10. Choosing the Right Axis: An institutional history of the Belgrade Eta forecast model[1]

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Introduction

Since the 1950s, it has become a usual assumption to look at the dramatic developments of computing technologies as a necessary condition in the business of weather prediction; the use of high-speed state of the art computers has been repeatedly described as a foundation for solving the complex mathematics of the even more complex physics of the atmosphere. Not only has the super-computer shortened the time of forecasts, it has also made an impact on theory in that it put numerical meteorology center stage. Thus Jule Charney wrote of the "great psychological stimulus that the very possibility of high-speed computation brought to meteorology", and Akira Kasahara claimed that "when it comes to the bottom line, whoever has the faster computer will win".[2] Kasahara was right: the people and institutions that developed and applied numerical weather forecast have always had access to the best machines and a steady income: Charney's group worked on von Neumann's Meteorology Project on ENIAC and the IBM machines at Princeton and Maryland in early 1950s. Thompson and Platzman gave courses in numerical prediction at MIT and Chicago in 1953, while the main research groups included the Air Force Cambridge Laboratory, the British Meteorological Office, and the International Meteorological Institute of the University of Stockholm. In Russia, Obukhov, Buleyev and Yudin worked on STRELA computers and kept pace with the groups on the other side of the iron curtain.

An important dimension of this research was and still is numerical modelling, a cooperative (at least ideally) work and development of algorithms and models designed to solve the equations of atmospheric dynamics: and the most important moments in the development of NWP are associated with American, Russian and Western European research teams. The issue can be raised to what extent has this research, done as it was in the big cold-war super power countries by people like Charney and Arakawa, excluded (or included) work and results of other research teams, those who, for example, had inadequate computing facilities and inadequate funding resources? The question is quite simple: if weather prediction research was a matter of expensive computer equipment and financial support – as it has been argued by those involved in it – could it be done on an as-it-were technological and financial periphery, in the countries and institutions that suffered from a chronic lack of resources?

My answer to this question will be incomplete of course, as I will merely scratch the surface of one case study, the numerical weather prediction modelling in Socialist Federative Republic of Yugoslavia during 1970s and 1980s. But even with this limitation, my answer will, I hope, point to a fascinating confluence of Yugoslavian weather modelling, needs of the local economy and the regional politics of knowledge. I want to show how this confluence resulted in the now one of the most skillful numerical models of weather prediction in the world, and how the model achieved such success despite the fact that it was designed in a country with erratic science funding and an inadequate computing equipment. Far from saying that the success of the model was entirely due to it being made in Belgrade, it is still true that the interests and the lines of research of its creators reflected priorities of local forecasting needs that, in turn, were defined by climate of Yugoslavia. As we will see in more detail below, Yugoslav climate is significantly influenced by the mountainous terrain of the South-west Balkan peninsula and the strong cyclogenesis in the west and central Mediterranean.

My emphasis on local circumstances shaping Yugoslav NWP – represented in research orientation, availability and quality of technologies, manpower, collaboration, and funding – is intended to alert us to the possibility that a "non-Western" socio-political actors could exert enough power to shape and "customize" local scientific research. Such a conclusion goes against some of the recent science and technology studies which tend to assert that the knowledge produced in less developed countries does not normally takes into account these countries economic needs: "by adopting Westernized science and Western organizational forms, less developed countries help to promote comparability and compatibility but not solutions to local problems". The positive correlation between economic wealth and research productivity may indicate the fact that "only wealthy countries can support the luxury of prestigious "fundamental" research".[3] The Eta research seems to contradict both claims partly because Yugoslavia of the 1970s was a country that was "less developed" in a different way than India, China, or Brazil and partly because the modellers acquired some of their expertise abroad. The story of Eta, however, demonstrates that the precondition for "fundamental" research and high-quality weather prediction depended neither on scientific funding nor fast computers. Rather, the models success could be credited to the very lack of those!

Early history of Eta: HIBU model

Eta model and its predecessor HIBU model were created by Fedor Mesinger and Zavisa Janjic, professors and researchers at the Meteorological Institute of the University of Belgrade. During the early 1970s, when he first thought of developing a regional model, Mesinger had already been associate professor at the University of Belgrade. During the 1960s, he had spent one year at the Department of Meteorology in Darmstadt, two years in Boulder at NCAR, half a year in Paris, and from 1967 to 1970 at UCLA working with the renown numerical meteorologists Akira Arakawa and Yule Mintz, whose style of research would remain a major factor in the history of Yugoslav model. Co-author Zavisa Janjic had by the early seventies finished his graduate work under Mesinger's supervision, have spent a year in Reading and had henceforth become an important force in the development of Eta. Clearly, Mesinger's and Janjic's was not merely a "home-grown" expertise. In Belgrade, however, new priorities began to conspire with their experience leading to a new project, a creation of a limited area model for weather prediction.

Belgrade in the sixties was not a major meteorological or scientific center; neither a member of Warsaw pact nor NATO, Yugoslavia was a political island of what some described as a socialism with the human face and a leader (with India and Egypt) of the so-called Non-Allied movement that comprised the today's "Third World". Yugoslavia was also one of the Balkan countries, bordering Italy in the west and Bulgaria, Romania and Greece in the East and South. University of Belgrade's Institute for Meteorology was a modest outfit with half-a-dozen researchers; work on NWP was done mainly by Petar Gburcik, but his approach was increasingly perceived as obsolete. The Federal Weather Bureau, where some of the early forecast were run, had an inadequate computing facilities (CDC 3600 and IBM 360/44), and the money available for research and development incomparably less than that given in the West.

Sometimes in the late 1960s, Mesinger, the creator of the first version of the model, suggested that a limited area model could and should be developed in Belgrade in order to provide reliable forecasts for Yugoslavia and the region. Aware of technical and institutional limitations, Mesinger thought that even if the numerical resolution for a Yugoslav limited area model (the resolution refers to how finely the atmospheric processes could be represented on a numerical grid) could not be better than the resolution used in the models of the major centers, "*more successful design, in particular regarding aspects of special regional significance*, could be expected to lead to better forecasts some of the time and hopefully when it really mattered; real-time access to in-house NWP data offered numerous application prospects superior to those if only access to an outside center were to be relied upon".[4] In other words, in Mesinger's view, a computational insufficiency would be compensated by the ingenuity of model's design and by the inclusion in the code of a most important parameter in Yugoslavian climate – the mountains.

The model is the so-called "limited area model" or "regional model" and is used to make short term – and presumably more accurate –forecasts for a limited geographic area. Limited area models were in a sense a spin off of the global (hemispheric) circulation modeling; as a field of research it emerged during the late 1960s, sometimes in the form of "subprograms" of the then very prominent Global Atmospheric Research Programme (GARP). If regional models – in a *numerical* sense – served the needs of specific regional weather services in a concrete *geographic and geopolitical* sense, it is worth asking what these needs were and whether they translated in the model design. Could a locally constructed "limited area model" be used in regions with different forecasting requirements? And should a regional model made *outside* major meteorological centers, necessarily reflect the status of computing facilities available to researchers in those local centers. Mountains, small computers and socialist science organization were to be the building blocks of a new model's algorithm. How did it look?

Mountains and Cyclones

Mesinger's primary considerations in the mid-seventies was the numerical introduction of mountains and cyclones in model's simulation. In a letter sent to a Yugoslav colleague in Cairo, he wrote: "I wrote a short paper on energy equations in sigma system, because, supposedly, that's what we need with all our mountains and so Djura Radinovic (a collaborator at the Weather Bureau) and I are now doing transformations of potential into kinetic energy for that case of Genoa cyclogenesis".[5] In 1971, when the Organizing Committee of the Global Atmospheric Research Programme begin to establish research centers, Mesinger thought the topographic simulation was an opportunity for Yugoslavian researchers to carve their niche in the arena of European and American meteorology . He wrote to Chairman of the Yugoslavian National Committee for Geophysics that “many of the aims of GARP are of extraordinary importance for a small country like Yugoslavia , and the problems associated with the specific meteorological conditions of the country (that is, the great influence of topography) cannot be expected to be solved by other countries”. Joining GARP would not only give Yugoslavian science an international lustre, it would enable that some of the resources of that community be used for local purposes.[6]

From the initial recommendation that members of WMO can submit sub-program project proposals within GARP, in 1971, Mesinger argued that Belgrade Institute should be a center for the project entitled “Regional Modelling in areas under significant influence of mechanical and thermal characteristics of the surface”. This document explained that the development of the numerical model for weather forecast, especially in the South-Eastern Europe, involved a research on problems of the influence of middle-range mountains on weather processes, thermic effects of surface ground in regional models, the problem of assimilation of initial conditions in small space ranges and the regional forecast with time-dependent boundary conditions. In 1974, after the proposal was accepted, the plans were underway to organize an international meeting on the topic in Montenegro’s seaside resort St. Stephan. The conference was a success: the guests included authorities such as Obuhov, Eliassen, and Egger.[7]

The problems listed in Mesinger’s GARP proposal were those on which he and Zavisa Janjic worked in the early seventies. A brief history of the model runs something like this: an early version was developed by Mesinger during the winter of 1973. The code is written by hand and contained about 400 lines. All subsequent versions of the code were alterations or expansions of this early versions but several principal elements of the code remained unchanged. Those included Arakawa’s approach to model’s dynamics, the so-called semi-staggered numerical grid and the formulation of lateral boundary conditions. In the next several years Janjic had added a new scheme for horizontal advection, the conservation of energy and enstrophy; and improved on Arakawa’s hydrostatic equation. Early stages of the implementation of the model in the work of Yugoslav Federal Weather Bureau were carried out from 1975, and the model was operational from January 1, 1978. By this time, Egypt and Ireland were considering using the model for daily operational use.

Several moments during this period are worth emphasizing so that they can elucidate the particularities of the model: First, during their early work in the seventies, Mesinger and Janjic were always conscious of the need to be economical in terms of computer resources. They also knew that this economy should not be achieved at the expense of accuracy and that it was not good use of model designer’s time to be more efficient by mastering the code possibilities of the specific computer: computers being creatures of a short life span, there was no sense in making a computer-specific code.

“Arakawa school” that Mesinger imbibed during the stay at UCLA was consistent with this attitude, as it had as one of its major principles avoidance of computational modes that generated noise at the smallest scales. This principle minimized the need to have artificial smoothing mechanisms in place at these scales. Smallest scales were not looked upon as a nuisance, with features to be filtered out, as many people did and still do, but scales to extract maximum benefit from that one can. Mesinger thus made two important early choices that helped the efficiency of the code and that differed from the ones used at several leading centers: the choice of the Arakawa’s E (or, B/E) horizontal grid, and the choice of the split-explicit time differencing scheme, of which Mesinger learned from Alan Gadd, at a meeting in Reading, May 1973.

As a result, in the mid- and late seventies Mesinger and Janjic were able to "squeeze" a decent-size, four-layer, model into an extremely small computer used at the Federal Weather Bureau. Later, when a comparison with the Nested Grid Model (NGM), the operational LAM of the U.S. National Meteorological Center (NMC), started to take place, the Eta was in its basic numerical design more efficient by a factor of four! Mesinger recently observed that this "compensated for an enormous NGM effort of extracting maximum advantage of the so-called vector-processing and special code features of the NMC's CYBER computer in the mid-eighties, so that, in formal efficiency, time per number of grid points, we were not behind".[8]

Secondly, in 1971, Mesinger pointed out the need for developing a long term project in numerical weather prediction (perhaps with Belgrade's collaboration with NSF, where such funds were available at the time). He argued that in a new model, high level atmospheric parameters would be taken as known, and the model would predict surface parameters. That way, he wrote, "it would be possible to use a known forecast from a big center and use it to make a local forecast".[9] This regional project, as the Bulgarian meteorologist Bojkov told Mesinger, could receive up to 800.000 dollars from WMO's development fund, but the funds were never released. Nevertheless, Mesinger and Janjic continued to build network with other Balkan researchers, hoping to establish a research center in Belgrade that would include countries neighboring Yugoslavia and have as its objective to develop the HIBU model for the so-called routine "fine-mesh" forecasting for the region.

One of the features of the model which particularly promised its regional use was its ability to correctly simulate the so-called Genoa cyclogenesis, a frequently formed center of the low pressure in the Italian Genoa Bay. The Genoa lows have a powerful impact not only on the Italian, but also and especially on Yugoslavian and Balkan weather. When in October 1976 Mesinger wrote to colleagues in Zagreb and Boulder about Janjic's improvement in the model's hydrostatic equation, he was excited that the simulation of Genoa cyclogenesis now worked better, with cyclogenesis taking place entirely below 500 mb, which, it should be added, was a considerable improvement. During late seventies, at least two Italian meteorologists took interest in HIBU model, because, according to one of them, it was "the only way to achieve new results on the lee cyclogenesis problem".[10] Mesinger pointed out that this was due to the fact that the model simulated the so-called "steep mountains, steeper than those one obtains by space averaging of the observed topography". The model used these mountains to better simulate the blocking effects of real topography.[11]

The third and related issue associated with HIBU modelling was the choice of the vertical coordinate. The vertical coordinate normally used to simulate topographic influences was the so-called sigma-coordinate, introduced by Norman Phillips in 1957. The sigma kept with the idea of the terrain following lowest coordinate surface, but from October 1975, Mesinger and Janjic saw that sigma system generated drastically unrealistic temperature forecasts (as well as other errors such as pressure gradient force, advection and lateral diffusion problems).[12] They eventually showed that the pressure gradient force error was not due to calculation. In 1984, Mesinger decided that a radical approach should be undertaken in entirely abandoning the sigma system (after almost 30 years of its use) and introducing the so-called *eta-coordinate* or eta-system which was based on the use of "step-mountains". The coordinate surfaces in this new *eta-model* remained everywhere quasi-horizontal and the sigma-system errors disappeared. The introduction of the step-coordinate and eta-system was a therefore motivated by the good results that the HIBU model was already obtaining with the simulation of “steep mountains” used in Genoa cyclogenesis.

Eta Model performed with flying colors: in the parallel run of Eta versus Sigma for the case of Genoa cyclogenesis, eta had lower noise than sigma. In the case of a 1984 Appalachian storm re-development, unlike eta’s faithful simulation, neither the then operational US National Meteorological Center’s Limited Area Forecast Model nor the Nested Grid Model successfully simulated the storm.[13] By early 1990s, the model has been further improved at NMC Washington, and was successfully implemented in the tropical forecasts, over Europe and many other areas all around the world. It is operational in the US NMC (today’s NCEP) since 1993. At this time, however, Janjic and Mesinger had secure posts at the Washington’s National Center for Environmental Prediction (formerly NMC) and their reputation grew as the model found more and more users. Today, Eta is operational for daily weather forecasts in Belgium, Brazil, Egypt, Finland, Greece, Iceland, Malta, Peru, South Africa, Tunisia, USA and Yugoslavia.

Concluding remarks

What does this brief history tell us about Yugoslavian weather modelling and of scientific work in “less developed” or socialist countries? First, we should note that the success of Eta did not come from the use of super-computers – on which Eta did eventually run – but from a meticulous optimisation of regional weather conditions which was geared toward the needs of the country’s weather services. This optimisation involved the Belgrade/Arakawa “kind of efficiency”, and the better choices of numerical schemes which yielded performance benefits. Second, unexpected benefits were coming from the sheer fact of doing research in 1970s Yugoslavia. It is possible, as Mesinger has recently done, to link the outstanding international success of Eta with to the Yugoslav (or perhaps, Eastern European) educational context. In his opinion, Yugoslav natural science education puts strong emphasis on *why* things work rather than on *how* they work, which, in Mesinger’s words, “stands in stark contrast to the style I’d say is typical of universities in the [United] States as I have gotten to know it, where the emphasis was on efficiency, on a lot of homework, on doing things, on doing a lot of them, and fast. Thus, we would question things which others did not, and we have taken our time to do it. This has paid off”.[14]

This does not mean that that Yugoslav scientist in general in the 1970s put more emphasis on “fundamental” research than did their counterparts in the US or Britain, but it does suggest that Belgrade meteorological Institute nurtured a particularly research-friendly climate that probed into questions overlooked by the large and well-funded institutes in the West. This also means that the crucial distinction between “why” and “how” approach was not only a matter of education culture or individual inclination – in case of Mesinger and Janjic there was a considerable degree of “cross-pollination” between East and West European and American learning styles – but the consequence of dynamics that allowed for more research time devoted to fundamental issues. Belgrade meteorologists were not pressured to produce papers to justify a research contract, which is typically achieved by running numerous experiments and writing reports. Such a practice leaves only a fraction of time for looking into major and untapped problems. It is well-known, as Mesinger observed,

> that one can hardly apply for a research contract to thinking about a problem. You apply for a research contract to do what you already know you can do. We engaged in much less activity of that kind than our counterparts at major say U.S. modelling centers; and we still could do some computing at modest computers in

Belgrade… our coming from a place of modest resources, did help, in making it possible for us to do well in Belgrade in the seventies, and in contributing significantly to our doing well in crucial comparisons with the NGM in the late eighties.[15]

Endnotes

[1] I greatly appreciate the help of Professor Fedor Mesinger in my attempt to grasp the history and scientific aspects of the Eta Model and for giving me permission to use his correspondence. I wish to extend my gratitude to the participants of the Symposium on the History of Meteorology at the Mexico City Congress for useful comments and references.

[2] Quoted in Frederik Nebeker, *Calculating the Weather: Meteorology in the 20th Century,* San Diego, Academic Press, 1995, pp. 152, 164.

[3] Wesley Shrum and Yehouda Shenhav, "Science and Technology in Less Developed Countries", in S. Jassanoff et al. eds., *Handbook of Science and Technology Studies,* London, Sage, 1995, 627-651, pp. 632, 631.

[4] Fedor Mesinger, "Limited Area Modelling: Beginnings, state of the art, outlook", in *50th Anniversary of NWP Symposium,* Potsdam, European Meteorological Society, 2000, 85-112, p. 88.

[55] Mesinger to Vesna Jurces, 23 November 1966. All correspondence is held at the Hydrometeorological Institute of the University of Belgrade.

[6] Mesinger to Abdulah Numinagic, 28 January 1971.

[7] Mesinger to Dusko Djuric, 21 April 1976.

[8] Mesinger, personal communication, June 2001.

[9] Mesinger to Dusko Djuric, 16 June 1971.

[10] Stefano Tebaldo to Zavisa Janjic, 5 January 1977.

[11] Mesinger to Akira Kasahara, 16 March 1977.

[12] Zavisa I. Janjic, "The Step Mountain Coordinate: Physical Package", *Monthly Weather Review,* 118 (1990), 1429-1443, p. 1429.

[13] Fedor Mesinger et. al., "The Step-Mountain Coordinate", *Monthly Weather Review,* 116 (1988), pp. 1493-1518.

[14] Mesinger, personal communication, June 2001.

[15] Mesinger, personal communication, July 2001.