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Economic Assessment of Hydro-Met Services and Products: A Value Chain Approach

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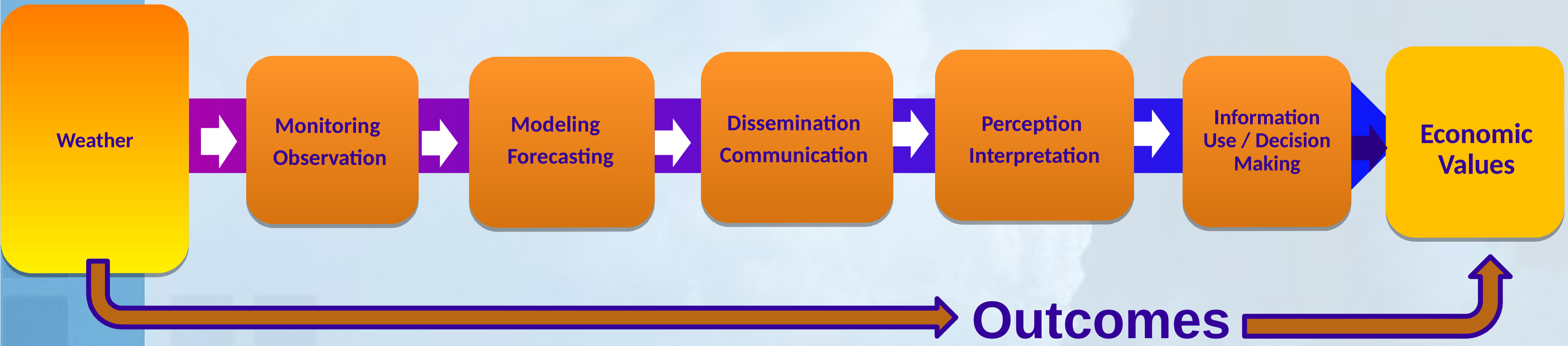
National Center for Atmospheric Research

Objective

Discuss

- work on economics and weather
- conceptual framework of the
  "*Weather Information Value Chain*"
- Connect weather with economics



- Boxes represent "processes that transform" information
- Arrows represent "processes that transfer" information

Outline

- **Why Economics?**
  - WMO/World Bank/USAID book
  - “Vulnerability” context
- **Thoughts on Verification and Economics**
- **Weather Information Value Chain**
  - Valuation methods
- **“What to Value?” Examples of value studies**
  - Forecasts for Solar Power
  - Warning Decisions Extreme Weather Events (WDEWE)
  - *Windshear detection and warning*
- **Recommendations**

Why economics?

- **Program evaluation / program justification**
  - Validating the provision of basic met/hydro services
  - Validating past and current investments in specialized met/hydro services
  - Justifying new investments in met/hydro services
- **Determining the value of NMHSs to user goals**
  - (is this the same as user-relevant verification)
- **Prioritization or reallocation of resources**
- **Study of human behavior / decision making**

❖ WMO, WBG, GFDRR & USAID. 2015. *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services*. World Meteorological Organization, World Bank Group, Global Facility for Disaster Reduction and Recovery, and United States Agency for International Development, WMO No. 1153, Geneva, Switzerland.

https://www.gfdrr.org/valuing-weather-and-climate-economic-assessment-meteorological-and-hydrological-services

What is the value of weather, water, and climate information?

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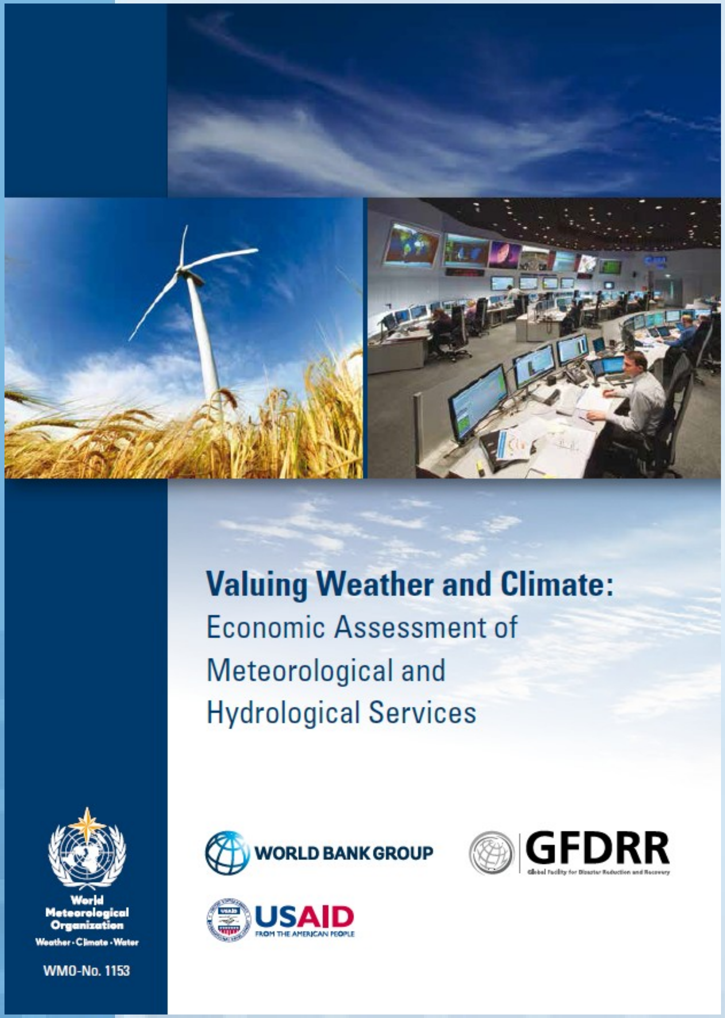

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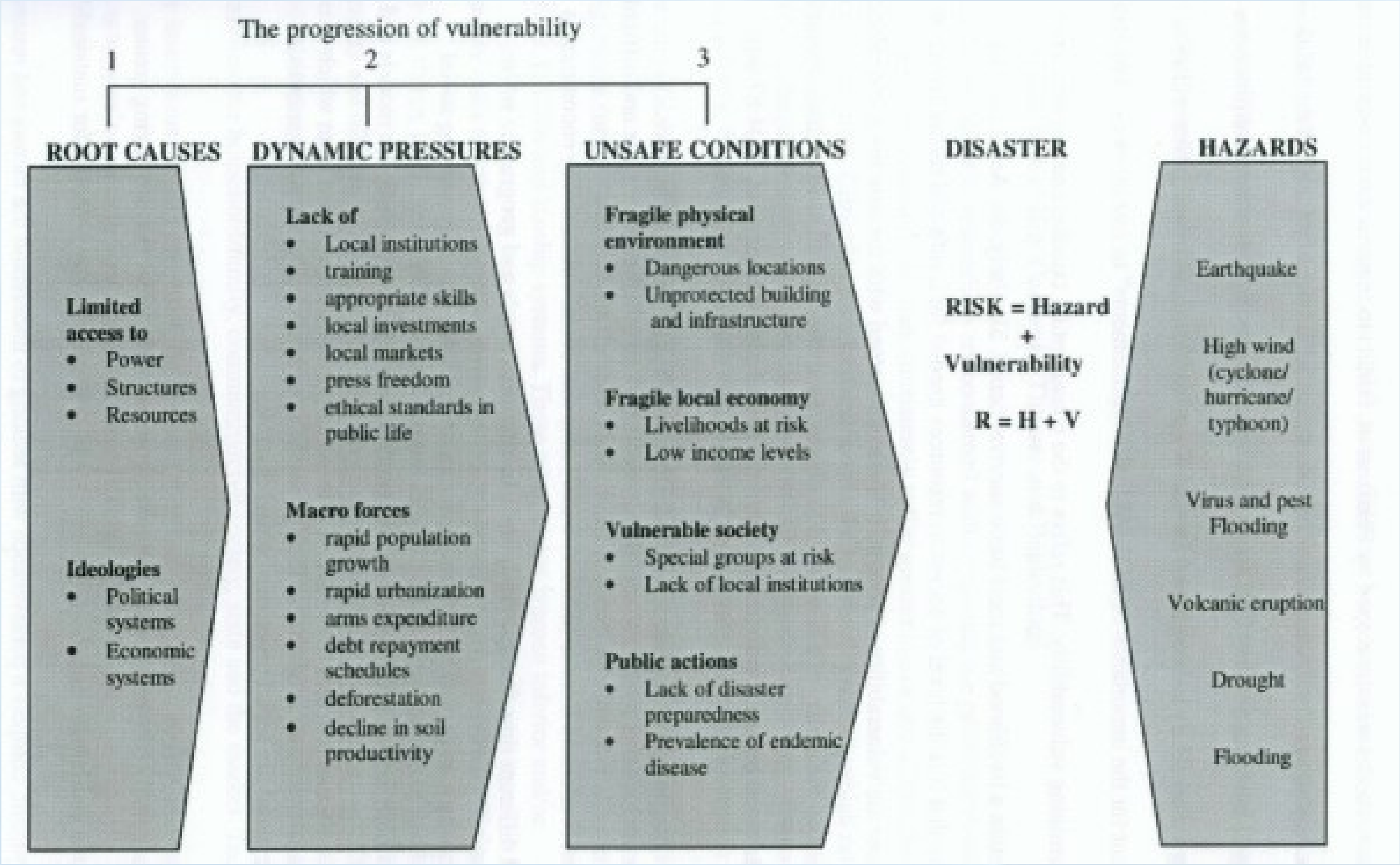
Value of weather info?

SEB Study	Geographic Location	Sectors	Benefits Methods/Measures	Benefit/ cost ratio
Contingent valuation study of the public weather service in the Sydney metropolitan area (Anaman et al., 1998)	Sydney, Australia	Households	Willingness-to-pay survey of households	4:1
Economic value of current and improved weather forecasts in the United States household sector (Lazo and Chestnut, 2002)	United States	Households	Willingness-to-pay (WTP) survey of households	4:1 +
Benefits of Ethiopia's Livelihoods, Early Assessment and Protection (LEAP) drought early warning and response system (Law, 2012)	Ethiopia	Households	Quantification of avoided livelihood losses and decreased assistance costs	3: 1 to 6:1
Success of the United States National Weather Service (NWS) Heat Watch/Warning System in Philadelphia (Ebi et al., 2004)	Philadelphia, Pennsylvania	Households/elderly	Regression analysis to determine lives saved; application of the U.S. EPA's Value of a Statistical Life estimate	2,000:1 +
The benefits to Mexican agriculture of an El Niño/ Southern Oscillation (ENSO) early warning system (Adams et al., 2003)	5-state region in Mexico	Agriculture	Change in social welfare based on increased crop production with use of improved information	2:1 to 9:1
The value of hurricane forecasts to oil and gas producers in the Gulf of Mexico (Considine et al., 2004)	Gulf of Mexico	Oil drilling	Value of avoided evacuation costs and reduced foregone drilling time	2:1 to 3:1
Economic efficiency of NMHS modernization in Europe and Central Asia (World Bank, 2008)	11 European and Central Asian countries	Weather-dependent sectors	Sector-specific and benchmarking approaches to estimate avoided losses	2:1 to 14:1
Benefits and costs of improving met/hydro services in developing countries (Hallegatte, 2012)	Developing countries	National level and weather-sensitive sectors	Benefits-transfer approach to quantify avoided asset losses, lives saved, and total value added in weather-sensitive sectors	4:1 to 36:1
Avoided costs of the FMI met/hydro services across economic sectors (Leviäkangas and Hautala, 2009)	Finland	Key economic sectors	Quantification of avoided costs and productivity gains; Also used impact models and expert elicitation	5:1 to 10:1
Social economic benefits of enhanced weather services in Nepal – part of the Finnish–Nepalese project (Perrels, 2011)	Nepal	Agriculture, transport, and hydropower	Need something on benefits measured or methods	10:1
Economic and social benefits of meteorology and climatology (Frei, 2010)	Switzerland	Transport, energy, aviation, agriculture, households	Benefits transfer, expert elicitation, decision modelling	5:1 to 10:1
Socioeconomic evaluation of improved met/hydro services in Bhutan (Pilli- Sihvola et al., 2014)	Bhutan	National level	Benefits transfer, expert elicitation, cardinal rating method	3:1

Context of the weather information value chain



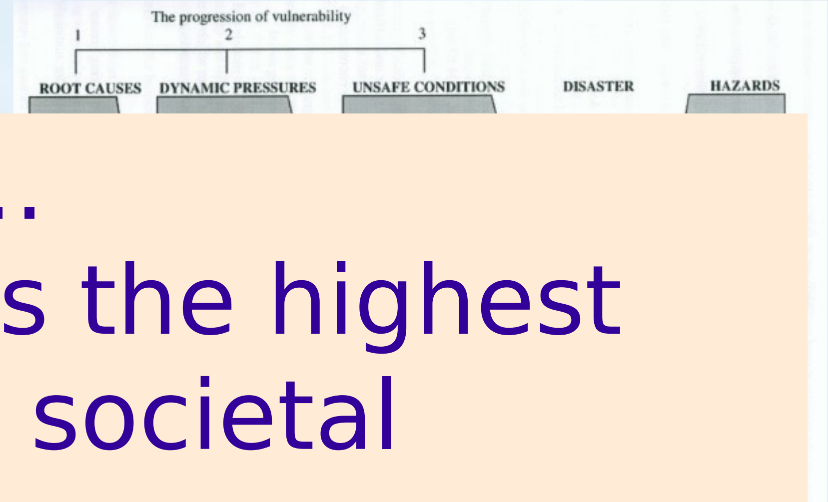
Pressure and Release Model of vulnerability to disasters

Blaikie, P., T. Cannon, I. Davis & B. Wisner. (1994). ***At Risk: Natural hazards, People's vulnerability, and disasters*****. London, Routledge.**

High impact weather

Talking about "High impact weather" and the context of peoples' vulnerability and ability to respond … Question – is there a difference between:

- **High impact weather forecasts defined as**



Interesting dilemma …

the "forecast that has the highest impact" results in no societal impact!

How do you verify that?

considerable importance on choices where to focus resources and research … and on societal outcomes!

Some initial thoughts on verification

Approach	What forecast is compared to …	Information needed to verify forecast …	Notes
Verification	Verify to observations	Observations	All the issues discussed last week and this week …
User-relevant verification	Verify relevant to intermediate- or end-user	Information on criteria or metric relevant to user	I'll learn more about this in next several presentations …
Economic verification	Verify economic value to end-user / society	Socio-economic outcomes	We don't have socio-economic data on at the spatial, temporal, user resolution to relate to forecast

Some thoughts on verification

- **Relationship between user-relevant and economic**
  - **If it is "useful" / "relevant" to the user then it also has economic value**
  - **Economic valuation provides an approach to aggregation across diverse users**
  - **(Socio-)economic valuation provides (ordinal) metric of what is better – (worth more money then "better")**
- **Economic value provides argument to policy makers on importance of forecasts**
  - probably more than verification does
  - perhaps more *or less* than user-relevant verification does

Weather Information Value Chain

"…tracing the information flow end-to-end from geospatial data acquisition system to decisions by end users…"

- **What is the weather information value chain?**
  - Conceptual model of the value creation process
  - Emphasize this is ***not*** linear in the real world!
  - End-to-end-to-end

Why the Weather Information Value Chain?

- **Use economic concepts to explicate mapping of the value of information from creation to valuation**
  - Stakeholders (Agents)
    - Objectives
    - Resources
    - Constraints
- **Tie information to value so value estimates are valid and reliable**
- **Explicate how user-relevant information can drive product and service development**
- **Detail potential contributions of other social sciences – to evaluating the chain and to enhancing value**

Weather Information Value Chain

Weather Information Value Chain

Weather …

… and water

… and climate

Weather Information Value Chain


http://celebrating200years.noaa.gov/historymakers/abbe/weatherradar650.html

Observations

- Satellites
- Radar
- Ground stations
- …
- Your car …
- Your cell phone …

http://www.weatherwise.org/Archives/Back%20Issues/2012/March-April%202012/UAVs-full.html

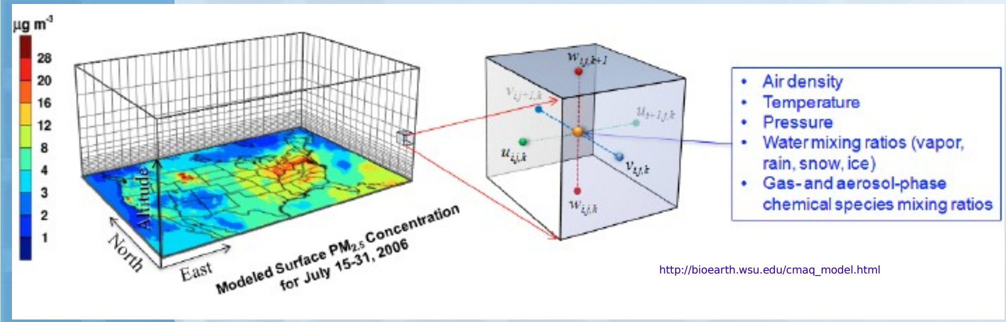

http://www2.ucar.edu/atmosnews/news/21287/3d-printed-weather-stations-fill-gaps-in-developing-world


http://www.lunar.org/docs/nasa/images/noaa-n.jpg

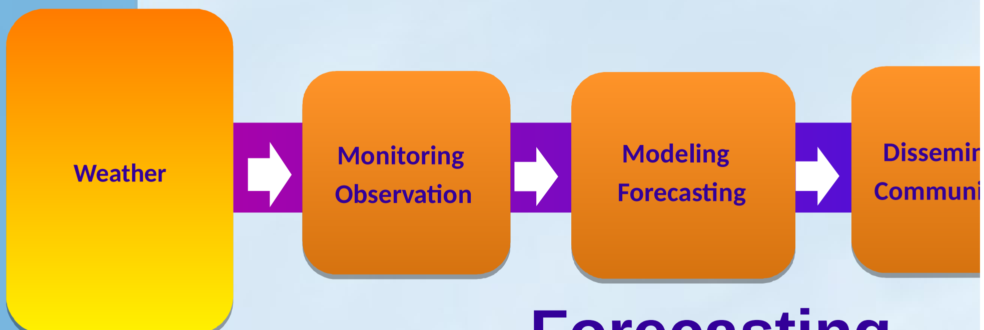
Weather Information Value Chain

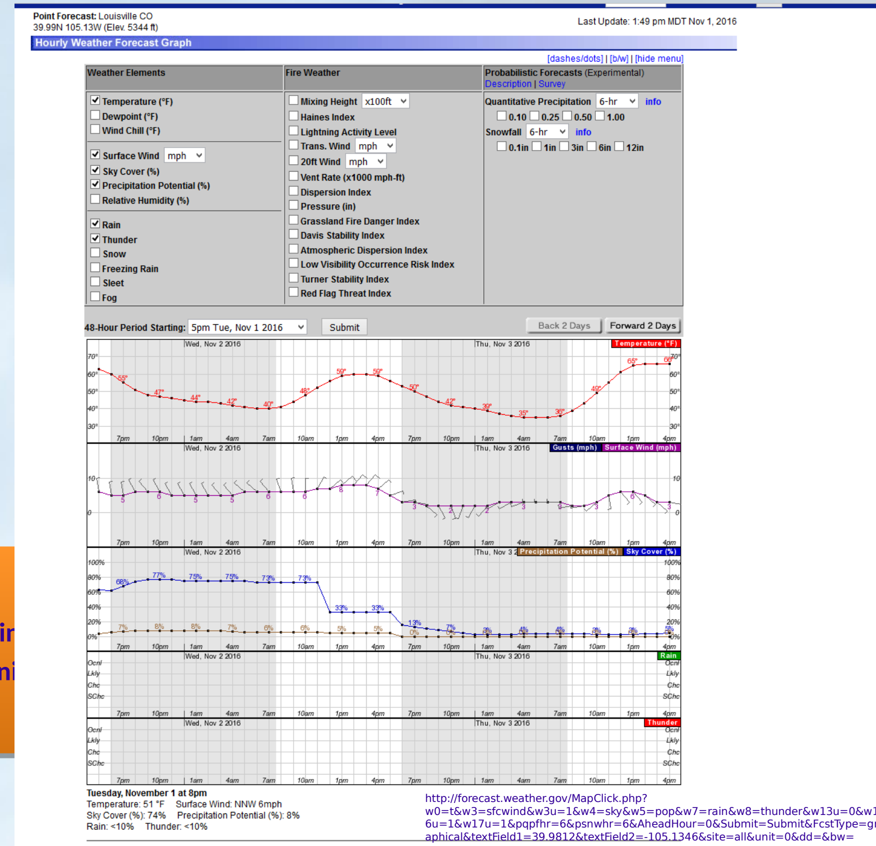
Modeling

Numerical Weather Prediction
Nowcasting
Climate models



Weather Information Value Chain





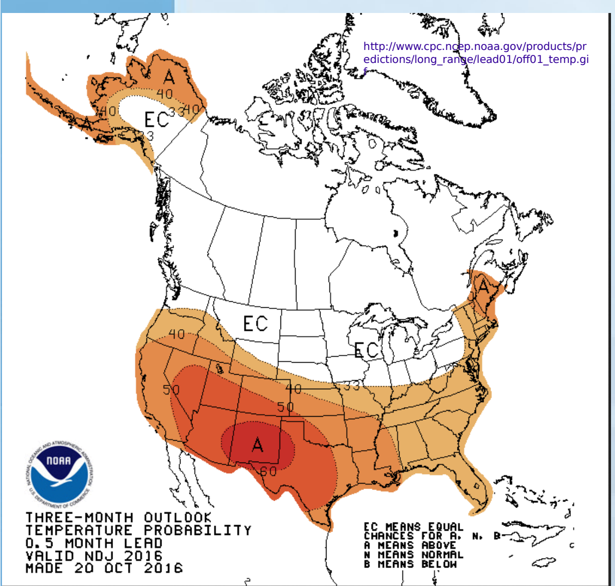
Forecasting

Weather forecast

Seasonal forecasts

Climate forecasts

Watches and warnings



Event: Air Quality Alert

Alert:

```
...AIR QUALITY ALERT IN EFFECT UNTIL MIDNIGHT AKDT WEDNESDAY
NIGHT FOR NORTH POLE...

THE FAIRBANKS NORTH STAR BOROUGH AIR QUALITY DIVISION HAS ISSUED
AN AIR QUALITY ALERT WHICH IS IN EFFECT UNTIL MIDNIGHT AKDT
WEDNESDAY NIGHT.
NORTH POLE HAS A STAGE 2 ALERT AND AIR QUALITY THERE IS
CLASSIFIED AS UNHEALTHY FOR SENSITIVE GROUPS.
FAIRBANKS HAS MODERATE AIR QUALITY AND NO ADVISORY.
FOR ADDITIONAL INFORMATION ABOUT AIR QUALITY IN THE BOROUGH
PLEASE ACCESS THE BOROUGH WEB SITE AT FNSB.US/AIRQUALITY (ALL
LOWER CASE).
```

Instructions:

Target Area: Middle Tanana Valley

https://alerts.weather.gov/cap/wwacapget.php?x=AK12561F46B1F8.AirQualityAlert.12561F55F564AK.AFGAQAAFG.0cea83c5a2b9072803849fb841d40c82

Weather Information Value Chain

http://technabob.com/blog/2012/07/24/weather-neue-sun-iphone-apps/

Weather → Monitoring Observation → Modeling Forecasting → Dissemination Communication → Perception Interpretation → Information Use / Decision Making → Economic Values

Dissemination

- Internet
- Television
- Radio
- Telephone
- Newspapers
- Sirens
- Word of mouth

http://video.denverpost.com/Colorado-weather-forecast-from-Denver7-31586020?playlistId=18376

https://www.cityofchicago.org/city/en/depts/oem/supp_info/alertready/warningsirens.html

Weather Information Value Chain

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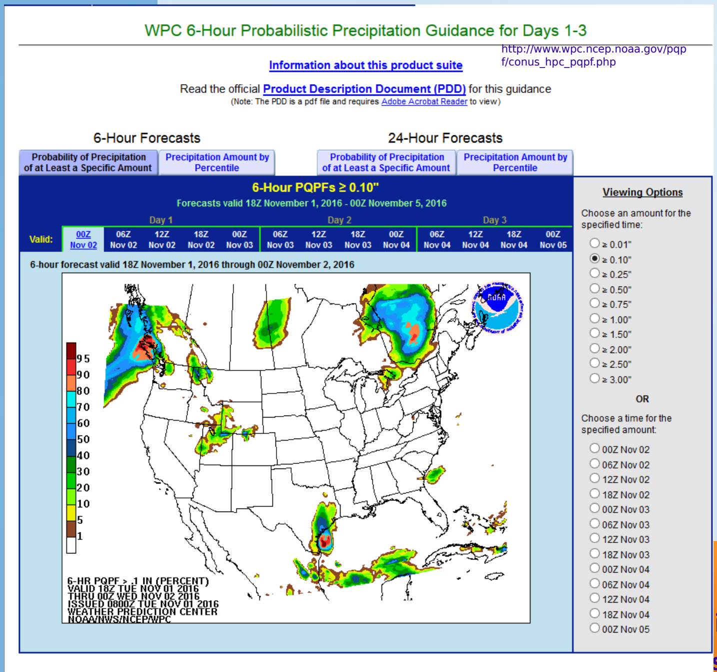


http://www.wpc.ncep.noaa.gov/pqpf/conus_hpc_pqpf.php

...ing / ...sting → Dissemination Communication → Perception Interpretation → Information Use / Decision Making → Economic Values

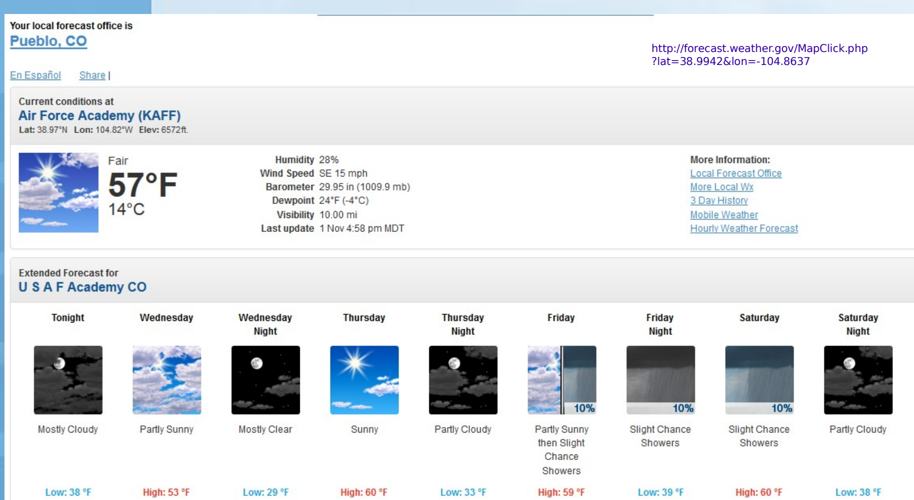
Communication

Format

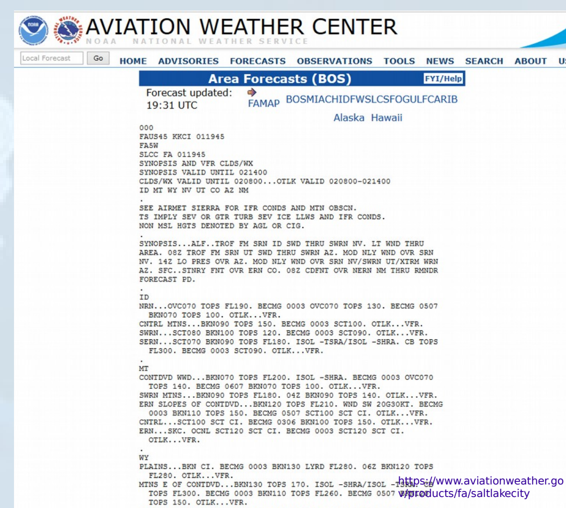
Content

Detail

Uncertainty

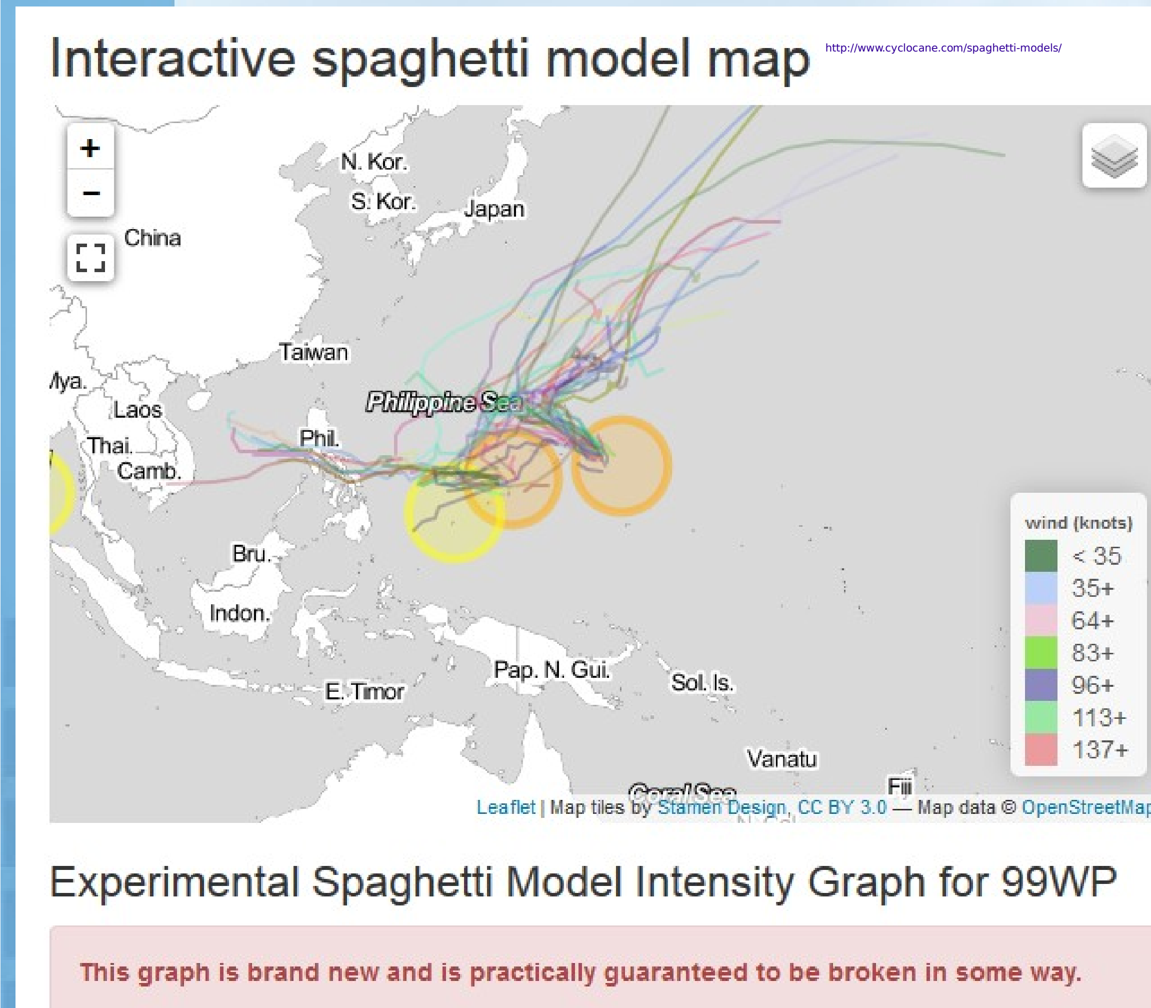


http://forecast.weather.gov/MapClick.php?lat=38.9942&lon=-104.8637



https://www.aviationweather.gov/products/fa/saltlakecity

Weather Information Value Chain



Perception / Interpretation

- Threat
- Impacts
- Probability
- Reliability / trust
- …

Weather Information Value Chain

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Weather → Monitoring Observation → Modeling Forecasting → Dissemination Communication → Perception Interpretation → Information Use / Decision Making → Economic Values

Decisions

- **Run / hide**
- **Buy / sell**
- **Sunglasses / coat**
- **…**

Weather Information Value Chain

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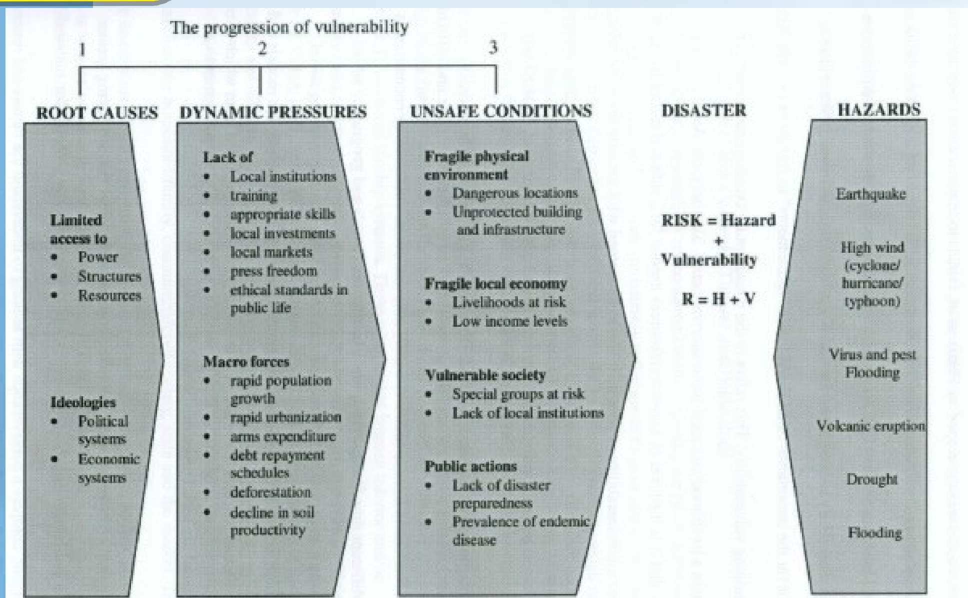


Decisions

- **Run / hide**
- **Buy / sell**
- **Sunglasses / coat**
- **…**

Subject to objectives, resources, constraints

Ex ante

Weather Information Value Chain

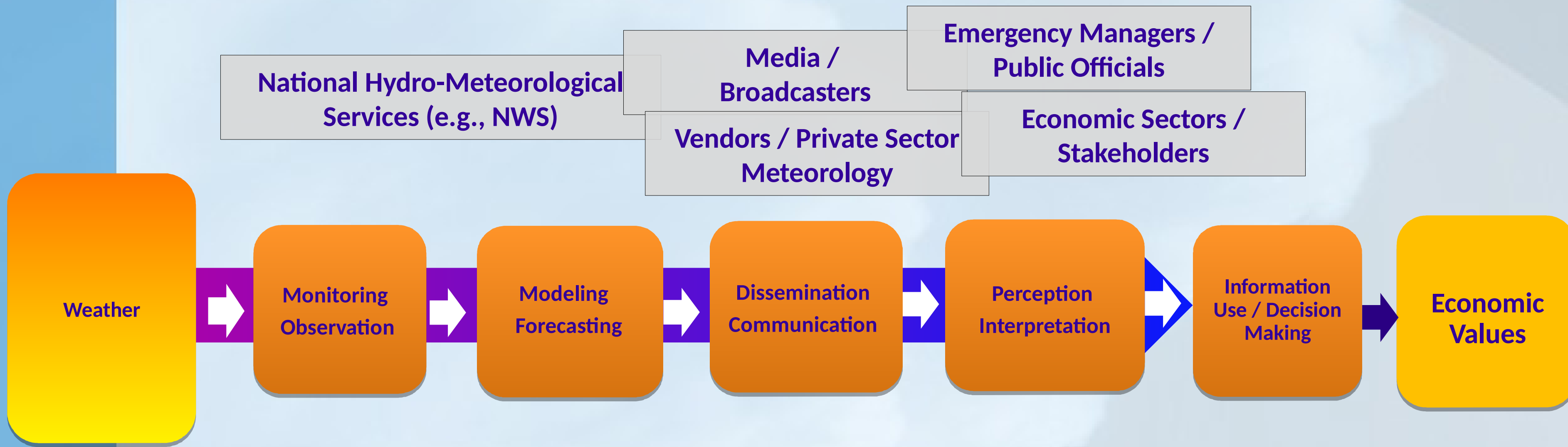
Weather → Monitoring Observation → Modeling Forecasting → Dissemination Communication → Perception Interpretation → Information Use / Decision Making → Economic Values

Outcomes

Live / die
Happy / sad
Warm / cold
Profit / loss
…

Ex post

Weather Information Value Chain

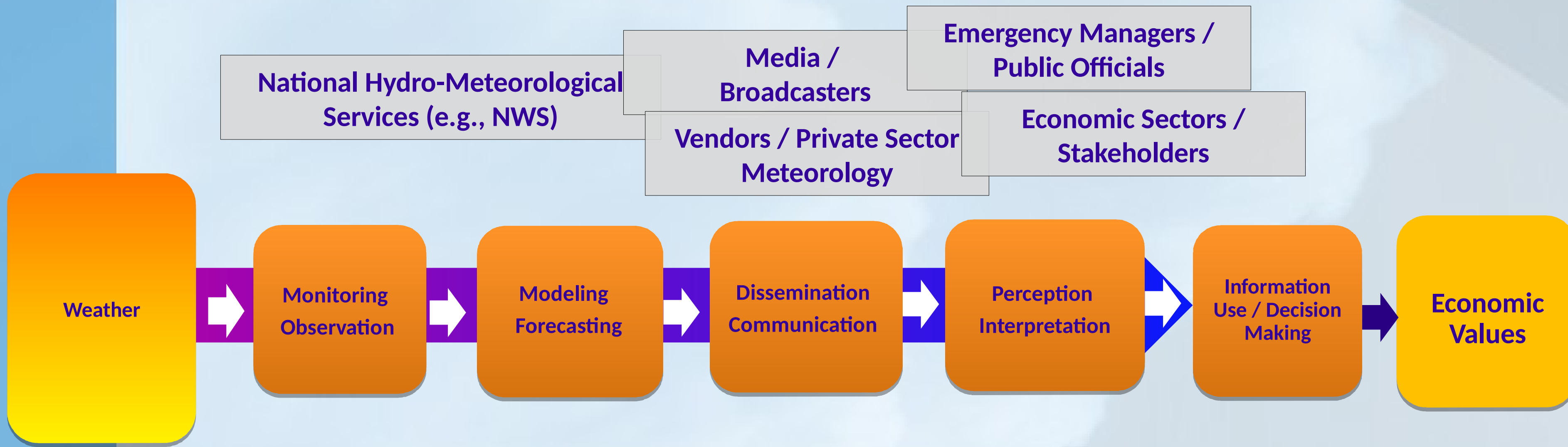


Each stakeholder, agent, and decision maker has his or her own set of:

- **objectives**
- **resources and**
- **constraints**

that frame their transformation or use of information

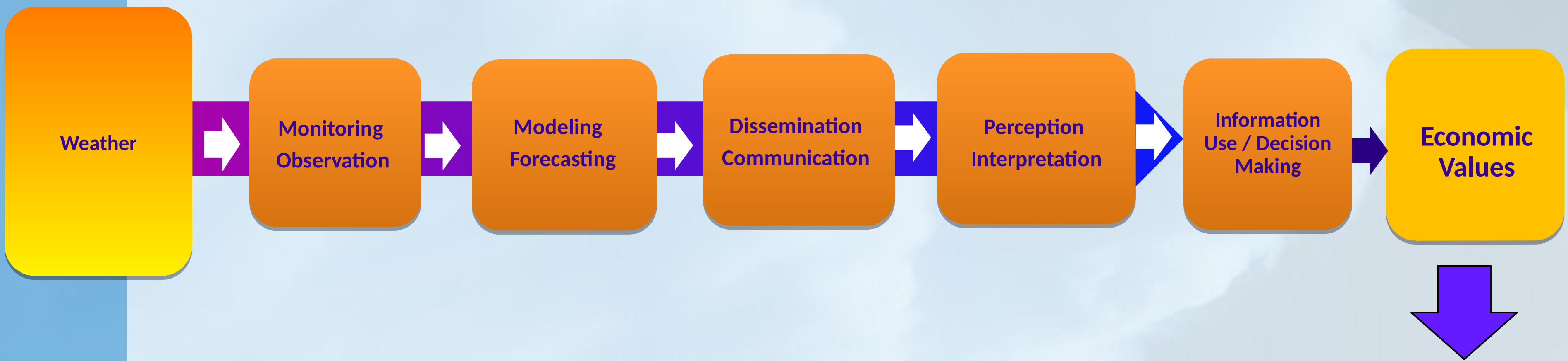
Weather Information Value Chain



Economic values are the result of a complex process

- **Ultimately value of information is a function of the ability of decision makers to receive, understand, and act on information on uncertain future events.**
- **Have to be able to tell the story end-to-end to derive valid benefit estimates.**

Valuation Methods



Valuation is at the end of the chain so valuation methods ultimately depend on the decisions and potential outcomes being evaluated

- Morbidity / mortality (VSL)
- Reduced costs
- Reduced damages
- Increased profits
- Improved welfare (WTP)

Economic valuation methods

Sector Specific / Benchmarking / Expert Elicitation

Non-market valuation techniques

- **Stated preference methods**
- **Revealed preference methods**

Economic decision modelling

- **Decision analysis**
- **Equilibrium models**
- **Econometric models**

Avoided cost/damage assessments

- **including avoided mortality and morbidity impacts**

Benefits transfer (BT)

Economic valuation methods

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Sector Specific / Benchmarking / Expert Elicitation

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Back of the envelope …

Economic decision modelling

- **Decision analysis**
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Benefits transfer (BT)

Primary methods …

Economic valuation methods

Sector Specific / Benchmarking / Expert Elicitation

Non-market valuation techniques

- **Stated preference methods**
- **Revealed preference methods**

Economic decision modelling

- Decision analysis
- Equilibrium models
- Econometric models

Avoided cost/damage assessments

- including avoided mortality and morbidity impacts

Benefits transfer (BT)

Important for valuing public goods (e.g. weather forecasts)!

Economic valuation methods

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Sector Specific / Benchmarking / Expert Elicitation

Non-market valuation techniques

- **Stated preference methods**
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Economic decision modelling

- **Decision analysis**
- **Equilibrium models**
- **Econometric models**

Avoided cost/damage assessments

- **including avoided mortality and morbidity impacts**

Benefits transfer (BT)

Secondary methods …

Economic valuation methods

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Sector Specific / Benchmarking / Expert Elicitation

Non-market valuation techniques

- Stated preference methods
- Revealed preference methods

Economic decision modelling

- **Decision analysis** ⟵ **Cost-loss model**
- Equilibrium models
- Econometric models

Avoided cost/damage assessments

- including avoided mortality and morbidity impacts

Benefits transfer (BT)

What to value?

- **Value of “Weather” and “Weather Information”**
  - Economic impact of weather
  - Value of current weather data and information
  - Value of current weather forecasts
  - Value of improved weather forecasts
  - Value of research to improve forecasts
  - Value of improving dissemination / comprehension / use / decision making / response …

Value Chain Examples

1. **Dept. of Energy (DOE) Solar**
   - verification and quality metrics
   - end user value model
2. **Weather Decisions – Extreme Weather Events (WDEWE)**
   - mental models and hurricane warning information
   - non-market valuation
3. **Aviation – Windshear Warning Product**
   - ex post case study
   - clear link from R&D to outcomes

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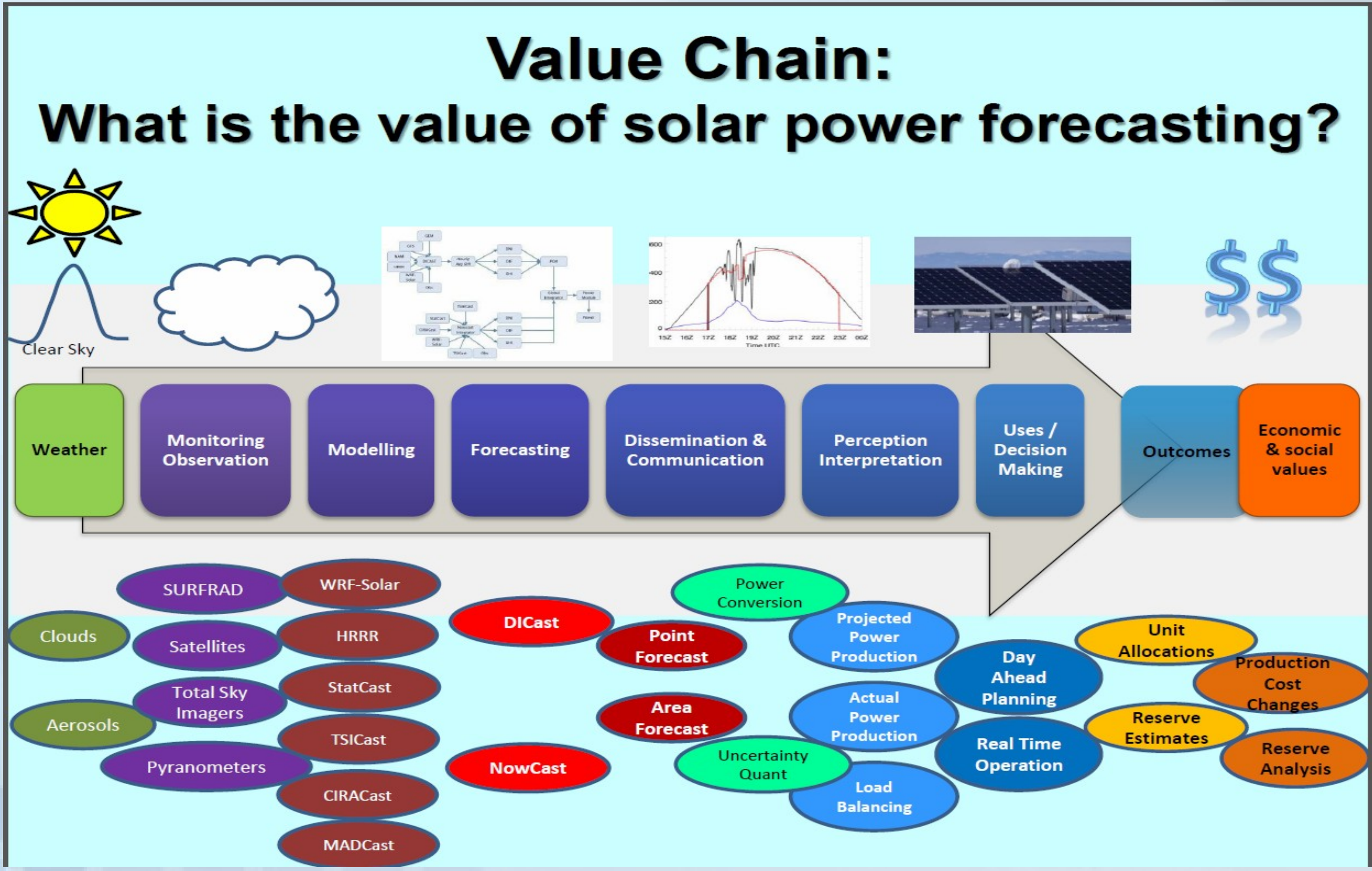
Economic Value of Research to Improve Solar Power Forecasting

Jeffrey K. Lazo*, Keith Parks**, Sue E. Haupt*, Tara L. Jensen*
* National Center for Atmospheric Research, Box 3000, Boulder, CO, 80307, USA
** Xcel Energy, Denver, Colorado

Weather Information Value Chain – Ex. 1 – DOE Solar



Value of improved solar power forecasts

PCM – used in day ahead decision making to decide what "assets" to use to meet demand based on demand (and solar power) forecasts – PCM runs cost minimization

PCM Costs with *current* forecast error

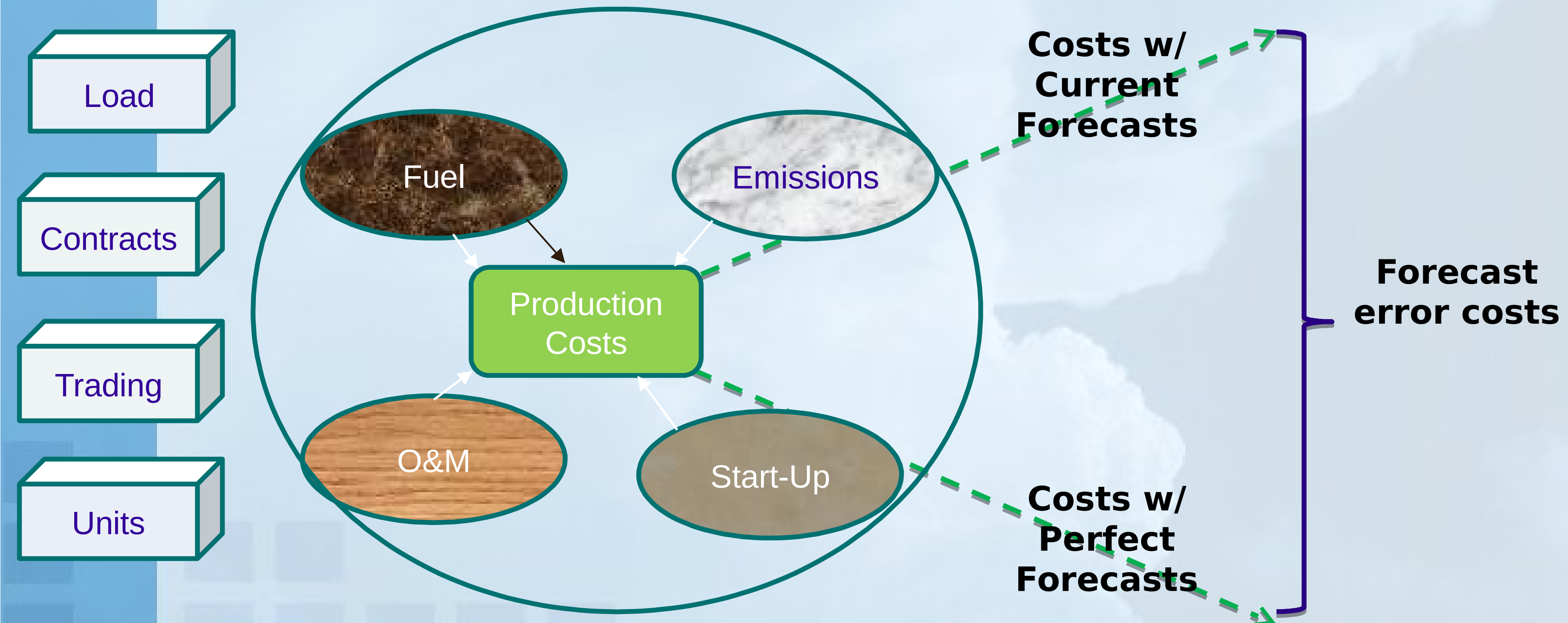
- PCM Costs with *reduced* forecast errors

Value of improved forecasts

- **For different levels of error reduction**
- **For different levels of solar generation**

Conceptual Model of Production Costs

Production Costs: The cost of generating power at an overall system level



Utilities use their own Production Cost Model (PCM) for analysis

Conceptual Model of Production Costs

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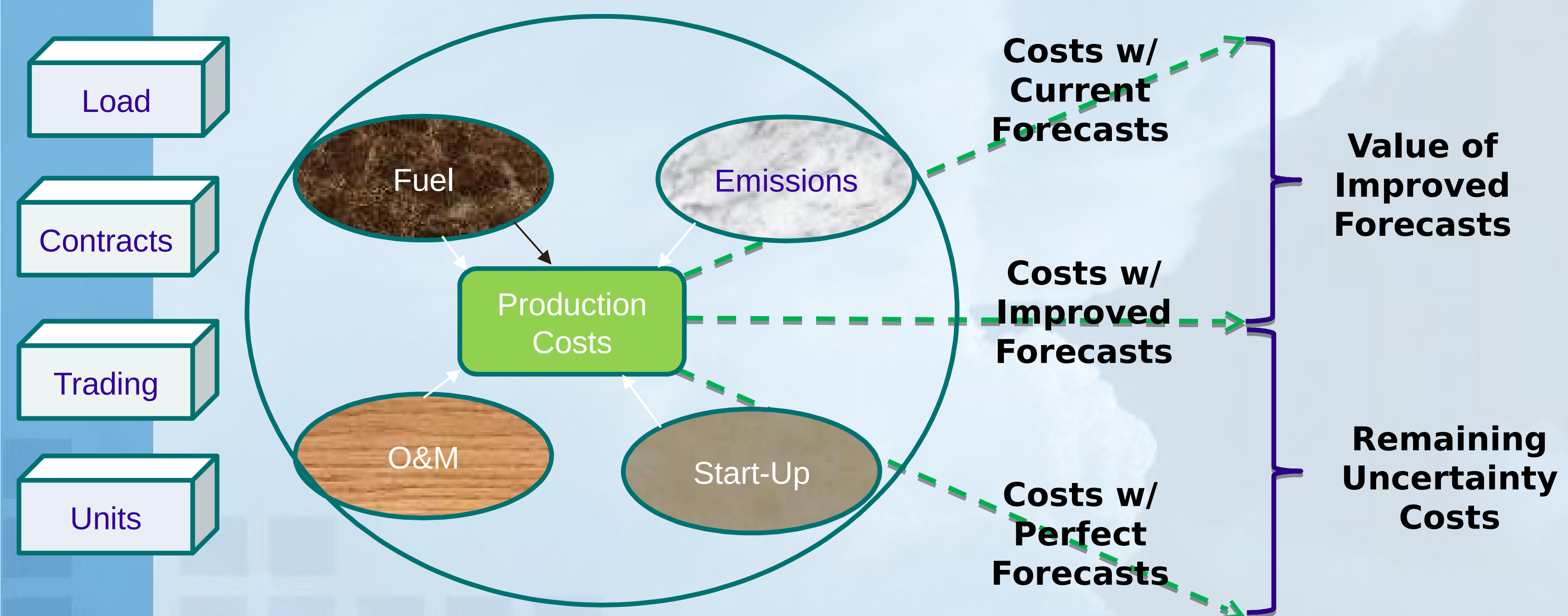
Production Costs: The cost of generating power at an overall system level



Utilities use their own Production Cost Model (PCM) for analysis

Xcel PCM modeling

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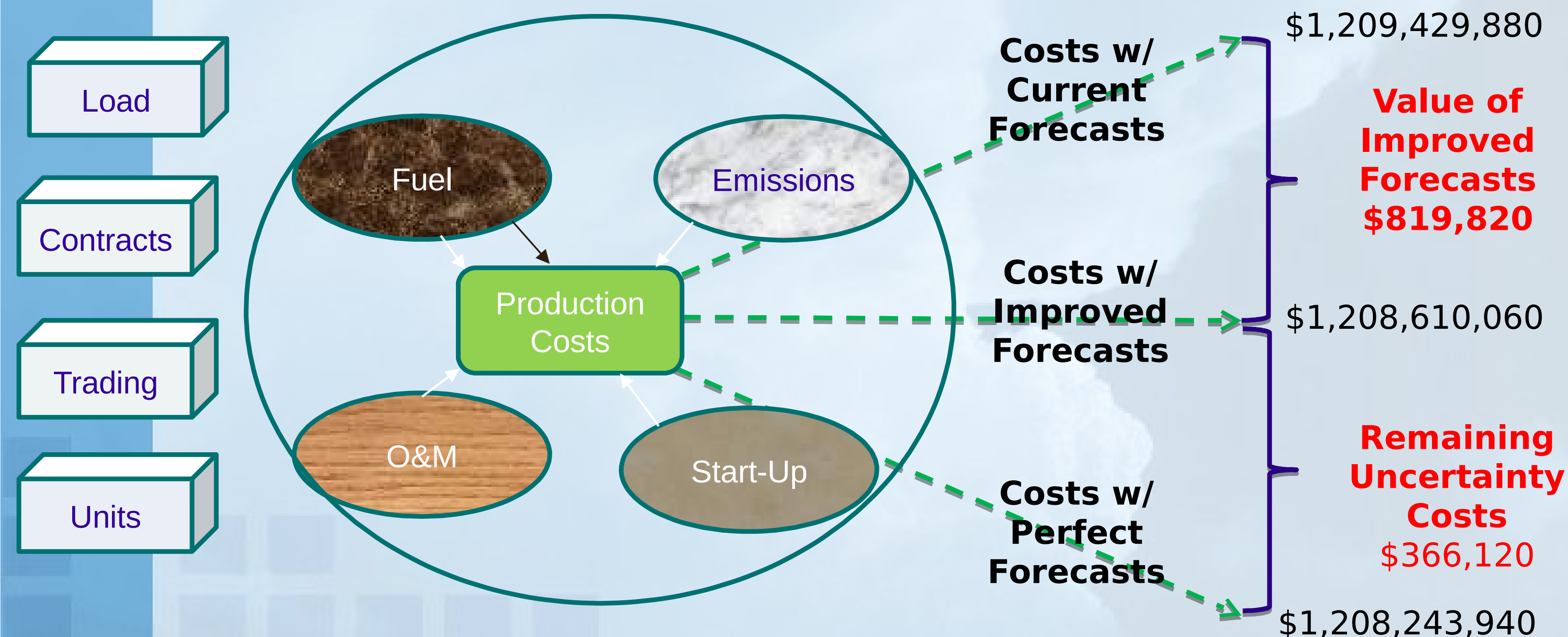
- **Modeling Scenario**
  - "An Integration Cost Study for Solar Generation Resources on the Public Service Company of Colorado System" May 27, 2016
  - "Set up" system for 2024 w/ 1,800 MW Solar Generation
    - 1148 MW Distributed / 652 MW Utility-scale
- **Solar forecast**
  - NREL 2011 published day-ahead forecast and realized solar generation pairs – adapted to 2024 scenario – 4,542 "observations"
  - Forecast error
    - MAE – 20.05%
    - 50% reduction in error for PCM scenario

Conceptual Model of Production Costs



Benefits estimates

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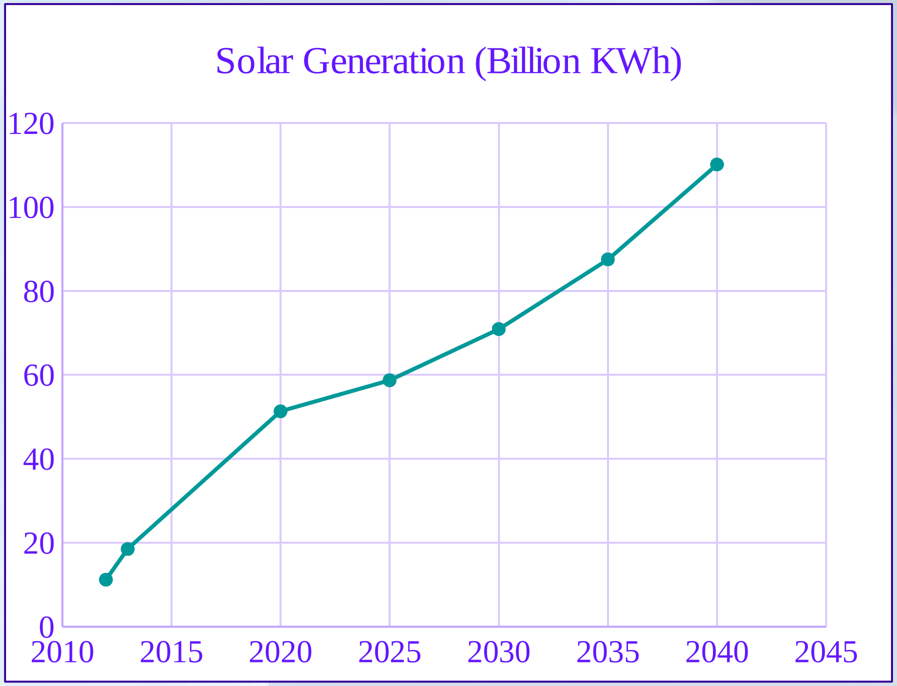
- **Analysis based on "Total cost" for one year**
- **Value per KwH for 50% reduction in MAE in power forecast**
- **Total reduction in forecast errors**
  - 290,755 MWh for the year
  - cost savings of $2.82 per MWh reduction in error
- **Regression analysis of all PCM data**
  - cost savings of $3.94 per MWh reduction in error

Aggregation to national values

- **EIA estimate of future solar penetration (nationally)** *
- **Assume 20% MAE reduced to 10% MAE**
- **Benefit: $3.94/MWh** **
- **Time period: 2015 to 2040**
- **Discount rate: 3%**



Present value total benefits: $454,854,415

* Source EIA. 2015, Table A.16).
** From regression analysis reported in Haupt et al. 2016

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Warning Decisions Extreme Weather Events (WDEWE)

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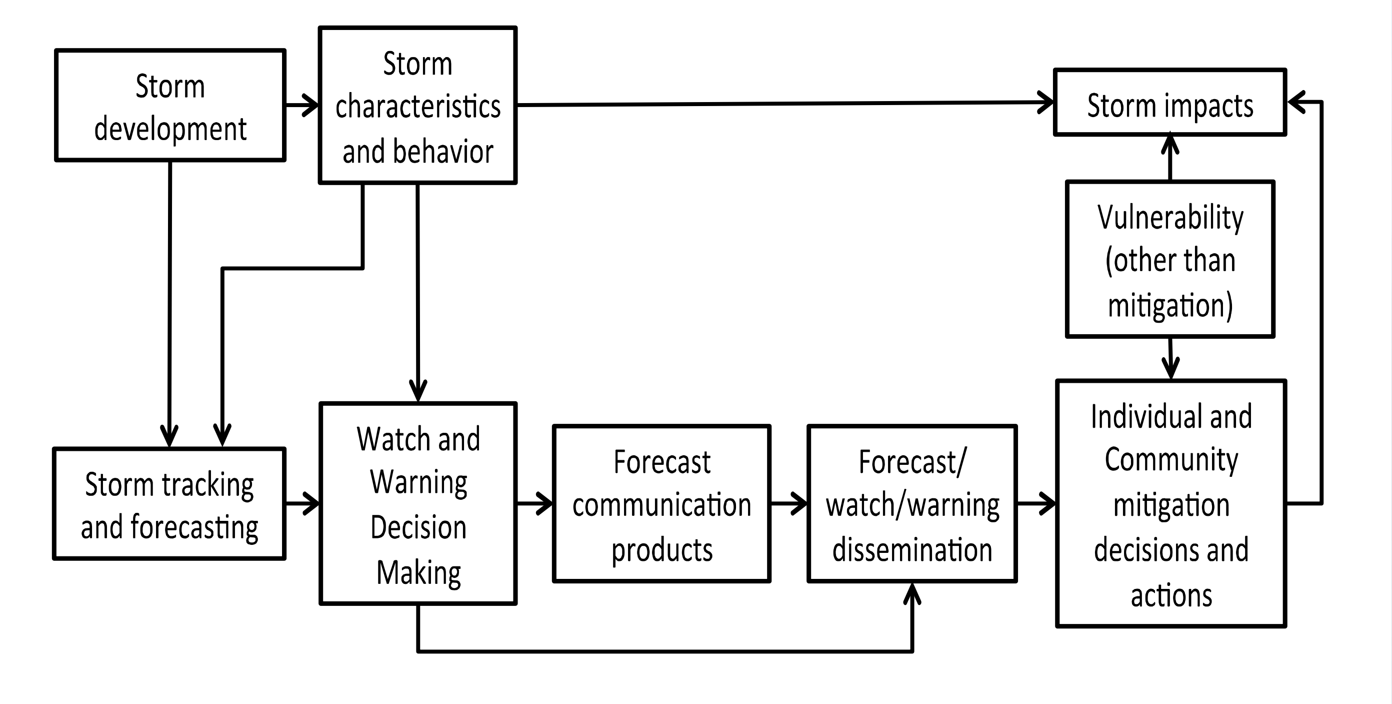

In depth mental model interviews with key stakeholders

- **Forecasters**
- **Broadcasters**
- **Emergency managers**
- **General public**

Survey of general public

Bostrom, A., R.E. Morss, Lazo, J.K., J.L. Demuth, H. Lazrus, and R. Hudson, forthcoming 2016. "A mental models study of hurricane forecast and warning production, communication, and decision making." ***Weather, Climate, and Society***

Warning Decisions Extreme Weather Events (WDEWE)

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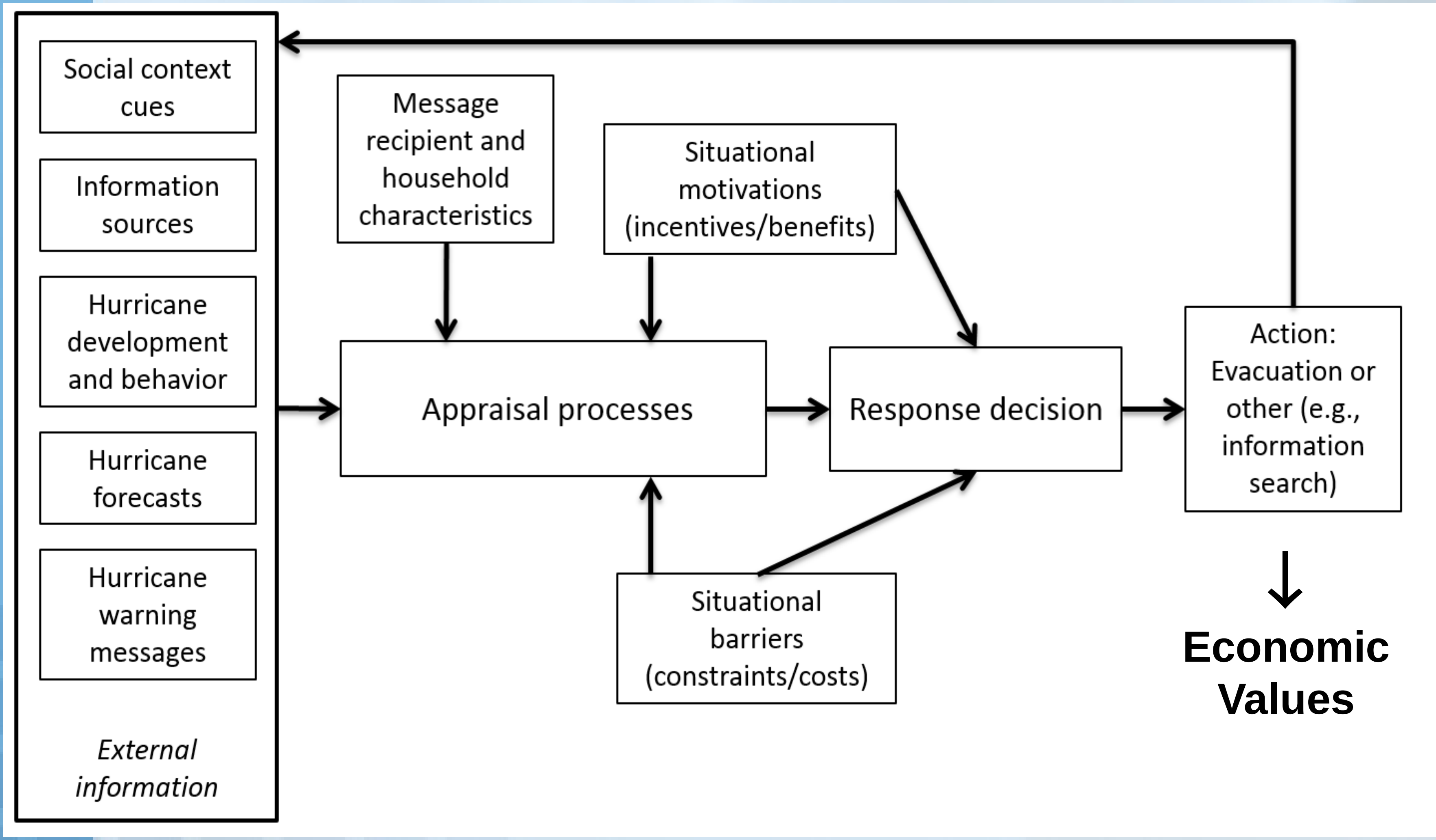


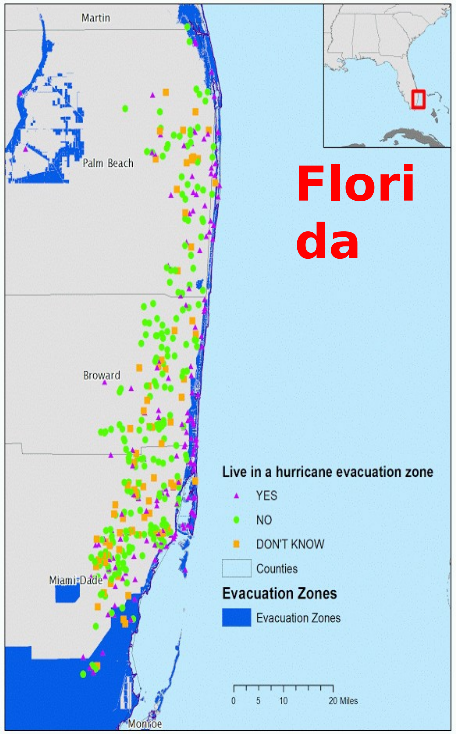
Lazo, J.K., A. Bostrom, R.E. Morss, J.L. Demuth, and H. Lazrus. 2015. Communicating Hurricane Warnings: Factors Affecting Protective Behavior. *Risk Analysis*. 35(10):1837-1857.

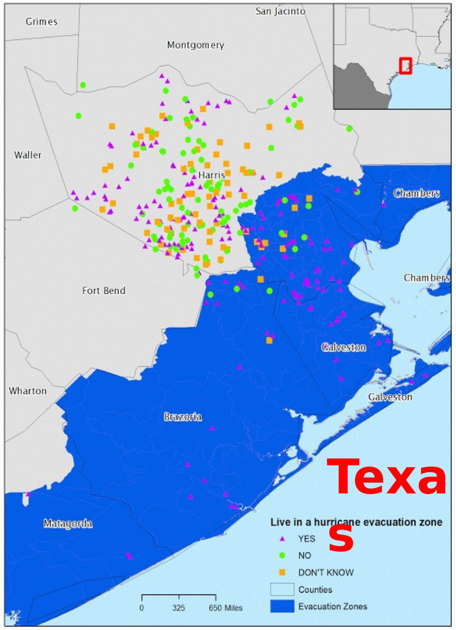
Public Survey – Methods

- **Survey development and pre-testing**
  - Mental models interviews with forecasters, broadcasters, emergency managers, and public
  - Prior hurricane-related survey work
  - Risk communication literature (e.g., psychometric paradigm)
  - Cultural theory (Leiserowitz, Douglas and Wildavsky)
  - Pre-tested with one-on-ones and small sample online
- **Implementation**
  - Online survey – available in Spanish
  - Knowledge Networks (KN) KnowledgePanel®
  - May 4-24, 2012
  - N=804 (61.6% of those invited to the survey)
    - 457 in the Miami-Dade area
    - 347 in the Galveston-Houston area
  - Missing values on some variables replaced with mean or median as appropriate (<1% of data points)

Respondents' Socio-Demographics (n=804)	
Characteristic	**Mean**
Age (Years)	47.11
Total Yrs in Hurricane Vulnerable Area	25.29
Education (Years)	13.67
Income (Thousands)	66.50
Dummy Variables	
Male	46.6%
Own Residence	68.4%
Children in House	36.8%
Took Survey In Spanish	18.7%
Single Family House – Detached	55.4%

All state-level data weighted to be representative of the areas sampled at the state level, and totals weighted to be representative of all areas sampled.





Warning Decisions Extreme Weather Events (WDEWE)

NCAR

Q25 Please indicate which Program you would prefer if you had to choose.

	Accuracy of Current Forecasts	Program D	Program E
Landfall location	within 50 miles	**25 miles**	No change
Maximum wind speed	within 15 miles per hour	No change	**7 mph**
Flooding from rainfall	detected 50% of the time	No change	No change
Storm surge information	no separate storm surge information	No change	**Separate storm surge information**
Increase in Annual Cost to Your Household		**$12 per year**	**$24 per year**
I would prefer (check one box)		**Program D** ☐	**Program E** ☐

Q26 **Would you prefer to keep forecast accuracy the way it is now (current levels of accuracy) with no increased costs to your household or the Program (D or E) you chose above at the cost indicated?**

- ☐ Keep forecast accuracy the way it is now with no increased costs to my household.
- ☐ Undertake the program (D or E) chosen above at the cost indicated.

Choice Set Attributes and Levels

Attribute	Description	Current Level	Improved Level
Landfall location	Forecasters predict where a hurricane will make landfall. Currently, two days before landfall, forecasts of the hurricane landfall location are accurate to within about 50 miles. Hurricane-force winds typically extend from 35-75 miles from the center of the storm, depending on the size and intensity of the hurricane.	50 miles	25 miles
Maximum wind speed	Forecasters predict what the maximum sustained wind speeds will be when a hurricane makes landfall. Currently, two days before landfall, forecasts of maximum sustained wind speed are accurate to within plus or minus 15 miles per hour.	15 mph	7 mph
Inland flooding from rainfall	Significant rainfall from hurricanes can cause inland flooding which can include flash floods. This is different from coastal flooding that is caused by storm surge. Inland flooding can be a threat hundreds of miles from the coast. Currently forecasters are able to accurately predict 50% of these inland flooding events.	50%	75%
Storm surge information	Hurricane warnings are based on forecasts of maximum sustained wind speeds and thus do not necessarily include information about the potential risk of storm surge. The depth of storm surge can vary considerably for any given category of hurricane. Currently, forecasters do NOT issue separate warnings for hurricane storm surge. If forecasters DID issue separate storm surge warnings, they would give specific information about the storm surge threat.	No separate storm surge information	Separate storm surge information
Cost	No current additional cost	No current additional cost	$6 per year $12 per year $24 per year $36 per year

Warning Decisions Extreme Weather Events (WDEWE)

NCAR

Q25 Please indicate which Program you would prefer if you had to choose.

	Accuracy of Current Forecasts	Program D	Program E
Landfall location	within 50 miles	25 miles	No change
Maximum wind speed	within 15 miles per hour	No change	7 mph
Flooding from rainfall	detected 50% of the time	No change	No change
Storm surge information	no separate storm surge information	No change	Separate storm surge information
Increase in Annual Cost to Your Household		$12 per year	$24 per year
I would prefer (check one box)		Program D ☐	Program E ☐

Q26 Would you prefer to keep forecast accuracy the way it is now (current levels of accuracy) with no increased costs to your household or the Program (D or E) you chose above at the cost indicated?

- ☐ Keep forecast accuracy the way it is now with no increased costs to my household.
- ☐ Undertake the program (D or E) chosen above at the cost indicated.

- ***11 total choice questions for each individual x 804 = 8,844***
- ***n for models = 8,733***

Value of Improved Forecasts

NCAR

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij}, \qquad i = A, B; \quad j = 1, \ldots, 8$$

Random Utility Model (RUM)

- **ε assumed independent, identically distributed, mean zero normal random variables, uncorrelated with x_{ij}, with constant unknown variance σ**
- **Under these assumptions, the probability of choosing program 1, for example, is:**

$$P_{ij}^{1} = P\left(U_{ij}^{1} > U_{ij}^{2}\right) = \Phi\left[\beta'\left(x_{ij}^{1} - x_{ij}^{2}\right) / \sqrt{2}\sigma_{\varepsilon}\right]$$

- **univariate standard normal cumulative distribution function**
- **Probit model for dichotomous choice**

Value of Improved Forecast

	Model 1	Model 2	Model 3	Model 4
Parameter	Est.	Est.	Est.	Est.
Landfall	0.27 ***	0.27 ***	0.27 ***	0.27 ***
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***
Flooding	0.11 ***	0.11 ***	0.11 ***	0.11 ***
Storm Surge Warning (SSW)	-0.04 **	-0.31 ***	-0.67 ***	-0.64 ***
Cost	-0.04 ***	-0.04 ***	-0.04 ***	-0.04 ***
SSW * Education		0.01 **	0.01	0.01
SSW * Children In Household		0.09 **	0.08 **	0.07 *
SSW * Own Residence		0.08 **	0.09 **	0.11 ***
SSW * Evac Likelihood – Order			0.06 ***	0.05 ***
SSW * Information Accuracy			0.04 *	0.03
SSW * Sources Factor Official			0.03 *	0.03 *
SSW * House Vulnerable to Surge				0.07 ***
SSW * Perceived Evacuation Zone				0.04

Value of Improved Forecast

NCAR

Parameter	Model 1 Est.	Model 2	Model 3	Model 4
Landfall	0.27 ***			[illegible] *
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***
Flooding	0.11 ***	0.11 ***	0.11 ***	0.11 ***
Storm Surge Warning (SSW)	-0.04 **	-0.31 ***	-0.67 ***	-0.64 ***
Cost	-0.04 ***	-0.04 ***	-0.04 ***	-0.04 ***
SSW * Education		0.01 **	0.01	0.01
SSW * Children In Household		0.09 **	0.08 **	0.07 *
SSW * Own Residence		0.08 **	0.09 **	0.11 ***
SSW * Evac Likelihood – Order			0.06 ***	0.05 ***
SSW * Information Accuracy			0.04 *	0.03
SSW * Sources Factor Official			0.03 *	0.03 *
SSW * House Vulnerable to Surge				0.07 ***
SSW * Perceived Evacuation Zone				0.04

Attributes of the information are important to preferences

Value of Improved Forecast

NCAR

	Model 1	Model 2	Model 3	Model 4
Parameter	Est.	Est.	Est.	Est.
Landfall	0.27 ***	0.27 ***	0.27 ***	0.27 ***
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***
Flooding	0.11 ***	0.11 ***	[illegible]	0.11 ***
Storm Surge Warning (SSW)	-0.04 **	-0.31 ***	[illegible]	[illegible]
Cost	-0.04 ***	-0.04 ***	-0.04 ***	-0.04 ***
SSW * Education		0.01 **	0.01	0.01
SSW * Children In Household		0.09 **	0.08 **	0.07 *
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SSW * House Vulnerable to Surge				0.07 ***
SSW * Perceived Evacuation Zone				0.04

Socio-demographics are important to preferences

Value of Improved Forecast

NCAR

	Model 1	Model 2	Model 3	Model 4
Parameter	Est.	Est.	Est.	Est.
Landfall	0.27 ***	0.27 ***	0.27 ***	0.27 ***
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***
Flooding	0.11 ***	0.11 ***	0.11 ***	0.11 ***
Storm Surge Warning (SSW)	-0.04 **	-0.31 ***	-0.67 ***	-0.64 ***
Cost	-0.04 ***	-0.04 ***	-0.04 ***	-0.04 ***
SSW * Education		0.01 **	0.01	0.01
SSW * Children In Household		[illegible]	[illegible]	0.07 *
SSW * Own Residence		[illegible]	[illegible]	0.11 ***
SSW * Evac Likelihood – Order		[illegible]	[illegible]	0.05 ***
SSW * Information Accuracy			0.04 *	0.03
SSW * Sources Factor Official			0.03 *	0.03 *
SSW * House Vulnerable to Surge				0.07 ***
SSW * Perceived Evacuation Zone				0.04

Perceptions of information quality and source are important to preferences

Value of Improved Forecast

Parameter	Model 1 Est.	Model 2 Est.	Model 3 Est.	Model 4 Est.
Landfall	0.27 ***	0.27 ***	0.27 ***	0.27 ***
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***
Flooding	0.11 ***	0.11 ***	0.11 ***	0.11 ***
Storm Surge Warning (SSW)	-0.04 **	-0.31 ***	-0.67 ***	-0.64 ***
Cost	-0.04 ***	-0.04 ***	-0.04 ***	-0.04 ***
SSW * Education		0.01 **	0.01	0.01
SSW * Children In Household		0.09 **	0.08 **	0.07 *
SSW * Own Residence		0.08 **	0.09 **	0.11 ***
SSW * Evac Likelihood – Order				
SSW * Information Accuracy				
SSW * Sources Factor Official			0.03 *	0.03 *
SSW * House Vulnerable to Surge				0.07 ***
SSW * Perceived Evacuation Zone				0.04

Vulnerability to hazards is important to preferences

Value of Improved Forecast

Model 1					
Parameter	Est.	Est.	Est.	Est.	
Landfall	**0.27 *****	0.27 ***	0.27 ***	0.27 ***	
Max Wind Speed	0.07 ***	0.07 ***	0.07 ***	0.07 ***	
Flooding	0.11 ***	0.11 ***	0.11 ***	0.11 ***	
Storm S[illegible]	[illegible]	[illegible]	-0.67 ***	-0.64 ***	
Cost	[illegible]	[illegible]	-0.04 ***	-0.04 ***	
SSW * E[illegible]	[illegible]	[illegible]	0.01	0.01	
SSW * Children in Household		0.09 **	0.08 **	0.07 *	
SSW * Own Residence		0.08 **	0.09 **	0.11 ***	
SSW * Evac Likelihood – Order			0.06 ***	0.05 ***	
SSW * Information Accuracy			0.04 *	0.03	
SSW * Sources Factor Official			0.03 *	0.03 *	
SSW * House Vulnerable to Surge				0.07 ***	
SSW * Perceived Evacuation Zone				0.04	

WTP for improving accuracy of landfall forecasts from ±50 miles to ±25 miles is $6.75 per year per household

Value Chain Examples

NCAR

1. **Dept. of Energy (DOE) Solar**
   - verification and quality metrics
   - end user value model
2. **Weather Decisions – Extreme Weather Events (WDEWE)**
   - mental models and hurricane warning information
   - Non-market valuation
3. **Aviation – Windshear Warning Product**
   - ex post case study
   - clear link from R&D to outcomes

Windshear Warning

NCAR

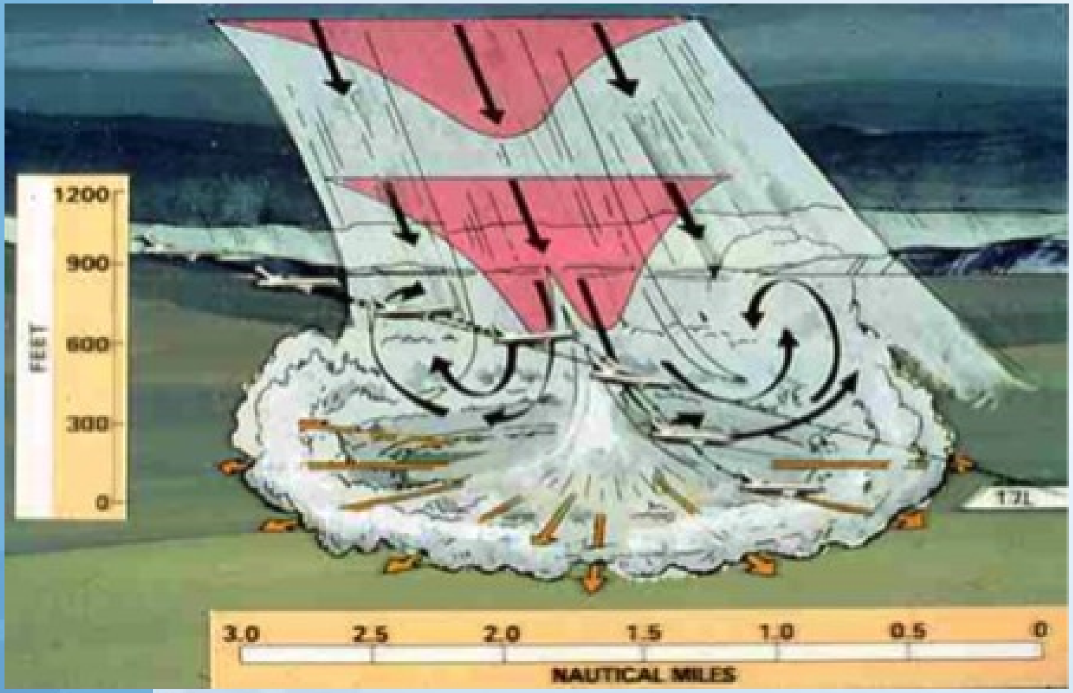
1. **Problem**
2. **Research**
3. **Products**
4. **Solution**
5. **Result**
6. **Valuation**

August 3rd 2016, Boeing 777-300, Emirates EK521 crashed at Dubai International Airport

http://www.aviation-accidents.net/emirates-boeing-b777-300-ek-521-flight-ek521/

Windshear Warning

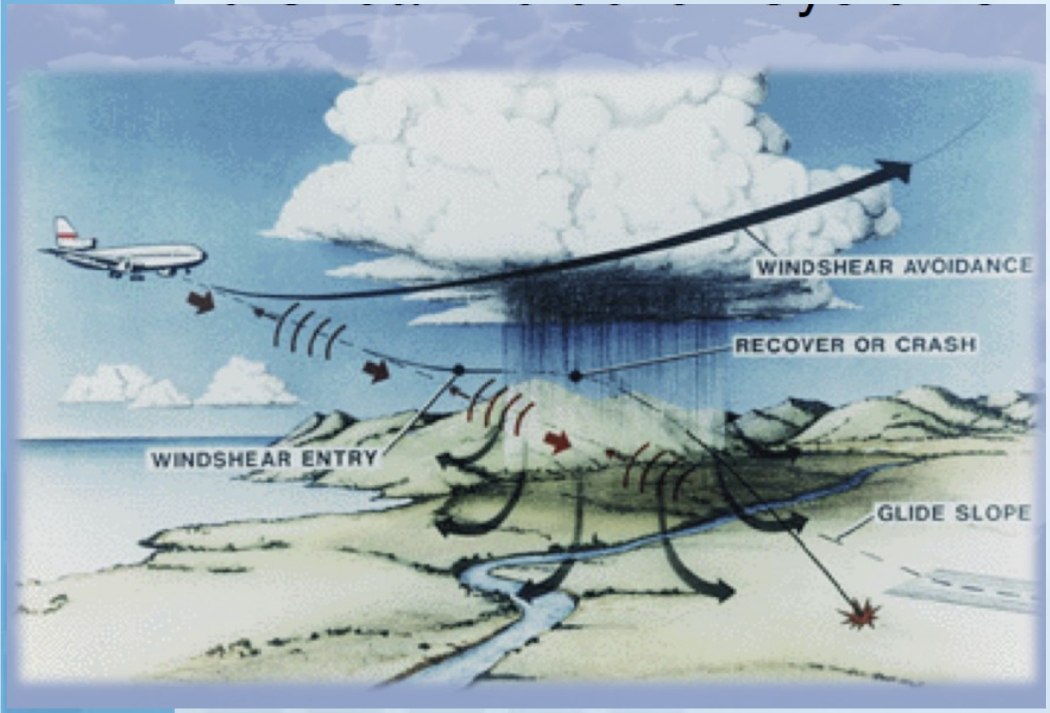
1. Problem



- **Windshear is any rapidly changing wind event**
- **A pilot flying into downburst will detect increased speed due to headwind and may decelerate**
- **As he crosses into other side he rapidly decelerates due to tailwind …**
- **… and may crash**
- **1973-1985 about 400 fatalities in windshear related accidents in U.S. – about 33 a year.**

Windshear Warning

1. Problem
2. **Research**



- **Scientists recognized downdraft as a potential atmospheric phenomena**
- **1982 – NCAR, U. Chicago, FAA – began research to prove or disprove the theory that microbursts existed**
- **Began to develop windshear detection and warning systems**
  - **Langley Research Center**
  - **FAA**
  - **NCAR**
  - **Lincoln Labs**

Windshear Warning

TDWR

1. **Pilot training – windshear recognition**
2. **Airborne detection**
3. **Ground based detection and warning systems**

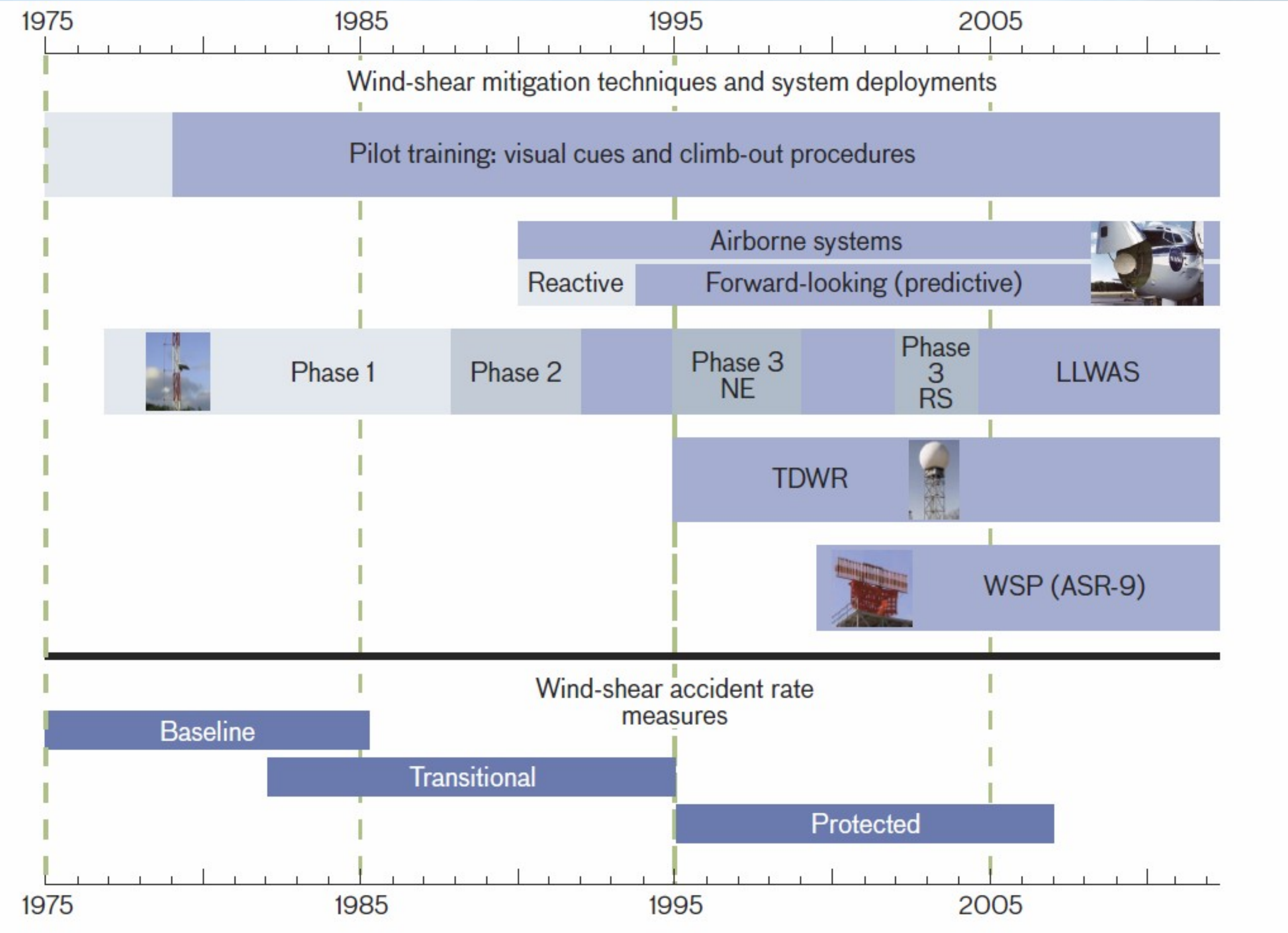
6. Valuation

ASR-9

LLWAS

Windshear Warning

1. Problem
2. Research
3. Products
4. **Solution**
5. Result
6. Valuation



Hallowell, R.G. and J.Y. N. Cho. 2010. Wind-Shear System: Cost-Benefit Analysis. Lincoln Laboratory Journal. 18(2):47-68

Windshear Warning

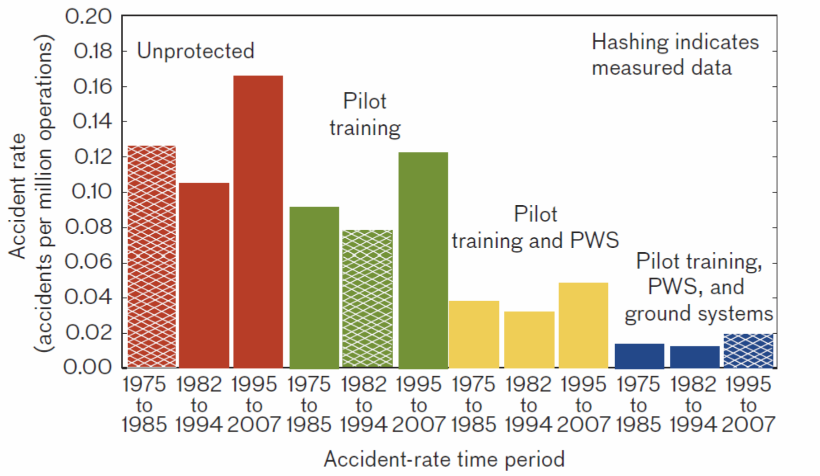


FIGURE 14. A comparison of measured and mitigation-adjusted accident rates permits the "filling out" of the entire chart. The bars with hatching are the measured accident rates. Modeling the other protection conditions from the measured data provides estimates of accident rates for all possible mitigations in each time period.

Hallowell, R.G. and J.Y. N. Cho. 2010. Wind-Shear System: Cost-Benefit Analysis. Lincoln Laboratory Journal. 18(2):47-68

Time Period	Fatalities	Average per year
1973-1985	400	33.3
1985-present	0	0

Windshear Warning

NCAR

1. Problem
2. Research
3. Products
4. Solution
5. Result
6. **Valuation**

Time Period	Fatalities	Average per year
1973-1985	400	33.3
1985-present	0	0
Statistical lives saved		33.3
VSL		$6.0 M/life
Benefit		$200,000,000/yr

Case Study Summary

Case Study	Value Chain	Valuation Method
Solar energy forecasts	Explicitly used in research as coordination tool	Production cost modeling
Hurricane warnings	Explicitly developed and assessed as focus of research	Stated-preference (choice experiment / survey)
Wind shear	Implicitly assumed as connection between warning system and outcomes	Value of statistical life (avoided damages)

Recommendations

- **potential value of connecting economic value methods and verification methods**
- **all major investments or changes in hydro-met services should undertake economics analysis**
- **fully characterizing the *Weather Information Value Chain* should be fundamental part of benefits studies**

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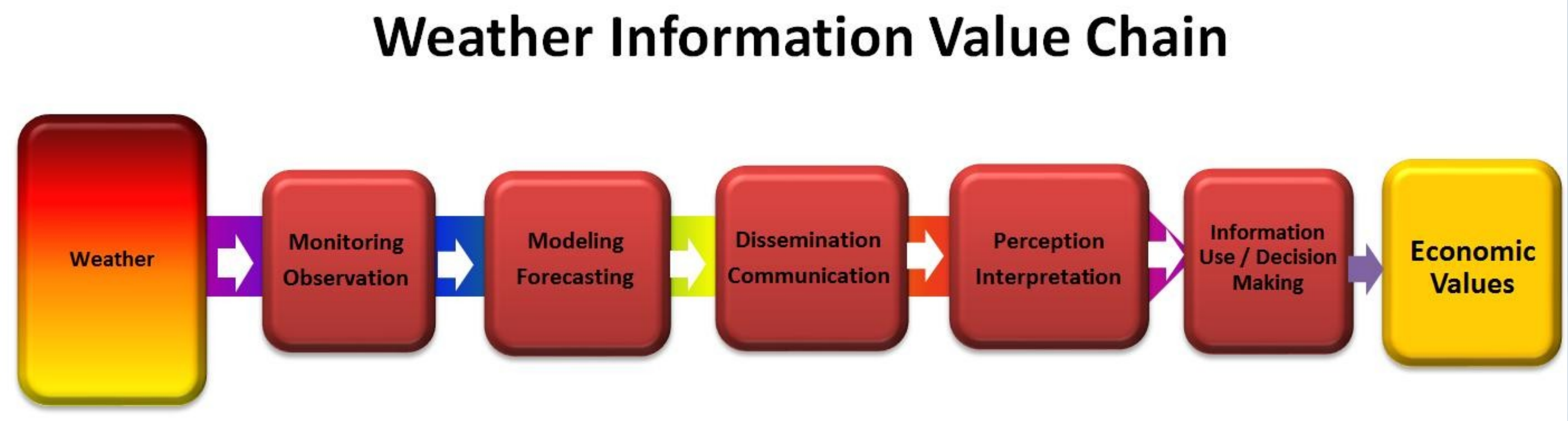

Thank You!

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