# CEOS AC-VC#22/WGCV-ACSG Joint Meeting 2026

*CEOS FRM assessment framework*

## Update on second pilot assessment exercise

**Paolo Castracane**
**Starion for ESA/ESRIN**

**03 June 2026**

Committee on Earth Observation Satellites

# Table of Contents

- Background and Objectives
- Endorsment Process: the CEOS-FRM Maturity Matrix
- 2nd round of exercises
- Way forward

# Background and Objectives

The concept of a Fiducial Reference Measurement (FRM) has been developed to highlight the need for precise and well-characterised measurements tailored explicitly to the post-launch calibration and validation (Cal/Val) of Earth Observation satellite missions [1].

Recently, this need has been enhanced with the emergence of new commercial satellite operators to ensure that users have a transparent and fair means to judge the adequacy of data products to meet their needs.

The Committee on Earth Observation Satellites (CEOS) Working Group Cal/Val (WGCV) has put in place a framework to assess the maturity and compliance of a "Cal/Val reference measurement" in terms of a set of community-agreed criteria which define it to be of CEOS-FRM quality. The assessment process is based on a maturity matrix that provides a visual assessment of the state of any FRM against each of a set of given criteria, making visible where it is mature and where evolution and effort are still needed. General information and the last version of the guidelines are available on the CEOS Cal/Val Portal [2].

[1] Goryl, P.; Fox, N.; Donlon, C.; Castracane, P. Fiducial Reference Measurements (FRMs): What Are They? *Remote Sens.* **2023**, *15*, 5017. https://doi.org/10.3390/rs15205017
[2] FRMs Assessment Framework on CEOS Cal/Val Portal: https://calvalportal.ceos.org/web/guest/frms-assessment-framework

# CEOS FRM Endorsement process

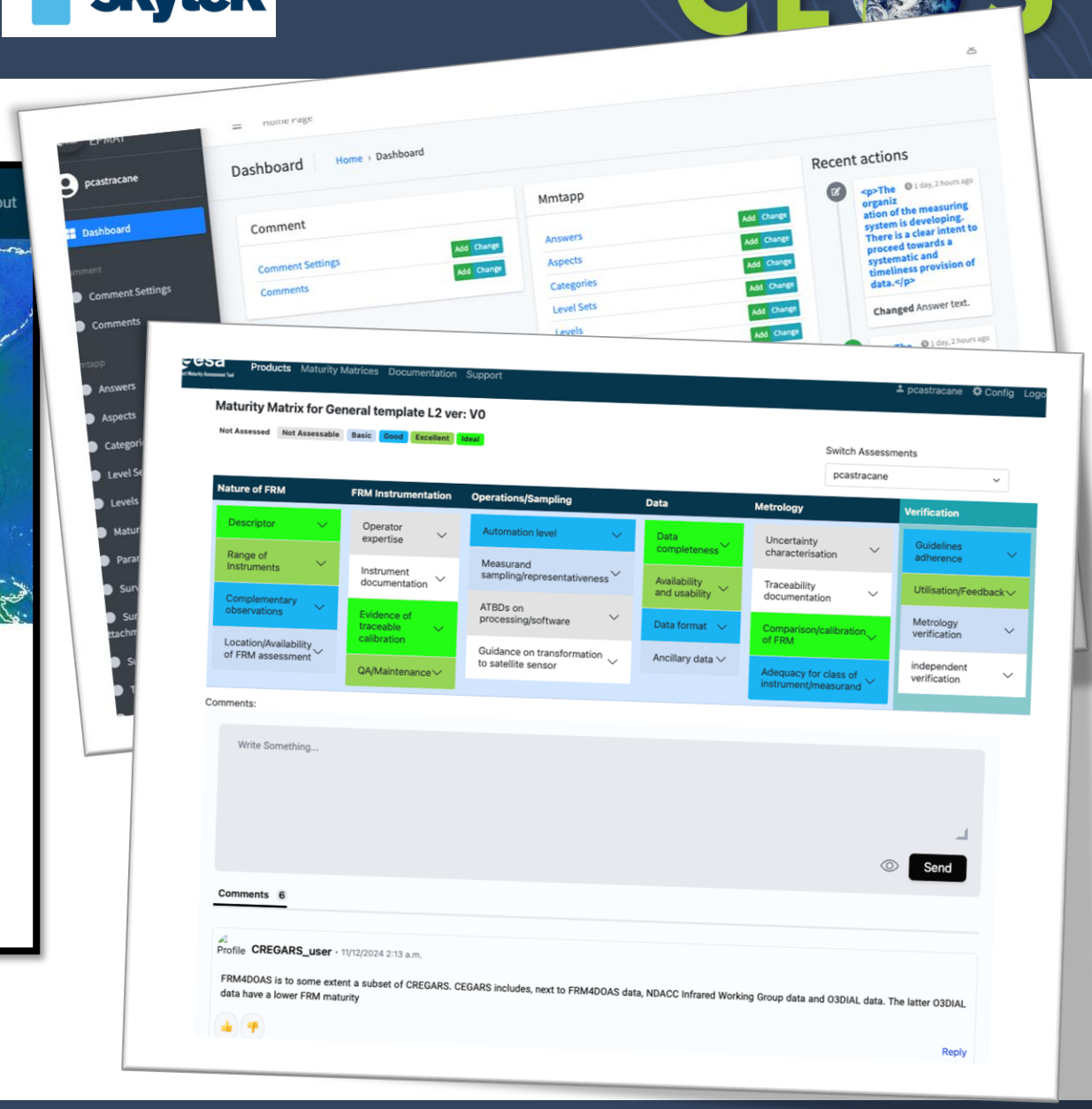
The proposed framework takes a pragmatic approach relying on ***self-assessment*** and transparency/accessibility of evidence against a set of criteria which are subject to peer ***review through a board of experts led by CEOS WGCV***

In order to be flexible, maximise inclusivity and encourage the development and evolution of FRM from new or existing teams compliance with criteria will be based on a ***gradation scaling rather than a simple pass/fail***

The degree of compliance and associated gradation is presented in a ***Maturity Matrix model*** - to allow intended users of the FRM to assess suitability for their application and indeed funders to decide on where and what aspects to focus any investment. The matrix model provides a visual “simple” assessment of the state of any FRM for all given criteria making visible where it is mature and where evolution and effort needs to be expended.

In addition to this broad-based summary an overall ***classification of the degree of compliance*** will be provided based on meeting specific gradations for particular criteria.

# Maturity Matrix Tool

# FRM Maturity Matrix

| Self-Assessment | | | | | | Independent Assessor |
|---|---|---|---|---|---|---|
| **Nature of FRM** | FRM Instrumentation | Operations/ Sampling (single instrument) | Data | Metrology | Completeness, coverage and distribution | Verification |
| Descriptor | Instrument documentation | Automation level | Data completeness | Uncertainty characterisation | Validation capacity | Guidelines adherence |
| Location/ availability of FRM | Evidence of traceable calibration | Measurand sampling/ representativeness | Availability and Usability | Traceability documentation | Geographical coverage | Utilisation/ Feedback |
| | | | | | Temporal sampling | |
| Range of sensors | QA Maintenance | ATBDs on processing/software | Data format | Comparison/ calibration of FRM | Centralized data, processing, quality assessment and adherence to community standards | Metrology verification |
| Complementary observations | Operator expertise | Guidelines on transformation to satellite sensor | Ancillary data | Adequacy for class of instrument/ measurand | Timeliness | Independent verification |
| | | | | | **FRM CLASSIFICATION** | A B C D |

**Class A** – Where the measurement fully meets all the criteria necessary to be considered an FRM for a particular class of instrument and measurand.
**Class B** – Where the measurement meets many of the key criteria and has a path towards meeting the Class A status in the near term.
**Class C** – Meets or has some clear path towards achieving the criteria needed to reach a higher class and provides some clear value to the validation of a class of satellite instruments/measurands.
**Class D** – Is a relatively basic adherence to the FRM criteria but there is a strategy and aspiration to progress towards a higher class. This can be considered an entry level class for those starting out on developing an FRM.

| Grade |
|---|
| Not Assessed |
| Not Assessable |
| Basic |
| Good |
| Excellent |
| Ideal |
| Not Public |

# Pilots for CEOS FRMs Maturity Matrix Assessment: 1st round of exercise

- **PGN** (Pandonia Global Network) - Stefano Casadio (Serco)
- **RadCalNet** (Radiometric Calibration Network) - Marc Bouvet (ESA/ESTEC)
- **ICOS** (Integrated Carbon Observation System – Ecosystem Component) - Fabrizio Niro (Serco)
- **FRM4DOAS** (Ground-Based DOAS Air-Quality Observations) - Michel Van Roozendael and Jean-Christopher Lambert (BIRA)
- **BAQUNIN** (PREDE-POM LUNAR) – Stefano Casadio (Serco)
- **CSIRO (DION)** –Janet Anstee and Matt Garthwaite (CSIRO)
- **Brewer Spectrometer - NO2 Vertical Column Densities (VCDs) Measurements** - Henri Diémoz (ARPA Valle d'Aosta) – BAQUNIN project
- **FRM4GHG 2.0 project –COCCON** (EM27/SUN) $XCO_2$, $XCH_4$, and XCO data. – Mahesh Kumar Sha (BIRA) - FRM4GHG team. [Sha, M.K.; De Mazière, M.; Notholt, J.; Blumenstock, T.; Bogaert, P.; Cardoen, P.; Chen, H.; Desmet, F.; García, O.; Griffith, D.W.T.; et al. Fiducial Reference Measurement for Greenhouse Gases (FRM4GHG). *Remote Sens.* **2024**, *16*, 3525. https://doi.org/10.3390/rs16183525]
- Tropical Centre for reactive trace gas remote sensing (**CREGARS**) in ACTRIS – Martine De Mazière (BIRA)

Maturity Matrix Tool https://mmt.skytek.dev

skytek

*Support provided by Jarek Dobrzanski (Skytek, Ireland https://skytek.com/)*

Dedicated credentials provided for all the selected users

# Pilots for CEOS FRMs Maturity Matrix Assessment: 2st round of exercise – March 2026

Pilots divided by Assessor and Verifier

16 Measurement types invoved in the exercise

The following items provided to the pilots:

- CEOS FRM Assessemnt framework guidelines
- Maturity Matrix Tool (MMT) User Guide
- Credentials for MMT

# Pilots for CEOS FRMs Maturity Matrix Assessment: 2st round of exercise – March-April 2026

Atmo

| Username | type | name | email | invited | Self-assessment | verification | comments |
|---|---|---|---|---|---|---|---|
| USGS_asr | assessor | Gross, Garrison | ggross@contractor.usgs.gov | 02/03/2026 | x | | Landsat sensors |
| USGS_vr | verifier | Anderson, Cody H | chanderson@usgs.gov | 02/03/2026 | | | |
| FRM4SM_asr | assessor | Alexander Gruber | alexander.gruber@geo.tuwien.ac.at | 02/03/2026 | x | | |
| FRM4SM_vr | verifier | Philippe Richaume | philippe.richaume@univ-tlse3.fr | 02/03/2026 | | x | |
| FRM4drones_asr | assessor | Agnieszka Bialek | agnieszka.bialek@npl.co.uk | 02/03/2026 | x | | |
| FRM4drones_vr | verifier | Nigel Fox | nigel.fox@npl.co.uk | 02/03/2026 | | | |
| RadCalNet_asr | assessor | Marc Bouvet | Marc.Bouvet@esa.int | 02/03/2026 | x | | |
| RadCalNet_vr | verifier | Fabrizio Niro | Fabrizio.Niro@ext.esa.int | 02/03/2026 | | x | |
| LANDHYPERNET_asr | assessor | Pieter De Vis | pieter.de.vis@npl.co.uk | 02/03/2026 | x | | |
| LANDHYPERNET_vr | verifier | Nigel Fox | nigel.fox@npl.co.uk | 02/03/2026 | | x | |
| WATERHYPERNET_asr | assessor | Kevin Ruddick | kruddick@naturalsciences.be | 02/03/2026 | | | |
| WATERHYPERNET_vr | verifier | Nigel Fox | nigel.fox@npl.co.uk | 02/03/2026 | | | |
| EUBREWNET_asr | assessor | Alberto Redondas | aredondasm@aemet.es | 03/03/2026 | | | |
| EUBREWNET_vr | verifier | | | | | | |
| NDACC_Dobson_asr | assessor | Glen McConville? | Glen.McConville@noaa.gov | 03/03/2026 | | | |
| NDACC_Dobson_vr | verifier | | | | | | |
| NDACC_FTIR_asr | assessor | Jim Hannigan?<br>Emmanuel Mahieu? | jamesw@ucar.edu<br>emmanuel.mahieu@uliege.be | 03/03/2026 | | | |
| NDACC_FTIR_vr | verifier | | | | | | |
| NDACC_Lidar_asr | assessor | Thierry Leblanc?<br>Wolfgang Steinbrecht? | thierry.leblanc@jpl.nasa.gov<br>Wolfgang.Steinbrecht@dwd.de | 03/03/2026 | | | |
| NDACC_Lidar_vr | verifier | | | | | | |
| NDACC_MWR_asr | assessor | Eliane Maillard Barras?<br>Gerald Nedoluha? | Eliane.MaillardBarras@meteoswiss.ch<br>gerald.nedoluha@nrl.navy.mil | 03/03/2026 | | | |
| NDACC_MWR_vr | verifier | | | | | | |
| NDACC_sonde_asr | assessor | Elisabeth Asher? Ryan Stauffer?<br>Roeland van Malderen? | elizabeth.asher@noaa.gov<br>Ryan.M.Stauffer@nasa.gov<br>roeland.vanmalderen@meteo.be | 03/03/2026 | | | |
| NDACC_sonde_vr | verifier | | | | | | |
| NDACC_3_asr | assessor | | | | | | |
| NDACC_3_vr | verifier | | | | | | |
| ACTRIS_CREGARS_asr | assessor | Bart Dils | Bart.Dils@aeronomie.be | 03/03/2026 | x | | |
| ACTRIS_CREGARS_vr | verifier | | | | | | |
| FRM4DOAS_asr | assessor | Michel Van Roozendael | michel.vanroozendael@aeronomie.be | 03/03/2026 | | | |
| FRM4DOAS_vr | verifier | | | | | | |
| PGN_asr | assessor | Alexander Cede? | alexander.cede@luftblick.at | 03/03/2026 | x | | |
| PGN_vr | verifier | | | | | | |

# LANDHYPERNET

Assessments

**Assessed By:** Assessed By: LANDHYPERNET_asr

**Verified By:** Verified By: LANDHYPERNET_vr

Survey Details by LANDHYPERNET_asr

Export Matrix

| LANHYPERNET_Report | |
|---|---|
| CEOS-FRM Overall Classification | Class **C** |

**Not Assessed** | **Not Assessable** | **Basic** | **Good** | **Excellent** | **Ideal**

| Nature of FRM | FRM Instrumentation | Operations/Sampling | Data | Metrology | Completeness Coverage and Distribution | Verification |
|---|---|---|---|---|---|---|
| Descriptor | Operator expertise | Automation level | Data completeness | Uncertainty characterisation | Temporal Sampling | Metrology verification |
| Complementary observations | Instrument documentation | Measurand sampling/representativeness | Availability and usability | Traceability documentation | Geographical Coverage | Utilisation/Feedback |
| Location/Availability of FRM assessment | Evidence of traceable calibration | ATBDs on processing/software | Data format | Comparison/calibration of FRM | Centralized data, processing and standards | Guidelines adherence |
| Range of Sensors | QA/Maintenance | Guidance on transformation to satellite sensor | Ancillary data | Adequacy for class of instrument/measurand | Timeliness | independent verification |
| | | | | | Validation Capacity | |

# Example of CEOS FRM Report

Preliminary Information

Categories, aspects with comments references and evidences

CEOS WGCV
The Committee on Earth Observation Satellites
Working Group on Calibration and Validation

## CEOS FRM for LANDHYPERNET

Preliminary Information

Submitted by LANDHYPERNET_asr on April 07, 2026 15:23

**FRM measured:**
Specify the FRM measured, e.g., Surface Reflectance, Total Column CO2, Land Surface Temperature, etc. Include information on the range of values the FRM will cover.
surface reflectance (HCRF)

**Instrument classes:**
List the instrument classes involved, e.g., very-high resolution imager, medium resolution imager, Lidar, atmospheric spectrometer, etc. Include characteristics of the observation, such as nadir or limb sounding, and allow freeform input if needed.
pointable hyperspectral radiometer (radiance and hemispherical irradiance optics)

**Spatiotemporal nature:**
Describe the temporal and spatial nature of FRM data collection, e.g., near continuous sampling, campaign-based, surface-based sensor, airborne, space, autonomous, or localised point sample-based.
measurement sequence scheduled every 30 minutes, measurement taken at range of different angles from a fixed location on a mast. Multiple sites across the world included within LANDHYPERNET network

**Best achievable uncertainties:**
Provide details about the best achievable uncertainties for the measurand for the defined class of sensor, including spatial, temporal, and vertical representativeness.
Uncertainties can be broken down in the following categories: Radiometric: Detailed uncertainty and error correlation information is provided in each of the LANDHYPERNET products. Typical uncertainties are on the order of 3% and the errors are mostly systematic (across wavelengths and between different sequences). Spatial: Varies from site to site. Best achievable uncertainties are 1–2% at Gobabeb site in Namibia Angular: Multiple geometries included within measurement sequence. When comparing to satellite with viewing geometry close to included LANDHYPERNET geometries, uncertainties are very small. If viewing geometries do not match, BRDF correction is needed. Best achievable uncertainties (e.g. for the GHNA case) <1%. Temporal: Measurements are interpolated between sequence before and after satellite overpass. Negligible uncertainties (<0.1%). Spectral: hyperspectral measurements (FWHM of 3nm in VNIR, 10nm in SWIR) allow to apply SRF of multispectral satellites with negligible uncertainties (<0.1%).

**Contact details:**
Provide contact details for the FRM owner/operator, including means to communicate with those responsible for all FRM-related information.
Pieter De Vis (pieter.de.vis@npl.co.uk)
Agnieszka Bialek (agnieszka.bialek@npl.co.uk)

CEOS WGCV
The Committee on Earth Observation Satellites
Working Group on Calibration and Validation

## CEOS FRM MM (+Network)

Maturity Matrix for General template L2 ver: V2

Assessments

Assessed By: LANDHYPERNET_asr
Verified By: LANDHYPERNET_vr

Survey Details by LANDHYPERNET_asr
Export Matrix

Not Assessed | Not Assessable | Basic | Good | Excellent | Ideal

| Nature of FRM | FRM Instrumentation | Operations/Sampling | Data | Metrology | Completeness Coverage and Distribution | Verification |
|---|---|---|---|---|---|---|
| Descriptor | Operator expertise | Automation level | Data completeness | Uncertainty characterisation | Temporal Sampling | Metrology verification |
| Complementary observations | Instrument documentation | Measurand sampling/representativeness | Availability and usability | Traceability documentation | Geographical Coverage | Utilisation/Feedback |
| Location/Availability of FRM assessment | Evidence of traceable calibration | ATBDs on processing/software | Data format | Comparison/calibration of FRM | Centralized data, processing and standards | Guidelines adherence |
| Range of Sensors | QA/Maintenance | Guidance on transformation to satellite sensor | Ancillary data | Adequacy for class of instrument/measurand | Timeliness | Independent verification |
| | | | | | Validation Capacity | |

Maturity Matrix

Overall Classification

# RADCalNet

Assessments

**Assessed By:** Assessed By — RadCalNet_asr

**Verified By:** Verified By — RadCalNet_vr

Survey Details by RadCalNet_asr

Export Matrix

| RADCalNet_Report | |
|---|---|
| CEOS-FRM Overall Classification | Class **C** |

**Not Assessed** | Not Assessable | Basic | Good | Excellent | Ideal

| Nature of FRM | FRM Instrumentation | Operations/Sampling | Data | Metrology | Completeness Coverage and Distribution | Verification |
|---|---|---|---|---|---|---|
| Descriptor | Operator expertise | Automation level | Data completeness | Uncertainty characterisation | Temporal Sampling | Metrology verification |
| Complementary observations | Instrument documentation | Measurand sampling/representativeness | Availability and usability | Traceability documentation | Geographical Coverage | Utilisation/Feedback |
| Location/Availability of FRM assessment | Evidence of traceable calibration | ATBDs on processing/software | Data format | Comparison/calibration of FRM | Centralized data, processing and standards | Guidelines adherence |
| Range of Sensors | QA/Maintenance | Guidance on transformation to satellite sensor | Ancillary data | Adequacy for class of instrument/measurand | Timeliness | independent verification |
| | | | | | Validation Capacity | |

# FRM4SM

Assessments

**Assessed By:** Assessed By — FRM4SM_asr

**Verified By:** Verified By — FRM4SM_vr

Survey Details by FRM4SM_asr

Export Matrix

| FRM4SM_Report | |
|---|---|
| CEOS-FRM Overall Classification | Class |

Not Assessed | Not Assessable | Basic | Good | Excellent | Ideal

| Nature of FRM | FRM Instrumentation | Operations/Sampling | Data | Metrology | Completeness Coverage and Distribution | Verification |
|---|---|---|---|---|---|---|
| Descriptor | Operator expertise | Automation level | Data completeness | Uncertainty characterisation | Temporal Sampling | Metrology verification |
| Complementary observations | Instrument documentation | Measurand sampling/representativeness | Availability and usability | Traceability documentation | Geographical Coverage | Utilisation/Feedback |
| Location/Availability of FRM assessment | Evidence of traceable calibration | ATBDs on processing/software | Data format | Comparison/calibration of FRM | Centralized data, processing and standards | Guidelines adherence |
| Range of Sensors | QA/Maintenance | Guidance on transformation to satellite sensor | Ancillary data | Adequacy for class of instrument/measurand | Timeliness | independent verification |
| | | | | | Validation Capacity | |

# Way Forward 1/2

- Exercise still in progress
  - RadCalNet Case: Classification could rise to “B” (Action on Guidelines – topic on “specific demand of Climate”)
  - Interesting case from USGS (use of satellite sensor as FRM) – to be discussed (“FRMsat”, use and update of the current guideline)
- Self-assessment, verification + interaction and peer review process (WGCV) to reduce subjectivity
- Possible improvement in the MMT tool:
  - For the self-assessment, make mandatory to fill in the "comments" field to include references and material.
  - Better visualization of the matrix contents (Export Matrix -> xml only)
  - Automatize the overall classification and reporting
  - Other?

# Way Forward 2/2

| | Data quality process review | | | | | | Validation and Verification |
|---|---|---|---|---|---|---|---|
| | **Nature of dataset** | **Instrumentation** | **Operations/ Sampling** | **Data** | **Metrology** | **Completeness and coverage** | |
| Descriptive | Data set descriptor | Instrument and traceability documentation | ATBDs on processing Software | Data format and metadata | Uncertainty Documentation | Validation capacity | Validation Documentation |
| Good practice | User guidelines | Evidence of traceable calibration | Measurand sampling Representativeness | Availability and usability | Uncertainty Characterisation | Geographical Coverage / sampling | Validation Method(s) |
| | Site and location consideration | Operation and maintenance plans | Automation level | Data completeness and availability of ancillary data | Comparison / Calibration | QA/ adherence to community standards | Independent peer review and verification |
| Adequacy | Site adequacy for intended application | | Sampling adequacy for intended application | | Uncertainty adequacy for intended application | Timeliness adequacy for intended application | Validation Results Compliance |
| | | | | | | **Class** | **A B C D (to be selected)** |

- Restructuring and generalising the FRM matrix (by E. Woolliams NPL)
- Communication and clarification
- CEOS-FRM Catalogue


thank you
danke
謝謝
merci
gracias
obrigado
dziękuję
bedankt
go raibh maith agat
teşekkür ederim
ngiyabonga
спасибо
рахмат
Баярлалаа
dank je
tapadh leat
mochchakkeram
sukriya
kop khun krap
terima kasih
감사합니다
ευχαριστώ
arigatô
dakujem
мерси
grazie
taiku
takk
hvala
mauruuru
sagolun
köszönöm
dhanyavadagalu
chnorakaloutioun
gratias ago
gràcies
sulpáy
djiere dieuf
dankie
kiitos
faafetai lava
vinaka
blagodaram
misaotra
matondo
paldies
grazzi
mahalo
barka
welalin
tack
spas
mersi
kia ora
xièxie
rahmat
rahmet
tanemirt
najis tuke
kam sah hamnida
didi madloba
mèsi
dēkuji
sobodi
enkosi
bayarlalaa
gràcie
nandri
nanni
dhanyavad
akun
dankon
aciū
djere dieuf
tau
дякую
mamnun
chokrane
murakoze
tenki
obrigada
asante
manana
хвала
shukriya
merci
diolch
trugarez
ありがとう
তোমাকে ধন্যবাদ