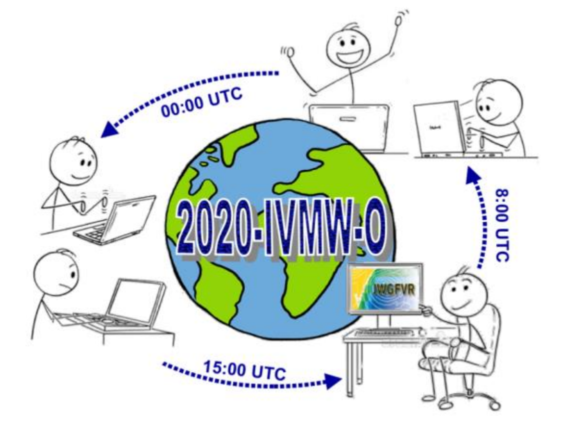
JUPITER™
Predicting risk in a changing climate

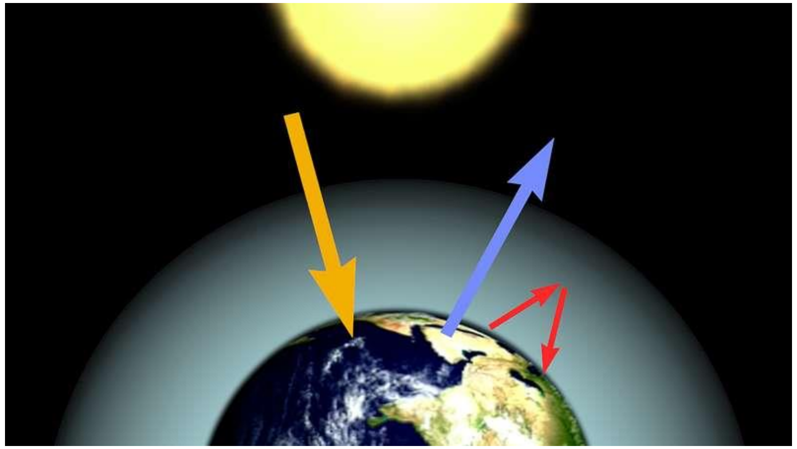


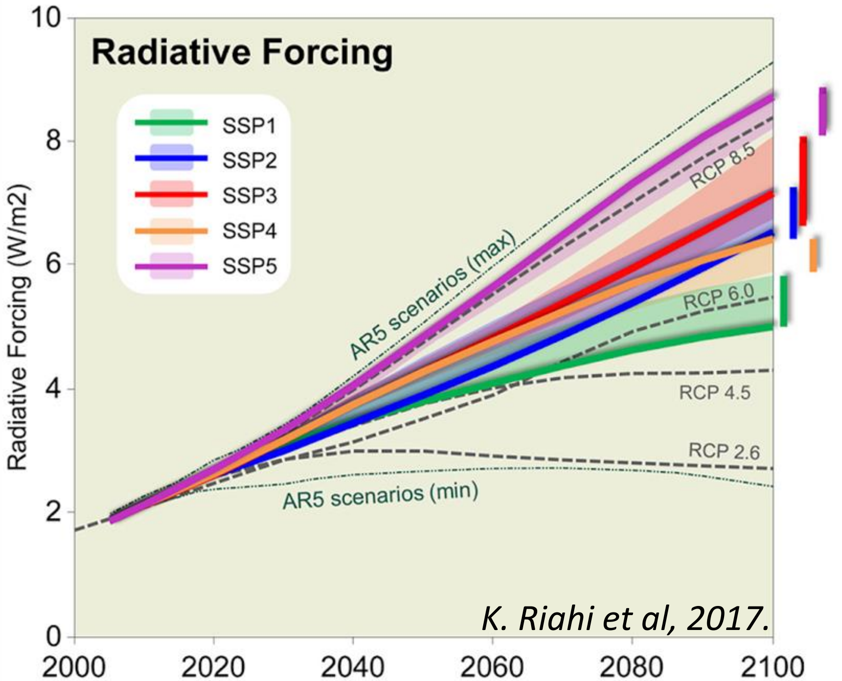
Validation and Verification of Climate Products

Nickitas Georgas, Betsy Weatherhead, Alan Blumberg
November 19, 2020

Outline

- What is verification and validation of climate products?
- Validation:
  - Are our approaches appropriate?
  - What are the uncertainties?
- Verification:
  - Do we recreate current conditions?
  - Can we verify future climate?
  - How confident can we be?
- Climate Products
  - What do users of climate information want to know?
  - Extreme events
  - Spatial considerations
  - Commonalities with weather V&V
- Future directions for climate verification





K. Riahi et al, 2017.

Climate Products

- Consumers of climate information are interested in many, many aspects of climate change: floods, fires, hail, severe precipitation, heat, lightning, icing, waves, tropical cyclones
- Means, extremes, combined effects; RISK = f (Likelihood and Exposure)
- Environmental impacts, human impacts and built environments
  - Finance, Insurance, Real Estate, Corporate and Other Assets

Climate Products:
What do users want to know?

- Strong preference for impactful events:
  - Extremes of wind, temperature, precipitation, drought, fire
- Intense interest in next year to decade(s).
- Large range of interest in technical verification details.

Some Typical Questions

Are my corporate locations at risk?

Is this real estate asset a good investment?

What should I do to bring my risk in line with my tolerance?

Will this asset become uninsurable?

Will this company's strategy make it a winner or a loser as the climate changes?

Should I be valuing this muni bond differently?

What should I be reporting to regulators?

Will this company's debt become impaired?

What do we mean by V&V of Climate Products?

- Validation: The methods and their applications are sound
  - Reasonable assumptions for future environmental conditions
  - A range of assumptions can be considered, based on different estimates of the future

  - State of the art climate projections
  - Best available models for estimating the future (<u>not just climate models</u>)

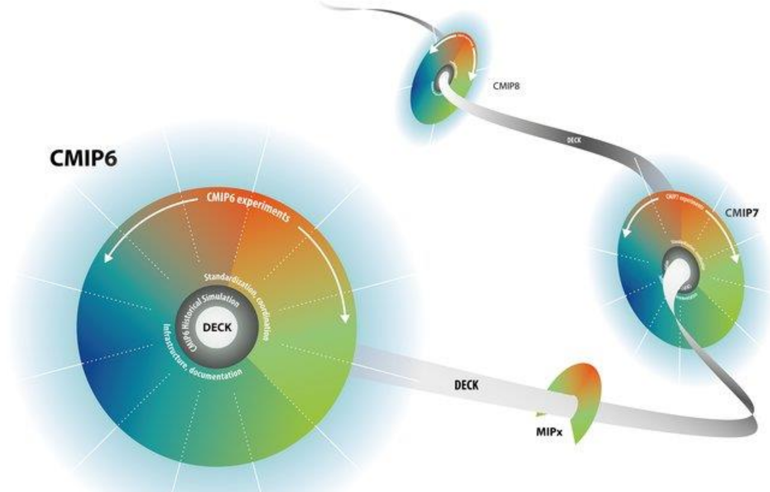
- Verification: Independent confirmation of projections, including baseline
  - Use of historical and current data
  - Comparison to independent projections
  - Estimation of uncertainty

Climate Models – estimating the future

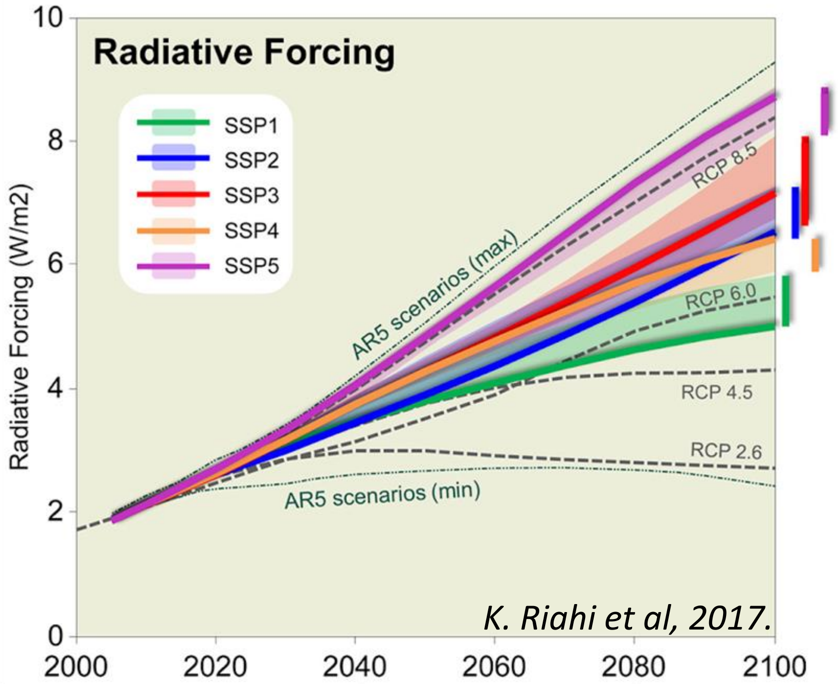
- Full acknowledgement that we don't "know" the future:
  - Future population?
  - Continued fossil fuel usage?
  - Land use?
  - Pollution/aerosol levels?

- Climate model output is a **projection** of a future climate.
  - It describes a range of futures that are consistent with pathways an
    the underlying assumptions

- Common CO2 assumptions for the future:
  - RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5 (among others) on a background
    different Shared Socioeconomic Pathways involving population, GD
    technological advances, etc.



V. Eyring et al, 2016.



K. Riahi et al, 2017.

Validation of Climate Models

- Climate models have a rich history and are heavily researched, characterized and vetted.

- Models are evaluated on multiple metrics:
    - Mean state, seasonal cycle, internal variability exhibited, geographic climatology; trends
    - There are no perfect climate models; each has strengths and weaknesses

- The most appropriate model choice may be dependent on the area, and climate hazard of interest.
    - Fortunately, there is significant, continual work in this area.

Arctic

Q. Shu et al.: Assessment of sea ice simulations in the CMIP5 models

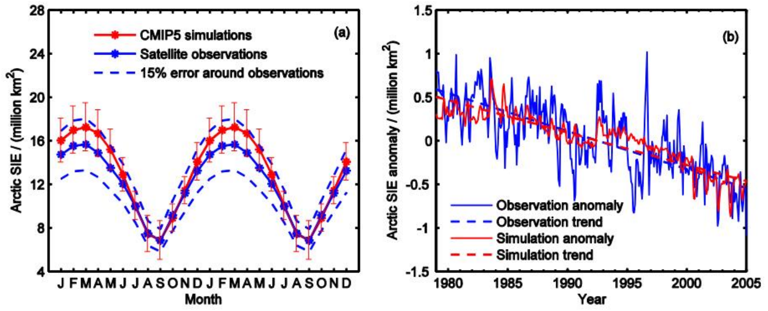
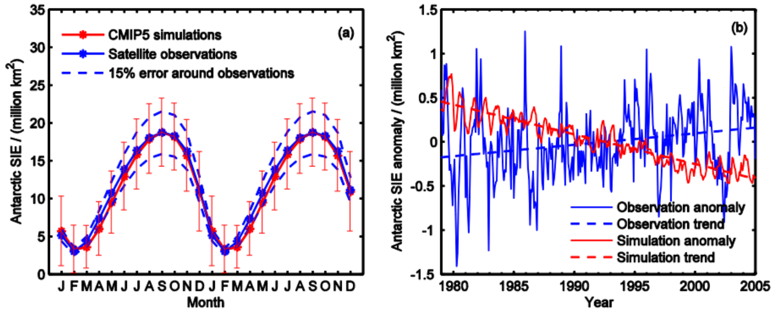


Figure 6. Climatology **(a)**, anomaly and linear trend **(b)** of satellite-observed and CMIP5-simulated Arctic sea ice extent during 1979–2005. Two annual cycles are plotted in **(a)**. The error bar is the range of 1 standard deviation.

Antarctic

Q. Shu et al.: Assessment of sea ice simulations in the CMIP5 models



Q. Shu et al, 2015.

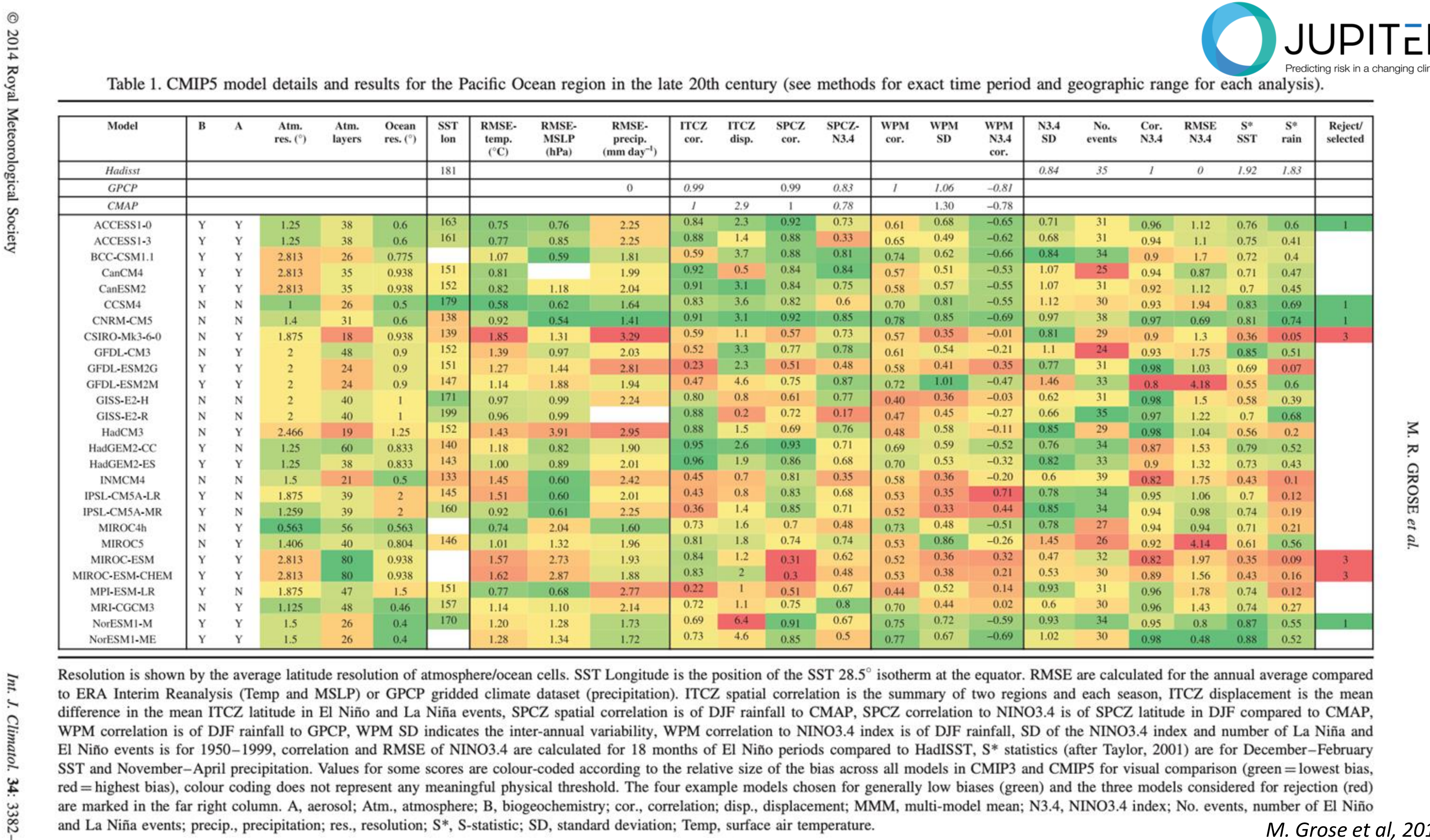


Table 1. CMIP5 model details and results for the Pacific Ocean region in the late 20th century (see methods for exact time period and geographic range for each analysis).

Model	B	A	Atm. res. (°)	Atm. layers	Ocean res. (°)	SST lon	RMSE-temp. (°C)	RMSE-MSLP (hPa)	RMSE-precip. (mm day^{-1})	ITCZ cor.	ITCZ disp.	SPCZ cor.	SPCZ-N3.4	WPM cor.	WPM SD	WPM N3.4 cor.	N3.4 SD	No. events	Cor. N3.4	RMSE N3.4	S* SST	S* rain	Reject/ selected
Hadisst						181											*0.84*	*35*	*1*	*0*	*1.92*	*1.83*	
GPCP									0	*0.99*		0.99	*0.83*	*1*	*1.06*	*–0.81*							
CMAP										*1*	*2.9*	1	*0.78*		1.30	–0.78							
ACCESS1-0	Y	Y	1.25	38	0.6	163	0.75	0.76	2.25	0.84	2.3	0.92	0.73	0.61	0.68	–0.65	0.71	31	0.96	1.12	0.76	0.6	1
ACCESS1-3	Y	Y	1.25	38	0.6	161	0.77	0.85	2.25	0.88	1.4	0.88	0.33	0.65	0.49	–0.62	0.68	31	0.94	1.1	0.75	0.41	
BCC-CSM1.1	Y	Y	2.813	26	0.775		1.07	0.59	1.81	0.59	3.7	0.88	0.81	0.74	0.62	–0.66	0.84	34	0.9	1.7	0.72	0.4	
CanCM4	Y	Y	2.813	35	0.938	151	0.81		1.99	0.92	0.5	0.84	0.84	0.57	0.51	–0.53	1.07	25	0.94	0.87	0.71	0.47	
CanESM2	Y	Y	2.813	35	0.938	152	0.82	1.18	2.04	0.91	3.1	0.84	0.75	0.58	0.57	–0.55	1.07	31	0.92	1.12	0.7	0.45	
CCSM4	N	N	1	26	0.5	179	0.58	0.62	1.64	0.83	3.6	0.82	0.6	0.70	0.81	–0.55	1.12	30	0.93	1.94	0.83	0.69	1
CNRM-CM5	N	N	1.4	31	0.6	138	0.92	0.54	1.41	0.91	3.1	0.92	0.85	0.78	0.85	–0.69	0.97	38	0.97	0.69	0.81	0.74	1
CSIRO-Mk3-6-0	N	Y	1.875	18	0.938	139	1.85	1.31	3.29	0.59	1.1	0.57	0.73	0.57	0.35	–0.01	0.81	29	0.9	1.3	0.36	0.05	3
GFDL-CM3	N	Y	2	48	0.9	152	1.39	0.97	2.03	0.52	3.3	0.77	0.78	0.61	0.54	–0.21	1.1	24	0.93	1.75	0.85	0.51	
GFDL-ESM2G	Y	Y	2	24	0.9	151	1.27	1.44	2.81	0.23	2.3	0.51	0.48	0.58	0.41	0.35	0.77	31	0.98	1.03	0.69	0.07	
GFDL-ESM2M	Y	Y	2	24	0.9	147	1.14	1.88	1.94	0.47	4.6	0.75	0.87	0.72	1.01	–0.47	1.46	33	0.8	4.18	0.55	0.6	
GISS-E2-H	N	N	2	40	1	171	0.97	0.99	2.24	0.80	0.8	0.61	0.77	0.40	0.36	–0.03	0.62	31	0.98	1.5	0.58	0.39	
GISS-E2-R	N	N	2	40	1	199	0.96	0.99		0.88	0.2	0.72	0.17	0.47	0.45	–0.27	0.66	35	0.97	1.22	0.7	0.68	
HadCM3	N	Y	2.466	19	1.25	152	1.43	3.91	2.95	0.88	1.5	0.69	0.76	0.48	0.58	–0.11	0.85	29	0.98	1.04	0.56	0.2	
HadGEM2-CC	Y	N	1.25	60	0.833	140	1.18	0.82	1.90	0.95	2.6	0.93	0.71	0.69	0.59	–0.52	0.76	34	0.87	1.53	0.79	0.52	
HadGEM2-ES	Y	Y	1.25	38	0.833	143	1.00	0.89	2.01	0.96	1.9	0.86	0.68	0.70	0.53	–0.32	0.82	33	0.9	1.32	0.73	0.43	
INMCM4	N	N	1.5	21	0.5	133	1.45	0.60	2.42	0.45	0.7	0.81	0.35	0.58	0.36	–0.20	0.6	39	0.82	1.75	0.43	0.1	
IPSL-CM5A-LR	Y	N	1.875	39	2	145	1.51	0.60	2.01	0.43	0.8	0.83	0.68	0.53	0.35	0.71	0.78	34	0.95	1.06	0.7	0.12	
IPSL-CM5A-MR	Y	N	1.259	39	2	160	0.92	0.61	2.25	0.36	1.4	0.85	0.71	0.52	0.33	0.44	0.85	34	0.94	0.98	0.74	0.19	
MIROC4h	N	Y	0.563	56	0.563		0.74	2.04	1.60	0.73	1.6	0.7	0.48	0.73	0.48	–0.51	0.78	27	0.94	0.94	0.71	0.21	
MIROC5	N	Y	1.406	40	0.804	146	1.01	1.32	1.96	0.81	1.8	0.74	0.74	0.53	0.86	–0.26	1.45	26	0.92	4.14	0.61	0.56	
MIROC-ESM	Y	Y	2.813	80	0.938		1.57	2.73	1.93	0.84	1.2	0.31	0.62	0.52	0.36	0.32	0.47	32	0.82	1.97	0.35	0.09	3
MIROC-ESM-CHEM	Y	Y	2.813	80	0.938		1.62	2.87	1.88	0.83	2	0.3	0.48	0.53	0.38	0.21	0.53	30	0.89	1.56	0.43	0.16	3
MPI-ESM-LR	Y	N	1.875	47	1.5	151	0.77	0.68	2.77	0.22	1	0.51	0.67	0.44	0.52	0.14	0.93	31	0.96	1.78	0.74	0.12	
MRI-CGCM3	N	Y	1.125	48	0.46	157	1.14	1.10	2.14	0.72	1.1	0.75	0.8	0.70	0.44	0.02	0.6	30	0.96	1.43	0.74	0.27	
NorESM1-M	Y	Y	1.5	26	0.4	170	1.20	1.28	1.73	0.69	6.4	0.91	0.67	0.75	0.72	–0.59	0.93	34	0.95	0.8	0.87	0.55	1
NorESM1-ME	Y	Y	1.5	26	0.4		1.28	1.34	1.72	0.73	4.6	0.85	0.5	0.77	0.67	–0.69	1.02	30	0.98	0.48	0.88	0.52	

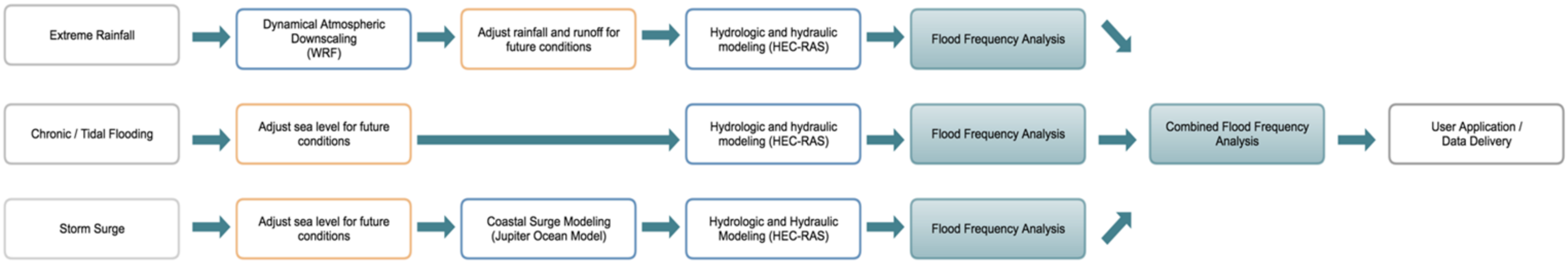
Resolution is shown by the average latitude resolution of atmosphere/ocean cells. SST Longitude is the position of the SST 28.5° isotherm at the equator. RMSE are calculated for the annual average compared to ERA Interim Reanalysis (Temp and MSLP) or GPCP gridded climate dataset (precipitation). ITCZ spatial correlation is the summary of two regions and each season, ITCZ displacement is the mean difference in the mean ITCZ latitude in El Niño and La Niña events, SPCZ spatial correlation is of DJF rainfall to CMAP, SPCZ correlation to NINO3.4 is of SPCZ latitude in DJF compared to CMAP, WPM correlation is of DJF rainfall to GPCP, WPM SD indicates the inter-annual variability, WPM correlation to NINO3.4 index is of DJF rainfall, SD of the NINO3.4 index and number of La Niña and El Niño events is for 1950–1999, correlation and RMSE of NINO3.4 are calculated for 18 months of El Niño periods compared to HadISST, S* statistics (after Taylor, 2001) are for December–February SST and November–April precipitation. Values for some scores are colour-coded according to the relative size of the bias across all models in CMIP3 and CMIP5 for visual comparison (green = lowest bias, red = highest bias), colour coding does not represent any meaningful physical threshold. The four example models chosen for generally low biases (green) and the three models considered for rejection (red) are marked in the far right column. A, aerosol; Atm., atmosphere; B, biogeochemistry; cor., correlation; disp., displacement; MMM, multi-model mean; N3.4, NINO3.4 index; No. events, number of El Niño and La Niña events; precip., precipitation; res., resolution; S*, S-statistic; SD, standard deviation; Temp, surface air temperature.

M. Grose et al, 2014.

Validation of Climate Products

- Often, climate products are not simply output from climate models.
- Compound modeling may be needed to estimate aspects of a future climate
    - Statistical downscaling
    - Dynamical downscaling
    - Sequential modeling

Overview of Modeling System for Jupiter's Flood Score Planning - Houston



Extreme Rainfall → Dynamical Atmospheric Downscaling (WRF) → Adjust rainfall and runoff for future conditions → Hydrologic and hydraulic modeling (HEC-RAS) → Flood Frequency Analysis

Chronic / Tidal Flooding → Adjust sea level for future conditions → Hydrologic and hydraulic modeling (HEC-RAS) → Flood Frequency Analysis → Combined Flood Frequency Analysis → User Application / Data Delivery

Storm Surge → Adjust sea level for future conditions → Coastal Surge Modeling (Jupiter Ocean Model) → Hydrologic and Hydraulic Modeling (HEC-RAS) → Flood Frequency Analysis

- Vetted methodology, QA/QC at every step: “The right results for the right reasons.”

Verification of Climate Products: Which products? Which decisions?

- Verification of climate products involves addressing a wide range of questions:
  - Which areas of the Earth will warm the most?
  - Will tropical cyclones increase? (intensity, frequency, area?)
  - What is the risk of a tornado in this town?
  - Will this warehouse flood?

- Increasingly, climate information is used to support decisions:
  - Business owner decisions: Ignore, fortify, move
  - Insurance risks: rates for specific perils; compound perils; exposure estimates
  - Governmental regulations: encourage development, change building codes

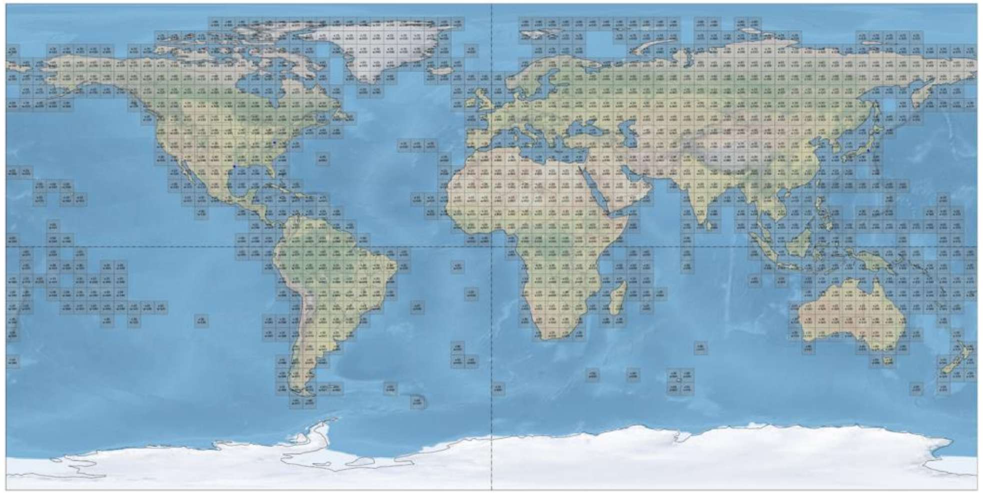
- Savvy users want probabilities of events occurring [under each projected scenario]

Verification Structure

- Evaluation of data
    - Physically realistic
    - Spatially and temporally consistent

- Comparison to current distributions
    - Data are rarely Gaussian, particularly extreme events
    - Long datasets are not always available
    - Full spatial resolution datasets are not always available

- Comparison to historical events
- Comparison to recent extreme events
- Comparison to other approaches



Jupiter ClimateScore Global
Image Courtesy of Galen Yacalis, Jupiter Intelligence

Summarizing Verification

- Report Cards for Verification
  - Examination by peril
  - Separate analysis for present day, near future, mid-century and late century
  - Classic verification for Baseline
  - Consistency and physical arguments for future years.
  - Scientific judgment at each step.
  - Support material backing every judgment.

Jupiter EOS Team CSG Product Assessment for Coastal Flood Peril	Baseline Average	Near Future (2025-	Mid Century (2040-	Late Century

Jupiter EOS Team CSG Product Assessment for Fire Peril	Baseline Average	Near Future (2025-	Mid Century (2040-	Late Century (2065-2100)

Jupiter EOS Team CSG Product Assessment for Drought Peril	Baseline Average	Near Future	Mid Century (2040-	Late Cent

Jupiter EOS Team CSG Product Assessment for **Heat Peril** (Link to applicable V&V confluence page).	Baseline Average (1986-2005)	Near Future (2025-2035)	Mid Century (2040-2060)	Late Century (2065-2100)
Technical Check (no missing data, appropriate values, basic consistency)				
North America	LM	LM	LM	LM
Europe	LM	LM	LM	LM
South America	LM	LM	LM	LM
Africa	LM	LM	LM	LM
Asia	LM	LM	LM	LM
Oceania	LM	LM	LM	LM
Return Level/Scenario consistency Checks				
North America	LM	LM	LM	LM
Europe	LM	LM	LM	LM

A word about observations

Validating flood model simulations using camera information and crowd source information

Emma Levin*
Alan Blumberg, Betsy Weatherhead, Victor Rodriguez, Venkatsundar Ramaswamy, and Firas Saleh

Earth and Ocean Systems Intern

JUPITER

Unmanned Aircraft Image of Charleston after Hurricane Florence.

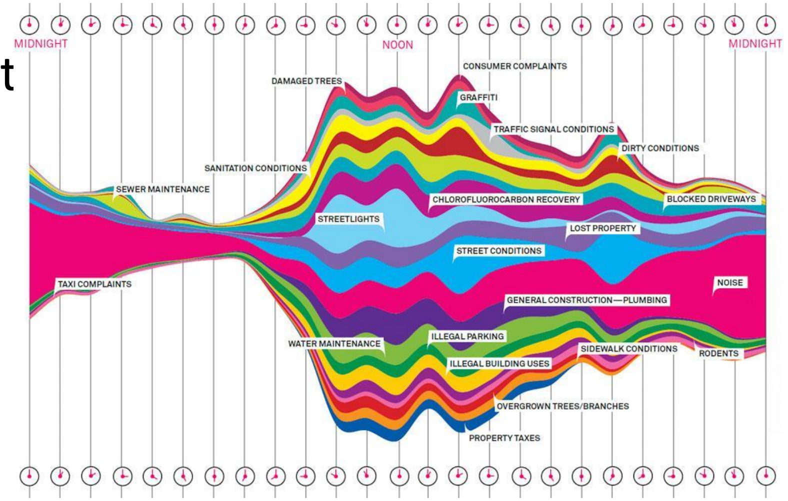
- Scarcity of long-term, high (consistent) quality datasets for floods, hail, tropical cyclones, droughts, etc.
- Novel, non-standard, emerging technologies are often the best available:
  - Citizen science (high water marks, personal reports, cell phones images, etc.)
  - Synthetic Aperture Radar (SAR)
  - Unmanned Aircraft
  - Traffic cameras (doorbell cameras!)
  - Proprietary information from customers, insurance, government
- Each idiosyncratic datasets requires its own use
  - Often not long-term, but offer partial information

2018-08-14 16:20:04

-, New York

2018-08-14T20:20Z

E. Levin et al, 2020
Helios System, L3Harris



J. Primatchuk, 2015
based on NYC 311 Data

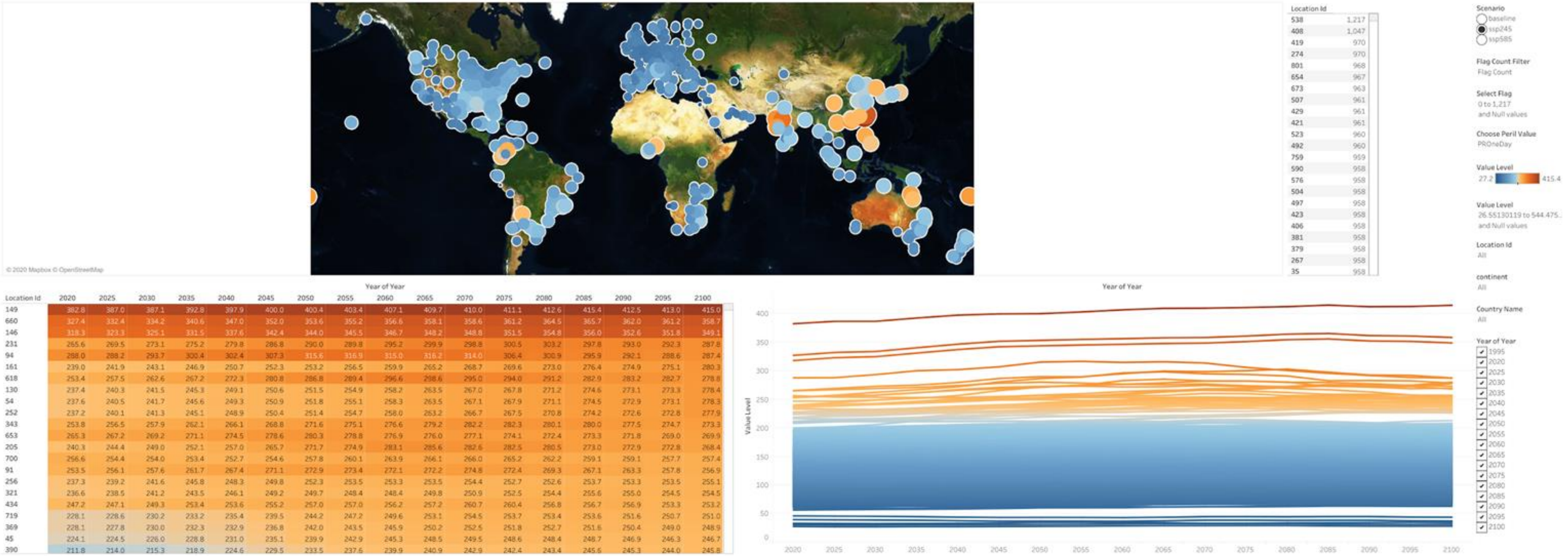
311 flood calls by hour to NYC

Summarizing verification

Quality Indicators >> Verification Indices >> Quality Acceptance Criteria	>=Good	<=OK
1. Technical Check (no missing data, appropriate values, basic consistency)	99%	1%
2. Return Level/Scenario consistency Checks	90%	10%
3. Spatial Consistency	100%	0%
4. Comparison to historical distributions, goodness of fit tests	82%	18%
5. Comparison to extreme past events	97%	3%
6. Comparison to select Jupiter CSP products	71%	29%
7. Comparison to other climate projections	68%	32%

JUPITER™
Predicting risk in a changing climate

In depth examination of future perils



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673	963
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759	959
590	958
576	958
504	958
497	958
423	958
406	958
381	958
379	958
267	958
35	958

Year of Year

Location Id	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
149	382.8	387.0	387.1	392.8	397.9	400.0	400.4	403.4	407.1	409.7	410.0	411.1	412.6	415.4	412.5	413.0	415.0
660	327.4	332.4	334.2	340.6	347.0	352.0	353.6	355.2	356.6	358.1	358.6	361.2	364.5	365.7	362.0	361.2	358.7
146	318.3	323.3	325.1	331.5	337.6	342.4	344.0	345.5	346.7	348.2	348.8	351.5	354.8	356.0	352.6	351.8	349.1
231	265.6	269.5	273.1	275.2	279.8	286.8	290.0	289.8	295.2	299.9	298.8	300.5	303.2	297.8	293.0	292.3	287.8
94	288.0	288.2	293.7	300.4	302.4	307.3	315.6	316.9	315.0	316.2	314.0	306.4	300.9	295.9	292.1	288.6	287.4
161	239.0	241.9	243.1	246.9	250.7	252.3	253.2	256.5	259.9	265.2	268.7	269.6	273.0	276.4	274.9	275.1	280.3
618	253.4	257.5	262.6	267.2	272.3	280.8	286.8	289.4	296.6	298.6	295.0	294.0	291.2	282.9	283.2	282.7	278.8
130	237.4	240.3	241.5	245.3	249.1	250.6	251.5	254.9	258.2	263.5	267.0	267.8	271.2	274.6	273.1	273.3	278.4
54	237.6	240.5	241.7	245.6	249.3	250.9	251.8	255.1	258.3	263.5	267.1	267.9	271.1	274.5	272.9	273.1	278.3
252	237.2	240.1	241.3	245.1	248.9	250.4	251.4	254.7	258.0	263.2	266.7	267.5	270.8	274.2	272.6	272.8	277.9
343	253.8	256.5	257.9	262.1	266.1	268.8	271.6	275.1	276.6	279.2	282.2	282.3	280.1	280.0	277.5	274.7	273.3
653	265.3	267.2	269.2	271.1	274.5	278.6	280.3	278.8	276.9	276.0	277.1	274.1	272.4	273.3	271.8	269.0	269.9
205	240.3	244.4	249.0	252.1	257.0	265.7	271.7	274.9	283.1	285.6	282.6	282.5	280.5	273.0	272.9	272.8	268.4
700	256.6	254.4	254.0	253.4	252.7	254.6	257.8	260.1	263.9	266.1	266.0	265.2	262.2	259.1	259.1	257.7	257.4
91	253.5	256.1	257.6	261.7	267.4	271.1	272.9	273.4	272.1	272.2	274.8	272.4	269.3	267.1	263.3	257.8	256.9
256	237.3	239.2	241.6	245.8	248.3	249.8	252.3	253.5	253.3	253.5	254.4	252.7	252.6	253.7	253.3	253.5	255.1
321	236.6	238.5	241.2	243.5	246.1	249.2	249.7	248.4	248.4	249.8	250.9	252.5	254.4	255.6	255.0	254.5	254.5
434	247.2	247.1	249.3	253.4	253.6	255.2	257.0	257.0	256.2	257.2	260.7	260.4	256.8	256.7	256.9	253.3	253.2
719	228.1	228.6	230.2	233.2	235.4	239.5	244.2	247.2	249.6	253.1	254.5	253.7	253.4	253.6	251.6	250.7	251.0
369	228.1	227.8	230.0	232.3	232.9	236.8	242.0	243.5	245.9	250.2	252.5	251.8	252.7	251.6	250.4	249.0	248.9
45	224.1	224.5	226.0	228.8	231.0	235.1	239.9	242.9	245.3	248.5	249.5	248.6	248.4	248.7	246.9	246.3	246.7
390	211.8	214.0	215.3	218.9	224.6	229.5	233.5	237.6	239.9	240.9	242.9	242.4	243.4	245.6	245.3	244.0	245.8

Scenario
○ baseline
● ssp245
○ ssp585

Flag Count Filter
Flag Count

Select Flag
0 to 1,217
and Null values

Choose Peril Value
PROneDay

Value Level
27.2 415.4

Value Level
26.55130119 to 544.475...
and Null values

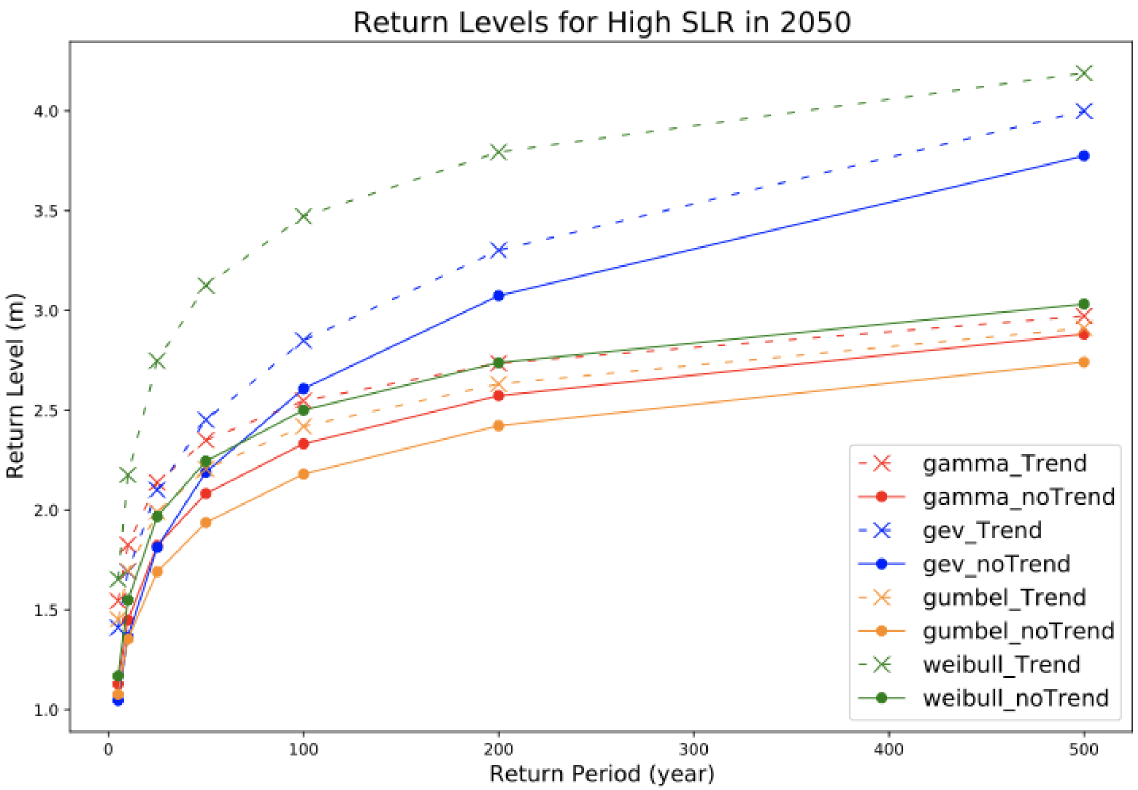
Location Id
All

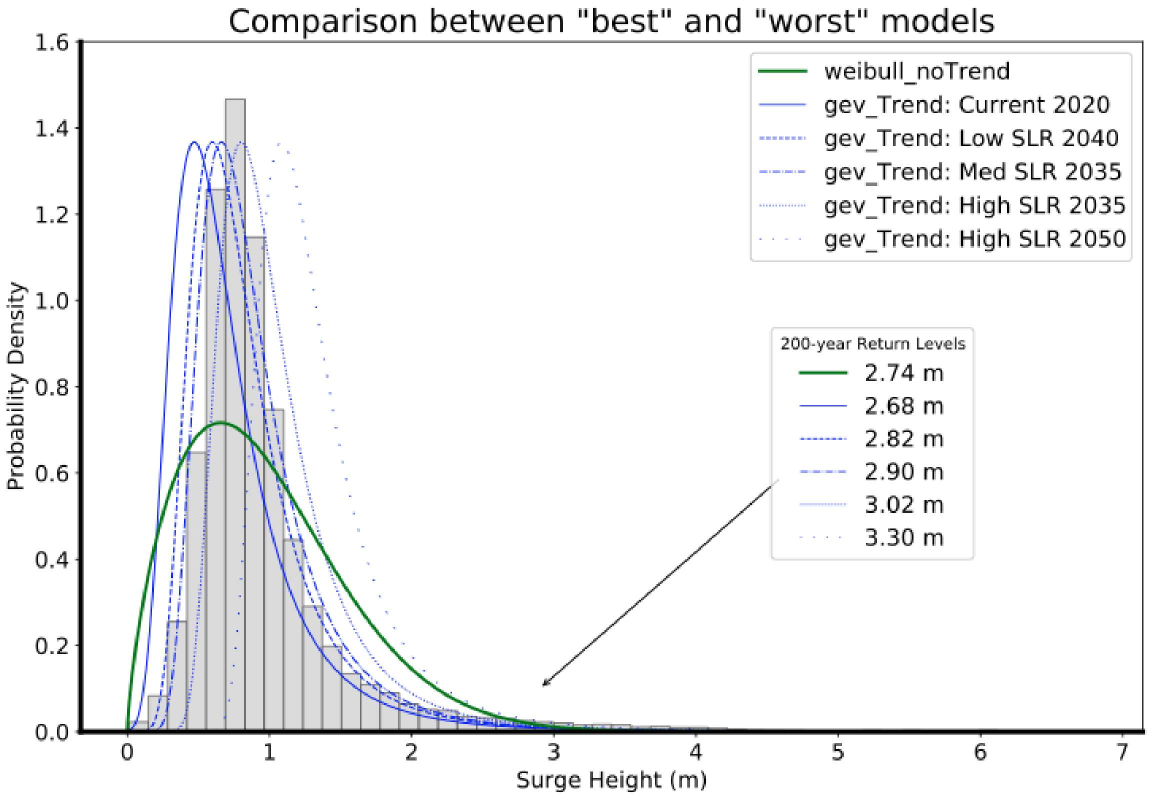
continent
All

Country Name
All

Year of Year
☑ 1995
☑ 2020
☑ 2025
☑ 2030
☑ 2035
☑ 2040
☑ 2045
☑ 2050
☑ 2055
☑ 2060
☑ 2065
☑ 2070
☑ 2075
☑ 2080
☑ 2085
☑ 2090
☑ 2095
☑ 2100

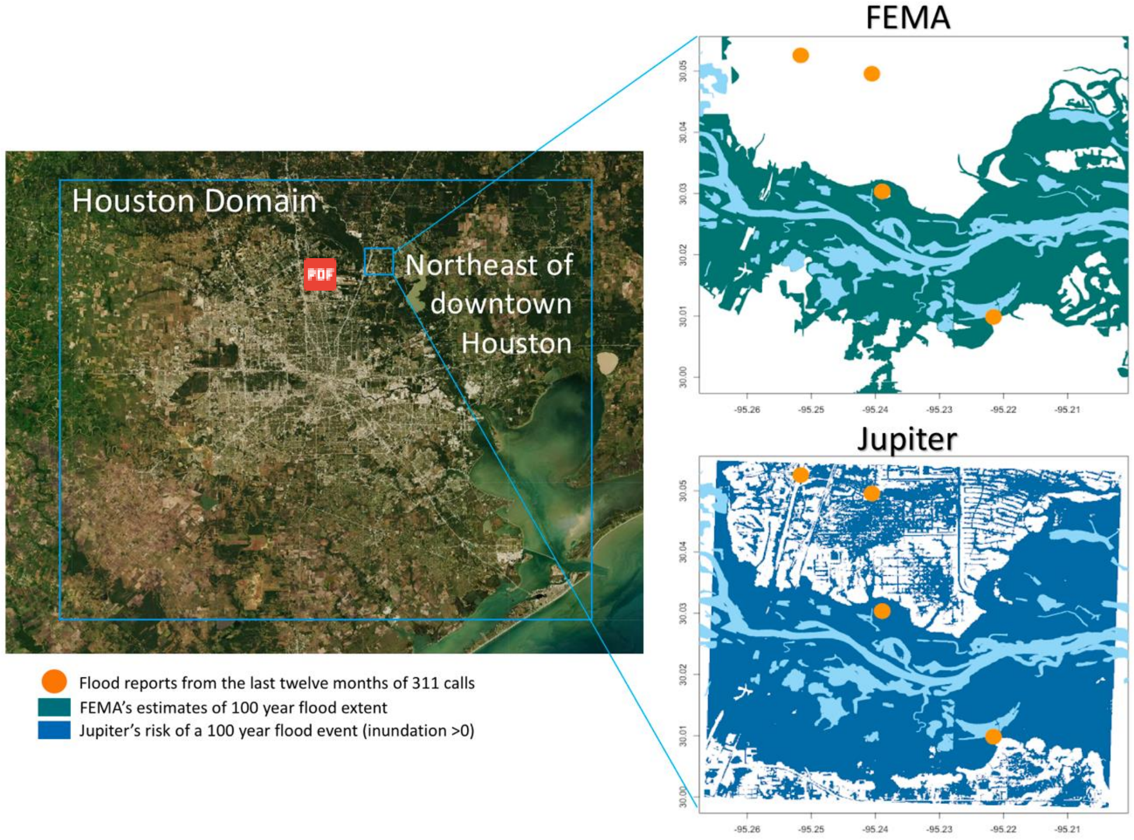
Exceedance Probabilities and Extreme Value fitting

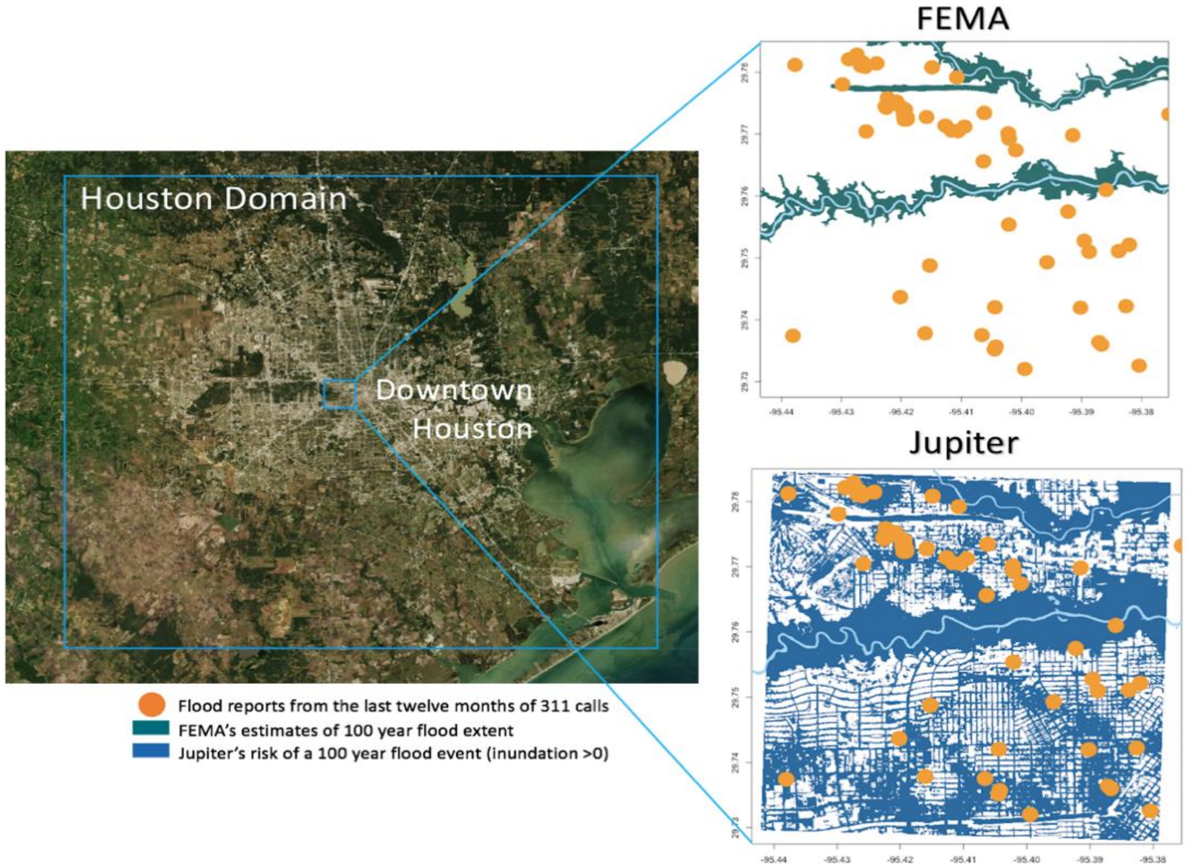




Figures Courtesy of Alexis Hoffman, Jupiter Intelligence

Comparison of 311 calls with FSP Hazards

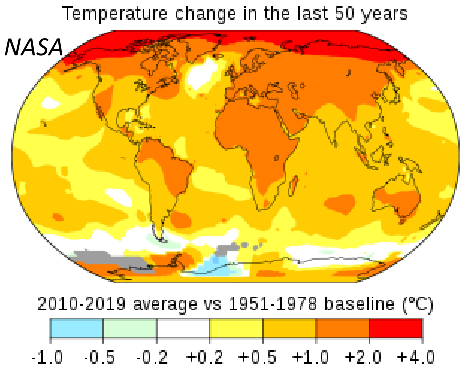




Figures Courtesy of Jupiter Intelligence

JUPITER
Predicting risk in a changing climate

Summary



- Verification of Climate Products is challenging
  - Covering many perils (tropical cyclones, droughts, flood, fire, etc.)
  - Addressing extreme events – always the hardest to verify
  - Sometimes involving layers of modeling
  - Without the luxury of *knowing* we are right.
- The public has a right to ask, “To what level can we trust this?”
- Validation requires using sound, current approaches (modeling, statistics, artificial intelligence)
- Verification requires multiple avenues to test for reasonableness, support from current observations, appropriateness from past observations.
- State of the Art Verification requires use of emerging observing technologies and analytical techniques
- **Scientific judgment at every step**