How can we use Satellite CDRs to support climate modelling?

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Met Office

Acknowledgements
Nick Rayner, Lizzie Good, SMHI, ECMWF
Topics covered

• How is satellite data used for climate research?
• Satellite climate datasets available
• Examples of use of datasets for climate modelling:
  • Climate monitoring and attribution
  • Validating climate model processes
  • Supporting climate services
  • Input to reanalyses
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<table>
<thead>
<tr>
<th>GCOS ECVs</th>
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STATE OF THE CLIMATE IN 2016

Special Supplement to the Bulletin of the American Meteorological Society Vol. 98, No. 8, August 2017
Assessing the State of the Climate

How do modellers use satellite climate datasets?

1. Evaluate the physical processes most relevant to reducing uncertainty in climate predictions (e.g. cloud, radiation budget, hydrological cycle, carbon cycle, surface processes)

2. Inform & prioritise key areas for developing and improving climate models

3. Assimilation in reanalyses (atmosphere, ocean or land)

4. Initialising seasonal to centennial model predictions

5. Provide observational constraint for model intercomparisons (e.g. CMIP)

6. Constraining climate model projections and attribution studies (natural and anthropogenic)
User survey on use of climate datasets

<table>
<thead>
<tr>
<th>GCOS ECV</th>
<th>Model Initialisation</th>
<th>Prescribe Boundary Conditions</th>
<th>Re-analyses</th>
<th>Data Assimilation</th>
<th>Model Development and Validation</th>
<th>Climate Monitoring/Attribution</th>
<th>Q/C in situ data</th>
<th>Climate process study</th>
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Key characteristics of good CDRs

- Simple documentation on datasets for modellers
- Uncertainty provided with data (e.g. from ensembles)
- Long term preservation of data archives
- Seamless access for users (e.g. Earth System Grid Federation for modelers)
- CDRs openly and independently verified, validated and assessed for their utility
- Consistency ensured with related ECVs
Consistency between datasets is important

**a. N34 SST Timeseries**

ENSO El Nino Southern Oscillation: Nino3.4 timeseries [190E/240E, 5S/5N]

CCI SST slightly warmer max SST than HadISST. CCI Clouds lower minima than CLARA. EC-Earth AMIP5 (prescribed SST), captures cloud variability, but higher than observed.

**b. N34 GLT Timeseries**

Clouds (°C)

CCIv2

CLARAa2

ECE AMIP

Nino3.4 SST timeseries

CCI SST/Cloud cci

yrs: 1992-2008 mean: -0.03 sa34: 0.14 en34: 0.61

Reference
Hovmöller diagrams for Pacific Ocean 5S-5N normalized anomalies for CCI SST, Sea Level, Chlorophyll and Cloud cover and longitudes between 100E to 270E
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Reprocessing Activities
Fundamental Climate Data Records

NASA (especially very old satellites)
NOAA STAR
ESA
EUMETSAT (CAF, CM-SAF)
EU (FIDUCEO, ..)
Other space agencies
Reprocessing Activities
Climate Data Records

ESA (GlobXXX, Climate Change Initiative)
EUMETSAT (CAF, CM-SAF)
EU (Copernicus, FIDUCEO)
NASA MEaSUREs Program
NOAA STAR (…)
SCOPE-CM
CCI+

- Long, stable satellite datasets for climate scientists
- Open and free access to the data: cci.esa.int
- Nine new Essential Climate Variables starting in 2018
- Research & development on already existing ECVs
- Knowledge Exchange activities
- Cross ECV activities
The scientific context for CMIP6 is the WCRP Grand Science Challenges:
1. Clouds, Circulation and Climate Sensitivity
2. Changes in Cryosphere
3. Climate Extremes
4. Regional Sea-level Rise
5. Water Availability
6. Near-Term Climate Prediction
7. Biogeochemical Cycles and Climate Change

Eyring et al., GMD, 2016
Observationally-based datasets for climate model evaluation. Obs4MIPs is a limited collection of well-established and documented datasets for the CMIP5 model output requirements and made available to all. Each Obs4MIPs dataset corresponds to a field that is output in one or more of the CMIP5 experiments.

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Monitoring and attribution

- Long-term records allow evaluation of variability in models
- Example shows Earth radiation budget since 1985
- Provides another perspective on model performance
- Also need long time series to examine trends and extremes

Stratospheric temperatures from SSU

1. Differences between 2 independently processed satellite datasets
2. CMIP5 models differ from observations
3. Impact of Pinatubo well modelled
4. Post eruption change in stratospheric temperature not so well modelled
Satellite and Model Temperature Comparisons

Santer et al 2017

Satellite data from MW sounders

37 Models from CMIP-5

Impact of major volcanic eruptions clear but models tend to overestimate or not represent them.
Satellite vs in-situ LST Time series


Anomaly correlations ~0.9.
~90% of CDR anomalies within CRUTEM4 uncertainties.

- Time series of LSTngt and T2m anomalies (August 1995 – March 2012)
- CRUTEM4 and LST Climate Data Record (CDR) agree remarkably well
- Data sets are completely independent
- Some evidence for temporal instability in CDR, particularly LSTday

Lizzie Good et al, JGR-Atm, 2017
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Creation of Early Satellite Climate Datasets

First Satellite data used to validate climate models
Earth Radiation Budget Measurements
Nimbus-6 ERB 1975 → CERES 2019

ISCCP Project started in 1982 but it took 15 years for modellers to use ISCCP data from Geo imagers 1983 – 2009 thanks to COSP ISCCP simulator

How to reduce this time?
Models are increasing in complexity and resolution - From AOGCMs to Earth System Models with biogeochemical cycles -

130 km resolution orography

25 km resolution orography

https://www2.ucar.edu/news/understanding-climate-change-multimedia-gallery
Higher resolution and regional detail

**Global model run at 10 km resolution**

Shows rainfall, cloud water and ice, SST, sea ice, snow.

We wish to evaluate this level of detail at the global scale.

Credit: Malcolm Roberts (Met Office) & Pier Luigi Vidale (University of Reading)
Model Evaluation: baseline comparisons

- Examine model-simulated climatologies
- Compare with long-term data sets
- Establish mean model biases
- Forms basis for more detailed evaluation

Source: IPCC AR5, Chapter 9
Need for Obs Simulators

Geophysical measurements (e.g. radiance, bending angle)

Retrieve model variables

Model grid variables (e.g. temp, water vapour, wind, etc)

Compare in model space
Need for Obs Simulators

- Geophysical measurements (e.g. radiance, bending angle)
- Model grid variables (e.g. temp, water vapour, wind, etc)

Compare measured and simulated measurements

Compute satellite measurements using simulator (e.g. COSP)
Need for Obs Simulators

Geophysical measurements
(e.g. radiance, bending angle)

Model grid variables
(e.g. temp, water vapour, wind, etc)

Both approaches are useful depending on the ECV
Use of satellite data by modellers becoming more sophisticated as we aim to make optimal use of the information to improve physical processes in models.
Evaluation of model in radiance space

- Allows direct comparison with measured radiances, etc
- Avoids ambiguities associated with comparing to retrieved quantities
- Example shows HIRS Channel 12 in previous version of Hadley Centre model
- RTTOV is now part of the COSP simulator

For further details see:
http://cfmip.metoffice.com/COSP.html
Comparison in Geophysical space UTH

UTH is relevant to anyone interested in the radiative heat balance of the clear troposphere. Upper-tropospheric moisture important for tracking, understanding, modelling and predicting convection and advection at low latitudes.

Example uses for UTH:
• Model evaluation
• Variability analysis
• Predictability research
• Physical process studies
• Monitoring

CM SAF product based on microwave observations, which are nearly all-sky.

CM SAF UTH v1 product minus ERA-Interim UTH for NOAA-18 (2006-2015, all overpass times)
Use of COSP in model development

(Williams and Bodas-Salcedo, *GMD*, accepted)

**CALIPSO**

**CloudSat**

- Software tools such as COSP enhance the value of comparisons between models and observations.
- Promotes wider use of the observations by modellers but also a positive feedback to the data providers - modellers tend to use the data in novel and interesting ways, building links and enabling production of new/improved data sets, e.g. targeted at particular model issues.
CM-SAF Solar Flux verification of ECMWF 3 day forecast

Normalized TOA reflected solar flux

Skill relative to ERA-Interim

- NH Extratropics
- Tropics
- SH Extratropics

• Understanding the drivers of sea level variability (incl. ocean reanalysis)

• Assessment of seasonal-to-decadal prediction skill

• Climate and ocean model evaluation and development

• To validate model estimates of regional variability for sea level projections
Vegetation phenology observations for model evaluation

Satellite observations vs JULES land surface model

Example: **Start of Season**

- Based on observed NDVI → (Satellite, ESA SPOT-VGT)
- Based on modelled NDVI → (Modelled, JULES)

Contributing to various projects:

- **land cover cci**
- **CRESCENDO**
Vegetation phenology observations for model evaluation
Satellite observations vs JULES land surface model

Example: **Start of Season**

Based on observed NDVI →
(Satellite, ESA SPOT-VGT)

**Mediterranean (seasonal dry) climate areas**
Observed Start of Season is 5-7 months LATER than modelled

**Possible reason:** JULES defines generic Plant Functional Types that do not represent the drought-adapted characteristics of species in seasonally dry climate zones.

...current focus of research.

Based on modelled NDVI →
(Modelled, JULES)
## Metrics for Climate Model assessment

**ESA CCI datasets**
- greenhouse gases
- ozone
- aerosol
- soil moisture
- sea ice
- cloud
- SST

**Assessment of climate models using ESMVal tool for several CCI datasets**

**Climate models**

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*From: Lauer et al. (2016), Remote Sensing of Environment*
Decadal prediction: Global mean surface temperature anomaly

Requires data for both initialisation and verification of forecasts.

D. Smith et al., Science 2007
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Example climate service:

Need:
- Near-real time, short-delay and static ECV products to be more consistent

**Forecasts initialised daily**
- Ocean and atmosphere ECVs, soil moisture

**Hindcasts initialised a few times a month**

**Advice on coming season**

**Verification**

**Monitoring of recent conditions**

**Short-delay updates to globally-complete ocean and atmosphere ECVs**

**Static, globally complete products of air temperature, precipitation, SST, pressure, etc**
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Towards a coupled earth system

**Climate Change**

**Reanalyses Produced at ECMWF**

### Atmosphere/land
1) 1979 - 1981 FGGE
2) 1994 - 1996 ERA-15
3) 2001 - 2003 ERA-40
4) 2006 - ... ERA-Interim
5) 2016 - ... ERA5

### Including ocean waves

### Ocean
- 2006 ORAS3
- 2010 - ... ORAS4
- 2016 - ... ORAS5

### Including sea ice

### Centennial
- 2013 - 2015 ERA-20CM/20C
- 2016 CERA-20C

### Enhanced land
- 2012 ERA-Int/Land
- 2014 ERA-20C/Land
- 2017 - ... ERA5L

### Atmospheric composition
- 2008 - 2009 GEMS
- 2010 - 2011 MACC
- 2017 - ... CAMS
Uncertainties in Reanalysis reduce with more and better observations

Sub-daily ensemble spread of upper-air temperature averaged over March–April–May
Newly reprocessed data sets

- Radiances: SSM/I brightness temp from CM-SAF, METEOSAT from EUMETSAT
- Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT, GOES-8 to 15, AVHRR METOP and NOAA
- Scatterometers: ASCAT-A, ERS 1/2 soil moisture
- Radio Occultation: METOP GRAS, COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x
- Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura MLS, OMI
- Altimeter: ERS1/2, ENVISAT, Jason-1

Extra data (not used in ERA-Interim)

- lack of infrastructure ERA-Interim
- IASI, ASCAT, ATMS, Cris, MWHS2, Himawari-8

Typically the latest instruments:

**ERA5 is more future proof!**

Improved data usage

- all-sky vs clear-sky assimilation,
- latest radiative transfer model,
Satellites have now been in orbit for >40 years which allows trends to be inferred and compared with climate model predictions.

Satellite FCDRs are now being generated by space agencies and CDRs are being generated by several centres.

Data portals for satellite climate data records (e.g. CCI, EUMETSAT, Obs4MIPS, NCEI) have been established.

Observation simulators for climate model comparisons are a key part of exploiting satellite data for climate model process studies.

The CMIPs are providing a rich source of model predictions to compare with satellite data.

Latest climate quality reanalyses assimilating both FCDRs and CDRs.
Any questions?