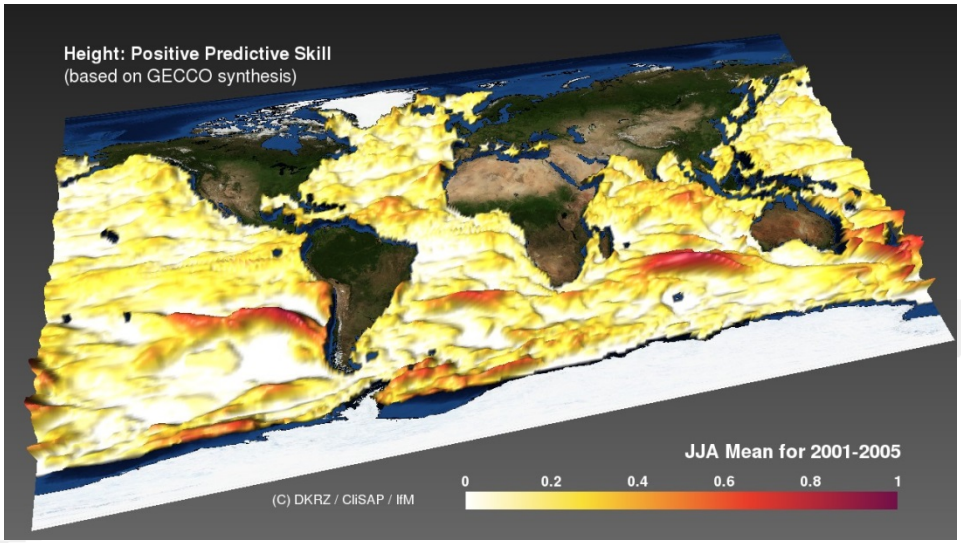
Forecast Skill Visualization in Climate Research

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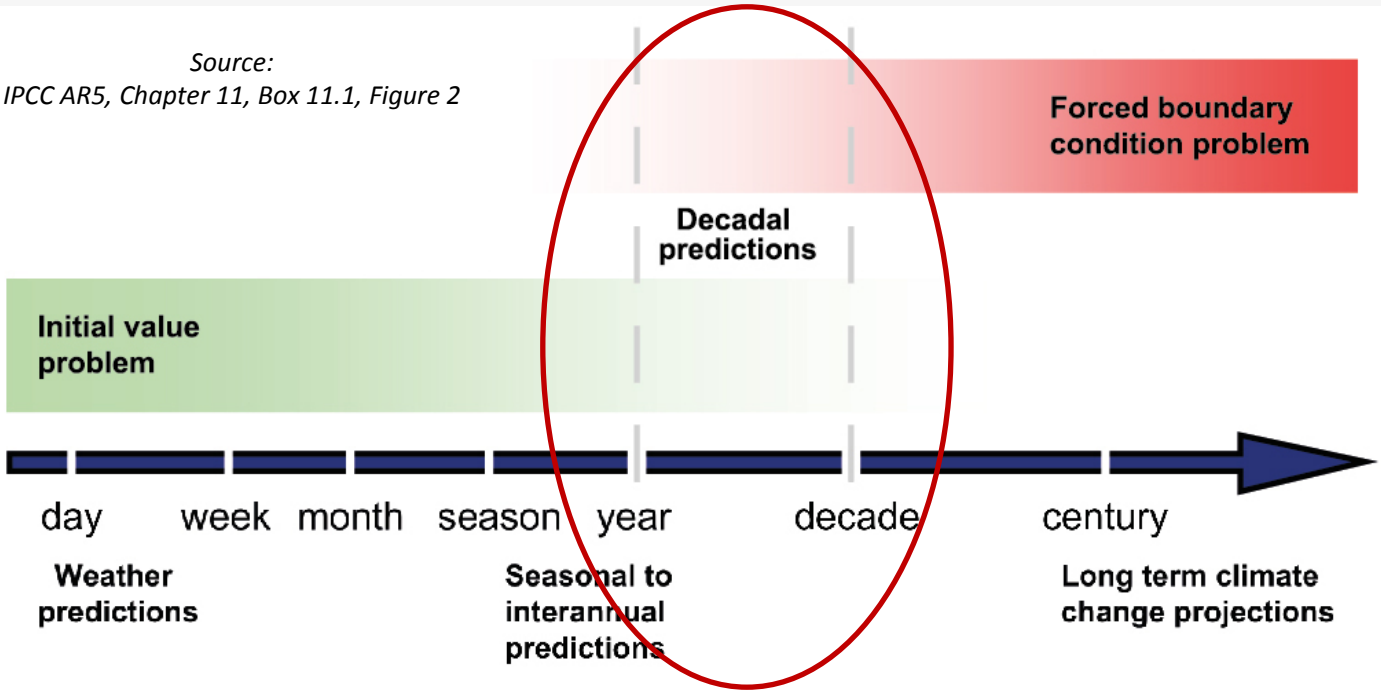
Uncertainty in Climate Simulations

"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

Source:
IPCC AR5, Chapter 11, Box 11.1, Figure 2



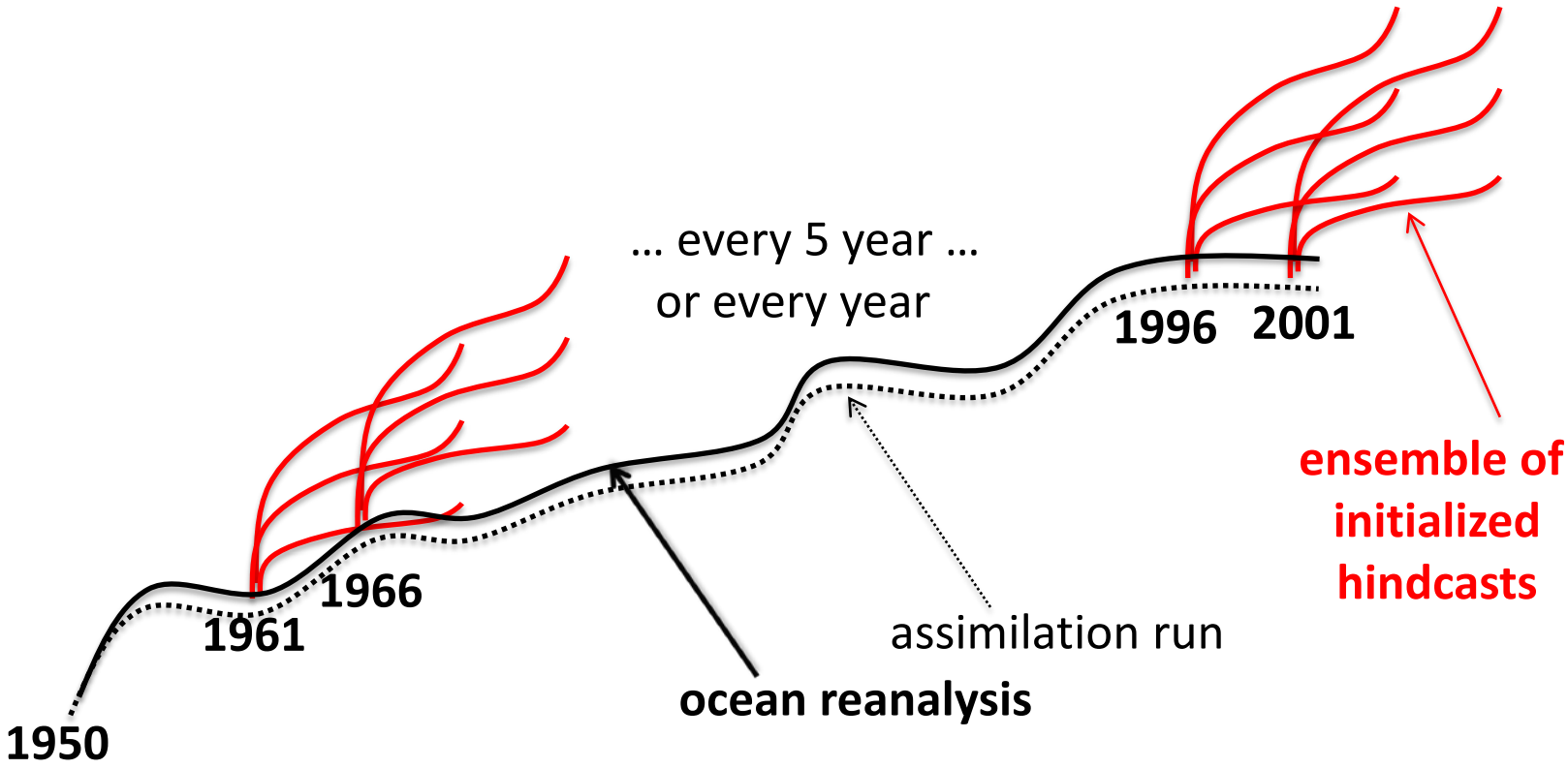
- Aim: predict natural **internal variability** over the next few years through knowledge of the observed climate state
- Initialization with observations (Atmosphere, Ocean, Sea Ice, Land, …)
  - 3D ocean state (Reanalysis, Assimilation)
- Ensemble simulation techniques

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Decadal Climate Predictions

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

Initialized retrospective predictions



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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

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The Data used

- Model system
  - UCLA/MITgcm coupled ocean-atmosphere model
  - Initialization with GECCO ocean synthesis (Koehl and Stammer, 2008)
  - Full state initalization 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)
- Described in Polkova et al., 2014, DOI 10.1007/s00382-013-1969-4

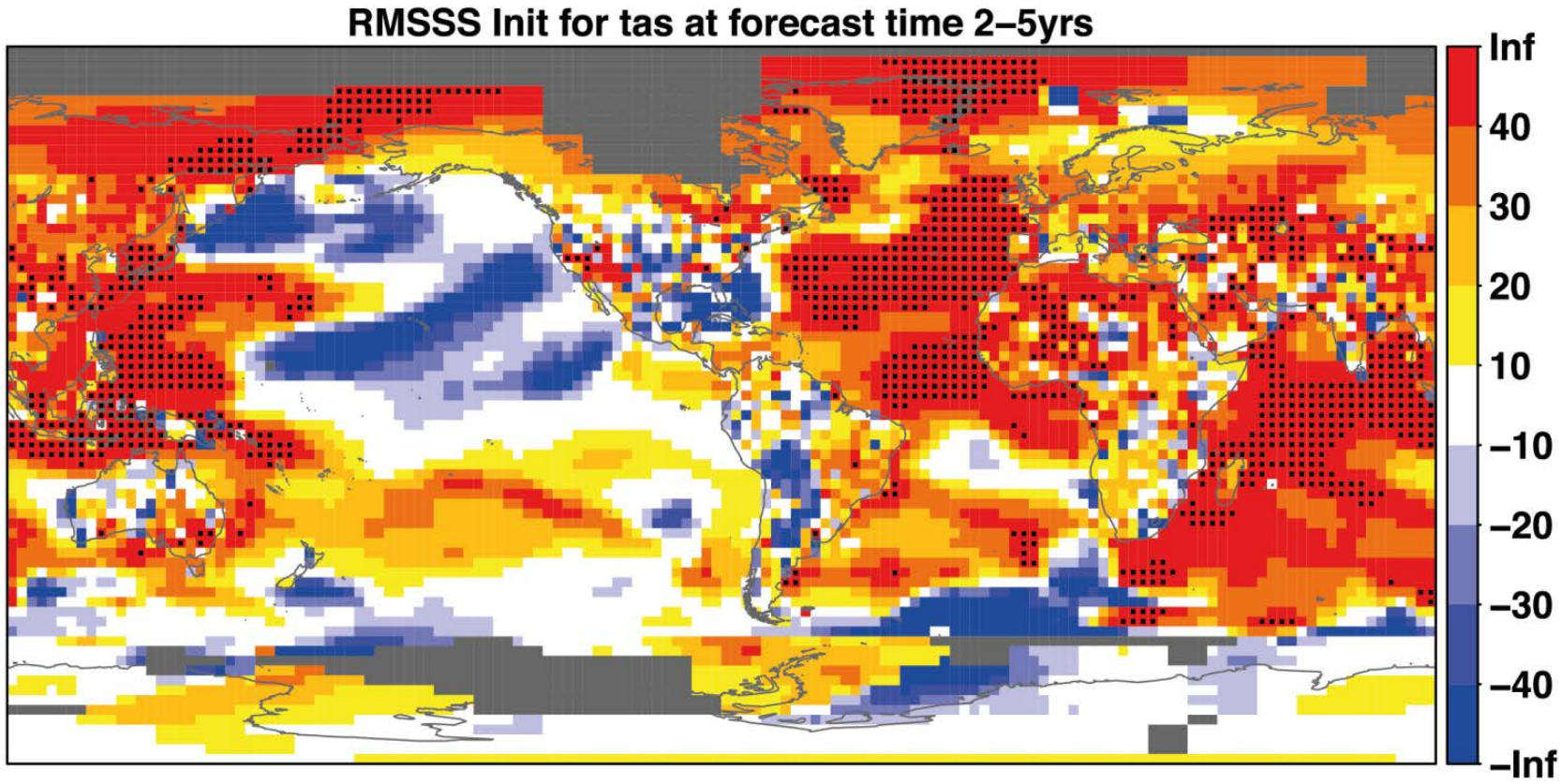
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Visualization Software used in the domain

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

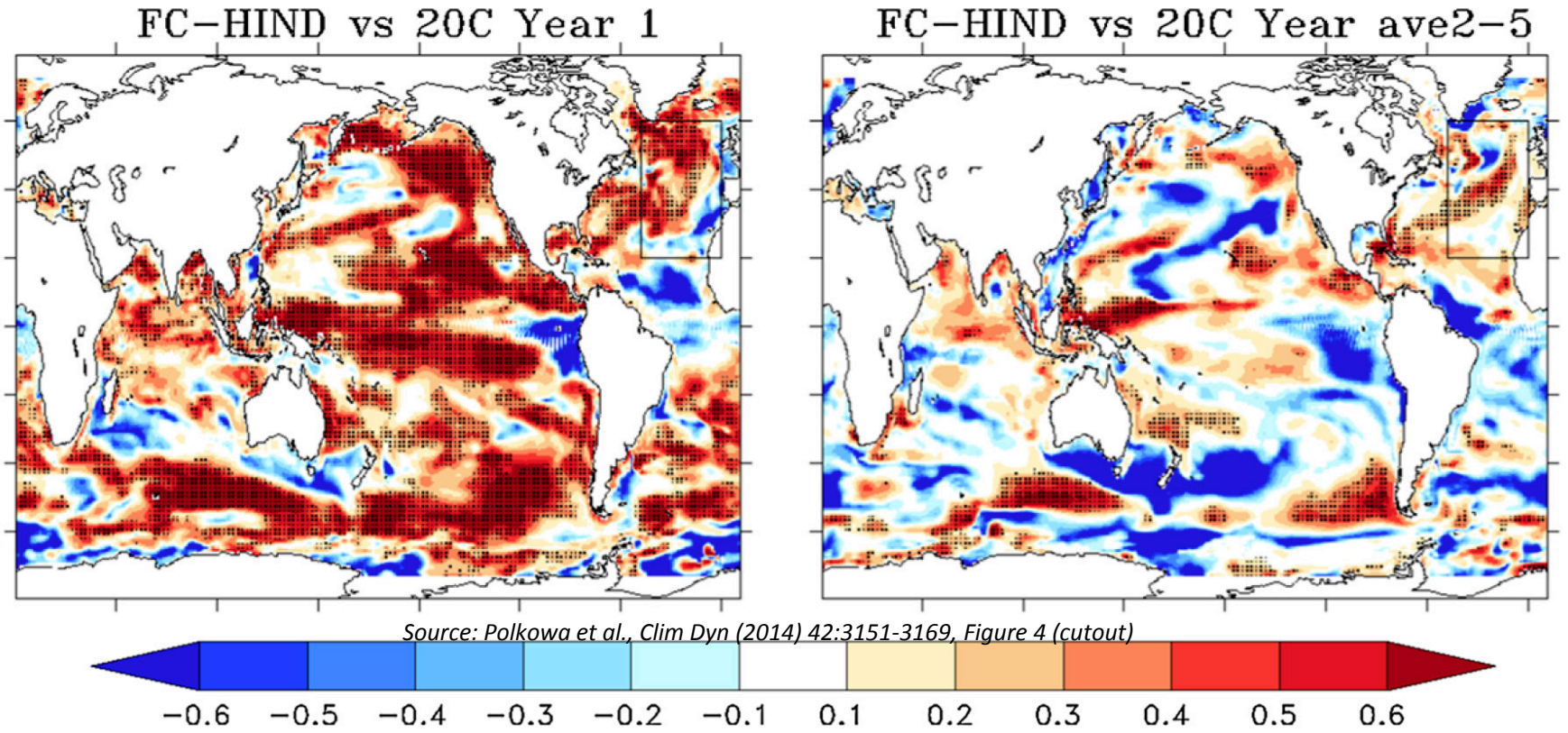
Multivariate 2D Visualizations used in the Domain

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



Source: IPCC AR5, WG1, Chapter 11, Figure 11-04

Multivariate 2D Visualizations used in the Domain



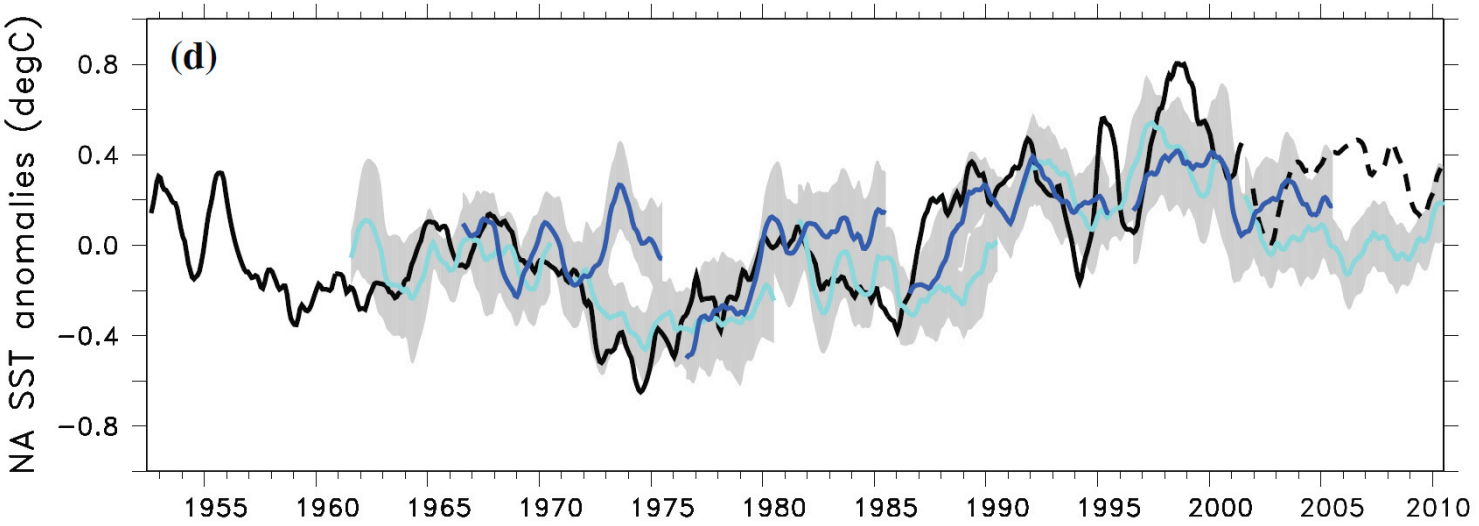
Source: Polkowa et al., Clim Dyn (2014) 42:3151-3169, Figure 4 (cutout)

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



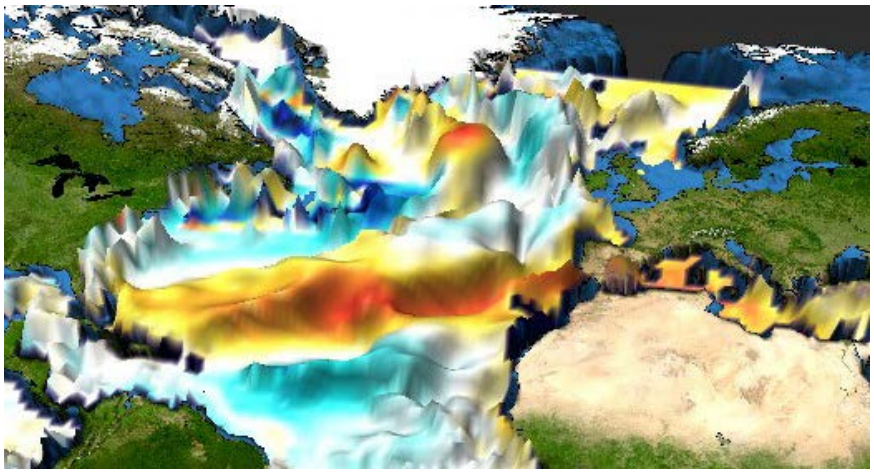
Source: Polkowa et al., Clim Dyn (2014) 42:3151-3169, Figure 5 (cutout)

- 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

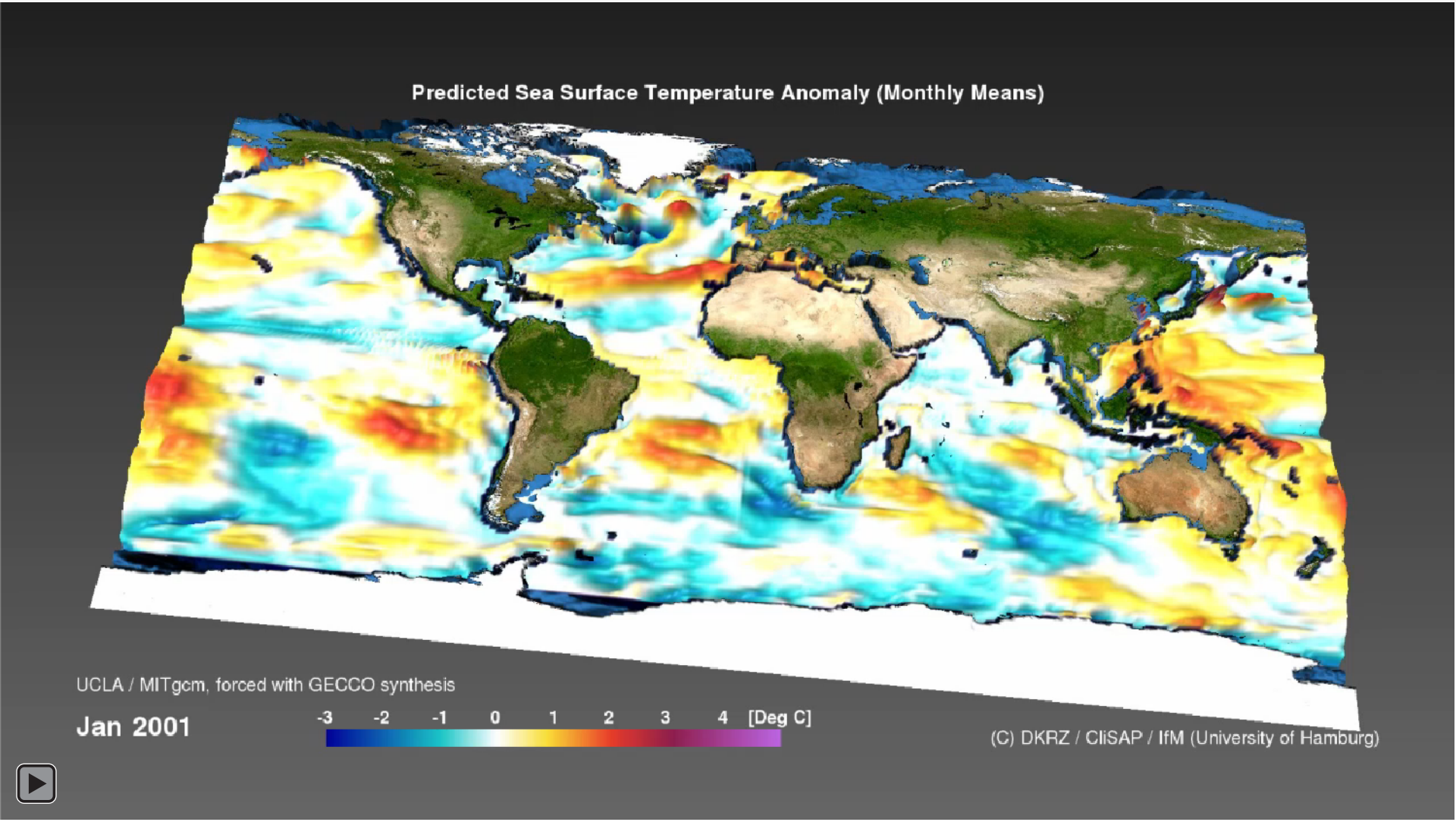
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Our Approach: 3D + Animation

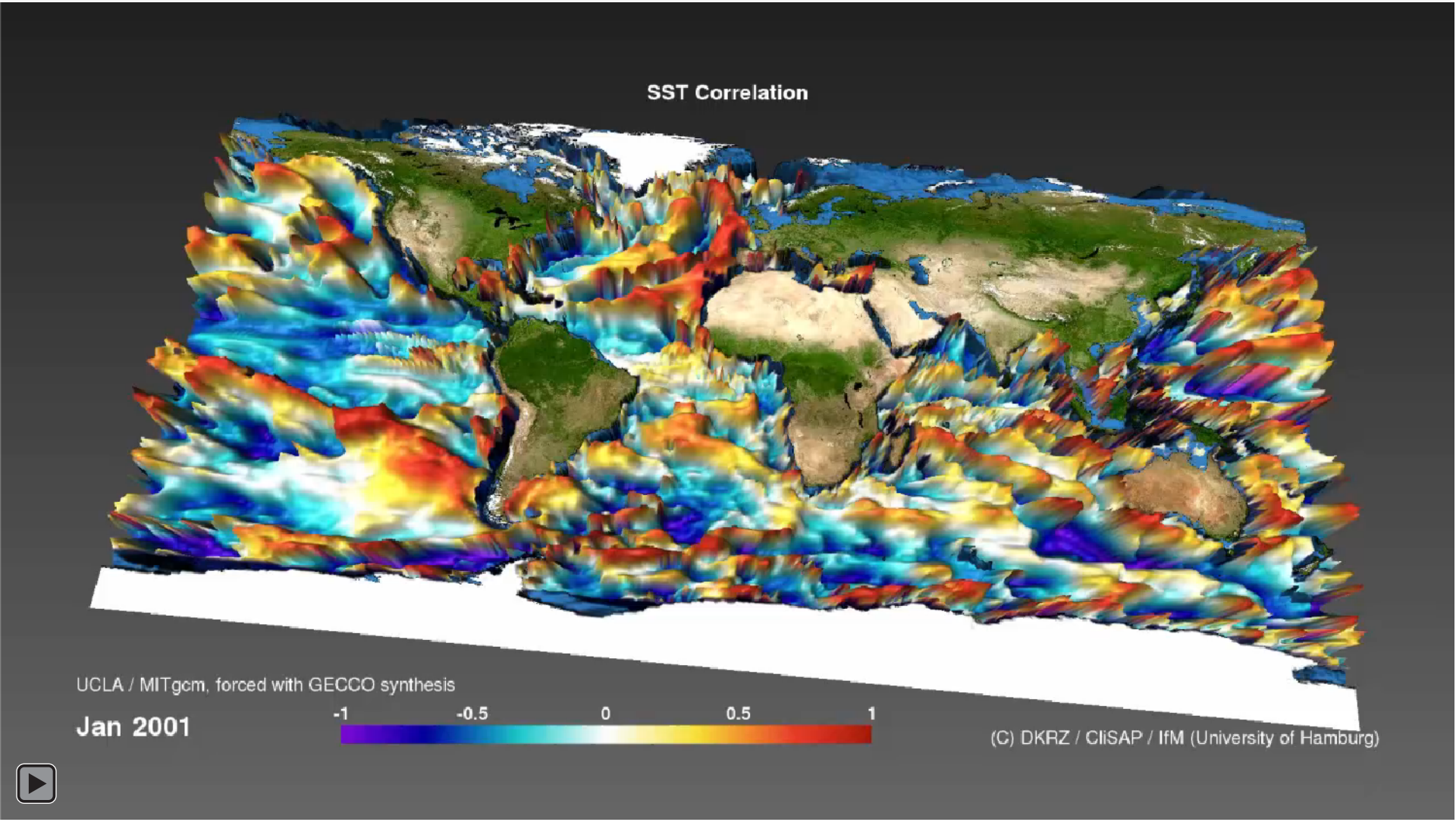
- Avizo Green (commercial 3D visualization system)
- Heightfield method
  - Color mapping & surface deformation according to physical and/or statistical values
  - Univariate or bivariate data visualization
  - Well suited for animation
- Geographical mapping
- Geographical context
- NetCDF CF



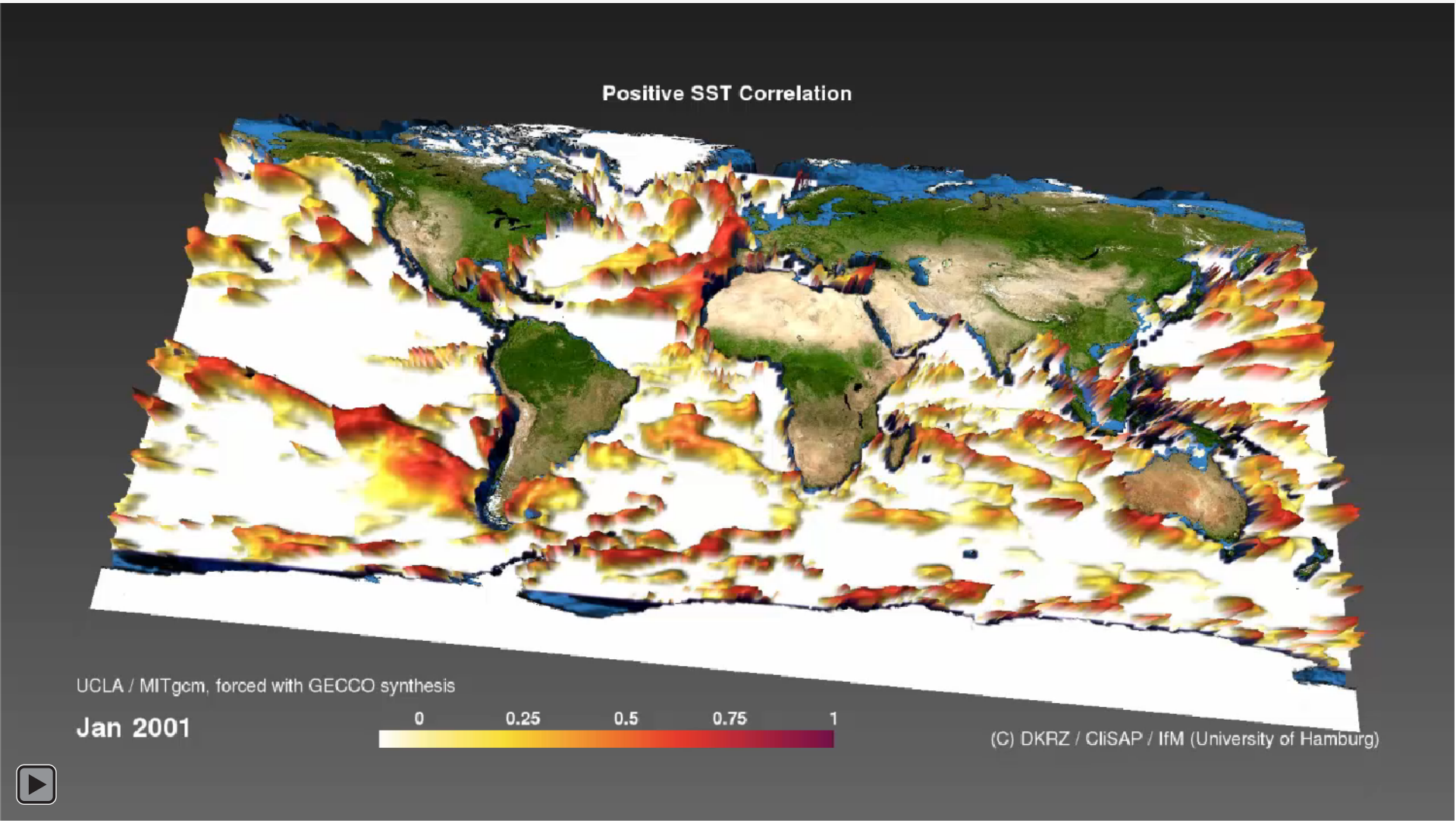
Temporal Patterns: SST Anomaly



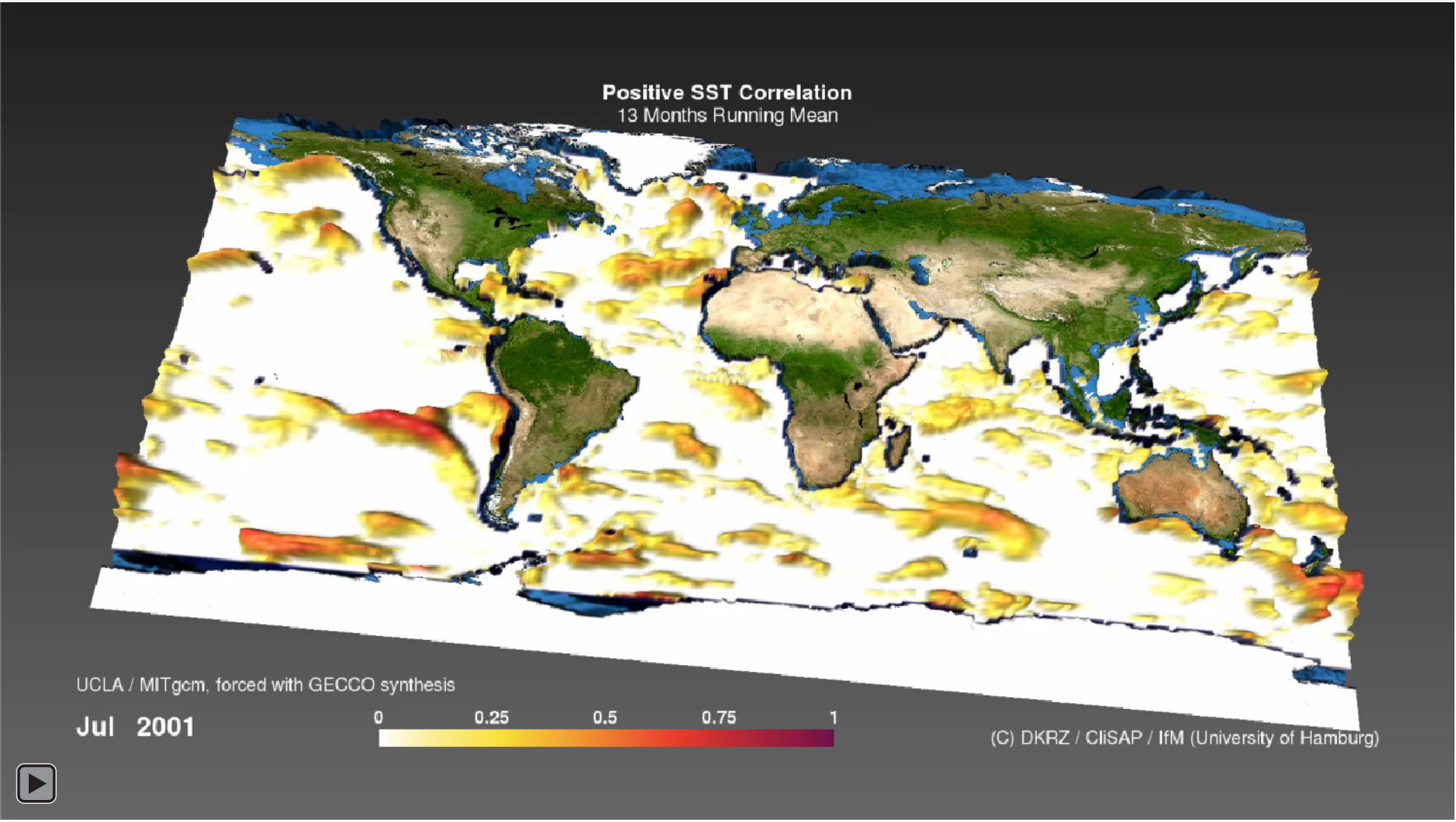
Temporal Patterns: SST Correlation (Skill)



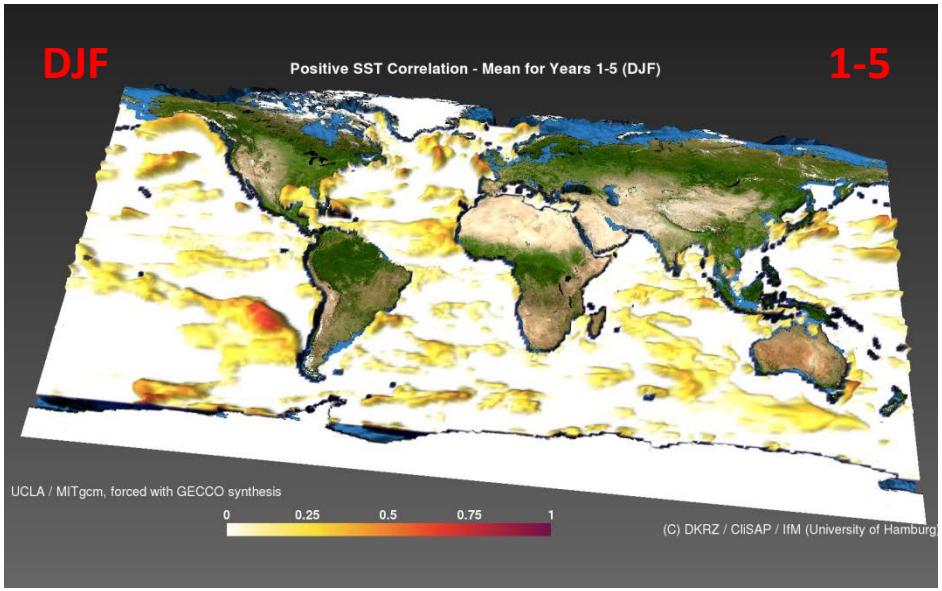
Positive SST Correlation (Skill)

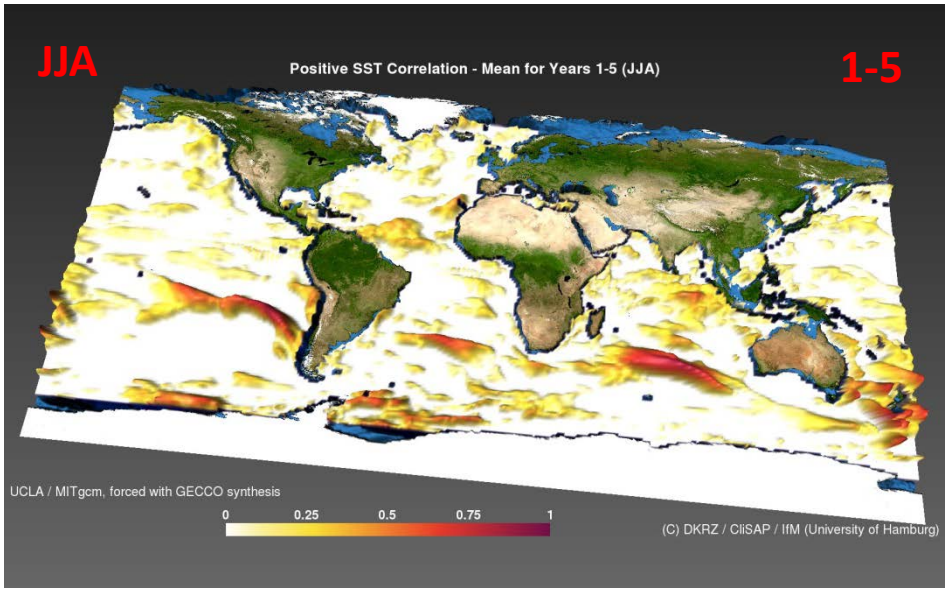


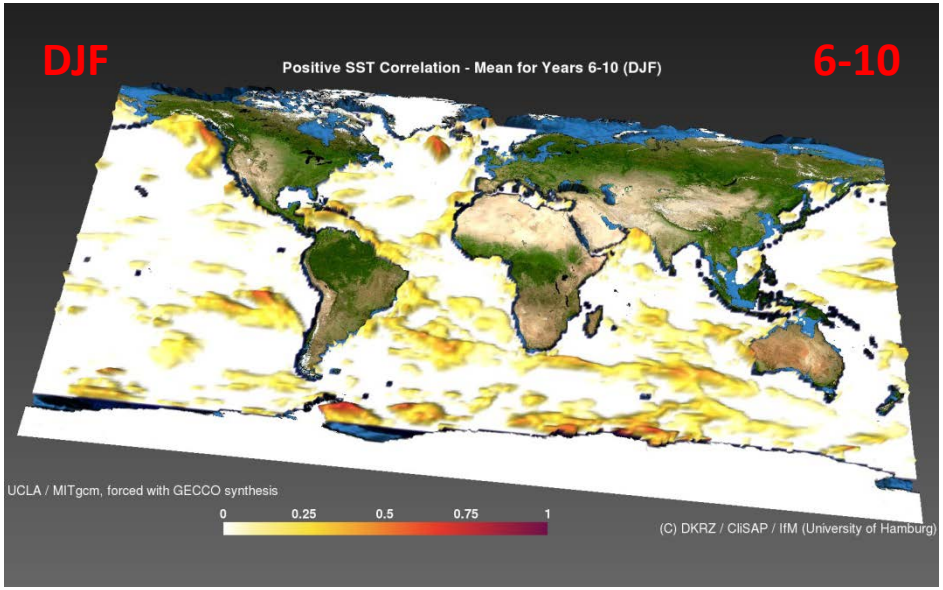
Low-pass filtered positive SST Correlation (Skill)

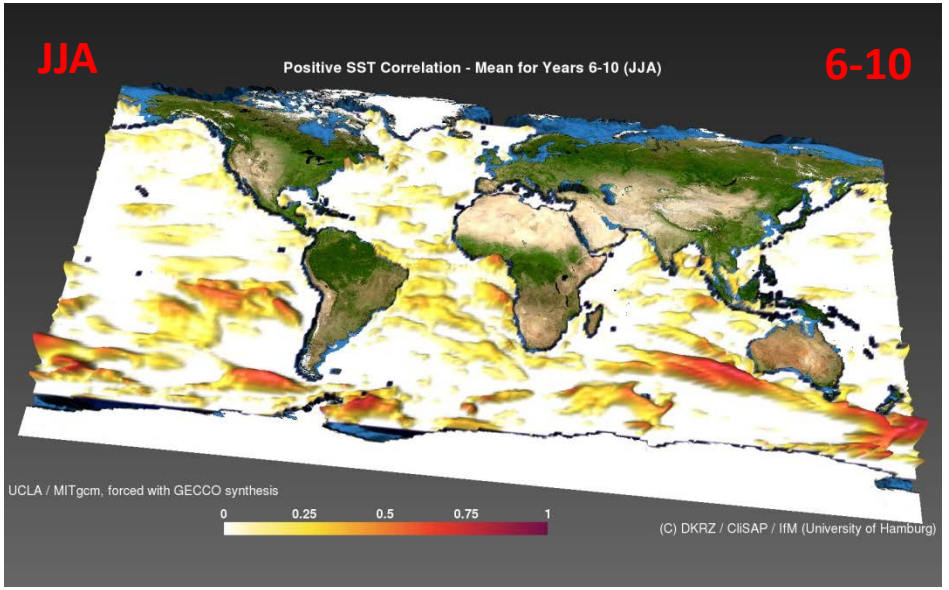


Seasonal Analyses

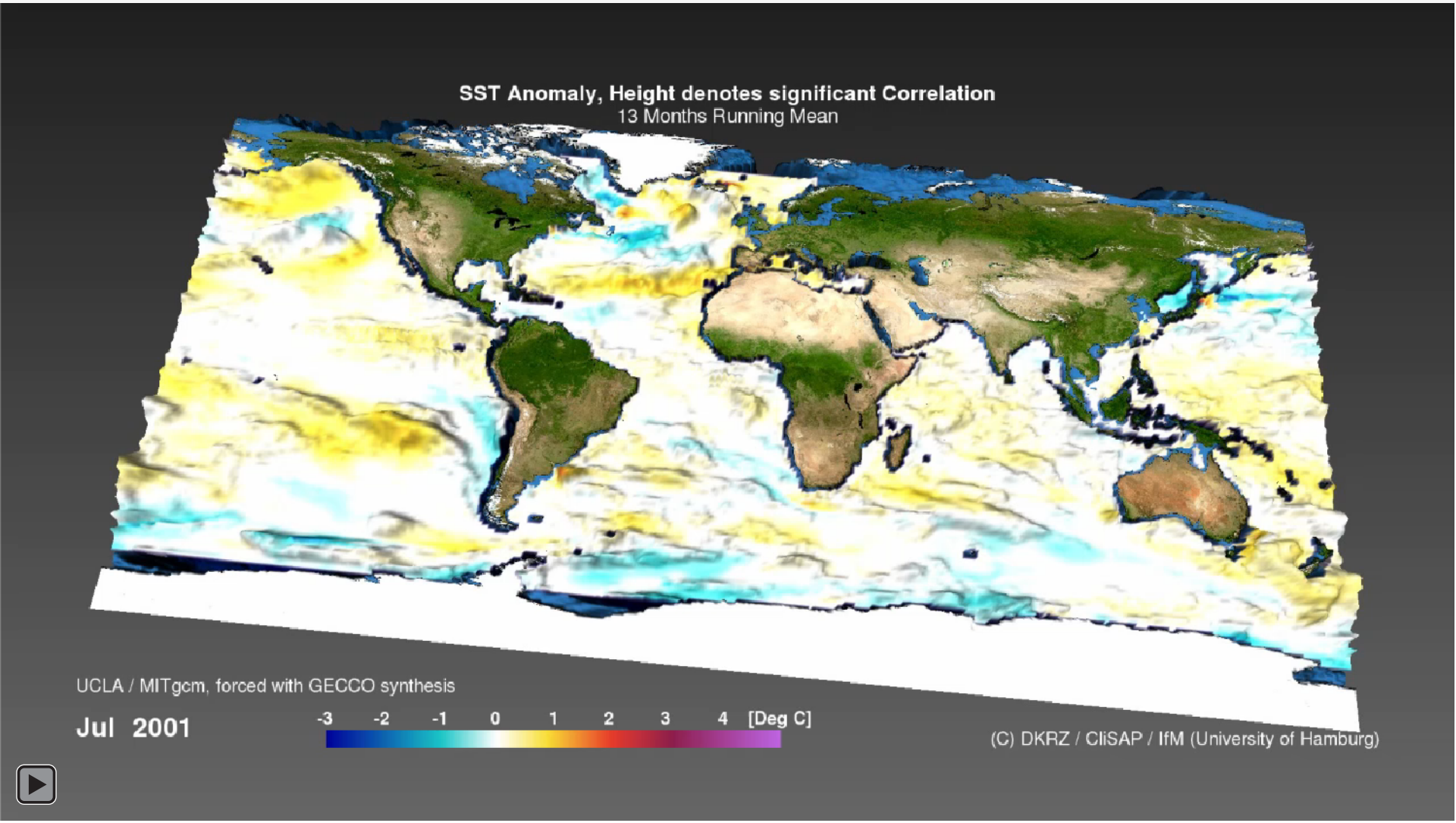




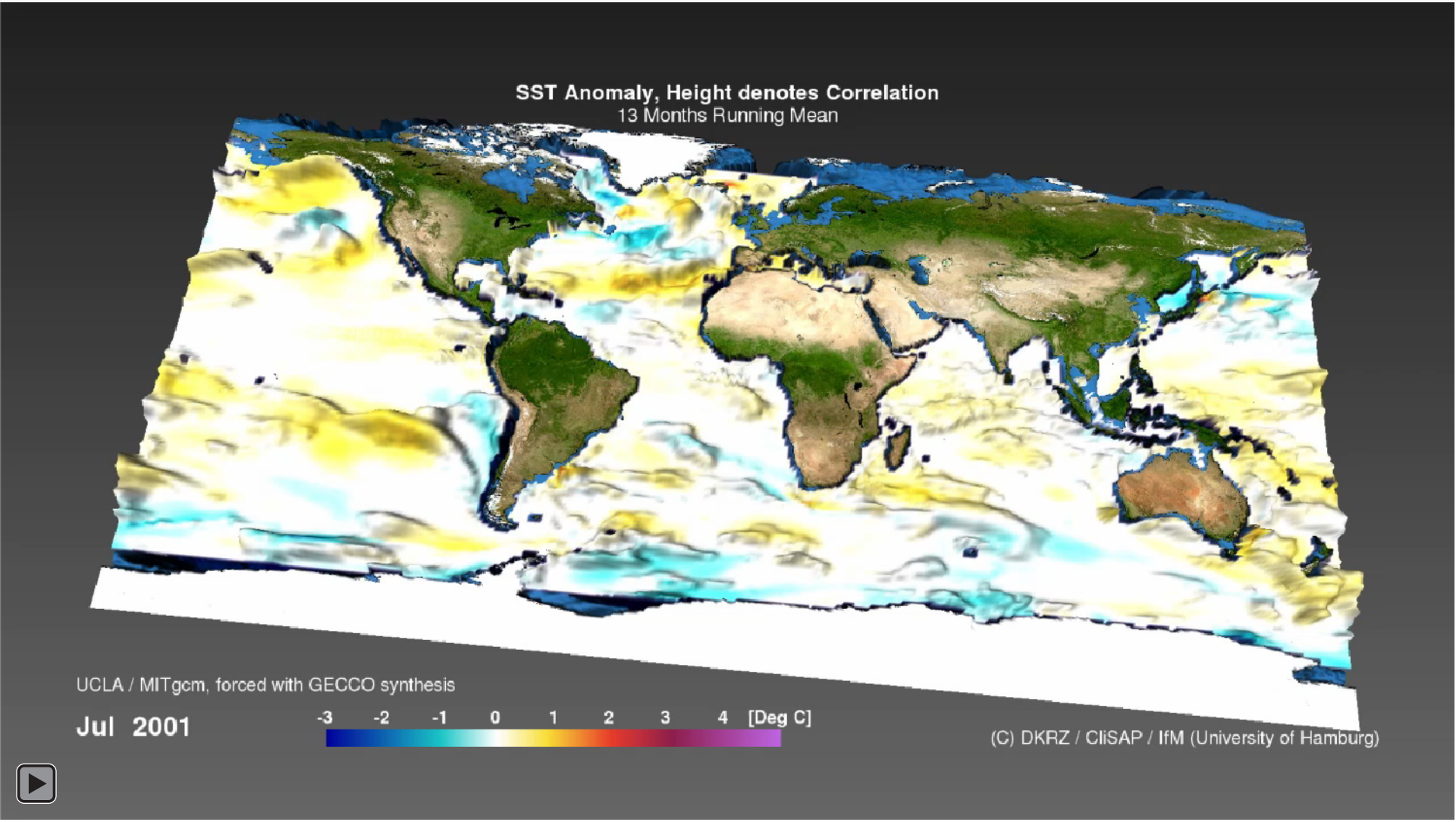




Low-pass filtered SST Anomaly and significant SST Correlation



Low-pass filtered SST Anomaly and positive SST Correlation



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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)

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Thank You!

<boettinger@dkrz.de>

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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