Forecast Skill Visualization in Climate Research

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Uncertainty in Climate Simulations

“Uncertainty is the only certainty there is, and knowing how to live with insecurity is the only security.” (John Allen Paulos)

- Four categories of uncertainty:
  - Model uncertainty
    - Parameterization
    - Spatial/temporal resolution
    - Processes
  - Internal variability and initial conditions uncertainty
  - Forcing and boundary condition uncertainty (past)
  - Scenario uncertainty (future)
Decadal Climate Predictions

- **Aim:** predict natural **internal variability** over the next few years through knowledge of the observed climate state
- **Initialization with observations** (Atmosphere, Ocean, Sea Ice, Land, ...)
  - 3D ocean state (Reanalysis, Assimilation)
- **Ensemble simulation techniques**

**Source:**
IPCC AR5, Chapter 11, Box 11.1, Figure 2
Decadal Climate Predictions

- Verification of climate predictions?
- Not possible for forecasts
- Instead, use hindcasts to derive the skill of the system
Initialized retrospective predictions

- Assimilation run
- Ensemble of initialized hindcasts
- Ocean reanalysis
- Every 5 years or every year

Years:
- 1950
- 1961
- 1966
- 1996
- 2001
Forecast Skill

- Quantify success of predictions
- Various definitions/methods used in literature
  - (Pearson’s) Correlation (used here)
  - Root Mean Square Skill Score (RMSSS)
- Significance level
  - e.g. t-test, bootstrap
  - correlation values lower than significance level are statistically insignificant
The Data used

- Model system
  - UCLA/MITgcm coupled ocean-atmosphere model
  - Initialization with GECCO ocean synthesis (Koehl and Stammer, 2008)
  - Full state initialization with heat and freshwater flux correction
  - Initialization every 5 years over 1961-2001

- SST anomalies over 2001-2010, ensemble mean over 3 ensemble members

- Predictive skill
  - correlation between predictions and GECCO synthesis
  - Significance level (t-test)

Visualization Software used in the domain

- 2D
- Script based
- Domain specific (Weather, Climate Oceanography)
- Examples:
  - NCL
  - GrADS
  - VCDAT
  - Ferret
  - GMT
  - ...

8 13.04.2015 EGU2015-15360 : Forecast Skill Visualization in Climate Research
Multivariate 2D Visualizations used in the Domain

RMSSS (color) and Significance > 95 % (black dots)

Source: IPCC AR5, WG1, Chapter 11, Figure 11-04
Multivariate 2D Visualizations used in the Domain

**SST RMSS.** *Hatched regions: significant skill at 90% level*

Figure shows temporal means for year 1 and year 2-5.
- Only limited information on the spatio-temporal structure of the skill!
- Only one threshold value visualized
- Not suited for animation
Temporal Analyses

- Temporal development for a spatial mean (here: 50°W-10°W, 20°N-60°N)
- Limited information on spatiotemporal patterns
- Alternative: time animations of 2D fields

Source: Polkowa et al., Clim Dyn (2014) 42:3151-3169, Figure 5 (cutout)
Our Approach: 3D + Animation

- **Avizo Green (commercial 3D visualization system)**
- **Heightfield method**
  - Color mapping & surface deformation according to physical and/or statistical values
  - Univariate or bivariate data visualization
  - Well suited for animation
- **Geographical mapping**
- **Geographical context**
- **NetCDF CF**
Temporal Patterns: SST Anomaly

Predicted Sea Surface Temperature Anomaly (Monthly Means)

UCLA / MITgcm, forced with GECCO synthesis

Jan 2001

(C) DKRZ / CliSAP / IIM (University of Hamburg)
Temporal Patterns: SST Correlation (Skill)
Positive SST Correlation (Skill)

UCLA / MITgcm, forced with GECCO synthesis

Jan 2001

(C) DKRZ / CliSAP / IIM (University of Hamburg)
Low-pass filtered positive SST Correlation (Skill)
Seasonal Analyses

DJF - Positive SST Correlation - Mean for Years 1-5 (DJF)

JJA - Positive SST Correlation - Mean for Years 1-5 (JJA)

DJF - Positive SST Correlation - Mean for Years 6-10 (DJF)

JJA - Positive SST Correlation - Mean for Years 6-10 (JJA)
Low-pass filtered SST Anomaly and significant SST Correlation

SST Anomaly, Height denotes significant Correlation
13 Months Running Mean

UCLA / MITgcm, forced with GECCO synthesis

Jul 2001

-3  -2  -1  0  1  2  3  4 [Deg C]

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Low-pass filtered SST Anomaly and positive SST Correlation
Conclusions

- 3D Visualization of 2D data
  - Qualitative Analysis of spatiotemporal predictive skill characteristics
  - Animated display of data and related (un)certainty information
  - For small ensembles: Positive correlation better suited than significance levels

- Future work
  - Combined visualization of forecast quantity, skill and standard deviation (-> EnvirVis 2015, co-located to EuroVis 2015, Cagliari, Sardinia)
Thank You!

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Related Work

- **Uncertainty Visualization**
  - Potter et al. 2009: Ensemble Vis
  - Sanyal et al. 2010: Noodles: A Tool for Visualization of Numerical Weather Model Ensemble Uncertainty
  - Brodlie et al. 2012: Review of Uncertainty in Data Visualization
  - Bonneau et al. 2014: State of the Art of Uncertainty Visualization
  - Obermaier et al. 2014: Future Challenges for Ensemble Visualization: feature based methods vs. location based methods

- **Decadal climate predictions**
  - Smith et al. 2007: First paper preparing the ground for decadal climate predictions
  - Meehl et al. 2009, 2013: Overview on the field, challenges
  - IPCC AR5 WG1, 2013: Chapter 11, Kirtman & Power 2013: Near-term climate change: State of the Art Review