Acknowledgements: David Carlson, Louis Uccellini, Yuanfu Xie, Steve Albers, Chris MacDermaid, Cecelia DeLuca, Carolyn Reynolds, Sharan Majumdar, Deon Terblanche, Paolo Ruti, Brian Golding, Thomas Jung, Andrew Robertson, Robert Vitard, Yuejian Zhu, Andre Methot, Rolf Langland, Jeff Whitaker, Yucheng Song

OMSZ Seminar, 27 May 2015
OUTLINE / SUMMARY

• THORPEX accomplishments – Adaptive methods
  – Targeted observations
  – Ensemble-based background covariance
  – Ensemble-based probabilistic forecasts

• New WWRP projects
  – Polar Prediction Project (PPP)
  – Sub-Seasonal to Seasonal Prediction Project (S2S)
  – High Impact Weather Project (HIWeather)

• US engagement
  – Agencies – Community initiative
    • Weather Hazard Reduction in Changing Climate?

• Enablers
  – EarthCube
  – Announcements of Opportunities
THORPEX 101 – 2005-2014

- **Objective**
  - Accelerate improvements in high impact weather forecasts

- **History**
  - WMO/WWRP sponsored program launched in 2004

- **Approach**
  - Modernize / optimize end-to-end forecast system
    - Observing, data assimilation, ensemble forecast, decision support systems
    - Allocate research resources to maximize overall economic impact
    - Adaptive & probabilistic approaches
      - Observations, covariances, physics, decision procedures
  - Coordination across
    - Components of forecast system
    - Nations & regions
    - Research & operational communities
MAJOR INTL. ACCOMPLISHMENTS

• **More organized** weather community
  – Focus on weather forecast research
  – Science Symposia, workshops, Working Group meetings

• **Global engagement**
  – Field campaigns (T-PARC), GEO projects – incl. Africa health initiative

• **End-to-end forecast process**
  – Use of forecasts included – Societal and Economic Research Applications (SERA)

• **Dialogue between academia & operations**
  – R2O projects, training of forecasters, etc

• **TIGGE** – THORPEX Interactive Grand Global Ensemble
  – Archive of operational global ensemble forecasts
    • 10 providers, 3 archive centers
“ADAPTIVE” – APPEARS 26 TIMES IN TIP

• Adaptive
  – “Case dependent modification of forecast procedures”
• Adaptive **reallocation of forecast resources**
  – Observations, DA, ensemble forecasting, products/services
• Adaptive observing systems
  – **Targeted observations** – *Winter Storm Reconnaissance*
• Adaptive use of voluminous observational datasets
  – (More)/less **data thinning** in (in)sensitive areas
• Adaptive **Quality Control**
  – Use ensemble-based variances
• Data assimilation
  – **Case dependent covariances** – e.g., *Hybrid GSI*
• Ensemble
  – Resolution vs membership **case dependent optimization**
  – Adaptive probability forecasts - *NAEFS*
• NWP system configuration
  – More resources for high impact areas / cases
MAJOR US ACCOMPLISHMENTS

• $20+M THORPEX-related investments by agencies
  – Field campaigns, AOs, archives, etc

  Developed, tested, & operationally implemented

• Adaptive observations
  – Winter Storm Reconnaissance (WSR) program
    • National Weather Service

• Ensemble based data assimilation
  – Hybrid GSI-EnKF - NCEP

• Multi-center ensemble forecasting
  – North American Ensemble Forecast System (NAEFS)
    • NCEP, Canada, Mexico
    • + FNMOC - National Unified Operational Prediction Capability
Study the lifecycle of perturbations as they originate from the tropics, Asia, and/or the polar front, travel through the Pacific waveguide, and affect high impact wintertime weather events over North America and the Arctic.

**Tropical flare-ups in western Pacific (IR)** merge with **Waves on westerly flow** to influence **Deep cyclogenesis in northeast Pacific**.}

Captured by Ensemble Transform KF targeting method.

**Expected forecast error reduction in verification region (07 Oct 12UTC)** due to adaptive observations around any grid point.

**Verification region**, 11 Oct 00UTC

**Sensitive area 1**, 11 Oct 00UTC

**Sensitive area 2**, 11 Oct 00UTC

**Verification region**, 14 Oct 12UTC
Dropsonde winds

WTPARC wind observation impact 12Z 20Jan2009

Forecast error reduction sum = -0.0399 J kg⁻¹
334 observations

Impact per-ob = Sum of impact / #ob data
Raob impact per ob: -0.79 e-5 J/kg
Drop impact per ob: -11.95 e-5 J/kg

Targeted observations have 15 times the impact of routinely taken observations

Global

Radiosonde winds

Global wind observation impact 12Z 20Jan2009

Forecast error reduction sum = -0.4688 J kg⁻¹
59,112 observations

Courtesy Rolf Langland
WSR Summary statistics for 2004-07

<table>
<thead>
<tr>
<th>Variable</th>
<th># cases improved</th>
<th># cases neutral</th>
<th># cases degraded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface pressure</td>
<td>21+20+13+25=79</td>
<td>0+1+0+0=1</td>
<td>14+9+14+12=49</td>
</tr>
<tr>
<td>Temperature</td>
<td>24+22+17+24=87</td>
<td>1+1+0+0=2</td>
<td>10+7+10+13=40</td>
</tr>
<tr>
<td>Vector Wind</td>
<td>23+19+21+27=90</td>
<td>1+0+0+0=1</td>
<td>11+11+6+10=38</td>
</tr>
<tr>
<td>Humidity</td>
<td>22+19+13+24=78</td>
<td>0+0+0+0=0</td>
<td>13+11+14+13=51</td>
</tr>
</tbody>
</table>

**OVERALL EFFECT:**

25+22+19+26 = 92 POSITIVE CASES
0+1+0 +0   = 1  NEUTRAL CASE
10+7+8 +11 = 36 NEGATIVE CASES

71.3% improved
27.9% degraded

Wind vector error, 2007

Without targeted data

With targeted data
HYBRID COVARIANCE

- Incorporate ensemble perturbations directly into variational cost function through extended control variable
  - Lorenc (2003), Buehner (2005), Wang et. al. (2007), etc.
  - Preconditioning ignored for simplicity

\[
J(x_f, \alpha) = \frac{1}{2} (x_f)^T B_f^{-1} (x_f) + \frac{1}{2} \sum_{n=1}^{N} (\alpha_n)^T L^{-1} (\alpha_n) + \frac{1}{2} (Hx_t - y)^T R^{-1} (Hx_t - y)
\]

\( \beta_f \) & \( \beta_e \): weighting coefficients for fixed and ensemble covariance respectively

\( x_i^r \): (total increment) sum of increment from fixed/static \( B \) (\( x_f^r \)) and ensemble \( B \)

\( \alpha_i \): extended control variable; \( \alpha \): ensemble perturbations

\( X_k^e \): analogous to the weights in the LETKF formulation

\( L \): correlation matrix [effectively the localization of ensemble perturbations]

From Daryl Kleist

From Jeff Whitaker
6-DAY NAEFS FORECAST OF COLD SPELL

Ensemble and Deterministic Forecasts issued 6 November 2014 12 UTC
Prévision d'ensemble et déterministe émises le 6 Novembre 2014 12 UTC

DENVER (DEN) 39.87 N 104.67 W/O

Thicknesses 1000-500/Épaisseurs 1000-500

ADAPTIVE PROBABILITIES

BIG PREDICTED CHANGE
DID IT HAPPEN?

Ensemble and Deterministic Forecasts issued 12 November 2014 00 UTC
Prévision d'ensemble et déterministe émises le 12 Novembre 2014 00 UTC

DENVER (DEN) 39.87 N 104.67 W/O

Thicknesses 1000-500/Épaisseurs 1000-500

November/Novembre 2014

- Global Model / Modèle global CMC
- Control Member / Membre contrôle CMC
- Control Member / Membre contrôle NCEP
POTENTIAL FOR BIG CHANGE PREDICTED

How to use low probabilities? Why only small number of members show extreme cold?
FUTURE RESEARCH OPPORTUNITIES

• **Stakeholder engagement**
  - Objective assessment of costs/benefits of weather research
    • Articulate societal need for / potential impact of weather research

• **Optimal design of observing systems**
  - Use OSSE etc not only for evaluation but design

• **Global scale nowcasting**
  - Cloud scale data assimilation w remote observations
  - Non-hydrostatic Earth System coupled forecasting

• **Impact forecasting** using multi-center ensembles
  - Decision support based on quantified forecast uncertainty
    • Forecast impact of weather – not only weather
Polar Prediction Project (PPP)

The Science Plan and Implementation Plan are available!

- **Objective:**
  “Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hourly to seasonal” (contribution to WMO GIPPS)

- **Research components:**
  - observations, modeling, data assimilation, ensemble forecasting
  - predictability, diagnostics, teleconnections
  - societal and economic research applications, verification


- **Synergies** with the WCRP Polar Climate Predictability Initiative (PCPI)

- **Project Office:** AWI, Germany

- **Trust fund:** from Canada, Norway and UK so far, further contributions welcome

**US participants:** C. Fairall, D. Bromwich, M. Holland, D. Perovich

Courtesy T. Jung, AWI
Objectives:
- To improve forecast skill and understanding on the S2S timescale with emphasis on HIW – 2 wks – 2 mos
- To promote uptake by operational centres and exploitation by the applications community
- To capitalize on the expertise of the weather and climate research communities to address GFCS priorities

Implementation underway: TIGGE-like multi-model data base being established, 5 sub-projects

Demonstration projects on extreme events (e.g. 2010 Russian heatwave, floods in Pakistan in 2010 and Australia in 2011, and 2012 European cold spell)

Project Office: NIMR, KMA, Jeju, Korea (official ceremony at EC-65) – S2S session and workshop (monsoon focus) 22-26 June 2015

Trust fund: from Australia, USA and UK so far, welcome further contributions from Members.

US Participants: A. Robertson, B. Kirtman, A. Kumar, D. Waliser, P. Dimmeyer
**High Impact Weather (HIWeather) Project**

**Mission:**
Promote Co-Operative International Research to achieve a Dramatic Increase in Resilience to High Impact Weather, worldwide, through improving Forecasts for timescales of minutes to two weeks and Enhancing their Communication & Utility in Social, Economic & Environmental Applications.

**Focus on Selected Hazards**

**Urban Flood:**
Reducing mortality, morbidity, damage and disruption from flood inundation by intense rain, out-of-bank river flow, coastal wave & surge overtopping and from consequent urban landslides.

**Wildfire:**
Reducing mortality, morbidity, damage and disruption from wildfires & their smoke.

**Extreme Local Wind:**
Reducing mortality, morbidity, damage and disruption from wind & wind blown debris in tropical & extra-tropical cyclones, downslope windstorms & convective storms, including tornadoes.

**Disruptive Winter Weather:**
Reducing mortality, morbidity, damage and disruption from snow, ice and fog to transport, power & communications infrastructure.

**Heat & Air Pollution in Megacities:**
Reducing mortality, morbidity and disruption from extreme heat & pollution in the megacities of the developing and newly developed world.

**New possible RDPs**

**A. MacDonald – High Impact Challenge**

**Lake Victoria RDP project – S. Goodman, S. Albers**

**US Participants:** S. Majumdar, R. Morss
US ORGANIZATION

• THORPEX ended Dec. 2014
  – Laura Furgione, US PR to WMO
    presented Certificates to contributors

• Transitional period in 2015
  – THORPEX Committees transform to
    • Interim Weather Research Committees
      – TORs developed for standing comm.
      – Membership established/expanded (FAA & DOE interest)

  – Interagency Weather Research Coordination Committee (IWRCC)
    • T. Lee, J. Cortinas, B. Lapenta, P. Harr, M. Peng, D. Eleutero
    • Oversees CWRSC

• US THORPEX Science Steering Committee =>
  – Community Weather Research Steering Committee (CWRSC)
    • Develop Science Plan; Fall 2015 Workshop
      – Carolyn Reynolds & Sharan Majumdar, Co-Chairs
WMO/WWRP International Legacy Projects

Sharan Majumdar & Carolyn Reynolds

Jonathan B. Shuker
US OBJECTIVES - IWRCC

- **Coordinate** US participation in 3 legacy & other WWRP projects
- **Align agency programs** w national / international projects
- Leverage / **optimize use of national research infrastructure**
- **Foster Research to Operations** (R2O) transition
- Review progress / provide **oversight of national projects**
- Provide **guidance on international weather research** to US PR

- **Develop community initiatives**
  - High impact weather research
    - With high socio-economic relevance
MOTIVATION / CONTEXT FOR CHOICE OF PROJECT –
30k VIEW OF “PROGRESS”

“Humanity is like a brakeless car accelerating on a
curvy downhill mountain road, its cheerful passengers oblivious of any problems ahead.”

Paraphrased quote from Edward Plunkett (1878-1957)

- Have we lost the breaks?
  - Acceleration not sustainable
  - At which curve may we lose control?
• **Climate change**
  – Changing extreme weather / drought
  – Ice-free Arctic
  – Rising sea level
  – Ocean acidification
  – Ecosystem collapse

• **Population growth**
  – Water & food shortage

• **Growing gap between rich & poor**

• **Environmental pollution**
  – “External” – Fresh water, ocean, land, ecosystem pollution
    • Chemicals including medicines
      – Endocrine disruptors, carcinogens, antibiotics, etc
  – “Internal” – Incidental / deliberate ingestion from environment
    • Genetic impact – Declining fertility, etc

**Growth as value? Is that sustainable?**
Under all RCPs the rate of sea level rise will very likely exceed that observed during 1971–2010.

Stabilising global mean surface temperature does not stabilise global mean sea level.
HOW SCIENCE CAN AFFECT CHANGE?

• Western sciences good at analysis, taking things apart

• **Less so with synthesis / integration**, putting things together

• **Work seamlessly across disciplines** to capture full reality
  – Weather & Climate - Ontologically one system
    • Dual perceptions due to different investigative methods
  – Nature & Society – Inseparable on global scale
    • Major human impact globally

• Only via **integration of natural laws & social policies** can we
  – Predict coupled Earth System (w prescribed or predicted *policies*)
  – Influence / shape future

*For societal (and not only “scientific”) relevance*
Proposed WCRP coastal megacities initiative

- 50% global population (70% by 2050)
- 70% global carbon emissions
- 90% of GDP
- Huge built infrastructure
- Microclimates
- Extensive water & food footprints
- Massive mitigation co-benefits
- Funding

Courtesy David Carlson
Multi-scales multi-components coupled modelling

- high resolution weather
- air quality
- storm surge models
- hydrologic models
- ecoscape models
- economic models
- transportation models
- coupled regional models
- opportunistic data sources

Massive data assimilation and integration challenge

Courtesy David Carlson
• Conceptual **4-var. model**: Nature, Wealth, Poor, Rich
  – 10 parameters based on Predator – Prey model
    • E.g., “Carrying Capacity” – maximum Population Nature can sustain
  – One of very few “quantitative” analyses

• Study “equilibrium” btw human activities & nature
  – Long-term behavior, not short-term forecasting

• **Over-exploitation** of Poor or Nature results in **collapse**

• Policies critical for staying in **equilibrium space** where
  – Sustainable steady state possible
POTENTIAL RESEARCH PROJECT: WEATHER HAZARD REDUCTION IN A CHANGING CLIMATE - 2050

Credits – David Carlson, Director, WCRP-WMO

- **Objective** - Develop & test new methods to
  - Predict and reduce multiple hazards amid increasing vulnerability due to changes in population, infrastructure, climate, and rising sea levels

- **Context** – Three major WWRP projects
  - Polar Prediction Project (PPP)
    - Polar – global interactions & predictability
  - Subseasobal to Seasonal (S2S) prediction
    - Extend predictability to weeks 3-4
  - High Impact Weather (HIWeather)
    - Impact (not only weather) forecasting

- **Approach** – Virtual experiment / simulations
  - Use global decadal prediction scenarios for ~ 2050
  - Downscale with regional / local models incl. hydrology/slosh etc models
  - Simulate weather, predictions, impact, Emergency Management / socioeconomic response
POTENTIAL RESEARCH PROJECT:
WEATHER HAZARD REDUCTION IN A CHANGING CLIMATE - 2050

Credits – David Carlson, Director, WCRP-WMO

• **Implementation**
  – Choose vulnerable coastal megacity – eg, New York City (Hurricane Sandy)
    • Floods/inundation/water resource man., winds (aviation / RE), heat waves / AQ, winter storms, etc
  – Partner w climate change research
  – Engage & collaborate w regional stakeholders (public/private)
  – Move methods performing best in simulations into real operations
  – Measure impact of research both in simulated & real environment

• **Infrastructure** – Build on EarthCube cyberinfrastructure
  – General & modular design

• **Organization** – Joint WMO WWRP-CWRP Research Demo Project (RDP)
  – ESPC, CLIVAR, OSTP interests?

• **Outcome** – Research results and relocatable virtual lab system
  – Applicable in other US or international locales
PROJECT DESIGN – FROM RESPONSE TO PREEMPTION
SHIFT BALANCE FROM MITIGATION TO PREPARATION

1. Identify Weather Threat
2. Assess Current Capability
3. Define Gaps (Metrics)
4. Weather Research
   Better Understand Nature
   Exploit Predictive Potential
   Improve Weather Info/Service
5. Test New Methods
   Enhanced Preemption,
   Reduced Recovery Period
6. Assess Added Value

What / how Impacts Society?
How Impacts Can Be Preempted?
Reduced Impact

NATURE

SOCIETY

Time

R2R - REFINE RESEARCH
R2O TRANSITION
WEATHER RESEARCH ENABLERS

- **Cyberinfrastructure development**
  - EarthCube – NSF community initiative

- **Community software approaches**
  - Code repositories, systems, environments, protocols, design

- **Opportunities**
  - R2O, USWRP, NASA, NSF, NRC, intl. engagement
EARTHCUBE

How to fit a sphere into a square?

- **Scope** - Develop / transform cyberinfrastructure to
  - Better understand/predict the Earth system from Sun to center of Earth

- **Objective** - Data-enabled geosciences research
  - Interoperability across disciplines
  - Global data discovery and knowledge management
  - Data sharing & integration

- **Approach** – 10-year NSF program started in 2011
  - Geosciences Directorate (GEO) & Division of Advanced Cyberinfrastructure (ACI)
  - Community of Earth, computer, & social scientists, educators, data managers

- **Accomplishments**
  - 25 domain workshops
  - Over 2,500 Community members
  - 27 funded projects
  - $25+ M project awards

*Chris MacDermaid*
Launched in 2011, EarthCube is a collaborative partnership between the US National Science Foundation's Geosciences Directorate (GEO) and the Division of Advanced Cyberinfrastructure. It's also a virtual community of contributors, including Earth, Ocean, Polar, Atmosphere, Geospace, computer and social scientists, educators, data managers, and many others. This community has done a great deal of collaborative work since EarthCube was first launched. In 2013 and 2014, two new rounds of NSF awards were made to develop key technologies, promote community building, explore integrative systems, and prototype a governance structure.

EarthCube by the numbers:

- More than $25 million in project awards
- 27 funded projects
- 25 domain workshops
- Over 2,500 Community members

EARTHCUBE ORGANIZATION

Chris MacDermaid
EARTHCUBE TESTBED

• **Objective** - Collaborative planning & testing of technologies

• **Approach** - Common ground for prototyping, testing & integration
  – Facilitate verification / validation of
    • Technologies, use cases, architecture design, components, scalability, interface specifications, & standards
  – Integrate separately funded EarthCube components / products

• **Outcome** - Demonstrate & showcase of EC technologies for
  – Science users, technologists, & broader geosciences community

*Chris MacDermaid*
COMMUNITY SOFTWARE APPROACHES

- **Code repositories** – Easy access to software
  - WRF, HWRF, GSI, MET (Developmental Testbed Center)

- **Protocols for code development** – Connect diverse models / data
  - ESMF, NEMS, NUOPC, ESPS, Web Services, OpenMI, OpenClimateGIS

- **Community developed major systems**
  - Radiative transfer models
    - CRTM (JCSDA), RTTOV (Europe), RRTMG (WRF), G-SDSU (NASA)
    - Combine / modularize algorithms into *common package*?

- **Object Oriented Design** – Planned
  - OOPS (ECMWF), CDAR (US)

- **Collaboration environments**
  - Virtual Lab (VLab, NOAA) – http://www.nws.noaa.gov/mdl/vlab/
  - Earth System CoG (CU) - https://earthsystemcog.org/projects/cog/

*Yuanfu Xie*
**Cloud Computing**

- **Distributed models / tools** – Networked ESMF components
  - Physically / organizationally scattered
  - Widely different scales, disciplines, etc

- **Coupling via web services**
  - 1- or 2-way coupling of ESMF components

- **Applications** use network of models - NEMS
  - Atmosphere, land, hydrology run on their own grid
  - Web services invoke highly localized models
  - Link with EarthCube Testbed - Prototype by end of 2015
**EARTH SYSTEM PREDICTION SUITE (ESPS)**

### Common modeling infrastructure
- U.S. weather, climate, & ocean modeling systems
  - ESMF compliant w NUOPC conventions

### Current components
- Coupled system
- Atmosphere, ocean, wave, sea ice

### Target systems
- NOAA - NEMS, CFSv3, MOM5
- US Navy – NavGEM – HYCOM - CICE, COAMPS (- TC)
- NASA - GOES-5, ModelE
DATA ACCESS

• **Dynamic access to**
  – Multidiscipl. data from multiple sources
  – Convert native to OpenClimateGIS format
    • End-user analysis ready format
      *Data manipulation on steroids*
  – Being integrated into ESMF

• **Earth System Documentation** – **ES-DOC**
  – Metadata standard to describe Earth system models
    • For better understanding & use of output data
  – Customizable questionnaire creates documentation
  – View, search, compare models
  – International effort w NOAA participation

*Legend*

Count of Daily Precipitation Values $\geq 9.62$ mm/day for July, 1990
(BCCA-CCMA-CGCM)
OPPORTUNITIES

- **USWRP** – OAR, linked w NOAA Testbeds
- **R2O** – NWS, next generation operational systems
- **NASA Roses** – Remote sensing
- **NSF** – EarthCube, Earth sciences research
- **NRC Associateship**
  - Lab Program Rep (LPR) – Zoltan
  - Guidelines for Advisers:
    - [http://sites.nationalacademies.org/PGA/RAP/PGA_056238](http://sites.nationalacademies.org/PGA/RAP/PGA_056238)
    - Adviser Information (special steps for CI advisors)
      - [http://sites.nationalacademies.org/PGA/RAP/PGA_046588](http://sites.nationalacademies.org/PGA/RAP/PGA_046588)
- **International example** - Germany
  - Waves to Weather – Collaborative Research Center Proposal
    - Multiscale processes shaping local weather
OUTLINE / SUMMARY

• **THORPEX accomplishments** – Adaptive methods
  – Targeted observations
  – Ensemble-based background covariance
  – Ensemble-based probabilistic forecasts

• **New WWRP projects**
  – Polar Prediction Project (PPP)
  – Sub-Seasonal to Seasonal Prediction Project (S2S)
  – High Impact Weather Project (HIWeather)

• **US engagement**
  – Agencies – Community initiative
    • Weather Hazard Reduction in Changing Climate?

• **Enablers**
  – EarthCube
  – Announcements of Opportunities
~ 30,000 k NEIS VIEW OF PLANET EARTH

The fitting of a sphere into a square

Courtesy
Stan Benjamin
~ 30,000 k SIMULATED VIEW OF PLANET EARTH THROUGH 3D GLOBAL CLOUD ANALYSIS

The fitting of a sphere into a square

Simulation via Radiative Transfer Model developed at GSD

Courtesy Steve Albers
Severe weather demonstration project

- Cascading forecasting process, from global to national level.
- Southeastern Africa, 5 countries involved, Regional Center in Pretoria.
- Related research topics: nowcasting, mesoscale modeling, radar meteorology, assimilation in mesoscale models.

**Recommendation:** better coordination between national NHMCs and regional specialized centers in order to coordinate also research activities.
~ 30,000 k SIMULATED VIEW OF PLANET EARTH THROUGH 3D GLOBAL CLOUD ANALYSIS

The fitting of a sphere into a square

Simulation via Radiative Transfer Model developed at GSD

Courtesy Steve Albers
Lake Victoria research priorities

- Develop a nowcasting system based on high-resolution modeling and satellite data
- Perform a case study for the Lake Victoria with a verification phase
- Prepare guidelines for operations

**Recommendation:**
- better collaboration between Universities and NMHSs must be established in the region
- partnership with the countries inside and outside of the region should be improved with higher responsibilities taken by RA I countries
COMMUNITY DATA ASSIMILATION

- Distinguish btw science algorithms vs software engineering – SE

- Handful of major systems – GSI, WRFDA, LAPS, DART, NAVDAS-AR, etc
  - Connected on algorithm level
  - Disjoint on software level – separate repositories
  - Major impediment for R&D, R2O, and Operations

- Community Data Assimilation Repository – CDAR (BAMS ms)
  - Invite DA community to discuss & adopt Object Oriented Design

- Benefits
  - Software-level interactions among DA groups – faster R&D
  - More direct R2O
  - Much wider selection of algorithms to tailor to each
    - Application
    - Operational suite
COMMUNITY DATA ASSIMILATION REPOSITORY (CDAR)

Functionalities under Process Oriented Design

Minimization

QC
Radiative Transfer

Functionalities under Object Oriented Design

A B C D E
RADIATIVE TRANSFER MODELS
For display, data assimilation, numerical modeling

- **LAPS** package – Albers 2015
  - Physically based
    - With empirical simplifications for speed
  - Vantage point / view
    - Looking in any direction from above, within, below atmosphere
  - Light source – Sun, Moon, stars, artificial light – Day & Night
  - Parallax correction – Important for fine scales

- **CRTM**
  - Strong on IR & Microwave, visible more recently added
  - Designed for Satellites and Aircraft looking downward

- **RRTMG** (in WRF)
  - Irradiance (integrated radiance) at gridpoints

- **Goddard Satellite Data Simulator Unit (G-SDSU)**
  - Easier to parallelize
  - Radar included
  - GOCART aerosol Microphysics included

- Combine / modularize algorithms into **common package**?
  - Ongoing discussion between CRTM – LAPS developers
“Humanity is like ... people packed in an automobile which is traveling downhill without lights at a terrific speed and driven by a four-year old child. The signposts along the way are all marked ‘Progress’”

Lord Dunsany, quoted in “Diet for a New America” by John Robbins

• Have we lost the breaks?
  – Acceleration not sustainable
  – At which curve may we lose control?
WHERE WE FAILED

• **Stakeholder Panel** never formed
  – Low funding level, less than expected impact

• **US coordination sub-optimal**
  – International engagement less productive

• R&D misses
  – **Optimal design of observing systems**
    • Evaluation, instead of design of observing systems
  – **DA for moist / finer scale processes**
  – **Global Interactive Forecast System (GIFS)**
    • Truly international probabilistic forecast effort
  – **SERA research**
    • Lack of funding
    • **Cost – benefit analysis** of new observing/DA/ensemble systems
OPPORTUNITIES

• Objective assessment of costs/benefits of weather research
  – **Articulate societal need for / potential of weather research**

• Coordinated national initiative
  – **Broaden coalition** - Engage more agencies

• R&D needs / gaps
  – **Global nowcasting** system
    • Cloud DA w remote observations
    • Non-hydrostatic, Earth System coupled forecasting
  – Decision support based on quantified forecast uncertainty
    • Forecasting **expected impact of weather** – not only weather
WHAT WE ACCOMPLISHED

• Weather community became *more organized / energetic*

• **Dialogue between academia & operations**

• More attention to **use of forecasts**

• R&D & R2O accomplishments
  – Adaptive observational techniques
    • *Winter Storm Reconnaissance (WSR) program*
  – Ensemble-based DA / covariance in variational DA
    • *Hybrid GSI*
  – Multi-center ensemble system
    • *North American Ensemble Forecast System (NAEFS)*
US ENGAGEMENT IN INTERNATIONAL EFFORTS

• Major contributions to THORPEX
  – Leadership/membership in WGs
  – T-PARC, TIGGE, NAEFS, hybrid GSI, WSR

• Momentum maintained
  – Interim Interagency Weather Research Coordination Committee
    • NOAA, NSF, US Navy, with others invited (NASA, FAA, DOE, etc)
  – Interim Community Weather Research Planning Committee
    • Carolyn Reynolds & Sharan Majumdar as co-chairs

• Objectives of new initiative
  – Promote socio-economically relevant weather research
  – Coordinate US response to legacy & new international projects
  – Leverage by creating research infrastructure serving multiple needs
ADAPTIVE PROBABILITIES

Forecast probability of above, below and near normal temperature (no calibration)
Period: 20141115-20141122

Probabilités prévues que les températures soient au dessus, sous et près de la normale (non-calibrées)
Période: 20141115-20141122

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