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Progress toward integrating the Finite-Volume Cubed-Sphere (FV3) dynamical core tangent linear and adjoint models into JEDI

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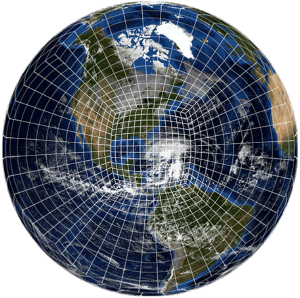
Introduction

Developed by GFDL, FV3 has been central to NASA's GEOS for several years and in FY19 FV3GFS should be operational. Through NGGPS several significant updates were added:

- Non-hydrostatic updates.
- Support for single precision numerics (∼30% faster).
- New advection schemes.
- New damping strategy.
- Nested grid capability.
- Major code reorganization.



This motivated redevelopment of the tangent linear and adjoint.

Why develop adjoint models?

- Hybrid 4D-Var continues to outperform ensemble based data assimilation, e.g. Bowler et. al. (2017, QJRMS).
- Observation impacts with FSOI.
- Computing singular vectors.
- Sensitivity to initial conditions.
- Constituent emission estimation.
- Significant focus back on automatic differentiation thanks to machine learning.

Development strategies

Computational:

- Use Tapenade automatic differentiation.
- Quick regeneration for quickly evolving code.
- Custom checkpointing to allow compile time precision choice, to avoid re-computation and to use pointers where possible.
- Option for fixed trajectory though main dynamics loop to save memory.

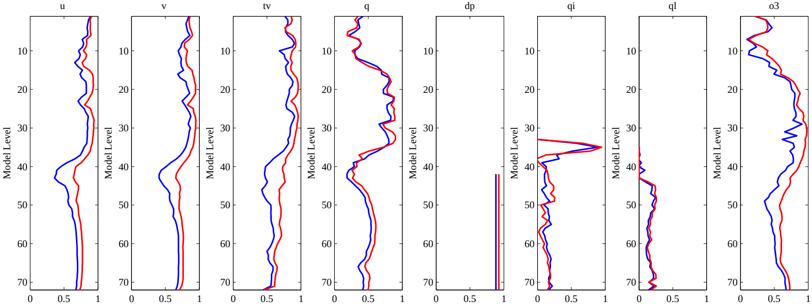
Scientific:

- Linear (3^{rd} & 5^{th} order) advection schemes.
- Increased damping to account for spurious oscillations close to steep gradients.
- Splitting so internal trajectory calculations use nonlinear schemes.
- Linear remapping from Lagrangian coordinate to Eulerian.

Linearzed model validity

Comparison of analysis increment evolution with nonlinear GEOS and tangent linear model.

Correlations computed at 6 and 24 hours. Blue: ∼7 year old version of FV3, red: NGGPS version.



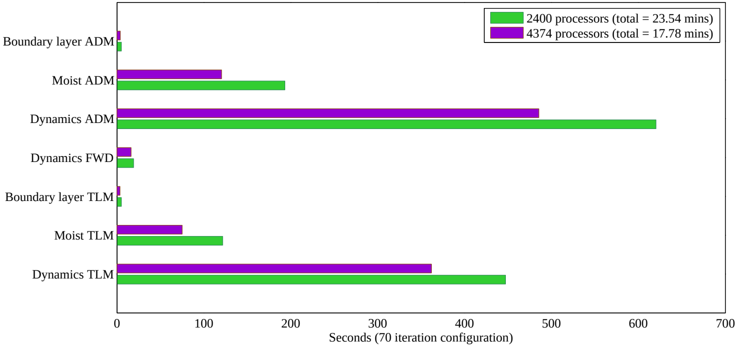
u':	0.96	v'	0.96	T_v'	0.93	q'	0.81	$\Delta p'$	0.98
	0.81		0.81		0.79		0.51		0.92

Custom trajectory handling

`call pushreal4array(var,dim)` to `call pushreal(var,dim)`

	Initialize	Forward call	Backward call
Iteration 1	-	Count calls Tapenade push	Tapenade pop
Iteration 2	Allocate integer*1 array to hold save status.	Count calls and bytes Tapenade push	Tapenade pop. Compare stack with active variable, record status in array, reduce byte counter.
Iteration 3	Allocate arrays to hold required reference state.	Save the variables if it is needed but to the array	Read back variable if it is needed
Iteration $\geq$4	Turn off forward calls	-	Read back variable if it is needed

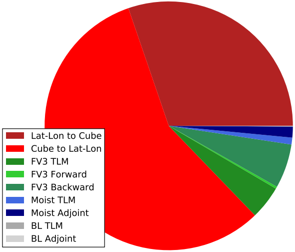
Testing: 4D-Var adjoint timing



Testing: GSI 4D-Var timing

Issues that would need to worked on for operationally viable hyrid 4D-Var

- Better parallelization of the algorithm (GSI plateaus at around 600 processors while GEOS uses 5400)
- Perform assimilation on cube sphere grid.



Move to JEDI

JEDI takes OOPS as a starting point and adds the necessary components to perform data assimilaiton for any model and grid.

- Ground up design to assimilate on the native model grid, avoiding costly interpolations.
- Scales well with increasing processors.
- Range of solvers including with time parallelisation.
- Good abstraction and separation of concerns.
- Highly collaborative and easy to work together.

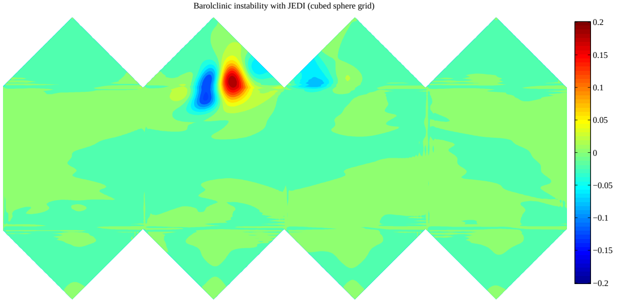
Progress incorporating FV3

Once the following steps are complete (as well as general JEDI work) it should be possible to perform offline hybrid 4D-Var on the FV3 grid.

Task	Status	Note
Geometry	Done	Both FV3GFS (R.Mahajan) and GEOS geometries incorporated.
Fields	In progress	Can read using FMS IO utility but not GEOS/ESMF.
Interpolation	In progress	Brian Flynt @ NOAA.
FV3 interface	Done	Nonlinear, tangent linear, adjoint and trajectory implemented.
Linear model tests	In progress	Currently finishing up the insertion of these.
Traj read	Not yet	Will need this ability initially.

FV3 Forecasts in JEDI

With the steps completed it is possible to integrate the FV3 model with the JEDI executable initialized from a file or with the FV3 idealized test cases.



Work plan moving forward

- Finish up implementation of required components.
- Start testing an offline assimilation, similar to how GSI works in separate executable mode. This requires background error covariances and UFO work.
- Add in linearized GEOS physics.
- Address questions associated with use of the adjoint, such as single precision mode and make adjoint refinements.
- Identify a target operational configuration of 4D-Var.
- Build single executable JEDI-GEOS and JEDI-FV3GFS.

Aim is to be producing hybrid 4D-Var results by end of 2018.

Future/side plans

- Develop more generic linearized physics coupling.
- Implement the FSOI capability within JEDI.
- Develop capability of running adjoint sensitivity with Lagrange multiplier.
- Develop generic singular vector calculation suite.
- Adapt JEDI-GEOS to JEDI-GEOSctm to perform emission estimation.
- 4D-Var with the FV3 nested grid if community interest.

Questions?