Stochastic Physics in FV3GFS

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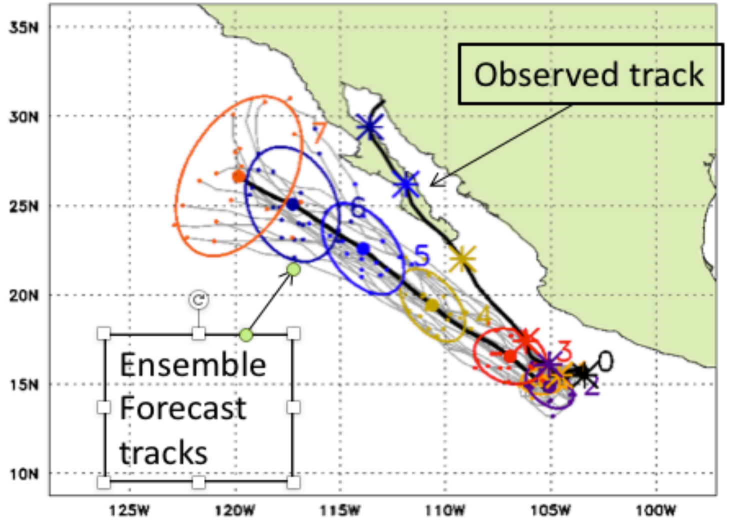
Why is there a need for stochastic physics?

- Even if the model is initialized with perfect initial conditions, there will be errors in the forecast due to model error.
- There are many sources of errors in the model:
  - Discretion in space and time of a continuous fluid
  - Errors in the physical parametrizations
  - Missing physics
- These errors manifest themselves as an overconfident forecast in an ensemble prediction system.
- Stochastic physics adds random perturbations to represent the uncertainty associated with unresolved processes.

Hurricane Odile: Initialized Sept. 11, 2014 at 00Z
GEFS operational ensemble



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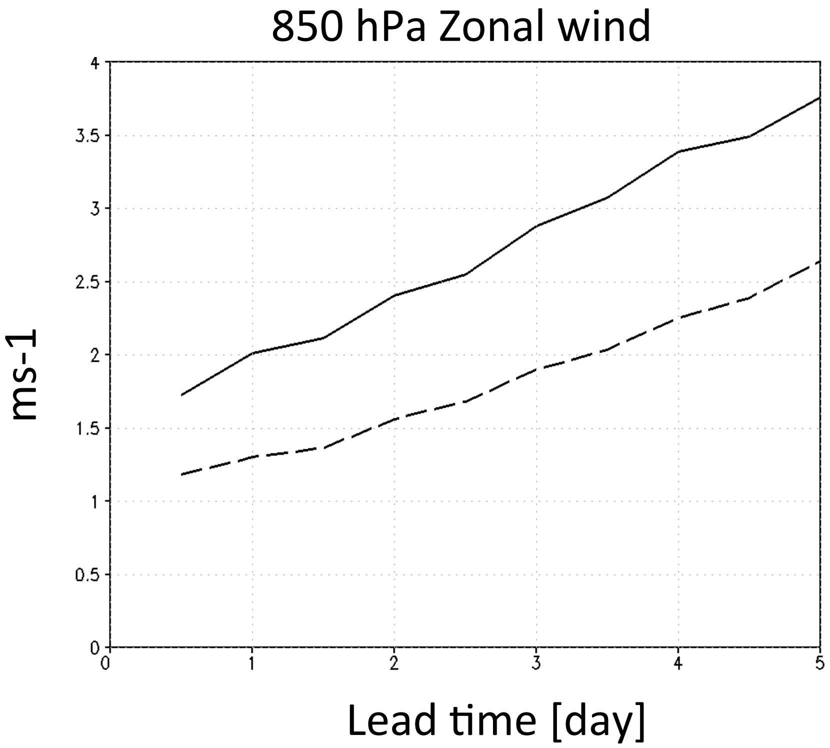
GFS ensemble was confident that the hurricane would stay off shore.

Benefit of stochastic physics

- Increase in ensemble spread, which makes the forecasts more reliable.
- A bonus result is a decrease in the Ensemble mean RMS error!



Ensemble mean error **without** stochastic physics

Ensemble spread **without** stochastic physics

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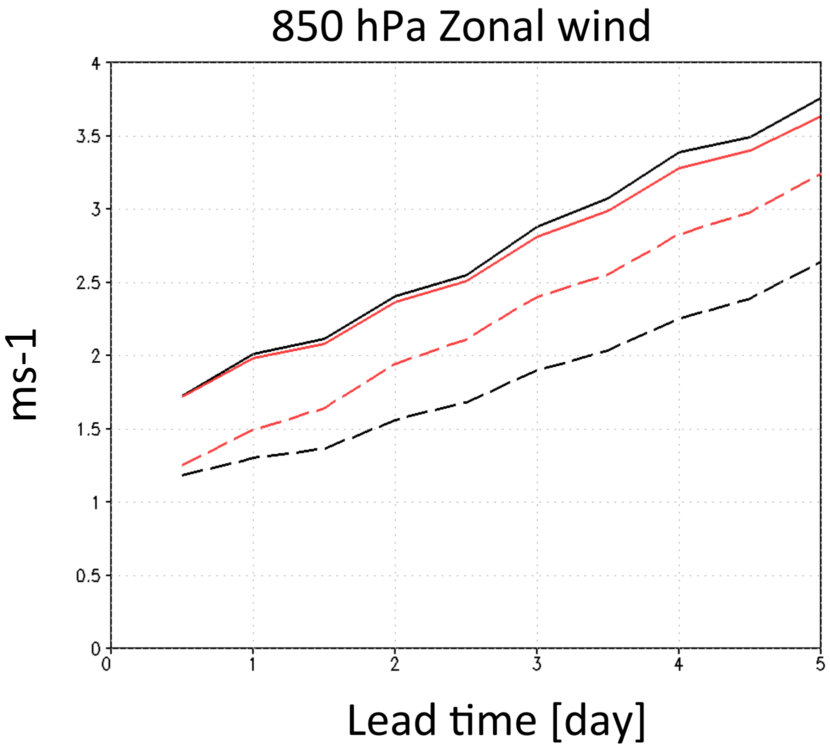


Ensemble mean error **with** stochastic physics

Ensemble spread **with** stochastic physics

What is implemented?

- **SKEB:** Stochastic Kinetic Energy Backscatter (Berner *et al.*, 2009)
  - Add wind perturbations to model state. Perturbations are random in space/time, but amplitude is determined by a smoothed dissipation estimate provided by the dynamical core.
  - **Addresses errors in the dynamics - more active in the mid-latitudes**

- **SPPT:** Stochastically Perturbed Physics Tendencies (Palmer *et al.*, 2009)
  - Multiply the physics tendencies by a random number O [0,2] before updated the model state**.**
  - **Addresses error in the physics parameterizations – most active in boundary layer and convective regions**

- **SHUM:** Specific HUMidity perturbations (inspired by Tompkins and Berner, 2008)
  - Multiply the low-level specific humidity by a small random number each time-step.
  - **Attempts to address missing physics - most active in convective regions**

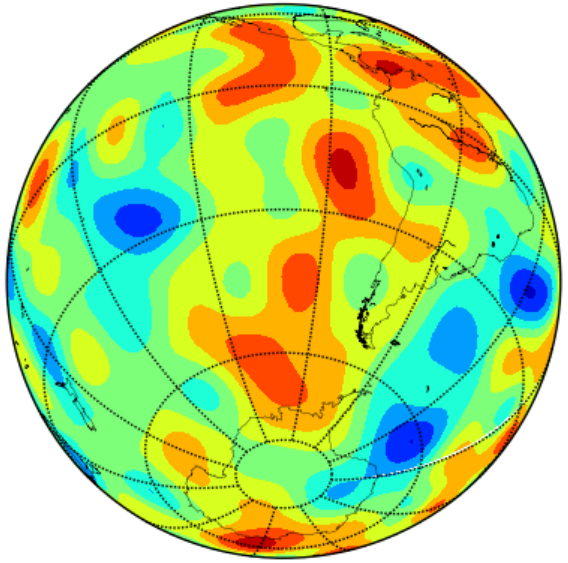
- **Land surface perturbations** (Gehne et al. 2018 Submitted):
  - Allow for land surface parameters such is Albedo, Soil Hydraulic Conductivity, LAI, roughness lengths to vary in space.
  - **Addresses error in the land model**

Special handling for stochastic physics

- Traditional physics operates on columns, and does not know about the surrounding neighbors.
- Stochastic physics requires that the random numbers used are correlated in space and time.
  - Time is easy, space is more complicated on the cubed-sphere grid.
- The random pattern generator is outside of the physics and dynamics.
- Currently uses spherical harmonics and spectral transforms transplanted from the GSM.

Creating random patterns correlated in space and time

- We aim for random patterns to have a spatial decorrelation scale on the order of 500 km and a 6-hour time-scale.
- The spectral resolution of the random patterns is independent of the ”C” resolution of the model, but due to the parallelization of the spherical harmonics, there is a minimum spectral resolution for a given number of mpi tasks.



Step-by-step

1. An AR(1) time-series is generated for each spherical harmonic:

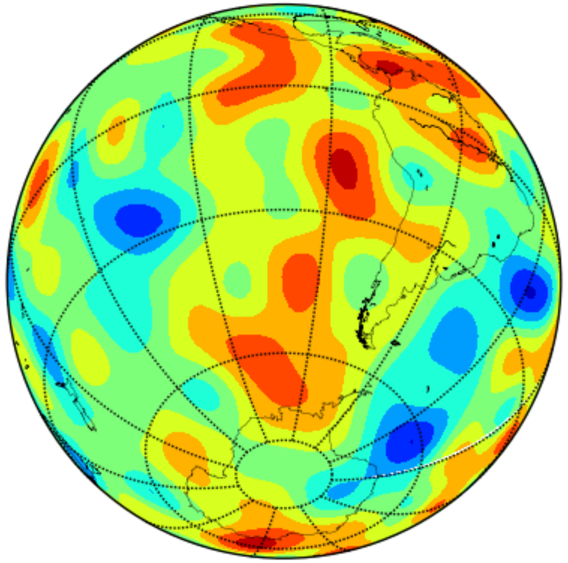
$$r_{mn}(t)=\phi r_{mn}(t-\Delta t)+\sigma_n\sqrt{1-\phi^2}\,\eta_{mn}(t)$$

$\boldsymbol{r_{mn}}$ spherical harmonic for zonal wave number $\boldsymbol{m}$ and total wavenumber $\boldsymbol{n}$

$\boldsymbol{\sigma_n}$ standard deviation of the time-series. Is a function of n, decorrelation length scale, and desired amplitude of the pattern

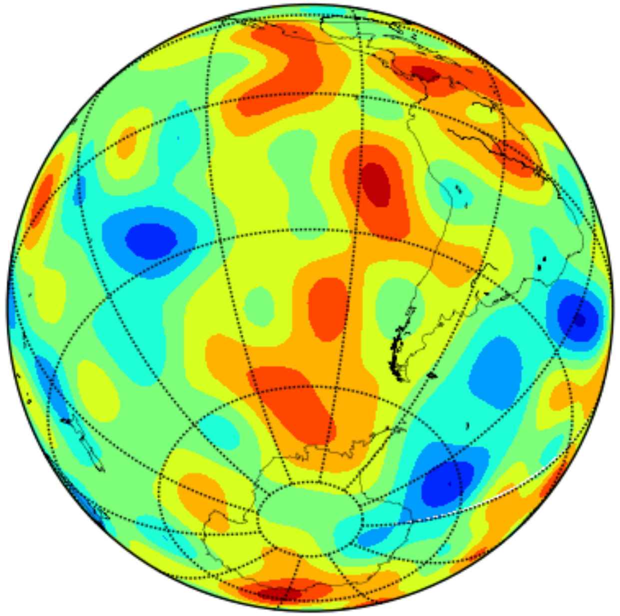
$\boldsymbol{\phi}$ temporal decorrelation

$\boldsymbol{\eta_{mn}}$ random gaussian number E(0,1)

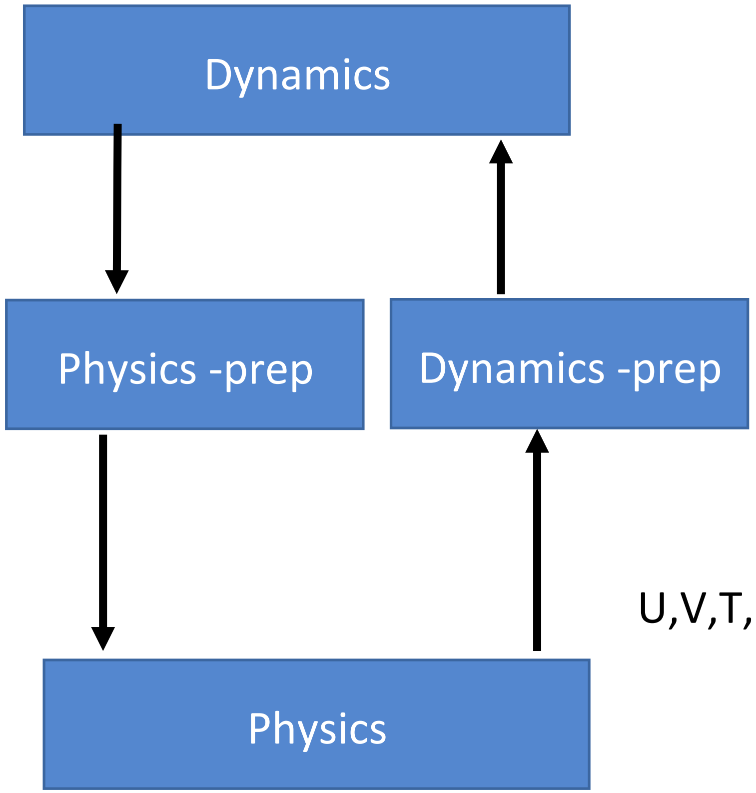


Step-by-step

2. A Legendre-Fourier transform converts the spherical harmonics to a random pattern on a gaussian grid.
3. Each mpi task gathers the entire global gaussian grid to interpolate to its piece of the cubed-sphere (inefficient)



Schematic without stochastic physics



Dynamics

Model state is put onto A-grid and flipped in vertical

Physics -prep

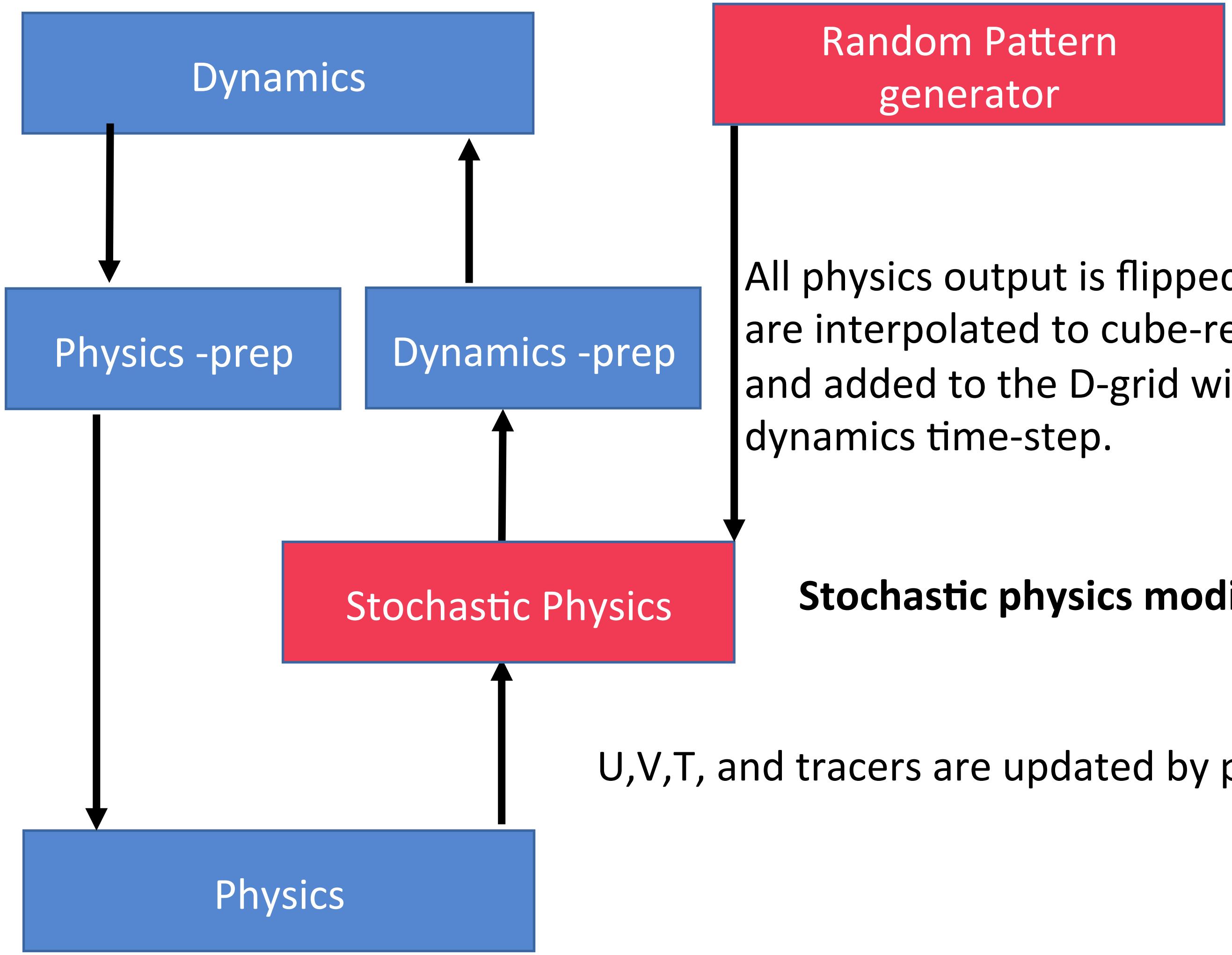
Dynamics -prep

All physics output is flipped, and U and V increments are interpolated to cube-relative D-grid locations and added to the D-grid winds output from the last dynamics time-step.

U,V,T, and tracers are updated by physics

Physics

Schematic with stochastic physics



Dynamics

Random Pattern generator

Model state is put onto A-grid and flipped in vertical

Physics -prep

Dynamics -prep

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Stochastic Physics

Stochastic physics modifies the physics output.

U,V,T, and tracers are updated by physics

Physics

Code overview

- Random pattern generation code: FV3/stochastic_physics/

- Stochastic physics initialized: GFS_driver.F90: GFS_initialize routine calls stochastic_physics.F90:init_stochastic_physics, which reads new namelist blocks: nam_stochy and nam_sfcperts.

- Random patterns are retrieved (and the AR(1) is propagated in time) by a call to from GFS_driver.F90: GFS_time_vary_step to stochastic_phyiscs.F90:run_stochastic_physics.

- The perturbations are applied by a call from atmos.F90 to IPD_Physics_Step2, which is mapped to GFS_stochastic_driver though the IPD, and GFS_abstraction layers.

Additional information

- Two new derived types are defined:
  - stochy_internal_state : contains mpi decomposition for spherical harmonics, spectral transforms and gaussian grid information
  - random_pattern : each type of stochastic physics (SPPT, SKEB etc.) has an instance of this type that contains the random pattern (amplitude, length/timescale) along with the spectral coefficients describing the pattern.
- The random patterns in grid space are contained in the physics Coupling container.

Stochastic Physics Namelist options

General Stochastic Physics:

NTRUNC: Spectral resolution (e.g. T126) of random patterns
LON_S,LAT_S: number of longitude and latitude point for the gaussian grid
FHSTOCH: forecast hour to write out random pattern in order to restart the pattern for a different forecast (used in DA), file is stoch_out.F<HHH>
STOCHINI: set to true if wanting to read in a previous random pattern (input file need to be named stoch_ini).

Controls for SPPT:

SPPT: Amplitudes of random patterns (0.8,0.4,0.2,0.08,0.04)*
SPPT_TAU: Decorrelation timescales in seconds (21600,1.728E5,6.912E5,7.776E6,3.1536E7)*
SPPT_LSCALE: Decorrelation spatial scales in meters (250.E3,1000.E3,2000.E3,2000.E3,2000.E3)*
SPPT_LOGIT: Should be true to limit the SPPT perturbations between 0 and 2. Otherwise model will crash.
ISEED_SPPT: Seeds for setting the random number sequence (ignored if stochini is true).
SPPT_SIGTOP1,SPPT_SIGTOP2: sigma levels to taper perturbations to zeros (default is 0.1, 0.025)
SPPT_SFCLIMIT: .T.=tapers the SPPT perturbations to zero at model's lowest level (helps reduce model crashes)
USE_ZMTNBLCK: .T.=do not apply perturbations below the dividing streamline that is diagnosed by the gravity wave drag, mountain blocking scheme

* SPPT uses 5 different patterns of varying time/length scales that are added together before being passed to physics

Stochastic Physics Namelist options

Controls for SHUM:

SHUM: Amplitudes of random patterns (0.004)
SHUM_TAU: Decorrelation timescales in seconds (21600)
SHUM_LSCALE: Decorrelation spatial scales in meters (250000)
SHUM_SIGEFOLD: e-folding lengthscale (in units of sigma) of specific humidity perturbations, default is 0.2)

Controls for SKEB:

SKEB: Amplitudes of random patterns (1.0)
SKEB_TAU: Decorrelation timescales in seconds (21600)
SKEB_LSCALE: Decorrelation spatial scales in meters (250)
ISEED_SKEB: Seeds for setting the random number sequence (ignored if stochini is true).
SKEBNORM: 0 - random pattern is stream function, 1- pattern is K.E. norm, 2- pattern is vorticity (default is 0)
SKEB_VARSPECT_OPT: 0- gaussian (default), 1-power law (not tested)
SKEB_NPASS: number of passes of the del^2 smoothing for the dissipation estimate (default is 11, minimum is 3)
SKEB_VDOF: the number of degrees of freedom in the vertical for the SKEB random pattern (default is 5)
SKEB_SIGTOP1,SKEB_SIGTOP2: (sigma levels to taper perturbations to zeros (default is 0.1, 0.025)

References

Berner, J., G. Shutts, M. Leutbecher, and T. Palmer, 2009: A spectral stochastic kinetic energy backscatter scheme and its impact on flow- dependent predictability in the ECMWF ensemble prediction system. *J. Atmos. Sci*., **66**, 603–626, doi:10.1175/2008JAS2677.1.

Gehne, M., T. Hamill, G. Bates, P. Pegion, W. Kolczynski 2018: Land-surface parameter and state perturbations in the Global Ensemble Forecast System. *Mon. Wea. Rev.* Submitted

Palmer, T. N., R. Buizza, F. Doblas-Reyes, T. Jung, M. Leutbecher, G. J. Shutts,M. Steinheimer, and A.Weisheimer, 2009: Stochastic parametrization and model uncertainty. *ECMWF Tech. Memo*. **598**, 42 pp

Tompkins, A. M., and J. Berner, 2008: A stochastic convective approach to account for model uncertainty due to unresolved humidity variability. *J. Geophys. Res.*, **113**, D18101, doi:10.1029/2007JD009284.