Replacement of Parameterized Physics with Look-up-tables (LUTs)

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A Novel New Approach to NWP Modeling

The current paradigm for increasing the forward speed of numerical weather prediction (NWP) models is to await faster processors to be released from microchip manufacturers.

- •Gains are increasing according to Moore's Law, where the number of transistors in a processor will double about every 24 months.
- •This pattern is assumed to continue, as it has for the past 35 years

However, any method of increasing forward speed of NWP models are of great interest to the modeling community:

- •These gains will be above and beyond those of the microchips, and will, hence increase efficiency of the models.
- •Any DoD interest which relies on timely delivery of NWP results will benefit.
  - •Enesemble forecasting becomes more of a reality, allowing faster/more accurate results to be given to battlefield planners and coordinators.
- •Any civilian interest which relies on timely delivery of NWP results will also benefit.
  - •Companies who produce energy can more accurately and efficiently target production levels to meet anticipated demands.

Any gain in forward speed will come by eliminating any inefficiencies within the parent code:

- •Gains will not come from the dynamical core. All models perform these same calculations by numerical integration of the governing equations.
- •Inefficiencies must lie within the parameterized physics of each individual NWP model
- •Parameterizations describing cumulus convection, cloud and precipitation driven microphysics, radiative transfer, land-surface interactions and turbulence are all candidates for replacement.

How will these time gains be achieved?

- •Replacement of the previously mentioned parameterizations with some form of look-up-table
  - •Since parameterizations are nothing more than "black boxes", if we can accurately recreate the outputs in a drastically reduced amount of time, nothing should change, except that faster results are achieved.
- •Various forms of LUTs can be developed:
  - •Hierarchical directory structures, EOF-based LUTs and even LUTs constructed using artificial intelligence techniques have been tested.

Hierarchical Directory Structure LUTs

The hierarchical directory structure LUT's aim is to use a storage device and associated directory structure to store data.

- •If inputs were temperature in Kelvin, the directory structure could look like this:
  - •…/310/304/299/291/287/…/data.dat

  where the data.dat file would contain the outputs

Time testing of the hierarchical LUTs showed no gains in forward speed:

LUT Name	# Data points/ values to Match	Elapsed Time (sec.)	Time minus Overhead	% Gain/Loss over Original
Driver Overhead		1.136	0.000	
Original Parameterization		3.812	2.676	
LUT2	10	19.620	18.484	591%
LUT3	20	46.430	45.294	1593%
LUT6	3	7.203	6.067	127%
LUT6a	3	3.810	2.674	-0.07%
LUT8	3	48.208	47.072	1659%
LUT8a	3	31.379	30.243	1030%

- •Matching more directories/input data values increase the time necessary to retrieve the outputs.
- •Considering most operational models use at least 30 model levels, it would be inappropriate to match only 3 numerical values when determining their corresponding output data set.

EOF Method

The EOF approach is probably best defined as a transfer scheme:

- •For a given lat/lon point, EOFs of the input field are determined from 3-hourly data.
- •Differing numbers of EOFs were retained in testing (anywhere from 50% to 97.5% of variance explained).
- •Rotated EOFs are used to give physical significance to the input patterns.
- •Any input sounding is then a weighted sum of the EOFs, yielding an output.

EOF testing shows promise as a replacement to parameterized physics, first from time tests:

- •EOFs are showing time increases between 10- and 20-fold over original

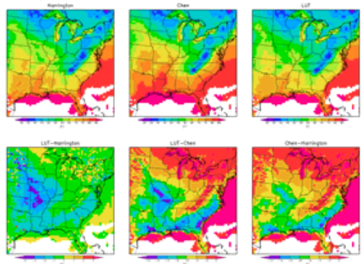
Scheme/EOF Name	% Gain/loss over Harrington
Harrington	N/A
Chen-Cotton	46.60%
EOF - 97.5% Var.	92.68% to 94.88%
EOF - 75% Var.	96.25% to 98.71%

- •EOF method is faster then either of the two main options for radiative flux divergence parameterization within RAMS

Accuracy of EOF method is typically within the range of results obtained from choosing either of the current radiation options within our NWP model, for a 72-hour model run:

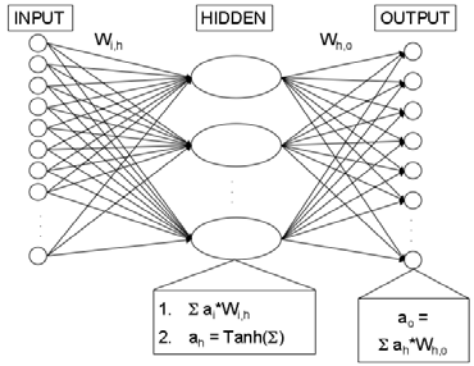
	Average Sign-Independent Differences		Maximum Sign-Independent Differences	
Meteorological Field	EOF - Harrington	Chen - Harrington	EOF - Harrington	Chen - Harrington
2m Temp	0.80ÞF	3.07ÞF	4.98ÞF	14.43ÞF
10m Wind	0.057m/s	0.125m/s	2.153m/s	1.197m/s
500mb Height	0.084m	0.161m	1.19m	1.22m
500mb Vert Velocity	0.29cm/s	0.36cm/s	16.5cm/s	16.5cm/s
250mb Wind	0.0134m/s	0.0173m/s	0.290m/s	0.348m/s

The difference in the 2m temperature field at the end of our 72-hour model run, shows the usefulness of the EOF-LUT as a replacement to the Harrington radiation scheme:



Artificial Neural Networks

Artificial neural networks are used to determine numerical patterns from an input data set to an output set



- •The input data is standardized and sent into the artificial neural network.
- •The hidden neurons use a hyperbolic tangent as the non-linearity to send the data to the outputs.
- •The outputs are standardized and are then transformed back into the real data.

Initial testing showed feasibility of artificial neural network approach:

- •The Mahrer-Pielke LW radiative flux divergence scheme was used a candidate for replacement
- •Small neural networks performed the best, both in accuracy and time testing (reduction in time of 50%).

Since many of the inputs within the different parameterizations are the same, it would be redundant to have many individual neural networks, so why not create a "universal" neural network?

- •This idea was postulated in a recent article (Pielke, et. al, 2007) where satellite data would be used to drive NWP models.
  - •This data would replace the need for parameterizations, since 3-D real-world interactions would be implicit within the construct of the process.
- •This satellite data could then be used to create and drive a neural network (or other LUT) based NWP model.

Continuing and Future Work

Proof-of-concept work has begun to show the feasibility of the Universal look-up-table concept.

- •Proof-of-concept revolves around replacing all portions of the radiative flux divergence parameterization.
- •This is to be done using inputs that can be directly measured using satellite data:
  - •3-dimensional temperature and moisture fields can be used as satellites proxy fields, and will eventually drive the future look-up-tables.

Once this is shown successful, more parameterizations will be added to the scheme, allowing for large portions of the parameterizations to replaced.

- •Other candidates for replacement, include:
  - •Cumulus convection
  - •Cloud and precipitation driven microphysics
  - •Land-surface interactions
  - •Turbulence
- •This could eventually save up to 90% of the model time from current NWP simulations.