Section 6

Developments in global forecast models, case studies, predictability investigations, global ensembles.

A scale separation method for application of fourth-order advection with physics

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ABSTRACT

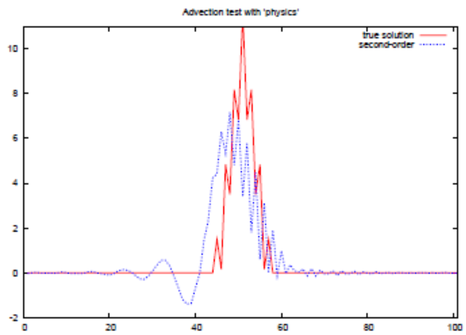
Although in idealized test studies fourth-order advection reduces the phase error of the solution, there are many reports that in NWP models with full physics it does not deliver the expected benefits. This study is a preliminary investigation of a method of scale separation where the "large scales" of motion are treated using the fourth-order advection scheme, while "short scales", those mostly affected by physics and orography influences, use the second-order scheme.

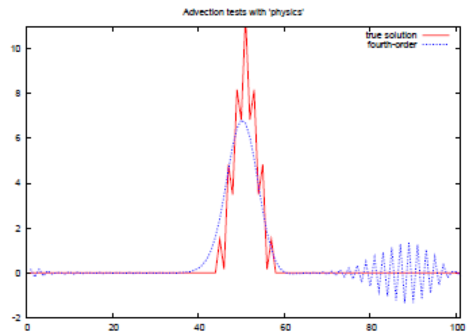
High-order, fourth- (e.g., Rančić 1988; Abramopoulos 1991; Janjic et al. 2011), and, in some instances, sixth-order (Chu and Fan 2001) approximations to horizontal advection, have been designed with the idea of providing a more accurate propagation of atmospheric systems and ocean flows in numerical simulations, by reducing the computational phase speed error. In idealized tests, high-order advection schemes indeed improve the solution, in accordance with their smaller truncation errors. However, though occasional reports confirm the benefits of high-order schemes in models with full physics (e.g., Juang and Hoke 1992; Skamarock and Klemp 2008), there is a general sense that they have not demonstrated the expected advantages.

A fourth-order scheme generates computational noise and its interference with the physics forcing, which takes place at the short end of spectrum, may explain to some extent the observed underperformance. Another factor, suggested by Janjic et al. (2011), is that the fourth-order scheme, due to a steeper inclination of the relative phase speed, has more profoundly wrong group velocity in the short portion of the wave spectrum than a corresponding second-order scheme. This means that a package of short waves, created by the model's physics, propagates more in the wrong direction in the case of the fourth- than in the case of the second-order scheme, which offsets the formally higher accuracy and negatively affects the overall performance.

One solution to this problem may be to introduce a nonlocal, "horizontally aware" physics, which was prophesized as inevitable for future high-resolution simulations by Arakawa (2000). Alternatively, one can spread the effect of physics forcing to the neighboring grid boxes through the application of spatial filters. In this short note a different solution is presented where the "large scales", which could be simply defined using a low-pass spatial filter of the considered field, are advected using the fourth-order scheme and the remaining field, the "perturbation", is advected using the second-order scheme.

An example of a one-dimensional version of the linear advection test suggested in Janjic et al. (2001), using, respectively, the second-, fourth- and combined schemes, is shown in Fig. 1 A short wave perturbation imposed on the triangle mimics the physics. The fourth-order scheme does not perform better than the second-order one. However, the combined scheme is able to provide a generally best solution. Preliminary testing has been done using the global NNMB-UJ model (Rančić et al. 2017). The objective, however, is to investigate the scale separation method as well as other mentioned approaches in order to successfully implement a high-order finite volume method (e.g., Ullrich et al.. 2010) in the new EMC's global FV3 model.





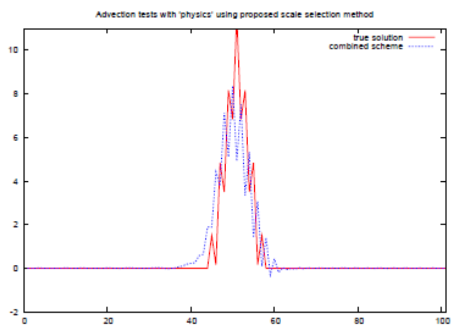


Fig. 1. Linear advection tests: upper left - second-order scheme; upper right - fourth-order scheme; down-left – combined scheme. The fourth-order scheme shows a runaway “physics package”, which in the combined scheme is kept together with the overall solution, providing clearly a better solution than that of the second-order scheme.

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Implementation of the NCEP GFS NEMS

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The National Centers for Environmental Prediction (NCEP) is upgrading the Global Forecast System in July 2017. The upgrade reformulates the GFS in the NOAA Environmental Modeling System (NEMS) superstructure and infrastructure and introduces modifications to the land surface and convection parameterizations, a new treatment of sea surface temperature and changes to data assimilation. Details on the changes and evaluation of the changes can be found at:

http://www.emc.ncep.noaa.gov/gmb/noor/GFS2017/GFS2017.htm

The physics changes include upgraded land parameterizations, higher resolution land surface climatologies, and new surface albedo data that improve surface upward radiation, near-surface fields and reduce patchiness, introduction of a stability parameter constraint that prevents the land-atmosphere system from fully decoupling and greatly reduces excessive cooling of 2m temperatures during sunset (00Z), changes to cumulus convection parameterization that improve summertime precipitation forecasts and a 50% reduction in Rayleigh damping in the upper stratosphere above 2 hPa that improves stratospheric fields. Near-Surface Sea Temperature (NSST) describes oceanic vertical temperature structure near surface due to the diurnal warming and sub-layer cooling physics processes and improves SST, data assimilation and tropical weather forecasts. Data assimilation is improved by additional data (some GPS data, AMVs, and some radiances), minor bug fixes mostly related to cloud water and preparation for future satellites (JPSS, GOES-16, COSMIC-2).

This upgraded system was tested for 749 days over three summers and two winters of forecasts and evaluated in coordination with other NCEP centers and National Weather Service regional headquarters and forecast offices. Maps of several months of real time operational and upgraded forecasts were available to operational forecasters for evaluation, and selected case studies recommended by forecasters were conducted.

Objective verification against observations and the model’s own analyses showed small changes in the troposphere and improvements in the stratosphere. The new GFS has stronger, more realistic winds. Analysis increments are reduced outside the tropics. Fits to radiosondes and aircraft observations are improved overall.

Precipitation forecasts over the continental US showed a reduction in the excessive drizzle seen in the GFS, increased bias for light to medium amounts, and significant improvements in skill for thresholds of 0.2 to 15 mm/day over forecast lengths of 0-24 to 72-96 hrs. Precipitation patterns averaged over several weeks showed improvements; the Aviation Weather Center and Weather Prediction Center noted improvements in tropical convection. NEMS forecasts better maintained convection over the western tropical Pacific.

In the GFS NEMS biases in 2 meter temperatures and dew points against observations were reduced more than increased over the United States, root-mean-square errors in 2 m dew points improved at all time of days, rms error in 2 m temperatures improved at 00UTC (reflecting reduced excessive cold bias at sunset) but were worse at 12UTC. 10 m winds were improved over the eastern United States but were worse over the western US.

In the numerous case studies examined, the GFS NEMS outperformed the operational GFS overall.

Over the three years tropical storms in the GFS NEMS showed short-term track forecast degradation in the Atlantic (48-72 hr) by about 9-10% and in the East Pacific (24-48 hr) by about 4-5%. The degradation in the Atlantic was due to poorer forecasts of three storms in 2016; the errors in these three storms did not appear systematic. East Pacific track forecasts improved beyond 48 hrs, genesis forecasts were significantly improved both in Atlantic and East Pacific and the lead time for Atlantic genesis forecasts gained by almost a day.

This is the last implementation with the current GFS; future implementations will be with the new FV3 dynamic core.

This implementation followed the new implementation procedure developed the previous year with a considerably longer official evaluation period and more active engagement with and participation of the other NCEP centers and NWS regional headquarters and forecast offices.