Vector Experiences: MM5 and WRF

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- MM5
  - Vector considerations
  - Automatic restructuring using FLIC
  - Additional hand restructuring
  - Some results
- WRF
  - Design and storage order

MM5 Vector/DM considerations

- At only 60% overall vectorization, MM5 had a lot of room for improvement on vector systems
- Decomposing only the J-dimension helps preserve vector length in I-dimension, but even so, the longest vector will only be the length of the I-dimension (~ 100)
- Vector-specific restructuring and optimization
  - Combining I & J in physics can give vector lengths of 500 or more
  - Mostly automatic FLIC approach demonstrated with a representative physics module: explicit moisture (Reisner1)
  - Substep loops require hand-restructuring; this can be managed with ifdefs.
- Community Model: Same source approach important for addressing vector performance in MM5

Combining I and J with FLIC

- MM5 physics routines are currently called for one J-index at a time, with iteration over I-index inside routine as innermost loop
  - Vector length is limited to the size of the domain in I-dimension
  - There are J vector startups for each complete sweep of the domain
- Modify routine to be called once for all points (less boundaries) of the domain
  - Vector length increases to approximately the product of the I and J dimensions
  - Only one vector startup per sweep
- FLIC:
  - Identifies and modifies the I and J array declarations
  - Identifies and modifies loops over I and J
- Hand restructuring:
  - Modify caller to call routine once only, for all J
  - Pass in appropriate run dimension over combined IJ dimension
  - Implement gathers and scatters of input and output arrays into and back out of IJ data space

Combining I and J with FLIC

```
      SUBROUTINE EXMOISR(QC3DTEN,QR3DTEN,QI3DTEN,QNI3DTEN,QV3DTEN,
     &                   T3DTEN,T3D,QV3D,QC3D,QR3D,QI3D,QNI3D,PP3D,
     &                   PSB,RPSB,RAINNC,IN,J,IST,IEN)

C INPUT ARRAYS
      REAL  T3D(MIX,MJX,MKX),       QV3D(MIX,MJX,MKX), . . .

C ARRAYS FOR QV

      REAL QAOUT(MIX,MKX),QVQVS(MIX,MKX), . . .

      DO 15 K=1,KX
        DO 15 I=2,ILXM
          TAOUT(I,K)=T3D(I,J,K)
   15   CONTINUE

      DO 20 K=1,KL
        DO 20 I=IST,IEN
          PRES(I,K)=(A(K)*PSB(I,J)+PTOP)*1000.+PP3D(I,J,K)
          RHO(I,K)=PRES(I,K)/(R*TAOUT(I,K))
         . . .
```

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Combining I and J with FLIC

```
      SUBROUTINE EXMOISR(QC3DTEN,QR3DTEN,QI3DTEN,QNI3DTEN,QV3DTEN,
     &                   T3DTEN,T3D,QV3D,QC3D,QR3D,QI3D,QNI3D,PP3D,
     &                   PSB,RPSB,RAINNC,IN,J,IST,IEN)
C
C INPUT ARRAYS
      REAL  T3D(MIX*MJX,1,MKX), QV3D(MIX*MJX,1,MKX), . . .
C
C ARRAYS FOR QV

      REAL QAOUT(MIX*MJX,MKX),QVQVS(MIX*MJX,MKX), . . .

      DO 15 K=1,KX
        DO 15 I= IST,IEN
          TAOUT(I,K)=T3D(I,J,K)
 15     CONTINUE

      DO 20 K=1,KL
        DO 20 I= IST,IEN
          PRES(I,K)=(A(K)*PSB(I,J)+PTOP)*1000.+PP3D(I,J,K)
          RHO(I,K)=PRES(I,K)/(R*TAOUT(I,K))
         . . .
```

Modify call to EXMOISR

```
 SUBROUTINE SOLVE(IEXEC,INEST,NN)
  . . .
     DO J=JBNES,JENES-1

       CALL EXMOISR(QC3DTEN,QR3DTEN,QI3DTEN,QNI3DTEN,QV3DTEN,T3DTEN
+           ,T3D,QV3D,QC3D,QR3D,QI3D,QNI3D,PP3D,PSB,RAINNC,INEST,J,
+           IBNES,IENES-1)

     ENDDO
  . . .
```

Modify call to EXMOISR

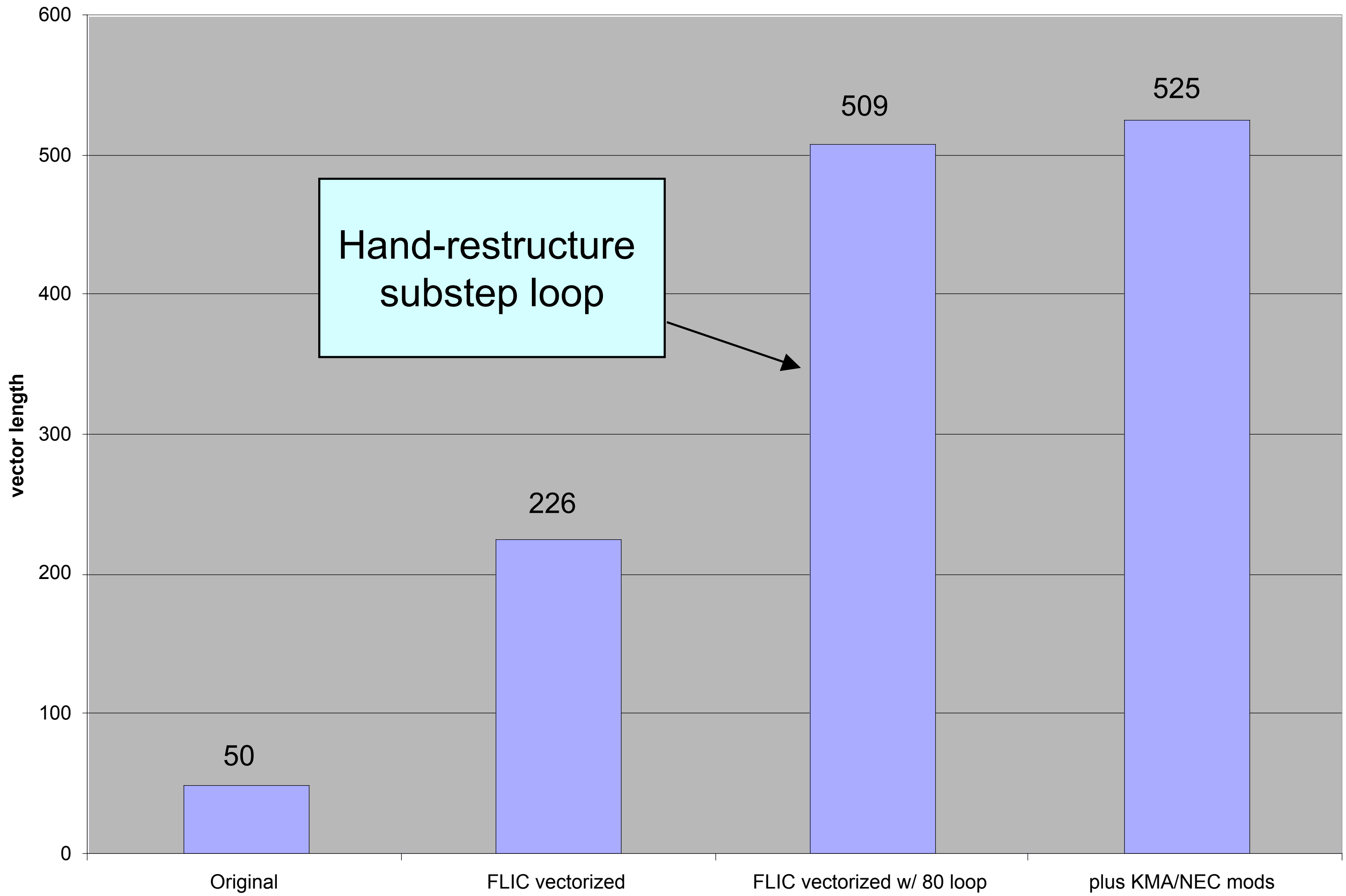
```
 SUBROUTINE SOLVE(IEXEC,INEST,NN)

 . . .
     CALL VECGATH( QC3DTEN,VEC_QC3DTEN,IBNES,IENES-1,
+                  JBNES,JENES-1,MKX,MIX,MJX,MKX,IP)
     CALL VECGATH( QR3DTEN,VEC_QR3DTEN,IBNES,IENES-1,
 . . .
     CALL EXMOISR(VEC_QC3DTEN,VEC_QR3DTEN,VEC_QI3DTEN,VEC_QNI3DTEN,
+         VEC_QV3DTEN,VEC_T3DTEN,
+         VEC_T3D,VEC_QV3D,VEC_QC3D,VEC_QR3D,VEC_QI3D,VEC_QNI3D,
+         VEC_PP3D,VEC_PSB,VEC_RPSB,VEC_RAINNC,INEST,
+         1,1,IP,0)
     CALL VECSCAT( VEC_QC3DTEN,QC3DTEN,IBNES,IENES-1,
+                  JBNES,JENES-1,MKX,MIX,MJX,MKX,IP)
     CALL VECSCAT( VEC_QR3DTEN,QR3DTEN,IBNES,IENES-1,
 . . .
```

Restructure sub-step in EXMOISR for Vectorization

```
C--COMPUTE THE FALLOUT TERMS:
      DO 80 I=IST,IEN
        NSTEP=1
        DO 90 K=1,KL
          FR(K)=G*RHO2*VT2R
          NSTEP=MAX0(IFIX(FR(K)*DT/DSIGMA(K)+1.),NSTEP)
   90   CONTINUE
        DO 100 N=1,NSTEP
          DO 110 K=1,KL
            FALOUTR(K)=FR(K)*SCR4R(I,K)
  110     CONTINUE
          DO 120 K=2,KL
            FALTNDR=(FALOUTR(K)-FALOUTR(K-1))/DSIGMA(K)
            QR3DTEN(I,J,K)=QR3DTEN(I,J,K)-FALTNDR/NSTEP
            FR(K)=AMAX1(FR(K)/DSIGMA(K),FR(K-1)/DSIGMA(K-1))*DSIGMA(K)
  120     CONTINUE
          RAINNC(I,J)=RAINNC(I,J)+FALOUTR(KL)*DTMIN*6000./G/NSTEP
  100   CONTINUE
   80 CONTINUE
```

Vector Length in EXMOISR

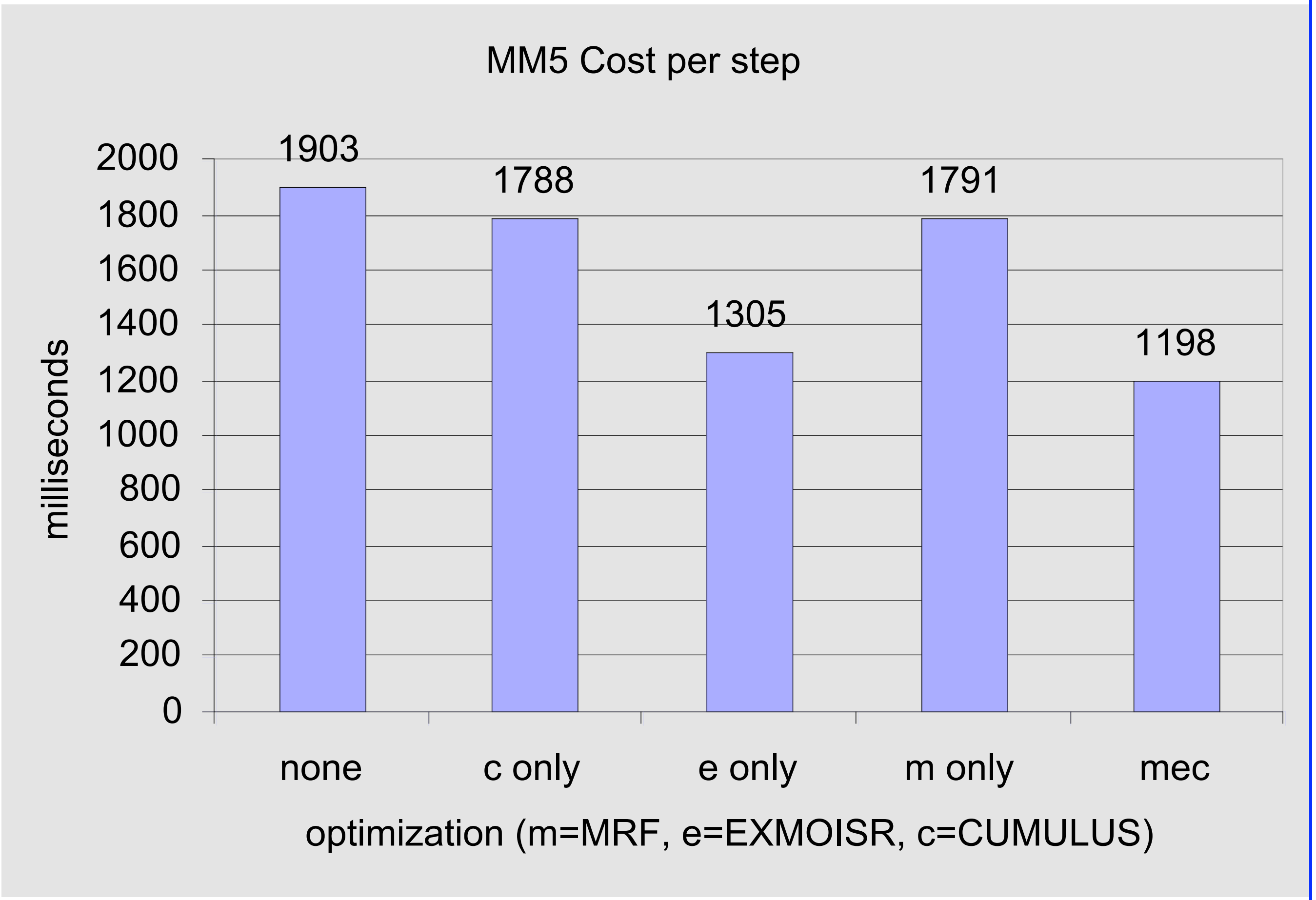


KMA/NEC Optimizations

- Modify divides to multiply by reciprocal
- Convert A**B to EXP(LOG(A)*B)
- Convert A**.5 to SQRT
- Convert A**.3333 to CBRT (where available), otherwise convert to EXP(LOG(A)*.3333)
- All of these, especially the power optimizations, also improve performance on Compaq and IBM
- Safe?

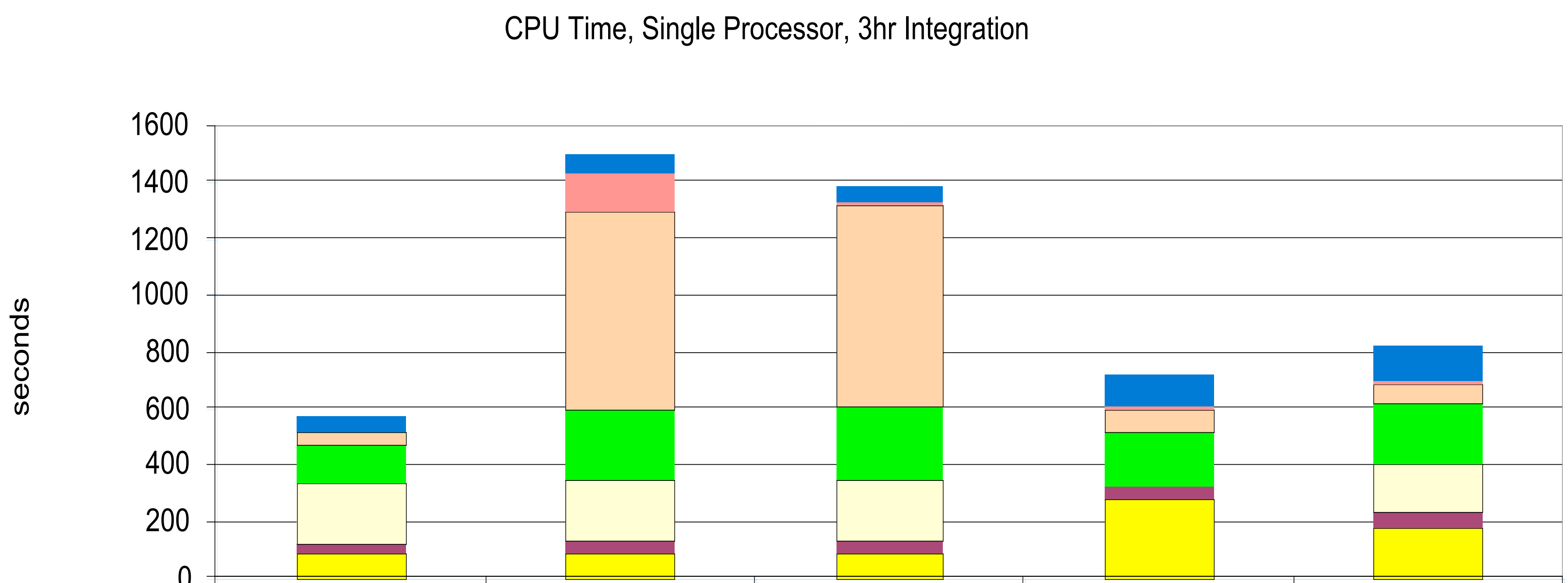
Improving MM5 Vector Efficiency

- Fujitsu VPP5000
  - Grell cumulus
  - MRF PBL
  - EXMOISR
- Automatic restructuring of MM5 physics routines to "collapse" IJ indices
- Also have incorporated SX/5 performance modifications (John Romo, HNSX)



Individual and collective effect on time per MM5 time step of automatic vector restructuring of physics packages

NEC SX5 Benchmarks (1 proc.)



	30 base	30N	30NN	5	10
remainder	50	61	61	117	122
rad	7 ★	140	6	4 ★	5 ★
microphys	36	704	720	85	76
intrins	138	246	255	185	209
cumulus	216 ★	216 ★	218 ★	0 ★	168 ★
pbl	40	43	43	52	56

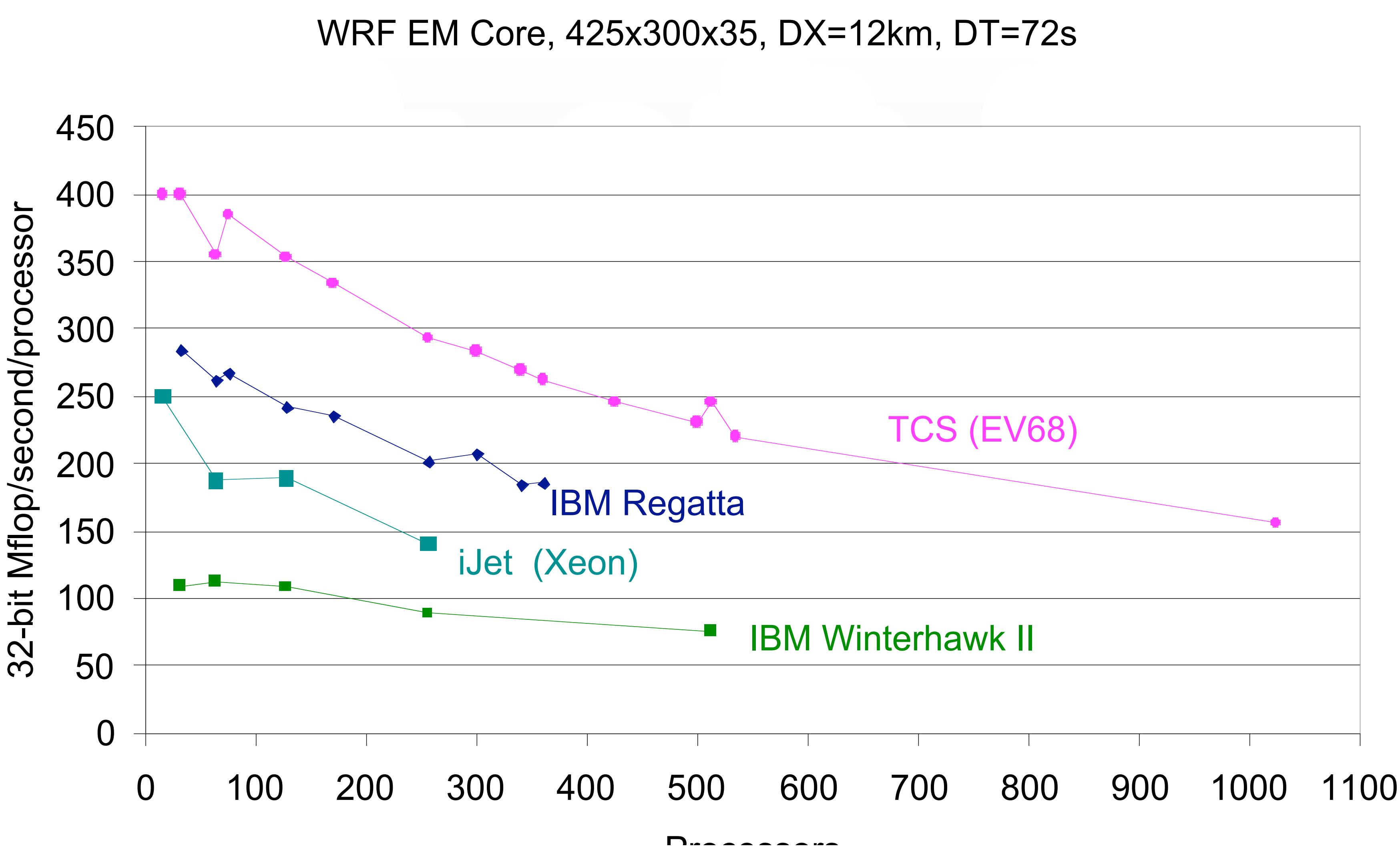
★ Vector-enhanced

Weather Research and Forecast Model

- Intended for but not yet ported to vector systems
- Vector considerations
  - Model layer interface facilitates I*J combining for routines without horizontal dependencies
  - Transposition is limited to mediation layer (solver)
  - Routines with horizontal stencils may need to be rewritten
  - WRF chose IKJ storage ordering as compromise between vector and super-scalar processors:

Michalakes, J., R. Loft, A. Bourgeois (2001): "Performance-Portability and the Weather Research and Forecast Model" in proceedings of the HPC Asia 2001 conference, Gold Coast, Queensland, Australia, September 24-28, 2001. CD-ROM ISBN: 0-9579303-0-5

WRF Performance



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Published Results (7):

SPECenvM2002 (7):

Tester Name	System Name	CPU	Process-Threads	Result	Full Disclosures
NREL (National Renewable Energy Lab)	IBM RS/6000 SP-375MHz T	56	16	28.68	| Text | HTML | PDF | PS | Config |
NREL (National Renewable Energy Lab)	IBM RS/6000 SP-375MHz T	56	32	53.52	| Text | HTML | PDF | PS | Config |
NREL (National Renewable Energy Lab)	IBM RS/6000 SP-375MHz T	56	48	71.79	| Text | HTML | PDF | PS | Config |
SGI	SGI 3800 128X 600MHz R14000A	128	128	281.12	| Text | HTML | PDF | PS | Config |
SGI	SGI 3800 16X 600MHz R14000A	16	16	48.99	| Text | HTML | PDF | PS | Config |
SGI	SGI 3800 32X 600MHz R14000A	32	32	96.67	| Text | HTML | PDF | PS | Config |
SGI	SGI 3800 64X 600MHz R14000A	64	64	175.40	| Text | HTML | PDF | PS | Config |

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URL: http://www.spec.org/hpg/hpc2002/results/envM2002.html

WRF web site:

www.wrf-model.org