94th AMS annual meeting, 2-6 Feb 2014
Analysis and Forecasting with Ensemble or Probabilistic Techniques III

Stochastic Representation of Dynamic Model Tendency : Formulation and Preliminary results

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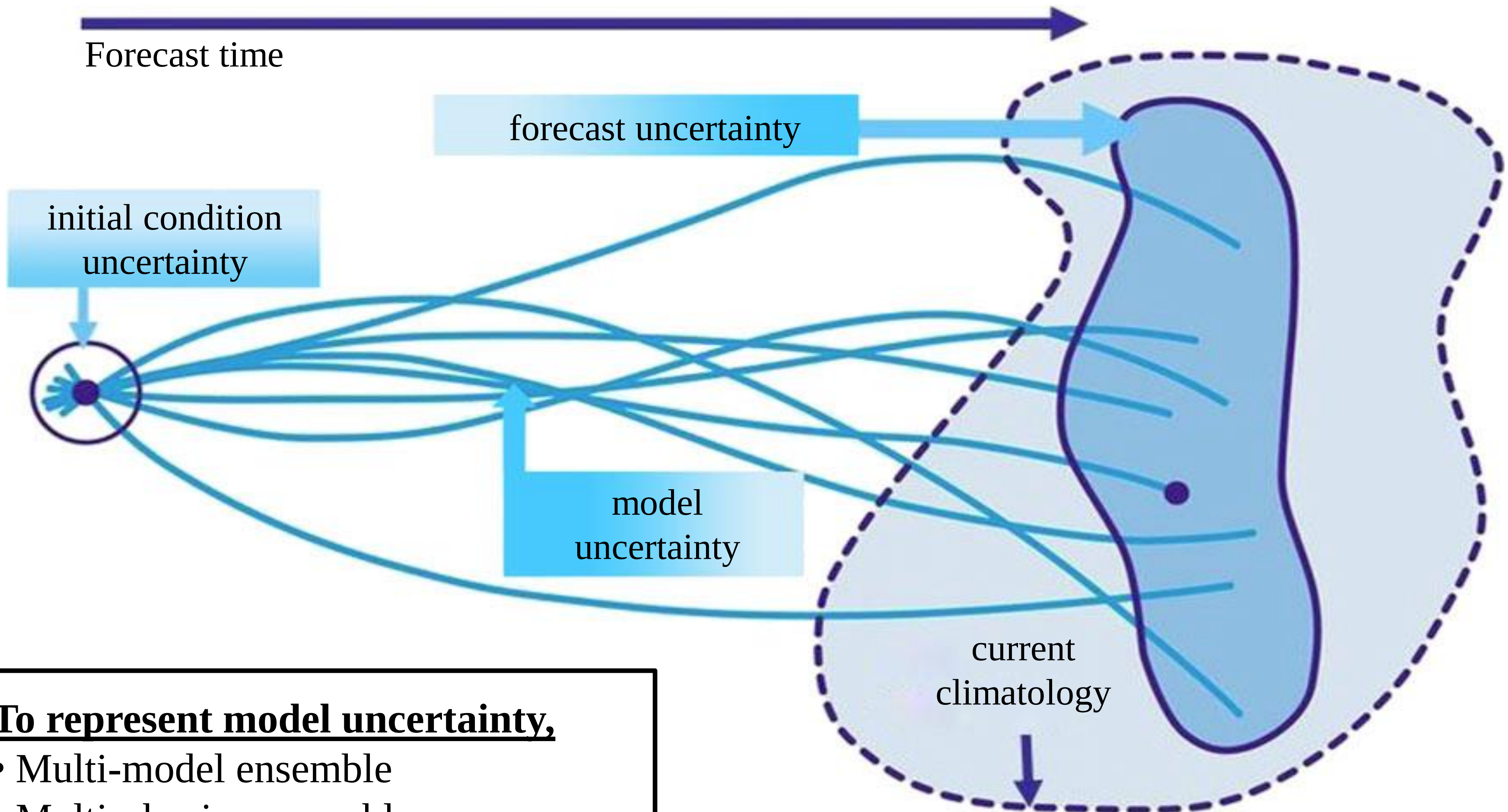
2014. 2. 4.

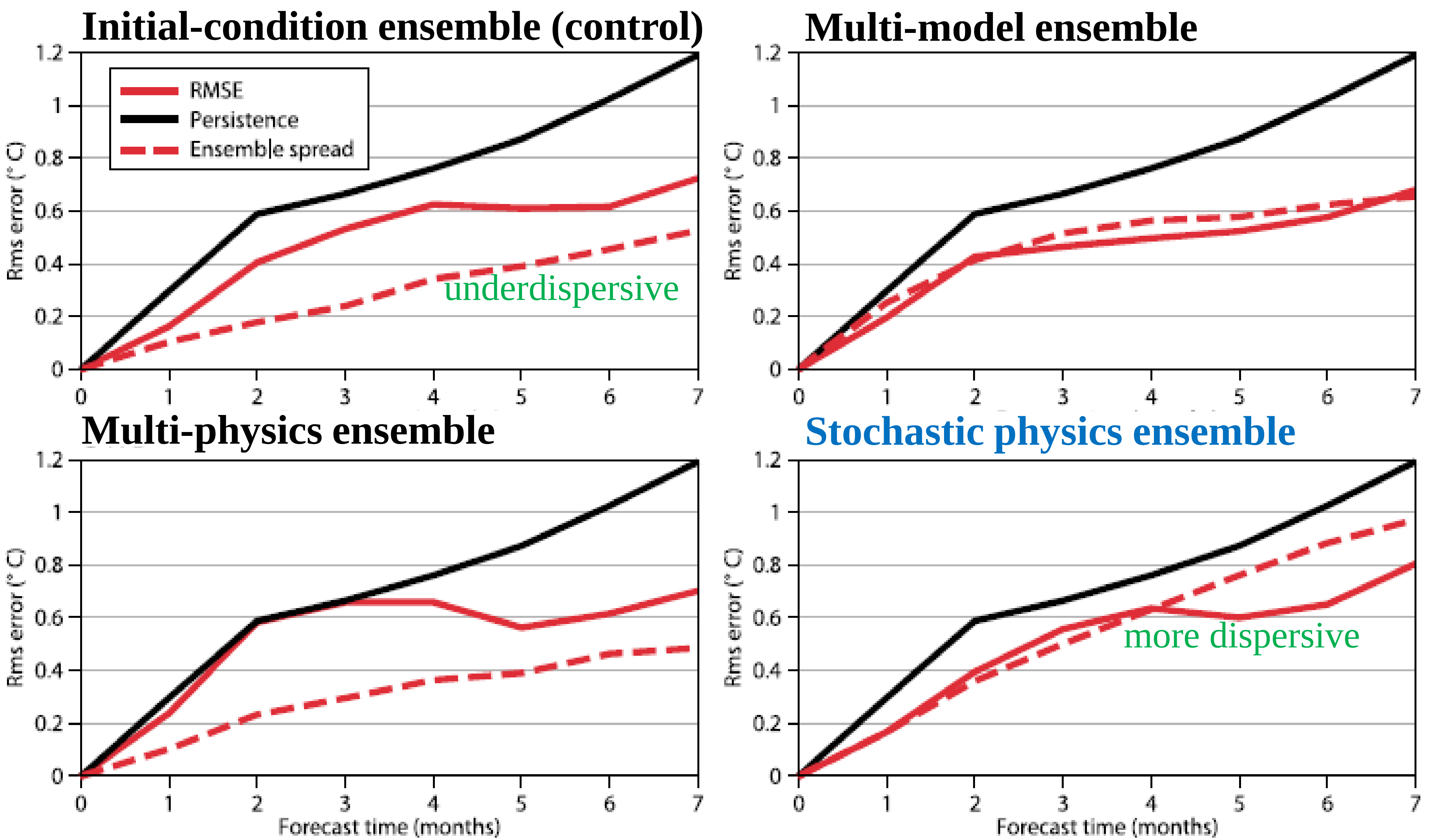
Uncertainty = Initial uncertainty + Model uncertainty



<u>To represent model uncertainty,</u>
- Multi-model ensemble
- Multi-physics ensemble
- Multi-parameter ensemble
- Stochastic approach

From Slingo and Palmer (2011)

Skill comparison for predicting Nino3 SST anomalies



From Weisheimer et al. (2011)

Why stochastic physics?

- Model error might arise from a misrepresentation of physical processes on unresolved subgrid-scales.

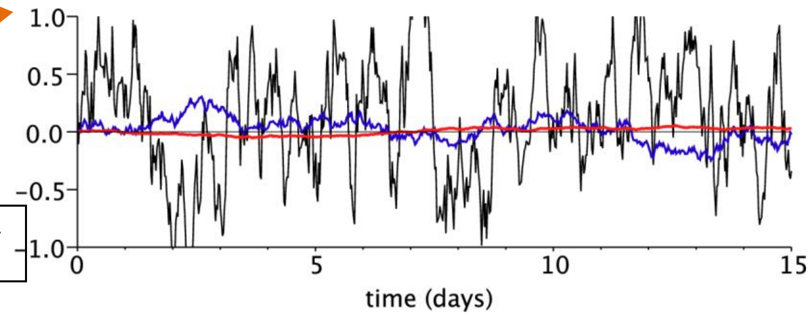
- Lorenz (1975) : *the ultimate climate models will be stochastic, i.e., random numbers will appear somewhere in the time derivatives.*

Stochastically perturbed physical tendency

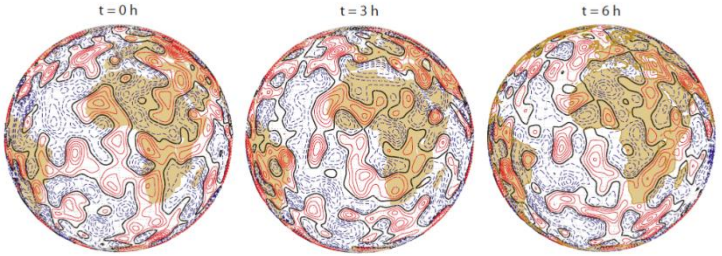
$$X_p = (1 + r_X)X_c$$

Random number

Total parameterized tendency



➔ In medium-range and seasonal prediction,
1) broad ensemble spread
2) reduced outlier



From Buizza et al. (1999) and Palmer et al. (2009)

Why stochastic dynamics?

- Approximation in governing equation

- Computational representation of governing equations, (i.e. spatial and temporal truncation)

- Physics : “*unknowns*”   dynamics: “*Uncertain*”

Stochastically perturbed dynamical tendency

Koo and Hong (manuscript in preparation)

Perturbed model tendencies

Nonlinear tendency

Linear tendency

$$\frac{\P c}{\P t} = \underbrace{[N + L]}_{D} + P$$

Dynamical tendency

Physical tendency

T

Total tendency

Random number

$$D_j' \equiv \langle r_j \rangle_{\chi} \left[\frac{\chi_j^{+} - \chi_j^{n-1}}{2\Delta t} \right]$$

$$P_j' \equiv \langle r_j \rangle_{\chi} \left[\frac{\chi_j^{n+1} - \chi_j^{+}}{2\Delta t} \right]$$

$$T_j' \equiv \langle r_j \rangle_{\chi} \left[\frac{\chi_j^{n+1} - \chi_j^{n-1}}{2\Delta t} \right]$$

*** Forcing strength is controlled by random interval (I=0.1, 0.2, 0.5, 1.0, and 2.0)**

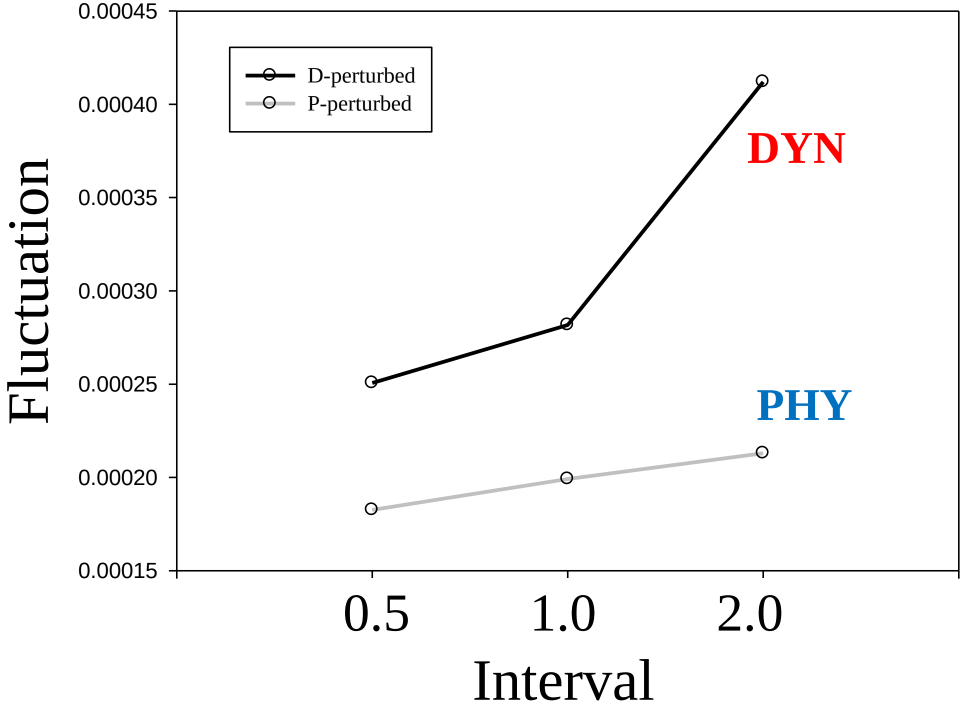
$$ex)\ \ I = 1.0:\ r_j \in [0.50, 1.50]$$

- No auto-correlations in space and variable

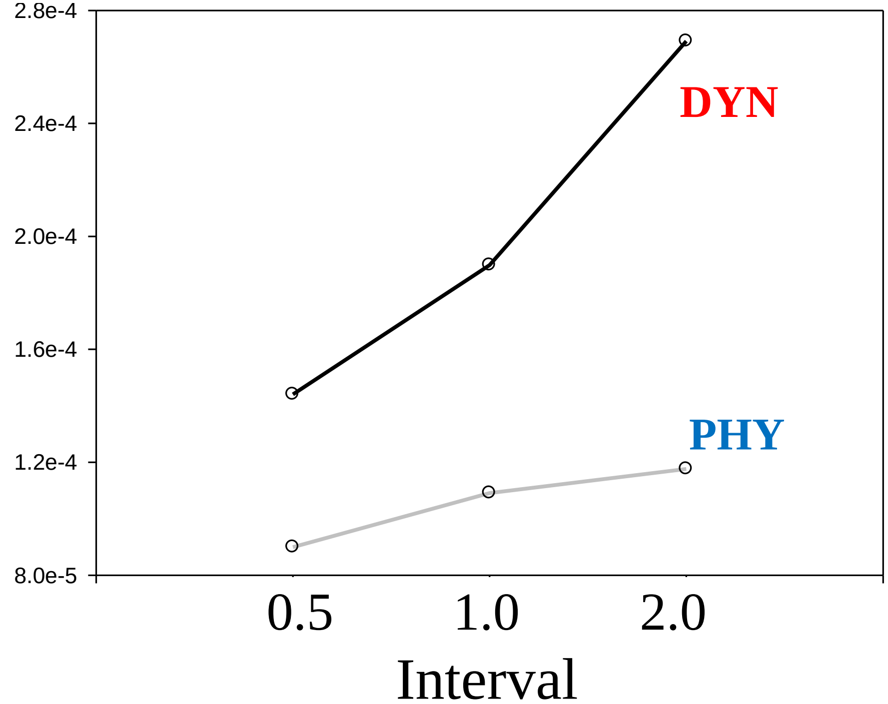
➔ differ from those of Buizza et al. (1999).

Sensitivity of tendencies to the perturbation size (T126)

U-wind tendency (dU/dt)



Temperature tendency (dT/dt)

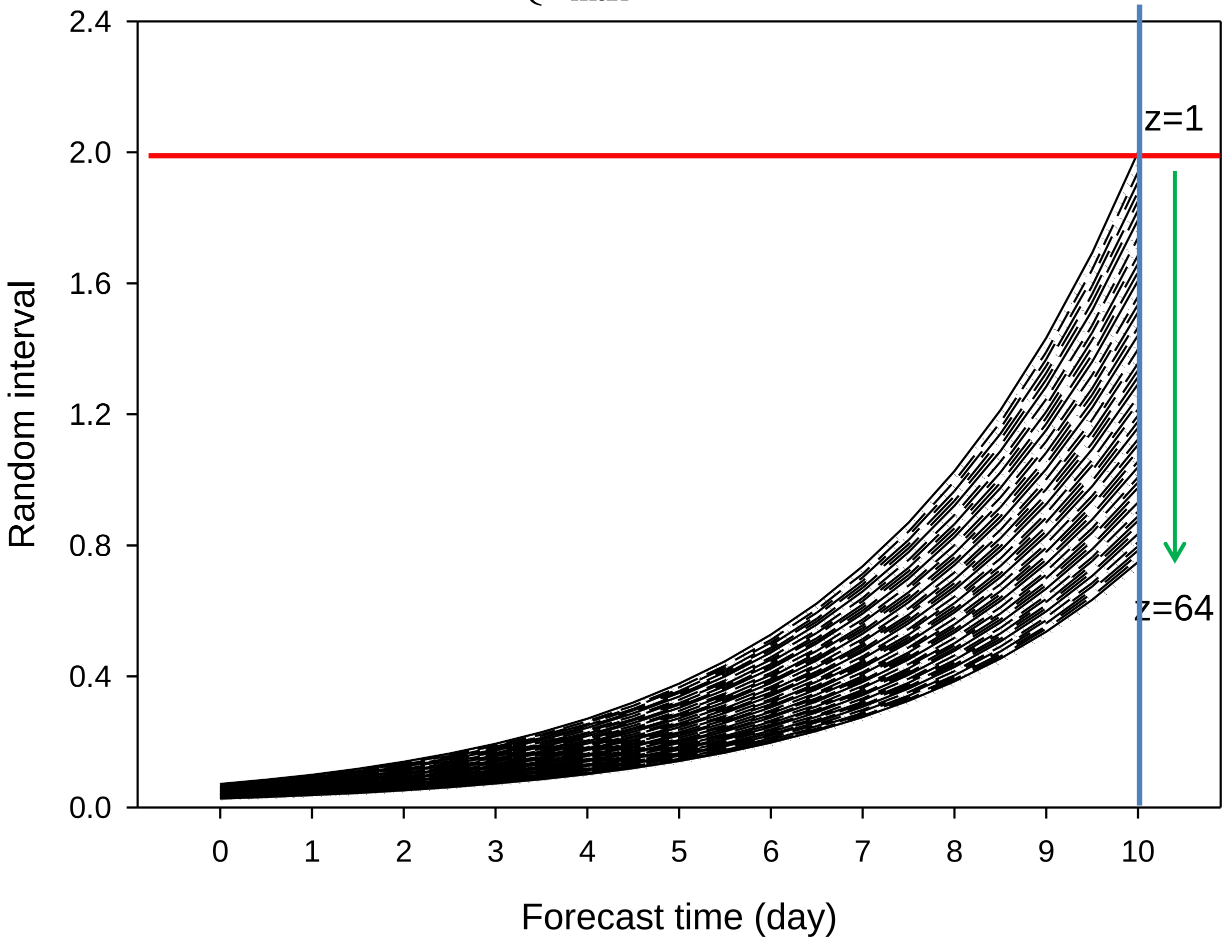


DYN: Perturbing dynamical tendency
PHY: Perturbing physical tendency

- Stochastic dynamics shows larger fluctuation
  ➔ favorable for the increase of ensemble spread

Parameterization of stochastic forcing

$$I(\eta,t)=\begin{cases} I_{\max}e^{\eta-1}e^{\frac{t-t_r}{3}}, & if\ t\le t_r \\ I_{\max}e^{\eta-1}, & if\ otherwise \end{cases}$$



Maximum interval

I_{max}=2.0

Vertical dependency

smaller with height

Reference time

t_r=10 day

Experimental design with GRIMs model

almost same

Experiment	Perturbed tendency	I_{max}	t_r	Temporal corrleation
CTL	-	-	-	-
DYN	Dynamical tendency	2.0	10 day	3 hour
PHY	Physical tendency	2.0	10 day	3 hour
TOT	Total tendency	2.0	10 day	3 hour
DPT	DYN+PHY	2.0	10 day	3 hour

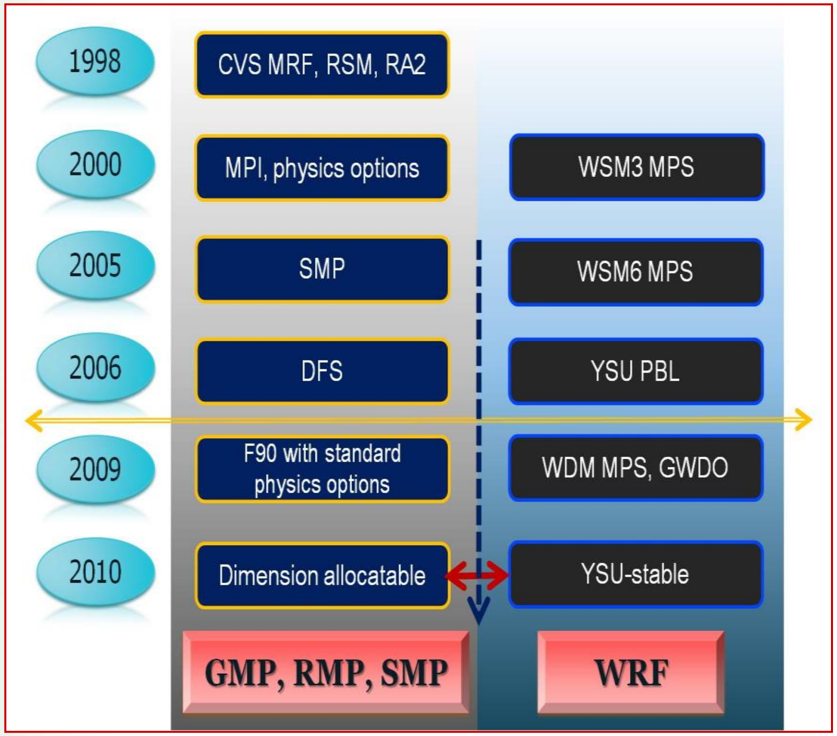
	Medium-range	Seasonal
Start time	2010. 8. 1~31. 00UTC (for boreal summer) 2010. 1. 1~31. 00UTC (for boreal winter)	1996. 5. 1~10. 00UTC (for boreal summer)
Forecast	15-day (at each day)	4-month (single month spin-up)

GRIMs http://grims-model.org

GLOBAL/REGIONAL INTEGRATED MODEL SYSTEM

History

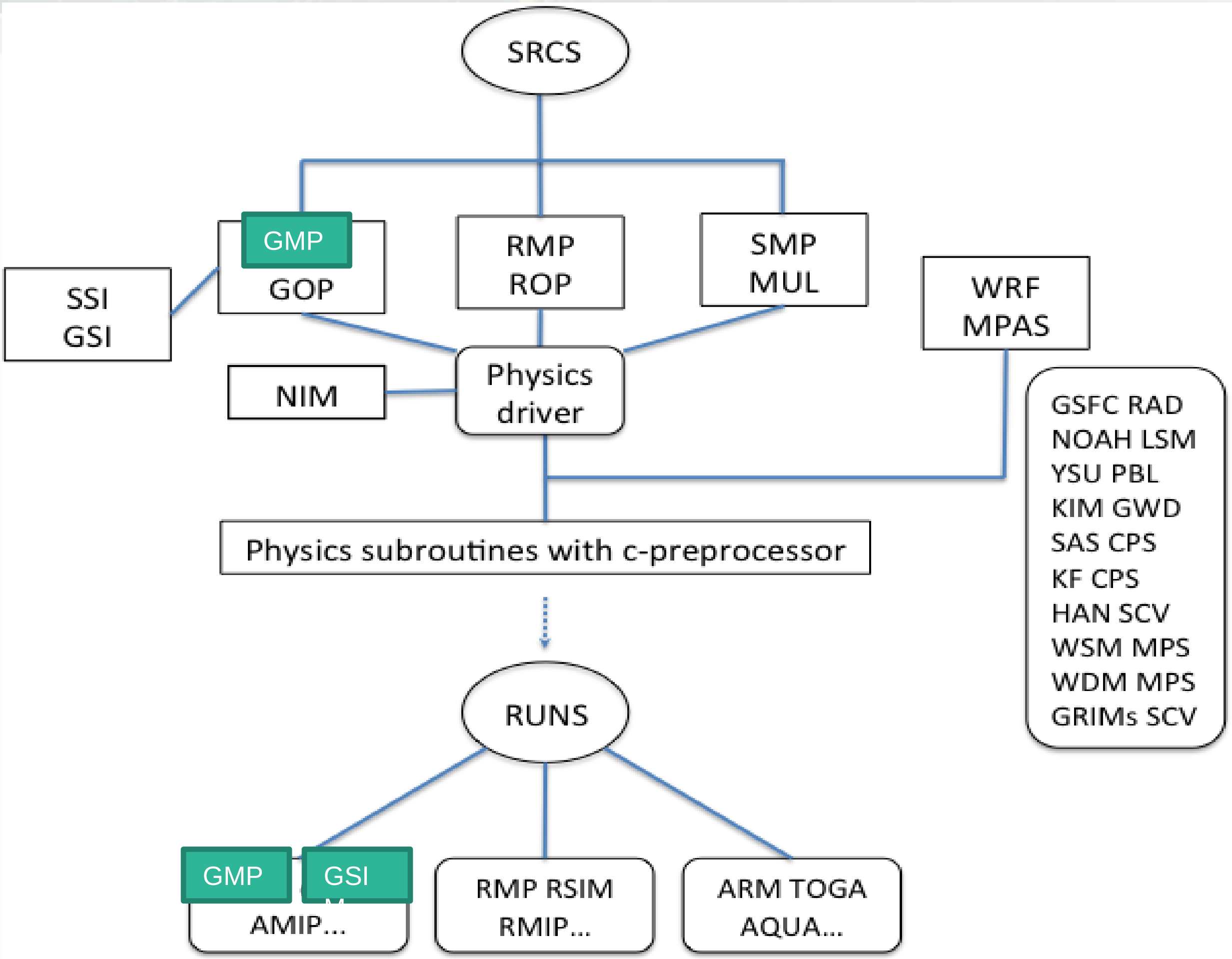
(Hong et al. 2013, APJAS)



▪ The GRIMs is an ocean/atmospheric model system designed for numerical weather prediction, seasonal simulations, and climate researches, from global to regional scales.

▪ Since 2000, the Numerical Modeling Laboratory in Yonsei University has developed the advanced dynamic core and physical processes.

Structure of the GRIMs



Configure-src

```
#
LIBS_DIR=/home/shong/libs
#
#    MODEL  .... sph, dfs, nim, mul, rmp, smp, ssi, gsi, gop, rop
#
#      SPH : spherical harmonics gmp
#      DFS : double fourier series spectral gmp
#      NIM : non-hydrostatic icosahedral model (noaa/esrl)
#      MUL : aqua-planet testbed - neale and hoskins (2001, asl)
#      RMP : regional model program
#      GOP : global ocean model program
#      ROP : regional ocean model program
#      SMP : single column model program
#      SSI : spectral statistical interpolation data assimilation
#      GSI : grid point statistical interpolation data assimilation
#      chm : global model program with aerosol chemistry module
#
MODEL=rop
#
# define model version
#     =  /v1.0/v2.0/v3.0/v4.0/gfs  (see doc/readme files for sub-versions)
#
VERSION=v3.2
```

GRIMs – Dynamical Core (Park et al. 2013)

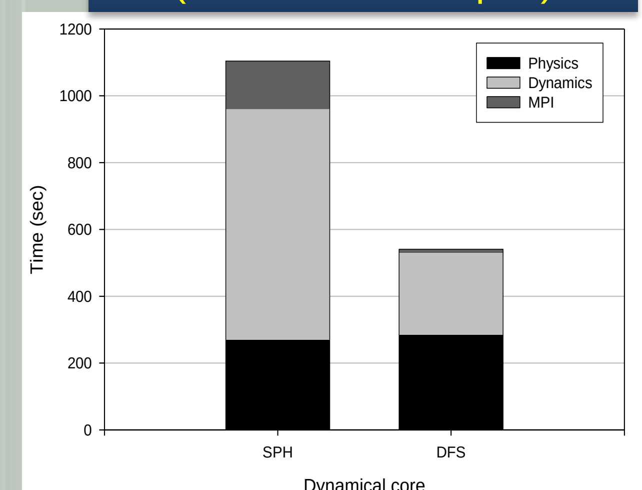
Spherical Harmonic (SPH)

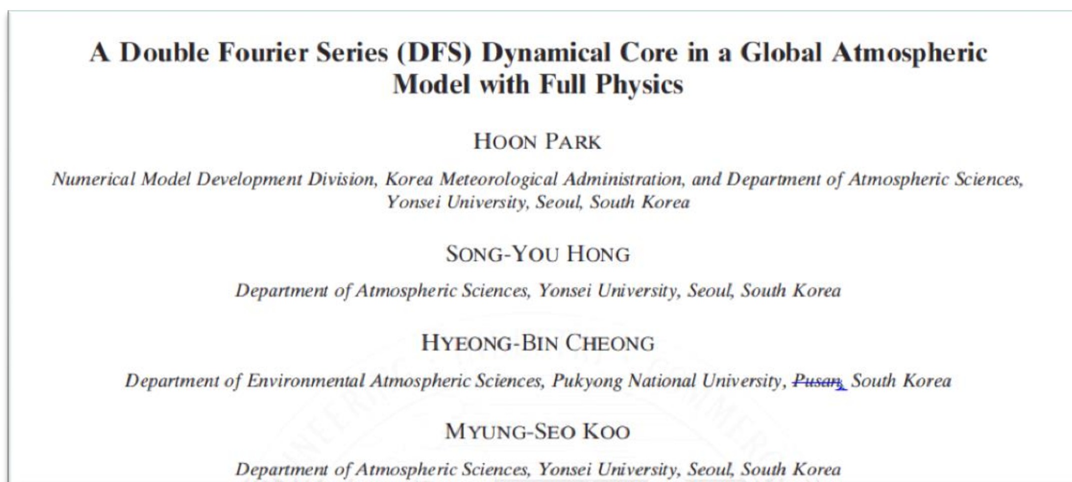
- Widely used in operational center
- Computational efficiency is of concern at high resolution
- References :
  - Juang (2005)
  - Kanamitsu et al. (2002)

Double Fourier Series (DFS)

- Unique core developed by Cheong (Cheong, 2006)
- Implemented by Park and Hong (Park et al. 2008, 2010)
- Alleviates the MPI problem, but still preserves the advantages of spectral core numerics

32 CPU
(4 nodes with 8 cpus)





A Double Fourier Series (DFS) Dynamical Core in a Global Atmospheric Model with Full Physics

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GRIMs – Physics package

Dynamics	Spherical Harmonics : Juang (2005), Kanamitsu et al. (2002) Double Fourier Spectral : Cheong (2006), Park et al. (2008, 2010) + Hybrid coordinate		
Physics version	GRIMS-phys1 (R2)	GRIMS-phys2	GRIMS-phys3 (3.2)
SW Radiation	SW : 1-Albedo (GSFC+GFDL) : Chou (1992), Chou and Lee (1996), Lasics and Hansen (1978)		SW: 4-albed, 12 bands, Chou and Lee (2005) Chou and Suarez (1999)
LW Radiation	GFDL: Fels and Schwarztkopf (1975)		GSFC: Chou et al. (1999)
LSM	OSU1 Pan and Mahrt (1987)	OSU1 + USGS SFC Kang and Hong(2008)	NOAH Yhang and Hong (2008), Chen and Dudhia (2001)
OSM	Charnock (1955)		Kim and Hong (2010)
Vertical diffusion	Hong and Pan (1996), Troen and Mahrt (1986)		Hong et al. (2006), Noh et al. (2003)
Stable BL	Louis (1979)		Hong (2010)
GWDO	Alpert et al. (1989)		Hong et al. (2008), Kim and Arakawa (1995)
GWDC	X		Jeon et al. (2010), Chun and Baik (1998)
Deep Convection	SAS Hong and Pan (1998) Pan and Wu (1995)	RAS Moorthi and Suarez (1992)	SAS Han and Pan (2011), Park and Hong (2007)
Shallow convection	Tiedke (1984)		Hong et al. (2013)
Micro Physics	WSM1 (Hong et al. 1998)		
Cloudiness	Campana et al. (1994)		Ham et al. (2009), Hong et al. (1998)
Chemistry	Diagnostic		Prognostic ozone

Collaboration with GRIMs

- **WRF and MPAS (NCAR)**

  WSM3, 5, 6, WDM5, 6, YSU PBL, GWDO

- **ECPC G-RSM (ECPC) ➔ FSU**

  SMP, WSM MPS, YSU PBL, ROM

- **NIM development (NOAA)**

  Physics modules and testbed

- **KAF-GRIMs**

  Operational since March 2012

- **KISTI-GRIMs**

  Web-based atmospheric model browser

- **Hanyang Univ., Polar Institute, SNU**

  Climate and Asian monsoon studies

Collaboration with GRIMs

Seoul National University

Chemistry modules and stratospheric dynamics

- **Korea Polar Research Institute (KORPI)**

  Polar research

- **UC San Diego**

  FLEXPART-GRIMs

- **Shanghai Meteorological Service**

  Model development

- **APCC, WMO**

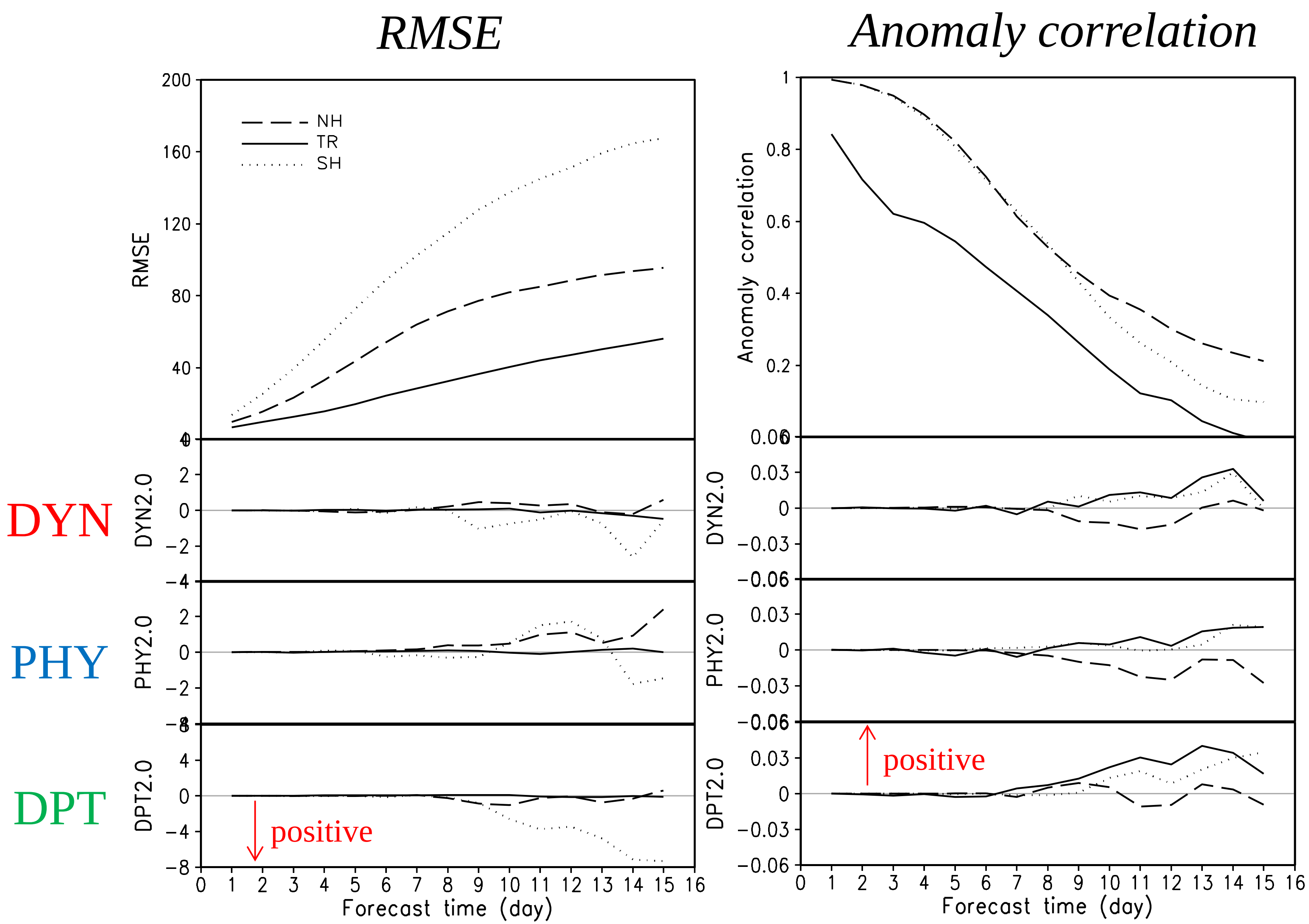
  RCM training tool

- **Pacific Northwest National Lab**

  Aerosol model (to be …)

Collaboration with GRIMs

Forecast skill in 500 hPa geopotential height (August 2010)



Eddy decomposition

overbar: time mean
bracket : zonal mean

Daily mean variable

$$v = [\overline{v}] + \overline{v}^* + v'$$

3-month zonal mean
: mean meridional circulation
(such as three-cell circulation)

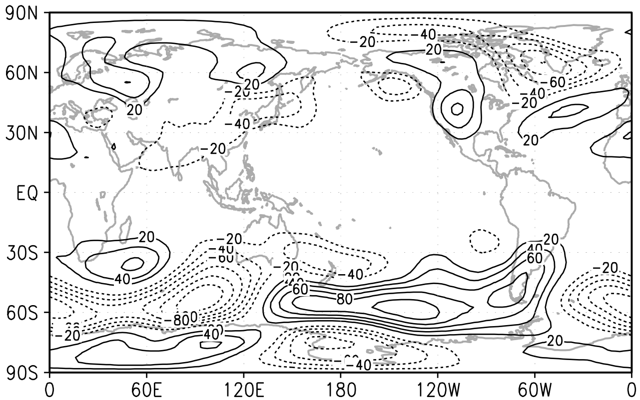
Daily transient eddy
: transient eddy
(such as weather systems = midlatitude cyclones and anticyclones)

3-month standing eddy
: stationary planetary waves
(such as the wavenumber 1-3 eddies)

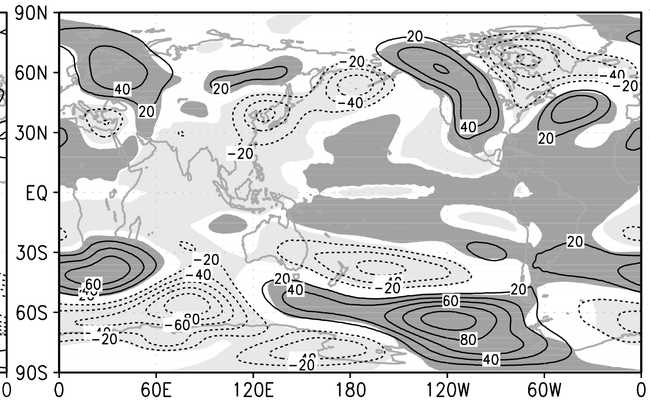
* For poleward heat flux, $\left[\overline{vT}\right] = [\overline{v}]\left[\overline{T}\right] + \left[\overline{v}^*\overline{T}^*\right] + \left[\overline{v'T'}\right]$

Standing eddy of 500 hPa geopotential height (JJA 1996)

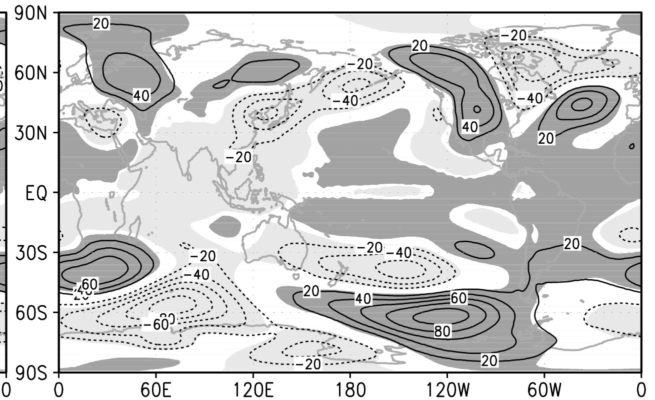
GFS



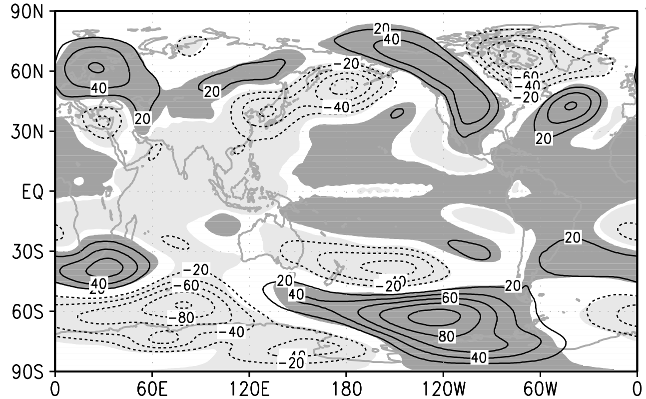
CTL (0.667)



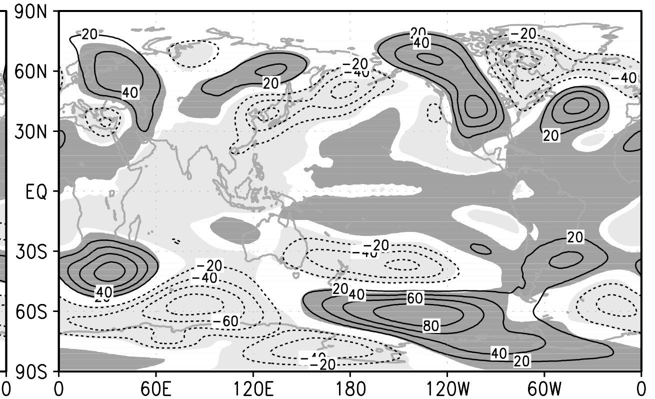
DYN (0.684)



PHY (0.661)



DPT (0.710)

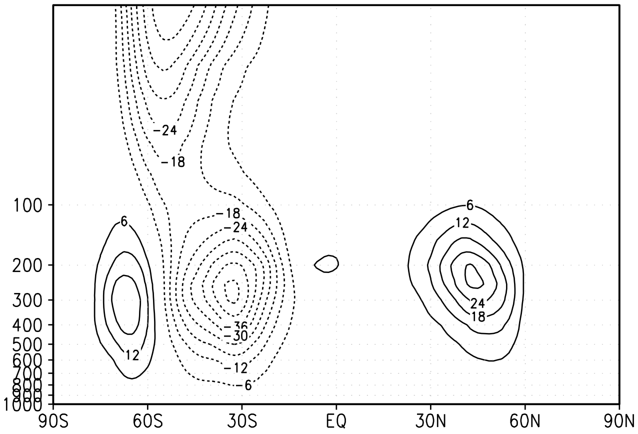


- contour: standing eddy
- shading: 95% confidence level
- parenthesis: spatial correlation against GFS

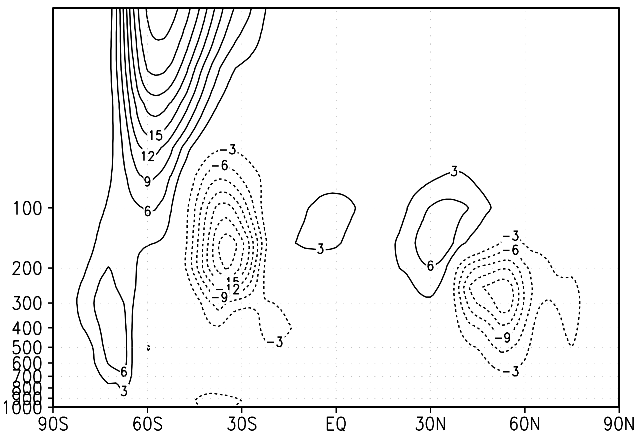
DPT > DYN > CTL > PHY

Transient eddy momentum flux (u’v’) (JJA 1996)

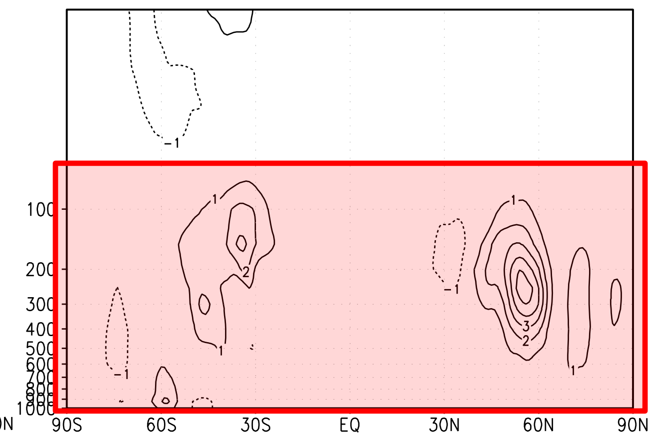
GFS



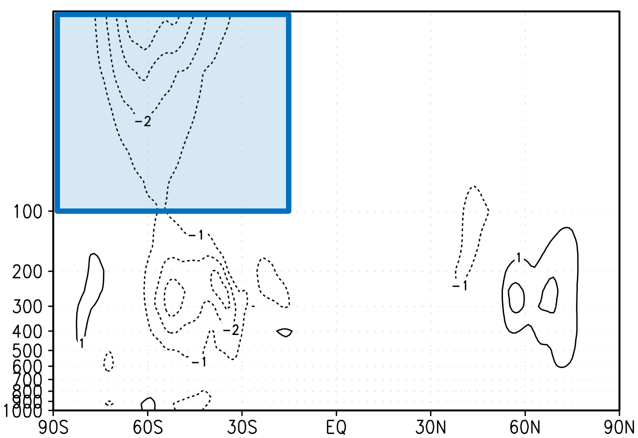
CTL-GFS



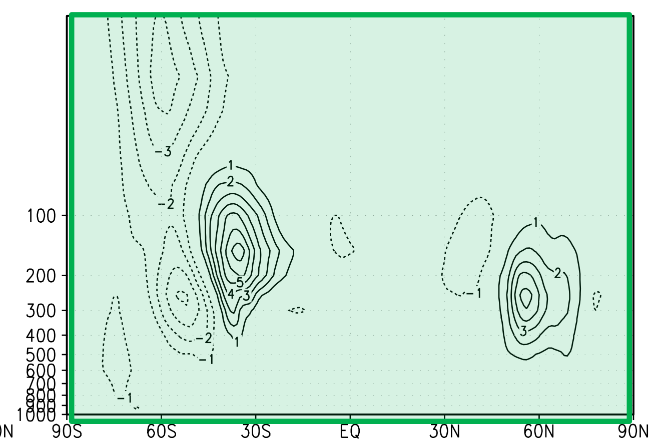
DYN-CTL



PHY-CTL

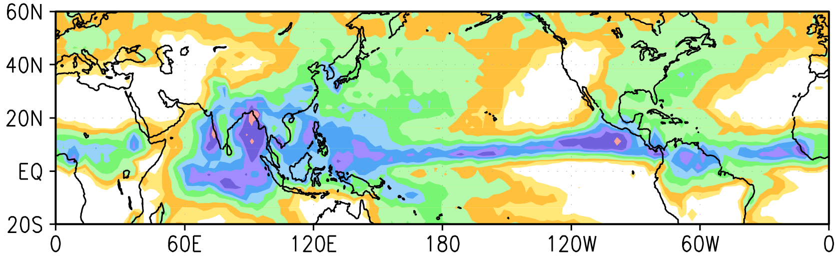


DPT-CTL

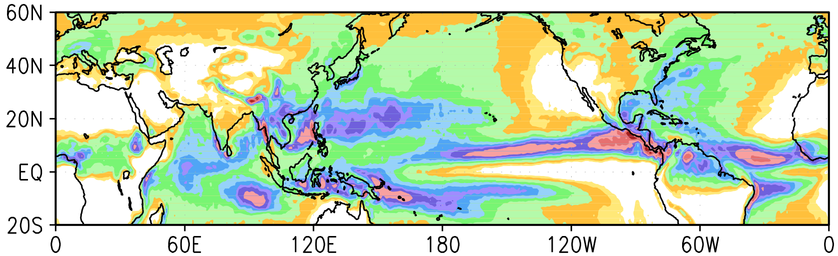


Skill scores of seasonal precipitation amount (JJA 1996)

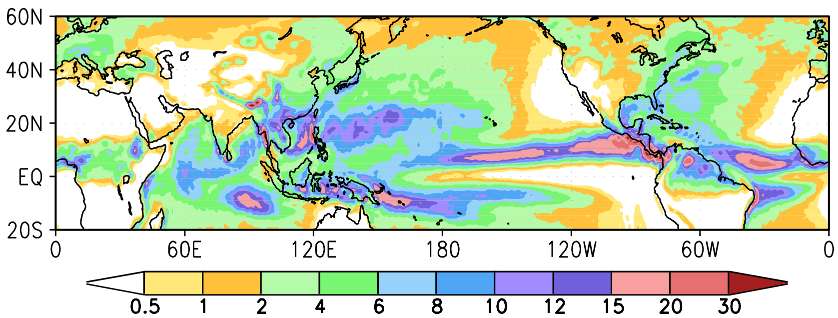
CMAP



CTL



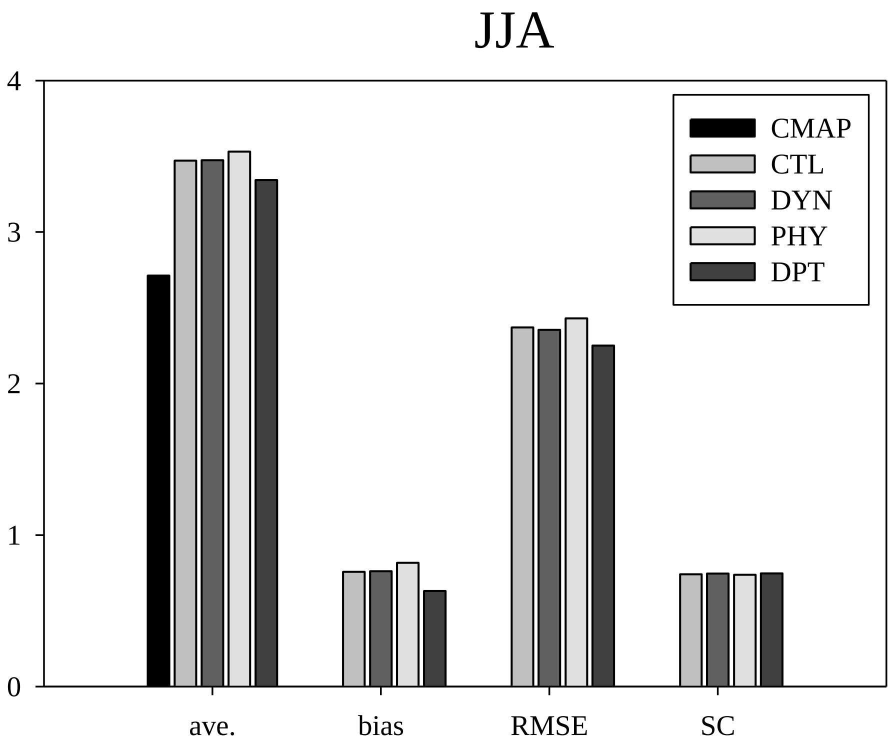
DPT

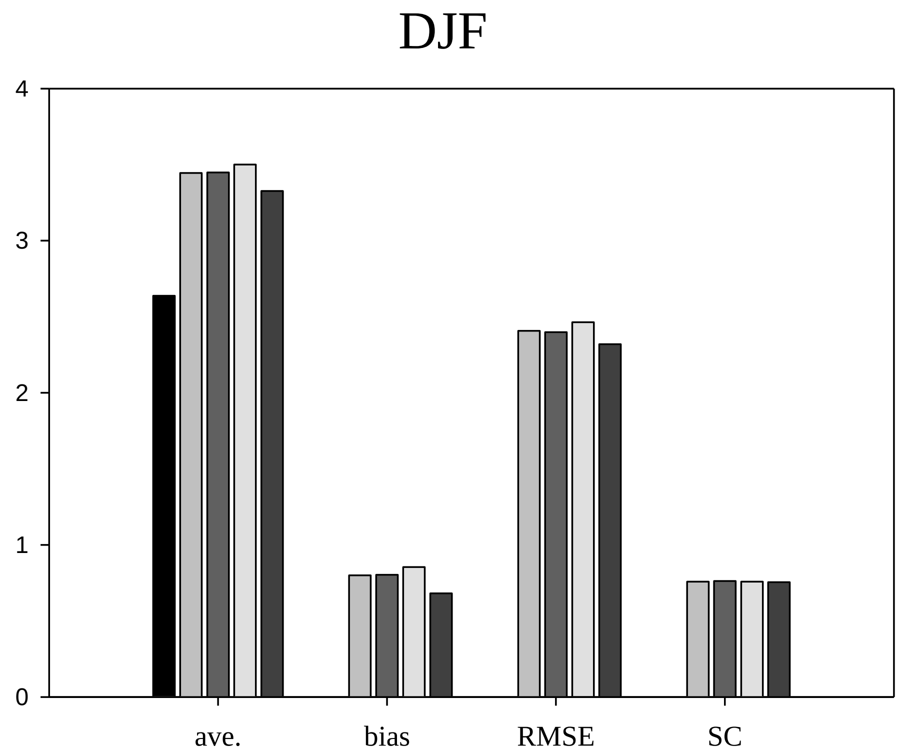


Exp.	mean	Bias	RMSE	Spatial Corr.
CMAP	2.71	-	-	-
CTL	3.43	0.722	2.519	0.716
DYN	3.44	0.728	**2.508**	**0.720**
PHY	3.48	0.767	2.592	0.707
DPT	**3.34**	**0.630**	**2.411**	**0.724**

*Boldface: better score than CTL

Skill scores of 10-yr averaged precipitation (1996 to 2005)

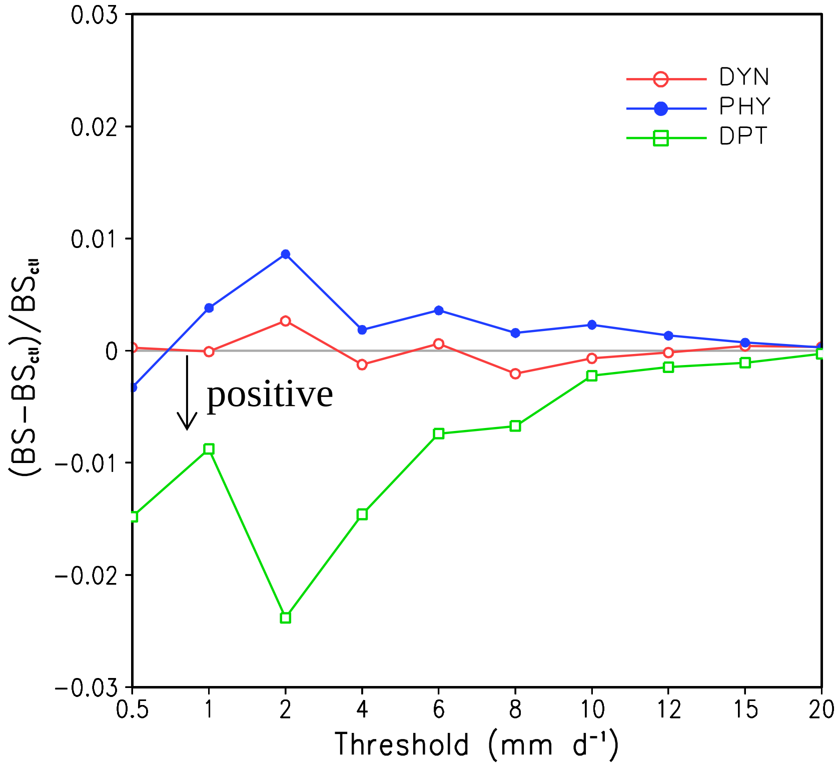




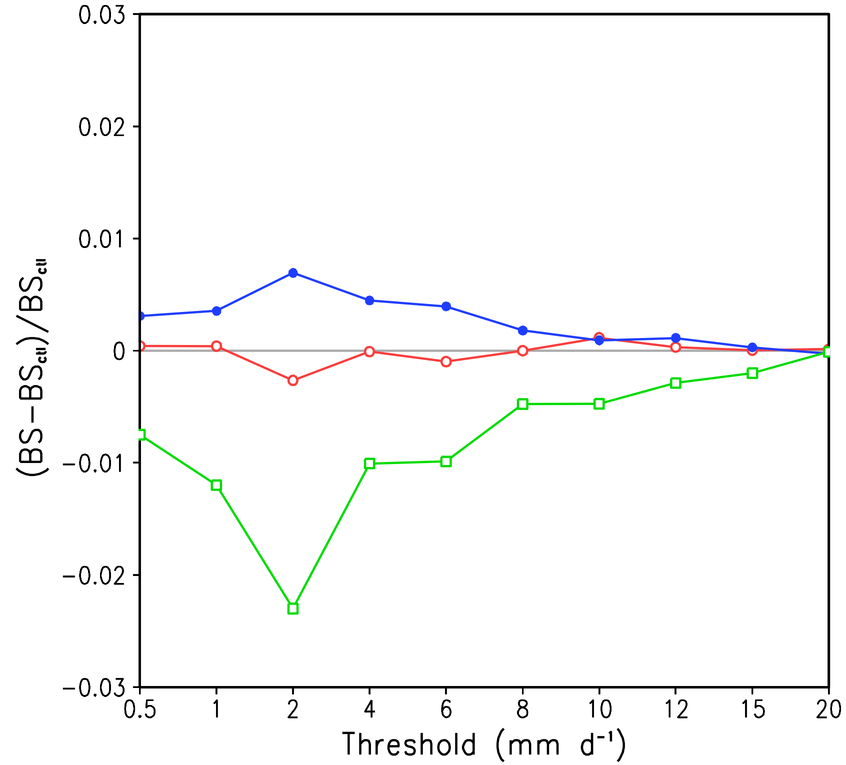
In terms of climatology, DPT > DYN ≈ CTL > PHY

Comparison of Brier score (1996 to 2005)

JJA



DJF

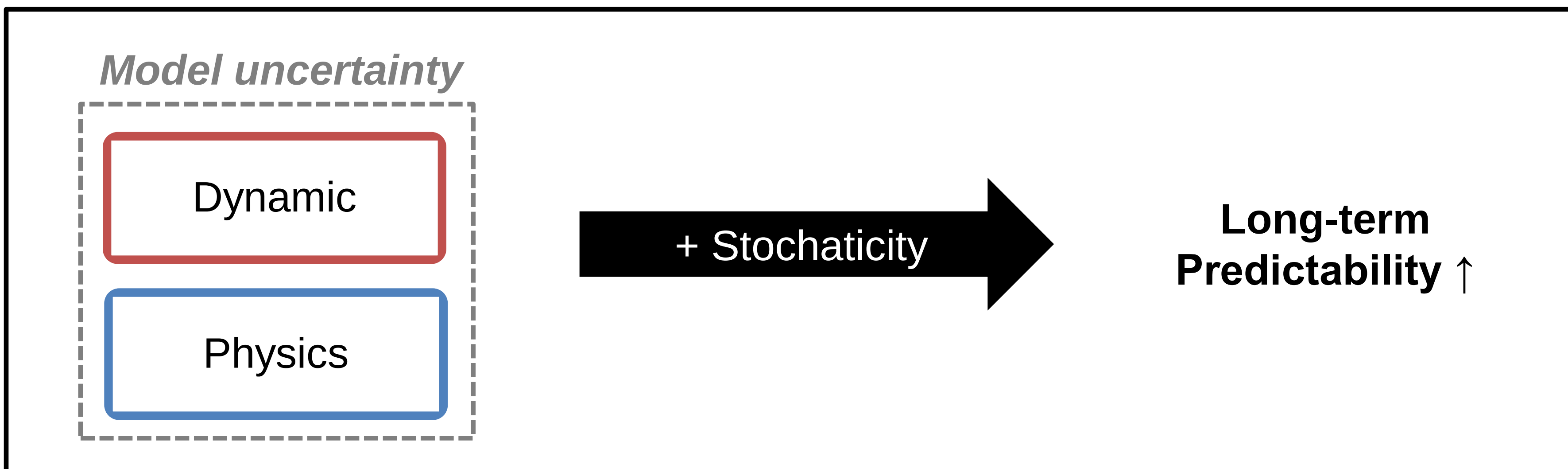


$$BS = \frac{1}{N}\sum_{t=1}^{N}\left(f_t - o_t\right)^2$$

In terms of climatology, DPT > DYN ≈ CTL > PHY

Suggestion :

- **Forecast skill was more sensitive to stochastic perturbation of dynamical tendency than that of physical tendency.**
- **The best results could be obtained by perturbing to both dynamical and physical tendencies**



Thank you for your attention

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