Streaming Satellite Data to Cloud Workflows for On-Demand Computing of Environmental Data Products

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Motivation

- Growing prevalence of sensors, continuously gathering observational data with high spatial and time granularity
- Increased resource needs for storing, managing, analyzing and sharing

→ Investigate Streams as first-class entities in Workflow Systems over heterogeneous resources

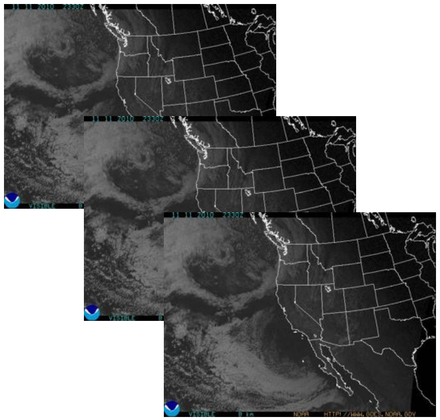
  - What programming abstractions?
  - How to provide these in Cloud/heterogeneous environments?
  - What (new) application areas can benefit from them?

Use-case: Reference Evapotranspiration

- Reference Evapotranspiration (ETo)
  - Planning daily water use (CA farmers, turf managers)
  - Defining water resource policies

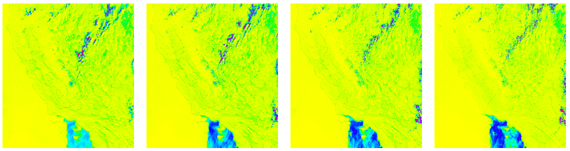
  →improve irrigation scheduling and monitor water stress.
- Current State
  - Single-machine, monolithic 'workflow' orchestrated by make
  - Executed once a day to create ETo maps for CA
- Computed from streaming observational data:
  - Geostationary Operational Environmental Satellite (GOES) (GOES-WEST)
  - California Irrigation Management Information System (CIMIS) stations

Use-case High-level Overview



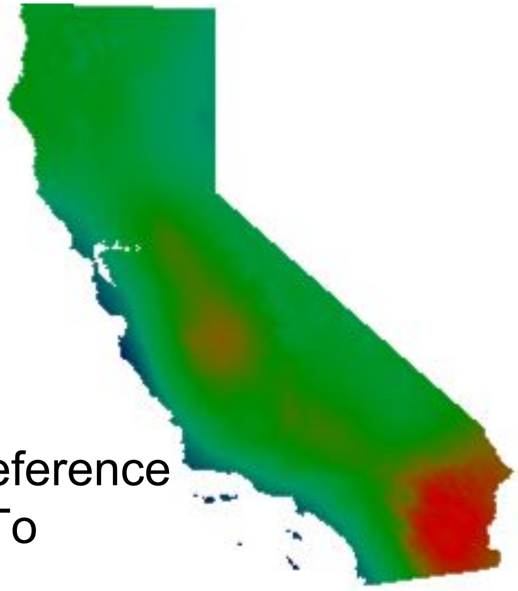
GOES West imagery

CIMIS weather station point data



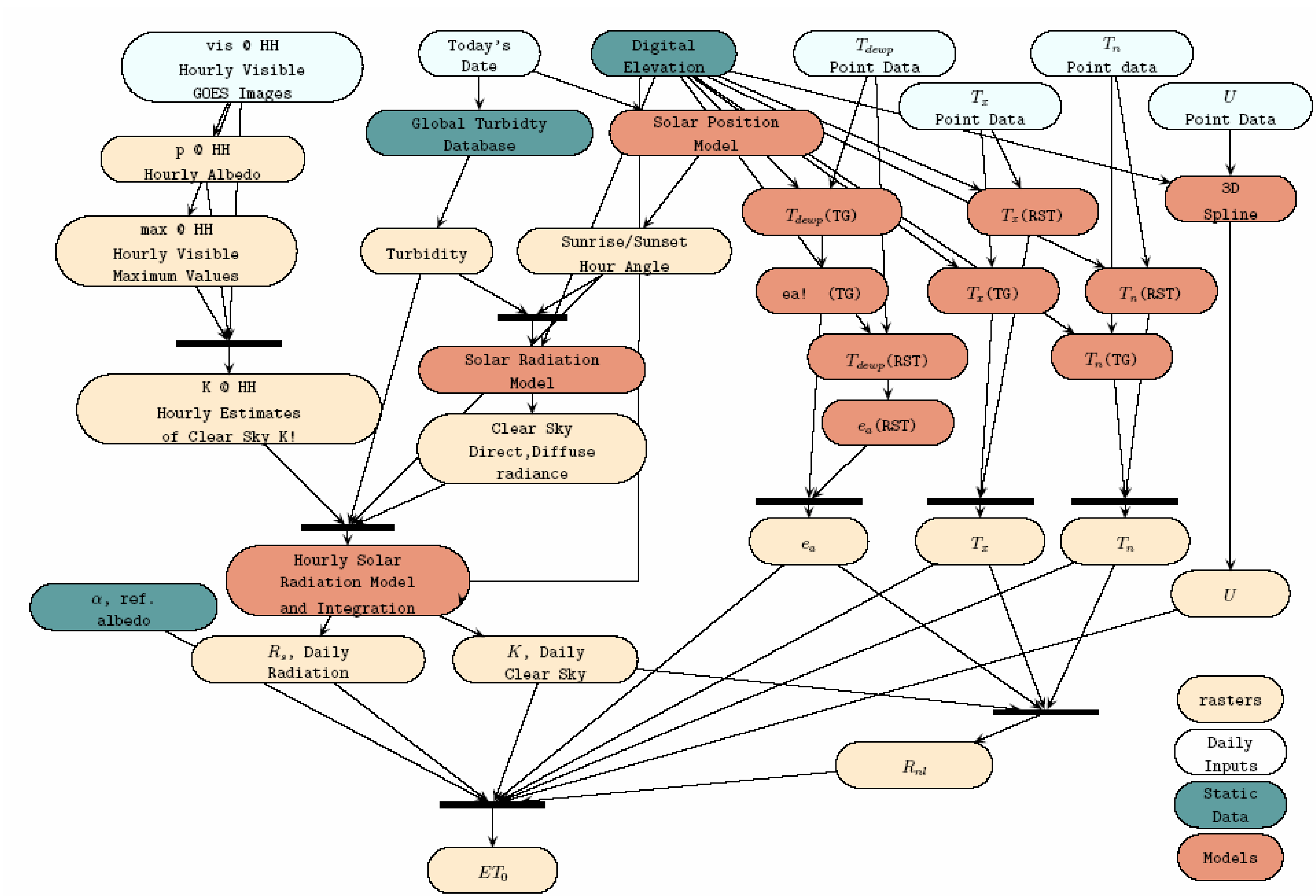
Hourly cloud cover

Complex Makefile Using GRASS GIS



Reference ETo

Use-case Overview



App Domain Requirements

- Need to scale existing applications for
  - Increased data quality [spatial and time]
  - Batch-processing of historic data with novel analysis algorithms
- Need to share computation and data with a large community

- Benefits from Scientific Workflow Technology and Streaming
  - **Streaming** as abstraction maps well to application domain
  - Better management of dataflow pipeline
  - Increased sharing of data and pipeline steps
- Benefits of the Cloud as computational platform
  - Theoretic CPU scale-out limited only by $$$
  - Pay-as you go storage abstractions (BLOB/Tuple store)
  - Simple service abstractions (BLOB, table, worker, …)
  - Relatively easy to access/maintain (vs. GRIDS, vs. owning cluster)

Challenges for Cloud Usage

- Application migration
- Data movement slower / more complex
  - Data-source to cloud
  - Cloud to desktop
  - Desktop to cloud
  - Intra-cloud movement between workers and persistent storage
- Unpredictability
  - Non-homogeneous data transfer rates
  - Non-homogeneous disk access rates
  - Non-homogeneous computation speeds

Contributions

- Migrating legacy script to a cloud-enabled workflow model
- Investigating data movement strategies
  - **BLOB** storage as easy-accessible persistent cloud storage
  - Direct **streaming** from Client to Cloud via TCP socket

  → Streaming faster by a *factor of 5*
- Investigating scale-out behavior
  - Ran 7 workflows in parallel

  → Almost linear speed-up for workflow steps *and* data movement

Workflow Design

- Workflow engine on client, that orchestrates workflow tasks

  Here, we use Restflow workflow system

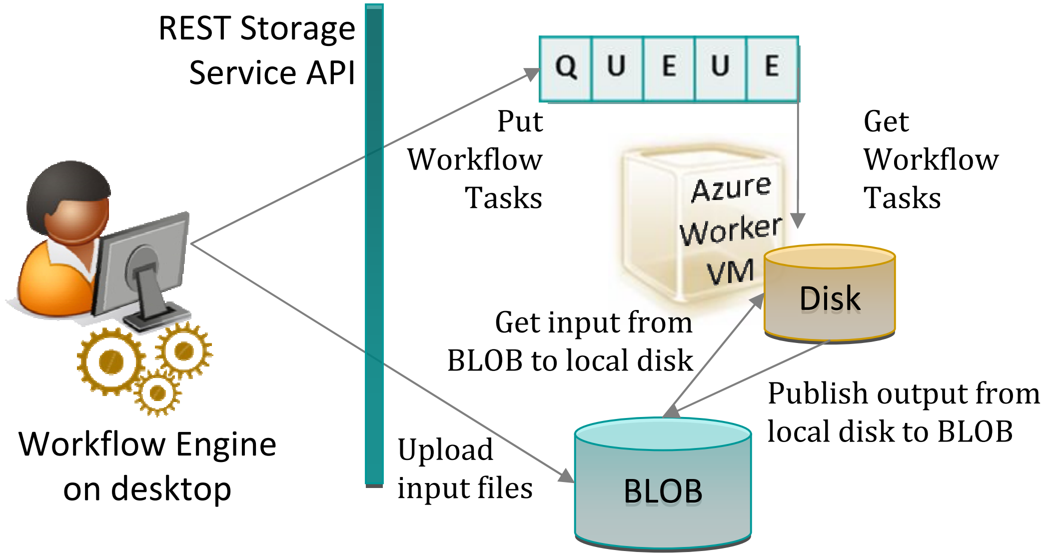
  - Light-weight, Java-based workflow engine with scripting capabilities and automated tracing of data flow and invocation timings

- Workflow tasks run on the Cloud, implement application logics

  Here, we use windows Azure cloud

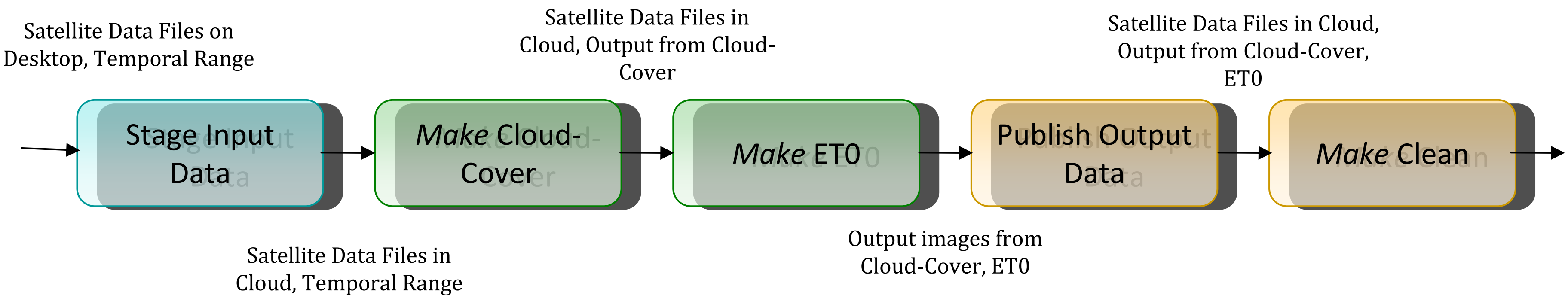
  - We used the PaaS (.Net program) infrastructure
  - Access queues, tables, and BLOB via REST interface

Client – Cloud Communication



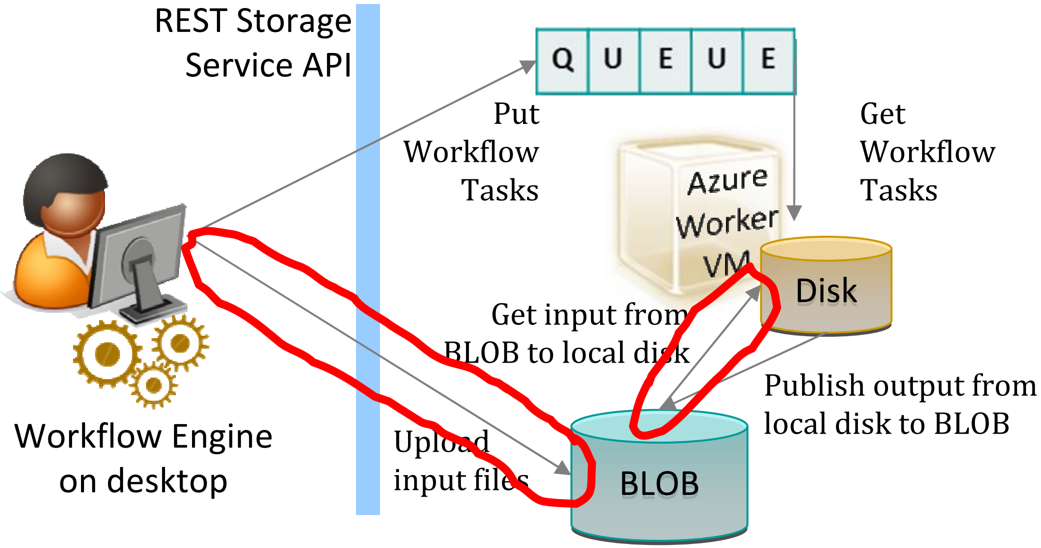
- Instructions via Message queues [Request/Response]
- Input / Output data via BLOB-store
- Workflow tasks are stateful, i.e. locally written files from earlier tasks are re-used by later tasks.
  → all tasks of a single ETo computation are run on the same cloud machine
  → achieved via reserving a cloud machine as first task and switching to private request/response queue

Cloud-Migrating of ETo computation

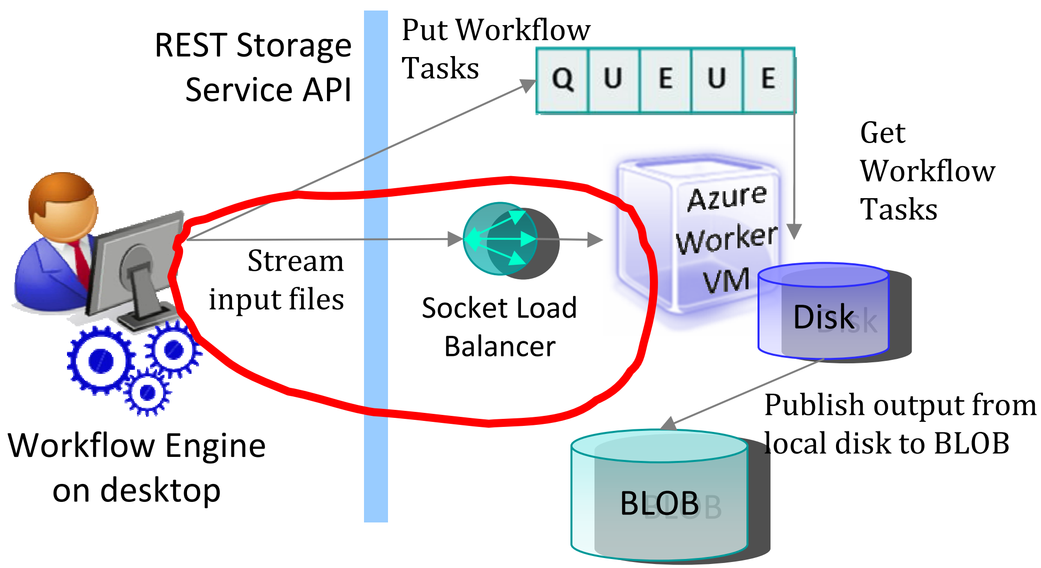


- Stage Input
  - Reserve worker, data up+download via BLOB; 14 days (315MB)
- Make Cloud-cover & Make ETo
  - Re-used legacy Make implementation that calls GRASS, Perl and bash scripts
- Publish Output data
  - Upload output data to BLOB and return URL for user
  - Served by Azure Web-hosting worker
- Make Clean and release worker VM

Improved Data Movement using Streams

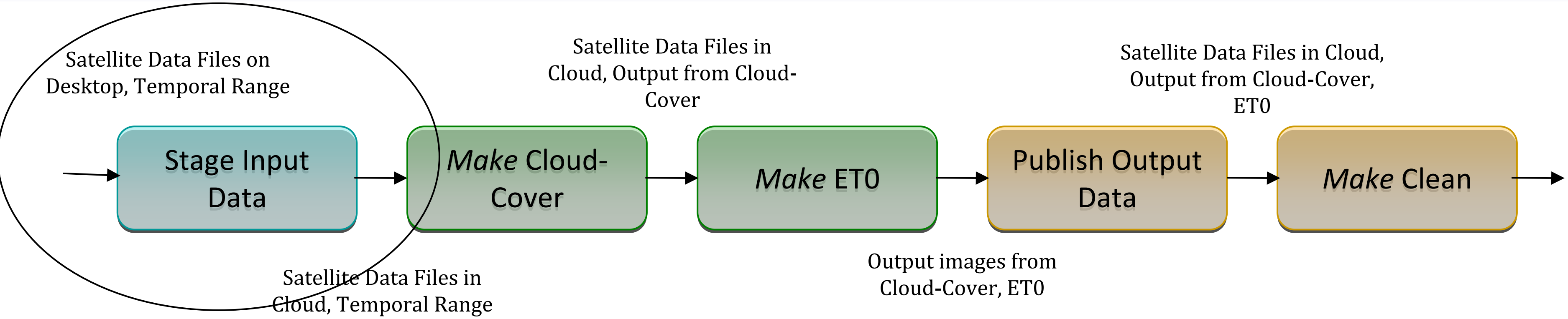


- ☺ Simple API
- ☺ Fault tolerance
- ☹ 2 Data transfers
- ☹ Slower bandwidth



- ☺ Direct transfer
- ☺ Application can work on incoming data incrementally
- ☹ Fault tolerance

Changes for Streaming



- Stage Input

  Reserve worker via "Socket Load Balancer"

  Stream input data to CloudVM directly

- *Rest is unaltered. We still communicate over queues,*

  And store the final output in BLOB for persistency.

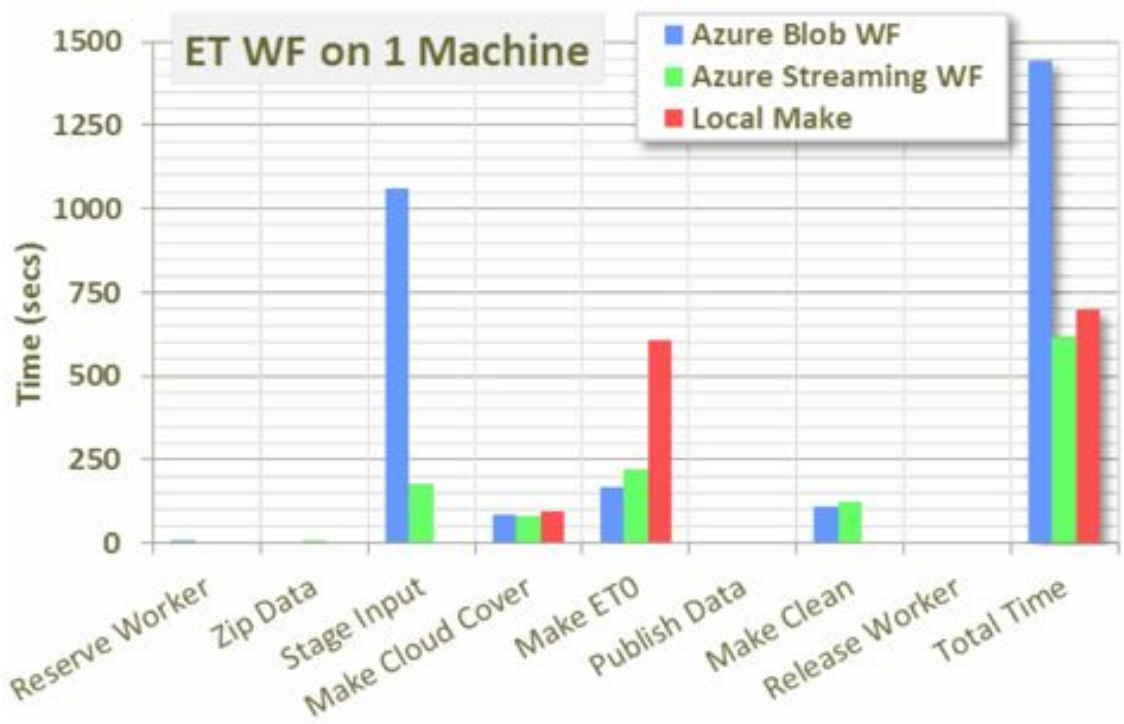
  - Make Cloud-cover & Make Et0
  - Publish Output data
  - Make Clean and release worker VM

Evaluation

- Investigate effectiveness of Cloud Implementation
  - Compare local vs. Cloud execution
  - Investigate Scale-out for 7 concurrent workflows
  - Compare BLOB vs. Streaming strategy
- Experimental Setup
  - Local production machine: 2-core, 2.8GHz, 2GB RAM, NFS-mounted home+data (20MB/s)
  - Client machine: gigabit to the internet
  - Azure worker machine: 1.6GHz, 1.7GB RAM, 250GB local disk space, running 64bit Windows Server 2008. Co-located with data storage account US North Central Data Center
  - Time measured by Restflow actor-invocation tracing capabilities
  - Experiments run 4 times, averages and std-dev reported

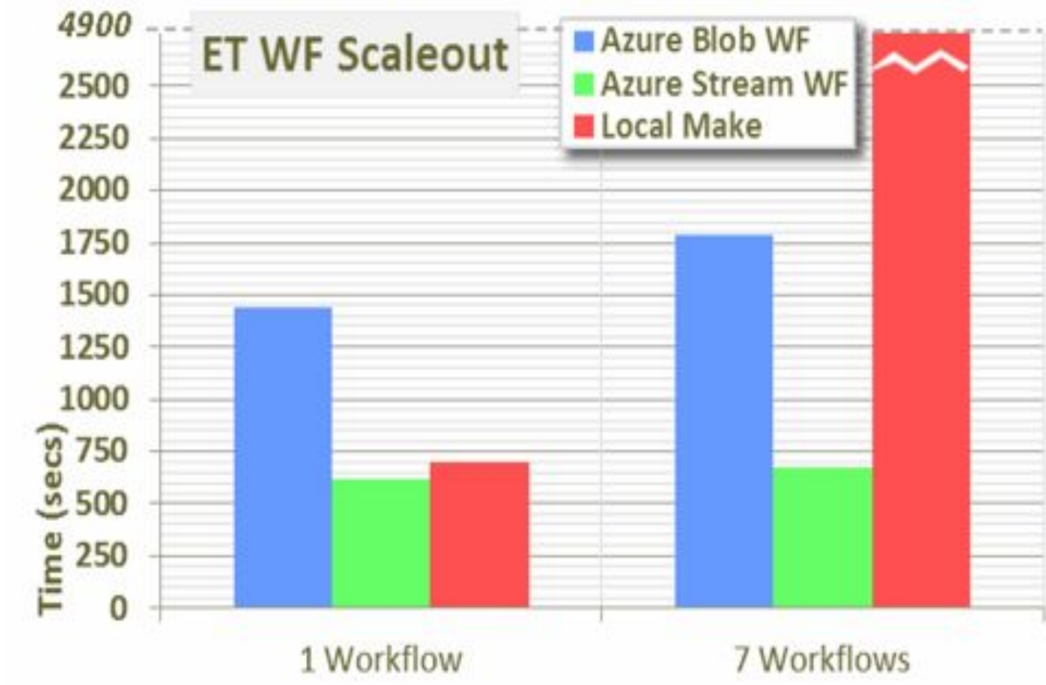
Single Local and Cloud Executions

- Cloud-cover comparable
- ETo performed better on cloud than on local machine (NFS)
- Local outperforms BLOB
- Streaming beats local by 11%



Speedup of Concurrent Cloud Workflows

- Ran 7 workflows in parallel (315MB input data each)
- Linear speedup of computational tasks
- 25% overhead for data movement
  (220s vs. 177s for streaming)
- Overhead for zipping input data on client



Summary:

BLOB: speedup/#proc = 0.80

Stream: speedup/#proc = 0.92

BLOB vs. Streaming Single WF

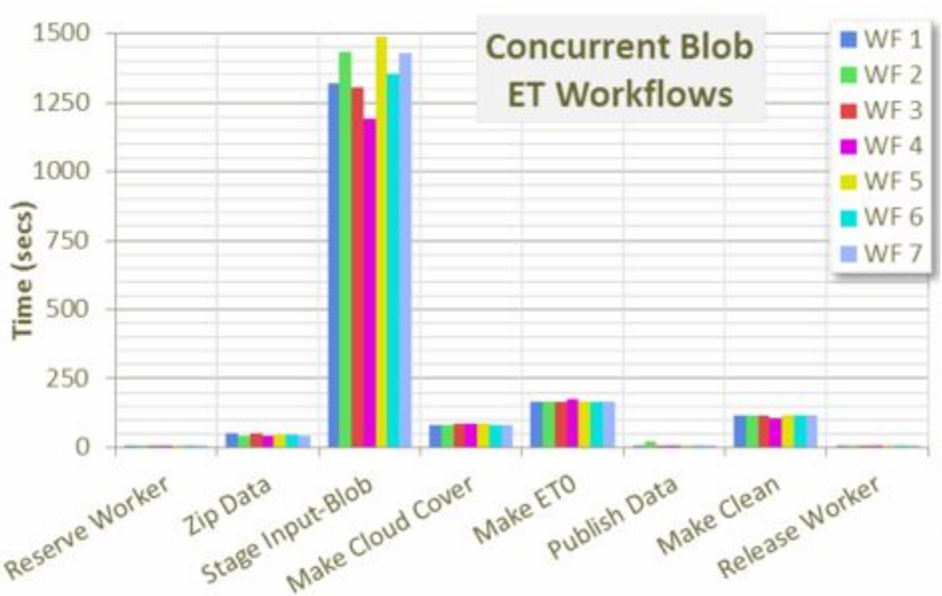
- 315 MB of data in 15 zip files
- BLOB
  - Client->BLOB: 1030s 13% stdev (300KB/s)
  - BLOB->VM: 32s (10MB/s)
- Stream
  - 180s 6%stdev (1.75MB/s)

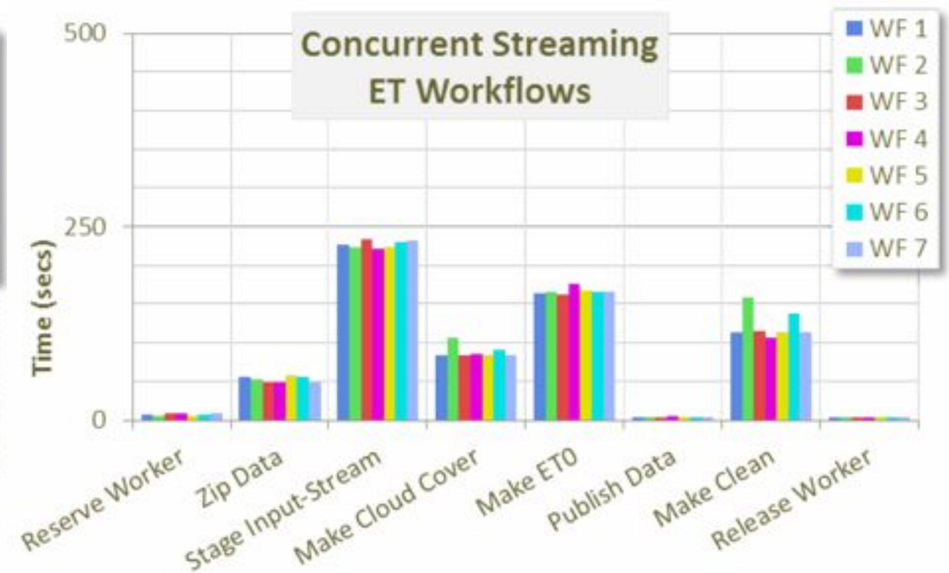
→ Streaming 5x faster, and more stable

BLOB vs. Streaming: Parallel WFs

- BLOB
  - Client->BLOB: 800s—1800s; avg:1172s; (270KB/s); **stdev 44%** *(1.8MB/s total)*
  - BLOB->VM: 32s (10MB/s) **stdev 35%** *(70MB/s total)*
- Stream
  - Avg: 227s 1.35MB/s **stdev 6%** *(9.7MB/s total)*

→ **Streaming faster by >5x and more stable**





→Overall time: streaming 130% / 160% faster (single/parallel)

Findings / Summary

- Migrating ETo to cloud resources feasible from performance-point-of-view
- Streaming paradigm fits application domain well
- Streaming data transport beneficial for performance
  - Much faster than going through BLOB storage
  - More consistent performance
- Streaming on average 5x faster than via BLOB;
  total wall-clock time improvement 130% / 160%

Related Work

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Z. Hill, J. Li, M. Mao, A. Ruiz-Alvarez, and M. Humphrey.
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K.R. Jackson, L. Ramakrishnan, K.J. Runge, and R.C. Thomas.
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Ongoing / Future Work

- Compare the impact of streaming on different cloud platforms
- Investigate service abstraction for streams
  - Easy to use such as BLOB, table, queues
  - Built-in fault-tolerance, persistence, and sharing
- Investigating novel streaming apps
  - Energy management (incoming smart-meter streams)
- Collaborative execution of workflows in the Cloud
- Incorporate pay-as-you-go cost model

Thank you.

Questions?