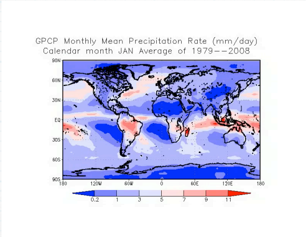
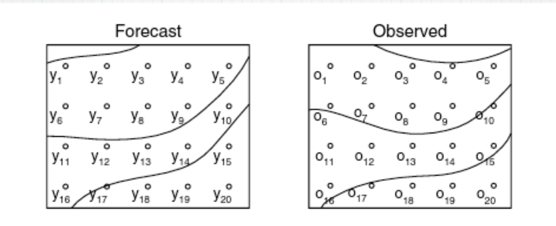


Evaluation of clouds in large-scale models

What? Why? How?
Part 3

Christian Jakob & Jean-Louis Dufresne

Evaluating fields more quantitatively



Represent model and observations on the same grid (interpolation)

Then treat each grid-point as one entry to the "forecast" and observation "vectors".

Calculate quantitative error measures.

Mean and RMS errors

Mean error (Bias)

$$ME = \frac{1}{N}\sum_{n=1}^{N}(f_n - o_n)$$

For example:
f_n - Forecast at point n
o_n - Observation/Analysis at point n

Mean absolute error

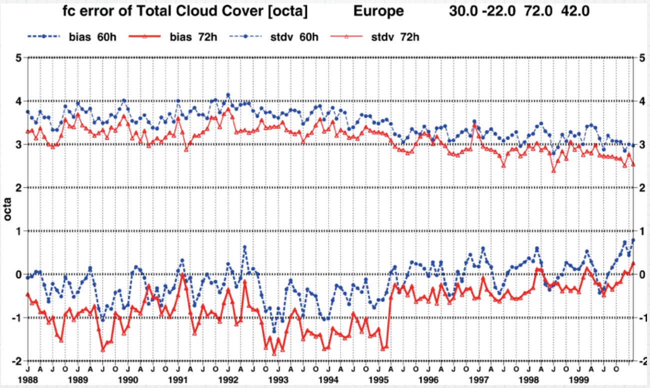
$$MAE = \frac{1}{N}\sum_{n=1}^{N}|f_n - o_n|$$

Root mean square error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(f_n - o_n)^2}$$

Note that in NWP the observations are often replaced (approximated by) the NWP analysis (initial state)

Mean error example



ECMWF cloud forecast over Europe

The Taylor diagram

Background

Based on root-mean square error:

$$E = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(f_n - o_n)^2}$$

For example:
f_n - Forecast at point n
o_n - Observation at point n

We can write:

$$E^2 = \overline{E}^2 + E'^2$$

with $\overline{E} = \overline{f} - \overline{o}$ and $E' = \sqrt{\frac{1}{N}\sum_{n=1}^{N}[(f_n - \overline{f}) - (o_n - \overline{o})]^2}$

E' can further be modified as: $E'^2 = \sigma_f^2 + \sigma_o^2 - 2\sigma_f\sigma_o R \longrightarrow c^2 = a^2 + b^2 - 2ab\cos\Phi$

Law of cosines

where $R = \frac{\frac{1}{N}\sum_{n=1}^{N}(f_n - \overline{f})(o_n - \overline{o})}{\sigma_f \sigma_o}$ is the correlation coefficient.

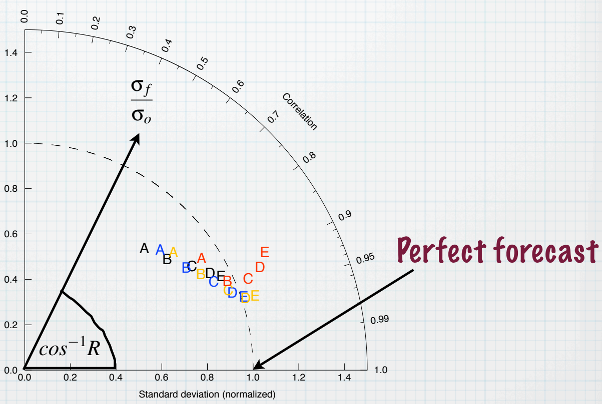
So E' denotes a **combination** of the **standard deviations** of the forecast and observed fields as well as the **correlation** between them. Construct a diagram from this!

The Taylor diagram

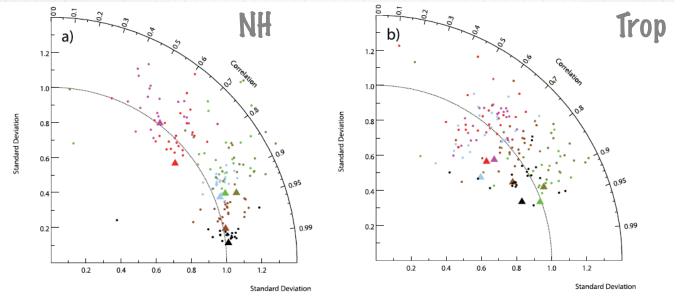
Beware:

In its normal form the diagram has no information on biases!

Hence, as with all measures, do not believe a model to be great just because it looks great here!



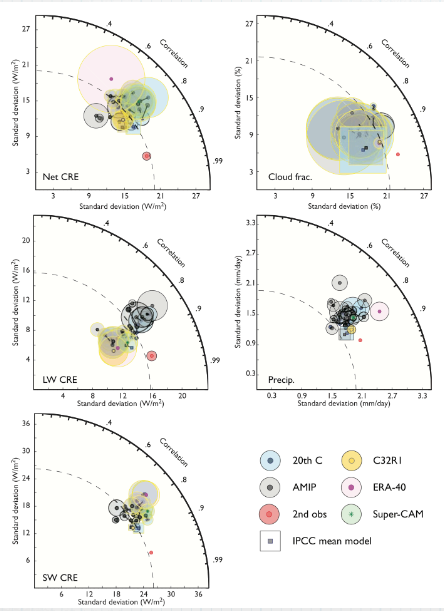
The Taylor diagram



Sea Level Pressure: ERA40 reference
Total Precipitation Rate: CMAP reference
Total Cloud Cover: ISCCP reference
LW Radiation TOA (OLR): ERBE reference
Reflected TOA Shortwave: ERBE reference
Air Temperature (850 hPa): ERA40 reference
Zonal Wind (850 hPa): ERA40 reference

CMIP3 model performance

Gleckler et al., JGR 2008



A Taylor diagram with bias information

CMIP3 model performance

Pincus et al., JGR, 2008

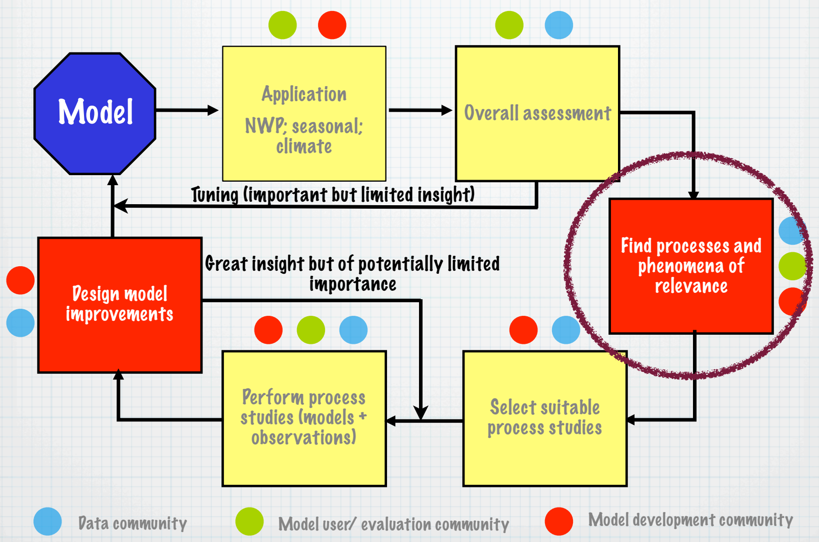
Metric

* **Origin:**
  * French: métrique, from mètre, meter
  * Latin: metricus, relating to measurement
  * Greek: metrike, (the art) of meter, feminine of metrikos, relating to measurement
* **Definitions:**
  * A standard of measurement
  * Mathematics: A geometric function that describes the distances between pairs of points in a space
  * Poetic meter

Metrics

* Quantitative **scalar** error measures used for climate models are often referred to as **performance METRICS**
* Pros:
  * provide quasi-objective evaluation
  * provide a history of performance
  * allow for "easy" comparison between models
* Cons:
  * a single metric cannot capture the complexity of model behaviour
  * Metrics per se do not provide insight into the causes of model error
  * Metrics can be easily misinterpreted and can hinder model development

Approaches to model evaluation

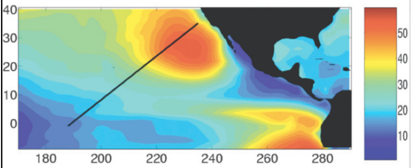


Regime-oriented model evaluation

* While useful in the context of model application, the overall evaluation of model results provides limited to no insight into the causes of model error.
* Can we devise techniques that decompose the model error into errors in different regimes? -> Divide and conquer
* Identifying the regimes that contribute the most to the model error might then help us understand the underlying processes.
* How do we define the regimes so that they have a "physical" meaning?

Geographic regimes

Total cloud cover



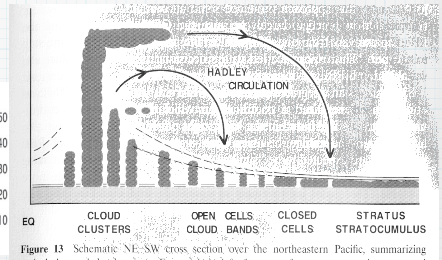
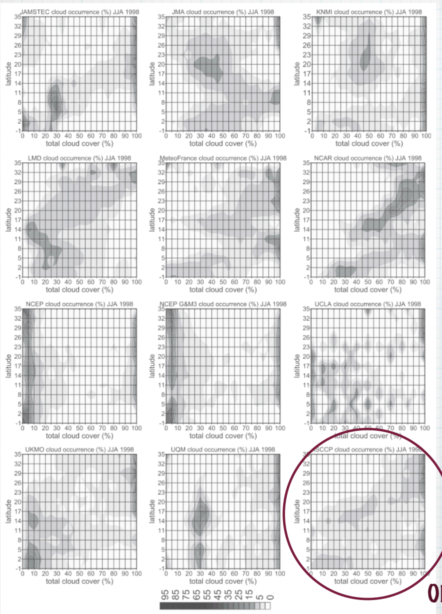


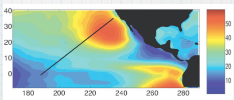
Figure 13 Schematic NE–SW cross section over the northeastern Pacific, summarizing typical observed cloud regimes. From right to left, the sea surface temperature increases and subsidence decreases. The stippled area is the PBL, the top of which is shown by the continuous and discontinuous double-stroked lines. The dashed lines above the cumulus clouds show an inversion layer, which is principally the trade wind inversion. (Redrawn from Arakawa, 1975.)

* Easiest regime definition: Use geographically distinct cloud regimes
* Works well in the relatively steady subtropics



Geographic regimes

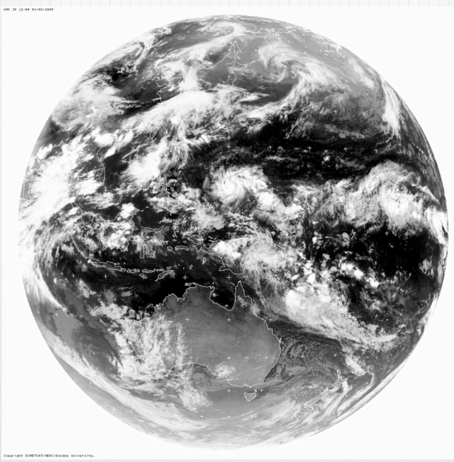
* Histograms of instantaneous 6-hourly cloud fraction as a function of latitude along the transect



Observations

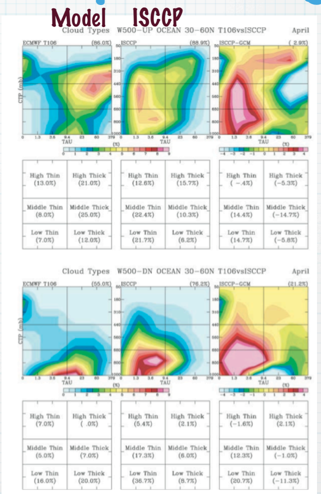
Teixeira et al., JCL, 2012

Geography is not always this kind



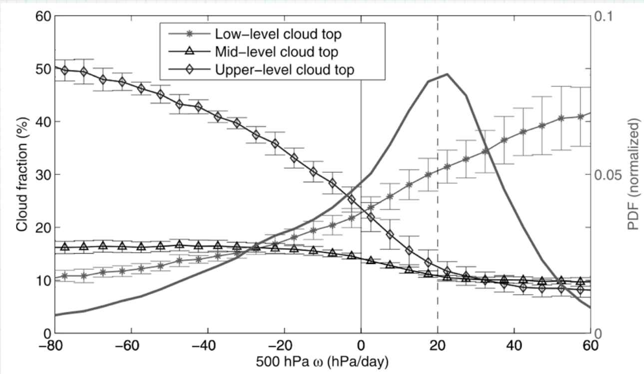
Vertical velocity sorting

* Sort cloud properties by some other variable
* Here: Instantaneous Vertical velocity at 500 hPa



Tselioudis and Jakob, JGR, 2002

Vertical velocity sorting

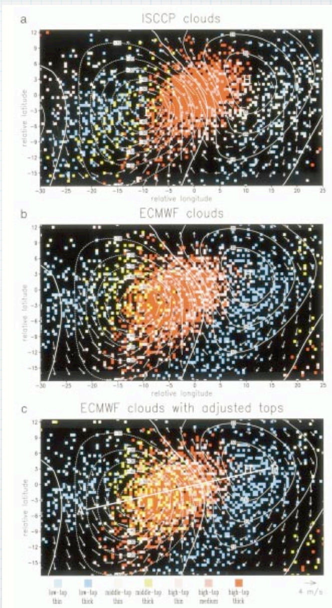


* Cloud cover in the tropics sorted by monthly mean vertical velocity

Bony an Dufresne, GRL, 2005

Compositing

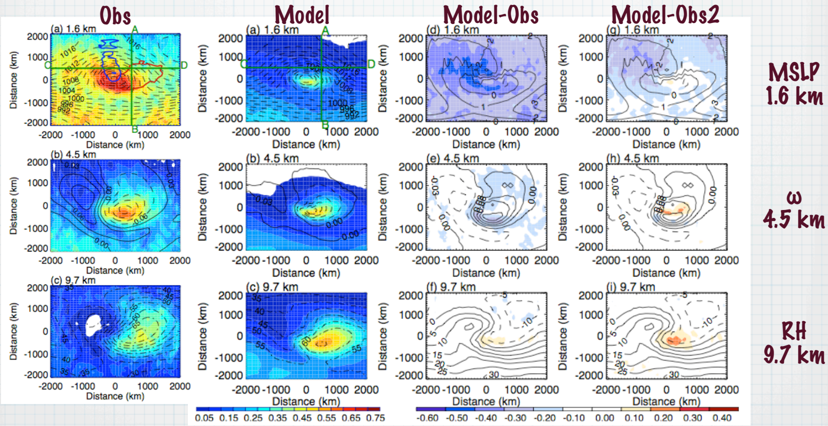
* Composite cloud fields around dynamical features
* Most prominent: Extratropical cyclones



Klein and Jakob, MWR, 1999

Composites

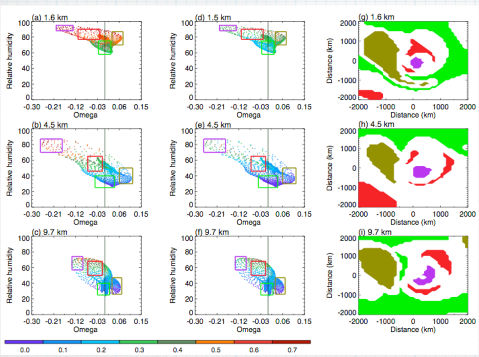
* CloudSat/CALIPSO cloud cover composites around Southern Ocean Cyclones

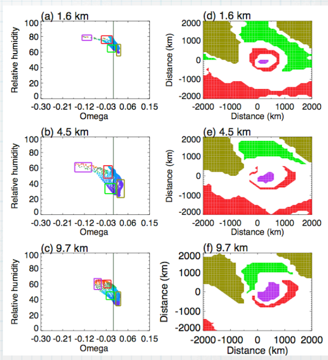


Govekar et al., 2013, in the works

Composites

* CloudSat/CALIPSO cloud cover composites around Southern Ocean Cyclones
* Relationships between cloud and dynamical variables

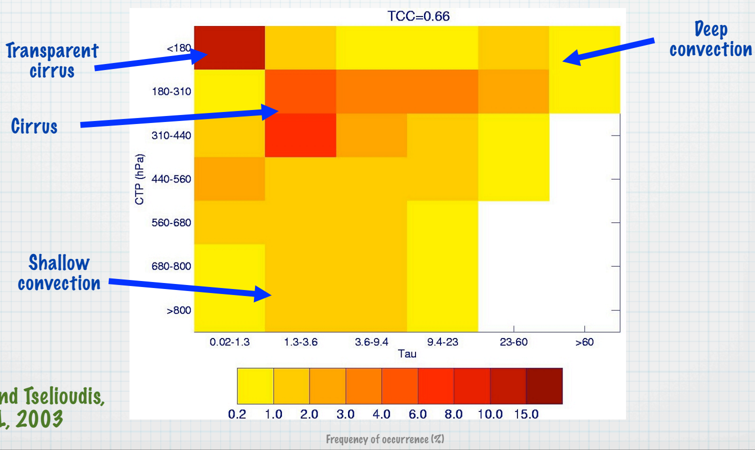




Govekar et al., 2013, in the works

ISCCP cloud regimes

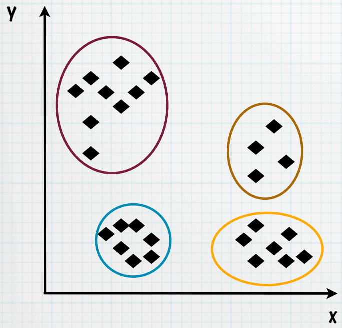
The ISCCP D1 data set provides **joint histograms of the frequency of occurrence of clouds with a certain cloud top-pressure and optical thickness in grid boxes of ca. 280x280km.** These histograms have a strong relationship to cloud types (e.g., Rossow and Schiffer, 1999). The example below shows the mean histogram for 1999-2000 averaged over an area in the Western Pacific (130-170 E, 10 N-10 S).



Jakob and Tselioudis, GRL, 2003

Cluster (and related analysis)

The basic idea



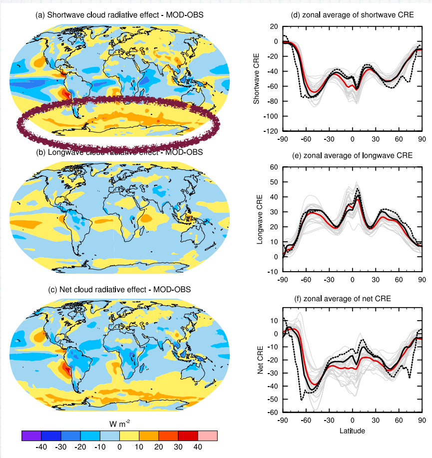
Measure the **distance between points** in the phase space and **group them** such that the distance to a point's group mean is shorter than that any other group's mean.

Each group is called a **cluster**.

Different mathematical techniques to do this exist - Hierarchical clustering, k-means, Self-Organizing Maps

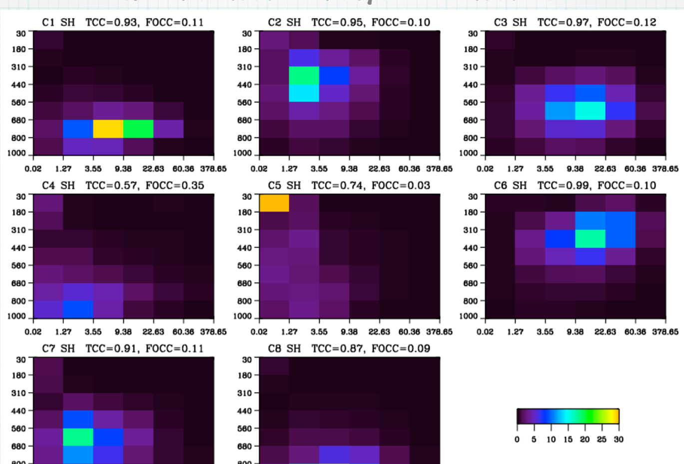
Beware: The analysis will find groups even if there is no real "clumping"! This can still be useful. (e.g., real numbers between 0 and 1)

CRE in CMIP5 models



SH Cloud regimes

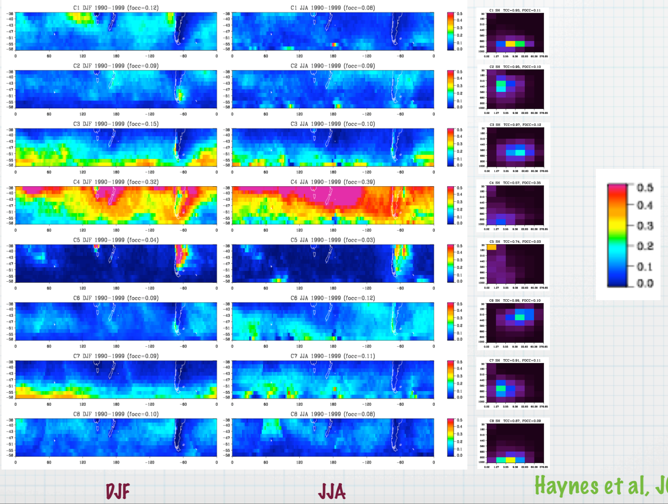
K-Means Cluster analysis - 8 clusters



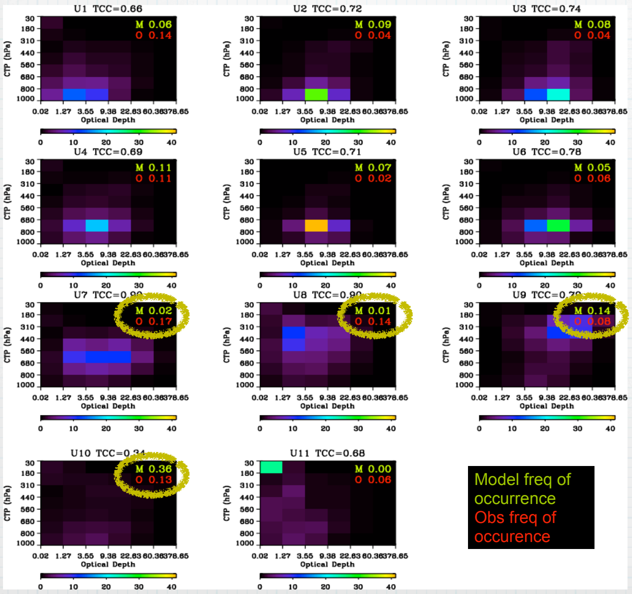
Haynes et al, JCL 2011

SH Cloud regimes

Frequency of occurrence

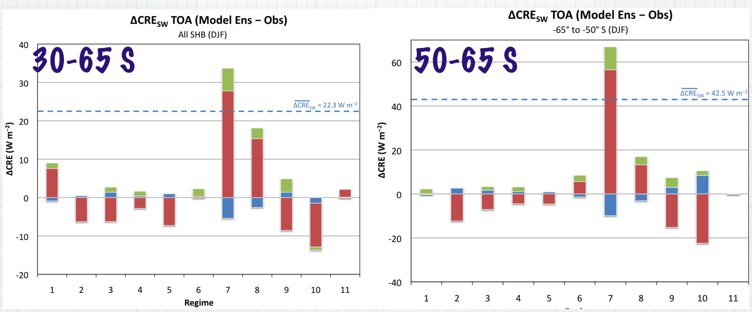


Haynes et al, JCL 2011



Hybrid model/ obs regimes

Model error decomposition

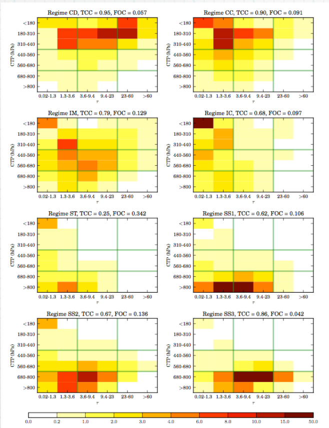


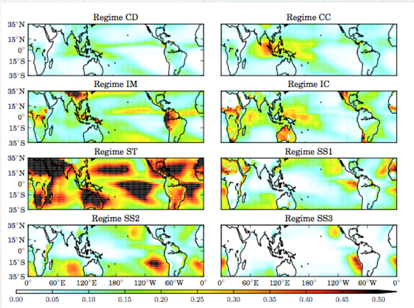
$$\Delta CRE = \sum_{r=1}^{11} RFO_r \Delta CRE_r + \sum_{r=1}^{11} CRE_r \Delta RFO_r + \sum_{r=1}^{11} \Delta RFO_r \Delta CRE_r$$

Total error = CRE error in regime + Error in occurrence + Cross Terms

ISCCP cloud regimes

Tropics

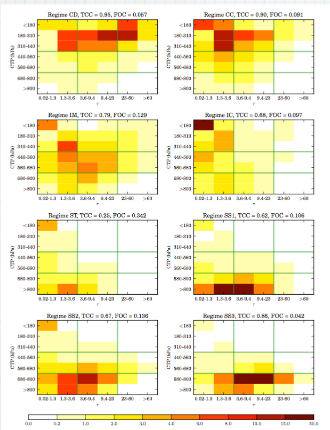


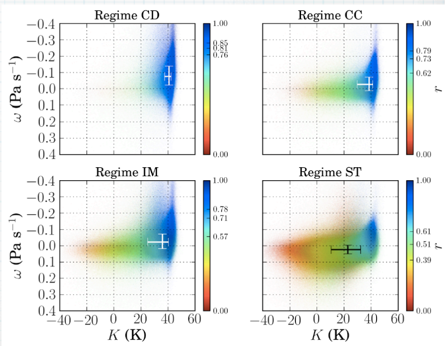


Tan et al, JCL 2013

ISCCP cloud regimes

Tropics





Tan et al, JCL 2013

Things we did not talk about

... but maybe should have!

* Process studies
* Categorical forecast evaluation
* Probabilistic forecast/projection evaluation
* Evaluation of non-cloudy, but cloud-related phenomena (e.g., Tropical waves, ...)

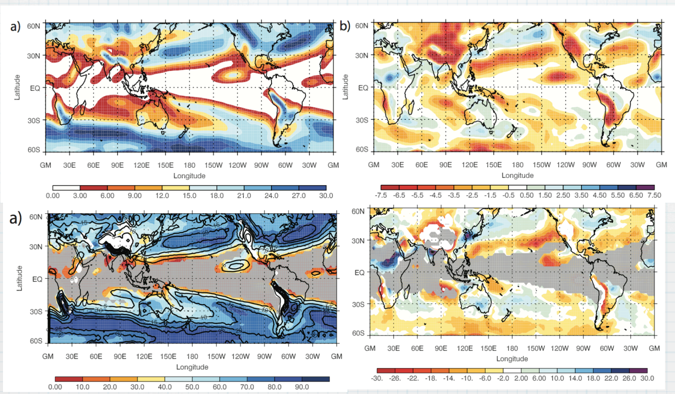
The future

* **Completing "the loop"** on a regular basis - SO clouds example was almost there
* **Evaluating relationships**, rather than single quantities, e.g., cyclone example
* **Bringing different approaches together** more rigorously
* Evaluating the **weather in climate models** - bringing communities together

How much rain comes from fronts?

ERA-Interim

Model-ERAI



Number of fronts (% of time)

Fraction of annual rainfall that is related to fronts (%)

ERA-Interim+GPCP

Model-ERAI/GPCP

Thank you for...

* ... your attention.
* ... your great questions.
* ... your enthusiasm.
* ... making this school a real fun experience.