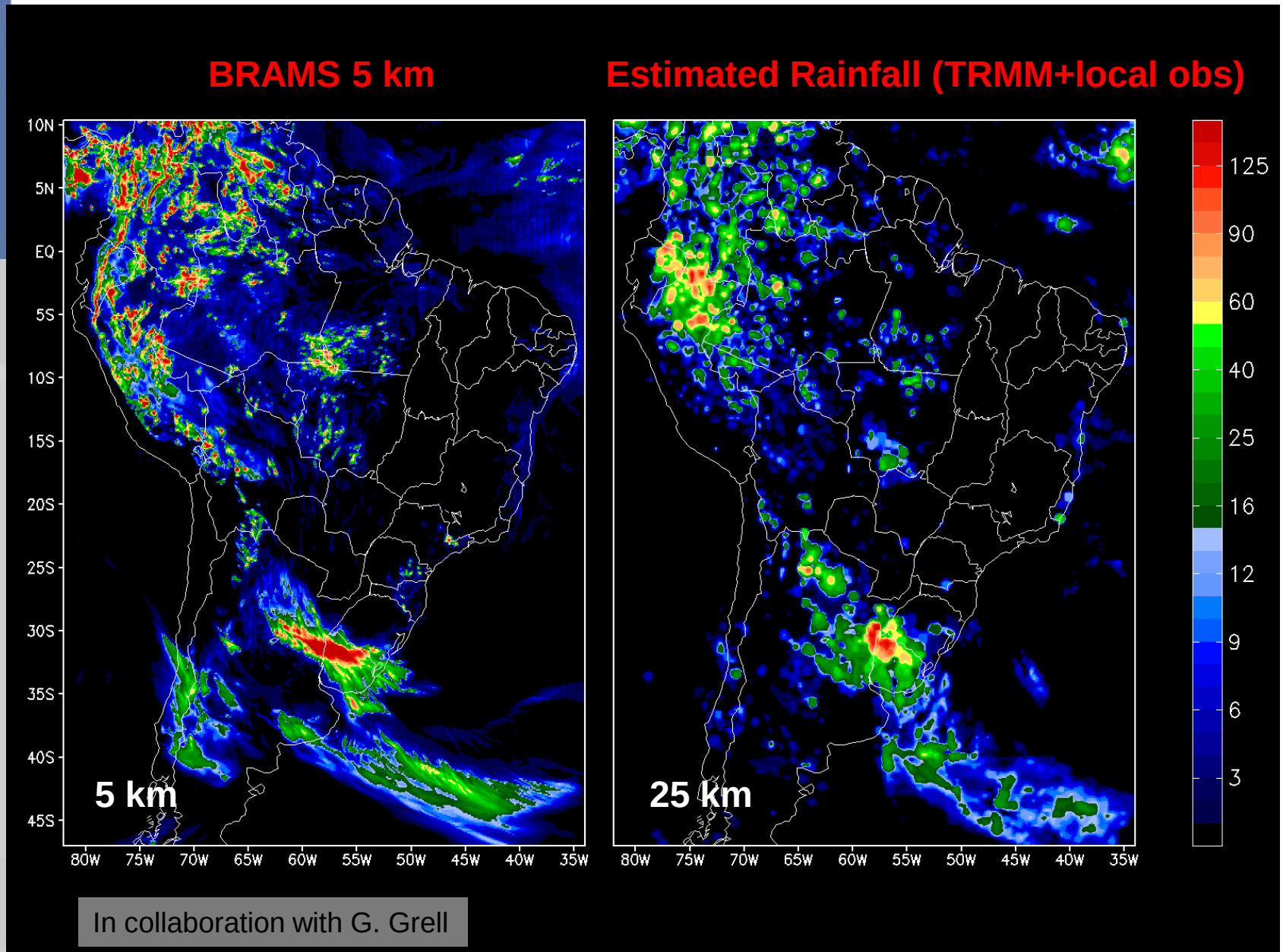
Slide from G. Grell

G3d: nine or more grid boxes



Slide from G. Grell

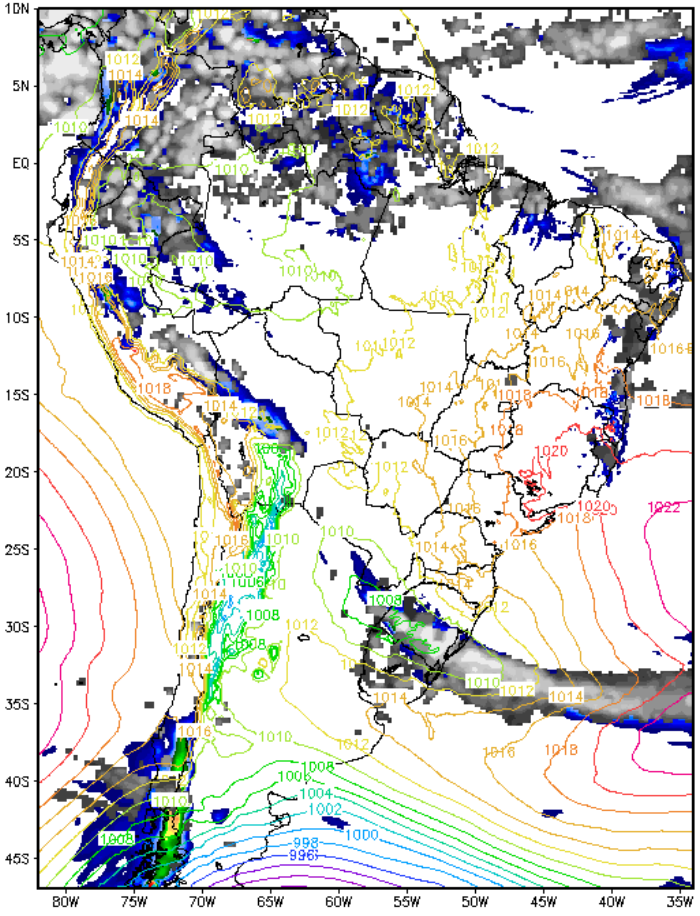
Application of BRAMS 5 km with G3d convection scheme (a visual comparison)



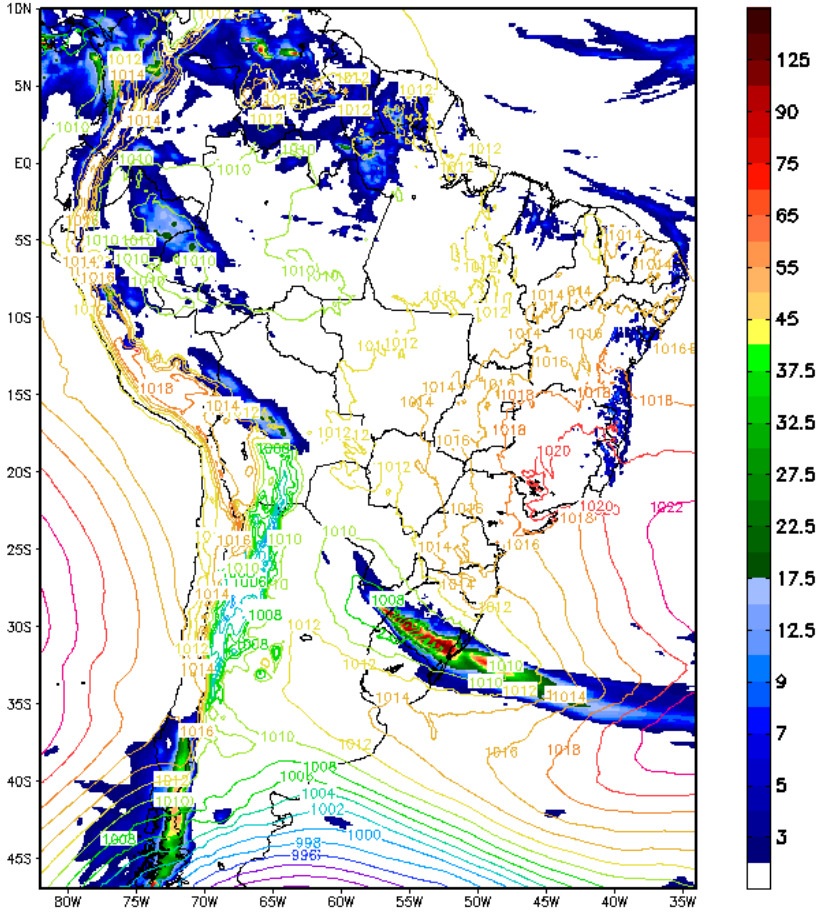
In collaboration with G. Grell

BRAMS 5 km resolution
Some examples of model performance

Remote Sensing Rainfall



Model Rainfall – 24 hr accum.

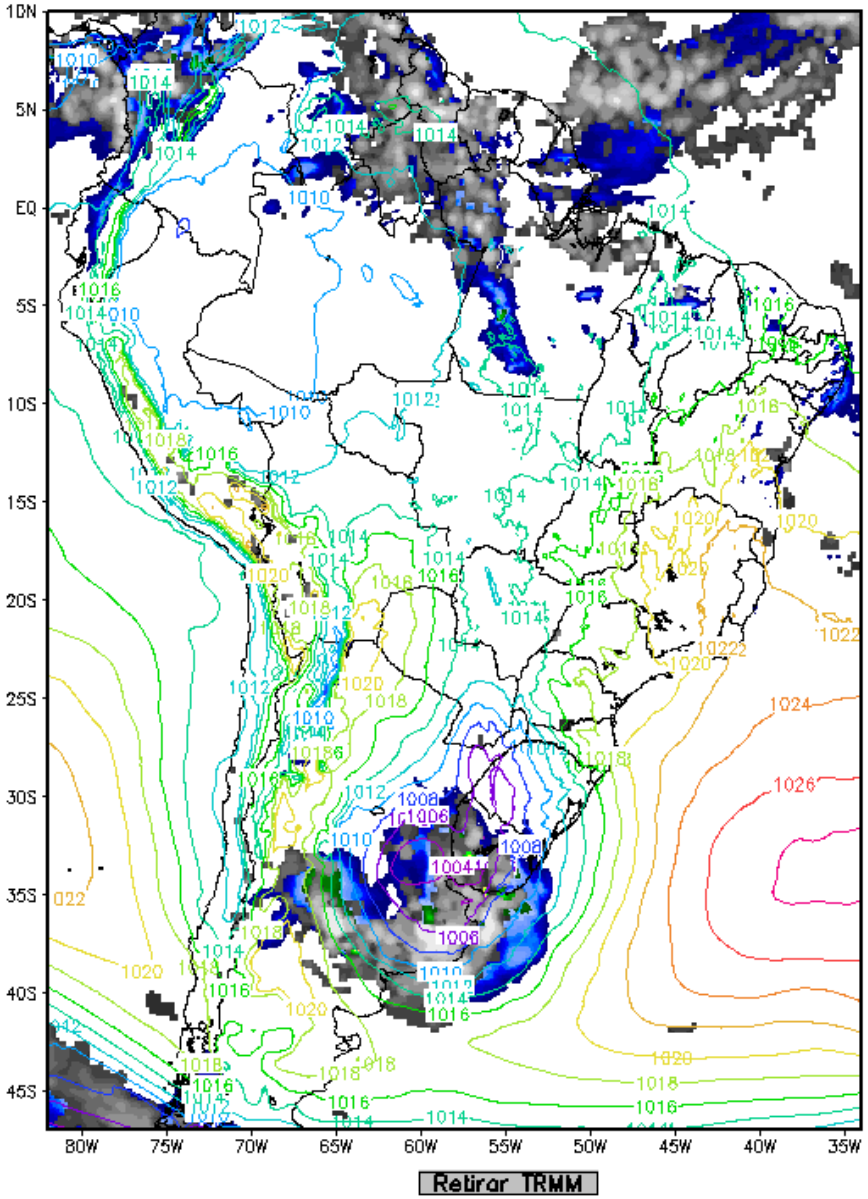


BRAMS 05 Km

Análise Inicializada em: 07/8/2012, 00 UTC (Terça-feira) Válida para: 08/8/2012, 12 UTC (Quarta

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



Retirar TRMM

BRAMS 05 Km

Análise Inicializada em: 07/8/2012, 00 UTC (Terça-feira) Válida para: 08/8/2012, 12 UTC (Quarta-feira)

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

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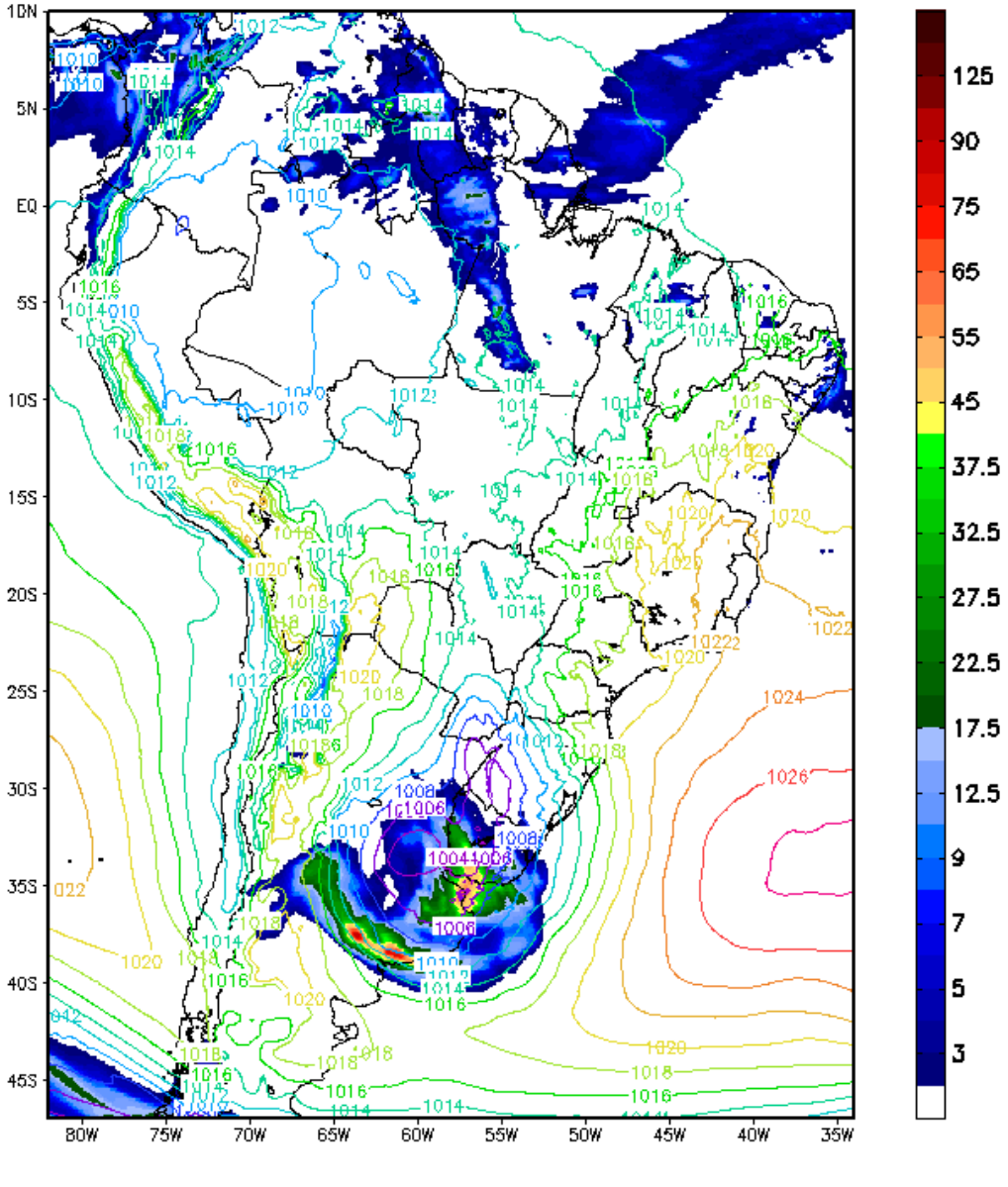
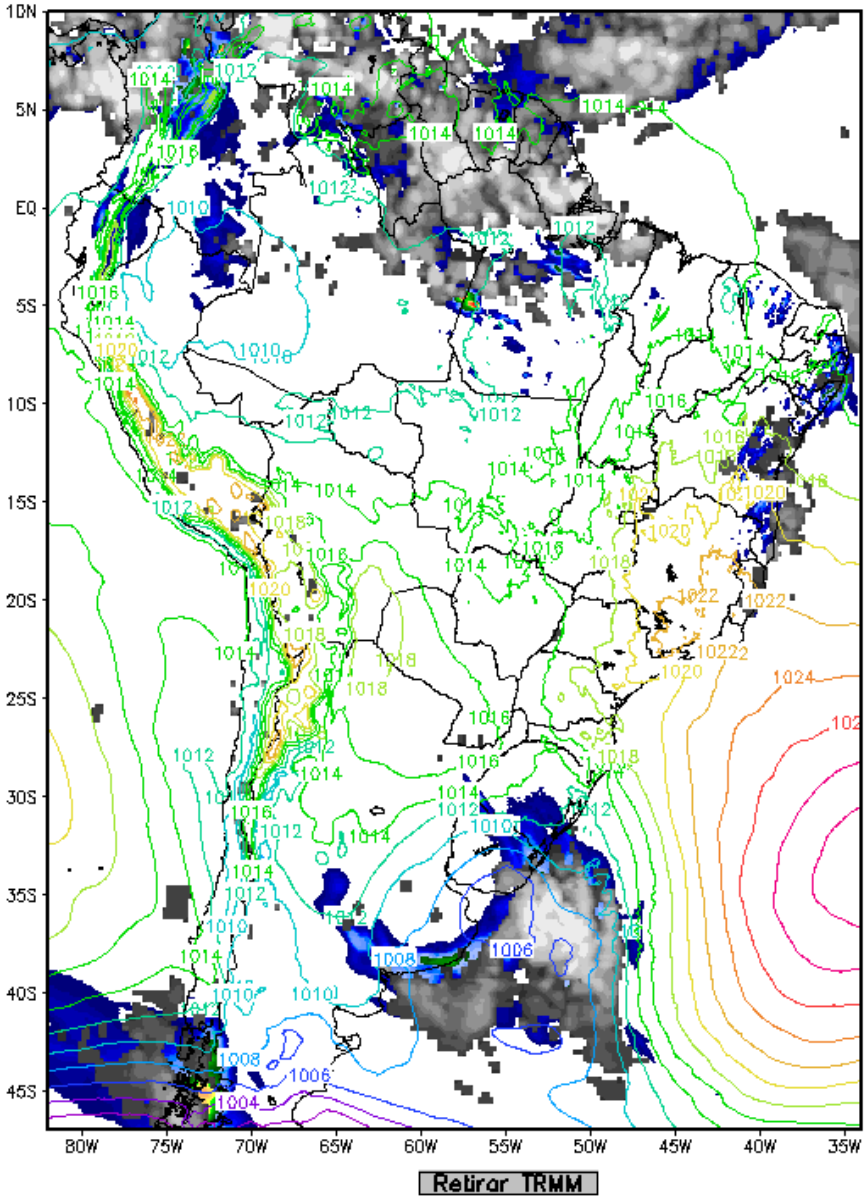


BRAMS 05 Km

Análise Inicializada em: 08/8/2012, 00 UTC (Quarta-feira) Válida para: 09/8/2012, 12 UTC (Quinta

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



Retirar TRMM

BRAMS 05 Km

Análise Inicializada em: 08/8/2012, 00 UTC (Quarta-feira) Válida para: 09/8/2012, 12 UTC (Quinta-feira)

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

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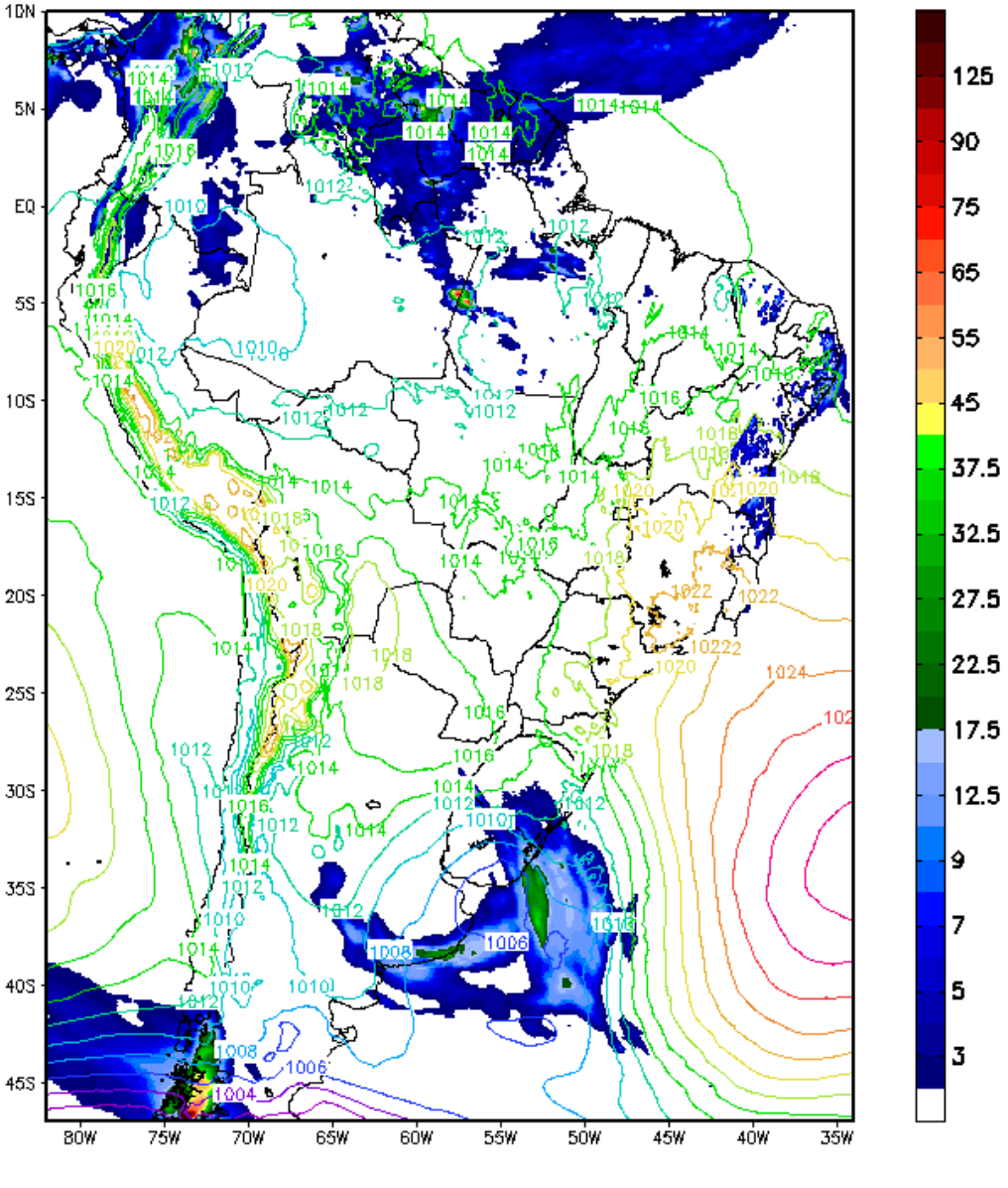
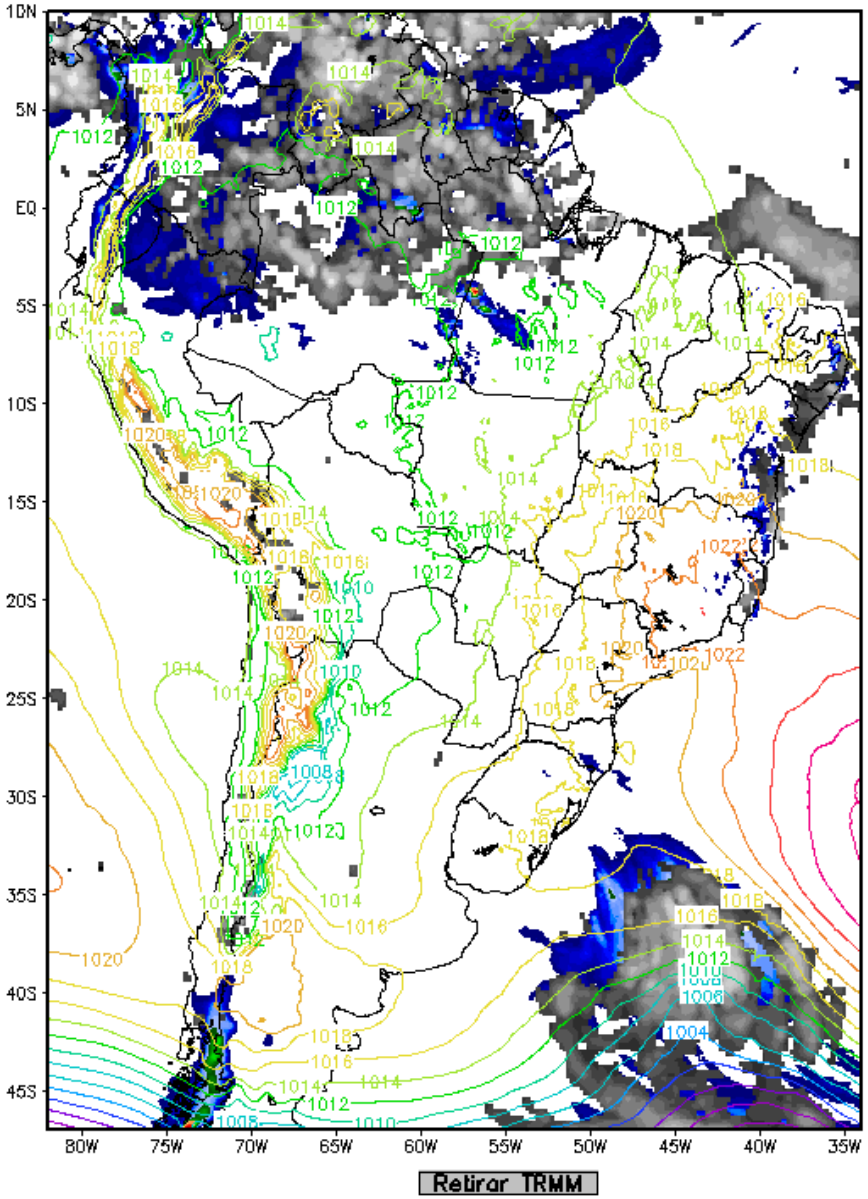


BRAMS 05 Km

Análise Inicializada em: 09/8/2012, 00 UTC (Quinta-feira) Válida para: 10/8/2012, 12 UTC (Sexta

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



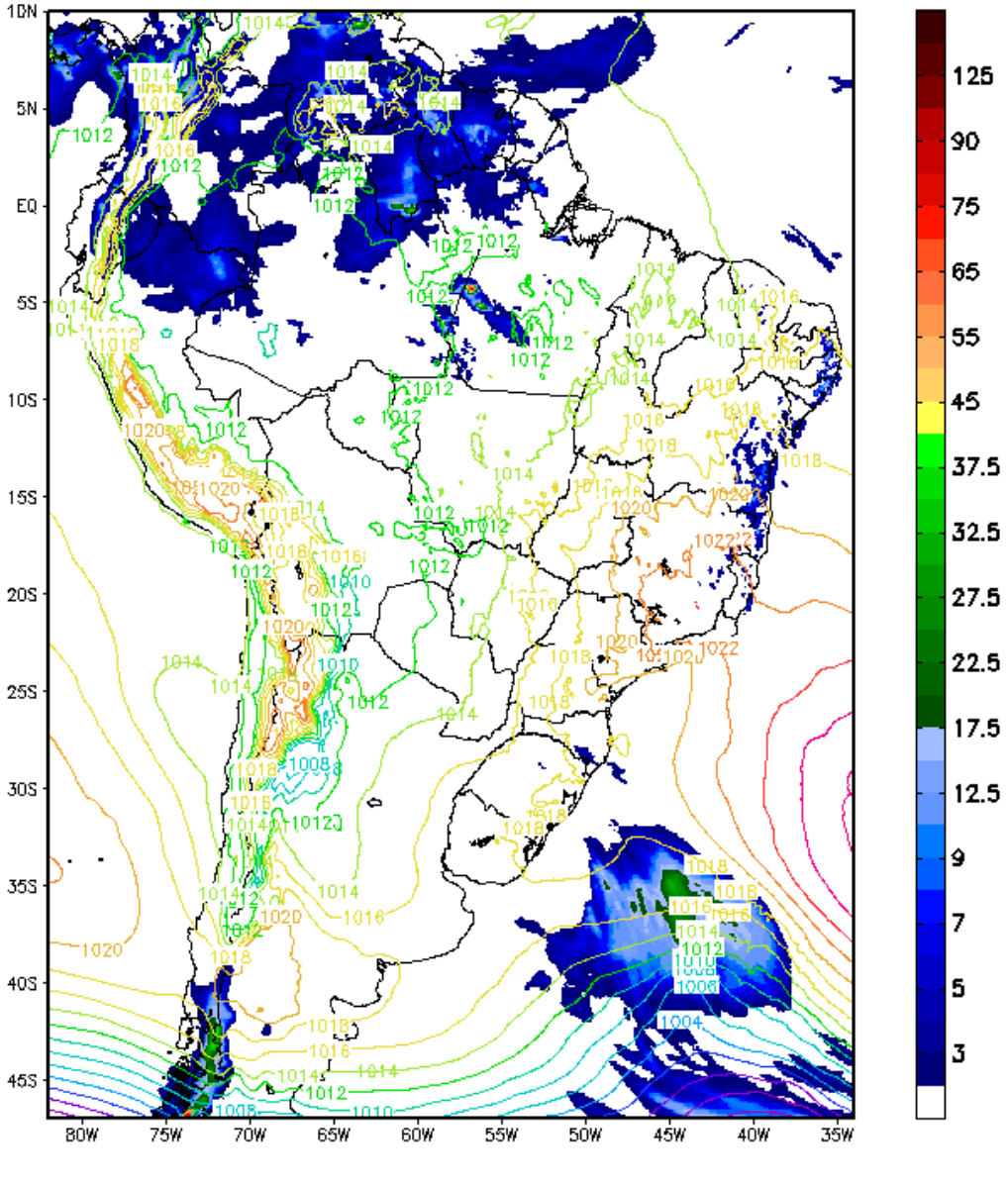
Retirar TRMM

BRAMS 05 Km

Análise Inicializada em: 09/8/2012, 00 UTC (Quinta-feira) Válida para: 10/8/2012, 12 UTC (Sexta-feira)

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE

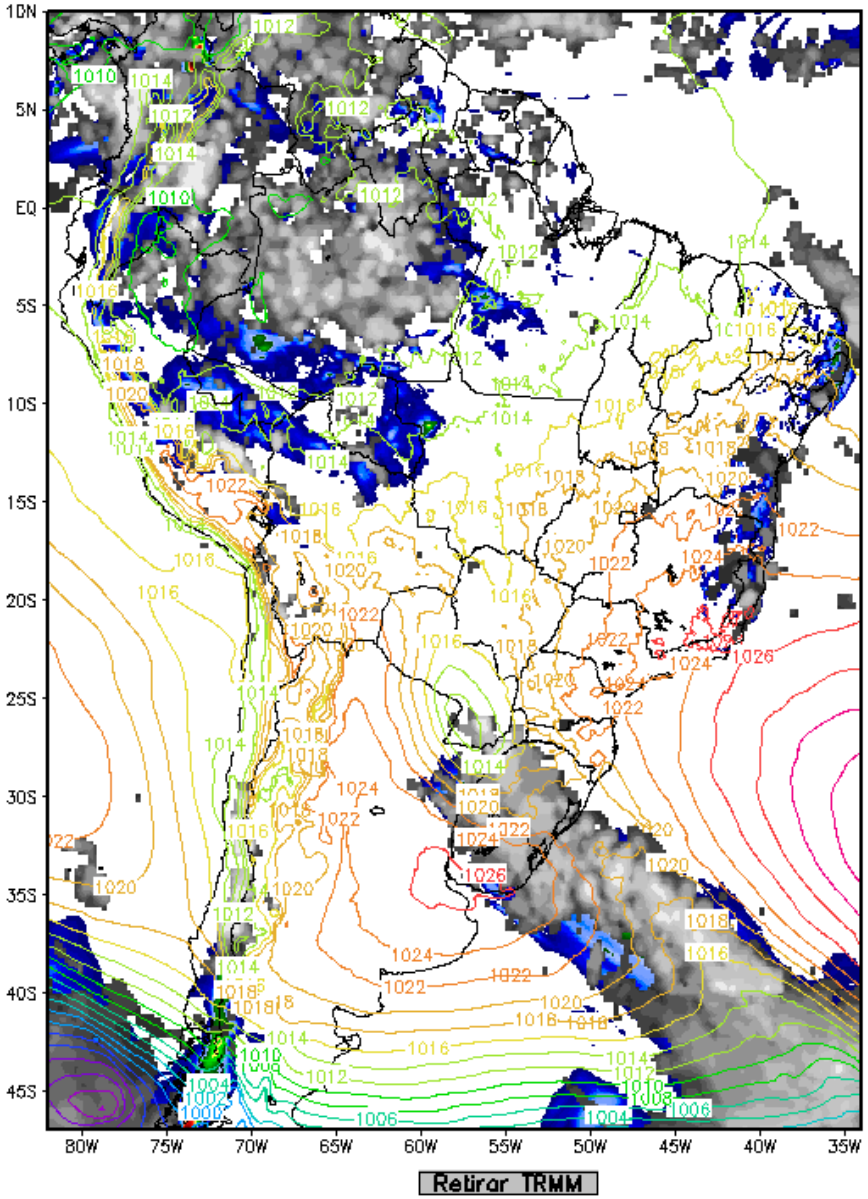


BRAMS 05 Km

Análise Inicializada em: 12/8/2012, 00 UTC (Domingo) Válida para: 13/8/2012, 12 UTC (Segunda

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



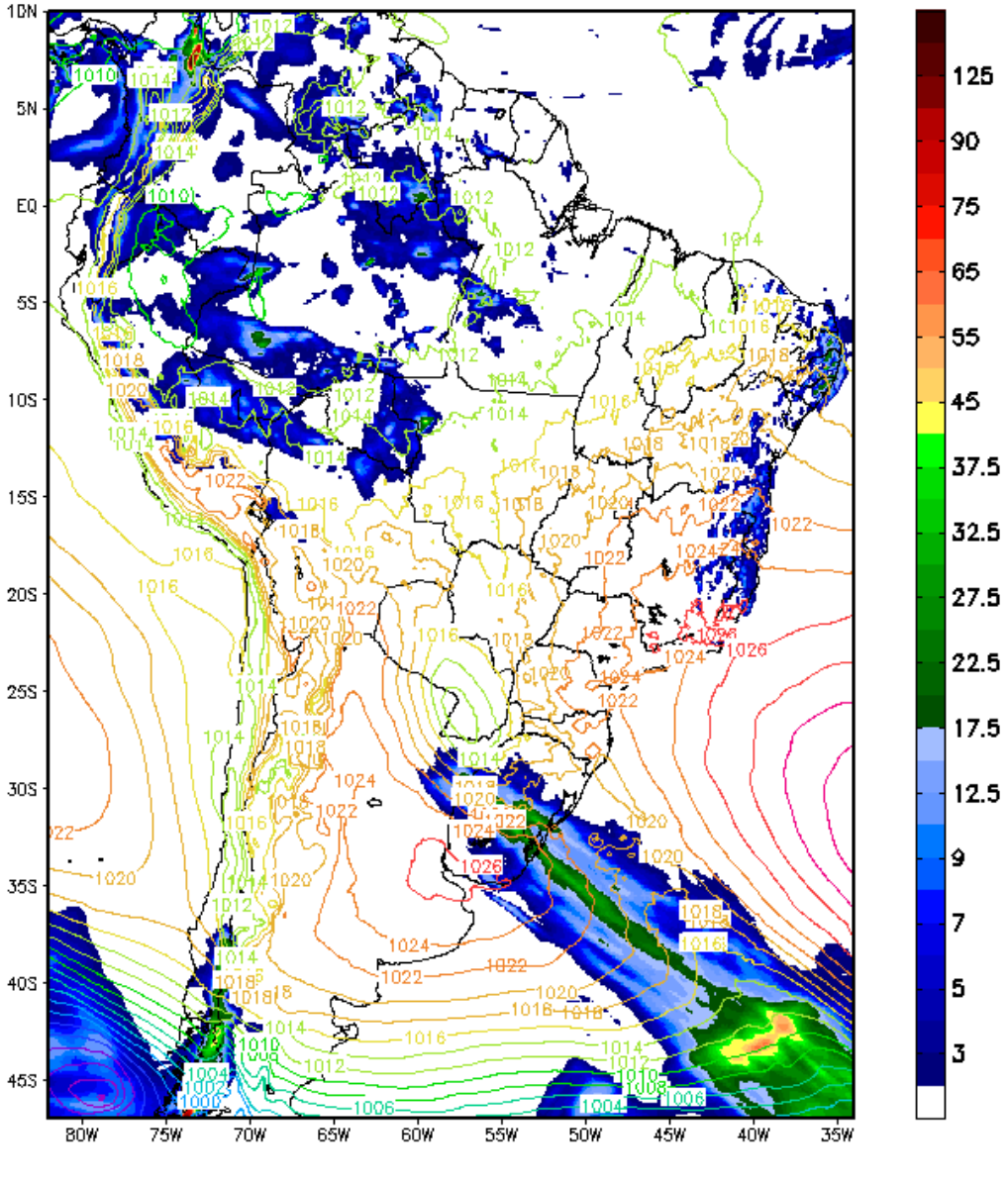
Retirar TRMM

BRAMS 05 Km

Análise Inicializada em: 12/8/2012, 00 UTC (Domingo) Válida para: 13/8/2012, 00 UTC (Segunda-feira)

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE

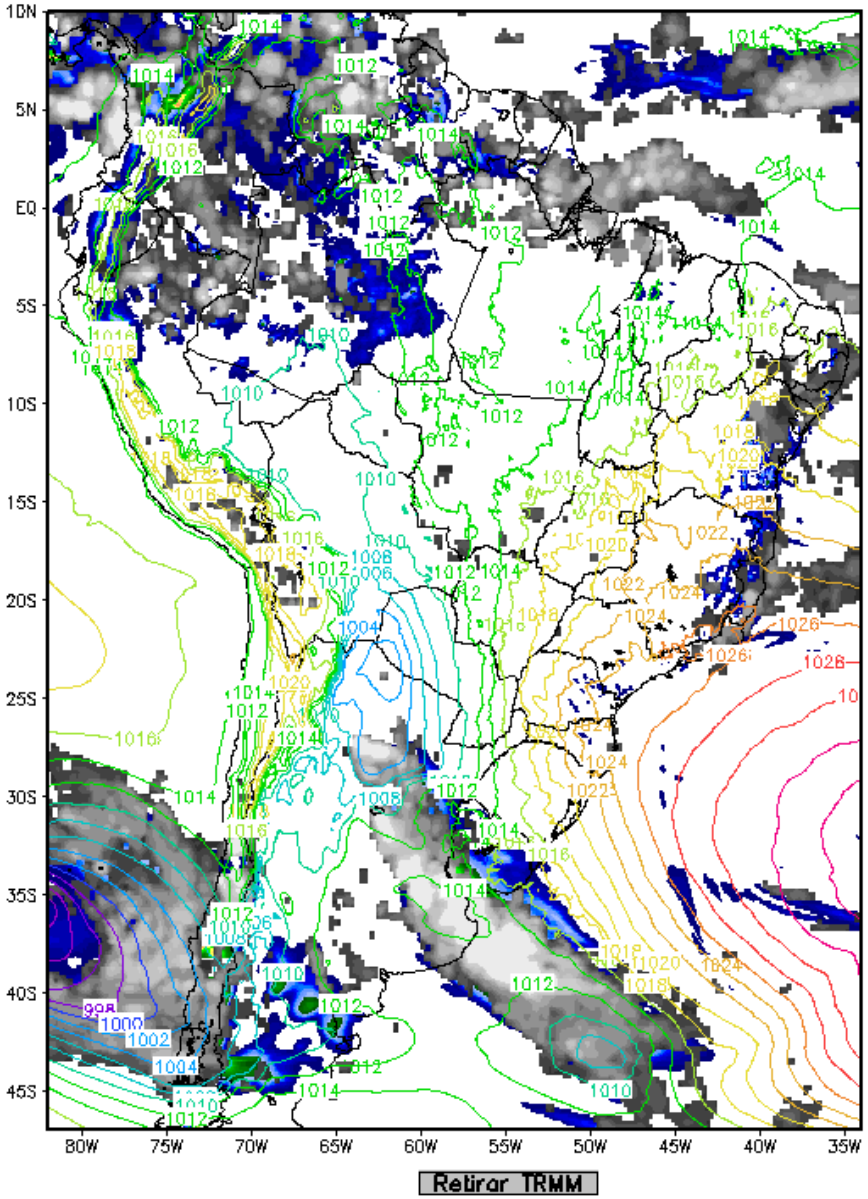


BRAMS 05 Km

Análise Inicializada em: 14/8/2012, 00 UTC (Terça-feira) Válida para: 15/8/2012, 12 UTC (Quarta

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



Retirar TRMM

BRAMS 05 Km

Análise Inicializada em: 14/8/2012, 00 UTC (Terça-feira) Válida para: 15/8/2012, 12 UTC (Quarta-feira)

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

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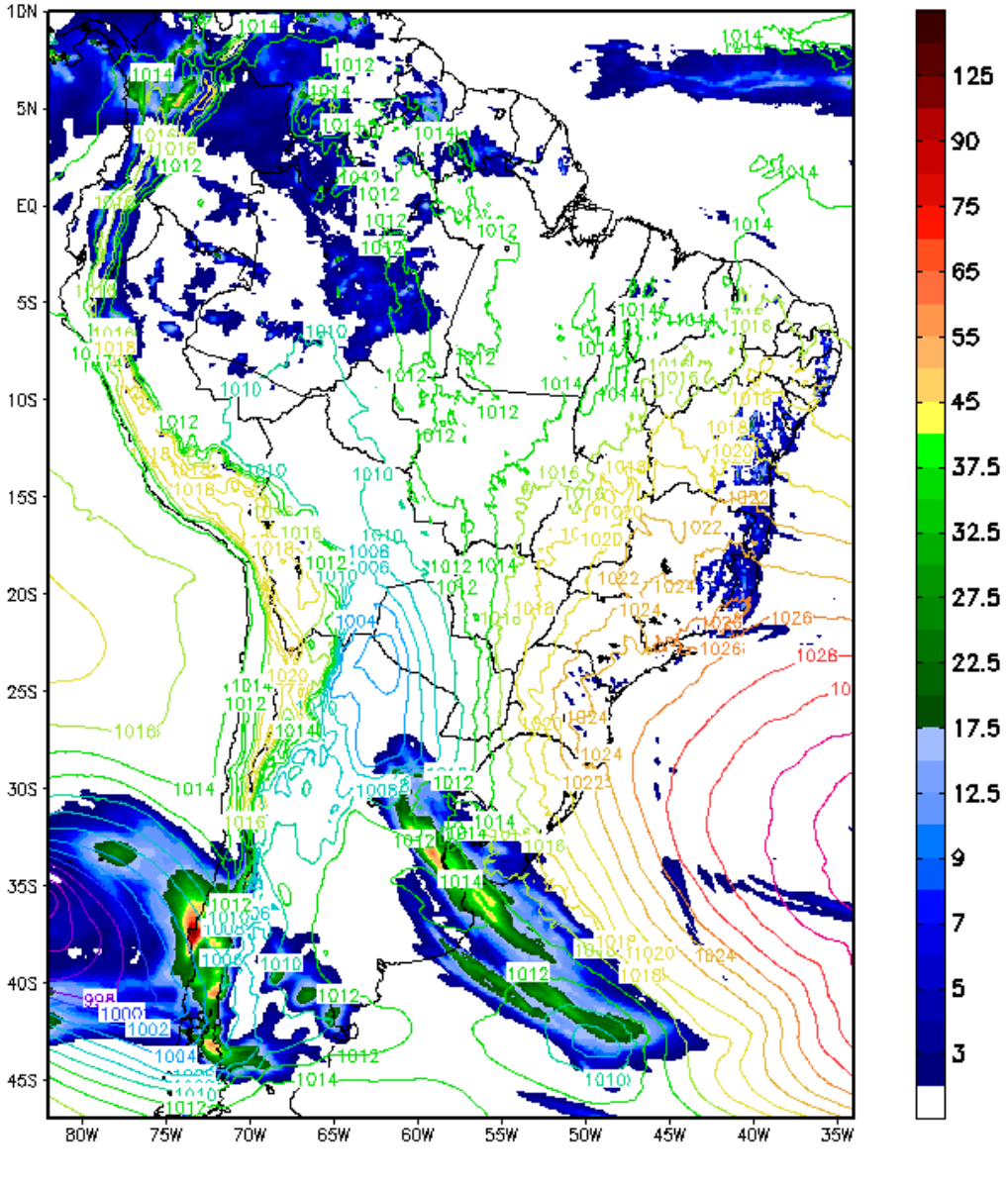
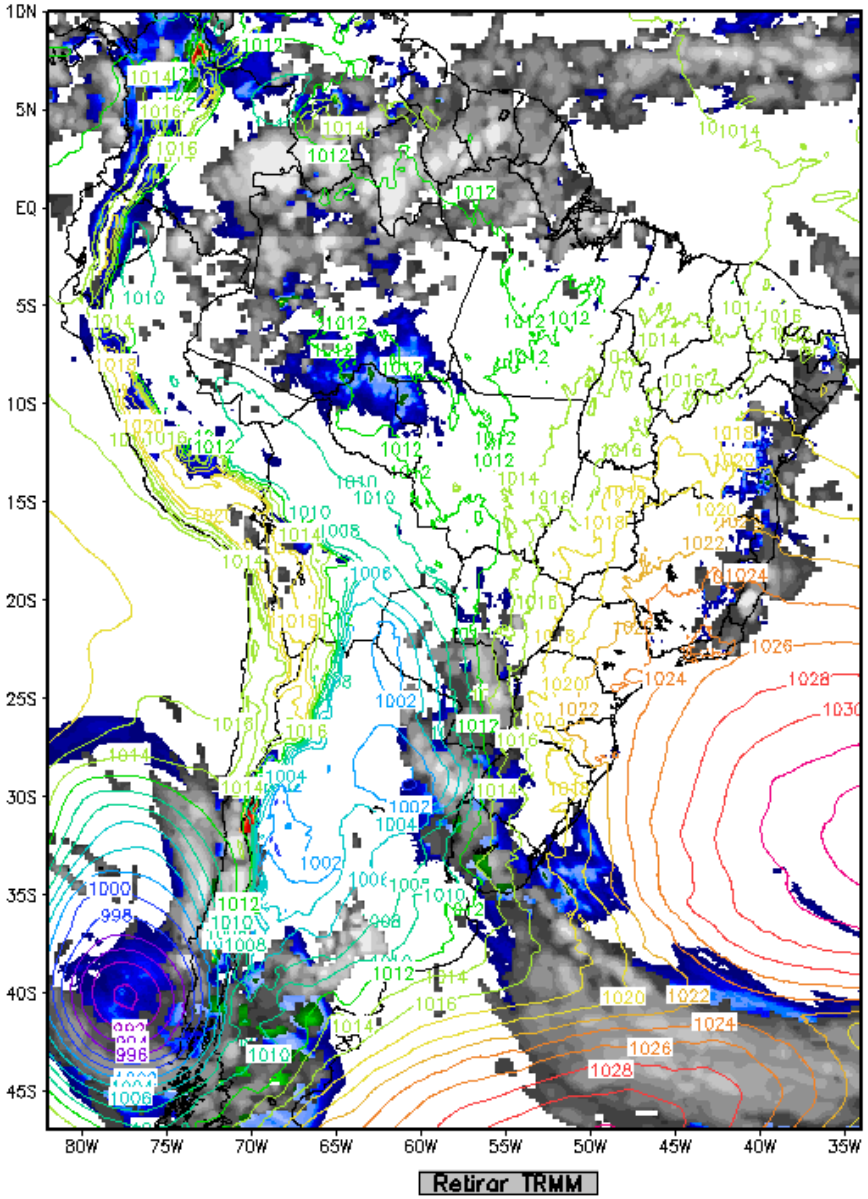


BRAMS 05 Km

Análise Inicializada em: 15/8/2012, 00 UTC (Quarta-feira) Válida para: 16/8/2012, 12 UTC (Quinta

Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

CPTEC/INPE



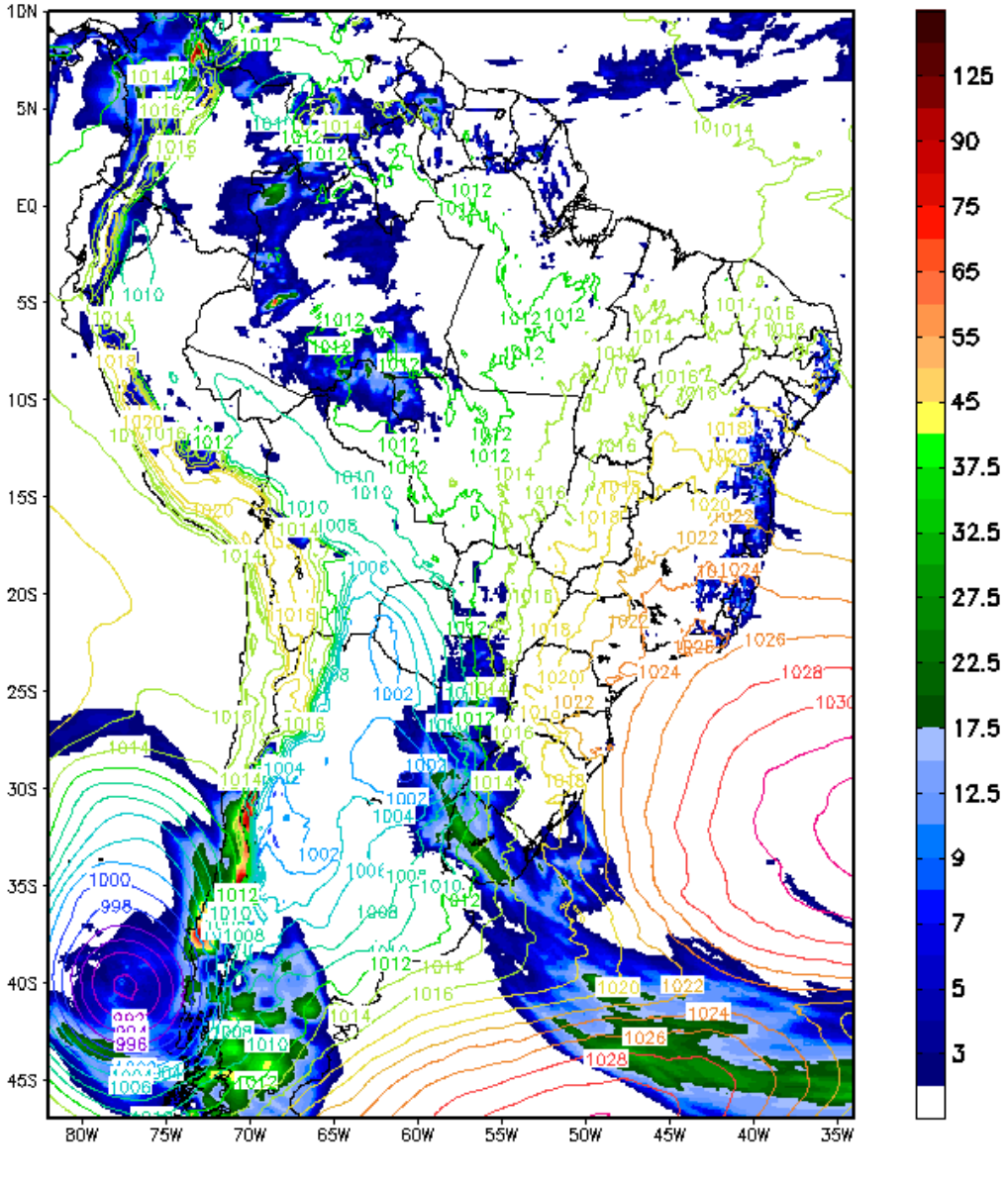
Retirar TRMM

BRAMS 05 Km

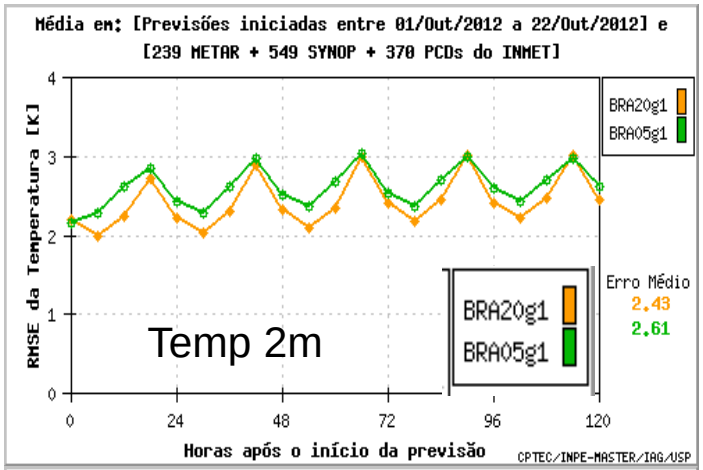
Análise Inicializada em: 15/8/2012, 00 UTC (Quarta-feira) Válida para: 16/8/2012, 12 UTC (Quinta-feira)

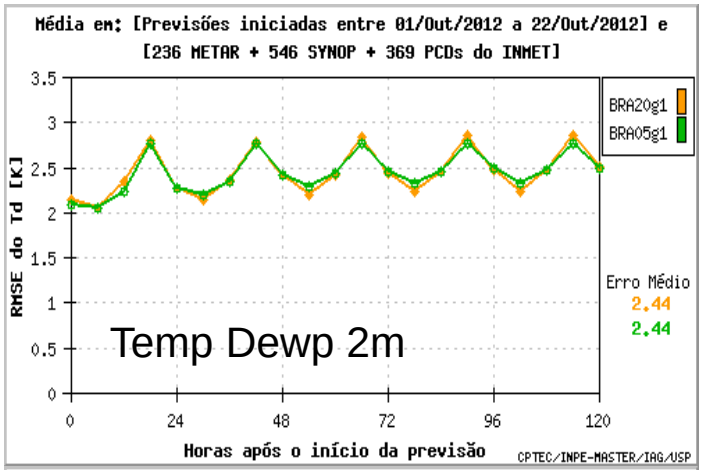
Variável: Precipitação Acumulada em 24h/Pressão ao nível médio do mar

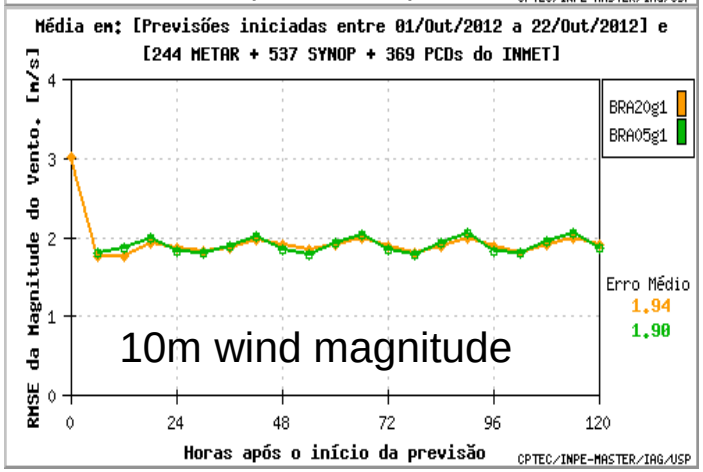
CPTEC/INPE

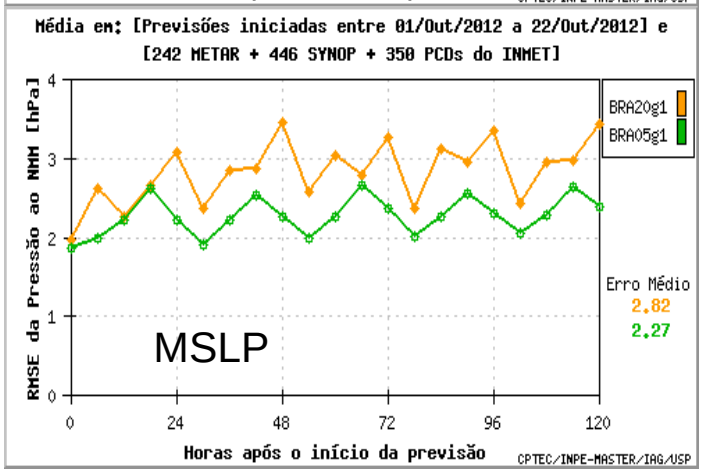


Comparison (RMSE) between BRAMS 20km and 5 km (with G3d convection scheme)









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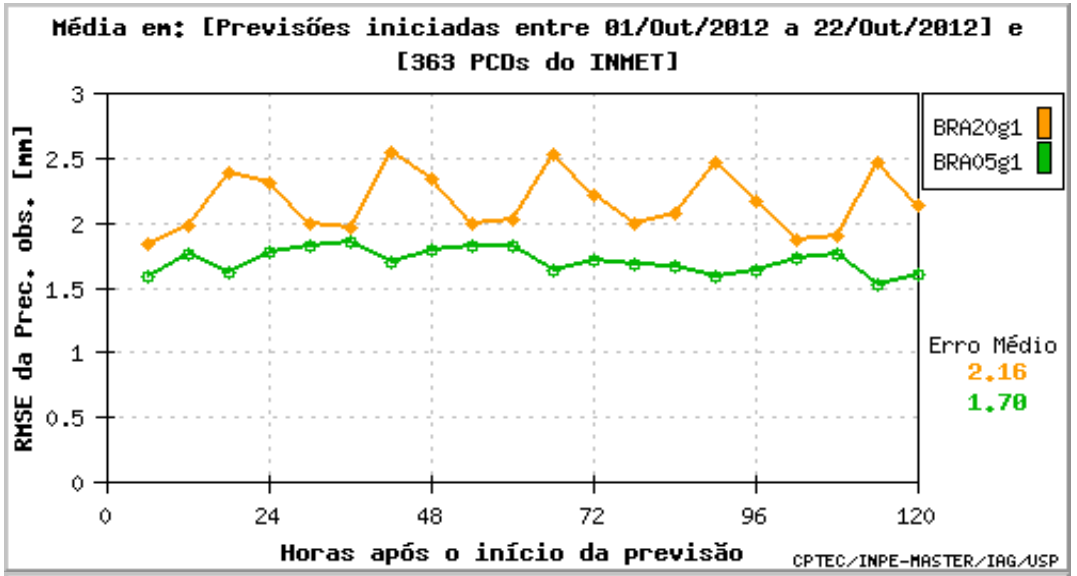
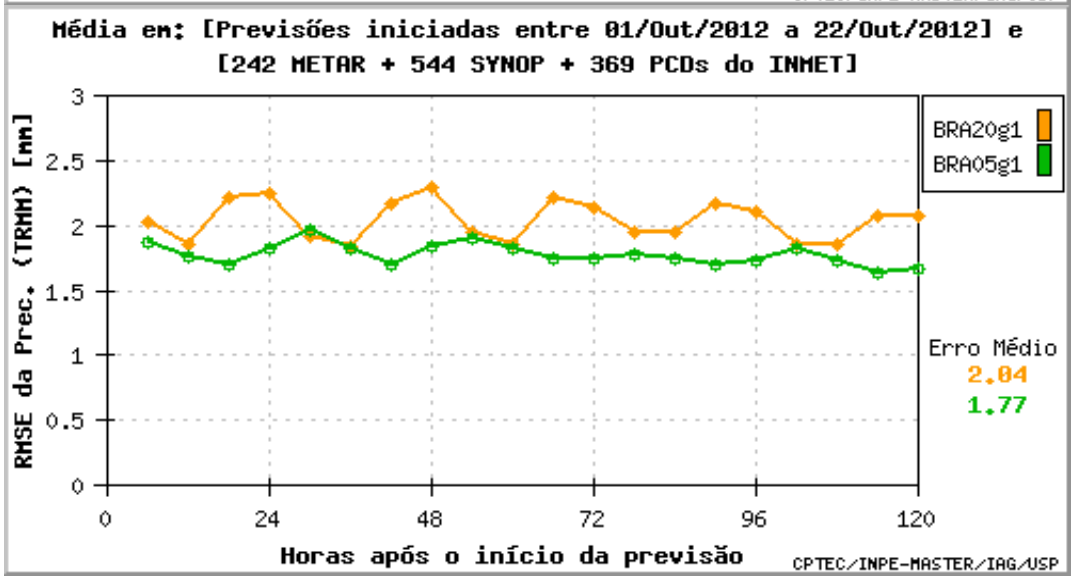
Rainfall using 363 rain gauges

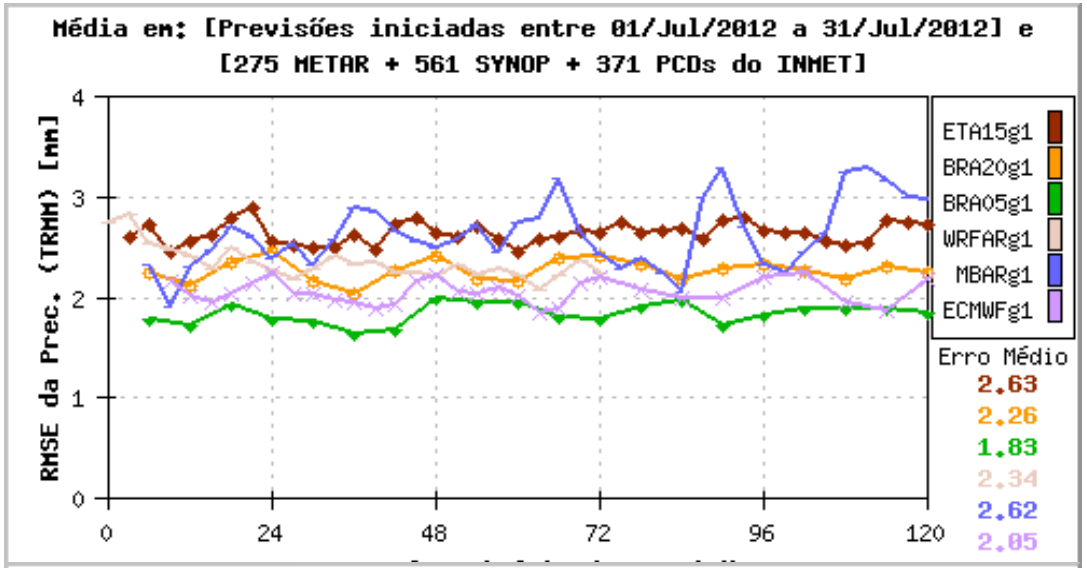


Rainfall using TRMM + 1000 observations

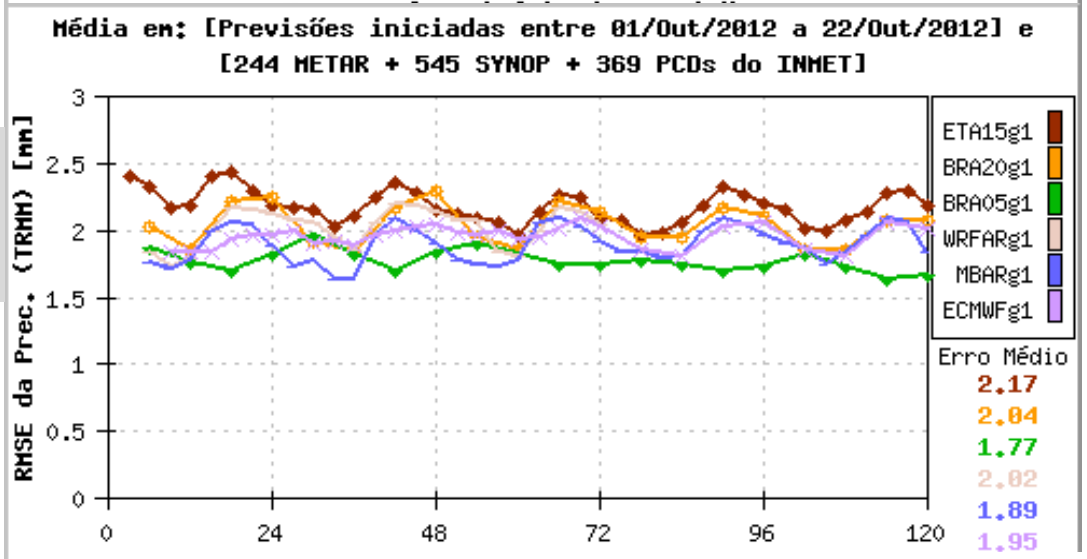


Examples of rainfall evaluation (RMSE)

July 2012

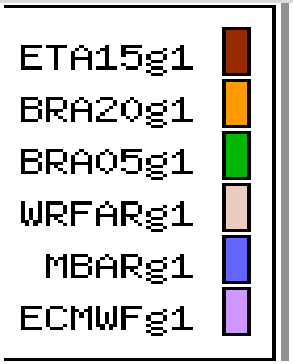


1-22/10/2012

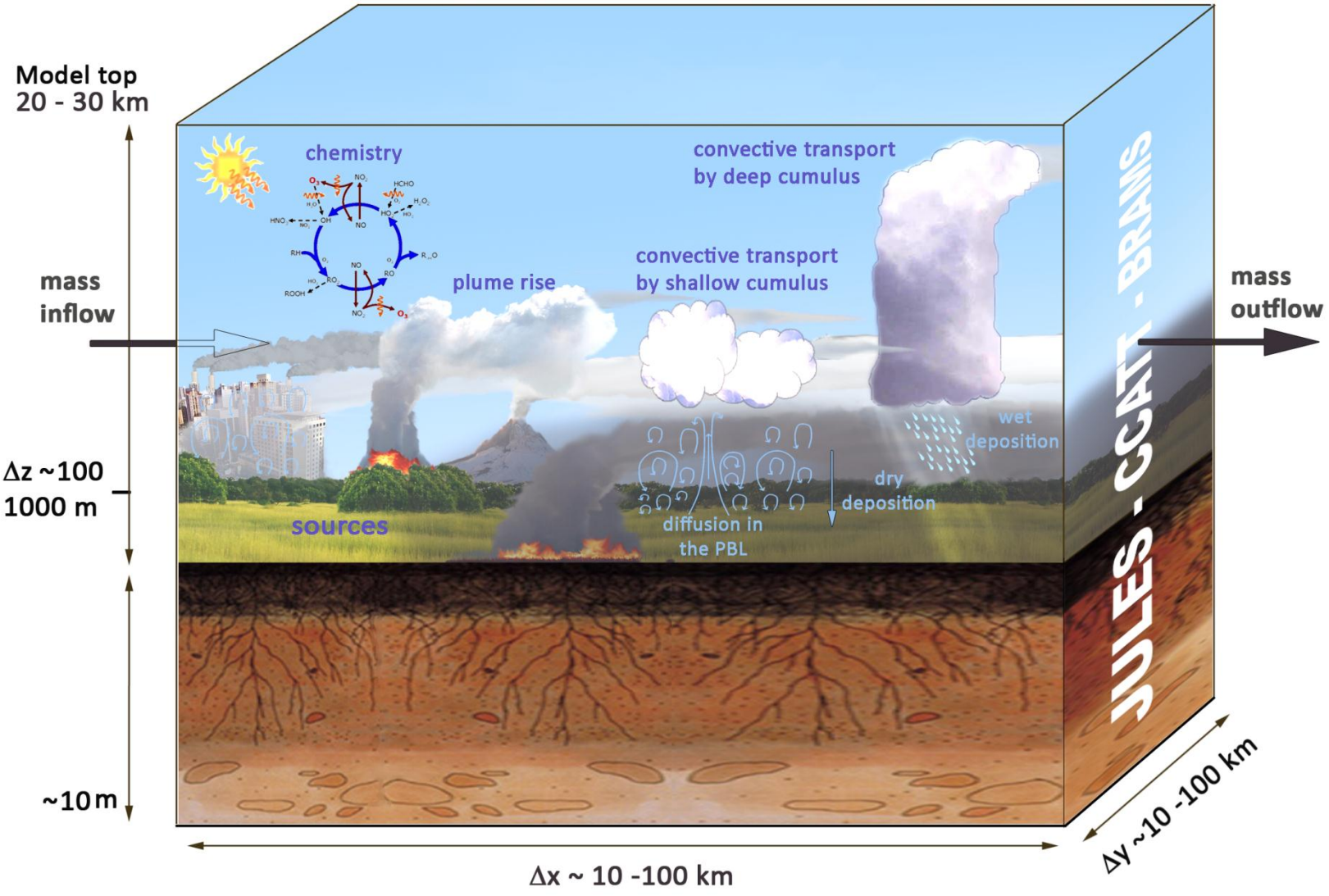


120 hours forecast

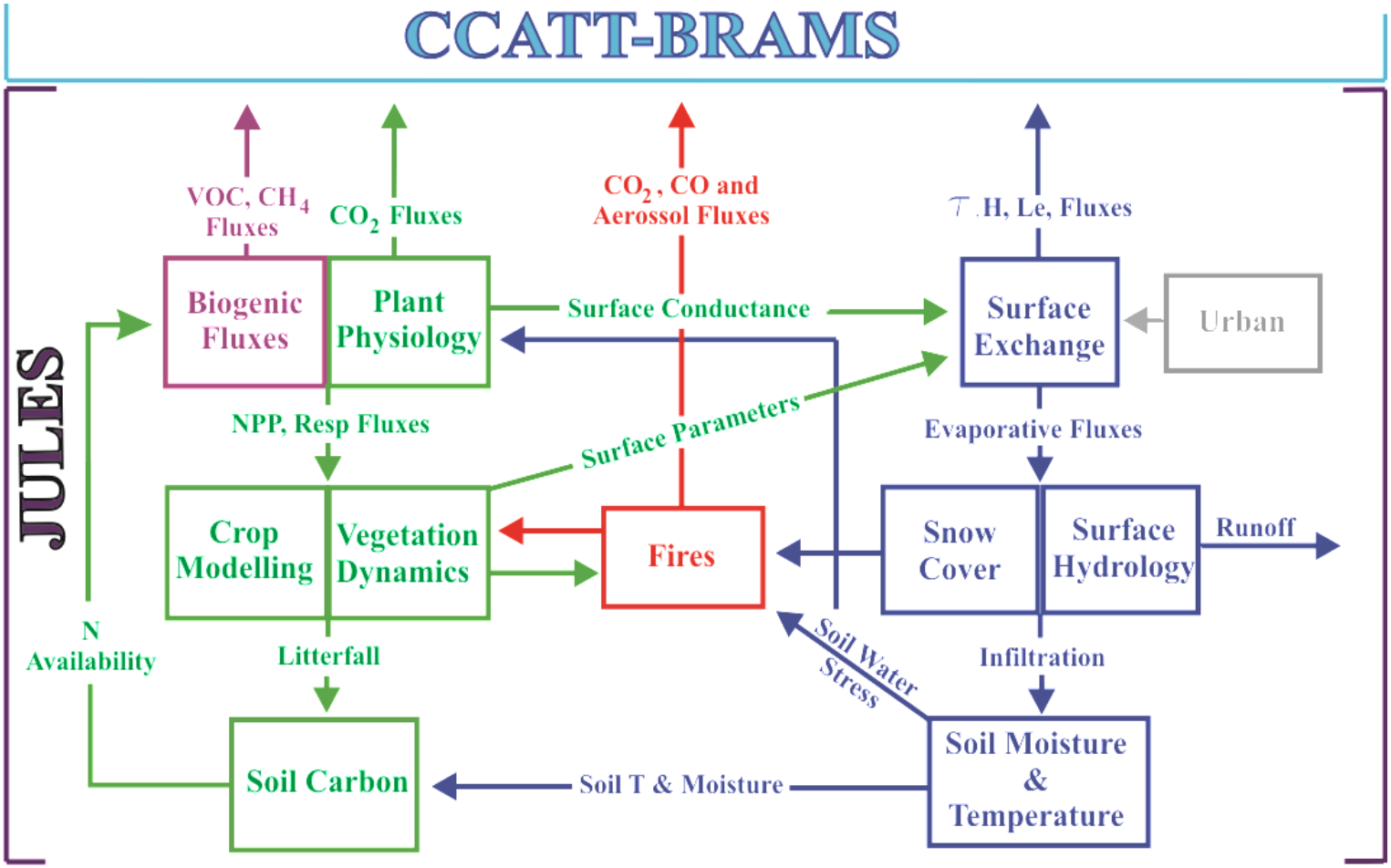
Some models running over S. America (on resolutions from 5 to 50 km):



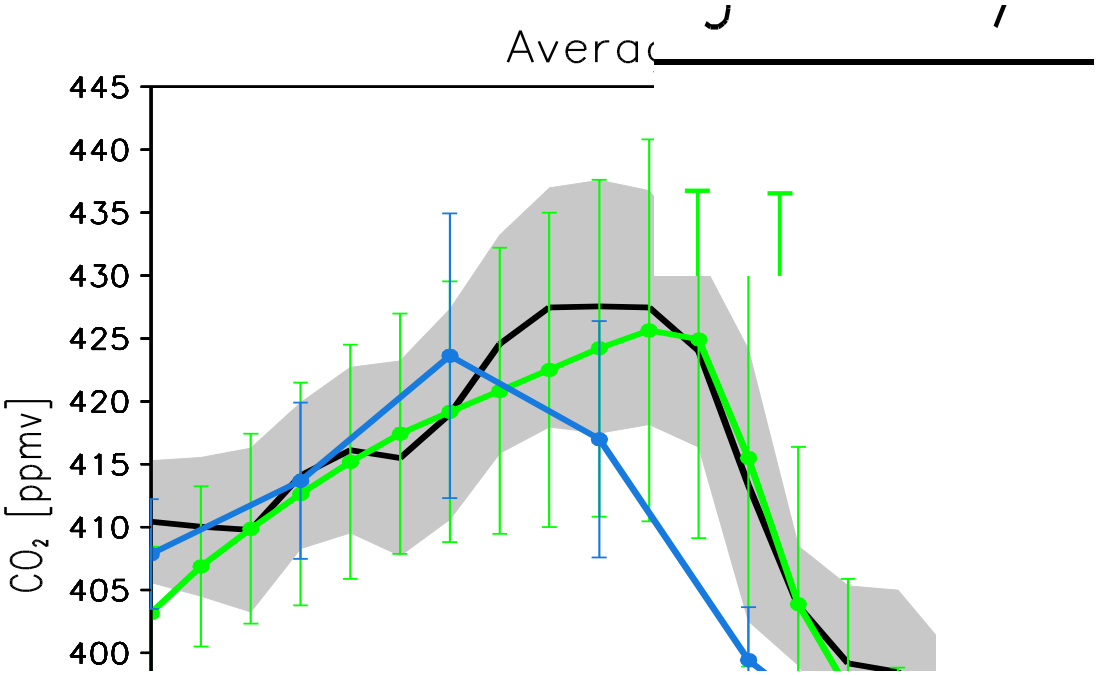
JULES-CCATT-BRAMS



Coupling between the land-surface scheme JULES and the atmospheric-chemistry model CCATT-BRAMS



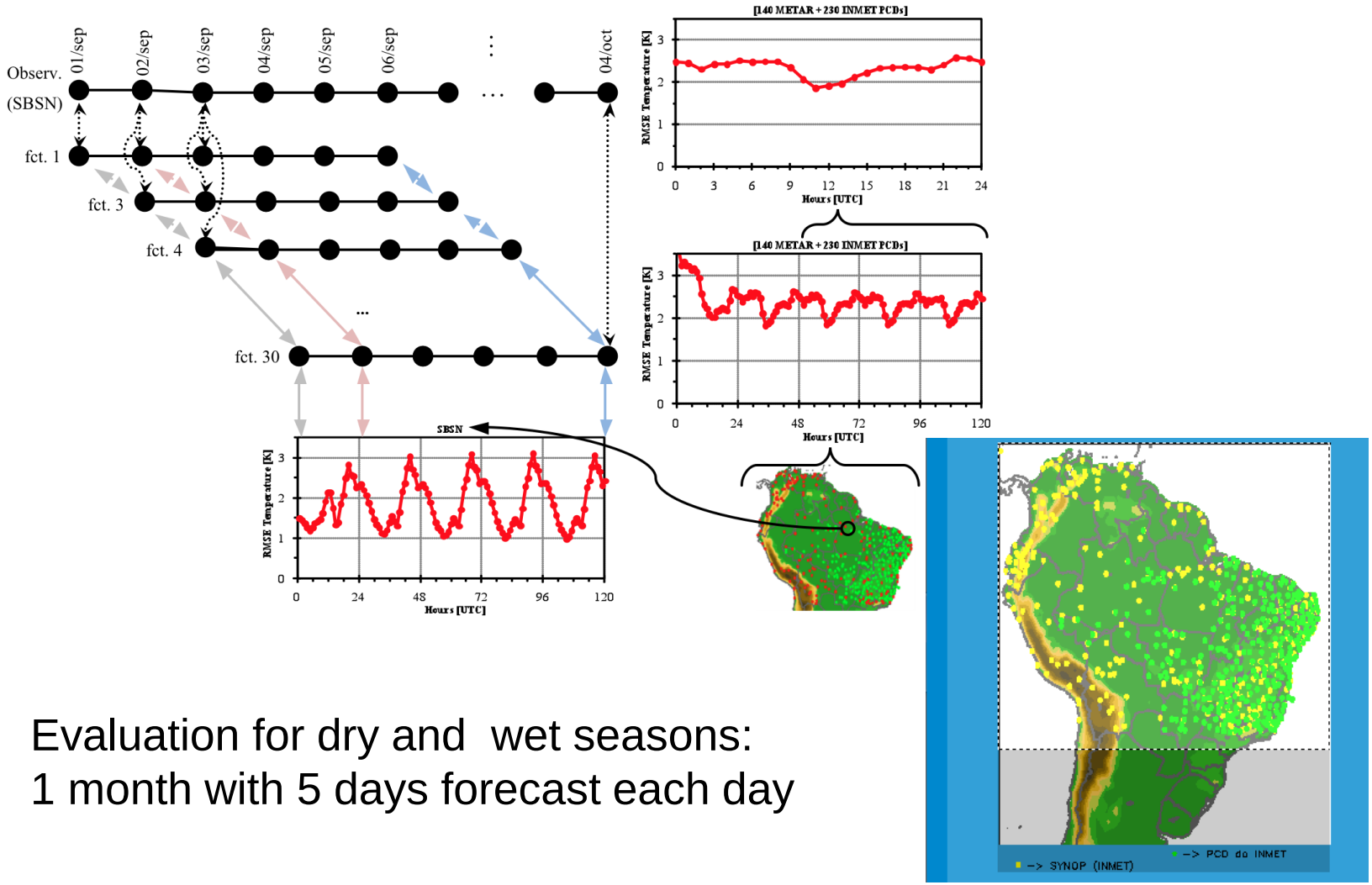
Coupling between the land-surface scheme JULES and the atmospheric-chemistry model CCATT-BRAMS



Comparison of near surface CO2 (LBA Tower km 67)

Moreira et al (in prep.)

BRAMS Weather Forecast Evaluation with JULES

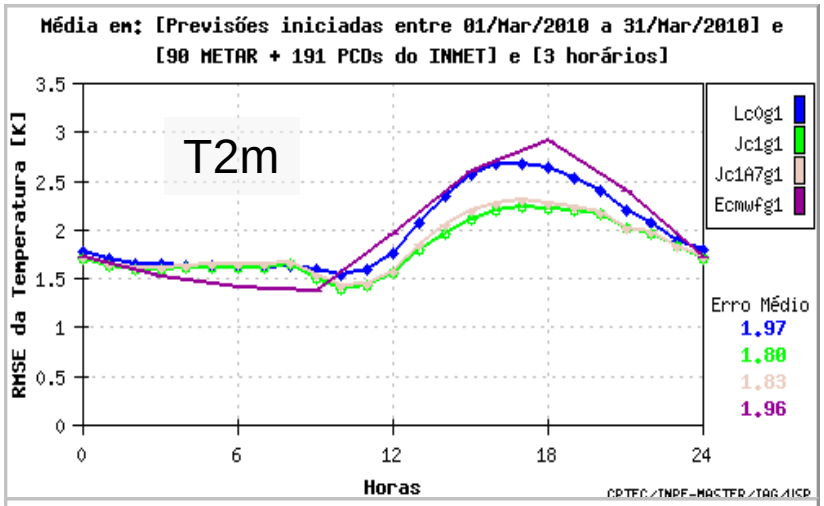


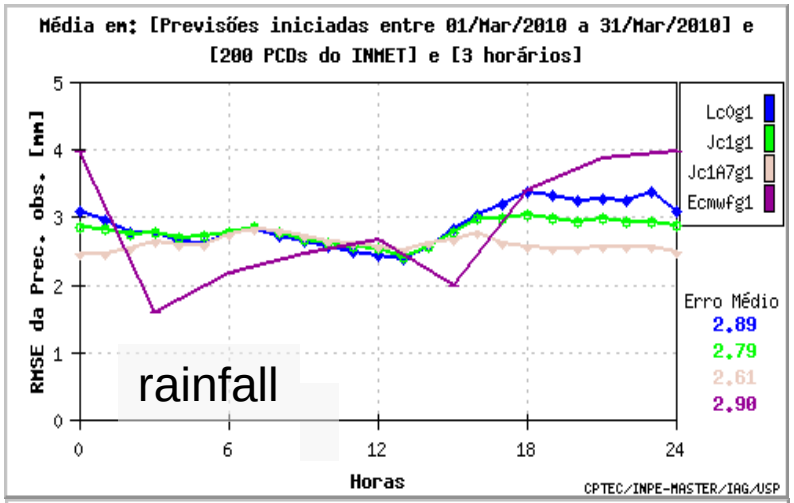
Evaluation for dry and wet seasons:
1 month with 5 days forecast each day

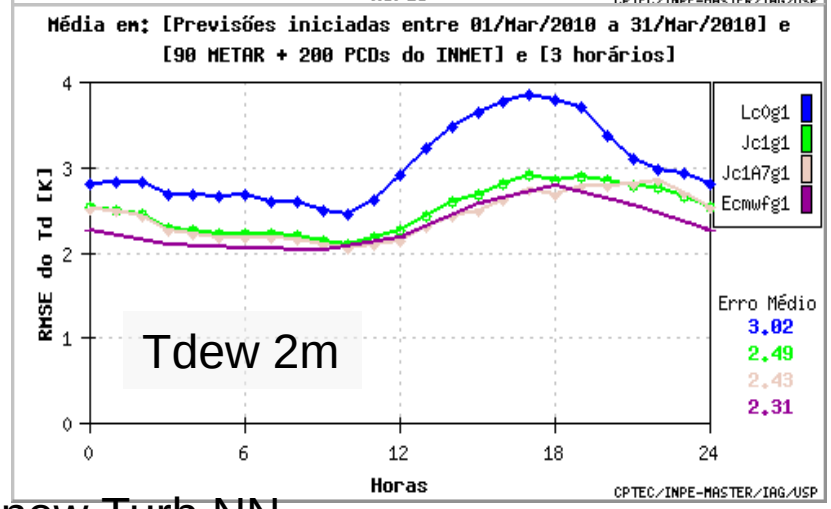
~ 300 stations

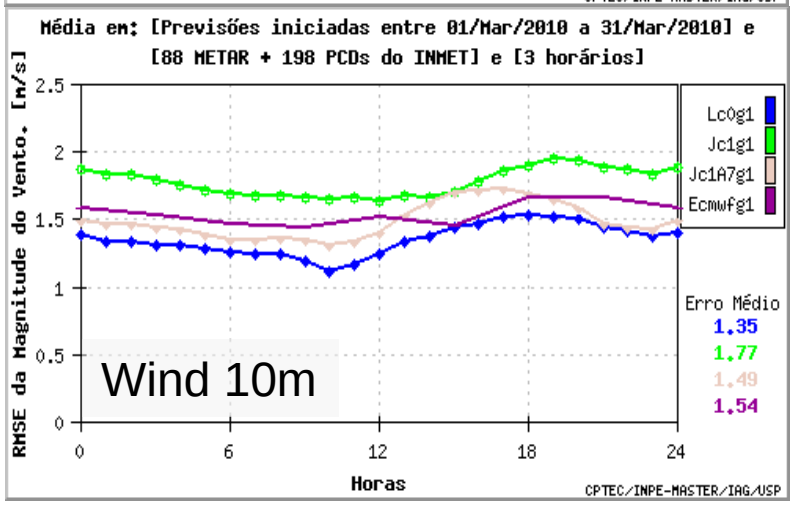
Model Evaluation:

BRAMS/LEAF; BRAMS/JULES+NewAdvection;
BRAMS/JULES+new Turbulence (NN) and ECMWF









LEAF
JULES
JULES new Turb NN
ECMWF

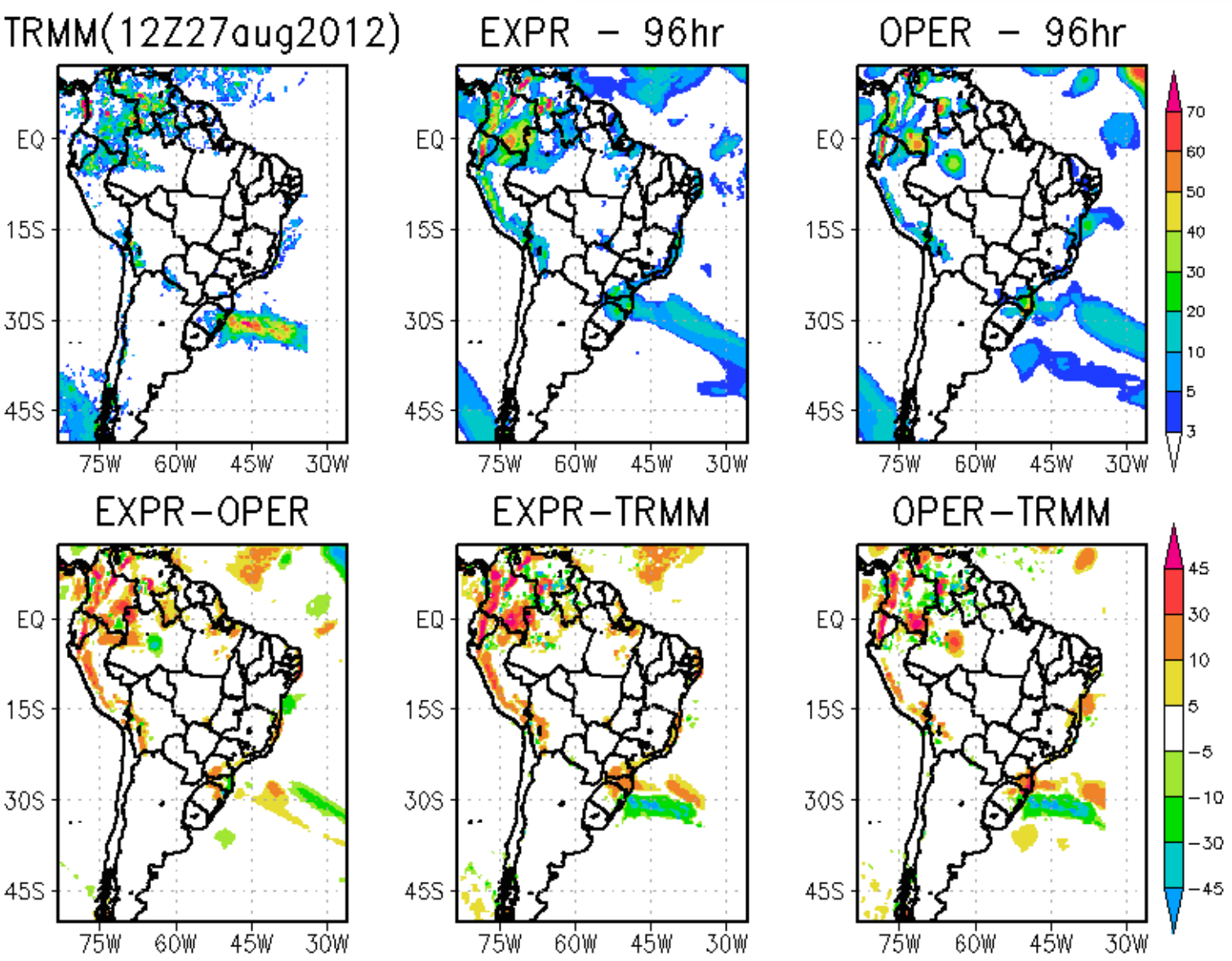
Moreira et al (in prep.)

- Global Atmospheric modeling

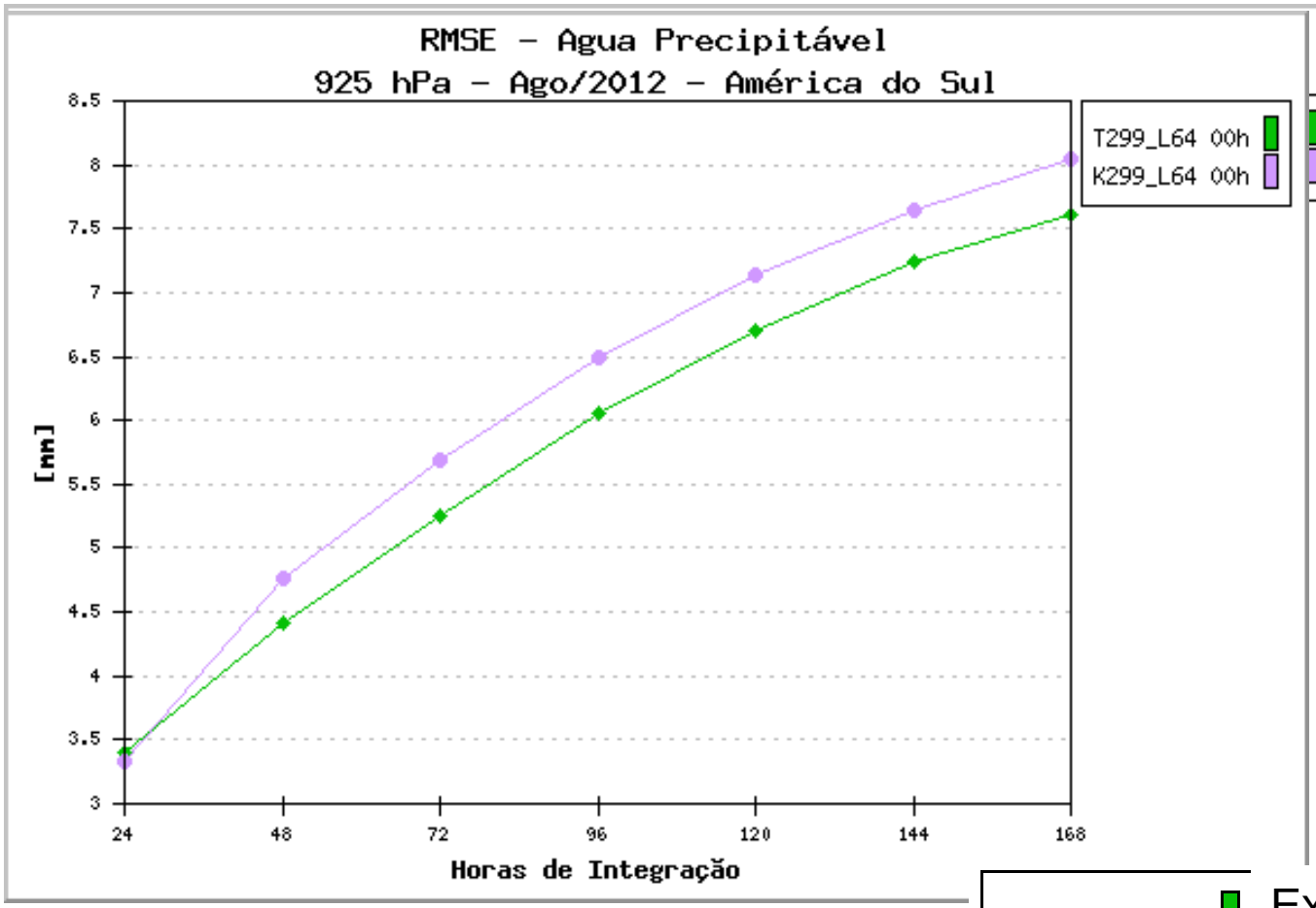
Experimental configuration for the CPTEC global atmospheric model

Configuração do MCGA-CPTEC/INPE TQ0299L64(~44 km)

Opcções	Descrição (OPERACIONAL)	Descrição (EXPERIMENTAL)
Dinâmica	Euleriana com grade Reduzida	Semi-Lagrangiano com grade Reduzida
Radiação de onda Curta	CLIRAD (Tarasova et al. 2007)	CLIRAD (Tarasova et al 2007)
Radiação de onda Longa	HASHVANADAN(1987)	HASHVANADAN(1987)
Camada Limite	MELLOR YAMADA 2.0 (1982)	Hostlag e Boville modificado (MY)(1992)
Esquema de Superfície	SSiB(1991)	IBIS(1996)-Modificado Kubota
Convecção Profunda	KUO(Kuo, 1965)	Grell e Devenyi(2002)-VersCPTEC
Convecção Rasa	TIEDKE(1983)	TIEDKE(1983)
P. de Larga escala	Precipitação de Larga escala (ajustamento devido a saturação)	Microfísica (Rasch and Kristjánsson (1998))
Onda de Gravidade	ALPERT(1988)	ALPERT(1988)
Fluxo sobre oceano	Bucket model (COLA)	Bulk aerodynamic algorithm (NCEP)

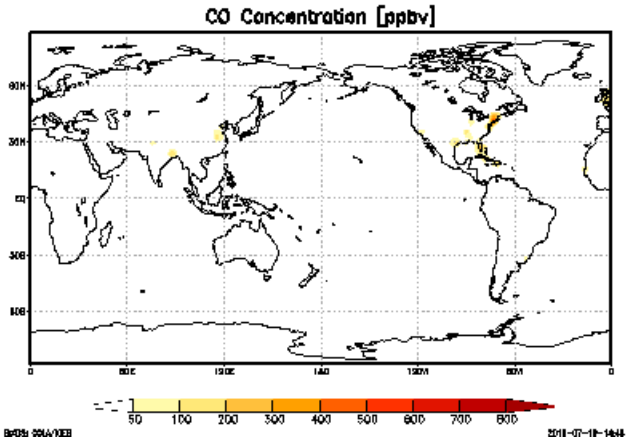

TRMM(12Z27aug2012)
EXPR – 96hr
OPER – 96hr
EXPR–OPER
EXPR–TRMM
OPER–TRMM
EQ
15S
30S
45S
75W
60W
45W
30W
70
60
50
40
30
20
10
5
3
45
30
10
5
−5
−10
−30
−45

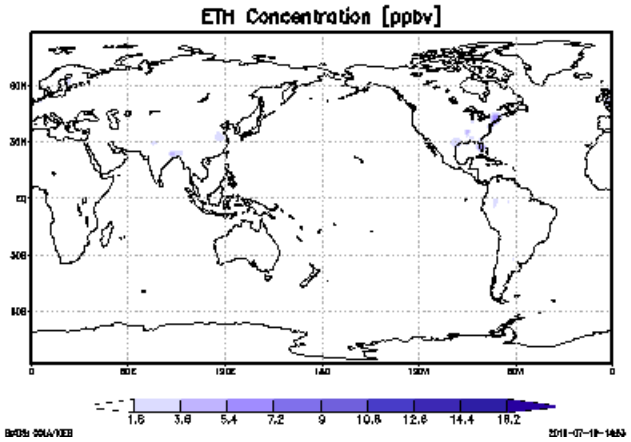
Experimental AGCM at CPTEC : Evaluation using RMSE

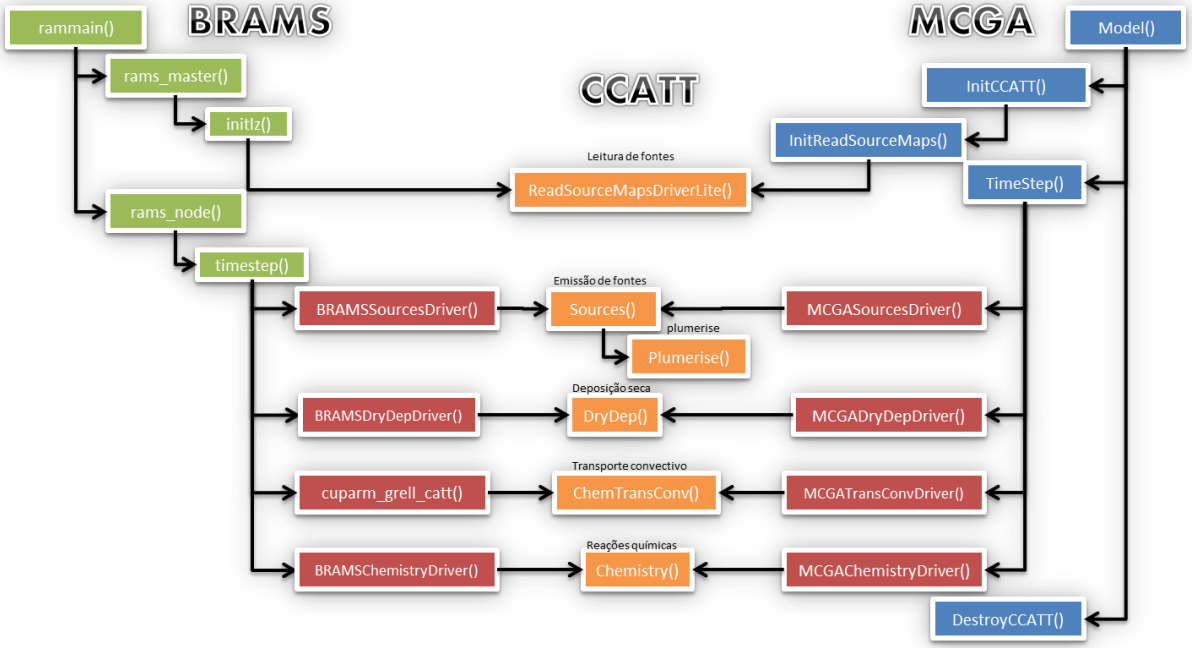


T299_L64 00h — Experimental
K299_L64 00h — Operational

Development of an on-line atmospheric chemistry global model based on coupling CCATT + CPTEC/AGCM





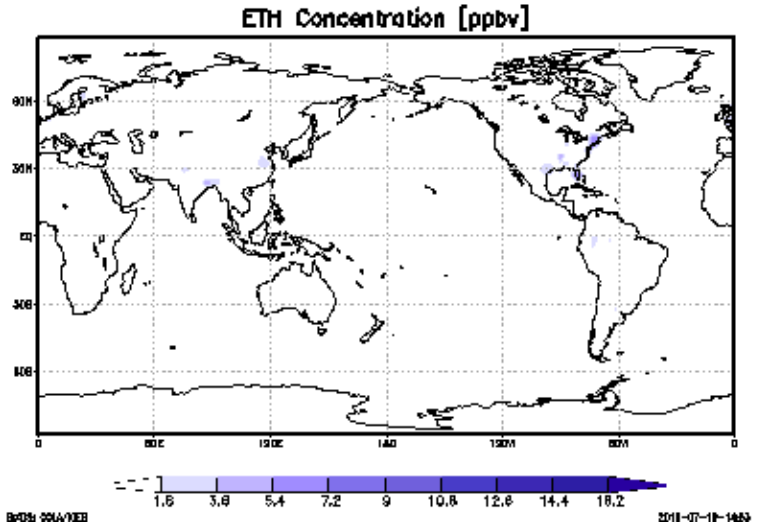


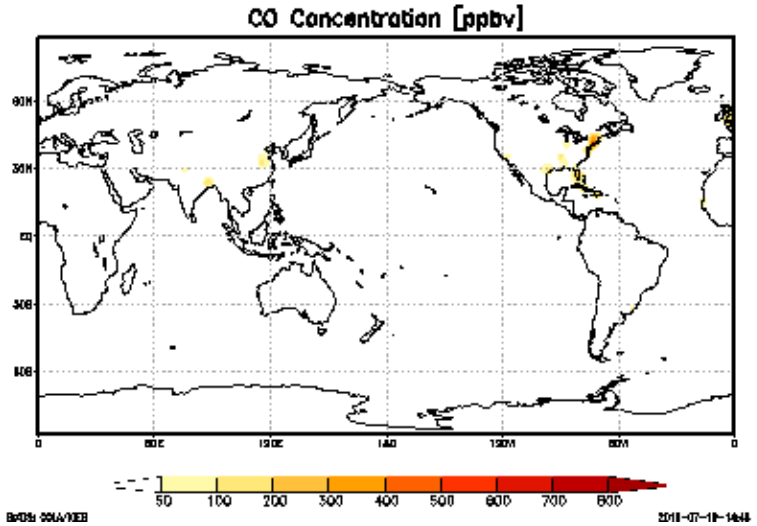
Development of the CCATT-MCGA

(Daniel Massaru, Paulo Kubota, Saulo Freitas, Saulo Barros)

Current Status

- ✓ Emissions including plume-rise for vegetation fires BRAMS e MCGA;
- ✓ Sedimentation/Dry deposition
- ✓ Advection by Semi-Lagrangean transport scheme (positive-definite, monotonic)
- ✓ Convective transport + wet removal of gases/aerosols fully coupled with cumulus scheme.
- ✓ Both model (regional and g presents similar results
- ✓ Bit reproducibility for different parallel runs





Data Assimilation

Current DA Status at CPTEC/INPE

CPTEC is replacing its former DA system (PSAS) by the Gridpoint Statistical Interpolation (GSI), currently at NCEP and NASA, starting in the GCM (T299L64) by the end of 2011. During 2013, the same system is going to be implemented in the regional BRAMS model. LETKF research continues with the mid/long term goal of a hybrid DA system

DA System	Operational?	Model/Config	Obs Type	Number of Obs	Remarks
Global PSAS	Since 2002	TQ213L42	Conventional, satellite retrievals	~10^5	Decommissioning on Mar/2013
Regional PSAS	Since 2000	Eta 40Km, 38 levs	Conventional, satellite retrievals	~10^5	Decommissioned on Mar/2012
Global GSI	In pre-ops since Jul/2012	T299L64	Conventional, Radiances, GPS	~10^6	To operational on Dec/2012
Global LETKF	Research Mode	T299L64	Conventional, satellite retrievals	~10^5	Towards inclusion radiances and GPS
Regional GSI	No	BRAMS, 5 km	Conventional, Radiances, GPS	~10^6	Begin of work on Jan/2013

GSI implementation at CPTEC/INPE

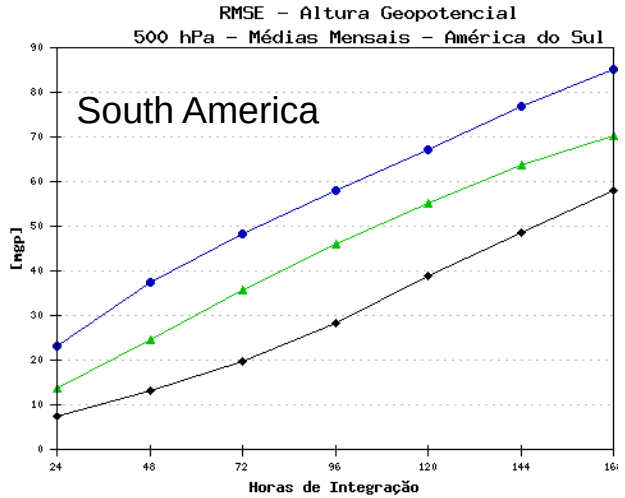
- Preliminary results comparing the newly implemented Global GSI system (G3DVar) against the current Global PSAS (GPSAS) operational DA are presented.

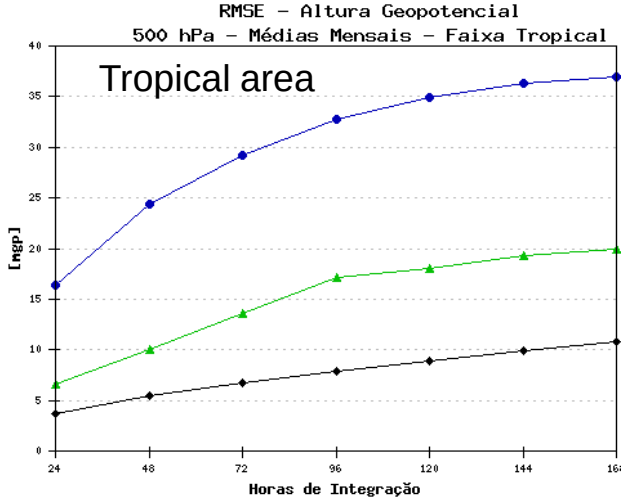
- RMSE and Biases averaged over Jun, Jul, Aug/2012 were computed for different regions: Northern (HN) and South (SH) Hemispheres, Tropical region and South America.

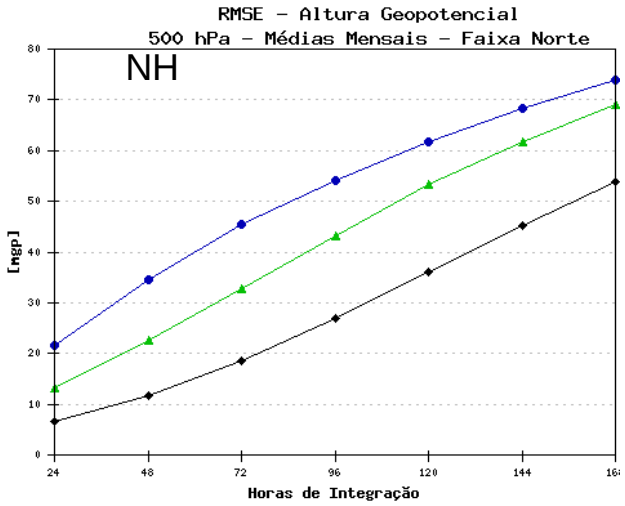
- In the panels that follow, GPSAS is shown in blue, G3DVar in green and GFS (for reference purposes only) in black.

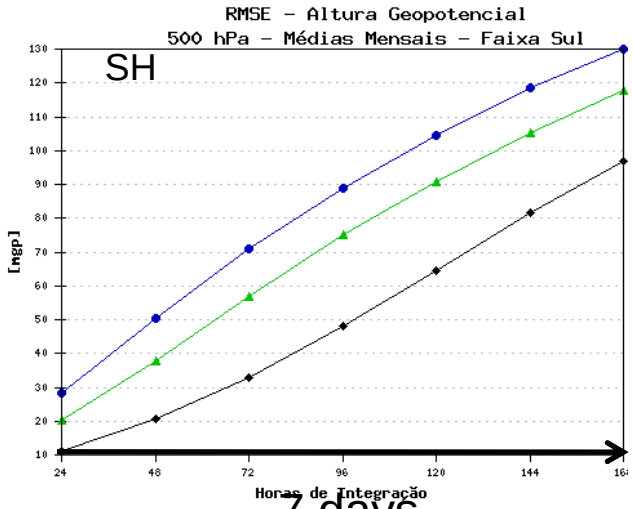
Geopotential Height at 500 hPa – RMSE

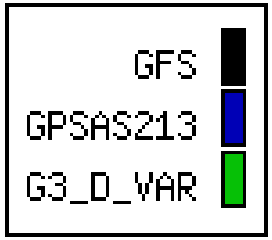
RMSE averaged over Jun, Jul, Aug/2012 for different regions: Northern (HN) and South (SH) Hemispheres, Tropical region and South America.







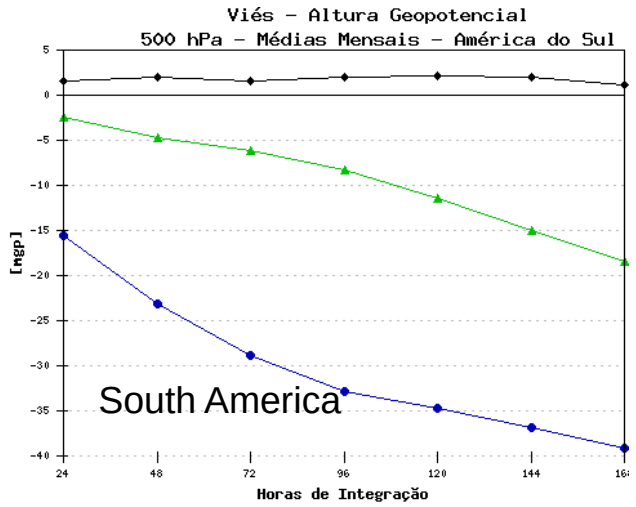


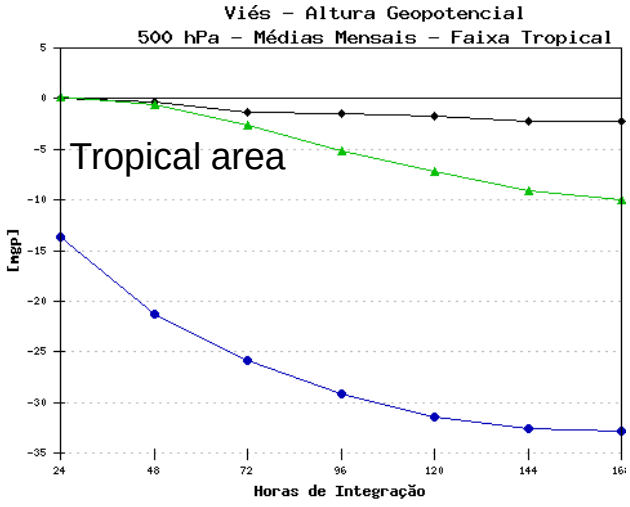


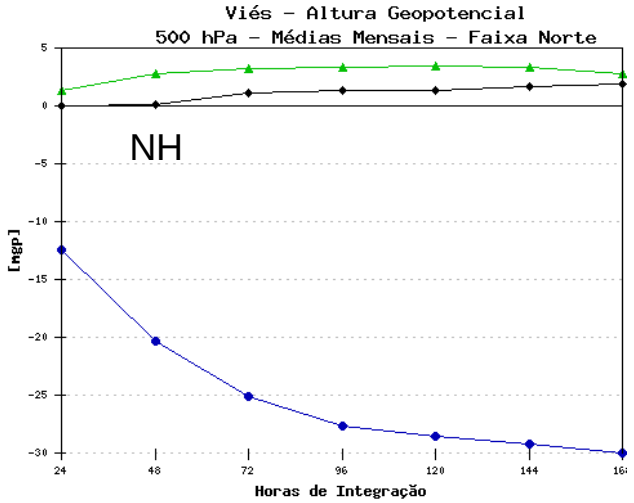
7 days

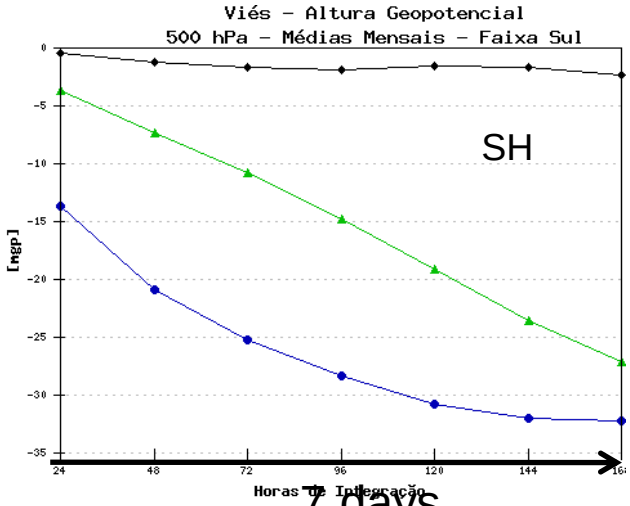
Geopotential Height at 500 hPa – Bias

Bias averaged over Jun, Jul, Aug/2012 for different regions:
Northern (HN) and South (SH) Hemispheres, Tropical region and South America







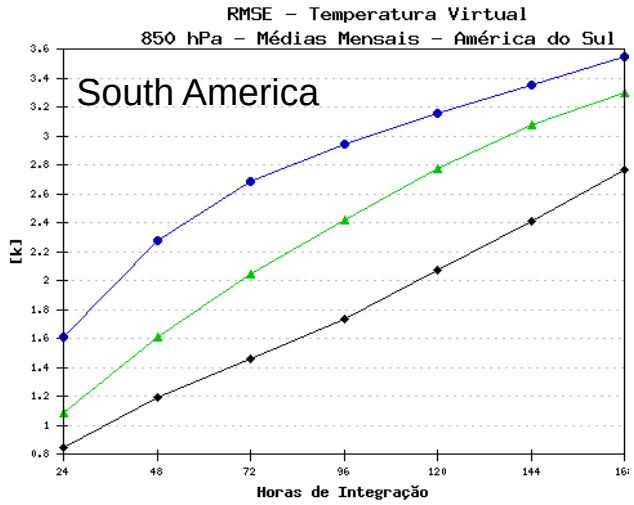


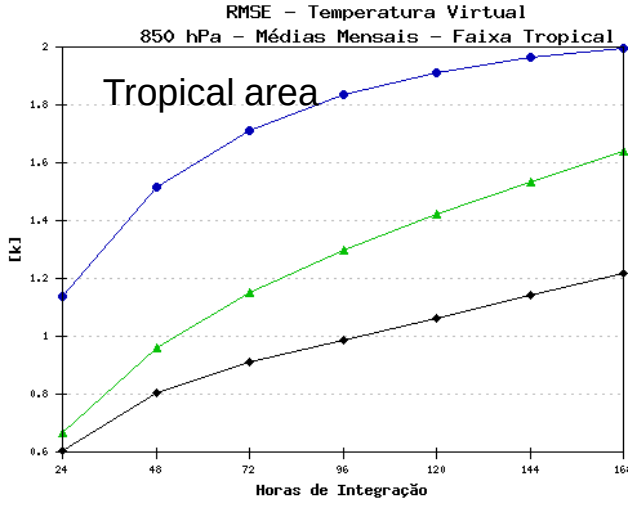
GFS
GPSAS213
G3_D_VAR

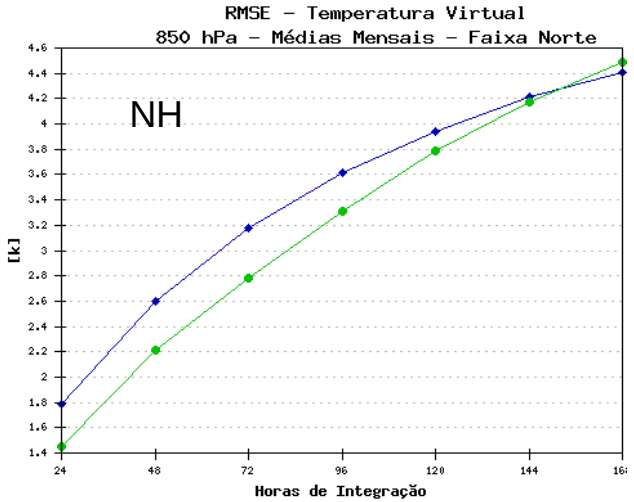
7 days

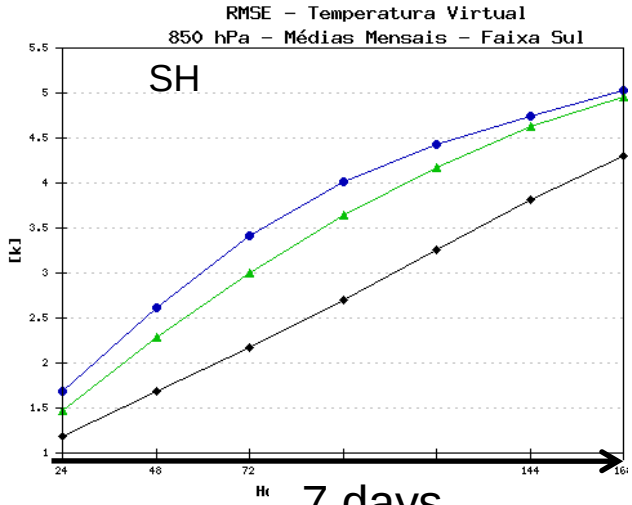
Virtual Temperature at 850 hPa – RMSE

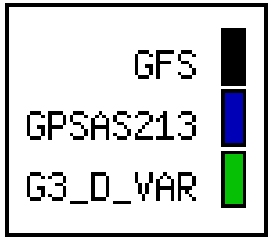
RMSE averaged over Jun, Jul, Aug/2012 were computed for different regions: Northern (HN) and South (SH) Hemispheres, Tropical region and South America. , GPSAS is shown in blue, G3DVar in green and GFS (for reference purposes only) in black.







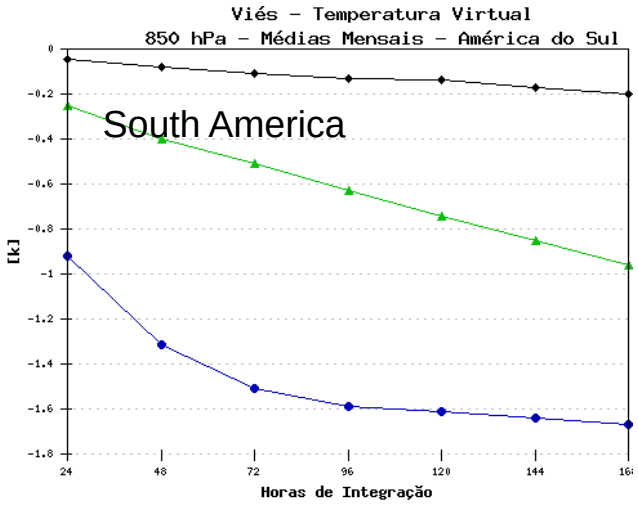


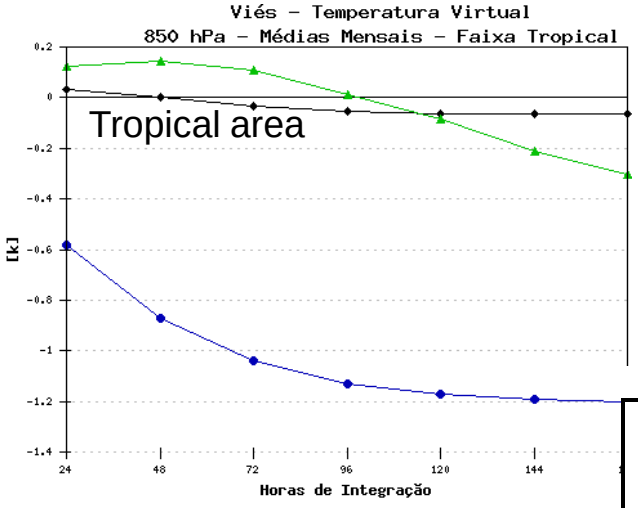


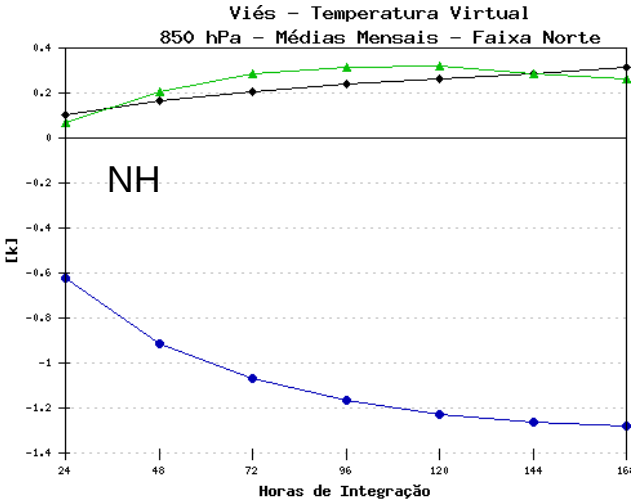
7 days

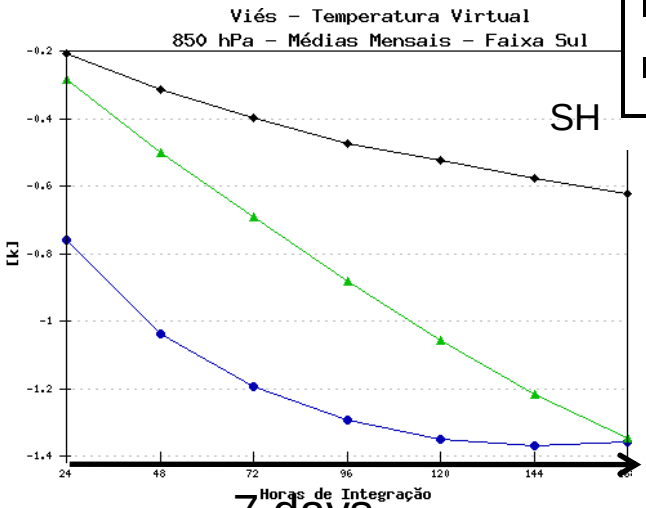
Virtual Temperature at 850 hPa – Bias

Bias averaged over Jun, Jul, Aug/2012 for different regions:
Northern (HN) and South (SH) Hemispheres, Tropical region and South America.







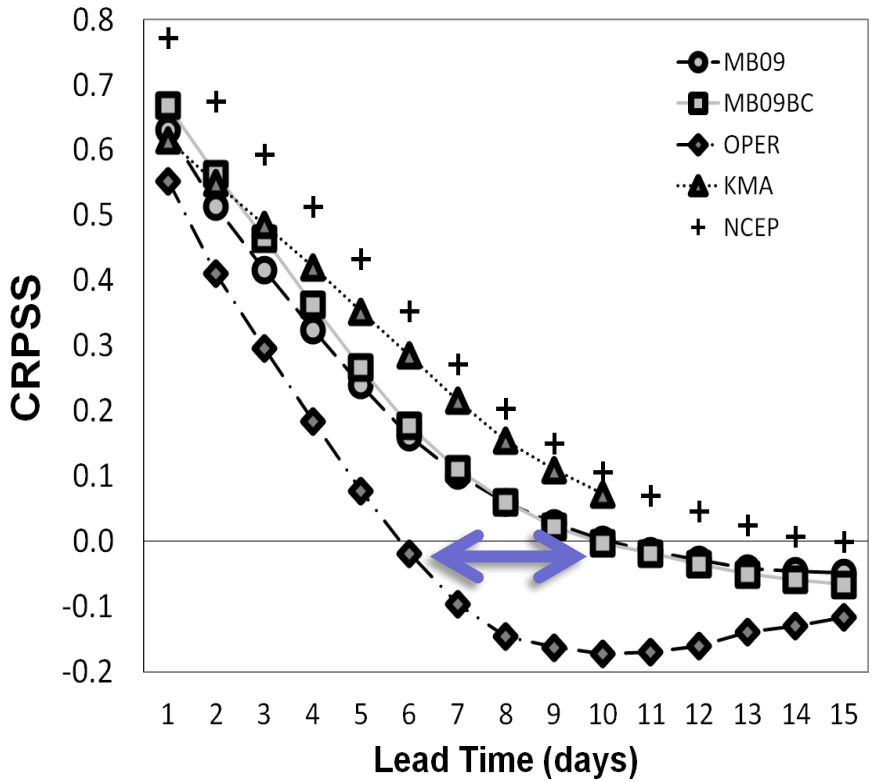


GFS
GPSAS213
G3_D_VAR

7 days

Ensemble Prediction on Global Scale

Improving the skill of the CPTEC-EPS with the methodology of Mendonça and Bonatti (2009)



Gain of 4 days with the new EPS (MB09BC)

OTHER ACTIVITIES

Projects aiming to develop products

- Applying of a probabilistic calibration method to the CPTEC-EPS outputs;
- Development of an extreme precipitation forecast index

A Forecast Demonstration Project

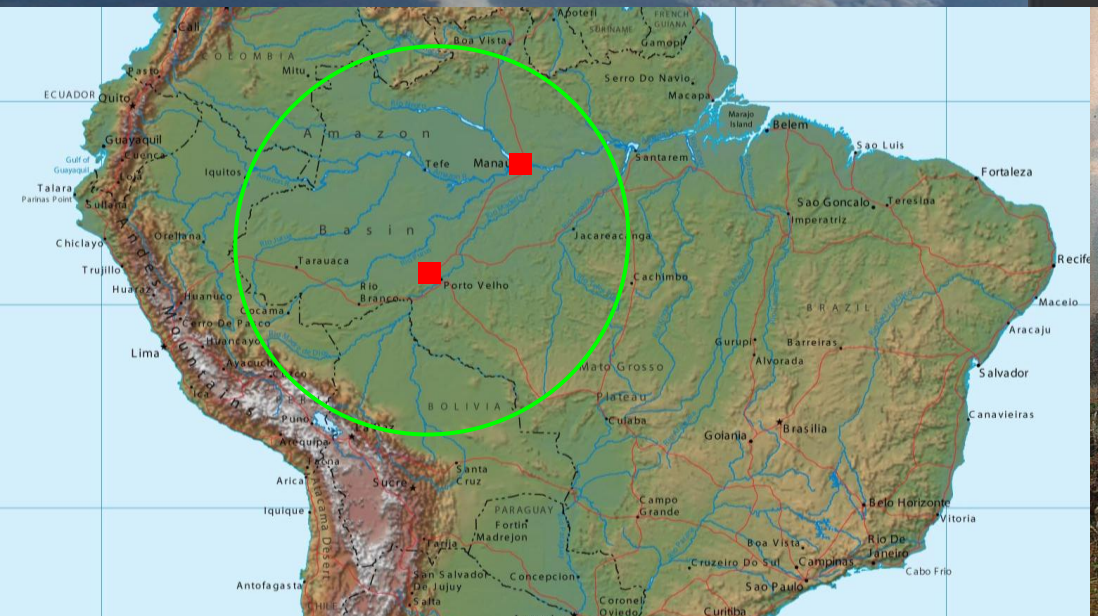
CPTEC is leading a pioneer initiative in partnership with CHUVA project aiming to create an ensemble of high resolution LAM (.LT. 5 km). Three high resolution LAM (Eta, BRAMS and WRF) will be driven by two TIGGE-EPS (CPTEC and NCEP). One member of each EPS will be selected.

The first tutorial of the CCATT-BRAMS modeling system CPTEC 22/01-03/02 /2012

- Over 50 participants: Brazil, Peru, Argentina, Colombia e Cuba

SAMBBA

(South American Biomass Burning Analysis)



SAMBBA partnership

MET OFFICE

Ben Johnson

Jim Haywood

INPE

Karla Longo

Saulo Freitas

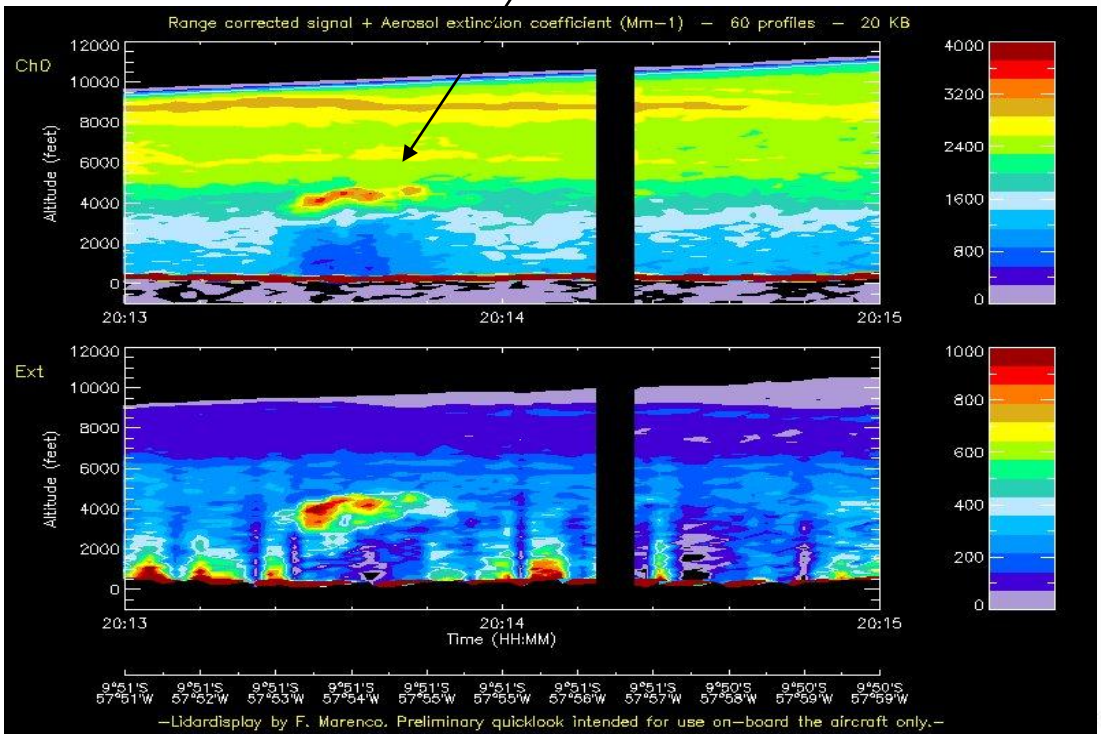
NERC

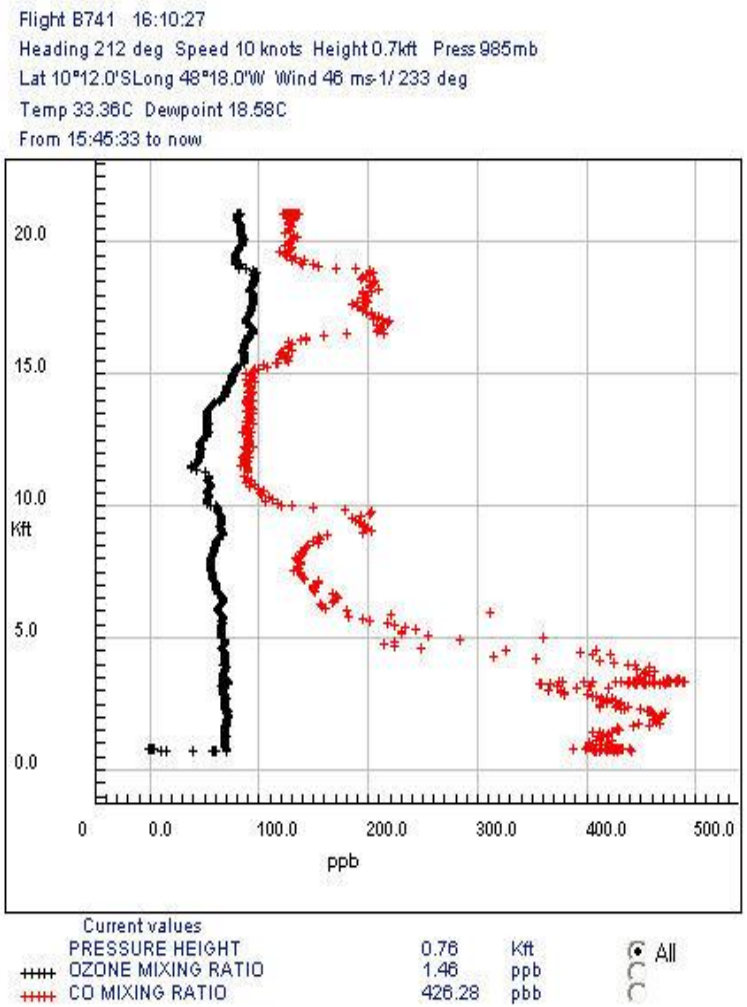
Hugh Coe et al.

University Sao Paulo

Paulo Artaxo

Smoke plume in LIDAR





On end of this November, INPE will host the 1st SAMBBA Modeling Workshop

Conclusions

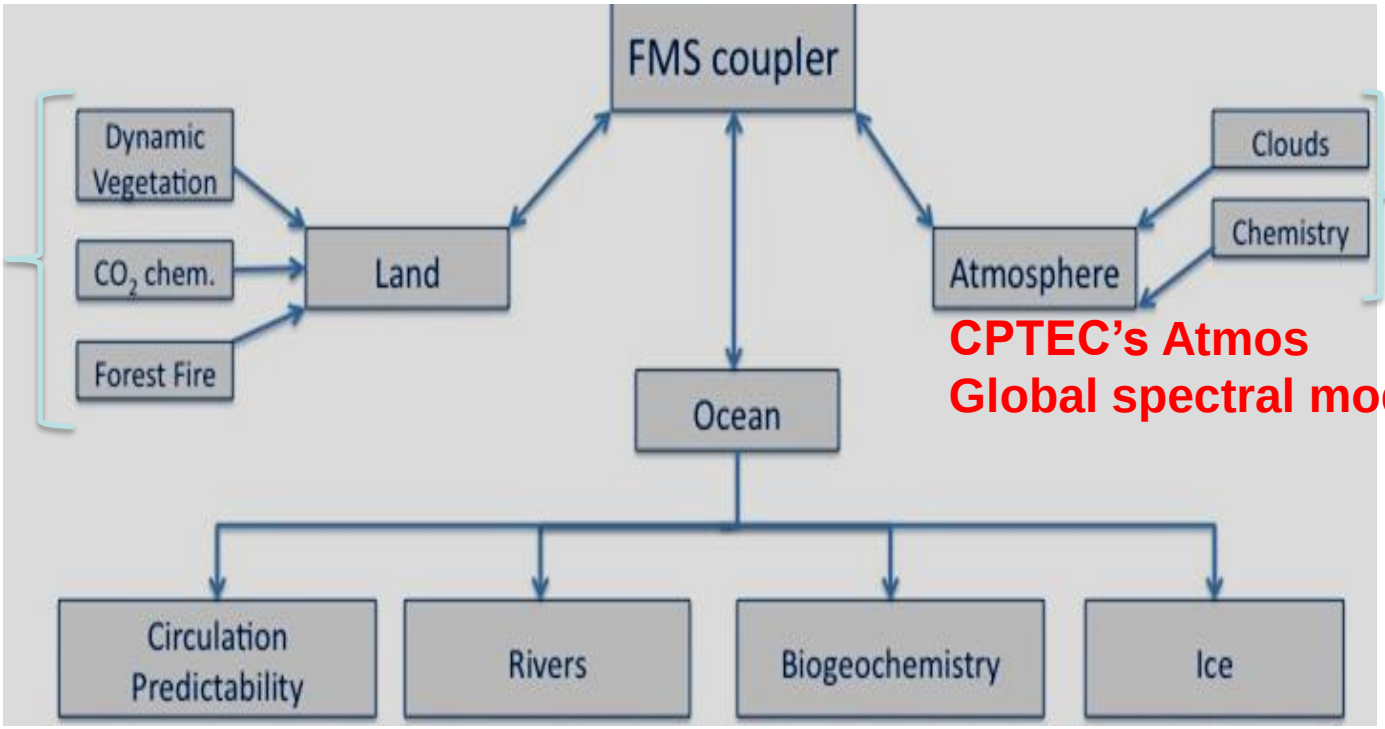
CPTEC has made some advances on NWP on several scales:

- On regional scale, a locally adaptive emergency system is running with BRAMS model on 1 km resolution to provide guidance on severe weather occurrence.
- Also a new product using BRAMS on 5 km resolution covering the entire South America is running and is under evaluation. Rainfall forecast presents good improvement. Very soon, a set of new physical parameterizations will be tested in this configuration.
- On global scale, preliminary results using an new set of physical parameterizations indicate better scores. More robust evaluation will appear soon.
- The GSI 3d-VAR data assimilation approach has been adopt by CPTEC and this system was implemented with the AGCM. The new analysis presents huge improvement in comparison with the old GPSAS system. Next January, the same methodology will be applied for the regional modeling with BRAMS.
- The ensemble forecast has been improved with new methodology for the application of random perturbations developed at CPTEC.

Thanks for your attention !

Backup slides

Brazilian Model of the Global Climate System



IBIS

CCATT-BRAMS

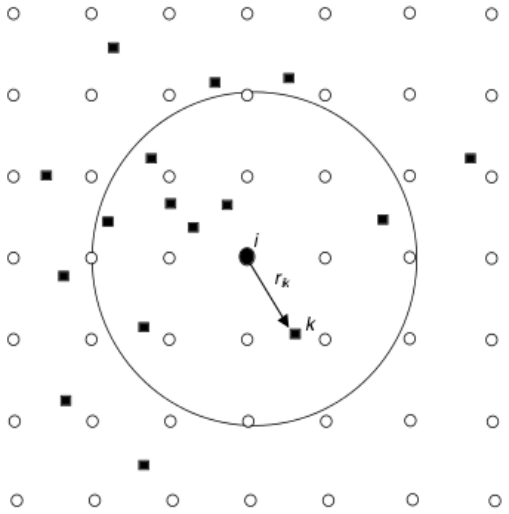
CPTEC's Atmos Global spectral model

GFDL's MOM4p1 + ISIS ocean ice model + Topaz ocean biogeochemistry model

Current and Future Data Assimilation System on CPTEC

Current Data Assimilation System: PSAS (3DVar/OI based system)
Future Data Assimilation System: LETKF (under implementation)

Physical-space Statistical Analysis Svstem



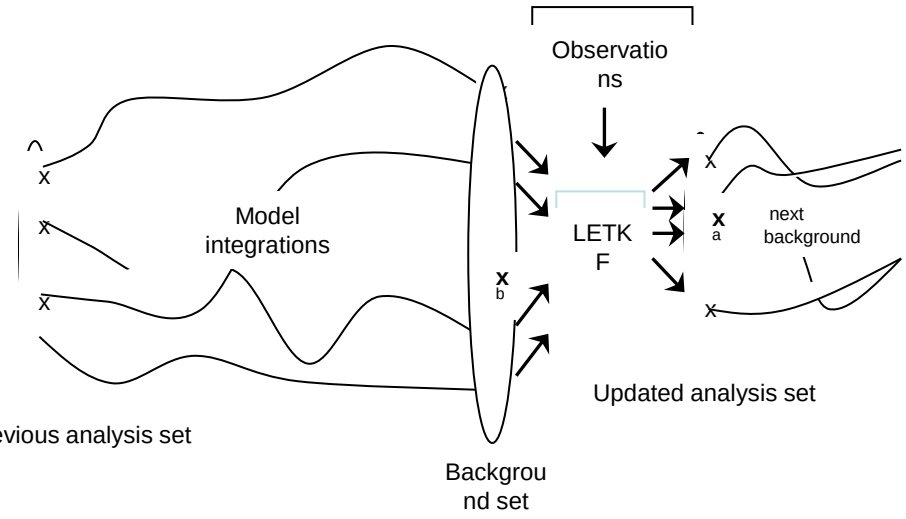
$$\delta \mathbf{x}_a = (\mathbf{BH}^T)(\mathbf{R} + \mathbf{HBH}^T)^{-1}\delta \mathbf{y}_o$$

(Analysis increment)

$$J(\mathbf{w}) = \frac{1}{2}\mathbf{w}^T(\mathbf{R} + \mathbf{HBH}^T)\mathbf{w} - \mathbf{w}^T[\mathbf{y}_o - H(\mathbf{x}_b)]$$

(Minimize cost function)

Local Ensemble Transform Kalman Filter



$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{E}_{loc} \cdot \tilde{\mathbf{K}} \cdot \mathbf{y}^o$$

(Kalman Filter Analysis update)

$$\tilde{\mathbf{K}} = (\mathbf{I} + \mathbf{Z}^T\mathbf{R}^{-1}\mathbf{Z})^{-1}\mathbf{Z}^T\mathbf{R}^{-1}$$

(Kalman Gain)

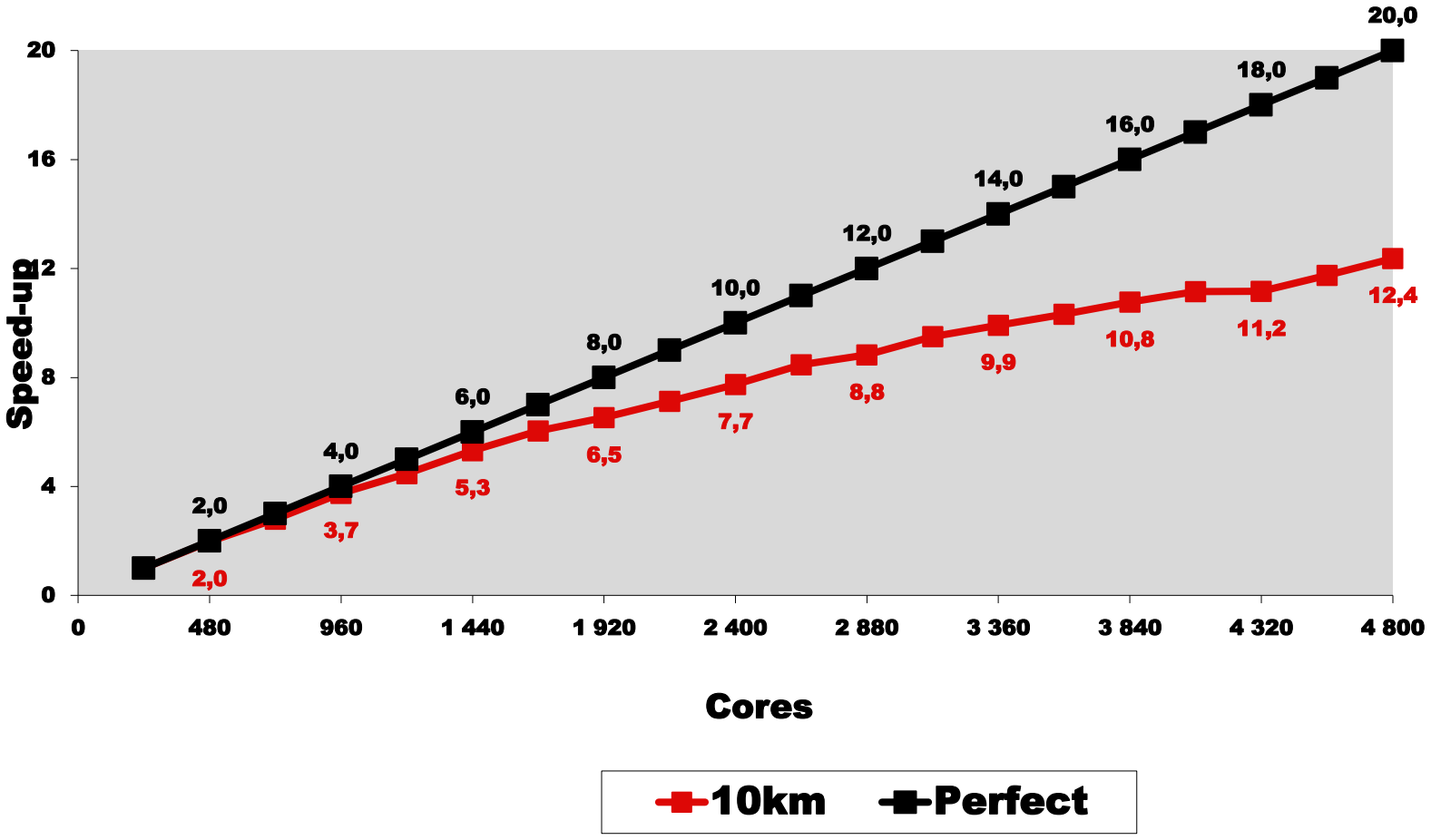
CPTEC's Global Model on CRAY XT6

STATUS	Production	Production Tests	Ready for Production Tests
CONFIGU-RATION	T299L64 Eulerian Red. Grid	T299L64 Eulerian Red. Grid	T666L96 SemiLagran Red. Grid
EXEC TIME/Day	920 s	540 s	447 s
CORES	384	576	2280
MPI / OpenMP	384 / 1	64 / 6	380 / 6

OpenMP

BRAMS Speed-up

One Fcst Day over South America @ 10km (20M Grid Points)



Current models resolution and expected for the next year

MODEL – FOCUS - DOMAIN – FORECAST TIME LENGHT	Current	Next Year
BRAMS – Severe Weather – 500x500 kmˆ2 over South America – 1 to 1 ½ day	1 km – under evaluation	1 km
Eta - Severe Weather – Southeast Brazil – 3 days	5 km	2 km
Eta - Weather – S. America - 7 days	15 km	5 km
BRAMS – Weather– S. America – 7 days	20 km	5 km
CCATT – Weather + Air Quality (on-line) – S. America – 3 days	25 km	15 km
AGCM with NCEP – Weather – Global – 7 days	63 km / L 42 45 km / L 64	20 km / L 96
AGCM with LETKF– Weather – Global- 7days	----------	45 km / L 64
OA-GCM– 30 days– Global	105 km / L 28	80 km / L 42
Eta – seasonal climate – S. America	40 km	10 km

Current model ensembles resolution and expected for the next year

MODEL – FOCUS - DOMAIN – FORECAST TIME LENGHT	Current	Next Year
Eta - NCEP analyses – 5 members	40km 5 days	20 km/ 38 levels
AGCM with NCEP – Weather – Global – 15 days	105 km/ L 28 15 members	80 km / L 42 51 members
AGCM with NCEP – Seasonal climate – Global – up to 6 months	210 km / L 28 105 members	100 km / L 42 105 members

CPTEC/INPE supercmputer 2010-2011

Cray XT6 supercomputer

1272 nodes, 2 six-core AMD Opteron, 192 Gflops, 32 GB, SeaStar2

Performance: 244 Tflops (storage capacity: 3,84 PB)

Sustained: 15.8 Tflops (CPTEC benchmark)

Peak performance: approximately 250 Tflops

8- FUTURA CONFIGURAÇÂO PNT—META TQ666L096 (20KM)

Tempo de Integração: 10 dias.
Integração no Tempo: Semi-Lagrangeana, GRADE: Reduzida
Radiação de Onda Curta: CLIRAD ou UK Met Office
Radiação de Onda Longa: UK Met Office
Esquema de Nuvem: CAM5 **Superfície:** IBIS estático
Camada Limite: CAM-5 (CLP-ÚMIDO) e ajustes com outras implementações
Arrasto por Ondas de Gravidade: NCEP
Convecção Profunda: Grell-Devenyi e **Convecção Rasa:** CPTEC
Precipitação de Grande Escala: Microfísica CAM-3 (ou CAM-5)
Umidade do Solo: anomalia da análise do CPTEC somada à climatologia de rodada
longa do MCGA
Temperatura da Superfície do Mar (TSM): Persistência da Média dos Últimos 5 Dias Proveniente da NOAA
Gelo Marinho: proveniente da NOAA, Campo Independente da TSM.
Neve: proveniente da NOAA
Concentração de CO_2: Campo Inicial Constante (370 ppm), Transportado e Iterativo
com a Radiação
Ozônio: Campo Inicial Proveniente da NOAA, Transportado e Iterativo com a Radiação
Transporte de Traçadores: CO_2, Ozônio, Água Líquida e outros para Micro-Física
Introdução da Química: Mesmo código que CCATT-BRAMS (exige PAD)

G3d scheme

- A three-dimensional application of the feedback to the model.
- Inner most/convective box only experiences lateral entrainment/detrainment
- The environmental subsidence is spread over neighboring grid points (currently only 9 neighboring grid points)
- When spreading is turned on, the fraction of resolved precipitation increases drastically, especially for large thresholds

Slide from G. Grell

CPTEC no contexto mundial

- TIGGE multi-model forecast reforecast-calibrated EPS fc
  - *Multi-model. Combining single forecasts from* several models multi-model forecast.
  - *Reforecast-calibration. Calibra single-model* forecasts with th specific training datasets
- multi-model ensemble seems t reliable approac for seasonal f
- THORPEX Interactive Gran Ensemble (TIGGE) – CPTE parte com dados desde 10/2

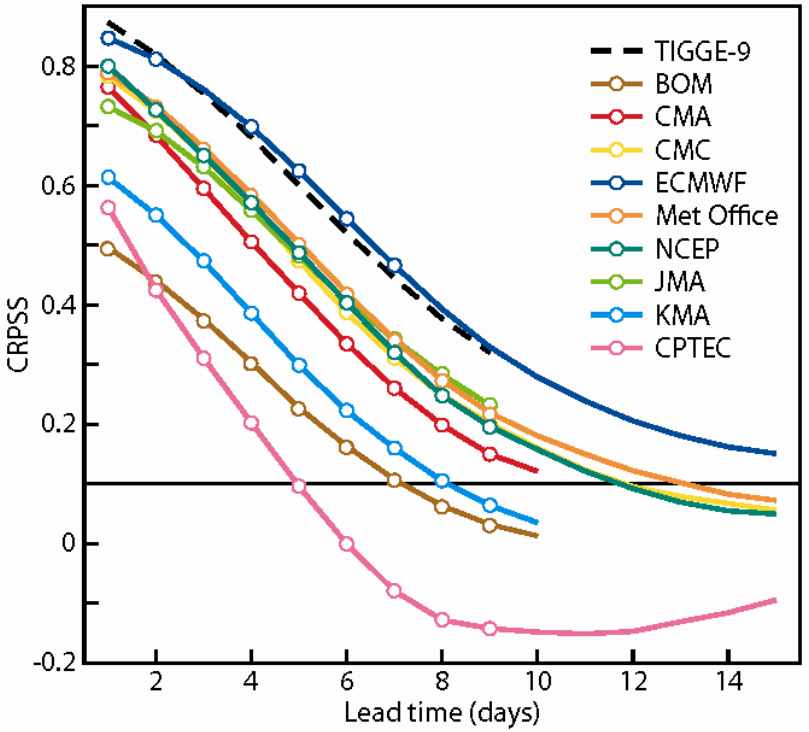


Figure 1 Continuous Ranked Probability Skill Score (CRPSS) versus lead time for 850-hPa temperature forecasts. The TIGGE-9 multi-model composed of nine single models and the scores of all nine contributing single models are shown. Symbols are only plotted for cases in which the single-model score differs significantly from the multi-model score on a 1% significance level. The significance levels have been assessed using a paired block bootstrap algorithm following *Hamill* (1999). All scores are for forecasts starting in DJF (December, January, February) 2008/09 and averaged over the northern hemisphere (20°–90°N).

$$CRPSS = \frac{\overline{CRPS}_{forecast} - \overline{CRPS}_{reference}}{\overline{CRPS}_{perfect} - \overline{CRPS}_{reference}}$$

No. 124 – Summer 2010

7- ENSEMBLE

META IMEDIATA: ter em operação uma versão atualizada do Sistema de Previsão por Conjuntos (SPCON) do CPTEC/INPE.
PRAZO: até o final de 2012
JUSTIFICATIVA: a versão que utiliza as modificações propostas por Mendonça e Bonatti (2009) na criação das condições iniciais perturbadas apresenta, de maneira geral, produz melhores índices que a versão atualmente em operação.

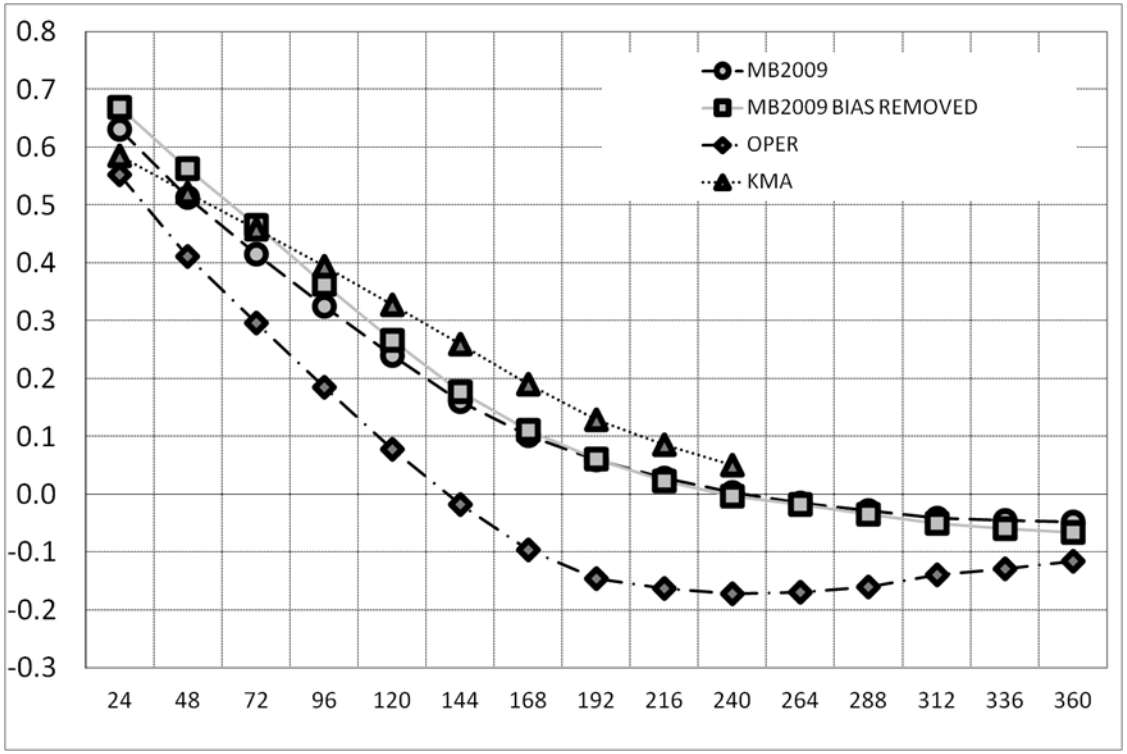
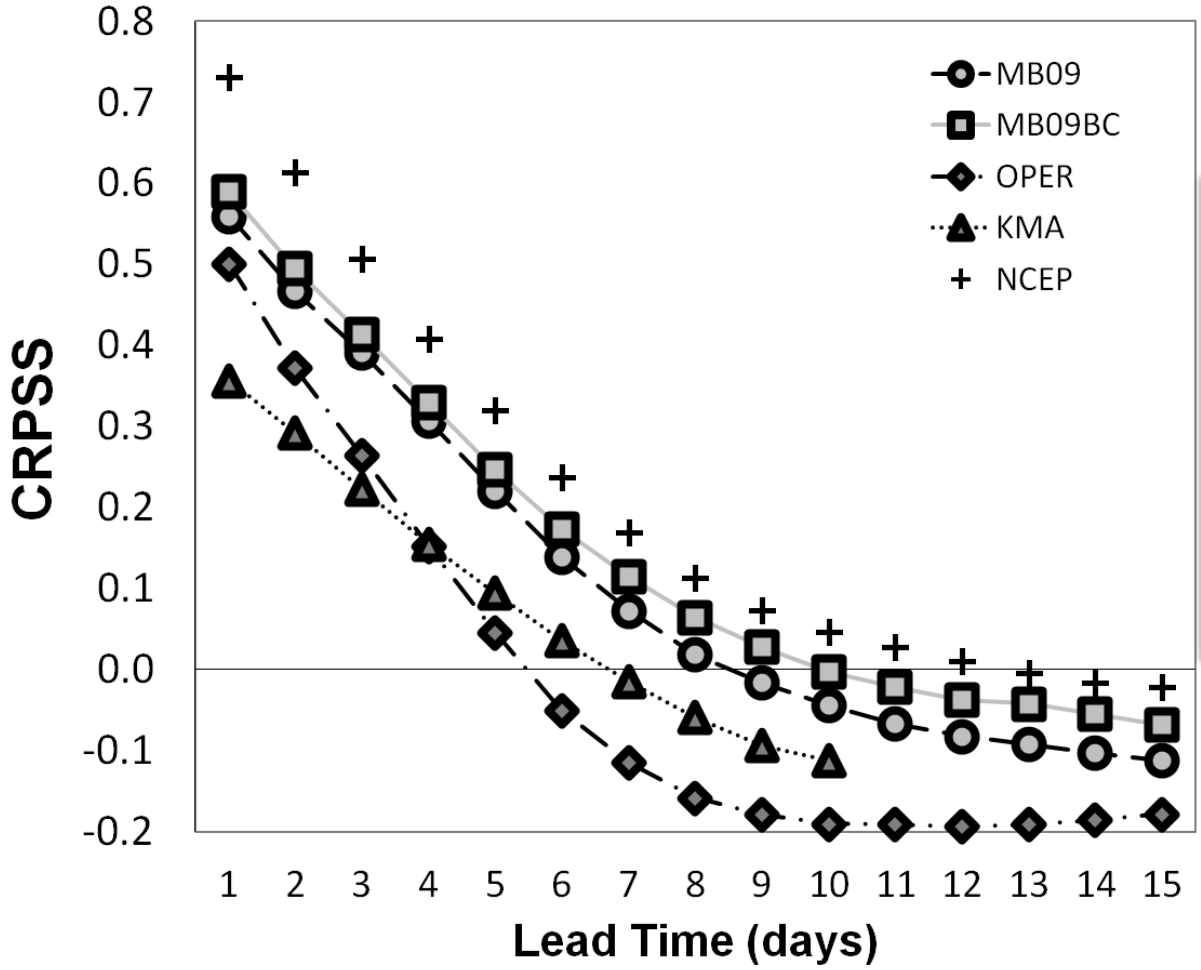


Fig. CRPSS de T850, médio no Hemisfério Norte . Losangos indicam o SPCON-OPER, círculos o SPCON-MB2009, quadrados o SPCON-MB2009 calibrado, e triângulos o SPCON da KMA. Este índice é uma média para o período DJF2008-09.

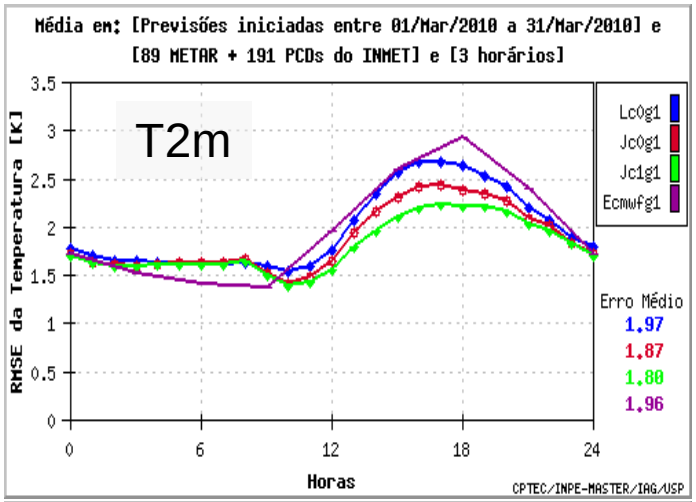
MAIN ACTIVITY

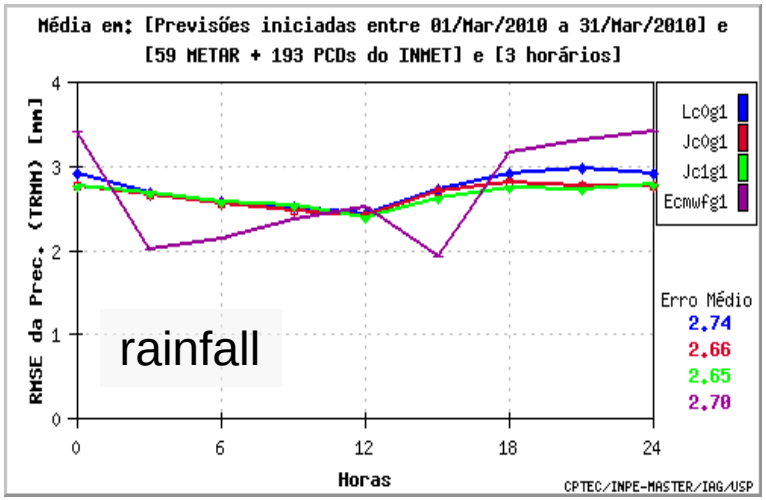
T850 - SH

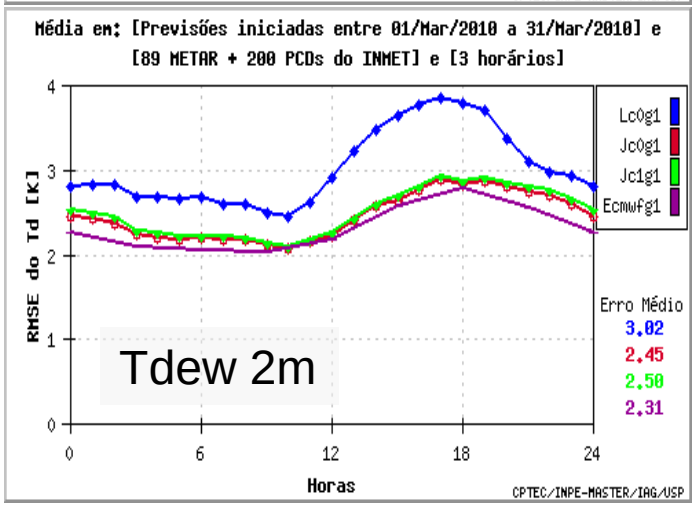


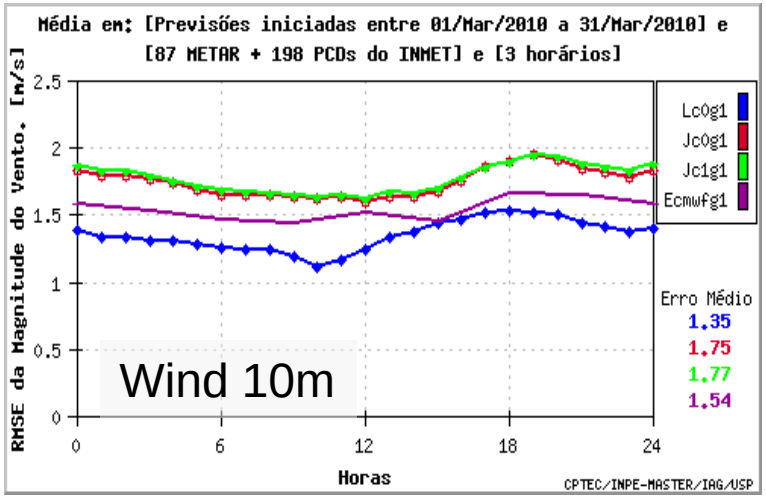
In the SH, besid
days improvem
there is a bette
ranking among
TIGGE partners

Model Evaluation (RMSE):
BRAMS/LEAF; BRAMS/JULES; BRAMS/JULES+NewAdvection and ECMWF







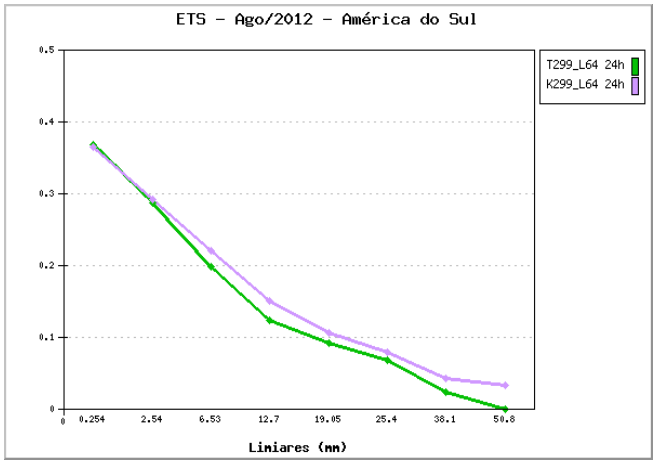


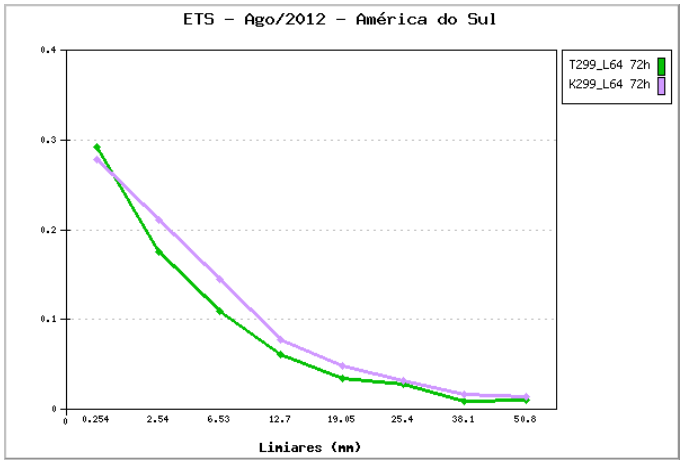
LEAF
JULES
JULES with MNT ADV
ECMWF

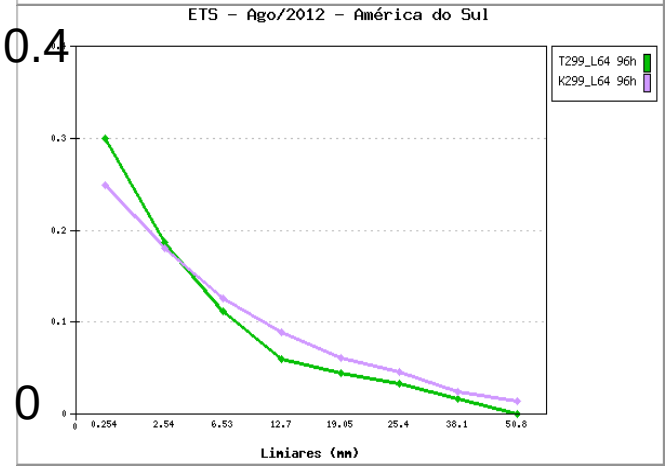
RMSE= root mean square error

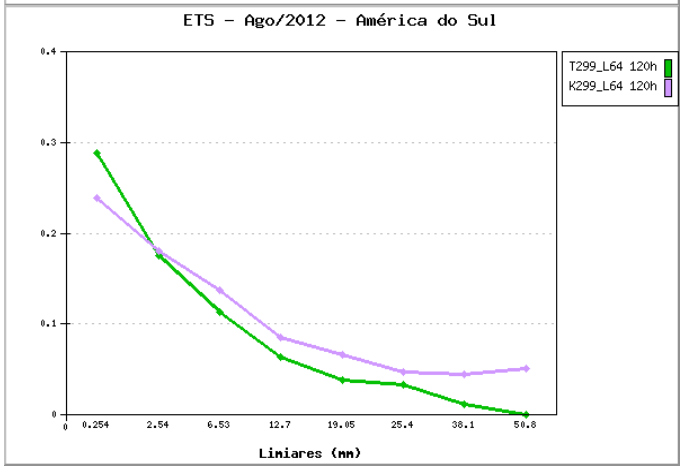
Moreira et al (in prep.)

Equitable threat score (ETS) for 24, 48, 72 and 96 hours forecast









0.4

0

0 12 50

T299_L64 00h Experimental

K299_L64 00h Operational