Summary of Findings of the National Research Council's Decadal Survey on Earth Sciences and Applications from Space

Michael J. Kavaya
NASA Langley Research Center
michael.j.kavaya@nasa.gov

Working Group on Space-Based Lidar Winds
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This presentation consists primarily of material taken from a report by the National Research Council that has been released to the public in Jan. 2007.

Who Did The Study?

National Academies
- National Academy of Science (NAS)
  - Division on Earth and Life Sciences
  - Division on Engineering and Physical Sciences
    - Space Studies Board
      - Committee on Earth Studies

Ad Hoc Committee on Earth Science and Applications from Space:
A Community Assessment and Strategy for the Future
- 20 members (18 at end)
  - 2 chairs (Richard A. Anthes, Berrien Moore III)
  - Chairs of 7 study panels
  - 11 at large members (9 at end)

111 RFI Responses

17 Reviewers

COMMITTEE ON EARTH SCIENCE AND APPLICATIONS FROM SPACE: A COMMUNITY ASSESSMENT AND STRATEGY FOR THE FUTURE

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BERRIEN MOORE III, University of New Hampshire, *Co-chair*
JAMES G. ANDERSON, Harvard University
SUSAN K. AVERY, University of Colorado, Boulder
ERIC J. BARRON, University of Texas, Austin
OTIS B. BROWN, JR.,[1] University of Miami
SUSAN L. CUTTER, University of South Carolina
RUTH DeFRIES, University of Maryland
WILLIAM B. GAIL, Microsoft Virtual Earth
BRADFORD H. HAGER, Massachusetts Institute of Technology
ANTHONY HOLLINGSWORTH, European Centre for Medium-Range Weather Forecasts
ANTHONY C. JANETOS, Joint Global Change Research Institute, Pacific Northwest National Laboratory/University of Maryland
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BRUCE MARCUS, TRW, Inc. (retired)
ARAM M. MIKA,[2] Lockheed Martin Space Systems Company
WARREN M. WASHINGTON, National Center for Atmospheric Research
MARK L. WILSON, University of Michigan
MARY LOU ZOBACK, Risk Management Solutions

PANEL ON WEATHER

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BRADLEY R. COLMAN, National Weather Service
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CHRISTOPHER RUF, University of Michigan
CARL F. SCHUELER, Raytheon Company
JEREMY USHER, Weathernews Americas, Inc.
CHRISTOPHER S. VELDEN, University of Wisconsin-Madison
ROBERT A. WELLER, Woods Hole Oceanographic Institution

ARTHUR CHARO, Study Director, Space Studies Board
CURTIS MARSHALL, Program Officer, Board on Atmospheric Sciences and Climate (from August 2006)
THERESA M. FISHER, Senior Program Assistant, Space Studies Board

PANEL ON WATER RESOURCES AND THE GLOBAL HYDROLOGIC CYCLE

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ANNE W. NOLIN, University of Oregon, *Vice Chair*
WILFRIED H. BRUTSAERT, Cornell University
ANNY CAZENAVE, Centre National d'Etudes Spatiales
CAROL ANNE CLAYSON, Florida State University
JEFF DOZIER, University of California, Santa Barbara
DARA ENTEKHABI, Massachusetts Institute of Technology
RICHARD FORSTER, University of Utah
CHARLES D.D. HOWARD, Independent Consultant
CHRISTIAN D. KUMMEROW, Colorado State University
STEVEN W. RUNNING, University of Montana
CHARLES J. VOROSMARTY, University of New Hampshire

ARTHUR CHARO, Study Director, Space Studies Board
WILLIAM LOGAN, Senior Staff Officer, Water Science and Technology Board
THERESA M. FISHER, Senior Program Assistant, Space Studies Board

What Was The Committee Asked To Do?

As detailed in the study statement of task (Appendix A), the NRC was asked to:

1. Review the status of the field to assess recent progress in resolving major scientific questions outlined in relevant prior NRC, NASA, and other relevant studies and in realizing desired predictive and applications capabilities via space-based Earth observations;
2. Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2015;
3. Take into account the principal federal- and state-level users of these observations and identify opportunities and challenges to the exploitation of the data generated by Earth observations from space;
4. Recommend a prioritized list of measurements, and identify potential new space-based capabilities and supporting activities within NASA ESE and NOAA NESDIS to support national needs for research and monitoring of the dynamic Earth system during the decade 2005-2015; and
5. Identify important directions that should influence planning for the decade beyond 2015.

By Who?

Sponsors: NASA SMD, NOAA NESDIS, USGS Geography

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Charge to Panels

1. Identify needs and opportunities for observations from space to advance Earth science and applications for the next decade and beyond;
2. Propose programs or missions to meet these needs and opportunities, in priority order;
3. Describe each proposed mission in terms of
   - Contributions to science and applications
   - How it meets prioritization criteria
   - Benefits to society
   - Technical aspects
   - Schedule
   - Costs
4. Briefly identify needs for obs that are needed to complement space-based obs
5. Identify essential other components (telemetry, data processing, management and stewardship

What Were the Criteria for Prioritization?

TABLE 2.3 The eight prioritization criteria used by the panels to create relative rankings of missions. Note that these are guidelines; they are not in priority order, and they may not reflect all of the criteria considered by the panels.

1. Contribution to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration)
2. Contribution to applications and policy making (societal benefits)
3. Contribution to long-term observational record of the Earth
4. Ability to complement other observational systems, including national and international plans
5. Affordability (cost considerations, either total costs for mission or costs per year)
6. Degree of readiness (technical, resources, people)
7. Risk mitigation and strategic redundancy (backup of other critical systems)
8. Significant contribution to more than one thematic application or scientific discipline

Extreme Event Warning

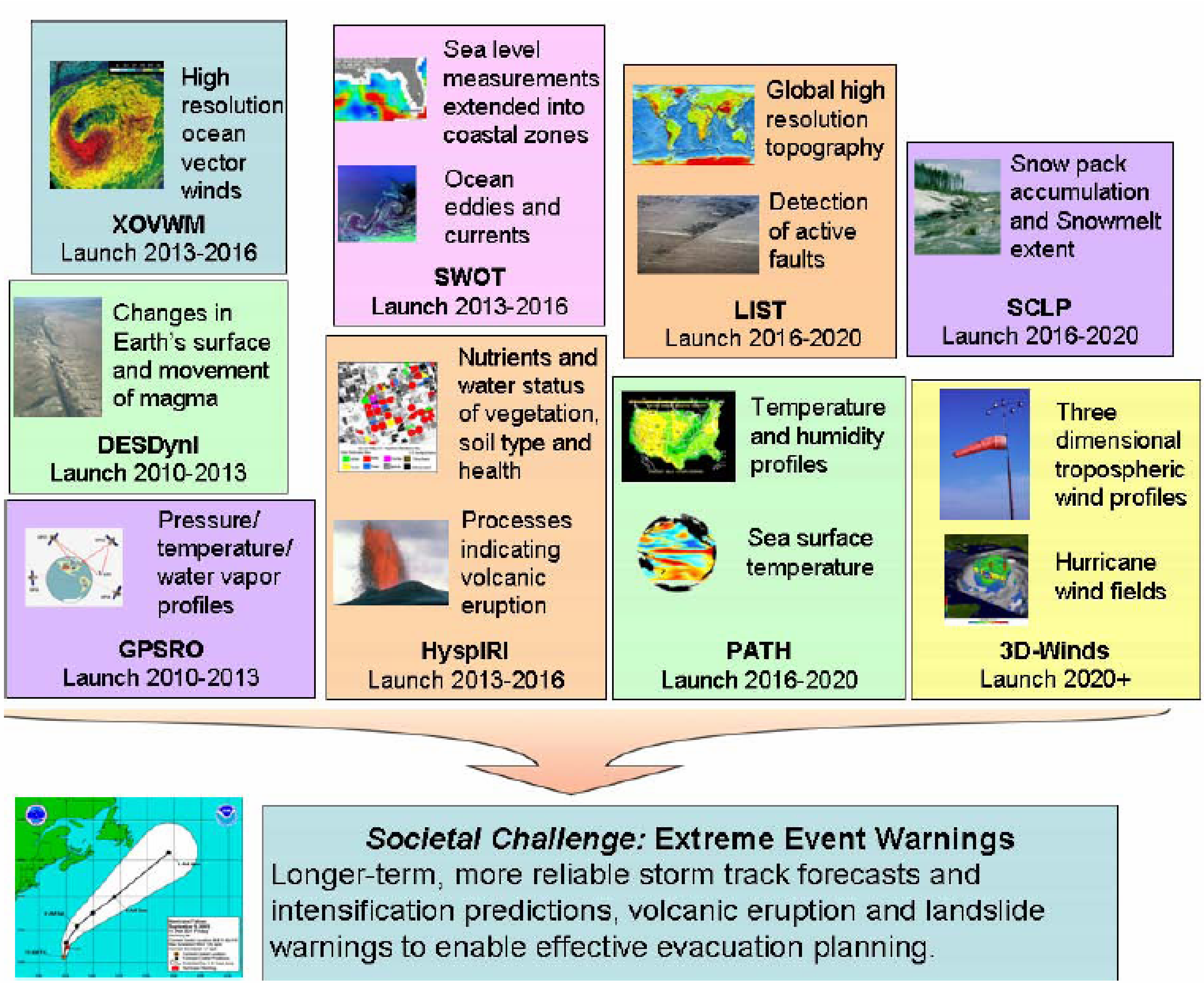

FIGURE 2.9 Recommended missions supporting extreme event warning need.

Human Health

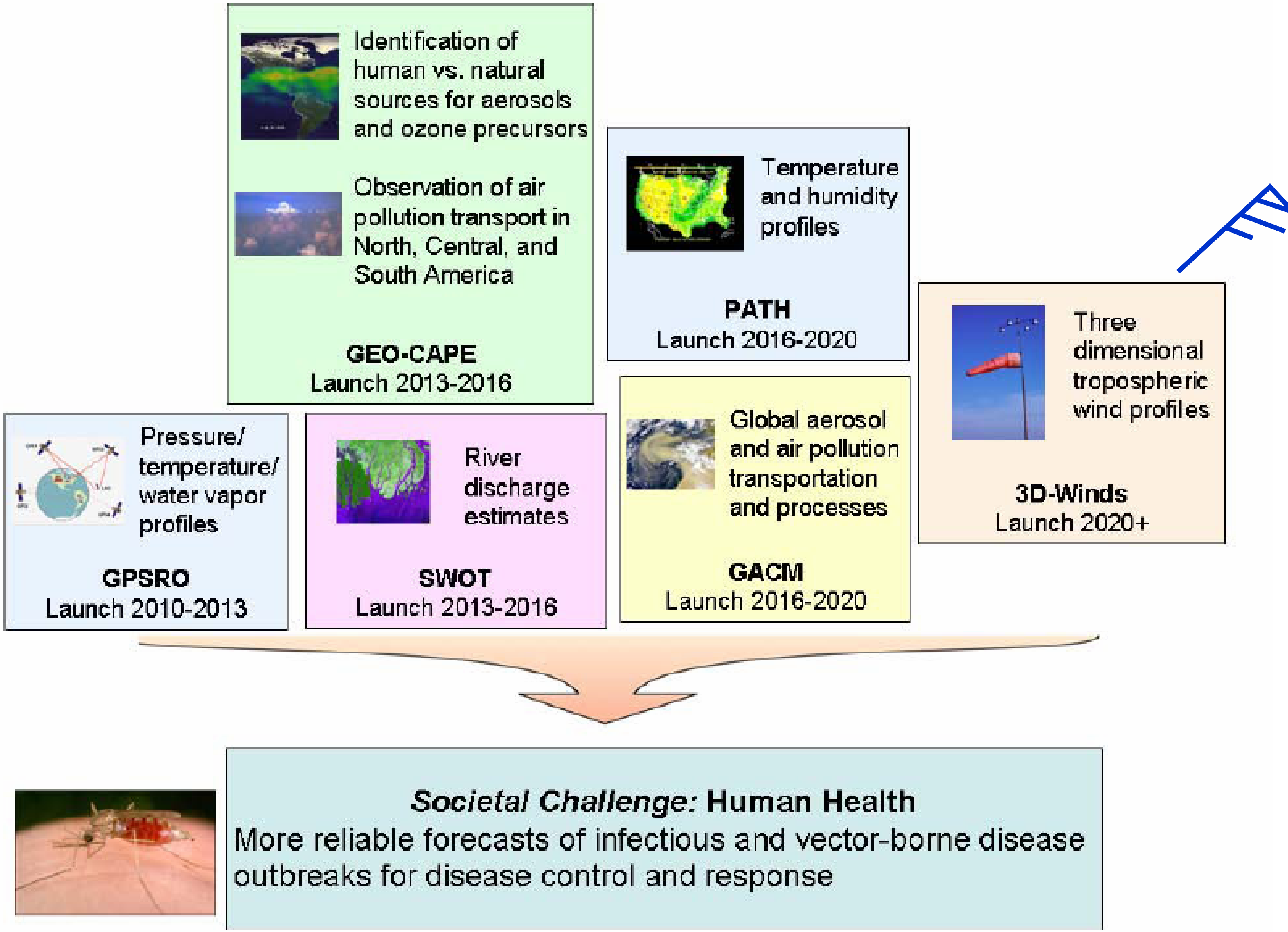

FIGURE 2.10 Recommended missions supporting human health needs.

Weather Prediction

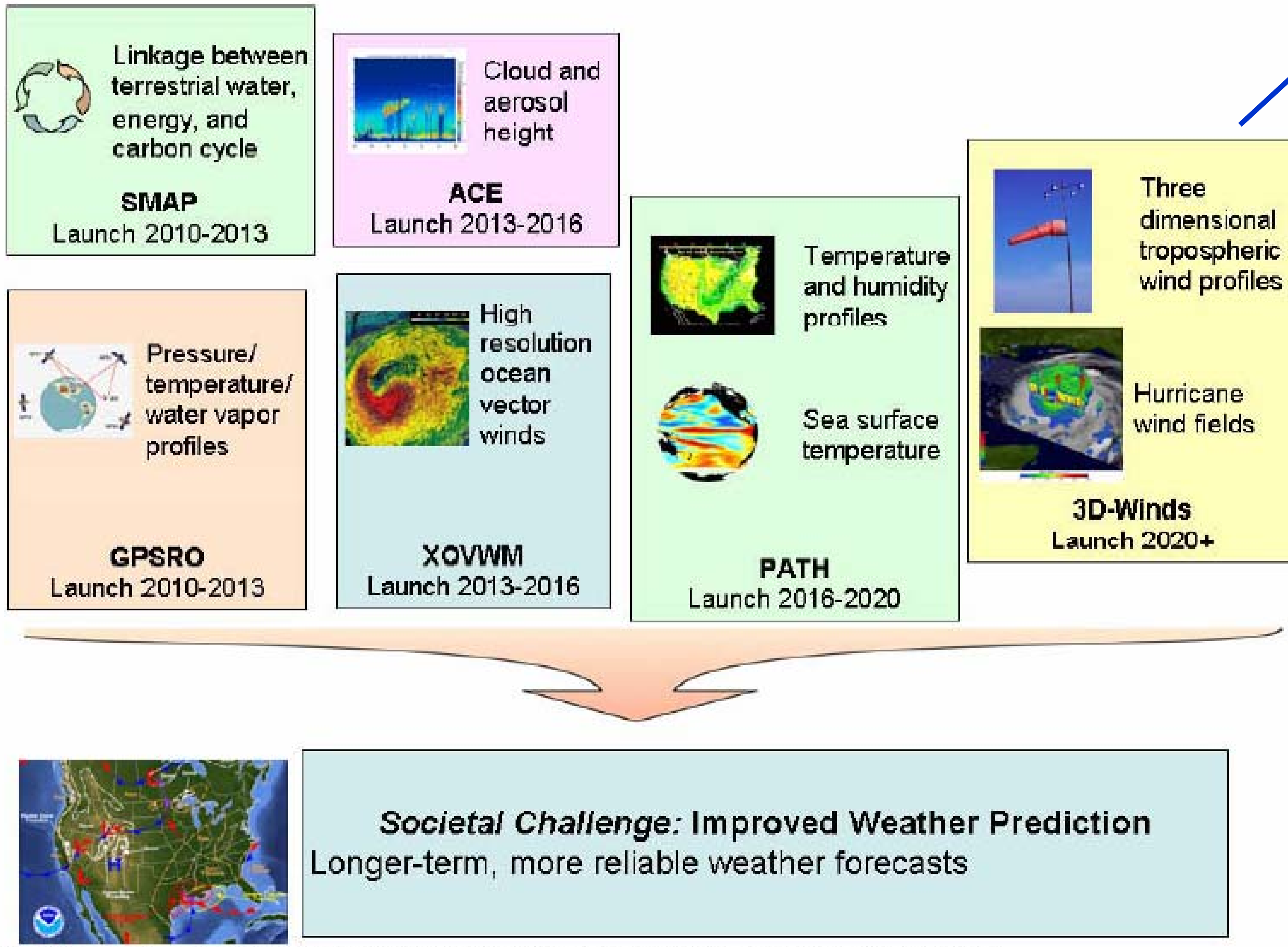

FIGURE 2.12 Recommended missions supporting improved weather prediction need.

No Tropospheric Winds for Climate Prediction???

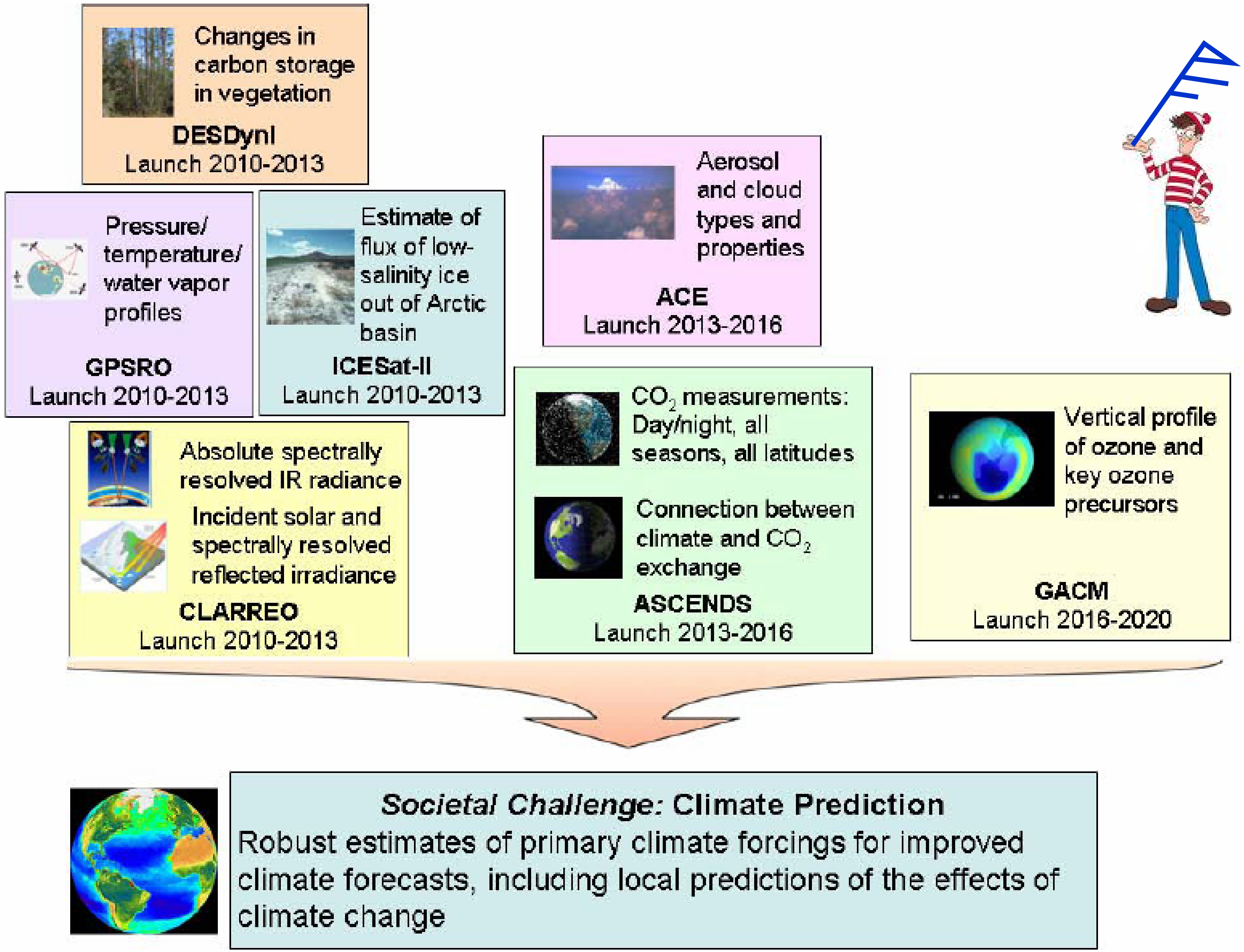

FIGURE 2.14 Recommended missions supporting climate prediction need.

Air Quality

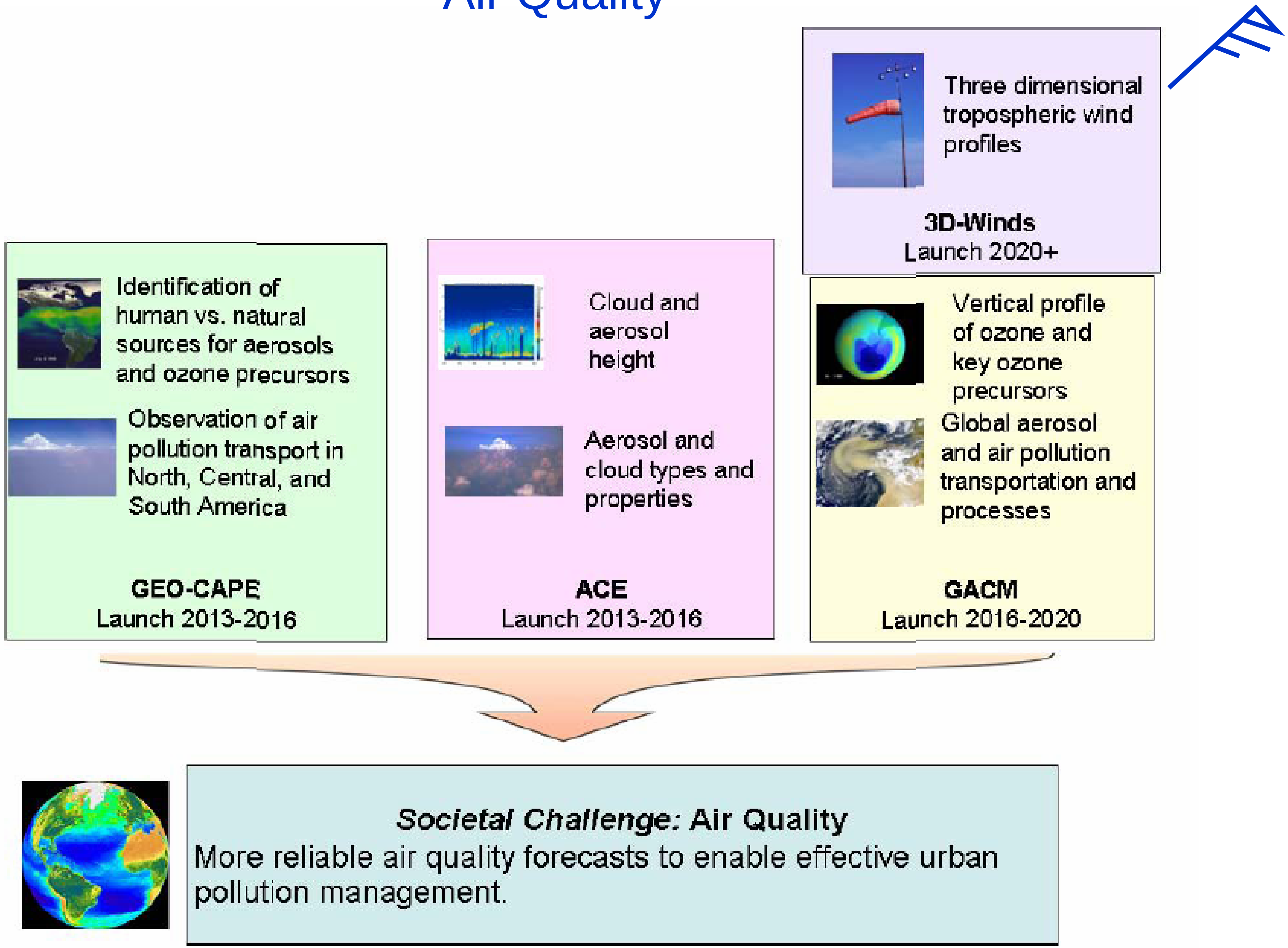

FIGURE 2.17 Recommended missions supporting air quality need.

Tropospheric Winds Not Included in Figures

- Earthquake early warnings
- Sea level rise prediction
- Climate prediction ???
- Fresh water availability
- Ecosystems services

Mapping Missions to Panels

TABLE 2.4 Mapping of how the recommended missions contribute to the priority science observation/mission types identified by the individual study panels as discussed in Part III.

Recommended Mission	Mission/Observation Type Recommended by Individual Panel	Panel
CLARREO	Radiance Calibration Ozone Processes	Climate Health
GPSRO	Radiance Calibration Ozone Processes Cold Seasons Radio Occultation	Climate Health Water Weather
SMAP	Heat Stress and Drought Algal Blooms and Water-Borne Infectious Disease Vector-Borne and Zoonotic Disease Soil Moisture and Freeze/Thaw State Surface Water and Ocean Topography	Health Health Health Water Water
ICESat-II	Clouds, Aerosols, Ice and Carbon Ecosystem Structure and Biomass Sea Ice Thickness, Glacier Surface Elevation, Glacier Velocity	Climate Ecosystem Water
ASCENDS	Carbon Budget Ozone Processes	Ecosystem Health
3D-Winds	Water Vapor Transport Tropospheric Winds	Water Weather

Some Decadal Survey Recommendations

To achieve the Decadal Vision, the committee makes the following overarching recommendation:

The United States government, working in concert with the private sector, academia, the public, and our international partners, should renew its investment in Earth observing systems and restore its leadership in Earth science and applications. The objectives of these partnerships would be to

- **NASA should implement a set of 15 missions with small (< $300M), medium ($ 300M - $ 600M), and large ($ 600 - $ 900M) cost ranges. These missions should be phased over the next decade. All of the appropriate LEO missions should include a GPS receiver to augment operational measurements of temperature and water vapor. The missions and their specifications are given in Table 2.2.**

Recommendation: U.S. agencies should aggressively pursue technology development that supports recommended missions; plan for transitions to continue demonstrably useful research observations on a sustained, or operational, basis; and foster innovative new space-based concepts. In particular:

- **NASA should increase investment in both mission-focused and cross-cutting technology development in order to decrease technical risk in the recommended missions and promote cost reduction across multiple missions. Early technology focused investments through extended mission Phase A studies are essential.**

Some Decadal Survey Recommendations

(Box 3.3). **The committee endorses the recommendation stating, "NASA/SMD (Science Mission Directorate) should develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction."**[5]

Recommendation: NASA should increase support of its Research and Analysis (R&A) program to a level commensurate with its ongoing and planned missions. Further, in light of the need for both a healthy R&A program that is not mission-specific, as well as the need for mission-specific R&A, the committee recommends to NASA that space-based missions should have adequate R&A lines within each mission as well as mission-specific operations and data analysis. These R&A lines should be protected within the missions and not used as mission reserves to cover cost growth on the hardware side.

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RECOMMENDATIONS

- Technology development in support of missions
  - NASA-invest in both mission-focused and cross-cutting technology development to decrease risk in missions and promote cost reduction across multiple missions
  - NASA-create new Venture class of low cost ($100-$200M) missions to foster innovation and train future leaders
  - NOAA-increase investment in research to operations

PROGRAMMATIC DECISION STRATEGIES AND RULES

- **Manage Technology Risk**
  - Sequence missions according to technological readiness and budget risk factors... technological investments should be made across all recommended missions.
  - If there are insufficient funds to execute the missions in the recommended timeframes, it is still important to make advances on the key technological hurdles.
  - Establish technological readiness through documented technology demonstrations before mission development phase.

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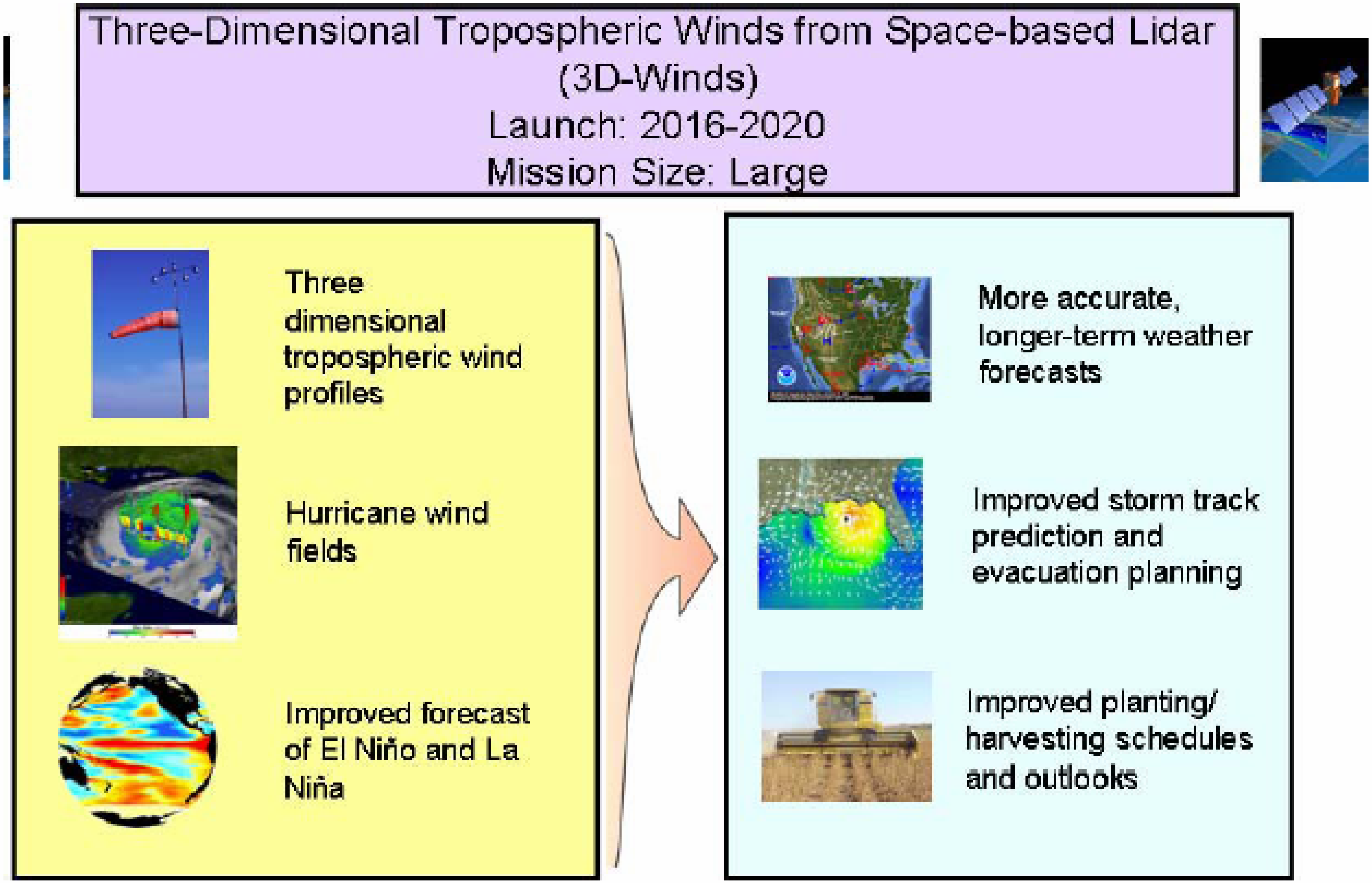
Part II:
Mission Summaries

4
Summaries of Recommended Missions

Three-Dimensional Tropospheric Winds from Space-based Lidar (3D-Winds)



More accurate, more reliable, and longer-term weather forecasts, driven by fundamentally improved tropospheric wind observations from space, would have a direct and measurable societal and economic impact. Tropospheric winds are the number one unmet measurement objective for improving weather forecasts.

First mission in this section

Mission Summary: Listed Benefits of Wind Mission

- More accurate, more reliable, and longer-term weather forecasts
- Public safety
- Forecast of extreme weather events
- Public confidence in hurricane warnings
- Superior description of hurricane wind fields, which will result in substantial numbers of lives saved
- Improved forecasts of severe weather outbreaks, tornadic storms, floods, and coastal high-wind events
- Specifying the initial potential vorticity
- Improve our understanding of sources and sinks of constituents such as atmospheric water
- Advances in understanding of El Niño, monsoons, and the flow of tropical moisture to the U.S.
- Improve the depiction of atmospheric dynamics, transport of air pollution, and climate processes

Mission Summary: Quotes

Mission and Payload: The Weather Panel determined that a Hybrid Doppler Wind Lidar (HDWL) in low Earth orbit (LEO) could make a transformational impact on global tropospheric wind analyses.

regions. The combination of these two DWL systems into a HDWL will allow for wind measurements to be made across most tropospheric and stratospheric conditions.

Due to the complexity of the technology associated with a HDWL, the Panel strongly recommends an aggressive program early on to address the high-risk components of the instrument package, and then design, build, aircraft-test, and ultimately conduct space-based flights of a prototype HDWL. This program should also complement and leverage where possible the work being performed by ESA with a non-coherent lidar system. The Panel recommended a phased development of the HDWL mission with the following approach: *Stage I:* Design, develop and demonstrate a prototype HDWL system capable of global wind measurements to meet demonstration requirements that are somewhat reduced from operational threshold requirements. All of the critical laser, receiver, detector, and control technologies will be tested in the demonstration HDWL mission. *Stage II:* Launch of a HDWL system that would meet fully-operational threshold tropospheric wind measurement requirements. This mission would represent a transformational change in the way global wind data is obtained to be assimilated into the latest NWP models.

Part III:

Reports from the Decadal Survey Panels

10
Weather Science and Applications

Recommendation: Create a NASA/NOAA Earth Science Applications Pathfinder (ESAP) Program. The ESAP would allow all special missions or instrument flights to quickly take advantage of new capabilities to realize Earth Science Societal and Economic Applications—from research into operations.

Societal Benefit

- Enhanced forecasts for hurricane and cyclone tracks, severe winter weather, floods.
- Public health-risk alerts associated with pollutant outbreaks and

Science Themes

- Ameliorate deficiencies in numerical model forecasts during severe weather events
- Improved understanding of causes of high intensity and track

Required Satellite Observations

- Direct 3-D winds over the oceans, the tropics, and the Southern Hemisphere where radiosonde observations are scarce.

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Weather Science and Applications

TABLE 10.2 Summary of Priority Missions*

Brief Description of Mission	Variables	Type of Sensor(s)	Coverage	Spatial Resolution	Frequency	Synergies with other panels	Related Planned or Integrated Missions (if any)
Tropospheric Weather							
Tropospheric Winds (3 options)	Vertical profile of horizontal winds	Wind lidar (preferred option)	Global	350 km horizontal; 1 km vertical	TBD	Climate Health Water	3-D Winds NPOESS
	Ocean surface vector winds	Scatterometer	Global	20 km	6-12 hr		
	Water-vapor tracked winds	Molniya Imager	N. Hemisphere	2km IR/WV imagery, 1km VIS imagery, ~25km vector spacing	15 min during 8 hr apogee dwell		
All-weather Temperature and Humidity Profiles	Temperature and humidity profiles in both clear and cloudy conditions; Surface precipitation rate; SST	Microwave array spectrometer; Precipitation radar	Regional or Global	25 km (humidity and precip. rate) and 50 km (temp) horizontal, 2 km (humidity and temp) vertical	15-30 minutes	Climate Health Water	PATH GPM
Radio Occultation	Temperature and water vapor profiles	GPS	Global	~200 m Vertical resolution	~ 2500 daily	Climate Health Water	GPSRO
Aerosol-Cloud Discovery	Physical and chemical properties of aerosols; Influence of	Multi-wavelength aerosol lidar, Doppler Radar	Global	200 m vertical	TBD	Climate Health	ACE

10
Weather Science and Applications

Phased Implementation of a Doppler Wind Lidar system (2015-2025)

The Panel recognizes that a Hybrid Doppler Wind Lidar (HDWL) in low Earth orbit (LEO) could dramatically improve weather forecasts (Baker et al., 1995; Atlas 2005), and that the HDWL is needed to make global measurements of the wind profile through the entire troposphere and into the lower stratosphere under a wide variety of aerosol loading conditions. In recognition of the importance of wind profile data, the ESAS Water Panel fully concurs with the Weather Panel's recommendation that the Lidar Horizontal Wind Profiling Mission should be a top priority.

Stage I: Because the ESA demonstration of a one-component wind lidar measurement with the non-coherent DWL technique does not address all the relevant techniques and technologies needed for the HDWL mission, the Panel recommends that NASA support the development and space demonstration of a prototype HDWL system capable of global wind measurements to meet demonstration requirements that are somewhat reduced from operational threshold requirements (NOAA/NASA Global Tropospheric Wind Sounder Workshop, 2001). A HDWL demonstration mission in the 2016 time frame should include the demonstration of a technique for both the coherent and non-coherent DWLs which would enable the global determination of two-dimensional (2-D) horizontal winds over the entire 0-20 km altitude range. All technologies critical to the operational demonstration mission, including all critical laser, receiver, detector, and control technologies, need to be demonstrated in this HDWL demonstration mission.

Stage II: Knowledge gained from the NASA HDWL demonstration mission, the ESA non-coherent DWL demonstration mission, and the ongoing NASA DWL technology program will be used to develop and launch a HDWL operational demonstration mission. This mission will demonstrate the full range of threshold wind measurement requirements for an operational HDWL system. The HDWL operational demonstration mission could be launched as early as 2022.

11
Water Resources and Global Hydrologic Cycle Panel

Water vapor transport is a major component of the global hydrologic budget. The fresh water flux (E-P) must ultimately be constrained by the divergence of water vapor over oceans, and by the divergence of water vapor, surface storage (soil moisture, snow water equivalent), and runoff over land. Being able to simultaneously measure as many of these terms as possible thus constitutes a strong constraint on each of the elements of the global hydrologic budget and is of very high value to research effort aimed at understanding the flows and fluxes of the global water budget. The transport of water vapor can be broken into two distinct problems: The measurement of the vapor profile and the three-dimensional motions that transport the moisture. The measurement of vapor profiles can be accomplished through a number of combined infrared/microwave sounders such as the current AIRS/AMSU instrument aboard EOS Aqua or the CrIS/ATMS instrument being planned for NPOESS. Advances in radio occultation measurements expected from the COSMIC constellation (Sokolovskiy et al., 2006) show great promise in adding valuable water vapor information in the atmospheric boundary layer. Together, these measurements and expected progress from research will form the basis for estimation of global 3-dimensional water vapor fields. Still missing are the 3-D wind fields that transport this moisture. This is a high priority observation for the Weather panel (Chapter 10), but it is important to the global water cycle as well.

TABLE 11.1 Candidate Missions in the Order Ranked

Brief Description of Mission	Variables	Type of Sensor(s)	Coverage	Spatial Resolution	Frequency	Synergies with other panels	Related Planned or Integrated Missions (if any)
Soil Moisture and Freeze/ Thaw State	Surface freeze/thaw state; Soil moisture	L-band radar, radiometer	Global	10 km (processed to 1-3 km)	2-3 day revisit	Climate Weather	SMAP Aquarius
Surface Water and Ocean Topography	River and lake elevation; Ocean circulation	Radar altimeter, Nadir SAR interferometer, microwave radiometer, GPS receiver	Global (to ~82° latitude)	Several cm (vertical)	3-6 days	Climate Ecosystems Health Weather	SWOT SMAP GPM NPP/ NPOESS
Snow and Cold Processes	Snow water equivalent; Snow depth; Snow wetness	SAR, Passive microwave radiometry	Global	100 m	3-15 days	Climate Ecosystems Weather	SCLP
Water Vapor Transport	Water vapor profile; Wind speed and direction	Microwave	Global	Vertical resolution		Weather Climate	3D-Winds PATH GACM GPSRO
Sea Ice Thickness, Glacier Surface Elevation, Glacier Velocity	Sea ice thickness; Glacier surface elevation; Glacier velocity	Lidar, InSAR	Global			Climate Solid Earth	DESDynI ICESat-II
Groundwater Storage, Ice Sheet Mass Balance, and Ocean Mass	Ground water storage; Glacier mass balance; Ocean mass distribution	Laser ranging		100 km		Climate Solid Earth	GRACE-II
Inland and Coastal Water Quality	Inland and coastal water quality; Land use/land cover change	Hyperspectral imager, Multispectral thermal sensor	Global or regional	45 m (global) 250-1500 km (regional)	~ days (global) Sub-hourly (regional)	Climate Ecosystems Health	GEO-CAPE

NOTE: The approved GPM mission, had it been ranked, would have been first.

NRC SLIDE

17 Missions

(Pink = <$900 M; Green = $300-$600 M; Blue = <$300 M)

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (NOAA portion)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometer	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate, and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	MEO, SSO	Backscatter radar	$350 M

Mission	Mission Description	Orbit	Instruments	$ Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	**Laser altimeter**	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR **Laser altimeter**	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	**Multifrequency laser**	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	**Backscatter lidar** Multiangle polarimeter Doppler radar	$800 M

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NRC SLIDE

Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	**Laser altimeter**	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or **laser ranging** system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	**Doppler lidar**	$650 M

*Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high-accuracy SST measurement

Other Comments by Ed Browell and Art Charo

- Over 120 people involved
- RFI responses were primary source of information
- Table of missions is not ranked, but listed by cost
- Price differences from NASA's mission studies not necessarily mistakes but rather different missions
- A mission is not necessarily one launch
- ESSP has caused risk by producing proposals with TRL's too low
- Report recommends return to 2000 earth science funding levels
- No substantive changes will be made to report, only editorial
- There was pure ranking by science only within the panels, but not by the overall study

Back Up

PREPUBLICATION COPY
Subject to Further Editorial Correction

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

Committee on Earth Science and Applications from Space:
A Community Assessment and Strategy for the Future

Space Studies Board
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

6
Human Health and Security

							NPP/NPOESS
Vector Borne and Zoonotic Disease	Meteorological conditions (surface temperature, precipitation, wind speed); Soil moisture; Landcover status; Vegetation state	Hyperspectral; High resolution multi-spectral, RADAR, LIDAR		10s of meters 1 km (surface temp, soil moisture, veg. state)	> monthly Twice daily	Ecosystems Weather Water	SMAP DESDynI HyspIRI LIST PATH SWOT LDCM

TABLE 6.3 Candidate meteorological and plume observing systems (adapted from Dabberdt et al., 2004).

Dispersion Variables	Meteorological Variables	Candidate Measurement Systems
Transport	Three-dimensional fields of wind speed and wind direction	Profilers; Doppler weather radar; RAOBs; mesonets; aircraft; tethersonde; Doppler lidar; satellite imagery
Diffusion	Turbulence; wind speed variance; wind direction variance; stability; lapse rate; mixing height; surface roughness	3D sonic anemometers; cup & vane anemometers; RAOBs; profilers; RASS; scanning microwave radiometer (maybe); tethersonde; satellite imagery
Stability	Temperature gradient; heat flux; cloud cover; insolation or net radiation;	Towers; ceilometers; profiler/RASS; RAOBs; aircraft; tethersonde; net radiometers; pyranometers; pyrgeometers; satellite imagery
Deposition, wet	Precipitation rate; phase; size distribution	Weather radar (polarimetric); cloud radar; profilers; satellite imagery
Deposition, dry	Turbulence; surface roughness	See "Diffusion" above
Plume rise	Wind speed; temperature profile; mixing height; stability	Profilers/RASS; RAOBs; lidar; ceilometer; tethersonde; aircraft; satellite imagery

NOTE: RAOB – rawinsonde observation; RASS – radio acoustic sounding system

Decadal Survey Quotes - Winds

Improving Weather Forecasts. Testing and systematically improving forecasts of weather with respect to meteorological, chemical, and radiative change places unprecedented demands on technical innovation, computational capacity, and developments in assimilation and modeling that are required for effective and timely decision and response structures. While weather forecasting has set in place the clearest and most effective example of the operational structure required, future progress depends in very important ways on a renewed emphasis on innovation and strategic investment for weather forecasting in its broader context. The U.S. has lost leadership to the Europeans in the international arena in an array of pivotal capabilities ranging from medium range weather forecasting to long-term climate forecasting. Without leadership in these and other forecasting capabilities, we lose economic competitiveness.

2013 to 2016, and 2016 to 2020. Missions seen to require significant technology development, such as high power, multi-frequency lasers, for 3-D winds and aerosol and ozone profiling, and thin-array microwave antennas and receivers for temperature and humidity sounding, were targeted for either mid or late periods of the next decade; the exact placement depended on the perceived scientific and forecasting impact of the considered observation. To avoid the problems associated with inadequate technology readiness, out-year missions should begin sooner rather than later and exploit the early timeframe to strengthen the technological foundation for the mid- and long-term missions. The committee recognizes

Decadal Survey Quotes - Winds

[5] The passive system does not provide useful wind direction for winds of 5 meters per second or less (scatterometer threshold is 2 meters per second). Moreover, wind direction errors for winds at 6 to 8 meters per second (the wind speed range that forces ENSO events) will double from those of the active scatterometer. The median global wind speed is about 7 meters per second, which suggests that a passive system will not provide reliable information on direction for about half of the winds. In addition, rain and land contamination of wind vectors will be greater from a passive system than from a scatterometer, which limits their use in forecasts of hurricanes and weather in coastal regions. See presentations at a NASA/NOAA workshop, "Satellite Measurements of Ocean Vector Winds: Present Capabilities and Future Trends," Florida International University, Miami, Fla., February 8-10, 2005, available at <http://cioss.coas.oregonstate.edu/CIOSS/workshops/miami_meeting/Agenda.html>.

Decadal Survey Quotes

- *Gain Leverage*. Resources of the many partners and related efforts, from other agencies to international programs to the private sector,[10] should be leveraged to the greatest extent possible to achieve the most comprehensive observing system possible within the available national resources.

requirements. By training the costing tool with actual mission cost information, the panels believe that given the assumed measurement requirements, cost estimates for the recommended missions vary from ± 50% for the smallest missions to ± 30% for the larger mission category. Of course, the cost estimates will depend directly on the exact measurement requirements for the eventual missions. The cost uncertainty rises for missions scheduled later in the next decade and for missions with the greatest technology development needs.

[2] It has been estimated that one third of the $10 trillion U.S. economy is weather-sensitive or environment-sensitive (NRC, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., 2003.).

Decadal Survey Quotes

The overall cost to implement the recommended NASA program (~ $7B over twelve years for the 15 missions) is estimated to exceed currently projected program resources, but fits well within funding levels provided to NASA Earth Science as recently as 2000 (Figures 2.5 and 2.7a). The committee

embrace new opportunities as they arise. *However, the missions are but one part of a larger program that is required to translate raw observations of Earth into useful information.* In this chapter, the committee highlights key additional elements of the overall program that must be supported to achieve the decadal vision. These include: (1) sustained observations from space for research and monitoring, (2) surface-based (land and oceans) and airborne observations that are necessary for a complete observing system; (3) models and data assimilation systems that allow effective use of the observations to make useful analyses and forecasts, and (4) planning, education and training, and other activities that strengthen and sustain the knowledge and information system. These elements are each complex and deserve

Manage Technology Risk

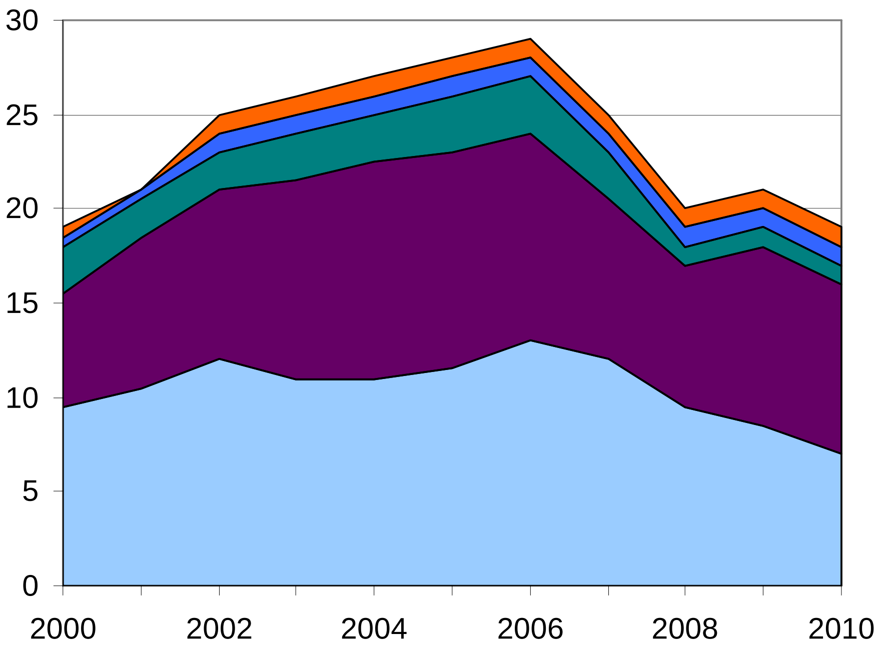
- Sequence missions according to technological readiness and budget risk factors. The budget risk consideration may give a bias to initiating lower cost missions first. However, technological investments should be made across all recommended missions.
- Reduce cost risk on recommended missions by investing early in the technological challenges of the missions. If there are insufficient funds to execute the missions in the recommended timeframes, it is still important to make advances on the key technological hurdles.
- Establish technological readiness through documented technology demonstrations before mission development phase, and certainly before mission confirmation.

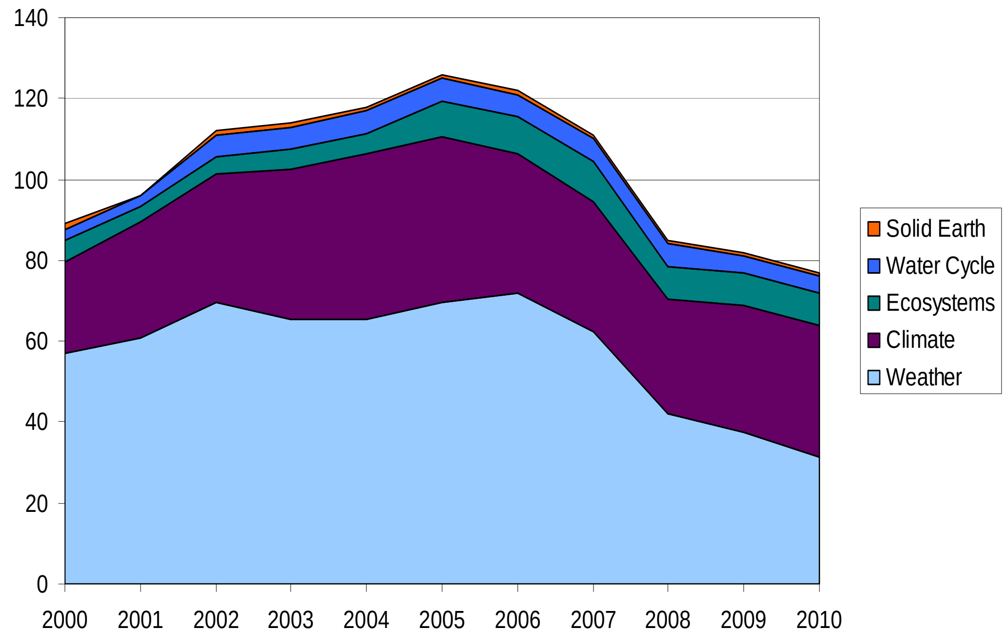
Decadal Survey Quotes

The primary work in developing the above decadal observing strategy took place within the Survey's science panels. The panels were created around major societal issues, namely, Climate, Water Resources, Ecosystem Health, Human Health, Solid-Earth Hazards, and Weather. This categorization is quite similar to the organizing structure used in the GEOSS process. The panels first prioritized candidate observations/missions by applying the *prioritization criteria* listed in Table 2.3 to a wide range of space-based measurement approaches and mission concepts. Recommendations from previous community-based reports such as the WMO were considered (e.g. GCOS 2003, 2004, 2006a, 2006b; WMO, 2005). The complete set of high priority observations/missions identified by the panels numbered approximately 35, down substantially from the over 100 possible missions suggested in the responses to NRC's Request for Information and numerous other mission possibilities raised by individual panel members. The assessment and subsequent prioritization were based on an overall analysis by panel members as to how well each mission satisfies the criteria and the top-level community objectives (see Table 2.4). The panel reports in Part III document this analysis.

Trends In Earth Observations From Space

NRC SLIDE





Number of Missions **Number of Instruments**

Need for Interdisciplinary Program

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Contributing Science Areas	Key Benefits Derived from Suggested Observations	Leading to Improvements In..
	Improved precipitation and drought forecasts to improve water resource management	Water & Food
	Improved geologic and oceanic characterization and improved understanding of local climate change impacts, enabling safer, more efficient exploration for and use of natural resources	Energy Security
	Longer-term, more reliable storm track forecasts and intensification predictions, volcanic eruption and landslide warnings to enable effective evacuation planning	Early Warning
	Improved land use, agricultural, and ocean productivity forecasts to improve planting and harvesting schedules and fisheries management	Ecosystem Services
	More reliable forecasts of infectious and vector-borne disease outbreaks for disease control and response; More reliable air quality forecasts to enable effective urban pollution management	Public Health/ Env. Quality

Science Areas

Solid Earth	Water	Weather
Climate	Health	Ecosystems

Weather: 4/5

Water: 3/5

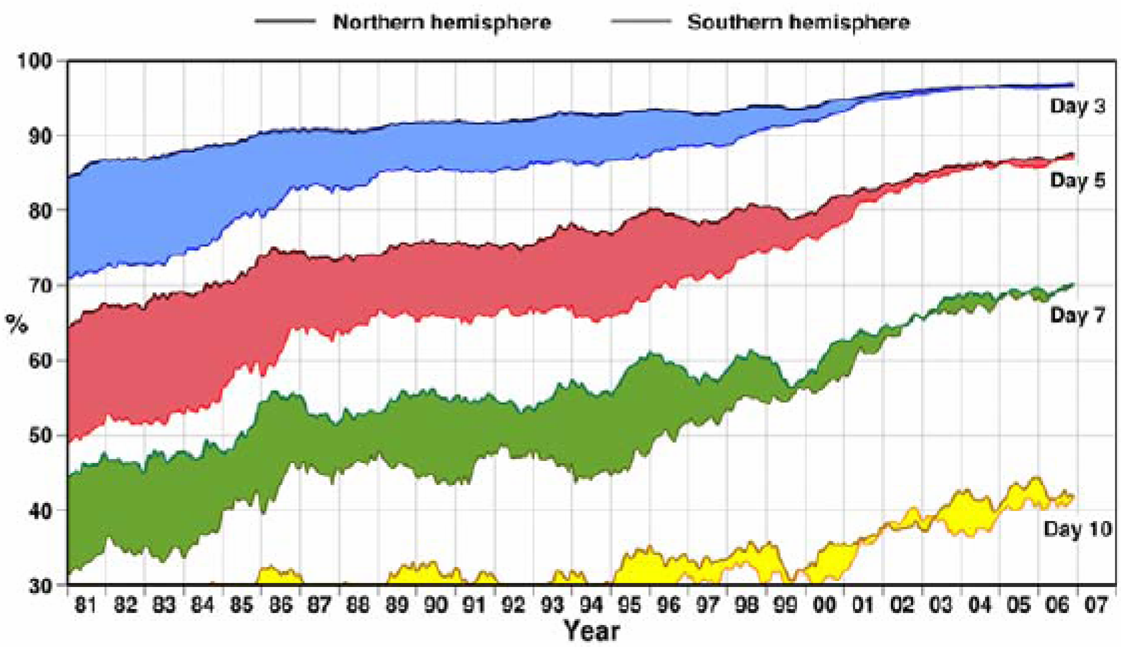

FIGURE 3.2 The correlation between 500 hPa anomalies (atmospheric features at about 5.5 km or 18,000 ft) in numerical weather prediction model forecasts at 3, 5, 7, and 10 days from the European Centre for Medium-Range Weather Forecasts (ECMWF). Higher correlations denote more accurate forecasts. Please see text for further interpretation. SOURCE: Courtesy of the European Centre for Medium-range Weather Forecasts.