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50+ Years of NWP: Supercomputers and the Models that Consumed Them: A sordid tale of codependence

Geoff DiMego

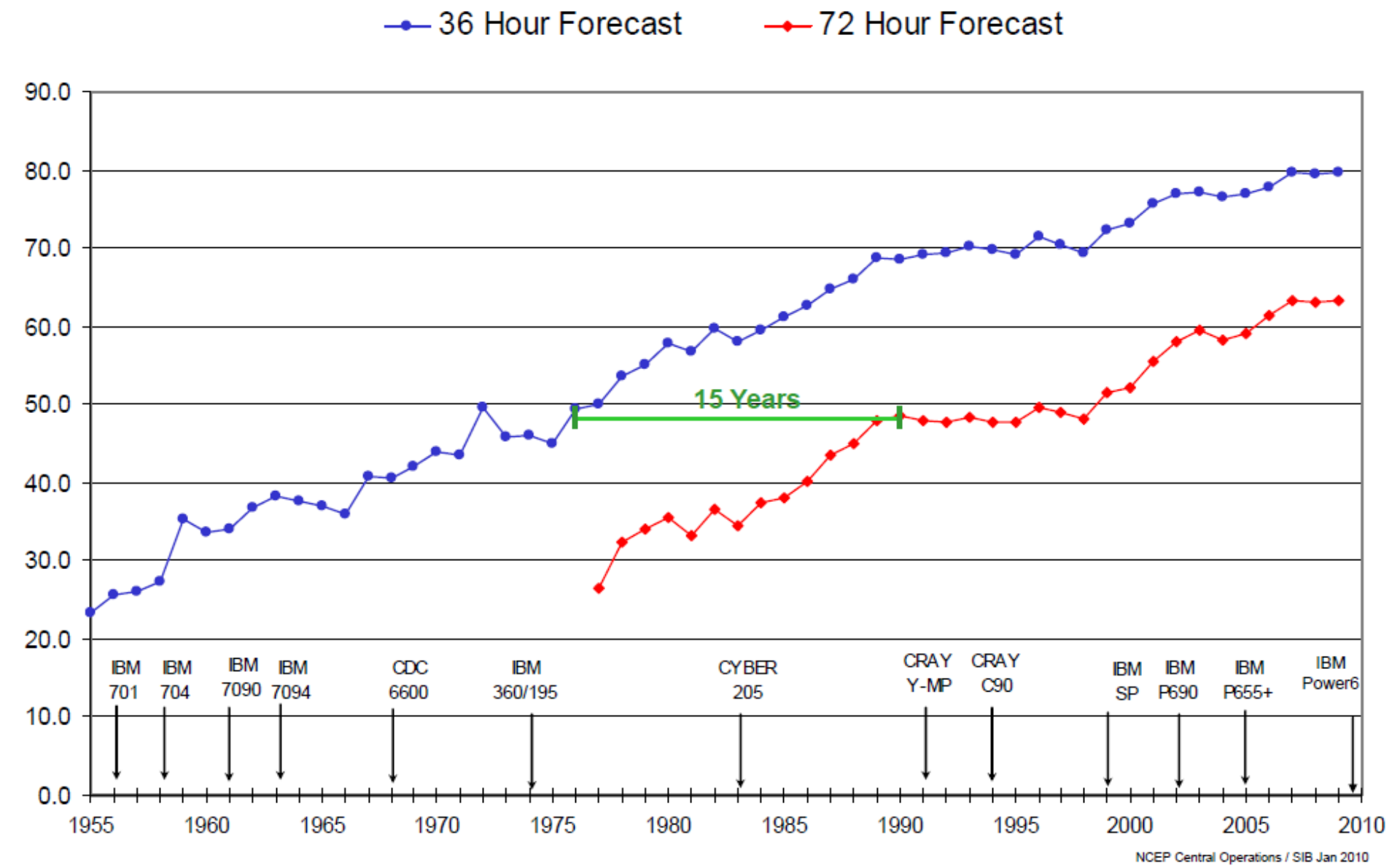
4 October 2010

where the nation's climate and weather services begin

NCEP Operational Forecast Skill

36 and 72 Hour Forecasts @ 500 MB over North Ameri

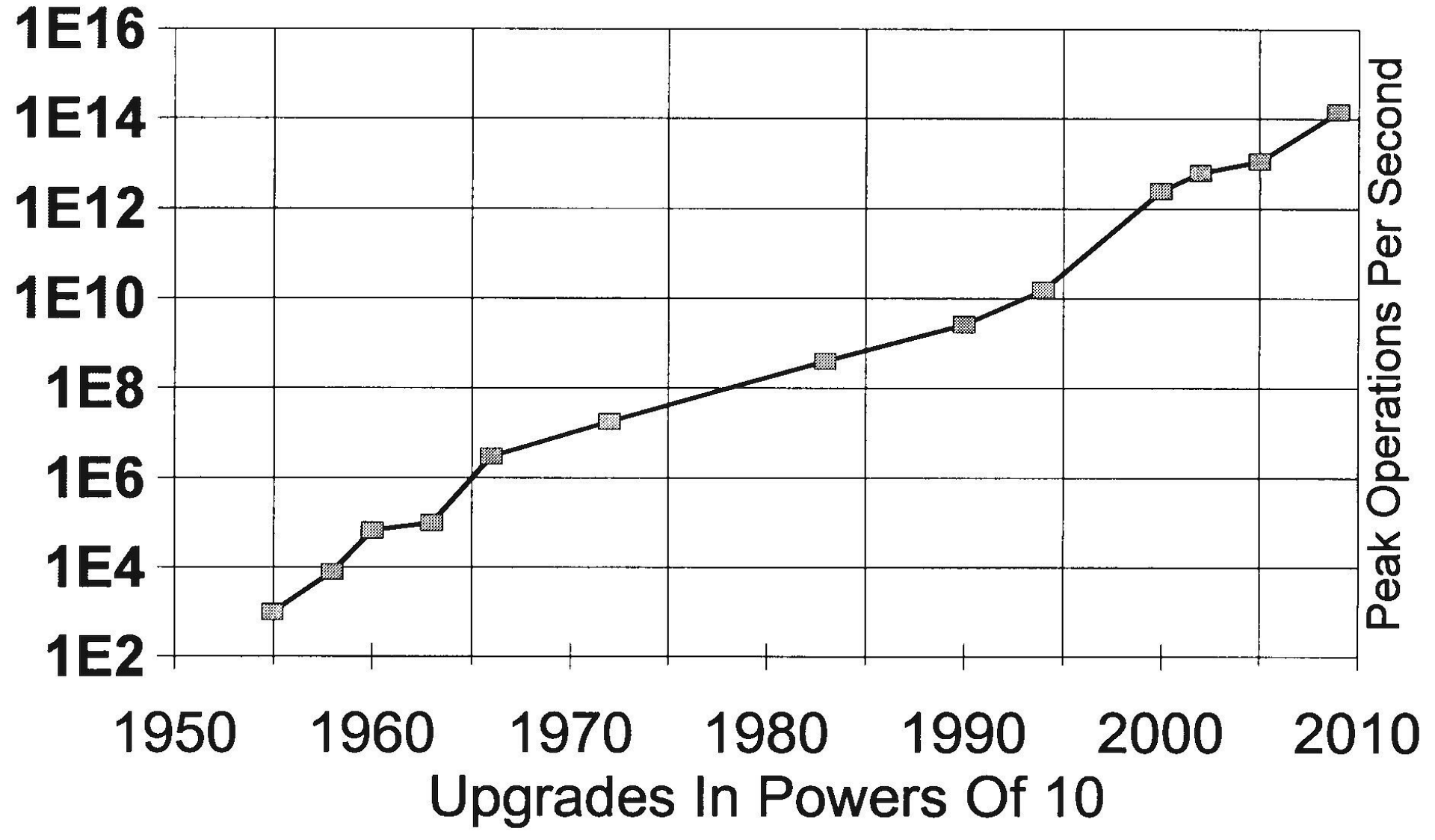
[100 * (1-S1/70) Method]



NCEP Central Operations / SIB Jan 2010

Peak Performance Trend

1954/JNWP Unit 1958/NMC 1997/NCEP



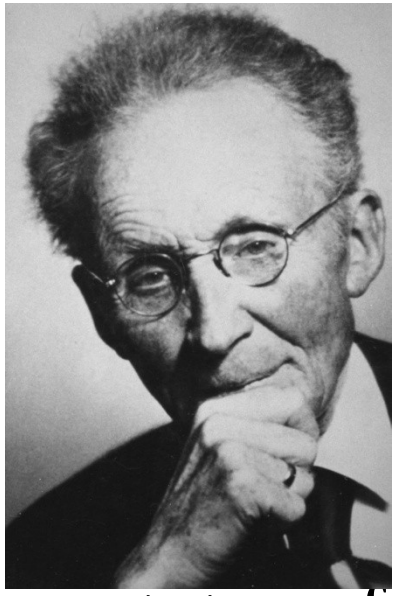
CAVEATS & APOLOGIES up front

- In fleshing out this story,
  - I will be biased towards US, NMC & NCEP
  - I will not cover everything (you expect)
  - I will not give credit to everyone (you would)
  - Therefore, by definition, I will disappoint some, if not, ALL of you.

- Sorry, you'll just have to deal with it.

Beginnings & First Transitions

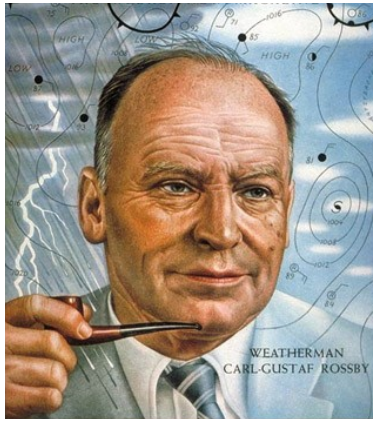
Vilhelm Bjerknes



who, in 1904, declared the problem of prognosis as the integration of the equations of motion for the atmosphere ... that future states of the atmosphere are dictated by its detailed initial state and known boundary conditions. His students at the Bergen School were strongly influenced by Bjerknes and would become future giants of our discipline: Carl-Gustav Rossby, Arnt Eliasen and Ragnar Fjortoft. (see Kalnay Cambridge Press)

C-G Rossby Mentorship Chain

From BAMS: Lewis, 1992



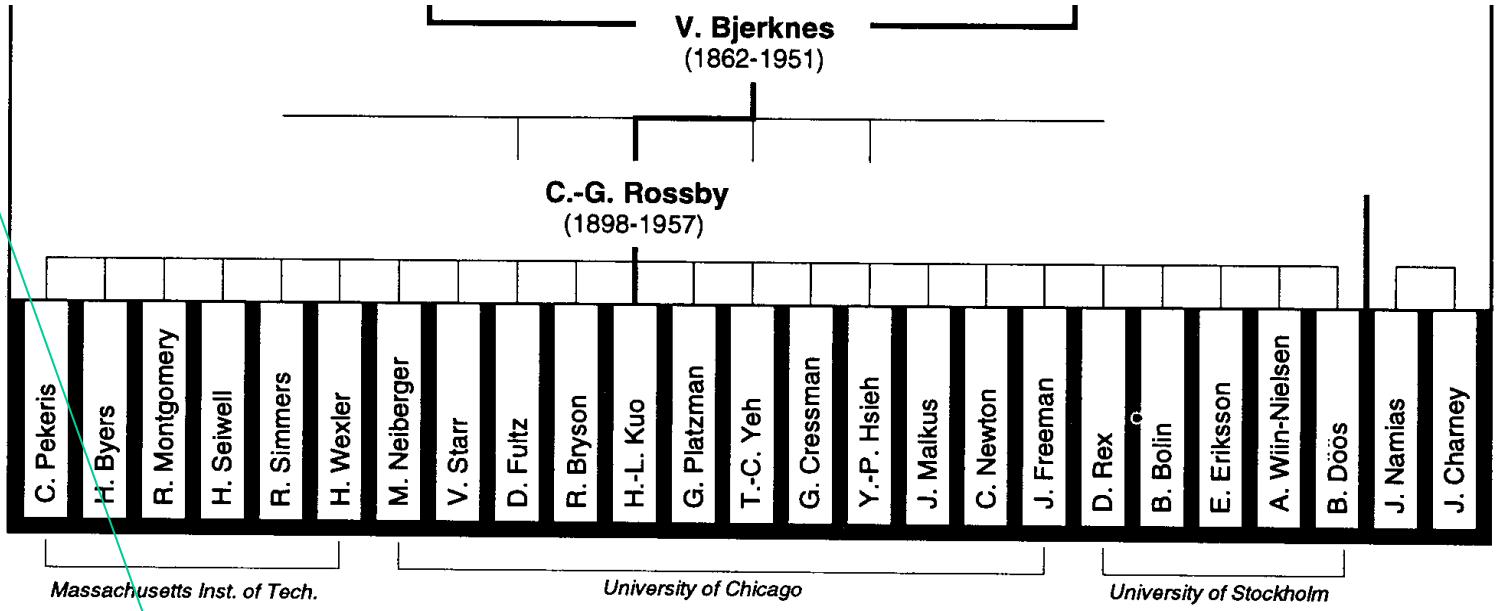


FIG. 7. The mentorship chain of C.-G. Rossby. The protégés are listed chronologically on the bottom from left to right, based on the date of the doctoral degree.

Norm Phillips, Fred Schuman et al.

Massachusetts Inst. of Tech.

C. Pekeris
H. Byers
R. Montgomery
H. Seiwell
R. Simmers
H. Wexler

University of Chicago

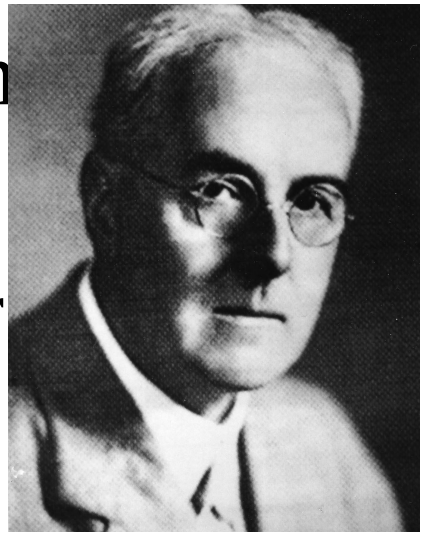
M. Neiberger
V. Starr
D. Fultz
R. Bryson
H.-L. Kuo
G. Platzman
T.-C. Yeh
G. Cressman
Y.-P. Hsieh
J. Malkus
C. Newton
J. Freeman

University of Stockholm

D. Rex
B. Bolin
E. Eriksson
A. Wiin-Nielsen
B. Döös
J. Namias
J. Charney

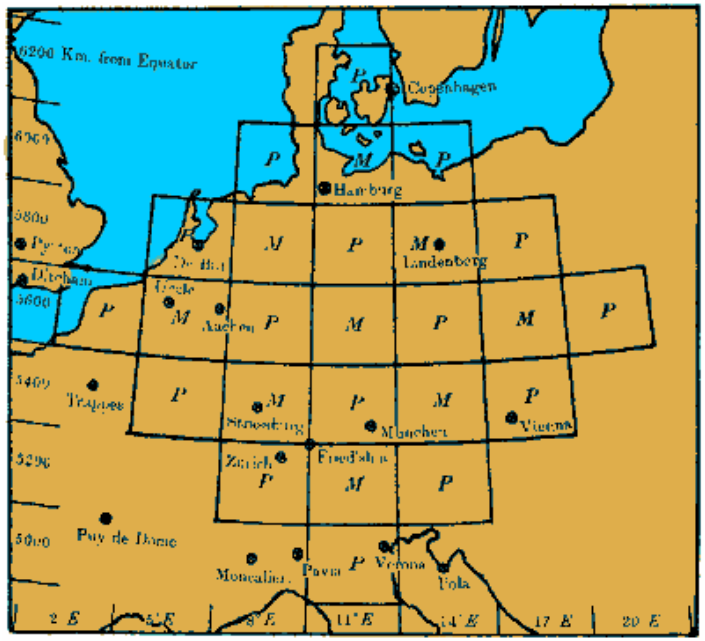
The First Attempt

L. F. Richardson



who first laid out a numerical model and actually performed the computations (by hand!) during WWI.

The grandfather of Numerical Weather Prediction (NWP)



He failed, in large part, due to his choice of an unfiltered form of the governing equations.

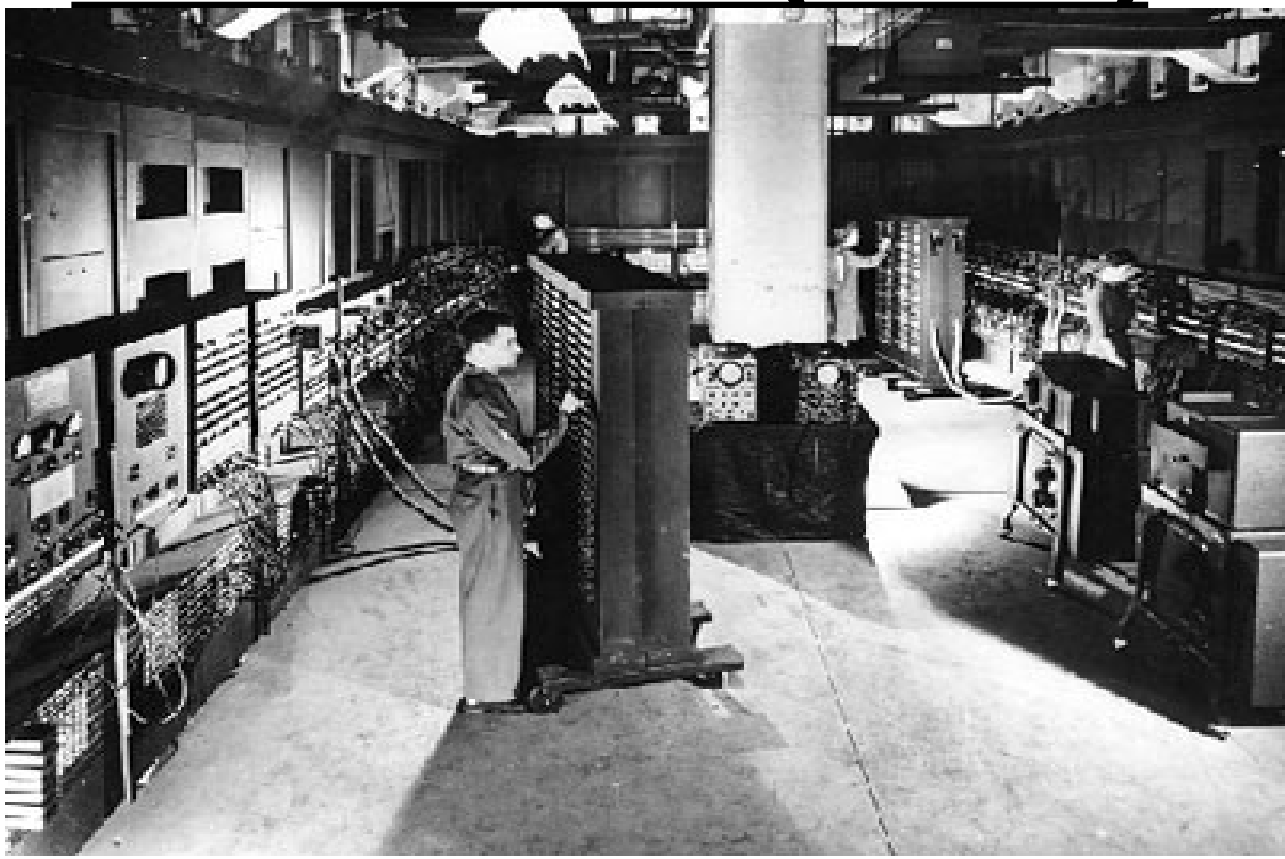
1906: De Forest Audion Vacuum Tube

through FORTY YEARS of countless developments, leads to ...

E N I A C (1946)

Electrical
Numerical
Integrator
And
Calculator

Aberdeen, MD



Jule Charney, Fjortoft, Eliassen and John von Neumann of Princeton's Institute of Advanced Studies made the first 48 hr barotropic filtered model forecast on ENIAC in 1949

1952: IBM Unveils the IBM-701

1952: IBM 701 - The Company's First Fully Electronic Computer

Thomas Watson, Sr. (seated) the CEO of IBM in 1952 using the IBM 701 computer, the company's first fully electronic model. This computer also had the ability to read/write magnetic tape, but at this stage it still relied mainly on punched cards for I/O. A total of nineteen 701's were installed during its three year lifespan at a monthly lease rate of about $15,000.

1954: Joint Numerical Weather Prediction Unit is formed … for which

Weather Bureau Buys Last IBM-701

Number	Shipped to	Date	Note
1	IBM World Hqtrs, NY	Dec. 1952	
2	Univ of Cal. Los Alamos	Mar. 1953	(a)
3	Lockheed Aircraft, CA	Apr. 1953	(b)
4	Nat'l Security Agy, DC	Apr. 1953	
5	Douglas Aircraft, CA	May 1953	(c)
6	General Electric, OH	May 1953	
7	Convair, Fort Worth	Jul. 1953	
8	U.S. Navy, Inyokern, CA	Aug. 1953	(d)
9	United Aircraft, CT	Sep. 1953	
10	North American Av., CA	Oct. 1953	(e)
11	Rand Corp., CA	Oct. 1953	(f)
12	Boeing Corp., WA	Nov. 1953	(g)
13	Univ of Cal. Los Alamos	Dec. 1953	
14	Douglas Aircraft, CA	Jan. 1954	(h)
15	Naval Aviation Supply, PA	Feb. 1954	
16	Univ of Cal. Livermore	Apr. 1954	
17	General Motors Corp., MI	Apr. 1954	
18	Lockheed Aircraft, CA	Jun. 1954	(h)
19	**U.S. Weather Bureau, DC**	**Feb 1955**	**(i)**

(a) Used for hydrodynamics calculations

(b) Mathematics Analysis Department used the 701 for problems in aircraft design, such as aerodynamic performance and stability, thermal dynamics and structural and flight dynamics

(c) Arrived on May 23, 1953, aboard a DC-6A aircraft. The 701 was used to get the DC-7 into production months ahead of schedule. It solved engineering & scientific problems on Douglas commercial aircraft,including DC-6B, DC-7, DC-7C & development of DC-8

(d) Used to calculate rocket and missile performance and to simulate flight conditions of these devices at the U.S. Naval Ordnance Test Station China Lake

(e) Handled engineering problems, from basic configuration selection through aerodynamic and structural design to the analysis of flight test data

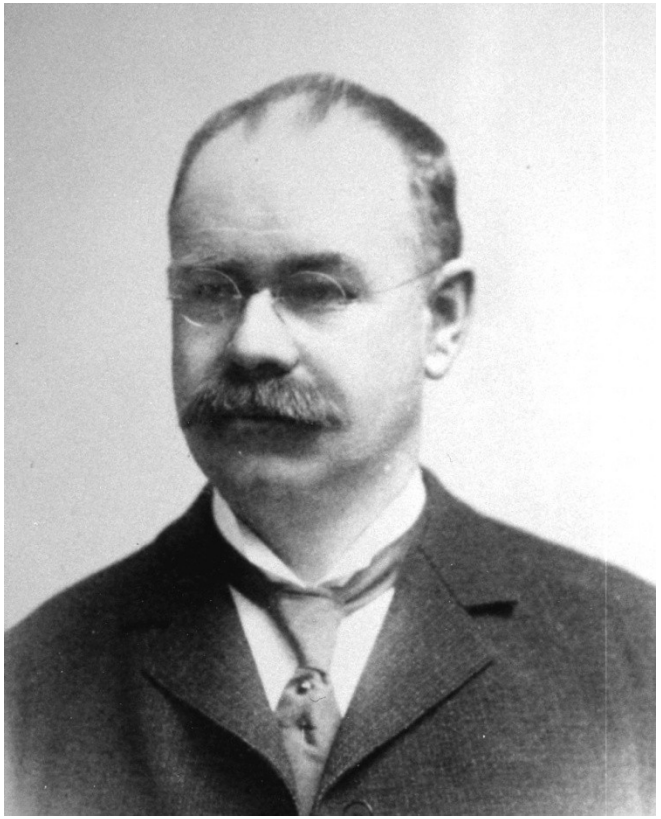
(f) Used to solve wide variety of problems in economics, mathematics, aircraft, missiles, electronics, nuclear energy and social sciences

(g) Used to assist engineers and designers in solving problems in aerodynamics, stress and structural development, and flight testing of supersonic and jet aircraft and guided missiles

(h) Solved engineering problems on U.S. Navy A3D Skywarrior, A4D Skyhawk and F4D Skyray programs, and USAF C-133 and RB-66 programs

(i) Produced from spare parts

Fir$t Computer Card$



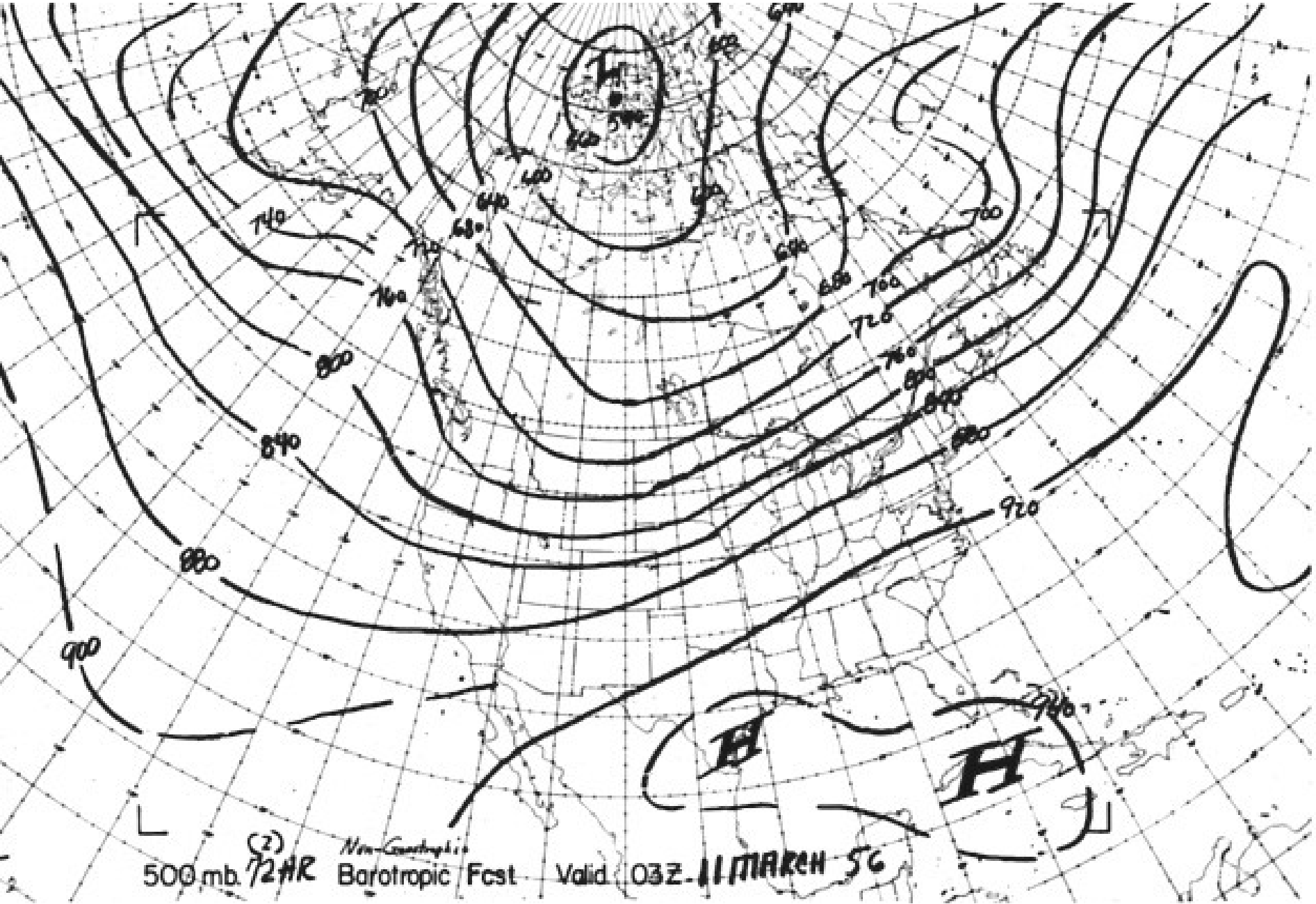
In 1890, Herman Hollerith made the size of the data-processsing card (later commonly known as the IBM card) equal to the dollar bill of that time - allowing the reuse of existing filing bins and similar equipment. Shown is a 1930 Silver Certificate that still had the same size. In 1929 the dollar bill was reduced by 20% in both dimensions.

1955 - First Operational Production Suite

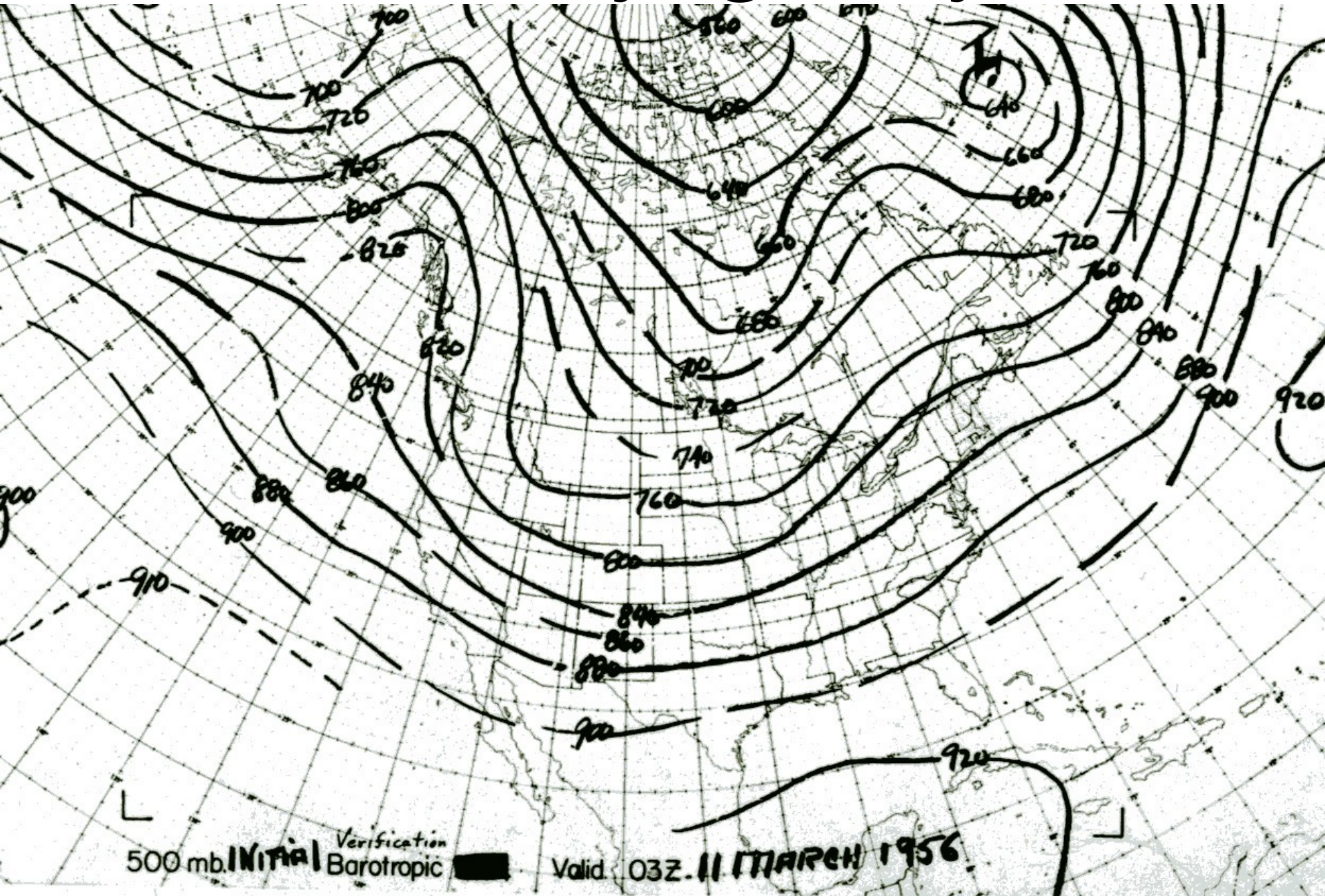
- Baroclinic 300 km / 3-layer CONUS to 36 hr
  - 1500z run started 2100z finished 2230z
- Thermotropic 375 km / 2 layer No. Am to 36 hr
  - 0300z run started 1000z finished 1230z
- Barotropic 600 km / 1 layer ~NHemis to 72 hr
  - 0300z run started 1230z finished 1300z
- NEED for more rapid transmission and processing of observational data

- LEGEND: green = new, blue = upgrade, blue = upgrade, black = original, and red = drivers for the next machine

1956 Model Guidance



1956 Verifying Analysis



Analysis Assemblyline

Objective Analysis
Comes to the Rescue

- Bergthorsson-Doos (1955), Cressman (1957) – develop the successive corrections analysis which is still used by Glahn & Ruth in today's gridded MOS

- Sasaki (1958) – variational analysis

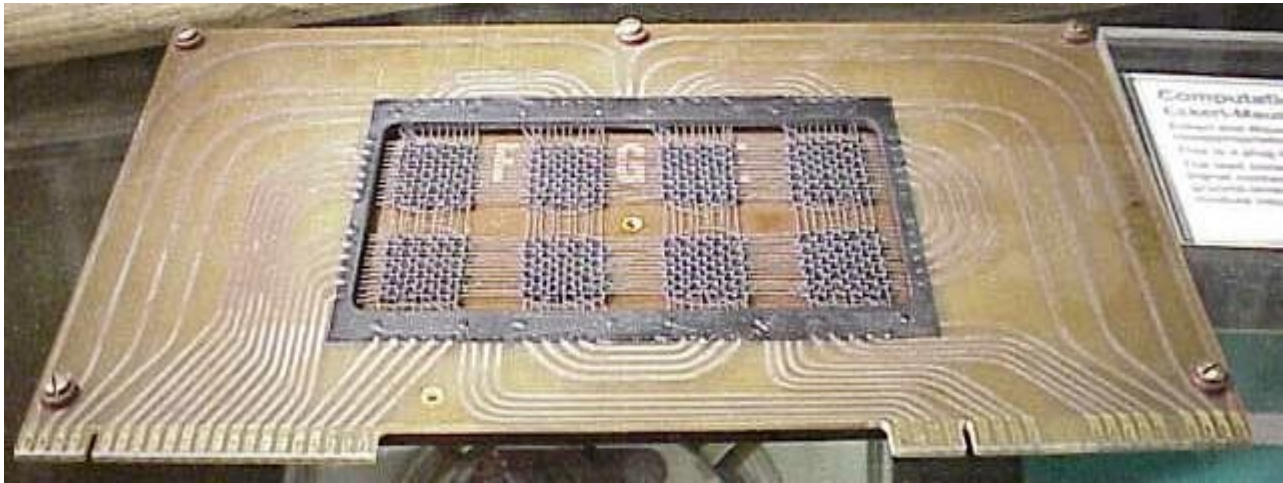
- Gandin (1967) – optimum interpolation

- Phillips (1960) – issues of balance and initial data for primitive equations

1957 USWB Buys IBM-704

One of ~4000 Logic Modules

First to use core memory which was fast,reliable but initially $$$

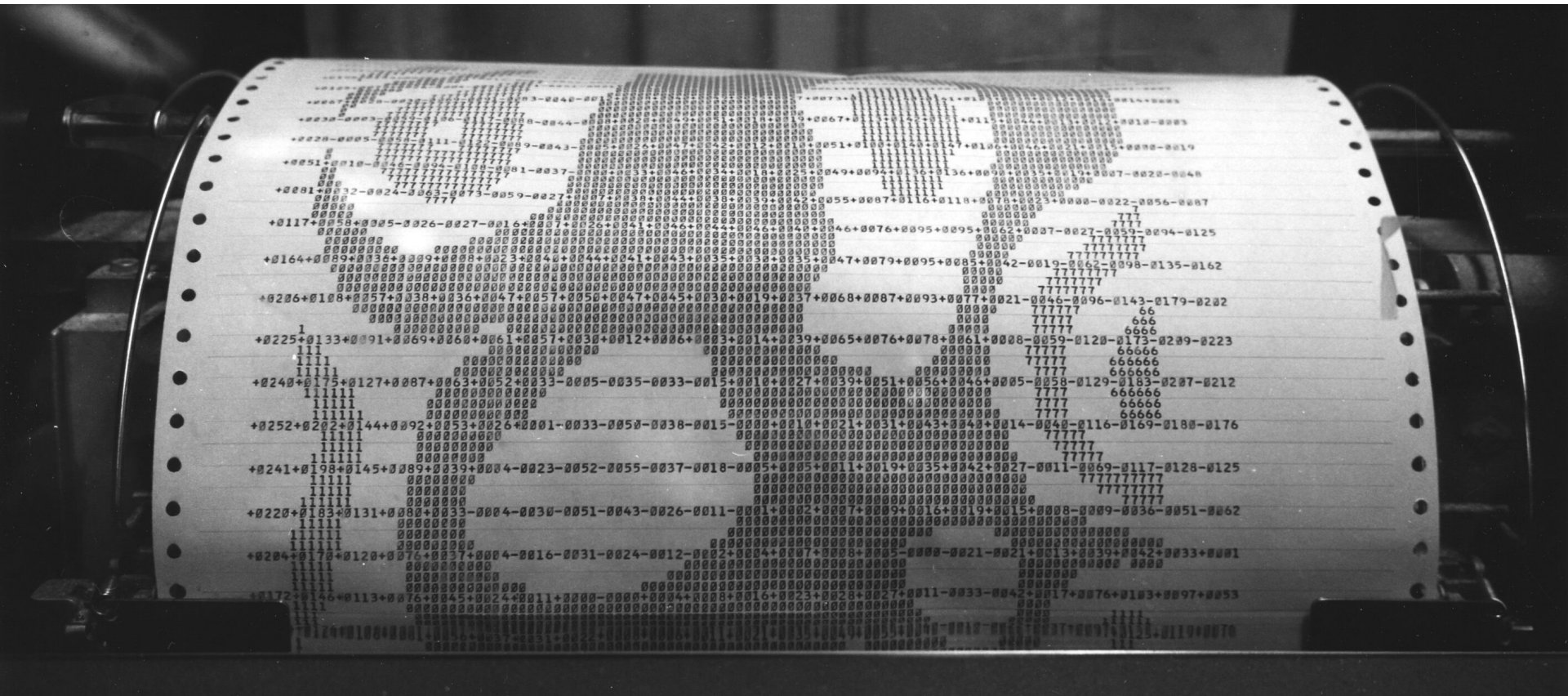


1957 IBM-704

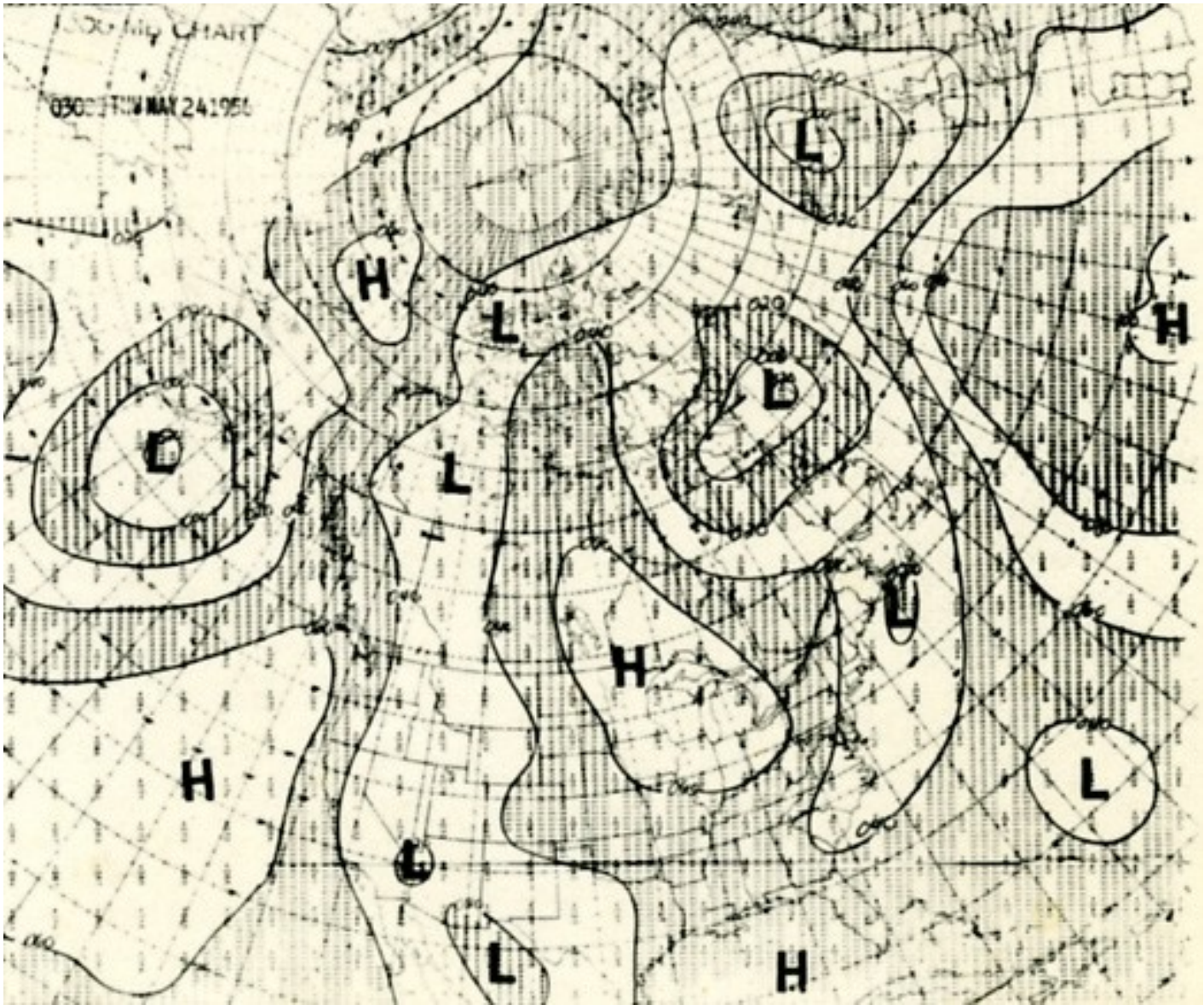
- Chief architect was Gene Amdahl
- IBM's first commercial machine with floating-point hardware
- First "modern" machine with: index registers, random access (core) memory, magnetic tape and card input and output, line printer output - console had programmable lights & sense switches but there was still no operating system
- First widely-used machine to use a high-level programming language - **FORTRAN**
- FORTRAN (FORmula TRANslation) was written by one of the IBM 704 designers - first compiler was so efficient, it took 15 years for it to be replaced, could use magnetic tape for intermediate storage (i.e. before availability of fast affordable disk), but could only read 72 of the 80 columns on card (hardware limitation)

1957 IBM-704 Line Printers

What would become the ubiquitous IBM line printer was a modified 407 accounting machine printer, which ran at 150 lines per minute. The printers were able to print lines of up to 132 characters on 17-inch-wide paper



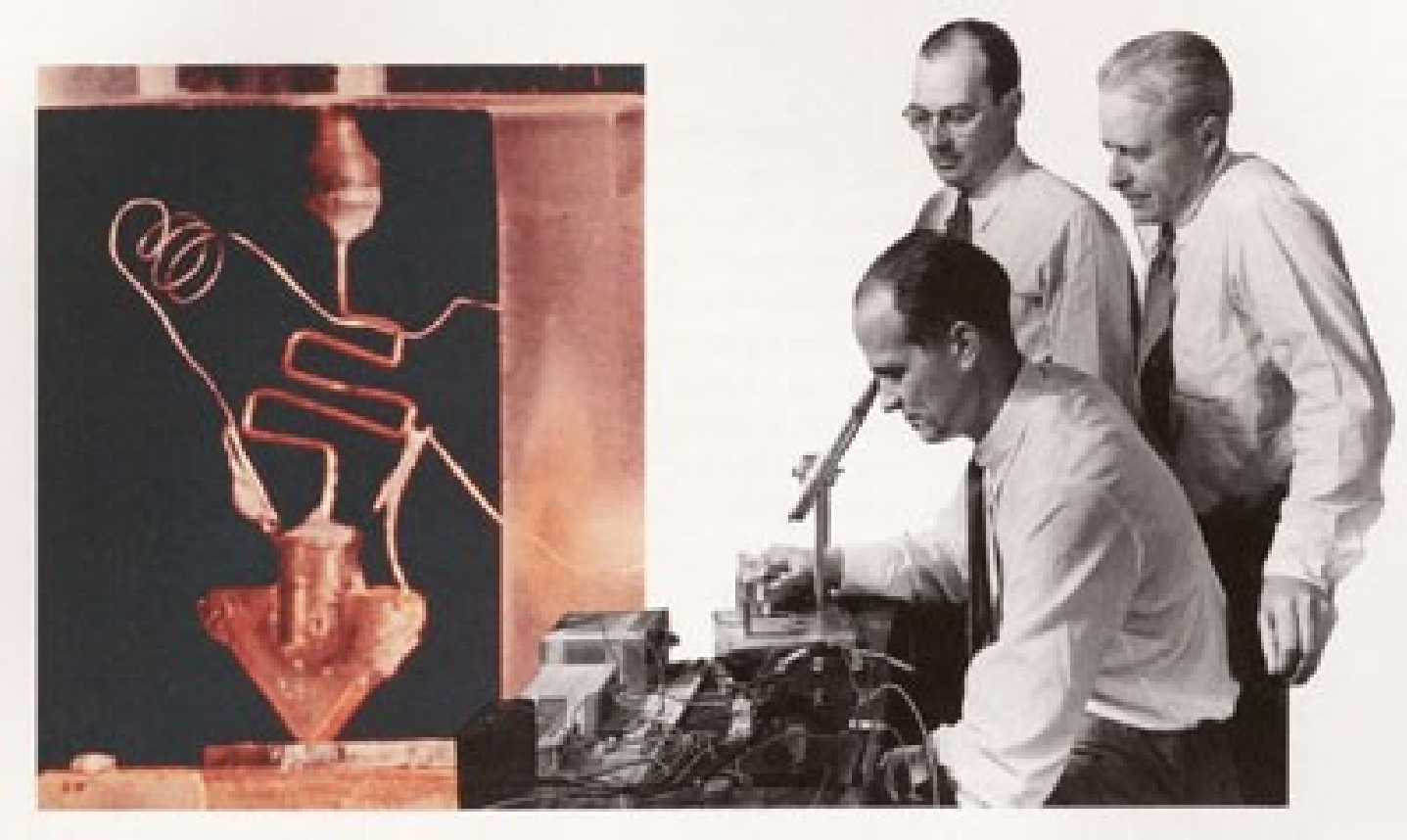
Early Primitive Graphics
1000 mb prog from grid-print “contouring”



1957-58 Production Suite

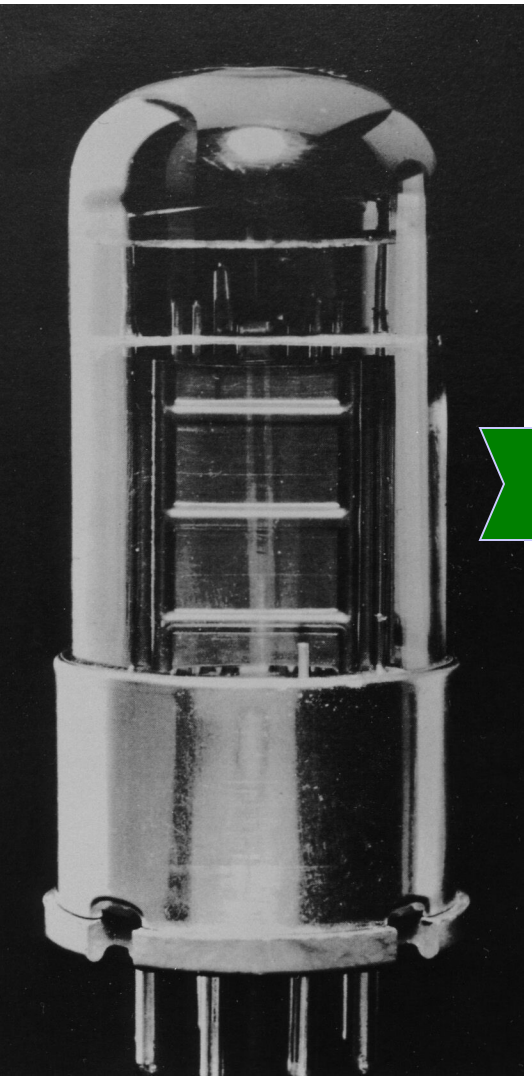
- Baroclinic replaced in 1958 by 2-layer CONUS
  - 1500z run started 2100z finished 2230z
- Thermotropic 375 km / 2 layer No. America
  - 0300z run started 1000z finished 1230z
- Barotropic upgraded in 1957 to 381 km using 1977 point No. Hemisphere octagon
  - First objective analysis and better numerics

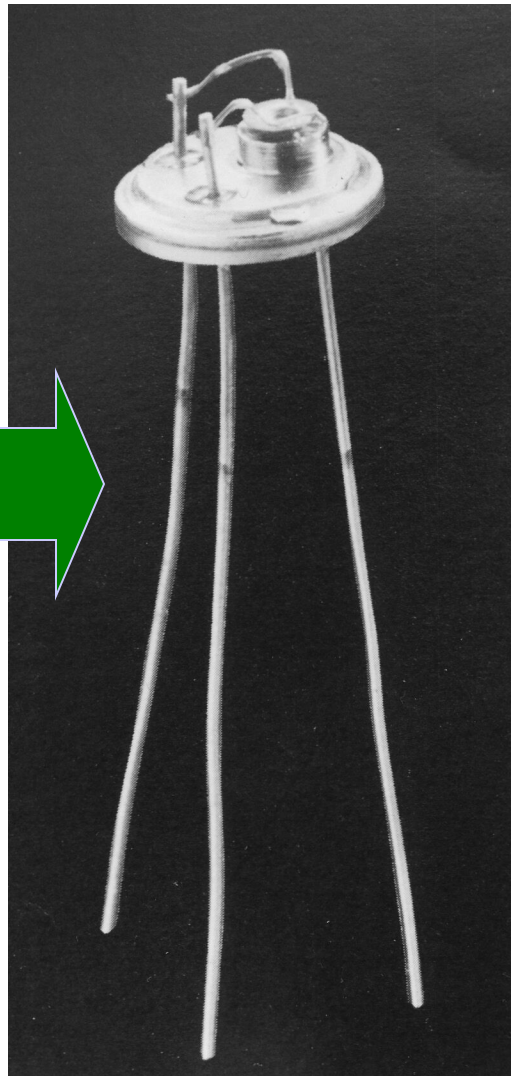
1947 - First Transistor



The first transistor (TRANSfer resISTOR) was invented at Bell Laboratories on December 16, 1947 by William Shockley (seated), John Bardeen (left) and Walter Brattain (right).

Tubes to Transistors IBM-704 to IBM-7090





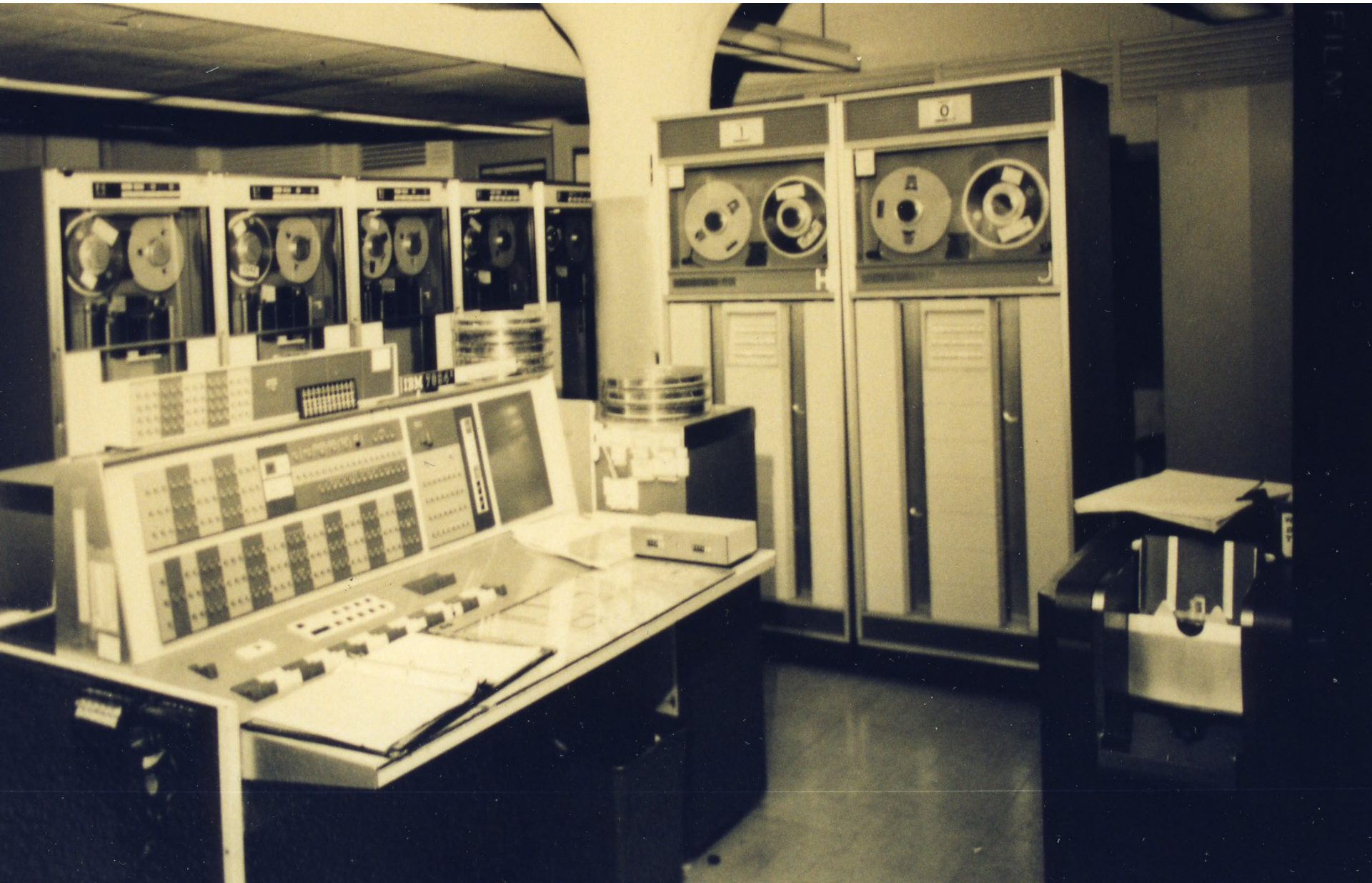
A 1960 successor to the tube-based IBM 704, the IBM 709 introduced distinct input-output channels, that allowed input output to proceed in parallel with computation. At government request IBM built a transistorized version, first designated to be the 709T. This machine, renumbered 7090, became the prime IBM scientific computer until the 360-series arrived in 1966.

“BIG IRON”

- IBM's "big iron" Data Processing Division was formed in 1956 to focus on the development and marketing of mainframe products. Within a short time, the company had developed:
  - the first commercial airline reservation system (SABRE), using 1958’s IBM 7090 data processing system
  - the Stretch supercomputer (IBM 7030) delivered to Los Alamos in 1961 which was 200 times faster than the IBM 701, 40 times faster than the IBM 709 and 7 times faster than the IBM 7090
  - the stretch became the IBM 7094 and was "basis" for CDC 6600
- Most of the old big-iron machines were scrapped long ago for precious metals content - check out the Stanford site: http://www.thegalleryofoldiron.com/

1960 USWB Buys an IBM 7090

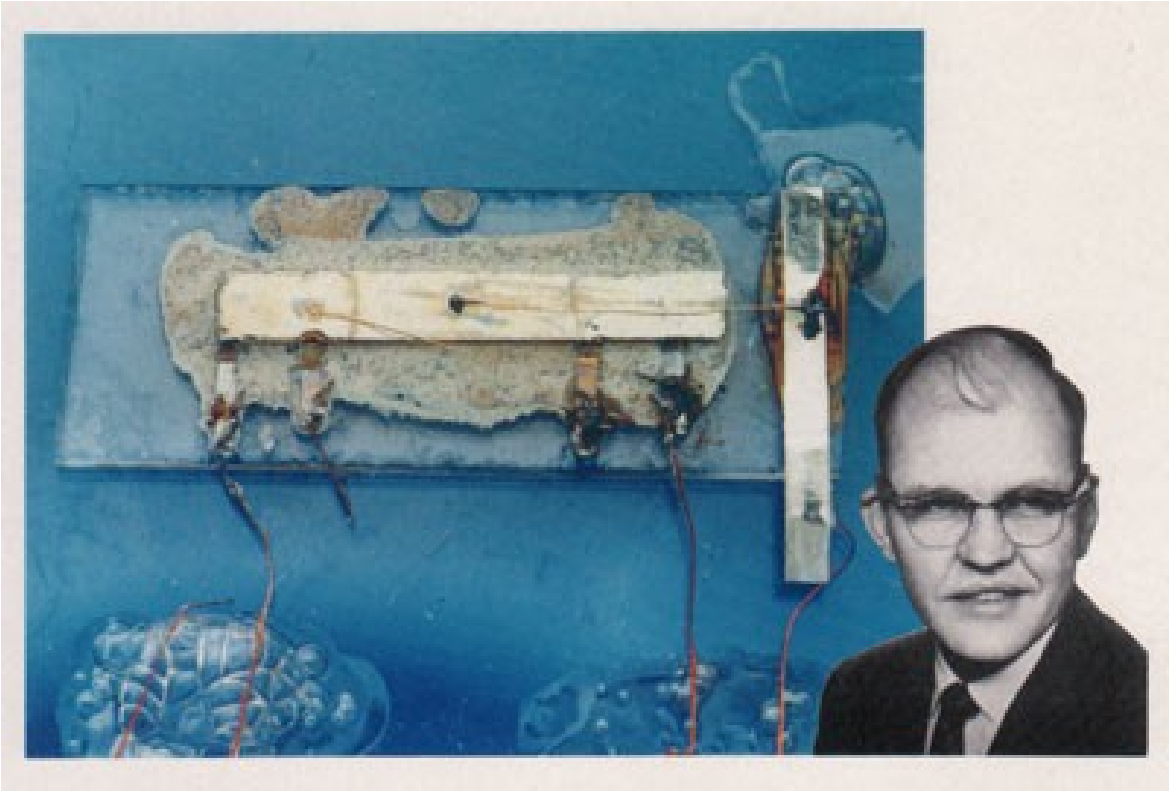
1963 USWB Buys an IBM 7094



1962-65 NMC Production Suite

- 2-layer Baroclinic replaced in 1962 by Cressman filtered 381 km/3-layer N.Hemis octogon to 36 hr
- Thermotropic 375 km / 2 layer No. Am to 36 hr
- Barotropic 381 km No. Hemis to 72 hr
- Added Reed Surface Model 381 km / 2 layer N.Hemisphere to 36 hr
- All models initialized with objective analysis
- Development of hemispheric and regional Primitive Equation models awaiting bigger computers to run them on

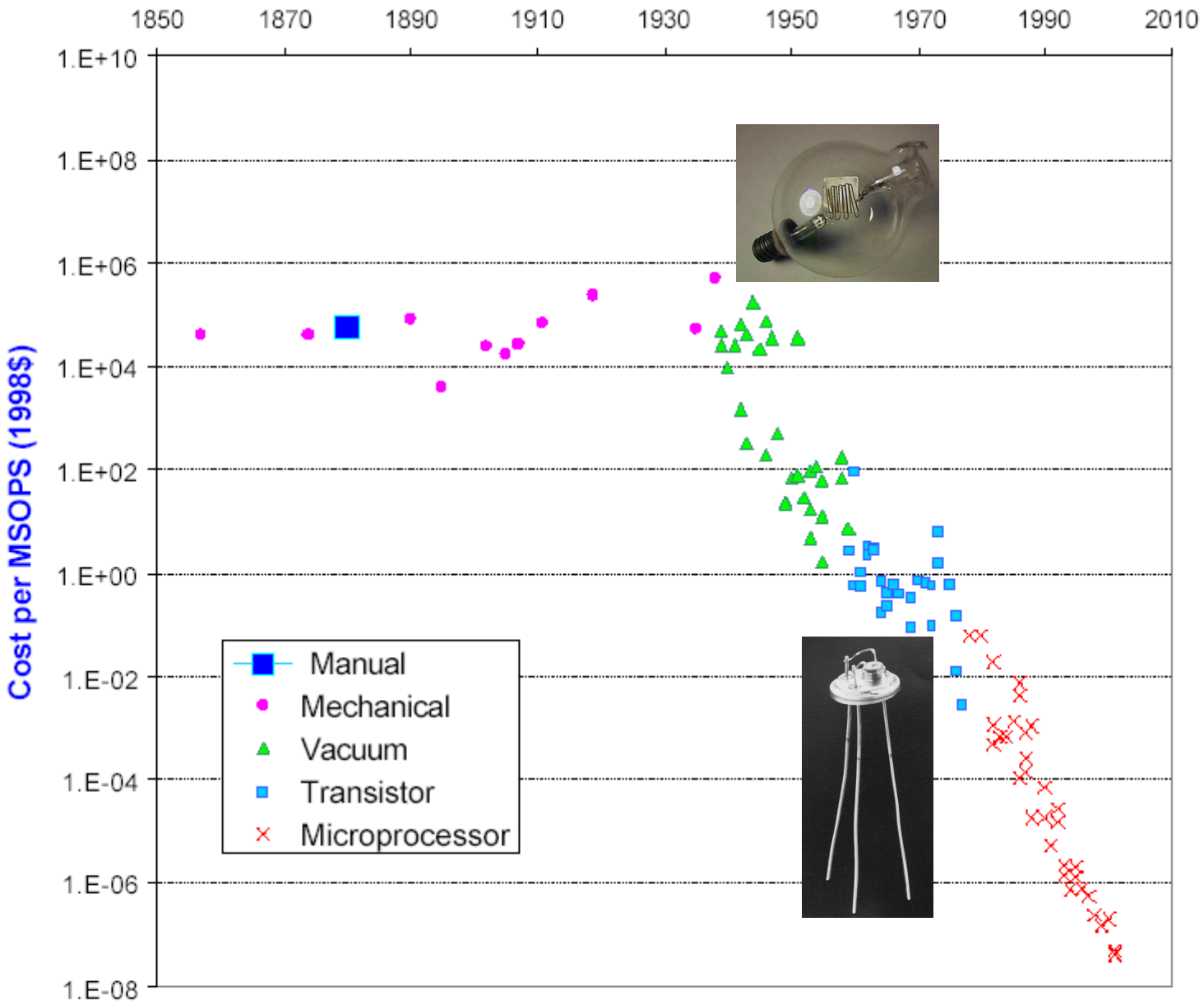
Transistors to Integrated Circuits



1958: The first Integrated Circuit is invented by Jack Kilby of Texas Instruments

Jack Kilby, an engineer at Texas Instruments, completed his first device (pictured) on September 12, 1958 which was actually constructed on germanium rather than silicon, as he could not find a suitable piece of silicon at the time. But the integrated circuit was fully functional, and TI officially announced it in January 1959.

Cost Drop With Technology Advance



1964 - CDC 6600

• Designed by Seymour Cray with **solid state** components using a sophisticated Freon cooling system and 60-bit word (vs 36-bit IBM).

• First “supercomputer” performing 3 mips with 10 ns clockspeed Fastest computer in the world until 1968 surpassed by CDC 7600

• Speed, in part, came from the computer´s distributed design, which had 10 small computers, known as peripheral processors, funneling data to a large central processing unit using reduced instruction set (RISC) many years before such a term had been invented

• First to have a CRT console (CDC checkout engineers created computer games such as Baseball, Lunar Lander, and Space Wars, which became incentives for getting the machines operational. These are thought to be the first computer games that used monitors.)

Personal Reflection

- While an undergrad at Penn State, I take my O N L Y formal computer class – a one credit programming class in FORTRAN IV

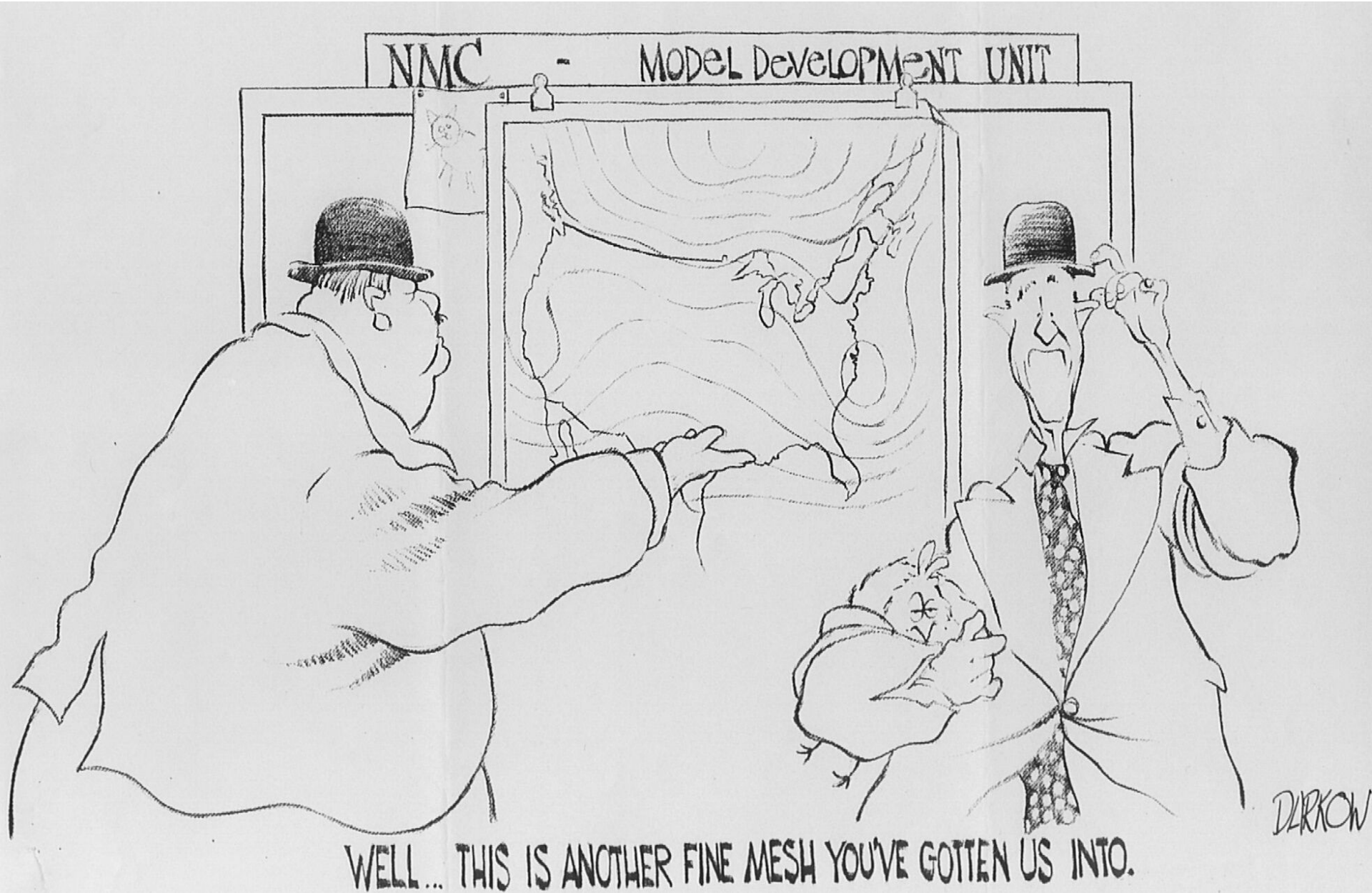
- In 1973, by exam, I use FORTRAN for my PhD language requirement – thank you SUNYA!

1966 USWB Buys a CDC 6600

1966-73 NMC Production Suite

- Cressman filtered 381 km/3 layer N.Hemis to 36hr
- Thermotropic replaced in 1966 by Shuman-Hovermale PE model 381 km / 6 layer N.Hemis 53x57 to 36 hr
- Barotropic 381 km N. Hemis to 72 hr
- In 1970 Barotropic extension of PE 84-144 hrs
- Reed Surface Model 381 km N.Hemis to 36 hr
- In 1971 Limited-area Fine Mesh (LFM) 190.5km/6 layer No. America to 24 hr
- TDL Wave model 381 km N.Hemis to 36 hr
- TDL Perf. Prog. & MOS off the 6-layer PE
- Development of global analysis and modeling systems awaiting bigger computers to run them on

Well…this is another FINE MESH…

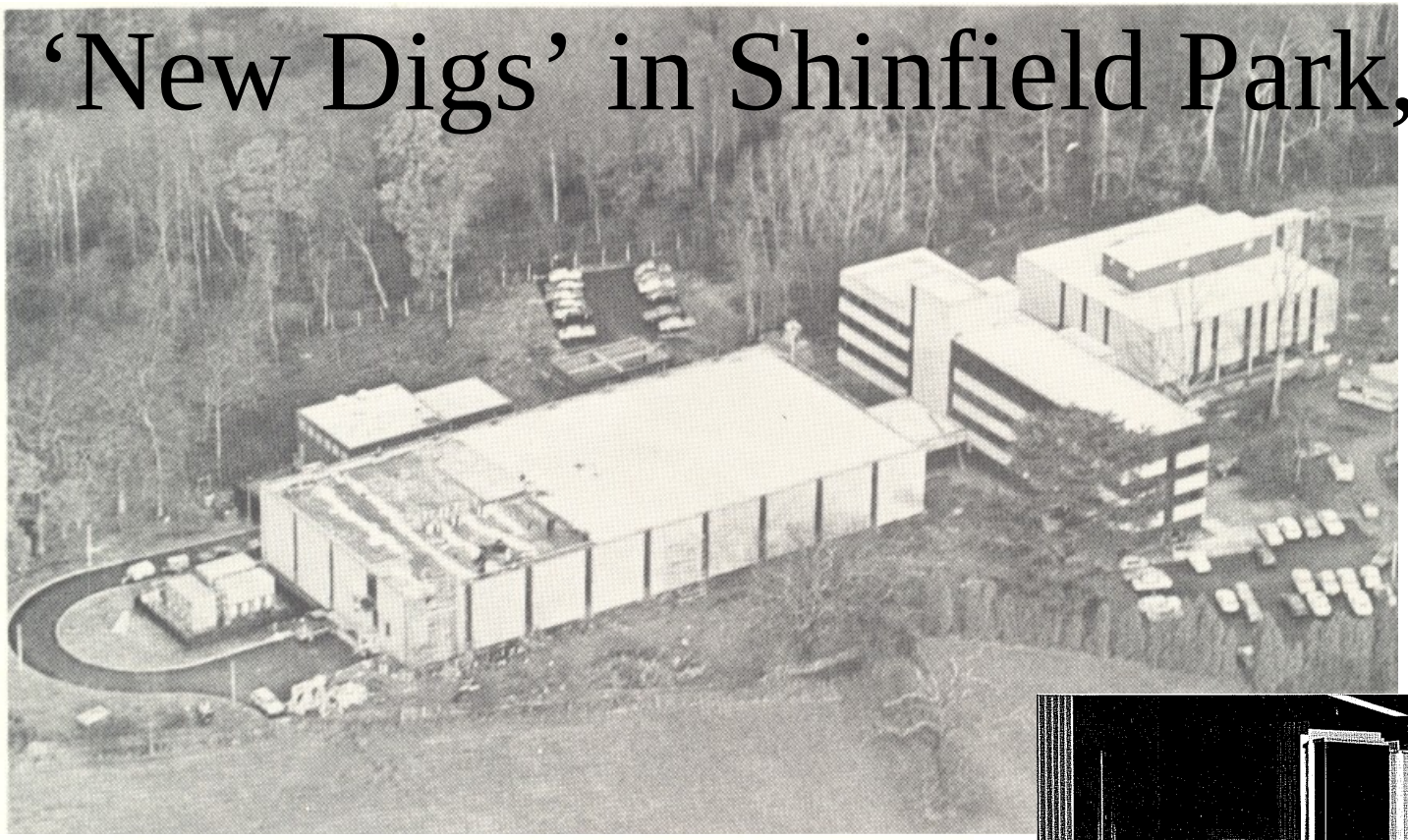


1971 IBM 360-195

1972 NWS Buys IBM 360-195

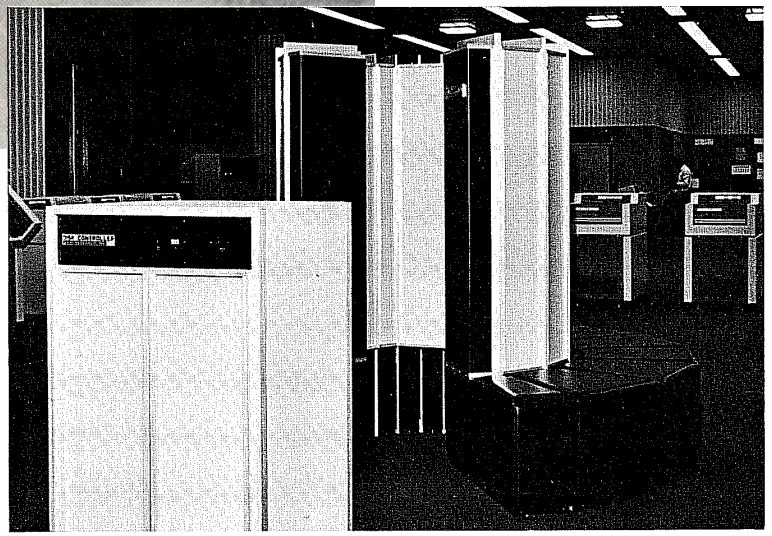
ESSA's NWS buys 2 IBM 360-195's and gets a third from GFDL in 1973 - first interactive development via IBM's TSO

ECMWF & Its CRAY-1 Move Into ‘New Digs’ in Shinfield Park, UK



European Centre for Medium Range

Weather Forecasts



The CRAY-1 Computer, installed in the Computer Block of the Centre’s permanent headquarters at Shinfield Park.

USA -- be afraid … be *very* afraid

Akira Kasahara said
“When it comes to the bottom line, whoever has the faster computer will win”.

Comparing Mission Requirements

Suite Element	Global NWP	Regional NWP	Fire Weather Rapid Update Hurricane	Air Quality	Global Ensembles	Regional Ensembles	Real Time Ocean	Seasonal / Interannual Climate
NCEP	X	X	X	X	X	X	X	X
ECMWF	X				X			X

ECMWF has twice the people, twice the computer, and less than half the mission requirements of NCEP

. . . but we're not bitter ^_^

Personal SUNYA Reflections

- DiMego, after losing an hours worth of code entry, kicks his 110 baud teletype terminal … not for the last time, but the experience forces him to learn how to save work on the nifty papertape gizmo attached ☺

- SUNYA & Air Force Global Weather have UNIVAC 1108s

1974-78 NMC Production Suite

- Flattery Hough Analysis for PE (‘74)
- Global PE 2.5 deg / 8 layer analysis cycle 12 hrly
- LFM extended from 24 to 36 (‘75) to 48 hr (‘76)
- Global PE 2.5 deg / 9 layer analysis cycle 12 hrly (’76)
- Vanderman PE 2.5 deg / 3 layer global to 242hr (‘77)
- PE 190.5km / 7 layer N.Hemis (129x129) to 84hr (‘78)
- Barotropic extension 381 km N.Hemis 84-240 hr (’78)
- Movable Fine Mesh for hurricanes 60 km / 10 layers 50x50 window to 48 hr (‘78)
- TDL adds more MOS
- Development of global spectral model, normal mode initialization, NGM etc await bigger computers

Norm Phillips Gets Down & Dirty at NMC

With model & MOS guidance
getting *so good*,
NWS' Len Snellman
sounds the warning of
meteorological cancer
and …
urges everyone to

Thanks to Eric Rogers with apologies to the Washington Post Weekend Magazine

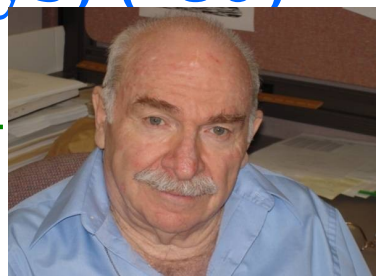
FGGE 1978-1979 = The BIG Stretch

The First GARP Global Experiment (FGGE) involved the detailed study of the entire atmosphere over a whole year (December 1978-November 1979), with a large number of organizations from around the world involved.

The pre-FGGE Data Systems Tests conducted at NMC, NASA, and GFDL were inconclusive but their design, construction and execution expanded *virtually every aspect* of global data assimilation and modeling and *pushed them to their limits* much more rapidly than would have happened otherwise.

1979-82 NMC Production Suite

- LFM-II 127 km / 7 layer (’79) with 4th order fin.dif. 190.5 km/7layer No. America to 48 hr (‘81)
- PE extension with 4th order finite differencing 381 km / 7 layer N.Hemis 60-144 hr (‘80)
- Barotropic extended to 240 hours (10 days) (‘80)
- Joe Sela’s Global Spectral model R-30 / 12 layer to 48 hr (‘80)

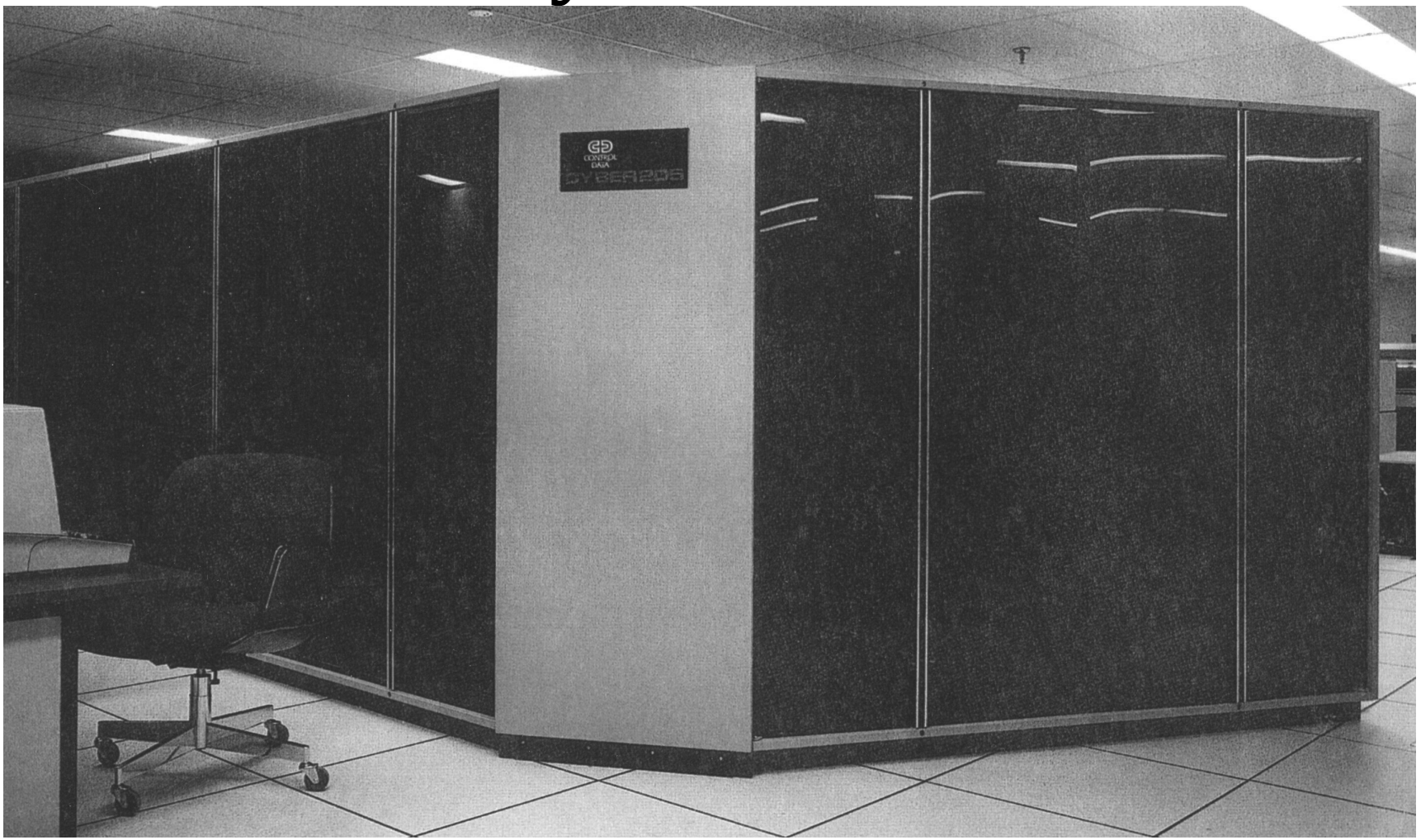


- Spectral extension R-24/12 layer N.Hemis 48-144hr
- Development of NGM, optimum interpolation (OI), Medium Range Forecast (MRF) await next machine

Personal Reflection

- ONLY jobs using no more than 256K bytes of memory and no more than 1 minute of cpu time were run on IBM 360-195's during the day - all other jobs ran overnight!
- Graphics jobs take an average of 3 days to turn around.

1981 NMC Buys a CDC CYBER 205



First parallel machine with two “pipes”, second machine in 1987.
MAJOR conversion effort - needed long vectors to get max speed.
IBM 360’s are kept as front-ends - eventually replaced by HDs.

1983-89 NMC Production Suite

- Global Spectral model R-40 / 12 layer to 240 hr (‘83)
- Global Spectral upgrade and MRF R-40 / 18 layer to 240 hr (‘85)
- Nested Grid Model (NGM aka Norm’s Great Model) + Regional OI 80 km / 16 layer No. America to 48 hr (‘85)
- NOAA Ocean Wave (NOW) 2.5 deg global to 72hr (’85)
- Global Spectral model upgrade T-80 / 18 layer to 240 hr (‘87 with arrival of 2nd Cyber 205)
- MFM hurricane model replaced by Quasi-Lagrangian Model of Mathur 40 km / 10 layer window (111x111) to 72 hr (‘88)
- Major physics upgrade to NGM 80 km / 16 layers expanded No. America to 48 hr (’88)
- Development of ensembles, Eta model, RDAS/ EDAS, Rapid Update Cycle (RUC)

Personal Reflection

- Regional OI (Optimum Interpolation) was first NMC analysis to use the significant level data from radiosondes
- Plentiful disk space on IBM 360-195's allowed an ONLINE 30-day rotating archive of both production runs
- Parallel testing becomes possible and commonplace

1990 NMC Buys a Cray Y-MP

Conversion to UNIX - application conversion less of an issue due to Cray's excellent compiler. Front ends replaced by J916's

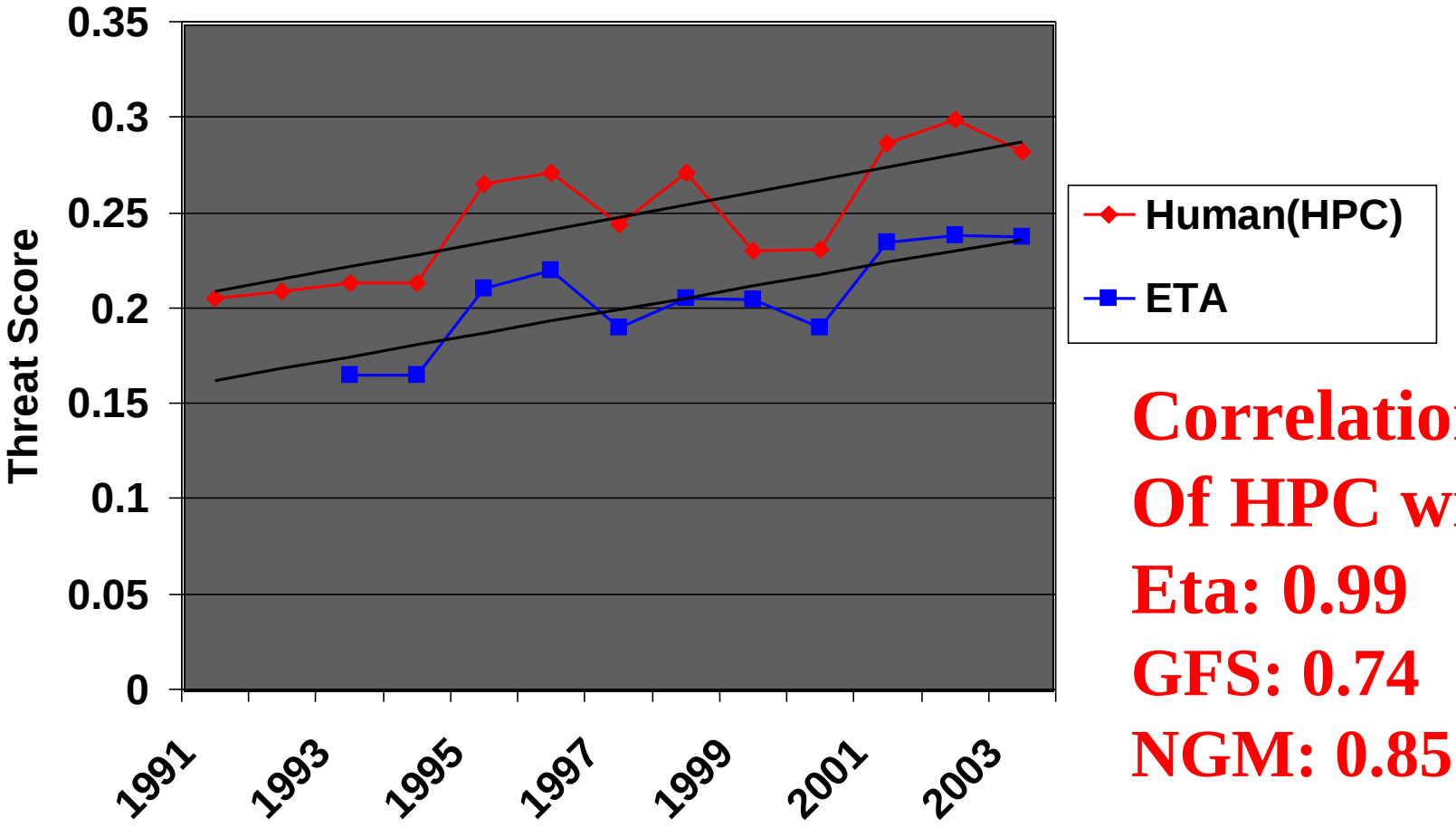
1990-93 NMC Production Suite

- Global Spectral model T-126 / 18 layer to 240 hr (‘91)
- Ensemble Spectral (3 members) T-62 / 18 layer global to 240 hr (‘92)
- LFM replaced by early Eta Model 80 km / 38 layers with step mountains No. America to 48 hr (’93)
- Global Spectral model upgrade T-126 / 28 layer to 240 hr (‘93)
- NGM 2-grid upgrade with RDAS 80 km/16 layers on greatly expanded No. America to 48 hrs (’91) FROZEN
- Development of Meso Eta, 3DVAR + EDAS, Rapid Update Cycle await next machine

No Meteorological Cancer at NCEP's Hydrometeorological Prediction Center (HPC)

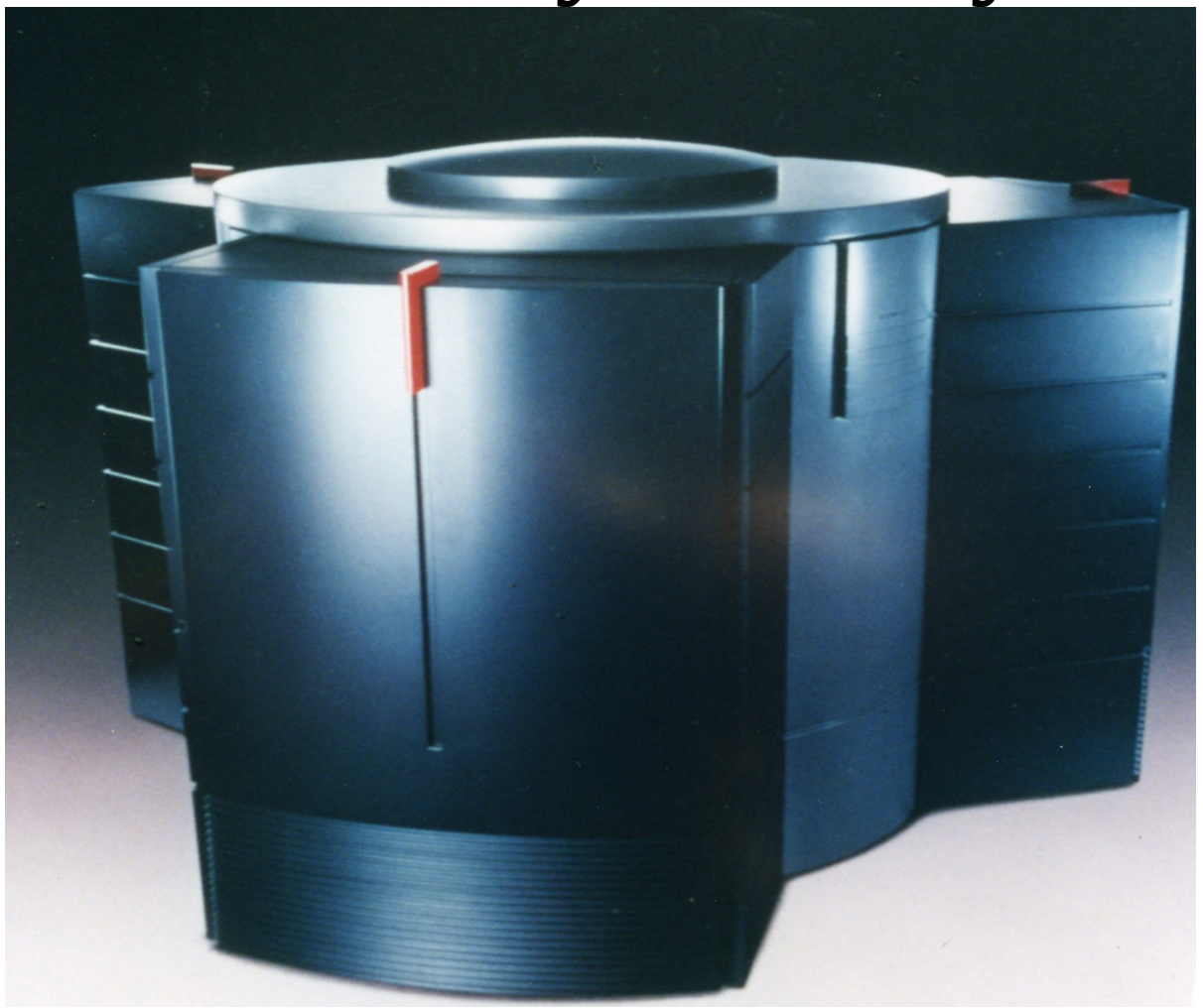
"As go the models, so go the forecasts"

Impact of Models on Day 1 Precipitation Scores



Correlations Of HPC with:
Eta: 0.99
GFS: 0.74
NGM: 0.85

1994 NMC Buys a Cray C9016



Awesome machine that would eventually succomb to a fire in a power supply that was extinguished with a corrosive fire retardant.

1994-95 NMC Production Suite

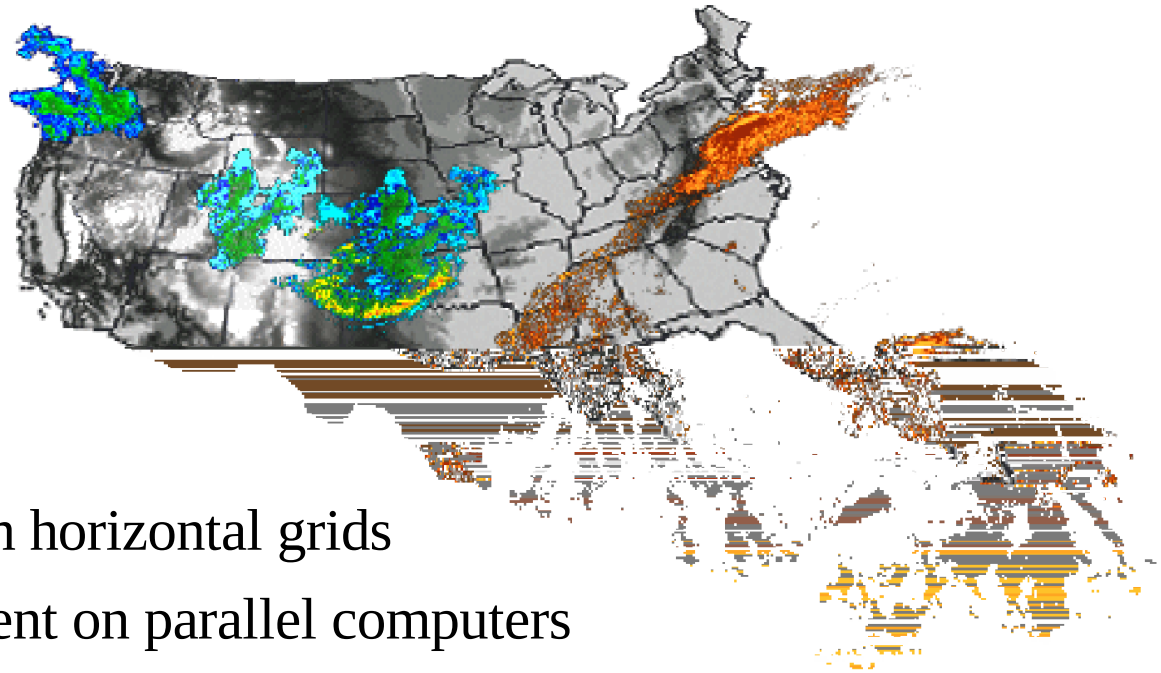
- Rapid Update Cycle (RUC) 60 km / 25 hybrid sigma/ isentropic layers to 12 hr every 3 hr (‘94)
- NOW replaced by WAM wave model 2.5 deg global to 72 hr (‘94)
- ENS Spectral upgrade (17 members) T-62 / 18 layer global to 384 hr (‘94)
- QLM hurricane replaced by GFDL model 1/6 deg / 18 layer movable window to 78 hr (’95)
- Meso Eta 29 km / 50 levels extended CONUS to 51 hr at 0300 and 1500 (‘95)
- Early Eta upgrade 48 km/38 layer with partial cycled EDAS over No.America to 48hr (’95)

1996-99 NCEP Production Suite

- Early Eta upgraded with coupled Land Surface Model 48 km / 38 layer No.Amer to 48 hr (’96)
- Regional Spectral Model (RSM) 10 km / 28 layer for Hawaii to 48 hr (’97)
- Sea-Ice Drift for Arctic and Antarctic to 384 hr (‘97)
- Early Eta and Meso Eta combined into 4/day with 3DVAR & fully cycled EDAS 32 km /45 layer No.America to 48 hr (’98)
- RUC-II upgrade to 40 km / 40 hybrid layer CONUS to 12 hr every 3 hr (‘98)
- Development of 10 km Meso Eta & NMM, Short Range Ensemble Forecast (SREF), WRF

Weather Research and Forecast (WRF) Modeling System

- Develop an advanced mesoscale forecast and assimilation system
- Promote closer ties between research and operations



Concept:

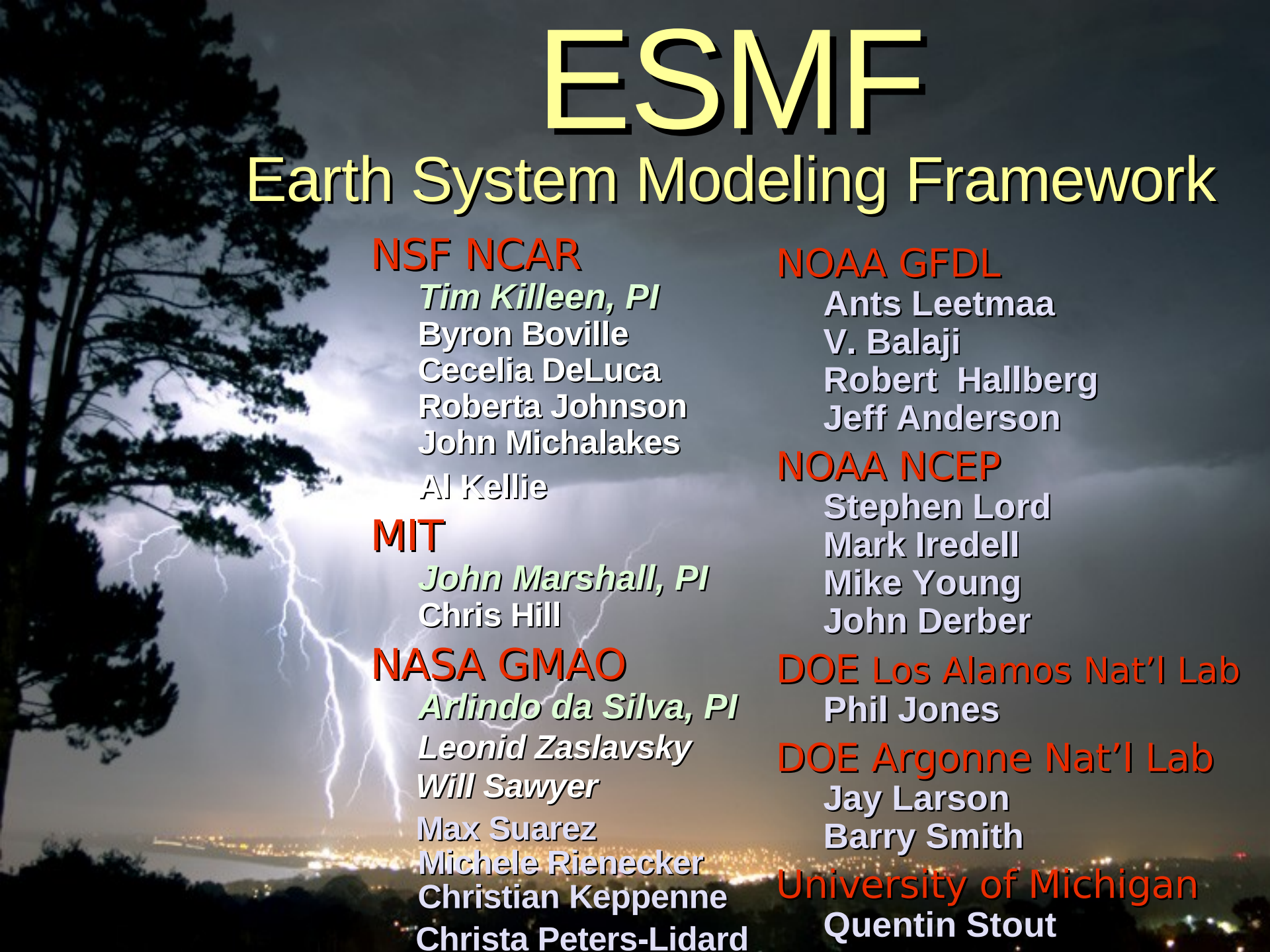
Design for 1-10 km horizontal grids

Portable and efficient on parallel computers

Well suited for a broad range of applications

Community model with direct path to operations

Collaborators: NCAR, NCEP/EMC, AFWA, Navy, NOAA/FSL, U. Okla.



ESMF

Earth System Modeling Framework

NSF NCAR
Tim Killeen, PI
Byron Boville
Cecelia DeLuca
Roberta Johnson
John Michalakes
Al Kellie

MIT
John Marshall, PI
Chris Hill

NASA GMAO
Arlindo da Silva, PI
Leonid Zaslavsky
Will Sawyer
Max Suarez
Michele Rienecker
Christian Keppenne
Christa Peters-Lidard

NOAA GFDL
Ants Leetmaa
V. Balaji
Robert Hallberg
Jeff Anderson

NOAA NCEP
Stephen Lord
Mark Iredell
Mike Young
John Derber

DOE Los Alamos Nat'l Lab
Phil Jones

DOE Argonne Nat'l Lab
Jay Larson
Barry Smith

University of Michigan
Quentin Stout

1999 NCEP Buys IBM SP2

- The Procurement from HELL -- I was on the team!
- Originally planned to put at NASA, but had to put it in FOB-4 →
- Power supply fell through the floor

- Found asbestos under the raised floor tiles so put in new floor, then …
- While installing equipment, they found asbestos above ceiling tiles (in air movers) and had to major abatement.
- Resulted in move of IBM to Bowie facility (good news)
- Cray fire on day of move (bad news)

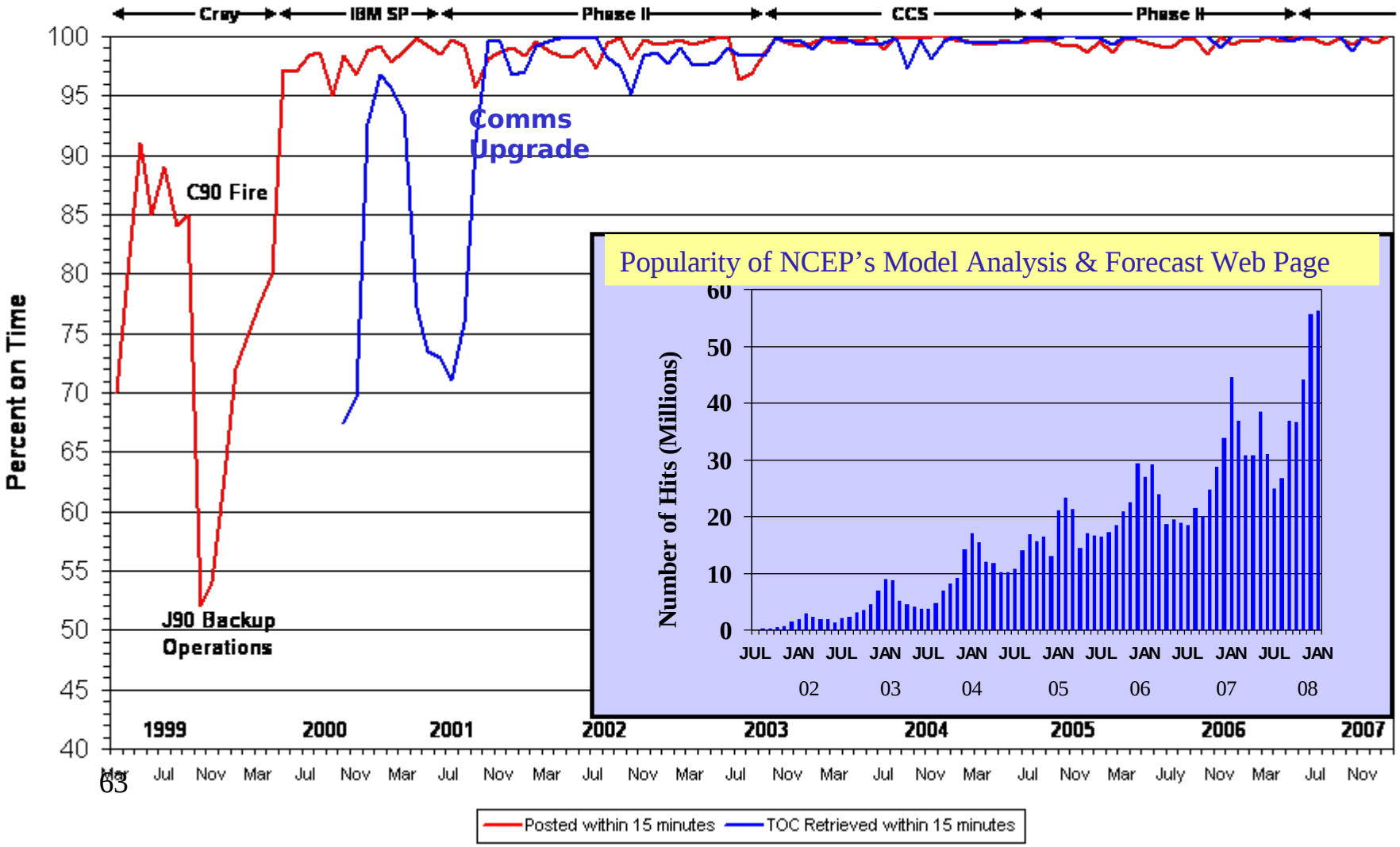
1999 NCEP Puts IBM SP2 in Bowie

After SP2 is upgraded, becomes one of the most stable & capable machines in NCEP's experience.

Personal Reflection

- First time Production was separated from Development – nearly guarantees that at least half the machine will be available for development – previously there was always a time when Prod used more (sometimes much more) than 50% of computer. At ECMWF, only 20% of machine used for their Production!
- IBM's reliability (helped by failover capability to the Development half) allows hourly RUC. In the past, for example, Cray Preventive Maintenance took 3 hours every Thursday when the Meso Eta would routinely be dropped.

Dependable, Reliable and Timely Performance, i.e. Product Delivery



2000-01 NCEP Production Suite

- Global Spectral upgrade T-170 / 42 layer global to 240 hr (‘00)
- ENS Spectral upgrade (23 members) T-126/28 layer for 00-84 hrs, T-62/18 layer to 84-384 hr (‘00)
- WAM replaced by NOAA Wave Watch 3 1.25 deg x 1 deg global to 126 hr (’00)
- Eta upgrade to 22 km /50 layer No.America to 60 hr [48 hr at off-times] (’00)
- GFDL hurricane adds URI coupled ocean in Atl basin 1/6 deg / 18 layer movable window (4 storms) to 126 hr (’01)

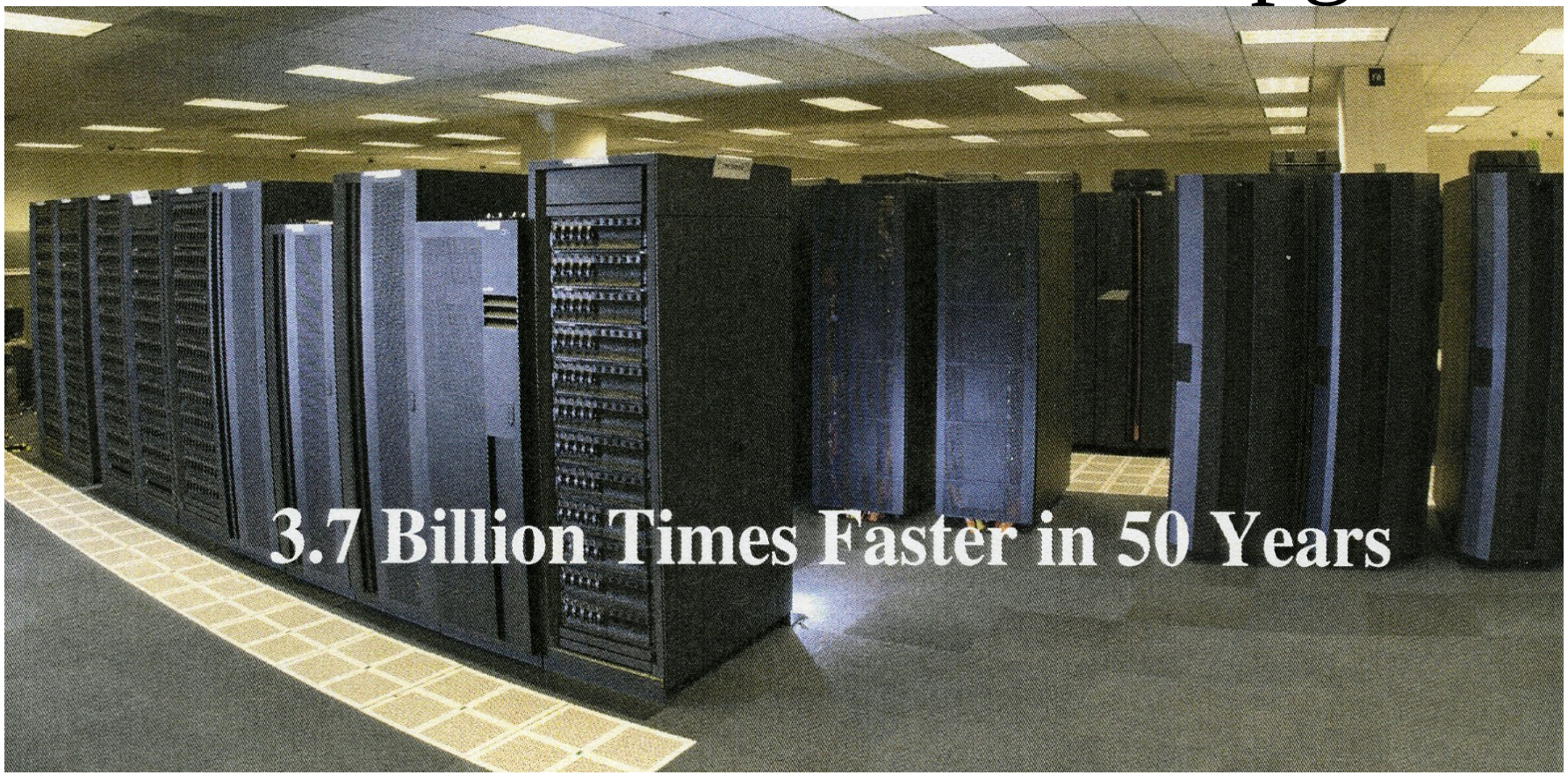
Personal Reflections

- The busted blizzard forecast in DC after IBM SP2 dedication January 2000 should warn folks from being overly optimistic especially in public.
- Forecasters were incredulous when 22 km Eta Model **over**predicted heavy QPF- early intolerance of any over-forecasting has disappeared – now all they want is perfection all the time everywhere

2001-02 NCEP Production Suite

- Global Climate Forecast System (CFS) to produce 7 month guidance (‘01)
- SREF (10 members Eta & RSM) 48 km No. Amer. To 63 hours (’01)
- HiResWindow nested Eta 10 km / 60 layer 1/3 CONUS & Alaska 1/day to 48 hr (’01)
- Meso Eta 4/day upgrade with new cloud scheme to 12 km / 60 layer No. Amer to 84 hr (ontime) 48 hr offtime (‘01)
- Princeton Ocean Model (POM) 10-20 km / 19 layer ocean off east coast to 48 hr (’02)
- Global Forecast System (GFS) upgraded T-254 / 64 layer 00-84hr, T-170 / 42 layer 84-180hr & T-126 / 28 layer 180-384 hr 4-per-day (’02)

2003 NCEP Gets IBM SP2 Upgrade



Primary housed in IBM facility in Gaithersburg, MD with a 100% backup housed in NASA facility in Fairmont, WV.

2002-04 NCEP Production Suite

- Meso Eta 4/day upgrade 12 km / 60 layer No. Amer to 84 hr at offtime (’03) with earlier delivery (’04)
- SREF upgrade (15 members Eta, RSM, Eta-Kain Fritsch) 48 km No. America to 63 hr (’03)
- HiResWindow nested Nonhydrostatic Mesoscale Model (NMM) of Janjic 8 km / 60 layer 1/3 CONUS & Alaska 1/day to 48 hr (’03)
- Fire Weather / IMET Support nested NMM selectable window 1/12 CONUS 8 km / 60 layer to 48 hr 48 km No. America to 63 hr (’03)
- ENS spectral upgrade (45 members) T-126 / 28 layer 00-180hr T-62 / 28 layer 180-384 hr (’04)
- NOAA Wave Watch 3 upgrade 1.25 deg x 1 deg global to 180 hr (’04)

2005 NCEP Gets IBM P5 Upgrade

2005-07 NCEP Production Suite

- Global Forecast System (GFS) and its SSI/GDAS upgraded to T-382(~35km) / 64 layer 00-180hr, T-190(~70km) / 64 layer 180-384 hr 4-per-day (05); hybrid vert coord (06)
- Unified Gridpoint Statistical Interpolation (GSI) analysis replaces SSI (07); unified NCEP model post-processor(07)
- North American Mesoscale (NAM) runslot (05)
- RUC upgraded from 20 km to 13.3 km
- Air Quality expands to cover CONUS
- GENS upgrade (84 members) T-126
- NOAA Environmental Modeling System (ESMF based) with Nonhydrostatic Multiscale Model on B-grid (NMMB)

2005-07 NCEP Production Suite

- In NAM, the Eta replaced by WRF-NMM (’06) 12km/60lev
- SREF upgrade (21 members Eta, RSM, WRF-NMM & WRF-ARW) 32-44 km No. America 4/day to 87 hr (07)
- HiResWindow EXPLICIT WRF-NMM & WRF-ARW
  4-5 km 2/3 CONUS, Alaska, HI & PR to 48 hr
- Hurricane WRF added
- Real Time Mesoscale Analysis (RTMA) CONUS (06)

Pyle Webpage Now Displaying Simulated Reflectivity

http://www.emc.ncep.noaa.gov/mmb/mmbpll/cent4km/v2/

Simulated radar reflectivity, lowest model level (dBZ)

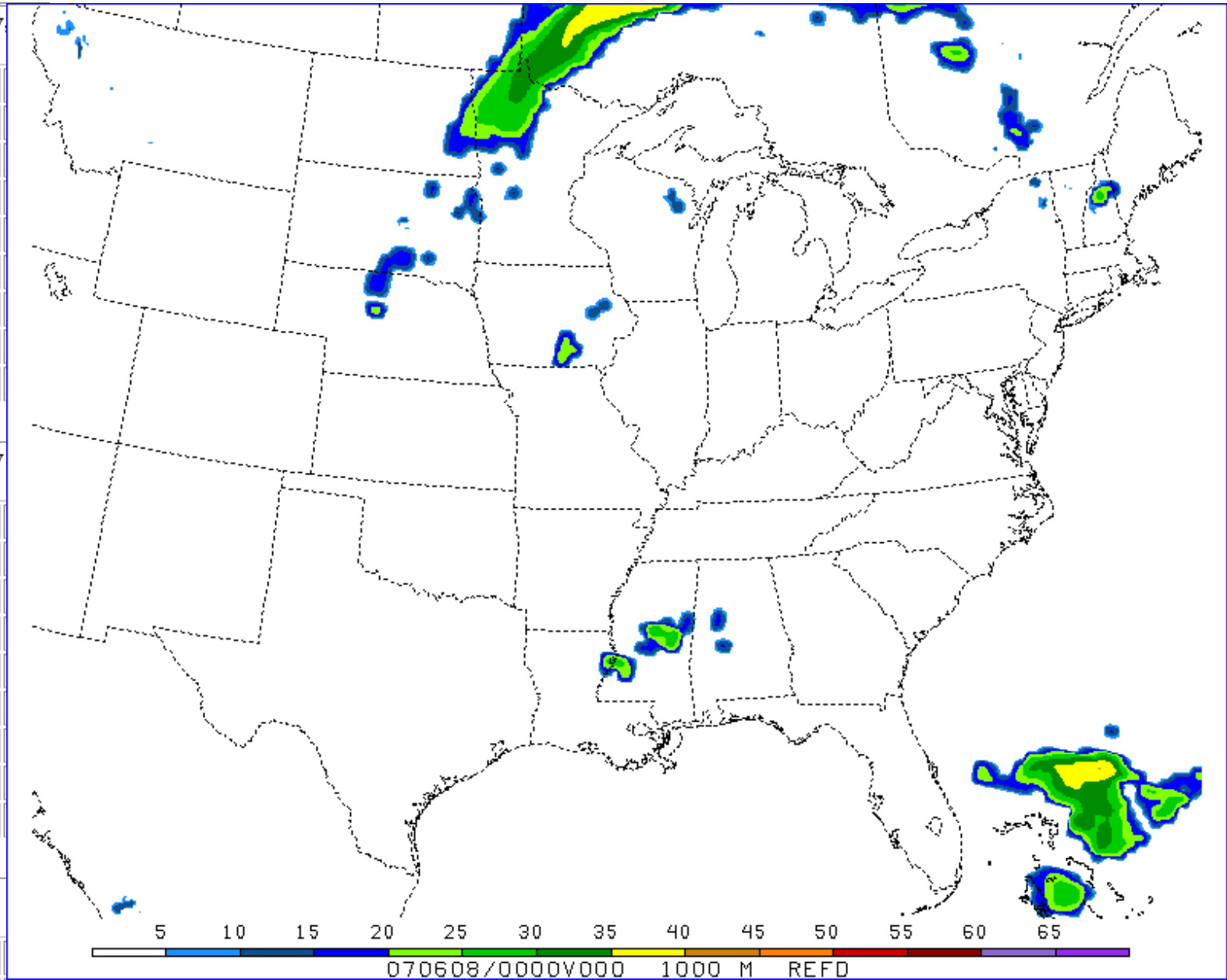
00h	01h	02h
04h	05h	06h
08h	09h	10h
12h	13h	14h
16h	17h	18h
20h	21h	22h
24h	25h	26h
28h	29h	30h
32h	33h	34h
36h	NMM WRF Loop	

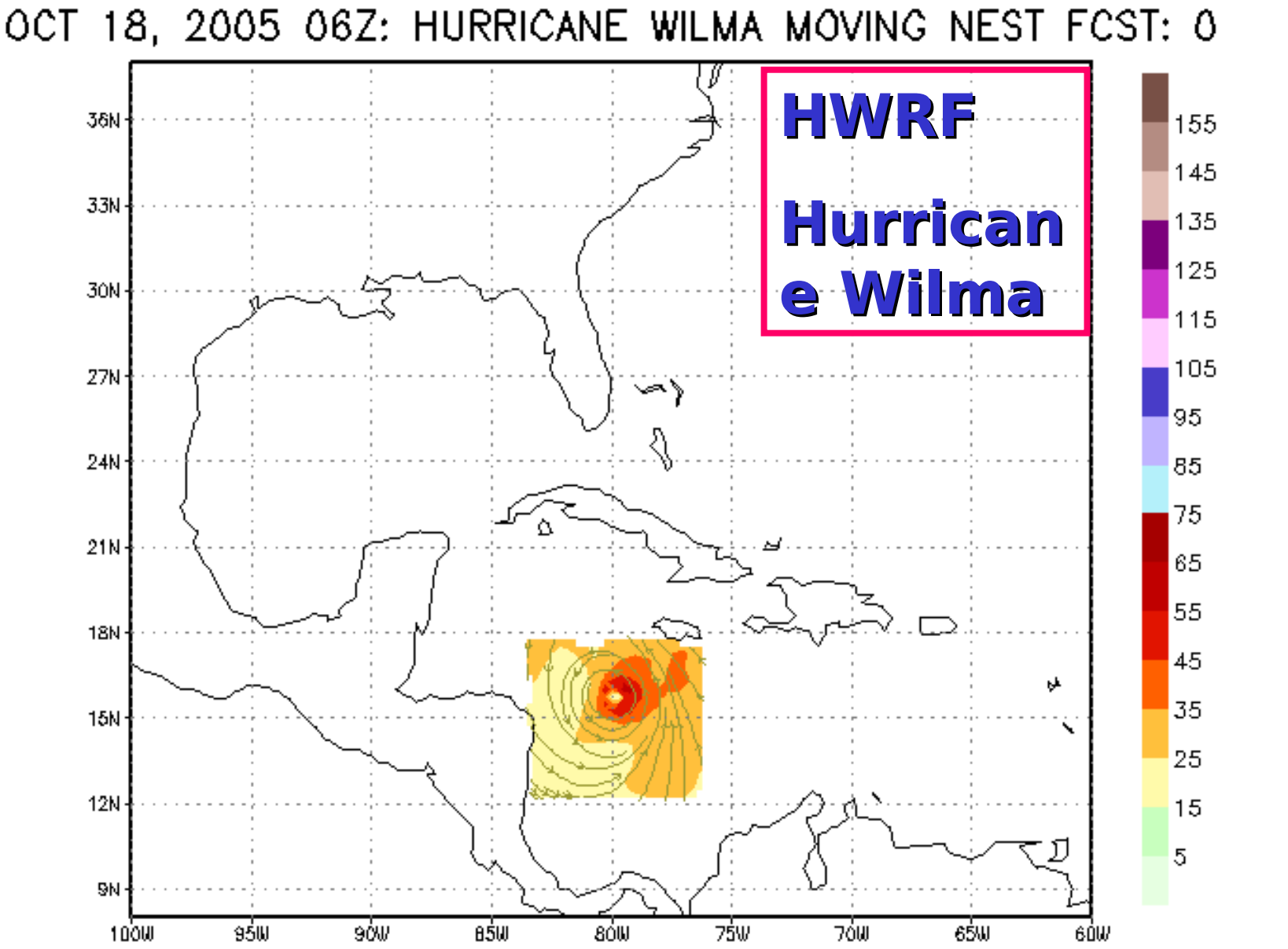
Simulated radar reflectivity (dBZ), 1000 m AGL

00h	01h	02h
04h	05h	06h
08h	09h	10h
12h	13h	14h
16h	17h	18h
20h	21h	22h
24h	25h	26h
28h	29h	30h
32h	33h	34h
36h	NMM WRF Loop	

Simulated composite radar reflectivity (dBZ)

00h	01h	02h




OCT 18, 2005 06Z: HURRICANE WILMA MOVING NEST FCST: 0
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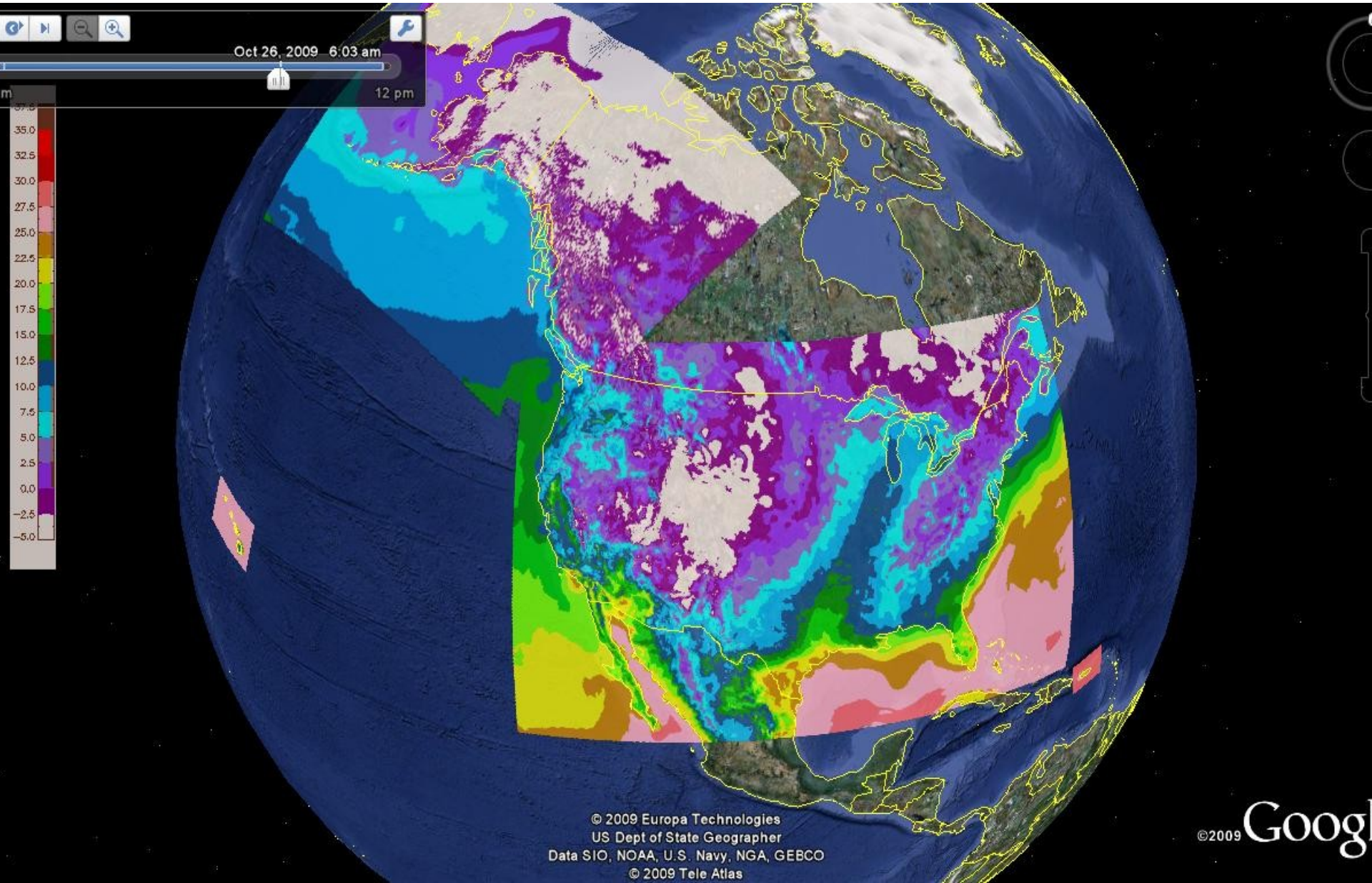
GrADS: COLA/IGES
2005-10-18-10:54

2007 NCEP Gets IBM P6 Upgrade

2008-10 NCEP Production Suite

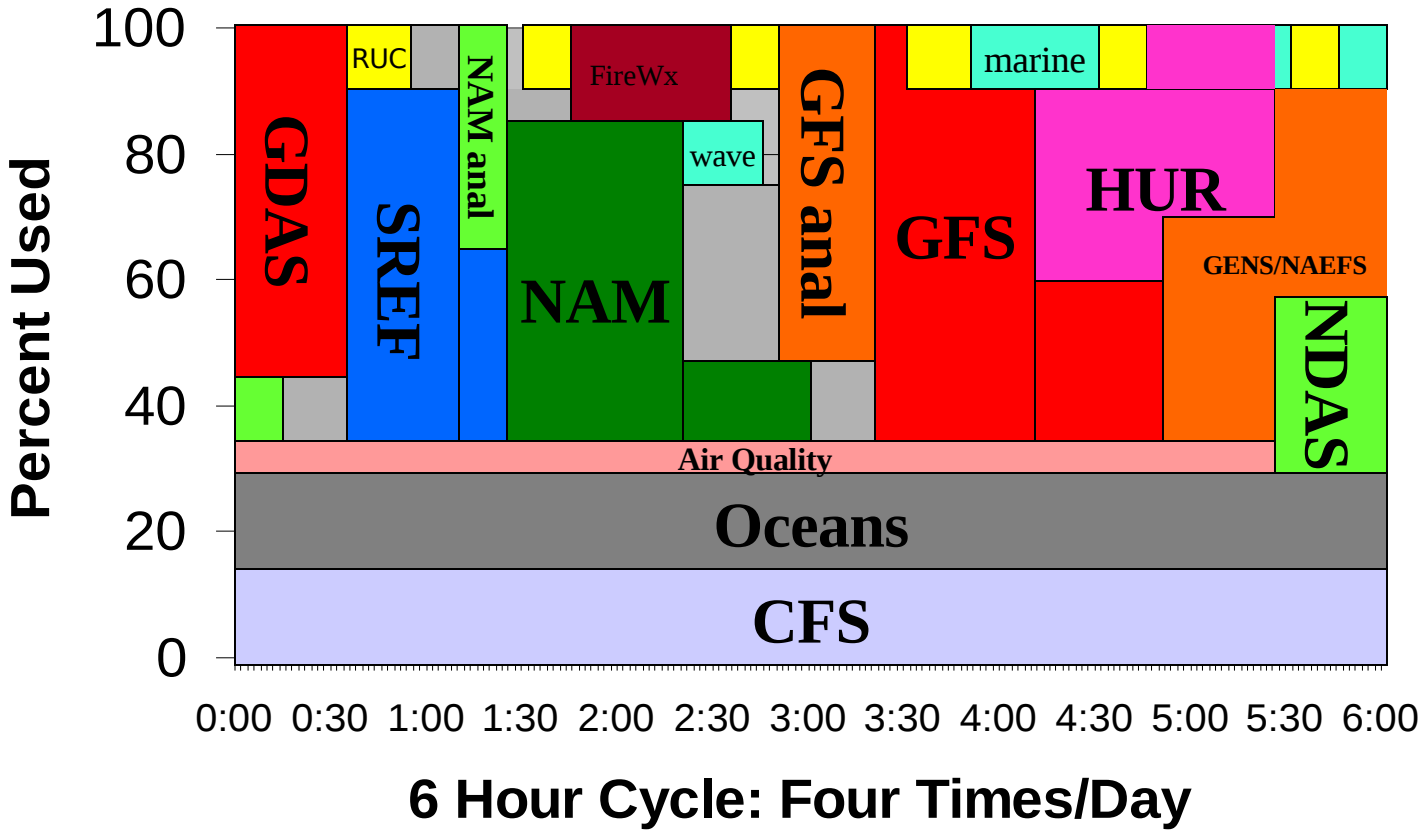
- NGM terminated 3 March 2009
- North American Mesoscale upgrades to WRf & gsi, partial cycling (08)
- SREF upgrade (21 members Eta, RSM, WRF-NMM & WRF-ARW) 32-35 km No. America 4/day to 87 hr
- HiResWindow upgrade explicit WRF-NMM & WRF-ARW 4-5 km to CONUS, Alaska, HI & PR to 48 hr
- RTMA adds Alaska(08), Hawaii (08), Puerto Rico (08)
- Hurricane WRF upgraded & coupled to POM
- GEFS upgrade (84 members) from T-126 to T-190 (~70KM) all the way out to 16 days
- Hybrid data assimilation (ensemble Kalman filter + 3D-/4D-VAR), movable nest in NEMS-NMMB

Google Map of 4 RTMA Domains



NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

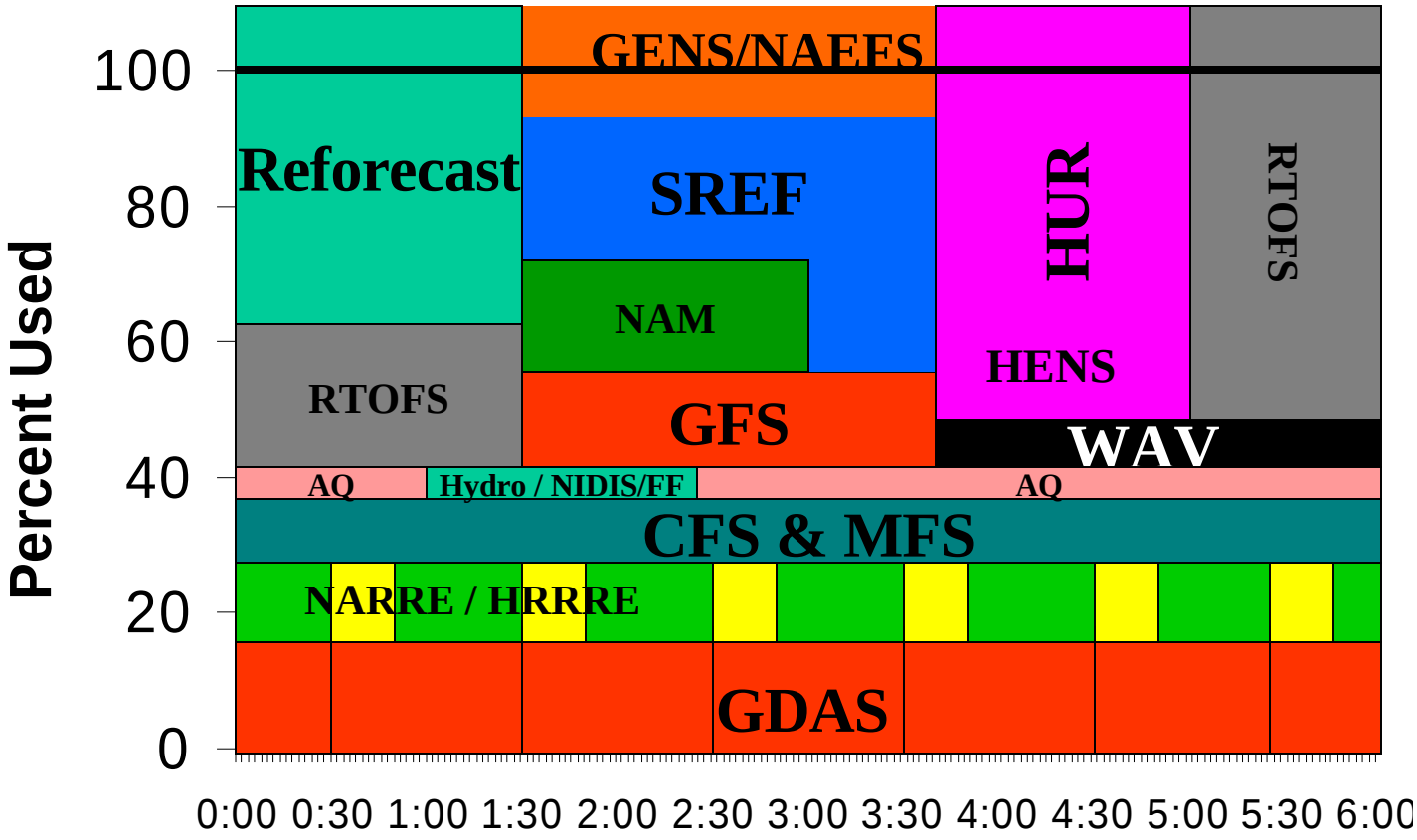
Current



NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

Next Generation Prototype
2017+

Computing x factor: > 240



6 Hour Cycle: Four Times/Da

Final Ruminations

WARNING:"I feel like I'm channeling Len Snellman"

- Is the NWP enterprise (at least in USA) facing another bout with cancer?
- When it seems we need them the most, our leaders are not providing anywhere near the resources we need to be competitive.
- Community models are breeding generations of model users or knobologists, who can NOT dive in and really develop numerical models
- Common modeling infrastructures are separating modelers from computer science, a synergy which has carried this fledgling science to where it is today.