Flexible Radiation codes for Numerical Weather Prediction Across Space and Time Scales

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LONG-TERM GOALS

We seek to develop radiation parameterizations for Navy models that are computationally efficient and work seamlessly across models at all time and space scales, especially from regional models to global models.

OBJECTIVES

We are adapting radiation codes developed for climate models for use in the Navy's global weather forecast model (NOGAPS/NAVGEM), with the possiblity of also introducing them into the limited area model (COAMPS). Our long-term goal is to develop codes that are scale-aware, computationally efficient across a range of computer architectures, and operate continuously rather than at discrete time steps.

APPROACH

We are developing radiation codes known as "PSrad" which are modeled on the RRTMG parametization (Mlawer et al. 1997; Iacono et al. 2008). We make use of the RRTMG descirption of gas optics, which is among the most accurate parameterizations available (Oreopoulos et al. 2012) and initially make many of the same algorithmic decisions, including the choice to neglect longwave scattering. Our codes are intended as a drop-in replacement for RRTMG (which has already been implemented in NOGAPS) but we have implemented it almost entirely from scratch (of the original code, only the subroutine that computes longwave gas optical properties remains). The most important technical difference lies in the organization: each of our subroutines is designed to operate on many columns at a time, a choice that increases computational efficiency on a wide range of platforms. Operational centers such as the European Centre for Medium-Range Weather Forecasts have often modified RRTMG in this way (Morcrette et al. 2008).

Sub-grid scale variability is treated using "sub-columns" (Räisänen et al. 2004; Pincus et al. 2006): discrete random samples, each treated as internally homogeneous, that are consistent with the distributions of possible cloud states within each column, including fractional cloudiness in each layer and assumptions about the vertical correlations between layers (so-called "cloud overlap"). This

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treatment is a generalization of the Monte Carlo Independent Pixel Approximation (Pincus et al. 2003) and is easily broadened to include other kinds of variability.

The main conceptual innovation in PSrad is support for a range of choices for spectral sampling, including broadband integration (most likely applied at relatively infrequent "radiation time steps") amd a finite number of pre-determined "leagues" of *g*-point teams as described below and in Pincus and Stevens (2012).

WORK COMPLETED

We have developed initial versions of these highly modular codes for the Navy's global model. We have revised the code to adapt to the Navy's computational environment including the inability to read netCDF files (which requires that we include many megabytes of static data statements). We have also reverted, at least temporarily, to the ice and liquid cloud optics schemes used by the default versions of the RRTMG code so our codes can be directly tested.

The code has been implemented in NOGAPS by Dr. Ming Liu of the Naval Research Lab. Results are consistent with RRTMG in the longwave and clear-sky shortwave but inconsistent with cloudy-sky shortwave fluxes at the 1% level. We are pursuing the source of this inconsistency. We also find that initial versions of the code are substantially slower than RRTMG due in part to choices made when we built the codes for the ECHAM climate model.

RESULTS

The main conceptual innovation in PSrad is support for a range of choices for spectral sampling, which we plan to use to explore a range of strategies for coupling radiation to the rest of the model. We are motivated by the fact that the impacts current strategy – infrequent broadband calculations, or what might be called a spectrally dense, temporally sparse approximation – has not been carefully examined, and are known to cause errors in at least some circumstances (Pauluis and Emanuel 2004). We have previously shown (Pincus and Stevens 2009)that large-eddy simulations can take the opposite (spectrally sparse, temporally dense) approach, using single *g*-points chosen randomly in space and time but applied at every time step, an approach that is unbiased but produces large instantaneous errors. When we tried this same strategy in a global model, however, forecast errors were quite large, which we traced to persistent surface temperature anomolies feeding back on the atmosphere. (Our previous simulations had used fixed surface properties.)

We developed an intermediate solution: using "teams" of g-points chosen to minimze the error in surface fluxes over some set of sample calculations. These teams are quite efficient in reducing the error for a given computational cost (see Figure 1) – efficient enough, in fact, that a randomly-chosen team can be used to compute a proxy for the radiative fluxes at every time step, allowing temporal variability (especially in cloud properties) to be captured.

Initial "perfect-model" experiments with a global model indicate that forecasts using this strategy are at least as good as forecasts using a relatively large radiation time step. We have submitted a journal article (Pincus and Stevens, 2012) describing the teams and demonstrating that our new spectral sampling strategies are effective in global models.

For the moment we have focused on computational correctness and efficiency but hope to explore tradeoffs between team size and forecast accuracy in NOGAPS where we will be able to make use of many analysis/forecast cycles.

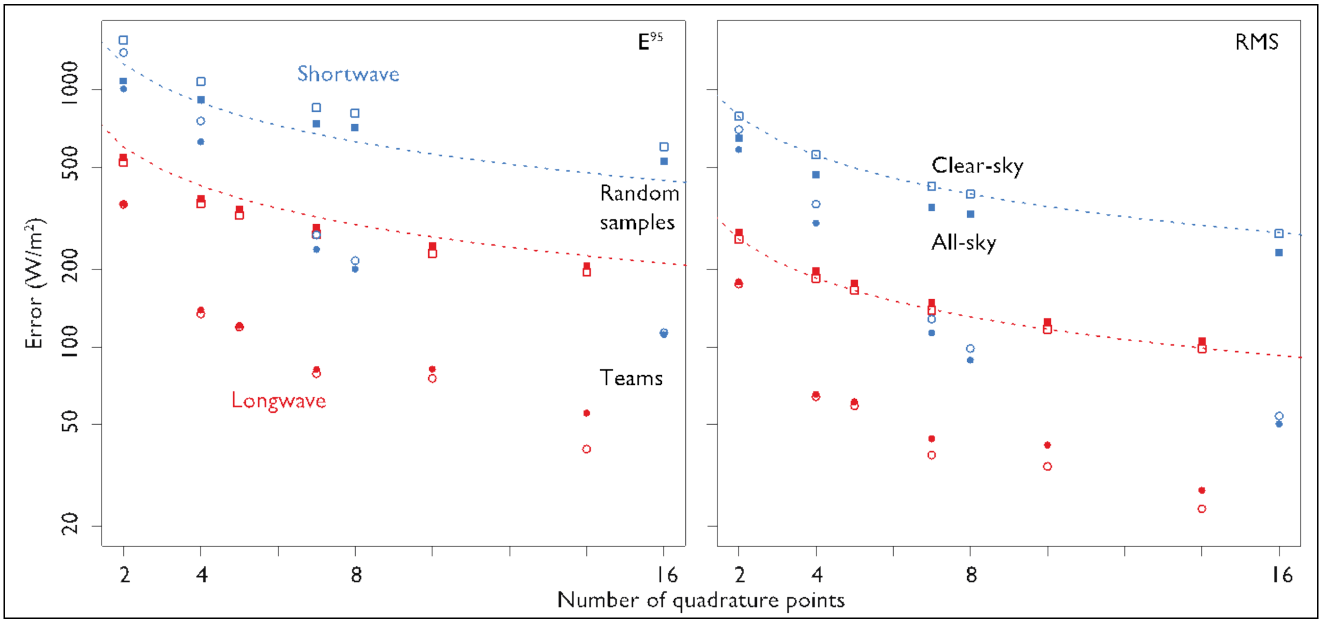

Figure 1: Error in surface fluxes as a function of the number of terms in the spectral integration. The left panel shows the 95th percentile ("worst case") error and the right panel the root-mean-sqaure error. Errors are assessed over ~73000 states from a global model. Errors in shortwave (blue) and longwave (red) surface fluxes for two spectral sampling strategies as a function of the number of quadrature points used. Errors are accumulated over roughly 73000 sample columns representing four snapshots from a single day of ECHAM. Root-mean square error (right panel) decreases as the inverse square root of the number of randomly-chosen samples, but both RMS and 95th percentile errors (left) decrease much more quickly using "teams" of g-points chosen to minimize the worst-case error (circles) than the same number of randomly chosen quadrate points. Errors for all-sky fluxes (closed circles) are marginally smaller in the shortwave and larger in the longwave than for the clear-skies used to optimize the team members primarily because clouds decrease SW surface and increase LW fluxes.

IMPACT/APPLICATIONS

We expect to have a version of NOGAPS using PSrad consistent with RRTMG in both efficiency and results by the end of 2012, at which point we will begin to explore alternative strategies for coupling radiation calculations to the rest of the model.

The European Centre for Medium Range Weather Forecasts has expressed interest in working with this code. They hope the ability to make more frequent calculations will help ameliorate certain biases in nocturnal stable boundary layers over complex topography.

RELATED PROJECTS

NONE at the present time

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