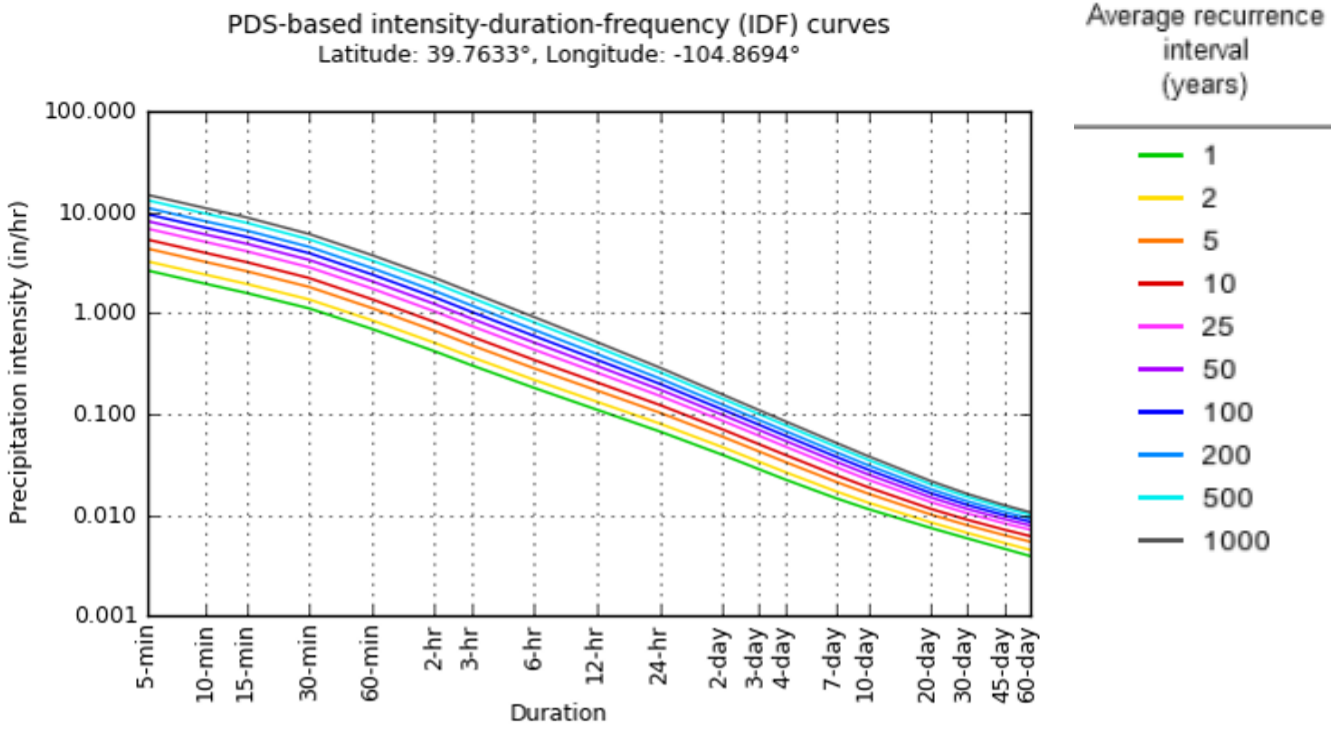
Projecting Future Extreme Events for Flood Planning

Page Weil, PE
Lynker Technologies

Study Purpose

- IDF curves are used as a basis for design and hazard assessment
- We provide ranges of how extreme precipitation intensities will change
- Pilot study for 4 stations in CO to test if significant models can be found
  (spoiler alert; yes.)

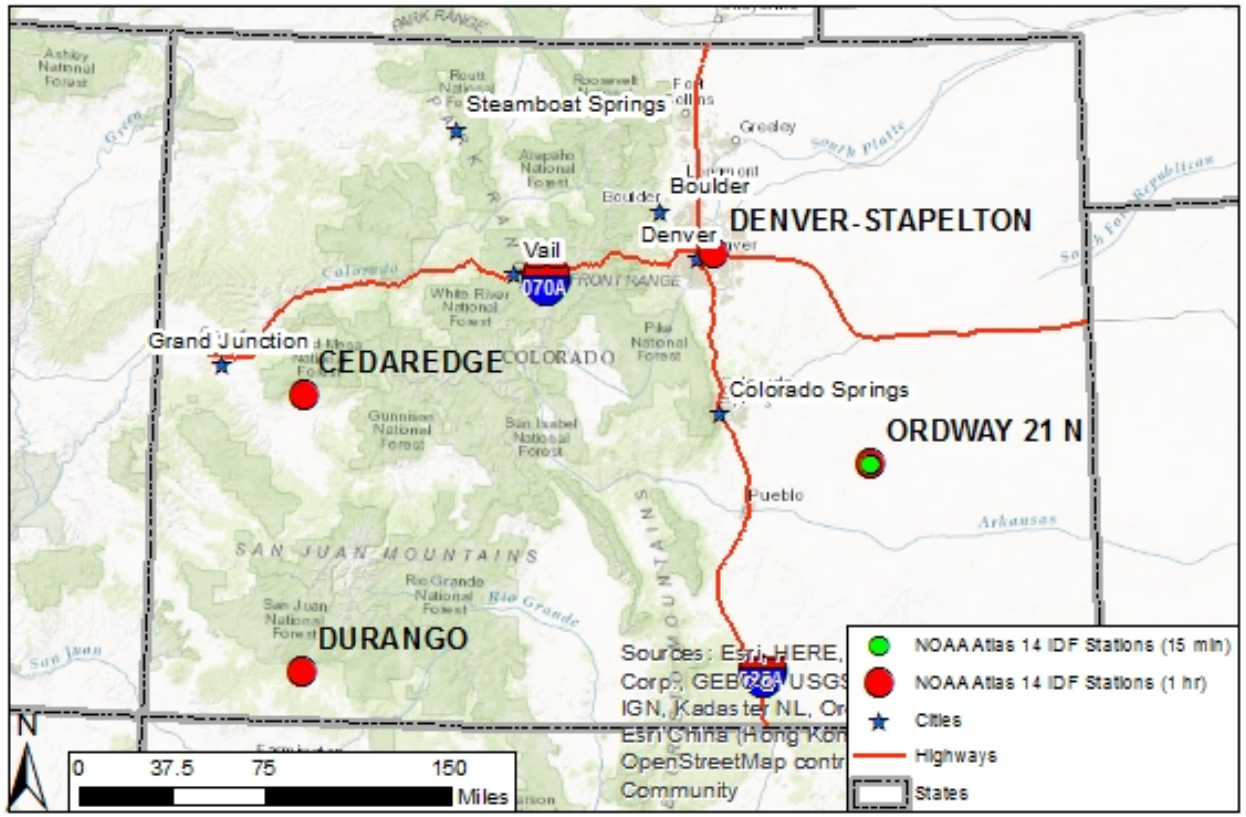


IDF Curve for Stapleton Station
(Storm Intensity of inches/hr by Duration)

LYNKER TECHNOLOGIES

Station Selection

- Chosen to reflect the range of CO conditions
- Generally need 30 years of data for a good fit



Station	Zone	Shortest IDF Event Duration	Elevation (ft)	Years of Historic Data
Stapleton	Denver Metro Area	1-hour	5,286	57
Ordway	Eastern Plains	15-minutes	4,315	46 (*24 for 15-min)
Cedaredge	Western Slope	1-hour	6,244	62
Durango	Southern Mountains	1-hour	6,600	62

Projected Change Factor Grids by station

- These grids show relative changes over historic IDF curves
  - (100% = no change from history)
- Highly multi-dimensional data, but the key is the range and upper bounds of results:
  - 15-min to 60-day Storm durations
  - 2, 5, 10, 25, 50 and 100 year return periods
  - 3 future periods (2040, 2050, 2070)
  - 346 Climate Models (and stats on those)

2-year return, 2070 period,
90th pctile of projections

Duration	Cedaredge	Durango	Ordway	Stapleton
15-min:	-	-	100%	-
30-min:	-	-	100%	-
45-min:	-	-	105%	-
1-hour:	118%	104%	102%	116%
2-hour:	118%	101%	102%	116%
3-hour:	118%	105%	108%	145%
6-hour:	105%	106%	102%	139%
12-hour:	104%	104%	108%	149%
1-day:	110%	104%	110%	143%
2-days:	110%	105%	113%	116%
3-days:	112%	104%	114%	115%
4-days:	112%	104%	114%	120%
7-days:	112%	107%	114%	119%
10-days:	112%	107%	122%	119%
20-days:	112%	109%	116%	119%
30-days:	113%	111%	116%	119%
45-day:	112%	111%	114%	117%
60-day:	112%	110%	116%	117%

In the case of this cell…
…at the Cedaredge Station…
…the 90th percentile of all climate projections…
…for the 2070 future period…
…shows an increase of 18% in the intensity…
…of the 1-hour event with a 2-year return period.

LYNKER TECHNOLOGIES

Methodology

- **Step 1:** Extract Relevant Global Climate Model Data
- **Step 2:** Fit Models for each Storm Duration
- **Step 3:** Forecast Intensity Change Factors and final IDFs

Key Assumptions

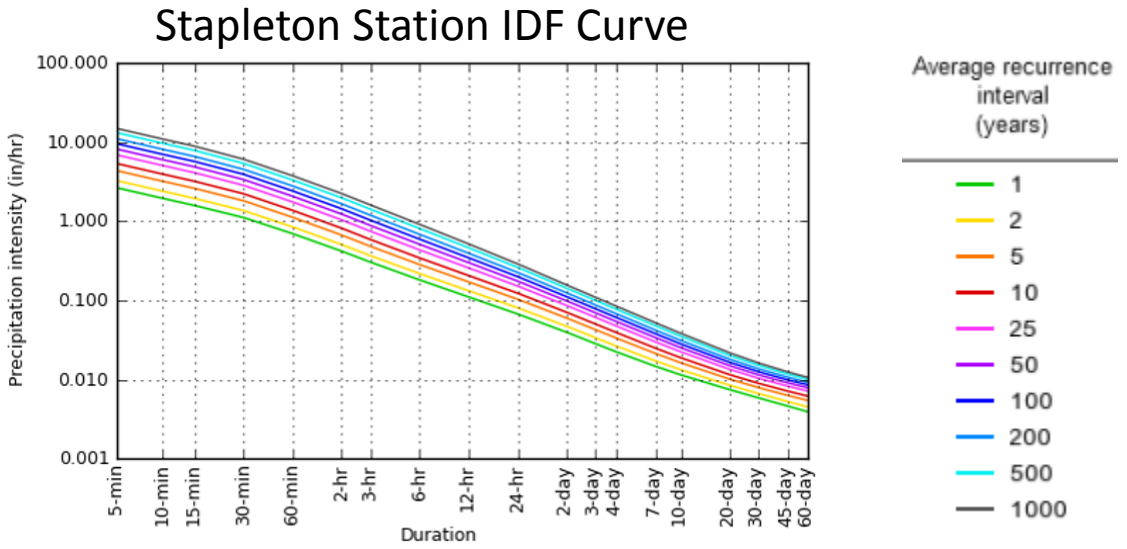
- **Global Climate Models are Representative:** The ensemble of GCMs represent the range of future climate

- **Non-Stationarity:** Significant relationships exist between climate and extreme events; extreme events will change over time

- **Best Statistical Model:** The GEV statistical distribution is assumed to be the most representative of extreme events (Fat tail).

Historical IDFs

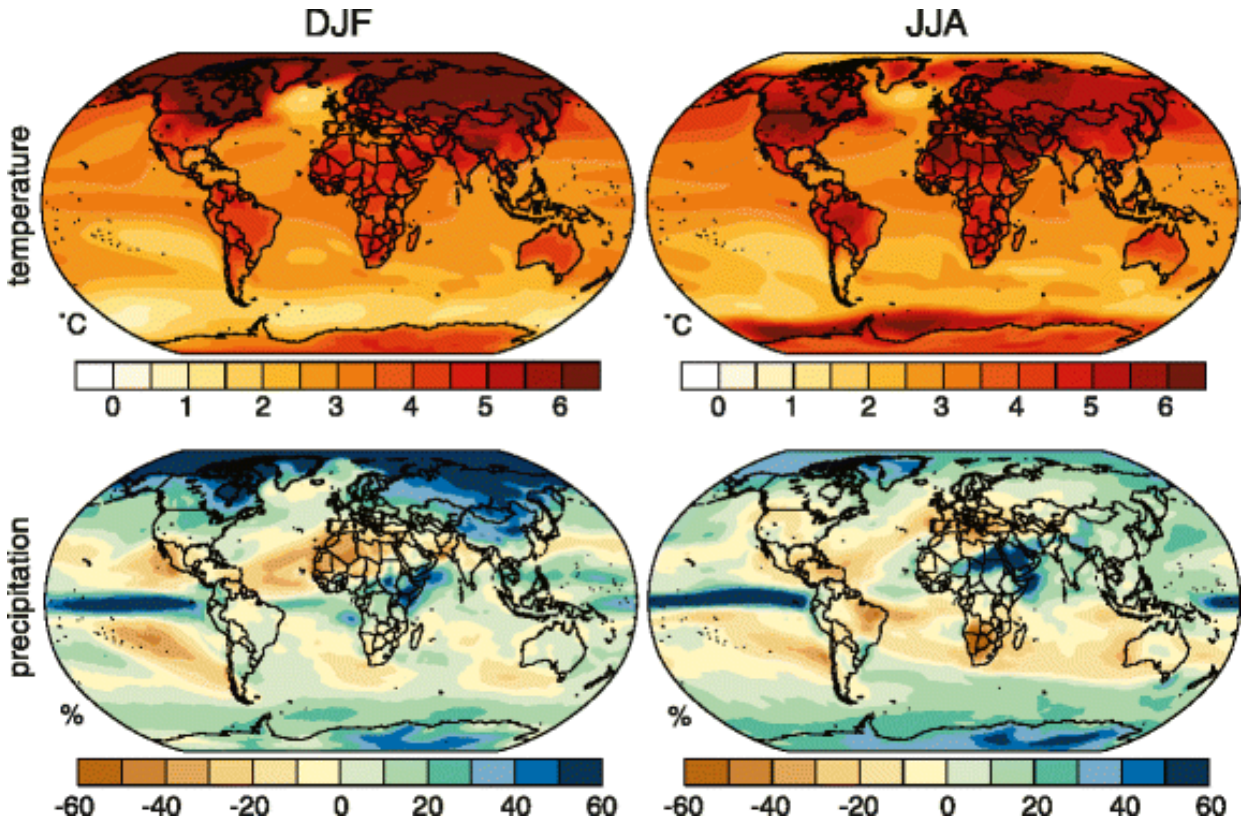
- All Historic IDF data and curves from NOAA Atlas 14
- Most stations are hourly, with a few having 15-minute data
- Short durations are generated from models when no data was available



100-year return intensity (inches/hr)				
Duration	**Cedaredge**	**Durango**	**Ordway**	**Stapleton**
15-min:	4.12	7.1	6.7	5.68
60-min:	1.45	2.15	2.77	2.41
12-hr:	0.17	0.24	0.34	0.34
24-hr:	0.1	0.14	0.18	0.2
2-day:	0.06	0.08	0.1	0.11
3-day:	0.04	0.06	0.07	0.08
4-day:	0.03	0.05	0.05	0.06
7-day:	0.02	0.03	0.03	0.04

Step 1: Future Climate

Warmer and “weirder”



Degree increase in Winter and Summer Temp
RCP8.5 scenario, 2080-2099 Average

% in Winter and Summer Precip
RCP8.5 scenario, 2080-2099 Average

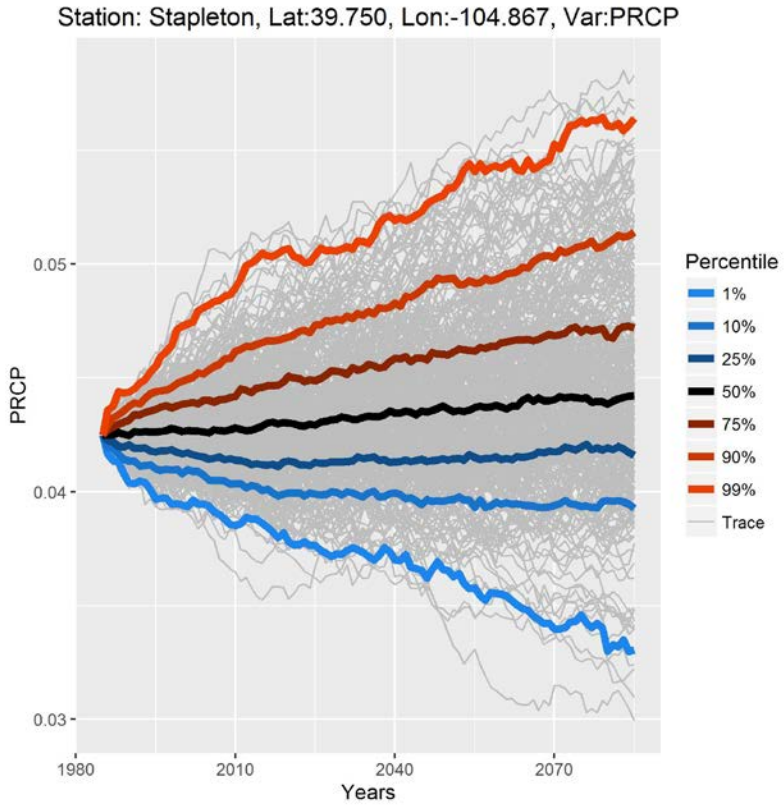
Diffenbaugh, N.S. & Giorgi, Climate change hotspots in the CMIP5 global climate model ensemble, F. Climatic Change (2012) 114: 813.

Climate Covariates

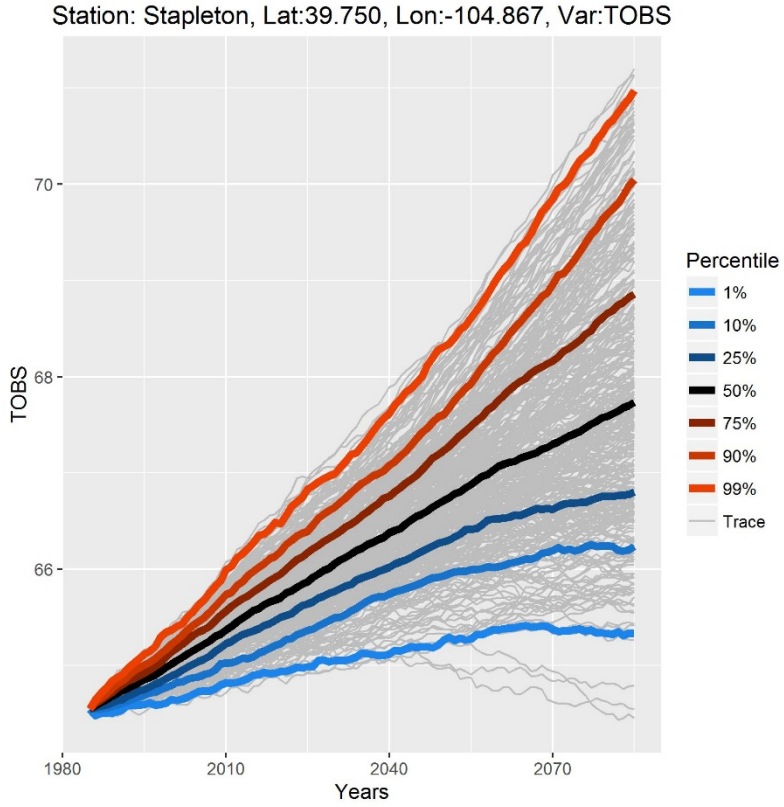
- “Covariates” are just data extracted from GCMs used for prediction
- 346 (112 CMIP3, 244 CMIP5) Global Climate Model runs on an 1/8th degree grid across CONUS
- Annual and monthly values assessed for Tmin, Tmax, Tavg, Precip and P*T for 66 total covariates
- GCM data weighted and bias corrected to generate covariates
  - Used 4 closest grid cells to each station
  - Adjusted historic climate used

Stapleton Station Projected Climate Traces

- 30-year running averages since individual modeled years are very noisy with cyclic effects



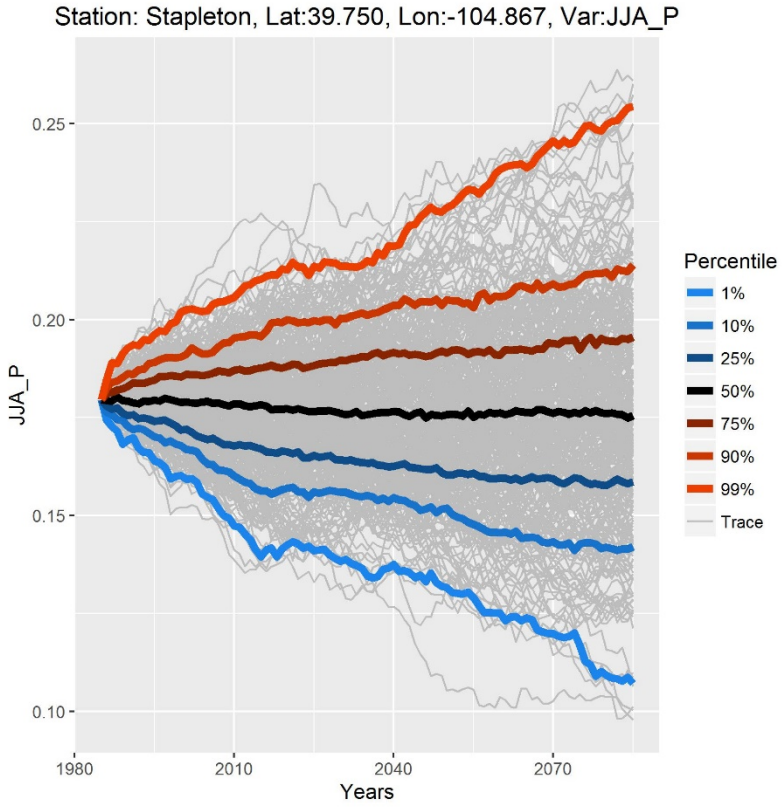
Mean Daily Precipitation



Mean Daily Temperature (F)

DON'T WORRY, IT'S ALL RELATIVE!!!

**median increase is 2.8 F, *75th percentile is 3.6 F*

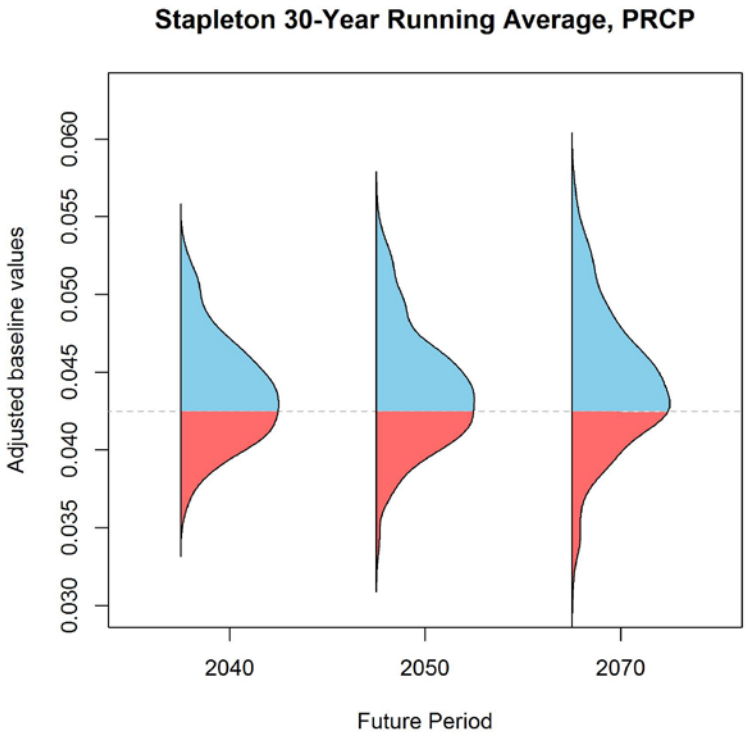


Mean Daily Precipitation in June, July and August

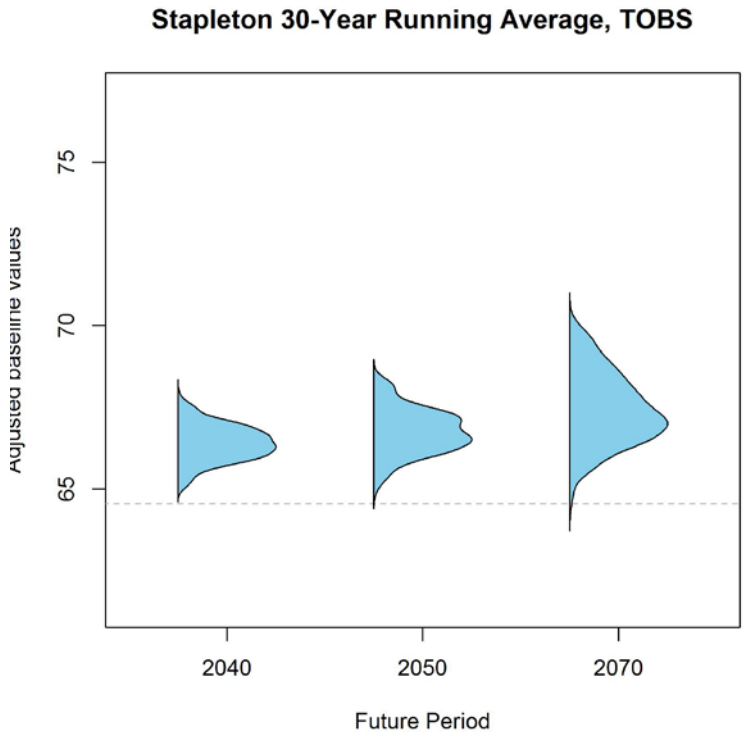
LYNKER TECHNOLOGIES

Stapleton Station Climate Covariates

- Covariates are for surrounding 30 years (i.e., 2070 covariate from 2055 to 2084)
  - Bias-correction by degree shift in temp and % change in precip calculated internally to each model



Mean Daily Precipitation



Mean Daily Temperature (F)

Mean Daily Precipitation in June, July and August

Blue shows increase over historical average

Step 2: Fit and Assess Models

- Fit covariate-parameter relationship
  - Same distribution as NOAA ATLAS 14 but assuming non-stationarity
- Assess significance and select the best model
- Perform skill-scoring
  - How well does each model re-predict history?

Covariate-parameter relationships

We fit models of distribution *parameters*

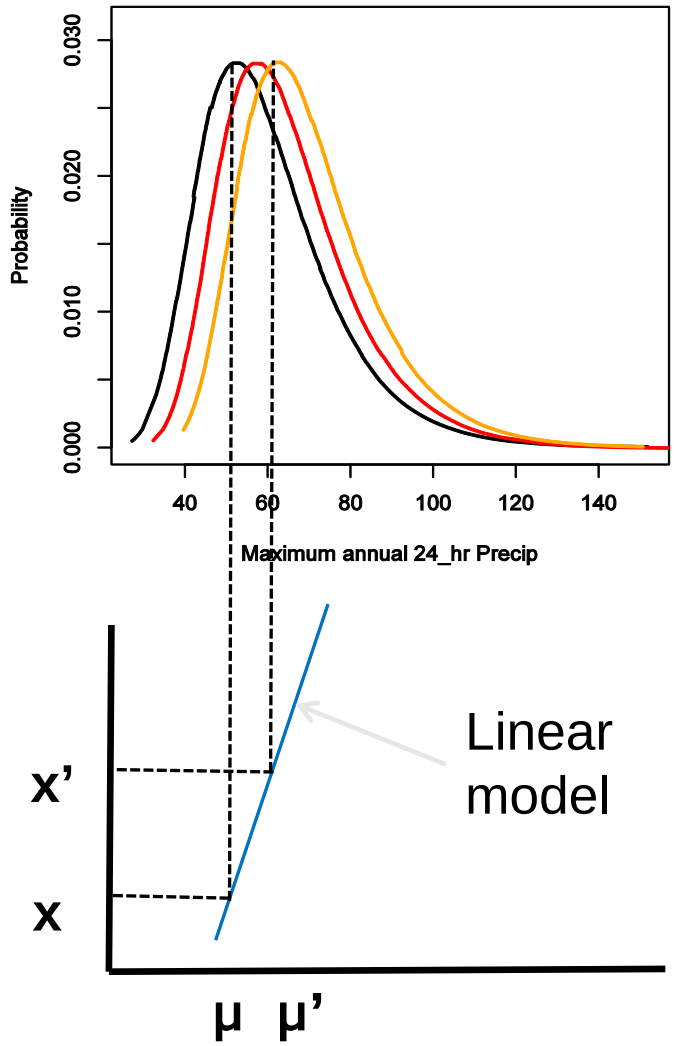
- Modeled sensitivity of distribution parameters to historic climate
- 3 parameters under the GEV (**location**, shape and scale), location was chosen for all models based on testing

Estimate Projected Values of Parameters

- Climate covariates used to estimate model parameters
- Parameters used to create new distribution for each GCM

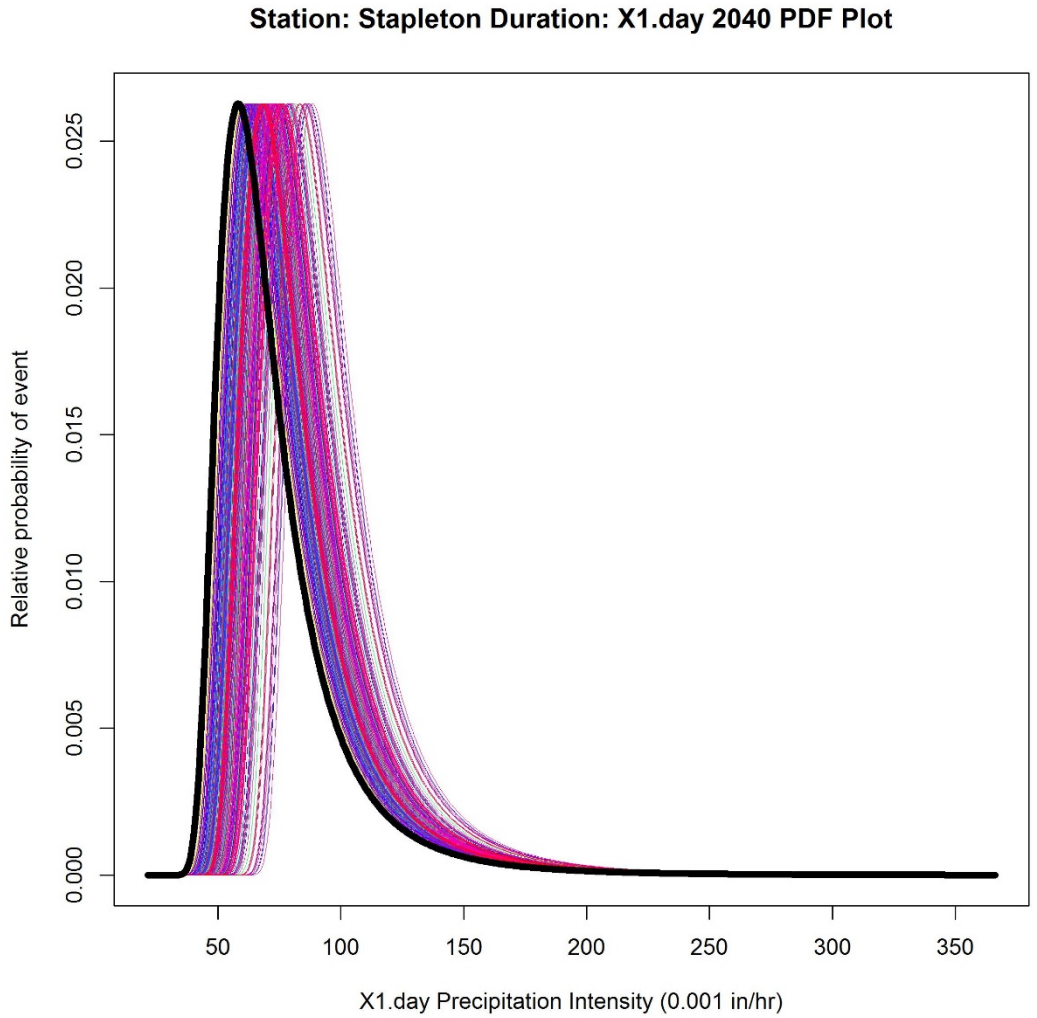
Estimate intensities from PDF

- At desired frequencies
- Separate model per storm duration



Curves generated

- Covariates used to create an ensemble of models
  - *(for each duration, one curve per GCM)*
- Black is baseline (generated with historic data)
- Ratio of results from black and colored lines used to generate change factors



Model validity and selection

- 66 covariates assessed for each storm duration (Tmax and Tmin not shown)
- P.value of <0.05 as significance criteria for model
  - **Significant models were found for every storm duration**
- Akaike Information Criterion (AIC) used to select highest quality model per duration

	1 hour	2 hours	3 hours	6 hours	12 hours	1 day	2 days	3 days	4 days	7 days	10 days	20 days	30 days	45 days	60 days
TOBS	0.932	0.937	0.924	0.869	0.808	0.008	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.001
TMAX	0.962	1.000	1.000	0.926	0.780	0.361	0.226	0.233	0.295	0.287	0.438	0.717	0.662	0.846	1.000
TMIN	0.959	0.958	0.948	0.888	0.832	0.051	0.014	0.016	0.027	0.013	0.031	0.056	0.023	0.049	0.084
PRCP	0.914	0.904	0.932	0.585	0.230	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PXT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JJA_P	0.041	0.002	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOBS.01	0.239	0.290	0.278	0.696	0.906	0.715	0.550	0.578	0.630	0.395	0.403	0.862	0.386	0.689	0.859
TOBS.02	0.142	0.155	0.165	0.180	0.225	0.564	0.774	0.673	0.564	0.853	0.993	0.775	0.936	0.939	0.951
TOBS.03	0.212	1.000	0.727	1.000	0.429	0.096	0.276	0.305	0.293	0.254	0.271	0.503	0.564	0.972	0.983
TOBS.04	0.872	0.419	0.533	0.443	0.220	0.251	0.067	0.067	0.073	0.140	0.033	0.009	0.006	0.014	0.006
TOBS.05	0.944	1.000	1.000	0.937	0.808	0.019	0.050	0.044	0.084	0.143	0.140	0.008	0.008	0.008	0.007
TOBS.06	0.902	0.930	0.913	0.777	0.043	0.723	0.001	0.000	0.001	0.003	0.007	0.002	0.000	0.000	0.000
TOBS.07	0.864	0.881	0.880	0.832	0.814	0.012	0.014	0.006	0.011	0.024	0.074	0.133	0.007	0.003	0.006
TOBS.08	0.855	0.748	0.810	0.851	0.816	0.533	0.295	0.263	0.172	0.105	0.117	0.138	0.074	0.162	0.197
TOBS.09	0.781	0.066	0.414	0.696	0.794	0.093	0.030	0.052	0.093	0.094	0.152	0.068	0.099	0.073	0.112
TOBS.10	0.849	0.886	0.468	0.820	0.975	1.000	0.727	0.829	0.993	0.926	0.810	0.588	0.887	0.656	0.809
TOBS.11	0.885	0.690	0.501	0.269	0.045	0.175	0.257	0.337	0.334	0.164	0.196	0.621	0.680	0.651	0.669
TOBS.12	0.905	1.000	1.000	1.000	0.132	0.073	0.012	0.012	0.039	0.061	0.130	0.205	0.247	0.053	0.108
PRCP.01	0.954	0.971	1.000	1.000	1.000	0.897	0.864	0.858	0.925	0.998	0.813	0.349	0.999	0.903	0.869
PRCP.02	0.954	0.971	1.000	0.974	0.097	0.200	0.125	0.097	0.102	0.213	0.309	0.168	0.376	0.269	0.375
PRCP.03	0.925	0.957	0.986	0.974	0.363	0.030	0.049	0.070	0.095	0.094	0.142	0.311	0.125	0.110	0.053
PRCP.04	0.923	0.913	0.931	0.420	0.125	0.419	0.273	0.226	0.184	0.123	0.013	0.012	0.003	0.002	0.002
PRCP.05	0.922	0.872	0.912	0.274	0.021	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
PRCP.06	0.929	0.954	0.936	0.260	0.002	0.004	0.001	0.000	0.000	0.002	0.012	0.007	0.002	0.001	0.000
PRCP.07	0.700	0.618	0.305	0.000	0.000	0.020	0.003	0.002	0.001	0.002	0.001	0.000	0.000	0.000	0.001
PRCP.08	0.764	0.015	0.795	0.010	0.005	0.046	0.004	0.010	0.005	0.010	0.000	0.000	0.001	0.001	0.002
PRCP.09	0.783	0.767	0.859	0.081	0.496	0.198	0.070	0.082	0.129	0.140	0.157	0.195	0.131	0.242	0.228
PRCP.10	0.951	0.961	0.983	0.964	0.576	1.000	0.686	0.708	0.839	0.435	0.541	0.371	0.313	0.198	0.226
PRCP.11	0.949	0.940	0.957	0.764	0.487	0.368	0.466	0.525	0.355	0.546	0.538	0.700	0.465	0.393	0.309
PRCP.12	0.945	0.970	1.000	0.963	0.074	0.129	0.117	0.174	0.274	0.162	0.452	0.162	0.258	0.074	0.104
PXT.01	0.851	0.753	0.907	0.850	0.728	0.473	0.624	0.709	0.750	0.890	0.860	0.409	0.881	0.998	0.942
PXT.02	0.868	0.681	1.000	0.614	0.067	0.082	0.119	0.097	0.106	0.199	0.327	0.194	0.410	0.308	0.446
PXT.03	0.480	0.714	0.795	0.772	0.346	0.046	0.072	0.100	0.135	0.130	0.203	0.425	0.166	0.141	0.067
PXT.04	0.594	0.352	0.243	0.343	0.164	0.485	0.394	0.320	0.266	0.158	0.026	0.032	0.008	0.004	0.006
PXT.05	0.437	0.199	0.209	0.131	0.018	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
PXT.06	0.718	0.669	0.305	0.101	0.003	0.005	0.001	0.000	0.000	0.003	0.016	0.012	0.004	0.003	0.001
PXT.07	0.000	0.000	0.000	0.000	0.000	0.021	0.004	0.003	0.001	0.003	0.001	0.001	0.000	0.001	0.001
PXT.08	0.004	0.001	0.002	0.005	0.004	0.043	0.004	0.009	0.005	0.010	0.000	0.000	0.001	0.000	0.001
PXT.09	0.009	0.008	0.010	0.061	0.435	0.153	0.072	0.085	0.132	0.159	0.175	0.214	0.145	0.259	0.246
PXT.10	1.000	0.809	0.709	0.669	0.531	0.961	0.647	0.797	0.932	0.496	0.594	0.452	0.373	0.241	0.258
PXT.11	0.632	0.250	0.217	0.170	0.032	0.193	0.529	0.581	0.402	0.669	0.678	0.809	0.532	0.459	0.353
PXT.12	0.332	0.771	0.921	0.258	0.076	0.046	0.147	0.219	0.326	0.201	0.521	0.183	0.297	0.104	0.132

LYNKER TECHNOLOGIES

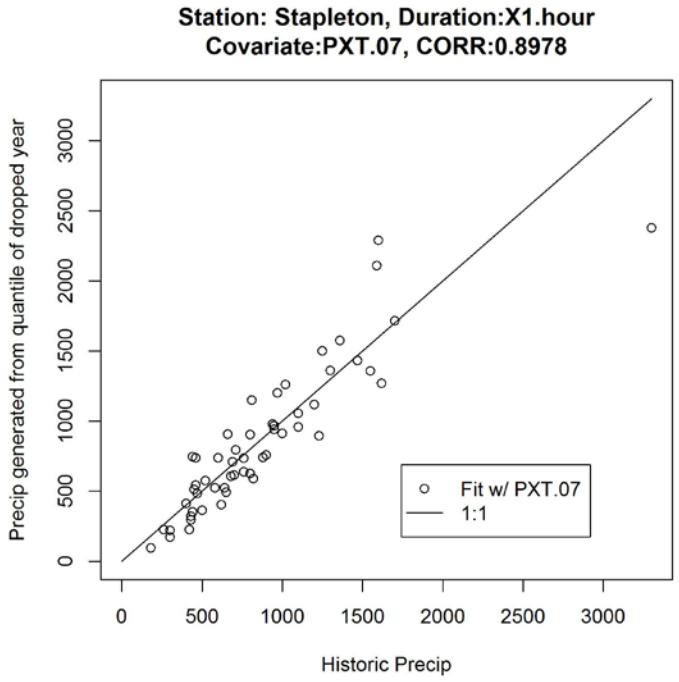
Best models selected

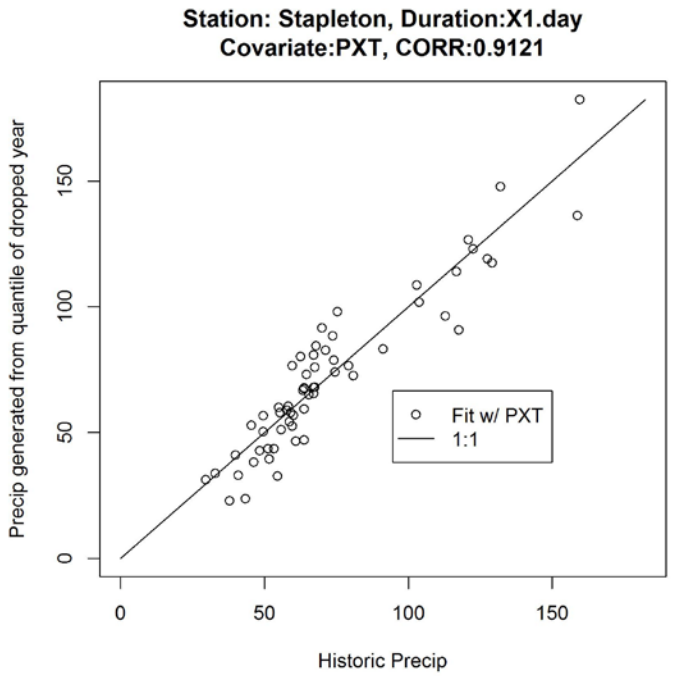
- Different regions of CO have different climate drivers
- Generally…
  - …Summer precipitation drove shorter events
  - …Annual precipitation drove longer events
  - …Temp alone was never the best model

Duration	Cedaredge	Durango	Ordway	Stapleton
15-min:	-	-	PRCP.07	-
30-min:	-	-	PRCP.07	-
45-min:	-	-	JJA_P	-
1-hour:	PXT.08	JJA_P	JJA_P	PXT.07
2-hour:	PXT.08	JJA_P	JJA_P	PXT.07
3-hour:	PXT.08	JJA_P	JJA_P	PXT
6-hour:	PRCP	JJA_P	JJA_P	PXT
12-hour:	PRCP	JJA_P	JJA_P	PXT
1-day:	PRCP	PRCP	JJA_P	PXT
2-days:	PRCP	PRCP	JJA_P	PRCP
3-days:	PRCP	PRCP	PRCP	PRCP
4-days:	PRCP	PRCP	PRCP	PRCP
7-days:	PRCP	PRCP	PRCP	PRCP
10-days:	PRCP	PRCP	PRCP	PRCP
20-days:	PRCP	PRCP	PRCP	PRCP
30-days:	PRCP	PRCP	PRCP	PRCP
45-day:	PRCP	PRCP	PRCP	PRCP
60-day:	PRCP	PRCP	PRCP	PRCP

Skill Scoring

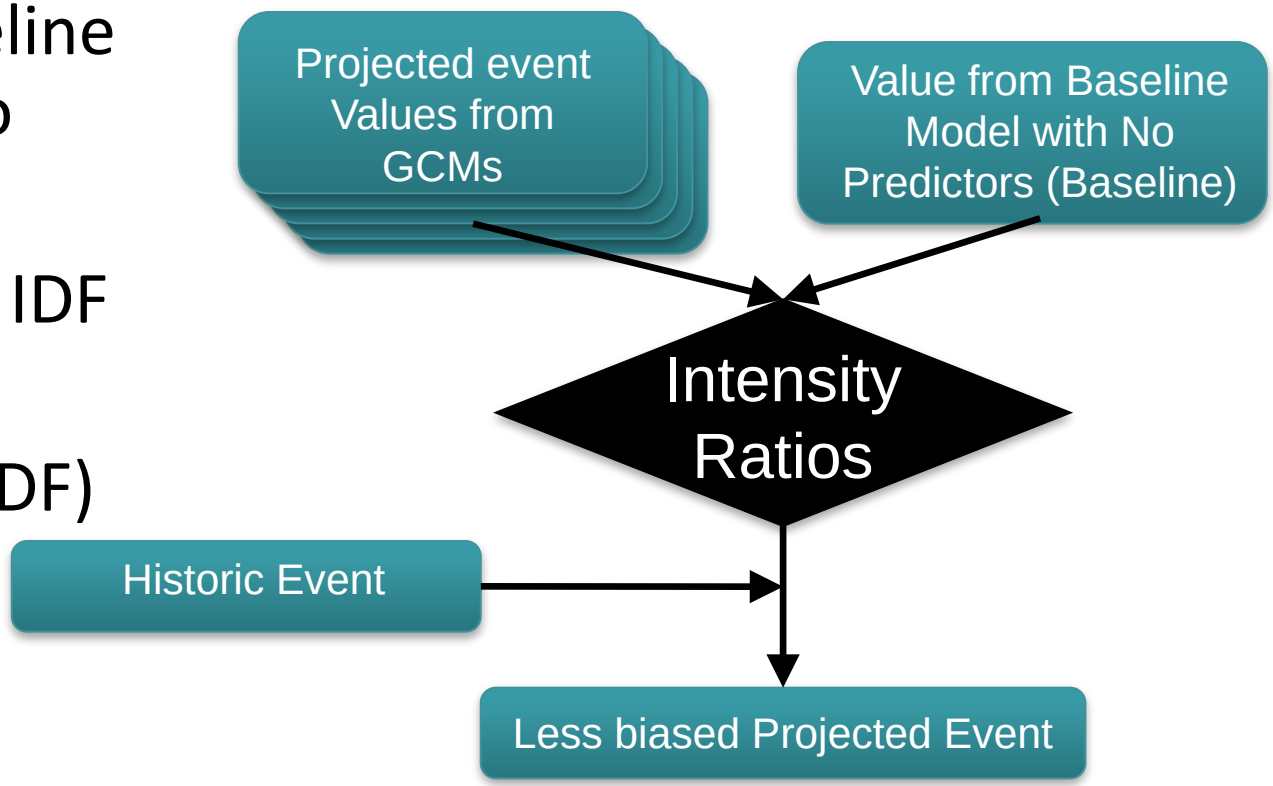
- Cross-validation approach
  - Fit model with a year dropped
  - Generate distribution with predictor from dropped year
  - Pull value off distribution





Step 3: Forecast Intensity Changes

- Baseline event created for each GCM
- “Projected Biased Event” and Baseline Event used to create Intensity ratio
- Intensity ratio applied to historical IDF
- Same results apply to intensities (IDF) and depths (DDF curves)



Projected Change Factor Grids by station

- Irregularities across durations due to changes in model predictors

- Generally, the model results show:
  - … The median of all models show increases in precip intensity across all stations.
  - … Farther into the future, events are projected to be more intense.
  - … The 100-year event increases by a smaller % than the 2-year event.
  - … It is site-specific how events of various durations change.

2-year return interval, 2070 period, 90th pctile of projections

Duration	Cedaredge	Durango	Ordway	Stapleton
15-min:	-	-	100%	-
30-min:	-	-	100%	-
45-min:	-	-	105%	-
1-hour:	118%	104%	102%	116%
2-hour:	118%	101%	102%	116%
3-hour:	118%	105%	108%	145%
6-hour:	105%	106%	102%	139%
12-hour:	104%	104%	108%	149%
1-day:	110%	104%	110%	143%
2-days:	110%	105%	113%	116%
3-days:	112%	104%	114%	115%
4-days:	112%	104%	114%	120%
7-days:	112%	107%	114%	119%
10-days:	112%	107%	122%	119%
20-days:	112%	109%	116%	119%
30-days:	113%	111%	116%	119%
45-day:	112%	111%	114%	117%
60-day:	112%	110%	116%	117%

Stapleton IDF Changes to 100-Year Event

Stapleton station, 100-year return, 2040 period

Duration	0.5	0.75	0.9	0.99
15-min:	-	-	-	-
30-min:	-	-	-	-
45-min:	-	-	-	-
1-hour:	101%	103%	104%	107%
2-hour:	101%	103%	104%	108%
3-hour:	106%	108%	110%	115%
6-hour:	105%	108%	110%	114%
12-hour:	107%	110%	113%	119%
1-day:	106%	108%	110%	115%
2-days:	101%	102%	104%	107%
3-days:	101%	103%	104%	107%
4-days:	101%	103%	105%	109%
7-days:	101%	103%	106%	110%
10-days:	101%	104%	106%	110%
20-days:	101%	105%	108%	113%
30-days:	102%	105%	109%	114%
45-day:	101%	105%	108%	114%
60-day:	101%	105%	108%	113%

Stapleton station, 100-year return, 2070 period

Duration	0.5	0.75	0.9	0.99
15-min:	-	-	-	-
30-min:	-	-	-	-
45-min:	-	-	-	-
1-hour:	101%	103%	106%	109%
2-hour:	101%	104%	107%	110%
3-hour:	109%	113%	116%	125%
6-hour:	109%	112%	115%	124%
12-hour:	111%	116%	120%	131%
1-day:	109%	112%	116%	125%
2-days:	101%	103%	106%	109%
3-days:	101%	103%	106%	110%
4-days:	101%	104%	107%	112%
7-days:	102%	104%	108%	113%
10-days:	102%	105%	109%	114%
20-days:	102%	106%	111%	118%
30-days:	102%	107%	112%	120%
45-day:	102%	106%	111%	118%
60-day:	102%	106%	110%	117%

Uncertainty

- **Future Scenarios:** 2040, 2050 and 2070 results provided though there are many unpredictable changes in climate and human impact during this time.

- **Global Climate Models:** Model sensitivity as well as the nature of how GCMs have been downscaled over CONUS provide some uncertainty.

- **GEV Distribution:** Some statistical uncertainty inherent in the model itself.

How to use these results

- **Assess risk of existing designs:** Median, 75th and 90th percentile results are presented to be conservative

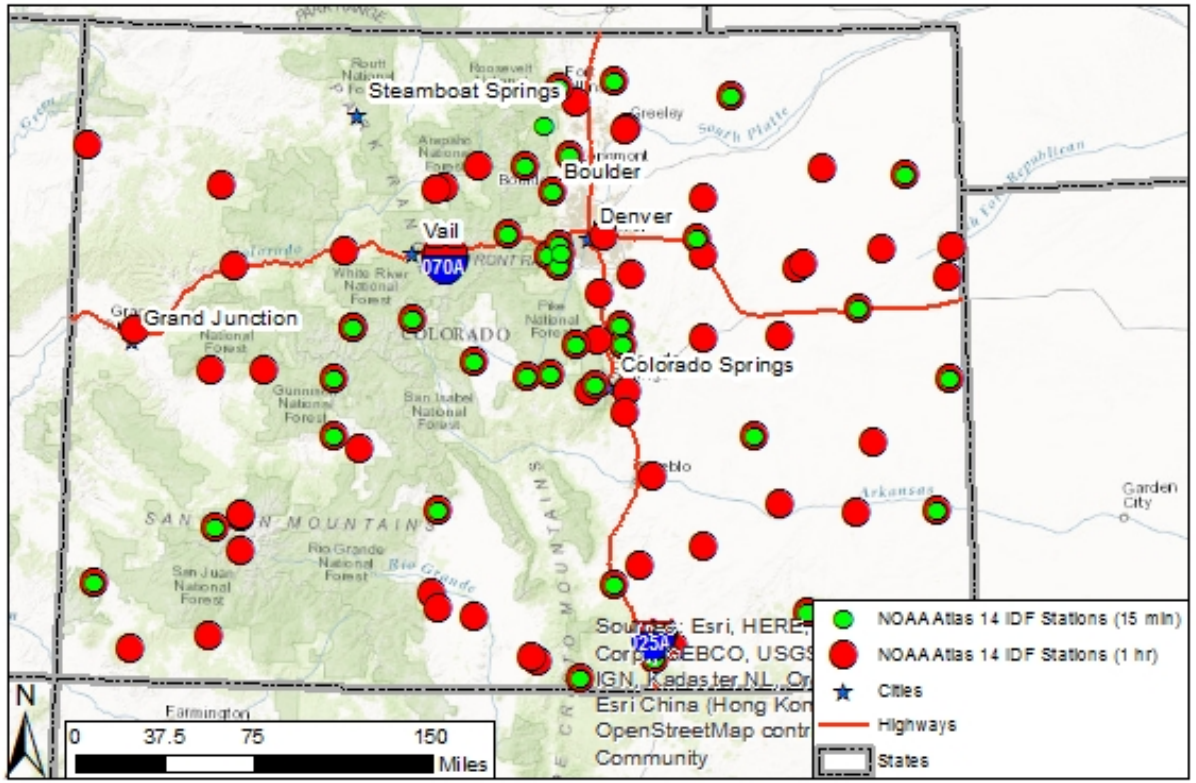
- **Resiliency planning:** Quantitative results for climate change adaptation planning

- **Flood Hydrology Modeling**: These updated intensities can be used to force existing hydrology models

Moving Forward

- **Change Factors and Intensities:** Results presented as change factors for clarity but are available as precipitation intensities.

- **Pilot Study:** We found that non-stationary IDF relationships exist for many stations in CO. This method can be applied to many other locations



All 15-minute and hourly stations in CO with >30 years of data

EXTRA SLIDES

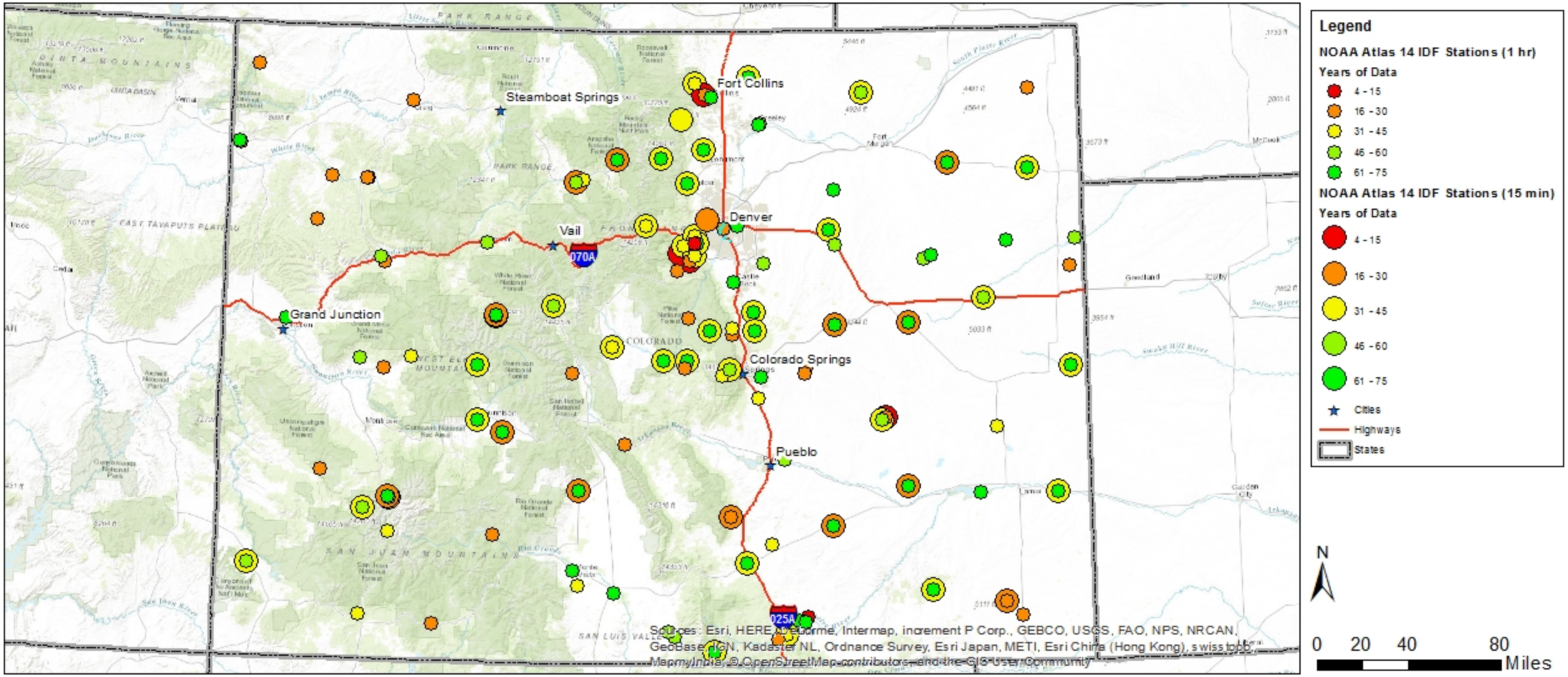
Model Skill Scores

Duration	Cedaredge	Durango	Ordway	Stapleton
15-min:	-	-	0.965	-
30-min:	-	-	0.929	-
45-min:	-	-	0.960	-
1-hour:	0.895	0.947	0.954	0.898
2-hour:	0.948	0.842	0.962	0.898
3-hour:	0.938	0.892	0.957	0.921
6-hour:	0.960	0.862	0.839	0.922
12-hour:	0.947	0.925	0.870	0.923
1-day:	0.922	0.946	0.852	0.912
2-days:	0.910	0.898	0.898	0.915
3-days:	0.904	0.924	0.910	0.918
4-days:	0.905	0.935	0.911	0.898
7-days:	0.911	0.943	0.900	0.905
10-days:	0.908	0.946	0.867	0.912
20-days:	0.917	0.892	0.899	0.914
30-days:	0.910	0.859	0.890	0.923
45-day:	0.908	0.891	0.907	0.923
60-day:	0.904	0.900	0.923	0.927

Results Browser

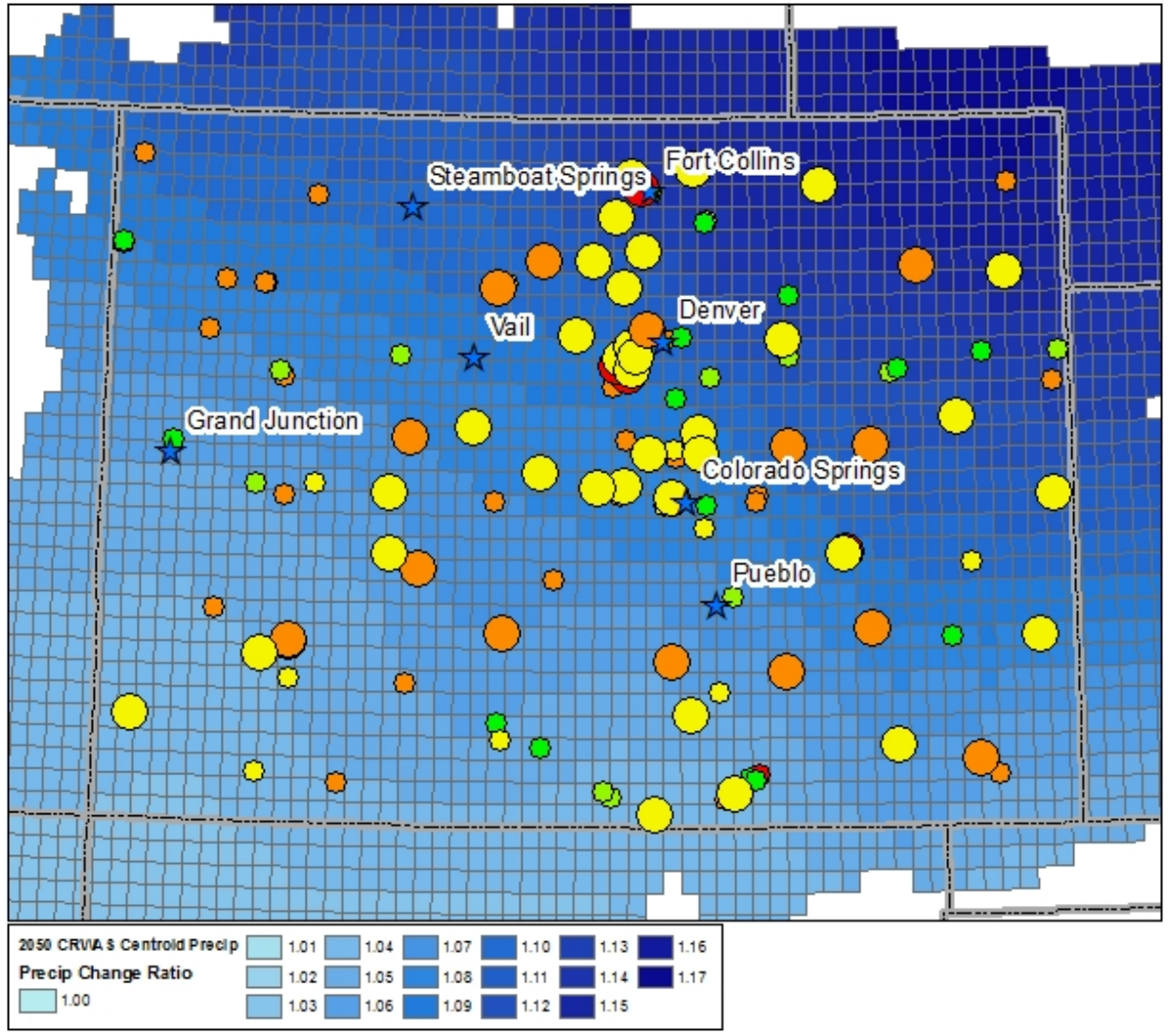
- "D:\Projects\Climate Flood Link\Report\Final Presentation\ChangeFactorsBrowser.xlsm“

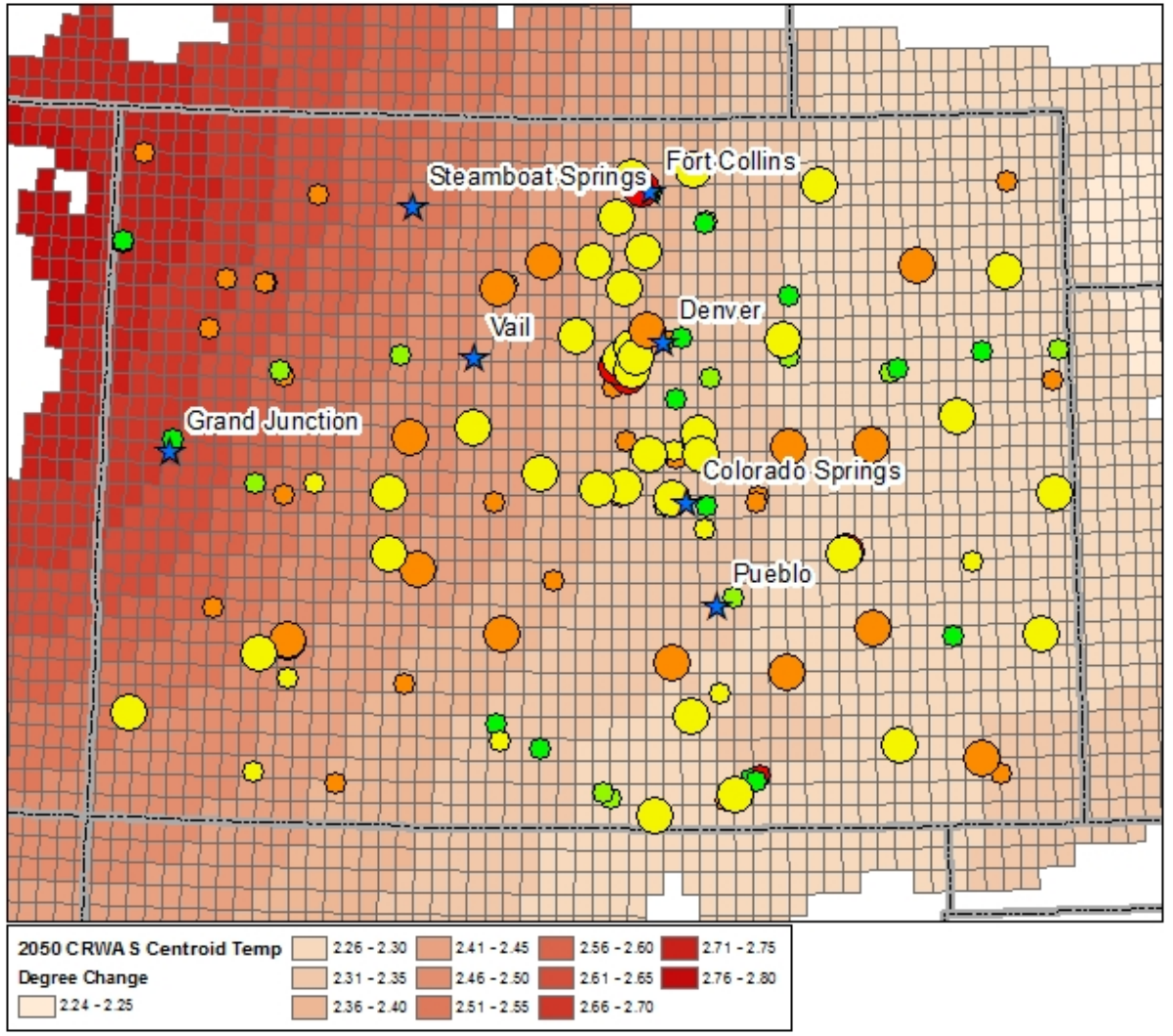
CO Atlas 14 IDF Stations (15-min and 1-hr)



LYNKER TECHNOLOGIES

Median 2050 Colorado Climate





LYNKER TECHNOLOGIES