Assimilation of Satellite Cloud and Precipitation Observations in NWP Models: Report of a Workshop

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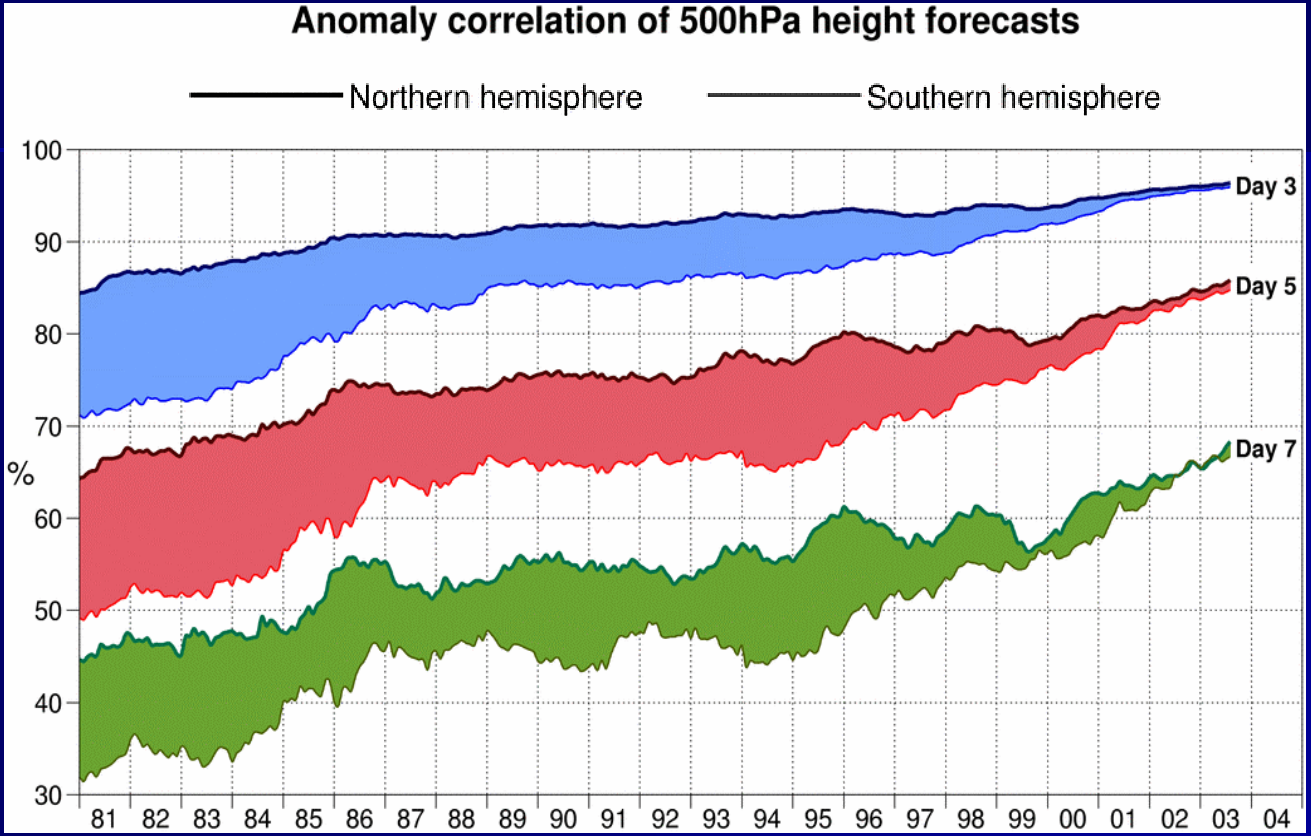
Skill of Weather Predictions



- Increased accuracy due to better models, observations, data assimilation, and computers

Observations in NWP

- Satellites provide over 90 % of data
- But most of the satellite radiances (about 75 %) are discarded because they are cloud- or rain-affected or redundant

Motivation for Assimilating Cloud and Precipitation Observations

- Improve forecasts: Cloudy/precipitating regions are sensitive ones for forecast impacts
  - Clouds cover more than 50 % of Earth; precip, 6 %
- Improve moist physics in models
- Develop better cloud data sets for climate and weather applications
- Define energy and hydrological cycles

Cloud-Precip Workshop

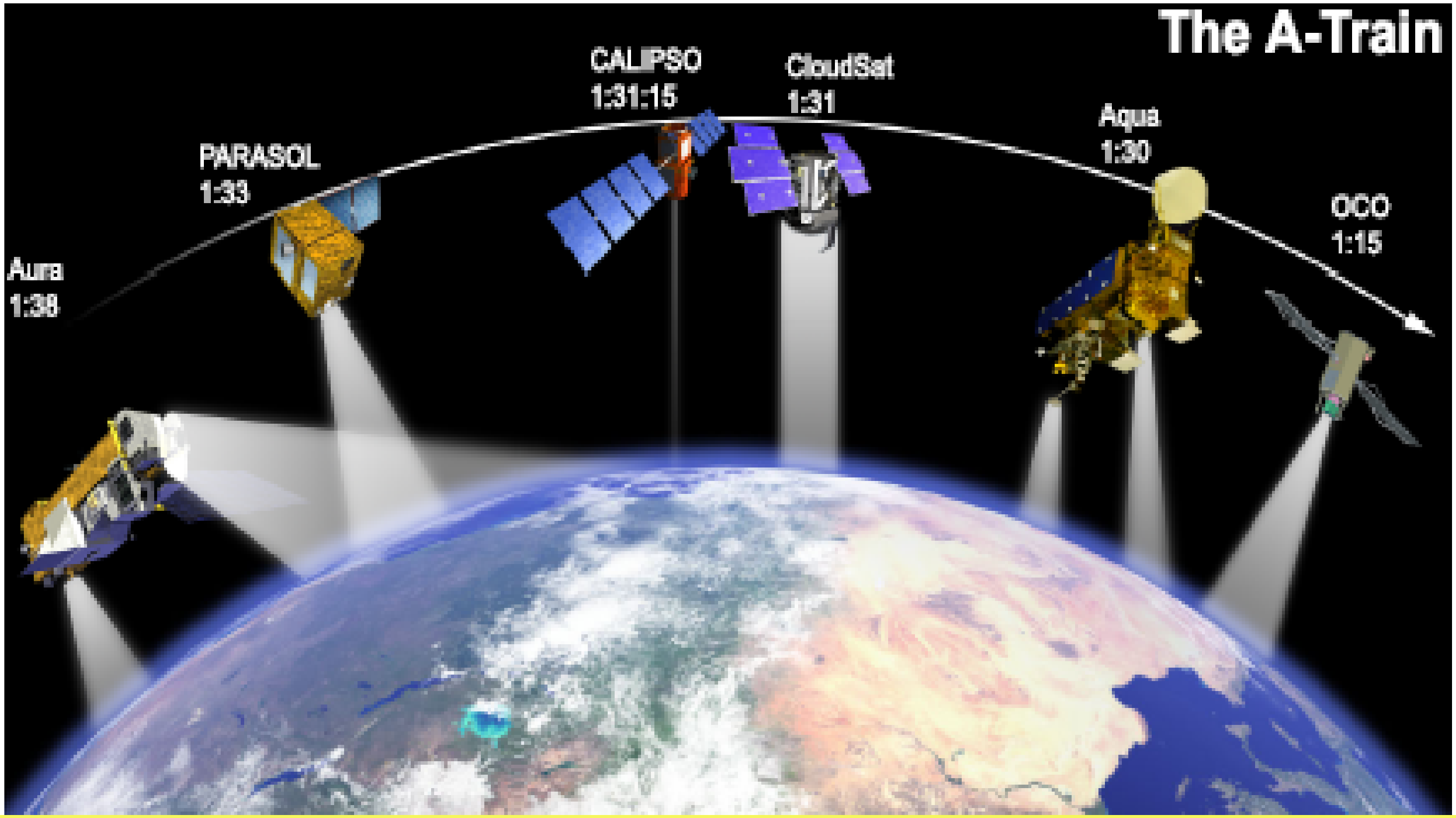
- Goal: accelerate progress in assimilating cloudy observations
- May 2-4, 2005; 45 international scientists
- Observations, modeling, assimilation
- Overviews, short talks, breakouts
- Output: Current capabilities, impediments to progress, recommendations

Observations
Current Capabilities- Instruments

- Passive - Global, 2.5 dimensional
  - Polar VIS, IR, and microwave imagers, and IR and microwave sounders
  - Geo VIS, IR imagers – frequent, time sequential
- Active - Global 3-dimensional observations
  - Scanning TRMM Precipitation Radar (250 m, 200 km swath)
  - Non-scanning CloudSat Radar (250 m, 2 km nadir)
  - Non-scanning Calipso 2-λ lidar (30-60 m, 5 km nadir),

Observations
Current Capabilities - Products

- Passive: Mostly cloud top or path integrated information; limited vertical structure
  - Outgoing radiances
  - Retrievals of:
    - Cloud amount, cloud top temperatures and heights, particle phase and Re, optical depths, LWP, IWP, rain rate
- Active: Vertical structure of clouds and precipitation
  - Reflected power
  - Retrievals of:
    - Precipitation particles
    - Cloud liquid water and ice content, and vertical cloud boundaries
    - Optically thin clouds - ice and water extinction profiles, cloud heights



By mid 2005, we expect to have a wide range of different sensors, active and passive, optical, infrared and microwave, hyper-spectral to coarse band, all approximately viewing Earth at the same time. We are left to pose a strategy that optimally combines these measurements, converting them to meaningful information with verified uncertainties. (Graeme Stephens)

Observations
Impediments to progress

- Inadequate ground-based validation observations
- Inadequate moist physics for clouds and convection (retrievals are constrained by model microphysics)
- Poor temporal sampling relative to time scales of precipitation development
- Lack of sensitivity to drizzle and snowfall
- Degraded temperature and water vapor observations in cloudy regions

Observations
Recommendations to accelerate progress

- Organize communication among and within the modeling, assimilation, and observation (remote sensing and in situ) communities regarding current problems and possible solutions; e.g., workshops on cloud **and** precipitation observation and modeling—leverage existing meetings whenever possible

Modeling Clouds and Precipitation
Current Capabilities

- Good predictions of clouds associated with large-scale organized systems
- Dynamics of operational NWP models handled well and not the largest error sources

Modeling Clouds and Precipitation
Impediments to Progress

- Physical parameterizations
  - Convection and planetary boundary layer
  - Cloud microphysics
  - Surface fluxes
  - Interactions between different physics schemes
- Poor knowledge of the statistical properties of clouds
  - Sub-grid variability of temperature, moisture, momentum, and various forms of condensate

Modeling Clouds and Precipitation *Impediments to Progress (Cont)*

- Lack of adequate staffing at some of major NWP centers
- Are cloud-resolving models able to reproduce salient radiometric signatures observed from space?
  - Problems will not be addressed just by increasing the spatial and temporal resolution of models alone

Modeling Clouds and Precipitation
Recommendations to accelerate progress

- Compare statistical distributions of satellite radiances (active & passive) against forecast radiances
- Develop improved moist convective schemes
- Simplify and linearize physics schemes
- Construct high-quality, independent cloud and precipitation verification data sets

Modeling Clouds and Precipitation
Recommendations to accelerate progress (cont)

- Are prognostic variables for precipitation needed?
- More effective discussions between modelers and data assimilators

Radiative Transfer
Current Capabilities

- Forward radiative transfer models for clouds and precipitation
- Analytic Jacobian schemes
- Community radiative transfer model (CRTM) framework

Radiative Transfer (RT)
Impediments to progress

- Different assumptions about cloud and precipitation properties in NWP and RT models
- Spatial inhomogeneity of clouds and precipitation
- Uncertainty in surface emissivity and reflectivity
- Lack of comprehensive data sets to assess RT schemes

Radiative Transfer

Recommendations to accelerate progress

- Work with modelers to better understand all assumptions used in NWP models
- Compare statistical distributions of satellite radiances and forecast radiances for cloudy conditions
- Develop a high-quality data set of satellite observations and in-situ information of cloud condensates to fully assess RT model performance
- Benchmark tests for fast RT model

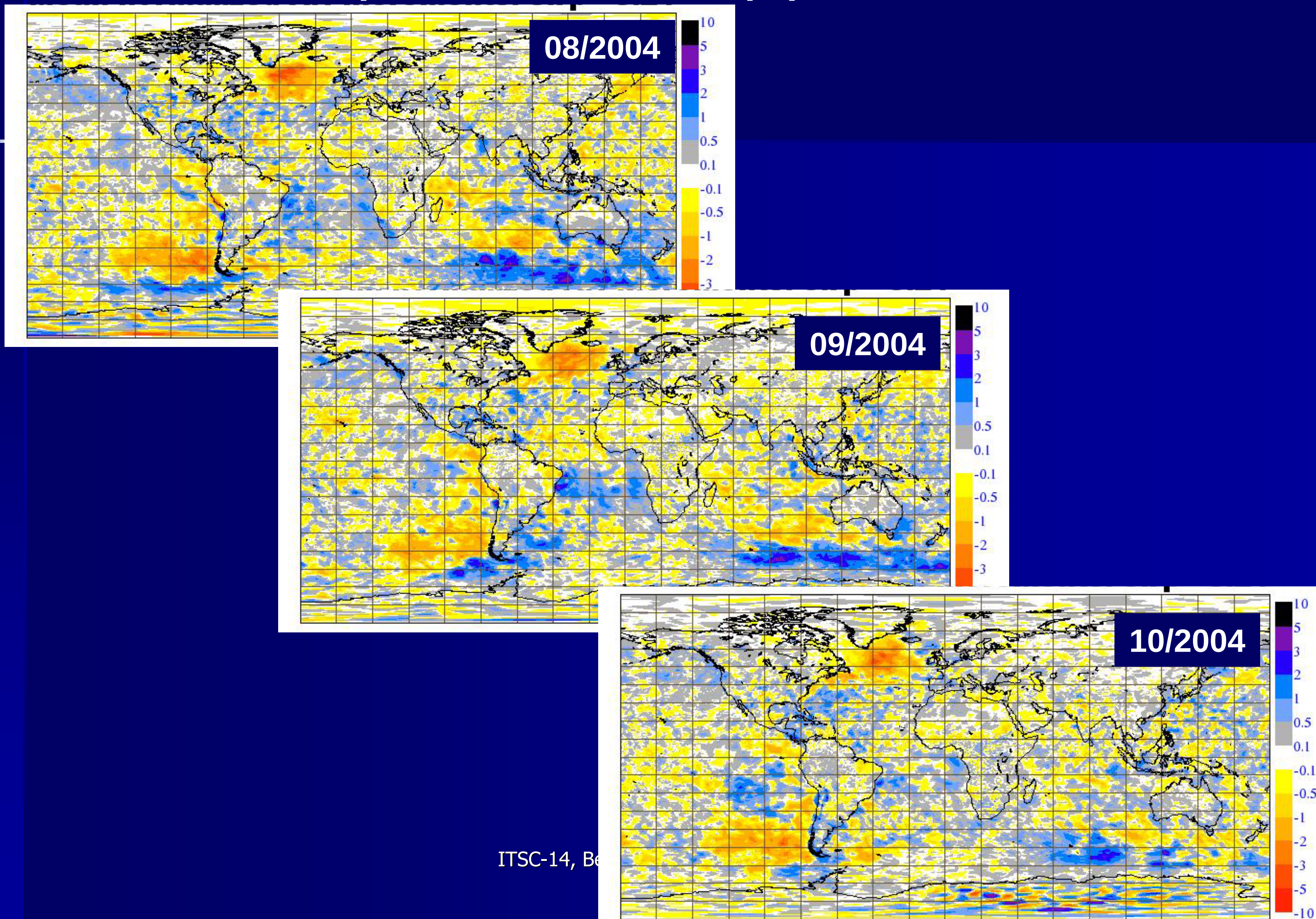
Assimilating Cloud and Precipitation Observations *Current Capabilities*

- Precipitation rates assimilated by some NWP centers (not variational techniques)
  - Significant but limited success
  - Improvements in model initial conditions not retained
- Some centers have active programs in variational assimilation
  - Average forecast impact is neutral
- Infrastructure in place
  - Data assimilation system must be improved

Variational Precipitation Assimilation: SSM/I radiances

Mean normalized TCWV analysis increments

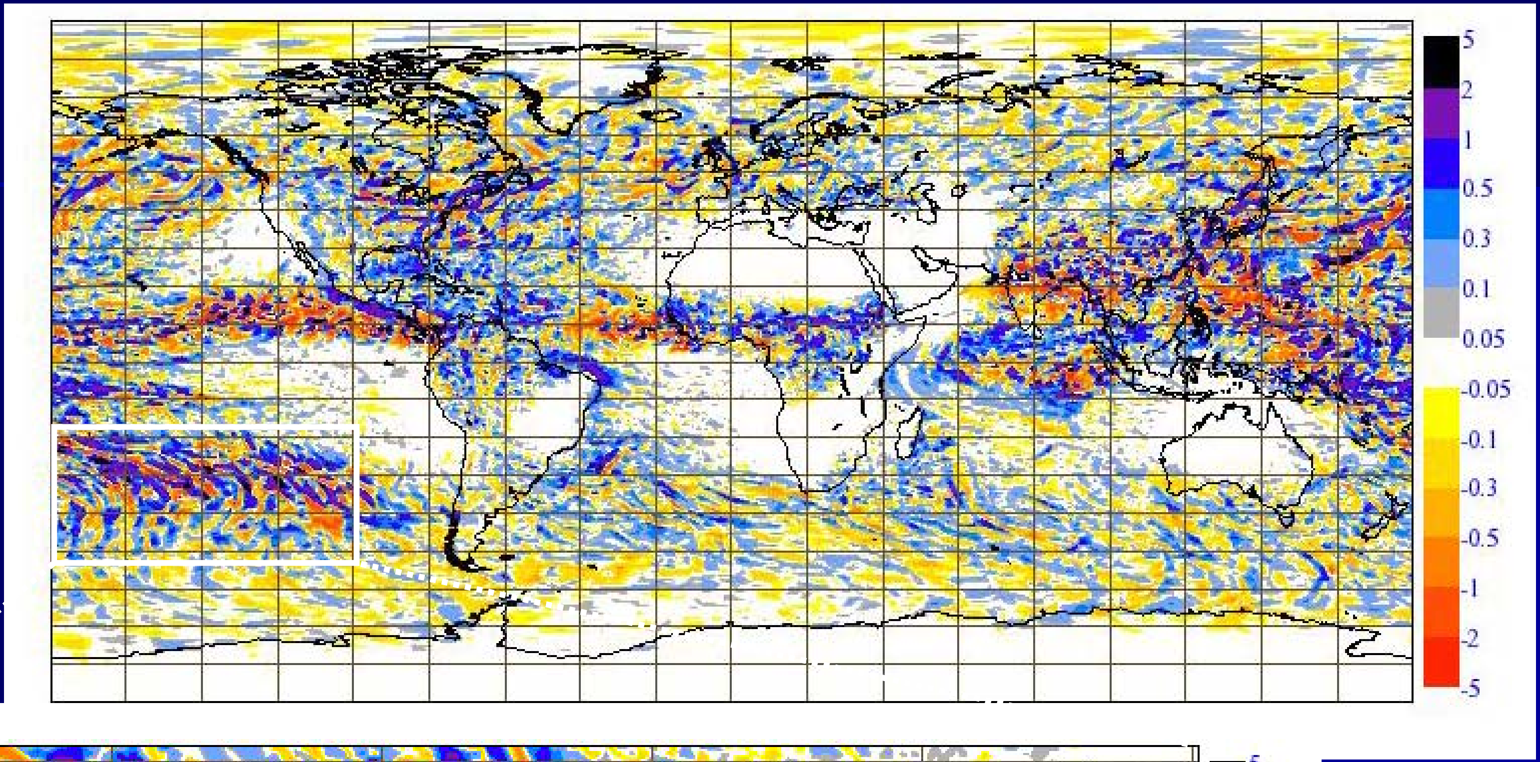
Experiment – Control (%)

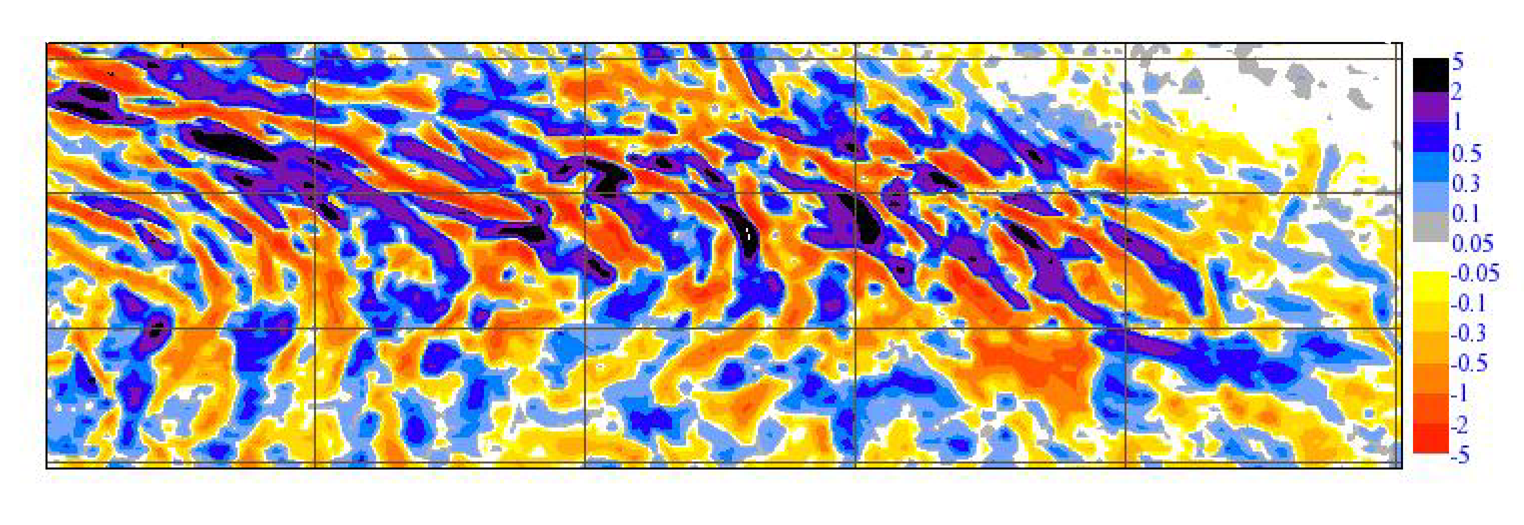


Variational Precipitation Assimilation

Mean 36h-12h Precipitation Difference, 200408

Experiment - Control (mm)





Assimilating Cloud and Precipitation Observations *Impediments to Progress*

- Fundamental difficulty of the problem
  - Broad range of space and time scales
  - Large and non Gaussian representativeness errors
  - Highly nonlinear moist physics
  - Poorly observed and modeled processes, e.g., moisture convergence and convection
- Basic issues not being investigated
  - Characterization of predictability limits
  - Little work at universities
  - Lack of critical assessment of past work

Assimilating Cloud and Precipitation Observations
Recommendations to Accelerate Progress

- Develop/implement capabilities even if methodology not mature
  - Monitor precipitation and cloud observational increments
  - Standardize and monitor precipitation and cloud forecast errors
- Support basic research, particularly at universities
  - Predictability
  - Adjoint-derived sensitivity analysis
  - Jacobian examination of parameterization schemes
  - Statistical considerations in sub grid modeling

Overarching Recommendation

- Cloud and precipitation assimilation require combined effort between observation, modelling and data assimilation communities
- These subjects are often entirely covered within NWP community but sometimes miss interaction with non-NWP communities of both modelling and observation

Main Community Interaction Topics

From modelling/observation for data assimilation:

- development of better model parameterizations for cloud and precipitation formation (special emphasis on convection, sub grid-scale representation of clouds/precipitation)

- information on constraining variational assimilation from observations (e.g. cloud/rain type, particle size distributions, cloud top height etc.)

- definition of background/modelling/observation errors

From data assimilation for modelling/observation:

- observational data usage in operational NWP systems for improving weather forecasts (severe weather)

- provision of comprehensive model evaluation tools (example: simulation of multi-spectral radiances to be compared to VIS/IR/MW satellite observations)

Main Community Interaction Topics (cont)

- Permanent communication between, e.g., GPM ground validation program and data assimilation community to avoid mismatch between Ground Validation program and requirements of data assimilation systems in 5 years

- Communication between operational and experimental (academia) data assimilation communities for better education of young scientists

Last Slide

- Workshop Organizing Committee
  - Ron Errico, Co-Chair, NASA GMAO
  - George Ohring, Co-Chair, NOAA/NESDIS
  - Fuzhong Weng, NOAA/NESDIS
  - Peter Bauer, ECMWF
  - Francois Mahfouf, CMC
  - Joe Turk, NRL
  - Ken Campana, NOAA/NCEP
- Workshop Presentations Posted at:

  http://www.jcsda.noaa.gov/CloudPrecipWkShop/program.html