Introdução à Assimilação de Dados (MET 563-3)

Híbrido Médio

Helena Barbieri de Azevedo

10/11/2025

Quem sou eu

Dra. Helena Barbieri de Azevedo

- 2010 - Bacharel em meteorologia (UFPEL)
- 2014, 2018 - Mestrado e doutorado em meteorologia (INPE)
  - Uso da Técnica de OSE para Avaliar o Impacto de Observações no Sistema de Assimilação de Dados Global Variacional Tridimensional do CPTEC/INPE
  - Ajuste dinâmico para análise híbrida entre um sistema variacional e o Filtro de Kalman por Conjunto

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Ajuste dinâmico para análise híbrida entre um sistema variacional e o Filtro de Kalman por Conjunto

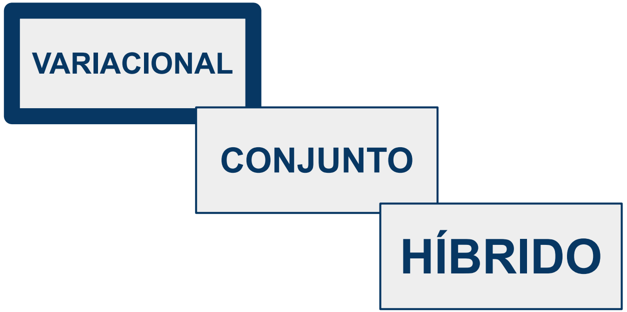
Motivação

VARIACIONAL

CONJUNTO

HÍBRIDO

Motivação

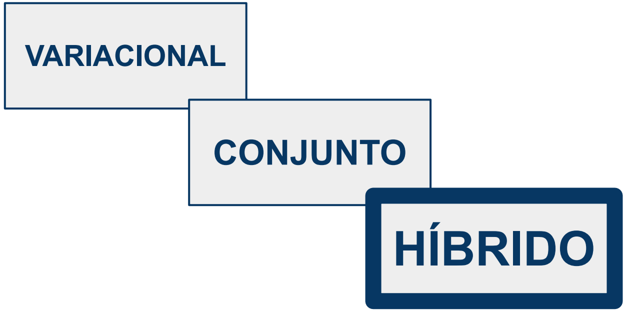


- **G3DVAR**
- Inclui os erros do modelo de forma ‘simplista’
- Matriz **B** é estática

Motivação

- **LETKF** - Local Ensemble Transform Kalman Filter
- Inclui os ‘erros do dia’
- Matriz $\mathbf{P}^b$ é atualizada
- Informações da incerteza - espalhamento

Motivação

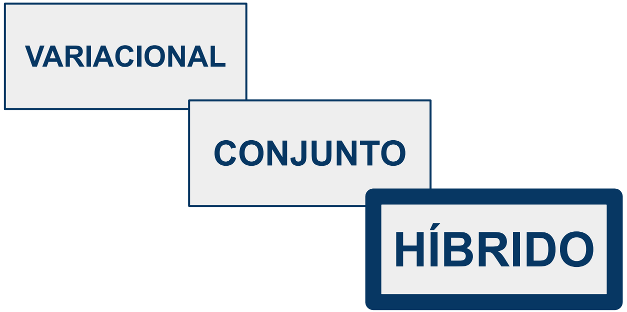


- Híbrido tradicional (**B**)
- Hammill e Snyder (2000)

$$\mathbf{B} = (1-\alpha)\mathbf{P}^b + \alpha\mathbf{B}_{3DVar} \qquad 0 \leq \alpha \leq 1$$

- Bastarz (2017)
- “São métodos que trouxeram melhorias para o framework variacional”

Motivação



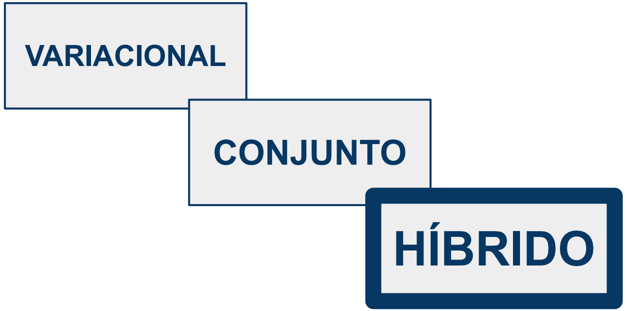
- Híbrido Médio
- Penny (2014)
  - LETKF + 3DVAR + Lorenz-96

$$\mathbf{x^a}_{HM} = (1-\alpha)\bar{\mathbf{x}}^a_{LETKF} + \alpha\mathbf{x}^a_{3DVar}$$

$$0 \leq \alpha \leq 1$$

- São métodos que trouxeram ‘estabilidade’ para o framework por conjunto
- Custo e implementação dependem dos sistemas envolvidos

Motivação



- Híbrido Médio
- Azevedo (2018)
  - LETKF + 3DVAR + SPEEDY

Motivação

VARIACIONAL

CONJUNTO

HÍBRIDO

The Hybrid Local Ensemble Transform Kalman Filter

STEPHEN G. PENNY

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(Manuscript received 22 April 2013, in final form 1 November 2013)

ABSTRACT

Hybrid data assimilation methods combine elements of ensemble Kalman filters (EnKF) and variational methods. While most approaches have focused on augmenting an operational variational system with dynamic error covariance information from an ensemble, this study takes the opposite perspective of augmenting an operational EnKF with information from a simple 3D variational data assimilation (3D-Var) method. A class of hybrid methods is introduced that combines the gain matrices of the ensemble and variational methods, rather than linearly combining the respective background error covariances. A hybrid local ensemble transform Kalman filter (Hybrid-LETKF) is presented in two forms: 1) a traditionally motivated Hybrid/Covariance-LETKF that combines the background error covariance matrices of LETKF and 3D-Var, and 2) a simple-to-implement algorithm called the Hybrid/Mean-LETKF that falls into the new class of hybrid gain methods. Both forms improve analysis errors when using small ensemble sizes and low observation coverage versus either LETKF or 3D-Var used alone. The results imply that for small ensemble sizes, allowing a solution to be found outside of the space spanned by ensemble members provides robustness in both hybrid methods compared to LETKF alone. Finally, the simplicity of the Hybrid/Mean-LETKF design implies that this algorithm can be applied operationally while requiring only minor modifications to an existing operational 3D-Var system.

1. Introduction

Hybrid data assimilation systems combine two approaches traditionally used in operational weather forecasting: ensemble Kalman filters (EnKF) and the 3D variational data assimilation (3D-Var) and 4D-Var methods. For example, a hybrid system based on the developmental work of Barker (1999), Hamill and Snyder (2000), Lorenc (2003), Buehner (2005), Buehner et al. (2010a,b), and Wang et al. (2007a,b, 2008a,b, 2013) has recently been implemented at the National Centers for Environmental Prediction (NCEP) for use in operational forecasting (Kleist 2012; Wang et al. 2013). Most of the justification given for the improved performance of the traditional hybrids over the variational methods has been that the background error covariance is better defined with an ensemble, due to flow dependence and the corresponding improvement in multivariate covariance information. While such hybrid approaches have been shown to improve upon the existing operational variational systems, it is unclear how the static covariance matrix and the minimization procedure of the variational systems benefit the EnKF.

We examine the impacts that a simple 3D-Var has on an EnKF in order to determine the source of these benefits. In an operational environment, the choices of ensemble size and observation coverage are limited by costs of computational facilities and observing equipment. Thus, it is important to identify the preferred algorithmic approach when these parameters are prescribed. We introduce a new hybrid using an EnKF combined with a simple 3D-Var and demonstrate its effectiveness from this perspective. Traditional hybrids start with a variational approach and incorporate the ensemble information through the ensemble-derived covariance matrix. Here we instead start with an EnKF and use a variational approach to apply a correction within the model space to stabilize the EnKF.

2. Methodology

a. Model

For the forecast model, we use the Lorenz-96 model on $m = 40$ grid points (Lorenz 1996),

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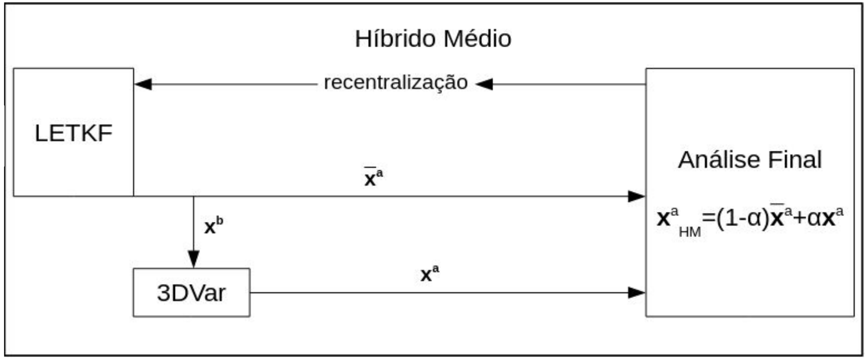
Híbrido médio - Penny (2014)

Realiza uma combinação entre análises

$$\mathbf{x}^a_{HG} = (1-\alpha)\bar{\mathbf{x}}^a_{LETKF} + \alpha\mathbf{x}^a_{3D-Var} \qquad 0 \leq \alpha \leq 1$$

$$\mathbf{J}(\mathbf{x}^a) = (\mathbf{x}^a - \bar{\mathbf{x}}^a)^T \mathbf{B}^{-1} (\mathbf{x}^a - \bar{\mathbf{x}}^a) + (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))$$



alfa = 0 ?
alfa = 1 ?

Híbrido médio - Penny (2014)

Realiza uma combinação entre análises

$$\mathbf{x}^a_{HG} = (1-\alpha)\bar{\mathbf{x}}^a_{LETKF} + \alpha\mathbf{x}^a_{3D-Var} \qquad 0 \le \alpha \le 1$$

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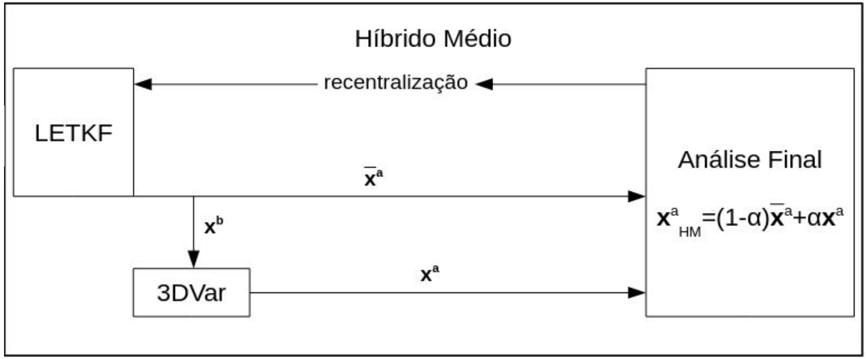

alfa = 0 = 100% LETKF
alfa = 1 ?

Híbrido médio - Penny (2014)

Realiza uma combinação entre análises

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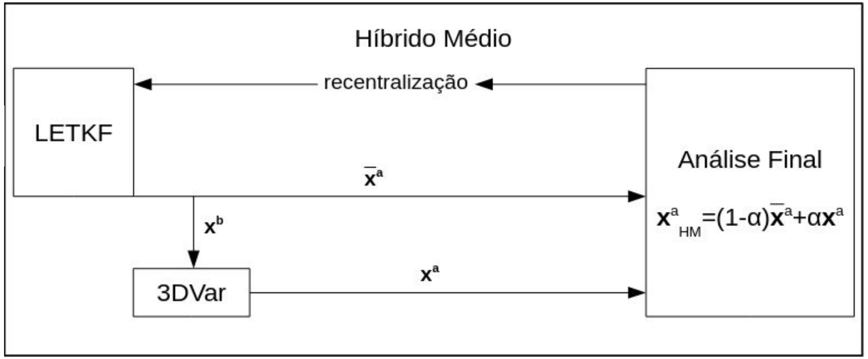

alfa = 0 = 100% LETKF
alfa = 1 ≠ 100% 3DVAR

Híbrido médio

EnKF and Hybrid Gain Ensemble Data Assimilation. Part II: EnKF and Hybrid Gain Results

MASSIMO BONAVITA, MATS HAMRUD, AND LARS ISAKSEN

European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom

(Manuscript received 20 February 2015, in final form 4 September 2015)

ABSTRACT

The desire to do detailed comparisons between variational and more scalable ensemble-based data assimilation systems in a semioperational environment has led to the development of a state-of-the-art EnKF system at ECMWF, which has been described in Part I of this two-part study. In this part the performance of the EnKF system is evaluated compared to a 4DVar of similar resolution. It is found that there is not a major difference between the forecast skill of the two systems. However, similarly to the operational hybrid 4DVar–EDA, a hybrid EnKF–variational system [which we refer to as the hybrid gain ensemble data assimilation (HG-EnDA)] is capable of significantly outperforming both component systems. The HG-EnDA has been implemented with relatively little effort following Penny's recent study. Results of numerical experimentation comparing the HG-EnDA with the hybrid 4DVar–EDA used operationally at ECMWF are presented, together with diagnostic results, which help characterize the behavior of the proposed ensemble data assimilation system. A discussion of these results in the context of hybrid data assimilation in global NWP is also provided.

1. Introduction

The development activities described in Hamrud et al. (2015, hereafter Part I) have led to the implementation of an operational standard EnKF-based data assimilation system at ECMWF. This system is able to effectively assimilate most of the operationally available observation types, it has good scalability properties and it is computationally efficient. It is thus a good base for further development and research activities. The availability of the EnKF allows performing a detailed comparison with the 4DVar system available at ECMWF under more controlled conditions than it would otherwise be possible. Results of this comparison are presented in section 2. The general conclusion that can be drawn is that, at this stage of development, the ECMWF EnKF-based data assimilation system has similar deterministic forecast performance to a 4DVar with the same nominal resolution using static background error covariance estimates.

A natural research question then is: Is it possible to combine these two data assimilation systems and improve on the performance of both? From a 4DVar perspective the answer is certainly positive and is based on introducing flow-dependent background error information from the EnKF or ensemble of data assimilations (EDA; Isaksen et al. 2010) in the standard 4DVar algorithm (Barker 1999; Hamill and Snyder 2000; Lorenc 2003; Buehner 2005; Buehner et al. 2010a,b; Wang 2010; Bonavita et al. 2012, 2015). From an EnKF perspective less work has been done. The basic limitation of the pure EnKF lies in the reduced dimensionality of the represented background error subspace, which limits the amount of observational information that can be extracted from nonlocal observations and, possibly, in regions with high density of observations (Lorenc 2003; Campbell et al. 2010). On the other hand, the full rank of the modeled background error covariance matrix used in variational assimilation means that 3–4DVar algorithms do not have this problem. This suggests that exploiting this property of the variational approach in an EnKF context would be advantageous. Recent work by Penny (2014), in an idealized setup, proposed a new hybrid variational–EnKF formulation that involves taking a weighted mean of the

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A Hybrid Global Ocean Data Assimilation System at NCEP

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DAVID W. BEHRINGER

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(Manuscript received 13 November 2014, in final form 14 June 2015)

ABSTRACT

Seasonal forecasting with a coupled model requires accurate initial conditions for the ocean. A hybrid data assimilation has been implemented within the National Centers for Environmental Prediction (NCEP) Global Ocean Data Assimilation System (GODAS) as a future replacement of the operational three-dimensional variational data assimilation (3DVar) method. This Hybrid-GODAS provides improved representation of model uncertainties by using a combination of dynamic and static background error covariances, and by using an ensemble forced by different realizations of atmospheric surface conditions. An observing system simulation experiment (OSSE) is presented spanning January 1991 to January 1999, with a bias imposed on the surface forcing conditions to emulate an imperfect model. The OSSE compares the 3DVar used by the NCEP Climate Forecast System (CFSv2) with the new hybrid, using simulated in situ ocean observations corresponding to those used for the NCEP Climate Forecast System Reanalysis (CFSR).

The Hybrid-GODAS reduces errors for all prognostic model variables over the majority of the experiment duration, both globally and regionally. Compared to an ensemble Kalman filter (EnKF) used alone, the hybrid further reduces errors in the tropical Pacific. The hybrid eliminates growth in biases of temperature and salinity present in the EnKF and 3DVar, respectively. A preliminary reanalysis using real data shows that reductions in errors and biases are qualitatively similar to the results from the OSSE. The Hybrid-GODAS is currently being implemented as the ocean component in a prototype next-generation CFSv3, and will be used in studies by the Climate Prediction Center to evaluate impacts on ENSO prediction.

1. Introduction

The National Centers for Environmental Prediction (NCEP) has used the same 3D variational data assimilation (3DVar) approach to provide initial conditions and verification of the ocean state since its development in the late 1980s (Derber and Rosati 1989). The computationally inexpensive 3DVar was implemented operationally at NCEP within the Global Ocean Data Assimilation System (GODAS) in 2003 (Behringer and Xue 2004; Behringer 2007) and as part of the Climate Forecast System (CFS) in 2004 (http://rda.ucar.edu/datasets/ds094.0; Saha et al. 2006). Increases in computing power and advances in data assimilation algorithms have made it practical to use higher-cost ensemble-based approaches that offer more representative error estimates and improvements in accuracy. For the atmosphere, a hybrid 3DVar–ensemble Kalman filter (EnKF) became operational in the NCEP Global Forecast System (GFS) in 2012 (Kleist 2012; Wang et al. 2013). That hybrid system is also intended as the

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Híbrido médio

December 2015 BONAVITA ET AL. 4865

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Modelo realístico do ECMWF

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EnKF + 4DVAR

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NCEP
Hybrid-GODAS

LETKF + 3DVAR +
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DECEMBER 2015 BONAVITA ET AL. 4865

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Tese doutorado

Matriz B
LETKF + 3DVAR +
SPEEDY

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α = 0.5

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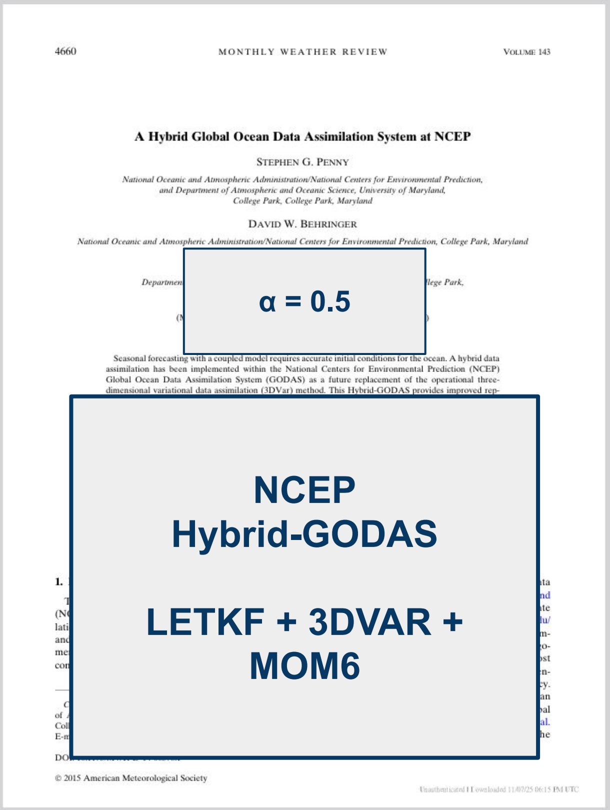

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Seasonal forecasting with a coupled model requires accurate initial conditions for the ocean. A hybrid data assimilation has been implemented within the National Centers for Environmental Prediction (NCEP) Global Ocean Data Assimilation System (GODAS) as a future replacement of the operational three-dimensional variational data assimilation (3DVar) method. This Hybrid-GODAS provides improved rep-

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α = 0.5

NCEP
Hybrid-GODAS

LETKF + 3DVAR + MOM6

WESPETAL, M. E.; PENNY, S. G.; KALNAY, E.; MIYOSHI, T.; GREYBUSH, S. J. Estimating climatological forecast error covariance for 3d-var and hybrid data assimilation using ensemble perturbations, and a comparison with the nmc method. **Monthly Weather Review. Submitted.**, 2018. 12, 14, 17, 98

α = 0.5

Tese doutorado

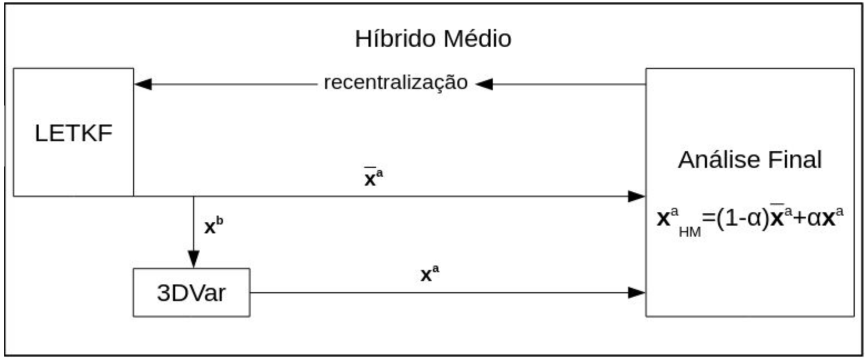
Matriz B
LETKF + 3DVAR + SPEEDY

Híbrido médio - Penny (2014)

Realiza uma combinação entre análises

$$\mathbf{x}^a_{HG} = (1-\alpha)\bar{\mathbf{x}}^a_{LETKF} + \alpha\mathbf{x}^a_{3D-Var} \qquad 0 \leq \alpha \leq 1$$

$$\mathbf{J}(\mathbf{x}^a) = (\mathbf{x}^a - \bar{\mathbf{x}}^a)^T \mathbf{B}^{-1} (\mathbf{x}^a - \bar{\mathbf{x}}^a) + (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))$$



alfa = 0 = 100% LETKF
alfa = 1 ≠ 100% 3DVAR

Híbrido médio - Azevedo (2018)

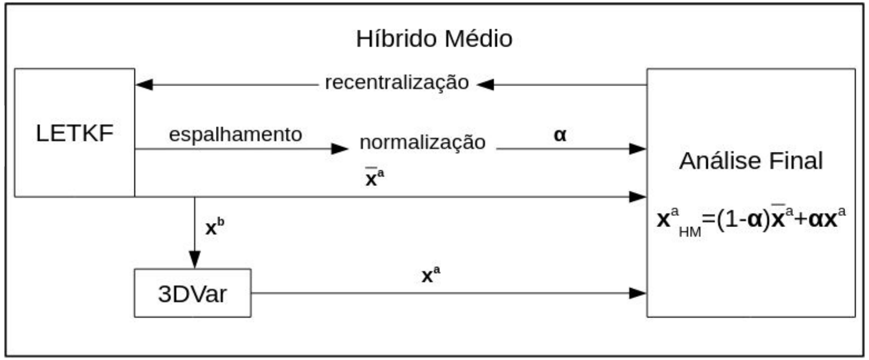
Realiza uma combinação entre análises

$$\mathbf{x}^a_{HG} = (1-\alpha)\bar{\mathbf{x}}^a_{LETKF} + \alpha\mathbf{x}^a_{3D-Var} \qquad 0 \leq \alpha \leq 1$$

$$\mathbf{J}(\mathbf{x}^a) = (\mathbf{x}^a - \bar{\mathbf{x}}^a)^T \mathbf{B}^{-1} (\mathbf{x}^a - \bar{\mathbf{x}}^a) + (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}(\mathbf{x}^a))$$

$$\sigma_{x_{ijl}} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left[(X^a_{ijl})_k - (\bar{x}^a_{ijl})\right]^2}$$

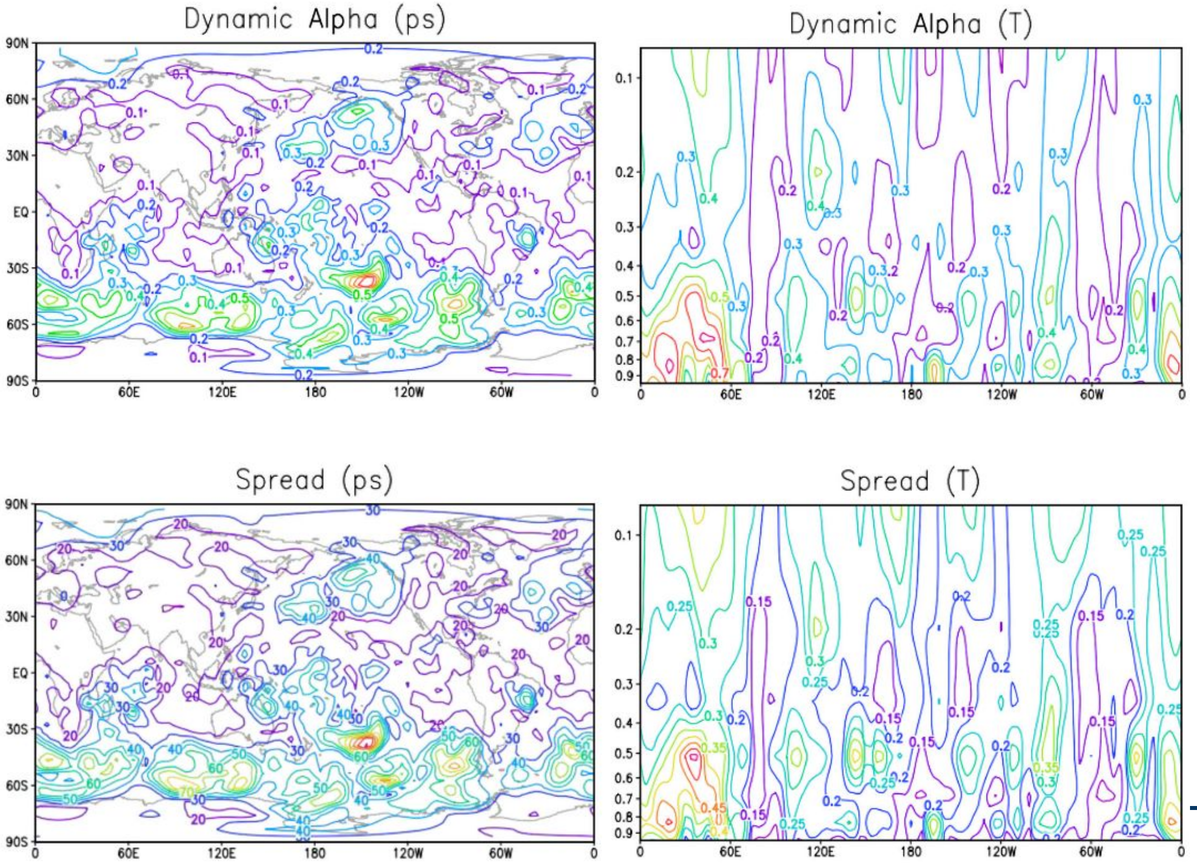
$$\alpha_{x_{ijl}} = \frac{\sigma_{x_{ijl}} - min(\sigma_{x_{ij}})_l}{max(\sigma_{x_{ij}})_l - min(\sigma_{x_{ij}})_l}$$



↓ espalhamento
↓ alfa
↑ LETKF

Houtekamer e Zhang (2016) - quando o tamanho do conjunto for pequeno, para se obter uma análise boa, o espalhamento deve ser pequeno também.

Híbrido médio



Experimentos

Modelo

- SPEEDY - Simplified Parameterizations, primitivE-Equation DYnamics
- Molteni (2003)
- T30L7
- vento zonal (u), vento meridional (v), temperatura (T), umidade (q) e pressão (ps)

Análises

- LETKF ($\alpha = 0$)
- 3DVAR
- α = 0.1, 0.3, 0.5, 0.7, 0.9, dyn

Previsões (120h)

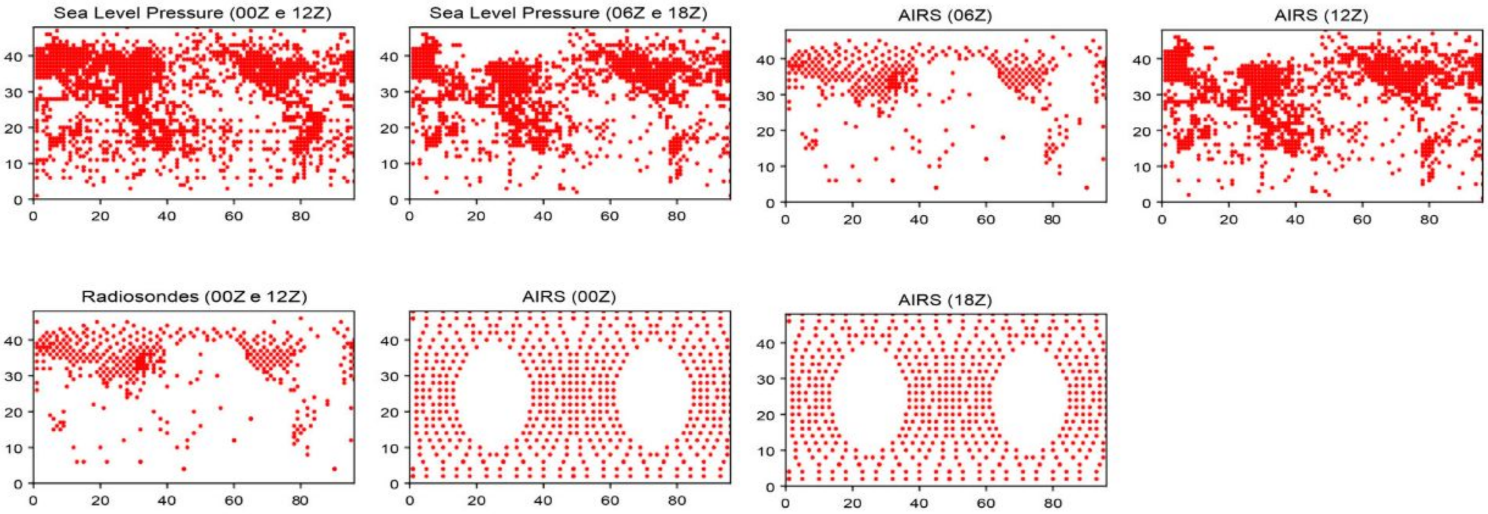
- LETKF ($\alpha = 0$)
- 3DVAR
- α = 0.1, dyn

16 membros

Inverno e **verão**

Experimentos

Observações sintéticas



Resultados

LETKF X 3DVAR - análises

Tabela 5.1 - RMSE médio da pressão em superfície (ps), temperatura (T), componente zonal e meridional do vento (u e v) e umidade (q) para o Globo nos sete níveis do modelo para o trimestre DJF.

	ps		T		u		v		q ($\times 10^{-4}$)	
	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR
1	28,5	45,8	0,13	0,20	0,40	0,67	0,40	0,71	1,14	1,72
2			0,15	0,24	0,42	0,73	0,40	0,74	1,21	1,20
3			0,17	0,28	0,46	0,80	0,44	0,82	0,86	1,49
4			0,23	0,36	0,61	1,08	0,60	1,13	0,85	1,42
5			0,24	0,38	0,80	1,46	0,83	1,54	0,62	1,07
6			0,26	0,42	0,81	1,66	0,83	1,66	0,22	0,38
7			0,27	0,47	0,36	0,78	0,36	0,83		

Tabela 5.2 - Idem à Tabela 5.1, porém, para o Hemisfério Norte.

	ps		T		u		v		q ($\times 10^{-4}$)	
	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR
1	22.83	38.02	0,11	0,16	0,28	0,53	0,28	0,60	0,60	0,95
2			0,13	0,21	0,27	0,54	0,28	0,61	0,67	1,15
3			0,14	0,23	0,28	0,57	0,30	0,65	0,57	0,94
4			0,16	0,26	0,38	0,72	0,40	0,82	0,41	0,69
5			0,17	0,27	0,46	0,88	0,50	1,00	0,22	0,39
6			0,17	0,30	0,45	0,90	0,47	1,00	0,09	0,16
7			0,19	0,36	0,27	0,58	0,28	0,66		

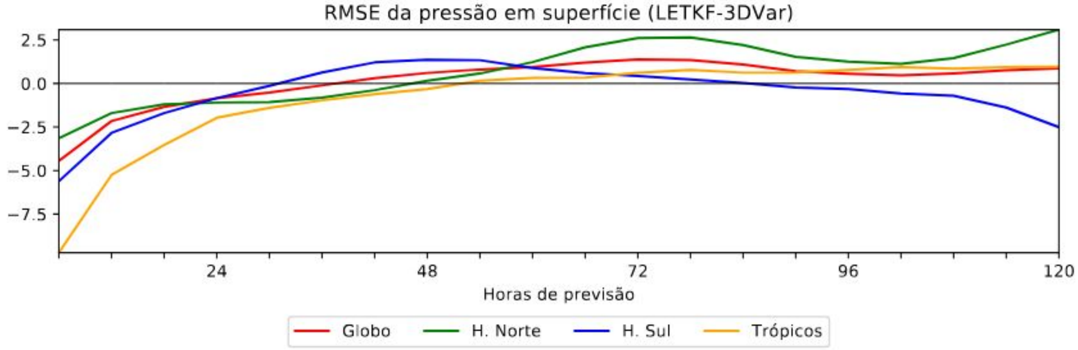
Tabela 5.3 - Idem à Tabela 5.1, porém, para o Hemisfério Sul.

	ps		T		u		v		q ($\times 10^{-4}$)	
	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR	EKF	VAR
1	32,71	53,03	0,14	0,23	0,42	0,75	0,43	0,83	1,00	1,57
2			0,17	0,30	0,38	0,72	0,38	0,82	1,06	1,90
3			0,17	0,30	0,39	0,74	0,40	0,86	0,82	1,43
4			0,23	0,38	0,52	0,94	0,55	1,08	0,69	1,17
5			0,23	0,37	0,67	1,23	0,73	1,42	0,37	0,65
6			0,23	0,37	0,68	1,40	0,73	1,60	0,11	0,18
7			0,23	0,43	0,31	0,84	0,33	0,98		

Resultados

LETKF X 3DVAR - previsões

Figura 5.13 - Diferença nos valores de RMSE da pressão em superfície entre o LETKF e 3DVar para as previsões de até 120 horas pertencentes ao período de dezembro, janeiro e fevereiro.

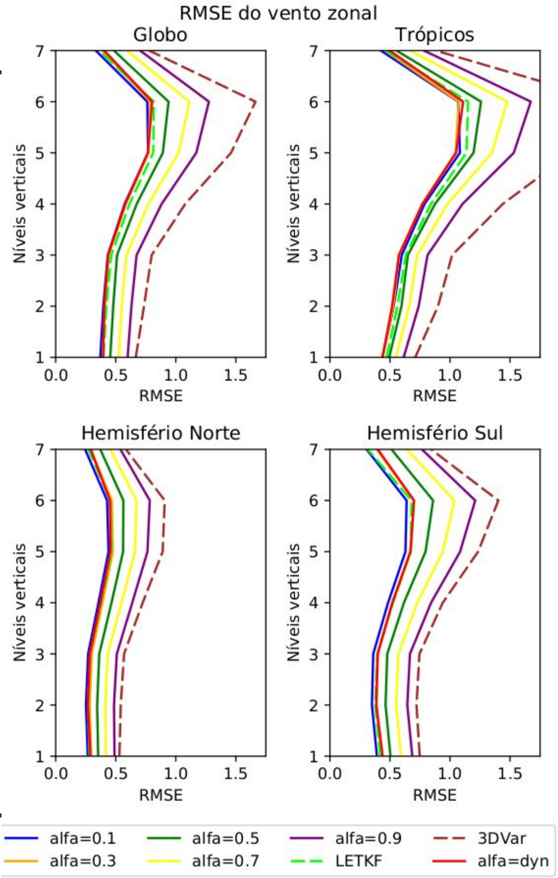


Resultados

Híbrido Médio - análises

Tabela 5.9 - RMSE médio da pressão em superfície para as quatro regiões: Globo, Trópicos, Hemisfério Norte e Hemisfério Sul, para os meses de dezembro, janeiro e fevereiro.

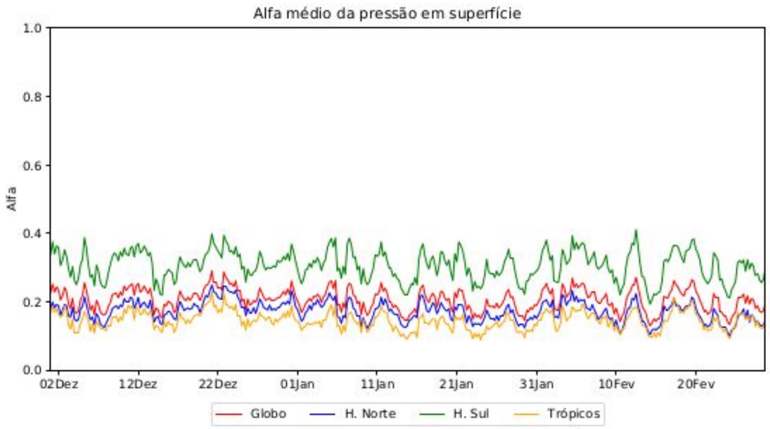
	Globo	Trópicos	H. Norte	H. Sul
$\alpha = 0,1$	27,08	27,81	21,87	31,03
$\alpha = 0,3$	28,89	29,05	23,69	33,41
$\alpha = 0,5$	33,07	32,91	27,44	38,35
$\alpha = 0,7$	37,85	37,31	31,67	44,05
$\alpha = 0,9$	43,13	42,33	36,36	50,15
alfa dinâmico	29,75	29,41	23,84	35,27

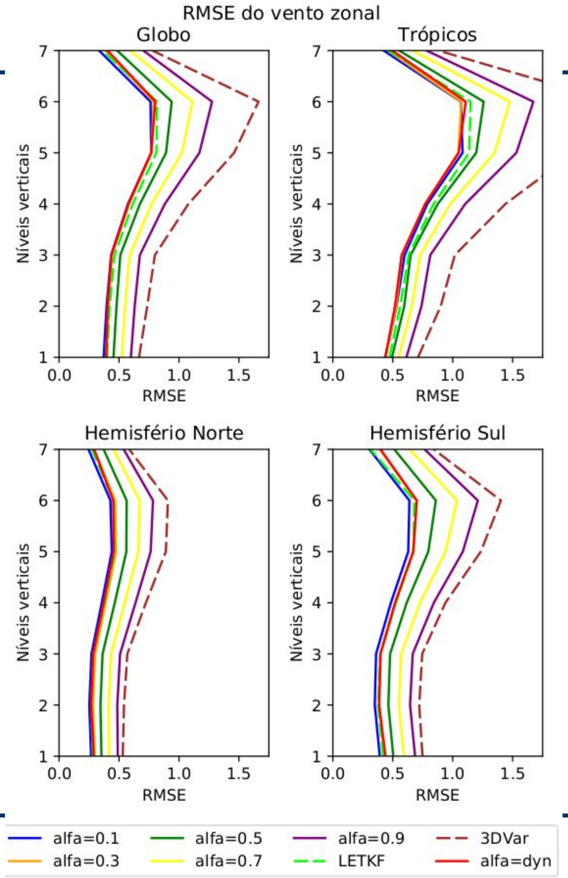


Resultados

Híbrido Médio - análises

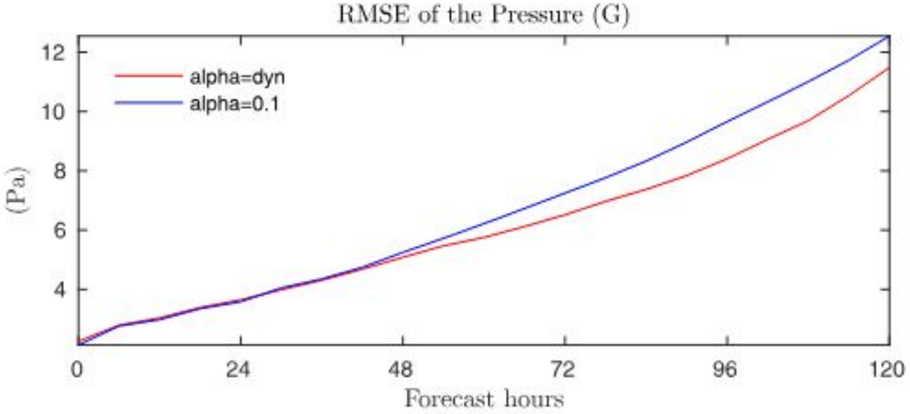
Figura 4.1 - Alfa médio na área da pressão em superfície ao longo do trimestre DJF.

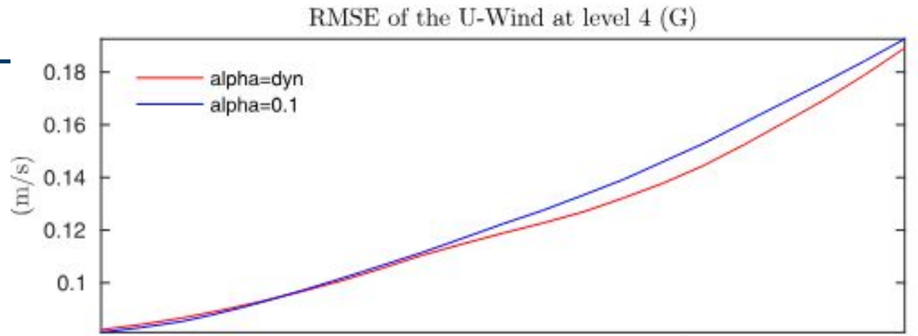


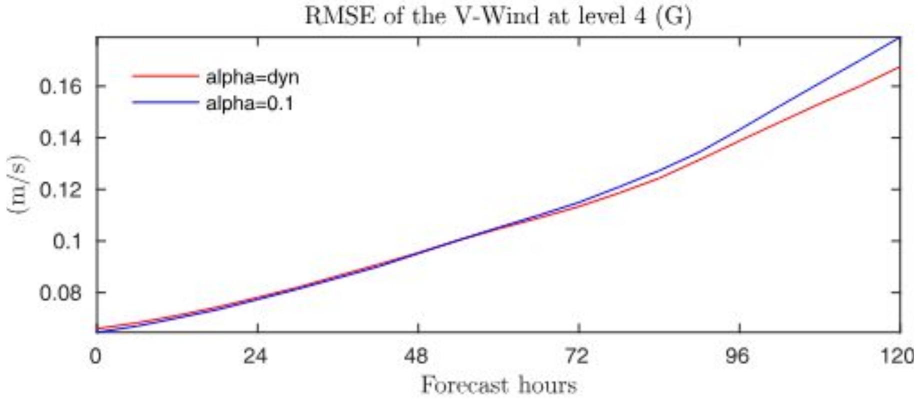


Resultados

Híbrido Médio - previsões

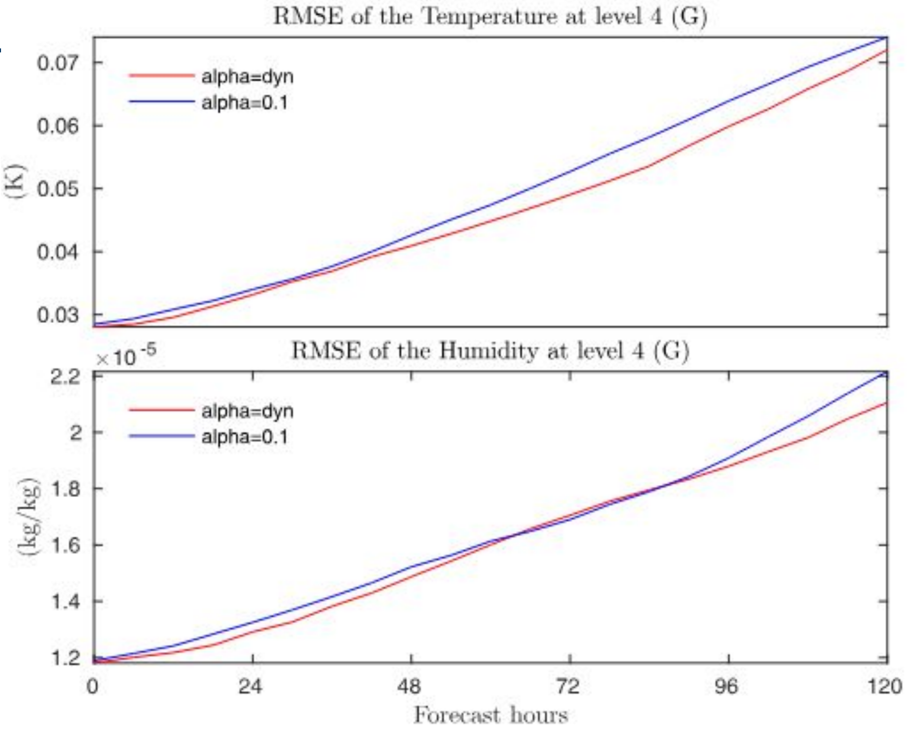






Resultados

Híbrido Médio - previsões



Resultados

Greybush et al. (2011) - balanço

Figura 5.24 - Média do vento ageostrófico em 500hPa para os oito experimentos: alfa dinâmico, $\alpha = 0,1$, $\alpha = 0,3$, $\alpha = 0,5$, $\alpha = 0,7$, $\alpha = 0,9$, LETKF e 3DVar.

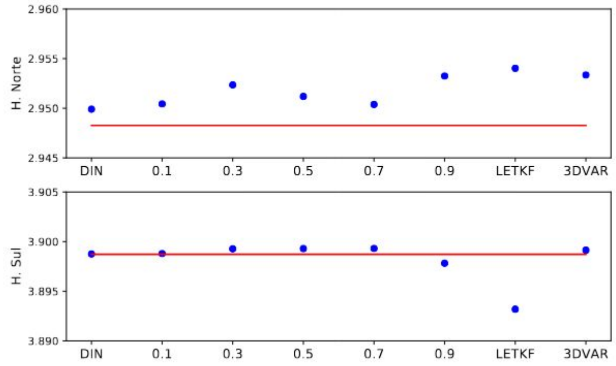
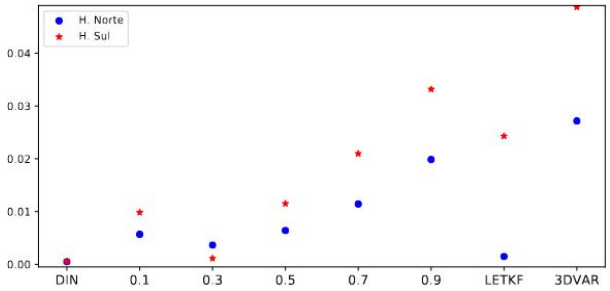
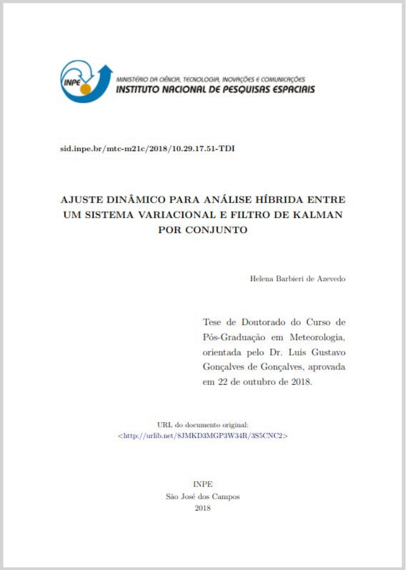


Figura 5.23 - Média do erro absoluto do vento em 500hPa para os oito experimentos: alfa dinâmico, $\alpha = 0,1$, $\alpha = 0,3$, $\alpha = 0,5$, $\alpha = 0,7$, $\alpha = 0,9$, LETKF e 3DVar.



Conclusões

- Híbrido médio
- LETKF + 3DVAR + SPEEDY
- Análises e previsões (até 120h)
- Hemisférios norte e sul, região tropical e globo
- Análises ➡ $\alpha = 0.1$
- Previsões ➡ α = dinâmico
- Balanço ➡ α = dinâmico



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AJUSTE DINÂMICO PARA ANÁLISE HÍBRIDA ENTRE UM SISTEMA VARIACIONAL E FILTRO DE KALMAN POR CONJUNTO

Helena Barbieri de Azevedo

Tese de Doutorado do Curso de Pós-Graduação em Meteorologia, orientada pelo Dr. Luis Gustavo Gonçalves de Gonçalves, aprovada em 22 de outubro de 2018.

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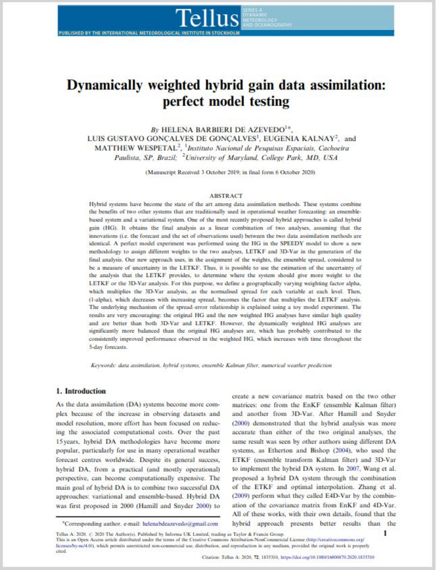

Tellus SERIES A DYANAMIC METEOROLOGY AND OCEANOGRAPHY
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Dynamically weighted hybrid gain data assimilation: perfect model testing

By HELENA BARBIERI DE AZEVEDO[1]*, LUIS GUSTAVO GONÇALVES DE GONÇALVES[1], EUGENIA KALNAY[2], and MATTHEW WESPETAL[2], [1]*Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, SP, Brazil;* [2]*University of Maryland, College Park, MD, USA*

(Manuscript Received 3 October 2019; in final form 6 October 2020)

ABSTRACT

Hybrid systems have become the state of the art among data assimilation methods. These systems combine the benefits of two other systems that are traditionally used in operational weather forecasting: an ensemble-based system and a variational system. One of the most recently proposed hybrid approaches is called hybrid gain (HG). It obtains the final analysis as a linear combination of two analyses, assuming that the innovations (i.e. the forecast and the set of observations used) between the two data assimilation methods are identical. A perfect model experiment was performed using the HG in the SPEEDY model to show a new methodology to assign different weights to the two analyses, LETKF and 3D-Var in the generation of the final analysis. Our new approach uses, in the assignment of the weights, the ensemble spread, considered to be a measure of uncertainty in the LETKF. Thus, it is possible to use the estimation of the uncertainty of the analysis that the LETKF provides, to determine where the system should give more weight to the LETKF or the 3D-Var analysis. For this purpose, we define a geographically varying weighting factor alpha, which multiplies the 3D-Var analysis, as the normalised spread for each variable at each level. Then, (1-alpha), which decreases with increasing spread, becomes the factor that multiplies the LETKF analysis. The underlying mechanism of the spread-error relationship is explained using a toy model experiment. The results are very encouraging: the original HG and the new weighted HG analyses have similar high quality and are better than both 3D-Var and LETKF. However, the dynamically weighted HG analyses are significantly more balanced than the original HG analyses are, which has probably contributed to the consistently improved performance observed in the weighted HG, which increases with time throughout the 5-day forecasts.

Keywords: data assimilation, hybrid systems, ensemble Kalman filter, numerical weather prediction

1. Introduction

As the data assimilation (DA) systems become more complex because of the increase in observing datasets and model resolution, more effort has been focused on reducing the associated computational costs. Over the past 15 years, hybrid DA methodologies have become more popular, particularly for use in many operational weather forecast centres worldwide. Despite its general success, hybrid DA, from a practical (and mostly operational) perspective, can become computationally expensive. The main goal of hybrid DA is to combine two successful DA approaches: variational and ensemble-based. Hybrid DA was first proposed in 2000 (Hamill and Snyder 2000) to create a new covariance matrix based on the two other matrices: one from the EnKF (ensemble Kalman filter) and another from 3D-Var. After Hamill and Snyder (2000) demonstrated that the hybrid analysis was more accurate than either of the two original analyses, the same result was seen by other authors using different DA systems, as Etherton and Bishop (2004), who used the ETKF (ensemble transform Kalman filter) and 3D-Var to implement the hybrid DA system. In 2007, Wang et al. proposed a hybrid DA system through the combination of the ETKF and optimal interpolation. Zhang et al. (2009) perform what they called E4D-Var by the combination of the covariance matrix from EnKF and 4D-Var. All of these works, with their own details, found that the hybrid approach presents better results than the

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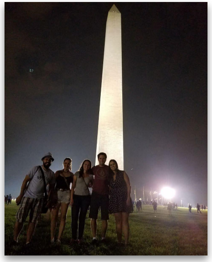
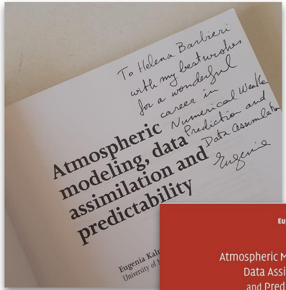
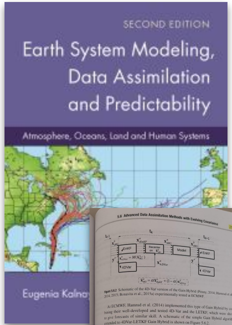
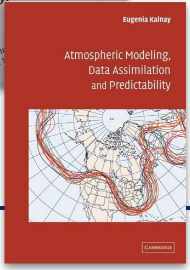
- Profa. Eugenia Kalnay
- maio - outubro (2017)

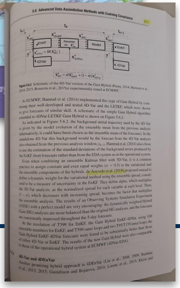











Dúvidas?

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