MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

19 a 22 de Setembro
XXXVII CONGRESSO NACIONAL DE MATEMÁTICA APLICADA E COMPUTACIONAL
CNMAC 2017
Matemática Aplicada e Computacional acelerando o desenvolvimento do país - São José dos Campos - SP

Breeding approach for predictability CPTEC-INPE Global Model

Luis Fernando Salgueiro Romero*   Sandra A. Sandri**
Haroldo F. de Campos Velho**
(*) M.Sc. (CAP-INPE)   (**) LAC-INPE

CNMAC 2017: São José dos Campos (SP), Brazil, September 19-22

Summary

- Predictability
- Low order systems
- Bred vector and predictability
- Global model: CPTEC-INPE
- Predictability: Ensemble prediction vs Bred Vector
- ~~Neuro-fuzzy: machine learning for inference~~ (not shown)
- Final Remarks

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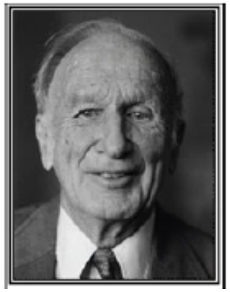
Predictability

History

- Edward N. Lorenz



Reprinted from Transactions of The New York Academy of Sciences
Ser. II, Volume 25, No. 4, Pages 409-432
February 1963

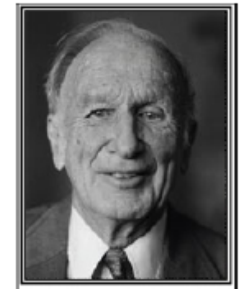
THE PREDICTABILITY OF HYDRODYNAMIC FLOW*†

Edward N. Lorenz
Massachusetts Institute of Technology, Cambridge, Mass.

Predictability

History

- Edward N. Lorenz



A study of the predictability of a 28-variable atmospheric model

By EDWARD N. LORENZ, *Det Norske Meteorologiske Institutt*[1,2]

(Manuscript received December 22; revised version February 1)

Predictability

AMERICAN METEOROLOGICAL SOCIETY
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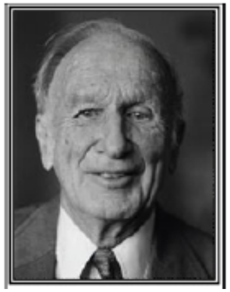
Abstract View

Volume 20, Issue 2 (March 1963)

Journal of the Atmospheric Sciences
Article: pp. 130–141 | Abstract | PDF (1.02M)

Deterministic Nonperiodic Flow

Edward N. Lorenz
Massachusetts Institute of Technology



(Manuscript received November 18, 1962, in final form January 7, 1963)
DOI: 10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2

Predictability

Lorenz's attractor

Edward N. Lorenz
Simplest chaotic system: the Lorenz Attractor.
A metaphor for weather unpredictability

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

Predictability

Lorenz's attractor

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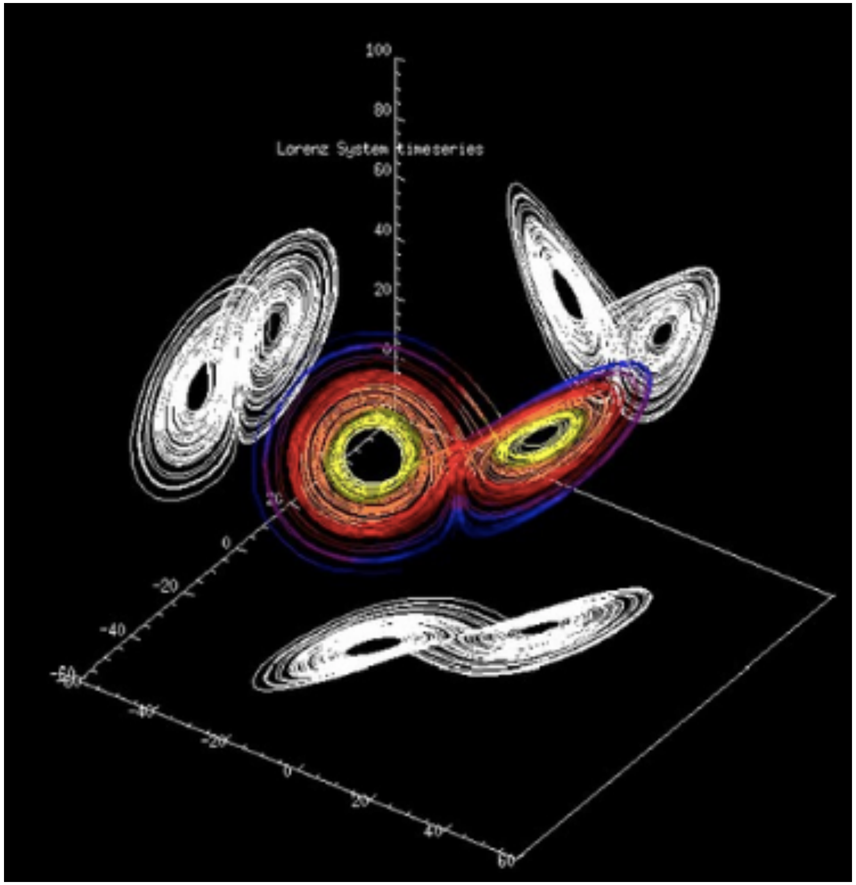
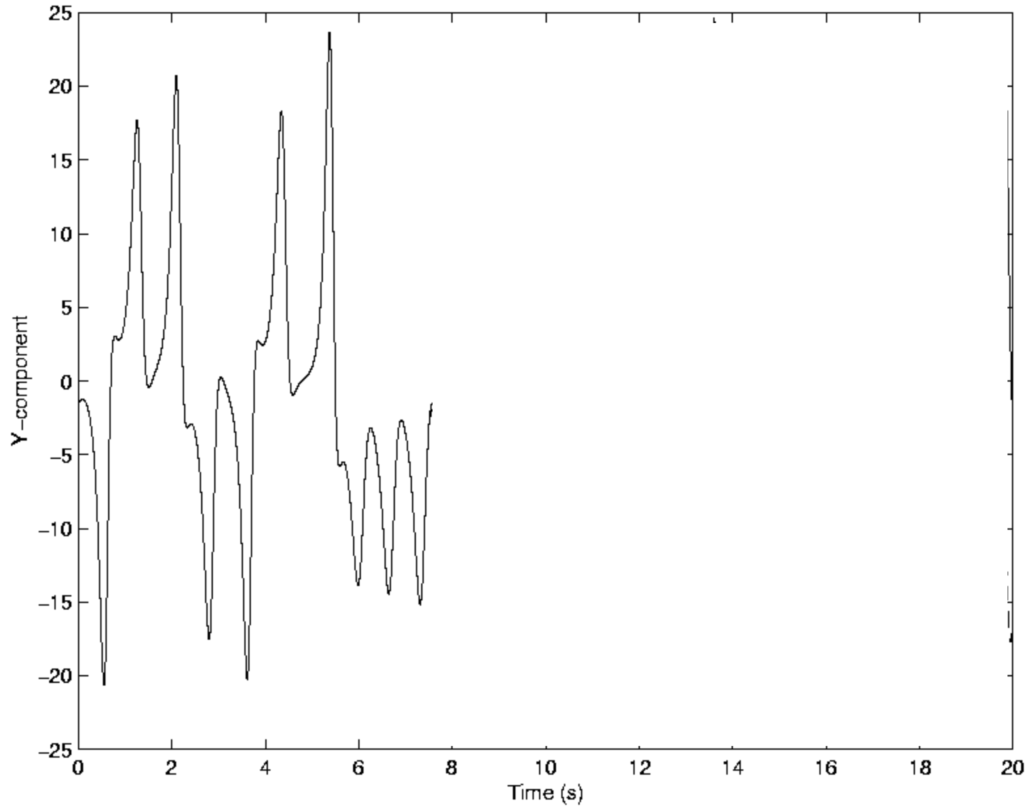


Predictability

Lorenz's system

- Two initial conditions (Y component): (w_0) and $(w_0+\Delta w)$



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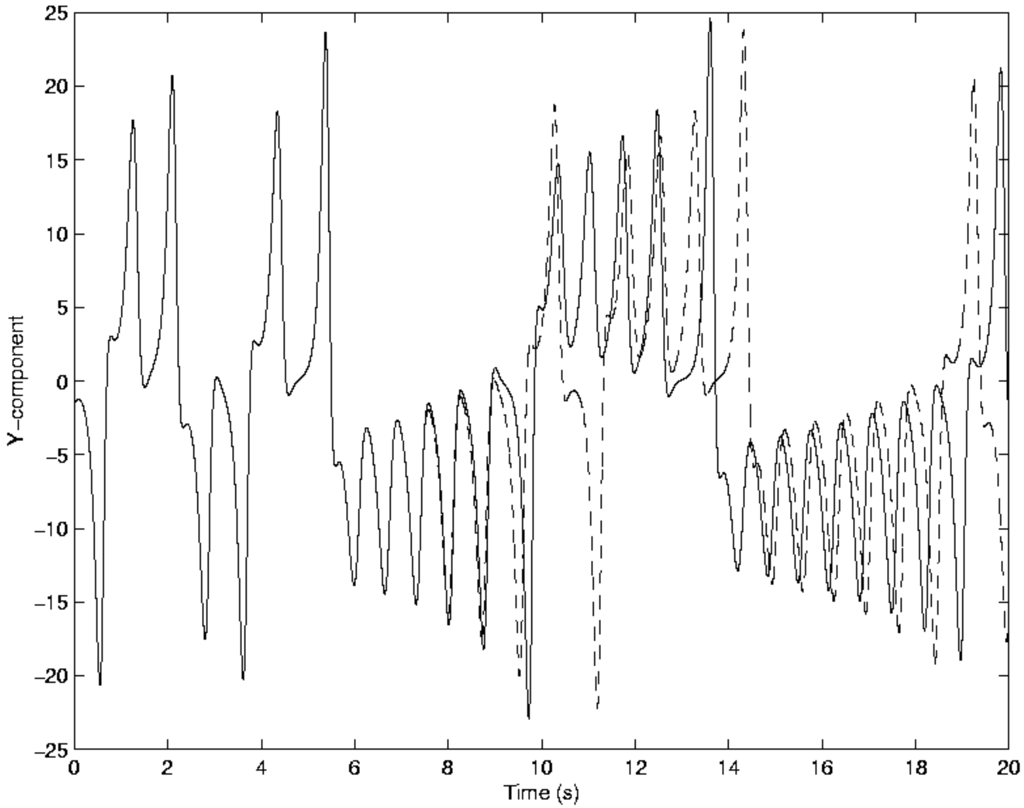

Predictability

Are the chaotic systems predictible?

- Chaotic regime: evolution non-linear differential equation
- Chaotic systems: determistic equations
- A class of chaos system: dynamics is confined in a region
- Strange attractors have fractal dimention
- They have at least one positive Lyapunov exponent

Predictability

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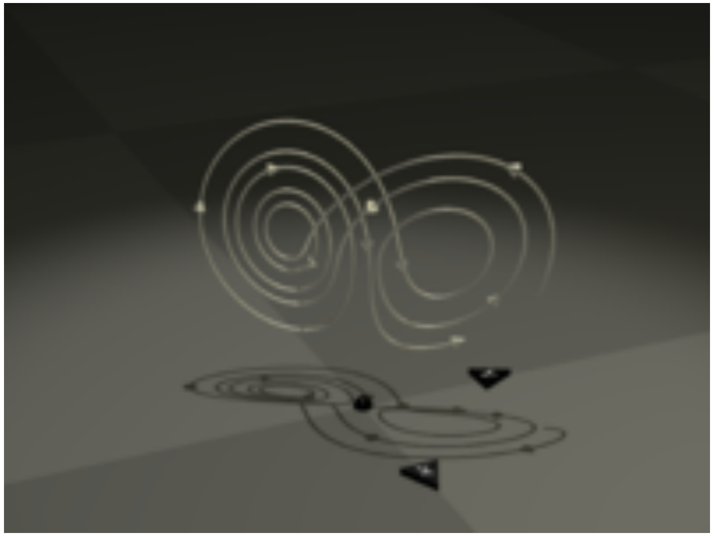
- Chaotic systems: determistic equations
- A class of chaos system: dynamics is confined in a region
- Strange attractors have fractal dimention
- They have at least one positive Lyapunov exponent
- **They are strongly dependent on the initial conditions**

Predictability

Are the chaotic systems predictible?

- Questions:
  - When will the changes go to occur in the dynamics?
  - How long will the new period be?



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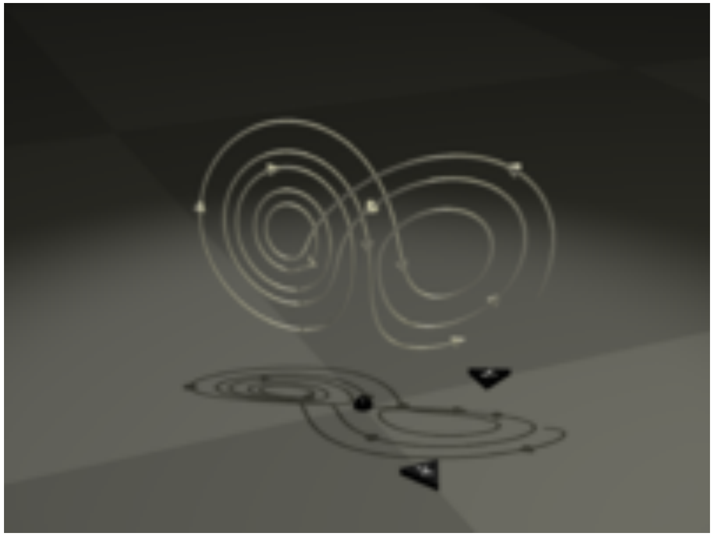

- Bred vectors can help us!

Predictability

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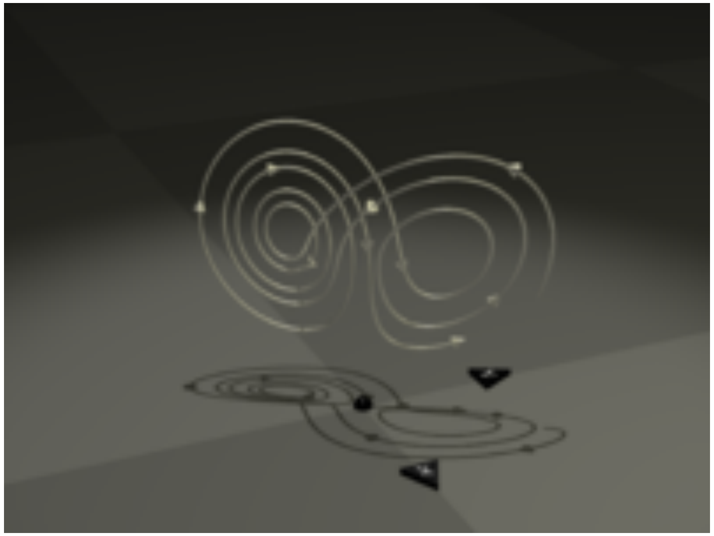
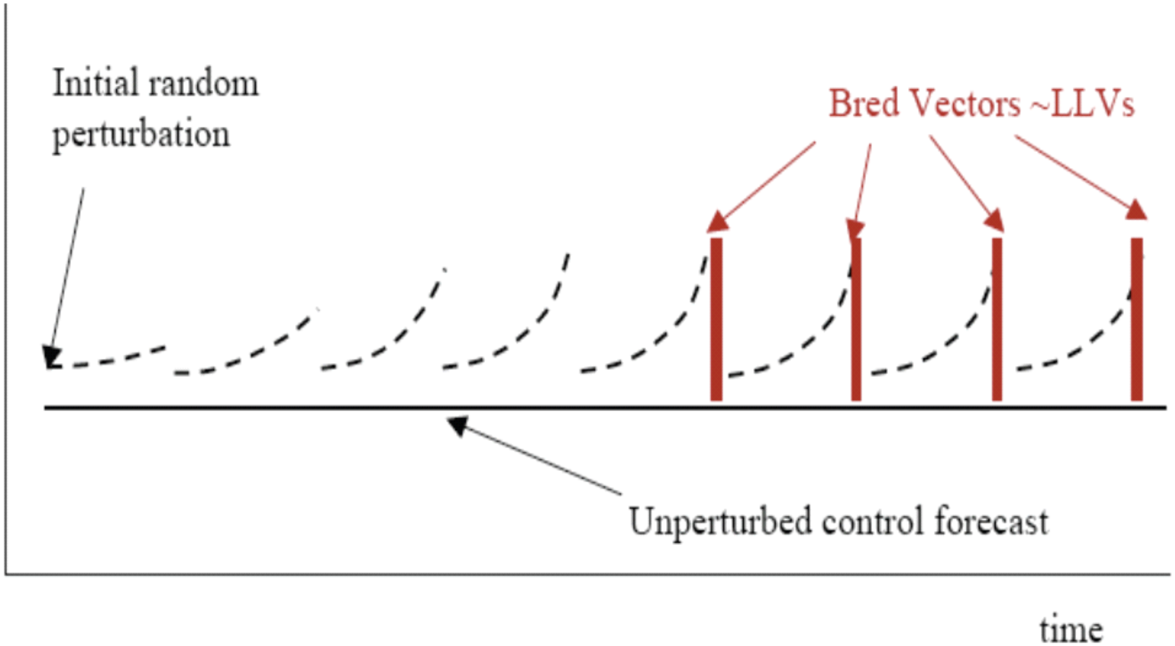


- Bred vectors can help us!
- What is bred vector?

Bred vector

- Bredding is a method to estimate forecast errors.
- It is applied in weather models (operational centers).
  - Bred vectors are simply the difference between two model runs:
  - The second originating from slightly perturbed initial conditions (periodically rescaled)



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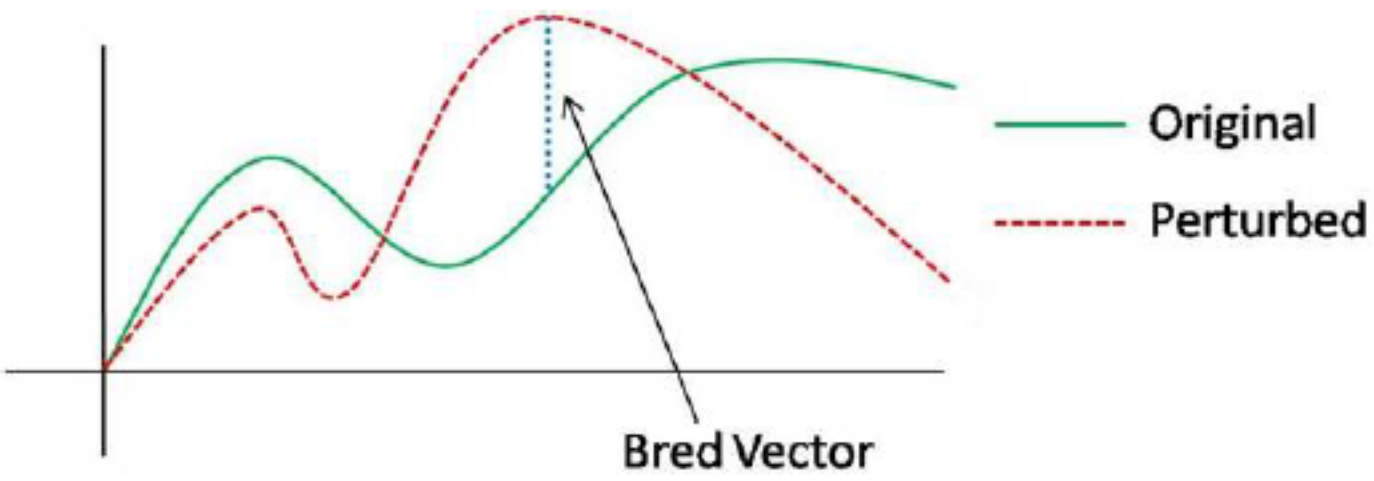

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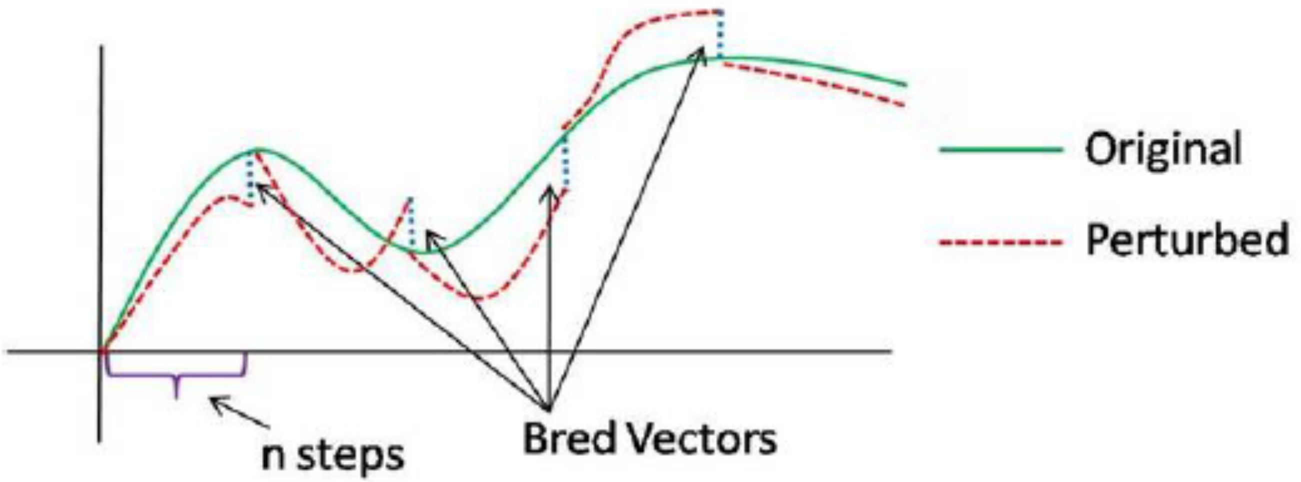


Bred vector

Mathematical implementation

1. Start with a initial perturbation: $\delta_{r_0} = \vec{r}_0 + \delta\vec{r}_0$
2. Evaluate de perturbation: $\left\| \delta\vec{r}_0 \right\|$
3. Evaluate perturbation propagation, after n time-steps

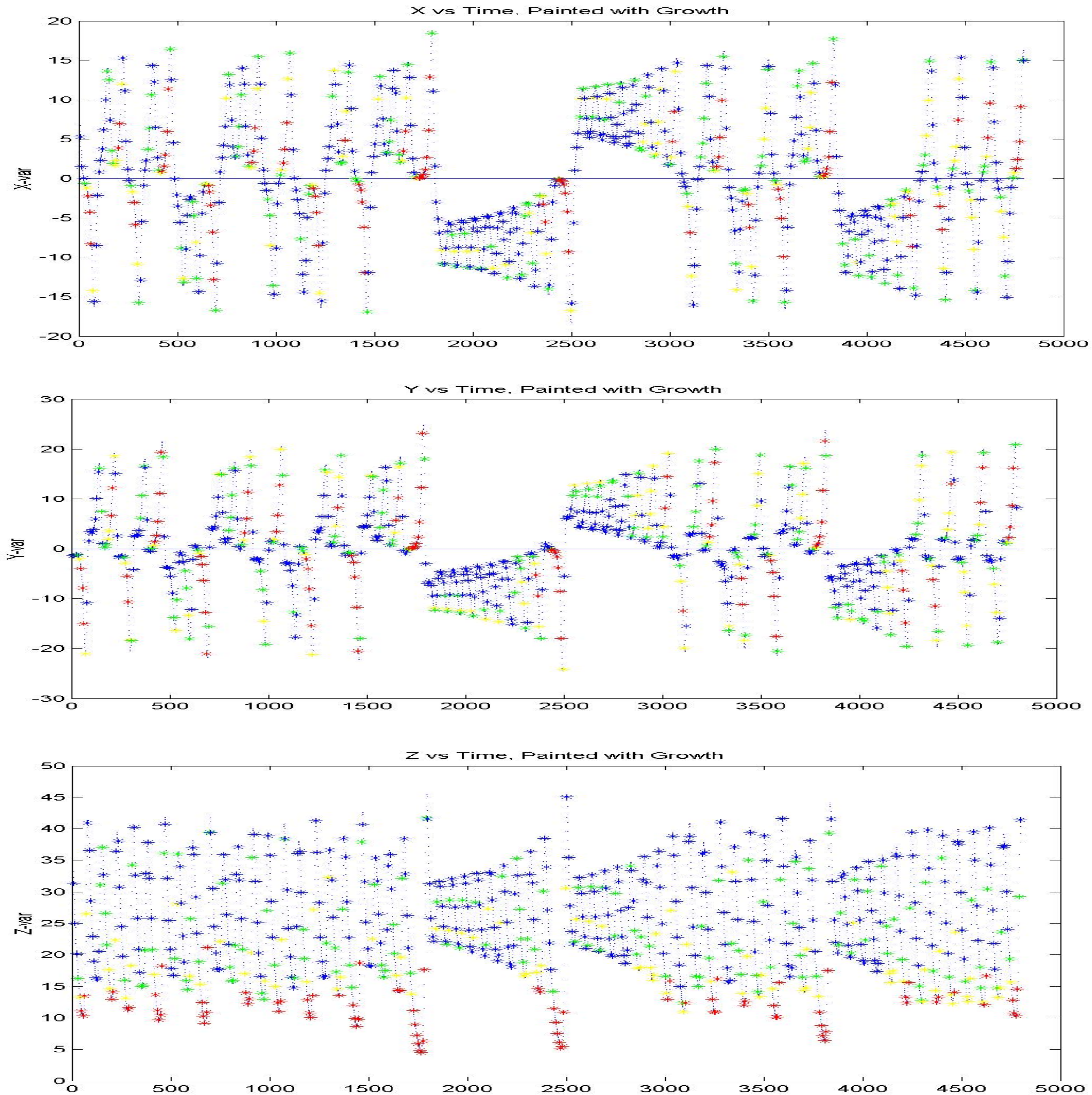
$$\delta\vec{r}(t) = \Phi(\vec{r}_0 + \delta\vec{r}_0, t_0 + n\Delta t) - \Phi(\vec{r}_0, t_0 + n\Delta t)$$

4. Evalute the growth ratio:

$$g = \frac{1}{n}\log\left(\frac{\left\| \delta\vec{r}(t) \right\|}{\left\| \delta\vec{r}_0 \right\|} \right)$$

5. Re-scale the perturbation, and repete the process.

Bred vector: Lorenz system



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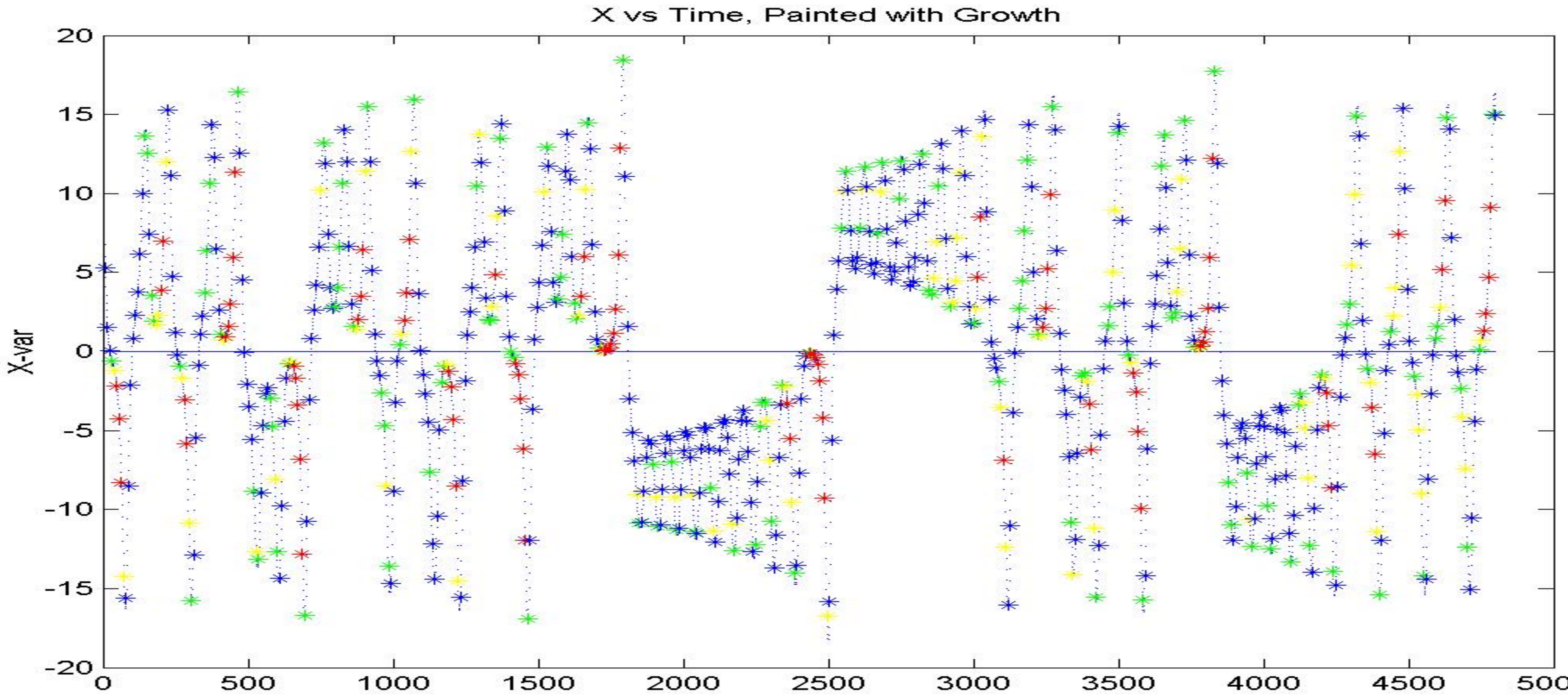
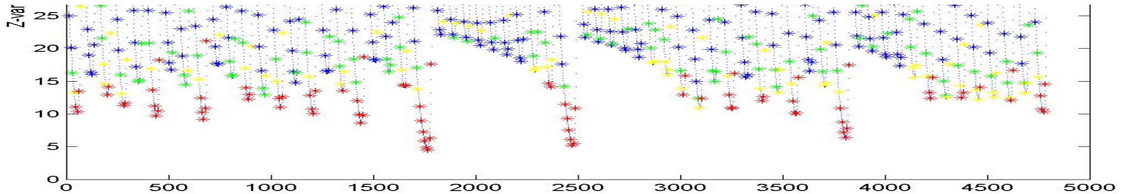
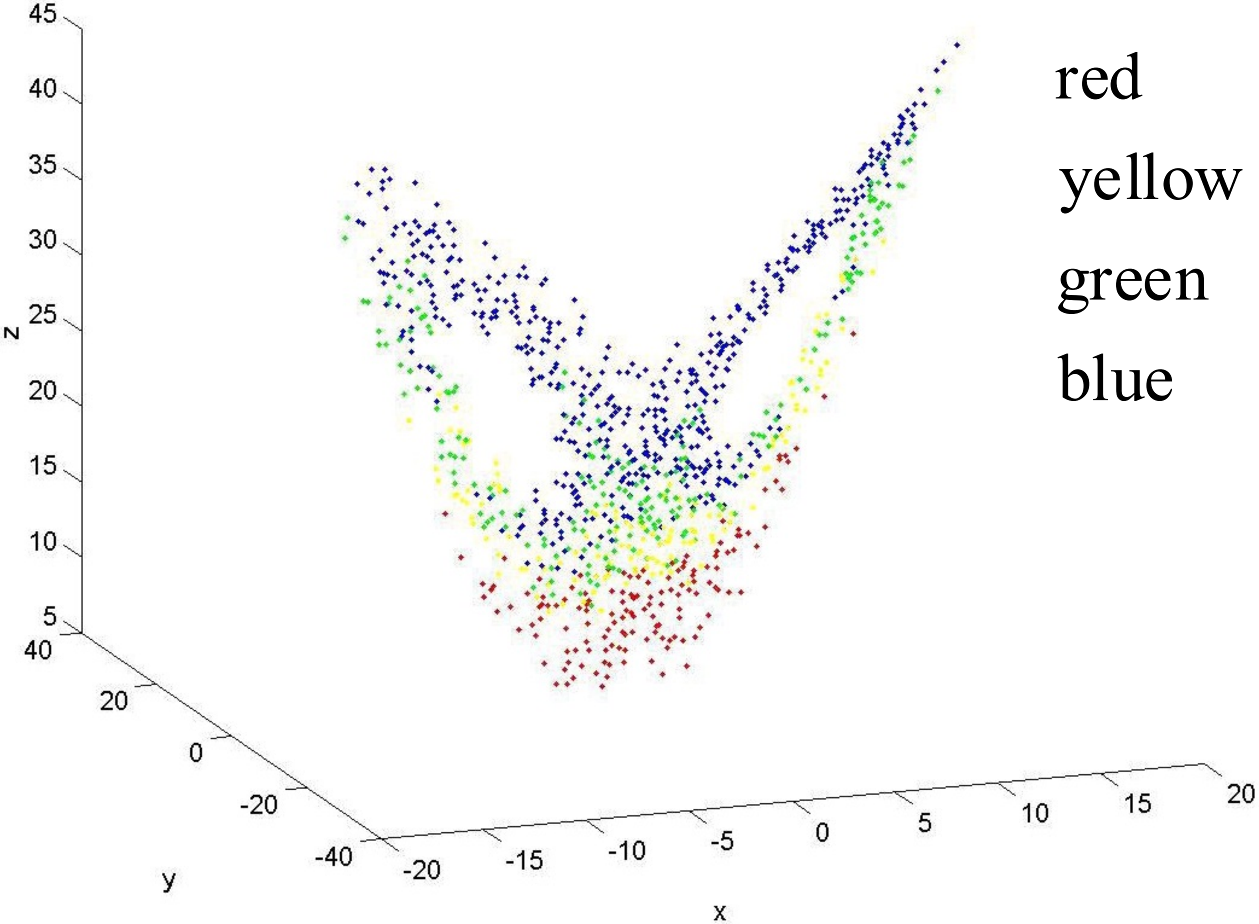
Bred vector: Lorenz system





Bred vector: Lorenz system

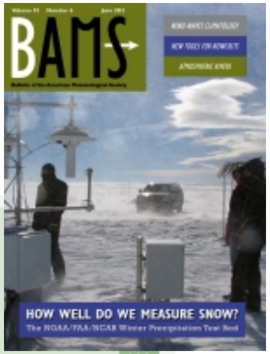


red	$g > 0.064$
yellow	$g \in [0.032, 0.064]$
green	$g \le 0.032$
blue	$g < 0$

Bred vector: Lorenz system

Bredding method for predictability

• Evan et al. (Bulletim of AMS, 85, 520-524, 2004) have investigated the bred vector ratio growth to infer some "prediction rules".

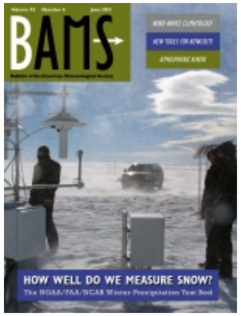


RISE UNDERGRADUATES FIND THAT REGIME CHANGES IN LORENZ'S MODEL ARE PREDICTABLE

BY ERIN EVANS, NADIA BHATTI, JACKI KINNEY, LISA PANN, MALAQUIAS PEÑA, SHU-CHIH YANG, EUGENIA KALNAY, AND JAMES HANSEN

UNDERGRADUATE

Bred vector: Lorenz system



Bredding method for predictability

- Evan et al. (Bulletim of AMS, 85, 520-524, 2004)
- Using bred vector approach two “prediction rules”:

1. When the growth rate exceeds 0.064 over a period of eight steps, as indicated by the presence of one (or more) red stars, the current regime will end after it completes the current orbit.
2. The length of the new regime is proportional to the number of red stars.

Predictability

How good is the prediction?

- Ensemble prediction
  - Data for statistical properties
  - Statistical tendencies
- Confidence interval
  - Large confidence interval: low predictability
  - Short confidence interval: high predictability

Predictability

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- Predictability: degree of confidence in forecast

Predictability

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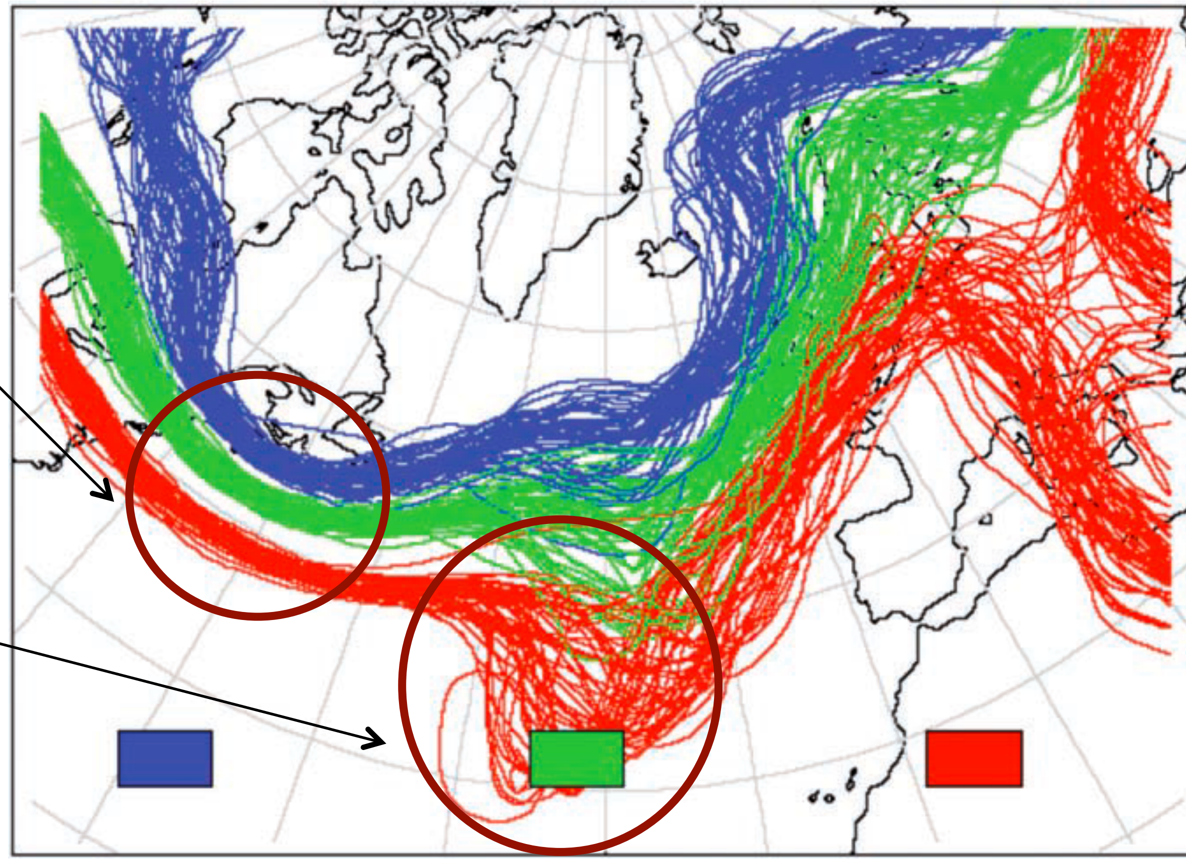
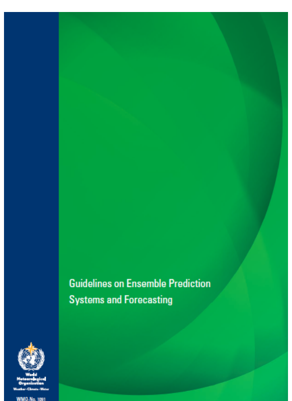
  - Data for statistical properties
  - Statistical tendencies
- Confidence interval
  - Large confidence interval: low predictability
  - Short confidence interval: high predictability
- Predictability: degree of confidence in forecast
- Predictability: quantifying uncertainty

Ensemble prediction

High predictability
(ensemble convergence)

Low predictability
(ensemble dispersion)

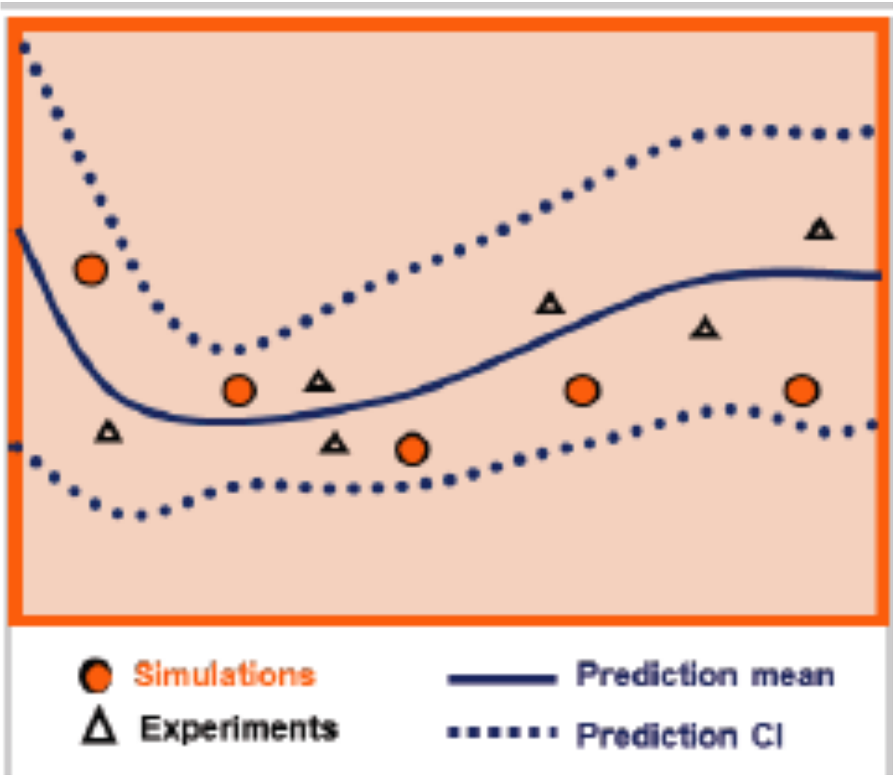




WMO's report describing/suggesting ensemble prediction

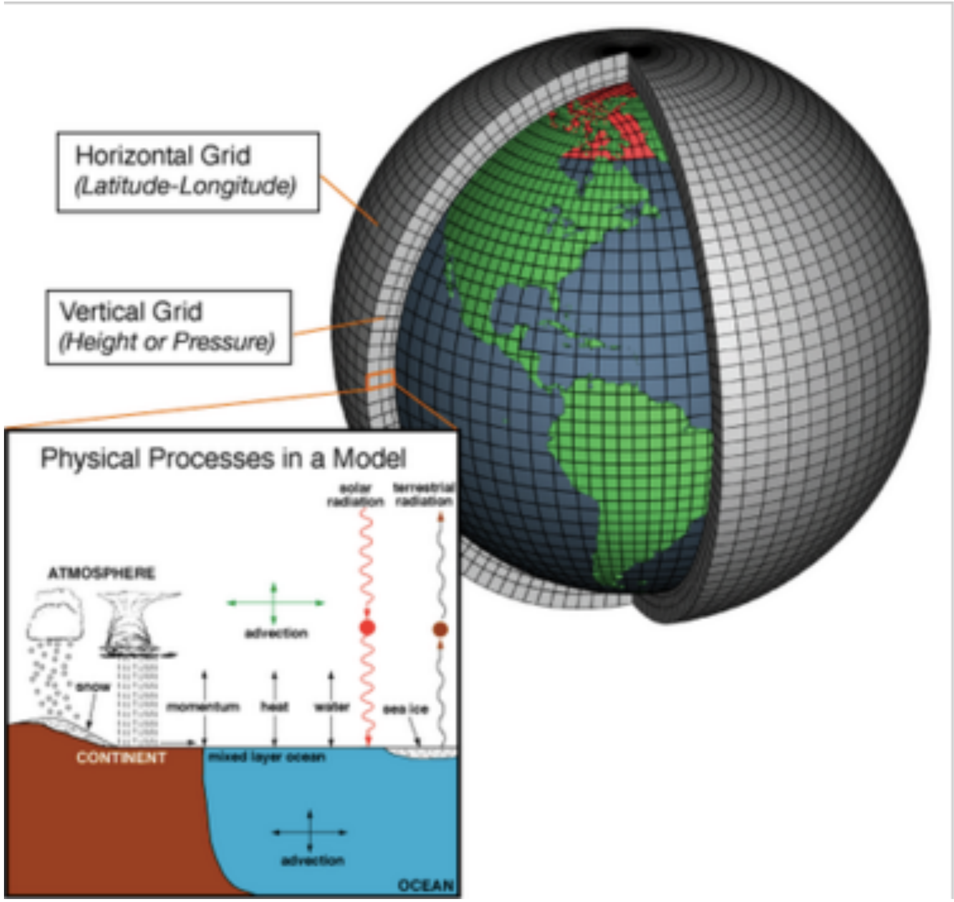
Ensemble prediction

Ensemble prediction and confidence interval



Ensemble prediction

- **Numerical Weather Prediction**
- Relevant and computer intensive simulation



Ensemble prediction

- **Numerical Weather Prediction:** equations

Movement Equation **(momentum)**

$$\frac{du}{dt} - fv + \frac{1}{\rho}\frac{\partial p}{\partial x} = 0 \qquad \frac{dh}{dt} + g + \frac{1}{\rho}\frac{\partial p}{\partial z} = 0 \qquad \frac{dv}{dt} + fu + \frac{1}{\rho}\frac{\partial p}{\partial y} = 0$$

Continuity Equation **(mass)**

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho h) = 0$$

Thermodynamic equation **(energy)**

$$p = f(T)\rho \;\rangle \Rightarrow \frac{f(T)}{T} = \frac{g(\rho)}{\rho} \equiv R(cte) \qquad p = g(\rho)T$$

$$p = \rho R T$$

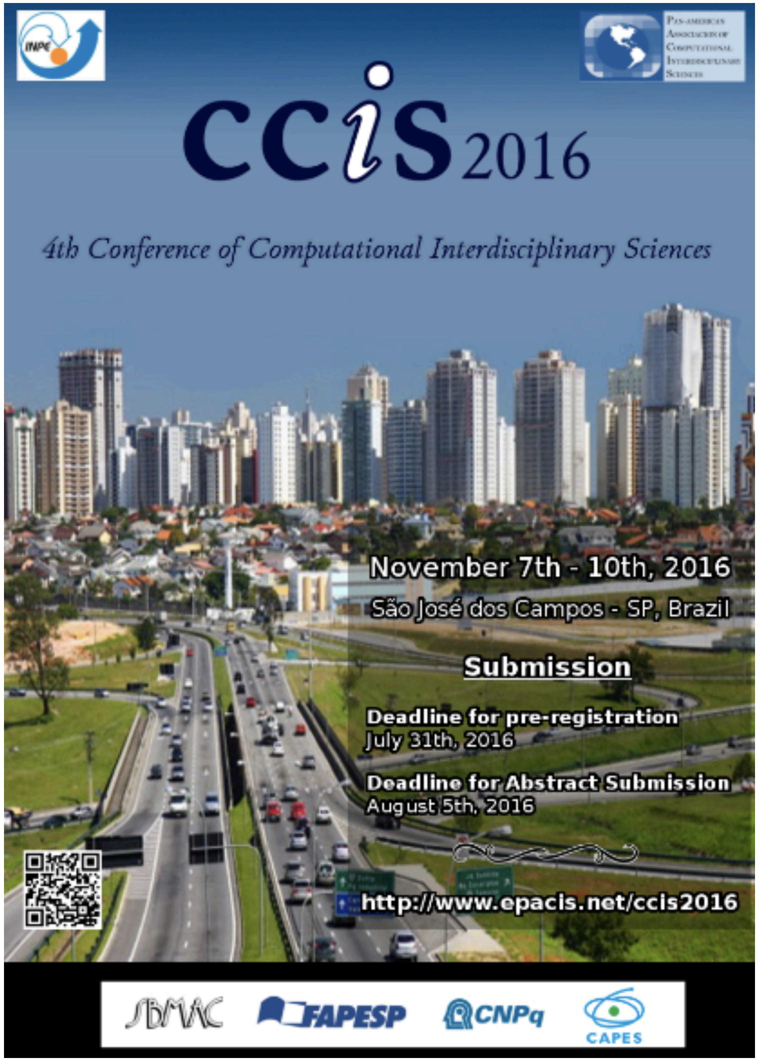
$$C_v \frac{dT}{dt} + p\frac{d(1/\rho)}{dt} = \frac{dq}{dt}$$

Analysis of the Breeding Technique applied to the CPTEC-AGCM Model

Luis F. Salgueiro Romero[1], Sandra A. Sandri and Haroldo F. de Campos Velho

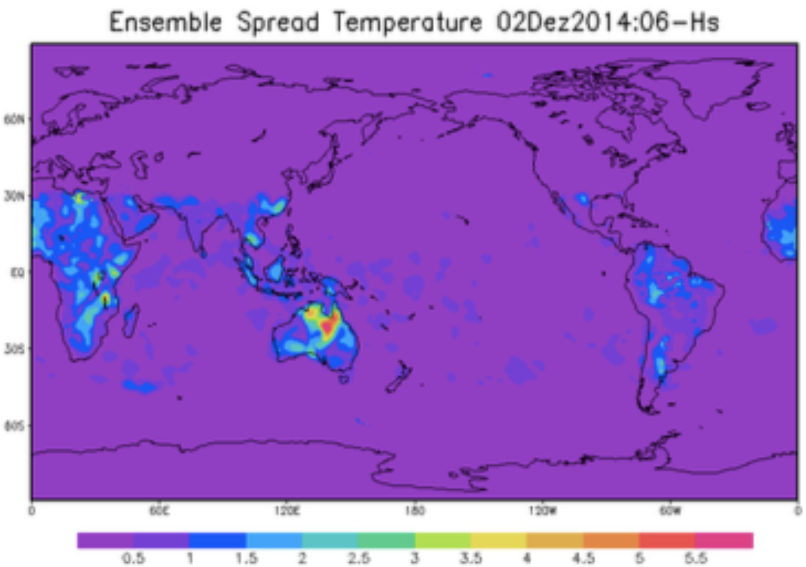
CCIS'16 Proceedings

www.epacis.net/ccis2016/en/

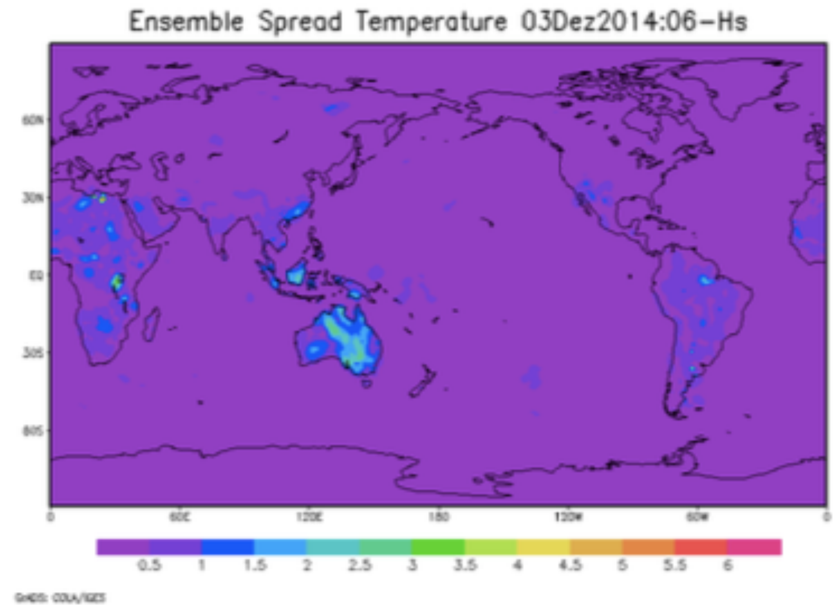


Ensemble prediction

Ensemble: 15 members



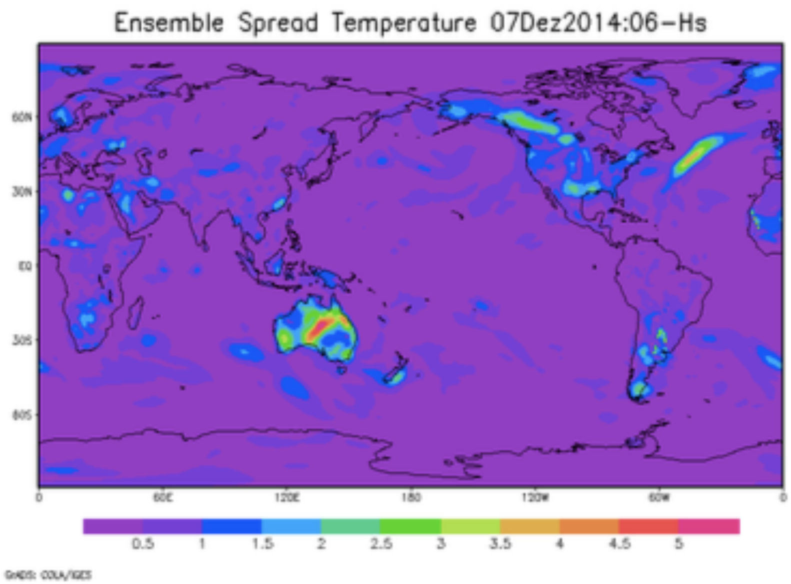
(a) 6 Horas de previsão



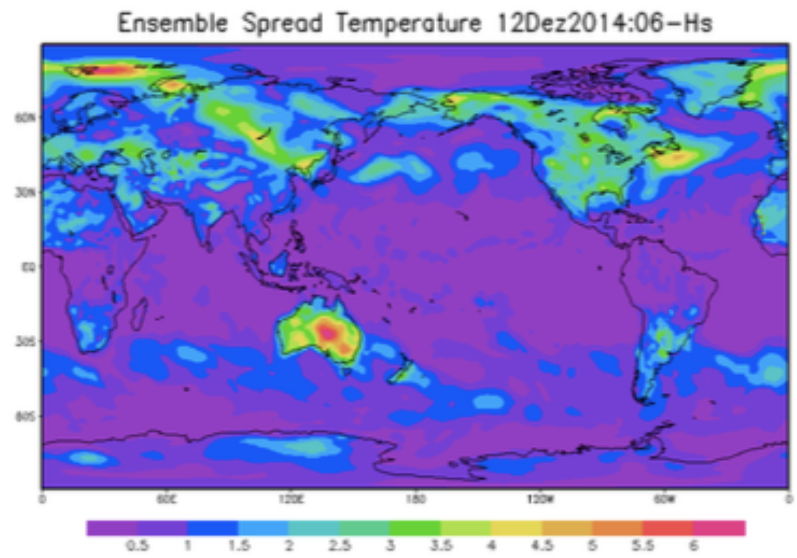
(b) 1 dia de previsão

Ensemble prediction

Ensemble: 15 members

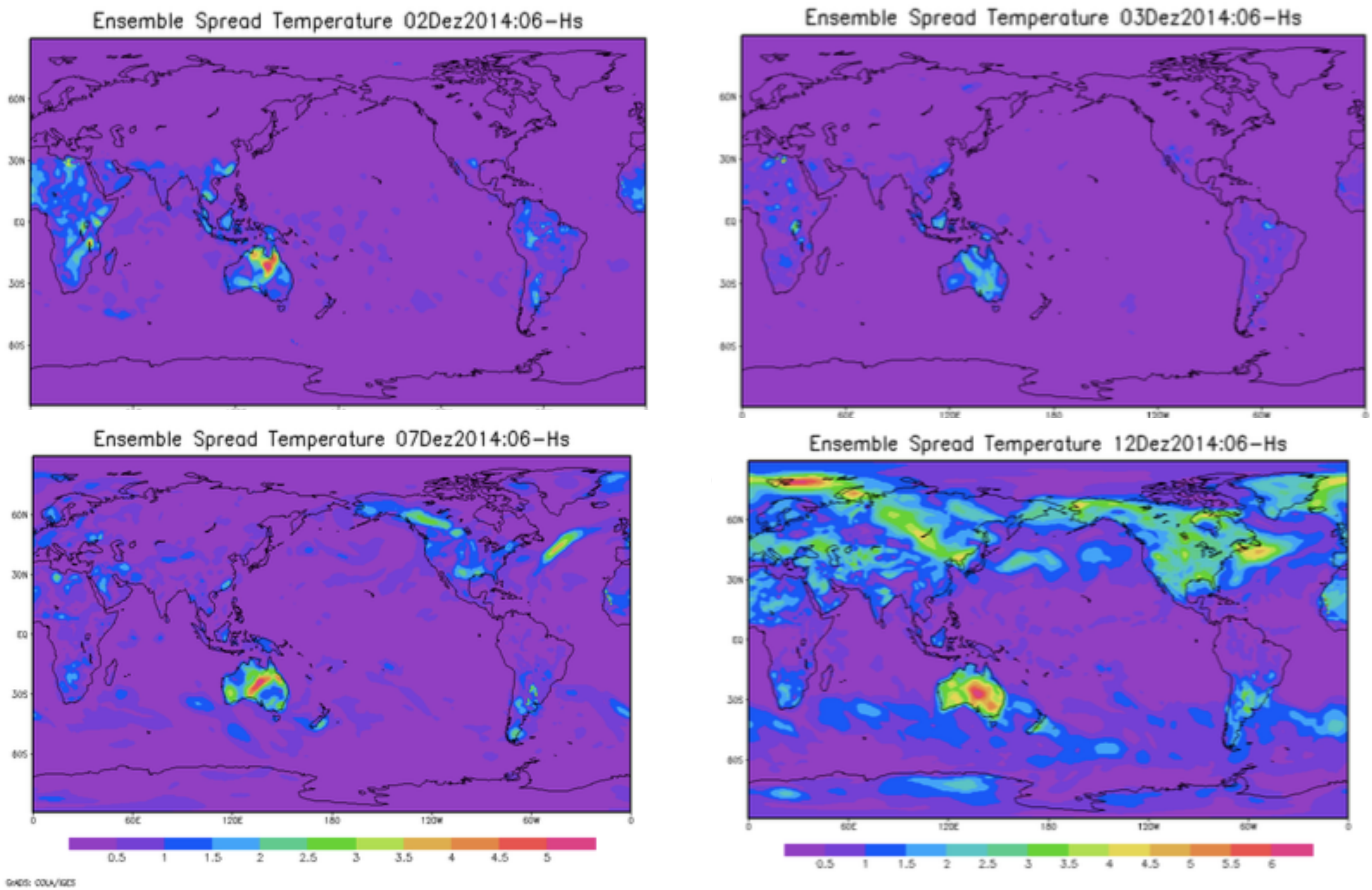


(c) 5 dias de previsão



(d) 10 dias de previsão

Ensemble prediction

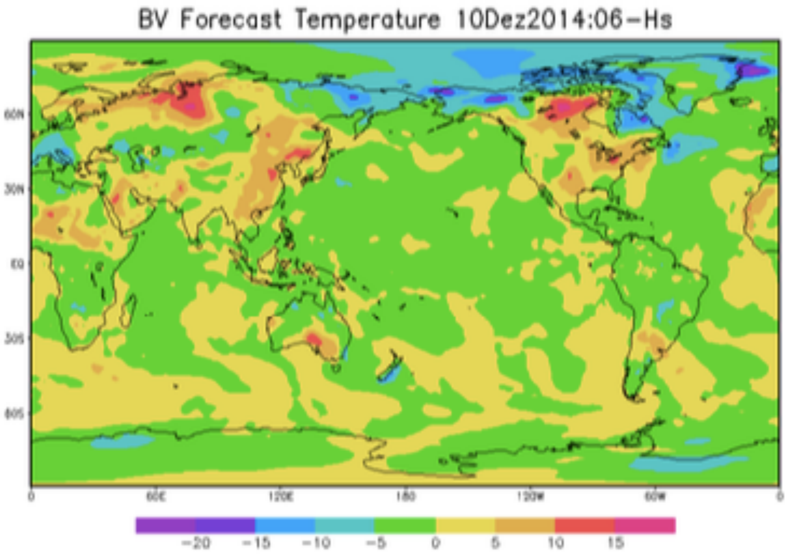


(c) 5 dias de previsão

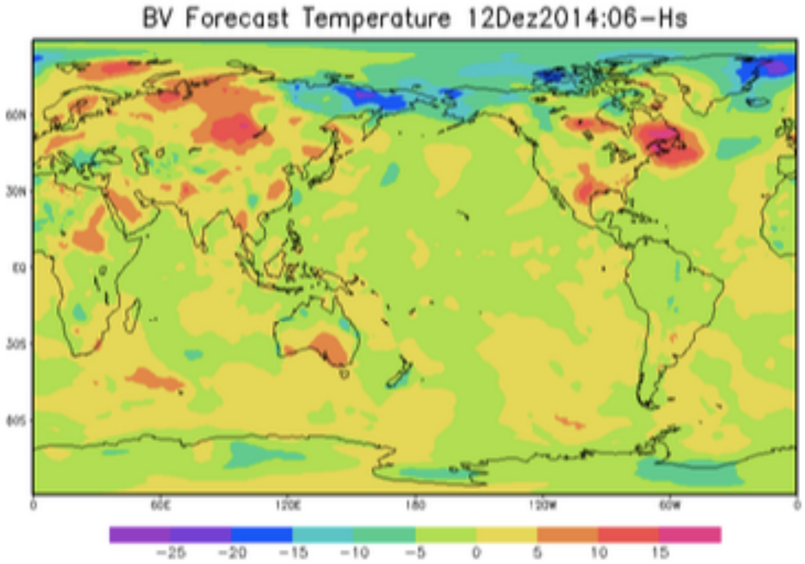
(d) 10 dias de previsão

Bred vector

Re-scaling at each 6 hours



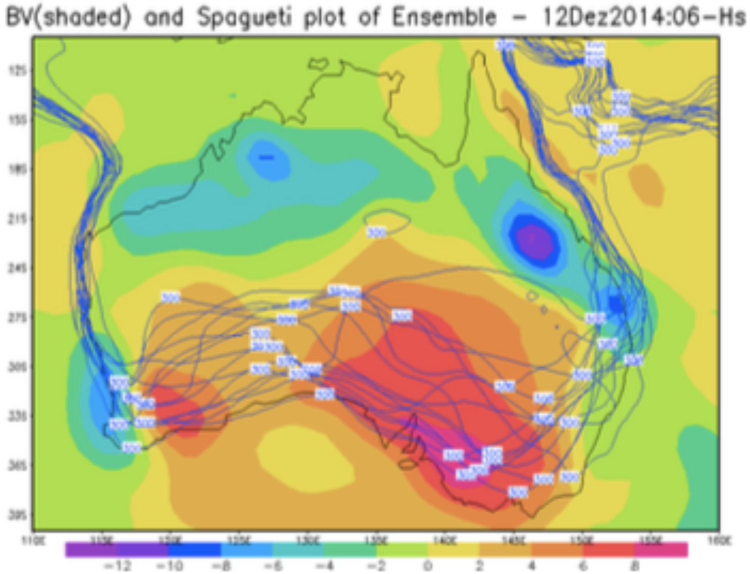
(a) 8 dias de Previsão



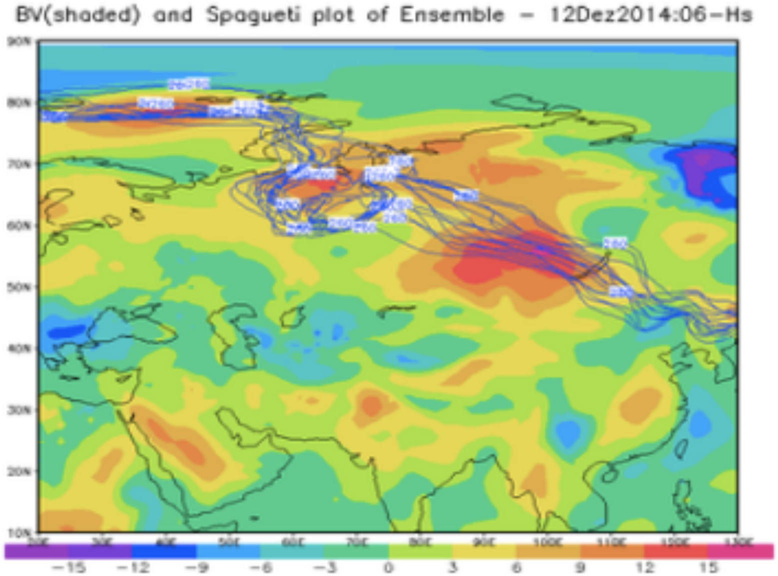
(b) 10 dias de Previsão

Ensemble x Bred vector

Re-scaling at each 6 hours (12/Dez/2014)



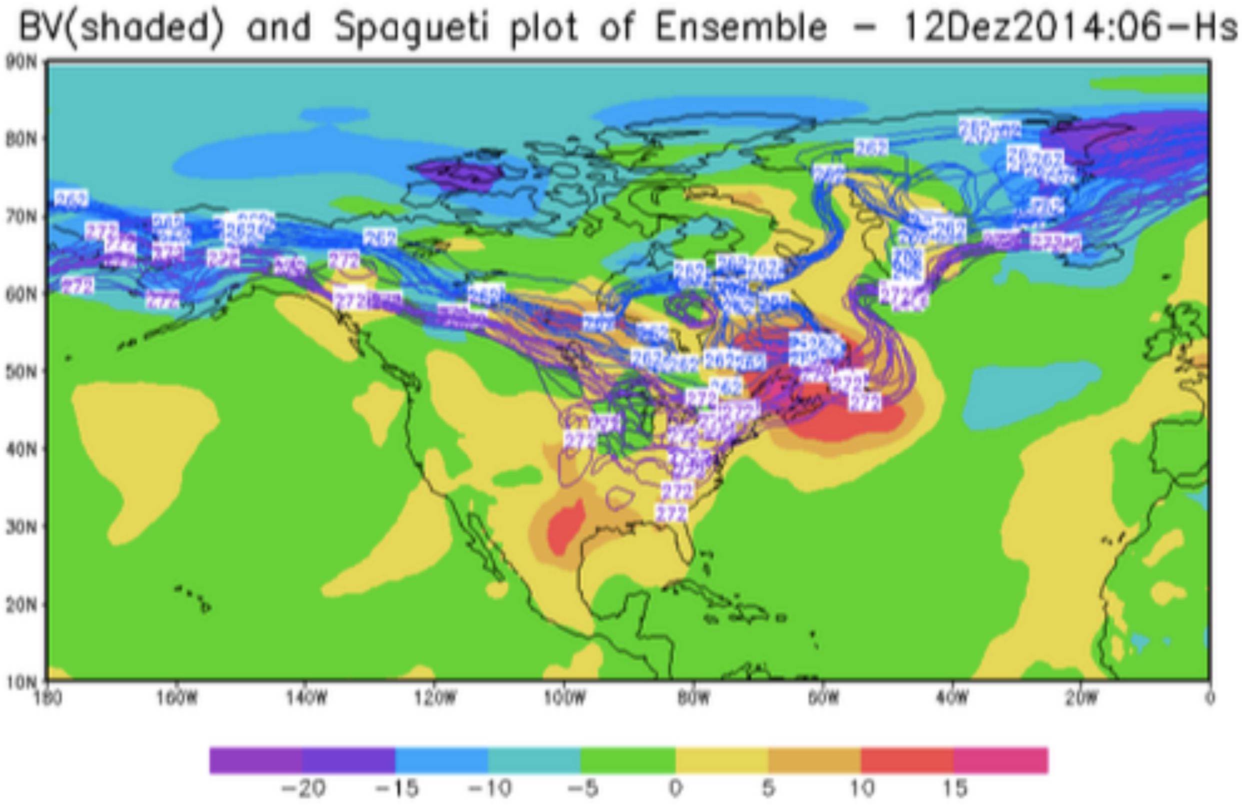
(a) Região de Austrália



(b) Região Norte de Europa e Asia

Ensemble x Bred vector

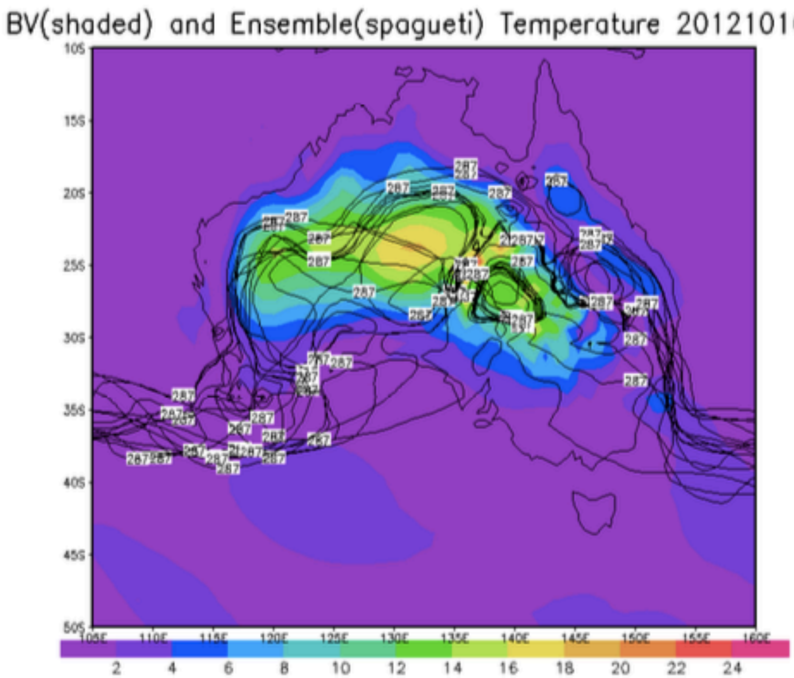
Re-scaling at each 6 hours (12/Dez/2014)



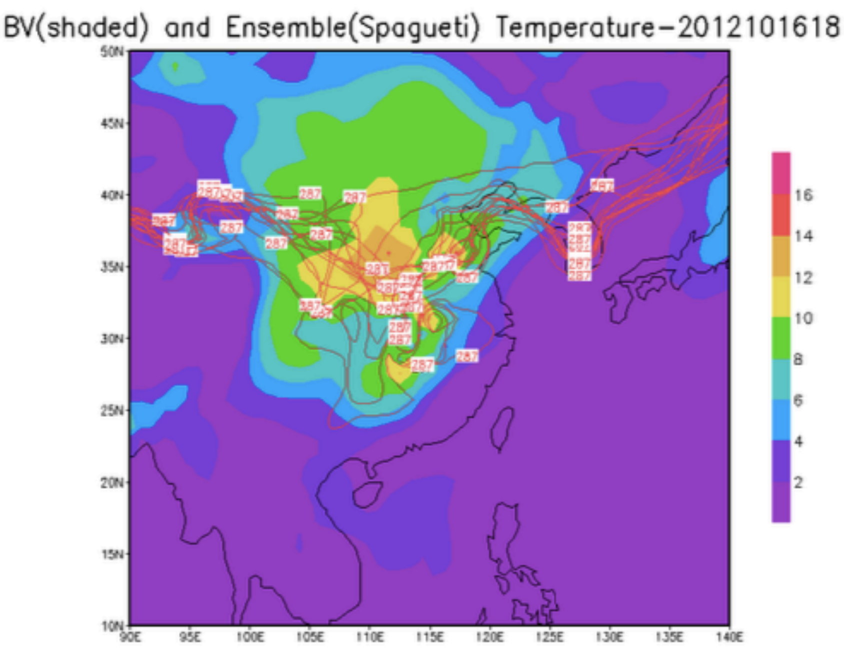
(c) Região de América do Norte

Ensemble x Bred vector

Re-scaling at each 6 hours (16/out/2012)



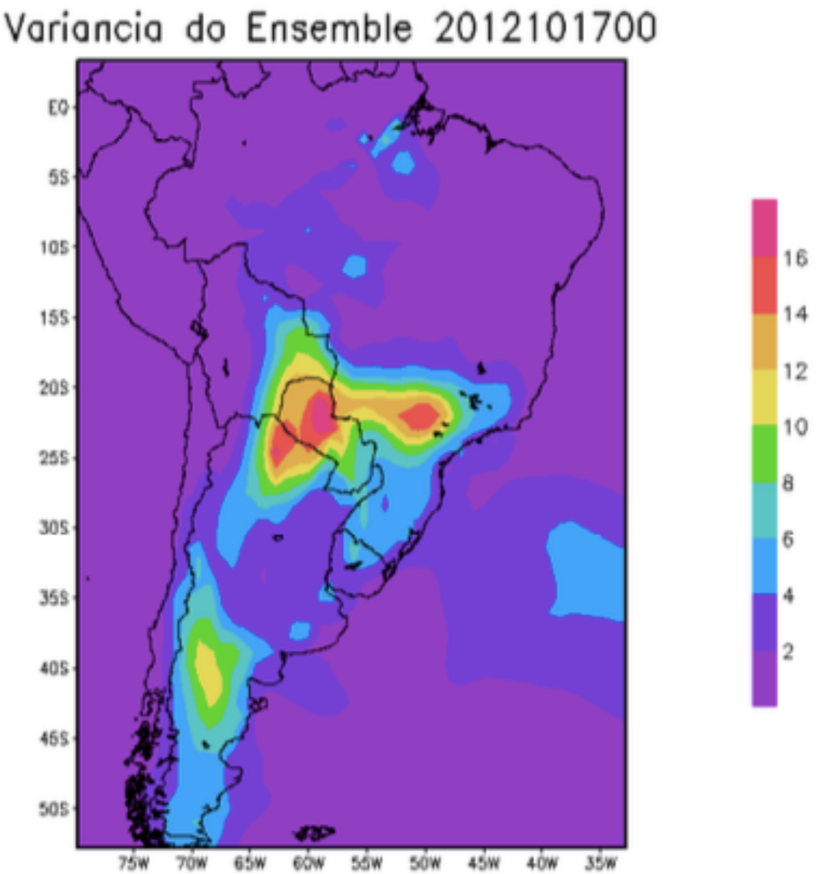
(a) Região de Australia

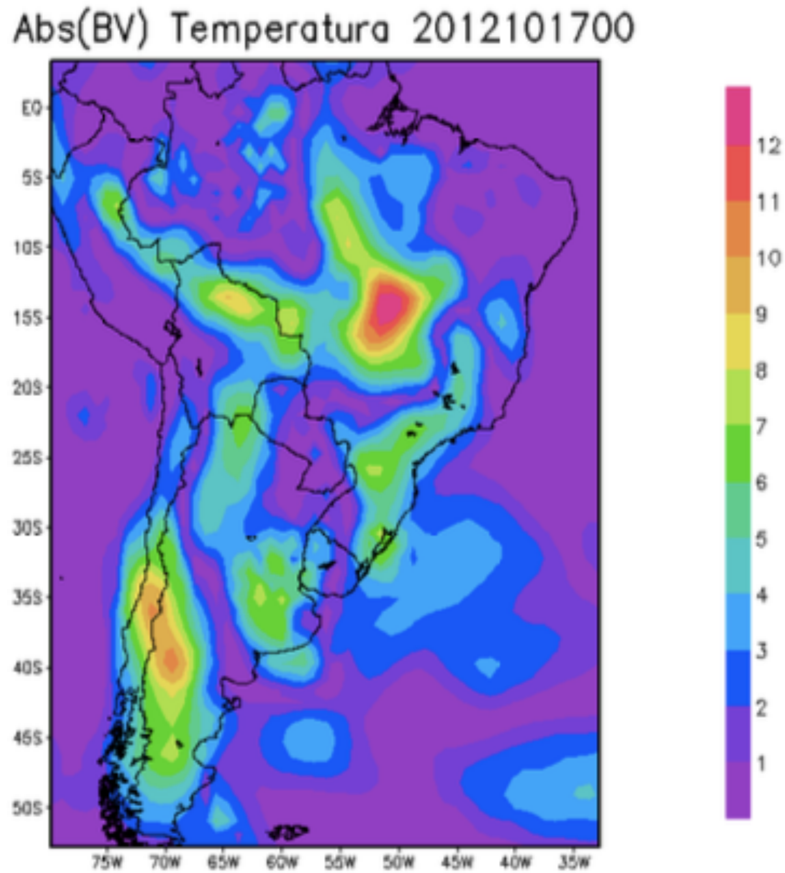


(b) Região de América do Norte

Ensemble x Bred vector

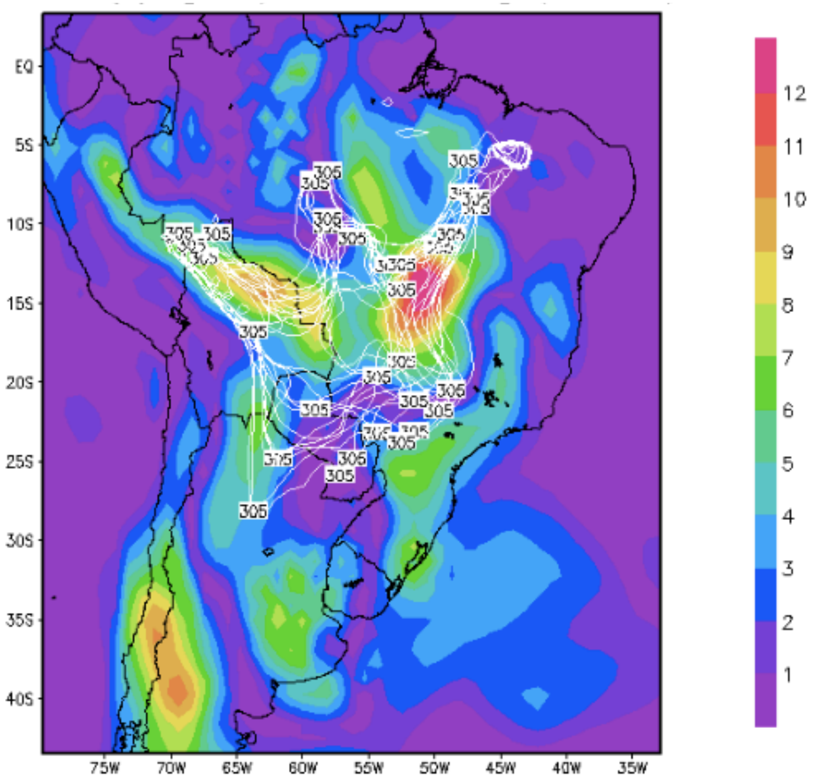
Re-scaling at each 6 hours



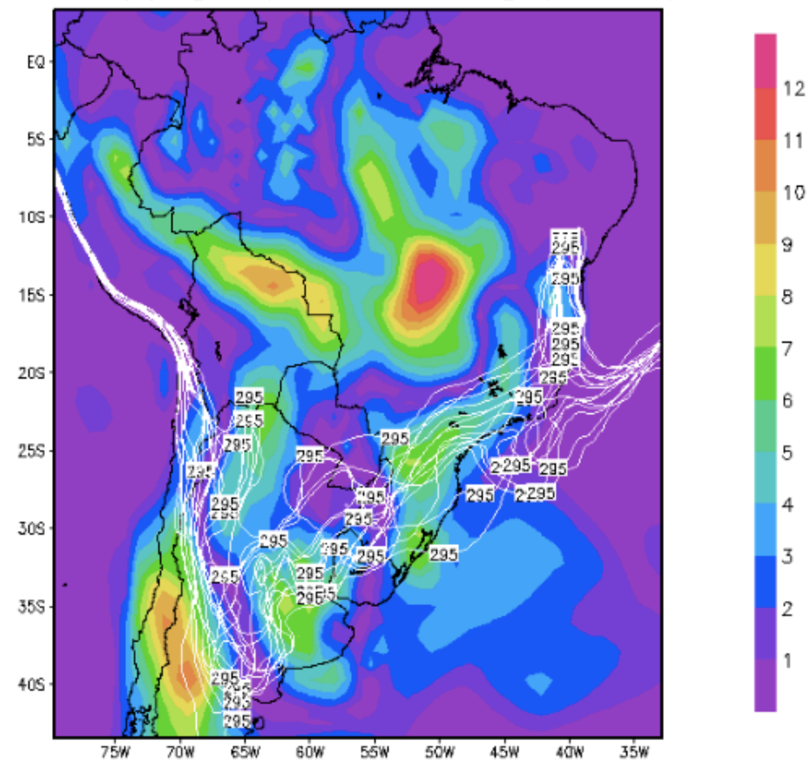


Ensemble x Bred vector

Ensemble: isoTemp 305



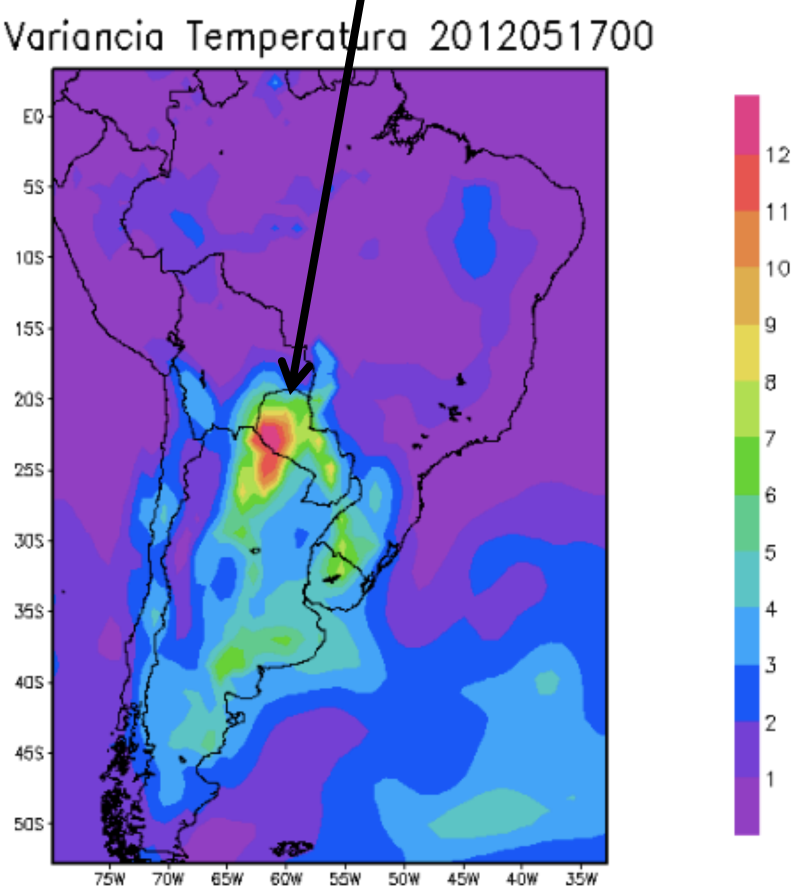
Ensemble: isoTemp 295

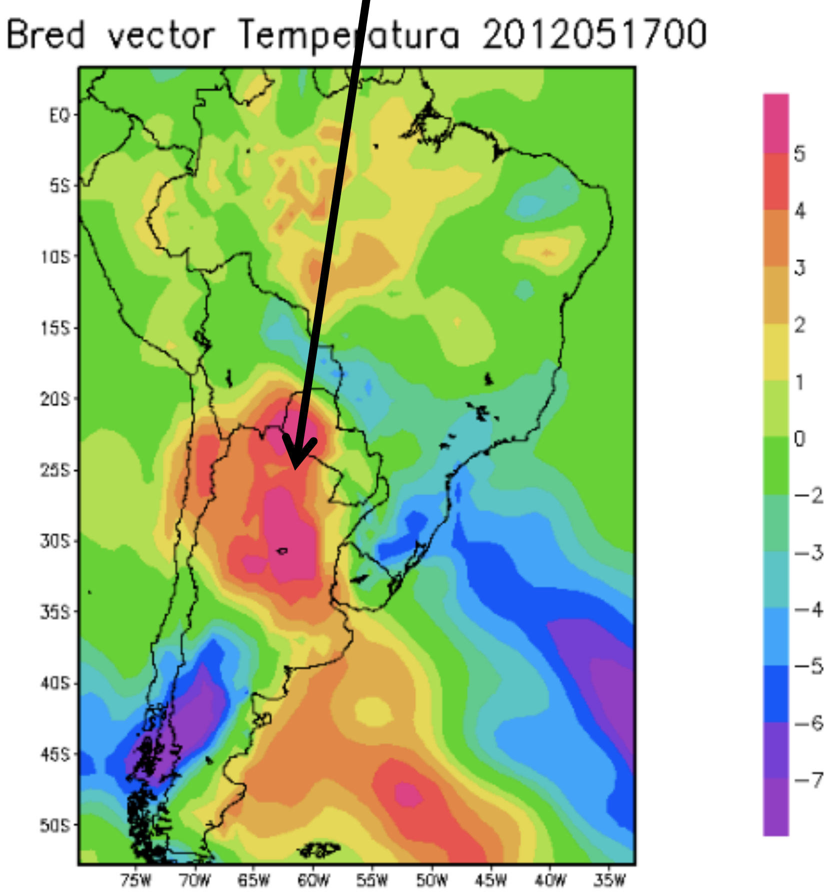


Ensemble x Bred vector

Ensemble: max-Var

BV: max value





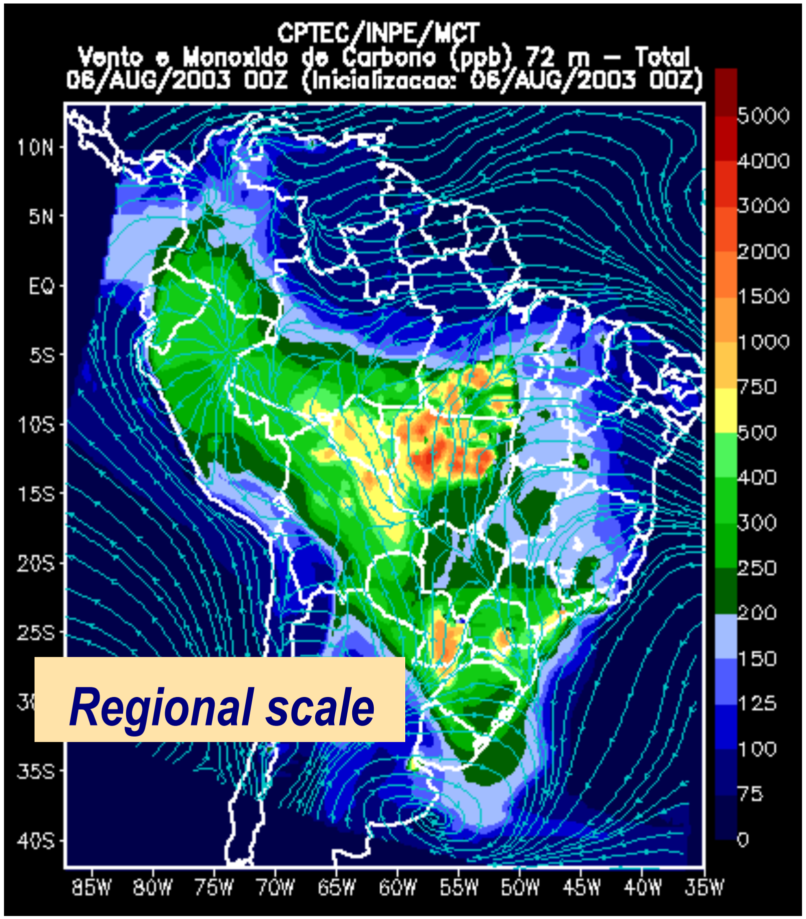
Ensemble x Bred vector

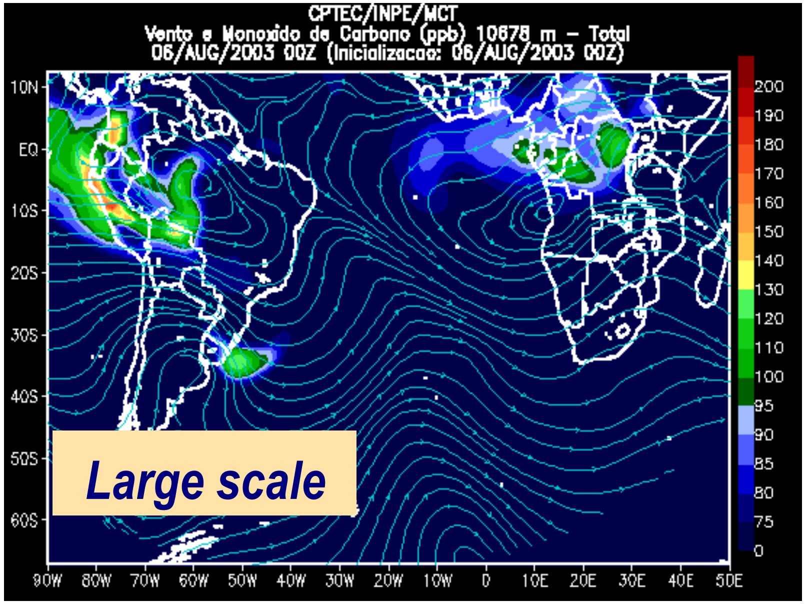
Predictability: some remarks

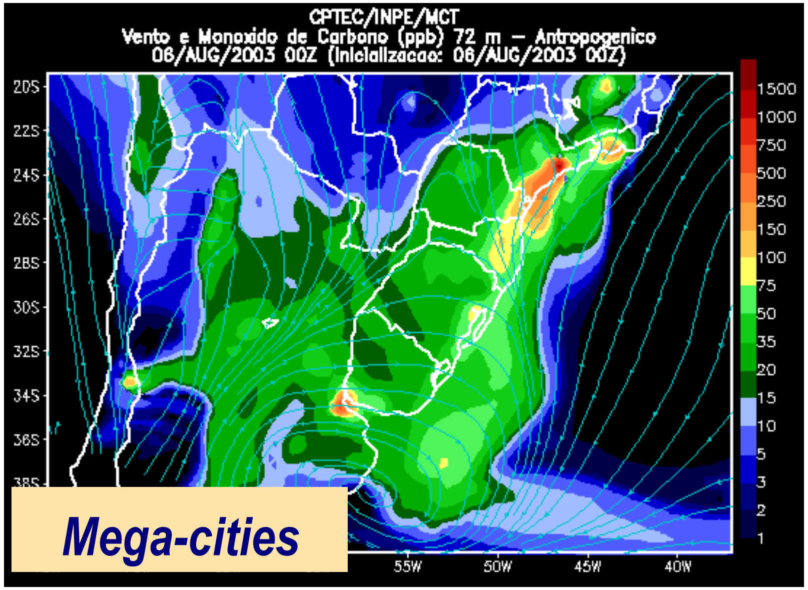
1. Bred vector demands less computer effort than ensemble prediction.
2. There is a good agreement between ensemble maximum variance and higher magnitude of BV.
3. When a desagreement is noted, the BV indicates a kind of low predictability – see South America case.
4. The BV technique can be employed to the CPTEC-INPE mesoscale prediction (BRAMS) and for SUPIM prediction.

BRAMS model

Pollutant emission by forest fires and urban-industries

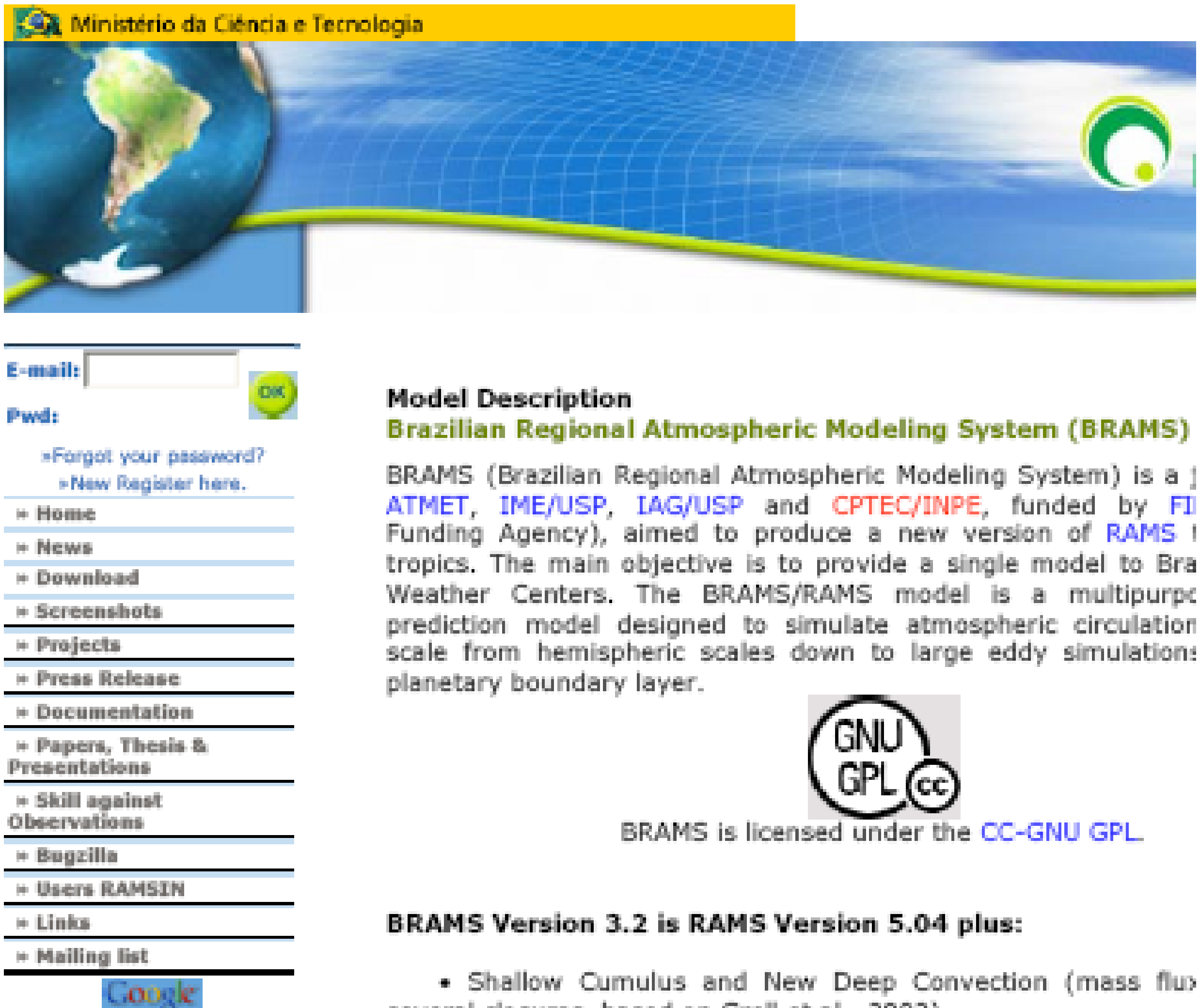






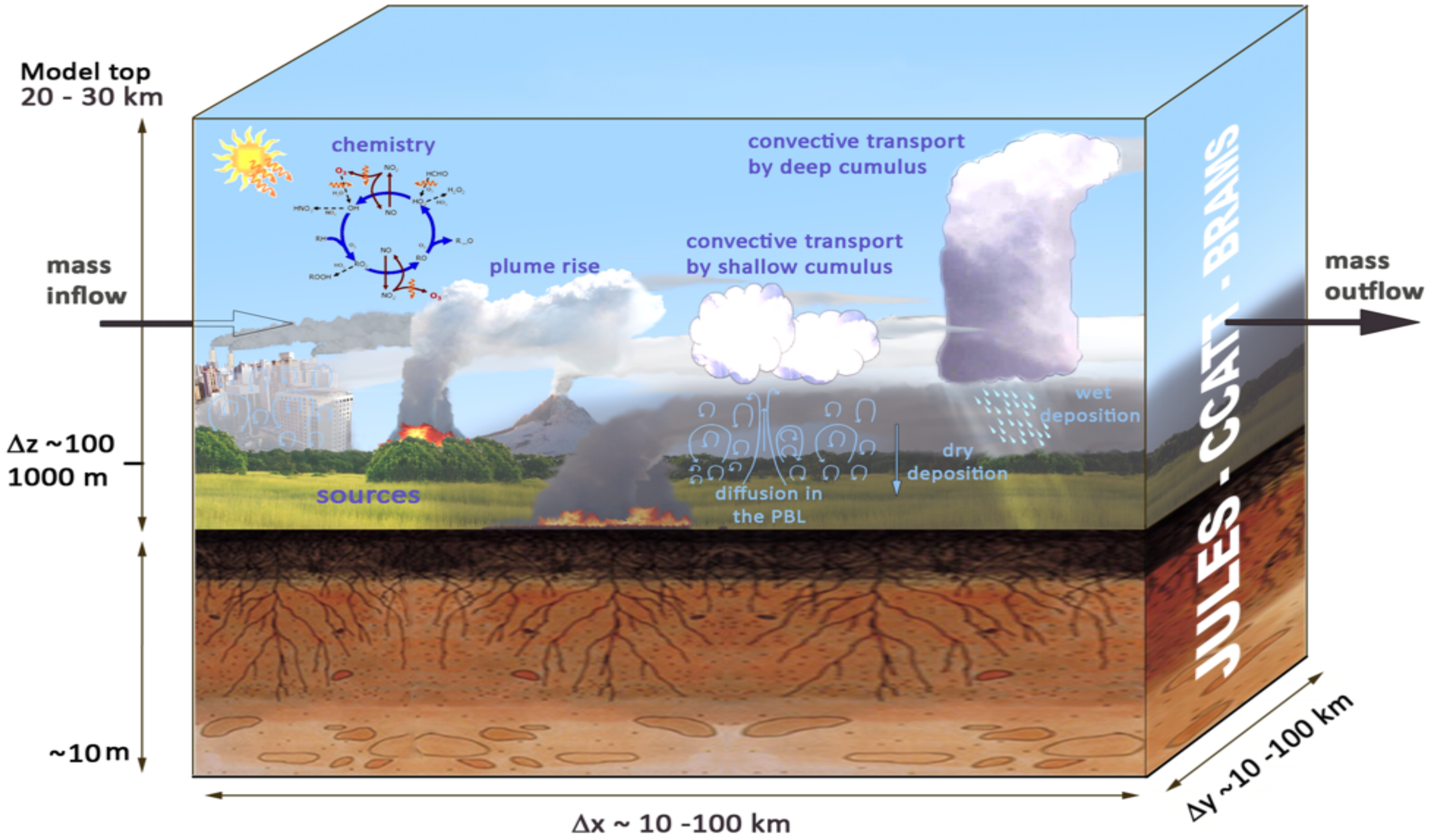
BRAMS model

http://brams.cptec.inpe.br



BRAMS model

BRAMS 5.2 (new version)
Air quality and weather prediction



BRAMS model

Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-130, 2016
Manuscript under review for journal Geosci. Model Dev.
Published: 7 June 2016

Geoscientific Model Development Discussions
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The Brazilian developments on the Regional Atmospheric Modeling System (BRAMS 5.2): an integrated environmental model tuned for tropical areas

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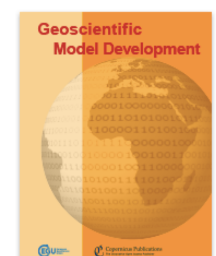

SUPIM model

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First results of operational ionospheric dynamics prediction for the Brazilian Space Weather program

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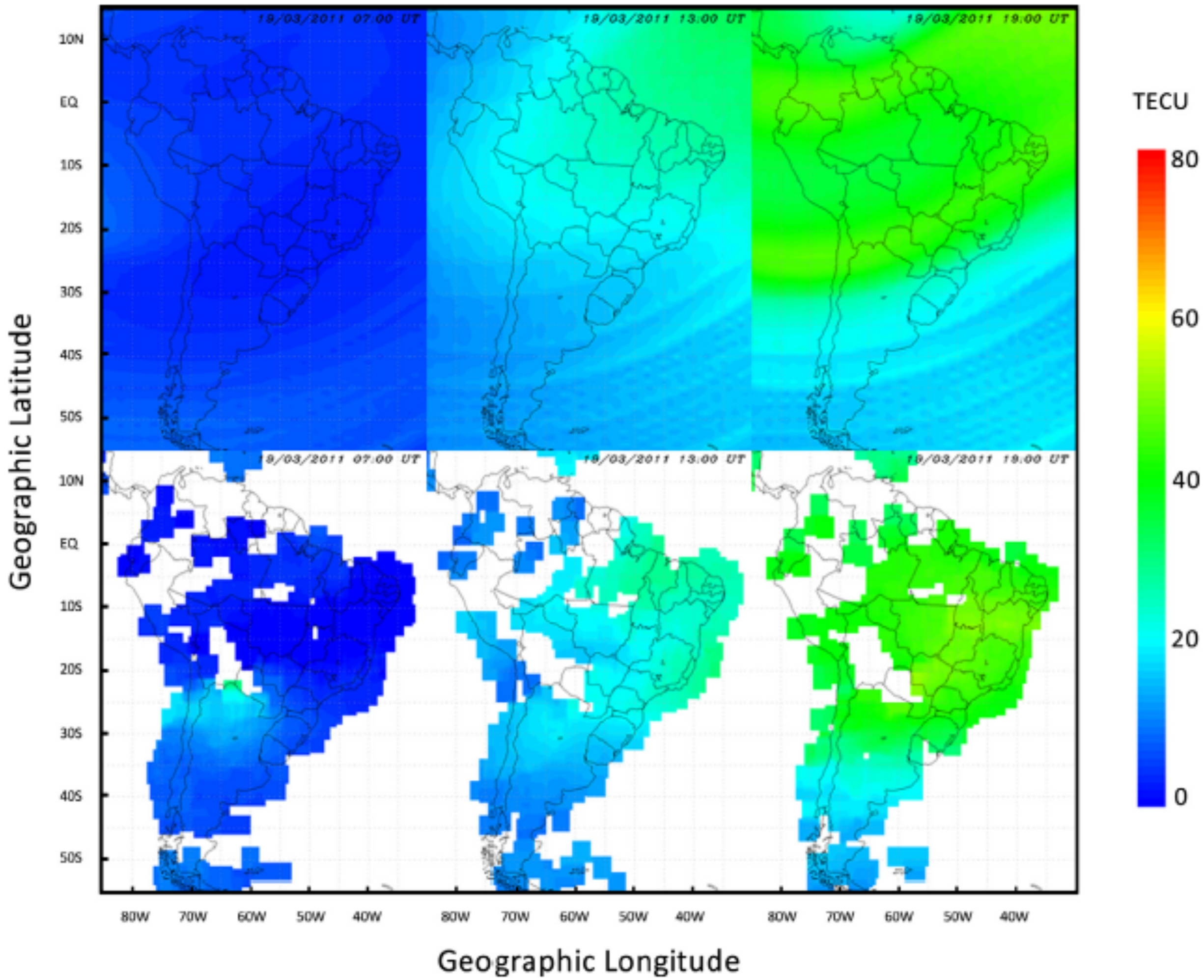
SUPIM model

- 7, 13, 19 UT: March 19th, 2011



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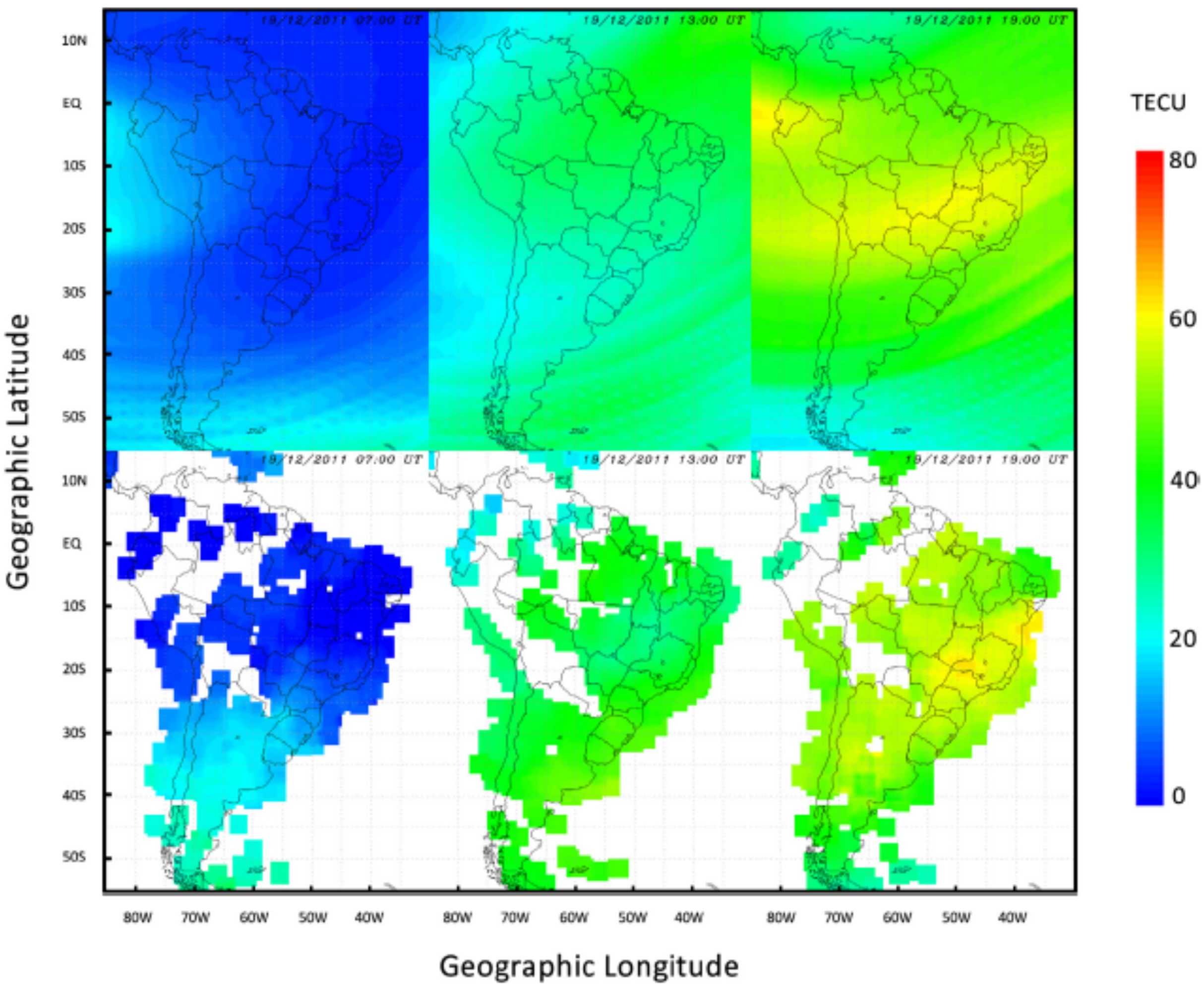

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