STATUS OF EUMETSAT STUDY ON RADIO OCCULTATION SATURATION WITH REALISTIC ORBITS

EUMETSAT

ECMWF

Overview

- Study Background
  - Early “random” distribution study results
  - Updated realistic study objectives
  - Scenarios investigated
  - EDA (Ensemble Data Assimilation)
- COSMIC-2 Impact Investigation
- COSMIC-2 Polar Mitigation Investigation
- Jason-CS Impact Investigation
- Summary

Background: Random Distribution ESA/ECMWF Study*

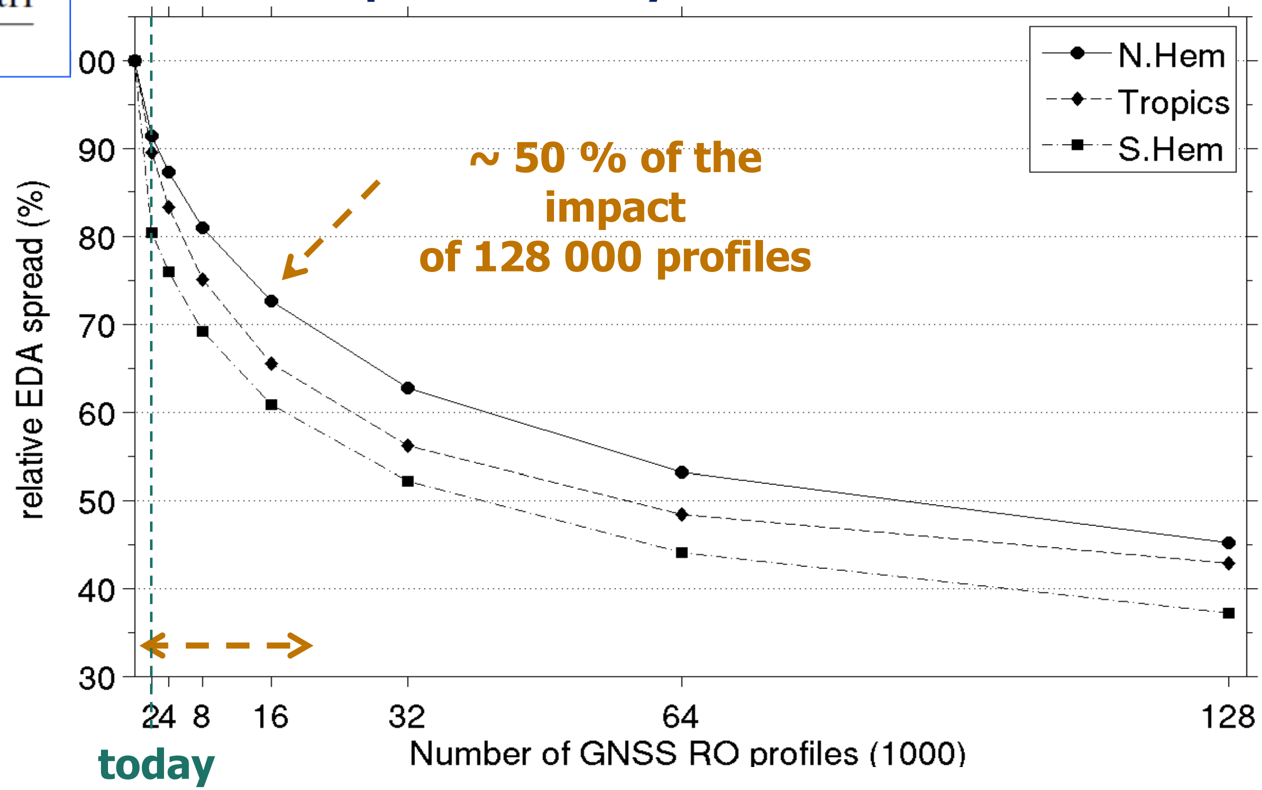
- Initially it was unclear whether there is a saturation number of radio occultation (GNSS-RO) observations, beyond which the NWP impact would be negligible
- In October 2011, ESA initiated a study with ECMWF on “Estimating the optimal number of GNSS radio occultation measurements for Numerical Weather Prediction and climate reanalysis applications”:
  - Use “Ensemble of Data Assimilations” (EDA) analyses approach to estimate optimal number of GNSS-RO.
  - Used up to 128,000 simulated observations per day (currently about 3,000 real observations)
  - **Conclusion: 16,000 occultations per day gives 50% improvement of 128,000 observations**
  - **Limitation: assumed randomly distributed events in time and space**
- Study results led to recommendations at IROWG and WMO workshops to aim for a constellations to make 10,000 to 16,000 GNSS-RO observations operationally available per day

* F. Harnisch, S. B. Healy, P. Bauer and S. J. English, 2013: Scaling of GNSS radio occultation impact with observation number using an ensemble of data assimilations, Mon. Wea. Rev., 141, 4395-4413. doi: http://dx.doi.org/10.1175/MWR-D-13-00098.1

Background: Random Distribution Results

$$\frac{\text{EDA\_}n - \text{EDA\_ctrl}}{\text{EDA\_ctrl}}$$

Temperature analysis at 100 hPa



- Large improvements up to about 16 000 profiles per day
- Even with 32,000 – 128,000 occs/day still improvements visible

  → no evidence of saturated impact up to 128 000 profiles (although the additional impact per observation is decreasing)

ECMWF EUMETSAT

Background: Realistic Distribution EUM/ECMWF Study

- To address the random distribution limitation, EUMETSAT initiated a study on "Impact of different Radio Occultation Constellations on NWP and Climate Monitoring" in 2013. Proposal received from ECMWF was selected, study was kicked-off in March 2014. Main study aims/setup:
  - Work with simulated LEO and GNSS orbits for realistic occultation distribution
  - Identified different scenarios to address the following questions/issues:
    - **Refine earlier ESA/ECMWF study with realistic future satellite orbits**
    - **Assess best observation constellation to achieve best distribution in space and time**
    - **Provide guidance on RO instrument deployments on future LEO satellites**
  - Study duration 18 month, final results in Q3/2015
  - Study period investigated: July 2008
  - Addresses/Relevant for CGMS Actions/Recommendations (summary also provided in IROWG-4 IROWG-WP-13 document):
    - Plenary IV.4 A40.06 (provides info)
    - WGII A40.23 (suggest closure; IROWG-4 workshop April '15, CEOS agencies present)
    - WGIII/2.1 R41.14 (provides info)
    - WGIII/2.2 A42.06 (suggest closure; study results presented early and at IROWG-4)
  - Main ECMWF scientists involved: Sean Healy, Andras Horanyi, (Florian Harnisch)

Background: Scenarios Selected

- Focus was time frame of > 2020, thus including missions:
  - EPS-SG, 2 satellites carrying RO with up to 4 GNSS observed
  - fully deployed COSMIC-2 constellations (full deployment from launch might take up to 2 years)
  - Jason-CS carrying an RO receiver
  - LEO opportunity missions in sun-synchronous orbit carrying RO receiver

- Scenarios investigated included:
  - impact of not having COSMIC-2 Equator and Polar
  - impact of not having COSMIC-2 Polar
  - adaptation strategies to compensate for COSMIC-2 Polar
  - impact of observing 4 GNSS in one orbit, thus having > 5,000 occultations at specific local solar times (EPS-SG, sun-synchronous orbits)

- *Full Scenario List available in WP and in Slide Backups*

Background: EDA Method

- Goal: derive information on the analysis and short-term forecast error statistics (uncertainties) of the NWP model system

- Account properly for the main analysis error sources in the NWP system that come from the:
  (1) observations, (2) model background and (3) model

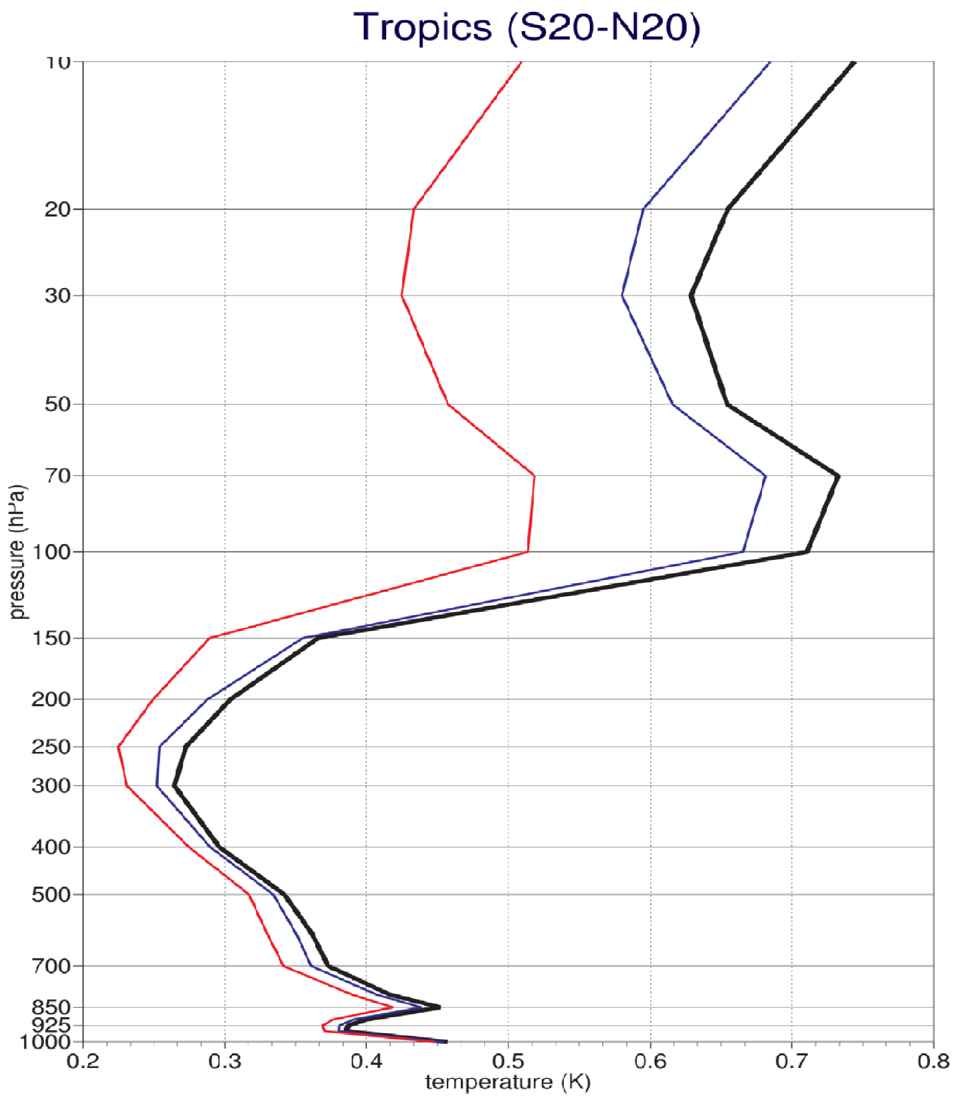
- Run an ensemble of independent 4D-Var data assimilation cycles
  → ensemble of analyses and forecasts provides information on analysis and forecast <u>error statistics</u>

(This is a well established method primarily used for data assimilation; see for instance Žagar et al. 2005; Isaksen et al. 2010, Bonavita et al. 2010, 2012)

→ Different to OSSEs, which simulate all observations from a known truth - the nature run.

COSMIC-2 Impact Investigation

COSMIC-2 Eq Impact: Temperature (tropics)

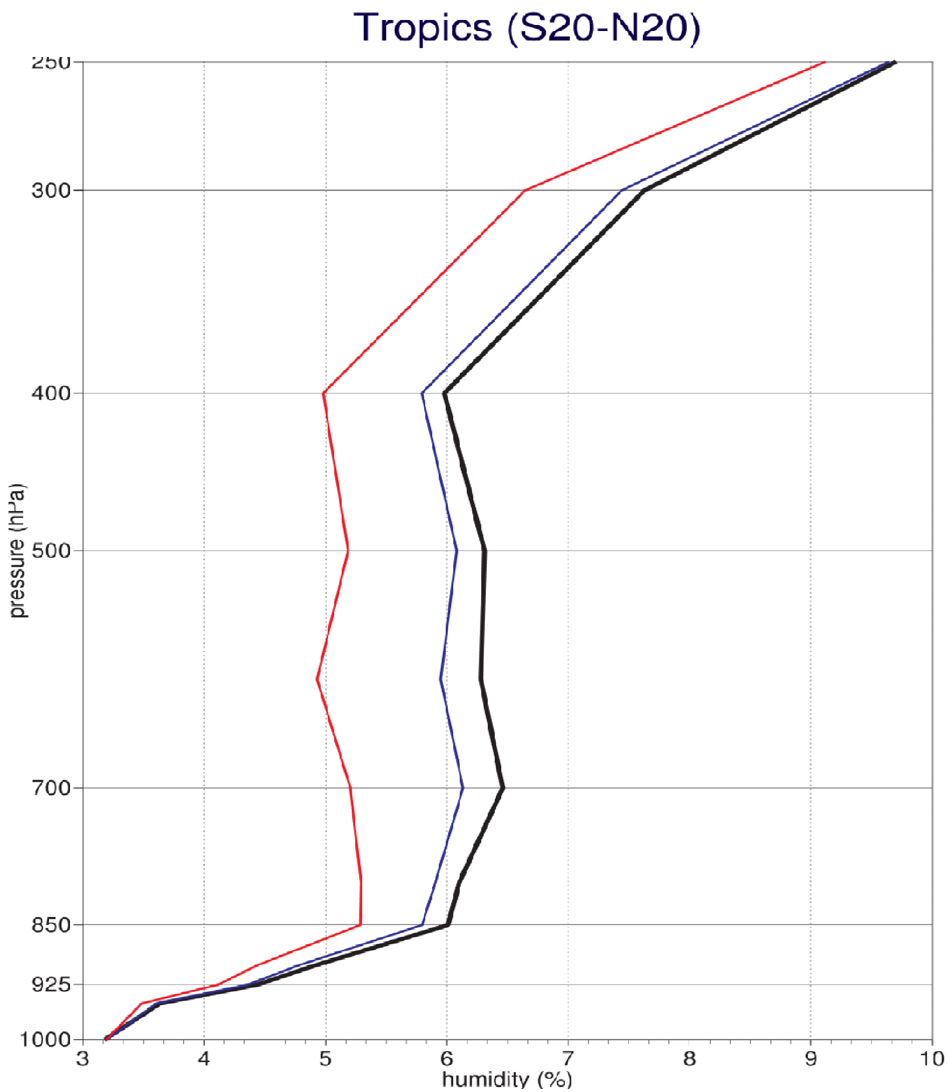


No RO

EPS-SG (2 sats with GPS, Galileo)
~2800 occs /day

EPS-SG+C2 Eq
~10500 occs/day

COSMIC-2 Eq Impact: Rel. Hum. (tropics)

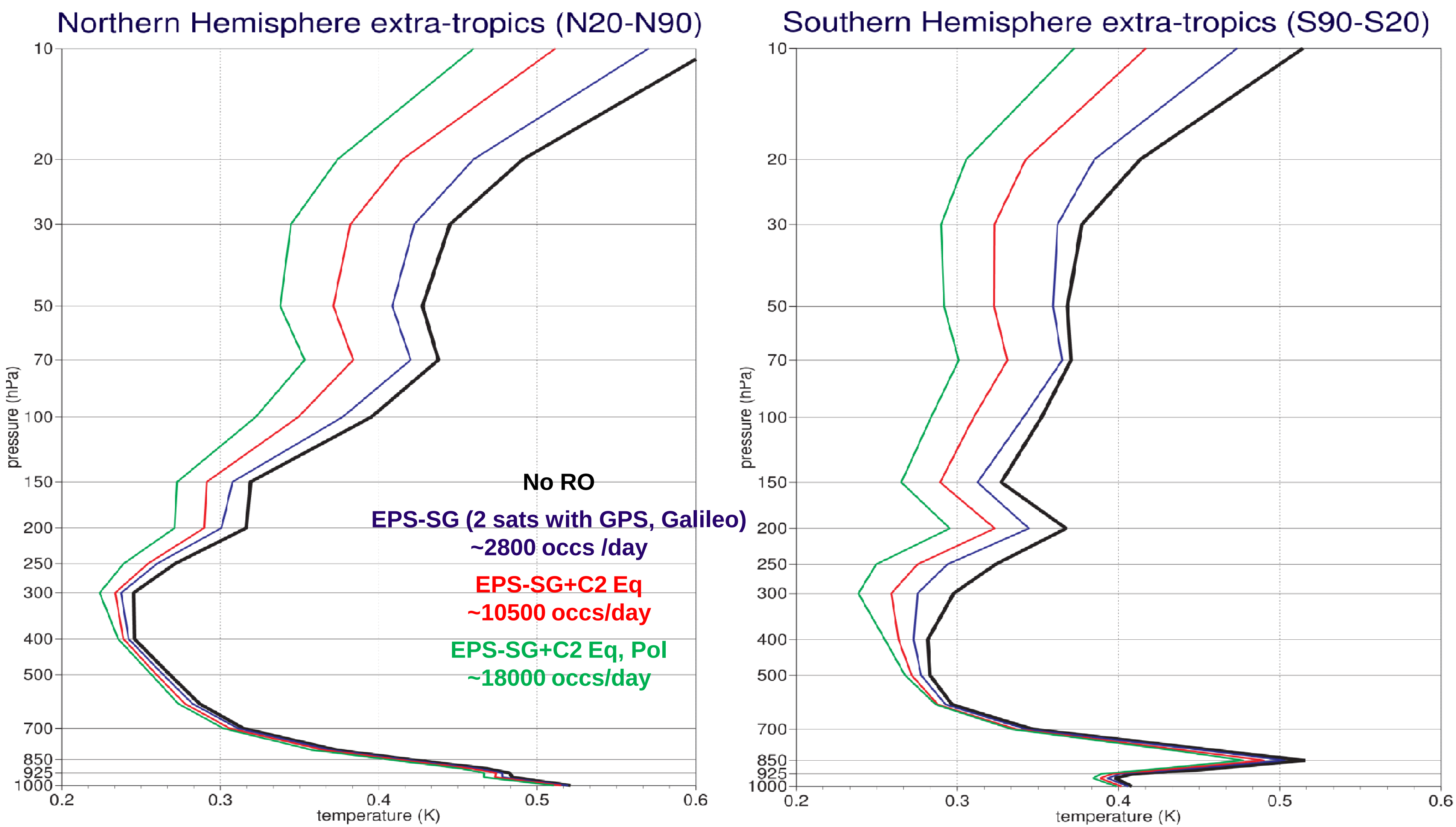


No RO

EPS-SG (2 sats with GPS, Galileo) ~2800 occs /day

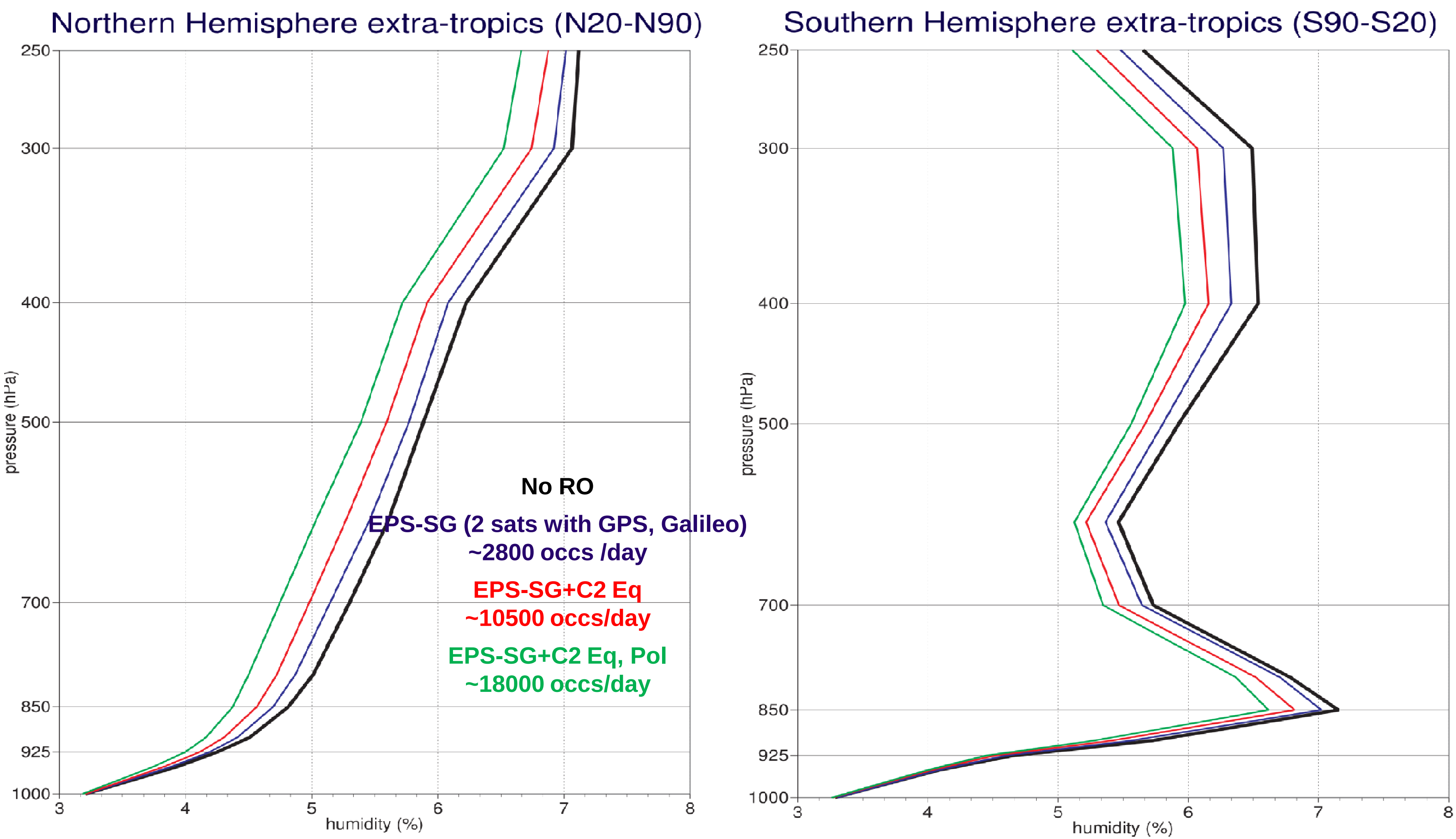
EPS-SG+C2 Eq ~10500 occs/day

COSMIC-2 Impact: Temperature (extra tropics)



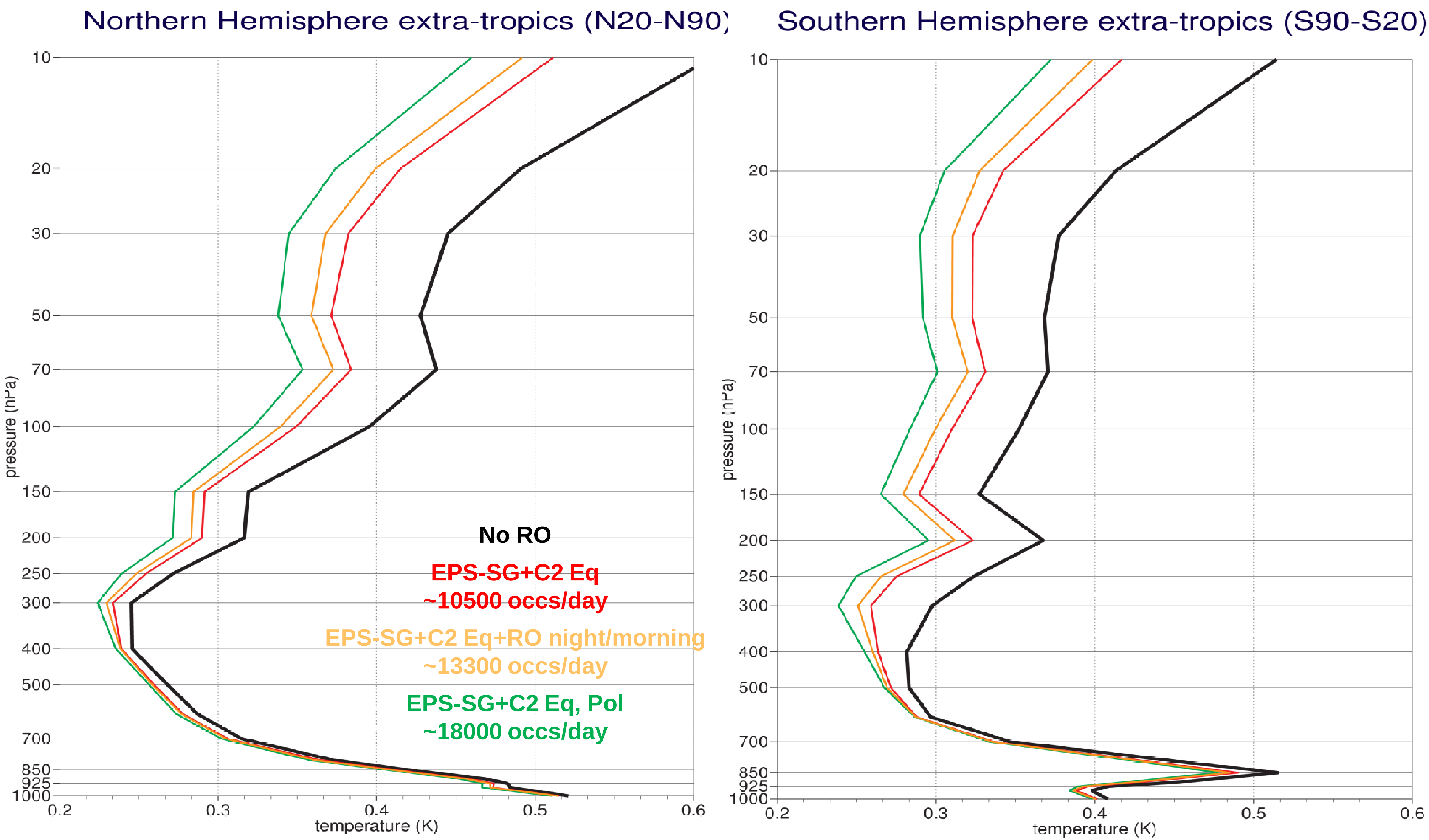
ECMWF EUMETSAT

COSMIC-2 Impact: Rel. Hum. (extra tropics)



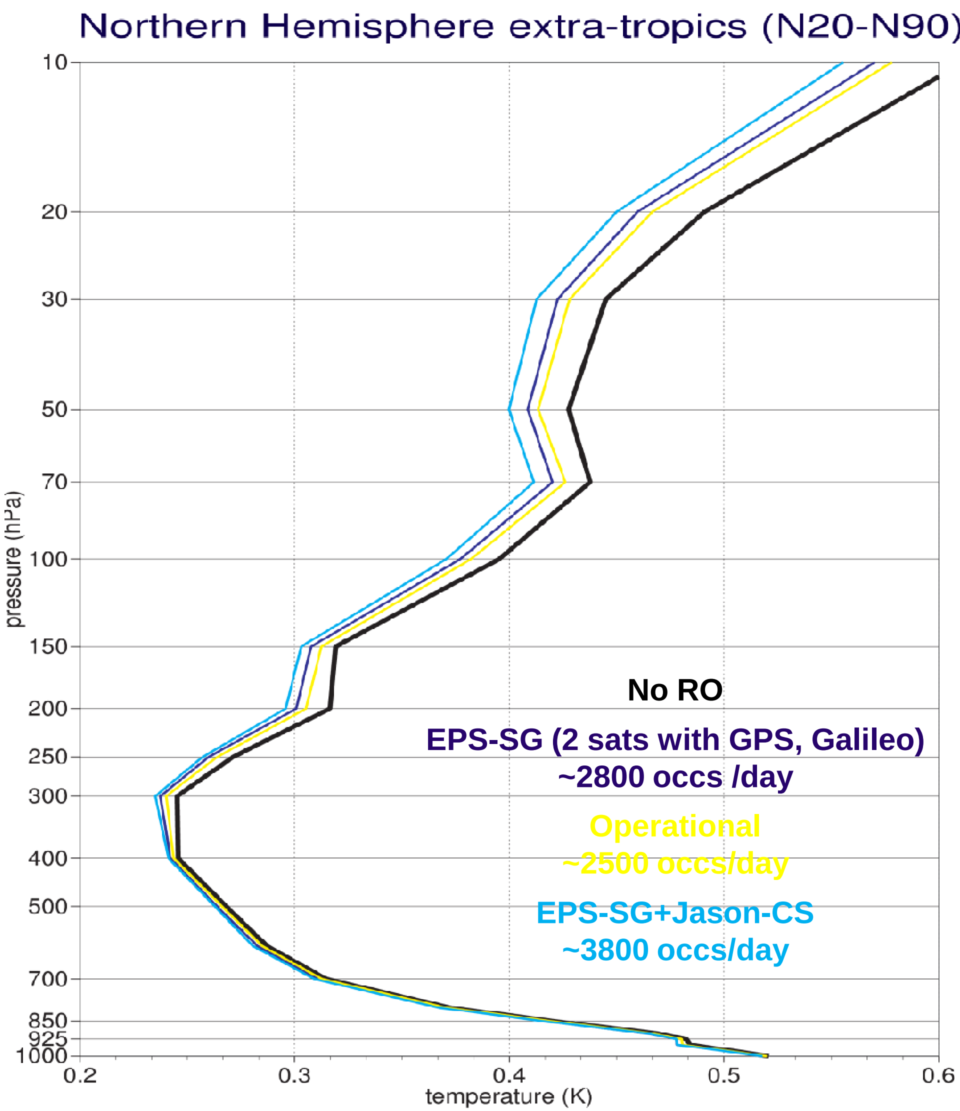
COSMIC-2 Polar Mitigation Investigation

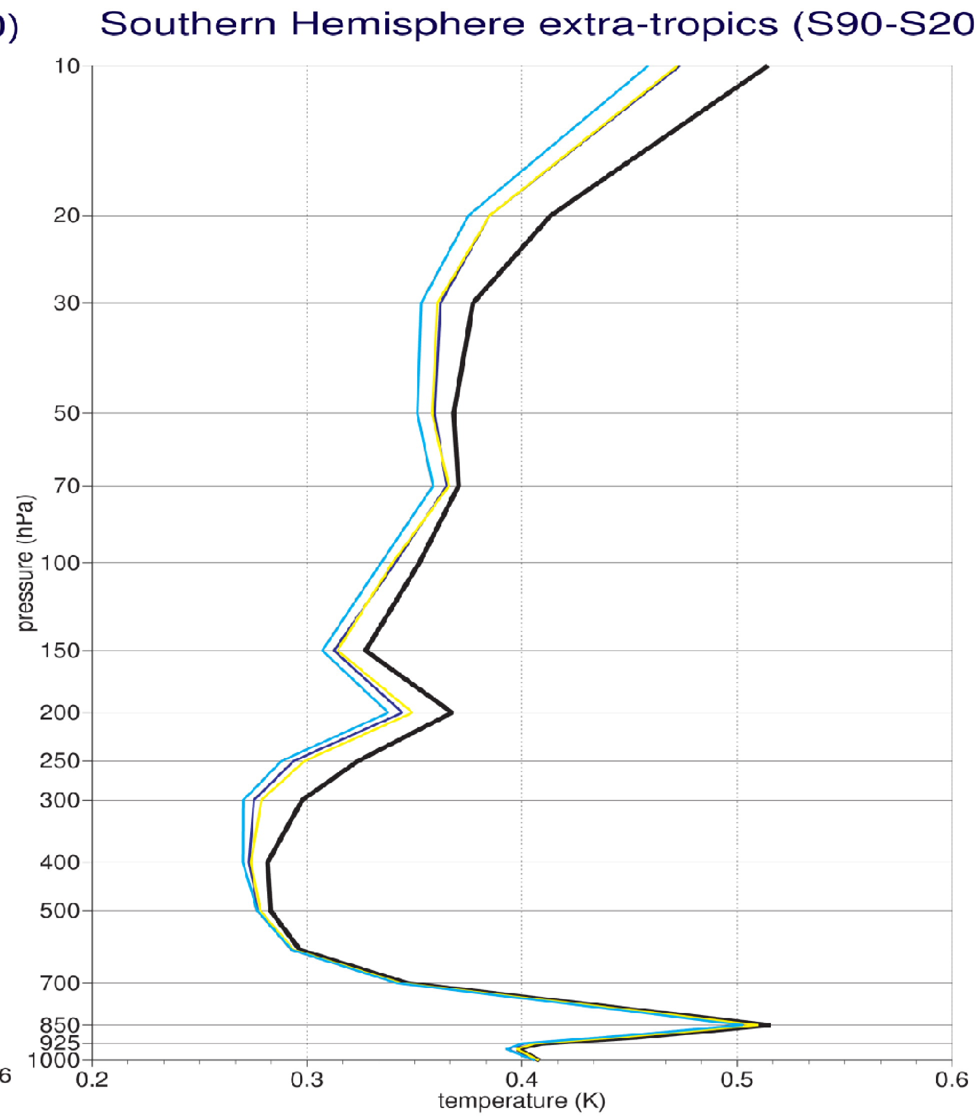
COSMIC-2 Pol Mitigation Impact: Temp (extra tropics)



Jason-CS Impact Investigation

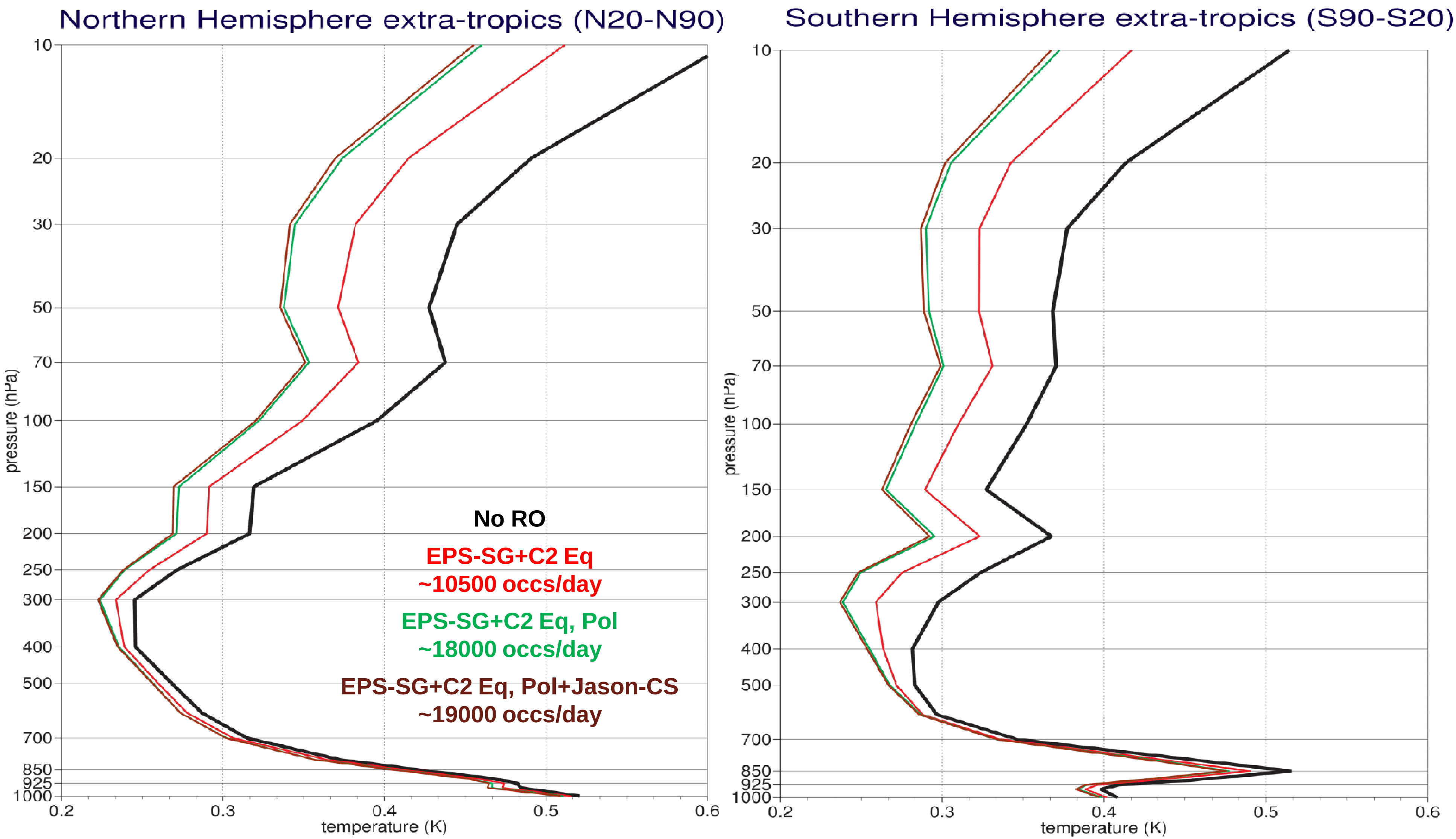
Jason-CS Impact (1): Temperature (extra-tropics)





ECMWF EUMETSAT

Jason-CS Impact (2): Temperature (extra-tropics)



ECMWF EUMETSAT

Summary / Open Points

Summary

- Investigated 2,000-19,000 observations per day. EDA spread values are determined mainly by observation numbers, rather than orbits.
- One can quantify impact of both COSMIC-2 Equator and COSMIC-2 Polar relative to EPS-SG. Full COSMIC-2 constellation has largest improvements.
- Main improvements above about 100hPa in temperature; relative humidity improvements (particularly at tropics within 300-850hPa) and in zonal wind (particularly at 100-400 hPa layer, and above 50 hPa; only shown in WP)
- 4 sun-synchronous RO satellites cannot compensate for COSMIC-2 Polar.
- Jason-CS & EPS-SG together have greater impact than current operational data.
- Jason-CS is particularly important in the absence of COSMIC-2 Polar.
- No saturation is seen in one orbit, even with 4 GNSS observed (only shown in WP).

Open Points

- As mission planning has long lead time the timely availability of ICDs is mandatory in order to exploit the new GNSS. For EPS-SG this in particular refers to GLONASS and BeiDou use (L1 & L5, CDMA signals).

- IROWG-4 NWP group recommends to further investigate EDA vs. OSSE

Backup/Further Information

Realistic Distribution Scenarios investigated

Scenario	LEO Satellites	GNSS Satellites	Info
4	EPS-SG A1, B1	GPS Galileo	2 EPS-SG satellites, about 2,800 occultations /day
6	EPS-SG A1 RO-Night	GPS Galileo	2 RO satellites, about 2,800 occultations/day; check 2 RO in one orbit plane to 2 RO in different ones
7	EPS-SG A1, B1	GPS Galileo GLONASS BeiDou	2 EPS-SG satellites, about 5,100 occultations /day; maximum number of occultations in one orbit, is a saturation visible in one orbit?
8	EPS-SG A1, B1 COSMIC-2 Eq	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, about 10,500 occultations/day; check impact of few occultations at high/mid latitudes
9	EPS-SG A1, B1 COSMIC-2 Eq COSMIC-2 Pol	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar satellites, about 18,000 occultations/day
10	EPS-SG A1, B1 RO-Night RO-Early Morning	GPS Galileo	4 RO satellites, about 5,400 occultations/day; check 4 RO coverage compared to COSMIC-2 Polar, Equator
11	EPS-SG A1, B1 COSMIC-2 Eq RO-Night RO-Early Morning	GPS Galileo	10 RO satellites, about 13,300 occultations/day; check how 4 sun-synchronous RO satellites compensate for no COSMIC-2 Polar
13	EPS-SG A1, B1 Sentinel-6	GPS Galileo	2 EPS-SG satellites, one Sentinel-6 (Jason-CS) satellite, about 3,800 occultations/day
14	EPS-SG A1, B1 COSMIC-2 Eq, Pol Sentinel-6	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar satellites, one Sentinel-6 (Jason-CS) satellite, about 19,000 occultations/day
15	EPS-SG A1, B1 COSMIC-2 Eq, Pol LEO-1 (06:00) LEO-2 (10:30) LEO-3 (13:30) Sentinel-6	GPS Galileo	2 EPS-SG satellites, 6 COSMIC-2 Equator satellites, 6 COSMIC-2 Polar satellites, Sentinel-6 satellite, one early morning LEO, one in close by EPS-SG orbits, one in early afternoon orbit, about 22,800 occultations/day

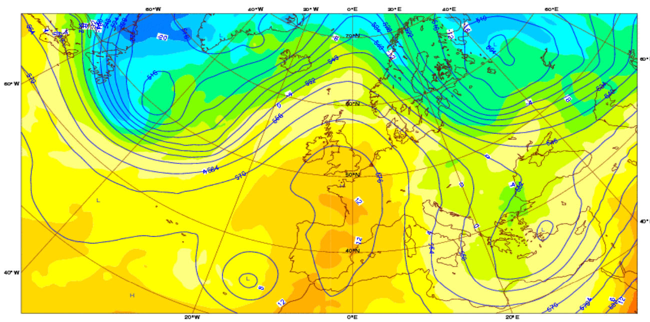
Note: Scenarios started from a "Wish List" and were then refined, thus some scenario were not investigated in study.

EDA: Setup

- The EDA spread is computed from the 00 and 12 UTC analyses.
- Mostly temperature spread is presented since the largest impact is in temperature
- Spread vertical profiles are plotted
- Time period for averaging: days July 11-25, 2008.
- Regions for averaging: NH extra-tropics (N20-N90), SH extra-tropics (S90-S20), tropics (S20-N20)

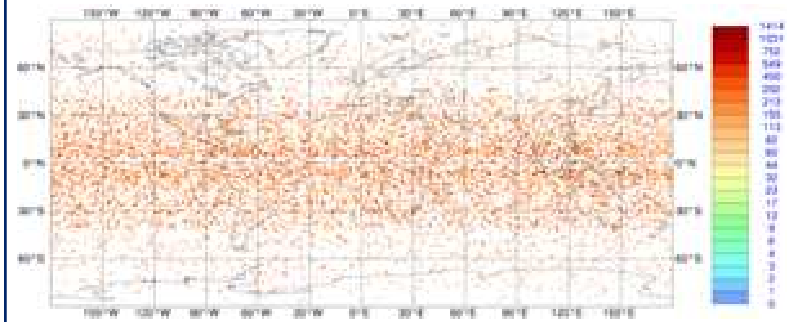
EDA: GNSS RO Observation Simulation

ECMWF NWP analysis at T799 (~25 km) and L91 → proxy for the 'truth'



interpolate

EUMETSAT: Realistically distributed observation time and location (lat, lon, limb-azimuthal angle)



2D bending angle operator *(Healy et al. 2007)*

add realistic observation errors

simulated bending angle profiles *a(a)*

bending angles on 247 fixed impact heights h (a - R_c) similar to operationally used GRAS data

ECMWF EUMETSAT

EDA: Comparison to OSSEs

- **OSSEs:** simulate all observations from a known truth - *the nature run*.
  - The simulated observations are assimilated into an NWP system, and **individual analysis and/or forecast errors**, **ε**, can computed because the truth is known.
  - The **statistics** of the analysis/forecast errors can be computed by averaging errors, **ε**, over the experiment.
- **EDA:** Estimates the analysis and forecast **error covariance matrices - not the forecast errors** - based on the assumed observation/model error statistics.