Federal Committee for Meteorological Services and Supporting Research (FCMSSR)

Dr. Neil Jacobs

Assistant Secretary for Environmental Observation and Prediction

and

FCMSSR Chair

April 30, 2018

Agenda

2:30 – Opening Remarks (Dr. Neil Jacobs, NOAA)

2:40 – Action Item Review (Dr. Bill Schulz, OFCM)

2:45 – Federal Coordinator's Update (OFCM)

3:00 – Implementing Section 402 of the Weather Research And Forecasting Innovation Act Of 2017 (OFCM)

3:20 – Federal Meteorological Services And Supporting Research Strategic Plan and Annual Report. (OFCM)

3:30 – Qualification Standards For Civilian Meteorologists. (Mr. Ralph Stoffler, USAF A3-W)

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4:10 – Open Discussion (All)

4:20 – Wrap-Up (Dr. Neil Jacobs, NOAA)

FCMSSR Action Items

AI #	Text	Office Responsible	Comment	Status	Due Date
2017-2.1	Reconvene JAG/ICAWS to develop options to broaden FCMSSR Chairmanship beyond the Undersecretary of Commerce for Oceans and Atmosphere. Draft a modified FCMSSR charter to include ICAWS duties as outlined in Section 402 of the *Weather Research and Forecasting Innovation Act of 2017* and secure ICMSSR concurrence.	OFCM, FCMSSR Agencies	• JAG/ICAWS convened. • Options presented to ICMSSR • then FCMSSR with a revised Charter • Draft Charter reviewed by ICMSSR. • Pending FCMSSR and OSTP approval to finalize Charter for signature. **Recommend new due date: 30 June 2018.**	Working	04/30/18
2017-2.2	Publish the Strategic Plan for *Federal Weather Coordination* as presented during the 24 October 2017 FCMMSR Meeting.	OFCM	1/12/18: Plan published on OFCM website	Closed	11/03/17

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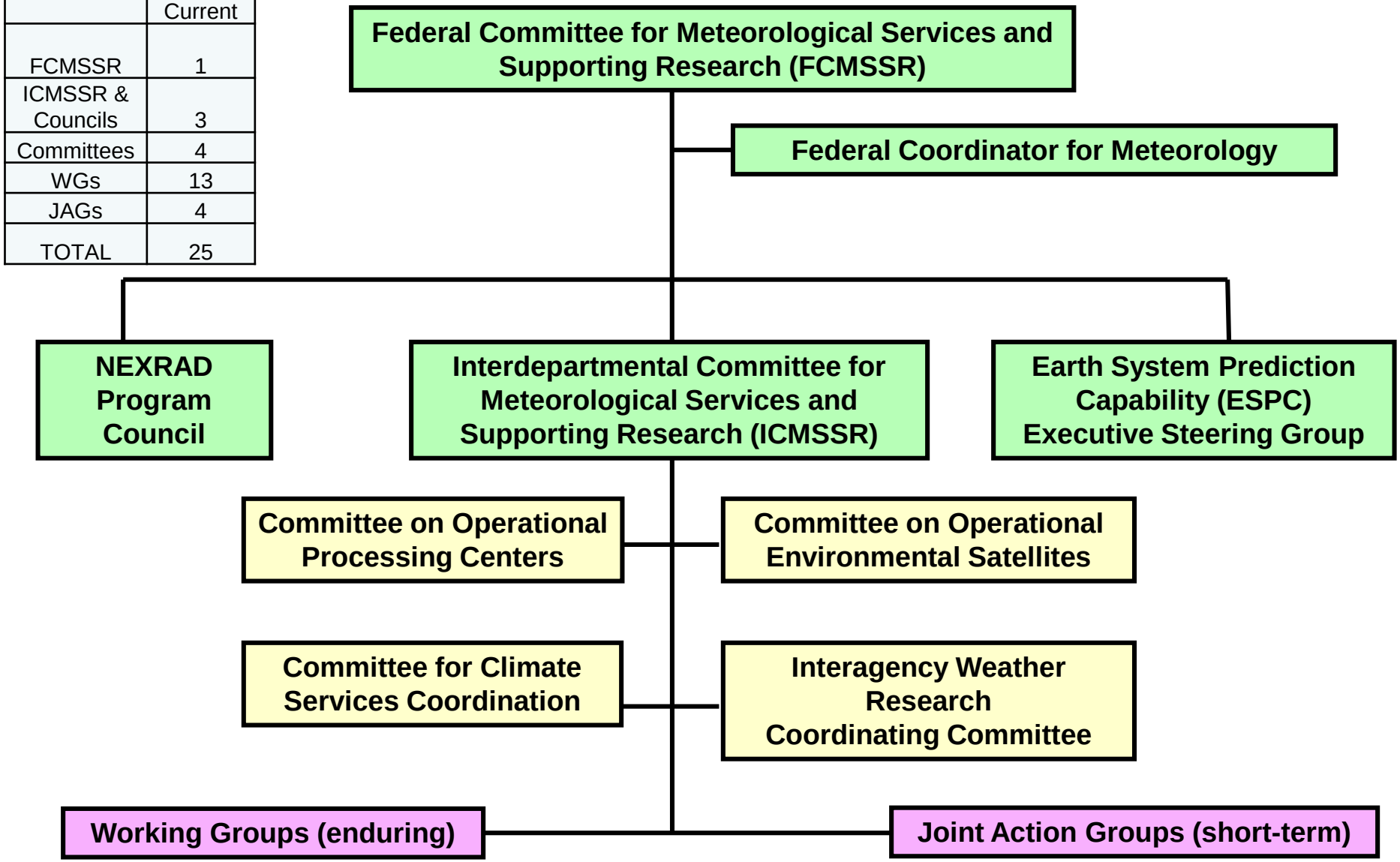
FEDERAL COORDINATOR'S UPDATE

Bill Schulz
Federal Coordinator

Federal Weather Enterprise Infrastructure

	Current
FCMSSR	1
ICMSSR & Councils	3
Committees	4
WGs	13
JAGs	4
TOTAL	25



Federal Coordinator's Update

1. **Released the "FY 19 Federal Weather Enterprise Budget and Coordination Report."**
2. **Tropical Cyclone Operations and Research Forum/Interdepartmental Hurricane Conference 2018 completed.**
   - Agreed to additional observations on approach to/turns around tropical cyclones
   - Hurricane Weather Research and Forecasting Model (HWRF) best performing Atlantic intensity model in '17. Updated HWRF implemented for Hurricane Season '18 – Global/Interagency benefits, e.g. through JTWC.
3. **Committee for Operational Production Centers**
   - Meets 8-9 May at 557th Weather Wing, Offutt AFB, NE; working on DoD transition plan for GOES-17
4. **Interagency Weather Research Coordination Committee**
   - Assisting US Rep. to World Meteorological Organization in preparation for Executive Council (June 2018) and WMO Congress (June 2019)
5. **National ESPC**
   - Hosted Subseasonal to Seasonal Metrics, Post-processing and Products Workshop
   - National Multimodel Ensemble (NMME) exceeding (esp. since '16) seasonal temperature forecast accuracy goals
6. **Working Group for Winter Storm Operations**
   - Formed to update the Nat'l Winter Storm ops Plan.

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Weather Act of 2017 § 402

402. Interagency weather research and forecast innovation coordination

(a) Establishment

The Director of the Office of Science and Technology Policy shall establish an Interagency Committee for Advancing Weather Services to improve coordination of relevant weather research and forecast innovation activities across the Federal Government. The Interagency Committee shall—

> **(1) include participation by the National Aeronautics and Space Administration, the Federal Aviation Administration, National Oceanic and Atmospheric Administration and its constituent elements, the National Science Foundation, and such other agencies involved in weather forecasting research as the President determines are appropriate;**
>
> **(2) identify and prioritize top forecast needs and coordinate those needs against budget requests and program initiatives across participating offices and agencies; and**
>
> **(3) share information regarding operational needs and forecasting improvements across relevant agencies.**

(b) Co-Chair

The Federal Coordinator for Meteorology shall serve as a co-chair of this panel.

(c) Further coordination

The Director of the Office of Science and Technology Policy shall take such other steps as are necessary to coordinate the activities of the Federal Government with those of the United States weather industry, State governments, emergency managers, and academic researchers.

Implementing Weather Act of 2017 § 402

Challenge: **The 2017 Weather Act directs OSTP to establish "an Interagency Committee for Advancing Weather Services (ICAWS)," with duties including identifying, prioritizing, and coordinating top forecast needs, and sharing needs and improvements across agencies.**

Recommendations:

- **Use a similar construct as that used in 1962 when OMB was tasked by law to produce an annual meteorological services budget report – had EOP (OMB) assign the task to an existing relevant agency (DoC).**
- **Since the FCMSSR and the supporting Federal weather enterprise coordination structure cover most ICAWS duties, assign those duties formally to FCMSSR, without creating another organizational entity.**
- **Have OSTP leadership endorse this plan; FCMSSR/OFCM adjust the charter to accommodate.**

Proposed Action:

- **FCMSSR approve recommending the implementation plan recommended here to the (Acting) Director, OSTP.** ***(Several of the options considered will be shown on following slides.)***
- **EOP/OSTP upon acceptance of the recommendation will formally request the Department of Commerce designate FCMSSR as responsible for the duties assigned to ICAWS; OSTP initiates legislative change request.**
- **FCMSSR approves modified FCMSSR (ICAWS) charter.**

Option A: Two, Equal Chairs: NOAA and OSTP

RECOMMENDED OPTION

FCMSSR charter re-written to include ICAWS duties

FCMSSR Chair: NOAA Administrator and senior OSTP representative

Legislative Change Request: OFCM to Executive Secretary vice Co-Chair

PRO:

- Satisfies spirit of 115-25 by having OSTP-led committee
- Other departments comfortable with EOP-level leadership
- Precedent for this model in SOST (a subcommittee under CENRS, which is co-chaired by NOAA/OSTP/NSF.)

CON:

- OSTP does not want to be responsible for managing lower level committees and associated “ground-level” or “tactical” issues **(NOT A SHOW STOPPER)**
- Need to have EOP support listing full membership of FCMSSR as part of the “other agencies involved …. as president determines are appropriate”

Option B: Two Chairs: NOAA permanent + rotator

(assumes FCMSSR charter re-written to include ICAWS duties)

FCMSSR Chair: Rotates among agencies; 1 or 2 serving concurrently

PRO:

- Other agencies provide balance to NOAA
- Committee gets a fresh perspective

CON:

- Lacks EOP leadership periodically
- Need to have EOP issue directive listing full membership of FCMSSR as part of the “other agencies involved …. as president determines are appropriate”
- Few agencies at ICMSSR were excited about being a co-chair

Option C: Two Chairs: OSTP permanent + rotator

(assumes FCMSSR charter re-written to include ICAWS duties)

FCMSSR Chair: Rotates among agencies; 1 or 2 serving concurrently

PRO:

- EOP leadership
- Committee gets a fresh perspective

CON:

- Large administrative burden on OSTP
- Influence of major weather resource managers periodically diminished
- Need to have EOP issue directive listing full membership of FCMSSR as part of the “other agencies involved …. as president determines are appropriate”
- Similar lack of enthusiasm by other ICMSSR agencies on being Chair

Proposed FCMSSR Charter Revisions

Section1:

- Change name to ICAWS
- Include reference to Weather Act 2017, retain reference to 87-843

Section 2:

- Name changes

Section 3:

- Add duties from PL 115-25 Section 402 (a)(2)and(3)
- These duties include "…coordinate those needs against budget requests and program initiatives across participating offices and agencies." Specify (for DoD): "only to extent required by PL 115-25."

Section 4:

- Add statement that per PL 115-25 Section 402 (c), participation of these agencies is "necessary to coordinate the Federal government" actions in this area.

Section 5:

- Name changes.

Section 6:

- Renew charter in 5 years

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Budget and Coordination Report FY19

- **e-Published to OFCM Web Site (30 April 2018)**
- **Pre-publish review by OMB**
- **Two sections:**

1. **Federal Coordination and Planning for Meteorological Services and Supporting Research** (with the goals and objectives of the *Strategic Plan for Federal Weather Enterprise Coordination* reprinted in this section for reference.)

2. **Agency Funding for Meteorological Services and Supporting Research**

Budget and Coordination Report FY19

1. Federal Coordination and Planning for Meteorological Services and Supporting Research

Section 1 lists actions that support the Strategic Plan for Federal Weather Enterprise Coordination, organized by committees and working groups. For example, the Committee for Operational Processing Centers (COPC) entry:

Committee for Operational Processing Centers (COPC)

Working Group for Cooperative Support and Backup (WG/CSAB)

- **Coordinated a solution for distributing the Himawari-8 data from NCEP across the COPC Network circuits to improve the IA posture, utilize the increased Navy bandwidths, and provide a more reliable data exchange. (Objective 1.2)**
- **Coordinated each OPC's GOES-R(16) data implementation strategy and the transition to GOES-East. (Objective 1.2)**
- **….etc….**

Working Group for Cooperative Support and Backup (WG/CSAB)

- **Establishing a new fiber connection between NOAA Satellite Operations Facility and the National Maritime Intelligence Center building…(Objective 2.1)**
- **…etc…**

Budget and Coordination Report FY19

2. Agency Funding for Meteorological Services and Supporting Research

Section 2 describes status and major changes in agency funding using a brief agency-provided narrative and two summary charts. This section is intended to satisfy the requirements of PL 87-843.

Budget and Coordination Report FY19

Table 1: Meteorological Services and Supporting Research (millions).

FY17 and FY18 amounts reflect Congressionally appropriated funds.

FY19 amounts reflect funding requested in the President's FY19 budget submission to Congress.

Agency	FY17	FY18	FY19
USDA	**74.88**	**112.7**	**109.50**
DOC/NOAA (Subtotal)	**3566.60**	**3541.77**	**2927.69**
NWS	1121.56	1114.02	1052.77
NESDIS	2202.27	2187.45	1640.02
OAR	174.90	172.60	164.60
NOS	31.97	32.00	32.00
OMAO	35.90	35.70	38.30
DOD (Subtotal)	**247.80**	**300.50**	**304.60**
Air Force	104.00	139.90	153.00
Navy	116.80	139.10	128.30
Army	27.00	21.50	23.30
DHS (Subtotal)	**32.12**	**32.13**	**32.23**
FEMA	1.92	1.93	1.93
USCG	30.20	30.20	30.30
DOI (Subtotal)	**43.36**	**39.51**	**37.72**
BLM	4.66	4.66	4.40
BOEM	0.00	1.76	0.57
NPS	3.20	3.09	2.75
USGS	35.50	30.00	30.00
DOT (Subtotal)	**254.50**	**275.50**	**203.50**
FAA	253.00	274.00	202.00
FHWA	1.50	1.50	1.50
EPA	6.36	6.22	2.12
NASA	**641.23**	**630.61**	**505.96**
NRC	**0.87**	**1.11**	**0.81**
DOE (Subtotal)	**229.68**	**240.96**	**130.16**
Science/BER	228.93	239.00	128.60
NNSA	0.35	0.40	0.35
EERE	0.40	1.56	1.21
DOS	**	**	**6.40**
Smithsonian	**0.02**	**0.02**	**0.02**
NSF	**134.10**	**134.10**	**126.60**
Total	**5231.52**	**5315.13**	**4381.31**

Budget and Coordination Report FY19

Table 2: Interagency Fund Transfers for Meteorological Operations and Supporting Research for FY2018, Estimated or planned.

Transferred			
From:	**To:**	**(.00 M)**	**Purpose**
DOC/NOAA			
NESDIS	NASA	150.10	Activities to continue development and implementation of JPSS program through Sep 2019. GOES-R series spacecraft, instruments, launch vehicles. GOES-NOP, POES/MetOp-A/MetOp-B on-orbit anomaly support
NESDIS	DOD	6.80	GOES-R technical and satellite support for satellite development programs
NESDIS	NTIA	2.65	Satellite Ground Services assistance with acquisition of a Radio Frequency Interference Monitoring System
NWS	NASA	2.56	Occupancy services provided by Stennis Space Center
NWS	NSF	1.20	Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) to plan, coordinate, and execute the Summer Institute component of the OWP Innovators Program
NWS	DOE (via NOAA OCIO)	1.07	Recapitalization funding for an additional rack of computing for the c4 partition, in support of the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act and Named Storm Event Model (NESM)
DOD			
Air Force	NRL	0.80	DMSP Sensor Support
Air Force	DOC/NOAA/NWS	7.88	DAPE, DOMSAT, JPSS, MDCRS, NEXRAD (NWS PME/DPEM)
Air Force	USARL	0.95	WS Live Virtual Constructive
Air Force	NSF/NCAR	1.50	Cloud Analysis Forecast (CAF)
Air Force	DOE/ORNL	7.90	Oak Ridge National Lab
Air Force	NWS/NOAA	4.89	NEXRAD Service Life Extension Program/Spares
Navy	NASA	2.30	Stennis Space Center, operations
Navy	NOAA	1.00	Satellite Data and Analysis
Army/ATEC	NCAR	3.46	4DWX Model Support
USACE	DOI/USGS	22.50	Hydro-meteorological collection
DOT			
FAA Weather	DOC/NOAA/NWS	19.00	IAA-Center Weather Service Unit
FAA Weather	DOC/NOAA/NWS	14.00	IAA-ASOS/ALDARS

Strategic Plan: Proposed Way Ahead

- **Continue to include the activity summaries in the annual Budget and Coordination Report.**
- **FCMSSR/ICMSSR (OFCM) conduct gap analysis and issue directions to Committees/Working Groups as appropriate.**
- **Leverage the existing Committee/Working Group structure to accomplish tasks from the 2017 Weather Act.**
- **Beginning CY20, revise/review Strategic Plan (via Joint Action Group), issue in CY21 for FY 22-26.**

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Federal Civilian Job Series 1340 (Meteorologist) Qualification Standards & Impacts to AFW

1. **Issue**: 1340 (Meteorologist) Qualification Standards drive unintended hiring consequences

- Reqmt for "Degree: Meteorology, Atmospheric Science, or other Natural Science major; Very specific course listing

- Or, "Combination of education and experience—coursework shown above, plus appropriate experience or additional education

2. Human resource processes across the government do not allow enactment of Part B

3. Transcript course titles across academia are non-standard

4. **Result**: Experienced and qualified candidates are not considered

5. **Recommendation**: Forward government change to OPM allowing for "some but not all coursework" phrasing for Part B

- AF is leading this change request

- Seeking interdepartmental (FCMSSR) coord and approval to approach OPM

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Future HPC Needs for Earth System Prediction Models

Dave McCarren
Mark Govett
30 April 2018

National ESPC
Earth System Prediction Capability

Earth System Prediction Computing Needs

- Need to better predict hazards at short time ranges *and* enable planning for weather-to-climate overlap
  - Weather predictions:
    - Strict time requirements (1 model day ≤ 8 min wall time)
  - Seasonal through decadal predictions:
    - Short run times for model evaluation, development
- Future computing needs will exceed 1000 times of today's existing computing
  - current prediction models on petaflops (10^{15} operations/s)
  - future models need **exaflops** (10^{18} operations/s)
- White paper

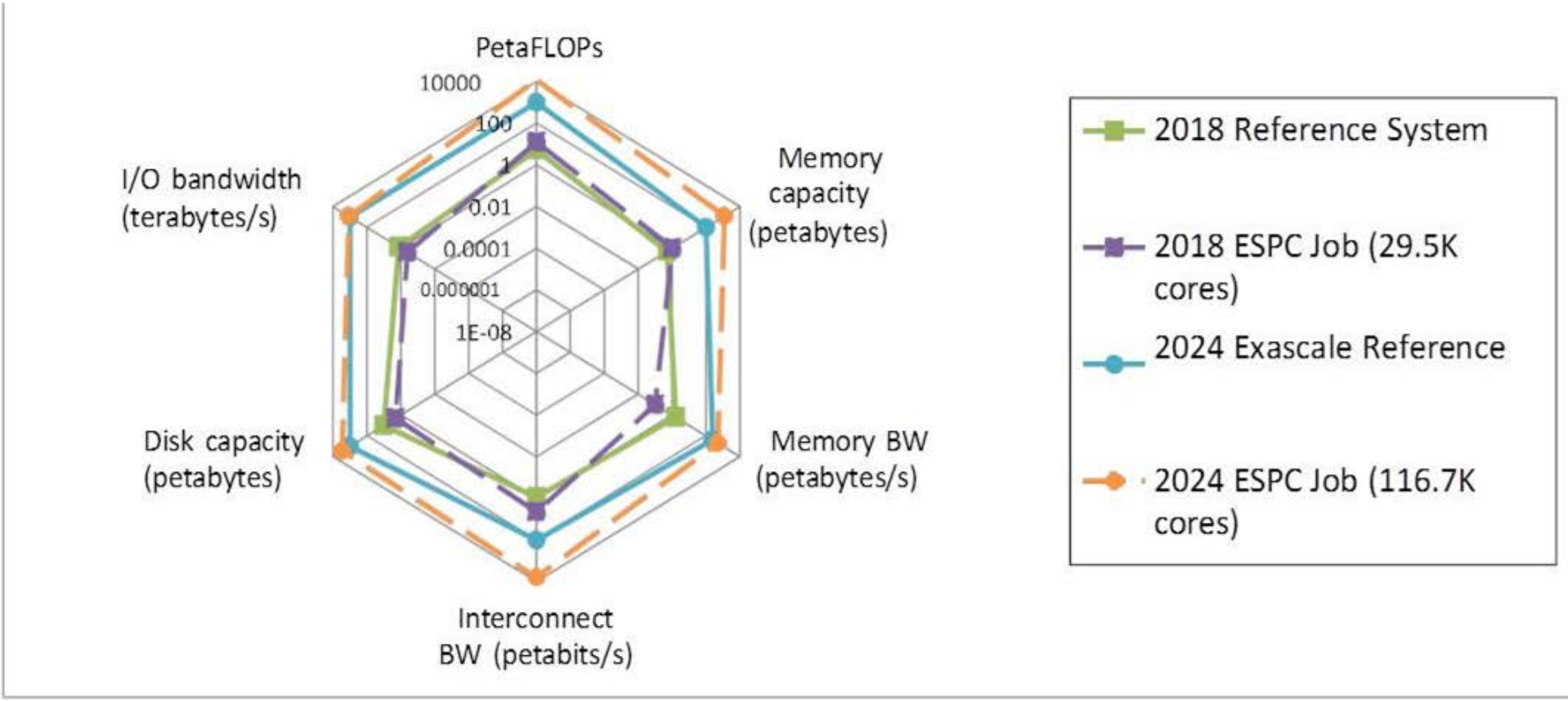
Earth System Modeling Requirements

- "HPC architectures are developing in the wrong direction for state-heavy, low computational intensity (CI) Earth system applications." - ESPC HPC White Paper
- Top500 #1 and #2 (June, 2017: https://www.top500.org):

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Sunway TaihuLight** - Sunway SW26010 260C 1.45GHz, NCRCP National Supercomputing Center in Wuxi **China**	10,649,600	93,014.6	125,435.9	15,371
			Developed for 25 flop/byte application		
2	**Tianhe-2** - TH-IVB-FEP Cluster, Xeon 12C 2.2GHz, Intel Xeon Phi, NUDT National University of Defense Technology **China**	3,120,000	33,862.7	54,902.4	17,808
			Developed for 7 flop/byte application		
5	**Titan** - XK7, Opteron 16C 2.2GHz, Gemini, NVIDIA Tesla P100, Cray Oak Ridge National Laboratory **United States**	560,640	17,590.0	27,112.5	8,210

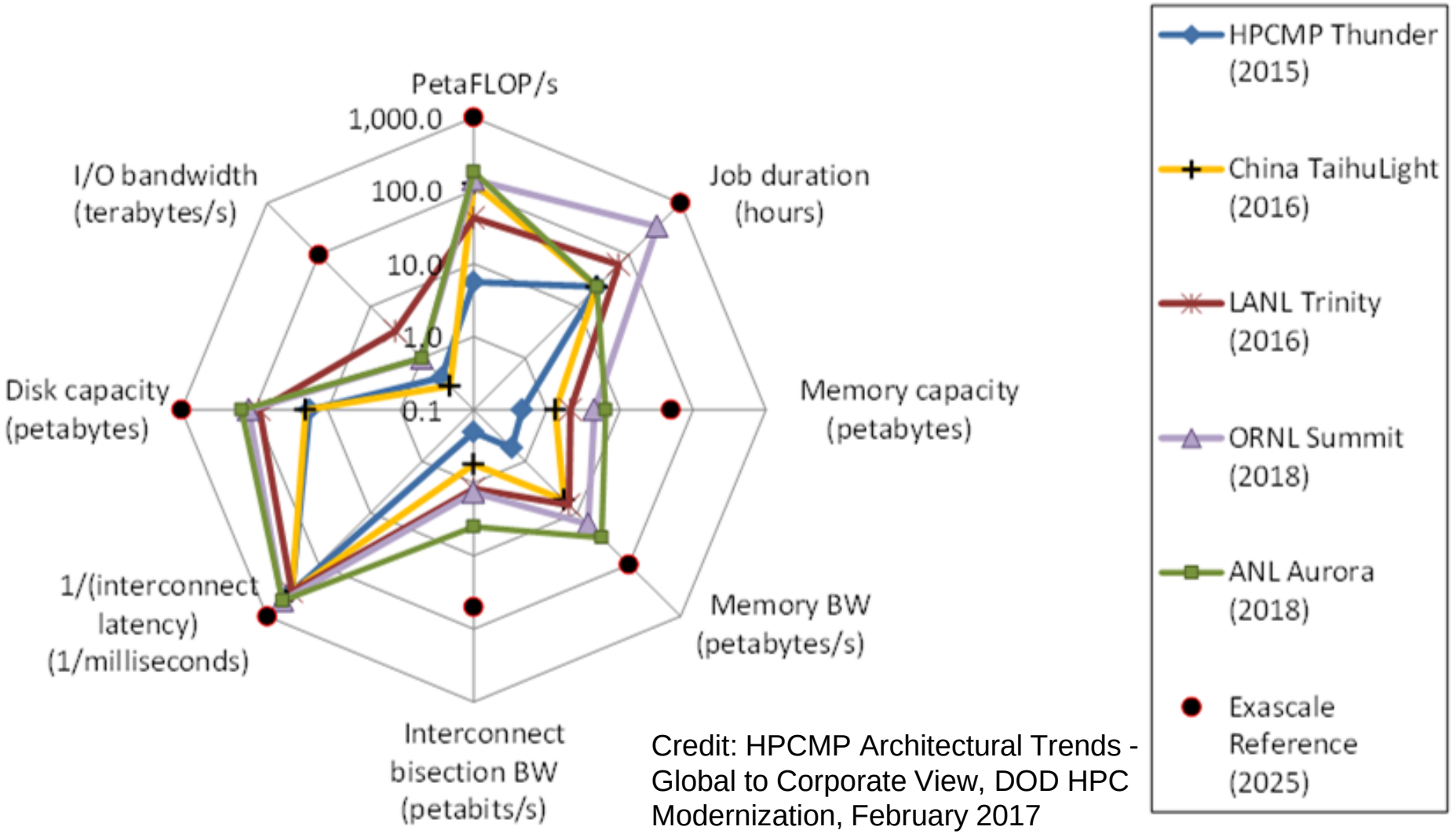
- Exascale systems will require applications providing upwards of 50 flops/byte [Goodacre, J., Manchester U., ECMWF Oct. 2016]
  - N.B.: most computationally intense components in **today's Earth system models rarely reach two operations per byte and typically run less than one operation per byte** over the full application. (Carman et al. 2017)

HPC Requirements for Earth System Modeling



Internal report: *The Future of DoD Climate, Weather and Ocean High Performance Computing Requirements*, 15 Aug 2016, Figure 24

HPC Outlook



Credit: HPCMP Architectural Trends - Global to Corporate View, DOD HPC Modernization, February 2017

HPC in the Exascale Era

- Exascale capability anticipated by ~2024
- HPC is not getting faster - end of Moore's Law (?)
  - Systems increasing beyond 10M cores (2024)
  - Inter-process communications, I/O are bottlenecks
  - Increasingly diverse processors
    - Fat nodes, thin nodes
    - Multi-level memory
    - Lightweight to heavyweight cores
- HPC development is being driven by market forces
  - Machine learning
  - Graphics processing

2018 Processors

Intel SkyLake - SP
48 cores

ARM

IBM POWER

AMD GPU

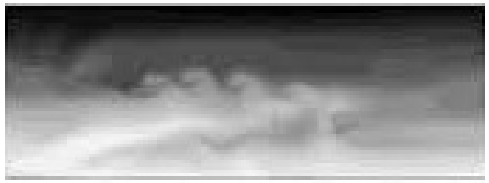
NVIDIA Volta GPU
5120 cores

Google TPU:
65,000 MXU

NVIDIA DGX-2
16 Volta V100
0.5TB HBM2 memory
2 PetaFlops, $400K
81920 cores

Earth System Prediction in the Exascale Era

- Improved prediction accuracy tied to HPC
  - More science (multiscale physics, ocean, chemistry)
  - Further system coupling
  - Run more ensemble members
  - Higher resolution – toward 1-km resolution
- Earth System Prediction Capability (ESPC) HPC working group formed to discuss the computing challenges now and in the future
  - NOAA, NASA, NCAR, Navy, DoE, DoD
  - Monthly meetings since 2016
  - Wrote position paper
  - Meeting at Supercomputing 2017



Carman, et al. “Position Paper on High Performance Computing Needs in Earth System Prediction.” National Earth System Prediction Capability (ESPC) program. April 2017. https://doi.org/10.7289/V5862DH3

National ESPC Earth System Prediction Capability

Supercomputing ‘17 Session

- Working group met with HPC SMEs across agencies, vendors
- Discussions demonstrated competing philosophies:
  - Computing design is inappropriate for the Earth system prediction problem; modeling community approaching point of no further progress: intersecting constraints
    - Limited available parallelism in Earth system models
    - Stalled processor clock speeds
    - Time-to-solution constraints imposed by mission requirements
  - Vendors build and measure performance according to their familiar metrics: Earth system community has no established/published performance metric for HPC, analogous to “Top500” measures
  - Earth system codes must be more flexible to accommodate multiple architectures both for interoperability and ease transition to new systems
    - Usually results in prohibitively costly computational inefficiencies . . .

National Strategic Computing Initiative (NSCI)

Lead agencies
Department of Energy
Department of Defense
National Science Foundation

Foundational R&D agencies
Intelligence Advanced Research Projects Activity
National Institute of Standards and Technology

Deployment agencies
National Aeronautics and Space Administration
Federal Bureau of Investigation
National Institutes of Health
Department of Homeland Security
National Oceanic and Atmospheric Administration

Goals

- Unite traditional HPC physical simulation focus with “big data”
- Preserve US HPC leadership by supporting users, vendors, developers, researchers
- Improve software interoperability between computers/architectures
- Provide widespread access to/training for HPC resources, to public and private sectors
- Develop post-silicon technologies for alternative computing

Earth System Modeling Application Challenges

- Models and assimilation methods are exceedingly complex
  - Millions of lines of code
  - Old design, architectures
  - Difficult to modify, upgrade, test
  - Limited opportunities to improve performance
- To run on exascale, codes will need to be adapted or re-written (yet again…)

Discussion Points

- To support national resilience, agencies need a voice in the development of new exascale computing architectures in the National Strategic Computing Initiative
  - DoE is investing in both exascale hardware and software. NOAA, DoD, and NASA need to invest in architectures supporting both general earth system modeling, and agency-specific mission needs
- Future HPC design should more closely fit software across the computation, storage, and networking system
  - Partnership across compute, storage, networking, and programmers
  - Document modeling and computation requirements
- Minimize disruption from hardware/software architecture changes to operational prediction missions
  - NOAA, DoD need to prepare codes for future architectures
- Transition current activities to a unified HPC strategy for earth system prediction across agencies and coordinate with international partners

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Open Discussion

Wrap-Up

- **OFCM will document any new Action Items and provide the meeting Record of Action within two weeks.**
- **Next FCMSSR meeting proposed for October 2018**
- **Wrap-Up (Chair)**

Backup material

What is National ESPC?

- An integrated National Capability meeting the U.S. Federal need for Earth System Prediction for the provision of operational products and services
  - For the protection of life and property in the US
  - For the economic development, aviation, maritime, shipping, agriculture of the US
  - National defense and homeland security (world wide)
  - Strategic decision making
- Includes:
  - Near term, medium range and extended range weather (< 90 days)
  - Seasonal/inter-annual (90 days – 2 yr)
  - Sub-decadal to decadal projections (2 to 30 yr)
- Leverages existing and planned Agency operational capabilities, and research and development programs and projects
- Work within missions/with contributions of each agency, to further a national goal

Effort is broadly consistent with WMO's S2S Prediction Plan and various national reports.

Strong need identified for inter-agency coordination

Technical Challenges

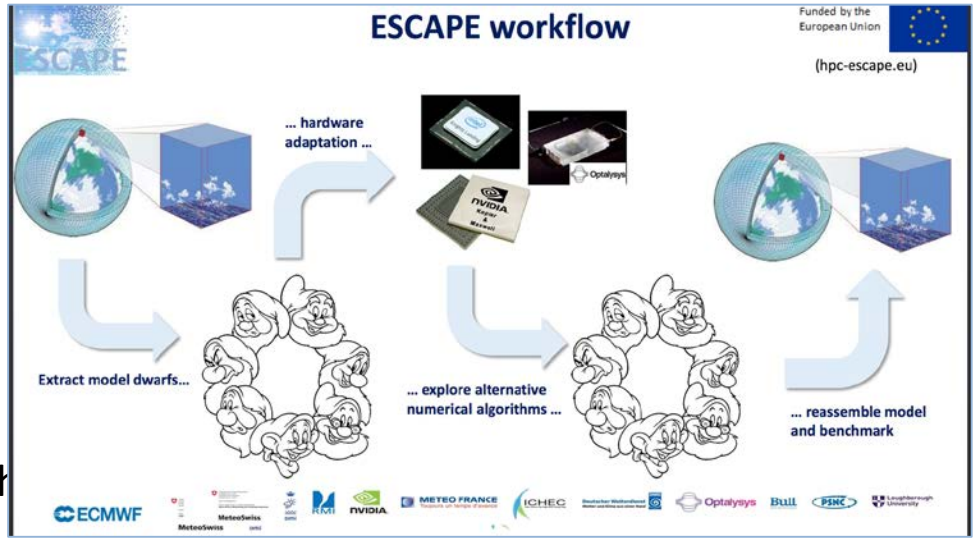
- What architecture will exascale computers have?
- What architecture should they have, for us to run efficiently and inform decisions across time scales?
- Near term pre-exascale HPC will be hybrid machines utilizing CPU + Accelerator.
- Running high performance codes at exascale requires recoding for each specific architecture types.
- Common technologies at the operational centers will simplify software compatibility.

Earth System Prediction Computing: Technical Challenges

- Models do not scale up efficiently:
  - Key: exploit parallelism, computational intensity
  - Performance wall: workload grows as 4th power of resolution, resources grow as 2nd power of resolution
  - fluid flow calculations are parallel in 3 spatial dimensions, limited by data bandwidth to memory, other supercomputer components
  - physical parameterizations are parallel in 2 spatial dimensions (parallelism in vertical is limited due to extremely fast physical coupling)
- Even those that do scale only use 6% available processing; tests of future models show 1-2% use

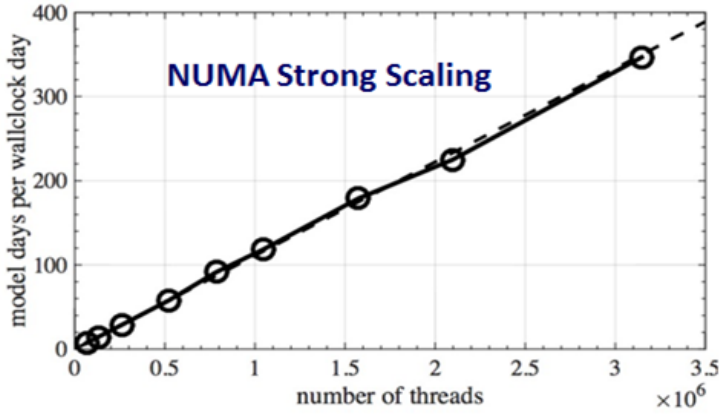
Model Development Targeting GPUs & Exascale

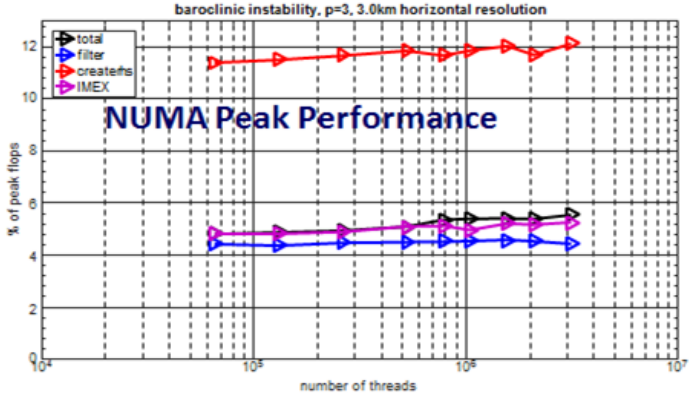
- Weather, climate models
  - MPAS (NCAR - IBM), Neptune (Navy)
  - COSMO (CSCS), ICON (DWD)
  - IFS (ECMWF)
  - NICAM (JMA), ASUCA (TokyoTech)
- Exascale focused efforts
  - LFRiC (UK-Met), FVM (ECMWF)
  - Energy-efficient and Scalable Algorith (ESCAPE)
  - European flagship Program on Extreme Weather and Climate Computing (EPECC)
  - ESiWACE, NextGenIO



Maximizing Peak Performance

- Not finding a way around memory-bandwidth issues means that even models that scale strongly will not be able to harness the full power of the hardware.
- On the left panel we show the scalability of NUMA on Mira (IBM BG/Q) using the full machine where, at 3 million MPI ranks, the model scales perfectly.
- On the right panel we show computation efficiency measured in percent of peak performance. The **red** curve is at around 12% while the rest of the code is below 6%.
- Today, most NWP codes will be around the 5-7% peak and this number needs to go up.
- Recommendation: even after using hardware-agnostic languages, we still need to optimize

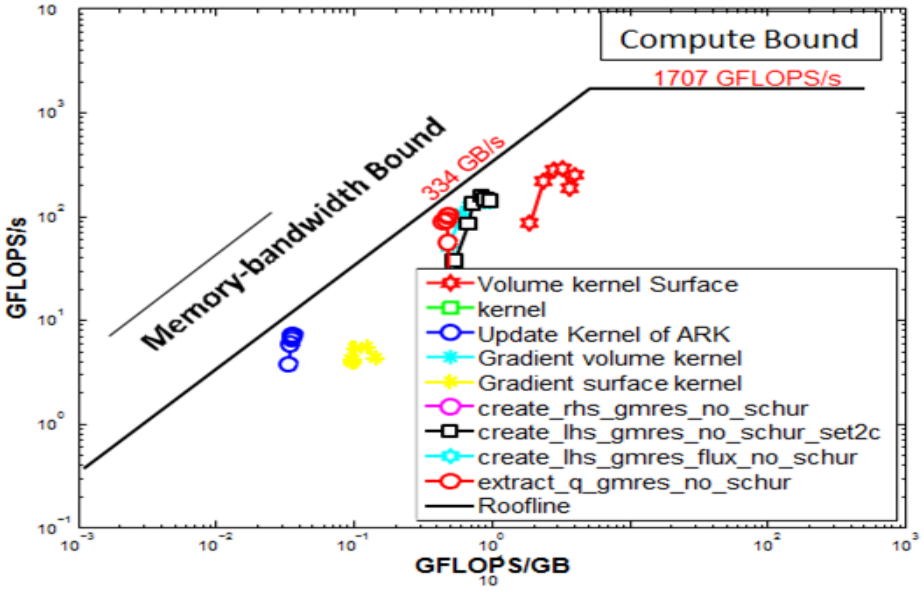




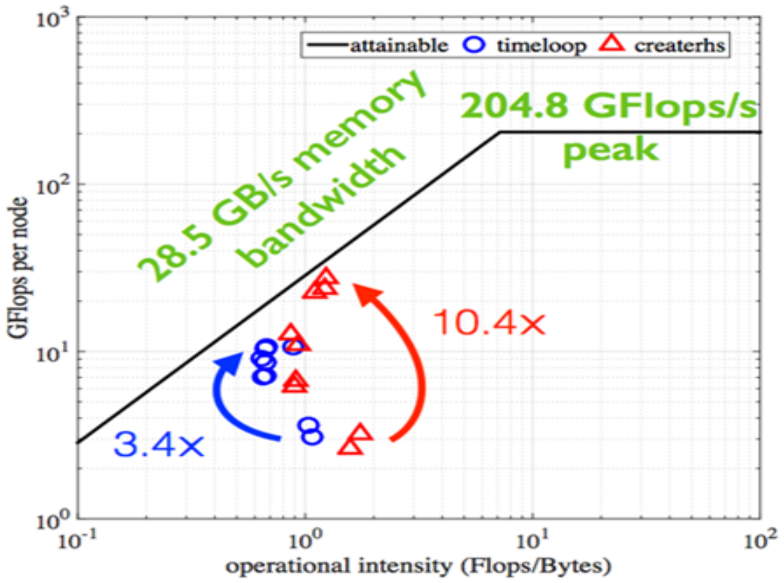
* Results from recent publica8on by Mueller-Kopera-Marras-Isaac-Wilcox-Giraldo

Memory vs. Compute Bound

- Current models are memory-bandwidth bound.
- Here we show roofline plots for the NUMA model on Titan (Nvidia K20 GPUs) on the left and on one node of Mira (IBM BG/Q) on the right.
- The sloped line shows the peak memory-bandwidth of the hardware and the flat line shows the peak computational performance. Note that all the different parts of the code are near the memory-bandwidth line (we are at the mercy of the communication speed of the hardware because we are moving way too much data). We desperately need to get around this barrier.



* Results from recent publication by Abdi et al. (2016)



* Results from recent publication by Mueller et al (2016).

Possible Solutions to Future HPC Challenges

- Two Approaches
  - Hardware-optimized: Different compute-kernels for each computer.
    - e.g., CUDA/OpenCL or OpenACC for GPUs and Intel Cilk or OpenMP for Xeon Phi
  - Hardware-agnostic: Write compute-kernels in one language, then write translators for each platform.
    - This is the idea behind OCCA* (Virginia Tech), Kokkos* (Sandia National Laboratory), Stella* (ETH), PSyclone (UK Met Office), and OpenACC*(NOAA) hardware-agnostic languages.
- Main Metrics
  - Time-to-solution (wallclock time)
  - Percentage of computer required
- A common modeling or computing technology would simplify this effort, but may not be possible.

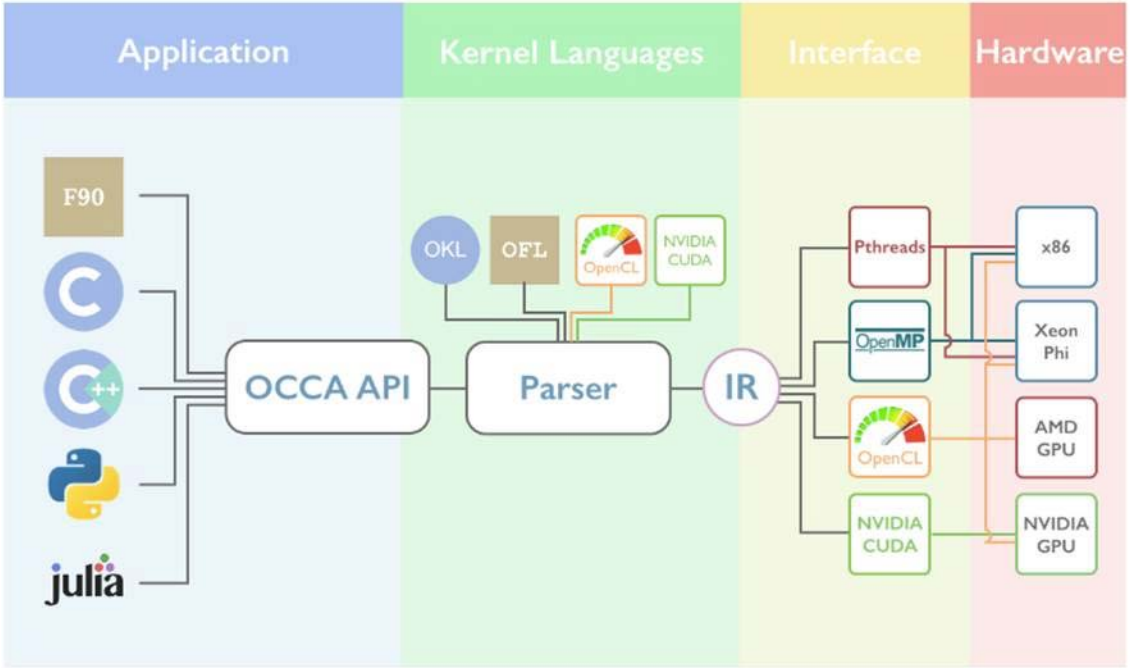
*OCCA: http://libocca.org/ *Kokkos: https://github.com/kokkos

One option: Hardware-optimized code

- Allows greatest efficiency of machine use by code, which may be critical for realizing exascale performance
- Machine constraints (dimensionality of problem, bandwidth) still apply
- Requires extensive model redesign and re-coding for every hardware type, and hardware update

Another option: Hardware-Agnosticism

- For discussion, take OCCA as hardware-agnostic language (there are many other options).
- The computer model codes are written in a **language** of modeler's choice.
- Software engineers pick a **specific kernel language.**
- The **library interface** translates to the language best suited for the **hardware**
- May be difficult to optimize multiple algorithms with specific computational characteristics



White paper by ESPC HPC Working Group:

> Carman, et al. “Position Paper on High Performance Computing Needs in Earth System Prediction.” National Earth System Prediction Capability (ESPC) program. April 2017. https://doi.org/10.7289/V5862DH3

“In contrast, ... today’s Earth system models typically run less than one operation per byte over the full application.”

“... average less than 2% of peak performance, constrained by their ability to perform sufficient calculations for each expensive access to memory.”

NEPTUNE: 0.4 flop/byte; < 2 percent D.P. peak fp; KNL

NUMA: 0.7 flop/byte (6 percent D.P. peak fp; Blue Gene Q)

WRF: ~2 percent S.P. peak fp; KNL (C.I. not available)

White paper by ESPC HPC Working Group:

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Programming challenges:

“Each processor design and system architecture requires specific coding structures optimized for that machine, forcing complete model redesign and rewriting for each subsequent and disparate hardware type.”

“Architecture-agnostic programming could offer a possible solution to portability but may present a challenge to achieving performance across vastly different hardware.”