John P. Boyd. Multiscale Numerical Algorithms for Weather Forecasting and Climate Modeling: Challenges and Controversies. *SIAM News*, 41(9) 2008

John Boyd (jpboyd@umich.edu) is a professor in the Department of Atmospheric, Oceanic, and Space Science at the University of Michigan. This article is based on the invited talk he gave in San Diego, at the 2008 SIAM Annual Meeting.

GCM: 在低分辨率网格上运行（相比forcast代码），模拟很长时间（many model years, and months of wall-clock time），从任意的初始条件，达到静态平衡，即climate模拟；

Global weather forcasting models (GWFM)：在很高分辨率网格上运行，模拟5~10天的过程，从观测的（或再分析数据）的初始条件，得到确定性的预报。

LAM (Limited Area Model)是macroadaptive：对飓风或大陆使用很高分辨率网格，内嵌在运行于低分辨率网格的GCM内。

每个模式有一个"dynamic core"，是流体力学，以及"physics"，是一个非常误导的名字：很多包含辐射传输、海气耦合、边界层湍流、云物理、水文循环以及生化循环等的子程序。GCM已超过百万行代码。上述很多过程都强非线性的，strongly耦合。

A GCM or GWFM is the computational embodiment of a bar fight in a John Wayne western. The code cowboys who wrangle these megacodes are acutely aware that they are herding not sheep, but rather a flock of subroutines, ornery and independent as a herd of professors.

数学家？

Mathematics department missionaries have often sallied forth to mathematize the eteorological primitives and spread the gospel of new algorithms. They are invariably surprised when the ungrateful savages tie them to a stake. As the bonfire is lit, they wail, “But it works for Burgers’ equation!”

气象学家？

Meteorologists don’t give a darn what works for Burgers’ equation. Real atmospheric models suffer from Brittle Bone Syndrome: With so many interacting nonlinear feedbacks, atmospheric models “break if you breathe on them,” to quote Mark Cane of Columbia.

自适应网格？

Adaptive mesh refinement (AMR) is a good illustration. Can “microadaptation,” which is a feature-following fine grid of complex topology, succeed?

Christiane Jablonowski实施了AMR有限体积法的气象模拟，能够很好模拟小尺度山地的波动，但实际上有很多山，网格会扭曲在一块。

Hence, the more spiritual code cowboys murmur the Adaptive Mesh Refiner’s Prayer:

*Please, God, No Waves!*

The “physics” is also perilous for AMR. 有些物理参数化方案对网格分辨率很敏感，如降雨，如图1，一座小山迫使空气抬升，绝热扩散，冷却、饱和，即使格子内的平均相对湿度小于100%。为允许压格子尺度的地形驱动的雷雨产生，模型对流必须当q<100%开始。逻辑上，q(h)阈值随着格子尺度*h*减小而增大。如此的与尺度相关的参数，有时脱离路线，在粗网格处产生降雨，但在细网格处，对流阈值更高，而不能降雨。如果自适应做的很好，对流应该是最强的。很多过程必须有相似的参数化，使得地球物理学家发出呐喊：

Deliver Us from the Physics!



其他的挑战！

mokita: something that we all know but agree not to talk about.

Logarithmic Law of Arithmurgy：见解随浮点运算数而对数形式增加。

Extended Moore’s Law：计算能力与科学数据也随着时间指数增加。

Corollary(必然结果): Linearity of Progress with Time：注定知识随着时间线性增加。

见图2.



图2 长期看来，知识随浮点运算（虚线）对数增长，知识随时间现象增长。网格空间变的足够细，求解新的现象或尺度，见解是跳跃式增加（实线）。

Lorenz现象

Similar behavior in real forecasting codes implies that an exponential improvement in initial conditions, number of grid points, and so on extends the window of useful forecasting only linearly, as illustrated in [1].

Current forecasts are useful for about five days, but it is theoretically impossible to extend the window more than two weeks into the future, if that. There is still room for progress, however: in doubling tornado warning times, narrowing hurricane tracks, and extending global forecasts another day or two. Even so, weather and climate are fields of incremental improvements rather than dramatic breakthroughs, such as the discovery of buckyballs.

不同的GCM，或相同GCM使用不同的参数，产生的结果是一个概率分布。

Gerard Roe andMarcia Baker [2] have argued convincingly that the nonlinear feedbacks, ostly positive and reinforcing, will never be known sufficiently well to narrow the probability distribution any time soon

Is climate prediction hopeless? Not quite. As Philip Thompson said in 1976,

“We can’t forecast weather beyond five days. So, now let’s do something really hard: predict climate decades into the future! Even so, it’s worth a try because the potential payoff is so huge.”

数学家与地球科学家的合作

The National Science Foundation’s Collaborations in Mathematics and Geosciences program has helped. We can hope that SIAM will be a breeding ground for the “mathematics plus” that is so badly needed in geophysical fluid dynamics.

## 参考文献

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