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Observational constraints on climate feedbacks: an pan-spectral approach

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CLARREO Societal Objectives

- **I. Societal objective of establishing a climate benchmark**: The essential responsibility to current and future generations to put in place a benchmark climate record, global in its extent, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards on-orbit.
- **II. Societal objective of the development of an operational climate forecast:** The critical need for climate forecasts that are tested and trusted through a disciplined strategy using state-of-the-art observations with mathematically rigorous techniques to systematically improve those forecasts.

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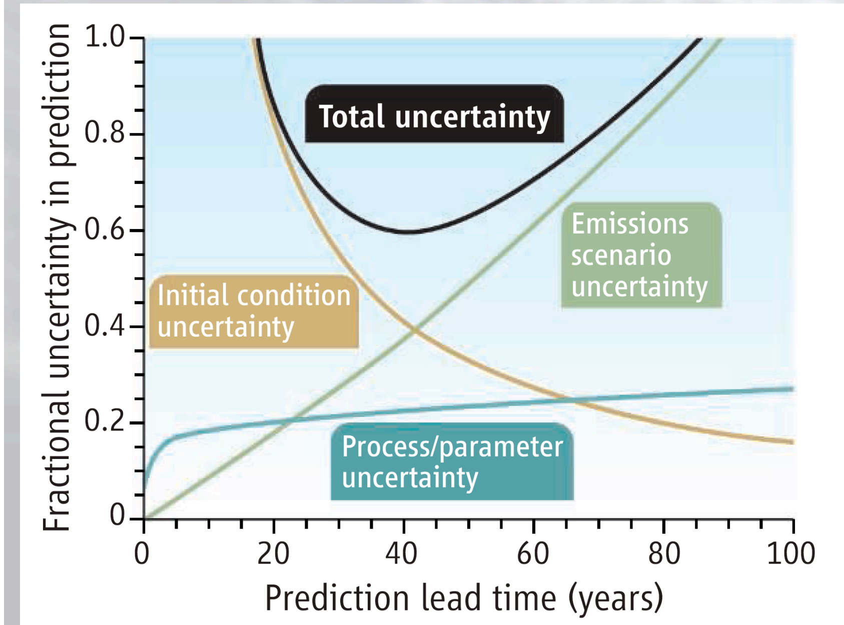
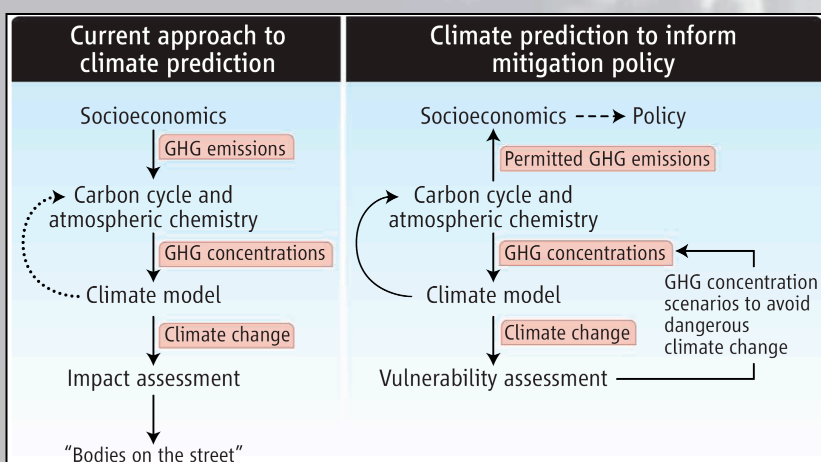
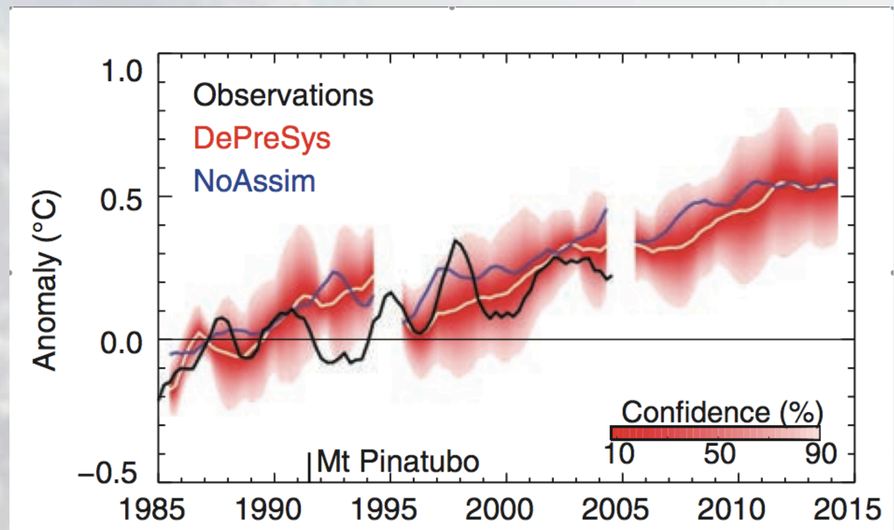
Changing Climate of Prediction

From "Changing Climate Of Prediction", Cox and Stephenson, Nature, 2007





"We can therefore envisage a climate diagnosis and prediction system that assimilates data into a climate model not only to define the initial conditions for decadal projections, but also to refine estimates of the key internal model parameters that influence climate sensitivity"



Smith *et al*, *Science*, 2007

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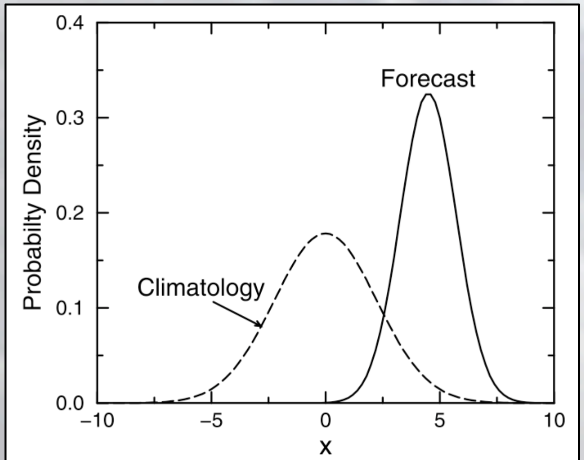
Predictability and information content



DelSole and Tippett, 2007

The statistical predictability of climate is still an open question.

The *information content* of an observing system can help evaluate predictability through the change in entropy, H, between a forecast, $\mathbf{x}_\tau$, with and without the observing system, $\mathbf{y}_t$

$$\Delta H = \int p(\mathbf{x}_\tau) \ln p(\mathbf{x}_\tau)\, d\mathbf{x}_\tau - \int p(\mathbf{x}_\tau \mid \mathbf{y}_t) \ln p(\mathbf{x}_\tau \mid \mathbf{y}_t)\, d\mathbf{x}_\tau$$

The goal is to maximize the information content of CLARREO radiances in order to improve the predictability of climate forecasts.

Similarly, the information content of CLARREO spectral radiances, $\mathbf{s}_t$, relative to the geophysical state, $\mathbf{y}_t$, that produced those radiances can be described by

$$\Delta H_y = \int p(\mathbf{y}_t) \ln p(\mathbf{y}_t)\, d\mathbf{y}_t - \int p(\mathbf{y}_t \mid \mathbf{s}_t) \ln p(\mathbf{y}_t \mid \mathbf{s}_t)\, d\mathbf{y}_t$$

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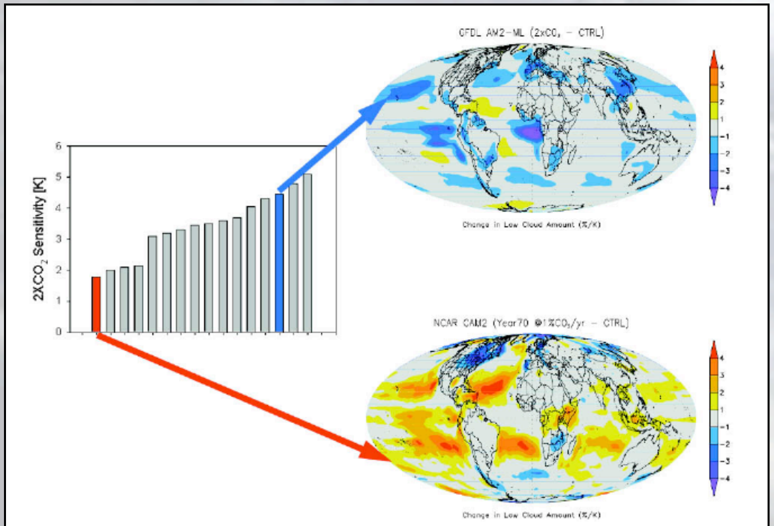
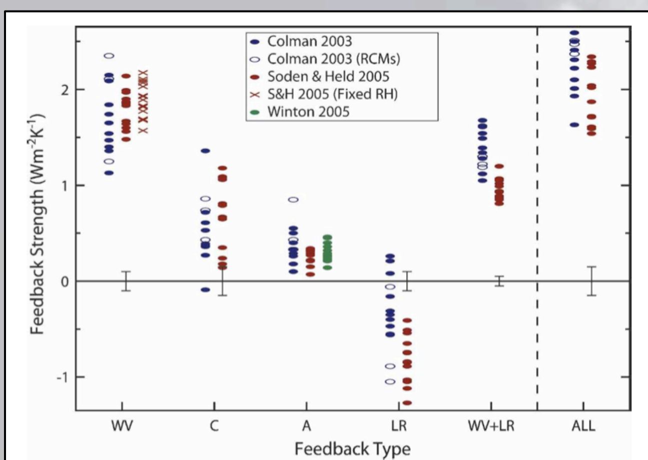
Key challenge in predictability climate feedbacks


Stephens/Soden, *J. Climate* 2005



Bony *et al. J. Climate,* 2006

- The IPCC indicates that climate feedbacks, and in particular, cloud feedbacks remain the largest source of uncertainty for climate prediction

- The main climate feedbacks are the radiative response of the hydrological cycle to anthropogenic forcing:
  - Water vapor feedback
  - Cloud feedback
  - Ice/Snow feedback

- These feedbacks are coupled to each other and to general atmospheric circulation

- Water vapor and clouds are distributed at unresolved GCM scales.

- However, regional climate models could help

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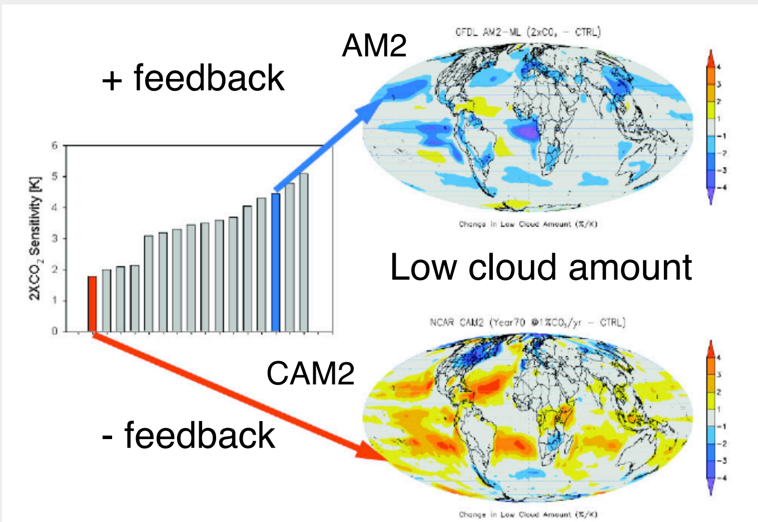
Observing system simulation experiment.

Uncertainty in climate feedbacks

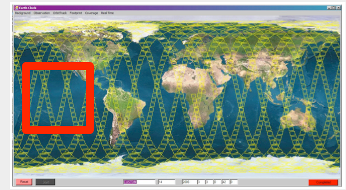


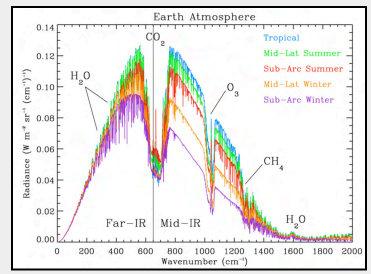
G. Stephens, J. Climate (2005)

CLARREO design

Spatio-temporal sampling

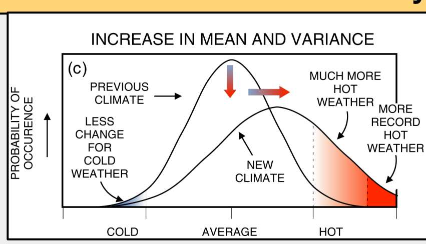
Spectral and spatial resolution, frequency range SNR





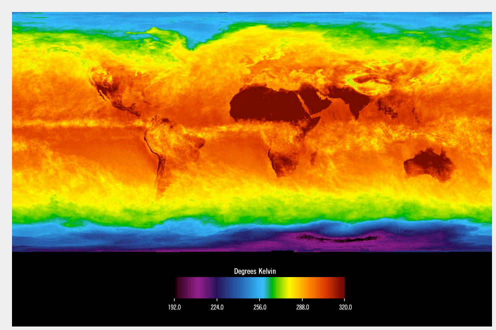
M. Mlynczak and D. Johnson, CLARREO workshop, 2007

Information content analysis



Does the information content from CLARREO reduce climate projection uncertainty within mission lifetime?

Virtual observations



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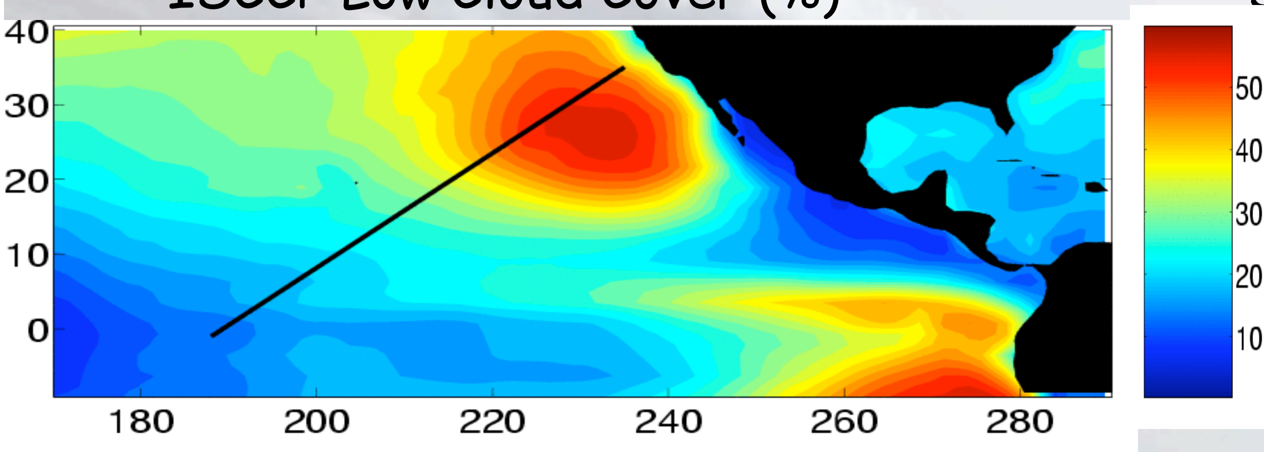
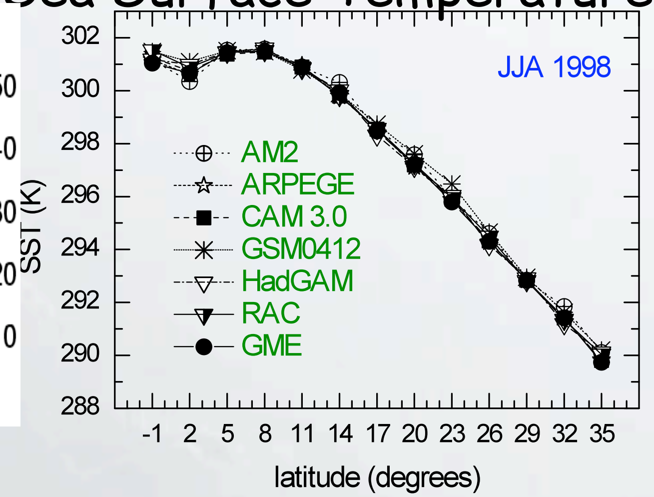
GCSS Pacific Cross-section Intercomparison (GPCI): Tropical and subtropical cloud regime transitions

ISCCP Low Cloud Cover (%)



Sea Surface Temperature



Courtesy C. Hannay

GCSS/WGNE Pacific Cross-section Intercomparison (GPCI) is a working group of the GEWEX Cloud System Study (GCSS)

Models and observations are analyzed along a transect from stratocumulus, across shallow cumulus, to deep convection

Models: GFDL, NCAR, UKMO, JMA, MF, KNMI, DWD, NCEP, MPI, ECMWF, BMRC, NASA/GISS, UCSD, UQM, LMD, CMC, CSU, GKSS

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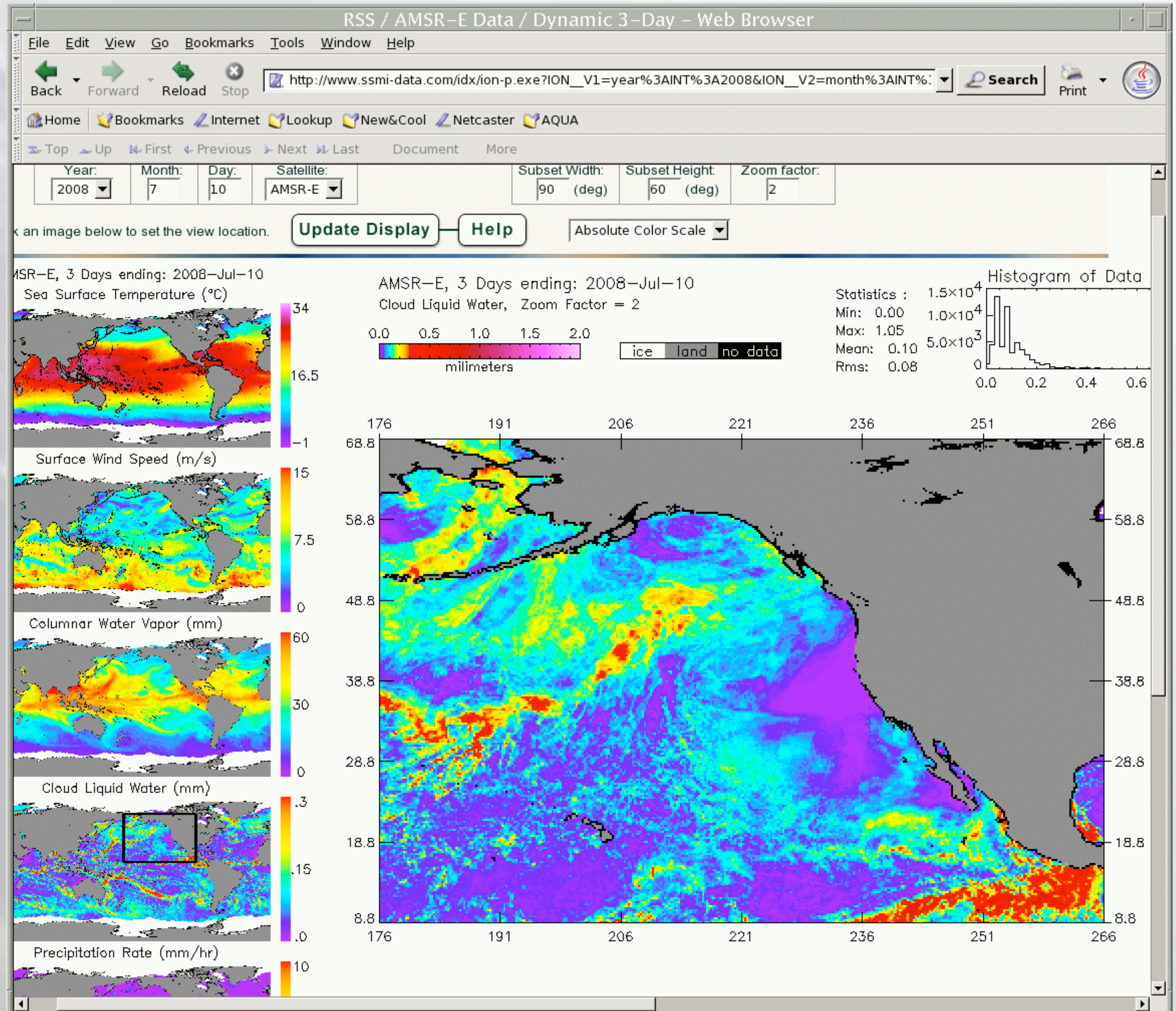
WRF simulation over GPCI region

2008-07-09
for 3 days



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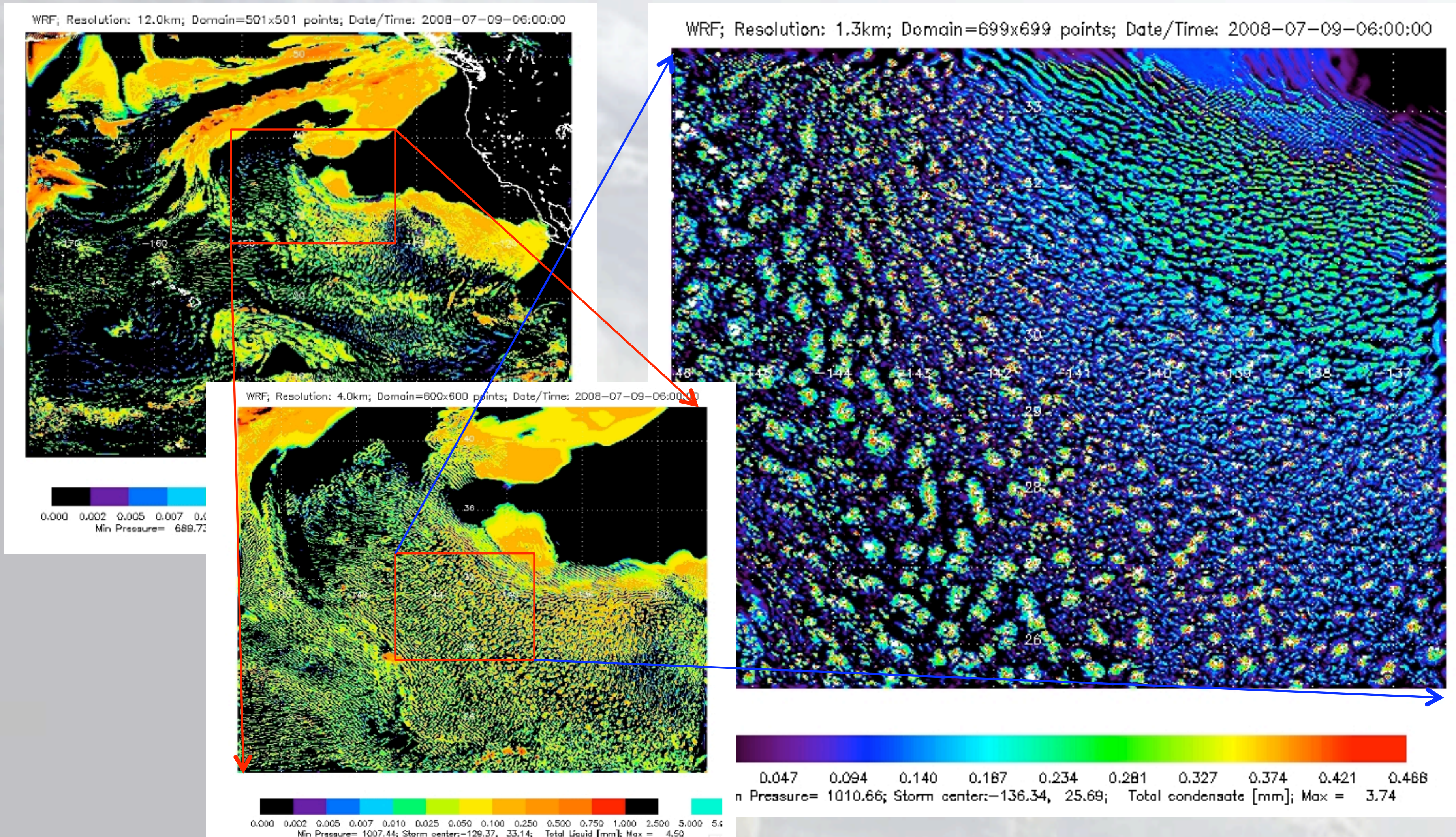
Cloud regimes



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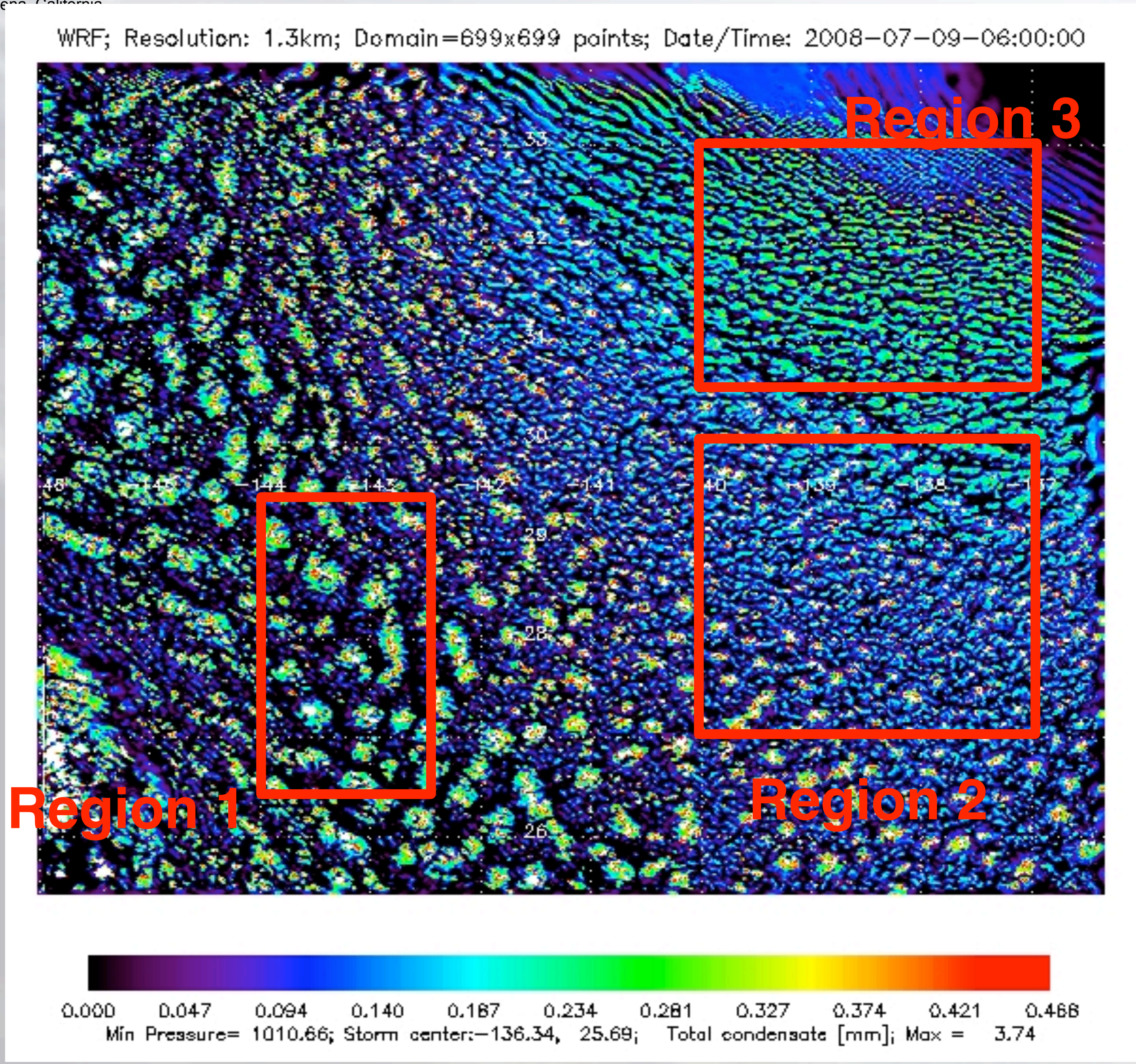
Regime analysis - 2008-07-09



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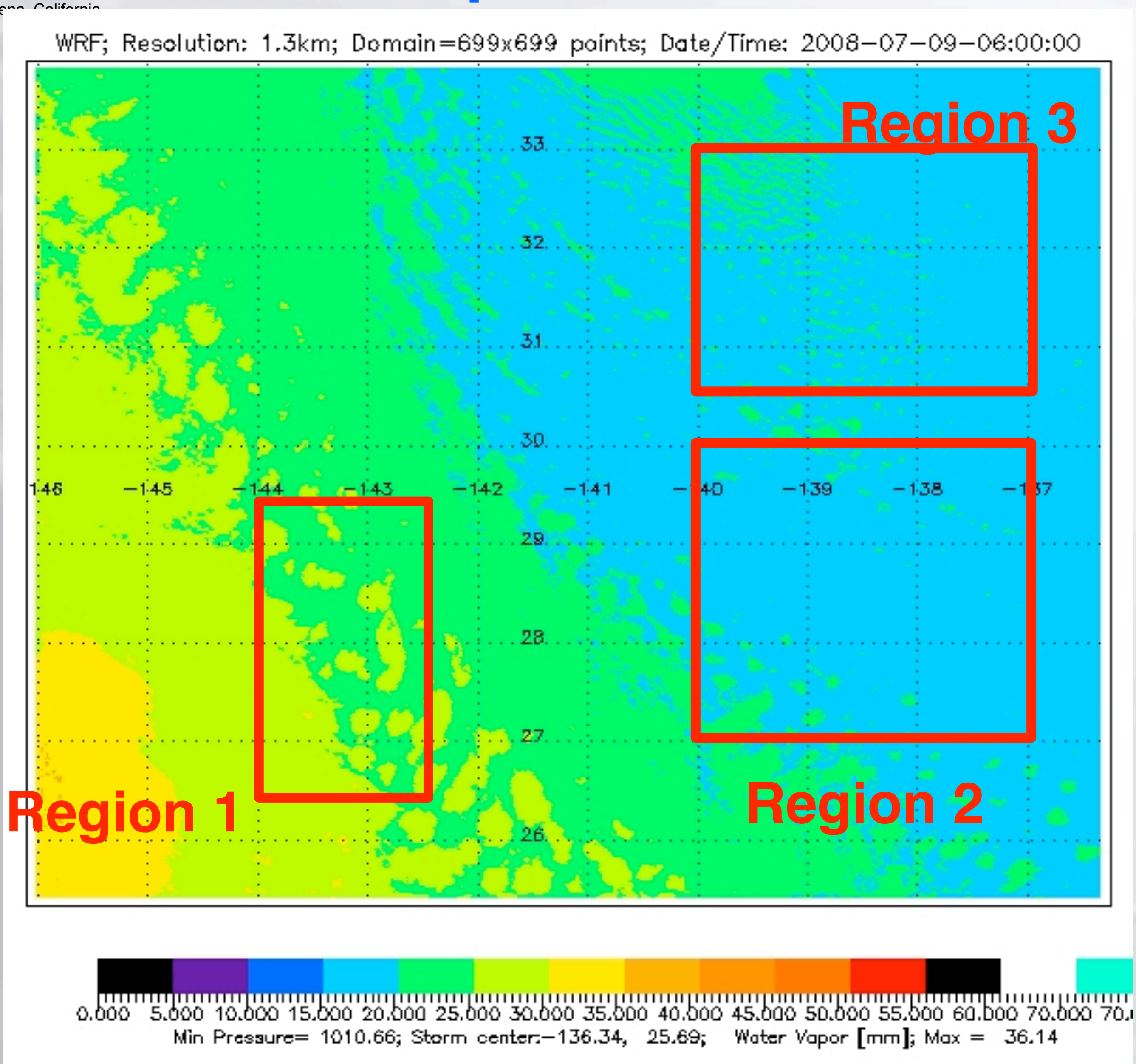
Water vapor distribution



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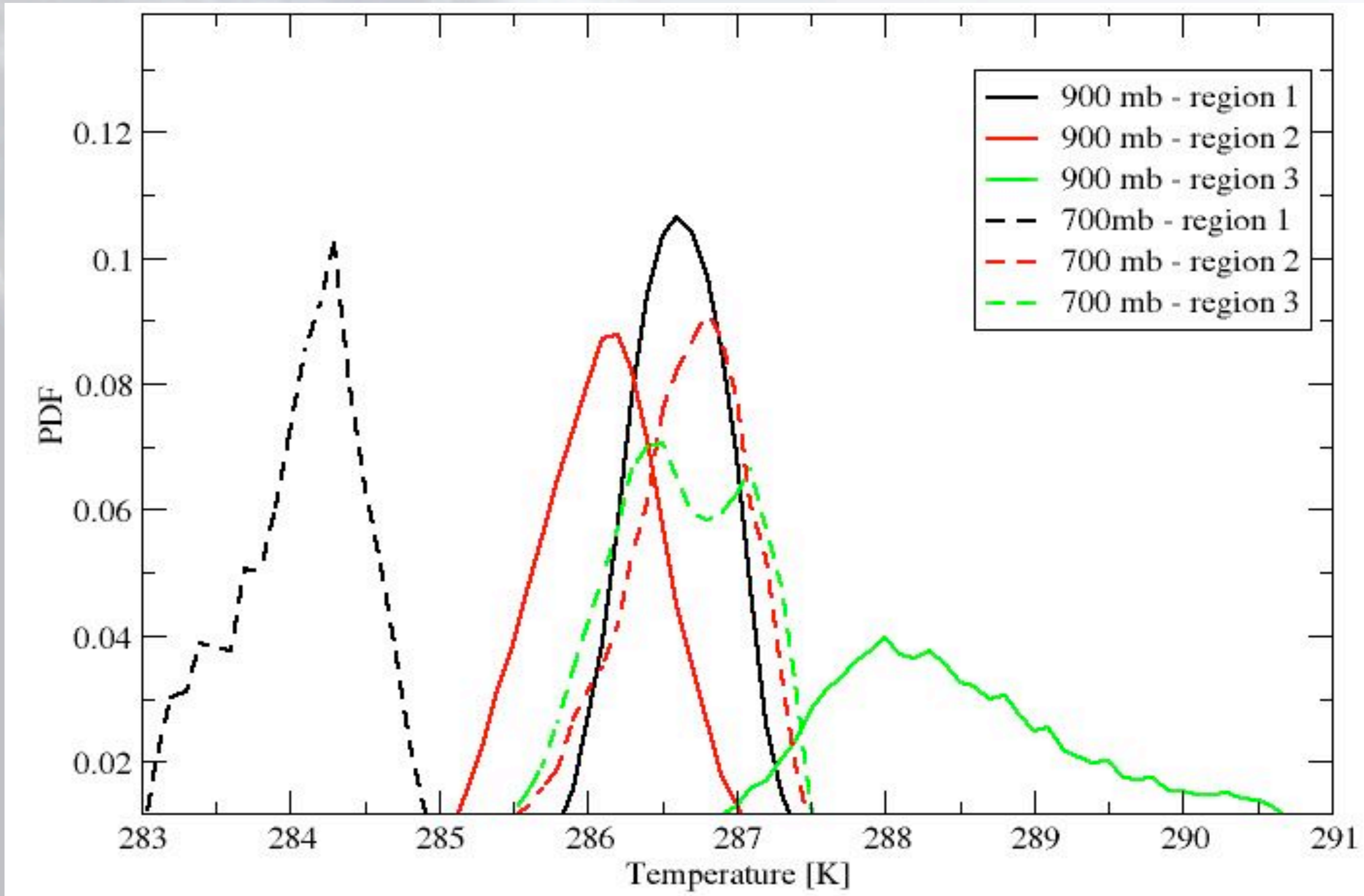
Temperature distribution within cloud regimes



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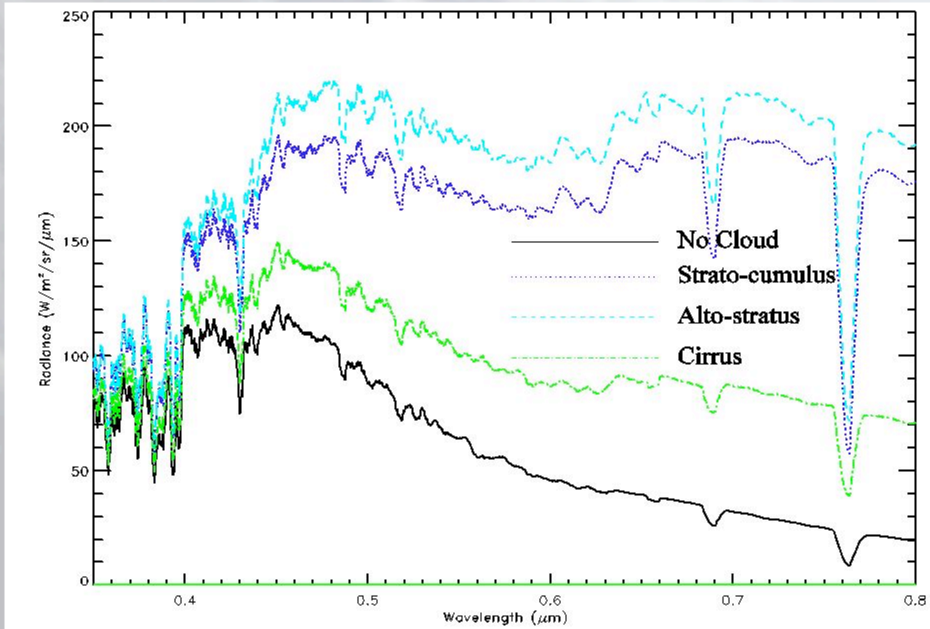
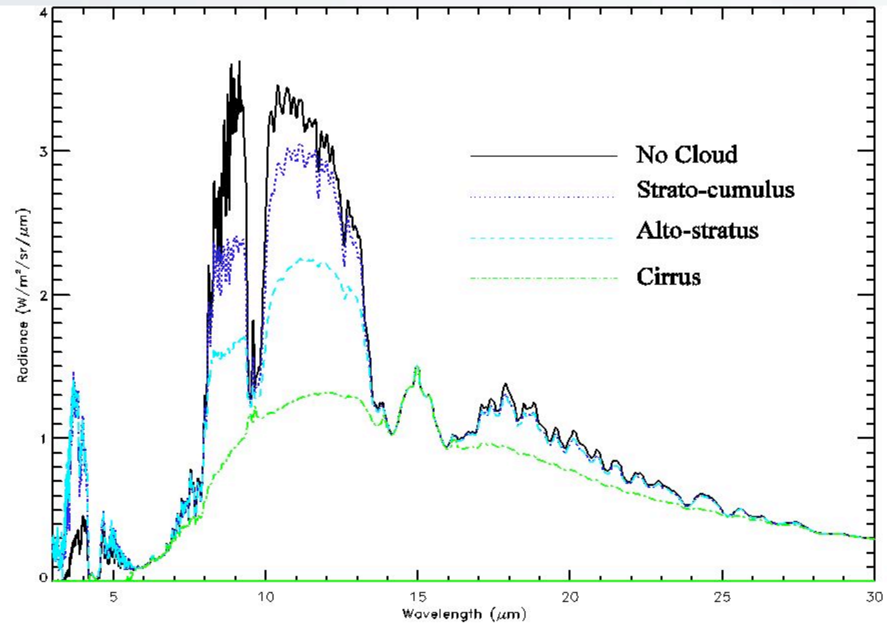
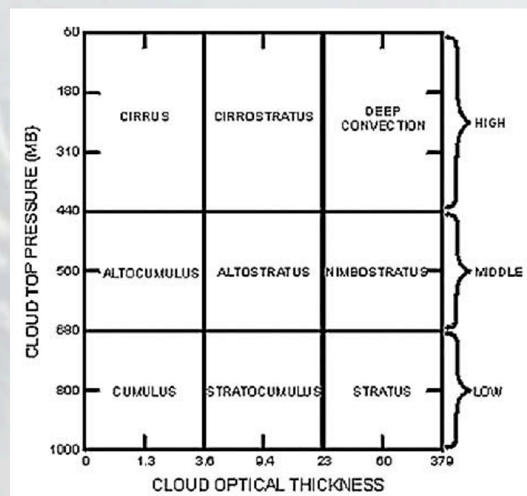
Radiative response of the hydrological cycle





- The visible and infrared provide complementary information about cloud types

- The impact of clouds on the pressure-broadening of trace gas lines can help determine cloud-top height



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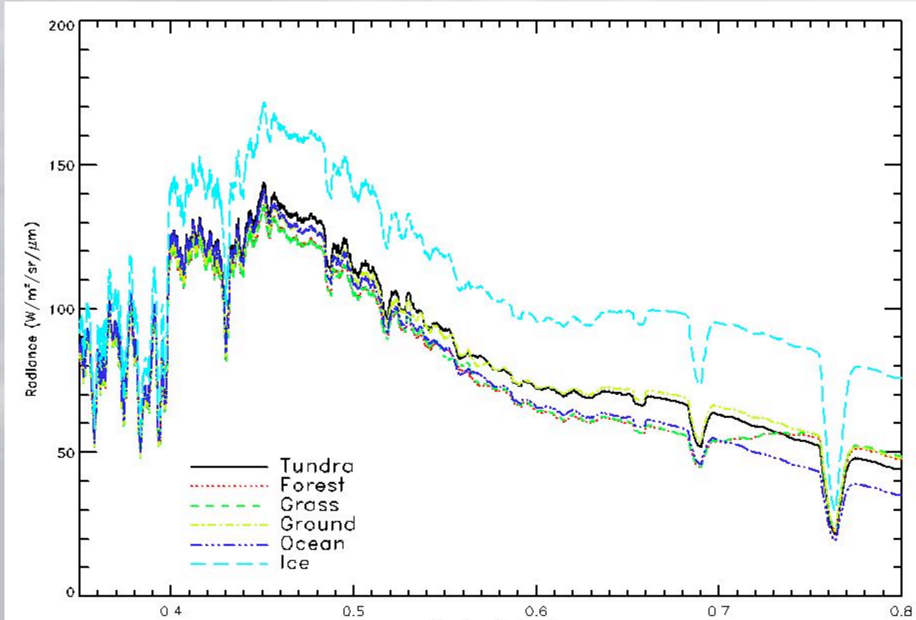
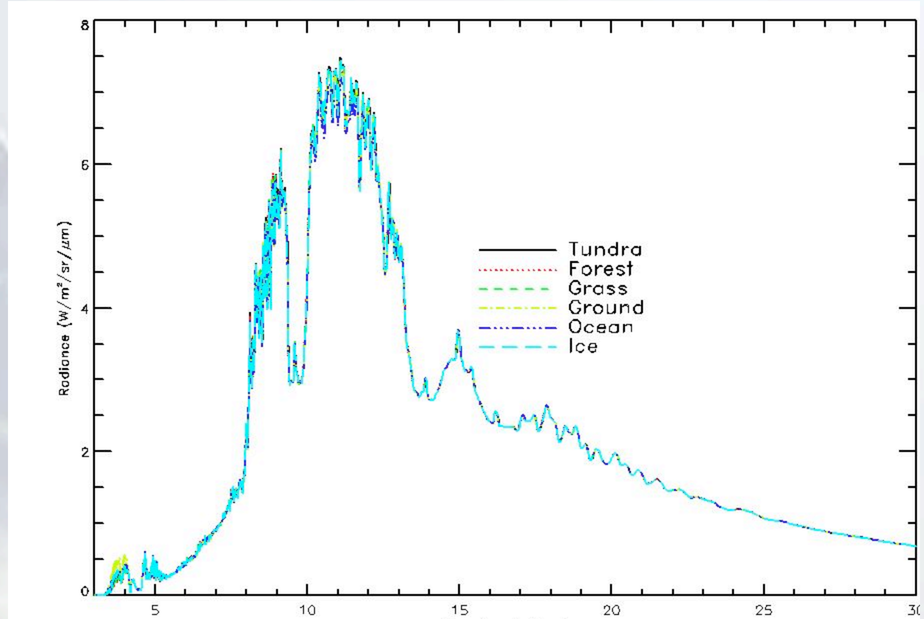
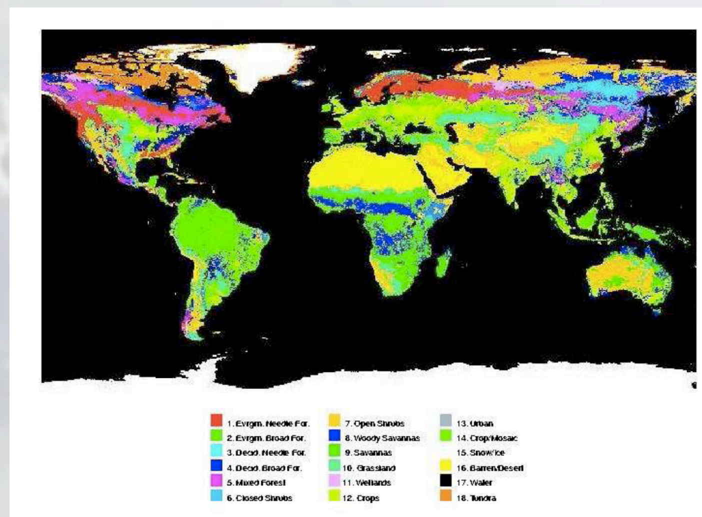
Radiative response from the surface





The variation in surface emissivity in the IR is small but relatively underexploited

Ice has a strong visible signature with some spectral dependence



International Geosphere Biosphere Programme (IGBP)
land use surface classification (Loveland and Belward, 1997).

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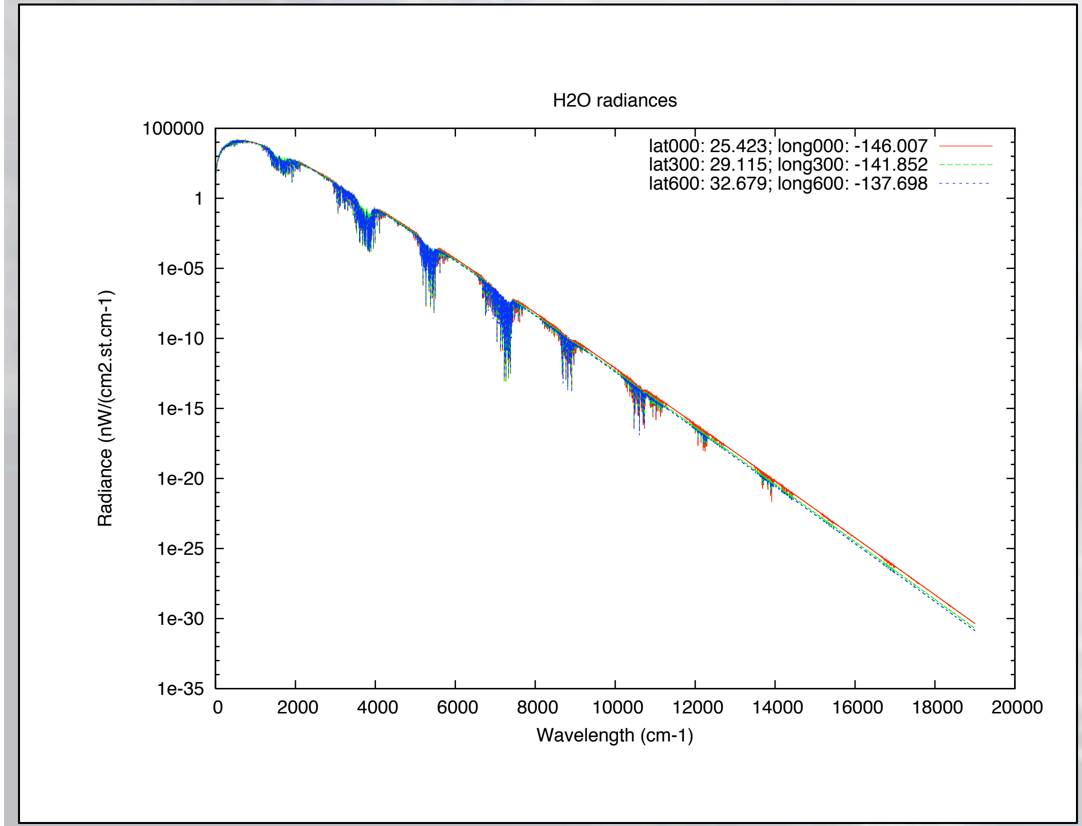
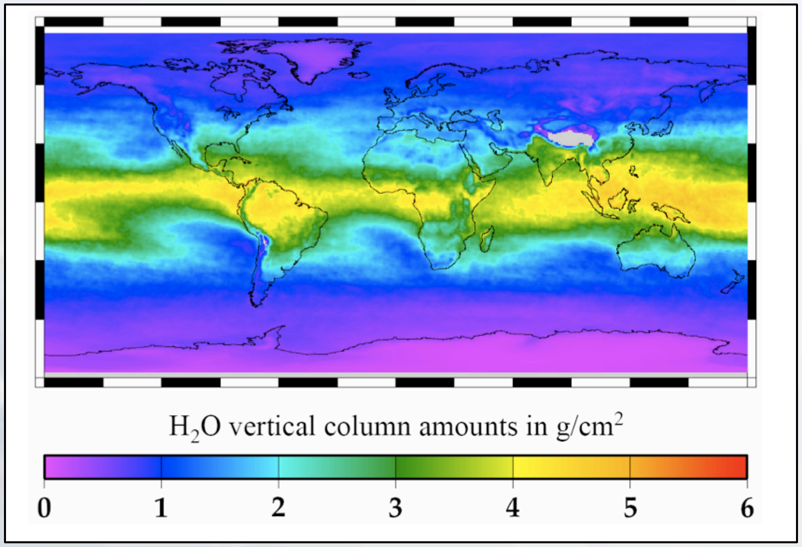
Water Vapor: the ties that bind





Water vapor columns have been retrieved in the visible, Mierech *et al*, *ACP* 2008

- Water vapor has a strong absorption throughout both the far-infrared, infrared, and visible bands
- Shown for H2O-only absorption
- Varies across the GPCI region.
- Could be used to cross-calibrate Vis and IR radiances

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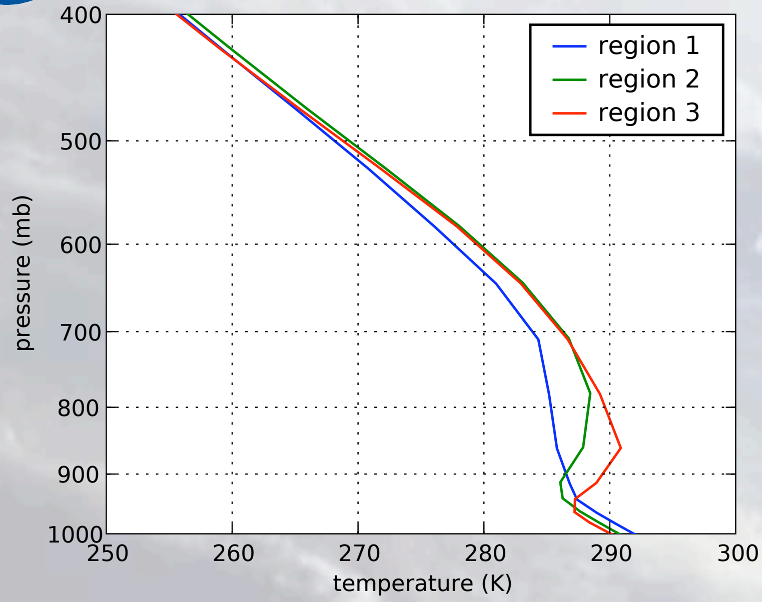
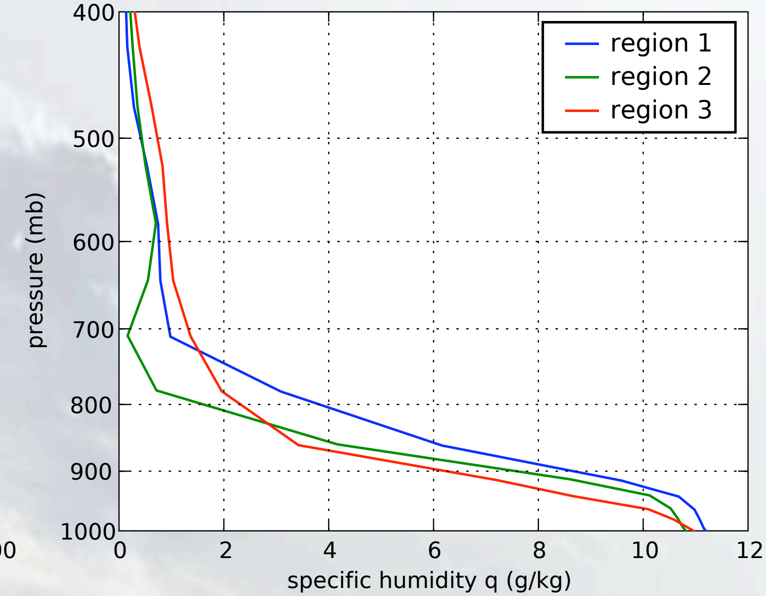
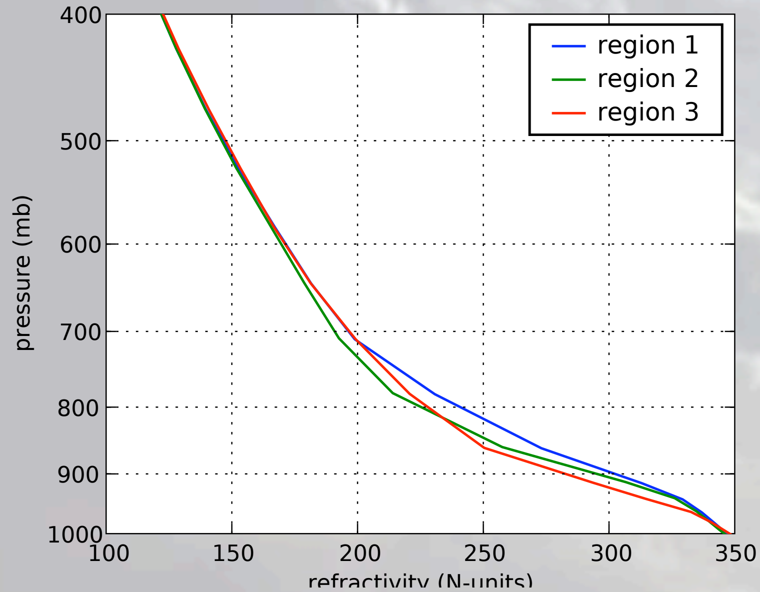
Peering through the clouds







GPS occultation can provide estimates of the temperature and water vapor in the presence of clouds

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Conclusions and Future Directions

- In order to improve climate predictions, the uncertainty in the radiative response of the hydrological cycle to anthropogenic forcing must be reduced
- The far-infrared, infrared, and visible spectra are sensitive water vapor, clouds, and snow/ice: the key variables that drive climate feedbacks
  - *Suggests that the information content of the combined spectra is higher than individual regions.*
- The spatial scales over which water vapor is distributed and clouds are formed are much less than 100 km
  - *Impact of finer spatial resolution of observations on predictability need to be investigated*
- WRF simulations over the GPCI region provides the necessary variation in cloud regimes to assess the information content of individual and combined spectral regions.
- We can assess the combined information content of the visible, IR, and GPS spectral regions with respect to individual regions.
- We plan to investigate the radiative response to different cloud regimes
- Forcing the WRF model with different GCMs under climate change scenarios could provide insight into the interaction of dynamics with clouds
- We hope to extend this analysis to include different viewing angles, i.e., off-nadir, and polarizations.

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