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Testimony to the
Environment Subcommittee of the
Committee on Science, Space, and Technology
United States House of Representatives

A Task of EPIC Proportions: Reclaiming U.S. Leadership in Weather Modeling and Prediction
November 20, 2019

Good afternoon Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee. My name is Cliff Mass and I am a professor of atmospheric sciences at the University of Washington.

The U.S. is behind in numerical weather prediction and we are *not* catching up. NOAA's global model is either third or fourth in skill, behind the European Center, the UKMET office, and the often the Canadian model. The U.S. has the leading weather research community in the world, and our nation invests heavily in weather prediction. We should be far ahead. But we are not. And our global model is not the only problem: U.S. weather prediction capabilities trail in other crucial aspects, including high-resolution ensembles and model post-processing.

In 2012, the nation became aware of the problem during Hurricane Sandy, and Congress responded with additional funds. Seven years later, objective numbers show we are not catching up. And the cost to the American people of this stagnation is huge. State-of-the-science forecasting will save lives, greatly aid the U.S. economy and serve as the first line of defense for extreme weather.

So why is the U.S. failing in this crucial arena?

Duplication of effort, poor organization, and lack of leadership, plus a profound deficiency in computer resources.

The enormous resources of the U.S. are spread over too many modeling systems. NOAA has at least three groups working on such models: the NWS Environmental Modeling Center, and NOAA's ESRL and GFDL labs. NASA has developed a global model and its own version of the regional WRF model. The Navy has developed both global and regional models. The Air Force acquired a foreign weather modeling system, and the National Center for Atmospheric Research, which encompasses the academic community, has developed *another* global modeling system,, in addition to its well-known WRF model.

The U.S. research community has mainly worked with NCAR weather models and NOAA has used their own. They are not working together, and thus NOAA is cut off from the innovations and energy of the academic community.

Such division of effort has undermined U.S. weather prediction, resulting in a large number of subcritical, inferior efforts.

But there is more. NOAA has been starved for computer resources, crippling research and testing, and blocking the operational application of promising approaches. My analysis, supported by colleagues in NOAA, is that the NWS could effectively use at least 100 times its current computer allocation.

All of these problems could be turned around quickly if our nation would reorganize how we develop, test, and run numerical weather prediction models. And the centerpiece must be bringing resources and personnel together in one national effort.

EPIC can be a big part of the solution.

EPIC must become the center of U.S. model development and testing, and resources should be concentrated there.

It must be a physical center, located outside of NOAA, and serve all agencies and groups in the U.S. government.

EPIC needs resources, independence, autonomy, stability and, most importantly, responsibility to deliver the best weather modeling system in the world.

It must be an exciting center of discovery, science and technology, that will attract our best scientists.

EPIC needs sufficient computer resources for development and testing.

It must entrain the capabilities and efforts of the U.S. Research Community, including the National Center for Atmospheric Research. And the participation of the National Science Foundation is crucial.

Finally, EPIC must develop and support a national community model, freely available to the nation.

EPIC can easily fail if it not given the primary responsibility and resources for creating the best weather prediction system in the world. It will fail if its goals are too narrow or designed as a service organization for a single agency.

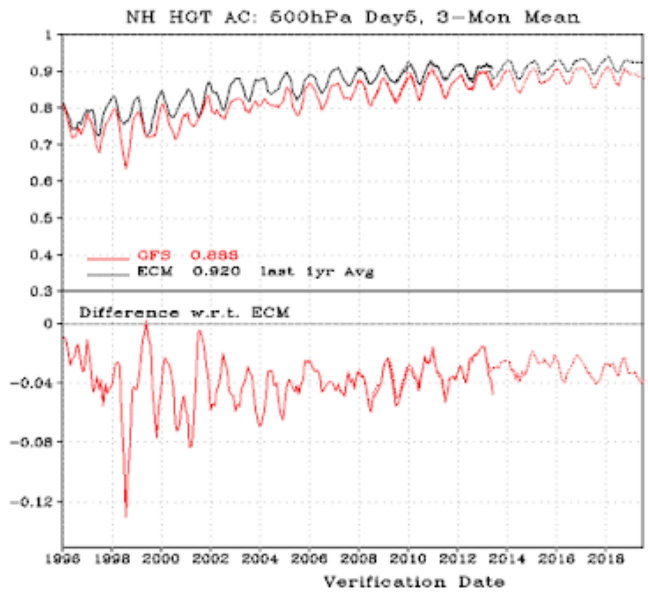
Our nation was the first in numerical weather prediction, but threw away leadership by dividing our efforts. It is time, through EPIC, to combine and rationalize how we develop our forecast models, with extraordinary benefits to the American people.

Cliff Mass Blog: August 2, 2019

EPIC: The Last Chance for National Weather Service Weather Modeling to Regain Leadership?

I have written at least a dozen blogs, a peer-reviewed paper, and given tens of conference talks on the unfortunate state of numerical weather prediction in the National Weather Service (which is part of NOAA, the National Oceanographic and Atmospheric Administration).

The bottom line: U.S. global weather prediction is in third place in the world. The plot below shows a comparison of the skill of the 5-day model forecast for the U.S. (red line) and the European Center (black line) at a mid-tropospheric level (500 hPa).   **We are not only behind, but we are not catching up.**



And more importantly than that, our weather prediction is substantially behind the state-of-the science.   That means not providing warnings of severe weather as far ahead as we could. It means an economy that is not benefiting from the best weather guidance (such as agriculture and aircraft routing). There are real national costs to this.

I have explained the origin of the problems in previous blogs. They include:

1. Too many Federal agencies or government-supported labs trying to do the same thing (NOAA/NWS, Air Force, NASA, Navy, NCAR)
2. The academic community working on different models than used by NOAA/NWS.
3. Poor organization within NOAA, with multiple groups having responsibility for weather prediction.
4. Lack of strategic planning.
5. Lack of sufficient computer resources.
6. No priority for excellence.

It has been kind of depressing. The nation with a huge weather research capability and ability to zoom ahead of the pack, stuck in third rate status.

But there is a rare chance right now, the best in decades. The stars are aligned.   And there is a critical meeting next week that might well decide which path the nation takes. **And it is all about EPIC.**

Why are the stars aligned?

1. The leadership of NOAA want to fix the problem.
2. The U.S. public and the U.S. Congress know there is a problem, with Congress even passing legislature (with funding) calling for major change.
3. The head of NOAA is a weather modeler (Neil Jacobs), as is the President's Science Advisor (Kelvin Drogemaier)
4. The private sector is demanding improvement.
5. THERE IS BIPARTISAN AGREEMENT ABOUT THIS.

Perhaps best of all, recent weather legislation calls for the development of national EPIC center, that would centralize U.S. efforts to build the best global forecast models in the world. (EPIC stands for Environmental Prediction Innovation Center).

Next week there is going to be a meeting on the nature of the EPIC that will take place in Boulder, Colorado. **An absolutely crucial gathering**--I will be giving a talk there and are part of the organizing committee.

Will self-interest, disciplinary fiefdoms, and legacy administrative structures give way to rational, more effective approach for developing U.S. weather modeling systems?   We may know the answer in one week.

And this may be the last chance for NOAA. Private sector companies are in the wing that will take on global weather prediction if NOAA fails to advance to first tier.   Not Space-X but Weather-X. And the U.S. Air Force already abandoned the U.S. modeling system for a non-American model (UKMET Office Unified Model). When the U.S. military gives up the American model, you know you have a problem. I will let all of you know what happens.

Wednesday, April 17, 2019

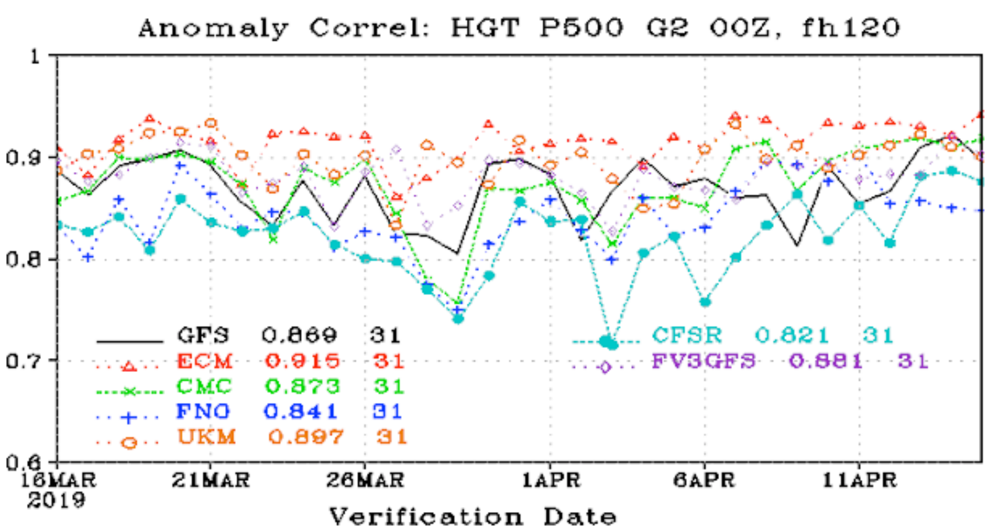
U.S. Numerical Weather Prediction: Darkest Before the Dawn?

U.S. operational weather prediction is undergoing a rough patch right now, with a new global modeling system that is proving not quite ready for prime time.

But there is reason for hope. A combination of new leadership and reorganization may turn things around during the next few years. The old saying, *it is darkest before the dawn*, may well prove true for operational numerical weather prediction in NOAA and the National Weather Service.

As I have described in many previous blogs, the U.S. is lagging behind in operational global weather prediction. Today and for many years, the U.S. global modeling system, the NOAA/ NWS GFS (Global Forecast System) model has trailed behind the world leader, the European Center Model, and is consistently less skillful than the UKMET office model run by the British. We are usually tied for third with the Canadian Model (CMC).   And we lag behind the others even though the U.S. has the largest meteorological research community in the world.

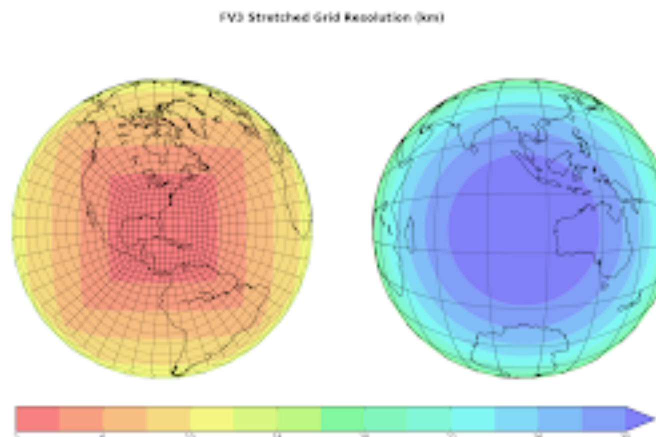
To illustrate the problems, here are the latest comparative statistics (anomaly correlations!) for the global skill of the 5-day forecast at 500 hPa (about 18,000 ft up) for a variety of models. 1 represents a perfect forecast. **The best forecast is the European Center (average of .915)**, next is the UKMET office (the British folks with a .897), third is the Canadians (CMC, .773), and **FOURTH is the U.S. GFS (.869).**



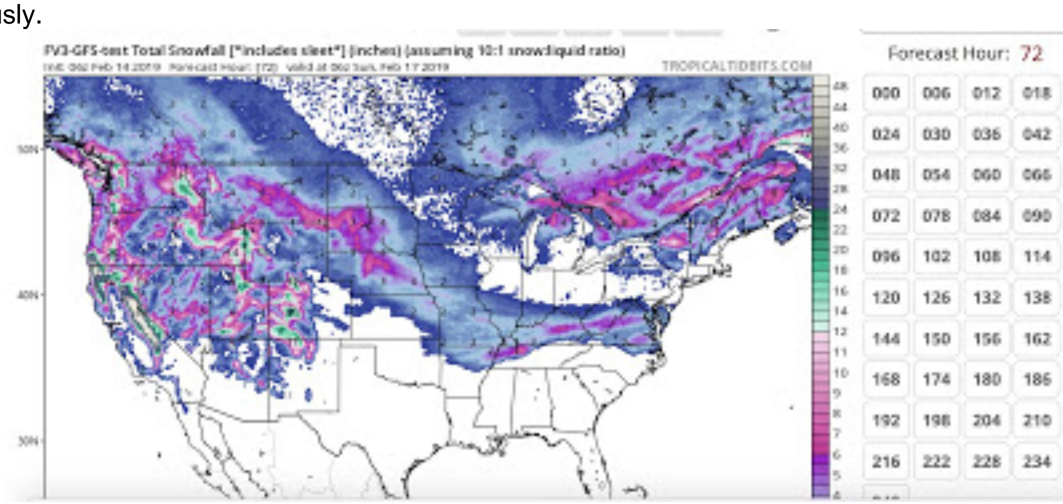
It is no secret why the GFS is behind: an old model, inferior data assimilation and use of observational assets, and relatively primitive model physics (e.g., how cloud processes, thunderstorms, turbulence, etc. are described). Inadequate computer resources contributed as well. *Data assimilation* is the step in which a wide variety of observational data is quality controlled and used to create a physically realistic three-dimensional description of the state of the atmosphere. The European Center does a very good job at this.

The inferiority of the U.S. global model has gotten a lot of press the last 6 years, particularly after the GFS showed itself to be clearly less skillful than the European Model for Hurricane Sandy.   The hue and cry in the media resulted in a computer upgrade for the National Weather Service and the acquisition of a new global model, the NOAA Geophysical Fluid Dynamics Lab (GFDL) FV3. This new model has been running in parallel for nearly a year now.

But there are problems with the new FV3. The FV3's verification scores are only slightly better than GFS, something shown in the statistics above (FV3 was at .881, **in third place**). Part of the problem is that the FV3 is using the same data assimilation system as GFS, which is not as advanced as the one used by the European Center.



But there is something else: during the cold period of the past winter, the FV3 was predicting crazy, excessive snow amounts. And more detailed verification indicated that the FV3 was too cold in the lower atmosphere. Disturbingly, the NWS evaluation protocols were not able to delineate the problems previously.



Coastal California was predicted by FV3 to be snowbound in February, It didn't happen.

The FV3 was supposed to go operational in January, but was delayed until February because of the government shut-down.   Then the snow/cold problem was revealed.   According to my contacts in NOAA, they have found some, but not all, of the problems.   **At this point, the operational implementation has been delayed indefinitely into the future.**

In some ways, this is NOAA's version of the Boeing Max disaster --in the hope of beating the competition, a software system was rushed into operations without sufficient testing and evaluation.

Another major problem?   It appears that there aren't enough people inside the National Weather Service (NWS) who actually understand the new FV3 model.

FV3 was developed outside the NWS by a team under a very capable weather modeler, S. J. Linn, of the NOAA Geophysical Fluid Dynamics Lab. In essence, the model was "thrown over the fence" to the Environmental Modeling Center (EMC) of the NWS and few people there actually understand FV3 in any depth. About 3, according to my sources. S. J. Linn has recently moved back to Taiwan and is no longer available.

In addition to lacking depth of knowledge about the core FV3 modeling system, the NWS does not have much of an effort to improve the physics of the FV3, such as the microphysics that describes how clouds and precipitation processes work in the atmosphere.   Physics is one of the key deficiencies of the U.S. models. And the data assimilation system was simply moved over from the inferior GFS.

But the situation is even worse than that. FV3 was supposed to be a *community modeling system*, one that could easily be run outside of the National Weather Service, including the universities and private sector.   Having others use the model is essential: instead of only a handful of folks inside the NWS working on and testing the model, you get hundreds or thousands doing so. You end up with a much better prediction system that way.

MPAS
Model for Prediction Across Scales

FV3: Finite-Volume Cubed-Sphere Dynamical Core

But the NWS has put virtually no effort and resources into making FV3 a community modeling system, TWO YEARS after making the decision to use it. I have tried myself to use the latest release. There is no support, no tutorials, no help desk. Nothing. The code release is incomplete and poorly documented. The model code is hardwired for NOAA computers and some of my department's most accomplished IT people can't get it to run.   Not good.

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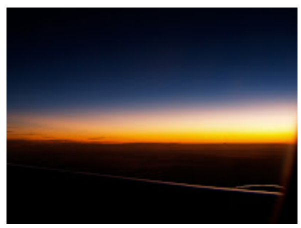
THE GOVERNMENT'S NEW WEATHER MODEL FACES A STORM OF PROTEST

In contrast, the major U.S. competition to FV3, the NCAR MPAS (NCAR is a consortium of many of the atmospheric sciences departments in the U.S.), is easy to run and has lots of support. One of my students got going on it in days.

The bottom line in all this is that the U.S. move to improved global prediction using FV3 is not going well.

The NWS has made the right move to hold off on implementation until FV3 is at least as good as the old GFS, considering the critical role the U.S. global model plays in American weather prediction.

But the dawn still beckons...

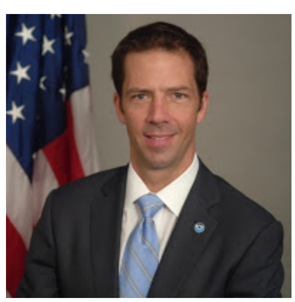


Things are pretty dark for U.S. global prediction right now. But there are some reasons for optimism.

First, the FV-3 is a better designed and more modern weather modeling system than the old GFS, including being more amendable to running on large numbers of processors. It can be the basis for improvement.

Second, NOAA/NWS leadership accepts there are problems and wants to fix it.

Of particular importance is that the key person responsible for U.S. operational prediction and observation, the Assistant Secretary of Commerce for Environmental Observation and Prediction and acting NOAA administrator, is Dr. Neal Jacobs, an extremely capable and experienced weather modeler, who led the successful effort at Panasonic before moving to NOAA. Dr. Jacobs knows the issues and wants to deal with them. Furthermore, there is a relatively new and highly capable head of the NOAA/NWS Environmental Modeling Center (where U.S. operational weather prediction takes place), Dr. Brian Gross.



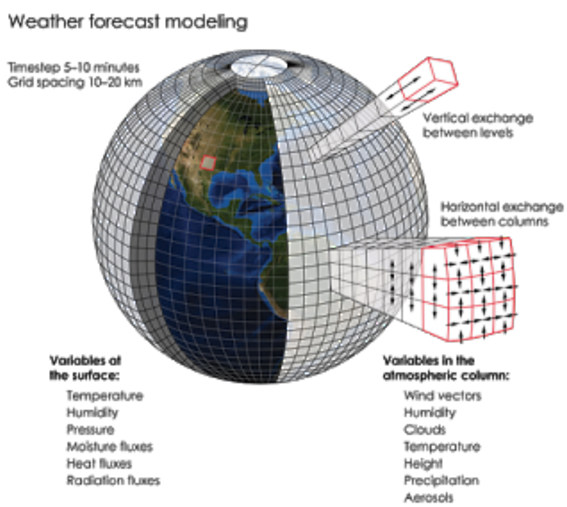
Dr. Neil Jacobs is now acting Administrator of NOAA

Add to that the new Presidential Science Adviser is Dr. Kelvin Droegemeier, an expert in high-resolution numerical weather prediction from the University of Oklahoma.

And consider that the U.S. Congress knows about the problem and has passed two pieces of legislation, the Weather Research and Forecasting Innovation Act of 2017 and National Integrated Drought Information System Reauthorization Act of 2018, that highlights problems with U.S. weather prediction and provides some needed resources.   Another positive is that leaders of the NOAA Earth Systems Research Lab (ESRL), a group responsible for development of new U.S. models, are now committed to working closely with the NWS operational folks. Five years ago this was not the case.

So we have extremely capable leadership in NOAA who want to fix the problem and a Congress who wants to help. That is good--but it is not enough.

Now we come to the real problem, and why I am for the first time in years really optimistic.



The key problem with U.S. operational numerical weather prediction has never been resources, it has always been about organization. About too many groups, with too much resource, working on similar projects in an uncoordinated way. Furthermore, the universities and the Federal government have rarely worked together effectively.

But this may all be changing. NOAA leadership, with support from Congress, is about to set up an entity that will be the central development center of U.S. numerical weather prediction.

This center is called EPIC (Environmental Prediction Innovation Center) and would combine the efforts of both NOAA and the universities (NCAR).   Done correctly, EPIC could lead to a much more effective and coordinated approach to developing a new U.S. global modeling capability. A modular, unified national modeling system shared between government, academia, and the private sector.

Will the U.S. FINALLY organize itself properly to regain leadership in global numerical weather prediction?   Time will tell. But I am more optimistic today than I have been in years.

Tuesday, April 21, 2015

The U.S. Air Force Turns to a Foreign Weather Forecasting System

The United States Air Force has decided to drop its American weather prediction system (the Weather Research and Forecasting model, WRF) for the forecasting system developed by the United Kingdom (UKMET Office Unified Model).

As described below, this decision is a terrible mistake and will ensure substantial damage to U.S. weather prediction capability, waste precious financial resources, and undermine the U.S. Air Force's capacity to provide the best possible forecasts for U.S. pilots and Air Force operations.

This blog will tell you about this unfortunate situation, document a flawed decision-making process, describe the downside of this decision, and call for better-informed public officials and legislators to intervene.

The current situation

Today, the US Air Force makes regional forecasts around the world using the WRF model. WRF is an extraordinary success story; developed at the National Center For Atmospheric Research (NCAR) in Boulder, Colorado, WRF is used by thousands of users in the U.S., and is the predominant model used in the research community and the private sector. WRF is also heavily used by the National Weather Service and by many thousands of individuals, groups, and weather forecast entities around the world. WRF is probably the best example of a community model: highly flexible, state of the art, adaptive, with advances from the research community flowing into the effort, resulting in constant improvement.

During the mid-2000s, the AF took on WRF as their main regional modeling tool, using the U.S. global GFS (Global Forecasting System) model for their global predictions. The global model is used to provide boundary conditions for the regional model (WRF).

The AF adoption of WRF was a win-win for the nation.   AF funding contributed to maintaining and improving WRF; in fact, the AF was the largest financial supporter of WRF.   The AF in turn had the best possible regional model, one that was easy to use and highly capable, and a model that took advantage of the efforts of the vast U.S. weather research community.   An improved WRF helped drive U.S. weather modeling research and was taken on by many private sector firms. The U.S. was clearly the world leader in this domain.

The Air Force fumbles

Late last year it became known the Air Force Weather Agency, which runs AF numerical forecast models, had decided to drop WRF and NOAA's GFS model, and turn to a foreign modeling system: the UKMET office model.   A recent story in the Washington Post discussed this decision.   This decision was made **without talking to U.S. national weather modeling partners (the National Weather Service and the U.S. Navy)** and appears to be the decision of one individual, Ralph Stoffler, acting head of the Air Force Weather Agency. Mr. Stoffler was an AF weather officer and has a BS in meteorology.

Ralph Stoffler

Checking with my contacts in the Air Force, I have learned that there were no long-term verification/comparison runs to demonstrate that the the UKMET office model would be superior to WRF. It is stunning that such a major decision would be taken without strong evidence of improvement.

Mr. Stoffler's plan greatly expands AF modeling into the global arena, moving to DUPLICATE the U.S. global prediction efforts completed by the National Weather Service and the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center.   There has always been an unfortunate relationship between Navy and Air Force weather operations, with substantial duplication of efforts.   But the new AF plan goes beyond this and is **highly wasteful of U.S. weather prediction resources**.

The Met.Office

To run a state-of-the-art global model requires large resources, including the acquisition and quality control of vast amounts of data from many different satellites. A high-resolution global model also demands huge computer resources. Clearly, Mr. Stoffler has not considered these issues in depth before proposing his new approach.

Let me underline the fact that there is no evidence that the UKMET office model is a superior regional model. WRF has far more physics options and is much more widely tested at high resolution around the world. UKMET Office global forecasts have slightly better verification scores in the Northern Hemisphere that the NOAA GFS, but these differences are small. Furthermore, the NOAA GFS model is now undergoing rapid improvements (made possible by the new supercomputers NOAA is getting this year) and I suspect that by the end of 2016, the GFS will be as good, if not better, than UKMET. Thus, the AF could well end up with an inferior global forecast.

But it is worse than that. The UKMET office model is known to be difficult and unwieldy to use, and there will be a hugely expensive spin up at the AF to run this model and connect it to their production suite of products. Resource demands in running a state of the science global model are huge. And as I have described in previous blogs, the U.S. has TOO MANY models running, resulting in division of effort and waste. The AF is taking the wrong road.

But let's be honest here. This situation is a warning to the National Weather Service and the U.S. weather modeling efforts---if the U.S. Air Force is making plans to use overseas modeling systems, this is not a good sign.

Major Impacts on WRF

Air Force funding has been critical for the viability of the national regional weather forecast system (WRF), the one used here at the University of Washington, by the way. The AF has been the main Federal financial supporter of WRF. The loss of AF funding will greatly undermine WRF and its future development (including the revolutionary global MPAS model that would be its successor). WRF is the model used in many key forecasting systems in the U.S., such as the National Weather Service High Resolution Rapid Refresh system. The economic and scientific impacts of the AF action would be large and damaging to the U.S. weather prediction enterprise.

What needs to be done

The U.S. meteorological community and others need to speak loudly to Air Force management, the current administration, Congress, and others to stop this ill-advised AF action. The damage to the U.S. weather prediction capacity and AF weather prediction will be substantial if the proposed plan is followed. There is time to turn this around and restore a rational approach to weather prediction modeling the in the Air Force. Here in Washington State, I hope our Senators, Patty Murray and Maria Cantwell, will intervene.

Sunday, March 18, 2012

The U.S. Has Fallen Behind in Numerical Weather Prediction: Part I

Part II found here.

It's a national embarrassment. It has resulted in large unnecessary costs for the U.S. economy and needless endangerment of our citizens. *And it shouldn't be occurring.*

What am I talking about? **The third rate status of numerical weather prediction in the U.S.** It is a huge story, an important story, but one the media has not touched, probably from lack of familiarity with a highly technical subject. And the truth has been buried or unavailable to those not intimately involved in the U.S. weather prediction enterprise. This is an issue I have mentioned briefly in previous blogs, and one many of you have asked to learn more about. It's time to discuss it.

Weather forecasting today is dependent on numerical weather prediction, the numerical solution of the equations that describe the atmosphere. The technology of weather prediction has improved dramatically during the past decades as faster computers, better models, and much more data (mainly satellites) have become available.

U.S. numerical weather prediction has fallen to third or fourth place worldwide, with the clear leader in global numerical weather prediction (NWP) being the European Center for Medium Range Weather Forecasting (ECMWF). And we have also fallen behind in ensembles (using many models to give probabilistic prediction) and high-resolution operational forecasting. We used to be the world leader decades ago in numerical weather prediction: NWP began and was perfected here in the U.S. Ironically, we have the largest weather research community in the world and the largest collection of universities doing cutting-edge NWP research (like the University of Washington!). Something is very, very wrong and I will talk about some of the issues here. And our nation needs to fix it.

But to understand the problem, you have to understand the competition and the players. And let me apologize upfront for the acronyms.

In the U.S., numerical weather prediction mainly takes place at the National Weather Service's Environmental Modeling Center (**EMC**), a part of **NCEP** (National Centers for Environmental Prediction). They run a global model (**GFS**) and regional models (e.g., **NAM**).

The Europeans banded together decades ago to form the European Center for Medium-Range Forecasting

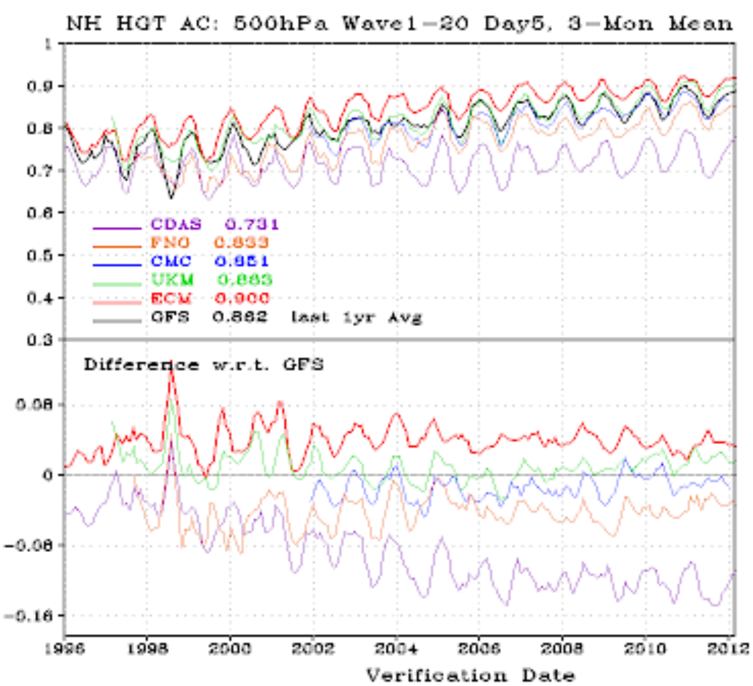
(ECMWF), which runs a <u>very</u> good global model. Several European countries run regional models as well.

The United Kingdom Met Office (**UKMET**) runs an excellent global model and regional models. So does the Canadian Meteorological Center (**CMC**).

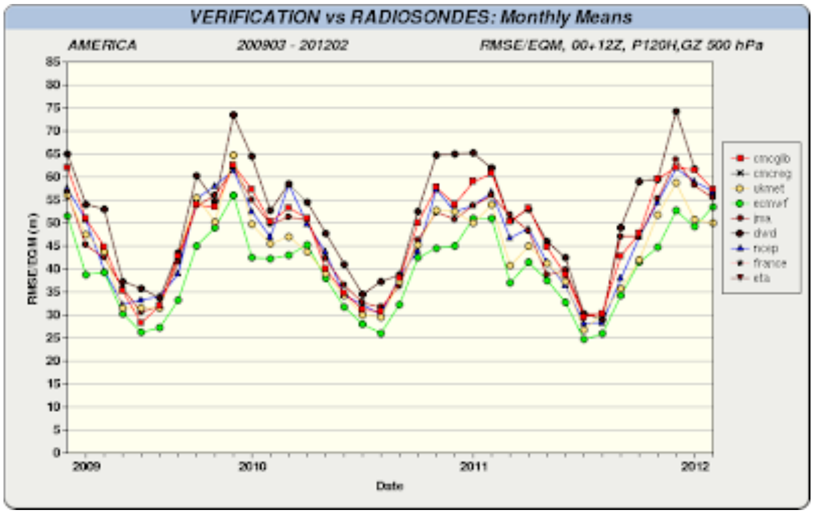
There are other major global NWP centers such as the Japanese Meteorological Agency (**JMA**), the U.S. Navy (**FNMOC**), the Australian center, one in Beijing, among others. All of these centers collect worldwide data and do global NWP.

The problem is that both objective and subjective comparisons indicate that the U.S. global model is number 3 or number 4 in quality, resulting in our forecasts being noticeably inferior to the competition. Let me show you a rather technical graph (produced by the NWS) that illustrates this. This figure shows the quality of the 500hPa forecast (about halfway up in the troposphere--approximately 18,000 ft) for the day 5 forecast. The top graph is a measure of forecast skill (closer to 1 is better) from 1996 to 2012 for several models (U.S.--black, GFS; ECMWF-red, Canadian: CMC-blue, UKMET: green, Navy: FNG, orange). The bottom graph shows the difference between the U.S. and other nation's model skill.

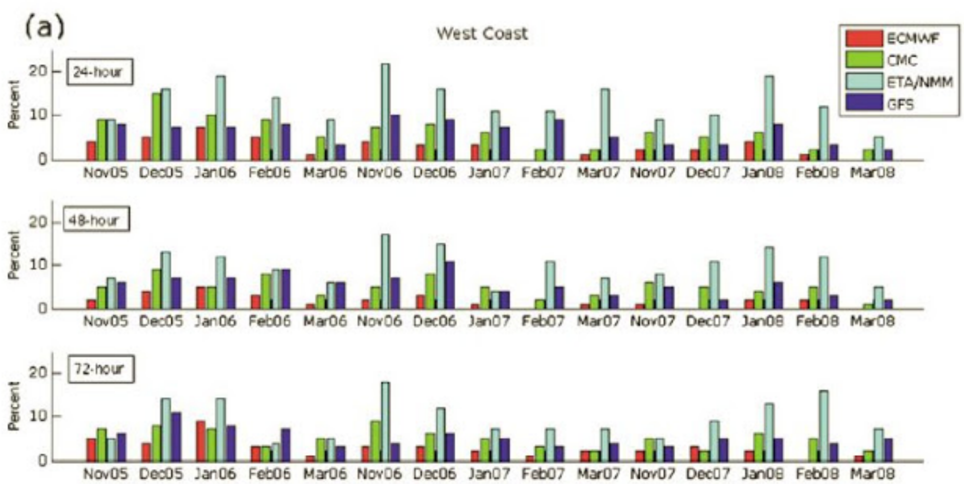
You first notice that forecasts are all getting better. That's good. But you will notice that the most skillful forecast (closest to one) is clearly the red one...the European Center. The second best is the UKMET office. The U.S. (GFS model) is third...roughly tied with the Canadians.



Here is a global model comparison done by the Canadian Meteorological Center, for various global models from 2009-2012 for the 120 h forecast. This is a plot of error (RMSE, root mean square error) again for 500 hPa, and only for North America. Guess who is best again (lowest error)?--the European Center (green circle). UKMET is next best, and the U.S. (NCEP, blue triangle) is back in the pack.



Lets looks at short-term errors. Here is a plot from a paper by Garrett Wedam, Lynn McMurdie and myself comparing various models at 24, 48, and 72 hr for sea level pressure along the West Coast. Bigger bar means more error. Guess who has the lowest errors by far? You guessed it, ECMWF.



I could show you a hundred of these plots, but the answers are very consistent. ECMWF is the worldwide gold standard in global prediction, with the British (UKMET) second. We are third or fourth (with the Canadians). One way to describe this, is that the ECWMF model is not only better at the short range, but has about one day of additional predictability: their 8 day forecast is about as skillful as our 7 day forecast. Another way to look at it is that with the current upward trend in skill they are 5-7 years ahead of the U.S.

Most forecasters understand the frequent superiority of the ECMWF model. If you read the NWS forecast discussion, which is available online, you will frequently read how they often depend not on the U.S. model, but the ECMWF. And during the January western WA snowstorm, it was the ECMWF model that first indicated the correct solution. Recently, I talked to the CEO of a weather/climate related firm that was moving up to Seattle. I asked them what model they were using: the U.S. GFS? He laughed, of course not...they were using the ECMWF.

A lot of U.S. firms are using the ECMWF and this is very costly, because the Europeans charge a lot to gain access to their gridded forecasts (hundreds of thousands of dollars per year). Can you imagine how many millions of dollars are being spent by U.S. companies to secure ECMWF predictions? But the cost of the inferior NWS forecasts are far greater than that, because many users cannot afford the ECMWF grids and the NWS uses their global predictions to drive the higher-resolution regional models--which are NOT duplicated by the Europeans. All of U.S. NWP is dragged down by these second-rate forecasts and the costs for the nation has to be huge, since so much of our economy is weather sensitive. Inferior NWP must be costing billions of dollars, perhaps many billions.

The question all of you must be wondering is why this bad situation exists. How did the most technologically advanced country in the world, with the largest atmospheric sciences community, end up with third-rate global weather forecasts? I believe I can tell you...in fact, I have been working on this issue for several decades (with little to show for it). Some reasons:

1. The U.S. has inadequate computer power available for numerical weather prediction. The ECMWF is running models with substantially higher resolution than ours because they have more resources available for NWP. This is simply ridiculous--the U.S. can afford the processors and disk space it would take. We are talking about millions or tens of millions of dollars at most to have the hardware we need. A part of the problem has been NWS procurement, that is not forward-leaning, using heavy metal IBM machines at very high costs.

2. The U.S. has used inferior data assimilation. A key aspect of NWP is to assimilate the observations to create a good description of the atmosphere. The European Center, the UKMET Office, and the Canadians using 4DVAR, an advanced approach that requires lots of computer power. We used an older, inferior approach (3DVAR). The Europeans have been using 4DVAR for 20 years! Right now, the U.S. is working on another advanced approach (ensemble-based data assimilation), but it is not operational yet.

3. **The NWS numerical weather prediction effort has been isolated and has not taken advantage of the research community.** NCEP's Environmental Modeling Center (EMC) is well known for its isolation and "not invented here" attitude. While the European Center has lots of visitors and workshops, such things are a rarity at EMC. Interactions with the university community have been limited and EMC has been reluctant to use the models and approaches developed by the U.S. research community. (True story: some of the advances in probabilistic weather prediction at the UW has been adopted by the Canadians, while the NWS had little interest). The National Weather Service has invested very little in extramural research and when their budget is under pressure, university research is the first thing they reduce. And the U.S. NWP center has been housed in a decaying building outside of D.C.,one too small for their needs as well. (Good news... a new building should be available soon).

4. **The NWS approach to weather related research has been ineffective and divided.** The governmnent weather research is NOT in the NWS, but rather in NOAA. Thus, the head of the NWS and his leadership team do not have authority over folks doing research in support of his mission. This has been an extraordinarily ineffective and wasteful system, with the NOAA research teams doing work that often has a marginal benefit for the NWS.

5. Lack of leadership. This is the key issue. The folks in NCEP, NWS, and NOAA leadership have been willing to accept third-class status, providing lots of excuses, but not making the fundamental changes in organization and priority that could deal with the problem. Lack of resources for NWP is another issue...but that is a decision made by NOAA/NWS/Dept of Commerce leadership.

This note is getting long, so I will wait to talk about the other problems in the NWS weather modeling efforts, such as our very poor ensemble (probabilistic) prediction systems. One could write a paper on this...and I may.

I should stress that I am not alone in saying these things. A blue-ribbon panel did a review of NCEP in 2009 and came to similar conclusions (found here). And these issues are frequently noted at conferences, workshops, and meetings.

Let me note that the above is about the modeling aspects of the NWS, NOT the many people in the local forecast offices. This part of the NWS is first-rate. They suffer from inferior U.S. guidance and fortunately have access to the ECMWF global forecasts. And there are some very good people at NCEP that have lacked the resources required and suitable organization necessary to push forward effectively.

This problem at the National Weather Service is not a weather prediction problem alone, but an example of a deeper national malaise. It is related to other U.S. issues, like our inferior K-12 education system. Our nation, gaining world leadership in almost all areas, became smug, self-satisfied, and a bit lazy. We lost the impetus to be the best. We were satisfied to coast. And this attitude must end...in weather prediction, education, and everything else... or we will see our nation sink into mediocrity.

The U.S. can reclaim leadership in weather prediction, but I am not hopeful that things will change quickly without pressure from outside of the NWS. The various weather user communities and our congressional representatives must deliver a strong message to the NWS that enough is enough, that the time for accepting mediocrity is over. And the Weather Service requires the resources to be first rate, something it does not have at this point.

Part II will discuss the problems with ensemble and high-resolution numerical weather prediction in the U.S.

U.S. Numerical Weather Prediction is Falling Further Behind: What is Wrong and How Can It Be Fixed Quickly?

Updated (see addition at the end)

It is a disappointing. The U.S. has the largest meteorological community in the world and led the development of numerical weather prediction for decades. The National Weather Service, stung by its relatively poor performance on Hurricane Sandy and publicity about inferior computers, was given tens of millions of dollars to purchase a world-class weather prediction system and to support forecast model development.

But the latest forecast statistics reveal an unfortunate truth: **U.S. operational weather prediction, located in NOAA's National Weather Service (NWS), is progressively falling behind the leaders in the field.** Even worse, a private sector firm, *using the National Weather Service's own global model*, is producing superior forecasts.

Something is very wrong and this blog will analyze why NWS global models are losing the race and **what can be done to turn this around**. As I will show, this situation could be greatly improved within a year, but to do so will require leadership, innovation, and a willingness to partner with others in new ways. I will also highlight a critical NOAA/NWS decision that will be made in the next several weeks, <u>one that will decide the future of US weather forecasting for decades.</u>

The Problem

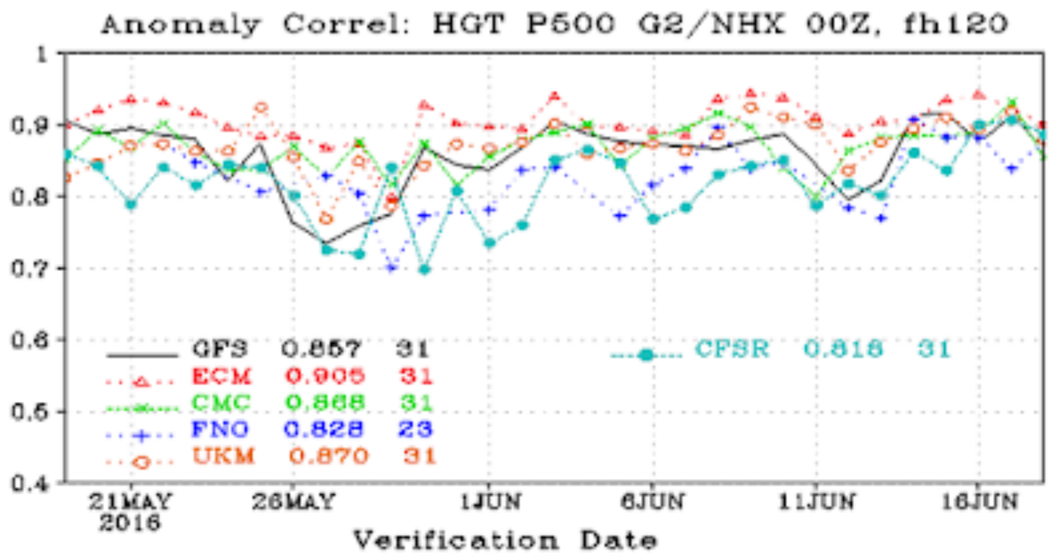
A number of media reports and several of my blogs have described the fact that U.S. numerical weather prediction (NWP) has fallen behind other nations and is a shadow of what this nation is capable of. **Global NWP is the foundation of all weather forecasts**, so it is critical to get this right. As we will see, it is not that U.S. global NWP is getting less skillful, but that other nations are innovating and pushing ahead faster.

For most of the last few years, U.S. operational global weather prediction, completed at the National Weather Service's Environmental Modeling Center (EMC) of NCEP (National Centers for Environmental Prediction), has been in third place: behind the world leader **ECMWF** (European Center For Medium Range Weather Forecasting) and the **UKMET** Office (the Brits). During the past several months, we have fallen further behind ECMWF and, to add insult to injury, the Canadians (the Canadian

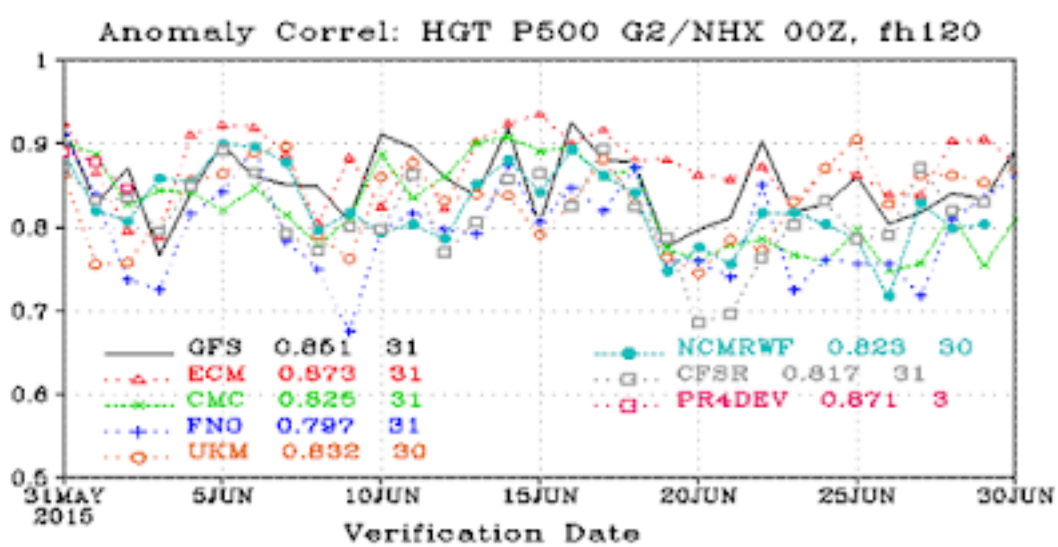
Meteorological Center, **CMC**) have moved ahead of us as well. US global weather prediction **is now in fourth place**, with substantial negative implications for our country. Let me demonstrate this to you.

One measure of forecast skill is *anomaly correlation (AC),* a measure of how well a forecast matches observations (it ranges up to 1, the best). Below is the AC for the Northern Hemisphere for the day 5 forecast, evaluated at the mid-troposphere (500 hPa, around 18,000 ft).

The ECMWF is the best (red triangles), with the UKM (yellow) second best. Black is the US global model (**GFS**). Note that the US GFS not only has generally lower skill, but sometimes has serious **dropouts**, periods of MUCH worse skill. The legend has summary numbers for the period, showing that the GFS is in fourth place, and the Canadians in third place (light green). These statistics are from a NOAA/NWS website.



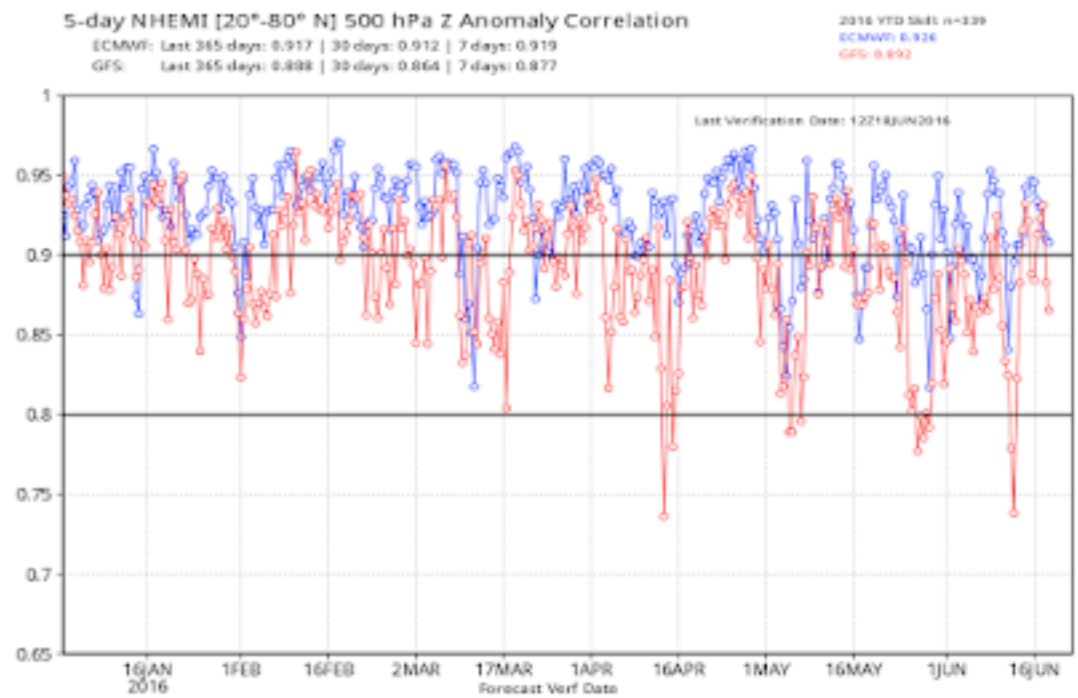
Let's compare this to the situation a year ago. Last June's statistics for the 5-day, Northern Hemisphere forecasts are shown below. We were ahead of the Canadians then. Look closely and you will see that difference between the US and ECWMF was less. I could show you many more plots like this that demonstrates that the US has fallen behind the leaders in global weather modeling.



During the past few months both the US and ECMWF upgraded their global models, but clearly the ECMWF upgrade was more effective, with ECMWF pulling further ahead.

A more detailed comparison (from WeatherBell analytics) of the US and ECWMF performance for 2016 is shown below (still 5 day forecast at 500 hPa) using the same verification measure (anomaly correlation).

ECMWF (blue color) is better nearly every day. Importantly, the ECWMF forecast is much more consistent, without the frequent (and substantial) drop outs of the US GFS. The U.S. (red colors) frequently declines to .8 or below, indicating of periods of large declines in skill. These are serious failure periods.



The bottom line is that Europeans and Canadians are pulling ahead of the U.S. National Weather Service in global weather prediction. I have a LOT more statistics to back this up if anyone has any doubts.

But it is worse than that. A private sector firm, Panasonic, has gone into the global weather prediction business **using the US global model (GFS) as a starting point**. Panasonic scientists have worked on fixing some of the obvious weaknesses in the U.S. modeling system and report they *have dramatically improved the forecasts over National Weather Service performance* (GFS model). They claim that their forecasts are not only better than the official US GFS model, but nearly equal to that of the vaunted ECMWF.

TV maker Panasonic says it has developed the world's best weather model

The company says it has beaten the GFS for a while and now equals the ECMWF.

by Eric Berger - Apr 6, 2016 8:36am PDT

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I have talked to the chief scientist at Panasonic, Neil Jacobs, and he has shared some of the verification statistics, which look good. I told him the only way to prove that they have the world's best global model would be to share the forecasts and let a neutral third party verify them. He agreed to do so, including sharing the forecasts with the University of Washington.   I doubt he would do that if their forecasts weren't as skillful as they claim.

Even worse? The US Air Force has abandoned the US GFS model, saying that it was inferior to the UKMET office model, which the AF will switch to.

So the National Weather Service's global model is falling behind international leaders AND a private sector firm starting with the same NWS model. Even the US military is abandoning it.   Can it get any worse?

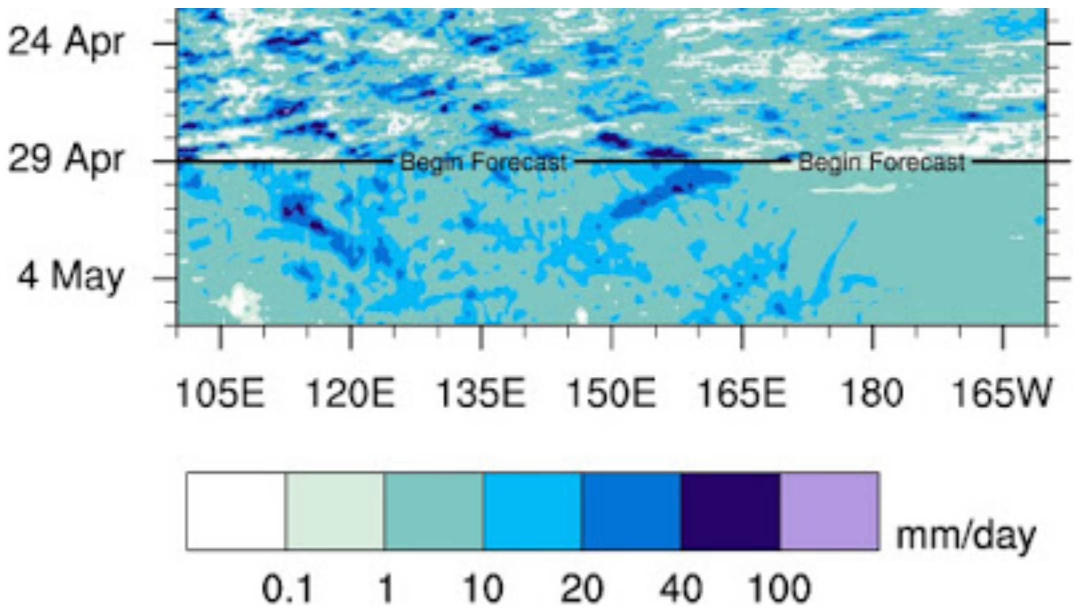
It can. The U.S. Congress gave the National Weather Service tens of millions of dollars for superb new computers, two CRAY XC-40s: one used for operations, and the other for development and backup.   Unfortunately, the operational computer is only being lightly used, with its vast capacity not being applied effectively to make critically needed improvements in U.S. NWP.

Key Deficiencies in U.S. Global Modeling

So why is US operational global weather prediction falling behind the leaders? Some of the problems with U.S. global weather predictions are well known and the essential "fixes" effected by Panasonic are no secret (and Panasonic should be commended for letting the community know what they are doing). To list only a few:

1.   T**he National Weather Service GFS has starkly inferior physics**, which means the descriptions of essential physical processes in the atmosphere. For example, the GFS model is using a primitive, two-decades old *microphysics scheme* (the software describing how clouds and precipitation work). As a result, there are serious errors in precipitation amounts and clouds, which in turn influences the evolution of the forecasts.

They are also using a very old and primitive *cumulus parameterization*, which describes the impacts of cumulus clouds and thunderstorms (called *convection*).
This results in poor prediction of convection, including critical features in the tropics (like the **Madden Julian Oscillation, MJO**), which in turn undermines extended range forecasts.



A plot of precipitation rate versus time and longitude for a portion of the western tropical Pacific (5N to 5S) for a two week period in April to early May 2016. Above the line are observations, and below the line is the US GFS model. Note how the character of the precipitation radically changes after the switch to the model. The model is doing a very poor job forecasting the character, amplitude, and movement of convection in the tropics. The ECMWF model is far better because they use a better cumulus parameterization (image courtesy of Michael Ventrice, the Weather Company, and University of Albany).

Importantly, the National Weather Service has few people working on model physics **and no strategic plan how to improve it.** Other centers (like ECMWF) have put great emphasis on physics and substantial scientific resources. Furthermore, the NWS has not entrained the expertise of the large US research community to help.

2. **The National Weather Service has less model resolution that its competitors.** The high-resolution ECWMF model has a grid spacing of 9 km compared to the 13 km used by the US GFS. More importantly, the ECMWF global ensemble system has TWICE the resolution of the American system (18 km grid spacing for ECMWF, 35 km for the US GFS). Ensemble systems play a critical role in data assimilation and probabilistic prediction. Considering the new computers acquired by the National Weather Service, this *resolution gap* is inexcusable.

ECMWF
EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS

3. The ECMWF, UKMET Office, and Panasonic have far superior **quality control** of observations. Quality control reduces the amount of bad data used in the forecast processes.

4. ECMWF, UKMET, and the Canadians use a superior *data assimilation* system called 4DVAR. Data assimilation uses observations and the model to produce the best possible initial state (the *initialization*) for the forecast. Better initial states produce better forecasts. ECWMF has been using 4DVAR since 1997.

5. The other leading weather modeling centers use a greater range and volume of observations in their data assimilation systems. ECWMF, for example, has applied a far greater range of satellite observations

than the US, and Panasonic has great volumes of aircraft data (called *TAMDAR*), that the National Weather Service has been unwilling to purchase.

6. The other major weather forecasting centers have detailed strategic plans and visions of their future directions. The National Weather Service has no real strategic plan for global weather prediction. Or any weather prediction. Recently, they began a process to acquire their next generation global model (called NGGPS, Next Generation Global Prediction System), something I will talk more about below.

TAMDAR data on short-haul aircraft, collected by Panasonic, can enhance the quality of forecasts.

7. Other major centers have entrained the help of the research community in an effective way. The National Weather Service, until very recently, was isolated and had a go-it-alone attitude towards global weather prediction. Even today, they have no rational, organized way to encourage and reap the benefits of academic community research. Trust me, this is something I know about.

8. Until last year, the National Weather Service had starkly inferior computing resources compared to ECMWF, UKMET, and other major centers. It provided an excuse for NWS prediction being second rate. Today, the National Weather Service has first class computing and Congress wants to keep it that way. So that excuse is gone. The National Weather Service has the computing power to push forward rapidly and innovate, if it has the will to do so.

The Big Decision: The New NWS Global Model--MPAS or FV3?

The National Weather Service is about to make a critical decision regarding the replacement of its out-of-date GFS global weather prediction model. And this decision is a huge one, deciding the fate of US global weather prediction for the next several decades.

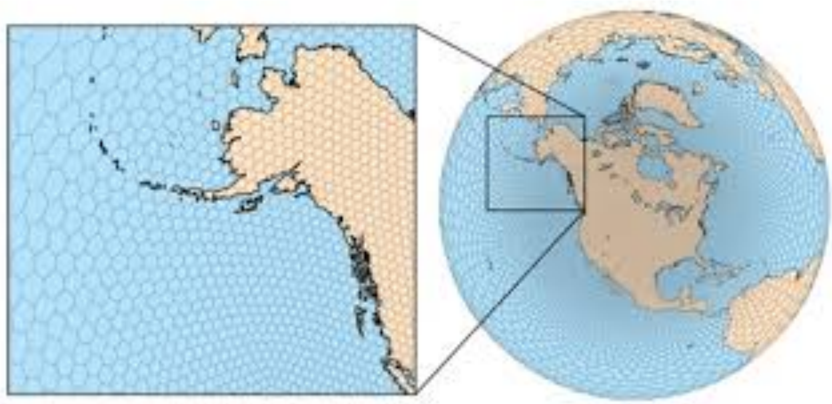
As noted above, this decision is part of a process called **NGGPS** and has been an attempt to rationally decide on the guts of the next US global model, something called its *dynamical core*. After testing a number of candidates, the choice is down to two.

The first is the MPAS model, developed by the National Center for Atmospheric Research, a consortium of US universities involved in atmospheric research. The second is the FV-3 model developed by the NOAA/NWS GFDL laboratory. As I have described in a previous blog, the clear choice is MPAS for many reasons.

MPAS
Model for Prediction Across Scales

MPAS uses an innovative geometry (hexagonal grid) that solves age-old model problems at the poles, while FV-3 uses a more traditional grid geometry. MPAS uses a superior grid structure (the "C" grid) that will produce far better high-resolution predictions than the problematic "D" grid of FV-3. And moving to high resolution is where global prediction is going.

MPAS allows local refinement of resolution without adding additional "nested grids", as shown by the figure below. And MPAS' superior numerics offer better inherent resolution for a particular grid spacing, so one can run with coarser grids than FV-3 and secure equally good results (which reduces computer demands).



But there is something that goes beyond grids and model numerics. **Something even more important.** By picking MPAS, the National Weather Service will combine efforts with the huge US atmospheric sciences research community, with that community's model innovations (including physics and data assimilation) flowing into the National Weather Service.   The isolation of NWS global prediction efforts would end.

But it is better than that. NWS research dollars could then help support global model research efforts that benefit both the operational and research communities. Other entities, such as the National Science Foundation, would able to help support research and development as well that would, in turn, improve operational skill, and hopefully a resurgent US global model, will bring the Air Force back into the fold.

But it is even better than that. A regional version of MPAS can be created and eventually replace the current regional model favored by the academic community, WRF, which was also developed at NCAR. So there is the potential for a national UNIFIED modeling system that could concentrate US weather modeling efforts, producing even more rapid advancement.

FV-3 grid

In contrast, the less innovative FV-3 model was developed by a small group in NOAA/GFDL with little experience in outreach and interaction with the university/research community.

You would think the global decision is obvious in favor of MPAS, but there are powerful voices inside NOAA that are pushing for an in-house solution.

The final decision on the future NWS global model will be made by Dr. Louis Uccellini, head of the National Weather Service. It will be one of the most important decisions he makes during his tenure. One choice, MPAS, will lead to a creative engagement with the US weather research community and the potential for the US to move rapidly into a leadership position in global weather forecasting. The other, FV-3, will continue and deepen National Weather Service isolation from the US academic community and continued mediocrity in global weather prediction.

In the mean time....

Even if MPAS is selected as the new U.S. global prediction model, it will take several years before the complete system is ready to go operational. As demonstrated by Panasonic, there are steps that the National Weather Service can take during the next six months to rapidly improve US global weather prediction. If I was the US weather prediction "czar", this is what I would do:

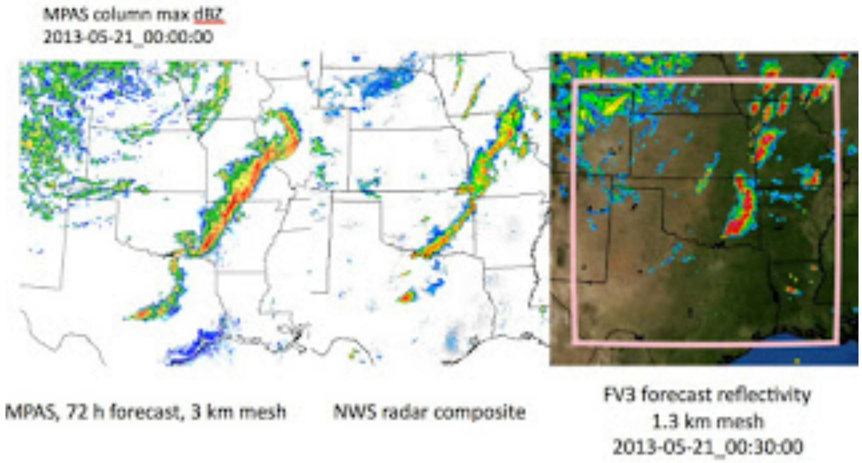
1. Start using the extraordinary capabilities of the new NOAA/NWS operational computers.

Increase the resolution of the US global ensemble system to 18 km (like ECMWF), increase the number of members to 50-75, and add physics diversity using stochastic physics. This will greatly improve US data assimilation and probabilistic prediction.

By increasing the resolution and quality of the global ensemble, the NWS can drop the redundant North America/only SREF (Short-Range Ensemble Forecast System), releasing more computer power for useful work.

2. Fix the obvious physics problems.

Update the model microphysics (moist physics) parameterization to something modern, like the well-regarded Thompson scheme used in WRF. Replace the old SAS convective scheme as well.



3. Improve quality control.

Follow the lead of Panasonic and upgrade the NCEP QC system.

4. *Work with the rest of the atmospheric science community (academia, private sector) to develop a detailed strategic plan for US numerical weather prediction and follow it.*

5. *Rework the structure and personnel of EMC, NCEP and NOAA labs to build coherent teams to work on key model issues (such as physics)*.

Final Comments

Numerical weather prediction is one of the most complex activities done by our species, requiring billions of dollars of hardware, understanding and modeling of physical processes from the microscale to the planetary scale, complex computer science issues, and much more. World leaders in numerical weather prediction understand this challenge and know that it requires organization, planning, coherence, a long-term view, and innovation.

For too long, the National Weather Service has developed it models in a disorganized ad-hoc way, in isolation from the US research community. They have learned the hard way that one can not do state-of-the-art weather prediction development and operations that way.

NOAA and the NWS must change the way they do global modeling if they are to provide that nation and the world with the best global weather prediction. The opportunity and resources are now in place. The question is whether NOAA/NWS leadership will take the right path.

Important Addendum: June 22

I disappointed by a NOAA presentation this morning regarding testing between the two global model finalists: the NOAA/GFDL FV3 and the NCAR MPAS. I will blog further about this, but a few major points:

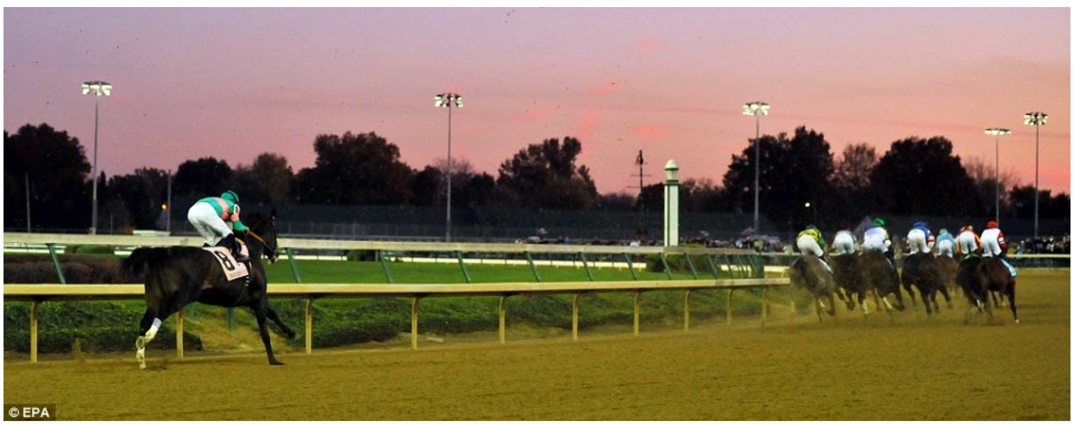
1. NCAR has pulled out because they feel the testing is inappropriate, and I have to agree.
2. All test models had to use the old GFS (current model) physics which are completely inappropriate at high resolution. In fact, GFS physics doesn't work well at any resolution. Like testing new racing cars on a muddy road--you can't do it.
3. The future of global prediction is at convection-allowing resolution (4 km or less grid spacing). But these resolutions were hardly tested (48 out of the 50 tests were at 13 km grid spacing or more).
4. Some of the results were clearly bogus, like the radically poor results of a 13-km forecast run and a hurricane simulation that had rain in the eye of the MPAS hurricane). Something was clearly wrong with the tests.
5. The testing had no vision of testing a configuration that might be used operationally in ten years (e.g., convection allowing over the globe). It was all about testing a configuration nearly identical to the current GFS.

Wednesday, October 29, 2014

The U.S. is Falling Further Behind in Numerical Weather Prediction: Does the Obama Administration Care?

The computational resources available to the U.S. National Weather Service (NWS) for numerical weather prediction **is rapidly falling behind leading weather prediction centers around the world**.

Unfortunately, the Obama administration does not seem to care and the U.S. is retreating into second tier status. Such a degradation is not only completely unnecessary, but needlessly weakens the economic competitiveness of the U.S. and puts our citizens at risk. Amazingly, Congress appropriated the money to address this problem **a year and a half ago**, but the administration has not made use of the funds. There are words to describe such inaction, but this is a family oriented blog.



Numerical weather prediction (NWP) is the central technology of weather forecasting. State-of-the-art weather prediction demands huge computer resources and thus the ability to forecast well **depends on access to the top supercomputers in the world**. Some numerical weather prediction models are run globally at moderate resolution, while others are run at ultra high resolution over smaller domains to predict small-scale features such as severe thunderstorms. Thus, a large nation, like the U.S., requires far more computer power than, say, South Korea or the United Kingdom.

During the past several years, I have blogged repeatedly about lack of computer power available to U.S. operational weather prediction, and particularly the forecasts made at the NOAA/NWS Environmental Modeling Center (EMC). Many others in the meteorological community have done the same. One and a half years ago, the U.S. Congress, recognizing the problem, provided NOAA with 25 million dollars to buy a more powerful supercomputer. **Amazingly, the U.S. administration has still not ordered the machine.**

The reason is that NOAA had signed a long-term contract with IBM (a bad move, by the way) and IBM sold their supercomputer hardware business to Lenovo, a Chinese firm. The administration did not want to purchase such a computer from a Chinese firm. And so nothing has happened.

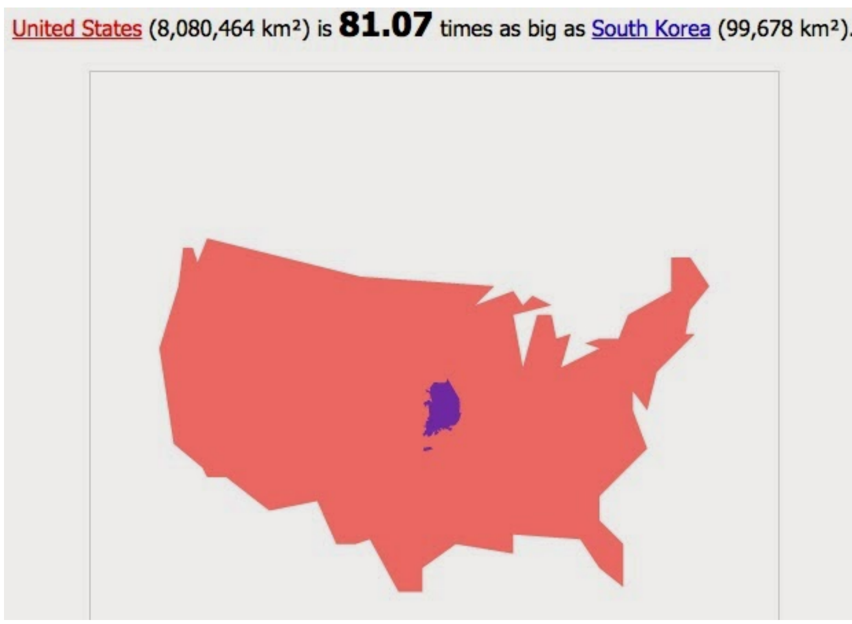
CRAY
THE SUPERCOMPUTER COMPANY

There were many options that could have fixed the problem. IBM could have purchased a supercomputer from CRAY, a U.S. firm. NOAA could have broken the contract with IBM. Or the administration could have gone ahead with the Lenovo machine (which was the same computer they would have bought anyway). But the Obama administration clearly is not very interested in weather prediction, and the problem has festered.

But it is worse than that. Other nations and groups are pushing ahead rapidly in weather computer acquisition, leaving the National Weather Service in the dust.

Yesterday, CRAY Computer announced the UK Met Office has ordered an extraordinary 125 million dollar system (CRAY's newest XC-40 hardware) that will delivery a throughput of roughly 15 petaflops (a petaflop is one quadrillion operations per second). The current NWS computer is capable of .21 petaflops and they are upgrading this fall to a machine of .8 petaflops. So the UKMET office will have TWENTY TIMES the computer power of the U.S. The area of the US lower 48 states is 33 times larger than that of the UK.

In June, the Korean Meteorological Administration (KMA) purchased TWO CRAY XC-30 computers, each capable of 3.1 petaflops. Yes, their new machines will be nearly FOUR TIMES faster than the UPGRADED U.S. weather computers. Let's see, Korea is 1/81 the size of the lower 48 states.



The European Center For Medium Range Weather Forecasting (ECMWF) just completed their first of several upgrades, buying two XC-30 computers from CRAY, each with 1.8 petaflops capacity--more than twice as fast as the U.S. upgrades. And importantly, ECMWF only does global prediction and thus does not have the responsibilities for high-resolution local forecasting like the National Weather Service. They need far less computer power, yet possess far more than the U.S. operational center.

Heard enough? I have more examples, but the message is clear: **the U.S. is rapidly falling behind in thecomputational resources necessary for high quality numerical weather prediction.** Sadly, this administration has the funds for a major upgrade, one that would at least secure a petaflop machine capable of revolutionizing U.S. weather prediction, but they can't seem to figure out how to buy it.

I know a lot of people inside NOAA and National Weather Service, including scientists working on the next generation of weather prediction models. Many are frustrated by the lack of computer power--one of them recently complained to me there is not enough computer resource to **test** promising advances.

My back-of-the envelope-calculation is that the National Weather Service needs a minimum of 20-30 petaflops of computer power to provide the American people with state-of-the science weather prediction that would improve the life of everyone in important ways.

For example, there are several reports by the U.S. National Academy of Sciences and other advisory groups suggesting that the U.S. needs ensembles (many forecasts run simultaneously) run at high resolution (2-3 km grid spacing) to provide better forecasts of thunderstorms, and particularly severe ones. Such ensembles would greatly improve the detailed weather forecasts for smaller-scale features in the rest of the country (Northwest folks, think Puget Sound convergence zone or mountain precipitation). But the NWS simply does not have the computer power to do it. New multi-petaflop machines would make it possible.

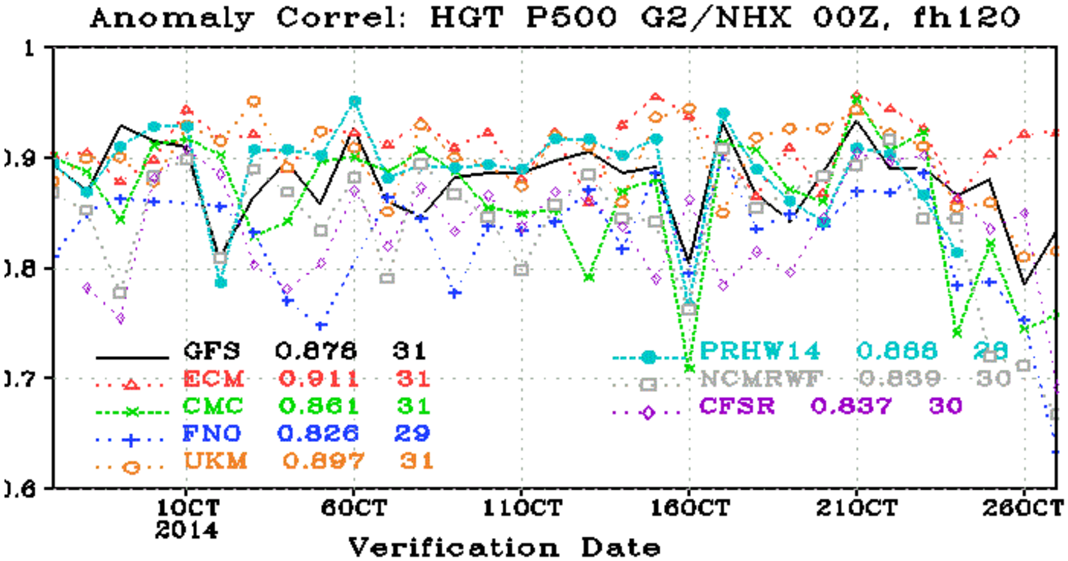
Defying drizzle: UK to build world's fastest weather forecasting supercomputer

By Sebastian Anthony on October 28, 2014 at 2:02 pm | 17 Comments

U.S. companies fork over millions of dollars a year to the European Center for the best forecasts...that would end with the new computers. And there are so many other critical forecast problems that would be lessened with more computer power, like better hurricane predictions days to a week out.

The U.S. atmospheric sciences community is the intellectual leader in meteorology and weather prediction and many of our research advances are applied overseas, such as at ECMWF and the UKMET office. The American people deserve to take advantage of the research they are paying for, but that can't happen with inferior computers and inferior forecasts. And yes, our forecasts are still inferior, with the NWS unable to match the resolution and data assimilation approaches of its rivals overseas.

Want proof? Here are the latest statistics for global 5-day forecasts at 500 hPa (about 18,000 ft above sea level) for several major international forecasting centers during the past month. Higher (closer to 1) is better. The top group is the European Center (ECM,the red triangle), with an average score of .911. The U.S model (GFS) is nearly always below them and had frequent and disturbing "drop outs" where forecast skill plummeted for a day or so (U.S. average is .876). Second place is the UKMET office (orange circles, .897) and expect them to soar with their new hardware. U.S. forecasters in their weather discussions frequently talk about their dependence on the European Model. Unfortunate.



And we can't simply use the European Center for our weather predictions, since they will **never** do the high-resolution prediction over the U.S. than we need, among other things. That is the job of the National Weather Service.

So folks, how do we fix this?

First, the Obama administration needs to start taking weather prediction seriously, which they obviously don't. The President's Science Adviser John Holdren seems to be fixated on climate issues and does not appear to appreciate that good weather prediction is a primary means of protecting the American people from current and future extreme weather events. The administration needs to figure out a way to order a large multi-petaflop machine for the National Weather Service, getting past the objections of some bureaucrats about Lenovo computers. Or simply order a CRAY (I had lunch with a CRAY representative and they are enthusiastic about helping).

The President and Science Advisor John Holdren need to give more priority to weather prediction

Second, the American people and the weather community need to complain loudly about the current situation. The media can help us get the message out, something they did to great effect to secure the funding in the Sandy supplement in the first place.

Third, our congressional representatives need to make this a major issue and push the administration to act.

As I have noted in my earlier blog, securing adequate computer resources is only the first step in producing a renaissance in U.S. weather prediction capabilities. But it is a critical and important first step, and it is time to finally deal with this self-inflicted problem. Weather prediction is essential national infrastructure, like highways and education. With second rate infrastructure, a nation declines.

If nothing is done by September 2015, the money for the new weather supercomputer will be lost. It would be a tragedy for U.S. weather prediction and the American people. Let's make sure this does not happen.

Time to teach ECMWF some humility

Clifford F Mass
Short Narrative Biography

Cliff Mass is a professor of atmospheric sciences at the University of Washington. His specialty is numerical weather and climate prediction and the meteorology of the western U.S.

Cliff Mass majored in physics at Cornell University, where he worked with Astronomer Carl Sagan on a model of the Martian atmosphere and with Stephen Schneider of NCAR on climate modeling.

After Cornell he entered the Ph.D. program at the University of Washington, with his doctoral work on African wave disturbances, the forerunners of tropical storms and hurricanes in the Atlantic.

Leaving the UW, Cliff joined the faculty of the Meteorology Department at the University of Maryland, where he taught synoptic meteorology and weather prediction, and worked on a variety of research topics, from Northwest weather circulations and high-resolution modeling, to the climatic implications of the Mount St. Helens eruption.

After three years at Maryland, Cliff moved to the University of Washington as an assistant professor in the Department of Atmospheric Sciences. During the next few decades, Cliff and his students have systematically studied the weather and climate of the western U.S., completing over seventy papers on West Coast phenomena as varied as orographic precipitation, coastal surges, the Catalina Eddy, and the Puget Sound convergence zone, to onshore pushes, downslope windstorms, and various local gap winds. Numerical simulation has been a key tool for his group, which now runs the most extensive local high-resolution prediction system in the United States. He is also heavily involved in regional climate modeling for the western U.S.

Cliff has been involved in a number of other initiatives, including the acquisition of coastal radar on the Washington coast, improving the infrastructure of the National Weather Service, the use of smartphone pressure observations for weather prediction, and the improvement of K-12 math education. He is the author of the 2008 book “The Weather of the Pacific Northwest” and broadcasts a weekly weather information segment on KNKX, a local public radio station. Cliff also writes a weather blog (cliffmass.blogspot.com)

Cliff Mass, a full professor at the UW, is a fellow of the American Meteorological Society, has been an editor of a number of meteorological journals, is a member of the Washington State Academy of Sciences, has published over 120 papers, and has served as a member of a number of National Academy committees. He is currently a member of the WRF Research Applications Board, a member of the NOAA/UCAR UMAC committee, and a member of several American Meteorological Society committees. He is now working on a new book "The Secrets of Weather Prediction."

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Ph.D., University of Washington 1978
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Doctoral Thesis: "A Numerical and Observational Study of African Wave Disturbances." J. R. Holton, adviser.

Professional Experience

Mid 1981 to present	Assistant, Associate Professor, and Professor, Department of Atmospheric Sciences, University of Washington.
1978 to mid 1981	Assistant Professor, Department of Meteorology, University of Maryland.

Books

The Weather of the Pacific Northwest, University of Washington Press
The Secrets of Weather Prediction, in preparation.

Refereed Publications

Conrick., R., J. Zagrodnik and C. F. Mass, 2019: Dual-polarization radar retrievals of coastal Pacific Northwest rain drop size distribution parameters using random forest regression. Submitted *to J. Atm. Ocean Tech.*

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Mass, C., and M. Albright, 1985: A severe windstorm in the lee of the Cascade mountains of Washington State. *Mon. Wea. Rev.*, **113,** 1261-1281.
Mass, C., and A. Robock, 1982: The short-term influence of the Mount St. Helens eruption on surface temperature in the northwest United States. *Mon. Wea. Rev.*, **110**, 614-622.
Robock, A., and C. Mass, 1982: The Mount St. Helens volcanic eruption of 18 May 1980: Large short-term effects. *Science*, **216**, 595-610.
Mass, C., 1982: The topographically forced diurnal circulations of western Washington State and their influence on precipitation. *Mon. Wea. Rev.*, **110**, 170-183.
Mass, C., 1981: Topographically forced convergence in western Washington State. *Mon. Wea. Rev.*, **109**, 1335-1347.
Mass, C., 1980: The Puget Sound convergence zone. *Weatherwise*, **33**, 272-274.
Mass, C., 1979: A linear primitive equation model of African wave disturbances. *J. Atmos. Sci.*, **36**, 2075-2092.
Mass, C., and S. H. Schneider, 1977: Statistical evidence on the influence of sunspots and volcanic dust on long-term temperature records. *J. Atmos. Sci.*, **34**, 1995-2004.
Holton, J. R., and C. Mass, 1976: Stratospheric vacillation cycles. *J. Atmos. Sci.*, **33**, 2218-2225.
Mass, C., and C. Sagan, 1976: A numerical circulation model with topography for the Martian southern hemisphere. *J. Atmos. Sci.*, **33**, 1418-1430.
Schneider, S. H., and C. Mass, 1975: Volcanic dust, sunspots, and temperature trends. *Science*, 190.

Electronic Publications

National Meteorological Center Grid Point Data Set CD-ROM (Versions I and II).
GALE Experiment CD-ROM.
North American Observational Data for August-December 1987 CD-ROM.
World Weather Disc CD-ROM.
Climate Analysis Center Global Gridded Data

Offices and Honors

Fellow, American Meteorological Society
Max Eaton Award, American Meteorological Society
President, Puget Sound Chapter, American Meteorological Society.
Program Chairman, Puget Sound Chapter, AMS.
Treasurer, Puget Sound Chapter, AMS.
Chairman, UCAR (University Corporation for Atmospheric Research), UNIDATA Data Access Committee.
Associate Editor, Monthly Weather Review.
Consulting Editor, Encyclopedia of Climate and Weather.
Chairman, UCAR Committee on Meteorological Data Sets
Chairman, 15th AMS Conference on Weather Analysis and Forecastings
Chairman, Special Workshop on Real-Time Mesoscale NWP in the University Community

Chairman, AMS Mesoscale Meteorology Committee
Chairman, DTC Science Advisory Board
Co-chair, AMS Committee on Communication

National Committees

Exec. Committee AMS Forecast Interest Group
AMS Membership Committee
AMS Board on Enterprise Communication
DTC Science Advisory Board
WRF Research Applications Board
NRC Committee on Atmospheric Predictability
AMS Ad-Hoc Committee on Community Fora
Chairman and member, USWRP CONDUIT committee
USWRP Science Advisory Board
WRF Science Board
Chairman and member, AMS Mesoscale Committee
USWRP PDT#4 on Mountain Meteorology
USWRP PDT#9 on Hydrology
AMS Committee on Weather Analysis and Forecasting
MM5 Community Oversight Committee
AMS Information Systems Committee
UCAR/NWS Local Digital Library Committee
UNIDATA Steering and Data Access Committees
National Academy of Sciences Geophysical Data Committee
UCAR COMET Advisory Committee
Search Committee for New NWS Director
Executive Committee, Board of Oceans and Atmosphere, National Association of State Universities and Land Grant Colleges
UCAR UCAM Committee

Regional Committees

Northwest Regional Modeling Consortium

University Committees and Organizations

Member and Chair: College Council, College of the Environment
Member, University Senate 1988-1990, 2004-2006
Department Computer Committee
Arts and Sciences Graduation Committee
Department Rules and Computer Committees

Past Graduate Students

Kucera, T., 1981: M.S. on mesoscale modeling in complex terrain.
Delman, A., 1981: M.S. on diurnal wind and temperature variations and air quality in Washington, D.C. area.
Dubofsky, D., 1981: M.S. on a diagnostic study of Hurricane David.
Dempsey, D., 1985: Ph.D. on mesoscale modeling in complex terrain.
Pam Speers, 1985: M.S. on precipitation diagnoses and modeling in complex terrain.
David Portman, 1988: M.S. Effects of major eruptions on surface temperature and pressure.
Daniel Brees,1988: M.S. Onshore push of the Pacific Northwest.
Brian Ulrickson, 1989: Ph.D. 3D primitive equation modeling of flow in the LA basin.
Garth Ferber,1991 M.S. Mesoscale pressure perturbations forced by the Olympic Mountains.
David Schultz, 1992, M.S. Structural analysis of a midlatitude cyclone over land.
Brian Colle, 1994, M.S. Northerly surges to the east of the Rocky Mountains.
Jim Steenburgh, 1995, Ph.D: Mesoscale modeling of synoptic/orographic interactions.
Brian Colle, 1997, Ph.D: Dynamics of windstorms in three dimensional terrain
Fang-Ching Chien, 1997, Ph.D: Interaction of fronts with coastal topography.
Ken Westrick, 1998, M.S.: Coupling of atmospheric and distributed hydrological models.
Richard Steed, 1999, M.S.: Initialization of mesoscale forecasting models.
Eric Grimit, 2001, M.S.; A Short-Range Ensemble Prediction System
Justin Sharp, 2002: M.S.: A Study of the Meteorology of the Columbia River Gorge
Tony Eckel, 2004: Ph.D. Effective Short-Range Mesoscale Ensemble Prediction.
Eric Grimit, 2004: Ph.D. Predicting Forecast Skill Using a Mesoscale Ensemble System
Justin Sharp, 2005, Ph.D. Modeling study of the flow in the Columbia River Gorge.
Brian Ancell, 2006, Ph.D. Adjoint and ensemble-based forecast sensitivity
Bri Dotson, 2007, M.S.. Structure and dynamics of major Pacific windstorms.
Garrett Wedam, 2008, M.S. Errors in numerical prediction models
Robert Hahn, 2008, M.S. Understanding of microphysical errors in numerical models.
Ken Dixon, 2013: M.S. Lightning Data Assimilation
Michael Warner, 2014. M.S. , Ph.D. Heavy precipitation events of the U.S. West Coast
Lee Picard, 2015. MS. An idealized model of orographic precipitation
Matt Brewer, 2017: Ph.D. Structure and dynamics of the thermal trough
Luke Madaus, 2016. Ph.D. Initiation of convection and smartphone data assimilation
Brandon McClung, 2019, M.S. Diablo Winds.